James L. Chen

A Guide to Hubble Space Telescope Objects

Their Selection, Location, and Significance

Graphics by Adam Chen

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Dedicated to my wife Vickie
and my two sons Adam and Alex,
without whose inspiration, ideas, and suggestions
this book could not have been accomplished.

Introduction

It was late November, 1990, around 8 o'clock in the evening. I had my newly acquired, 130 mm apochromatic refractor on a classic 1950s vintage weight-driven equatorial mount set up in my front yard, aimed at Mars during the 1990 opposition. My observing notes of that night reflect my enthusiasm for my new toy, as I described the sight of Mars at its closest approach as the size of a basketball! Just a slight case of hyperbole!

Sitting on my observing chair, peering through my telescope eyepiece, trying to visually separate the low contrast subtle shades of yellow, yellow-orange, orange, red-orange, orange-red, and red that characterize Mars, my neighbor from across the street was just coming home from his job as a Hubble Space Telescope engineer at Goddard Space Flight Center. He had been working long hours since April, when it was discovered that the much hyped "perfect optics" of the Hubble was, in fact, ground to the wrong curvature. The HST was decidedly near-sighted and in need of a pair of glasses.

My neighbor saw me with my telescope and crossed the street to take a look. We exchanged pleasantries, and as he took a look through my telescope, he remarked on the sharpness and clarity of the Mars image. I cracked an unfortunate joke about my telescope's quality versus the Hubble's. He smiled and remarked that once the optics were corrected, the HST would make history.

My neighbor was right. Following the Space Shuttle Endeavor's STS-61 Service Mission to repair Hubble in 1993, the Hubble Space Telescope has gone on to make history, producing a great number of memorable astronomical images. The Hubble images have been awe-inspiring to both scientists and the public. The significant discoveries for the deep space and planetary HST images have led to mankind's greater understanding of the universe.

Ironically, many people don't realize many of the Hubble images are of celestial objects that can be observed through a telescope in their own backyard. The backyard telescope view of these objects won't look anything like the Hubble pictures, but many of these objects have held the fascination of astronomers and scientists for decades or centuries. An appreciation for all that fascination can be obtained by observing these same objects from a backyard telescope.

The goal of this book is to present a select number of Hubble images and show the reader how to find these objects in the night sky. Photos of the same objects, imaged by amateur astronomers, are also provided to set the backyard observer's expectations of what can be seen through a backyard telescope. Historical and observational descriptions are provided with each object to complete the story. The objects are arranged according to the seasons that can be best viewed in the evenings. I am sure there are some lunatic fringe observers who might attempt to observe most or all in one night. More power to you! Finder charts for all the Hubble objects in this book are also provided.

The planets chapter does not contain finder charts, since the planets move. The reader is invited to refer to many of the popular astronomy magazines or Internet sites to find the current location of your favorite planet.

If some of the words in Chap. 2 seem familiar to readers of my first book, *How to Find the Apollo Landing Sites*, they are. From my experience in the commercial sales side of the astronomy hobby, much of my advice concerning telescopes and accessories remains the same. The message within Chap. 2 of this book has been tailored towards deep sky observing as opposed to the earlier book's focus on lunar and planetary observing.

Read, observe, and enjoy!

Gore, VA, USA James L. Chen

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Contents

Biographies

James L. Chen (Author) Retired Department of the Navy and Federal Aviation Administration Radar and Surveillance Systems Engineer. Guest lecturer at local Washington DC/Northern Virginia/Maryland astronomy clubs on amateur astronomy topics of eyepiece design, optical filters, urban and suburban astronomy, and lunar observing. Author of an Astronomy Magazine article on Dobsonian telescope design in November 1989 issue. First book, published in June 2014 by Springer, entitled *How to Find the Apollo Landing Sites*. Served as a part-time technical and sales consultant for two Washington DC area telescope stores for over 30 years.

Adam Chen (Graphics Designer) Former Program Manager of media support for NASA Headquarters in Washington DC. Creator and executive producer of major NASA publications, including the book and web-book application documenting the history of the Space Shuttle Program "Celebrating 30 Years of the Space Shuttle Program." Currently works in marketing for Brown Advisory, an investment firm in Baltimore, MD.

Chapter 1

The Short, Yet Surprisingly Long History of the Hubble Space Telescope

Space Shuttle Discovery stood on Launch Pad 39B at Kennedy Space Center on April 24, 1990, poised to carry and deliver its most important scientific payload. Shuttle mission STS-31, with Mission Commander Loren J. Shriver, Pilot and future NASA Administrator Charles F. Bolden Jr., and Mission Specialists Steven A. Hawley, Bruce McCandless II, and Kathryn D. Sullivan, was assigned the primary mission of deploying the Hubble Space Telescope into a 380 mile orbit above the Earth.

At 8:33:51 EDT, the Shuttle Discovery lifted off on its historic mission of placing into orbit what has become one of the most famous telescopes in history, one that has produced scientific discoveries and captured the imaginations of this era. The Hubble Space Telescope, or HST for short, got off to a somewhat rocky start after its insertion into orbit. But the HST has since proved to be one of the most productive scientific instruments in history.

To the public, this launch was the beginning. But, in truth, the beginning occurred years earlier. In fact, decades earlier.

The concept of a telescope in space was first described in 1923 by Hermann Oberth. Oberth was an Austro-Hungarian born doctoral candidate, who published *Die Rakete zu den Planetenräumen* (The Rocket to Planetary Space) in which he suggested a telescope could go into space aboard a rocket. Oberth would become a well regarded pioneering German rocket scientist whose pupils included Dr. Wernher von Braun. Both Oberth and von Braun would immigrate to the United States and work on the US space program. The idea of a telescope in space came up again in a paper entitled "Astronomical advantages of an extraterrestrial observatory" published in 1946 by accomplished astrophysicist Lyman Spitzer Jr. Part of Spitzer's rationale for a space-based telescope included the fact that an instrument placed above Earth's atmosphere would be freed of atmospheric transparency limitations in

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the visual spectrum, and the platform could also carry out observations at the infrared and ultraviolet portions of the spectrum that are otherwise blocked by Earth's atmosphere and magnetosphere. By 1962, a space telescope concept like the Hubble was being developed. Spitzer served as an advocate for space borne observatory platforms, such as the Orbiting Astronomical Observatory (OAO) satellite, by pushing the U.S. Congress and the scientific community for support. With his track record of high achievement, Spitzer was among those who persuaded Congress in 1969 to approve the idea of building a large space telescope.

NASA began preliminary studies in 1975, and the Hubble Space Telescope project was funded by Congress and built between 1977 and 1985. The Hubble Space Telescope was built by NASA with contributions from the European Space Agency. The fabrication of the instrument was managed by NASA Marshall Space Flight Center, with the critical mirror optics made by the Perkin-Elmer Corporation.

Work began on the mirror in 1979, with completion in late 1981. The task of grinding and figuring the 2.4 m primary mirror was given to the Perkin-Elmer Corporation.

The HST optical design is a Ritchey-Chrétien variant of the Cassegrain reflecting telescope. This design gives a wide field of view with excellent image quality across the field. In fact the Ritchey-Chrétien design is now used by the majority of modern large optical telescopes. The design's only disadvantage is that the primary and secondary mirrors are hyperbolic in shape and thus are difficult to fabricate and test.

As the HST is designed to be used at ultraviolet, visible, and infrared wavelengths, the telescope had to achieve the desired diffraction limited optics. This meant that its mirror needed to be polished to an accuracy of 10 nm, or about 1/65 of the wavelength of red light.

Construction of the Perkin-Elmer mirror began in 1979, using Corning ultra-low expansion glass. To minimize weight, it consisted of inch-thick top and bottom plates sandwiching a honeycomb lattice. The mirror polishing was completed in 1981 and it was then washed using hot, deionized water before received a reflective coating of aluminum under a protective coating of magnesium fluoride.

The seeds of the Hubble optical problems were sown because of the stringent optical requirements and funding pressures. Schedule delays and cost growth of the Hubble program caused both the contractor and government agency to look for areas to reel in the schedule and reduce cost growth. As a result, an over-reliance on a single test devise spelled trouble for the HST. A testing device called a null corrector had been incorrectly assembled, with one of its lenses assembled out of position by 1.3 mm. During the initial grinding and polishing of the mirror, Perkin-Elmer analyzed the mirror's surface with two conventional null correctors. During the final figuring step, Perkin-Elmer opticians switched to the custom-built null corrector, designed explicitly to meet very strict tolerances. With this custom null corrector assembled incorrectly, the mirror was extremely precise, but shaped to the wrong curve. There was one final opportunity to catch the error, since a few of the final tests needed to use conventional null correctors for various technical reasons. These tests correctly indicated that the mirror suffered from spherical aberration, with the perimeter of the mirror being too flat by about 2,200 nm. But both Perkin-Elmer and NASA relied on the custom-built null corrector results based on the assumption of its greater precision, and to save both time and money. Thus the flaw remained during final assembly of the Hubble spacecraft.

The tragic loss of the Space Shuttle Challenger on 28 January 1986 caused the Space Shuttle program to be suspended. The suspension caused the HST to be stored and maintained by Lockheed in California, at the cost of $6 million per year. From its original total cost estimate of about $400 million, the telescope had suffered a cost growth of over $2.5 billion to construct. The cost growth can be attributed to the difficulty of estimating the costs of building something that had never been built before, and the storage cost after the Challenger mishap.

Space Shuttle Discovery stood on Launch Pad 39B at Kennedy Space Center on April 24, 1990. The countdown was briefly halted at T-31 seconds when Discovery's computers failed to shut down a fuel valve line on ground support equipment. Engineers ordered the valve closed and the countdown continued. And at 8:33:51 EDT, Discovery lifted off on its mission to carry the Hubble Space Telescope into orbit.

To deploy HST into an orbit that provided a long service life, Discovery rocketed to a record 370 miles. The deployment of the Hubble was not without some technical problems. One of the HST's solar arrays failed to completely unfurl. While NASA ground controllers searched for a way to command HST to complete the unfurling of the solar array, Mission Specialists McCandless and Sullivan began preparing for a contingency extravehicular spacewalk in the event that the array could not be deployed by ground control. The array eventually came free and unfurled through ground control commands. Astronaut Hawley, controlling the Remote Manipulator System arm, then deftly plucked the massive Hubble out of the shuttle cargo bay and deployed it in orbit.

During the initial tests of the optical system after the launch of the telescope, it became obvious that there was a serious problem with the optical system. Stellar images which should have been approximately 0.1 arc sec across were more than 1 arc sec across—basically equivalent to those of ground based telescope images. On 27 June 1990, some 2 months after HST was placed in orbit, Dr. Edward Weiler, Chief Scientist for the Hubble Space Telescope announced to the public in clear terms: "*It's broken and we're going to have to fix it*".

Fortunately, the HST had a modular design in order to accept service upgrades during its lifetime. NASA embarked on what became a 3 year development effort to remedy the flawed optics.

Two solutions were developed. First, astronomers and opticians had to characterize the nature of the optical flaw by analyzing the faulty images and the ill-assembled null corrector. A replacement Wide Field and Planetary Camera, or WFPC (popularly pronounced whiff-pick) had to be designed with corrective optics within it. The resultant WFPC2 carried optics with an inverse error built-in that completely cancelled the aberration of the primary mirror.

Additionally, corrective optics were developed for other instruments that did not carry their own optical systems. An external device known as the Corrective Optics Space Telescope Axial Replacement, shortened to COSTAR, was designed to correct the spherical aberration for light focused on the Faint Object Spectrograph

(FOS), Faint Object Camera (FOC), and the Goddard High Resolution Spectrograph (GHRS). To fit the COSTAR system onto the telescope, one of the other instruments had to be removed, and astronomers selected the High Speed Photometer to be the sacrificial lamb.

During the 3 years of developing the corrective optics for Hubble, scientific data was collected. The HST still carried out a large number of productive observations of less demanding targets. The error was well characterized and stable, enabling astronomers to optimize the results obtained using computer image processing techniques.

During this time, NASA noticed another annoying problem that needed a remedy. As the Hubble orbit took the spacecraft from the darkness behind the Earth's shadow into the bright sunlight, the sudden heating caused the solar arrays to "ping", a vibration that reverberated through the telescope from the rapid heat expansion. The unfortunate effect also repeated as the telescope entered the Earth's shadow, as the arrays rapidly cooled off. These 12-m solar arrays, vibrated 16 times a day each time the telescope orbited. The arrays, originally provided to the mission by the European Space Agency, needed to be replaced with a redesign that dampened the expansion and contraction vibrations.

Finally, on December 2, 1993, the Space Shuttle Endeavour lifted off Launch Pad 39B to perform Service Mission 1 to the Hubble Space Telescope, with Mission Commander Richard O. Covey, Pilot Kenneth D. Bowersox, Payload Commander F. Story Musgrave, Mission Specialists Kathryn C. Thornton, Claude Nicollier, Jeffrey A. Hoffman and Thomas D. Akers. Service Mission 1 was the most difficult and complicated mission ever planned, involving at total of five extra-vehicular activities (EVA) over the span of 4 days, with each EVA lasting approximately 7 h.

The importance of Service Mission 1 cannot be understated. NASA's reputation was severely tarnished from the tragic loss of the Space Shuttle Challenger, the Hubble problems, and loss of several space craft. In the most embarrassing incident, Mars Climate Orbiter went silent on September 23, 1999 as it disintegrated in the Martian atmosphere because the contractor engineers used English units of measurement while the NASA engineers used the metric system for calculating a key spacecraft navigation operation. Oops! The spacecraft approached Mars on a trajectory that brought it too close to the planet, causing it to pass through the upper atmosphere and break apart.

Fortunately, NASA got things right on STS-61. The first 2 days of the mission consisted of Endeavour performing a series of burns that allowed the shuttle to close in on the HST at a rate of 60 nautical miles (110 km) per 95-minute orbit. By the third day, Hubble was sighted by the astronauts looking worse than expected. One of the solar arrays had a 90 degree bend in it. Despite this little surprise, the crew of the Endeavour used the Remote Manipulator System arm to grapple the HST, and safely nestle it into the shuttle cargo bay. Over the course of the next few days, WFPC 2, COSTAR, and two new solar arrays were installed on Hubble. During a record five space walks amounting to 35 hours and 28 minutes, two teams of astronauts completed the first servicing (NASA used the term "repair") of the Hubble Space Telescope. Many of the tasks were completed earlier than expected,

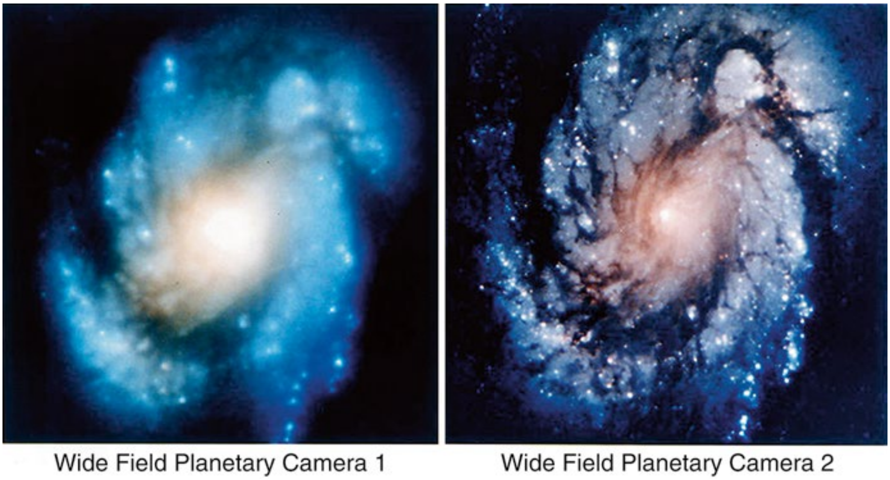

Fig. 1.1 Hubble images before and after (NASA/ESA)

and those few glitches that arose were handled adroitly. The HST was then boosted to a slightly higher orbit at 370 miles or 595 km on mission day 8.

On 13 January 1994 NASA formally announced the mission, one of the most complicated and demanding in NASA history, had been a complete success as they released the first of many much sharper images to come from Hubble (Fig. 1.1).

In March of 1994, the Robert J. Collier Trophy for 1993 was awarded to the Hubble Space Telescope Repair Team. Regarded as the highest award in US aviation, the Collier Trophy was established in 1911. Presented annually by the National Aeronautic Association, the Collier Trophy is granted "for the greatest achievement in aeronautics or astronautics in America, for improving the performance, efficiency, or safety of air or space vehicles, the value of which has been thoroughly demonstrated by its actual use during the preceding year." The citation accompanying the award read "For outstanding leadership, intrepidity, and the renewal of public faith in America's space program by the successful orbital recovery and repair of the Hubble Space Telescope." The seven astronaut crew members and four ground managers of STS-61 were named as the recipients of the award and represented more than 1,200 people who had a direct involvement in this mission.

Just a few months after Servicing Mission 1 had corrected the HST optical performance, Comet Shoemaker-Levy 9 broke into pieces and slammed into Jupiter. Hubble was able to capture this historic and rare event with amazing details (Fig. 1.2).

It was during the post-Service Mission 1 period that images of the Orion Nebula revealed proto-planetary disks, dubbed proplyds. These images provided evidence of the developmental process of stars with planets in the process of forming.

Fig. 1.2 Comet Shoemaker-Levy 9 impacts on Jupiter (NASA/ESA)

With the Hubble aimed at a relatively starless area near the Ursa Major constellation, an image was assembled from 342 separate exposures taken during December 1995 with the WFPC2. Known as the Hubble Deep Field (HDF), the image revealed nearly 3,000 galaxies, with some of the youngest galaxies and some of the farthest galaxies ever studied by astronomers. With the later Hubble Deep Field-South, known as HDF-S, the original HDF became known as HDF-N.

Four additional service missions have been carried out since the dramatic initial upgrade of the Hubble, for a total of five service missions. Those familiar with the NASA numbering system of the Service Missions may find the nomenclature of the missions somewhat puzzling, since the final Space Shuttle mission to Hubble is referred to as Service Mission 4. Stay tuned, an explanation is forthcoming.

STS-82 was the 22nd flight of the Space Shuttle Discovery and designated as Service Mission 2 to Hubble on February 1997. The crew assigned to STS-82 consisted of mission commander Ken Bowersox, pilot Scott Horowitz, mission specialists Joe Tanner, Steve Hawley, Greg Harbaugh, Mark Lee, and Steve Smith. Discovery's crew repaired and upgraded the telescope's scientific instruments and increased its research capabilities. Four precisely choreographed spacewalks were required to remove the Goddard High Resolution Spectrograph (GHRS) and the Faint Object Spectrograph (FOS). In those vacated spots were installed the Space Telescope Imaging Spectrograph (STIS) and the Near Infrared Camera and Multi-Object Spectrometer (NICMOS). In addition to installing the new instruments, astronauts replaced other existing hardware with upgrades and spares, mostly dealing with the telescope's pointing and guidance subsystems, and data recording. Discovery's maneuvering jets fired several times during the mission to boost telescope's orbit by over 8 miles. Hubble redeployed to its highest altitude ever flown, a 385 mile (620 km) by 369 mile (594 km) orbit. Initial checkout of new instruments and equipment during the mission showed all were performing nominally. After a calibration of two new science instruments took place, Hubble continued its mission and making history.

Following Service Mission 2, an image similar to the Hubble Deep Field was planned for the Earth's southern hemisphere. An area in the constellation Tucana was selected far from the Milky Way's galactic disk. With hundreds of exposures by the WFPC2 during September and October of 1998, a composite image similar to HDF-N was developed, and became known as Hubble Deep Field—South, or HDF-S. The HDF-N and HDF-S images, along with the Ultra Deep Field and eXtreme Deep Field are shown and discussed in a later chapter.

The original Service Mission 3 was scheduled for June 2000, but by December 1999, three of the six on-board gyroscopes that controlled the pointing of the Hubble had failed. NASA, in accordance with the established flight rules, decided to move up the service mission before a fourth gyro failure resulted in a non-operational space telescope. Thus, Service Mission 3 was split into the STS-103 Service Mission 3a of December 20, 1999, and STS-109 Service Mission 3b of March 1, 2002. Hence, the strange numbering for the five service missions.

Assigned to STS-103 was commander Curtis Brown Jr., pilot Scott Kelly, and mission specialists Steve Smith, Jean-Francois Clervoy, John Grunsfeld, C. Michael Foale, and Claude Nicollier. Using Space Shuttle Columbia, STS-103 flew into orbit to replace all six gyroscopes, based on an understanding of the root cause of the gyro failures. The HST gyroscopes were designed to spin at a constant rate of 19,200 rpm on gas bearings. This gyroscope wheel was mounted in a sealed cylinder, which floated in a thick fluid. Electricity was carried to the motor by human hair thin wires. The original manufacturing process for the gyros used oxygen in the pressurized air, causing the wires to corrode and break. The new gyros were assembled using nitrogen in place of oxygen.

In addition to replacing the gyroscopes, the crew replaced a Fine Guidance Sensor (FGS) and the HST on-board computer was upgraded with new hardware with faster processing and greater memory. The archaic tape recorders were upgraded to solid-state recorders, along with replacements for other failed equipment and renewed thermal insulation.

Drawing the assignment for STS-109 were commander Scott Altman, pilot Duane Carey, mission specialists John Grunfeld, Nancy Currie, Richard Linnehan, James Newman, and Michael Massimo. New equipment for the HST included the Advanced Camera for Surveys (ACS), new rigid solar arrays (SA3), a new Power Control Unit (PCU) and an experimental cryocooler for the NICMOS. The ACS was designed to be the primary imaging instrument aboard the Hubble, but unfortunately was plagued with electronic problems throughout 2006 and 2007. The final Service Mission 4 returned one of the channels, the Wide Field Channel into service, but the High Resolution Channel (HRC) remains non-functional.

The Hubble has seen extensive use in observing the minor planet Pluto, not only providing images of the distant object, but also discovering four additional moons besides Charon, Pluto's moon that was discovered in 1978. Two of the new moons of Pluto were discovered in 2005. Named Nix and Hydra, the smaller Nix orbits at a distance of 48,700 km and the larger Hydra at 64,800 km from Pluto.

Following the Service Missions 3a and 3b, the most significant discovery of Hubble was the non-standard object SCP 06F6. Discovered on February 21, 2006, in the constellation Boötes, the object is of an unknown type, displaying a spectrum in the blue region with broad line features, while the red region presents continuous emission. It brightened over a period of 100 days, then dimmed over a similar period. The spectrum did not match known supernova spectrum characteristics, showing only a handful of spectral lines. But astronomers have failed to match any of the spectral lines to a known element. Standard redshift techniques cannot be used on SCP 06F6 because of its unusual spectral characteristics. It is possible that SCP 06F6 lies outside the Milky Way Galaxy. Like many Hubble observations, there have been a number of scientific papers written in an attempt to explain this unusual supernova.

Over the history of the Hubble Space Telescope, there have been the contributions of Hubble data and observations that have led to the establishment of a connection between galaxies and the presence of black holes at their cores. The high resolution images and spectrographic data have provided data that established that black holes are prevalent at the cores of galaxies, and also the masses of the core black hole and the characteristics of the host galaxy are related.

The fifth mission to service the Hubble, the misleadingly named Service Mission 4, almost didn't happen. The mission was planned for February 2005. Unfortunately, following the successful Columbia STS-103 mission, the next Columbia flight proved to be its last. The loss of the Columbia during re-entry had a wide range of ramifications on Hubble program. NASA Administrator Sean O'Keefe imposed new Space Shuttle flight rules that all future shuttle missions had to be able to reach the International Space Station (ISS) in case of damage or other problems or malfunctions.

Unlike the recent movie *Gravity*, where fictional astronauts traversed from a Hubble service mission to the safety of the ISS (in just spacesuits and a thruster pack, no less!), the orbits of the ISS and the Hubble are radically different. Not only does the Hubble reside in an orbit over 100 miles higher than the ISS, but the difference in orbital inclination is too large to stay within the confines of the new flight rules. No shuttles were capable of reaching both HST and the ISS during the same mission, and all future manned service missions to Hubble were therefore canceled.

The outcry from the public, professional astronomers, and Congress was enormous. NASA studied the idea of a robotic service mission to Hubble as an alternative, and this concept was found infeasible. With the James Webb Space Telescope scheduled to be launched no earlier than 2018, the Hubble seemed destined to die a slow death as parts and subsystems slowly degraded without maintenance.

With the appointment of a new NASA administrator, Michael D. Griffin, a ray of hope arrived. Soon after his appointment, Griffin authorized Goddard Space Flight Center to proceed with preparations for a manned Hubble maintenance flight, and an 11-day mission by the Space Shuttle Atlantis was scheduled for October 2008. The task of replacing a failed data handling unit was added to the mission at the last moment because of an on-board Hubble failure, and pushed back the service mission to May 11, 2009.

With Scott Altman serving as mission commander, Greg Johnson as pilot, and mission specialists Mike Good, Megan McArthur, John Grunsfeld, Mike Massimino, and Andrew Feustel, the fifth and last service mission to Hubble was accomplished on a 13 day mission. The mission added two new instruments to Hubble. The first instrument, the Cosmic Origins Spectrograph (COS) provided the most sensitive ultraviolet spectrograph installed on the telescope. The COS far-UV channel is 30 times more sensitive than previous instruments and the near-UV is twice as sensitive. The second instrument, the Wide-Field Camera 3 (WFC3) replaced the WFPC2 camera, allowing for a wide range of photographic imaging in ultraviolet, infrared, and visible light. The infrastructure of the telescope was upgraded by replacing the Fine Guidance Sensor, installing a set of six new gyroscopes, replacing batteries, and installing a new outer blanket layer to provide improved insulation. The astronauts also installed a Soft Capture and Rendezvous System, which enables a future rendezvous, capture, and safe disposal of Hubble by either a crewed or robotic mission.

The technology upgrades from Service Mission 4, plus a laundry list of maintenance tasks, are expected to keep Hubble operation at least through 2014, and hopefully until the James Webb Space Telescope is online.

Following the installation of the new WFC3 camera, the Hubble was tasked to investigate the potential for rings around Pluto and plan a safe route through the Pluto system for the New Horizons spacecraft as it performs a flyby of Pluto on July 14, 2015. The images of the Pluto system revealed two additional moons in the system, Kerberos discovered in 2011, and Styx in 2012.

A measure for the success and impact of the Hubble Space Telescope on the scientific community is the number of scientific papers generated from the Hubble images and spectrographic data in over 21 years since its launch. Over 10,000 referenced papers have been written by thousands of astronomers from over 35 countries that have engaged in Hubble-based research.

The papers are based on Hubble observations that cover nearly every frontier in astronomy. Topics of the science papers include: the search for distant supernovae used to characterize dark energy; the precise measurement of the universe's rate of expansion; the apparent link between galaxy mass and central black hole mass; early galaxy formation in the Hubble Deep Field; the search for dark matter; and the evolutionary models for low-mass stars and brown dwarfs.

The discoveries reported by these papers include: the ever expanding Universe is increasing in acceleration caused by dark energy; the distribution and clumps of dark matter throughout the Universe; and that gamma ray bursts typically occur in galaxies that are actively forming stars and are low in elements heavier than helium.

The number of science papers written based on Hubble archival data exceeds the number of papers resulting from new observations, with the Hubble archive containing data from over 1 million exposures. Generations of astronomers will be mining this astronomical treasure trove for decades to come, long after the Hubble program has ended and the James Webb Space Telescope begins operation.

The first science paper from a Hubble observation was submitted on October 1, 1990, by Tod Lauer of the National Optical Astronomy Observatory in Tucson, Ariz. This paper reported observations of the environment around a suspected black hole in the core of galaxy NGC 7457.

The lead author of the 10,000th paper is Zach Cano of the Astrophysics Research Institute, Liverpool John Moores University, Liverpool, United Kingdom. A gamma-ray burst was first detected on March 16, 2010, by the NASA Swift high-energy space telescope. In a collaborative effort, The Faulkes Telescope South and the Gemini Telescope South observatories joined Hubble in making parallel observations of the gamma-ray burst's location in visible and infrared light. The paper reported on the identification of the faintest supernova ever associated with a long-duration gamma-ray burst.

Nearly half of the papers utilize data from Hubble's longest operating camera, WFPC2. The next most highly ranking instrument is the ACS, which was installed by the Service Mission 3b, and is still operating. This is followed by three of the spectrograph instruments: the STIS, the NICMOS, and the FOS.

Chapter 2

What You Need to Know About Telescopes

Most of the celestial objects photographed by the HST are faint distant objects that can be a challenge for both the beginning, casual, and serious backyard observer. Equipped with the right visual aid, in the form of a telescope or occasionally binoculars, the backyard observer will be able to locate and observe some of the brighter targets of Hubble interest. The reader is reminded that what can be seen from the backyard will not be Hubble-quality in detail, resolution, or image size.

With optical aids of either a good pair of binoculars or a good telescope, the larger star clusters can be observed with details. A good pair of 7×35 or 7×50 binoculars can resolve some of the major open clusters, locate the brighter globular clusters, and the Galilean moons of Jupiter.

But, objects unseen by the binocular becomes observable once the observer starts using a telescope. Keeping in mind the limited performance of telescopes used the pioneering astronomers such as Galileo, Herschel, and Messier used, modern telescopes with apertures beginning at 60 mm can locate some of the Hubble objects, although the brightness and, resolution, and detail is lacking. The term “aperture fever” quickly becomes part of an amateur astronomer’s vocabulary, in the search for brighter, higher resolution, and greater detail.

There are bookshelves full of books, and there are numerous websites on the Internet that offer advice in selecting telescopes, and telescope accessories. Many are well-written, thoughtful, and informative. In fact, readers familiar with the first book of this “How to Find” series will recognize some of the information and recommendations in this chapter. The approach in this chapter is to offer the common sense approach for selecting the right telescope for the right use. If some of the words in this chapter seem familiar to readers of the author’s first book, *How to*

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Find the Apollo Landing Sites, they are. The discussions and recommendations here has been tailored towards deep sky observing as opposed to lunar and planetary observing.

Buying a Telescope

A useful analogy in buying a telescope is looking at a parking lot of a local grocery store. There are a variety of cars and trucks parked there. Why? Because different people purchase vehicles for different reasons. Soccer moms need mini-vans to haul their kids to soccer fields. Handymen need pickup trucks to haul plywood and plumbing tools. The thrill-seeker will own a high-performance sports car. And a business man will drive a prestige high priced car to show off wealth and fame.

The same process of selection also applies to telescopes. In this case, there are telescopes that are best used for deep sky objects such as nebulas, galaxies, and star clusters. There are telescopes that excel in astrophotography. And in the case of this book, there are telescopes that excel in observing the Moon and the planets of our solar system.

First-time buyers are faced with a myriad array of telescope choices, and more-often-than-not purchase the wrong telescope for their use. The wrong telescope purchase will end up in the closet gathering dust, or worst yet, in a garage sale. So here are a few basic all-encompassing guidelines in selecting telescopes for astronomy use, especially for viewing the Moon.

- *Buy your second telescope first*. The common advice for years from all amateur astronomers is don't buy a department store telescope. In today's world that advice extends to warehouse stores and sporting goods stores. Most so-called beginners' telescopes are plagued with poor optics, shaky telescope mounts, and in some cases poor electronics. Many of these telescopes are aimed at well-intentioned consumers that haven't taken the time to study the telescope market, and just want a big box under the Christmas tree or at the birthday party. Grandparents especially fall into this trap. By using the term second telescope, most telescope owners who survive the trials of these beginners' telescopes and still want to pursue the hobby naturally learn to buy a quality telescope the second time around. Save money now by being educated and buy the right equipment first.
- *A smaller telescope will get used more than a larger telescope*. There is a strange ailment that afflicts every backyard astronomer known as aperture fever. In this bigger-is-better society, the desire for a larger telescope that shows more detail and gathers more light is sometimes overwhelming. But there is a point where a telescope becomes so large and cumbersome to use that the usage of said telescope becomes less and less. A smaller and more portable, telescope with easy setup gets used more.
- *The telescope mount is as important as the telescope optics*. A good, solid and stable telescope mount encourages observers to use their telescope. Nothing is more frustrating than trying to focus a telescope on a weak and poorly designed mount that shakes and vibrates with a slight touch or a slight breeze.

- *The right eyepieces for the right job*. As with telescope designs, certain eyepiece designs are suited for wide-angle extended celestial objects such as nebulas and open star clusters, while others are intended to high contrast detailed assignments. With the cost of eyepieces ranging from $30 to over $1,000 each, a meaningful and careful selection is appropriate.
- *Buy the right telescope that suits your personal skills*. Some telescopes are well-suited for the technically inclined. Some telescopes are simple to use. The potential first-time telescope owner needs to understand their own personal skills and acknowledge their abilities before making a telescope selection. Namely, if you can't change a car tire, or your digital oven clock is always flashing 12 o'clock, certain astro equipment should avoided. And as with the size of the telescope, the easier the telescope is to use, the more likely it will be used.
- *Consider a neutral density or polarizing filter for the telescope eyepiece*. The Moon, especially when it's full, can get uncomfortably bright. Not dangerously bright, like the Sun, just uncomfortable. An appropriate filter will tone down the glare to a comfortable level.
- *Never point your telescope at the Sun unless properly equipped*. This is important. Serious damage to the human eye occurs when viewing through an unfiltered telescope. Telescope vendors sell appropriate white-light and hydrogen-alpha filters for safe viewing of the Sun. The previously mentioned neutral density or polarizing filters for the Moon do not offer enough filtering protection for the human eye for solar observing.
- *Buy quality*. The old adage "You get what you pay for" applies here. Telescopic images are clear and sharp. Mounts work smoothly and are free of spurious vibrations. Focusers have a buttery smoothness that allows for fine tuning of the focus. High quality telescopes allow the observer to enjoy astronomy without problems getting in the way. In fact, there are numerous examples of quality apochromatic refractors that have appreciated in value, and sell on the used market for more than the original purchase price.
- *Support your local telescope store*. Believe it or not, the astronomy industry is not a big money, high profit business. With the exception of two dominant major companies, many telescope businesses, either manufacturers or stores, are Mom and Pop operations run by people who love science and astronomy. They have expertise in amateur astronomy, provide quality products, provide personalized service, and are able to perform many repairs in their own shops. The smaller telescope shops struggle to compete with high volume Internet or mail-order firms who offer little or no service and rely on manufacturers to repair faulty equipment. Consumers need to understand the retail business. There are three criteria for competition: Quality, Service and Price. The consumer can only get two of the three. A lower price means the consumer sacrifices either service or quality. It is astounding to note that profit margins of major name brand telescopes are miniscule. For example, a well-known large Schmidt-Cassegrain computer controlled telescope costing over $3,000 will net a profit to a store of $100. Smaller stores rely on accessory sales, service work, and loyal customers to stay in business. Remember, at your local telescope store, there are real people

(not a disembodied voice on the phone) who know astronomy, sell and support quality products, support local astronomy clubs, and can fix any problems with telescope equipment (often on the spot).

The Telescopes

The world of astronomy is inhabited by a menagerie of telescopes (Fig. 2.1). There are short-focus and long-focus refractors, Dobsonian reflectors, Schmidt- or Maksutov-Cassegrains, Newtonian reflectors, GOTO telescopes, achromats, apochromats, … the list goes on and on. There are telescopes of every size and for every budget. Some with manual altitude-azimuth mounts, some with German equatorial mounts, and some with very sophisticated electronic GOTO mountings. It's no wonder that a person new to astronomy gets confused and intimidated.

The following discussions on telescope types demands a definition of focal ratio, or f/ratio. Quite simply, the f/ratio is the focal length of the telescope divided by the diameter of the main lens or mirror. The smaller the f/ratio, the lower the magnification and the wider the field of view with any specific eyepiece. Higher magnification is easily attained with a higher the f/ratio, but with the cost of a smaller field of view.

In order to simplify the world view of amateur astronomy, it is best to organize telescopes into the three basic categories: refractors, reflectors, and catadioptrics.

Fig. 2.1 Group photo of the author's collection of telescopes (James Chen)

The Refractors

Ask someone to close their eyes and picture in their mind a telescope. Or better yet, ask a child to take a crayon and draw on a piece of paper a picture of a telescope. More likely than not, the image of a long tube pointed at the skies with an observer peering through the opposite end is the result. The refractor is the intuitive concept of a telescope.

Historically, the refractor is the earliest design for telescopes, with the earliest examples appearing in the Netherlands in 1608. Spectacle makers Hans Lippershey and Zacharias Janssen are two of the early creators of the design. Within a year or two Galileo created his own improved refractor design, pointed his telescope into the night sky, and history was made.

Conceptually, a refractor is a system of lenses with an objective lens system to gather light and an eye lens system to focus the light gathered by the objective lens into an image for the observer. Hence, the intuitive mental picture of a long tube with an objective lens pointed at the sky and an observer viewing through the opposite end focusing the eyepiece.

Inch-for-inch, refractors are regarded by the astronomy community as the best performing telescopes. Sharp, pin-point star images, and high contrast planetary images are their hallmark. Four inch or larger diameter refractors are the primary instruments of lunar and planetary observers. Astrophotographers have adopted apochromatic refractors as their go-to telescopes, producing the sharp and contrasty images that rival professional observatories.

In today's world of refractor telescopes, there are achromats and apochromats, terms created to differentiate the levels of color correction of the respective lens systems. Grade school science demonstrates that sunlight passing through a prism separates sunlight into its constituent colors. In optical systems, such as telescopes, all types of optical glasses exhibit some degree of separation and dispersion of light into primary and secondary colors (Fig. 2.2).

A classic achromatic refractor uses a two lens objective, with one lens made of crown glass, and the other lens made of flint glass. With the lenses ground with proper curves and using glasses with different refractive indices, the result is a telescope that can bring to focus two of the three prime colors of light, typically red and blue wavelengths. So conceptually, the achromat can produce an improved image of a distant object over a single lens objective of the type used by Galileo. In practice, there are some color errors, or chromatic aberrations, that creep into the

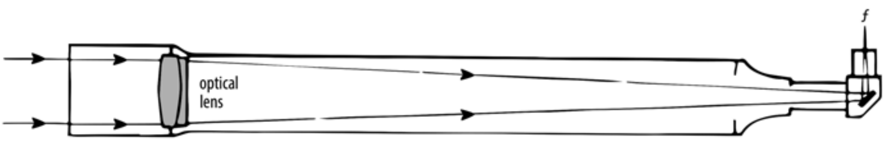


Fig. 2.2 Classic doublet achromatic refractor (Adam Chen)

visual performance of an achromatic refractor, especially at shorter focal lengths. The primary colors do not focus at the same point, resulting in a color fringe around Moon, planets or bright stars. This chromatic aberration also results in diminished sharpness and definition in the telescope image. Many classic early refractors typically have focal ratios of f/11, f/15, or f/20 or greater to minimize chromatic aberrations and become "color-free". Even at long focal lengths, achromats can display chromatic aberrations, where the secondary colors of yellow and purple wavelengths do not come to focus.

This technical discussion gives the impression that achromats are flawed. That couldn't be farther from the truth. Today's achromatic designs use different types and combinations of Extra-low Dispersion, or ED, glass to lower the chromatic aberrations to a minimum. Modern designs of achromats have minimized the false color to a high degree. One current builder of high quality refractors has taken advantage of new glass technology and our light polluted skies. With a combination of ED glasses, altered lens curves, and adjusting the air spacing between the two lenses of the doublet, the color error in the violet wavelengths match the not-quite-black-really-deep-purple light polluted background sky, resulting in an excellent performing telescope that produces sharp and crisp images with the color error conveniently and cleverly hidden in the background. There are specialized long focus 102 mm achromatic refractors on the market with f/11 focal ratios or greater specifically designed for viewing the Moon and the planets. These modern "planet killers" take advantage of low dispersion glasses and long focal length to provide images that rival apochromatic refractors at one third the cost. In the case of viewing deep sky objects, there are affordable achromats, up to 6 inches in aperture, that offer the refractor's higher contrast than reflecting designs, and any chromatic aberration effects are less detectable on the dimmer deep sky objects (Fig. 2.3).

Sometime in the 1980s, the apochromatic refractor became commercially available to the amateur astronomy market. Sophisticated designs appeared using combinations of two, three, or four lenses of exotic glasses. Advanced telescope owners found themselves developing and reveling in a new vocabulary that included terms such as fluoro-crown, lanthanum, fluorite, FPL-51 or -53, APO-triplet, and Petzval. These apochromats offered improved sharpness, contrast, and color correction over the classic achromat refractors, while at the same time creating a more portable telescope with f-ratios of f/8 or less. But this optical performance improvement is costly. Apochromats are typically 2–10 times more expensive that an equivalent aperture achromatic refractor. Apochromats get expensive very quickly as the size increases.

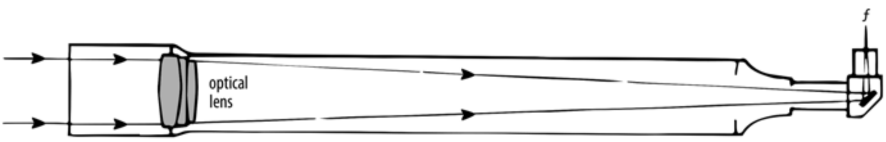


Fig. 2.3 Modern triplet apochromatic refractor (Adam Chen)

A typical 80 mm apochromat retails in the $700 range. A 102 mm triplet can easily cost over $2,500. 130 mm apochromats range fall into the $4,000–$5,000 realm, and you can buy a car with the money needed for larger apochromats.

The old telescope salesman explanation of an achromat refractor is a "color-free image", meaning no color fringing in the telescopic image. The telescope salesman pitch for an apochromat is "this time, I'm serious! It's color-free!". Depending on the sensitivity and sensibility of the observer, the image improvement of an apochromat over an achromat can be either a slight or a day-night difference. A lot depends on the sensitivity and sensibility of the refractor owner. From a technical viewpoint, there is no question that the apochromatic refractor offers the best telescopic images over an achromatic refractor. In fact, as discussed later in this chapter, an argument can be made that an apochromat is inch-for-inch better than every other telescope design, whether refracting, reflecting, or catadioptric.

The Reflectors

Countless astronomy books and websites over the years have presented valid arguments that the Newtonian reflector represents the most "bang for the buck" in telescopes (Fig. 2.4). Originally designed by Sir Isaac Newton in 1668, this telescope represents a simple design using either a spherical or parabolic main mirror to collect light and a flat diagonal mirror to reflect the collected light to the eyepiece and the observer. By limiting the number of optical surfaces that need to be accurately figured and polished to two, the cost for a Newtonian telescope can be minimized. In contrast, a doublet refractor needs four optical surfaces, and a triplet apochromat needs six optical surfaces to be accurately ground, figured, and polished. The Newtonian design, being reflective in nature, has no chromatic aberrations and can be constructed from less expensive materials. During the explosive growth of Newtonian telescopes in the 1980s, with John Dobson's unique implementation of the design, Newtonians could be made from Pyrex glass, cardboard tubes, and plywood.

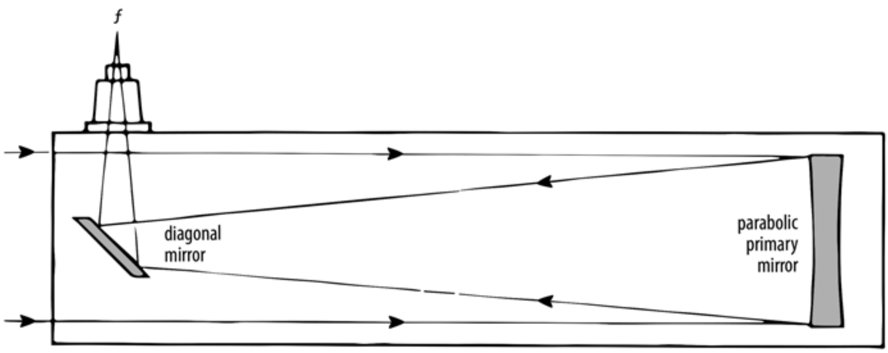


Fig. 2.4 The Newtonian reflector (Adam Chen)

Sounds like the perfect telescope. An 8-inch Newtonian reflector on a Dobsonian mount can be easily acquired for the price of a 3-inch achromat refractor. That is a lot of performance for the money.

But there is a catch. Ask any telescope dealer, any telescope salesman, or any member of your local astronomy club, "What is the most common telescope problem?" Nine times out of ten, owners of Newtonian telescopes are unable to align the optics of their telescopes. The main mirror is tilted, the diagonal is not centered, the tilt of the diagonal needs adjustment, or a combination of all three leads to frustration for the telescope owner, resulting in a telescope that ends up in the closet. Whereas refractors and some catadioptric designs do not need collimation alignment under normal use, Newtonian telescopes require frequent maintenance. Transporting the Newtonian by car, or just the act of moving the telescope for inside a home to the patio can jar the Newtonian's optics to misalignment. Owners of Newtonians must acquire the skill for re-alignment of their telescopes. This alignment skill is easily acquired by some, while others find the alignment task difficult. Some telescope owners take collimation in stride, while others find it a nuisance.

The Catadioptrics

Catadioptric telescopes are a category of telescopes that combine lens and mirror technology to produce compact and transportable instruments (Figs. 2.5 and 2.6). With a clever combination of a lens and mirrors, the incoming light path is folded upon itself, and any optical aberrations of the reflecting surfaces can be corrected by the refracting lens.

Catadioptrics are available in two popular forms: Schmidt-Cassegrain telescopes, or SCT and the Maksutov-Cassegrain telescope. Maksutov-Cassegrains appeared on the commercial market in the mid-1950s, and SCT's burst into popularity in the 1970s. As a family, catadioptrics offer a high degree of optical performance and low maintenance in a small compact package.

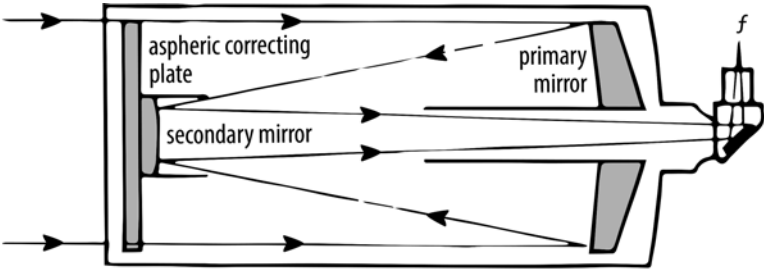


Fig. 2.5 The Schmidt-Cassegrain telescope (SCT) (Adam Chen)

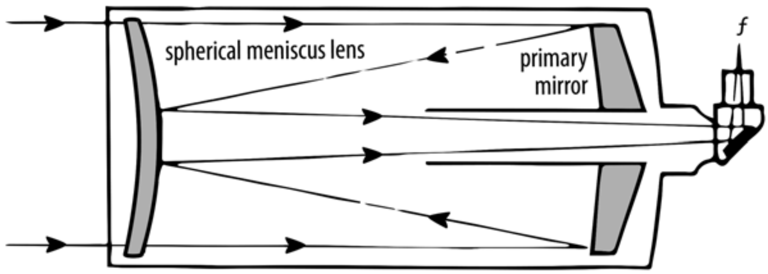


Fig. 2.6 The Maksutov-Cassegrain telescope (Adam Chen)

Although SCTs are available in sizes from 5-inch to massive 14 and 16 inch apertures, the most popular and best-selling telescope since the 1970s has been the 8-inch SCT. The 8-inch SCT is the basic core product for not one, but two major telescope companies. The reason for this popularity stems from the all-around versatility that the design provides. As an analogy, the 8-inch SCT is the Olympic Decathlon Champion of telescopes. The Olympic Decathlon gold medalist doesn't excel in any singular competition, such as the 100 m dash or the high jump, but is able to perform ten different events better than anyone else can perform those same events. Versatility and a high level of performance are outstanding attributes of an 8-inch SCT. The 8-inch aperture allows for light gathering for deep sky objects, the typical f/10 focal length enables high magnification for lunar and planetary observations, numerous attachments are available for photographic use, and the compact size ensures frequent usage. But it's not perfect for any singular use. Newtonian telescopes are available at a cheaper price in larger sizes for deep sky light gathering. Refractors produce images that are of better quality in contrast and sharpness. Many amateur astronomers tend to own two, three, or more telescopes in order to optimize their viewing. But if a person is only going to own one single telescope that is capable of handling multiple astronomy tasks, the 8-inch SCT is the likely choice.

Maksutov-Cassegrain, or Maks for short, are highly popular smaller telescopes in the 3.5–6 inch diameter range. Costing from $400 to an astronomical (pardon the pun!) $4,000, these little gems of the telescope world are available in every configuration conceivable. Maks tend to have long focal lengths in the f/12 to f/15 range, which helps to improve contrast but limits the field of view. Available on simple manual mounts, to equatorial mountings, to high tech computerized go-to systems, Maks are as versatile as their SCT counterparts. Due to the compact size, Maks make excellent travel scopes.

The natural question that arises from all these discussions of telescope design is: What telescope is ideal? Recalling the car analogy, it depends on the type of observing.

For observing the Moon and planets, the answer is clear. Refractors offer the sharpest, clearest, and most contrasty images. But why? A discussion is needed on the difference between unobstructed and obstructed optics. As seen in Figs. 2.4, 2.5, and 2.6, the Newtonian and the catadioptric designs share a common attribute of a secondary mirror that is centrally located along the light path. These secondary mirrors allow for the folding of the light path to direct the incoming light to the eyepiece. In the case of the Newtonian, the secondary diagonal serves to guide the light to the side of the telescope to the focuser. In both catadioptric designs, the secondary mirror fold the light path creating a very compact telescope that enables portability. The commercially available Newtonians have secondary mirrors that measure approximately 30–35 % the diameter of the primary mirror. Most SCTs and Maks the central obstruction of the secondary mirror constitutes 40 % the diameter of the primary mirror. The main impact of the central obstruction is a decrease in sharpness and contrast in the telescope image. What is the difference in performance between the unobstructed refractor and an obstructed design? The best analogy is to compare the familiar standard definition TV versus HDTV. A good SCT or short-focus Newtonian will offer a good lunar image like that of a standard 480i digital TV image, but a good ED achromat or apochromatic refractor is like watching a 1080p high-definition TV.

Any of these telescope designs can be used to view the HST objects. If the reader of this book currently owns a telescope, proceed to the following chapters and find the HST objects and enjoy. To those looking to purchase a telescope, the following recommendations are offered based on telescope technology, decades of amateur astronomy field experiences, and telescope retail experience:

- For lunar and planetary observing, an 80–102 mm refractor is the top choice. These refractors are light, portable, and low maintenance telescopes that offer sharp contrasty images of the Moon and planets. Remember, the reason that large telescopes exist is to act as light buckets and gather the faint distant light of stars, galaxies, and nebulas. The Moon is bright. Really bright. Light gathering is the least of your problems in lunar observing. The major planets are bright, too. Larger apertures do help with planetary viewing when the observer is seeking greater detail. When aperture fever occurs, and a larger bulkier telescope is acquired, the refractor takes the role of the easy-to-use, grab-and-go scope. No wasted money here.
- As discussed earlier, it's hard to argue against an 8-inch SCT. Yes, the lunar and planetary images are a little soft compared to a 102 mm apo refractor, but the overall versatility cannot be denied.
- A long focus f/10 or greater Newtonian has a central obstruction approximately 25 % of the primary diameter, and comes very close to refractor image quality. These telescopes are difficult to find in the commercial market, but there are some of these gems on the used market.
- 90–125 mm Maksutov-Cassegrains should also be considered, especially when small size is a requirement. However, these telescope will be aperture and wide-field challenged when viewing deep sky objects.

The Eyepieces

Telescope design is only half of the optical story (Fig. 2.7). The rest of the story are the eyepieces at the focus end of the telescope. And here again, there's another zoo filled with strange and wonderful denizens that are vying to complete the optical train. Kellner, Abbe, Konig, Brandon, and Nagler are all names of optical designers who have lent their names to their eyepiece designs, and are now an accepted part of the astronomy vocabulary. There are 0.965, 1.25, and 2 inch eyepieces. Some designs have been around for over a century, and some designs are less than a decade old. And most have valid use in astronomy (Fig. 2.8a, b).

Two of the oldest and simplest of the compound eyepiece designs are the Ramsden and Huygens. Originating from the 1700s, these eyepieces serve as historic curiosities. Occasionally, an antique Ramsden will show up at swap meets, eBay, or even antique stores. The Huygens eyepieces are still supplied in 0.965 inch size on cheap beginner telescopes sold at department stores and big-box stores. Both designs are flawed, with narrow apparent fields, chromatic aberration, and short eye relief (Fig. 2.9).

In the mid-1800s, the Kellner eyepiece was developed by replacing the singlet eye lens element of a Ramsden with an achromat doublet. This resulted in a better performing design with a wider field, better color correction, and less spherical aberrations. When used on long focus telescopes, Kellners still produce a reasonably

Fig. 2.7 The author's collection of telescope eyepieces (James Chen)

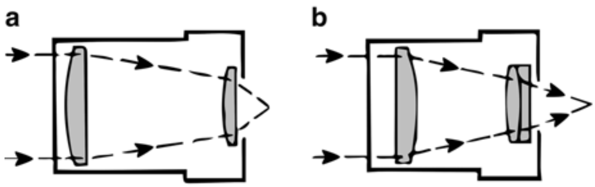


Fig. 2.8 (**a**) Huygens, (**b**) Ramsden (Adam Chen)

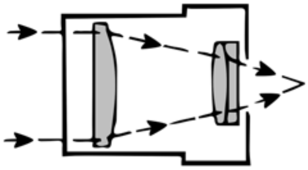


Fig. 2.9 Kellner design (Adam Chen)

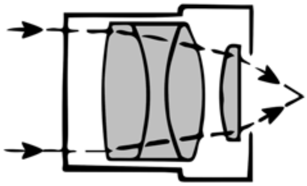


Fig. 2.10 The Abbe orthoscopic (Adam Chen)

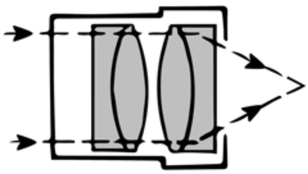


Fig. 2.11 The Plossl orthoscopic (Adam Chen)

good image. The main shortcoming of the Kellner is ghosting when looking at bright objects. So Moon watchers beware! The design exists today under various names, including Modified Achromat, RKE, and modified Kellner. These eyepieces are a good economical alternative for those on a budget (Figs. 2.10, 2.11, and 2.12).

An examination of the patents for the Abbe, Plossl, and Konig eyepiece designs describes all three as orthoscopic designs. The term "orthoscopic" means free from distortion. In common astronomy vernacular, the term orthoscopic has evolved to become synonymous in name with the Abbe design.

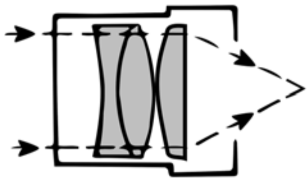


Fig. 2.12 The Konig orthoscopic (Adam Chen)

The Abbe has stood the test of time. Since the 1950s, through the growth of amateur astronomy in the 1960s and 1970s, the Abbe design has been highly regarded for sharp and high contrast images. The classic "volcano top" Abbe orthoscopic, so named for its distinctive beveled shape, are well-known and are highly desired. These Abbe eyepieces have been made by an optician from Japan named Tani-san, whose retirement in 2013 brought an end to decades of Circle T volcano top eyepieces. But don't fret, Abbe orthoscopic eyepieces are available through other sources. The Abbe orthoscopic eyepiece was held up as the pinnacle of eyepieces until the advent of new revolutionary wide-angle and high eye relief eyepieces in the 1980s. Today, dedicated lunar and planetary observers still insist on Abbe eyepieces today.

The Plossl eyepiece has an interesting reputation in the amateur astronomy world. In the 1960s, the Plossl only existed as a rare and mysterious eyepiece, commercially available from a small vendor in Europe. Then in the 1980s, Plossls suddenly became widely available, to the point now where it is so commonplace that the eyepiece is considered mediocre by average backyard astronomer . Nothing could be further from the truth. Although poorly manufactured examples exist, a premium Plossl is an extraordinary eyepiece, versatile in lunar, planetary, and deep sky use. There exists a number of variants of the design in which an extra lens or two to the system, somewhat blurring the definition of a Plossl, but these variants tend to be of high quality and offer high performance.

Not as widely available as the other orthoscopics, the Konig design has its fans. Depending on the implementation, the Konig potentially offers a wider field-of-view than the Abbe or Plossl. In practice, the Konig achieves a wider field, but with a slight sacrifice of edge of field sharpness, and slightly shorter eye relief.

A variant of the Konig design is the Brandon eyepiece. Chester Brandon developed his eyepiece design during his time at the Frankford Arsenal in Philadelphia. The eyepiece design was widely used during World War II in U.S. Army optics. The Brandon design differs from the Konig by using three high index glass types and four different lens radii. When marketed in the 1950s as a high priced premium eyepiece, the Brandons were priced at $15.95. My how times have changed, with the price of Brandons and many premium eyepieces in the three-digit range. With sharp crisp contrasty images, the Brandon reputation exceeded that of any other 1950s eyepiece, and is still the go-to eyepiece for many lunar and planetary observers today (Fig. 2.13a, b).

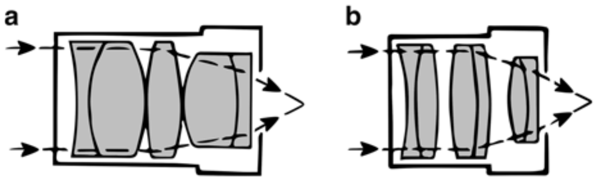


Fig. 2.13 (**a**) The Erfle, (**b**) modern wide-angle (Adam Chen)

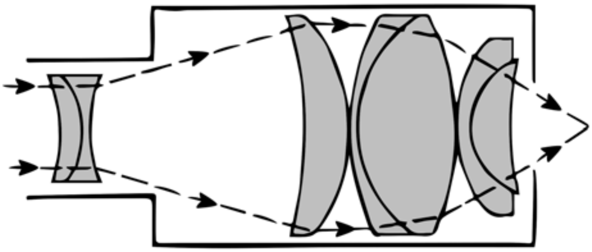


Fig. 2.14 The Nagler and related ultra wide angle eyepieces (Adam Chen)

During World War II, a number of scopes used for spotting or for aiming weaponry by the American armed forces were equipped with Erfle eyepieces. In the 1950s and 1960s, war surplus Erfle eyepieces became available for amateur astronomers seeking wide-angle views through their telescopes. With an apparent field of view of approximately 60 degrees, these large eyepieces created a demand for wide field eyepieces. That wide-angle demand has grown over the years, to the point now where the consumer demand for ever wider fields of view drives the eyepiece industry. The Erfle does not display as sharp an image in the center of the field as the orthoscopic eyepiece, and a degradation of the image occurs in the outer third of field. Newer modern wide-field designs use exotic glass types and different lens configuration and curves to correct the edge degradation, while at the same time providing a wider field of view (Fig. 2.14).

The quest for an ever wider field-of-view exploded with the introduction of the Nagler eyepiece. Competitors quickly followed, with virtually every telescope company offering their version of an over 80 degree field-of-view eyepiece. The ante was raised again with the introduction 100 degree and even wider field-of-view eyepieces in recent years. These eyepieces contain seven or more lenses in their complex designs in an effort to provide wide fields without sacrificing sharpness at the edge of the field. These eyepieces are not cheap, with many exceeding the cost of many telescopes! These eyepieces are outstanding for deep sky and wide field applications. However the complex design, high number of optical surfaces, plus the inevitable, although slight, light absorption caused by the amount of glass in the light path, these ultra wide angle eyepieces do not offer the same level of sharpness and contrast for planetary and lunar observing as the simpler orthoscopic designs (Fig. 2.15).

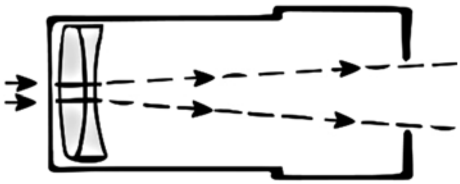


Fig. 2.15 The Barlow lens (Adam Chen)

While not an eyepiece, a Barlow lens is a useful addition to every eyepiece case. A Barlow lens is a negative lens system placed along the light path between the objective and the eyepiece that increases the effective focal length of the telescope, therefore increasing the magnification. Typically, Barlows double (2×) or triple (3×) the magnification. Newer focal extenders using three or four lens elements are available to quadruple (4×) or quintuple (5×) the focal length. These accessories are useful in three ways. A single Barlow lens effectively doubles the number of magnifications available in an eyepiece collection. The use of a focal extender also allows longer focal length eyepieces with their higher eye relief to be used at higher magnifications for eyeglass wearers. The use of a Barlow lens can improve the off-axis edge sharpness of some eyepiece designs. The Barlow lens and related focal extenders are also useful for astrophotography.

Some discussion is needed on the subject of zoom eyepieces. In the 1960s, the zoom eyepiece earned a reputation for mediocre optics and was not worth the money. Today's zoom eyepieces deserve some attention. Improvements in lens coatings, the introduction of high index glass, and improved manufacturing has yielded a modern zoom that is worthy of a spot in an observer's eyepiece case. Although still narrower in field-of-view at longer focal lengths, and wider at shorter focal lengths, the performance has been greatly improved. A zoom eyepiece will not take the place of an eyepiece collection for critical observing, but serves the role for quick look situations, or when showing the night sky to children whose short attention spans don't allow for the changing and refocusing of conventional eyepieces to change magnification.

The driving criteria for eyepiece selection for lunar and planetary observing is sharpness and contrast. The rule of thumb for selecting the right eyepieces for viewing the planets and the Moon is "the simpler the better". The classic Abbe, Plossl and Brandon designs are the preferred choices. There are more esoteric lunar and planetary eyepiece designs based on the monocentric design, or on proprietary designs. These are not discussed here due to their low availability.

There is an Achilles heel to the three classic orthoscopic designs. The older eyepiece designs perform best in longer focal length telescopes. In the era in which these designs originated, telescopes had long focal lengths, typically f/10 or greater. At f/20, even the lowly Ramsden design performs well. But many of today's telescopes have much shorter focal lengths, often f/6 or shorter. The classic designs suffer from loss of edge sharpness because of the steeper angle of the light cone from the objective as it enters the eyepiece. Modern designs take into account the shorter focal length telescopes of today. The design rationale for many of the updated configurations of the Plossl design has been to widen the field-of-view and improve performance with short focal length telescopes.

The recommendation for the ideal eyepiece for general observing is as follows:

- For telescopes with a focal length of f/7 or greater, the Abbe or Plossl designs will perform at the highest level.
- For telescopes with focal lengths of less than f/6, the modern wide-field and ultra-wide field designs are suggested.
- For observers who must wear glasses while viewing, there are some proprietary eyepiece designs that provide 20 mm of eye relief. These tend to be premium eyepieces that use exotic lens configurations and glasses, and therefore are not cheap. But they are recommended for eyeglass wearers.
- Consider using a Barlow in combination with a low- or medium-power eyepiece in order to obtain higher magnifications. The comfortable eye relief from this combination is often preferred by both eyeglass wearers and non-eyeglass wearers. The classic orthoscopic high power (4 mm and 6 mm) eyepieces are notorious for their near-pinhole sized eye lens.

The Filters

There are a number of filters available to telescope owners, such as nebula filters, light pollution filters, and color filters. These filters are very useful in many applications where the goal is to reveal very dim low contrast objects and features.

The question of light pollution filters and nebula filters is important, since the majority of the HST objects featured in this book are deep sky objects. These are remarkable telescope accessories that can produce a significant increase in contrast, and therefore observability, or dim deep sky objects. These filters are made of many layers of specialized coatings, with each coating formulated to filter a specific wavelength of light. It is important to remember that light pollution filters and nebula filters do not brighten the object, but darken the background and increase the contrast.

In general, light pollution reduction filters, often referred to as LPR filters, are broadband filters designed to filter the wavelengths of light associated with high- and low-pressure sodium streetlights, mercury vapor streetlights, and various wavelengths associated with houselights. These filters are no substitute for dark skies, but darken the background view through an eyepiece to the point of making a barely visible nebula or planetary readily visible. These are relatively mild filters when compared to the nebula filter cousins, and can be used with limited effectiveness in viewing galaxies and star clusters. Galaxies and star clusters are broadband objects, and the wavelengths of the streetlights will be filtered out of the objects frequency range, thus dimming the galaxy or cluster. The darker background may or may not be beneficial when viewing galaxies or clusters.

Nebula filters are designed and formulated to allow specific wavelengths of light through while suppressing most of the other light from an emission nebula or planetary nebula object. Nebula filters are useful for improving viewing of emission and planetary nebulas in dark skies as well as light polluted skies. Nebula filters take advantage of the physics of emission and planetary nebula. The nebula cloud atoms are ionized and excited into fluorescence causing the ghostly glow that characterize these objects. Because the nebula cloud is composed of mostly ionized hydrogen atoms, the glow comes from the far-red and blue portion of the visible spectrum. Additionally, a characteristic green glow is emitted from two spikes of ionized oxygen. Therefore, narrowband nebula filters are formulated to allow oxygen-III, hydrogen-beta, or a combination of both to perform their magic. Commercially, these filters are known as O-III filters, H-beta filters, and the combination results in the term UHC filters, with UHC for Ultra High Contrast.

How well do these work? For example, the author used to live in an area with Washington, DC to the west, Baltimore to the north, and Annapolis, MD to the east. To compound the light pollution problems caused by neighborhood streetlights, there was a shopping center ½ mile south and an elementary school to the north, both with mercury vapor parking lot lights. Needless to say, the sky was never really dark. In attempting to view the Owl Nebula in Ursa Major, even with an 11-inch SCT on a GOTO mount, the nebula could not be seen through the eyepiece without the aid of filtering. Adding a LPR filter darkened the ambient background to allow the Owl Nebula to be seen with averted vision (looking to the side of the object to take advantage of more sensitive areas of the eye). However, replacing the LPR with a UHC or O-III filter allowed the direct viewing of the Owl Nebula!

A word of caution to the astro-consumer: The hydrogen-beta filters are of limited use. In the northern hemisphere, the only objects for the backyard astronomer where the H-beta filter proves to be useful are the Horsehead Nebula and the California Nebula. There is more versatility to be gained in owning an LPR, UHC, and O-III filter.

The Mounts

A solid telescope mount completes the total system needed for viewing the Moon, and beyond (Fig. 2.16). There are two basic flavors of mounts: the altitude-azimuth mount, mostly referred to as the Alt-Azimuth or AltAz mount; and the equatorial mount. Each type can come either as manual, driven by hand controls or motors, and computer-driven GoTo models. Equatorial mounts and some computer-driven mounts compensate for the Earth's rotation and will track the Moon, planet, or other celestial object, thereby keeping the object in the field of view of the telescope (Fig. 2.17).

The most intuitive and easiest telescope mount is the altazimuth mount. Right-left and up and down. Simple in operation. In fact, it's the perfect mount for young people to use. Four year old kids have been seen at star parties using a refractor on

Fig. 2.16 The author's telescopes featuring an Alt-Az with slow motion controls, two German equatorials, and computerized GOTO mount (Adam Chen)

Fig. 2.17 AltAzimuth mount with slow motion controls (Adam Chen)

Fig. 2.18 The Dobsonian mount (Hands-on-Optics Photo Archive)

an alt-az mount viewing the Moon with little supervision. Altazimuth mounts are considerably lighter than equatorial mounts, and are therefore well suited for grab-and-go scopes or for traveling. No set up is needed. The main drawback is the lack of tracking. The observer manually adjusts the positioning of the telescope, becoming the human tracking motors! (Fig. 2.18).

A notable example of an alt-azimuth mount is the implementation made famous by John Dobson in the early 1980s. Known as the Dobsonian mount (with the entire assembly including the Newtonian telescope being referred to as the Dobsonian telescope), is a simple, low center of gravity alt-azimuth mount made of wood and Teflon bearings. The Dobsonian caused a resurgence in homemade telescopes in the 1980s and 1990s. In today's market, telescope manufacturers dominate the 12-inch Dobsonian and smaller sizes because of the economies of scale. Larger sizes are economically attractive for homebuilt projects, and for those with the funds, can be obtained as commercially produced telescopes. The Newtonian telescope on a Dobsonian mount offers by far the biggest "bang-for-the-buck". But they can be big and bulky, and the Newtonian optics still requires frequent alignment (Fig. 2.19).

Fig. 2.19 German equatorial mount (James Chen)

With the exception of fork mounted Schmidt- and Maksutov-Cassegrains, the most popular form of equatorial mount in the amateur world is the German equatorial. The German mount is a tilted axis contraption with the right ascension axis pointed and aligned in the direction of the North Pole (for those down-under, the South Pole). A tracking motor applied to the right ascension axis drives the mount to keep the observed object in the eyepiece. German equatorial mounts are awkward and heavy. Care must be taken to balance the telescope on the mount, which explains the presence of the large counterweight that is a characteristic of the design. And polar aligning of this mount can be a chore. But if astrophotography is a goal, the German mount is a necessity (Fig. 2.20).

A GoTo telescope mount is quite simply a telescope system that is able to find celestial objects in the night sky, and then track them. The GoTo mount can be set up in an alt-azimuth or equatorial fashion, and after the proper alignment procedure, the finderscope is not needed for the rest of the evening. Some of the newer GoTo telescopes have electronics that will perform the alignment procedure automatically.

These telescope mounts are wonderful pieces of technology. The GoTo technology allows for more efficient use of observing time by quickly finding objects in the night sky. Built into the hand controller is a microprocessor, firmware, and built-in memory catalog of the positions of thousands of stars, galaxies, nebulae, open star clusters, globular clusters, planetary nebulae, our solar system planets,

Fig. 2.20 Computer GoTo mounted Schmidt-Cassegrain (James Chen)

and of course the Moon. And the Moon is the one object that does not need a computer assist to find.

There is a tradeoff when buying a GoTo mount. These mounts are not cheap. Often consumers are faced with the dilemma of either a smaller telescope with a GoTo mount, or a larger aperture telescope on a non-computerized mount. In the case of viewing the Moon, a GoTo mount is not needed. If you can't find the Moon, it's either during the new moon phase, or you've got other problems! The Moon is an easy target.

A tip to GoTo owners: When using a telescope on an alt-azimuth GoTo mount, always use Polaris as one of your alignment stars. The computer algorithm used in programming the mount goes through less mathematical gymnastics when aligning with declination 0 degrees, right ascension 0 degrees. The GoTo accuracy is improved tenfold.

The Binoviewer Option

The majority of telescope owners make their observations through an eyepiece using one eye (Fig. 2.21). The human brain is designed to process visual images through two eyes. There are two options for viewing the Moon, the planets and stars

Fig. 2.21 The binoviewer (James Chen)

with two eyes. One is REALLY expensive—binocular telescopes. The other option is relatively affordable—the binoviewer. The binoviewer uses a system of prisms to split the single light path of a telescope into two separate light paths to two eyepieces. This beam-splitting fools the eyes and the brain into thinking it is seeing an object in stereo. The results are spectacular when viewing the Moon. At certain high magnifications, and by allowing the Moon to drift through the field-of-view, the observer gets the sensation of orbiting the Moon and seeing the view that the Apollo command module pilot would see in orbit. With both eyes open, the lunar landscape seems to glide smoothly past. Even when tracking, the lunar landscape seems to take on three dimensions. The downside to owning a binoviewer is threefold:

- There is a slight light loss using a binoviewer because of the additional light splitting optics. But for a bright object like the Moon, this is not a problem. For planetary views, the light loss is not of great impact. Deep sky observing can be problematic, especially with dim objects.

- There is the additional expense of the binoviewer and buying two of every eyepiece. And you are limited to 1.25 inch sized eyepieces.
- Many telescopes do not have enough in-focus to accommodate a binoviewer. SCTs and Maks focus by moving the primary mirror and binoviewers work well with these types. Some refractors are manufactured with shorter tubes to accommodate the binoviewer, and provide extension tubes to use for mono viewing. Many binoviewers have an optional Barlow-like attachment to allow focusing with other types of telescopes, which limits the low power magnification range.

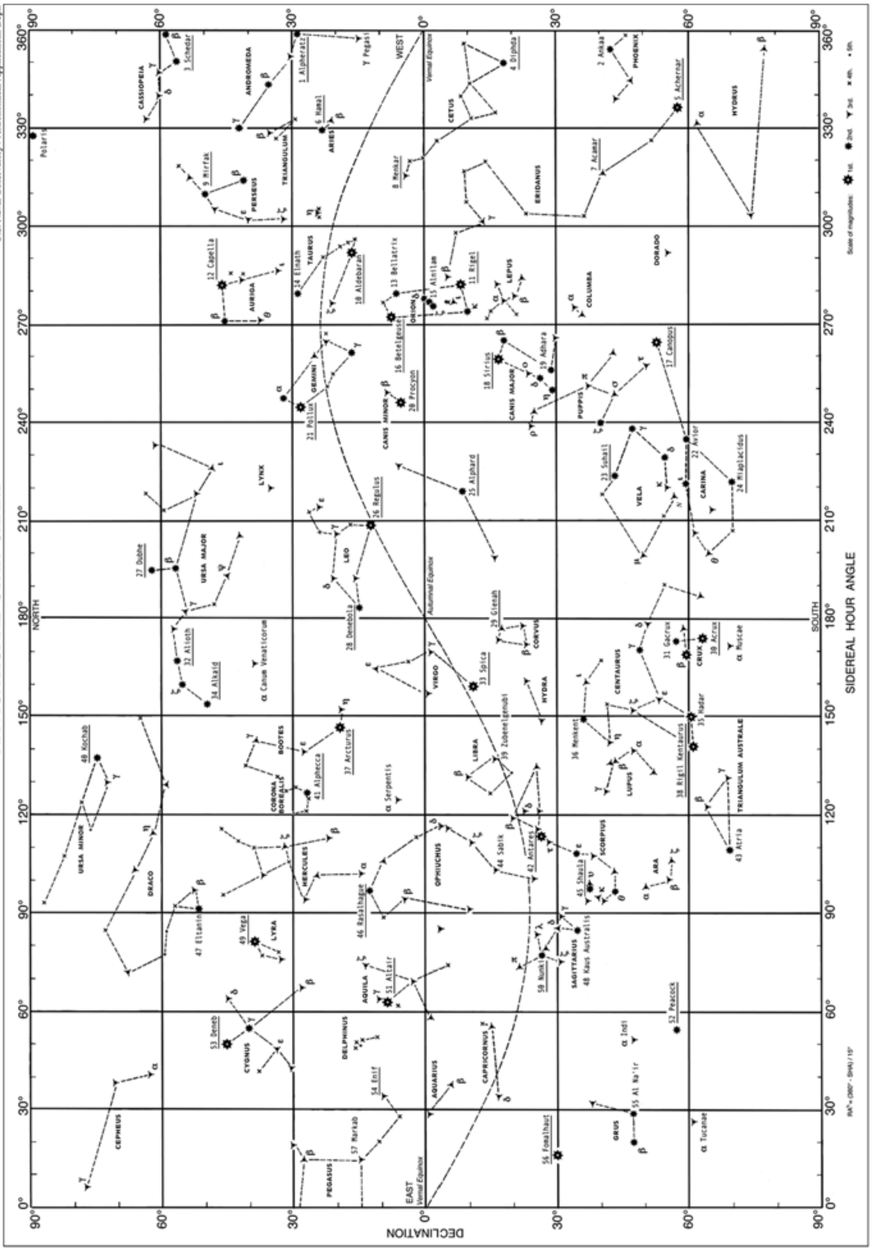
The Recommendation

Many of the readers of this book already own a telescope, on a stable mount, with a case or two of eyepieces and accessories. These readers are suitably equipped to search and observe the Hubble Space Telescope objects.

To the readers without a telescope, get one. Astronomy is a wonderful hobby, filled with potential personal discoveries. For the price of a pair of bifocal high index eyeglasses, a nice 80 mm refractor on an alt-azimuth mount with two Plossl eyepieces can be obtained. This setup serves as a great care free introduction to the hobby, and when aperture fever takes hold (it always does) and a larger telescope is procured, the 80 mm refractor still has a role as a grab-and-go scope. The 80 mm refractor's sharp images are always appreciated.

However, the 80 mm refractor is light gathering challenged. There is a reason why large telescopes exist, they gather up much more light than small telescopes and make dim objects brighter. A telescope of 200 mm or greater is much more capable of observing the HST objects. A 200 mm or 250 mm SCT, Newtonian, or Dobsonian can produce very pleasing views of all the HST objects listed in this book.

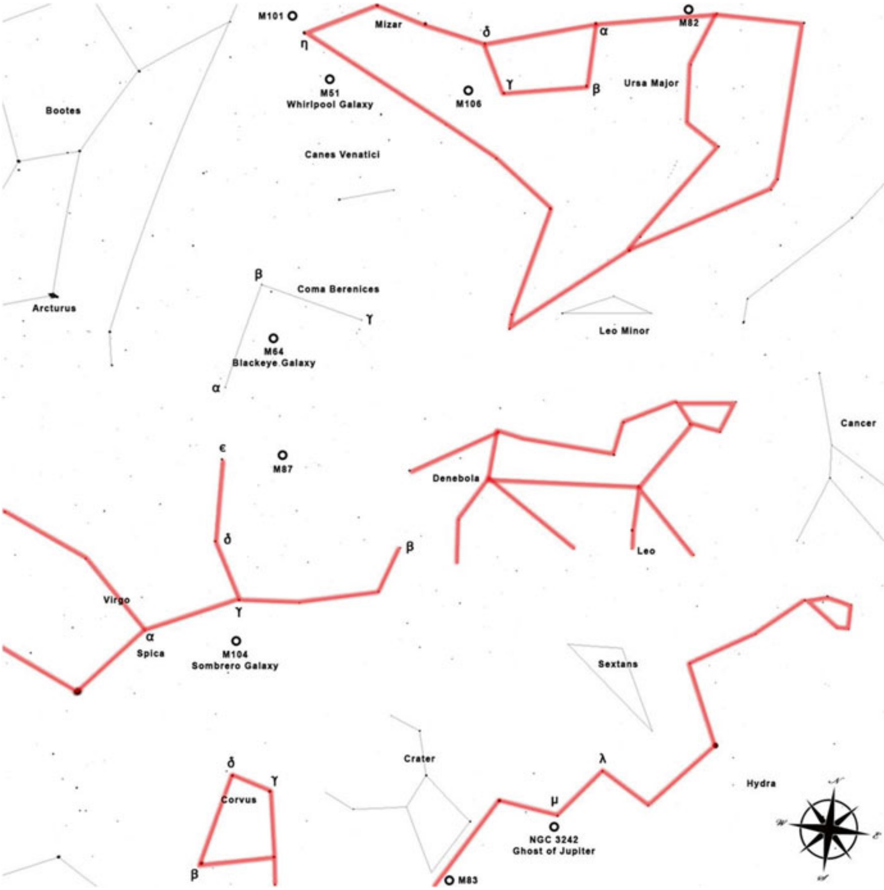
At the risk of complicating matters, there is an argument to be made for the use of a smaller sized refractor instead of the larger but optically obstructed optical designs. Refractors by nature offer the high contrast and sharpest images of all the optical designs. As a practical result, many objects seen in a 200 mm SCT can be equally observed visually with a 120 mm or 130 mm refractor, due to the tighter star images and higher contrast background.



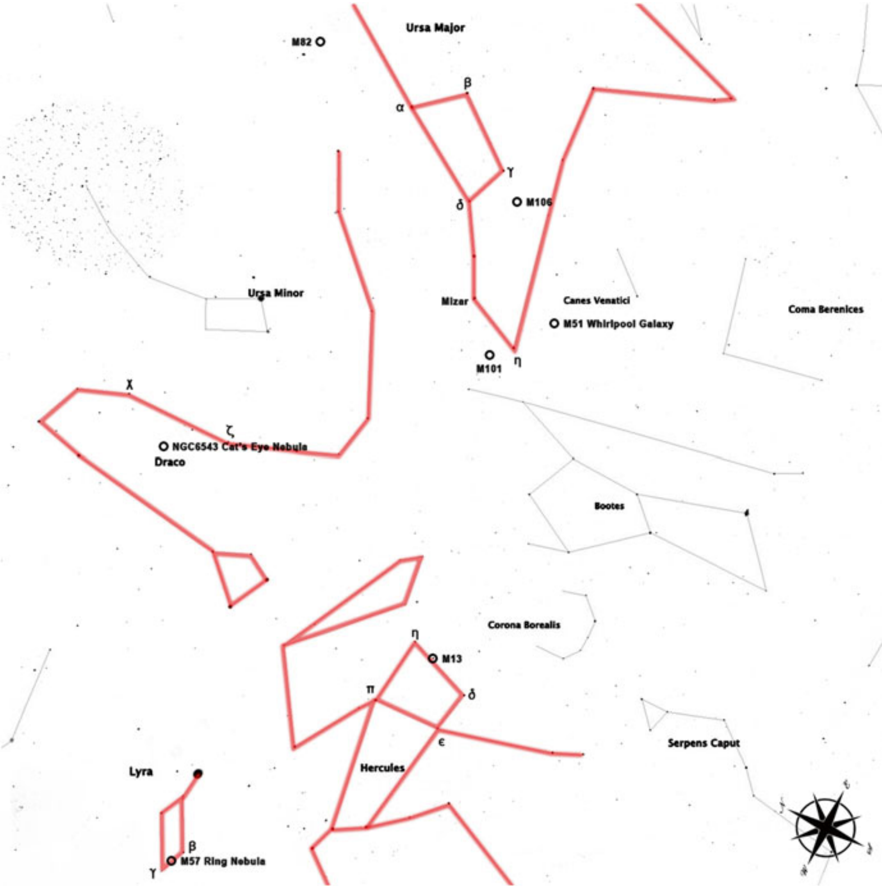
Navstarchart

Finder Charts

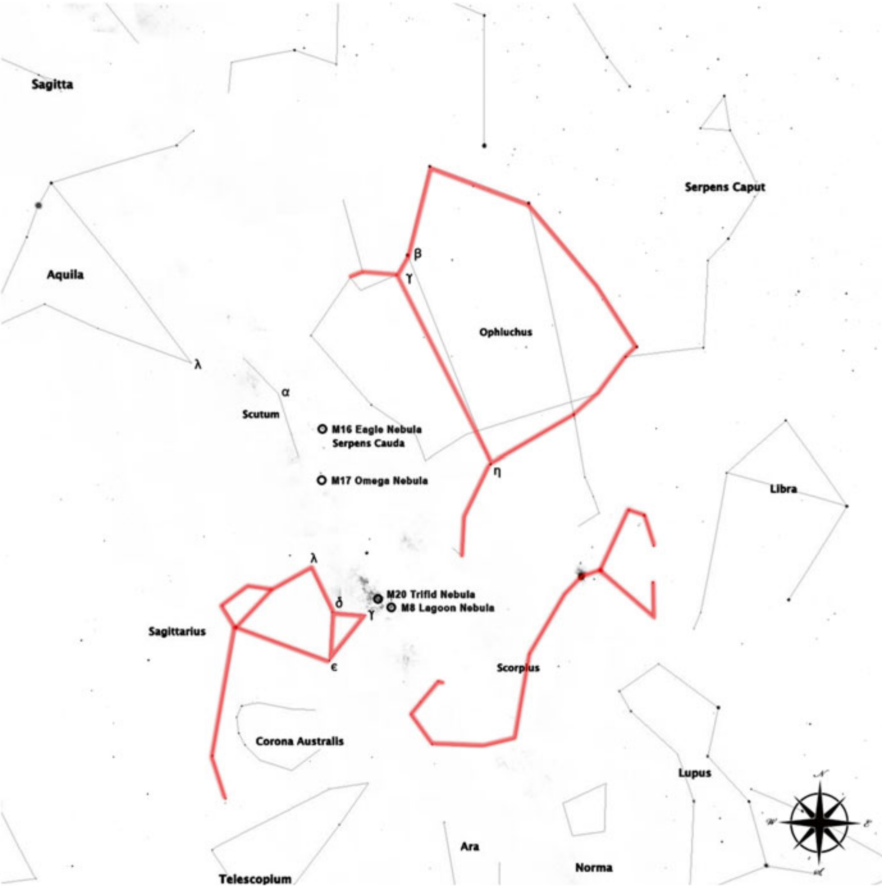
Finder Chart #1 spring_01



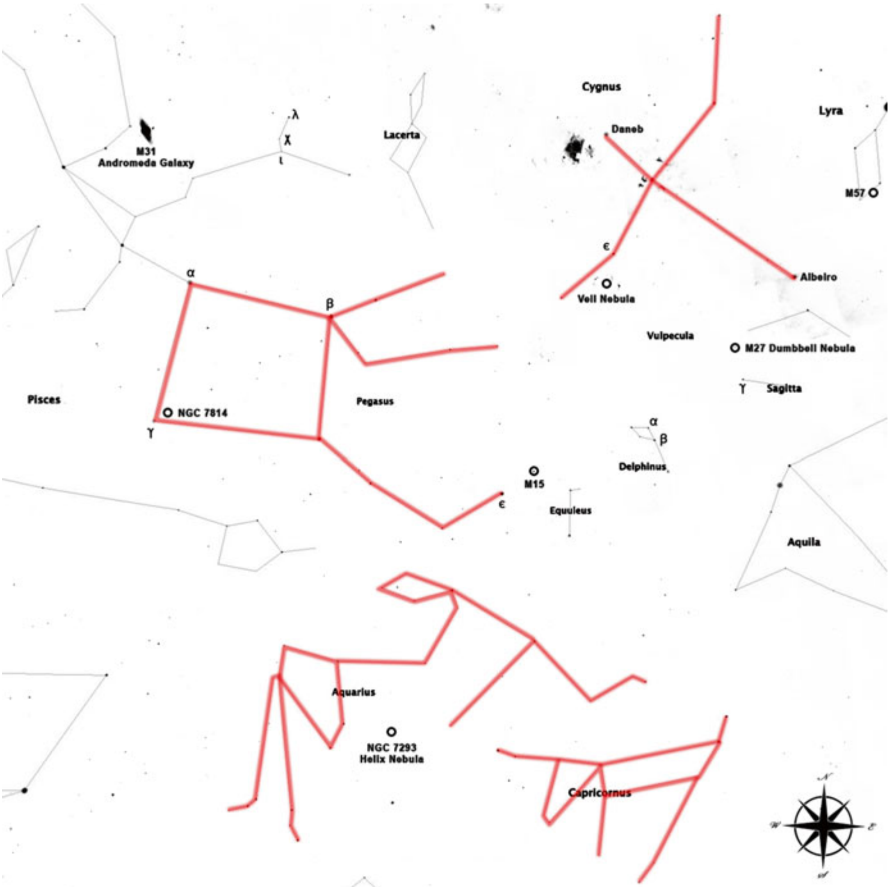
Finder Chart #2 summer_01



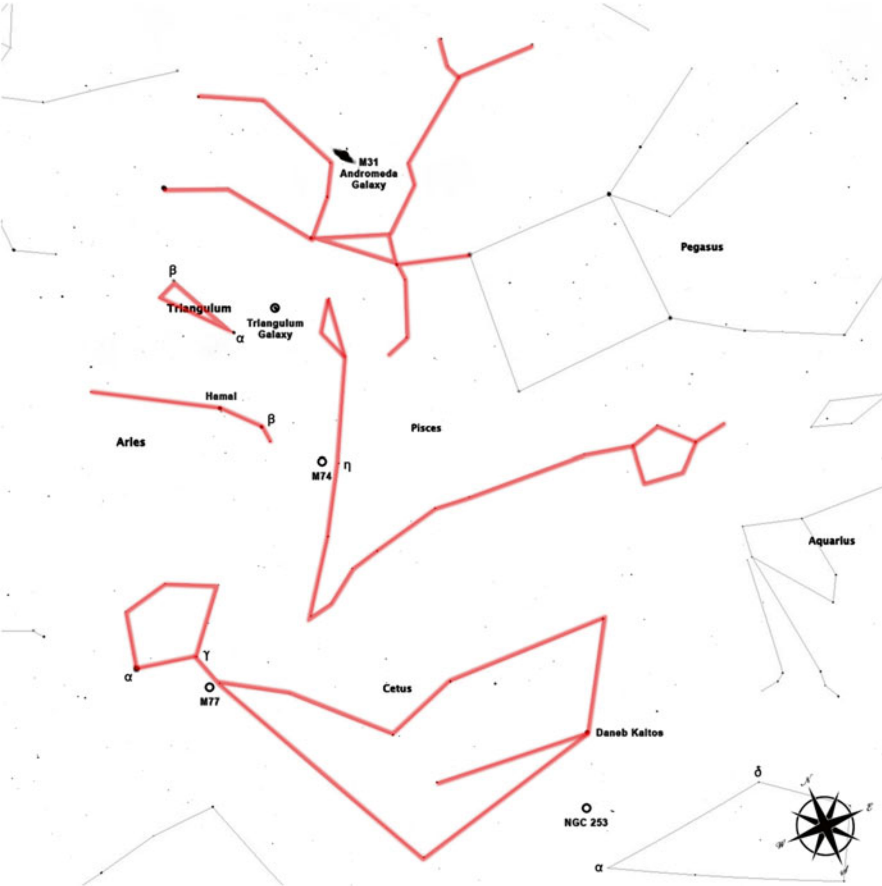
Finder Chart #3 summer_02



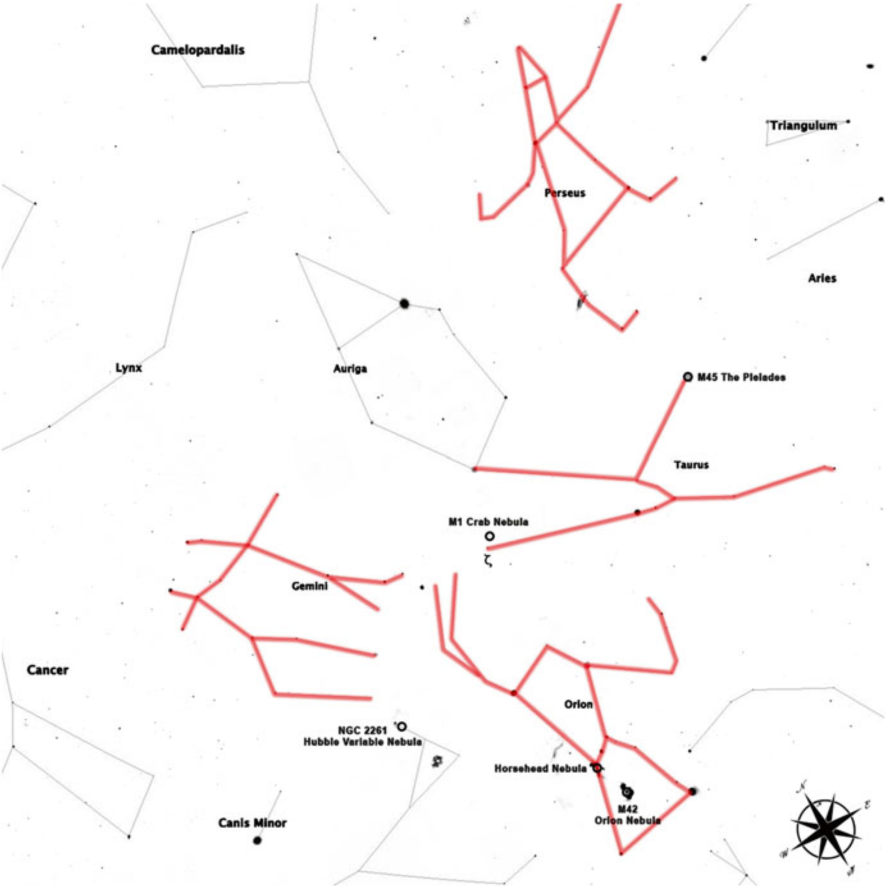
Finder Chart #4 autumn_01



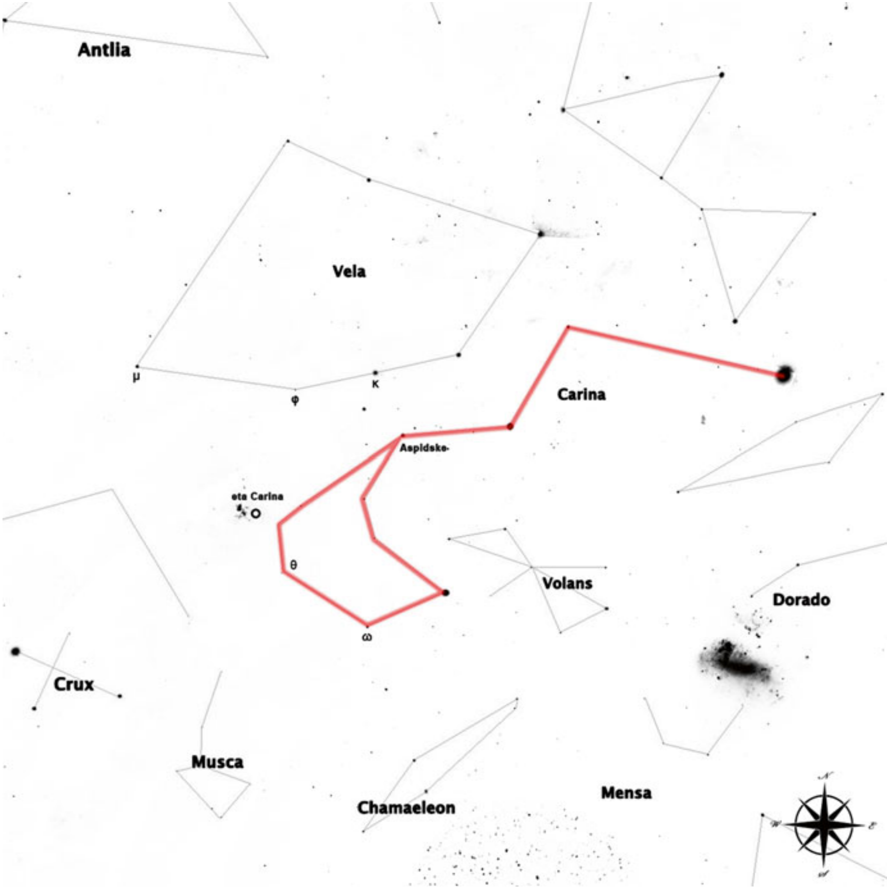
Finder Chart #5 autumn_02



Finder Chart #6 winter_01



Finder Chart #7 winter_02



Chapter 3

Spring Objects

Spring is a wonderful time of the year for backyard astronomers. No longer is it necessary to bundle up and wear layer upon layer of clothing to resist the wintry chill. Warm gloves and stocking caps can be packed away for 6 or 7 months. And the heat, humidity, and the insects of summer is still 3 months away.

For backyard astronomy, spring represents the golden time of the year for viewing galaxies. The major portion of the Milky Way is low on the horizon, and offers little distractions to the backyard observer. The wonders of extra-galactic objects in the sky becomes the playground for amateur telescope owners.

All of the Hubble objects discussed in this chapter are galaxies. The Hubble studies of galaxies are centered on discovering, characterizing, and weighing the supermassive black holes in the centers of many galaxies. Studies of galaxies, their internal movement, and the interactions on a cosmic scale have led to new insights on dark matter and dark energy.

Naturally, the HST was not limited to imaging these galaxies during the spring. But for the adventurous amateur astronomer, spring offers the optimum time for observing these objects.

It is recommended that for telescope owners living in urban or suburban settings, spring is the time to seek out the dark skies of the country side. Unlike planetary, diffuse, or emission nebulas whose details can be enhanced by the technology of filters, galaxies are best seen from dark skies. Light pollution filters offer a slight help in viewing galaxies from a less than optimum location, but the best galactic observing accessories are a car, car keys, and a car ride away from civilization's artificial light.

Telescope aperture is important in viewing galaxies. All of the galaxies in this chapter can be seen in a 3–4-inch telescope in dark skies (sometimes with the help

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The Patrick Moore Practical Astronomy Series, DOI 10.1007/978-3-319-18872-0_3

of averted vision), but often the details of these objects do not become readily apparent until the aperture size reaches 8 inches and beyond. In the amateur astronomy world, a condition known as aperture fever can quickly take hold, as backyard astronomers buy or build larger and larger telescopes to see dimmer objects and observe subtle details. In the 1960s, a Newtonian telescope of 12.5 inches accepted was considered large. Nowadays, it is common to attend major star parties where amateur telescope owners setup and observe through instruments with apertures of 17 inches, 24 inches, and even 30 inches.

High quality wide field eyepieces are the order of the day (actually night!) when viewing galaxies. Low-to-medium focal lengths will serve well. Save the high power eyepieces for planets, the Moon, or planetary nebulas.

M64 The Black Eye Galaxy

Alternative Nomenclature: NGC 4826, the Evil Eye Galaxy, Sleeping Beauty Galaxy
Constellation: Coma Berenices

Right Ascension: 12h56m43.7s
Declination: +21deg40min58s
Magnitude: 8.5 (Fig. 3.1)

Fig. 3.1 Hubble image of M64 (NASA and The Hubble Heritage Team (STScI/AURA))

M64, nicknamed the Black Eye Galaxy, was discovered by Edward Pigott on March 23, 1779, just 12 days before Johann Elert Bode found it independently on April 4, 1779. A year later on March 1, 1780, Charles Messier independently rediscovered it and cataloged it as M64.

From Pigott's notes on the discovery:

> "… on the 23rd of March [1779], I discovered a nebula in the constellation of Coma Berenices, hitherto, I presume, unnoticed; at least not mentioned in M. de la Lande's Astronomy, nor in M. Messier's ample Catalogue of nebulous Stars [of 1771]. I have observed it in an achromatic instrument, three feet long, and deduced its mean R.A. by comparing it to the following stars Mean R.A. of the nebula for April 20, 1779, of 191d 28′ 38″. Its light being exceedingly weak, I could not see it in the two-feet telescope of our quadrant, so was obliged to determine its declination likewise by the transit instrument. The determination, however, I believe, may be depended upon to two minutes: hence, the declination north is 22d 53″1/4. The diameter of this nebula I judged to be about two minutes of a degree."

Unfortunately, Pigott never received recognition for the discovery in his lifetime. Pigott's report of the discovery was published only after being read before the Royal Society in London on January 11, 1781. Bode's paper was published during 1779 and Messier's report of the discovery was in late summer, 1780. It was only recently, in April 2002, that Pigott's report was recognized as the initial discovery of M64.

Sir William Herschel is responsible for the nickname:

> "A very remarkable object, much elongated, about 12′ long, 4′ or 5′ broad, contains one lucid spot like a star with a small black arch under it, so that it gives one the idea of what is called a black eye, arising from fighting."

William Parsons, the Third Earl of Rosse, upon observing M64 in his 72″ telescope, known as the Leviathan of Parsonstown, interpreted the partly resolvable nucleus as a "close cluster of well-defined little stars".

Rev. T.W. Webb described M64, in his *Celestial Objects for Common Telescopes*, as "Magnificent large bright neb., blazing to a nucleus."

Robert Burnham, Jr., in his *Burnham's Celestial Handbook*, describe's M64 as follows:

> "The structure of M64 is somewhat unusual, and the galaxy has been classified as type Sa by some authorities, type Sb by others. The spiral arms show a beautifully smooth and uniform texture with no trace of resolution into star clouds or knots of nebulosity. Separating and defining the arms are thin, dusky bands which appear similarly smooth and soft-textured. In the region of the central nucleus, however, a huge dust cloud suddenly makes its appearance, bordering the entire north and east side of the oval central mass."
>
> "The visibility of the dark mass is naturally controversial point among observers, but it is definitely within the capabilities of a good 6 or 8-inch glass; J.H. Mallas has detected it in a 4-inch refractor."

Fig. 3.2 Amateur astrophoto of M64 (Jon Talbot)

Messier 64 is a spiral galaxy, which is a prototypical ESWAG galaxy. ESWAG is short for Evolved Second Wave Activity Galaxy, which are a class of galaxies noted for star forming. After an initial star forming phase, the first group of stars experienced their life cycle and began slowly dying out. As the matter was flowing back from the evolved stars, by stellar wind, supernovae, and planetary nebula activity, more and more interstellar matter could accumulate again, so that finally there was enough matter to start the formation of new young stars again. The Black Eye Galaxy is now undergoing a second wave of star formation that has apparently reached the region where the dark dust lane appears.

As can be seen in Finder Chart #1, M64 is located in the neighborhood roughly between the bright star Arcturus in the constellation Bootes and the almost as bright, but slightly dimmer, Denebola in the constellation Leo. A prerequisite for observing M64 are dark, country skies. Urban or suburban light pollution will completely washout this object. When sighting M64, there is a likelihood of stumbling upon the globular cluster M53. Do not mistake the two, M53 is clearly a round ball of stars, while M64 is a tilted spiral galaxy (Fig. 3.2).

As Burnham noted, M64 has a prominent dark band of absorbing dust surrounding the galaxy's bright nucleus that can be seen visually, thus its nickname of the "Black Eye". At first glance, M64 seems to be a fairly normal pinwheel-shaped spiral galaxy. Most normal pinwheel-shaped spiral galaxies rotate in the same direction. All of the stars in M64 are rotating in the same direction, clockwise as seen in the Hubble WFPC2 image Fig. 3.1. However, the interstellar gas in the outer regions of M64 rotates in the opposite direction from the gas and stars in the inner regions. Astronomers believe that the oppositely rotating gas arose when M64 absorbed a satellite galaxy that collided with it, approximately more than one billion years ago. This small galaxy has now been almost completely absorbed, but evidence of the collision persists in the counterclockwise motion of gas at the outer edge of M64. Active formation of new stars is occurring in the shear region where the oppositely rotating gases collide, are compressed, and contract. Particularly noticeable in Fig. 3.1 are hot, blue young stars that have just formed, along with pink clouds of glowing hydrogen gas that fluoresce when exposed to ultraviolet light from newly formed stars.

M82 The Cigar Galaxy

Alternative Nomenclature: NGC 3034
Constellation: Ursa Major

Right Ascension: 09h55m52.2s
Declination: +69deg40min47s
Magnitude: 8.4 (Fig. 3.3)

Fig. 3.3 The Hubble image of M82 (M82, NGC 3034 NASA, ESA, and The Hubble Heritage Team (STScI/AURA))

M82 was discovered on the same night as M81 by Johann Elert Bode, who found the pair on December 31, 1774.

According to Bode's historical notes:

> "I found through the seven-foot telescope, closely above the head of UMa, east near the star d at its ear, two small nebulous patches separated by about 0.75 degrees, the positions of which relative to the neighbored small stars are shown in the tenth figure. The patch Alpha (M81) appears mostly round and has a dense nucleus in the middle. The other, Beta, on the other hand, is very pale and of elongated shape. I could determine the separation of Alpha to d as 2deg 7′, to Rho as 5deg 2′ and to 2 Sigma as 4deg 32′ with some accuracy; Beta was too faint and disappeared from my eyes as soon as I shifted apart the halves of the objective glass."

Pierre Mechain independently recovered both galaxies in August 1779 and reported them to Charles Messier.

Messier added the galaxy to his catalog after his position measurement on February 9, 1781, and wrote:

> "Nebula without star, near the preceding [M81]; both are appearing in the same field of the telescope, this one is less distinct than the preceding; its light faint and [it is] elongated: at its extremity is a telescopic star. Seen at Berlin, by M. Bode, on December 31, 1774, and by M. Mechain in the month August 1779."

In 1837, Admiral William Henry Smyth wrote about the details of M82 and its nearby companion M81:

> "No. 81 is a fine bright oval nebula, of a white colour, in the Great Bear's ear, which was first registered by M. Messier in 1781, and exhibited a mottled nebulosity to WH [William Herschel]. Its major axis lies np [north preceding, NW] to sf [south following, SE]; and it certainly is brightest in the middle. There are several minute companions [stars] in the field, of which a close double star in the sp [south preceding, SW] quadrant is No. 1386 in Struve's grand Catalogue, and by him marked vicinae; the members are both of 9th magnitude, and trend np [north preceding, NW] to <7>sf [south following, SE], about 2″ apart, forming a fine though difficult object. With a low power, No. 82 M. can be brought into the north part pf the same field of view, although they are half a degree apart. It is very long, narrow, and bright, especially at its northern limb, but rather paler than No. 81. A line drawn through three stars in the sp [south preceding, SW] to a fourth in the nf [north following, NE] passes directly through the nebula. The two nebulae precede Lambda, in the end of Draco's tail, by 25deg, but as the vicinity is deficient of large [bright] stars, they are not readily fished up. The apparent place here taken, is that of a small star between the two nebulae, which was differentiated with 29 Ursae Majoris, and every care taken in the reduction. The bright star in the animal's chest, south of 29, viz. Phi, is pronounced to be double, both companions being of the 5th magnitude, and only half a second asunder."

William Parsons, the Third Earl of Rosse, after viewing M82 through the Leviathan of Parsonstown, was the first to note the dark dust lanes and dark patches that could be seen through the 72-inch telescope while viewing the central portion of the galaxy.

Halton Arp has included M82 as No. 337 in his Catalog of Peculiar Galaxies.

Fig. 3.4 Amateur backyard astrophoto of M82 (Jon Talbot)

As can be seen in Finder Chart #1, to find M82, first look at the bowl of the Big Dipper in Ursa Major. The four stars of the Big Dipper bowl are Megrez (star at the handle), Merak (the star diagonally across from Megrez), Dubhe (the star with Merak that form the pointer stars to Polaris), and Phecda (the star diagonally opposite Dubhe). Identify Dubhe and Phecda, and extend a line in the direction from Phecda to Dubhe of equal distance beyond Dubhe, with a slight bias towards Polaris. Bingo!

Visually, M82 will appear to be white silvery sliver with a slightly off-center bright core (Fig. 3.4).

Messier 82 is usually classified as irregular, though probably a distorted disk galaxy, and famous for its heavy star-forming activity, thus a prototype member of the class of star burst galaxies. M82 is the prototype of a “disk” irregular type 2 galaxy.

The M82 core seems to have suffered dramatically from a semi-recent close encounter with M81, being in a heavy starburst and displaying conspicuous dark lanes. The Hubble images have revealed 197 young, bright, compact super globular star clusters in M82’s central region. Throughout the galaxy’s center, young stars are being born in a very energetic and high density environment, at a rate ten times faster than those of the Milky Way. A violent galactic encounter occurred between M82 and its neighboring galaxy M81 approximately 600 million years ago and lasted for 100 million years. This massive event caused the formation of these super star clusters. This turbulence caused an explosive gas flow that is also a strong source of radio noise, as discovered by Henbury Brown in 1953. The radio source was first called Ursa Major A (strongest radio source in UMa) and cataloged as 3C 231 in the Third Cambridge Catalogue of Radio Sources.

M83 The Southern Pinwheel

Alternative Nomenclature: NGC 5236
Constellation: Hydra

Right Ascension: 13h37m00.9s
Declination: −29deg51min57s
Magnitude: 7.5 (Fig. 3.5)

Fig. 3.5 Hubble photo of M83 The Southern Pinwheel (NASA, ESA, and The Hubble Heritage Team (STScI/AURA))

M83 was discovered by Abbe Nicholas Louis de la Caille at the Cape of Good Hope on February 23, 1752 and was the first outside our Local Group to be cataloged.

Despite its very low position for Paris, it was next cataloged by Charles Messier on February 17, 1781 who said:

> "Nebula without star, near the head of Centaurus: it appears as a faint and even glow, but it is difficult to see in the telescope, as the least light to illuminate the micrometer wires makes it disappear. One is only able with the greatest concentration to see it at all."

Although it would be detected by Sir William Herschel, it was his son John who would later write from the Cape of Good Hope:

> "Very bright; very large; suddenly brighter toward the middle to a centre resembling a star of 9 m, diameter 8″, of a resolvable character like a globular cluster, surrounded by an immensely large, extremely dilute almost equable light 7′ or 8′ diam, somewhat oval, and passing with an excessive suddenness into the central light."

Burnham's Celestial Handbook describes M83 as:

> "This is one of the brightest galaxies of the southern sky, a magnificent system whose dynamic appearance conveys a strong impression of whirling motion. The two principal arms of the spiral pattern form a reversed letter S, and there is a third fainter arm segment starting from the south side of the nucleus and sweeping out toward the southwest. M83 is thus sometimes described as a "three-branch" spiral, while other astronomers, from the structure of the central mass, suggest a classification among the barred-types."

Fig. 3.6 Amateur astrophoto of M83 (Jon Talbot)

M83 is one of the most conspicuous spiral galaxies in the sky. Situated in constellation Hydra, it is also the southernmost galaxy in Messier's catalog.

M83 is located in a low southern position, as is Eta Carinae, discussed later in this book. These objects are difficult to find in the northern hemisphere, unless the observing is done in the deep southern states of the U.S., the Caribbean, or the southern hemisphere. Start by identifying Gamma or Pi Hydra, as seen in Finder Chart #1. From Gamma it is northwest from Pi and about an equal distance southwest. If you are in the southern hemisphere, locate Iota and Theta Centauri and simply star hop 1, 2, 3, 4, 5 to M83. From the north it will require at least a 3–4″ telescope and dark skies, while southerners can spot it easily with small binoculars (Fig. 3.6).

The spectacular Wide Field Camera 3 (WFC3) installed on NASA's Hubble Space Telescope during Servicing Mission 4 delivered the most detailed view of star birth in the graceful, curving arms of the nearby spiral galaxy M83.

The Hubble image shows M83 is undergoing more rapid star formation than the Milky Way galaxy, particularly in its nucleus. The WFC3 has captured hundreds of young star clusters, ancient swarms of globular star clusters, and hundreds of thousands of individual blue supergiants and red supergiants stars within the Southern Pinwheel.

Figure 3.7, taken in August 2009, provides a close-up view of the myriad stars near the galaxy's core, the bright whitish region at far right.

WFC3's broad wavelength range, from ultraviolet to near-infrared, reveals stars at different stages of evolution, allowing astronomers to dissect the galaxy's star-formation history.

The image reveals in unprecedented detail the current rapid rate of star birth in this spiral galaxy. The new generations of stars are forming largely in clusters on the edges of the dark dust lanes, the backbone of the spiral arms. These fledgling stars, only a few million years old, are bursting out of the interstellar dust and illuminating huge regions of reddish glowing hydrogen gas. Gradually, the young stars' fierce winds (streams of charged particles) blow away the gas, revealing bright blue star clusters. These stars are about 1 million to 10 million years old. The older populations of stars are not as blue.

A bar of stars, gas, and dust slicing across the core of the galaxy may be instigating most of the star birth in the galaxy's core. The bar funnels material to the galaxy's center, where the most active star formation is taking place. The brightest star clusters reside along an arc near the core.

The remains of about 60 supernova blasts, the deaths of massive stars, can be seen in the image, five times more than known previously in this region. WFC3 identified the remnants of exploded stars. By studying these remnants, astronomers can better understand the nature of the progenitor stars, which are responsible for the creation and dispersal of most of the galaxy's heavy elements.

M87

Alternative Nomenclature: NGC 4486, Virgo A
Constellation: Virgo

Right Ascension: 12h30m49.4s
Declination: 12deg23min28s
Magnitude: 8.6

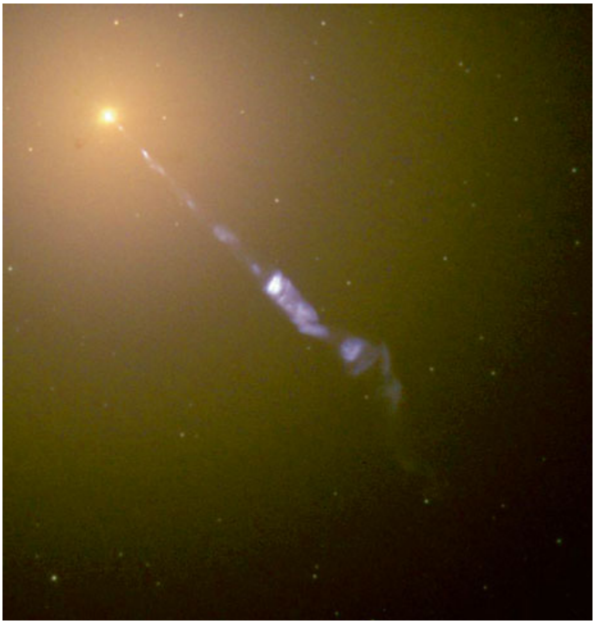

Fig. 3.7 Hubble close-up of M87 nucleus and relativistic jet (NASA and The Hubble Heritage Team (STScI/AURA))

M87 was discovered by Charles Messier on the night of March 18, 1781, along with seven other galaxies of the Virgo Cluster. Messier wrote in his notes:

> "Nebula without star, in Virgo, below and very near a star of eighth magnitude, the star having the same Right Ascension as the nebula, and its Declination was 13d 42′ 21″ north. This nebula appears at the same luminosity as the two nebulae Nos. 84 and 86."

William Herschel also observed M87, and described it as a "large, brighter, much brighter to the middle, but diminishing very gradually in brightness."

Astronomer Heber Curtis, using the historic Lick Observatory 35 inch Crossley Reflector in 1918 made the following observation:

> "Exceedingly bright; the sharp nucleus shows well in 5m exposure. The brighter central portion is about 0.5′ in diameter, and the total diameter is about 2′; nearly round. No spiral structure is discernible. A curious straight ray lies in a gap in the nebulosity in p.a. 20deg, 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. 20s.n."

Edwin Hubble himself categorized M87 as a type of elliptical extra-galactic nebula with no apparent elongation. Messier 87 continued to be called an extragalactic nebula for many years thereafter, but by 1956 it had been identified as an E0-type galaxy.

In 1947 and confirmed in 1953, a strong radio source was discovered in the direction of Virgo and overlapped the location of M87. This radio source came to be known as Virgo A, and M87 was confirmed as the origin.

From a series of Aerobee missile instrumented flights in the mid-1960s, M87 was also identified as a strong source of X-rays, and sits near the center of a hot, X-ray emitting cloud extending far over the Virgo cluster.

Because of its history, Messier 87 is among the most heavily researched objects in the Hubble catalog.

The giant elliptical galaxy Messier 87 (M87, NGC 4486), also called Virgo A, is one of the most remarkable objects in the sky. It is perhaps the dominant galaxy in the closest big cluster to us, the famous Virgo Cluster of galaxies. The Virgo Cluster lies at the distance of this cluster of about 60 million light-years from Earth, with M87 buried in the heart of the galactic cluster. It's galactic neighbors include M84, M86, NGC 4476, NGC 4478, NGC 4486A, and NGC 4486B.

Fig. 3.8 Amateur astrophoto of M87 (Jon Talbot)

As referenced in Finder Chart #1, a dark country night sky is in order to find M87, with a clear view of the constellation Virgo. The where M87 is situated in teeming with galaxies. The reader can now experience the awe and wonder Charles Messier experienced on the night of March 18, 1781 when he discovered the Virgo cluster of galaxies. Visually, in a backyard telescope, M87 appears as a fuzzy blob with the rounded edges fading into a diminishing mist. M87 will have the look of a globular cluster, but with unresolvable stars (Fig. 3.8).

The most notable feature, receiving a great deal of study by astronomers and by Hubble, is the relativistic jet that extends from the nucleus of M87 to a distance of 5,000 light-years. M87 has a violently active nucleus powered by a massive black hole of about 2–3 billion solar masses, concentrated within the innermost core with a radius of 60 light years. This black hole core is surrounded by a rapidly rotating gaseous accretion disk. The disk around a rapidly spinning black hole has magnetic field lines that entrap ionized gas falling toward the black hole. These particles, along with radiation, flow rapidly away from the black hole along the magnetic field lines. The rotational energy of the spinning accretion disk adds momentum to the outflowing jet.

Early in the life of M87 a "seed" black hole may have formed in its nucleus from the merger of small black holes created by the explosion of massive stars, or perhaps from the gravitational collapse of gas leftover from the formation of M87. Once formed, the seed black hole would grow by feeding on gas and stars that passed by too closely. As the mass of the black hole increased, its gravity began to dominate an increasingly larger volume of space. Stars once freely orbiting in and out of the M87 core would be gradually pulled towards the center and then into orbits closely bound to the black hole. The whole core of the galaxy progresses towards a collapse inward, and the density of stars near the very center becomes extreme. Some of these stars eventually are consumed by the black hole, fueling its growth further.

M101

Alternative Nomenclature: NGC 5457, The Pinwheel
Constellation: Ursa Major

Right Ascension: 14h03m12.6s
Declination: 54deg20min57s
Magnitude: 7.8 (Fig. 3.9)

Fig. 3.9 Hubble image of M101 (NASA, ESA, and The Hubble Heritage Team (STScI/AURA))

The Pinwheel Galaxy was discovered by Pierre Mechain on March 27, 1781, and added as one of the last entries in Charles Messier's catalog as M101.

Charles Messier wrote in his notes:

> "Nebula without star, very obscure and pretty large, of 6 or 7 minutes in diameter, between the left hand of Bootes and the tail of the great Bear. It is difficult to distinguish when one lits the [grating] wires."

William Herschel noted in 1784 that:

> "[M101] in my 7, 10, and 20-feet [focal length] reflectors shewed a mottled kind of nebulosity, which I shall call resolvable; so that I expect my present telescope will, perhaps, render the stars visible of which I suppose them to be composed."

William Parsons, the Third of Rosse, using the 72″ Leviathan of Parsonstown, was the first to make extensive note of the spiral structure and made several sketches.

Fig. 3.10 Amateur image of M101 (Jon Talbot)

M101 is a face-on spiral galaxy, larger than the Milky Way. With a diameter of 170,000 light-years it is 70 % larger than the Milky Way. It has a disk mass on the order of 100 billion solar masses, along with a small central bulge of about 3 billion solar masses.

The Pinwheel galaxy can be spotted under less than perfect sky conditions, but like all galaxies, M101 requires a good, dark country sky for observation. Using Finder Chart #1, M101 is easily located by finding the first star (Eta) in the handle of the "Big Dipper" asterism in Ursa Major. It lays almost exactly the same distance north as the distance between Eta and the second star in the handle, Mizar-Alcor pair (Zeta). Simply form a mental triangle with the northern apex as your target. It is possible to spot M101 with large 80 mm or 100 mm binoculars as a vague, misty round patch, but it can be a challenge. The bright nucleus of the galaxy needs the aid of an 8-inch telescope, and to show the spiral structure, telescopes with apertures 12-inches or greater are needed. The outer edges are very vague and will test the observer's ability to detect details with averted vision. Glimpses of the patchy outside structure are actually star forming regions on Messier 101's periphery (Fig. 3.10).

M101 has four prominent NGC companion galaxies: NGC 5204, NGC 5474, NGC 5477, and NGC 5585. The gravitational tidal interaction between M101 and its companion galaxies may have triggered the formation of the grand spiral design pattern in M101. M101 has also probably distorted the companion galaxy NGC 5474

In 2001, the X-ray source P98, located in M101, was identified as an ultra-luminous X-ray source by the Chandra X-Ray Observatory (see Chap. 9). Designated M101 ULX-1, in 2005, both Hubble and the European XMM-Newton orbiting X-ray observatory showed the presence of an optical counterpart, strongly indicating that M101 ULX-1 is an X-ray binary.

M104 The Sombrero Galaxy

Alternative Nomenclature: Messier 104, NGC 4594, The Sombrero Galaxy
Constellation: Virgo

Right Ascension: 12h39m59.4s
Declination: −11deg37min23s
Magnitude: 8.0 (Fig. 3.11)

Fig. 3.11 Hubble image of M104 The Sombrero Galaxy (NASA and The Hubble Heritage Team (STScI/AURA))

Pierre Mechain, in a letter to Daniel Bernoulli in Berlin in a letter dated May 6, 1783, listed among his discoveries what has now become known as M104. This letter was presented to the Berlin Royal Academy of Sciences and Arts, and printed in the Memoirs of that academy for the year 1782 (*Nouveaux Mémoires* de l'Académie Royale des Sciences et Belles-Lettres, année MDCCLXXXII), p. 46–51.

Mechain wrote:

> "On May 11, 1781, I have discovered a nebula above Corvus; it did not appear to me to contain stars; it is faint & very difficult to see when the wires of the micrometer are illuminated; I have compared it on this day & the following to the Ear of Virgo [Spica], & I have derived its right ascension 187d 9′ 42″, its south. declin. 10d 24′ 49″. It is not included in the *Connoissance des tems*."

Messier 104 was not included in Messier's originally published catalog. However, Charles Messier added it by hand to his personal copy on May 11, 1781, and described it as a "very faint nebula."

In March 1837, Admiral William Henry Smyth wrote about the details of M104:

> "A lucid white elliptical nebula, between the Virgin's right elbow and the Raven, in an elegant field of small stars; discovered by WH [William Herschel] in May, 1784, and No. 1376 in his son's Catalogue. It lies nearly parallel to the equatorial line of the instrument, and on intense attention may be seen to blaze in the middle. The half dozen principal stars form a great Y, with the nebula as the centre. But it seems a mere wisp of subdued light, insomuch that my telescope does not afford me even the doubts inspired with the 20-foot reflector; for Herschel remarks that there is a faint, diffused oval light all about it, and that he is almost positive that there is a dark interval or stratum, separating the nucleus and the general mass of the nebula from the light above it. "Surely, no illusion."
>
> "The general form of elongated nebulae is elliptic," says WH, "and their condensation toward the centre is almost invariably such as would arise from the superposition of luminous elliptic strata, increasing in density toward the centre." This must be another of those vast flat rings seen very obliquely, already spoken of, and is an elegant example of that celestial perspective; it bears due west from Spica, and is 11d distant from that star, forming nearly a right angle with Beta Hydrae, which lies 12d to the southward."

Nicolas Camille Flammarion and Helen B. Sawyer Hogg identified and re-identified, respectively, the galaxy as M104.

Wrote Flammarion:

> "It has the position of the nebula H I.43 found by Wm. Herschel, and is No. 4594 of the NGC of Dreyer. We can add it to Messier's catalog and give it the number 104. The result is that Messier's catalog from now on is reckoned as numbering 104 instead of 103."

And Sawyer Hogg:

> "… a long-overlooked letter by Pierre Méchain was found in Bode's Jahrbuch for 1786. … He also lists four nebulae which he has discovered, and these should logically be given Messier numbers as follows: NGC 4594 as M104; NGC 3379 as M105; NGC 4258 as M106; and NGC 6171 as M107. Flammarion, from pencilled notes in Messier's records, has already suggested the inclusion of NGC 4594 as M104, though this letter published by Méchain was apparently unknown to him."

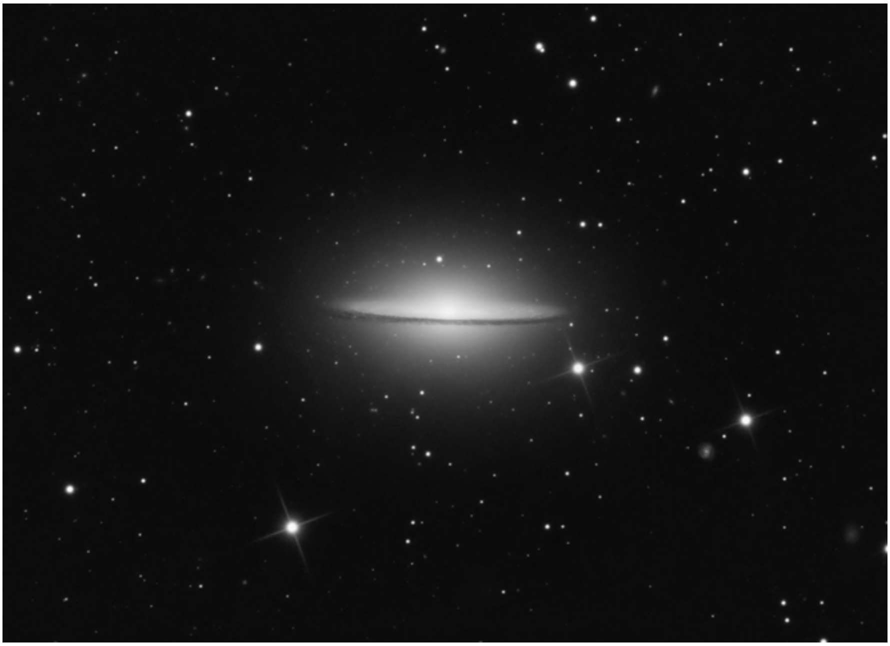

Fig. 3.12 Amateur astrophoto of M104 (Jon Talbot)

M104 is an unbarred spiral galaxy about 28,000,000 light-years from Earth. It has a bright nucleus, an unusually large central bulge, and a prominent dust lane in its slightly inclined disk.

M104 is easily found exactly 11 degrees from Spica, as seen in Finder Chart #1. Again, this galaxy must be viewed from a dark sky site. It can be spotted in binoculars as a small, eye-shaped patch of nebulosity. In telescopes as small as 3 inches in aperture, it takes on a galactic signature and its dark dust lane can be detected with telescopes of 4.5 inches in aperture. This is one object where aperture fever can really take hold, as more light gathering reveals more of the beautiful Sombrero Galaxy (Fig. 3.12).

This brilliant galaxy was named the Sombrero Galaxy because of its appearance, with its a rather thick dark rim of obscuring dust and bulbous nucleus.

Studies from the Hubble images easily resolves the rich system of globular clusters that surround M104. Estimated to be nearly 2,000 in number, M104 has more than ten times as many globular clusters as does the Milky Way galaxy. The ages of the clusters are similar to the clusters in the Milky Way, ranging from 10 to 13 billion years old. Embedded in the bright core of M104 is a smaller disk, which is tilted relative to the large disk. X-ray emission suggests that there is material falling into a 1-billion-solar-mass central black hole that resides at the core.

Chapter 4

Summer Objects

Summer's here! It gets dark late. It's hot during the day, warm and humid in the evening and night. And the insects and other denizens of the dark are out.

But some of the Northern Hemisphere's greatest celestial showcases are on display during the summer. The Hubble has been used to image and observe these same objects. They are beautiful, spectacular, and scientifically fascinating.

With the exception of M51 and M106, the Hubble objects discussed in this chapter are within the Milky Way, and are accessible and observable from suburban locations. The nebulas may require a little technological aid in the form of light pollution and nebula filters. The planetary nebulas discussed here are often best viewed using medium-to-high magnification. Globular clusters at higher magnifications can reveal their inner layers of stars, especially when using a telescope with 8″ or greater aperture.

Galaxies M51 and M106, as with the Spring Hubble objects, are best viewed from a dark sky location. If the conditions are hazy and heavy with humidity, these two galaxies can be difficult to see. Wait for a night with lower humidity to view these two galaxies. And always remember to choose moonless nights whenever observing galaxies.

As far as observing in the environmental conditions of summer, here are a few recommendations:

- Wear comfortable clothing.
- Use insect repellant (some camping references recommend repellant with DEET).
- If possible, have an oscillating fan sweeping your observation area. Mosquitoes are weak flyers and have difficulty finding their intended targets (i.e. you) when fighting against a wind (i.e. the oscillating fan).
- Humidity may cause a decrease in sky transparency in the observing conditions, but the seeing conditions (the steadiness of the sky) will likely be excellent. Often, steady but slightly hazy conditions will yield good planetary observing.

J.L. Chen, A. Chen, *A Guide to Hubble Space Telescope Objects*,
The Patrick Moore Practical Astronomy Series, DOI 10.1007/978-3-319-18872-0_4

M8 The Lagoon Nebula

Alternative Nomenclature: NGC 6523, the Evil Eye Galaxy
Constellation: Sagittarius

Right Ascension: 18h03m37s
Declination: −24deg23min12s
Magnitude: 4.6 (cluster), 6.0 (nebula) (Fig. 4.1)

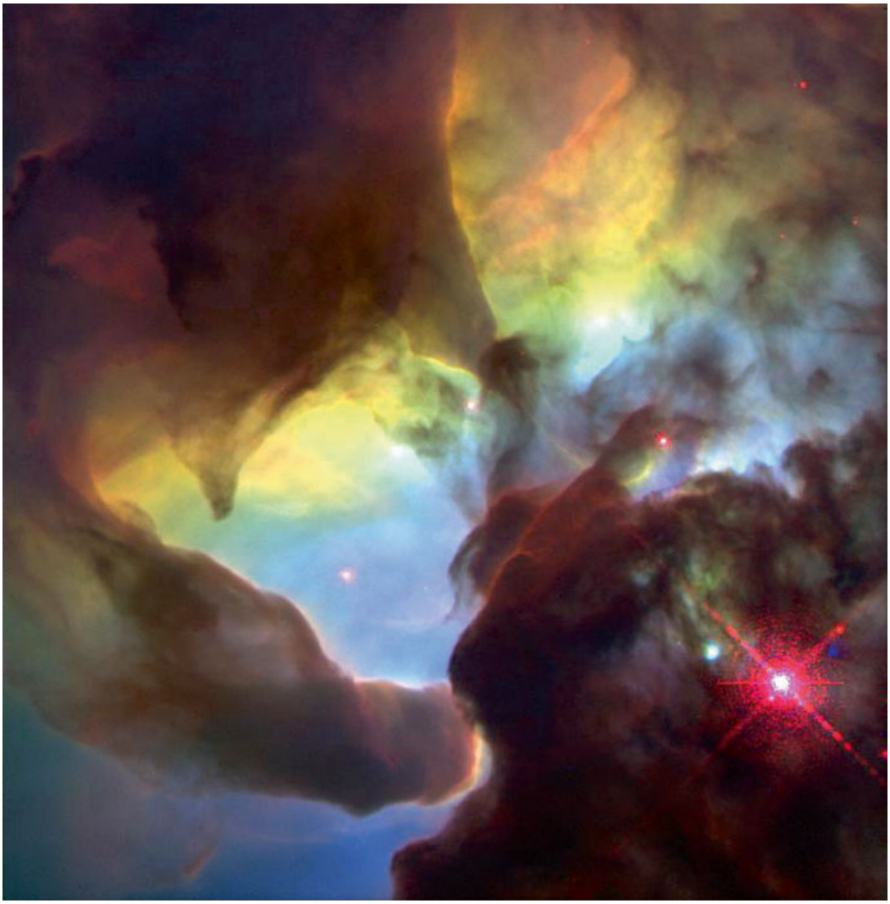

Fig. 4.1 The Hubble image of M8 core (NASA, ESA, and STSci)

The history of the discovery of the Lagoon Nebula is long and convoluted. A good part of the confusion stems from the fact that M8 can be viewed as both a diffuse nebula and an associated star cluster. And there is reason to question the quality of the telescope optics being used at the time.

First discovered by Giovanni Battista Hodierna before 1654, who classified it as "nebulosa". It was then rediscovered by John Flamsteed around 1680, who cataloged it as a nebula and listed it as his Number 2446. Then in 1746, Philippe Loys de Cheseaux could only resolve stars, and as a result classified it as a cluster. One year later in 1747, Guillaume Le Gentil sighted it and described it as both a nebula and a cluster. Nicholas Louis de Lacaille had written down the Lagoon Nebula in his 1751–1752 works as Lacaille III.14.

By the time Charles Messier cataloged this object on May 23, 1764, it became famous at last:

> "I also have determined, in the same night [May 23 to 24, 1764], the position of a small star cluster which one sees in the form of a nebula, if one views it with an ordinary [non-achromatic] refractor of 3 feet [FL], but when employing a good instrument one notices a large quantity of small stars: near this cluster is a rather brilliant star which is surrounded by a very faint light: this is the ninth star of Sagittarius, of seventh magnitude, according to the catalog of Flamsteed: this cluster appears in an elongated shape which extends from North-East to South-West. I observed its position during its passage of the Meridian, comparing it with the star Delta Sagittarii, and I determined its right ascension as 267d 29′ 30″, and its declination as 24d 21′ 10″ south. This star cluster could have an extension, from North-East to South-West, of about 30 minutes of arc."

William Herschel assigned separate catalog numbers to two objects within, or parts of, the Lagoon Nebula: H V.9 (GC 4363, NGC 6526) and H V.13 (GC 4368, NGC 6533) which are described as large and faint nebulae in the New General Catalogue. His son John Herschel subsequently catalogued the open cluster as NGC 6530 and the diffuse nebula as NGC 6523.

Fig. 4.2 Amateur astrophoto of M8 and M20 (Jon Talbot)

Fig. 4.3 Amateur astrophoto of M8 (Chris Miskiewicz)

The Lagoon Nebula is one of the finest and brightest star-forming regions in the sky. It is a giant cloud of interstellar matter which is currently undergoing vivid star formation, and has already formed a considerable cluster of young stars.

With the help of Finder Chart #2, locating M8 involves first locating the Sagittarius constellation's characteristic teapot shape. Find the star at the top of the handle of the teapot. This star is known as Nunki. Line up Nunki with the star at the top of the teapot. This star is Kaus Borealis. Extend the line from Nunki, through Kaus Borealis to a distance not quite the distance of these two stars and M8 can be found. On a dark night, even in a pair of binoculars or a lowly finderscope, the faint fuzzy patch of M8 can be seen.

On an average, suburban night, its likely that the associated star cluster NGC 6530 will be seen and averted vision might allow a glimpse of M8. Add an OIII or Ultra-High Contrast filter, and M8 should pop into view, with a greyish nebula glow. The observer is now viewing the birthplace of stars (Figs. 4.2 and 4.3).

Messier 8 is roughly 5,000 light-years away, and is estimated to be 50 light-years across. The Hubble images have enhanced the astronomer's identification of two types of proto-stellar formations. The Lagoon nebula contains several dark, collapsing clouds of proto-stellar material known as Bok globules. These Bok globules of collapsing clouds have been measured to be about 10,000 Astronomical Units, or A.U., across.

Also identified within M8 are at least four Herbig-Haro objects within the hourglass-like central structure of the nebula. Herbig-Haro objects are patches of nebulosity associated with newly-born stars, where narrow jets of gas ejected by young stars collide with clouds of gas and dust. The HST observations have revealed the complex evolution of HH objects over the period of years, as parts of the nebula fade while others brighten as they collide with the clumpy material of the gas and dust clouds. The Hubble images clearly show the active nature of these Herbig-Haro objects, with the ejected jets aligned with its rotational axis traveling at speeds of several hundreds of miles per second.

M13 The Great Globular in Hercules

Alternative Nomenclature: NGC 6205, the Hercules Globular Cluster
Constellation: Sagittarius

Right Ascension: 16h41m41.24s
Declination: +36deg27min35.5s
Magnitude: 5.8 (Fig. 4.4)

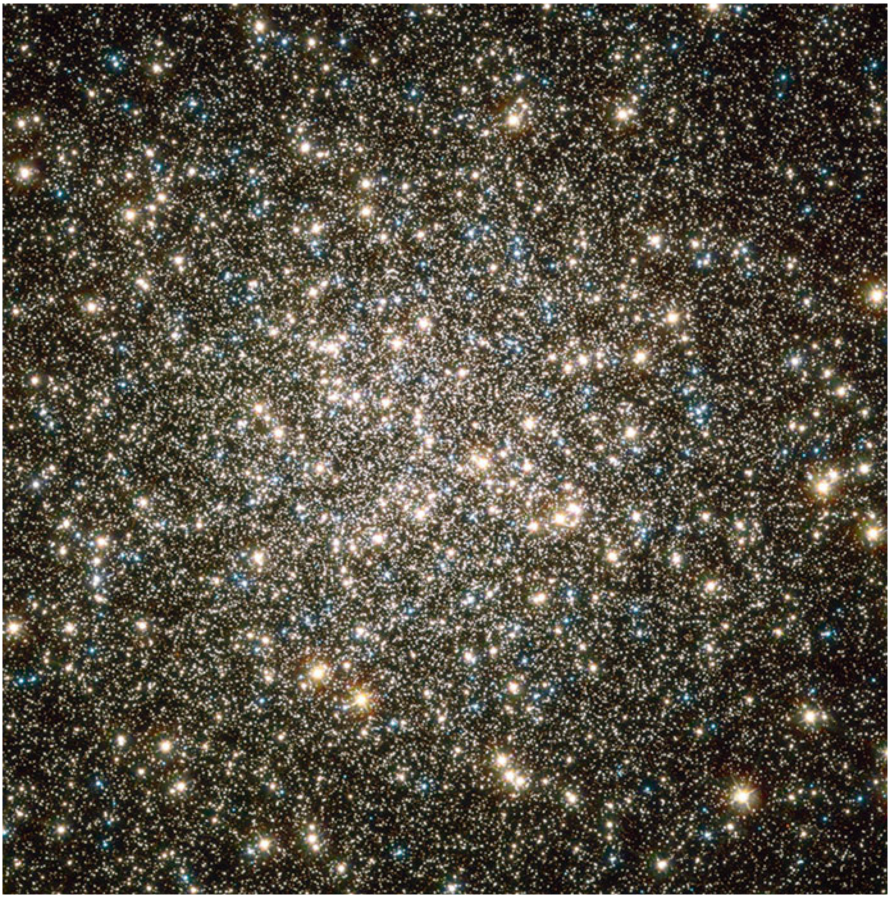

Fig. 4.4 The Hubble image of M13 (NASA, ESA, and The Hubble Heritage Team (STScI/AURA))

The Great Globular in Hercules was first discovered by Sir Edmond Halley in 1714. In his account, where he curiously refers to himself by name, he recounts the discovery:

> "The Sixth and last was accidentally hit upon by M. *Edm. Halley* in the Constellation of *Hercules*, in the Year 1714. It is nearly in a Right Line with Zeta and Eta of Bayer, somewhat nearer to Zeta than to Eta: and by comparing its Situation among the Stars, its Place is sufficiently near in [Scorpio] 26 deg 1/2 with 57 deg 00. North. Lat. This is but a little Patch, but it shews itself to the naked Eye, when the Sky is serene and the Moon absent."

Charles Messier catalogued the globular as M13 on June 1, 1764:

> "June 1, 1764. 13. 16h 33m 15s (248d 18′ 48″) +36d 54′ 44″
>
> A nebula without a star, discovered in the belt of Hercules; it is round & brilliant, the center is more brilliant than the edges, one perceives it with a telescope of one foot [FL]; it is near two stars, both of 8th magnitude, the one above and the other below it: the nebula's position was determined by comparison with Epsilon Herculis. M. Messier has reported it on the chart of comet of 1779, which was included in the volume of the Academy of that year. Seen by Halley in 1714. Seen again Jan. 5 and 30, 1781. It is reported in the English *Celestial Atlas*. (diam. 6′)"
>
> "[*Mem. Acad.* for 1771, p. 441 (first Messier catalog)] In the night of June 1 to 2, 1764, I have discovered a nebula in the girdle of Hercules, of which I am sure it doesn't contain any star; having examined it with a Newtonian telescope of four feet and a half [FL], which magnified 60 times, it is round, beautiful & brilliant, the center brighter than the borders: One perceives it with an ordinary [non-achromatic] refractor of one foot [FL], it may have a diameter of three minutes of arc: It is accompanied by two stars, the one and the other of the ninth magnitude, situated, the one above and the other below the nebula, & little distant. I have determined its position at its passage of the Meridian, and compared with the star Epsilon Herculis; its right ascension has been concluded to be 248d 18′ 48″, & its declination 36d 54′ 44″ north. It is reported in the Philosophical Transactions, *no. 347, page 390*, that Mr. Halley discovered by hasard that nebula in 1714: it is, he says, almost on a straight line with Zeta & Eta according to Bayer, a bit closer to the star Zeta than to Eta, & when comparing its situation between the stars, its place is rather close to Scorpius 26d 1/2 with 57 degrees Northern [ecliptical] latitude, it is nothing but a small patch; but one sees it well without a telescope when the weather is fine, & if there is no light of the moon. [p. 455] 1764.Jun.1. RA: 248.18.48, Dec: 36.54.44.B, Diam: 0. 3. Nebula without stars, in the girdle of Hercules, at 2 degrees below the star Eta of that constellation."

William Herschel, upon viewing M13 on August 22, 1779 wrote:

> [PT 1814, p. 275–276, reprinted in Scientific Papers, Vol. 2, p. 535] May 16, 1787. 20 feet telescope. "The 13th of the *Connoiss.* [M 13 = NGC 6205] is a most beautiful cluster of stars. It is exceedingly compressed in the middle and very rich. The most compressed part of it is round and is about 2 or 2 1/2′ in diameter, the scattered stars which belong to it extend to 8 or 9′ in diameter, but are irregular."

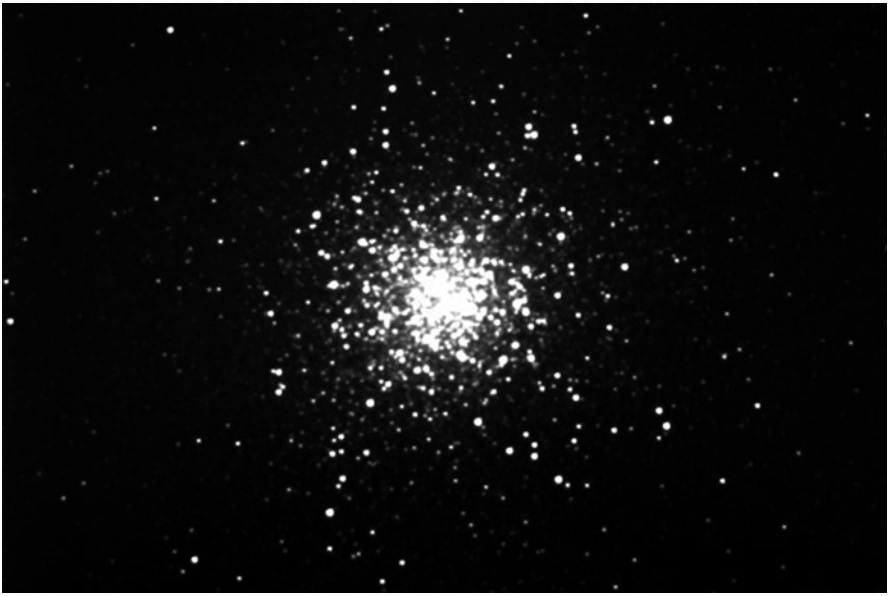

Fig. 4.5 Amateur astrophoto of M13 (John Brooks)

Fig. 4.6 Another amateur astrophoto of M13 (Chris Miskiewicz)

M13 is one of the most prominent and best known globulars visible in the Northern celestial hemisphere. Messier 13 is one of the easier objects to locate in the summer sky. Using Finder Chart #3, locate the “Keystone” asterism of Hercules. On the western side of the asterism are the two stars Eta Herculis and Zeta Herculis. Between Eta and Zeta, biasing slightly towards Eta, the backyard observer will easily locate the round, fuzzy snowball of M13. Even in congested suburbs, M13 can be seen with a 3 inch refractor. Again, M13 is one of those celestial objects that benefits from aperture fever. With a telescope of 10 inches or greater, the “Oh Wow” factor kicks in. Big backyard telescopes allow for the resolution of individual stars that seemingly extend to the center of the cluster. M13 has long been one of the showpieces of the summer sky (Figs. 4.5 and 4.6).

M13 is home to over 100,000 stars and located at a distance of 25,000 light-years. These stars are packed so closely together in a ball, approximately 150 light-years across, that they will spend their entire lives whirling around in the cluster.

Near the core of this cluster, the density of stars is about a hundred times greater than the density in the neighborhood of our sun. These stars are so crowded that occasional collisions can occur with each other. Such collisions can cause the formation of a new blue star, sometimes referred to as a straggler.

The brightest reddish stars in the cluster are ancient red giants. These aging stars have expanded to many times their original diameters and cooled. The blue-white stars are the hottest in the cluster.

Globular clusters can be found spread largely in a vast halo around our galaxy. M13 is one of nearly 150 known globular clusters surrounding our Milky Way galaxy.

The late, great science fiction writer Isaac Asimov wrote a Hugo-award winning short story *Nightfall* that imagined an inhabited world that resided within the dense star environment that is typified by a globular cluster like M13. The inhabitants of his fictional world Lagash never experienced the darkness of night. Through a fluke of orbital mechanics, the six-sun solar system of his story would bathe the fictional planet Lagash in the darkness of night every 2,000 years, spreading terror across the civilization. To many sci-fi aficionados, *Nightfall* is considered one of the greatest scientific stories of all time. Recommended reading.

Globular clusters have some of the oldest stars in the universe. They likely formed before the disk of our Milky Way, so they are older than nearly all other stars in our galaxy. Studying globular clusters therefore tells us about the history of our galaxy.

M16 The Eagle Nebula (The Pillars of Creation)

Alternative Nomenclature: NGC 6611, IC 4703, the Star Queen Nebula
Constellation: Serpens Cauda

Right Ascension: 18h18m48s
Declination: −13deg49min0.0s
Magnitude: 6.0 (Figs. 4.7 and 4.8)

Fig. 4.7 Hubble image of M16 (NASA, ESA, and The Hubble Heritage Team (STScI/AURA))

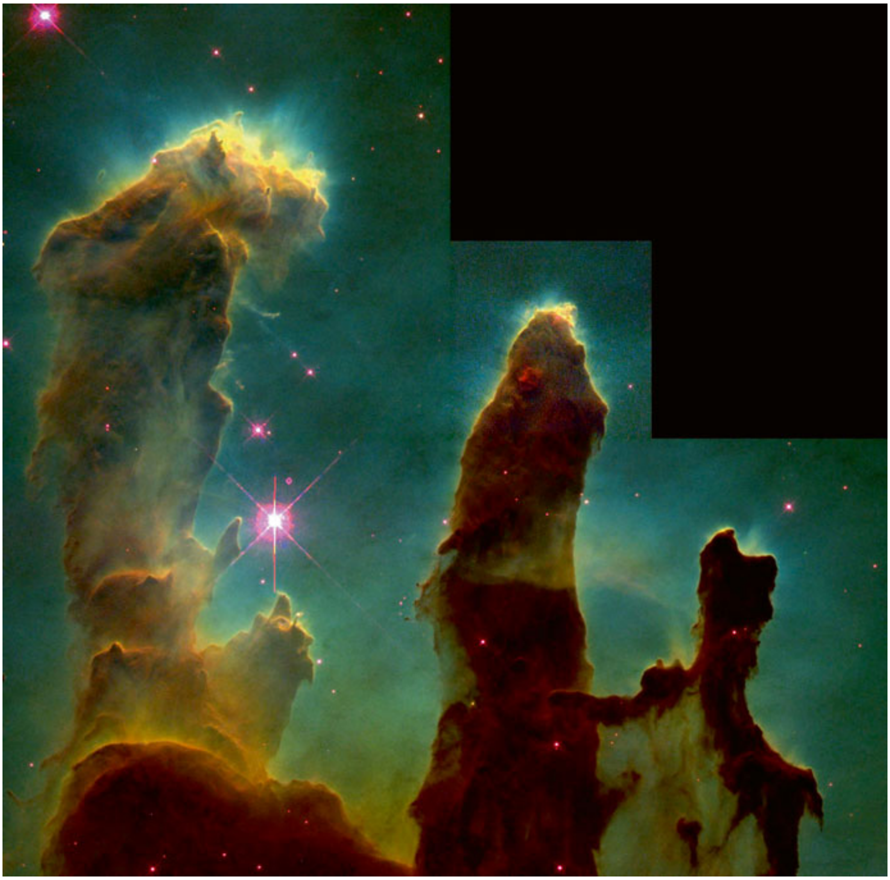

Fig. 4.8 Hubble image of the M16 "The Pillars of Creation" (NASA, ESA, and The Hubble Heritage Team (STScI/AURA))

The star cluster associated with M16 was discovered by Philippe Loys de Chéseaux in 1745–1746. Catalogued as De Chéseaux: No. 4, he wrote:

> "A star cluster between the constellations of Ophiuchus, Sagittarius, and Antinous [now Scutum], of which RA is 271d 3′ 10″ and southern declination is 13d 47′ 20″."

Charles Messier rediscovered it on June 3, 1764, as noted in his catalog:

> "June 3, 1764. 16. 18h 05m 00s (271d 15′ 03″) −13d 51′ 44″
>
> A cluster of small stars, enmeshed in a faint glow, near the tail of Serpens, at little distance to the parallel of Zeta of this constellation; with an inferior telescope this cluster appears like a nebula. (diam. 8′)
>
> [*Mem. Acad.* for 1771, p. 442 (first Messier catalog)] In the same night of June 3 to 4, 1764, I have discovered a cluster of small stars, mixed with a faint light, near the tail of Serpens, at little distance from the parallel of the star Zeta of that constellation: this cluster may have 8 minutes of arc in extension: with a weak refractor, these stars appear in the form of a nebula; but when employing a good instrument one distinguishes these stars, & one remarkes in addition a nebulosity which contains three of these stars. I have determined the position of the middle of this cluster; its right ascension was 271d 15′ 3″, & its declination 13d 51′ 44″ south. [p. 455] 1764.Jun.3. RA: 271.15. 3, Dec: 13.51.44.A, Diam: 0. 8. Cluster of small stars mixed with nebulosity, near the tail of Serpens, little distant from the parallel of the star Zeta of that constellation."

The Eagle Nebula is a conspicuous region of active star formation, situated in Serpens Cauda. M16 is a star-forming nebula, a giant cloud of interstellar gas and dust, containing a considerable cluster of young stars. The cluster is also referred to as NGC 6611, the nebula as IC 4703.

Using Finder Chart #2 for guidance, the easiest way to find M16 is to identify the constellation of Aquila and begin tracing the stars down the eagle's back to Lambda. Once reaching that point, continue to extend the line through to Alpha Scuti, then southwards towards Gamma Scuti. In an image correct finderscope, aim at Gamma Scuti and put it in the 7:00 position. In the finderscope, M16 will show as a faint haze. If Gamma is in the lower left hand corner of your vision—then M16 is in the upper right hand. The open star cluster can be easily detected. To see the faint nebulosity will require the use of a UHC filter or OIII filter. Large aperture telescopes and dark country skies offer a great advantage in seeing this nebula well. The star cluster of M16 is easy, but the nebula is a challenge (Figs. 4.9 and 4.10).

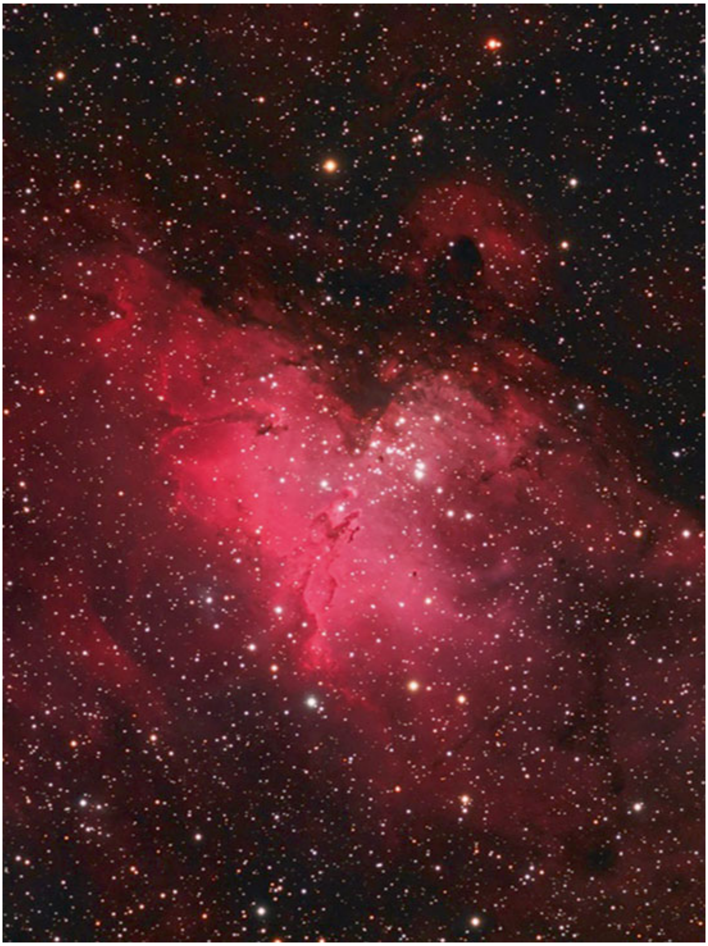

Fig. 4.9 An excellent amateur astrophoto of M16 (Jon Talbot)

Fig. 4.10 Another excellent amateur image of M16 (John Brooks)

M16 is some 7,000 light years distant in the constellation Serpens, close to the borders to Scutum and Sagittarius, and in the next inner spiral arm of the Milky Way galaxy, known as the Sagittarius or Sagittarius-Carina Arm. The Eagle Nebula is a great cloud of interstellar gas and dust undergoing a vivid process of star formation. Open star cluster M16 has formed from this great gaseous and dusty cloud, the diffuse Eagle Nebula IC 4703, which is now caused to shine by emission light, excited by the high-energy radiation of its massive hot, young stars. It is actually still in the process of forming new stars, this formation taking place near the dark central columns. The star formation process can be seen from the Hubble image in Fig. 4.9, famously known as the Pillars of Creation, with the small dark areas in the photograph believed to be protostars. These pillars are composed of interstellar hydrogen gas and dust, which act as incubators for new stars. Inside the columns and on their surface astronomers have found knots or globules of denser gas, nicknamed EGGs for Evaporating Gaseous Globules. Stars are being formed inside some of these EGGs.

Hot gas observed by Spitzer Telescope in 2007 suggests that the pillars in M16 may already have been destroyed by a supernova explosion some 8,000–9,000 years ago. Due to the distance of the nebula, the light from the supernova would have reached Earth between 1,000 and 2,000 years ago. The more slowly moving shock wave from the supernova would have taken a few thousand years to move through the nebula, and would blow away the delicate pillars—but the light showing us the destruction likely will not reach the Earth for another thousand years.

M17 The Omega Nebula

Alternative Nomenclature: NGC 6618, the Swan Nebula, Checkmark Nebula, Lobster Nebula, Horseshoe Nebula
Constellation: Sagittarius

Right Ascension: 18h20m26s
Declination: −16deg10min36s
Magnitude: 6.0 (Fig. 4.11)

Fig. 4.11 Hubble image of M17 (NASA, ESA, and The Hubble Heritage Team (STScI/AURA))

The Omega Nebula Messier 17, also called the Swan Nebula, the Horseshoe Nebula, or in the southern hemisphere known as the Lobster Nebula, was discovered by Philippe Loys de Chéseaux in 1745–1746. The Omega was one of only six identified by Chéseaux as a nebula in his catalog. As with M16, his discovery was lost and forgotten, until Charles Messier rediscovered it on June 3, 1764.

Philippe Loys de Chéseaux wrote:

"Finally, another nebula, which has never been observed. It is of a completely different shape than the others: It has perfectly the form of a ray, or of the tail of a comet, of 7′ length and 2′ broadth; its sides are exactly parallel and rather well terminated, as are its two ends. Its middle is whiter than the borders; I have found its RA for this year as 271d 32′ 35″ and its southern declination as 16d 15′ 6″. It has an angle [PA] of 50 deg with the meridian."

On that fruitful June 3, 1764, Charles Messier entered into his famous list:

"June 3, 1764. 17. 18h 07m 03s (271d 45′ 48″) −16d 14′ 44″

A train of light without stars, of 5 or 6 minutes in extent, in the shape of a spindle, & a little like that in Andromeda's belt but of a very faint light; there are two telescopic stars nearby & placed parallel to the equator. In a good sky one observes this nebula very well in an ordinary telescope of 3.5-foot [FL]. Seen again 22 March 1781. (diam. 5′)

[*Mem. Acad.* for 1771, p. 442–443 (first Messier catalog)] In the same night [June 3 to 4, 1764], I have discovered at little distance of the cluster of stars of which I just have told, a train of light of five or six minutes of arc in extension, in the shape of a spindle, & in almost the same [shape] as that in the girdle of Andromeda; but of a very faint light, not containing any star; one can see two of them nearby which are telescopic & placed parallel to the Equator: in a good sky one perceives very well that nebula with an ordinary [non-achromatic] refractor of 3 feet & a half [FL]. I have determined its position in right ascension of 271d 45′ 48″, & its declination of 16d 14′ 44″ south. [p. 456] 1764.Jun.3. RA: 271.45.48, Dec: 16.14.44.A, Diam: 0. 5. Train of light without stars, little distant from the preceding star cluster."

John Herschel wrote of M17:

"The figure of this nebula is nearly that of the Greek capital Omega, somewhat distorted and very unequally bright. It is remarkable that this is the form usually attributed to the great nebula in Orion, though in that nebula I confess I can discern no resemblance whatever to the Greek letter. Messier perceived only the bright preceding branch of the nebula now in question, without any of the attached convolutions which were first noticed by my Father. The chief peculiarities which I have observed in it are, 1st, the resolvable knot in the following portion of the bright branch, which is in a considerable degree insulated from the surrounding nebula; strongly suggesting the idea of an absorption of nebulous matter; and 2ndly, the much feebler and smaller knot in the north preceding end of the same branch, where the nebula makes a sudden bend at an acute angle. With a view to a more exact representation of this curious nebula, I have at different times taken micrometrical measures of the relative places of the stars in and near it, by which, when laid down on the chart, its limits may be traced and identified, as I hope soon to have better opportunity to do than its low situation in this latitudes will permit."

Fig. 4.12 An extraordinary amateur astrophoto of M17 (Jon Talbot)

Fig. 4.13 A representative view of M17 (Chris Miskiewicz)

The Omega Nebula, Messier 17, is also called the Swan Nebula, the Horseshoe Nebula, or in the southern hemisphere the Lobster Nebula. It is a region of star formation and shines by excited emission, caused by the higher energy radiation of young stars. Unlike in many other emission nebulae, these stars are not obvious visually, but hidden in the nebula. Stars are still actively forming in M17. A small cluster of about 35 bright but obscured stars is imbedded in the nebulosity.

M17 is large and prominent, with a distinctive swan-floating-in-water shape. With Finder Chart #2, finding M17 requires the identification of the constellation of Aquila and tracing the stars down the eagle's back to Lambda. When you reach that point, continue to extend the line through to Alpha Scuti, then southwards towards Gamma Scuti. M16 is slightly more than 2 degrees southwest of this star. This nebula is bright enough to even cut through suburban light polluted skies with ease, with the technological aid of nebula filters improving the viewing (Figs. 4.12 and 4.13).

The Hubble image Fig. 4.11 captures a small region of star formation within M17. The wave-like patterns of gas have been sculpted and illuminated by a torrent of ultraviolet radiation from young, massive stars, which lie outside the picture to the upper left. The glow of these patterns accentuates the three-dimensional structure of the gases. The ultraviolet radiation is carving and heating the surfaces of cold hydrogen gas clouds. The warmed surfaces glow orange and red in this Hubble image. The intense heat and pressure cause some material to stream away from those surfaces, creating the glowing veil of even hotter greenish gas that masks background structures. The pressure on the tips of the waves may trigger new star formation within them.

M20 The Trifid Nebula

Alternative Nomenclature: NGC 6514
Constellation: Sagittarius

Right Ascension: 18h02m23s
Declination: −23deg01min48s
Magnitude: 6.3 (cluster), 9.0 (nebula) (Fig. 4.14)

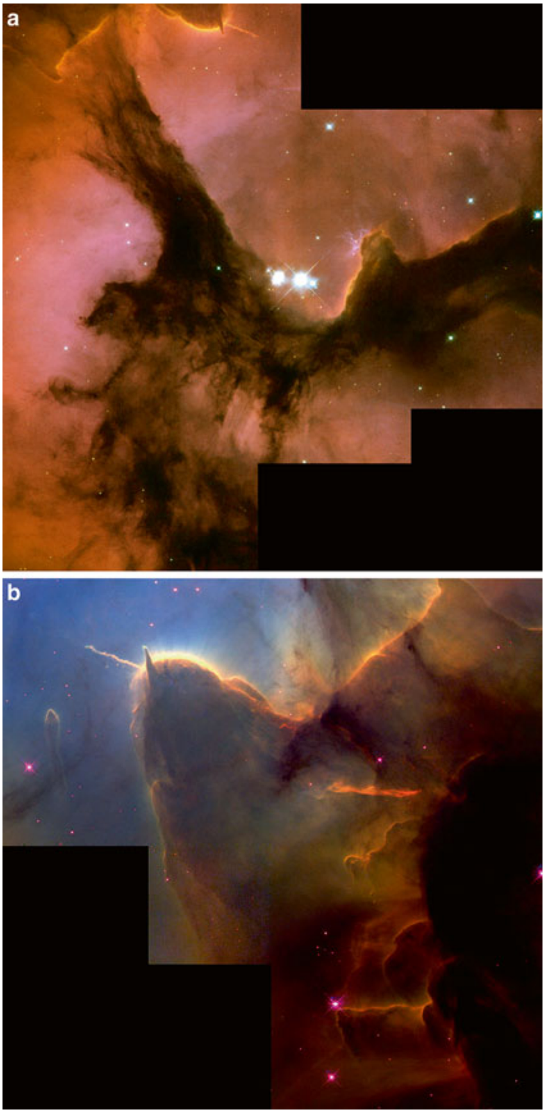

Fig. 4.14 (**a**) Hubble Image of M20 (NASA, ESA, and STSci), (**b**) Hubble image detail of stellar jets within M20 (NASA, ESA, and Arizona State University)

The Trifid Nebula was discovered by Charles Messier on June 5, 1764:

?June 5, 1764. 20. 17h 48m 16s (267d 04′ 05″) −22d 59′ 10″

Cluster of stars, a little above the Ecliptic, between the bow of Sagittarius & the right foot of *Ophiuchus*. Seen again March 22, 1781.

From Messier's description of M21:

"The nearest neighboring known star to these two clusters is 11 Sagittarii, 7 mag, according to Flamsteed. The stars of both these clusters are of 8–9 magnitude, enveloped in nebulosity."

"In the same night [June 5 to 6, 1764] I have determined the position of two clusters of stars which are close to each other, a bit above the Ecliptic, between the bow of Sagittarius & the right foot of *Ophiuchus:* the known star closest to these two clusters is the 11th of the constellation Sagittarius, of seventh magnitude, after the catalog of Flamsteed: the stars of these clusters are, from the eighth to the ninth magnitude, environed with nebulosities. I have determined their positions. The right ascension of the first cluster, 267d 4′ 5″, its declination 22d 59′ 10″ south. The right ascension of the second, 267d 31′ 35″; its declination, 22d 31′ 25″ south. [p. 456] 1764.Jun.5 RA: 267. 4. 5, Dec: 22.59.10.A. Cluster of stars a little above the Ecliptic, between the bow of Sagittarius & the right foot of *Ophiuchus*."

John Herschel was the first to use the term Trifid in describing M20, taken from his notes:

"Sweep 30 (July 1, 1826) RA 17h 51m 64.3s, NPD 113d 0m 6s (1830.0) vL; trifid, three nebulae with a vacuity in the midst, in which is centrally situated the double star Sh 379, neb = 7′ in extent. A most remarkable object. very large; trifid, three nebulae with a vacuity in the midst, in which is centrally situated the double star Sh 379, the nebula is 7′ in extent. A most remarkable object."

Fig. 4.15 An excellent amateur astrophoto of both M8 and M20 (Jon Talbot)

The Trifid Nebula, in the constellation Sagittarius, is a remarkable and beautiful object consisting of both an emission nebula and a reflection nebula component.

Once familiar with the Sagittarius region, using Finder Chart #2 as guidance, finding Messier 20 is an easy 2 degrees northwest of Messier 8, the Lagoon Nebula. At magnitude 9, M20 is a difficult target for binoculars and small telescopes. Again, either a UHC or O-III nebula filter will be of great aid in observing the Trifid. M20 is more attainable with an 8 inch or larger aperture telescope (Fig. 4.15).

M20 was the subject of an investigation by astronomers using the HST in 1997, using filters to reveal hydrogen, ionized sulfur, and double-ionized oxygen. The Hubble close-up look, seen in Fig. 4.14a, is of the center of the Trifid Nebula, near the intersection of the dust bands, where a group of recently formed, massive, bright stars are easily visible. These stars, which astronomers classify as belonging to the hottest and bluest types of stars known, type "O," are releasing a flood of ultraviolet radiation that dramatically influences the structure and evolution of the surrounding nebula. The stars illuminate a dense pillar of gas and dust to the right of the image, producing a bright rim on the side facing the stars. At the upper left tip of this pillar, there is a complex filamentary structure also on the side closest to the center of the nebula. The structure has a bluish color because it is made up of glowing oxygen gas that is evaporating into space.

Star formation is no longer occurring in the immediate vicinity of the conspicuous group of bright O-type stars, because their intense radiation has blown away the gas and dust from which stars are made. However, not far away there are signs of interstellar material collapsing under its own gravity, leading to ongoing star formation. One such example is a very young star that is still surrounded by a ring of gas and dust left over from the star's formation. These circumstellar rings, called protoplanetary disks, or "proplyds" for short, are believed to be the locations where planetary systems are formed. A proplyd in the Trifid Nebula is visible near the lower right of the main Hubble image. An image enlargement of the proplyd is shown in the lower left box, where its elongated shape can be seen.

The images also showed a finger-like stalk to the right of the jet. It points from the head of the dense cloud directly toward the star that powers the Trifid nebula. This stalk is a prominent example of EGG's, similar to those seen in M16. The stalk has survived because its tip is a knot of gas that is dense enough to resist being eaten away by the powerful radiation from the star.

M51 The Whirlpool Galaxy

Alternative Nomenclature: NGC 5194 and NGC 5195, M51a and M51b
Constellation: Canes Venatici

Right Ascension: 13h29m52.7s
Declination: +47deg11min43s
Magnitude: 8.4 (Fig. 4.16)

Fig. 4.16 Hubble image of M51 (NASA and ESA)

Discovered by Charles Messier on October 13, 1773, he apparently recognized only the large portion, and it was left to his associate Pierre Mechain on March 21, 1781 to report the smaller formation. Messier described it as “very faint nebula, without stars”. Mechain then reported it as “It is double, each has a bright center, which are separated 4′ 35″. The two “atmospheres” touch each other, the one is even fainter than the other.” Hence the sometimes reference to M51 being comprised of M51a and M51b (Fig. 4.17).

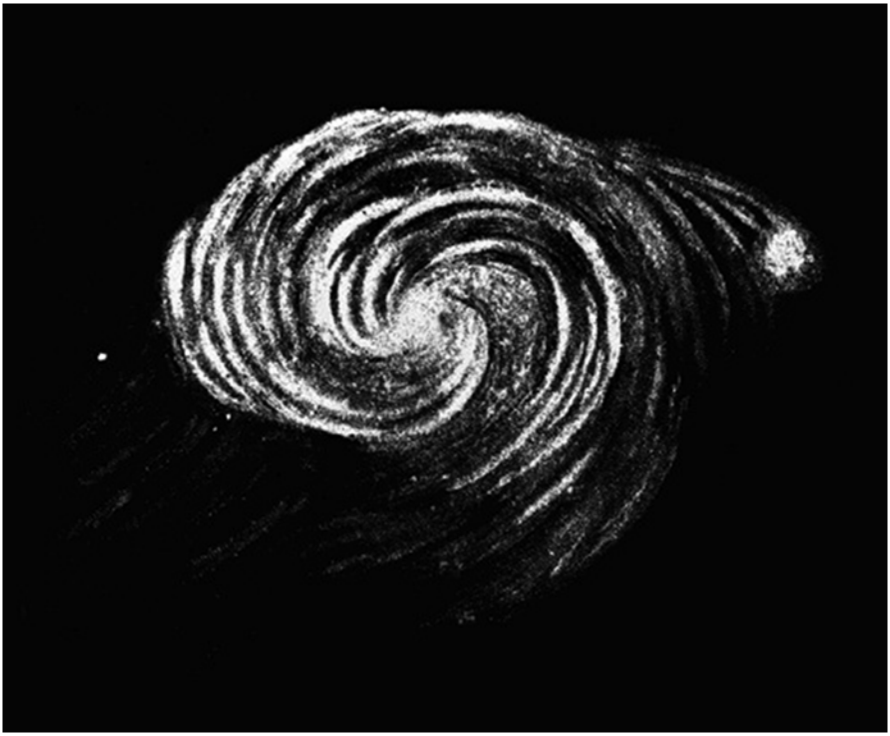

Fig. 4.17 William Parsons, third Earl of Rosse sketch of the spiral structure of M51

It was not until William Parsons, third Earl of Rosse, using the famous 72″ speculum reflector *The Leviathan of Parsonstown* in Ireland, observed and drew, see Fig. 4.17, the now recognizable spiral structure of M51.

Up until the time of Edwin Hubble and the mid-1920s, objects such as M51 and M31 were referred to as spiral nebulae. It was not until January 1, 1925, when Edwin Hubble released his landmark findings to the American Astronomical Society, did science recognize these objects as galaxies. Edwin Hubble's observations of Cepheid variables within M31 and M51, among others, revealed the true nature of these objects as external to the Milky Way.

Fig. 4.18 Amateur astrophoto of M51 (John Brooks)

Fig. 4.19 Another amateur astrophoto of M51 (Jon Talbot)

The Whirlpool galaxy is one of the most conspicuous and recognizable spiral galaxies in the sky. A large aperture amateur telescope is helpful in observing this deep sky object, 8-inches or greater.

Using either Finder Chart #1 or #3, to find M51, first find the star Alkaid at the end of the Big Dipper handle in Ursa Major. Center your telescope there and move slowly southwest towards Alpha Canes Venatici, known as Cor Caroli, and the faint fuzzy glow of M51 is stumbled upon. M51 cannot be seen with moonlight present, nor is it visible in the presence of streetlights and other neighborhood ambient light. High humidity conditions will also hamper observing this galaxy. As with all galaxies, the best telescope accessory is a dark country-side sky (Figs. 4.18 and 4.19).

The Whirlpool's most striking feature is its two curving arms, a hallmark of so-called grand-design spiral galaxies. Many spiral galaxies possess numerous, loosely shaped arms which make their spiral structure less pronounced. These arms serve an important purpose in spiral galaxies. They are star-formation factories, compressing hydrogen gas and creating clusters of new stars. In the Whirlpool, the assembly line begins with the dark clouds of gas on the inner edge, then moves to bright pink star-forming regions, and ends with the brilliant blue star clusters along the outer edge.

Some astronomers believe that the Whirlpool's arms are so prominent because of the effects of a close encounter with NGC 5195 (M51b), the small, yellowish galaxy at the outermost tip of one of the Whirlpool's arms. At first glance, the compact galaxy appears to be an extension the arm. Hubble images show that, in actuality, NGC 5195 is passing behind the Whirlpool. The small galaxy has been gliding past the Whirlpool for hundreds of millions of years.

The movement of NGC 5195 (M51b) with its galactic gravity creates waves within the Whirlpool's pancake-shaped disk. The waves are like ripples in a pond generated when a rock is thrown in the water. When the waves pass through orbiting gas clouds within the disk, they squeeze the gaseous material along each arm's inner edge. The dark dusty material looks like gathering storm clouds. These dense clouds collapse, creating a wake of star birth, as seen in the bright pink star-forming regions. The largest stars eventually sweep away the dusty cocoons with a torrent of radiation, hurricane-like stellar winds, and shock waves from supernova blasts. Bright blue star clusters emerge from the mayhem, illuminating the Whirlpool's arms like city streetlights.

M57 The Ring Nebula

Alternative Nomenclature: NGC 6720
Constellation: Lyra

Right Ascension: 18h53m35s
Declination: +33deg01min45s
Magnitude: 8.8 (Fig. 4.20)

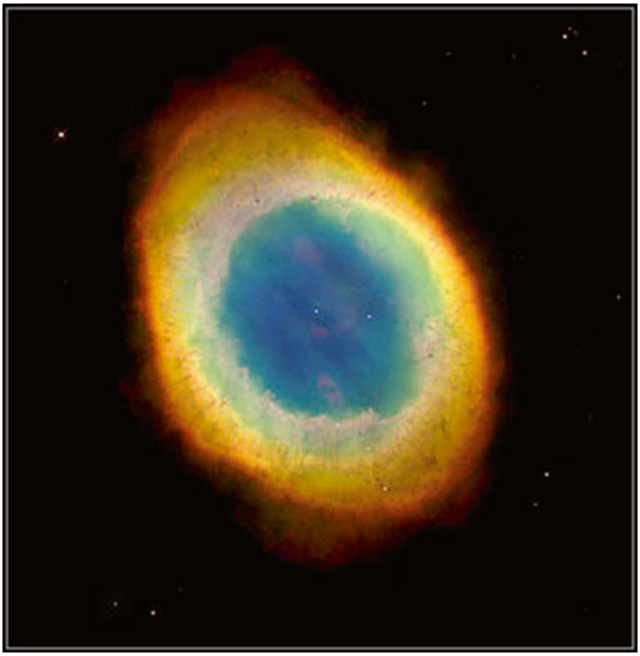

Fig. 4.20 Hubble image of M57 (NASA, ESA, and The Hubble Heritage Team (STScI/AURA))

M57 was first discovered in early January 1779 by Antoine Darquier who wrote in his notes:

> "This nebula, to my knowledge, has not yet been noticed by any astronomer. One can only see it with a very good telescope, it is not resembling any of those [nebula] already known; it has the apparent dimension of Jupiter, is perfectly round and sharply limited; its dull glow resembles the dark part of the Moon before the first and after the last quarter. Meanwhile, the center appears a bit less pale than the remaining part of its surface."

It is believed Darquier's observation preceded Messier's independent recovery made on January 31, 1779, since Messier acknowledges that Darquier observed it before him:

> "A cluster of light between Gamma and Beta Lyrae, discovered when looking for the Comet of 1779, which has passed it very close: it seems that this patch of light, which is round, must be composed of very small stars: with the best telescopes it is impossible to distinguish them; there stays only a suspicion that they are there. M. Messier reported this patch of light on the Chart of the Comet of 1779. M. Darquier, at Toulouse, discovered it when observing the same comet, and he reports: "Nebula between gamma and beta Lyrae; it is very dull, but perfectly outlined; it is as large as Jupiter and resembles a planet which is fading"."

William Herschel, not knowing the concept of planetary nebulas, wrote:

> "Among the curiosities of the heavens should be placed a nebula, that has a regular, concentric, dark spot 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; so that, if the stars form a circle, its inclination to a line drawn from the sun to the center of this nebula must be about 56 degrees. The light is of the resolvable kind [i.e., mottled], and in the northern side three very faint stars may be seen, as also one or two in the southern part. The vertices of the longer axis seem less bright and not so well defined as the rest. There are several small stars very bear, but none seems to belong to it. It is the 57th of the *Connoissance des Temps*. Fig. 5 is a representation of it."

Fig. 4.21 An amateur astrophoto of M57 (John Brooks)

Fig. 4.22 Another amateur astrophoto of M57 (Jon Talbot)

The Ring nebula, M57, is a highly recognizable example a planetary nebula, and a showpiece deep sky object in the northern hemisphere summer sky.

Perhaps the easiest planetary nebula to locate, find the constellation Lyra using the Naval Observatory chart and Finder Chart #3. Identify the bright star Vega and the parallelogram asterism in Lyra. M57 is located in-between the two stars of the parallelogram furthest from Vega, otherwise known as Beta Lyrae and Gamma Lyrae. M57 can be spotted as a small ghostly grey ring-shaped object even with a modest telescope of the 60–80 mm size. In light polluted suburbs, M57, despite its magnitude 8.8 brightness, is an easily accessible object to observe for the backyard astronomer. Nebula filters enhance the view of the Ring Nebula, but due to the brightness of this planetary, not necessary (Figs. 4.21 and 4.22).

The Hubble image Fig. 4.20 captured the sharpest view yet of the most famous Ring Nebula (M57). In this October 1998 image, the telescope has looked down a barrel of gas cast off by a dying star thousands of years ago. This photo reveals elongated dark clumps of material embedded in the gas at the edge of the nebula; the dying central star floating in a blue haze of hot gas. The nebula is about a light-year in diameter and is located some 2,000 light-years from Earth in the direction of the constellation Lyra.

The colors are approximately true colors. The color image was assembled from three black-and-white photos taken through different color filters with the Hubble telescope's Wide Field Planetary Camera 2. The color blue isolates emission from very hot helium, which is located primarily close to the hot central star. Green represents ionized oxygen, which is located farther from the star. Red shows ionized nitrogen, which is radiated from the coolest gas, located farthest from the star. The gradations of color illustrate how the gas glows because it is bathed in ultraviolet radiation from the remnant dwarf central star, whose surface temperature is a white-hot 216,000 degrees Fahrenheit.

M106

Alternative Nomenclature: NGC 4258
Constellation: Canes Venatici

Right Ascension: 12h18m57.5s
Declination: +47deg18min14s
Magnitude: 8.3 (Fig. 4.23)

Fig. 4.23 Hubble image of M106 (NASA, ESA, and The Hubble Heritage Team (STScI/AURA and R. Gendler))

This galaxy was originally discovered by Pierre Mechain in July, 1781:

> "In July 1781 I found another nebula close to the Great Bear [Ursa Major] near the star No. 3 of the Hunting Dogs [Canes Venatici] and 1 deg more south, I estimate its right ascension 181d 40′ and its northern declination about 49d. I will be going to determine the more accurate position of this one shortly."

M106 was later appended to the Messier Catalog. Historically, it was Helen Sawyer Hogg who, in 1947, added M106, along with M105 and M107 officially to the list.

The bright Sb spiral galaxy Messier 106 is estimated at 21–25 million light years distant. It is receding at 537 km/s.

Using either Finder Chart #1 or #3, locate Phecda (Gamma Ursa Majoris), the bottom corner star at the bottom of the handle of the Big Dipper asterism. Locate Cor Caroli (Alpha Canes Venatici), and M106 lies roughly halfway between Phecda and Cor Caroli. Accessible with almost any size telescope, M106 is one galaxy that can be seen from a suburban backyard (Fig. 4.24).

M106 is at a distance of about 22–25 million light-years away. Seen in visible light, M106 appears like a normal spiral galaxy. But when observed in other wavelengths, it becomes clear that M106 has a higher luminosity at its core than normal. It is a member of the Seyfert family of galaxies. Due to the presence of high X-ray radiation and unusual emission lines detected, it is suspected that at the heart of M106 is a supermassive black hole.

Fig. 4.24 An amateur astrophoto of M106 (Jon Talbot)

Seyfert galaxies and quasars are the two families of active galaxies, with highly luminous and bright sources of electromagnetic radiation emanating from their nuclei. Seyfert galaxies have a very high surface brightness, and a spectra with strong high ionization emission lines. Seyfert galaxies have supermassive black holes at their nucleus, with an accretion disc of matter surrounding the black hole. The material from the accretion disc is sucked into the black hole, with a resultant emission of ultraviolet radiation. M106 exhibits the signature ultraviolet emission and absorption lines.

Seyfert galaxies are classified as either Type I or II, depending on the emission lines shown by their spectra. The spectra of Type I Seyfert galaxies show broad lines that include both allowed lines, like H-I, He-I or He-II and narrower forbidden lines, like O-III. Forbidden lines are spectral lines that occur due to highly improbable electron transitions not normally allowed by the selection rules of quantum mechanics. This odd term "forbidden" relates to the highly improbable nature of these transitions, but they are not impossible. Type I Seyfert show some narrower allowed lines as well, but even these narrow lines are much broader than the lines shown by normal galaxies. However, the spectra of Type II Seyfert galaxies show only both permitted and forbidden narrow lines. M106 is categorized as a Type II Seyfert.

Figure 4.23 is an unusual Hubble photograph. Unlike most of the Hubble images in this book, Fig. 4.23 was processed by an amateur. Renowned astrophotographer Robert Gendler has taken science data from the Hubble Space Telescope archive and combined it with his own ground-based observations to assemble the M106 image shown in Fig. 4.23. There is no Hubble image of M106 in its entirety. Instead, Gendler and fellow astrophotographer Jay GaBany assembled it from multiple images taken from the Hubble archive to form a mosaic of M106, adding his own images to fill in gaps in the mosaic where no Hubble data exists.

NGC 3242 The Ghost of Jupiter

Alternative Nomenclature: NGC 3242, the Eye Nebula, Caldwell 59, H IV.27, h 3248, GC 2102, Jupiter's Ghost
Constellation: Hydra

Right Ascension: 10h24m46.1s
Declination: −18deg38min32.6s
Magnitude: 7.8 (Fig. 4.25)

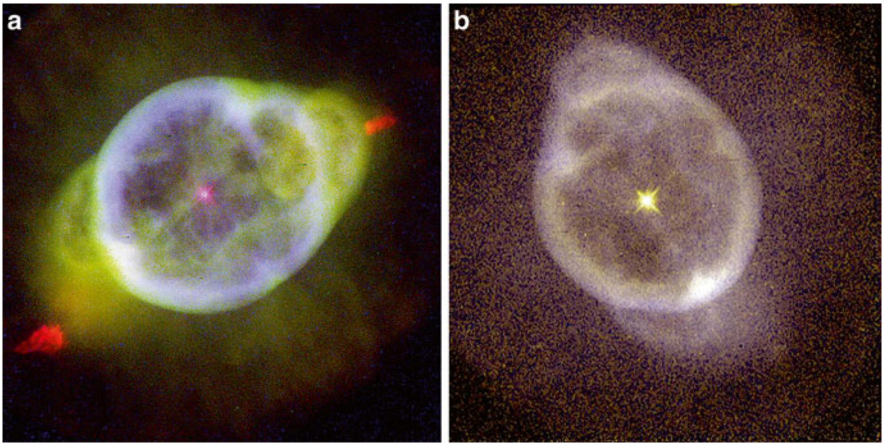

Fig. 4.25 (**a**) Hubble image of NGC 3242 (NASA and ESA), (**b**) another HST image of NGC 3242 (NASA and ESA)

William Herschel discovered this planetary nebula on February 7, 1785:

> "Beautiful, brilliant, planetary disk ill defined, but uniformly bright, the light of the colour of Jupiter."

William Herschel coined the term "planetary nebula", and the description for his catalog H IV.27 object provided the seed that would eventually lead to the moniker "the Ghost of Jupiter". Herschel's son John Herschel would later observe it from the Cape of Good Hope, South Africa.

The name the Ghost of Jupiter did not actually appear in print until Robert Burnham, Jr.'s *Celestial Handbook Vol. 2*, where Burnham wrote:

> "In the small telescope it shows as a pale bluish softly glowing disc measuring about 40″ × 35″, appearing like a "ghost of Jupiter". The total magnitude is about 9; the central star is 11.4 visually.
>
> … The bluish-green tint is due to the strong emission of doubly ionized oxygen (5007 and 4959 angstroms) but color photographs show that other fainter tints are also present."

This planetary nebula became known as NGC 3242 in 1888 when John Louis Emil Dreyer published the *New General Catalogue of Nebula and Clusters of Stars*.

Fig. 4.26 An amateur astrophoto of The Ghost of Jupiter (Jon Talbot)

NGC 3242, commonly known as the Ghost of Jupiter, is planetary nebula located in the constellation Hydra. The nebula measures around 2 light years across, with a central white dwarf with an apparent magnitude of 11. The inner layers of the nebula were formed some 1,500 years ago.

NGC 3242 is a challenging object to locate. Returning to Finder Chart #1, the Ghost of Jupiter inhabits a rather drab, featureless Hydra constellation that lacks outstanding road markers that aid the finding of the planetary nebula. The nebula, once located, is easily observable, but from a suburban location, the constellation Hydra can be difficult to see.

In a suburban setting, the advantages of owning a GOTO telescope in locating NGC 3242 becomes quite clear. Using starhopping skills, it is best to attempt the Ghost of Jupiter on a moonless night in a dark, countryside location. Under those conditions, locate Hydra's brightest star Alphard (Alpha Hydrae). East-southeast of Alphard is an isosceles triangle formed by Lambda, Nu, and Mu Hydrae. NGC 3242 is about 2 degrees south of Mu Hydrae.

In 80–100 mm telescope, NGC 3242 appears as a small blue-green disk that definitely is not a star against a black background. Using a larger 6-inch or greater aperture telescope, the blue-green disk becomes more apparent. With higher magnifications, the observer can see a brighter center in NGC 3242, with a fainter outer shell. It is possible with the larger aperture telescopes to catch a glimpse of the central star, which is buried in the brightness of the nebula itself.

As noted by Burnham, NGC 3242 is characterized by doubly ionized oxygen in its emission spectra. The Ghost of Jupiter is an ideal object to use a O-III nebula filter to enhance the visual image (Fig. 4.26).

The "Ghost of Jupiter" is as noteworthy and eye-catching as the more famous Ring Nebula in the constellation Lyra. Like the Ring Nebula, NGC 3242 is a planetary nebula, the last hurrah of a star that's run out of fuel and approaches the end of its life as a white dwarf star.

The formation of most planetary nebulae begins at the end of the star's life. During a star's red giant phase, the outer layers of the star are expelled by strong stellar winds. Eventually, after most of the red giant's atmosphere is dissipated, the exposed hot, luminous core emits strong ultraviolet radiation that ionizes the ejected outer layers of the star. Absorbed ultraviolet light energizes the shell of nebulous gas around the central star, appearing as a bright colored planetary nebula at several discrete visible wavelengths. Meanwhile, the core collapses to form a white dwarf star.

A curious aspect of Fig. 4.25 Hubble image of the nebula is the presence of the two red flare-like features on both poles of the nebula. The gas comprising these objects is believed to be younger and moving at a much faster rate than that of the nebula.

NGC 6543 The Cat's Eye Nebula

Alternative Nomenclature: NGC 6543, Caldwell 6
Constellation: Draco

Right Ascension: 17h58m33.4s
Declination: +66deg37min59.5s
Magnitude: 8.1 (Fig. 4.27)

Fig. 4.27 Hubble image of the Cat's Eye Nebula, NGC 6543 (NASA, ESA, HEIC, and The Hubble Heritage Team (STScI/AURA))

William Herschel first observed the Cat's Eye Nebula on February 15, 1786. As with Herschel's previous encounters with planetary nebulas, the Cat's Eye was believed to be made up of unresolvable stars. The first evidence that this was not the case came in August 29, 1864, when William Huggins investigated the nature of the object with a spectroscope. The resultant spectrum caused Huggins to recognize that the true nature of planetary nebulae consisted of hot gases rather than a conglomeration of stars.

NGC 6543 is a planetary nebula in Draco that has one of the most complex internal structures for planetary nebulae. In its center, the Cat's Eye Nebula contains a bright and hot star; which around 1,000 years ago lost its outer envelope, thus producing the nebula.

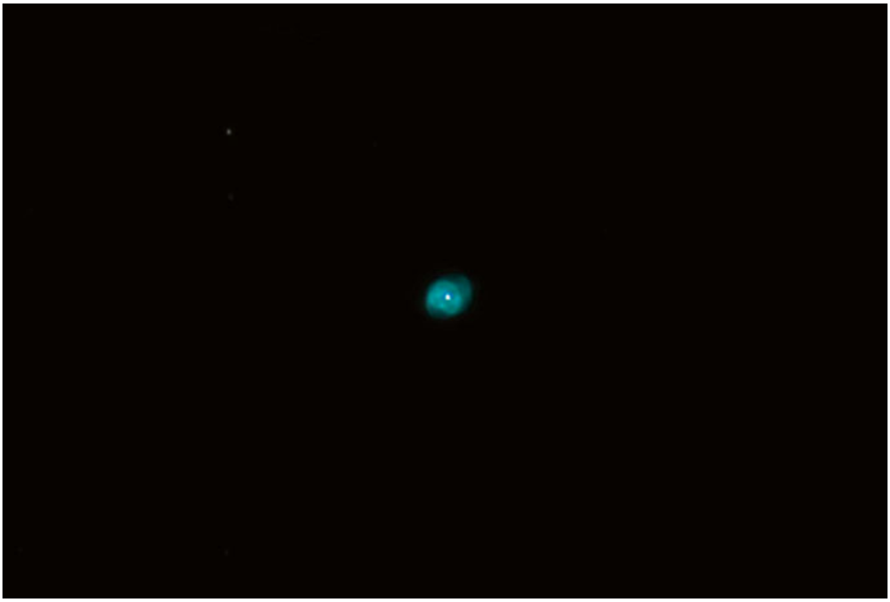

Fig. 4.28 Amateur astrophoto of the Cat's Eye Nebula (James Chen and Adam Chen)

Using Finder Chart #3 as a guide, NGC 6543 is located roughly halfway between the third magnitude stars Delta and Zeta Draconis, about 10′ northwest of the north ecliptic pole. As with NGC 3242, in a suburban setting, the advantages of owning a GOTO telescope in locating NGC 6543 become quite clear.

Through an 80–90 mm telescope, the Cat's Eye Nebula tends to appear as a bloated star, with any nebulosity seemingly imagined. In a 4-inch (102 mm) to 5-inch (127 mm) telescope, with high power and an O-III filter, NGC 6543 begins to reveal its planetary nebula nature. Again, with an 8-inch (208 mm) or greater, the Cat's Eye Nebula shows its real beauty (Fig. 4.28).

In 1994, the Hubble image shown in Fig. 4.27, first revealed NGC 6543's surprisingly intricate structures, including concentric gas shells, jets of high-speed gas, and unusual shock-induced knots of gas. This image was taken with Hubble's Advanced Camera for Surveys (ACS) revealing the full beauty of a bull's eye pattern of 11 or even more concentric rings, or shells, around the Cat's Eye. Each shell is actually the edge of a spherical bubble seen projected onto the sky—that's why it appears bright along its outer edge.

Observations suggest that the central star ejected its mass in a series of pulses at 1,500-year intervals. These mass ejections created dust shells, with each dust shell containing the equivalent of as much mass as all of the planets in our solar system combined. These concentric shells make a layered, onion-skin structure around the dying star. The view from Hubble is like an onion cut in half, where each layer of the onion is discernible.

Until recently, it was thought that such shells around planetary nebulae were a rare phenomenon. However, Romano Corradi of the Isaac Newton Group of Telescopes, Spain and collaborators, in a paper published in the European journal Astronomy and Astrophysics in April 2004, have instead shown that the formation of these rings is likely to be the rule rather than the exception.

The bull's-eye patterns seen around planetary nebulae came as a surprise to astronomers because they had no expectation that episodes of mass loss at the end of stellar lives would repeat every 1,500 years. Several explanations have been proposed, including cycles of magnetic activity somewhat similar to our own Sun's sunspot cycle, the action of companion stars orbiting around the dying star, and stellar pulsations. Another school of thought is that the material is ejected smoothly from the star, and the rings are created later on due to formation of waves in the outflowing material. There is no clear explanation at this time, and continued observations and studies will be required to answer this baffling mystery.

NGC 7814 The Electric Arc

Alternative Nomenclature: NGC 7814, Caldwell 43, H II-240
Constellation: Pegasus

Right Ascension: 00h03m14.9s
Declination: +16deg08min44s
Magnitude: 10.6 (Fig. 4.29)

Fig. 4.29 Hubble image of NGC 7814 (NASA, ESA, and STSci)

Discovered by William Herschel during his observations of October 8, 1784, where he described it as:

"Pretty faint, pretty large, irregularly round, easily resolvable."

Famous astronomer-artist Lucien Rudaux, upon seeing a Lick Observatory photograph of NGC 7814 taken by James Keeler in 1899, is the source for its nickname:

"It bears a curious resemblance to an electric arc between two pointed electrodes."

NGC 7814, also known as Caldwell 43, is a spiral galaxy located approximately 40 million light-years away. Visually located in the constellation Pegasus, NGC 7814 is an edge-on galaxy.

Use Finder Chart #4 as a guide. Locating NGC 7814 requires a dark, country sky and recognition of the Great Square of Pegasus. Identify the Great Square corner star Algenib, Gamma Pegasi. With a wide angle eyepiece giving a 3 degree field of view, place Algenib, imagine a diagonal 45 degree line from Algenib, to the opposing corner star Scheat. Below that line by 15 degrees or so in the field of view is NGC 7814. Visually, NGC 7814 is not impressive (Fig. 4.30).

NGC 7814 lies some 49 million light-years away and is part of the Pegasus Spur of galaxies. It has a recession velocity of 1,047 km/s and an estimated diameter of 79,000 light-years. Astronomers categorize it as either an early-type spiral or a lenticular system, since its orientation and dust lane obscures a more definitive classification.

Fig. 4.30 An Amateur astrophoto of NGC 7814 (John Brooks)

Chapter 5

Autumn Objects

As backyard astronomers, the warm humidity of summer observing gives way to the cooling air of autumn. Slowly, the observing wardrobe of shorts and t-shirts evolves to long pants and long sleeves to light jackets and eventually heavier coats.

The celestial objects of summer also gives way to clusters, nebulae, and galaxies of the fall. The Earth's position in its orbit around the Sun also changes the perspective of the sky. No longer are astronomers gazing into the heart of the Milky Way, but more towards intergalactic treats.

As the backyard astronomer experiences the cooling weather, some lessons of preparedness are required.

- Never underestimate the cooling temperatures. Since observing through a telescope means sitting quietly with eye to eyepiece, the chill of the night can have an effect. Dress in layers and warmer than necessary. Coats, hats, gloves, and blankets are the dress code.
- Let the telescope and eyepiece acclimate to the ambient temperature. Going from a warm home or car to a cool outdoor environment will require at least 30 minutes to adjust to the cooler air.
- Beware of dewing. As the temperature drops, optics can attract a layer of dew. There are two ways of combating dew: dew caps for the front of the telescope, and dew heater devices to gently maintain the temperature of the optics a few degrees above the dew point. Avoid observing objects directly overhead. Once infected with dew, a brief exposure to the warm air of a hairdryer may help, but then the optics will have to acclimate to the ambient temperature all over again.

J.L. Chen, A. Chen, *A Guide to Hubble Space Telescope Objects*,
The Patrick Moore Practical Astronomy Series, DOI 10.1007/978-3-319-18872-0_5

- Beware of fogging, and condensation. It is easy to fog over eyepieces and finderscopes by inadvertently breathing on them. Don't!
- Early autumn, the bugs and insects that bite and sting may still be a problem. As the weather gets colder, some remaining denizens may find a warmer home in eyepiece cases, telescope cases, and telescopes and mounts. Check all equipment before packing it in for a night.

M15

Alternative Nomenclature: NGC 7078
Constellation: Pegasus

Right Ascension: 21h29m58.3s
Declination: +12deg10min01.2s
Magnitude: 6.3 (Fig. 5.1)

Fig. 5.1 Hubble image of M15 (NASA and The Hubble Heritage Team (STScI/AURA))

M15 was discovered by Jean-Dominique Maraldi on September 7, 1746 while he was looking for a comet:

> “On September 7 I noticed between the stars Epsilon Pegasi and Beta Equulei, a fairly bright nebulous star, which is composed of many stars, of which I have determined the right ascension of 319d 27′ 6″, and its northern declination of 11d 2′ 22″.”

Charles Messier rediscovered what because cataloged as Messier 15, or M15, and wrote:

> In the night of June 3 to 4, 1764, I have discovered a nebula between the head of Pegasus & that of Equuleus it is round, its diameter is about 3 minutes of arc, the center is brilliant, I have not distinguished any star; having examined it with a Gregorian telescope which magnifies 104 times, it had little elevated over the horizon, & maybe that observed at a greater elevation one can perceive stars: I have compared it with the star Delta Equulei; its right ascension has been concluded at 319d 40′ 19″, & its declination at 10d 40′ 3″ north. I have also marked that nebula in the chart of the apparent path of the Comet of 1764. In the Memoirs of the Academy for 1746, M. Maraldi speaks of that nebula. “I have perceived, he says, between the stars Epsilon Pegasi & Beta Equulei, a rather bright nebulous star which is composed of many stars, of which I have determined the right ascension of 319d 27′ 6″, & its northern declination of 11d 2′ 22″.”

John Herschel observed M15 in 1825, some 20 years after his father William Herschel viewed it. William Herschel’s described M15 as “perfectly round and insulated.”

John Herschel’s description provided a through description of M15:

> A magnificent globular cluster; comes up to a perfect blaze in the centre, like a protuberance or nipple; not the condensation of a homogeneous globe; it has straggling streams of stars, as it were, drawing to a centre. It is not *round*. Has a * 8 m, 30s following in parallel.
>
> very bright; very large; irregularly round; gradually brightening and very suddenly much brighter toward the middle.

Admiral William Henry Smyth wrote about the details of M15:

> “A globular cluster between the mouths of Pegasus and Equuleus, forming the northern vertex of a triangle, obtuse and nearly isosceles, of which the base is Beta Pegasi and Delta Equulei. This fine object was discovered by Maraldi in 1745, and registered as “une étoile nébuleuse, assez claire, qui est composée de plusieurs étoiles.” Messier could not quite make this out, but in 1764 described it as a nebula with [actually without] a star, its form circular and centre brilliant; and the place he assigned to it is very considerably in error. Thus it remained till 1783, when Sir William Herschel resolved it into stars, and found it a good object for proving the telescope’s space-penetrating power; he estimated its profundity to be of the 243rd order.
>
> Although this noble cluster is rated as globular, it is not exactly round, and under the best circumstances is seen as in the diagram, with stragglers branching from a central blaze. Under a moderate magnifying power, there are many telescopic and several brightish stars in the field; but the accumulated mass is completely insulated, and forcibly strikes the *senses* as being almost infinitely beyond those apparent *comites*. Indeed, it may be said to appear evidently aggregated by mutual laws, and part of some stupendous and inscrutable scheme of involution; for there is nothing quiescent throughout the immensity of the vast creation.”

Fig. 5.2 An amateur astrophoto of M15 (Jon Talbot)

M15 is one of the oldest known globular clusters, with an age estimated at 12.0 billion years old. M15 is about 176 light years in diameter and 33,600 light years away. Astronomers estimate that M15 is home to over 100,000 stars, with 112 variable stars, six pulsars, and one double neutron star system.

Reference Finder Chart #4. Locating M15 is easy. Find the extended front leg of Pegasus, whose elbow (knee?) star is Theta Pegasi and end star is Enif, or Epsilon Pegasi. Look beyond along the extended leg from Theta Pegasi through Enif, and a fuzzy ball of stars that is M15 will be sighted. Telescopes of 80–130 mm will not resolve any individual stars within this globular, with slightly larger apertures in the 150–200 mm resolving the outer stars. The "Oh Wow" factor kicks in with 10-inch or greater apertures, as stars within the core become resolved.

Photographically, a small planetary nebula called Pease 1, has been identified within M15. With most backyard telescopes, even with the aid of nebula filters the planetary nebula cannot be seen visually (Fig. 5.2).

M15 is perhaps the densest of all (globular) star clusters in our Milky Way galaxy. The Hubble Space Telescope has photographically resolved its superdense core, as seen in Fig. 5.1. M15's core has undergone a process of contraction called "core collapse", which is common in the dynamic evolution of Milky Way globular clusters. This central core is extremely small compared to the cluster, only about

0.14 arc minutes (8.4 arc seconds) in angular diameter, corresponding to a linear extent of roughly 1.4 light years. The half-mass radius is 1.06 arc minutes, or linearly about 10 light years—half the mass of this cluster is concentrated in the innermost sphere of that radius. It is still unclear if the central core of M15 is packed so dense simply because of the mutual gravitational interaction of the stars, or if the core is home to a black hole. M15 is among the nearest and better observable globulars to possess a collapsed core, since it is only little more remote than the Galactic Center and is not obscured by dense interstellar matter. Similar Messier globulars M30 and M70 also contain collapsed cores and are also being investigated in greater detail.

A total of 112 variables have been identified within M15, with one identified as a Cepheid Type II. Eight pulsars have been also identified within M15.

M27 The Dumbbell Nebula

Alternative Nomenclature: NGC 6853, Apple Core Nebula
Constellation: Vulpecula

Right Ascension: 19h59m36.3s
Declination: +22deg43min016s
Magnitude: 7.3 (Fig. 5.3)

Fig. 5.3 Hubble image of M27 (NASA and The Hubble Heritage Team (STScI/AURA))

Another discovery by Charles Messier in July 12, 1764. From his notes:

"Nebula without star, discovered in Vulpecula, between the two forepaws, & very near the star 14 of that constellation, of 5th magnitude according to Flamsteed; one can see it well with an ordinary telescope of 3.5-foot; it appears of oval shape, & it contains no star."

It was John Herschel who gave M27 its famous name in his notes of August 17, 1828:

"A nebula shaped like a dumb-bell, with the elliptic outline completed by a feeble nebulous light. Position of the axis of symmetry through the centres of the two chief masses = (by micron.) 30.0deg .. 60.0 deg nf..sp. The diam of the elliptic light fills a space nearly equal to that between the wires (7′ or 8′). Not resolvable, but I see on it 4 distinct stars 1 = 12 m at the sf edge; 2 = 12.13 m, almost diametrically opposite; 3 = 13 m in the n p quarter, and 1 = 14.15 m near the centre. Place that of the centre."

And again from John Herschel's notes of July 12, 1830:

"Like a double-headed shot or a dumb-bell. The light perfectly milky; the s p head is a v l brighter. The outline is filled up elliptically with a F nebulosity as in figure, which, I think leaves ansae as if inclined to form a ring. Two S st in it and many more near, one close to edge (No. 1 of Sw 166). A most amazing object. Position of greater axis of the elliptic outline = 117.1deg; of axis of symmetry 31.4deg (microm)."

Fig. 5.4 An amateur astrophoto of M27 (John Brooks)

Fig. 5.5 Another amateur astrophoto of M27 (Jon Talbot)

M27 approximate dimensions are 1.44 light years by 1.01 light years, and is about 1,360 light year from Earth.

Since it is in the very inconspicuous constellation Vulpecula that is virtually invisible in a suburban setting, a GOTO mount for a telescope is a very valuable tool in locating the Dumbbell Nebula.

Reference Finder Chart #4. In the absence of a GOTO mount, first locate the star Albireo, or Beta Cygni. Vulpecula lies in-between Albireo and the constellation Sagitta. Sagitta is brighter than Vulpecula, and has an arrow pattern that is easily identifiable through binoculars or a 50 mm finderscope. This arrow pattern points to Gamma Sagittae. Take note of the distance between Delta and Gamma Sagittae and then just aim your binoculars or finderscope exactly that same distance due north of Gamma. The sixth magnitude 14 Vulpeculae is within 0.5 degree from M27.

It is a challenge to find M27, but well worth the effort. With or without an OIII or UHC nebula filter, M27 is a large and impressive sight. The Dumbbell is certainly an impressive planetary nebula, as the angular diameter of the luminous body is nearly 6 arc minutes, with a faint halo extending out to over 15′, half the apparent diameter of the Moon (Figs. 5.4 and 5.5).

The Hubble Space Telescope close-up of M27 shows many knots of gas streaking through space, with varying shapes. Some look like fingers pointing at the central star, located just off the upper left of the image; others are isolated clouds, with or without tails. Their sizes typically range from 11 to 35 billion miles (17 to 56 billion kilometers), which is several times larger than the distance from the Sun to Pluto. Each contains as much mass as three Earths.

The knots are forming at the interface between the hot (ionized) and cool (neutral) portion of the nebula. This area of temperature differentiation moves outward from the central star as the nebula evolves. In the Dumbbell astronomers are seeing the knots soon after this hot gas passed by. Dense knots of gas and dust seem to be a natural part of the evolution of planetary nebulae. They form in the early stages, and their shape changes as the nebula expands. Similar knots have been discovered in other nearby planetary nebulae that are all part of the same evolutionary scheme. They can be seen in Hubble telescope photos of the M57, the Ring Nebula, among several other planetary nebulae that the HST has imaged. The detection of these knots in all the nearby planetary nebulae, such as the Eskimo Nebula (NGC 2392) and the Helix Nebula (NGC 7293), imaged by the Hubble telescope allows astronomers to hypothesize that knots may be a feature common in all planetary nebulae.

M31 The Andromeda Galaxy

Alternative Nomenclature: NGC 224, the Great Andromeda Nebula
Constellation: Andromeda

Right Ascension: 00h42m44.3s
Declination: +41deg16min09s
Magnitude: 3.44 (Figs. 5.6 and 5.7)

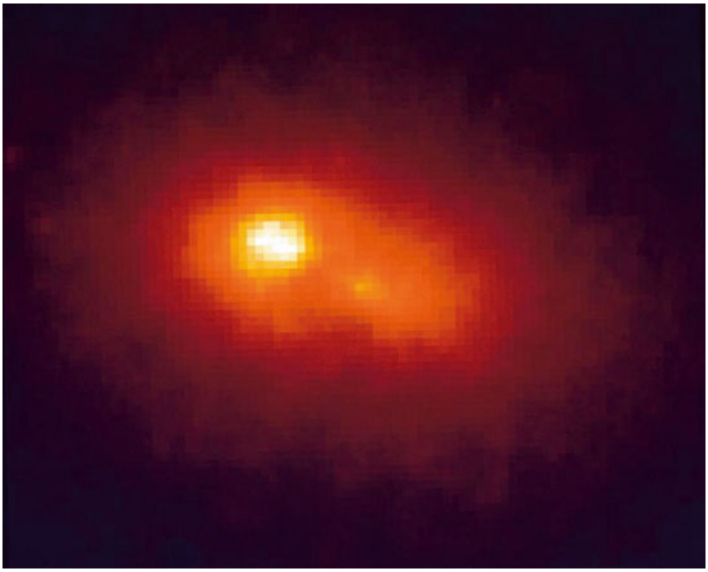

Fig. 5.6 NASA/STScI image of M31 with Hubble image of Andromeda Double Nucleus (WIYN/KPNO Image Credit: T. Rector and B. Wolpa (NOAO/AURA/NSF). Hubble Image Credit: NASA, ESA, and T. Lauer (NOAO))

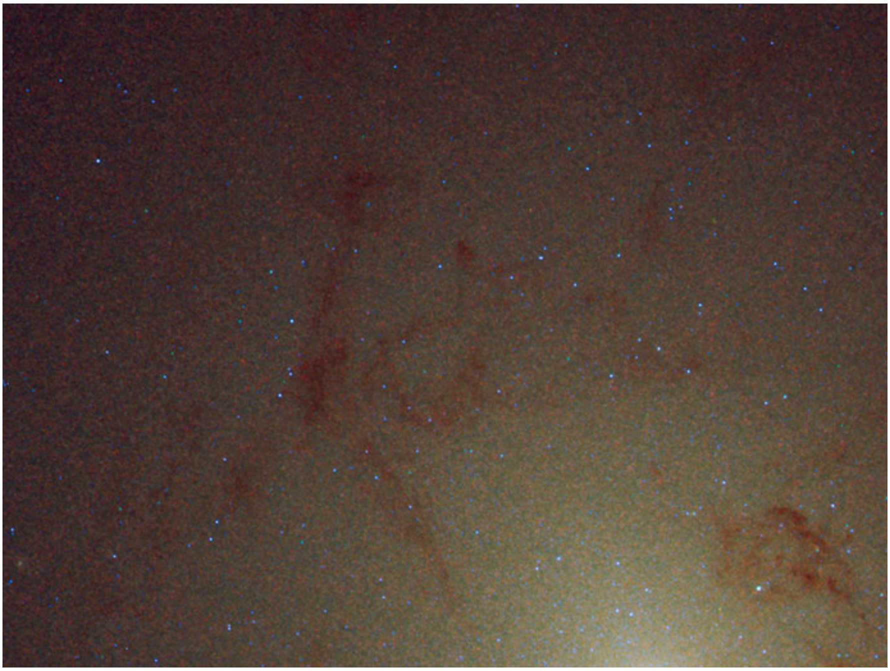

Fig. 5.7 Hubble image close-up WF/PC3 and Panchromatic Hubble Andromeda Treasury (PHAT) detail of M31 showing rare Ultra-Blue Stars (NASA, ESA, and B. Williams and J. Dalcanton (University of Washington, Seattle))

The Andromeda Galaxy is one of two objects in this chapter that were known by astronomers prior to the invention of the telescope. Persian astronomer Abd-al-Rahman Al-Sufi knew about this "little cloud" around 905 AD and depicted it in 964 AD in his *Book of Fixed Stars*. A Dutch star map of 1500 also shows the presence of the galaxy.

Charles Messier catalogued the M31 as a nebula, and from his personal notes:

> "I have employed different instruments, especially an excellent Gregorian telescope of 30 feet FL, the large mirror 6 inches in diameter, magnification 104×. The center of this nebula appears fairly clear in this instrument without any stars appearing. The light gradually diminishes until it becomes extinguished. The former measurements were made with a Newtonian telescope of 4.5 feet FL, provided with a silk thread micrometer. Diameter 40′. August 3, 1764."

All the historical astronomers, from Hodierna, Halley, William Herschel, John Herschel, Admiral Smyth, Bode, Dreyer, Huggins, etc. observed and wrote of M31 as a nebula that was within the confines of the Milky Way.

It was not until 1917 that the idea that M31 was an independent universe began, with observations of a nova within M31 by Heber Curtis. The nova initiated a search of the photographic record by Curtis, and discovered 11 more novae. All the novae uncovered by Curtis were curiously 10 magnitudes fainter than those novae observed elsewhere. As a result he was able to come up with a distance estimate of 500,000 light-years (3.2×10^{10} AU). He became a proponent of the so-called "island universes" hypothesis.

Edwin Hubble in 1925, using the 100-inch Hooker telescope at Mount Wilson, identified extragalactic Cepheid variable stars for the first time on astronomical photos of M31. By using the Cepheid variables, Hubble was able to determine the distance of M31. His measurement demonstrated conclusively that M31 was not a nebula within our Galaxy, but an entirely separate galaxy located a significant distance from our own.

Fig. 5.8 Amateur astrophoto of M31 (John Livermore)

The Andromeda Galaxy is located about 2.5 million light years from Earth, and is the Milky Way's nearest neighbor. The Andromeda Galaxy is the largest member of what astronomers refer to as the Local Group. The Local Group is the collection of galaxies gravitationally bound, including the Milky Way, M31, and M33 among the total of 54 major and dwarf galaxies. The Andromeda Galaxy and the Milky Way represent the gravitational center of the Local Group, with M31 containing approximately 1 trillion stars and the Milky Way containing up to 400 billion stars.

Finding the Andromeda Galaxy is simple. Using Finder Chart #4, first identify the Great Square of Pegasus. The northernmost star is Alpha. Stay with the northern chain of stars and scan from Alpha for another easily seen star. Follow along the chain of stars. Look north for a dimmer star that looks like it has a fuzzy football nearby. The fuzzy football is the Andromeda Galaxy (Fig. 5.8).

The apparent magnitude of the Andromeda Galaxy is 3.44, making it one of the brightest deep sky objects for the backyard astronomer. On dark, moonless nights, it is possible to see M31 with the naked eye, thus proving why the galaxy was

Fig. 5.9 Hubble image of the double nucleus within M31 (NASA, ESA, and T. Lauer (NOAO/AURA/NSF))

known by the Persians of the 900 AD era. In actuality, M31 stretches six Moon diameters across the naked-eye sky, only the brighter central region is visible to the naked eye or when viewed using binoculars or backyard telescopes (Fig. 5.9).

As seen in Fig. 5.6 and magnified in Fig. 5.9, the HST has revealed that the Andromeda galaxy M31 has a double nucleus. The probable cause for this second nucleus may be a result of a collision with another galaxy, leaving the remnant core. Another explanation for the duplicity of Andromeda's nucleus could be an illusion caused by a dark dust cloud obstructing parts of a single nucleus in the center of M31.

The Hubble detailed image deep inside the hub of M31 in Fig. 5.7 reveals a large, rare population of hot, bright stars. Blue is typically an indicator of hot, young stars. In this case, however, the stellar oddities are aging, Sun-like stars that have prematurely cast off their outer layers of material, exposing their extremely blue-hot cores. The Wide Field Camera 3 was used to find roughly 8,000 of these ultra-blue stars in a stellar census made in ultraviolet light, which traces the glow of the hottest stars. Figure 5.7 image is part of a multi-year Panchromatic Hubble Andromeda Treasury Study, also known as PHATS. PHATS is an effort to map the stellar populations of the Andromeda Galaxy. These blue stars are dimmer and have a range of surface temperatures different from the extremely bright stars observed in the star-forming regions of Andromeda.

Astronomers have offered two possible explanations for these ultra-blue stars.

1. The stars are rich in chemical elements other than hydrogen and helium. Radiation from the star is more efficient at pushing on gas laced with heavy elements, which drives away the material, like wind moving a thick sail. Although all the stars in the core are enriched in heavy elements, the bright blue stars may contain especially high amounts, which help trigger the mass loss.
2. The blue stars are in close binary systems and have lost mass to their partners. This mass loss would expose the stars' hot cores. The astronomers were surprised to find that the ultra-blue stars are distributed in the galaxy in the same way as a population of binary stars with similar masses that were found in X-ray observations by NASA's Chandra X-ray Observatory.

Astronomers are still studying the M31 ultra-blue stars, and are in the process of developing simulations to account for their existence.

M33 The Triangulum Galaxy

Alternative Nomenclature: NGC 598, NGC 604, informally Pinwheel Galaxy
Constellation: Triangulum

Right Ascension: 01h33m50s
Declination: +30deg39min37s
Magnitude: 5.7 (Fig. 5.10)

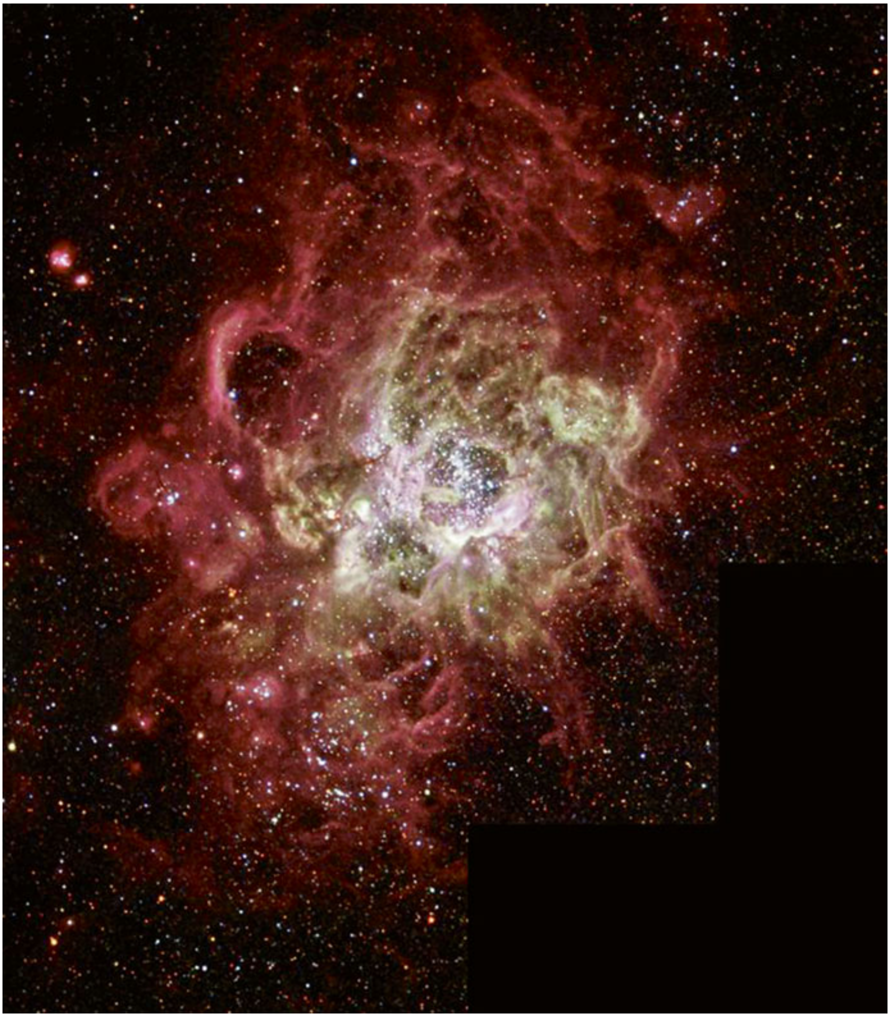

Fig. 5.10 Hubble image of NGC 604 within a spiral arm of M33 (NASA and The Hubble Heritage Team (STSci/AURA))

The Triangulum Galaxy was probably discovered by the Italian astronomer Giovanni Battista Hodierna prior to 1654, where in his work *De systemate orbis cometici; deque admirandis coeli caracteribus* he listed it as a cloud-like nebulosity or obscuration and gave the cryptic description, “near the Triangle hinc inde”. This is in reference to the constellation of Triangulum as a pair of triangles. The magnitude of the object matches M33, so it is most likely a reference to the Triangulum galaxy.

Independently discovered by Charles Messier on August 25, 1764, where he described it as:

> “Nebula discovered between the head of the Northern Fish & the great Triangle, a bit distant from a star of 6th magnitude: The nebula is of a whitish light of almost even density, however a little brighter along two-third of its diameter, & contains no star.”

Although observed by William Herschel, John Herschel, and Admiral William Henry Smyth, it was not recognized as a spiral until William Parsons, the third Earl of Rosse observed it over a period of nights in September of 1849, using the light gathering and resolving power of the 72″ Leviathan of Parsonstown:

> “September 6, 1849. - A spiral.”
>
> “September 16, 1849. - New spiral: Alpha the brighter branch; Gamma faint; Delta short but pretty bright; Beta pretty distinct; Epsilon but suspected; the whole involved in a faint nebula, which probably extends past several knots which lie about it in different directions. Faint nebula seems to extend very far following: drawing taken.”

Fig. 5.11 An amateur astrophoto of M33 (Jon Talbot)

Fig. 5.12 Another astrophoto by the same amateur of M33 (Jon Talbot)

Messier 33 is the third largest member of the Local Group, and is located approximately 3 million light years away. Reference Finder Chart #5 to locate M33.

Located in another very inconspicuous constellation Triangulum that is virtually invisible in a suburban setting, a GOTO mount for a telescope is a very valuable tool in locating the Triangulum Galaxy. Suburban observers are handicapped by the presence of streetlight, parking lot lights, and houselights in observing M33. A car ride to the dark skies of the country is highly recommended. On a Moonless night, of course.

In a dark sky site on a night with no Moon, it is possible to spot the Triangulum Galaxy with the naked eye. M33 is an outstanding sight in good binoculars, but as its total brightness is distributed quite evenly over an area of nearly four times that covered by the full Moon, its surface brightness is extremely low. When using a telescope, use the lowest magnification possible.

In the absence of a GOTO mount, first locate the Great Square of Pegasus. The northeast corner of the Great Square is Alpha Pegasi, and scanning through the finderscope directly east is Alpha Trianguli. M33 lies roughly 2 degrees short of Alpha Trianguli during the east scan towards Alpha Trianguli.

By the integrated magnitude of 5.7, Triangulum would seeming be an easy target. But its surface brightness is spread thinly over a wide area, making it a challenge to view using telescopes of 6-inches or smaller. Apertures of 8-inches or greater have the advantage in observing this large galaxy (Figs. 5.11 and 5.12).

Messier 33 is officially named the Triangulum Galaxy, although many amateurs have mistakenly referred to it as the Pinwheel Galaxy. Messier 101 is officially recognized as the Pinwheel Galaxy.

M33 is classified as an unbarred galaxy. The nucleus of the Triangulum Galaxy contains an ultra-luminous X-ray source. However, the nucleus seems to contain a large, but not supermassive black hole, as the core has a mass equivalent to approximately 3,000 suns. To qualify as a supermassive black hole, the object would need to possess a mass in the order of hundreds of thousands to billions of solar masses.

The size and scale of M33 is too large for the Hubble cameras to capture in its entirety. Of great interest to astronomers is a region of star birth within one of M33's spiral arms. Figure 5.8 is actually a Hubble image of a nebula that is cataloged as NGC 604. NGC 604 lies in a spiral arm of the Triangulum Galaxy. NGC 604 contains more than 200 hot, bright stars within a cloud that is nearly 1,300 light-years across. In comparison, another new star nursery, the famous M42 Orion Nebula, contains just four bright central stars and is 100 times smaller than NGC 604. Most of the brightest and hottest stars form a loose cluster located within a cavity near the center of the nebula. Stellar winds from these hot blue stars, along with supernova explosions, are responsible for carving out the hole at the center. The bright stars in NGC 604 are extremely young by astronomical standards, having formed a mere 3 million years ago. The most massive stars in NGC 604 exceed 120 times the mass of our Sun, and their surface temperatures are as hot as 72,000 degrees Fahrenheit (40,000 Kelvin). Ultraviolet radiation floods out from these hot stars, making the surrounding nebular gas fluoresce.

As a member of the Local Group of galaxies, M33 is linked to the Andromeda Galaxy (M31) by several streams of stars and hydrogen, giving evidence of an encounter between the two galaxies in the past. Astronomers predict another encounter between M33 and M31 in some 2.5 billion years in the future, and a possible encounter with the Milky Way. The next encounter could result in M33 being torn apart and absorbed by M31, fueling the Andromeda Galaxy with hydrogen to form new stars. A merger of M33 with either the Milky Way or Andromeda could occur, or M33 could be ejected from the Local Group.

About 54 globular clusters have been identified in the Triangulum Galaxy. The globular clusters appear to be several billion years younger than the globular clusters of the Milky Way, and cluster formation appears to have increased during the past 100 million years. This increase is correlated with an inflow of gas into the center of the galaxy.

M74

Alternative Nomenclature: NGC 628
Constellation: Pisces

Right Ascension: 01h36m41.8s
Declination: +15deg47min01s
Magnitude: 9.4 (Fig. 5.13)

Fig. 5.13 Hubble image of M74 (NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration)

Discovered by Pierre Méchain at the end of September 1780, and reported to his friend Charles Messier, who documented it in his catalog on October 18, 1780:

> "Nebula without stars, near the star Eta Piscium, seen by M. Méchain at the end of September 1780, & he reports: "This nebula doesn't contain any stars; it is fairly large, very obscure, and extremely difficult to observe; one can recognize it with more certainty in fine, frosty conditions". M. Messier looked for it & found it, as M. Méchain describes it: it has been compared directly with the star Eta Piscium."

Father and son William and John Herschel, had difficulty in identifying M74.

A series of notes by William Herschel shows that M74 seemingly was at the limit of his instruments:

> "1783, 1784, 7 feet telescope. With 100 and 120 it its a collection of very small stars; I see many of them."
>
> "1799, 1801, 10 feet telescope. Several of the stars are visible; it is a very faint objects."
>
> "1784, 20 feet telescope. Some stars are visible in it; the edges are not resolvable."
>
> "1799, December 28, 40 feet telescope. Very bright in the middle, but the brightness confined to a very small part, and is not round; about the bright middle is a very faint nebulosity to a considerable extent. The bright part seems to be of resolvable kind, but my mirror has been injured by condensed vapours." By the observations of the 7 feet telescope, the profundity of the nearest part of this cluster must be of the 243d order, but most probably a succession of more distant stars was seen in the larger telescopes."
>
> "1805, 1810, large 10 feet telescope. With 108 it consists of extremely small stars, of an irregular figure; a very faint object of nearly 12 minutes diameter."

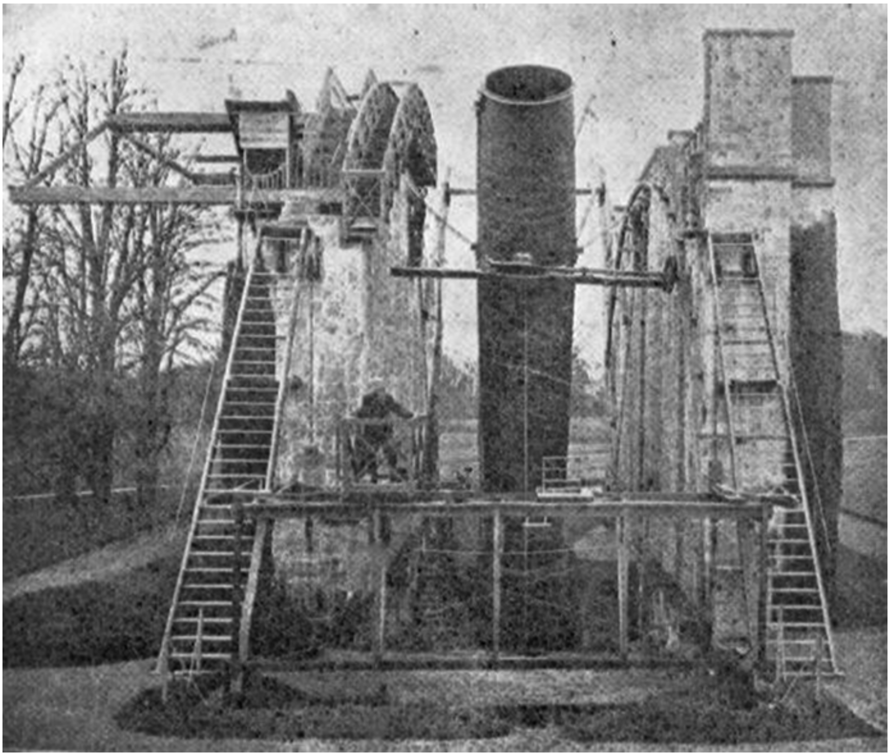

Fig. 5.14 The Leviathan of Parsonstown (William Parsons)

John Herschel went so far as to misidentify M74 as a globular cluster in 1860:

> "Globular cluster; faint; very large; round; very gradually, then pretty suddenly much brighter to the middle; partially resolved"

Again, William Parsons, the third Earl of Rosse's Leviathan telescope, Fig. 5.14, came through again, as the true nature of M74 began to be revealed by Lord Rosse as a spiral nebula. It can be said that the remarkable 72″ Leviathan of Parsonstown was the Hubble Space Telescope of the eighteenth century.

The "grand Design" spiral galaxy M74 is located some 32 million light years away, and is home to about 100 billion stars.

Fig. 5.15 Amateur astrophoto of M74 (Jon Talbot)

M74 is a challenging object to find. Reference Finder Chart #5 as a guide. As previously stated with galaxies and suburban locations, spotting M74 requires a drive to dark country skies. Locate Hamal, aka Alpha Arietis, and Beta Arietis. Draw a line between Hamal and Beta, and extend it through to Eta Piscium. Center your finderscope at Eta and shift the view about 1.5 degrees northeast. There it is!

M74 has the second lowest surface brightness of all the Messier objects. With M101 having the lowest. It may be very difficult to see unless the sky is dark, clear, and moonless. Any high humidity may obscure this galaxy. Try to use low magnification and averted vision, especially if a telescope of less than 5-inches in aperture is used (Fig. 5.15).

M74 is the brightest member of the M74 Group. This group has 5–7 member galaxies, and includes as one of its group members NGC 660. The exact number and membership of the M74 Group is still uncertain.

Messier 74 is one of the nicest examples of so-called "grand-design" spiral galaxies seen face-on, so that its spiral structure stands out conspicuously in astrophotographs. With its comparatively low surface brightness, it is one of the more difficult objects in Messier's catalog for an amateur to observe in detail from their backyard. Located some 32 million light years away, it is receding at a rate of 793 km/s. It is roughly 95,000 light years across, about the same size as our Milky Way and its spiral arms are over 1,000 light years across. Inside those arms are clusters of blue young stars and pinkish colored diffuse gaseous nebulae called H II regions where star formation is happening. The remarkably symmetric appearance over the whole galaxy is probably caused by the global phenomenon of density waves sweeping around M74's gaseous disk, probably induced by gravitational interaction with neighboring galaxies. When gas clouds orbiting within the disk encounter such density waves, they are accelerated into the spiral shaped wave crest, and then slowed down, so that they converge toward the spiral arm, enhancing the density wave. Moreover, collisions and mergers of neighboring clouds occur, which are thought to induce the observed star birth activity along the spiral arms.

M77 Seyfert Galaxy

Alternative Nomenclature: NGC 1068
Constellation: Cetus

Right Ascension: 02h42m40.7s
Declination: −00deg00min48s
Magnitude: 8.9 (Fig. 5.16)

Fig. 5.16 Hubble image of M77 (NASA, ESA, and STSci)

Discovered by Pierre Méchain on October 29, 1780. Charles Messier made note in his catalog:

> "Cluster of small stars, which contains some nebulosity, in Cetus & on the parallel of the star Delta, reported of the third magnitude, & which M. Messier estimated to be hardly of the fifth. M. Méchain saw this cluster on October 29, 1780 in the form of a nebula."

Admiral William Henry Smyth wrote and an extensive description of M77:

> "A round stellar nebula, near Delta in the Whale's lower jaw, and about 2 1/2 deg from Gamma on the line towards Epsilon, or s. by w. This was first classed by M. in 1780 as a mass of stars containing nebulosity. It is small, bright, and exactly in a line with three small stars, one preceding and two following, of which the nearest and largest is a 9th-magnitude to the *sf* [south following, SE]. There are other minute companions in the field; and the place is differentiated from Gamma Ceti.
>
> 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 centre of gravity of the whole system. Sir William Herschel, after repeatedly examining it, says, - "From the observations of the large ten-feet telescope, which has a gauging power of 75.82, we may conclude that the profundity of the nearest part is at least of the 910th order." That is, the 910 times as far off as the stars of the first magnitude!"

Fig. 5.17 Amateur astrophoto of M77 (Jon Talbot)

The barred spiral galaxy M77 is located about 47 million light years away from Earth.

M77 can be easily found less than a degree east/southeast from the fourth magnitude Delta Ceti, as can be seen in Finder Chart #5. This face-on spiral galaxy can be spotted with smaller binoculars from a dark sky location as a round contrast change and can be seen in 80–102 mm telescopes. As aperture increases, so does detail and high magnification works well with this galaxy. M77 is bright enough to be seen in some suburban skies and the first 5 days of the waning Moon. The test is being able to spot Delta Ceti. If you cannot see Delta Ceti, pack up the telescope and grab the car keys! (Fig. 5.17).

The M77 galaxy is one of the largest galaxies in the Messier catalog, its bright part measuring about 120,000 light years, but its faint extensions going perhaps out to nearly 170,000 light years. Its appearance is that of a classic spiral with broad structured arms, which in the inner region show a quite young stellar population, but more away from the center, and is dominated by a smooth yellowish older stellar population. M77 is an active galaxy with an Active Galactic Nucleus, or AGN, with an expanding core of star birth.

M77 is classified as a Seyfert galaxy.

Seyfert galaxies, when seen with visible light, appear to be typical spiral galaxies. They are named for the astronomer Carl Seyfert, who studied them extensively in the 1940s.

But Seyfert galaxies have unusual properties in their cores.

- A large amount of energy is coming from the core of the galaxy.
  - Luminosity of the core is comparable to the luminosity of a whole galaxy like the Milky Way.
- The energy emission is non-stellar.
  - In the form of infrared and radio radiation.
  - The presence of emission lines from highly ionized iron, for example.
- The core luminosity can vary on time scales of less than 1 year, indicating the energy source is less than 1 light year in size.
- The emission lines are very broad.
  - This suggests that the emission is coming from gas that is moving very fast.
  - Some is moving away from us, some toward us.
- The Doppler shift spreads out the spectral line.

There are two distinct subclasses of Seyfert galaxies, depending on the presence or absence of broad bases on the permitted emission lines in their spectra. Seyfert 2 galaxies show only one set of emission lines which are comparatively narrow and originate from low-density ionized gas (electron density 10^3–10^6 electrons per cm^3) with widths corresponding to several 100 km/s as indicated from the line width, which is somewhat broader than the emission lines from non-active galactic nuclei. These lines are frequently referred to as “narrow lines” and occur for both permitted and forbidden spectral lines. Seyfert 1 galaxies, in addition, show a set of "broad lines" corresponding to velocities up to 1,000 km/s, occurring only for the permitted lines, which indicates higher densities (10^9 electrons per cm^3).

The terms permitted and forbidden spectral lines refer to quantum mechanics. Forbidden lines refer to spectra that occur due to electron transitions not normally allowed by the selection rules of quantum mechanics, but that still have a small probability of spontaneously occurring. The term "forbidden" refers to electron transitions that are highly improbable, not necessarily forbidden. M77 is classified as a Type II Seyfert galaxy because of the existence in its spectral of both permitted and forbidden spectral lines.

NGC 253 The Sculper Galaxy

Alternative Nomenclature: Silver Coin Galaxy, Silver Dollar Galaxy, Caldwell 65
Constellation: Sculper

Right Ascension: 00h47m33s
Declination: −25deg17min18s
Magnitude: 7.6 (Figs. 5.18 and 5.19)

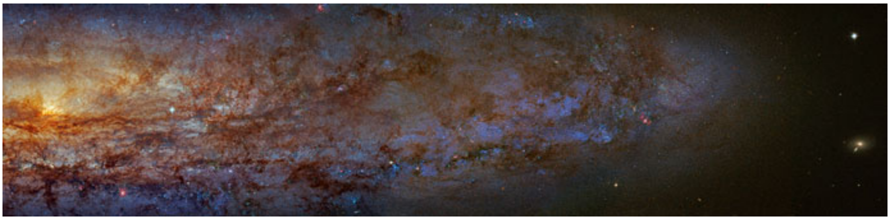

Fig. 5.18 Hubble image of a portion of NGC 253 (NASA, ESA, Hubble Legacy, Robert Gendler)

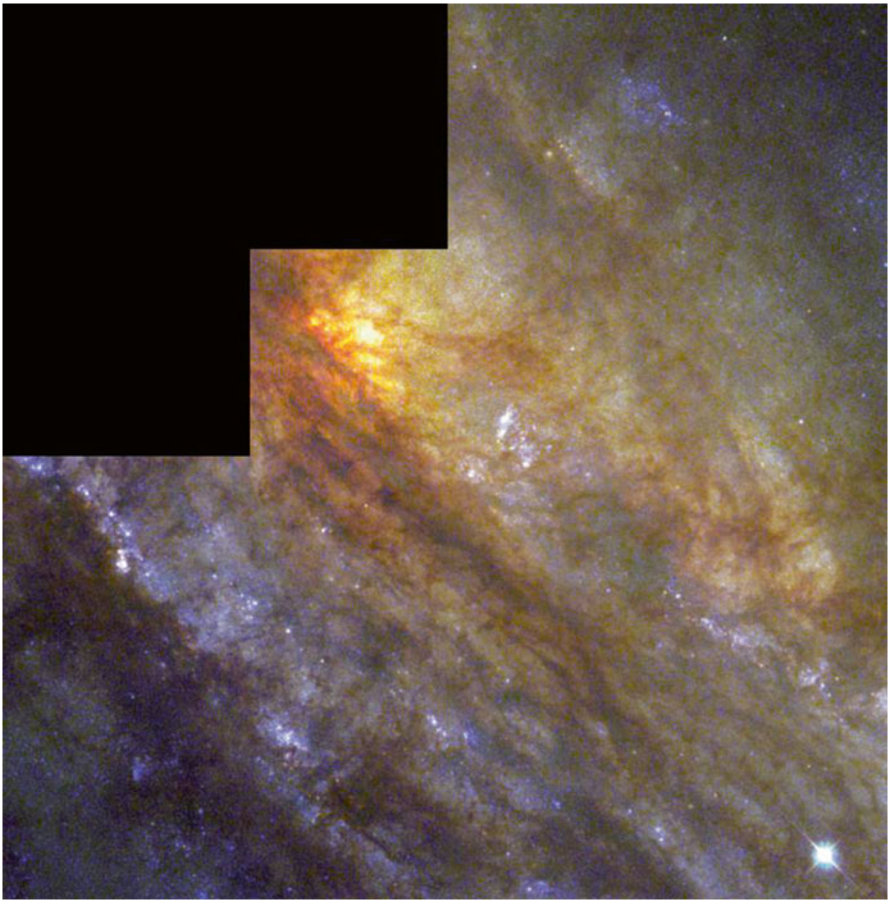

Fig. 5.19 Close-up Hubble image of the nucleus core of NGC 253 (NASA, ESA, and The Hubble Heritage Team (AURA/STScI/NASA))

While searching for comets, Caroline Herschel discovered the Sculper Galaxy in 1783.

In William Herschel's notes, he wrote:

> "This nebula was discovered by my sister Caroline Herschel with an excellent small Newtonian sweeper of 27 inches focal length, and a power of 30. I have therefore marked it with the initial letters C.H. Of her name."

On November 30, 1835, her nephew John Herschel observed the Sculper Galaxy using an 18.75 inch aperture speculum reflector, during his time at the Cape of Good Hope. From his notes, he described it as:

> "very bright and large (24′ in length); a superb object…. Its light is somewhat streaky, but I see no stars in it except 4 large and one very small one, and these seem not to belong to it, there being many near…"

Fig. 5.20 Amateur astrophoto of NGC 253 (Jon Talbot)

NGC 253 is known as a starburst galaxy, undergoing a period of intense star formation within it. The Sculptor Galaxy is located about 11.4 million light years away.

The easiest way to find NGC 253 is with a dark moonless night free of light-pollution (dark, country skies again! Grab the car keys!). This is an object best observed in southern locations. Use Finder Chart #5 as a guide.

Look 7.5 degrees south-southwest of Deneb Kaitos, the second magnitude Beta Ceti star. If the fourth magnitude Alpha Sculptoris is visible, NGC 253 lies between Deneb Kaitos and Alpha Sculptoris.

The Sculptor Galaxy can be seen through binoculars, and is considered one of the most easily viewed galaxies in the sky after the great Andromeda Galaxy, M31. Small telescopes will view it as an elongated flattened fuzzy football with little detail. Large amateur telescopes of 12-inches or greater apertures will begin to detect a dark dust lane and a slight bulge at its nucleus (Fig. 5.20).

The NASA Hubble Space Telescope images shown in Figs. 5.18 and 5.19 are of the core of the nearest starburst spiral galaxy, NGC 253, revealing violent star formation within a region 1,000 light-years across. A starburst galaxy has an exceptionally high rate of star birth, first identified by its excess of infrared radiation from warm dust. The HST Wide Field Planetary Camera 2 high resolution allowed astronomers to quantify complex structures in the starburst core of the galaxy for the first time, including luminous star clusters, dust lanes which trace regions of dense gas, and filaments of glowing gas. Hubble identified several regions of intense star formation, which include a bright, super-compact star cluster. These observations confirm that stars are often born in dense clusters within starbursts, and that dense gas coexists with and obscures the starburst core.

Evidence suggested the presence of a supermassive black hole at the core of NGC 253, with a mass exceeding 5 million solar masses.

NGC 6960, NGC 6992 The Veil Nebula

Alternative Nomenclature: NGC 6995, NGC 6974, IC 1340, Cygnus Loop, Cirrus Nebula, Filamentary Nebula, Witch's Broom Nebula (NGC 6960), Caldwell 33, Caldwell 34, Pickering's Triangle
Constellation: Cygnus

Right Ascension: 20h45m8.23s
Declination: +30deg42min30s
Magnitude: 7.5 (Fig. 5.21)

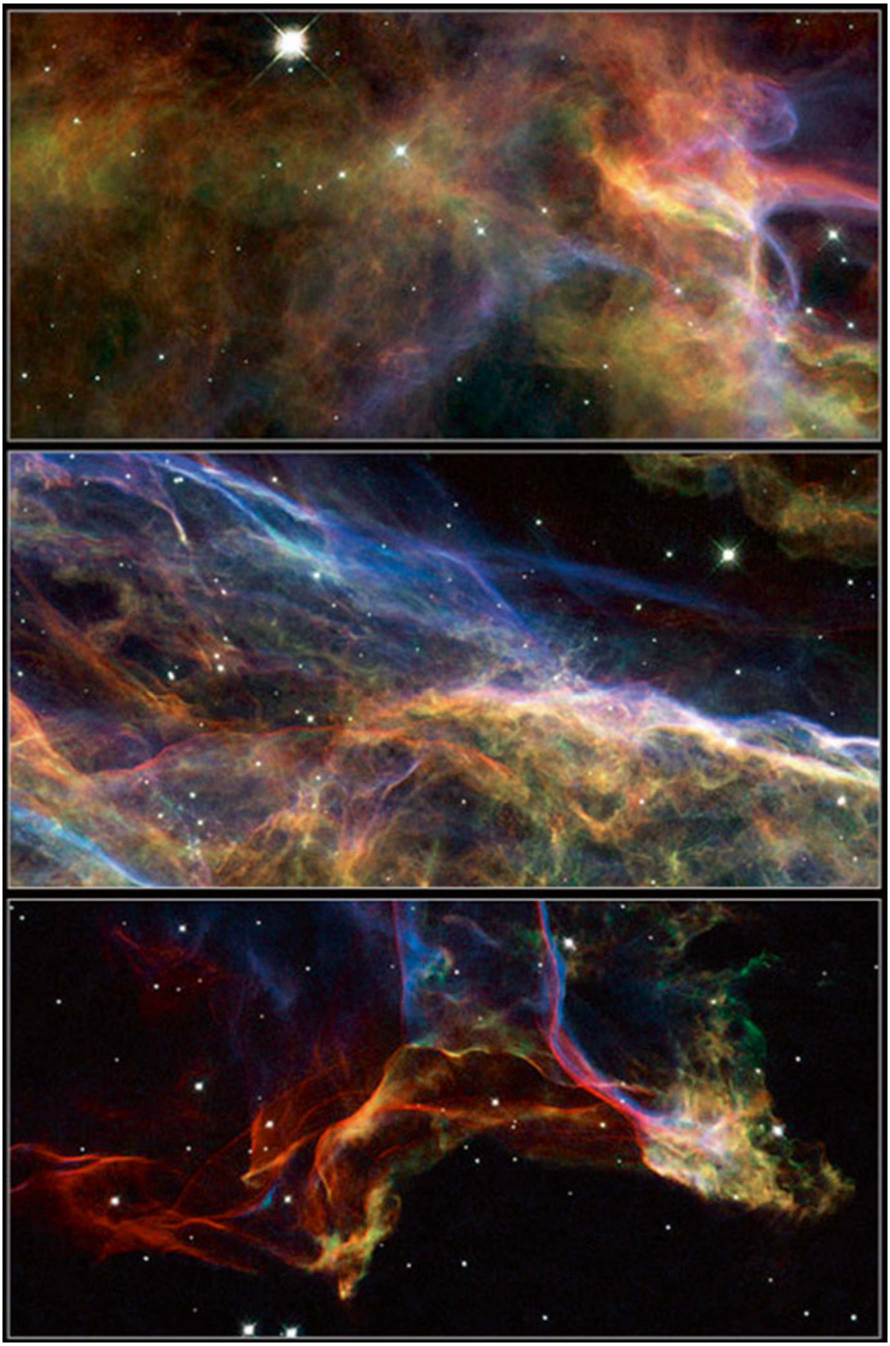

Fig. 5.21 Hubble images of the Veil Nebula segments (NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration)

The nebula was discovered on 1784 September 5 by William Herschel. He described in his observational notes the western end of the nebula as:

> "Extended; passes thro' 52 Cygni… near 2 degree in length"

Herschel then went on to describe the eastern end of the Veil Nebula as:

> "Branching nebulosity… The following part divides into several streams uniting again towards the south."

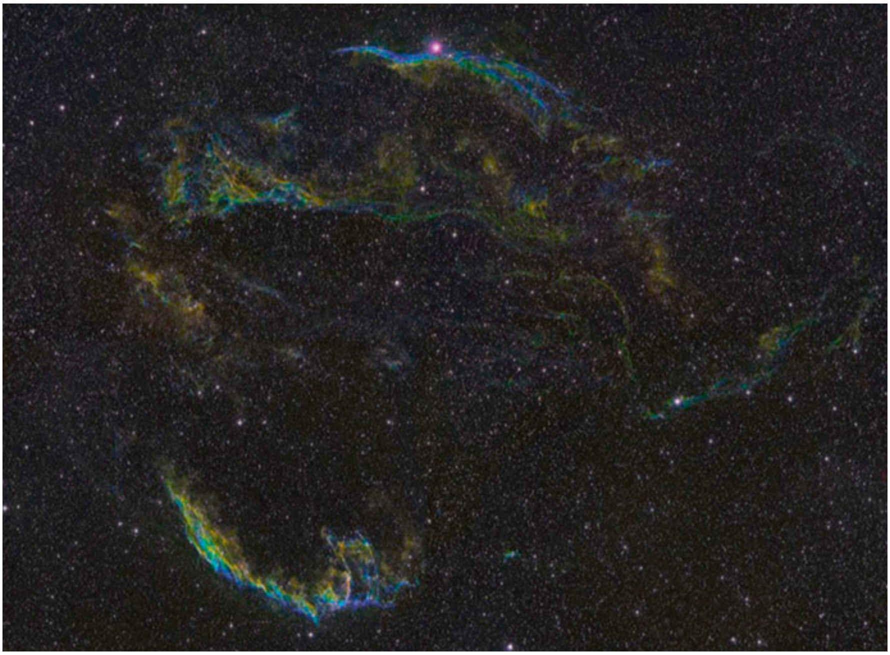

Fig. 5.22 An amateur astrophoto of the Veil Nebula (Jon Talbot)

The Veil Nebula is a supernova remnant of heated and ionized gas and dust located some 1,470 light years from Earth. The progenitor star exploded somewhere between 5,000 and 8,000 years ago, and the remnants have since expanded to cover an area in the visual range of roughly 3 degrees in diameter. The Veil Nebula is visually about six times the diameter, or 36 times the area, of the full moon.

To view the Veil Nebula, a combination of a dark, moonless night away from city lights (car keys!) and the technology of an O-III filter will be needed. Remember, the Veil Nebula is large, and is made up of several parts. As can be seen in the many names and nomenclatures for the Veil, the observer will be observing the separate components that make up the Veil.

There are three main visual components, plus faint patches:

The Western Veil (Caldwell 34), consisting of NGC 6960 (the "Witch's Broom" or Filamentary Nebula).

The Eastern Veil (Caldwell 33), whose brightest area is NGC 6992, trailing off farther south into NGC 6995 and IC 1340.

Pickering's Triangle, brightest at the north central edge of the loop, but visible in photographs continuing toward the central area of the loop.

NGC 6974 and NGC 6979 are faint patches of nebulosity on the northern rim between NGC 6992 and Pickering's Triangle.

The Veil Nebula is a favorite target among amateur astronomers, for the beauty and delicacy of its components. Using Finder Chart #4 as a guide, locate the bright star of Cygnus known as Epsilon Cygni. Roughly in a line from the brightest star in Cygnus, Deneb, through Epsilon Cygni, lies a 4.2 magnitude star 52 Cygni. With a wide-angle, low power eyepiece and the help of an O-III filter, the nebula will be visible in the neighborhood of 52 Cygni. The O-III filter works the best, since virtually all the visible light from the Veil Nebula is due to doubly ionized oxygen.

The size of the Veil Nebula is impressively huge, measuring 3.5 degrees by 2.7 degrees. A modern 102-mm short focus (f/5 – f/7) refractor and an ultra wide field, low power eyepiece can encompass a large portion of the Veil at one time (Fig. 5.22).

The Veil Nebula is the remains of a star that went supernova and exploded approximately 5,000–8,000 years ago. The star that left these scattered remains was once much larger than our own Sun. Instead of dying out to a white dwarf, as do stars the size the Sun, large stars die the violent death of a supernova. The explosion swept out a huge bubble in its surroundings, heating up gas and dust, and the remnants are visible in telescopes.

It's likely that the progenitor star that exploded creating the Veil Nebula was a spectacular sight to humans on Earth 10,000 years ago. Unfortunately, this explosion pre-dates recorded history, so mankind's reaction to this amazing supernova is lost to time.

NGC7293 The Helix Nebula

Alternative Nomenclature: Caldwell 63, The Helix, The Eye of God Nebula, The Helical Nebula
Constellation: Aquarius

Right Ascension: 22h29m38.5s
Declination: −20deg50min13.6s
Magnitude: 7.6 (Fig. 5.23)

Fig. 5.23 Hubble image of the Helix Nebula (NASA, NOAO, ESA, the Hubble Helix Nebula Team, M. Meixner (STScI), and T.A. Rector (NRAO))

The Helix Nebula was discovered by Karl Ludwig Harding, the exact date is not known. It is known that this part of the sky was well studied by such notables as Charles Messier, William Herschel, and his son John. Messrs. Messier, W. and J. Herschel most likely missed it because its light is spread over a large area and they possibly looked right through it.

The planetary nebula known as the Helix Nebula is located about 695 light years away from Earth.

The Helix Nebula will most likely accessible to those observers living in the southern regions. In the USA, this means Florida, Texas, Mississippi, Arizona, New Mexico, et al. At magnitude 7.6 the Helix Nebula is the brightest planetary nebula in the sky. At least it would seem to be an easy target, and in fact it is visible with just binoculars at a dark site on a moonless evening. But again, dark country (southern) skies are required. This is due to its large surface area and resulting low surface brightness. At its widest point the main nebula covers 18 arc minutes with the much fainter outer halo spanning some 28 arc minutes—close to the diameter of the full Moon.

Fig. 5.24 Amateur astrophoto of the Helix Nebula (Jon Talbot)

Use Finder Chart #4 as a guide. Although the immediate area surrounding the Helix Nebula is devoid of any particular bright stars, the region can be relatively easily located by star-hoping. The nebula lies roughly halfway along an imaginary line connecting 1.2 magnitude Fomalhaut, the brightest star in the southerly constellation of Piscis Austrinus, and Iota Aquarii (magnitude 4.3). Just over 1 degree to the east of the Helix Nebula is Upsilon Aquarii. At magnitude 5.2, this star is relatively easy to locate with the naked eye under dark skies. Spotting Upsilon Aquarii greatly simplifies the search for the Helix Nebula (Fig. 5.24).

Prior to the Hubble images, the Helix was thought to be a simple doughnut structure. However, new findings based on Hubble's Advanced Camera for Surveys (ACS) images, and measurements from ground based optical and radio telescopes indicate otherwise. Based on speed and direction of outflows of material for the dying star, the Helix has been found to be a more complex shape. A larger disk of material surrounds the previously known doughnut structure. This disk is a wide, flat ring oriented perpendicular to the inner filled doughnut (getting hungry yet?). The dying star has expelled material into two surrounding disks rather than the one. The Helix has at least two axis of symmetry. The possible reason for two axis of symmetry may be due to the possibility that the progenitor star had a companion star in a double star system configuration.

The astronomers also believe the disks formed during two separate epochs of mass loss by the dying star. The inner disk was formed about 6,600 years ago; the outer ring, about 12,000 years ago. The inner disk is expanding slightly faster than the outer disk. Perhaps, as with the Cat's Eye Nebula, there is a repeating cycle occurring.

Chapter 6

Winter Objects

For many backyard astronomers, the winter is prime time for observing. The skies are dark and transparent because of low humidity. No insects crawling up the legs or flying and buzzing around the head. The trees have lost their leaves and allow more sky to be seen. And rising from his summertime slumber, Orion rises above the horizon to welcome the astronomers to another wintry observing night.

But boy, is it COLD! There are challenges to amateur astronomy during the winter, all surrounding the fact that it's COLD! The two main challenges are keeping warm, and keeping astronomy equipment functioning.

First and foremost, check the weather forecast and plan for dressing as if its at least 20 degrees colder than the weatherman predicts. Why? This is not a sporting event where a person is in constant motion, and consequently generates internal body heat. Astronomy is an activity that requires lots of sitting or standing at an eyepiece. Without proper precautions, all sort of winter nasties can occur—shivering, frostbite, exposure, and worse. Dress in layers, wear a winter cap or hat, cover the ears, gloves, several layers of socks, boots, long underwear … imagine Ralphie's little brother in the classic movie *A Christmas Story*. By dressing in layers, if it's too warm, just peel off a layer.

When it's cold outside, eat a good meal before going out into the field. Also, go to the bathroom before bundling up. Even if the observing site has a rest room or port-a-potty nearby, using the facility can be a challenge at night. Peeling down the layers to "eliminate" is a nuisance and will cause a loss of all the warmth built up.

Outdoor sports supply stores sell wonderful hand-warmer packs. These work. When hands get cold, these chemically activated packets will do wonders in warming up fingertips.

J.L. Chen, A. Chen, *A Guide to Hubble Space Telescope Objects*,
The Patrick Moore Practical Astronomy Series, DOI 10.1007/978-3-319-18872-0_6

If the winter observing is done in the backyard of your home, take breaks from the eyepiece to go inside and warmup. Just so long as it's dark inside the house to preserve night vision, there is no harm in warming up.

However, out in a dark country site, away from creature comforts, observe while the comfort level is good, but pack it in when the cold becomes a problem. Don't be a hero, this isn't a competition. Don't worry, the sky and the stars will be there on another night.

As far as the telescope equipment is concerned, there are a few preparations and precautions with the cold temperatures of the winter.

As with the autumn, the telescope needs to become acclimated to the outside ambient temperature. If the telescope is stored in a warm cozy house, it needs to sit outside for at least 20–30 minutes for the optics to adjust to the cold. If the temperature differential is greater, be prepared for a longer adjustment period. Rechargeable batteries should be fully charged. Fresh batteries installed if disposable batteries are used.

If the user is mechanically inclined, special lubricants that work well at temperature extremes should be used on telescope mounts, focusers, and any other mechanical parts. Conventional oils and greases have a tendency for thickening and stiffing in cold temperatures. Nothing is worse than being unable to focus the telescope because the focuser is frozen in place! If not mechanically inclined, seek out the nearest telescope dealer to help.

M1 The Crab Nebula

Alternative Nomenclature: NGC 1952, Sharpless 244
Constellation: Taurus

Right Ascension: 05h34m32s
Declination: +22deg00min52.2s
Magnitude: 8.4 (Fig. 6.1)

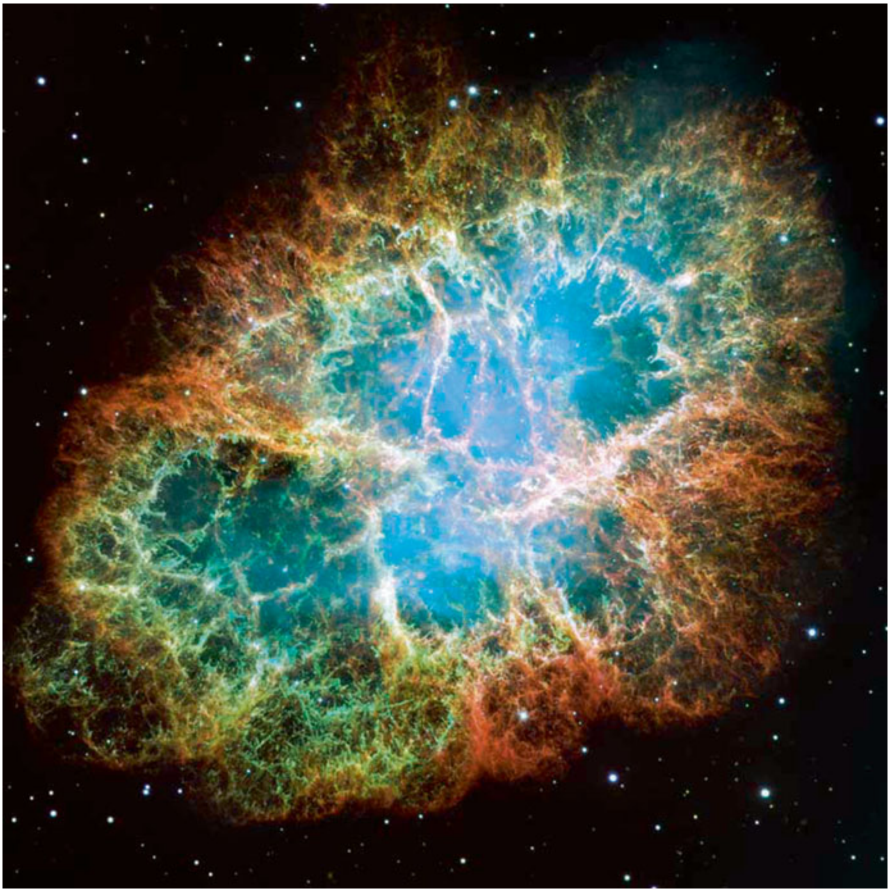

Fig. 6.1 Hubble image of the Crab Nebula (NASA and The Hubble Heritage Team (STScI/AURA))

The Crab Nebula is the only supernova remnant listed in Charles Messier's famous catalog. The supernova associated with the Crab Nebula was noted on July 4, 1054 A.D. by Chinese astronomers as a new or "guest star," and was about four times brighter than Venus, or about magnitude –6. According to the records, it was visible in daylight for 23 days, and 653 days to the naked eye in the night sky. It was probably also recorded by Anasazi Indian artists (in present-day Arizona and New Mexico), as findings in Navaho Canyon and White Mesa (both Arizona) as well as in the Chaco Canyon National Park (New Mexico) indicate.

The supernova remnant itself was discovered by physician and amateur astronomer John Bevis in 1731, 27 years before Charles Messier rediscovered it independently. Messier was informed by Bevis in a June 10, 1771 letter, and Messier acknowledged the Bevis discovery in the later publications of his catalog.

Messier wrote in his catalog:

> "Nebula above the southern horn of Taurus, it doesn't contain any star; it is a whitish light, elongated in the shape of a flame of a candle, discovered while observing the comet of 1758. See the chart of that comet, *Mem. Acad.* of the year 1759, page 188; observed by Dr. Bevis in about 1731. It is reported on the English *Celestial Atlas*."

It was Messier's search for the return of Halley's Comet that resulted in the creation of his famous catalog. According to calculations in 1757 by Alexis Clairaut and his colleagues, a prediction of the return of the comet was to occur in 1758. The Halley's Comet was to appear in the constellation of Taurus. It was during the search for Halley's Comet that Charles Messier first encountered the Crab Nebula, which he at first thought to be Halley's comet. After some observation, noticing that the object that he was observing was not moving across the sky, Messier concluded that the object was not a comet. Messier then realized the necessity of a catalogue of comet-like fuzzy celestial objects, but fixed in the sky, to avoid mistaking them as comets.

William Parsons, the third Earl of Rosse, is credited with bestowing the moniker "Crab Nebula" upon M1. While using a 36-inch telescope at Birr Castle in 1844, Lord Rosse created a drawing of M1 that looked like a crab, as seen in Fig. 6.2.

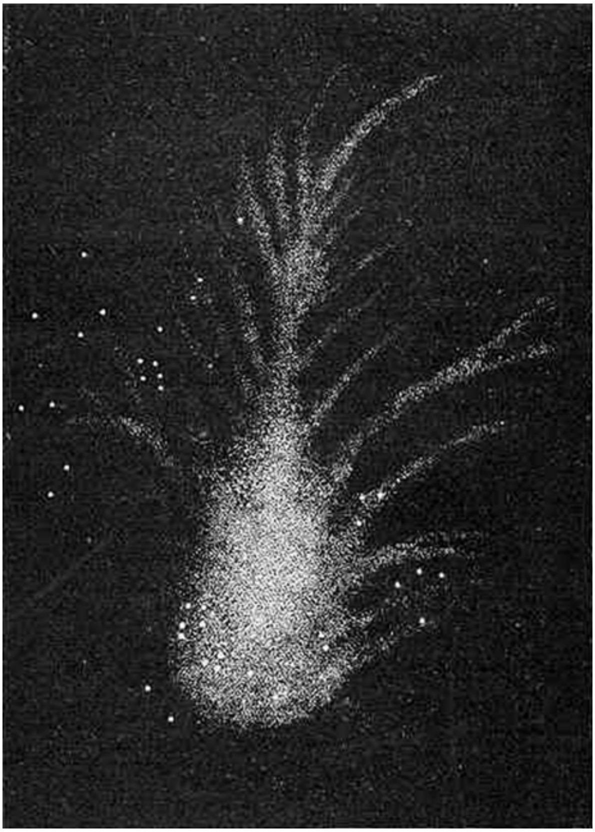

Fig. 6.2 Lord Rosse's drawing of Messier 1 (William Parsons)

Lord Rosse wrote in 1844 of his observation of M1:

> "… a cluster; we perceive in this [36-inch telescope], however, a considerable change of appearance; it is no longer an oval resolvable Nebula; 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 stubbed with stars, mixed however with a nebulosity probably consisting of stars too minute to be recognized. It is an easy object, and I have shown it to many, and all have been at once struck with its remarkable aspect. Everything in the sketch can be seen under moderately favourable circumstances."

The Crab Nebula is a supernova remnant located about 6,500 light years from Earth. It has been the object of intense study by astronomers due to the presence of a pulsar at its heart.

Fig. 6.3 Amateur astrophoto of M1 (Jon Talbot)

With Finder Chart #6 as a guide, Messier 1 can be located by identifying Zeta Tauri, a third magnitude star located northeast of the first magnitude star Aldebaran. M1 is situated approximately 1 degree north and 1 degree west of Zeta Tauri. With dark sky conditions, M1 can be seen at low magnification as a tiny, hazy patch in small telescopes. Moonlight and light pollution can easily washout any viewing of M1. A UHC or O-III nebula filter is a must for suburban viewing of the Crab Nebula. Telescopes with apertures of at least 4″ will begin to reveal some details in shape and brighter patches within the structure. Larger telescopes of 10″–12″ aperture or greater will reveal more detailed filaments (Fig. 6.3).

Messier 1 is a supernova remnant, with an expanding cloud of gas created during the explosion of a star. This material has been spread over a volume approximately 10 light years in diameter, and is still expanding at the velocity of approximately 1,500 km/s. M1 displays spectral emission lines that are split into both red and blue-shifted components, revealing an image of a tangled web of bright filaments. These gaseous filaments and a continuum background are the leftovers from the outer layers of the former star and the highly polarized synchrotron radiation, which is emitted by high-energy electrons in a strong magnetic field.

M1 is also a strong source of radio radiation and an X-ray source. It also contains a pulsating radio source—a radio pulsar—and an optical pulsar known by supernova's variable star designation, CM Tauri. At M1's heart is a rapidly rotating neutron star, with a rotational rate of 30 times per second.

M42 The Great Orion Nebula

Alternative Nomenclature: NGC 1976, Sharpless 281
Constellation: Orion

Right Ascension: 05h35m17.3s
Declination: −05deg23min28s
Magnitude: 4.0 (Figs. 6.4, 6.5, 6.6, and 6.7)

Fig. 6.4 Hubble image of M42 (NASA, ESA, M. Robberto (Space Telescope Science Institute/ESA) and the Hubble Space Telescope Orion Treasury Team)

Fig. 6.5 Close-up Hubble image of M42 (NASA, ESA, and The Hubble Heritage Team (STScI/AURA))

Fig. 6.6 Hubble image of Proplyds within M42 (NASA, ESA, and The Hubble Heritage Team (STScI/AURA))

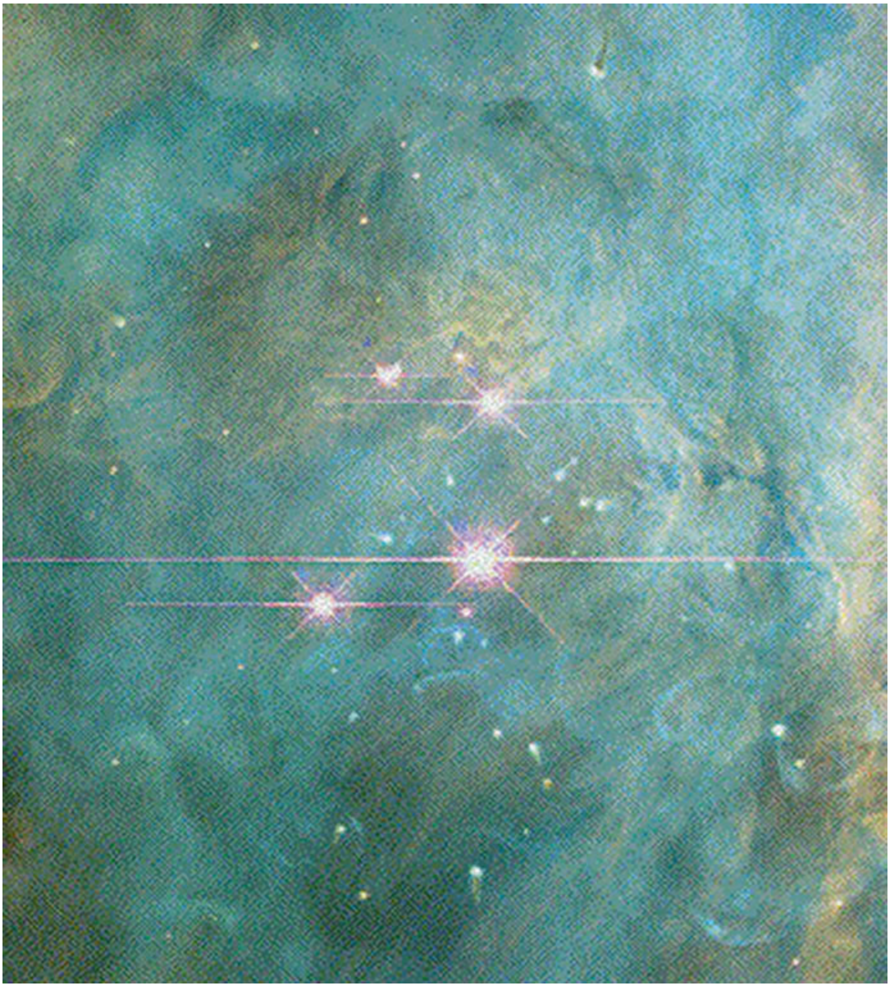

Fig. 6.7 Hubble image of the Trapezium within M42 (NASA, ESA, and The Hubble Heritage Team (STScI/AURA))

The first discovery of the diffuse nebulous nature of the Orion Nebula is generally credited to French astronomer Nicolas-Claude Fabri de Peiresc. Recorded on November 26, 1610, Peiresc observed the nebula through his patron's refracting telescope.

The first published observation of the nebula was by the Jesuit mathematician and astronomer Johann Baptist Cysatus in his 1619 monograph on the comets (describing observations of the nebula that may date back to 1611). Cysatus described the nebula as:

> "one sees how in like manner some stars are compressed into a very narrow space and how round about and between the stars a white light like that of a white cloud is poured out".

Galileo observed the Trapezium on February 4, 1617, but he did not observe the nebula itself. This was probably the result of the small aperture, narrow visual field of view, and poor optics (Fig. 6.8).

The first known drawing of the Orion Nebula was sketched by Giovanni Batista Hodierna around 1654. Figure 6.8 shows three stars within the nebula, probably Theta1, Theta2 A, and Theta2 B Orionis. They probably are not the three brightest Trapezium stars, because Hodierna's instruments were incapable of resolving the Trapezium, which Hodierna probably saw as one star, Theta1.

All of these discoveries were lost or the knowledge was not well distributed. Historically, Christian Huygens was credited with the discovery in 1656:

> "There is one phenomenon among the fixed stars worthy of mention, which as far as I know, has hitherto been noticed by no one and indeed, cannot be well observed except with large telescopes. In the sword of Orion are three stars quite close together. In 1656 as I changed viewing the middle one of these with the telescope [a 23-foot FL refractor], twelve showed themselves - not an uncommon circumstance, Three of these almost touched each other and, with four others, shone through a nebula so that the space around them seemed brighter than the rest of the heavens which was entirely clear and appeared quite black, the effect being that of an opening in the sky through which a brighter region was visible."

Fig. 6.8 The Orion Nebula drawing by Giovanni Batista Hodierna (Giovanni Batista Hodierna)

Charles Messier listed the Orion Nebula as Messier 42 in his first catalog, with his comments:

> "I have examined a large number of times the nebula in the sword of Orion, which Huygens discovered in the year 1656, & of which he has given a drawing in the work which he has published in 1659, under the title *Systema Saturnium* [Saturnian System]. It has been observed since by different Astronomers. M. Derham, in a Memoir printed in the Philosophical Transactions, *no. 428, page 70*, speaks of that nebula which he has examined with a reflecting telescope of 8 feet. Here is the translation [actually here, the text] of what he has reported in this Memoir. "only that in *Orion*, hath some Stars in it, visible only with the Telescope, but by no Means sufficient to cause the Light of the *Nebulose* there. But by these Stars it was, that I first perceived the Distance of the *Nebulosae* to be greater than that of the Fix'd Stars, and put me upon enquiring into the rest of them. Every one of which I could very visibly, and plainly discern, to be at immense Distance beyond the Fix'd Stars near them, whether visible to the naked Eye, or Telescopick only; yea, they seemed to be as far beyond the Fix'd Stars, as any of those Stars are from Earth." M. le Gentil also examined this nebula with ordinary refractors of 8, of 15 & of 18 feet length; as well as a Gregorian telescope of 6 feet, which belongs to Mr. Pingré. He has published his observations in a Memoir which can be found printed in the Volumes of the Academy, *year 1759, page 453*. There is a joint of the drawings which he had made of it at that time, as well as those of Huygens & of Picard; these drawings differ from each other, so that one may suspect that this nebula is subject to sort of variations. Here is what I have reported about that nebula in the Journal of my Observations. On March 4, 1769, the sky was perfectly serene, Orion was going to pass the meridian, I have directed to the nebula of this constellation a Gregorian telescope of 30 pouces focal length, which magnified 104 times; one saw it perfectly well, & I drawed the extension of the nebula, which I compared consequently to the drawings which M. le Gentil has given of it, I found some differences. This nebula contains eleven stars; there are four near its middle, of different magnitudes & strongly compressed to each other; they are of an extraordinary brilliance: here is the position of the brightest of the four stars, which Flamsteed, in his catalog, designated by the greek letter Theta, of fourth magnitude, 80d 59′ 40″ in right ascension, & 5d 34′ 6″ in southern declination: this position has been deduced from that which Flamsteed has given in his catalog. [p. 458] 1769.Mar. 4. RA: 80.59.40, Dec: 5.34. 6.A. Position of the star Theta in the Sword of Orion, which is situated in the middle of the nebula in that constellation."

M42 is the greatest, grandest, most beautiful, most intriguing … every superlative that one can think of, deep sky object visible in the Northern Hemisphere. This diffuse nebula is located approximately 1,344 light years away.

Reference Finder Chart #6. Finding Messier 42 is very easy from a suburban backyard by centering on the glowing region in the center of Orion's sword. If the sword is not visible, aim the telescope slight south of the three prominent stars that form Orion's Belt. M42 is a very bright and large object that can be seen in all sky conditions and a variety of binoculars and telescopes. Any size telescope will reveal the grandness of M42. The larger the aperture, the more extensive and intricate detail will be revealed to the observer. Try using light pollution filters or any nebula filter to enhance the view. Be advised that nebula filters may suppress the Trapezium (Figs. 6.9, 6.10, and 6.11).

Fig. 6.9 Amateur astrophoto of the Orion Belt and M42 and M43 Region (Jon Talbot)

Fig. 6.10 Amateur astrophoto of M42 (Chris Miskiewicz)

Fig. 6.11 Another amateur astrophoto of M42 (Chris Miskiewicz)

The Orion Nebula is part of a much larger cloud of dust and gas, called the Orion Molecular Cloud Complex, that encompasses a large part of the Orion constellation. This nebulous cloud encompasses features such as Barnard's Loop, the reflection nebula Messier 78, Messier 43, the Flame Nebula, and the famous feature to be discussed later in this chapter (and included in Fig. 6.9), the Horsehead Nebula.

M42 is one of the most studied and photographed objects of the night sky by both professional and amateur astronomers, hence the intense study of M42 by the Hubble scientists. The nebula is rich with astronomical highlights, including collapsing clouds of dust and gas, protoplanetary disks, called proplyds, infant brown dwarfs, rotating and irregular movements of gas, brown star binary systems, and Herbig-Haro objects.

The study of the Orion Nebula has given astronomers a virtual primer on star formation, with the presence of young massive stars to regions of dense dust and gas that represent the birthplace of stars. The Trapezium is home to four massive young stars that flood the cavity in which they reside with ultraviolet light. The light from the Trapezium is the major source of the energy it takes to illuminate the Orion Nebula with its characteristic and beautiful glow. The massive energy output of the Trapezium stars have scattered the star making material in their region.

Nearby the Trapezium are stars with disks of material encircling them, as seen in Fig. 6.7. These disks are protoplanetary disks, or proplyds, and these proplyds represent one of the most significant discoveries from the Hubble images. The youngest and brightest stars within the Orion Nebula are thought to be less than 300,000 years old, and the brightest possibly only 10,000 years in age.

In 2005, the HST's Advanced Camera for Surveys finished capturing the most detailed image of the nebula yet taken. The image was taken through 104 orbits of the telescope, capturing over 3,000 stars down to the 23rd magnitude, including infant brown dwarf stars and binary dwarf stars. A year later, astronomers using Hubble images announced the first ever masses of a pair of eclipsing binary brown dwarfs. The pair are located in the Orion Nebula and have approximate masses of 0.054 solar mass and 0.034 solar mass. The pair had an orbital period of 9.8 days, and the more massive of the pair proved to be less luminous. The Hubble's near-infrared capabilities have enabled astronomers to identify at least 50 brown stars, owing to the brown stars retaining much of their heat from the process of formation.

The Horsehead Nebula

Alternative Nomenclature: IC 434, Barnard 33
Constellation: Orion

Right Ascension: 05h40m59s
Declination: –02deg27min30s
Magnitude: dark nebula (Figs. 6.12 and 6.13)

Fig. 6.12 Hubble image of the Horsehead Nebula in infrared wavelengths (NASA, ESA, and The Hubble Heritage Team (STScI/AURA))

Fig. 6.13 Hubble image of the Horsehead Nebula, Barnard 33 (NASA, NOAO, ESA and The Hubble Heritage Team (STScI/AURA))

The Horsehead Nebula was first recorded on a photographic plate by Scottish astronomer Williamina Fleming in 1888, using the Harvard College Observatory. Fleming discovered the Horsehead on Harvard plate B2312. In describing the bright nebula that surrounds the Horsehead, now known as IC 434, she described the nebula as having:

"a semicircular indentation 5 minutes in diameter 30 minutes south of Zeta Orionis."

A bit of early controversy surrounds the initial discovery of the Horsehead Nebula. Upon reviewing Fleming's notes, William Henry Pickering, who had taken the photograph plate B2312, speculated that the spot was dark obscuring matter. Yet all subsequent articles and books denied both Williamina Fleming and W.H. Pickering credit. The compiler of the first Index Catalogue, J.L.E. Dreyer, eliminated Fleming's name from the list of objects then discovered by Harvard, attributing them all instead merely to "Pickering", causing users of the catalog to assume E.C. Pickering, director of Harvard College Observatory, as the discoverer. By the release of the second Index Catalogue by Dreyer in 1908, Fleming and others at Harvard were famous enough to receive proper credit for later object discoveries, but not for the earlier discoveries of IC 434 and the now-famous Horsehead Nebula.

Located some 1,500 light years away, the Horsehead Nebula is a challenging object to observe visually.

The area where IC 434 and the Horsehead Nebula is perhaps the easiest to find in this book. As seen in Finder Chart #6, locate the Belt of Orion, and locate Alnitak, the belt star on the left. And look slightly below Alnitak.

Now the tough part, observing the Horsehead Nebula. Primarily a photographic object, the Horsehead can be and has been seen visually by amateur astronomers. But it is a tough object. Although telescopes of at least 8–10 inches aperture have been used to observe the Horsehead, apertures of 17 inches or greater are often necessary to see it successfully. Extremely dark, transparent skies are a must. A hydrogen-beta nebula filter is necessary to provide an increase in contrast. And with all that in hand, it will still be a challenge to view.

The difficulty with which it can be seen can change dramatically in the space of hours and also from individual to individual. It is a very difficult target in any scope under 16 inches in aperture.

The ease with which it can be seen are dependent on many things:

1. The darkness of the skies. The darker, the better.
2. The transparency of the skies. Low humidity is a must. No high cirrus clouds.
3. Clean optics in the scope are a must.
4. A well baffled scope is a must. This has a major effect on contrast.
5. High grade optics yield better contrast than low grade optics, making it marginally easier to see.
6. Use an eyepiece that yields a suitable exit pupil. 3–5 mm is ideal as this effects contrast and target luminosity.
7. Use a high quality eyepiece with good light throughput and contrast.
8. Use a nebula filter. A Hydrogen-Beta filter helps enormously and a narrowband or UHC filter helps a lot.
9. And most importantly, the sensitivity to red light are the individual observers eyes. A very significant portion of the light emitting from the background emission nebula IC434 is at the red end of the spectrum and observers with eyes that are less sensitive to red light will simply not see it irrespective of the conditions, because they cannot see the background emission nebula very well.

If and when the Horsehead is spotted, it is not in the upright position often seen in photographs. Since IC 434 is oriented downwards and slightly trending to the leftward direction, the Horsehead profile will be on its side, as if the horse was looking in the direction of Alnitak (Fig. 6.14).

As with M42, Barnard 33, the Horsehead Nebula is part of the Orion Molecular Cloud Complex. It is one of the most identifiable nebulae because of the shape of its swirling cloud of dark dust and gases, and thus had the distinction of being the most publicly requested targets for the Hubble to image.

The heavy concentrations of dust in the Horsehead Nebula region and neighboring Orion Nebula are localized, resulting in alternating sections of nearly complete opacity and transparency. The darkness of the Horsehead is caused mostly by thick

Fig. 6.14 Amateur astrophoto of the Horsehead Nebula (Chris Miskiewicz)

dust blocking the light of stars behind it. The visible dark nebula emerging from the gaseous complex is an active site of the formation of "low-mass" stars. Bright spots in the Horsehead Nebula's base are young stars just in the process of forming.

M45 The Pleiades

Alternative Nomenclature: Melotte 22, Seven Sisters, Subaru
Constellation: Taurus

Right Ascension: 03h47m24s
Declination: +24deg07min00s
Magnitude: 1.6 (Figs. 6.15 and 6.16)

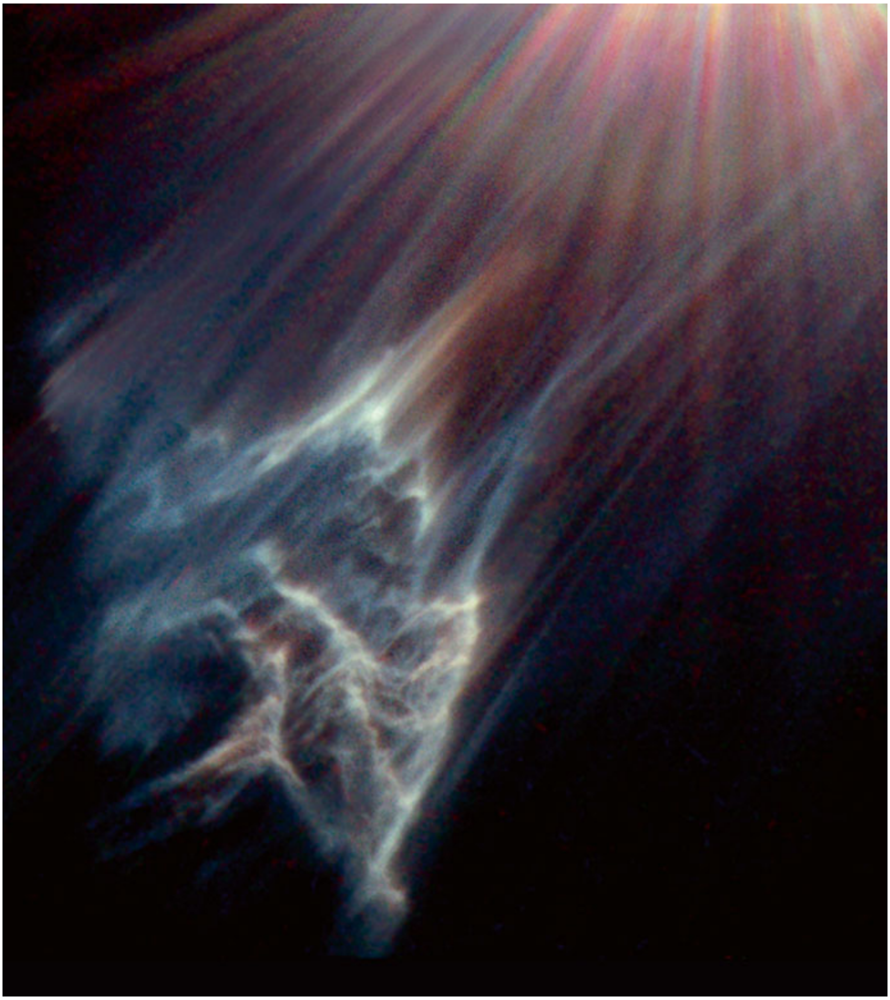

Fig. 6.15 Hubble image of the Pleiades reflection nebula near Merope (NASA and The Hubble Heritage Team (STScI/AURA))

Fig. 6.16 Composite photo of the Pleiades (NASA, ESA, AURA/Caltech, Palomar Observatory)

Unlike all the most of the other deep sky objects of this and previous chapters that are either faint or invisible to the naked eye, the Pleiades are a prominent sight during the winter and can be seen without any optical aid. This star cluster has been known to mankind since before the written word. The Pleiades have impacted human culture more than any other deep sky object in this book.

The Pleiades are among the first stars mentioned in written form, appearing in Chinese annals of about 2350 BC.

Any early mention of the Pleiades can be found in Homer's *Iliad*, from about 750 B.C., and the *Odyssey*, about 720 B.C. From the *Iliad*:

> He made the earth upon it, and the sky, and the sea's water, and the tireless sun, and the moon waxing into her fullness, and on it all the constellations that festoon the heavens, the Pleiades and the Hyades and the strength of Orion and the Bear, whom men give also the name of the Wagon, who turns about in a fixed place and looks at Orion and she alone is never plunged in the wash of the Ocean.
>
> *Iliad* 18. 483–89 (translated by R. Lattimore)

Hesiod from Ascra was a famous poet in ancient Greece, living about 740–670 B.C., also wrote of the Pleiades in his work *Works and Days*, dated about 720–700 B.C.:

> More hands mean more work and more increase. If your heart within you desires wealth, do these things and work with work upon work. When the Pleiades, daughters of Atlas, are rising, begin your harvest, and your ploughing when they are going to set.

And later in *Works and Days*:

> But when the Pleiades and Hyades and strong Orion begin to set, then remember to plough in season: and so the completed year will fitly pass beneath the earth. But if desire for uncomfortable sea-faring seize you when the Pleiades plunge into the misty sea to escape Orion's rude strength, then truly gales of all kinds rage.

Besides the Chinese and the Greeks, the Pleiades appears in the legends and lore of cultures in every inhabited continent on Earth.

The Greek myth of the Pleiades tells the story of the Titan, Atlas, who was forced to carry the heavens on his shoulders. Orion began to pursue all of the Seven Sisters, and Zeus transformed them first into doves, and then into stars to comfort their father Atlas and the sea nymph Pleione. The constellation of Orion still pursues them across the night sky to this very day.

The legend of seven maidens transported to the sky by the Great Spirit appears in the storytelling of the Kiowa tribe in North America. The Navajo, the Western Mono Indians, the Inuit, Cheyenne, Cherokee, Hopi, Lakota, Nez Perce and Blackfoot tribes also told their stories relating to the Pleiades.

The star cluster appears in the mythology and cultures of the Norse, Celtic, Ukraine, Incas, Aztecs, India, Indonesia, Japan, Philippines, Thailand, Australia, Hawaii, and New Zealand. The star cluster appears in the Swahili language and Sesotho language of Africa.

Even in today's culture, the Pleiades appears in song, literature, and more recently science fiction. Characters and plot lines in Isaac Asimov's Foundation Trilogy and the many series of Star Trek have referenced the Pleiades. And take a look at the emblem of a Subaru sports-utility vehicle. Yes, that's the Pleiades, since the Japanese name for M45 is Subaru!

The Pleiades open star cluster is estimated to be between 390 and 480 light years away from Earth.

The Pleiades is easiest deep sky object to find with the unaided eye. The Finder Chart #6 will probably not be needed to locate M45, but is available. Look for a very visible cluster of stars in the direction northwest of Orion. M45 can be seen in almost any suburban location, barring standing in the middle of a brightly lit parking lot. It is an ideal object for binoculars. Use a low power, wide field eyepiece when using a telescope. To see the nebulosity around Merope and the other members of the cluster, dark skies and larger apertures are required. An 8 inch telescope is quite adequate for the task, and the combination of dark sky, 4-inch refractor and a broadband nebula filter can accomplish the task (Figs. 6.17 and 6.18).

As one of the closest of star clusters to Earth, the Pleiades is populated with hot blue stars that have only formed within a cosmic scale short time. Ages for star clusters can be estimated by comparing the Hertzsprung-Russell diagram for the cluster with theoretical models of stellar evolution. Using this technique, ages for the Pleiades of between 75 and 150 million years have been estimated.

The nine brightest stars of the Pleiades are named for the Seven Sisters of Greek mythology: Sterope, Merope, Electra, Maia, Taygete, Celaeno, and Alcyone, along with their parents Atlas and Pleione. As seen in Figs. 6.15 and 6.16, nebulosity accompanies the stellar members of the cluster. Astronomers first believed the dust and gas was left over from the formation of the cluster. However, the proper motions of the stars and of the nebulosity are not the same. The Pleiades are actually moving through a cloud of interstellar dust. In total, there are about 1,000 stars that comprise the cluster.

The Hubble Space Telescope's Fine Guidance Sensors refined the distance to the Pleiades to about 440 light-years, and the cluster is slowly moving in the direction of Orion. Hubble Fine Guidance Sensors measured slight changes in the apparent positions of three stars within the cluster when viewed from different sides of Earth's orbit. Astronomers took their measurements 6 months apart over a 2½-year period. Calculating accurate measurements to nearby stars is crucial in obtaining accurate distances to faraway objects. Astronomers have only one direct means for gauging distances to stars, called the parallax method. With current telescopes, this method gives accurate results only for distances up to about 500 light-years. Distances beyond that limit must be determined by indirect methods, based on comparing the brightness of distant stars with those of nearer ones of the same type, and making the assumption that both objects have the same intrinsic, or true, brightness. Astronomers can build up a "distance ladder," based on ever-farther objects, ultimately leading to the use of supernovae as "standard candles" for the most distant reaches of the universe.

Like most open clusters, the Pleiades will not stay gravitationally bound forever. Some component stars will be ejected after close encounters with other stars; others will be stripped by tidal gravitational fields. Astronomers suggest that the cluster will take about 250 million years to disperse, with gravitational interactions with the spiral arms of the Milky Way and giant molecular clouds also conspiring to hasten the breakup.

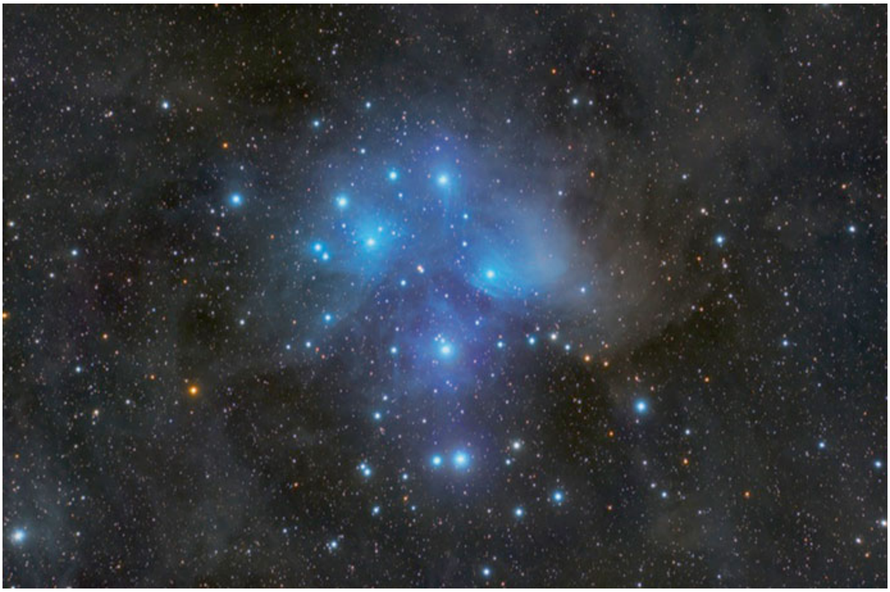

Fig. 6.17 Amateur astrophoto of M45 (Jon Talbot)

Fig. 6.18 Another amateur astrophoto of M45 (John Livermore)

Hubble's Variable Nebula

Alternative Nomenclature: NGC 2261, Caldwell 46
Constellation: Monoceros

Right Ascension: 06h39m10s
Declination: +08deg44min00s
Magnitude: 9.0 (variable) (Fig. 6.19)

Fig. 6.19 Hubble image of NGC 2261 (NASA and The Hubble Heritage Team (STScI/AURA))

William Herschel discovered this reflection nebula on December 26, 1783, describing it as:

"Considerably bright and fan shaped. About 2 minutes long from the center."

The director of the Athens Observatory J.F. Julius Schmidt, using a 6-inch refractor in 1861 discovered a fluctuation of brightness of the light source of the nebula, R Mons, although at irregular intervals.

It was Edwin Hubble in 1916 who first studied the changes in brightness and structure of NGC 2261 while studying images of the nebula in photographs. The story was that John Mellish, an amateur astronomer volunteering at Yerkes, made note that NGC 2261 had a changing appearance that caused him to mistake it as a comet. Edwin Hubble was at the time a first-year grad student at Yerkes, and took on the task of determining the variability of the nebula. This led to Hubble's first journal paper, and the nebula that would eventually bear his name.

NGC 2261 was the first light and first photographic image taken by the famous 200-inch Hale Telescope at Palomar Observatory on January 26, 1949. The image was taken by Edwin Hubble, who carried on his study of the nebula that he began during his time at Yerkes Observatory and later at Mt. Wilson Observatory.

Hubble's Variable Nebula is located 2,500 light years from the Earth.

Reference Finder Chart #6. Hubble's Variable Nebula is located in a part of the sky that also contains additional deep sky treats. Use a 4 inch refractor or larger telescope with a wide field low power eyepiece. Locate the feet of the constellation Gemini. Move the telescope southward and parallel to Orion, to find a group of deep sky treats. Grouped together are the Christmas Tree Cluster, the Cone Nebula, and just a little farther south is NGC 2261. Just a little farther south, as an added bonus are Caldwell 49, the Rosette Nebula, and Caldwell 50, an open cluster (Fig. 6.20).

Fig. 6.20 Amateur astrophoto of Hubble's Variable Nebula (Jon Talbot)

Hubble's variable nebula is a fan-shaped cloud of gas and dust which is illuminated by R Monocerotis (R Mon), the bright star at the bottom end of the nebula. Dense condensations of dust near the star cast shadows out into the nebula, and as they move the illumination changes, giving rise to the variations first noted by Hubble. The star itself, lying about 2,500 light-years from Earth, cannot be seen directly, but only through light scattered off of dust particles in the surrounding nebula. R Mon is believed to have a mass of about ten times that of the Sun, and to have an age of only 300,000 years. Astronomers believe there is probably a symmetrical counterpart of the fan-shaped nebula on the southern side of the star, but it is heavily obscured from view by dust lying between this lobe and our line of sight.

Eta Carinae Nebula

Alternative Nomenclature: Eta Carinae (star), Homunculus Nebula, NGC 3372, Carina Nebula
Constellation: Carina

Right Ascension: 10h45m3.6s
Declination: −59deg41min4.3s
Magnitude: variable −0.8 to 7.9 (Figs. 6.21, 6.22, and 6.23)

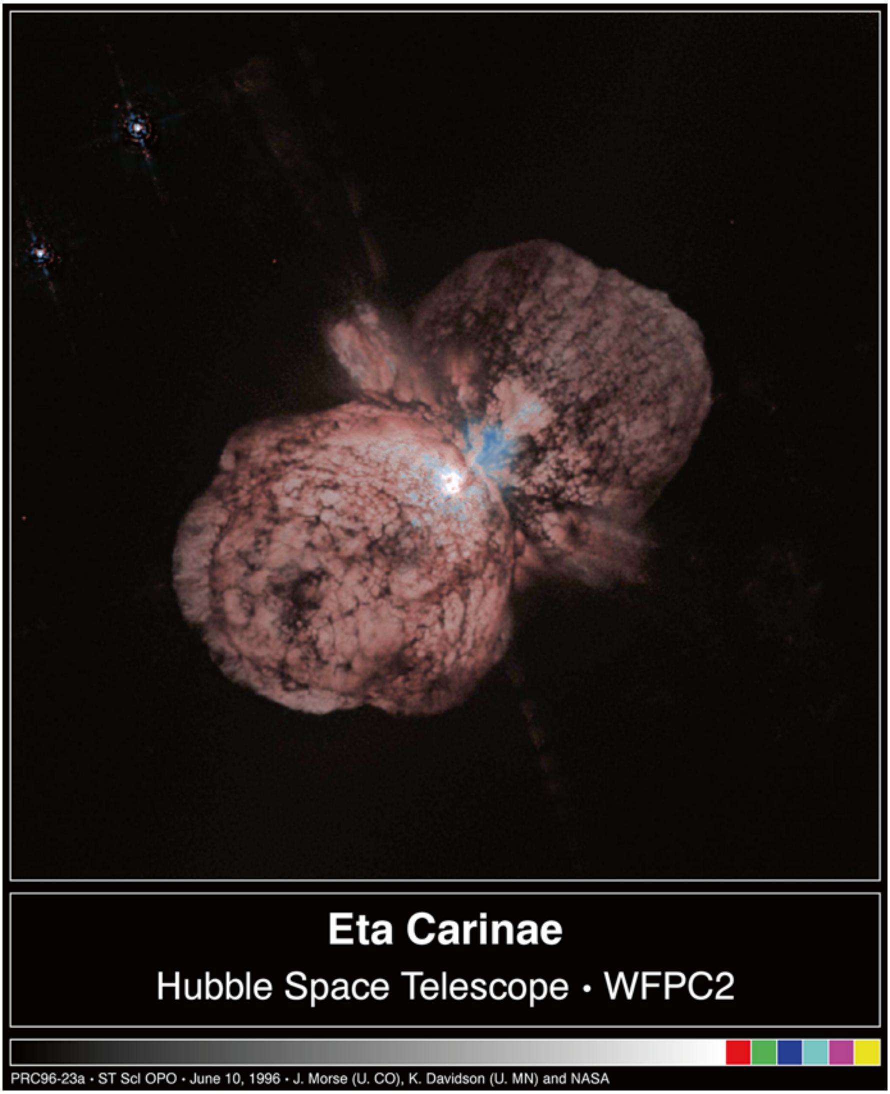

Fig. 6.21 Hubble image of Eta Carinae and the Homunculus Nebula (Jon Morse (University of Colorado), and NASA)

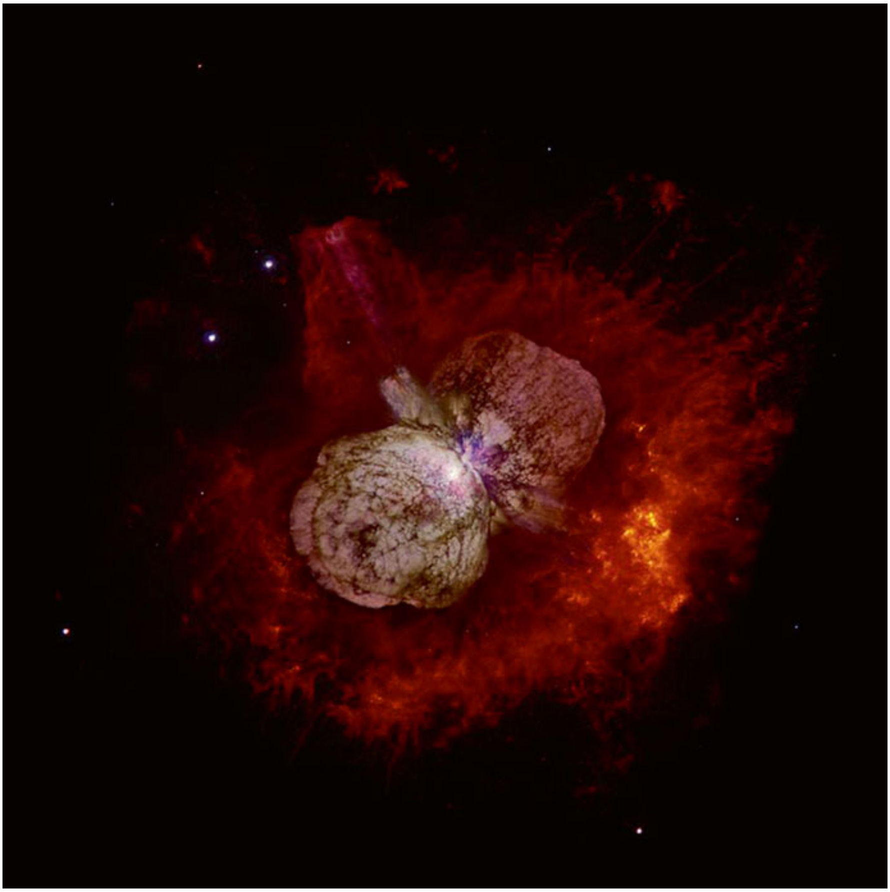

Fig. 6.22 Another Hubble image of Eta Carinae, the Homunculus Nebula, and some of the Carina Nebula (Nathan Smith (University of California, Berkeley), and NASA)

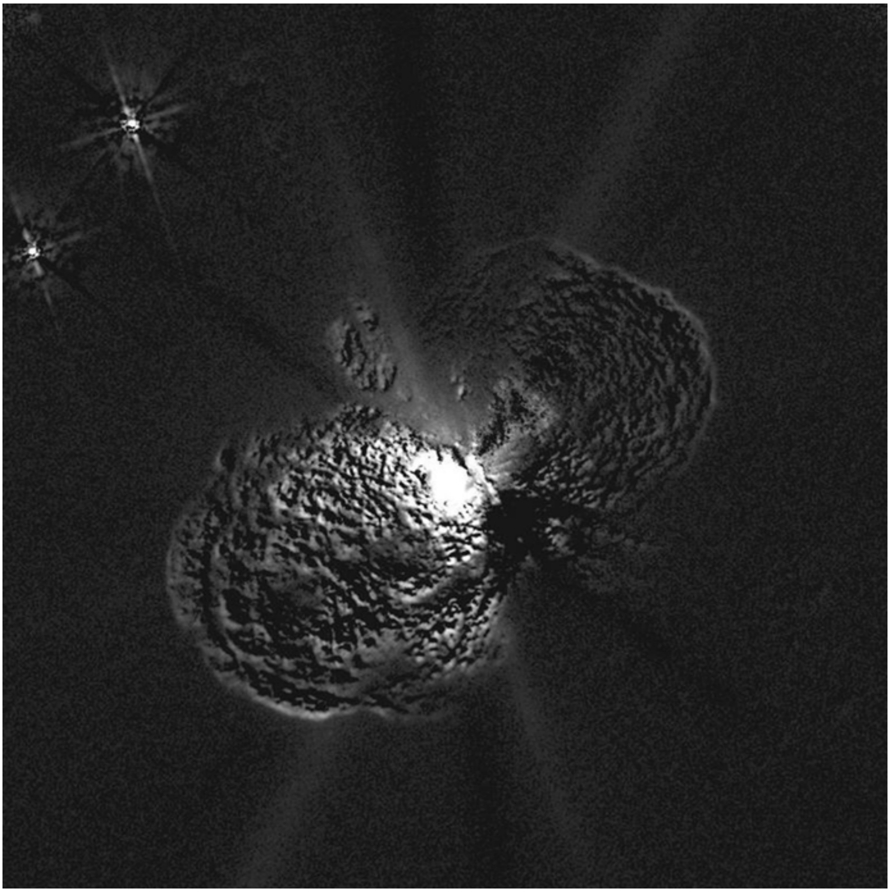

Fig. 6.23 Another Hubble image Eta Carinae and the Homunculus Nebula in Violet light from the WPC2 camera. (Jon Morse (University of Colorado), Kris Davidson (University of Minnesota), and NASA)

When Eta Carinae was first catalogued in 1677 by Edmond Halley, it was a fourth magnitude star. By 1730, astronomers noted it had brightened and became one of the brightest stars in the constellation Carina.

The Eta Carinae Nebula was discovered by Nicholas Louis de Lucaille during his 2-year journey to the Cape of Good Hope in 1751–1752. Lacaille made two catalog entries situated in the region covered by this object: Lac III.5 and Lac III.6, which the elder literature both identifies with NGC 3372. While the description of III.6: "Large group of a great number of small stars, little compressed, and filling out the space of a kind of a semi-circle of 15–20 minutes in diameter; with a slight nebulosity widespread in space", matches well with what Lacaille should have seen in his 0.5-inch refractor, he describes III.5 as:

> "Two small stars surrounded by nebulosity".

Subsequently Eta Carinae dimmed, and by 1782 it appeared to have reverted back to its former fourth magnitude brightness. In 1820, it was observed to be growing in brightness again. By 1827, it had brightened more than tenfold and reached its greatest apparent brightness in April 1843. With a magnitude of −0.8, it was the second brightest star in the night-time sky, with Sirius maintaining its stature as the brightest night sky star. After 1843, Eta Carinae faded again, and between about 1900 and 1940 it was only eighth magnitude, invisible to the naked eye. A sudden and unexpected doubling of brightness was observed during 1998–1999 time period. In 2007, at magnitude 5, Eta Carinae again could be seen with the naked eye.

In the case of NGC 3372 and Eta Carinae, the author freely admits never having observed this object through a telescope. The author's current residence lies at a latitude 39 degrees 18 minutes North.

Reference the Naval Observatory chart and Finder Chart #7 to help locate Eta Carinae.

According to the Astronomical Society of South Australia:

> Once you have found the Southern Cross move about 24 degrees West (to the right) where you will find **NGC 3372** (the **Eta Carina Nebula**). Near its centre there is a very bright orange star - this is **Eta Carina**. In 1843 this star was the second brightest star next to Sirius.

Eta Carinae, the star system, the accompanying Homunculus Nebula and the surrounding Carina Nebula are not visible north of latitude 30 degrees North. Those observers south of that latitude will be treated to an extraordinary sight. Observer's south of 30 degrees South will find Eta Carinae as a circumpolar object (Fig. 6.24).

Fig. 6.24 Amateur astrophoto of Eta Carinae (Jon Talbot)

To clarify this object, Eta Carinae is a star, most likely a double star system. The accompanying Homunculus Nebula is the result of the violent eruption witnessed in 1843, producing two lobes and a large, thin equatorial disk, all moving outward at about 1.5 million miles per hour. Eta Carinae and the Homunculus Nebula lie within star birth region NGC 3372, the Great Carina Nebula or Eta Carinae Nebula.

Eta Carinae is one of the most massive stars in the universe, with estimates of its mass ranging between 120 and 150 solar masses. It is about 4 million times brighter than the Sun, making it also one of the most luminous stars known. Eta Carinae radiates 99 % of its luminosity in the infrared part of the spectrum, where it is the brightest object in the sky at 10–20 μm wavelength.

Situated in the star forming nebula NGC 3372, Eta Carinae is a recently formed star in the cosmic timescale. Such massive stars have a comparatively short expected lifetime of roughly 1 million years. Astronomers expect Eta Carinae to go supernova within the next 100,000 years or sooner.

Chapter 7

The Hubble Deep Field, Ultra-Deep Field, and eXtreme Deep Field

On January 15, 1996, NASA released to the public one of the most extraordinary astronomical images of all time. The Hubble Deep Field (Fig. 7.1), a composite of 342 separate WFPC2 exposures taken from December 18–28, 1995, covered an area of the sky of only 2.5 arc-minutes, and is located in a nearly featureless area in Ursa Major (Fig. 7.2).

The backyard observer is invited to aim their telescope to this area of Ursa Major, and when doing so find very little, if anything remarkable to view.

Yet, as seen in Fig. 7.1, about 3,000 distinct galaxies have been identified by astronomers within the HDF image, with only 20 Milky Way stars visible in the foreground.

The Hubble Deep field is located at 12h 36m 49.4000s +62d 12′ 58.000″ (epoch 2,000.0). The criteria for selecting this particular area for the survey were:

- The field is optimally placed in what Hubble planners termed the Northern Continuous Viewing Zone (CVZ), with the declination near +62 deg. This allowed continual exposures without interference from the Earth, Moon, or Sun.
- The northern hemisphere was chosen to allow for follow up observations from the Very Large Array (VLA) in New Mexico, the Keck Observatory in Hawaii, and the Kitt Pike National Observatory (KPNO) in Arizona.
- The HDF is several degrees away from any bright star (more than 2 degrees from stars 2 magnitude or brighter).
- The field is devoid of bright nearby galaxies, stars, known nearby clusters, and bright radio sources.
- The Hubble Deep Field is away from the congestion of the Milky Way galactic disk.

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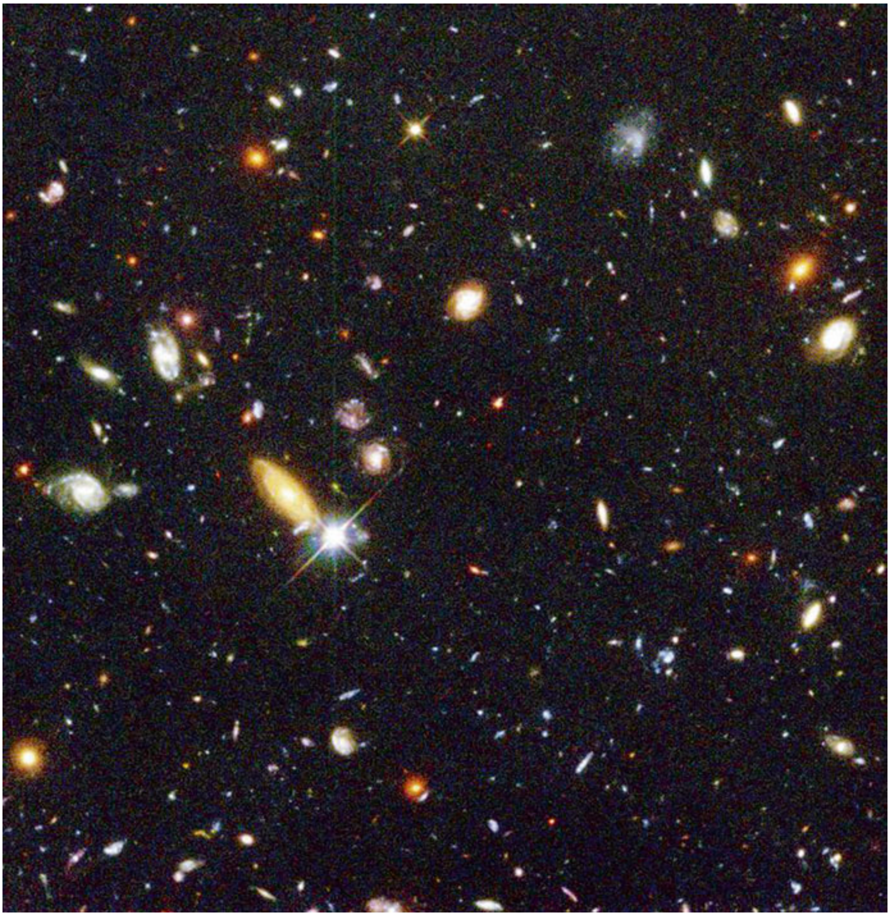

Fig. 7.1 The Hubble Deep Field (Robert Williams and the Hubble Deep Field Team (STScI) and NASA)

- The field has low infrared cirrus flux, as judged from IRAS maps. Infrared cirrus are filamentary structures seen in infrared light. The name is given because the structure looks cloud-like in appearance.
- Low extinction (E(B-V) =0.00). The astronomical use of the term extinction refers to the absorption and scattering of electromagnetic radiation by interstellar dust and gas between an astronomical object and the observer, in this case Hubble.
- Low hydrogen column density (log(N_H)=20.24). Hydrogen column density is the density projected in the line of sight to the observed object.

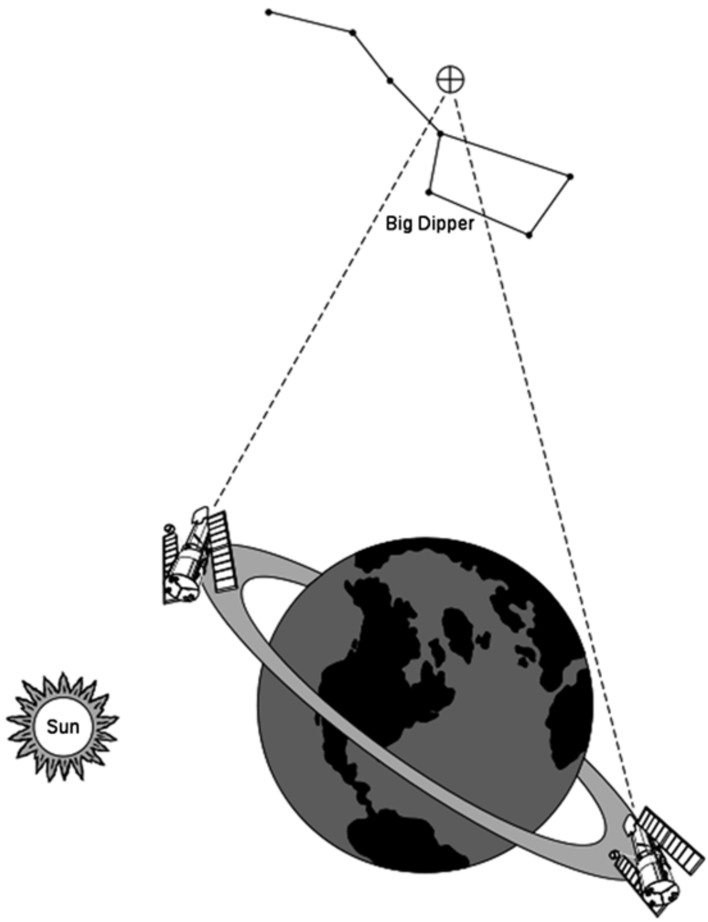

Fig. 7.2 NASA finder chart for the HDF area (NASA)

An HDF counterpart in the southern celestial hemisphere was created in 1998, known as the HDF-South or HDF-S. Obviously not visible from the northern hemisphere, the HDF-S provided southern hemisphere observatories with a deep optical image of the distant universe similar to the original HDF, now known as HDF-N. As with HDF-N, the field selection criteria were similar, although the field is closer to the galactic plane than the HDF-N, meaning that it contains more Milky Way stars.

The field chosen was in constellation Tucana at 22h 32m 56.22s and −60d 33′ 02.69″. The HDF-S field is in Hubble's Continuous Viewing Zone (CVZ), this time in the south, allowing twice the normal observing time per orbit. One drawback to the Tucana deep field chosen is the occasionally interfering presence of the South Atlantic Anomaly. The South Atlantic Anomaly (SAA) is an area where the Earth's

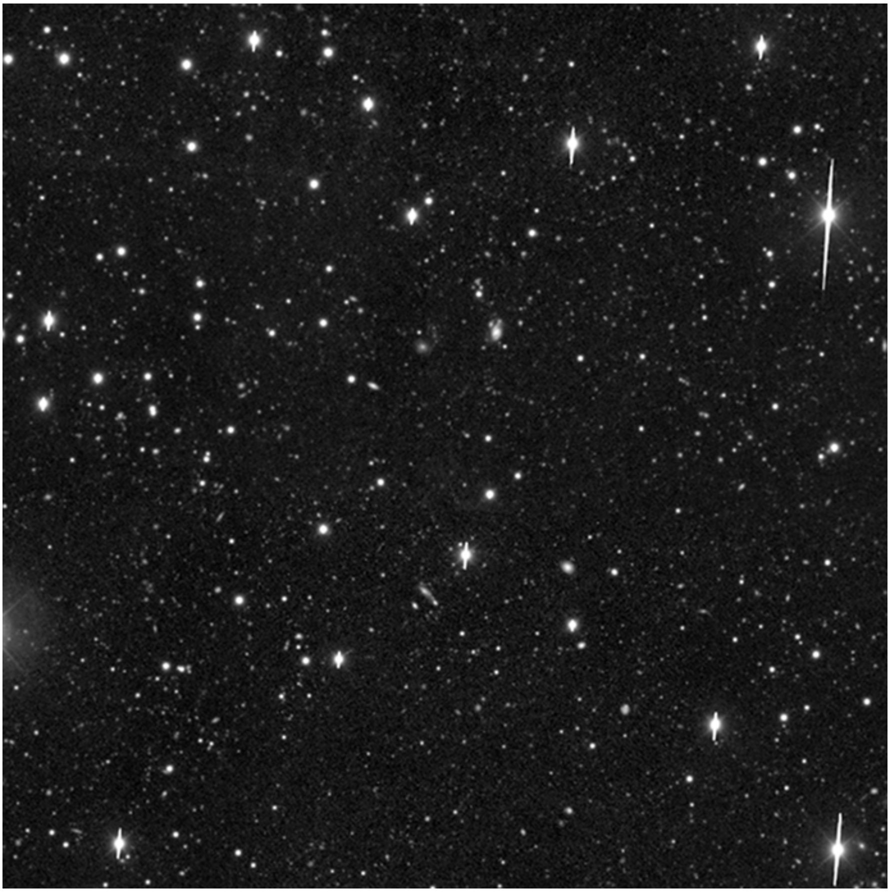

Fig. 7.3 HDF-South (NASA/ESA)

innermost Van Allen belt dips down to an altitude of approximately 125 miles over the Earth's surface. NASA planners therefore had to manage the Hubble exposures more closely, as the HST was exposed to higher levels of radiation as it passed through the anomaly. The HST does not make observations during passage through the South Atlantic Anomaly (Fig. 7.3).

The HDF-S used the same WPPC2 setup as the HDF-N exposures. The WFPC2 exposures were taken over a period of 10 days in the early October 1998. Unlike HDF-N, the HDF-S field was simultaneously imaged by the STIS and the NICMOS. The final HDF-S WFPC2 image is of an area 5.3 sq. arc-minutes.

Over the period from September 24, 2003, through to January 16, 2004, the Hubble Team collected images that formed the Hubble Ultra-Deep Field (HUDF) from an area in the southern hemisphere constellation Fornax. Located at 3h 32m 40.0sec and −27deg 48″ 00″, the HUDF composite image resulted in a coverage

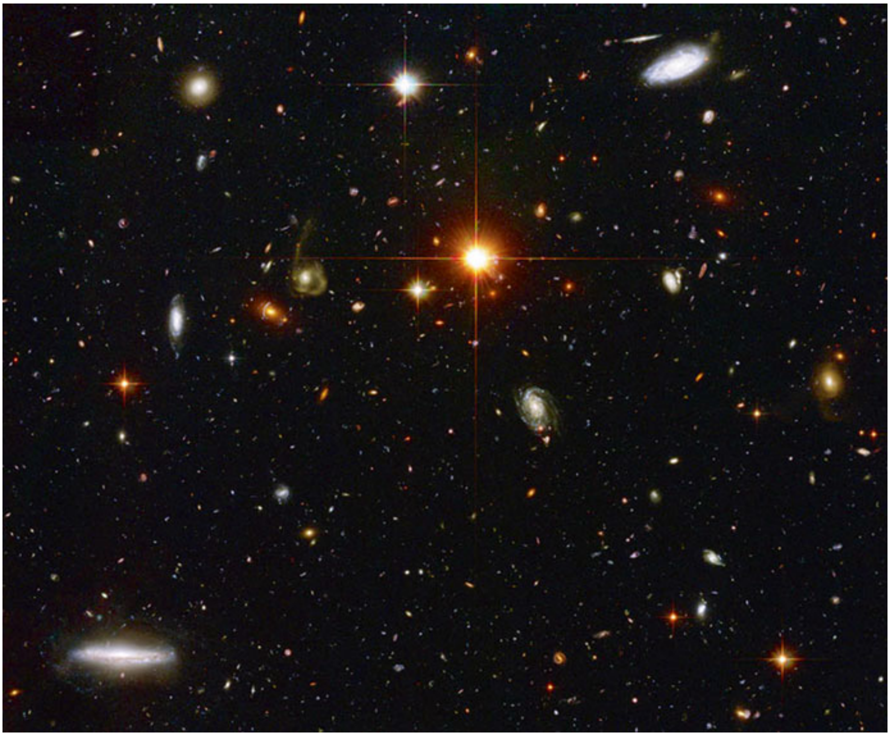

Fig. 7.4 Hubble Ultra-Deep Field (NASA/ESA/STSci)

area of 3 arc-minutes square. Unlike the previous HDF-N and HDF-S, the HUDF used the images taken from the ACS and NICMOS, revealing galaxies deeper in time and space than either of the deep field predecessors. The HUDF detected objects as faint as 30th magnitude. By comparison, the dimmest the human eye can detect are sixth magnitude objects. Ground-based telescopes theoretically can detect 30th-magnitude objects, however Earth's atmosphere and the glare of brighter, nearby galaxies tend to hide the farther reaches. The HUDF image reveals approximately 10,000 galaxies (Fig. 7.4).

Unlike the HDF-N and HDF-S, the HUDF does not lie in Hubble's Continuous Viewing Zone (CVZ). Since the ACS with its lower earthshine noise characteristic was being used instead of the WFPC2, the limitation imposed by the CVZ was no longer significant (Fig. 7.5).

As with the previous two deep field images, the selection of the HUDF field was required to contain very little emission from our galaxy, with little interfering dust or galactic light. It was also decided to select a field that could be observed from ground-based observatories in both northern and southern hemispheres, such as the Atacama Large Millimeter Array in Chile and the numerous observatories located in Hawaii. The field selection was also influenced by the Chandra Deep Field South

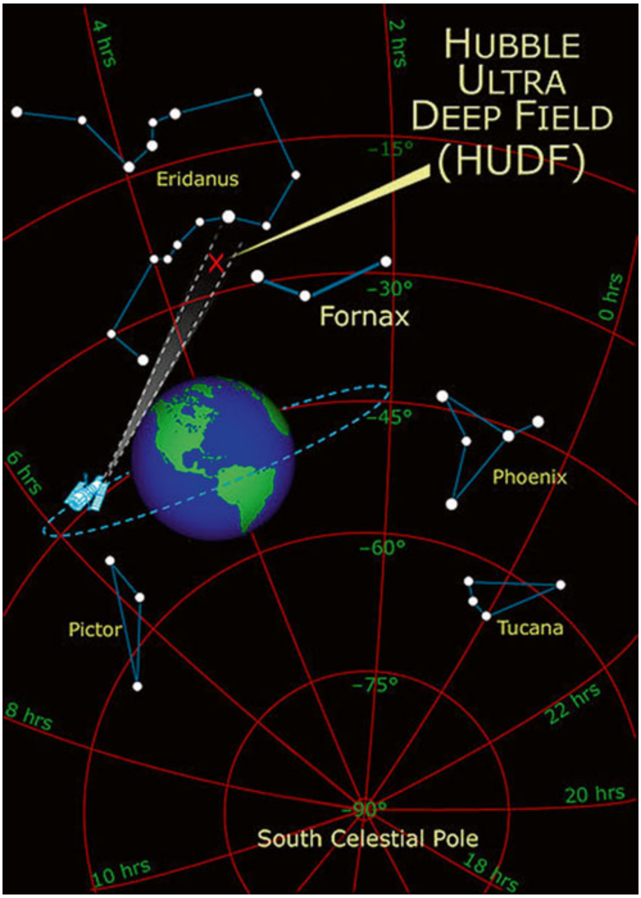

Fig. 7.5 NASA finder chart for the Hubble Ultra-Deep Field (NASA)

image taken by the Chandra X-Ray Observatory satellite, which identified a relatively clear hole through the hydrogen gas clouds of the Milky Way galaxy.

A derivative of the HUDF was released in September of 2012. The image, named the Hubble eXtreme Deep Field (XDF) took 10 years of previous images compiled over the years and processed them to reveal the deepest image of space yet achieved (Fig. 7.6).

XDF is not a new survey of a new area, but a subset of the HUDF, showing a center portion of the HUDF area and covering a 2.3 arc-minute by 2.0 arc-minute area. The XDF image added another 5,500 galaxies to those already shown in the HUDF images, and penetrated deeper into space and time than ever before. Galaxies approximately 13.2 billion years old were imaged from 2 million seconds over 50 days of exposure data. Hubble pointed at the tiny patch of Fornax using the WF/PC 3 and ACS for more than 2,000 images of the same field.

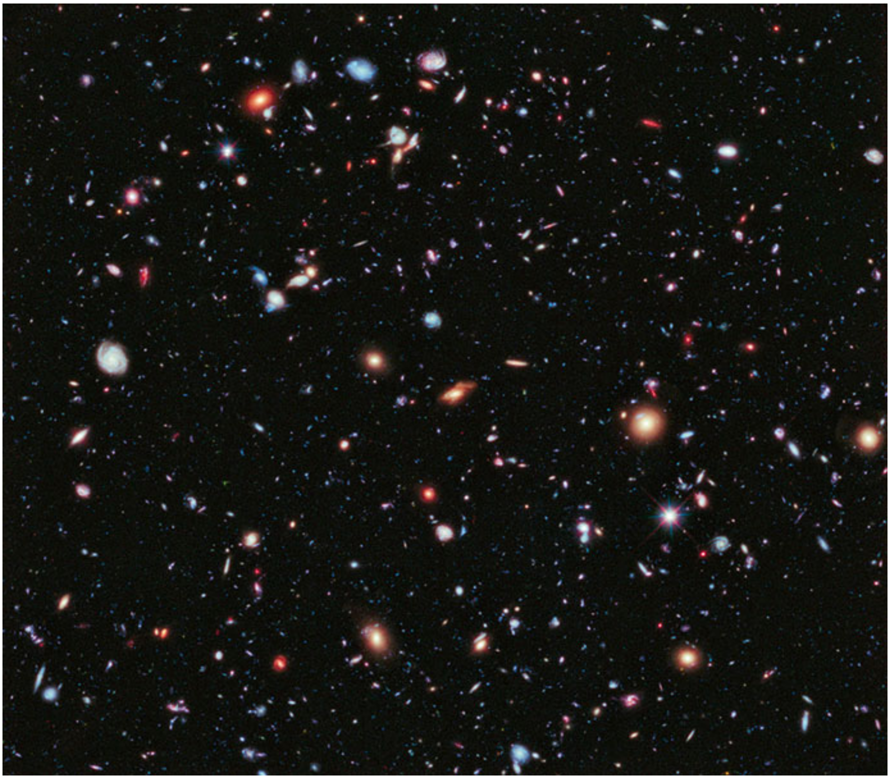

Fig. 7.6 The Hubble eXtreme Deep Field (NASA/ESA)

What is the significance of the four Deep Field images? The HDF-N, HDF-S, HUDF, and XDF have enabled astronomers to delve deeper into space and further back in time than ever before, within a stones throw away from the time of the Big Bang. These Deep Field images, along with the spectrographic data and subsequent supporting ground-based telescope observational data, have contributed to the astronomer's better understanding of the events following the Big Bang, galaxy formation and evolution, and stellar evolution.

Prior to Hubble, conventional ground telescopes peered into the heavens to a depth of a mere 7.0 billion light-years away. The HDF-N and HDF-S images extended the astronomer's view to a depth of 12 billion light-years, with each deep field image revealing over 3,000 new and previously unknown galaxies. HUDF extended the view deeper to approximately 13 billion light-years and showed approximately 10,000 galaxies, and XDF a mind-boggling 13.2 billion light-years. With the age of the Universe recognized by cosmologists as 13.7 billion years old, the light from the faintest galaxies on the XDF image is a view 13.2 billion years into the past, adding to the UDF total an additional 5,500 galaxies theoretically formed only 500 million years after the Big Bang.

Astronomers looked for galaxies with very high redshifts from near the beginning of the universe in the HDF, HUDF, and XDF. As a result of the expansion of the universe, light from distant galaxies shifts towards longer wavelengths. The process is called redshift. The popular analogy to this Doppler effect describes a train whistle increasing in pitch as it approaches, and decreasing in pitch as the train recedes. The redshift of a galaxy indicates how much the light from that galaxy has shifted in wavelength since it was initially emitted. For example, a redshift of 2 means that light from a source has tripled in wavelength since it was emitted, a redshift of 3 means that light from a source has quadrupled in wavelength since it was emitted, and a redshift of 0 means that there was no change in the wavelength of light since emission. Since the redshift of a source tells astronomers how much smaller the universe was when the source emitted its light, astronomers are able to use the redshift of Deep Field galaxies to determine the age of the universe at that time.

The early galaxies from the Deep Field data have at redshifts of between 6 and 10, which corresponds to between 900 and 500 million years after the Big Bang. Since the age of the universe is 13.7 billion years old, then the Hubble data is showing galaxies that are just 47 % of its recognized age.

The Deep Field images have allowed astronomers to observe the evolution of galaxy formation. The oldest galaxies shown are the furthest away. Beginning with the HDF, and followed by the HUDF and XDF, the images show a large proportion of early galaxies were disturbed and irregular in shape than the closer-in and previously known galaxies. These first-generation galaxies were small, irregularly shaped and turbulent formations containing large (estimated up to three times the size of the Sun) stars with little or no heavy elements. Galaxy collisions and mergers were more frequent in the young universe as it was much smaller than today, since the Universe was significantly smaller in size. The Deep Field images revealed the progression of these small oddly shaped galaxies combining and forming larger galaxies, and eventually merging together to form the spiral and elliptical galaxies that scientists are familiar with today (Fig. 7.7).

The stellar spectra observed in these early galaxies show starlight spectra of young stars that have not exhausted their hydrogen fuel. The heavier elements are not formed during a star's lifetime until all the star's hydrogen is depleted during the process of fusion.

During the life of a normal star of a size similar to the Sun, as the hydrogen fuel is depleted, helium fusion takes over, followed by carbon, nitrogen, and oxygen, with the star growing into a red giant. The eventual fate of the normal star is the blowing away of a heavier element outer shell and the formation of a dense white dwarf star fusing even heavier elements until it fizzles out.

If the size of the star is three or more times greater than the Sun, the process becomes more violent. The star as it depletes its hydrogen grows to be a red supergiant star, with a series of nuclear reactions occurring to form different elements in shells around the iron core. Eventually the core collapses in less than a second, causing an explosion called a supernova, in which a shock wave blows off the outer layers of the star. The central core can either be destroyed by the explosion, or collapse into either a neutron star or a black hole, dependent on the mass star.

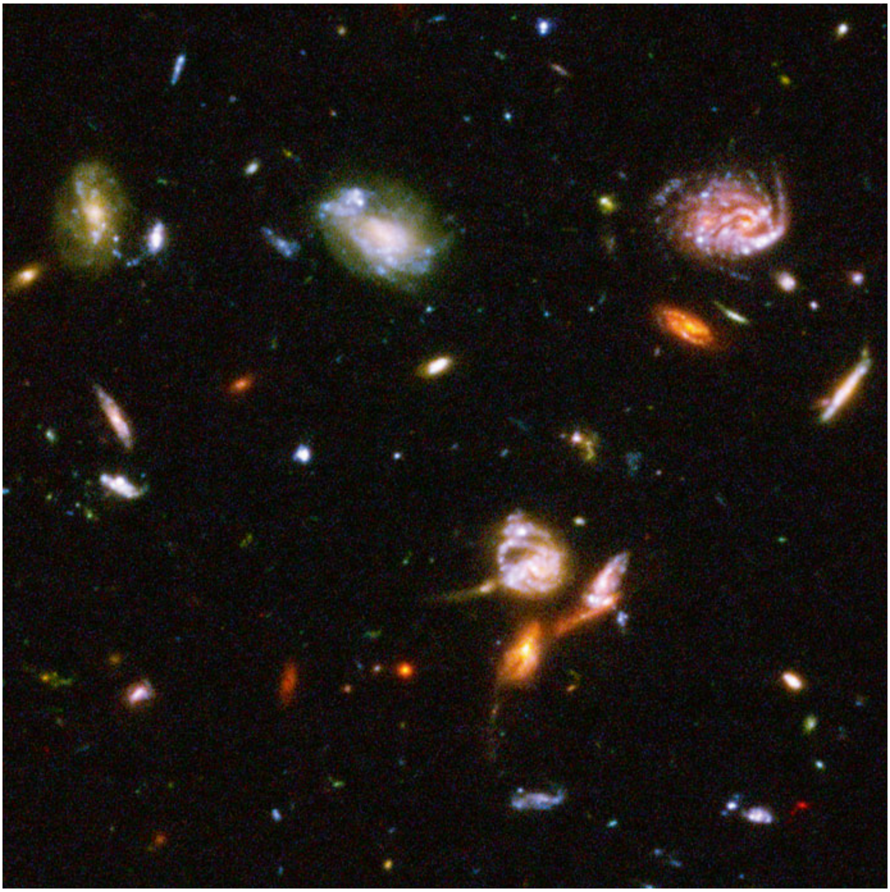

Fig. 7.7 Detail of HUDF showing oddly shaped early galaxies (NASA/ESA and STSci)

The resultant outward expansion of the supernova contains all the heavy elements of the periodic table.

The Hubble spectra of the early galaxies are devoid of heavy metals, and helps provide evidence of the age of these galaxies.

In June of 2014, NASA released a new image called the Ultraviolet Coverage of the Hubble Ultra Deep Field. The new image provides the missing link in the astronomer's study of star formation. Using ultraviolet light, astronomers have combined the full range of colors available to Hubble, stretching all the way from ultraviolet to near-infrared light to generate Fig. 7.8 image. Ultraviolet light comes from the hottest, largest and youngest stars. By observing at these wavelengths, researchers get a direct look at which galaxies are forming stars and where the stars are forming within those galaxies.

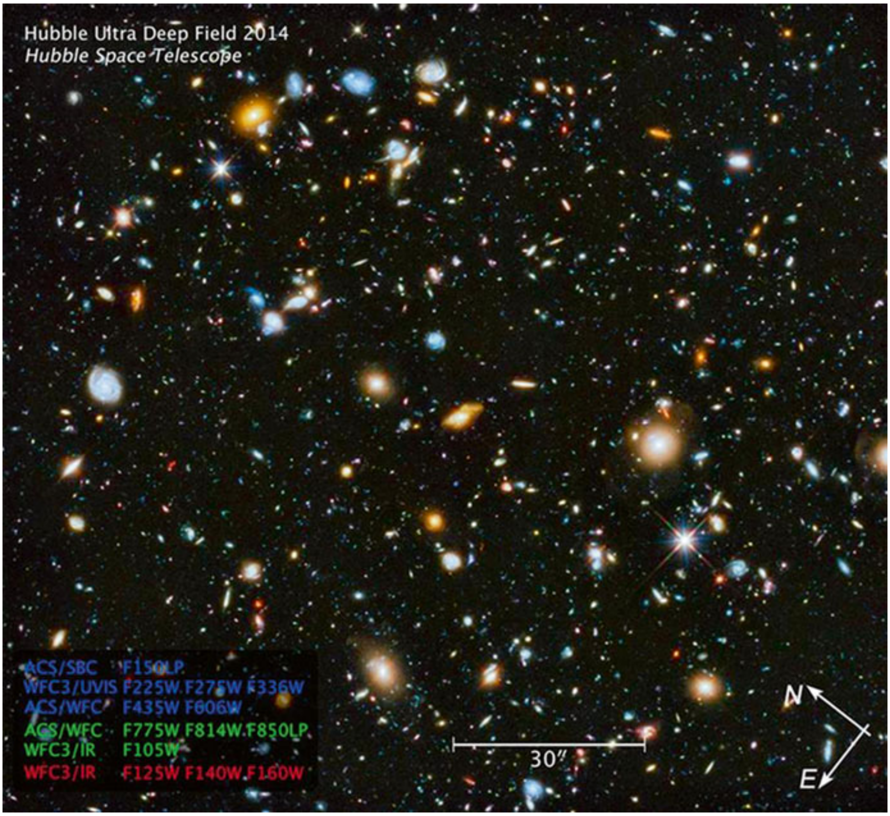

Fig. 7.8 The Hubble Ultraviolet Coverage of the Ultra Wide Field 2014 (NASA/ESA and STSci)

The HDFs, HUDF, and XDF images, by showing galaxies at different stages of their evolution, have allowed astronomers to estimate the variation in the rate of star formation over the lifetime of the universe. With the Deep Field evidence, astronomers believe that star formation was occurring at its maximum rate 8–10 billion years ago, and that today's rate has decreased by a factor of 10.

Research and scientific papers are still being conducted in the analysis of the HDF-N, HDF-S, HUDF, and XDF. Light from the first stars and galaxies is substantially redshifted due to the expansion of the universe since the Big Bang. The redshifts of these early stars and galaxies are so significant that images in the visible wavelength spectrum have become a limiting factor. The future James Webb Space Telescope, with its optics and instrumentation optimized for infrared spectrum, will delve deeper into the infrared portion of the spectrum, with the great hope of future discoveries that will enhance the astronomer's knowledge of the early Universe.

Chapter 8

The Planets

The term *planet* comes from the ancient Greek word for wandering star. The ancient astronomers observed that five *stars* were not stationary against the stellar background, but actually changed position over time.

Beginning with Copernicus, astronomers have gained an almost complete understanding of the movement and dynamics of the major planets. It is now recognized that these wandering stars are actually planets orbiting the Sun, and that Earth, along with seven other major planets, several dwarf planets (including the controversial demotion of Pluto to the dwarf planet category), asteroids, comets, the Kuiper Belt objects and the Oort Cloud all constitute our solar system.

This chapter is structured differently from the earlier chapters, since the planets are not in constant position in the sky. The reader is invited to reference the popular astronomy magazines, astronomy computer applications and software, or access astronomy websites for the current location of a planet of interest.

Conspicuous by their absence are any HST photos of the solar system's innermost planets Mercury and Venus. One of the limitations of the Hubble is its inability to observe the Sun, or any objects near the Sun. Hubble's instrumentation is too sensitive for exposure to the intense heat and sunlight from the Sun. The risk of damage to the Hubble cameras and spectroscopic equipment is too high to view inner planets Mercury and Venus. These planets can be seen by a backyard astronomer, so long as care is taken because of the same risks shared with Hubble.

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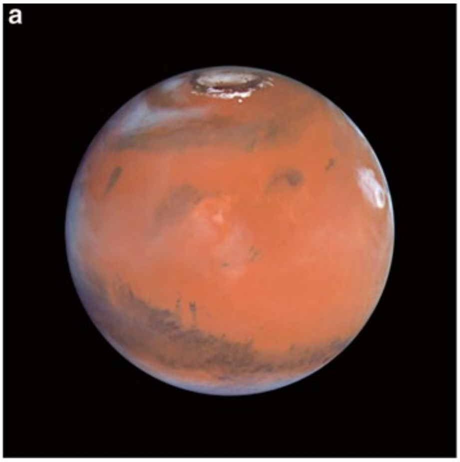
Mars



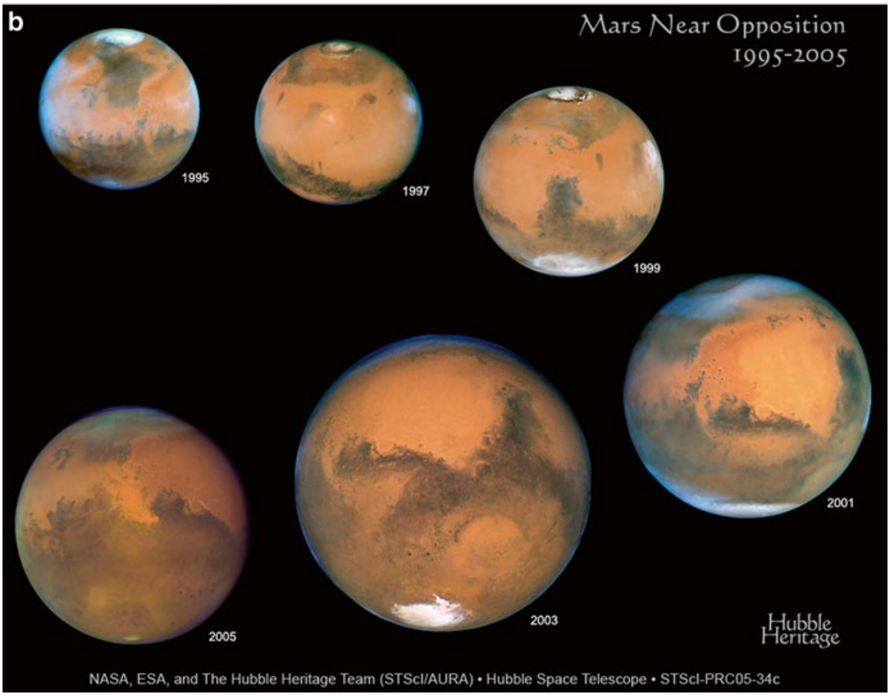


Fig. 8.1 (**a**) Hubble image of Mars in 2001 (NASA and The Hubble Heritage Team (STScI/AURA)), (**b**) Composite Mars images taken by Hubble (NASA and The Hubble Heritage Team (STScI/AURA))

The earliest record of the fourth planet of the solar system being observed dates back to the Bronze Age and the ancient Egyptians. Ancient Egyptian astronomers were familiar with the planet and the apparent retrograde motion of Mars. Images of Mars can be found on the ceiling of the tomb of Seti I, on the ceiling of the memorial temple of Pharaoh Ramses II (called the Ramesseum), and in the Senenmut star map (Fig. 8.1).

The Chinese independently recorded the existence and the motions of Mars towards the end of the Shang Dynasty and just prior to the Zhou Dynasty, roughly around 1045 BC.

By 1543, Nicolaus Copernicus successfully explained the apparent retrograde motion of Mars, Jupiter, and Saturn in his heliocentric model of the solar system. With the Sun at the center of the solar system and when Mars and the other outer planets are on the opposite side of the sky from the Sun, the apparent retrograde motion is evident to observers on the Earth.

Galileo was the first person known to use a telescope to make astronomical observations. He began observing Mars through his telescope in September 1610 (Fig. 8.2).

Fig. 8.2 Amateur astrophoto of Mars during the 2014 Opposition (John Livermore)

Mars is the fourth planet from the Solar System, and is the next to the smallest major planet, with Mercury being the smallest. Named after the Roman god of war, Mars is often referred to as the Red Planet due to its reddish-rust appearance. Like Mercury, Venus, and the Earth, Mars is a rocky planet with a thin atmosphere. It is theorized that the two Martian moons, Deimos and Phobos, are captured asteroids, because of their small size and irregular shape.

Observing Mars can be a disappointing experience to the novice astronomer, and a challenge for the most experienced backyard astronomer. When observed at anytime other than at opposition, Mars is no better than a very small reddish-orange sphere with no distinguishing features visible, even at high power. Even when the planet is closest to the Earth at opposition, Mars is a difficult-to-observe and low contrast object. At opposition, Mars displays low contrast areas of red, red-orange, orange-red, orange, orange-yellow, yellow-orange, and yellow hues, along with variations of those colors in between.

Opposition is when periodically both Earth and Mars are on the same side opposite of the Sun for a close approach to each other. These oppositions occur roughly 390 days after conjunction, when the Earth and Mars are exactly across from each other, with the Sun in the middle. So an opposition occurs approximately every 2 years and 2 months. After that period of time, the Earth has moved around the sun exactly one time more than Mars, or 2.135311456 times, while Mars completed 1.135311456 revolutions, so that Earth and Mars are again in a line from the Sun.

It is at these opposition times amateur and professional astronomers alike point their telescopes at the fourth planet.

Even with the closest of approaches (remember the Earth's and Mars's orbits are elliptical, and some oppositions are closer than others), Mars is a challenge to observe. Mars is a low contrast planet to observe visually, requiring the best of optics (preferably a refractor), clean optics, transparent skies, and a red #25 or red-orange #23A color filter. Mars observing also requires high magnification.

The Hubble Space Telescope was used extensively to observe entire Martian weather systems and provide updated planetary weather reports on Mars to help plan the Mars Spirit, Opportunity, and Curiosity missions. Information captured by Hubble and the National Radio Astronomy Observatory (NRAO) showed that Mars is more often cloudy than dusty. Mars experiences abrupt planet-wide shifts from hot dusty conditions to cold cloudy conditions. These shifts in climate are driven by three important factors: Mars' thin atmosphere, its elliptical orbit around the sun, and strong climatic interactions between dust and water ice clouds in the atmosphere. Mars' atmosphere is so thin that it weighs less than 1 % of Earth's atmosphere. Mars' atmosphere is paper-thin and there are no oceans to store up heat from the sun. Therefore, the surface changes and atmospheric heating by the sun causes the planet's temperatures change rapidly and intensely. There are also much larger annual changes in sunlight falling on Mars than on Earth, because Mars' distance from the sun varies by 20 % in its orbit around the sun every 2 years.

Jupiter

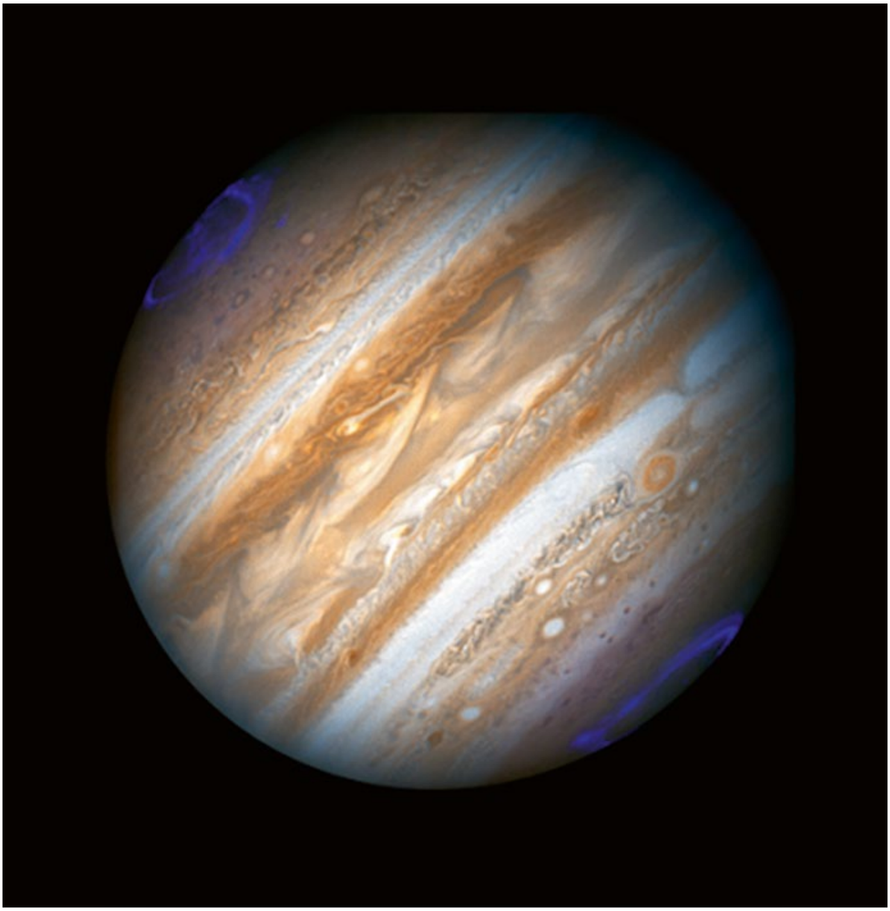


Fig. 8.3 Hubble image of Jupiter with aurora (NASA, ESA, and The Hubble Heritage Team (AURA/STScI))

Jupiter is the fifth planet from the Sun, and is the largest major planet in the Solar System. Jupiter is a gas giant planet with a diameter of 88,846 miles across its equator. Named after the Roman god Jupiter, there are 67 moons orbiting the planet, along with a very faint ring system (Figs. 8.3 and 8.4).

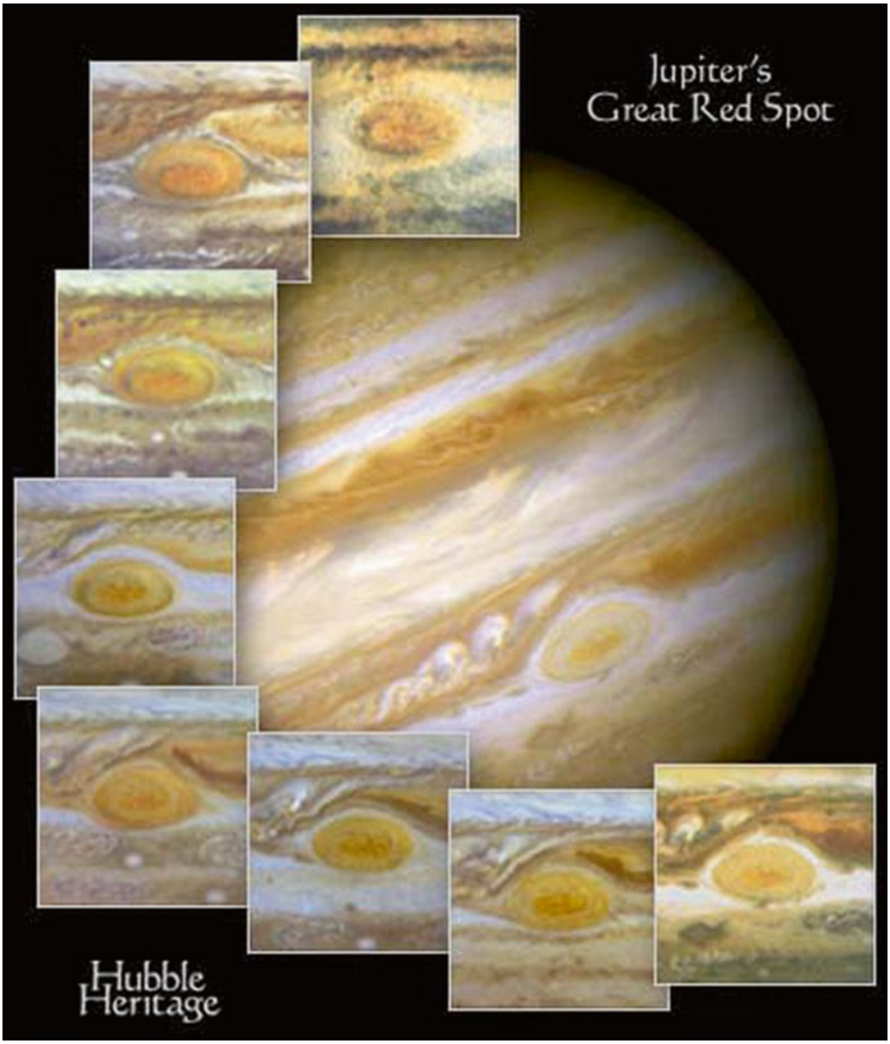


Fig. 8.4 Hubble image composite of Jupiter and the Great Red Spot (NASA and The Hubble Heritage Team (STScI/AURA))

Astronomers of ancient Babylon first observed Jupiter around the seventh or eighth century B.C.

Chinese astronomer Gan De also is recognized for making some of the first detailed observations of Jupiter in recorded history, which he described as "very large and bright". In one of his observations on Jupiter, he recorded a "small reddish star" next to Jupiter. Somewhat controversially, Chinese historian Xi Zezong claims that in 385 B.C. Gan De made a naked eye sighting of the Jovian moon Ganymede. This claim would precede Galileo's discovery of Ganymede in 1610. Galileo and all modern astronomers require the aid of a telescope to view Ganymede or any of the Jovian moons. His red description also provides evidence to question the Gan De discovery, since the Jovian moons are very faint, and in modern telescopes appear as white. The human eye is least sensitive to red frequencies under low light conditions, the Xi Zezong claim is highly questionable.

In 1610, Galileo aimed his telescope upon Jupiter and discovered the four largest moons. Now referred to as the Galilean moons, the moons were named Io, Europa, Ganymede, and Callisto. The importance of this discovery by Galileo was the first recognition of celestial movement that was not Earth-centric, thus providing support to the Copernican heliocentric theory.

The discovery and first observation of Jupiter's Great Red Spot is under dispute. Some attribute the discovery to Robert Hooke in 1664, while Giovanni Cassini's sighting in 1665 may have been the first.

The earliest known detailed drawing of the Great Red Spot did not appear until 1831, when Heinrich Schwabe recorded his observations of the planet. Schwabe went on to be awarded in 1857, the Gold Medal of the Royal Astronomical Society for his work in discovery of and observations of sunspots (Figs. 8.5 and 8.6).

Fig. 8.5 Amateur astrophoto of Jupiter taken in 2013 (John Livermore)

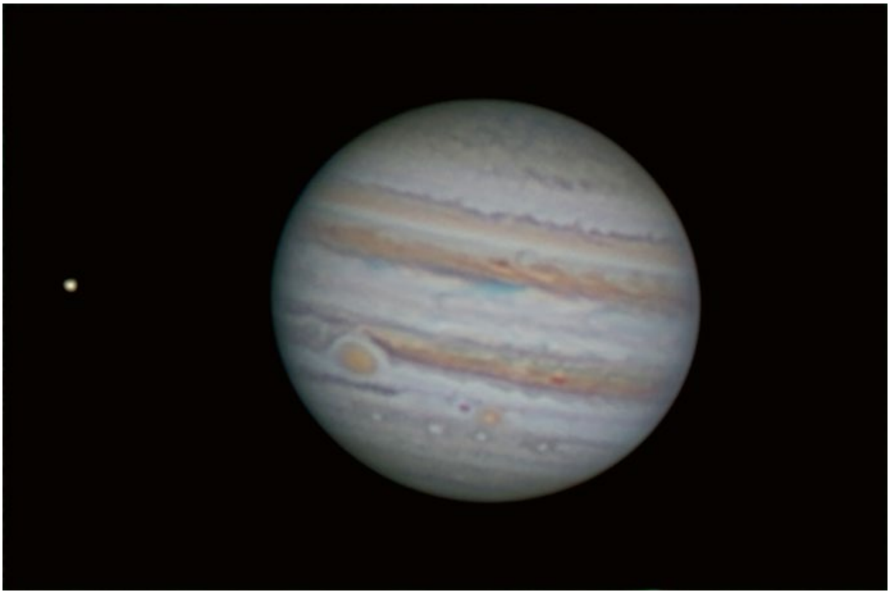


Fig. 8.6 Another amateur astrophoto of Jupiter taken in 2012 (Jon Talbot)

Jupiter is one of the showcase objects of the night sky. It is a satisfying planet no matter what size telescope is used. Medium-to-high magnification can be used, depending on the steadiness of the atmosphere.

The ever-changing positions of the four Galilean moons provide endless opportunities to witness the transits across the face of the planet, or seeing a moon slowly emerging from behind Jupiter. Often during a transit, the shadow of the transiting moon can be seen cast as a small black dot on the top cloud layer.

Jupiter is a very interesting object to study through a telescope using various filters to reveal the giant planet's details. Using a light blue filter, either #38A or #80A, enhances the contrast within the bright zones on this planet and sharpens boundaries of faint cloud currents. Since Jupiter's belts are brown both the green #57 and blue #47 filters will darken them. A yellow #11, #12, or #15 filter will darken the blue festoons that appear near the North Equatorial Belt's south edge and equatorial zone. A magenta #30 filter is great to brighten and enhance those white ovals seen in the South Temperate Belts and Zone. At times the famous Great Red Spot may be difficult to see, since through small telescopes the Red Spot will look a little salmon-pink colored. By trying different color filters, the Great Red Spot often pops out to the observer. Experiment with color filters to see which works best.

One of the discoveries derived from the Hubble Space Telescope images has been that the fabled Great Red Spot is shrinking. Recent HST observations confirm the Great Red Spot now is approximately 10,250 miles across, less than half the size of some historical measurements.

Astronomers have followed this downsizing since the 1930s. Historic observations from the late 1800s scaled the storm to be 25,500 miles on its long axis. NASA Voyager 1 and Voyager 2 flybys of Jupiter in 1979 measured it to be 14,500 miles across. In 1995, a Hubble WF/PC2 photo showed the long axis of the spot at an estimated 13,020 miles across. And in a 2009 photo, it was measured at 11,130 miles across. Astronomers using the Hubble Space Telescope calculate that the GRS is narrowing by about 580 miles a year, much faster than before. As of May, 2014, based on the latest Hubble images, the GRS has shrunk to the size of 10,250 miles across.

As seen in Fig. 8.3, Hubble has provided photographic evidence of aurora activity on Jupiter. Aurora are caused by the interaction of charged particles with a planet's atmosphere as particles spiral along the magnetic field lines. The light generated by the charged particle interaction causes atoms in the atmosphere are excited, displaying colors of different wavelengths. Jupiter's aurora are seen generally in the ultraviolet and near infrared wavelengths. Like the giant planet's other superlative properties, the aurora on Jupiter are also the most intense seen in the solar system.

On Jupiter, auroral emission ions are seen in three distinct forms or regions—a main oval shape around the magnetic pole that remains steady and rotating with the planet, a polar aurora that is highly variable with time and location, and in the form of footprints of Jupiter's larger moons as distinct spots. The moon auroral footprints are caused by the electrical currents produced at the moon and move along Jupiter's magnetic field.

As described in Chap. 1, just a few months after Servicing Mission 1 had corrected the HST optical performance, Comet Shoemaker-Levy 9 broke into pieces and slammed into Jupiter. Hubble was able to capture this historic and rare event with amazing details, seen in Fig. 1.2. This event was the first observed comet impacting a planet in the Solar System, and has helped draw attention to the possibilities of such an event occurring on Earth.

Saturn

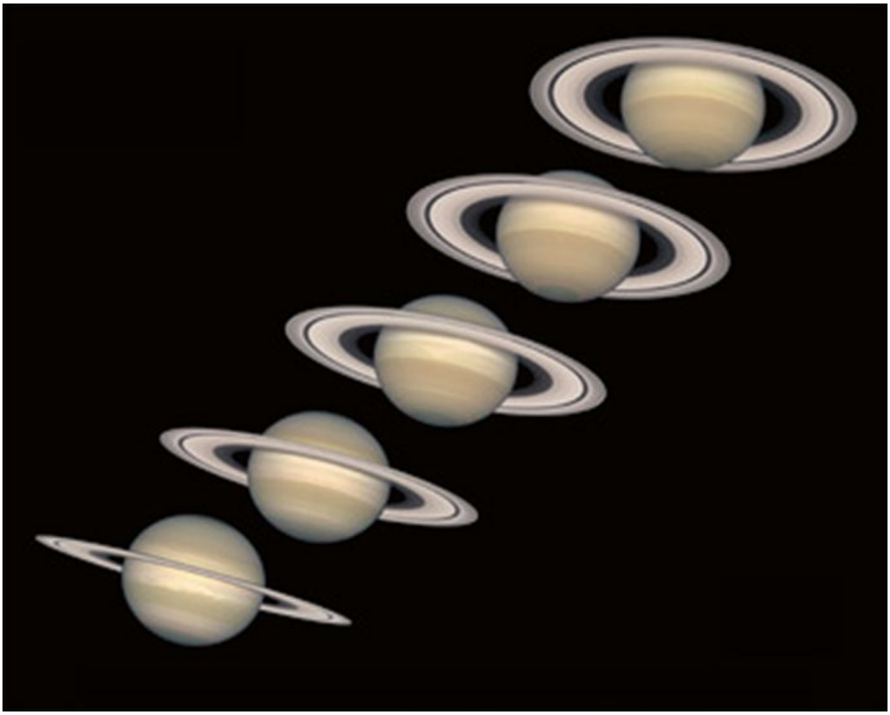


Fig. 8.7 Hubble image compilation of Saturn (NASA and The Hubble Heritage Team (STScI/AURA))

Saturn is the sixth major planet from the Sun, and is the second largest planet in the Solar System. Like Jupiter, Saturn is a gas giant, with a diameter of 74,896 miles. In Roman mythology, Saturn was the god of agriculture. The most notable feature of Saturn is its ring system, which can be seen from almost any small telescope on Earth. In addition to its complex ring system, there are 62 moons orbiting the sixth planet (Fig. 8.7).

As with Jupiter, ancient Babylonian astronomers observed Saturn, and observed its motion in the sky. To the ancients, Saturn displayed the retrograde motion in the sky, now known to be a visual evidence of a heliocentric solar system. Saturn was known to the ancient Chinese and Japanese cultures as an earth star, based on the ancient Asian beliefs of Five Natural Elements.

In 1610, Galileo's optically challenged telescope was not able to resolve Saturn's ring structure, although his drawings do reveal what he believed to be two attendant moons to either side of the planet. Christian Huygens, equipped with a more capable telescope, was the first to see Saturn's rings in 1655. Huygens described what he believed as a solid single ring as:

> "a thin, flat ring, nowhere touching, and inclined to the ecliptic."

It was during his 1655 observations of Saturn that Huygens also discovered Saturn's largest moon, Titan (Fig. 8.8).

Fig. 8.8 Amateur astrophoto of Saturn (Chris Miskiewicz)

Saturn is the great showcase astronomical object that amateur astronomers to use to introduce astronomy to youngsters and adults. Peering through the eyepiece of a telescope for the first time to see Saturn and its ring system always brings gasps of wonder.

Like its next-door neighbor, Saturn has bright and dark cloud bands similar to Jupiter, although more subtle than the larger planet. The brighter zones appear off-white and slate-gray or yellowish at times. On the other hand, Saturn's belts exhibit bluish-gray, brown and reddish colors, easily seen using the same filters as for Jupiter. Brighter patches sometimes appear on this ringed planet and are best seen as green or blue-green light. The rings are highlighted using a light green #57 filter and at times a magenta filter #30.

Saturn does appear slightly smaller than its Jovian counterpart. Additional magnification is in order. To see the Cassini Division in the ring structure requires a minimum of a 4 inch refractor or a 6 inch reflector or compound telescope.

Figure 8.9 was the first image of Saturn's ultraviolet aurora taken by the Space Telescope Imaging Spectrograph (STIS) on board the Hubble Space Telescope in October 1997, when Saturn was a distance of 810 million miles (1.3 billion kilometers) from Earth. The STIS, when used as a camera, provided more than ten times the sensitivity of previous Hubble instruments in the ultraviolet. STIS images revealed never before seen detail in the auroral curtains of light that encircles the north and south poles of Saturn. Saturn's aurora rise more than a thousand miles above the cloud tops.

Unlike the Earth, Saturn's aurora is only seen in ultraviolet light that is invisible from the Earth's surface, hence the aurora can only be observed from space. The Hubble images reveal ripples and overall patterns that evolve slowly, appearing generally fixed in place and independent of planet rotation. At the same time, the curtains show local brightening that often follow the rotation of the planet and exhibit rapid variations on time scales of minutes. These variations and regularities indicate that the aurora is primarily shaped and powered by a continual tug-of-war between Saturn's magnetic field and the flow of charged particles from the Sun.

In May 22, 1995, Hubble captured four images from previously undiscovered moons of Saturn. Two of the new moons, called S/1995 S1 and S2, lie inside Saturn's thin, eccentric "F" ring. The third moon, S3, lies just outside the F ring; and the fourth moon, S4, is 3,700 miles beyond the F ring. The moons are no bigger than about 45 miles across.

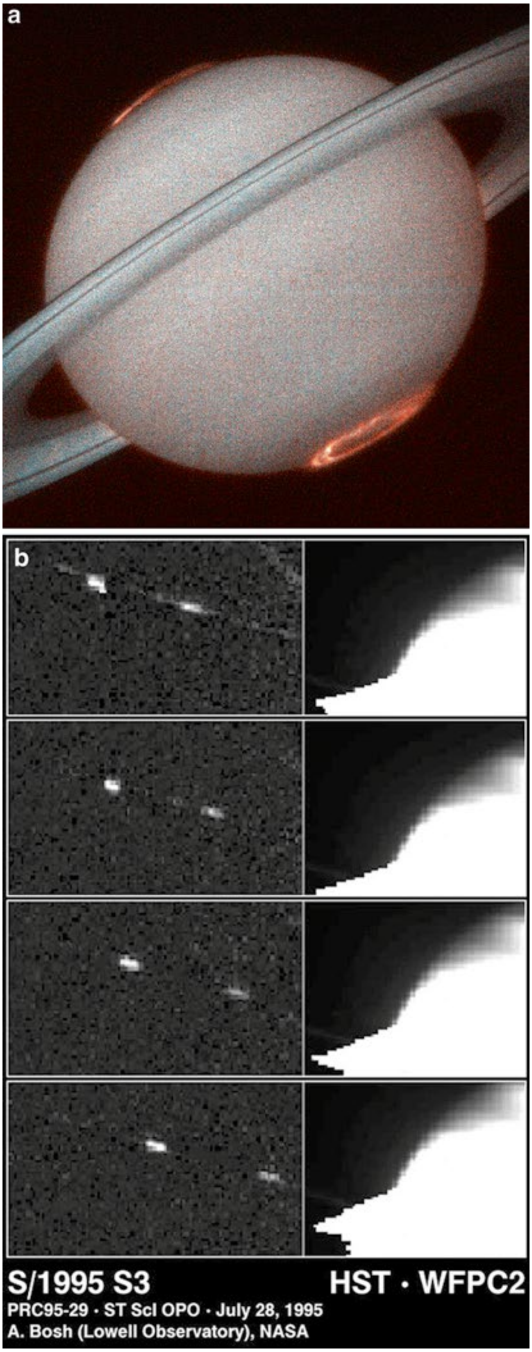


Fig. 8.9 (**a**) Hubble image of Saturn's aurora (J.T. Trauger (Jet Propulsion Laboratory) and NASA), (**b**) Hubble images of the discovery of the S3 moon (Amanda S. Bosh (Lowell Observatory), Andrew S. Rivkin (Lowell Observatory and University of Arizona/Lunar Planetary Lab), High Speed Photometer Instrument Definition Team (R.C. Bless, PI), and NASA)

Uranus

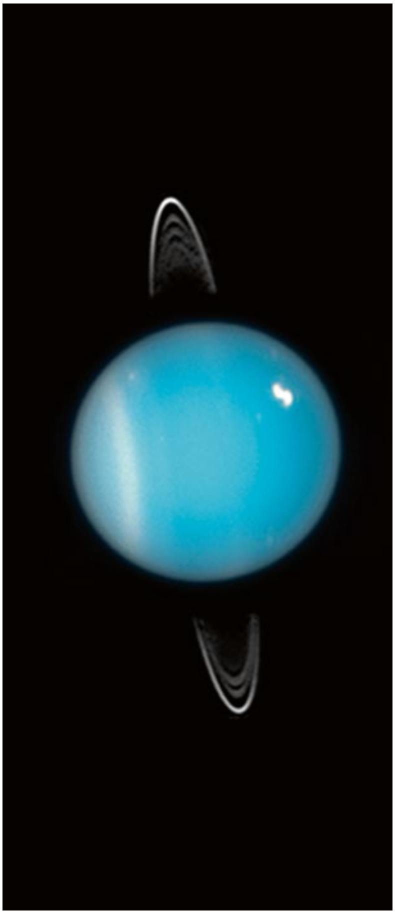


Fig. 8.10 Hubble image of Uranus (NASA, ESA, and Hubble Heritage Team)

Uranus is the seventh major planet from the Sun, and is the third largest planet in the Solar System (Fig. 8.10). Uranus is sometimes characterized as an ice planet, as opposed to Jupiter and Saturn, because of the presence of water, ammonia, methane, and hydrocarbon ice crystal clouds in its atmosphere. A faint ring system and 27 moons circle the planet. The most unusual aspect of Uranus is its axial tilt of 97.77 degrees, so its axis of rotation is approximately parallel with the plane of the Solar System. This gives it seasonal changes completely unlike those of the other major planets. Other planets can be visualized to rotate like tilted spinning tops on the plane of the Solar System, whereas Uranus rotates more like a tilted rolling ball. This unusual position results in one pole facing the Sun continuously whereas the other one faces away during the seasonal solstice. Only a narrow strip around the equator experiences a rapid day–night cycle, but with the Sun very low over the horizon as in the Earth's polar regions. At the other side of Uranus's orbit the orientation of the poles towards the Sun is reversed. Each pole gets around 42 years of continuous sunlight, followed by 42 years of darkness. Only during the time of seasonal equinoxes does the equator of Uranus experience a "normal" day-night cycle.

William Herschel announced the discovery of Uranus on March 13, 1781. Previous to Herschel's announcement, Uranus had been observed by both ancient astronomers and by pioneering astronomers of the 1600s, but recognized as only a star. The earliest recorded sighting was in 1690 by John Flamsteed, who observed it at least six times, cataloging it as 34 Tauri. Pierre Lemonnier observed Uranus at least 12 times between 1750 and 1769, including on four consecutive nights.

Herschel's initial observations led him to believe that Uranus was a comet, but he was confused by several characteristics that were different from comets:

> "The power I had on when I first saw the comet was 227. From experience I know that the diameters of the fixed stars are not proportionally magnified with higher powers, as planets are; therefore I now put the powers at 460 and 932, and found that the diameter of the comet increased in proportion to the power, as it ought to be, on the supposition of its not being a fixed star, while the diameters of the stars to which I compared it were not increased in the same ratio. Moreover, the comet being magnified much beyond what its light would admit of, appeared hazy and ill-defined with these great powers, while the stars preserved that lustre and distinctness which from many thousand observations I knew they would retain. The sequel has shown that my surmises were well-founded, this proving to be the Comet we have lately observed."

In his letter to the Astronomer Royal, Nevil Maskelyne:

> "I don't know what to call it. It is as likely to be a regular planet moving in an orbit nearly circular to the sun as a Comet moving in a very eccentric ellipsis. I have not yet seen any coma or tail to it"

Contemporaries of Herschel's, such as Anders Johan Lexell and Johann Elert Bode, examined Herschel's "comet", and came to the conclusion that because of the near-circular orbital elements, that this moving star was indeed a planet. By 1783, even William Herschel acknowledged that he had discovered a new "primary planet of Our Solar System."

Bode is credited with naming the sixth planet Uranus, using the logic that Saturn was the father of Jupiter, and Uranus was the father of Saturn in mythology (Fig. 8.11).

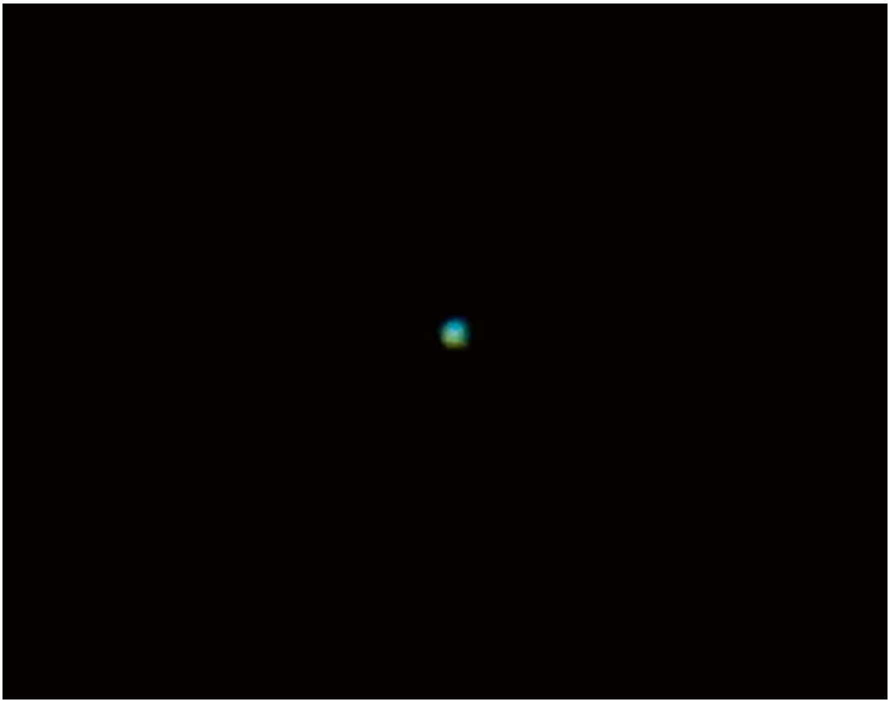


Fig. 8.11 Amateur astrophoto of Uranus (Chris Miskiewicz)

Uranus is by no means a showcase planet to observe. The best a backyard astronomer can hope to achieve is recognizing a small blue-green sphere with little or no detail. Yellow-green #12, green #57, and magenta #30 filters are recommended on these bluish and greenish planets, such as Uranus and Neptune. Observing Uranus is difficult in the average backyard telescope. Uranus's blue-greenish color begins to change to a bright blue using a moderate to large aperture telescope of 12–24 inches in size (Fig. 8.12).

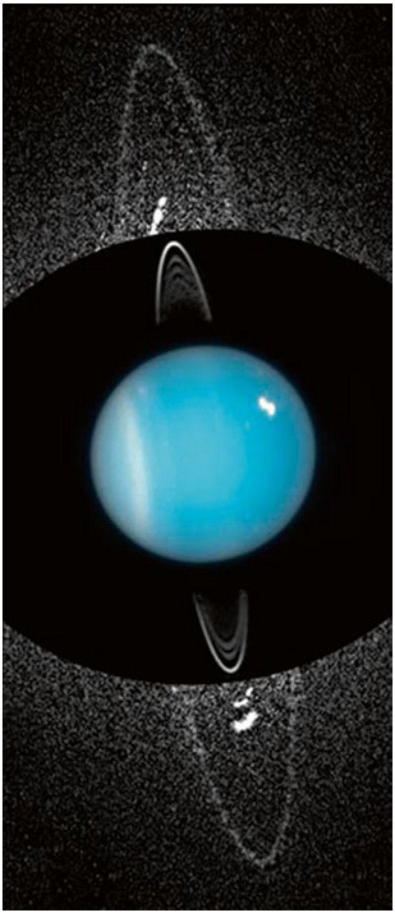


Fig. 8.12 Hubble composite image of Uranus and new rings (NASA, ESA, and M. Showalter (SETI Institute))

In December 2005, the HST detected a pair of previously unknown rings. The largest is twice the diameter of the planet's previously known ring system, first discovered in the late 1970s. These new rings are so far from Uranus that they are called the "outer" ring system. Hubble also spotted two small satellites, named Mab and Cupid, with Mab sharing its orbit with the outermost newly discovered ring.

Mab is probably the source of the fresh dust that keeps replenishing the ring with new material being knocked off the small moon from meteoroid impacts. Without such replenishment, the dust in the ring would slowly spiral in toward Uranus. Collectively, these new discoveries mean that Uranus has a youthful and dynamic system of rings and moons. Because of the extreme tilt of Uranus's axis, the ring system appears nearly perpendicular relative to rings around other gas giant planets like Saturn. Also, unlike Saturn, the rings are very dark and dim because they are mostly dust rather than ice.

Neptune

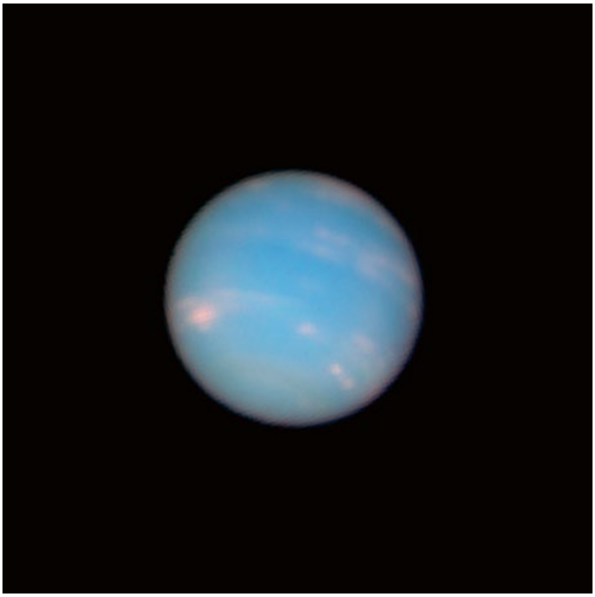


Fig. 8.13 Hubble image of Neptune (NASA, ESA, and Hubble Heritage Team)

Neptune is the eighth and furthest major planet from the Sun, since Pluto was recategorized as a dwarf planet in 2006 (Fig. 8.13). Named for the Roman mythology god of the sea, Neptune is the fourth-largest planet by diameter and the third-largest by mass. Although physically smaller than Uranus, it is more dense than the seventh planet. Still considered a gas giant like Uranus, it also is referred to as an ice giant because of the presence of water, methane, ammonia, and trace hydrocarbons in icy clouds in its atmosphere. Neptune possesses a faint ring system, and has 14 known moons orbiting the planet. With an equatorial diameter of 30,776 miles, Neptune is smaller than Uranus, but its density exceeds that of its sister ice giant planet.

Galileo was the first to observe Neptune, categorizing it as a star, on December 28, 1612, and again on January 27, 1613.

The discovery of Neptune was based on gravitational perturbations of the calculated orbit of Uranus. Beginning in 1821, leading astronomers were led by their calculations to search for another planet that was gravitationally influencing the orbit of Uranus. By 1845–1846 timeframe, a race developed between John Couch Adams and Cambridge Observatory director James Challis, and the Urbain Le Verrier and Berlin astronomer Johann Gottfried Galle to find the missing planet. On 23 September 1846, Neptune was discovered by Galle within 1 degree of where Le Verrier had predicted it to be, and about 12 degrees from Adams' prediction. Up until 1998, Le Verrier and Adams shared the credit of Neptune's discovery. However, historians reviewing all the historical documentation concluded that "Adams does not deserve equal credit with Le Verrier for the discovery of Neptune. That credit belongs only to the person who succeeded both in predicting the planet's place and in convincing astronomers to search for it" (Fig. 8.14).

Fig. 8.14 Hubble image of Neptune (Chris Miskiewicz)

As with Uranus, yellow-green #W12, green #57, and magenta #30 color filters are recommended on these blue-green planets. Again as with Uranus, observing Neptune is difficult and their blue-greenish color begins to change to a bright blue using moderate to large aperture amateur telescopes of 12–24 inches.

Prior to the advent of Hubble, the best view of Uranus and Neptune was provided by the 1986 flyby of Uranus and the 1989 flyby of Neptune by the Voyager 2 deep space probe. The high resolution photos from Voyager 2 were phenomenal, but a short duration snapshot of the gas and ice giant. The HST has provided the capability for extended study and monitoring of both Uranus and Neptune, although at a slightly less resolution level than Voyager because of the distance. Hubble has been able to provide astronomers with photo sequences, allowing views of cloud formation and cloud movement on these distant planets and extending the scientific knowledge of weather systems on other worlds (Fig. 8.15).

For instance, in 1989, Voyager 2 imaged on Neptune a large storm, dubbed the Great Dark Spot, similar to Jupiter's Great Red Spot. In November 1994, the HST was unable to find the Great Dark Spot, but found a similar type of storm in Neptune's northern hemisphere (Fig. 8.16).

In July, 2013, NASA announced that the Hubble Space Telescope had discovered a new moon orbiting Neptune, increasing the total number of moons known to be circling the giant planet to 14. The moon, designated S/2004 N 1, is estimated

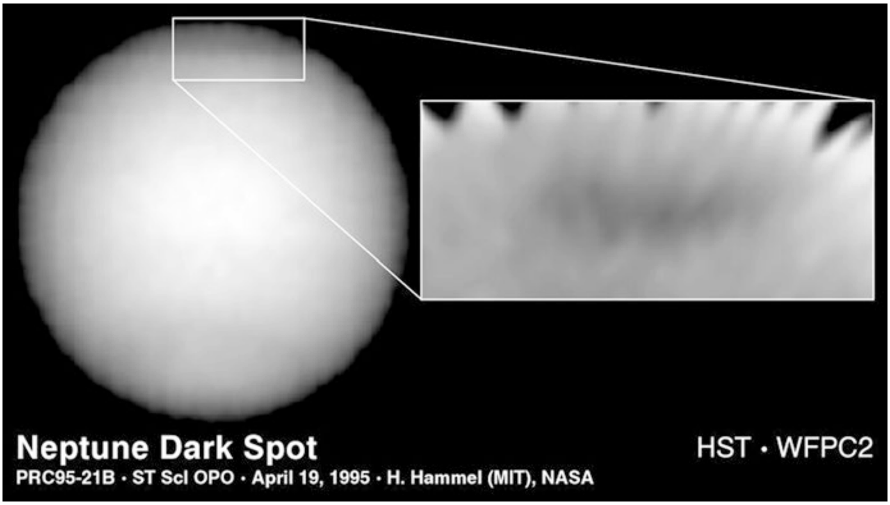


Fig. 8.15 Hubble image of Neptune and the new Dark Spot (H. Hammel (Massachusetts Institute of Technology) and NASA)

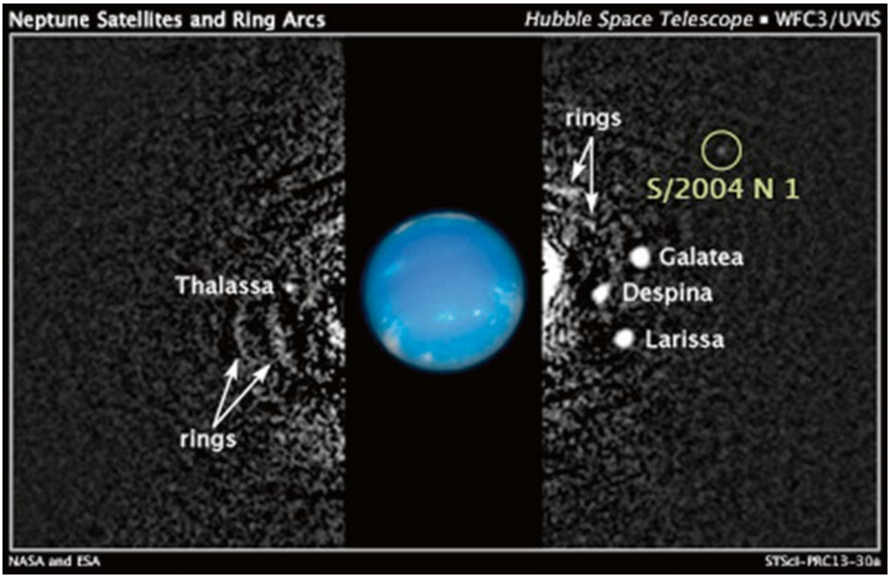


Fig. 8.16 Composite Hubble image of Neptune and the newly discovered 14th moon (NASA, ESA, and M. Showalter (SETI Institute))

to be no more than 12 miles across, making it the smallest known moon in the Neptunian system. It is so small and dim that it is roughly 100 million times fainter than the faintest star that can be seen with the naked eye.

Pluto, Ceres, and the Dwarf Planets

According to the International Astronomical Union, which sets definitions for planetary science, a dwarf planet is a celestial body that:

- Orbits the sun.
- Has enough mass to assume a nearly round shape.
- Has not cleared the neighborhood around its orbit.
- Is not a moon.

The main distinction between a dwarf planet and a planet is that planets have cleared the path around the sun of leftover debris while dwarf planets tend to orbit in zones of similar objects that can cross their path around the sun, such as the asteroid and Kuiper Belt. Dwarf planets also are generally smaller than the planet Mercury.

The first five recognized dwarf planets are Ceres, Pluto, Eris, Makemake, and Haumea. Scientists believe there may be dozens or even more than 100 dwarf planets awaiting discovery.

The IAU recognized Pluto's special place in our solar system by designating dwarf planets that orbit the sun beyond Neptune as plutoids. Eris, which orbits far beyond Neptune, is a plutoid while Ceres, which orbits in the main asteroid belt between Mars and Jupiter is a dwarf planet (Fig. 8.17).

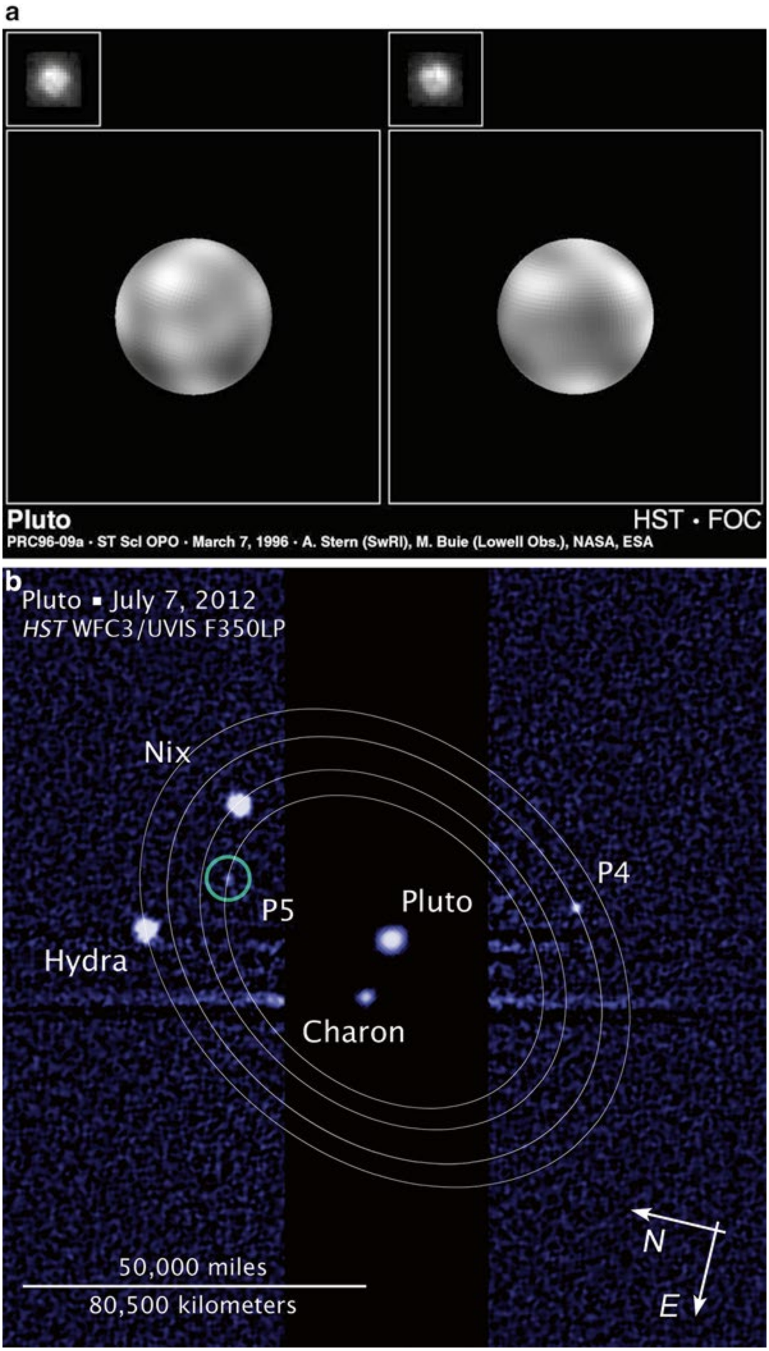


Fig. 8.17 (**a**) Hubble images of Pluto (NASA, ESA, Alan Stern (Southwest Research Institute), Marc Buie (Lowell Observatory)), (**b**) Hubble images of Pluto moons (NASA, ESA, and L. Frattare (STScI))

Discovered in 1930 by Clyde Tombaugh, Pluto was originally classified as the ninth planet in the Solar System. Named after the Roman god of the underworld, Pluto's name was suggested by an 11-year-old schoolgirl named Venetia Burney. The story goes that the young girl suggested the name Pluto for Tombaugh's new discovery to her grandmother, a former librarian at Oxford's Bodleian Library, who then passed the name on to Prof. Herbert Hall Turner. Turner then cabled the name suggestion to colleagues in the United States, and on March 30, 1930, Tombaugh's discovery became officially named Pluto.

However, with the discovery of Kuiper Belt Trans-Neptunian Objects of comparable sizes, such as Eris, Pluto's classification became questioned. After years of controversy and debate, the International Astronomical Union (IAU) met in Prague, Czech Republic in 2006 to settle the issue. The IAU resolution redefined Pluto as a dwarf planet, and assigned the similarly sized and shaped Ceres, Eris, Makemake, and Haumea to the same classification. A further refinement was issued by the IAU in 2011, with the sub-category of dwarf planets with trans-Neptunian orbits would be known as plutoids. Thus, Pluto, Eris, Makemake, and Haumea are dwarf planets in the plutoid sub-category (Fig. 8.18).

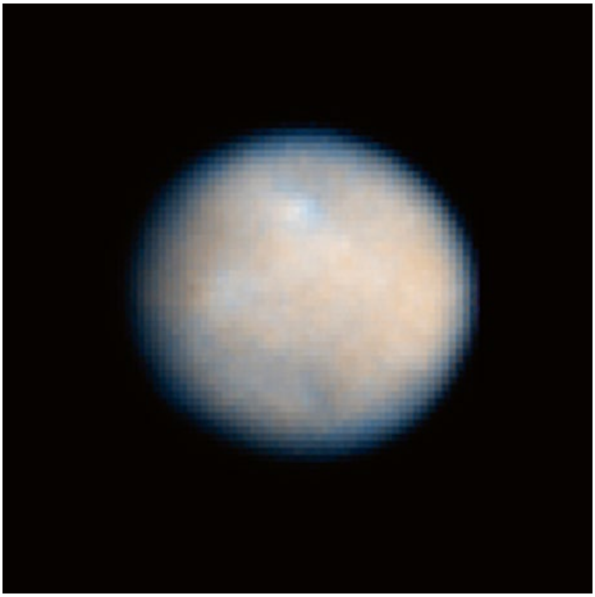


Fig. 8.18 Hubble image of Ceres (NASA and ESA)

Historically, the reclassification of Pluto was a repeat of a debate in the nineteenth century that began with the discovery of Ceres in 1801. Astronomers treated Ceres as a planet located between Mars and Jupiter. Within 4 years, however, the discovery of two more objects with comparable sizes and orbits had cast doubt on this new thinking. By 1851, the number of planets had grown to 23, and it was clear that hundreds more would eventually be discovered. Astronomers began cataloging them as asteroids and the area between Mars and Jupiter became known as the asteroid belt.

Observing any dwarf planet is possible by backyard astronomers, but expectations must be kept in check. Ceres and Pluto are accessible by backyard telescopes, but only as star-like points of light against the starry night. Only patient observation and/or photographing on consecutive nights will reveal the movement of Ceres or Pluto against the non-moving background stars. Sighting and tracking dwarf planets is strictly an advanced activity. Trans-Neptunian Objects other than Pluto are generally outside the backyard astronomer's capabilities. However, don't be surprised if some backyard astrophotographer captures Eris or some other plutoid. These guys are good!

The naming of Eris carries an interesting storyline. Eris is named after the Greek goddess of strife and discord. But prior to the official naming on September 13, 2006, it was provisionally designated as 2003 UB_{313}. Informally, the discovery team of Michael Brown, Chad Trujillo, and David Rabinowitz referred to the object as Xena, named after the heroine of the popular television show Xena—Warrior Princess. With the discovery of an accompanying moon, the discovery team added the name Gabrielle, also the traveling companion of the television heroine Xena. This playfulness of Xena and Gabrielle names continued until the official nomenclatures of Eris and Dysnomia were assigned in 2006.

Makemake takes its name from the creator deity of the mythology of the Rapanui people of Easter Island. The same discovery team of Michael Brown, Chad Trujillo, and David Rabinowitz received a provisional designation of 2005 FY_9 for the new object in March 2005, although internally referring to the new object as Easterbunny.

Haumea is named after the Hawaiian goddess of childbirth. Until it was given a permanent name, the Caltech discovery team of Michael Brown, Chad Trujillo, and David Rabinowitz used the nickname Santa, since the discovery was made just after Christmas on December 28, 2004. The use of a Hawaiian goddess was in deference to the Mauna Kea Observatory images used for the discovery.

Chapter 9

Call for Proposals: The HST Object Selection Process

Unlike on many previous NASA space science missions, anyone can apply for observing time on the Hubble Space Telescope. The selection process for observing time on the Hubble is similar to the time management and scheduling processes used for most Earthbound research telescopes, both optical and radio. The application process is open to worldwide competition without restrictions on nationality or academic affiliation.

Competition for time on the telescope is extremely intense. Potential investigators must show that their observations can only be accomplished with Hubble's unique capabilities and are beyond the capabilities of ground-based telescopes. The demand for time on Hubble is so great there are typically six times as many observing proposals for the telescope as those that actually are selected. This is because of Hubble's unique technological and space-based capabilities cannot be duplicated from ground-based telescopes.

Telescope observing time is measured by the number of orbits required for a successful observation. Programs requiring many orbits get much greater scrutiny. The observations must address a significant astronomical mystery.

Call for Proposals

Calls for proposals to use HST are issued annually. The time allocated for a cycle lasts approximately 1 year. Proposals are divided into several categories such as solar system objects, star formation, black holes in active galaxies, and the far universe. This book highlights examples of just a few studies and investigations out of the hundreds of proposals successfully submitted every year.

J.L. Chen, A. Chen, *A Guide to Hubble Space Telescope Objects*,
The Patrick Moore Practical Astronomy Series, DOI 10.1007/978-3-319-18872-0_9

Observing time is managed by the Space Telescope Science Institute (STScI). STScI solicits proposals for HST observing, archival research, and theoretical research.

The Call for Proposals (CP) invites the astronomical community to propose for observing time on HST in a given cycle (nominally 1 year in duration). It summarizes the policies and procedures for proposing in that cycle of HST observing, including requests for funding research on archival HST data. It also provides an overview of HST's expected capabilities for that observing cycle, including information about the telescope and the available scientific instruments.

Phase 1 Proposal for HST Observing Time

A Phase I proposal provides:

1. A summary of the observing program.
2. The scientific justifications for the program.
3. A list of targets with their celestial coordinates.
4. The instrument(s) to be used with desired modes, filters, and dispersers.
5. An estimate of the number of spacecraft orbits needed to accomplish the observing program (a means to calculate this number is provided in the Phase I instructions).

Potential investigators are required to be fully knowledgeable of the Hubble instrumentation and capabilities to make full use of the Hubble resources. Scientists and investigators typically request the amount of telescope time they desire in orbits. It takes 96 minutes for the telescope to make one trip around the Earth, but because the Earth usually blocks the target for part of the orbit, the typical observing time is only about 55 minutes per orbit.

Longer observations require a more compelling justification since only a limited number of orbits are available.

Phase 1 Review and Selection Process

A Telescope Allocation Committee (TAC), organized by the Space Telescope Science Institute (STScI), reviews and evaluates the submitted Phase I proposals. The committee is subdivided into panels that review the proposals submitted within a particular astronomical category. Examples of these categories include stellar populations, solar system objects, and cosmology. The committee organizers take care to safeguard the process from conflicts of interest, as many of the panel members are likely to have submitted, or to be a co-investigator, on their own proposals.

Proposals are broken down into two major categories as general observer (GO), which range in size from a single orbit to several hundred, or snapshot, which require only 45 minutes or less of telescope time. Snapshots are used to fill in gaps within Hubble's observing schedule that cannot be filled by general observer programs. The proposals are peer reviewed annually by the Time Allocation Committee (TAC), which is broken up into selected disciplines: planetary science, stellar physics, active galaxies, etc. The committee looks for the best possible science that can be conducted by HST and seeks a balanced program of small, medium, and large number of orbits. The TAC recommends a list of programs to the STScI Director for preliminary approval and implementation. The STScI director then approves the final selection and the winning lead investigators on the research teams are notified. Upon final approval by the Director, a successful proposal enters into the Phase II stage of proposal preparation.

Phase II—Observing Details

Following a favorable TAC review and approval by the director, proposers must provide the details required by the ground system to schedule HST and obtain their observations.

Observers are assigned two points of contact at STScI: a Program Coordinator (PC) and a Contact Scientist (CS). The PC helps the observer to deliver a Phase II proposal which is syntactically correct and will schedule successfully on the telescope. The CS provides advice on observing strategies to meet the scientific objectives of the program, answers questions about instrument performance, and can provide technical help in the data analysis phase of the observing program. The CS is an Instrument Scientist involved in the calibration and characterization of the primary instrument used in the observer's program.

Programs are not considered fully accepted until the following items have been completed:

1. An error-free Phase II proposal has been submitted.
2. Duplication checks against similar exposures in previous and current HST programs have been performed and any conflicts have been resolved.
3. All technical feasibility reviews (such as bright object checking, special requirements, etc.) have been completed and approved.

After an observer submits a Phase II program to STScI, a Program Coordinator checks the proposal into a database at STScI. If the proposal is acceptable and if suitable guide stars (if necessary) can be found, the observations (called visits) in a proposal are assigned scheduling windows by the Long Range Planning (LRP) group. These windows range in width from a half day to 8 weeks and represent times that an observation could be conducted on HST. They are subject to change, but STScI does try to hold to these windows whenever possible.

HST Scheduling

After observing time is awarded, the STScI creates a long-range plan. This plan ensures that the diverse collection of observations are scheduled as efficiently as possible. This task is complicated because the telescope cannot be pointed too close to bright objects like the Sun, the Moon, and the sunlit side of Earth. Adding to the difficulty, most astronomical targets can only be seen during certain months of the year; some instruments cannot operate in the high space-radiation areas of Hubble's orbit; and the instruments regularly need to be calibrated. These diverse constraints on observations make telescope scheduling a complex optimization problem that STScI staff are continually solving, revising, and improving.

Preparing for an observation also involves selecting guide stars to stabilize. the telescope's pointing and center the target in the instrument's field of view. The selection is done automatically by the Institute's computers, which choose two stars per pointing from a catalog of almost a billion stars. These guide stars will be precisely positioned within the telescope's fine guidance sensors, ensuring that the target region and orientation of the sky is observed by the desired instrument.

The actual observations onboard HST are scheduled on week-long calendars, starting every Monday, 00 Universal Time. Using a pool of observations already prepared for scheduling by the Program Coordinator Team, the Short Term Scheduling group begins to construct a given week's calendar 3 weeks prior to the start of its execution onboard HST. The actual command loads used to operate the HST spacecraft and its instruments are generated from these calendars.

Approximately 5 days before the start time of a calendar's execution, the command loads to be uplinked to HST are sent to Goddard Space Flight Center for final checking and verification.

Director's Discretionary Observing Time

Using Director's Discretionary (DD) observing time, HST is undertaking a revolutionary deep field observing program to peer deeper into the Universe than ever before and provide a first glimpse of JWST's universe. These Frontier Fields will combine the power of HST with the natural gravitational telescopes of high-magnification clusters of galaxies. Using both the Wide Field Camera 3 and Advanced Camera for Surveys in parallel, HST will produce the deepest observations of clusters and their lensed galaxies ever obtained, and the second-deepest observations of blank fields (located near the clusters). These images will reveal distant galaxy populations approximately 10–100 times fainter than any previously observed, improve our statistical understanding of galaxies during the epoch of re-ionization, and provide unprecedented measurements of the dark matter within massive clusters.

Director's Discretionary observing time was used for the execution of the Hubble Deep Field and Hubble Ultra Deep Field.

Chapter 10

HST and the James Webb Space Telescope

The Fate of the Hubble

The HST is one of the most successful and productive scientific instruments ever built. It has provided images and scientific data that has advanced mankind's knowledge of the universe, and not since the lunar missions of Apollo has the public consciousness been so stimulated. With Service Mission 4, completed in 2009, the HST received a life extension of 5 years or more. As long as the Hubble equipment continues to function, and congressional and international funding is provided, the HST should stay functional and operational past the original decommissioning date in 2014, and hopefully until the James Webb Space Telescope becomes operational sometime in 2018.

HST may stay in orbit for a few more years, but its orbit will slowly decay due the drag caused by the tenuously thin atmosphere that exists at the altitude of its orbit. Service Mission 4 fitted a docking adapter onto Hubble that will enable a robotic spacecraft to dock with the telescope and bring it into controlled reentry over the Pacific Ocean. Most of the telescope will be destroyed during the reentry, although the mirror or other portions may survive to impact the ocean.

There were early plans to bring Hubble back to Earth at the end of its operational life and placing it on display in the Smithsonian Museum. The plans proved to be unfeasible, and were abandoned for reasons of cost and safety. It was estimated that a dedicated Space Shuttle mission for this purpose would cost around $1 billion, with substantial risk to the lives of astronauts. With the Space Shuttle fleet retired in 2010, any recovery mission is now mote.

J.L. Chen, A. Chen, *A Guide to Hubble Space Telescope Objects*,
The Patrick Moore Practical Astronomy Series, DOI 10.1007/978-3-319-18872-0_10

NASA and the Great Observatories Program

The Hubble program was part of NASA's Great Observatories Program. The Great Observatories Program goal was to examine, collect, and analyze radiation emitted in space throughout the entire electromagnetic (EM) spectrum. The Great Observatories Program was made up of four space-based observatories designed to conduct astronomical studies over visible, gamma rays, X-rays, and infrared spectrum. An important aspect of the Great Observatory program was to overlap the missions to enable astronomers to make observations of an object at different spectral wavelengths.

Each observatory was named for a famous astronomer or scientist, with the HST named after Edwin Hubble, whose work established the study of galaxies beyond the Milky Way, and supported the use of the redshift in spectrography for the study of an expanding Universe. The Compton Gamma Ray Observatory was named in honor of Dr. Arthur Holly Compton, who won the Nobel Prize in physics for work on the scattering of high-energy photons by electrons. The Chandra X-Ray Observatory honors the late Indian-American Nobel laureate, Subrahmanyan Chandrasekhar. Chandra, as he was often referred to, was widely regarded as one of the foremost astrophysicists of the twentieth century. The Spitzer Space Telescope was the fourth and final element of the Great Observatories Program, and was named after Lyman Spitzer, previously discussed in Chap. 1.

The Compton Gamma Ray Observatory (CGRO) was the second of NASA's Great Observatories. Compton, at 17 tons, was the heaviest astrophysical payload ever flown at the time of its launch on April 5, 1991, aboard the space shuttle Atlantis. The CGRO mission collected data on some of the most violent physical processes in the Universe, characterized by their extremely high energies (Fig. 10.1).

Compton had four instruments that covered an extraordinarily wide electromagnetic spectrum, from 30 keV to 30 GeV. In order of increasing spectral energy coverage, these instruments were the Burst And Transient Source Experiment (BATSE), the Oriented Scintillation Spectrometer Experiment (OSSE), the Imaging Compton Telescope (COMPTEL), and the Energetic Gamma Ray Experiment Telescope (EGRET). For each of the instruments, an improvement in sensitivity of better than a factor of 10 was realized over previous missions.

The CGRO discoveries and scientific contributions include:

- Discovered hundreds of previously unknown sources of gamma rays, including 30 exotic objects.
- Detected gamma rays streaming from: black holes, exploding stars, and from the Sun.
- Helped astronomers determine how black holes trigger massive jets of X-rays and gamma rays that move outward at nearly the speed of light.
- Detected more than 2,600 gamma ray bursts.
- Divided gamma ray bursts into two kinds:
  - short duration that last less than 2 seconds, and
  - long duration that last longer than 2 seconds.

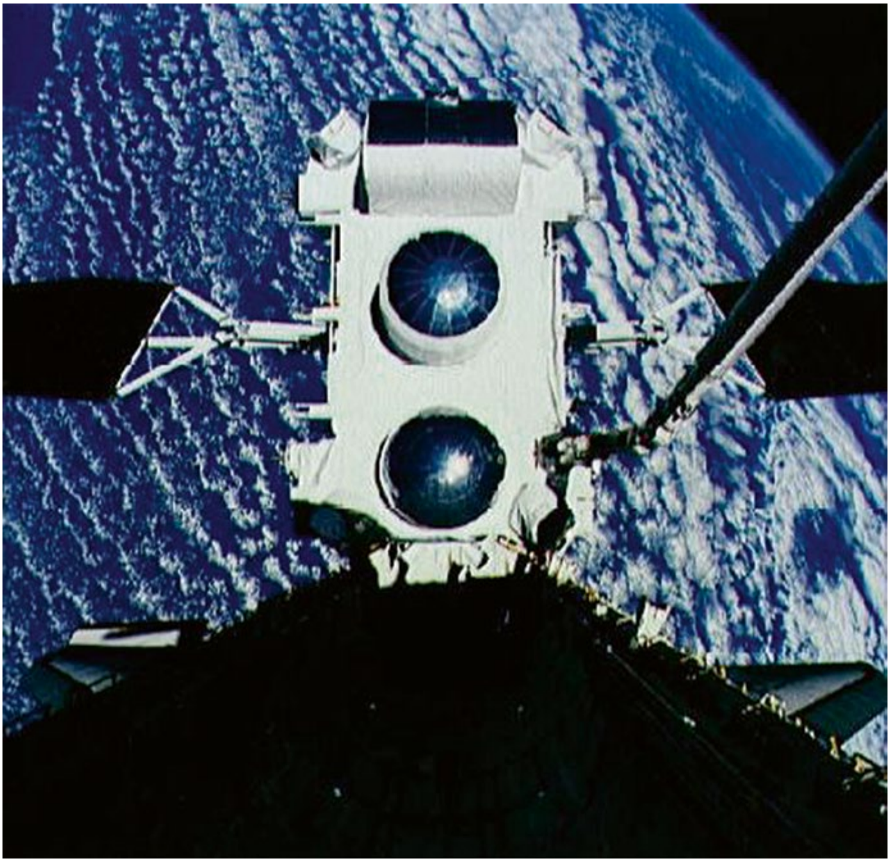


Fig. 10.1 The Compton Gamma-Ray Observatory (NASA)

After one of its three gyroscopes failed in late 1999, NASA made the decision to de-orbit the observatory. At the time, Compton was still operational, but the failure of another gyroscope would have made de-orbiting much more difficult and dangerous. Compton was safely de-orbited and re-entered the Earth's atmosphere on June 4, 2000.

The third member of the Great Observatory family, the Chandra X-Ray Observatory (CXO), was deployed from Space Shuttle Columbia and boosted into a high-Earth orbit in July 1999. This observatory is still operational in observing such objects as black holes, quasars, and high-temperature gases throughout the X-ray portion of the EM spectrum (Fig. 10.2).

Chandra detects and images X-ray sources that are billions of light years away. The images Chandra makes are 25 times sharper than the best previous X-ray telescope. The CXO improved sensitivity makes it possible for more detailed studies of black holes, supernovas, and dark matter.

Fig. 10.2 The Chandra X-Ray Observatory (NASA)

The CXO discoveries and scientific contributions include:

- Spotted the first X-ray emission seen from the supermassive black hole, Sagittarius A, at the center of the Milky Way.
- Discovered a new type of black hole in galaxy M82, a mid-mass black hole.
- Sound waves from violent activity were observed in the Perseus Cluster around a supermassive black hole.
- Identified that nearly all stars on the main sequence emit X-rays.
- Found strong evidence that dark matter exists by observing supercluster collisions.

The Spitzer Space Telescope represents the fourth and final element in NASA's Great Observatory program. Spitzer fills in an important gap in wavelength coverage not available from the ground—the thermal infrared (Fig. 10.3).

The Spitzer Space Telescope was launched into space by a Delta rocket on August 25, 2003. Spitzer obtained images and spectra by detecting the infrared energy, or heat, radiated by objects in space between wavelengths of 3 and 180 μm. Most of this infrared radiation is blocked by the Earth's atmosphere and cannot be observed from the ground.

Consisting of a 0.85-m telescope and three cryogenically-cooled science instruments, Spitzer is the largest infrared telescope ever launched into space. Its highly sensitive instruments gives astronomers a unique view of the Universe and allows astronomers to view into regions of space which are hidden from optical telescopes. Many areas of space are filled with vast, dense clouds of gas and dust which block the view. Infrared light penetrates those clouds, allowing imaging into regions of star formation, the centers of galaxies, and into newly forming planetary systems. Infrared also provides information about the cooler objects in space, such as smaller stars which are too dim to be detected by their visible light, extrasolar planets, and giant molecular clouds. Organic molecules have unique signatures in the infrared, and are detectable by Spitzer.

The Spitzer telescopes's discoveries and scientific contributions include:

- First telescope to directly capture the light from planets orbiting other stars (although not directly imaging them).
- Spotted a faintly glowing body called L1014 that may be the youngest star ever seen.
- Surveyed and mapped the Milky Way galaxy, and has established it as a barred galaxy.
- Successfully mapped the atmospheric temperature of exoplanet HD 189733b, thus obtaining the first map of any kind of an extrasolar planet.
- Researchers from Germany, the Netherlands and Hungary found from Spitzer data that amorphous silicate transformed into crystalline form by an outburst from a star.
- The discovery of Serpens South, a cluster of 50 young stars in the Serpens constellation otherwise obscured by interstellar dust.

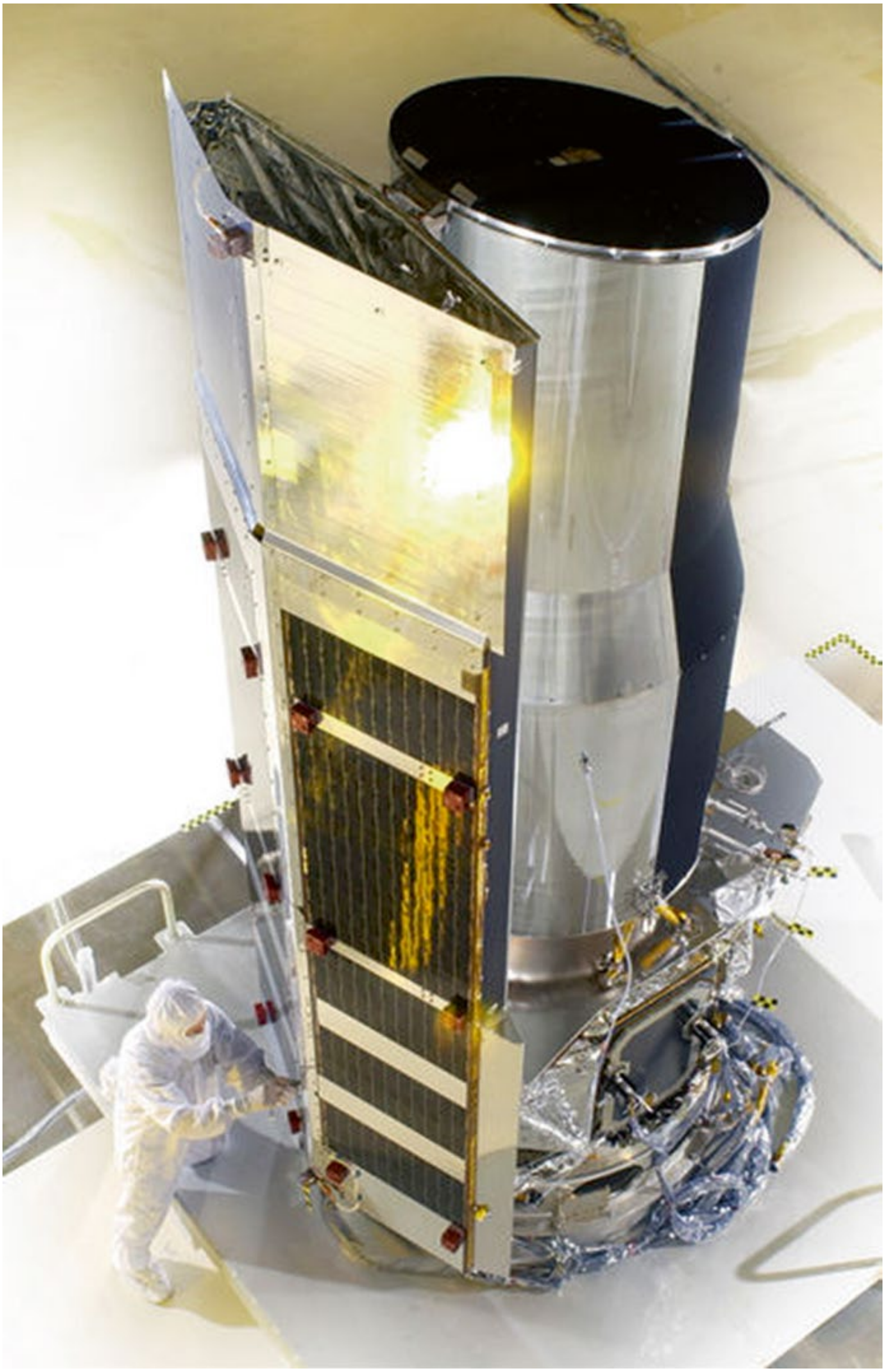


Fig. 10.3 The Spitzer Space Telescope (NASA)

The James Webb Space Telescope

Beginning in 1996, planning began for the scientific successor to the Hubble and Spitzer Space Telescopes. Originally named the Next Generation Space Telescope, or NGST, early stages of planning conceived the new telescope as the successor to the Hubble. The James Webb Space Telescope (JWST) was named in 2002 in honor of the former NASA administrator during the Apollo glory years. The JWST has evolved into a sophisticated orbiting infrared observatory that will complement and extend the discoveries of the Hubble and Spitzer Space Telescopes, with longer wavelength coverage into the infrared spectrum with greatly improved sensitivity.

The older galaxies are extremely redshifted towards and into the infrared region of the spectrum, thus necessitating JWST to investigate deeper into the infrared to detect objects farther away. The longer wavelengths will enable the JWST to look much closer to the time of the Big Bang and to hunt for the previously undetected formation of the first galaxies, as well as to look inside dust clouds where stars and planetary systems are forming (Fig. 10.4).

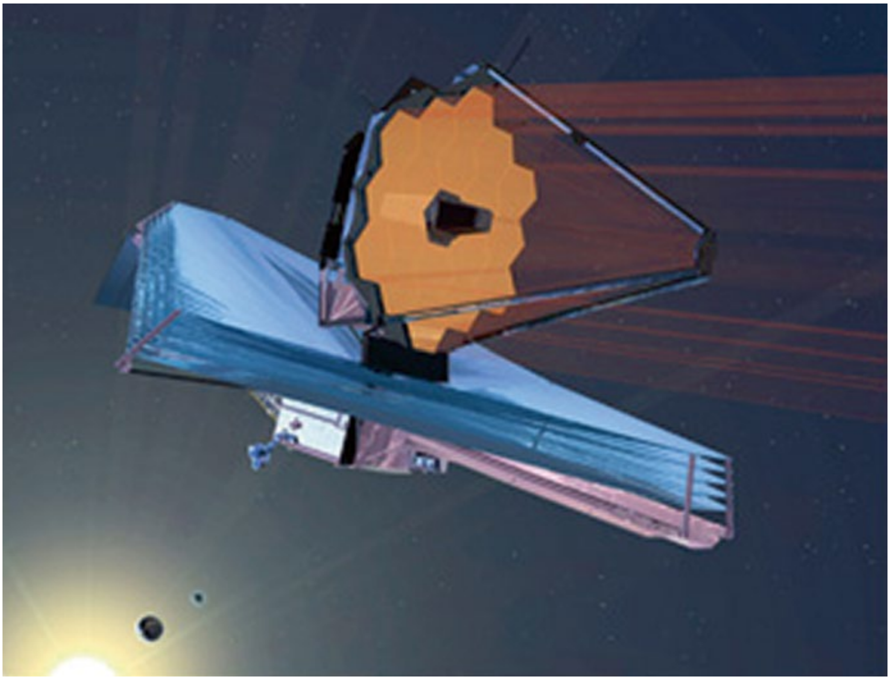


Fig. 10.4 The James Webb Space Telescope (NASA)

The mission goals of the JWST are as follows:

- Search for the first galaxies or luminous objects formed after the Big Bang.
- Determine how galaxies evolved from their formation until now.
- Observe the formation of stars from the first stages to the formation of planetary systems.
- Measure the physical and chemical properties of planetary systems and investigate the potential for life in those systems.

To achieve these goals, the JWST has many new and innovative technologies incorporated into its design. These include a folding, segmented primary mirror, adjusted to shape after launch; ultra-lightweight beryllium optics; detectors able to record extremely weak signals, micro-shutters that enable programmable object selection for the spectrograph; and a cryocooler for cooling the mid-IR detectors to 7 degrees K.

Webb is an international collaboration between NASA, the European Space Agency (ESA), and the Canadian Space Agency (CSA). The NASA's Goddard Space Flight Center (GSFC) is managing the development effort, with the prime contractor being Northrup Grumman. As with the Hubble, the Space Telescope Science Institute will operate the JWST after its insertion into space.

The scientific instrumentation to be included within the Integrated Science Instrument Module (ISIM) are:

- Near Infrared Camera (NIRCam)—NIRCam will detect light from: the earliest stars and galaxies in the process of formation; the population of stars in nearby galaxies; as well as young stars in the Milky Way and Kuiper Belt objects. NIRCam is equipped with coronagraphs, instruments that allow astronomers to take pictures of very faint objects around a central bright object, like stellar systems. NIRCam's coronagraphs work by blocking a brighter object's light, making it possible to view the dimmer object nearby—just like baseball outfielders shielding the sun with their glove to see a fly ball. With the coronagraphs, astronomers hope to determine the characteristics of planets orbiting nearby stars. NIRCam is being built by the University of Arizona and Lockheed Martin.
- Near Infrared Spectrograph (NIRSpec)—Many of the objects that the JWST will study, such as the first galaxies to form after the Big Bang, are so faint, that the JWST giant mirror must stare at them for hundreds of hours in order to collect enough light to form a spectrum. In order to study thousands of galaxies during its 5 year mission, the NIRSpec is designed to observe 100 objects simultaneously. The NIRSpec will be the first spectrograph in space that has this remarkable multi-target capability. To make it possible, a new technology micro-shutter system to control how light enters the NIRSpec is being developed. The NIRSpec is being built by scientists and engineers at NASA's Goddard Space Flight Center in Maryland.
- Mid Infrared Instrument (MIRI)—The Mid-Infrared Instrument (MIRI) has both a camera and a spectrograph that sees light in the mid-infrared region of the electromagnetic spectrum, with wavelengths that are longer than a human eye can see.

MIRI covers the wavelength range of 5–28 μm. Its sensitive detectors will allow it to see the redshifted light of distant galaxies, newly forming stars, and faintly visible comets as well as objects in the Kuiper Belt. MIRI's camera will also provide wide-field, broadband imaging that will continue the breathtaking astrophotography that has made Hubble famous. The spectrograph will enable medium-resolution spectroscopy, providing new physical details of the distant objects it will observe. MIRI is being built by the MIRI Consortium, a group that consists of scientists and engineers from European countries, a team from the Jet Propulsion Lab in California, and scientists from several U.S. institutions.

- Fine Guidance Sensor/Near Infrared Imager and Slitless Spectrograph (FGS/NIRISS)—The Near Infrared Imager and Slitless Spectrograph part of the FGS/NIRISS will be used to investigate the following science objectives: first light detection, exoplanet detection and characterization, and exoplanet transit spectroscopy. It has a wavelength range of 0.8–5.0 μm, and is a specialized instrument with three main modes, each of which addresses a separate wavelength range. FGS acts as a guider for pointing the telescope. The FGS/NIRISS is being built by the Canadian Space Agency.

Like its predecessor the Spitzer, the Webb will be positioned in space in a non-traditional orbit. The Spitzer observatory trails behind Earth as it orbits the Sun and drifts away from Earth at about 1/10th of one astronomical unit per year. This innovative orbit allowed the deep space environment to cool the telescope, with the Spitzer design augmenting the cooling with 360 liters of liquid helium coolant. This supply of helium coolant lasted for around 5.5 years. In comparison, Spitzer's predecessor, the Infrared Astronomical Satellite, used 520 liters of cryogen in only 10 months.

This unique orbital trajectory also keeps the observatory away from much of Earth's heat, which can reach 250 Kelvin (−23 degrees Celsius, or −10 degrees Fahrenheit) for satellites and spacecraft in more conventional near-Earth orbits.

The James Webb Space Telescope will observe primarily the infrared light from faint and very distant objects. But all objects, including telescopes, also emit infrared light. To avoid swamping the very faint astronomical signals with radiation from the telescope, the telescope and its instruments must be very cold. Therefore, Webb has a large shield that blocks the light from the Sun, Earth, and Moon, which otherwise would heat up the telescope, and interfere with the observations. To have this work, Webb must be in an orbit where all three of these objects are in about the same direction. The answer is to put Webb in an orbit around the L2 point. And unlike the Spitzer, liquid helium coolant will not be required.

The L2 orbit is an elliptical orbit about the semi-stable second Lagrange point. It is one of the five solutions by the mathematician Joseph-Louis Lagrange, who in the eighteenth century was investigating the three-body problem. Lagrange was searching for a stable configuration in which three bodies could orbit each other yet stay in the same position relative to each other. He found five such solutions, and they are called the five Lagrange points in honor of their discoverer.

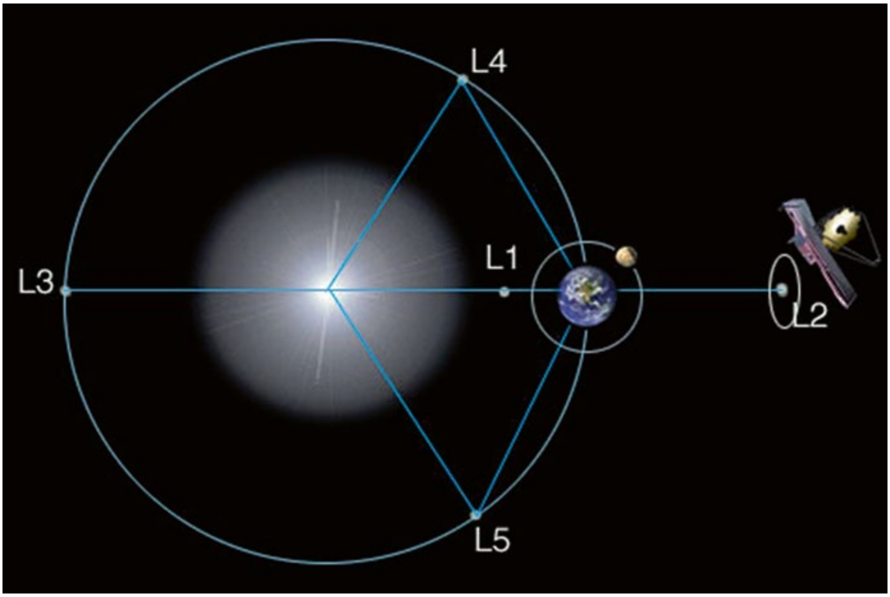


Fig. 10.5 LaGrange points and the L2 point for the JWST (NASA)

In three of the solutions found by Lagrange, the bodies are in line (L1, L2, and L3); in the other two, the bodies are at the points of equilateral triangles (L4 and L5). The five Lagrangian points for the Sun-Earth system are shown in Fig. 10.5. An object placed at any one of these five points will stay in place relative to the other two.

In the case of Webb, the three bodies involved are the Sun, the Earth and the Webb. Normally, an object circling the Sun further out than the Earth would take more than 1 year to complete its orbit. However, the balance of gravitational pull at the L2 point means that Webb will keep up with the Earth as it goes around the Sun. The gravitational forces of the Sun and the Earth can nearly hold a spacecraft at this point, so that it takes relatively little rocket thrust to keep the spacecraft in orbit around L2 (Fig. 10.6).

The Webb will be launched from Arianespace's ELA-3 launch complex at European Spaceport located near Kourou, French Guiana. The planned launch vehicle is an Ariane 5 ECA with the cryogenic upper stage. It will take approximately 30 days to reach its L2 LaGrange position.

The ultimate operational position of the Webb clearly defines the reliability parameters that the telescope will have to operate. Unlike the Hubble, which was designed for maintenance missions and equipment upgrades, the JWST must work right from the beginning. Neither NASA nor any other space agency has the capability to launch a manned repair/maintenance mission to the L2 position of Webb. The Webb will be operating at a distance from Earth four times the distance away

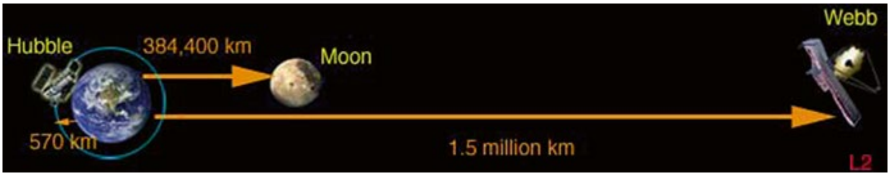


Fig. 10.6 The distance the JWST will have to travel to reach L2 (NASA)

from Earth than manned operations has ever flown (the Apollo program set the current distance record for manned spacecraft).

As a result, the design and construction of the JWST has been painstakingly careful and precise. Webb implements several new technologies, requiring detailed testing and validation many years prior to launch. The program has a 7-year integration and test (I&T) plan to validate the flight hardware in an incremental and thorough way. NASA program managers and GSFC engineers have purposely phased the contingency funding to ensure it fully covers this I&T phase, to minimize risk, and to help resolve any problems that are identified during I&T.

The JWST is being tested incrementally during its construction, with individual mirrors, cameras, spectrometers, and equipment, and building up to the full observatory. The JWST mirrors and the telescope structure are first each tested individually, including optical testing of the mirrors and alignment testing of the structure inside a cold thermal-vacuum chamber. The mirrors are then installed on the telescope structure in a clean room at GSFC. In parallel to the telescope assembly and alignment, the instruments are being built and tested, again first individually, and then as part of an integrated instrument assembly. The integrated instrument assembly will undergo testing in a thermal-vacuum chamber at GSFC using an optical simulator of the telescope. This testing makes sure the instruments are properly aligned relative to each other and also provides an independent check of the individual tests. After both the telescope and the integrated instrument module are successfully assembled, the integrated instrument module will be installed onto the telescope. The combined system will then be sent to Johnson Space Flight Center (JSC) where it will be optically tested in JSC's largest vacuum chamber, which is being retrofitted for deep cryogenic operation. The process includes testing the 18 primary mirror segments acting as a single primary mirror, and testing the end-to-end system. The final system test will assure that the telescope and all instruments are focused and aligned properly, and that the alignment, once in space, will be within the range of the actively controlled optics. The optical problems of Hubble will not be repeated on the Webb. In general, the individual optical tests of instruments and mirrors are the most accurate. The final system tests provide a cost-effective check that no major problem has occurred during assembly. Additionally, independent optical checks of earlier tests will be made as the full system is assembled, providing confidence that there are no major problems.

The lessons learned from Hubble are being applied to the development and construction of the JWST. The most expensive tests of this large space telescope are the final system tests. The Hubble Space Telescope did not have a final system test because it was deemed too complex and costly. Such a test could have caught the problem in the fabrication of the Hubble primary mirror. Since the JWST cannot be serviced like the Hubble, the JWST has to be 100 % capable before launch. The challenge has been to design a cost-effective test strategy that assures success. The JWST test plan emphasizes incremental testing, accompanied by independent checks at each level of assembly to minimize the uncertainties left for the final system test. The plan does include a final system test, and making use of the Webb active optics. This final test will assure that Webb can be aligned while in its L2 position, making the test cost effective yet retaining adequate redundancy and accuracy to detect any problems.

Even the failure prone gyros of the Hubble-era have been replaced with new technology. The gyroscopes on HST are mechanical devices dependent on bearings for their function, which faced wear problems and bearing failures typical of such designs. GSFC engineers have adopted a different gyroscope technology for use on the JWST. The patented Hemispherical Resonator Gyroscope (HRG) design uses a quartz hemisphere vibrating at its resonant frequency to sense the inertial rate. The hemisphere is made to resonate in a vacuum, and the hemisphere's rate of motion is sensed by the interaction between the hemisphere and separate sensing electrodes on the HRG housing. The result is an extremely reliable package with no flexible leads and no bearings. The internal HRG operating environment is a vacuum, thus once the gyroscope is in space any housing leaks would not affect performance, and actually could improve performance. The HRG eliminates the bearing wear-out failure mode, leaving only random failure and radiation susceptibility of the electronics (which all such devices share, and which can be mitigated by screening and shielding). Stress analyses of HRGs show a mean time before failure (MTBF) of 10 million hours. HRGs have a history of successful use in other space applications, having accumulated more than 18 million hours of continuous operation in space on more than 125 spacecraft without a single failure.

With a planned launch dated in 2018, both scientists and the public are looking forward to the wonders and discoveries in store from the data returned from the James Webb Space Telescope.

Appendix A

Glossary, Abbreviations and Acronyms

This book contains a number of scientific terms, mixed with NASA abbreviations and acronyms, with a little scientific and technical jargon on the side. Hopefully, this appendix will clear the reader's mind of the gobbledygook of terminology. Some of these maybe familiar to those who have read the author's first book, *How to Find the Apollo Landing Sites*.

Those of us who have spent our careers in Government and military service are familiar with the term "Alphabet Soup". The U.S. Government, the U.S. Armed Services, and in the case of the lead government agency of U.S. space exploration NASA (yes, an abbreviation. See…Alphabet Soup!) all use shortened abbreviations and acronyms to simplify and manage ideas, concepts, and equipment. In technical fields, abbreviations and acronyms work well as vocabulary shorthand. A good number of the following acronyms are NASA alphabet soup.

ACS—Advanced Camera for Surveys

Achromatic refractor, achromat—two lens objective, with one lens made of crown glass, and the other lens made of flint glass.

AGN—Active galactic nucleus

Apochromatic refractor, apo, apochromat—Sophisticated telescope designs using combinations of two, three, or four lenses of exotic glasses for near perfect color correction.

Astronomical Unit—a unit of distance, roughly the distance from the Earth to the Sun.
Black hole—A compacted mass that forms a region of space-time from which gravity prevents all matter and light from escaping.

J.L. Chen, A. Chen, *A Guide to Hubble Space Telescope Objects*,
The Patrick Moore Practical Astronomy Series, DOI 10.1007/978-3-319-18872-0

Catadioptric telescopes—a category of telescopes that combine lens and mirror technology to produce compact and transportable instruments.
CSA—Canadian Space Agency
CVZ—Hubble's Continuous Viewing Zone
COS—Cosmic Origins Spectrograph
COS far-UV—Cosmic Origins Spectrograph with extended range into the ultra-violet range.
COSTAR—Corrective Optics Space Telescope Axial Replacement
Dark matter—A type of matter in astronomy that is hypothesized to account for the effects that appear to be the result of an undetectable mass.
EGG—Evaporating Gaseous Globules
ESA—European Space Agency
ESWAG—Evolved Second Wave Activity Galaxy, which are a class of galaxies noted for star forming.
FGS—Fine Guidance Sensor
FGS/NIRISS—Fine Guidance Sensor/Near Infrared Imager and Slitless Spectrograph
FOC—Faint Object Camera
FOS—Faint Object Spectrograph
Galaxy—A massive, gravitationally bound system consisting of stars, stellar remnants, an interstellar medium of gas and dust, and dark matter.
GHRS—Goddard High Resolution Spectrograph
Globular cluster—A spherical collection of stars that orbits a galactic core as a satellite.
GOTO—computerized telescopes that automatically point the telescope towards the requested object.
Great Observatories Program—NASA's four orbiting observatories whose goal was to examine, collect, and analyze radiation emitted in space throughout the entire electromagnetic (EM) spectrum. The four observatories consisted of the Hubble Space Telescope, the Compton Gamma-Ray Observatory, the Chandra X-Ray Observatory, and the Spitzer Space Telescope for infrared investigations.
GSFC—NASA's Goddard Space Flight Center
HDF—Hubble Deep Field, eventually being re-named Hubble Deep Field-North, or HDF-N.
HDF-S—Hubble Deep Field-South
Herbig-Haro objects—nebulosity associated with newly-born stars, where narrow jets of gas ejected by young stars collide with clouds of gas and dust.
HRC—High Resolution Channel
HRG—Hemispherical Resonator Gyroscope
HSP—High Speed Photometer
HST—Hubble Space Telescope
HUDF—Hubble Ultra Deep Field
I&T—Integration and test.
ISS—International Space Station
JSC—NASA's Johnson Space Center

JWST—James Webb Space Telescope, the scientific successor to the Hubble and Spitzer Space Telescopes.
LaGrange point—Five solutions by the mathematician Joseph-Louis Lagrange in the eighteenth century to the three-body problem. Lagrange was searching for a stable configuration in which three bodies could orbit each other yet stay in the same position relative to each other. He found five such solutions, and they are called the five Lagrange points in honor of their discoverer.
LPR—a light pollution reduction filter to aid in visual observing by filtering streetlight, porch light, and general light pollution.
Maksutov-Cassegrain—a catadioptric design telescope using a meniscus lens design as the front element.
MIRI—Mid Infrared Instrument
MTBF—mean time before failure
NASA—National Aeronautics and Space Administration
Newtonian reflector—a telescope design using either a spherical or parabolic main mirror to collect light and a flat diagonal mirror to reflect the collected light to the eyepiece and the observer.
NICMOS—Near Infrared Camera and Multi-Object Spectrometer
NIRCam—Near Infrared Camera
NIRSpec—Near Infrared Spectrograph
NRAO—National Radio Astronomy Observatory
O-III filter—a nebula filter design to filter out all wavelengths of light except the two ionized oxygen wavelengths.
PCU—Power Control Unit
Planetary nebula—The gas and dust outer shell-like remnant of a dying star.
Proplyds—proto-planetary disks
Ritchey-Chrétien—variant of the Cassegrain reflecting telescope
SA2, SA3—solar arrays. SA2 installed during Service Mission 1, and SA3 installed during Service Mission 3B
SAA—The South Atlantic Anomaly is an area where the Earth's innermost Van Allen belt dips down to an altitude of approximately 125 miles over the Earth's surface.
SCT—Schmidt-Cassegrain telescopes
Seyfert galaxies—Galaxies with highly luminous and bright sources of electromagnetic radiation emanating from their nuclei.
STIS—Space Telescope Imaging Spectrograph
UHC—a nebula filter design to filter out all wavelengths of light except the two ionized oxygen wavelengths and the hydrogen-beta wavelength.
WFC3—Wide-Field Camera 3
WFPC—Wide Field and Planetary Camera
XDF—eXtreme Deep Field

Appendix B

Hubble Space Telescope Timeline

1923—Conception of a Space Telescope

Famed rocket scientist Herman Oberth publishes an article speculating on telescopes in orbit. Space pioneer Hermann Oberth was considered by many to be the most famous mentor of the late Dr. Wernher von Braun, the first director of the NASA Marshall Space Flight Center in Huntsville, Alabama.

1969—The LST (Large Space Telescope)

Astrophysicist Lyman Spitzer gathered the support of other astronomers for a "large orbital telescope". In 1969, the National Academy of Sciences gave its approval for the Large Space Telescope (LST) project, and the hearings and feasibility studies continued.

1977—Congress approves funding for The Hubble Space Telescope

NASA names its largest, most complex, and capable orbiting telescope in honor of Edwin Hubble.

1981—Space Telescope Science Institute (STScI)

Operations begin in Baltimore, Maryland. The STScI was built as the astronomical research center for the Hubble Space Telescope.

1990—Hubble Space Telescope (HST) Deployed

April 24, 1990: (STS-31) Launch of Shuttle Discovery
April 25, 1990: Hubble Space Telescope deployed into orbit
June 25, 1990: Spherical aberration discovered in Hubble's primary mirror

J.L. Chen, A. Chen, *A Guide to Hubble Space Telescope Objects*,
The Patrick Moore Practical Astronomy Series, DOI 10.1007/978-3-319-18872-0

COSTAR Approved: the creation of a complex packaging of five optical mirror pairs which would rectify the spherical aberration in Hubble's primary mirror

1993—Servicing Mission 1 (SM1)

December 2, 1993: (STS-61) Launch of Shuttle Endeavour
COSTAR corrective optics installed, replacing HSP
WFPC2 replaced WFPC

1997—Servicing Mission 2 (SM2)

February 11, 1997: (STS-82) Launch of Shuttle Discovery
STIS replaced FOS
NICMOS replaced GHRS

1998—HST Orbital Systems Test (HOST)

October 29, 1998: (STS-95) Launch of Shuttle Discovery
HOST mission was flown to test new technologies for installation into Hubble during servicing missions 3A and 3B

1999—Servicing Mission 3A (SM3A)

December 19, 1999: (STS-103) Launch of Shuttle Discovery
Replacement of RSU (Rate Sensing Units containing gyroscopes)
Installation of new computer
General maintenance
November 13, 1999: Hubble placed in safe mode after the failure of a fourth gyroscope.

2002—Servicing Mission 3B (SM3B)

March 1, 2002: (STS-109) Launch Shuttle Columbia
Installation of ACS
Installation of NCS
Replace SA2 with SA3 (solar arrays)

2009—Servicing Mission 4 (SM4)

May 11, 2009: (STS-125) Launch Shuttle Atlantis
Remove Wide Field and Planetary Camera 2 (WF/PC2) and install Wide Field Camera 3 (WFC3) in its place
Remove the Corrective Optics Space Telescope Axial Replacement (COSTAR) and install the Cosmic Origins Spectrograph (COS) in its place
Replace all gyroscopes
Replace one Fine Guidance Sensor (FGS)
Replace all batteries
Install New Outer Blanket Layers (NOBLs)
Install Soft Capture Mechanism (SCM)
Replace Science Instrument Control and Data Handling (SIC&DH) unit
Repair the Space Telescope Imaging Spectrograph (STIS)
Repair the Advanced Camera for Surveys (ACS)

Appendix C

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