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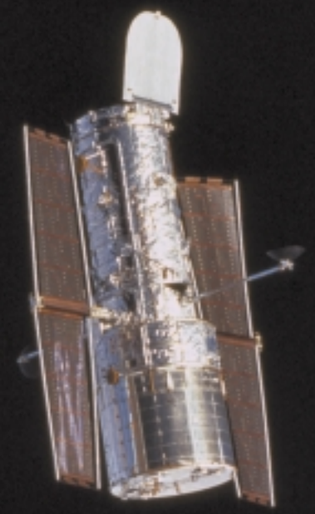
NP-2000-3-026-GSFC

The Hubble Story

Where we are and how we got here.



It all began back in 1946 as a dream — Lyman Spitzer's dream — to build a Large Space Telescope. Yet, it would be another 21 years before NASA could pursue Dr. Spitzer's dream.

Deployed on April 25, 1990, Hubble Space Telescope marked the beginning of an exciting new era in astronomy. In the decade since Hubble first turned its powerful eyes on the universe, it has unraveled age-old mysteries and forced astronomers to rethink long-held beliefs. From proto-galaxies at the farthest reaches of the universe to proto-planetary disks surrounding young stars in our own galaxy, Hubble's discoveries raise at least as many questions as they answer – even as they help us understand our universe and our role within it.

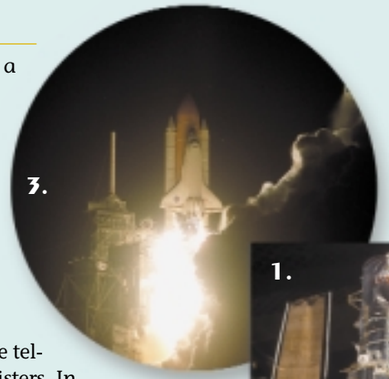
1. Hubble – a School Bus in the Sky

Hubble Space Telescope is very big – about the size of a large school bus or tanker truck. The tubular part of Hubble's body is 14 feet across, and the telescope stands 43 feet tall – about as high as a five-story building. On the ground, it would weigh over 25,000 pounds, but in space it weighs nothing. When the Space Shuttle Discovery carried Hubble into orbit, the telescope completely filled Discovery's cargo bay. Hubble is pictured in Discovery's cargo bay during the December 1999 servicing mission.

Hubble orbits about 370 miles above the Earth, and takes about 97 minutes to complete one orbit. It is designed to receive regular tune-ups from the astronauts, who keep Hubble healthy and fit it with the latest technology. Hubble Space Telescope is a joint effort between NASA and the European Space Agency.

2. The Design & Build of Hubble

The idea of putting a telescope in space has been around for a long time. Earth's atmosphere distorts light and causes a great deal of viewing problems for ground telescopes. A telescope above the atmosphere has a much clearer view of the universe. Finally, after many years of dreaming, the orbiting telescope took shape during the 1970's and 1980's. Its designers were wise to realize that technology would advance dramatically during Hubble's long life, so they built Hubble to be upgraded by astronauts. Hubble was built, integrated and tested at Lockheed Martin's Sunnyvale, CA, plant.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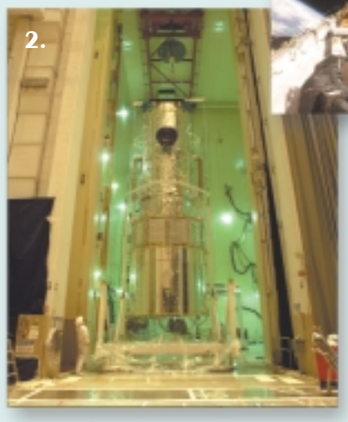
1.

Many of Hubble's major structures are visible in this picture. The telescope is divided into sections that are stacked together like canisters. In the front is the aperture door and light shield that protect the sensitive mirror and instruments from bright light. Next is the forward shell that encloses the optical telescope assembly mirrors. Then comes the equipment section that houses most of the Hubble subsystems. At the rear of Hubble is the aft shroud that covers the science instruments. The solar arrays and communications antennas are attached to the side of the telescope.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The photograph shows Hubble being lifted into the upright position in the Vertical Processing Facility at Kennedy Space Center in preparation for launch. Hubble was launched on April 24, 1990, aboard the Space Shuttle Discovery.

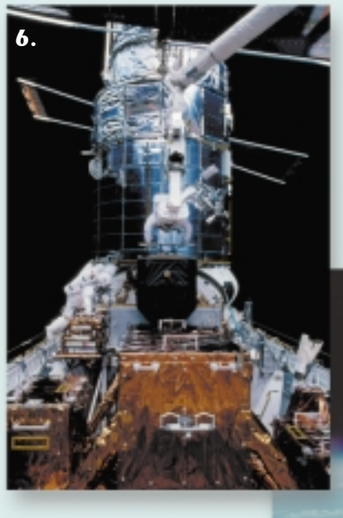
3. Servicing Improves Hubble

This picture shows the start of a servicing mission with the launch of a space shuttle. Hubble is designed for on-orbit servicing by a team of astronauts. Servicing missions allow for planned, periodic replacement and improvement of Hubble's science instruments and other equipment. During a servicing mission the crew maneuvers the shuttle to rendezvous with Hubble, uses a robot arm to place the telescope in the shuttle's cargo bay, and then installs the new equipment. After the work is complete, the crew sets Hubble free and returns it to duty.

The Hubble Space Telescope's purpose is to spend 20 years probing the cosmos from the nearby planets of our own solar system to the farthest and faintest galaxies. Crucial to fulfilling this objective is a series of on-orbit servicing missions. Hubble was placed in orbit on April 25, 1990, and subsequent servicing followed in December 1993 and February 1997. The third in the series of planned servicing missions for the Hubble Space Telescope was scheduled for June 2000. This third servicing mission has been separated into two flights. The first of these flights, Servicing Mission 3A, was in December 1999, and the second, Servicing Mission 3B, is scheduled for 2001.

4. Hubble's Optics

Hubble operates on the same principle as reflecting telescopes invented in the 17th century by Newton, Cassegrain, and Gregory. A Cassegrain telescope is a reflecting telescope in which light is reflected from a large primary mirror onto a secondary mirror, which then focuses the light back through a hole in the primary mirror to a point behind the mirror. The main mirror in Hubble is about 8 feet in diameter. Light enters the telescope and strikes the main mirror. The science instruments are located directly behind the primary mirror. In Hubble the primary mirrors are exactly configured to eliminate the optical aberrations of ordinary telescopes.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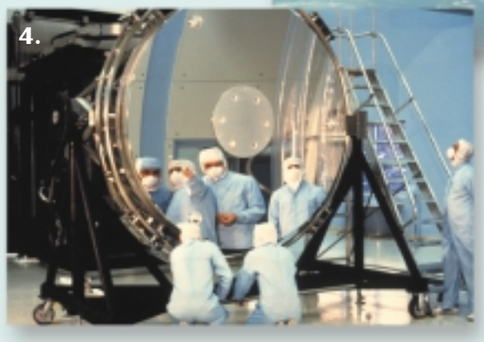
After launch in 1990, NASA discovered that the large mirror was flawed. The flaw was tiny, about 1/50th the thickness of a piece of paper, but significant enough to distort Hubble's vision. During Servicing Mission 1, astronauts added corrective optics to compensate for the flaw. The optics acted like eyeglasses to correct Hubble's vision.

5. Hubble's Orbit

Hubble orbits the Earth at an altitude of about 370 miles. It takes about 97 minutes to complete one orbit around the Earth. Hubble passes into the shadow of the Earth for 28 to 36 minutes in each orbit. The orbit inclines at a 28.5-degree angle. This orbit is high enough that Hubble is above the Earth's atmosphere and can conduct its science operations without the negative effects of the atmosphere.


5.

Seeing through Earth's atmosphere is similar to looking at objects through a pool of water. Remember how little you can see when you open your eyes under water and how much better you can see when you are out of the water. It is very similar as far as science is concerned with the telescope. The Earth's atmosphere acts similarly to water and greatly reduces what we can see in space from the ground. Hubble is in orbit above the atmosphere so it has unrestricted visibility into space and can "see" much better than anyone or anything on the ground.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6. Fine Guidance Sensors

This photo shows a team of astronauts replacing one of three Fine Guidance Sensors in Hubble during a servicing mission. These sensors are located at 90-degree intervals around the circumference of the focal plane structure. Each Fine Guidance Sensor enclosure houses a very precise optical system called an interferometer. The telescope's high pointing accuracy and stability are due largely to the Fine Guidance Sensors. Any two Fine Guidance Sensors are normally used in observations to locate and lock onto a target star while observations are made with a science instrument. From time to time one of the Fine Guidance Sensors is also used to perform scientific measurements, determining highly precise positions and motions of stars and detecting the positions of companion stars. The process of determining the positions of stars is called astrometry.

One recertified Fine Guidance Sensor was installed as a replacement during the second servicing mission and another recertified Fine Guidance Sensor was installed as a replacement during Servicing Mission 3A. The Fine Guidance Sensors were built by Hughes Danbury Optical Systems in Danbury, CT.

7. Hubble's Control Center

Command and control for Hubble is done at the Space Telescope Operations Control Center at NASA's Goddard Space Flight Center in Greenbelt, MD. Here, ground controllers send commands and computer instructions to Hubble and monitor data from Hubble to ensure that the observatory is functioning properly. This picture was taken in the Space Telescope Operations Control Center during Servicing Mission 3A.

Hubble Space Telescope operations are of two types: science operations and mission operations. Science operations are carried out by the Space Telescope Science Institute which plans and conducts the Hubble science program of observing celestial objects and gathering scientific data. Mission operations, conducted from the Space Telescope Operations Control Center, commands and controls Hubble to implement the observation schedule and maintain the Telescope's overall performance. Science programs are integrated into day-to-day operations programs for Hubble. The Space Telescope Operations Control Center controls and monitors the execution of the programs on the spacecraft.


7.

8. Space Telescope Science Institute

The Space Telescope Science Institute in Baltimore, MD, selects observing proposals, plans observations, retrieves and archives Hubble data, and makes the information available to the public. In this photo, astronomers at the Space Telescope Science Institute eagerly awaiting results from the impact of Comet P/Shoemaker-Levy 9 with the planet Jupiter in July 1994.

Each year astronomers from dozens of countries submit proposals to the Institute. An international panel of scientists judges them on a list of criteria, selecting the best. Typically, the Institute receives more than 1,000 proposals a year and selects about 300.

The data from Hubble's observations are sent to Earth by way of a NASA relay satellite. The data are then forwarded to the Institute where they are analyzed and stored. Observers may then study the data at the Institute or from a remote location.


9.

9. Solar Arrays

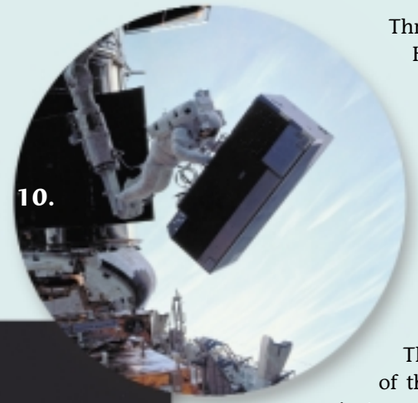
Power for Hubble comes from the electrical power system. The major components are two solar array wings, six nickel-hydrogen batteries, six charge current controllers, one power control unit and four power distribution units. The solar arrays are the primary source of electrical power. The arrays are nearly 8 feet by 40 feet. Each array has a solar cell blanket that converts sunlight into electrical energy. Electricity produced by the solar arrays charges Hubble's batteries. The solar arrays supply power to the spacecraft and charge the batteries while in the sunlit part of the orbit. The batteries take over supplying power during the night portion of the orbit (when Hubble is in the Earth's shadow).


8.

This photo shows Astronaut Kathy Thornton jettisoning the damaged solar panel into space. During Servicing Mission 1, when the solar panels were changed out, astronauts detected a bend in the panel casing. The panel couldn't safely be returned to Earth and was jettisoned into space.

10. Hubble Science Instruments

The science instruments in Hubble are large, complex devices. Some are similar in size and shape to a telephone booth and others are similar to a grand piano. The telescope was designed to hold four telephone booth-sized instruments and four piano-shaped instruments. The instruments take digital pictures of stars and send the picture data to the ground where scientists analyze the data to make discoveries about our universe. This picture shows an astronaut removing the Goddard High Resolution Spectrograph in preparation for a new instrument during Servicing Mission 2 in 1997.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Three instruments are in active scientific use on Hubble: the Wide Field and Planetary Camera 2, the Space Telescope Imaging Spectrograph, and a Fine Guidance Sensor. Other instrument bays are occupied by the Near Infrared Camera and Multi-Object Spectrometer, which is now dormant due to the depletion of its coolant; the Faint Object Camera; and the corrective optical device called COSTAR, which is no longer needed. During the next servicing mission, the Faint Object Camera will be replaced by a new instrument, the Advanced Camera for Surveys. The final servicing mission will feature the removal of the COSTAR and the installation of another new instrument, the Cosmic Origins Spectrograph.


11.

11. Wide Field and Planetary Camera

The Wide Field and Planetary Camera 2 (WFPC2) is the "workhorse" camera for Hubble. It provides us with pictures of the universe on a grander scale than any camera to date. The camera can detect stars over one billion times fainter than we can see with our eyes. This picture shows astronauts removing the Wide Field and Planetary Camera 1, to be replaced by WFPC2. WFPC2 is shaped somewhat like a grand piano and weighs 619 pounds.

WFPC2 records two-dimensional images through a selection of 48 color filters covering a spectral range from far ultraviolet to red wavelengths. WFPC2 has four charge-coupled detector cameras arranged to record simultaneous images in four separate fields of view at two magnifications. The planetary camera provides a magnification about 2.2 times larger than the Wide Field Camera. The Planetary Camera provides the best sampling of the Telescope's images at visible wavelengths and is used whenever the finest spatial resolution is needed.


12.

12. Space Telescope Imaging Spectrograph

This picture shows the Space Telescope Imaging Spectrograph (STIS) in a caddy, prior to the mission, in a clean room at Ball Aerospace in Boulder, CO, where it was manufactured. STIS resides in an axial bay behind the Hubble main mirror. STIS is nearly 7 feet by 3 feet by 3 feet and weighs over 800 pounds. STIS is designed to work in three different wavelength regions, each with its own detector. Scientists using STIS focus their science on many areas, including the search for massive black holes; measurement of distribution of matter in the universe and the study of stars forming in distant galaxies; and imaging large (Jupiter-sized) planets around nearby stars.

The STIS instrument provides enhanced capabilities over the two original spectrograph instruments. STIS covers a broader wavelength range with two-dimensional capability, adds a coronograph capability, and has a high time-resolution capability in the ultraviolet. This instrument also images and provides objective prism spectra in the intermediate ultraviolet.

13. Simulating Weightlessness

In preparation for servicing missions to Hubble, astronauts undergo extensive training. A huge underwater tank provides the closest training environment for weightlessness. The astronauts wear special underwater pressurized suits similar to the suits worn on orbit during this training. This 40-foot-deep tank contains full-scale underwater mockups of Hubble, the instruments being changed out and the carriers that hold the instruments. Astronauts spend many weeks in this underwater training accompanied by weeks of classroom instruction.

This underwater training is performed at NASA's Johnson Space Center Neutral Buoyancy Laboratory. Johnson Space Center also trains the astronauts using virtual reality, and a thermal vacuum chamber which simulates the space environment with temperature variations of –200 to +200 degrees F. Additional training is conducted at NASA's Goddard Space Flight Center, where the astronauts train with high-fidelity mockups of Hubble, the flight instruments, and the flight tools required to service Hubble.


13.

14. Goddard's Clean Room

The Spacecraft Systems Development and Integration Facility (SSDIF) is an 86,000-square-foot building used to integrate and test space hardware. Located at Goddard Space Flight Center, this facility houses the 1.3-million-cubic-foot High Bay Clean Room. The largest of its kind anywhere, this clean room plays an important role in preparing for Hubble servicing. The STS-103 astronauts trained in this room, as did the crews from the two previous Hubble servicing missions. Using the clean room's very precise mechanical and electrical simulators, they practiced installing the actual Hubble hardware. This is where the platform resides that is used to anchor Hubble to the shuttle during a servicing mission. It is also home to the shuttle carriers that take new Hubble instruments, tools and other hardware to orbit.

This picture shows the carriers used to hold the flight hardware for the STS-61 Mission in 1993. These carriers are transported to Kennedy Space Center where they are integrated into the shuttle bay. Wide Field and Planetary Camera 2 is visible on the cart on the right side of this photo.


14.


15.

15. Training in the Clean Room

The astronauts shown here are training on the electrical section of Hubble. This is a full-size mockup of the section of Hubble that houses the electrical components, such as transmitters, batteries, tape recorders, and electronics to operate other parts of Hubble. Astronauts come to Goddard several times prior to each mission to familiarize themselves with Hubble's components and the tools required to service them.

Everyone entering this room must wear a "bunny suit" – special coveralls, hoods, boots, gloves and masks. This gear helps protect the sensitive flight hardware from particles that could interfere with performance.

16. Astronaut Tools

Astronaut Steve Smith is holding a power ratchet tool on orbit in front of the Hubble Aft Shroud compartment. Hubble Space Telescope is the first spacecraft designed with replaceable parts and instruments for planned servicing. To enable astronauts to change out parts, special tools and aids had to be designed, tested and built.

Hubble was built with 225 feet of handrails and 31 astronaut restraint platforms to give astronauts safe, convenient worksites as they orbit Earth at 17,000 mph to service the Telescope. In addition, many special-purpose tools have been developed to meet the unique change-out requirements for the Telescope. The power ratchet tool is a 3/8"-drive right-angle power tool used for tasks requiring controlled torque, speed and/or turns. This tool is one of two power tools designed, built, and tested at NASA's Goddard Space Flight Center and Johnson Space Center to be strong and reliable enough to withstand the harsh environment of space. They have been used successfully on the three Hubble servicing missions.


16.


18.


17.

17. Replacing a Data Recorder

This photo shows an astronaut holding a reel-to-reel tape recorder prior to stowing it for return to the ground. Hubble originally used reel-to-reel tape recorders to store data that could not be sent to the ground in real time. The on-board recorders would record the engineering or science data and then the ground controllers would command a playback or tape recorder dump at a later time when communications permitted it.

During the second servicing mission, the first Solid State Recorder was installed, replacing one of the original reel-to-reel recorders. A second recorder was installed during Servicing Mission 3A. The new recorders have no reels or tape, and no moving parts to wear out and limit lifetime. Data is stored digitally in computer-like memory chips until the ground controllers command the recorders to play the data back to the ground. The new recorders are the same size as the reel-to-reel tape recorders but they store over 10 times more data than the old recorders. The new recorders can record two data streams at one time so both engineering and science data can be recorded. In addition, data can be recorded and played back at the same time.

18. Insulation Repair In Space

This photo shows STS-82 Astronaut Scott Horowitz with an MLI repair patch. During Servicing Mission 2, astronauts detected damage to insulation on the outside of Hubble. Astronauts working inside the shuttle created repair patches with the materials they had on hand. Multi-layer insulation covers 80 percent of Hubble's exterior. This insulation, coupled with supplemental electric heaters, maintains the temperature of the equipment and optics within safe limits. If insulation deteriorates or becomes damaged over time, the insulation must be repaired or replaced to maintain the correct temperature environment for the satellite.

In space, care must be taken to ensure that equipment and systems do not become too cold or too hot. Hubble's insulation blankets are 15 layers of aluminized Kapton, with an outer layer of aluminized Teflon. Aluminized or silvered flexible reflector tape covers most of the remaining exterior. These coverings protect against the cold of space and reflect excessive heat from the Sun. Hubble is thermally designed to maintain safe component temperatures even for worst-case conditions in space.

Engineering, Design and Maintenance

19. Photo Documentation In Space

This photo of astronaut Mark Lee was taken by fellow crew member Steven Smith during the second servicing mission for HST. Mark Lee is preparing to document the day's activities using one of the EVA cameras. It is critical that astronauts take pictures of Hubble when they first see it and that they document their completed work photographically. Since engineers cannot walk into a building and view Hubble, they rely on this photo documentation to accurately design and build new hardware. This photo activity is important as we continue servicing the Hubble Space Telescope.

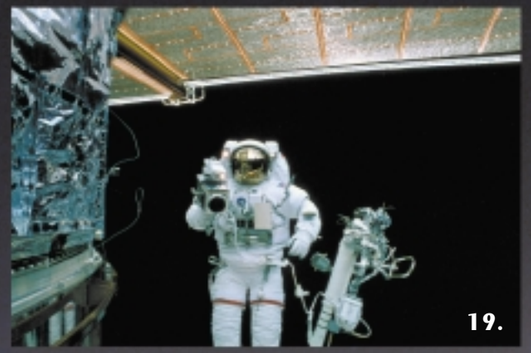
In addition to hand-held EVA cameras, there are video cameras mounted on each of the four corners of the orbiter bay and in two places on the Remote Manipulator System (RMS) or "robotic arm." The crew members inside the shuttle have a Hasselblad camera and various 35mm and video cameras to document all on-board activities.

20. Hubble Returns to Duty

Servicing Mission 3B

Following the successful Servicing Mission 3A, Hubble is refreshed and back to work producing amazing science images. There are two more scheduled servicings in Hubble's future, Servicing Mission 3B in 2001; and Servicing Mission 4 in 2003.

Servicing Mission 3B will focus on the installation of the Advanced Camera for Surveys and more efficient, rigid solar arrays. Astronauts also will install the aft shroud cooling system, which will allow the science instruments to operate simultaneously at lower temperatures. In addition, an advanced cooling system will be installed on the Near Infrared Camera Multi-Object Spectrometer, which became dormant after its solid nitrogen coolant was exhausted in January 1999. The application of new external thermal coverings will be completed.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Servicing Mission 4 will see the addition of two new science instruments, the Cosmic Origins Spectrograph and the Wide Field Camera 3. Also, a refurbished Fine Guidance Sensor will be installed, completing the refurbishment of all Fine Guidance Sensors on Hubble.

Hubble is scheduled to be decommissioned in 2010.

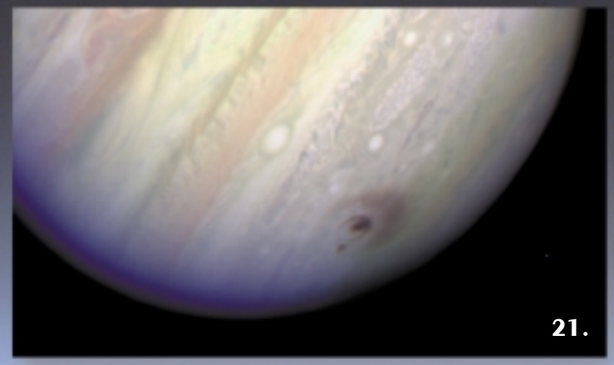

20.

21. Jupiter/PSL9

Scientists worldwide watched Comet Shoemaker Levy 9 slam into Jupiter in July 1994, representing the first time in human history that scientists were able to discover a body in the sky, predict its impact and then record with an armada of ground- and space-based telescores the comet's fiery plunge. In this Hubble image, taken nearly two hours after one of the fragments struck, the planet looks bruised. The impact area features a central dark spot 1,550 miles (2,500 km) in diameter, surrounded by rings that also are thousands of miles in diameter. Evidence suggests that the darkened spots on Jupiter and all the mighty plumes that soared into the planet's upper atmosphere occurred because of an object no more than one mile (1-1/2 km) in diameter. Originally, scientists believed the comet measured at least six miles (9 km) in diameter before it broke up into fragments after an earlier pass by the planet in 1992. Despite its small size, scientists agree that Comet Shoemaker Levy 9 packed a mighty powerful punch.

22. Saturn in Ultraviolet

Saturn was 810 million miles (1.3 billion kilometers) away when the Hubble Space Telescope took this ultraviolet image of the planet, revealing a vivid auroral display rising thousands of miles above the cloud tops over both of the planet's poles. These spectacular light shows are caused by an energetic solar wind that sweeps over the planet, much like it does on Earth. However, unlike on Earth, Saturn's aurora can be seen only in ultraviolet light, and therefore is visible only from space using instruments sensitive to ultraviolet radiation. The new Hubble images reveal ripples and overall patterns that evolve slowly, appearing generally fixed in our view and independent of planet rotation. These variations indicate that the aurora is primarily shaped and powered by a tug-of-war between Saturn's magnetic field and the flow of charged particles from the Sun. Study of Saturn's aurora began in 1979 when the Pioneer 11 spacecraft observed a far-ultraviolet brightening on Saturn's poles. The Saturn flybys of Voyager 1 and 2 in the early 1980's then provided a basic description of the planet's enormous magnetic field.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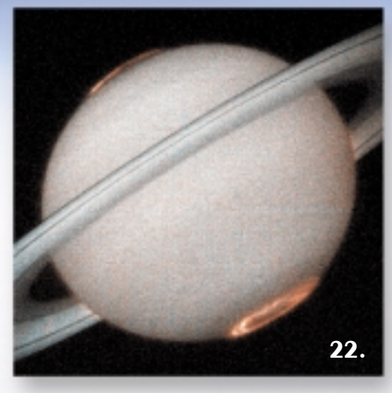
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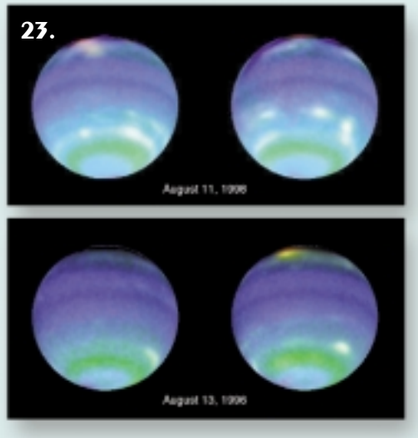
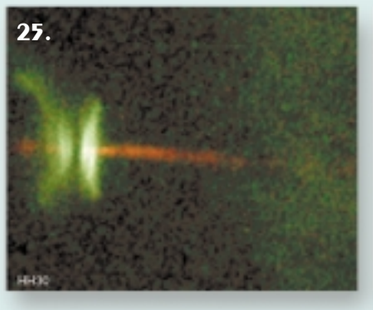
23. Neptune Storm

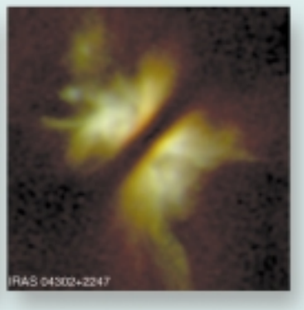
The Sun's energy heats the atmosphere and the oceans, which then drive the weather on Earth. On Neptune, though, the Sun is 900 times dimmer. What then causes the monster storms and the 900 mile-per-hour equatorial winds captured here in this Hubble image? Astronomers are trying to find out. Using Hubble and NASA's Infrared Telescope Facility in Hawaii, a team of scientists created a time-lapse rotation movie of Neptune that allowed them to watch the ebb and flow of the distant planet's weather. They measured Neptune's circulation, mapped its cloud tops and discovered distinct bands of weather that run parallel to the planet's equator. These bands encircle the planet and, in some respects, may be similar to the equatorial region of the Earth, where tropical heat provides the energy to make clouds.

24. Eagle Nebula Pillars

The three columns of dust and gas in this Hubble Space Telescope image are located in the Eagle Nebula, a nearby star-forming region 7,000 light-years away in the constellation Serpens. The tallest pillar of cool hydrogen gas and dust (on the left) is about a light-year long. In many ways, these eerie-looking structures could be compared to desert buttes, which were formed by erosion. In this case, though, ultraviolet light from hot, massive newborn stars (off the top edge of the picture) sculpted the columns in a process called "photoevaporation." As the ultraviolet light slowly erodes away the pillars, small globules of even denser gas emerge from within the columns themselves. These globules, called EGG's for Evaporating Gaseous Globules, are actually the birthplace of embryonic stars. However, the same process that sculpted the columns will eventually cut off their food source, and these embryonic stars will eventually succumb to photoevaporation and stop evolving.







25. Young Stellar Objects

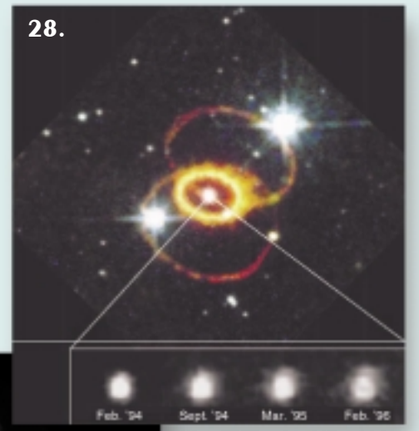
These Hubble images don't show actual planets, but rather the edge-on disks of gas and dust that eventually condense to form planets around young stars. Although astronomers have discovered about 30 possible extra-solar planets over the past few years, they have never gotten such detailed pictures of the planet-forming environments around newborn stars. Located 450 light-years away in the constellation Taurus, the stars all sport dusty disks that appear as dark bands. The disks are believed to be eight to 16 times the diameter of Neptune's orbit. In addition, the images show that raw material is still falling into these disks and driving jets of gas from the forming stars.

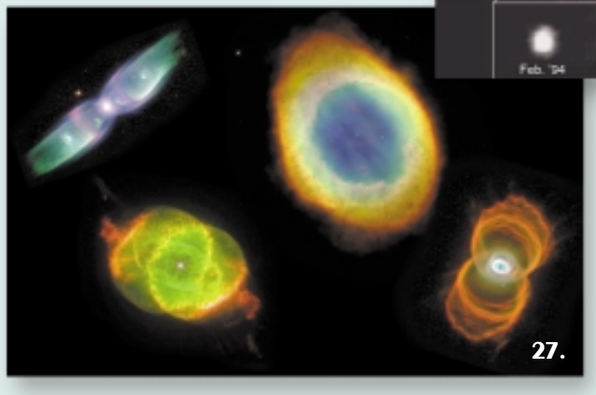
26. Stellar Dust Rings

Unlike the extensive disks of dust seen around other young stars, the ring around this young star is 6.5 billion miles from the star itself, which would be equivalent to the distance separating the orbits of Mars and Uranus in our own Solar System. The dust rings intrigue astronomers because of what they signify. All dust rings, whether around stars or planets, only remain intact by some mechanism confining the dust. Otherwise, particle collisions would cause the ring to spread both inward and outward until it finally lost its identity. The mechanism holding together this ring is probably the formation of new planets, astronomers believe. Just visible to the naked eye, the star, HR 4796A, is located 220 light-years away in the southern constellation Centaurus.

27. Planetary Nebula Gallery

A star's death was once thought to be a simple affair. The star cast off a shell of glowing gas and lived the remainder of its time as a white dwarf. This collection of images, however, is forcing researchers to rethink their theories of how Sun-like stars die. In particular, they believe the stars' intricate patterns, which resemble everything from lawn sprinklers to goblets, may be woven by a star's interaction with unseen companions, including planets, brown dwarfs or smaller stars. The question researchers now ask is how do so-called planetary nebulae (a name that was given them long before astronomers knew that these objects were actually dying stars) shape themselves. Hubble's ability to detect intricate details is giving researchers plenty to digest. From this collection, they found unexplained disks and "donuts" of dust girdling a star, strange glowing "red blobs" placed along the edge of some nebulae and jets of high-speed particles. Researchers say that these images give us a preview of our own Sun's fate some 5 billion years from now.





28. Supernova 1987A

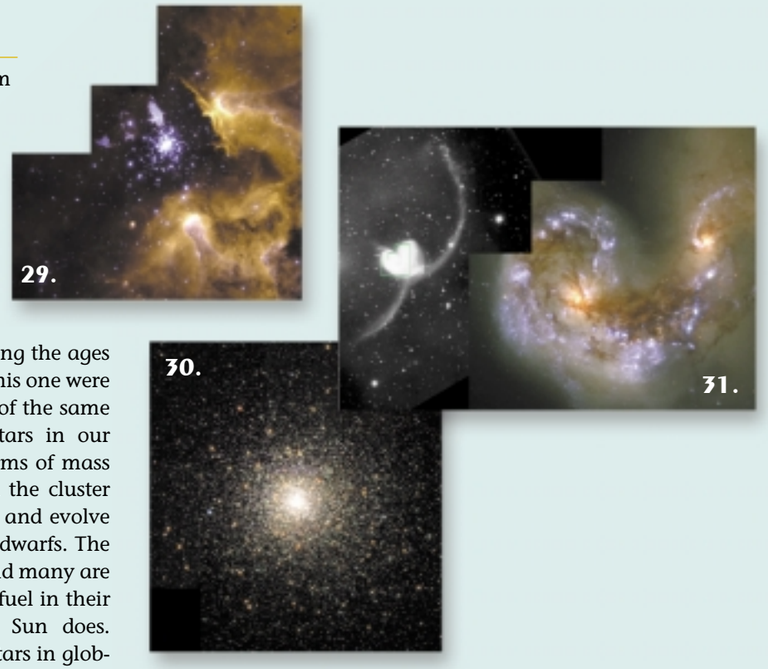
The brightest supernova in four centuries lit up the southern sky in 1987, but astronomers waited nearly a decade for the ballooning fireball to become large enough – about one-sixth of a light-year – to be resolved from Earth's orbit. With the Hubble Space Telescope astronomers have watched the remnant of the blast develop into a dumbbell-shaped structure consisting of two blobs of debris expanding away from each other at nearly 6 million miles per hour. They believe the dim area between the blobs may be related to the equatorial belt of material around the supernova that existed before the star exploded. The ring was illuminated by radiation from the supernova explosion and slowly faded thereafter. However, recently the ring has begun to light up again as debris from the blast crashes into it.

Scientific Achievements

29. NGC 3603

The Hubble Space Telescope captures in one single view the entire life cycle of stars. In the upper left of this picture of galactic nebula NGC 3603 is the evolved blue supergiant, called Sher 25. Like the famous 1987A supernova, a unique ring of glowing gas encircles it. The grayish-blue color of the ring and the blobs to the upper right and lower left of the star indicate the presence of chemically enriched material. Near the center, young, hot massive stars dominate the starburst cluster. Meanwhile, the dark clouds at the upper right, which are called Bok globules, probably are in the early stages of star formation. To the lower left of the cluster are two compact, tadpole-shaped emission clouds, which scientists believe may be evidence of protoplanetary disks, which eventually condense to form planets.

30. NGC 6093



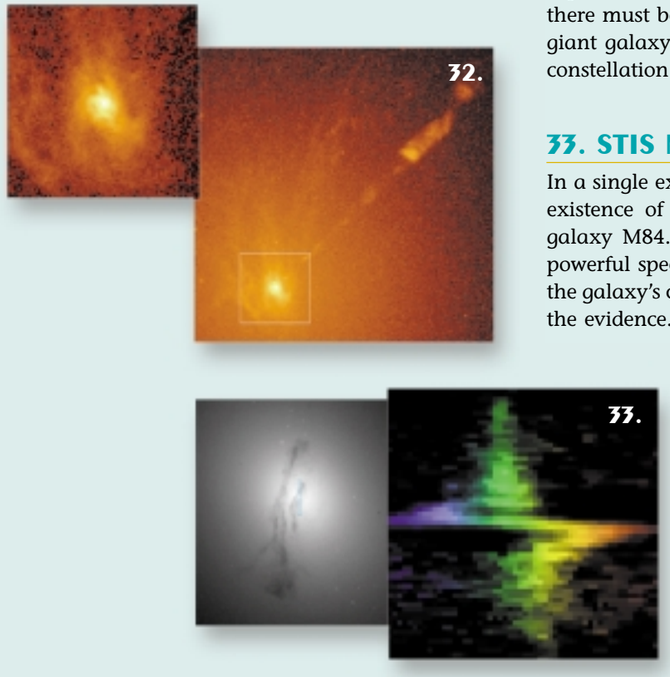
Located about 28,000 light-years from Earth, this swarm of stars, known as NGC 6093, is one of the densest globular star clusters in the Milky Way. The cluster contains hundreds of thousands of stars, all held together by their mutual gravitational attraction. In addition to being beautiful, clusters such as this one tell us much about stellar evolution and provide a means of measuring the ages of stars. All the stars in a cluster like this one were formed at the same time and so are of the same age. They are among the oldest stars in our galaxy. Yet they cover a range in terms of mass and size. The more massive stars in the cluster burn their nuclear fuel more quickly and evolve into red giants and ultimately white dwarfs. The less massive stars have longer lives and many are still burning their original hydrogen fuel in their central cores, much like our own Sun does. Hubble is able to resolve individual stars in globular clusters, covering an unprecedented range of mass, size and degree of evolution, and to accurately measure their brightness and colors. By comparing these accurate measurements to theoretical models describing how stars evolve, Hubble can measure the age of the entire cluster. A lot of work remains to be done. But Hubble's accurate measurements, coupled with recent improvements in the measurement of the clusters' distances, has led to revised estimates of the ages of the oldest stars in our galaxy – about 13-14 billion years.

31. Antennae Galaxies

Galaxies don't crash into one another as often as they used to. That's why scientists were so thrilled when they discovered this head-on collision and observed the results of the galactic smack-up – the creation of more than 1,000 bright, young star clusters. Star clusters are groups of stars born at almost the same time and place, and live together as units for billions of years because of the mutual gravitational attraction of their member stars. By studying the so-called Antennae galaxies, scientists hope to understand the evolution of colliding galaxies and why some galaxies are spiral shaped and others are elliptical or round. They also hope to get a better idea of how star clusters evolve, too. They once thought that these star-packed objects were the relics of the earliest generations of stars. It now appears that star clusters begin in giant molecular clouds that are squeezed by hot gas heated during a galactic collision. These clouds then light up in a great burst of star formation almost like a string of firecrackers. The Antennae galaxies, located 63 million light-years away in the constellation Corvus, got their unusual name because they have a pair of long tails of luminous matter that look like an insect's antennae.

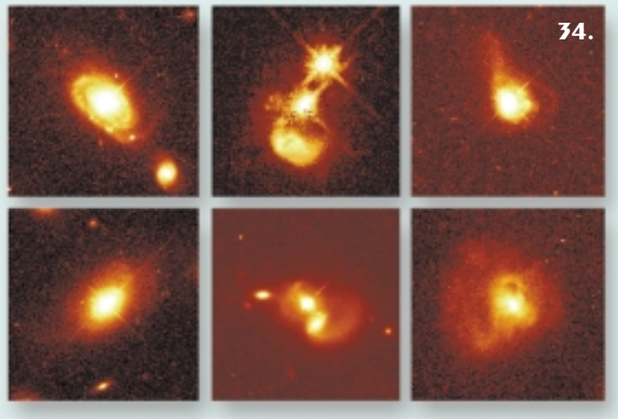
32. M87 with Jet

Earlier Hubble observations suggested that a massive black hole lived in the center of M87, but this observation proved it practically beyond doubt. Astronomers discovered that a disk of hot gas in the galactic core is rotating so rapidly that it contains a massive black hole at its hub. A black hole, which Albert Einstein predicted in his general theory of relativity, is an object so massive and compact that nothing can escape its gravitational pull, including light. The object at the center of M87 fits that description. It weighs as much as three billion suns, but is concentrated in a space no larger than the Solar System. The region contains only a fraction of the number of stars needed to create such a powerful attraction, leading astronomers to believe that there must be something else there that can't be seen. The giant galaxy is located 50 million light-years away in the constellation Virgo.



33. STIS M84

In a single exposure, astronomers were able to confirm the existence of a supermassive black hole in the center of galaxy M84. They did this by using the telescope's more powerful spectrograph to map the rapid rotation of gas at the galaxy's center. The colorful zigzag on the right provides the evidence. If no black hole were present, the line would be nearly vertical. The Space Telescope Imaging Spectrograph measured a velocity of 880,000 miles per hour within 26 light-years of the galaxy's center. This measurement allowed astronomers to calculate that the black hole contains at least 300 million solar masses. M84 is located in the Virgo Cluster of galaxies, 50 million light-years from Earth, and a nearby neighbor to the more massive M87 galaxy, which also contains an extremely massive black hole. The image on the left shows the galaxy's center in visible light.



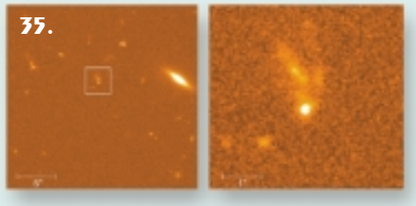
34. Quasar Host Galaxies

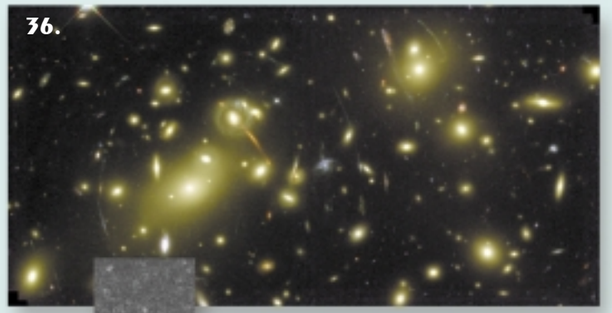
When seen through ground-based telescopes, quasars are compact, mysterious light sources that resemble stars, yet they are billions of light-years away and several hundred billion times brighter than the average star. Some of these objects can emit the energy output of 10 billion Suns. Given the incredible energy output, astronomers believe that quasars, which is short for quasi-stellar radio sources, turn on when a massive black hole at the center of a galaxy feeds on gas and stars. As the matter falls into the black hole, intense radiation is emitted. Eventually, the black hole will stop emitting radiation once it consumes all nearby matter. These Hubble images show different quasar homes, which range from normal to highly disturbed galaxies. The top left image, for example, is of a normal spiral galaxy, while the bottom right depicts the merger of two galaxies. Both quasars are more than a billion light-years from Earth.

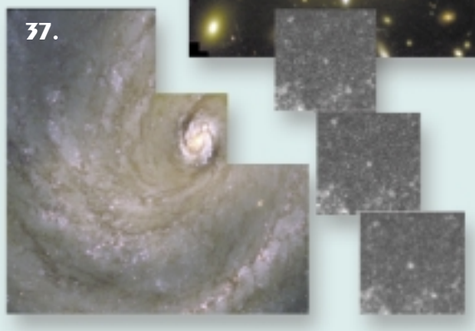
Scientific Achievements

35. Gamma Ray Burst 990123

Astronomers have known about gamma-ray bursts for more than 20 years; however, tracking them has always been difficult because they happen without warning and typically last for only a few seconds and come from any direction in the sky. Within only the past couple of years, astronomers have found that these mysterious bursts of radiation are extremely far away and are caused by tremendous, still unexplained explosions. But they got their first break in early 1999. Using orbiting observatories and ground-based telescopes, astronomers tracked the visible glow of the most energetic gamma-ray burst ever recorded. For a brief moment, the light from the blast was equal to the radiance of one million galaxies. When the Hubble Space Telescope observed the target a few days after the burst (left image), the object had already faded to one four-millionth of its original brightness. The telescope captured the fading fireball embedded in a galaxy located two-thirds of the way to the horizon of the observable universe. Further Hubble observations showed that the galaxy was neither a classic spiral nor an elliptical. It looked distorted as if its shape had been changed due to a collision with another galaxy, which would induce rapid star-birth. The observations support the idea that these mysterious powerful explosions happen where vigorous star formation takes place.







36. Abell 2218

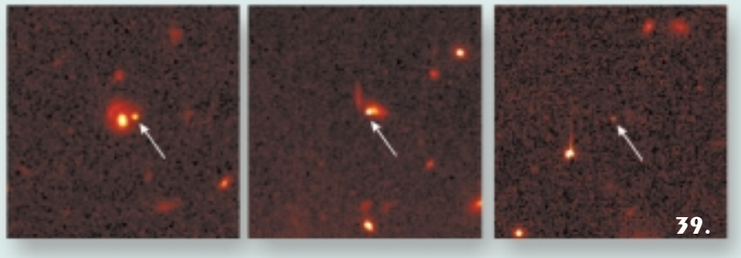
Abell 2218, an enormous cluster of galaxies that resides in the constellation Draco some 2 billion light-years from Earth, is so massive that its gravitational field magnifies, brightens and distorts the light of more distant objects. The phenomenon, known as a gravitational lens, is evident by the arc-shaped patterns found throughout the Hubble image. These "arcs" are actually distorted images of very distant galaxies, which lie five to 10 times farther than Abell 2218. This distant population existed when the universe was just a quarter of its current age. The tiny red dot just left of top center also intrigues researchers. They believe it may be an extremely remote object made visible by the cluster's magnifying powers. This is the second time Hubble observed this cluster. In 1994, scientists analyzed a black and white Hubble image and discovered more than 50 remote, young galaxies. The color imagery shown here is even more useful. Colors yield clues to ages, distances and temperatures of stars.

37. M100

M100, a majestic spiral in the Virgo Cluster of galaxies, contains a rare class of pulsating stars called Cepheid Variable stars. Cepheids, which Hubble detected within M100's spiral arms, are reliable cosmic distance mileposts. This is demonstrated in the top three frames of this image. The star in the center of each box changes brightness. The interval it takes for the Cepheid to complete one pulsation is a direct indication of the star's intrinsic brightness. This value can then be used to make a precise measurement of the galaxy's distance, which turns out to be 56 million light-years, making M100 the most distant galaxy in which Cepheids have been measured accurately. By understanding M100's distance from Earth, astronomers can calculate how fast the universe is expanding, which is crucial for understanding the age and size of the universe.

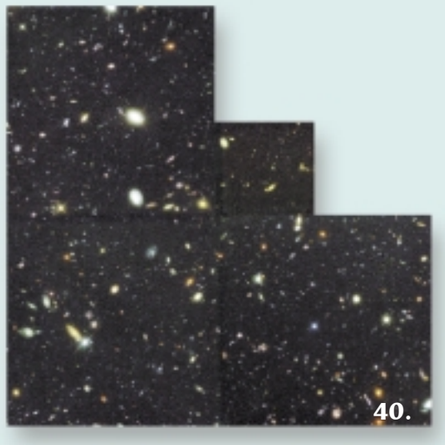
38. NGC 4414

In 1995, Hubble observed this majestic spiral galaxy, known as NGC 4414, as part of a key astronomical mission to accurately determine distances of many galaxies from Earth. The key was to find stars that vary in brightness. Called Cepheids, astronomers use these stars as standard distance indicators. Knowing distances allows astronomers to more accurately determine the universe's rate of expansion. This value is used to calculate distances, sizes and the luminosity of other objects in the universe, as well as the age of the universe itself. However, the observation was incomplete. Given the galaxy's very large size, Hubble could only view half the galaxy, requiring a return visit to capture the other half. In 1999, the telescope did just that, producing this stunning, full-color portrait. The new image shows that the central region of the galaxy is typical of most spiral-shaped galaxies: it contains mostly yellow and red stars, an indication that they are much older than the blue-colored stars residing in the galaxy's spiral arms. The arms also are rich in interstellar dust, which is seen as dark patches and streaks silhouetted against the starlight.



39. Distant Supernovae

Researchers are studying very distant supernovae to determine whether the expansion of the universe was decelerating long ago but now is accelerating. Between May and June 1997, Hubble observed the three supernovae to measure their brightness and create a light curve. Researchers then used the light curve to make an accurate estimate of the distances to the supernovae. They combined the estimated distance with the measured velocity of the supernova's host galaxy to determine the expansion rate of the universe in the past (5 to 7 billion years ago) and compare it with the current rate. SN 1997ck (right) exploded when the universe was half its current age, erupting 7.7 billion years ago making it the most distant supernovae ever discovered; the other two supernovae – SN 1997cj (left) and SN 1997cj (center) – exploded about 5 billion years ago.



40. Hubble Deep Field

In late 1995, researchers trained the Hubble Space Telescope on a speck-sized spot in the sky to produce this "deep field" view of the heavens – the most detailed optical view ever taken of the universe. Although the 10-day observation covers just a fraction of the sky, researchers consider it fairly representative of the universe, which statistically looks largely the same in all directions. In this particular view, researchers found a bewildering assortment of at least 1,500 galaxies at various stages of evolution. Most are nearly four billion times fainter than can be seen with the human eye, and date back to nearly the beginning of time. In that sense, this image is like using a time machine to look into the past to witness the early formation of galaxies, perhaps less than one billion years after the universe's birth in the Big Bang.

Scientific Achievements