Hubble Space Telescope

Introduction

Since the earliest days of astronomy, since the time of Galileo, astronomers have shared a single goal — to see more, see farther, see deeper. The Hubble Space Telescope's launch in 1990 sped humanity to one of its greatest advances in that journey. Hubble is a telescope that orbits Earth. Its position above the atmosphere, which distorts and blocks the light that reaches our planet, gives it a view of the universe that typically far surpasses that of ground-based telescopes. Hubble is one of NASA's most successful and long-lasting science missions. It has beamed hundreds of thousands of images back to Earth, shedding light on many of the great mysteries of astronomy. Its gaze has helped determine the age of the universe, the identity of quasars, and the existence of dark energy.

Changing Astronomy

Hubble's discoveries have transformed the way scientists look at the universe. Its ability to show the universe in unprecedented detail has turned astronomical conjectures into concrete certainties. It has winnowed down the collection of theories about the universe even as it sparked new ones, clarifying the path for future astronomers. Among its many discoveries, Hubble has revealed the age of the universe to be about 13 to 14 billion years, much more accurate than the old range of anywhere from 10 to 20 billion years. Hubble played a key role in the discovery of dark energy, a mysterious force that causes the expansion of the universe to accelerate. Hubble has shown scientists galaxies in all stages of evolution, including toddler galaxies that were around when the universe was still young, helping them understand how galaxies form. It found protoplanetary disks, clumps of gas and dust around young stars that likely function as birthing grounds for new planets. It discovered that gamma-ray bursts — strange, incredibly powerful explosions of energy — occur in far-distant galaxies when massive stars collapse. And these are only a handful of its many contributions to astronomy. The sheer amount of astronomy based on Hubble observations has also helped make it one of history's most important observatories. More than 6,000 scientific articles have been published based on Hubble data. The policies that govern the telescope have contributed to its incredible productivity. The telescope is an instrument for the entire astronomical community — any astronomer in the world can submit a proposal and request time on the telescope. Teams of experts then select the observations to be performed. Once observations are completed, the astronomers have a year to pursue their work before the data is released to the entire scientific community. Because everyone gets to see the information, the observations have given rise to a multitude of findings — many in areas that would not have been predicted by the telescope’s original proposals. Hubble's success with these policies has helped spread them throughout the astronomical community, and they are becoming common with other observatories.

Why A Space Telescope?

The Hubble Space Telescope is the direct solution to a problem that telescopes have faced since the very earliest days of their invention: the atmosphere. The quandary is twofold: Shifting air pockets in Earth's atmosphere distort the view of telescopes on the ground, no matter how large or scientifically advanced those telescopes are. This "atmospheric distortion" is the reason that the stars seem to twinkle when you look up at the sky. The atmosphere also partially blocks or absorbs certain wavelengths of radiation, like ultraviolet, gamma- and X-rays, before they can reach the Earth. Scientists can best examine an object like a star by studying it in all the types of wavelengths that it emits. Newer ground-based telescopes are using technological advances to try to correct atmospheric distortion, but there's no way to see the wavelengths the atmosphere prevents from even reaching the planet. The most effective way to avoid the problems of the atmosphere is to place your telescope beyond it. Or, in Hubble's case, 353 miles (569 km) above the surface of Earth.

How It Works

Every 97 minutes, Hubble completes a spin around Earth, moving at the speed of about five miles per second (8 km per second) — fast enough to travel across the United States in about 10 minutes. As it travels, Hubble's mirror captures light and directs it into its several science instruments. Hubble is a type of telescope known as a Cassegrain reflector. Light hits the telescope's main mirror, or primary mirror. It bounces off the primary mirror and encounters a secondary mirror. The secondary mirror focuses the light through a hole in the center of the primary mirror that leads to the telescope's science instruments. People often mistakenly believe that a telescope's power lies in its ability to magnify objects. Telescopes actually work by collecting more light than the human eye can capture on its own. The larger a telescope's mirror, the more light it can collect, and the better its vision. Hubble's primary mirror is 94.5 inches (2.4 m) in diameter. This mirror is small compared with those of current ground-based telescopes, which can be 400 inches (1,000 cm) and up, but Hubble's location beyond the atmosphere gives it remarkable clarity. Once the mirror captures the light, Hubble's science instruments work together or individually to provide the observation. Each instrument is designed to examine the universe in a different way. The Advanced Camera for Surveys (ACS), Hubble's most recent instrument, sees visible light. It is designed to study some of the earliest activity in the universe. ACS helps map the distribution of dark matter, detects the most distant objects in the universe, searches for massive planets, and studies the evolution of clusters of galaxies.

The Near Infrared Camera and Multi-Object Spectrometer (NICMOS) is Hubble's heat sensor. Its sensitivity to infrared light — perceived by humans as heat — lets it observe objects hidden by interstellar dust, like stellar birthsites, and gaze into deepest space. The Space Telescope Imaging Spectrograph (STIS) acts something like a prism, separating light from the cosmos into its component colors. This provides a wavelength "fingerprint" of the object being observed, which tells us about its temperature, chemical composition, density, and motion. STIS stopped working due to a technical failure on August 3, 2004, but will be restored in a future servicing mission. The Wide Field and Planetary Camera 2 (WFPC2), is the instrument behind many of the most famous Hubble pictures. It is used to observe just about everything, recording razor-sharp images of faraway objects in relatively broad views. Its 48 filters allow scientists to study objects in a range of wavelengths. Finally, the Fine Guidance Sensors (FGS) are devices that lock onto "guide stars" and keep Hubble pointed in the right direction. They can be used to precisely measure the distance between stars, and their relative motions. All of Hubble's functions are powered by sunlight. Hubble sports solar arrays that convert sunlight directly into electricity. Some of that electricity is stored in batteries that keep the telescope running when it's in Earth's shadow, blocked from the Sun's rays.

Data on the Move

A quartet of antennae on the telescope send and receive information between Hubble and the Flight Operations Team at the Goddard Space Flight Center in Greenbelt, Md. Engineers use satellites to communicate with the telescope, giving it directions and commands. The telescope has two main computers and a number of smaller systems. One of the main computers handles the commands that point the telescope and other system-wide functions. The other talks to the instruments, receives their data, and sends it to satellites that in turn transmit it to the ground.

Once the ground station transfers the data to Goddard, Goddard sends it to the Space Telescope Science Institute (STScI), where staff translate the data into scientifically meaningful units — such as wavelength or brightness — and archive the information on 5.25-inch magneto-optical disks. Hubble sends the archive enough information to fill about 18 DVDs every week. Astronomers can download archived data via the Internet and analyze it from anywhere in the world. Hundreds of engineers and computer scientists at Goddard Space Flight Center and STScI are responsible for keeping Hubble operating and monitoring its safety, health, and performance. At Goddard, controllers monitor the telescope's health while they direct its movements and science activities. STScI staff also schedule use of the telescope, monitor and calibrate the instruments, operate the archive and conduct public outreach. Astronomers from around the world compete for time to use Hubble. More scientists want to use the telescope than there is time to use it, so a review committee of astronomy experts has to pick out the best proposals from the bunch. The winning proposals are the ones that make the best use of the telescope's capabilities while addressing pressing astronomical questions. Each year around 1,000 proposals are reviewed and approximately 200 are selected, for a total of 20,000 individual observations.

We Have a Problem

Almost immediately after Hubble went into orbit, it became clear that something was wrong. While the pictures were clearer than those of ground-based telescopes, they weren't the pristine images promised. They were blurry. Hubble's primary mirror, polished so carefully and lovingly over the course of a full year, had a flaw called "spherical aberration." It was just slightly the wrong shape, causing the light that bounced off the center of the mirror to focus in a different place than the light bouncing off the edge. The tiny flaw — about 1/50th the thickness of a sheet of paper, was enough to distort the view. Fortunately, scientists and engineers were dealing with a well-understood optical problem — although in a wholly unique situation. And they had a solution. A series of small mirrors could be used to intercept the light reflecting off the mirror, correct for the flaw, and bounce the light to the telescope's science instruments. The Corrective Optics Space Telescope Axial Replacement, or COSTAR, could be installed in place of one of the telescope's other instruments in order to correct the images produced by the remaining and future instruments. Astronauts would also replace the Wide Field/Planetary Camera with a new version, the Wide Field and Planetary Camera 2 (WFPC2), that contained small mirrors to correct for the aberration. Astronauts and NASA staff spent 11 months training for one of the most complex space missions ever attempted. In addition to the critical nature of the mission, it would be the first test of the telescope's vaunted ability to be serviced and repaired in space.

Repair Crew

On December 2, 1993, the Space Shuttle Endeavor carried a crew of seven into orbit for a mission that would involve five days of spacewalks and repairs. They removed the High Speed Photometer and replaced it with COSTAR. They replaced the original Wide Field Camera with the newer WFPC2, which corrected the blurry image. They performed a host of other tasks, replacing solar panels, fuse plugs, and other hardware. By December 9, they were finished. NASA released the first new images from Hubble's fixed optics on January 13, 1994. The pictures were beautiful; their resolution, excellent. Hubble was transformed into the telescope that had been originally promised. Hubble would be successfully serviced and repaired several times afterwards. In February, 1997, astronauts replaced the Goddard High Resolution Spectrograph and the Faint Object Spectrograph with improved instruments, the Near Infrared Camera and Multi-Object Spectrometer and the Space Telescope Imaging Spectrograph. In December 1999, they replaced a transmitter, all six gyroscopes, and one of three Fine Guidance Sensors, which allow fine pointing and keep Hubble stable during operations. Finally, in February 2002, astronauts added the Advanced Camera for Surveys (ACS), the first new instrument to be installed in Hubble since 1997. ACS doubled Hubble's field of view, using a much more sensitive detector than WFPC2. Each time astronauts performed a servicing mission, they also performed routine repair work — fixing solar panels and thermal blankets, and upgrading equipment.

Future Plans

Hubble's next and final servicing mission was scheduled for 2006. But on Febuary 1, 2003, the Space Shuttle Columbia, returning from a research mission, broke apart while re-entering Earth's atmosphere. Shuttles were grounded. Then-NASA Administrator Sean O'Keefe called the Hubble mission off, citing the safety guidelines that had been developed following the Columbia tragedy. Current NASA Administrator Mike Griffin revisited the cancellation upon his appointment in 2005, and expressed support for another mission. On October 31, 2006, he announced that Hubble will be serviced one more time. The mission is expected to take place in September 2008. In the meantime, Hubble continues to beam images of the heavens back to Earth, transferring about 120 gigabytes of data every week. Scientists continue to churn out research based on Hubble's observations. Hubble's successor, the James Webb Space Telescope (JWST), is currently in the works. JWST will study objects from the earliest universe, objects whose light has "redshifted," or stretched into infrared light. From its orbit 940,000 miles (1.5 million km) away from Earth, JWST will unveil secrets about the birth of stars, solar systems, and galaxies by peering through the dust that blocks visible light. The telescope is scheduled to launch in 2013.

All Good Things

Eventually, Hubble's time will end. At some unknown point in the future — around 2013 with the 2008 servicing mission, or earlier without — Hubble's components will degrade to the point at which the telescope stops working. When that happens, Hubble will continue to orbit the Earth until its orbit decays, allowing it to spiral toward Earth. Astronauts or a robotic mission could either bring Hubble back to Earth or crash it safely into the ocean. But Hubble's legacy — its discoveries, its trailblazing design, its success in showing us the universe in unparalleled detail — will live on. Scientists will rely on Hubble's revelations for years as they continue in their quest to understand the cosmos — a quest that has attained clarity, focus, and triumph through Hubble's rich existence.