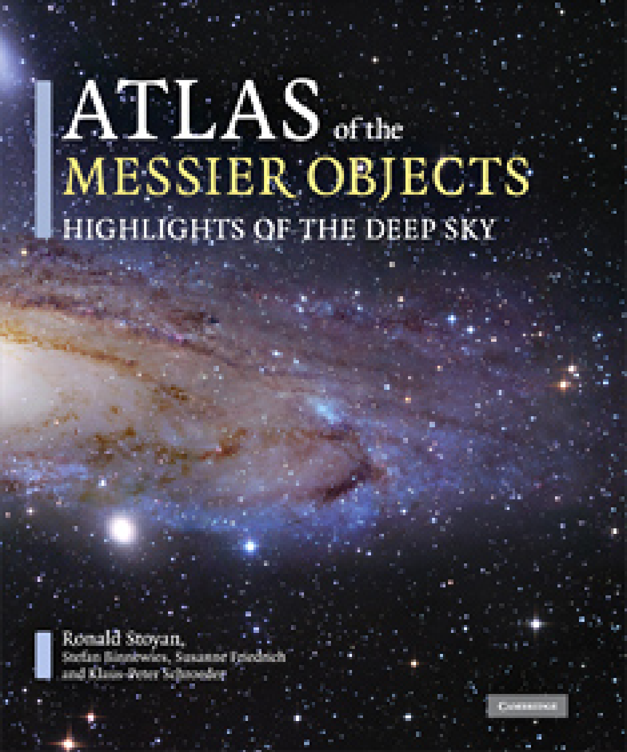

ATLAS of the MESSIER OBJECTS

HIGHLIGHTS OF THE DEEP SKY

Ronald Stoyan,
Stefan Binnewies, Susanne Friedrich
and Klaus-Peter Schroeder

CAMBRIDGE

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Atlas of the Messier Objects
Highlights of the Deep Sky

The 110 star clusters, nebulae and galaxies of Messier's catalog are among the most popular of all the deep sky objects and are beautiful targets for amateur observers of all abilities. This new atlas presents a complete account of all of the Messier objects, detailing, for each object:

- its astrophysical significance
- well-researched background on its discovery
- clear observational descriptions from naked eye through to large telescopes
- observations and anecdotes from Messier himself and other famous observers from the past

In addition, this atlas has some of the world's finest color astrophotos, inverted photos that have been labeled to point to hidden details and neighboring objects, and historical sketches alongside new deep sky drawings, helping to bring the Messier objects to life.

Painting an engaging portrait of Charles Messier's life and observations, this is the most far-reaching and beautiful reference on the Messier objects there has ever been, and one that no observer should be without!

RONALD STOYAN is editor-in-chief of *interstellarum*, one of Germany's main astronomy magazines. He was the founding director of the German deep sky organization 'Fachgruppe Deep-Sky', and has authored and coauthored six books on practical astronomy.

STEFAN BINNEWIES is a leading astrophotographer and travels around the world to get the best shots. He has worked on several amateur observatory projects, including helping to establish the Capella Observatory near Windhoek, Namibia.

SUSANNE FRIEDRICH is an editor for *interstellarum* and a visiting scientist at Max-Planck-Institute for extraterrestrial physics. A trained astrophysicist, she has been observing the sky both visually and photographically for more than 25 years.

KLAUS-PETER SCHROEDER is Professor of Astronomy at the University of Guanajauto, Mexico. An avid amateur astronomer and photographer since youth, he has published several books on astrophotography and is a regular contributor writing for amateur astronomy magazines.

Cover illustration: A majestic view of M 31, M 32, and M 110, our intergalactic neighbors. This image was taken by Robert Gendler in September and November, 2005. A 20-inch reflector was used at 4000mm focal length, total exposure was 90 hours with a SBIG CCD camera STL-11000XM, from Nighthawk Observatory, New Mexico, USA.

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CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK
Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521895545

First published in print format 2008

ISBN-13 978-0-511-42329-1 eBook (EBL)

ISBN-13 978-0-521-89554-5 hardback

Dedicated to the memory of my brother Norman Stoyan (1975–2003)

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Foreword

David H. Levy

Why yet another Messier catalog book? With Kenneth Glyn-Jones, Stephen James O'Meara, and Ken Graun, haven't we had enough? No, I say! And especially no when the latest addition to the canon is Ronald Stoyan's scholarly, historical, astrophysical, and superb look at the great comet hunter and the list of objects he compiled during his lifetime.

This book is the first scholarly look at the catalog since Glyn-Jones, and that effort is almost half a century old. Stoyan explores the latest astrophysical research concerning each of Messier's 110 deep sky objects. Stoyan could well devote his entire book to the astrophysics of Messier's first object, the Crab Nebula, and I still subscribe to the belief that I read years ago that astronomy has two parts: that of the Crab and that of everything else. From the first time I looked at M 1 on September 1, 1963, I've been fascinated by the ghostly luminescence of the Crab, but never more so than when it seemed ablaze again not with a new supernova, but with nearby Saturn visiting at nearly the same spot from which the original star first became visible on July 4, 1054.

Next comes the historical view: I cannot get enough of the life of Charles Messier, who lived, observed, searched, and suffered some two hundred years ago. This observer's life story is compelling, and Stoyan's retelling adds new material. Although he was not the first person to discover a comet with a telescope, Messier was most likely the first to organize a successful survey program specifically devoted to the search for comets. For that accomplishment he certainly deserves a place with the greats like William Herschel, Kaoru Ikeya, and Leslie Peltier. In Stoyan's biographical summary we learn a little more about Messier's famous accident, in which he fell into a pit. Although he recovered enough to resume his work, we know for the first time that he never *completely* got well again, and he finished his life with a continuing limp. A fortunate fall, to be sure, for he is lucky to have survived it in the first place.

What if Messier were to return to our time? He would be amazed at the ease by which visual comet hunting can be done, as well as the increased difficulty in finding a comet when well-funded electronic searches compete with amateur astronomers. With a computer star chart riding with my telescope, I know instantly what my telescope is showing at any particular moment. On the morning of October 2, 2006, for example, the chart showed a rich field of stars with the planet Saturn in the field center; it did not display, however, the faint fuzzy spot that turned out to be my 22nd comet discovery, a new comet that will make a close approach to the Earth when it returns at the end of 2011. Messier obviously did not have such technology at his disposal; he used his telescope and a printed star atlas, trusted friends that remained the classic way to search the sky until just a few years ago.

For all of Messier's brilliance, his famous catalog was primarily an observing tool, and Stoyan's writing confirms this crucial footnote to history: by keeping a record of the objects that could be mistaken for comets, Messier provides himself and posterity an invaluable resource. The pages you are about to read delve further into what his list looks like after 200 years, and particularly the astrophysics that lies behind each of the clusters, nebulae, and remote galaxies that constitute it. Stoyan does not take a position on one of the questions of our time – should the double cluster in Perseus be added to the list?

Yes, there is a need for "yet another" Messier catalog book. Stoyan has done a masterful job giving his readers a modern look at Messier's greatest accomplishment. May this book inspire you to learn about the man and his project, and more importantly, may it encourage you to don a coat, grab a telescope, and enjoy this window into the deep sky for yourself.

Preface

The catalog gathered by the French astronomer Charles Messier (1730–1817) has been the most popular compilation of astronomical objects beyond our Solar System for more than 200 years. It contains 110 star clusters, nebulae, and galaxies, among them most of the brightest and finest deep sky highlights that are visible from northern skies.

Amateur and professional astronomers alike have turned their telescopes time and again to the Messier objects. Numerous books have covered them, and numerous websites attest to their unwavering popularity. However, a current overall picture of the catalog and its objects was missing, as much information currently disseminated is actually outdated. So, for the first time since Robert Burnham's famous *Celestial Handbook*, a thoroughly investigated new account with historical, astrophysical, and observational information on all the objects had to be conducted.

Many discrete tasks were associated with this book. Historical information on Charles Messier, his observations and his catalog had to be compared to latest level of knowledge. In addition to our own research, the biography published by Jean-Paul Philbert in the French language proved especially helpful. The main task was the compilation of recent astrophysical information on all of the objects. More than 500 scientific papers were compiled and evaluated. These texts are complemented by extensive observational notes, which incorporate the visual use of large modern reflectors.

A major part of the book is the more than 150 fantastic photos by leading amateur astrophotographers from all over the world. Occasionally, these images are accompanied by photographs from the Hubble Space Telescope, where this adds value. In addition, an extensive collection of visual drawings is shown, both from the classical era of the nineteenth century, as well as modern sketches drawn by the author himself.

The compilation of this book took much effort over the past five years. Many of the images were prepared exclusively from such exotic spots as Greece, Chile, and Namibia. They combine more than 5000 minutes of photographical exposure and 150 hours of visual observation. From the original German edition, which was released in 2006, information and photos have been updated and improved.

I owe a very personal thank you to the co-authors of this book. Stefan Binnewies, the well-known German astrophotographer, conducted the orchestra of his colleagues. Susanne Friedrich, professional astronomer and amateur alike, ensured the quality of the astrophysical information. Finally, Prof. Klaus-Peter Schroeder, also a professional astronomer, who has worked in the United Kingdom and the United States for decades, translated and updated the texts.

A deeply felt thank you goes to the astrophotographers who contributed so much to this book, especially to the teams of Volker Wendel and Bernd Flach-Wilken, Josef Pöpsel and Dietmar Böcker, and Robert Gendler and Jim Misti. I would also like to thank Lutz Clausnitzer, Klaus Wenzel, Arndt Latusseck, Wolfgang Steinicke and Matthias Juchert, who helped in many respects on the German edition.

The fact that this book appears in an English language edition is almost a miracle. Among the many people who have helped that this dream became reality are Owen Brazell, David Eicher, Phil Harrington, Yann Pothier, and Stewart Moore. Additionally, I am greatly indebted to Sue French, who proofread the manuscripts and supported this project to a very great extent, and David Levy, who authored the foreword in his unparalleled manner. Finally, I would like to thank Vince Higgs and the team at Cambridge University Press for their support, work, and faith.

May this book give you new insights into your favorite deep sky highlights.

Erlangen, Germany
Ronald Stoyan

User guide

The data files

Degree of difficulty: rating of the observational difficulty:

1 object easily visible to the naked eye
2 object difficult to see with the naked eye
3 object easily visible in 8×30 binoculars
4 object easily visible in 10×50 binoculars
5 object difficult to see with 10×50 binoculars

For more information about visual and photographic difficulty, see page 63.

Minimum Aperture: minimum aperture required to see the object under a dark mountain sky, according to the personal experience of the first author. There are four categories:

- naked eye
- 15mm
- 30mm
- 50mm

Designation: catalog number in the NGC (New General Catalogue) or the IC (Index Catalogue).

Type: Object type. For a more detailed introduction to the different types, see page 53.

Class: Classification of the object, specific to its type:

- Galactic nebulae: distinction between emission nebula and reflection nebula, see page 53
- Open clusters: Trümpler classification, see page 55
- Globular clusters: concentration class, see page 56
- Galaxies: Hubble classification scheme, see page 61

Distance: Distance from Earth in light-years. As far as possible, uniform sources have been used, i.e.:

- galactic nebulae and open clusters: K2005 (Kharchenko, N.V., et al.: "Astrophysical parameters of galactic open clusters," Astronomy and Astrophysics 438, 1163 (2005)
- globular clusters: Rww2005 (Recio-Blanco, A., et al.: "Distance of 72 galactic globular clusters," Astronomy and Astrophysics 432, 851 (2005)
- galaxies: H2000 (multiple authors: "The Hubble Space Telescope Key Project on the Extragalactic Distance Scale," Astrophysical Journal 529, 698, 745, 786 (2000)
- Virgo cluster galaxies: V2004 (Sanchis, T., et al.: "The origin of HI-deficiency in galaxies on the outskirts of the Virgo cluster. II. Companions and uncertainties in distances and deficiencies," Astronomy and Astrophysics 418, 393 (2004)
- Virgo cluster galaxies: V2002 (Solanes, J.M., et al.: "The Three-dimensional Structure of the Virgo Cluster Region from Tully-Fisher and HI data," Astronomical Journal 124, 2440 (2002)
- extragalactic HII regions: HK83 (Hodge, P.W., Kennicutt, R.C., Jr.: "An atlas of HII regions in 125 galaxies," Astronomical Journal 88, pp. 296 (1983)

In addition, alternative results have been quoted, in order to demonstrate the uncertainty of the distances given. If available, the distance measurement method is indicated.

Size: physical diameter of the object, as calculated from its actual distance and angular diameter. The resulting values may differ from the ones stated by original sources. Spiral galaxies seen under some inclination may be underestimated.

Constellation: Latin name of the constellation in which the object is located

R.A.: Ascension for the equinox 2000.0

Decl.: Declination for the equinox 2000.0

Magnitude: apparent total visual brightness

Surface brightness: mean visual brightness in magnitudes per square arcsecond (not given for star clusters)

Apparent diameter: apparent (angular) photographic diameter

The texts

History

The historical sections include translations from the original quotations of historic observers from the seventeenth to the early twentieth century. In part, these have been translated from the original. Where not available, they had to be taken as quotes from secondary literature. English quotations are given, as far as available, in their original wording.

Frequently, the term "resolution" (of an object) is used in historic texts – not just for star clusters, but for galaxies and nebulae as well. In the nineteenth century, that did not necessarily mean the resolution into individual stars, as we use the term today, but rather resolution of any kind of detail.

A short introduction to every historic observer quoted in this book can be found on page 28.

Astrophysics

Ever since the publication of the famous "Burnham's Celestial Handbook" in the 1970s, amateur astronomers have been waiting for a new, up-to-date compilation of astrophysical data on all Messier objects. A lot of literature, internet sources in particular, refers to outdated values.

For this book, the content of over 500 professional, up-to-date publications was researched. This was made possible by the use of the Internet and the free NASA service known as the Astrophysical Data System (ADS), which is an on-line collection of almost all scientific publications in astronomy. The exact citations are given in the Appendix.

Where possible, no sources older than 10 years were used, but a few objects have received little attention in modern references. Other objects (M 1, M 31, M 42) catch a lot of professional attention, and the vast amount of literature dealing with them would easily permit a much more detailed treatment. However, space restrictions limited this book to the most relevant information.

In many cases, the research presents surprises: modern scientific results often disagree completely with what is commonly believed as the result of outdated literature. This trend will continue, as there is a steady stream of new observations and their astrophysical interpretation. Hence, the statements made in this book must be regarded as only a momentary picture of our knowledge from the years before 2007. Many questions remain unanswered, and we expect new insight into topics such as dark matter, black holes or the age of the Universe. This may affect how some aspects of the Messier objects will be explained in the future.

Another common problem is the disagreement of modern sources from one another. Different authors have different opinions, and different methods yield different results. Generally accepted knowledge grows out of long debate and testing. This is part of the lively nature of a quickly developing science such as modern astrophysics.

Observation

The information and advice given for the visual observation of each object is based on the personal experience and observation of the first author, using telescopes of different apertures. Each object has been observed on several occasions, some more than a dozen times. The instrumentation used consisted of:

- 3.5×15 opera glass, "Theatis" made by Carl Zeiss Jena
- 8×30 binoculars, "Deltrintem" made by Zeiss Jena
- 10×50 binoculars, "Dekarem" made by Carl Zeiss Jena
- 20×100 binoculars, made by Miyauchi
- 120/1020mm (4.7-inch) refractor "Star 12ED," made by Astro-Physics, magnifications from 25× to 255×, in exceptional cases 340× and more
- 360/1780mm (14-inch) Newtonian on a Dobsonian mount, magnifications from 45× to 593×, entirely manual operation, observing sites in the German countryside (Kreben, naked-eye limiting magnitude 6.5, sky surface brightness 21.0 mag/arcsecond^2) and Austrian Alps (Tiefenbachferner, naked-eye limiting magnitude 7.0 mag, sky surface brightness 21.6 mag/arcsecond^2)
- 500/2500mm (20-inch) Newtonian on a Dobsonian mount, magnifications from 63× to 625×, Farm Tivoli, Namibia (naked-eye limiting magnitude 7.5, sky surface brightness 21.8 mag/arcsecond^2)

Observing comments refer to a very experienced observer and excellent observing sites with a dark, moonless sky. We have purposely omitted star charts and all advice on finding the objects, since there is already a vast literature on these aspects, useful even to the first-time observer. However, we recommend a versatile software-based approach, "Eye & Telescope." It produces star charts and visibility information based on actual sky conditions and the instrument used.

The pictures

Selected images showcase the fantastic results of the amateur astrophotographer's community. To document astrophysical aspects beyond the reach of amateur photos, we have complemented the material with NASA pictures of many Messier objects, obtained by the Hubble Space Telescope (HST).

Some Messier objects are particularly popular with amateurs, and good images are abundant. Others grab almost no attention and only a few pictures of lower quality are available. It's virtually impossible to get photos of uniform quality for all 110 objects. For this reason, the scale and depth (i.e., limiting magnitude) of the photos vary from object to object.

The photos printed in this book were taken in the years between 1995 and 2007. The most common technique is tri-color (red, green, blue) photography with a cooled CCD camera and (L)RGB filter wheel. With a few exceptions, traditional film-based photography can no longer compete, while the new era of digital cameras and DSLRs is just about to begin. For accurate technical information on each picture, refer to the picture credits in the appendix section.

The color reproduction is neither uniform, nor should it be regarded as quantitatively correct. Color-balance and saturation depend on a number of factors, such as chip-characteristics, filter-transmission, software and personal judgment during image processing. The result is often subjective, perhaps aimed at reproducing the colors of professional photos. After all, techniques of absolute color calibration are time-consuming and do not apply to some types of astronomical objects, most notably the emission nebulae.

The techniques used by amateur astronomers for their image-processing work differ a lot from person to person, and there are no general standards. Some photographers would remove traces of planetoids, satellites or ghost-images by hand, on a pixel-to-pixel basis, others accept them as part of the authentic picture. Composite images made from several different exposures change the perception of the intensity range. This technique is used to accommodate large intensity variations and to avoid "burnt-out" central regions. But it may make stars on bright nebulous background appear significantly less brilliant than they are in reality. A good example is the Trapezium in the Orion Nebula. Hence, a quantitative interpretation of such a photo is impossible, but amateur astrophotographers are happy to accept that, in order to produce the most appealing image of an object.

Together with the photographs, historical and modern drawings have been reproduced here. The manual sketch of an object as perceived through the telescope eyepiece was the only scientific method of recording until the late nineteenth century, after which photography finally took over. This book shows a large number of fine sketches from the pre-photographic era. Differentiating real physical changes in the objects from artistically diverse sketching styles and personal

A photo in the works: M 42. At left is a single image taken with the green filter, in the middle a raw tri-color image, at right the fully processed LRGB composite.

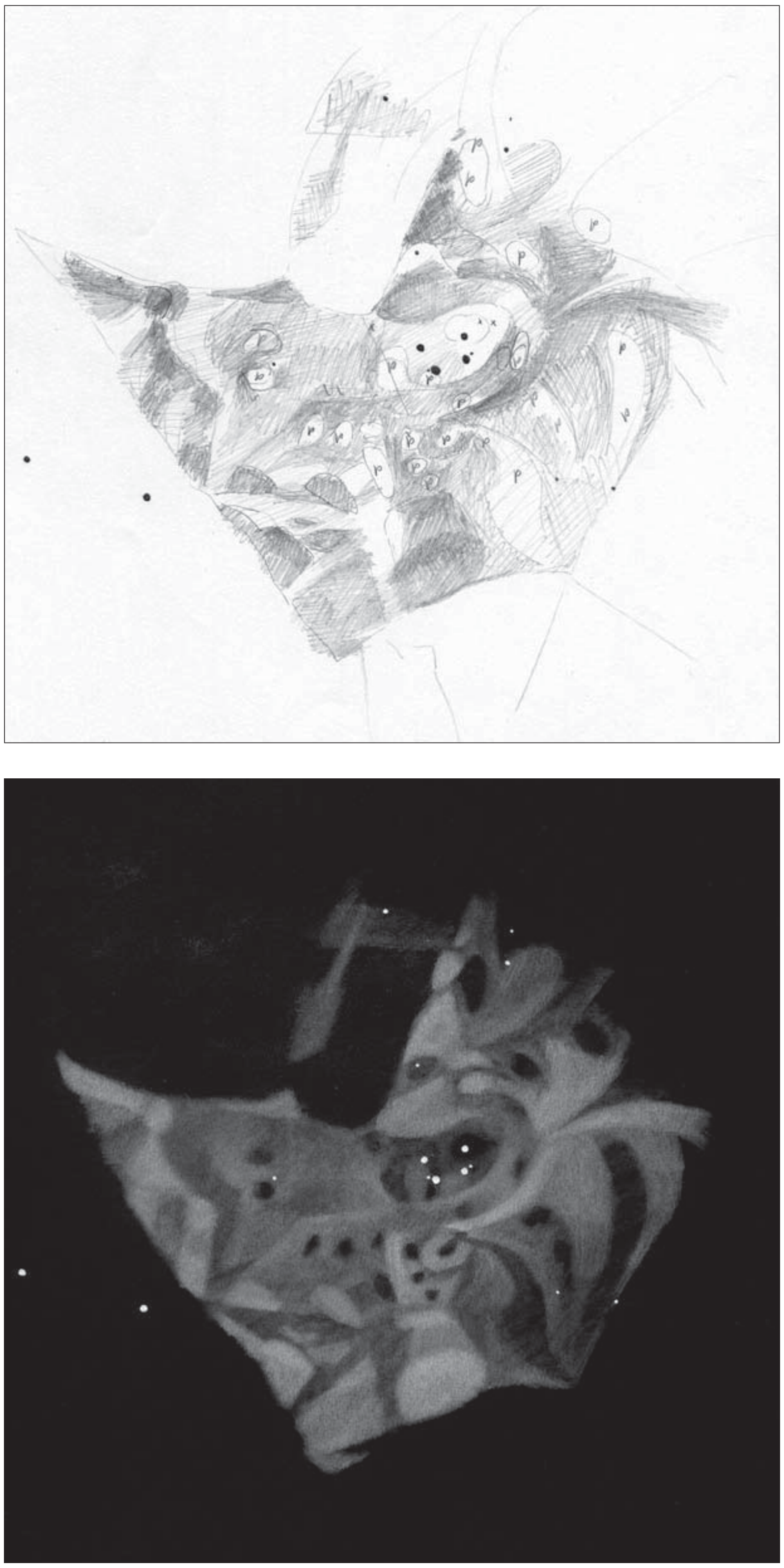
perceptions had been a continual problem. Today, amateurs keep the tradition of astronomical drawings alive, in order to sketch their visual impression of a specific object.

Drawings are subjective and contain erroneous perceptions. Nevertheless, this method is an independent recording technique, complementary to the capabilities of photography. Before criticizing historical drawings for their misconceptions, we should keep in mind that it is always easier to verify a known feature than to discover it. In that sense, the historic drawings must be regarded as more "honest" than their modern counterparts. Even the most critical modern observer cannot avoid the subconscious knowledge of an object by modern photography and its influence on his or her perception of it.

Drawings differ from photographs in a number of ways. For one, the eye can not accumulate light over a long time, as a photographic emulsion or chip can. Furthermore, the visual response to a large brightness range is much more logarithmic than the photographic response. And finally, the spectral response of the eye also differs from that of photographic emulsions or chips. With emission nebulae, in particular, visual and photographic views emphasize different features.

The author's drawings were specifically made for this book. The objects were observed several times with different apertures. Frequently, several attempts were required before an acceptable result was achieved. All the sketches are of a cumulative nature: each drawing summarizes the visual impressions of an object collected over many hours or even nights under a dark sky in the countryside, in the mountains or in the Namibian desert. The results are not to be confused with a quick sketch made by the eyepiece! The observing time involved was at least an hour, as for a simple elliptical galaxy, and up to three nights for large objects with a lot of detail.

The original sketches are drawn with pencil, black on white. So are the proper drawings, using in addition an eraser and a smudging tool. For an inversion to white on black, the drawing is scanned and the tonal range adjusted, but no further digital manipulations are made. Subtle contrasts are over-pronounced by the drawings, as they would otherwise be lost in print.



A drawing in its work-stages: M 42. Above is the original pencil sketch, below the properly redrawn and then inverted result.

Charles Messier

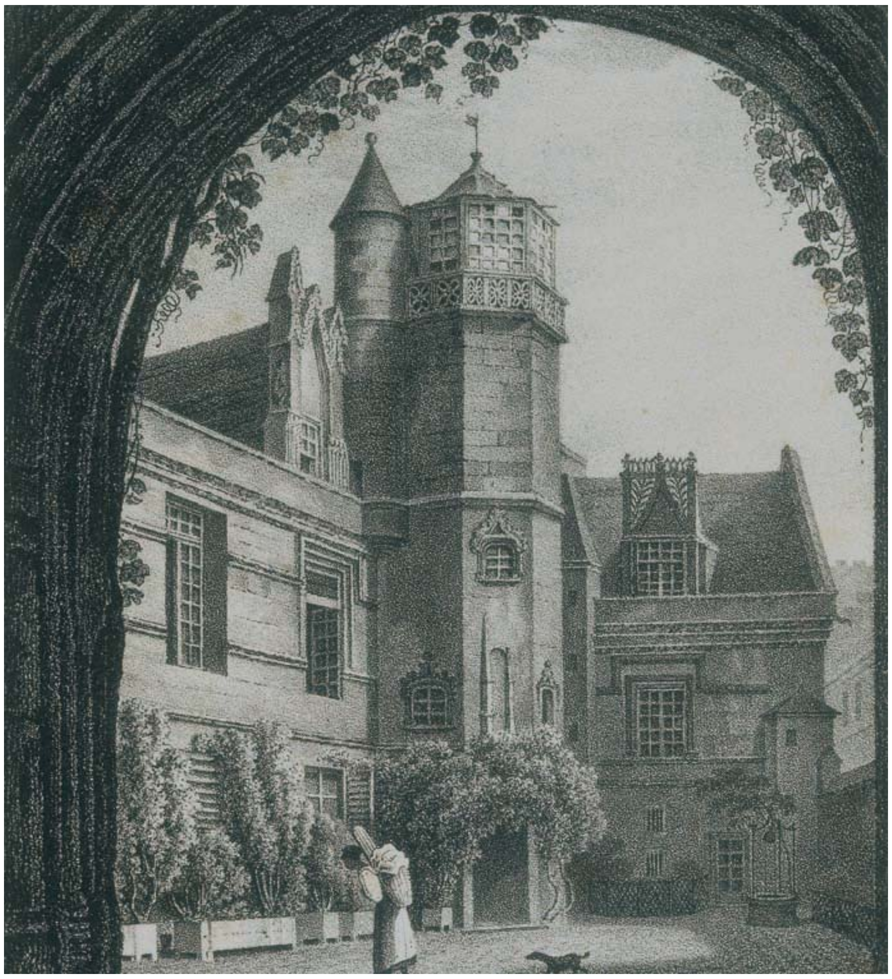
1730 to 1751: Childhood and adolescence

Charles Messier was born on the 26th of June 1730 in Badonviller, as the tenth child of the court bailiff Nicolas Messier (1682–1741) and his wife Françoise (maiden name Grandblaise, deceased 1765). His home village lies near the former German–French language border in the western part of the Vosges Mountains in Lorraine. In Messier's days, that region did not belong to France but to the independent dukedom of Salm. The Messier family was one of the richest in the little state, with high-ranking positions and excellent connections, which would later be very helpful to the young Charles.

He grew up in a house opposite the evangelic church of Badonviller, by a square which today bears his name. Six of his siblings died in their early childhood. An important role in Charles' life was played by his eldest brother Hyacinthe, who was older by 13 years. Hyacinthe started his professional career as an auctioneer and, eventually, became the highest financial officer of the dukedom. When their father died in 1741 – Charles was only 11 years old then – Hyacinthe was already able to take care of the Messier family. He gave Charles an apprenticeship in his office, mostly involving paper work. That helped develop the boy's good writing and drawing skills, and the accuracy required for finance and business. His first interest in astronomy was sparked by the large, six-tailed comet of 1744, discovered by the Swiss de Chéseaux, and the annular solar eclipse of 1748.

The year 1751 brought important changes to the life of the Messiers. The dukedom of Salm lost its independence by becoming part of Lorraine, which later fell to France by annexation. Only the former residence of the dukes of Salm, the village Senones, a few kilometers from Badonviller, retained its independence and was to become the new home of the Messier family. Now at the age of 21, it was time for Charles to seek a life of his own. With the help of a good family friend, who had contacts in important circles in Paris, an assistantship at the new Naval Observatory in Paris became available to Charles Messier. It was not really his interest in astronomy which got him the offer, but his good skills as an office assistant. He left Badonviller on the 23rd of September 1751.

Charles Messier at the age of 40, painted by Ansiaume. Messier commented that his portrait was most appropriate but made him look younger than he really was.



Drawing of the Hôtel de Cluny, from the beginning of the nineteenth century. The octagonal sheltered platform of the tower is Messier's observatory.

Today, the Hôtel de Cluny is one of the most beautiful medieval buildings of central Paris. It hosts the National Medieval Museum, but there is no commemoration of the work of Charles Messier.

1751 to 1757: Assistant of the Naval Observatory

Joseph-Nicolas Delisle (1688–1768), who taught mathematics and astronomy at the Collège Royal in Paris (later to be the Collège de France), built a private observatory on the stair-tower of the Hôtel de Cluny in 1747, opposite to the Collège Royal. Originally, the Hôtel de Cluny was the Parisian residence of the Benedictine monks from the great abbey in Burgundy. Later, it became the property of the French Navy. In 1754, the aged Delisle made a deal: he signed over the observatory to the Navy and in return, he received the custom-tailored title "Astronomer of the Navy."

Delisle's humble observatory stood in the shadow of the established Royal Observatory of Paris, which was well known as a leading European institution for astronomers like Huygens, Cassini, and Maraldi. Delisle, by contrast, was not part of the French astronomy establishment. Hence, Messier entered a professional environment which allowed him to pursue his astronomical interests without any scientific obligations, but which also branded him from the outset as an outsider to professional astronomy.

The childless Delisle couple received and hosted Messier as though he were their own son, and he lived with them in their apartment in the Collège. Delisle's assistant Libour introduced Messier to the basics of astronomy, and the young Messier's first tasks were to make hand-drawn copies of maps and to write the observing logs.

Delisle had been in personal contact with the late, famous English scientists Newton and Halley. The latter had pointed out in his famous work of 1705 that the comet apparitions of 1456, 1531, 1607, and 1682 were due to the same physical comet, which would reappear in 1758. Delisle made an independent calculation of the comet's orbit and derived April 1759 for the perihelion passage. Based on his master's work, Messier drew a map of the comet's path among the stars and had orders to watch for it from the summer of 1758 onward. That comet hunt was the first real astronomical task given to the 28-year-old, who so far had carried out only basic observations. Messier understood that this was the chance of a lifetime; he wanted to be the first to prove Halley's milestone work.

But life took a different course. While Messier did rediscover the comet on the 21st of January 1759, he soon had to learn that a farmer in Saxony had beaten him by about a month: the previously unknown amateur astronomer Johann Georg Palitzsch (1723–1788) from Prohlis near Dresden had already spotted Halley's Comet on Christmas night 1758. Messier had confined his search to Delisle's orbital path for too long. And to his great dismay, Messier could not even get his master's permission to publish his independent discovery, since Delisle did not believe that he'd made a mistake in his calculations. He thought the comet was an unrelated object. Messier bowed to the wishes of his master and host and withheld his obser-

City map of Paris from the year 1771. The Hôtel de Cluny (1) and the Royal Observatory of Paris (2) are circled.

Custos Messium – a constellation for the comet hunter

In 1775, the first version of the now enormously popular Messier catalog of 110 nebulae had been out for one year, with then only 45 objects. However it was his achievements as a record-breaking comet discoverer that made Charles Messier the publicly best-known astronomer of his country. In fact, Messier had discovered practically all the comets of the past 15 years. He had been a member of the elite circle of the French Academy of Sciences since 1770. But now, a very special honor was awarded to him, unprecedented in the history of astronomy.

The constellation Custos Messium (Harvest Guardian), pictured in Johann Elert Bode's "Vorstellung der Gestirne" (1782).

Jerôme de Lalande (1732-1807), a famous author, professor and colleague of Messier, created a new constellation on his freshly published stellar globe: "Custos Messium" (lat.), the "Harvest Guardian." Concerning his motives, Lalande wrote: "This name will remind future astronomers of the courage and diligence of our industrious observer Messier, who since 1757 appears occupied with the sole task of patrolling the sky to discover comets." Contemporary French star charts happily included the new constellation under its French name "Messier," picturing a guardian who watched over a cornfield.

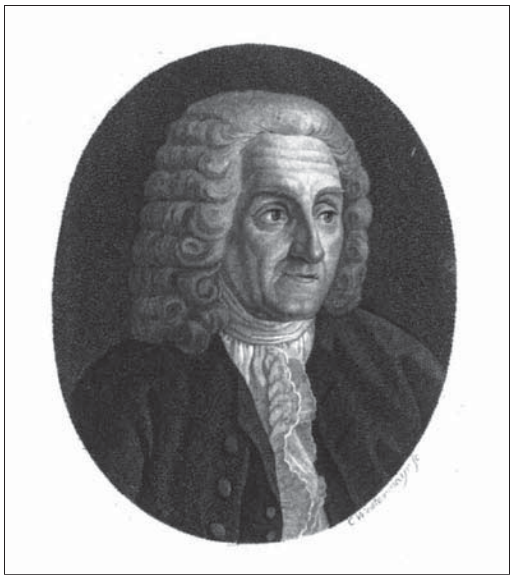
The "Harvest Guardian" had its place north of Cepheus, Cassiopeia, and Camelopardalis. Today, its space has become part of these three constellations. Messier's constellation held only one noticeable star, 40 Cas, and no remarkable deep-sky objects. As Messier related, Lalande chose that particular part of the sky, because it once hosted the comet of 1774, discovered by Montaigne. It was the only one of 14 comets that, following the death of his wife, Messier failed to discover himself. These were two big losses, which Messier could not bear – and Lalande must have been aware of that.

Lalande created two other new constellations: "Felis," the cat (between Hydra and Antlia), in memory of his favorite pet, and "Globus Aerostaticus" (between Capricornus and Piscis Austrinus) to commemorate the invention of the hot-air balloon by the brothers Montgolfier and their first air-borne voyage in 1799. All three constellations were included in J.E. Bode's Prussian star atlases – despite, certainly, some national rivalry. But in return, Lalande would include in his atlases the "Brandenburg Scepter," "Frederick's Honor," and the "Mural Quadrant," which Bode had invented. Nevertheless, all these new constellations fell out of use only 80 years later.

Joseph Jérôme le Français de Lalande, colleague and friend of Messier. Engraving by André Pujos.

vations for three months, until it was finally clear that Delisle was wrong. However, the long-delayed publication aroused suspicion and skepticism among the royal astronomers in Paris. His independent discovery was not acknowledged – a disappointment that Messier would not forget for a long time.

In hindsight, we know that the by-products of Messier's diligent comet hunt were much more rewarding. In August 1758, when he was observing the comet discovered by de la Nux, Messier came across a yet unknown nebula which looked exactly like the comet. This discovery sparked the idea for his catalog, which retains Messier's name to this day. Hence, Messier made good use of that chance of a lifetime, after all – albeit in quite a different way than he, the comet enthusiast, had anticipated.



Johann Georg Palitzsch succeeded in what Messier tried in vain: he was the first to rediscover Halley's comet on its return in 1758.

1759 to 1770: Comet discoveries and recognition

Comet hunting became an obsession for Charles Messier. Between 1758 and 1804, he spent more than 1100 nights on this task. He became the first real "comet hunter" in history, with a prototypical character: a most diligent observer with humble equipment but much enthusiasm, who would search for new comets with systematic endurance. He observed 44 comets altogether, more than were known to science before him. He discovered 21 comets, 6 of which are regarded today as co-discoveries. Messier was, in fact, the first observer who systematically used the telescope for comet hunting. Before him, comets were usually discovered with the naked eye. But he did not leave it with the discovery of a comet. He would observe every comet for as much and as long as possible; his record was 71 nights over a period of 6 months. Furthermore, Messier measured comet positions to make orbit calculations possible. He never did that himself, though, as he was entirely devoted to observation. None of his many publications would contain a single bit of math or theoretical work.

In that respect, Messier's close friendship with Jean Baptiste Gaspard Borchart de Saron (1730–1794) was most beneficial. Saron came from an established, noble family and was soon to become the royal state-attorney, and later even president of the parliament. Theoretical astronomy was one of his hobbies – a perfect match: Saron's quick calculations were essential to Messier's success, because these allowed him to find a comet again, even after a long period of bad weather.

Joseph Nicolas Delisle, teacher and benefactor of Messier. Engraving by Konrad Westermayr.

For the discovery of the great comet of 1760, Messier was still a day late. But only a few days later, on the 26th of January 1760, he discovered the first comet named after him. In the following years, Messier nearly achieved a monopoly on comet discoveries: all eight known comets between 1763 and 1771 were discovered by him!

Messier was active in other respects, too. Between 1752 and 1770, he observed 93 lunar occultations and 400 eclipses of Jupiter's satellites, he watched 5 solar eclipses, 9 lunar eclipses, and he measured 400 stellar positions. Over the course of his lifetime, Messier followed four Mercury and two Venus transits, and he did a lot of planetary observing, especially on Saturn. In 1767, he made a three-month-long sea cruise to test astronomical clocks on the coasts of the Netherlands and Belgium.

Recognition by the international science community was soon to follow. In 1764, he became elected a fellow of the English and Dutch scientific academies. Such academies were of crucial importance in the eighteenth century. Only their membership made it possible to exchange correspondence with the leading scientists of the time and gave access to the accumulated knowledge of their libraries. Messier had to wait a long time for admission to the French academy of the sciences – in Paris, the skepticism aroused by his long withheld observations of Halley's comet were still not forgotten. But, at least, his salary was raised in 1765, after the retirement of Delisle from active research. Messier's breakthrough with the French astronomy establishment came with his discovery of the great comet of the year 1769. That comet was a spectacular sight, and it made its discoverer's name so popular with the general public that the king would personally receive a map drawn for him by Messier. The king nicknamed Messier "the comet nest-robber," because for many years not a single comet "slipped out of its egg" that hadn't already been discovered by Messier. This idea then developed into the popular nickname "the comet-ferret."

The role-model: Nicolas-Louis de Lacaille

Nicolas-Louis de Lacaille (1713–1762) was born on the 15th of May 1713 in Rumingy near Reims. As a son of noble parents, he began to study theology in Paris. He was 26 when he made his first recorded astronomical observations. Soon, he became professor at the Collège Mazarin in Paris, where in 1746 he constructed an observatory, and finally in 1741 he was admitted to the French Academy of Sciences, with the support of the Duke of Bourbon.

Lacaille was well known for his accurate observations and an over-eagerness to work – in fact, he died of overwork on March 21st, 1762. Hence, in 1751, the French academy chose him for a longer stay at the Cape of Good Hope, in order to accurately measure geographic longitudes and the positions of southern stars. Meanwhile, his scholar Lalande was his counterpart in Berlin for a program of simultaneous observations, which led to improved distance measurements of the planets and the Moon.

Abbé Nicolas-Louis de Lacaille, painted by Melle Le Jeuneux, 1762

Lacaille arrived in South Africa in April 1751. At the foot of Table Mountain, which he honored with the constellation "Mensa," he began the observations for a southern star catalog in August 1751. For that work, Lacaille used a mural quadrant, equipped with a very small telescope of only ½-inch (12.5mm) aperture and a magnification of 8×. A year later, in July 1752, this catalog contained the positions of 9776 stars.

While cataloging the heavens, Lacaille made a list of the nebulous objects he came across, which he published in 1755. It was the first of its kind, and it is appended to Messier's third and final catalog. Thirteen new southern constellations were created by Lacaille as a by-product of his work: Antlia, Caelum, Circinus, Fornax, Horologium, Mensa, Microscopium, Norma, Octans, Pictor, Reticulum, Sculptor, and Telescopium. With these, Lacaille filled in the coarser pattern of southern constellations created 150 years earlier by Keyzer. In addition, Lacaille changed the name of the constellation Abies into Musca – not to be confused with a lost northern constellation of that name – and he suggested splitting the huge constellation Argo Navis into Carina, Vela, Pyxis, and Puppis. About 100 years later, these suggestions became widely accepted as astronomical conventions.

The next year (1770), Messier discovered a comet, which was identified by the Swedish observer Lexell as a periodic comet. Two weeks after that discovery, Messier was finally admitted to the French Academy of Sciences, followed by membership in nearly all of the remaining foreign scientific associations. In addition, he received another pay rise and, in 1771, he inherited the title invented for Delisle, "Astronomer of the Navy."

1770 to 1789: Changing private fortunes and observational successes

On the 26th of November 1779, Messier married the daughter of a noble professor, Marie-Madeleine Dordolot de Vermauchampt, who was three years his junior. For 15 years, they had lived under the same roof in the Collége Royal. But in the absolutistic France of that time, a marriage between a bourgeois and a noble lady would have been impossible. Only the recent great success of Charles Messier changed their fortunes. In 1771, they moved into an apartment of their own in the Hôtel de Cluny – it was then only a few steps from Charles' bedroom to the observatory.

1771 must have been one of the best years in Messier's life. Besides his personal good fortune, he discovered two comets and completed the first version of his catalog, then totalling 45 nebulous objects, although Messier considered the latter a mere by-product of his searches, as he just wanted to avoid confusion when he was comet-hunting.

On the 15th of March 1772, there was another reason for Messier to rejoice: his wife gave birth to a son, Antoine-Charles. But then his fortunes changed dramatically: a week later, Marie-Madeleine Messier died of puerperal fever, and the little baby followed her on the 26th of March. Messier's reaction to this heavy double-blow to his private life is difficult to assess. The fact is, however, that he started a four-day observing campaign on comet Montaigne – the first comet in almost 10 years which had not been discovered by him – the very night his son died.

In August 1772, Messier travelled to the dukedom of Salm, which in his own words he regarded as his "Fatherland." He stayed some time with his eldest brother in Senones, following earlier visits in the years 1758, 1762, and 1770. Not surprisingly, Messier continued an intense observing schedule during that family visit. On his return to Paris, he was accompanied by his nephew Joseph-Hyacinthe and by his sister Barbe, who would take care of her brother until her death in 1797.

The following years were characterized by continued comet observations. In 1780, Messier published the second version of his catalog, which contained 68 nebulous objects. The first new objects were found soon after his original catalog was printed. But Messier did not keep looking systematically for new objects, he just recorded accidental findings during his comet observations. Nevertheless, the third version of his catalog, with 103 objects, came out in 1781. This was mostly due to the wealth of input from his new colleague Pierre Méchain (1744–1804). Despite more such discoveries by Méchain after 1781, there were no further catalog versions.

Table: 44 comets, observed by Charles Messier

Popular name	Old designation	Messier's first observation	Messier's last observation	Number of nights observed	Date of discovery	Discoverer
		Aug 14,1758	Nov 2,1758	31	May 26, 1758	de la Nux
P/Halley	1759I	Jan 21, 1759	May 1, 1759	47	Dec 25, 1758	Palitzsch
Great Comet	1759III	Jan 8, 1760	Jan 30, 1760	6	Jan 7, 1760	Chevalier
Messier	1759II	Jan 26, 1760	Mar 18, 1760	22	Jan 26, 1760	Messier
		May 28, 1762	Jul 5, 1762	20	May 17, 1762	Klinkenberg
Messier	1763	Sep 28, 1763	Nov 24, 1763	29	Sep 28, 1763	Messier
Messier	1764	Jan 3, 1764	Feb 11, 1764	16	Jan 3, 1764	Messier
Messier	1766I	Mar 8, 1766	Mar 15, 1766	8	Mar 8, 1766	Messier
P/Helfenzrieder	1766II	Apr 8, 1766	Apr 12, 1766	5	Apr 8, 1766	Helfenzrieder
Messier	1769	Aug 8, 1769	Dec 1, 1769	42	Aug 8, 1769	Messier
P/Lexell	1770I	Jun 14, 1770	Oct 3, 1760	47	Jun 14, 1770	Messier
Great Comet	1770II	Jan 10, 1771	Jan 20, 1771	4	Jan 10, 1771	Messier
Messier	1771	Apr 1, 1771	Jun 15, 1771	48	Apr 1, 1771	Messier
		Mar 26, 1772	Apr 3, 1772	4	Apr 8, 1772	Montaigne
Messier	1773	Oct 12, 1773	Apr 14, 1774	71	Oct 12, 1773	Messier
		Aug 18, 1774	Oct 25, 1774	41	Aug 11, 1774	Montaigne
Bode	1779	Jan 19, 1779	May 19, 1779	63	Jan 6, 1779	Bode
Messier	1780I	Oct 27, 1780	Nov 28, 1780	13	Oct 27, 1780	Messier
Méchain	1781I	Jun 30, 1781	Jul 16, 1781	14	Jun 28, 1781	Méchain
Méchain	1781II	Oct10, 1781	Nov 5, 1781	12	Oct 9, 1781	Méchain
		Nov 27, 1783	Dec 21, 1783	13	Nov 19, 1783	Pigott
		Feb 3, 1784	May 25, 1784	13	Jan 24, 1784	Cassini
Messier	1785I	Jan 7, 1785	Jan 16, 1785	6	Jan 7, 1785	Messier
Méchain	1785II	Mar 13, 1785	Apr 16, 1785	14	Mar 11, 1785	Méchain
P/Encke	1786I	Jan 19, 1786		1	Jan 17, 1786	Méchain
		Aug 1, 1786	Oct 26, 1786	43		C. Herschel
Méchain	1787	Apr 11, 1787	May 20, 1787	6	Apr 10, 1787	Méchain
Messier	1788I	Nov 25, 1788	Dec 29, 1788	20	Nov 25, 1788	Messier
		Jan 3, 1789	Jan 6, 1789	2	Dec 21, 1788	C. Herschel
		Jan 19, 1790		1	Jan 7, 1790	C. Herschel
P/Tuttle	1790II	Jan 10, 1790	?	7	Jan 9, 1790	Méchain
		May 1, 1790	Jun 9, 1790	45	Apr 17, 1790	C. Herschel
		Dec 26, 1791	Jan 28, 1792	12	Dec 15, 1791	C. Herschel
		Feb 1, 1793	Feb 14, 1793	6	Jan 10, 1793	Gregory, Méchain
		Sep 27, 1793	Dec 8, 1793	25	Sep 24, 1793	Perny
Messier	1793I	Sep 27, 1793	Jan 7, 1794		Sep 27, 1793	Messier
		Aug 16, 1797	Aug 30, 1797	13	Aug 14, 1797	Bouvard
Messier	1798I	Apr 12, 1798	May 24, 1798	27	Apr 12, 1798	Messier
		Dec 7, 1798	Dec 12, 1798	4	Dec 6, 1798	Bouvard
Méchain	1799I	Aug 10, 1799	Oct 25, 1799	44	Aug 7, 1799	Méchain
Méchain	1799II	Dec 28, 1799	Jan 6, 1800	5	Dec 26, 1799	Méchain
Pons	1801	Jul 12,1801	Jul 21, 1801	5	Jul 12, 1801	Pons, Messier, Méchain, Bouvard
		Aug 30, 1802	Sep 5, 1802	7	Aug 26. 1802	Pons
		Mar 11, 1804	Mar 17, 1804	6	Mar 7. 3. 1804	Pons

adopted from: Philbert, J.P.: Charles Messier – le furet des comètes

The 13th of March in that same year saw the discovery of the planet Uranus by William Herschel in England. At first, Herschel took his new object for a possible comet and asked Charles Messier for his opinion. The same day he received Herschel's letter, Messier observed Uranus. Messier passed his positional measurements down to de Saron to calculate the orbit. His mathematical friend was quick to realize that Uranus was not a comet but a new planet.

After 1781, Herschel would find over 2000 new nebulous objects with his much better telescopes. However it was not only this superior competition that stopped Messier working on nebulae, but also another blow of fate: on the 6th of November 1781, Messier was on a walk with his family in the Park Monceaux. His curiosity led him to inspect the entrance to a basement, when he slipped and fell 8 m (24 feet) into a deep ice-storage cellar. Messier was seriously injured, and had broken his upper leg, upper arm, two ribs and the wrist of his hand. He lost a lot of blood from an open wound over his eye. It took him the better part of 1782 to recover from this bad accident. His leg had to be broken again, after the bones had healed at an angle. Messier was bed-bound for a long time, and he always limped thereafter. Herschel, who paid him a personal visit in Paris 20 years later, remarked that Messier never fully recovered from that injury. It was a full year after that accident before Messier was back in his observatory, on the occasion of the Mercury transit of the 12th of November 1782.

The competitor: Johann Elert Bode

Messier not only reinvented comet hunting, he also sparked new interest with his contemporaries in the observation of nebulae and star clusters. The German astronomer Johann Elert Bode (1747–1826), who like Messier published an annual almanac, entered into a direct competition with the French astronomer in 1777, by presenting his own catalog of nebulous objects.

Bode developed an interest in astronomy at a young age. He observed the night sky from a hatch in the roof of his parents' house in Hamburg. By chance, a math professor saw Bode's notes and encouraged him to write a popular astronomy book. In 1768 at just 21 years old, Bode published the guidebook "Deutliche Anleitung zur Kenntnis des gestirnten Himmels" ("Concise manual to the knowledge of the starry sky"), which was received very well and reprinted several times. A later edition was used to publish the formula for the distances of the planets, which was soon known as the "Titius-Bode-Law."

Johann Elert Bode

Still an amateur astronomer, Bode observed the Venus transit of 1769. But in 1772, he began to work at the royal observatory of Berlin, and a few years later, in 1779, Bode discovered his first comet. Much like Messier, that discovery gave him recognition. He eventually became the director of Berlin Observatory in 1787 and kept that office for 38 years. Bode gained some fame as the founder of the "Berliner Astronomisches Jahrbuch" ("Berlin Astronomical Almanac") and with his book "Vorstellung der Gestirne" ("Introduction to the Constellations," 1782) and the monumental celestial atlas "Uranographia" (1801). By contrast to Messier, Bode was well connected in scientific circles. The name "Uranus" for the new planet discovered by William Herschel was his suggestion. And as director of the Berlin Observatory, he had excellent contacts all over Europe. In 1774, three years after the publication of Messier's first catalog of 45 nebulae, Bode started his own search for new nebulae and star clusters. He succeeded with some genuine discoveries (M 81, M 82, M 53, M 92) and a larger number of independent findings. In 1777, he compiled his "Complete Catalog of all Observed Nebulae and Star Clusters," based on his own observations as well as on all references he could find in the literature. At its time the largest deep-sky catalog, this included 75 objects. Bode continued to observe, and he always encouraged other observers to publish their data in his almanac. The 1779 volume contains a listing of objects found by Köhler from Dresden, and other editions reproduced the notes of Oriani and a translation of Messier's catalog.

An updated and enlarged list of contemporary observations of nebulae, still without knowledge of Messier's third catalog version but including the 68 objects of his second, was published by Bode in 1782 within the "Vorstellung der Gestirne." This list not only included several new discoveries, presumably made by Bode himself, but also the objects IC 4665 (already mentioned by Al Sufi) and h & χ Persei. Despite the substantial work of Bode in this field, his name is hardly known today, by contrast to popular Messier. One good reason may be that Bode did not check the positions of objects contributed from other observers. That caused many errors in his list. His listing of 1782, for example, contains three different entries for M 8, because Bode did not realize that the different positions from Messier, Le Gentil, and Köhler all referred to the same object. Hence, despite Bode's strive for completeness, Messier's final catalog of 1781 was, at its time, second to none in terms of quality.

1789 to 1804: In the turmoil of the French Revolution

The French Revolution began with the storming of the Bastille in Paris on the 14th of July 1789. As for so many, the following years brought chaos and insecurity to Messier. The structures of the French Navy were dissolved and maintenance of the observatory ceased. Frequently, Messier had to borrow oil for his observing lamp from his good colleague Lalande. The latter was now director of the former Royal Observatory of Paris, and they knew each other well from the days when they both taught at the Collège Royal. In 1793, by decree of the revolutionary directorate, all academies were dissolved, with serious consequences for Messier. A further tragic event for Messier was to follow on the 20th of April 1794 when his good friend and benefactor de Saron was guillotined under the reign of terror. Already in prison, he calculated his last comet orbit for Messier.

Fundamental changes were also imposed upon Lorraine. In 1793, the dukedom of Salm became part of revolutionized France by annexation, with significant consequences for the Messier family, which was closely involved with the local nobility. Some family members emigrated from France to Germany, following the dukes of Salm.

In 1795, a new astronomical institute was founded in Paris: the Bureau des Longitudes. Its original purpose was to outstrip the superiority of the English clocks. Messier was not among its founding members, like Méchain or Cassini, but he replaced the latter in the next year.

In 1798, still living in the Hôtel de Cluny, Messier was on his own again, after the death of his sister in the previous year. From Senones, his younger brother and his niece Josephine now came to live with him. Josephine would take care of Charles Messier until his death.

In 1801, Messier made his last comet discovery at the age of 71. Thereafter, he just lived off his past fame, which was finally recognized by the new regime. Napoleon personally bestowed him with the Cross of the Legion of Honour. This led Messier to make, in 1808, a connection between his discovery of the great comet of 1769 and the simultaneous birth of "the Napoleon the Great." This idea was so close to astrology that it did not go over well with most contemporary astronomers.

The colleague: Pierre Méchain

Thirty of the now so-called "Messier objects" were, in fact, discovered by Pierre Méchain (1744–1804). He was a close collaborator of Messier and helped complete his final catalog in the years 1779 to 1781.

Pierre Méchain was born in Laon. He planned to become an architect, but lack of finances forced him to abandon his studies. Rumour has it that he even had to sell his telescope, which he had bought as an amateur astronomer, and that the buyer turned out to be Jérôme de Lalande, later (1794) to become the director of Paris observatory.

Lalande had been astronomy professor at the Collège Royal from 1760 to 1767, as the successor of Delisle, and from 1794 to 1807 he was also editor-in-chief of the Connaissance des Temps. In 1772, he managed to get Méchain a job at the treasury of the French Navy in Versailles. Two years later, Méchain obtained the official position of a "calculator." The connection with Messier's friend Lalande initiated Méchain's contribution to the Messier catalog.

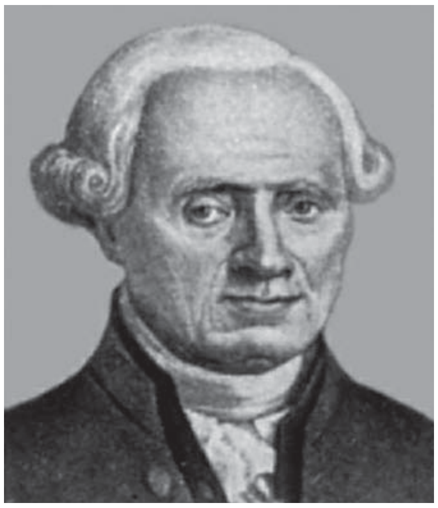
In 1781, Méchain found two new comets – eventually, his total score grew to eight discoveries. Unlike Messier, he was able to calculate his own orbits. His most famous discovery was the comet of 1786, which was proved by Encke's orbital calculations to be the second-known periodic comet (after Comet Halley).

From 1786 on, Méchain was engaged in longitude measurements. This work requires clocks much more accurate than those available at the time – a big problem for offshore navigation, as well as for geodesy on land. Hence, in 1791, the French Academy of Sciences started a project to define the French prime meridian from Dunkirk in the north to Barcelona in the south.

After the project finished in 1795, Méchain found an error of 3" in the calculated latitude of Barcelona (about 90 meters on the ground). We know now that this was due to a combination of instrumental inaccuracies and some deviation of the globe from a perfect sphere – but Méchain expended considerable effort trying to further increase the accuracy of the calculations.

In 1798, he succeeded Lalande as director of the Observatory of Paris. In 1804, during field work in Spain to revise the measurements along the French prime meridian, Méchain contracted yellow fever and died on the 20th of September 1804.

Pierre Méchain, painted by Hurle.



Portrait of the comet hunter from 1801, at the age of 71, drawn by Cless from Weimar. Messier was reasonably tall for his time, measuring 1.68m (5 feet 6 inches), a little chubby, and his hair turned white around the age of 60.

The last comet that Messier was able to observe was the great comet of 1807. Thereafter, he suffered from failing eyesight. After 1808, he could no longer read or write. In 1812, he became paralyzed on one side, and dropsy set in around 1815. Messier finally died on the 11th of April 1817 at the age of 87 years. Three days later, he was buried in the cemetery of Père Lachaise.

The speech at Messier's grave was given by Delambre, secretary of the reconstituted Royal Academy of Sciences. He commemorated the comet hunter with the words: "He did not write a single book, nor any treatise in general or in particular, but his observations will for a long time enrich the collection of the Academy. His famous colleague Lalande has created a constellation in his honor, the only one bearing the name of an astronomer. It will keep the memory of him alive, but his name will remain with science, independent of this honouring act of friendship: in terms of the catalog of comets, in which the name Messier has been recorded as often as honestly."

William Herschel continued with Messier's work. Painting by Contel, from an engraving.

The Observations

Work on the catalog

M 1 and M 2: Beginnings and motivation

Charles Messier's first encounter with a nebulous object occurred during his preparations for the return of Comet Halley. When he observed Comet de la Nux for that purpose in August 1758, he came across an object in Taurus, which looked very similar to the comet, but it did not move. It was the 28th of August 1758 when Messier discovered the Crab Nebula, now known as M 1. He obtained the position of this apparently new nebula two weeks later (12th of September). Messier did not know then that M 1 had already been found by Charles Bevis in England in 1731, and so took his observation for a new discovery. That kindled an interest that would eventually lead to his famous catalog. As he described it in 1801:

> *What made me produce this catalog was the nebula which I had seen in Taurus, September 12, 1758, while I was observing the comet of that year. The shape and brightness of that nebula reminded me so much of a comet, that I undertook to find more of its kind, to save astronomers from confusing these nebulae with comets. I continued to observe with telescopes suitable for the discovery of comets, which was the purpose I had in mind when producing this catalog.*

Messier did not start a systematic search straight away. However, it was two years before he found M 2, with a Gregorian reflector of 30-inch focal length and a power of 104×. Only later was he to learn, during a search for comet observations from other astronomers, that this object had already been discovered in 1746 by Jean-Dominique Maraldi (1709–1788). Again, Messier was not the original discoverer.

M 3 to M 40: Systematic search for nebulae

In May 1764, Messier finally started systematic work on the catalog of nebulae. He began with the "nebulosae" in the lists and literature known to him, in particular those from Hevelius, Huygens, Derham, Halley, de Chéseaux (of which, apparently, he had only an incomplete knowledge), Lacaille, and Le Gentil. In addition, he discovered new objects of his own; some of these, like M 39 and M 40, while trying to verify entries from old catalogs. In only five months, Messier observed and measured the positions of M 3 to M 40, including 19 genuine first discoveries. Hence, the first version of his catalog was more or less accomplished within half a year of work, from spring to fall 1764. That time must be considered the most productive phase in the life of Charles Messier as a "deep-sky observer," as we would put it today, and it laid the foundation for his lasting popularity.

M 41 to M 45: Completion of the first catalog

Early in 1765, Messier found the open cluster M 41. For a long time, this was the last entry in his observing log. The subsequent pause of four years saw his boat journey to the Netherlands in 1767 and further comet discoveries – apparently, Messier was pondering whether to publish his list of nebulae or not. In March 1769, he finally made up his mind and completed the catalog with the inclusion of several well-known objects as his entries M 42, M 43, M 44, and M 45, listed under the date of the 4th of March 1769. All of these objects are impossible to confuse with a comet, and it remains a matter of speculation why he added them. Perhaps having a catalog with 41 objects did not satisfy Messier's sense of symmetry, and he wanted to exceed the 42 entries in the catalog of his role-model, Lacaille. In his foreword, Messier mentioned the motivation for making a list of all nebulous patches in the sky, rather than just those which look like a comet. However, he did not include other significant objects in that respect, e.g., the double cluster h & χ Persei, which apparently did not bother him much. There simply were not enough such objects left to round the number up to an even better sounding total of 50 entries.

The manuscript for the first catalog was finally completed on the 16th of February 1771. It was printed in that same year for the 1774 edition of the Mémoires de l'Académie Royale des Sciences.

M 46 to M 52: Further discoveries

Only three nights after the manuscript of the first catalog was finalized (19th of February 1771), Messier discovered four more objects: three more star clusters (M 46 to M 48) and the first galaxy of the Virgo cluster, M 49. Later that same year, on the 6th of June an object was discovered but its position not measured until 1779, which gave it a much later entry as number 62. Instead, on the 5th of April 1772, Messier finally found a nebula from a note of Cassini, for which he had been looking since 1764, now his M 50 – not much more than a week after his wife and newborn child had died.

During an observation of the Andromeda Galaxy on the 10th of August 1773, Messier discovered the companion galaxy M 110. But for reasons that are not known, he did not include this object in his catalog. The observation and a drawing were finally published in 1798 – for this, M 110 was accepted as a Messier object in the twentieth century. Also in 1773, Messier came across M 51, while he was following the comet of that year which he had discovered himself. He saw only the central part of the main galaxy. The double-nature of this object was noticed later by Méchain, whom he got to know in that year (1773). M 52 in 1774 was then for some time Messier's last discovery; he did not engage himself again with nebulous objects until 1777.

M 53 to M 70: Completion of the second catalog version

In February 1777, Messier found M 53 and the faint M 54, and M 55 followed on the 24th of July 1778, while he was looking again for an object described by Lacaille (M 55), which he had failed to find in the night of the 29th of July 1764. Meanwhile, in 1777, Bode had entered into a direct competition with Messier with his catalog of 75 nebulous objects. Then in 1779, the 6th of January, the German challenged Messier in his very domain: Bode discovered his first comet. Messier saw it only 13 nights later. The comet then happened to pass near M 56, which Messier happily added to his list. Further nebulous objects were soon found along the path of Bode's comet by different observers: M 57 on the 31st of January 1779 by Darquier, the Virgo galaxies M 59 and M 60 on the 11th of April by Köhler (four days later independently discovered by Messier, together with M 58), and M 61 by Oriani, on the 5th of May. The latter galaxy was seen by Messier the same night, but confused with the comet; he noticed his mistake six nights later. The other galaxies of the Virgo cluster had not yet been observed.

June 1779 saw the first contribution to the Messier catalog by a discovery of Méchain: M 63. In March and April 1780, Messier had a very productive phase again: he discovered M 64, M 65, M 66, M 67, and M 68. The much grown number now motivated him to publish a second version of his catalog. It was printed in the 1783 edition of the French Almanac, the Connaissance des Temps. Two more objects (M 69 and M 70) found by Messier on the 31st of August 1780, and making a pleasantly round number, were added on in the annex of the same edition.

M 71 to M 103: Méchain's discoveries and the final catalog version

Again, new discoveries were made immediately after the publication of the catalog. More than 32 new objects were observed between October 1780 and March 1781. The personal discoveries achieved by Messier were M 73 (when he was looking for M 72 of Méchain), M 84, M 86, and M 87 to M 93

Observations of nebulae before Messier

For the earliest astronomers, non-stellar (fixed) objects had little importance and hardly any attention was paid to them. The only exception was the easily resolved and bright star cluster of the Pleiades, which played an important role in astronomical calendars and mythology. For example, the tradition of All Saints Day and Halloween is based on the culmination time of the Pleiades. Nebulae were not noticed by the ancient Greek scholars, only Hipparchus mentioned, apart from the Pleiades, the other two cloud-like objects, M 44 and h & χ Persei.

The great star catalog of the second century AD, the Almagest produced by Ptolemy (83–161), already contained seven objects characterized as "cloud-like" or "nebulous." But apart from M 7, M 44, and h & χ Persei, they are not real but rather chance alignments of stars that remain unresolved and therefore appear nebulous to the naked eye. Not even the two most obvious of the real nebulae, M 31 and M 42, are mentioned in the Almagest, nor elsewhere in antiquity. This demonstrates the lack of interest in such objects. The first note on M 31 came from the Persian scholar Al Sufi in the tenth century, when he worked on a revision of the Almagest. And the discovery of M 42 had to wait until the first telescopic observations in the early seventeenth century. In 1611, several astronomers discovered the Orion Nebula almost at the same time – the very first of them was Nicholas Peiresc.

The first telescopes were also used for several other non-stellar objects. Galileo found that M 44 was not a nebula but a cluster of faint stars. About the same time, Simon Marius discovered M 31, which was still unknown in Europe. After him, Giovanni Batista Hodierna (1597–1660) made a series of discoveries. His list of 19 observed objects contains nine genuine discoveries (including M 6, M 36, M 37, M 38, M 41, M 47, and perhaps M 33, and M 34), but his notes were lost and remained entirely unknown until their rediscovery in the twentieth century.

For quite some time not much progress was made; nebulae were still objects of little interest. In 1647, Johannes Hevelius published one of the last large star catalogs achieved without the use of a telescope, he therein mentioned 14 "nebulous" objects, mostly taken from Ptolemy. As in the Almagest, these "nebulae" are mostly accidental stellar patterns, which are not resolved by the naked eye. However, with the advent of this widely known publication, nebulous objects gained a bit more attention for the next hundred years. In 1733, Hevelius' original listing of 14 objects was translated from Latin into English by William Derham and supplemented with M 7 and NGC 6231. In this form, it came to Charles Messier, who tried to verify these 16 objects in 1764. Since most of them were not real, they could not be identified as a nebula through the telescope. Only Hevelius No. 14 survived as M 40, as Messier included it in his catalog, although he only saw a faint double star and no nebulous object.

Not long after the work of Hevelius, M 22 (Ihle, 1665) and M 11 (Kirch, 1681) were found by telescopic observation, the first discoveries made from Germany. In England, meanwhile, Edmond Halley was quite active. Best known for his long-period comet, he had already discovered ω Cen in the southern sky in 1677. From home, he found M 13 in 1714. In a 1715 publication, he also described M 42, M 31, M 22, and M 11.

But it wasn't until Messier's time, when the quality of telescopes had improved sufficiently, that more progress could be made. In 1746, the Swiss aristocrat de Chéseaux (1718–1751) listed 21 observed nebulae, which include eight genuine discoveries. But as in the case of Hodierna, his notes were not published, because de Chéseaux was not a member of any important scientific society, so he was not accepted by the scientific establishment. This was different with Nicolas Louis de Lacaille (1713–1762), who presented a list of 42 nebulous objects in 1755 as a by-product of his star survey of the southern sky. Despite the very small aperture he had used, this first real nebula catalog contained a significant number of genuine discoveries and was of very good quality, especially in terms of positional information. Certainly, it was the best example for Messier, who reprinted Lacaille's list as an annex to his 1771 catalog.

Hence, many southern objects were known before Messier's work, while the northern sky was still almost untouched. Concurrently with Messier, Guillaume Le Gentil (1725–1792) made a few discoveries. Like Messier, he once was a student of Delisle in the Collège de France. In his publication, submitted in 1749 but not printed until 1755, Le Gentil mentioned M 32, M 8, M 41, M 36, and M 38.

Some astronomers who paved the way for Messier: Hevelius, Flamsteed, Halley, Peiresc, de Mairan, Huygens.

Hevelius "Nebulosae," 1647

Derham's number	Constellation	Derham's description	Modern identification
1	Andromeda	In Andromeda's girdle	M 31
2	Cancer	Praesepe	M 44
3	Capricornus	In the forehead of Capricorn	σ Cap
4	Capricornus	Another, preceding the eye of Capricorn	π Cap
5	Capricornus	Another following it	o Cap
6	Cygnus	Preceding above the Swan's tail and last in its northern foot	ω Cyg
7	Cygnus	One of two following the Swan's tail, outside the constellation	?
8	Hercules	At the tip of Hercules' left foot	88 Her
9	Hercules	In the left leg of Hercules	90 Her
10	Hercules	In the head of Hercules	32, 33, 34 Oph
11	Libra	Under the beam of the western scale	ζ, 17, 18 Lib
12	Pegasus	Following the ear of Pegasus	34, 35, 37 Peg
13	Scutum	Below the western border of the shield	?
14	Ursa Major	Above the back of Ursa Major	?

Visual observers after Messier

From the seventeenth to the nineteenth century, visual observation at the telescope's eyepiece was the common scientific means of documentation in astronomy. The observers would produce drawings and descriptions, which were then reproduced in professional publications. It was not until the end of the nineteenth century that emerging photographic techniques evidently became the more accurate and less subjective form of recording positions and intensities than visual observation.

Nevertheless, descriptions from the great historic visual observers are still most valuable for the modern amateur for comparison with his or her own visual observations. We have to keep in mind that those historic observers could not "cheat" and look at a photograph to get some help; they depended entirely on the capabilities of their eyesight.

Frederick William Herschel (1738–1822)

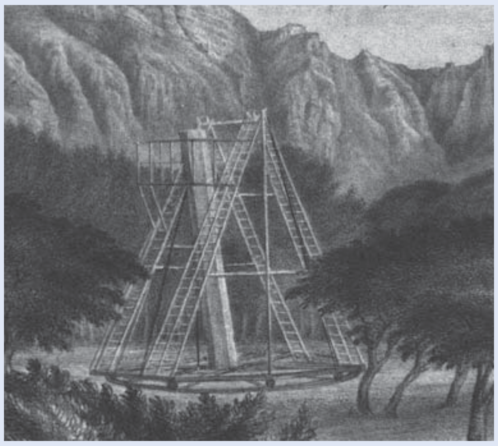
William Herschel was a musician, born in the German town of Hanover, who had emigrated to England. He became the first observer to undertake a systematic search for nebulae for their own sake. Most likely, he was inspired by Messier's catalog. Within 20 years, he compiled a huge catalog of 2500 nebulae and star clusters.

Herschel had produced home-made telescopes and mirrors since 1774, for himself as well as for other astronomers. For his nebula observations, which he started in 1782, he used a very large, modified Newtonian telescope with 18 inches (475mm) of aperture and 20-feet (6m) focal length. His standard magnification was 157× with a field of view of 15', with which he was systematically scanning the sky. He combed through a zone of 4 minutes to 5 minutes in right ascension with a length of 12° to 14° in declination and noted all newly found objects for a later, accurate position measurement. This procedure was then repeated in a band of right ascension adjacent to the preceding field. Wanting a larger objective for this project, Herschel finished building the then largest telescope in the world in 1789, with a huge 47-inch (1.2m) metal mirror of 40-feet (12m) focal length, but it proved too bulky for scanning purposes, so he would instead use it for detailed observations of individual objects.

Herschel's first discovery, on the 7th of September 1782, was the Saturn Nebula NGC 7009. By 1785, he had found about 1000 more nebulous objects, another 1000 by 1789, and a final 500 by 1802. Hence, his 20 years of work increased the number of known nebulae by a factor of more than 20 – an immense achievement. William Herschel is probably the most industrious deep-sky observer of all time.

John Herschel (1792–1871)

John diligently continued the work of his father. He shipped the venerable 18-inch telescope to South Africa, where he systematically searched the southern sky for nebulae. In the years 1834 to 1838, he discovered 1689 new objects. In 1864, he finally combined his own and the revised observations of his father into the General Catalogue (GC) of Nebulae and Star Clusters. It became the basis for the famous New General Catalogue (NGC) of 7840 entries. The latter, created by Johann Dreyer in 1888, included all the objects then known and is still in widespread use today.

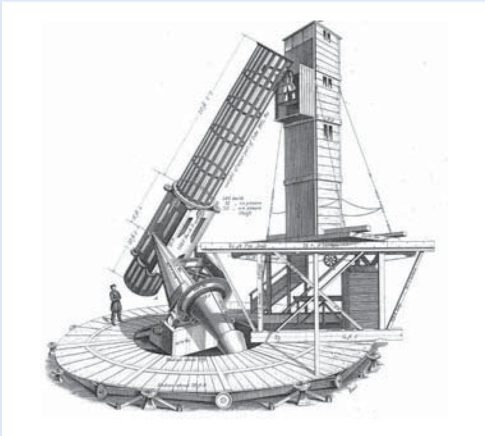


William Smyth (1788–1865)

The retired English admiral discovered astronomy as his hobby and built his own private observatory with a 6-inch refractor. In close contact with John Herschel, he observed numerous deep-sky objects. In 1844, he published the "Bedford Catalogue," the "grandmother" of all deep-sky observing guides, which included descriptions of 98 nebulae and 72 star clusters. His work offers rich insights into the practice of amateur astronomy 160 years ago.

William Lassell (1799–1880)

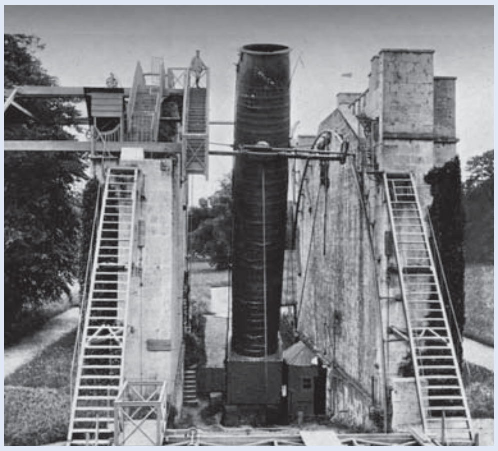
This wealthy brewer and amateur astronomer from Liverpool, England, was able to spend considerably more money for his astronomical desires than his contemporaries. In 1845, he built a 24-inch Newtonian on a fork-mount, which he used to do numerous observations and drawings of nebulae. In 1858 in Liverpool, he had a reflec-



tor with a 48-inch mirror made, one of the largest telescopes of its time. He shipped it to Malta in 1861, to take advantage of the far superior observing conditions there.

William Parsons, Lord Rosse (1800–1867)

The third Earl of Rosse was a rich Irish nobleman who developed an enthusiasm for observing due to his contact with John Herschel. In April 1845, after considerable experimentation with the techniques needed to build very large reflectors, he constructed his huge telescope, "Leviathan," which had a 72-inch (1.8m) mirror. Then the largest telescope in the world, it was set up in the gardens of his Irish estate at Birr castle and was so cumbersome that several people were required to operate it. Nevertheless, the Lord himself and several assistants made a large number of observations and drawings of nebulae in the decades to follow. One of his most important discoveries was the spiral structure of some galaxies. However, this success later tricked him into seeing spiral patterns even in star clusters. The assistants of Lord Rosse were: J. Rambaut (1848), B. Stoney (1850–1852), R. Mitchell (1853–1858), S. Hunter (1860–1864), S. Ball (1866–1867), C.E. Burton (1868–1869), R. Copeland (1871–1874), J. Dreyer (1874–1878).



Heinrich d'Arrest (1822–1875)

D'Arrest, a descendent of Huguenot immigrants to Germany, was director of the Copenhagen Observatory near the Danish capital. His published notes, "Siderosum Nebulorosum," which contain observations of 1942 objects and include 321 discoveries, prove that he was a very diligent observer. For most of his work, he used the 11-inch refractor at the Copenhagen observatory.

Léopold Trouvelot (1827–1895)

This French painter received considerable recognition for his precise drawings of plants and animals. His sketches of the aurora borealis finally caught the attention of Harvard astronomers in Cambridge (USA), who invited him to hone his talents with telescopic observation. In 1875, he was hired by the US Naval Observatory in Washington (DC), where he subsequently produced more than 7000 drawings of astronomical objects – still the finest of their kind. However, after his death, Trouvelot acquired a bad reputation in the USA because he introduced the European gypsy moth, whose caterpillars have caused a lot of damage to US agriculture ever since.

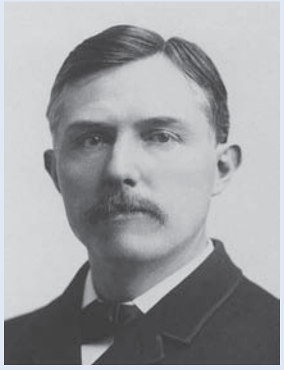
Wilhelm Tempel (1821–1889)

With a very humble, provincial family background in the east of Germany, he received his first recognition from abroad. His breakthrough came in 1859 when he discovered a comet and the nebula in the Pleiades that surrounds Merope – both feats were achieved with his small 4-inch refractor. In 1874, Tempel started work at the Arcetri Observatory near Florence (Italy), where he carried out numerous observations of nebulae and made 146 discoveries of new objects.

Leo Brenner (1855–1936)

Spiridon Gopčević is one of the most debated observers of all time. In 1894, he started to approach the public under his pseudonym Leo Brenner. On the Mediterranean island of Lussin, which then belonged to Austria (today the Croatian island Lošinj), he built a private observatory with a 7-inch refractor and published many incredibly detailed, but often fictitious, reports. In 1909, after he had lost almost all his credibility with professional astronomers, he simply vanished from the astronomical scene. His descriptions are relevant for the German-speaking community, though, because in 1902 he published the first ever observing guide on the deep-sky in the German language.

Edward Emerson Barnard (1857–1923)



This American is regarded as perhaps the best visual observer of all times. He had the combined gift of a keen eye and a well-trained, accurate perception. Coming from a very poor family background, Barnard started his career as a laboratory assistant in a photography shop and observed the night sky as an amateur astronomer. He soon became known as the discoverer of several comets. In 1887, he was hired by the Lick Observatory, where he made some spectacular discoveries with the 36-inch refractor, then the largest refractor in the world. Apart from his skills as a visual observer, he was also a very successful pioneer of deep-sky astrophotography.

Star chart with the observed path of the comet of 1764, according to Messier's positional measurements.

– all other new objects were contributed by Méchain, but verified by Messier through observation and positional measurement.

The last version of the catalog was supposed to have the round number of 100 entries. However, Méchain was discovering new objects in such quick succession, that Messier could not verify them all in time for the submission deadline of the manuscript. Hence, he added M 101, M 102, and M 103 to the finalized list with the remark: "From M. Méchain, have not yet been observed by M. Messier." The objects M 108 and M 109 had been mentioned only in the note on M 97. Apparently, this third version of the catalog was prepared under considerable time pressure. It was printed already in spring 1781, for the 1784 edition of the Connaissance des Temps.

M 104 to M 109: After press

Shortly after he received his personal copy of the third catalog from the printer, Messier made a hand-written note in it about a further discovery of Méchain's from the 11th of May 1781: M 104. Messier also added positions for the now-measured objects M 102 and M 103, as well as for M 108 and M 109 (in the note on M 97). Hence, initially, there was no indication that this would be the last version of Messier's catalog.

Also, Méchain remained active. Not only did he discover his first two bright comets on the 28th of June and the 9th of October of 1781, in July he also discovered the nebula now known as M 106. In addition, a discovery made by Méchain in March that year, M 105, had simply been overlooked in those final hectic days of work on the catalog. The next year (April 1782), M 107 was found by Méchain. Nevertheless, a new, updated version of the Messier catalog would never come. That may well be "blamed" on William Herschel.

De Chéseaux's list of nebulae

Philippe Loys de Chéseaux was a rich, Swiss nobleman living in the countryside near Lausanne, where he had his own observatory. He became known as a result of his independent discovery of comet Klinkenberg (C/1743 X1), on the 13th of December 1743. On the 13th of August 1796, he discovered another comet, C/1746 P1. Using a 2-foot (focal length) Gregorian reflector, he drew up a list of 21 star clusters and nebulae in 1746. For eight of those objects (M 4, M 16, M 17, M 25, M 35, M 71, NGC 6633, and IC 4665), he is the original discoverer.

He sent his list to his grandfather Reaumur, who was a member of the French Academy of Sciences, and who presented the list at an Academy meeting on the 6th of August, 1746. However, no printed publication followed, and de Chéseaux's work was forgotten until its rediscovery in 1884. Messier mentioned the list in the foreword to his first catalog version, but apparently, he had no complete knowledge of it.

Star clusters:

1.	*M 6*	*Between Scorpius, Ophiuchus, and Sagittarius, there is a very beautiful one, of which the principal stars have this year RA 260° 52' 30" and southern declination 32° 1' 30".*
2.	*IC 4665*	*Above the shoulder, beta of Ophiuchus, a cluster of stars of which the two principal stars have this year: RA 264° 46' 50" and southern [should read northern] dec. 6° 50' 20"; RA 264° 31' 55" and southern [should read northern] dec. 7° 00' 10".*
3.	*NGC 6633*	*Near the tail of Serpens in which there is a small cluster of stars, a bit separated from the rest to the west; its RA is at 273° 32' 30" and its southern [should read northern] declination is 6° 19' 20".*
4.	*M 16*	*A cluster of stars between the constellations of Ophiuchus, Sagittarius, and Antinous, of which RA is 271° 3' 10" and southern declination is 13° 47' 20".*
5.	*M 25*	*Another [star cluster] between the bow and the head of Sagittarius, of which RA is about 274° 17' and southern decl. is 19° 11' 30".*
6.	*NGC 869*	
7.	*NGC 884*	*Two clusters of stars in the hilt of Perseus' sword, earlier observed by M. Flamsteed.*
8.	*M 8*	*Another [star cluster] in the bow of Sagittarius, observed by the same.*
9.	*NGC 6231*	
10.	*M 7*	*The last two [objects] of the catalogs of Messieurs Derham and Maupertuis.*
11.	*M 44*	*That in Cancer, ordinarily called Praesepe, the position of which is known.*
12.	*M 35*	
13.	*M 71*	*Two others of which I have not yet determined the positions, one above the northern feet of Gemini, and the other below and very close to Sagitta.*
14.	*M 11*	*Lastly, a prodigious cluster of small stars, near one of the feet of Antinous of which RA is 279° 21' 10" and southern decl. is 6° 32' 20"; it has about 4 1/8' in diameter.*

These 14 nebulae contain among them almost as many stars visible in telescopes of 25 feet as the greater part of the sky contains as visible to the naked eye. Here now are the rightly styled nebulae which, when seen in the largest telescopes, never appear as anything but white clouds:

17.	*M 22*	*A third, discovered by Abraham Ihle, between the head and the bow of Sagittarius, of which I found the RA of 275° 14' 10" and southern dec. 24° 5' 30". It is 5' in diameter, it is round, of a reddish color, whereas the Andromeda Nebula is yellowish and that of Orion, transparent.*
18.	*NGC 5139*	*That in Centaurus, discovered by Mr. Halley; it is invisible in Europe.*
19.	*M 4*	*One which is close to Antares, of which I have found for this year, RA 242° 1' 45" and southern dec. 25° 23' 30". It is white, round and smaller than the preceding ones; I do not think it has been found before.*
20.	*M 17*	*Lastly, one other nebula, which has never been observed. It has a shape quite different from the others: it has the perfect form of a ray, or of the tail of a comet, 7' long and 2' wide; its sides are exactly parallel and quite well terminated, the same for the two ends. The center is whiter than the edges. I found its RA for this year as 271° 32' 35" and its southern declination as 16° 15' 6". It makes an angle of 30° with the meridian.*
21.	*M 13*	*I have not yet found that in Hercules, discovered by M. Halley. I very much hope that the Messieurs astronomers of Paris will be willing to indicate its position for me.*

The catalog of Abbé Lacaille						
No.	**Present designation**	**Con.**	**R.A.**	**Decl.**	**Pos.-error**	**Type**
First section: Nebulae without stars						
Lac I.1	NGC 104	Tuc	$0^h 33.41^{min}$	−72° 4'	41'	GC
Lac I.2	NGC 2070	Dor	$5^h 38.4^{min}$	−69° 10'	5'	GN
Lac I.3	NGC 2477	Pup	$7^h 50.9^{min}$	−38° 37'	15'	OC
Lac I.4	NGC 4833	Mus	$12^h 59.7^{min}$	−70° 49'	4'	GC
Lac I.5	NGC 5139	Cen	$13^h 26.8^{min}$	−47° 29'	0'	GC
Lac I.6	M 83	Hya	$13^h 37.1^{min}$	−29° 52'	2'	Gx
Lac I.7	NGC 5281	Cen	$13^h 46.6^{min}$	−62° 56'	1'	OC
Lac I.8	NGC 6124	Sco	$16^h 25.6^{min}$	−40° 39'	0'	OC
Lac I.9	M 4	Sco	$16^h 23.7^{min}$	−26° 31'	2'	GC
Lac I.10	NGC 6242	Sco	$16^h 55.6^{min}$	−39° 28'	0'	OC
Lac I.11	M 69	Sgr	$18^h 30.0^{min}$	−33° 29'	1,2°	GC
Lac I.12	M 22	Sgr	$18^h 36.4^{min}$	−23° 55'	1'	GC
Lac I.13	(NGC 6777)	Pav	$19^h 26.8^{min}$	−71° 30'	2'	Ast
Lac I.14	M 55	Sgr	$19^h 40.1^{min}$	−30° 57'	2'	GC
Second section: Star clusters						
Lac II.1	–	Hor	$4^h 3.0^{min}$	−44° 28'	0'	Ast
Lac II.2	Collinder 140	CMa	$7^h 26.2^{min}$	−34° 09'	2,1°	OC
Lac II.3	NGC 2516	Car	$7^h 58.9^{min}$	−60° 50'	9'	OC
Lac II.4	NGC 2546	Pup	$8^h 11.2^{min}$	−37° 13'	28'	OC
Lac II.5	IC 2391	Vel	$8^h 38.8^{min}$	−53° 6'	17'	OC
Lac II.6	Collinder 203	Vel	$8^h 46.8^{min}$	−42° 16'	19'	OC
Lac II.7	NGC 3228	Vel	$10^h 21.4^{min}$	−51° 43'	2'	OC
Lac II.8	NGC 3293	Car	$10^h 35.9^{min}$	−58° 13'	2'	OC
Lac II.9	IC 2602	Car	$10^h 43.1^{min}$	−64° 24'	1' (37")	OC
Lac II.10	NGC 3532	Car	$11^h 6.5^{min}$	−58° 40'	10'	OC
Lac II.11	–	Cen	$11^h 22^{min}$	−58° 21'	2'	Ast
Lac II.12	NGC 4755	Cru	$12^h 53.7^{min}$	−60° 22'	1'	OC
Lac II.13	NGC 6231	Sco	$16^h 54.2^{min}$	−41° 50'	1'	OC
Lac II.14	M 7	Sco	$17^h 53.8^{min}$	−34° 45'	3'	OC
Third section: Stars with nebulosity						
Lac III.1	nonexistent	Pic	$5^h 3.4^{min}$	−49° 30'	1' (52")	Single star
Lac III.2	NGC 2547	Vel	$8^h 10.7^{min}$	−49° 15'	7'	OC
Lac III.3	IC 2395	Vel	$8^h 42.4^{min}$	−48° 6'	2'	OC
Lac III.4	IC 2488	Vel	$9^h 27.8^{min}$	−57° 0'	4'	OC
Lac III.5	Collinder 228	Car	$10^h 44.0^{min}$	−60° 7'	3'	OC
Lac III.6	NGC 3372	Car	$10^h 44.3^{min}$	−59° 30'	10'	GN
Lac III.7	NGC 3766	Cen	$11^h 36.2^{min}$	−61° 37'	0'	OC
Lac III.8	NGC 5662	Cen	$14^h 35.3^{min}$	−56° 34'	4'	OC
Lac III.9	–	Cir	$15^h 22.7^{min}$	−59° 10'	2'	Ast
Lac III.10	NGC 6025	TrA	$16^h 3.8^{min}$	−60° 30'	5'	OC
Lac III.11	NGC 6397	Ara	$17^h 40.7^{min}$	−53° 42'	2'	GC
Lac III.12	M 6	Sco	$17^h 40.1^{min}$	−32° 13'	3'	OC
Lac III.13	M 8	Sgr	$18^h 3.9^{min}$	−24° 22'	1'	OC+GN
Lac III.14	–	Ind	$21^h 31.1^{min}$	−56° 53'	1'	Ast

Ast = asterism. The coordinates are the positions given by Lacaille as for equinox 2000.0.

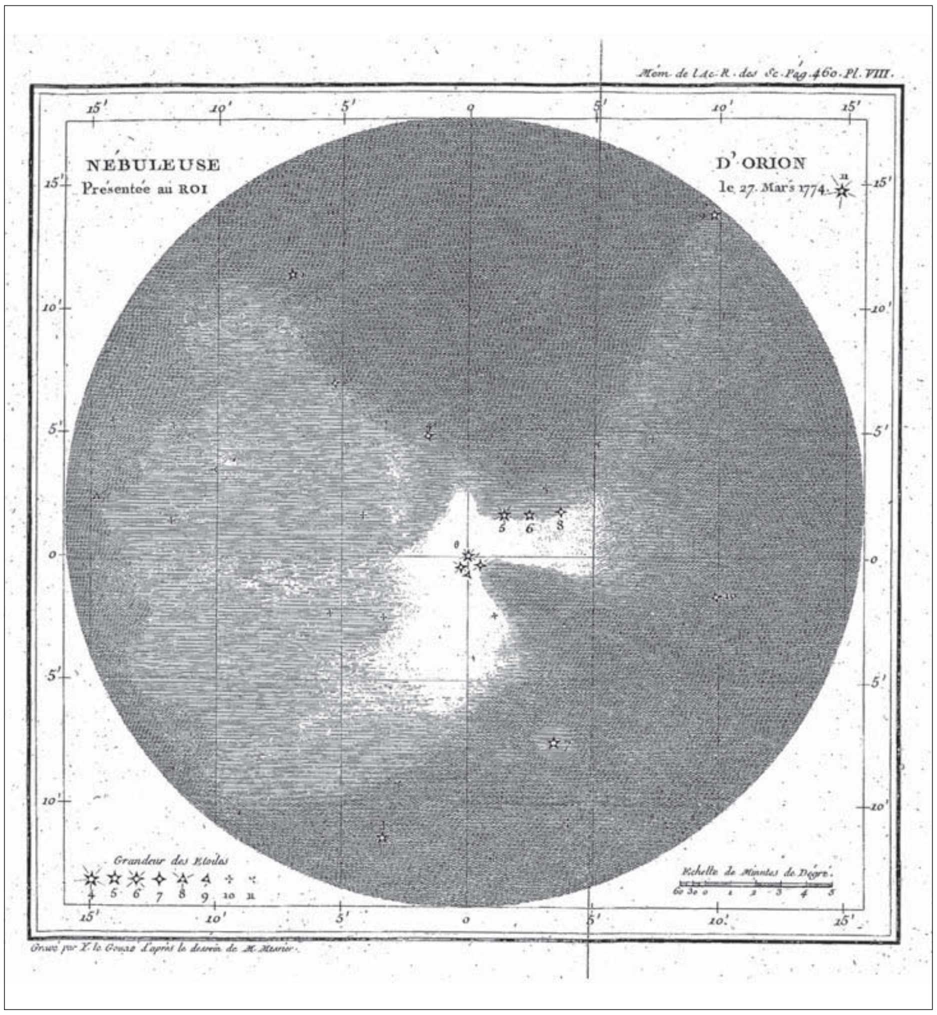
Lacaille's catalog of nebulae

It seems astounding that the very first catalog of deep-sky objects, presented in 1755 by Abbé Nicholas-Louis de Lacaille – 14 years before Messier's first catalog of 45 objects – was actually devoted to the southern sky. In any case, Lacaille's catalog was the first significant work of its kind, which also became widely known and accepted. Earlier object lists either had been very short (like the one by Halley), or had not reached the wider scientific community (like those of Hodierna in 1654, or de Chéseaux in 1746).

Lacaille's catalog of 42 objects was published in 1755 in the Memoirs of the French Academy of Sciences, and again in 1784 as an annex to Messier's work. Lacaille's

The frontispiece of Lacaille's catalog depicts a contemporary view of the Paris Observatory.

list has three sections: "Nebulae without Stars," "Star Clusters," and "Stars with Nebulosity." Incidentally, each of the sections contains exactly 14 objects. This equipartition already puzzled Kenneth Glyn Jones in the 1960s. Perhaps it satisfied a baroque desire for symmetry. Lacaille himself remarked on his list as follows: "I have found a large number of nebulae of these three types in the southern sky, but I would not believe that I have noticed all of them; in particular of the first and third type, because these are visible only after dusk and in the absence of the Moon. Nevertheless, I hope that this list is more or less complete for the most remarkable objects of the three types." For his task, Lacaille had only very humble optical equipment. He wrote: "I have wished dearly to present a more detailed and informative work. But the simple refractors available to me at the Cape of Good Hope, of 15 and 18 inches [focal length], were neither adequate nor sufficient for this kind of observation." Since his telescopes were probably non-achromatic with focal ratios of around f/10, their apertures cannot have exceeded 40mm (1½ inches). The fact that Lacaille could not resolve ω Centauri (NGC 5139) into individual stars, or open clusters like NGC 6124, reveals the poor quality of his instruments.



Messier's drawing of M 42, published in the annex of the first catalog. For this observation, Messier used an achromatic Dollond-refractor with an aperture of 40 lines (90mm), a focal length of 3.5 feet (1.14m), and a magnification of 68×, on the nights of the 25th and 26th of February, and the 19th, 23rd, 25th, and 26th of March 1771. The circular border represents the edge of the actual field of view, about 30'. South is above.

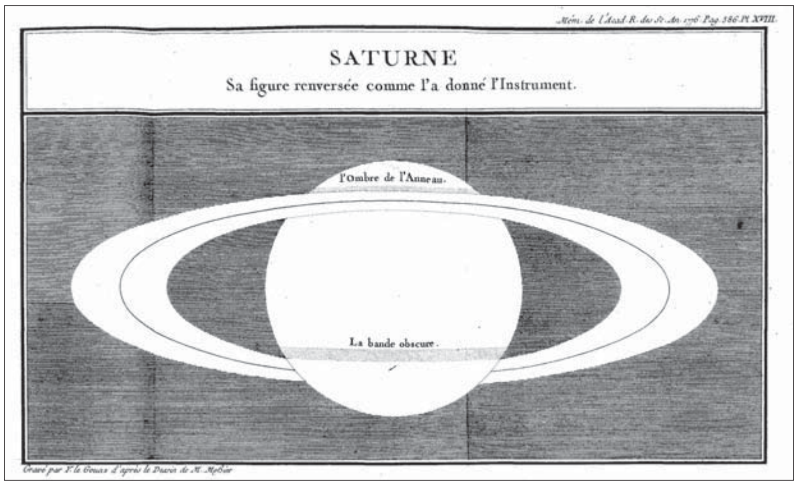
The German-born musician, who had emigrated from Hanover to England, became famous for a discovery he made on the night of the 13th of March 1781 – only four days after the last official entry to Messier's catalog. At first, Herschel took his new object for a comet, and so he asked Messier, the famous expert on comets, for his opinion. Messier observed the new object, measured its position over several nights, and had his friend de Saron calculate the orbit. The result was sensational: Herschel had found a new planet, Uranus.

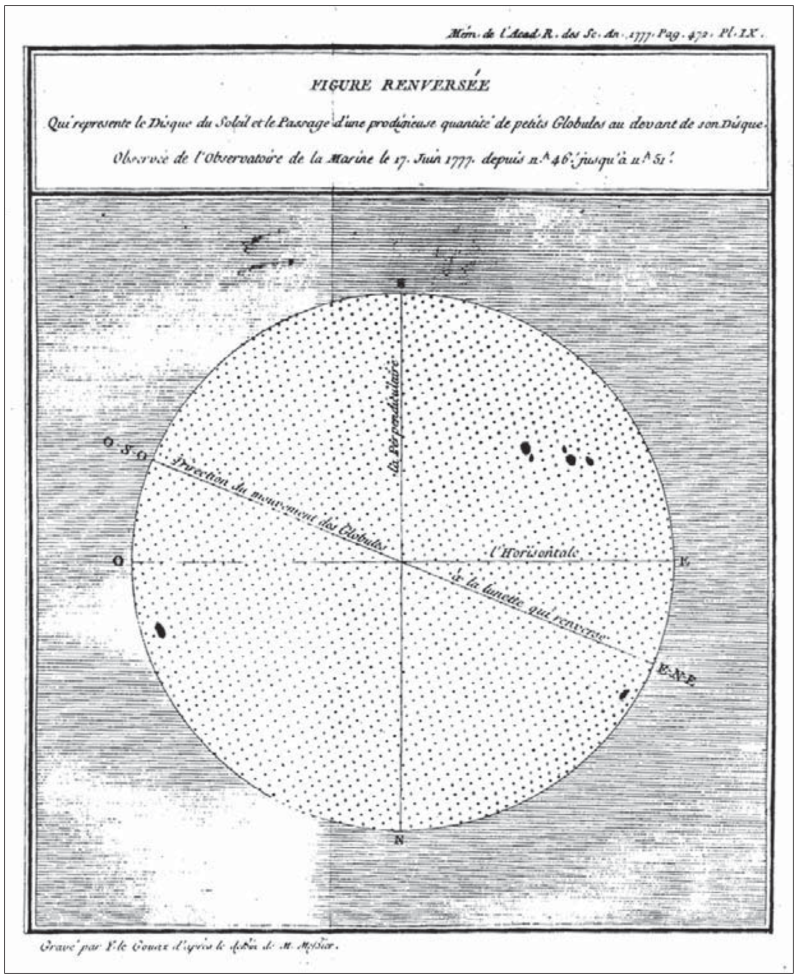
With the fame of this discovery, Herschel received a royal salary, which finally allowed him to concentrate fully on astronomical work. In 1782, he began an extensive search for new nebulous objects and, due to both his superior Newtonian telescopes and his dedication, made about 1000 new discoveries by 1786. By the end of that project in 1802, Herschel had compiled a huge list of about 2500 nebulae. It was the Messier catalog (he received his copy on the 7th of December 1781) that almost certainly gave him the idea.

At the same time, the unlucky Messier had to abandon all his work after his serious accident (6th of November 1781). After a long, painful recovery, he did not resume his search for new nebulae – in 1802 he described why:

> *After me, the famous Herschel published a catalog of 2000 [nebulae] which he had observed. Unveiling the sky in his way, with instruments of large aperture, is not useful for comet seeking. Hence, my objective is different from his: I only need the nebulae that are visible in a telescope of 2 ft [focal length]. I have observed more, meanwhile. I will publish them in the future, organized by right ascension, for the sake of finding them more easily, and so that those who are looking for comets have less uncertainty.*

But such a final publication never came to be.





Examples of Messier's observing results: a drawing of Saturn, the occultation of Saturn by the Moon on the 18th of February 1775, and the sunspots of the 17th of July 1777.

The "missing" Messier objects

Messier's catalog was of high quality and contained relatively few errors. For each object, Messier took the position relative to a bright neighbor star. Furthermore, a large number of objects was observed more than once, especially for the third version of the catalog.

Nevertheless, Messier could not entirely avoid making mistakes. Consequently, there are a few objects for which the identification remained ambiguous and matter of debate. Glyn Jones called these the "missing Messier objects," which has become the adopted choice of words. There is now broad consensus about most identities, except the case of M 102.

M 47

Messier's position lies in a field without any recognizable star clusters. Hence, astronomers after Messier long believed that M 47 did not exist. However, in 1959, T.F. Morris was able to prove an assumption that Oswald Thomas made in 1934: Messier made a sign-related mistake in his calculation of the position. As a curious result, M 47 has two NGC entries: a false one, NGC 2478, in its wrong position, and the true one, NGC 2422, with the correct coordinates from Herschel.

M 48

The same night he recorded M 47, Messier made another simple calculation mistake with M 48, putting it exactly 5° too far south. Again, Oswald Thomas and T.F. Morris found the right identity: NGC 2548 has now been commonly accepted as M 48.

M 91

With this galaxy, a positional error is also the most likely explanation. There is no sufficiently bright galaxy at the position given by Messier, only a lot of faint galaxies of the Virgo Cluster. Owen Gingerich suggested that M 91 may just be an accidentally repeated observation of M 58, a galaxy only 2.7° south of Messier's position. But in 1969, W.C. Williams showed that Messier used a galaxy as his reference point for M 91 (there are hardly any bright stars in this field) and that he sim-

Bode's catalog of nebulae

In 1777, three years after Messier presented his first catalog, the Berlin astronomer Johann Elert Bode undertook the same endeavor. In his publication "On several newly discovered nebulous stars and a complete listing of all known so far" he wrote: "I wanted to search for nebulous stars [objects] with diligence. Since I had the pleasure to discover a number of new ones, which until then, at least, I had not found with any other astronomer, I herewith wish to communicate them." With the use of several different sources, including Messier's first catalog, Bode managed to collect 75 objects north of –35° declination. However, the diverse origin of the data was also the problem with Bode's catalog. We only know with certainty of eleven objects that Bode observed himself. Of these, M 53, M 81, and M 82 were his own discoveries. All of the other objects had been copied from the literature without any verification, as Bode admits: "I have to add that I myself have not yet had the opportunity to observe all of the nebulae discovered by other astronomers." As an example, this explains why M 8 has been listed three times – with different positions.

The problem of non-verified entries was the death-sentence for Bode's list, despite his good reputation as an astronomer. He printed it once again in 1782 in his star atlas "Vorstellung der Gestirne," expanded with some new discoveries (including M 92, IC 4665, and the star pattern near χ Dra known as the "little Cassiopeia"), but the catalog never achieved widespread international use.

The catalog of Johann Elert Bode

Bode's No.	Present designation	Original source	Bode's No.	Present designation	Original source
1	?	own observation	39	M 6	Lacaille
2	M 32	Messier	40	90 Her	Hevelius
3	M 31	Messier	41	M 7	Lacaille
4	Muster 1° W λ Cas	own observation	42	M 23	Messier
5	M 33	Messier	43	4 Sgr	Flamsteed
6	55 And	Flamsteed	44	5 Sgr	Flamsteed
7	M 34	own observation	45	M 8	Le Gentil
8	M 45	–	46	M 69	Lacaille
9	M 38	Messier	47	M 20	Messier
10	M 42	Messier	48	7 Sgr	Flamsteed
11	M 1	Messier	49	M 8	Messier
12	M 36	Messier	50	M 21	Messier
13	M 37	Messier	51	M 24	Messier
14	M 35	Messier	52	M 16	Messier
15	M 41	Messier	53	M 18	Messier
16	M 50	own observation	54	M 17	Messier
17	M 81	own observation	55	γ Sct	Hevelius
18	M 82	own observation	56	M 25	Messier
19	Cr 140	Lacaille	57	M 22	Lacaille
20	M 44	–	58	M 28	Messier
21	NGC 2477	Lacaille	59	M 26	Messier
22	NGC 2546	Lacaille	60	ν^1 Sgr	Flamsteed
23	M 40	Messier	61	ν^2 Sgr	Flamsteed
24	M 40	Hevelius	62	M 11	Messier
25	M 51	own observation	63	M 55	Lacaille
26	M 53	own observation	64	σ Cap	Hevelius
27	M 83	own observation	65	π Cap	Hevelius
28	ξ^1 , ξ^2, 17, 18 Lib	Hevelius	66	ο Cap	Hevelius
29	M 5	Messier	67	M 27	Messier
30	M 13	Messier	68	M 30	Messier
31	M 4	Lacaille	69	M 29	Messier
32	M 12	own observation	70	M 2	Messier
33	M 10	own observation	71	M 15	Messier
34	32, 33, 34 Oph	Hevelius	72	ω^{1+2} Cyg	Hevelius
35	M 19	Messier	73	34, 35, 37 Peg	Hevelius
36	M 9	Messier	74	?	Hevelius
37	M 14	Messier	75	M 39	Messier
38	88 Her	Hevelius			



Three people had a significant influence on the extension of the Messier catalog: Camille Flammarion (1842–1925, French writer of popular astronomy), Helen Sawyer Hogg (1905–1993, professional Canadian astronomer), and Oswald Thomas (1882–1963, founder of the planetarium of Vienna).

ply confused M 89 with M 58. This yields the real identity of M 91 as NGC 4548.

M 102

The identity of this object has remained a matter of debate to the present day. Many modern US publications regard this object as "missing," while most European sources identify it with the galaxy NGC 5866.

This discussion has its origin in a letter, which Pierre Méchain wrote two years after the third version of the Messier catalog was completed, on the 6th of March 1783. He sent it to Bernoulli in Berlin, because Messier's list of nebulae was also published in the Berlin Astronomical Almanac. Méchains letter was printed in the 1786 edition of the same almanac. In it, a passage reads:

> *I would only like to add that Nr. 101 & 102 on p. 267 of the Connaissances des Temps for 1784 are nothing else than one and the same nebula, which was taken for two because of an error in the charts.*

In other words, Méchain said that M 102 was his accidentally repeated observation of M 101. Hartmut Frommert, however, came up with some serious doubts. Firstly, the descriptions of M 101 and M 102 given in the catalog differ from each other. And then, like M 103, M 102 had actually been observed and measured by Messier himself, as we know from his handwritten positions in his personal copy of the printed catalog. For M 103, there is an error of 1°, while there is no object near the position he noted for M 102. However, if he had made a simple mistake with the calculation, again by 5° as with M 48, but this time in right ascension, then there would be an object in the right place, which also matches the description of M 102: NGC 5866. Hence, it is quite possible that Méchain accidentally observed M 101 twice, indeed, but that Messier then, while looking for the acclaimed object, found a real nebula – M 102 alias NGC 5866 was probably his last nebula discovery.

The supplementary Messier objects

The original Messier catalog of 1784 contains 103 explicit entries. Nevertheless, today's commonly accepted number of Messier objects is 110. The supplements have been added on in the twentieth century, according to evidence for objects observed by Messier but not (or not explicitly) included in his catalog. An important role is played by the above-mentioned letter of Méchain to Bernoulli, because it contains comments on further observed objects.

The other important source is Messier's personal copy of the catalog, which contains his handwritten notes. In 1924, Camille Flammarion discovered and bought that very copy, and he found Messier's notes in it. One of them is about a further "very faint nebula in Virgo." In his letter, Méchain wrote about this object and three others:

M 104

> *On 11th May 1781, I discovered a nebulous patch above Corvus which did not appear to me to contain single stars. It has a weak light and is difficult to find if the wires of the micrometer are illuminated. I compared it to Spica this day and the following and inferred the right ascension as 187° 9' 42", the southern*

Discoverers of the Messier objects

Name	Discoverer	Messier's Observation
M 1	Bevis 1731	August 28th, 1758
M 2	Maraldi 1746	September 11th, 1760
M 3	Messier 1764	May 3rd, 1764
M 4	de Chéseaux 1746	May 8th, 1764
M 5	Kirch 1702	May 23rd, 1764
M 6	Hodierna 1654	May 23rd, 1764
M 7	Ptolemy 130	May 23rd, 1764
M 8	Flamsteed 1680	May 23rd, 1764
M 9	Messier 1764	May 28th, 1764
M 10	Messier 1764	May 29th, 1764
M 11	Kirch 1681	May 30th, 1764
M 12	Messier 1764	May 30th, 1764
M 13	Halley 1714	June 1st, 1764
M 14	Messier 1764	June 1st, 1764
M 15	Maraldi 1746	June 3rd, 1764
M 16	de Chéseaux 1746	June 3rd, 1764
M 17	de Chéseaux 1746	June 3rd, 1764
M 18	Messier 1764	June 3rd, 1764
M 19	Messier 1764	June 5th, 1764
M 20	Messier 1764	June 5th, 1764
M 21	Messier 1764	June 5th, 1764
M 22	Ihle 1665	June 5th, 1764
M 23	Messier 1764	June 20th, 1764
M 24	Messier 1764	June 20th, 1764
M 25	de Chéseaux 1746	June 20th, 1764
M 26	Messier 1764	June 20th, 1764
M 27	Messier 1764	July 12th, 1764
M 28	Messier 1764	July 27th, 1764
M 29	Messier 1764	July 29th, 1764
M 30	Messier 1764	August 3rd, 1764
M 31	Al Sufi 964	(1757) August 3rd, 1764
M 32	Le Gentil 1749	(1757) August 3rd, 1764
M 33	Messier 1764	August 25th, 1764
M 34	Messier 1764	August 25th, 1764
M 35	de Chéseaux 1746	August 30th, 1764
M 36	Hodierna 1654	September 2nd, 1764
M 37	Hodierna 1654	September 2nd, 1764
M 38	Hodierna 1654	September 25th, 1764
M 39	Messier 1764	October 24th, 1764
M 40	Messier 1764	October 24th, 1764
M 41	Hodierna 1654	January 16th, 1765
M 42	Peiresc 1611	March 4th, 1769
M 43	de Mairan 1744	March 4th, 1769
M 44	–	March 4th, 1769
M 45	–	March 4th, 1769
M 46	Messier 1771	February 19th, 1771
M 47	Hodierna 1654	February 19th, 1771
M 48	Messier 1771	February 19th, 1771
M 49	Messier 1771	February 19th, 1771
M 50	Cassini 1711	April 5th, 1772
M 51	Messier 1773	October 13th, 1773
M 52	Messier 1774	September 7th, 1774
M 53	Bode 1775	February 26th, 1777
M 54	Messier 1778	July 24th, 1778
M 55	Lacaille 1752	July 24th, 1778
M 56	Messier 1779	March 19th, 1779
M 57	Darquier 1779	January 31st, 1779
M 58	Messier 1779	April 15th, 1779
M 59	Köhler 1779	April 15th, 1779
M 60	Köhler 1779	April 15th, 1779
M 61	Oriani 1779	May 11th, 1779
M 62	Messier 1771	June 7th, 1771
M 63	Méchain 1779	June 14th, 1779
M 64	Pigott 1779	March 1st, 1780
M 65	Messier 1780	March 1st, 1780
M 66	Messier 1780	March 1st, 1780
M 67	Köhler 1779	April 6th, 1780
M 68	Messier 1780	April 9th, 1780
M 69	Lacaille 1752	August 31st, 1780
M 70	Messier 1780	August 31st, 1780
M 71	de Chéseaux 1746	October 4th, 1780
M 72	Méchain 1780	October 4th, 1780
M 73	Messier 1780	October 4th, 1780
M 74	Méchain 1780	October 18th, 1780
M 75	Méchain 1780	October 5th, 1780
M 76	Méchain 1780	October 21th, 1780
M 77	Méchain 1780	December 17th, 1780
M 78	Méchain 1780	December 17th, 1780
M 79	Méchain 1780	December 17th, 1780
M 80	Messier 1781	January 4th, 1781
M 81	Bode 1774	February 9th, 1781
M 82	Bode 1774	February 9th, 1781
M 83	Lacaille 1752	February 17th, 1781
M 84	Messier 1781	March 18th, 1781
M 85	Méchain 1781	March 18th, 1781
M 86	Messier 1781	March 18th, 1781
M 87	Messier 1781	March 18th, 1781
M 88	Messier 1781	March 18th, 1781
M 89	Messier 1781	March 18th, 1781
M 90	Messier 1781	March 18th, 1781
M 91	Messier 1781	March 18th, 1781
M 92	Bode 1777	March 18th, 1781
M 93	Messier 1781	March 20th, 1781
M 94	Méchain 1781	March 24th, 1781
M 95	Méchain 1781	March 24th, 1781
M 96	Méchain 1781	March 24th, 1781
M 97	Méchain 1781	March 24th, 1781
M 98	Méchain 1781	April 13th, 1781
M 99	Méchain 1781	April 13th, 1781
M 100	Méchain 1781	April 13th, 1781
M 101	Méchain 1781	1781
M 102	Méchain 1781	1781
M 103	Méchain 1781	1781
M 104	Méchain 1781	May 11th, 1781
M 105	Méchain 1781	not observed
M 106	Méchain 1781	not observed
M 107	Méchain 1782	not observed
M 108	Méchain 1781	March 24th, 1781
M 109	Méchain 1781	March 24th, 1781
M 110	Messier 1773	August 10th, 1773

declination 10° 24' 49". It is not tabulated in the Connoissance des Temps.

M 105

M. Messier thereat reports [in the catalog of 1774] p. 264 and 265, two nebulous stars, which I found in the Lion. I could not find fault with the noted positions, which were obtained by comparing them to Regulus. But there is a third a bit to the north, which is more vivid than the two preceding. I discovered it on March 24th, 1781, 4 or 5 days after I found the two others. On April 10th, I compared its position with γ, obtaining a right ascension 159° 3' 45" and its southern declination 13° 43' 58".

M 106

In July 1781 I found another nebulous patch near the Great Bear next to the star No. 3 of the Hunting Dogs and 1° farther south, I estimated its right ascension 181° 40' and the northern declination approximately 49°. I will shortly try to determine the exact position of the same.

M 107

In April 1782 I discovered a small nebulous patch on the left shank of Ophiuchus between the stars ζ and θ, whose position I have not yet observed closely.

In 1947 Helen Sawyer Hogg, who rediscovered the reprint of Méchains letter, suggested adding these four objects to the official Messier list in the order in which they are described.

The printed catalog already mentioned M 108 and M 109 implicitly, in the note on M 97. These discoveries are also mentioned in the letter of Méchain, see below. This led Owen Gingerich to suggest, in 1953, adding them to the official Messier list, too.

M 108, M 109

Page 265 No. 97. A nebulous patch near β in the Great Bear. M. Messier remarks on two others, while noting its position, which I discovered as well and of which one is close to it, the other lies near γ in the Great Bear, I have not been able to determine their positions yet.

The last supplemental object (M 110), the second companion galaxy of M 31, was made an official Messier object by Kenneth Glyn Jones. As a matter of fact, Messier had already observed and sketched that dwarf galaxy in 1773. But for unknown reasons, he did not include it in his catalog, and his observing notes were published only in 1798, in the 1801 edition of the Connaissance des Temps.

Did Messier and Méchain find any other objects? Apart from the above-cited hints given by Messier, there is also supporting evidence in Méchain's letter to Bernoulli:

On page 262 and 263 [of his last catalog version], M. Messier mentions several nebulous patches in the Virgin which I have indicated to him. But, there are more of them in the said area, which he did not see, and of which I will determine the positions, as soon as I have a convenient observing place, which will not be delayed too much.

However, like Messier, Méchain did not continue with his nebula search. Apparently, he never found "a more convenient observing place," and he was soon to become involved in other demanding work.

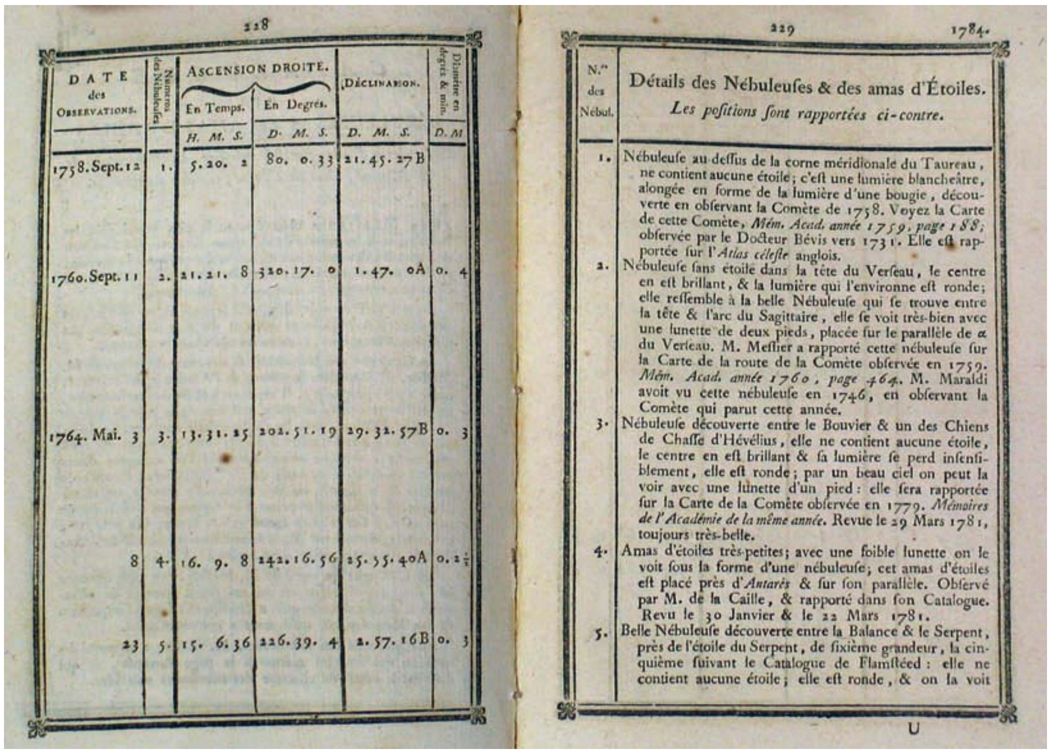
The catalog

Messier's catalog exists in three versions:

1. First version from 1771, published in the Mémoires de l'Académie des Sciences, 1774 edition, objects 1 to 45.
2. Second version from 1780, published in the Connaissance des Temps, 1783 edition, objects 1 to 68.
3. Third version from 1781, published in the Connaissance des Temps, 1784 edition, objects 1 to 103.

The following descriptions are a translation of the notes of the last version (from 1781). For each object, Messier also gives the date of his observation (which also is the equinox for the position), the right ascension in hours as well as in degrees, the declination in degrees, and (for most but not all objects) the angular diameter. Positive declinations are indicated by an "A," negative by a "B." For many objects discovered by Méchain, Messier lists both positional measurements, his and Méchain's.

The translation tries to maintain the character of the old-fashioned language, as well as Messier's very individualistic use of a ":" for a ";." Messier also indicates his other publications, referring to himself as "M.[onsieur] Messier." The telescopes are characterized by their focal length.



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DATE des Observations.	Numeros des Nébuleuſes	Ascension droite. En Temps.	Ascension droite. En Degrés.	Déclinaison.	Diamètre en degrés & min.
		H. M. S.	D. M. S.	D. M. S.	D. M
1758. Sept. 12	1.	5. 20. 2	80. 0. 33	21. 45. 27 B	
1760. Sept. 11	2.	21. 21. 8	320. 17. 0	1. 47. 0 A	0. 4
1764. Mai. 3	3.	13. 31. 25	202. 51. 19	29. 32. 57 B	0. 3
8	4.	16. 9. 8	242. 16. 56	25. 55. 40 A	0. 2½
23	5.	15. 6. 36	226. 39. 4	2. 57. 16 B	0. 3

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N.os des Nébul.	Détails des Nébuleuſes & des amas d'Étoiles. *Les poſitions ſont rapportées ci-contre.*
1.	Nébuleuſe au-deſſus de la corne méridionale du Taureau, ne contient aucune étoile; c'eſt une lumière blancheâtre, alongée en forme de la lumière d'une bougie, découverte en obſervant la Comète de 1758. Voyez la Carte de cette Comète, *Mém. Acad. année 1759, page 188*; obſervée par le Docteur Bévis vers 1731. Elle eſt rapportée ſur l'*Atlas céleſte* anglois.
2.	Nébuleuſe ſans étoile dans la tête du Verſeau, le centre en eſt brillant, & la lumière qui l'environne eſt ronde; elle reſſemble à la belle Nébuleuſe qui ſe trouve entre la tête & l'arc du Sagittaire, elle ſe voit très-bien avec une lunette de deux pieds, placée ſur le parallèle de α du Verſeau. M. Meſſier a rapporté cette nébuleuſe ſur la Carte de la route de la Comète obſervée en 1759. *Mém. Acad. année 1760, page 464*. M. Maraldi avoit vu cette nébuleuſe en 1746, en obſervant la Comète qui parut cette année.
3.	Nébuleuſe découverte entre le Bouvier & un des Chiens de Chaſſe d'Hévélius, elle ne contient aucune étoile, le centre en eſt brillant & ſa lumière ſe perd inſenſiblement, elle eſt ronde; par un beau ciel on peut la voir avec une lunette d'un pied: elle ſera rapportée ſur la Carte de la Comète obſervée en 1779. *Mémoires de l'Académie de la même année*. Revue le 29 Mars 1781, toujours très-belle.
4.	Amas d'étoiles très-petites; avec une foible lunette on le voit ſous la forme d'une nébuleuſe; cet amas d'étoiles eſt placé près d'*Antarès* & ſur ſon parallèle. Obſervé par M. de la Caille, & rapporté dans ſon Catalogue. Revu le 30 Janvier & le 22 Mars 1781.
5.	Belle Nébuleuſe découverte entre la Balance & le Serpent, près de l'étoile du Serpent, de ſixième grandeur, la cinquième ſuivant le Catalogue de Flamſtéed: elle ne contient aucune étoile; elle eſt ronde, & on la voit

U

The first catalog page of Messier's third version from 1781 with the objects M 1 to M 5. For each object, the entries are the date of observation, object number, right ascension in h/min/s and deg/min/s, declination and diameter in degree/arcmin.

Table of the nebulae and, consequently, also the star clusters, which are found among the stars above the horizon of Paris, observed from the Observatory of the Navy.

1 Sep 12th 1758 5h 20min 2s 80° 0' 33" 21° 45' 17"B
Nebula below the southern horn of the Bull, does not contain any star; it is a whitish light, elongated in the shape of a candle's light, discovered while observing the Comet of 1758. See the Chart of this Comet, Mem. Acad. year 1759, page 188; observed by Doctor Bevis about 1731. It is reported on the English star Atlas.

2 Sep 11th 1760 21h 21min 8s 320° 17' 0" 1° 47' 0"A 0° 4'
Nebula without star in the head of the Water-Bearer, the center of it is brilliant, and the light which surrounds it is round; it resembles the fine Nebula which is found between the head and the bow of the Archer, it is very well seen in a refractor of two feet, placed on the parallel of a of the Water Bearer. M. Messier reported this nebula on the Chart of the path of the Comet observed in 1759, Mem. Acad. year 1760, page 464. M. Maraldi had seen this nebula in 1746, while observing the Comet that appeared in that year.

3 May 3rd 1764 13h 31min 25s 202° 51' 19" 29° 32' 57"B 0° 3'
Nebula discovered between the Herdsman & one of the Hunting Dogs of Hevelius; it does not contain any star, its center is brilliant & and its light fades insensibly, it is round; in a good sky one can see it with a refractor of one foot; it is reported on the Chart of the Comet observed in 1779. Memoirs of the Academy of the same year. Re-observed on March 29th 1781, always very beautiful.

4 May 8th 1764 16h 9min 8s 242° 16' 56" 25° 55' 40"A 0° 2½'
Cluster of very small stars; with a weak refractor it is seen in the form of a nebula; this star cluster is placed near Antares & at its parallel. Observed by M. de la Caille, & reported in his Catalogue. Re-observed on January 30th & March 22nd 1781.

5 May 23rd 1764 15h 6min 36s 226° 39' 4" 2° 57' 16"B 0° 3'
Fine Nebula discovered between the Scales & the Serpent, near the star of the Serpent, of the sixth magnitude, which is the fifth according to the Catalogue of Flamsteed: it does not contain any star; it is round, & one can see it very well, in a good sky, with a simple refractor of one foot. M. Messier reported it on the Chart of the Comet of 1763. Mem. Acad. year 1774, page 40. Re-observed on Sept. 5th 1780, January 30th & March 22nd 1781.

6 May 23rd 1764 17h 24min 42s 261° 10' 39" 32° 10' 34"A 0° 15'
Cluster of small stars between the bow of the Archer & the tail of the Scorpion. With the naked eye, this cluster seems to form a nebula; but with the smallest instrument which is employed to examine it, one sees a cluster of small stars.

7 May 23rd 1764 17h 38min 2s 264° 30' 24" 34° 40' 34"A 0° 30'
Cluster of more considerable stars than the previous; this cluster appears to the naked eye like a nebula, it is little away from the previous, placed between the bow of the Archer & the tail of the Scorpion.

8 May 23rd 1764 17h 49min 58s 267° 29' 30" 24° 21' 10"A 0° 30'
Cluster of stars which appears in the form of a nebula when it is viewed with a simple refractor of three feet; but with an excellent instrument one does notice only a great number of small stars; near this cluster is a quite brilliant star, surrounded by a very faint light; this is the ninth star of the Archer, of the seventh magnitude, according to Flamsteed: this cluster appears in an elongated shape, which extends from North-east to South-west, between the bow of the Archer & the right foot of Ophiuchus.

9 May 28th 1764 17h 5min 22s 256° 20' 36" 18° 13' 26"A 0° 3'
Nebula, without star, in the right leg of Ophiuchus; it is round & its light faint. Re-observed on March 22nd 1781.

10 May 29th 1764 16h 44min 48s 251° 12' 6" 3° 42' 18"A 0° 4'
Nebula, without star, in the girdle of Ophiuchus, near the thirtieth star of that constellation, of sixth magnitude according to Flamsteed. This nebula is fine & round; one can see it only difficultly with a simple refractor of three feet. M. Messier reported it on the second Chart of the path of the Comet of 1769. Mem. Acad. year 1775, plate IX. Re-observed on March 6th 1781.

11 May 30th 1764 18h 30min 23s 279° 35' 43" 6° 31' 1"A 0° 4'
Cluster of a great number of small stars, near the star K of Antinous, that cannot be seen except in good instruments; with a simple refractor of three feet it resembles a Comet: this cluster is mingled with a faint light; in this cluster there is a star of 8th magnitude. M. Kirch observed it in 1681. Transact. Philos. No. 347, page 390. It is reported in the great English Atlas.

12 May 30th 1764 16h 34min 53s 248° 43' 10" 2° 30' 28"A 0° 3'
Nebula discovered in the Serpent, between the arm & the left side of Ophiuchus: this nebula does not contain any star, it is round & its light faint; near that nebula is a star of ninth magnitude. M. Messier reported it on the second Chart of the Comet observed in 1769. Mem. Acad. 1775, pl. IX. Re-observed on March 6th 1781.

13 Jun 1st 1764 16h 3min 15s 248° 18' 48" 36° 54' 44"B 0° 6'
Nebula without star, discovered in the girdle of Hercules; it is round & brilliant, the center brighter than the borders, one perceives it with a refractor of one foot; it is near two stars, both of 8th magnitude, one of them above & the other below: the nebula has been determined by comparing it with ε of Hercules. M. Messier reported it on the Chart of the Comet of 1779, included in the Memoirs of the Academy, of the year 1784. Seen by Halley in 1714. Re-observed on Jan. 5th & 30th 1781. It is reported in the English star Atlas.

14 Jun 1st 1764 17h 25min 14s 261° 18' 29" 3° 5' 45"A 0° 7'
Nebula without star, discovered in the garment covering the right arm of Ophiuchus, & and placed on the parallel of of the Serpent; this nebula is not large, its light is faint, because of this it can be seen with an ordinary refractor of three & a half feet; it is round. Near it is a small star of the ninth magnitude; its position was determined by comparing it with of Ophiuchus, & M. Messier reported its position on the Chart of the Comet of 1769. Memoirs of the Academy, year 1775, plate IX. Re-observed on March 22nd 1781.

15 Jun 3rd 1764 21h 18min 41s 319° 40' 19" 10° 40' 3"B 0° 3'
Nebula without star, between the head of Pegasus & that of the small Horse; it is round, the center in it is brilliant, its position determined by comparing it with d of the small Horse. M. Maraldi, in the Memoirs of the Academy of 1746, speaks of this nebula: "I have seen, he said, between the star ε of Pegasus & β of the small Horse, a star-nebula quite bright, that is composed of several stars; its right ascension is 319d 27' 6", & its southern declination is 11d 2' 22".

16 Jun 3rd 1764 18h 5min 0s 271° 15' 3" 13° 51' 44"A 0° 8'
Cluster of small stars, mingled with a faint light, near the tail of the Serpent, at small distance from the parallel of ζ of that constellation; with a weak refractor it appears in the form of a nebula.

17 Jun 3rd 1764 18h 7min 3s 271° 45' 48" 16° 14' 44"A 0° 5'
Train of light without stars, of five to six minutes in size, in the shape of a spindle, & a little bit like that in the girdle of Andromeda, but of a very faint light; there are two telescopic stars among & placed parallel to the Equator. In a good sky, one can see it very well with a simple refractor of three & a half feet. Re-observed March 22nd 1781.

18 Jun 3rd 1764 18h 6min 16s 271° 34' 3" 17° 13' 14"A 0° 5'
Cluster of small stars, a bit below the nebula above, No. 17, surrounded by a slight nebulosity, this cluster is less apparent than the previous, No. 16: with a simple refractor of three feet & a half, this cluster appears in the form of a nebula: but with a good refractor one only sees stars.

19 Jun 5th 1764 16h 48min 7s 252° 1' 45" 25° 54' 46"A 0° 3'
Nebula without stars, on the parallel of Antares, between the Scorpion & the right foot of Ophiuchus: this nebula is round; it is seen very well with a simple refractor of three & a half feet; the nearest known star to that nebula is the twenty-fifth of Ophiuchus, 6th magnitude, acc. Flamsteed. Re-observed on March 22nd 1781.

20 Jun 5th 1764 17h 48min 16s 267° 4' 5" 22° 59' 10"A
Cluster of stars, a little above the Ecliptic, between the bow of the Archer & the right foot of Ophiuchus. Re-observed on March 22nd 1781.

21 Jun 5th 1764 17h 50min 7s 267° 31' 35" 22° 31' 25"A
Cluster of stars, near the previous; the nearest known neighboring star of these two clusters is the eleventh of the Archer, seventh magnitude according to Flamsteed. The stars of these two clusters are of the eighth to ninth magnitude, surrounded by nebulosity.

22 Jun 5th 1764 18h 21min 55s 275° 28' 39" 24° 6' 11"A 0° 6'
Nebula, below the Ecliptic, between the head & the bow of the Archer, near a star of seventh magnitude, the twenty-fifth of the Archer, according to Flamsteed, this nebula is round, does not contain any star, & and can be seen very well with a simple refractor of three feet & a half; the star λ of the Archer served for the determination. Abraham Ihle, German, discovered it in 1665, while observing Saturn. M. le Gentil observed it in 1747, & and he made an engraving of it, Memoirs of the Academy, year 1759, page 470. Re-observed on March 22nd 1781: it is reported in the English Atlas.

23 Jun 20th 1764 17h 42min 51s 265° 42' 50" 18° 45' 55"A 0° 15'
Cluster of stars, between the extremity of the bow of the Archer & the right foot of Ophiuchus, very near the star 65 of Ophiuchus, according to Flamsteed. The stars of the cluster are very near each other. Its position determined with μ of the Archer.

24 Jun 20th 1764 18h 1min 44s 270° 26' 0" 18° 26' 0"A 1° 30'
Cluster of stars near the stars n & o of Antinous, among them is one of more light: with a telescope of three feet they cannot be distinguished, one has to employ a good instrument. This cluster does not contain any nebulosity.

25 Jun 20th 1764 18h 17min 40s 274° 25' 0" 19° 5' 0"A 0° 10'
Cluster of small stars in the neighborhood of the two previous clusters, between the head & the extremity of the bow of the Archer: the nearest known star to this cluster is the 21st star of the Archer, sixth magnitude, according to Flamsteed. The stars of this cluster are easily seen with a simple refractor of three feet; no nebulosity can be perceived. Its position was known by the star μ of the Archer.

26 Jun 20th 1764 18h 32min 22s 278° 5' 25" 9° 38' 14"A 0° 2'
Cluster of stars near the stars n & o of Antinous, among them is one of more light: with a telescope of three feet they cannot be distinguished, one has to employ a good instrument. This cluster does not contain any nebulosity.

27 Jul 12th 1764 19h 49min 27s 297° 21' 41" 22° 4' 0"B 0° 4'
Nebula without star, discovered in the Fox, between the two forelegs, & very near the 14th star of this constellation, 5th magnitude according to Flamsteed; it is well seen with a simple refractor of 3 feet & a half: it appears in an oval shape, & does not contain any star. M. Messier reported its position on the Chart of the Comet of 1779, which will be engraved for the volume of the Acad. of the same year. Re-observed on January 31st 1781.

28 Jul 27th 1764 18h 9min 58s 272° 29' 30" 24° 57' 11"A 0° 2'
Nebula discovered in the upper part of the bow of the Archer about one degree from the star γ & little distant from the fine nebula which

is between the head & arc. It does not contain any star; it is round, it cannot be observed without difficulty with a simple refractor of 3 feet ½. Its position was determined with γ of the Archer. Re-observed on March twentieth 1781.

29 Jul 29th 1764 20h 15min 38s 303° 54' 29" 37° 11' 57"B
Cluster of seven or eight very small stars, which are below γ of the Swan, which are seen with a simple refractor of 3 feet & a half in the form of a nebula. Its position is determined with γ of the Swan. This cluster is reported on the Chart of the Comet of 1779.

30 Aug 3rd 1764 21h 27min 5s 321° 46' 18" 24° 199' 4"A 0° 2'
Nebula discovered below the tail of the Capricorn, very near the 41st star of that constellation, 6th magnitude, according to Flamsteed. It can be seen with difficulty with a simple refractor of 3 feet ½. It is round & does not contain any star; its position determined by ζ of the Capricorn. M. Messier reported it on the Chart of the Comet of 1759. Mem. Acad. 1760, pl. II.

31 Aug 3rd 1764 0h 29min 46s 7° 26' 32" 39° 9' 32"B 0° 40'
The beautiful nebula in the girdle of Andromeda, in the shape of a spindle; M. Messier examined it with different instruments, & did not recognize any star: it resembles two cones or pyramids of light opposed by their base, the axis of which is in direction North-west to South-east; the two points of light or apexes are about 40 minutes of a degree apart; the common base of the two pyramids 15 minutes. This nebula was discovered in 1612, by Simon Marius, & observed since then by different astronomers. M. le Gentil gave a drawing of it in the Memoirs of the Academy of 1759, page 453. It is reported in the English Atlas.

32 Aug 3rd 1764 0h 29min 50s 7° 27' 32" 38° 45' 34"B 0° 2'
Small nebula without stars, below & by several minutes off that in the girdle of Andromeda; this small nebula is round, the light fainter than that of the girdle. M. le Gentil discovered it on October 29th 1749. M. Messier viewed it, for the first time, in 1757, & did not recognize any change.

33 Aug 25th,1764 1h 40min 37s 20° 9' 17" 29° 32' 25"B 0° 15'
Nebula discovered between the head of the northern Fish & the great Triangle, at a small distance from a star of 6th magnitude: the nebula is of a whitish light, of almost equal density, however a little brighter for two thirds of its diameter, & does not contain any star. It can be seen difficultly with a simple refractor of one foot. Its position determined by comparing it with α of the Triangle. Re-observed on Sept. 27th 1780.

34 Aug 25th 1764 2h 27min 27s 36° 51' 37" 41° 39' 32"B 0° 15'
Cluster of small stars, between the head of the Medusa & the left foot of Andromeda, nearly on the parallel of γ: with a simple refractor of 3 feet the stars can be distinguished. Its position was determined with β of the head of the Medusa.

35 Aug 30th1764 5h 54min 41s 88° 40' 9" 24° 33' 30"B 0° 20'
Cluster of very small stars, near the left foot of Castor, at little distance from the stars μ & η of this constellation. M. Messier reported its position on the Chart of the Comet of 1770. Mem. Acad. 1771, pl. VII. Reported in the English Atlas.

36 Sep 2nd 1764 5h 20min 47s 80° 11' 42 34° 8' 6"B 0° 9'
Cluster of stars in the Charioteer, near the star ϕ: with a simple refractor of 3 feet & a half the stars are barely discerned, the cluster does not contain any nebulosity. Its position determined with ϕ.

37 Sep 2nd 1764 5h 37min 1s 84° 15' 12 32° 11' 51"B 0° 9'
Cluster of small stars, little distant from the previous, on the parallel of χ of the Charioteer; the stars are very small, very close & contain nebulosity; with a simple refractor of 3 feet & a half, the stars are barely visible: this cluster is reported on the Chart of the second Comet of 1771, Mem. Acad. 1777.

38 Sep 25th 1764 5h 12min 41s 78° 10' 12 36° 11' 51"B 0° 15'
Cluster of faint stars in the Charioteer, near the star σ, at small distance from the two previous clusters; this one is of a square shape & does not contain any nebulosity, if examined with care in a good instrument. Its extent may be 15 minutes of a degree.

39 Oct 24th 1764 21h 23min 49s 320° 57' 10 47° 25' 0"B 1° 0'
Cluster of stars near the tail of the Swan; they can be seen with a simple refractor of 3 feet & a half.

40 Oct 24th 1764 12h 11min 2s 182° 45' 30 59° 23' 50"B
Two stars very near each other & very small, placed at the onset of the tail of the great Bear: they are barely distinguished with a simple refractor of 6 feet. These two stars have been observed while searching for the nebula placed above the back of the great Bear, reported in the book on the shape of celestial bodies, which must have been in 1660, 183d 32' 41" of right ascension, & 60d 20' 33" of north declination, which M. Messier could not see.

41 Jan 16th 1765 6h 35min 53s 98° 58' 12" 20° 33' 0"A
Cluster of stars below Sirius, near ρ of the great Dog; this cluster appears nebulous with a simple refractor of one foot: but it is only a cluster of small stars.

42 Mar 4th 1769 5h 23min 59s 80° 59' 40" 5° 34' 6"A
Position of the beautiful nebula of the sword of Orion, with the star θ which is contained there with three other smaller stars which cannot be seen except in good instruments. M. Messier went into great detail on this great nebula; he has given a drawing of it, made with the most care, which can be seen in the Memoirs of the Academy, year 1771, plate VIII. It was Huyghens who discovered it in 1656: it was since then observed by a large number of astronomers. Reported in the English Atlas.

43 Mar 4, 1769 $5^h 24^{min} 12^s$ 81° 3' 0" 5° 26' 37"A

Position of the small star which is surrounded by nebulosity & which is below the nebula in the sword of Orion. M. Messier reported it on the drawing of the great one.

44 Mar 4, 1769 $8^h 7^{min} 22^s$ 126° 50' 30" 20° 31' 38"B

Cluster of stars known by the name of the nebulae of Cancer, the reported position is that of star C.

45 Mar 4, 1769 $3^h 33^{min} 48^s$ 53° 27' 4" 23° 22' 41"B

Cluster of stars, known by the name of the Pleiades. The reported position is that of the star Alcyone.

End of the printed catalog by M. Messier.

Those that follow have been observed by M. Messier, after the printing of his memoir.

46 Feb 19^{th} 1771 $7^h 31^{min} 11^s$ 112° 47' 43" 14° 19' 7"A

Cluster of very small stars, between the head of the great Dog & the two hindlegs of the Unicorn, determined by comparing this cluster with the 2^{nd} star of the Ship, 6^{th} magnitude, according to Flamsteed; the stars are not visible except in a good refractor; this cluster contains a bit of nebulosity.

47 Feb 19^{th} 1771 $7^h 44^{min} 16^s$ 116° 3' 58" 14° 50' 8"A

Cluster of stars little distant from the prev. the stars larger, the middle of the cluster compared with the same star, the second of the Ship. The cluster does not contain any nebulosity.

48 Feb 19^{th} 1771 $8^h 2^{min} 24^s$ 120° 36' 0" 1° 16' 42"A

Cluster of very small stars, without nebulosity; this cluster is at a little distance from three stars which are at the onset of the tail of the Unicorn.

49 Feb 19^{th} 1771 $12^h 17^{min} 48^s$ 184° 26' 58" 9° 16' 9"B

Nebula discovered near the star δ of the Virgin. It is not without difficulty that this nebula can be seen in a simple refractor of 3 feet & a half. The Comet of 1779 was compared to this nebula by M. Messier on April 22^{nd} & $23^{rd:}$ the Comet & the Nebula had the same brightness. M. Messier reported this nebula on the Chart of the path of this Comet, which appeared in the volume of the Academy on the same year 1779. Re-observed on April 10^{th} 1781.

50 Apr 5^{th} 1772 $6^h 51^{min} 50^s$ 102° 57' 28" 7° 57' 42"A

Cluster of small stars more or less brilliant, below the right thigh of the Unicorn, above the star θ of the ear of the great Dog, & near a star of 7^{th} magnitude. M. Messier observed this cluster while observing the Comet of 1772. It is reported on the Chart of this Comet, on which it is traced. Mem. Acad. 1772.

51 Jan 11^{th} 1774 $13^h 20^{min} 23^s$ 200° 5' 48" 48° 24' 24"B

Very faint nebula, without stars, near the ear of the southern of the Greyhounds, below the star η of 2^{nd} magnitude of the tail of the Great Bear: M. Messier discovered this nebula on October 13^{th} 1773, while observing the Comet which appeared in this year. One cannot see it but difficultly with a simple refractor of 3 feet ½: near it is a star of 8^{th} magnitude. M. Messier reported its position on the Chart of the Comet observed in 1773 & 1774. Memoirs of the Academy 1774, plate III. It is double, each one with a brilliant center, separated from each other 4' 35". The two atmospheres touch each other. One is fainter than the other. Re-observed several times.

52 Sep 7^{th} 1774 $23^h 14^{min} 38^s$ 348° 39' 27" 60° 22' 12"B

Cluster of very small stars, mingled with nebulosity, which cannot be seen except in an achromatic refractor. While observing the Comet which appeared in that year, M. Messier saw this cluster, which had been near the Comet on September 7^{th} 1774: it is below the star d of Cassiopeia: this star d served to determine the star cluster & the Comet.

53 Feb 26^{th} 1777 $13^h 2^{min} 2^s$ 195° 30' 26" 19° 22' 44"B

Nebula without stars, discovered below & near the hair of Berenice, at a little distance from the 42^{nd} star of this constellation, according to Flamsteed. This nebula is round & conspicuous. The Comet of 1779 was compared directly to this nebula, & M. Messier reported it on the Chart of this Comet, which will be included in the volume of the Academy for 1779. Re-observed on April 13^{th} 1781: it resembles the nebula which is above the Hare.

54 Jul 24^{th} 1778 $18^h 40^{min} 52^s$ 280° 12' 55" 30° 44' 1"A

Very faint nebula, discovered in the Archer; its center is brilliant & does not contain any star, as seen with an achromatic refractor of 3 feet ½. Its position was determined with ζ of the Archer 3^{rd} magnitude.

55 Jul 24^{th} 1778 $19^h 26^{min} 2^s$ 291° 30' 25" 31° 26' 27"A

Nebula that is a whitish patch, about 6 minutes in extent, the light is even & appears not to contain any star. Its position was determined with ζ of the Archer, by means of an intermediate star of 7^{th} magnitude. This nebula was discovered by M. Abbé de la Caille. Mem. Acad. 1755, p. 194. M. Messier had searched for it without success on July 29^{th} 1764, as reported in his Memoir.

56 Jan 23^{rd} 1779 19^h 8^{min} 0^s 287° 0' 1" 29° 48' 14"B

Nebula without star, having little light; M. Messier discovered it on the same day as the discovery of the Comet of 1779 on January nineteenth. On the 23^{rd}, he determined its position by comparing it to the star No. 2 of the Swan, according to Flamsteed: it is near the milky way, near to it is a star of 10^{th} magnitude. M. Messier reported it on the Chart of the Comet of 1779.

57 Jan 31^{st} 1779 18^h 45^{min} 21^s 281° 20' 8" 32° 46' 3"B

Mass of light placed between γ & β of the Lyre, discovered while observing the Comet of 1779, which passed nearby: it seems that this mass of light, which is rounded, is composed of very small stars: with the best telescopes it is not possible to perceive them, there is only a suspicion left that they are there. M. Messier reported this mass of light on the Chart of the Comet of 1779. M. Darquier, in Toulouse, discovered this nebula, while observing the same Comet, & and he reports: "Nebula between γ & β of the Lyre; it is quite lacklustre, but perfectly terminated; it is large as Jupiter & resembles a fading Planet."

58 Apr 15^{th} 1779 12^h 26^{min} 30^s 186° 37' 23" 13° 2' 42"B

Very faint nebula discovered in the Virgin, near the parallel of ε 3^{rd} magnitude. The least light to illuminate the micrometer wires causes it to disappear. M. Messier reported it on the Chart of the Comet of 1779, which can be found in the volume of the Academy of the same year.

59 Apr 15^{th} 1779 12^h 30^{min} 47^s 187° 41' 38" 12° 52' 36"B

Nebula in the Virgin & in the neighborhood of the previous, on the parallel of ε, which served for the determination: it is of the same light as that above, just as faint. M. Messier reported it on the Chart of the Comet of 1779.

60 Sep 15^{th} 1779 12^h 32^{min} 28^s 188° 6' 53" 12° 46' 2"B

Nebula in the Virgin, a little bit more apparent than the two previous ones, likewise on the parallel of ε, which has served for the determination. M. Messier reported it on the Chart of the Comet of 1779. He discovered these three nebulae while observing this Comet which passed very near to them. The latter passed very near on April 13^{th} & 14^{th}, that being both in the field of the refractor, he could not see it; it was not until the 15^{th}, while searching for the Comet, that he saw this nebula. These three nebulae do not appear to contain any star.

61 May 11^{th} 1779 12^h 10^{min} 44^s 182° 41' 5" 5° 42' 5"B

Very faint nebula & difficult to perceive. M. Messier took this nebula for the Comet of 1779 on May 5^{th}, 6^{th} & 11^{th}; on the 11^{th} he recognized that this was not the Comet; but a nebula which was found on its path & at the same point in the Sky.

62 June 4^{th} 1779 16^h 47^{min} 14^s 251° 48' 24" 29° 45' 30"A

Very fine nebula, discovered in the Scorpion, it resembles a small Comet, its center is brilliant & surrounded by a faint light. Its position was determined by comparing it to the star τ of the Scorpion. M. Messier had already seen this nebula on June 7^{th} 1771, without having determined the position but approximately. Re-observed on March 22^{nd} 1781.

63 June 14^{th} 1779 13^h 4^{min} 22^s 196° 5' 30" 43° 12' 37"B

Nebula discovered by M. Méchain in the Hunting Dogs. M. Messier located it; it is faint, it has about the same brightness as the nebula reported under No. 59: it does not contain any star, & the least light to illuminate the wires of the micrometer causes it to disappear: there is a star of 8^{th} magnitude near it, which precedes the nebula on the hour wire. M. Messier reported its position on the Chart of the path of the Comet of 1779.

64 Mar 1^{st} 1780 12^h 45^{min} 51^s 191° 27' 38" 22° 52' 31"B

Nebula discovered in the hair of Berenice, which is half as apparent as that one which is below the hair. M. Messier reported its position on the Chart of the Comet of 1779. Re-observed on March seventeenth 1781.

65 Mar 1^{st} 1780 11^h 7^{min} 24^s 166° 50' 54" 14° 16' 8"B

Nebula discovered in the Lion; it is very faint & does not contain any star.

66 Mar 1^{st} 1780 11^h 8^{min} 47^s 167° 11' 39" 14° 12' 21"B

Nebula discovered in the Lion; its light very faint & very near the previous: they appear both in the same field of the refractor. The Comet observed in 1773 & 1774 had passed between these two nebulae from November 1^{st} to 2^{nd} 1773. M. Messier did not see them then, without doubt, because of the light of the Comet.

67 Apr 6^{th} 1780 8^h 36^{min} 28^s 129° 6' 57" 12° 36' 38"B

Cluster of small stars with nebulosity, below the southern Claw of the Crab. The position determined with the star α.

68 Apr 9^{th} 1780 12^h 27^{min} 38^s 186° 54' 33" 25° 30' 20"A

Nebula without stars below the Raven & the Hydra; it is very faint, very difficult to perceive with the refractors; near it is a star of the sixth magnitude.

Extension of the Catalog of Nebulae & Star Clusters of M. Messier, included in the Connoiss. des Temps for 1783, page 225, & year 1784, page 255 & following.

69 Aug 31st 1780 18^h 16^{min} 47^s 274° 11' 46" 32° 31' 45"A 0° 2'

Nebula without stars, in the Archer, below his left arm & near the arc; near it is a star of 9th magnitude: its light is very faint, one cannot see it but in good weather, & the least light employed to illuminate the wires of the micrometer causes it to disappear: its position was determined by ε of the Archer: this nebula was observed by M. de la Caille, & reported in his catalog; it resembles the nucleus of a small Comet.

70 Aug. 31st 1780 18^h 28^{min} 53^s 277° 13' 16" 32° 31' 7"A 0° 2'

Nebula without star, near the previous, & on the same parallel: near it is a star of the ninth magnitude & four small telescopic stars, nearly on a straight line, very near each other, & are placed above the nebula, as seen in an inverting refractor; the nebula determined by the same star ε of the Archer.

71 Oct 4th 1780 19^h 43^{min} 57^s 295° 59' 9" 18° 13' 0"B 0° 3 ½'
M. Méchain 296° 0' 4" 18° 14' 21"

Nebula discovered by M. Méchain on June 28th 1780, between the stars γ & δ of the Arrow. On the following October 4th, M. Messier located it: its light is very faint & does not contain any star; the least light causes it to disappear. It is placed about 4 degrees below that which was discovered by M. Messier in the Fox. See No. 27. He reported it on the Chart of the Comet of 1779.

72 Oct 4th 1780 20^h 41^{min} 23^s 310° 20' 49" 13° 20' 51"A 0° 2'
M. Méchain 310° 21' 10" 13° 21' 24"

Nebula seen by M. Méchain the night of August 29th to 30th 1780, above the neck of the Capricorn. M. Messier located it on October 4th & 5th following: its light faint as the previous; near it is a small telescopic star: its position determined with the star ν of the Water-Bearer, fifth magnitude.

73 Oct 4th & 5th 1780 20^h 46^{min} 52^s 311° 43' 4" 13° 28' 40"A

Cluster of three or four small stars, which resemble a nebula at first glance, contains a bit of nebulosity: this cluster is placed on the parallel of the previous nebula: its position was determined by the same star ν of the Water-Bearer.

74 Oct 18th 1780 1^h 24^{min} 57^s 21° 14' 9" 14° 39' 35"B
M. Méchain 21° 17' 0" 14° 36' 0"

Nebula without star, near the star η of the Link of the Fishes, seen by M. Méchain at the end of September 1780, & and of which he reports: "This nebula does not contain stars; it is quite large, very obscure, extremely difficult to observe, one can determine it more exactly in good frosts." M. Messier located it & found it, as M. Méchain described it: it was compared directly with the star η of the Fishes.

75 Oct 18th 1780 19^h 53^{min} 10^s 298° 17' 24" 22° 32' 23"A
M. Méchain 298° 17' 30" 22° 32' 0"

Nebula without star, between the Archer & the head of the Capricorn: seen by M. Méchain on August 27th & 28th 1780. M. Messier located it on October 5th following & on the eighteenth compared it with the star No. 4, sixth magnitude of the Capricorn, according to Flamsteed: it appears to M. Messier that it is composed only of very small stars, containing nebulosity: M. Méchain reported it as nebula without stars. M. Messier saw it on October 5th; but the Moon was on the horizon, & it was not until the eighteenth of the same month that he was able to judge its appearance & determine its position.

76 Oct 21st 1780 1^h 28^{min} 43^s 22° 10' 47" 50° 28' 48"B 0° 2'
M. Méchain 22° 10' 26" 50° 28' 12"

Nebula on the foot of Andromeda, seen by M. Méchain on Sept. 5th 1780, & of which he reports: "This nebula does not contain stars; it is small & faint." On the following October 21st M. Messier located it with his achromatic refractor, & it seemed to him that it was composed of nothing but very small stars, which contained nebulosity, & the least light employed to illuminate the wires of the micrometer caused them to disappear: the position determined with the star ϕ of Andromeda, fourth magnitude.

77 Dec 17th 1780 2^h 31^{min} 30^s 37° 52' 33" 0° 57' 43"A
M. Méchain 37° 52' 58" 0° 57' 44"

Cluster of small stars, which contain nebulosity, in the Whale, & on the parallel of the star δ reportedly of third magnitude, & which M. Messier estimated to be only of the fifth. M. Méchain saw this cluster on October 29th 1780 in the form of a nebula.

78 Dec 17th 1780 5^h 35^{min} 34^s 83° 53' 35" 0° 1' 23"A 0° 3'
M. Méchain 83° 53' 2" 0° 0' 31"

Cluster of stars, with much nebulosity in Orion & on the parallel of the star δ of the Belt, which served in determining its position; the cluster follows the star on the hour wire by 3d 41' & the cluster above the star by 27' 7". M. Méchain has seen this cluster in the beginning of 1780, & reports hence: "On the left side of Orion, 2 to 3 minutes of diameter, there are two fairly brilliant nuclei, surrounded by nebulosity."

79 Dec 17th 1780 5^h 15^{min} 16^s 78° 49' 2" 24° 42' 57"A
M. Méchain 78° 47' 10" 24° 44' 46"

Nebula without star, placed below the Hare, & on the parallel of a star of the sixth magnitude: seen by M. Méchain on October 26th 1780. M. Messier located it on December seventeenth following: this nebula is fine; the center brilliant, the nebulosity little diffuse: its position determined by the star ε of the Hare, fourth magnitude.

80 Jan 4th 1781 16^h 4^{min} 0^s 240° 59' 48" 22° 25' 13"A 0° 2'
M. Méchain 241° 0' 26" 22° 27' 58"

Nebula without star, in the Scorpion, between the stars γ & δ, compared with γ to determine its position: this nebula is round, the center brilliant & resembles the nucleus of a small Comet, surrounded by nebulosity. M. Méchain saw it on January 27th 1781.

81 Feb 9th 1781 $9^h 37^{min} 51^s$ 144° 27′ 44″ 70° 7′ 24″B
M. Méchain 144° 27′ 0″ 70° 4′ 0″

Nebula near the ear of the great Bear, on the parallel of the star d, of the fourth to the fifth magnitude: its position determined with this star. This nebula is slightly oval, the center clear, & it can be seen very well with a simple refractor of three feet & a half. It was discovered at Berlin, by M. Bode, on December 31st 1774, & by M. Méchain, in the month August of 1779.

82 Feb 9th 1781 $9^h 37^{min} 57^s$ 144° 29′ 22″ 70° 44′ 27″B
M. Méchain 144° 28′ 13″ 70° 43′ 5″

Nebula without star, near the previous; both appear in the field of the refractor at the same time, this one less apparent than the previous, its light is faint & elongated: at its extremity is a telescopic star. Seen at Berlin, by M. Bode, on December 31st 1774, & by M. Méchain, in the month August of 1779.

83 Feb 17th 1781 $13^h 24^{min} 33^s$ 201° 8′ 13″ 28° 42′ 27″A

Nebula without star, near the head of the Centaur: it appears as a faint & even light, but so difficult to observe, that the least light to illuminate the wires of the micrometer causes it to disappear. It is only with much attention that it can be seen: it forms a triangle with two stars estimated of the sixth and seventh magnitude: determined with the stars l, i, k, h, of the head of the Centaur: M. de la Caille had already determined this nebula. See at the end of this Catalog.

84 Mar 18th 1781 $12^h 14^{min} 1^s$ 183° 30′ 21″ 14° 7′ 1″B

Nebula without star, in the Virgin; its center is rather bright, surrounded by a light nebulosity: its brightness & its appearance resemble those of this Catalog, Nos. 59 & 60.

85 Mar 18th 1781 $12^h 14^{min} 21^s$ 183° 35′ 21″ 19° 24′ 26″B
M. Méchain 183° 35′ 45″ 19° 23′ 0″

Nebula without star, above & near the spike of the Virgin, between the two stars of the hair of Berenice, Nos. 11 & 14 of Flamsteed's Catalog: this nebula is very faint. M. Méchain determined its position on March 4th 1781.

86 Mar 18th 1781 $12^h 15^{min} 5^s$ 183° 46′ 21″ 14° 9′ 52″B

Nebula without star, in the Virgin, on the parallel & very near of the nebula above, No. 84: their appearance is the same, & both appear the same field of the refractor.

87 Mar 18th 1781 $12^h 19^{min} 48^s$ 184° 57′ 6″ 13° 38′ 1″B

Nebula without star, in the Virgin, below & quite near of a star of eighth magnitude, the star having the same right ascension as the nebula, & its declination is 13d 42′ 21″ north. This nebula appears of the same brightness as the two nebulae Nos. 84 & 86.

88 Mar 18th 1781 $12^h 21^{min} 3^s$ 185° 15′ 49″ 15° 37′ 51″B

Nebula without star, in the Virgin, between two small stars & and one star of the sixth magnitude, which appear at the same time as the nebula in the field of the refractor. Its light is one of the faintest & resembles that reported in the Virgin, No. 58.

89 Mar 18th 1781 $12^h 24^{min} 38^s$ 186° 9′ 36″ 13° 46′ 49″B

Nebula without star, in the Virgin, at a little distance from & on the same parallel as the nebula reported above, No. 87. Its light was extremely faint & rare & it is not without trouble that it can be perceived.

90 Mar 18th 1781 $12^h 25^{min} 48^s$ 186° 27′ 0″ 14° 22′ 50″B

Nebula without star, in the Virgin: its light as faint as the previous, No. 89.

91 Mar 18th 1781 $12^h 26^{min} 28^s$ 186° 37′ 0″ 14° 57′ 6″B

Nebula without star, in the Virgin, above the previous No. 90: its light is still fainter than those above.
Note. The constellation of the Virgin, & especially its northern wing, is one of the constellations which encloses many Nebulae: this Catalogue contains 13 of them determined: namely, the Nos. 49, 58, 59, 60, 61, 84, 85, 86, 87, 88, 89, 90 & 91. All these nebulae appear without stars: they cannot be seen except in a very good sky, & near their passages of the Meridian. The majority of these nebulae were indicated to me by M. Méchain.

92 Mar 18th 1781 $17^h 10^{min} 32^s$ 257° 38′ 3″ 43° 21′ 59″B 0° 5′

Nebula, fine, conspicuous, & of a great brightness, between the knee & the left leg of Hercules, seen very well with a refractor of one foot. It does not contain any star; the center is clear & brilliant, surrounded by nebulosity & resembles the nucleus of a big Comet: its light, its magnitude, come very near to that of the nebula which is in the girdle of Hercules. See No. 13 of this Catalog: its position was determined by comparing it directly to the star ο of Hercules, fourth magnitude: the nebula & star on the same parallel.

93 Mar 20th 1781 $7^h 35^{min} 14^s$ 113° 48′ 35″ 23° 19′ 45″A 0° 8′

Cluster of small stars, without nebulosity, between the great Dog & the prow of the Ship.

94 Mar 24th 1781 $12^h 40^{min} 43^s$ 190° 10′ 46″ 42° 18′ 43″B 0° 2 ½′
M. Méchain 190° 9′ 38″ 42° 18′ 50″

Nebula without star, above the heart of Charles, on the parallel of the star No. 8, sixth magnitude, of the Greyhounds, according to Flamsteed: its center is brilliant & the nebulosity slightly diffuse. It resembles the nebula which is below the Hare, No. 79: but this one is finer & more brilliant; M. Méchain did discover it on March 22nd 1781.

95 Mar 24th 1781 $10^h 32^{min} 12^s$ 158° 3′ 5″ 12° 50′ 21″B
M. Méchain 158° 6′ 23″ 12° 49′ 50″

Nebula without star, in the Lion, above the star l: its light is very faint.

96 Mar 24th 1781 10h 35min 5s 158° 46′ 20″ 12° 58′ 9″B
M. Méchain 158° 48′ 0″ 12° 57′ 33″

Nebula without star, in the Lion, near the previous; this one is less apparent, both on the parallel of Regulus: they resemble the two nebulae in the Virgin, Nos. 84 & 86. M. Méchain saw both on March twentieth 1781.

97 Mar 24th 1781 11h 1min 15s 165° 18′ 40″ 56° 13′ 30″A 0° 2′

Nebula in the great Bear, near β: it is difficult to observe, reports M. Méchain, especially when illuminating the wires of the micrometer: its light is faint, without star. M. Méchain saw it for the first time on February 16th 1781, & the position is given according to him. Near this nebula he has seen another, which has not been determined yet, also a third one which is near to γ of the great Bear.

98 Apr 13th 1781 12h 3min 23s 180° 50′ 49″ 16° 8′ 15″B

Nebula without star, of an extremely faint light, above the northern side of the Virgin, on the parallel & near the star No. 6, fifth magnitude, according to Flamsteed. M. Méchain saw it on March 15th 1781.

99 Apr 13th 1781 12h 7min 41s 181° 55′ 19″ 15° 37′ 12″B

Nebula without star, of a very rare light, but a little bit more clear than the previous, placed on the northern side of the Virgin, & near the same star, No. 6, of the hair of Berenice. The nebula is between two stars of the seventh & eighth magnitude. M. Méchain observed it on March 15th 1781.

100 Apr 13th 1781 12h 11min 57s 182° 59′ 19″ 16° 59′ 21″B

Nebula without star, of the same brightness as the previous, placed in the spike of the Virgin. Seen by M. Méchain on March 15th 1781. These three nebulae, Nos. 98, 99 & 100, are very difficult to distinguish, because of the faintness of their light: they cannot be seen except in good weather, & near their passages of the Meridian.

By M. Méchain, which M. Messier has not yet seen.

101 Mar 27th 1781 13h 43min 28s 208° 52′ 4″ 55° 24′ 25″B 0° 7′

Nebula without star, very obscure & pretty large, 6 to 7 minutes in diameter, between the left hand of the Herdsman & the tail of the great Bear. It can be barely distinguished when the wires are lit.

102

Nebula between the stars ο of the Herdsman & ι of the Dragon: it is very faint; near it is a star of the sixth magnitude.

103

Cluster of stars between ε and δ of the leg of Cassiopeia.

Remarks on Messier's catalog

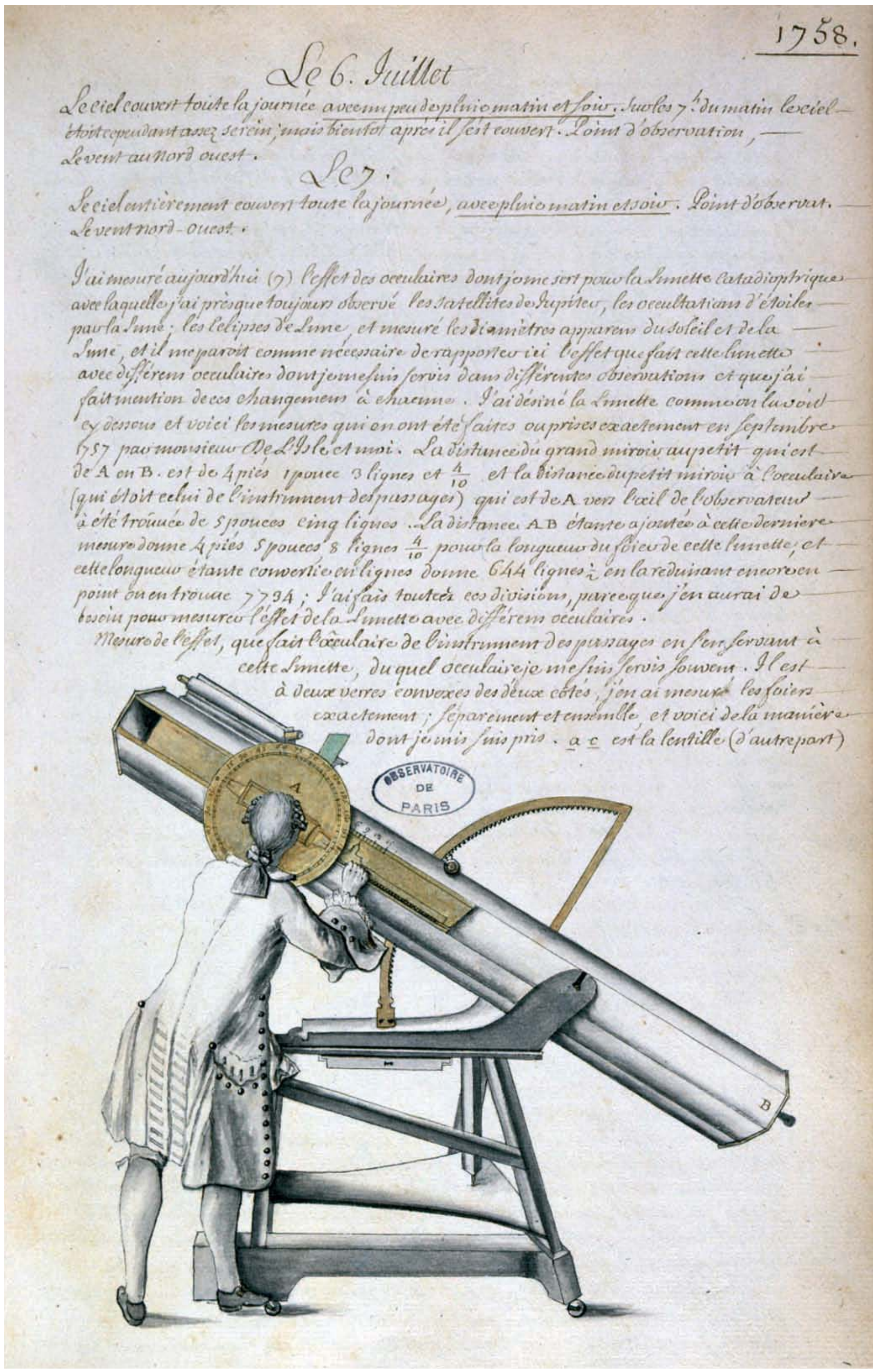
Messier's catalog is, by no means, a uniform series of observations. The descriptions stem from the use of different telescopes (see box) and are, consequently, of varying quality. The object brightness, which Messier would still see or describe as faint, varies accordingly.

The faintest object of the first catalog version is also its first, M 1 with magnitude 8.4. Almost all other entries are brighter than 8th magnitude, most fall even into the range of 5th to 7th magnitude. Apart from M 31, M 32, and M 33, no galaxies are listed in the first catalog version; they were too faint for Messier's instrumentation at that time. Hence, most of the first 45 entries are open clusters, some globular clusters and a few galactic nebulae, plus one single planetary nebula.

For his second catalog, Messier was able to use better optical instruments. By 1773 he had received one of the first achromatic refractors from the collection of his friend de Saron. This telescope is mentioned in detail in the description of Messier's drawing of M 42. From then on, Messier's discoveries reach nearly down to magnitude 10, including many galaxies. This trend continues with the third part, which includes objects at the perception limit of a modern 2-inch telescope under a dark sky. Many of these were contributed by Méchain, who worked at the Royal Observatory – we may safely assume that his instruments were better than Messier's.

Messier's first catalog (M 1 to M 45) contains exact descriptions of the telescopes and magnifications he used. The telescope mentioned in almost every more detailed description is a Gregorian reflector of 30 inches (French) focal length, 6 inches aperture and a (probably fixed) magnification of 104×. Modern notation would have it as a 6.4-inch f/5 system (162mm aperture, 810mm focal length) with an eyepiece focal length of 7.8mm. With an apparent field of view of 30°, it covered 17' in the sky. This telescope is mentioned in the descriptions of M 2, 3, 5, 9, 10, 11, 15, 19, 22, 26, 27, 28, 30, 31, 35, 42, and 43, while for M 13 and M 31, a Newtonian telescope of 4.5-feet focal length and a power of 65× is noted.

It is most likely that Messier made his discoveries with smaller telescopes, which he used for comet hunting. The purpose of the larger optics was to make detailed descriptions and to measure the positions of the new objects. In the third catalog, Messier ranks his telescopes according to their focal length in five categories. These were also used by him to characterize the difficulty of an object:



A page from Messier's observing logbook. In his entry made on the 7th of July 1758, Messier describes the reflector with which he observed the moons of Jupiter and stellar occultations. As shown here, the telescope is set up for measurements of the exact eyepiece focal length.

1 foot

observed objects: M 3, M 5, M 13, M 33, M 41, M 92

The faintest of these targets is M 92 at magnitude 6.4. M 41 was not recognized by Messier as a star cluster but taken for a nebula. Since its brightest stars reach magnitude 6.9, the limiting magnitude of this telescope under the Parisian night sky must have been between magnitudes 6.5 and 7.0.

2 foot

observed objects: M 2

The optical performance of this telescope cannot have been much better than that of the 1-foot telescope.

3 foot

observed objects: M 8, M 10, M 11, M 25, M 26, M 30, M 34, M 35

The faintest of these objects is M 26 with magnitude 8.0. However, M 10 at magnitude 6.6 was already characterized as “difficult” by Messier, and resolving the stars of M 25 beginning at magnitude 6.7 was not easy for him, either. He barely resolved M 34 (brightest stars magnitude 7.3), but not M 11 (brightest stars magnitude 8) which he described as a nebula when seen with this instrument, likewise with M 35, which Messier could resolve only with the Gregorian telescope. Hence, the limiting magnitude of the 3-foot refractor must have been between magnitudes 7.5 and 8.0.

3.5 foot

observed objects: M 14, M 17, M 18, M 19, M 22, M 23, M 26, M 27, M 28, M 29, M 30, M 32, M 36, M 37, M 39, M 49, M 51, M 81

The faintest of these objects is the Virgo cluster galaxy M 49 at magnitude 8.4. Like M 28, M 30, and M 51, it appeared “very faint” to Messier. Some star clusters remained unresolved: M 18 (brightest stars magnitude 8.7), M 29 (brightest stars 8.6), M 36 (brightest stars 8.7), and M 37 (brightest stars 9.2). This indicates a limiting magnitude of 8.5.

6 foot

The only time Messier mentions this focal length is in connection with M 40. He described this stellar pair of magnitudes 9.0 and 9.3 as nebulous, and we may infer a limiting magnitude of around 10.0 from that.

For the remaining objects, Messier did not specify which telescopes were used. These include many of the entries in the third version of the catalog. However, it is likely that Messier chiefly employed the 3.5-inch f/12 achromatic refractor (89mm aperture, 1067mm focal length), which he had received from de Saron and described as his favorite instrument. This telescope was mentioned without full details several times, for example in the descriptions for M 54 (observed 1778) and M 76.

One criterion Messier used to describe an object as faint was its inability to be seen even when the micrometer’s illumination was set at its lowest level. In this category we find M 58, 59, 63, 69, 71, 76, 83, 88, 89, 90, 91, 97, 98, 99, and M 100, all observed after 1779. The faintest of these are M 76, M 98, and M 91 at magnitude 10.1. Messier could resolve the brightest stars in the clusters M 4 (magnitude 10.8), M 46 (brightest stars 8.7), M 52 (brightest stars 8.2), and M 67 (brightest stars 9.7). But M 71 (brightest stars magnitude 12.1) and other globular clusters remained a “nebula without stars.” Hence, the telescopic limiting magnitude must have been about 11.0 for the 6.4-inch Gregorian he used in the first edition, as well as for the 3.5-inch Dollond he prefered later.

Modern visual observers are puzzled by the lack of observed detail reported by Messier. The only globular cluster in which he was able to see the brightest stars was M 4 – the rest remained a “nebula without stars” to him. By contrast, a modern 3.5-inch refractor under dark skies would resolve the brightest stars in at least half a dozen of Messier’s globular clusters. Furthermore, it appears that Messier had not seen any of the true nebulosity of M 20, and he probably mistook M 76 and M 78 for star clusters. He even believed that he saw stars in M 57, which had been described correctly as a nebulous disk by its discoverer Darquier already.

Méchain, in particular, seems to have carried out better observations than Messier in that respect. Good examples are their different descriptions of the four objects M 75 to M 78, in which Messier disagrees with Méchain’s notes:

Why were some showpieces left out by Messier?

The Messier catalog includes most of the finest showpieces in the night sky, but a few were left out. Since these missing objects were easily within reach of Messier’s telescopes, many deep-sky observers have been puzzled about their omission. The reason is simple: Messier was not interested in deep-sky objects for their own sake. Instead, he did not want to confuse them with comets. He did not look for them in a systematic way, not even during those few months of intensive searching. That separates him from William Herschel, who started to work on his impressive catalog in 1782. But considering the often accidental findings of Messier, his catalog is rather surprisingly complete.

The puzzling question in this context is: why then did Messier add four well-known spectacular objects, M 42 to M 45, to his initial list of 41? Certainly, these were not to be confused with a comet. Probably, in this one instance, Messier was tempted to round up his list to a number larger than the 42 objects of his role-model Lacaille. But at the same time, there were not enough showpieces to make it to the next round number, 50 – so he left some out.

The most prominent example is the double cluster h & χ in Messier’s days known as χ Per. Messier must have known it, and his contemporary Bode described its field as “to the north of the star χ a lot of small stars, looks nice in telescopes.” The fact that this object already had a proper designation and was shown by all star-charts may have been the very reason why Messier did not include it in his list.

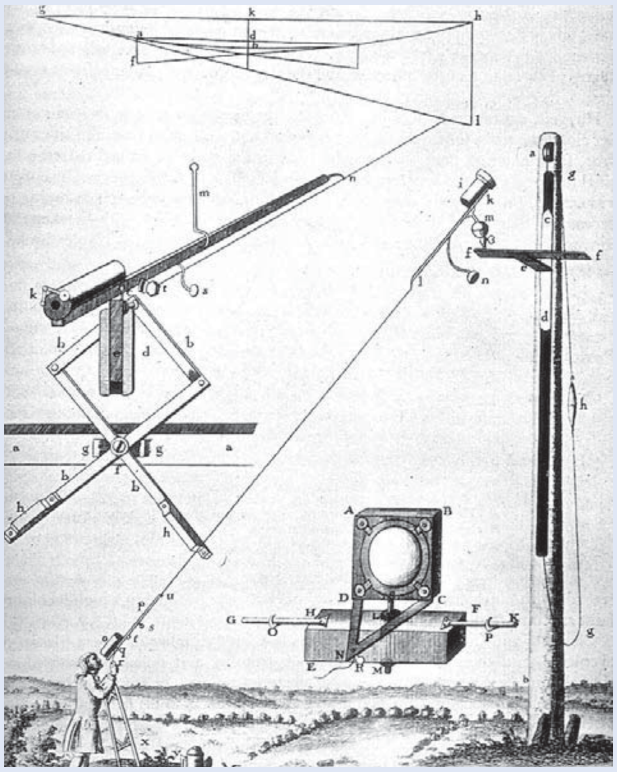
Several other bright objects were just too large for the field of view of Messier’s telescopes. Good examples are the widely spread star clusters IC 4665 or the “coat-hanger,” Collinder 399, which would not have been obvious through Messier’s eyepiece. Messier also knew of some objects in the southern sky, but he wanted a catalog of objects that are all observable from Paris, and which he had observed in person. And it is this last of his principles that made his catalog stand out in quality from the lists of his contemporaries. The resulting low number of errors in Messier’s list also made his catalog successful.

Messier's telescopes

Which telescopes did Messier use to discover and to observe his 110 objects? The answer is not easy to give, for three reasons: firstly, hardly any sources have survived which would describe the contemporary instrumentation of the observatory at the Hôtel de Cluny. Secondly, Messier used a variety of telescopes of five different categories, as we know from his descriptions. And thirdly, with the gradual availability of achromatic lenses, there was a tremendous change in optical telescope quality around the time the catalog was accomplished.

In the seventeenth century, telescopes with chromatic lenses (i.e., refractors without color-correction) were the standard. They had a single objective lens and an eyepiece made of two lenses. The construction principles had been optimized by Christian Huygens. In order to keep the chromatic aberration of the objective lens within limits, these refractors had to have extremely long focal lengths: an aperture of 70mm required a length of 8m! Therefore, the telescopes were made of two movable parts, both riding on a long rod. With the longest telescopes, they were connected only by a rope under tension. The objective lens was at the far upper end, mounted on a high pole or stepladder by means of a simple ball-head. The eyepiece at the lower end by the observer resided on a small stepladder. Equatorial mounts were not yet known, and a tube would have been too heavy for these long telescopes. The long focal lengths imposed magnifications of over 100× and very small fields of view.

In our time, it is hard to imagine how cumbersome any telescopic observation must have been in those days. First, the object had to be carefully aimed at with the rod. Then, with a most gentle touch, the remote ball-head, supporting the objective lens at the far end, had to be fixed. Tracking the object with this clumsy construction and a magnification of over 100× must have required a lot of training and patience. Despite such disadvantages, all major astronomical discoveries between 1650 and 1730 had been achieved with this kind of chromatic refractor, and even whole maps of the moon had been drawn!



Contemporary impression of a tubeless chromatic refractor in the seventeenth century. The objective (i) is mounted and counterbalanced (k–l) on a ball-head (m). It is connected with the eyepiece (o) by a rope under tension. This cumbersome construction was dictated by the long focal length of the single objective lens, required to keep the chromatic aberration as small as possible.

We can be pretty certain that Messier's "ordinary refractors" of 1, 2, 3, 3.5, and 6-foot focal length were exactly that kind of clumsy, chromatic telescope. He favored the smaller telescopes with focal lengths of 1 meter or less, because these had a tube which reduced stray light and greatly facilitated their use. But even Messier's 6-foot refractor was a dwarf compared to the longest contemporary refractors with focal lengths of over 30m.

Around the mid-eighteenth century, coinciding with Messier's active period, the time of these monstrous telescopes finally came to an end as the result of two new developments: first, James Short (1710–1768), a London-based optician, developed a method to produce telescope primary mirrors from shiny metal-alloys (front-silvered glass-mirrors would come only later). From 1743 to 1768, Short was the first to produce telescopes in large numbers. 1400 Short-reflectors were made by his little company, mostly employing the Gregorian design and mounted on a short table-top stand or ordinary tripod.

For quite some time, Short's reflectors were regarded as the best telescopes worldwide. His largest mirrors would reach 22 inches diameter!

The second important invention was made only a little later, also in London: the achromatic (color-corrected) refractor. The idea of combining lenses from two different types of glass to minimize the color aberration already existed, but it was the optician John Dollond (1706–1761), who secured the patent rights and started large-scale production of achromatic refractors in 1758. After his death, his son took over and expanded the company.

In the beginning, Dollond's refractors were very expensive, due to extraordinary demand. Hence, working in an observatory with humble financial means, Messier had to wait many years before he could lay his hand on one of these fine telescopes – which was not until his rich friend de Saron gave him one.

In 1772, Dollond's patent rights expired, and in the face of new competition, the prices for his telescopes dropped considerably. Still, for many years Dollond's company remained the most important producer of achromatic refractors – a technical term, by the way, which was coined by John Bevis, the discoverer of M 1.

In the 1807 edition of the Connaissance des Temps, Messier published a list of telescopes he had used in the years 1765 to 1769, in his work on the first catalog of 45 objects. However, their specifications almost exclusively refer to the focal lengths, given in the French foot (slightly larger than the respective English units: 1 French foot = 0.3248 m

= 12 French inch, 1 French inch = 2.7cm), rarely to the aperture. However, from that source, and from a few more remarks in the literature, we know at least some of the telescopes available to Messier:

Dollond refractors, the first achromatic refractors produced in large numbers, arrived on the optical market in 1758. Messier used such a telescope with 90mm (3.5 inches) of aperture for many of his deep-sky observations.

Gregorian reflectors made by Short were in widespread use at the end of the eighteenth century. Apart from a large telescope with a 310mm aperture, Messier used a smaller model similar to the one pictured here.

1) Chromatic refractors of short focal length ("lunettes ordinaires" or "ordinary refractors") and, possibly, draw-tube telescopes with erect images. The focal lengths were between 1 foot and 3.5 feet, none of the apertures were more than 3.5 inches (80mm), and their optical performance scarcely reached that of modern binoculars.
2) Chromatic refractors of long focal length (25 to 30 feet or 8.1m to 9.7m), with magnifications of 102× to 138×. These were built according to the principles developed by Huygens, with an f-ratio of over 1:100 to keep color aberration under control. Hence, the respective telescopes at hand for Messier would have been between 70/8100 mm and 80/9740 mm. It was already pointed out how cumbersome their use was in nightly practice, providing only a very small field of view, and this is why Messier as a comet hunter hardly ever used them. In addition, a Campani refractor is mentioned, with a magnification of 64× and coming from a seventeenth-century optical workshop. It, too, had a chromatic lens with very long focal length.
3) Achromatic Dollond-refractor with 3¼ French-foot (1.07 m) focal length and a magnification of 120×. This telescope appears to be the one which Messier had described as his favorite instrument, given to him by de Saron. It was specified (in English measurements) as having a 42-inch focal length and 3.5-inch aperture (89/1067mm) and had the same magnification of 120×. It is mentioned in the descriptions of M 54 and M 76. We have to consider, however, that the late-eighteenth-century optics had no coating and, because of their inferior transmission, had a smaller effective aperture by today's standards. In 1771, Messier used a low-power (27×) 3.5-feet achromatic refractor for comet observation, also given to him by his friend de Saron. For his stay in Lorraine in 1772, he took another achromatic refractor from de Saron with him. It had a focal length of 5 feet, magnified 60×, and was made by the optician Lestang. He also took an "ordinary [chromatic] refractor" of 3.5 feet and a possibly achromatic refractor of 2 feet ("lunette de nuit"). In the publication of a solar observation in 1777, Messier reported use of a 3.5-feet achromat with a triplet-lens objective. And in 1781, he mentioned a small achromatic refractor of 405mm focal length, as well as a "large achromatic refractor on an equatorial machine" – equatorial mounts would become more common observatory equipment only in the nineteenth century, after Joseph Fraunhofer invented what is known today as the German equatorial.
4) Gregorian reflector made by Short with 6-feet (1.95m) focal length and a magnification of 110×. The optical specifications of Short's telescopes are known very well from his price lists. A telescope of such a focal length had the remarkable aperture of 12 inches. In addition, Messier mentioned a Short reflector of only 1 foot focal length with 44× magnification, which must have had 3 inches of aperture as a Gregorian. The Gregorian-reflector he initially used, for the first catalog version, had an 810mm (32-inch) focal length and an aperture of 162mm (6.4 inches).
5) Newtonian reflector of 4.5-feet (1.46m) focal length and a magnification of 60×, with 8 inches of aperture. This telescope belonged to the Royal Observatory, but Messier was allowed to use it occasionally, as for detailed observations of M 42 and Comet Halley.

- M 75: Messier believed that he saw individual stars, Méchain reported just a nebula. And indeed, at magnitude 14.6, even the brightest individual stars are far below the perception limit of Messier's and Méchain's telescopes.
- M 76: as above, Messier reported individual stars, Méchain just a nebula, but the object does not contain any stars brighter than 13th magnitude. Messier could not have seen them.
- M 77: as above, Messier took it for a star cluster, while Méchain saw a nebula. In fact, it is a galaxy with a star-like core.
- M 78: Messier saw a star cluster with nebulosity, Méchain a nebula with two bright cores. In reality, this is a reflection nebula with two embedded 9th-magnitude stars.

For some other objects, Messier's observational impressions are obviously so vague that he was misled in determining the type of object. Some discrepancies are so large that several modern astronomers have started to doubt whether Messier saw the respective objects at all. One is the Trifid Nebula M 20, which was classified by Messier as a star cluster. Another example is the aforementioned M 57, where Messier believed the Ring Nebula consisted of stars. A different case is M 16. Here, Messier correctly reported a star cluster with nebulous background, but the real nebula is too faint to have been seen by him. It was discovered photographically in the early twentieth century and received a separate designation as IC 4703.

However, this may well be a misjudgment of Messier's visual talents. We may simply be underestimating the light pollution of nocturnal Paris in the eighteenth century. In fact, at that time, Paris was the largest city in the world with a population of 800,000. There are contemporary descriptions of how chaotic the situation was in the large city. Smoke from oven-heated houses, numerous factories and open fires must have created air pollution considerably worse than today's, scattering and absorbing more starlight. In addition, all public streets and squares were floodlit by oil-burning lamps every winter (October to March) from 1667 until their gradual destruction after the French revolution in 1789. Not surprisingly, the Royal Observatory (founded in 1667) was given a location outside the city, but the Observatory of the Navy was quite central. Hence, Messier's night sky may have been much worse than we imagine.

Messier's notes themselves give an impression of the severity of light pollution in his day. Assuming a loss of transmission due to uncoated optics of 30% in his 3.5-inch Dollond refractor would lead to an equivalent aperture of 3 inches or 75mm. Such an instrument has a limiting magnitude of about 12 under dark rural skies (naked-eye limit 6.5). As analyzed above, the faintest stars Messier could actually see with this instrument were around 11.0, which leads to a naked eye limit of about 5.5 – similar to a severely polluted suburban sky today.

Messier's telescopic limit with the 6.4-inch Gregorian was at about 11th magnitude, as he could see individual stars in M 4 at 10.8, but not resolve any other globular cluster. We know that the metal mirrors of Messier's time had a very poor reflectance and losses totalled up to 50%, effectively downsizing the 6.4-inch to a mere 4.5-inch. This instrument would have a limiting magnitude of about 11, if the naked eye limit was only 4.5 – which is equivalent to observing conditions frequently occurring today in large cities.

Another point to consider is the illumination used by Messier for his star-charts, his notes and his reticle. He had no electric light at his disposal; everything was lit with oil lamps and torches – the thought of which would invoke horror in any visual observer today.

So, compared to many modern deep-sky observers, Messier was seriously disadvantaged in terms of instrumentation, and yet he also had to deal with the light pollution many of us experience. With this in mind, we can understand Messier's mistakes and award him the credit he deserves.

Statistics of the Messier objects

When Charles Messier observed the objects that eventually made up his famous catalog, his visual impressions only allowed him to distinguish between “amas d’étoiles” (star clusters) and “nebuleuse” (nebulae). By our modern methods of astrophysics, we can finally classify Messier’s objects according to their physical categories. His catalog contains:

- 6 Galactic nebulae
- 28 Open clusters
- 4 Planetary nebulae
- 29 Globular clusters
- 40 Galaxies
- 3 other objects

In this list, M 8 has been counted as an open (star) cluster, because Messier noted the star cluster as the main object. M 16, of which Messier could not see the surrounding nebulosity, is registered as a star cluster, while the nebula has its separate catalog designation (IC 4703). M 20, regarded by Messier as a star cluster like the other two objects, is classified as a galactic nebula today. But in reality, modern classification is still a bit ad hoc. For example, the galactic nebulae M 17, M 20, and M 42 are best known for their dust-enshrouded, young star clusters in the process of formation, only hidden in visual light.

M 45, the Pleiades, is the brightest Messier object with a total magnitude of 1.2. This bright star cluster is visible to the naked eye even under a light-polluted sky. The status of the faintest Messier object is shared by M 76, M 91, and M 98, all at a total magnitude of only 10.1. The largest in angular size of all Messier objects is undoubtedly the Andromeda Galaxy (M 31) at 4° × 1°. Under a very dark, transparent sky, a visual size of as much as 5° has been reported. However, in absolute terms, the galaxy M 101 is the physically largest object of the Messier catalog. With a diameter of 184,000 light-years, it reaches 1½ times the size of our neighbor galaxy M 31 and almost twice the size of our own galaxy. M 31 just happens to be the nearest large spiral galaxy, at only 2.5 million light-years distance, which is what makes it look so large.

By contrast, the object with the smallest angular diameter is M 40, a pair of stars separated by only 49”, followed by M 73 and M 76 at just 1’ in diameter. Planetary nebula M 76 appears to be, if its supposed distance of 2550 light-years is correct, the physically smallest Messier object with a diameter of 0.7 light-years, while both M 40 and M 73 are not physical objects at all.

69 objects in Messier’s list are members of our own Milky Way and thus relatively near: only 430 light-years separate us from the Pleiades, but we are 78,000 light-years from globular cluster M 75, the farthest galactic Messier object. The 41 extragalactic objects are all galaxies, with one exception: M 54 is a globular cluster of the near dwarf galaxy SagDEG. The most distant Messier object is the galaxy M 109 with considerable 67.5 million light-years – that is 157,000× more distant than M 45!

On an age scale, the Messier objects cover an even larger range than their distances do. The youngest object, M 1, was created less than 1000 years ago by a supernova, recorded by historic civilizations in the year 1054. The globular clusters M 69 and M 92 have, by contrast, an age of 12 to 13 thousand million years, almost as old as the whole Universe.

The galactic nebulae

Galactic nebulae make up a most diverse category, which includes all of the diverse gaseous and dusty nebulae in our galaxy. The Messier catalog contains several star-forming HII regions, a reflection nebula, and a supernova remnant.

HII regions contain mostly hydrogen gas that has a very low density by laboratory standards and is ionized by the ultraviolet (UV) light of nearby hot stars. While cool, neutral hydrogen (HI) remains unobservable in visual light, ionized hydrogen (HII) recombines and emits in the Balmer lines of H_α at 656nm, and H_β at 486nm. From the traces of heavier elements in these gaseous nebulae, we also receive line emission in visual light from doubly ionized oxygen ([OIII], at 501nm and 496nm) and of singly ionized nitrogen ([NII], at 658nm and 655nm).

In order to get any nearby or surrounding hydrogen gas to glow, a star must have a sufficiently energetic ultraviolet radiation field. Hence, HII regions are created only by very hot stars of spectral type O and early B. These short-lived, luminous, and massive stars are found only in young star clusters and star-forming regions, which are surrounded by an HII region – gas that was not consumed by the star formation process, often found to survive in the dense, dusty and opaque interior of the cloud. Here, globules are found: dense, round dark nebulae that contain a proto-star. M 42 is a good example of how the energetic ionizing radiation of the luminous hot stars forms an opening in the inner cloud of dust and gas by radiation-driven erosion, while the youngest part of the star cluster still remains hidden inside. M 20, by contrast, appears more spherical, as there is only one dominating hot star in its center, which creates an HII region equally distributed around it.

Stars with cooler photospheres may be very luminous, but their weak ultraviolet radiation may not be sufficient to ionize the surrounding gas. Instead, if dust is present, their light can be reflected off the dust particles and scattered. This is what we see as a reflection nebula. Since the scattering process is more efficient in blue light, these nebulae appear bluish – like the part of M 20, which contrasts with the ionized, red H-emitting part. The only pure reflection nebula in the Messier catalog is M 78. Well known but faint are the reflection nebulae around the Pleiades. They do not represent leftover material from the formation of the stars, but rather an unrelated interstellar cloud accidentally passed by the cluster. A rare case consists of the orange nebulae that reflect the light of red supergiant Antares, near M 4 and M 80.

A very different type of object is M 1: it is the remnant of a very massive star that was destroyed by a supernova explosion nearly 1000 years ago. Such a catastrophic event is caused by the gravitational collapse of a massive stellar core, following the exhaustion of its nuclear fuel. It leaves behind a chaotically structured shell of material expanding at up to 20,000 km/s, the nebulous supernova remnant, and a super-dense stellar remnant, a neutron star. It is so dense because, during the gravitational collapse, electrons and protons have merged to neutrons, which are now packed as densely as in an atomic nucleus. The enormous reduction in size, in combination with conservation of angular momentum, has, for the M 1 neutron star, led to a super-fast rotation of 33 times per second. The magnetic field has been compressed by a factor of 10 million. Its axis is inclined with respect to the rotation axis, and as the intense field lines move rapidly through the surrounding electron gas, a bluish glimmer of synchrotron radiation is created. This is the same process as observed by physicists in large electron accelerator rings. The neutron star in M 1 is also known as a pulsar from radio observations.

M 1 lies at a distance of 6200 light-years, which is almost five times further than to the star-forming nebulae M 42, M 43, and M 78, all part of the Orion cloud, and greater still than the distances to M 8 and M 17.

The open clusters of the Messier catalog

No.	Magnitude	Angular size	Distance	Physical size	Members	Age
M 45	1.5	2°	425 Ly	15 Ly	332	100 Myr
M 44	3.1	1.2°	610 ly	15 ly	1000	500–700 Myr
M 7	3.3	80'	980 ly	23 ly	750	220 Myr
M 39	4.6	30'	1010 ly	9 ly	60	240–480 Myr
M 42	?	3'	1300 ly	4 ly	>300	0.1 Myr
M 6	4.2	20'	1590 ly	10 ly	64	80–100 Myr
M 47	4.4	30'	1600 ly	14 ly	117	30–100 Myr
M 34	5.2	35'	1630 ly	17 ly	94	225 Myr
M 25	4.6	30'	2020 ly	17 ly	220	100 Myr
M 23	5.5	35'	2050 ly	20 ly	177	300 Myr
M 41	4.5	40'	2260 ly	26 ly	70	190 Myr
M 48	5.8	30'	2510 ly	22 ly	165	300 Myr
M 20	8.5	20'	2660 ly	15 ly	>120	0.3– 0.4 Myr
M 35	5.1	28'	2710 ly	22 ly	2700	150 Myr
M 50	5.9	15'	2870 ly	13 ly	2050	100 Myr
M 67	6.9	25'	2960 ly	21 ly	500	3700 Myr
M 93	6.2	24'	3380 ly	23 ly	?	400 Myr
M 38	6.4	15'	3480 ly	15 ly	?	150–250 Myr
M 26	6.6	10'	3740 ly	10 ly	229	4–6 Myr
M 21	5.9	18'	3930 ly	20 ly	105	4–8 Myr
M 18	6.9	5'	4220 ly	6 ly	40	50 Myr
M 36	6.0	12'	4300 ly	15 ly	178	20–40 Myr
M 8	5.8	7'	4310 ly	9 ly	>130	2.3 Myr
M 46	6.1	20'	4480 ly	26 ly	500	500 Myr
M 37	5.6	25'	4510 ly	33 ly	2000	500 Myr
M 52	6.9	16'	4630 ly	22 ly	6000	25–165 Myr
M 29	8.0	8'	5160 ly	12 ly	69	90 Myr
M 16	6.0	21'	5600 ly	35 ly	376	2–6 Myr
M 17	?	5'	5910 ly	10 ly	2200	1 Myr
M 11	5.8	13'	6120 ly	23 ly	2900	250 Myr
M 103	7.4	6'	7150 ly	17 ly	77	16–25 Myr

in order of their distances, based on: Kharchenko, N. V. et al.: Astrophysical parameters of Galactic open clusters, Astronomy and Astrophysics 438, 1163 (2005)

The open clusters

Open (star) clusters, loose accumulations of a few dozen to several thousand stars, are the result of a star formation process that once consumed a dense cloud of interstellar material. Initially hidden inside the gaseous cloud (M 17, M 42), the hottest O-type giants emerge first (M 8, M 16). Depending on its total mass and on the gravitational interactions with its environment, a star cluster can hold together for several million to even a few thousand million years. But with time, the cluster stars are lost to the galactic disk.

Large molecular clouds can create a number of neighboring star clusters of similar age that form an association. M 36 and M 37, for example, belong to the Auriga-OB-association. OB indicates that the hottest spectral types are still present in this young formation. These luminous stars burn faster and the most massive members very soon explode as supernovae. The other massive stars evolve to become red giants. M 37, M 50, and M 103 are examples of open clusters that already contain their first red giants.

Hence, the youngest star clusters can be recognized by the very hot and massive stars among their members. A good example is 2-million-year-old M 8 with 9 Sgr. Even younger are the clusters still in the process of formation in M 42, M 20, and M 17. At the other extreme is M 67 with an age of 3.7 thousand million years. To a large extent, it owes its long survival to its sparsely populated galactic environment.

The poorest Messier clusters are M 18 and M 39 with only 40 and 60 confirmed member stars each. They are also the smallest clusters of the Messier catalog at only about 10 light-years in diameter. The richest open cluster in the Messier catalog is probably M 52 (about 6000 stars), followed by M 11 (2900) and M 35 (2700). M 11, together with M 37, is also among the largest open clusters in general. With a diameter of 50 light-years, each is the size of a small globular cluster.

Plotting the open clusters in the galactic plane around the Sun at their proper distances, we obtain a pattern that coincides with the spiral arms of our galaxy. Most of the nearer open clusters, beginning with the Pleiades at a distance of only 430 light-years, are in the Orion arm. The Sun itself lies in the inner edge of that same arm. Towards the galactic center, a number of clusters mark the Sagittarius arm. It hosts, for example, M 11, M 16, and M 8. In the opposite direction lies the Perseus arm with M 103 (at a distance of 7200 light-years) and h & χ Persei. Even further away (12,000 light-years) towards the galactic edge is NGC 2158, which in the sky appears to be a close neighbor of M 35.

The planetary nebulae

Messier's catalog contains only four planetary nebulae. These objects are a by-product of the creation of white dwarfs. This is the evolutionary fate of most stars, except the most massive ones which will undergo a supernova explosion. A planetary nebula, by contrast, is formed by a gradual process: in the final, very cool supergiant stages with a highly compressed stellar core, the star's surface gravity becomes extremely low. Under these conditions, a cool, slow, and relatively dense wind or "superwind" removes all of the remaining outer stellar layers in the final twenty- to fifty-thousand years. With the exposure of a now "naked" hot core, a much thinner, hot and very fast wind starts. As it pushes outwards, accompanied by ionizing ultraviolet radiation, an ionized shell is formed inside the cool, still slowly expanding circumstellar gas and dust – a glowing nebula with emission lines, not unlike an HII region, but for very different physical reasons. The higher densities in the shells of planetary nebulae favor [OIII] line emission over the hydrogen Balmer lines (i.e., H_α, H_β – the intensity ratio can

Trümpler classification of open clusters

This classification scheme was introduced in 1930 by Robert J. Trümpler. Born in Switzerland, he emigrated to the USA early in the twentieth century. He thought that clusters of similar appearance (same Trümpler class) would be physically alike (e.g., have the same size). If so, the distances to open clusters could be estimated, and they could be used to trace galactic structure. The Trümpler classification has four parameters, which describe:

Appearance

I with strong central concentration, standing out well.
II cluster with weak central concentration, standing out well.
III cluster without any noticeable concentration, stars distributed thinly but evenly, standing out well.
IV cluster, which does not stand out well from the background but appears like a concentration in the star field.

Brightness distribution of cluster stars

1 most cluster stars have nearly the same brightness.
2 moderate brightness distribution of the stars.
3 cluster composed of bright and faint stars, typically a few very bright and several moderately bright stars standing out from a large group of faint stars.

Number of cluster stars

p poor cluster with less than 50 stars.
m moderately rich cluster with 50 to 100 stars.
r rich cluster with more than 100 stars.

Additional indicators

e elongated.
u asymmetrical.
n contains nebulosity.

According to this scheme, M 45 has been classified as I3m, M 37 as I2r and M 39 as III2m. Today the Trümpler classification system is hardly ever used, since it is very subjective and depends on the observing method. Modern distance measurements and the determination of cluster age now rely on precise photometry of cluster stars and their colors, and a quantitative interpretation by computer models of stars and their evolution.

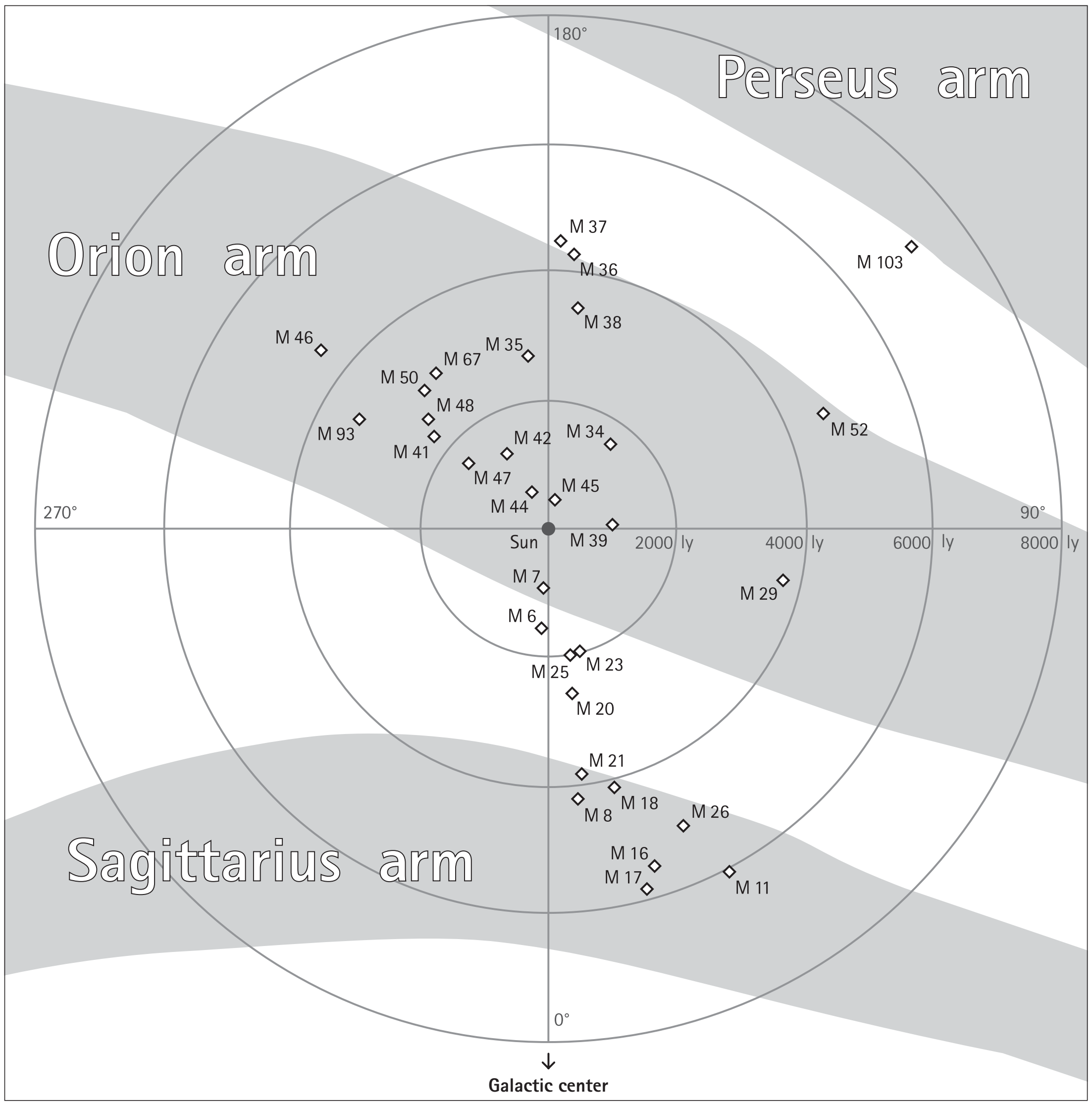
be twice as high. The ionizing power of the hot wind and ultraviolet radiation fades on a timescale of about 10,000 years. At the same time, the now aged planetary nebula begins to disperse, just like the last breath of a "dying" star.

Planetary nebulae reach sizes of only a few light-years. In the Messier catalog, they span about the range of 0.7 (M 76) to 3.5 (M 97) light-years. Exact sizes and distances, however, are notoriously difficult to assess for these objects.

The globular clusters

Globular clusters are dynamically stable objects, due to their large total mass. Their name relates to their mostly spherical form. About 150 of these objects are known in the Galaxy, which they surround in a widespread halo. However, that number is dwarfed by the quantity of globular clusters surrounding other galaxies, e.g., 16,000 around the giant galaxy M 87. Looking at the distribution of our globular clusters in the sky, there is a remarkable concentration towards the galactic center – the inner halo. These globular clusters are frequently found in, or crossing, our galactic disk while orbiting the galactic center.

The nearest globular clusters have distances comparable to those of open clusters. M 4 at about 5600 light-years, for example, is nearer to us than M 11. Towards the galactic center, however, we not only see globular clusters in front of it (like M 22), but also next to it (like M 28) or on its far side (M 72). Towards M 75 at a distance of 78,000 light-years, our view crosses two-thirds of the galactic diameter.



The distribution of open clusters and galactic nebulae of the Messier catalog on the galactic plane, within a radius of 10,000 light-years around the Sun. The nearest spiral arms are indicated.

A special case among the globular clusters is M 54. It is not a galactic object but belongs to the small dwarf galaxy SagDEG. Hence, at a distance of 85,000 light-years, this is the most distant globular cluster of the Messier catalog.

The physical size and the mass of globular clusters differ greatly. The smallest example is M 71: with 40,000 solar masses and fewer than 100,000 stars, it is not much larger than the largest open clusters. At the other extreme are M 19 and M 54, each with several million stars and a mass of 1.5 million solar masses, approximately that of a dwarf galaxy.

Photographs, in particular, give the impression of very high star densities in globular clusters. In reality, however, there are between 10 and 1000 stars per cubic light-year at their centers – which means that the average distance between stars is still 0.1 to 0.5 light-years. Only when a globular cluster has undergone a core collapse (by dynamical instability and transfer of kinetic energy out of the core region) are super-densities of up to 100,000 stars per cubic light-year reached. A visual measure of the degree of concentration is the classification of globular clusters into class I (extremely compact) to XII (very loose), analogous to the "Trümpler classes" for open clusters. While this scheme has no relevance to astrophysical research any more, it is a very useful one for the visual amateur observer. The most concentrated globular cluster in the Messier catalog is M 2 (II), the loosest examples are M 55 and M 71 (XI).

Galactic globular clusters have ages of about 10 to 13 thousand million years – about 100 times older than most open clusters. Having lost their interstellar matter, globular clusters cannot form new stars. Hence, all their member stars are very old, which is why they show the elemental composition of earlier stages of the Universe. Elements heavier than hydrogen and helium can form only by the central nuclear processes of stars and supernova explosions, and they are dispersed into the interstellar medium by supernovae and stellar winds to feed new star formation. Hence, globular clusters give testimony of the early Universe when heavy elements were much less abundant, and that distinguishes them from all other stellar clusters.

Low abundance of heavy elements and low stellar mass bring about a special group of variables, typical for globular clusters: the pulsating RR Lyrae stars. Lacking a static equilibrium between radiation pressure and gravity, these stars oscillate over the course of a few hours and show brightness variations of about 0.5 to 2 magnitudes. In addition, there are other types of variables in globular clusters. The record holder is M 3 with 274 known variable stars, while in M 10 only four variables have been discovered so far.

Luminous stars of spectral type O and B are not found in globular clusters, because these stars "die" very young. Oddly enough, a few blue stars are found in globular clusters: "blue stragglers." Hence, these must have been formed recently – supposedly by the merging of close, old binary stars. Some globular clusters even host pulsars. The record holder in the Messier catalog is M 62 with six of them.

The planetary nebulae of the Messier catalog

No.	Magnitude	Angular size	Distance	Physical diameter	Age
M 76	10.1	67"	2550 ly	0.7 ly	?
M 57	8.8	86" × 62"	2300 ly	0.9 ly	10,000–20,000 years
M 97	9.9	170"	4140 ly	3.5 ly	6000–12,000 years
M 27	7.4	8.4' × 6.1'	1150 ly	3.0 ly	~ 9000 years

The globular clusters of the Messier catalog

No.	Magnitude	Angular size	Distance	Physical diameter	Mass	Variables
M 4	5.8	35'	5640 ly	57 ly	$100 \times 10^3 M_\odot$	65
M 22	5.1	33'	10,440 ly	100 ly	$500 \times 10^3 M_\odot$	78
M 71	8.0	7'	18,330 ly	40 ly	$40 \times 10^3 M_\odot$	23
M 55	6.3	19'	19,300 ly	110 ly	$250 \times 10^3 M_\odot$	40
M 12	6.8	14'	20,760 ly	85 ly	$250 \times 10^3 M_\odot$	5
M 10	6.6	19'	24,750 ly	140 ly	$200 \times 10^3 M_\odot$	4
M 13	5.7	21'	25,890 ly	160 ly	$600 \times 10^3 M_\odot$	40, Pulsar
M 5	5.7	20'	26,620 ly	150 ly	$800 \times 10^3 M_\odot$	143
M 92	6.5	14'	27,140 ly	110 ly	$400 \times 10^3 M_\odot$	20
M 107	7.8	13'	27,370 ly	105 ly	$200 \times 10^3 M_\odot$	23
M 56	8.4	7'	27,390 ly	55 ly	$200 \times 10^3 M_\odot$	14
M 30	7.3	12'	29,460 ly	100 ly	$300 \times 10^3 M_\odot$	13
M 3	5.9	19'	34,170 ly	190 ly	$800 \times 10^3 M_\odot$	274
M 28	6.8	10'	34,480 ly	100 ly	$500 \times 10^3 M_\odot$	19, Pulsar
M 70	7.8	8'	34,770 ly	80 ly	$200 \times 10^3 M_\odot$	>10
M 62	6.7	11'	34,930 ly	110 ly	$1000 \times 10^3 M_\odot$	>200, 6 Pulsars
M 68	7.6	11'	36,580 ly	120 ly	?	42
M 69	7.7	10'	36,920 ly	110 ly	$300 \times 10^3 M_\odot$	13
M 15	6.0	18'	39,010 ly	200 ly	$450 \times 10^3 M_\odot$	131
M 2	6.4	16'	40,850 ly	190 ly	$900 \times 10^3 M_\odot$	30
M 79	7.7	6'	45,000 ly	80 ly	$400 \times 10^3 M_\odot$	7
M 19	6.7	14'	45,000 ly	180 ly	$1500 \times 10^3 M_\odot$	8
M 9	7.6	11'	46,090 ly	150 ly	$300 \times 10^3 M_\odot$	16
M 80	7.3	9'	48,260 ly	125 ly	$400 \times 10^3 M_\odot$	10
M 14	7.6	11'	55,620 ly	180 ly	$1200 \times 10^3 M_\odot$	68
M 72	9.2	6'	58,510 ly	100 ly	$200 \times 10^3 M_\odot$	51
M 53	7.7	13'	61,270 ly	230 ly	$750 \times 10^3 M_\odot$	67, Pulsar
M 75	8.6	7'	77,840 ly	160 ly	$500 \times 10^3 M_\odot$	46
M 54	7.2	12'	84,650 ly	300 ly	$1500 \times 10^3 M_\odot$	211

in order of their distances, based on: Recio-Blanco, A. et al.: Distance of 72 Galactic globular clusters, Astronomy and Astrophysics, 432, 851 (2005)

The galaxies

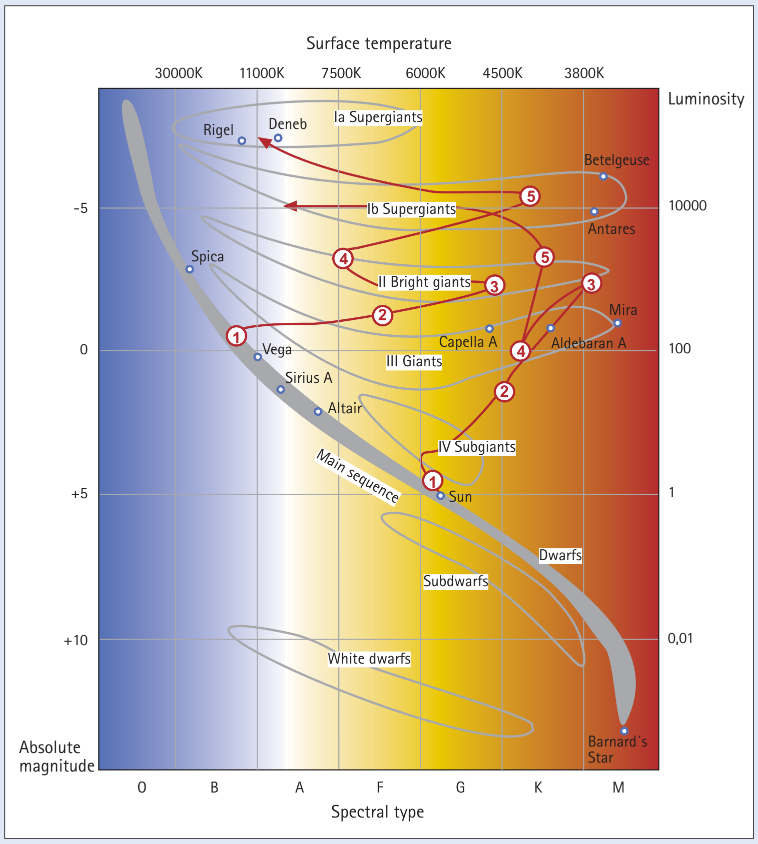
An older technical term for galaxies was "extragalactic nebulae." However, that does not reflect their true nature as distant milky ways in their own right, with many thousand millions of stars, thousands of open clusters, globular clusters, and HII regions. In the nearest galaxies, the members of our Local Group, we are able to observe such individual objects. The Andromeda Galaxy (M 31) in particular is a nice example of a large spiral galaxy. It has a diameter of about 160,000 light-years and 300 to 400 thousand million solar masses. By contrast our other neighbor, M33, has only about one tenth of the mass of M 31.

With increasing distance from us, groups and clusters of galaxies become more obvious in the sky. M 81 and M 82 are 12 million light-years away, M 51 is 27 million light-years. These form two small, widely scattered galaxy groups with other, smaller galaxies, mostly dwarfs. A large and dense gathering of galaxies, by contrast, is the center of the Virgo galaxy cluster at a distance of 45 to 62 million light-years. About 2500 galaxies are packed within a diameter of 10 to 15 million light-years, 14 of them are found in the Messier catalog. The most distant example of all Messier galaxies is M 109 at about 67.5 million light-years. It is 26 times farther away than M 31, 770 times more distant than M 54, and 150,000 times farther than M 45.

Dwarf galaxies like M 32, which is tied by gravity to its mother galaxy M 31, may have diameters of only a few thousand light-years. At the other extreme, M 101 measures about 185,000 light-years, almost twice as much as our own Milky Way. Any accurate assessment of galaxy diameters, however, is made difficult by their inclination from a perfect face-on view.

Spectral types of stars and stellar evolution

Very generally speaking, all stars are built the same way: in a dense, hot core, hydrogen fuses to helium. The core is surrounded by outer layers that provide the right conditions to transport the energy outside, by radiation or by convection. Depending on mass, however, stars can have very different temperatures (from 3000K to 100,000K) and densities in their photospheres. The conditions in these outermost layers can be determined by a detailed spectral analysis of the star's light. Although developed 120 years ago, the spectral classification scheme below is still used today by professional astronomers, because it immediately gives an approximate temperature value.



The Hertzsprung-Russell diagram. The location of the main sequence and evolution tracks of two stars are plotted: A) the Sun – 1: present state; yellow main-sequence "dwarf," hydrogen-burning in core, 2: first giant branch; hydrogen-burning in shell, 3: "helium flash," 4: helium-burning in core, 5: asymptotic giant branch; helium- and hydrogen-burning shells, mass loss by a "cool wind" leaves a white dwarf. B) massive star – 1: blue main-sequence star, hydrogen-burning in core, 2: hydrogen-burning in shell, 3: smooth onset of helium-burning, 4: "blue loop;" helium-burning in core, 5: red supergiant; helium- and hydrogen-burning shells, later carbon-burning in core, mass loss by a "cool wind."

The spectral types of stars are characterized by specific absorption lines from different elements and ions in the photosphere – corresponding to a specific temperature range:

O	**>30,000K**	very hot, blue stars, lines of ionized helium
B	**11,000–30,000K**	hot, blue stars, lines of neutral but excited helium and hydrogen
A	**7500–11,000K**	white stars, lines of excited hydrogen
F	**6000–7500K**	nearly white stars, lines of ionized calcium
G	**5000–6000K**	yellow stars, lines of ionized iron and other metals
K	**3800–5000K**	cool, orange stars, lines of neutral metals
M	**<3800K**	very cool, red stars, lines of titanium-oxide and neutral metals

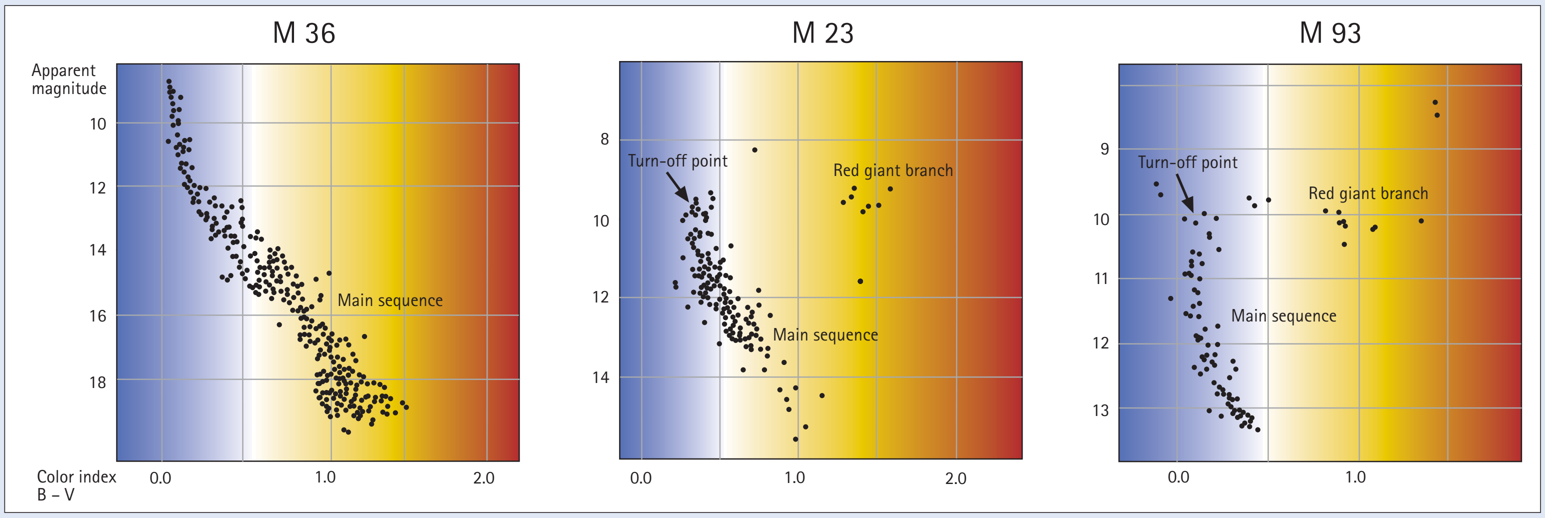
Every spectral class is divided into 10 subclasses from 0 to 9. For very cool, red stars, there are two additional, special classes:

S	**<3800K**	very cool stars, additional lines of rare-earth elements (i.e., Zr)
C	**<3800K**	very cool stars, very strong carbon lines

In addition, there are luminosity classes, as the more luminous stars display better defined lines due to much lower gravity and density in their photospheres:

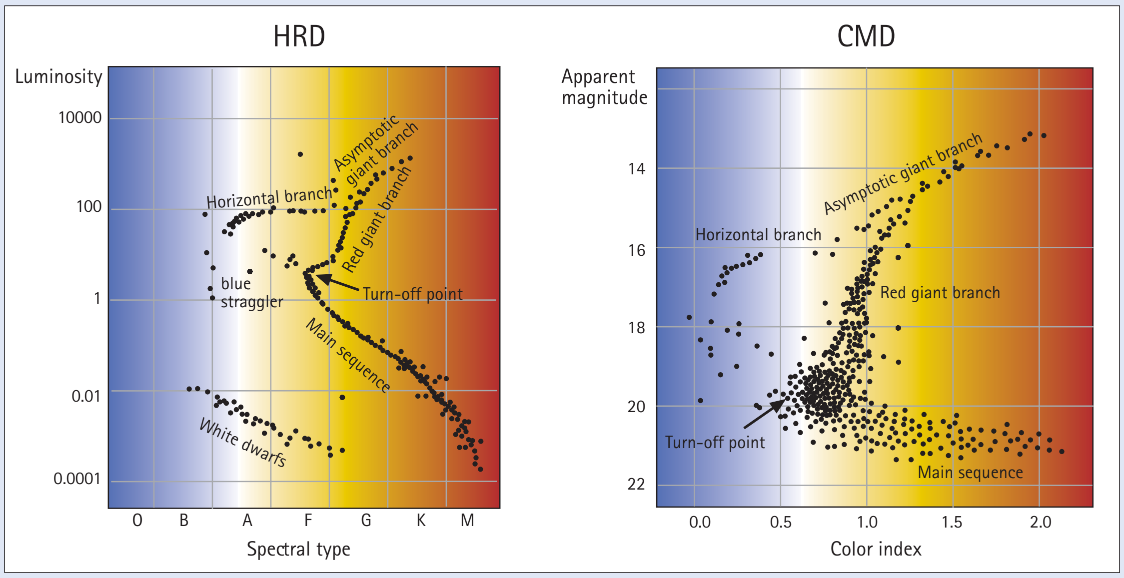
I	supergiant
II	bright giant
III	giant
IV	subgiant
V	dwarf (main-sequence star)
VI	subdwarf

Each luminosity class could be divided into two or three subclasses: a, ab, and b. Together with the spectral type, a complete characterization of the star results. The Sun is a G2V star, a yellow dwarf.
If the stars are plotted on a Hertzsprung-Russell diagram by luminosity class versus spectral type, a characteristic pattern emerges: the majority of the stars form the so-called main sequence, on which a star spends most of its life. In their cores, main sequence stars burn hydrogen – by far the longest-lasting stellar source of nuclear energy. Massive stars are hotter and blue, by contrast to low-mass stars (red, low luminosity), but they burn their energy so fast that they have much briefer lives than, for example, the Sun. Because of this, stellar masses and even ages can be estimated from spectral class.
The giants and supergiants are very evolved stars, with very compact cores that burn helium or (in massive stars) even carbon. A highly evolved core is enveloped in an outer shell of burning hydrogen and an inner shell of burning helium. The surrounding layers of the giant star



In a color-magnitude diagram, apparent visual brightness is plotted against the B–V color index (brightness in blue light minus brightness in visual light) for all the stars of a specific cluster. By contrast to a Hertzsprung-Russell diagram, no absolute physical properties are used. Nevertheless, a color-magnitude diagram of an open cluster yields the relative distance and age, as shown here by three examples:
M 36 is only 20–40 million years old; all stars are on the main sequence.
M 23 is 190 million years old; the most massive stars have already left the main sequence and are now cool giants.
M 93 is 400 million years old; all brighter main sequence stars have reached or passed their red giant stages.

become extremely extended, in response to the highly compact core and the now more extreme boundary and equilibrium conditions. As a result, the giant's photosphere has very low gravity and density, and is relatively cool.
Low-mass helium-burning stars with low abundances of heavy elements, as found in globular clusters, can be quite hot by comparison to normal helium-burning stars. Hence, instead of being K-giants, they form the horizontal branch in the Hertzsprung-Russell diagram.
A special group of these stars are the RR Lyrae variables. After the stellar core of an RR Lyrae variable has consumed its helium, the star becomes a red giant again. Heavier elements then processed in the core can reach the surface by means of convection, and the very evolved star could become class C or S. Increasing mass loss in the form of a stellar "cool wind" eventu-



Hertzsprung-Russell diagram and color-magnitude diagram of a globular cluster (M 80). The highly advanced age is revealed by the very low turn-off point on the main sequence at spectral type F. The evolved, helium-burning stars here form a "horizontal branch," on which we also find RR Lyrae variables. In the color-magnitude diagram of a globular cluster, the position of the relatively bright horizontal branch is a good distance indicator.

ally leads to the gradual loss of the outer layers of every red giant star, and the exposure of its hot core, as well as to the relatively brief (10,000–20,000 years) phenomenon of a planetary nebula. The emerging white dwarf does not produce energy, it just cools down very slowly.
Evolved massive stars are more luminous and warmer ("blue loop" stage) during their core helium-burning phase than the Sun will be. Some become pulsating Cepheid variables, whose period-luminosity relation is of great consequence for the determination of astronomical distances. Only the most massive stars (over 10 solar masses) do not end up as white dwarfs but instead finish their lives with a catastrophic core collapse, visible as a type II supernova. The resulting stellar remnant will then become a neutron star or black hole.

Spiral galaxies are quite flat. Compared to elliptical or nearly spherical galaxies of the same diameter, they cover much less volume and possess significantly less mass. Hence, the most massive galaxy of the Messier catalog is the giant elliptical galaxy M 87 in the center of the Virgo cluster with 2700 thousand million solar masses. At the other extreme is the dwarf galaxy M 32 with only 3 thousand million solar masses – a feather-weight by comparison.

One focus of the extragalactic research of the last decade has been on galactic nuclei. In many of these, we find physical processes at work that release enormous quantities of energy. In LINER-type galaxies, emission-line spectra show the ionization of the gas surrounding the galactic nuclei. Seyfert galaxies show significantly more intense emission, in addition to synchrotron radiation and radio emission from the core region. Such "activity" (these nuclei are often called AGN, for "active galaxy nuclei") is powered by a super-massive central object. This can be a central super star cluster, but in many cases it appears to be a black hole. The masses involved here vary from a modest 10,000 solar masses in the nucleus of M 33 – less than a globular cluster – to an incredible 2 or 3 thousand million solar masses at the center of M 87 – as much as a whole dwarf galaxy.

Star formation activity, too, can vary a lot from galaxy to galaxy. Elliptical galaxies contain very little interstellar gas, and there are no star-forming regions at all. Hence, most of the stars are quite old. In contrast, spiral galaxies are rich in gas and contain numerous HII regions and young star associations, even star-burst regions which create a very large number of stars simultaneously, including some very massive ones. It is in such places that we may observe a supernova. In 17 of the 40 Messier galaxies, supernovae have indeed been observed. The record holder is M 83 (6 supernovae), followed by M 61 and M 100 (4 supernovae), and M 99, M 51, and M 84 (3 supernovae).

The non-physical objects

Three of the 110 Messier objects are not physical objects but only give the impression of being so as seen from our perspective.

M 40 is an optical stellar pair – not a physical binary of two stars orbiting a common center of gravity, but a chance alignment of two stars of very different distances, about 490 and 1860 light-years away. That would make star A the second-closest (after M 45) Messier object, although it is only "half" the object.

A similar case is M 73, which is a chance alignment of four stars at distances between 900 and 2600 light-years. Such accidental star patterns are found elsewhere in the sky, but the probability of finding four stars brighter than 12^{th} magnitude within 1', away from the dense star fields of the Milky Way, is quite low.

M 24, finally, presents a special case of a 1.5° portion of the Milky Way. Unlike a physical star cloud such as NGC 206 in M 31, however, this apparent cloud is actually a "window" in the opaque interstellar clouds of our galactic plane. Its stars are not in the same place but spread out over distances of 12,000 to 16,000 light-years – the full width of a galactic spiral arm.

Hubble classification of galaxies

Edwin Hubble developed a morphological classification scheme for galaxies, which was later improved by Sandage and de Vaucouleurs. The main types are:

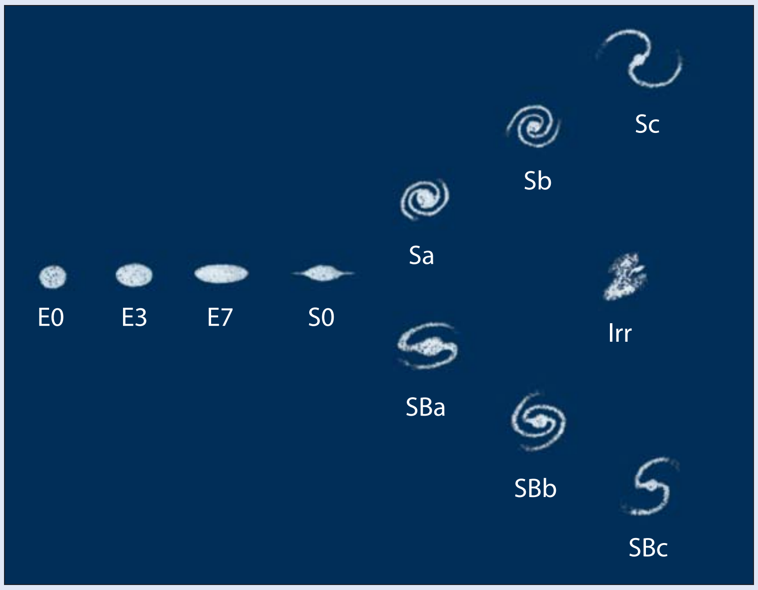
E elliptical galaxies, from spherical (E0) to very elongated (E7) examples
S spiral galaxies, with tightly wound arms (Sa) to wide open arms (Sd)
SB barred spirals, with tightly wound arms (SBa) to wide open arms (SBd)
Irr irregularly shaped galaxies

In addition, the following indicators are used:

s S-shaped spiral arms
r ring-shaped spiral arms
rs mixture of S- and ring-shaped spiral arms
m “Magellanic-type” shape, only for irregular galaxies

Originally, Hubble saw in this scheme an evolutionary sequence. Today we know this is not true. In fact, elliptical galaxies are mostly very old objects that are the results (through mergers), not the progenitors, of spiral galaxies. Examples in the Messier catalog are:

E0 spherical elliptical galaxy (M 89)
E1 nearly spherical elliptical galaxy (M 87, M 105)
E2 slightly elongated elliptical galaxy (M 32, M 60)
E3 noticeably elongated elliptical galaxy (M 86)
E4 distinctly elongated elliptical galaxy (M 49)
E5 strongly elongated elliptical galaxy (M 59)
E6 very strongly elongated elliptical galaxy (M 110)
E7 extremely elongated elliptical galaxy (–)
S0 spindle-type galaxy with bright central region (M 84, M 85, M 102)
Sa spiral galaxy with tightly wound arms (M 65, M 96, M 104)
Sb spiral galaxy with open arms (M 31, M 63, M 64, M 66, M 77, M 81, M 90, M 94, M 98, M 106)
Sc spiral galaxy with wide open arms (M 33, M 51, M 61, M 74, M 83, M 88, M 99, M 100, M 101, M 108)
SBa barred spiral with tightly wound arms (–)
SBb barred spiral with open arms (M91, M 95)
SBc barred spiral with wide open arms (M 58, M 109)
SBc barred spiral with wide open arms (M 58, M 109)
Irr irregularly shaped galaxies (M 82)



The Hubble classification scheme.

The galaxies of the Messier catalog							
No.	**Magnitude**	**Angular size**	**Distance**	**Physical diameter**	**Mass**	**Mass of central object**	**Supernovae**
M 31	3.4	3.5° × 1°	2.57 Mly	157,000 ly	300–400 × 10^9 $M_\odot$		
M 32	8.1	9' × 7'	2.57 Mly	6500 ly	3 × 10^9 $M_\odot$		
M 110	8.0	22' × 11'	2.57 Mly	16,000 ly	10 × 10^9 $M_\odot$		
M 33	5.7	71' × 42'	2.74 Mly	60,000 ly	10–40 × 10^9 $M_\odot$	0.01 × 10^6 $M_\odot$	
M 82	8.4	11' × 4'	11.4 Mly	37,000 ly	50 × 10^9 $M_\odot$		1
M 81	6.8	27' × 14'	11.8 Mly	92,000 ly	50 × 10^9 $M_\odot$	60 × 10^6 $M_\odot$	1
M 83	7.5	13' × 12'	14.7 Mly	55,000 ly			6
M 94	8.2	11' × 9'	17.3 Mly	50,000 ly	60 × 10^9 $M_\odot$		
M 64	8.5	11' × 5'	18.3 Mly	56,000 ly			
M 101	7.7	29' × 27'	21.8 Mly	184,000 ly			
M 74	8.5	11' × 10'	25.1 Mly	77,000 ly	300 × 10^9 $M_\odot$		1
M 106	8.3	19' × 7'	25.7 Mly	135,000 ly		39 × 10^6 $M_\odot$	1
M 63	8.6	13' × 7'	26.7 Mly	98,000 ly	140 × 10^9 $M_\odot$		1
M 51	8.4	15' × 7'	26.8 Mly	87,000 ly			3
M 90	9.5	10' × 4'	30.7 Mly	85,000 ly			
M 95	9.7	7' × 5'	32.6 Mly	70,000 ly	50 × 10^9 $M_\odot$		
M 65	9.3	10' × 3'	32.8 Mly	94,000 ly			
M 66	9.0	9' × 4'	32.8 Mly	87,000 ly			
M 96	9.2	8' × 5'	34.3 Mly	76,000 ly	80 × 10^9 $M_\odot$		1
M 105	9.3	5' × 5'	37.9 Mly	55,000 ly	100 × 10^9 $M_\odot$	200 × 10^6 $M_\odot$	
M 102	9.9	7' × 3'	40.8 Mly	71,000 ly			
M 98	10.1	10' × 3'	44.2 Mly	126,000 ly	200 × 10^9 $M_\odot$		
M 104	8.0	9' × 4'	44.7 Mly	105,000 ly	300 × 10^9 $M_\odot$	1000 × 10^6 $M_\odot$	
M 108	10.0	9' × 2'	46.0 Mly	100,000 ly			1
M 77	8.9	7' × 6'	46.9 Mly	100,000 ly	1000 × 10^9 $M_\odot$	100 × 10^6 $M_\odot$	
M 85	9.1	7' × 6'	47.8 Mly	99,000 ly	400 × 10^9 $M_\odot$		1
M 59	9.6	5' × 4'	48.3 Mly	76,000 ly		300 × 10^6 $M_\odot$	
M 61	9.6	7' × 6'	49.6 Mly	94,000 ly	70 × 10^9 $M_\odot$	0.1 × 10^6 $M_\odot$	4
M 100	9.3	7' × 6'	49.6 Mly	107,000 ly	200 × 10^9 $M_\odot$		4
M 89	9.7	5' × 5'	49.9 Mly	74,000 ly		1000 × 10^6 $M_\odot$	
M 99	9.9	5' × 5'	52.7 Mly	83,000 ly	100 × 10^9 $M_\odot$	100 × 10^6 $M_\odot$	3
M 91	10.1	5' × 4'	52.9 Mly	83,000 ly			
M 49	8.4	10' × 8'	53.1 Mly	157,000 ly	200 × 10^9 $M_\odot$	500 × 10^6 $M_\odot$	
M 60	8.8	7' × 6'	53.2 Mly	115,000 ly		4000 × 10^6 $M_\odot$	
M 87	8.6	8' × 7'	54.9 Mly	132,000 ly	2700 × 10^9 $M_\odot$	2000–3000 × 10^6 $M_\odot$	
M 86	8.9	9' × 6'	56.7 Mly	147,000 ly			
M 88	9.6	7' × 4'	57.2 Mly	115,000 ly	250 × 10^9 $M_\odot$		1
M 84	9.1	7' × 6'	57.8 Mly	110,000 ly		1500 × 10^6 $M_\odot$	3
M 58	9.6	6' × 5'	62.5 Mly	107,000 ly	300 × 10^9 $M_\odot$		2
M 109	9.8	8' × 5'	67.5 Mly	137,000 ly	250 × 10^9 $M_\odot$		1

Visual observation of the Messier objects

One of the most popular projects undertaken by amateur astronomers worldwide is the observation of all 110 Messier objects with their own telescopes. The choice of instrumentation depends on the respective observing site. Messier himself did not have the benefit of good observing conditions, and he used telescopes with limited optical capability – comparable to modern binoculars or small telescopes. His favorite telescope was an uncoated but achromatic 3.5-inch refractor.

Under similar conditions today, a 3-inch refractor is sufficient for an experienced observer, even though some objects remain difficult to observe. With the exception of M 91, all objects are visible even in 10×50 binoculars under dark skies, even though many of them are quite difficult to observe. Less experienced observers should be able to see all 110 objects with a 4-inch telescope.

Messier objects recommended for beginners

Season	Object	Popular name
Winter	M 42	Orion Nebula
	M 35	
	M 44	Beehive Cluster
Spring	M 104	Sombrero Galaxy
	M 81	Pair with M 82
	M 5	
Summer	M 13	Hercules Cluster
	M 8	Lagoon Nebula
	M 27	Dumbbell Nebula
Autumn	M 31	Andromeda Galaxy
	M 15	
	M 45	Pleiades

The degree of observational difficulty varies a lot from object to object. M 45 can be spotted with the naked eye even from a large city. However, with just a little light pollution, M 91, M 74, or M 76 can be a challenge even to an experienced observer, when tried with a small telescope. The most difficult Messier objects to observe are considered to be M 76, M 98, and M 108. M 91 and M 98 are among the 16 Messier galaxies of the Virgo cluster, which is a challenging but rewarding terrain for visual observers. In their vicinity, there are a number of other galaxies beyond Messier's catalog which are not much fainter. M 91 is probably the most difficult to observe of all Messier objects, as it is not visible in 10×50 binoculars even by experienced observers and poses an observing challenge to a 2-inch refractor in a dark sky.

The faintest Messier objects

Object	Type	Brightness
M 76	PN	10.1
M 91	Gx	10.1
M 98	Gx	10.1
M 108	Gx	10.0

The total brightness is not the only criterion for how difficult an observation is. More important, especially with light-polluted skies and direct interference of artificial lighting, is the surface brightness of an object. For example, the spiral galaxy M 33 has a low average surface brightness of 23.1 mag/arcsecond^2, but a total magnitude of 5.7. To be visible, it must meet or exceed a certain contrast value with respect to the background sky. This can be computed from the combined surface brightness of the desired object and the sky background, divided by the surface brightness of the sky background. The result must be sufficiently higher than the threshold of detection of the human eye. The remaining difference, the contrast above threshold, will give a direct measure of how easily a certain object can be perceived. Software such as "Eye & Telescope" can compute this ratio.

The results show that, under polluted skies, only the small, relatively bright core of M 33 can be made out even in a large telescope. Hence, in the city, M 33 is one of the most difficult Messier objects to observe, while it is a naked-eye object in a clear, dark mountain sky.

Visibility of M 33

Telescope aperture	Countryside sky (surface brightness 21.0)	Average light-polluted sky (surface brightness 19.5)	Severely light-polluted sky (surface brightness 18.0)
3 inches	easy	at the limit	invisible
8 inches	easy	difficult	invisible

The problem with nebulae of low surface brightness under light polluted and hazy city skies, regardless of whether they are extended or small, does not go away with a larger telescope. At the same magnification, a larger telescope provides a brighter image of an object than a smaller telescope does. However, it also brightens the sky background by the same amount. Hence, for many objects, the choice of the observing site and the quality of the night is more important than the telescope.

Messier objects most affected by light pollution		
Object	**Surface brightness**	**Effect of light pollution**
M 8	22 mag/arcsecond²	only core region visible
M 20	22 mag/arcsecond²	nebula invisible
M 31	22.5 mag/arcsecond²	only core region visible
M 33	23.1 mag/arcsecond²	only small nucleus visible
M 51	21.9 mag/arcsecond²	both galaxies invisible
M 61	22.3 mag/arcsecond²	only small nucleus visible
M 63	22.5 mag/arcsecond²	only small nucleus visible
M 74	23.3 mag/arcsecond²	only small nucleus visible
M 81	21.9 mag/arcsecond²	only core region visible
M 83	22.1 mag/arcsecond²	completely invisible
M 86	22.8 mag/arcsecond²	only core visible
M 90	22.5 mag/arcsecond²	only small nucleus visible
M 91	22.2 mag/arcsecond²	completely invisible
M 95	22.4 mag/arcsecond²	completely invisible
M 97	22.4 mag/arcsecond²	completely invisible
M 98	22.1 mag/arcsecond²	completely invisible
M 101	23.7 mag/arcsecond²	only core visible
M 106	22.7 mag/arcsecond²	completely invisible
M 108	21.9 mag/arcsecond²	completely invisible
M 109	22.4 mag/arcsecond²	only small nucleus visible
M 110	22.8 mag/arcsecond²	completely invisible

Nebula filters for Messier objects	
Object	**Recommended filter**
M 1	[OIII]
M 8	UHC, [OIII]
IC 4703 in M 16	UHC, [OIII]
M 17	[OIII]
M 20	UHC, [OIII]
M 27	[OIII]
NGC 604 in M 33	[OIII]
M 42	[OIII], Hβ
M 43	[OIII], Hβ
NGC 2438 in M 46	[OIII]
M 57	[OIII]
M 76	UHC, [OIII]
M 78	no filter
M 97	UHC, [OIII]

For planetary and emission nebulae, narrowband nebula filters are helpful, which transmit the emission lines characteristic for these gaseous nebulae, but block the light pollution in the rest of the spectrum. Broadband filters are sometimes used for observing galaxies and reflection nebulae, but they help relatively little. While cutting out common wavelengths of light pollution, they also cut these same bands from the continuum emission of stars.

Narrowband filters, also referred to as UHC filters (ultra-high contrast), have a narrower bandwidth of about 30nm, but are suitable for emission and planetary nebulae only.

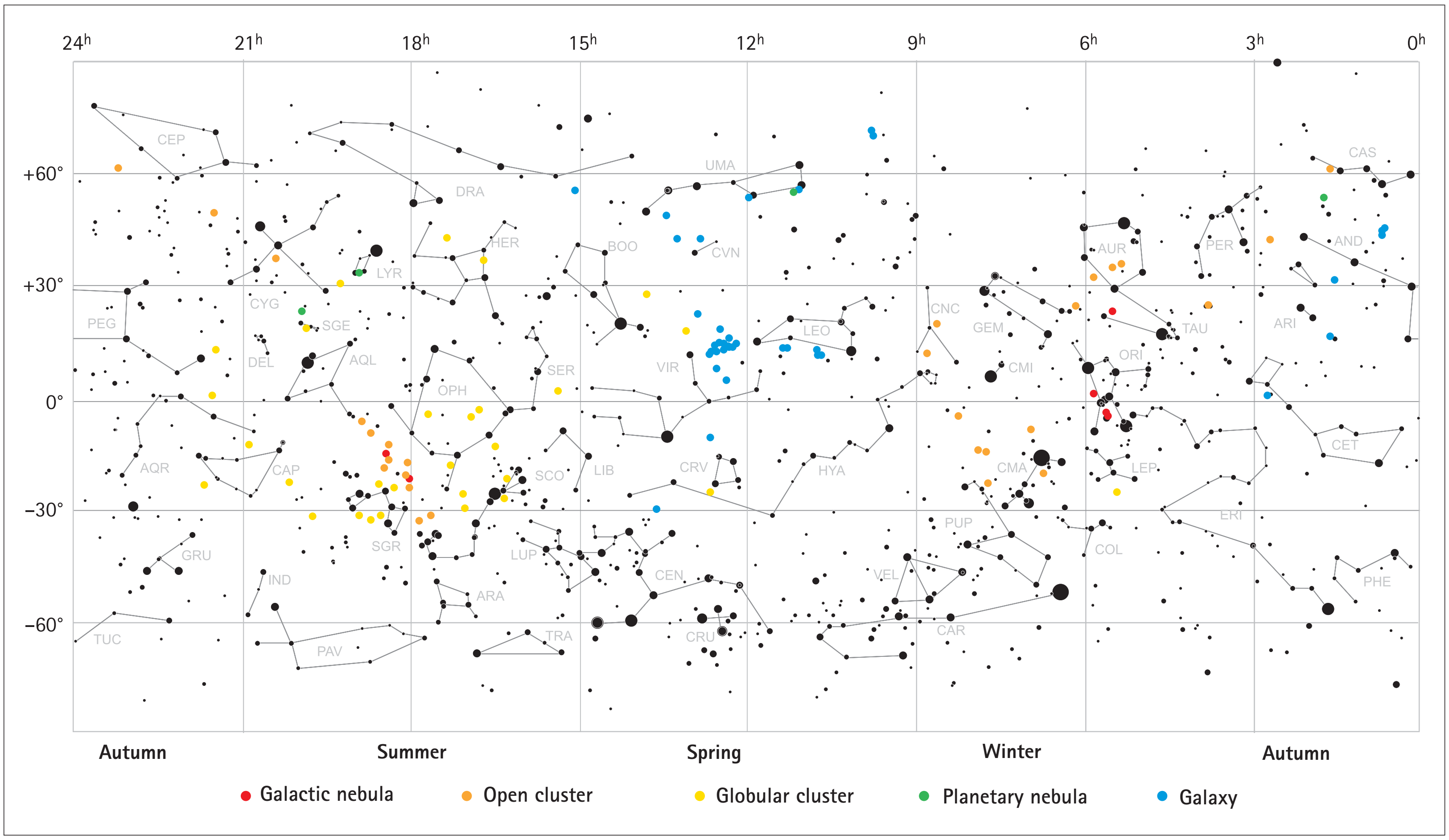
Line filters with a bandwidth of about 10nm allow us to distinguish between the two most important emission lines visible to the eye, [OIII] and H_β. [OIII]-filters are ideal for planetary nebulae and many other emission nebulae, while H_β-filters are best for some HII regions only.

Stellar objects are less affected by light pollution, including the star clusters. Best seen under very polluted skies are open clusters with many bright stars, i.e., M 44, M 45, and M 41, and concentrated globular clusters, i.e. M 3, M 5, and M 92. In general, and for globular clusters in particular, it is true that higher magnifications (15× to 25× per inch of aperture) bring out more faint stars. The background then is darker, but the stars as point sources remain the same, if the seeing is good.

It takes most amateurs many years or even decades to see all Messier objects. It is, in fact, not at all difficult to do them all in the course of one year. Sometimes, it is even possible to see all of the objects in one night (see “Messier Marathon”), but that requires good preparation. Objects at higher northern declinations are visible for a longer period of time. M 82 and M 81 at +70° declination can be observed at any time throughout the year, as they are circumpolar at observing sites as far south as 25° to 20°N latitude. At 50°N latitude, M 103, M 76, M 34, M 108, M 97, M 109, M 106, M 94, M 63, M 51, M 101, M 92, M 39, and M 52 never set. Even M 31 with its companions M 32 and M 110 does so, but actually can barely be observed on spring nights.

For observers at mid-northern latitudes, the southern Messier objects cause more of a problem, because they are affected by inferior observing conditions near the horizon. The southernmost object M 7 is all but impossible to see from latitudes north of 55°N; the northernmost sightings have been reported from 53° 11’. Fortunately, it is also one of the brightest Messier objects (magnitude 3.3) and can be spotted very low above the horizon. Much more critical in that respect are the loose globular cluster M 55 and the galaxy M 83. The galaxy’s low surface brightness of 22.1 mag/arcsecond² requires a dark sky with a naked-eye

The southernmost Messier objects	
Object	**Declination**
M 83	–29° 52'
M 62	–30° 07'
M 54	–30° 29'
M 55	–30° 58'
M 6	–32° 13'
M 70	–32° 18'
M 69	–32° 21'
M 7	–34° 49'



Distribution of the Messier objects in the sky. Most of the open clusters follow the band of the Milky Way, while the globular clusters show a concentration towards the galactic center in Sagittarius. The galaxies, by contrast, are found outside the Milky Way.

limiting magnitude of 6.0 at a distance of only 10° from the horizon. That leaves observers only very few very clear nights between March and May to detect M 83.

The distribution of Messier objects over the sky is uneven. All objects are north of –35° declination, and there are fewer in the fall sky. In fact, it is the gap between M 30 and M 74 (while M 52 is circumpolar to about 35°N latitude) which enables us to do a complete Messier Marathon on a spring night. The highest concentration of Messier objects is in the Virgo galaxy cluster, which hosts 15 of them in a field of 10° × 10°. In addition, there are a number of attractive pairs or groups of Messier objects. Many are pairs of same object type, but M 20 / M 21, M 72 / M 73, and M 97 / M 108 contain two very different objects.

Groups and pairs of Messier objects

Objects	Type	Separation
M 42, 43	GN	8'
M 84, 86	Gx	17'
M 65, 66	Gx	20'
M 59, 60	Gx	25'
M 31, 32, 110	Gx	30' / 35'
M 81, 82	Gx	37'
M 20, 21	GN, OC	40'
M 89, 90	Gx	40'
M 95, 96, 105	Gx	42' / 48'
M 97, 108	PN, Gx	48'
M 88, 91	Gx	50'
M 58, 59	Gx	1.1°
M 46, 47	OC	1.3°
M 72, 73	GC, Ast	1.3°

Messier Marathon

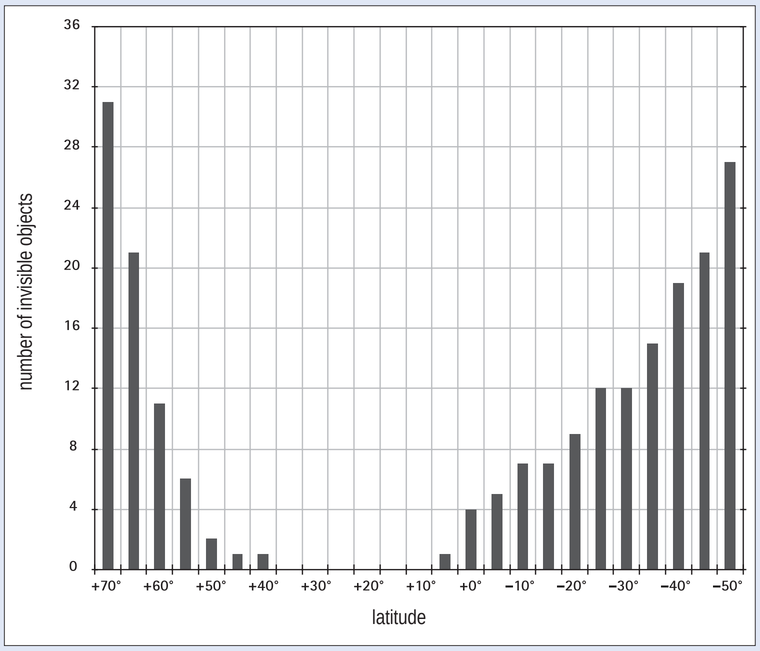
Messier Marathon results (milestones)			
March 24/25 1977	Ed Flynn, 6-inch	98 objects, Pittsburgh	very first Messier Marathon
March 25/26 1977	Tom Hoffelder, 10-inch	101 objects	
April 11/12 1977	Tom Reiland, 6-inch	103 objects	
March 12/13 1980	Don Machholz	109 objects, California	missed only M 30
March 19/20 1984	Don Machholz, 10-inch	109 objects, California	three days after full moon
March 23/24 1985	Gerry Rattley, 10-inch	110 objects, Arizona	first complete Marathon
March 23/24 1985	Rick Hull, 10-inch	110 objects, California	completed just 1hr after Rattley
March 15/16 1987	Don Machholz, 20×80 binoculars	107 objects, California	first Marathon with binoculars, missing: M 74, M 110, M 30
March 19/20 1988	Tim Hunter & Dan Krauss, 24-inch	84 objects, Arizona	first photographic Marathon
March 19/20 1993	Ronald Stoyan, 4.7-inch	103 objects, Germany	missed: M 74, 69, 70, 54, 55, 75, 30
March 24/25 2001	Arto Oksamen & Harri Hyvönen	82 objects, Finland	first CCD Marathon, only 83 objects are possible from Finland
October 29/30 2002	Don Machholz, 6-inch	106 objects, California	first October Marathon, missed: M 4, 104, 68, 83
March 16/17 2004	Christian Busch, 8-inch	108 objects, Germany	missed: M 55, M 30
March 20/21 2004	Petra Saliger & Gernot Stenz, 4-inch	110 objects, Tenerife	first complete European Marathon

The idea of observing all Messier objects in one night was born in the US. In the 1970s, some observers realized that there are no Messier objects between ecliptic longitude 320° and 30°, a gap of 70°. Hence, a new-moon night in March, used from dusk to dawn, provides the chance to see all 110 Messier objects in one run. A second opportunity is provided by an October night. Still, on any other night of the year, northern observers can see at least 95 of the Messier objects.

The goal to see all of the 110 objects is not quite achievable for observers based in northern Europe or the northern US. M 30 and M 55 are invisible in March, while M 83, M 104, and M 6 cannot be observed in October. They remain too close to the horizon at dusk or dawn. Observers from latitudes further south are better off: between +10° and +35°, all 110 objects can be done, because the duration of dusk and dawn is shorter, and the critical objects are higher above the horizon. In the whole southern hemisphere, the Messier Marathon is impossible, because many objects are far north of the celestial equator.

In a Messier Marathon, success depends on the hours of dusk and dawn. In March, M 74 and M 33 have to be observed as early as possible; they set before the end of twilight in most of the US and Europe. The situation is even more critical in the morning: while M 30 is usually out of reach, there are M 69, M 70, M 54, M 72, M 73, M 2, M 75, and M 55 all to be observed as soon as they have risen above the western horizon. At that time, it is a race against the advancing dawn. In general, the situation becomes more critical in the evening sky for nights later in March. The available time is reduced by six minutes every day. At the same time, only two minutes per day are won in the morning, because the nights get shorter.

Hence, good preparation for finding the objects quickly is required most for the morning and evening hours of a Messier Marathon. The midnight hours leave much more time for each object visible then. On average, reckoning a night of 10 hours, there are about 6 minutes, time per object. This can easily be beaten with some practice, especially with observing experience and by smartly combining neighboring objects.



Number of invisible Messier objects over geographic latitude for the 21st of March. A complete Marathon can only be accomplished between 10° and 35° north latitude.

Number of invisible Messier objects at 50°N latitude over the calendar year. Best scores are reached late in March and October.

Seasonal order of Messier objects, by date of midnight culmination

Object	NGC designation	Constellation	Midnight culmination
M 41	2287	CMa	Jan 1
M 50	2323	Mon	Jan 6
M 47	2422	Pup	Jan 14
M 46	2437	Pup	Jan 15
M 93	2447	Pup	Jan 16
M 48	2548	Hya	Jan 24
M 44	2632	Cnc	Jan 30
M 67	2682	Cnc	Feb 2
M 81	3031	UMa	Feb 18
M 82	3034	UMa	Feb 18
M 95	3351	Leo	Mar 3
M 96	3368	Leo	Mar 3
M 105	3379	Leo	Mar 4
M 97	3587	UMa	Mar 10
M 108	3556	UMa	Mar 10
M 65	3623	Leo	Mar 12
M 66	3627	Leo	Mar 12
M 98	4192	Com	Mar 15
M 109	3992	UMa	Mar 21
M 99	4254	Com	Mar 27
M 106	4258	CVn	Mar 27
M 40	–	UMa	Mar 28
M 61	4303	Vir	Mar 28
M 84	4374	Vir	Mar 28
M 85	4382	Com	Mar 28
M 100	4321	Com	Mar 28
M 86	4406	Vir	Mar 29
M 49	4472	Vir	Mar 30
M 87	4486	Vir	Mar 30
M 88	4501	Com	Mar 30
M 89	4552	Vir	Mar 31
M 90	4569	Vir	Mar 31
M 91	4548	Com	Mar 31
M 58	4579	Vir	Apr 1
M 68	4590	Hya	Apr 1
M 104	4594	Vir	Apr 1
M 59	4621	Vir	Apr 2
M 60	4649	Vir	Apr 2
M 94	4736	CVn	Apr 4
M 64	4826	Com	Apr 5
M 53	5024	Com	Apr 9
M 63	5055	CVn	Apr 10
M 51	5194	CVn	Apr 14
M 83	5236	Hya	Apr 16
M 3	5272	CVn	Apr 17
M 101	5457	UMa	Apr 22
M 102	5866	Dra	May 5
M 5	5904	Ser	May 11
M 80	6093	Sco	May 26
M 4	6121	Sco	May 28
M 107	6171	Oph	May 30
M 13	6205	Her	Jun 1
M 12	6218	Oph	Jun 3
M 10	6254	Oph	Jun 5
M 62	6266	Oph	Jun 6
M 19	6273	Oph	Jun 7
M 92	6341	Her	Jun 10
M 9	6333	Oph	Jun 11
M 6	6405	Sco	Jun 16
M 14	6402	Oph	Jun 16
M 7	6475	Sco	Jun 20
M 23	6494	Sgr	Jun 20
M 8	6523	Sgr	Jun 22
M 20	6514	Sgr	Jun 22
M 21	6531	Sgr	Jun 22
M 16	6611	Ser	Jun 26
M 18	6613	Sgr	Jun 26
M 24	–	Sgr	Jun 26
M 17	6618	Sgr	Jun 27
M 28	6626	Sgr	Jun 27
M 25	IC 4725	Sgr	Jun 29
M 69	6637	Sgr	Jun 29
M 22	6656	Sgr	Jun 30
M 70	6681	Sgr	Jul 2
M 26	6694	Sct	Jul 3
M 11	6705	Sct	Jul 4
M 54	6715	Sgr	Jul 5
M 57	6720	Lyr	Jul 5
M 56	6779	Lyr	Jul 11
M 55	6809	Sgr	Jul 17
M 71	6838	Sge	Jul 20
M 27	6853	Vul	Jul 22
M 75	6864	Sgr	Jul 23
M 29	6913	Cyg	Jul 28
M 72	6981	Aqr	Aug 4
M 73	6994	Aqr	Aug 6
M 2	7089	Aqr	Aug 14
M 15	7078	Peg	Aug 14
M 39	7092	Cyg	Aug 14
M 30	7099	Cap	Aug 16
M 52	7654	Cas	Sep 11
M 31	224	And	Oct 1
M 32	221	And	Oct 1
M 110	205	And	Oct 1
M 33	598	Tri	Oct 14
M 103	581	Cas	Oct 14
M 74	628	Psc	Oct 15
M 76	650	Per	Oct 17
M 34	1039	Per	Nov 1
M 77	1068	Cet	Nov 1
M 45	–	Tau	Nov 17
M 79	1904	Lep	Dec 12
M 38	1922	Aur	Dec 13
M 1	1952	Tau	Dec 14
M 36	1960	Aur	Dec 15
M 42	1976	Ori	Dec 15
M 43	1982	Ori	Dec 15
M 78	2068	Ori	Dec 18
M 37	2099	Aur	Dec 19
M 35	2168	Gem	Dec 23

These are the general rules for a fair Messier Marathon:

- any type of telescope may be used, including hand-held binoculars.
- every object has to be seen through the main telescope. Sightings with the naked eye or finder do not count.
- The objects have to be located manually. Goto-systems and electronic aids are not permitted.

Several hundred amateur astronomers have already undertaken a Messier Marathon. Since the mid-1980s, more than a dozen US amateurs have succeeded in a complete Marathon (all 110 objects), and photographic concourses have also been held. While a complete Marathon was accomplished on Tenerife, nobody has yet succeeded on mainland Europe.

Photography of the Messier Objects

Very few astrophotographers have taken a complete set of images of Messier objects. This is certainly due to the large differences from object to object in location, brightness, and, in particular, size. The disparity in size demands the use of different focal lengths to record each object well. By far the largest Messier object at 4 × 1°, M 31 requires a focal length of at most 500mm (for the 36mm × 24mm format) or equivalent (depending on the chip size). On the other hand, the planetary nebula M 76 has a size of only 1', and the stellar pair of M 40 is separated by only 49". Resolving these objects requires a focal length of at least 1000mm, and a detailed image may even need 5000mm.

The optimal exposure times differ from each other as much as the required focal lengths. Star clusters with bright stars and nebulae with high surface brightness may be recorded in just a few seconds. This includes M 44, M 45, the central region of M 42, and a few small galaxies of high surface brightness, such as M 94. By contrast, objects with low surface brightness, especially if their total brightness is low as well (e.g., M 74 and M 76), need the longest exposures – at least several minutes.

Man-made light pollution hampers astrophotographers as much as visual observers. A brighter background forces a reduction of exposure time and the faintest objects are lost.

Photographic images capture nebulous detail and stellar colors more easily than visual observations. Most objects, however, do not show a large variety of hues, with just a few colorful exceptions.

A nice set of photos of all 110 objects makes an impressive album or poster. However, there are only a few examples. In the 1970s, the US amateur Evered Kreimer published his photos in a book ("Messier Album"), together with the visual observations of John Mallas. At about the same time, Hans Vehrenberg collected a series of very deep exposures in his volume "Deep Sky Splendours" – both books were an important inspiration to many amateurs. In recent years, members of the National Optical Astronomy Observatories (NOAO) have created an impressive collection of professional photos, available on the Internet. The NOAO photos include images from very different instruments and photographers. By contrast, the German amateur Thomas Jäger presented a nice Messier poster in the magazine "interstellarum" – he took all the photos himself with a home-made CCD camera and a small telescope.

A complete set of Messier object drawings is even rarer than a photographic collection. The only example known to us is the book "The Messier Objects" by Stephen James O'Meara, for which he sketched all of the objects using a 4-inch refractor – with the exception of M 102, which he does not accept as a separate Messier object.

Colors of Messier objects

Type	Color	Dominating Wavelength	Remarks
Stars	blue	350nm–450nm	Hot young stars
	yellow	500nm–600nm	Cool older stars
	red	600nm–700nm	Red giants
Nebulae	blue	<450nm	Reflection nebulae
	green	501nm	Emission nebulae, [OIII] line
	red	656nm	Emission nebulae, H-alpha line
Galaxies	blue	350nm–450nm	Star-forming regions
	yellow	500nm–600nm	Old stellar populations
	red	656nm	Emission nebulae

Recommended focal lengths for the Messier objects

No.	36mm × 24mm format	15mm ×10mm format	No.	36mm × 24mm format	15mm ×10mm format	No.	36mm × 24mm format	15mm ×10mm format
M 1	4000mm	2000mm	M 38	1200mm	600mm	M 75	5000mm	2500mm
M 2	3000mm	1500mm	M 39	1000mm	500mm	M 76	8000mm	4000mm
M 3	4000mm	2000mm	M 40	4000mm	2000mm	M 77	6000mm	3000mm
M 4	3000mm	1500mm	M 41	1200mm	600mm	M 78	4000mm	2000mm
M 5	4000mm	2000mm	M 42	1200mm	600mm	M 79	6000mm	3000mm
M 6	1500mm	750mm	M 43	4000mm	2000mm	M 80	6000mm	3000mm
M 7	1500mm	750mm	M 44	600mm	300mm	M 81	3000mm	1500mm
M 8	1000mm	500mm	M 45	600mm	300mm	M 82	6000mm	3000mm
M 9	4000mm	2000mm	M 46	1000mm	500mm	M 83	4000mm	2000mm
M 10	3000mm	1500mm	M 47	1000mm	500mm	M 84	5000mm	2500mm
M 11	2000mm	1000mm	M 48	1000mm	500mm	M 85	6000mm	3000mm
M 12	3000mm	1500mm	M 49	4000mm	2000mm	M 86	5000mm	2500mm
M 13	3000mm	1500mm	M 50	1000mm	500mm	M 87	5000mm	2500mm
M 14	4000mm	2000mm	M 51	4000mm	2000mm	M 88	5000mm	2500mm
M 15	4000mm	2000mm	M 52	2000mm	1000mm	M 89	5000mm	2500mm
M 16	2000mm	1000mm	M 53	4000mm	2000mm	M 90	5000mm	2500mm
M 17	2000mm	1000mm	M 54	4000mm	2000mm	M 91	5000mm	2500mm
M 18	2000mm	1000mm	M 55	3000mm	1500mm	M 92	4000mm	2000mm
M 19	3000mm	1500mm	M 56	5000mm	2500mm	M 93	3000mm	1500mm
M 20	2000mm	1000mm	M 57	8000mm	4000mm	M 94	5000mm	2500mm
M 21	2000mm	1000mm	M 58	5000mm	2500mm	M 95	5000mm	2500mm
M 22	2000mm	1000mm	M 59	6000mm	3000mm	M 96	5000mm	2500mm
M 23	1000mm	500mm	M 60	6000mm	3000mm	M 97	6000mm	3000mm
M 24	500mm	250mm	M 61	6000mm	3000mm	M 98	5000mm	2500mm
M 25	2000mm	1000mm	M 62	3000mm	1500mm	M 99	5000mm	2500mm
M 26	4000mm	2000mm	M 63	4000mm	2000mm	M 100	5000mm	2500mm
M 27	4000mm	2000mm	M 64	4000mm	2000mm	M 101	4000mm	2000mm
M 28	4000mm	2000mm	M 65	4000mm	2000mm	M 102	6000mm	3000mm
M 29	4000mm	2000mm	M 66	4000mm	2000mm	M 103	4000mm	2000mm
M 30	4000mm	2000mm	M 67	1200mm	600mm	M 104	5000mm	2500mm
M 31	500mm	250mm	M 68	4000mm	2000mm	M 105	5000mm	2500mm
M 32	4000mm	2000mm	M 69	5000mm	2500mm	M 106	4000mm	2000mm
M 33	1500mm	750mm	M 70	5000mm	2500mm	M 107	4000mm	2000mm
M 34	1200mm	600mm	M 71	5000mm	2500mm	M 108	4000mm	2000mm
M 35	1200mm	600mm	M 72	5000mm	2500mm	M 109	4000mm	2000mm
M 36	1200mm	600mm	M 73	5000mm	2500mm	M 110	4000mm	2000mm
M 37	1200mm	600mm	M 74	4000mm	2000mm			

M 1

The Crab Nebula

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	NGC 1952
Type	Galactic nebula
Class	Supernova remnant
Distance	6200 ly (1999) 5250 ly (proper motion, 1993)
Size	10 ly
Constellation	Taurus
R.A.	5^h 34.5^{min}
Decl.	+22° 1'
Magnitude	8.4
Surface brightness	20mag/arcsec^2
Apparent diameter	6'×4'
Discoverer	Bevis, 1731

History

On the 4th of July 1054 or maybe even earlier, in April or May that year, a new bright star near the Sun was observed in the constellation of Taurus by witnesses in Italy, Armenia, Iraq, China, Japan, and North America. The unusual object appeared with a magnitude between –4 and –7.5 and was visible to the naked eye, even in the daytime sky. Apparently, maximum brightness coincided with the solar conjunction. Chinese astronomers observed the star in daylight until the 27th of July 1054, and they were able to see it in the night sky until the 17th of April 1056, before it faded from naked-eye visibility. In Europe, sightings of the supernova were probably censored, since the catholic church saw this celestial event as a bad omen in connection with the split from the orthodox church in the same year.

In 1731, the English physician and self-taught astronomer John Bevis, without any knowledge of the related historic observations, discovered a nebula at the position of the supernova. Independently, Charles Messier found the nebula on the 28th of August 1758, while following a comet for the first time. In fact, at first he took M 1 for the comet. Messier wrote: "Nebula, contains no star; it is a whitish light, elongated in the shape of a candle's light." Only later did Messier learn of Bevis' observation and recognized the Englishman's priority on the discovery.

William Herschel described the object as "very bright, of irregular figure, full 5' in longest direction," and he speculated that "it consists of stars." His son John described M 1 as a "fine object, very large, extended, very gradually brightening a little toward the middle, mottled, 4' long, 3' broad." Admiral Smith spoke of a "pearly-white nebula" and added: "It is of oval form, with a major axis from northwest to southeast, and the brightest portion toward the south."

In 1844, Lord Rosse devoted an extended study to the "Crab Nebula," so called after an earlier observing report by him. Because of its fine-structure, he mistook it for a star cluster: "We see resolvable filaments singularly disposed, springing principally from its southern extremity, and not, as is usual in clusters, irregularly in all directions. Probably greater power would bring out other filaments, and it would then assume the ordinary form of a cluster. It is studded with stars, mixed however with a nebulosity probably consisting of stars too minute to be recognized."

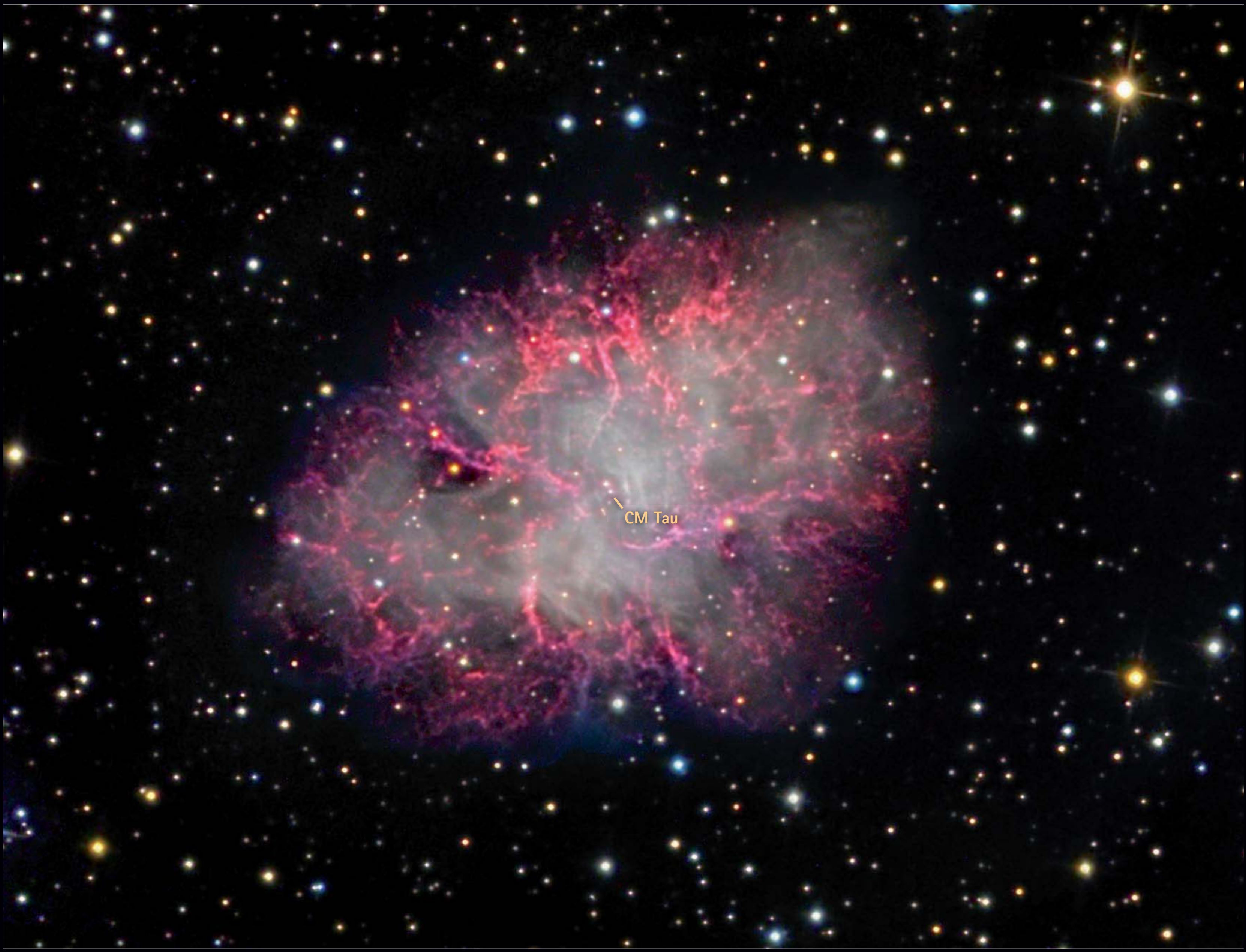
A few years later, William Lassall, too, mentioned the filaments, after his observations from Malta: "Long filaments run out from all sides, there appears to be a number of very minute and faint stars scattered over it. The brightest parts are 2' long, while its extensions reach 6'."

On the eve of the 19th century, Leo Brenner wrote about the popular name of the nebula: "So called, because Rosse pictured it in his fantastic drawing like a crab, with which it shows no resemblance, however. It rather likens a sponge. A broad, deep bulge, not containing any nebular masses, is located on its north-eastern side; a smaller bay is partially filled with nebulosity."

A first photo of M 1 was obtained in 1892, and Slipher's spectroscopic work of 1913–1915 showed split spectral lines in the vicinity of the outer filaments. Later, this was explained by means of the Doppler effect in combination with a fast expansion of the nebula.

Not without some doubt, Curtis characterized the Crab Nebula in 1918 as a planetary nebula – a contemporary assumption, but a mistake, which reappeared in some catalogs until the 1960s. On this occasion, however, the central star got mentioned for the first time: "Two stars of mag 16 are close together near the center but it is not certain that either of them is a central star. This very complex and interesting object is nearly 6'×4' in P.A. about 125°. It is not a typical planetary in form and it is doubtful whether it is properly to be included as a member of the class."

Lampland, in 1921, found displacements of filamentary detail when comparing photos of different age. The same year, Duncan found an expansion rate of 0.2'' per year from such a comparison, and dated the possible creation of the nebula to 900 years back. Lundmark, also in 1921, then suggested the historic supernova of 1054 as the cause of the nebula, which nowadays is a commonly ac-



M 1. The only supernova remnant in the Messier catalog is also the youngest Messier object, with an age of only 950 years. Bernd Flach-Wilken, Volker Wendel.

cepted fact. In 1968, the central pulsar was discovered by the radio telescope in Arecibo.

Astrophysics

The Crab Nebula is the only supernova remnant in the Messier catalog. Because of its proximity, its young age, and the interesting astrophysics related to it, M 1 is regarded as the most-studied deep-sky object in the Galaxy.

M 1 measures about 10 light-years in diameter. The nebula consists of about five solar masses, and its absolute magnitude is –3, corresponding to about a thousand solar luminosities. In visual light, two components of nebular emission can be distinguished by spectroscopy. One shines in the green and red light of the [OIII] and Hα emission lines of the filaments. It represents the former outer layers of the progenitor star, which have been expelled at high speed in the supernova event of 1054 and are now colliding with the surrounding interstellar medium. The gas is heated in shock fronts and forms today's filamentary emission nebula. The other, blue component shows a continuous spectrum and is highly polarized. Here we have synchrotron radiation, found on Earth only when generated by large particle accelerators. It is caused by accelerated electrons in a strong magnetic field. Hence, M 1 can be regarded as the best extraterrestrial laboratory for the observation of this type of emission, which is detectable from the radio to the X-ray range of the electromagnetic spectrum. This was first recognized by Shklovsky in 1953.

M 1. The red and green, filamentary structure is the debris of the supernova progenitor star. Bluish, by contrast, is the haze of synchrotron emitting nebulosity. Philipp Keller.

M 1 can be studied throughout the electromagnetic spectrum: in 1948, strong radio emission was found, and X-rays were detected in 1964. Hence, the Crab Nebula has additional designations as the Taurus A or 3C 144 radio source and as Tau X-1. Its radiated X-ray flux exceeds its optical flux by more than a hundredfold, and the total energy output has been quoted as 5×10^{11} joules per second.

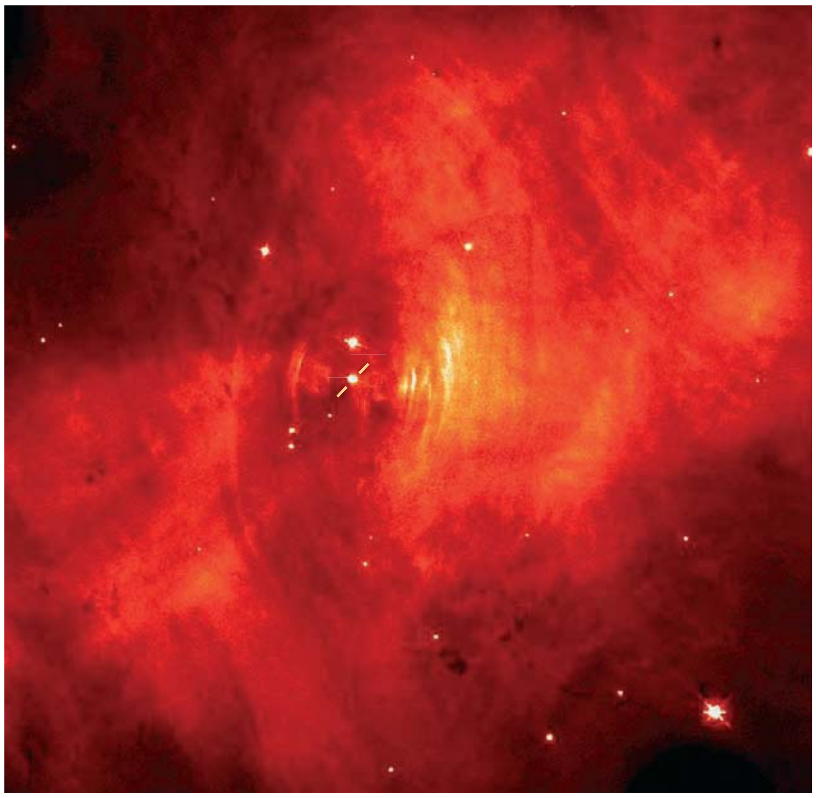
The collapsed core of the star that caused the supernova is still present in the center of the nebula. In its intense magnetic field, charged particles get accelerated near the field poles and emit collimated radiation along the magnetic field axis, which is tilted with respect to the rotation axis of the rapidly spinning neutron star. As Earth happens to be in the right direction to be hit by one of these sweeping radiation beams, a sharp pulse is observed every revolution, and hence this type of neutron star is called a "pulsar."

The M 1 pulsar measures only 10 km in diameter but has an absolute magnitude of +4.5, slightly brighter than the Sun. A cubic centimeter of its matter would weigh a thousand million tons – so much has it been compressed in the gravitational collapse of the supernova!

The pulsar in M 1 was the first of its kind for which an optical counterpart was found. This 16^{th}-magnitude star, registered as CM Tauri, sends pulses of light with the same period as the radio pulses, 33.085 milliseconds. This makes it a valuable object for scientific study, as very few other optical pulsars are yet known.

Modern X-ray observations and high-resolution images from the Hubble Space Telescope show rings of highly energetic particles around the pulsar of M 1, at distances of 0.1 to 1 light-year, and jets emerging perpendicular to the ring plane. Fine structure resolved by Hubble in 1995 includes a knot of emission only 1500 AU from the pulsar, which has been interpreted as a shock in the jet – a region where material piles up as the jet meets the surrounding nebula. Image sequences revealed its outward velocity as half the speed of light! The jets stop at a halo of blue light with 80'' radius, which shows delayed brightness fluctuations, reflecting the arrival of bright knots.

The supernova's progenitor star has been estimated to have had 8–13 solar masses. The supernova event released 400 thousand million solar luminosities, leaving the debris of the star expanding with velocities of up to 2500 km/s, while the blue halo expands with 1160 km/s. This expansion and the energy losses of the pulsar lead to a decrease of the synchrotron radiation by 0.5% per year, as shown by Smith (2003). At the same time, the expansion velocity seems to increase: present expansion rates would suggest an explosion time of 1130, more recent by 76 years. This effect is caused by the hot stellar wind that pumps additional kinetic energy into the expanding nebula.



M 1. This false color image shows the pulsar and ring-shaped structure at a 550 nm wavelength. Hubble Space Telescope.

Observation

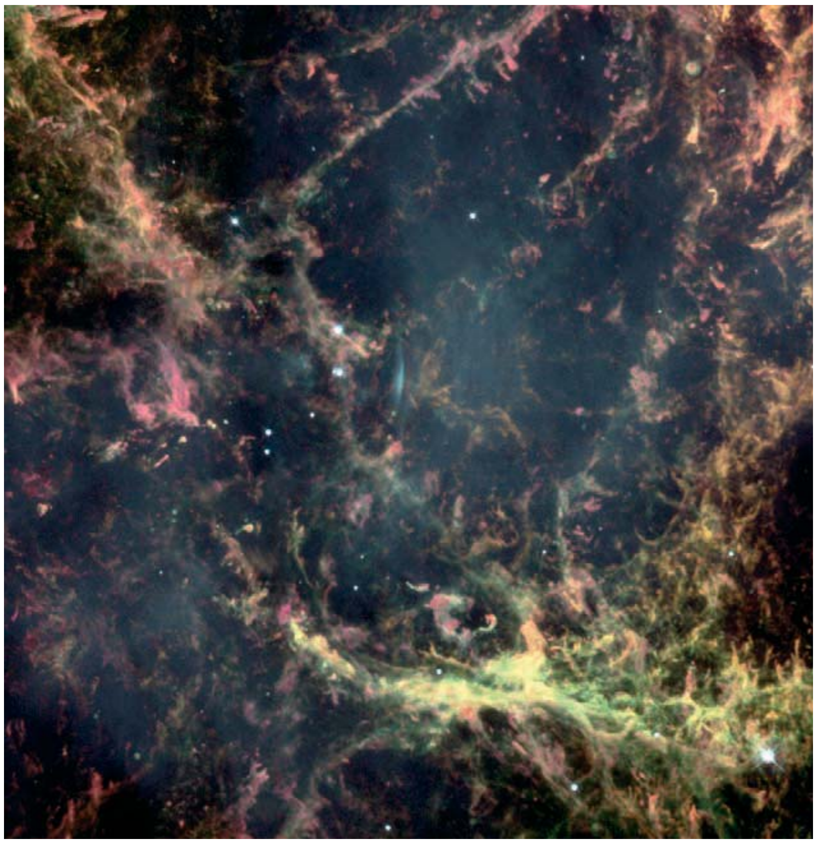
M 1 is relatively faint and by far the most difficult object to observe among the 45 entries of the first version of the Messier catalog. 10×50 binoculars show just a little smudge. With a telescope of 2" aperture, hardly any shape is recognized, but M 1 already appears as noncircular.

A 4.7-inch refractor shows an irregular nebula of about 5'×4' size, with an S-shaped main body in a northwest to southeast orientation. The southeastern side is fainter and ends in an extension, which is separated from the nebula in the north by a vague dark zone.

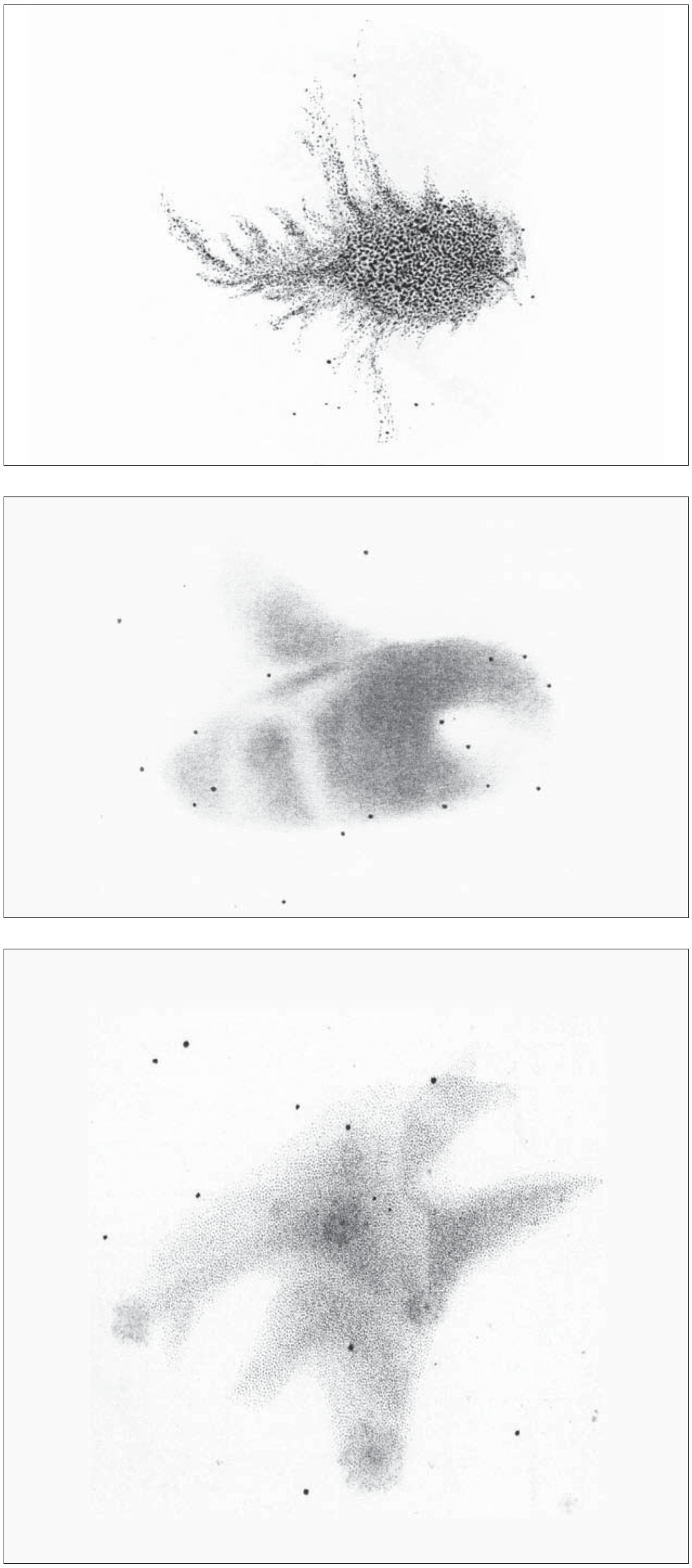
Even with large apertures, it is difficult to make out detail in M 1. 14 inches show an irregular, longish nebula. The northeastern border is straight, three 12th-magnitude stars line up along it. The northwestern tip is fainter but clearly visible, while the southwestern border is irregular. A dark bay reaches into the southeast and divides it into a brighter southern and a fainter northern branch. These were interpreted by Rosse as the claws of his "crab." In the middle of the nebula, a darker area can be made out. In it, two 16th-magnitude stars are visible under best observing conditions. The somewhat fainter, southern star is the pulsar. Four other stars are found elsewhere in the nebula.

With an [OIII] filter, the visual appearance of M 1 changes significantly: the shape is rather round, and both the northwestern tip and southeastern bay have disappeared. Instead, a bright, curved filament dominates the view. Originating in the west near an 11th-magnitude star, it stretches all across the nebula to the east. Beginning in the west, other, fainter filaments become visible, reaching into the rest of the nebula. Since their synchrotron radiation is strongly polarized, interesting changes of shape and structure appear when a variable polarizing filter is used in different PAs.

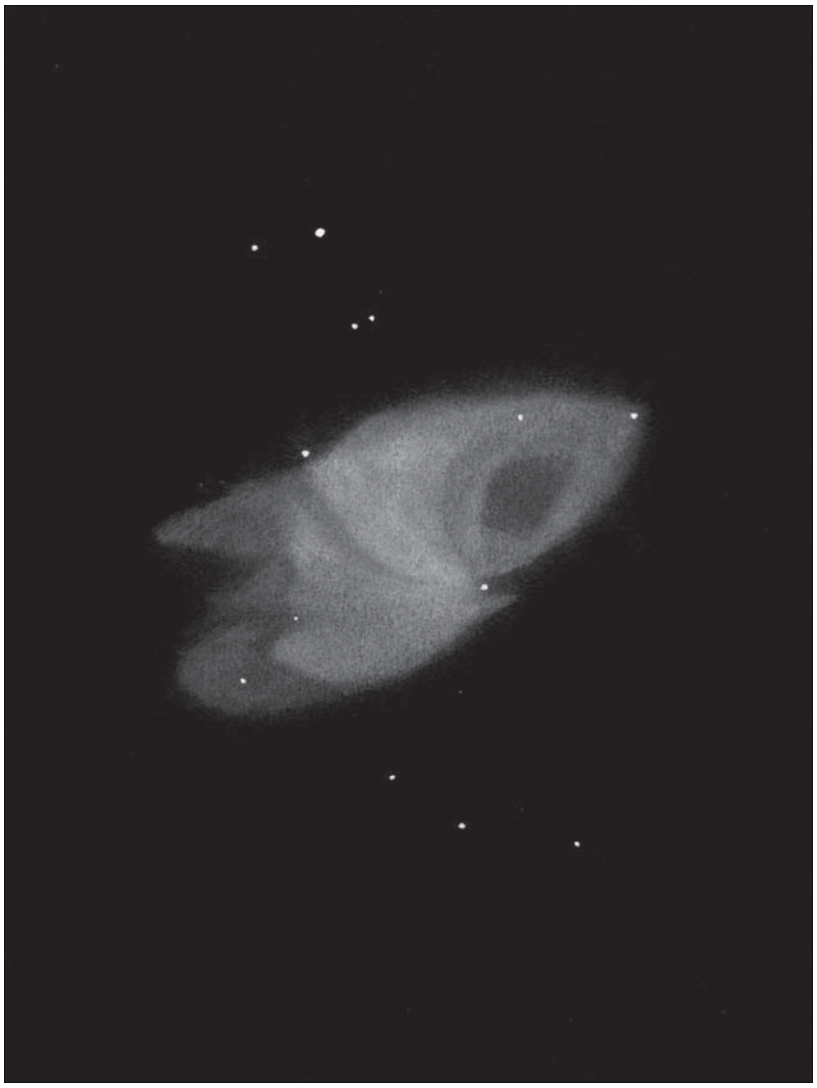
The bright double star Σ 742 is found 26' east of M 1. It consists of components of magnitudes 7.2 and 7.8, separated by 3.9" in PA 14°.



M 1. Close-up of the inner region of the nebula. Hydrogen is pictured orange, nitrogen red, sulphur pink, and oxygen green. Hubble Space Telescope.



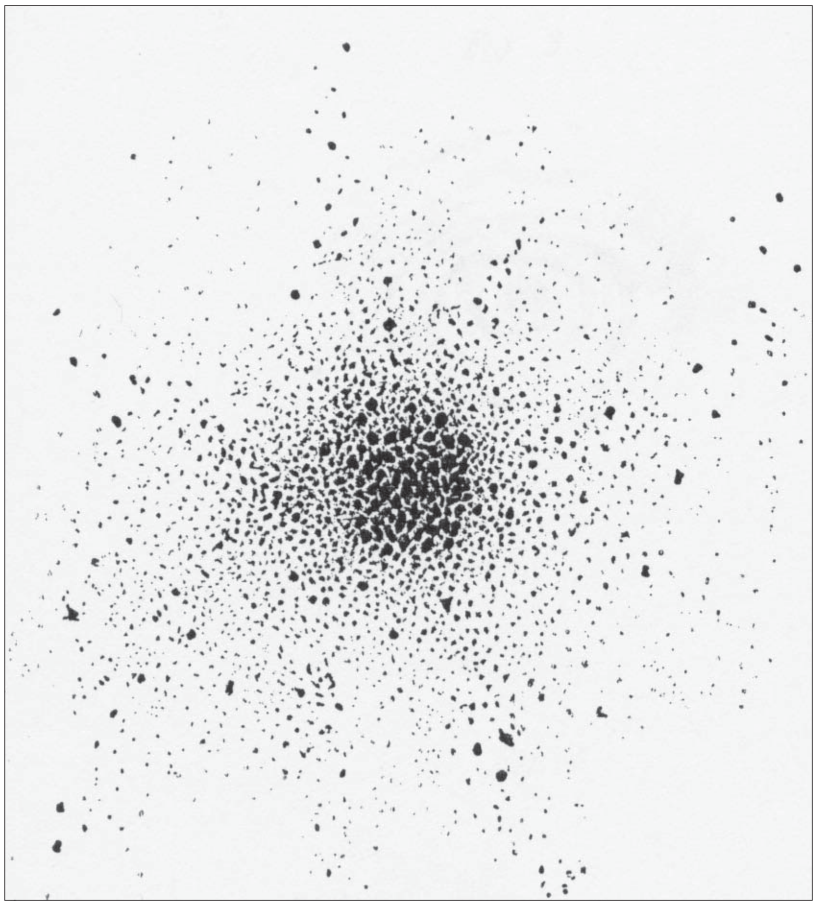
M 1, historical drawings. Lord Rosse (1844, 1853), William Lassell (1864).



M 1, drawing. 14-inch Newtonian. Ronald Stoyan.

M 2

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 7089
Type	Globular cluster
Class	II
Distance	40,850 ly (R2005) 41,460 ly (Hipparcos, 2001) 43,210 ly (RR Lyr, 1999)
Size	190 ly
Constellation	Aquarius
R.A.	21^h 33.5^{min}
Decl.	–0° 49'
Magnitude	6.4
Surface brightness	–
Apparent diameter	16'
Discoverer	Maraldi, 1746



M 2, historical drawing. Lord Rosse (1844).

History

M 2 was discovered on the 11th of September 1746, by Jean-Dominique Maraldi, while searching for the comet discovered by de Chéseaux in the same year. The Frenchman described this object as "round, well defined and brighter towards the center, about 4' to 5' in size, without any star around it to quite some distance in the whole field of the telescope. I find this most singular, because most so-called nebulous objects are surrounded by faint stars, too small to be seen in the largest telescopes, which suggest that the nebula is an effect of the light of a mass of stars. At first, I took this nebula for the comet."

Charles Messier made an independent discovery of M 2 exactly 14 years later, to the day, in 1760, when he was out to observe the comet of 1759. Later, however, he pointed out the priority of Maraldi's observation. That night, he noted: "Nebula without star, the center of it is brilliant, and the light which surrounds it is round; it resembles the beautiful Nebula [M 22] which is found between the head and the bow of the Archer. 4' diameter." However, by 1779, William Herschel recognized M 2 as a "cluster of very compressed, exceedingly small stars."

John Herschel compared M 2 with a "heap of fine sand" and noted "with 9 inches aperture I can just see the stars; with 6 inches it is resolvable. A most superb cluster; round; stars 12, 13, 14th magnitude; they are evidently globularly arranged, and not internally condensed towards the center more than the spherical form would make them appear to be; but in the middle they blend into a blaze of light."

Smyth reflected the visual appearance in the eyepiece with his characteristic enthusiasm: "This magnificent ball of stars condenses to the center, and presents so fine a spherical form, that imagination cannot but picture the inconceivable brilliance of their visible heavens, to its animated myriads."

Lord Rosse stated, less emotionally: "streams of stars branch out, taking the direction of tangents." In 1918, a first photographic diameter of only 7' was found by Curtis.

Astrophysics

Its distance of 40,850 light-years places M 2 beyond the galactic center. It consists of about 1,500,000 stars with a total mass of 900,000 Suns, and it has a true diameter of 190 light-years. The class II rating, indicative of the degree of concentration, shows M 2 as the most concentrated of all Messier globular clusters. It has been assigned a small degree of ellipticity (0.11 in PA 135°).

The brightest stars of M 2 reach magnitude 13.1, while Sawyer-Hogg found that the 25 brightest stars have an average brightness of 14.6p. The horizontal branch stars start at magnitude 16.1.

M 2 contains 30 known variable stars, the first of which was discovered in 1895 by Bailey. These comprise types RR Lyrae and W Virginis, typical variables for globular clusters, plus an RV Tauri star near the eastern cluster border. It was discovered by the French amateur Chevremont in 1897, and it changes brightness from magnitude 12.5 to 14.0 and back in 67 days. M 2 has a relatively bluish central region, taking on slightly warmer hues further out, while the outskirts appear bluish, again.

M 2 is the most compact globular cluster in the Messier catalog. Chevremont's variable has been marked. Daniel Verschatse.

Observation

M 2 can be seen with the naked eye under exceptional clear mountain skies. 10×50 binoculars show a bright nebulous ball with a bright center.

Telescopes up to 4 inches do not show any, or only a very few, individual stars in M 2, except for a 10th-magnitude foreground star, 4.5' northeast of the cluster's center. The visual diameter of the cluster grows from 6' with an aperture of 4 inches to 12' with a 14-inch telescope. The latter finally provides complete resolution of M 2. Chevremont's variable lies about 2' east of the cluster's center. With its changing brightness, the face of M 2 also changes.

A 14-inch telescope vaguely suggests dark spots near the eastern border of the core region, while the cluster itself appears a little elongated in the north-south direction. This impression is fostered by yet another vaguely darker region between the 10th-magnitude foreground star and the cluster's center.

The phantom object NGC 7088, better known as "Baxendell's Unphotographable Nebula," was supposed to lie 25' north of M 2. A century ago, a British amateur believed that he'd found in this position an extended, round nebula with a distinct southern edge only 7' north of M 2, which no contemporary photograph would show. Despite later claims of visual sightings, it is an established fact today that Baxendell must have been deceived by a reflection in his eyepiece. Neither a nebula nor a star cluster exists in this position.

M 3

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 5272
Type	Globular cluster
Class	VI
Distance	34,170 ly (RR Lyr 2001) 32,330 ly (Hipparcos, 2001)
Size	190 ly
Constellation	Canes Venatici
R.A.	13^h 42.2^{min}
Decl.	+28° 23'
Magnitude	5.9
Surface brightness	–
Apparent diameter	19'
Discoverer	Messier, 1764

History

Charles Messier discovered M 3 on the 3rd of May 1764. He saw a "Nebula; it does not contain any star, its center is brilliant & its light fades insensibly, it is round, 3' diameter." This was Messier's first true discovery, and it certainly boosted his motivation to create a list of nebulous objects, as the next entries followed swiftly.

William Herschel recognized the true nature of M 3 when he saw a "beautiful cluster of stars about 5' or 6' diameter." John Herschel remarked: "A most superb object. Not less than 1000 stars 11th magnitude and under. They run into a blaze at the center, and form as it were radiating lines and pointed projections from the mass, with many stragglers."

Admiral Smyth commented: "It blazes splendidly towards the center, and has outliers in all directions, except the south following, where it is so compressed that, with its stragglers, it has something of the figure of the luminous oceanic creature called Medusa pellucens." This comparison with a jellyfish reflects more the enthusiasm of the Englishman than an accurate observation.

Lord Rosse reported: "Rays running out on every side from a central mass in which there are several small, dark holes." Today we know that those dark structures, as observed in globular clusters in the early days, do not represent any real dark clouds of interstellar dust. An even better example is M 13.

Curtis estimated the photographic size of "the main portion of this very beautiful cluster" as "about 8' diameter."

Astrophysics

M 3 is a rich globular cluster with over half a million stars and an estimated total mass of 800,000 Suns.

The present distance of M 3 is 34,170 light-years. But its galactic orbit is highly elliptic (0.4) and its distance from the galactic center varies between 15,000 and 50,000 light-years during its orbital period of 300 million years. Still, M 3 always stays within the inner galactic halo.

The brightest stars of M 3 reach magnitude 12.7. The average magnitude of the 25 brightest stars is 14.2p, according to Sawyer-Hogg. The horizontal branch stars start at magnitude 15.7.

In 1889, Pickering discovered the first variable star in M 3. Currently, at least 274 variables are known, including 222 RR Lyrae stars. Because of the large number of these variables, typical for globular clusters, M 3 has been the object of a number of studies aiming at a further classification of RR Lyrae stars. Those of the most common subclass, the type RRab, show a steep increase and a slow decline, pulsating in their principal mode. By contrast, the RRc stars exhibit a faster, more sinusoidal light curve, oscillating in their first overtone. RRd variables show a combination of these two types of pulsation, and RRe stars oscillate in their second overtone. Some stars were even found to switch between two oscillation modes within just a few weeks.

A number of apparently young blue stars are found in this cluster, which should not exist in a globular cluster many thousand million years old. Such stars are called "blue stragglers" and must have been created in more recent mergers of old low mass stars in tight binary systems. However, in 2001 Meusinger and colleagues found out that some of the acclaimed blue stragglers of M 3 are, in fact, background quasars! Indeed, the field around this globular cluster is very rich in quasars: 175 of these objects have been detected within the 10 square-degrees around M 3, down to magnitude 19.7b.

Observation

M 3 can be seen as a nearly star-like object with small 15mm glasses. O'Meara and Skiff even claim naked-eye visibility, but a 5th-magnitude star 30' southwest of the cluster can only be distinguished from M 3 with much difficulty.

Resolving individual stars is more difficult with M 3 than with M 5 or M 13. It requires an aperture of at least 4 inches, but resolution then sets in all over the cluster. Some observers report their impression of an asymmetrically west-shifted cluster center. The total visual cluster diameter of M 3 grows from 7' with 4-inch telescopes to over 15' with 14 inches of aperture, which places it between the sizes of M 5 and M 13. The bright and dense central region of M 3 measures about 4' and is between the cores of M 13 and M 92 in brightness. The "small dark holes" of Lord Rosse are not visible, not even at high magnification, but the radial rays of stars are. These give the outskirts

M 3. Many of the blue stars are so-called “blue stragglers,” while RR Lyrae variables appear rather yellowish. Josef Pöpsel.

of M 3 rather a corona-like appearance, by contrast to the star chains seen with many other globular clusters.

The double star ES 442, with two stars of magnitude 8.3 and 12.9 separated by 7.4” (PA 243°), lies only 11’ south of M 3. The brightest galaxy in this field is NGC 5263, 29’ west of the globular cluster. Several very faint, tiny galaxies can be found in the outskirts of M 3. The brightest of these reach 16^{th} magnitude and are within reach of a 20-inch telescope at high magnification.

M 4

Degree of difficulty	2 (of 5)
Minimum aperture	15mm
Designation	NGC 6121
Type	Globular cluster
Class	IX
Distance	5640 ly (CMD, 2004)
Size	57 ly
Constellation	Scorpius
R.A.	16^{h} 23.4^{min}
Decl.	–26° 32'
Magnitude	5.8
Surface brightness	–
Apparent diameter	35'
Discoverer	de Chéseaux, 1746

M 4. The millisecond pulsar is located near the cluster's center (marked by a green circle). Hubble Space Telescope.

History

In 1746, the Swiss amateur astronomer Philippe Loys de Chéseaux discovered a nebula "near Antares, white, round and smaller than the previous [M 31, M 42,...]." But de Chéseaux's observations were not published, and that made Nicolas Louis de Lacaille an independent discoverer of M 4. In 1752, from Cape Town, he saw a "Nebula without stars, resembles the small core of a faint comet."

Messier observed M 4 on the 8^{th} of May 1764 and noted: "Cluster of very small stars; with a weak refractor it is seen in the form of a nebula; 2.5' diameter." In fact, M 4 is the only globular cluster that Messier was able to resolve into individual stars.

In 1783, William Herschel also resolved M 13 and noted "a rich cluster of considerably compressed small stars surrounded by many straggling ones. It contains a ridge of stars running through the middle from south preceding to north following. The ridge contains 8 or 10 pretty bright stars." Admiral Smyth found M 4 elongated in a north-south direction, as Herschel did, with respect to the distribution of the brightest stars.

Astrophysics

With a distance of 5600 light-years (Richter et al. 2004), M 4 is the closest of all globular clusters. NGC 6397 in the southern sky takes a clear second place at 7500 light-years. M 4 is even closer than some open clusters, for example M 103. Physically, it is a relatively small globular cluster.

M 4 suffers significantly from interstellar absorption, because it is only 2000 light-years above the galactic plane. Its stellar content has been estimated as at least 100,000 stars, of which more than 10,000 are brighter than 19^{th} magnitude. The mean magnitude of the 25 brightest stars is 13.1p, but the brightest star reaches as much as magnitude 10.8. In its concentration class IX, M 4 is considered one of the loosest globular clusters in the Messier catalog.

The age of M 4 has been stated as 12.7 thousand million years, with a safe lower limit of 9 to 10 thousand million years; a typical age for globular clusters. Since M 4 is situated in front of the northern part of the galactic bulge, it has been used as a calibration tool to measure the distance to the galactic center; recent sources put it at 25,900 light-years.

At least 65 variable stars are known in M 4, among them is the millisecond-pulsar (PSR B1620-26), discovered in 1987 at a visual magnitude 21.3. This rare object with about 1.4 solar masses is part of a triple system with a white dwarf and a planet-like object of 0.01 solar masses. The latter could have been "stolen" from a different system. It has an orbital period of about 100 years and, presently, a separation from the pulsar of 35 AU. The period of the pulsar is 11ms, three times faster than that of the pulsar in M 1.

In 1997, the Hubble Space Telescope photographed 258 white dwarfs in M 4. Altogether, there should be about 40,000 of them. In 2001, deep HST-exposures of M 4, the "Globular Deep Field" led to recorded member stars down to magnitude 30.

Observation

Only 1.5° west of brilliant Antares, M 4 is hard to see with the unaided eye. But 10×50 binoculars provide pretty views of a round nebula.

Even a 2-inch refractor begins to resolve individual stars. An aperture of 4.7 inches shows the 2.5' long bar of stars described by

M 4 is the closest globular cluster, hardly more distant than the Lagoon Nebula (M 8). Bernd Flach-Wilken, Volker Wendel.

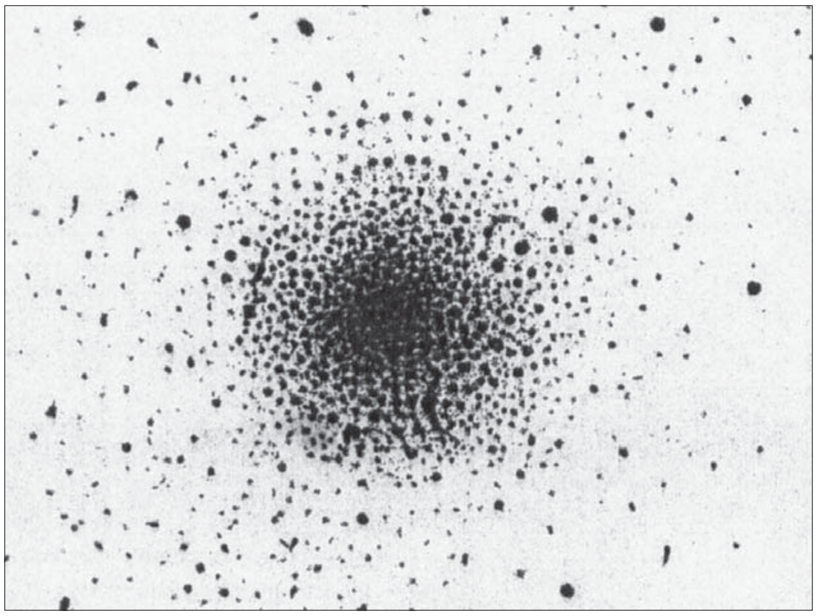
Herschel, which crosses the center at a PA of 12°. The cluster reaches a visual diameter, including extensions, of a respectable 10'.

Larger apertures provide a better perception of the open character of M 4. This impression is supported by a bright stellar pair (magnitudes 10.8/10.9, 17" separation, PA 220°) 3' southeast of the core and by several brighter stars a little further away from the core, to its southwest. The visual diameter reaches 15', but that is still only a fraction of the photographic diameter of 35' – greater than the apparent size of the Moon!

The fainter globular cluster NGC 6144 (magnitude 9.0) is found 1° northeast of M 4. It is only a small nebulous dot in small telescopes and its resolution requires apertures of 8 inches or more.

M 5

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 5904
Type	Globular cluster
Class	V
Distance	26,620 ly (R2005) 25,210 ly (CMD, 2004) 25,560 ly (RR Lyr, 2001)
Size	150 ly
Constellation	Serpens
R.A.	15^h 18.6^{min}
Decl.	+2° 5'
Magnitude	5.7
Surface brightness	–
Apparent diameter	20'
Discoverer	Kirch, 1702



M 5, historical drawing. John Herschel (before 1833).

History

The globular cluster M 5 was first noted by Gottfried Kirch in Berlin, Germany, as a "nebulous star," on the 5th of May 1702. This observation was not published at the time and had to be rediscovered in the notebook of Kirch's wife. For this reason, Charles Messier is rightfully considered an independent discoverer of M 5. On the 23rd of May 1764, he wrote: "Beautiful Nebula; it does not contain any star; is round, & one can see it very well, in a good sky, with a simple refractor of one foot [focal length], 3' diameter."

In 1791, William Herschel reported that M 5 is actually a star cluster and counted about 200 stars "but the middle of it is so compressed that it is impossible to distinguish the stars." His son John referred to M 5 as a "most magnificent, excessively compressed cluster of a globular character. Stars 11th to 15th magnitude; the more condensed part projected on a loose irregular ground of stars. The condensation is progressive up to the center, where the stars run into a blaze, or like a snowball; the scattered stars occupy nearly the whole field."

In the words of Smyth, a few years later, we recognize the passionate observer: "This superb object is a noble mass, refreshing to the senses after searching for faint objects; with outliers in all directions, and a bright central blaze, which even exceeds M 3 in concentration." Lord Rosse gave M 5 a "more than 7' or 8' diameter, with a very compact central part of about 1' diameter."

Edward Emerson Barnard wrote: "Much more beautiful than M 13, which is more suitable for smaller apertures. In good seeing, a number of ink-black patches or holes are visible, not in the densest part, but nearby to the southwest and southeast. Under best conditions, they almost look like black, obscuring masses. Apparently near the cluster center is a group of six or seven small bright stars, which in small telescopes give the impression of a core of M 5."

In 1918, after the inspection of deep exposures of M 5, Curtis wrote: "A beautiful bright globular cluster: the main portion is about 12' diameter." In 1890, Common found the first variable stars in M 5, and by 1899, Bailey discovered a total of 85 variables. By 1959, this number had risen to 97.

Astrophysics

At its distance of 26,620 light-years, M 5 has a physical size of 150 light-years, if we take its angular diameter as 20'. Its shape is slightly elliptical towards PA 50°. An eccentric orbit around the galactic center with a period of a thousand million years leads M 5 to a maximal distance of 150,000 light-years; presently, however, its distance from the galactic center is 20,000 light-years.

M 5 comprises about 800,000 solar masses. Among its many member stars, the brightest of which reach magnitude 12.2, there are 120 known RR Lyrae stars, variables typical for globular clusters. Another variable in M 5 is a rare dwarf nova with a period of 5.8 hours and brightness fluctuations between magnitudes 19.8 and 22.5. In addition, some variable "blue stragglers" (see M 3) of the SX Phoenicis type and half a dozen eclipsing binaries have been found. Hence, M 5 has at least 143 variable member stars.

The age of globular clusters is regarded as a lower limit to the age of the Universe. Earlier determinations were in conflict with contemporary cosmological models. New cosmological models, based on evidence for an accelerated expansion of the Universe, now suggest an older cosmos. At the same time, recent distance measurements of globular clusters, using the Hipparcos satellite, suggest larger distances, which result in younger cluster ages. For M 5, Chaboyer et al. (1998) found an age of 8.9 thousand million years; Jimenez and Padoan soon after gave 10.6 thousand million years – in any case, M 5 is one of the youngest objects of its kind in the Milky Way.

M 5. Edward Emerson Barnard regarded this globular cluster as "much more beautiful than M 13." Bernd Flach-Wilken.

Observation

Despite a total magnitude of 5.7, M 5 remains a difficult object for the naked eye to observe. The 5^{th}-magnitude star 5 Serpentis is only 20' southeast and hampers the observation. 10×50 binoculars show the typical nebulous ball of a globular cluster.

The first individual stars are resolved with a 2.5-inch refractor. But it requires 4 to 6 inches to have an overall resolved impression of M 5, with a highly concentrated nebula in its center and a visual cluster diameter of 6'.

The visible extent of M 5 more than doubles to 15' with the use of larger telescopes. It then even beats the size of M 13! The very dense central region of M 5 remains nebulous in character in a 14-inch telescope, and it has only about half the size of the wider and looser core of M 13. A chain of 5 to 6 stars in east-west direction is noticed 2' north of the center of M 5. A variable star (No. 46) 3' southwest of the center can rise from magnitude 12.1 to 10.6 and stand out distinctly from the rest of the cluster. Star chains in the outskirts are best seen with modest magnifications. They give M 5 a much more spider-like appearance than M 13. The most noticeable chain starts with the variable and reaches 5' southward.

The bright 5 Serpentis, 20' southeast of M 5, actually is a nice double star with an 11^{th}-magnitude companion at a distance of 11" from the 5.2 primary. The faint (magnitude 15.6) galaxy IC 4537 can be made out 15' west of M 5. It is actually the brightest of a rich group of faint galaxies. The very faint globular cluster Palomar 5 lies 2.3° south of M 5 – a really challenging object for a 14-inch telescope.

M 6

The Butterfly Cluster

Degree of difficulty	1 (of 5)
Minimum aperture	Naked eye
Designation	NGC 6405
Type	Open cluster
Class	II3m
Distance	1590 ly (K2005) 1590 ly (2002)
Size	10 ly
Constellation	Scorpius
R.A.	17^{h} 40.1^{min}
Decl.	–32° 13'
Magnitude	4.2
Surface brightness	–
Apparent diameter	20'
Discoverer	Hodierna, 1654

History

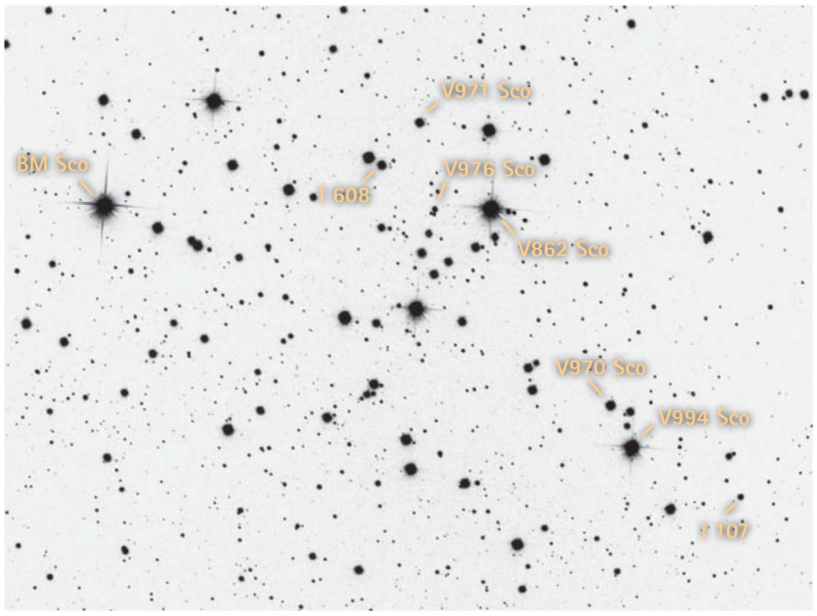
By contrast to its bright neighbor M 7, M 6 was not known in pre-telescopic times. The first sighting has been attributed to Giovanni Batista Hodierna on or before 1654. The Sicilian observer counted 18 stars. Later, independent discoveries were made by the Swiss observer de Chéseaux in 1745 or 1746, and by Louis de Lacaille from the Cape of Good Hope in 1752. The latter described M 6 as a "singular cluster of small stars, placed in three parallel bands, forming a lozenge of 20' to 25' diameter and filled with nebulosity." He registered it under his number III.12.

Messier knew of Lacaille's observation. He studied M 6, together with M 7, on the 23rd of May 1764, and wrote: "With the naked eye, this cluster seems to form a nebula; but with the smallest instrument which is employed to examine it, one sees a cluster of small stars; 15' diameter."

A century later, John Herschel commented: "a fine, large, discrete cluster of stars of 10th to 11th magnitude; one star is 7th magnitude, one 7th to 8th. Fills field."

Astrophysics

The open star cluster M 6 consists almost entirely of blue stars with spectral types A and B. Near the eastern end, we find an orange star of spectral type K3. This is the variable BM Sco with a period of 850 days. It can reach the status of brightest cluster star with its maximum magnitude of 5.8, equivalent to 1900 solar luminosities. At its minimum, however, it is only magnitude 8.0. There are at least a dozen more variables in M 6.



In 1972, Antalová claimed membership for 120 stars, while Schneider confirmed 64 members brighter than magnitude 11.8 in 1985. These include several Ap stars, which have strong magnetic fields tilted with respect to their rotation axes and which show extra strong absorption lines of ionized metals and rare earth elements.

M 6 has an age of only 80 to 100 million years and a diameter of only 10 light-years. At its distance of 1590 light-years, almost twice as far away as M 7, it is located only 20 light-years below the galactic plane, in the region between the Orion and the Sagittarius spiral arms, not far from M 23 and M 25 in Sagittarius.

Observation

M 6 is one of the brightest open clusters in the sky. With magnitude 4.2, it is not much fainter than its larger neighbor, M 7; and not suffering from a bright background, M 6 can be seen as easily with the naked eye as M 7.

10×50 binoculars show about 20 stars in an elongated layout 25'×20' in size. It was Burnham who likened it to a butterfly with outspread wings – which led to the popular name for M 6. In a telescope, this perception requires a low power of under 40×.

Larger apertures show the reddish hue of BM Scorpii at the eastern edge of the cluster. Another variable is V862 Scorpii, a γ Cassiopeiae type. From its normal magnitude 8.5, it can occasionally rise up to even 2nd magnitude, to be by far the brightest cluster star. Two close double stars in M 6 are interesting objects for larger telescopes:

Double stars in M 6

Designation	Magnitude	Separation	PA
I 608	9.0/10.8	1.8"	48°
I 107	10.0/10.5	1.7"	137°

M 6. The Butterfly Cluster's stars offer an impressive array of spectral types. Rainer Sparenberg.

M 7

Degree of difficulty	1 (of 5)
Minimum aperture	Naked eye
Designation	NGC 6475
Type	Open cluster
Class	I3m
Distance	980 ly (K2005) 980 ly (proper motion, 2002) 910 ly (Hipparcos, 1999)
Size	23 ly
Constellation	Scorpius
R.A.	17^h 53.9^{min}
Decl.	–34° 49'
Magnitude	3.3
Surface brightness	–
Apparent diameter	80'
Discoverer	Ptolemy, 130 BC

History

M 7 was already known to Ptolemy as a nebulous patch following the sting of the scorpion when he compiled his star catalog, the Almagest, in 130 BC. 1000 years later, the Persian scholar Al Sufi assigned it a brightness of magnitude 4.5.

Because of its very southerly position, M 7 remained unnoticed by many European observers. Hodierna counted 30 stars in 1654, and he was probably the first to recognize M 7's true nature as a star cluster. Lacaille observed it in 1752 from South Africa and wrote: "Group of 15 to 20 stars, very close to each other, in the form of a square." He registered M 7 as his number 14 in the category of star clusters.

Charles Messier made his observation of M 7 on the 23rd of May 1764, and noted: "Cluster of stars more considerable than the previous [M 6]; this cluster appears to the naked eye like a nebula; 30' diameter." Of the later observers, John Herschel gave M 7 some attention and characterized it as "cluster; very bright; pretty rich; little compressed; stars from 7th to 12th magnitude."

Astrophysics

With a total magnitude of 3.3, M 7 is one of the very brightest Messier objects; it takes third place closely behind M 44. At just under 1000 light-years distance, this open cluster gains much of its apparent brightness from its proximity. It still belongs to the local spiral arm, located on its inner side with respect to the galactic center. The rich star fields in the background, however, are made by the galactic bulge, almost 30,000 light-years away.

The main body of M 7 consists of 24 stars with a magnitude between 5.6 and 9.3, distributed over a diameter of 80'. However, of the about 100 stars brighter than 10th magnitude in this field, only 50% really belong to the star cluster. The others are field stars in the background or foreground. The brightest star of a total of 750 cluster members is magnitude 5.6 and spectral type G8. Some of the other brightest member stars, however, have "blue spectral types. Two of them, V957 Sco (magnitude 5.9, B6) and HD162586 (magnitude 6.1, B8) are blue stragglers," which are better known to occur in globular clusters (see M 3). By contrast, V906 Sco Sgr is an eclipsing binary (magnitude 6.0 to 6.2, period: 2.78 days) with a third, distant component, separated by 0.2" in PA 286°. On the whole, the binary content of M 7 is above average.

With a diameter of 23 light-years, M 7 is an average, if not even smallish star cluster. Since stars of spectral types A to F are among the brightest members still fusing hydrogen in their cores, the cluster's estimated age is about 200 million years.

Observation

With a declination of –35°, M 7 is the southernmost Messier object. Hence, despite its brightness, it effectively cannot be seen from latitudes much north of 50°.

In terms of apparent diameter, total brightness and number of cluster stars, M 7 competes with the Praesepe. Nevertheless, M 7 does not come across as impressive as M 44, not even from sufficiently southern sites. The reason for this is its set-up against a bright Milky Way background in the direction of the galactic center. M 7 rather appears as the bright core of a large, rich region of our galaxy. For most of the USA, as well as for southern and central Europe, it forms the southernmost conclusion of our beautiful summer Milky Way.

M 7 is a classic binocular target. 10×50s show 30 stars with a central, nebulous concentration, in front of an unparalleled, rich starry background. The dark nebula B 287 at the southern edge of M 7 forms an appealing contrast with the cluster, when observed from southern sites such as Namibia. The dark cloud is elongated in the east-west direction and has an extension, which reaches southward from its eastern end.

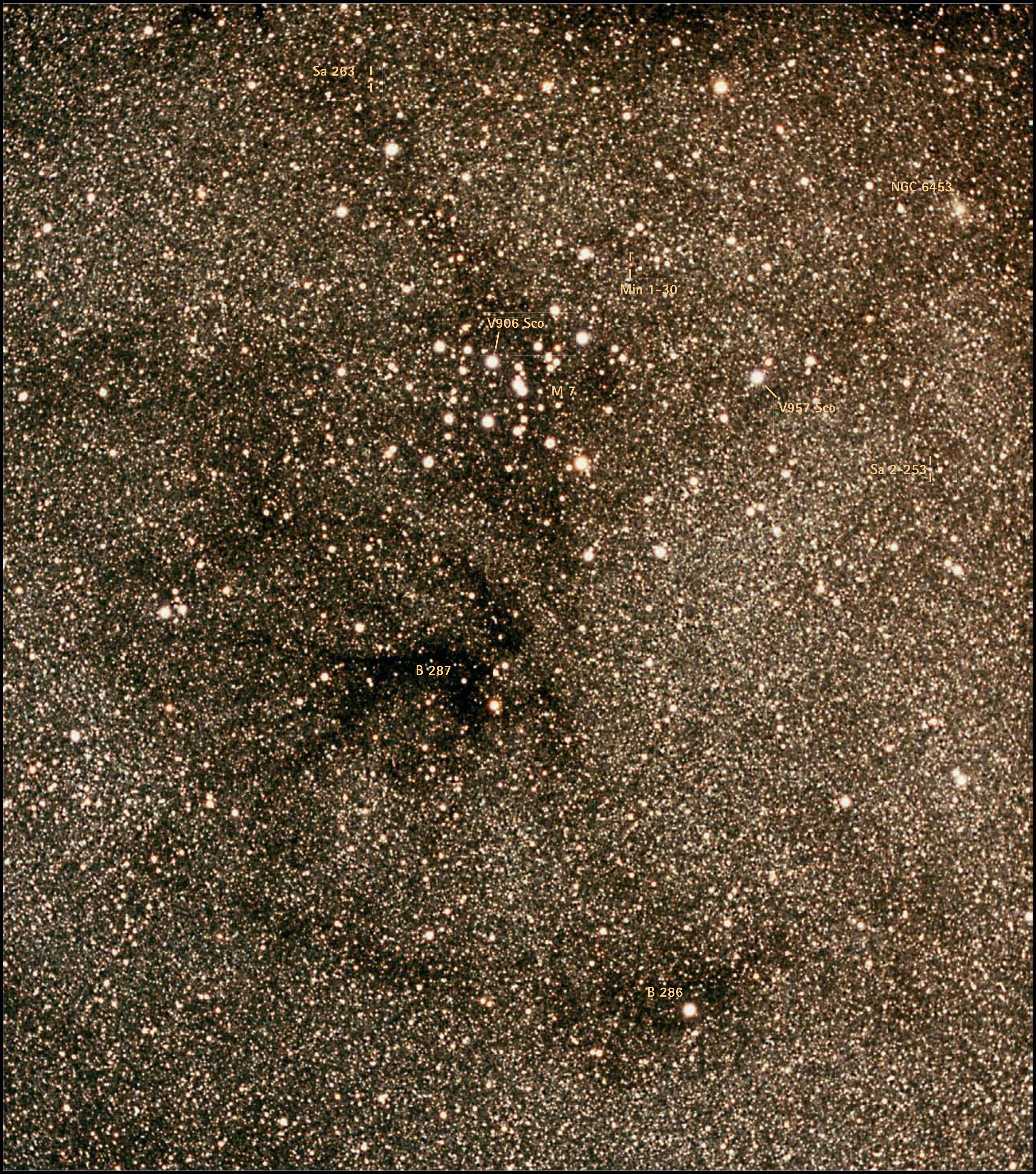
The impact of the view through binoculars is lost with the use of a telescope. The brightest cluster stars are arranged in the form of a "K." A bright, yellowish star to the southwest turns out to be a nice pair of stars with magnitudes 6.4 and 7.2.

There are a lot of deep sky objects in and around M 7. NGC 6453 at its western edge is a distant globular cluster with a total magnitude of only 10.2. Even with large apertures, it remains an unresolved, nebulous ball 2' in diameter. NGC 6444 is an open cluster, 50' west of M 7. A mid-sized telescope shows about 30 stars of 11th magnitude and fainter, with little concentration.

Three little planetary nebulae share the field with M 7. All three appear star-like, even at high magnification. But quick changes of the view with and without an [OIII] filter ("[OIII]-blinking") help to identify them. The two Sanduleak objects are within reach of an 8-inch telescope, but Minkowski 1-30 requires a significantly larger aperture.

Planetary nebulae in the field of M 7

Designation	Magnitude	Diameter
PK 355-4.2 (Min 1-30)	14.7p	5"
PK 355-4.1 (Sa 2-253)	14.0	11"×8"
PK 356-4.1 (Sa 2-263)	12.2	2"×3"



M 7 lies in one of the richest regions of the Milky Way, in the direction of the galactic center. Herrmann von Eiff.

M 8

with the Lagoon Nebula

Degree of difficulty	1 (of 5)
Minimum aperture	Naked eye
Designation	NGC 6530, NGC 6523
Type	Open cluster, Galactic nebula
Class	II2mn
Distance	4310 ly (K2005) 4890 ly (proper motion, 1997)
Size	9 ly; 115× 50ly
Constellation	Sagittarius
R.A.	18^h 3.8^{min}
Decl.	–24° 23'
Magnitude	5.8; 4.6
Surface brightness	22mag/arcsec^2
Apparent diameter	7'; 90'×40'
Discoverer	Flamsteed, 1680; le Gentil 1749

History

In 1680, John Flamsteed noted a "nebula, preceding the bow of Sagittarius." His small telescope simply could not resolve the star cluster (NGC 6530). De Chéseaux, in 1746, also observed the cluster.

The nebula itself (NGC 6523) was first noticed by Guillaume le Gentil in 1749. He wrote: "west of a star cluster; this nebula has the exact shape of a slightly elongated, equilateral triangle, tip pointing south-west. I have observed it with a refractor of 18 to 20 foot, and it always appeared to me nebulous and transparent; its base touches a rather beautiful star, seen in the refractor, which is the brightest of all those which form the star cluster I have mentioned." Three years later, and with a much smaller telescope, Lacaille described M 8 as "three stars, engulfed in a band of nebulosity parallel to the equator."

On the 23rd of May 1764, Charles Messier pointed his telescope to M 8 and noted: "Cluster of stars which appears in the form of a nebula when it is viewed with a simple refractor of three feet; but with an excellent instrument one does not notice but a great number of small stars; near this cluster is a quite brilliant star, surrounded by a very faint light; this cluster appears in an elongated shape, which extends from North-east to South-west, 30' diameter." Hence, for Messier, the star cluster mainly makes up his object No. 8; the nebula is mentioned only in passing.

William Herschel registered the nebula as an object of its own, but skipped the cluster in consideration of the priority of Messier's published catalog. In 1785 he wrote: "An extensive milky nebulosity divided into two parts; the most north being the strongest. Its extent exceeds 15'; the southern part is followed by a parcel of stars which I suppose to be the 8th [object] of the Connoissance des Temps."

In 1830, John Herschel described M 8 in some detail: "A collection of nebulous folds and matter surrounding and including a number of dark, oval vacancies and, in one place, coming to so great degree of brightness as to offer the appearance of an elongated nucleus. Superimposed upon this nebula and extending in one direction beyond its area, is a fine and rich cluster of scattered stars which seems to have no connection with it as the nebula does not, as in the region of Orion, show any tendency to congregate about the stars." With this latter opinion, however, this experienced observer was wrong – as distance measurements would demonstrate nearly 100 years later.

M 8 acquired its popular name from an 1890 description by Agnes Clerke, who likened its appearance to that of a dark lagoon surrounded by bright fog. Curtis noted, after the inspection of deep photographs: "very bright, and of wonderfully intricate structure; covering an area of at least 50'×36'."

Astrophysics

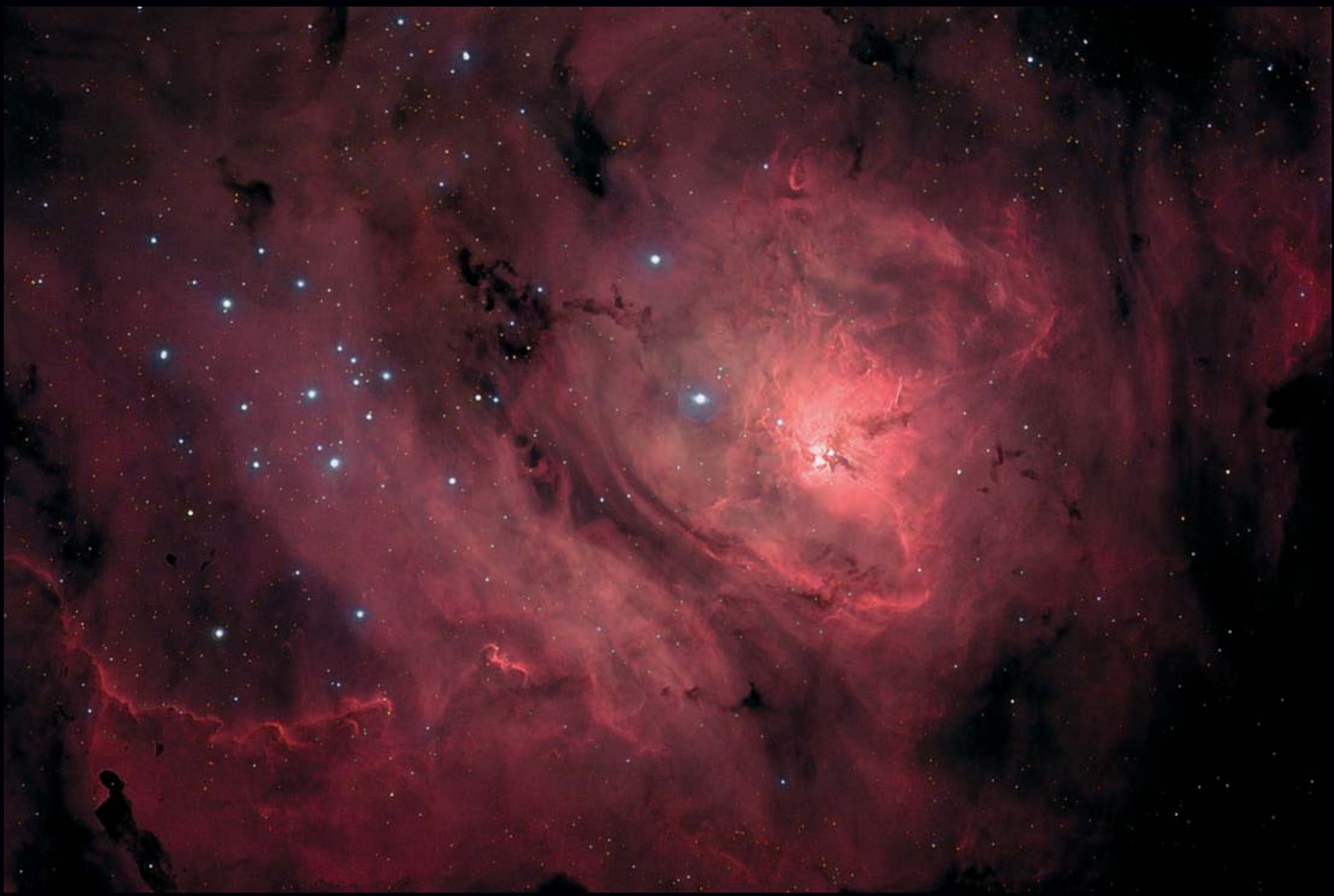
M 8 is a magnificent example of a young stellar cluster that is part of an active star forming-region. On the facing side of a gigantic molecular cloud (see also M 42), a number of recently born stars are emerging from the surrounding excited nebula. In the background, active star formation continues and more stars emerge from the molecular cloud.

The ionization of the nebula is due to several very luminous stars, dominated by the magnitude 6.0 star 9 Sagittarii of spectral type O4. With an absolute magnitude of –10.7, 9 Sagittarii is one of the most powerful stars of all. Recently, though, it was discovered spectroscopically to be a double star. It is located 2.5' northeast of the brightest region of the nebula. HD 164816 (magnitude 7.1, O9) with about 8000 solar luminosities, 3' north, and HD 164740 (magnitude 7.7, O8), 12' northeast, also contribute to the excitation of the gas. The most apparent bright star of the southeast part of the cluster, HD 165052 (magnitude 6.9, O6), is involved, too, and so is HD 165246 (magnitude 7.2, O8) in the eastern part of the nebula. However, 7 Sagittarii, 15' west, is only a foreground star.

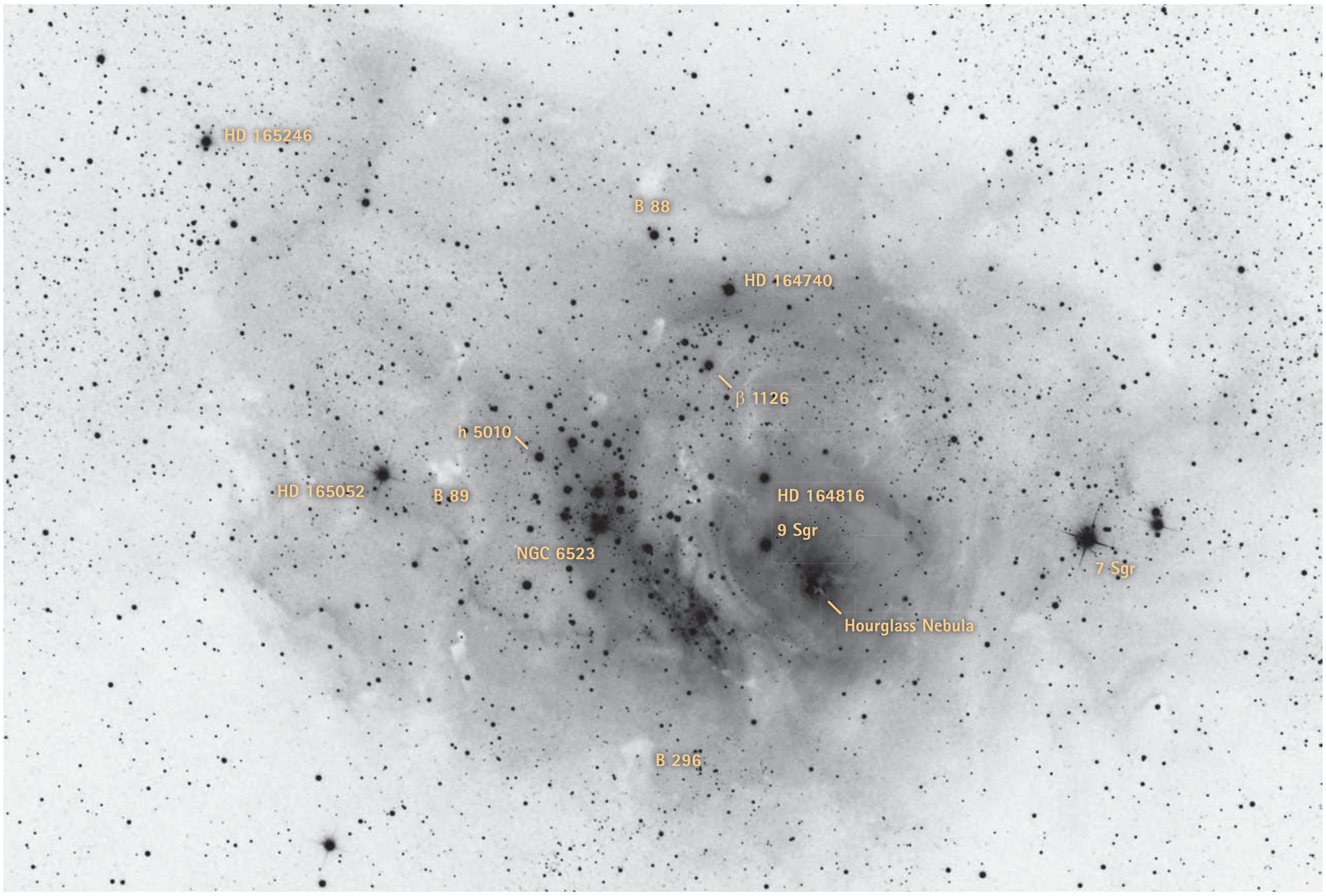
The star cluster NGC 6530 has a distance of about 4310 light-years and a diameter of 9 light-years. It contains numerous young stars down to a magnitude of 17, among them at least 80 of the same typical nebular variables known from the Orion Nebula (see M 42). The brightest stars, of magnitude 6.9 and several around 7.5, together make the star cluster shine at magnitude 5.8 and, in fact, form the brightest cluster in the constellation of Sagittarius.

By far the brightest part of the nebula, southwest of 9 Sagittarii, is the Hourglass Nebula right next to a magnitude 9.5 star (Herschel 36, O7). It has been created by the interaction of the hot radiation of that star with the relatively dense gas around it. Photos taken by the Hubble Space Telescope in 1997 show that the hourglass shape has been carved out of thick dust clouds by the energetic radiation

M 8 consists of the bright star cluster NGC 6530 and the emission nebula NGC 6523. A long, dark "laguna" of obscuring dust traversing the center of this object gave the nebula its popular name. Stefan Binnewies, Bernd Schröter.



M 8. The central region with the Hourglass Nebula. Josef Pöpsel, Rainer Sparenberg.



of Herschel 36 and other hot stars nearby ("photo-evaporation"). The temperature difference between the still cold interior of the clouds and their hot, UV-excited surfaces leads to tornado-like shapes. The Hourglass Nebula must be very young; it is supposed to have an age of about 10,000 years. It is located at the far side of the visible nebular complex, near the front of the background molecular cloud. Not far from the Hourglass Nebula, Stecklum et al. (1998) believe they have found a protostellar cloud, similar to the "proplyds" in M 42, which contains a star in the making.

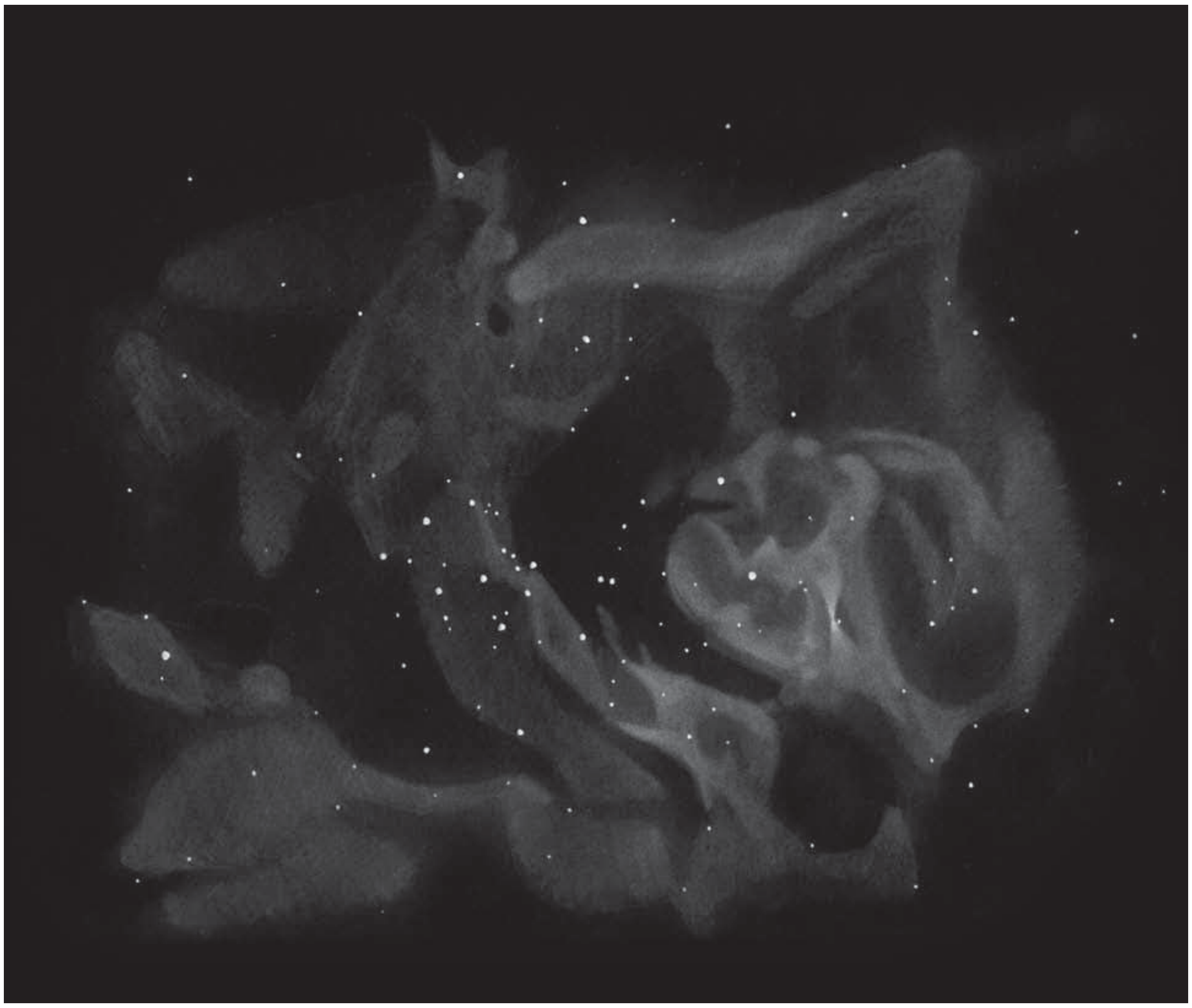
Dark globules stand out in several regions of the nebula. Three of them have been listed as dark nebulae in the catalog of Barnard (B 88, 89, 296). Deep exposures of high resolution also show some very small, black dots. These objects are protostellar clouds of just a few tens of thousands AU in diameter, which withstand the ionizing radiation of the surrounding hot stars only by virtue of their high densities. Inside are new stars in their final stages of formation.

In deep field photos, the nebula NGC 6523 can be traced to a maximum size of 90'×40'. At a distance of 4310 light-years away, this corresponds to a physical size of 115×50 light-years. This is several times the size of the Orion nebula, which would be dwarfed by M 8, if seen from the same distance. M 8 is part of the larger association of young stars Sagittarius OB1 in the Sagittarius spiral arm of the Galaxy, which also includes the Messier object M 21, while M 20 is closer to us. The apparently brightest star of this association is μ Sagittarii (magnitude 3.9, B8), about 5° northeast of M 8.

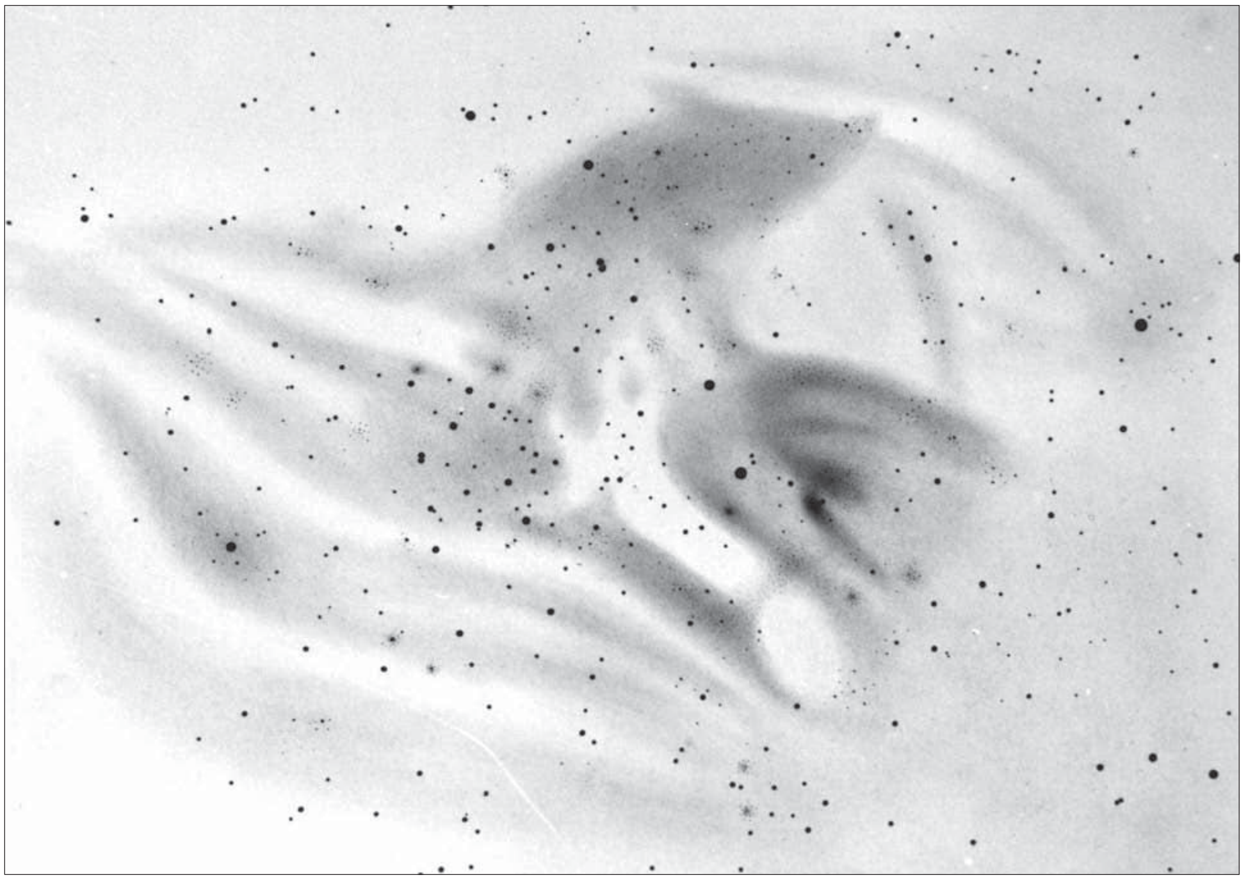
Observation

M 8 is an impressive sight for the naked eye, as a longish nebulous spot southwest of μ Sagittarii. 10×50 binoculars offer fascinating views: the open cluster NGC 6530 with about a dozen stars of 7th to 10th magnitude is seen against a nebulous background, which partly comes from unresolved and partly from true nebulosity. The bright stellar pair of 9 Sagittarii (south) and HD 164816 (north), separated by 3', lies 10' south of the cluster – conspicuously surrounded by nebulosity. The bright star 7 Sagittarii and its stellar company, 15' west, adds further glamour to this field. A nebula filter shows the whole area in a diffuse glow – certainly the most spectacular nebulous field of the whole summer sky!

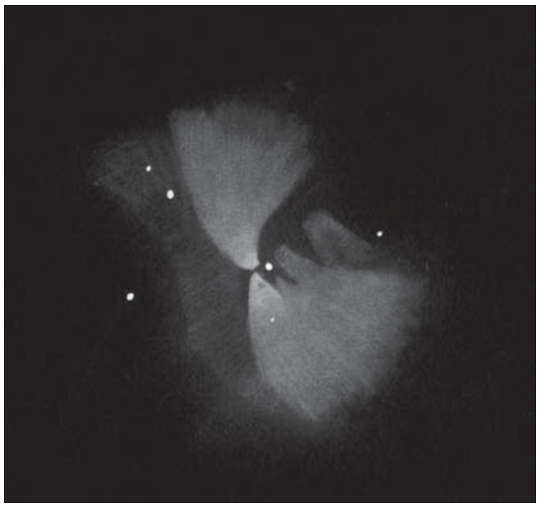
A 2-inch refractor with a magnification of 80× resolves the brightest nebulosity, 2.5' southwest of 9 Sagittarii, into a small object just east of a 9th magnitude star; a 4.7-inch telescope reveals its hourglass shape. The full complexity of M 8 is obvious at low magnification, with the same aperture: originating from the dark central lagoon of about 6' diameter, a dark 1' wide canal divides the bright nebulosity,



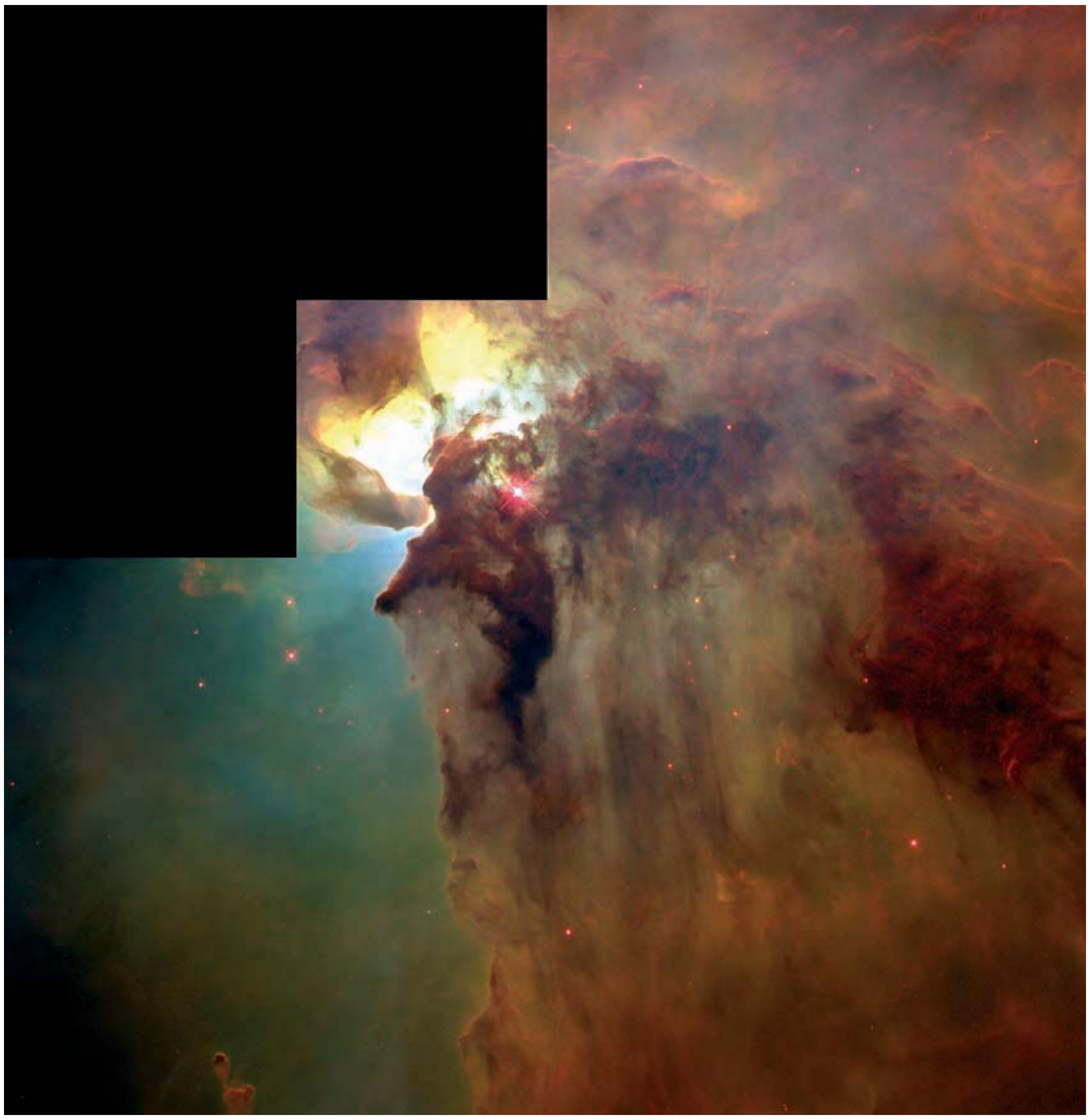
M 8, drawing. 14-inch Newtonian. Ronald Stoyan.



M 8, historical drawing. Wilhelm Tempel (1877).



M 8, drawing. Detail around the Hourglass Nebula. 20-inch Newtonian. Ronald Stoyan.



M 8. The Hourglass Nebula with the double star Herschel 36. Ionized sulphur emission is coded in red, doubly ionized oxygen in blue, and hydrogen in green. Hubble Space Telescope.

aiming southwest. The lagoon is surrounded by a faint, structureless glow on all sides. The star cluster in the east shows about 30 members.

The richness of detail is boosted dramatically by the use of 14 inches of aperture. The dark canal is decorated with stars and bordered by bright nebulous structures at both sides. Just before exiting via a dark bay in the southwest, it is crossed by a faint bridge of nebulosity, 5' south of 9 Sagittarii. A bright region with structures aligned northeast-southwest joins in the east. It splits towards the northeast: one branch forms the bright background of NGC 6530, the other one turns east to a bright star 10' east of the cluster. A 6'×3' size dark nebula (B 89) stands out distinctly, on the northwest side of that star.

The nebulous region in the west offers details on the smallest scales – especially around the Hourglass Nebula, which is by far the brightest feature of the whole nebula. The northern and southern extensions of the hourglass lead into an 8'×5' nebulous arc, concave towards the south. It encircles five stars on a dark background. The northern part of the region consists of a 15'-long, nearly straight nebulous bar, orientated east-west. Several small dark nebulae are visible at its eastern end, 8' north of the star cluster. A few weaker ones can be perceived right by the cluster's northern edge and in the fainter nebulosity east of it.

Observed with a 20-inch telescope, the hourglass itself is seen in the company of a ragged dark nebula, 20" west of it. Excellent seeing reveals a small dark dot in the southern half of the hourglass.

The apparent visual size of M 8 reaches 46'×32', when measured with 14 inches of aperture and maximum exit pupil (i.e., low power). With the use of an [OIII] filter, the nebula spreads from a nebulous patch near 7 Sagittarii to some very faint wisps and bands 20' east of the star cluster. The third dark nebula in this field, B 296, becomes visible as a dark bay in the nebula, 10' south of the star cluster.

Two double stars can be found in M 8. Burnham 1126 has components of magnitude 8.8 and 9.6. Its separation of only 0.6" (PA 55°) is a challenge for large telescopes. By contrast, h 5010, with a 3.6" separation (PA 94°) and two stars of magnitudes 9.6 and 10.0, is resolved by smaller telescopes. In addition, there are a lot of variables in M 8, many with as yet unknown properties.

IC 4678 is a small nebula about 35' northeast of NGC 6530, around an 8th magnitude star. It appears blue in color photos, and slightly elongated in northeast-southwest direction when seen with a 14-inch telescope – a nice example of a reflection nebula.

M 9

Degree of difficulty	3 (of 5)
Minimum aperture	30mm
Designation	NGC 6333
Type	Globular cluster
Class	VIII
Distance	46,090 ly (RR Lyr, 1999)
Size	150 ly
Constellation	Ophiuchus
R.A.	17^h 19.2^{min}
Decl.	–18° 31'
Magnitude	7.6
Surface brightness	–
Apparent diameter	11'
Discoverer	Messier, 1764

History

Charles Messier discovered M 9 on the 28th of May 1764, as a “nebula without star” and added: “it is round & its light faint, 3’ diameter.” Exactly 20 years later, William Herschel reported that this object was actually a very rich star cluster. In the 1830s, Admiral Smyth observed M 9 in more detail and noted: “This fine object is composed of a myriad of minute stars, clustering into a blaze in the center, and wonderfully aggregated, with numerous outliers seen by glimpses.” Lord Rosse remarked: “The outline not round; on south side is an outlying portion separated from the chief portion by a dark passage.” The German observer Heinrich d’Arrest, by contrast, believed he saw an “almost double-core cluster” and noted an elongation in the north-south direction.

In 1918, Curtis remarked that M 9 maintained the relatively small diameter of 3’ on photographic plates. But modern studies, based on much deeper exposures, have almost quadrupled this number.

Astrophysics

M 9 has a distance of about 14,000 light-years from the galactic center, situated on its far side, just beyond the galactic bulge. The distance to us is 46,000 light-years, and its diameter of 150 light-years is quite average, as is its total mass of about 300,000 solar masses.

Because of its position behind the fields of dusty interstellar clouds in Ophiuchus, M 9 suffers from about one magnitude of interstellar absorption, in particular in its northern and western parts. Also, according to Shapley, M 9 did not appear exactly spherical, he rather regarded it as slightly elliptical (0.9).

The brightest individual star of M 9 reaches magnitude 13.5, the mean magnitude of the 25 brightest cluster members is 15.5. 16 RR Lyrae stars have been cataloged for M 9, and two other variables, one of which is a type II cepheid.

Observation

M 9 is seen as a distinct but very small spot with 10×50 binoculars. A small telescope also shows a small nebulous ball of only 3’, which has an almost star-like center. Individual cluster stars are not resolved, until an aperture of at least 6 inches is used. Worth mentioning is a pair of 10th magnitude stars just south of M 9.

Larger apertures show M 9 as a compact but well-resolved globular cluster. The central region measures about 2’, outskirts can be traced to a size of 4’. An asymmetry can be noticed in terms of an elongated (in northeast-southwest direction) region in the northwestern part of the cluster, separated from its core by a dark band. However, no trace is seen of a general elongation in PA 110°, as reported by Skiff and Luginbuhl.

There are two smaller globular clusters in the immediate neighborhood of M 9: NGC 6356, 1° northeast, and NGC 6342, 1° southeast. Both objects are visible as small round nebulae even with a 2.5-inch refractor. The beginning of resolution into individual stars, however, requires an aperture of 14 inches. The dark cloud B 64 lies directly west of M 9, its outskirts partially covering the globular cluster. B 64 can be well seen with 10×50 binoculars: it is a 25’×15’, peanut-shaped object with a dark “head” northwest.

M 9. The distance to this globular cluster is equal to the radius of our Galaxy. Bernd Flach-Wilken.

M 10. Old, yellow giant stars dominate the globular cluster. Daniel Verschatse.

M 10

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 6254
Type	Globular cluster
Class	VII
Distance	24,750 ly (Hipparcos, 2001)
Size	140 ly
Constellation	Ophiuchus
R.A.	$16^h\ 57.1^{min}$
Decl.	–4° 6'
Magnitude	6.6
Surface brightness	–
Apparent diameter	19'
Discoverer	Messier, 1764

History

Charles Messier discovered M 10 on the 29th of May 1764, just a night after its fainter neighbor M 9, and a night before he found its close neighbor M 12. He observed "a nebula without star" and added: "This nebula is beautiful & round; one can see it only with difficulty in a simple refractor of 3 ft. 4' diameter."

20 years later, William Herschel's telescope showed "A very beautiful, and extremely compressed, cluster of stars" and no trace of nebulosity. Herschel compared M 10 with M 53. His son John wrote in 1831: "A superb cluster of very compressed stars, gradually brighter toward the middle. The stars are of 10th to 15th magnitude, and run up to a blaze in the center, but I see no nucleus. Diameter about 6'; a noble object."

Admiral Smyth used a 5.9-inch refractor and saw a "rich globular cluster of compressed stars. This noble phenomenon is of a lucid white tint, somewhat attenuated at the margin, and clustering to a blaze in the center. Easily resolved with medium magnification." Lord Rosse reported, after his observation with his giant telescope: "A dark lane above the center quite across, or rather the upper one-sixth of cluster is much fainter than the rest."

The description of Curtis, based on his photographs, says: "Fine bright globular cluster, diameter about 8'. Central brighter part about 2'."

Astrophysics

With a distance of 24,750 light-years, M 10 is a little farther away than its close neighbor M 12, and its true diameter of 140 light-years is larger than the latter's.

With about 250,000 solar masses, M 10 is a rather average globular cluster. Its stars are metal-poor, which distinguishes them from the surrounding, younger stars of the Milky Way, with which the cluster seems to move on a similar orbit that keeps it within the inner halo.

The mean magnitude of the 25 brightest stars is magnitude 14.1. Among these, a hot, blue star of 13th magnitude stands out, which seems to have just finished its evolution as a cool, bright giant and is now starting to expose its hot core. Currently, only four variables are confirmed in M 10, two of which are type II cepheids.

Detailed dynamic models for M 10 predict a "core collapse" within the next 10 thousand million years, which will create an extremely high star density in its very center, as much as some hundred thousand stars per cubic light-year. This has already happenend to a few globular clusters (see M 15). After such a collapse, the cluster dynamics must find a new equilibrium, and many models predict an expansion that would include the outer core regions.

Observation

Contrary to its apparent 'twin' M 12, M 10 can be seen by unaided eyes under pristine mountain skies. It is easily visible as a nebulous spot in modest 30mm binoculars.

The first individual stars are resolved with a 3-inch refractor. With 4.7 inches of aperture, the globular cluster appears fully resolved, but a nebulous background remains. It is perfectly spherical, has a dense center and an apparent diameter of 10', and it looks more compact than M 12.

Larger telescopes show an extended halo 15' in size around a denser central region of 4'. In the outskirts, some cluster stars form chains that have a tangential rather than radial orientation. This may give a subtle visual impression of spiral structure. However, the dark zone south of the center of M 10, as reported by Lord Rosse, remains doubtful.

M 12 lies about 3° northwest of M 10. This more open globular cluster is, on close inspection, not quite a twin of M 10.

M 11

The Wild Duck Cluster

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 6705
Type	Open cluster
Class	II2r
Distance	6120 ly (K2005) 6120 ly (proper motion, 2002) 5420 ly (proper motion, 1997)
Size	23 ly
Constellation	Scutum
R.A.	18^h 51.1^{min}
Decl.	–6° 16'
Magnitude	5.8
Surface brightness	–
Apparent diameter	13'
Discoverer	Kirch, 1681

With over 2900 member stars, this is one of the richest open clusters in the Messier catalog. Robert Gendler.

History

M 11 was discovered in Leipzig, Germany, by Gottfried Kirch on the 1st of September 1681, with his "tubus opticus" of four feet focal length. He described his find as "a nebulous star" and likened it to the core of a comet. Subsequent observers referred to this object as "Kirch's Nebula." So did Halley in 1715, who saw M 11 as "a small obscure spot, but has a star that shines through it, which makes it the more luminous." In 1733, William Derham was the first person to resolve M 11 into individual stars, using a reflector with an eight-foot focal length. A few years later, de Chéseaux independently came to the same result; he noted a diameter of 4.1'.

On the 10th of October 1749, le Gentil pointed his telescope towards M 11 and mainly confirmed the above observations. In addition, he observed "a remarkable cluster of very small stars, a whitish cloud which apparently is just a star cluster. The northern part contains a real nebula, which, I presume, is that of Mr. Kirch. It is poorly constrained on its western side, which creates a certain similarity with the tail of a comet."

Charles Messier targeted this well-observed object on the 30th of May 1764, and he noted: "Cluster of a great number of small stars, that one can only see with good instruments; with a simple refractor of three feet it resembles a Comet: this cluster is mingled with a faint light; in this cluster there is a star of 8th magnitude, 4' diameter." Finally, using a fine telescope of 5.5 inches aperture, William Herschel recognized that M 11, in fact, did not contain any nebulosity at all. He wrote: "11th magnitude stars divided into five or six groups noted independently." Furthermore, he was the first to recognize that this cluster can be seen with the naked eye.

John Herschel commented around 1830: "A beautiful irregularly round cluster 10' or 12' in diameter. The stars are all of 11th magnitude except one which is of 9th magnitude. Examined with high magnifiers; it is broken into five or six distinct groups with rifts or cracks between them." The description given by his contemporary Admiral Smyth became somewhat famous, as his expressed enthusiasm led to the now popular name for this cluster: "This object, which somewhat resembles a flight of wild ducks in shape, is a gathering of minute stars, with a prominent 8th-magnitude in the middle, and two following; but by all analogy these are decidedly between us and the cluster."

D'Arrest's description better resembles William Herschel's note. Observing from Copenhagen, the German astronomer saw a "wonderful cluster, which consists of uncountable stars. It does not have a regular shape, and in the telescope it appears as if it was composed of several groups." And finally, in 1918, after studying photographs of this cluster, Curtis correctly commented: "bright, rather open cluster, 6' in diameter. Not globular."

Astrophysics

M 11 is considered one of the richest and most compact galactic clusters. As seen from its center, the night sky would be filled with several hundred stars as bright as 1st magnitude, which would all have distances of about a light-year or less. The mean density of 2.4 stars per cubic light-year resembles that of a globular cluster of class X.

A total of 2900 member stars have been attributed to M 11, of which 870 are brighter than magnitude 16.5, and 500 brighter than

M 11 lies on the northern edge of the Scutum star cloud, one of the richest Milky Way regions. Stefan Heutz.

14th magnitude. A recent Chinese study finds 547 stars down to magnitude 15.5b within a 25' field.

The brightest star by far stands out from the rest of the cluster, as its magnitude 8.0 contrasts with the magnitude of 10 of the next-brightest stars. According to Brian Skiff, it does not belong to the 30 or so red giants in M 11. However it remains unclear whether the blue variable BS Scuti (magnitude 11.0–12.4), 15' to the east, is actually a physical cluster member. The age of M 11 is, according to Sung et al., about 250 million years.

The distance, quoted as 6120 light-years, places M 11 in the Sagittarius spiral arm of the Milky Way, much like M 16 and M 17 further south. The physical diameter of the visible cluster, seen as 13' in the sky, is 23 light-years. Including the extensions observed by Sung et al. spanning 32', M 11 reaches a total size of 60 light-years.

Observation

M 11 is quite hard to spot with the naked eye. This is due to its position in the Milky Way, on the northern edge of the prominent Scutum star cloud, which creates a bright background. Binoculars show a nebulous patch with one star, just like Halley's description from 300 years ago.

This view changes dramatically when a 2-inch refractor is used. From a magnification of 90× upward, it begins to resolve the nebula into numerous stars. 2.5 inches of aperture show about 100 of them, plus a prominent pair of 9th-magnitude stars outside (southeast) of the cluster.

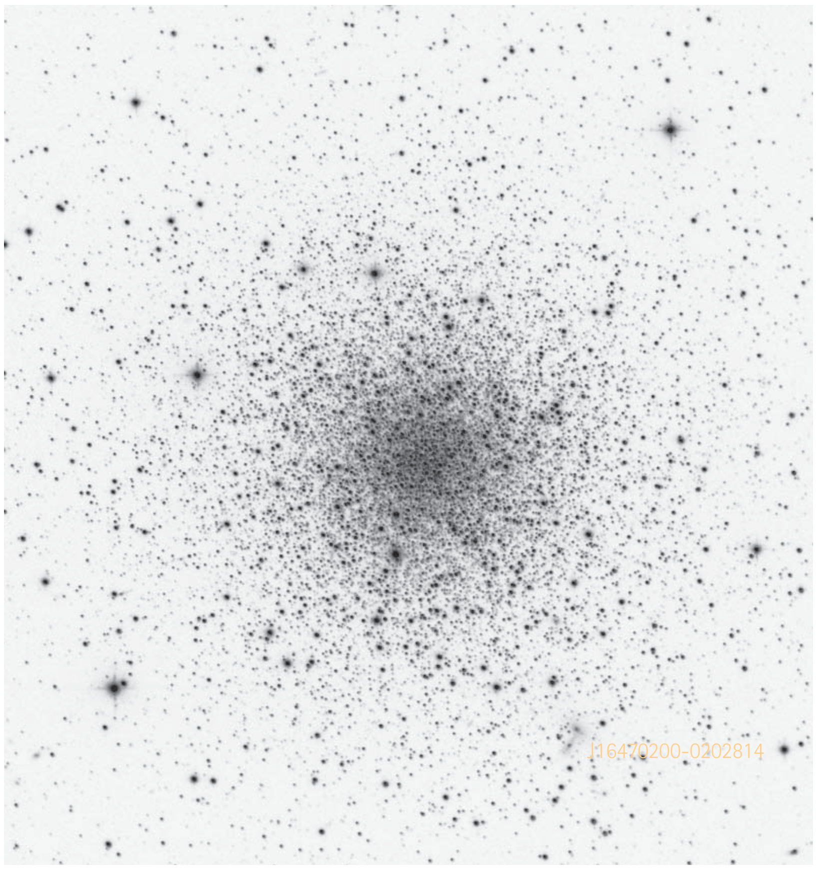
A 4.7-inch refractor reveals about 400 cluster stars, vividly packed into a diameter of only 7'. The general cluster shape is a little triangular, pointed towards the northwest. Much more imagination is required to see Smyth's V-shaped formation of flying ducks. The outstandingly bright star appears of orange color to some observers, but it actually has spectral type A.

Larger apertures show more and more stars, as well as the less star-rich extensions of M 11. This brings the total visual cluster diameter to about 15', but the triangular impression gets more and more lost.

The variable star R Scuti lies 1° northwest of M 11. Its brightness changes semi-regularly with a period of 143 days, between magnitudes 4.8 and 6.0. Nearby is the southwest edge of the large dark cloud B 111, which defines the northern border of the Scutum star cloud. It misses the northwestern edge of M 11 by only a few arcminutes. B 111, as well as B 112 located south of M 11, are both nice objects for large binoculars. More difficult to observe is the elongated dark cloud B 318, south of M 11; a 14-inch telescope gives only a partial view of it.

M 12

Degree of difficulty	2 (of 5)
Minimum aperture	15mm
Designation	NGC 6218
Type	Globular cluster
Class	IX
Distance	20,760 ly (R2005) 20,880 ly (Hipparcos, 2001)
Size	85 ly
Constellation	Ophiuchus
R.A.	$16^{h}\ 47.2^{min}$
Decl.	–1° 57'
Magnitude	6.8
Surface brightness	–
Apparent diameter	14'
Discoverer	Messier, 1764



History

Charles Messier discovered M 12 on the 30th of May 1764. "This nebula does not contain any star, it is round & its light faint; near that nebula is a star of ninth magnitude; 3' diameter." In 1783, William Herschel was able to resolve this object into individual stars and called M 12 "a brilliant cluster, 7' or 8' in diameter; the most compressed parts about 2'." John Herschel, too, saw a "very rich globular cluster" and remarked: "has stragglers in lines and branches extending some distance from the most condensed part, which is 3' in diameter. Comes almost up to a blaze in the middle, has a star of 10th or 11th magnitude in the center." Retired Admiral Smyth saw "several very bright spots near the center" and noticed "a cortège of bright stars, and many minute straggling outliers." Lord Rosse even thought he could see some spiral structure in M 12.

The photographic description given by Curtis (1918) says: "Fine globular cluster; central part about 2'; outer about 8' in diameter. Apparently somewhat less compact than most globular clusters."

Astrophysics

M 12 appears almost as a twin of its close neighbor M 10, only a little smaller and fainter. Its class IX designates the small degree of concentration of this globular cluster.

The distance of 20,760 light-years is somewhat nearer than that of M 10. Hence, the true diameter of M 12, about 85 light-years, is even smaller than M 10, smaller than the relative appearance in the sky would suggest. The total mass of M 12 is estimated to be 200,000 times the Sun's.

M 12 is a globular cluster of the inner galactic halo. On its 130-million-year orbit, it never exceeds a distance of 20,000 light-years from the galactic center. Its current location is 2000 light-years above the galactic plane. For comparison: the Sun never deviates from the galactic plane by more than 250 light-years, and is currently placed only 50 light-years above it.

The very brightest stars in M 12 reach magnitude 12.0, the mean magnitude of the 25 brightest is 14.0p, and the horizontal branch starts at magnitude 14.9. Only five variables have been cataloged for M 12: two eclipsing binaries, two RR Lyrae stars, and one type II Cepheid.

Lehmann and Scholz measured the outermost diameter of M 12 including stars down to 20th magnitude and arrived at an impressive 30'. Buonanno (1976) suggested, based on structural and other similarities between M 12 and M 10, that both globular clusters might have been formed together and may still influence each other. Their current separation is about 5000 light-years.

Observation

M 12 cannot be seen with the naked eye, but even small binoculars show it as a nebulous spot. A 2.5-inch refractor at high magnification gives the round nebula a grainy appearance, and a 4.7-inch telescope resolves individual stars all over the nebulous background of the 5' cluster. A foreground star lies on the cluster's southeastern edge, another one only a cluster diameter northwest.

Larger apertures give the impression of a relatively open globular cluster with little concentration, and with a central region about 2.5' across. Including chains of stars and other extensions, M 12 reaches a total visual diameter of 10'.

M 12 is about 5000 light-years away from its neighbor in the sky, M 10. Rainer Sparenberg.

M 13

The Great Hercules Cluster

Degree of difficulty	1 (of 5)
Minimum aperture	Naked eye
Designation	NGC 6205
Type	Globular cluster
Class	V
Distance	25,890 ly (R2005) 24,530 ly (CMD, 1998)
Size	160 ly
Constellation	Hercules
R.A.	16^{h} 41.7^{min}
Decl.	+36° 28'
Magnitude	5.7
Surface brightness	–
Apparent diameter	21'
Discoverer	Halley, 1714

History

In 1714, Edmond Halley noticed, more or less by accident, a "nebulous patch" in the constellation of Hercules. A year later, he wrote up a list of the six nebulae then known to him (M 42, M 31, M 22, ω Cen, M 11, and M 13) and commented about the latter: "This is but a little patch, but it shows itself to the naked eye, when the sky is serene and the moon absent." Charles Messier observed M 13 on the 1st of June 1764, and noted: "Nebula without star, discovered in the girdle of Hercules; it is round & brilliant, the center brighter than the borders; it is near two stars, both of 8th magnitude, one of them above & the other below; 6' diameter."

It was left to William Herschel to recognize the true nature of this star cluster in 1784: "A most beautiful cluster of stars. It is exceedingly compressed in the middle and very rich. About 14,000 stars can be counted." 40 years later, John Herschel commented: "Very rich cluster; irregular figure; very large; very gradually much brighter toward the middle; stars from 10th to 15th magnitude, of which there must be thousands; does not come up to a nucleus; has hairy-looking curvilinear branches." This impression was shared by Lord Rosse, who pointed his large 72-inch mirror towards M 13: "singularly fringed appendages to the globular figure out into the surrounding space." His drawing shows a Y-shaped dark structure over the whole central region of the cluster. D'Arrest, too, saw "arm-shaped outliers" with a magnification of 95×.

100 years ago, Palmer counted, one-by-one, 5482 stars in M 13. Not much later, this number was radically revised upwards to 100,000 by Shapley, and Otto Struve taxed it to at least half a million. This corresponds to about half the number of cluster members estimated today.

Astrophysics

With its diameter of 160 light-years, the famous globular cluster M 13 is one of the largest examples of its kind, but at least M 15 and M 53 are, in fact, larger. M 13 probably does not exceed one million stars with a total of 600,000 solar masses. On its 500-million-year, eccentric orbit around the galactic center, it can get as far out as 80,000 light-years from the galactic center. Presently, M 13 has a distance from Earth of just 26,000 light-years.

The diameter of the cluster appears to be only a bit more than 10' when based solely on the distribution of stars brighter than magnitude 15, i.e., those which most amateur telescopes would show. However, studying automated star counts down to 20th magnitude, Lehmann and Schulz (1997) found a much larger diameter of 47.6' and a tidal tail of stars ripped away from M 13 by the galactic gravitational field.

The very brightest stars of M 13 reach a respectable magnitude of 11.9, which is, however, not as bright as those in M 22 or M 4. Furthermore, only 40 variables are known so far in M 13 – less than in most other globular clusters. At least nine of these are of the RR Lyrae type. In 1989, a pulsar with a period of only 10 milliseconds was discovered, which is not bound in a binary system.

In 1960, Roberts studied the probability of a chance formation of the areas in M 13 with an apparent deficit of stars. He favored, however, an explanation involving absorption by dark clouds. Their properties, would have to be much different from other, well-known dark clouds, as pointed out by Dickman et al. These authors concluded that there are real local stellar density deficits in M 13, especially in the numbers of red giants, which dominate the visual impression.

Observation

As mentioned by Halley, it is possible to spot M13 with the naked eye on a sufficiently clear, dark and moonless night. The visual limiting magnitude required to see the magnitude-5.7 cluster (other sources give it between 5.3 and 5.9) is 6.0.

Binoculars show a nebulous patch, flanked by two 7th-magnitude stars to the east and southwest. Resolution of the cluster into individual stars starts with 2.5 inches of aperture, which makes the outer zones appear grainy. Slightly larger telescopes deliver a firm perception of individual stars.

A 4.7-inch refractor shows a large, round and very bright nebula with an extended, bright central region. Many individual stars are now resolved. In the outskirts of the globular cluster, they appear grouped into irregular extensions. The visual extent of M 13 reaches 8'.

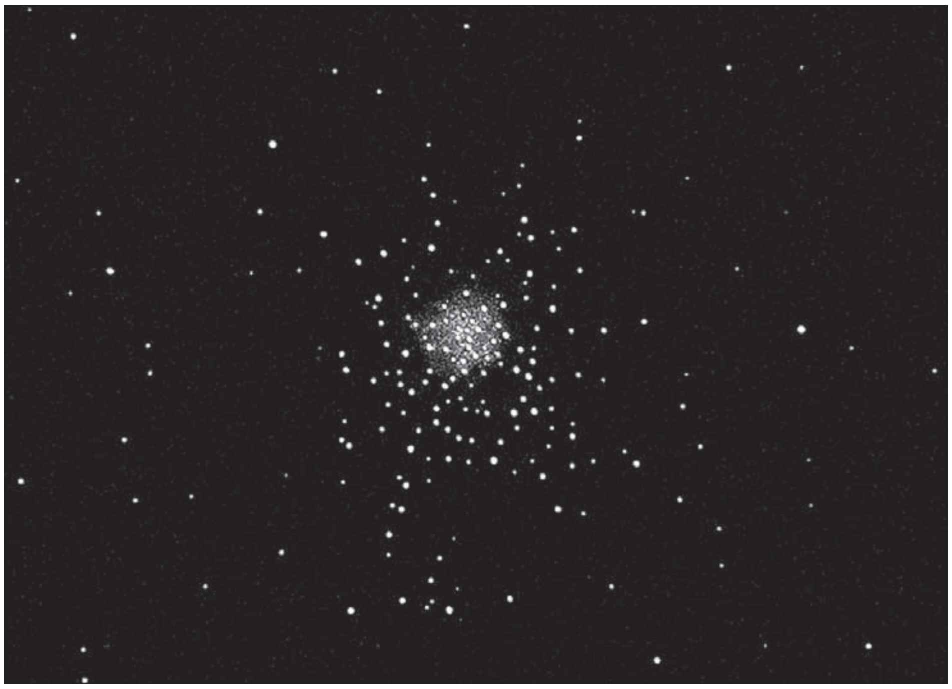
Larger apertures show individual stars everywhere, including in the bright glow of the central region. With a 14-inch telescope, the individually visible stars seem to be arranged in two curved strands, which stand out in this cluster with its otherwise rather open appea-

M 13 is regarded as the most impressive globular cluster by observers in northern latitudes. Stefan Binnewies.

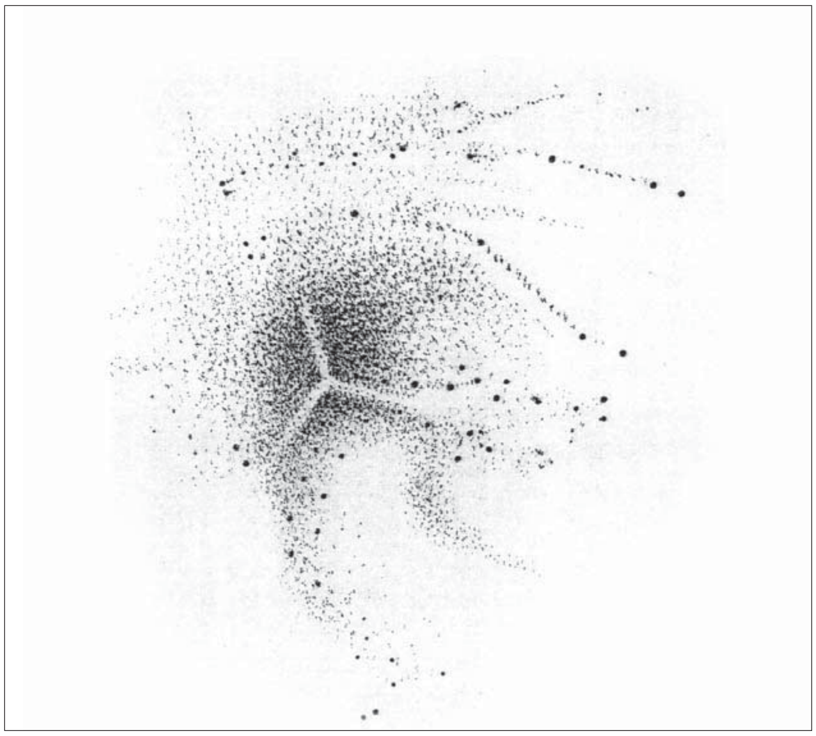
M 13. Dark lanes are interlaced with the glow of this globular cluster. Bernd Liebscher.

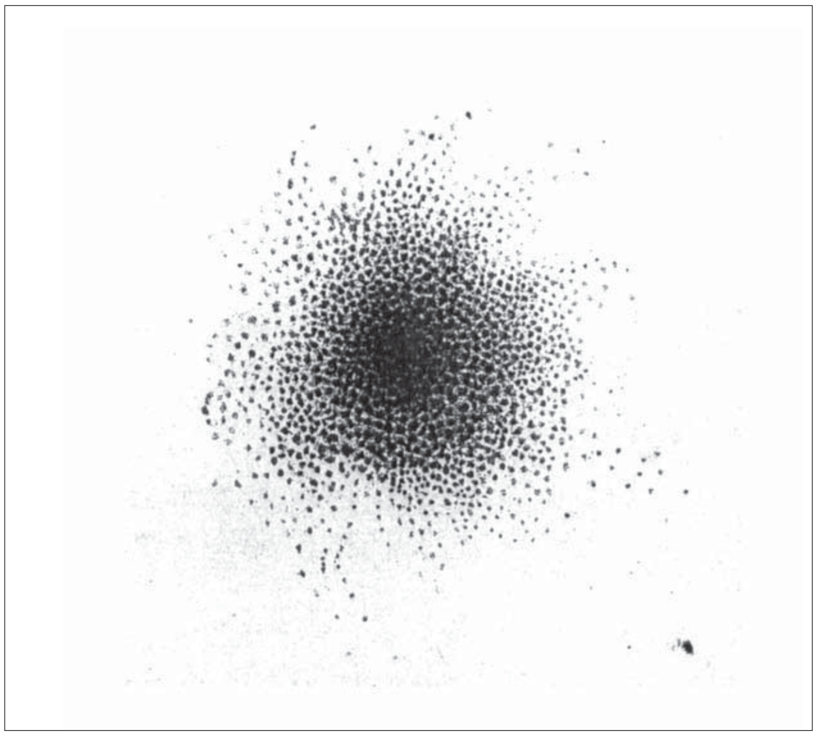
rance. The degree of central concentration is relatively low, and the central region takes on a rather large size of 5'. Visibility of the dark features, which have been described by many observers, depends a lot on the telescope and magnification used. The Y-shaped feature, turned on its side as first described by Lord Rosse, can be perceived vaguely. Many photographs show at least the left branch of this Y as an elongated, darker feature in the southeastern part of the cluster.

The small background galaxy IC 4617 lies 15' north of M 13. Despite its meager brightness of only magnitude 15.5, it is quite an easy object for a 14-inch telescope. It appears as a small elongated dot with two faint stars to its east. A move of 40' in that same direction finds the bright magnitude-11 galaxy NGC 6207, which can even be seen with a 4-inch telescope.



M 13, historical drawing. Léopold Trouvelot (1877).





M 13, historical drawings. Bindon Stoney and Lord Rosse (1851), John Herschel (before 1833).

M 14

Degree of difficulty	3 (of 5)
Minimum aperture	30mm
Designation	NGC 6402
Type	Globular cluster
Class	VIII
Distance	55,620 ly (R2005)
Size	180 ly
Constellation	Ophiuchus
R.A.	17^h 37.6^{min}
Decl.	–3° 15'
Magnitude	7.6
Surface brightness	–
Apparent diameter	11'
Discoverer	Messier, 1764

History

M 14 was discovered by Charles Messier on the 1st of June 1764, within days of finding its neighbors and fellow globular clusters M 9, M 10, and M 12. Messier wrote: "Nebula without star; the nebula is not large, its light is faint, it is round. Near it is a small star of the 9th magnitude; 7' diameter." By contrast, 19 years later, William Herschel found M 14 "extremely bright, easily resolvable" and wrote: "With 300× I can see the stars. The cluster is considerably behind the scattered stars, as some of them are projected upon it." For John Herschel, too, M 14 was "a striking object." In 1833 he noted: "Very large; 8' or 10' diameter; the stars so excessively minute as to be scarcely discernible." Admiral Smyth described a "lucid white color." Heinrich d'Arrest saw M 14 as "elegant, comet-like, almost round, irregularly terminated, resolved with 226×."

Astrophysics

While M 14 appears over a magnitude fainter than its neighbors M 10 and M 12, and is on a par with M 9, it is in fact the most luminous of these four globular clusters in Ophiuchus, in absolute terms. M 14 suffers as much as two magnitudes of extinction due to its much greater distance and interstellar absorption by dust in the Milky Way. This puts its brightest stars at magnitude 14 instead of 12, as with M 10 and M 12. With an estimated 1.2 million solar masses, M 14 exceeds its neighbors by a considerable factor.

The distance of M 14 is still debated. Until recently, it was given as about 25,000 light-years, much like its two brighter neighbors. But the Recio-Blanco catalog (2005) now puts it at over 55,000 light-years. That distance implies a large physical diameter of 180 light-years. The stars of this cluster are metal-poor. Among the 68 known variables, there are 55 RR Lyrae stars, which are typical for globular clusters, and 5 of them are type II cepheids.

In 1938, a nova appeared in M 14. However, it escaped discovery until 1964, when a collection of photographic plates covering the period from 1932 to 1963 was studied. The nova appeared on eight plates, between the 21st and 28th of June, as a star of 16th magnitude. It is only the second classical nova in a globular cluster caught on photographic plates (see M 80). No unambiguous identification of the present-day star has been achieved, not even with the Hubble Space Telescope.

Observation

Although shown as a nebulous spot even by small binoculars, M 14 remains just an unresolved, but perhaps grainy, 3' nebula when observed through a small telescope.

From 8 inches of aperture upwards, and beginning with the outer zones, resolution of individual stars is achieved. M 14 appears slightly elongated in the east-west direction. The number of individually visible cluster stars stays fairly low even in large telescopes. Irregular chains of stars reach northeast and southwest, while the central region appears grainy or mottled, but unresolved. A vaguely darker region marks the southeastern side of the central region, which has a diameter of about 4'. It is surrounded by a halo of stars of 8' diameter.

M 14 is among the more distant globular clusters in the Messier catalog. Due to interstellar dust, the brightness of its stars is reduced by significant absorption. Daniel Verschatse.

M 15

Degree of difficulty	1 (of 5)
Minimum aperture	Naked eye
Designation	NGC 7078
Type	Globular cluster
Class	IV
Distance	39,010 ly (R2005) 32,560 ly (proper motion, 2004) 38,510 ly (RR Lyr, 2001)
Size	200 ly
Constellation	Pegasus
R.A.	21^h 30.0^{min}
Decl.	+12° 10'
Magnitude	6.0
Surface brightness	–
Apparent diameter	18'
Discoverer	Maraldi, 1746

M 15. The planetary nebula Pease 1 is clearly visible, northeast of the core region, in this detailed image. Hubble Space Telescope.

History

M 15 was discovered on the 7th of September 1746, by the French astronomer Jean-Dominique Maraldi. He described the object as "a quite bright, nebulous star, which is composed of many stars." Although Maraldi had already resolved individual stars, Messier's observing report of the 3rd of June 1764 reads: "Nebula without star; it is round, the center of it is brilliant, 3' diameter." It appears that Messier's telescope was considerably inferior to the one Maraldi was using 20 years before.

In 1783, William Herschel also resolved individual stars in M 15, which he considered a good test object. His son John commented: "A magnificent globular cluster; comes up to a perfect blaze in the center, like a protuberance or nipple; not the condensation of a homogeneous globe; it has straggling streams of stars, as it were, drawing to a center. It is not round." D'Arrest, too, saw an asymmetry and wrote: "Most magnificent cluster, very bright, with beautiful arm-like extensions apparent. The nucleus is eccentric, being displaced to the east." Buffham reported a dark patch near the center and two dark, weak lanes.

In 1918, Curtis summarized the photographic appearance of M 15 with the words: "A bright and unusually beautiful globular cluster, 8' diameter."

Astrophysics

M 15 is a large globular cluster in the intermediate galactic halo. Its orbit, which is inclined to the galactic plane by 40°, takes 250 million years to complete. Presently, M 15 is 39,000 light-years away from us, from which a physical diameter of 200 light-years can be deduced.

M 15 has at least 450,000 solar masses. Its brightest red giants reach magnitude 12.6, corresponding to 1000 solar luminosities. This globular is populated by a large number of variable stars. Among the at least 180 registered cases, there is one type II cepheid, and eight pulsars – remnants of past supernovae. Presumably, PSR 2127+11C is part of a neutron star binary and it shows effects of relativistic kinematics in a strong gravitational field: perihelion motion, deflection of light, and energy losses by gravitational radiation. The supposed optical counterpart is a blue variable of about 15th magnitude. At its position, White and Angelini (2001) discovered two bright X-ray sources with only 2.7" separation, which are interpreted as a massive binary.

In very high resolution images, M 15 shows an extraordinarily dense center with more than 30 stars per square arcsecond! This indicates that the core region of the globular has already suffered a dynamical collapse (a "core-collapse"). In this rapid process, ever closer stellar encounters gather more and more stars in the very center, and the mutual distances are reduced to solar system size, i.e. they can be as small as the distance between the Sun and Pluto! Some authors have even been suggesting a black hole of up to 1000 solar masses in the center of M 15. But Hubble Space Telescope images support the core-collapse scenario instead, according to which the rest of the globular cluster is now in an expanding phase (see M 10). However, theoretical studies and the observed stellar kinematics can not entirely rule out the black hole hypothesis.

M 15 has become famous for its planetary nebula, which was cataloged by Küstner in 1921 as a magnitude 13.8 star. Undertaking spectroscopic observations at the Mount Wilson Observatory in 1928, Pease finally recognized the true nature of this object, which is the

M 15 contains 8 pulsars and more than 130 variables. Planetary nebula Pease 1 is marked. Stefan Binnewies, Josef Pöpsel.

best example of the very few planetary nebulae that have been found in globular clusters. Its popular name is Pease 1; the catalog designation is PK 65–27.1. Older observations of the nebula suggest a brightness of magnitude 14.6 and an angular diameter of 3". But recent Hubble Space Telescope pictures yield a larger size. The very hot and young central star of magnitude 15.0 has a temperature of 40,000 K and about 0.6 solar masses. Pease 1 is only about 4200 years old and reaches a physical diameter of 0.6 light-years. In total, the HST-image from 1994 covers 28 light-years at the distance of M 15.

Observation

M 15 can be spotted with the naked eye, and appears like a difficult double star with a 6th-magnitude star only 20' to its east. 10×50 binoculars show a bright, nebulous ball. M15 and its equally bright stellar neighbor now show nicely contrasting extended and point sources of light, respectively.

Resolution of individual cluster stars near the edge of M 15 begins with a 2.5-inch refractor, and full resolution of the globular cluster is achieved with 4.7 inches of aperture, since the brightest stars reach magnitude 12.6. The visual extent of the cluster appears to be 6'. M 15 remains nebulous in the bright compact center that makes it one of the most attractive globular clusters for visual observation.

A 14-inch telescope doubles the visual extent to 12'. The nebulous, irregular central region has a size of 1'. Any perception of its asymmetry, as reported by historic observers, remains ambiguous.

Pease 1 is found near the edge of the core region, 1.5' north of the center. At 14th magnitude, it appears quite bright in a 14-inch telescope, but high magnification, good seeing, and knowledge of its exact location are required to spot the planetary nebula among the densely packed stars of similar brightness around it. Rapid swaps ("blinking") with an [OIII] filter help with its identification.

M 16

with the Eagle Nebula

Degree of difficulty	1 (of 5)
Minimum aperture	Naked eye
Designation	NGC 6611
Type	Open cluster
Class	II3mn
Distance	5600 ly (K2005) 7500 ly (1999)
Size	35 ly
Constellation	Serpens
R.A.	$18^h\ 18.8^{min}$
Decl.	–13° 47'
Magnitude	6.0
Surface brightness	–
Apparent diameter	21'
Discoverer	de Chéseaux, 1746

History

M 16 was discovered as a star cluster in 1745 or 1746, by the Swiss observer Philippe Loys de Chéseaux. Charles Messier independently discovered this object on the 3rd of June 1764, since he had no concrete knowledge of Chéseaux's observation. Messier saw a "Cluster of small stars, mingled with a faint glow. In a weak telescope this cluster appears in a nebular form. 8' diameter." However, what he saw was not the nebula around the cluster, but the diffuse light of unresolved cluster stars. Later visual observers did not notice the nebula either, despite considerably larger telescopes. Its discovery was left to Barnard (1895) and Roberts (1897), who independently found it on their photographs. The nebula received the separate identification IC 4703.

John Herschel, in the mid-ninetheenth century, saw "at least 100 large and small stars" in M 16. Admiral Smyth described this object as "a scattered but fine large stellar cluster. As the stars are disposed in numerous pairs among the evanescent points of more minute components, it forms a very pretty object in a telescope of tolerable capacity."

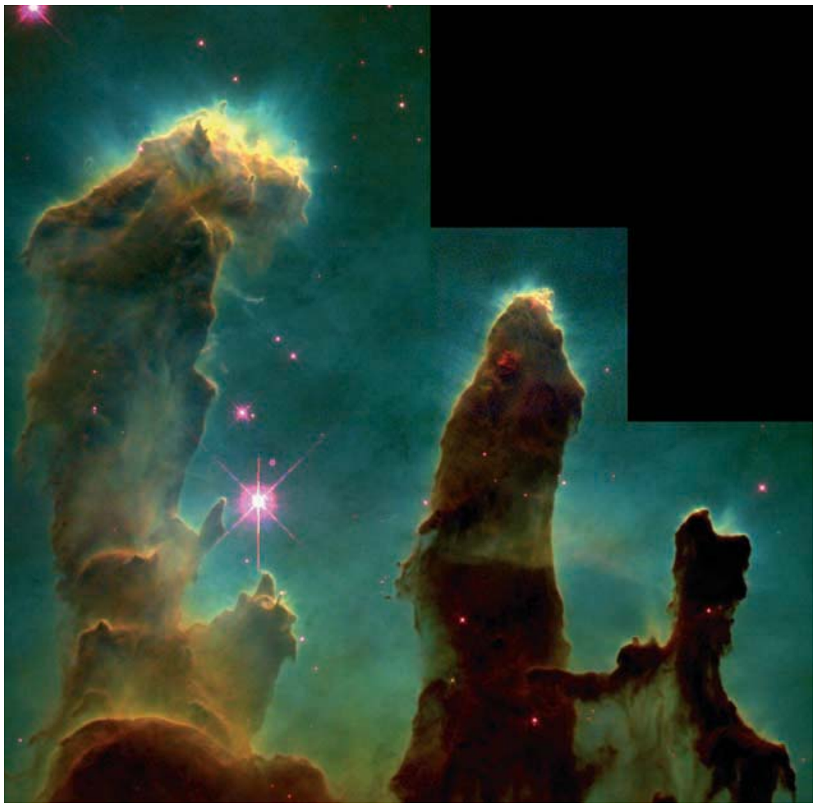
Astrophysics

M 16 is one of the most luminous and youngest open clusters in the Messier catalog. 376 member stars are tightly packed into a 15' patch. The brightest of these has magnitude 8.2, and an additional 13 stars are brighter than 10th magnitude. M 16 has more hot stars of spectral type O than any other Messier cluster. The oldest M 16 stars are only 6 million years of age, most are as young as 1 to 2 million years old.

In fact, M 16 would be a lot more impressive if it did not suffer from a significant interstellar absorption of 3.1 magnitudes, caused by the dark dust clouds of the "Great Rift," which obstruct it, only a few hundred light-years from us. This absorption hampers large parts of the Serpens OB1 association of young stars further north, to which M 16 belongs.

Duchene et al. (2001) studied the 60 brightest O stars of M 16 and found that 18% of them belong to close binary systems. Furthermore, they found over 50 stars in a circular region around the cluster which are variable, most of them weak T Tauri stars of 17th magnitude or fainter.

Star formation continues in dark "elephant trunks" in M 16. These have been formed by the interaction of the massive, UV-bright stars and their nebulous environment, carved out by "photo-evaporation." A 1995 Hubble Space Telescope photo of three of these "pillars of creation" in the very core of the Eagle nebula may have become one of the most popular astronomical photos of all, due to their majestic appearance. The dark trunks or pillars are each about one light-year long and contain some very small, ultra-compact, dusty molecular



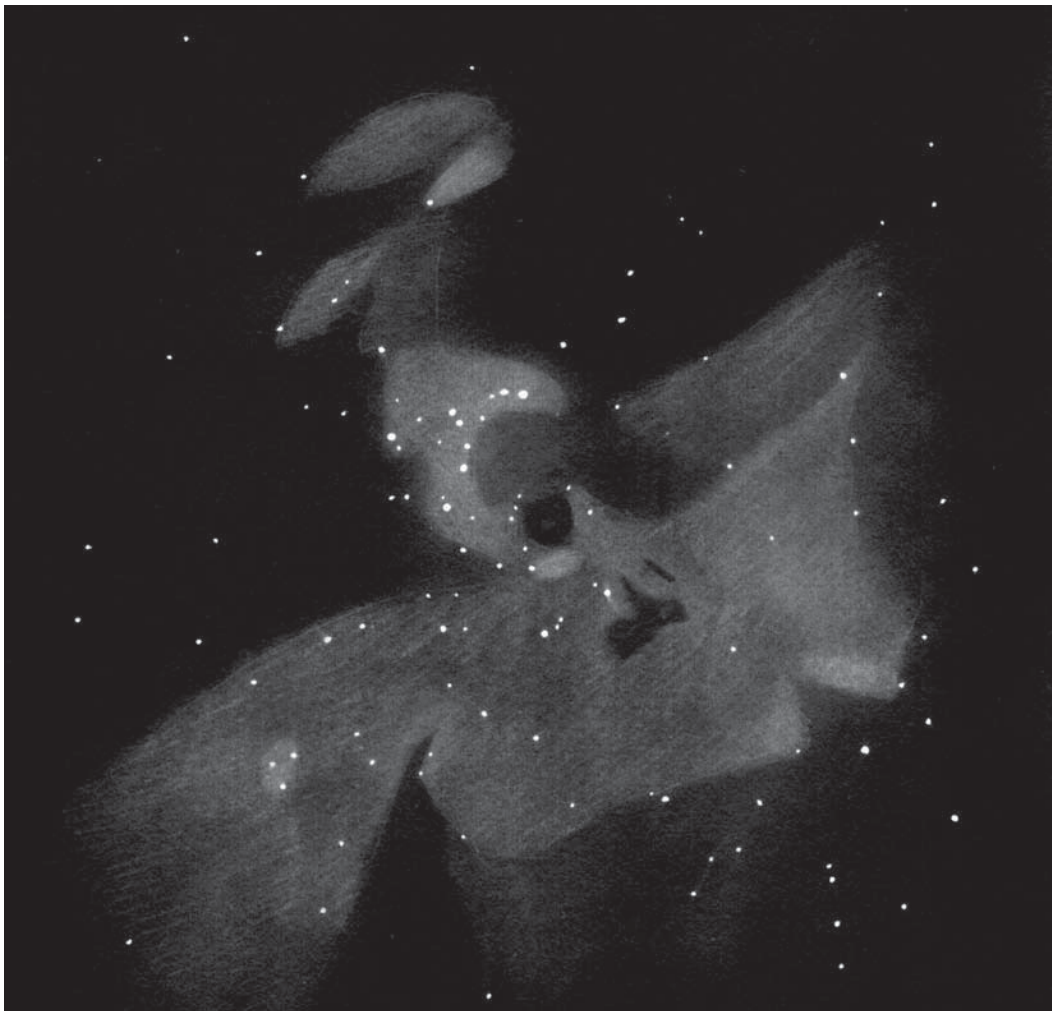
M 16. The "Elephant Trunks" hide infant stars. Singly ionized oxygen is shown in red, doubly ionized oxygen blue, and hydrogen green. Hubble Space Telescope.

M 16. This detailed image shows the "Elephant Trunks" in full. Rainer Sparenberg, Stefan Binnewies.

M 16 consists of the bright star cluster NGC 6611 and the emission nebula IC 4703. Bernd Flach-Wilken, Volker Wendel.

clouds ("EGGs," see also M20), not much larger than the Solar System, in which stars are in their final stages of formation.

M 16 has a distance of about 5600 light-years and a physical diameter of about 35 light-years. The surrounding nebula IC 4703 can photographically be detected to a size of up to 35'×28', which corresponds to a physical size of 60×45 light-years.



M 16, drawing. 20-inch Newtonian. Ronald Stoyan.

Observation

The star cluster of M 16 is quite recognizable to the naked eye, since it is near the edge of the dark, central band of the Milky Way. Binoculars resolve the brightest stars, about a dozen or so on an unresolved milky background of fainter cluster members. A nebula filter, held between the eyepiece and the eye, even reveals some of the emission nebula as a glow in the outskirts of M 16.

A 3-inch telescope shows about 25 stars, which include a bright pair of magnitude 8.2 and 8.8 components separated by 27" (PA 350°) near the western edge of the 5' star cluster. The emission nebula becomes quite distinct, when a narrow-band filter is used. Its outskirts are poorly defined, but they may reach a visual size of 15'×7'. The brightest nebulosity is inside the star cluster and south of it.

Despite its fairly low surface brightness, the nebula becomes the most interesting part when observing with a 14-inch telescope. The eagle shape is now distinctly visible, with the head (7'×4') facing northwest and the body (35'×10') oriented northeast-southwest. A triangular dark nebula of 5'×4' above the northeastern shoulder emphasizes this figure, while the outer wings of the eagle remain faint even with the use of a nebula filter. Finally, a nebulous extension off the "beak" of the eagle may be of interest to the observer. The star cluster features about 50 members and an apparent size of 12' in a 14-inch telescope.

The famous dark absorption cloud in the center of M 16, which consists of two dark pillars, appears vaguely with apertures of 8 inches. In the 14-inch telescope with a magnification of 200×, it is seen without difficulty as a well-defined, divided object 2'×1' in size with a 1'-long, dark finger pointing northwest. The brighter and larger pillar in the northwest, easily visible in photographs, cannot be recognized by the visual observer, but the two foreground stars to its sides can be seen. Additional dark markings are reserved for large apertures. A 20-inch telescope reveals a dark patch northwest of the dark pillars and a large dark structure 6' farther northwest.

M 17

The Omega or Swan Nebula

Degree of difficulty	1 (of 5)
Minimum aperture	Naked eye
Designation	NGC 6618
Type	Galactic nebula
Class	Emission nebula
Distance	5910 ly (K2005) 8160 ly (CMD, 2003)
Size	70 ly
Constellation	Sagittarius
R.A.	$18^h\ 20.8^{min}$
Decl.	−16° 11'
Magnitude	6.0
Surface brightness	21mag/arcsec^2
Apparent diameter	40'×30'
Discoverer	de Chéseaux, 1746

History

M 17 was found in 1745 or 1746 by the Swiss observer Philippe Loys de Chéseaux. He described his discovery: "It has perfectly the shape of a ray, or of a comet tail, of 7' length and 2' width, its sides are exactly parallel and quite well defined, much like its ends. The middle is whiter than the edges."

Charles Messier did not know of de Chéseaux's note, because it was not published in print. Hence, his first observation of M 17 on the 3rd of June 1764 was an independent discovery. He noted: "Train of light without stars, of 5' to 6' in size, in the shape of a spindle, & a little bit like that one in the girdle of Andromeda [M 31], but of a very faint light; there are two telescopic stars near & placed parallel to the Equator."

William Herschel saw much more, when he enthusiastically wrote in 1783: "A wonderful nebula. Very much extended, with a hook on the preceding side; the nebulosity of the milky kind; several stars visible in it, but they seem to have no connection with the nebula, which is far more distant. I saw it only through short intervals of flying clouds and haziness; but the extent of the light including the hook is above 10'." To Herschel, too, there was some resemblance to M 31. It took 100 years for it to become clear that M 17 is, in fact, an object within our Galaxy.

John Herschel studied M 17 in more detail. Two of his descriptions have been documented; in the first, he makes a remarkably accurate connection with M 42 and comments: "A most curious object, not unlike the nebula in Orion. There is in it a resolvable portion or knot distinctly separated from and insulated in the rest as if it had absorbed the nebula near it." His second description is the source of today's popular name, the Omega Nebula: "A large extended nebula. Its form is that of a Greek Omega with the left base-line turned upwards. The curved part is very faint, and has many stars in it. The preceding base-line hardly visible. The following, which is the principal branch, occupies nearly half the field. Its light is not equable, but blotty."

Smyth noted: "A magnificent, arched, and irresolvable luminosity occupies more than one third of the area, in a splendid group of stars." Chambers likened the shape to a "swan floating on the water," which led to the other popular name for M 17, the Swan Nebula.

Curtis' note of 1918 says: "The 'Horse Shoe' or 'Omega Nebula.' Very bright, very large nebulosity, showing a wealth of detail, filling an area about 26'×20'."

Astrophysics

M 17, the Omega nebula, is – much like M 42 – an active star-forming region. In a small 5'×5' area west of the swan's neck, a young cluster hardly one million years old with more than 8000 to 10,000 member stars lies mostly hidden inside the nebula. The core alone (2'×2') contains 750 stars. These very young objects have between 5 and 20 solar masses each, and nine very luminous cluster members of spectral type O must weigh about 60 solar masses. However their light has been extinguished by 30 magnitudes of absorption by the dust within the nebula, in addition to 1.8 magnitudes of interstellar extinction. Only five of these stars are visible at all. They are brighter than magnitude 14.2, two of them even brighter than 10th magnitude in visible light. The rest of this cluster can only be studied in infrared light, where the absorption by dust is less severe.

The large molecular cloud around and to the southwest of M 17 contains sufficient interstellar matter for another 10,000 stars of solar mass. M 17 is, according to Harper et al., one of the most luminous HII regions of all, with 560,000 solar luminosities. The nebula remains in part obscured, where dense, cold dust clouds prevail, but it is ionized and excited by the emerging young stars in other parts, which radiate strongly in Hα and other emission lines. The Hubble Space Telescope took images of part of the central region of M 17 in high resolution. A small inky black cloud stands out, only ten times the size of our Solar System. Here, star formation is ongoing.

With a distance of 5900 light-years, M 17 is located in the Sagittarius spiral arm of the Milky Way, much like its neighbor M 16. The pair may be separated in space by only about 300 light-years, if we can trust the distances to that precision. The bright and longish main body of M 17 measures 20 light-years, and counting the fainter extensions of up to 40' by 30', M 17 has a physical size of 70×50 light-years.

Observation

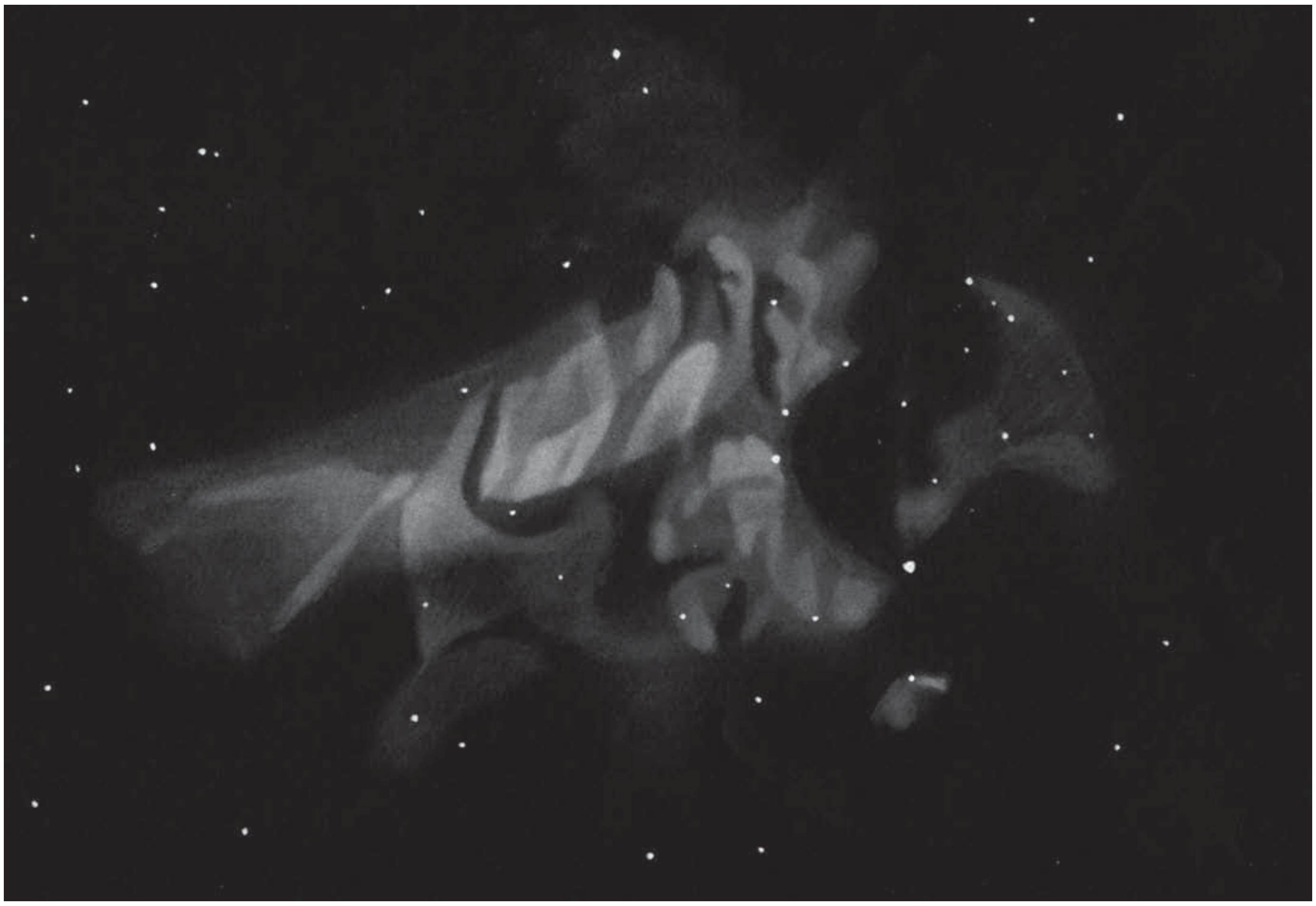
M 17 resembles a swan much more than the uppercase Greek letter omega (Ω). Nevertheless, the 'Omega Nebula' has prevailed as the popular nickname. Estimates of the total visual brightness range widely from magnitude 7.0 to 5.0. Considering the naked-eye visibility of M 17, the brighter end seems to be nearer to the truth.

10×50 binoculars show a nebulous band, which reminds us of the historic description by Messier. In a 2-inch telescope, this main part reaches a visual size of 6'×2'. Furthermore, a bunch of 8th- to 10th-magnitude stars north of the western end is noticed. However, visibility

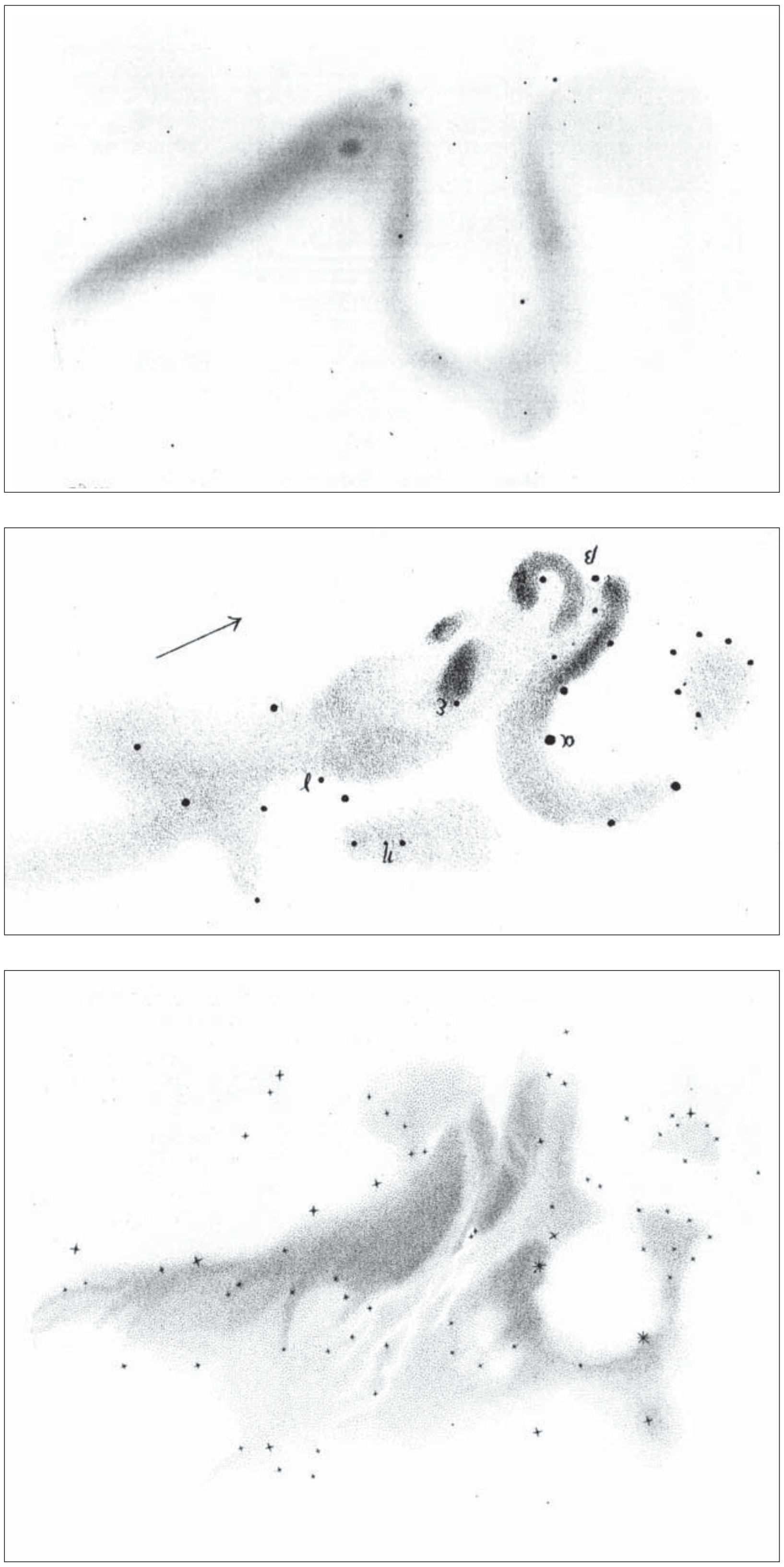
M 17, the Omega or Swan Nebula, is one of the most luminous galactic nebulae. The dark clouds southwest of it provide more "food" for star formation. Stefan Binnewies, Bernd Schröter.

M 17. The central region shows globules and "Elephant Trunks," typical of star-forming regions. Stefan Binnewies, Rainer Sparenberg.

M 17. This close-up shows details of the western end of the nebulous bar. Hubble Space Telescope.



M 17, drawing. 14-inch Newtonian. Ronald Stoyan.



M 17, historical drawings. John Herschel (before 1833), Lord Rosse (1854), William Lassell (1862).

M 17, historical drawing. Léopold Trouvelot (1875).

of the swan's neck, which bends south from the western end, requires the use of a nebula filter or larger aperture.

When observed with a 4.7-inch refractor, M 17 takes second place in the Messier catalog, after M 42, for richness in detail. Its bright bar is crossed by dark markings in the northeast-southwest direction, and it hosts four or five stars. The neck consists of individual patches. There is a bright 10th-magnitude star at the northwestern border of its brightest bit, and another at the tip of the head. The western extensions are difficult to see even with a narrowband filter. Hence, the shape of Herschel's omega remains difficult to perceive. A faint nebulous region about 10'×3' in size lies 13' south of the bright bar. It can be perceived as part of a curved extension from the central part. Another nebulous patch lies 9' northeast of the center of M 17, linked with the previous by a faint bridge of light. This brings the total visual extent as seen in a 4.7-inch telescope to 20'×15'.

In a 14-inch telescope, the outer regions of M 17 appear more distinct. Low-power wide-field views fill the field with impressive nebulosity spreading across 30'×20'. A dark fringe in the north is completely surrounded by faint nebulosity, and a dark wedge intrudes from the east.

The main body of M 17 shows fascinating detail and chaotic fine structure that is further emphasized with the use of a nebula filter. Dark elongated patches alternate with bright dots aplenty. The eastern end of the now 10'×2.5' bar forms two pointed stings. Further prominences from the back of the swan inspire a diabolic appearance. The swan's neck is almost detached from the rest of the nebula, and it is fragmented by dark structures in the east. Just 1' southwest of the neck's end, a 40"×30" nebulous spot nestled against a 12th-magnitude star hovers above the swan's head like a little crown. Herschel's omega shape remains fragmentary even in a 14-inch telescope, but the enclosed dark nebula is distinctly perceived.

The faint emission nebula IC 4706 can be found 15' northwest of M 17, separated by a dark lane. A diffuse nebula is seen in a 14-inch telescope, which surrounds two 9th-magnitude stars.

M 18

Degree of difficulty	3 (of 5)
Minimum aperture	30mm
Designation	NGC 6613
Type	Open cluster
Class	II3pn
Distance	4220 ly (K2005) 5170 ly (2002)
Size	6 ly
Constellation	Sagittarius
R.A.	$18^h\ 19.9^{min}$
Decl.	–17° 8'
Magnitude	6.9
Surface brightness	–
Apparent diameter	5'
Discoverer	Messier, 1764

M 18 is found between M 17 and M 24, in a neighborhood rich in nebulosity. Hermann von Eiff.

History

On the 3rd of June 1764, Charles Messier added M 18 to his list and noted: "Cluster of small stars; a bit below the nebula above, No. 17, surrounded by a slight nebulosity, this cluster is less apparent than the previous, No. 16; in a simple refractor of 3½ foot this cluster appears in the form of a nebula, but with a good refractor, one only sees small stars."

As the most inconspicuous star cluster in Messier's list, and with its close proximity to the spectacular objects M 17 and M 8, M 18 did not catch the attention of many observers. John Herschel wrote around 1840: "A poor and coarse cluster. Contains about a dozen stars 10th magnitude and 15 or 20 more 12th to 15th magnitude."

Astrophysics

At a distance of 4200 light-years, the little open star cluster M 18 is located on the near side of the Sagittarius spiral arm. Hence, it is closer to us than its neighbors in the sky, M 17 (5900 light-years) and M 16 (5600 light-years), which are on the far side of the same spiral arm, or NGC 6603 in M 24, much more distant at 10,000 light-years, which lies even further towards the galactic core in the Norma spiral arm. M 18 is dimmed by about 1.4 magnitudes of interstellar absorption.

Only about 40 stars are attributed to M 18. The brightest of them is a blue B2 star with magnitude 8.6. As the next brightest stars are also blue and hot, a relatively young cluster age of 50 million years has been deduced.

Observation

In binoculars, M 18 appears as a small, nebulous knot of stars. A 2.5-inch refractor shows about a dozen stars within a radius of 8'. The brightest cluster members are arranged in a triangular shape, that gives some observers the impression of a letter "S."

Larger telescopes show many fainter stars belonging to both the cluster and to the rich Milky Way background. Consequently, the outline of M 18 becomes ill defined. Also, it appears poorly concentrated and loses its charm with higher magnification.

The faint emission nebula IC 4701 (Sharpless 44) is found 1° northwest of M 18. A 14-inch telescope in combination with a narrowband filter shows only hints of a patchy, 60'×50' nebula.

M 19

Degree of difficulty	2 (of 5)
Minimum aperture	15mm
Designation	NGC 6273
Type	Globular cluster
Class	VIII
Distance	45,000 ly (RR Lyr, 1999)
Size	180 ly
Constellation	Ophiuchus
R.A.	$17^h\ 2.6^{min}$
Decl.	–26° 16'
Magnitude	6.7
Surface brightness	–
Apparent diameter	14'
Discoverer	Messier, 1764

History

M 19 was discovered by Charles Messier on the 5th of June 1764, as a "nebula without stars." Messier noted: "This nebula is round, it is seen very well in a refractor of 3½ feet, 3' diameter."

Only 20 years later did William Herschel succeed in resolving this cluster into individual stars. His son John Herschel described M 19 with the words: "A fine globular cluster, stars very small, of 12th to 18th magnitude, with one of 10th magnitude, and one of 10th to 11th magnitude; nearly round; very gradually pretty much brighter toward the middle, but does not come up to a blaze. Insulated; 3' diameter." Admiral Smyth saw M 19 as having a "creamy white tinge" and described it as "slightly lustrous in the center."

Astrophysics

M 19 can be considered the second most luminous globular cluster of the Galaxy – second only to Omega Centauri, if M 54 is discounted for being a member of the SagDEG dwarf galaxy. M 19 has a distance of 45,000 light-years, which is well beyond the galactic center. It is the most elliptical globular cluster in the sky: Shapley rated it as E3–E4 in a PA of 15°.

The rich and compact visual impression of the cluster reflects its large mass of 1.5 million solar masses. Despite being close to the galactic bulge, where enrichment with heavy elements first started in the Galaxy, M 19 is a metal-poor globular cluster. Only eight variables have been confirmed so far, which comprise three RR Lyrae stars, and four type II cepheids. The best-known variable is FK Ophiuchi, which was discovered in 1928 just 1.8' north of the cluster's center, and which varies between magnitude 13.5b and 15.6b. The very brightest stars of M 19 reach magnitude 14.0, and the mean magnitude of the 25 brightest stars, according to Sawyer-Hogg, is magnitude 14.8.

M 19 has a distinctly elliptical shape. Bernd Flach-Wilken

Observation

10×50 binoculars show M 19 as a bright, round nebula. In a small telescope, it measures 2.5'×3' with a noticeable north-south elongation.

For successful resolution into individual stars, apertures of 5 to 6 inches are required. An 11th-magnitude star in the northeastern part of the cluster stands out. The asymmetrical shape becomes even more pronounced with larger apertures, and the total visual size reaches 7.5'×5'.

More globular clusters can be found in close proximity to M 19: NGC 6293 is 2° east, NGC 6284 1.6° north. The impressive complex of dark clouds nicknamed the "Pipe Nebula" begins with B59, 3° southeast of M 19.

M 20

The Trifid Nebula

Degree of difficulty	2 (of 5)
Minimum aperture	30mm
Designation	NGC 6514
Type	Galactic nebula
Class	Emission nebula
Distance	2660 ly (K2005)
Size	15 ly
Constellation	Sagittarius
R.A.	18^h 2.6^{min}
Decl.	–23° 2'
Magnitude	8.5
Surface brightness	$22 mag/arcsec^2$
Apparent diameter	20'
Discoverer	Messier, 1764

M 20. The multiple star system HN 40, which consists of six components, marks the center of the nebula. Hubble Space Telescope.

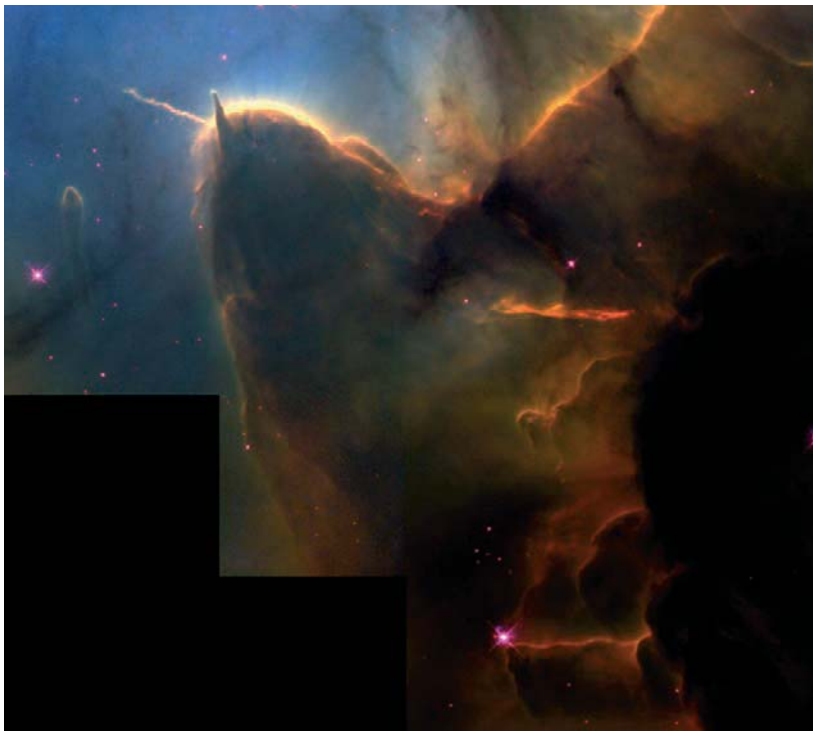
History

On the 5th of June 1764, Charles Messier discovered a “Cluster of stars, a little above the Ecliptic, between the bow of the Archer & the right foot of Ophiuchus.” In the subsequent description of M 21, he adds: “The stars of these two clusters are of 8th to 9th magnitude, surrounded by nebulosity.” It must be assumed that Messier, like Smyth and other observers after him did not really see the nebula but, because of his imperfect, chromatic refractor, saw an unresolved agglomeration of stars instead.

The discovery of M 20 has sometimes been attributed to Le Gentil. This is based on a misidentification in the nineteenth century by Bigourdan, who mistook Le Gentil’s description of M 8 for one of M 20, based on erroneous coordinates.

William Herschel was, despite his northerly location in England, the first to unambiguously recognize the nebula. He catalogued M 20 in three different portions and reported: “Three nebulae, faintly joined, form a triangle. In the middle is a double star.” On the 26th of May 1786, he added a note on the separate northern part.

The popular name of M 20, the Trifid Nebula, goes back to John Herschel, when he noted: “trifid, three nebulae with a vacuity in the midst, in which is centrally situated the double star.” This central, dark cavity was later registered by Barnard as entry No. 85 in his catalog of dark nebulae. Curtis, in 1918, finally determined the total angular size of M 20 from deep exposures as 24’ by 20’.



M 20. This dark nebula with tentacle-shaped extensions in the southeastern part of the nebula hosts some very young stars. Hubble Space Telescope.

M 20. The Trifid Nebula consists of an emission nebula, shown red on color photographs, and a cocoon of dust which scatters the blue starlight. Robert Gendler.

Astrophysics

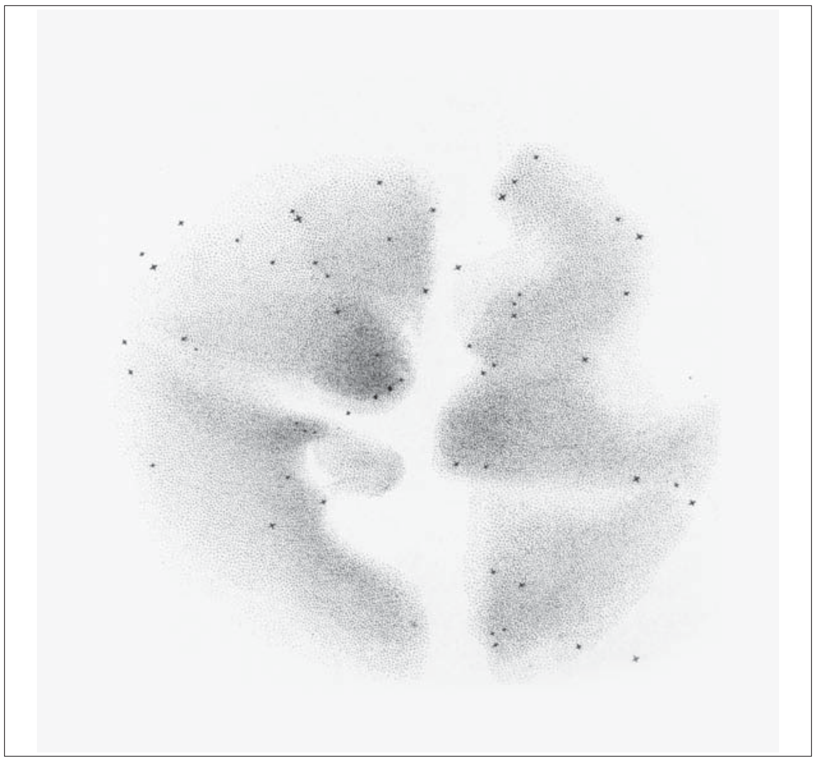
In a physical sense, M 20, the threefold or Trifid Nebula, rather consists of two components: as is nicely shown by color photos, the round central H-II region, glowing in red Hα light, is surrounded by the blue halo of a reflection nebula. The idea of tripartition, however, refers to the visual impression of the central part only. It is cut into three, or on closer inspection four, parts of different size, by long dark clouds. The star HD 164492, spectral type O7, sits near the center of the nebula right next to the confluence of these dark lanes. It is the brightest component of a very young multiple stellar system, similar to the Trapezium in M 42, and it provides the powerful radiation that makes the surrounding nebula glow.

M 20 is a very young star-forming region in an earlier evolutionary stage than that of the Orion Nebula. The shape of the HII region still appears round and regular, and most of the stars are still hidden inside the dark, dense part of the nebula. Hence, the age of this star cluster (HN 40 or ADS 10991) is under 400,000 years. The total size of the M 20 nebula is 15 light-years, and its distance of 2660 light-years makes it a foreground object to its neighbors in the sky, M 20 and M 21. Consequently, it does not belong to the Sagittarius OB1 association.

In 1997, photos taken with the Hubble Space Telescope show a dense cloud of gas and dust near the center of M 20. On its tip, facing the hot radiation of the central star, several "evaporating gaseous globules" (EGGs) were found. These very compact and small clouds have so far withstood evaporation and each of them contains a star in the final stages of formation. Furthermore, a jet-like finger of gas, about half a light-year long, emerges from the dark cloud, originating from a very young star. All these structures are due to be destroyed by the radiation from the hot central star within the next 10,000 years.

The magnitude 7.5 star (HD 164514) north of the red emission nebula is bright, but not hot enough to ionize its surrounding gas. Hence, its blue light is scattered by the dust component of the outer nebula of M 20. Deep photographs reveal that this reflection nebula, one of the largest of its kind, entirely surrounds the central part like a veil. Hence, the central star's light may also contribute to it.

The field of M 20 contains numerous variables of 14th magnitude and fainter, including 85 T Tauri stars, which are typical for young nebulae. The components of the central star are not, however, variable.



M 20, historical drawing. William Lassell (1862).

Observation

M 20 looks spectacular on photographs, but it is not a bright object for visual observers. Estimates of its total brightness range from magnitude 6.3 to 9.0, which underlines the uncertainty of assessment by visual observers.

In binoculars, M 20 is a difficult object to observe – just a faint smudge around a bright magnitude 6.9 central star. This impression does not change much with small telescopes. The surface brightness of the nebula is quite low. However in a dark sky, even the faint northern part of M 20 is visible with large binoculars. It surrounds a 7th-magnitude star 8' north of the central star.

The tripartition of the brighter southern part of M 20 can be seen with giant binoculars (20×100) or telescopes from 4 inches up, if the object is high enough in the sky. The dark lanes meet next to the central star HD 164492 (HN 40, ADS 10991), which itself is in the brightest part of the nebula. Small telescopes can resolve this multiple star into two components of magnitude 7.5 (A) and 10.0 (B), separated by 6.3" in PA 20°, plus a third component C with magnitude 8.7 lying 11" south. The latter has a magnitude-10.5 companion (D) at 2.3" in PA 281°, which requires larger apertures. A much fainter component E lies 6" south of C, and A is an extremely close binary with a separation of only 0.04" – which makes a multiple system of 6 stars in total.

The multiple star HN 40

Designation	Magnitude	Separation	PA
HN40 AB	7.5/10.0	6.3"	20°
HN40 AC	7.5/8.7	11"	212°
HN40 CD	8.7/10.5	2.3"	281°
HN40 CE	8.7/13.2	6"	190°

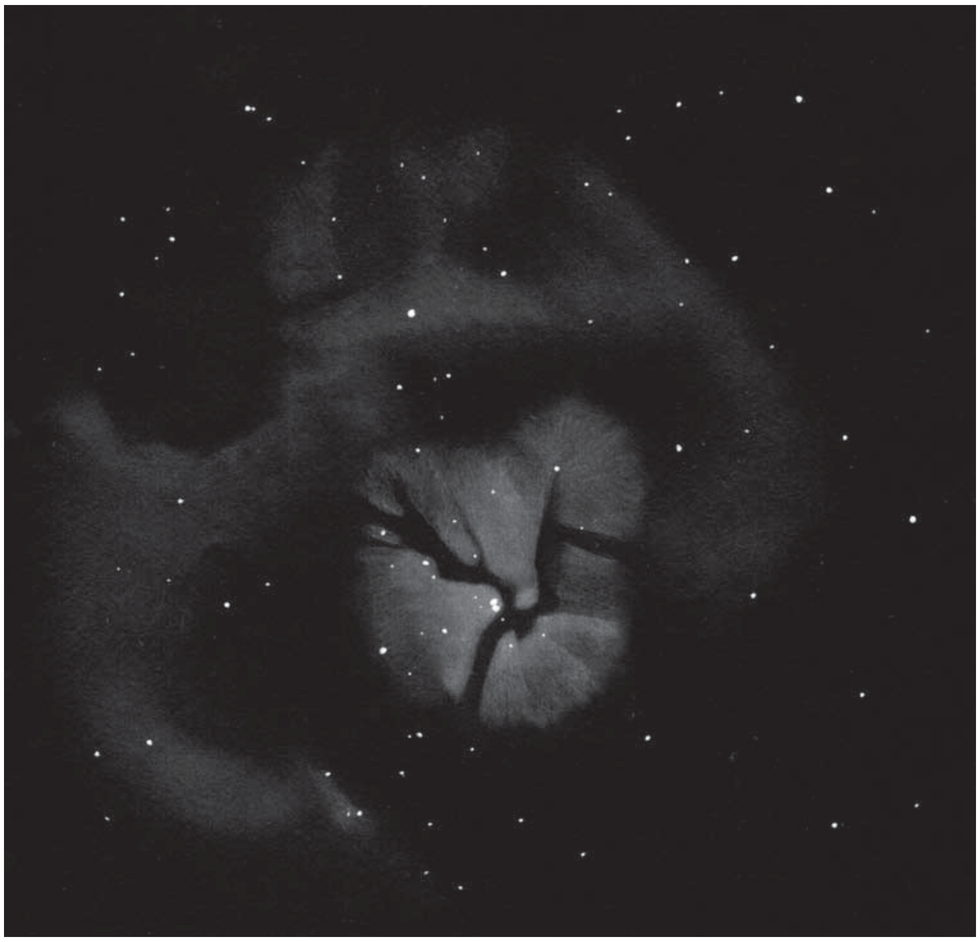
The view through an 11-inch telescope shows M 20 as an impressive object, rich in detail, and compares well to its photographic appearance. The nebula's central region has a size of 7'×7'. Three dark lanes invade it from the southeast, west and east, to meet southwest of the central multiple star. This part of the nebula also hosts about 25 visible stars. Many of these are known or suspected to be variables, like the stars in the Orion Nebula. Separated by a 3'-wide absorbing

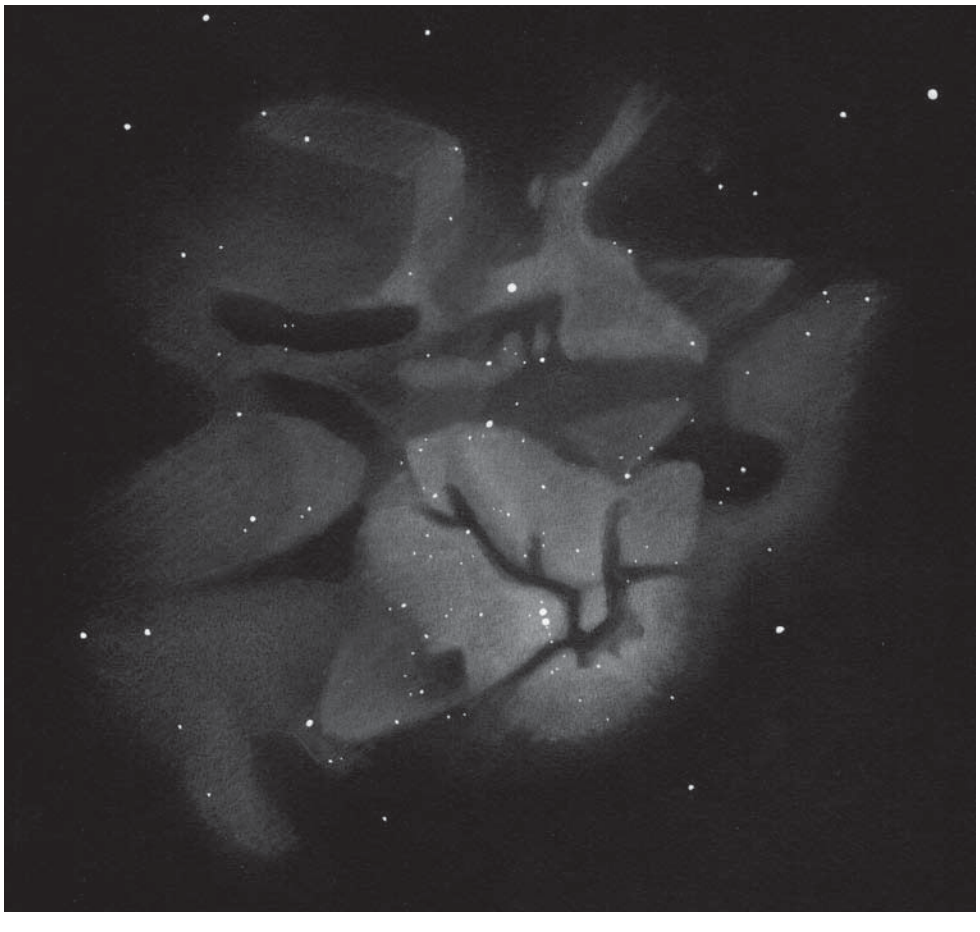
M 20. The central region of the Trifid Nebula with the multiple star HN 40. Josef Pöpsel, Beate Behle.

mass, the reflection nebula in the north is intermingled with dark nebulae and brightest around the star it engulfs.

Very faint reflection nebulosity envelops the entire eastern side of M 20 and touches the emission region in the northeast. Still dimmer nebulosity fringes the northwest, but the west and southwest are free of this cocoon. The total visual size of M 20 reaches 17'×20'.

Observing M 20 with an aperture of 20 inches and near the zenith, as from Namibia or Australia, allows the difference in color between the two parts of the nebula to be percieved. The bright central emission nebula has a slightly rosy tint due to its Hα emission, which is now intense enough for the human eye. By contrast, the cocoon appears bluish. The number of stars visible in the bright central emission nebula exceeds 50, and at least as many are seen in the fainter outskirts. These are surrounded by dark clouds as much as by the cocoon of the reflection nebula. The latter still remains open in the southwest.

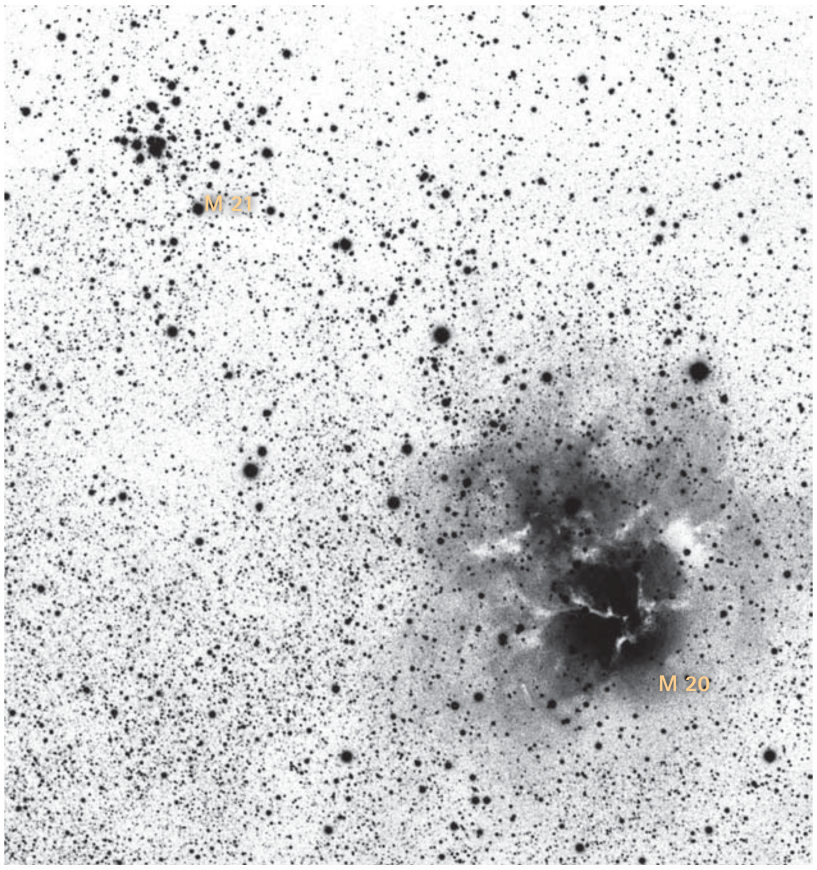




M 20, drawings. 11-inch Schmidt-Cassegrain, 20-inch Newtonian. Ronald Stoyan.

M 21

Degree of difficulty	2 (of 5)
Minimum aperture	15mm
Designation	NGC 6531
Type	Open cluster
Class	I3p
Distance	3930 ly (K2005) 4110 ly (CMD 2001)
Size	20 ly
Constellation	Sagittarius
R.A.	$18^h\ 4.6^{min}$
Decl.	–22° 30'
Magnitude	5.9
Surface brightness	–
Apparent diameter	18'
Discoverer	Messier, 1764



History

M 21 was discovered by Charles Messier, together with the objects M 19 to M 22, on the 5th of June 1764. The Frenchman noted: "Cluster of stars, near the previous. The stars of these two clusters are of 8th to 9th magnitude, surrounded by nebulosity." Apparently, Messier's telescope was not good enough to show either object correctly: neither is M 20 a star cluster, nor does any nebulosity exist around M 21.

John Herschel and Admiral William Smyth both called this cluster scattered and coarse. M 21 did not receive much attention from later observers, either.

Astrophysics

At its distance of 3930 light-years, this open cluster is located in the Sagittarius spiral arm of the Galaxy, like M 8 but a bit closer to us. M 21 is also part of the Sagittarius OB1 association and, like all its members, it is a very young object. There may be evidence for two separate phases of cluster formation, as Park and colleagues found several stars in M 21 with an age of only 4 million years, while for the majority of the cluster members they derived an age of 7.5 to 8 million years.

In 1996 Forbes identified about 105 cluster members among all stars brighter than magnitude 15.5 in a field of 18' diameter. The brightest cluster star, HD 164863 of spectral type B0, is magnitude 7.3. Most authors regard M 21 as a rather concentrated cluster and give it the Trümpler class I3r or I3p.

Observation

Considering its brightness of magnitude 5.9, and the fact that its brightest star reaches a respectable magnitude 6.7, M 21 should be within reach of the naked eye. However, with several 6th-magnitude stars and the Trifid Nebula M 20 directly south of it, this object is difficult to distinguish from its close neighbors.

In binoculars, M 21 appears as a small knot of stars. A small telescope resolves about a dozen cluster members on a nebulous background. The center is occupied by a very compact group of three stars. With larger apertures, the number of cluster stars rises to 40 or 50 and the unresolved background disappears. The cluster's borders are not well defined against the rich background, so it is difficult to judge the shape of M 21. Its approximate size is 7' in smaller and 15' in larger telescopes.

M 21 contains three double stars of interest for the visual observer:

Double stars in M 21

Designation	Magnitude	Separation	PA
South 698	7.9/8.8	29.6"	60°
ARA 1841	12.4/12.7	7.7"	30°
ARA 1843	9.7/13.4	11.1"	84°

The large (53'×20') but low-surface-brightness emission nebula Sharpless 34 can be found 1° northeast of M 21. A 14-inch telescope shows it as a nebulous finger, pointing northwest to the Sagittarius cloud. Nothing is seen, however, without a narrowband nebula filter. There is a similar structure further north, but that consists of faint stars, as it does not change contrast with the filter.

M 21 forms an apparent group in the sky with M 20 and M 8. But in real space, M 20 is a foreground object, while M 8 is not much farther away than M 21. Herrmann von Eiff.

M 22

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 6656
Type	Globular cluster
Class	VII
Distance	10,440 ly (R2005)
Size	100 ly
Constellation	Sagittarius
R.A.	$18^h\ 36.4^{min}$
Decl.	–23°54'
Magnitude	5.1
Surface brightness	–
Apparent diameter	33'
Discoverer	Ihle, 1665

M 22. This close-up of the central region recorded about 83,000 stars. Hubble Space Telescope.

History

M 22 was the first globular cluster to be discovered. Abraham Ihle found it in 1665 at Leipzig, Germany, while observing Saturn. The subsequent observers Halley, de Chéseaux, and Messier all mention Ihle as the discoverer, even though not much else is known about him. In 1747, Le Gentil described M 22 as a nebula “spreading some kind of rays of light all around.” Hence, he may have come close but still failed to resolve this cluster into individual stars – like Lacaille in 1757, who spoke of a “small core of a comet,” and Messier in 1764, who noted on the 5th of June: “This nebula is round, does not contain any star, & it is seen very well with a simple telescope of 3½ ft; 6’ diameter.”

It was left to William Herschel to recognize the true nature of M 22 towards the end of the eighteenth century. His son John commented later: “A superb, very much compressed, round cluster. Stars of 11th to 15th magnitude; not very well defined. Rather more compressed to the north following [northeastern] side than at the center.” His contemporary, retired Admiral Smyth, agreed that this is a “fine globular cluster” and wrote: “it consists of very minute and thickly condensed particles of light.”

Astrophysics

The impressive appearance of M 22 comes mostly from its relatively close distance of 10,400 light-years. Of the globular clusters in the Messier catalog, only M 4 is closer. In absolute terms, M 22 is a very average globular cluster: it has a diameter of 100 light-years and half a million solar masses.

On its 200-million-year-long orbit around the galactic center, M 22 never exceeds 5000 light-years from the galactic plane, and it never moves farther than 30,000 light-years from the galactic center.

Half a century ago, Shapley and Pease counted 70,000 stars in M 22. Today, however, a single photo taken by the Hubble Space Telescope shows 83,000 stars in only a small field 3.3 light-years in diameter at the distance of M22. The brightest stars in the cluster reach magnitude 10.7, which makes M 22 the globular cluster with the brightest apparent individual stars. At least 78 member stars are variables – a formerly counted Mira variable has recently been excluded from cluster membership.

In 1999, the Hubble Space Telescope observed a possible gravitational micro-lensing event in M 22. For 18 days, a star in the galactic bulge in the background of the cluster’s dense center appeared brighter than usual. Such an event occurs when a faint, low-mass cluster star crosses the line-of-sight to the background star. Its gravity then bends and temporarily focuses the light of the background star for us. Anderson and colleagues (2003), however, thought that the background star was a dwarf nova undergoing an outburst. Since then, other authors have shared doubts about the micro-lensing event.

In 1989, the planetary nebula GJJC 1 (or PK 9-7.1) was discovered in M 22 and identified as the optical counterpart of the infrared source IRAS 18333-2357. This was, after Pease 1 in M 15, only the second planetary nebula found in a globular cluster. The nebula has an apparent brightness of magnitude 15.0, a size of 10” by 7”, and surrounds a central star of magnitude 14.3. Together with M 22, the nebula moves through the interstellar medium with a relative speed of 200 km/s. This compresses the planetary nebula’s shell and sweeps its material out of the cluster.

M 22 is about twice as far away as M4 but less than half the distance of M 13. Bernd Flach-Wilken.

Observation

M 22 is brighter and has a larger visual size than M 13. In addition, its brightest stars are more than a magnitude brighter than those of M 13. In the whole sky, M 22 is surpassed only by the southern globular clusters ω Centauri and 47 Tucanae.

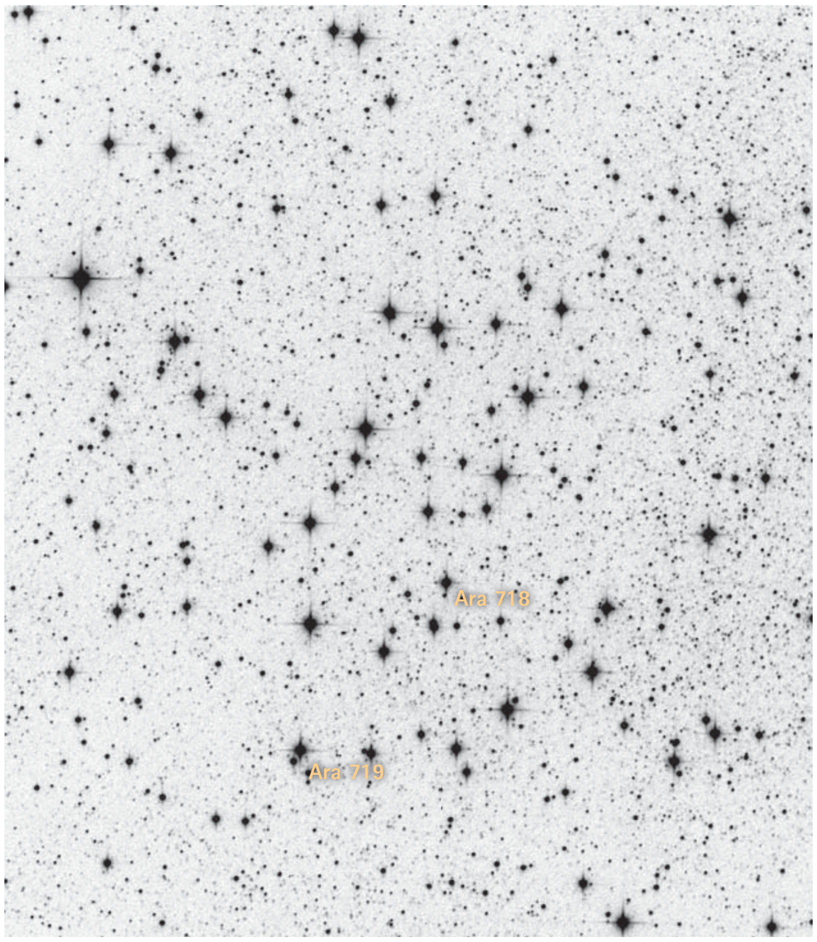
M 22 is an easy object for the naked eye to see. Only 1° away from the ecliptic, the cluster is often seen in close encounters with a planet – it's easy to see how one of these events led to the discovery by Ihle.

Binoculars show a nebulous ball, but a modest 2.5-inch telescope starts to resolve M 22 into individual stars. A slightly oval shape can be noticed, elongated in PA 25°. When observed with larger apertures, M 22 gives the impression of being rather open. A dark, linear structure cuts the central region unevenly into a larger southwest region and a smaller clump, northeast. The visual diameter measures about 9' with 2.5 inches of aperture, and reaches even 20' with a 14-inch telescope.

The planetary nebula GJJC 1 lies 1' south of the cluster's center. It forms a very small compact group with two stars of 15th magnitude, only 2" north of it. Several observers have reported successful sightings using 20-inch or larger telescopes, but all that can be seen is the central part of the nebula, easily mistaken for the central star. It requires magnifications of over 600× and the very best seeing to distinguish the nebula and to resolve it from the other two stars. The author remained unsuccessful when observing this object with a 20-inch telescope from Namibia.

M 23

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 6494
Type	Open cluster
Class	III1m
Distance	2050 ly (K2005) 2050 ly (proper motion, 2002)
Size	20 ly
Constellation	Sagittarius
R.A.	17^{h} 56.8^{min}
Decl.	–19° 1'
Magnitude	5.5
Surface brightness	–
Apparent diameter	35'
Discoverer	Messier, 1764



History

M 23 was discovered by Charles Messier, together with the neighboring objects M 24, 25, and 26, all on the night of the 20^{th} of June 1764. Messier wrote about this cluster: “The stars of the cluster are very near each other, 15’ diameter.”

70 years later, John Herschel reported: “A star 10^{th} magnitude in the center of a beautiful discrete cluster of 60 or 70 stars of 10^{th} and 11^{th} magnitude and one of 9^{th} or 10^{th}. They run in lines and arches. It is loose and straggling, and the sky around it has a dotted appearance.” Admiral Smyth was even more enthusiastic about the appearance of M 23 and wrote: “This is an elegant sprinkling of telescopic stars over the whole field, under a moderate magnifying power; the most clustering portion is oblique, in the direction south preceding [southwestern] to north following [northeastern], with a 7^{th}-magnitude star in the latter portion.”

Astrophysics

M 23 is only 2050 light-years away, which puts this open cluster halfway between us and the Sagittarius arm, the nearest spiral arm towards the galactic center. The true diameter of the cluster is about 20 light-years.

The brightest cluster star is only magnitude 9.2 and is of spectral type B9. Most of the cluster stars are 9^{th} to 11^{th} magnitude and fall into the spectral classes A, F, and G. This suggests an advanced cluster age of 300 million years.

Sanders and Schroeder listed a total of 177 stars as probable cluster members, covering a field of 34’ in angular diameter. The Trümpler class has been given, by a variety of authors, as I2r, II2r, or III1m.

Observation

From most of Europe and the northern US, M 23 is not visible to the naked eye, but it can be spotted from southern locations. Binoculars reveal a loose cluster southeast of a 6^{th}-magnitude star. About 40 stars of 9^{th} to 12^{th} magnitude distributed over a diameter of 25’ are shown by a small telescope. The apparent star chains and groupings have been associated with Chinese temples or with bats by some observers.

At least two double stars in M 23 are interesting objects for moderate telescopes. They are well separated, but the faint companions require more than a small aperture.

Double stars in M 23

Designation	Magnitude	Separation	PA
ARA 718	10.9/12.3	5.0"	16°
ARA 719	9.8/13.0	14.9"	151°

M 23 is a loose star cluster with just under 200 members. Dietmar Böcker.

M 23 and its nearest neighbors M 24, M 25, M 17, and M 18 form one of the most beautiful regions of the night sky. Jim Misti, Robert Gendler.

M 24

The Small Sagittarius Star Cloud

Degree of difficulty	1 (of 5)
Minimum aperture	Naked eye
Designation	–
Type	Star cloud
Class	–
Distance	12,000 – 16,000 ly
Size	–
Constellation	Sagittarius
R.A.	18^h 16.9^{min}
Decl.	–18° 29'
Magnitude	2.5
Surface brightness	–
Apparent diameter	90'×30'
Discoverer	Messier, 1764

History

When, on the 20th of June 1764, Charles Messier noted "large nebulosity in which there are several stars of different magnitudes: the light which is diffused over this cluster is divided into several parts. 1°30' diameter," he did not mean NGC 6603, as has been believed by many later observers.

80 years later, John Herschel correctly wrote: "A glorious concentrated part of Milky Way, almost amounting to a globular cluster. Stars 14th and 15th magnitude." The last remark clearly refers to NGC 6603, which appears to lie inside M 24. Smyth gave a similar description: "A beautiful field of stars, and in a richly clustering portion of the Milky Way, has a peaking spot with a lot of stardust."

In 1905, Agnes Clerke commented: "Visible to the naked eye as a dim cloudlet near μ Sagittarii and named by Secchi as 'Delle Caustiche' from the peculiar arrangement of its stars in rays, arches, caustic curves and intertwined spirals."

When he inspected photographic plates in 1918, Curtis described the neighboring dark nebulae, which were discovered by Barnard in 1913: "Two dark nebulae, the larger western object is about 14'×8', and the contrast between the dense Milky Way region and the vacant spots is very striking."

Astrophysics

The designation M 24 has been given to the Small Sagittarius Star Cloud, which should be distinguished from the Large Sagittarius Cloud south of M 8. M 24 does not hold any other catalog names, as it does not have any physical identity. In reality, this is just a large number of stars at a considerable range of distances from 12,000 to 16,000 light-years, seen through a 1.5° by 0.5° window of reduced absorption in the curtain of interstellar dust, making them appear as a star cloud in projection along our line of sight.

The window to M 24 is remarkable, because it opens up a view through both our local spiral arm and the Sagittarius-Carina spiral arm – in which we find quite a number of the neighboring Messier objects – deep into the next spiral arm inward, the Norma arm, towards the galactic center. Usually, our views near the galactic plane are limited to just a few thousand light-years, because the average interstellar absorption in the Milky Way is around 1 magnitude per 1000 light-years. But the actual extinction varies greatly due to the uneven distribution of interstellar dust clouds, and in the direction of M 24 we can see more than halfway to the galactic center. An even more transparent region further south near the star μ Sgr [Sagittarii] which is known as Baade's Window gives us a view of the inner galactic bulge at a distance of 30,000 light-years. It even shows globular clusters behind the galactic center, which is only 4° away.

Within M 24, we find the open cluster NGC 6603 at a distance of 12,000 light-years and with a diameter of 18 light-years. This very compact object is reminiscent of M 11, but it lies more than 2.5 times further away in the Norma spiral arm. Its light suffers from an interstellar extinction of only 1.5 magnitudes. The age of this distant open cluster is an estimated 200 million years.

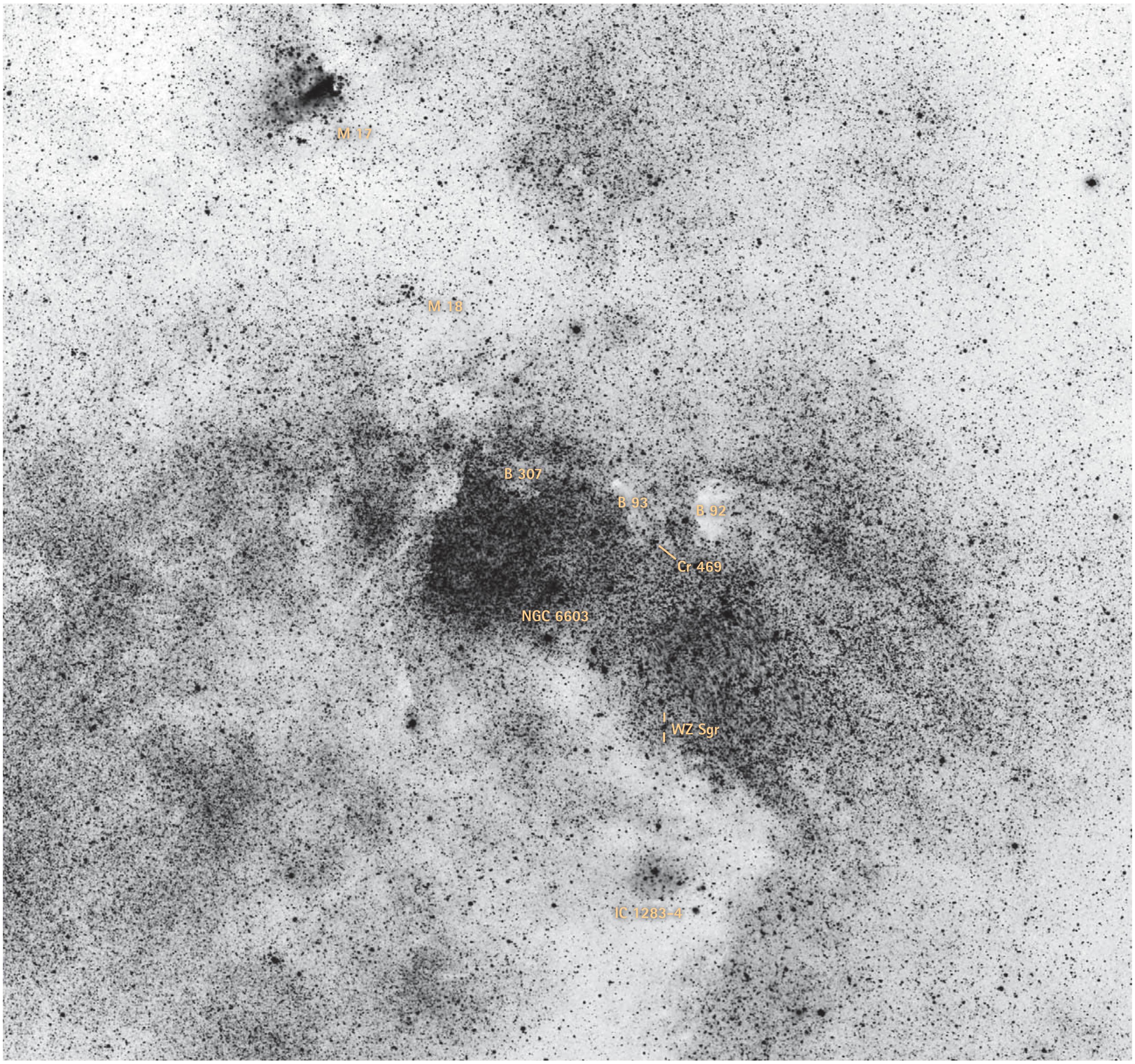
The depth of view within M 24 is demonstrated by two other objects nearby. The double star Burnham 639, 10' south of NGC 6603, lies in the Sagittarius-Carina spiral arm, at a distance of 7800 light-years. The magnitude-6.4 primary star is gravitationally bound to a magnitude-7.9 companion, 18" away (PA 52°). Even closer to us are the two small, but compact, dark clouds B 92 and B 93 at the northern edge of M 24. They belong to our local spiral arm and mark, so to speak, the entrance of the viewing-tunnel at only a few hundred light-years away. Another foreground object, at a distance of 4100 light-years, is the tiny planetary nebula NGC 6567 just east of the star cloud M 24, as well as the δ Cephei variable WY Sagittarii to the south, with a period of 21.85 days and a brightness variation between magnitude 7.5 and 8.6. Additional objects in M 24 include the open clusters Collinder 469 at 4700 light-years, with 32 certain and 14 possible member stars, and Markarian 38 (= Biurakan 5) at a similar distance, with 12 probable member stars.

Observation

M 24 is easily recognized by the naked eye as a small, bright and elongated star cloud. It takes center stage amid nine naked-eye Messier objects in a richly structured swath of the Milky Way.

There is hardly any other Messier object as impressive in simple binoculars. Under a dark sky, even 8×30 glasses show the rectangular elongated shape and the immense richness of this star cloud. Two most impressive examples of dark nebulae, B 92 and B 93, are

M 24. Through a "tunnel" in the Milky Way, our view reaches half the distance to the galactic center, while the surrounding dark dust clouds obscure all stars beyond several thousand light-years away. Philipp Keller.



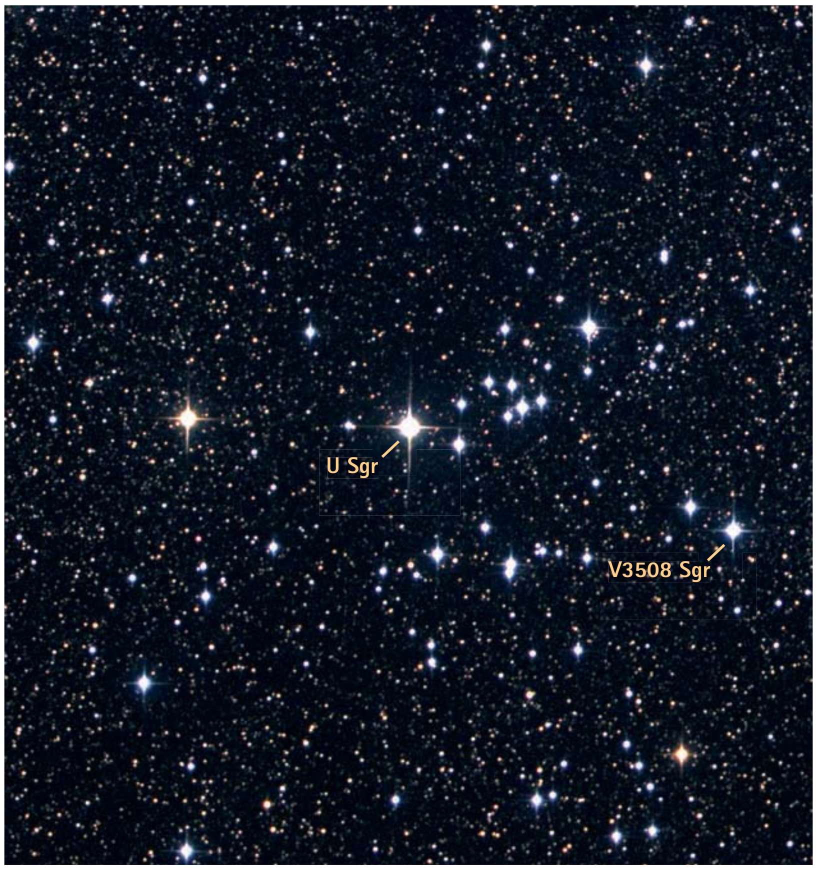
found near the northern edge of M 24. More dark clouds are to the east and southeast.

When using large 20×100 binoculars, the two dark nebulae in M 24 stand out particularly well. They appear ink-black with diffuse, nebulous borders. Only B 92 features even a single star in its dark region. Not far from the northern edge of M 24, two dark bands run across the star cloud, fragmenting it into long islands. They have their origin near B 92 and spread southwest from there. M 24 itself is resolved into myriads of stars, the brightest of which reach 8th magnitude. The apparent star density is among the very highest in the whole sky and makes M 24 stand out against its foreground. LDN 294, 318, and 325 form the dark cloud complex along the southern and eastern edges of M 24. The eastern edge is particularly impressive: a 3°-long, straight cut.

The 11th-magnitude star cluster NGC 6603 in the eastern part of M 24 is easily overlooked in small telescopes. Its resolution requires 8 inches of aperture, since the brightest cluster stars are only 14th magnitude. With a 14-inch telescope, a compact cluster of 80 stars is seen with a diameter of only 10'.

M 25

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	IC 4725
Type	Open cluster
Class	I3m
Distance	2020 ly (K2005) 2020 ly (proper motion, 2002)
Size	17 ly
Constellation	Sagittarius
R.A.	$18^h\ 31.6^{min}$
Decl.	–19° 15'
Magnitude	4.6
Surface brightness	–
Apparent diameter	30'
Discoverer	de Chéseaux, 1746



M 25 is dominated by the cepheid U Sagittarii. Dietmar Böcker.

History

M 25 was discovered by the Swiss observer Philippe Loys de Chéseaux in 1745 or 1746. However, this was not known to Messier: while at the time de Chéseaux did send a letter to the Paris Academy of Sciences to report his discoveries, it was only read to a meeting and was not published in print. Hence, Messier made a truly independent discovery of this "cluster of small stars" on the 20th of June 1764, and wrote: "The stars of this cluster are difficult to observe with a simple refractor of 3 feet, no perceivable nebulosity. 10' diameter."

Later, Admiral Smyth noted: "A loose cluster of large and small stars in the Galaxy. The gathering portion of the group assumes an arched form, and is thickly strewn in the south, on the upper part, where a pretty knot of minute glimmerers occupies the center, with much star-dust around."

The Herschels did not observe M 25. Hence, despite the observations of Smyth and others, it did not receive an NGC designation. In 1866, Julius Schmidt rediscovered this cluster, observing from Athens, but it was not until 1908 that M 25 was included in the second Index Catalog as its entry No. 4725, after a positional measurement by Bailey.

Astrophysics

The characteristic appearance of the open cluster M 25 is shaped by its brightest star, U Sgr [Sagittarii], a variable of the classical δ Cephei type. Its brightness varies regularly between magnitudes 6.3 and 7.1 with a period of 6.75 days (Irwin, 1956). This star yields a relatively certain cluster distance of 2020 light-years, from which a physical diameter of 17 light-years can be derived. This places M 25 in the gap between our local spiral arm (Orion-Cygnus arm) and the next, inner Sagittarius-Carina spiral arm, and about 150 light-years below the galactic plane.

M 25 has about 220 known member stars, which suffer from up to 1.6 magnitudes of extinction and significant reddening by interstellar dust. The total cluster mass has been estimated to 2000 solar masses, and values between 30 and 100 million years have been given for its age.

The second brightest star in the cluster, to the northeast, has magnitude 6.8 and is a very suitable comparison red for photometry on U Sagittarii. M 25 contains another variable, V3508 Sagittarii (magnitude 7.7–8.0), which is of the γ Cassiopeiae type, as well as five hot Be stars with emission lines.

The cluster's classification varies from author to author; especially astonishing are their different interpretations of its richness. Trümpler classes I2p, I3m, and IV3r have been suggested for M 25.

Observation

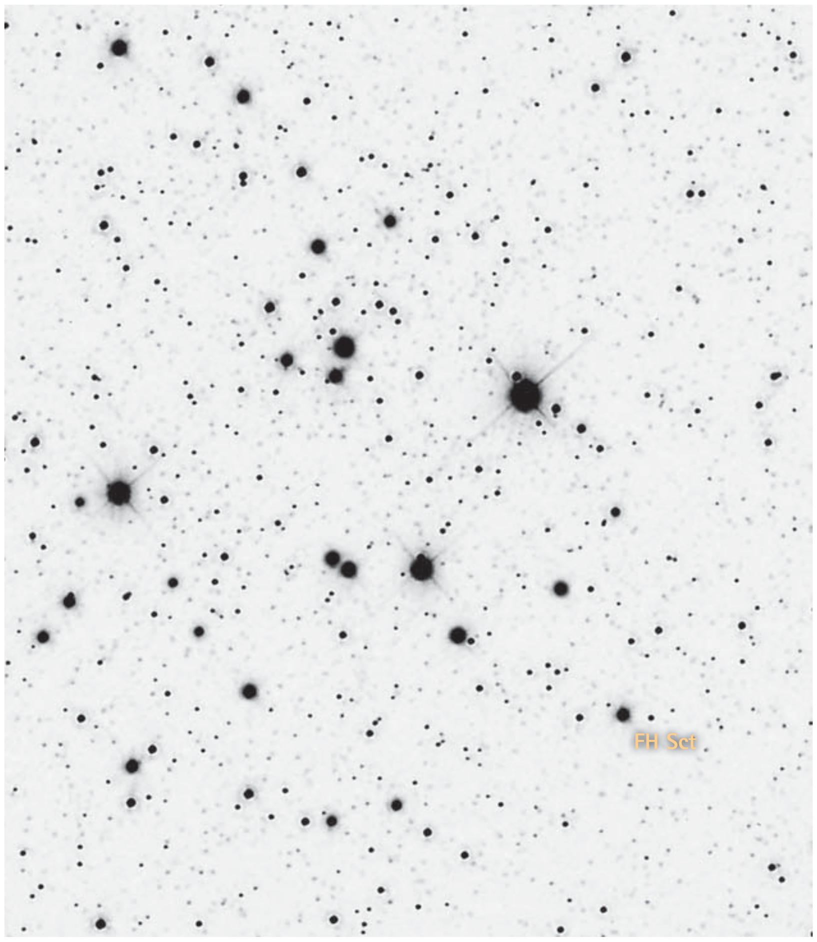
M 25 can be located with the naked eye 5° east of M 24. Binoculars are a good choice for observing this open cluster; they resolve about a dozen stars.

With a small telescope, low power is best. It resolves the 30' cluster into about 50 stars; a denser group occupies the center. Two curved star chains run through the cluster from east to west.

Larger apertures show the yellow color of the bright dominating star near the center, the variable U Sagittarii. It is also a double star (Burnham 966): a magnitude 9.6 companion is 66.5" away in PA 253°.

M 26

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 6694
Type	Open cluster
Class	II3m
Distance	5160 ly (K2005)
Size	12 ly
Constellation	Scutum
R.A.	18^h 45.2^{min}
Decl.	–9° 24'
Magnitude	8.0
Surface brightness	–
Apparent diameter	8'
Discoverer	Messier, 1764



History

Charles Messier discovered M 26 on the 20th of June 1764, and described a star cluster: "With a telescope of 3 ft they cannot be distinguished, one has to employ a good instrument. This cluster does not contain any nebulosity; 2' diameter." Occasionally, the discovery of M 26 has been attributed to le Gentil, in 1749, but that is not correct. While the Frenchman gave a position near M 26, he in fact reported an observation of "Kirch's Nebula," M 11.

M 26 was not very popular with later observers. John Herschel characterized it as "considerably large; pretty rich; pretty compressed; stars from 12th to 15th magnitude," while Smyth reported: "A small and coarse, but bright, cluster of stars. The principal members of this group lie nearly in a vertical position with the equatorial line."

Astrophysics

M 26 is quite an ordinary open cluster and one of the least-well-studied Messier objects. At a distance of about 5200 light-years, it has a physical diameter of about 12 light-years. The brightest cluster star is only magnitude 10.3 and has the spectral type B8. It suffers an extinction of 1.8 magnitudes by the rich interstellar dust in its line-of-sight. With an age of about 90 million years, M 26 is moderately young to average.

According to Grubissich, at least 69 stars can be attributed to the cluster. In a 1940 study, Cuffey noticed that within 3' from the center there are apparently fewer cluster stars, which may find an explanation in a small, interstellar dark cloud in front of the cluster. Different Trümpler classifications have been given to M 26: II2r, I1m, or II3m.

An interesting cluster member is the R Coronae-Borealis star FH Scuti. Its brightness can drop on a short time scale, without any kind of warning, from the normal value of magnitude 13.4 to as faint as 16.8. These events are caused by the sporadic formation of clouds of circumstellar dust in the outer atmosphere of this very cool supergiant star. Whenever this happens on its facing side, only a small fraction of the normal luminosity remains visible.

Observation

M 26 appears as a faint, small nebula in a star-rich field, near the southern edge of the Scutum cloud, when observed with binoculars. It takes higher powers to resolve this cluster into individual stars.

In a 2-inch refractor, M 26 gives a poor impression; only five stars are seen next to the brightest cluster member. A better view is given by an aperture of 4.7 inches; it shows 15 to 20 stars on a nebulous backdrop.

Telescopes of 12 to 14 inches show 30 to 40 cluster stars. Higher magnifications are required to make the by far brightest star of 10th magnitude stand out from the others. A starless void, north of the center, is now noticeable – the brighter stars appear to be grouped around it. The cluster's visual size is 8'.

M 26 is an unimpressive star cluster in the Sagittarius spiral arm of the Milky Way. Stefan Binnewies.

M 27

The Dumbbell Nebula

Degree of difficulty	2 (of 5)
Minimum aperture	30mm
Designation	NGC 6853
Type	Planetary nebula
Class	III+II
Distance	1150 ly (2004) 1350 ly (1999)
Size	3 ly
Constellation	Vulpecula
R.A.	19^h 59.6^{min}
Decl.	+22° 43'
Magnitude	7.4
Surface brightness	–
Apparent diameter	8.4'×6.1'
Discoverer	Messier, 1764

History

The discovery of M 27 by Charles Messier on the 12th of July 1764, was the first discovery of a planetary nebula. He described his find with the words: "Nebula without star; it is well seen with a simple refractor of 3½ feet; it appears in an oval shape & does not contain any star, 4' diameter."

William Herschel was the first to recognize the peculiar dumbbell shape but believed it was a "double stratum of stars of a very great extent, one end of which is facing us." Later, his son John gave the nebula its now popular name: "a nebula shaped like a dumbbell." He continues his description: "with the elliptic outline completed by a feeble nebulous light. Position of the axis of symmetry through the centers of the two chief masses 30° to 60°. The diameter of the elliptic light fills a space nearly equal to that between the wires (7' or 8'). Not resolvable, but I see on it four distinct stars: 1st 12th magnitude at the south following edge; 2nd 12th magnitude to 13th magnitude, almost diametrically opposite; 3rd 13th magnitude in the north preceding quarter, and 4th 14th to 15th magnitude near the center." In a later description, John Herschel called M 27 "shaped something like an hourglass, filled into an oval outline with a much less dense nebulosity. The central mass may be compared to a vertebra or a dumbbell. The southern head is denser than the northern."

Admiral Smyth enthusiastically spoke of a "magnificent and singular object, it is one of those splendid enigmas which are proposed by God."

Lord Rosse devoted a detailed study to M 27 using his huge telescope. The Irish nobleman wrote: "It requires an extremely fine night and a tolerably high power; it is then seen to consist of innumerable stars, mixed with nebulosity; and when we turn the eye from the telescope to the Milky Way, the similarity is so striking that it is impossible not to feel a pretty strong conviction that the nebulosity in both proceeds from the same cause." Of course, he could not know how wrong he was with this impression.

Heinrich d'Arrest described M 27 as "very large and luminous, two objects with a transition between each other. In the brighter, southern part, an eccentrically positioned spot can be recognized, the northern part is not quite so bright." It took over 100 years after the discovery until William Huggins was able to explain the nature of this nebula by using the then new method of spectroscopy: "The light of this nebula, after passing through the prisms, remained concentrated in a bright line. This line appeared nebulous at the edges. No trace of the other lines was perceived, nor was a faint continuous spectrum detected." This observation made clear that M 27 was not composed of faint unresolved stars, but of luminous gas.

In 1918, Curtis commented on M27 with the words: "The 'Dumbbell' Nebula in Vulpecula. One of the 'giants' of the planetary class and of great importance in theories of planetary structure because of the easy visibility of intrinsic details."

Astrophysics

In terms of total apparent brightness of planetary nebulae, M 27 holds second place at magnitude 7.4, right after the much closer Helix Nebula NGC 7293 at 7.3 – but with a much higher surface brightness. As a textbook example of its object class, the Dumbbell Nebula has become the best-studied planetary nebula except for M 57, the Ring Nebula.

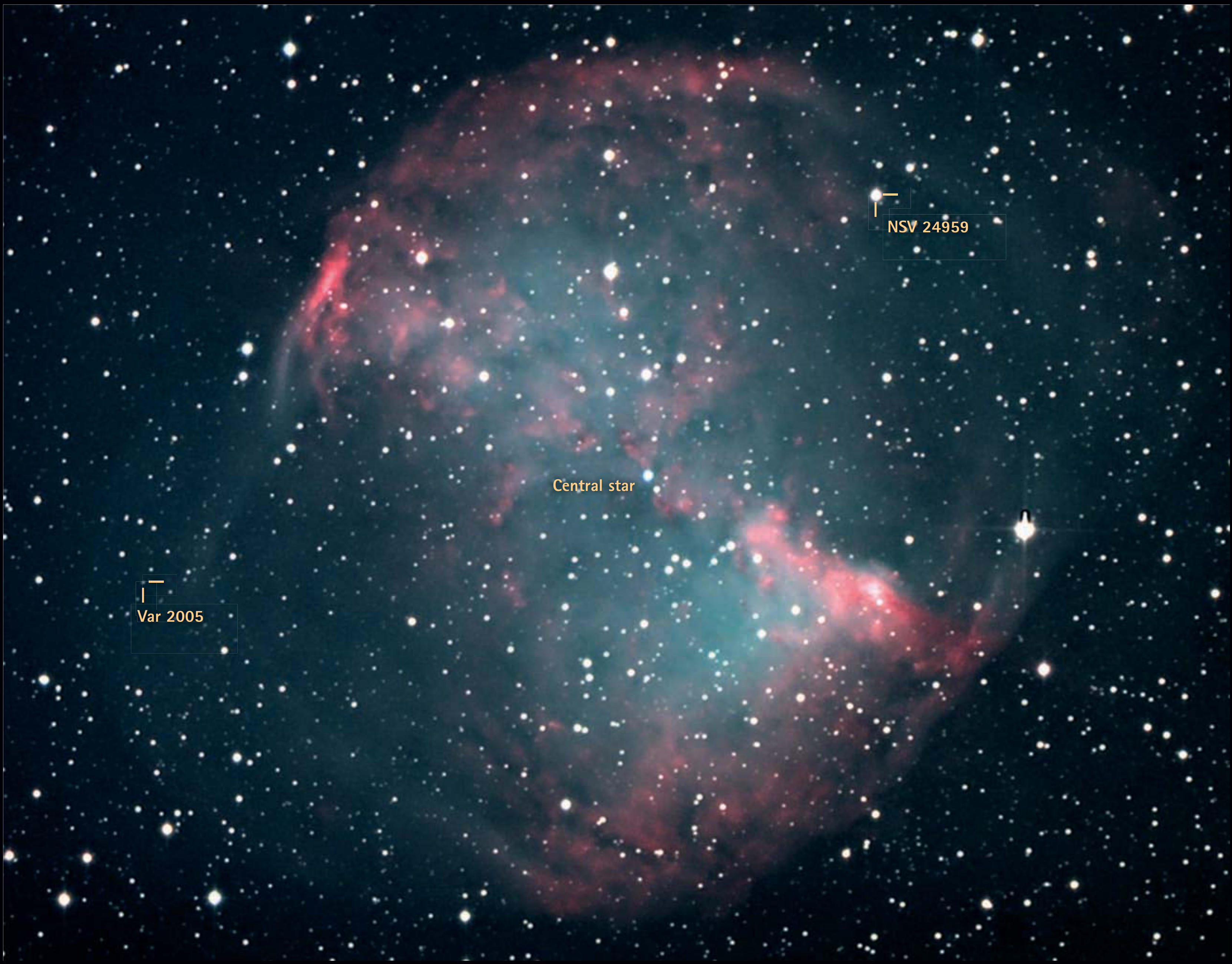
The small central star that causes the ionization of the surrounding nebula has a magnitude of only 13.5 but a very hot spectral type (O7, 85,000K). There is a 17th-magnitude companion to the central star at 6.5" distance in PA 214°, found in the early 1970s by Cudworth. The stars are only about 2500 AU away from each other.

The morphology of the nebula is complex. The innermost elliptical shell that surrounds the central star measures 1.2' by 0.8' and is elongated in PA 130°. Perpendicular to this, the luminous hourglass-shaped part of the nebula spans 4.5' by 2.5'. The hourglass component is then embedded in the fainter ellipse (8.4' by 6.1' in PA 125°), which was documented by John Herschel.

Kwitter and colleagues (1991) discovered a faint, 15.5' by 13.3' halo with the same orientation as the bright central part. Papamastorakis later reported an extension of up to 17'. The surface brightness of the outer halo is about 1000 times lower than that of the main component of the nebula, and it is deformed in PA 60° as a result of the proper motion of M 27 through the interstellar medium.

When comparing the Hα/Hβ images of M 27 with the image in the [OIII] emission line, both appearance and size differ. The Hα image shows a lot of mottled sub-structure, while in [OIII] light, the inner nebula appears quite homogeneous.

Dimensions of the Dumbbell Nebula		
Main Nebula	7.8'×6.2' (Hα)	8.4'×6.1' ([OIII])
Halo	17'×13.2' (Hβ)	16'×11.5' ([OIII])



M 27. The Dumbbell Nebula is the brightest planetary nebula in the Messier catalog. Philipp Keller.

M 27. Only long photographic exposures reveal the faint halo. Gerald Rhemann, Michael Jäger.

The total physical diameter of M 27 could be as large as 6 light-years, if the farther distance of 1350 light-years applies, which results from the parallax measurements of the Hubble Space Telescope for the central star. This would make M 27 a very large planetary nebula.

The inner region of the Dumbbell Nebula appears very ragged and full of knots, when imaged at high resolution, as by the Hubble Space telescope in 2001. These substructures have sizes of 20 to 60 million kilometres (i.e., fractions of an AU) and contain about three Earth masses each. They lie near the chaotic boundary between the hot and ionized gas pushing from inside, and the cool, neutral outer envelope in the shape of a torus (i.e. a donut). The expanding ionization exposes the more resistant cool clumps, which have an origin in the earlier dust-driven wind of the former supergiant.

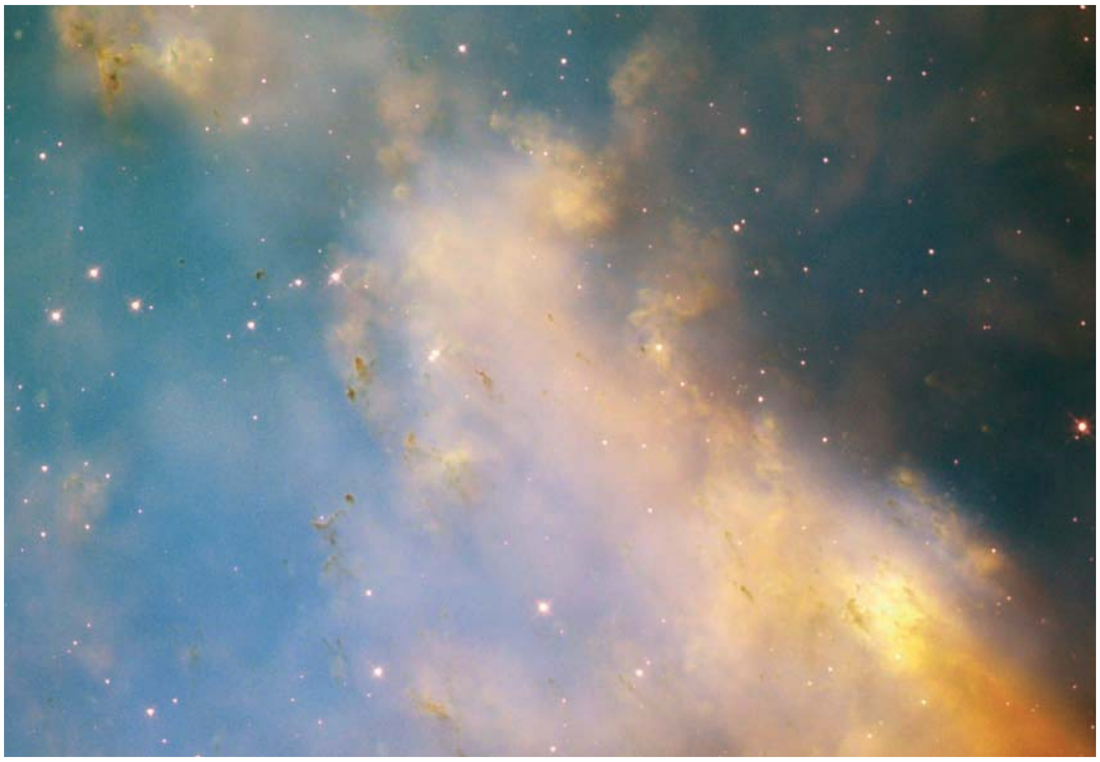
The strongest ionization in the inner nebula is found in two structures, which emerge from the central star in PA 70° and 240°, and which may indicate the rotation axis of the central star. These structures have sufficient density to be opaque and they cast "shadows," ionisation gaps, onto the outer regions of the nebula.

The outer nebula expands at a rate of 2.3" per century. This represents the remains of the cool wind of the former cool supergiant, built up over a few tens of thousands of years. The inner regions are faster at 6.8" per century and push into the slower, cool envelope. Counting from the emergence of the hot central star, recent estimates suggest that M 27 is about 9000 years old. That would make the Dumbbell Nebula younger than the more distant Ring Nebula, M 57.

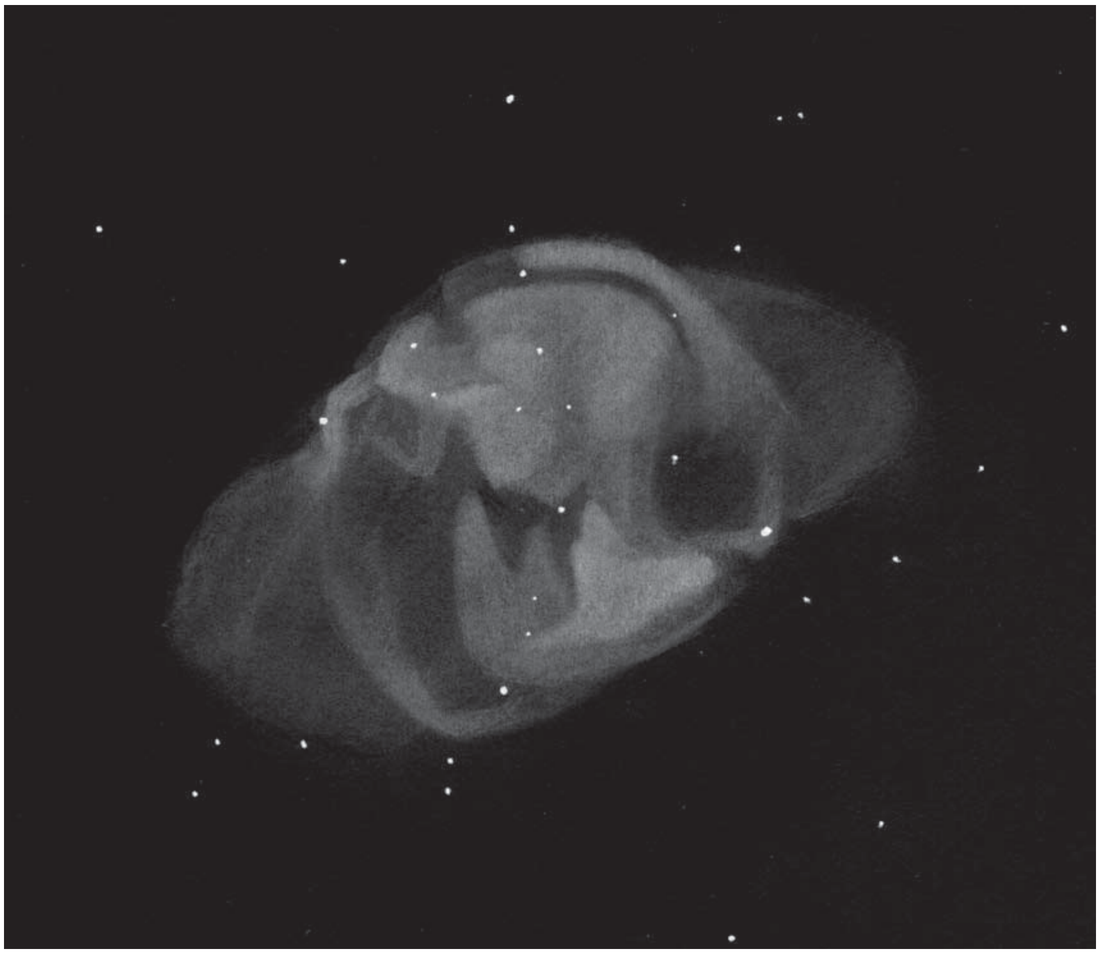
Observation

M 27 is a very nice object for telescopes of all sizes. Even 30mm binoculars show this nebula as a small puff of light. The view with 50mm glasses even hints at the hourglass shape.

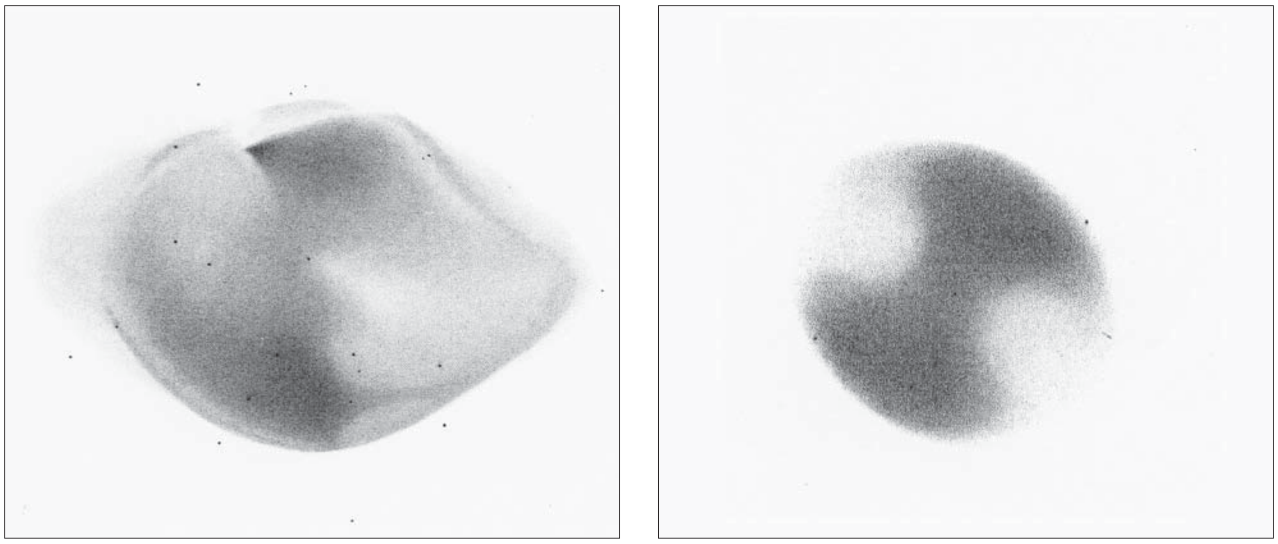
With a 2.5-inch telescope, M 27 appears elongated in PA 30° with rounded ends on the long axis of the hourglass and diffuse borders to the northwest and southeast. There is a brighter star at the southwestern edge, and two faint stars can be seen inside the nebula. The brightest part of the nebula



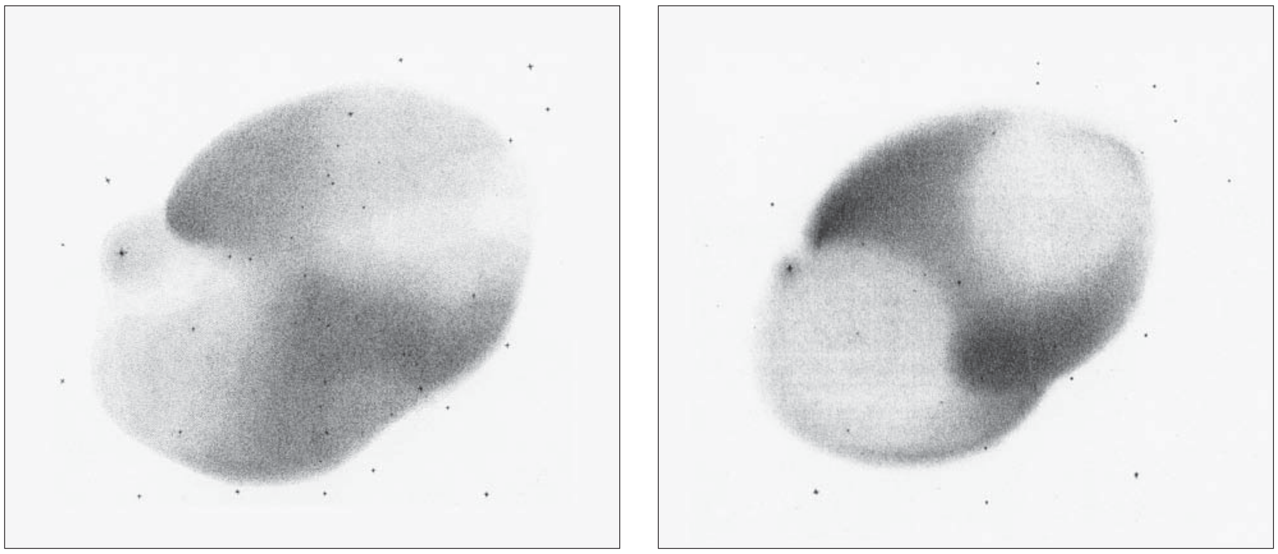
M 27. Detail from the southwest quadrant of the nebula. Oxygen emission is coded in blue, hydrogen in green, and the combined sulfur and nitrogen lines in red. Hubble Space Telescope.



M 27, drawing. 14-inch Newtonian. Ronald Stoyan.



M 27, historical drawings. Bindon Stoney and Lord Rosse (1849), John Herschel (before 1833).



M 27, historical drawings. William Lassell (1862), Herrmann-Carl Vogel (1885).

is an asymmetrical pyramid in the southern half of the hourglass that reaches from the center to the southeastern edge. The region east of the center is mottled, and the northern half of the nebula is brightest at its edges. The faint extensions of the nebula are best seen at low power with a nebula filter. They stretch out to both sides along the minor axis of the hourglass. These "ears" included, M 27 has a visual extent of 5'×6', without them only 5'×3'.

In larger telescopes, the "ears" are so apparent that the brighter hourglass now defines only the minor axis, while the ears form the major axis in PA 120°. A 14-inch telescope shows a total of 14 stars in the nebula. These include the bright 10th-magnitude star in the southwestern corner, which is now visibly inside M 27. The brightest part of the nebula starts from a point 20" west of the 13th-magnitude central star and reaches southward, where it widens and merges with the southern edge. Nebulous filaments spread out from here to the east and west to surround the center. The northern part of M 27 has a much more complex structure and contains more stars. Most noticeable is a bright, curved filament at the northeastern edge, as well as a bright borderline which starts from 3' north of the center and turns southwest. There are also distinct dark regions, directly south and east of the central star, as well as north of the 10th-magnitude star mentioned above.

Faintly visible is the filamentary structure of the "ears"; the one in the east appears to be a little fainter. Both become very bright in an [OIII] line filter, which enlarges the visible size of M 27 to 9'×6', elongated in PA 115°. A dark interruption of the oval edge is seen in the southwest. Even the brightest filament of the faint halo, stretching 3' west of the main nebula, can be perceived vaguely.

The variable star NSV 24959 lies at the northwestern edge of M 27. It was discovered by Leos Ondra in 1991, simply from a comparison of different pictures of the nebula on the cover pages of various astronomical magazines. It is a background Mira star with a suspected period of 213 days and a brightness variation between at least magnitudes 14.3 and 15.1. A final assessment of its type and its status as a confirmed variable is still awaited. In the summer of 2005, an even fainter variable was found in the field of M 27. This is probably a dwarf nova of the WZ Sagittae type, which changes brightness between magnitudes 15.5 and 22.5.

M 28

Degree of difficulty	3 (of 5)
Minimum aperture	30mm
Designation	NGC 6626
Type	Globular cluster
Class	IV
Distance	34,480 ly (2001)
Size	100 ly
Constellation	Sagittarius
R.A.	$18^h\ 24.5^{min}$
Decl.	–24°52'
Magnitude	6.8
Surface brightness	–
Apparent diameter	10'
Discoverer	Messier, 1764

M 28 is three times as distant as its neighbor in the sky, M 22. Bernd Flach-Wilken.

History

Charles Messier discovered M 28 on the 27th of July 1764, only 3° away from the already-known M 22. He noted that night: "It does not contain any star, it is round, it cannot be observed without difficulty with a simple refractor of 3½ ft, 2' diameter."

A few years later, William Herschel succeeded in resolving M 28 into individual stars and had to disagree with Messier's characterization. His son John described it as an "excessively compressed globular cluster, not very bright; but very rich, stars of 14th to 15th magnitude." Smyth agreed with the cluster stars being "very small."

Astrophysics

M 28 and M 22 each have a physical diameter of 100 light-years, but M 28 is more than three times farther away at 34,500 light-years. Its total mass is estimated to be 500,000 solar masses.

M 28 is one of the globular clusters of the galactic bulge. Despite its proximity to the galactic center, where heavy elements were first formed in the galaxy, M 28 shows the same low metallicity as the globular clusters further out in the galactic halo. Perhaps changes in its galactic orbit brought M 28 from the halo to its present place.

Shapley noticed the elliptical shape of this cluster and gave an axis-ratio of 9:10. Hogg determined the average magnitude of the 25 brightest cluster stars to be of magnitude 14.7.

In 1949, Joy discovered a variable cluster star with a period of 19 days, belonging to the W Virginis type. Another variable in M 28 is V2342 Sagittarii of the RV Tauri class with a period of 92 days. This star, 1' southeast of the cluster's center, changes its brightness between magnitudes 13.1 and 13.8. In addition, 13 RR Lyrae variables, very typical for globular clusters, are known in M 28, as well as four red irregular variables. A special find is the millisecond pulsar (see M 4) with a period of 3ms, discovered in 1987. Only recently, ten pulsars have been found in M 28 with the Green Bank Radio Telescope. M 28 now has the largest known pulsar population of any Messier cluster.

Observation

Its apparent proximity to the popular M 22 dooms M 28 to be a rarely visited Messier object, even though its brightest individual stars reach a respectable magnitude of 12.0. Resolution of its member stars can even be achieved with an aperture of 4 inches – not, however, in the 2' central region. The irregular visual impression is resolved into chains of stars with larger apertures. The most noticeable chain aims northward, starting near the core. In combination with a second curved chain farther west, this almost gives the impression of a pair of scissors that ends with a 12th-magnitude star 1.7' north of the cluster center. The total visual size of M 28 reaches 5' in a 14-inch telescope.

The significantly smaller and fainter globular cluster NGC 6638 (magnitude 9.1) lies 1.5° southeast of M 28. It is visible with apertures of 2.5 inches or more.

M 29

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 6913
Type	Open cluster
Class	I2mn
Distance	3740 ly (K2005) 5220 ly (2004)
Size	10 ly
Constellation	Cygnus
R.A.	$20^h\ 23.9^{min}$
Decl.	+38° 32'
Magnitude	6.6
Surface brightness	–
Apparent diameter	10'
Discoverer	Messier, 1764

M 29 suffers significantly from interstellar extinction. Stefan Heutz, Wolfgang Ries.

History

M 29 was found by Charles Messier on the 29th of July 1764, and described as a "Cluster of seven or eight very small stars, which are seen in a simple refractor of 3½ feet in the form of a nebula." This remark demonstrated how poor the chromatic lenses of Messier's time must have been.

John Herschel, already using large reflectors, later characterized M 29 as "A coarse cluster of 8 large stars (10th magnitude), and a dozen or 20 smaller in a roundish form." Admiral Smyth found it more attractive with a smaller aperture and noted: "a neat but small cluster of stars." Curtis' description (1918) of the photographic appearance is, by contrast, very dry: "Cluster, poor, little compressed, large and small stars."

Astrophysics

M 29 is not a particularly obvious open cluster. However, were it not lying right in the Milky Way and suffering from 3.5 magnitudes of extinction by the interstellar dust in the line of sight (Hiltner, 1954) – which lets only 5% of its light pass – we would instead see a brilliant 3rd-magnitude cluster in our sky. The foreground extinction actually shows small-scale structure, so much that some stars to the north and south of the cluster center are dimmed by as much as 5 magnitudes!

Together with the neighboring clusters IC 4996 and Be 86, M 29 belongs to the same OB1 association of young and hot stars that give the Cygnus star cloud much of its brightness. Additional members of this association include the variables P Cygni, 44 Cygni, and the Crescent Nebula NGC 6888, which is a rare Wolf–Rayet stellar-wind envelope.

The five brightest stars of M 29 are blue supergiants with spectral types B0 and B1 and luminosities of 160,000 Suns. At least two of these are variables: HD 194378 (V2031 Cygni) is an eclipsing binary with brightness changes between magnitudes 8.5 and 8.7. However, Boeche et al. have argued that it is not actually a physical member of the cluster. HD 229221 (V1322 Cygni) is a γ Cassiopeiae type variable which changes its brightness between magnitudes 8.8 and 9.7. HD 229239, the third-brightest star in M 29, may also be a variable. These hot luminous stars strongly suggest a very young cluster age. Massey et al. have put it at 4 to 6 million years.

Gerts counted 229 stars with probable cluster membership, which form a 5' core region and a 32' "corona." On the Trümpler classification, several authors differ significantly from each other. In the literature, we find assignments of III3pn, II3m, and I2mn. The 'n' refers to the extensions of the nebula around γ Cygni, notably the branch of DWB 51 just 20' west of M 29.

Observation

M 29 can be glimpsed with the naked eye as a faint "star," but a definite sighting requires binoculars. The compact cluster then appears as a knot of stars, while resolution into individual stars is achieved with a small telescope at 50×. A small telescope shows the characteristic pattern of M 29, which looks like a smaller version of the Pleiades – an appealing view despite a certain lack of luster. The number of cluster stars rises from only a dozen in a 4-inch telescope to about twice as many with a 14-inch. Worth mentioning are the faint stars inside the bright box pattern, which seem to form a chain in the north-south direction.

The nebula DWB 51, part of the γ Cyg [Cygni] complex, lies 50' northwest of M 29 and can be seen with a 14-inch telescope and narrowband filter.

M 29 lies in a rich part of the Milky Way, not far from γ Cygni. Stefan Binnewies.

M 30

Degree of difficulty	3 (of 5)
Minimum aperture	30mm
Designation	NGC 7099
Type	Open cluster
Class	V
Distance	29,460 ly (R2005) 30,730 ly (CMD, 1999)
Size	100 ly
Constellation	Capricornus
R.A.	21^h 40.4^{min}
Decl.	–23° 11'
Magnitude	7.3
Surface brightness	–
Apparent diameter	12'
Discoverer	Messier, 1764

History

On the 8th of August 1764, Charles Messier found a "nebula" in Capricorn and noted: "It can be seen with difficulty in a simple refractor of 3½ ft; it is round & does not contain any star, 2' diameter."

In 1783, with his superior home-made reflectors, William Herschel was able to resolve M 30 into individual stars. He noted: "Towards the north are two rows of bright stars, four or five in a line." Almost 50 years later, his son John commented in more detail: "Fine cluster; irregularly round, with two projections at its northern side. One is directed from the central brightness and consists of three or four bright stars of 12th magnitude; its position taken with micrometer is 350.4°; the other originates in the preceding side of the center, and is directed in a position 331.7° in a line not passing the center; diameter 6', stars of 12th magnitude; has a star of 9th magnitude preceding it." Smyth, observing with a significantly smaller aperture (5.9 inches) than John Herschel, described: "A fine pale white cluster. This object is bright, and from the straggling streams of stars on its northern verge, has an elliptical aspect, with a central blaze; and there are but few other stars, or outliers, in the field."

Astrophysics

The globular cluster M 30 lies at a distance of 30,000 light-years from us, below the galactic plane. Its orbit around the galactic center is inclined at 50° to the galactic disk and it takes 160 million years to complete. This incline makes the distance of M 30 from the galactic center vary between about 10,000 and 25,000 light-years.

The true diameter of M 30 measures about 100 light-years, and its total mass has been estimated to be 300,000 solar masses. The stars in the core of M 30 are very densely packed, since this globular cluster has already suffered a core collapse (see M 15), a dynamical process in which the central star density of the cluster grows dramatically.

At least 13 variable stars are known in M 30, including a dwarf nova. Only two other globular clusters, M 5 and NGC 6712, have a variable of this rare type, but the radial velocity and the color now give reason to doubt the cluster membership of this object. Furthermore, two pulsars (see M 28) were discovered in M 30 in 2004, with periods of 11 and 13 milliseconds.

There is an unusually large number of "blue stragglers" in M 30. In its 20"central region, they constitute 25% of the stars, more than in any other cluster, the central region giving an unusually blue color. These stars appear to be younger and more massive than the normal cluster stars, although all the stars of the globular cluster are supposed to have formed at the same time. It is generally assumed, therefore, that "blue stragglers" developed more recently, by the merging of two stars or by mass-transfer in a close binary system. The more frequent occurrence of such stars in the dense core regions of globular clusters, especially in the super-dense core of M 30, seems to support at least the merger hypothesis.

Observation

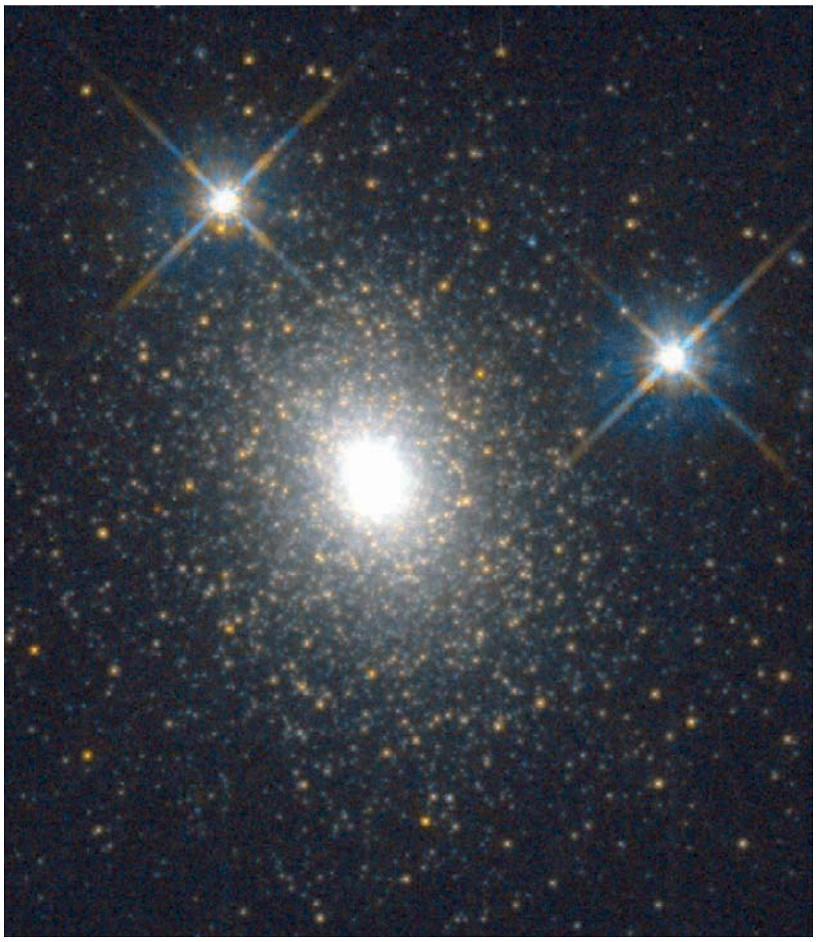
Even though M 30 can be seen with binoculars as a small nebulous ball, it remains a tough object to observe in small telescopes. Resolution into individual stars is unsuccessful, unless at least 6 to 8 inches of aperture are available. The strongly concentrated center remains nebulous even then. There is an 8th-magnitude star 7' west of M 30. The lines of stars mentioned by Herschel are well visible: one leaves the cluster center to the north, the other runs in parallel to it, northwest of M 30, and misses the cluster center. In a 14-inch telescope, the cluster's total visual size is 4', while its unresolved core has 1' diameter.

M 30. Its richness in “blue stragglers” gives this globular cluster a bluish hue. Daniel Verschatse.

M 31

The Andromeda Galaxy

Degree of difficulty	1 (of 5)
Minimum aperture	Naked eye
Designation	NGC 224
Type	Galaxy
Class	Sb
Distance	2.57 Mly (H2000) 2.53 Mly (PN, 2000) 2.58 Mly (Cepheids, 2003) 2.59 Mly (RR Lyr, 2004)
Size	160,000 ly
Constellation	Andromeda
R.A.	0^h 42.7^{min}
Decl.	+41° 16'
Magnitude	3.4
Surface brightness	22.8mag/arcsec^2
Apparent diameter	3,5°×1°
Discoverer	Al Sufi, 964



M 31. G 1 is the brightest globular cluster of M 31. It lies 2.5° southwest of the core of its mother galaxy. Hubble Space Telescope.

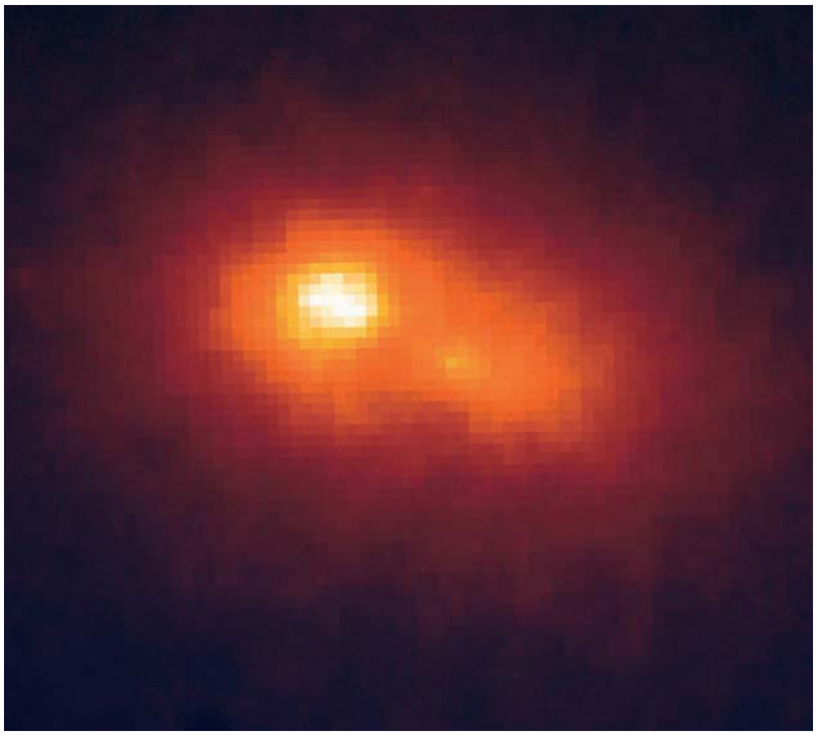
History

Around the year 964 AD, the Persian scholar Abd-al-Rahman Al Sufi was the first to make a note of a "small cloud" in the constellation Andromeda. However, this nebula may well have been known to Persian astronomers by 905 AD or earlier.

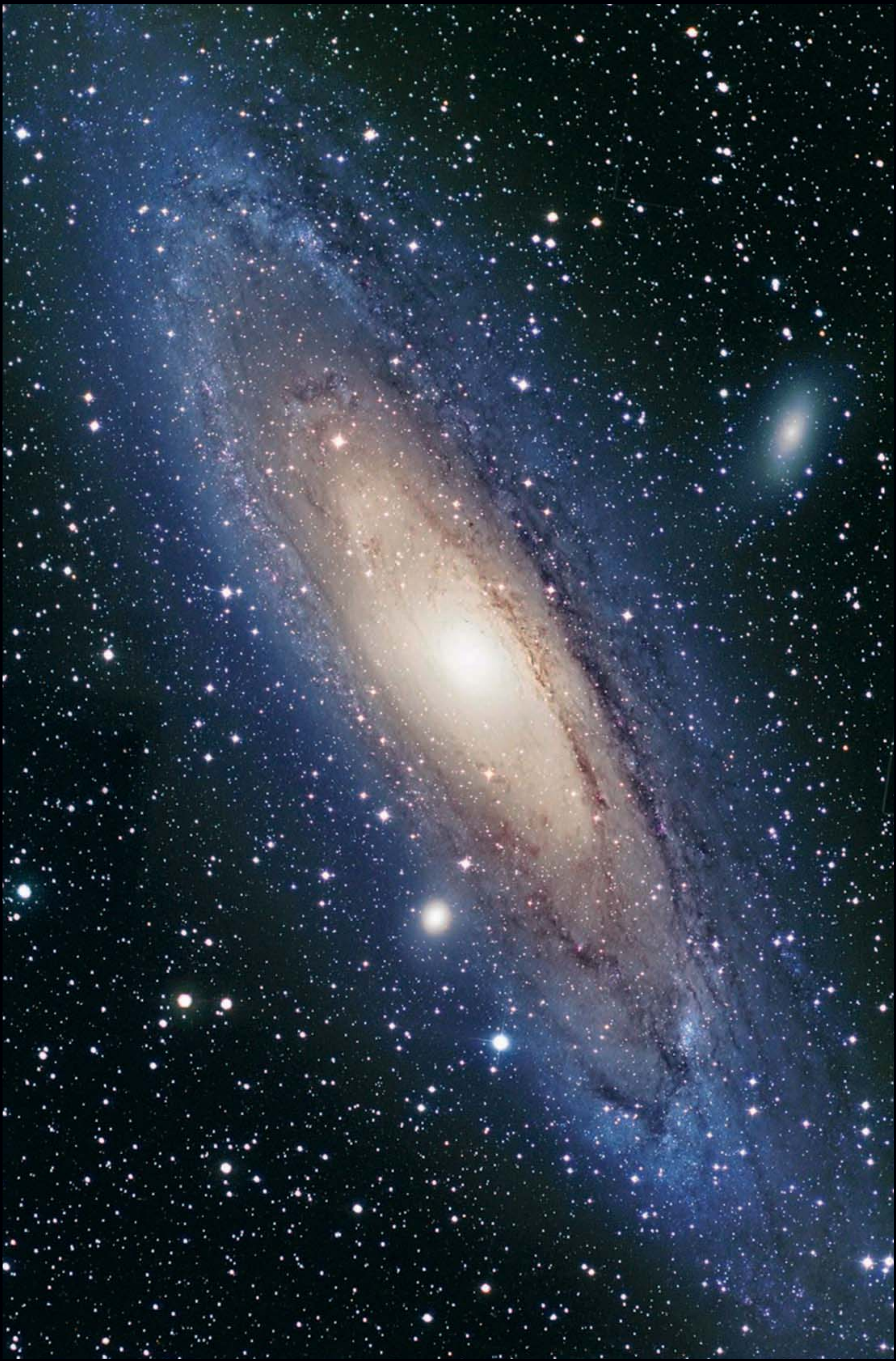
These early medieval observations were long forgotten, when in 1612, just after the invention of the telescope, Simon Marius tried out his small refractor in Gunzenhausen, Germany. His rediscovery of M 31 may well be considered as an independent discovery of the nearest spiral galaxy. He wrote: "looks like a candle flame seen through transparent horn. No stars can be seen, only glimmering rays which are brighter closer to the center." Since Marius' observation was not known to later observers either, we may also consider Hodierna (1654) and Bullialdus (1661) as independent discoverers.

From today's perspective, it is not obvious why a telescope should have been necessary to discover M 31. But before the invention of the telescope, naked-eye nebulae were virtually unknown (except for M 44, the prototypical "nebulosa"), and there was simply no interest in this kind of phenomenon. Hence, M 31 may well have been seen by other pre-telescopic astronomers, but it was plainly ignored as not being important to them.

Charles Messier observed M 31 several times and also produced a drawing. His note from the 3rd of August 1764, reads: "The beautiful nebula in the girdle of Andromeda, in the shape of a spindle; it resembles two cones or pyramids of light, facing each other at their bases, with an axis directed from northwest to southeast; the two points

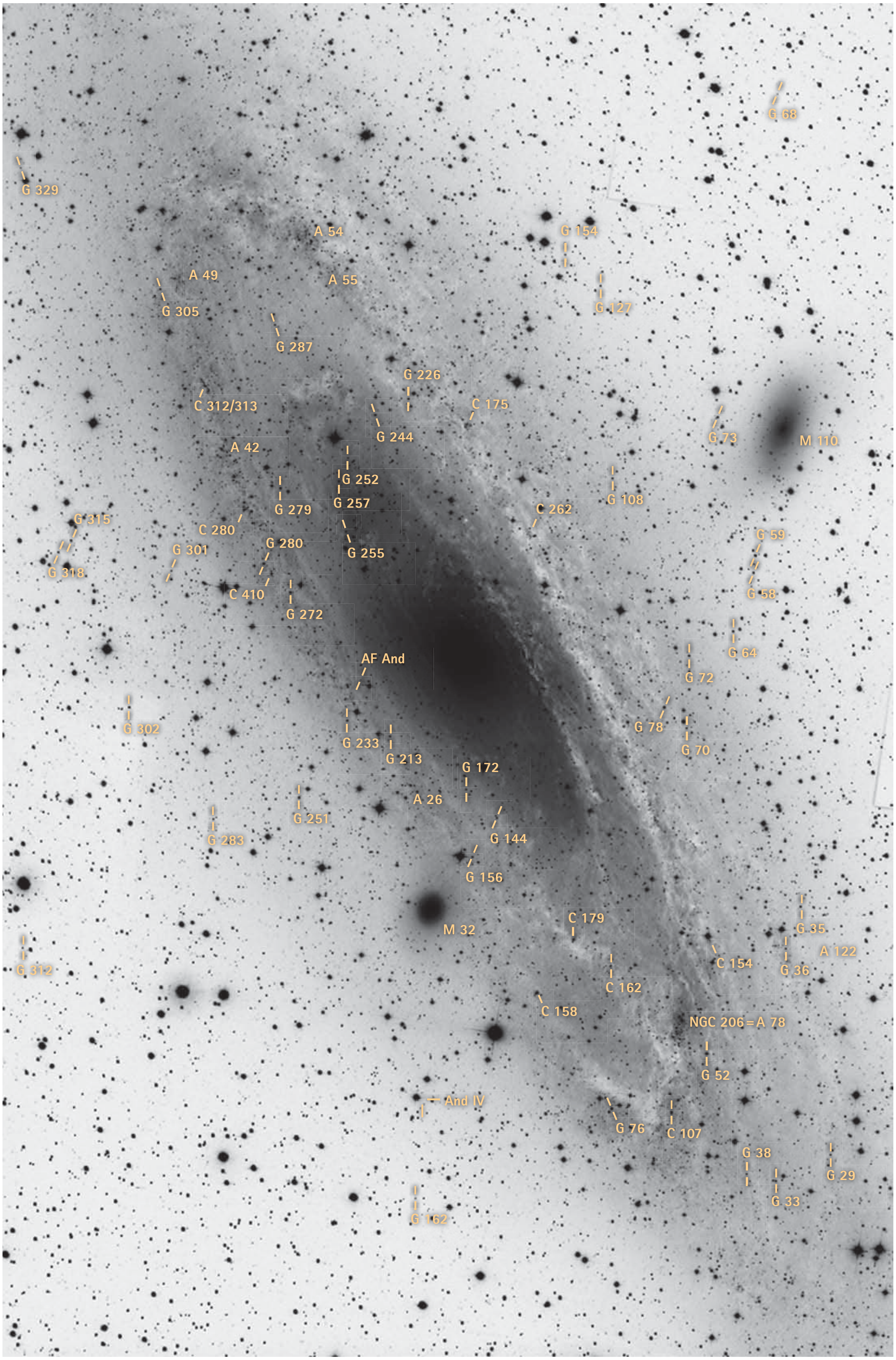


M 31. The core of the Andromeda Galaxy has an unusual double structure. Hubble Space Telescope.



M 31. Our neighboring galaxy, 2.5 million light-years away, is one of the most impressive objects in the night sky. This photograph shows it with its two companion galaxies M 32 (below the center) and M 110 (above right). Cord Scholz.

M 31. Detailed photograph of NGC 206 and the southern region of the galaxy. Cord Scholz.


G 68
G 329
A 54
G 154
A 49
A 55
G 305
G 127
G 287
G 226
C 312/313
C 175
G 244
G 73
M 110
A 42
G 252
G 257
G 279
G 108
C 262
G 315
C 280
G 280
G 255
G 59
G 301
G 318
C 410
G 272
G 58
G 64
AF And
G 72
G 302
G 78
G 233
G 213
G 70
G 172
A 26
G 251
G 283
G 144
G 156
C 179
M 32
G 35
C 154
A 122
G 312
G 36
C 162
C 158
NGC 206 = A 78
G 52
And IV
G 76
C 107
G 38
G 29
G 33
G 162

M 31, drawing. 14-inch Newtonian. Ronald Stoyan.

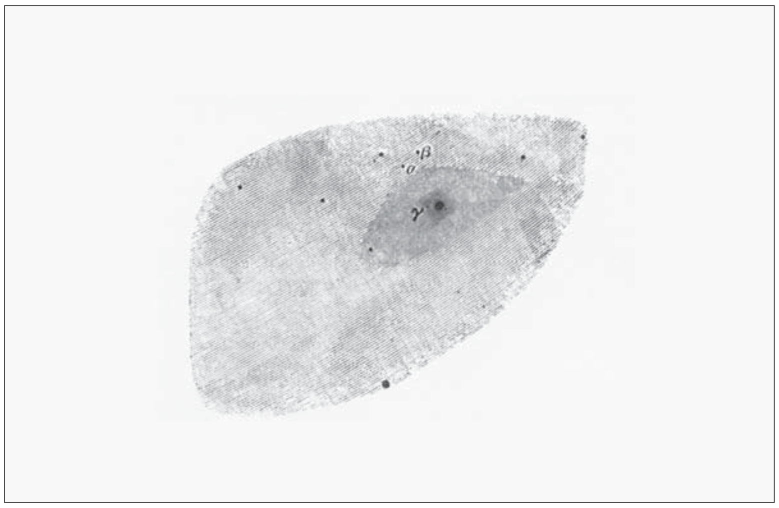
of light or apices are about 40' apart; the common base of the two pyramids 15'." In the description of the elongation, however, Messier was confused about the true direction.

In 1785, William Herschel prophetically supposed M 31 to be a "sister of the Milky Way," but his distance estimate of 2000 times that of Sirius was far too small. He described M 31 as "undoubtedly the nearest of all the great nebulae. Its extent is more than a degree and a half in length, and in even one of the narrowest places, not less than 16' in breadth."

Smyth very appropriately spoke of a "milky irresolvable nebulosity." while Lord Rosse thought he recognized individual stars. Leo Brenner had the same impression at the beginning of the 20^{th} century, after observations with his 6-inch refractor: "With magnification 660× uncountable tiny stars 13^{th} to 15^{th} magnitude distributed all over the field of view, like fine sand over a grey marble plate. Although I have observed this nebula many times before and afterwards, only that one time did I achieve this resolution, from which can be concluded that it is possible only under exceptionally good seeing conditions and a telescope of especially fine quality."

The true distance and nature of the "nebula" M 31 became clear only in the following years. In 1912, Slipher measured an approaching radial velocity of 300 km/s, which made it obvious that this was an extragalactic object. But the first distance measurement had to wait until 1923, when Edwin Hubble discovered the first cepheids in M 31. Then it was finally clear that the Andromeda Nebula and many other similar spiral nebulae represent milky ways of their own.

Curtis wrote in 1918, based on the first set of photographs: "This wonderful object, the largest of the spiral nebulae, is too well known to need description. Exposures of 1min to 3min show an almost stellar nucleus, with traces of spiral structure in the surrounding nebular matter."



M 31, historical drawing of the core region. R. Mitchell and Lord Rosse (1857).

Astrophysics

M 31 is regarded as the best-studied galaxy of all. Its proximity and inclination allow consistent studies of various classes of objects, which in our own galaxy are hidden behind the dense interstellar dust in the galactic disk.

With a diameter of about 160,000 light-years, the spiral galaxy M 31 is significantly larger than our Milky Way, but it seems to be less massive. A recent study by Evans et al. (2000), who included the halo of M 31, gives it some 700 thousand million solar masses, but this impressive figure is still less than the estimated mass of our own galaxy, some 1000 thousand million solar masses.

There are at least 337 gravitationally bound globular clusters around M 31, and a further 688 have been listed as candidates. G 1 (Mayall II), the brightest of the M 31 globular clusters, was closely studied with the Hubble Space Telescope in 1994. An estimated number of stars, magnitude 22.5 and brighter, is 300,000, and a mass of as much as 14 to 17 million Suns has been derived. This makes G 1 a giant compared to the globular clusters in our Milky Way. It has a distance from the center of its parent galaxy of 170,000 light-years and a strong ellipticity of 0.2. Consequently, some authors suspect that G 1 is actually the remnant-core of a dwarf galaxy that was cannibalized by M 31.

M 31 possesses an extended system of companion galaxies. Their brightest, M 32 and M 110, are even fellow members of the Messier catalog. Arp discovered a faint light bridge between M 31 and M 32; therefore, this pair has been included in his catalog of interacting galaxies. A past close encounter with M 32 has led to a deformation of the spiral arms in M 31.

Apart from these two Messier objects, NGC 147 and 185 are notable companion galaxies of M 31, and there is a whole family of faint Andromeda dwarf galaxies (And I to IX) – altogether at least 12 companions surround their parent galaxy. And IV has, meanwhile, been discounted as a background object, while And VIII and IX have been found in more recent years. And VIII appears to be located in front of M 31 and near M 32 – it is being destroyed by tidal forces. This case resembles a near companion of the Milky Way, the SagDEG dwarf galaxy (see M 54). It is about 30,000 light-years across and still contains up to 3 globular clusters and 12 planetary nebulae. And IX, on the other hand, is a small and extremely faint dwarf galaxy about 150,000 light-years behind M 31.

In 2004, a very faint object with a surface brightness of only 20mag/$arcmin^2$ was found 3° northeast of M 31. It is possible that this is a distant extension of M 31 that became detached during a close encounter with a companion galaxy, or that it is the remnant of another cannibalized companion.

In 1991, the core of M 31 was studied with the Hubble Space Telescope. This led to the discovery of a double structure with only 0.5" separation, of which the physical core of M 31 forms the fainter component. Here, a black hole with a mass of 55 million solar masses has been suggested.

So far, only one supernova has been observed in M 31: on the 20^{th} of August 1888, Ernst Hartwig found a 6^{th}-magnitude new star, using the famous Fraunhofer-refractor in Dorpat. This star, today known as S Andromedae, dimmed to magnitude 16 by February 1890 and was the first supernova observed in another galaxy. In 1989, the 4m Mayall Telescope was able to identify the supernova remnant of that star. However, novae are quite common, with several objects recorded each year.

Of the approximately 35,000 known variables in M 31, the classical cepheids deserve special interest, because their period-luminosity relation allows the distance to M 31 to be determined, which is an important step in the cosmological distance ladder. Since the first studies of Hubble 1921, this value has changed several times. The currently assumed distance of 2.5 million light-years is significantly larger than early distance estimates for M 31, which were based on an incorrect calibration of the cepheid relation.

Observation

M 31 is the only extragalactic object in the northern sky that is visible to the naked eye without any difficulty. It is fascinating to imagine its vastly larger distance of 2.5 million light-years in comparison to the "only" few hundred light-years of its foreground stars in our Milky Way. The central regions of M 31 can be seen as a nebulous star even under mediocre skies with a limiting magnitude of at least 5.0; only badly light-polluted urban sites do not show it. In a dark, clear mountain sky, M 31 becomes a truly impressive, 3.5°×1°, large oval nebula. A faint star of magnitude 6.9 southeast of the southern galaxy's edge is a good marker when estimating the visible length of the Andromeda Galaxy.

In good binoculars and rich-field telescopes, the visible length of M 31 can reach even 4° or more. In 1953, Robert Jonckheere noted the impressive total extent of 5.2°×1.1°, perceived with his 50mm binoculars.

The most obvious feature of M 31 is the bright star-like nucleus, which is visible in small telescopes – especially with higher magnification. Around it, suburban skies show only a 1°-long, oval nebula without any further detail. A dark sky, however, reveals that this is only the well-defined central region of a galaxy that's three times as large. Its edge is particularly distinct towards M 110. With 3 inches of aperture or more, the inner dust lane becomes vaguely visible there. With prolonged observation, faint structure can be perceived in the outer regions of the galaxy. The most distinct detail there is the star cloud NGC 206 (A 78), which was first noticed by William Herschel in 1786.

Using an aperture of 6 inches and observing patiently over hours, M 31 reveals more structure. NGC 206 turns out to be only the most obvious of many brighter spots, which are separated from each other by dark lanes, that follow the spiral pattern of the galaxy. The most prominent absorption features are the two dark lanes in the northwest side of M 31 and a curved section in its southern half. A 6-inch telescope is also capable of showing the first globular clusters of M 31, i.e. G 213, 272, 280, 78, 76, and 1. G 1 is by far the brightest of these with a magnitude of 13.7, and sightings with only 4 inches of aperture have been reported.

A 14-inch telescope offers so much visible detail in M 31 that several nights are required to record it all. The very bright nucleus remains stellar in appearance. It is surrounded by an elliptical nebula of 10' length with a strong brightness gradient but no other visible detail. 5' and 10' west of the core are two dark lanes, each is 3' wide. These lanes show a large contrast with their bright background, and the brighter region between

Companion galaxies of M 31

Designation	R.A.	Decl.	Mag.	Size	Surface brightness
M 32	$00^h 42^{min} 41.8^s$	+40° 51' 57"	8.1	8.5'×6.5''	10.1
M 110	$00^h 40^{min} 22.1^s$	+41° 41' 07"	7.9	19.5'×11.5'	13.2
NGC 147	$00^h 33^{min} 11.6^s$	+48° 30' 28"	10.5	13.2'×7.7'	14.6
NGC 185	$00^h 38^{min} 57.7^s$	+48° 20' 14"	10.1	11,9'×10,1'	13.7
And I (PGC 2666)	$00^h 45^{min} 39.8^s$	+38° 02' 28"	12.8	2,5'×2,5'	16.0
And II (PGC 4601)	$01^h 16^{min} 29.8^s$	+33° 25' 09"	12.7	3,6'×2,5'	15.9
And III (PGC 2121)	$00^h 35^{min} 33.8^s$	+36° 29' 52"	14.2	4,5'×3,0'	16.4
And V	$01^h 10^{min} 17.1^s$	+47° 37' 41"	15.9	2'	15.9
And VI (Pegasus Dwarf)	$23^h 51^{min} 46.3^s$	+24° 34' 57"	13.3	4'×2'	15.4
And VII (Cassiopeia Dwarf)	$23^h 26^{min} 31.0^s$	+50° 41' 31"	12.9	2,5'×2'	14.6
And VIII	$00^h 42.3^{min}$	+40° 37'	9.1	45'×10'	15
And IX	$00^h 52^{min} 53.0^s$	+43° 11' 45"	–	4'	17.9

A selection of the brightest individual objects in M 31

Designation	Type	R.A.	Decl.	Mag.	Size
G 1	GC	$0^h 32^{min} 46.8^s$	39° 34' 42"	13.8	
G 72	GC	$0^h 40^{min} 52.9^s$	41° 18' 43"	14.9	2.2"
G 76	GC	$0^h 40^{min} 59.0^s$	40° 35' 48"	14.3	3.6"
G 78	GC	$0^h 41^{min} 01.3^s$	41° 13' 45"	14.2	3.2"
G 185	GC	$0^h 42^{min} 44.5^s$	41° 14' 28"	14.5	
G 205	GC	$0^h 43^{min} 09.6^s$	41° 21' 27"	14.8	2.9"
G 213	GC	$0^h 43^{min} 14.4^s$	41° 07' 21"	14.7	2.5"
G 272	GC	$0^h 44^{min} 14.5^s$	41° 19' 20"	14.8	3.4"
G 280	GC	$0^h 44^{min} 29.8^s$	41° 21' 37"	14.2	2.7"
A 42	Ass	$0^h 44^{min} 55.5^s$	41° 30' 2"	16	240"
A 49	Ass	$0^h 45^{min} 34.0^s$	41° 46' 50"	16	180"×120"
A 54	Ass	$0^h 44^{min} 35.2^s$	41° 52' 24"	16	240"
A 55	Ass	$0^h 44^{min} 16.3^s$	41° 48' 58"	16	180"
NGC 206 (A 78)	Ass	$0^h 40^{min} 32.7^s$	40° 44' 31"		250"×90"
A 122	Ass	$0^h 39^{min} 44.4^s$	40° 52' 17"	16	240"×180"
C 107	OC	$0^h 40^{min} 30.4^s$	40° 35' 58"	14.9	
C 154	OC	$0^h 40^{min} 23,0^s$	40° 52' 46"		
C 158	OC	$0^h 41^{min} 45.2^s$	40° 45' 15"	16.5	30"
C 175	OC	$0^h 42^{min} 57.4^s$	41° 36' 39"		
C 179	OC	$0^h 41^{min} 12.0^s$	40° 51' 34"		
C 280	OC	$0^h 44^{min} 44.7^s$	41° 26' 30"		
C 312/3	OC	$0^h 45^{min} 9.0^s$	41° 36' 17"		
C 410	HII+OC	$0^h 44^{min} 25.1^s$	41° 20' 42"	16.0	0,7'
G 253	HII	$0^h 43^{min} 56.0^s$	41° 26' 35"		
AF And	Star	$0^h 43^{min} 33.1^s$	41° 12' 10"	15.3–17.6	

M 31 and M 32. It remains unclear whether the companion of M 31 is actually in front or behind the mother galaxy. Robert Gendler.

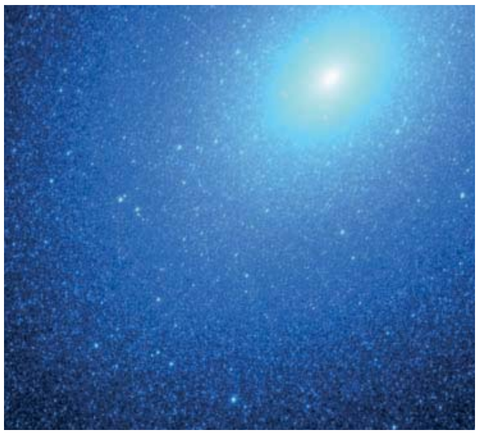
them appears mottled. The inner side of the inner lane, in particular, displays a very ragged small-scale structure. Especially rich in detail is the neighborhood of NGC 206. The bright cloud itself fragments into bright spots when observed with high magnification, and its eastern edge is well defined. The star cloud A 80, 7' south, contains the open cluster C 107, which is visible as a small, elongated spot. Further west lies G 76, one of the brightest globular clusters of M 31. Finally, C 202/3 is a fairly well visible pair of open clusters, 20' south of the galaxy's nucleus.

A lot of detail is present on the northeastern side of the Andromeda Galaxy. Starting from a point 15' east of the core, a chain of bright star clouds reaches 18' northward. Its most noticeable components are A 40, 41, 42, and A 91. The globular clusters G 272 and G 280 are placed in between and appear as tiny nebulous spots. The small, elongated spot of C 410 is found 1.5' south of G 280. It is the brightest HII region of M 31, associated with a star cluster. Another grouping of globular clusters forms an "avenue," starting from near M 110 and trending southeast. It is comprised of G 58, 64, 72, and G 78. Another interesting object is A 54, a relatively bright and isolated star cloud 20' north of the nucleus of M 31. Large apertures resolve internal dark structure in A 54. The blue, luminous variable of the S Doradus type, AF Andromedae, lies about 10' southeast of the nucleus. On average, it is the brightest star of the Andromeda Galaxy, with a magnitude of 16.5.

Two background galaxies shine right through the light of M 31: Markarian 957 and 5Zw 29 are both visible as faint dots of 14th magnitude. The closest companion galaxies of M 31, And I, II, and III, are not visible with a 14-inch telescope, but all three are within reach of a 20-inch instrument.

M 32

Degree of difficulty	3 (of 5)
Minimum aperture	30mm
Designation	NGC 221
Type	Galaxy
Class	E2
Distance	2.57 Mly (see M 31) 2.45 Mly (PN, 2000)
Size	6,500 ly
Constellation	Andromeda
R.A.	0^h 42.7^{min}
Decl.	+41° 52'
Magnitude	8.1
Surface brightness	21.2mag/arcsec^2
Apparent diameter	8,7'×6,5'
Discoverer	Le Gentil, 1749



M 32. The galaxy has been resolved into individual stars by the Hubble Space Telescope.

History

M 32 was discovered on the 29th of October 1749, by Guillaume-Joseph-Hyacinthe-Jean-Baptiste Le Gentil de la Galaziere. The Frenchman describes the discovery: "While observing the Andromeda Nebula with a fine telescope of 18 feet [focal length], I saw another, small nebula, about 1' diameter, which appeared to throw out two small rays, one to the right, one to the left." Charles Messier had already observed M 32 in 1757, but the description in his catalog is dated the 3rd of August 1764: "Small nebula without stars, round, 2' diameter." Much later, working with much larger apertures, John Herschel characterized this galaxy, by contrast: "Extremely bright; pretty large; there is a brighter middle to a star of 10th magnitude; 40" diameter; a small star follows it [east] 11.5s." Heinrich d'Arrest found M 32 "almost circular, brighter toward center, core resembles a star of 10th magnitude."

Evaluating M 32's appearance on his photographic plates, Curtis commented: "Exceedingly bright. In the long exposures it appears as a 'burnt-out' oval of 2.6'×1.8', with no trace of spiral character in the outer portions. The shortest exposures show a nucleus which is nebulous, surrounded by bright nebular matter far brighter than the brightest parts of the nebula in Andromeda."

Astrophysics

Like M 110, M 32 is a physical companion of the Andromeda Galaxy – apparently close to it, just 22' south of the core of M 31. The real separation in space, however, is not known, but it is certainly larger than the visual impression suggests. Unfortunately, it is not unambiguously clear, whether M 32 stands in front of or behind M 31, from our perspective. The latest studies seem to suggest a location behind the parent galaxy.

M 32 is an elliptical dwarf galaxy of only 6500 light-years diameter and about 3 thousand million solar masses. Its minor axis is shorter by 20% than the major axis (in PA 163°). This small galaxy probably owes its survival in the gravitational field of M 31 to its very compact core region. A super-massive object of 2.5 million solar masses has been suspected in the core of M 32, from which X-ray emission was confirmed only recently. Bekki et al. (2001) have proclaimed that M 32 was once a spiral galaxy, of which only the central bulge survived the last encounter with M 31.

The stars of M32 have ages of 4 to 8 thousand million years, which is quite old, but their range of metallicities includes larger values, by contrast to that of globular clusters. There is very little dust and gas left in this dwarf galaxy, which explains the stalled star formation, and it has lost its globular clusters. Only a few planetary nebulae are known. The central star density reaches a remarkable 1500 stars per cubic light-year. An observer on the edge of M32 would enjoy a marvellous night sky, half of which would be richly populated with the stars of M 32, and the other half filled with the Andromeda Galaxy in all its splendor.

The astrophysical characteristics of M 32 are those of the core of an elliptical galaxy. This supports the idea that this galaxy was much larger originally, but has since lost much of its mass in a close encounter with M 31. This is consistent with the observed deformations of the spiral arms of M 31.

On the 31st of August 1998, the Lick Observatory survey program discovered a nova of magnitude 16.5, only 35.7" southwest of the core of M 32. Another two were found recently – on the 5th of January 2004, by J.D. Neill, at magnitude 17.2 and 1.5' northeast of the galaxy core, and by F. Manzini on the 27th of July 2006, at magnutide 17.2, located about 1' northwest of the nucleus. At the time of writing, no supernova has yet been observed in M 32.

Observation

Of all the companion galaxies of the Andromeda Nebula, M 32 is the one easiest to see – even in 8×30 binoculars. However its visual impression remains that of a fuzzy star of magnitude 8.1, even in small telescopes at low power.

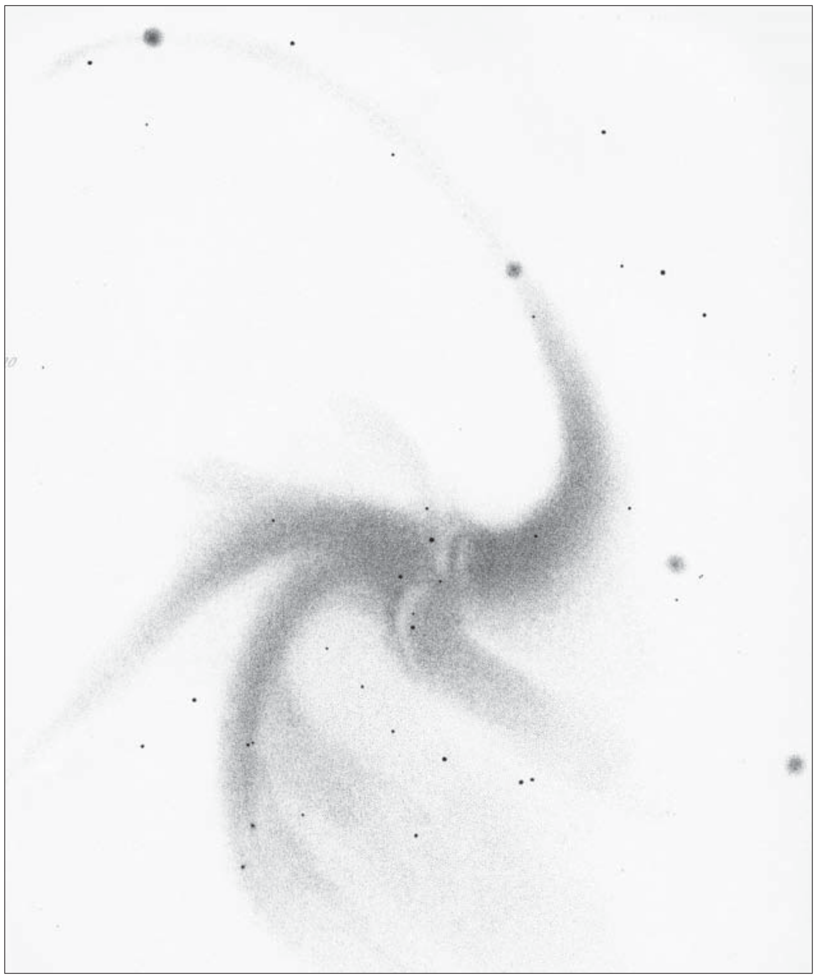
An aperture of 14 inches shows an oval nebula, elongated 4'×3' in north-south direction with a core of stellar appearance. M 32 is entirely emerged in the bright background of M 31, which makes it difficult to determine a total visual diameter.

A faint globular cluster of the M 31 system, G 156, lies 6.3' northwest of M 32. With a magnitude of 15.6, it takes a 20-inch telescope to show it as an apparent star.

M 33

The Triangulum Galaxy

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 598
Type	Galaxy
Class	Sbc
Distance	2.74 Mly (H2000) 3.06 Mly (PN, 2004) 2.76 Mly (CMD, 2004) 2.62 Mly (Cepheids, 2002)
Size	60,000 ly
Constellation	Triangulum
R.A.	$1^{h}\ 33.9^{min}$
Decl.	+30° 48'
Magnitude	5.7
Surface brightness	23.1mag/arcsec^2
Apparent diameter	71'×42'
Discoverer	Messier, 1764



M 33, historical drawing. R. Mitchell and Lord Rosse (1851).

History

M 33 may have been observed sometime before 1654 by Giovanni Batista Hodierna, but his notes are ambiguous and may not refer to this object. We know with certainty about the observation of Charles Messier on the 25th of August 1764, with a 3-inch reflector at 44×: "The nebula has a whitish light of nearly even density, however a little brighter for two-thirds of its diameter, does not contain any star. Seen with difficulty in a simple refractor of 1 foot. 15' diameter." William Herschel studied M 33 at length and discovered NGC 604, the bright emission nebula in the northern spiral arm. His son John characterized M 33 as "enormously large. The diffused nebula extends 15' south and as much nearly to the north. It has irregularities of light, and even feeble subordinate nuclei and many small stars." He also recognized a 12th-magnitude star northeast of the core.

Smyth was using 5.9 inches of aperture and saw "a large and distinct, but faint pale white nebula with a bright star a little north preceding [northwest], and five others following [east] at the same distance, between which and the object, there is an indistinct gleam of mere nebulous matter."

In 1850, Lord Rosse studied M 33 intensively by means of detailed drawings. He explained: "This figure represents the central portion of a very large nebula. The nebula itself has not been sufficiently examined, but as yet no other portion appears to have a spiral, or indeed any regular arrangement. The sketch is not very accurate, but represents sufficiently well the character of the central portion."

Heinrich d'Arrest, too, studied M 33 in detail, and he found the brighter knots NGC 588, 592, and 595. The discovery of NGC 603 is attributed to Lord Rosse, but this object has since been classified as a foreground double star and it is not a physical part of M 33.

Curtis had his first deep exposures of M 33 at his disposal when he wrote in 1918: "A close rival to the Nebula of Andromeda as the most beautiful spiral known. With its faintest extensions it covers an area at least 55'×40'. 588, 592, 595, and 604 are simply brighter portions of 598. It is uncertain whether there is an actual stellar nucleus. A multitude of stellar condensations in the whorls; the spiral which furnishes the best known example of 'resolution' into stars."

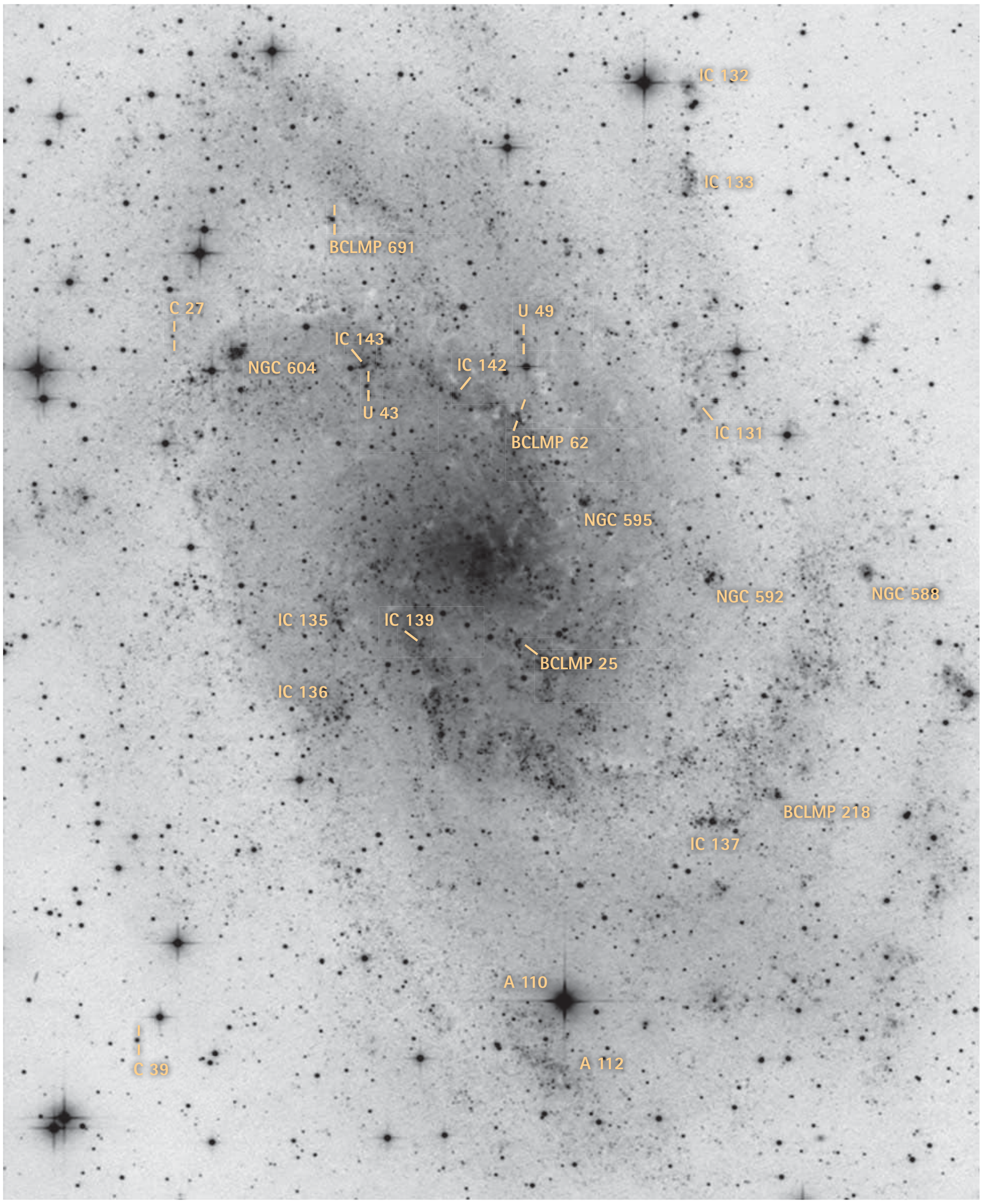
Astrophysics

M 33 is one of the nearest galaxies to us and a member of the Local Group of galaxies. Its mass of 10 to 40 thousand million solar masses appears small by comparison with M 31 and the Milky Way, but M 33 is still the third largest in the Local Group of galaxies. It even has a companion of its own, the dwarf galaxy LGS 3.

A study of classical cepheids in M 33 with the Hubble Space Telescope in 1991 has confirmed that this galaxy is slightly more distant

M 33 is a spiral galaxy of the Local Group that impresses the visual observer as much as the photographer. Cord Scholz.

than the Andromeda Galaxy, M 31. While the latter is about 2.5 million light-years away from us, the values derived for M 33 lie between 2.6 and 3.1 million light-years. Considering the respective uncertainties, a best distance measure of 2.74 million light-years is obtained.



M 33 has a main diameter of 50,000 light-years, up to 60,000 light-years including extensions. As seen from our vantage point, this galaxy is spinning clockwise, taking about 200 million years for one revolution. The Hubble Space Telescope was able to resolve the central region of M 33. There is no super-massive object at its center, as seen in other galaxies. Rather, the core was resolved into several massive luminous star clusters with an apparent brightness of 14^{th} magnitude and a mass of about 10,000 solar masses. Two different generations of stars are found here: a young one with an age of 40 million years, and a relatively old one, of one thousand million years. Furthermore, the central region of M 33 hosts a binary with a black hole, which represents the strongest continuous X-ray emitter in the Local Group, as well as a luminous blue supergiant just 1" north of the galaxy core.

The integrated light of the galaxy M 33 appears blue, due to numerous star-forming regions with young stars, mingled with nebulous HII regions. The most prominent object of this kind is NGC 604 in the northern spiral arm of M 33. It is one of the largest HII regions known. Its true diameter of 1500 light-years would make it reach from the Earth to the Orion Nebula, which would be dwarfed beside this huge gas cloud. The Hubble Space Telescope has discovered more than 200 massive stars within that have just formed, with 15 to 120 solar masses each. They form a massive, very young star cluster that has already started to erode the nebula. Cavities have been formed in less than 3 million years.

Sarajedini and Mancone cataloged 451 star cluster candidates in M 33, of which 255 are confirmed clusters. Until the present day, no supernovae have been observed in M 33. We know about 350 cepheids and several novae. By 2007, more than 37,000 stars in the field of the galaxy had been checked for variability with the Spitzer Space Telescope, and 2923 variable stars attributed to M 33 were found. About 70 individual stars of M 33 exceed an apparent brightness of magnitude 17.7. These include about a dozen irregular, luminous blue variables (LBVs) with very large masses and a maximum brightness of 14.5. The best-known example is "Romano's star," 17' northeast of the galaxy core (magnitude 16.5p–17.8p). By comparison, the brightest of the 20 or so globular clusters of M 33 reaches an apparent brightness of magnitude 15.9.

Observation

M 33 can be regarded as the most distant object visible to the unaided human eye, if exceptional sightings of M 81 and M 83 by a very few individuals are not counted. A total visual brightness of magnitude 5.7 together with a total visual extent of 20' to 30' result in a very low surface brightness for M 33. Most of the disk has only 23.1 mag/arcsec^2. This is comparable to the surface brightness of a very good night sky with limiting magnitude 6.8. Therefore, the naked-eye visibility of M 33 depends on a very clear, very dark sky, and even then it is just a spooky nebulous patch that requires indirect vision.

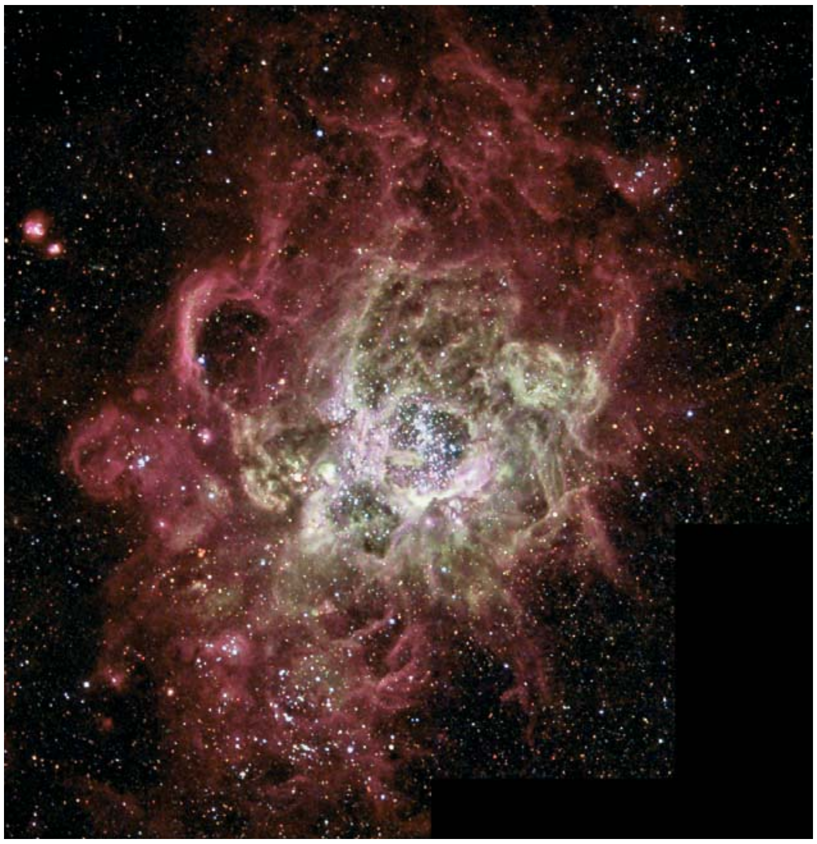
In binoculars, M 33 becomes a distinct large nebulous patch with a hint of an extension to the northeast, the brightest spiral arm. Under a dark sky, its real spiral structure is revealed even by telescopes with 3 to 6 inches used at low power. Under mediocre skies, however, M 33 remains a diffuse nebula without contrast even in large telescopes.

A 4.7-inch refractor shows M 33 with enough detail to keep the observer busy for a long time. At least two diffuse spiral arms start from a small but extended core. The most distinct arm runs 7' north, and then turns east. It reaches out to the 1'-wide, bright spot of NGC 604, located 13' northeast of the galaxy's core. A narrowband filter enhances the emission nebula, and it can then be seen with only 2.5 inches of aperture. The southern spiral arm appears more diffuse and more mottled. It has a width of about 5', and its brightest part is 10' southwest of the core, where a star marks its southern edge. With 4.7 inches of aperture, there is a hint of other spiral arms between these two main arms, but it takes 14 inches to see them clearly. The visual extent of M 33 rises from 30' with 4.7 inches of aperture to 45' with 14 inches.

A 14-inch telescope reveals fantastic fine structure within M 33. This galaxy breaks up into an unusually richly detailed object, hardly matched by any other in the sky. The southern spiral arm is now resolved into two

Individual objects in M 33

Designation	Type	R.A.	Decl.	Magnitude	Size	Alternate designation
NGC 588	HII	$1^h 32^{min} 45.7^s$	+30° 38' 54"	11.5	39"	BCLMP 280
BCLMP 218	HII	$1^h 33^{min} 0.7^s$	+30° 30' 51"	11.9	27"	A 128
NGC 592	Ass	$1^h 33^{min} 12.0^s$	+30° 38' 45"	13.0	105"	BCLMP 277, A 59
IC 131	HII	$1^h 33^{min} 15.0^s$	+30° 45' 05"	12.5b	33"	BCLMP 290A
IC 133	Ass	$1^h 33^{min} 15.8^s$	+30° 53' 03"	12.2	27"	BCLMP 623
IC 132	HII	$1^h 33^{min} 16.0^s$	+30° 56' 40"		40"	
NGC 595	HII	$1^h 33^{min} 34.0^s$	+30° 41' 30"	13.1	63"	BCLMP 49, A 62
IC 137	Ass	$1^h 33^{min} 38.8^s$	+30° 31' 21"		45"	BCLMP 204, 205
A 112	Ass	$1^h 33^{min} 40^s$	+30° 20' 54"			
A 110	Ass	$1^h 33^{min} 42^s$	+30° 22' 52"			
BCLMP 62	HII	$1^h 33^{min} 44.8^s$	+30° 44' 47"	11.2	33"	A 66
BCLMP 25	Ass	$1^h 33^{min} 45.0^s$	+30° 36' 28"	13.3	21"	A 48
U 49	GC	$1^h 33^{min} 45.1^s$	+30° 47' 46"	16.2		
IC 142	HII	$1^h 33^{min} 55,8^s$	+30° 45' 20"	14.2	30"	BCLMP 301
IC 140	HII	$1^h 33^{min} 58.1^s$	+30° 33' 00"			
IC 139	HII	$1^h 33^{min} 59.3^s$	+30° 34' 31"	13.9b		u.a. BCLMP 8a, A 4 5
U 62	GC	$1^h 34^{min} 10.1^s$	+30° 45' 29"	16.5		
IC 143	Ass	$1^h 34^{min} 11.1^s$	+30° 46' 39"	11.4b	20"	BCLMP 688
IC 135	HII	$1^h 34^{min} 15.5^s$	+30° 37' 10"		35"	BCLMP 88, A 95, 96
IC 136	Ass	$1^h 34^{min} 15.9^s$	+30° 33' 40"	11.0b	35"	BCLMP 711, A 101
BCLMP 691	HII	$1^h 34^{min} 16.4^s$	+30° 51' 55"	14.1		
NGC 604	HII	$1^h 34^{min} 33.0^s$	+30° 47' 00"	11.5b	117"	BCLMP 680
C 27	GC	$1^h 34^{min} 43.7^s$	+30° 47' 38"	16.5		
C 39	GC	$1^h 34^{min} 49.6^s$	+30° 21' 56"	15.9	2"	
Romanos Star	St	$1^h 35^{min} 09.7^s$	+30° 41' 57"	16.5–17.8p		



M 33. NGC 604 is the largest emission nebula of the galaxy. Hubble Space Telescope.

separate strands. The southern branch makes an abrupt turn to the west, about 5' south of the core, near the star associations A 4 and A 5. Nearby IC 136 is a star cluster embedded in the star cloud A 10. Further to the west lies IC 137, a very elongated region with a foreground star superimposed on its center. Its surroundings glow with a nebula filter, and so does the clump of A 128, northwest of IC 137. There are several fainter clouds further south, including A 110 / 112 just south of the bright foreground star 18' south of the galaxy's core.

The northern spiral arm appears much more compact and brighter than its southern counterpart. The bright, round cloud of NGC 595 lies a little outside the western part of the arm. With a narrow-band filter, its enhanced glow can be seen even with 4.7 inches of aperture. Following the arm to the northeast, we find A 66 south of a foreground star. Then turning east, there are IC 142 and IC 143, which jointly form a 5'-long stretch at the northern edge of the spiral arm. Further east we come to NGC 604, the absolute highlight of the region. A nearly horseshoe-shaped arrangement around a darker central region is shown vaguely by a 14-inch telescope, and distinctly in a 20-inch. About half a dozen individual star clusters and supergiants can be distinguished. After passing a field star, the northern spiral arm ends with A 85 further east.

M 33, drawing. 14-inch Newtonian. Ronald Stoyan.

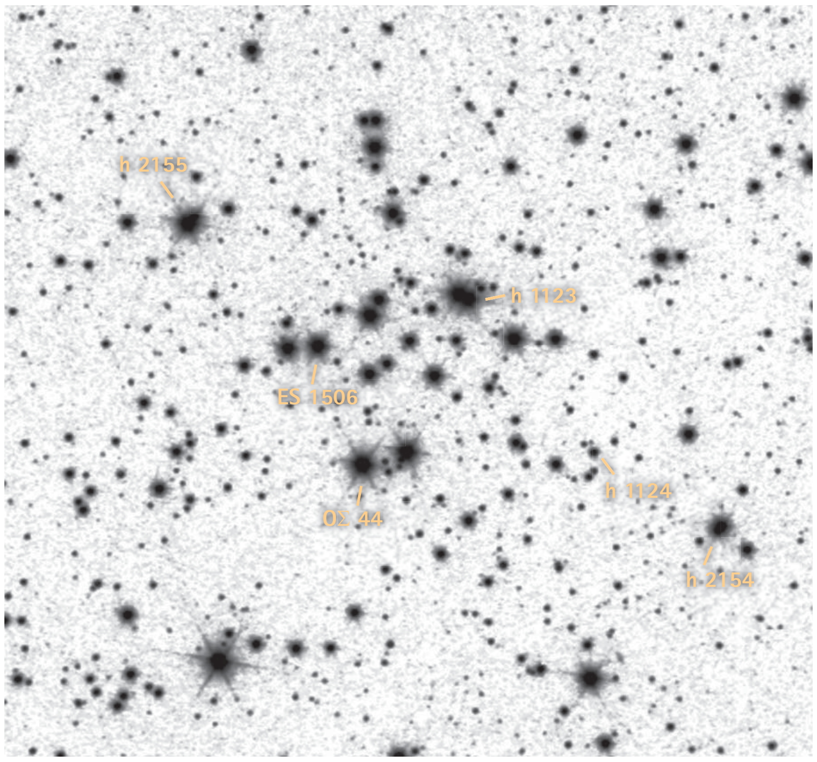
The northwestern part of the galaxy shows only a few bright islands on a faint background, when observed with the 14-inch telescope. The most distinct objects are NGC 592, a star cluster that disappears when viewed through a nebula filter, with a faint individual star at its southern edge, and NGC 588, a quite bright nebula with a core of stellar appearance. The diffuse region A 131 lies southwest of NGC 588 and has a bright foreground star west of it. The two small spots of A 28 and IC 131 can be found north of NGC 592. The isolated regions of IC 132 (further north) and finally IC 133 are found 18' northwest of the core of M 33. The former nebula is emphasized by a narrow-band line filter. There are two faint stars directly south of it.

The core of M 33 appears asymmetric, with a bright protrusion pointing south. A nucleus of nearly stellar appearance marks the center, and there is a foreground star just north of the core.

The brightest individual stars (magnitude 15.8) and globular clusters of M 33 are in reach with a 20-inch telescope, and so is Romano's star at the eastern edge of the galaxy. The brightest globular cluster, C 39 (magnitude 15.9), was seen as slightly non-stellar by Jakiel; five fainter clusters are near the limit of a 20-inch telescope and appear stellar.

M 34

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 1039
Type	Open cluster
Class	II3r
Distance	1630 ly (K2005) 2040 ly (2004) 1630 ly (proper motion, 2002)
Size	17 ly
Constellation	Perseus
R.A.	2^h 42.0^{min}
Decl.	+42° 47'
Magnitude	5.2
Surface brightness	–
Apparent diameter	35'
Discoverer	Messier, 1764



Bright double stars in M 34

Designation	Magnitudes	Separation	PA
h 1123	8.0/8.5	19.7"	248°
OΣ 44	7.9/8.5/8.3	1.4"/86.3"	55°/290°
h 1124	8.0/11.6	16.6"	151°
ES 1506	8.9/14.0	5.7"	
h 2154	8.9/11.3	8.7"	141°
h 2155	8.3/10.3	16.8"	322°

History

M 34 may have been observed by Giovanni Batista Hodierna before 1654, but the identification is uncertain. This cluster was seen with certainty by Charles Messier on the 25th of August 1764, as a "cluster of small stars; with a simple refractor of three foot the stars can be distinguished, 15' diameter." John Herschel called M 34 a "fine cluster, fills field," and he counted "about 20 stars of 9th, 10th...11th magnitude, and as many fainter." Brenner gave the rather large number of 117 stars down to magnitude 9 and said M 34 would be "best seen with weak magnification, nice object even for a 2-inch telescope."

In 1983, Eigen found out that the spatial proper motion of M 34 coincides with that of M 44, NGC 2516, IC 2602, and Mel 20. He called this kinematic group a "local association of star clusters."

Astrophysics

M 34 is one of the looser Messier clusters with a total of about 100 stars down to magnitude 16. Its core region measures only 8 light-years, about twice the distance from the Sun to α Centauri. In total, the cluster has a diameter of 17 light-years, at a distance of 1600 light-years. The brightest member star is magnitude 7.3, has a spectral type of B8, and is 275 times the luminosity of the Sun. In 1957, van Hoerner gave the cluster an age of 110 million years, but contemporary studies put it at 225 million years.

M 34 has a few close double stars. In 2003, 17 out of 94 member stars were resolved as close pairs with separations between 0.09" and 6.4". However, it remains unclear which of these double stars are, indeed, physical binaries. Two variables of the γ Doradus type have also been found, which have brightness changes caused by nonradial pulsations.

Observation

To the naked eye, M 34 is visible as a distinct nebulosity, although it has the same total brightness as the difficult to observe M 33. This difference is due to the low surface brightness of M 33, while the brightest stars of M 34 reach almost 7th magnitude.

Small binoculars begin to show the first dozen stars, and large 70mm binoculars achieve full resolution of this cluster. A 2.5-inch telescope shows 30 stars, while in 12 inches of aperture not more than 100 stars in a loose distribution are visible.

The faint (magnitude 14.4) planetary nebula Abell 4 (PK 144–15.1) lies 40' east of M 34. A 14-inch telescope shows a round disk; with an [OIII] filter, the ring structure can be seen vaguely. The faint edge-on background galaxy CGCG 539-91 (PGC 2201333) is only 48" southeast of Abell 4 and almost seems to touch it. So far, attempts to observe it visually have not been successful.

M 34 is one of the nearest star clusters in the Messier catalog. Stefan Seip.

M 35

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 2168
Type	Open cluster
Class	III3r
Distance	2710 ly (K2005) 3590 ly (2004) 2940 ly (CMD, 2003) 2660 ly (proper motion, 2002)
Size	22 ly
Constellation	Gemini
R.A.	$6^h\ 8.9^{min}$
Decl.	+24° 20'
Magnitude	5.1
Surface brightness	–
Apparent diameter	28'
Discoverer	de Chéseaux, 1746

History

The star cluster M 35 was discovered in 1745 or 1746 by Phillippe Loys de Chéseaux. However, the observations of this Swiss observer were not published. The Englishman John Bevis made an independent discovery of this cluster before 1750. That observation was known to Charles Messier, when he noted on the 30th of August 1764: "Cluster of very small stars, near the left foot of Castor, at little distance from the stars μ & η of this constellation."

Smyth calls M 35 a "gorgeous field of stars from the 9th to the 16th magnitudes" and remarks: "the small stars being inclined to form curves of three or four, and often with a large one at the root of the curve." John Herschel, using a much larger aperture and a smaller field of view, was a little less impressed with the view: "A large, coarse, pretty rich cluster of stars of 9th to 16th magnitude, which fills 2 or 3 fields, but chiefly one in which are about 100 stars."

Lassell, observing with an aperture of 24 inches, commented: "field of view is perfectly filled with brilliant stars, of exquisite beauty." Lord Rosse counted about 300 stars in a field of 26'. A century ago, Leo Brenner remarked: "Splendid object, in particular in larger scopes. The entire field of view of 20' is littered with stars of 8th to 12th magnitude, all very close to each other."

Astrophysics

M 35 has 20 member stars down to an apparent brightness of 10th magnitude, and 120 to 13th magnitude. To the 21st magnitude, there are about 2700 stars that might physically belong to M35. The most luminous of all, and with magnitude 7.5 the brightest cluster star, has 700 times the solar luminosity and is a blue-white giant of spectral type B3. The same hot spectral type is found with the second-brightest star, which is magnitude 8.2. The earliest spectral types of the genuine main-sequence stars in M 35 are B6 and B7, with magnitudes 8.8 and 9.2. In addition, there are some yellow and orange giants, spectral classes G and K, which have already left the main sequence. Instead of hydrogen, they are now burning helium in their cores. The brightest example is a K0 giant with magnitude 8.6 and 250 solar luminosities. Matching stellar evolution models suggest a young cluster age of about 100 to 150 million years, rather than the sometimes quoted 200 million years.

In 2002, von Hippel and colleagues discovered a faint, 21.4-magnitude white dwarf in M 35, which should be unusually massive, not so far from the Chandrasekhar stability limit of 1.44 solar masses, if it has the same young age as the cluster. In 2004, Korean astronomers found two variables in M35: one eclipsing binary with a normal brightness of magnitude 16.4, and one δ Scu [Scuti] type variable with a brightness variation between magnitude 16.8 and 17.2.

According to the most recent publications, M 35 should have a distance of 2700 light-years but, not long ago, in 2004, 3600 light-years was derived. The former value results in a physical cluster diameter of 22 light-years, and in a mean star density of three stars per cubic light-year. The interstellar absorption is a moderate 0.5 magnitudes.

Directly southwest of M 35, we find the very compact open cluster NGC 2158, which was discovered by William Herschel. At its much larger distance of 12,000 light-years, it is already at two thirds of the distance to the edge of the Galaxy and one of the most distant galactic objects which we can observe. The total brightness of NGC 2158 is magnitude 8.6 over an angular diameter of 5'. The brightest of its approximately 1000 stars reach magnitude 12.5 and suffer from a still moderate extinction of 1.5 magnitudes.

A very great age of 2 thousand million years is attributed to NGC 2158 – it owes its long survival to its richness and compactness, and it is one of the oldest known open clusters in the Milky Way (see M 67). Arp even regarded NGC 2158 as an intermediate type of cluster, in between the globular clusters and the open clusters. Recent studies have identified 57 variables in the field of NGC 2158, including a cataclysmic star with an amplitude of 2.5 magnitudes, which, however, is probably not a physical member of this cluster.

Observation

On dark winter nights, M 35 is easily visible to the naked eye as a full-moon-size patch of nebulosity. 3.5×15 opera glasses begin to resolve the cluster into 20 to 30 stars.

This open cluster is so dense that, even with a 2-inch telescope, some nebulous impressions persist due to the many unresolved stars. There is a noticeable chain of stars, 6' long and curved, in the northern part of the cluster. The northern end is marked by the double

M 35 forms an impressive cluster pair with NGC 2158, which is five times farther away. Robert Gendler.

star ADS 4744 (ΟΣ 134), with components of magnitude 7.3 and 9.1, separated by 31" in PA 188°.

In a 4.7-inch refractor, over 100 stars are seen, distributed over a diameter of 28'. With larger aperture, extensions appear which boost the total visual cluster diameter to 1°. A region void of stars in the center, below the curved star chain, attracts the attention of the observer.

A 2-inch telescope shows NGC 2158, the much more distant open cluster southwest of M 35, as a distinct nebula. A magnitude 10.5 star lies southeast, and larger apertures reveal two fainter companions directly north. A 4.7-inch refractor begins to resolve the first cluster stars, but the general impression remains that of a nebula, even with significantly larger apertures. An aperture of 14 inches resolves about 20 stars of 12^{th} to 15^{th} magnitude. A straight star chain forms the southern edge of the cluster, and a brighter star lies at its eastern border.

M 36

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 1960
Type	Open cluster
Class	I3r
Distance	4300 ly (K2005) 4240 ly (CMD, 2000)
Size	15 ly
Constellation	Auriga
R.A.	5^h 36.1^{min}
Decl.	+34° 8'
Magnitude	6.0
Surface brightness	–
Apparent diameter	12'
Discoverer	Hodierna, 1654

History

M 36 was discovered before 1654 by the Sicilian observer Giovanni Batista Hodierna as a "nebulous patch." However, his observations were soon forgotten and his notes were rediscovered only in 1984. For this reason, le Gentil must be considered a true independent discoverer of this cluster, which he found in 1749. Messier made his observation on the 2nd of September 1764, and wrote: "Cluster of stars in the Charioteer, with a simple refractor of 3½ foot the stars are barely discerned, the cluster does not contain any nebulosity. 9' diameter."

John Herschel called M 36 a "very pretty object which fills the field." Smyth described it as "the device of a star whose rays are formed by very small stars." D'Arrest must have had a similar impression when he wrote: "extremely rich and pretty cluster. Originating from the center, many stars are arranged in three thin spirals."

Leo Brenner recommended the observation of M 36 to his fellow amateur observers, about 100 years ago, with the words: "very large, rich and bright, consisting of somewhat scattered stars of 8th to 10th magnitude, which include the double star Σ 737 of 8th and 9th magnitude stars, separated 10.6". A rewarding object even for 3-inch telescopes and low magnifications."

Astrophysics

M 36 is the least rich of the three Messier clusters in Auriga. Only 178 stars are regarded as physical cluster members. The brightest star (magnitude 8.8) is a blue giant with the early spectral type B2 and 360 times the solar luminosity. All of the other bright stars are also spectral type B, and there are no red giants in M 36.

Therefore, the cluster's age is thought to be as young as 20 to 40 million years.

At its distance of 4300 light-years, M 36 is located at the outer edge of our local spiral arm. At the same distance, not far away, we find the Auriga OB-association of young, jointly formed stars, spanning a space of 560 by 260 light-years. The brightest member of that association is χ Aur with magnitude 4.7. However, it remains unclear whether the formation history of M 36 is connected in any way with the Auriga OB-association.

Some of the stars in M 36 are very fast rotators, much like the Be stars in the cluster of the Pleiades (see M 45), the best-known young cluster. M 36 is even younger, and it seems to share some morphological aspects with the Pleiades – but it lies at ten times the distance.

A noteworthy object only 25' southwest of M 36 is the very red carbon star OW Aurigae with an apparent visual magnitude that varies between 12.3 and 13.6.

Observation

M 36 can be spotted with the naked eye as a faint star, but only from sites high in the mountains. Small binoculars show a little nebula, which is resolved into individual stars with 10×50 glasses.

Small telescopes show about 30 stars in M 36, and twice as many are seen in a 4.7-inch refractor. A tight stellar pair in the cluster's center is the double Σ 737 with components of magnitude 9.1 and 9.4, separated by 11". It is well resolved with a 2-inch refractor. Two north-south star chains, east and west of the cluster, appear to frame M 36.

The small, 1' emission nebula NGC 1931 lies 1° west of M 36. A 4.7-inch refractor shows four tightly packed stars in its center. These are the brightest members of the star cluster Stock 9, which is physically associated with NGC 1931.

M 36 shows how the Pleiades would look from ten times the distance. Stefan Seip.

M 37

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 2099
Type	Open cluster
Class	I2r
Distance	4510 ly (K2005) 6720 ly (2004) 4510 ly (proper motion, 2002) 6660 ly (CMD, 2001)
Size	33 ly
Constellation	Auriga
R.A.	5^h $52{,}5^{min}$
Decl.	+32° 33'
Magnitude	5.6
Surface brightness	–
Apparent diameter	25'
Discoverer	Hodierna, 1654

History

M 37 was discovered before 1654 by Giovanni Batista Hodierna, who saw a "nebulous patch." Unaware of Hodierna's observation, Messier made an independent discovery of M 37 on the 2nd of September 1764, and described a "cluster of faint stars, at little distance from the previous [M 36]; the stars are very faint, close, and contain some nebulosity."

Around 1830, Smyth noted enthusiastically: "The whole field being strewed as it were with sparkling gold-dust; and the group is resolvable into about 500 stars, from the 10th to the 14th magnitudes, besides the outliers." John Herschel, too, saw a "very fine large cluster, all resolved into stars of 10th to 13th magnitude. It fills 1½ fields, but the straggling stars extend very far. There may be 500 stars." Heinrich d'Arrest even believed he saw "wonderful loops and curved star patterns," while Mädler remarked: "no particular compression can be noticed toward the middle."

Leo Brenner described M 37 in detail in his observing guide for amateur astronomers, about 100 years ago: "A splendid object for small scopes. Visible already in small finder scopes as a nebulous star, 24' diameter. The larger the telescope, the more splendid the view. With a 27-inch telescope, I estimated the number of visible stars 10th to 14th magnitude to about 600, but also in a 7-inch we see about 550, and a 4-inch at 120× magnification still shows nearly 500. Stars are more crowded towards the middle."

Astrophysics

With over 2000 member stars, of which 150 are brighter than magnitude 12.5, and 500 brighter than magnitude 15, M 37 is one of the very richest galactic Messier clusters. Color images reveal 35 red giants in M 37, which include the brightest cluster star at magnitude 9.2. The upper end of the main sequence is marked by a moderately young B9 star, which suggests that M 37 is more evolved than M 36 and M 38. This explains the significant population of white dwarfs in this cluster, for which an age of 500 million years has been suggested.

24 variables in M 37 have been cataloged recently by Korean astronomers among 12,000 field stars down to 22nd magnitude, including seven eclipsing binaries and nine δ Scuti variables (see M 44). However the latter may be background objects.

The distance from us is at least 4500 light-years; some recent studies suggest even 6700 light-years. If the latter were true, M 37 would be much further away than M 36, which, however, is commonly believed to be a true, close neighbor in space. Based on a 4500 light-year distance, M 37 still has a very respectable physical diameter of 33 light-years.

Observation

Naked-eye visibility of M 37 requires very good observing conditions. In 10×50 binoculars, the visual impression remains that of a nebula, only the two brightest stars can be glimpsed. It takes 70mm binoculars or a 2-inch telescope with a power of 30× to resolve the cluster into individual stars.

2 to 4 inches of aperture show 40 to 50 stars, arranged in small groups of two or three. M 37 gives a noticeably more concentrated impression than M 36 or M 38. A 4.7-inch telescope shows the brightest cluster star distinctly orange, against a background of about 100 stars.

Larger telescopes bring out the triangular shape of the central cluster region, which has a size of about 16', its tip pointing east. A dark lane appears to separate this tip from the rest of the cluster. A 25' spherical halo of fainter stars surrounds the bright central region.

M 37 is one of the richest star clusters in the Messier catalog. Its brightest star is a red giant, which indicates the advanced age of this cluster. Stefan Seip.

M 38

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 1912
Type	Open cluster
Class	II2r
Distance	3500 ly (K2005)
Size	15 ly
Constellation	Auriga
R.A.	$5^h\ 28.7^{min}$
Decl.	+35° 51'
Magnitude	6.4
Surface brightness	–
Apparent diameter	15'
Discoverer	Hodierna, 1654

History

M 38 was, as the other two Auriga clusters, discovered by Giovanni Batista Hodierna, before 1654, and was described by him as "nebulous patch." Le Gentil, unaware of Hodierna's observations, made an independent discovery in 1749 and recognized M 38 as a star cluster. On the 25th of September 1764, Messier noted: "Cluster of faint stars, at small distance from the two previous clusters [M 36 and M 37], this one is of a squared shape and does not contain nebulosity, if examined with care in a good instrument. Its extent is about 15'.

Admiral Smyth saw "an oblique cross, with a pair of large stars in each arm, and a conspicuous single one at the center," while John Herschel noticed the "irregular figure" and wrote: "large and small stars, very rich." Leo Brenner's description comes astonishingly close to that of Messier: "In one field of view with NGC 1907, 15' diameter, of irregular, rather squared shape, with bright central star, very large and rich, consists of many bright and fainter stars."

Astrophysics

Until recently, it was assumed that M 38 would have a distance of 4200 light-years, like M 36, and be its close neighbor in space, only 150 light-years away. While the interstellar extinction for both clusters is indeed about the same, around 1 magnitude, recent studies have nevertheless corrected the distance of M 38 downwards to 3500 light-years. The true diameter then becomes 15 light-years.

The brightest cluster star (magnitude 7.9) is a G0 giant with 900 times the solar luminosity. If the Sun was placed next to this giant in M 38, it would be seen only as a faint 14th-magnitude star. The G0 giant already burned all the hydrogen in its core into helium, while it was a main sequence star, and it is now burning the helium to carbon. From this, a cluster age of 150 to 200 million years can be derived.

The very compact and small open cluster NGC 1907 is only 30' southwest of M 38. Most sources have suggested a distance similar to that of M 38, which would make these two clusters close neighbors, with perhaps as little as a 30-light-year separation in space. Some authors have also suggested similar ages for these two clusters. But according to the most recent studies, NGC 1907 seems to lie 1000 light-years further away than M 38, closer to M 36 and M 37. Furthermore, this little cluster is about twice as old as M 38. At a 4300 light-year distance, its physical size is only 5 light-years, and its brightest star is magnitude 10.5.

Observation

Like the other Messier clusters in Auriga, M 39 requires the ideal conditions of a clear mountain night to be spotted with the naked eye.

10×50 binoculars show a nebulous patch with glimpses of the first individual stars. Full resolution of this open cluster is achieved with a 2.5-inch refractor.

A 4.7-inch telescope shows a beautiful, rich cluster. Its brightest stars are arranged in the shape of a Greek ϖ, but they may also give the impression of Smyth's cross. To perceive the yellowish color of the brightest star at the northeastern edge of the cluster and of several other cluster stars, larger apertures are required.

Nearby NGC 1907 appears as a little nebulous but granulated cloud with a 4.7-inch telescope; a few stars can be glimpsed. An aperture of 14 inches resolves this cluster into a dense swarm of 11th- to 13th-magnitude stars at high magnification, while low power still shows a nebula. There are two bright stars immediately south of it. NGC 1907 is only 5' across and has a total brightness of magnitude 8.2, but it may well be the most beautiful cluster of its constellation.

M 38 (above) is accompanied by NGC 1907 – it remains unclear whether these star clusters form a physical pair. Herrmann von Eiff, Werner Klug.

M 39

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 7092
Type	Open cluster
Class	III2m
Distance	1010 ly (K2005) 1010 ly (Hipparcos, 1999)
Size	9 ly
Constellation	Cygnus
R.A.	21^h 32.2^{min}
Decl.	+48° 27'
Magnitude	4.6
Surface brightness	–
Apparent diameter	30'
Discoverer	Messier, 1764

History

Some sources state that Aristotle had already described this region of the night sky as nebulous in 325 BC. However, without an exact position and with the rich Milky Way all around M 39, we may seriously doubt that he referred specifically to this cluster. Nor was M 39 discovered, as often stated, by le Gentil. In his own words, he wrote about his observation: "At the tip of the tail of Cygnus. It appears to be of a nature different from all nebulae observed so far and to the Milky Way, across which it lies, making a right angle with it. It is a large cloud, wider on one end than the other, the smaller end facing southeast. The cloud is about 6° away from the tail of the Swan, it appears opaque and very dark; it can be seen without a telescope." This may be the first mentioning of the longish dark nebula directly beside M 39, the "Dark Cigar" B 168, one of the most obvious dark nebulae of the Milky Way. Consequently, it was Charles Messier who finally discovered M 39 on the 24^{th} of October 1764. He wrote: "Cluster of stars near the tail of the Swan, 1° diameter." Later observers weren't very impressed with Messier's find: John Herschel called it "very coarsely scattered," Smyth noted "rather splashy field of stars" and Lord Rosse observed "little concentration."

Astrophysics

According to McNamara and Sanders, the galactic open cluster M 39 has only 30 real member stars in the brightness range of 6.8 to 10.0 magnitude, which stand in front of a rich Milky Way background. Hence, 10% to 20% of the stars in the field of M 39 and brighter than 10^{th} magnitude do not physically belong to the cluster. To about 11^{th} magnitude, non-member stars make 80% of the total, and to 12^{th} magnitude this figure becomes 90%. In 1987, Zelwanowa identified 37 additional cluster members in an extended field around M 39 of 5° diameter. In a field of 2° by 2°, Platais found 60 stars down to magnitude 16 with a suggested cluster membership probability of more than 50%. In 2006, 228 stars in the field were studied photometrically to determine variability, which was suspected for 10 stars in the sample.

With its distance of 1000 light-years and diameter of 9 light-years, M 39 is one of the closest and smallest Messier clusters. Hence, the loose character of its visual impression and the large angular diameter are caused by the relative proximity of this cluster.

All bright member stars are still on the main sequence, burning hydrogen in their cores. The star with the earliest spectral type is B9; it is the group's brightest star at magnitude 6.6. Without exception, the rest of the bright stars are of the later spectral type A. This leads to an age estimate for M 39 of 240 to 280 million years.

In the older literature, values for the total cluster brightness between magnitude 5.2 (Glyn Jones) and 6.0 (Gray) can be found. The commonly accepted value at present is 4.6.

Only 40' northwest of M 39 is the faint open cluster Platais 1 with about 40 stars all fainter than 12^{th} magnitude in a field with a 10' diameter. Among its members is the cepheid V1726 Cyg [Cygni], which has a period of 4.2 days and a rather small brightness change between magnitudes 8.87 and 9.06.

Observation

To the naked eye, M 39 appears as a brighter spot within the rich and structured Milky Way around it. The smallest optical instrument resolves individual stars in this open cluster.

The outline of the cluster is triangular in shape. With a small telescope, a very uneven stellar pair in the center and a curved star chain south of it are noticeable. A nice view of M 39 requires more than 1° of field, which makes large telescopes unsuitable. Two double stars in M 39 are suitable objects for amateur telescopes:

Double stars in M 39

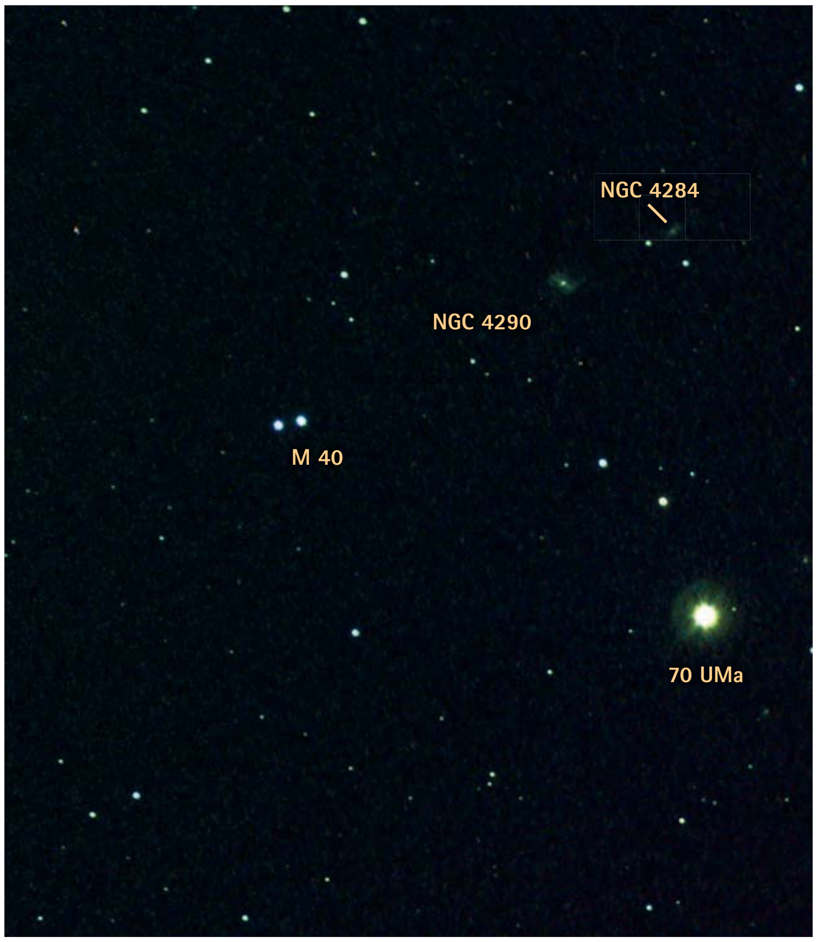
Designation	Magnitudes	Separation	P.A.
h 1657	9.4/12.5	21.6"	18°
A 770	8.8/11.3	7.0"	40°

Obvious to the naked eye, but a splendid object for large binoculars, is the dark nebula Barnard 168, 3° east of M 39. This dust cloud has the shape of a large cigar, 120'×20' in P.A. 120°, seen in stark contrast with the bright Milky Way background. Its eastern, slim and well-defined end hosts the Cocoon Nebula (IC 5146). This faint object is physically embedded in the dust cloud. Its observation requires at least a 4.7-inch refractor and an Hβ line filter.

M 39 with Platais I (above right). Stefan Seip.

M 40

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	WN 4
Type	Optical double star
Class	–
Distance	1860 ly, 490 ly (2002)
Size	–
Constellation	Ursa Major
R.A.	$12^h\ 22.4^{min}$
Decl.	+58° 5'
Magnitude	9.0/9.3
Surface brightness	–
Apparent diameter	53"
Discoverer	Messier, 1764



M 40 is not a real object but a coincidental alignment of two stars at very different distances. Dietmar Böcker.

History

M 40 stands out as the most odd object in Messier's list: just a stellar pair! The Frenchman came across it on the 24th of October 1764, while searching for one of the "nebulous" objects, which the brewer and astronomer Hevelius had reported to have seen with his very long, tubeless telescopes from Danzig (Gdansk, Poland). Although Messier was not sure he really found Hevelius' object, and despite not seeing any nebulosity, either, he nevertheless added that stellar pair to his list. He wrote: "Two stars very near each other and very faint, they are barely distinguished with a simple refractor of 6 feet [focal length]."

For a long time, M 40 was believed to be lost, until in 1966 John Mallas came up with the correct identification as the double star Winnecke 4. The German astronomer Friedrich August Theodor Winnecke cataloged it in 1863 in Pulkova as his No. 4 in a list of seven newly discovered double stars, without knowing its identity coincided with M 40. He measured its separation as 49.16", PA 88.02°.

Today, we also know that M 40 it is not identical to Hevelius' object, now known to be single star 74 UMa, which is over a 1° away:

Hevelius: 12h 30min, +58° 27'

Messier: 12h 22min, +58° 5'

Neither of these two purely stellar objects has any nebulosity and there are no sufficiently bright galaxies in their neighborhood. It remains a mystery as to why Hevelius should have seen a nebula there.

Astrophysics

M 40, or Winnecke 4, is a chance alignment of two stars which form a close, optical pair, as stated by Richard Nugent in 2002. In fact, the Hipparcos parallax measurement gives the pair of a K0 star and a G0 star a distance of 510 light-years, from which follows a spatial separation of at least 5000 AU, too much for a physical binary. Additionally, the observed quite large change of the position angle suggests, given this large distance, an optical pair of stars.

It is well known, meanwhile, that the standard procedure of Hipparcos parallax measurements leads to systematic errors with binaries and other objects close to each other in the sky. This may well be the case with M 40 (see M 73): according to the spectroscopic study undertaken by Nugent, the two stars have very different distances, i.e., 1860 and 490 light-years, which clearly rules out any physical connection between them.

According to more recent (1991) measurements, the position angle has decreased to 77°, and the separation increased to 53", since Winnecke's measurement. Star A (magnitude 9.0) has been cataloged as HD 238107, star B (magnitude 9.3) as HD 238108.

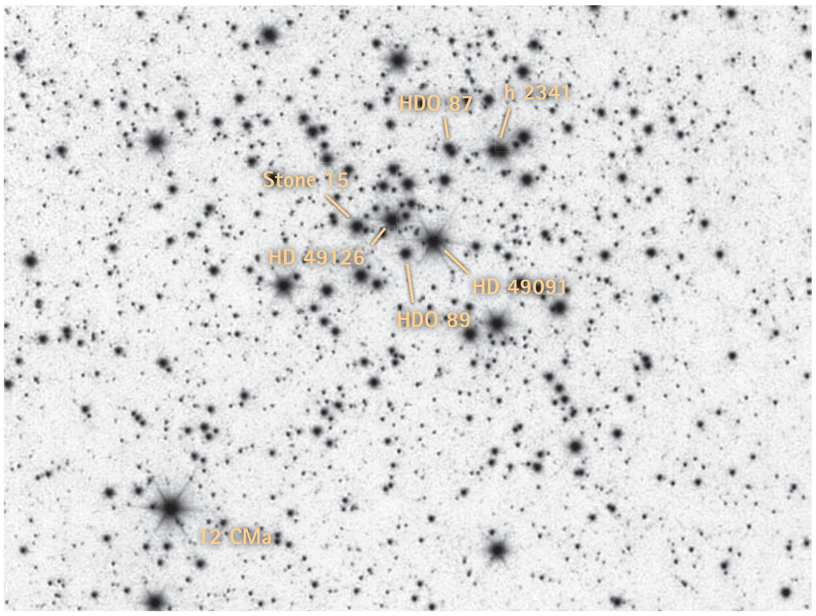
A noteworthy object 12' west of M 40 is the 12.5-magnitude galaxy NGC 4290. Photos reveal a small barred spiral, whose distance to us is about 125 million light-years.

Observation

M 40 is well resolved in 10×50 binoculars, without giving any impression of a nebulous character. Worth mentioning for telescopes over 8 inches aperture are two background galaxies: NGC 4290, 12' west, and even fainter NGC 4284, 17' west.

M 41

Degree of difficulty	1 (of 5)
Minimum aperture	Naked eye
Designation	NGC 2287
Type	Open cluster
Class	I3r
Distance	2260 ly (K2005) 2260 ly (proper motion, 2002)
Size	26 ly
Constellation	Canis Major
R.A.	6^h 46.0^{min}
Decl.	–20° 45'
Magnitude	4.5
Surface brightness	–
Apparent diameter	40'
Discoverer	Hodierna, 1654



History

John Ellard Gore pointed out that M 41 may be the longest-known deep-sky object, of all: a passage in Aristotle's Meteorologica from the year 325 BC says: "One of the stars of the Dog had a tail, though a dim one: if you looked hard at it the light used to become dim, but to a less intent glance it became brighter." Without doubt, the antique scholar here describes the phenomenon of 'averted vision' but the identification with M 41 remains unclear because of the ambiguous positional information. A.A. Barnett suggested that the Milky Way near δ CMa could have been referred to instead.

There is proper evidence, however, for the discovery observation by Hodierna in 1654, and for the independent discoveries by Flamsteed in 1702, and by Le Gentil in 1749. Messier observed M 41 on the 16th of January 1765, and commented: "Star cluster below Sirius, this cluster appears nebulous in a refractor of 1 foot, but it is only a cluster of faint stars." This remark indicates that Messier's refractor of 1-foot focal length must have been a very simple chromatic spyglass telescope of poor quality.

Much later, Webb noticed the reddish star in the cluster's center. Otherwise, however, very little attention was given to this cluster. This also reflects in the description given by Curtis, based on his photographic images: "A large, very coarse and sparse cluster, about 25' in diameter."

Astrophysics

The open cluster M 41 is dominated by several red giants of spectral types G and K, with apparent brightnesses in the magnitude range of 6.9 to 8.0. The brightest of these is a K3 giant (HD 49091) with 700 times the solar luminosity. By contrast, the brightest main sequence star in M 41 (HD 49126) has a spectral type of B8 and a slightly variable brightness of magnitude 7.2 to 7.3. Age estimates of the cluster based on this upper end of the main sequence yield 190 million years. In terms of total life span, cluster properties and dynamics suggest a life expectancy of 500 million years for M 41, before it will have disintegrated.

Among the stars brighter than 12th magnitude in the field of M 41, cluster membership was confirmed for 70 stars, leaving an equal number of field stars. The bright star 12 CMa nearby, southeast of M 41, is not a cluster member. This blue giant of spectral type B 7 has a distance of only 670 light-years and is clearly a foreground star.

Up to 80% of the cluster stars may be bound in binaries, a remarkably large fraction. The interstellar extinction towards M 41 is only about 0.2 magnitudes, which is very low for a distance of 2300 light-years. Based on that distance and an angular size of 40', the physical diameter of the cluster is 26 light-years. An alleged physical connection with Collinder 121, 4.6° southeast of M 41, does not exist, since Collinder 121, in fact, lies much further away, at a distance of 3500 light-years.

Observation

On dark nights, M 41 can be seen with the naked eye without difficulty as a nebulous patch, 4° due south of Sirius. Even 3.5×15 opera glasses show the brightest stars in it, and 10×50 binoculars fully resolve this open cluster.

With a telescope, the bright orange giant star in the center stands out. Closer inspection yields several more reddish stars. The strong visual impression of M 41 is lost at higher magnification, which shows just a rich star field. But a bright stellar pair northwest of the center attracts attention. This is h 2341 with components of magnitudes 8.3 and 9.1, separated by 45". Among the other double stars, the following are worth mentioning:

Double stars in M 41

Designation	Magnitudes	Separation	PA
HDO 89	10.0/11.0	5.2"	40°
HDO 87	10.0/11.5	8.0"	81°
Stone 15	9.6/9.6	2.6"	142°

M 41 may have been known since antiquity. Stefan Seip.

M 42

The Great Orion Nebula

Degree of difficulty	1 (of 5)
Minimum aperture	Naked eye
Designation	NGC 1976
Type	Galactic nebula
Class	Emission and reflection nebula
Distance	1300 ly (K2005) 1470 ly (2003), 1530 ly (2001)
Size	35 ly
Constellation	Orion
R.A.	5^h 35.3^{min}
Decl.	–5° 23'
Magnitude	3.7
Surface brightness	20mag/arcsec^2
Apparent diameter	90'×60'
Discoverer	Peiresc, 1611

History

M 42, the Great Orion Nebula, was not known to the pre-telescopic observers. Neither do we find hints in the documents of antiquity that would suggest sightings of this nebula with the naked eye. Rather, both Ptolemy and Tycho cataloged, at the position of M 42, a star: θ Orionis.

The Frenchman Nicholas-Claude Fabri de Peiresc was the first to mention this nebula in 1611. By 1609, Galileo Galilei had made a sketch of that star field with his telescope. He counted 80 stars but, mysteriously, did not recognize M 42. However, an independent discovery was made in 1611 by Johann Baptist Cysatus.

The first of a large number of historic drawings of this nebula was made by Giovanni Batista Hodierna in 1654. Two years later, Christian Huygens observed M 42 and described the view with the words: "In the sword of Orion, three stars are rather close to each other. In 1656, when I observed the one of them in the middle with my telescope, twelve stars appeared. Three of them nearly touched each other [the Trapezium] and, together with four other, were shining through a nebula, so that the space around them was brighter than the rest of the sky, which was perfectly clear and dark; it formed the effect of an opening in the sky, through which a brighter region became visible."

Following this first mention of the Trapezium, the fourth Trapezium star was discovered in 1673 by Picard, and confirmed by Huygens in 1684. Le Gentil made a drawing in 1758 and gave the first description of the nebula region named after him and the "wings" of the nebula: "It appears to have the shape of an open claw of an animal. To the west, I observed an extension of light, forming a rectangle: this light is very diffuse. The three stars in a straight line in the 'lower claw' appear entirely detached from the nebula. The four stars in the center appear extraordinarily brilliant."

Charles Messier added the already well-known Orion Nebula to his catalog with an observation made on the 4th of March 1769. Apparently, his motivation was to reach an even number of objects, and to match or perhaps surpass the catalog of 42 objects of Lacaille from the year 1755. His drawing shows, apart from the four Trapezium stars and the three θ^2 stars, further faint stars.

In 1774, studying M 42 was the first observing object for William Herschel with a home-made 6-inch reflector. Later, in 1789, he described it as "an unformed fiery mist, the chaotic material of future Suns" – hardly could this great observer have found better words! Johann Hieronymus Schröter studied the Orion Nebula for many years, using a large mirror made for him by Herschel, and he believed that he saw changes. In 1797 he found a "new, bright but very dull band of light" across the dark bay in the central region of the nebula, which would later receive his name.

John Herschel, too, devoted a lot of attention to M 42. He made drawings of it in 1826 and 1837, to see if he could find any variability. With 18 inches of aperture, he described the appearance of the central nebular masses as "a curdling liquid or surface strewn with flocks of wool – or like the breaking up of a mackerel sky. Not very unlike the mottling of the Sun's disk, only coarser and the flocculi not round but wisps." Lassell formulated his impressions in a similar way: "large heaps of cotton-wool packed one behind another, the edges pulled out so as to be a bit transparent." With a 48-inch telescope on the Mediterranean island of Malta he cataloged many stars in the central region and characterized the nebula as "of pea-green color."

Otto Struve, despite observing from Pulkovo near St. Petersburg, where M 42 never gets higher than 25° above the southern horizon, found numerous variable stars in it. D'Arrest, too, made accurate drawings of the Orion Nebula and was the first to discover the wisps of nebulosity which reach from the three θ^2 stars southward. The most impressive drawing, however, was the work of George P. Bond in the years 1857 to 1865. With an enormous effort and using a 15-inch refractor, he sketched the nebula and measured 1100 stars. Later, Holden tried visual photometry with 26-inch aperture and used an eyepiece-micrometer in order to find variability in the nebular structure – in vain. These efforts became pointless, when Draper presented his first good photograph of the Orion Nebula in 1882.

Visual observers had also turned their attention to the Trapezium. In 1826, Wilhelm Struve found its E-component with the 9-inch refractor of Dorpat, John Herschel the F-component in 1830 with 12 inches. Earlier observers had made the mistake of using magnifications that were too low and so missed out on these faint stars of only 11th magnitude. Some later observers, i.e., Porro, Secchi, and South, even believed they saw up to six more stars, but Burnham proved them wrong in 1888. In that year, the powerful 36-inch Lick refractor allowed new, faint stars to be discovered in the Trapezium: component G by the telescope builder A.G. Clark, and the pair H and the

M 42. The Great Orion Nebula is probably the most beautiful deep sky object in the northern sky. Bernd Liebscher.

extremely faint star X by one of the best visual observers of all time, E.E. Barnard.

Using spectroscopy in 1865, Huggins could show that M 42 was made of glowing gas. In 1880, he further demonstrated that the Trapezium did indeed have a physical connection with the gas masses. Finally, in 1931 Trümpler found the large, hidden cluster of young stars around the Trapezium on deep infrared photographs.

Astrophysics

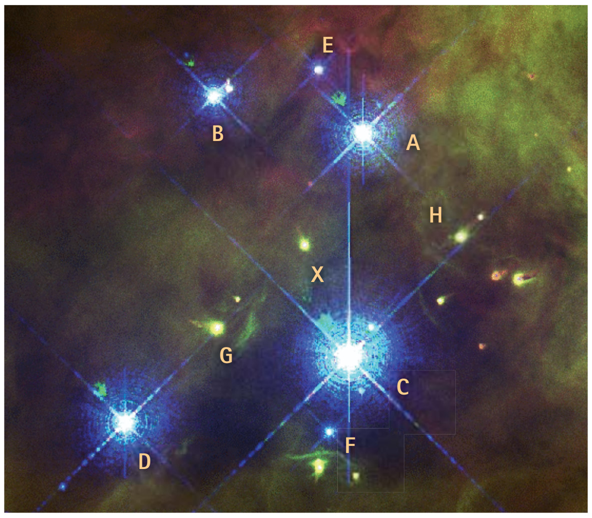
M 42 is the prototype of a galactic nebula and continues to fascinate astronomers – regardless of whether it is observed with a pair of binoculars or with the Hubble Space Telescope. It offers us a view into the glowing cavity of a large molecular cloud, in which stars have just been formed and have started to rid themselves of their surrounding cocoon of dust. Since this is happening at a distance of only 1300 light-years, we have an excellent opportunity to study all aspects of star formation in detail.

M 42 is only the brightest part of the facing side of a much larger (10°), dark cloud: OMC-1, which consists of mostly cool dust and gas. It comprises M 78, NGC 1973/75/77 and the famous Horsehead Nebula. In contrast to those objects, an extremely young (only 10,000 to 100,000 years) star cluster is emerging from M 42. Most of these cluster stars are still enshrouded in the surrounding dust and gas masses of their birthplace.

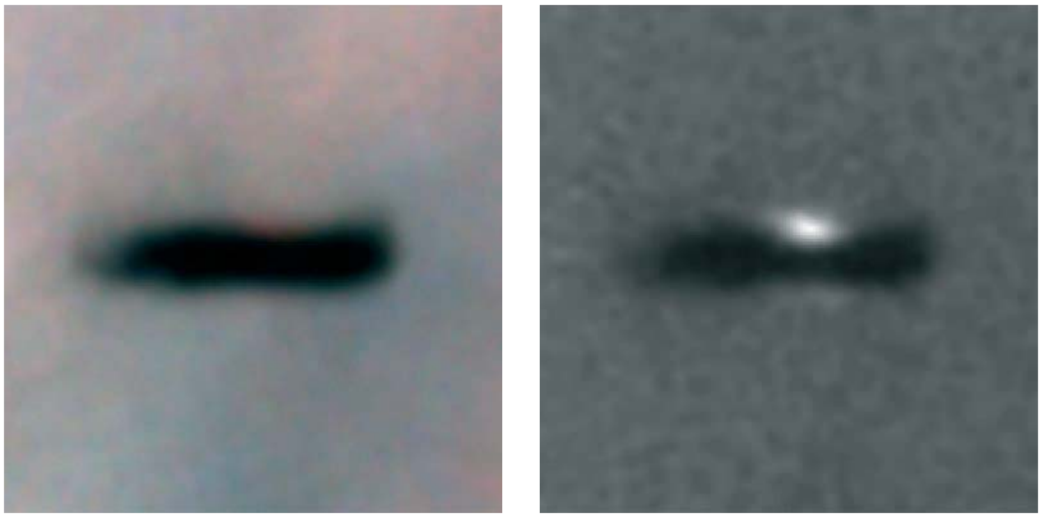
The stars in the Huygens region in M 42

Variable	Designation according to			Magnitude according to*		
GCVS	Struve	Bond	Herbig	Bond	Herbig	Yerkes Obs.
MR Ori	70	635	1885	10.5	10.5	10.3–12.0
MT Ori	75	647	1910	12.1	12.0	11.2(–13.0)
	88	671	1961	11.5	12.3	11.7
LQ Ori	57	575	1771	11.9	13.5	11.8–13.0
AF Ori	78	654	1927	12.3	15.7	11.9–16.1
AC Ori		622	1869	12.7	13.8	12.0–12.9
LV Ori		589	1784	12.7	12.4	12.1–13.3
AE Ori		641	1884	14.8	13.0	12.3–13.3
AD Ori		651	1925	13.1	13.4	12.6(–15)
V494 Ori		676	1973	13.1	13.4	12.7
V348 Ori		618	1862	13.1	13.0	(12.6–)13.3
		612	1842	13.5	13.2	13.3
		636	1893	13.1	–	13.6
		648	1913	14.3	13.9	13.6–14.7
		642	1909	15.6	14.7	14.0–16.6
		631	1896	14.3	13.6	14.1
		602	1826	14.3	13.9	14.2
		608	1844	14.3	14.6	14.4–15.2
		595	1807	13.9	12.8	15.0
		625	1870	15.6	14.5	15.2–16.5
		621	1871	15.6	14.5	15.8
		686	2008	15.6	14.2	–
		688	1992	15.6	13.9	–

*) Brightness determined visually (Bond), photographically (Herbig), and photometrically (Yerkes)

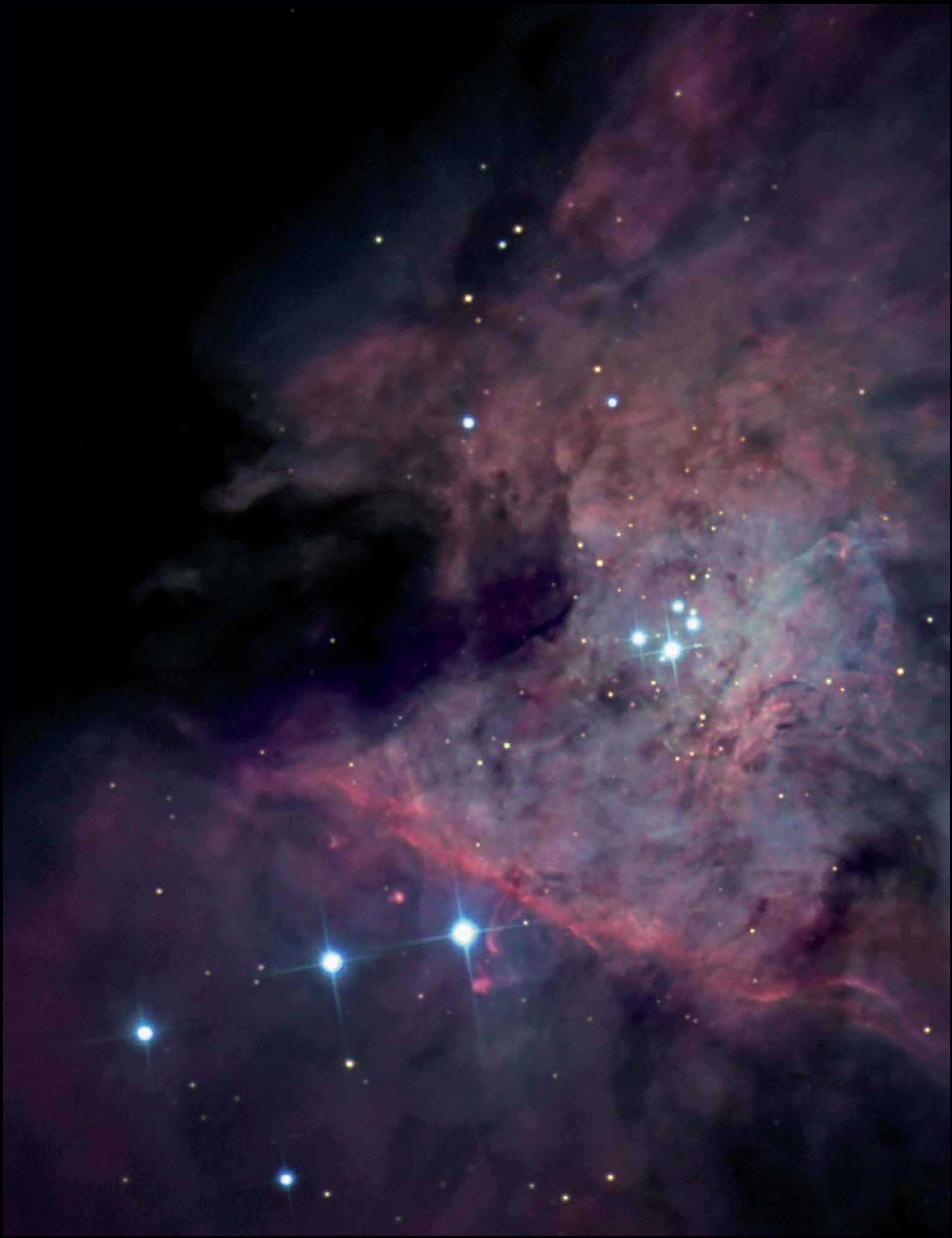


M 42. The Trapezium contains numerous faint components. However, only the two brightest are within the reach of amateur telescopes. Hubble Space Telescope.

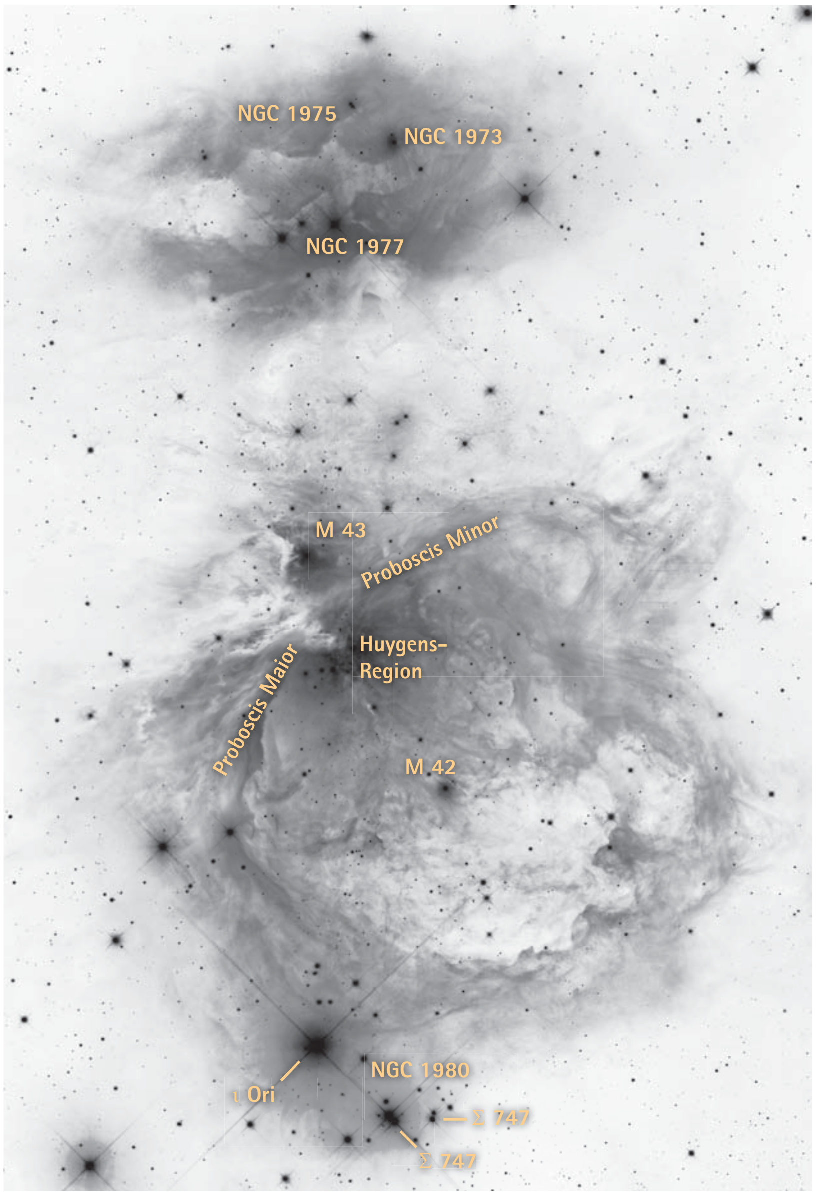


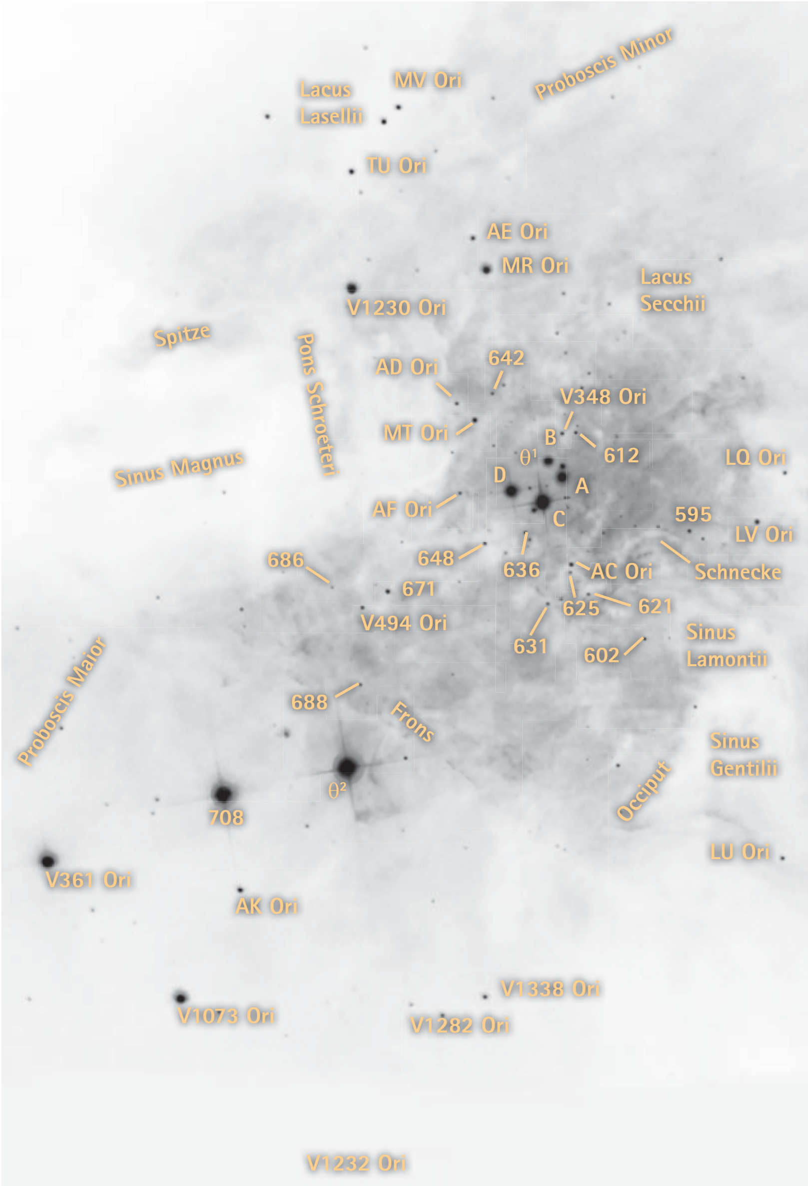
M 42. These high-resolution images show "proplyds": young stars surrounded by dust disks. Hubble Space Telescope.

M 42. Fantastic view of a star-forming region 1300 light-years away. Robert Gendler.



M 42. The center of the well-defined Huygens region hosts the Trapezium, the region's central stars. Stefan Binnewies.





Only the fourfold Trapezium has already fully opened the curtain of nebulosity by the power of its intense radiation.

The Trapezium cluster, mostly consisting of stars with a half to two solar masses, has a spectacular star density of 6000 stars per cubic light-year, which makes it the richest open cluster we know. However, in visual light, an extinction of about 10 magnitudes makes most of these stars invisible. Only 300 cluster members brighter than 17th magnitude can be found within a radius of 3'.

Many of these very young stars have not yet reached the main sequence but are still in the process of contraction and mass accretion. Hubble images have shown that their planetary systems are still forming: many stars are surrounded by proto-planetary disks ("proplyds"). Many of these proplyds around low-mass stars will however be destroyed by the intense radiation of the more massive and faster-forming stars around them.

Northwest of the Trapezium, several young stars have been detected in the Becklin-Neugebauer and Kleinman-Low cloud complex, which are fully hidden in the molecular cloud in the background. Most recent studies indicate that one star in the Becklin-Neugebauer cloud has actually been ejected from a close binary in the Trapezium and could be the youngest known "runaway star." Its former primary appears to be the brightest Trapezium star (θ^1 Orionis C).

More than 50 stars in the Trapezium cluster are variable, and there is presumably a large number of unaccounted variables. These are

The Trapezium stars in M 42

Designation	Variable	Magnitude	Note
θ^1 Ori A	V1016 Ori	6.7–7.7	Trapezium
θ^1 Ori B	BM Ori	7.9–8.7	Trapezium
θ^1 Ori C	NSV 2294	5.1–5.4	Trapezium
θ^1 Ori D	NSV 2295	6.7	Trapezium
θ^1 Ori E	NSV 2291	11	Struve's Star
θ^1 Ori F	NSV 1196	11	Herschel's Star
θ^1 Ori G		16	Barnard's Star
θ^1 Ori H	NSV 2291	16	Barnard's Pair
θ^1 Ori X		?	Barnard's Object

irregular "nebula-variables" of the types T Tauri, FU Orionis, and UV Ceti. UV Ceti variables are flare stars, which can undergo brightness changes of several magnitudes within minutes. The most extreme of its kind is AF Orionis, a rather faint star found by Otto Struve in John Herschel's notes. It has, for this reason, been named "Herschel's variable." At maximum light, AF Orionis is one of the brightest stars in the central region of M 42, but at minimum it cannot be visually sighted in even the largest telescopes.

Some of the Trapezium stars are variable themselves. θ^1 Orionis C, the brightest of them at magnitude 5.1 and about 45 solar masses, largely powers the ionization of the surrounding gas by its intense radiation and varies irregularly by about 0.3 magnitudes. By contrast, θ^1 Orionis A (V 1016) is an eclipsing variable with a long period of 65.43 days and an eclipse duration of less than a day. These two variables were discovered only in 1975 by the Hamburg Observatory (Germany) astronomer Eckmar Lohsen.

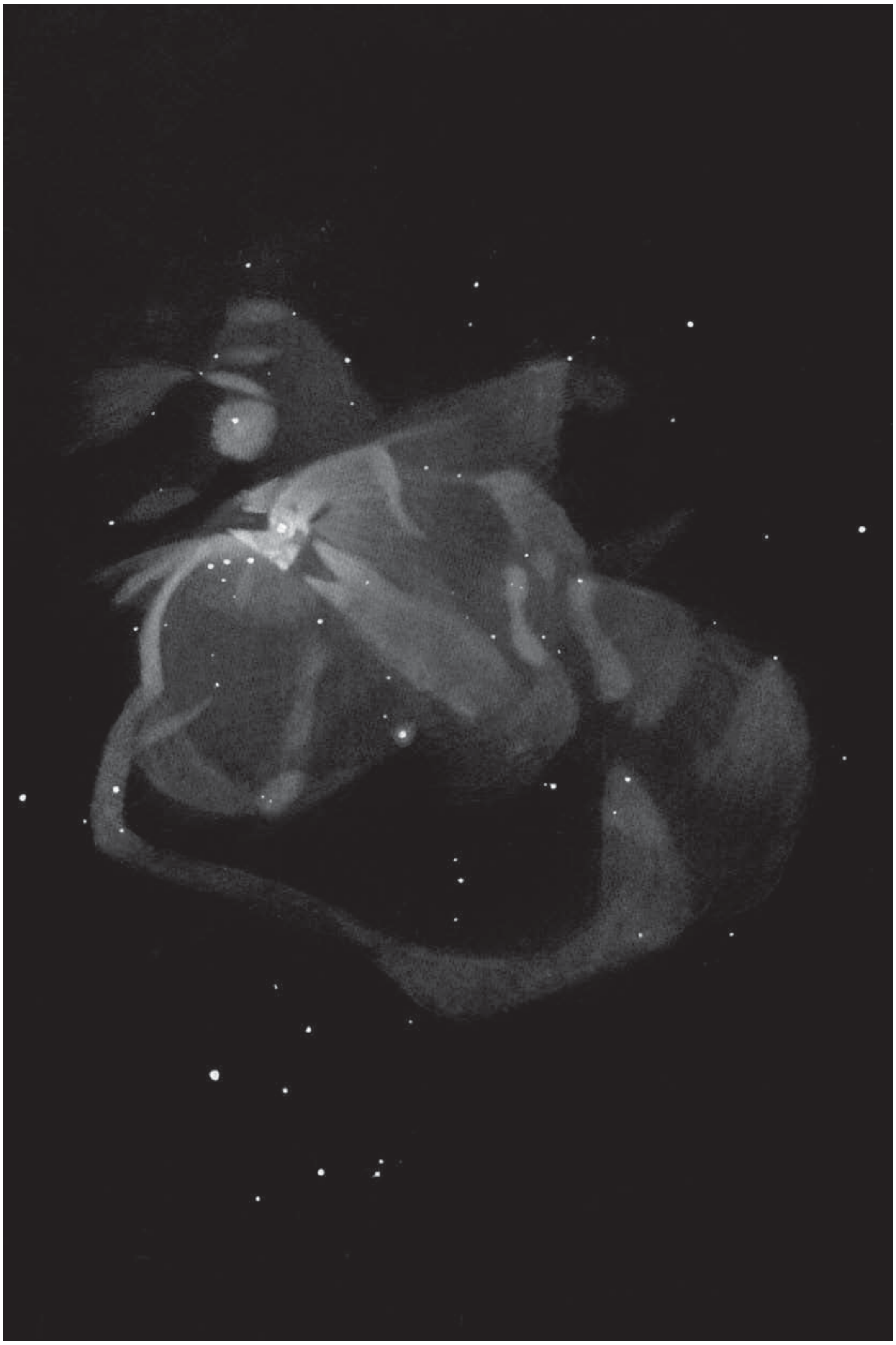
Another eclipsing variable, known longer, is the faintest (magnitude 7.95) of the four Trapezium stars, θ^1 Orionis B, or BM Orionis. It has a period of 6.47 days and an eclipse amplitude of 0.6 magnitudes. Its eclipses last 18 hours, of which totality lasts 6 hours. Only θ^1 Orionis D has no proven variability, yet.

The projected distances between the Trapezium stars are only 0.3 light-years, while the bright inner region of the nebula measures about 2 light-years. That size is more comparable to a planetary nebula than an open cluster. But the entire nebulous complex of M 42, 66' by 60' size, has a more respectable physical diameter of 35 light-years.

Observation

The Orion Nebula is regarded as synonymous with cosmic beauty. It offers a variety of shape, color and intensity beyond description – as Heinrich d'Arrest noted: "Circumsitae nebulae descriptio res deo improba." Consequently, the following lines cannot give a complete description of this wonderful region of the night sky, but are meant to select some of its highlights.

To the naked eye, M 42 appears as an indistinct spot in the middle of Orion's sword. The unaided eye cannot distinguish the nebula from the multiple star θ Ori, but already opera glasses achieve that with ease. The magnitude 2.8 star θ Ori, not far south, adds further glamor to this region. 10×50 binoculars resolve θ Ori into four stars: component θ^1 in the center of the nebula, and three stars in one line (magnitudes 5.1, 6.4, 8.2) forming θ^2 Orionis. In 10×70 glasses, the "wings" of the Orion Nebula and the full splendour of the nebula can be grasped. Furthermore, there is a dark bay entering the central region of M 42 from the northeast, the "Sinus



M 42, drawing, total view. 4.7-inch refractor. Ronald Stoyan.

Trapezium, near the edge of Sinus Magnus. Some small dark patches appear here – vaguely seen with 4.7 inches of aperture, better with 14 inches. The largest of these, near the northern edge of the Huygens region, has been named "Lacus Secchii."

The dark bay of Sinus Magnus is about 3' long in PA 80° and 1' wide. There is a fine bridge of nebulosity ("Pons Schröteri") crossing perpendicularly, 42" before the end of the bay. There, a 4.7-inch telescope begins to show faint "islands," better seen with a 14-inch. Some nebulosity intrudes down from the north, near the tip of Sinus Magnus, much like a cape on a coastline.

The three stars of θ^2 Orionis line up side-by-side with Sinus Magnus, south of it. Of the three wisps of nebulosity here, found by d'Arrest, only the westernmost can be seen with certainty in a 4.7-inch refractor; the other two remain uncertain even with 14 inches of aperture.

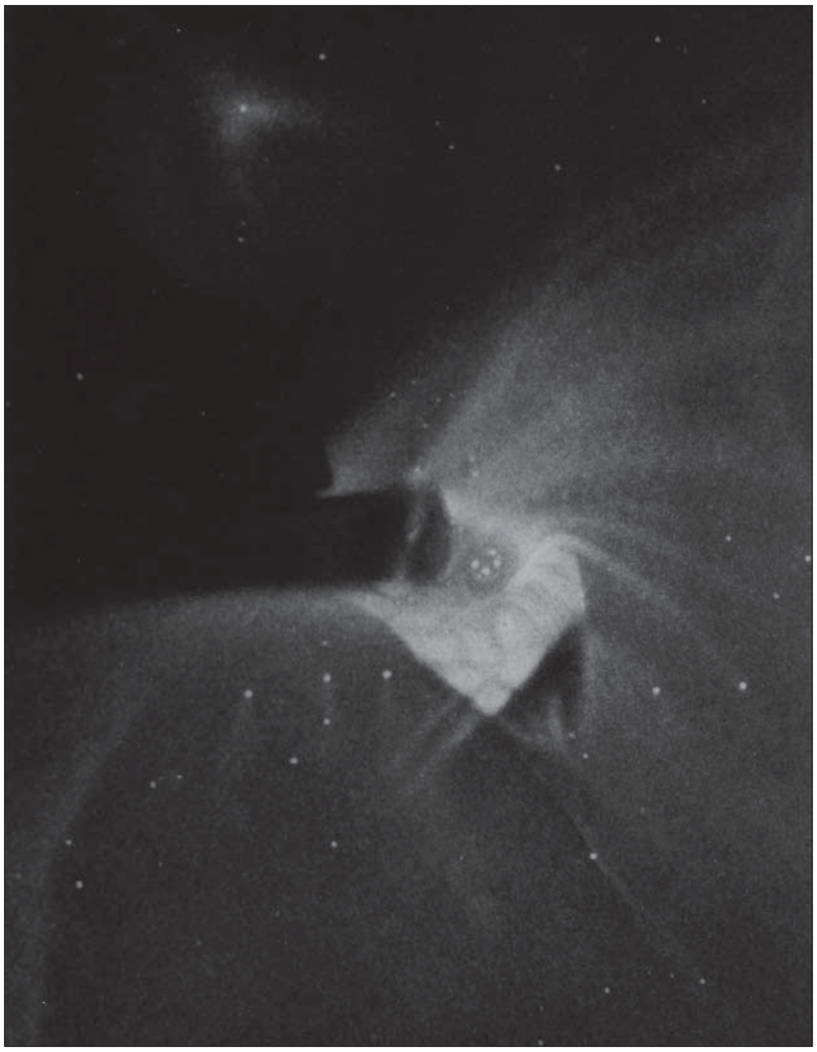
The eastern outskirts of M 42 are dominated by a long, thin wing that aims southeast and originates near Sinus Magnus. It can even be made out in a 2-inch refractor, and it is a well-defined feature with a 4.7-inch telescope. Its width varies from only 50" in the bright northern part to 70" in the fainter southern extension. The brightest part of that wing ends after 15' near a 7th magnitude star. A faint filament starts here and aims at a faint stellar pair inside the nebula. 15' south of the Trapezium, next to a small group of stars, an isolated nebulous spot is found even through a 4.7-inch refractor. Another nebulous spot west of it surrounds the brighter star V372 Ori. This is a small but distinct reflection nebula within M 42.

The darker region southwest of the central nebula was described by Le Gentil over 200 years ago. Consequently, it is called "Regio Gentilii." To the west, it is joined by brighter nebulosity, which has a lot of substructure and consists of several arms, even shown by a 4.7-inch refractor with moderate power. Numerous faint stars lie in front of this part of the nebula.

With a large exit pupil (i.e., with low magnification) under a dark sky, the eastern wing is seen to continue in a large loop until it merges with the southwestern part of M 42, about 30' southwest of the Trapezium. This southern loop is faintest north of the star ι Orionis, but it can be seen in full even with a 4.7-inch refractor. If the loop, M 43 and some nebulous islands north of it are included, then the total visual extent of M 42 reaches 48'×45'.

Different stuctures within the nebula can be emphasized by the use of narrowband Hβ and [OIII] line filters, depending on the particular physical conditions that favor either the one or the other type of line emission. For example, the main strand of the eastern wing appears even brighter in [OIII], while Hβ brings out a faint strand parallel to it. The complex structure of the western part of the nebula gains in Hβ, too, while low power and an [OIII] filter show more of the bubble character of the outermost regions of M 42.

The Great Orion Nebula is bright enough to offer real color perception to the visual observer. A moderate telescope may already show the Huygens region as greenish, caused by its [OIII] emission. With larger apertures, any color perception becomes more distinct but, depending on the observer, it may vary from plain green over turquoise to even a pale blue. From 12 inches upward, the edge of the Frons has a red glow, or – by mixture with green – bright orange. A 20-inch

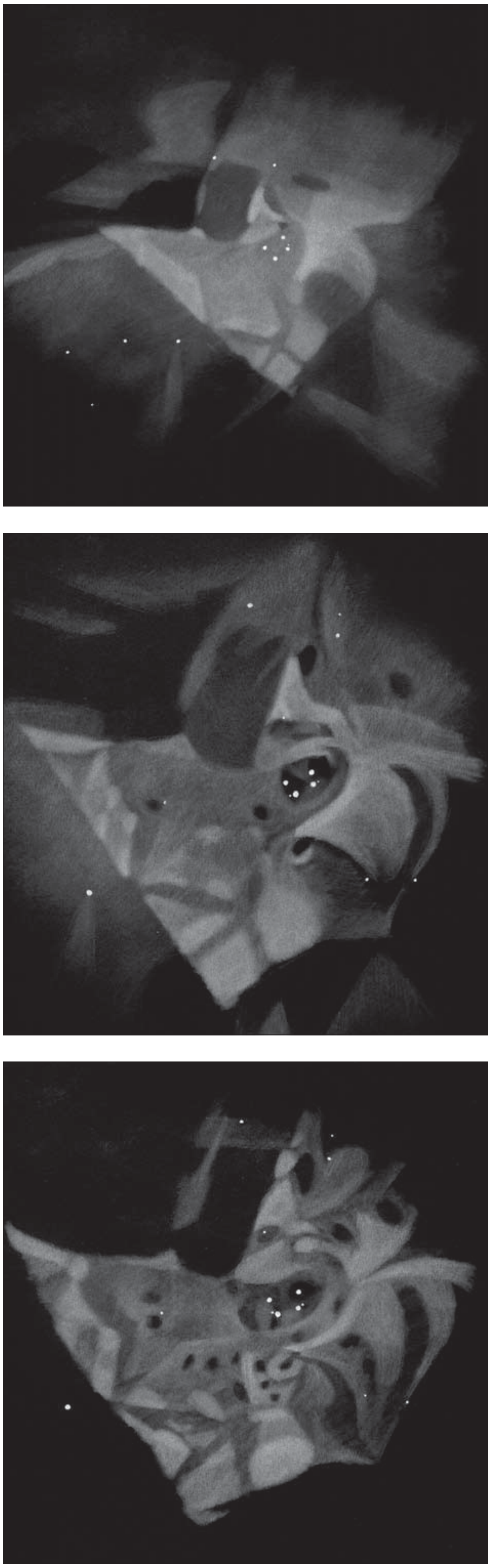


M 42, historical drawing. George Bond (1865).

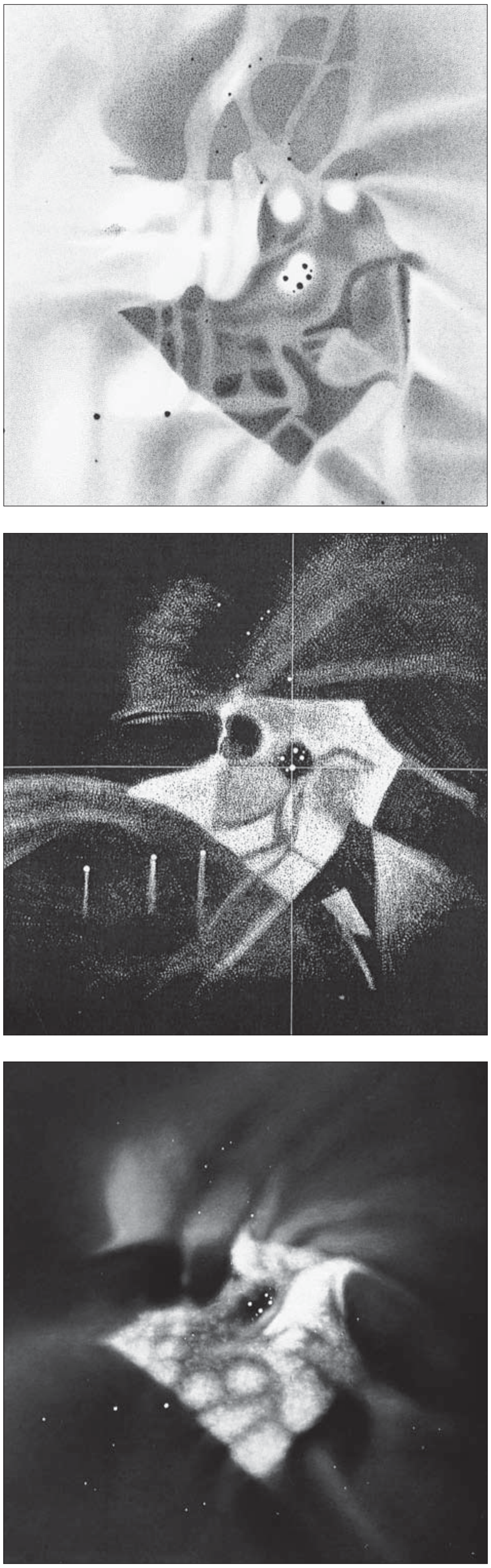
Magnus." The total visual extent of the nebula in binoculars reaches 45'×30'.

The Trapezium can be resolved into four stars by a 2-inch refractor. Its visual impression can be noticeably different when one or both of its variable components A and B are at their minimum. The two additional components E and F of 11th magnitude are within reach of a 4-inch refractor, but require magnifications over 150×. An extreme challenge for visual observers, even with very large telescopes, are the innermost components G and X, and the pair H. No sightings have been reported since Barnard's time.

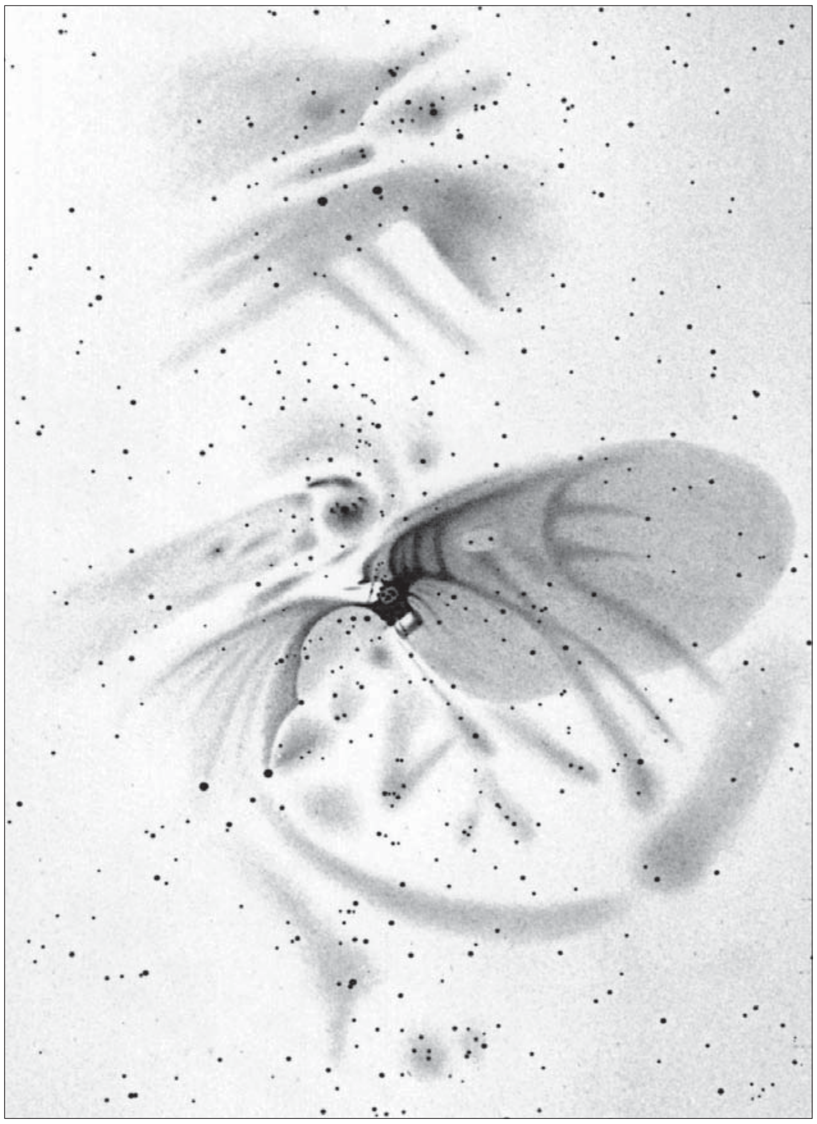
The bright and sharply defined central nebula around the Trapezium is called the "Huygens region," seen well even with 2 inches of aperture. Its southeastern edge is formed by the 3.7'-long "Frons" (PA 50°), and the shorter southwest edge by the "Occiput" (PA 130°). These edges meet to form a well-defined right angle, 2' south of the Trapezium. A 4.7-inch telescope resolves the Frons into small, bright islands, and in the southern part of the Huygens region, it shows two dark channels that cross each other. The brightest part of the nebula lies 40" southwest of the Trapezium, along the western side of the northbound canal. A 14-inch telescope resolves a snail-like structure here. Another bright part of the nebula lies 50" northeast of the



M 42, drawings. Huygens region: 4.7-inch refractor (above), 14-inch Newtonian (center), 24-inch Cassegrain (below). Ronald Stoyan.



M 42, historical drawings. Lord Rosse (1864, above), Heinrich d'Arrest (1872, center), S. Hunter and Léopold Trouvelot (1875, below).



M 42, historical drawings. Wilhelm Tempel (1861, left), William Lassall (1854, right above), Bindon Stoney and Lord Rosse (1852, right below).

telescope brings a green color to the eastern wing and a faint, reddish hue to the regions enclosed by it, caused by Hα emission. In fact, the perception of Hα light depends on both the large exit pupil and sufficient magnification that only a large aperture can provide. With 14 inches, only the brightest parts of M 42 are visible in Hα.

Small telescopes do not show any stars in the central part of M 42, with the obvious exception of the Trapezium. The difficulty in observing stars in the Orion Nebula comes from the bright background light. Hence, a 14-inch telescope with a limiting magnitude of normally 16.5 reaches only magnitude 13.5 in the Huygens region. An orange filter helps, because its absorption properties cut out the strong emission of [OIII] and Hβ lines. CCD detectors have the advantage of an extended infrared sensitivity and they see less extinction in the nebula. Therefore, moderately deep CCD exposures may give more of a star-cluster impression.

The easiest stellar targets are cataloged as variables. Fainter stars are listed by their numbers in the G.P. Bond catalog. MR Orionis, for example, is a borderline object for a 4-inch telescope, followed by MT Orionis and Bond 671 for 6 to 8 inches of aperture. With an orange filter, a 14-inch telescope, and a lot of patience, Andreas Alzner was able to detect 15 stars in the Huygens region, the Trapezium excluded. A peculiar visual effect allows faint stars to be glimpsed at 80×, yet they remain invisible at higher magnifications, until really high powers of 300× to 500× are reached. However, excellent seeing is the most important factor, more so than good transparency.

M 43

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	NGC 1982
Type	Galactic nebula
Class	E
Distance	1300 ly (see M 42)
Size	3 ly
Constellation	Orion
R.A.	5^h 35.6^{min}
Decl.	–5° 16'
Magnitude	6.8
Surface brightness	22mag/arcsec^2
Apparent diameter	6'×3'
Discoverer	de Mairan, 1733

History

Today, M 43 is regarded as just a part of M 42, but the early observers cataloged it as a separate object. In 1733, Jean-Jaques Dortous de Mairan was the first to notice the apparently separate nebula. He wrote: "Brightness around a star, similar to the atmosphere of our Sun, if it was dense and extended enough to be visible in telescopes from such a distance." The Frenchman was wrong about this comparison, but his thoughts reflected the ideas of his time concerning the formation of the Solar System.

Messier added M 43 to his catalog on the 4th of March 1769, the same day as the Orion Nebula. He characterized M 43 as "a small star, which is surrounded by nebulosity." Later, in 1771, Messier included it in his drawing of the Orion Nebula. In 1783, William Herschel described M 43 as a "circular glory of whitish nebulosity, faintly joined to the great nebula." From later observations, however, he believed that the central star in M 43 was instead located behind the nebula, shining though it like the moon through thin clouds. His son John was the first to recognize the "tail" of the nebula towards the north, and he also saw a dark division cutting into the nebula.

Lord Rosse believed that he saw a nebula with spiral structure around the star. Secchi agreed to that and likened the general shape to a mirror-image of a comma. In the 1870s, Holden observed small dark dots to both sides of the "central star." By that time, de Mairan's nebula was long considered an integral part of the M 42 complex.

Astrophysics

M 43 is physically a part of the Great Orion Nebula, M 42. This nebula appears to be a separate object only by virtue of the dark dust clouds in front of the complex. It is illuminated and ionized by the hot and young variable NU Orionis, which has not yet reached the main sequence and has a spectral type of O7. It varies irregularly between magnitudes 6.5 and 7.6. In 2001, O'Dell discovered two "proplyds," proto-planetary disks, in M 43. These are dusty disks around young stars in which planetary systems can form. In the whole of the Orion region, about 50 of these objects have been found.

Deep infrared images reveal that the Trapezium Cluster in the center of M 42 reaches to the southwestern side of M 43. The physical size of M 43 is 3 by 2 light-years, if the extensions to the north and west are discounted.

Observation

M 43 can be seen with 10×50 binoculars as a pale patch around its 7th-magnitude "central star." It is separated from M 42 by a stretch of darkness, about 3' wide. The comma-shape described by Secchi appears even in small telescopes. With a 4.7-inch refractor, dark markings that cut in from the east become vaguely visible. A 14-inch telescope shows M 43 as a bright nebula with at least three noticeable, dark bays in its eastern side. The comma-shaped northern part is separated from the main nebula by a darker region west of the central star, leading south. There are three faint stars, one in that darker region, one at the northern tip of the "comma," and one at the southern edge of M 43. Color photographs show the visually bright regions as green, indicating [OIII] emission, and the fainter areas as red Hβ emission. The use of an Hβ line filter noticeably reduces the contrast between the dark bays and the "comma."

East of M 43 is a dark canal, beyond which distinct nebulosity can be seen in a narrowband filter. The total visual extent of M 43 reaches 6'×3.5' in a 14-inch telescope. Closer inspection at low power reveals extensions reaching 6' further north and 3.5' east.

Seventeen variables can be found in and around M 43. These include the bright "central star" NU Orionis (magnitude 6.8 to 6.9); the much fainter but strongly variable MS Orionis (magnitude 13.8 to16.6) and MU Orionis (magnitude 13.8 to15.8), both directly west of M 43; and NQ Orionis (magnitude 12.1- 14.1), 1.5' northwest of NU Orionis.

M 44

The Beehive Cluster or Praesepe

Degree of difficulty	1 (of 5)
Minimum aperture	Naked eye
Designation	NGC 2632
Type	Open cluster
Class	II2r
Distance	610 ly (K2005) 610 ly (proper motion, 2002), 560 ly (proper motion, 2000)
Size	15 ly
Constellation	Cancer
R.A.	8^h 40.1^{min}
Decl.	+19° 59'
Magnitude	3.1
Surface brightness	–
Apparent diameter	1.2°
Discoverer	–

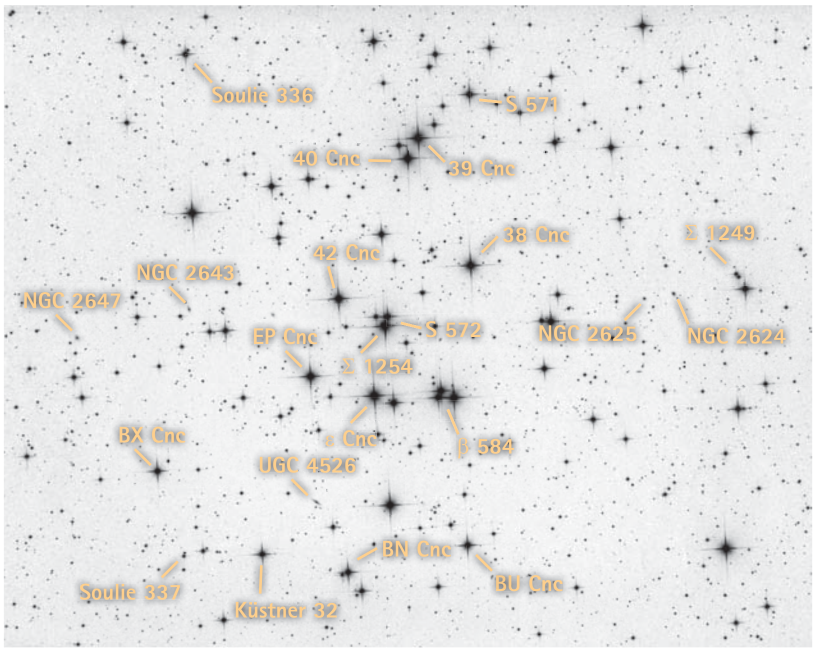
History

The open cluster M 44 has been known since classical times. Messier used it, together with the Pleiades, only to round up his list of nebulous objects up to a number of 45 entries. During his observation on the 4th of March 1769, he described it as the "nebula of Cancer," according to the constellation it is in.

The mythological name of M 44 is Praesepe, the Latin word for a crib. It refers to the crib of the two donkeys, which are represented by the stars Asellus Borealis and Asellus Australis (northern and southern donkey) to either side of Praesepe. These donkeys belonged to the Greek gods Dionysus and Silenus, who were riding on them while going into battle against the giants. The animals frightened the giants so much that, against all odds, the two gods were able to win.

The first mentioning of the Praesepe dates back to Aratus in the year 260 BC. He characterized this patch of light in the constellation Cancer as a "small nebula." In 130 BC, Hipparcos spoke of the "small cloud." Furthermore, the Praesepe is one of the nebulous objects in the Almagest. In general, in antiquity, "nebulosa" meant M 44 as the only known object of its kind, from which the word "nebula" was coined, as used by Messier and others. The true nature of M 44, however, remained unknown to ancient scholars.

This nebula was first resolved by Galileo in 1609 during his initial telescopic observation of M 44: "The so-called nebula Praesepe is not a single star but consists of a mass of more than 40 stars." Most later astronomers, however, gave little attention to this star cluster, and



so we find only a few historic descriptions of it. Webb noticed "two triangles" near the center, and remarked "full of fine combinations." Brenner, about 100 years ago, summarized his observations nicely: "Already the naked eye recognizes this object as a star cluster, while a telescope cannot grasp the whole object even in its weakest magnification. As the stars lie far from each other, this group looks like an ordinary rich star field with colored stars."

Astrophysics

With a distance of only 610 light-years, the Beehive Cluster is one of the nearest open clusters, as seen from Earth. The brightest cluster star is ε Cancri (magnitude 6.3), which shows in its spectrum unusually strong lines of heavy elements. More than 200 stars have been attributed to M 44, of which 24 are brighter than magnitude 8.0. A study of 280,000 stars in a field around M 44 of 10° by 10°, published in 2001, revealed about 1000 possible cluster members, which would span a total cluster size of 100 light-years. Altogether, 630 solar masses are attributed to M 44.

The bright central region of M 44, however, measures only 6 light-years. If the outer regions of the visible cluster are included, which cover about 1.2° in the sky, then the physical diameter is 15 light-years. Hence, M 44 compares well with the Pleiades in physical size. Various authors have given somewhat different Trümpler classifications for the Beehive Cluster as I2r, II2m, or II2r.

There is an unusually large number of variables in M 44; about 100 are known. Among these are δ Scuti stars of spectral type A, which have very recently left the main sequence in the HR diagram. They are now on their way to the giant branch. Three of the brightest cluster stars have already made it to giants and stand out in color photos for their reddish tint. TX Cancri, finally, is a fast eclipsing variable with a period of only 0.38 days and brightness changes between magnitudes 10.0 and 10.4.

Matching stellar evolution models for the brighter cluster stars suggests an age of 500 to 700 million years. This is very much the same as the age of the even closer Hyades (Melotte 25) in Taurus. Sin-

M 44 with Jupiter. Since this open cluster lies near the ecliptic, it is often visited by the planets. Stefan Binnewies.

M 44. There are numerous double and triple stars in the Praesepe cluster, and its background is rich in distant galaxies. Robert Gendler.

ce the proper motions of both clusters, followed backwards, suggest a common point of origin, it is likely that both clusters formed together. Both are remnants of a long-disintegrated OB-association, which has by now made three orbits around the galactic center. Today, the separation between M 44 and the Hyades has grown to 500 light-years.

In 2000, Holland et al. presented evidence from a spectroscopic study that M 44 is merging with a small sub-cluster of 30 stars, which they discovered only 10 light-years away from the center of M 44. The mixed cluster dynamics, which result from the present merging process, may trigger the disintegration of M 44 in the 'astronomically' near future.

Observation

Under normal circumstances, the Beehive is easily seen with the naked eye as a full-moon-sized nebula. A popular saying goes that not seeing M 44 would be a sign of bad weather approaching. Indeed, it takes significant cirrus cloud cover, as within half a day before an approaching warm front, not to see M 44. It is, in fact, easier to see than the central part of the Andromeda Galaxy. Hence, to miss Praesepe, the limiting magnitude must drop below 5^{th} magnitude, such as under a very polluted city sky or in a night lit by the full moon.

Several keen observers have reported naked-eye visibility of individual stars in M 44. This does not seem impossible, given a dark sky, since the three brightest cluster stars are brighter than magnitude 6.5. O'Meara has claimed to have spotted even a dozen Praesepe stars in a clear, dark mountain sky.

In any case, the brightest 20 stars, which are organized in a peculiar pattern, are even visible through opera glasses. However, the most beautiful impression of the cluster is given by large binoculars, through which the brightest stars sparkle against a backdrop of fainter suns. However, it only takes smaller binoculars to see a number of double stars in M 44, as well as the brighter cluster stars form several triangles.

In large telescopes, about 10 faint background galaxies can be observed between the bright stars of M 44. The five NGC objects 2624, 2625, 2637, 2643, and 2647 were discovered by Albert Marth on the 19^{th} of October 1864, using a 48-inch reflector. However, a quarter of that aperture would be sufficient to see them. Furthermore, CGCG 89-56 is a tiny double galaxy which may be in reach of a 20-inch telescope. UGC 4526 is a nice edge-on galaxy apparent on deep photographs of the cluster.

The brightest stars in M 44

Designation	R.A.	Decl.	Mag.	Spectral Class	Note
35 Cnc	$8^h 35^{min} 20^s$	+19° 35' 24"	6.6	G0	
HD 73210	$8^h 37^{min} 47^s$	+19° 16' 02"	6.8	A5	
HD 73294	$8^h 38^{min} 23^s$	+20° 12' 26"	7.8	F7	
HD 73449	$8^h 39^{min} 06^s$	+19° 40' 36"	7.5	A9	variable?
38 Cnc	$8^h 39^{min} 43^s$	+19° 46' 42"	6.7	F0	BT Cnc, variable
HD 73574	$8^h 39^{min} 43^s$	+20° 05' 09"	7.7	A5	
BU Cnc	$8^h 39^{min} 45^s$	+19° 16' 31"	7.7	A7	variable
HD 73598	$8^h 39^{min} 51^s$	+19° 32' 27"	6.6	K0	South 571, variable?
HD 73618	$8^h 39^{min} 57^s$	+19° 33' 10"	7.3	A	Burnham 584, variable?
HD 73619	$8^h 39^{min} 58^s$	+19° 32' 31"	7.5	A	variable?
39 Cnc	$8^h 40^{min} 06^s$	+20° 00' 28"	6.4	K0	variable?
40 Cnc	$8^h 40^{min} 12^s$	+19° 59' 16"	6.6	A1	
HD 73711	$8^h 40^{min} 18^s$	+19° 31' 55"	7.5	F0	
HD 73712	$8^h 40^{min} 20^s$	+19° 20' 55"	6.8	A9	
HD 73709	$8^h 40^{min} 21^s$	+19° 41' 11"	7.7	F2	South 572
HD 73710	$8^h 40^{min} 22^s$	+19° 40' 11"	6.4	K0	Σ 1254
ε Cnc	$8^h 40^{min} 27^s$	+19° 32' 42"	6.3	A	
BN Cnc	$8^h 40^{min} 39^s$	+19° 13' 42"	7.8	A9	type variable δ Sct
42 Cnc	$8^h 40^{min} 43^s$	+19° 43' 09"	6.9	A9	
EP Cnc	$8^h 49^{min} 56^s$	+19° 34' 49"	6.8	A6	non-member, 270 ly
HD 73871	$8^h 41^{min} 15^s$	+20° 28' 37"	6.7	A0	non-member, 950 ly
HD 73890	$8^h 41^{min} 18^s$	+19° 15' 39"	7.9	A7	Küstner 32, variable?
HD 73974	$8^h 41^{min} 50^s$	+19° 52' 27"	6.9	K0	
BX Cnc	$8^h 42^{min} 07^s$	+19° 24' 42"	8.0	A7	variable

Bright double stars in M 44, separation under 1'

Designation	R.A.	Decl.	Magnitude	Separation	PA
Σ 1249	$8^h 37^{min} 41.0^s$	+19° 45' 38"	9.5/9.5	25.3"	40°
South 570 AB	$8^h 39^{min} 06.1^s$	+19° 40' 37"	7.4/8.5	57.2"	84°
South 571 AC	$8^h 39^{min} 50.7^s$	+19° 32' 27"	6.9/7.2	45.0"	157°
Σ 1254 AB	$8^h 40^{min} 22.1^s$	+19° 40' 12"	6.4/10.4	20.1"	54°
Küstner 32	$8^h 41^{min} 18.4^s$	+19° 15' 40"	8.0/10.2	2.1"	166°
Soulie 336	$8^h 41^{min} 53.2^s$	+20° 09' 34"	8.5/11.1	31.5"	328°
Soulie 337	$8^h 41^{min} 54.0^s$	+19° 15' 00"	10.4/11.8	22.7"	343°

Background galaxies in M 44

Designation	R.A.	Decl.	Magnitude	Size
NGC 2624	$8^h 38^{min} 09.6^s$	+19° 43' 33"	14.6	0,7'×0,5'
NGC 2625	$8^h 38^{min} 23.1^s$	+19° 42' 59"	14.5p	0,4'
CGCG 89-56	$8^h 38^{min} 23.8^s$	+19° 35' 46"	15.2	0,7'×0,2'
CGCG 89-62	$8^h 39^{min} 14.1^s$	+19° 28' 54"	15.6	0,4'
IC 2388	$8^h 39^{min} 56.5^s$	+19° 38' 43"	15.7	0,5'×0,3'
UGC 4526	$8^h 40^{min} 53.8^s$	+19° 21' 17"	14.8p	1,4'×0,2'
NGC 2637	$8^h 41^{min} 13.5^s$	+19° 41' 27"	15.4	0,5'×0,4'
NGC 2643	$8^h 41^{min} 51.8^s$	+19° 42' 08"	15.6	0,7'×0,4'
NGC 2647	$8^h 42^{min} 43.1^s$	+19° 39' 01"	15.1	0,7'×0,6'

M 45

The Pleiades or Seven Sisters

Degree of difficulty	1 (of 5)
Minimum aperture	Naked eye
Designation	–
Type	Open cluster
Class	I3rn
Distance	425 ly (K2005) 430 ly (2004), 385 ly (Hipparcos, 1999)
Size	15 ly
Constellation	Taurus
R.A.	3^h 47.5^{min}
Decl.	+24° 6'
Magnitude	1.5
Surface brightness	–
Apparent diameter	2°
Discoverer	–

M 45. IC 349, Barnard's Merope Nebula, is only 30" from the bright star. Hubble Space Telescope.

History

Charles Messier placed the Pleiades, well known since prehistoric times, at the end of his first catalog, as his object No. 45. Obviously, he wanted to publish a longer list than the 42 objects of his predecessor Lacaille, and the number 45 suited Messier's baroque sense of symmetry. He undertook an observation of the Pleiades on the 4th of March 1769, without any further description – the same night in which he added M 42, M 43, and M 44 to his list of nebulous objects for its first publication.

This open cluster, which appears to the naked eye as a brilliant object, is part of the folklore and myths of many cultures. The name Pleiades is of Greek origin and means the daughters of Atlas and Pleione: Alcyone, Asterope, Electra, Maia, Merope, Taygeta, and Celaeno. While this list makes 9 altogether, only 6 to 8 stars are easily visible. For a long time, that promoted the idea of a "lost Pleiad." In the end, the "Seven Sisters" or "Seven Stars" prevailed. The names coming from other cultures ring a bell, too: the Japanese name "Subaru" is used by a car company, which even shows the Pleiades in their emblem; and the Persian Queen Soraya bears their name. In large parts of medieval Europe, the image of a hen with its chicks was quite common.

Early descriptions date back to Mesopotamian mythology of about 2500 BC. Only recently discovered was the now very famous ancient image of the Pleiades on the Nebra skydisk from Germany, which is believed to have been made about 1600 BC. About 4000 years ago, the Pleiades marked the intersection between the ecliptic and the celestial equator, and thus served as a very important benchmark for calibrating ancient calendars. In particular, conjunctions with the young moon were observed to recalculate annual lunar and solar cycles.

Homer mentions the Pleiades in his Odyssey, and it features in the Bible in three places in the Old Testament. The Greeks Eudoxus and Aratus regarded the prominent cluster as a small constellation of its own.

More than the well-known six or seven stars were first mentioned by the keen-eyed Mästlin, teacher to Kepler, who sketched 11 stars in 1579. With the invention of the telescope, this number jumped upwards: Galileo counted 36 stars, Hooke saw 78, and Wolf, about hundred years ago, finally found about 500 on photographs down to 14th magnitude.

The Sicilian observer Giovanni Batista Hodierna supplied the first astronomical description of the cluster in 1654: "the first and most brilliant of all star groupings; six or seven stars stand out from the rest," and he counted 37 stars. In 1767, John Mitchell calculated the probability of any purely chance alignment of such a group of stars as 1 in 496,000. This strongly supported the understanding that star clusters are real, physical entities.

In 1846, Heinrich Mädler interpreted precise positional measurements and proper motions in support of the physical nature of this star cluster, but he also came up with the bizarre idea that Alcyone would be the center of gravity of the universe. Wilhelm Tempel turned more attention towards M 45 when, on the 19th of October 1859, he discovered a nebula (NGC 1435) around Merope with just 4 inches of aperture. Appropriately, he described it "like the breath on a mirror." A long

M 45. The Pleiades are the nearest Messier Object. The star cluster is currently moving through a dust cloud, which is lit in blue light by the brightest stars. Bernd Flach-Wilken.

M 45. The peculiar structure of the reflection nebula around the Pleiades has been created by interstellar magnetic fields. Bernd Liebscher.

controversy followed about the existence and any possible variability of the nebula. This was finally ended by the photographs of the brothers Henry, who also found the nebula around Maia (NGC 1432). With further, deeper photos, the Henrys could later, in 1888, show the full complexity of the Pleiades nebulosity. In 1890, using the 36-inch Lick observatory refractor visually, Edward Emerson Barnard recognized an additional, very small nebula very close to Merope (IC 349).

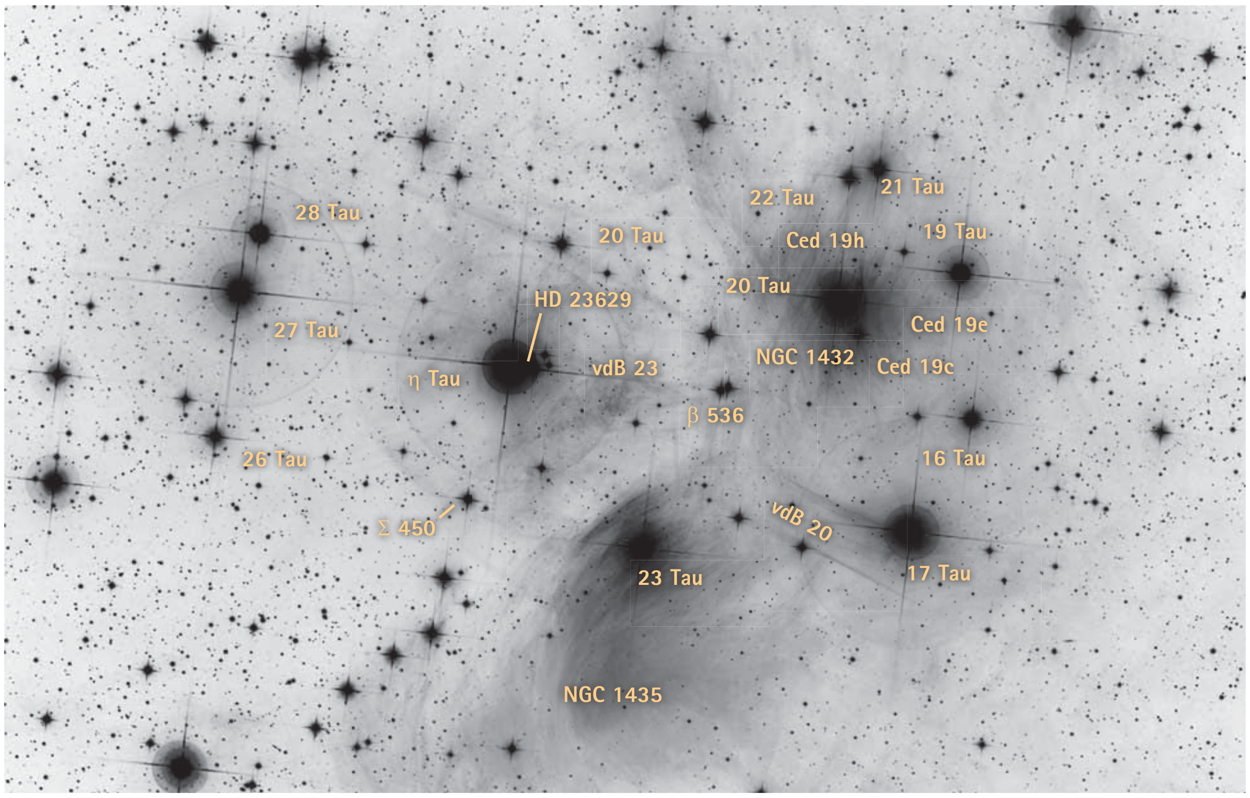
Astrophysics

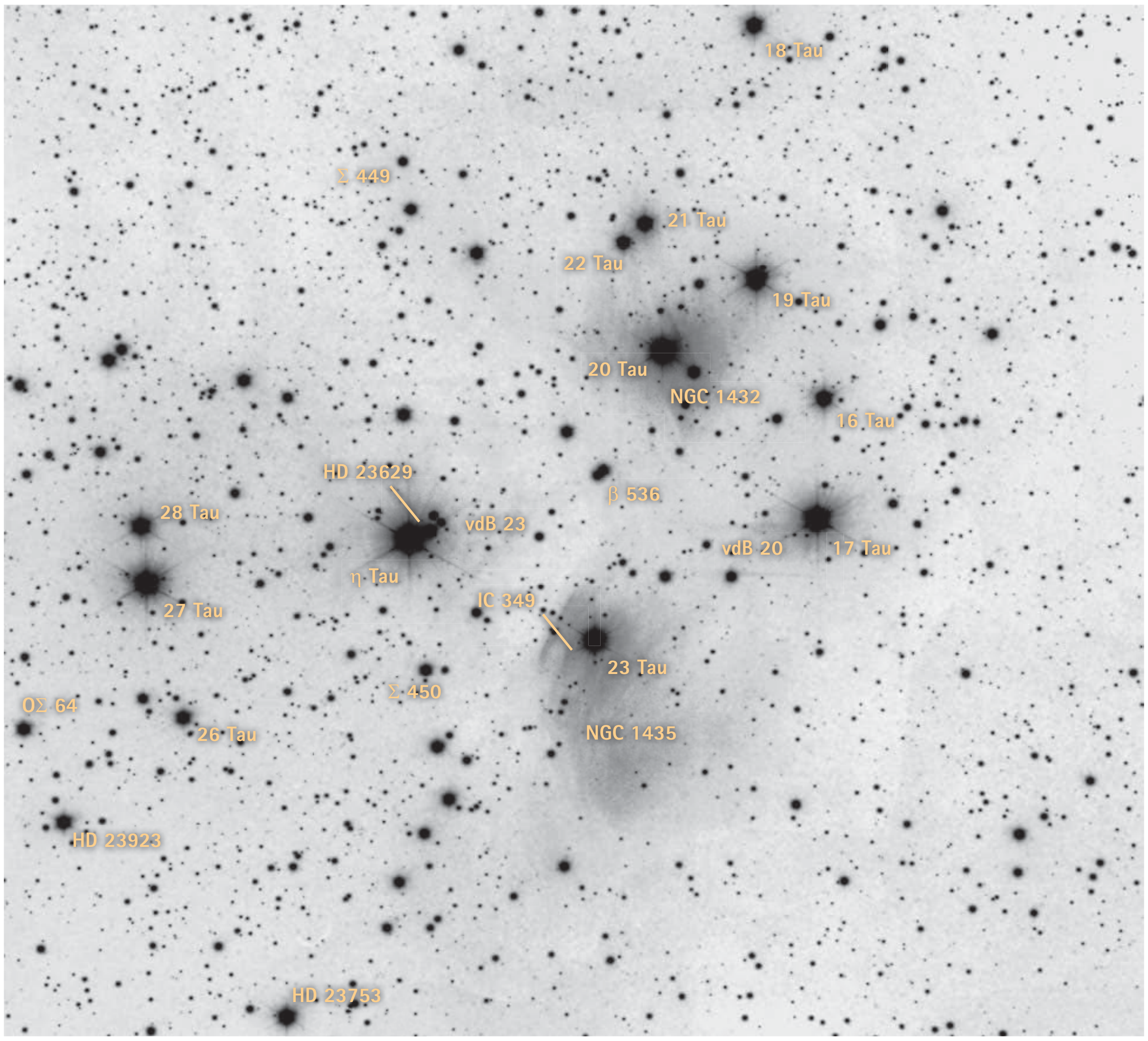
With a distance of only 425 light-years, the Pleiades is one of the very nearest open clusters, considerably nearer than the Beehive Cluster. This is why M 45 can be observed so well from Earth. In a field of 2° by 2°, 500 stars have been counted, of which 197 are regarded to be true cluster members. In addition, there are 135 possible cluster stars in a field of 9° by 9°, which would bring the cluster diameter from 15 to 70 light-years. The innermost region, as covered by the 6 to 8 Pleiades stars visible to most naked eye observers, measures only 7 light-years.

M 45 is regarded as the "Rosetta Stone" for a calibration of the astronomical distance scale, in which open clusters play a very important role. Earlier, indirect methods suggested a distance to the Pleiades of 500 light-years, until the Hipparcos satellite provided direct parallax measurements, from which a mean cluster distance of 390 light-years was derived. Most recently, several independent studies have suggested corrections, and the presently accepted value is a Pleiades distance of 425 light-years.

Those 6 to 8 bright blue cluster stars visible to the naked eye are young main-sequence stars with several solar masses. The mass of the entire Pleiades cluster has been quoted as 800 solar masses. In 1993, a cluster age of 100 million years was derived by fitting the group to stellar evolution models. Glyn Jones gave the Pleiades a further life span of 250 million years, before it would disintegrate under the external gravitational strain.

The small number of white dwarfs in M 45 comes as a bit of a surprise; only one of the few found in this field really belongs to the cluster, while evolution models predict a larger number. This discre-





pancy, which also occurs with the Hyades and the Beehive Cluster, can be resolved, however, if a large fraction of the white dwarfs are hidden in binary stars as the much fainter component. Indeed, binaries make up about 70% of the cluster stars.

Popular with modern studies are brown dwarfs: star-like, cool objects with a mass too low to ever start hydrogen burning (i.e., under 0.08 solar masses). In M 45, brown dwarfs with only 0.028 solar masses have been found. These objects gain the little energy required for their faint red glow by slow contraction, which converts potential energy into heat and radiation.

With 1000 times the solar luminosity, by contrast, Alcyone is the brightest star of the Pleiades. To its west, it is accompanied by three stars and is regarded as a multiple system. Maia is the third brightest star and was suspected by Otto Struve of some small-amplitude variability on a time scale of hours. He even suggested that Maia could be the prototype of a new class of variables – however, modern observations have not shown any variability at all.

Pleione is certainly variable, with brightness changes between magnitudes 4.77 and 5.50. Like a number of other Pleiades stars, it is rotating very quickly. Three times since 1888, Pleione underwent phases during which it formed a thin circumstellar shell, as spectroscopic observations revealed. Between 1938 and 1952, as well as between 1972 and 1987, the star's brightness first rose above and then later fell below the normal level. It is still unclear whether at the end of those phases the shells were lost or rather fell back into the star. Pleione may have an unresolved companion with an orbital period of 35 years.

Furthermore, the Pleiades host a large number of faint flare stars, which can change their brightness within minutes. They make up the large majority of the over 600 variables in a field of 5° radius around M 45. In 2003, the magnitude 6.9 star HD 23642 was found to be an eclipsing variable, and HD 23628 is a recently discovered δ Scuti variable.

The dusty reflection nebulae around the Pleiades are not, as often quoted earlier, the remnants of the cloud in which this cluster formed. Considering the difference in the radial velocities between nebulae and cluster of 11 km/s, we may safely assume today that the Pleiades are just passing through the outskirts of the Taurus-Auriga complex of dark nebulae. Over a time span of 3000 years, this cluster motion will result in an apparent move equivalent to a full Moon's diameter in our sky.

The blue color of the reflection nebulae is due to the blue light of the brightest stars, which is scattered by the surrounding dust, and due to enhanced scattering of blue light by the small dust particles. Only in one place in the southern part of the Pleiades, a slightly red color is found, which indicates that there the gas component has

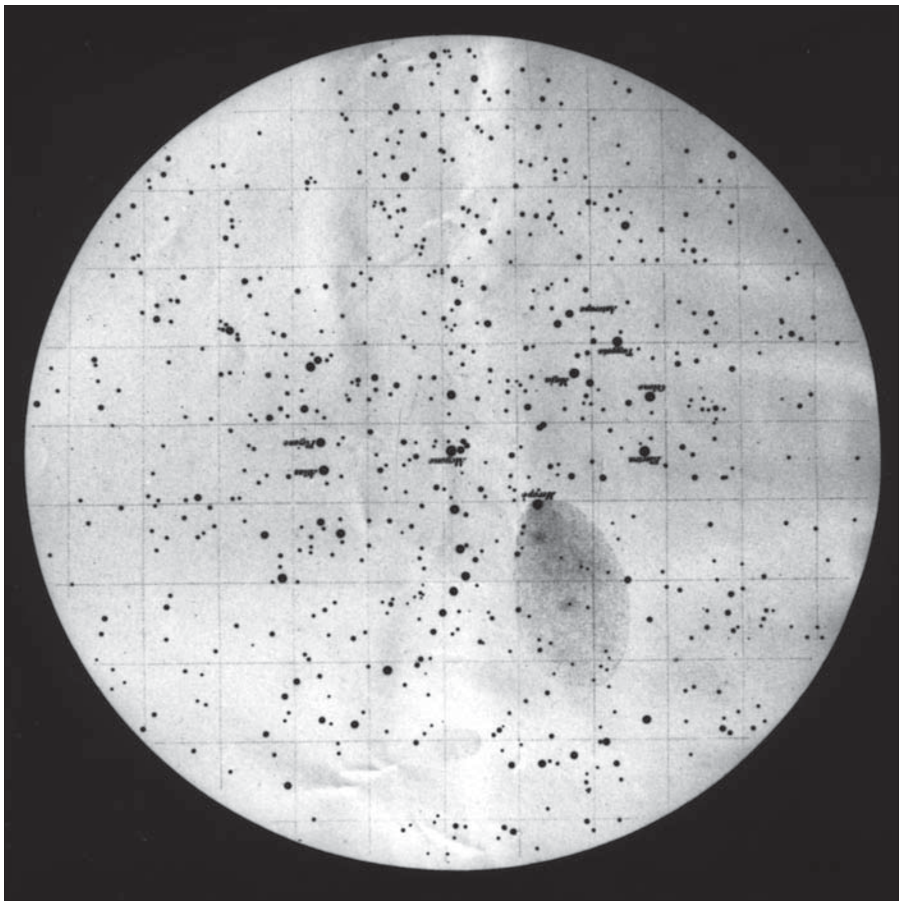
M 45, drawing. 14-inch Newtonian. Ronald Stoyan.

The brightest stars in M 45

Designation	Common Name	R.A.	Decl.	Magnitude	Spectral Class	Nebula
16 Tau	Celaeno	$3^h\,44^{min}\,48^s$	+24° 17' 22"	5.5	B7	Ced 19c
17 Tau	Elektra	$3^h\,44^{min}\,52^s$	+24° 06' 48"	3.7	B6e	vdB 20 (Ced 19d)
18 Tau	HD 23324	$3^h\,45^{min}\,10^s$	+24° 50' 21"	5.7	B8	
19 Tau	Taygeta	$3^h\,45^{min}\,13^s$	+24° 28' 02"	4.3	B6	Ced 19e
20 Tau	Maia	$3^h\,45^{min}\,50^s$	+24° 22' 04"	3.9	B8	NGC 1432 (vdB 21, Ced 19f)
21 Tau	Asterope	$3^h\,45^{min}\,55^s$	+24° 33' 16"	5.8	B8e	Ced 19h
22 Tau	HD 23441	$3^h\,46^{min}\,03^s$	+24° 31' 40"	6.4	A0	Ced 19h
23 Tau	Merope	$3^h\,46^{min}\,20^s$	+23° 56' 54"	4.2	B6	NGC 1435 (VdB 22, Ced 19j-k) + IC 349 (Ced 19i)
HD 23629	Companion to Alcyone	$3^h\,47^{min}\,21^s$	+24° 06' 59"	6.3	A0	vdB 23 (Ced 19l)
η (25) Tau	Alcyone	$3^h\,47^{min}\,29^s$	+24° 06' 19"	2.9	B7e	vdB 23
HD 23753		$3^h\,48^{min}\,21^s$	+23° 25' 17"	5.5	B8	
26 Tau		$3^h\,48^{min}\,56^s$	+23° 51' 26"	6.5	F0	Foreground star 240 ly
27 Tau	Atlas	$3^h\,49^{min}\,10^s$	+24° 03' 12"	3.6	B8	Ced 19o
28 (BU) Tau	Pleione	$3^h\,49^{min}\,11^s$	+24° 08' 12"	5.1	B7e	Ced 19p
HD 23923		$3^h\,49^{min}\,44^s$	+23° 42' 43"	6.2	B8	

been ionized by the otherwise insufficient UV radiation of the cluster stars.

Merope is surrounded by the brightest of the Pleiades nebulae. The very small nebula IC 359 is only 30" or 0.06 light-years away from the star. The Hubble Space Telescope revealed the superbly ragged and disrupted structure of the nebula, caused by the radiation pressure from Merope. This arranges the dust particles by their size. Small grains are blown away; larger ones are only deflected in their motion. The large-scale linear structure of the nebulous veil, however, is sculpted by magnetic fields.



M 45, historical drawing. Wilhelm Tempel (1859).

Observation

The Pleiades are the most impressive star cluster for naked eye observations. Generally, six bright stars are seen. Under good conditions, three more stars can be perceived: Pleione, Celaeno, and Asterope – raising the total number to nine. Under superb alpine skies, the author has seen 10 stars with certainty, and some observers have reported a naked-eye visibility of up to even 18 stars! The main difficulty is not the brightness of the cluster stars, but the ability to distinguish them from each other. Some observers have used some simple means to cover Alcyone or other bright stars. With this, even a naked-eye visibility of the Merope Nebula has been claimed, but there is hardly any credible confirmation.

A pair of binoculars is the ideal optical instrument to observe the Pleiades, which are shown with an impressive brilliance. Atlas and his wife Pleione follow their seven blue-white daughters at a little distance, 30 fainter stars make a nice background. Under a dark, clear sky, the Merope Nebula (NGC 1435, south of Merope) and the stars 3' northwest of Alcyone are visible with 10×50 binoculars.

A telescope resolves a number of interesting double stars; some of them require high magnifications. The easy pair Burnham 536 in the cluster center is of special interest: north of the northwestern component is a faint (12th-magnitude) companion star.

Double stars in M 45			
Designation	**Magnitude**	**Separation**	**PA**
Burnham 536 AB	8.3/8.4	41"	125°
Burnham 536 BC	8.4/12.7	18"	8°
Σ 450	7.3/10.4	6.1"	265°
Σ 449	8.5/11.0	6.8"	330°
OΣ 64	6.7/9.8/9.0	3.2"/10"	238°/236°

A 4.7-inch refractor gives a clear view of the reflection nebula around Merope and a vague hint of nebulosity east of Maia. NGC 1435 appears triangular in shape, pointing southwest from Merope, and is about 20' long. Directly east of the star, close inspection reveals a brighter edge with a hint of fringed structure. However, NGC 1432 near Maia remains a very difficult object to observe.

With a 14-inch telescope, use of modest magnification under a clear, dark sky transforms the Pleiades into a fine-structured region of nebulosity. Patient observers may even find the various streaks not too difficult to perceive – this is particularly true for NGC 1435 (Ced 19j-k), south of Merope. The triangular nebula has a visual extent of 12'×15'×17'. Its northeastern edge is brightest and sharply defined, hinting at the filamentary structure revealed by deep photographic exposures. 3' northeast of Merope, a 7'-long but merely 30"-thin filament is seen as the easiest part of the Pleiades nebula; it crosses two 12th-magnitude stars. A diffuse, nearly round nebula lies 10' west of Alcyone (vdB 23, Ced 19l). There are some very difficult, diffuse wisps of nebulosity, west and north of it.

Impressive, though very faint, is a 15'-long, about 1'-wide stretch of nebulosity (vdB 20, Ced 19d), which reaches from the center of the Pleiades to Electra, aiming slightly to the south of that star. There is a hint of an even fainter wisp parallel to Ced 19d, 3' south of it. Bright by comparison is the Maia Nebula NGC 1432 (Ced 19f). Its most distinct part is a triangle 1.5' west of Maia. From it, six nebulous extensions stretch to all sides. The two aiming west (Ced 19c and 19e) merge to form a diffuse curtain near Taygeta and Celaeno. To the north, Asterope is reached by faint Ced 19h. Pleione and Atlas, by contrast, appear to be clear of nebulosity.

The most challenging nebulous object in the Pleiades is Barnard's IC 349 only 36" south of Merope. It takes magnifications of over 400× and excellent seeing to distinguish this small object from the bright star. If Merope is covered by a thin wire or thread, mounted in the focal plane of the eyepiece, IC 349 may even be visible with a 12-inch telescope.

M 46

Degree of difficulty	3 (of 5)
Minimum aperture	Naked eye
Designation	NGC 2437
Type	Open cluster
Class	II2r
Distance	4480 ly (K2005) 4490 ly (proper motion, 2002)
Size	26 ly
Constellation	Puppis
R.A.	7^h 41.8^{min}
Decl.	–14° 49'
Magnitude	6.1
Surface brightness	–
Apparent diameter	20'
Discoverer	Messier, 1771

History

M 46 was discovered by Charles Messier on the 19th of February 1771, as the first object after the completion of his initial catalog of 45 objects. He described this object as "cluster of very small stars, the stars are not visible except in a good refractor, the cluster contains a bit of nebulosity." In 1786, William Herschel found the planetary nebula NGC 2438 in this cluster. His son John later described the view: "A very fine rich cluster which fills the field. Within the cluster at its northern edge is a fine planetary nebula." He characterized the latter as "exactly round, of a faint equable light. Has a very minute star north of center. It is not brighter to the middle nor fading away, but a little velvety at the edges."

Leo Brenner recommended M 46 to amateur observers, about 100 years ago, with the words: "Splendid object, even for smaller telescopes. 30' diameter, very rich and bright. Stars of 10m and lower. The cluster contains a planetary or ring-shaped nebula of 3.75' diameter and of considerable brightness."

Curtis, based on the photographic images, gave a characterization of M 46 which does not quite agree with its visual appearance: "a very large, bright, sparse cluster about 25' in diameter, in which is involved the planetary nebula 2438."

Astrophysics

M 46 and M 47 form a very appealing cluster pair in the winter sky. In real space, though, they are by no means close. Rather, M 46 is supposed to be two to three times farther away than M 47. M 46 has a position 400 light-years above the galactic plane and is among the richest Messier clusters. There are 186 stars brighter than 13th magnitude, and in total probably even 500 member stars. The brightest star in M 46 has magnitude 8.7 and spectral type A2. In addition, the cluster contains a few red giants, which help us estimate the cluster age as about 500 million years.

Much younger is the planetary nebula NGC 2438, only about 45,000 years old, which is seen in the northern region of M 46. Many authors have argued that NGC 2438 is a chance-aligned foreground object, but a study from 1996 shows that it has the same radial velocity, about 60 km/s, as the cluster – as measured with four brighter stars – a very strong indication that the planetary nebula is a physical member of M 46, after all.

The physical diameter of NGC 2438, which measures 66" in the sky, is estimated to be one light-year. On a deep exposure, David Malin demonstrated the existence of a faint halo four times larger – a typical feature of many planetary nebulae. Apparently, the faint central star (magnitude 17.5) has already lost its radiation power and no longer ionizes the nebula. Since the visible light is generated by ongoing recombination processes, this nebula will probably become invisible in a few thousand years, after the reservoir of ionized gas has been consumed.

Observation

In 10×50 binoculars, M 46 appears as a full-moon-sized patch of nebulosity, a little east of M 47. A single star in the western part can be glimpsed. The view changes a lot with a small refractor, which shows a swarm of more than 50 stars.

The nice impression of the cluster is lost with larger apertures and higher powers, since the stars of M 46 are grouped loosely, without any condensation. Larger telescopes show a bright orange star just west of the brightest cluster star. From the many stellar pairs in M 46, two double stars have been cataloged: Barton 1889 (magnitudes 11.1/11.8, PA 203°) and Barton 1891 (magnitudes 11.9/12.2, PA 2°), both with the same separation of 4.5".

The planetary nebula NGC 2438 in the northeastern part of the cluster has a magnitude of 10.8 and is visible as a diffuse ring with an 11th magnitude star almost right in its middle in a 4.7-inch refractor. A 14-inch telescope shows the asymmetry of the ring: its fainter part points west, while the brightest bits are on its northern edge. Faint stars are visible in the dark interior of the ring and on its southeast edge. But there are no reports from visual observers of a halo, nor of the true central star. An [OIII] line filter reduces the brilliance of the surrounding star field but emphasizes the details of the nebula.

M 46. This open cluster contains a planetary nebula. Jim Misti, Robert Gendler.

M 46. The cluster membership of the planetary nebula NGC 2438 is still a matter of debate. Dietmar Böcker.

M 47

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 2422
Type	Open cluster
Class	III2m
Distance	1600 ly (K2005) 1620 ly (Hipparcos, 1999)
Size	14 ly
Constellation	Puppis
R.A.	7^h 36.6^{min}
Decl.	−14° 29'
Magnitude	4.4
Surface brightness	–
Apparent diameter	30'
Discoverer	Hodierna, 1654

History

M 47 was discovered before 1654 by the Sicilian astronomer Giovanni Batista Hodierna. He described his find plainly as "a nebulosa between the two dogs." Hodierna's observations were forgotten until the booklet with his observing notes was rediscovered in 1984.

Hence, Charles Messier made an independent discovery of M 47 on the 19th of February 1771. He noted that night: "Star cluster, not far from previous [M 46]. The stars are larger; the cluster does not contain nebulosity." In the calculation of the position, however, Messier made a sign-related mistake and, consequently, M 47 became a missing object for many observers after him. Oswald Thomas finally identified M 47 with NGC 2422 in the year 1934 – quite possibly, by some good luck. It was left to T.F. Morris in 1959 to fully resolve this case by going through Messier's calculations and finding his mistake. An interesting catch is that the missing M 47, the "ghost object," received an NGC number of its own: 2478.

William Herschel did not know of all this, when he independently discovered M 47 on the 4th of February 1785. His son John later commented on this cluster: "a large, pretty rich, straggling cluster." Smyth saw "a very splendid field of large and small stars, disposed somewhat in lozenge shape," and he also noticed the brightest (7th magnitude) cluster star with a companion at about 20" distance. Reverend Webb commented on M 47: "grand broad group visible to naked eye, too large even for 64×."

Astrophysics

The open cluster M 47 has a visual appearance which differs strikingly from M46, its apparent neighbor in the sky, which is actually three times as distant. Hence, these two clusters are not a physical pair.

M 47 hosts at least about 50 stars within an angular diameter of 30'; some sources suggest 117 members. The true diameter is rather humble, 12 to 15 light-years. The Trümpler class of M 47 differs, like those of other clusters, from author to author. II3m, I3m, and III2m have all been suggested.

Wallenquist stated a mean star density of 0.2 stars per cubic light-year, which would reach 3.5 in the very center. However the cluster does not look that rich, because a large number of faint members are dominated by a few bright cluster stars, all blue giants. In this, M 47 resembles the Pleiades. The brightest star of M 47 is magnitude 5.7, which corresponds to a total luminosity of 1250 times that of the Sun. The extinction of 0.2 magnitudes, caused by interstellar dust in the line of sight towards M 47, is quite small – about 0.5 magnitudes would be normal for that distance.

It remains unclear whether the two red giants in the field of M 47, with about 200 solar luminosities each, are true cluster members or not. With this uncertainty, age estimates for this cluster are divided over two alternatives: around 100 million or about 30 million years, respectively.

The brightest of several Be emission line stars in M 47 is HD 60856, southwest of the cluster's center, at magnitude 8.0. Another noteworthy cluster member is KQ Puppis with a very large amplitude of about 5th magnitude! Photos nicely reveal that this star is a very red giant. Finally, there is the double star Σ1121, a pair of two 7.9-magnitude stars with a separation of 7.4", right in the cluster's center.

Observation

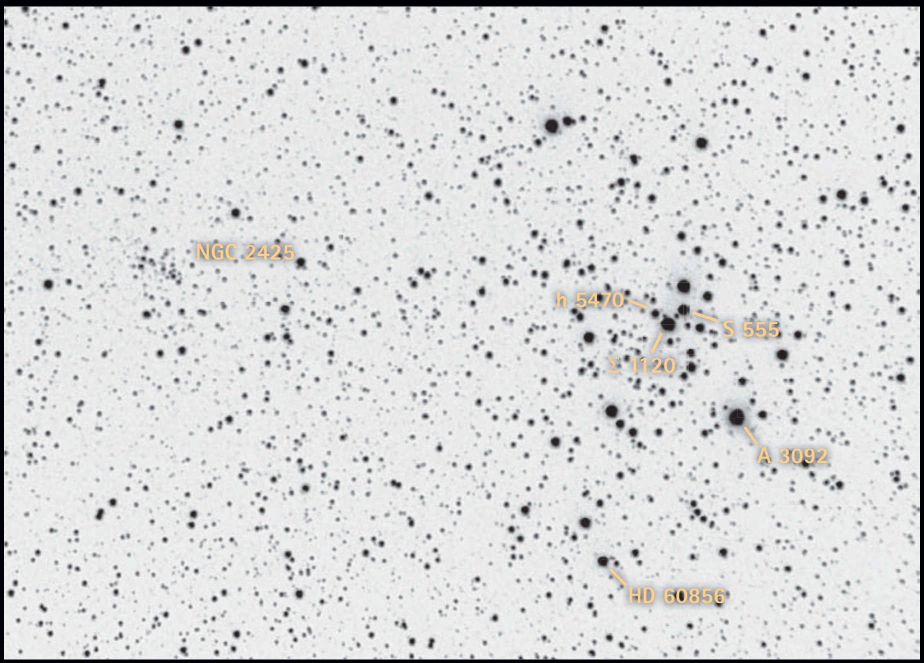
M 47 can be perceived as a knot of stars with just the naked eye, since the cluster's brightest stars are noticeably above the limiting magnitude of a very dark night sky. The most impressive views are provided by binoculars; the blue cluster stars give the field splendor. When observed with telescopes at magnifications over 50×, the cluster loses that character. Instead, the voids between the few bright stars are emphasized. Only a few short, curved star chains are noticeable.

Even small telescopes resolve the double star in the cluster's center. The brightest cluster star in the west of M 47 is a double, too, with a 9.5 magnitude companion (Σ 1120) 19" away – the one mentioned by Smyth. Three more double stars are in reach of amateur telescopes:

Double stars in M 47

Designation	Magnitude	Separation	PA
South 555	7.9/9.1	95.8"	228°
h 5470	9.0/10.0	0.6"	230°
Aitken 3092	5.6/12.2	5.2"	176°

The faint open cluster NGC 2423 lies 40' north of the center of M 47. In 10×50 binoculars, it appears only as a nebula, but a telescope reveals a loose cluster of stars of 11th magnitude and fainter, scattered over 15', with one bright star of 9th magnitude standing out. In real terms, NGC 2423 is twice as distant as the larger M 47 with its size of 30'. In a wide field of view, the clusters make a nice contrast. M 46 is not far away either; only 1.5° to the east.



M 47 and M 46 form a fascinating (but not physical) pair of open clusters. M 47 resembles the Pleiades at three times the distance, while M 46 is one of the richest clusters of the Messier catalog, even at ten times the distance of the Pleiades. Stefan Binnewies.

M 48

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 2548
Type	Open cluster
Class	I3r
Distance	2510 ly (K2005) 2540 ly (CMD, 2005) 2510 ly (proper motion, 2002)
Size	22 ly
Constellation	Hydra
R.A.	8^h 13.8^{min}
Decl.	−5° 45'
Magnitude	5.8
Surface brightness	–
Apparent diameter	30'
Discoverer	Messier, 1771

History

M 48 was discovered by Charles Messier on the 19th of February 1771. He describes this object as a "cluster of very faint stars without nebulosity." As with M 47 that same night, he made a mistake in his calculation of the coordinates and ended up 5° north of the true position. Hence, M 48 was considered one of the lost Messier objects, and the cluster was known only as NGC 2548 – until in 1959 T.F. Morris pointed out its identity as Messier's missing object.

Hence, Johann Elert Bode made an independent discovery of this star cluster in 1782. In his small star atlas, we find this object in its true place, as well as "Messier 48" in its wrong position, 5° north. Another independent discovery of M 48 was made by William Herschel's sister Caroline in 1783. She saw "a beautiful cluster of very compressed stars, pretty rich, 10' or 12' diameter."

50 years later, Smyth wrote about M 48: "A splendid group, in a rich splashy region of stragglers, which fills the field of view, and has several small pairs, chiefly of the 9th magnitude." Around the same time, John Herschel praised a "a superb cluster which fills the whole field; stars of 9th and 10th to the 13th magnitude – and none below, but the whole ground of the sky on which it stands is singularly dotted over with infinitely minute points."

Lord Rosse believed the cluster been "riddled with dark lanes and openings," while Mädler counted about 100 stars and wrote: "without distinct boundaries, so that some stars lie far out. In the denser part there is a nice double star." Brenner, too, called M 48 a "very beautiful object" and mentions the double star "near the middle, 7" separation."

Astrophysics

M 48 lies 500 light-years away from the galactic disk and has a distance of 2500 light-years from us. This is about six times the distance of the Pleiades. Stragglers extend M 48 to an angular diameter of 54', but the major, central part measures 30', which corresponds to a physical diameter of 22 light-years.

M 48 consists of at least 80 members, and recent studies suggest 323 cluster stars with a membership probability of 30%, and 165 of over 70%. Among these are three orange giants of spectral types G and K. In their cores, these evolved stars are already burning helium. The brightest of these is magnitude 8.2; it is the most luminous cluster star. By contrast, the brightest main sequence star has the spectral type A1 and a magnitude of 8.8. This puts the cluster age at about 300 million years.

Here, too, we find disagreement over the issue of the Trümpler class. Classifications of I2m, I2r, and I3r can all be found in the literature.

Observation

M 48 is located in the western part of the lengthy constellation Hydra, not far from the Winter Milky Way. Under good conditions, this large open cluster can be seen quite easily with the naked eye. The cluster character is already hinted at in the view through 10×50 binoculars: a central knot of stars is surrounded by a halo of fainter suns.

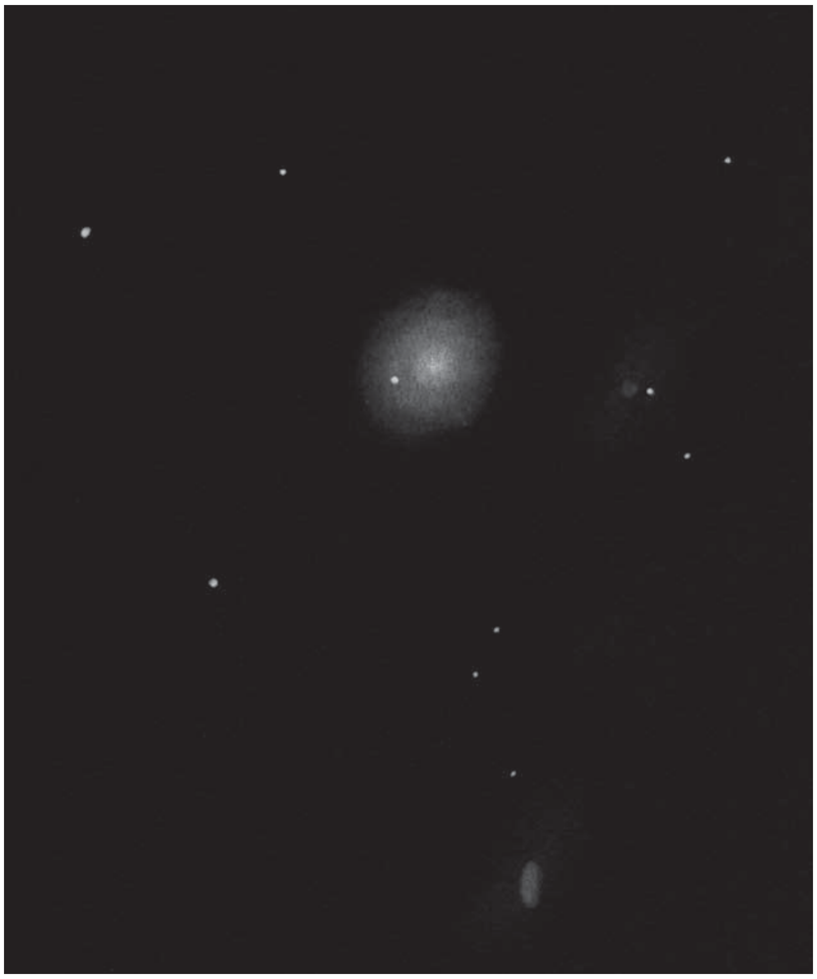
A small telescope gives an even clearer impression of this bipartition: the central region of 20' by 10', elongated in PA 30°, consists of brighter pairs of stars and short chains. It is embedded in a loose scattering of fainter stars, which span almost 1° in diameter. The outskirts of M 48 appear to be elongated in PA 120°, at a right angle to the central region.

There is a remarkable number of pairings in the cluster's center, and it's impossible to determine which double star Mädler and Brenner were referring to: h 2435 (magnitudes 9.6/9.7, 6.9" separation, PA 207°) or Burnham 904 (magnitudes 9.2/10.8, 3.3" separation, PA 183°). The best view is given, regardless of aperture, by lower magnifications between 15× and 50×.

Extensions included, M 48 reaches almost twice the angular size of the full moon. Stefan Seip.

M 49

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	NGC 4472
Type	Galaxy
Class	E4
Distance	53.1 Mly (V2004) 50.3 Mly (2000) 46.9 Mly (PN, 2000) 54.4 Mly (SBF, 2000)
Size	157,000 ly
Constellation	Virgo
R.A.	12^h 29.8^{min}
Decl.	+8° 0'
Magnitude	8.4
Surface brightness	22.1mag/arcsec^2
Apparent diameter	10,2'×8,3'
Discoverer	Messier, 1771



M 49, drawing. 14-inch Newtonian. Ronald Stoyan.

History

M 49 became the first of the Virgo cluster galaxies seen by a human eye. Charles Messier discovered it on the 19th of February 1771, and characterized it plainly as "nebula." In 1779, a comet passed through the Virgo cluster, which had a brightness that compared well to that of M 49. On that occasion, the Italian observer Oriani made an independent discovery of M 49 – Messier had not yet made public his find of this galaxy. Admiral Smyth, in his Bedford Catalog, later confused the dates of these two discovery observations, which has led to frequent false citations of Oriani as the primary discoverer of M 49. Smyth noted on his own observation of M 49: "A bright, round, and well-defined nebula. With an eyepiece magnifying 93 times, there are only two telescopic stars in the field, and the nebula has a very pearly aspect." His countryman and contemporary John Herschel found M 49 "extremely bright."

A few years later, d'Arrest believed that he saw "countless groups of stars; at 147×, the nebula periphery can be resolved into stars of the 13th and 14th magnitude." Obviously, not knowing of the true nature of M 49, d'Arrest thought he saw a globular cluster. Such a misinterpretation was not uncommon in the early days of visual observation, when astronomers were not yet swayed by photographic images.

Curtis looked carefully at the photographic appearance of M 49 and wrote: "The very bright nucleus is not stellar; shown well in a 3min exposure. Nearly round, 2' in diameter, fading out rapidly toward the edges. No structure discernible, though spiral character is suspected near the center in the short exposures."

Astrophysics

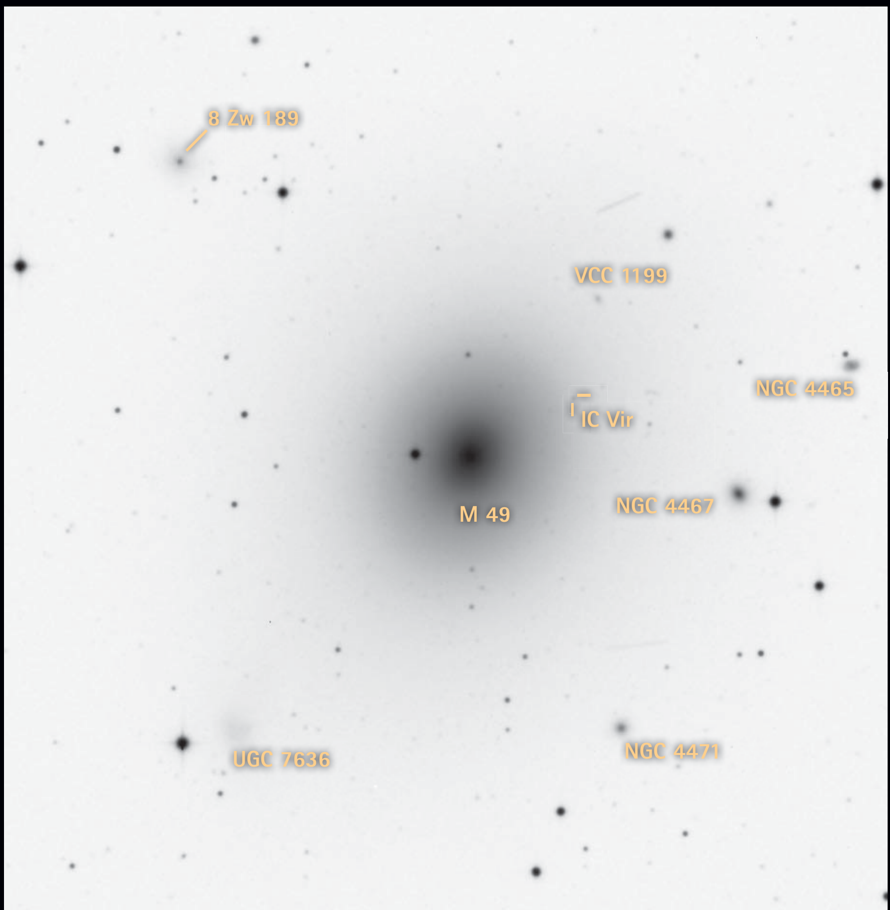
M 49 is the second-brightest galaxy of the Virgo cluster, and it forms its secondary center. It is only a little less distant than M 87 and has a radial velocity of 1000 km/s towards the principal Virgo cluster center. The outermost diameter of M 49 is about 160,000 light-years, within which the brighter central region takes up about 85,000 light-years.

M 49 is of a more yellow color than most galaxies in the Virgo cluster, which indicates a larger average age of for its stars and a lack of gas and dust to form new stars. It has been classified as an elliptical galaxy of type E4, despite evidence for some spiral structure in

Galaxies around M 49

Designation	R.A.	Decl.	Location	Mag.	Shape
NGC 4471 (VCC 1203)	12^h 29^{min} 41^s	7° 54' 40"	4.7' SW	15.3	elliptical
VCC 1190	12^h 29^{min} 35^s	8° 03' 29"	3.4' NW	15.5	elliptical
NGC 4467	12^h 29^{min} 30^s	7° 59' 34"	4.2' W	14.8	elliptical
UGC 7636	12^h 30^{min} 01^s	7° 55' 50"	5.5' SE	15.8p	irregular
8Zw 189 (VCC 1254)	12^h 30^{min} 05^s	8° 04' 24"	6.8' NE	15.0	compact
NGC 4465	12^h 29^{min} 24^s	8° 01' 34"	6.2' NW	15.6	spiral

M 49 is the central galaxy of the southern part of the Virgo cluster. Stefan Heutz, Wolfgang Ries.



the innermost, usually over-exposed central region. Arp has included M 49 in his list of peculiar galaxies as his object No. 134. He regarded the faint galaxy UGC 7636 to the southeast as an interacting companion. In 1998, several blue objects – young, massive stars only 100 million years old – were found in UGC 7636, and in 1994, a tail of 5' was discovered. Both findings are substantial evidence for an interaction – in the future, UGC 7637 will probably be torn apart by the tidal forces imposed on it by M 49.

Earlier estimates saw M 49 as the most massive object of the Virgo cluster but, by today's consensus, M 87 is now regarded as the principal galaxy. Nevertheless, the visible (i.e., luminous) matter of M 49 alone represents about 200 thousand million solar masses, and this is probably only the "tip of the iceberg." Including invisible "dark matter," M 49 may have up to ten times as much mass. In its center, there is a massive black hole of about 500 million solar masses. In addition, Chandra and ROSAT X-ray images have revealed a hot gas tail pointing from M 49 into our line-of-sight, which reflects the proper motion of this galaxy relative to the inter-galaxy gas of the Virgo cluster.

The system of globular clusters surrounding M 49 is estimated at an impressive 5700 objects, found within an angular distance from the galaxy core of 23'. There is a noteworthy peculiarity: it seems to comprise two different age groups. Some authors have, accordingly, been speculating about a galaxy merger in the distant past, from which M 49 could have inherited globular clusters of two different formation ages. Other authors rather see this simply as a matter of two different metallicities, instead of different ages.

One supernova has been found so far in M 49; 1969Q reached magnitude 13.0 in June that year and became only a little fainter than the foreground star east of the galaxy core. In front of the northwestern part of M 49, there is an RR Lyrae variable in our galactic halo, IL Vir. It reaches a maximum brightness of magnitude 19.0 and has the coordinates 12h 29min 41s, +8° 0' 55".

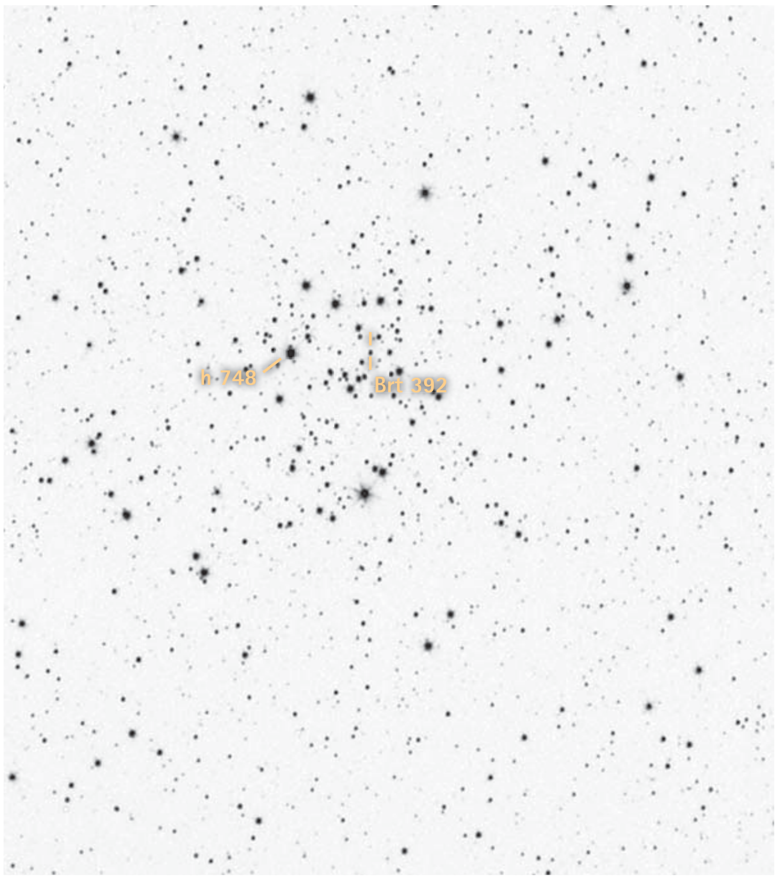
Observation

M 49 is bright and can be seen easily with 10×50 binoculars. However, it remains structureless even in larger telescopes. Small refractors show a round, bright core with a large halo of about 3' diameter.

A magnitude 12.5 star, 45" east of the galaxy's center, can be seen with larger apertures. The very small, compact galaxy NGC 4467 (magnitude 14.5), 4.2' west of the core of M 49, is the brightest of several companion galaxies (see table), and the only one visible with a 14-inch telescope.

M 50

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 2323
Type	Open cluster
Class	II3r
Distance	2870 ly (K2005) 3260 ly (CMD, 2003)
Size	13 ly
Constellation	Monoceros
R.A.	7^h 2.7^{min}
Decl.	−8° 23'
Magnitude	5.9
Surface brightness	–
Apparent diameter	15'
Discoverer	Cassini, 1711



History

Quite possibly, Giovanni Domenico Cassini discovered this open cluster in 1711, according to a communication from Cassini's son, issued after his father's death. Charles Messier must have looked for that "nebula" in 1771, but not until the 5th of April 1772 did he find a "cluster of small stars, more or less bright" – by good luck, since he happened upon it while observing the comet of that year. Bode – uninformed of Messier's find – was looking for Cassini's cluster in 1774 and found "a small star cluster under the belly of the Unicorn, on a nebulous background, with four small stars to the west."

Sixty years later, John Herschel commented on M 50: "Superb cluster; fills whole field; irregularly round; stars of 11th to 15th magnitude; not compressed in the middle; straggling stars extend over a circle 30' in diameter." By contrast, d'Arrest considered M 50 a "cluster of small stars" and saw a "red star close to one edge." Admiral Smyth noted: "an irregularly round and very rich mass, occupying with its numerous outliers more than the field, and composed of stars from the 8th to the 16th magnitudes."

Leo Brenner recommended M 50 as a "splendid object for small scopes" and gave its diameter as 30'.

Astrophysics

The open cluster M 50 has a distance of about 2900 light-years from us and lies only 70 light-years beneath the galactic plane. Its apparent size of 15' by 20' corresponds to a true diameter of about 13 light-years, while the dense inner region of 10' measures only 8 light-years. The Trümpler classifications disagree with each other, and assignments of I2m, II3m, to II3r have been made for M 50.

Claria et al. identified 109 probable cluster members among 175 stars in the field of M 50, while Wallenquist finds only 50 probable cluster stars. Recent studies, however, going down to a much fainter limiting magnitude of 23, suggest 2050 member stars.

The brightest cluster star is a red giant of spectral type K3 with a brightness of magnitude 7.8, located 7' south of the cluster's center. By contrast, the second-brightest star (magnitude 8.3) is blue and can be found in the northeastern part of the cluster.

Contrary to earlier belief, M 50 does not belong to the very young CMa-OB1 association, which is physically linked with the nebula IC 2177 and the star cluster NGC 2353. Early age estimates placed M 50 at about 78 million years, but these have recently been revised upwards, to an older 100 million years.

Observation

Under the best of conditions, M 50 is visible even to the naked eye. 10×50 binoculars show a bright cluster with glimpses of about 10 stars in front of a nebulous background. M 50 appears slightly elongated in P.A. 45°; its brightest star lies a little outside, to the south.

In small telescopes, 50 stars of 8th magnitude and fainter are irregularly clumped. In larger telescopes, up to 150 stars can be counted. The outer cluster members appear to be arranged in groups and loops. Voids without stars diminish the brightness of the cluster.

Modest apertures show an orange star south of the cluster's center. A 14-inch telescope reveals another one near the cluster's eastern border. Furthermore, two double stars suitable for small telescopes are worth mentioning: h 748 consists of two stars of magnitudes 8.5 and 10.6, separated by 6.8" in PA 173°; Barton 392 is fainter with magnitudes of 11.5 and 11.6, and a separation of 4.2" (PA 217°).

M 50 may contain more than 2000 stars, according to modern studies. Stefan Seip.

M 51

The Whirlpool Galaxy

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	NGC 5194-5
Type	Galaxy
Class	Sc/Irr
Distance	26.8 Mly (2003) 27.1 Mly (1996)
Size	87,000 ly/43,000 ly
Constellation	Canes Venatici
R.A.	13^h 29.9^{min}
Decl.	+47° 12'
Magnitude	8.4
Surface brightness	22.0mag/arcsec^2
Apparent diameter	11,2'×6,9'/5,6'×4,5'
Discoverer	Messier, 1773/Méchain, 1781

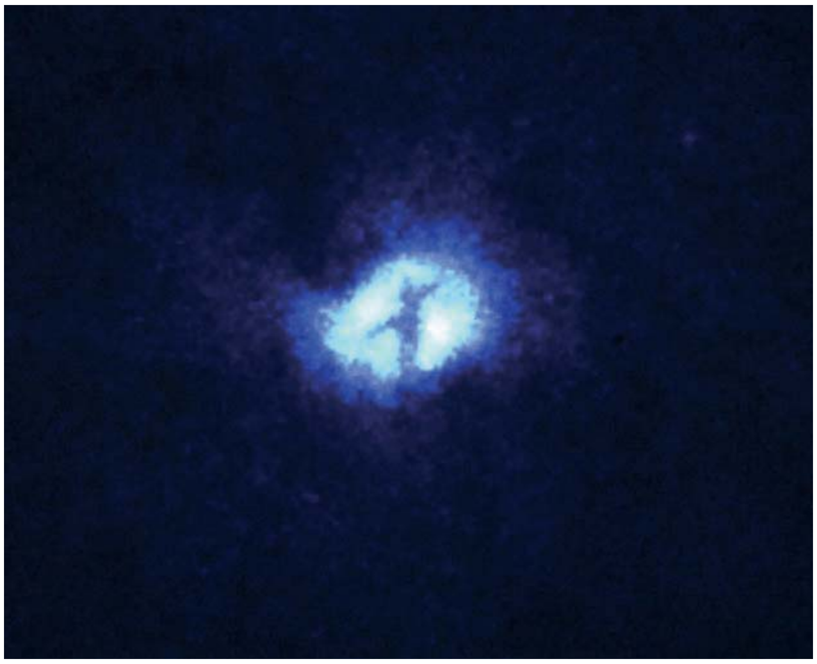
M 51. The impressive central region of the galaxy features numerous star clusters and HII-regions. Hubble Space Telescope.

History

This famous spiral galaxy was discovered by Charles Messier on the 13th of October 1773, when he was following the comet of that year. However he evidently saw only the brighter of the two cores (NGC 5194), since his original note, reproduced in his second catalog version, reads: "very faint nebula without stars." A later, hand-written note of Messier gives credit to Pierre Méchain as the discoverer of the second core (NGC 5195) on the night of the 21st of March 1781. Accordingly, his third catalog edition says: "it is double, each one with a brilliant center, separated from each other 4' 35." The two atmospheres touch each other. The one is fainter than the other."

Johann Elert Bode made an independent discovery of M 51 on the night of the 5th of January 1775. He described the galaxy as "a small, weakly luminous nebula, probably of elongated shape," which is pretty much the visual appearance in a small, modern telescope. Hence, while he did not specify NGC 5195 as a separate object, he was the first to see light from the companion galaxy.

In 1833, John Herschel saw "a very bright round nucleus surrounded at a distance by a nebulous ring." Today, this observation is considered the first hint of the spiral nature of a galaxy. Herschel himself thought of M 51 as a distant Milky Way. The really famous observations of M 51, however, were made by the 3rd Earl of Rosse from Birr Castle in Ireland. In September 1843, with a smaller telescope, he could not yet see Herschel's "ring." But in 1845, Lord Rosse aimed



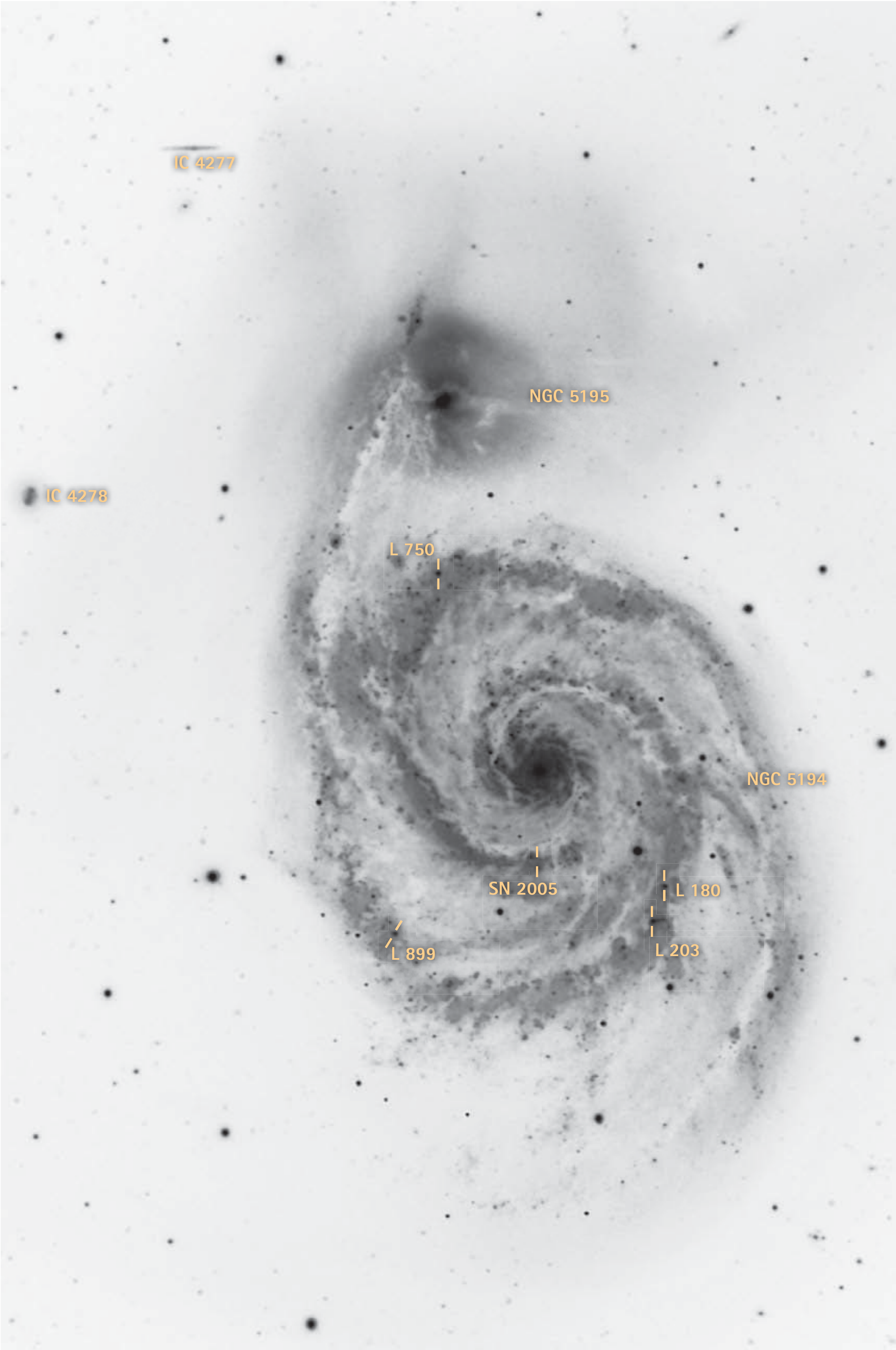
M 51. The galaxy core shows a peculiar "X"-shaped structure. Hubble Space Telescope.

M 51 is the prototype of an interacting galaxy pair, composed of the objects NGC 5194 (below) and NGC 5195 (above). Robert Gendler.

his new giant telescope towards M 51 and noted: "Spiral structure; with successive increase of optical power, the structure has become more complicated. The connection of the companion with the greater nebula is not to be doubted. The most conspicuous of the spiral nebulae." A country-wide famine in Ireland then affected the Earl's astronomical activities, and his next observation of M 51 dates from the 26th of April 1848, when he "saw the spirality of the principal nucleus very plainly; saw also spiral arrangement in the smaller nucleus."

Heinrich d'Arrest had, by comparison, only a modest aperture of 11 inches at his disposal, when he noted: "Core A is very large and bright, it is surrounded by a bright double-ring, which is brighter in PA 37° and 98°. Core B is large and becomes brighter to its center."

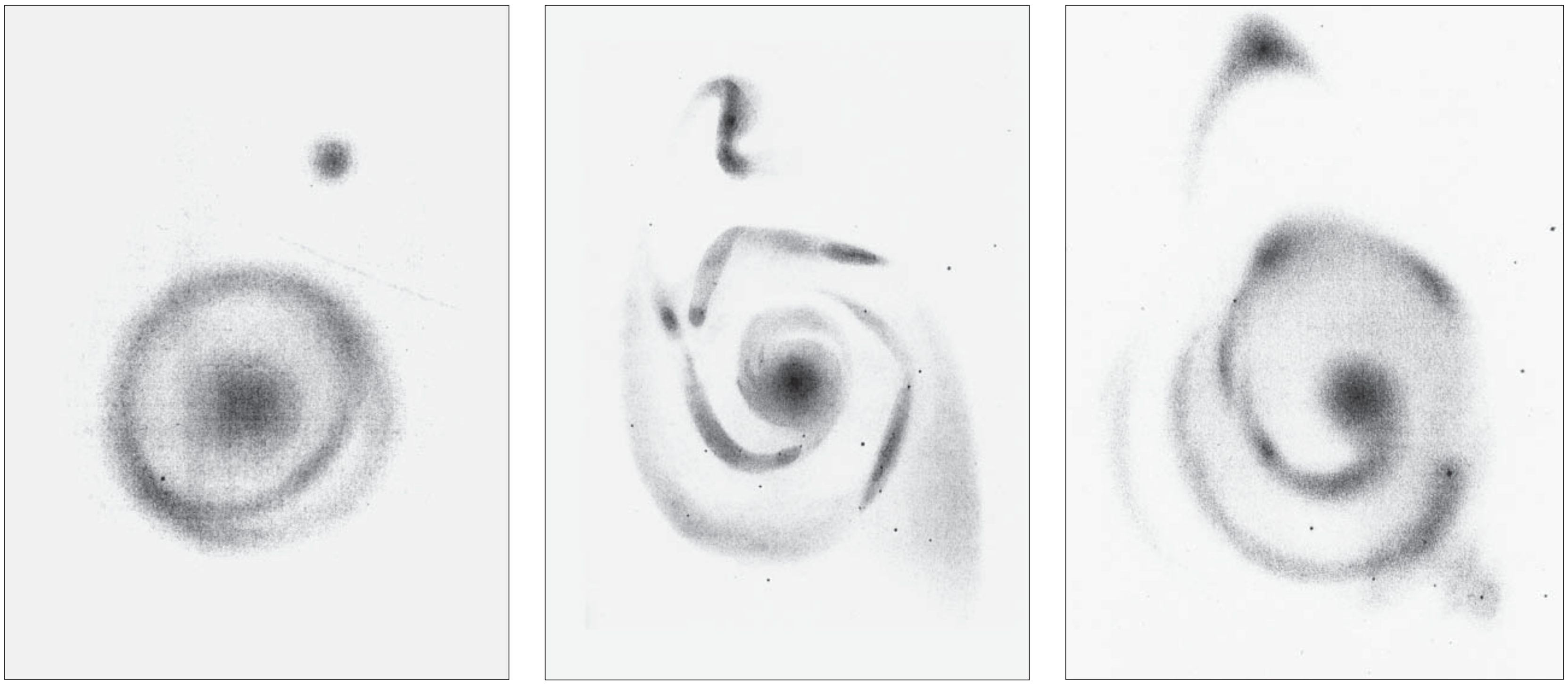
The first photos to show the full beauty of this galaxy and its spiral structure were made in 1889. Curtis produced a detailed description of M 51 in 1918, as seen on deep exposures: "The beautiful spiral M 51 in Canes Venatici. Including very faint matter to the north of NGC 5194, scarcely visible in any of the very numerous published reproductions, it covers an area about 12'×6' in PA approximately 30°. A sharp stellar nucleus in NGC 5194, and the whorls show a multitude of stellar condensations. The satellite nebula, NGC 5195, has a bright, elongated nucleus; its nebulosity is of a more diffuse type, without discernible spiral structure, and with several rifts which suggest absorption effects."



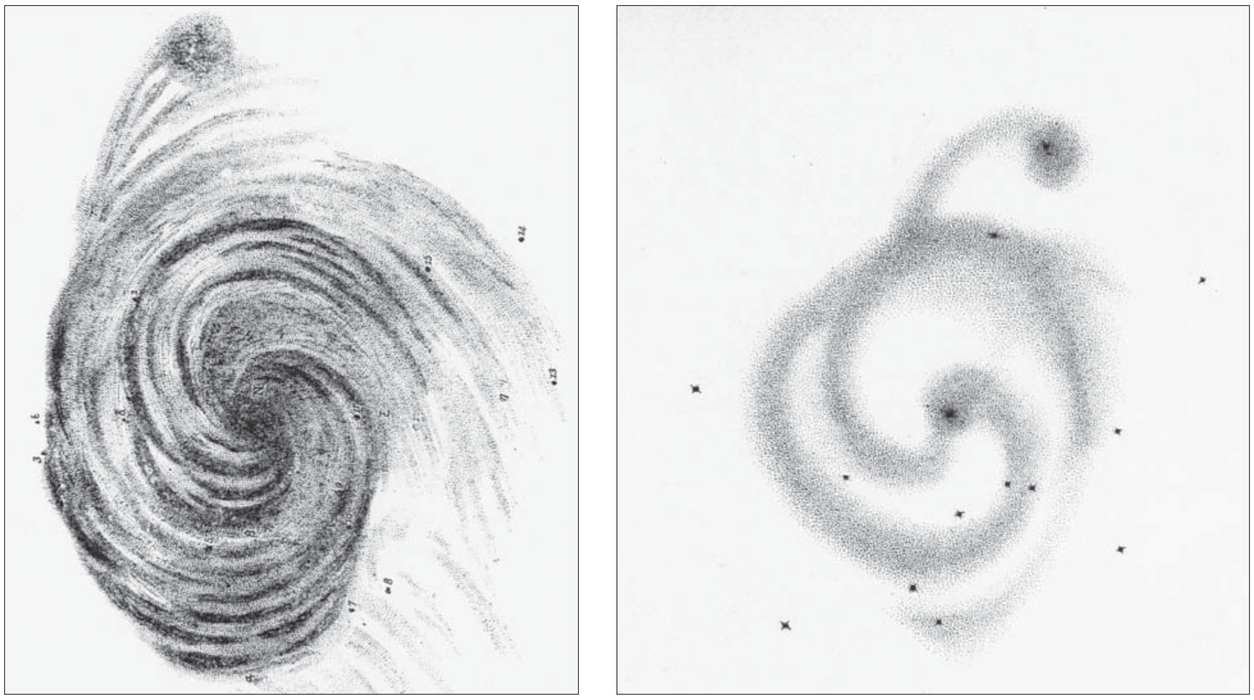
Astrophysics

NGC 5194 and NGC 5195, which together form Messier's object No. 51, represent the most popular example of a pair of interacting galaxies in our sky. The smaller galaxy NGC 5195 orbits the large spiral NGC 5194 with an inclination to the spiral's galactic plane of 73°. Presently, the companion is located about 500,000 light-years behind the northern spiral arm of the main galaxy, and the last close encounter was about 400 million years ago.

That event was not without consequences for these two galaxies. NGC 5194 shows pronounced spiral arms, after tidal interaction with NGC 5195 triggered wave after wave of enhanced star formation in the spiral. Some of the over 1000 cataloged star-forming regions and young star clusters, visible as red and blue knots, are no older than 10 million years. A striking feature is the spiral arms that are asymmetrically bent and streched towards the companion. In deep exposures, NGC 5195 itself shows tidal tails, in which stars have been accelerated into highly eccentric orbits that lead them far outside the galaxy.



M 51, historical drawings. John Herschel (before 1833, above left), S. Hunter and Lord Rosse (1864, above center), Hermann-Carl Vogel (1885, above right).



M 51, historical drawings. Lord Rosse (1845, left), William Lasell (1862, right).

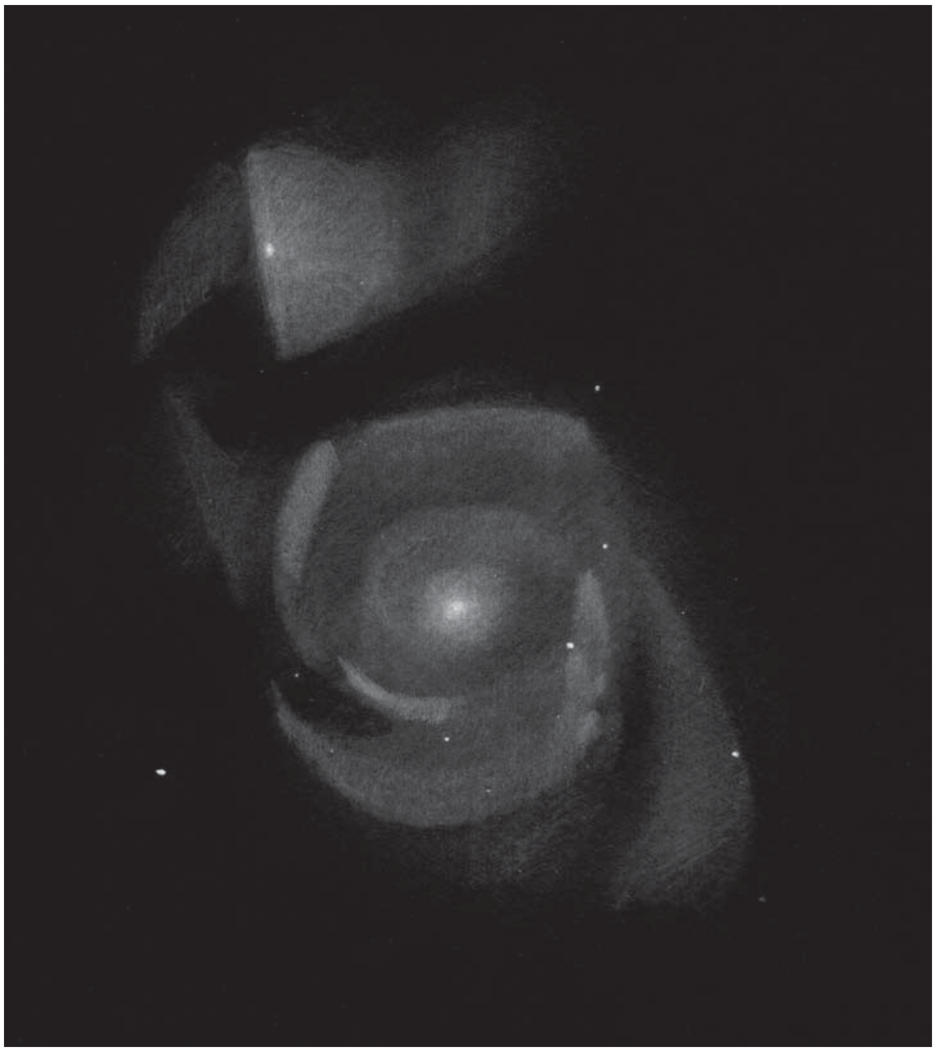
The Hubble Space Telescope not only permitted a very precise distance measurement of M 51, it also offered high-resolution views deep into the center of the main galaxy. The 120 light-year central region is known as a UV and radio source, as well as a Seyfert-2 object (see M 77), and features an "X"-shaped absorption structure. It contains an object only 5 light-years wide, but with about a million times the solar luminosity, which could be the accretion disk of a black hole. Observations with the Planetary Camera of the HST have, however, given evidence for a galaxy core hidden in dust, with a massive, central star cluster. From the inner 45 light-years diameter, the equivalent of 23 million solar luminosities are emitted. Radio observations have shown a bipolar core structure with a northern arc and a southern gas cloud, which could be heated by a jet from the core.

The extended, oval region of 11"×16" (1500×2100 light-years) around the center has a luminosity of 100 million Suns and a mass of 40 million solar masses. Red giants stand out here; they have an age of 5 to 8 million years. On HST images, Lamers and colleagues (2002) also found 30 blue point sources, which are placed along the spiral arms, between magnitude 21.4 and 24.3 within 1000 light-years of the core. Presumably, these are luminous, single stars with 12 to 120 solar masses. Bik et al. found 877 star clusters within 3000 to 10,000 light-years from the core, but no clear evidence of enhanced star-forming activity, which should have been triggered by the close encounter with NGC 5195, 400 million years ago. According to Lamers and colleagues, the presently available gas suffices for another 200 to 400 million years of further star formation.

The main galaxy, NGC 5194, has a total diameter of 87,000 light-years, which makes it just a bit smaller than our Milky Way, but it contains only 10% of the Milky Way's mass. The companion, NGC 5195, was first classified as an irregular galaxy of the M 82 type (I0). Recent studies, however, indicate that it is a barred spiral (SB0psc or SB0a(r)). The last encounter led to a large starburst, which consumed most of the gas and dense molecular clouds in this galaxy. Hence, there are few stars younger than spectral type B5 now in NGC 5195. Its central core region, 120 light-years in diameter, is covered by the spiral arm of NGC 5194, and suffers an extinction of 1.3 to 2.0 magnitudes.

M 51, or Arp 85 in the catalog of interacting galaxies, forms the center of gravity of a galaxy group at about 27 million light-years distance. Apart from M 63, other members are NGC 5023 and 5229, as well as UGC 8313, 8331, and 8683.

Three supernovae have been observed in M 51, so far. SN 1945A went off in the companion, NGC 5195, and reached 14th magnitude on the 8th of April 1945. The US amateur astronomers Armstrong and Puckett discovered a supernova on the 2nd of April 1994, only 2000 light-years from the core of NGC 5194. Very recently, on the 27th of June 2005, the German amateur Wolfgang Kloehr was the lucky discoverer of yet another supernova in this galaxy (2005cs), this time 40" south of the core, magnitude 14.0.



M 51, drawing. 14-inch Newtonian. Ronald Stoyan.

Observation

The two cores of M 51 can be spotted faintly in 10×50 binoculars. With a small telescope, both galaxies appear as small nebulae, separated by 6'.

In a 4.7-inch refractor, M 51 is bright and quite impressive for its double-structure but otherwise remains featureless. The main galaxy, NGC 5194, shows a bright, extended core surrounded by a halo of diffuse light of 3' in size, without any hint of spiral structure. NGC 5195 measures only 1'; it is seen as a nebula with a star-like center, slightly elongated in the north-south direction.

It takes an aperture of 8 inches at medium power to see the first signs of the spiral structure of M 51. With a 14-inch telescope, it becomes truly impressive and well defined. Through both the symmetry and asymmetry of its spiral arms, the double galaxy gains a unique appeal. Featuring some bright, diffuse spots, one arm starts in the south and bends northeast. It then aims straight towards NGC 5195, only to abruptly bend westward just 2' south of its core. Here, the arm appears brightest and can be followed a further 3' to the southwest, before it disappears in the diffuse background glow.

The other spiral arm starts 1.5' west of the core, clearly detached from it. Leading south, it first passes a foreground star and then describes a semicircle around the core, keeping a distance of 3'. It is well separated from the other spiral arm by darkness, until it finally ends 2.2' east of the galaxy's center. A faint fan, reaching southward, is seen at the southwest edge of the galaxy.

In the core of NGC 5194, three brightness levels can be distinguished in a 14-inch telescope, with diameters of 20", 1', and 2', slightly elongated in PA 10°. By contrast, the core of the companion galaxy NGC 5195 remains almost stellar in appearance. It is embedded in a bright, cigar-shaped bar of 1.7' length in PA 175°. In the west, the bar is joined by a semicircular halo, which appears a bit brighter at the outer edge and in the middle. East of the bar, there is only a faint structure, which aims at NGC 5194 but does not appear to meet its approaching spiral arm. This "bridge," as well as the tidal tails around NGC 5195, requires larger apertures or deep photographic exposures. Of the numerous faint foreground stars, a 14-inch telescope would show only one with certainty, 2' southwest of the core of NGC 5194.

Two faint galaxies lie in the background of M 51, which require a larger aperture for visual observation than 14 inches. The delicate needle of IC 4277 is 4' northeast of the core of NGC 5195; IC 4278 can be found 5' south of it.

M 52

Degree of difficulty	2 (of 5)
Minimum aperture	30mm
Designation	NGC 7654
Type	Open cluster
Class	I2r
Distance	4630 ly (K2005) 4470 ly (2001)
Size	22 ly
Constellation	Cassiopeia
R.A.	$23^h\ 24.8^{min}$
Decl.	+61° 36'
Magnitude	6.9
Surface brightness	–
Apparent diameter	16'
Discoverer	Messier, 1774

History

M 52 is another chance discovery by Charles Messier, made while he was following a comet. The French observer noted, on the 7th of September 1774: "Cluster of very small stars, which cannot be seen except in an achromatic refractor, mingled with nebulosity."

50 years later, John Herschel described this cluster and saw "a ruddy star of 9th magnitude in the preceding [western] part of a pretty rich irregular cluster of stars of 13th magnitude, all separate, 6' diameter; a very little more compressed in the south following [southeastern] part."

His countryman Admiral Smyth commented on M 52: "This object assumes somewhat of a triangular form, with an orange-tinted 8th magnitude star at its vertex, giving it the resemblance of a bird with outspread wings. It is preceded by [east of] two stars of 7th and 8th magnitudes, and followed by [west of] another of similar brightness; and the field is one of singular beauty under a moderate magnifying power." With his large telescope, Lord Rosse estimated that there were 200 cluster stars.

Curtis referred to the photographic appearance of the cluster when he wrote: "A very sparse, open cluster 16' in diameter, of stars 12th–16th magnitude."

Astrophysics

After M 11, M 52 is one of the richest open clusters in the Messier list. In 1959, Wallenquist counted 193 cluster members within a radius of 9'. More recent sources state 130 cluster stars and 30 field stars down to 14th magnitude, plus more than 6000 cluster stars and about as many field stars down to magnitude 19.5. The star density in the cluster's center is about one star of 15th magnitude (or brighter) per square arcsecond or, in absolute terms, 1.5 stars per cubic light-year.

A yellowish giant star of spectral type G8 is the brightest star of the cluster at magnitude 8.2. The brightest blue main sequence star (B7) is magnitude 11.0. M 52 contains five known variables and a hot Of-star with an emission line spectrum. The extinction varies on small scales and diminishes the cluster stars by up to 1 magnitude, which complicates precise assessments.

The literature gives quite a range of age estimates, between 25 million and 165 million years. It seems possible that M 52 was formed in, not one, but two consecutive phases star forming. Distance values between 3000 and 7000 light-years have been suggested. With the more recent measurements of 4500 light-years (Pandey et al., 2001) or 4600 light-years (Kharchenko et al., 2005), we obtain a physical cluster diameter of 22 light-years.

Observation

M 52 can be spotted as a small round nebula even with very small binoculars. A small 2-inch refractor begins to resolve the brightest cluster stars.

4.7 inches aperture reveals about 60 stars, nearly equally faint (between 12th and 14th magnitude), distributed over an area of 10' diameter. This gives the open cluster a homogeneous and rich appearance. At higher magnification, the orange tint of the brightest star in the western part of the cluster becomes noticeable. Another yellowish star lies 10' southeast of M 52.

A 14-inch telescope shows about 100 cluster stars, many quite densely packed. Only the western region of the cluster is less rich. The visual extent of the cluster reaches 15'.

There is another, much poorer galactic cluster only 20' southeast of M 52: Czernik 43. Larger telescopes show about 10 stars against a nebulous background.

A galactic emission nebula, the "Bubble Nebula" around the star BD+60°2522, lies 35' southwest of M 52. It is quite popular with photographers; visual observers need a narrowband filter to see a hint of it with telescopes of 4 inches and more. Observed in a 14-inch telescope, this nebula is impressive: its brightest part is attached to a bright star and gives way to a sharply defined bubble, open towards the south, with a diameter of just under 1'. An inhomogeneous, diffuse nebulous region 5' in size lies to the north of the star.

M 52 with Czernik 43 (left) and NGC 7635. Stefan Binnewies.

M 52. A yellow giant is the brightest star of up to 6000 cluster members. Robert Gendler.

M 53

Degree of difficulty	2 (of 5)
Minimum aperture	30mm
Designation	NGC 5024
Type	Globular cluster
Class	V
Distance	61,270 ly (R2005)
Size	230 ly
Constellation	Coma
R.A.	13^h 12.9^{min}
Decl.	+18° 10'
Magnitude	7.7
Surface brightness	–
Apparent diameter	13'
Discoverer	Bode, 1775

History

M 53 was discovered in the early morning hours of the 3rd of February 1775 by Johann Elert Bode in Berlin (Germany). Bode described it as "lively and round." Charles Messier had no knowledge of Bode's observation and discovered M 53 independently on the 26th of February 1777 as a "nebula without stars." He later likened it to M 79 and commented: "round and conspicious."

Only a few years later, William Herschel succeeded with his fine, home-made reflectors in resolving this globular cluster into individual stars. He likened M 53 to M 10 and wrote enthusiastically: "One of the most beautiful objects I remember to have seen in the heavens. The cluster appears under the form of a solid ball, consisting of small stars, quite compressed into one blaze of light, with a great number of loose ones surrounding it, and distinctly visible in the general mass." On the 14th of March 1783, he discovered the neighboring, but much fainter, globular cluster NGC 5053.

"A most beautiful, highly compressed cluster" was the comment on M 53 made later by John Herschel. He stated the brightness of its individual stars as magnitudes 12 to 20 and said that the visual appearance would be "indicating a round mass of pretty equable density."

Lord Rosse was under the impression that M 53 was "not compressed to one point but apparently to four or five different points within a small area," and he gave a diameter of only 3'. Photographic images, however, instead suggest 10', according to Curtis.

Astrophysics

M 53 has the quite large distance of about 63,000 light-years from us, as well as from the galactic center. In absolute terms, it is much larger than the nearer M 13: M 53 has a diameter of 230 light-years and about 750,000 solar masses.

Its wide orbit leads M 53 through the outer galactic halo and takes about a thousand million years to complete. It reaches a maximal distance from the galactic center of 100,000 light-years but, at present, M 53 is approaching us at 70 km/s.

According to Shapley, M 53 has the concentration class V. The brightest stars reach magnitude 13.8; Sawyer-Hogg calculated an average magnitude of 15.1 for the 25 brightest cluster stars, and the horizontal branch starts at 16.9. The stars of M 53 have the very low metal abundances typical for globular clusters of the galactic halo, which formed from almost primordial gas. There are 59 known RR Lyrae and 8 SX Phe [Phoenicis] variables. The latter belong to the 151 recorded blue stragglers of M 53 (see M 30).

In 1989, a pulsar with a period of 33 milliseconds was found in M 53 by the Arecibo Radio Telescope. Signal shifts show that it is orbiting another star over a 256-day period. After its formation in a type Ia supernova, this millisecond-pulsar must have received extra angular momentum by interaction with its partner star in a close binary. In globular clusters, such a partner may later be lost in close encounters with other stars (see M 13). The rather slow rotation of the M 53 pulsar suggests an age of one thousand million years.

1° to the east of M 53 is the very faint globular cluster NGC 5053. It is unusual for its very low star density, very low metallicity, and the absence of a dense core. With its smaller distance of 53,500 light-years, NGC 5053 is not a real neighbor of M 53 in space, but it truly is much smaller in absolute terms, with a diameter of 160,000 light-years and only 40,000 solar luminosities. Its brightest stars are, like those of M 53, magnitude 13.8; the horizontal branch stars reach magnitude 16.7, but the total brightness of this cluster is a mere 9.5.

Observation

M 53 appears as a small nebulous ball in 10×50 binoculars, and the same impression is maintained when a small refractor is used.

With an aperture of 4.7 inches, a round nebula with an extended core is seen. Some observers call the central region triangular. To resolve individual stars, larger apertures of 6 to 8 inches are required.

A 14-inch telescope fully resolves M 53 into individual stars; a nebulous background remains present only in the bright and compact central region. Towards the outskirts of the globular cluster, its stellar distribution becomes irregular and assumes a wispy character. There is a magnitude-11.5 foreground star northeast of the cluster center.

The fainter globular cluster NGC 5053, 1° southeast, may already be seen as a faint nebulous glow in 20×100 giant binoculars under good observing conditions. In a 14-inch telescope, a large, diffuse mass appears. It has fine speckles; a central condensation is not noticeable.

The bright star α Comae 1° southwest of M 53 is a binary (Σ 1728) with two equal components of magnitude 5.2, which orbit each other in 25.8 years. We look at the orbit from nearly edge-on. Hence, while the separation was only 0.3" in 2003, it will increase to 0.65" in 2010. Likewise, the position angle changes rapidly after periastron, from 12° to 192°.

A much easier to observe double star is Σ 648, only 6.2' southeast of M 53. It has two stars of magnitude 9.5, separated by 87".

M 53 is much larger, in absolute terms, and more massive than M 13. Stefan Binnewies, Josef Pöpsel.

M 54

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 6715
Type	Globular cluster
Class	III
Distance	84,650 ly (RRLyr, 2002)
Size	300 ly
Constellation	Sagittarius
R.A.	$18^h\ 55.1^{min}$
Decl.	–30° 28'
Magnitude	7.2
Surface brightness	–
Apparent diameter	12'
Discoverer	Messier, 1778

M 54 is the most distant globular cluster in the Messier catalog. It belongs not to the Milky Way, but to the dwarf galaxy SagDEG. Rainer Sparenberg, Volker Robering.

History

Messier discovered M 54 on the 24th of July 1778 – apparently, while he was searching for M 55, which was already listed in Lacaille's catalog. He characterized M 54 as a "very faint nebula, the center is bright, does not contain any star."

John Herschel, by contrast, found it easy to resolve M 54, even with his weaker left eye, but he was observing with a much larger telescope and from South Africa. He noted: "resolved into stars of 15th magnitude, with a few outliers of magnitude 14." Other historic observers had very little interest in this very southern Messier object, which is difficult to observe from northern latitudes.

Curtis characterized M 54 in 1918 as a "remarkably condensed globular cluster 2' in diameter," based on its photographic appearance.

Astrophysics

M 54 is exceptional among the globular clusters in the Messier catalog, since it is the only one which is gravitationally bound not to the Milky Way, but to the elliptical dwarf galaxy SagDEG.

The Sagittarius Dwarf Elliptical Galaxy was discovered as recently as 1994, during the course of a study of the star density in the Milky Way. It has the coordinates 18h 55.1min and –30° 29', and covers an area of 3.2° by 8.2°. It is our nearest companion galaxy, even closer than the Magellanic Clouds, but it lies right behind the densest parts of the Milky Way. Its proximity will determine its destiny: strong tidal forces are leading to its disintegration. Its orbit around our galactic center has led it into ten close encounters, the last one about 200 million years ago. It will probably not survive the next one, which is due in only a few tens of millions of years. In fact, it is surprising that SagDEG survived this long at all – it has been suggested that it may contain extra mass in the form of dark matter.

Apart from M 54, the globular clusters Arp 2, Terzan 7, and 8, as well as Palomar 12 all belong to SagDEG, but the latter may have been lost already to the Milky Way, stripped off the dwarf galaxy by tidal forces. The location of M 54 coincides with one of the two concentrations in SagDEG. With its large distance of 85,000 light-years, M 54 is roughly three times farther away than its apparent neighbors M 69 and M 70, and its physical size is an impressive 300 light-years; only Omega Centauri is larger! Furthermore, with about 1.5 million solar masses, M 54 already contains 1/40 of the mass still left in SagDEG.

M 54 has a very concentrated appearance and was characterized by Shapley as a class III cluster. The brightest individual stars are only magnitude 15.5, due to their large distance, and the horizontal branch starts at magnitude 17.7. Most of the known 211 variables are RR Lyrae stars; two semi-regular red variables show periods of 77 and 101 days.

Observation

M 54 is regarded as the faintest globular cluster in the Messier catalog, and its southerly position in the sky makes it an even more difficult object to observe. 10×50 binoculars show only a faint, unsharp star.

In amateur telescopes, M 54 appears as a strongly concentrated ball of nebulosity with a core of almost stellar appearance. Several 12th-magnitude foreground stars fake resolution into individual cluster stars. True resolution, though still partial, is gained with a 14-inch telescope, but not in the luminous center. The visual extent remains small, only 2'.

M 55

Degree of difficulty	3 (of 5)
Minimum aperture	30mm
Designation	NGC 6809
Type	Globular cluster
Class	XI
Distance	19,300 ly (RR Lyr, 2001) 19,660 ly (RR Lyr, 1999)
Size	110 ly
Constellation	Sagittarius
R.A.	19^h 40.0^{min}
Decl.	–30° 57'
Magnitude	6.3
Surface brightness	–
Apparent diameter	19'
Discoverer	Lacaille, 1752

History

M 55 was discovered already between 1751 and 1752 by Nicholas-Louis de Lacaille, when he carried out his southern star survey from South Africa. He registered this globular cluster as his 14th object in the class "nebula without stars" and likened it to an obscure core of a large comet.

Messier was hoping to repeat Lacaille's observation on the 29th of July 1764 for his first catalog, but he could not find this very southern object. However, almost exactly 14 years later, on the 24th of July 1778, he was finally successful, right after discovering M 54 by accident the same night. He noted on M 55: "Nebula, which is a whitish patch of about 6' in extent, its light is even and appears not to contain any star."

The debated Australian observer James Dunlop also failed to resolve this globular cluster into individual stars. He described M 55 as a "beautiful large round bright nebula, about 2' diameter, slight condensation to the center." Only William and John Herschel resolved cluster stars and saw a better part, 10', of the pretty large angular diameter of M 55.

Curtis gave this description, according to photographic images: "A fine globular cluster 10' in diameter. The background of faint stars is less dense near the center than in most clusters of this type."

Astrophysics

With its generous angular diameter of 19', M 55 is among the (apparently) largest globular clusters in our sky. However, with its distance of just over 19,000 light-years, it has a fairly average physical diameter of 110 light-years. Its moderate mass has been estimated as equivalent to that of 250,000 Suns, and its luminosity to that of 100,000 solar luminosities.

M 55 is a globular cluster of the galactic bulge. It never exceeds a distance of 20,000 light-years from the galactic center, but it can get as close to it as 5,000 light-years. Its orbit has an inclination of 60° to the galactic plane and takes about 100 million years to complete. The age of M 55 has been estimated as 12.5 thousand million years, a typical value for globular clusters.

M 55 is almost the least concentrated object of its kind in the Messier catalog; Shapley gave it his class XI. Only M 71 is looser. A good explanation is that during the many passages of M 55 through the dense inner galactic bulge, it must have lost a lot of its stars.

The brightest stars of M 55 reach a remarkable magnitude 11.2. Sawyer-Hogg gave 13.6 as the mean magnitude of the 25 brightest cluster stars. About 40 variables have been found in this globular cluster, including 15 RR Lyrae stars and three eclipsing variables. Furthermore, 24 of the 74 confirmed "blue stragglers" are variables of the SX Phoenicis type.

In 1996, Mateo and Mirabel discovered that a considerable fraction of the stars in this field actually belong to the dwarf galaxy SagDEG, which lies only 9° east of M 55 (see M 54). These include 3 RR Lyrae stars, which, at their larger distance of 85,000 light-years, are not physical members of M 55, but lie far behind it.

Observation

O'Meara has reported naked-eye sightings of this cluster, but any confirmation seems to require very southerly sites. 10×50 glasses hint not only at the large apparent size, but also at the relatively low surface brightness of M 55.

Under good observing conditions, this globular cluster can be resolved into individual stars with a 4-inch telescope. The poor concentration of its central region is very noticeable, and it is quite easy to resolve. Larger apertures yield a visual diameter of 12'. Skiff and Glyn Jones reported a dark bay in the southeastern part of the cluster. However, a better impression of the large number of cluster stars of 17th-magnitude and fainter, as well as of the full large diameter of M 55, is only provided by a good photograph.

M 55 is a very open globular cluster. Daniel Verschatse.

M 56

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	NGC 6779
Type	Globular cluster
Class	X
Distance	27,390 ly (2003)
Size	55 ly
Constellation	Lyra
R.A.	19^h 16.6^{min}
Decl.	+30° 11'
Magnitude	8.4
Surface brightness	–
Apparent diameter	7'
Discoverer	Messier, 1779

History

Charles Messier found M 56 on the 19th of March 1779, on the same night that he made an independent discovery of a comet, which had been previously found by Bode without his knowledge. On the 23rd, when he finally reobserved M 56 to measure its position, he noted: "nebula without star, has little light, near to it is a star of 10th magnitude." Five years later in 1784, John Herschel succeeded in resolving this globular cluster into individual stars, thereby proving Messier's note wrong. Herschel described M 56 as a "fine compressed cluster, round, inclining to triangular form, brighter towards the middle, stars of 12th to 14th magnitude."

Observing with an 11-inch refractor, d'Arrest noted: "A star cluster, which contains a large number of stars, none of which is brighter than 12th to 13th magnitude. With 356× magnification resolved into minute stars." Reverend Webb even thought he had resolved M 56 with his very modest 3.7-inch refractor.

Curtis' description of the photographic appearance reads: "Rather bright, condensed cluster, 3' in diameter. Probably globular."

Astrophysics

M 56 is a poorly concentrated globular cluster of the Shapley class X. Only M 55 and M 71 are even less concentrated. Shapley was the first to notice the slightly elliptical shape of M 56 in PA 45°.

Its very eccentric, but low-inclination, orbit around the galactic center takes M56 out to distances of 40,000 light-years. But then, 125 million years later, it gets as close as just a few thousand light-years to the galactic core. The current distance of M 56 from us is 27,000 light-years, as it passes through the outer half of its orbit. In 2000, an X-ray tail was discovered, which is trailing the globular cluster. This

seems to indicate an interaction between the cluster and the galactic halo gas through which it moves.

With just about 200,000 solar masses, M 56 has only a third of the mass of M 13. Its brightest stars reach magnitude 13.0, and Sawyer-Hogg found an average magnitude of 15.3 for the 25 brightest cluster stars; the horizontal branch begins at magnitude 16.2. The brightest star of the cluster is a variable of the RV Tauri type. There are five more known variables of this kind in M 56, others have been found in Omega Centauri, M 2, M 5, M 10, and M 28. The variable reaches a maximum magnitude of 13.0b and was discovered in 1940 by Davis; its period is 90 days. At least 13 more variables have been found in M 56, including the two next brightest cluster stars at about 13th magnitude. Even the neighborhood of the cluster is quite rich in variables: six more have been found within a distance of 10' from the center of M 56.

Observation

Seen through a pair of 10×50 binoculars, M 56 looks like a small, nebulous ball. This impression becomes more distinct in a small telescope, which also shows a nearby 10th-magnitude star to the west.

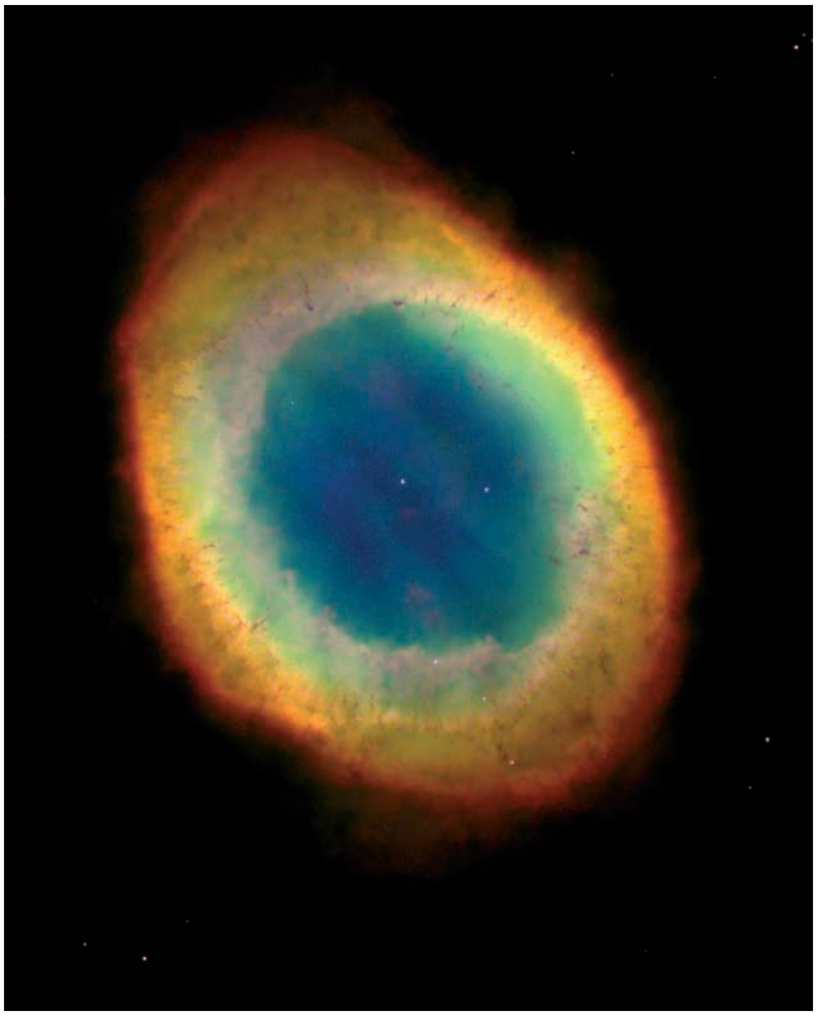
In a 4.7-inch refractor, glimpses of the first individual stars can be seen, but the globular cluster is still not fully resolved. Its elliptical shape remains unnoticeable. 6 to 8 inches of aperture fully resolve M 56 into individual stars, 10 inches the relatively open center. A 14-inch telescope shows a wide central region of 5' diameter without any real core, perfectly resolved, with apparent chains of stars reaching westward. There is a semicircle of brighter stars, south of the central region of M 56, seen against a nebulous background. These may be field stars of the rich surrounding Milky Way.

M 56 is ten times further away than its prominent neighbor, M 57. Stefan Seip.

M 57

The Ring Nebula

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	NGC 6720
Type	Planetary nebula
Class	IV
Distance	2300 ly (1997)
Size	0.9 ly
Constellation	Lyra
R.A.	18^{h} 53.6^{min}
Decl.	+33° 2'
Magnitude	8.8
Surface brightness	–
Apparent diameter	86"×62"
Discoverer	Darquier, 1779



M 57. The nebula expands at a rate of about 1" per century. Hubble Space Telescope.

History

The Ring Nebula in Lyra was only the second planetary nebula to be found. The comment on M 57 made by its discoverer, Antoine de Darquier de Pellepoix, led to the name for this class of objects. In January 1779 he wrote: "It is very dull, but perfectly outlined; as large as Jupiter and looks like a fading planet." Soon, Charles Messier learned of Darquier's observation and looked for this nebula himself. His note from the 31st of January 1779 reads: "It seems that this mass of light, which is rounded, is composed of very faint stars. Even with the best telescopes it is not possible to perceive them, there is only a suspicion that they are there." Observing with a small telescope of today, we can easily agree with Darquier's description, while we are certainly bewildered by Messier's impression. However, without any knowledge of the true, gaseous nature of M 57, historic observers tried to resolve it into individual stars until the late-nineteenth century.

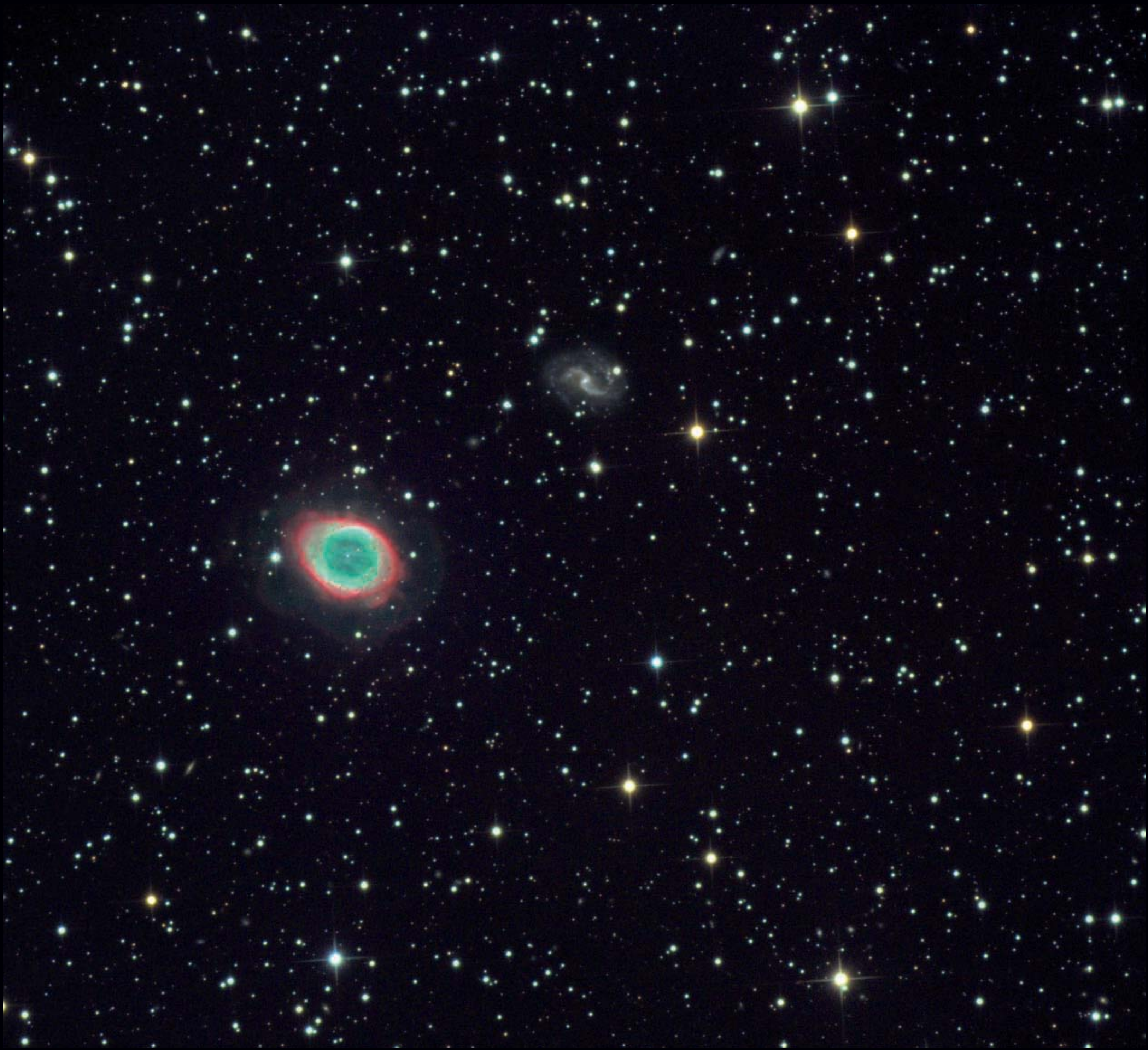
The great observer William Herschel remarked: "Among the curiosities of the heavens should be placed this nebula, which has a regular, concentric, dark patch in the middle, and is probably a Ring of stars. It is of an oval shape, the shorter axis being to the longer as about 83 to 100. The light is of the resolvable kind, and on the northern side three very faint stars can be seen, as well as one or two in the southern part. The endings of the longer axis seem less bright and not so well defined as the rest." So, even Herschel succumbed to the mistaken impression that M 57 was composed of stars.

The wealthy German amateur astronomer Friedrich von Hahn had built an observatory next to his castle in Remplin (in northern Germany) and used an 18-inch mirror made by Herschel. In 1803, he reported: "A few years ago, the inside of the ring was so clear that in its middle I could make out a small telescopic star. Now there appear faint, fine clouds and the small star is not visible any more." With this first mention of the central star of M 57, the myth of its variability was born.

Johann Hieronymus Schröter, another German customer of Herschel's fine large mirrors during that time, was actually the first to mention the nebulosity inside the bright ring of M 57, and he very appropriately described it as "like the moonlit sky." Later, in 1830, John Herschel confirmed this observation and remarked: "The edges exhibit a curdled and confused appearance, like stars out of focus. The interior is far from absolutely dark. It is filled with a feeble but very evident nebulous light, which I do not remember to have seen noticed by former observers."

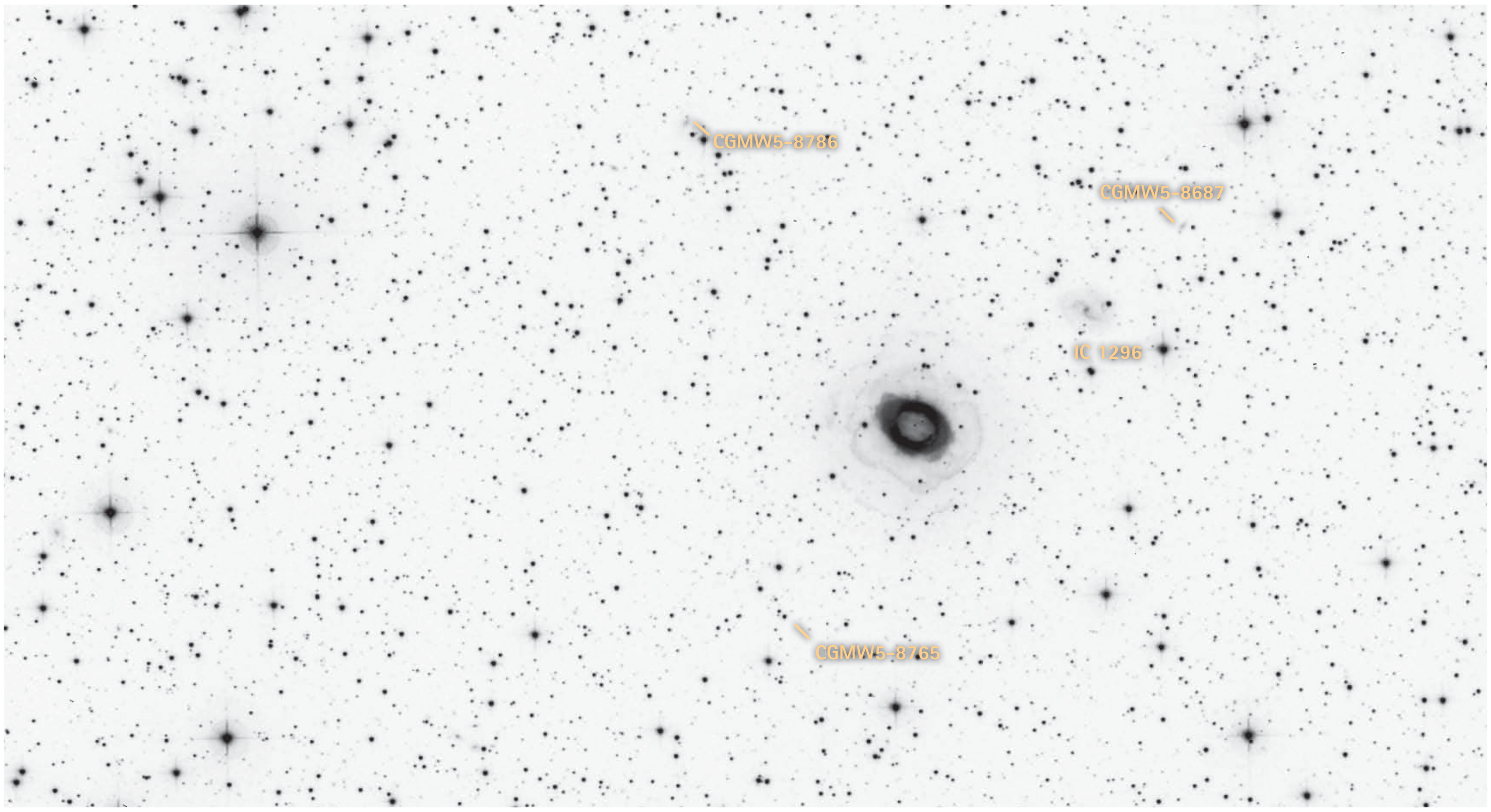
Lord Rosse saw remarkable detail in his giant telescope in 1844: "The filaments proceeding from the edge become more conspicuous under increasing magnifying power within certain limits, which is strikingly characteristic of a cluster." In 1850, after another obser-

M 57. The Ring Nebula in Lyra. Stefan Binnewies, Josef Pöpsel.



M 57. The Ring Nebula is regarded as a textbook example of a planetary nebula. Stefan Binnewies, Josef Pöpsel.

M 57. The outer halo structure. Stefan Binnewies, Josef Pöpsel.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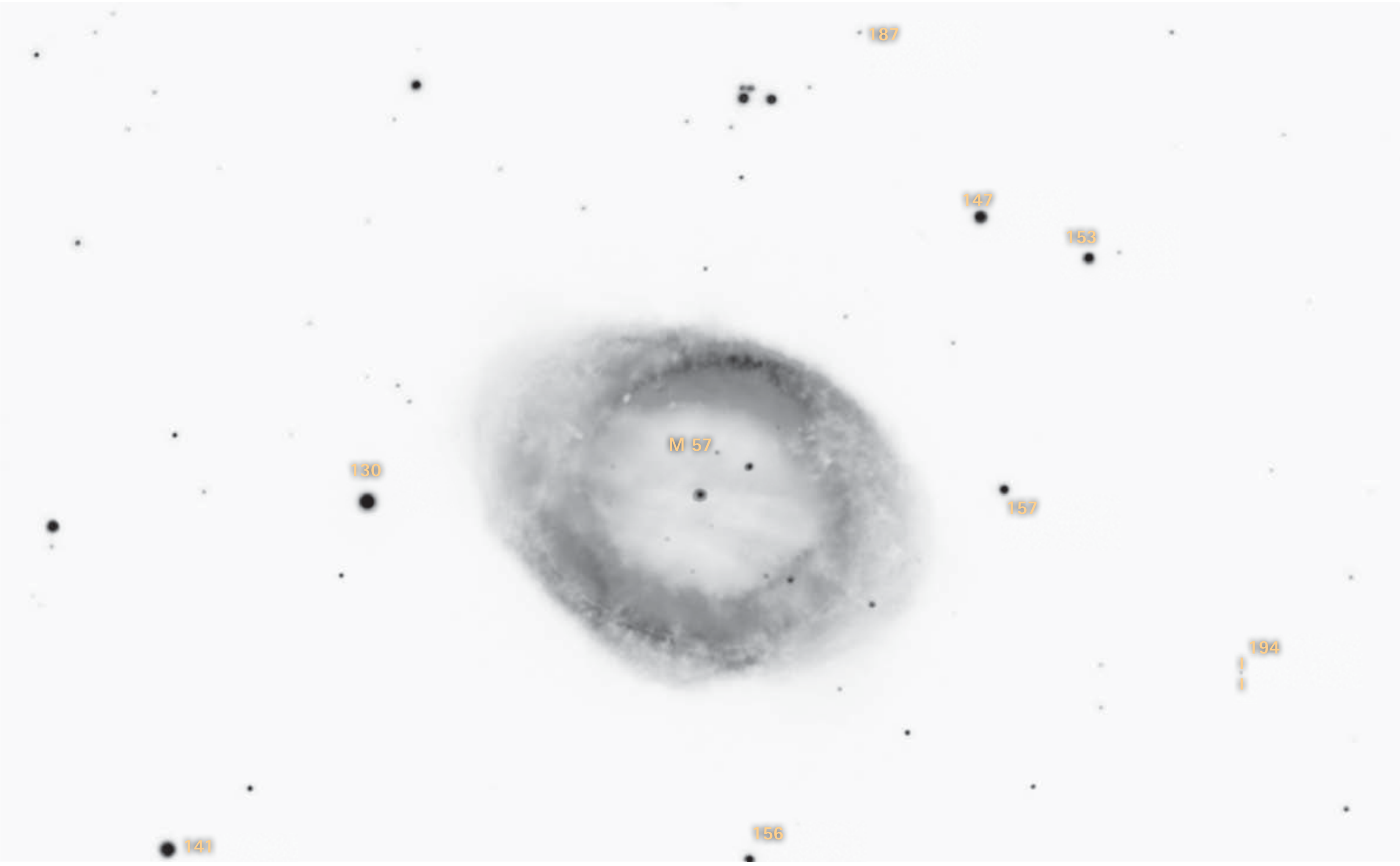
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M 57
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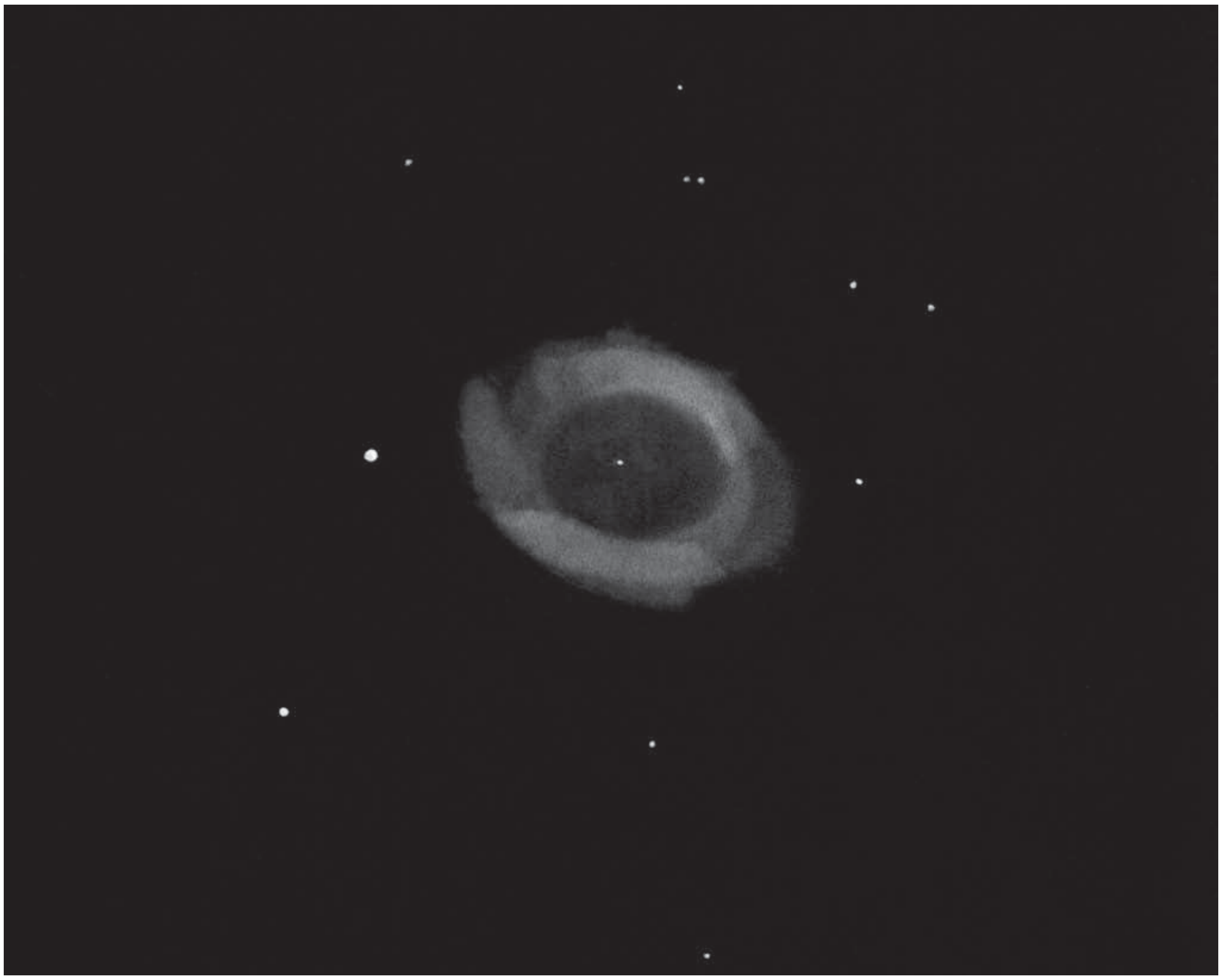


M 57, drawing. 14-inch Newtonian. Ronald Stoyan.

vation of the Ring Nebula, he wrote: "There is a rather bright star in it, southeast of the center, and more very small stars. In the ring, especially on the outsides of the small axis, are several small stars, but there is still a lot of nebulosity which cannot be seen as individual stars." In addition, he saw "wisps and cloudlets on the inside; the evenness of the outside is interrupted by diverging appendages, seen best around the small axis."

A number of nineteenth-century observers reported resolution of the nebula into faint stars. The last prominent example was Angelo Secchi, who thought he saw "a ring of stars, glittering like diamond dust." We may, from today's perspective, explain some of these claims in terms of true nebular fine-structure. Only William Huggins' pioneering spectroscopic observations finally taught the visual observers that M 57 is a ring of gas.

Hence, Holden's detailed description of M 57, as seen through a 26-inch refractor in 1875, reads: "Northern edge of small axis very well defined, there is a bright spot near the northern end of the small axis. Occasional visibility of the star inside the ring. Glittering spots in the inner part are perceivable. Nebulous filaments branch out from the southern end of the small axis, they may extend up to 30", very faint. Two brighter patches in the north preceding [northwestern] and south following [southeastern] part of the ring can be seen, probably exists a third one in the south preceding [southwestern] part."

In 1861 d'Arrest reported another faint star near the central star. Four years later, H. Schultz described five stars inside the ring, later observers up to eleven, but none of these extra stars is real. A reliable visual observation was made by the great Edward Emerson Barnard in 1894 with an aperture of 40 inches, and he saw only the "17^{th} magnitude companion 8.5" northwest of the central star inside the nebula."

In 1937, on deep exposures, Duncan discovered the faint outer halo of M 57. The "appendages" seen by Lord Rosse on the outside of the ring actually belong to the inner, brighter part of this halo.

Astrophysics

M 57 probably is the most popular planetary nebula. The bright, central ring measures 86" by 62". It is surrounded by a faint inner halo of about 156" by 136" and a very faint outer halo of about 3.8' diameter. The surface brightnesses of these three morphological components form a ratio of 5000:5:1. Early studies gave large distances for M 57, up to 4100 light-years (Cudworth, 1974). At the other extreme, 1000 light-years was suggested by Kwok (2000). But Harris and colleagues (1997) obtained an improved geometrical parallax of the central star and determined a reliable distance of 2300 light-years. From this, a physical size of of 0.9 light-years is derived for the ring, while the outer halo has a diameter of 2.5 light-years.

Earlier models of M 57 described its appearance in the sky in terms of a bipolar cylinder, tighter in its middle, into which we look along its long axis. The ring of M 57 is then just a projection of a nebulous object which, seen from the side, would resemble the Dumbbell Nebula M 27.

In 1994, Bryce, Balick and Maeburn published a refined model, in which the main body of the M 57 nebula has not a cylinder but an ellipsoidal shape, with open poles and an aspect angle of 45°. Even this densest part of M 57 has, by laboratory standards, a very low gas density. The surrounding inner halo would be bipolar and tilted by 30°, embedded in a spherical outer halo. Guerrero and colleagues refined that model in 1997 for the inner halo, which they describe as just the UV-excited, inner region of a single outer halo, which is shaped by the bipolar output of UV-photons from the polar openings of the inner nebula.

In 2000, Japanese astronomers measured the filamentary knots in the inner and outer haloes. They found typical sizes from 1.2" to 3.2", from which they derived life spans of 400 to 1200 years for these delicate structures. They are bubbles formed by the hot and fast wind from the central star, where it clashes with the slowly expanding halo gas. The latter is the cool wind envelope, which left at only 10 to 15 km/s some 20,000 years ago, when the star was still a red giant. The central ellipsoidal part of M 57, which appears to us as the ring, expands at 50 km/s, pushed outwards from inside by the hot wind. Its expansion is equivalent to about 1" per century. This sets a lower limit for the age of M 57 of about 10,000 years. Hence, it is probably older than the planetary nebulae M 27 and M 97.

The central star is very hot and compact. It is the now-exposed hot core of the former red giant. It has about one solar luminosity, with a temperature of 100,000 to 120,000 K, and mainly radiates in UV light. In fact, color photos nicely show the successively decreasing degree of ionization of the surrounding gas: blue-violet in the inner, central part, green ([OIII] emission) along the inner side of the ring, and red (Hα emission) in the ring of M 57 itself.

Observation

M 57 can be spotted in 10×50 binoculars, but it appears only as a faint star. In small telescopes, when locating it with low power, M 57 looks like an unsharp star.

A magnification of about 100× brings out its famous appearance, like a ring of smoke. Even under a moonlit, urban sky, a 60mm refractor will do this. However, the ring then appears rather round; perception of the oval form is improved against a darker sky. This is because the faint ends on the major axis of this nebula are lost in a bright background.

A 4.7-inch refractor used at high power shows a bright oval ring with an elongation ratio of 1:1.26 in PA 60°. There is a distinct 12th-magnitude star just 1' south of the nebula's center, well outside the ring. The brightest parts of the nebula are formed by the thinner sides of the ring on the minor axis, while the ring is wider but dimmer along the major axis. Northwest and southeast of the center, the ring's brightness appears to be somewhat uneven, but no distinct structure can be perceived. Observing with a low power, the nebulous disk gives a pale-bluish impression.

Using a good 14-inch telescope, the central star is within reach, but it requires excellent seeing and a high magnification of around 500×. There is a 14th-magnitude star 1' west outside the nebula. The northern side of M 57 appears to be the brightest part. Here a bright, slightly mottled structure reaches west where it spreads out. Hence, the western end bears resemblance to the "ears" of M 27. The southern part of the ring is not quite as bright as the northern part, but it is very well defined at its eastern edge. Here, an outer edge appears and gives the impression of a helical structure. Small extensions like flames at the perimeter of the ring can be perceived in the north and, more distinctly, the south. Also, a shallow bulge is seen in the south. The inside of the ring is filled with homogeneous light. The total size of the ring is 90"×62", with a ring width of 12" on the minor axis and 25" on the major axis.

With classic, blue-sensitive photographic emulsions, M 57 is fainter (magnitude 9.7) than visually (magnitude 8.8), and its bluish central part is enhanced to a 60" sized disk. By contrast, a red image (which includes Hβ) emphasizes the 90" ring, and shows it dark inside. However, any visual perception of its colors, red and blue, requires really large apertures. There are positive reports with 25 to 30-inch telescopes.

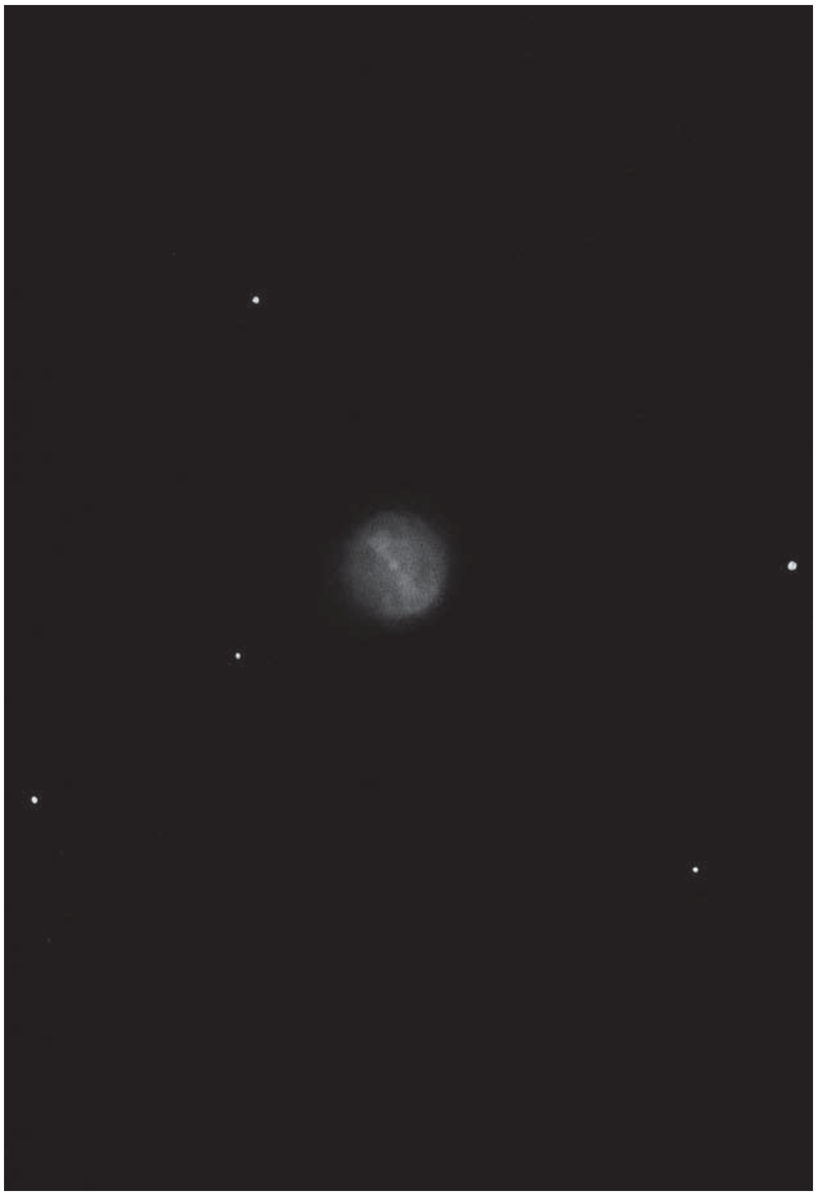
No sightings have been reported by modern visual observers of Lord Rosse's wisps of nebulosity across the inner part of the ring. The same is true for the photographically recorded 170" halo and its 216" outskirts. Its extremely low surface brightness of around 16 magnitudes per square-arcminute, by contrast to the 9.5mag/arcmin^2 of the ring, would require the darkest of clear nights at high altitude.

The visibility of the central star (magnitude 15.8 according to Harris et al.) has been a matter of debate for 200 years. It depends strongly on the quality of the seeing, since the size of its disk needs to be small enough to reach a surface brightness higher than that of the surrounding nebulous background. At least 12 inches, or better yet 16 inches, of aperture and a magnification of over 400× are required. To have a chance of spotting the central star, the observer should be able to make out stars as faint as magnitude 16.5 outside M 57. Sightings of the second star inside the ring have been reported from amateurs with 20- and 25-inch telescopes. Two more stars in front of the bright ring in the southeast of M 57, however, have not been mentioned so far. Deep photographic exposures show numerous faint stars of about 20th magnitude.

By far the brightest and best-known galaxy near the Ring Nebula is the small barred spiral IC 1296 (magnitude 14.8), 5' northwest of M 57. A multiple star 1.2' north of the central star is known to photographers as a nice test of image quality.

M 58

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 4579
Type	Galaxy
Class	SBc
Distance	62.5 Mly (V2002)
Size	107,000 ly
Constellation	Virgo
R.A.	12^h 37.7^{min}
Decl.	+11° 49'
Magnitude	9.6
Surface brightness	21.9mag/arcsec^2
Apparent diameter	5,9'×4,7'
Discoverer	Messier, 1779



M 58, drawing. 14-inch Newtonian. Ronald Stoyan.

History

Charles Messier discovered M 58 when he was observing the comet of that year, on the 15th of April 1779. He characterized this object as a "very faint nebula." In 1830, John Herschel observed a size of 5' by 4' and described M 58 as "rather mottled as if with stars," which may be the first hint of the spiral structure of this galaxy. Lord Rosse even noticed the bar "a little extended south preceding [southwest] to north following [northeast]." D'Arrest perceived the central region as only a bit elliptical, 100" by 80".

Astrophysics

M 58 is a member of the Virgo cluster of galaxies, at a distance of 63 million light-years. This galaxy measures a respectable 107,000 light-years in diameter and contains 300,000 solar masses.

M 58 is one of four barred spiral galaxies (SBb or SBc) in Messier's catalog, the other three are M 91, M 95, and M 109. Some authors see M 58 as a transitional case between a normal spiral (type Sab, according to Maoz et al.) and a real barred spiral. Tully classified it as SABc.

The central region of M 58 contains an active galactic nucleus and has been classified as a LINER by Filippenko and Sargent in 1985 (see M 81). The Hubble Space Telescope resolved it and a diameter of 0.11" was measured.

On the 18th of January 1988, Ikeya found a type II supernova only 40" south of the core of M 58. SN 1988A reached an apparent brightness of magnitude 13.5. A year and a half later, on the 28th of June 1989, Kimeridze discovered yet another supernova (SN 1988A), this time 50" northwest of the galaxy's center, which reached magnitude 12.2.

Observation

A 7th-magnitude star directly west of M 58 makes it fairly easy to find this galaxy. With 10×50 binoculars it appears as just a rounded nebulous spot. 4.7 inches of aperture show a bright, elliptical galaxy, elongated east-west. A bright central region is surrounded by a faint halo of light.

With a 14-inch telescope, the visual extent of M 58 becomes 3'×2'. There is now a core of almost stellar appearance, which is a little elongated in the same direction as the whole galaxy. The mottled bar of the galaxy is vaguely visible. From the core, it points to PA 40° and 240°. To the north, bar and core are well defined by their contrast with a neighboring, distinctly darker region. Further outside the galaxy, a diffuse darker region and a spiral arm can be made out. The latter is seen best about 1' southwest of the core, where it branches off the bar. However, no consistent picture of spiral structure can be perceived. M 58 remains a tough object to observe, the spirals difficult to grasp in visual observation.

M 58 is a barred spiral galaxy in the Virgo cluster. Jim Misti, Robert Gendler.

M 59

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 4621
Type	Galaxy
Class	E5
Distance	48.3 Mly (V2004) 47.6 Mly (2004) 61.3 Mly (SBF, 1999)
Size	76,000 ly
Constellation	Virgo
R.A.	12^h 42.0^{min}
Decl.	+11° 39'
Magnitude	9.6
Surface brightness	21.4mag/arcsec^2
Apparent diameter	5,4'×3,7'
Discoverer	Köhler, 1779

M 59, drawing. 14-inch Newtonian. Ronald Stoyan.

History

M 59 was discovered together with M 60 by Johann Gottfried Köhler in Dresden, Germany, on the 11th of April 1779, while he was observing the comet of that year. Köhler used an achromatic refractor of about one-meter focal length. Also following the comet, Oriani and Messier independently found that same galaxy only days later. Messier's note says: "it is of the same light as that above [M 58], just as faint."

In 1830, John Herschel credited M 59 with only a tiny diameter of 20" and characterized it as faint and round. D'Arrest did not seem to be too enthusiastic about this galaxy, either. His notes simply read: "becoming denser toward the center like most of the nebulae in this region."

Astrophysics

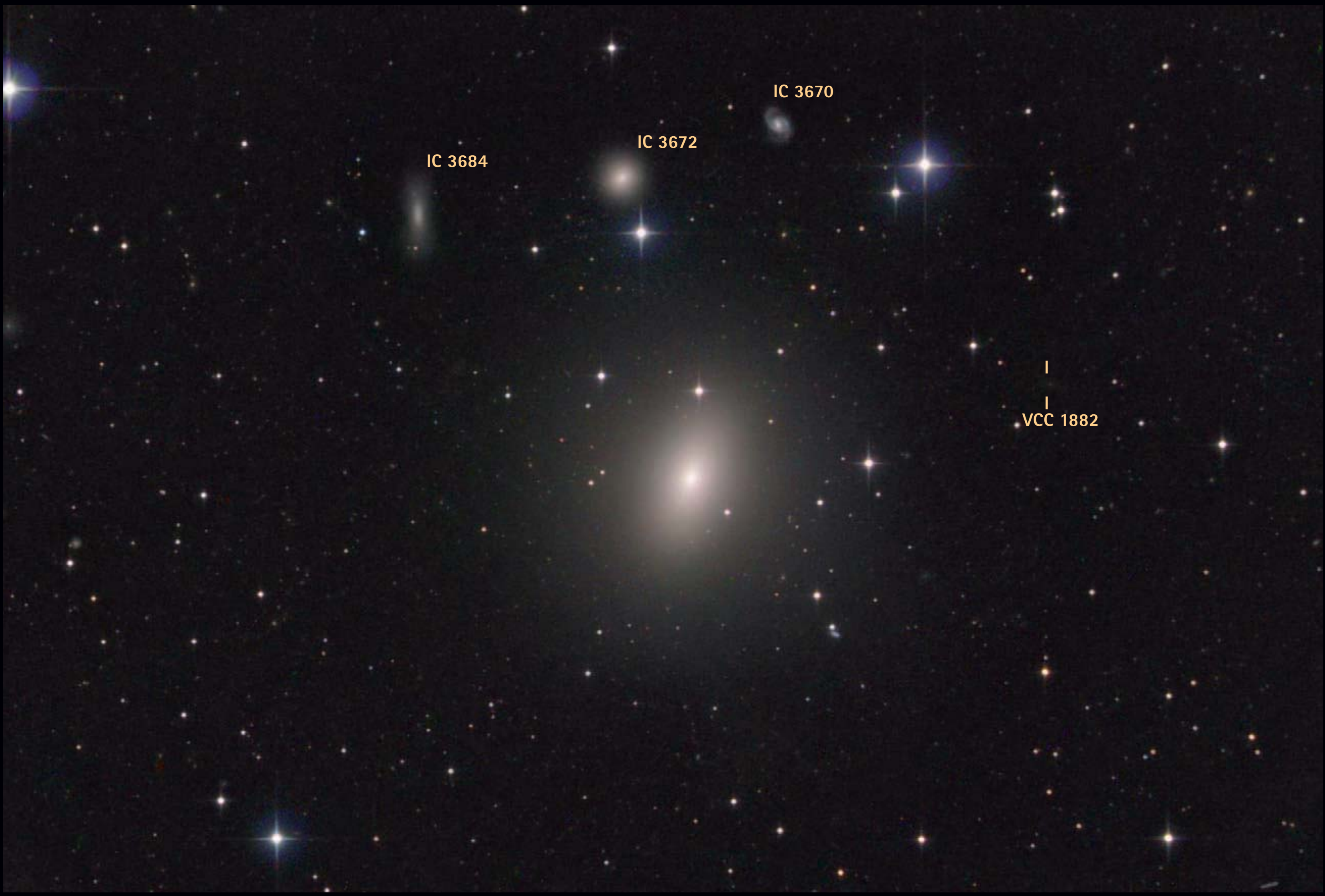
The elliptical galaxy M 59 is one of the smaller members of the Virgo cluster. It has an oval shape, and has received classifications of E3 to E5. A modest diameter for M 59 of 76,000 light-years has been derived.

This apparently uninspiring ellipse, however, hides interesting kinematics. A very bright core, 200 light-years diameter, rotates in the opposite direction to the rest of the galaxy (see M 64), and it appears to consist of young stars. The apparent size of this region is only 1". It is surrounded by a bright disk 5" to 7" in size. Its rotation curve seems to indicate the existence of a central black hole, or some other kind of massive central object, of 300 million solar masses. M 59 is thought to possess 2200 globular clusters, of which 69 have been cataloged.

Observation

M 59 is faintly visible in 10×50 binoculars. A small telescope shows an oval patch of nebulosity with a star-like core. 4.7 inches reveal the elliptical shape more clearly. There is a 12.1-magnitude star 1.8' north of the galaxy's center.

In a 14-inch telescope, the galaxy's bright core stands out. It is almost stellar, but high magnifications reveal its elongation in PA 30°. This core is surrounded by a bright central region only 1.5'×1.0' in size. The fainter, halo-like glow around it brings the total visual extent of M 59 to 2.0'×1.5'. However, the galaxy is still too small to touch the magnitude-12.1 star. There is also a 15th-magnitude star, only 1' southwest of the galaxy's center. M 59 is considerably fainter than M 60, which is just 25' away to the east.



M 59. This elliptical galaxy hosts a black hole of 300 million solar masses. Wolfgang Ries.

M 60

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 4649
Type	Galaxy
Class	E2
Distance	53.2 Mly (V2004) 53.2 Mly (2000) 56.2 Mly (SBF, 1999) 47.6 Mly (PN, 1999)
Size	115,000 ly
Constellation	Virgo
R.A.	12^h 43.7^{min}
Decl.	+11° 33'
Magnitude	8.8
Surface brightness	$21.7 mag/arcsec^2$
Apparent diameter	7,4'×6,0'
Discoverer	Köhler, 1779

M 60, drawing. 14-inch Newtonian. Ronald Stoyan.

History

Like M 58, M 59, and M 61, M 60 was discovered because the comet of that year, which Bode had discovered, moved through this part of the Virgo cluster while it was followed by several keen observers of that time. It was Johann Gottfried Köhler who actually saw M 60 first, right after his discovery of M 59, on the 11th of April 1779. He noted: "Two very small nebulae, hardly visible in a 3-foot telescope, the one above the other."

Barnabus Oriani found M 60 only a day later and remarked: "very pale, looking like the comet." Messier noticed it, finally, on the 15th of April, without any knowledge of the other observations. He wrote: "[The comet] passed very near, on April 13th and 14th, that being both in the field of the refractor, but it [M 60] became visible to him [Messier] only on the 15th, when looking out for the comet." Messier described this galaxy as "a little more distinct than the two previous [M 58, M 59]."

Admiral Smyth called M 60, together with NGC 4647 (discovered by William Herschel), a "double nebula, the preceding [western] one being extremely faint." John Herschel, too, characterized the view as a double nebula and wrote: "a very fine and curious object. The preceding [NGC 4647] is very faint, the following [M 60] very bright; both large, estimated distance of centers is 4'; position angle 45° north preceding."

Similarly, d'Arrest's note reads: "Double nebula. M 60 is round and much brighter in the center, its diameter is 100"; NGC 4647 also round, not more than 3' diameter."

As seen in photos, Curtis gave this description of M 60 in 1918: "2' in diameter, growing rapidly brighter to a very bright central portion, which shows no true nucleus in short exposures; no spiral whorls discernible."

Astrophysics

M 60 is the easternmost Messier galaxy of the Virgo cluster and forms a chain with M 58 and M 59. The latter is only 25' away. The structureless elliptical galaxy M 60 belongs to the larger galaxies of the Virgo cluster, with a diameter of 115,000 light-years and a luminosity of 60 thousand million suns. Its large mass holds on to a large halo of an estimated 3700 globular clusters. The center of M 60 has been studied with the Hubble Space Telescope. It hosts a super-massive object, presumably a black hole, of 4 thousand million solar masses.

Only 2.5' northwest, at a projected distance from M 60 of 40,000 light-years, is the barred spiral NGC 4647. It has no visible connection with M 60, and there are no overlapping structures, but Arp included this galaxy pair in his catalog of peculiar galaxies, as entry number 116. He was under the impression that there is heavier absorption on one side of NGC 4546's spiral, but subsequent studies still disagree on whether NGC 4647 lies actually behind or in front of M 60. In any case, the pair is more separated than the projected distance suggests.

M 60 and NGC 4647. It is not clear whether these two Virgo cluster galaxies form a physical pair. Josef Pöpsel, Rainer Sparenberg.

Observation

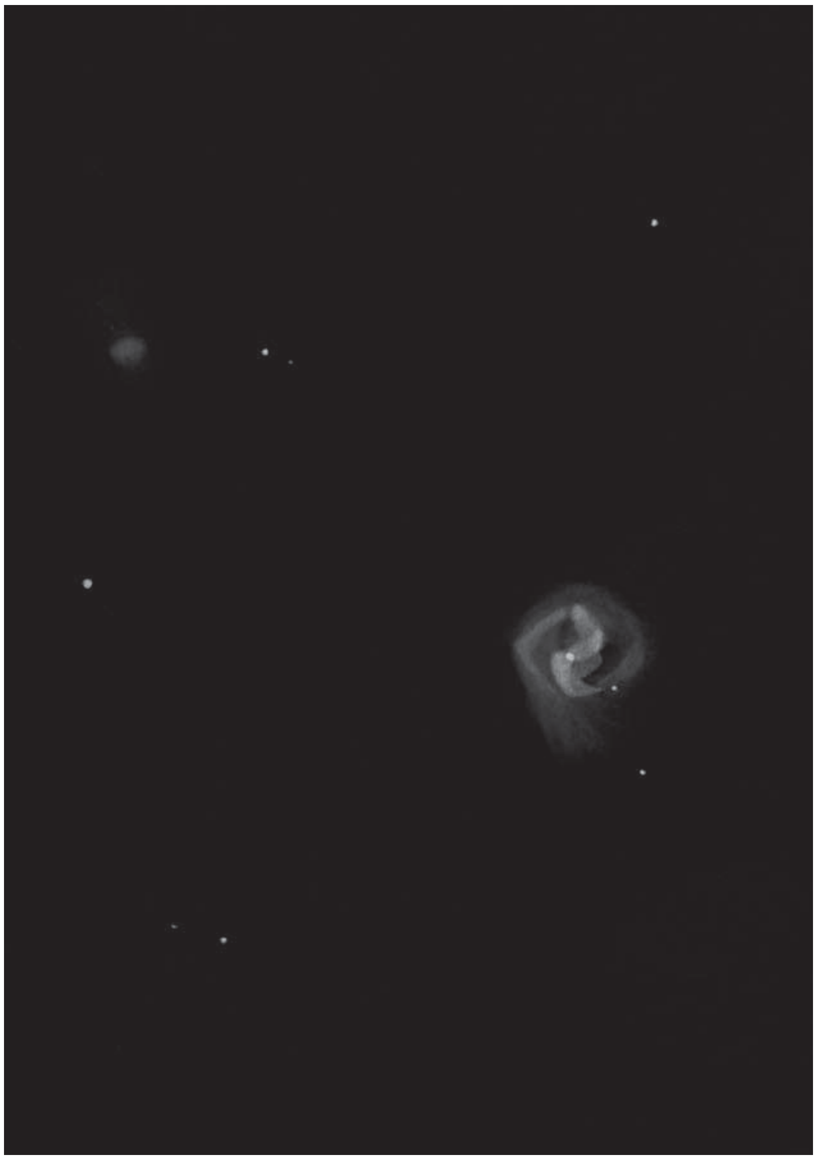
M 60 is the third brightest galaxy of the Virgo cluster. Even 10×50 binoculars show it distinctly as a round nebula. The companion galaxy NGC 4647, however, is not an easy object to observe, despite its total brightness of magnitude 11.3. Due to its low surface brightness, it requires 3 to 4 inches of aperture.

With a 14-inch telescope, M 60 reaches a visual size of 1.5'×1.8'. The very bright, very wide, oval core of 30" size stands out, but there are no other details in this galaxy. NGC 4647 is separated from M 60 by a dark lane. The evenly faint coreless nebula has a mottled appearance, but individual details cannot be grasped.

Deep photographic exposures show many globular clusters around M 60, as well as the impressive morphological differences between the two galaxies, which unfortunately cannot be perceived visually.

M 61

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	NGC 4303
Type	Galaxy
Class	Sc
Distance	49.6 Mly (V2004)
Size	94,000 ly
Constellation	Virgo
R.A.	12^{h} 21.9^{min}
Decl.	+4° 28'
Magnitude	9.6
Surface brightness	22.3mag/arcsec^2
Apparent diameter	6,5'×5,8'
Discoverer	Oriani, 1779



M 61, drawing. 14-inch Newtonian. Ronald Stoyan.

History

The Italian Barnabas Oriani discovered this galaxy on the 5th of May 1779, when he was following comet C/1779 A1 Bode, and described M 61 as "very pale and looking exactly like the comet."

Charles Messier independently found M 61 that same night, but he first took it to be the comet. It took him six days to discover his mistake, on the 11th of May. Messier characterized M 61 as a "very faint nebula and difficult to perceive."

50 years later, John Herschel described the view with the words: "Bright nucleus in a very faint atmosphere of 2' diameter, gradually fading away." His contemporary, Lord Rosse, recognized the spiral structure of M 61 with his giant 72-inch telescope. He also noticed two knots, which he may have confused with faint foreground stars. D'Arrest was unable to see the spiral structure with the 11-inch refractor at his disposal and commented: "Halo of diffuse light around a core, like a mag 13 bright star."

The photographic description by Curtis reads: "Nearly round; 6' in diameter; very bright. A beautiful spiral, with a very bright, almost stellar nucleus, and many almost stellar condensations in its open, somewhat irregular whorls."

Astrophysics

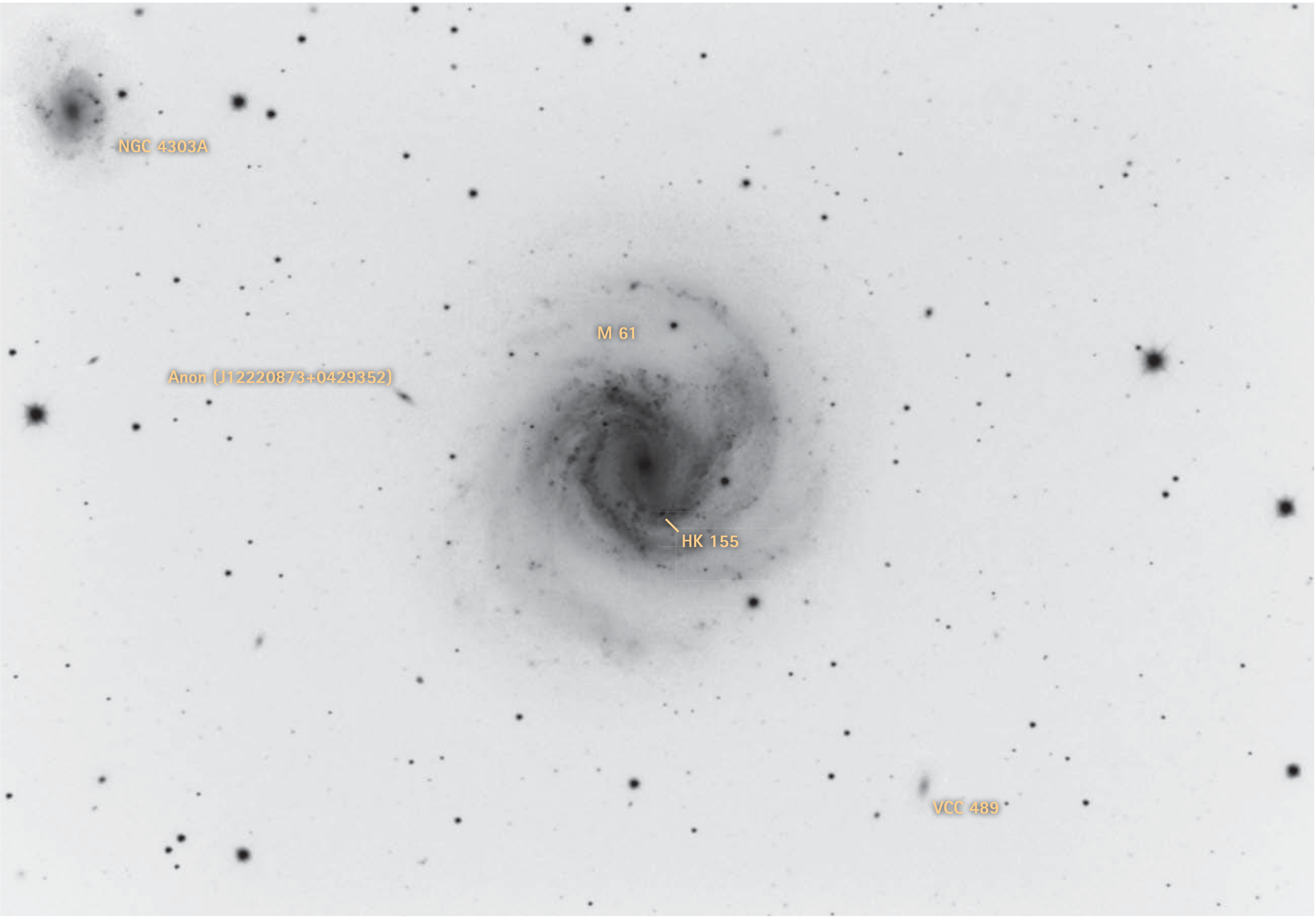
Like all three previous Messier objects, M 61 is a member of the Virgo cluster, at a distance of about 50,000 light-years. Its 6' total size yields an outer diameter of 94,000 light-years, and it contains about 70 thousand million solar masses.

Well-resolved photos of M 61 show a bright, round central region of 10." This is a star-forming disk with a total mass of 500 million suns, in which new stars are being born. Short exposures of this inner region reveal a spiral structure with a bar and numerous star-forming regions. The core itself emits an emission-line spectrum, which makes it a transitional case between a Seyfert-2 galaxy and a LINER object. Spanish astronomers found out in 2003 that this active core is in close co-existence, within just 10 light-years, with a young super star cluster (SSC) of 100,000 solar masses and only 4 million years of age.

The spiral arms continue outwards into an open, diffuse pattern. This, and the large number of star formation and HII regions, could hint at a possible gravitational interaction with the neighboring galaxies NGC 4303A and NGC 4292. Another hint comes from the oddly angled spiral arms. This type of structure, called Vorontsov-Velyaminov chains, probably has its origin in density fluctuations of the galaxy's gas.

Five supernovae have been observed in M 61; all reached brightnesses of 12 to 15 magnitudes.

M 61. This spiral galaxy has unusually angled spiral arms. Jim Misti, Robert Gendler.



Supernovae in M 61			
Designation	**Date**	**Discoverer**	**Magnitude**
1926A	May 1926	Wolf, Reinmuth	12.8
1961I	June 3rd, 1961	Humason	13.0
1964F	June 11th, 1964	Rosino	12
1999gn	December 17th,1999	Dimai	13.4
2006ov	November 24th, 2006	Itagaki	14.8

Observation

10×50 binoculars show M 61 as a round patch of nebulosity. The same appearance, albeit more distinct, is given by a small refractor.

With 4.7 inches aperture, the galaxy core of nearly stellar appearance is seen embedded in a bar, which is aligned north-south and displaced a bit to the south. The spiral arms cannot be perceived individually, but as a mottled, diffuse halo. Outside the galaxy, there is a faint, magnitude 14 star, 3' southwest of the core.

With a 14-inch telescope, the spiral structure of M 61 is amazing. A very small, but not star-like, core resides in an irregular bar of about 1' length in PA 150°. The southern spiral arm bends westward and meets a magnitude 14.5 star, 1.3' southwest of the core. From there, a fainter arm fragment reaches northward. The northern spiral arm turns towards the east and features unusual, angled bends. A somewhat diffuse region continues eastward. The total visual size of M 61 reaches 2.6'×2.2'.

Two NGC galaxies share the field with this Messier object: 10' northeast is NGC 4303A (magnitude 13). Deep photographs make it look like a miniature of M 61 but, observed visually with the 14-inch, it is just an oval-shaped, nebulous patch of light, 1'×0.5' in PA 90°. Brighter NGC 4292 is 12' northwest of M 61 and is magnitude 12.2. 14 inches of aperture show two small cores in a north-south alignment within it.

Deep photographs of M 61 reveal two more, much smaller galaxies behind M 61: one is 1.5' north of the core, the other 2' northeast.

M 62

Degree of difficulty	2 (of 5)
Minimum aperture	15mm
Designation	NGC 6266
Type	Globular cluster
Class	IV
Distance	34,930 ly (R2005)
Size	110 ly
Constellation	Ophiuchus
R.A.	$17^h\ 1.2^{min}$
Decl.	–30° 7'
Magnitude	6.7
Surface brightness	–
Apparent diameter	11'
Discoverer	Messier, 1771

History

Messier discovered this globular cluster on the 7th of June 1771, but it took him eight years, until the 5th of June 1779, to observe it again and finally measure its position. Hence, this object received a higher number in Messier's catalog than if he had added it at its first date of observation (i.e., No. 50). Messier described M 62 as a "very fine nebula, it resembles a small comet, its center is bright and surrounded by a faint light."

Only a few years later, William Herschel succeeded in resolving this cluster into individual stars. John Herschel, like his father, was challenged by the low height of M 62 above the English horizon, but he noticed its asymmetrical shape. In 1847, he described this globular cluster as "well resolved into stars of 15th magnitude."

Heber D. Curtis characterized M 62's morphology as seen on photographic images: "Bright globular cluster, greatly condensed at center, this central part is 1.5' in diameter, main part of cluster 6' diameter."

Astrophysics

M62 is located behind the galactic center. Its distance to us is 35,000 light-years, less than it is to its apparent neighbor M 19. M 62 belongs to the globular clusters of the galactic bulge and never moves far away from the galactic center. Its total mass is equivalent to that of 1 million Suns.

Tidal interaction with the galactic center has been blamed for some irregularity in the shape of this cluster, the center of which appears to be displaced slightly to the southeast. Shapley, using star counts, found a PA of 75° for this elongation.

Well over 200 variable stars are known in M 62, including 205 RR Lyrae stars, which are often found in globular cluters. By contrast, the apparent neighbor M 19 has only eight known variables! What makes M 62 special are the six millisecond pulsars found in it (see M 53); this is the largest number in any Messier globular cluster. This unique feature may be due to the high star density in the core of the cluster, which has experienced a core collapse (see M 15). The fastest of these pulsars rotates in only 2.295 milliseconds. At least three of them are part of binary systems with white dwarfs, in which the components orbit each other in just a few days.

Observation

M 62 is easily seen as a small, round nebula in 10×50 binoculars. Under a very dark southern sky, it may even be within reach of the naked eye.

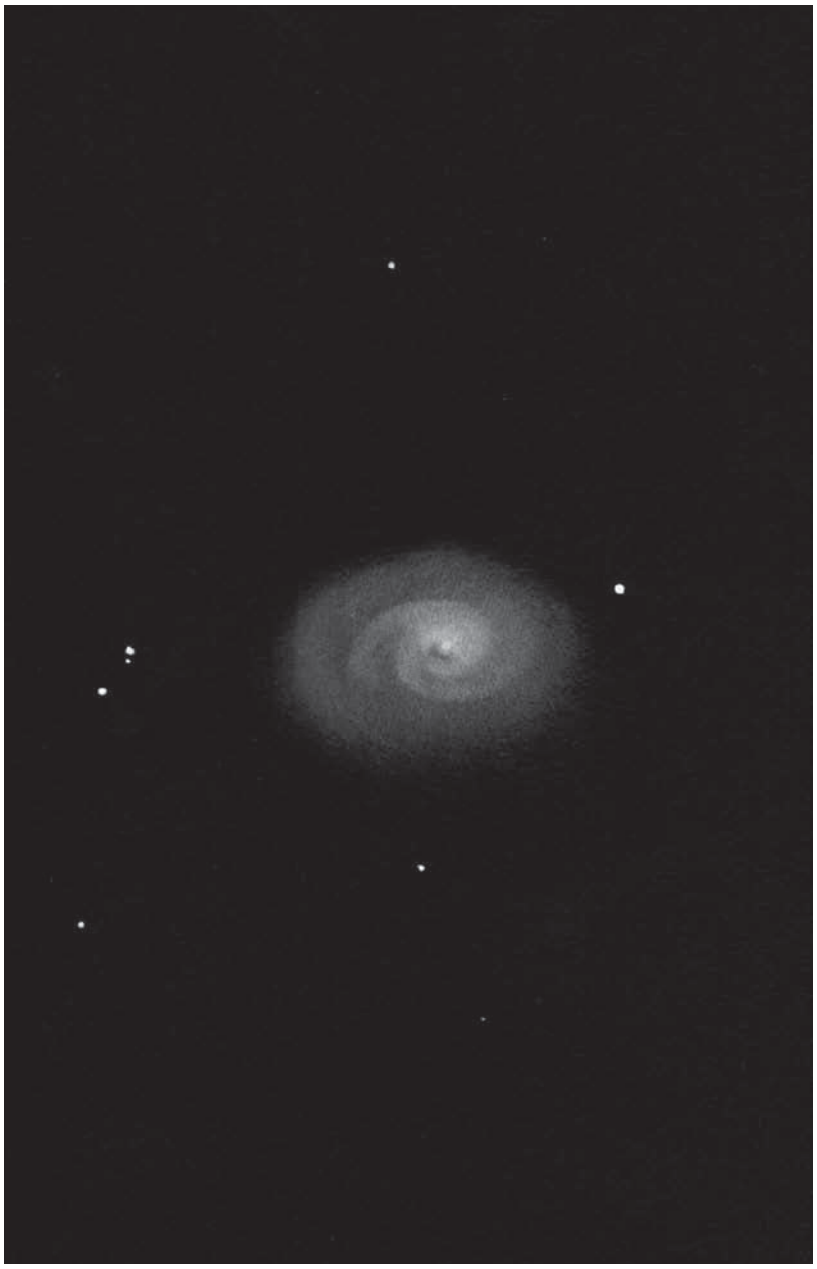
Under ideal observing conditions, 4 inches of aperture will suffice to resolve M 62 into individual stars. However, due to its low position above the southern horizon in the summer sky, observers based in northern temperate latitudes would usually require noticeably larger apertures. The small, very bright but hardly resolvable core of M 62 appears displaced to the southeast, which gives the whole object a comet-like shape with a "tail" of stars towards the northwest. O'Meara had the visual impression of several concentric rings around the cluster core, arranged like waves.

M 62 contains six millisecond pulsars among its stars. Dietmar Böcker, Ernst von Voigt.

M 63

The Sunflower Galaxy

Degree of difficulty	3 (of 5)
Minimum aperture	30mm
Designation	NGC 5055
Type	Galaxy
Class	Sb
Distance	26.7 Mly (2003)
Size	98,000 ly
Constellation	Canes Venatici
R.A.	13^h 15.8^{min}
Decl.	+42° 2'
Magnitude	8.6
Surface brightness	22.5mag/arcsec^2
Apparent diameter	12,6'×7,2'
Discoverer	Méchain, 1779



M 63, drawing. 14-inch Newtonian. Ronald Stoyan.

History

M 63 was the first discovery of a nebula by Messier's colleague Pierre Méchain, prompted by the close passage of a bright comet he was following in the first half of 1779. Messier observed M 63 on the 14th of June 1779, and wrote: "it has about the same brightness as the nebula registered under No. 59, it does not contain any star. There is a star of 8th magnitude near it, which precedes [west of] the nebula."

William Herschel estimated M 63 to be 9' to 10' long and 4' wide. He remarked: "it has a very brilliant nucleus." His son John determined the PA of the elongation to be 150° and noticed the nearly stellar appearance of the core. He also noted: "The south following [southeastern] end more diffused. Has a bright star north preceding [northwest] and a double star following."

Admiral Smyth, in particular, described the oval shape of M 63 and its "milky-white tint," while Lord Rosse was able to see hints of spiral structure. Heinrich d'Arrest found a diameter of only 85" and commented: "nucleus like magnitude 11 star."

Curtis summarized the photographic appearance with the words: "A bright, beautiful spiral 8'×3' in PA 98°. Has an almost stellar nucleus. The whorls are narrow, very compactly arranged, and show numerous almost stellar condensations."

Astrophysics

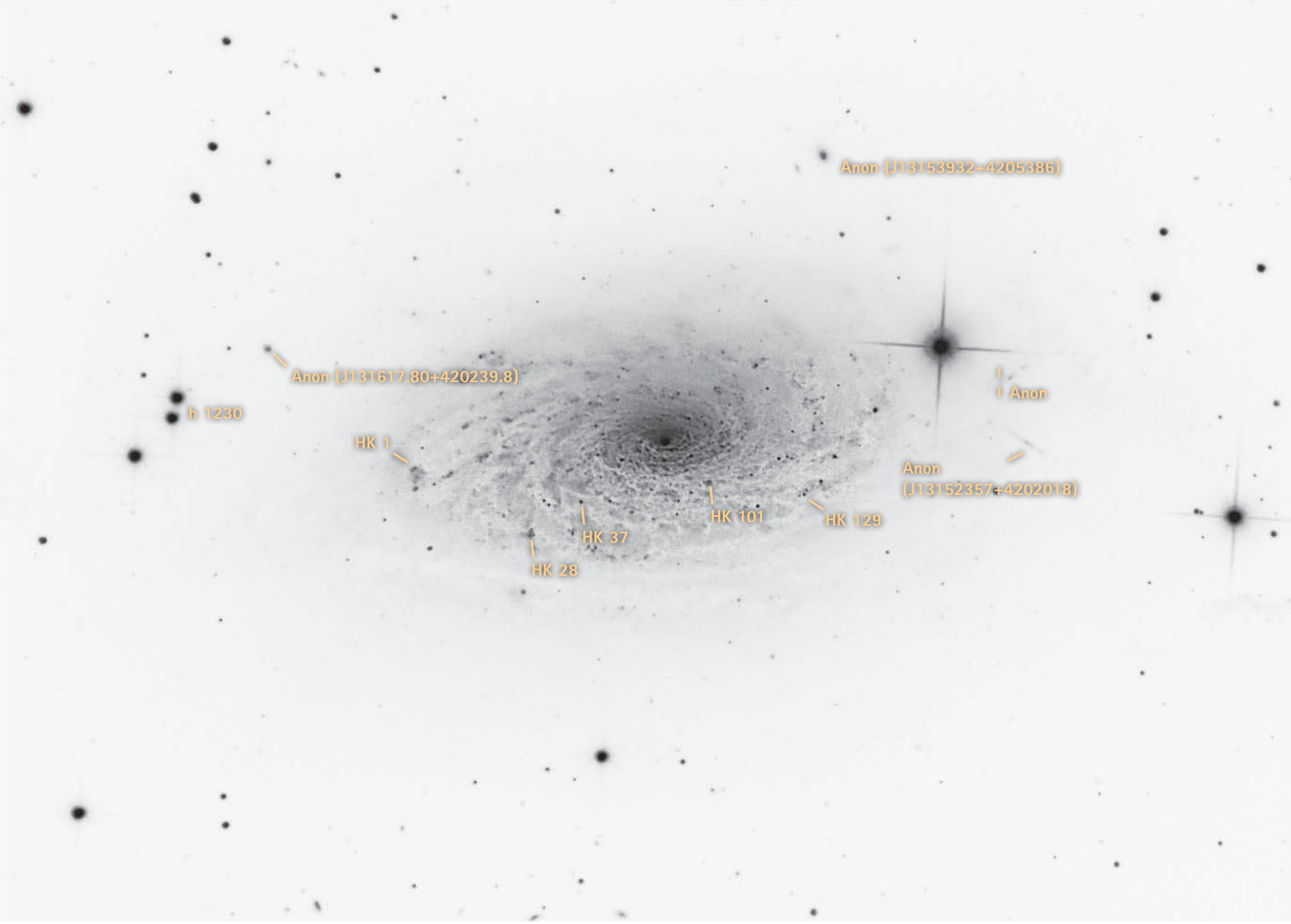
M 63 is often considered the most beautiful Messier galaxy on photographs, and it has been nicknamed the "Sunflower Nebula." This idea refers to the fragmented ("flocculent") or multiple spiral arm structure which probably comes quite close to the morphology of our own Galaxy. The southern, more dust-rich side of M 63 is closer to us and on a much smaller scale produces an effect similar to the "black eye" in M 64.

M 63 belongs to the M 51 group of galaxies at about 27 million light-years distance. That group probably includes NGC 5023, 2° north of M 63, and UGC 8320 more than 4° south. M 63 has been classified as an Sc or Sb spiral, its size just falls short of 100,000 light-years and it contains about 140 thousand million solar masses.

The bright central region of M 63, only 6" in size, could contain a core with 900 million solar masses, which represents, as Pismis et al. (1994) phrased it, a "mildly active nucleus." According to its emission line spectrum, it is a LINER object (see M 81). The galactic disk of M 63 is surrounded by a cool, flattened envelope of neutral hydrogen (HI), which is tilted 20° with respect to the plane of the galaxy.

The only supernova observed so far in M 63, SN 1971I, reached a peak brightness of magnitude 11.8 on the 25th of May 1971.

M 63. The "multiple-arm-spiral" of the Sunflower Galaxy consists of numerous fragments of spiral arms. Robert Gendler.



Observation

10×50 binoculars show M 63 as a small nebula, 4' east of a magnitude 8 foreground star. The bright galaxy core, almost star-like, stands out even in small telescopes. With a 4.7-inch refractor, it turns out to be embedded in a 1' long, east-west orientated central region. High power reveals mottled brightenings in the surrounding halo, but these cannot be grasped individually.

The spiral structure can be perceived with a 14-inch telescope, but it is not obvious and requires rather patient observing. A nucleus of almost stellar appearance lies in a small core-region of only 15" diameter. A magnification of 500× shows a dark spot of 15"×7" (PA 60°) right to the southeast, around which the knotted, innermost spiral arm is wound. A second spiral arm on the opposite side is significantly more diffuse but can be traced along a full 360° turn around the galaxy. However, after the first 180°, it splits up into fragments and becomes more difficult to grasp. The southern part of M 63 appears to be cut off. Photos reveal that dark dust clouds dominate this region of the galaxy. The total visual diameter of M 63 reaches 7'×4' in a 14-inch telescope; deep photographs can yield twice that extent.

Two very small background galaxies, which look like faint stars, lie within the photographically recorded outskirts of the galaxy, 4' northwest and 5' east of the core. Very deep exposures show two galaxy-like objects of very low surface brightness, southwest of the bright, 8th-magnitude foreground star. It remains unknown whether this is a small, physical companion or not. Further in that direction, there is the extremely faint (magnitude 15.9) dwarf galaxy UGCA 342, 8' east of the core of M 63.

The double star h 1230 is found only 3.6' east of M 63; it has two stars of magnitude 10.5 and 11.0, separated by 16.3".

M 64

The Black Eye Galaxy

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	NGC 4826
Type	Galaxy
Class	Sb
Distance	18.3 Mly (2003)
Size	56,000 ly
Constellation	Coma
R.A.	12^h 56.7^{min}
Decl.	+21° 41'
Magnitude	8.5
Surface brightness	21.3mag/arcsec^2
Apparent diameter	10,5'×5,4'
Discoverer	Pigott, 1779

M 64. Detailed view of the "black eye" region. Hubble Space Telescope.

History

M 64 was discovered by the English astronomer Edward Pigott, on the 23rd of March 1779, using an achromatic refractor with a focal length of 3 foot (nearly 1m). Pigott wrote about his discovery: "Its light being exceedingly weak, I could not see it in the two-feet telescope of our quadrant." Only 12 days later, Johann Elert Bode made an independent discovery of this galaxy, which he described as a "small nebulous star." Charles Messier had no knowledge of either observation when he found M 64 on the 1st of March 1780. He characterized it as a bit fainter than M 53.

50 years later, John Herschel wrote this about M 64: "I am much mistaken if the nucleus not be a double star, in the general direction of the nebula: magnification 320× much increases this suspicion; 240× shows well a vacuity below (north of) the nucleus." With that "vacuity," Herschel was the first to recognize the now popular "Devil's Eye," "Evil Eye," or "Black Eye" in M 64. Heinrich d'Arrest missed this detail. He commented about an "unexpectedly brighter center which may be partially resolvable" and measured the visual angular size as 140" by 95". Even more convinced about resolving M 64 into stars was Lord Rosse. Unaware of the large distance and true nature of this object, he wrote: "Of a round shape, with a dark and a bright spot on one side. With much certainty, this is a starcluster."

In 1918, Curtis delivered a substantial description of this galaxy, based on deep photographic exposures: "The central portion of this fine nebula is very bright, and there is a bright, almost stellar nucleus. It is 8'×4' in PA 110°. The whorls are rather compact, and of very uniform texture, without irregularities or condensations. The most striking feature of this spiral is the somewhat irregular, but very clear-cut, absorption area on the north of the nucleus."

Astrophysics

The "Black Eye" of M 64 on the northern side of the galaxy core is formed by a complicated structure of absorbing dark clouds. These are concentrated on the southern side of the galaxy disk, which is tipped toward us. Thus, the dark, dusty complex of clouds stands out against the bright central region behind it only on one side of the nucleus.

Detailed images obtained with the Hubble Space Telescope show a large number of HII and star-forming regions, embedded between the dark clouds of dust. These regions become more numerous towards the galaxy core, while there is very little structure in the outer regions. This led de Vaucouleurs to a classification of M 64 as a SA(rs)ab spiral.

Braun and colleagues (1994) found that the many star-forming regions in M 64 are created by a steep gradient in the rotational velocity of the gas. The central region, within a radius of 3000 light-years, actually rotates against the sense of the outer parts of the galaxy disk. The star formation sites are observed in the only 1500-light-year wide zone of rotational inversion, from +180 km/s to –200 km/s. A possible origin of this unusual kinematics could lie in the cannibalization of a former companion galaxy, but some authors suggest M 64 was simply born that way.

M 64. The "black eye" is a curved, dark absorption structure around the core. Volker Wendel.

In the core of M 64, some signs of activity can be observed. Weak spectral emission structures led to a classification of a Seyfert-2 galaxy (see M 77). Some authors see M 64 as a transitional case towards LINER objects (see M 81). In addition, M 64 has been identified as the radio source PKS 1254+21.

The distance of this galaxy, which has a radial velocity away from us of 377 km/s, has been revised substantially in the past. Holmberg believed in a membership of the Virgo cluster and suggested 44 million light-years, but more recent studies have suggested much smaller distances, down to 13.5 million light-years. At 18 million light-years away, determined in 2003, M 64 is one-third the distance of the Virgo cluster.

NGC 4789A, 7.4° to the east, is a physical companion of M 64. De Vaucouleurs suggested that these two galaxies form a small group with M 94, which has a similar distance from us.

Observation

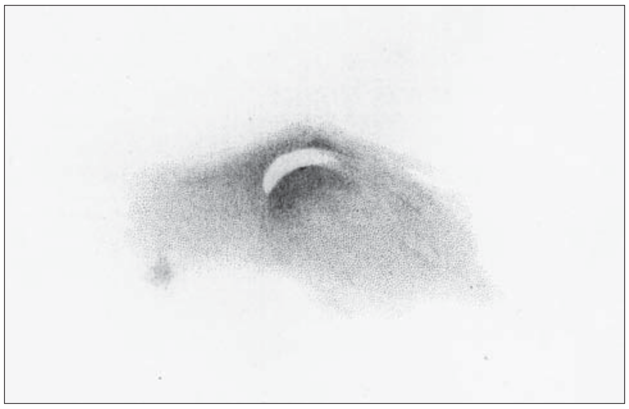
M 64 looks like a faint star in 10×50 binoculars. Small telescopes show it as a small, oval nebula of large surface brightness, but without a core.

A 4.7-inch refractor reveals a core of almost stellar appearance in an elongated galaxy with a ratio of 2:1. Northeast, near the core, a dark, peanut-sized absorption can be perceived with higher magnification, the "black eye."

A 14-inch telescope shows the eye immediately as a banana-shaped shadow. It keeps a distance of 20" from the bright, 5" oval core, which is hosted by a central region of 40"×25". The dark crescent starts narrow at PA 110°, then gets wider and diffuse, and finally fades away at PA 0°, directly north of the core. The outer edge of the eye is brighter than the surrounding galaxy and contributes to the inner side of a 1.2'×0.8' diffuse ring, elongated in PA 115°. Further outside follows a very diffuse darker zone northeast of the core, which leads into a second, outer ring of 5.5'×2.2', with the same orientation as the inner one. This is a distinct feature only on the "black eye" side – on the other side, the galaxy's light decreases more gradually outward from the core.

There is a faint, magnitude-15 star on the southern edge of the galaxy. Two other, fainter foreground stars in the eastern part of M 64 are not visible with 14 inches of aperture. A bright star, 4' northeast, marks the exact position angle of the black eye.

M 64, drawing. 14-inch Newtonian. Ronald Stoyan.



M 64, historical drawings. John Herschel (before 1833), William Lassell (1862).

M 65

Degree of difficulty	3 (of 5)
Minimum aperture	30mm
Designation	NGC 3623
Type	Galaxy
Class	Sa
Distance	32.8 Mly (see M 66)
Size	94,000 ly
Constellation	Leo
R.A.	11^{h} 18.9^{min}
Decl.	+13° 5'
Magnitude	9.3
Surface brightness	21.3mag/arcsec^2
Apparent diameter	9,8'×2,9'
Discoverer	Messier, 1780

M 65, drawing. 14-inch Newtonian. Ronald Stoyan.

History

Kenneth Glyn Jones gave credit for the discovery of M 65 and M 66 to Pierre Méchain. Charles Messier, who observed both galaxies on the 1st of March 1780, did not make any mention of Méchain in this case, although he credited all the other discoveries of his colleague. It may just be possible that Glyn Jones was mistaken here; after all, there are no other sources in support of Méchain. Hence, we consider Messier as the discoverer of this nice galaxy pair. The Frenchman remarked on M 65: "it is very faint and does not contain any star."

William Herschel saw "two opposite very faint branches" and noted the total length of the galaxy as 12'. In 1830, John Herschel described M 65 as having "a large, resolvable center with two faint branches, extended in a PA 45° north preceding [northwest] to south following [southeast]."

Lord Rosse observed M 65 on several occasions. In 1848, he remarked: "A curious nebula with a bright nucleus; resolvable; a spiral or annular arrangement about it; no other portion of the nebula resolved." "Resolution" did not necessarily mean to the lord and his contemporaries the visibility of individual stars, but this term equally refers to resolving structure and dots in a diffuse object. In 1854, Rosse saw "curious dark spots to both sides of the nucleus," which were only later identified as dust lanes.

Heinrich d'Arrest observed with an 11" refractor from near Copenhagen, Denmark, and gave this description: "very beautiful, strongly elongated, gradually brighter toward center, at 147× resolvable into faint stars: arms stretched out from both sides, almost in north-south direction." We may safely assume that the German astronomer did not truly see individual stars in M 65 – rather, perhaps, brighter dots, like Lord Rosse.

The well-known German lunar observer Mädler described M 65 more realistically as a "very longish nebula, consisting of a core and two arms, which stretch out with decreasing light intensity 3.3' in opposite directions. The whole has a length towards 7.7' and a dark appearance. No stars can be distinguished in it."

The photographic appearance has been documented by Curtis with the words: "A beautiful, bright spiral 8'×2' in PA 174°. Whorls rather indistinct, with one almost stellar condensation; bright, almost stellar nucleus. Absorption lane on the east."

Astrophysics

M 65 is a type Sa spiral galaxy that we see 74° inclined to our line of sight. M 66, only 20' to the east, is a physical companion. The galaxies may be separated by only 200,000 light-years, if they have exactly the same distance from us. Joining this Leo group of galaxies are NGC

M 65. The yellowish galaxy core consists of stars formed about five thousand million years ago. Volker Wendel.

M 65 and M 66 with NGC 3628: the "Leo Triplet." Robert Gendler.

M 65, drawings. Lord Rosse (1850), John Herschel (before 1833).

3628 in the north and NGC 3593, close to the west. Similar distances are found for the galaxy group around M 96, with M 95 and M 105, and we may conclude that these groups are loosely associated.

M 65 itself consists of a central lens of yellowish older stars, and of tightly wound spiral arms with prominent dust lanes and a few bluish star-forming regions. In contrast to M 66, M 65 does not seem to have undergone any recent close encounters with another galaxy. This has been confirmed by a study of Afanasiev, focusing on the five thousand million year old starburst-ring with a 15” diameter around the core. Hence, in terms of star formation, M 65 cannot compete with the much more active M 66.

Observation

Observed with 10×50 binoculars, M 65 and M 66 form a nice pair of faint nebulous spots. In a small telescope, M 65 appears as the more elongated of the two galaxies. Its orientation is almost exactly in the north-south direction.

A 4.7-inch refractor shows the strong elongation of M 65 very clearly; it has a 4:1 ratio and a PA of 10°. A bright, oval core is embedded asymmetrically in a 5’ long, nebulous bar. In addition, there is a 12^{th}-magnitude star 2.5’ southeast of the galaxy center.

When observing with 14 inches of aperture, the visual extent of M 65 reaches 6’×2’. A small, oval core of less than 10” diameter is embedded in a bright central region that has a sharp edge on its eastern border. This is due to a dark lane along the galaxy’s eastern side, of which only a vague perception can be obtained. 25” east of the core, there is a faint star right on this dust lane. Dark spiral structure and fragments of arms become more distinct towards the north and south. However, their rotational sense cannot be determined. The galaxy ends on both sides with diffuse, slightly brighter regions, of which the southern one is more distinct and irregular.

M 66

Degree of difficulty	3 (of 5)
Minimum aperture	30mm
Designation	NGC 3627
Type	Galaxy
Class	Sb
Distance	32.8 Mly (H2000) 33.5 Mly (Cepheids, 2000)
Size	87,000 ly
Constellation	Leo
R.A.	11^h 20.2^{min}
Decl.	+12° 59'
Magnitude	9.0
Surface brightness	$21.4 mag/arcsec^2$
Apparent diameter	9,1'×4,2'
Discoverer	Messier, 1780

M 66, historical drawing. William Lassell (1862).

History

As with M 65, Glyn Jones credited the discovery of M 66 to Pierre Méchain. Charles Messier, however, made no such note in his description, although he did in all other cases, and there are no other hints to any initial observation by Méchain. With certainty, though, we have the observation by Messier made on the 1st of March 1780. He describes this galaxy as "very weak" and recounts: "The comet observed in 1773 and 1774 passed right through these two nebulae [M 65 and M 66] on the 1st and 2nd of November 1773. Messier did not see them, without doubt due to the light of the comet."

John Herschel noted a size of 3' by 2' in PA 60° and saw it "suddenly brighter toward the middle." Later, Lord Rosse made out "dark dots to both sides of the core," while d'Arrest characterized M 66 as a twin of M 65. Curtis gave this description in 1918, based on photographic images: "A very bright, beautiful, spiral 8'×2.5' in PA 180°. Bright, slightly elongated nucleus; the whorls are somewhat irregular and show numerous condensations."

Astrophysics

Together with M 65 and NGC 3628, M 66 forms the popular Leo Triplet, with a distance of 33 million light-years. However, there is also a fourth, more widely separated member of this group of galaxies, NGC 3593.

M 66 has a very similar size to M 65. Two spiral arms originate from the ends of a short, bright bar in the center. While the eastern arm is closely wound around the galaxy, we find the western arm somewhat angled and, apparently, angled away from the galaxy. The true 3D morphology of M 66 is a bit different: in fact, the spiral arms are warped with respect to the well-inclined galaxy plane, and the eastern arm curves to cover part of the central region.

This deformation is the result of a past encounter with another galaxy in the Leo Triplet. The most likely candidate is NGC 3628 in the north: in very deep exposures, a 40'-long cloud of gas and stars is seen stretched out eastwards over nearly 400,000 light-years. It has been suggested that an encounter with M 66 lost a total of some hundreds of thousands of solar masses about a thousand million years ago. Hence, Halton Arp rightfully added M 66 to his list of peculiar galaxies as entry number 16, while the entire Leo group is an additional entry as number 317.

M 66 has also been classified as a LINER (see M 81), or as a transitional case, since its core spectrum shows some features typical of Seyfert-2-galaxies (see M 77). The radio spectrum of the core resembles that of a low-luminosity AGN (active galactic nucleus).

Three supernovae have been discovered in M 66. SN 1979R reached magnitude 15 on the 12th of December 1973. SN 1989B was discovered by the Australian amateur astronomer Evans, on the 31st of January 1989, and it reached magnitude 12.2 the next day. On the 15th of April 1997, SN 1997bs was discovered at Lick Observatory at magnitude 17. Considering this low brightness, van Dyck and colleagues later (2000) argued that it was, in fact, not a real supernova but an η-Carinae-type outburst, like the supposed "supernova" 1961V in NGC 1058, and 1954J in NGC 2403.

M 66. In contrast to M 65, spiral galaxy M 66 possesses young, bluish star clusters. Philipp Keller, Christian Fuchs.

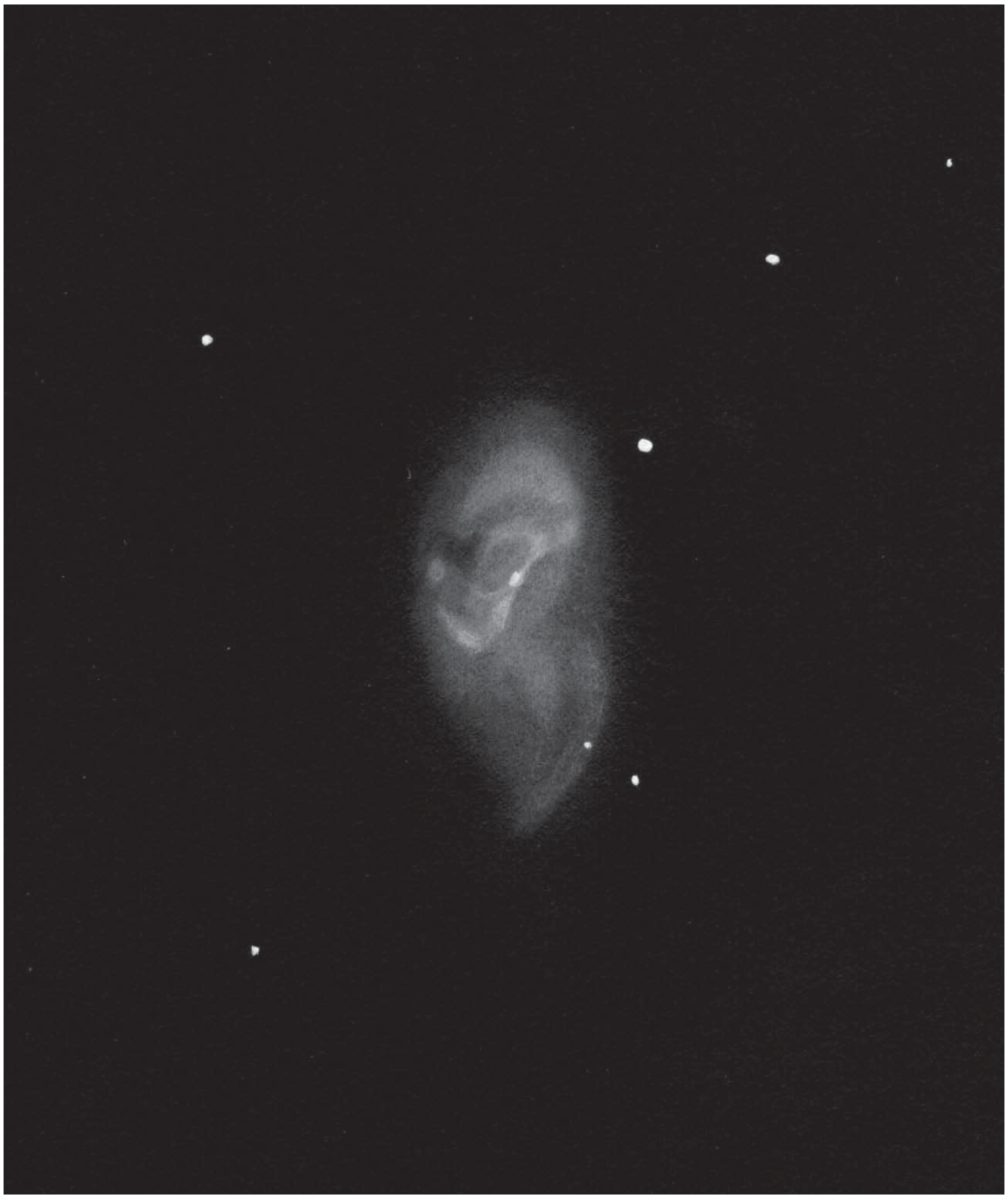
Observation

Under a dark sky, the beautiful pair of M 65 and M 66 can be seen nicely through 10×50 binoculars. With a separation of only 20’, these galaxies remain in the same field of view in a telescope with low or medium power.

With a 4.7-inch refractor, M 66 appears as bright as M 65. With a visual size of 4.5’×2’, it is elongated in the north-south direction, while the 1.5’-long central region is a little tilted at PA 20°. There is a bright foreground star only 2.5’ northwest of M 66.

Observed with a 14-inch telescope, M 66 is one of the most fascinating galaxies in the Messier catalog. In total, it reaches a visual extent of 5’×2.5’ in PA 0°. Reaching out from a core of almost stellar appearance, a very narrow bar stretches out over 2’, more to the northwest, in PA 150°. In the southeast, separated by a darker region, spiral arms branch off towards the east. In a distinct, dark patch 1’ northeast of the galaxy core, they appear to dissolve into mottles until they continue by the northern border, now diffuse and spread out, almost forming a ring.

The western galaxy edge contains a cut-in, 1’ southwest of the core. This is the origin of a very faint spiral arm with a dark lane in its middle. It reaches south, out to 3’ distance from the core. There is a star in front of this arm, which is revealed as a double star by large telescopes or good photographs.



M 66, drawing. 14-inch Newtonian. Ronald Stoyan.

M 67

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 2682
Type	Open cluster
Class	II2r
Distance	2960 ly (K2005) 2890 ly (2004) 2960 ly (proper motion, 2002) 2450 ly (CMD, 1999)
Size	21 ly
Constellation	Cancer
R.A.	8^h 51.4^{min}
Decl.	+11° 49'
Magnitude	6.9
Surface brightness	–
Apparent diameter	25'
Discoverer	Köhler, 1779

History

M 67 was discovered by Johann Gottfried Köhler in Dresden, Germany, before or in 1779. He described it as a "rather prominent nebula of longish shape," but his observation was not published. Hence, Messier made an independent discovery of this cluster when he found it on the 6th of April 1780, and saw a "cluster of small stars with nebulosity."

A few years later, William Herschel described M 67 as a "very beautiful and pretty much compressed cluster of stars, easily to be seen by any good telescope and in which I have observed above 200 stars at once in the field of view of my great reflector, with a power of 157." His son John gave a brightness range of magnitude 11 to 15 for the cluster stars and wrote: "It is preceded by a rich region of stars of 9th and 10th magnitude." D'Arrest saw a "dainty star cluster, the stars have a brightness of magnitudes 11 to 13," while Smyth likened its shape to that of a "Phrygian cap," like those worn by bishops.

Heinrich Maedler saw, like William Herschel, "about 200 stars in a space of 12' to 15' diameter. The stars differ a lot in their shimmer, and there is only little concentration toward the middle." Leo Brenner commented: "In the viewfinder apparent as a nebulous patch, but already in low magnification recognizable as a star cluster and a splendid object. Surrounded by a semicircle of brighter stars, there are laid out 230 stars of magnitude 9 to 12.5." Finally, Curtis quoted a photographic diameter of 16'.

Astrophysics

M 67 is one of the oldest open clusters known. A recent estimate published by Michaud and colleagues (2004) gives 3.7 thousand million years, which is almost the age of our Solar System. It will continue to exist for a further five thousand million years, which is its remaining dynamical lifespan. Only a very few open clusters are older: NGC 188 is one of these, at 6.4 thousand million years old. A controversial case is NGC 6791, for which ages between 2.4 and 8 thousand million years have been derived.

M 67 owes its long survival and large dynamical lifespan to its richness and, in particular, to its large distance from the galactic plane and the galactic center, which let it avoid disruptive gravitational interactions. At a distance of just under 3000 light-years, a total diameter of 21 light-years is derived.

The great age of M 67 allows us to see a large number of highly evolved stars in this cluster. It is rich in red giant stars – at least 20 are confirmed, with nearly 1.5 solar masses – and there are over 150 white dwarfs, according to Richer and colleagues. In addition, 23 "blue stragglers" have been found, which are more typical of the older and denser globular clusters. According to Sandquist, the brightest blue straggler is one of the brightest stars in M 67 at 10th magnitude and has a luminosity 50 times higher than the Sun.

Because of this remarkable diversity of the M 67 stars, this cluster has been the subject of many photometric studies. Thus, its 13 brightest stars, in particular, have been photometric standard stars for the UBVRI and ubvyβ filter systems for decades.

A total of 776 stars down to magnitude 17 are supposed to be true cluster members according to Balaguer-Núñez (2007). These include 8 confirmed and 4 suspected variables and, in particular, 4 W UMa eclipsing variables. One of them is AH Cnc, which varies between magnitude 13.3 and 13.7 with a period of only 0.36 days. Some blue stragglers of the RS CVn type also exhibit small brightness variations.

The cluster M 67 has been classified on the Trümpler scale by different authors as II2r, II2m, or II3r.

Observation

On a clear mountain night, M 67 can be spotted with the naked eye, as reported by O'Meara. In a small binocular with 15mm lenses, M 67 appears as an elongated, nebulous patch. 10×50 binoculars reveal a granulated cloud of light with a star on its northern edge. A telescope of 2 inches, used with a magnification of 50×, resolves the 12' cluster into individual stars – this demonstrates the relatively poor optical quality of the instruments of the discoverer of M 67, Köhler.

The number of visible cluster stars grows significantly with telescope aperture. There are about 30 with 2.5 inches, 50 with 6 inches, and over 100 with 12 inches. In large telescopes, the richness of the cluster is impressive; it reaches a visual diameter of 20', and is round in shape. With smaller apertures, however, the cluster appears slightly elongated in the east-west direction.

A number of observers have commented metaphorically on the apparent star chains of M 67. Smyth saw a bishop's cap, Flammarion a bunch of corn, Skiff and Luginbuhl a fibreglass-tree, and O'Meara a cobra's head.

M 67 is the oldest open cluster in the Messier catalog, with an age of about 3.7 thousand million years. Rainer Sparenberg.

M 68

Degree of difficulty	2 (of 5)
Minimum aperture	50mm
Designation	NGC 4590
Type	Globular cluster
Class	X
Distance	36,580 ly (R2005) 35,610 ly (RR Lyr, 2001)
Size	120 ly
Constellation	Hydra
R.A.	12^h 39.5^{min}
Decl.	–26° 45'
Magnitude	7.6
Surface brightness	–
Apparent diameter	11'
Discoverer	Messier, 1780

History

Charles Messier observed M 68 on the 9th of April 1780 as a "nebula without star, very faint, difficult to see with telescopes, nearby is a star of 6th magnitude." In his book, Glyn Jones names Méchain as the discoverer, but there is no mention of this elsewhere. Hence, in agreement with most authors, we give the credit of discovery to Messier.

William Herschel described M 68 as "a beautiful cluster of stars, extremely rich, and so compressed that most of the stars are blended together." His son John saw it "all clearly resolved into stars of 12th magnitude, very loose and ragged at the borders."

Smyth, by contrast, was hampered by his smaller telescope and the haze of English midlands. He only saw a "large, round and very pale nebula." His countryman and contemporary, Reverend Webb, however, described M 68 as "well resolved" and noticed a red star.

Astrophysics

M 68 not only appears to be far away from the Milky Way as seen from our viewpoint, but it is also a typical cluster of the outer galactic halo. Its 500-million-year orbit has a considerable eccentricity of 0.5 and leads M 68 up to 100,000 light-years away from the galactic center.

Its present distance to Earth is 36,000 light-years, which yields a moderate physical diameter of 120 light-years for this cluster. Its class X means that M 68 has one of the lowest concentrations of all Messier globular clusters.

M 68 is over 10 thousand million years old and has a low metal abundance (see M 79). 42 variables are known in it, including 2 SX Phoenicis and 40 RR Lyrae stars. Twenty-seven of these were found by Shapley. By contrast, nearby FI Hydrae is a variable unrelated to M 68, northeast of the cluster. The brightest individual stars reach magnitude 12.6, and Hogg found 25 stars brighter than magnitude 14.8. The horizontal branch stars, which are a good distance indicator for globular clusters, reach magnitude 15.6. There is, however, still disagreement over the total brightness of M 68. Glyn Jones quoted 8.2, modern catalogs 7.3, and O'Meara finds 7.6 the most adequate value.

Observation

O'Meara regards M 68 as a "wonderfully challenging" object for naked-eye detection, but any successful sighting would certainly require an excellent site high in the mountains.

The visibility of M 68 as a small nebula in 10×50 binoculars, however, is certain. Since the brightest cluster stars have the same brightness as those of the more popular M 3, resolution of M 68 should begin with a modest aperture of about 4 inches. This is almost impossible to achieve from sites in Europe and the northern USA, because of the bad seeing caused by this object being so low above the horizon.

If located high in the sky, as from southern latitudes, M 68 can be resolved into individual stars even in the center with a telescope of 8 to 10 inches. With a diameter of 10', it is one of the visually larger globular clusters. It has a noticeably wide center, and 5' northwest of its core is a reddish star.

The magnitude 5.4 star HD 109799 lies 45' southwest of M 68. It has a challenging companion (van den Bos 230) of magnitude only 11.3, just 1.4" away in PA 179°. Furthermore, the Mira star FI Hydrae, with a period of 324 days, is only 7.4' away northeast of M 68. The view of the cluster changes significantly as this variable ranges between its maximum (mag 10.2) and minimum (mag 17.4).

M 68. The variable FI Hya lies outside this field, to the northeast. Daniel Verschatse.

M 69. Directly south of the cluster center is the variable star V 1894 Sgr (marked). Bernd Flach-Wilken.

M 69

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 6637
Type	Globular cluster
Class	V
Distance	36,920 ly (R2005)
Size	110 ly
Constellation	Sagittarius
R.A.	18^h 31.1^{min}
Decl.	–32° 21'
Magnitude	7.7
Surface brightness	–
Apparent diameter	10'
Discoverer	Lacaille, 1752

History

Nicholas Louis de Lacaille carried out positional measurements of southern stars from the Cape of Good Hope in 1751 and 1752, and during that time he discovered 42 star clusters and nebulae, including M 69. Entry I.11 in his catalog published in 1755 reads: "nebula without star, resembles the small nucleus of a comet." Charles Messier looked for this object without success in 1764, since the position given by Lacaille was wrong by 1.2°. 16 years later, on the 31st of August 1780, Messier finally succeeded in rediscovering this southern globular, which became his No. 69. He recognized that this was Lacaille's object and commented: "Nebula without stars, near it is a star of the 9th magnitude. Its light is very faint."

John Herschel saw M 69 as a star cluster and characterized it as "bright, large, round, well resolved, stars from 14th to 16th magnitude." Curtis' photographic description reads: "Bright globular cluster 3' in diameter."

Astrophysics

The distance to M 69, which is 37,000 light-years, gives this cluster a location 5000 light-years behind the galactic center, but also 5000 light-years below the galactic plane. Hence, M 69 belongs to the inner galactic bulge, which it never leaves. Its age is about 14 thousand million years, and the largest angular diameter in deep, modern photographs of 10' corresponds to a total physical size of 110 light-years. Its mass is an estimated 300,000 solar masses. For a globular cluster, it has quite a generous abundance of heavy elements, related to its origin near the galactic center.

The individual stars, the brightest reach magnitude 13.2, are grouped around a relatively compact center. 61 variables have been found in M 69, among them 8 RR Lyrae stars, 48 variables of the SX Phoenicis type, and 10 eclipsing binaries. They include the two brightest cluster members and two Mira stars: V1894 Sgr (magnitude 13.3–18.8) 1.5' southeast of the center, and V3480 Sagittarii (magnitude 15.5–18.2) 5' west. In 1986, a star with a temporary magnitude of 12.5 and a spectrum with emission lines was observed. A later analysis showed that it was not a nova but an unusual Mira variable.

Observation

Southeast of an 8th-magnitude field star, a very small nebula can be made out even in 10×50 binoculars. In a telescope, this round object assumes a size of 2.5'. To see individual stars, a telescope with 6 to 8 inches of aperture is required. Then, a dark region near the southern edge of the cluster appears like a gap or dark line. The central region has been reported as elongated in a north-south direction by some observers, while a small central core remains almost stellar in appearance. O'Meara mentioned a dark lagoon north of the core, which the author was not able to confirm.

M 70

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 6681
Type	Globular cluster
Class	V
Distance	34,770 ly (R2005)
Size	80 ly
Constellation	Sagittarius
R.A.	$18^h\ 43.2^{min}$
Decl.	–32° 18'
Magnitude	7.8
Surface brightness	–
Apparent diameter	7,8'
Discoverer	Messier, 1780

M 70. In 1995, Comet Hale-Bopp was discovered in the course of an observation of this globular cluster. Rainer Sparenberg, Stefan Binnewies.

History

Charles Messier discovered M 70, together with M 69, on the night of the 31st of August 1780, and characterized both, stereotypically, as "nebula without star." William Herschel, however, succeeded in resolving M 70 into individual stars, despite his English observing site and the low culmination height of this southern cluster. The great observer commented on M 70 as a "miniature of M 3."

The Australian observer James Dunlop observed M 70 five times and described his view as "a pretty bright, round nebula, 1.5' diameter, very much condensed to the center."

In 1918, Curtis noted, on photographic images of M 70: "bright, condensed cluster 2' in diameter, doubtless globular."

Astrophysics

M 70 is only slightly closer to us than M 69, and it, too, is a globular cluster of the galactic bulge. M 70's orbit never leaves the galactic bulge. Presently, it is receding from us at 200 km/s and has a distance of 7000 light-years from the galactic center. Consequently, it should suffer from tidal interaction. The brighter region of the cluster has a 4' diameter, but its halo reaches 7.8'. The latter gives M 70 a total physical size of 80 light-years; it has a total mass of 200,000 Suns.

The core region of M 70 is densely packed with stars. This cluster has already undergone a core collapse, as about 20% of all globular clusters in the Milky Way have. This is a dynamical instability that, in the course of numerous close encounters, relatively quickly leads to a very high star density in the central region, driven by gravitational attraction and by a transfer of kinetic energy into the outer regions of the cluster.

The brightest individual stars of M 70 reach only a meager magnitude 14.0, due to the distance and interstellar extinction. Only very few variables have been found: the first two RR Lyrae stars were discovered by Rosino in 1962; Liller added another four in 1983. Spectroscopy with the Hubble Space Telescope helped to identify the two brightest stars in the center of the cluster as probable "blue stragglers" (see M 30).

In 1995, not far east from M 70, the US amateur astronomers Alan Hale and Thomas Bopp discovered their bright comet.

Observation

M 70 is faintly visible even with 50mm binoculars. In a small telescope, it appears as a small, nebulous ball. It differs from nearby M 69 only in having a much denser, yet extended, core – the visual testimony of the core collapse mentioned above.

With an aperture of 8 inches, individual stars are successfully resolved. In the outskirts northeast of M 70, a wide pair of two stars of magnitude 11 points due north. Another pair can be found further away to the north. The visual diameter of M 70 is only about 3'.

The planetary nebula IC 4776, 1° south of M 70, has a magnitude of 10.4 and can be seen even in a 4-inch telescope.

M 71

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	NGC 6838
Type	Globular cluster
Class	XI
Distance	18,330 ly (R2005) 16,050 ly (CMD, 2004)
Size	40 ly
Constellation	Sagitta
R.A.	19^h 53.8^{min}
Decl.	+18° 47'
Magnitude	8.0
Surface brightness	–
Apparent diameter	7,2'
Discoverer	de Chéseaux, 1746

History

M 71 was discovered in 1745 or 1746 by the Swiss amateur astronomer Phillipe Loys de Chéseaux. It received No. 13 in his short list of nebulous stars, which, unfortunately, was only read before the Paris Academy of Sciences and was never published in print. Hence, this and all other observations of de Chéseaux were soon forgotten.

A new discovery of this object was made by Johann Gottfried Köhler in Dresden, Germany, some time between 1772 and 1779. He described it as a "very pale nebulous patch in Sagitta." Köhler's observations took a long time to become known in France. Even the third discovery of M 71, on the 28th of June 1780, by Pierre Méchain, must be regarded as independent. He delegated his find to Charles Messier, who remarked on the 4th of October 1780: "it is very faint and does not contain any star."

William Herschel was able to resolve this globular cluster into individual stars, and his son John characterized it very nicely: "Irregularly round cluster of very small stars, inclining to triangular form." In a more extended description written in 1830, he also said: "A fine object; stars of 11th to 16th magnitude; the most condensed part is 3' in diameter, of a triangular figure, the angle northward." Webb commented that in his 3.7-inch refractor, M 71 appeared "hazy to low power, yielding to a cloud of faint stars to higher powers."

On the first photographs of the early twentieth century, Curtis spotted only a "rather sparse globular cluster 5' in diameter."

Astrophysics

Is M 71 an old, compact open cluster, or a loose globular cluster? This question remained unsolved for many decades and is sometimes debated still today. Morphologically M 71 bears similarity to both the compact open cluster M 11, as well as the poor, hardly concentrated globular cluster M 68. Hence, Shapley and Trümpler considered M 71 as an open cluster. In 1943, James Cuffey, on the other hand, classified it as a loose globular cluster of concentration class X to XII. However, his CMD (color-magnitude diagram) obtained in 1959 rather bears characteristics of an open cluster.

Even the abundance of heavy elements and metals, which is rather high for its age, does not settle this case either way. Nevertheless, by today's consensus M 71 is a globular cluster, and a modern study draws some parallels to NGC 104 (47 Tucanae), which undoubtedly is a true globular.

M 71 has a distance of 18,000 light-years from us. On its mildly eccentric (0.2) orbit around the galactic center, which takes the cluster 160 million years to complete, it always remains within the galactic disk. Frequent close encounters with other galactic objects probably explain its remaining mass of only 40,000 Suns and its unusually small size, when compared with other globular clusters, of only 40 light-years.

The brightest individual stars in M 71 reach a respectable magnitude of 12.1, but most cluster stars are fainter than 14. Only 40 variables have been found in M 71, but no RR Lyrae stars, the typical globular cluster variable. Z Sagittae, discovered in 1912 by Silbernagel, with a brightness change of mag 13.6b to 15.8b, is one of over six red giants in M 71. Park and Nemec identified a few eclipsing binaries, 24 were recently found by Korean astronomers (2006). The brightest example is QU Sagittae (mag 15.2p to 17.0p). Furthermore, there are a few blue pulsation variables of the SX Phoenicis type. Thirteen suspected 50 "blue stragglers" (see M 80) were confirmed in 2000 by Geffert and Maintz as true cluster members. Not physically belonging to M 71, however, is the eclipsing variable FX Sagittae 8' east of the cluster center. Its brightness varies between magnitudes 14.4 and 15.8 with a period of 1.15 days.

Observation

M 71 is seen with relative ease in 10×50 binoculars as a small diffuse nebulous spot. The impression remains that of a nebula when using a small telescope. With 3 inches aperture, the brightest stars of M 71 become visible, but they are hardly noticeable among the many stars of the rich, surrounding field of the Milky Way.

A 4.7-inch refractor, used with medium to high magnification, shows a swarm of about 30 faint stars. The triangular form of M 71 appeals to the observer, and the low degree of concentration is also obvious. The visual diameter is 5'.

With larger telescopes, the impression of this cluster becomes ever richer in stars, but it is difficult to distinguish between the cluster stars and foreground or background stars of the rich Milky Way. The most prominent feature of M 71 is the rounded tip of its denser central region, which points southwest. A few visual observers have reported an impression of dark eyes in the central region, or of linear dark structures in the eastern part of this globular cluster.

M 71 is a globular cluster with little concentration and rather poor in stars. Stefan Binnewies, Rainer Sparenberg.

M 72

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 6981
Type	Globular cluster
Class	IX
Distance	58,510 ly (R2005) 62,750 ly (RR Lyr, 2001)
Size	100 ly
Constellation	Aquarius
R.A.	20^{h} 53.5^{min}
Decl.	–12° 32'
Magnitude	9.2
Surface brightness	–
Apparent diameter	6'
Discoverer	Méchain, 1780

History

It was Pierre Méchain who discovered M 72 on the night of the 29^{th} to the 30^{th} of August 1780. He reported his find to Messier who observed it on the 4^{th}/5^{th} of October the same year and described it as a "nebula, its light faint as the previous [M 71], near it is a telescopic star."

Three years later, William Herschel recognized the true nature of this globular cluster. In 1810, the great observer described at length how M 72 looked to him at 280× magnification: "It is a cluster of stars of a round figure, but the very faint stars on the outside of globular clusters are generally a little dispersed so as to deviate from a perfectly circular form. It is very gradually extremely condensed in the center, but, with much attention, even there, the stars may be distinguished. It is not possible to form an idea of the number of stars that may be in such a cluster; but I think we cannot estimate them by hundreds."

His son John agreed with that in his first note on this cluster: "Pretty bright; very compressed cluster; irregularly round; barely resolved; very gradually brighter toward the middle; resolved into very small stars; many straggling stars near, but none so small as those of the cluster." But after a later observation of M 72, he had a somewhat different impression: "Faint; round; 2' diameter; resolvable, but I do not see the stars separated enough to count them. Is rather an insignificant object."

Admiral Smyth, who was in close contact with John Herschel, saw M 72 resolved in his 5.9-inch refractor as a "globular cluster of minute stars." Heinrich d'Arrest was using a telescope twice that diameter and, for him, M 72 looked "bright, irregularly round, partially resolved with 95× magnification. Very rich heap of the most minute stars, well resolved with 132× magnification. Shape irregular or nearly oval."

Heber Curtis summarized the photographic appearance in 1918: "small, bright cluster 3' in diameter, globular, comparatively open."

Astrophysics

At 58,000 light-years away, M 72 is one of the most distant globular clusters in Messier's list. Its location lies far beyond the galactic center, and the cluster circles the galaxy in a retrograde orbit. Hence, it has been speculated that M 72 was once captured from a companion galaxy, after a close encounter. A good candidate for the victim is the Sagittarius dwarf galaxy (Sgr Dwarf, not to be confused with the SagDEG, which hosts M 54).

Due to the large distance, the brightest individual stars of M 72 reach only magnitude 14.2. According to Hogg, the 25 brightest members have an average magnitude of 15.9. M 72 shows little concentration and has been classified as a class IX globular cluster. Only a handful of the Messier globulars, i.e. M 55 and M 71, are even less compact. The total mass of M 72 has been estimated as a meager 200,000 Suns.

This metal-poor cluster belongs to the objects of the outer galactic Halo. 51 variables are known in M 72, the first 34 were found by 1920 by Shapley and Ritchie. Unsurprisingly, they are mostly of the RR Lyrae type.

1.6° north of M 72, we find the faint dwarf galaxy MCG-2-53-3, better known as the "Aquarius Dwarf." It is located far in the background of the cluster, at a distance of 3 million light-years.

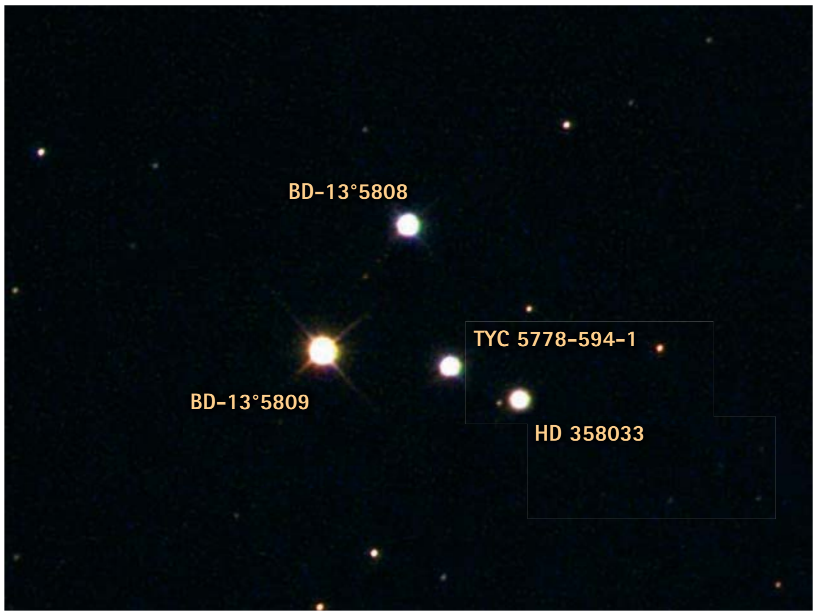
Observation

In 10×50 binoculars, M 72 is seen as just a faint small nebulous spot. In modest telescopes, it is a more distinct but starless ball of nebulosity, 2' in diameter. There is also a foreground star of magnitude 9.5' east. Resolution of this globular cluster into individual stars requires telescope apertures as large as 8 inches or more. Then, faint stars become visible even in front of the loosely concentrated central region. With a 14-inch telescope, a brighter central region of 3' is seen, with brighter cluster stars in front of a nebulous background. The outer region of the cluster reaches only a diameter of 5'. Here, just a handful of stars are seen against a nebulous background of a granular appearance. A wedge-shaped dark region interrupts these outskirts in the northeast.

Like M 54, M 72 may have originated in a different galaxy. Daniel Verschatse.

M 73

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	NGC 6994
Type	Asterism
Class	–
Distance	900–2590 ly (2002)
Size	–
Constellation	Aquarius
R.A.	$20^h\ 58.9^{min}$
Decl.	–12° 38'
Magnitude	9.7
Surface brightness	–
Apparent diameter	1,4'
Discoverer	Messier, 1780



M 73 is a chance pattern of stars at different distances from us. Rainer Sparenberg, Volker Robering.

History

M 73 belongs in the category of odd Messier objects. On the night of the 4th to the 5th of October 1780, while obviously looking for Méchain's M 72, Messier came across a "cluster of three or four faint stars, which resembles a nebula at first glance, contains some nebulosity." He made a mistake with the position, but it turned out all right, although he was using HD 19843 as his reference star instead of, as noted, Aqr. Later observers located M 73, even though it is not very spectacular. These four stars of Messier even made it into John Herschel's 'General Catalogue' of (GC 4617, "extremely poor"), and from thereon into the NGC.

Even later, M 73 remained the subject of confusion; Per Collinder confused it with M 72 and classified it as a globular cluster. This mistake was then transcribed into many subsequent catalogs.

Astrophysics

Now, is M 73 the poor remains of an old open cluster, or is it a coincidental alignment, from our perspective, of some physically unrelated stars?

The certain facts are these: four stars with magnitudes 10.5, 11.3, 11.9, and 11.9 fill a small area with 1.4' diameter, and all four stars are evolved giants. But did they form at the same time, and are they at the same distance?

In 1979, Murdin, Allen, and Malin made the following calculation: The probability of finding four stars brighter than magnitude 12 within a specific patch of 1' is two in a thousand million. However 150 million such areas fill the sky. In total, there remains a fair 1 in 4 chance. Nevertheless, those authors held M 73 for a physical object and gave its distance as 2000 light-years.

In 2000, Bassino, Waldhausen, and Martinez also regarded M 73 as an open cluster, which they give a larger outer diameter of 9'. In this field, they studied 144 stars, of which they find 24 to be cluster members; these include all stars brighter than magnitude 14.5. The authors derived a cluster age for M 73 of two to three thousand million years.

But in 2002, Odenkirchen and Soubiran disagreed with this. Their study is based on spectroscopic observations of the six brightest stars, within 6' around the four Messier stars, carried out with the 1.93m telescope of the Haute-Provence Observatory (France), and it produced no evidence for a common origin. Proper motion measurements do not support that interpretation, either. Hence, M 73 is probably just a chance alignment, and the table below lists the suggested distances and accurate positions of the four Messier stars.

Observation

Messier's impression of a nebulous object is suggested only by very small or poor telescopes. Even a refractor of 3 inches shows M 73 as three stars, forming an equilateral triangle, and a fourth, fainter star nearby, to the west of the western triangle tip.

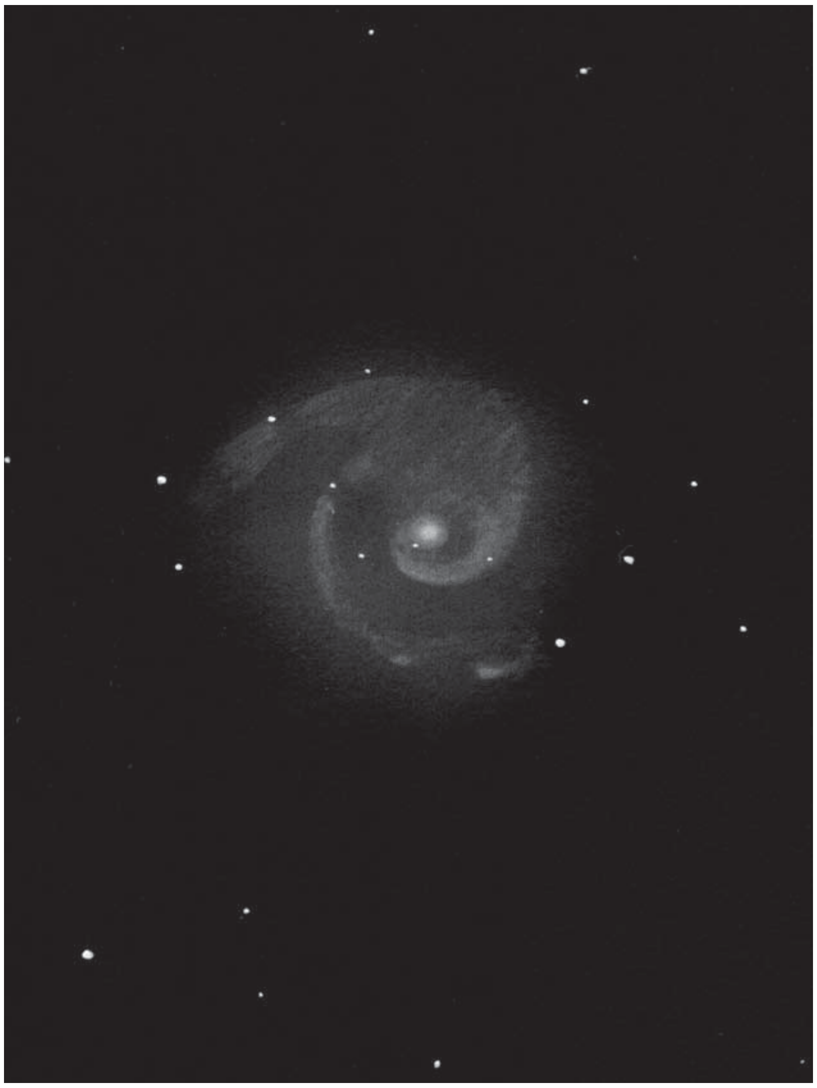
The nice double star Hussey 82, two stars of magnitudes 9.2 and 9.6 separated by 2.6" in PA 7°, can be found only 12' west of M 73.

The four stars of M 73

Designation	Tycho No.	R.A.	Decl.	Mag.	Distance
BD –13°5809	TYC 5778-802-1	$20^h\ 58^{min}\ 56.8^s$	–12° 38' 29"	10.5	2590 ly
HD 358033	TYC 5778-509-1	$20^h\ 58^{min}\ 57.8^s$	–12° 37' 45"	11.3	1080 ly
BD –13°5808	TYC 5778-492-1	$20^h\ 58^{min}\ 54.8^s$	–12° 38' 04"	11.9	900 ly
	TYC 5778-594-1	$20^h\ 58^{min}\ 53.5^s$	–12° 37' 54"	11.9	2475 ly

M 74

Degree of difficulty	5 (of 5)
Minimum aperture	50mm
Designation	NGC 628
Type	Galaxy
Class	Sc
Distance	25.1 Mly (2005) 31.3 Mly (SN, 2005) 23.6 Mly (2003)
Size	77,000 ly
Constellation	Pisces
R.A.	$1^h\ 36.7^{min}$
Decl.	+15° 47'
Magnitude	8.5
Surface brightness	23.3mag/arcsec^2
Apparent diameter	10,5'×9,5'
Discoverer	Méchain, 1780



M 74, drawing. 20-inch Newtonian. Ronald Stoyan.

History

Late in September 1780, Pierre Méchain discovered this faint galaxy, which he described as "very obscure and extremely difficult to observe." Three weeks later, on the 18th of October, Messier made a control observation. He plainly noted "nebula without star" and gave it number 74 in his catalog.

John Herschel described his first view as "extremely faint; 5' diameter with a brighter mass of 1' diameter in the center, and this again pretty suddenly brighter toward the middle to a suspected star. Several very small stars nearby." After a later observation, he had mistakenly convinced himself that M 74 was a globular cluster and noted now: "Globular cluster; faint; very large; round; very gradually, then pretty suddenly much brighter to the middle; partially resolved."

Rosse, in 1844, recognized spiral structure in M 74, but in 1851 he wrote: "Center formed of stars, easily seen to be such." Foreground stars probably deceived the great observer.

D'Arrest characterized M 74 as "pale and tenuous, very much denser toward the center; the central part is almost round," and he measured a visual diameter of only 40". The misclassification as a globular cluster, however, survived into the twentieth century – probably due to the authority of John Herschel. It is found even in some 40-year-old catalogs and star charts. In 1918, Curtis made it absolutely clear, based on his deep photographs, that M 74 is "an unusually beautiful and symmetric spiral, showing numerous, almost stellar condensations. Nucleus bright and small, but not stellar."

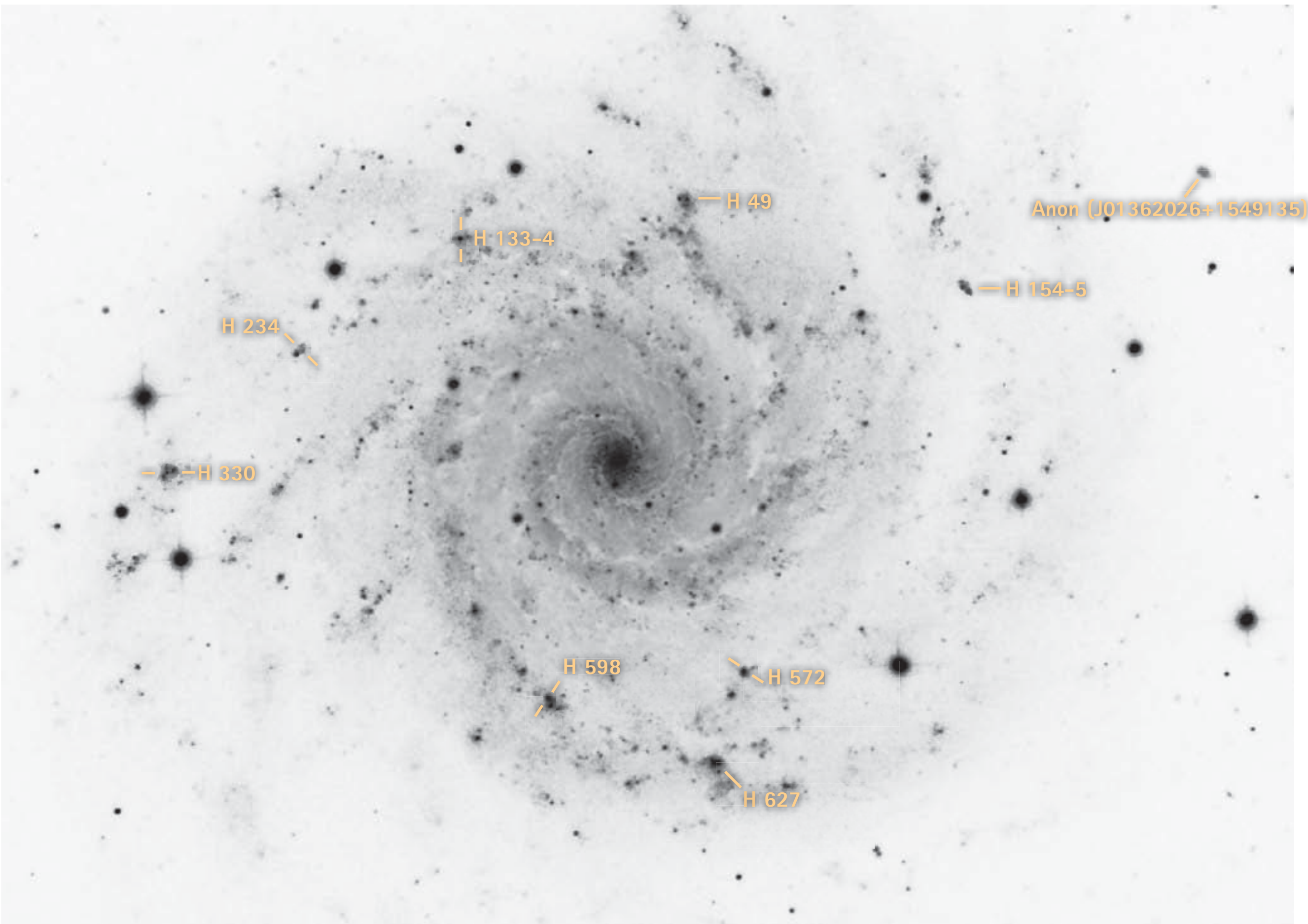
Astrophysics

M 74 certainly is a grand-design spiral galaxy, and de Vaucouleurs classified it as a type SA(s)c. Our modern distance measures (as of 2005) still vary between 25 and 31 million light-years, depending on the method used. Its total mass has been estimated as 300 thousand million solar masses, while its physical diameter depends on its actual distance: between 77,000 and 96,000 light-years.

The approximately 7000 light-year-wide spiral arms are made up of bluish, young star clusters and red HII regions, which are testimony to an active star-forming history in the past 500 million years. In 1976, Hodge cataloged 730 HII regions in M 74, and Ivanov et al. found 147 star associations.

M 74 is embedded in a disk of neutral hydrogen, twice the size of the galaxy itself. It shows disruptions, although there are no galaxies nearby that would be candidates for recent encounters. The formation of the spiral arms is usually explained in terms of density waves, which can also be induced by gravitational interaction during an encounter with another galaxy. The star-forming regions and spiral arms mark the locations of density maxima in the waves.

M 74. Small, reddish HII regions outline the spiral arms of the galaxy. Stefan Binnewies, Josef Pöpsel.



Latest studies have found evidence for an oval structure in the center of M 74, which may be interpreted as a small bar. It is surrounded by a ring of young stars, while no O and B stars are observed in the reddish galaxy center. Krauss et al. (2003) discovered a bright, variable X-ray source, which undergoes radiation changes by an order of magnitude within just 30 minutes. Therefore, the source must be very compact, comparable in size to the inner solar system, and it could be a micro-quasar. There may also be some connection with the active star-forming regions nearby.

M 74 is the gravitational center of a small group of galaxies. This includes the barred spiral NGC 660 and the fainter galaxies UGC 891, UGC 1176, UGC 1195, UGC 1200, and UGCA 20. According to Sharina and colleagues, UGC 1171 and 1104 are additional group members.

On the 29th of January 2002, the Japanese amateur astronomer Yoji Hirose discovered a supernova in M 74, 4.5' southwest of the galaxy's core and of magnitude 14.5. SN 2002ap considerably increased its brightness in the following days, to 13.4 on the 31st of January and 12.5 on the 3rd of February. It reached maximum brightness with a plateau at magnitude 12.3 between the 5th and the 12th of February 2002. Its considerable brightness and its spectrum led to a classification of a type Ib/c supernova, the result of the collapse of a very massive star. The peak brightness of a hundred times that of an ordinary type Ia supernova made some authors even talk about SN2002ap as a 'hypernova.' The progenitor star had an estimated 40 solar masses.

Only a year later, on the 12th of June 2003, Robert Evans discovered yet another supernova in M 74, SN 2003gd, about 3' south of the core in the southern spiral arm. It was magnitude 13.2 at discovery, and continuously faded to 16.2 by the 30th of July of that year.

Observation

M 74 is regarded, after M 91, as the second most difficult Messier object for visual observation. Because it has the lowest surface brightness of all, this is particularly true under a light-polluted sky. For any successful observation, the quality of the night sky matters more than the telescope.

10×50 binoculars show M 74 as a faint, nebulous spot. Small telescopes display a small galaxy core, surrounded by a faint, round halo with a diameter of 5'. This visual impression remains more or less the same with increasing aperture.

With a 14-inch telescope, a core of about 1' diameter is seen, which resembles the core of an unresolved globular cluster. A faint foreground star at its southern side adds to this impression. The spiral arms take a lot of concentration and can be made out only with much difficulty. The brighter arm emerges from the central glow in the southwest, near a second foreground star. It then makes a half-turn around the northern side of the core, increasing in distance. The fainter arm appears to emerge northeast of the core and then turns southwest.

The spiral structure is easier to verify with an aperture of 20 inches, but still not without some effort. A telescope of this size even shows the brightest HII regions and gives a visual extent to the galaxy of 6'×4', elongated in PA 140°. The northern spiral arm is now seen to emerge from the southeast of the core region, near the position of the first, nearer foreground star. It is well defined but loses a lot of substance further along its course. The origin of the southern spiral arm remains vague, but it can be perceived quite clearly southeast and south of the galaxy core. It contains the two brightest HII regions of M 74, Hodge 627 and 598, seen as faint spots 2' south and 2.5' southwest of the galaxy center.

M 75

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 6864
Type	Globular cluster
Class	I
Distance	77,840 ly (R2005) 62,000 ly (1996)
Size	160 ly
Constellation	Sagittarius
R.A.	20^h 6.1^{min}
Decl.	–21° 55'
Magnitude	8.6
Surface brightness	–
Apparent diameter	7'
Discoverer	Méchain, 1780

History

This faint globular cluster was discovered by Pierre Méchain on the 27^{th} of August 1780, and he described it as a nebula. Messier confirmed Méchain's find with two observations, made on the 5^{th} and 18^{th} of October the same year, but his impression was one of very faint stars. This seems unlikely, though; only William Herschel was truly able to resolve this star cluster with his much larger apertures, four years later. He characterized M 75 as a miniature version of M 3. Smyth appeared disappointed and described M 75 as a "lucid white mass among some glimpse stars." He criticized Messier as "courageous" to have included this cluster in his catalog.

Heinrich d'Arrest had 11 inches of aperture at his disposal, twice as much as Smyth. Hence, he wrote about M 75 that it was "very bright, much brighter in the center. Accompanied by many small stars, one with mag 12." He also determined a visual diameter of 75" to 80".

Curtis again gave a description of the photographic appearance of M 75: "A bright, compact globular cluster 2' in diameter, greatly condensed at center."

Astrophysics

At a distance of 78,000 light-years, M 75 is the second-farthest globular cluster in the Messier catalog. Its location is 40,000 light-years beyond the galactic center, below the galactic plane. Its size is a reasonable 160 light-years; M 75 has 500,000 solar masses and a luminosity of 160,000 Suns. This globular cluster is remarkable for its very compact appearance and concentration towards the center, which gave it the highest concentration classification of class I according to Shapley. Typical for a cluster of the outer galactic halo, M 75 is very metal-poor, which means that all elements heavier than helium have a very much lower abundance than found in the Sun.

Due to the large distance, the brightest stars of M 75 only reach magnitude 14.6, and Hogg determined an average magnitude of 17.1 for the 25 brightest cluster stars. 50 variables are known in M 75, among which are 38 RR Lyrae stars, typical for globular clusters. Catelan et al. (2002) found 26 "blue straggler" candidates (see M 30).

Observation

M 75 looks like a faint star in 10×50 binoculars. A small telescope shows it as a 2' nebula with a highly concentrated center. There is a magnitude 11.7 star 4' southeast.

Even under good observing conditions, it takes 8 to 10 inches of aperture to resolve the first cluster stars. The center of M 75 remains unresolved except for a few stars in its periphery, even in much larger telescopes. At high power, the cluster core appears like a knot of stars.

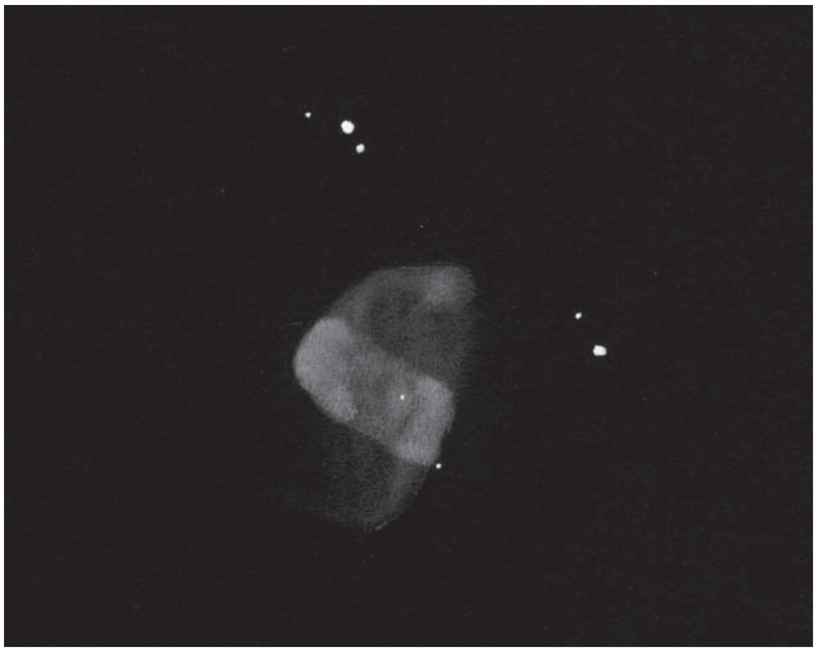
A 12.5-magnitude star, 1.5' southeast of the core, marks the edge of the cluster. Some observers report a slight elongation in PA 45°. Deep photographs show faint background galaxies in the southern outskirts of M 75. The brightest of these is just northwest of the 11.7-magnitude star that sits southeast of the cluster.

M 75 is the second-most distant globular cluster in the Messier catalog, after M 54. Daniel Verschatse.

M 76

The Little Dumbbell Nebula

Degree of difficulty	5 (of 5)
Minimum aperture	50mm
Designation	NGC 650, 651
Type	Planetary nebula
Class	III + VI
Distance	2550 ly (2004)
Size	0.7 ly
Constellation	Perseus
R.A.	$1^h\ 42.3^{min}$
Decl.	+51° 34'
Magnitude	10.1
Surface brightness	–
Apparent diameter	95"×42"
Discoverer	Méchain, 1780



M 76, drawing. 14-inch Newtonian. Ronald Stoyan.

History

Pierre Méchain discovered M 76 on the 5th of September 1780, and wrote: "this nebula contains no stars, it is small and faint." Messier observed this object on the 21st of October, after receiving the note from his colleague Méchain and, oddly enough, he wrote that it consisted of "nothing but very small stars." With his much larger telescopes, William Herschel correctly saw, seven years later: "two nebulae close together, both very bright." He took only one of these for the Messier object and made two separate entries for M 76, which later became the NGC numbers 650 and 651.

In 1837, Admiral Smyth saw an "oval, pearly white nebula." Isaac Roberts delivered the first photograph of M 76 in 1891 and suggested that it could be a bright bar around a torus of nebulosity, seen from the side. Curtis focused his description on the outer regions as he saw them on his deep exposures.

Astrophysics

At first sight, M 76 bears some similarity to the Dumbbell Nebula, M 27, which is why it's called the Little Dumbbell. Yet Isaac Roberts had already suggested in 1891 that this planetary nebula could be similar to the Ring Nebula (M 57) seen from the side. The bright central nebulous region, 95" by 42" in PA 35°, is a gas torus, seen at an angle of 75°, i.e., almost looking onto its equator. Bryce and colleagues measured expansion velocities of 43 to 60km/s for it. Perpendicular to this ring, there are bipolar loops of nebulosity in PA 125° and 305°. The southeastern loop has a slightly larger distance from the central star (165") than the northwestern (135") on the facing side. This material left the star before the birth of the planetary nebula, as a slow cool wind with a speed of 5 to 20km/s. It is now freshly excited by the present, fast bipolar outflow. Its direction depends on the rotational axis of the central star and on the magnetic field orientation.

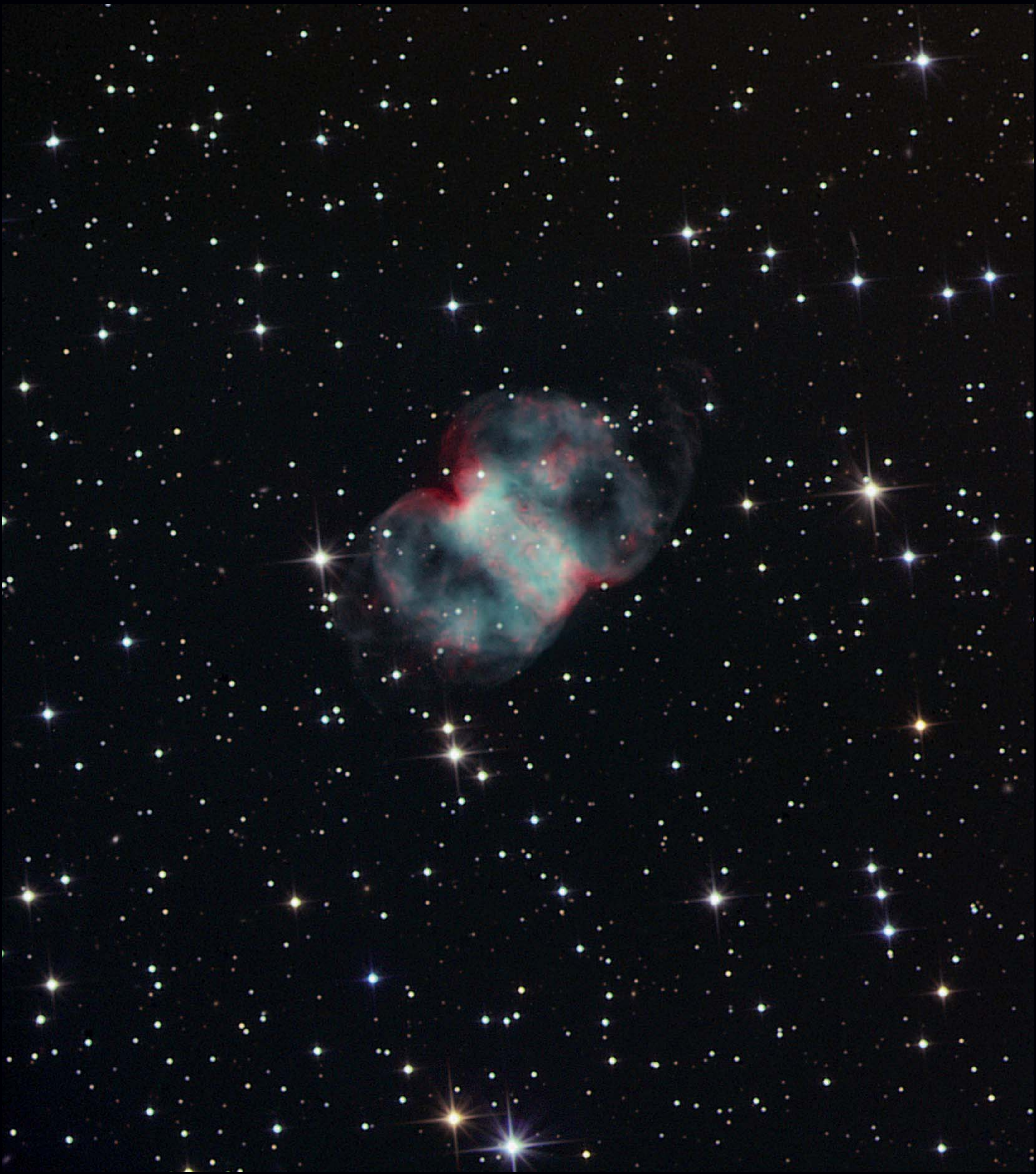
For the distance to M 76, values of between 2550 light-years (as of 2004) and 3900 light-years (from an earlier study with the Hubble Space Telescope) have been published. The very hot but tiny central star has a visual magnitude of only 17.5. Nevertheless, at 140,000 K it is one of the hottest known stars. It represents the hot, dense core of a former red giant, and now has between 0.6 and 0.9 solar masses.

Only 1.33" southeast of the central star (PA 135°) is a very close, faint stellar pair (magnitudes 18.4 and 19.2, 0.16" separation) in the background, 15,000 to 20,000 light-years away.

Observation

The third planetary nebula in Messier's catalog is also the faintest. Still, M 76 is a nice object which shows a lot of detail in modest and larger telescopes. With 2 inches of aperture it is still at the limit of perception, but 2.5 inches distinctly show a faint bar with brighter tips – indicative of the double nature described by Herschel.

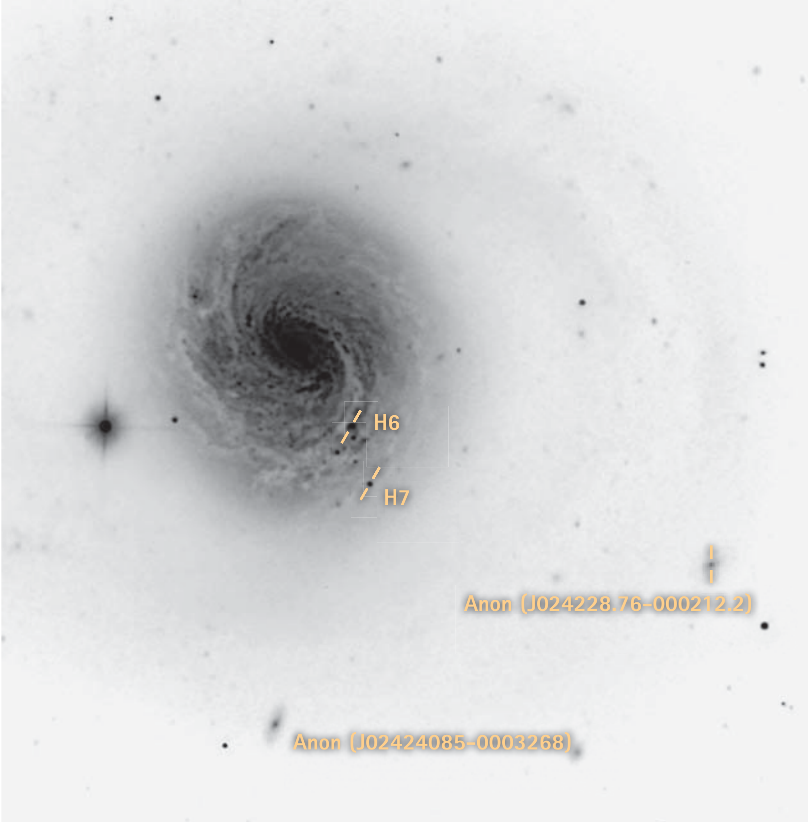
M 76 appears quite bright and with some detail in a 4.7-inch refractor. The western end of the almost rectangular bar is the brightest part. Two star-like condensations are embedded in it. The eastern end is bright, too, but fainter than the western. Vague structure appears in the central part of the bar, difficult to grasp. An [OIII] line filter reveals the two nebulous loops, which reach north from the east side of the bar, and south from the west side. They become much better defined with a 14-inch reflector: the northern loop ends in a faint, patchy condensation, while the southern loop returns to the bar. One of the two brighter spots in the western end of the central part turns out to be a star of magnitude 13.



M 76 looks like a bright nebulous bar, surrounded by faint loops. Stefan Seip.

M 77

Degree of difficulty	33 (of 5)
Minimum aperture	50mm
Designation	NGC 1068
Type	Galaxy
Class	Sb
Distance	46.9 Mly (1988)
Size	100,000 ly
Constellation	Cetus
R.A.	$2^h\ 42.7^{min}$
Decl.	–0° 1'
Magnitude	8.9
Surface brightness	22.1mag/arcsec^2
Apparent diameter	7,1'×6,0'
Discoverer	Méchain, 1780



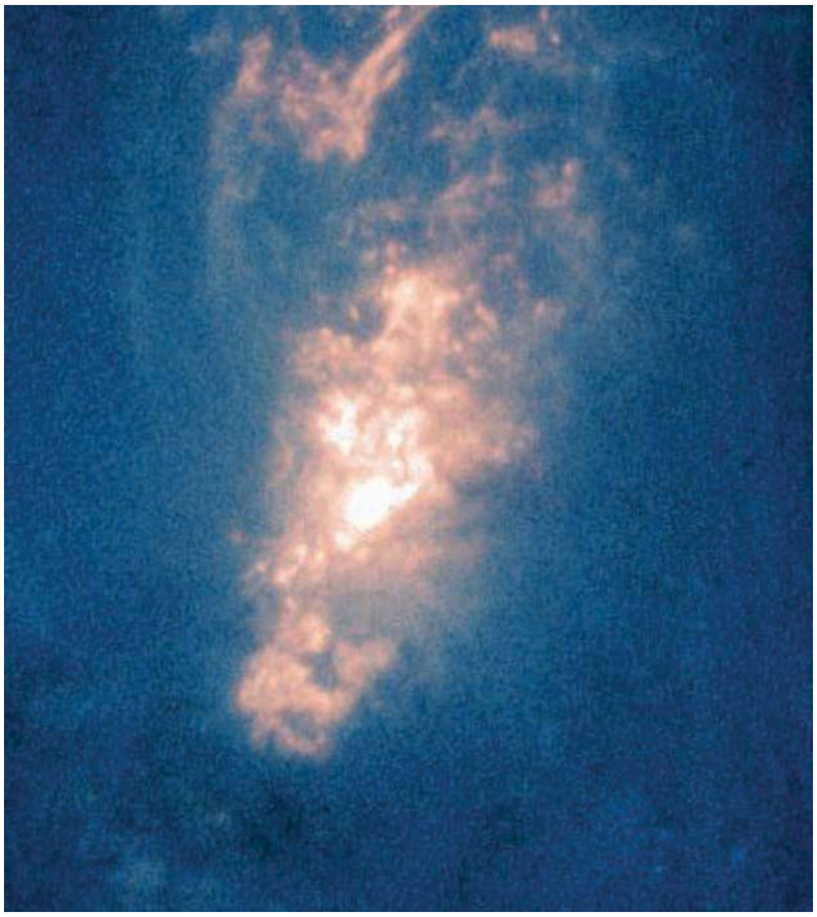
History

On the 29th of October, 1780, Pierre Méchain discovered a small nebula and reported this to Charles Messier, who observed it on the 17th of December 1780. Messier saw a "cluster of small stars, which contains nebulosity." William Herschel also took M 77 for a star cluster, resolvable in large telescopes. William Smyth speculated, following an observation with his 5.9-inch refractor: "This object is wonderfully distant and insulated, with presumptive evidence of intrinsic density in its aggregation; and bearing indication of the existence of a central force, residing either in a central body or in the center of gravity of the whole system." As we now know, the retired admiral came close to the truth with this note, but of course he was unaware of the true dimensions of this galaxy.

In 1848, Lord Rosse recognized M 77 as a "blue spiral," and in 1851 he confirmed: "the central part is, I'm sure, spiral," while John Herschel followed his father in believing that "there is a nucleus which is partially resolved, some stars seen near it." Heinrich d'Arrest stated "no clustering of stars" and observing with the 11-inch Merz refractor noted: "perfectly round at 356 power, nucleus seems stellar."

Only photography would finally resolve the dispute of whether M 77 was a cluster or a galaxy. H. D. Curtis summarized the result in 1918: "A very bright and beautiful spiral. Several, almost stellar condensations on the periphery of the brighter central portions, near the bright nucleus, which is apparently not stellar. The whorls are compactly arranged."

In 1908, E.A. Fath at Lick Observatory discovered that the core of M 77 exhibits strong emission lines in a spectroscope. Slipher confir-



M 77. Structure in the near vicinity of the core. Hubble Space Telescope.

M 77 is a Seyfert galaxy with a core of 100 million solar masses. Josef Pöpsel, Beate Behle.

med this observation in 1917. B.Y. Mills showed in 1952 that M 77 is a strong radio source, later classified as Cetus A and 3C 71.

Astrophysics

For a long time M 77 was thought to be the most distant Messier object, as its redshift is 0.0038. More recent distance evaluations, however, put it at a little under 50 million light-years, which is comparable with the distances of the Messier galaxies in the Virgo cluster.

Nevertheless, M 77 is one of the largest galaxies in the catalog: while its disk has a diameter of 100,000 light-years, faint extensions have been traced out to over 170,000 light-years. The morphology is that of a spiral with broad, structured arms. The inner disk of 40'' apparent diameter, tilted at 51° to our line-of-sight, is composed of a starburst ring of young blue stars, formed in the past 4 to 40 million years. While this ring contains 27 million solar masses, the total galaxy mass is estimated to reach a thousand thousand million solar masses.

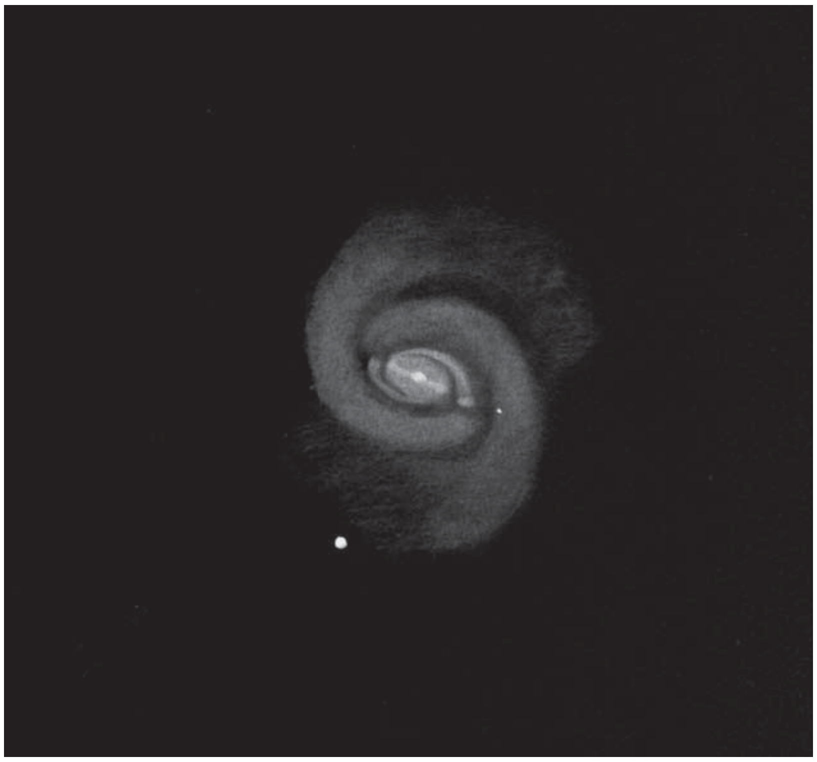
M 77 is famous for being a unique galaxy, exhibiting broad spectral emission lines of Hβ, [OII], [NIII], and [OIII]. After Carl Seyfert, who studied M 77 in 1943, this type of galaxy is called a Seyfert galaxy. M 77 is the nearest and brightest of this class.

The origin of the emission lines is a strong energy source in the nucleus of the galaxy. It is powered by a very small and super-massive central object, which ejects gas in large amounts and with high velocities. Infrared observations with the 10m Keck telescope demonstrated that the core of M 77 is only 12 light-years across, surrounded by an elongated halo of gas 100 light-years in diameter. By means of radio observations, it was possible to resolve the central object into a nucleus and a disk, five light-years wide, consisting of water molecules. In 2004, the dust shell around the nucleus, measuring only a few light-years, was resolved for the first time. M 77 is regarded as an especially "dusty" object with a large infrared brightness.

Active Seyfert nuclei such as in M 77 were compared to small quasars by Osterbrook and Parker in 1977. A super-massive central object – the estimated mass is 100 million suns for the one in M 77 – attracts matter from its environment and emits large amounts of radiation across the entire spectrum. This same phenomenon is observed in quasars, BL Lacertae objects, and radio galaxies, yet with different viewing geometries and intensities. Currently, most astronomers believe Seyfert galaxies to be BL Lac objects by nature, but observed by us from an oblique angle – not down the jet in the axis of the accretion disk – so that the central object is partially obstructed by a surrounding dust torus.

Paradoxically, M 77 is listed in the Arp catalog of interacting galaxies as No. 37. Halton Arp called it "a spiral with a low surface brightness companion on one arm," but no evidence for this claim is found on modern photographs.

M 77 is the main galaxy of a group comprising NGC 1055, NGC 1073, UGC 2161, UGC 2275, UGC 2302, UGCA 44, and Mrk 600. Several other galaxies in the neighborhood, NGC 1087, NGC 1090, and NGC 1094, are in fact distant background galaxies with higher redshifts.



M 77, drawing. 20-inch Newtonian. Ronald Stoyan.

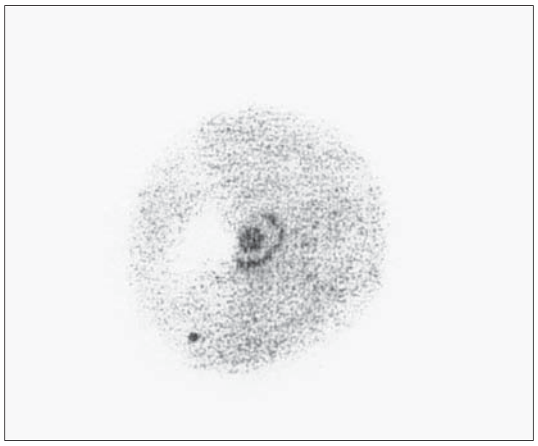
Observation

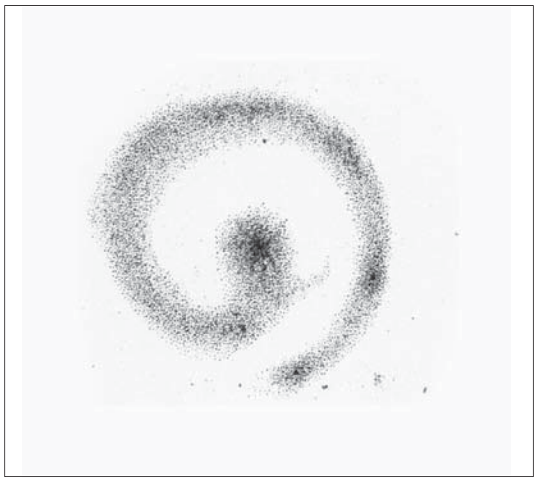
M 77 appears quite conspicuously as a stellar object in 10×50 binoculars. Small telescopes show only the bright galaxy core west of a magnitude-10.7 star. With 4.7 inches of aperture, M 77 appears bright and stretched in an east-west direction. It has a large core, while the visual galaxy barely exceeds 1'.

The central 60" are resolved by a 14-inch telescope into an impressive spiral. The nucleus of the galaxy appears star-like, symmetrically surrounded by a very minute bar in PA 135°. This bar is embedded in the glow of a central area measuring 30"×20", which includes two subtle inner spiral arms, originating at each bar end. As displayed wonderfully in a 20-inch telescope, the western arm is more pronounced and ends in a small knot, after a half-turn around the core. A dark gap of 10" separates the central region and its spiral arms from an outer spiral structure, which is more diffuse and broader. These outer arms can be followed over a full turn around the core. The southern bar end points to a small star-like condensation, just visible in the 20-inch, glowing at magnitude 17.7, which is the brightest of the HII regions of M 77. To make out these fine details in the central region, powers of 300× to 500× are required.

Visually, M 77 shows a size of 2.5'×2.0' in the 20-inch, and its outskirts do not reach the 10.7-magnitude star to the east. Only deep photographs show the outermost parts of the spiral arms, which are very faint and cover an overall size of 7'×6'. By contrast, the peculiar emission lines of the star-like nucleus of the galaxy can be observed visually in a spectroscope.

3.2' to the west and 2.8' to the south of M 77, the brightest of a large number of very small, anonymous field galaxies can be found. M 77 itself is sometimes confused with NGC 1005, 20' north, which looks much more like a galaxy. On photographs, this edge-on galaxy displays a fine dust lane, bisecting it along its length.

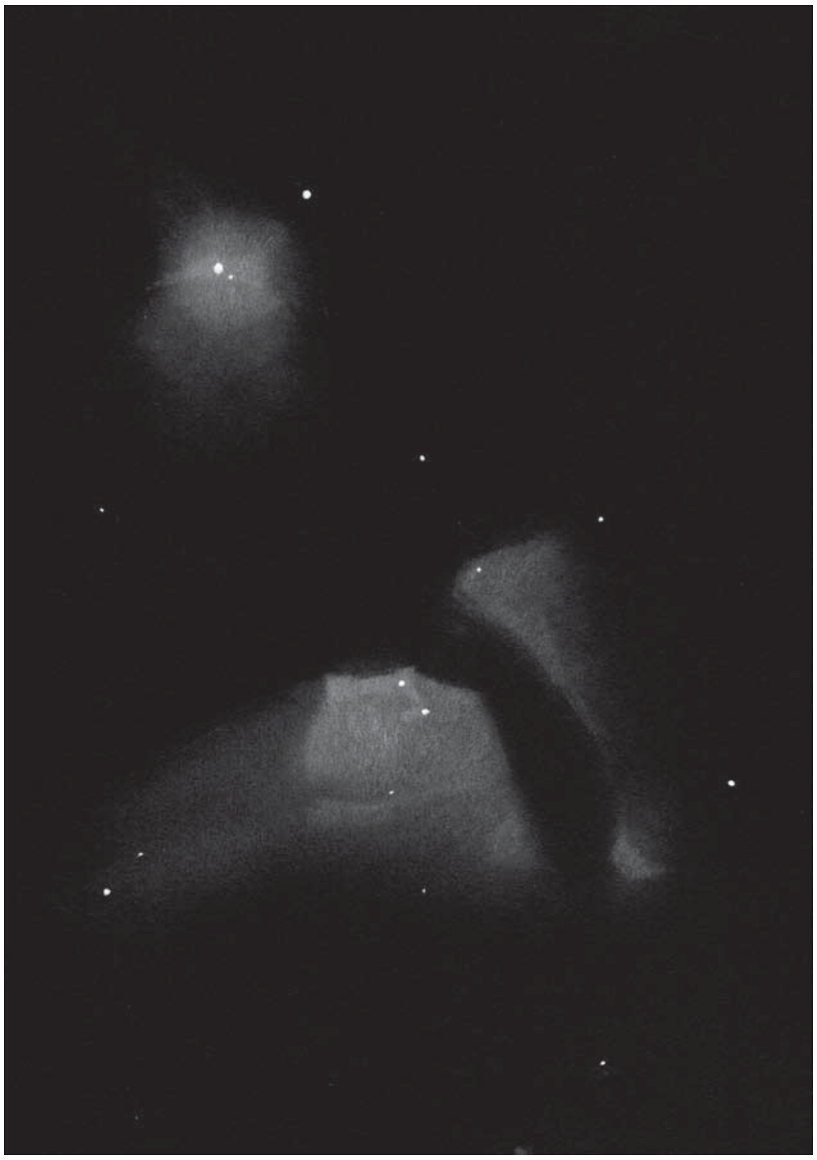




M 77, historical drawings. Lord Rosse (1851), William Lassell (1862).

M 78

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	NGC 2068
Type	Galactic nebula
Class	Reflection nebula
Distance	1300 ly (2004)
Size	3 ly
Constellation	Orion
R.A.	5^h 46.7^{min}
Decl.	+0° 3'
Magnitude	8.0
Surface brightness	–
Apparent diameter	8'×6'
Discoverer	Méchain, 1780



M 78, drawing. 14-inch Newtonian. Ronald Stoyan.

History

Early in 1780, Pierre Méchain discovered a nebulous object in the constellation Orion and characterized it very adequately as "two fairly bright nuclei, surrounded by nebulosity." Charles Messier observed this object almost a year later, on the 17th of December 1780. Oddly, he noted a "cluster of stars, with much nebulosity."

William Herschel discovered the detached nebula NGC 2071 north of the main complex. Still very representative for the view of M 78 in moderate telescopes is the mid-nineteenth-century description given by Admiral Smyth, after an observation with his 5.9-inch refractor: "Two stars in a wispy nebula. It is a singular mass of matter trending from a well defined northern disc into the south following quadrant, where it melts away. Its most compressed portion is the wide double star." Likewise, John Herschel saw "two stars equally bright at 9m in a wispy nebula. It extends 5'; terminating abruptly to the north," but he also noticed a third star.

Lord Rosse claimed in 1851 to see spiral structure, which connected the two bright stars. In 1858, however, he renounced that dubious observation. Heinrich d'Arrest reported, after his observation with an 11-inch refractor in Copenhagen: "6' or 7' diameter, with an enclosed pair. Irregular shape, approximately oval. The northern edge is well defined, the southern less so." Prior to this, d'Arrest had found a very faint nebula southwest of M 78, which is now known as NGC 2064. Its northern extension, NGC 2067, may have been sighted a few years earlier by Wilhelm Tempel.

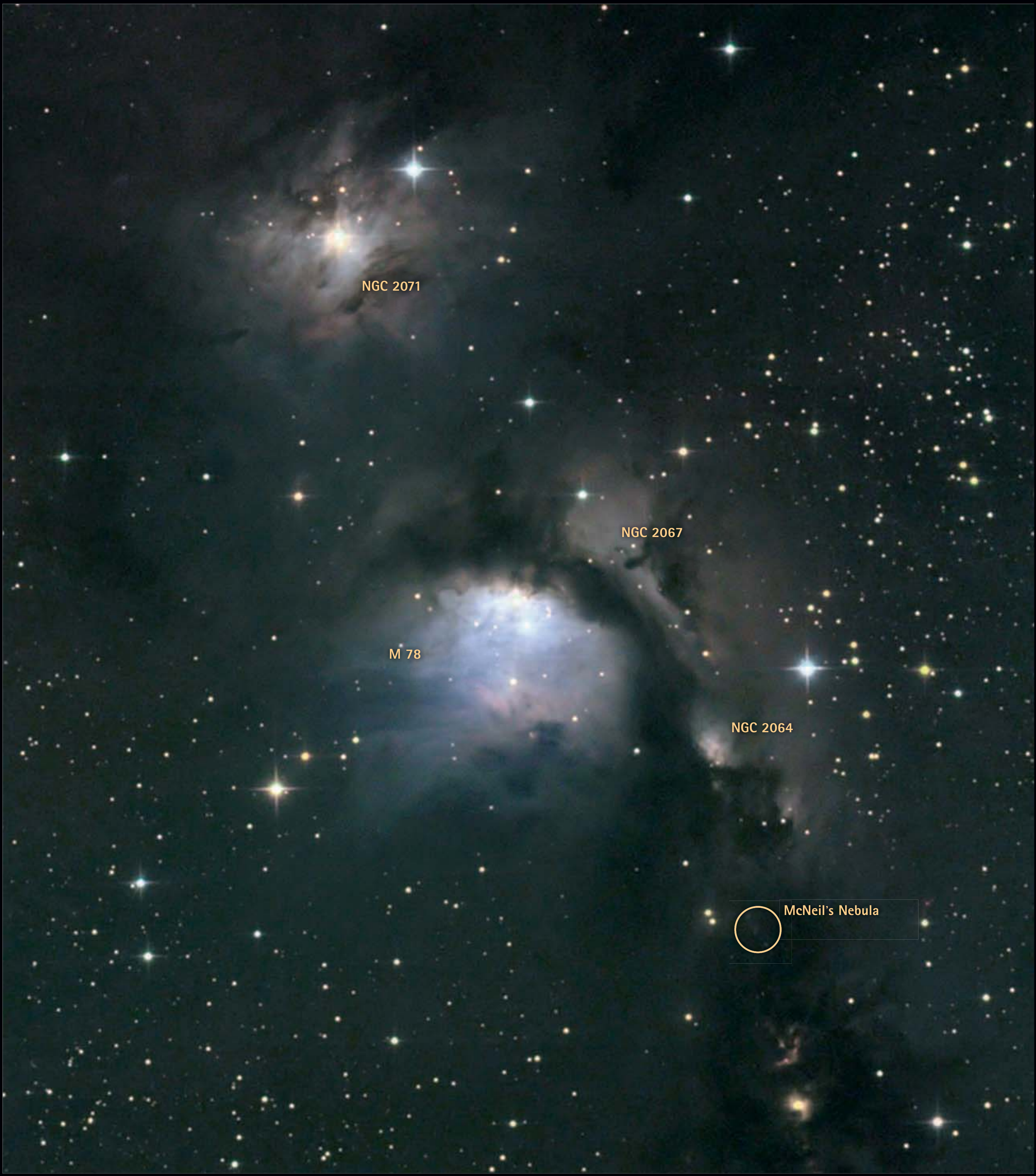
Leo Brenner observed in M 78 a "triple star: one has 8th magnitude, its companion mag 8.5 is separated by 51" and consists itself of two stars, 1.7" apart."

Heber D. Curtis described the photographic appearance as a "a mass of rather irregular, fairly bright, diffuse nebulosity, whose brighter portion is 6'×4', involving two 10th magnitude stars. Two fainter patches lie 6' west, apparently separated from the main mass by a wide lane of dark matter."

It was Vesto M. Slipher at Lowell Observatory in 1919, analyzing spectra of M 78, who found out that, contrary to all other gaseous nebulae known then, this one shines purely in reflected starlight.

Astrophysics

M 78 is a part of the larger Orion nebula complex with M 42/43 as its most prominent object. It is the only principal reflection nebula in the Messier catalog: the light of the stars HD 38563A and HD 38563B (magnitudes 10.2 and 10.6, separation 51" in PA 202°) does not provide sufficient power in the UV to ionize the interstellar gas and to make it glow. Hence, light is reflected only by the dust component of the interstellar clouds. The nebula has a blue color because the young central stars are blue, and because small dust particles have better reflectivity in blue light.



M 78. Dark dust clouds cover large parts of the constellation Orion, lit up by stars only in a few places. Cord Scholz.

M 78 with McNeil's nebula (marked), discovered in January 2004. Bernd Flach-Wilken, Volker Wendel.

M 78 is like a small illuminated island in the 8°-wide, dark molecular cloud Orion B. Other parts of that cloud lit up by stars are the nebulae NGC 2071 north of M 78, the fainter NGC 2064 (southwest), NGC 2067 (northwest), and NGC 2024 / 2023 with the Horsehead Nebula. This whole region has a size of 200 light-years.

Similar to famous M 42, M 78 hosts a large number of very young (several 100,000 years) stars, most of which have not even reached their equilibrium position on the main sequence yet. These are still T Tauri variables (see M 42), which show irregular light variations of up to three magnitudes in a short time.

In 1991, infrared observations with the 1.3m Kitt Peak telescope revealed four star clusters in this region, which are totally hidden in visual light by the dark absorbing cloud. Furthermore, Zhao and colleagues (1999) found 17 Herbig-Haro objects around M 78. These are mostly bipolar nebulous knots which betray the presence of embedded protostars with jets that are heating the surrounding interstellar material they hit.

The US amateur astronomer Jay McNeil made a CCD picture of M 78 on the 23rd of January 2004, using his 3" refractor. After image processing, he discovered a new nebulous object 10' south of M 78, which is absent on older images. It is associated with the star IRAS 05436-0007, a possible FU Ori [Orionis] type variable. Well-resolved images have now revealed that this star forms the southern tip of the 0.5'-long, new nebula, which must have been formed in an outburst in October 2003 and then gained five magnitudes within four months. This wasn't the first such event, though: some much older photographs show a nebula here, too.

Observation

M 78 appears as just a faint spot in 10×50 binoculars. A 70mm aperture and a magnification of 16× are enough to reveal its characteristic comet-like appearance, by which it engulfs two stars.

The well-defined northwestern edge of the nebula becomes very noticeable in a 4.7-inch telescope. Next to it is the brightest part of M 78, which hosts the two magnitude-11 stars. The nebula fades out gradually towards the southeast, where there is a third, much fainter star of 13th magnitude. Facing the northwest edge of M 78, separated by a dark canal, lies the faint nebulosity NGC 2067, elongated in northeast-southwest direction. It narrows towards the southwest and ends there at a star of magnitude 12. Further southwest is NGC 2064 – at the limit of perception with 4.7 inches of aperture.

By contrast, NGC 2071, 20' north of M 78, can be seen even in a 2" telescope. 4.7 inches of aperture show it round and bright, surrounding a star of 10th magnitude. A somewhat fainter star to the northwest is clear of nebulosity.

A 14-inch telescope brings out structure in pale M 78. The brightest part of the nebula is its northern edge of the 6'×5' main part, north of the two bright stars. Faint extensions can be seen reaching southwest and east. Dark clouds become visible immediately south of the third, faint star in M 78. NGC 2067 and NGC 2064 appear vaguely connected, but visibility of the McNeil's new nebula, further south, remains uncertain; it is at the very limit of the telescope. NGC 2071 in the north, by contrast, appears clearly structured in a 14-inch. It features a bright filament of 4' length and 1.5' width, stretched out in an east-west direction. There is a faint companion right southwest of its main star. The companion of the bright star in M 78, the one seen by Leo Brenner, remains invisible.

M 79

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	NGC 1904
Type	Globular cluster
Class	V
Distance	45,000 ly (R2005)
Size	80 ly
Constellation	Lepus
R.A.	5^h 24.2^{min}
Decl.	–24° 32'
Magnitude	7.7
Surface brightness	–
Apparent diameter	6'
Discoverer	Méchain, 1780

M 79 lies on the opposite side of the galactic center, where many globular clusters are found. Bernd Flach-Wilken.

History

Pierre Méchain discovered M 79 on the 26th of October 1780. Messier observed this globular cluster two months later, on the 17th of December, and noted: “Nebula without star, the center bright, the nebulosity a little diffuse.” Thereafter, hardly any attention was given to M 79 – perhaps due to its low southerly position in the sky.

Astrophysics

At a distance of 45,000 light-years, M 79 lies far beyond the galactic center, from which it presently has its maximum distance. In 200 million years, its mildly eccentric orbit will have brought it to a minimal distance of still 14 million light-years from the galactic center. M 79 is, in absolute terms, a very average globular cluster with an estimated 400,000 solar masses, 80 light-year diameter and up to 900,000 stars.

M 79 is known for its large number of very blue stars on the horizontal branch in the Hertzsprung-Russell diagram. Cheng and colleagues discovered 91 such stars, which are very evolved, burn helium in their cores, and are not far away from their stellar “death.” The properties of these stars suggest that M 79 is one of the oldest globular clusters of the Galaxy, and some age estimates exceed even the 15 thousand million years supposed to be the age of the universe. This age conflict with at least some globular clusters is an old, persisting problem in astrophysics, but it has already improved with better stellar and cosmological models.

M 79 is slightly elliptical in PA 45°. Among the individual cluster stars up to magnitude 13, only seven have deen identified as variables. In 2004, Martin et al. found that M 79 does not have a galactic origin, but – together with NGC 1851, 2298, and 2808 – once belonged to the Canis Major dwarf galaxy. This companion of our Milky Way is being torn apart by tidal forces, and our galaxy has already succeeded in winning over those globular clusters. The dwarf galaxy has also lost many of its stars, which are now orbiting the Milky Way in the so-called “Monoceros-Ring.”

Observation

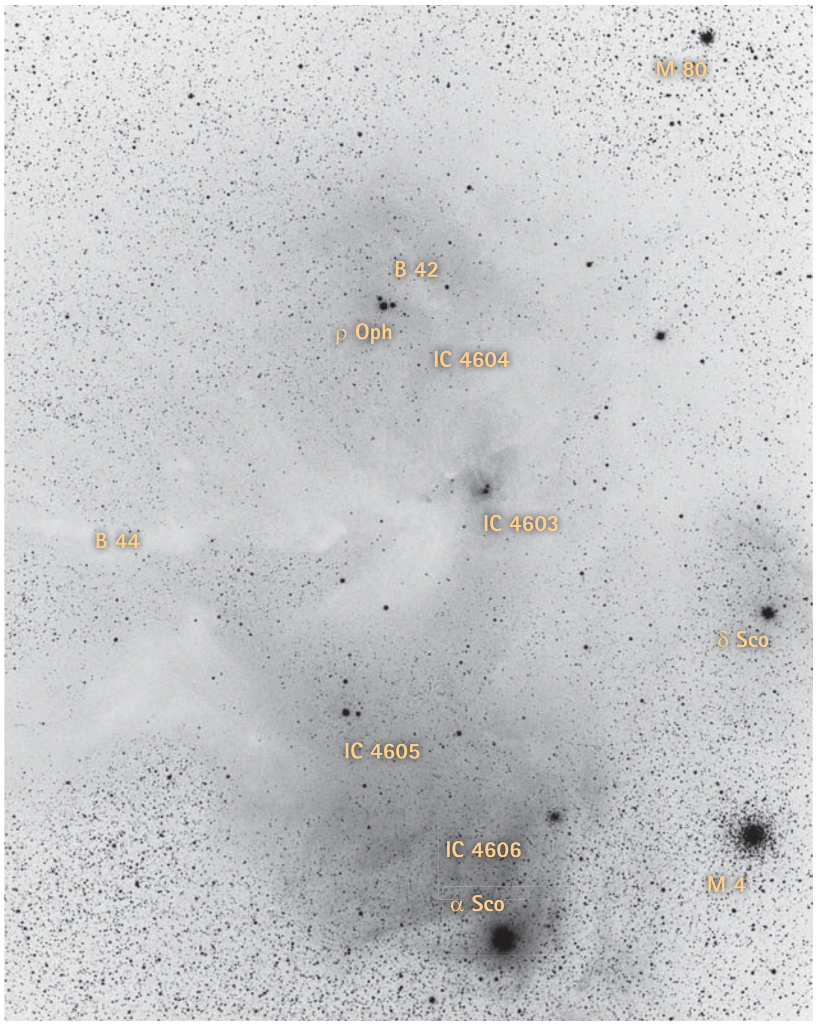
O’Meara has claimed a naked-eye sighting of M 79 under very good conditions, with a naked-eye limiting magnitude 7.5. However, there are no other reports to confirm this. 10×50 binoculars show M 79 as a small ball of nebulosity. Under good conditions, the globular cluster can be resolved into individual stars with 4-inch and larger telescopes. At the same time, M 79 appears luminous and strongly concentrated, with a visual diameter of 3’. There is a 9th-magnitude star in the north and another in the south.

Larger telescopes show extensions of M 79, which reach up to 5’. A star of magnitude 12 marks the northern side of the cluster. The nice double star h 3752 lies 30’ southwest of M 79. It consists of two stars magnitudes 5.5 and 9.2, separated by a generous 63”.

M 80

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	NGC 6093
Type	Globular cluster
Class	II
Distance	48,260 ly (2005)
Size	125 ly
Constellation	Scorpius
R.A.	16^{h} 17.0^{min}
Decl.	–22° 59'
Magnitude	7.3
Surface brightness	–
Apparent diameter	9'
Discoverer	Messier, 1781

M 80. Total view of this very concentrated globular cluster by the Hubble Space Telescope.



History

On the morning of the 4th of January 1781, Messier came across a "nebula without star, round" in the constellation of Scorpio. He added: "bright center, resembles the nucleus of a small comet, surrounded by nebulosity."

Four years later, William Herschel was able to resolve this globular cluster into individual stars. He described M 80 later as "one of the richest and most compressed clusters of small stars I remember to have seen; is on the western border of the Opening in the Heavens." With the last remark, this great observer referred to the dark, starless cloud seen around ρ Ophiuchi, which Herschel held rather for a real hole in the Milky Way, devoid of stars.

Smyth described M 80 in 1837 with the words: "Fine and bright object, from the blazing center and attenuated disc, it has a very cometary aspect."

Astrophysics

This globular cluster is almost four times as far away as the famous M 4 in its immediate neighborhood. M 80 contains nearly a million stars of over 400,000 solar masses. It is one of the densest and most compact globular clusters of the Galaxy. Its orbit around the galactic center takes only 70 million years to complete and keeps M 80 always inside the outer galactic bulge.

The brightest stars of M 80 reach a respectable magnitude 13.4, suffering only from a very modest – considering the distance and location – 0.5 magnitudes of interstellar absorption. With the Hubble Space Telescope, a large number (305) of "blue stragglers" were discovered in 1999, almost twice as many as known in M 3 (170). These stars are bluer, more luminous and more massive and, hence, they should be younger than all the ordinary cluster stars. It has been suggested that they are the merged end-products of stellar collisions,

M 80 (top right) with M 4 (below right) and Antares. This region between Scorpius and Sagittarius offers an impressive display of blue and yellow reflection nebulae. Stefan Binnewies.

M 80 is the most compact globular cluster in the Messier catalog. Daniel Verschatse.

for which the dense centers of globular clusters provide sufficient probability. M 80 with its high density and large number of "blue stragglers" seems to support this plausible explanation.

On the 21st of May 1860, Wilhelm Auwers discovered a nova in M 80 at 7.5 magnitudes from Berlin. Today known as T Scorpii, it reached a maximum of 6.8, outshining the whole cluster, then the star fainted to mag 10.5 by the 16th of June 1860. To the present day, very few novae have been discovered in other Messier clusters, only in M 5, M 14, and M 30. In 1995, M 80 was searched for other nova candidates, of which there could be up to 200. Apart from T Scorpii, only 10 variables have been found in M 80.

Observation

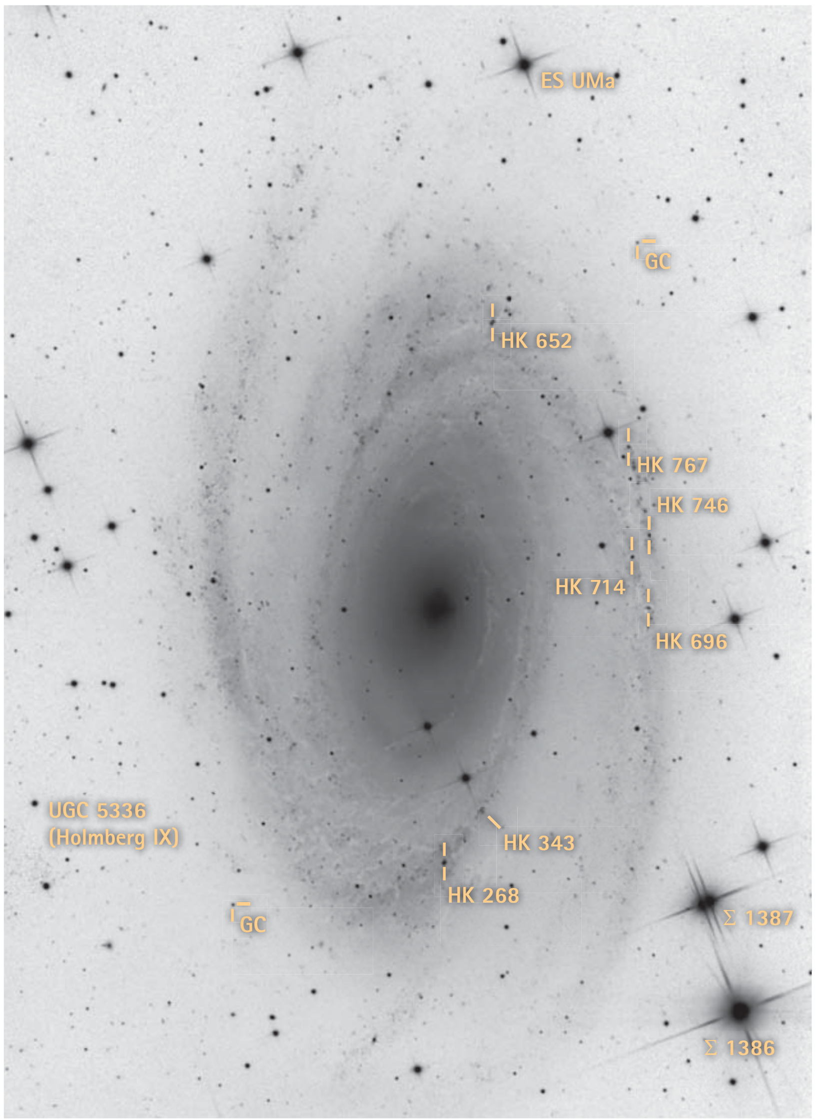
In 10×50 binoculars, M 80 appears as a very small, round nebula. A small telescope makes it look like a strongly concentrated ball of nebulosity, with a magnitude 8 star 4' northeast.

With 4.7 inches of aperture, the cluster center becomes noticeable; it has an almost stellar appearance. Individual stars cannot yet be resolved but they cause the mottled character of the cluster, which now appears to have a diameter of 5'. Full resolution of M 80 into individual stars requires relatively large telescopes.

Two Mira variables can be found in the neighborhood of M 80. R Scorpii, 8' east, changes between magnitudes 9.8 and 15.5 with a period of 224.61 days. S Scorpii is 10' northeast of the cluster, and its brightness changes between 9.5 and 15.5 with a period of 177.9 days.

M 81

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 3031
Type	Galaxy
Class	Sb
Distance	11.8 Mly (H2000) 12.5 Mly (PN, 2001) 11.8 Mly (Cepheids, 2000) 13.1 Mly (SBF, 2000)
Size	92,000 ly
Constellation	Ursa Major
R.A.	9^h 55.6^{min}
Decl.	+69° 4'
Magnitude	6.8
Surface brightness	21.9mag/arcsec^2
Apparent diameter	26,9'×14,1'
Discoverer	Bode, 1774



History

The German astronomer Johann Elert Bode, director of the royal Berlin observatory, discovered M 81 on the night of New Year's Eve (31st of December) in 1774. Consequently, especially in England, this galaxy is known as Bode's Nebula. Bode described his find as "round with a dense nucleus in the middle." Messier made his first observation of M 81 two months later, on the 9th of February 1781, and noted: "slightly oval, the center bright."

Apparently, the spiral structure was not recognized, neither by the Herschels nor by later visual observers. Smyth only saw a "fine bright oval nebula, of a white color," and Brenner estimated its visually perceivable extent to 15' by 5'. He also noted: "Two stellar pairs southwest, of mags 9.5 and 8.2, of 9" and 2" separation, respectively." Finally, deep photographs revealed the spiral nature of this galaxy. Curtis wrote about M 81: "very beautiful spiral, 16'×10'. Short exposures show that the nucleus is almost stellar."

Astrophysics

M 81 is the primary galaxy in the nearest galaxy group, which is comparable to our 'local group'. At least ten galaxies are recognized members of this M 81 group: M 82, NGC 2366, 2403, 2976, and 3077, IC 2574, UGC 4459, and the dwarf galaxies Holmberg I, II, and IX. M 82 is a physical close companion of M 81 at a projected distance of only 125,000 light-years.

M 81 is a good example of a "grand design" spiral with open, uninterrupted arms. An interesting detail is the bend in the eastern spiral arm which points towards M 82. Apparently, the close encounter of these two galaxies about 10 million years ago resulted in this deformation of the spiral pattern, as well as in the pronounced spiral arms and extra absorption structures near the core of M 81. In the galaxy center, a super-massive object of 60 million solar masses was discovered. From its immediate surroundings, we receive an emission line spectrum of the LINER type (low ionization nuclear emission region). Hence, M 81 has been considered a weakly active galaxy, or containing a "low-luminosity active galactic nucleus." Its central object, quite likely a massive black hole, accretes matter from its surroundings. The resulting energetic radiation has ionized the gaseous envelope of the core, which leads to the observed emission line spectrum. There are some LINER galaxies, though, which take their energetic radiation not from an accreting, super-massive central object but from a compact central starburst region.

A study of the radial velocity curve of M 81 in 1994 revealed that it does not contain much dark matter. By contrast to our Galaxy, the rotation velocity in M 81 is decreasing outwards, while it is continuing to rise in the Milky Way. In total M 81 has about 50 thousand million solar masses, considerably less than our Galaxy.

In 1993, the Hubble Space Telescope observed 31 cepheids in M 81 and gave a reliable distance measurement of 11 million light-years.

M 81 consists of an older central region with yellowish stars and younger spiral arms with numerous HII regions and star clusters. Volker Wendel.

M 81 and M 82 make the most impressive galaxy pair in the sky. Their projected distance is 125,000 light-years. Robert Gendler.

The presently accepted value lies between 11.8 and 13.1 million light-years and yields a physical diameter for M 81 of 92,000 light-years.

A bright supernova, discovered on the 28th of March 1993 by the Spanish amateur astronomer Francisco Garcia with his 10” Newtonian at 111× magnification, fetched a lot of attention. It reached magnitude 10.5 in the best observing season and became visible even to a 2.4-inch refractor. Worldwide VLBI radio-interferometry was able to resolve the small supernova remnant only 6 months later.

Chandar and colleagues (2001) cataloged 114 open clusters in M 81 down to 22nd magnitude. In addition, 44 globular clusters have been found; the brightest are of 18th magnitude. Their estimated total number of 210 is close to that of the Milky Way.

Observation

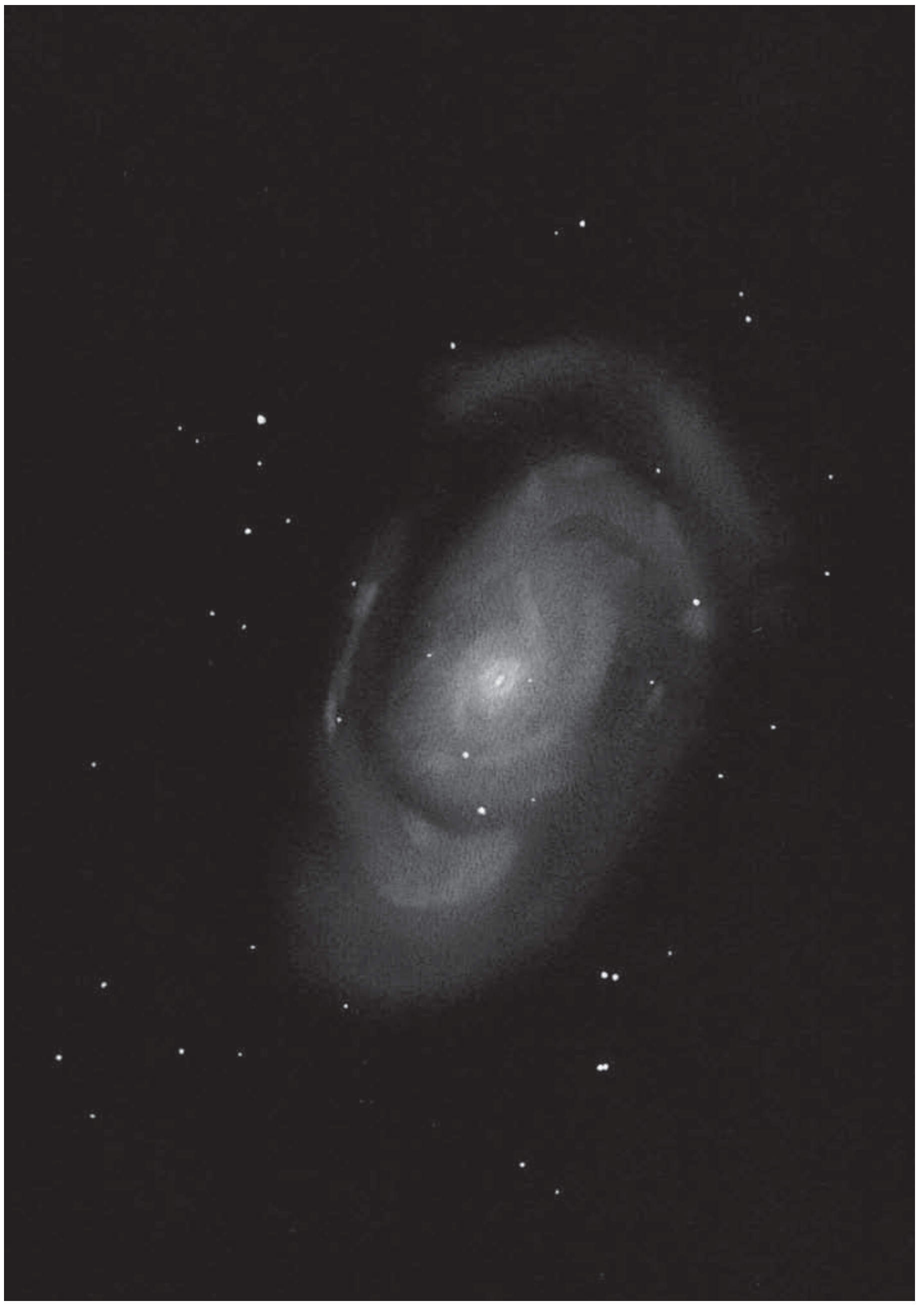
M 81 can be seen with the naked eye in very clear spring nights high in mountain skies (naked-eye limiting magnitude > 7.3). To do so, it is crucial to have a map with stars down to about 7.5 magnitudes to distinguish the faint glow of the galaxy from neighboring stars. The author has been able to see this galaxy in an exceptionally clear sky in the Alps at an altitude of 2800m.

In 10×50 binoculars, M 81 is visible as a large, 12’ nebula with a bright core. This impression remains the same with small telescopes; the bright core appears stellar.

With an aperture of 14 inches this galaxy reaches the considerable visual size of 20’×12’ in PA 155°. A very small, but not star-like, nucleus is surrounded by a bright core region of 1.5’, elongated in a different direction from the galaxy in general, PA 130°. This, in turn, is embedded in a brighter oval of nebulosity (now PA 155°) of 3’×2’. A mottled region south of the core, and south of two foreground stars, gives way to the visually brightest spiral arm of M 81. With a width of only 1’, this arm is most distinct near two foreground stars 4’ and 5’ east of the galaxy’s core. It then becomes more diffuse in its turn around the northern end of the galaxy. The less distinct beginnings of the western spiral arms can be seen north of the galaxy’s core, on the major axis. Dark clouds give structure mainly to two regions, northwest and directly southeast of the core, supporting the impression of a spiral. Otherwise, the whole oval area covered by the galaxy is filled with a homogeneous, diffuse light.

There are two bright double stars southwest of the core. Q 1387, consisting of two components of magnitude 10.9 separated by 9.0” in PA 112°, is easier to resolve than the brighter pair of 1386, just to its south, with two stars of magnitude 9.5, only 2.1” apart in PA 271°. Consequently, the latter double star requires a high magnification.

Only under excellent conditions can a 20-inch telescope give a glimpse of the companion galaxy Holmberg IX (UGC 5336), which has a very low surface brightness and lies 10’ east of the core of M 81.



M 81, drawing. 14-inch Newtonian. Ronald Stoyan.

M 82

Degree of difficulty	2 (of 5)
Minimum aperture	30mm
Designation	NGC 3034
Type	Galaxy
Class	Irr
Distance	11.4 Mly (2003)
Size	37,000 ly
Constellation	Ursa Major
R.A.	9^h 55.8^{min}
Decl.	+69° 41'
Magnitude	8.4
Surface brightness	21.7mag/arcsec^2
Apparent diameter	11,2'×4,3'
Discoverer	Bode, 1774

M 82. The center of the galaxy is densely populated by young star clusters. Hubble Space Telescope.

History

M 82 was discovered together with its brighter neighbor M 81 by Johann Elert Bode on the 31st of December 1780 in Berlin. He described this galaxy as "pale and elongated." Messier observed M 82 on the 9th of February 1781, and he described it as a "nebula without star, its light is faint and elongated, near one end is a telescopic star." Ever since, the sight of this unusual galaxy has fascinated numerous observers.

Smyth characterized M 82 as "very long, narrow, and bright, especially at its northern limb." William Herschel saw it as a "beautiful ray of light," while Lord Rosse noticed the dark absorption streaks perpendicular to the long axis. Heinrich d'Arrest described M 82 in more detail: "fine bright rays, luminous and sparkling, 7' long and 100" wide with two nuclei eccentrically placed on the major axis. It sparkles as if with innumerable bright spots." Brenner remarked later that M 82 looked like a "bent strip" to him.

Heber Curtis, studying deep exposures of this galaxy, still could not quite figure out its true nature. He noted: "A very patchy and irregular, elongated mass, showing numerous rifts; an irregular lane divides it approximately along the shorter axis. It is possibly a very irregular spiral seen edgewise."

Astrophysics

M 82 is regarded as the textbook example of a starburst galaxy. Photographic images show large regions with massive starburst activity, as well as dark, absorbing clouds and bright, ionized gaseous nebulae in a seemingly chaotic pattern. M 82 is the brightest infrared-galaxy in our sky. This is due to the numerous young stars, which are still embedded and hidden (in optical light) in dust clouds warmed up by their radiation. In an area of only 30" diameter near the core of M 82, there are more stars being born than in all of our Milky Way.

The cause of this ongoing, strong star formation activity are the close encounters with its ten times more massive "sister" galaxy M 81. The tidal interaction of an encounter induces density waves, which trigger waves of star formation. Soon, many young, massive stars blow up as supernovae, which collectively create a galactic superwind. That drives out large amounts of gas from M 82 with velocities of up to 500 to 800 km/s. The superwind clashes with the surrounding halo gas, and a lot of its material falls back into the galaxy. Large amounts of in-falling gas are excited by the young, hot stars and show strong emissions in the red hydrogen Hα and nitrogen lines. While the body of M 82 has a disk size short of only 40,000 light-years, traces of ejected gas clouds can be detected out to 34,000 light-years on either side!

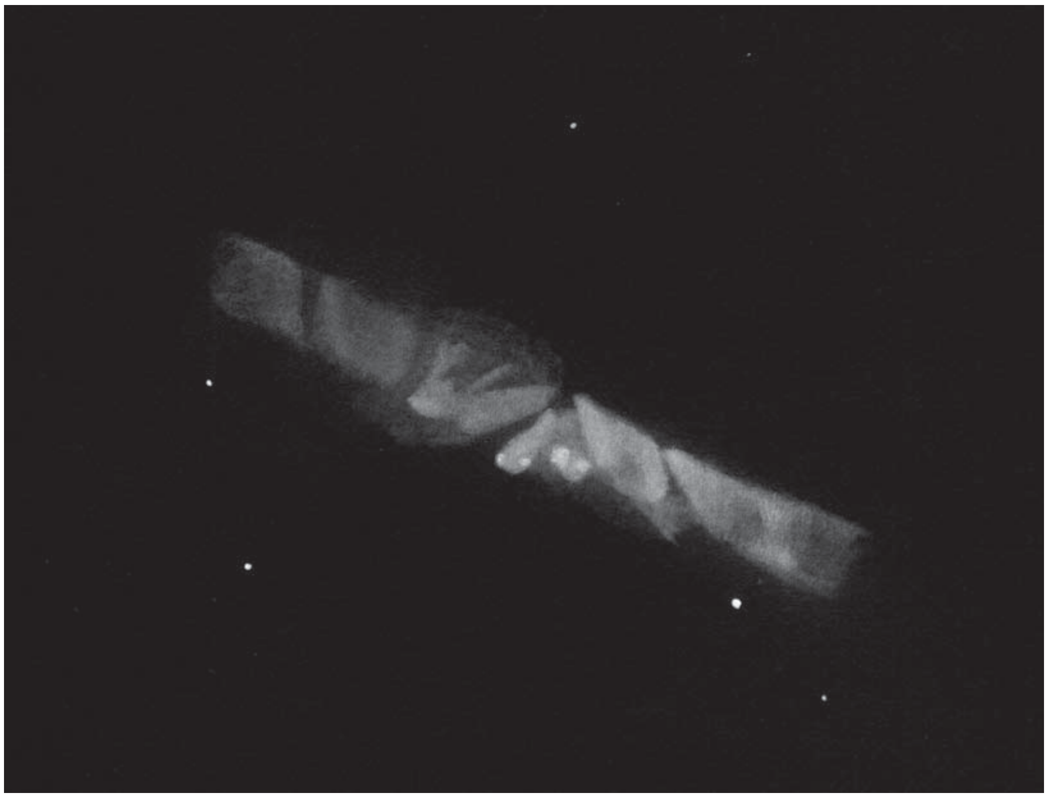
Most of the star formation activity in M 82 appears to be related to an earlier close encounter, about 600 million years ago. In addition, there is a fresh new starburst, which has been triggered by the most recent close encounter, about 10 million years ago. That encounter has disrupted the whole structure of M 82. It does not show a typical core, nor any other characteristic galaxy structure. A visible example is the chaotic absorption features seen in front of most of the galaxy.

In 1953, Brown and Harald discovered a radio source near M 81, which in 1961 was identified with M 82 by Lynds, now known under its designations UMa A or 3C231. In 1997, a detailed study of the

M 82. Red glowing hydrogen gas clouds dominate this fantastically irregular galaxy.
Philipp Keller, Christian Fuchs.

central star formation region of M 82 was carried out with the Hubble Space Telescope. In the brightest region, M 82A, 100 young super star clusters (SSCs) were found, none older than 50 million years. As a result of the combined energetic radiation and its effect on the surrounding interstellar gas and dust, the region M 82A alone is five times as luminous, in absolute terms, as the whole Milky Way. Each SSC contains over 100,000 very young stars, has about a million solar masses and is 10 to 20 light-years in diameter. Many of the stars have not even reached the main sequence yet, but in the distant future, many M 82 SSCs will have evolved into something similar to a globular cluster.

The less bright region M 82B contains several massive star clusters with 10,000 to about a million solar masses each. Here, the starburst activity came to an end around 20 million years ago, and M 82B will probably fade away within the next 30 million years. This region contains M 82F, which is the second-largest SSC in M 82 with 1.2 million solar masses. It has an age of 60 million years. Smith and Gallagher found out that it does not contain any stars with less than two or three solar masses. A reason for this may be that the exceptionally intense radiation of the massive, young stars disrupted the slower formation of the less massive stars. As a result, no star of this SSC will ever stay on the main sequence for more than one or two thousand million years. Hence, this super-cluster will not last long enough to become a globular cluster.



M 82, drawing. 14-inch Newtonian. Ronald Stoyan.

In 2004, the first supernova was found in M 82, only 35” west of its core. It exploded in November 2003, as seen on pre-discovery photographs, in a very dusty environment. Hence, it suffered a lot of interstellar absorption inside M 82 and reached a maximum magnitude of only 16.0 around the 21st of November 2003.

Observation

M 82 can be seen, jointly with M 81, even in small binoculars. In a small telescope, its long-drawn bar of light appeals to the observer and contrasts with its oval sister galaxy.

From about 4 inches of aperture upwards, dark perpendicular absorption lanes gain visibility. The most distinct of these nearly zigzags through the center of the galaxy, which now has a visual size of 6’×1.5’. More dark incursions from the south are seen in the western half of M 82, while east of the main dark lane, bright condensations can be perceived. The galaxy’s eastern end appears cut off, by contrast to the gradually fading western end.

Under a dark sky, a 14-inch telescope shows an overwhelmingly torn object, which takes a whole night to capture in a detailed drawing. A good starting point is two brighter stars southwest of the galaxy, nearly pointing to its center. A faint 16th-magnitude star 1’ northeast of the closer of those two stars is at the limit of perception with 14 inches of aperture. Here, the southern edge of M 82 forms a deep bay, which turns into a dark bar that crosses the whole galaxy in PA 35°. The part of the galaxy to the west features at least one more dark bar before it fades away into the background.

The central region of M 82 is characterized by large star-forming regions. The huge region M 82A of magnitude 13.8 measuring 20” stands out in the south of the galaxy, with two noticeably separated parts. The brightest star clusters reach only 16th magnitude but, repeatedly, several points of light seem to flash into perception. This effect becomes more pronounced with even larger apertures than 14 inches. M 82E lies just 1’ west of M 82A and it, too, is visibly non-stellar. Only 20” further west, there is just another dot of light. The northern edge of the central region is also bright, but individual condensations cannot be resolved here – even though M 82F (mag 16.3) should potentially be within reach of a 14-inch telescope.

Towards the east, the central region is bordered by the dark absorption bar in PA 70°. The area beyond it shows structure, which is more pronounced near the southern side, but significantly fainter than the central region. A perpendicular, straight absorption lane ends this region abruptly in the east. The remaining eastern part of M 82 is pretty faint and has only a vague structure.

The visual extent of M 82 in a 14-inch telescope is 7.5’×1.5’, in PA 65°. Deep photographs show a much thicker galaxy body because it reveals the masses of gas, which stream in from the sides. However, these remain beyond the reach of visual observation.

M 83

Degree of difficulty	2 (of 5)
Minimum aperture	30mm
Designation	NGC 5236
Type	Galaxy
Class	Sc
Distance	14.7 Mly (Cepheids, 2003)
Size	55,000 ly
Constellation	Hydra
R.A.	13^h 37.0^{min}
Decl.	−29° 52'
Magnitude	7.5
Surface brightness	22.1mag/arcsec^2
Apparent diameter	12,9'×11,5'
Discoverer	Lacaille, 1752

History

M 83 was only the third galaxy discovery, after M 31 and M 32, when Nicholas Louis de Lacaille found it in 1751 or 1752 during his observing campaign at the Cape of Good Hope. His entry under number I.6 reads: "nebula without star, small and shapeless." Messier, who knew Lacaille's catalog, finally managed to see this very southerly galaxy on the 17th of February 1881. He saw a "nebula without star, it appears as a faint and even light."

The Australian observer James Dunlop described this galaxy in detail as his catalog number 62B: "A very beautiful round nebula, with an exceedingly bright well-defined planetary disk or nucleus, about 7" or 8" diameter, surrounded by a luminous atmosphere or chevelure [mane], about 6' diameter. The nebulous matter is rather a little brighter towards the edge of the planetary disk, but very slightly so. I can see several extremely minute points or stars in the chevelure, but I do not consider them as indications of its being resolvable, although I have no doubt it is composed of stars." Dunlop probably glimpsed the many prominent star clusters in the spiral arms of M 83. William Lassell observed this galaxy from Malta. With a large aperture, he recognized it as a "three-branched spiral." Most historical observers skipped M 83 because of its southerly position.

Curtis summarized the photographic appearance in 1918 very appropriately with the words: "A bright and unusually beautiful spiral. A large number of almost stellar condensations in the rather open whorls of this fine object."

Astrophysics

Undoubtedly, M 83 is one of the most beautiful spiral galaxies in the whole Messier catalog. De Vaucouleurs characterized it as a transitional object between a barred spiral and a normal spiral galaxy, and he classified it as SAB(s)c. M 83 is seen nearly face-on, with an inclination to our line of sight of only 24°.

Many prominent blue young star clusters outline the spiral arms of M 83. By contrast, the core and the bar of the galaxy consist of fairly old yellowish stars. Hubble Space Telescope images led to the discovery of gigantic, young star clusters (super star clusters, SSCs) in the immediate vicinity of the galactic core, within a radius of only 3" to 7". Each cluster and SSC contains between 10,000 and about a million solar masses, and they are less than 10 million years old. In the same central region, two rings of dust were found in 1998, an inner one with a radius of 2.8", and an outer with 8.6"; the latter is not centered on the galaxy's nucleus. These two dust rings frame the star burst region between them.

The core of M 83 appears to be double (2.7", PA 243°), similar to the one in M 31, and each part contains about 130 million solar masses. It shows an emission line spectrum, which may hint at a super-massive central object.

The radial velocity of M 83 is +337 km/s, which led to early distance estimates, simply by using the Hubble law and ignoring any peculiar velocity, of 22 to 25 million light-years. By contrast, Thim et al. derived 14.5 million light-years. At that distance, M 83 has a relatively small diameter of 55,000 light-years. Studying Thim's data again in 2003, Bonanos and Stanek discovered 112 cepheids and even 2 eclipsing variables, the first outside the Local Group, which have helped to pin down the distance of M 83 to 14.7 million light-years with an even better accuracy. M 83, together with M 31, is now even regarded as a calibration tool for other distance measuring methods.

M 83 and Centaurus A (NGC 5139) form two sub-centers of a joint galaxy association. Galaxies considered to be gravitationally dominated by M 83 are, among others, NGC 5264, 5253, and 5408. NGC 5253, only 2° south of M 83 and with 1/10 of the mass of the latter, has been held responsible for the young, inner starburst ring and the deformation of the spiral arms of M 83. Dynamical studies suggest that both galaxies had a close encounter only some million years ago.

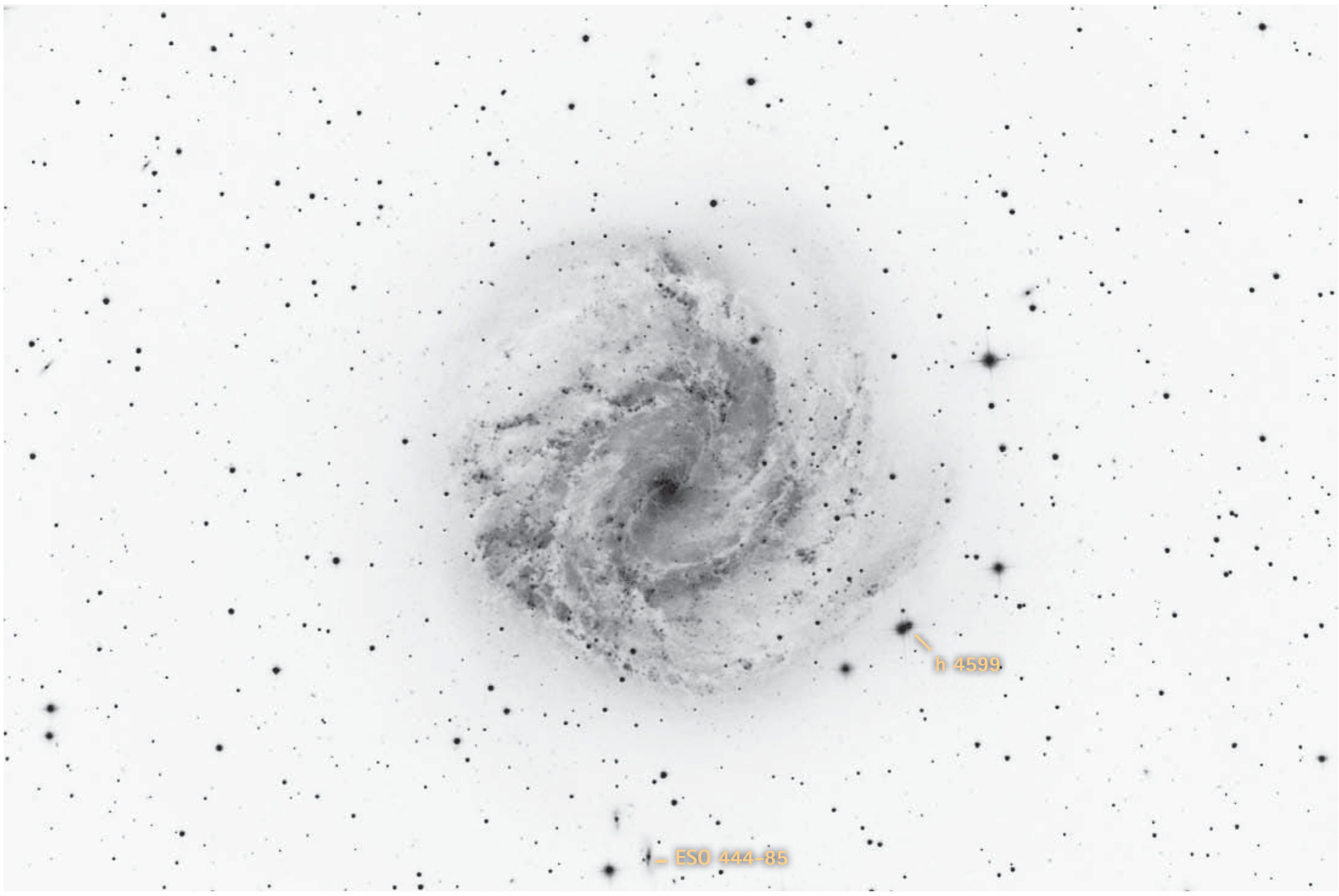
With a count of six, M 83 holds the supernova record among all Messier galaxies, and it is only just behind the seven observed events of NGC 6946, the galaxy with the largest number of supernovae discoveries. Interestingly, SN 1945B was discovered as late as 1990 by Liller on old photographic plates of the Bloemfontein Observatory. Its light curve could be obtained from photos until 1950. The supernova of 1968 was discovered by the well-known amateur astronomer Bennett, of South Africa, while searching for comets. It had a position only 5" west of the galaxy nucleus.

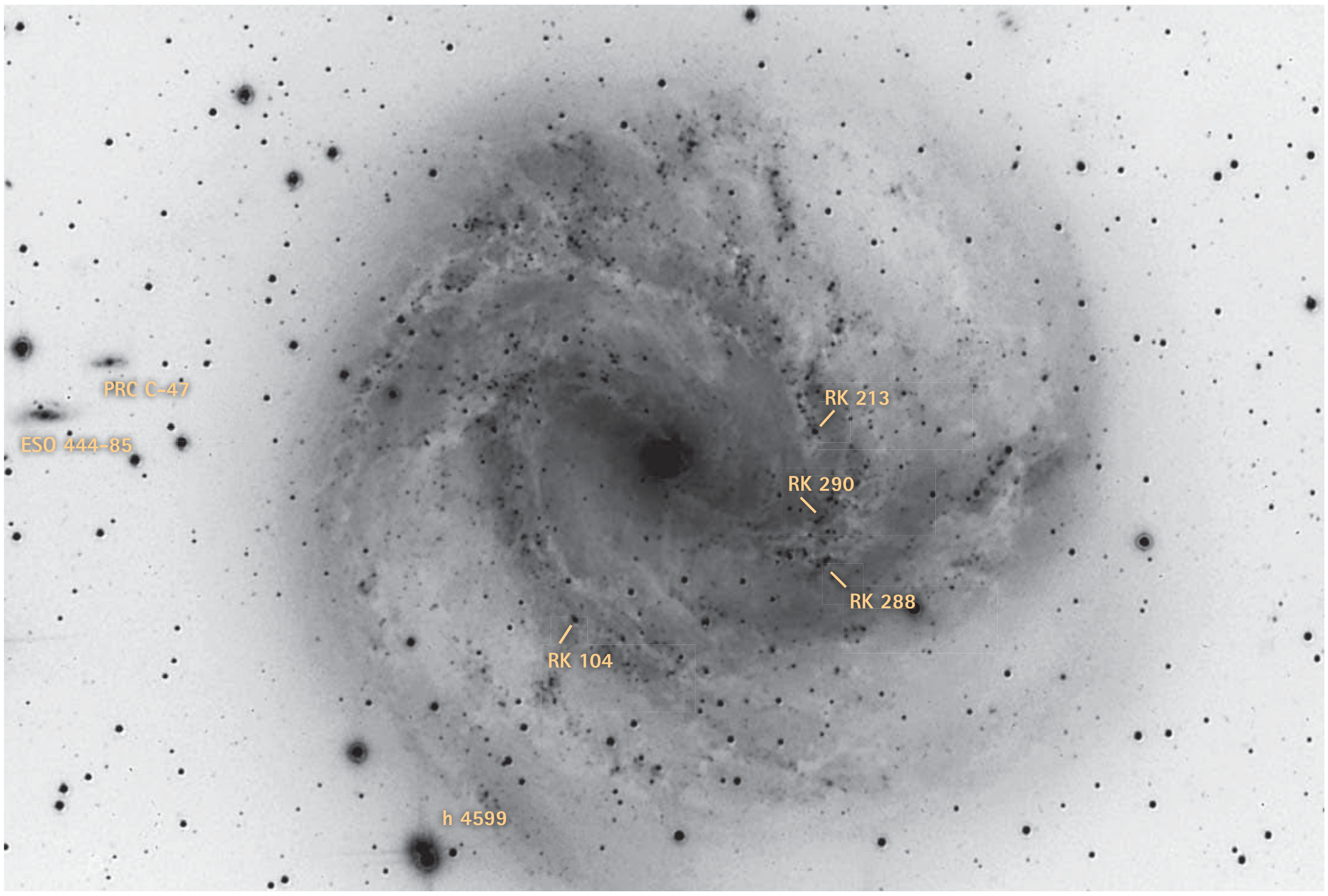
Supernovae in M 83

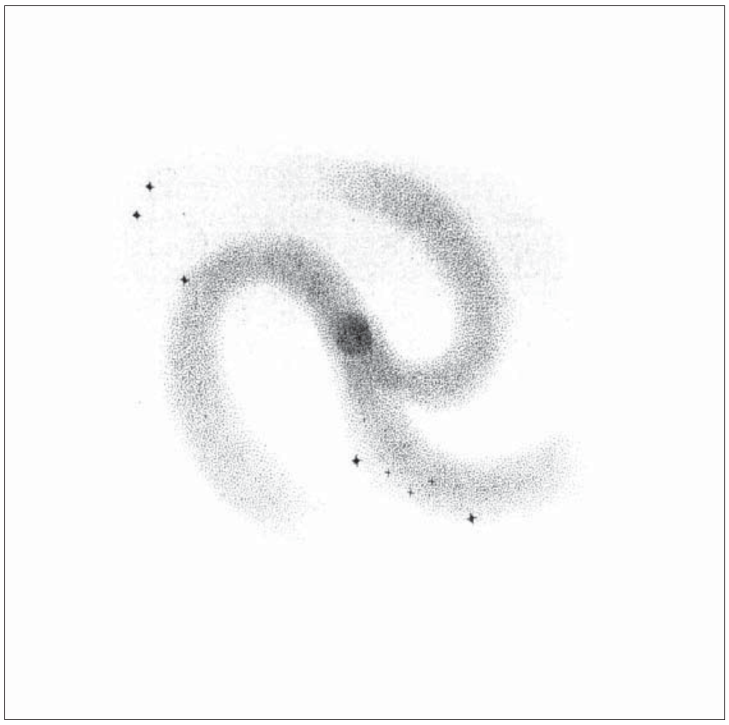
Designation	Date	Discoverer	Maximum magnitude
1923A	May 19th, 1923	Lampland	14.0pg
1945B	July 13th, 1945	Liller	14.2pg
1950B	March 15th, 1950	Haro	14.5pg
1957D	December 28th, 1957	Gates	15.0pg
1968L	July 17th, 1968	Bennett	11.9b
1983N	July 3rd, 1983	Evans	11.4b

M 83. This beautiful spiral is one of the brightest galaxies in our sky. Josef Pöpsel, Rainer Sparenberg.

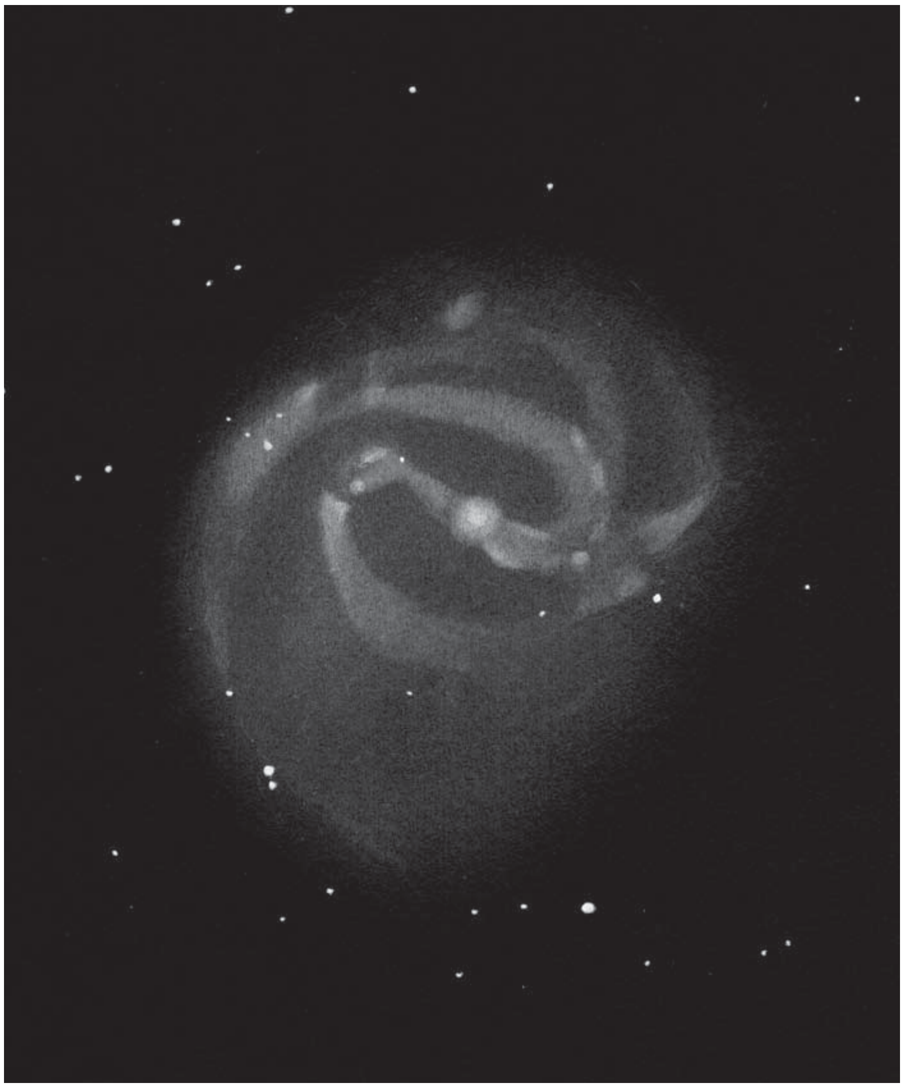
M 83. This galaxy is characterized by complex spiral arms full of star clusters and HII regions. Volker Wendel.


h 4599
ESO 444-85


PRC C-47
ESO 444-85
RK 213
RK 290
RK 288
RK 104
h 4599



M 83, historical drawing. William Lassell (1862).



M 83, drawing. 20-inch Newtonian. Ronald Stoyan.

Observation

M 83 may be regarded as one of the most splendid galaxies for visual observation, very rich in detail. However, observers from most of Europe and the northern USA cannot appreciate it as such. M 83 is thought to be one of the most difficult objects to observe in the Messier catalog, due to its very southerly declination. Often, there are only a few nights in April and May that would offer a successful observation.

While M 83 can be spotted with 10×50 binoculars without problem, it can remain just a pale patch of a few arcminutes size even in larger telescopes in less-than-ideal observing conditions.

On a good night, however, a 4.7-inch refractor shows a 30" core region, surrounded by a somewhat elongated (PA 60°) nebulous halo of 6.5' by 5'. Asymmetrical structures can be made out, indicative of spiral arms, between the center and an 11^{th}-magnitude star 3' southwest of the core, right on the major axis of the galaxy. With an aperture of 14 inches, a clearer view emerges: the round core expands into a bar to either side of the major axis. From the south, a dark structure touches the bar, east of the core. Spiral arms can be seen to begin at the western bar and to bend northward, likewise southward from the eastern bar end. Near the latter, there are two stars of magnitude 13.

A really impressive view of the structure of M 83, however, can only be obtained from a southern location. A 20-inch telescope in Namibia shows a large (10'×8', in PA 65°) galaxy with a small core in a 4'-long bar. From its southwest side, two spiral arms emerge, rich in structure. The inner one makes a close, nearly full turn around the northern side of the galaxy and fizzles out about 6' south of the core. The outer one features a remarkable right-angled bend. In the north, faint extensions link it with the inner arc. The southern spiral arm, which emerges from the northeastern side of the bar, is much shorter. Throughout the inner 5' of M 83, there are numerous knots. Two regions 2' east of the core respond well to the use of an [OIII] narrowband filter.

ESO 444-85, presumably a background galaxy, lies 8' east of the core of M 83. Furthermore, there is a bright star 5.5' southeast of the core, which is not shown on GSC computer-generated star charts. At high power, it turns out to be a nice double star of two components with magnitudes 10.4/11.2 separated by 10.4" in PA 215° (h 4599).

M 84

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 4374
Type	Galaxy
Class	S0
Distance	57.8 Mly (V2004) 51.5 Mly (PN, 2000) 62.2 Mly (SBF, 2000)
Size	110,000 ly
Constellation	Virgo
R.A.	12^{h} 25.1^{min}
Decl.	+12° 53'
Magnitude	9.1
Surface brightness	$21.2 mag/arcsec^2$
Apparent diameter	6,5'×5,6'
Discoverer	Messier, 1781

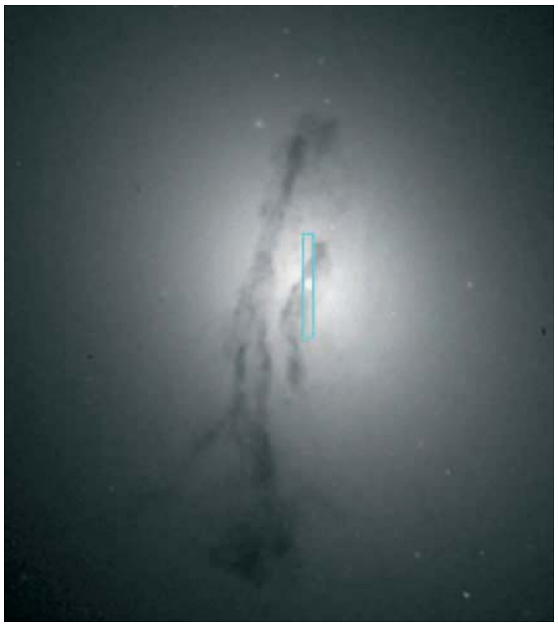
M 84, drawing. 14-inch Newtonian. Ronald Stoyan.

History

The night of the 18^{th} of March 1781 turned out to be a very productive observing session for Charles Messier. What was supposed to be a confirmation observation of M 85, just found by Méchain, led to the discovery of six new nebulae: M 84 to M 91. These nebulae have been cataloged in order of their right ascension, except for the last (by mistake). Messier described M 84 as a "nebula without star, its center is rather bright, surrounded by light nebulosity, its brightness and appearance resembles No. 59 and 60 of this catalog."

To John Herschel, M 84 looked "very bright, pretty large, round, pretty suddenly brighter in the middle, scarcely resolvable." D'Arrest's description is similar to the one he gave for M 86: "Luminous nucleus, round, gradually increasing brightness towards the center. The nucleus is equivalent to a 10^{th} or 11^{th} magnitude star."

Curtis wrote, after studying his deep exposures of M 84: "Very bright; round, 1' in diameter. Center large. No spiral structure discernible."



M 84. Dark structures cross the core of the galaxy. Hubble Space Telescope.

Astrophysics

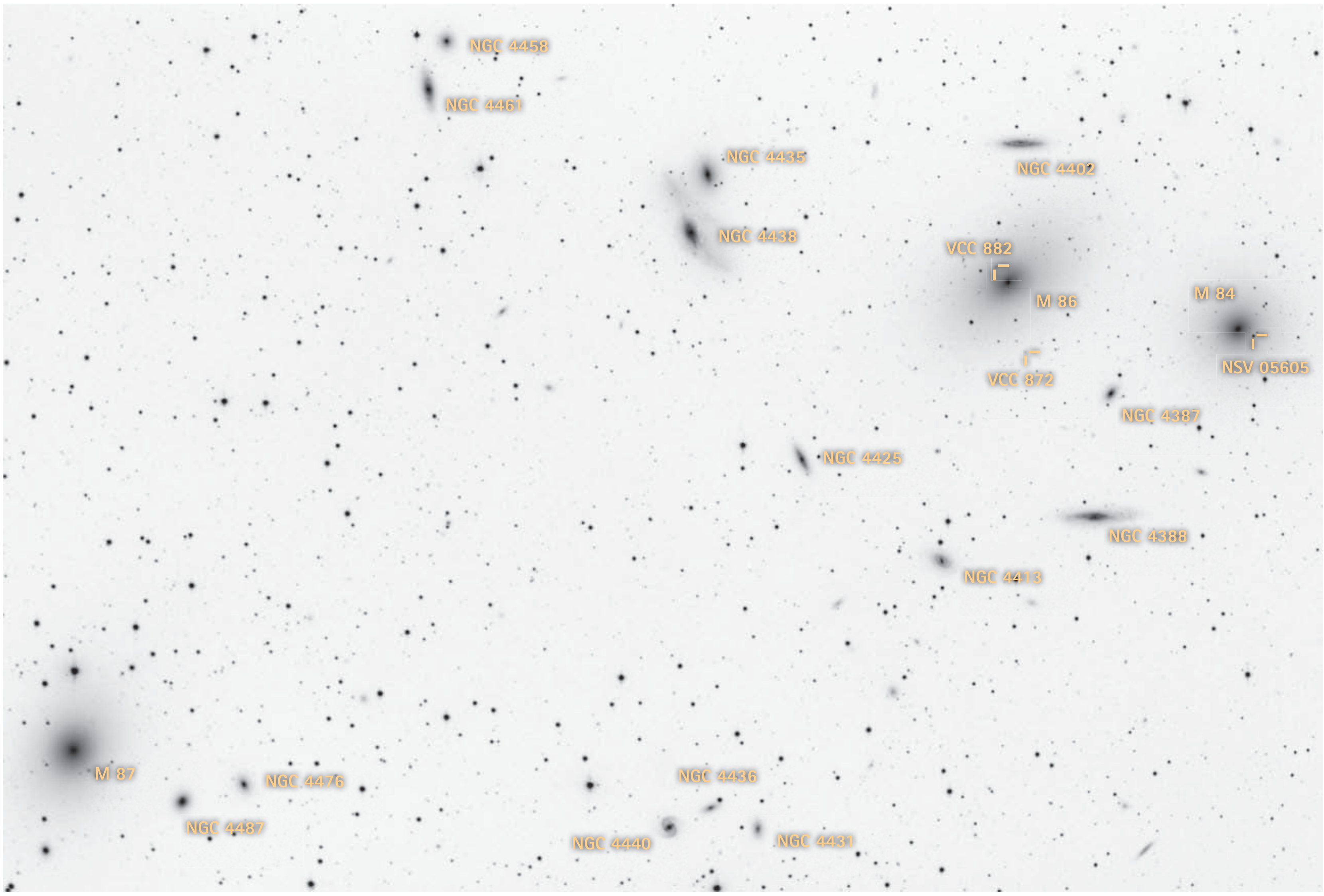
M 84 lies in the central region of the Virgo cluster of galaxies. Only 17' east is M 86, which is probably also physically close to M 84.

M 84 has often been classified as an elliptical galaxy of type E1, but there are speculations it could be a spindle-shaped or lenticular galaxy seen face-on, of type S0. Very similar to M 86, M 84 contains mainly old, yellow stars and a significant halo of an estimated 1775 globular clusters, of which 98 have already been identified.

In 1997, a study of the galaxy center with the Hubble Space Telescope produced evidence for a super-massive object of about 1.5 thousand million solar masses. The diameter of the surrounding accretion disk is only 50 light-years. Its rotational velocity suggests that the central object is, indeed, a black hole. Furthermore, the HST images show dark lanes superimposed on the central region over an 18"×10" field, orientated in an east-west direction. They can also be traced on good photos from the ground. The nucleus appears as a bright, elongated core (PA 72°), about 5" across.

In addition, M 84 has two jets leaving the core, similar to M 87 but on a much smaller scale. The jets are radio-bright and emit synchrotron radiation, which is generated when high-energy particles are forced into a spiralling motion by strong magnetic fields.

M 84 and M 86, with M 87. The central region of the Virgo cluster is populated with bright and faint galaxies. Cord Scholz.



Three supernovae have been found in M 84. SN 1957B was discovered on the 18th of May 1957, by Romano. The 13th-magnitude object was later discovered on photographs taken from Mount Palomar a month before the discovery. On the 13th of June 1980, Rosker found a supernova of 14th magnitude (SN 1980I), for which some authors dispute a physical connection with M 84. The most recent event occurred on the 3rd of December 1991 (SN 1991bg, 14th magnitude).

Only 1.4' northeast of the core of M 84 is the very faint galaxy VPC 379 (at 12h 24min 58.4s, 12° 54' 14"), which could be a small physical companion.

Observation

M 84 can be seen fairly easily with a pair of 50mm binoculars next to M 86. Small telescopes show it as a round patch without detail, looking like a twin of M 86.

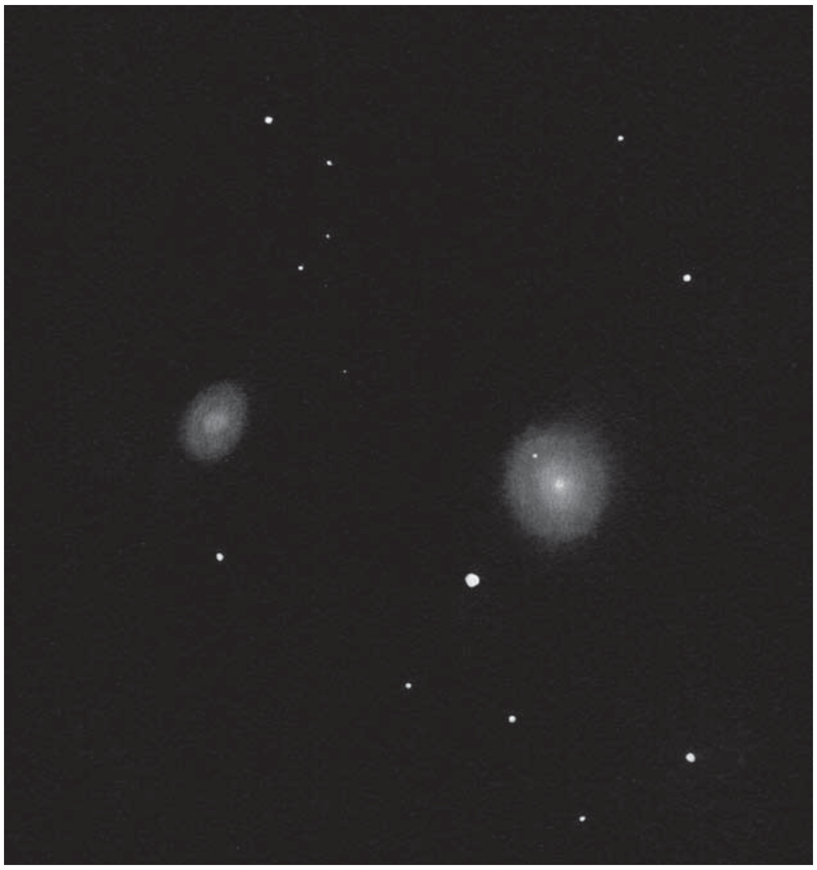
In a 4.7-inch refractor, the bright core of M 84 becomes visible, with an almost stellar appearance. The slightly oval galaxy has a visual diameter of 1.5' and appears a bit smaller than its close neighbor, M 86.

An aperture of 14 inches shows M 84 as a galaxy of 2'×1.5' size, slightly elongated in PA 130°. It can no longer be regarded as a twin of M 86 – M 84 is noticeably smaller and less elongated. The core region is bright but does not, by contrast to M 86, contain a star-like nucleus. The dark structures in front of the M 84 core region remain, unfortunately, invisible. The whole galaxy appears less homogeneous than its neighbor. A star is distinctly visible only 1.5' west of the core, just outside the visible galaxy. This is the variable NSV 05605, which changes between magnitudes 13.4 and 14.3.

Apart from many galaxies (see M 86), there are several quasars in the neighborhood of M 84. Particularly close are LBQS 1222+130, mag 18.7, 4' west, and QSO B1222+131, 2.5' south, which may be identified in deep photographs.

M 85

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 4382
Type	Galaxy
Class	S0
Distance	47.8 Mly (PN, 2000) 61.9 Mly (SBF, 2000)
Size	99,000 ly
Constellation	Coma
R.A.	$12^h\ 25.4^{min}$
Decl.	+18° 11'
Magnitude	9.1
Surface brightness	21.9mag/arcsec^2
Apparent diameter	7,1'×5,5'
Discoverer	Méchain, 1781



M 85, drawing. 14-inch Newtonian. Ronald Stoyan.

History

Pierre Méchain found M 85 on the 4th of March 1781. Soon after receiving that message, Messier observed the object on 18th of the same month. He saw a "nebula without star, very faint." John Herschel described M 85 as "Very bright; round; brighter toward the middle." Heinrich d'Arrest noticed the nearby galaxy, NGC 4394, and wrote: "large, bright, denser toward centre. Another nebula follows in close distance."

Curtis characterized M 85 as "Very bright oval, very slight traces of spiral structure."

Astrophysics

M 85's location is in the northern part of the Virgo galaxy cluster, and it is the northernmost Messier galaxy in it. Morphologically it strongly resembles M 84, but its estimated mass of 400 thousand million solar masses is a little less – though still making it a significant galaxy.

Usually, M 85 is classified as a lenticular, spindle-type S0 galaxy. However, very deep exposures show traces of spiral structure to the north and south of the core, which had already been noticed by Curtis. The spiral arms seem to be influenced by the small barred spiral NGC 4394, only 8' east, with which M 85 is in close interaction.

Another likely consequence of that interaction could be the relatively young stars in the core region of M 85. These are atypical for a spindle-type galaxy, which normally have strongly reduced star-formation rates. But McDermid showed in 2004 that this central region rotates against the rotational sense of the rest of M 85! Hubble Space Telescope images revealed two brightness peaks in the core region, which resemble the double core of M 31.

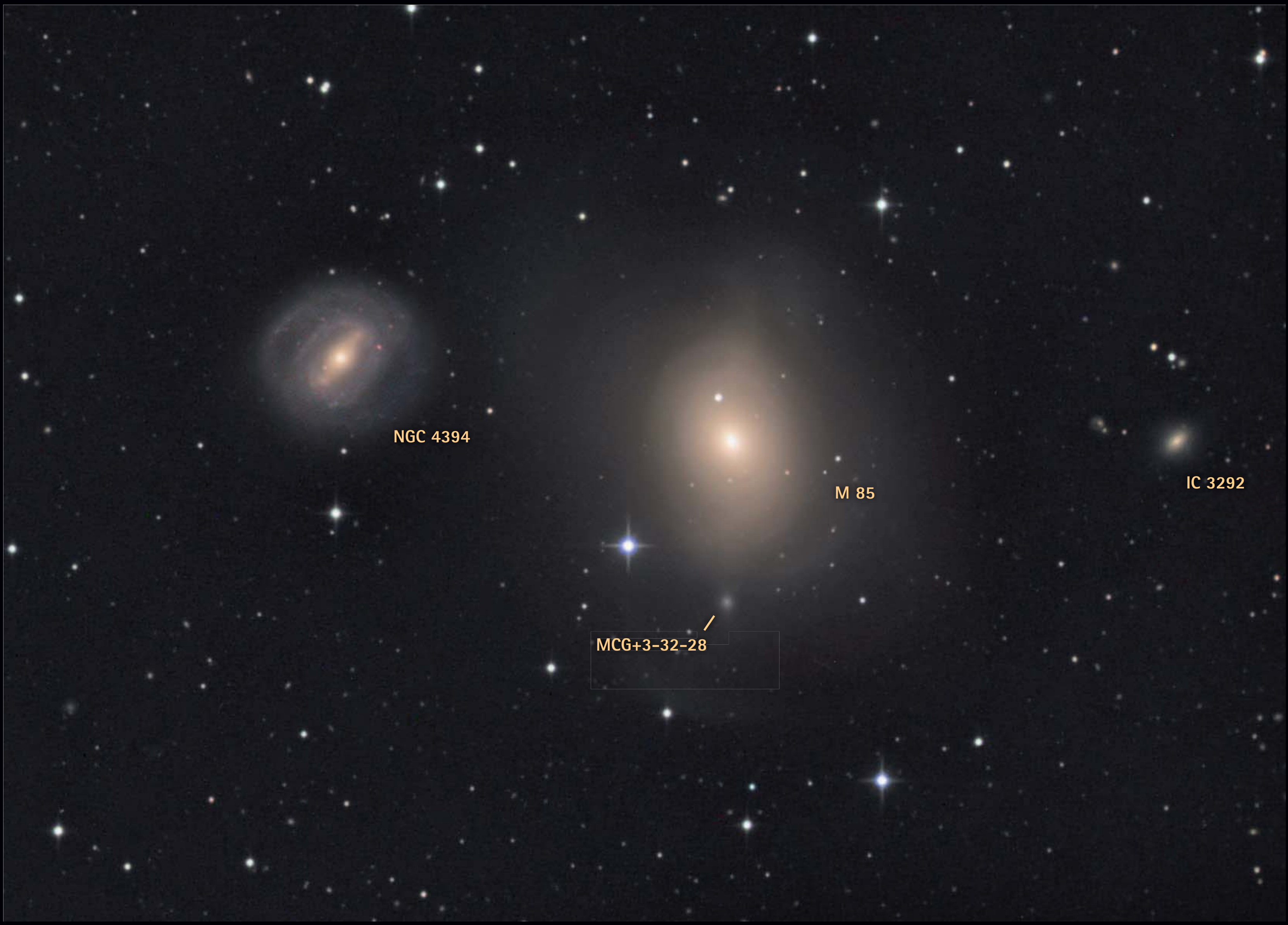
A total of 58 individual X-ray sources were found all over M 85. Most of them are supposedly X-ray binary stars. On the 20th of December 1960, a Supernova was discovered in M 85 (SN 1960R). It reached a magnitude of 11.7 and topped even the foreground star in the northern outskirts of the galaxy.

Observation

Even 10×50 binoculars show M 85 clearly. In a 2.5-inch refractor, it appears as a bright, oval nebula with a distinct, almost stellar core. With apertures of 3 inches and upwards, the companion galaxy NGC 4394 is visible, too.

To an observer with a 4.7-inch telescope, the almost star-like core becomes very obvious. It is surrounded by a 2'×1.5' oval halo. There is a bright star to the southeast, and another, faint 12.5-magnitude foreground star may, with some patience, be perceived just 50" north of the galaxy core. It has repeatedly been mistaken for a supernova. The galaxy NGC 4394 makes a pale patch of light, 7' to the east.

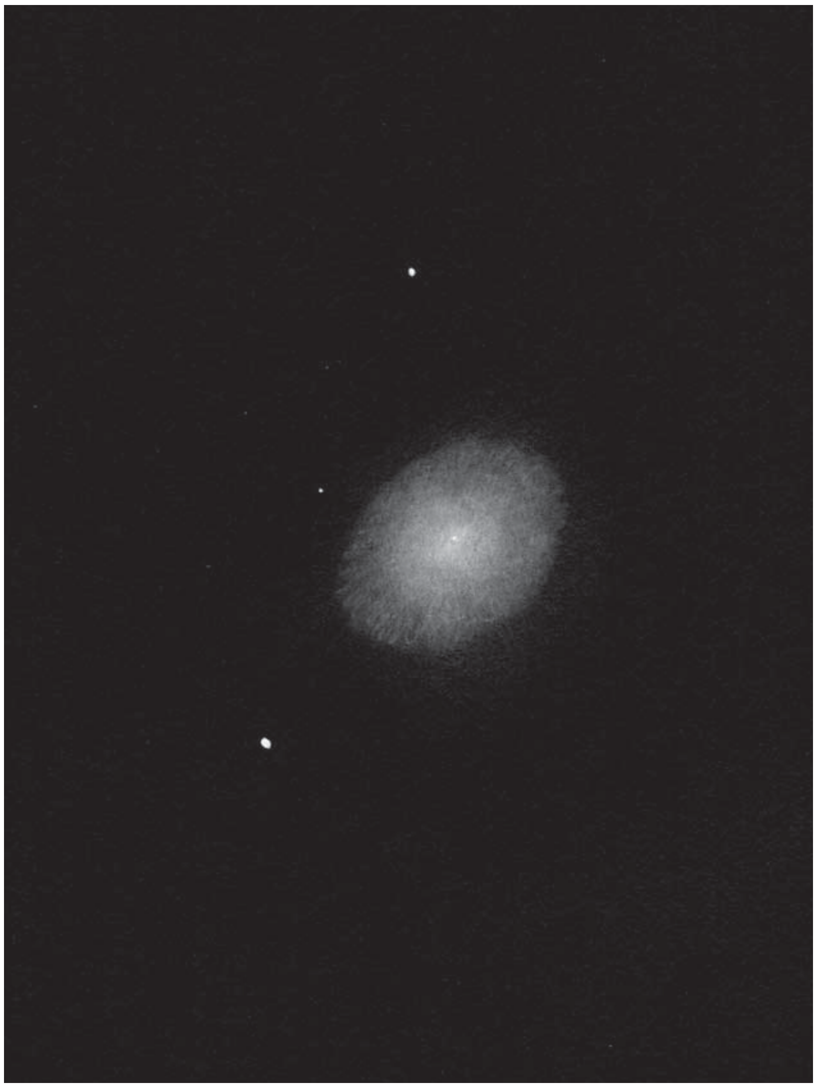
The visual impression of M 85 in a larger telescope has often been likened to that of an unresolved globular cluster. This is mainly due to the small, but not at all star-like, core 15" in diameter and the faint foreground star mentioned above. In a 14-inch telescope, the galaxy covers 3'×2' with moderate elongation in PA 35°. The same aperture shows NGC 4394 as a diffuse, oval nebula with a size of 1.5'×1' (PA 145°) and a non-stellar core. The other, much fainter companions – i.e., IC 3292, magnitude 15.5 and 8.5' west, and MCG+3-32-28, magnitude 17.0 and 3.5' south – remain invisible in the 14-inch Newtonian.



M 85 is interacting with its close neighbor galaxy NGC 4394. Stefan Heutz, Wolfgang Ries.

M 86

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 4406
Type	Galaxy
Class	E3
Distance	56.7 Mly (V2004) 52.4 Mly (PN, 2000) 60.2 Mly (SBF, 2000)
Size	147,000 ly
Constellation	Virgo
R.A.	$12^h\ 26.6^{min}$
Decl.	+12° 57'
Magnitude	8.9
Surface brightness	22.8mag/arcsec^2
Apparent diameter	8,9'×5,8'
Discoverer	Messier, 1781



M 86, drawing. 14-inch Newtonian. Ronald Stoyan.

History

Charles Messier discovered M 86 on the 18th of March 1781, together with its companion M 84. But because he ordered the galaxies discovered that night by right ascension, M 85 comes between. Messier described M 86 as a "Nebula without star, very near the nebula above, No. 84: their appearance is the same, and both appear in the same field of the refractor."

John Herschel saw M 86 as "Very bright; large; round; gradually brighter toward the middle where there is a nucleus; mottled." Heinrich d'Arrest noted: "Large, bright nebula, circular, brightness of nucleus equivalent to a star of 11th to 12th magnitude." Curtis described the photographic appearance in 1918 with the words: "Slightly oval, bright centre, which is not stellar in short exposures; no spiral structure discernible."

Astrophysics

M 86 is a little more distant than M 87 and lies near the back side of the Virgo cluster of galaxies. According to Kenney et al. (2007), it is the dominant galaxy in a sub-cluster merging with the rest of the main cluster. It forms a physical pair with M 84, but even modern measurements cannot agree on which of the two is nearer to us. Sanchis and colleagues (2004) see M 86 about one million light-years behind M 84.

M 86 is a giant galaxy of the elliptical type E3, or maybe S0. It may be considered a transitional object between elliptical and spindle-type galaxies. M 86 possesses an impressive halo of an estimated 3800 globular clusters, which is more than M 84 but still considerably less than M 87. 108 of these globular clusters have been identified and cataloged. The very small dwarf galaxy VCC 882, to the east, is a physical companion.

The radial velocity of M 86 has led to some confusion. The galaxy is approaching us at 227 km/s, although the Virgo cluster is receding at about 1100 km/s. This had at first given reason to doubt the cluster membership of M 86 and some authors suspected it to be a much nearer object. But today, a very large relative velocity of M 86 with respect to the Virgo cluster (over 1300 km/s) has been fully accepted. A close encounter with another galaxy can cause such an unusually large velocity. But most importantly, observational evidence for a large relative velocity came in 1976 from Forman and colleagues, later confirmed by Rangarajan in 1995: the gas of M 86 collides with the intracluster gas and is ripped off ("ram pressure stripping"). In addition, Elmegreen and colleagues (2000) observed that M 86 is also stripping interstellar matter from VCC 882; both galaxies are connected by a tail of gas and dust at least 90,000 light-years long.

M 86 is the starting point of a chain of galaxies, which has been named after the Armenian astronomer Markarian. Further members are NGC 4435, 4438, 4458, 4461, and 4473, to mention only the brightest examples. The end point is formed by M 88. This chain

M 86 and M 84. These two galaxies resemble each other, but only at first glance. Robert Gendler.

seems to be physically real in 3D space. Its western end approaches us, its eastern end recedes with twice the speed.

Observation

M 86 forms the northern center of the visually observable Virgo galaxy cluster. Even in small telescopes, every field of view contains up to half a dozen galaxies, which sometimes makes it hard to navigate.

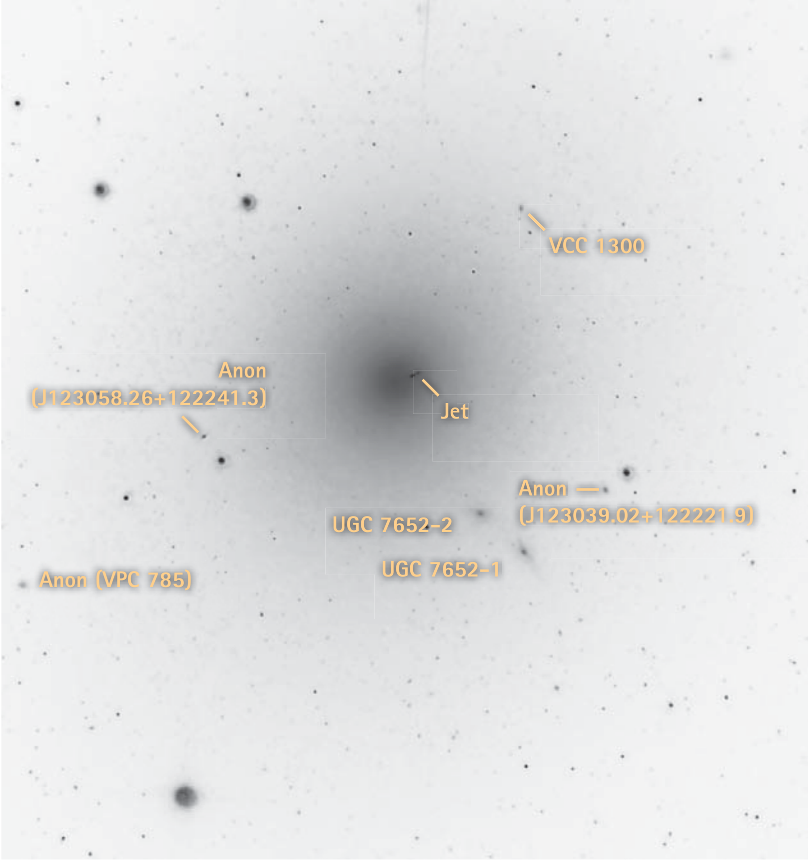
10×50 binoculars show M 86 merely as one of two nebulous spots, paired with M 84. In small telescopes, both galaxies remain diffuse, oval spots which do not differ from each other. An aperture of 4.7 inches shows M 86 to be a bit larger than its neighbor, with a diameter of 2', and slightly elongated in PA 30°. A bright, but not star-like, core dominates the galaxy.

A 14-inch telescope shows the differences between M 86 and M 84 more clearly. With a visual size of 4'×3', M 86 now appears almost twice as large and more noticeably elongated. In addition, its core region is much larger and hosts a faint, apparently stellar nucleus. 2' east of the galaxy center is a faint magnitude-14.6 star.

The field around M 86 is rich in fainter galaxies. Even in a 4.7-inch telescope, eight other galaxies appear in the same field of view: NGC 4402, 10' north; the pair 4435/4438, 23' east; 4387, 10' southwest; 4388, 17' south; and 4425, 20' southeast. But none of the immediate companions of M 86 can be seen with 14 inches of aperture. Really large telescopes and deep photographs may show VCC 882 (magnitude 16.7, 1.2' east) and VCC 872 (around 17th magnitude, 5' south), to name the nearest companions.

M 87

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 4486
Type	Galaxy
Class	E1
Distance	54.9 Mly (V2004) 47.6 Mly (PN, 2000) 57.2 Mly (SBF, 2000)
Size	132,000 ly
Constellation	Virgo
R.A.	12^{h} 30.8^{min}
Decl.	+12° 24'
Magnitude	8.6
Surface brightness	$21.6 mag/arcsec^{2}$
Apparent diameter	8,3'×6,6'
Discoverer	Messier, 1781



History

M 87 was discovered by Messier on the night of the 18th of March 1781, together with several other prominent members of the Virgo galaxy cluster. He described this object as a "Nebula without star. This nebula appears of the same brightness as the two nebulae No's. 84 & 86."

To John Herschel, M 87 looked "very bright, pretty large, round, much brighter in the middle where there is a distinct nucleus." Heinrich d'Arrest had a very similar perception of this galaxy: "very large and bright, circular, 85" in diameter; brighter to the middle, centre likens a star of 9th or 10th magnitude."

Heber Curtis studied in detail the first deep exposures of M 87. His 1918 description is the first to mention the famous jet near the galaxy's nucleus: "Exceedingly bright; No spiral structure is discernible. A curious straight ray lies in a gap in the nebulosity in PA 20°, apparently connected with the nucleus by a thin line of matter. The ray is brightest at its inner end, which is 11" from the nucleus."

Astrophysics

M 87 is the dominant, central galaxy of the Virgo cluster and a very interesting object in astrophysical terms. This elliptical giant galaxy (type E1 or E0) has a diameter of 132,000 light-years. That appears to be just a bit larger than the Milky Way, but its elliptical shape gives it a much larger volume. According to J.C. Brandt and R.G. Roosen, M 87 has a total mass of as much as 2700 thousand million Suns! It is probably the most massive galaxy we know. Its absolute magnitude is −22 (or 50 thousand million times the Sun's luminosity), at least.

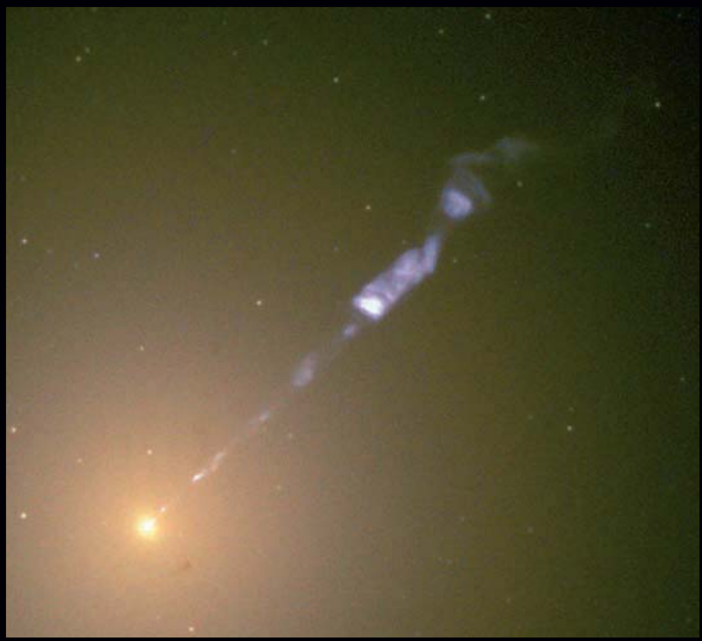
In very deep exposures with the 3.3m telescope of the Anglo-Australian Observatory, David Malin was able to detect an outermost diameter of M 87 of even 0.5°, which corresponds to a physical size of 500,000 light-years. In addition, he discovered a plume of stellar matter which reaches 300,000 light-years outwards, along the major galaxy axis in a southeastern direction. The faint outer parts of M 87 appear disrupted by interaction with other galaxies of the cluster. Quite possibly, they are formed by aggregation of material, gained from mergers with small, colliding companion galaxies.

M 87 possesses a large number of companion galaxies. Among the brightest are NGC 4476, 4478, 4486A, and 4486B. A gigantic halo of an estimated 16,000 (!) globular clusters surrounds M 87; 5700 of these have already been identified in observations. The brightest globular clusters reach 23rd magnitude.

A distance to M 87 of 55 million light-years has been measured by Whitmore and colleagues (1995) with the Hubble Space Telescope, using the globular cluster properties. Observations of planetary nebulae and mean surface brightness measures confirmed this value in 2000, and so did Sanchis et al. (2004), who published a distance of 54.5 million light-years.

M 87 has become famous for its central jet, 65,000 light-years (or 25") long, which was discovered by Curtis in 1918. Its light is continuous, bluish, and strongly polarized. Here, fast particles, near the speed of light, are interacting with strong magnetic fields and emit synchrotron radiation. In 1977, Halton C. Arp was able to resolve the jet into a series of small knots, in photographs made with the 5m Palomar telescope. In 1996, he discovered a second jet, leaving the nucleus in the opposite direction. For these unusual structures, Arp added M 87 to his catalog of peculiar galaxies as his 152nd object.

M 87 is the most massive and largest object in the Messier catalog and the central galaxy of the Virgo cluster. Bernd Flach-Wilken.



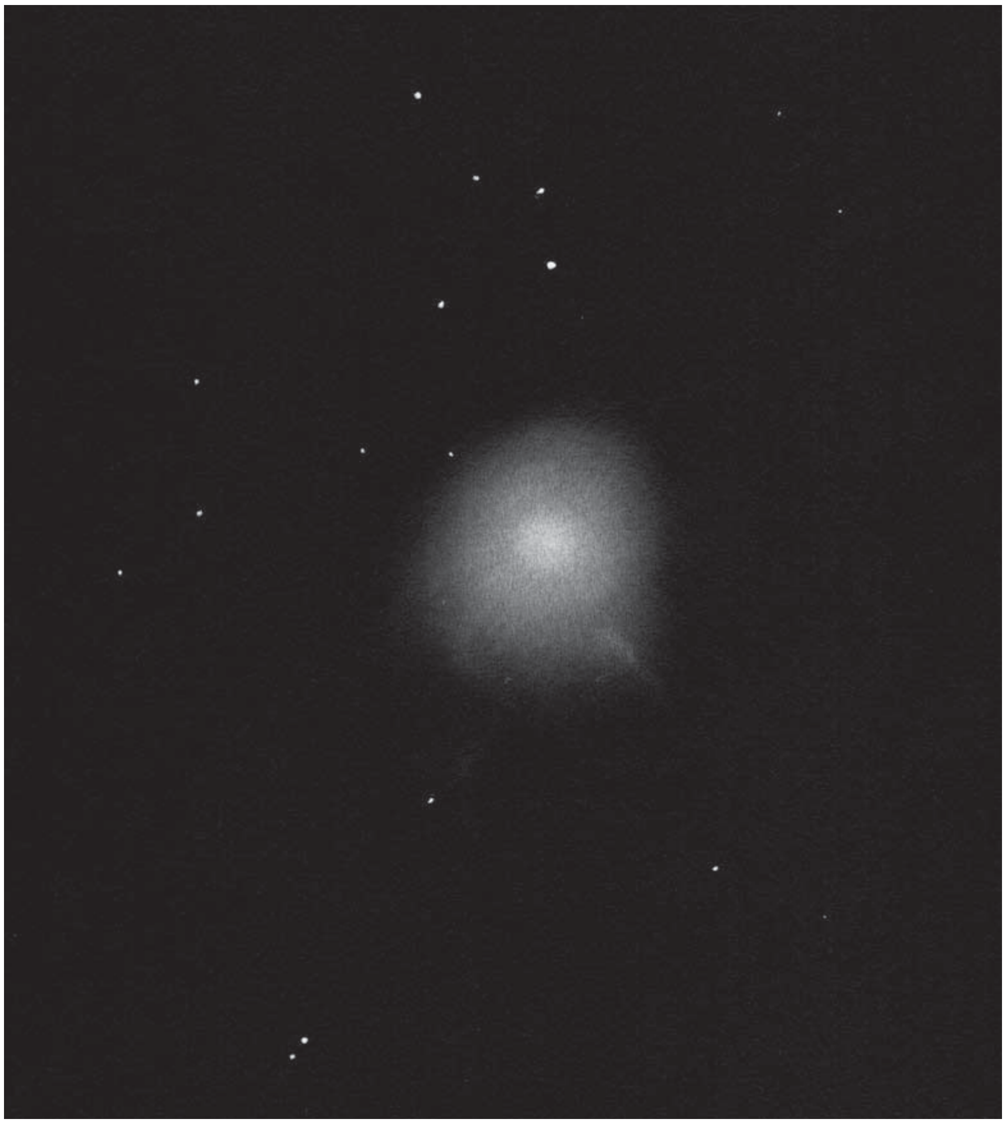
M 87. A jet, in which particles nearly reach the speed of light, is ejected by the galaxy core. Hubble Space Telescope.

Recent observations have shown that recurrent outbursts continually change the observed jet structures. In 2003, a newly formed knot, only 0.8" from the nucleus, was even brighter than the latter in visual light. The jet outflow is relativistic, and apparent velocities beyond the speed of light have been observed, caused by projection effects.

The jet originates from a central region only 60 light-years wide, but which contains a mass of 2 to 3 thousand million solar masses. An accretion disk surrounds, we may safely assume, a super-massive black hole. Tsvetanov et al. have registered brightness variations of about a factor of 2 within two and a half months, from the innermost region of 16 light-years diameter. Apart from these variations, there are other characteristics of the nucleus of M 87 which coincide well with those of BL Lacertae objects (see M 77) and LINER-type galaxy cores, including the relativistic jet. Atypical, however, is the relatively faint nucleus of M 87. That may be the result of the inclination of the M 87 core region by 30° to 35° from our line of sight, causing obstruction, while BL-Lac objects are seen fully face-on.

Furthermore, the nucleus of M 87 is one of the most luminous radio sources in our sky (Virgo A), which was discovered in 1954 by Baade and Minkowsky. Owen and colleagues (1999) discovered a radio halo around M 87 that spans 200,000 light-years and is heated by the jet. And we know that M 87 is a prominent X-ray source as well.

The single supernova observed so far in M 87 occurred in February 1919. It was only discovered three years later, by Balanowsky, on photographic plates. The maximum brightness must have been around magnitude 11.5. In 2002, Shara and Zurek reported the findings of over 400 novae in M 87. In 2004, special attention was attracted by an event, which most probably was a nova in one of the M 87 globular clusters – which would be only the second nova in a globular cluster since the first such sighting in 1860 (see M 80).



M 87, drawing. 14-inch Newtonian. Ronald Stoyan.

Observation

With a pair of 10×50 binoculars, M 87 is relatively well visible as a round, nebulous spot. Almost the same appearance is maintained in telescopes of all sizes.

With an aperture of 4.7 inches, M 87 appears noticeably brighter than the neighboring Messier galaxies, and with a visual size of 3' it is also one of the largest. An apparently stellar nucleus dominates the otherwise featureless galaxy.

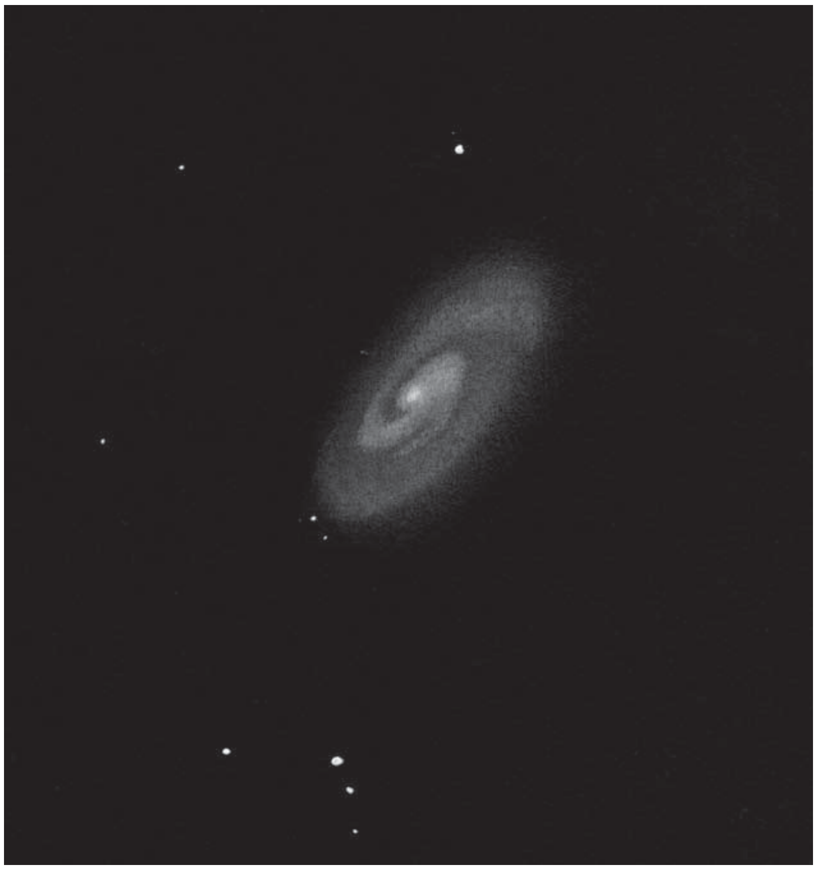
A 14-inch telescope shows a very small, but not star-like, core embedded in a round, bright central region of about 2' diameter. It is surrounded by a faint halo, which reaches a total visual size of 5'. The sparseness of the surrounding star field is quite remarkable. There are only two faint (15th-magnitude) stars near M 87, northeast of it.

The jet gains visibility only in telescopes with a relatively large aperture and magnifications over 300×. It then reaches a length of 20" in PA 290°, right off the core. The jet is sometimes confused with the 16th-magnitude galaxy pair UGC 7652-1/2, because it is aligned radially (in PA 215°). These galaxies are totally unrelated to the jet, but they are demanding visual targets for large telescopes, and can be detected with 14 inches of aperture under dark skies.

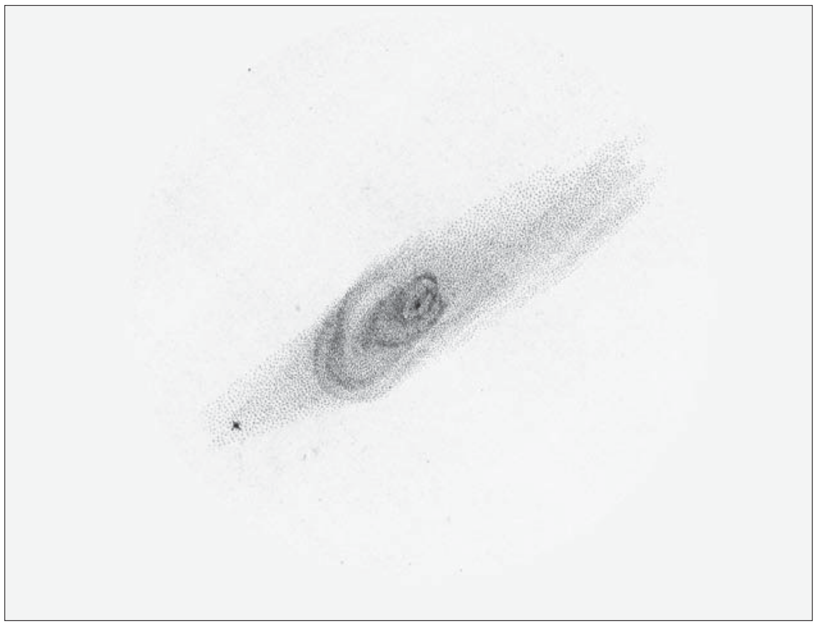
A galaxy of much better visibility is 11th-magnitude NGC 4478, 10' southwest of M 87. The foreground Mira variable CV Vir, 7' southeast of the galaxy core, can be seen only from time to time: its magnitude changes between 14.2 and 16.5 with a period of 146 days.

M 88

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 4501
Type	Galaxy
Class	Sc
Distance	57.2 Mly (V2002)
Size	115,000 ly
Constellation	Coma
R.A.	12^h 32.0^{min}
Decl.	+14° 25'
Magnitude	9.6
Surface brightness	21.5mag/arcsec^2
Apparent diameter	6,9'×3,7'
Discoverer	Messier, 1781



M 88, drawing. 14-inch Newtonian. Ronald Stoyan.



M 88, historical drawing. William Lassell (1862).

History

M 88 was discovered by Charles Messier on the 18th of March 1781 – the night he came across several important members of the Virgo cluster. He noted about this galaxy: “Nebula without star. Its light is one of the faintest and resembles No. 58 in the Virgin.”

William Herschel reported a companion, “another nebula, just following [east] M 88,” but that object (H II 118) was never found again. To John Herschel, M 88 looked “bright; very large; very much extended; 8’ long, 1’ broad. The northern half is brighter than the southern.” In 1850, Lord Rosse observed remarkable detail with his large telescope: “The whorls are rather close, and show numerous condensations.” Heinrich d’Arrest determined the visual extent of M 88 to 7’ by 1.5’.

Curtis described M 88 in 1918, based on deep photographs: “A bright, beautiful spiral. Bright, elongated nuclear region, including a bright, almost stellar nucleus. The whorls are rather close, and show numerous condensations.”

Astrophysics

M 88 is a member of the Virgo galaxy cluster and forms the endpoint of the Markarian galaxy chain, which starts with M 86. M 88 has been classified as a multiple spiral (type Sc), and it is inclined 58° to our line of sight. Its physical diameter is about 115,000 light-years, its mass is that of 250 thousand million Suns – similar to our Galaxy.

As with many other galaxies, emission lines are found in the spectrum of the 5” core of M 88. This hints at an accreting, super-massive central object and makes M 88 a Seyfert-2 galaxy (see M 77). At longer wavelengths, Japanese astronomers discovered two sub-centers of the galaxy core. The radial velocity of 2000 km/s (receding) of M 88 is much higher than the rest of the Virgo cluster, which means that this galaxy moves quite fast through the cluster.

On the 29th of May 1999, a supernova was discovered in M 88 at Lick Observatory. SN 1999cl reached a maximum magnitude of 13.4 on the 12th of June 1999, well observable with amateur telescopes.

M 88 is one of the most massive spiral galaxies in the Virgo cluster. Philipp Keller, Christian Fuchs.

As a type Ia supernova, it helped refine the distance to M 88 (see M 96).

7’ south of M 88 is the faint variable AL Comae, better known as “Rosino’s star,” named after its discoverer in 1961. Its light changes irregularly between 13th and 20th magnitude, sometimes within only a few days, bearing some similarity to U Geminorum stars.

Observation

In 10×50 binoculars, M 88 is just a tiny, faint spot. In a small telescope, it is seen as a nice oval nebula, right next (5’ north) to a pair of stars (magnitudes 11.5/12.5, 30” separation in PA 210°). Another 12th-magnitude star lies only 3.5’ north of the galaxy’s core.

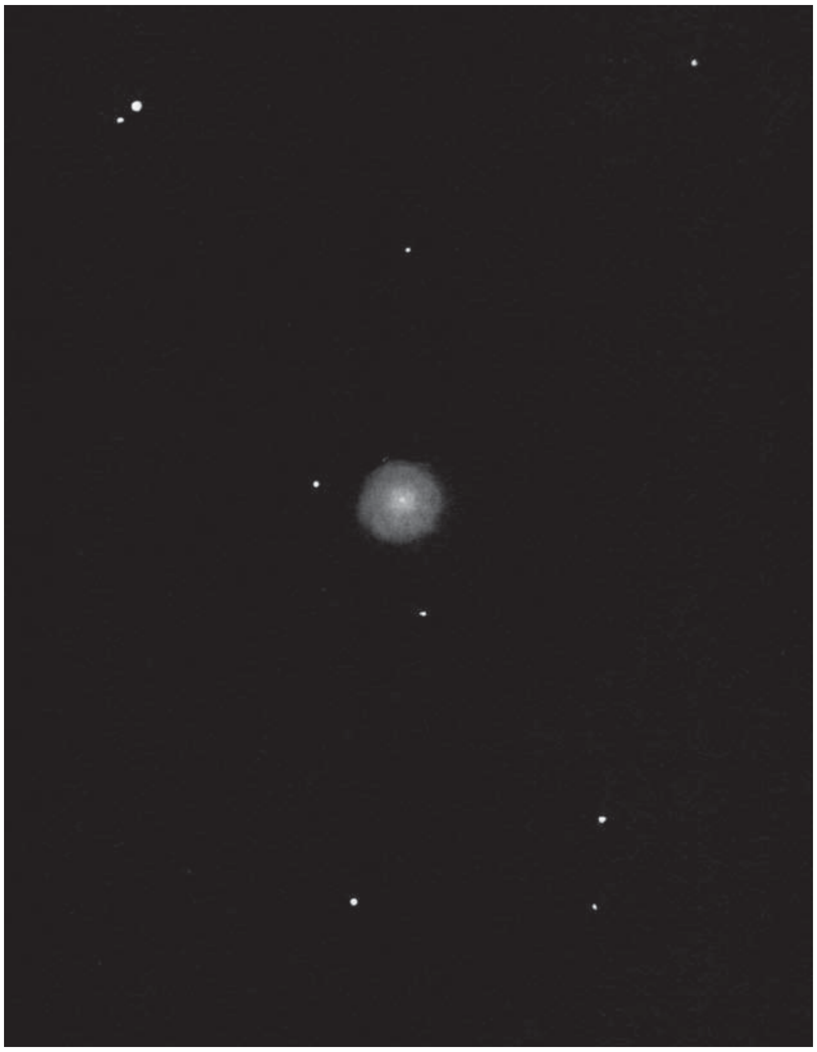
With an aperture of 4.7 inches, this is a respectable, bright and noticeably elongated (in PA 140°) galaxy. Its core appears small and bright, surrounded by a 3’×1.5’ halo.

In a 14-inch telescope, M 88 turns out to be one of the most beautiful spiral galaxies of the Virgo cluster. The core, which does not appear stellar but has a diameter of about 5”, resides in a 2’-long central region which stands out well from the rest of the galaxy. Dark dust lanes spiral into this brighter central region from the south and east. The spiral arms remain difficult to perceive and may be seen better in the southern part of M 88. The total visual extent reaches 5’×1.8’, while a length of as much as 6’ appears on photographs.

There is a faint pair of stars (magnitudes 13.8/14.2) at the southeast tip of the galaxy, with 15” separation in PA 200°. In fact, the fainter star is a double star itself, which can be recognized only with really large telescopes.

M 89

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 4552
Type	Galaxy
Class	E0
Distance	49.9 Mly (V2004) 65.2 Mly (2003) 51.6 Mly (2000)
Size	74,000 ly
Constellation	Virgo
R.A.	$12^h\ 36.7^{min}$
Decl.	+12° 33'
Magnitude	9.7
Surface brightness	21.2mag/arcsec^2
Apparent diameter	5,1'×4,7'
Discoverer	Messier, 1781



M 89, drawing. 14-inch Newtonian. Ronald Stoyan.

History

On the 18th of March 1781, Charles Messier discovered one more "nebula without star" in the Virgo galaxy cluster, M 89. In addition, he noted "Its light was extremely faint and rare, and it is not without trouble it is perceived." John Herschel described this rather insignificant Messier object as, nevertheless: "Pretty bright; pretty small; round; gradually much brighter toward the middle." D'Arrest characterized M 89 as "very pretty, round, 45" in diameter, considerably brighter in the centre. Brightness of the nucleus equivalent to a star of 10th magnitude."

Astrophysics

Like its neighbors in the sky, M 89 is a member of the Virgo galaxy cluster. Recent distance measurements still disagree a little: 50 to 65 million light-years have been published in 2003 and 2004. Even deep exposures show no structure in M 89, because it is a perfectly round elliptical galaxy (type E0).

In 1979, David Malin boosted interest in M 89 when he recorded three concentric shells in his very deep exposures, which are of 5', 7', and 10' diameter. This halo structure is most prominent north-northwest and south-southeast of the core. In a southwest direction, outside the halo, Malin recognized a 10.4' long jet, which corresponds to a physical length of 151,000 light-years at a distance of 50 million light-years. Malin suggested that this might be the remains of a small companion galaxy in the process of destruction, torn apart by tidal forces from M 89. A modern study suggests that this material was left behind after a close encounter with a (surviving) companion galaxy.

M 89 is known to have a super-massive central object of a thousand million solar masses, probably a black hole, from which we receive a characteristic emission line spectrum, emitted by heated, accreting mass. Hence, M 89 is considered a weak Seyfert galaxy (see M 77), or at least a LINER object (see M 81). The Hubble Space Telescope recorded strong UV brightness fluctuations of the nucleus in the 1990s, which could have been the signature of a ripped-apart star falling into the central black hole.

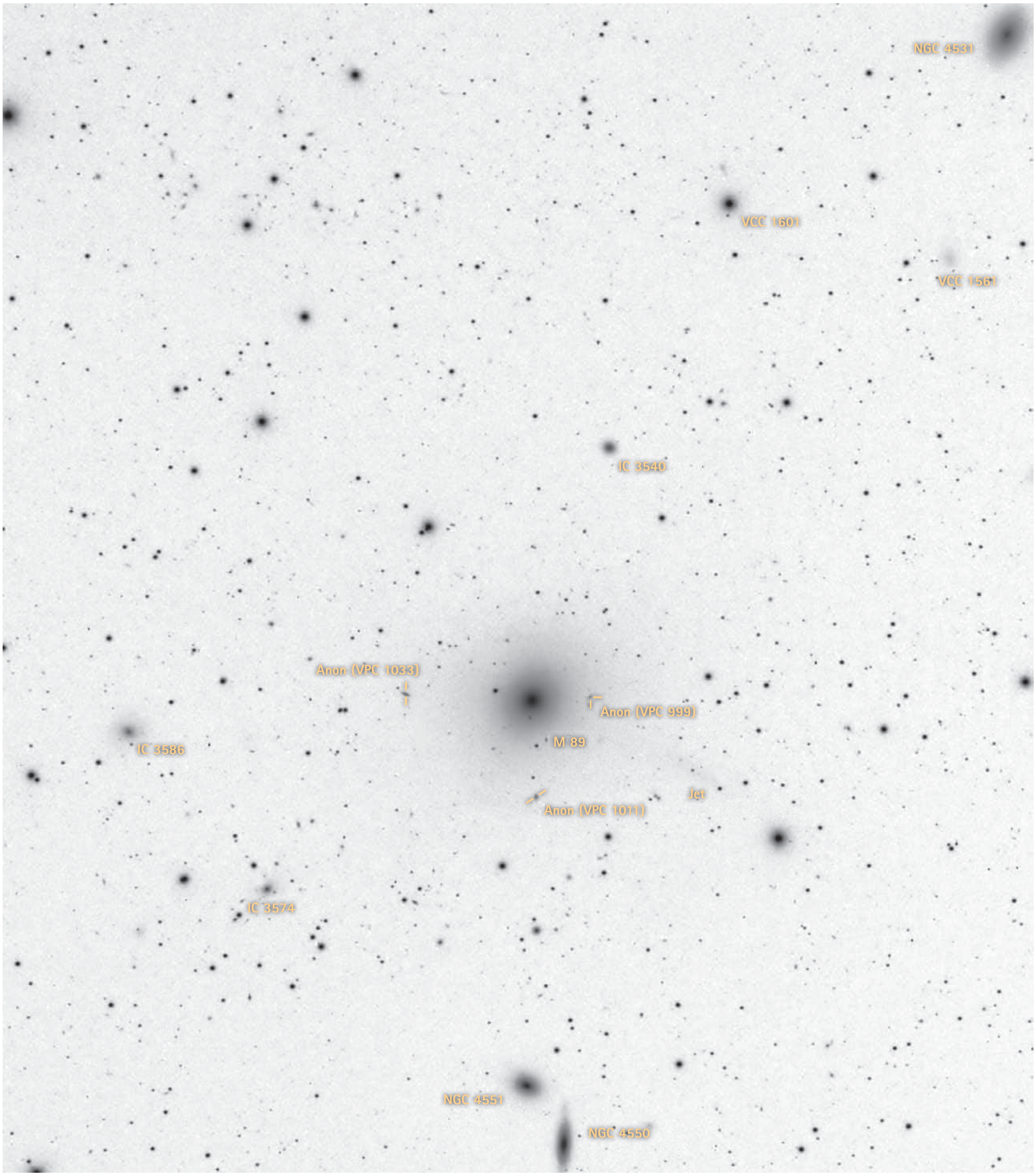
Observation

M 89 is one of the least spectacular Messier objects for visual observation. 10×50 binoculars show it close to the limit of perception. In small telescopes, it is seen as a small round nebula, much like Messier saw it more than 200 years ago. With an aperture of 4.7 inches, the visual size of M 89 reaches 1.5', and a structureless nebula surrounds a star-like nucleus.

With a 14-inch telescope, two nearby field stars are visible: a bright one (magnitude 12.8) in the east, and a faint one (magnitude 15.3) in the south. The round galaxy appears 1.5' across, with an obvious, bright, almost stellar nucleus. Three anonymous background objects, 3' west, 5' south, and 6' east, are too faint for the visual observer. The bright galaxy M 90 is only 40' away, to the south of M 89.

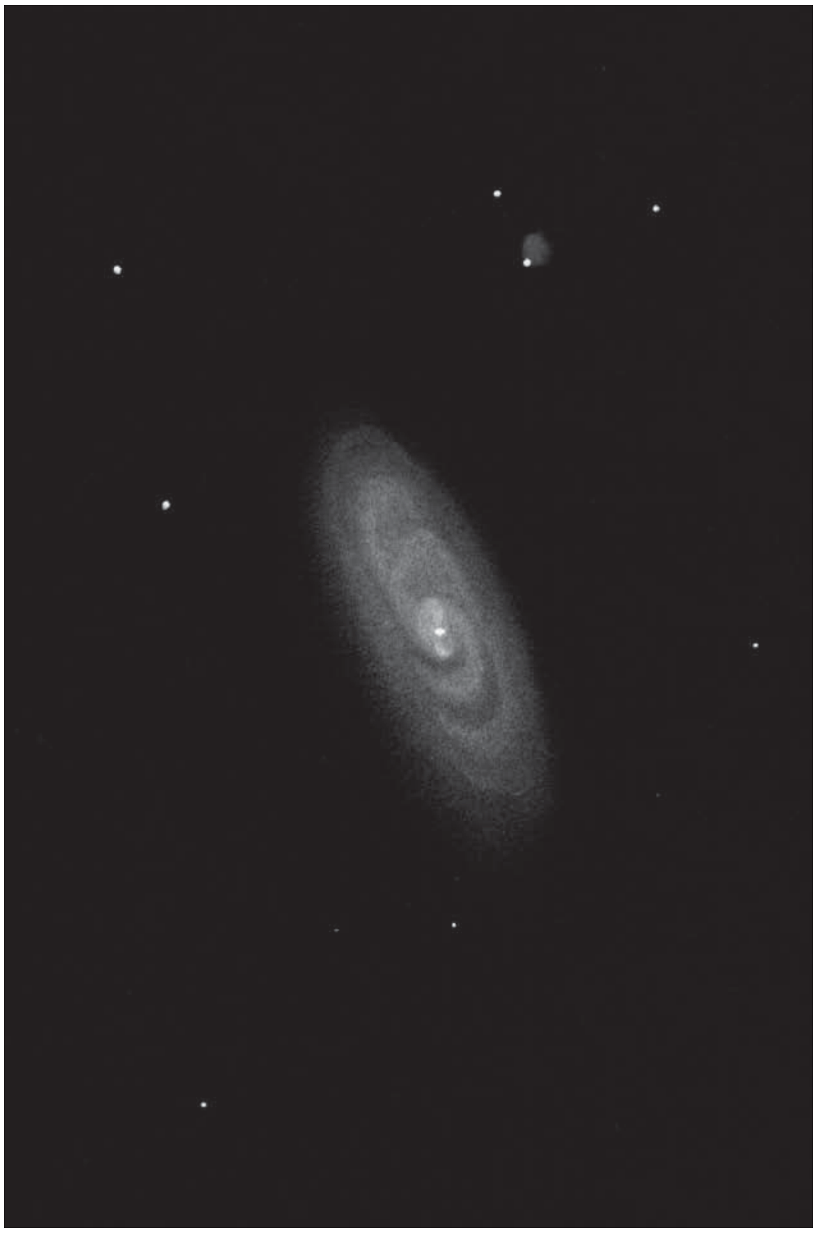
M 89 enjoys a rich neighborhood in the Virgo cluster. Stefan Seip.

M 89, an elliptical galaxy. Stefan Heutz, Wolfgang Ries.


NGC 4531
VCC 1601
VCC 1561
IC 3540
Anon (VPC 1033)
Anon (VPC 999)
IC 3586
M 89
Jet
Anon (VPC 1011)
IC 3574
NGC 4551
NGC 4550

M 90

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 4569
Type	Galaxy
Class	Sb
Distance	30.7 Mly (V2004, V2002) 65.3 Mly (2003)
Size	85,000 ly
Constellation	Virgo
R.A.	12^h 36.8^{min}
Decl.	+13° 10'
Magnitude	9.5
Surface brightness	22.5mag/arcsec^2
Apparent diameter	9,5'×4,4'
Discoverer	Messier, 1781



M 90, drawing. 14-inch Newtonian. Ronald Stoyan.

History

Charles Messier discovered M 90, along with several other galaxies of the Virgo cluster, on the 18th of March 1781, when he was looking for Méchain's find (M 85). His note about M 90 reads: "Nebula without star, its light as faint as the previous No. 89."

Around 1830, using much larger telescopes, John Herschel characterized this galaxy as "Pretty large; brighter toward the middle where there is a nucleus." Heinrich d'Arrest took a closer look in 1864 and gave this description: "Very large, elongated nebula, size 7'× 2', which surrounds a star of 12th magnitude. The nucleus appears as if a star was shining through fog here; it is closer to the preceding [western] part."

Astrophysics

M 90 is a pretty spiral galaxy in the direction of the Virgo cluster. Its western side is tilted towards us. On color photos, its tightly wound arms have a yellowish tint. This hints at an older stellar population and very little star formation in the recent past of this galaxy. However, shorter exposures of the bright central region of M 90 reveal a very different picture there. In this central starburst region, about two new stars are born every year.

The very star-like, bright nucleus, 1" in diameter or less, is an unusual feature of the morphology of M 90. In 1956, Humason even took it for a foreground star. Still in 1996, Keele held this as a possibility, when even the Hubble Space Telescope could not resolve it. But he concluded that the M 90 nucleus would most probably consist of an unusually bright cluster of A-type supergiants. The observed emission lines in the spectrum of the core have led several authors to classify it as a LINER object (see M 81), despite a lack of intensity. The alternative characterization as a low-luminosity AGN (see M 77) has been dropped, since X-ray observations have produced no evidence for it.

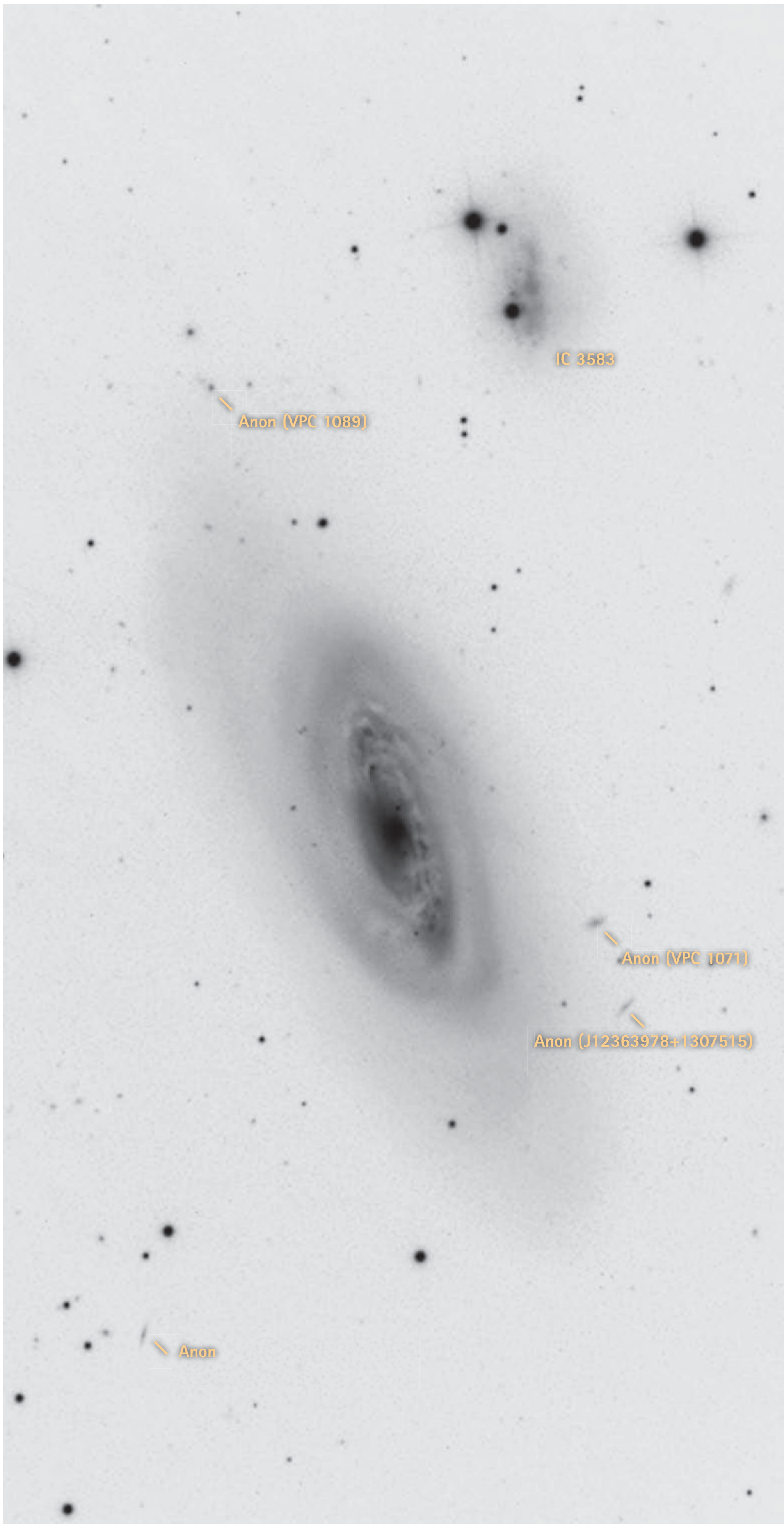
An ongoing very controversial issue is that of the galaxy's membership in the Virgo cluster of galaxies. The distance measures of M 90 disagree with each other more than for any galaxy in the Virgo cluster. In a study published in 2003, 65 million light-years had been concluded but, in 2002 and 2004, Spanish astronomers derived a three-dimensional picture of the cluster in which M 90 is a foreground galaxy, at a distance of only 30 million light-years. The distance measurement methods used may have been confused by the interaction of M 90 with its close companion galaxy IC 3583, as well as by an unusually low content of neutral hydrogen. Indirect evidence for a nearer location of M 90 comes from the fact that at the further distance of the Virgo cluster it would be considerably overproportioned. A size of 85,000 light-years at a distance of 30 million

M 90. The distance of this beautiful spiral galaxy is still being debated – perhaps it is not a member of the Virgo cluster. Robert Gendler.

light-years is much more in line with common spiral galaxy diameters.

M 90 approaches us with a velocity of 235 km/s, while the Virgo cluster recedes with about 1100 km/s. However, this is not an argument against cluster membership (see M 86). Close encounters can accelerate a galaxy considerably. Furthermore, a large relative velocity within the cluster would explain nicely how M 90 lost most of its neutral hydrogen. Vollmer et al. have suggested that M 90 may have crossed the denser cluster center about 300 million years ago.

M 90 and its companion IC 3583, only 6' north, have been cataloged as the interacting galaxy pair Arp 86. While there is a visible impact of this interaction on the small companion, hardly any traces of it can be detected in M 90, at least not in visible light. A halo of an estimated 1000 globular clusters surrounds M 90, but only 30 of these have actually been identified and catalogued.



Observation

For 10×50 binoculars, M 90 is an object close to the limit of perception. The galaxy remains a faint object in small telescopes. Apart from its inclined 1:3 orientation in PA 25° and a brighter nucleus, hardly any details can be made out.

With 4.7 inches aperture, the bright, apparently stellar nucleus is obvious. The oval galaxy has quite a low surface brightness but, with a visual size of 4'×1.5', it is one of the largest galaxies in the Virgo cluster.

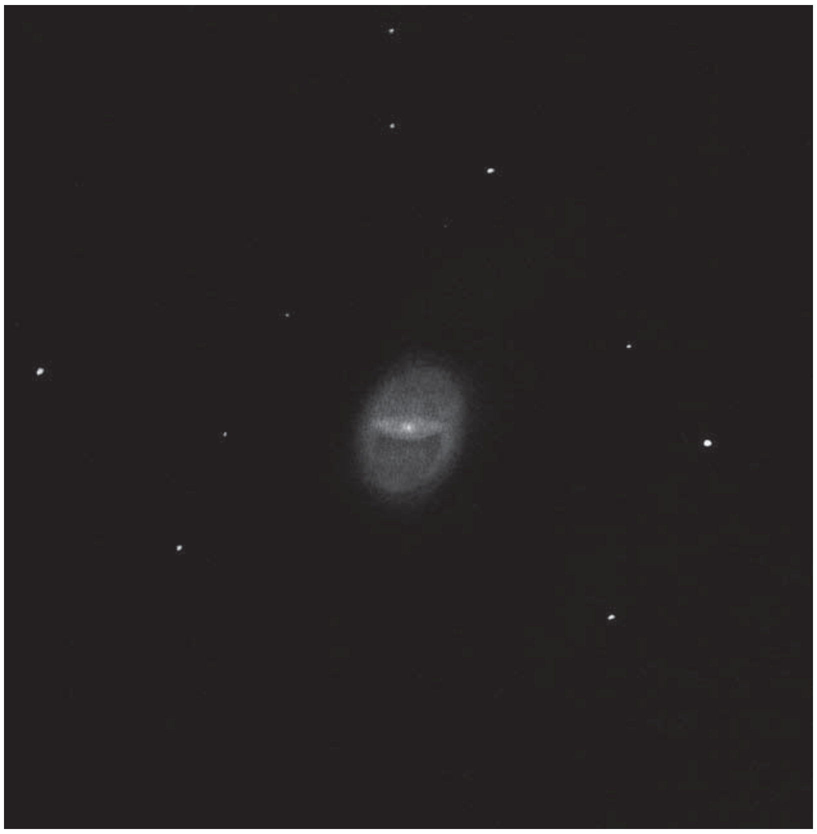
With a 14-inch telescope, its spiral structure is visible, even though it appears diffuse and of low contrast. The nucleus, which maintains a stellar appearance even under high magnification, looks like a 12th-magnitude foreground star. It is embedded in a 2'-long, brighter central region, which follows the orientation of the inclined galaxy. A dark dust lane spirals in from the east. In the diffuse oval halo of 6.5'×2.5', further spiral structure can be seen, but only vaguely. In general, the galaxy makes a pale impression.

To the north, IC 3583 appears faint and coreless in a 14-inch telescope. Several stars are in its immediate neighborhood, one of these (12th magnitude) is right at its southeastern edge.

Deep photographs show a few field stars in front of M 90 and countless faint galaxies in its background. The most distinct of these tiny Milky Ways lies only 2.5' southwest of the nucleus of M 90. It may just be in reach of visual observers with large telescopes.

M 91

Degree of difficulty	5 (of 5)
Minimum aperture	60mm
Designation	NGC 4548
Type	Galaxy
Class	SBb
Distance	52.9 Mly (H2000, V2002) 52.0 Mly (Cepheids, 1999)
Size	83,000 ly
Constellation	Coma
R.A.	12^h 35.4^{min}
Decl.	+14° 30'
Magnitude	10.1
Surface brightness	22.2mag/arcsec^2
Apparent diameter	5,4'×4,3'
Discoverer	Messier, 1781



M 91, drawing. 14-inch Newtonian. Ronald Stoyan.

History

For a long time, M 91 was one of the "missing Messier objects." On the 18th of March 1781, Charles Messier noted, upon his discovery observation: "Nebula without star, above the previous No. 90: its light is still fainter than those above." However, he made a mistake with the position of M 91. At the erroneous position, there isn't any object, which would have been bright enough for Messier's telescopes. In earlier attempts to explain M 91, it has been suggested that Messier came across a comet, or that he may have confused it with M 58. Even much too faint (magnitude 11.3) NGC 4571 was proposed as the mysterious M 91. It was W.C. Williams who finally resolved this mystery in 1969, when he reconstructed Messier's mistake in detail: instead of coming to M 91 from M 89, as he thought he would, he headed out from M 58. Hence, we now know that M 91 is, in fact, identical to NGC 4548.

That same galaxy was described by John Herschel as: "Pretty bright; round; brighter toward the middle; 60" [diameter]." Other historic observers, however, did not pay much attention to this seemingly anonymous object, because of its long-unknown identity with M 91.

Astrophysics

M 91 is a member of the Virgo cluster of galaxies. It is a nice example of a barred spiral, and deep exposures show a lot of dust in its main spiral arms; they become broader and split up, as they spread out. The bright bar is very conspicuous, and the nucleus was found to be of the LINER type (see M 81), by the emission lines in its spectrum.

M 91 is located in the densest part of the Virgo cluster and belongs to the subgroup around M 87. Its radial velocity of 486 km/s (receding) shows, compared to the Virgo cluster velocity of about 1100 km/s, that it has a considerable relative velocity (about 600 km/s) within the cluster. This may be reflected in the atypical (for a spiral galaxy) scarceness of neutral hydrogen in M 91 (see M 86). However, past close encounters with other cluster galaxies could also be blamed for that.

The distance to M 91 has been measured repeatedly by means of cepheid variables. Using the Hubble Space Telescope in 1999, this method gave a distance of 52 million light-years, which agrees very well with all more recent results.

Observation

M 91 is the most difficult of all Messier objects to observe visually. It is the only one which cannot be seen in 10×50 binoculars.

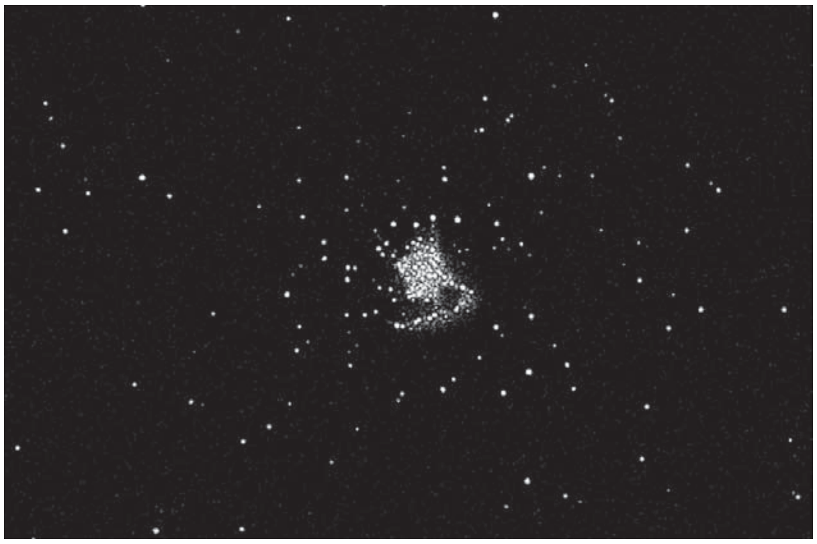
With small telescopes, or under inferior observing conditions, only the bright central part of the galaxy with its nucleus and bar is visible. It then appears elongated in PA 80°. A faint, round halo, made of the diffuse light of the spiral arms, appears only under very good conditions.

A 14-inch telescope shows an oval nebulosity of 3'×2' (PA 160°). A very bright, round core of 10" size marks the center of the distinctly visible galaxy bar, 1.5' long. In addition, a star-like nucleus appears in moments of good seeing. South of the bar, a distinctly darker area is seen, but the spiral arms remain very vague. Their true sense of "rotation" cannot be perceived.

M 91 is a classical barred spiral. Rainer Sparenberg, Volker Robering.

M 92

Degree of difficulty	2 (of 5)
Minimum aperture	Naked eye
Designation	NGC 6341
Type	Globular cluster
Class	IV
Distance	27,140 ly (CMD, 2000) 28,550 ly (RR Lyr, 1992)
Size	110 ly
Constellation	Hercules
R.A.	$17^h\ 17.1^{min}$
Decl.	+43° 8'
Magnitude	6.5
Surface brightness	–
Apparent diameter	14'
Discoverer	Bode, 1777



M 92, historical drawing. Léopold Trouvelot (1877).

History

M 92 is a discovery of Johann Elert Bode. He found this globular cluster on the 27th of December 1777, observing from Berlin. Messier, still unaware of Bode's observations, made an independent discovery in his very productive observing night of the 18th of March 1781. He saw a "Nebula, fine, conspicuous and of a great brightness. It does not contain any star; the center is clear and brilliant, surrounded by nebulosity, and resembles the nucleus of a big comet."

Two years later, William Herschel was able to resolve M 92 into many "very small stars." His son John later commented: "very bright; very large, well resolved; small stars." Admiral Smyth noticed the bright, hardly resolvable core of M 92. Lord Rosse, however, seems to have had too-high expectations, when he wrote: "It is possible that the core is spiral-shaped, there are dark mottles; the nucleus is, if at all, only vaguely resolvable."

In 1918, Curtis described M 92, according to his deep photographic exposures, as a "bright, unusually condensed globular cluster." About that same time, the first variable was discovered in M 92 by Woods (1916).

Astrophysics

At 27,000 light-years, M 92 is not much more distant than the famous M 13. But with only 400,000 solar masses and a diameter of 110 light-years, it is considerably smaller. A detailed photometric study by Buonanno et al. made this globular cluster a good calibration object for determining limiting magnitudes: M 92 contains 511 stars brighter than magnitude 17.5, 74 brighter than 16.5, and still 20 brighter than 14.5.

M 92 is an especially metal-poor globular cluster and hence has been considered one of their oldest examples. More recent stellar modeling gives this cluster an age of 14 thousand million years, close to the currently assumed age of the universe. Earlier stellar modeling of globular cluster stars was even in direct conflict with contemporary age values for the universe, then still based on a decelerating expansion.

M 92 contains 25 recognized variables, of which 17 are RR Lyrae type stars, typical for globular clusters, and seven are SX Pheonicis type stars. In addition, there is an eclipsing binary of the W Ursae Maioris type, which is rare in globular clusters. Apparently, the high star density with frequent, close stellar encounters in globular clusters disrupts many of their binaries. Recent studies even suggest this variable (V798 Herculis) is not even a physical member of M 92.

M 92 orbits the galactic center once every 200 million years. A large eccentricity leads it as close as 5000 light-years, and as far as 35,000 light-years from the galactic core. In about 14,000 years, as a result of the precession of the rotation axis of Earth, M 92 will be within 1° of the celestial north pole.

Observation

Under good mountain skies, M 92 can be seen with the naked eye by keen observers, who reach a visual limiting magnitude of 7.0. In a pair of binoculars, this object shows up as a bright, round nebulous patch.

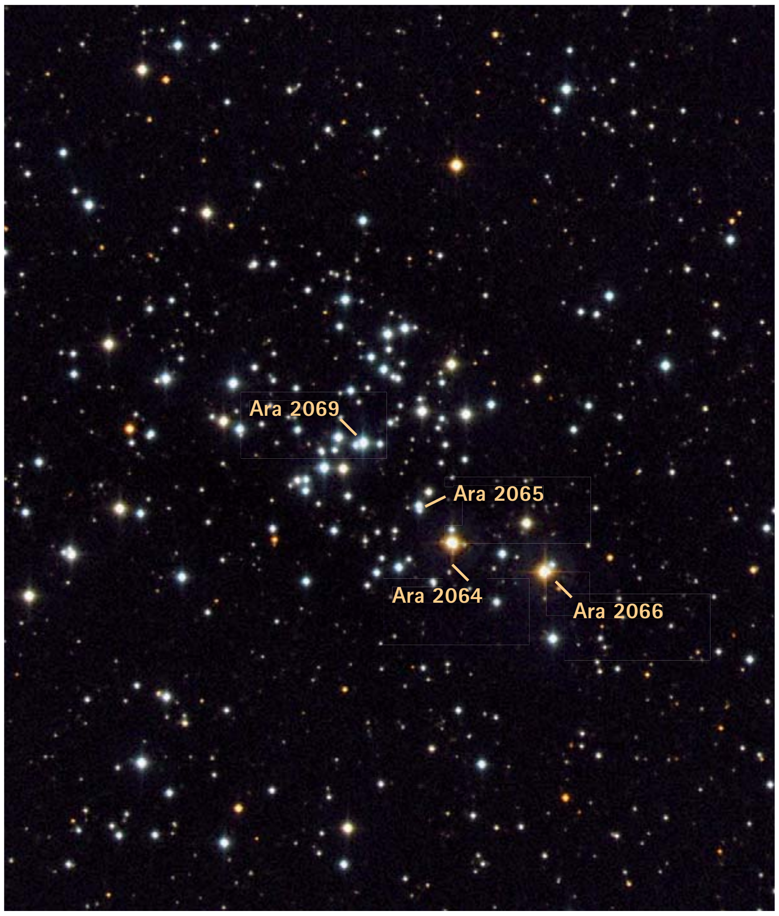
In a small telescope, the well-concentrated cluster center is seen as a nebulous core. Since the brightest individual stars reach magnitude 12.1, the cluster center appears mottled, or almost resolved from an aperture of 2.5 inches upwards. Resolution into individual stars in the outer regions of M 92 is provided even by telescopes of 3 to 4 inches.

But it takes 12 inches to fully resolve the whole cluster. This is due to a stronger degree of concentration than, for example, its brighter and famous neighbor M13. The amount of concentration is the main difference between these two globular clusters in Hercules. That has led to the popular but unjustified belief that M 92 would not be as beautiful. In fact, in a 14-inch telescope, M 92 reaches two-thirds of the visual extent of M 13. Its bright core resembles that of M 5 and appears to be split unevenly, from northwest to southeast, by a dark line. But unlike M 5 or M 13, no marked star chains are seen in M 92.

M 92 has less mass than M 13, but its center is more compact. Stefan Binnewies.

M 93

Degree of difficulty	3 (of 5)
Minimum aperture	30mm
Designation	NGC 2447
Type	Open cluster
Class	I3r
Distance	3380 ly (K2005) 3260 ly (2005) 3450 ly (2000)
Size	23 ly
Constellation	Puppis
R.A.	$7^h\ 44.5^{min}$
Decl.	–23° 51'
Magnitude	6.2
Surface brightness	–
Apparent diameter	24'
Discoverer	Messier, 1781



The stars of M 93 include two blue supergiants and eight red giants. Stefan Heutz, Wolfgang Ries.

History

M 93 is the last object in his catalog that Messier discovered by himself. He did so on the 20th of March 1781, and noted: "Cluster of small stars, without nebulosity." Thereafter, hardly any attention was paid to this open cluster by other historic observers – obviously, its very southern, low position in the sky is to blame. There is a single reported observation of this object, by William Smyth, whom it reminded of a starfish.

Astrophysics

Looking in the direction of M 93, our view spans a long part of the approaching Orion spiral arm. This open cluster is located on its far side, 3380 light-years from us, and it is very close to the galactic plane.

Bonatto and Birca measured a total cluster diameter of 23 light-years and a core diameter of 2.3 light-years. The total mass is an estimated 1700 solar masses.

The brightest cluster stars, which reach magnitude 8.1, are blue supergiants of spectral type B9 but, in addition, M 93 contains eight red giants. This has led to an age estimate for this galactic cluster of 400 million years.

Observation

From the northern latitudes of the USA, Canada, and Europe, naked-eye sightings of M 93 seem just out of reach. But observers living further south, like Walter Scott Houston, have repeatedly pointed out that this is possible.

In 10×50 binoculars, a bright but small cluster is seen. The central region of M 93 is perceived as an elongated (in the east-west direction) knot, which forms a western tip, and which is surrounded by a halo of fainter stars. A small telescope shows about 50 stars, which are tightly grouped in a pattern of triples. Like the 'starfish' of Smyth, the view of this cluster has inspired the imagination of many observers. Some have felt reminded of a butterfly or a spider. Two orange stars lie in the southwest region, on the tip of the triangle. These are the two brightest red giants of the cluster.

An aperture of 14 inches shows over 100 stars, but also the very rich stellar background of the Milky Way. This takes away the impression of a rich cluster, as given by smaller optics. Four double stars of the catalog of Aravamudan have been found in M 93, including the brightest cluster star, Ara 2066:

Double stars in M 93

Designation	Magnitudes	Separation	PA
Ara 2069	10.1/10.1	11.0"	180°
Ara 2066	9.0/10.8	9.9"	62°
Ara 2064	9.1/11.7	13.1"	2°
Ara 2065	9.5/10.1	0.7"	1°

M 94

Degree of difficulty	3 (of 5)
Minimum aperture	30mm
Designation	NGC 4736
Type	Galaxy
Class	Sb
Distance	17.3 Mly (2003) 13.7 Mly (2000)
Size	56,000 ly
Constellation	Canes Venatici
R.A.	12^h 50.9^{min}
Decl.	+41° 7'
Magnitude	8.2
Surface brightness	22.6mag/arcsec^2
Apparent diameter	11.2'×9.1'
Discoverer	Méchain, 1781

History

M 94 was discovered by Pierre Méchain, on the 22nd of March 1781. Quickly informed by Méchain, Messier observed it only two nights later. His note of the 24th of March reads: "Nebula without star, its center is brilliant, the nebulosity slightly diffuse. It resembles the nebula which is below the Hare, No. 79: but this one is finer and more brilliant."

Smyth characterized M 94 as a "fine pale-white object, with evident symptoms of being a compressed cluster of small stars." John Herschel, too, got a bit deceived by the mottled, visual appearance of this galaxy, as we read at the end of his note: "Very bright; very suddenly much brighter toward the middle; 4' diameter. Not resolved but resolvable."

Lord Rosse pointed his giant telescope to M 94 in 1855. He reported some remarkable detail: "A dark ring surrounds the nucleus, followed by a bright ring outside. This ring is not closed but disrupted and mottled; hence, it probably is a spiral." D'Arrest's impression of M 94 was less accurate: "Very pretty, an almost circular disk with a very bright core, similar to a star of 8th or 9th magnitude, surrounded by clear, extended nebulosity."

Only photography proved Lord Rosse and his observation right, and clearly showed the spiral structure of M 94. Curtis described it as: "A beautiful object. From the very bright, large nucleus spring many bright, closely packed whorls. These inner whorls show many stellar condensations, whose sharpness and proximity to the nucleus would seem to make this one of the most favorable examples known for the investigation of motions in spirals." Only later would it become clear that extragalactic distances are too large to allow proper motions in other galaxies observed directly.

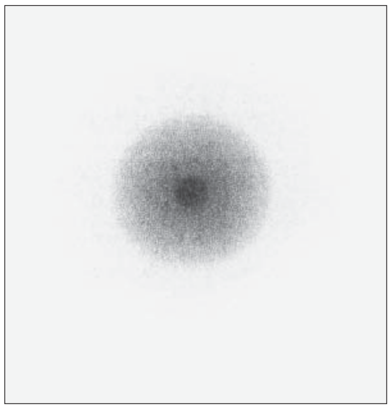
Astrophysics

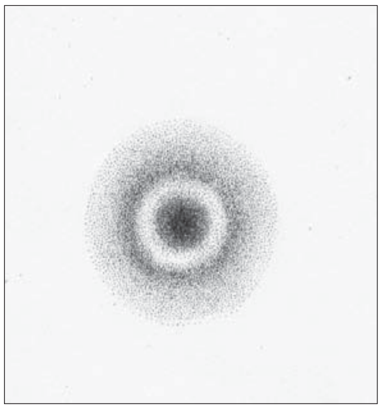
The remarkable galaxy M 94 is only 17 million light-years away. It is probably a member of the M 106 galaxy group, but some authors count it in with the CVn I cloud of galaxies with M 64. M 94 is a modest galaxy, it has a diameter of 56,000 light-years and contains 60 thousand million solar masses.

M 94 is a so-called "starburst-galaxy" (see M 82). In certain regions, we see the simultaneous formation of many new stars. This process is triggered by density waves, which compress interstellar matter enough to collapse into protostars. In M 94, the main starburst region has the shape of a ring of 1.1' diameter and 10" thickness. Such a structure is the result of a Lindblad resonance of the density waves with the local rotation velocity of the galaxy.

The central region consists, by contrast, of very old, reddish stars. Its age has been estimated at 10 thousand million years. Again, outside the starburst ring, at 2' to 4' from the galaxy's nucleus, old stars dominate. The outer edge is outlined by a ring, 7' in diameter, with weak star formation. In addition, in very deep exposures with the Mount Palomar 48-inch telescope, a very faint outermost ring with a diameter of 15' was found. Hence, this galaxy resembles an onion with four layers. M 94 is a rare case of a galaxy with two simultaneous waves of star formation.

In 1995, Möllenhoff and colleagues found traces of a 21" long bar in PA 28°, inside the bright inner ring, with some deviation from the major axis in PA 90°. The nucleus is of the LINER type (see M 81) and hosts a strong X-ray source. Between the bar and the bright ring, photos show some spiral structure, which has been classified as (R) Sab(s), (R)SA(r)ab, or RSab(r).





M 94, historical drawings. John Herschel (before 1833), William Lassell (1862).

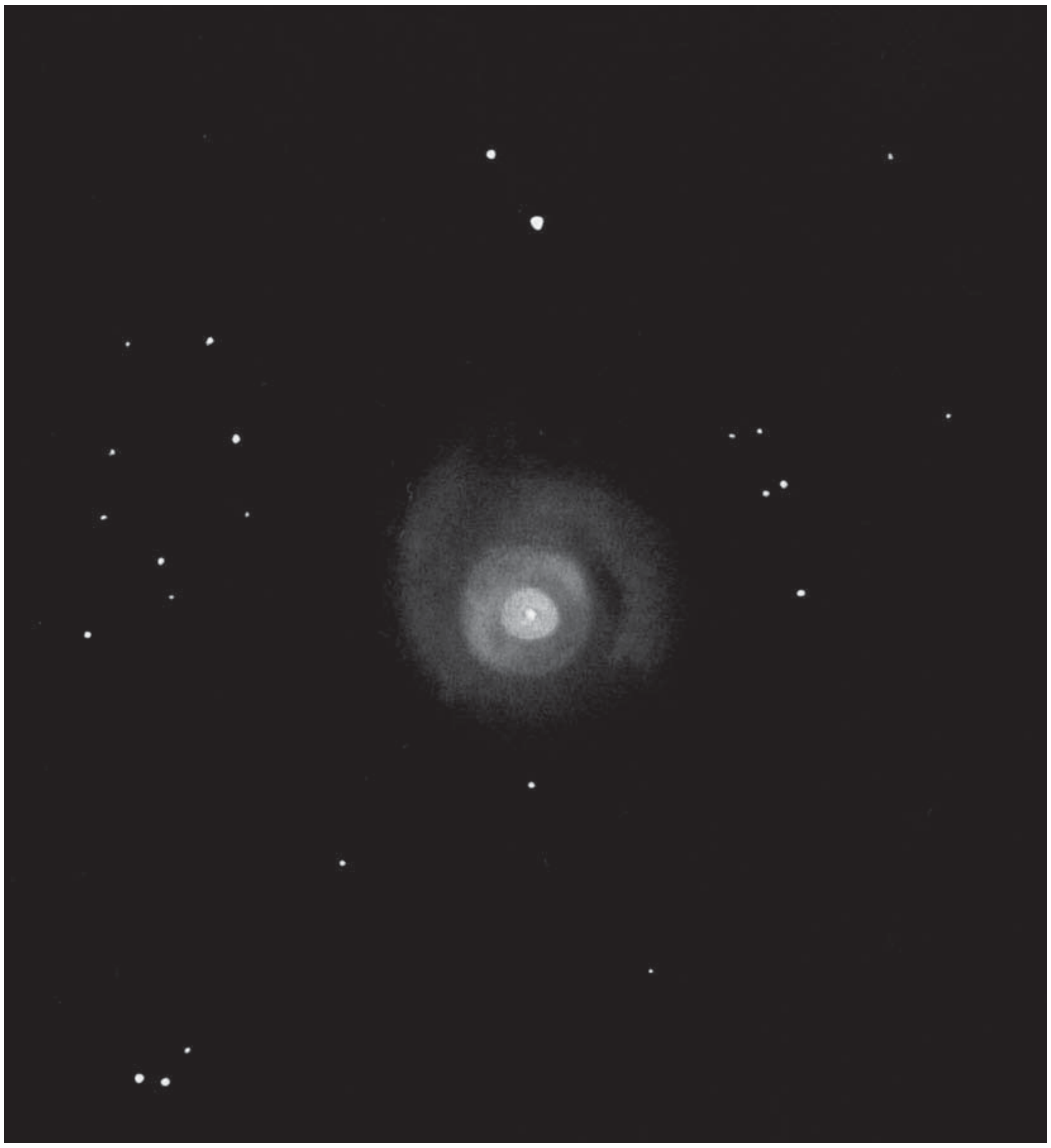
M 94 consists of several rings instead of spiral arms. The galaxy is surrounded by a very faint halo. Volker Wendel, Bernd Flach-Wilken.

Observation

The bright core of M 94 grants it visibility as a faint, apparently stellar object in 8×30 binoculars. A 10×50 shows a tiny, well-defined and bright disk, which looks almost like a planetary nebula.

In small telescopes, M 94 appears as a small, bright and round nebula with a clearly non-stellar core. A first impression of the multiple ring-structure of M 94 is obtained when observing with an aperture of 4.7 inches. Now, a very luminous core, 25” in diameter, is surrounded by a well-limited, bright, and round region of 1’ size. It is embedded in a diffuse halo of up to 3’ in diameter, which is not quite round.

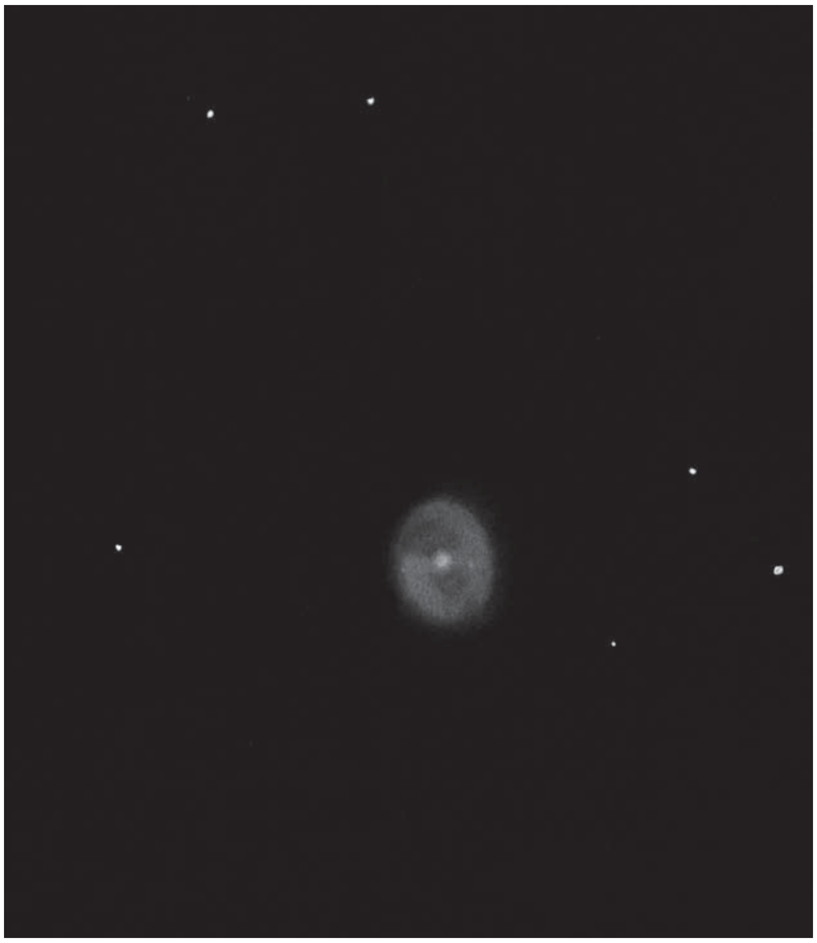
A 14-inch telescope reveals more inner and outer shell structure. The bright core turns out to be a slightly oval ring (PA 100°) of 20”–25” size with an elongated (5”–10”, PA 25°) nucleus inside, which very much looks like a tiny planetary nebula. The surrounding 1’ region appears homogeneous and almost circular, with a sharp edge. Outside follows a much darker area, enclosed in a diffuse, oval ring (PA 130°), 3’–4’ in diameter. This, in turn, is embedded in a faint shell of 5’–7’ size, which is not steadily visible. Under exceptional conditions, the sighting of the very faint, outer 15’ halo has been reported, which the author has not yet been able to confirm.



M 94, drawing. 14-inch Newtonian. Ronald Stoyan.

M 95

Degree of difficulty	5 (of 5)
Minimum aperture	50mm
Designation	NGC 3351
Type	Galaxy
Class	SBb
Distance	32.6 Mly (H2000) 32.8 Mly (Cepheids, 1999)
Size	70,000 ly
Constellation	Leo
R.A.	10^{h} 44.0^{min}
Decl.	+11° 42'
Magnitude	9.7
Surface brightness	22.4mag/$arcsec^{2}$
Apparent diameter	7,4'×5,0'
Discoverer	Méchain, 1781



M 95, drawing. 14-inch Newtonian. Ronald Stoyan.

History

M 95 was discovered, jointly with neighboring M 96, by Pierre Méchain on the 20^{th} of March 1781. Messier observed these two galaxies only four days later and characterized M 95 as a "nebula without star, its light is very faint." 50 years later, Admiral Smyth described it as a "lucid white nebula. This nebula is round and bright, and perhaps better defined on the southern than on the northern limb." Lord Rosse saw two ellipses with his giant telescope and had the impression that the "center is possibly resolvable." Heinrich d'Arrest commented on M 95 as an object "pretty and very bright, a little small and oval, much denser in the central region."

Heber Curtis devoted a detailed description to M 95 in 1918: "A beautiful object; nearly round. The whorls are rather faint and form an almost complete ring; a wide band of matter extends across the nebula from one side to the other; an example of the θ-type spiral. The centre is exceedingly bright, and of unusual structure. It is about 12" in diameter, and appears trinuclear; the center of the disk is not marked by any condensation, but on its periphery has two stellar nuclei, and a short, very bright, slightly curved mass."

Astrophysics

M 95 belongs to the Leo I group of galaxies, of which M 96 is the major galaxy (see M 96). With a diameter of 70,000 light-years, M 95 is the slightly smaller galaxy of the two, with only 50 thousand million solar masses.

M 95 is one of only a few barred spirals in the Messier catalog. It has been classified as SBb or SB(r)ab. Its spiral arms are almost closed into rings, so that A. Sandage called it a "typical ring-galaxy." The core is surrounded by a small, inner ring of active star formation regions, 14" in diameter (2000 light-years), which was described by Curtis. It is surrounded by HII regions, which make this central part 1' in diameter. These rings have been formed by resonance effects (see M 94).

Observations of cepheids, using the Hubble Space Telescope, gave a distance to M 95 of 31.2 million light-years. After subtle recalibrations, today's value is 32.6 million light-years. Hence, several sources now agree with each other that M 95 is closer to us than M 96.

Observation

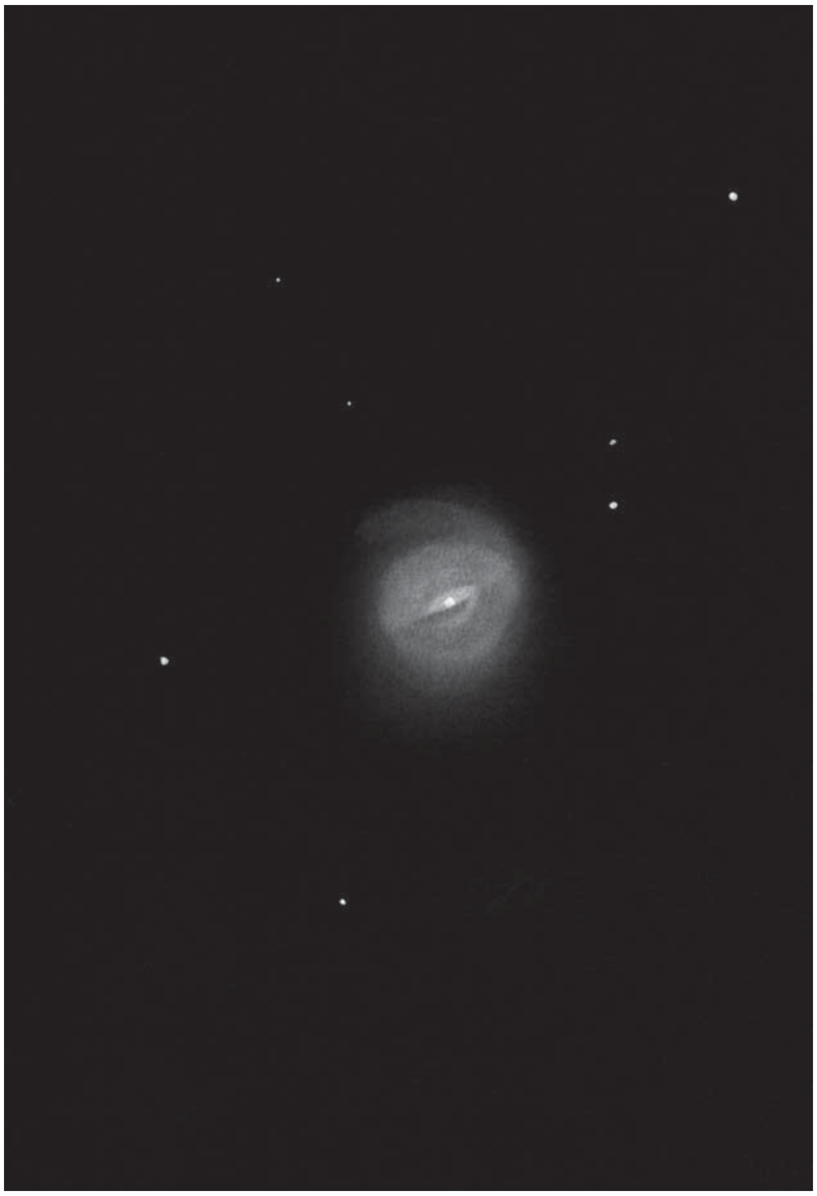
M 95 is at the limit of visibility in 10×50 binoculars. A small telescope shows it as the faintest member of a group of four, with M 96, M 105, and NGC 3384. Its shape is slightly oval, and there is a very faint, apparently stellar nucleus in its center. 4.7 inches aperture reveal a better view of the nucleus, which still looks almost like a star, and M 95 appears more clearly oval than its brighter neighbor M 96.

In a 14-inch telescope, the bright core gives the impression of a planetary nebula. There are strong irregularities in it, but even with 400× magnification, they cannot be grasped with certainty. The well-defined bar has a length of 1.5' in PA 120° and a brighter western side. The spiral arms are difficult to perceive, even with this aperture. While the edge of M 95 does appear slightly brighter, this is not enough to give the impression of a ring. The visual diameter of the oval galaxy reaches 3' in PA 15°.

M 95 is the classical example of a barred spiral galaxy in the Messier catalog. Philipp Keller, Christian Fuchs.

M 96

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 3368
Type	Galaxy
Class	Sa
Distance	34.3 Mly (H2000) 31.3 Mly (PN, 2000) 39.4 Mly (SBF, 2000) 35.8 Mly (Cepheids, 2000)
Size	76,000 ly
Constellation	Leo
R.A.	$10^h\ 46.8^{min}$
Decl.	+11° 49'
Magnitude	9.2
Surface brightness	$21.8 mag/arcsec^2$
Apparent diameter	7,6'×5,2'
Discoverer	Méchain, 1781



M 96, drawing. 14-inch Newtonian. Ronald Stoyan.

History

Pierre Méchain discovered M 96, together with M 95, on the night of the 20th of March 1781. While these discoveries were actually made after he found M 97 to M 100, their order got changed in the Messier catalog, because Messier chose to confirm the discoveries of M 95 and M 96 first. On the 24th of March 1781, M 96 appeared to him as a "nebula without star, near the previous [M 95]; this one is less apparent, they resemble the two nebulae in the Virgin, Nos. 84 and 86."

Smyth described M 96 as "round but not equally well defined nebula, large, and of a pale white colour." D'Arrest regarded it as "a twin of M 95, but it appears to be superior in luminosity. A cluster which has an ill-defined boundary. Resolved at 226× magnification." D'Arrest must have been misled by the mottled structure of the central region, which only shows its true, spiral character on photographic images. Hence, Curtis wrote in 1918: "A fine strong spiral. Bright stellar nucleus; the outer whorl of the brighter structure forms a nearly complete oval ring; a much fainter whorl outside."

Astrophysics

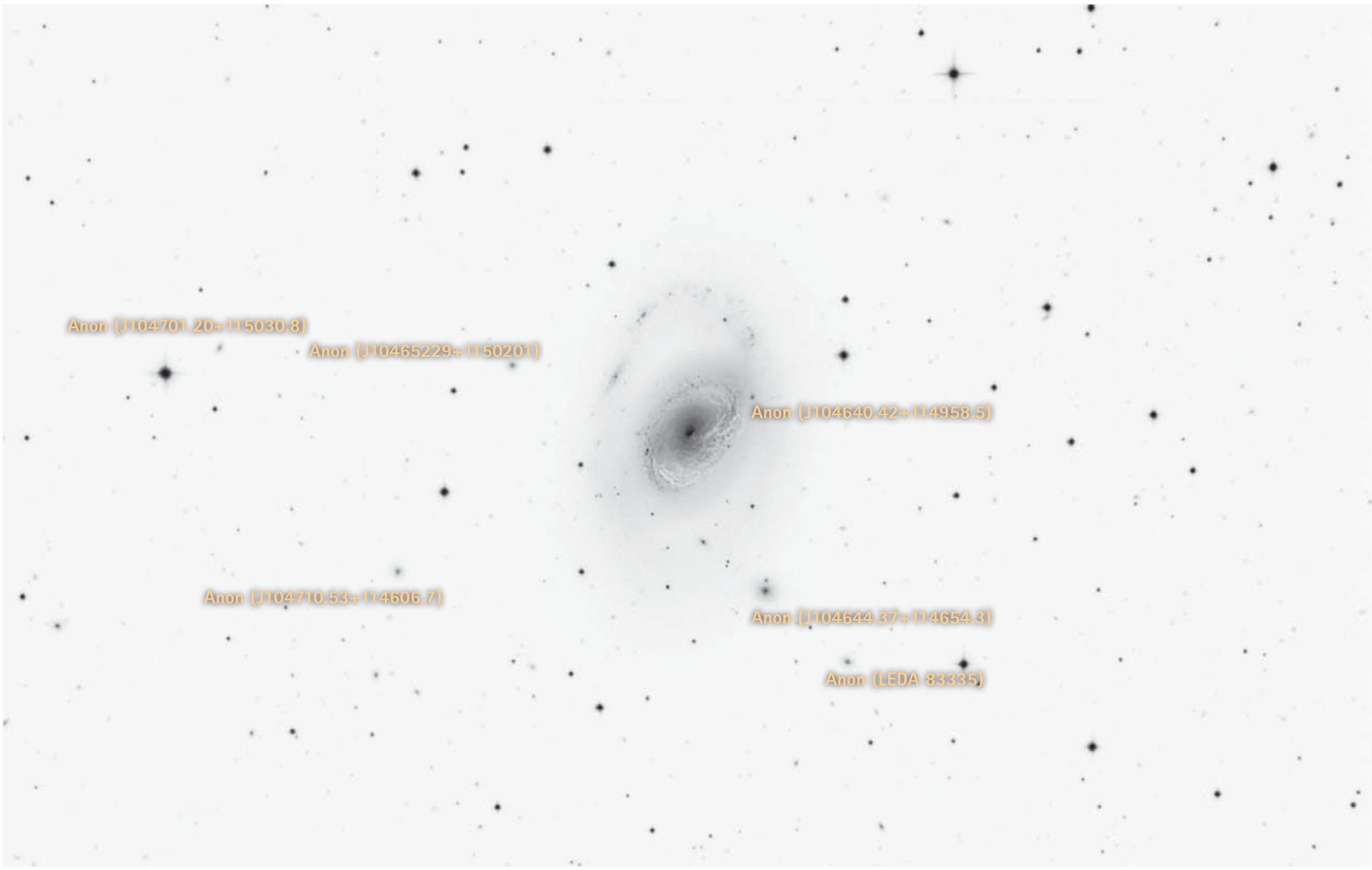
M 96 is the brightest member of the Leo I galaxy group. The other members are M 95, M 105, NGC 3299, 3377, 3384, 3412, 3489, 3627, and UGC 5889. There may also be a physical association with the M 65 group, which has a very similar distance from us. The distance to M 96 has been measured by means of eight cepheids, observed with the Hubble Space Telescope; the result was 31.9 million light-years. In 1997, 31.2 million light-years were derived. More recent studies, depending on the method used, have produced values between 31 and 39 million light-years.

M 96 is a spiral galaxy with a diameter of 76,000 light-years and a total mass of 80 thousand million Suns. The central region contains older, yellowish stars, which form a very small, bar-like structure (PA 35°). They are surrounded by a ring of young, blue star clusters. Another very faint outer ring of fragments of old spiral arms borders the galaxy. It is connected with the rest of the galaxy by a spiral arm fragment in the north.

There is visible dust, which apparently is concentrated in the western half of M 96. However, this is due to our perspective: the galaxy is inclined to the line of sight by 55°. Furthermore, there is some evidence for a ring of dust perpendicular to the innermost bar, and for an intergalactic cloud of neutral hydrogen right in between M 96 and its close neighbor NGC 3384.

A supernova (SN 1998bu) was discovered in M 96 on the 5th of May 1998, by the Italian amateur astronomer Mirko Vili, 1' north

M 96 is a much-studied calibration object for astronomical distance measurements. Stefan Heutz, Wolfgang Ries.



of the galaxy core, at 13th magnitude. A few days later, it reached a maximum brightness of 11.8.

This event was of considerable interest, since it provided an opportunity to improve the calibration of the distance scale by type Ia supernovae, after the distance of M 96 had already been determined with good precision by means of cepheids. Only type Ia supernovae show the required consistency in peak brightness and light curves. This qualifies them for being calibrated "standard candles" in measurements of large distances. In such an event, it's not a single, massive star that's exploding, but rather an accreting white dwarf in a close binary system. At some point, the white dwarf reaches its critical mass limit (the Chandrasekhar limit) of 1.44 solar masses and collapses into a neutron star. By contrast, type II and Ib supernovae involve a large variety of very different stellar envelopes, depending on the individual, massive star collapsing, and every light curve and peak brightness turn out differently.

Observation

M 96 is only 42' east of M 95. Both galaxies are faintly visible in binoculars. A small telescope shows M 96 as the brightest object in a group of four, with M 95, M 105, and NGC 3384 – all fitting into a field of view of 1.5° or more. M 96 appears round, with an apparently stellar, faint nucleus. With 4.7 inches, M 96 is also a bit brighter than M 95, round and marked by a nearly star-like nucleus.

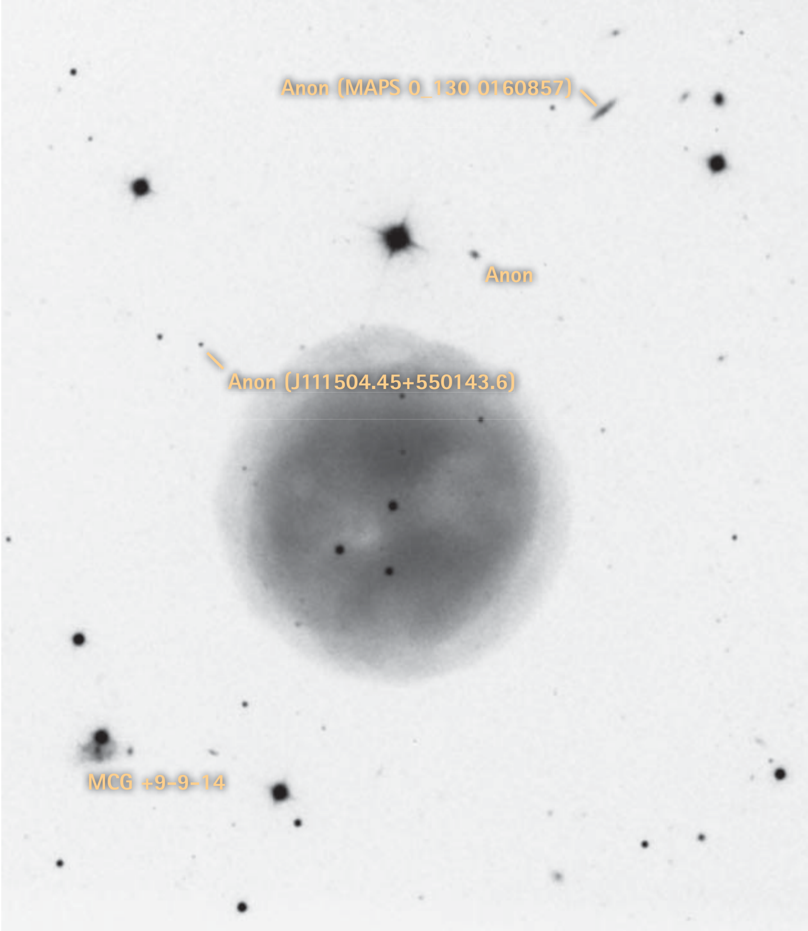
A 14-inch telescope shows a bright core of 5" diameter, embedded in an elongated (in PA 130°), 50"×15" central region. It extends into a 2.5'-long bar, which reaches the visual edges of the galaxy. Streched out in PA 145°, M 96 reaches a diameter of 3'. Just south of the central region is an elongated, dark structure, bordered to the south by a spiral arm fragment. This, together with a northern arm fragment, gives the visual impression of an eye or a ring, but all detail remains diffuse, especially in the northern region. The outer edges of the galaxy are bright, starting from the bar ends and turning clockwise. The dark structures inside create the visual illusion of a double-ringed spiral, although diffuse.

The very faint, outer ring of spiral arms surrounding M 96 is a challenge, even for photographers. There are several faint background galaxies nearby, among them a strongly reddened edge-on galaxy seen right through that outer ring.

M 97

The Owl Nebula

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 3587
Type	Planetary nebula
Class	IIIa
Distance	4140 ly (1999)
Size	3 ly
Constellation	Ursa Major
R.A.	11^h 14.8^m
Decl.	+55° 1'
Magnitude	9.9
Surface brightness	22.4mag/arcsec^2
Apparent diameter	170"
Discoverer	Méchain, 1781



History

The Owl Nebula was discovered on the 16th of February 1781, by Pierre Méchain. Messier observed it, together with several other recent discoveries by his close colleague, on the night of the 24th of March 1781. He noted: "Nebula, it is difficult to observe, its light is faint, without star." William Herschel, using his large, home-made metal mirrors, saw much more of M 97: "A very bright, round nebula of about 3' in diameter; it is nearly of equal light throughout, with an ill defined margin of no great extent."

Admiral Smyth apparently had his difficulties with this object, when he reported: "This very singular object is circular and uniform, and after a long inspection looks like a condensed mass of attenuated light, seemingly of the size of Jupiter." Webb commented: "Large pale planetary nebula, very remarkable object."

In March 1848, Lord Rosse and his assistant Rambaut pointed the giant 72-inch telescope at M 97 on six nights and saw "two stars considerably apart in the central region; dark penumbra around each spiral arrangement, with stars as apparent centres of attraction; stars sparkling in it, resolvable; night excellent." A friend of Lord Rosse, T.R. Robinson, who had the privilege of joining the observations at the large telescope, gave a description which reflects Rambaut's sketch of M 97: "A most intricate group of spiral arcs disposed around two starry centres, looking like the visage of a monkey." In his later observations, however, Lord Rosse did correct himself: "On many occasions only one star seen and spiral structure doubtful." It was also Rosse who likened the dark patches in M 97 to the eyes of an owl.

Later observers had their difficulties with the early M 97 observation of Lord Rosse. For example, Leo Brenner commented at the end of the nineteenth century: "Planetary nebula, which appears like the face of a monkey in Rosse's drawing, because Rosse saw in it two stars surrounded by darkness which equal a pair of eyes. However, despite all efforts with magnifications 40×, 52×, 70×, 98× and 137×, I could see nothing but a nebulous disk of uniform brightness, without details." In 1907, Barnard devoted a detailed visual-observing study to M 97 to verify Lord Rosse's sketch. He could confirm the dark patches and, in one of them, a faint star – but there truly is no second star. Where the second star of Lord Rosse has gone remains a mystery.

In 1866, Huggins observed the spectrum of M 97 and proved its gaseous nature. This observation made clear that the nebula could neither consist of stars, nor be a spiral galaxy.

In 1918, Curtis gave this description, which still is valid today: "The central star is visual magnitude 14 (Burnham), and about 12 photographically. The brighter central oval lies in PA 12°, and the diameter along this line is 199"; at right angles to this direction it is 203" in diameter to outside the whorls. Aside from the outer whorls all structural details are very vague and indistinct."

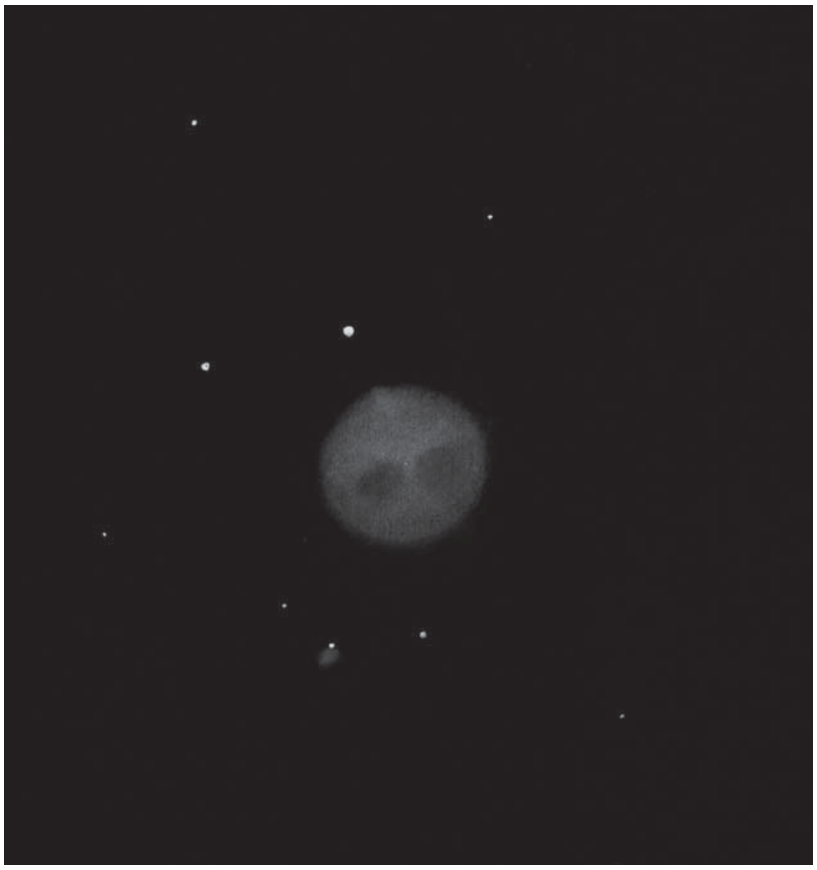
M 97 is a mature planetary nebula about three light-years in diameter. Philipp Keller, Christian Fuchs.

Astrophysics

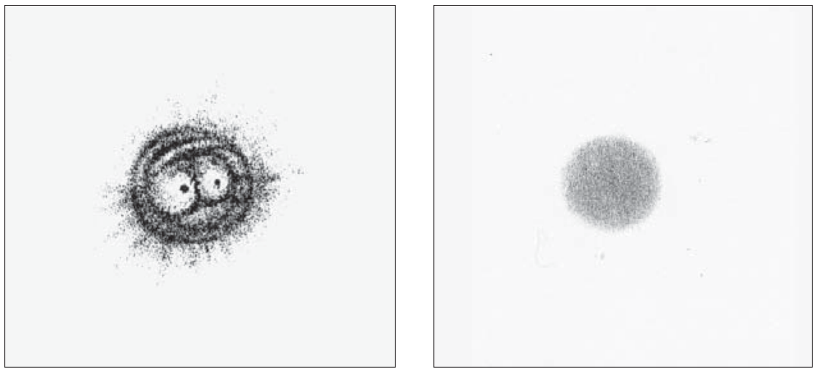
The Owl nebula is a planetary nebula, like M 27 or M 57. It shows a triple shell structure: the inner shell of 182”×168” is slightly elongated in P.A. 20° and dominates the visual appearance. Two less bright regions along the major axis form the “eyes of the owl.” They are caused by a bipolar cavity in the central shell. The second shell of 218” is nearly circular and, because of its Hα emission, appears red in color photos. It is surrounded by a faint, round but asymmetric halo, best recorded in the light of the [OIII] line, which reaches a diameter of 350”. The shells have similar expansion velocities of 40 to 45 km/s.

Distance measures of planetary nebulae are notoriously uncertain, since their physical properties are difficult to calibrate and depend a lot on the individual case. For M 97, distances between 1300 and 12,000 light-years have been derived. A study published in 1999 quotes 4100 light-years, Guerrero et al. (2003) assume 3300 light-years. This would give M 97 a physical diameter of 3 light-years, similar to M 27, and a shell of 0.5 solar masses.

For the same reasons as above, it is difficult to derive an accurate age for a planetary nebula. For M 97, ages between 6000 and 12,000 years have been suggested. The advanced state of the shell, in which the inner hot wind has already lost its expansion-driving power (Guerrero et al. 2003), would rather indicate the older age, which is similar to the other two planetary nebulae in the Messier catalog.



M 97, drawing. 14-inch Newtonian. Ronald Stoyan.



M 97, historical drawings. Lord Rosse (1848), John Herschel (before 1833).

Observation

Because it radiates strongly in the green [OIII] emission line, which is quite characteristic for planetary nebulae and happens to coincide with the highest spectral sensitivity of the human eye, M 97 appears much brighter visually (magnitude 9.9v) than photographically (magnitude 12.2p). But modern photography now has the edge in recording the deep-red Hα emission line structures of the hydrogen gas, which are well defined – by contrast to the more diffuse blue-green image.

Even 10×50 binoculars show a very faint, round nebula without detail. In a small telescope, the pale nebulous disk remains without detail. An [OIII] line-filter improves the view a bit when used with low powers.

With an aperture of 4.7 inches, the “eyes of the owl” are vaguely visible. Here, a line filter is not helpful: in brightening the nebula, those two dark regions get filled in with light and the contrast with the surrounding nebula is lost. From 8 inches upwards, the faint central star can be seen. It lies on the bridge of brighter nebulosity, right between the two “eyes.” But good seeing and high magnifications are required to achieve sufficient contrast between the nebula and the small diffraction disk of the central star (see M 57).

The obscure “eye”-patches become more distinct with larger apertures, but they are not entirely void of nebulosity and remain low-contrast structures; the southeastern eye is easier to perceive. The two fainter stars in M 97 have not yet been mentioned by visual observers.

The irregular structure visible on photos taken in the wavelength Hα on the edge of the nebula is not visible, not even with very large telescopes. Hence, visually, M 97 remains a diffuse object without sharp contours. Photographs show a star 3.5’ southeast of M 97 with a nebulous attachment, the 16th-magnitude galaxy MCG+9-19-14. Visually, it can be glimpsed in a 14-inch telescope, while a 20-inch shows it unambiguously, apparently attached to the foreground star.

M 98

Degree of difficulty	5 (of 5)
Minimum aperture	50mm
Designation	NGC 4192
Type	Galaxy
Class	Sb
Distance	44.2 Mly (V2002)
Size	126,000 ly
Constellation	Coma
R.A.	12^h 13.8^{min}
Decl.	+14° 54'
Magnitude	10.1
Surface brightness	22.1mag/arcsec^2
Apparent diameter	9,8'×2,8'
Discoverer	Méchain, 1781

M 98, drawing. 14-inch Newtonian. Ronald Stoyan.

History

Pierre Méchain discovered M 98 on the 15th of March 1781, and reported this to Messier, who observed the new nebula on the 14th of April 1781. Messier wrote: "Nebula without star, of an extremely faint light." Only two years later, William Herschel commented (referring to Messier's note): "A large, extended fine nebula. Its position shows it to be M. Messier's 98th; but from its description it appears, that that gentleman has not seen the whole of it, for its feeble branches extend above a quarter of a degree, of which no notice is taken. Near the middle of it are a few stars visible, and more suspected. My field of view will not quite take in the whole nebula.

John Herschel saw M 98 as a "ray, much brighter toward the middle almost to a nucleus; 10' long," while Smyth with his much smaller aperture describes a "fine and large, but rather pale nebula, but on keeping a fixed gaze it brightens up towards the centre." The spiral structure was recognized only on good photographs. Curtis characterized M 98 in 1918 as "An open, elongated spiral. Bright stellar nucleus; numerous almost stellar condensations. Absorption effects on east side."

Astrophysics

M 98 is a member of the Virgo galaxy cluster and is located on its facing side. It has a radial velocity of only 125 km/s, this is almost 1000 km/s less than the average Virgo cluster velocity. Hence, Holmberg even took M 98 for an unrelated foreground galaxy. However, today it is believed that a close encounter with M 99 brought M 98 into its present fast track towards us.

M 98 has been characterized as a transitional object, the core of which has LINER characteristics (see M 81), and exhibits HII regions surrounding it also. These are photo-ionized by many young, hot stars, not by an active galaxy nucleus.

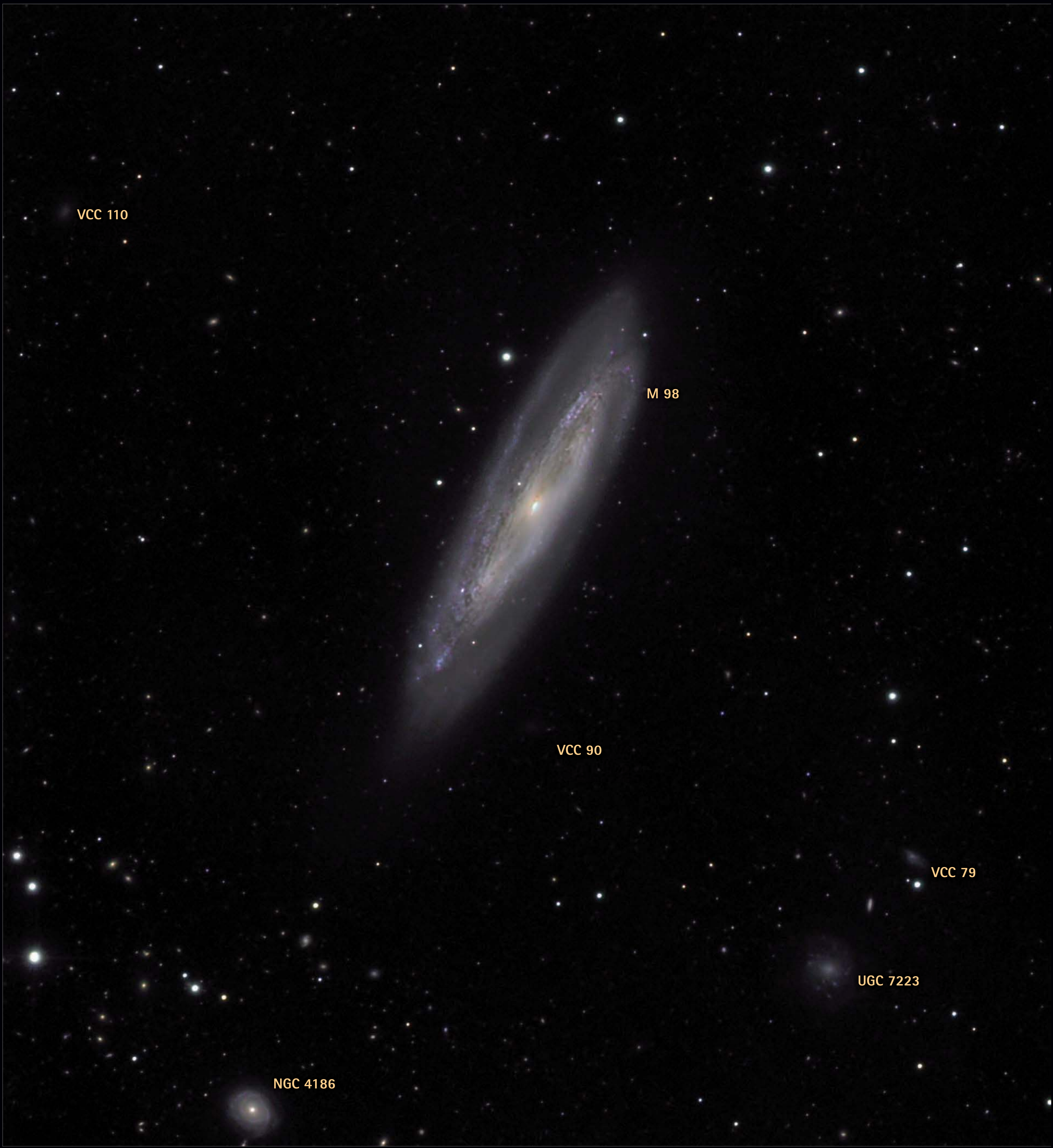
With a diameter of 126,000 light-years and 200 thousand million solar masses, M 98 is among the largest Virgo cluster galaxies. We observe this spiral nearly edge-on, at an angle of 10°. Just 5' south, there is NGC 4186, and very deep exposures reveal the faint dwarf galaxy VCC 90, only 2' west of the southern tip of M 98.

Observation

M 98 ties with M 91 for the faintest Messier galaxy. 10×50 binoculars can just show it at the very limit of perception. In small refractors, M 98 can be seen only at low power, and an elongated shape in the north-south direction is all that can be recognized.

A 4.7-inch telescope shows an elongated, 5'-long spindle of light with a barely pronounced core region. Mottled structure in the southern part of the galaxy gives the false impression of faint stars, but it rather indicates bright star formation regions.

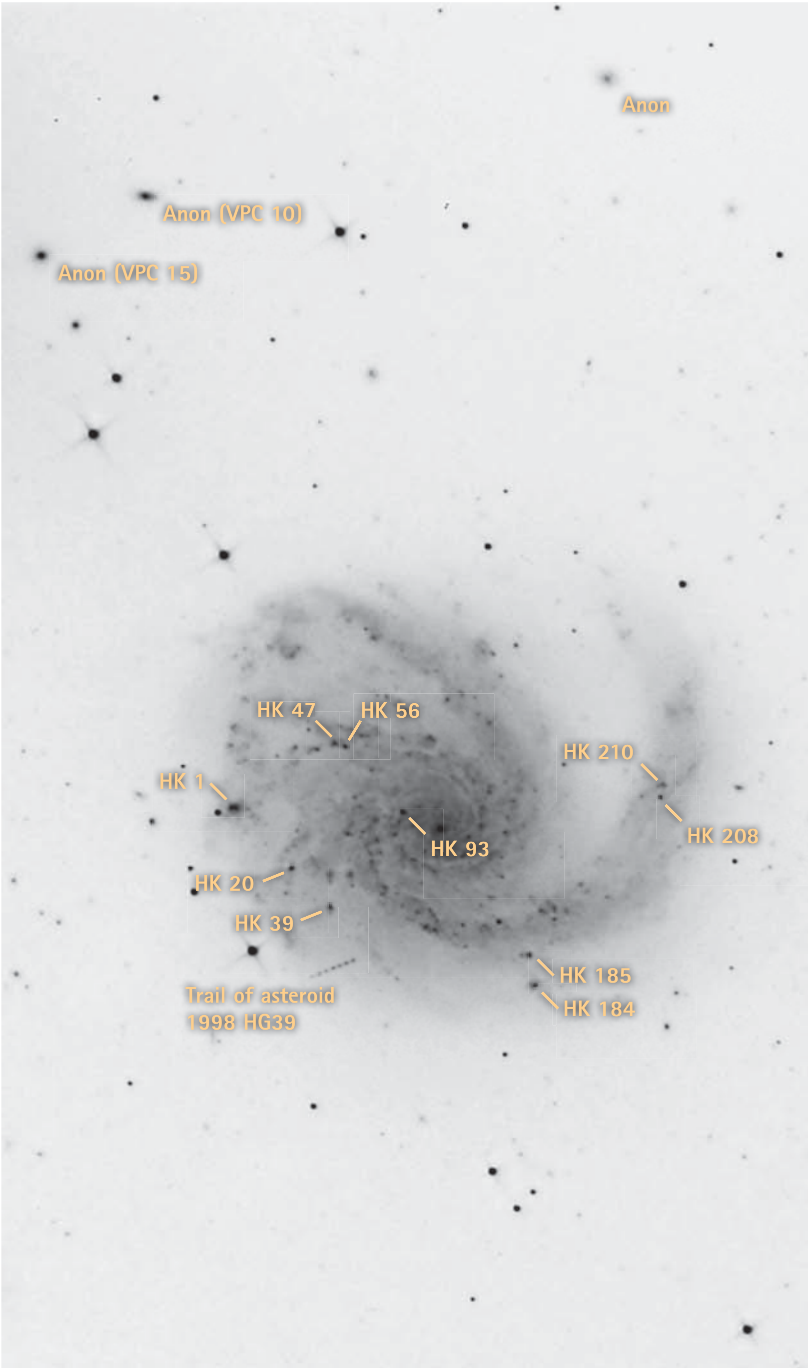
M 98 remains the most difficult spiral galaxy of the Messier catalog for visual observers even with an aperture of 14 inches. Clearly visible is an elongated core of up to 15" size. The rest of the 7.5'×1.5', slim galaxy is very faint. A dark absorption lane north of the core can be recognized vaguely. Both ends of the galaxy appear a little brighter and wider, which is a pointed hint to its spiral structure. The surrounding field is clear of foreground stars, with the exception of a 13th-magnitude star, 3' north of the galaxy center.



M 98. We see this spiral galaxy not far from an edge-on perspective. Bernd Flach-Wilken.

M 99

Degree of difficulty	5 (of 5)
Minimum aperture	50mm
Designation	NGC 4254
Type	Galaxy
Class	Sc
Distance	52.7 Mly (V2002) 65.3 Mly (2003)
Size	83,000 ly
Constellation	Coma
R.A.	12^h 18.8^{min}
Decl.	+14° 25'
Magnitude	9.9
Surface brightness	21.9mag/arcsec^2
Apparent diameter	5,4'×4,7'
Discoverer	Méchain, 1781



History

M 99 was discovered, together with the neighboring M 98 and M 100, by Pierre Méchain in the night of the 15th of March 1781. Messier observed this galaxy a month later, the 14th of April, and saw a “nebula without star, of a very rare light, but a little clearer than the previous. The nebula is between two stars of the seventh & eighth magnitude.”

All John Herschel saw was a mottled, round nebula. Lord Rosse in 1846, however, discovered the spiral structure of M 99 – exactly a year after his famous observation of M 51. In 1848, he described his observations with his giant 72-inch telescope: “Spiral with a bright star above; a thin portion of the nebula reaches across this star and some distance past it. Principal spiral at the bottom, and turning toward the right.” Not much later, d’Arrest summarized his observation with the words: “large and round spiral: the nucleus is more or less resolvable. Apparently scattered along the margins.”

R. H. Allen called M 99 the “Pinwheel Nebula” and celebrated it as “one of the pyrotechnics in the sky.” Curtis described the photographic appearance in 1918 as “A very bright, approximately round spiral 4.5’ in diameter. Nucleus almost stellar. There are two main whorls, rather open, which show many almost stellar condensations.”

Astrophysics

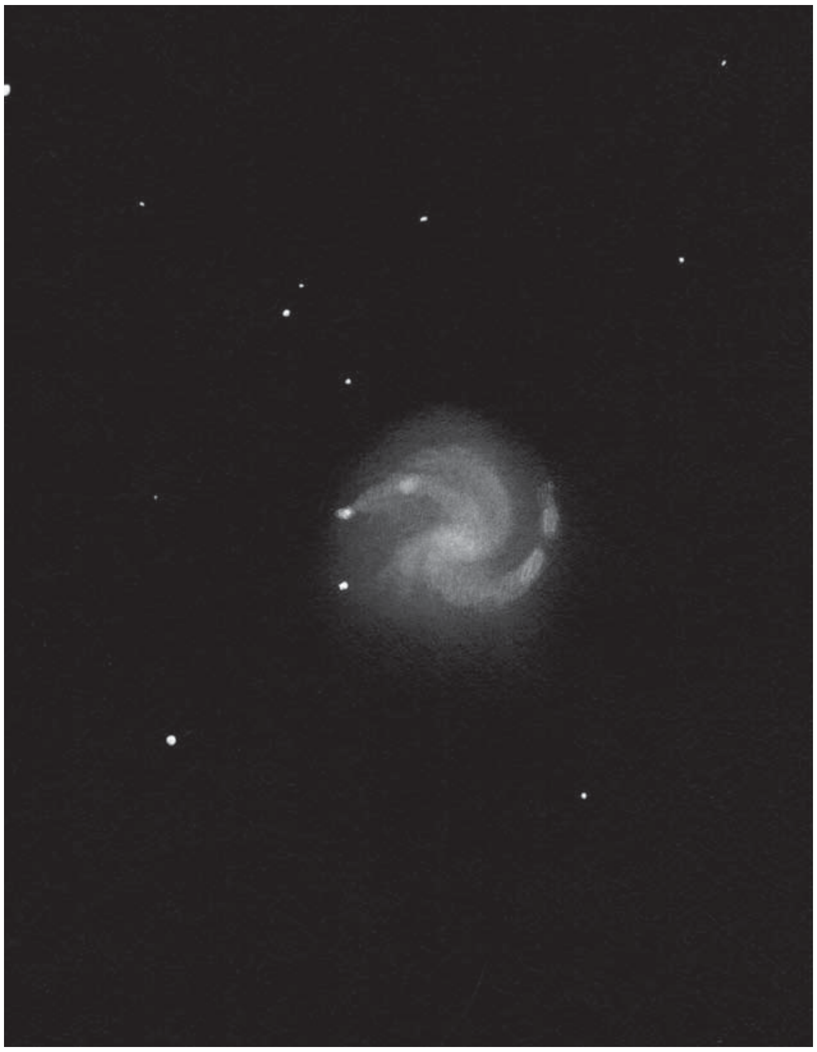
M 99 is a physical member of the Virgo cluster, at a distance of about 53 million light-years. A very recent study of the 3D structure of this galaxy cluster places M 99 about 4 million light-years behind M 100. Its radial velocity of 2407 km/s is the largest of all Messier objects, and it exceeds that of the Virgo cluster by a remarkable 1300 km/s.

M 99 has a diameter of 83,000 light-years and contains about 100 thousand million solar masses – less than our Milky Way. The stars in the Sc spiral rotate clockwise around the nucleus, which contains 100 million solar masses.

M 99 is of an unusual, asymmetric shape with a displaced core and unequal spiral arms. It is a rare example of a galaxy with one dominant spiral arm. The strong star formation in this arm may indicate density waves induced by a past encounter with another galaxy, which would also explain the large relative velocity of M 99 within the Virgo cluster. But the galaxies in the immediate neighborhood appear to be too small to have done this. The dominance of this one spiral arm is, instead, related to the infall of 23 million solar masses of hydrogen gas, observed with radio telescopes.

Three supernovae have been observed in M 99. In June 1967, SN 1967H reached a peak brightness of 14, while SN 1972Q only made it

M 99. The asymmetric spiral is populated by many star clusters and HII regions. Philipp Keller, Christian Fuchs.



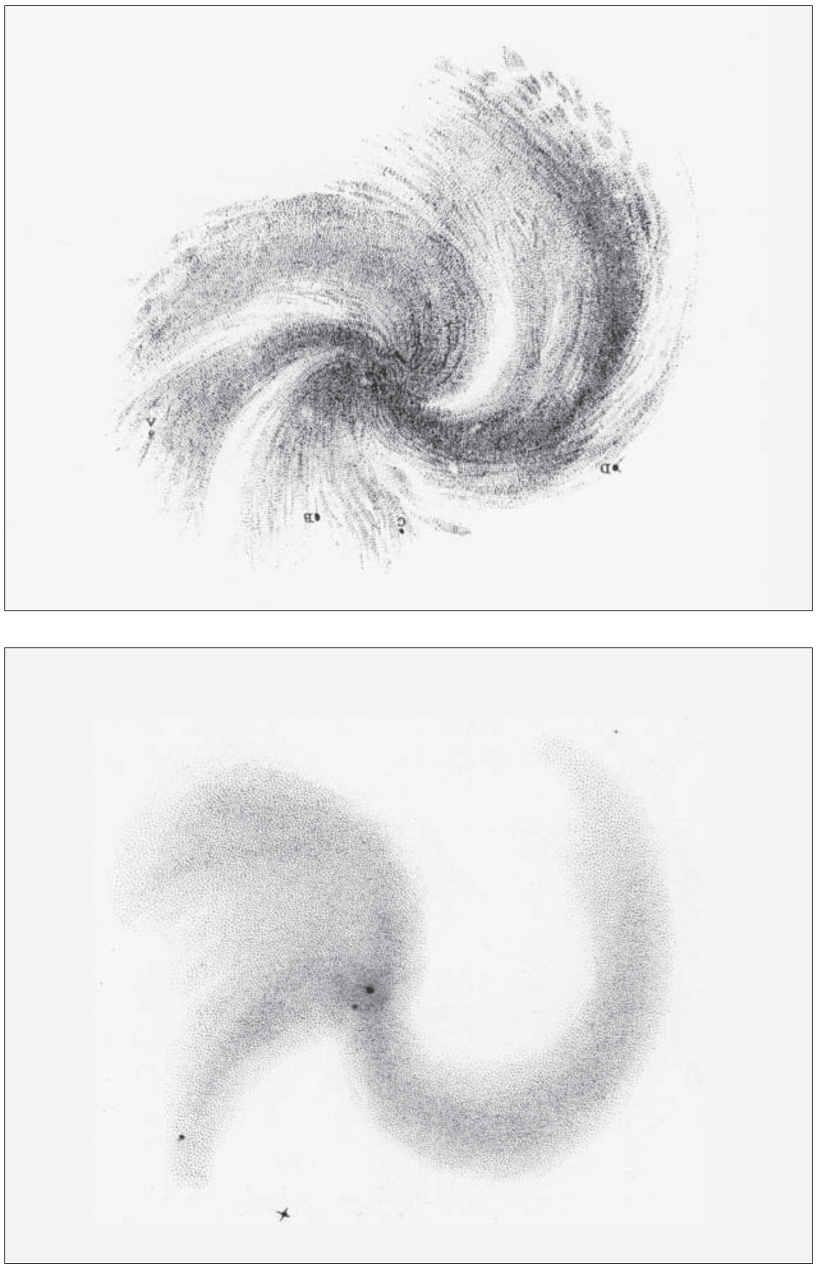
M 99, drawing. 14-inch Newtonian. Ronald Stoyan.

to 15.6 on the 16th of December 1972. Finally, SN 1986I was discovered at 14th magnitude on the 17th of May 1986.

Observation

M 99 is regarded as a galaxy with a relatively easily seen spiral structure. In 10×50 binoculars, it is well visible as a round nebulous spot. A 2.5-inch refractor shows a distinctly round nebula with a bright, nonstellar core embedded in a diffuse halo.

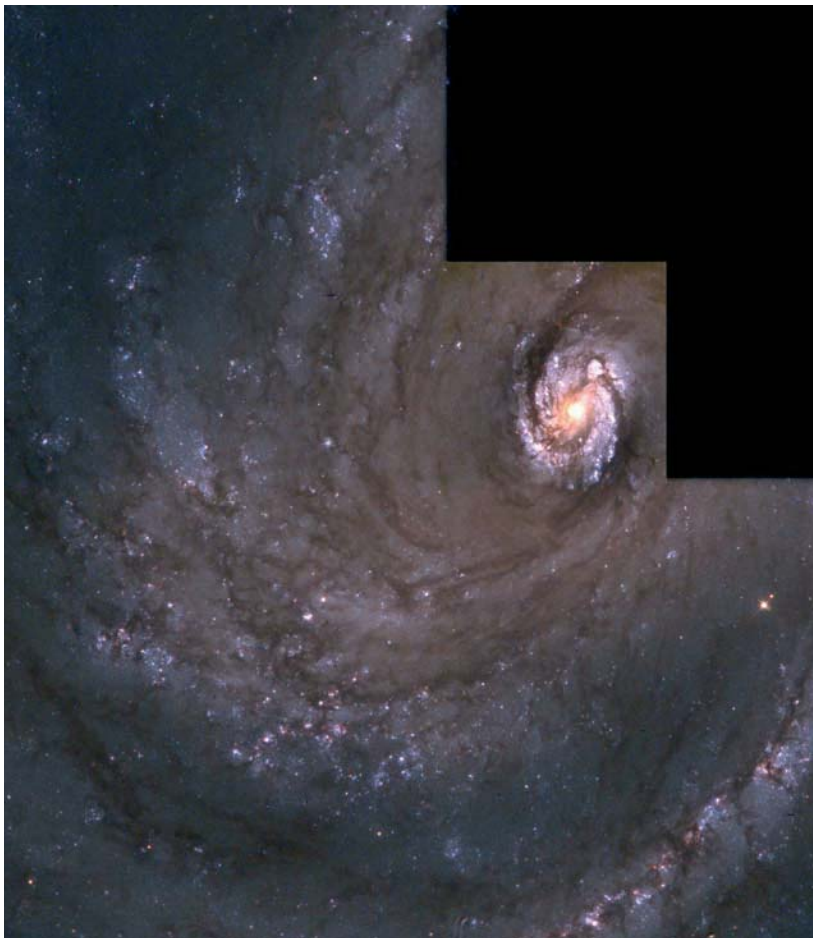
In a 4.7-inch telescope, the galaxy appears round with a bright, small core. The spiral structure still remains invisible. But with 10 inches of aperture, the most prominent arm towards the south can be recognized. It requires 14 inches, however, to see M 99 as an impressive three-armed spiral. It is slightly elongated in PA 60° with a size of almost 4'. The southern arm is the most distinct of the three and there is a dark separation between it and the rest of the galaxy. Bright spots indicate large star-formation regions. The northwestern arm is shorter, and the northeastern arm appears to be the one least-well defined, but it ends with a distinct, bright knot, 2' east of the core. This is star A in the sketch made by Lord Rosse, and it is the HII region No. 1 in the list of Hodge and Kennicutt.



M 99, historical drawings. Lord Rosse (1846), William Lassell (1862). The stars A and D in Rosse's sketch are, in fact, the brightest star-formation regions of the galaxy, while B and C are foreground stars.

M 100

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 4321
Type	Galaxy
Class	Sc
Distance	**49.6 Mly (H2000, V2002)** 52.7 Mly (Cepheids, 2000) 65.3 Mly (2003)
Size	107,000 ly
Constellation	Coma
R.A.	12^h 22.9^{min}
Decl.	+15° 49'
Magnitude	9.3
Surface brightness	21.9mag/arcsec^2
Apparent diameter	7.4'×6.3'
Discoverer	Méchain, 1781



M 100. This detailed picture shows the complex spiral structure. Hubble Space Telescope.

History

Pierre Méchain found M 100 on the 15th of March 1781, and Messier verified that discovery a month later, on the 13th of April. He noted: "Nebula without star, of the same brightness as the previous [M 99]." Initially, M 100 was supposed to be the final entry of Messier's list; all further objects are annexes or later add-ons by other authors.

William Herschel estimated the apparent diameter of M 100 as 10' and commented: "there is in the middle of it, a small, bright cluster of supposed stars." Admiral Smith was clearly misled by his view of M 100: "A round nebula, pearly white. This is a large but pale object, of little character, though it brightens from its attenuated edges towards the centre; and is therefore proved to be globular."

Lord Rosse discovered the spiral nature of M 100 but believed that a planetary nebula would form its center. Lastly, Curtis described this galaxy very well, as seen on deep photographs: "A bright, regular, nearly round spiral 5' in diameter. Very faint stellar nucleus surrounded by bright, short whorls, forming a central oval. The outer whorls are rather open, quite regular, and show many stellar condensations."

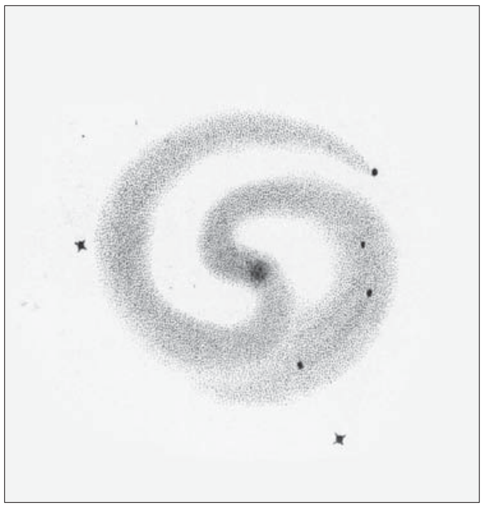
Astrophysics

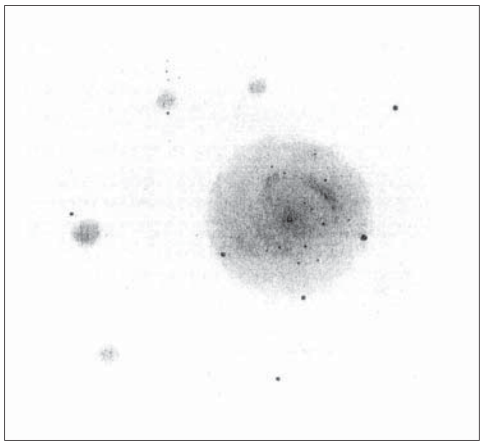
M 100 is one of the largest spiral galaxies in the Virgo cluster. With a diameter of 107,000 light-years and 200 thousand million solar masses, it is comparable to the Milky Way in size and mass. Our view of the two major spiral arms is face-on. Blue, young star clusters and star formation regions outline the main arms while fragments of weak arms are found in between. Overall, the structure of M 100 appears a little asymmetric, with the major arms slightly bent. This impression agrees with detailed studies which reveal a larger amount of young stars south of the galaxy core. The central region was imaged by the Hubble Space Telescope in 1993. It is very bright and like a small spiral of its own within the large galaxy. NASA's Ultraviolet Imaging Telescope on board the Astro-1 satellite recorded intensive UV radiation from the central region of M 100. There is a ring of intense star formation, 7.5" to 20" in diameter, with many young, massive stars. This bright ring gave historic observers the impression of a planetary nebula or a central star cluster. Its formation, as well as the asymmetric appearance of the galaxy as a whole, can be attributed to past encounters with other Virgo cluster galaxies, and the related action of tidal forces.

In 1993, with the use of the Hubble Space Telescope, M 100 became the first Virgo cluster galaxy in which cepheids were observed. Twenty such variables with 24th to 26th magnitude were found and a distance of 55.8 million light-years was derived. Later recalibration reduced that distance measure to 52.7 million light-years, and most recent data give preference to an even slightly lower value of 49.6 million light-years.

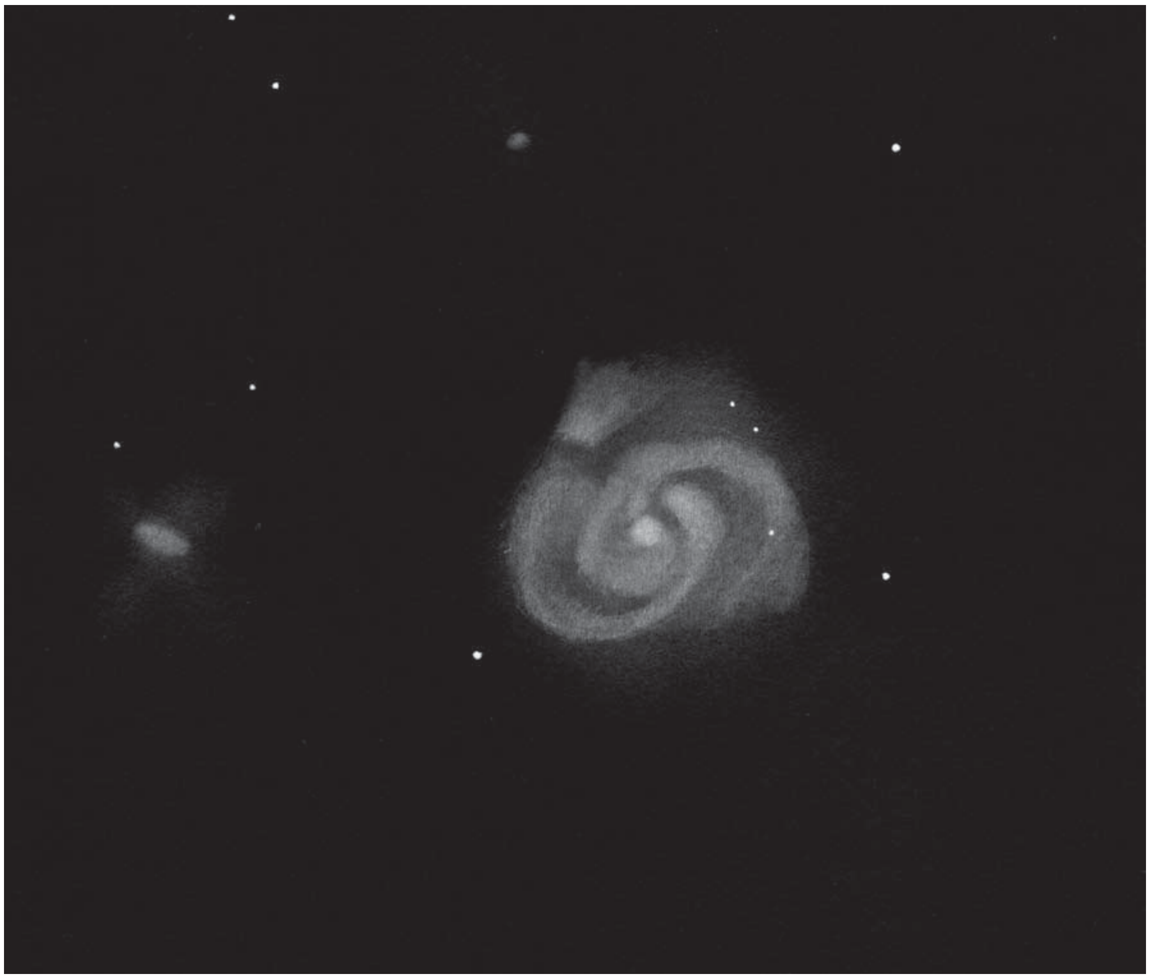
M 100 has produced five observed supernovae so far. SN 1901B reached magnitude 15.6 in March 1901; similarly SN 1914A attained magnitude 15.7 in February 1914. SN 1959E reached its maximum of only magnitude 17.5 in August 1959, before its actual discovery in February 1960. The brightest by far supernova in M 100 was SN

M 100. Thanks to the observation of cepheids in this spiral galaxy, the first precise distance measure of the Virgo cluster was obtained. Philipp Keller, Christian Fuchs.





M 100, historical drawings. William Lassell (1862), Wilhelm Tempel (around 1875).



M 100, drawing. 14-inch Newtonian. Ronald Stoyan.

1979C, which appeared on the 14th of April 1979. It reached a remarkable magnitude of 11.6, and high-resolution images from 1990 and 1991 have already resolved the remnant of this event. Type Ia Supernova 2006X went off near the bright southern spiral arm and reached magnitude 14.1 around the 22nd of February 2006.

Observation

In 10×50 binoculars, this fabulous spiral appears only as a round nebulous patch. A 2.5-inch refractor shows a nearly stellar core with a diffuse, round halo.

With a 4.7-inch telescope, the spiral structure can vaguely be perceived under a clear mountain sky. But it takes an aperture of 14 inches to see it in its full beauty. Then, M 100 turns out to be a great spiral with two tightly wound, diffuse arms, which both make a full turn around the galaxy's center. The arm that ends in the north is fainter, and it is mottled towards its end; its root, however, is brightly marked and well distinguished from the core. The south-ending arm is better defined, and it becomes diffuse before it vanishes towards the south.

In its visual appearance, M 100 is an oval in PA 105°, which is almost perpendicular to the major axis of the photographic image (PA 30°). In a 14-inch telescope, this galaxy reaches a visual size of 3.5'. The bright and mottled core is extended with a size of 20".

There are several stars at the western edge of M 100, which is surrounded by a number of other faint galaxies. Of these, NGC 4322, 5' north, is very faint in a 14-inch telescope, while NGC 4328, 6' east, can be perceived more distinctly as a faint spindle in PA 60°. Other field galaxies are NGC 4312, 18' north-northeast, and IC 783 18' southeast.

M 101

The Pinwheel Galaxy

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	NGC 5457
Type	Galaxy
Class	Sc
Distance	**21.8 Mly (H2000)** 24.1 Mly (2006) 23.5 Mly (2001) 21.9 Mly (Cepheids, 1996)
Size	184,000 ly
Constellation	Ursa Major
R.A.	14^h 3.2^{min}
Decl.	+54° 21'
Magnitude	7.7
Surface brightness	23.7mag/arcsec^2
Apparent diameter	28.8'×26.9'
Discoverer	Méchain, 1781

History

M 101 was discovered on the 27th of March 1781, by Pierre Méchain. He described the new find as "Nebula without star, very obscure and pretty large, 6' to 7' in diameter." This galaxy was found just before the final version of Messier's catalog was going into print. In a last-minute effort, M 101 made it into an appendix, together with two more objects found by Méchain that night (M 102 and M 103).

On the 14th of April 1789, William Herschel observed M 101 and discovered three nebulous spots within its glow. These are now known as NGC 5461, 5462, and 5447. William Smyth got very inspired by this object, although misled about its nature, when he wrote in the 1830s: "It is one of those globular nebulae that seem to be caused by a vast agglomeration of stars, rather than by a mass of diffused luminous matter; and though the idea of too dense a crowd may intrude, yet the paleness tells of its inconceivable distance, and probable discreteness." Lord Rosse finally noticed and sketched the spiral structure of M 101 with its knots, and he made out a diameter of 14'.

To d'Arrest, who had a much smaller telescope at his disposal, this galaxy looked much different: "The outer margin is very faint and difficult to perceive. The nebula is not quite round, its nucleus diffuse. This is a complex object with two centres linked to each other; that, however, is not easily recognized."

Curtis, in 1918, had good photographs to characterize M 101: "This unusually beautiful spiral is about 16' in diameter. There is an almost stellar nucleus, with two bright condensations very close which give a tri-nuclear appearance. The open whorls show a multitude of stellar condensations. 5449, 5450, 5451, 5453, 5455, 5458, 5461, 5462, are simply brighter knots in the great nebula."

Astrophysics

M 101 is the textbook example of a "grand design" spiral, type Sc, which we see face-on, and which is only half so far as the distance of the Virgo cluster and the spiral galaxies there (see M 99). Only a close inspection reveals some asymmetries; it shows that the nucleus appears a little displaced from the geometric center. Arp characterized M 101 as a "spiral with one heavy arm" and included it in his list of interacting galaxies, as No. 26.

These interactions must have their origin in the near companion galaxies NGC 5477, NGC 5474, and Holmberg IV. Close encounters would have caused deformations of spiral arms and initiated new star-formation regions. Other less close members of the M 101 galaxy group are NGC 5204, NGC 5238, and UGC 8882, UGC 8837, and UGC 9405. In addition, there is a small, anonymous galaxy near the end of the northern spiral arm of M 101, which is probably a background object.

M 101 is an important object in the calibration and comparison of various distance measurement methods and distance indicators. In 1995, the Hubble Space Telescope found several cepheids, from which a distance of 24 million light-years was derived. Hipparcos data suggested 27 million light-years, and recent cepheid recalibrations correct the Hubble data to a distance of 22 million light-years. Even this smallest distance value for M 101 yields a very large physical diameter of 184,000 light-years – almost twice as large as our Milky Way!

Along the spiral arms, numerous bluish spots with active star formation and red HII regions stand out. Ten of these knots have received individual NGC identifications (5447, 5449, 5450, 5451, 5453, 5455, 5458, 5461, 5462, and 5471). Some of these knots contain the mass of more than 10 million Suns and rival the mass of a dwarf galaxy. In 1990, Hodge cataloged 1264 HII regions in M 101, and Jurcevic et al. (2007) found 3000 probably young open clusters along the spiral arms.

Three supernovae have so far been observed in M 101. SN 1909A was discovered on the 26th of January 1909, by Max Wolf at Heidelberg Observatory (Germany), and reached magnitude 12.1. SN 1951H followed in September 1951 with only magnitude 17.5, and SN 1970G finally made it to magnitude 11.5 on the 30th of January 1970. A lot of observers got deceived, though, by a foreground star of magnitude 12.5 just 1.2' north of the galaxy core, which really is in the right place and has the right brightness to be taken for a supernova.

Observation

M 101 is the third-largest galaxy in the Messier catalog, by appearance in the sky. This is already obvious in 10×50 binoculars, which show M 101 as an unambiguous nebula without a core. Even a sighting with the naked eye may not be impossible, but no such observation has been reported so far.

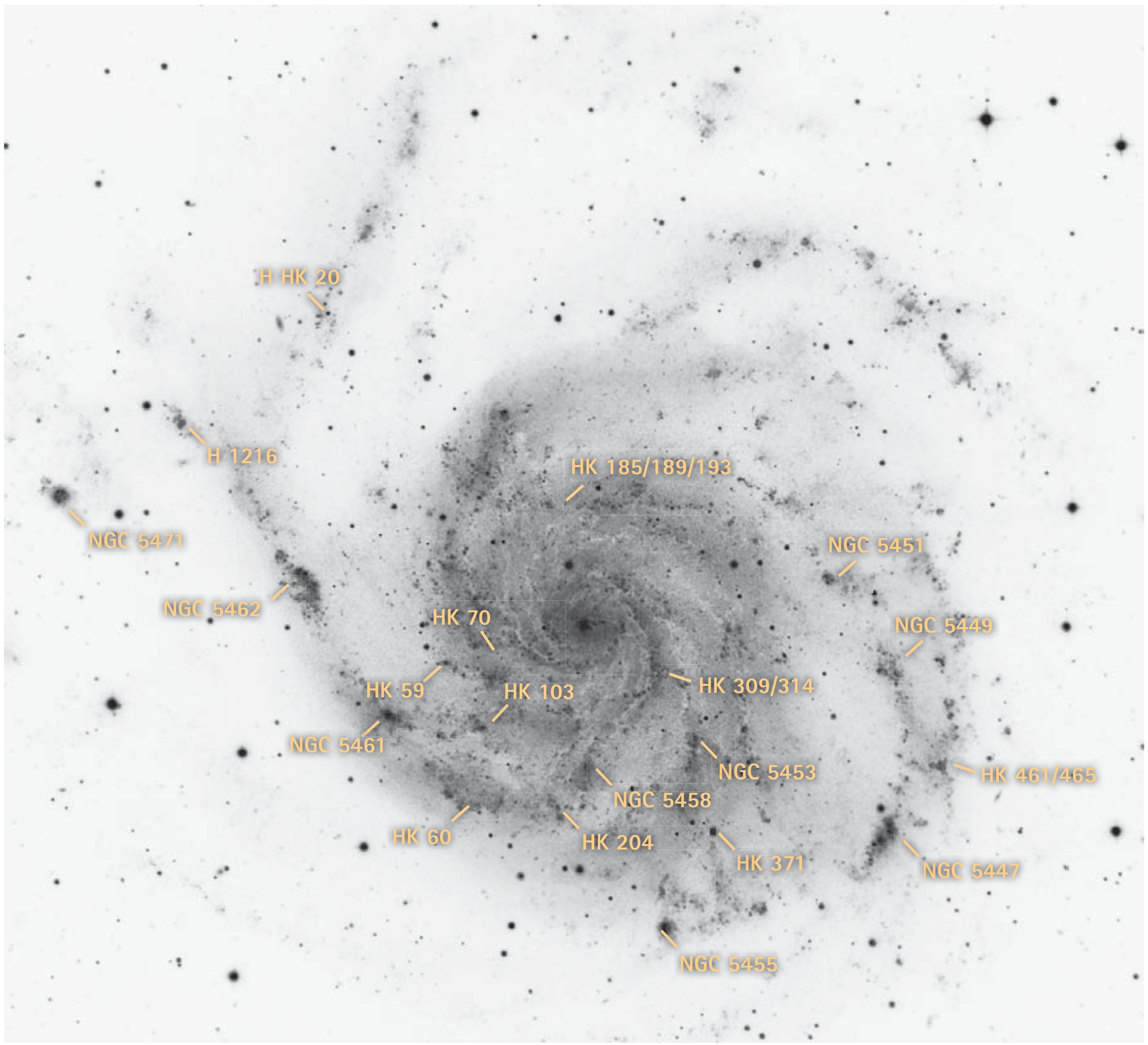
M 101. The Pinwheel Galaxy is mottled with red HII regions, the brightest of which have NGC numbers of their own. Josef Pöpsel.

A small refractor shows M 101 as a pale, oval patch with a bright nucleus and no further structure. Under a dark sky, the vast size of this galaxy reaches 2/3 of the lunar disk.

A 4.7-inch refractor reveals the brightest star clouds and nebulae in M 101. The joint patch of NGC 5447 and NGC 5450 appears elongated, NGC 5455 stellar in a pale background, and NGC 5461 and 5462 are visible as small spots. They indicate the outline of the southwestern spiral arm.

With 14 inches aperture, M 101 has gained so much detail that a whole night is required to record it all. The spiral pattern remains weak and is best seen as chains of knots rather than well-defined arms. The eastern spiral arm makes a full turn around the galaxy. It starts 10' northeast of the nucleus, at H 1216 (Hodge, 1990), which appears almost stellar but very faint. Nearby NGC 5471 looks much like a magnitude 13.7 star. The arm is a faint glow here, which reaches NGC 5462, an oval, clumpy nebula of 1' length and magnitude 14.0. Further on towards the core, there is NGC 5461, which is a bit smaller than NGC 5462 but clearly visible. Both these NGC objects gain by the use of narrowband filters. From here on, the spiral arm is wider and splits up: its southern part is marked by star-like HK 60 and the bent spot NGC 5458, where it turns north. The northern part appears mottled with HK 103. The spiral arm reunites southwest of the galaxy core, passes it in the west and leads to HK 309/314, which appears stellar. After another turn here, the arm merges with the brighter, central region; nearby is a 12th-magnitude foreground star.

The southern spiral arm makes only a half-turn. It starts at NGC 5455, visible with 15.0 magnitudes, very compact and of almost stellar appearance. Next is HK 371, also star-like, and then the slightly diffuse patch of NGC 5453. There are two faint foreground stars further to the north, and the spiral arm now turns east, then south and finally

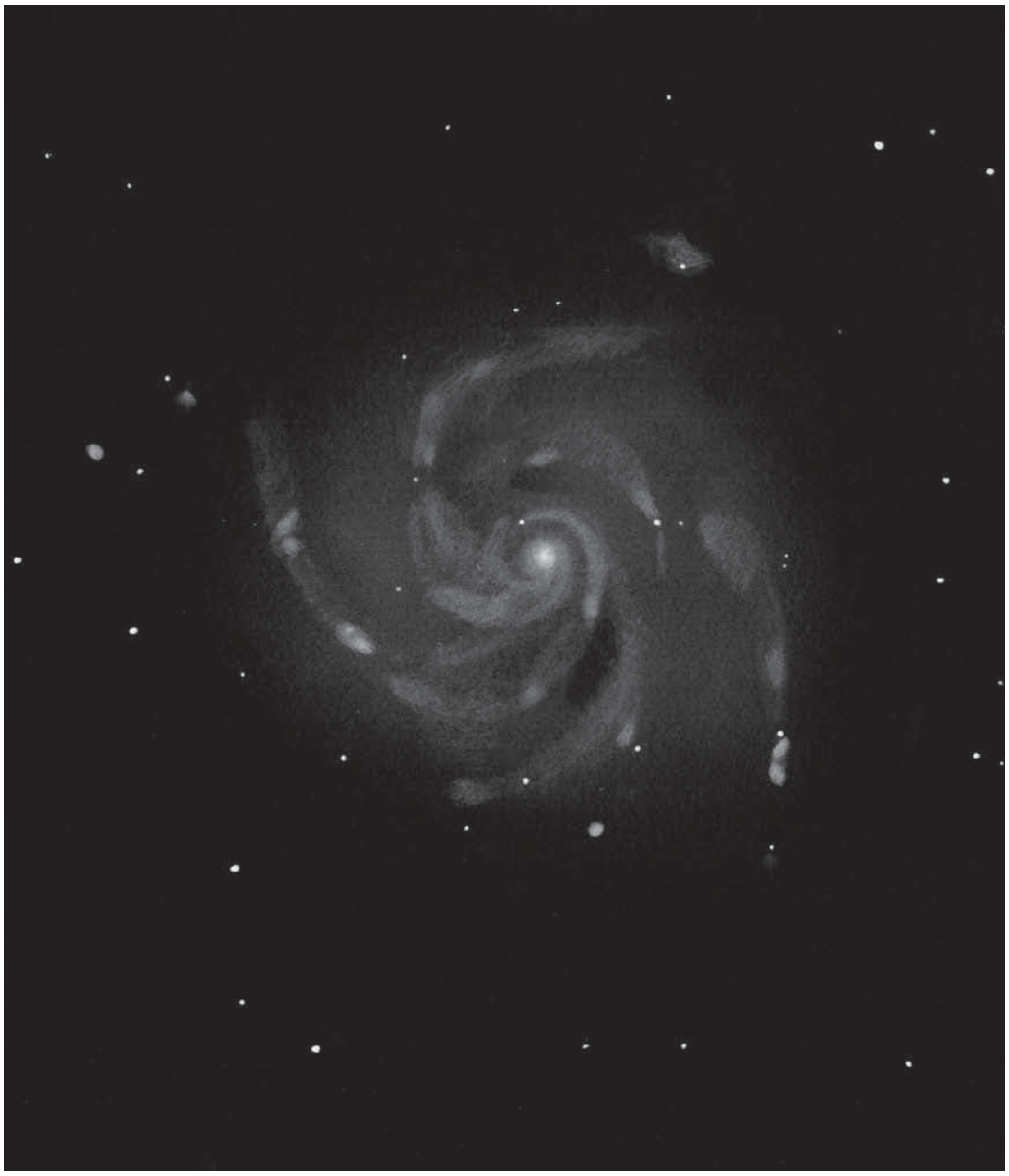


Individual objects in M 101				
Designation	**R.A.**	**Decl.**	**Magnitude**	**Size**
HK 461/465	14h 2min 23.9s	+54° 17' 47"		
NGC 5449	14h 2min 27.3s	+54° 19' 49"		30"
NGC 5447	14h 2min 27.9s	+54° 16' 35"		80"
NGC 5451	14h 2min 37.0s	+54° 21' 45"		
HK 371	14h 2min 54.3s	+54° 16' 26"	13.8	
NGC 5453	14h 2min 56.4s	+54° 18' 29"		
NGC 5455	14h 3min 01.1s	+54° 14' 29"	15.3	
HK 309/314	14h 3min 02.2s	+54° 20' 03"	13.9	
NGC 5458	14h 3min 12.4s	+54° 17' 55"	15.5	
HK 70	14h 3min 25.0s	+54° 19' 50"		
HK 103	14h 3min 27.2s	+54° 18' 45"		
HK 70	14h 3min 30.6s	+54° 20' 38"		
HK 60	14h 3min 32.4s	+54° 17' 21"		
HK 59	14h 3min 33.8s	+54° 20' 26"		
NGC 5461	14h 3min 41.1s	+54° 19' 05"	14.2	40"
HK 20	14h 3min 49.4s	+54° 27' 38"		
NGC 5462	14h 3min 53.0s	+54° 21' 56"	14	60"
H 1216	14h 4min 12.4s	+54° 25' 27"		
NGC 5471	14h 4min 29.0s	+54° 23' 48"	13.7	15"

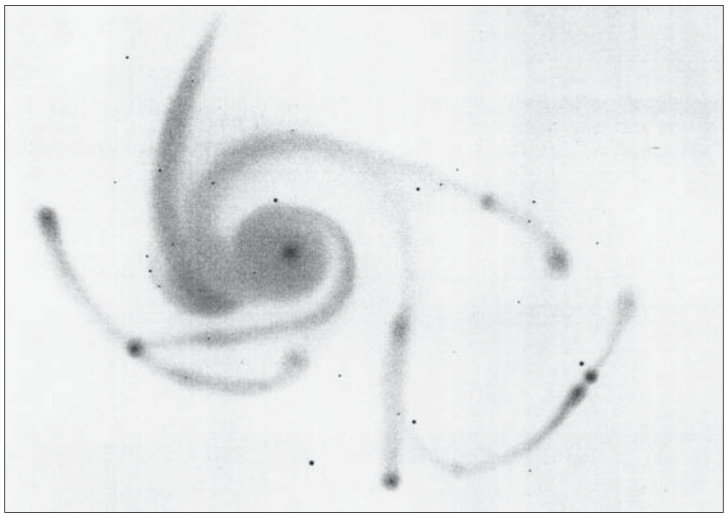
merges with the central region, east of the nucleus.

The western spiral arm is quite faint in its middle part. Its beginning is marked by NGC 5447 and NGC 5450, which is the largest super-association in M 101 with an irregularly narrowing figure pointing south and a faint star on its northern edge. This patch is divided in about its middle by a dark lane, which leads to the two separate NGC entries, with NGC 5450 being the southern object. Further on, HK 461/465 appears small and faint. North of it is NGC 5449, which in photos is distinctly resolved into two knots, but is an oval patch in a 14-inch telescope. NGC 5451 is small and slightly elongated. The spiral arm becomes invisible further north, but continues north of the galaxy center, where it turns south and becomes wider and brighter. HK 70 here appears only stellar. The spiral arm now marks its southern turning point and merges with the bright central region, not far from the eastern arm.

Deep photographic exposures show even more structure and the galaxy is stretched out over 25’.



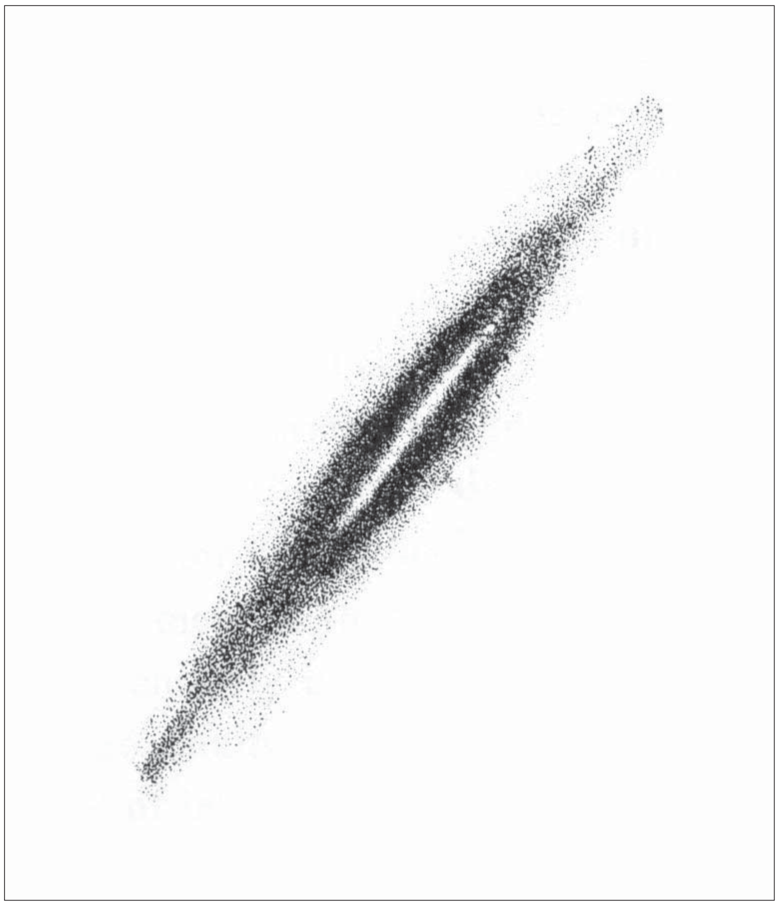
M 101, drawing. 14-inch Newtonian. Ronald Stoyan.



M 101, historical drawing. Lord Rosse (1861).

M 102

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 5866
Type	Galaxy
Class	S0
Distance	40.8 Mly (2003)
Size	71,000 ly
Constellation	Draco
R.A.	$15^h\ 6.5^{min}$
Decl.	+55° 46'
Magnitude	9.9
Surface brightness	20.8mag/arcsec^2
Apparent diameter	6,5'×3,1'
Discoverer	Méchain, 1781



M 102, historical drawing. Lord Rosse (1848).

History

On the 27th of March 1781, Pierre Méchain reported another discovery: "Nebula between the stars ο of the Herdsman and ι of the Dragon: it is very faint; near it is a star of the sixth magnitude." Messier added this object to his last catalog, as his No. 102, in a last-minute appendix. The confusion about this object started two years later, on the 6th of May 1783, with a letter by Méchain, who wrote to Bernoulli in Berlin: "M. Messier lists under No. 102 a nebula which I have discovered between Omicron Boötis and Iota Draconis; this is a mistake. This nebula is the same as the preceding No. 101. Mr. Messier, due to an error in the sky charts, has confused this one in the list of my nebulous stars communicated to him."

So, does M 102 = M 101? This remains a debated issue, but it appears quite likely that Messier, searching for an object at the erroneous position given by Méchain actually did find a new nebula there: NGC 5866. Messier's description of M 102 does not match the appearance of M 101 (see discussion on page 36), and NGC 5866 is in the right place and of sufficient brightness to be the object seen by Messier. This is now a commonly accepted view in Europe and, hence, the author does not believe that M 102 is just a doubling of M 101.

William Smyth saw this galaxy as a "bright-class oval nebula. It is rather faint at the edges, though not so as to obscure the form." Lord Rosse studied M 102 with his giant telescope in 1848 and commented: "A very bright resolvable nebula, but none of the component stars to be seen distinctly even with a power of a thousand. A perfectly straight line and longitudinal division in the direction of the major axis. Resolvability most strongly indicated towards the nucleus."

In 1918, Curtis gave his description, based on the first photographs of this object: "No spiral structure is discernible, but it appears to be a spiral of the Andromeda type seen edgewise. Its most striking feature is a narrow, clear-cut dark lane along the middle, making a slight angle with the major axis."

Astrophysics

M 102 is a beautiful example of a spindle-type galaxy, seen edge-on. Based on over-exposed photos, it was at first misclassified as an E6-type, elliptical galaxy. De Vaucouleurs corrected that to SA0sp, and modern notations now simply use S0. The galaxy has a disk and a central bulge like a spiral galaxy, but it lacks spiral arms. Japanese scientists have concluded that the disk is composed of relatively young stars, while the bulge contains old stars, like in our own galaxy.

The orientation of M 102 is so exactly edge-on that the dust lane in the galaxy's plane appears as a remarkably sharp, 3" thin, black line. In 1959, Burbidge found a slight warp in this dust lane. Recent studies (Kacprazk, Welch 2003) focused on the continuing star formation in the disk and concluded that it would be fed by stellar winds, planetary nebulae, and supernovae from the already existing stars – a recycling of stellar material, so to speak. Ciardullo and colleagues (2002) found 11 probable planetary nebulae in the halo of M 102 and used them to derive a distance of 45 million light-years; a study in the following year adopts a value of 41 million light-years. With this, M 102 has a physical diameter of 71,000 light-years.

M 102. We see this spindle-type galaxy almost edge-on. Volker Wendel.

M 102 is the brightest galaxy in a small group of its own, which also includes the nice edge-on galaxy NGC 5907, and the objects NGC 5879, 5866B, 5862, 5905, 5908, IC 1099, and UGC 9776. NGC 5866A, however, is a faint, unrelated foreground galaxy. To the present day, no supernova has been found in M 102. The very faint background galaxy NGC 5867 lies 2' south of the center of M 102.

Observation

In 10×50 binoculars, M 102 is just a faint and tiny smudge. However, thanks to its high surface brightness, it is distinct and elongated (PA 130°) even in a small refractor. There is an 11th-magnitude star 1.6' northwest of the galaxy. But it requires a moderately large telescope to recognize the spindle form with its slender tips and the embedded oval core. A faint 13th-magnitude star lies 1.5' southwest of the galaxy, along its minor axis.

With a 14-inch telescope and high magnification, M 102 is an impressive sight. The straight and fine – less than 10" wide – dark absorption line cuts right through the middle of the brightest part of the galaxy, creating a stunningly symmetrical appearance. On close inspection, the northern half of the galaxy is vaguely brighter. The total visual size of the galaxy reaches 4.5'×1.5', but the absorption line can be recognized only over a partial length of 1.5'. Here, the central region of 2'×0.8' size has a high surface brightness. A very faint 15th-magnitude star is visible 1.5' north of the galaxy core.

M 102, drawing. 14-inch Newtonian. Ronald Stoyan.

M 103

Degree of difficulty	3 (of 5)
Minimum aperture	30mm
Designation	NGC 581
Type	Open cluster
Class	II2m
Distance	7150 ly (K2005) 9790 ly (CMD, 1999) 5220 ly (CMD, 1998)
Size	17 ly
Constellation	Cassiopeia
R.A.	1^h 33.4^{min}
Decl.	+60° 40'
Magnitude	7.4
Surface brightness	–
Apparent diameter	6'
Discoverer	Méchain, 1781

History

M 103 is the last entry of Messier's original list. It made it into a last-minute annex with M 101 and M 102, after its discovery by Pierre Méchain on the 27th of March 1781, when the catalog of originally 100 nebulous objects was already set up for printing. Méchain recognized it correctly as a "Cluster of stars between ε and δ of the leg of Cassiopeia."

50 years later, Admiral Smyth described M 103 as a "fan-shaped group, diverging from a sharp star in the north following [northeast] quadrant. The cluster is brilliant from the splash of a score of its largest members, the four principle ones of which are from the 7th to the 9th magnitude; and under the largest, in the southeast, is a red star of the 8th magnitude." A similar view, expressed in fewer words, had d'Arrest: "A pretty, reddish star stands out, of a rosé tint. An uneven cluster, consisting of stars of 9th, 10th, and 11th magnitude." Leo Brenner observed M 103 with a 7-inch telescope and noticed its double star: "pretty with magnification 93×, triangular, with pretty double star magnitudes 6 and 10, 13" to 14" separation, furthermore a beautiful red star of 8th magnitude, otherwise stars of 9th to 10th magnitudes."

Astrophysics

With a likely distance of 7200 light-years, M 103 is about as far away as the famous double cluster h and χ in the Perseus arm of the Milky Way, and it is the farthest open cluster in the Messier catalog. The interstellar extinction, probably 1.5 magnitudes, makes precise distance and age determinations for M 103 difficult. Shapley characterized this object as a loose and poor cluster, and he even questioned its physical existence, but Wallenquist recognized 40 member stars. Sanner et al. (1999) studied 228 stars brighter than magnitude 14.5 in a field of 10' radius and confirmed 77 of them as cluster members.

The brightest cluster star, at the northern tip, is a blue giant. It has magnitude 7.2 (or about 40,000 solar luminosities), a spectral type B5 and two companions, one of which is a Be star. The second-brightest star (magnitude 8.5) of the cluster is a red M1 giant with 10,000 solar luminosities. Earlier sources claimed that these stars were not physical members of M 103, but Sanner et al. (1999) confirmed the membership of both. They also showed that the bright star which marks the southeastern corner of the cluster, a suspected variable, does not belong to it. A group of Polish astronomers discovered six variables in M 103.

In 1993, G. Meynet derived an age of 25 million years for M 103. According to Sanner et al. (1999), the cluster is probably even younger, 16 million years. The true cluster diameter is 17 light-years, and the Trümpler classification is II3m, according to Trümpler himself, or II2m, according to Götz.

M 103 is part of the young (age 20 to 25 million years) Cas OB8 association. Other members are the neighboring clusters, in order of increasing age, NGC 654, 659, and 663. The brightest star in that association is the giant HD 9973 with magnitude 6.9 and spectral type F5.

Observation

Even through 8×30 binoculars, M 103 is visible as a compressed, mottled patch of light, not far northeast of the bright star δ Cas. A small refractor shows half a dozen stars in a triangular arrangement. At low power, M 103 is just one of many highlights in a rich star field, which includes NGC 663, 654, 659, and Trümpler 1 – all these objects are confined within a 3° radius.

A medium-sized telescope shows 20 to 30 stars, which are densely packed into a triangular shape. The colors of the stars become well perceivable with a 14-inch telescope. A red star near the cluster center contrasts nicely with a white-golden star at the southwest corner. The bright double star at the northern tip (Σ 131, ADS 1209) is white. It has a blue companion of magnitude 10.9, separated by 13.8" (PA 142°), and another magnitude 10.9 star, twice as far away in the same direction (28.2", PA 145°). A much fainter double star can be found in the southeastern part of the cluster: Stein 232 consists of two stars magnitudes 11.9 and 14.4 with a separation of 12.3", PA 20°.

M 103 impresses with member stars of different colors. Stefan Seip.

M 104

The Sombrero Galaxy

Degree of difficulty	3 (of 5)
Minimum aperture	50mm
Designation	NGC 4594
Type	Galaxy
Class	Sa
Distance	44.7 Mly (2003) 27.9 Mly (2001) 31.9 Mly (2001)
Size	105,000 ly
Constellation	Virgo
R.A.	$12^{h}\ 40.0^{min}$
Decl.	–11° 37'
Magnitude	8.0
Surface brightness	20.5mag/arcsec^2
Apparent diameter	8,7'×3,5'
Discoverer	Méchain, 1781

History

M 104 was discovered on the 11th of May 1781, by Pierre Méchain, who noted: "nebula which did not appear to me to contain any single star. It is of a faint light." Messier knew about Méchain's discovery, since he added a hand-written note of it to his printed copy of his final catalog, and it is likely that he observed this object himself. However, this object came too late to make it into the original catalog. Finally, the well-known French popular astronomy writer Camille Flammarion found Messier's note in 1921 and awarded this galaxy the merits of a Messier object.

William Herschel was able to see much more of M 104 than Méchain. He described it as "A faint diffused oval light" and observed the dark lane bisecting the galaxy. His son John confirmed in 1833 "that there is a dark interval or stratum separating the nucleus and general mass of the nebula from the light above it. Surely no illusion."

A few years later, Admiral Smyth speculated: "This must be another of those vast flat rings seen very obliquely, already spoken of, and is an elegant example of that celestial perspective." Heinrich d'Arrest, however, saw just a "bright ray, small nucleus like a star of 10th magnitude." It took the first deep photographic exposures in the early 20th century to reveal the full beauty of this galaxy. Curtis wrote: "A remarkable, slightly curved, clear-cut dark lane runs along the entire length to the south of the nucleus; probably the finest known example of this phenomenon. There are very slight traces of spiral whorls." M 104 became the first galaxy known to have a large radial velocity in 1912, when Vesto M. Slipher obtained a value of 1000 km/s away from us. The modern value (Burkhead, 1986) is 625 km/s. In addition, Slipher discovered the rotation of this galaxy from Doppler-shift measurements across M 104.

Astrophysics

Remarkably, the distance of this famous spiral galaxy still remains unclear. The latest values range from 28 to 45 million light-years. In any case, M 104 is not a member of the Virgo cluster but a foreground object. We see it edge-on, at an angle of only 6° south of the galaxy's plane. From this perspective, the dark dust lane dominates the view. The many micron-size dust particles alone have an estimated mass of, at least, 10 million Suns, and the whole galaxy contains several hundred thousand million solar masses.

Short exposures show, despite the edge-on perspective, well-defined spiral arms near the core region. Hence, in 1951, Lindblad characterized M 104 as a multiple-arm spiral with fragmented spiral arms. Hubble classified it (in 1961) as between types Sa and Sb. Today, however, M 104 is instead considered to be a transitional object between a spiral and an elliptical galaxy. Very deep exposures taken by David Malin show an extended halo of elliptical shape, partially deformed by interaction with neighboring galaxies.

The center of the galaxy hosts a super-massive object, probably a black hole, which contains a thousand million solar masses. In 1988, M 104 was one of the first such galaxies to be found with this kind of nucleus. That has also become known as a X-ray source, discovered by the Einstein satellite. Hence, M 104 is a LINER galaxy (see M 81), even though the X-ray emission is relatively weak and extended. According to standard accretion theory, this black hole should be 200 times more luminous in X-rays.

The central bulge of M 104 is remarkably pronounced. It comprises about a quarter of all the mass of that galaxy, while the bulge of our Milky Way contains only one seventh of the total mass. In addition, M 104 possesses a very large halo of an estimated 2000 globular clusters, of which 1200 have already been identified. It may be the largest halo of all known spiral galaxies and reaches out to 20' from the galaxy core. The brightest globular clusters reach magnitude 19.1. This globular cluster system has been studied in detail since it may serve as a standard for extragalactic distance measures.

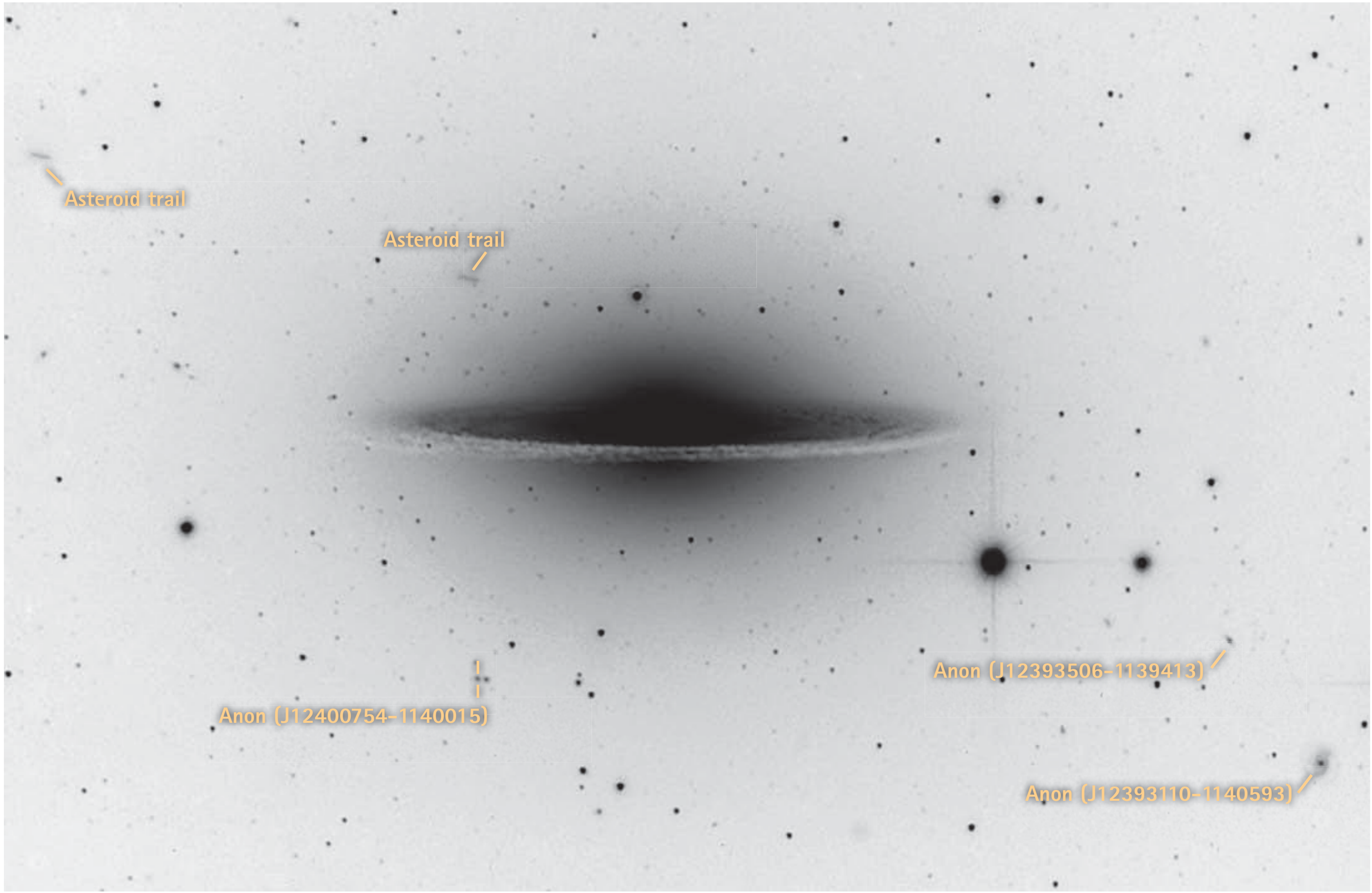
Observation

M 104 is visible as a small, elongated nebulous spot in 10×50 binoculars. Small telescopes show an elongated nebula, while the dust band requires larger apertures. With a 4.7-inch refractor, a strongly elongated (PA 90°) spindle becomes visible, with a sharp southern borderline and a rounded, detached southern part. The dust band makes a vague appearance with indirect vision. It is directly visible, as it cuts off the faint southern part from the bright, extended core, only with 12 inches of aperture and more. It measures about 15" in width. An elliptical halo surrounds the galaxy and reaches a 12th-magnitude star 1.5' north of the core. In total, M 104 has a visual extent of 5'×3', while photographic images show almost twice the size. The brightest globular clusters remain beyond the reach of visual observation, but they look like a swarm of bees in deep photographic exposures of the Sombrero Galaxy.

The double star Σ 1669 lies 1.4° southeast of M 104. With two almost equally bright components of magnitudes 6.0 and 6.1, and a separation of 5.2", it makes a nice object for small telescopes.

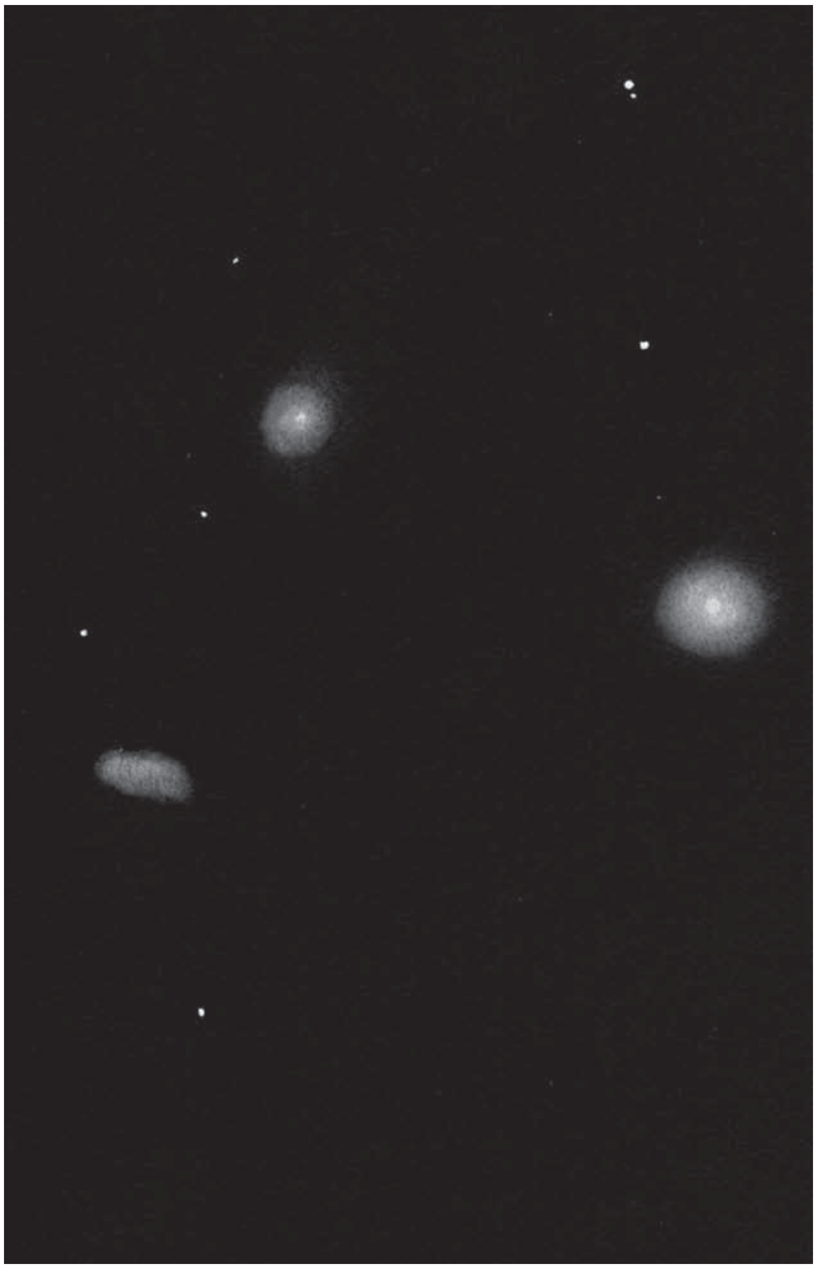
M 104. A swarm of globular clusters surrounds the galaxy. Rainer Sparenberg, Stefan Binnewies.

M 104. The Sombrero Galaxy is dominated by its dust lane, a mere 2500 light-years thick. Volker Wendel, Bernd Flach-Wilken.



M 105

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 3379
Type	Galaxy
Class	E1
Distance	37.9 Mly (2000) 32.8 Mly (PN, 2000) 35.5 Mly (SFB, 2000)
Size	55,000 ly
Constellation	Leo
R.A.	10^h 47.8^{min}
Decl.	+12° 35'
Magnitude	9.3
Surface brightness	21.0mag/arcsec^2
Apparent diameter	5,4'×4,8'
Discoverer	Méchain, 1781



M 105, drawing. 14-inch Newtonian. Ronald Stoyan.

History

M 105 was discovered by Pierre Méchain on the 24th of March 1781, just a few days after the neighboring galaxies M 95 and M 96. He reported this in a letter to Bernoulli: "Mr. Messier mentions two nebulous stars, which I have discovered in the Lion. There is, however, a third one, somewhat more northerly, which is even more vivid than the two preceding ones." Messier knew of that third nebula but, apparently, he had not enough time in those last days before his final catalog went into print to observe and include it. Hence, M 105 was added to the Messier list only much later, in 1947, by Helen Sawyer-Hogg.

The mid-nineteenth century observer Reverend Webb described the view of M 105 with his 3-inch refractor as "two faint nebulae, preceding [the western] much larger and brighter, with stellar nucleus." Herschel made out a third, faint nebula, forming with the others "a right-angled triangle." These other two objects are nearby galaxies, as we can read in the description given by Curtis: "This, with NGC 3384 and 3389, forms a striking group, a right-angled triangle whose shorter sides are 7' long. 3379 is nearly round, 2' in diameter; very bright; no spiral structure discernible."

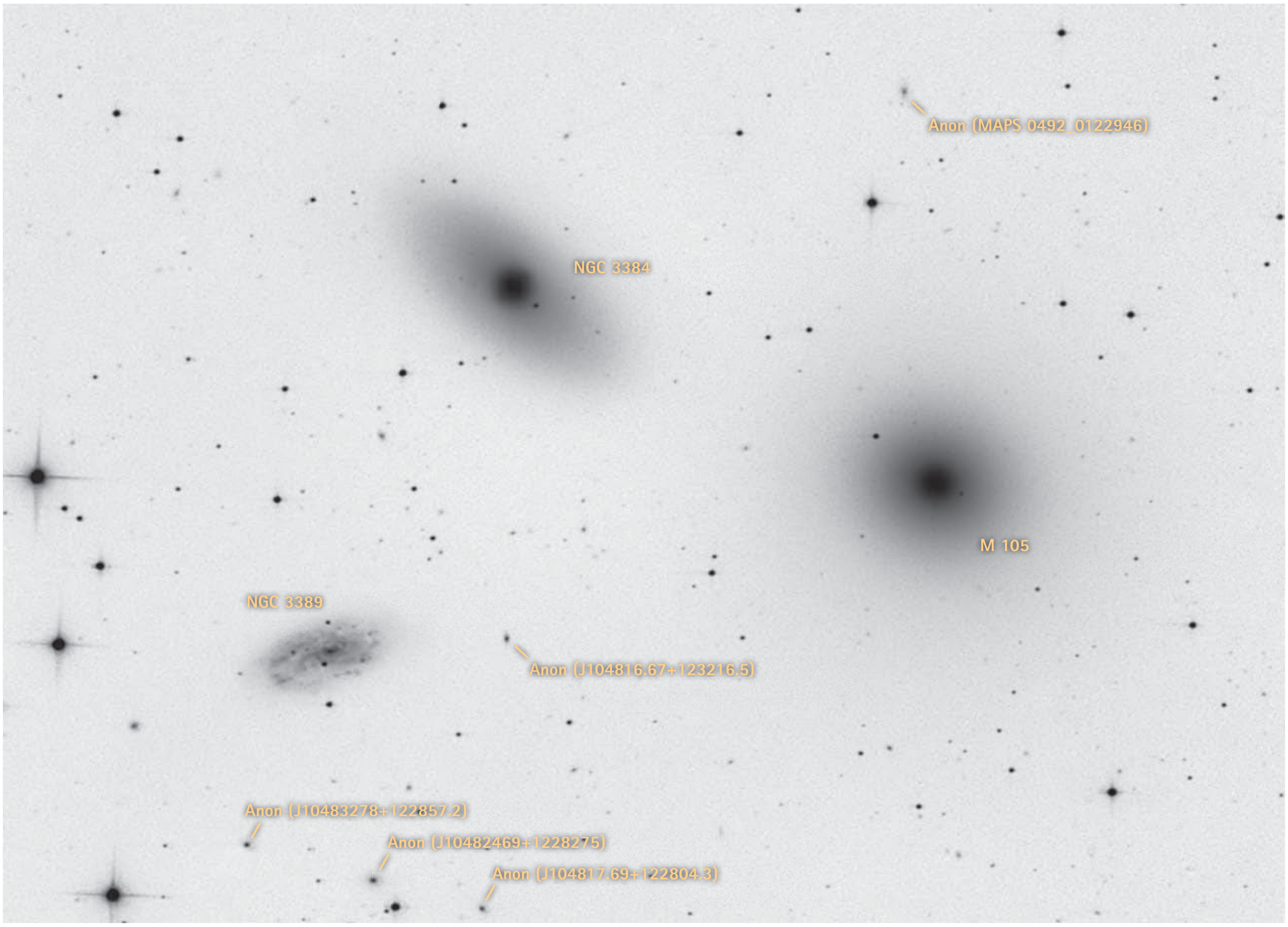
Astrophysics

M 105 is a member of the Leo I galaxy group, together with M 96 and M 95. Consequently, the distance to this elliptical, structureless galaxy is in the range of 33 to 38 million light-years. In projection, if the distances were exactly equal, M 105 would be separated from M 96 by only 450,000 light-years. With about 100 thousand million solar masses, M 105 is almost as massive as the Milky Way, but at 55,000 light-years in diameter, it is much smaller in size.

Because of its textbook elliptical appearance and lack of structure, M 105 is used as a photometric standard for the density distribution in elliptical galaxies. According to van den Bergh, it is the best-studied elliptical galaxy of all. Nevertheless, Capaccioli claimed in 1987 that it should be classified as an S0-type (spindle) galaxy or, at least, as an oblate elliptical seen face-on.

High-resolution images of the core of M 105, obtained with the Hubble Space Telescope, have revealed a dark band-like structure near the nucleus. The stars here are in fast orbits around the galaxy's center, which indicates a super-massive object there, possibly a black hole of 200 million solar masses. This observation confirms a sugge-

M 105 with NGC 3384 and NGC 3389. Volker Wendel, Bernd Flach-Wilken



stion by Nieto and Vidal made in 1984 after earth-bound observations of the M 105 core region.

There appears to be a relatively small number of globular clusters around M 105. In 1984, Pritchet and van den Bergh counted 140 globular clusters brighter than magnitude 24.5. In 2003, Whitlock confirmed such a low count, finding 133.

The nearby spiral galaxy NGC 3389 has a similar mass, but it is twice as far away as M 105. It shows a considerably larger radial velocity, 1306 km/s (Leo I group: 850 km/s) and is a member of the NGC 3338 galaxy group, formed by NGC 3338, 3389, and 3346. But NGC 3384, by contrast, seems to be a true, physical companion of M 105 and is counted as a Leo I group member.

Observation

In 10×50 binoculars, M 105 is faintly, but unambiguously, visible. The field of a small telescope shows the appealing arrangement of a small galaxy group, formed by M 105 with M 95 and M 96. With at least 2.5 inches of aperture, the fainter galaxy NGC 3384 becomes visible, and the even fainter NGC 3389 requires 4-inches. M 105 itself shows a brighter core and remains round.

In a 14-inch telescope, M 105 appears hardly larger than 1.5' and almost circular. It is characterized by a small but resolved nucleus of 5" diameter. NGC 3384 is a smaller version of M 105, with a 1' diameter and no recognizable elongation. By contrast, NGC 3389 appears clearly elongated (PA 80°) and without a core. Here, too, the visual observer sees only the central region of the galaxy.

M 106

Degree of difficulty	3 (of 5)
Minimum aperture	30mm
Designation	NGC 4258
Type	Galaxy
Class	SAb
Distance	25.7 Mly (H2000) 25.2 Mly (Cepheids, 2001)
Size	135,000 ly
Constellation	Canes Venatici
R.A.	12^{h} 19.0^{min}
Decl.	+47° 18'
Magnitude	8.3
Surface brightness	22.7mag/arcsec^2
Apparent diameter	18.6'×7.2'
Discoverer	Méchain, 1781

M 106, drawing. 14-inch Newtonian. Ronald Stoyan.

History

Pierre Méchain reports his discovery of this nebula in the same letter to Bernoulli, written on the 6th of May 1783, in which he mentions M 102, M104, and M 107. Méchain also informed Messier of his find, but the latter may never have observed M 106. And it was already too late for an entry in his last catalog version, anyway. It was Helen Sawyer-Hogg who suggested in 1948 adding this galaxy to the famous Messier list.

William Herschel appropriately described this object in 1788 as "Very brilliant. Bright Nucleus. With faint milky branches north preceding [northwest] and south following [southeast]. 15' long and to the south following running into very faint nebulosity extending a great way. The nucleus is not round." His son John noted: "Very bright; very large; very suddenly very much brighter toward the middle to an oval nucleus; 8' or 9' long, 4' or 5' broad," and Webb very nicely characterized M 106 as a "scaled-down image of the Andromeda galaxy."

Astrophysics

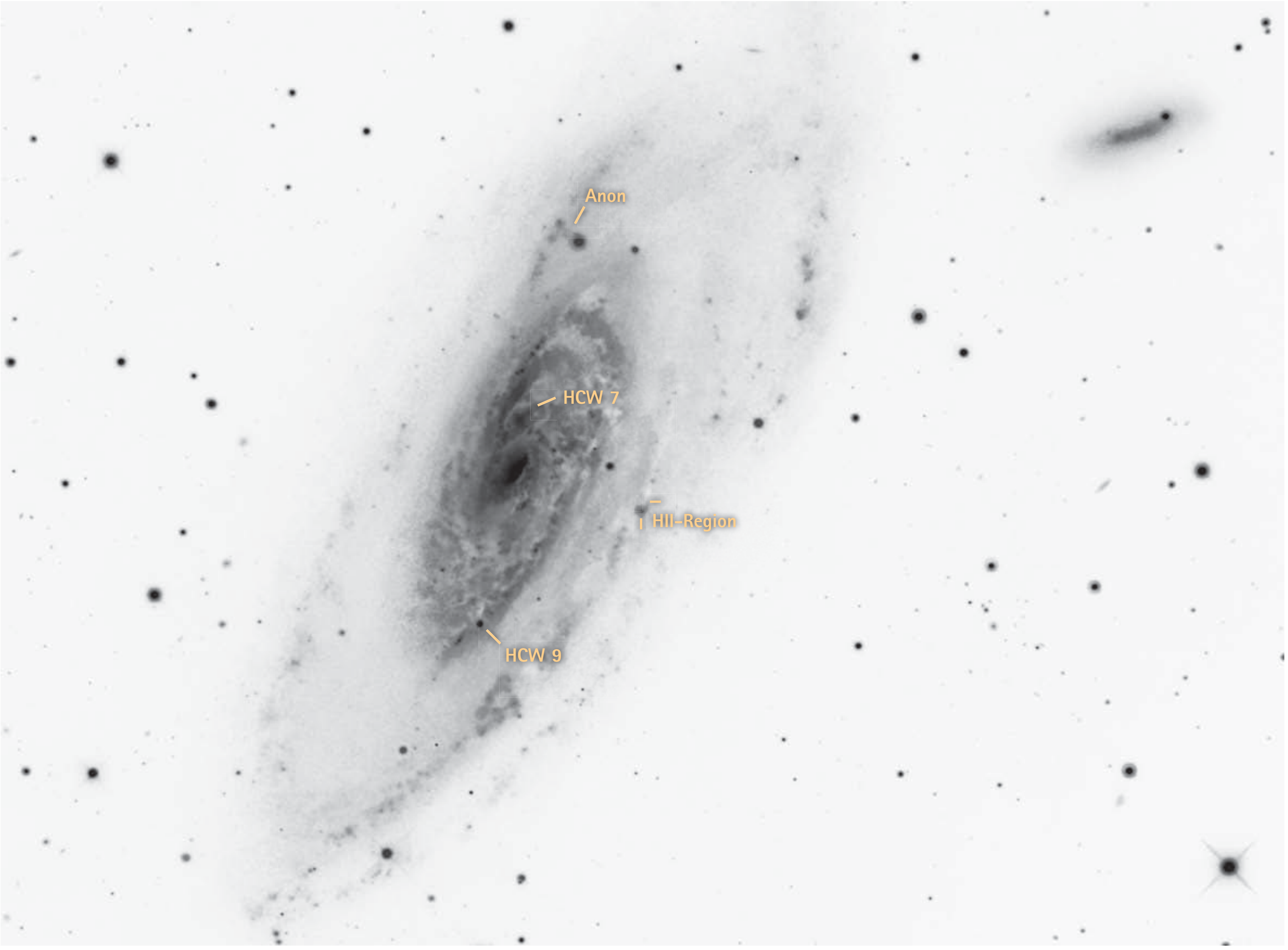
The bright Sb spiral M 106 should be considered one of the finest galaxies of the catalog. According to Sandage, the match by radial velocity (537 km/s) may suggest membership in the Ursa Major group of galaxies, which includes M 108 and M 109. But the most recent distance values of 23.5 to 26.0 million light-years place it half as far away. Such a close distance yields a large physical diameter of 135,000 light-years, in better agreement with the size of other spirals than what it would be at any larger distance. Tully regards M 106 as a member of the Coma-Sculptor galaxy association, which forms a bridge between the M 64 group and NGC 253. M 106 itself is the center of a galaxy group of 17 objects, which include the beautiful edge-on galaxy NGC 4242, the galaxy pair NGC 4485/4490, and the irregular galaxy NGC 4449 in the neighborhood of M 106.

Tully considers M 106 a transitional object between a spiral and a barred spiral and has classified it as SABbc. Most authors, however, agree with Webb's historic remark, and see a strong morphologic similarity to M 31. That has led to a classification of SAb or Spb.

The spiral arms of M 106 are accompanied by prominent clouds of dust that reach to the core. Blue star clusters and red HII regions outline the spiral structure further outside. Courtes et al. (1993) cataloged a total of 137 HII regions in M 106.

Already in 1943, Seyfert discovered characteristic emission lines in the spectrum of the nucleus of M 106, which shows it is a LINER-type galaxy (see M 81), a mild form of a compact, active galactic nucleus. This was confirmed in 1995 when observations with the VLA radio telescope revealed a strong radio source. There is a massive central object, probably a black hole, of about 39 million solar masses (moderate, though, by comparison with other galaxies) and a diameter of only 1/12 to 1/24 light-year (2700 to 5300 AU). It is surrounded by a dense accretion disk and consumes about 1% of a solar mass every year.

M 106 resembles M 31, but it is ten times as far away. Robert Gendler.



In addition, Tully and colleagues (1995) discovered a bipolar jet that leaves the nucleus of M 106, similar to the ones in M 87, which are especially prominent in radio emission. They are inclined by 30° to the galaxy's plane and stimulate motions in the low-density halo gas, which make it plunge into the gas-rich galaxy disk. X-ray images are dominated by apparent "abnormal spiral arms," a projection effect. 2800 and 5500 light-years away from the galaxy nucleus, "hot spots" are formed by the jets where they shock the surrounding halo gas – visible in radio and X-ray emission.

Only one supernova has been observed in M 106, so far. SN 1981K reached magnitude 16 in August 1981.

Observation

M 106 and M51 have the most easily visible spiral structure of all the galaxies in Messier's catalog. Even small 8×30 binoculars show M 106 as a faint nebulous spot. With 2 inches of aperture, it appears bright and distinctly elongated. A core of almost stellar appearance easily shows up in small telescopes.

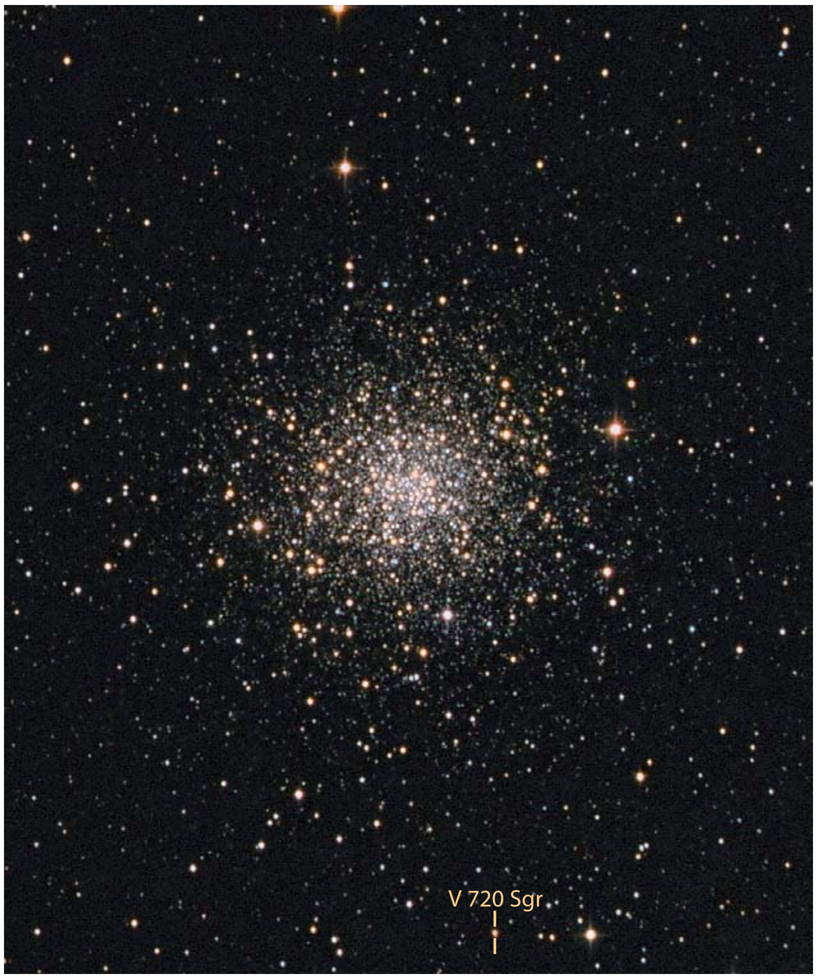
4.7 inches of aperture show the nucleus embedded in a bar perpendicular to the major axis of the galaxy's body. Two spiral arms start at the ends of the bar and run along the northeast and southwest edge of the luminous spindle. The northern arm is the more distinct of the two and reaches out to a star of 11^{th} magnitude 5' north of the galaxy's center.

With larger apertures, M 106 is an object with an impressive richness in detail. Observed with a 14-inch telescope, dark dust lanes spiral outwards. The 15" small core is oval (PA 120°) and leads into the 2.5'-long bar (PA 110°), outlined by the dust lanes. The bar ends are the starting points for two spiral arms, of which the northern is brighter and wider, and the southern appears narrower and straighter. Both arms are structured by dark mottles and bright condensations, the northern arm appears to give way to an inward-spiralling structure. Both spiral arms reach out to 4' on the major axis. Outside is a halo of vaguely visible, faint spiral structure which engulfs the 11^{th}-magnitude star to the north. This gives the galaxy a total visible length of 14' (PA 165°). Photographic images reveal an extent of an impressive 20'!

There are several faint galaxies in the immediate neighborhood of M 106. The nearest is NGC 4248, 13' northwest, which can be seen from 12 inches of aperture and upwards.

M 107

Degree of difficulty	3 (of 5)
Minimum aperture	30mm
Designation	NGC 6171
Type	Globular cluster
Class	X
Distance	27,370 ly (R2005) 32,330 ly (RR Lyr, 2001) 20,230 ly (CMD, 1992)
Size	105 ly
Constellation	Ophiuchus
R.A.	16^{h} 32.5^{min}
Decl.	–13° 3'
Magnitude	7.8
Surface brightness	–
Apparent diameter	13'
Discoverer	Méchain, 1782



M 107 is a typical globular cluster of the galactic bulge. Stefan Heutz, Wolfgang Ries.

History

M 107 is the Messier object with the latest discovery date: it was found in April 1782 by Pierre Méchain, who saw a "small nebula in the left side of Ophiuchus between the stars ζ and ϕ." Méchain informed Messier of this find, but it came much too late for the last edition of his catalog. Messier may not have observed this object himself, but his handwritten notes prove that he knew of it. Hence, in 1948, Helen Sawyer-Hogg suggested adding this globular cluster to Messier's famous list as object No. 107.

In 1793, William Herschel described M 107 as a "very beautiful extremely compressed cluster of stars, extremely rich, 5' or 6' in diameter, gradually more compressed toward the centre." Reverend Webb, observing with a 3" refractor, could only see a "large, faint star cluster, best with low power." From deep photographic exposures, Curtis measured an outer cluster diameter of 8' and a core diameter of 3'.

Astrophysics

M 107 is a globular cluster at a distance of about 27,000 light-years – but older distance values disagree by over 5000 light-years, either way. In any case, M 107 is a globular cluster of the galactic bulge. Its orbit, which is inclined 45° to the galactic plane and takes 100 million years to complete, never leaves the bulge for the galactic halo around it. Globular clusters near the galactic center are usually not as metal-poor as those from the outer halo.

The above distance and its largest diameter in modern deep photographs give M 107 a physical size of 105 light-years. Its total mass is equivalent to only a meager 200,000 Suns, because the concentration of this globular cluster is remarkably low (class X). Deep photos show a few dark absorption patches, and the brightest cluster stars, all giants, reach magnitude 13. The giant branch leaves the main sequence (turn-off point) at about magnitude 15.6. Hence, most cluster stars are even fainter than that. So far, 23 variables are known in M 107.

Observation

M 107 appears bright and almost stellar in 10×50 binoculars. Telescopes with apertures of less than 6 inches show this globular cluster as a nebulous patch without concentration. With a 4.7-inch refractor, the first stars can be made out, and the cluster is well resolved everywhere from 8 inches and upwards. Because of the low degree of concentration, this globular cluster appears loose and of low density; there is hardly a denser center. The brightest stars occupy the northwestern region of the cluster, while a darker zone can be perceived near the southeastern edge. In large telescopes, apparent chains of outer stars may look a bit like the spiral arms of a galaxy.

The Mira variable V720 Ophiuchi lies in the same field as M 107, only 9' south. Its brightness changes semi-regularly with a period of 332 days between magnitudes 12.1 and 17.0.

M 108

Degree of difficulty	5 (of 5)
Minimum aperture	50mm
Designation	NGC 3556
Type	Galaxy
Class	Sc
Distance	46.0 Mly (H2000)
Size	100,000 ly
Constellation	Ursa Major
R.A.	11^{h} 11.5^{min}
Decl.	+55° 40'
Magnitude	10.0
Surface brightness	21.9mag/arcsec^{2}
Apparent diameter	8,7'×2,2'
Discoverer	Méchain, 1781

M 108, drawing. 14-inch Newtonian. Ronald Stoyan

History

This object has no entry of its own in the original Messier catalog, but it is mentioned there in a note on M 97. Pierre Méchain discovered this galaxy on the 19th of February 1781, and Messier observed it on his own three weeks later: "nebula near the previous [M 97], it is even fainter." Hence, this object should have received No. 98, as even suggested so in a handwritten note of Messier. Nevertheless, he changed his mind and did not give it any proper entry in his final catalog; we only find it mentioned in that note on M 97. In 1953, Owen Gingerich suggested adding this object to the original Messier list as its No. 108.

In 1789, William Herschel observed M 108 and described it as "Very bright, much extended, resolvable. 10' long, 2' broad. There is an unconnected pretty bright star in the middle." To Smyth, this object appeared "milky-white" and he wrote: "It is faint but well defined, being much elongated with the major axis trending south preceding and north following across the parallel, and a small star, like a nucleus, in its center." Leo Brenner's note on M 108, after an observation with his fine 7" refractor, uttered doubt about Herschel's claim "resolvable." Furthermore, the colorful amateur of Serbian origin here proved his debated observational skills, as he was able to see the faint companion of the difficult double star in front of the central galaxy region.

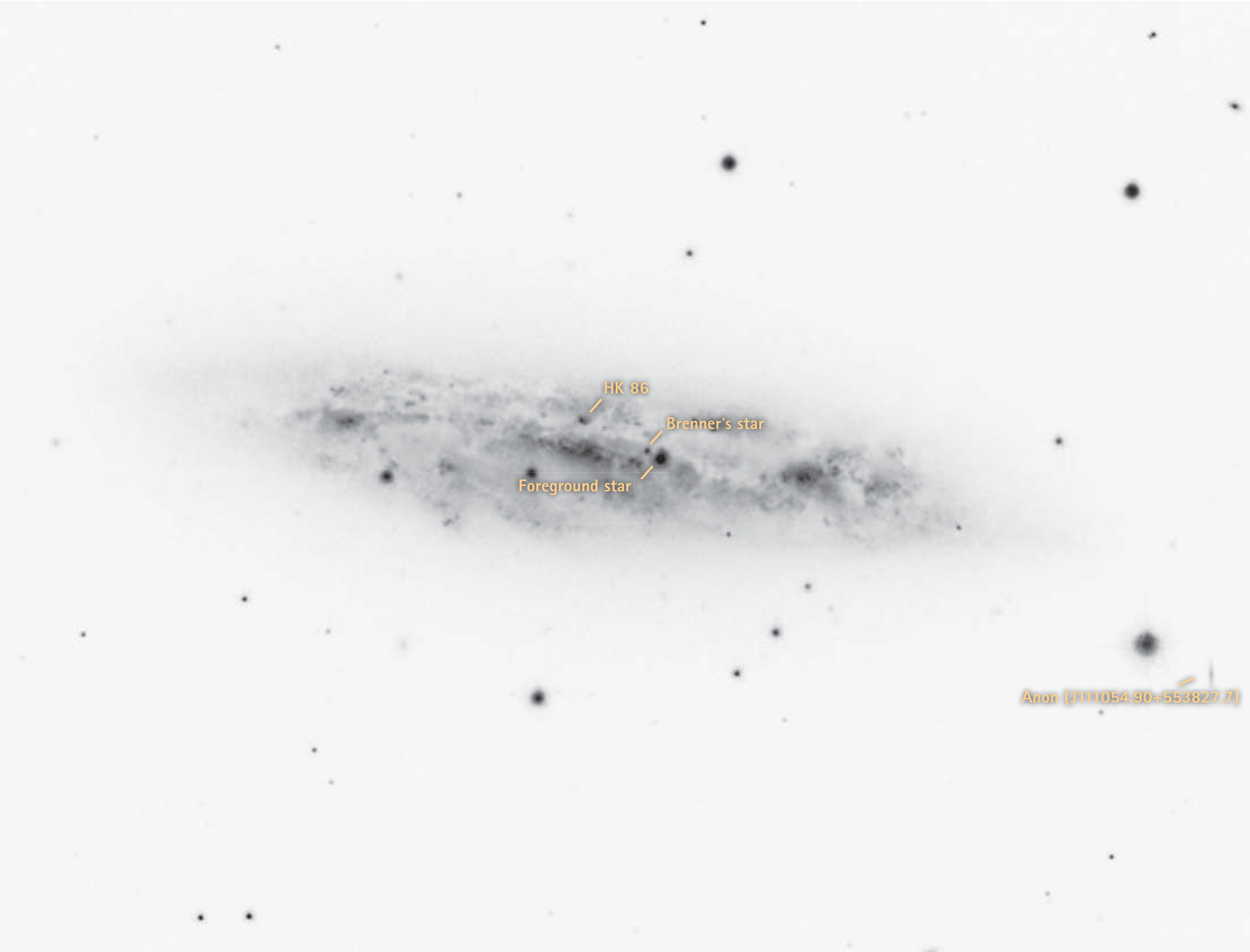
Curtis described M 108, as seen on photographic images, as "an irregular, patchy spiral; quite bright. Has a faint nucleus and shows a number of condensations, three of which are almost stellar; a star of 11th magnitude near the nucleus."

Astrophysics

M 108, together with M 109, belongs to the long-stretched Ursa Major group of galaxies at around 45 million light-years distance. It has a diameter of about 100,000 light-years, and we see it almost edge-on, at an angle of 8° from the galaxy's plane. This perspective makes it difficult to classify, but by general consensus this is a spiral galaxy of type Sc. Tully considered it as a barred spiral (SBcd), and de Vaucouleurs as a transitional object (SAB(s)cd). This galaxy appears as a disk mottled with detail but without a bright center. Along its major axis, there is a conspicuous dark absorption structure. A few HII regions and young star clusters appear against this seemingly chaotic background. There is only little evidence for a well-defined spiral structure.

On both sides of the galaxy, shells of neutral hydrogen have been discovered, 10,000 to 20,000 light-years long. They contain a total mass of 50 million Suns and may have been created by jets from an active galactic nucleus (AGN) about 50 million years ago, but that process would have consumed a lot of energy. Alternatively, Giguere and Irwin have suggested that these shells may be maintained by a large magnetic field. In addition, X-ray observa-

M 108. The bright star near the galaxy's center is a foreground object. Volker Wendel.



tions with the Chandra satellite show a lot of interaction with very hot gas.

The only supernova observed so far in M 108 (SN 1969B, discovered on the 23rd of January 1969) reached a peak brightness of 13.9 magnitudes.

Observation

M 108 is one of the objects with the lowest surface brightness in the Messier catalog. 10×50 binoculars may show this galaxy only with utmost difficulty, very near M 97, 1° southeast. A faint bar of light is visible in a small refractor. In apertures over 6 inches, some irregular structure appears. A 12th-magnitude star near the center is not the galaxy's core but a foreground object. It has sometimes been mistaken for a supernova. After an observation with his 4-inch refractor, John Mallas described M 108 nicely as a "silvery-white beauty, saucer-shaped and very well defined, central region surrounded by bright and dark knots."

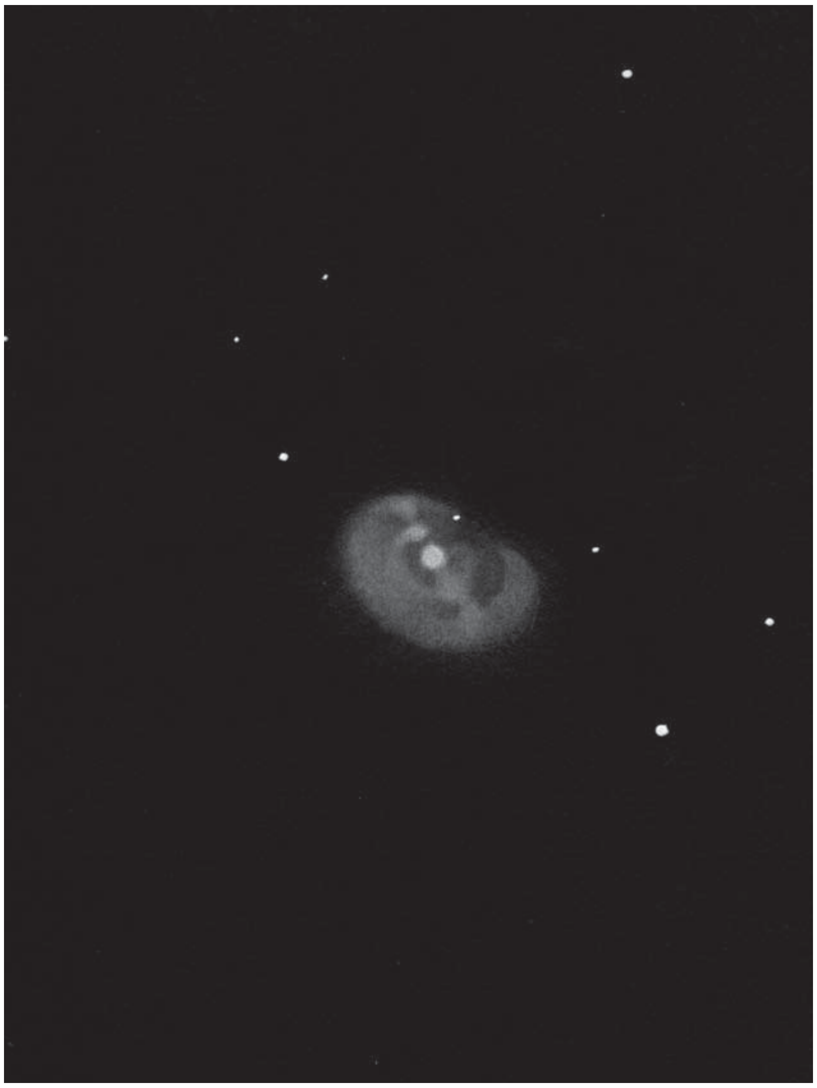
With larger apertures, this cigar-shaped object is characterized by numerous dark and bright structures. Dark absorption bands stretch along the galaxy's body, while the brightest parts are just east of the magnitude-12 star, as well as in the eastern tip. There is a faint star immediately southwest of that tip, and another one half way toward the star near the center, both seen with difficulty through a 14-inch telescope. To resolve the 14th-magnitude companion of the "central star," which was first mentioned by Leo Brenner, requires a mirror of at least 20 inches and over 300× magnification.

Visually, the galaxy reaches a length of 8.5' with an elongation ratio of 8:1. Photographic images of M 108 show a spindle over 10'-long and a halo.

There is an easy double star 11' west of the galaxy's core: h 2560 with two components of magnitudes 9.6 and 12.7 at a separation of 40".

M 109

Degree of difficulty	5 (of 5)
Minimum aperture	50mm
Designation	NGC 3992
Type	Galaxy
Class	SBc
Distance	67.5 Mly (H2000)
Size	137,000 ly
Constellation	Ursa Major
R.A.	$11^h\ 57.6^{min}$
Decl.	+53° 23'
Magnitude	9.8
Surface brightness	22.4mag/arcsec^2
Apparent diameter	7,6'×4,7'
Discoverer	Méchain, 1781



M 109, drawing. 14-inch Newtonian. Ronald Stoyan.

History

Like M 108, this galaxy was not included in the original Messier catalog, but it is mentioned in the same note on M 97 as M 108. Pierre Méchain discovered this galaxy on the 12th of March 1781, and Messier must have observed it himself. A handwritten note in a draft catalog manuscript even suggested it as object No. 99, but it did not make it into the final, printed version as such. In 1953, Owen Gingerich suggested adding this object to the original Messier list as its No. 109.

William Herschel observed M 109 with his large reflectors and described it as “Considerably bright. Bright resolvable nucleus with very faint extended branches to position angle 30° north preceding to south following [northwest to southeast].” John Herschel quoted a visual diameter of 3’.

From the first deep photographs, Heber Curtis described M109 as “a beautiful, slightly oval spiral 7’ in length. Bright, almost stellar nucleus; whorls are rather open and show a number of faint condensations; the central portions show signs of ϕ-type formation.”

Astrophysics

M 109 is a barred spiral galaxy. In the year 2000, a distance of 67 million light-years was derived from cepheid observations. This galaxy is a member of the widely spread Ursa Major group of galaxies. Its 79 members possess only 5% of the mass of the Virgo cluster. With a diameter of 137,000 light-years and an impressive mass of 250 thousand million Suns, M 109 is one of the largest galaxies of that association and forms a galaxy group of its own, with 25 members. In fact, the total mass of M 109 would suggest an even larger luminosity and size, as if the galaxy was rather more distant by 10 million light-years. There are three companion galaxies, of the same type as the Magellanic Clouds, in the immediate neighborhood of M 109: UGC 6923, 14’ southwest; UGC 6940, 8’ south; and UGC 6969, 11’ east.

The bar of M 109 is quite short and it ends soon give way to two spiral arms, which give the central region a θ-shape. Hence, this galaxy has been classified as SBc or SB(rs)bc. Further out, we find four tightly wound spiral arms full of star formation regions; their longest segment makes a 270° turn around the core. Cepa and Beckman (1989) cataloged 394 HII regions.

Thus, the spiral arms are characterized by a generally younger, bluish stellar population, while the bar, by contrast, contains older, reddish stars. In this region, within 50” around the nucleus, there is practically no gas left and star formation ceased long ago. Wilke et al. (2000) explained this in terms of a dynamical effect related to the bar.

On the 17th of March 1956, the only supernova of M 109 (SN 1956A) was discovered – it reached a brightness of magnitude 12.8.

M 109 is the most distant object in the Messier catalog. Volker Wendel.

Observation

M 109 is one of the faintest objects in the Messier catalog. It is at the very limit of 50mm binoculars. A 2.5-inch refractor doesn't show much more than the bright central region 5' northeast of a 10th-magnitude star. Ghost images of the bright star γ Ursae Majoris (Phekda, magnitude 2.4), only 1° away, interfere with the observation.

4.7 inches of aperture show the galaxy elongated with a ratio 2:1, aiming at the 10th-magnitude star. The central region appears brighter, but lacks a nucleus. With larger apertures, a very faint halo can be perceived. With 14 inches, the spiral arms become visible, but only with difficulty. A structureless region north of the core appears as a void. The core is extended, 20" in size and mottled, but discrete structure cannot be grasped. A 12th-magnitude star lies just 1' north of it. Northeast of the center is a brighter condensation that indicates the position where the bar turns into the first spiral arm. The galaxy has a visual extent of 4'×2.5' (PA 55°); photographic images show up to 7.5'×3.5' (PA 70°), with the 11th-magnitude star northeast of the core right outside the edge of the galaxy. No observations of the companion galaxies have been reported so far.

M 110

Degree of difficulty	4 (of 5)
Minimum aperture	50mm
Designation	NGC 205
Type	Galaxy
Class	dSph Irr
Distance	2.57 Mly (see M 31) 2.82 Mly (PN, 2000)
Size	16,000 ly
Constellation	Andromeda
R.A.	0^h 40.4^{min}
Decl.	+41° 41'
Magnitude	8.0
Surface brightness	22.8mag/arcsec^2
Apparent diameter	21,9'×11,0'
Discoverer	Messier, 1773

History

M 110 was discovered by Charles Messier on the 10th of August 1773, but it never occurred to him to include it in his catalog. Almost thirty years after his initial observation, he finally published the following note in the Connaissances des Temps, 1801: "On the 10th of August, 1773, I studied the beautiful nebula in the girdle of Andromeda (No. 31) under a very good sky, using my achromatic refractor with a 68× magnification, in order to produce a drawing like the one for the nebula in Orion. I saw the nebula which LeGentil had discovered on Oct. 29, 1749 (No. 32). In addition, I saw a new, fainter situated north of the large one. It seemed unbelievable to me, that the faint nebula would not have been noticed by astronomers and myself since the discovery of the large one by Simon Marius in 1612, since the small one is in the same field of the telescope when observing the large one." Finally, it was Kenneth Glyn Jones, in 1966, who suggested making this galaxy the last addition to the Messier catalogue, as No. 110.

An independent discovery of M 110 was made by Caroline Herschel on the 27th of August 1783. Her brother William then described her object as "a very considerable, broad, pretty faint, small nebula. It shows the same faint color as the great one, and is, no doubt, in the neighbourhood of it." Admiral Smyth characterized M 110 in 1836 as "a large faintish nebula of an oval form," and Reverend Webb wrote: "Large faint oval nebula, best with low powers, a very large field includes it with M 32 and M 31. Seems to sparkle."

The description by Curtis, based on the first deep photographic images, mentions the two absorption patches (see below), and also "traces of rather irregular spiral structure."

In 1932, Hubble discovered eight globular clusters in his photographs of M 110, and Walter Baade was the first, in 1944, to succeed in resolving this galaxy into individual stars. He was using the 2.5m Hooker Telescope on Mt. Wilson, and two war-related circumstances actually assisted him: the ordered blackout of nearby Los Angeles, and that his native colleagues were drawn by the US army while he, a German immigrant, was not wanted and could continue to use the telescope. Baade noticed that reddish stars make up most of the suns in M 110 and M 32, which helped him to develop his theory of two different stellar populations, I and II. It was also he, in 1951, who studied the two dark nebulae in M 32 and discovered a dozen related young bright stars in the galaxy's core – in apparent contradiction to the mass of old, reddish stars around them.

Astrophysics

M 110 is, like M 32, a physical companion of the great Andromeda Galaxy, M 31, and has about the same distance of 2.5 million light-years. It contains about 10 thousand million solar masses, which make it the largest companion of M 31. However, with its diameter of only 16,000 light-years, it still is a dwarf within our local galaxy group. Sidney van den Bergh coined the expression "spheroidal galaxy" for M 110, as well as for the fainter M 31 satellites NGC 147 and NGC 185, and Sandage would even classify M 110 as an S0-type galaxy. Modern terminology classifies M 110 as a spheroidal dwarf galaxy, by contrast to earlier characterizations as an elliptical dwarf of type E5 or E6.

In 1973, Hodge cataloged a total of twelve dark nebulae in M 110 and described its general shape as elliptical, deformed by tidal interaction with M 31. Corradi and colleagues (2005) found 75 planetary nebulae in the field of M 110. After deduction of those belonging to M 31, they concluded that 35 belong to M 110.

The only recognizable structures in this galaxy are the two dark patches near its center. These dust-clouds are rather atypical features for an elliptical or spheroidal dwarf galaxy, which has lost most of its interstellar gas and dust during encounters with the main galaxy – as

Possible globular clusters in M 110

Designation	R.A.	Decl.	Magnitude
G 9 / Bol 291	0^h 36^{min} 05.0^s	+42° 02' 09"	16.6
G 11 / Bol 293	0^h 36^{min} 20.5^s	+40° 53' 37"	16.3
G 41 / Bol 317	0^h 39^{min} 55.5^s	+41° 47' 47"	16.5
Bol 320	0^h 40^{min} 15.5^s	+41° 48' 30"	18.2
G 73 / Hubble 3 / Bol 20	0^h 40^{min} 55.6^s	+41° 41' 32"	14.9
G 51 / Hubble 5 / Bol 324	0^h 40^{min} 20.8^s	+41° 40' 50"	16.9
Bol 326	0^h 40^{min} 23.6^s	+41° 41' 10"	18.0
G 53 / Bol 327	0^h 40^{min} 24.1^s	+40° 36' 22"	16.6
Bol 329	0^h 40^{min} 24.5^s	+41° 47' 22"	18.4
G 54 / Bol 328	0^h 40^{min} 24.9^s	+41° 40' 23"	17.6
G 56 / Bol 330	0^h 40^{min} 25.6^s	+41° 42' 53"	17.7
G 57 / Bol 331	0^h 40^{min} $26,4^s$	+41° 42' 05"	18.2
Bol 333	0^h 40^{min} $29,6^s$	+41° 40' 26"	19.1
G 61 / Bol 9	0^h 40^{min} 31.2^s	+41° 36' 57"	16.9
G 63 / Hubble 2 / Bol 11	0^h 40^{min} 32.6^s	+41° 39' 19"	16.8
Bol 450	0^h 40^{min} 47.0^s	+41° 40' 32"	19.0

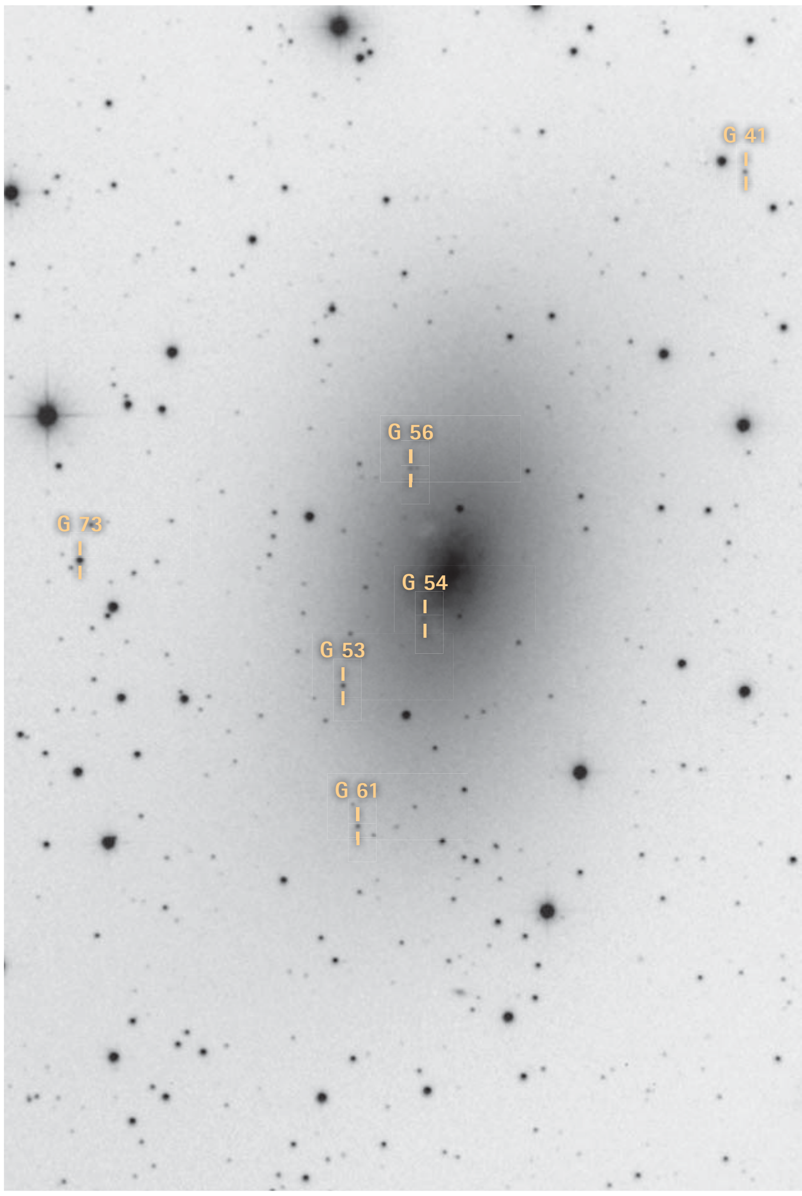
M 110. The companion of M 31 features dark, absorbing clouds near the center. Gerald Rhemann, Michael Jäger.

has M 110, in which the normal star formation stopped about 500 million years ago. However, a recent close encounter must have sparked the formation of the young B stars, now 10 to 20 million years old, within a 40” radius from the center. Some of these stars have already developed into red giants, and the nearby dust clouds seem to be fed by the collective stellar mass loss of these young stars. The vast majority of the stars in M 110, however, are old, yellowish suns. Among them, 30 RR Lyrae variables, well known from globular clusters, have been found and cataloged.

The remaining interstellar gas in M 110 has about one tenth of the normal gas density in a galaxy and rotates against the rotational sense of the stars, which probably is another consequence of the last encounter with M 31. In addition, very deep exposures show a faint light bridge between M 31 and M 110. This 1°-long stream of stars begins in the northwest quadrant of M 31, and it is recognizable by its stars showing M 110 properties (old, reddish), rather than those of M 31. McConnachie et al. (2004) found further observational evidence for this being a direct link between the two galaxies in terms of a stream of stars.

M 110 possesses more than a dozen globular clusters brighter than magnitude 18.5. The brightest is G 73 with a visual apparent brightness of 14.9. Next is G 11, which is over 1° away but is a confirmed member of M 110. Membership is not certain for G 9, G 51, and G 53, which seem to be younger objects not physically related to M 110.

As of 2005, five supernovae have been observed in M 110, all but one in recent years. Zwicky found one in 1957, 7’ north of the nucleus. In 1997, the Peking supernova search project found a new 18^{th}-magnitude star 7’ southwest of the nucleus. The Lick search programme was successful on the 15^{th} of August 1999 with a supernova of magnitude 17.5, 4’ north of the galaxy’s center. In 2002 and 2004, two more supernovae of magnitude 17 were found in M 110. In addition, Shara and Neil estimate a nova rate for this galaxy of two per year.



Observation

Under good conditions, M 110 is visible even in 10×50 binoculars, faint but distinct. In a telescope, it appears as a structureless oval (PA 165°) smudge. Contrary to photographic images, there is no bright core. With 14 inches aperture, a star-like nucleus becomes visible, surrounded by a brighter, elongated central region. The dark structures are vaguely visible with this aperture. A faint star lies directly north of the center on the major axis of the galaxy, which reaches a visual size of 16’×8’. Photographically, an extent of even 26’×16’ can be recorded. The southern end of the ellipse and the light of M 31 are then separated by only 6’. On a very clear mountain night, with a large exit pupil, the light bridge between the two galaxies can be perceived.

The globular cluster G 73 appears as a stellar object with an aperture of as little as 8 inches. Of the fainter globular clusters, only a sighting of G 63 with a 20-inch telescope has been reported. With 14 inches, G 58 can be seen 15’ south of M 110’s core, but this object belongs to M 31.

Glossary of technical terms

Absorption line dark line in a spectrum, caused by the excitation of a bound electron in an atom. The wavelength of the photons captured in this process of *excitation* is given by the energy difference between the lower and upper energy levels and is characteristic of the absorbing atom.

Accretion disk galaxies that host cores which emit extremely large quantities of energy, namely Seyfert galaxies and quasars. The core regions of active galaxies are mostly very small but contain extremely large masses. This suggests the presence of massive black holes.

Active galaxy galaxies that host cores which emit extremely large quantities of energy, namely Seyfert galaxies and quasars. The core regions of active galaxies are mostly very small but contain extremely large masses. This suggests the presence of massive black holes.

Angular measures given in degrees of arc, minutes of arc and seconds of arc (1° = 60' = 3600"). The horizontal circle is devided into 360°, the angle from horizon to zenith is 90°. The apparent lunar angular diameter is about 0.5° or 30'.

Ap star star of spectral type B, A, or F with anomalously strong absorption lines of ionized metals and rare-earth elements. Most of these stars possess a strong magnetic field, inclined against their rotation axis.

Association (of stars) loose group or cluster of stars once formed together, now spread out over some hundred light years. O- and OB-associations are characterized by very hot stars.

Astronomical Unit (AU) mean distance between Earth and Sun; 149,597,870 kilometers or 92,958,000 miles.

Be star star of spectral type B with strong emission lines and fast rotation.

BL Lac(ertae) Object type of active galaxy with a stellar appearance and very large, strongly variable luminosity, but without strong emission lines; related to quasars.

Black hole object with so highly concentrated a mass and such strong gravity that even particles moving at the speed of light, including photons, cannot escape it. Indirect evidence has been found for black holes of stellar mass, of intermediate mass (50–1000 solar masses) and for super-massive black holes in the centers of *active galaxies* (in the range of 10^4 to 10^7 solar masses).

Blue straggler blue, hot star in a globular cluster, which in a Hertzsprung-Russell diagram is plotted above the turn-off point on the main sequence, where all other stars have already left, as a result of their evolution. Blue stragglers appear younger and more massive than the age of the globular cluster would permit, and they are thought to be more recent mergers of close binary stars. Blue stragglers are observed in larger numbers, particularly in those globular clusters which possess very dense central regions.

Cannibalism merging of a smaller with a larger galaxy. Contrary to what this word suggests, only the structure of the smaller galaxy is destroyed, not the individual stars.

Chandra satellite NASA X-ray satellite, launched 1999.

Chandrasekhar limit theoretical upper mass limit of 1.44 solar masses for white dwarfs. This limit makes stars with initial masses of over 8 solar masses end their lives as neutron stars or black holes instead of white dwarfs, despite some considerable mass-loss towards the end of their stellar evolution.

Collision can happen between stars in globular clusters or whole galaxies, see *cannibalism.*

Color-magnitude diagram (CMD) shows apparent magnitudes of the stars of a cluster plotted over their color indices (e.g., blue – visual magnitude). Comparing a CMD with that of a cluster of known distance i.e., the differences in their magnitude scales, gives a measure of distance.

Core collapse dynamical instability in the center of a globular cluster, leading to a relatively sudden increase of the stellar concentration in its core. The distances between cluster stars can shrink to the size of the Solar System i.e., to the distance Sun–Pluto.

Dark matter not directly visible matter, which is noticeable only by means of its gravitational influence. Modern research suggests that there is more dark matter in the universe than there is visible matter.

Doppler shift apparent shift of wavelengths in an electromagnetic spectrum, which is recorded from a source in radial motion with respect to the observer. Increasing distance causes a red-shift towards longer wavelengths, decreasing distance results in a blue-shift.

Dwarf galaxies small galaxies, mostly found as one of many companions to a larger galaxy, to which they are gravitationally bound.

Edge-on galaxy-orientation, pointing the edge of its disk towards the observer.

Elephant trunk like a *globule,* but elongated.

Ellipticity degree of deviation from a circular shape, defined as the difference between polar and equatorial diameter, divided by the equatorial diameter.

Emission line spectral line appearing bright against its spectral background, caused by the change of energy of a bound electron from a higher to a lower atomic energy level. The wavelength of the emitted photons is given by the energy difference and is characteristic of the emitting atom or ion.

Hα red, first line of the Balmer series of hydrogen at 656.3 nm, by transitions between the third and second energy levels of neutral hydrogen atoms.

Hβ green, second line of the Balmer series at 486.1 nm, by transitions between the fourth and third energy levels of neutral hydrogen atoms.

[OIII] see *forbidden line*, an emission line of double-ionized oxygen at 501 nm.

Emission nebula gaseous nebula whose spectrum consists of emission lines of excited elements and ions. Includes objects such as *HII regions*, planetary nebulae, and supernova remnants.

Evaporating Gaseous Globules (EGG) small, compact gaseous clouds in *HII regions*, which contain extremely young, hot stars.

Excitation change of the energetic state of a bound electron in an atom, from lower to higher energy. To absorb the required energy difference, a photon capture or collision has to take place.

Extinction continuous absorption of the light received from astronomical objects, caused by interstellar and intergalactic matter, which weakens blue light more strongly than red light.

Face-on galaxy-orientation, frontal view.

Galactic bulge central, thick part of the galactic disk with a thickness of about 16,000 light years.

Galactic disk discus-shaped, major part of the Galaxy, consisting of stars and clouds of interstellar matter orbiting around the galactic center in or near the galactic plane. Substructure includes spiral arms, the "thin" and a "thick" (older) disk. It reaches a radius of nearly 50,000 light years and becomes thicker towards the center, where it forms the *galactic bulge*.

Galactic halo extended spherical system of globular clusters and old, low-mass and metal-poor stars, which surrounds the galactic disk and bulge. The galactic halo has a typical radius of about 50,000 light years and may be embedded in an even larger halo of *dark matter*.

Galactic plane plane of symmetry, dividing the Galaxy (galactic disk, bulge, and halo) into two even halves along the galactic equator. The Sun is located a little north (by about 45 light years) of the galactic plane.

Globule dense, spherical concentration of interstellar matter in *HII-regions*, surrounding a star undergoing formation.

HI region gaseous nebula made of cool, neutral hydrogen.

HII region gaseous nebula made of mostly ionized hydrogen (around 10,000K), strongly emitting light in the Hα-line.

Hα Hβ see *emission line*

Herbig-Haro (HH) objects small nebulae near very young stars, created by the interaction of collimated stellar winds with the surrounding interstellar medium.

Hertzsprung-Russell diagram (HRD) diagram to characterize stellar physical quantities, developed independently by E. Hertzsprung and H. N. Russell around 1920. In the HRD, luminosity or absolute magnitude is plotted over effective temperature or spectral type. Some distinct regions populated by stars in specific evolutionary stages stand out i.e., *main sequence, giant branches, horizontal branch*.

Hipparcos satellite astrometry satellite operating from1989 to 1993, which has measured stellar parallaxes with hitherto unknown precision.

Horizontal branch region in the *HRD* or *CMD*, in which we find old, low-mass, and metal-poor stars (such as in globular clusters) during their phase of central helium burning.

Hubble classification morphologic classification scheme for galaxies after Hubble, see p. 59, originally thought of as an evolutionary sequence.

Hubble Space Telescope (HST) largest optical, ultraviolet, and near-infrared space telescope operated by NASA, with participation by ESA. Since 1990, the HST has delivered spectra and images of unprecedented quality.

Ionization state of electron deficiency or surplus of atoms or molecules (by one or several electrons, each), thus becoming charged particles, or the processes leading to this state i.e., by energetic collisions or absorption of UV-photons.

Jet long, thin emission structure, associated with objects on very different scales, quasars, radio galaxies, young stars, or comets. This phenomenon represents mostly a supersonic, highly collimated outflow of hot gas, interacting with its intergalactic or interstellar environment, and it is often associated with an accretion disk around a central object.

Light-year distance travelled at the speed of light in a year 9.460×10^{12} km, 5.905×10^{12} miles, or 63,240 AU.

Lindblad resonance resonance (inner or outer) between the orbital period of a spiral arm and the period of an object orbiting in the galaxy (inside or outside the spiral arm). Even ratios result in systematic gravitational pull from the spiral arm.

Low Ionization Nuclear Emission Region (LINER) type of *active galaxy* akin to *Seyfert galaxies* with emission lines caused by ionization from energetic radiation, but is much less ionized and shows less broad lines.

Luminous Blue Variable (LBV) hot variable stars with over 100,000 times the solar luminosity, spectral type A to O, and a variability amplitude of over 0.5 magnitudes. This class includes P Cygni, η Carinae, and S Doradus stars.

Main sequence see *Herzsprung-Russell diagram*; long stretch in the HRD from upper left to lower right, well populated by those stars ("dwarfs") which in their cores burn hydrogen to helium i.e., the longest-lasting phase of stellar evolution.

Mass exchange mass transfer mainly in close, evolving binaries and during near-galaxy encounters, mass can escape from the gravitational field of one object in order to join the other.

Metallicity total abundance of all elements heavier than helium. Since these elements have been created gradually in the fusion processes of stellar cores, metallicity indicates the stellar *population* (e.g., galactic disk / halo stars) and relative age.

Micro-quasar supposedly a stellar *black hole* or *neutron star*, embedded in an accretion disk, with two high-speed polar *jets*. As observed first with quasars, due to projection effects, their jet structure can show apparent velocities in excess of the speed of light.

Millisecond-pulsar *pulsar* with unusually short rotation periods (milliseconds), probably older objects recently accelerated by means of mass and angular momentum transfer in a close binary system.

Molecular cloud dense, very cool (10–100K) interstellar HI clouds, which host complex, mostly organic molecules, shielded from ambient radiation.

Nebula variable see *variables, T Tau.*

Neutron star extremely dense, collapsed stellar remnant, which consists almost entirely of neutrons. Neutron stars with about one solar mass have a radius of only 10 km.

Nova subtype of cataclysmic variables, which exhibit sudden bursts of brightness of about 10 magnitudes in visual light. Novae are formed in close binary systems with a mass-receiving white dwarf and they mark the detonation of accumulated, yet unburned, hydrogen on the surface of the white dwarf.

Parallax angular displacement of a sufficiently near object against its cosmic background, reflecting the orbital motion of Earth. The displacement of 1 AU (sideways) causes a parallax π of 1" with a star at 1 parsec (1 parsec = 3.26 light years) distance, and less with larger distances d (i.e., distance/parsec = $1/\pi$). Hence, this is an important, direct astronomical method of measuring distances, which currently (*Hipparcos satellite*) reaches out to objects about 1000 light years away.

Photometry exact measures of the brightness of a star, relative to a comparison star, using a set of standard filters (i.e., the UBVRI standard system of Johnson with well-defined spectral ranges covering the near UV to the near IR).

Population generation of stars, characterized by *metallicity*; Population I comprises relatively young stars, including massive, luminous and blue stars in spiral arms, with a larger abundance of heavy elements. Population II stars, as found in the *galactic halo*, are relatively old, low-mass, and cool, and they have a low metallicity. The very first stars, which would be made of a pure hydrogen-helium gas mixture, but which have not been observed yet, are hypothetically called Population III.

Position Angle (PA) angle counted counter-clockwise from north (0°) via east (90°), south (180°), and west (270°).

Proplyd proto-planetary disk around a young star.

Pulsar spinning *neutron star* with a strong magnetic field, inclined in respect of its rotation axis. The interaction of the fast-moving magnetic field-lines with the electron gas surrounding the neutron star causes polar beams of electromagnetic radiation – best observed in radio waves as regular pulses, whenever a beam sweeps past the line of sight, similar to a lighthouse.

Quasar quasi-stellar radio source; *active galaxy* at high *redshift*, with a stellar appearance in visual light. By virtue of the large distance and a rapid variability (on a time scale of days), these objects are extremely luminous, but very small (the size of the Solar System). Super-massive black holes fed by accretion disks have been suggested.

Radial velocity velocity component in the line of sight towards the object.

Radiation transmission of energy in the form of electromagnetic waves (or fast particles), e.g.:

IR infrared radiation, with wavelengths between 750nm and 0.1mm.

optical visual light, radiation with wavelengths between 380nm and 750nm.

radioelectromagnetic radiation with wavelengths longer than a few centimeters.

UV ultraviolet radiation with short wavelengths, between 10nm and 380nm.

X-ray energetic radiation with very short wavelengths, between 0.1nm and 10nm.

Radiation pressure pressure exerted on an absorbing or reflecting body by electromagnetic *radiation*. Hence, intense stellar radiation e.g., can drive a *stellar wind*.

Red giant highly evolved star of spectral type K or M with relatively low surface temperature but large (30 to 1000 times the solar) radius. In the HRD, red giants form the *giant branches*.

Redshift shift of the entire spectrum of an astronomical object towards longer wavelengths, caused by a considerable relative velocity away from the observer (*Doppler-shift*), or by the general expansion of the cosmos (cosmological redshift, as for distant galaxies and *quasars*), or by the presence of a strong gravitational field.

Reflection nebula caused by stellar light reflected at the dust in an interstellar cloud, in the absence of bright Hα emission from the gas, when the illuminating star is not hot enough (spectral type "later" than B1) to ionize the hydrogen.

Rosat satellite German imaging X-ray satellite, operating from 1990 to 1999.

Runaway star galactic star with unusually large proper motion (50–250 km/s), probably accelerated by a supernova explosion or by a gravitational interaction during a near encounter with a more massive star.

Seyfert galaxy type of *active galaxy* with lower absolute brightness than quasars. Two sub-types can be defined by their spectral characteristics: Seyfert 1 galaxies show Balmer lines distinctively broader than the *forbidden lines*, while with Seyfert 2 galaxies, both types of emission lines have about the same width.

Solar luminosity total power of the solar radiation over the entire spectrum 3.847×10^{26}W.

Solar mass total mass of the Sun 1.989×10^{30}kg.

Spectral type defined empirically by the occurrence of different, characteristic absorption lines in the spectrum, classes O, B, A, F, G, K, M, as well as special classes S and C, are distinguished. Each class is further divided into 10 subclasses. Classes O to M form a temperature sequence, "early" spectral types O to A are hot, blue stars, the "later" types F to M are relatively cool and appear yellow to red.

Spectrum distribution of the electromagnetic radiation, organized by wavelength λ or frequency; particle radiation spectra are arranged by kinetic energy. The electromagnetic spectrum reaches from long radiowaves (about 1 km to 1 m) via microwaves (1 mm to 1 cm), the infrared (IR, 700 nm to 0.1 mm), optical (380 nm to 750 nm) and ultraviolet light (UV, 100 nm) to X-rays (1 nm) and gamma-rays (1 pm).

Spiral arm characteristic feature of a spiral galaxy in the plane of its disk, formed by young stars and interstellar clouds.

Star burst short but very intense phase of star formation.

Stellar wind gaseous outflow from a star, leading to mass loss; can be hot, fast (2000km/s) and highly ionized, or cool, slow (10 to 100km/s) and even forming dust or soot-like particles.

Supergalactic wind hot, gaseous outflow from a galaxy into the extragalactic medium, driven by the radiation pressure, supernova explosions, and hot stellar winds of a large *starburst* region (see *M 82, p. 278*).

Supergiants the most luminous stars with up to 1000 solar radii, in all spectral classes from O (blue supergiants) to M (red supergiants).

Supermassive object extremely massive and small, compact object; normally a *black hole*.

Supernova (SN) sudden increase of a star's luminosity by 20 magnitudes (a factor of 100 million!), triggered by the gravitational collapse of the highly evolved core of a massive star. Remnants are made up of a nebula in fast expansion (the former outer layers of the star) and a neutron star or, possibly, a black hole.

Surface brightness measure of the light emitted per surface area by an astronomical object, often given in apparent magnitude per square arcsecond.

Surface brightness fluctuations (SBF) indirect method of distance measurement by means of the spatial fluctuations in the surface brightness of a galaxy on a CCD chip, employing the discrete nature of the many superimposed stellar images.

Synchrotron radiation electromagnetic radiation emitted by very fast (near the speed of light) charged particles, spiralling in a strong magnetic field.

Telescope aperture usually given as the diameter of the telescopes primary lens or mirror in inches (e.g., 1 inch = 25.4 mm, 4.7 inches = 120 mm, 14 inches = 360 mm).

Tidal forces differential forces between far and near side of a body orbiting in a gravitational field, which cause changing levels of atmospheres, solid and liquid surfaces (as the tides in the Earth-Moon system), and which can even destroy a loosely bound object too close to the central body.

Trümpler classification morphological classification scheme for open star clusters, see *p. 53*.

Variables all types of stars, which change their luminosity periodically, semi-periodically, or irregularly, for physical or geometrical (i.e., eclipses) reasons, in particular:

Cataclysmic variables characterized by large, irregular or semi-regular eruptions of light, including the classes of AM Her stars, dwarf novae and novae. These are double stars with a white dwarf in an accretion disk, fed by a mass-overflow from the companion star.

Cepheids large class of pulsating variables. Their luminosity obeys a tight relation with the period (and, to some extent, the metallicity). Hence, these stars are excellent distance indicators. Changes of their internal absorption processes systematically transfer a small fraction of their radiation energy into the pulsation. Periods range between 1 and 50 days, amplitudes between 0.1 and 2 magnitudes.

Eclipsing binaries binary system of which the orbital plane lies in the line of sight, allowing regular eclipses to occur.

Flare stars see *variables*; *UV Ceti*

Mira stars long-period pulsation variables; periods range from about 80 to 1000 days, amplitudes are very large, from 2.5 to 11 magnitudes in visual light. Miras are very evolved red supergiants of spectral classes K5 to M9, S or C, with around 2 solar masses and a strong mass loss, up to 10–4 solar masses per year. Different types of light curves indicate different modes of pulsation, and most Mira spectra show emission lines.

Pulsating variables pulsating stars in general, which periodically change their radius, temperature, and luminosity.

R CrB supergiants of spectral classes C, F to G, which show sudden drops of luminosity by 1m to 9m, which can last several weeks, months or even years, probably caused by large and dark, transient circumstellar clouds of carbon-rich dust particles.

RR Lyr large class of pulsating variables with periods between 0.2 and 1.2 days and amplitudes between 0.2 and 2 magnitudes. These variables are old stars on the horizontal branch and populate the galactic halo and globular clusters. They all have very similar luminosity (around absolute magnitude +0.7, or 40 solar luminosities), which make them good distance indicators. For subtypes, see *M 3, p. 76*.

RV Tau small class of very luminous pulsation variables, mainly yellow supergiants of spectral type G and K, much less F, with 1 to 3 solar masses and 50 to 100 times the solar luminosity. Their light curves are characterized by alternating shallow and deep minima, periods are between 30 and 150 days.

SX Phe dwarf cepheids with very short pulsation periods between 0.05 and 0.21 days, and with amplitudes of 0.3 to 0.8 magnitudes, spectral classes A to F, apparently including some *blue stragglers* in globular clusters. These variables are somehow similar to δ Scu stars in being evolved main sequence stars of 1.5 to 2 solar masses, but their light curves bear more similarity to those of RR Lyr stars.

T Tauri irregular variables; very young (pre-main-sequence) stars of spectral classes F to M with emission line spectra. They are several times the size of the Sun, still in the phase of contraction and mass accretion, with masses between about 0.2 to 2.5 solar masses.

UV Ceti flare stars; class of irregular, eruptive variables due to the occurrence of flares, similar to, but much more powerful than, solar flares. It is thought that sudden reconnection of twisted magnetic fields lines generate bursts of energy. These stars are low-mass (about 0.1 solar masses) main-sequence stars of spectral type M with a relatively young age of about 100 million years.

W Ursa Majoris very close, eclipsing binaries. The highly deformed components have assumed an elliptical shape, which leads to a nearly sine-shaped light curve.

W Virginis similar to cepheids, but these stars are much older and mostly belong to the *Population II*. They are low-mass (around 0.6 solar masses) giant stars of spectral type A2 to K, with periods between 1 and 100 days, amplitudes up to 2 magnitudes, and light-curves less regular than those of cepheids.

δ Scuti pulsating variables of spectral type A2 to F6 and very short periods of 0.03 to 0.2 days, with amplitudes of 0.003 to 0.1 magnitudes. Similar to RR Lyr variables, but these stars are evolved main-sequence stars of about 1.5 to 2 solar masses.

γ Doradus small class of pulsating variables akin to δ Scuti stars, with spectral classes A to F and amplitudes of some 0.001 to 0.1

magnitudes, but they are more evolved (to subgiants) and have longer periods (0.3 to 3 days) and sine-shaped light-curves.

Very Large Telescope (VLT) telescope built by ESO, located on the Cerro Paranal in Chile; four telescopes with 8.2m aperture each, which can be used in a combined mode as an interferometer.

Very long baseline interferometry (VLBI) long-distance interferometry with large radio telescopes.

White dwarf very compact star, compressed to about Earth size; remnant of the burned-out stellar core, if the initial masss was under 8 solar masses. White dwarfs mostly consist of carbon and oxygen, start very hot and then cool down very slowly. Temperatures between a few thousand K and up to 200,000K are observed.

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M 42 Hubble Space Telescope, Mark McCaughrean (Max-Planck-Institut für Astronomie), C. Robert O'Dell (Rice University), and NASA, January 1994 and March 1995 • Hubble Space Telescope, John Bally, Dave Devine, and Ralph Sutherland, Jan. 14th 1997 • Bernd Liebscher, 12-inch reflector, 940mm, CCD image, SBIG STL11000, 75min + 10min + 5min, Oct. 28th 2005, Tiefenbachferner, Austria • Robert Gendler, 20-inch reflector, 4064mm, 12.5-inch reflector, SBIG STL11000XM, Mosaik, 5400min, December 2005 to January 2006, New Mexico, USA • Stefan Binnewies, 24-inch reflector, 4800mm, CCD image, SBIG ST10XME, 3min, Sept. 3rd 2003, Amani Lodge, Namibia • George Bond, 15-inch refractor, 1857–1865, Cambridge, USA • Ronald Stoyan, 4.7-inch refractor, 170×, 255×, without filters, Nov. 9th 2001, Kreben, Germany • Ronald Stoyan, 14-inch Newtonian, 81×, 200×, without filters, Feb. 5th 2005, Kreben, Germany • Ronald Stoyan, 24-inch Cassegrain, 250×, without filters, Mar. 3rd 2005, Nürnberg, Germany • Heinrich d´Arrest, 11-inch refractor, 1865–1871, Copenhagen, Denmark • S. Hunter, Lord Rosse, 72-inch Newtonian, 1861 to 1864, Birr Castle, Ireland • Léopold Trouvelot, Edward S. Holden, 26-inch refractor, 1875, Washington, USA. Science Museum/Science and Society Picture Library • Wilhelm Tempel, 1861, Marseille, France • William Lassell, 24-inch Newtonian, Winter 1853/1854, Liverpool, England • Bindon Stoney, Lord Rosse, 72-inch Newtonian, 1852, Birr Castle, Ireland

M 44 Stefan Binnewies, 4-inch refractor, 600mm, 400 ASA, 6min, Mar 23rd 2003, Much, Germany • Robert Gendler, 6-inch refractor, 1085mm, CCD image, SBIG STL11000, Avon, Connecticut, USA

M 45 Hubble Space Telescope, Wide Field Planetary Camera, NASA, and the Hubble Heritage Team (STScI/AURA), George Herbig and Theodore Simon (Institute for Astronomy, University of Hawaii), Dec. 6th 2000 • Bernd Flach-Wilken, 10.7-inch reflector, 900mm, ASA 200, 40min, Nov. 14th/15th 1999, Gornergrat, Switzerland • Bernd Liebscher, 12-inch reflector, 940mm, CCD image, SBIG STL11000, 75min + 10min + 5min, Oct. 28th 2005, Tiefenbachferner, Austria • Ronald Stoyan, 14-inch Newtonian, 81×, 2003, Kreben, Germany • Wilhelm Tempel, 4-inch refractor, 24×, Oct 19th 1859, Venice, Italy

M 46 Robert Gendler, Jim Misti, 32-inch reflector, CCD image, SBIG STL11000 • Dietmar Böcker, 24-inch reflector, 4800mm, CCD image, SBIG ST10XME, 74min, Mar. 20th 2004, Amani Lodge, Namibia

M 47 Stefan Binnewies, 3.2-inch refractor, 640mm, 100 ASA hyp, 50min, Dec. 30th 1991, La Palma, Spain

M 48 Stefan Seip, 4-inch refractor, 420mm, CCD image, SBIG ST2000XM, 112min, Dec. 8th 2003, Stuttgart, Germany

M 49 Stefan Heutz, Wolfgang Ries, 18-inch reflector, 1700mm, CCD image, SBIG ST10XME, 127min, Mar. 25th 2007, Altschwendt, Austria • Ronald Stoyan, 14-inch Newtonian, 200×, Apr. 1st 2005, Kreben, Germany

M 50 Stefan Seip, 4-inch refractor, 420mm, CCD image, SBIG ST2000XM, 112min, Dec. 7th 2003, Stuttgart, Germany

M 51 Hubble Space Telescope, Advanced Camera for Surveys, NASA, ESA, S. Beckwith (STScI), and the Hubble Heritage Team (STScI/AURA), January 2005 • Hubble Space Telescope, the Faint Object Spectrograph and Wide Field Planetary Camera, H. Ford (JHU/STScI) and NASA • Robert Gendler, 12.5-inch and 20-inch reflectors, CCD image, SBIG STL-11000XM, 2520min, 2006, Nighthawk Observatory, New Mexico, USA • Ronald Stoyan, 14-inch Newtonian, 200×, 300×, Apr. 2nd 2005, Kreben, Germany • William Lassell, 48-inch Newtonian, 285×, 466×, Jun. 27th and Jul. 2nd 1862, Malta • Lord Rosse, 72-inch Newtonian, April 1845, Birr Castle, Ireland • S. Hunter, Lord Rosse, 72-inch Newtonian, May 6th 1864, Birr Castle, Ireland • H.-C. Vogel, 26-inch refractor, Jun. 3rd and 4th 1885, Wien, Austria

M 52 Robert Gendler, 12.5-inch reflector, 2857mm, CCD image, SBIG STL11000, 210min, Avon, Connecticut, USA • Stefan Binnewies, 4-inch refractor, 600mm, CCD image, SBIG ST10XME, 190min, Nov. 8th 2005, Much, Germany

M 53 Stefan Binnewies, Josef Pöpsel, 24-inch reflector, 4800mm, CCD image, SBIG STL11000M, 60min, May 14th 2007, Skinakas Observatory, Greece

M 54 Rainer Sparenberg, Volker Robering, 24-inch reflector, 4800mm, CCD image, SBIG ST10XME, 8min, May 12th 2004, Amani Lodge, Namibia

M 55 Daniel Verschatse, 14.5-inch reflector, 3000mm, CCD image, SBIG STL-11000, 105min, Jul. 19th 2006, San Esteban, Chile

M 56 Stefan Seip, 36-inch reflector, 3200mm, CCD image, SBIG STL-11000M, 31min, Jun. 12th 2006, Welzheim, Germany

M 57 Hubble Space Telescope, the Hubble Heritage Team (AURA/STScI/NASA), October 1998 • Stefan Binnewies, Josef Pöpsel, 24-inch reflector, 4800mm, CCD image, SBIG STL11000M, 180min, Aug. 23rd 2006, Skinakas Observatory, Greece • Ronald Stoyan, 14-inch Newtonian, 200×, 300×, 350×, 450×, Sep. 19th 2003, Tiefenbachferner, Austria

M 58 Robert Gendler, Jim Misti, 32-inch reflector, CCD image, SBIG STL11000, Night Hawk Observatory, New Mexico, USA • Ronald Stoyan, 14-inch Newtonian, 200×, Apr. 14th 2004, Kreben, Germany

M 59 Stefan Heutz, Wolfgang Ries, 18-inch reflector, 1700mm, CCD image, SBIG ST10XME, 127min, Apr. 8th to 10th 2007, Altschwendt, Austria • Ronald Stoyan, 14-inch Newtonian, 200×, 300×, Apr. 1st 2005, Kreben, Germany

M 60 Josef Pöpsel, Rainer Sparenberg, 24-inch reflector, 4800mm, CCD image, SBIG STL11000M, 180min, May 16th 2007, Skinakas Observatory, Greece • Ronald Stoyan, 14-inch Newtonian, 200×, Apr. 1st 2005, Kreben, Germany

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M 62 Dietmar Böcker, Ernst von Voigt, 24-inch reflector, 4800mm, CCD image, SBIG ST10XME, 25min, Mar. 18th 2004, Amani Lodge, Namibia

M 63 Robert Gendler, 12.5-inch and 20-inch reflectors, CCD image, SBIG STL-11000XM, 1620min, 2006, Nighthawk Observatory, New Mexico, USA • Ronald Stoyan, 14-inch Newtonian, 200×, 300×, 350×, 450×, May 4th 2003, Kreben, Germany

M 64 Hubble Space Telescope, Wide Field Planetary Camera 2, NASA and the Hubble Heritage Team (AURA/STScI) and S. Smartt (Institute of Astronomy) and D. Richstone (U. Michigan) • Volker Wendel, 15-inch reflector, 3000mm, CCD-image, SBIG ST10XME, 145min, Pfalz, Germany • Ronald Stoyan, 14-inch Newtonian, 200×, Feb. 18th 2002, Kreben, Germany • William Lassell, 39-inch Newtonian, 285×, Apr. 22nd 1862, Malta • John Herschel, 18-inch Newtonian, before 1833, Slough, England

M 65 Volker Wendel, 15-inch reflector, 3000mm, CCD image, SBIG ST10XME, 190min, Pfalz, Germany • Robert Gendler, 12.5-inch reflector, CCD image, SBIG ST10 and IMG1024, Avon, Connecticut, USA • Ronald Stoyan, 14-inch Newtonian, 200×, 300×, June 1st 2003, Kreben, Germany • Lord Rosse, 72-inch Newtonian, before 1850, Lord Rosse, Birr Castle, Ireland • John Herschel, 18-inch Newtonian, before 1833, Slough, England

M 66 Philipp Keller, Christian Fuchs, 32-inch reflector, 3557mm, CCD image, SBIG ST10E, 54min, Feb. 17th 2002, Bayerischer Wald, Germany • Ronald Stoyan, 14-inch Newtonian, 200×, 300×, Jun. 1st 2003, Kreben, Germany • William Lassell, 48-inch Newtonian, 285×, Apr. 21st 1862, Malta

M 67 Rainer Sparenberg, 4.5-inch refractor, 805mm, Canon 20D Hutech, 70min, Feb. 15th and Mar. 11th 2007, Haltern am See, Germany

M 68 Daniel Verschatse, 14.5-inch reflector, 3300mm, CCD image, SBIG STL11000, 108min, Apr. 9th 2005, San Esteban, Chile

M 69 Bernd Flach-Wilken, 16-inch reflector, 3200mm, CCD image, SBIG STL6303, 90min, Farm Tivoli, Namibia

M 70 Rainer Sparenberg, Stefan Binnewies, 24-inch reflector, 4800mm, CCD image, SBIG ST10XME, 8min, May 12th 2004, Amani Lodge, Namibia

M 71 Stefan Binnewies, Rainer Sparenberg, 24-inch reflector, 4800mm, CCD image, SBIG STL11000M, 60min, May 15th 2007, Skinakas Observatory, Greece

M 72 Daniel Verschatse, 14.5-inch reflector, 3300mm, CCD image, SBIG STL11000, 110min, Jun. 5th 2005, San Esteban, Chile

M 73 Rainer Sparenberg, Volker Robering, 24-inch reflector, 4800mm, CCD image, SBIG ST10XME, 5min, May 14th 2004, Amani Lodge, Namibia

M 74 Stefan Binnewies, Josef Pöpsel, 24-inch reflector, 4800mm, CCD image, SBIG STL11000M, 260min, Aug 23rd and 25th 2006, Skinakas Observatory, Greece • Ronald Stoyan, 20-inch Newtonian, Aug. 13th 2004, Farm Tivoli, Namibia

M 75 Daniel Verschatse, 14.5-inch reflector, 3300mm, CCD image, SBIG STL11000, 105min, Jun. 5th 2005, San Esteban, Chile

M 76 Stefan Seip, 36-inch reflector, 4900mm, CCD image, SBIG STL11000M, 330min, Oct. 17th 2006, Welzheim, Germany • Ronald Stoyan, 14-inch Newtonian, 200×, 350×, [OIII]-Filter, Aug. 17th 2002, Kreben, Germany

M 77 Hubble Space Telescope, Faint Object Camera, Duccio Macchetto (ESA), William Sparks and Alessandro Capetti (STScI), January 1994 • Josef Pöpsel, Beate Behle, 24-inch reflector, 4800mm, CCD image, SBIG ST10XME, 42min, Oct 26th 2003, Amani Lodge, Namibia • Ronald Stoyan, 20-inch Newtonian, 115×, 280×, 420×, Aug. 15th 2004, Farm Tivoli, Namibia • William Lassell, 48-inch Newtonian, 760×, Nov. 17th 1862, Malta • Lord Rosse, 72-inch Newtonian, Nov. 24th 1851, Bindon Stoney, Birr Castle, Ireland

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M 79 Bernd Flach-Wilken, 16-inch reflector, 3200mm, CCD image, SBIG STL-6303, 96min, Sep. 2007, Farm Tivoli, Namibia

M 80 Hubble Space Telescope, Wide Field Planetary Camera 2, Hubble Heritage Team (AURA/ STScI/ NASA) • Stefan Binnewies, 4-inch refractor, 600mm, 400 ASA, 75min • Jul. 19th 1995 Farm Tivoli, Namibia • Daniel Verschatse, 14.5-inch reflector, 3300mm, CCD image, SBIG STL11000, 108min, Apr. 24th 2006, San Esteban, Chile

M 81 Volker Wendel, 15-inch reflector, 3000mm, CCD image, SBIG ST10XME, 160min, Pfälzer Wald, Germany • Robert Gendler, 12.5-inch reflector, CCD image, SBIG ST10XME, STL1100, Night Hawk Observatory, New Mexico, USA • Ronald Stoyan, 14-inch Newtonian, 81×, 200×, 300×, 450×, May 16th 2004, Kreben, Germany

M 82 Hubble Space Telescope, NASA, ESA, and R. de Grijs (Inst. of Astronomy, Cambridge) • Philipp Keller, Christian Fuchs, 32-inch reflector, 3557mm, CCD image, SBIG ST10XME, 74min, Bayerischer Wald, Germany • Ronald Stoyan, 14-inch Newtonian, Feb. 24th 2003, Kreben, Germany

M 83 Josef Pöpsel, Rainer Sparenberg, 24-inch reflector, 1800mm and 4800mm, CCD image, SBIG ST10XME, 260min, Amani Lodge, Namibia • Volker Wendel, Bernd Flach-Wilken, 16-inch reflector, 3200mm, CCD image, STL6303, 180min, • Ronald Stoyan, 20-inch Newtonian, 190×, Aug. 12th 2004, Farm Tivoli, Namibia • William Lassell, 48-inch Newtonian, May 20th and 22nd 1862, Malta

M 84 Hubble Space Telescope, Wide Field Planetary Camera, L. Woodgate, G. Bower (NASA), May 12th 1997 Cord Scholz, 4-inch refractor, 600mm, CCD image, SBIG ST10XME, Rinteln, Germany • Ronald Stoyan, 14-inch Newtonian, 2004

M 85 Stefan Heutz, Wolfgang Ries, 18-inch reflector, 1700mm, CCD image, SBIG ST10XME, 181min, Feb. 9th and 22nd 2007, Altschwendt, Austria • Ronald Stoyan, 14-inch Newtonian, 200×, 350×, Apr. 14th 2004, Kreben, Germany

M 86 Robert Gendler, 12.5-inch reflector, CCD image, STL11000, Mosaik, 480min, Avon, Connecticut, USA • Ronald Stoyan, 14-inch Newtonian, 2004, Kreben, Germany

M 87 Hubble Space Telescope, Wide Field Planetary Camera 2, NASA, and the Hubble Heritage Team (STScI/AURA), 1998 • Bernd Flach-Wilken, 16-inch reflector, 3200mm, CCD image, SBIG STL6303, 140min, Farm Tivoli, Namibia

M 88 Philipp Keller, Christian Fuchs, 48-inch reflector, 5100mm, CCD image, SBIG ST10E, 50min, Trebur, Germany • Ronald Stoyan, 14-inch Newtonian, 200×, 300×, May 29th 2003, Kästel, Germany • William Lassell, 48-inch Newtonian, 285×, May 21st 1862, Malta

M 89 Stefan Heutz, Wolfgang Ries, 18-inch reflector, 1700mm, CCD image, SBIG ST10XME, 84.5min, Apr. 12th and 25th 2007, Altschwendt, Austria • Stefan Seip 6-inch refractor, 1100mm, CCD image, SBIG STL 11000M, 90min, May 23rd 2004, Farm Okumitando, Namibia • Ronald Stoyan, 14-inch Newtonian, 300×, Apr. 14th 2004, Kreben, Germany

M 90 Robert Gendler, 12.5-inch reflector, 2860mm, CCD image, 220min, Avon, Connecticut, USA • Ronald Stoyan, 14-inch Newtonian, 120×, 200×, Jun. 2nd 2003, Kreben, Germany

M 91 Rainer Sparenberg, Volker Robering, 24-inch reflector, 4800mm, CCD image, SBIG ST10XME, 120min, May 13th 2004, Amani Lodge, Namibia • Ronald Stoyan, 14-inch Newtonian, 200×, 300×, Apr. 16th 2004, Kreben, Germany

M 92 Stefan Binnewies, Josef Pöpsel, 24-inch reflector, 1800mm, CCD image, STL-11000M, 120min, Jul. 23rd, 25th, Skinakas Observatory, Greece • Léopold Trouvelot, June 1877, Harvard Observatory, USA

M 93 Stefan Heutz, Wolfgang Ries, 18-inch reflector, 1700mm, CCD image, SBIG ST10XME, 56.5min, Feb. 23rd 2007, Altschwendt, Austria

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M 96 Stefan Heutz, Wolfgang Ries, 18-inch reflector, 1700mm, CCD image, SBIG ST10XME, 98.5min, Altschwendt, Austria • Ronald Stoyan, 14-inch Newtonian, 200×, 300×, Mar. 24th 2003, Kreben, Germany

M 97 Philipp Keller, Christian Fuchs, 32-inch reflector, 3557mm, CCD image, SBIG ST10E, 34min, Bayerischer Wald, Germany • Ronald Stoyan, 14-inch Newtonian, Mar. 4th 1995, Kreben, Germany • Lord Rosse, 72-inch Newtonian, Mar. 5th to Apr. 3rd 1848, Birr Castle, Ireland • John Herschel, 18-inch Newtonian, before 1833, Slough, England

M 98 Ronald Stoyan, 14-inch Newtonian, 200×, Mar. 31st 2005, Kreben, Germany • Bernd Flach-Wilken, 16-inch reflector, 3200mm, CCD image, SBIG STL6303, 210min, Farm Tivoli, Namibia

M 99 Philipp Keller, Christian Fuchs, 32-inch reflector, 3557mm, CCD image, SBIG ST10E, 70min, Feb. 18th 2002, Bayerischer Wald, Germany • Ronald Stoyan, 14-inch Newtonian, 200×, Mar. 22nd 2003, Kreben, Germany • William Lassell, 48-inch Newtonian, 285×, Mar. 31st 1862, Malta • Lord Rosse, 72-inch Newtonian, 1846, Birr Castle, Ireland

M 100 Hubble Space Telescope, Wide Field Planetary Camera 2, J. Trauger, JPL and NASA, Dec. 31st 1993 • Philipp Keller, Christian Fuchs, 32-inch reflector, 3557mm, CCD image, SBIG ST10XME, 50min, Bayerischer Wald, Germany • Ronald Stoyan, 14-inch Newtonian, 200×, Mar. 22nd 2003, Kreben, Germany • William Lassell, 48-inch Newtonian, 285×, 474×, Apr. 26th 1862, Malta • Wilhelm Tempel, 11-inch refractor, about 1875, Arcetri, Italy

M 101 Hubble Space Telescope, NASA, and ESA, K.D. Kuntz (GSFC), F. Bresolin (University of Hawaii), J. Trauger (JPL), J. Mould (NOAO), and Y.-H. Chu (University of Illinois, Urbana), 1994–2003 • Stefan Binnewies, 24-inch reflector, 1800mm, CCD image, SBIG STL11000M, 320min, Jul. 5th/6th 2007, Skinakas Observatory, Greece • Ronald Stoyan, 14-inch Newtonian, 120×, 200×, May 17th 2004, Kreben, Germany • Lord Rosse, 72-inch Newtonian, Apr. 29th to May 12th 1861, S. Hunter, Birr Castle, Ireland

M 102 Volker Wendel, 15-inch reflector, 3000mm, CCD image, SBIG ST10XME, 85min, Pfälzer Wald, Germany • Ronald Stoyan, 14-inch Newtonian, 120×, 200×, 300×, 350×, Jun. 2nd 2003, Kreben, Germany • Lord Rosse, 72-inch Newtonian, Apr. 27th 1848, Birr Castle, Ireland

M 103 Stefan Seip, 6-inch refractor, 1100mm, CCD image, SBIG ST2000XM, 112min, Dec. 23rd 2003, Stuttgart, Germany

M 104 Rainer Sparenberg, Stefan Binnewies, 24-inch reflector, 4800mm, CCD image, SBIG ST10XME, 185min, May 12th 2004, Amani Lodge, Namibia

M 105 Volker Wendel, Bernd Flach-Wilken, 15-inch and 16-inch reflectors, 3200mm, CCD image, SBIG ST10XME, 110min, Pfälzer Wald and Wirges, Germany • Ronald Stoyan, 14-inch Newtonian, 200×, 300×, Feb. 19th 2004, Kreben, Germany

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M 107 Stefan Heutz, Wolfgang Ries, 18-inch reflector, 1700mm, CCD image, SBIG ST10XME, 122.5min, and Apr. 12th and 25th 2007, Altschwendt, Austria

M 108 Bernd Flach-Wilken, Volker Wendel, 16-inch and 15-inch reflectors, CCD image, SBIG ST10XME and STL6303, 270min, Pfalz and Westerwald, Germany • Ronald Stoyan, 14-inch Newtonian, 200×, 300×, Feb. 19th 2004, Kreben, Germany

M 109 Volker Wendel, 15-inch reflector, 3000mm, CCD image, SBIG ST10XME, 230min, Pfälzer Wald, Germany • Ronald Stoyan, 14-inch Newtonian, 200×, 300×, Mar. 24th 2003, Kreben, Germany

M 110 Gerald Rhemann, Michael Jäger, 13.4-inch reflector, 1054mm, CCD image, Starlight SXV-H9, 35min, Eichgraben, Austria

Index of sources

This listing contains the most important sources used to compile the data for this book. Extended use was made of NASA's Astrophysics Data System (ADS).

Abbreviations of astronomical journals:

A&A	Astronomy and Astrophysics
A&AS	Astronomy and Astrophysics Supplement
AJ	Astronomical Journal
AJS	Astronomical Journal Supplement
AN	Astronomische Nachrichten
ApJ	Astrophysical Journal
ApJS	Astrophysical Journal Supplement
MNRAS	Monthly Notices of the Royal Astronomical Society
PASP	Publications of the Astronomical Society of the Pacific
PASJ	Publications of the Astronomical Society of Japan

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