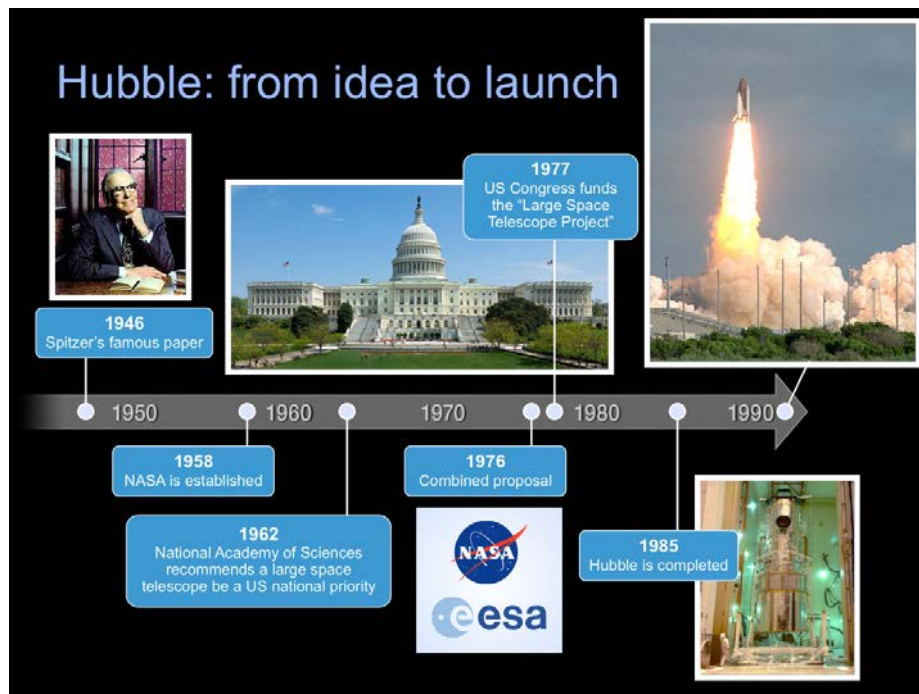




Hubble Space Telescope, launched in April 1990, celebrates its 25th anniversary in 2015.



In 1946, while working for the RAND Corporation, Lyman Spitzer wrote a white paper about the benefits of putting a telescope into space. Because Earth's atmosphere blurs the images of ground-based telescopes, the major benefit of a space telescope was the clearer view that would be obtained by locating it above Earth's atmosphere.

Note that 1946 is before the start of the space age. Even before they had the capacity to build them, astronomers were dreaming of space telescopes. This image of Lyman Spitzer was taken decades later at Princeton University.

In July, 1958, the National Aeronautics and Space Administration (NASA) was formed under the National Aeronautics and Space Act, less than a year after the launch of Sputnik on Oct. 4, 1957.

A 1962 study by the National Academies of Sciences recommended that a space telescope become one of the US national science priorities. This report spawned numerous groups to develop ideas for the observatory and its scientific instruments, not just in the US, but around the world.

In 1976, NASA and the European Space Agency (ESA), joined their space telescope proposals. This collaboration helped provide broader support for the project and spread the considerable financial responsibility.

In 1977, The US Congress funded what was then known as the Large Space Telescope project.

In 1985, the telescope was completed but launch was delayed due to the Challenger tragedy.

When the Space Shuttle program resumed after the Challenger disaster, the Hubble Space Telescope was launched aboard the Space Shuttle Discovery on April 24, 1990. The lower right image shows the launch of STS-31 from launch pad 39B.

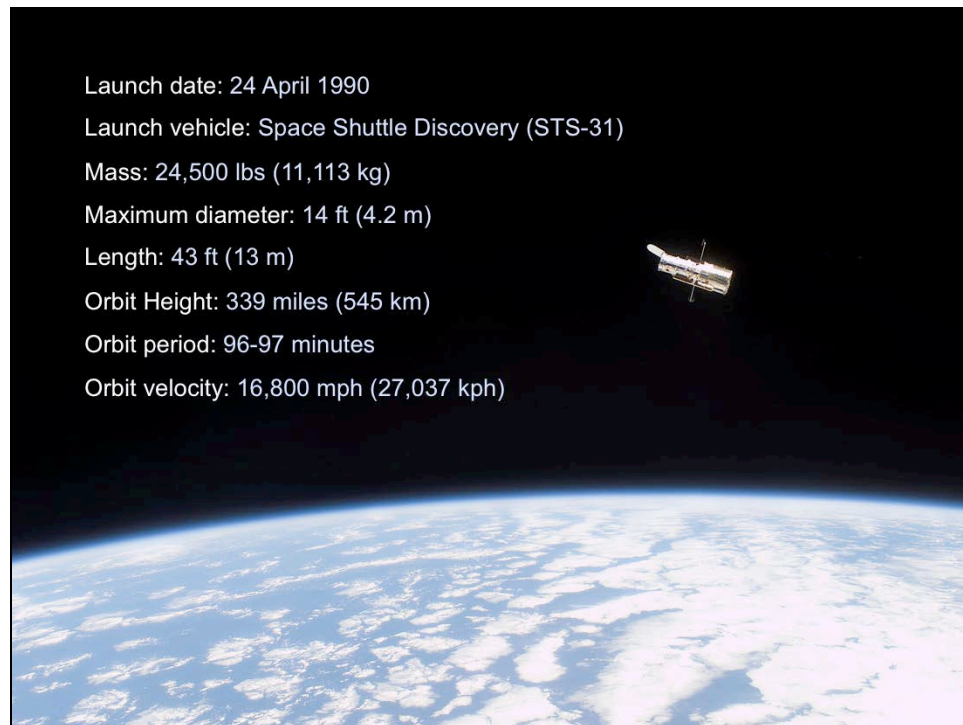
National Academy of Science photo credit: MAXWELL MACKENZIE/NAS

Capitol Building photo credit: Architect of the Capitol

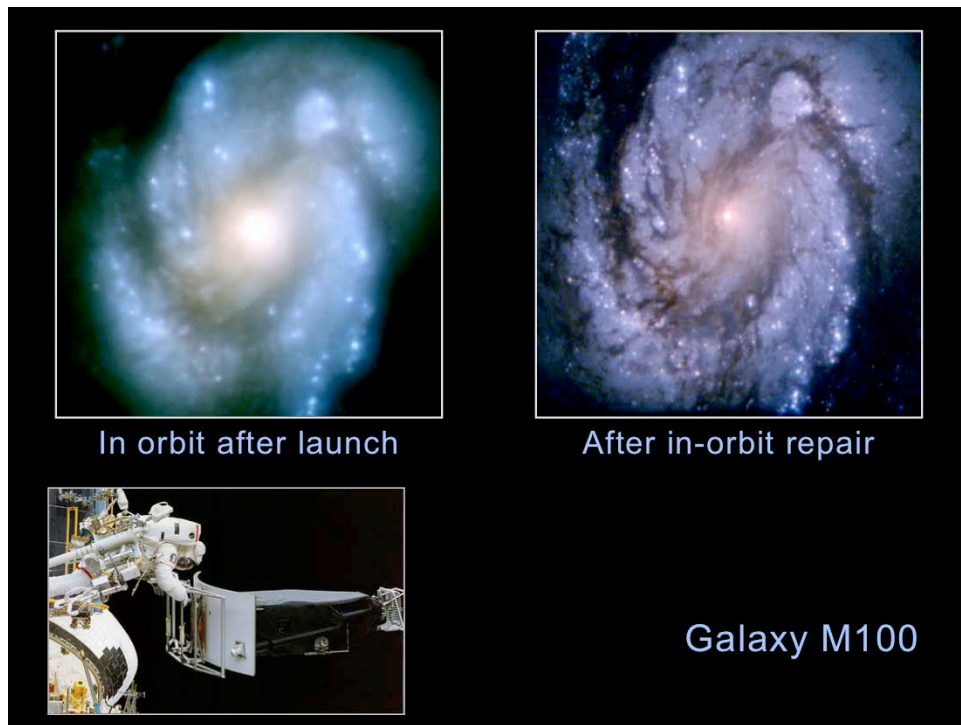
Shuttle Launch credit: NASA/KSC

Lyman Spitzer credit: NASA

Hubble construction: NASA



On April 25, 1990, the Hubble Space Telescope was deployed into low-Earth orbit by the crew of STS-31. Hubble orbits the Earth approximately every 96 minutes.

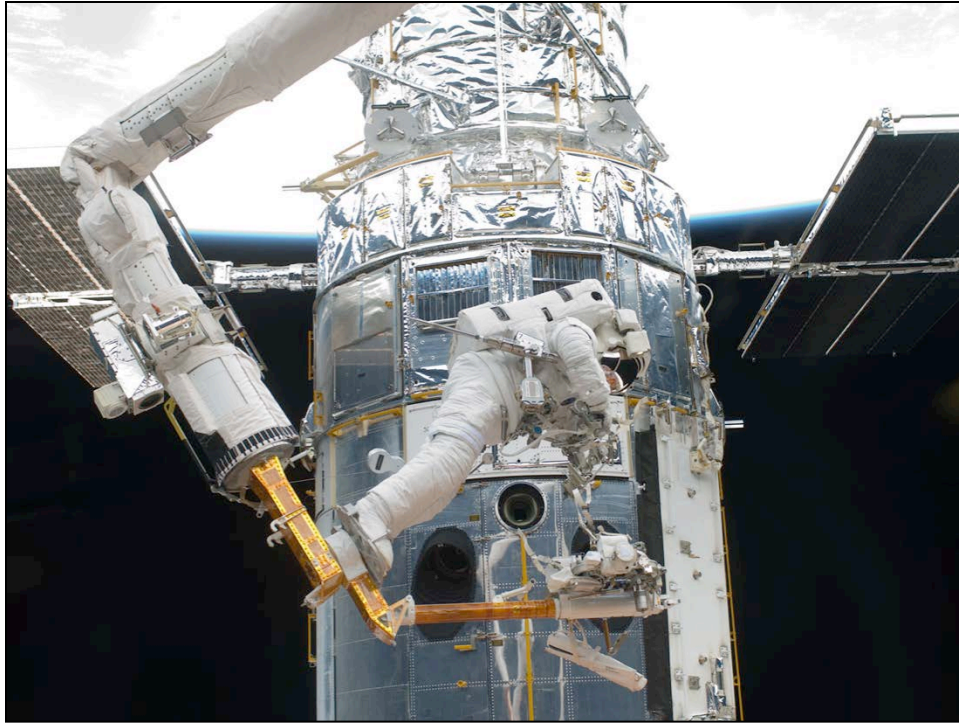


Astronomers quickly realized that Hubble had a flaw. Its mirror was slightly the wrong shape, causing the light that bounced off the center of the mirror to focus in a different place than light bouncing off the edge. This “spherical aberration,” about 1/50th the thickness of a sheet of paper, was corrected during the first servicing mission in 1993 with installation of the Corrective Optics Space Telescope Axial Replacement (COSTAR). The result was high-resolution imaging as shown in the image of galaxy M100. Since then, all of Hubble’s instruments have had corrective optics built in, eventually making COSTAR unnecessary. It was removed from the telescope in 2009.

Hubble was upgraded four more times with improved instruments. The inset image is from Servicing Mission 1 (STS-61, Space Shuttle Endeavor) which took place in December 1993. Astronauts installed COSTAR and replaced Wide-Field Planetary Camera 1 (WFPC1) with Wide-Field Planetary Camera 2 (WFPC2), the first instrument to have the correction built into its optics. The image shows astronauts replacing WFPC1 with WFPC2.

Detailed note: The two images of the center of galaxy Messier 100 show WFPC1 and WFPC2 data and demonstrate how well Servicing Mission 1 corrected the mirror flaw. Hubble could now achieve its design specifications.

<http://hubblesite.org/newscenter/archive/releases/1994/01/>



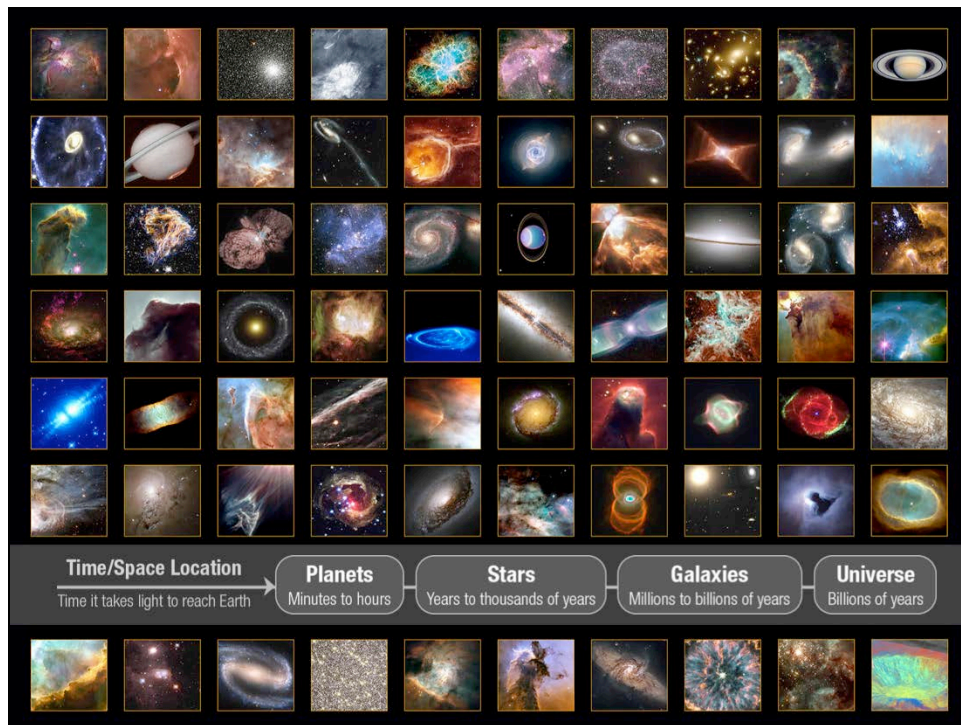
This image shows repairs being performed during Servicing Mission 4 (May 2009). Servicing Mission 4 was the final mission to Hubble (and actually the 5th visit to Hubble, since Servicing Mission 3 was conducted in two parts). The list of work to be done was long and ambitious, including the primary objectives of installing the new Wide-Field Camera 3 (WFC3) and the Cosmic Origins Spectrograph (COS). WFC3 would provide significantly enhanced ultraviolet and infrared capabilities for Hubble's main cameras.

Astronauts also repaired the Advanced Camera for Surveys and the Space Telescope Imaging Spectrograph, although neither was designed for servicing in space. Both instruments continue to function extremely well and are used regularly.

Despite a few sticky problems during five long spacewalks, the astronauts accomplished everything. The crew left Hubble in the best shape it has ever been.

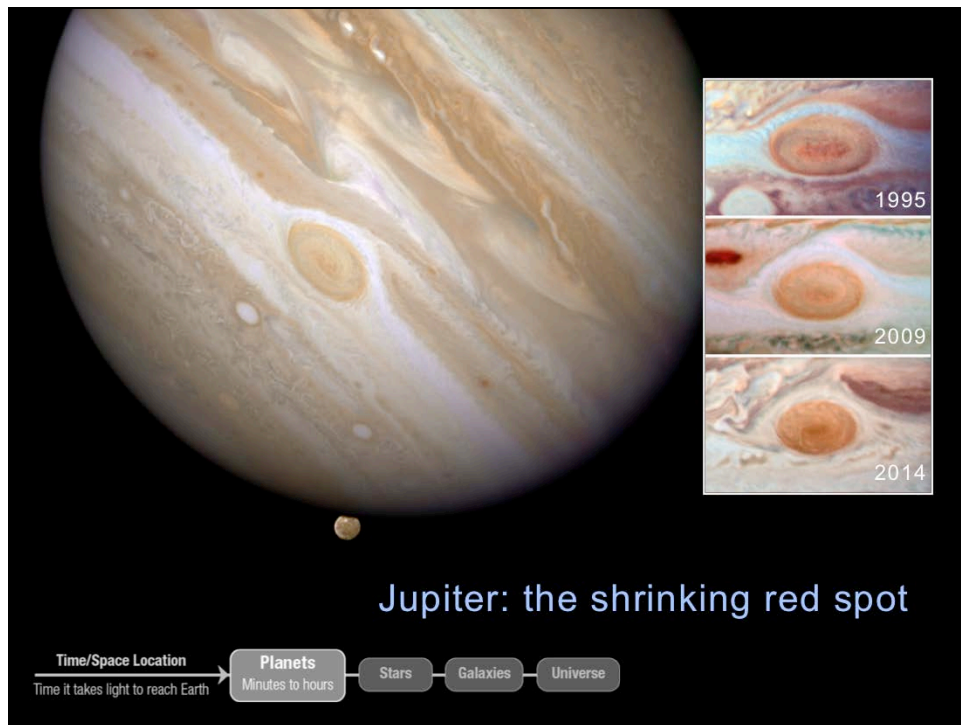
Pictures from the servicing mission:

http://asd.gsfc.nasa.gov/archive/sm4/multimedia/gallery10_space-day4.html



Presenter please note: Much of the discussion in these slides, and most of the public's attention, is focused on Hubble's enormous repertoire of images. Here is a montage of some of Hubble's best images that symbolize the breadth and depth of Hubble observations and the research being done.

In each image that follows, a timeline (shown here) will be shown so that viewers have an appreciation for how far away the object is and how long it takes for the light to travel to Hubble from that object.



Watching the weather patterns on the giant outer planets (Jupiter, Saturn, Uranus, and Neptune) has been an ongoing activity throughout Hubble's lifetime.

Jupiter's monster storm, the Great Red Spot, was once so large that three Earths would fit inside it. But new measurements by Hubble reveal that the largest storm in our solar system has downsized significantly. The Red Spot, which has been raging for at least a hundred years, is now only the width of one Earth. The storm images were taken in 1995, 2009, and 2014. The images were taken with Wide Field and Planetary Camera 2 (1995) and Wide Field Camera 3.

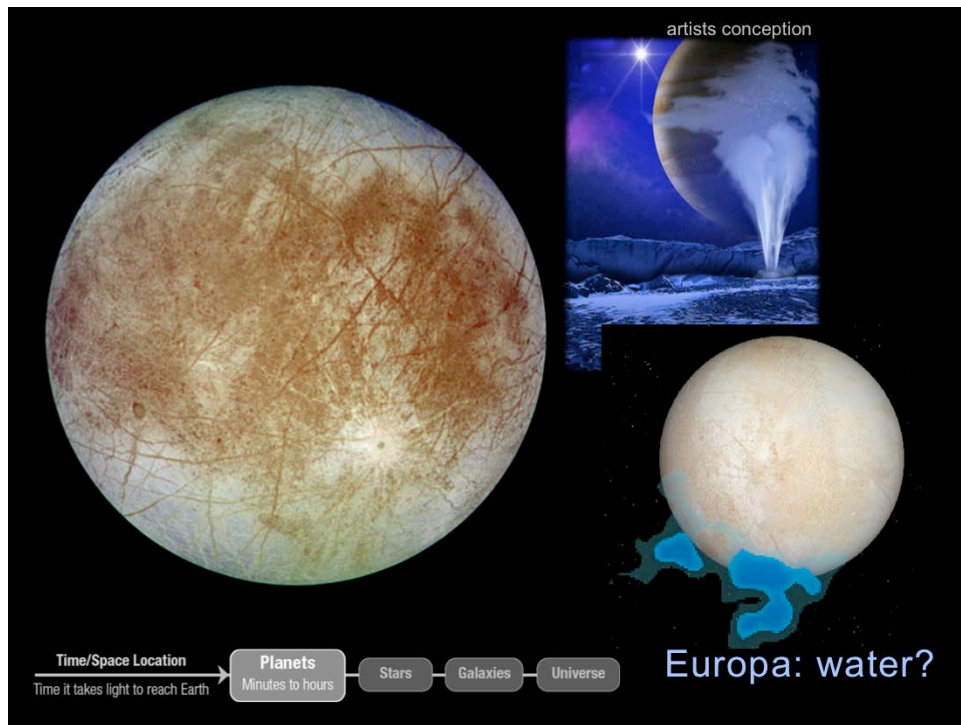
The large Wide Field Camera 2 image of Jupiter was obtained in 2007, with its moon, Ganymede, just emerging from behind the planet.

The semi-major axis of Jupiter's orbit about the Sun is 5.2 astronomical units (483 million miles or 778 million km). The planet has a diameter of roughly 88,789 miles (142,984 km) at the equator.

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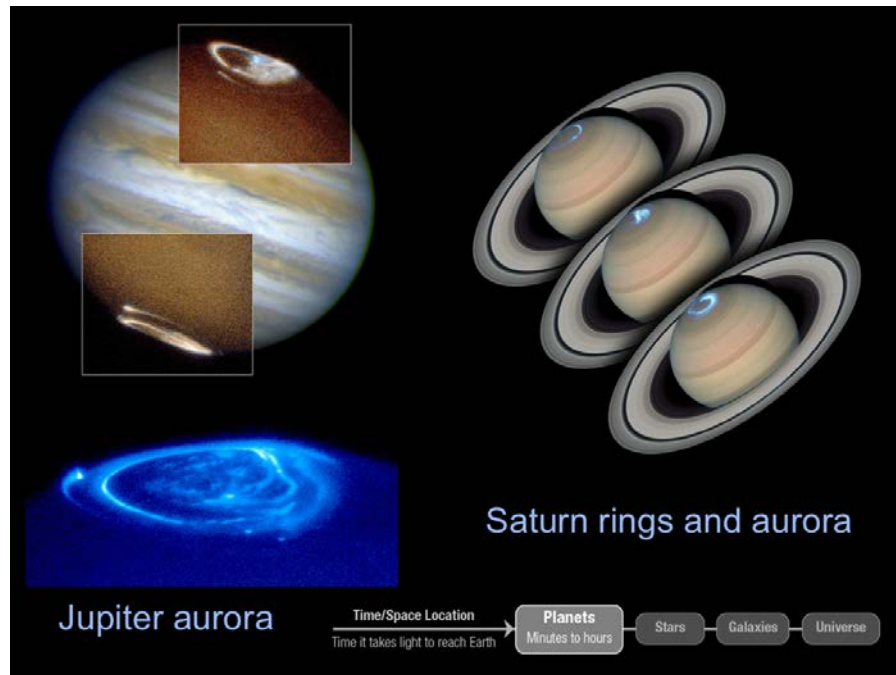
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This image of Europa is derived from a global surface map generated from combined NASA Voyager and Galileo space probe observations. The graphic shows the location of water vapor detected over Europa's south pole by Hubble in December 2012. The Hubble observations provide the best evidence to date of water plumes erupting off Europa's surface. Hubble didn't photograph plumes, so the plume and the illustration in the center are artist's conceptions. However, Hubble observers used the Space Telescope Imaging Spectrograph to spectroscopically detect auroral emissions from oxygen and hydrogen. The aurora is powered by Jupiter's magnetic field. This is only the second moon in the solar system found ejecting water vapor from the frigid surface. Another of Jupiter's moons, Ganymede, is also likely to have a subsurface ocean.

Europa is the sixth closest Jovian moon. It is the smallest of the four Jovian satellites discovered by Galileo Galilei, but still the sixth largest moon in the Solar System. Europa was discovered by Galileo in 1610.

<http://hubblesite.org/newscenter/archive/releases/2013/55/>



Images taken in ultraviolet light by Hubble's Space Telescope Imaging Spectrograph (STIS) show both Jupiter auroras in 1998, the oval-shaped objects in the inset photos. Ground-based telescopes cannot view these phenomena in ultraviolet light, as it is blocked by the Earth's atmosphere.

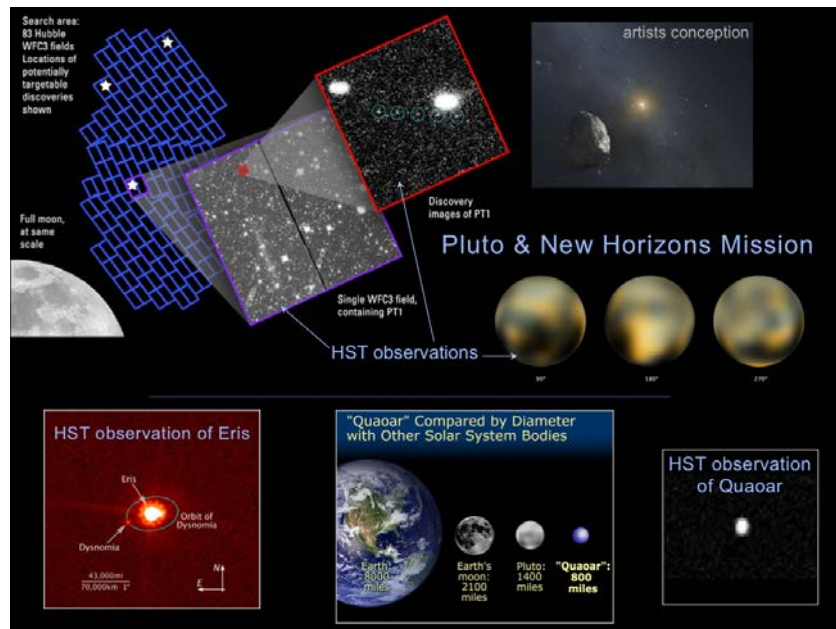
Auroras are curtains of light resulting from high-energy electrons racing along the planet's magnetic field into the upper atmosphere. The electrons excite atmospheric gases, causing them to glow.

The electric-blue image of Jupiter's northern aurora shows the main oval of the aurora, which is centered on the magnetic north pole, plus more diffuse emissions inside the polar cap. Though the aurora resembles the same phenomenon that crowns Earth's polar regions, the blue Hubble image shows unique emissions from the magnetic "footprints" of three of Jupiter's largest moons. (These points are reached by following Jupiter's magnetic field from each satellite down to the planet). Jupiter has at least 68 moons. Auroral footprints can be seen in this image from Io (along the left-hand limb), Ganymede (near the center), and Europa (just below and to the right of Ganymede's auroral footprint). These emissions, produced by electric currents generated by the satellites, flow along Jupiter's magnetic field, bouncing in and out of the upper atmosphere. They are unlike anything seen on Earth.

This ultraviolet image of Jupiter was taken with the Hubble Space Telescope Imaging Spectrograph (STIS) on November 26, 1998. In this ultraviolet view, the aurora stands out clearly, but Jupiter's cloud structure is masked by haze.

Saturn's aurora was observed with Hubble in 2005. Images were obtained with the Advanced Camera for Surveys in the optical and STIS in the ultraviolet. The aurora appeared in Saturn's southern polar region for several days. Hubble snapped a series of photographs of the aurora dancing in the sky. The snapshots show that Saturn's auroras differ in character from day to day -- as they do on Earth -- moving around on some days and remaining stationary on others. But compared with Earth, where auroral storms develop in about 10 minutes and may last for a few hours, Saturn's auroral displays always appear bright and may last for several days.

<http://hubblesite.org/newscenter/archive/releases/1998/04/>
<http://hubblesite.org/newscenter/archive/releases/2000/38/>
<http://hubblesite.org/newscenter/archive/releases/2005/06/>



Recently, NASA's New Horizons mission imaged Pluto and two of its moons, Nix and Hydra, which were discovered by Hubble in 2005. Peering out to the dim, outer reaches of our solar system beyond Pluto, Hubble uncovered three Kuiper Belt objects (KBOs) that the agency's New Horizons spacecraft could potentially visit after it flies by Pluto in July 2015. The KBOs were detected through a dedicated Hubble observing program by a New Horizons search team that was awarded telescope time for this purpose.

The lower set of Pluto images shows Hubble Space Telescope data from the Advanced Camera for Surveys exhibiting an icy, mottled, dark molasses-colored world undergoing seasonal surface color and brightness changes. Pluto has become significantly redder, while its illuminated northern hemisphere is getting brighter. These changes are most likely consequences of surface ice melting on the sunlit pole and then refreezing on the other pole, as the dwarf planet heads into the next phase of its 248-year-long seasonal cycle. Analysis shows the dramatic change in color took place from 2000 to 2002. Note that Hubble found four of Pluto's five moons – Nix, Hydra, Styx and Kerberos.

<http://hubblesite.org/newscenter/archive/releases/2014/47/full/>
<http://hubblesite.org/newscenter/archive/releases/solar-system/pluto/2010/06/>
<http://hubblesite.org/newscenter/archive/releases/solar-system/pluto/2012/32/> and related links
http://www.nasa.gov/nh_new-horizons-spots-small-moons-orbiting-pluto/#.VPnIP2TF_b4
<http://pluto.jhuapl.edu/>

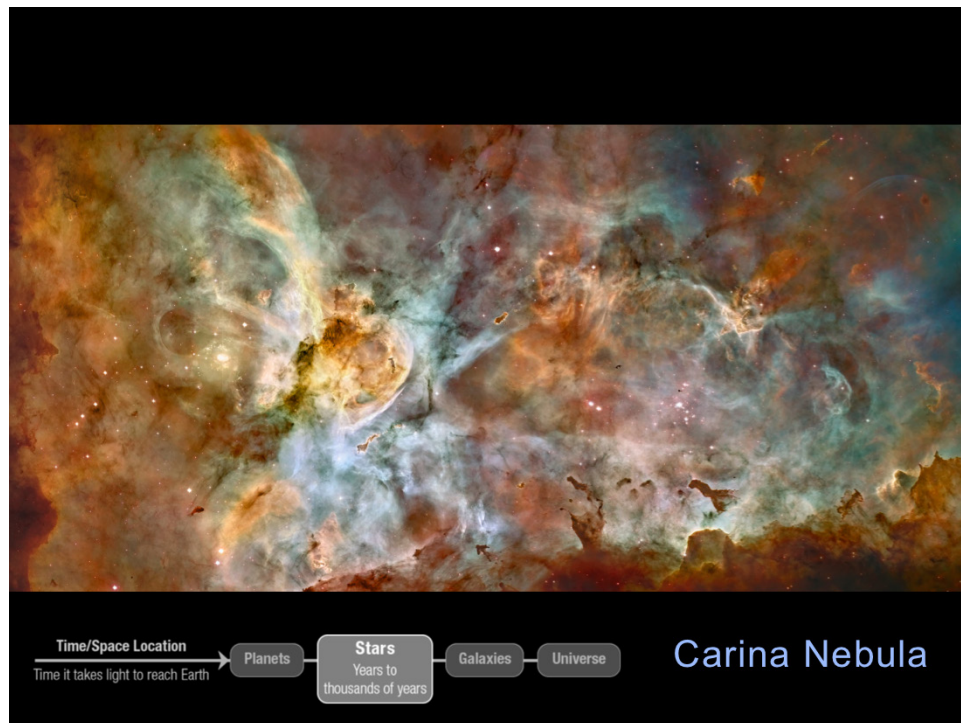
Other outer solar system objects:

Eris is 1.27 times the mass of Pluto, and formerly the largest member of the Kuiper Belt of icy objects beyond Neptune. Hubble observations in 2006 showed that Eris is slightly physically larger than Pluto. But the mass could only be calculated by observing the orbital motion of the moon Dysnomia around Eris. Multiple images of Dysnomia's movement along its orbit were taken by Hubble and Keck.

<http://hubblesite.org/newscenter/archive/releases/solar%20system/2007/24/image/c/format/web/>

Also in 2002, Hubble measured a large object discovered in the outer solar system. It was the largest outer solar system object discovered since Pluto and was superseded by the observation of Eris. Approximately half the size of Pluto, the icy world is called "Quaoar" (pronounced kwa-whar). Quaoar is about 4 billion miles away, more than a billion miles farther than Pluto. Like Pluto, Quaoar dwells in the Kuiper belt, an icy belt of comet-like bodies extending 7 billion miles beyond Neptune's orbit.

<http://hubblesite.org/newscenter/archive/releases/2002/17/>



Beyond the solar system, Hubble has studied star formation and death in our Galaxy and nearby galaxies.

As a first example, this image of the Carina Nebula was released for Hubble's 17th anniversary. At the time (2007), it was one of the largest panoramic images ever taken with Hubble's Advanced Camera for Surveys. It is a 50-light-year-wide view of the central region of the Carina Nebula, where a maelstrom of star birth -- and death -- is taking place. The nebula is sculpted by the action of outflowing winds and scorching ultraviolet radiation from the monster stars that inhabit this inferno. The stars are shredding the surrounding material that is the last vestige of the giant cloud from which the stars were born.

The immense nebula contains at least a dozen brilliant stars that are roughly estimated to be at least 50 to 100 times the mass of our Sun. The most unique and opulent inhabitant is the star Eta Carinae, at far left. Eta Carinae is in the final stages of its brief and eruptive lifespan, as evidenced by two billowing lobes of gas and dust that presage its upcoming explosion as a titanic supernova.

The outflow in the Carina region started three million years ago when the nebula's first generation of newborn stars condensed and ignited in the middle of a huge cloud of cold molecular hydrogen. Radiation from these stars carved out an expanding bubble of hot gas. The island-like clumps of dark clouds scattered across the nebula are nodules of dust and gas that are resisting being eaten away by photoionization. The blast of stellar winds and blistering ultraviolet radiation within the cavity is now compressing the surrounding walls of cold hydrogen. This is triggering a second stage of new star formation.

Carina is about 7,500 light years away (2,300 parsecs).

<http://hubblesite.org/newscenter/archive/releases/2007/16/>



This is the first of a sequence of three images to be shown relatively rapidly. We begin the anniversary year by revisiting a legendary image: the “Pillars of Creation” in the Eagle Nebula. This image was the first Hubble image to fascinate the public, and still remains one of Hubble’s most popular images. It was obtained in 1995 with the Wide Field and Planetary Camera 2 (WFPC2). Inside the gaseous towers, which are light-years long, the interstellar gas is dense enough to collapse under its own weight, forming young stars that continue to grow as they accumulate more and more mass from their surroundings. The object is 6,500 light years away (2,000 parsecs). Like the pillars in Carina, these dark clouds are being eroded by winds and radiation from hot, young stars. The stars forming within the pillars give them their “creation” nickname.

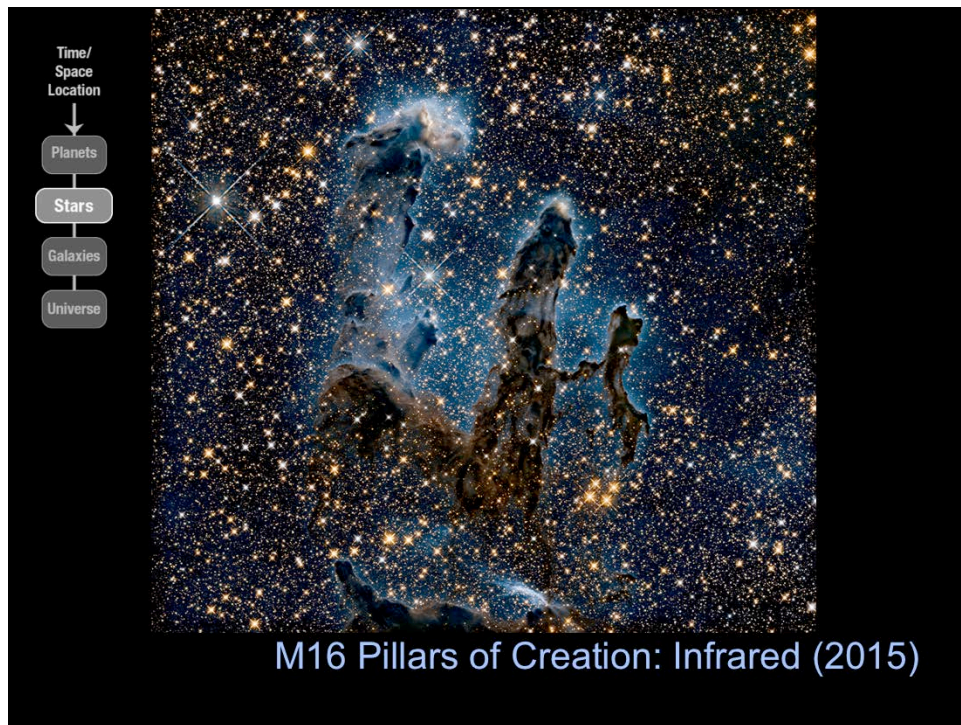
<http://hubblesite.org/newscenter/archive/releases/1995/44/>



Using Hubble's newer cameras provides a stunning image of an old favorite. This image of the Pillars of Creation in the Eagle Nebula has twice the resolution, several times the area, and more than twenty times the pixels of the 1995 version. The image was obtained with the optical bands of the Wide Field Camera 3 (WFC3) in 2015.

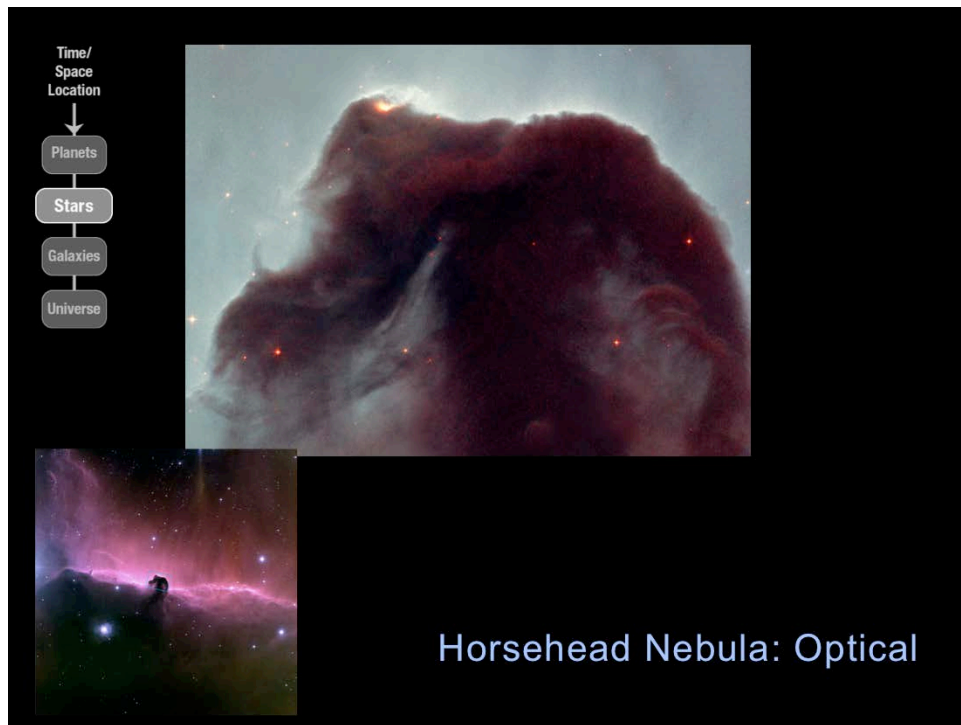
This taller image includes the gas at the bottom of the pillars being blown down and trailing away. Numerous small features indicate the pervasiveness of pillars of every size in this region.

<http://hubblesite.org/newscenter/archive/releases/2015/01/>



Using the infrared capabilities of Wide Field Camera 3 (WFC3), one can see the pillars in a whole new light. Much of the gas of the nebula is transparent to the longer wavelengths of infrared light, revealing a tremendous number of stars. The seemingly solid, visible-light pillars are shown in the infrared to be a combination of dense clouds and the shadows they cast behind them. Such high resolution visible light and infrared light comparisons point toward a bright future when Hubble and James Webb Space Telescope observations can be similarly compared and contrasted.

<http://hubblesite.org/newscenter/archive/releases/2015/01/>



This is the first of two images to be shown of the Horsehead Nebula. The transition should be done without too much delay to the next image.

In 2001, after asking the public which object should be observed, the Hubble Heritage Project took this image of the Horsehead Nebula with the Wide Field and Planetary Camera 2 (WFPC2).

While the nebula makes for a striking silhouette, the dark cloud is short on detail in a visible light image. The small inset shows a ground-based optical image of the surrounding region. The distance to the object is about 1,200 light years (490 parsec).

<http://hubblesite.org/newscenter/archive/releases/2001/12/>

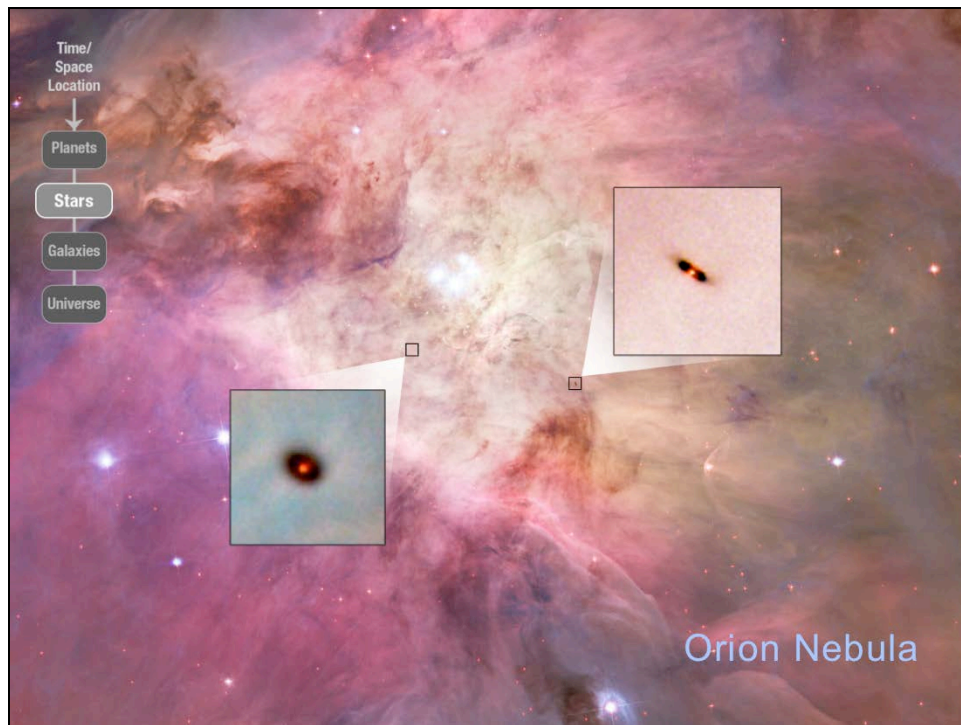


Using the enhanced infrared sensitivity of Wide Field Camera 3, Hubble was able to get much more detail in this 2013 infrared portrait of the Horsehead. The relatively featureless dark clouds are transformed into a glowing gaseous landscape that almost appears three-dimensional in the image.

There are videos that zoom into the nebula and also show the 3D effect.

<http://hubblesite.org/newscenter/archive/releases/2013/12/video/>

<http://hubblesite.org/newscenter/archive/releases/2013/12/>



This image of the Orion Nebula shows the discovery of debris disks – planetary systems in formation around newly created stars. As the gas and dust collapses under gravity, stars are born, and in the process, disks and planets often form out of the residual material. The distance to the Orion Nebula is 1,500 light years (460 parsecs).

<http://hubblesite.org/newscenter/archive/releases/1995/45/>

A beautiful composite image of the Orion Nebula from both the HST ACS and the ESO MPI at La Silla is available:

<http://hubblesite.org/newscenter/archive/releases/2006/01/>

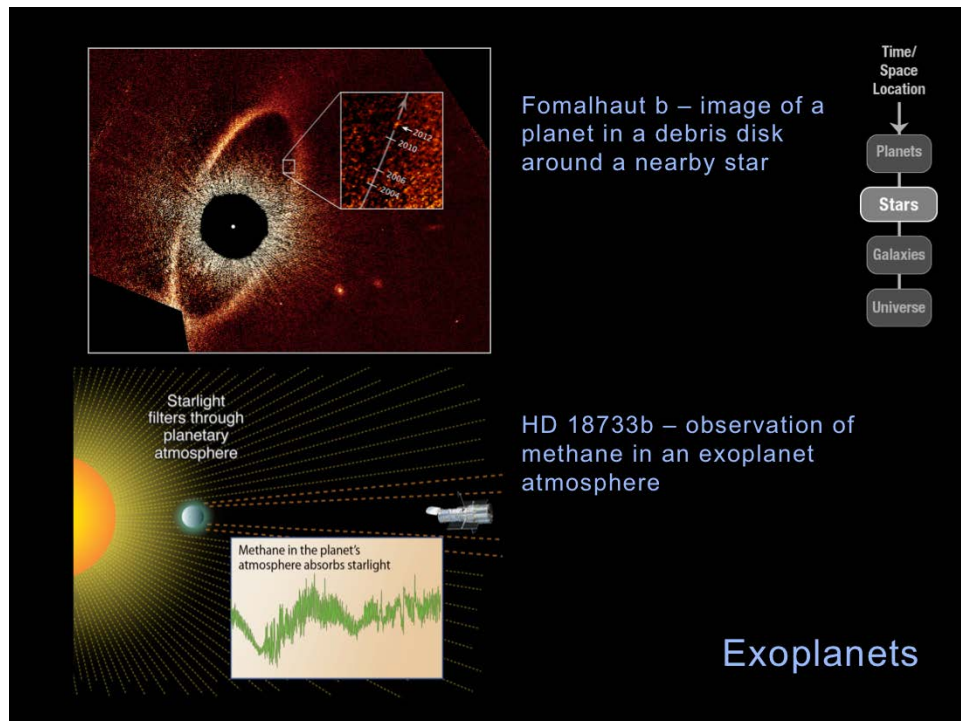
Supplemental Movies:

Orion Fly through:

<http://hubblesite.org/newscenter/archive/releases/2001/13/video/a/>

Zoom into Orion:

<http://hubblesite.org/newscenter/archive/releases/2001/13/video/a/>

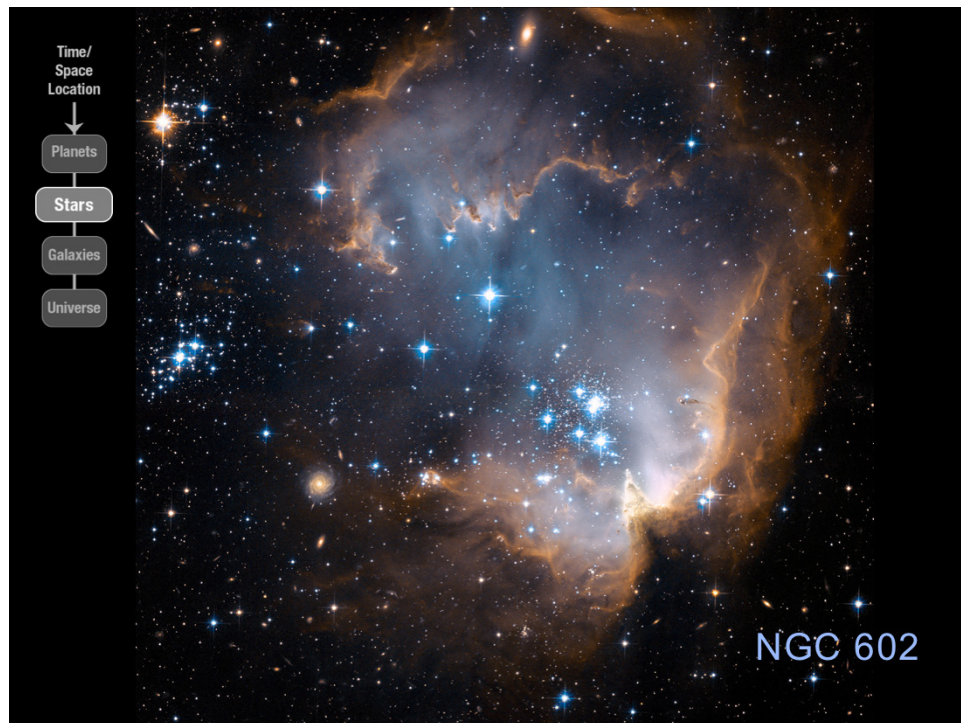


The upper image, taken by Hubble, reveals the orbital motion of the planet Fomalhaut b. Based on these observations, astronomers calculated that the planet is in a 2,000-year-long, highly elliptical orbit around its parent star, Fomalhaut. The planet will appear to cross a vast belt of debris around the star roughly 20 years from now. If the planet's orbit lies in the same plane with the belt, icy and rocky debris in the belt could crash into the planet's atmosphere. The black circle at the center of the image is caused by a device called a coronagraph, which blocks out the otherwise overwhelming light from the bright star and allows reflected light from the belt and planet to be photographed. The Hubble images were taken with the Space Telescope Imaging Spectrograph in 2010 and 2012. Fomalhaut is 25 light years (8 parsecs) away.

<http://hubblesite.org/newscenter/archive/releases/2013/01/>

The lower graphic demonstrates Hubble's first detection ever of an organic molecule in the atmosphere of a Jupiter-sized planet orbiting another star. This breakthrough is an important step toward eventually identifying signs of life on a planet outside our solar system. The molecule found by Hubble is methane, which under the right circumstances can play a key role in prebiotic chemistry — the chemical reactions considered necessary to form life as we know it. The graphic shows a spectrum of methane with the configuration of the star and the planet (not to scale) in relation to Hubble. The object is 63 light years (19 parsecs) away.

<http://hubblesite.org/newscenter/archive/releases/2008/11/>



At the heart of this star-forming region lies star cluster NGC 602. It is a cluster of newly formed stars that are blowing a cavity in the center of a star-forming region in the Small Magellanic Cloud, a companion galaxy to our own Milky Way. The high-energy radiation blazing out from the hot young stars is sculpting the inner edge of the outer portions of the nebula, slowly eroding it away and eating into the material beyond. The diffuse outer reaches of the nebula prevent the energetic outflows from streaming away from the cluster.

Ridges of dust and gaseous filaments are seen surrounding the cluster. Elephant trunk-like dust pillars point towards the hot blue stars and are telltale signs of their eroding effect.

It is possible to trace how the star formation started at the center of the cluster and propagated outward, with the youngest stars still forming today along the dust ridges. The Small Magellanic Cloud, in the constellation Tucana, is roughly 200,000 light-years from the Earth. Its proximity to us makes it an exceptional laboratory to perform in-depth studies of star formation processes and their evolution in an environment slightly different from our own Milky Way.

This image was taken with Hubble's Advanced Camera for Surveys.
<http://hubblesite.org/newscenter/archive/releases/2007/04/>

X-ray from Chandra plus Hubble observations:
<http://hubblesite.org/newscenter/archive/releases/2013/17/image/a/>



The Cat's Eye Nebula, formally cataloged NGC 6543, was one of the first planetary nebulae to be discovered. Hubble observations show it is one of the most complex such nebulae seen in space. A planetary nebula forms when Sun-like stars gently eject their outer gaseous layers, which eventually form bright nebulae with amazing and confounding shapes. This image taken with Hubble's Advanced Camera for Surveys (ACS) reveals the full beauty of a bull's eye pattern of eleven or even more concentric rings, or shells, around the Cat's Eye. Each 'ring' is actually the edge of a spherical bubble seen projected onto the sky — that's why it appears bright along its outer edge.

Observations suggest the star ejected its mass in a series of pulses at 1,500-year intervals. These convulsions created dust shells, each of which contains as much mass as all of the planets in our solar system combined (still only one percent of the Sun's mass). These concentric shells make a layered, onion-skin structure around the dying star. The view from Hubble is like seeing an onion cut in half, where each skin layer is discernible. The Nebula is 3000 light years (1000 parsecs) away.

<http://hubblesite.org/newscenter/archive/releases/2004/27/>



This beautiful image was taken soon after Servicing Mission 4 as part of the release announcing Hubble's return to science operations. This planetary nebula is the material blown off of a dying star. A disk around the center restricts the outflows into two oppositely directed lobes, creating a distinct resemblance to a butterfly.

Although named the Bug Nebula, many began calling this object the Butterfly Nebula after this image was released.

<http://hubblesite.org/newscenter/archive/releases/2009/25/>



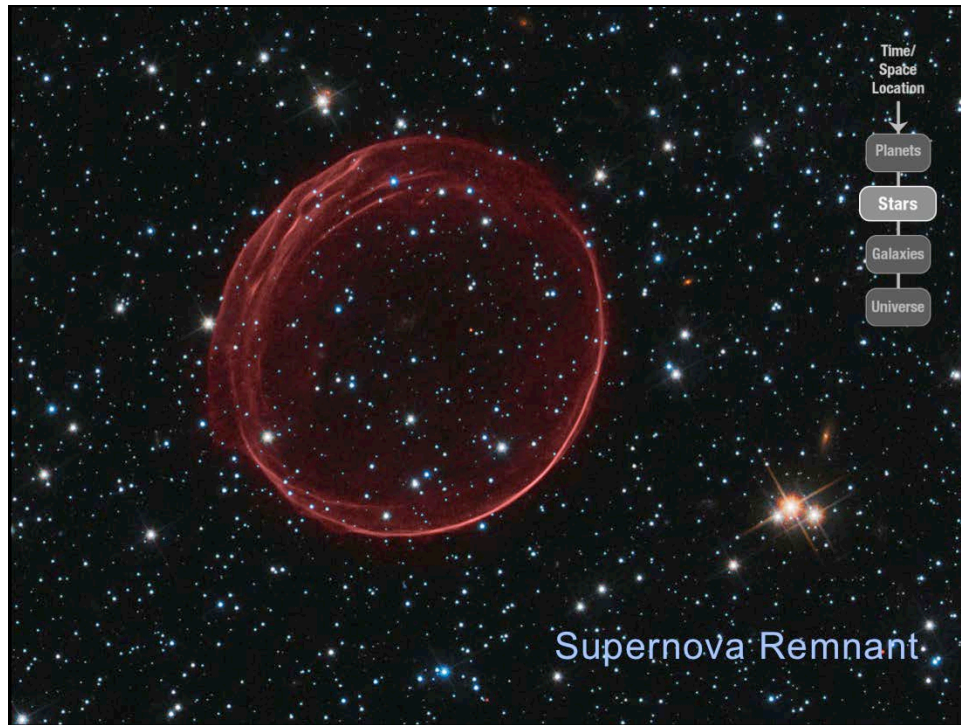
The Crab Nebula derived its name from its appearance in a drawing made by Irish astronomer Lord Rosse in 1844, using a 36-inch telescope. The Crab Nebula is a six-light-year-wide expanding remnant of a star's supernova explosion. Japanese and Chinese astronomers recorded this violent event nearly 1,000 years ago in 1054, as did -- almost certainly -- Native Americans. This composite image was assembled from 24 individual exposures taken with the Hubble Space Telescope's Wide Field and Planetary Camera 2 in October 1999, January 2000, and December 2000.

The orange filaments are the tattered remains of the star and consist mostly of hydrogen. The rapidly spinning neutron star embedded in the center of the nebula is the dynamo powering the nebula's eerie interior bluish glow. The blue light comes from electrons whirling at nearly the speed of light around magnetic field lines from the neutron star. The neutron star, like a lighthouse, ejects twin beams of radiation that appear to pulse 30 times a second due to the neutron star's rotation. A neutron star is the crushed ultra-dense core of the exploded star.

<http://hubblesite.org/newscenter/archive/releases/2005/37/>

Supplemental movie: Crab Pulsar Wind

<http://hubblesite.org/newscenter/archive/releases/2002/24/video/a/>



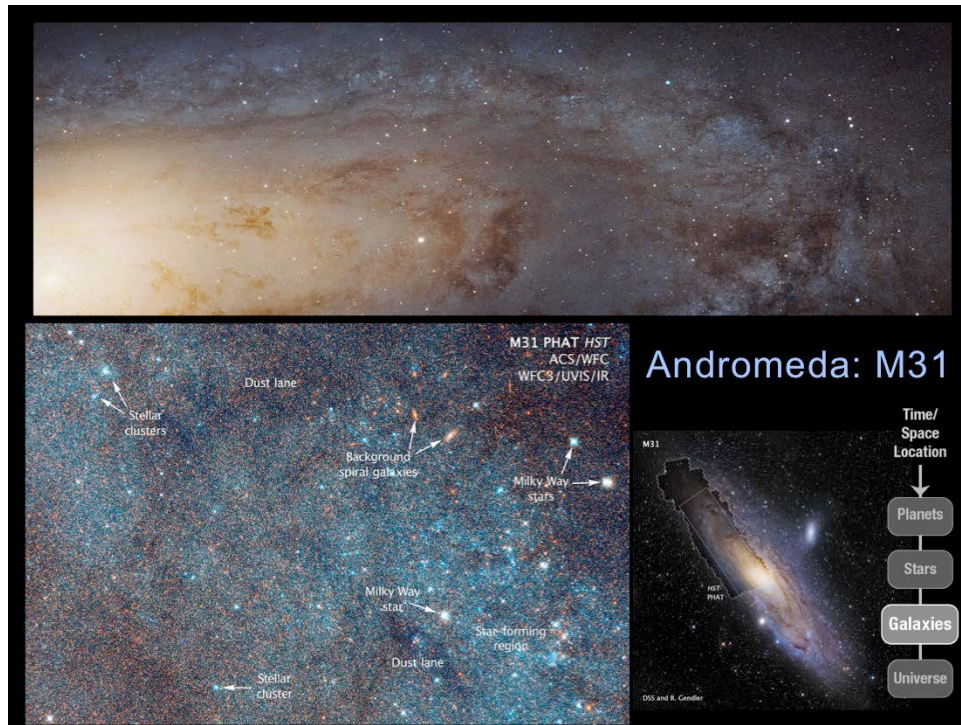
This shell, or bubble, is the result of gas that is being shocked by the expanding blast wave from a supernova. Notice its completely different appearance from the Crab Nebula in the previous slide.

Called SNR 0509-67.5 (or SNR 0509 for short), the bubble is the visible remnant of a powerful stellar explosion in the Large Magellanic Cloud (LMC), a small galaxy about 160,000 light-years from Earth. Ripples in the shell's surface may be caused by either subtle variations in the density of the ambient interstellar gas, or possibly driven from the interior by pieces of the ejecta. The bubble-shaped shroud of gas is 23 light-years across and is expanding at more than 11 million miles per hour (5,000 kilometers per second).

<http://hubblesite.org/newscenter/archive/releases/2010/27/>

Supplemental Movie: 3D look at SN remnant

<http://hubblesite.org/newscenter/archive/releases/2010/27/video/a/>



The largest Hubble Space Telescope image ever assembled, this sweeping view of a portion of the Andromeda galaxy (M31) is the sharpest large composite image ever taken of our galactic neighbor. Though the galaxy is over 2 million light-years away, Hubble is powerful enough to resolve individual stars in a 61,000-light-year-long stretch of the galaxy. The Andromeda galaxy is only 2.5 million light-years from Earth, making it a much bigger target in the sky than the myriad galaxies Hubble routinely photographs that are billions of light-years away.

The Hubble survey is assembled into a mosaic image using 7,398 exposures taken over 411 individual pointings. The data were taken with the Advanced Camera for Surveys. The lower left inset points out the numerous types of objects seen in the image. The lower right inset is a composite made from a series of ground observations that shows the entire M31 galaxy and the portion imaged by Hubble.

<http://hubblesite.org/newscenter/archive/releases/2015/02/>

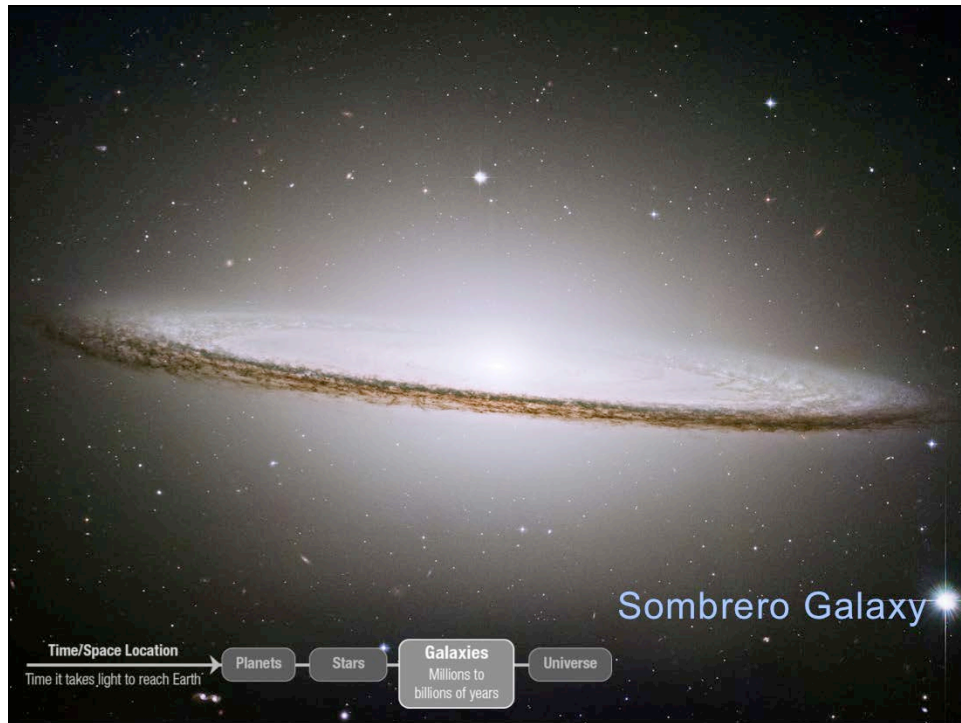
Supplemental movies: Three movies on the PHAT survey
<http://hubblesite.org/newscenter/archive/videos/survey/phant/>



This 91-million pixel mosaic of the Whirlpool Galaxy (M51) was released to celebrate Hubble's 15th anniversary. Beyond the sheer beauty of the image, the details along the spiral arms follow the progression of star formation from dark dust clouds through pink star-forming regions to blue newborn star clusters. Some astronomers believe that the Whirlpool's arms are so prominent because of the effects of a close encounter with NGC 5195, the small, yellowish galaxy at the outermost tip of one of the Whirlpool's arm.

The distance to M51 is 23 million light years (7 megaparsecs).

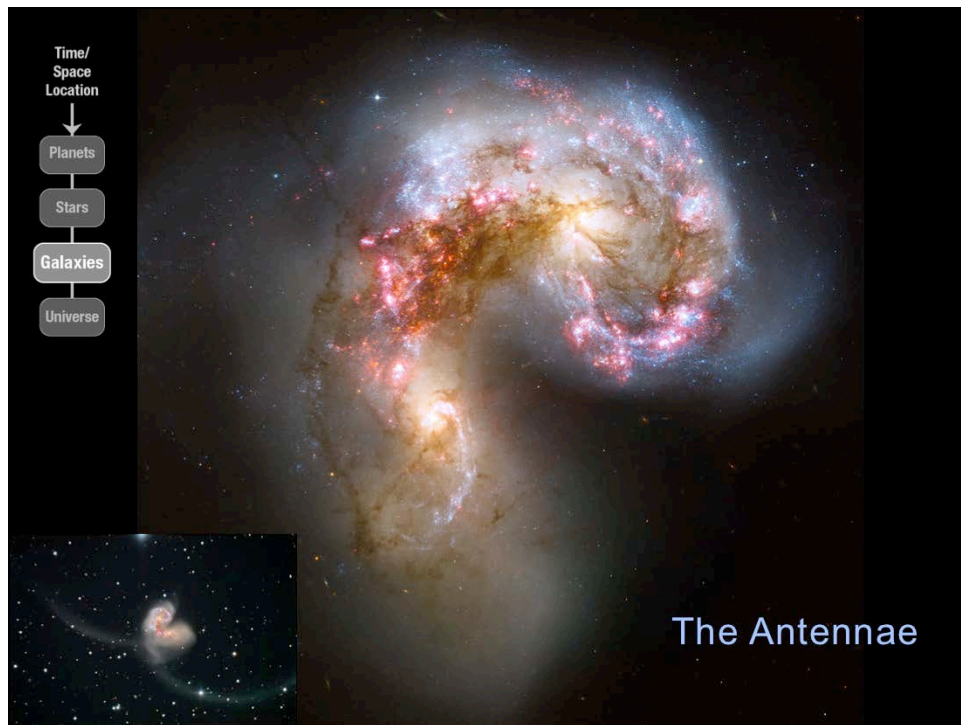
<http://hubblesite.org/newscenter/archive/releases/2005/12/>



This image of the Sombrero Galaxy is one of the first large mosaics produced from the Advanced Camera for Surveys instrument. Combining data from six pointings, the full resolution image contains over 70 million pixels. The Sombrero is cataloged as Messier 104 (M104).

The galaxy's hallmark is a brilliant white, bulbous core encircled by the thick dust lanes comprising the spiral structure of the galaxy. As seen from Earth, the galaxy is tilted nearly edge-on. We view it from just six degrees north of its equatorial plane. This brilliant galaxy was named the Sombrero because of its resemblance to the broad rim and high-topped Mexican hat. Sombrero is 28 million light years (9 megaparsecs) away.

<http://hubblesite.org/newscenter/archive/releases/2003/28/>



These two spiral galaxies started to interact a few hundred million years ago, making the Antennae galaxies one of the nearest and youngest examples of a pair of colliding galaxies. Nearly half of the faint objects in the Antennae image are young clusters containing tens of thousands of stars.

The orange blobs to the left and right of image center are the two cores of the original galaxies and consist mainly of old stars criss-crossed by filaments of dust, which appear brown in the image. The two galaxies are dotted with brilliant blue star-forming regions surrounded by glowing hydrogen gas, appearing in the image in pink. The image allows astronomers to better distinguish between the stars and super star clusters created in the collision of two spiral galaxies. The Antennae are 62 million light years (19 megaparsecs) away.



Galaxy interactions are not always the grand collisions seen in the Antennae galaxies. These two interacting galaxies, called the Rose Galaxy or catalog name Arp 273, have produced less pronounced distortions in each others' shape. The larger of the spiral galaxies, known as UGC 1810, has a disk that is tidally distorted into a rose-like shape by the gravitational tidal pull of the companion galaxy below it, known as UGC 1813. A swath of blue jewels across the top is the combined light from clusters of intensely bright and hot young blue stars. These massive stars glow fiercely in ultraviolet light. The smaller, nearly edge-on companion shows distinct signs of intense star formation at its nucleus, perhaps triggered by the encounter with the companion galaxy.

Some called this picture a “rose” of galaxies, with the upper galaxy as the bloom, and the lower galaxy as the stem. The pair is 340 million light years (105 megaparsecs) away.

<http://hubblesite.org/newscenter/archive/releases/2011/11/>

Supplemental animation: Arp 273 Zoom in

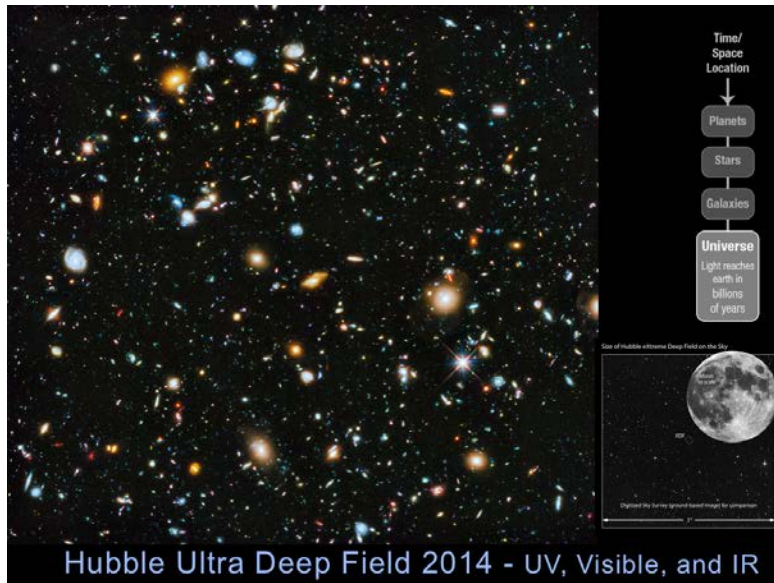
<http://hubblesite.org/newscenter/archive/releases/2011/11/video/b/>

3D animation:

<http://hubblesite.org/newscenter/archive/releases/2011/11/video/c/>

Scientific visualization of galaxy collisions:

<http://hubblesite.org/newscenter/archive/releases/2008/16/video/d/>



This image, the Hubble Ultra Deep Field 2014, covers only a small portion of the sky, yet there are around 10,000 galaxies, giving insight into the enormity of the universe and variety of galaxies throughout time.

The smallest of the tiny red dots represent some of the most distant and earliest galaxies ever detected. This is because those galaxies are so distant that light took billions of years to reach us; thus we see them as they looked billions of years ago. The universe is estimated to be about 13.8 billion years old. The smallest of the tiny red dots represent what galaxies looked like about 13 billion years ago, a mere several hundred million years after the Big Bang.

This composite image was released in 2014 and contains Hubble data taken over approximately 10 years of this small region of sky (2002-2012) with Hubble's Advanced Camera for Surveys and Wide Field Camera 3. It includes data across many wavelengths, including ultraviolet, visible, and infrared light. This iteration of the Hubble Ultra Deep Field (UV-HUDF) includes all prior HUDF data, including visible and infrared data from the XDF (2012) and HUDF-2012 campaigns, along with new ultraviolet data. The added ultraviolet data provides a missing link in star formation.

The inset image of the full moon gives the relative field-of-view of the XDF image, which is the same field-of-view of the UV-HUDF image shown on this slide. This is roughly equivalent to the observed area of FDR's eye on a dime held at arm's length - or, about 1/12th the width of the full moon as seen from Earth.

Astronomers previously studied the Hubble Ultra Deep Field (HUDF) in visible and near-infrared light in a series of images captured from 2003 to 2009. The HUDF shows a small section of space in the southern-hemisphere constellation Fornax. Now, using ultraviolet light, astronomers have combined the full range of colors available to Hubble, stretching all the way from ultraviolet to near-infrared light. The resulting image — made from 841 orbits of telescope viewing time — contains approximately 10,000 galaxies, extending back in time to within a few hundred million years of the big bang.

Prior to the ultraviolet coverage of this Hubble Ultra Deep Field study of the universe, astronomers were in a curious position. Missions such as NASA's Galaxy Evolution Explorer (GALEX) observatory, which operated from 2003 to 2013, provided significant knowledge of star formation in nearby galaxies. Using Hubble's near-infrared capability, researchers also studied star birth in the most distant galaxies, which appear to us in their most primitive stages due to the significant amount of time required for the light of distant stars to travel into a visible range. But for the period in between, when most of the stars in the universe were born — a distance extending from about 5 billion to 10 billion light-years — they did not have enough data. Until now.

<http://hubblesite.org/newscenter/archive/releases/2014/2014/27/>

Supplemental movie: HUDF zoom in

<http://hubblesite.org/newscenter/archive/releases/2014/27/video/a/>

Zoom into the XUDF before the UV observations

<http://hubblesite.org/newscenter/archive/releases/2012/37/video/b/>



The next step in observing the deep universe with Hubble is to use natural gravitational lenses. A gravitational lens is created when a clump of matter (such as a cluster of galaxies) distorts the natural path of light around the mass and concentrates it to the observer. The lens both distorts and magnifies background objects. Astronomers are spending the three years peering at six massive clusters of galaxies that are such lenses in Hubble's Frontier Fields program. With the boost from such natural "zoom lenses" found in space, Hubble's Frontier Fields observations should be able to uncover galaxies that are as much as 100 times fainter than what the Hubble, Spitzer, and Chandra space telescopes can typically see. The Frontier Fields program is looking at galaxy cluster fields in different directions in the universe to ensure a more complete picture of the early state of the formation of the cosmos.

Astronomers anticipate that these observations will reveal populations of never-before-seen galaxies that existed when the universe was only a few hundred million years old. The Hubble and Spitzer data are being combined to measure the galaxies' distances and masses more accurately than either observatory could measure alone, demonstrating the synergy of these Great Observatories for such studies. The Chandra X-ray Observatory will also peer deep into the fields, imaging them at X-ray wavelengths to help determine the masses and lensing power of the clusters, and to identify background galaxies with massive black holes.

The observations in this image were taken with the Advanced Camera for Surveys and Wide Field Camera 3. Abell 2744 is a very efficient lens located about 3.5 billion light years (1.1 billion parsecs) away at a redshift of $z=0.308$.

<http://hubblesite.org/newscenter/archive/releases/2014/01>

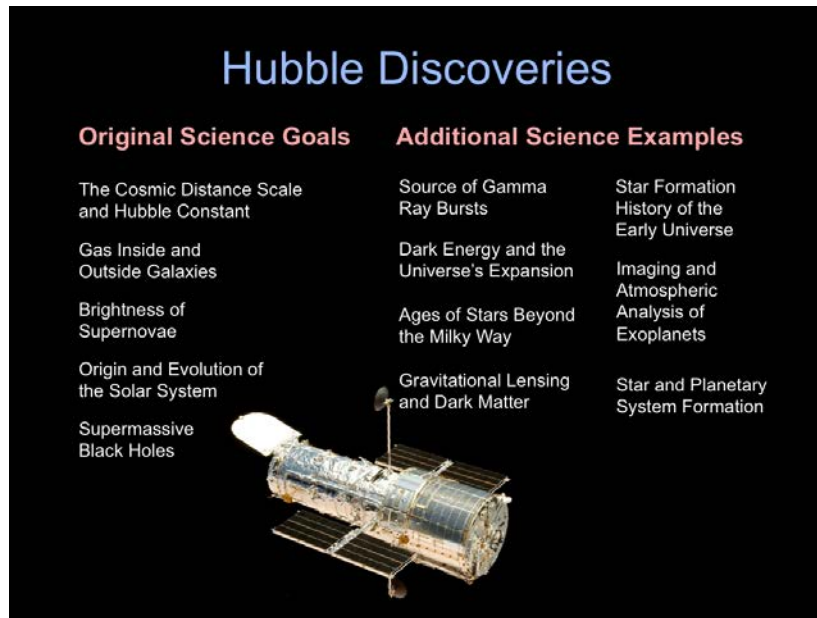
Supplemental movie: Overview of Frontier Fields

<http://hubblesite.org/newscenter/archive/releases/2014/01/video/a/>

Illustration of a black hole visiting Baltimore Harbor

https://www.youtube.com/watch?feature=player_embedded&v=1VNQ6T0W1bM

http://hubblesite.org/videos/video_details/25-a-black-hole-visits-baltimore



Hubble has made tremendous discoveries in the past 25 years. Shown here are some of the main science themes that Hubble was designed to explore (left) and some of the additional science themes Hubble was able to explore after new technology, installed during servicing missions, enabled new science (right).

It is important to note that these are broad science themes. The presenter can parse these in a way that best suits their presentation.

Hubble's contributions to exploring, resolving, and opening up new mysteries within these science themes comes about because of the technological capabilities of Hubble. For the anticipated science (left), many key observational constraints were achievable due to Hubble's design. For example:

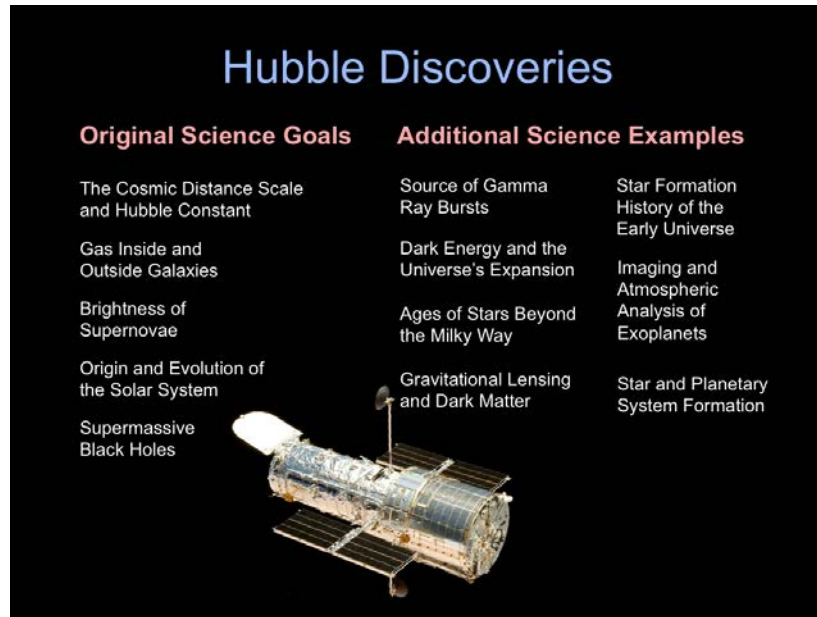
The Cosmic Distance Scale relied on sensitive measurements of the Hubble constant (H_0), which depended upon diffraction-limited optics to achieve the highest angular resolution possible and incredible imaging sensitivity provided by Hubble's instruments.

The understanding of the host galaxies of quasars (QSOs), active galactic nuclei (AGN), and the supermassive black holes proposed to be responsible for high-energy output from the centers of galaxies relied on Hubble's stable capabilities:

- Black Holes in galaxies – spectroscopy at the diffraction limit
- AGN emission lines – ultraviolet spectroscopy at the diffraction limit
- QSO host galaxies – diffraction-limited optics and high-contrast imaging

A better understanding of the material between galaxies – the intergalactic medium (IGM), and the material between stars within a galaxy – the interstellar medium (ISM), relied greatly on the use of the light from distant QSOs passing through the intervening IGM (and possibly ISM of particular galaxies) and capturing the spectra of that light to look for deficits, or absorption lines, that tell us the chemical composition of those regions. This technique of using QSO absorption lines (QALs) to understand the IGM and ISM required UV spectroscopy – a hallmark of Hubble's capabilities.

(Continued from previous page)



Hubble has made many unanticipated contributions, at least unanticipated at launch in 1990. The benefits of servicing missions not only provided a fix to Hubble's optics, but provided instruments that had greater capabilities in terms of sensitivities, field-of-views, and wavelength coverage. This is true for cameras and spectrographs added to Hubble after launch. Here are a few of the specifics:

Understanding galaxy formation via the Hubble Deep Field – The Hubble Deep Field was a program that used director's discretionary time from then-director of the Space Telescope Science Institute, Robert Williams (1995). The Hubble Deep Field required diffraction-limited optics and high imaging sensitivity.

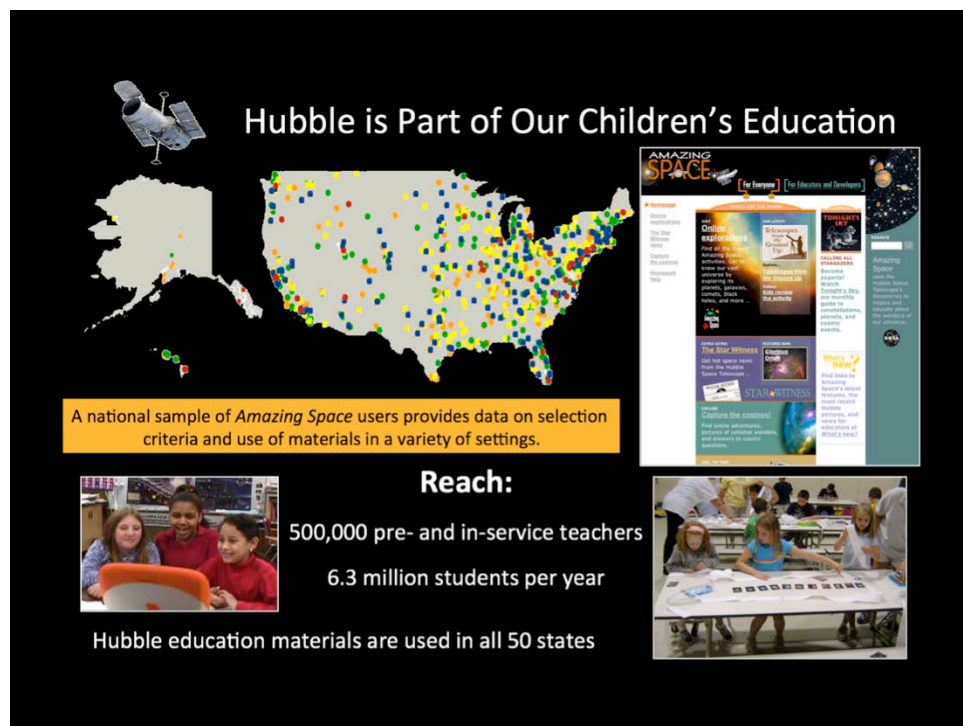
The discovery of dark energy – The discovery of dark energy required very careful observations and follow-up analysis of Type Ia supernovae. This, too, required diffraction-limited optics.

Follow-up study of the host galaxies of gamma-ray bursts (γ -ray bursts) – this, too, required diffraction-limited optics.

Planet formation via the study of debris disks – this, too, required diffraction-limited optics as well as high-contrast imaging.

Direct imaging of extrasolar planets required excellent photometric stability.

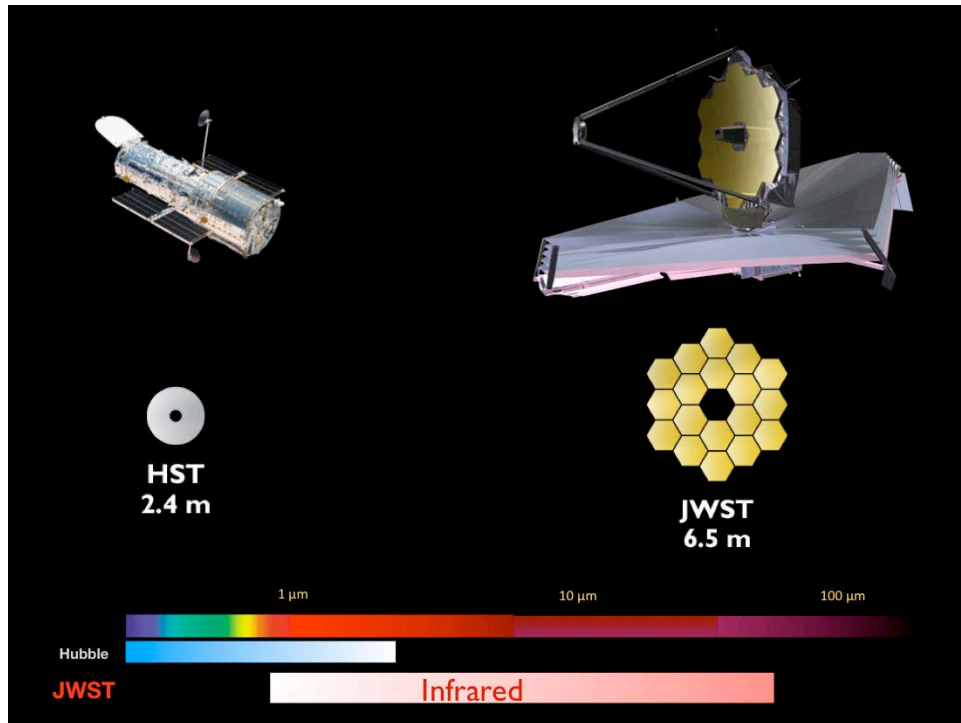
Analysis of extrasolar planet atmospheres required excellent spectroscopic stability and sensitivity.



Besides providing engaging imagery and science results, what is Hubble's "Return on Investment" for the public?

Hubble is a key part of science, technology, engineering, mathematics and art education (STEM and STEAM). Hubble inspires new generations of students, and makes science accessible to the public.

Science museums across the globe use Hubble resources and in the U.S., Hubble research is used in both K-12 school systems and community/state colleges that educate the next generation of teachers.



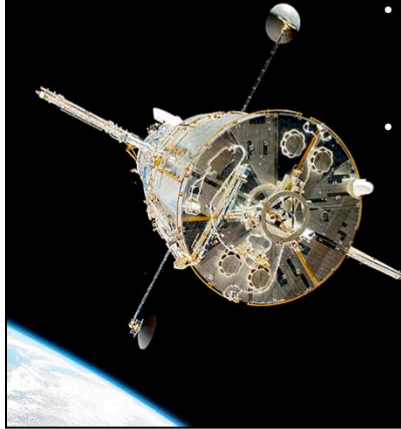
What is next? The James Webb Space Telescope is NASA's next orbiting observatory and the successor to the Hubble Space Telescope. A tennis court-sized telescope orbiting far beyond Earth's moon, Webb will detect infrared radiation as well as Hubble sees in visible light. JWST will launch in 2018 and represents an important step forward in technology, science capability and potential discoveries. As shown in the illustration, JWST has a 6.5-meter diameter segmented mirror, compared to the 2.5-meter monolithic mirror of Hubble. This gives JWST much more sensitivity to probe deeper into the universe as well as to investigate exoplanet systems in detail.

General information can be found at <http://webbtelescope.org/>

Supplemental movies: Many covering all topics regarding JWST
<http://jwst.nasa.gov/videos.html>

See especially the timelapse of the JWST sunshield deployment
<http://jwst.nasa.gov/videos/JWSTSunshieldDeployment.wmv>

Hubble 2020 Vision



- HST continues operation through 2020
 - Most productive observatory
 - Strong science synergy with James Webb Space Telescope in 2019-2020 timeframe
- HST Status
 - Healthy instruments, more powerful than ever
 - Healthy spacecraft (gyros, reaction wheels)
- Examples of trending science topics
 - Properties of planetary systems
 - Stellar evolution throughout time
 - Nature of dark matter and dark energy
 - Black hole properties on all scales (stellar to supermassive)
 - Origin and evolution of galaxies
 - Cycles of matter and energy in galaxies

How long will Hubble continue to operate? As long as it remains scientifically productive. Hubble is healthy and as powerful as ever. Hubble continues to be the most scientifically productive astronomical observatory as measured by the number of scientific papers published in peer-reviewed scientific journals each year (approximately 800 papers per year). The mission's "2020 Vision" ensures that Hubble will continue to operate at peak performance in the coming years and should enable Hubble to continue operations through 2020.

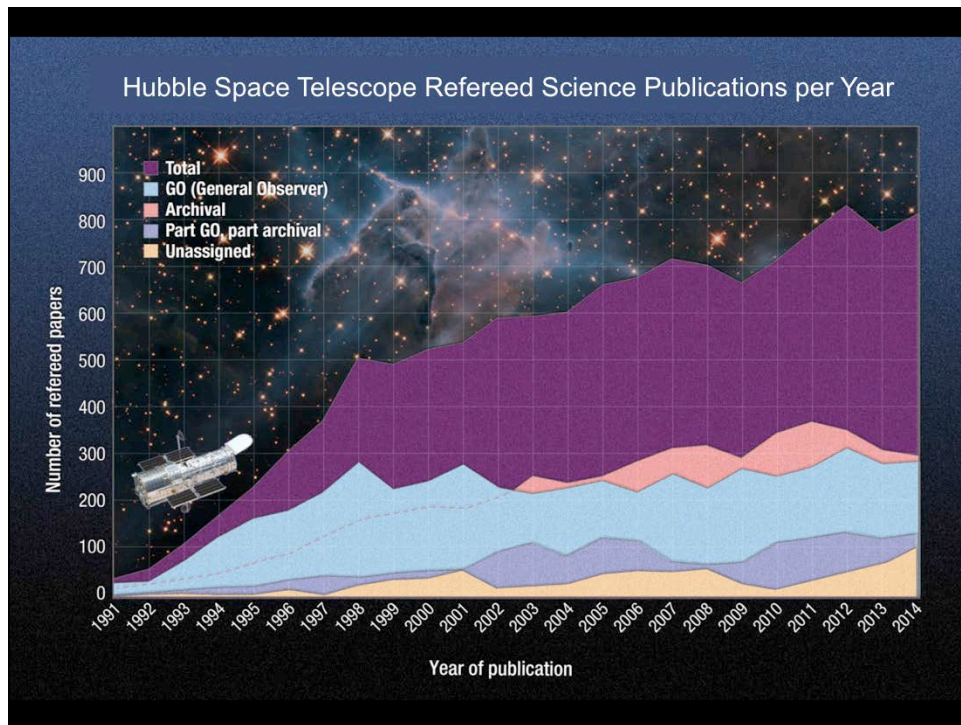


Hubble25th.org has resources for Hubble's anniversary. There are many links to supplemental materials. Visit the main website hubblesite.org for even more material.

Supplemental Slides

Shuttle Missions for Hubble Launch, Repair, and Refurbishment					
Launch	Servicing Mission 1	Servicing Mission 2	Servicing Mission 3A	Servicing Mission 3B	Servicing Mission 4
STS-31 Discovery	STS-61 Endeavour	STS-82 Discovery	STS-103 Discovery	STS-109 Columbia	STS-125 Atlantis
					
	Wide Field Planetary Camera 2 Corrective Optics Space Telescope Axial Replacement Gyros Solar Arrays	Space Telescope Imaging Spectrograph Near Infrared Camera and Multi-Object Spectrometer Fine Guidance Sensor	Advanced Computer Gyros Fine Guidance Sensor	Advanced Camera for Surveys Near Infrared Camera and Multi-Object Spectrometer Cooling System Power Control Unit Solar Arrays	Wide Field Camera 3 Cosmic Origins Spectrograph Space Telescope Imaging Spectrograph Repair Advanced Camera for Surveys Repair Science Instrument and Data Handling Unit Gyros New Outer Blanket Layer Soft Capture Mechanism Batteries Fine Guidance Sensor
					
April 1990	December 1993	February 1997	December 1999	March 2002	May 2009

Servicing Mission detail: This slide details Hubble's five servicing missions, and the repairs and upgrades performed. Servicing Mission 3 was split into two parts (in 1999 and 2000) due to the urgency of addressing the failure of Hubble's third gyroscope. (Gyroscopes are necessary for pointing the telescope.) The mission, designed for preventative repairs, was originally scheduled for June 2000, but NASA managers scheduled an early mission (Servicing Mission 3a) for December 1999. Servicing mission 3b was launched in March 2002 to complete the installation of the new instruments, a power unit and new solar arrays.



This is a supplemental slide. Although Hubble has produced amazing discoveries and astonishing images, the scientific productivity is equally if not more important. By the measure of refereed science papers, Hubble has been incredibly productive. This plot shows that papers based on both new and old (i.e., archival) Hubble data have grown to about 800 per year. The cumulative total is over 13,000 as of the end of 2014. Hubble is easily the most productive space mission of all time, and the most productive telescope in history.

The GO or General Observer papers are those originated by the team that proposed the observation. The Archival papers are those that are purely archival (no originating Team member on paper). Those that are combined part GO and part archival have some but not all team members as authors. Unassigned papers are other types of publications (calibration, statistics, review papers, etc.)