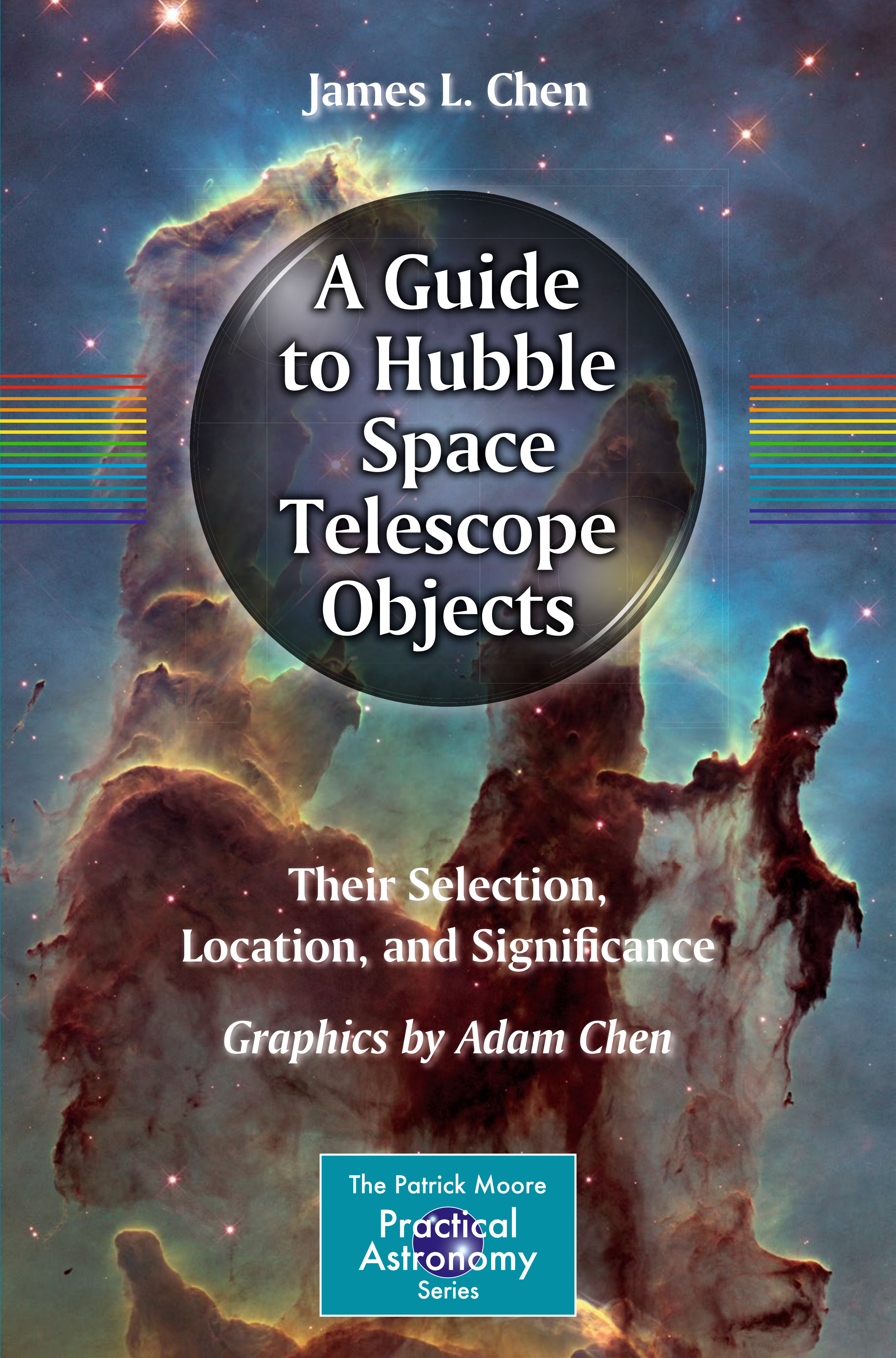

James L. Chen

A Guide to Hubble Space Telescope Objects

Their Selection, Location, and Significance

Graphics by Adam Chen

The Patrick Moore Practical Astronomy Series

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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

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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,

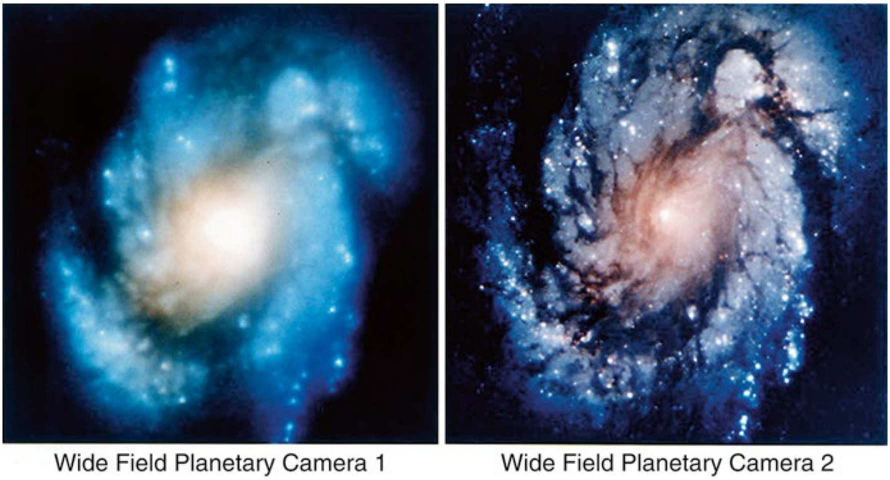

Fig. 1.1 Hubble images before and after (NASA/ESA)

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.