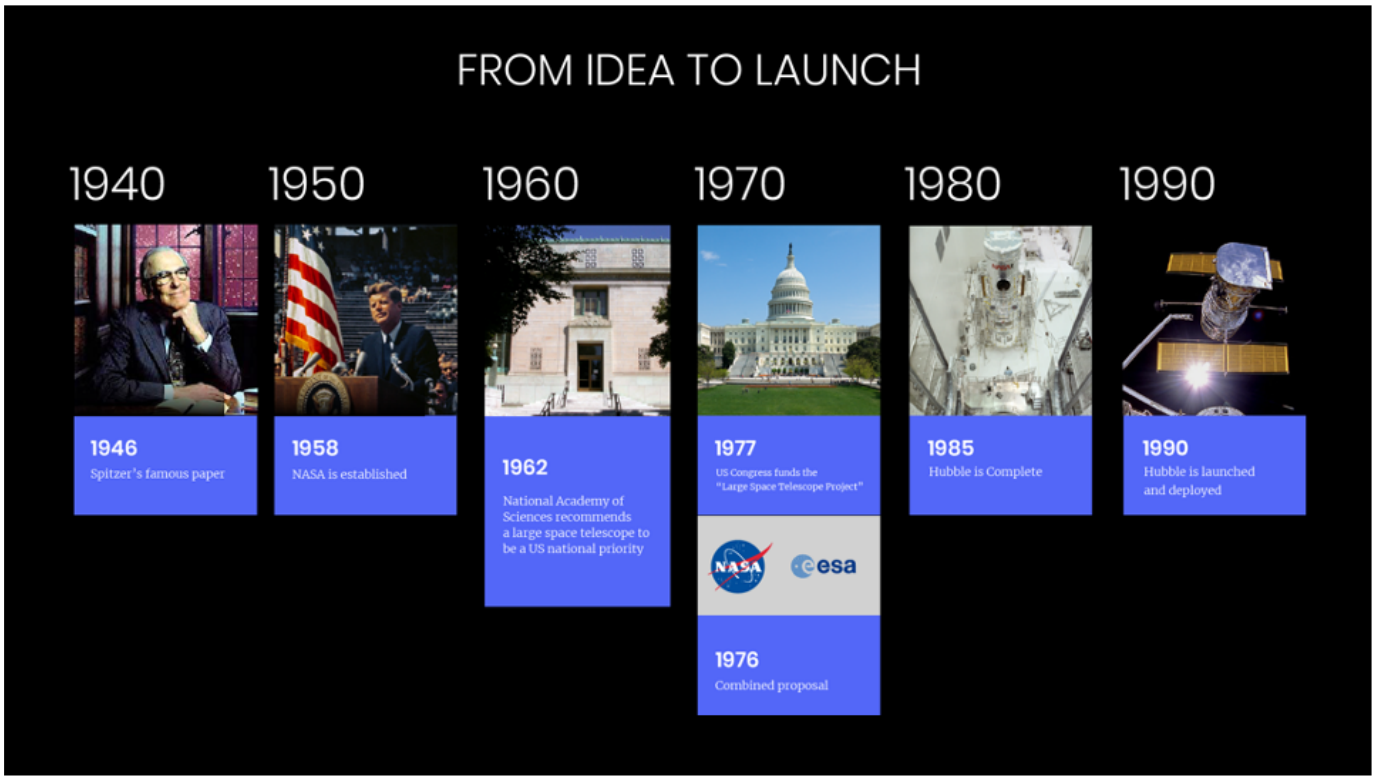
Hubble Space Telescope, launched in April 1990, celebrates its 30th anniversary 2020.



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

Lyman Spitzer credit: NASA

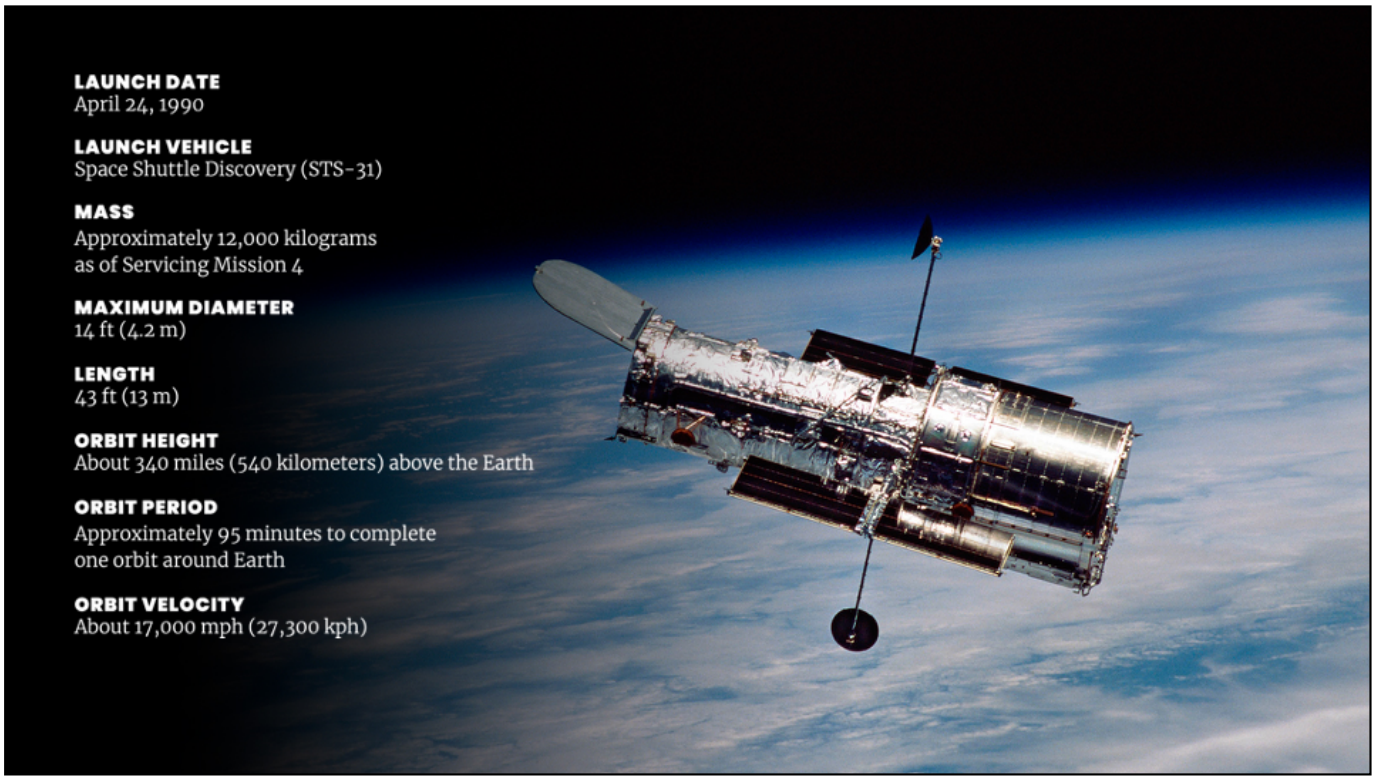
President Kennedy credit: NASA

National Academy of Science credit: JD Talasek/National Academy of Sciences

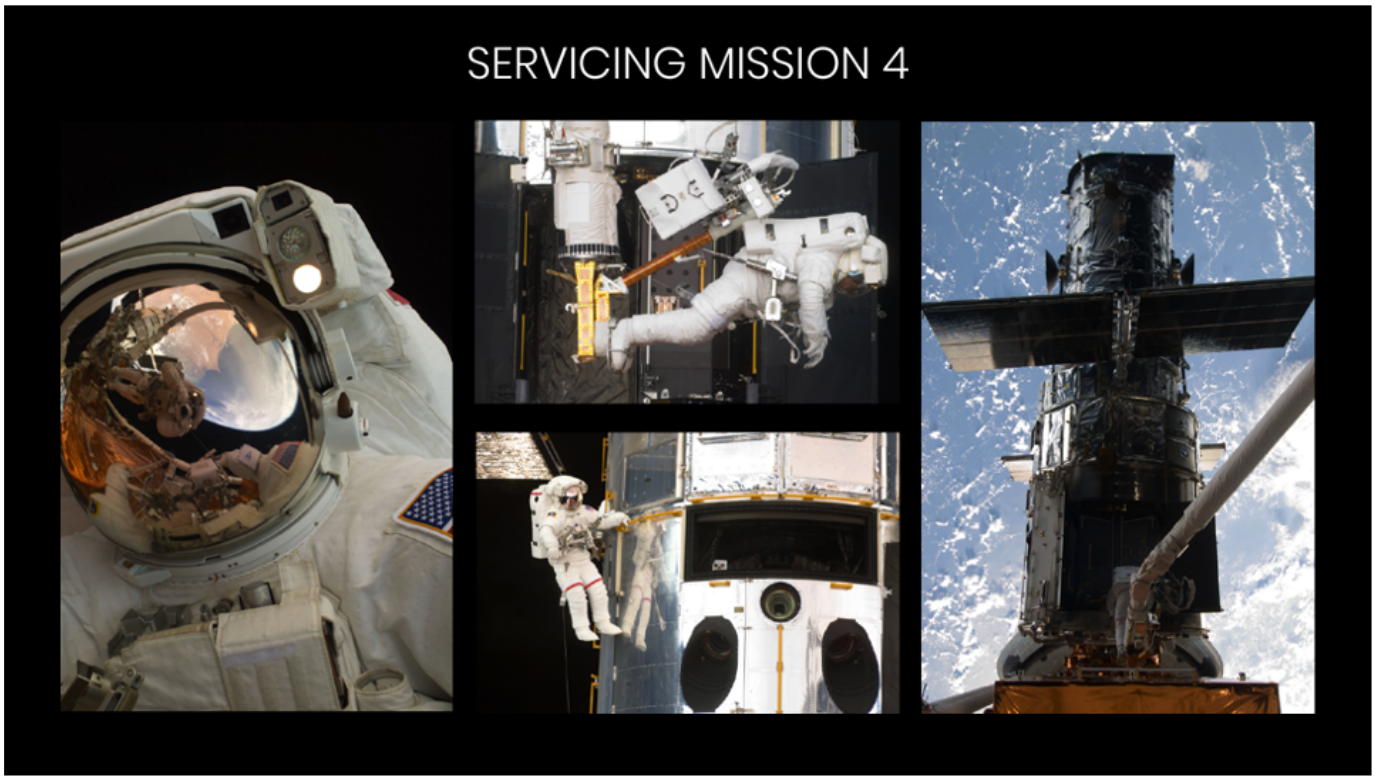
Capitol Building photo credit: Architect of the Capitol

Hubble construction: NASA

Hubble deployment credit: 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 95 minutes.



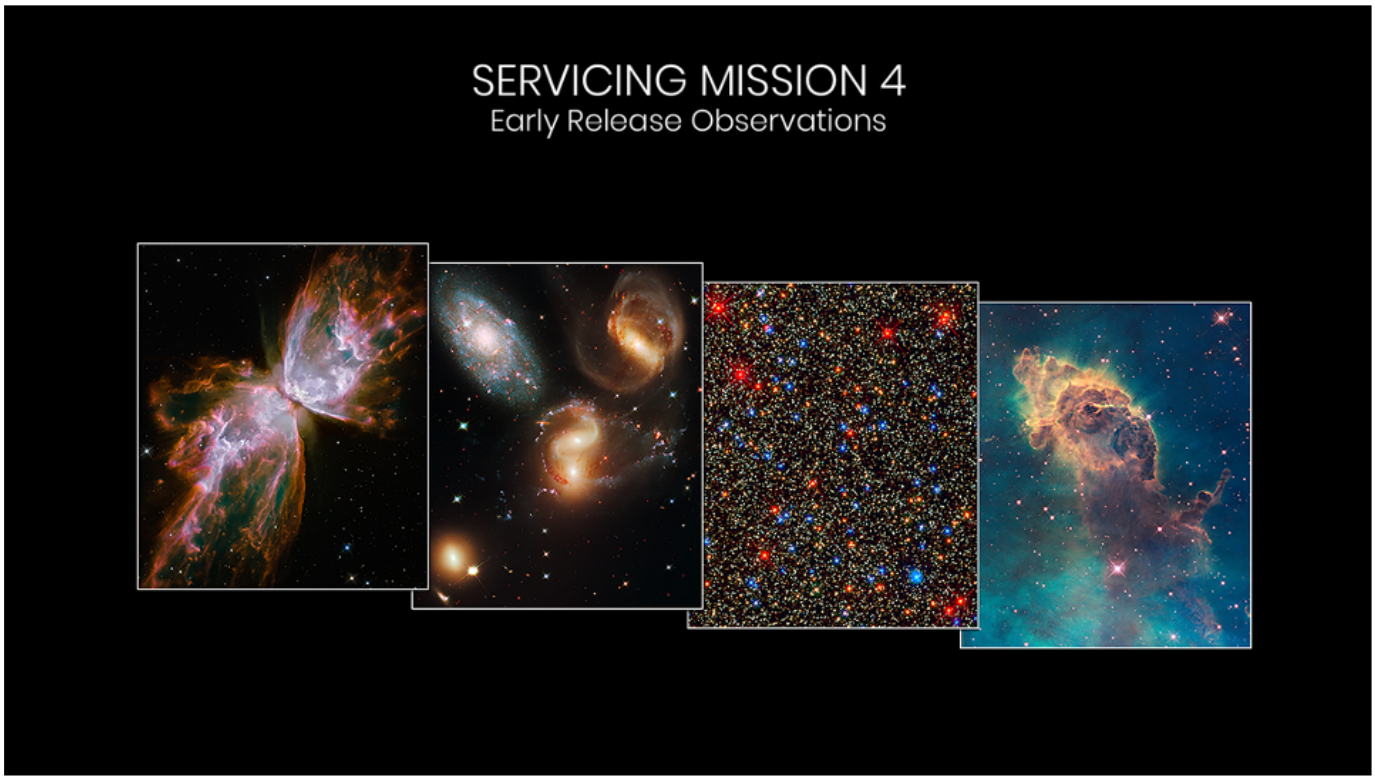
This image shows repairs being performed during Servicing Mission 4 (May 2009). Servicing Mission 4 was the final mission to Hubble (and actually the 5th visit to Hubble, since Servicing Mission 3 was conducted in two parts). The list of work to be done was long and ambitious, including the primary objectives 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:

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

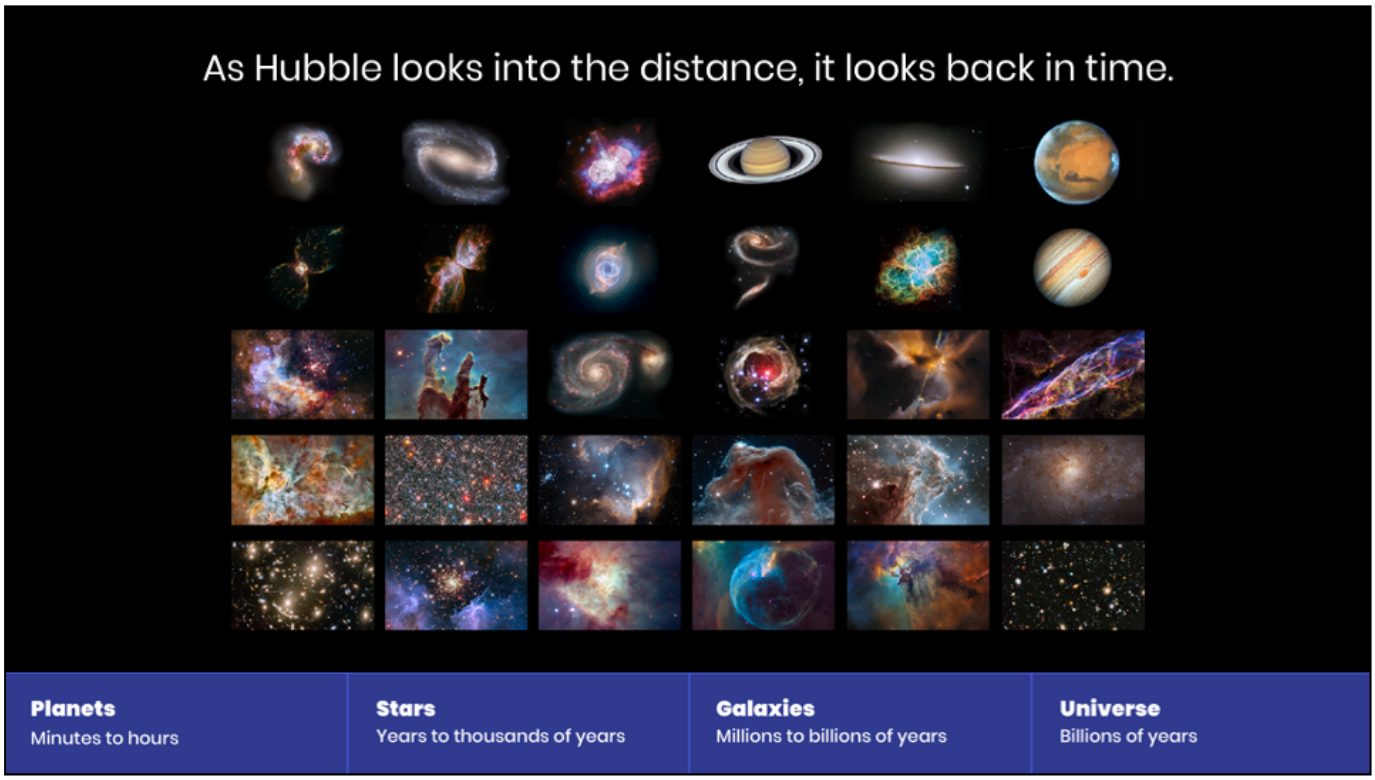


In 2009 Servicing Mission 4 (STS-125) updated and repaired the, at the time, 19-year telescope. This collage of images represents the first observations from two new instruments, the Wide Field Camera 3 (WFC3) and Cosmic Origins Spectrograph (COS), that were installed, and two repaired instruments, the Advanced Camera for Surveys (ACS) and Space Telescope Imaging Spectrograph (STIS).

Topping the list of exciting new views are colorful multi-wavelength pictures of far-flung galaxies, a densely packed star cluster, an eerie "pillar of creation," and a "butterfly" nebula. With its new imaging camera, Hubble can view galaxies, star clusters, and other objects across a wide swath of the electromagnetic spectrum, from ultraviolet to near-infrared light. A new spectrograph slices across billions of light-years to map the filamentary structure of the universe and trace the distribution of elements that are fundamental to life. The telescope's new instruments also are more sensitive to light and can observe in ways that are significantly more efficient and require less observing time than previous generations of Hubble instruments.

This was the last Servicing Mission and these updates and repairs have enabled another decade of science, with more to come.

https://hubblesite.org/contents/news-releases/2009/news-2009-25.html

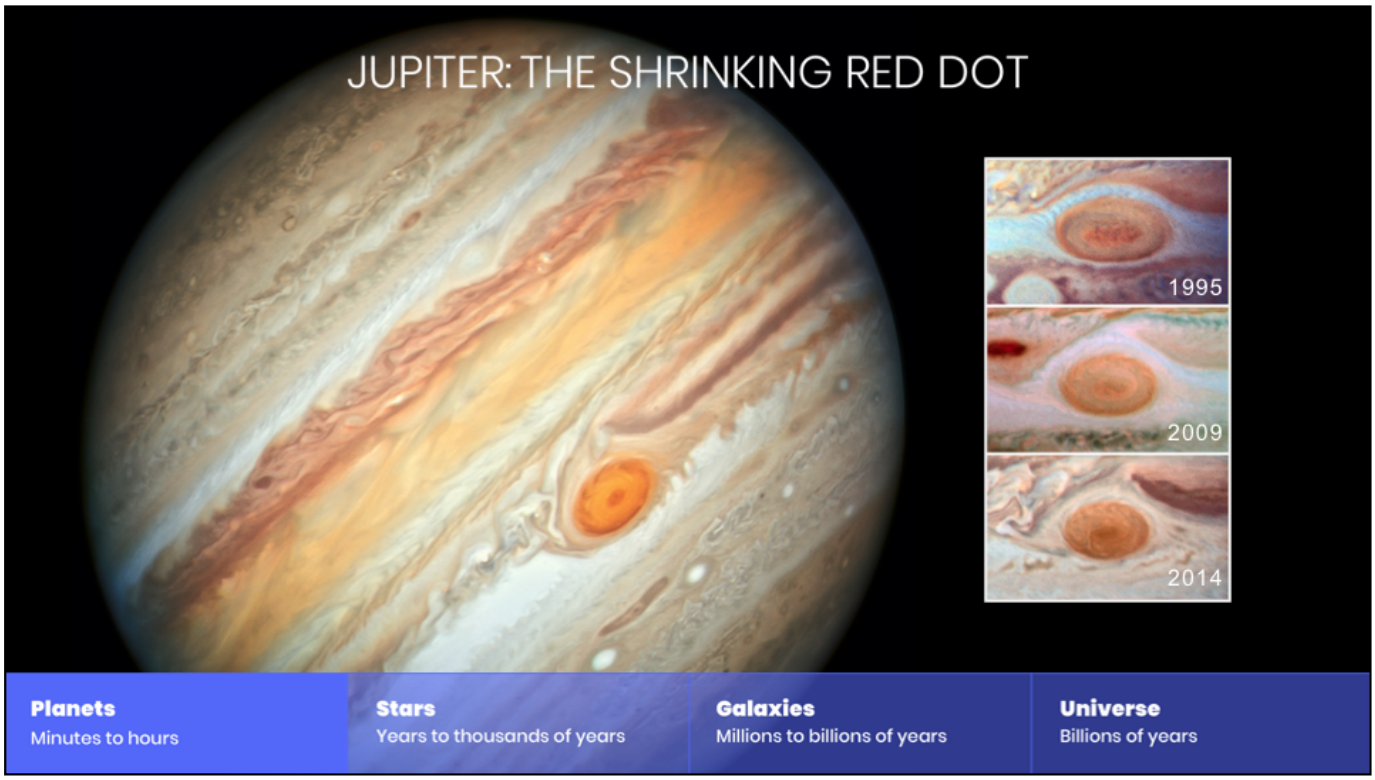


Presenter please note: Much of the discussion in these slides, and most of the public's attention, is focused on Hubble's enormous repertoire of images. Here is a montage of some of Hubble's best images that symbolize the breadth and depth of Hubble observations and the research being done.

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.

https://hubblesite.org/resource-gallery/images

https://hubblesite.org/hubble-30th-anniversary/images



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 3 image of Jupiter was obtained in 2019, as part of the yearly Outer Planets Atmospheres Legacy program.

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.

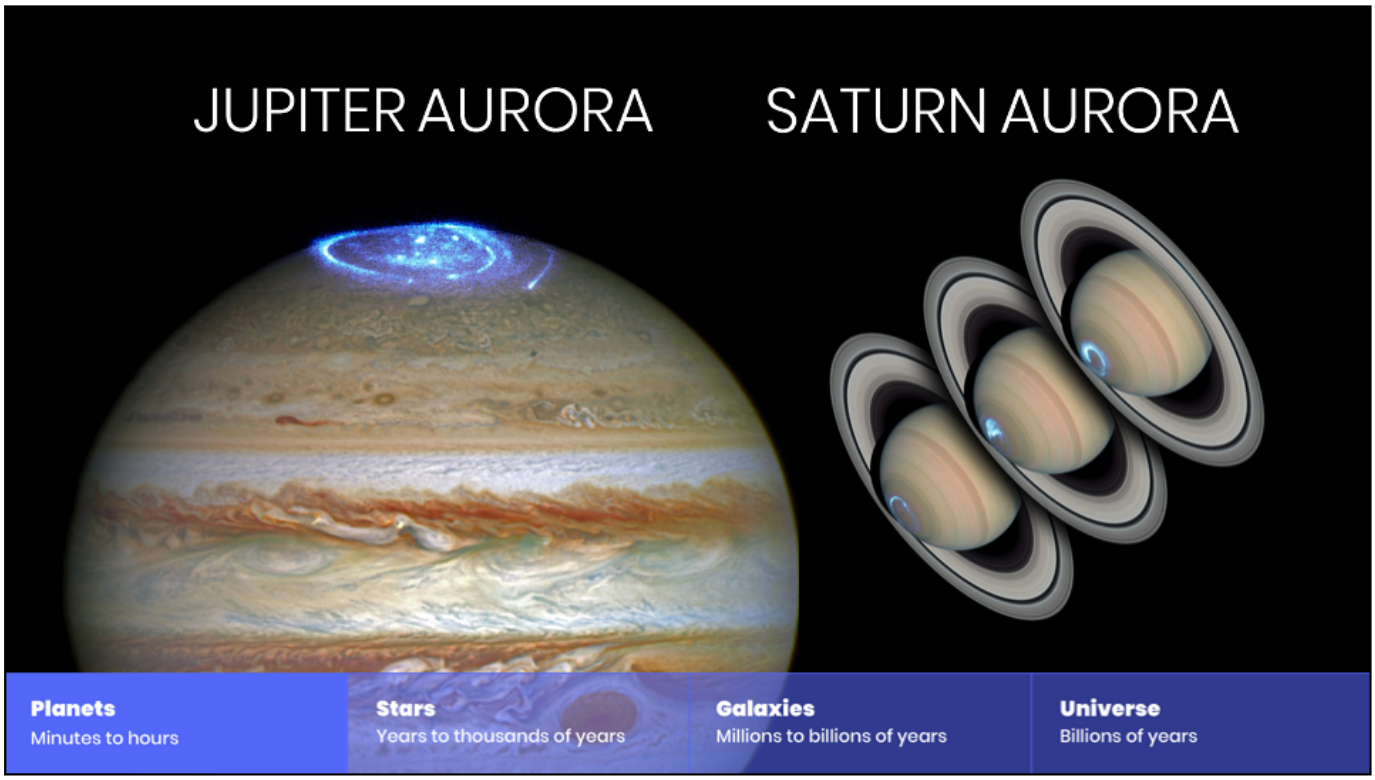
https://hubblesite.org/contents/news-releases/2014/news-2014-24.html
https://hubblesite.org/contents/news-releases/2015/news-2015-37.html
https://hubblesite.org/contents/news-releases/2019/news-2019-36.html

This image of Europa is a color composite of a global surface map generated from Galileo space probe observations. The graphic shows water-ice plumes thought to erupt from Europa's southern hemisphere with Io in the background. 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.

https://hubblesite.org/contents/news-releases/2013/news-2013-55.html
https://hubblesite.org/contents/news-releases/2016/news-2016-33.html
https://hubblesite.org/contents/news-releases/2017/news-2017-17.html

https://hubblesite.org/contents/news-releases/2019/news-2019-37.html



Images taken in ultraviolet light by Hubble's Space Telescope Imaging Spectrograph (STIS) show both Jupiter auroras in 2016. Ground-based telescopes cannot view these phenomena in ultraviolet light, as it is blocked by the Earth's atmosphere. The 2016 observations coincided with NASA's Juno spacecraft orbiting Jupiter and measuring the properties of solar wind, which affect the aurora.

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 Jupiter's largest moons. Auroral footprints are 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 Jupiter image is a combination of a full-color map of Jupiter taken with WFC3 superimposed by an ultraviolet image of the aurora of Jupiter was taken with the Hubble Space Telescope Imaging Spectrograph (STIS). In this ultraviolet view, the aurora would stand out clearly, but Jupiter's cloud structure would be masked by haze.

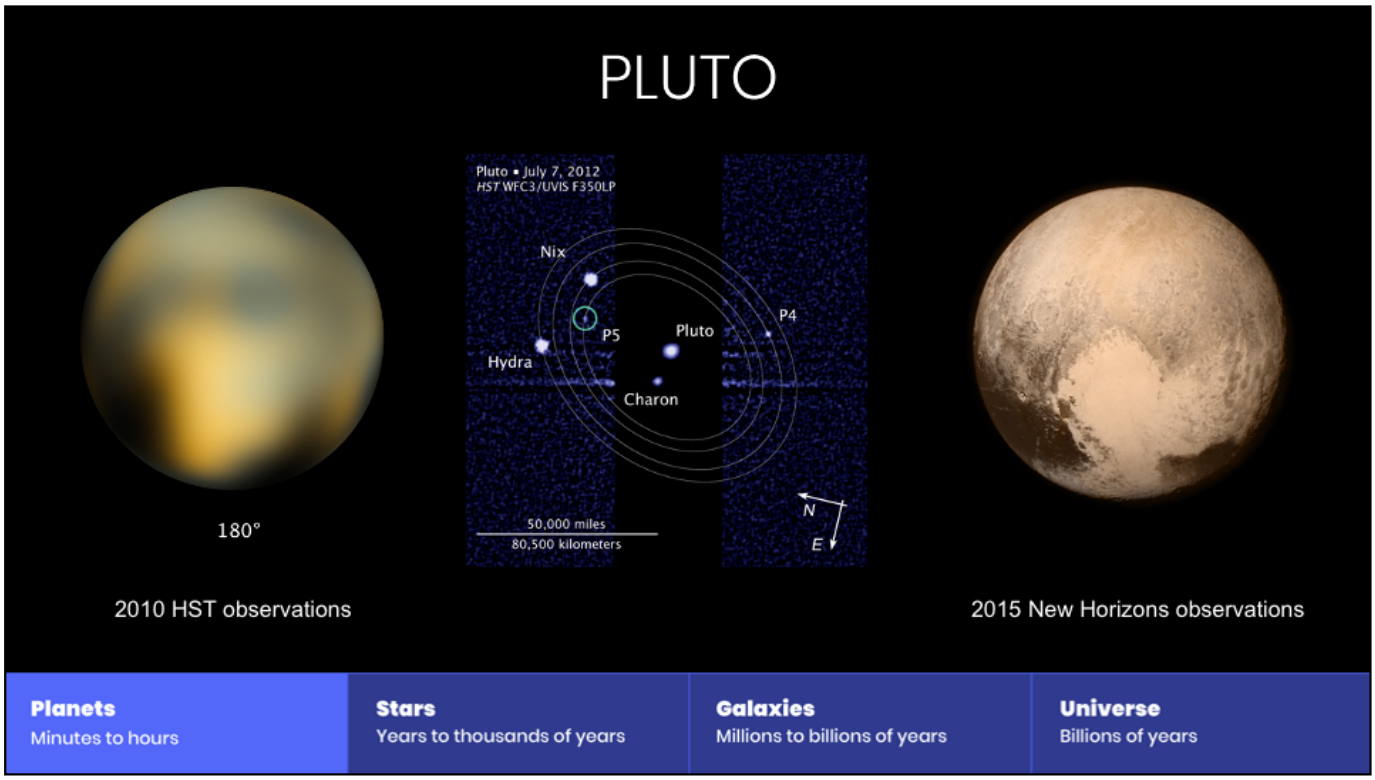
Saturn's aurora was observed with Hubble in 2005. Images were obtained with the Advanced Camera for Surveys in the optical and STIS in the ultraviolet. The aurora appeared in Saturn's southern polar region for several days. Hubble snapped a series of photographs of the aurora dancing in the sky. The 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.

https://hubblesite.org/contents/news-releases/1998/news-1998-04.html

https://hubblesite.org/contents/news-releases/2000/news-2000-38.html

https://hubblesite.org/contents/news-releases/2005/news-2005-06.html

https://hubblesite.org/contents/news-releases/2016/news-2016-24.html



In 2015, NASA's New Horizons mission flew by and imaged Pluto and its moons. Nix, Hydra, Kerberos, and Styx are moons of Pluto that were discovered by Hubble in 2005 (Nix and Hydra), 2011, and 2012, respectively. Hubble surveyed the Pluto system prior to New Horizons' arrive to identify potential hazards for the spacecraft.

Peering out to the dim, outer reaches of our solar system beyond Pluto, Hubble additionally uncovered three Kuiper Belt objects (KBOs) that the agency's New Horizons spacecraft could potentially visit after it flies by Pluto in July 2015. One of the objects, nicknamed Ultima Thule, was chosen for the 2019 flyby. 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 left Pluto image shows 2010 Hubble Space Telescope data from the Advanced Camera for Surveys showing in some of the best detail prior to New Horizons. The image is part of a series that shows seasonal variations in the surface color and brightness.

The right image was taken during the New Horizon's flyby in 2015, showing

the varied terrain of planet in astounding detail.

Image credit: *NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute*

Presenter note: the high-resolution image on the right is an image taken by New Horizons not Hubble.

https://hubblesite.org/contents/news-releases/2014/news-2014-47.html

https://hubblesite.org/contents/news-releases/2010/news-2010-06.html

https://hubblesite.org/contents/news-releases/2012/news-2012-32.html

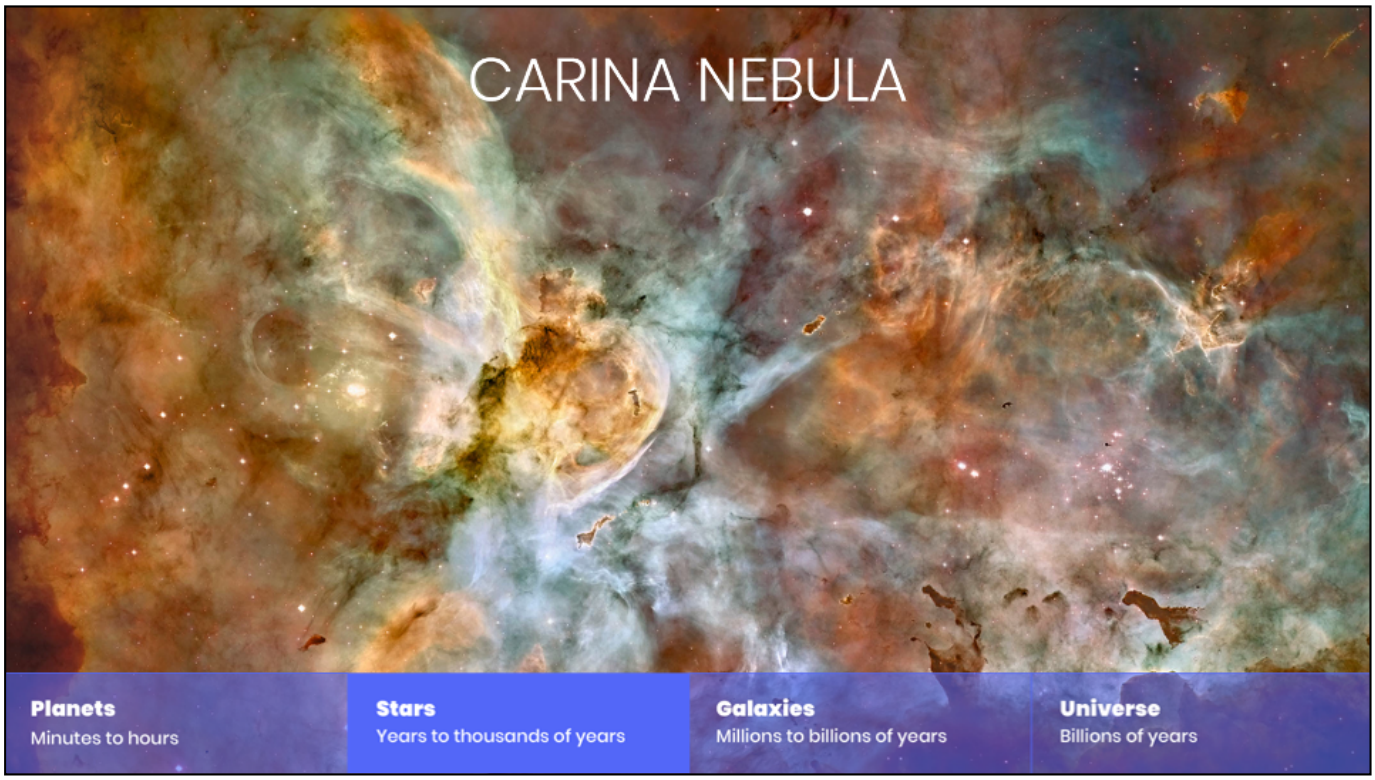
https://hubblesite.org/contents/news-releases/2015/news-2015-24.html

https://hubblesite.org/contents/news-releases/2014/news-2014-35.html

http://www.nasa.gov/nh_new-horizons-spots-small-moons-orbiting-pluto/#.VPnlP2TF_b4

http://pluto.jhuapl.edu/

http://pluto.jhuapl.edu/News-Center/News-Article.php?page=20150714



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.

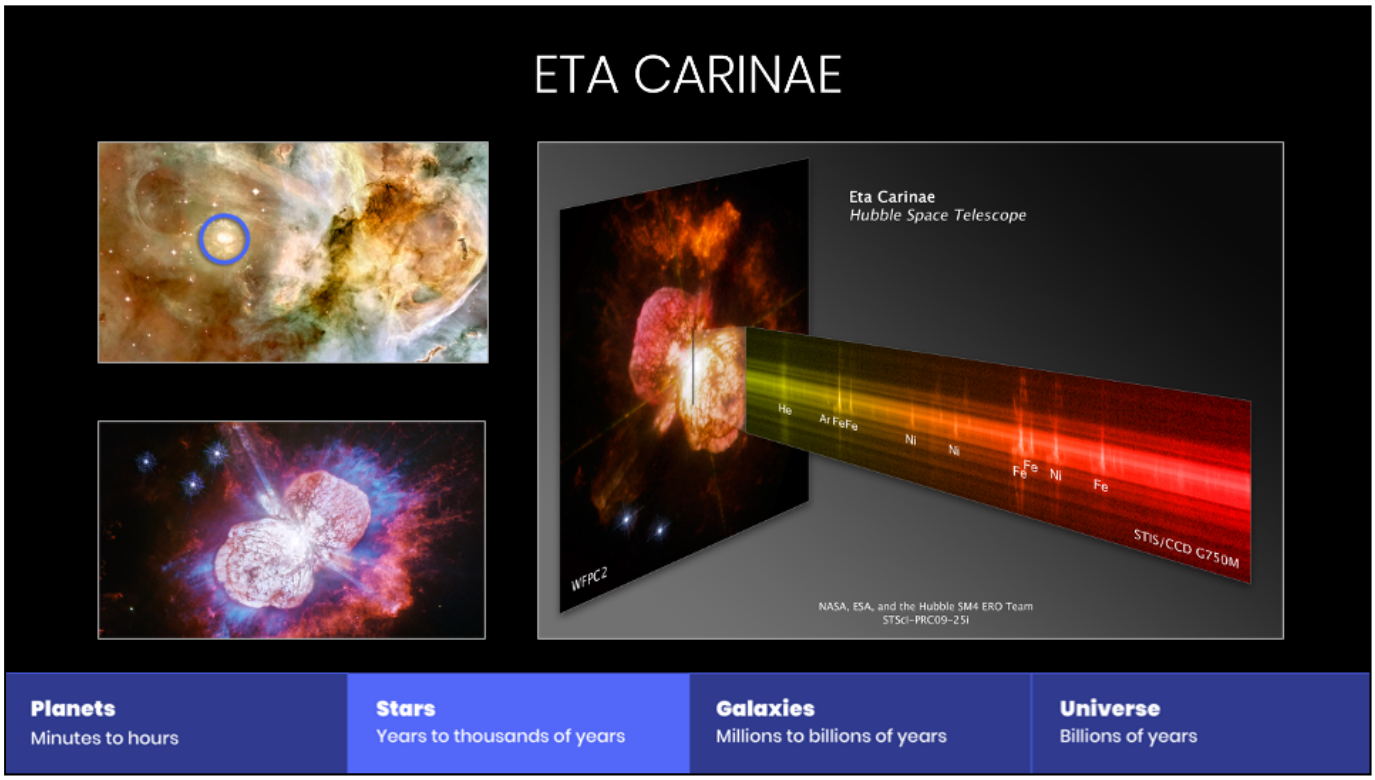
The immense nebula contains at least a dozen brilliant stars that are roughly estimated to be at least 50 to 100 times the mass of our Sun. The most unique and opulent inhabitant is the star Eta Carinae, at far left. Eta Carinae is in the final stages of its brief and eruptive lifespan, as evidenced 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).

https://hubblesite.org/contents/news-releases/2007/news-2007-16.html



The signature balloon-shaped clouds of gas blown from a pair of massive stars called Eta Carinae have tantalized astronomers for decades. Eta Carinae has a volatile temperament, prone to violent outbursts over the past 200 years. Eta Car A, the primary star, is one of the most massive and most visible stars in the sky. Because of the star's extremely high mass, it is unstable and consumes its fuel very quickly, compared to other stars. Such massive stars also have a short lifetime, and astronomers expect that Eta Carinae will explode within a million years.

On the upper left, Eta Carinae's location is highlighted in the larger Carina Nebula mosaic.

https://hubblesite.org/contents/news-releases/2007/news-2007-16.html

On the lower left, Eta Carinae's balloon-shaped clouds are shown in intricate detail from observations in ultraviolet light taken with Hubble's Wide Field Planetary Camera 3

https://hubblesite.org/contents/news-releases/2019/news-2019-18.html

Shown in the image on the right is a composite of a WFPC2 image and

spectroscopic data of Eta Carinae taken by the Space Telescope Imaging Spectrograph (STIS) aboard Hubble. The STIS observations, which allow astronomers to dissect the light from Eta Cariinae into its component colors, reveal a stream of charged particles from a massive stellar wind. Some of the chemical elements seen in this STIS spectrum were ejected in the eruption recorded by astronomers in the middle of the nineteenth century. STIS resolved the chemical information along a narrow section of one of the giant lobes of ejected material. In the resulting spectrum, iron and nickel define the outer material cast off in the nineteenth century from Eta Carinae. STIS also reveals the interior material being carried away by the ongoing wind from Eta Car A, the primary star. The amount of mass being carried away by the wind is the equivalent of one sun every thousand years.

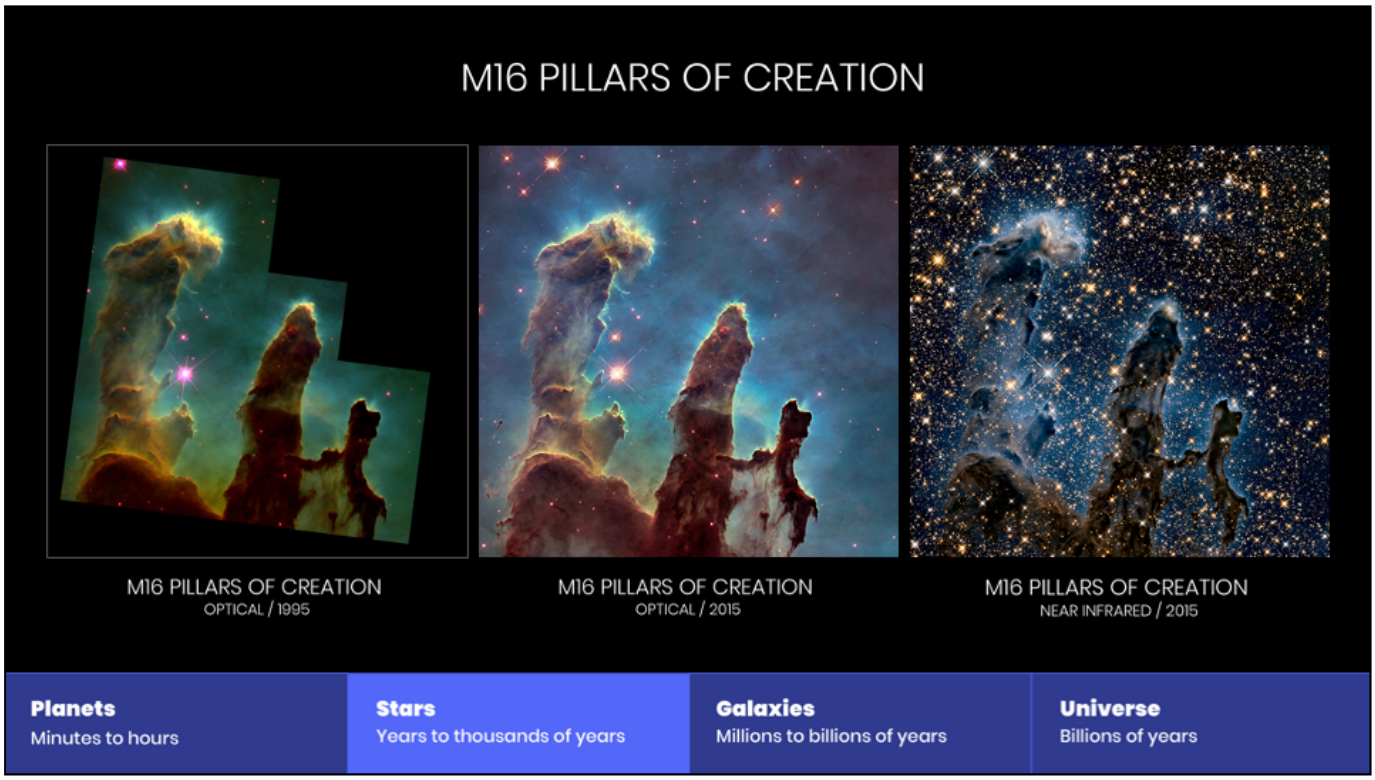
https://hubblesite.org/contents/news-releases/2009/news-2009-25.html

Note to presenters. This slide introduces the concept of a spectrum. Hubble is famous for its stunning images of the universe. But many of Hubble's most amazing discoveries come from its spectroscopic observations of astronomical objects. Astronomers measure the brightness of the light as a function of color to create a spectrum of the light observed. Objects beyond the solar system are too far away to visit, but astronomers can learn about the physical and chemical properties of distant objects by studying these spectra.

You can learn more about spectra here:

https://hubblesite.org/contents/articles/spectroscopy-reading-the-rainbow

https://hubblesite.org/contents/articles/the-electromagnetic-spectrum



This slide shows a sequence of three images of the “Pillars of Creation” in the Eagle Nebula.

The leftmost 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.

https://hubblesite.org/contents/news-releases/1995/news-1995-44.html

In 2015, using Hubble’s newer cameras provided 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). 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.

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.

https://hubblesite.org/contents/news-releases/2015/news-2015-01.html

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).

https://hubblesite.org/contents/news-releases/1995/news-1995-45.html

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

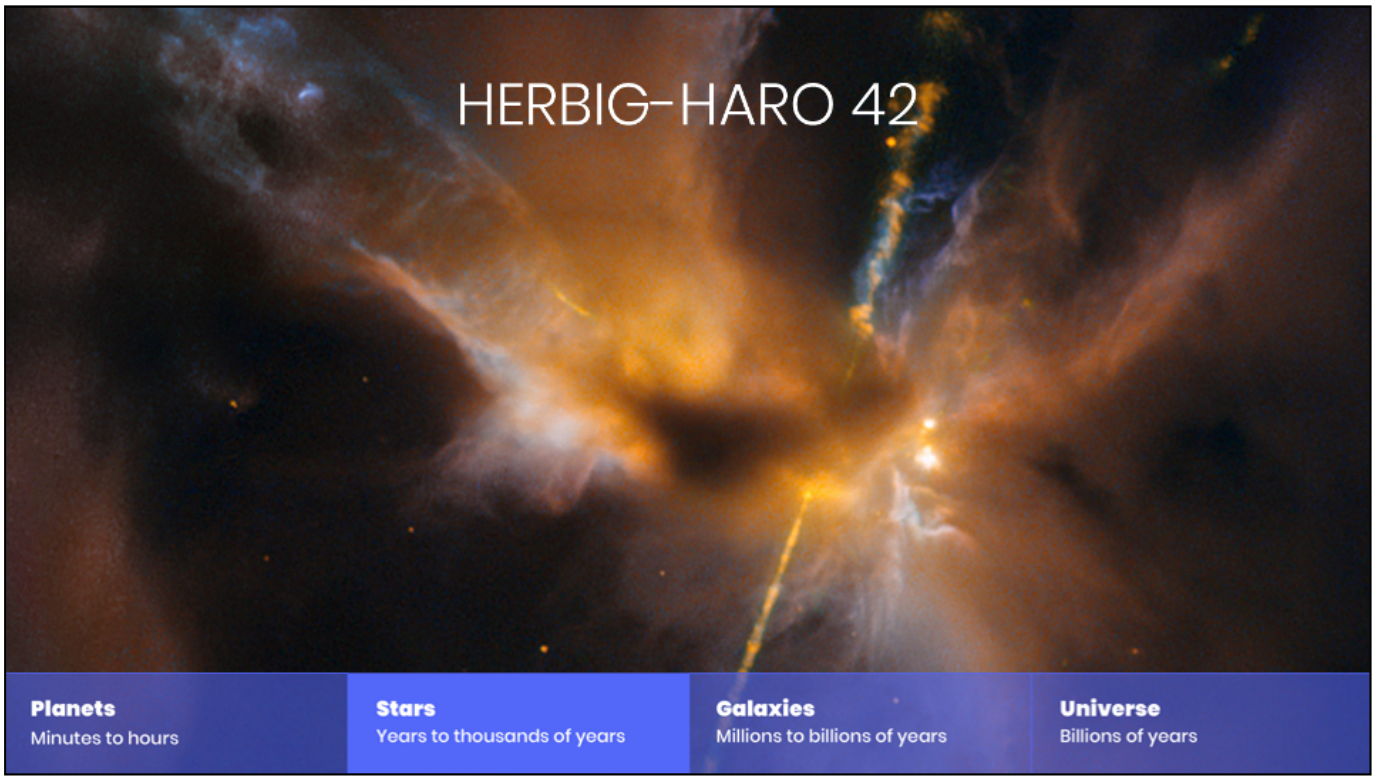
https://hubblesite.org/contents/news-releases/2006/news-2006-01.html

Supplemental Movies:

Multi-wavelength Fly through: https://hubblesite.org/contents/news-releases/2018/news-2018-04.html

Orion Fly through: https://hubblesite.org/contents/media/videos/2001/13/227-Video.html

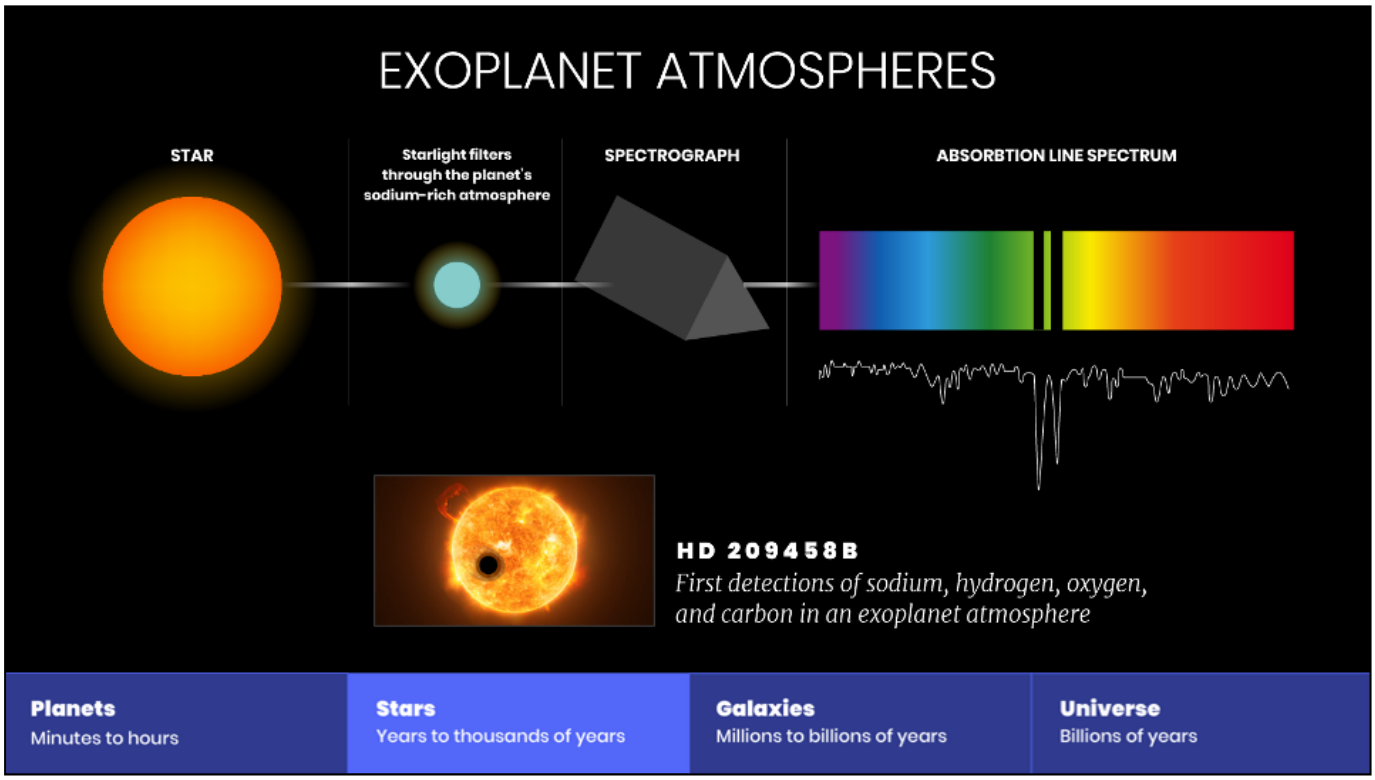
Zoom into Orion: https://hubblesite.org/contents/media/videos/2001/13/229-Video.html



In the center of the image, partially obscured by a dark, cloak of dust, a newborn star shoots twin jets out into space as a sort of birth announcement to the universe. Gas from a surrounding disk rains down onto the dust-obscured protostar and engorges it. The material is superheated and shoots outward from the star in opposite directions along an uncluttered escape route – the star's rotation axis. Much more energetic than a science fiction lightsaber, these narrow energetic beams are blasting across space at over 100,000 miles per hour. It's inside a turbulent birthing ground for new stars known as the Orion B molecular cloud complex, located 1,350 light-years away in the Milky Way.

https://hubblesite.org/contents/news-releases/2015/news-2015-42.html and included links

Additional links include artist concept of the phenomena and fly throughs.



The Hubble Space Telescope pioneered the detection and analysis of extrasolar planet atmospheres. In 2001, astronomers released results showing that they used Hubble to make the first direct detection of an atmosphere of a planet orbiting a star outside our solar system – HD 209458b. Their unique observations of sodium in HD 209458b demonstrated that it was possible with Hubble and other telescopes to measure the chemical makeup of alien planet atmospheres and to potentially search for the chemical markers of life beyond Earth. The planet orbits a yellow, Sun-like star called HD 209458, located 150 light-years away in the constellation Pegasus. This was followed up by results released in 2004 of the first ever detection of oxygen and carbon in the atmosphere of a planet outside of our solar system, again in HD 209458b. The Space Telescope Imaging Spectrograph (STIS) was used in both of these studies.

https://hubblesite.org/contents/news-releases/2001/news-2001-38.html
https://hubblesite.org/contents/news-releases/2004/news-2004-44.html

In the illustration at the top of this slide, sodium gas in an extrasolar planet's atmosphere is detected from the transit spectroscopy method. As the planet travels in front of the star with respect to our line-of-sight, the starlight passes through the planet's atmosphere, and certain colors are absorbed depending on the chemical elements present in the planet's atmosphere. The light is

captured by Hubble and passed through one of its spectrographs, where the light is broken up into its constituent colors. By comparing the stellar spectrum when the planet (and its atmosphere) transits in front of the star with the spectrum recorded when the planet (and its atmosphere) is not in front of the star, astronomers found the fingerprint of sodium in the planet's atmosphere. The missing colors can be attributed to the atoms and molecules in the extrasolar planet's atmosphere that absorbed the light.

The lower illustration is an artist's rendering of an exoplanet transiting, moving in front, of its host star.

Hubble has made many contributions to the field of exoplanet studies. Additional press release can be found at: https://hubblesite.org/news/news-releases

Additional information on Hubble's discoveries of exoplanet atmospheres can be found here:

https://hubblesite.org/science/exoplanets

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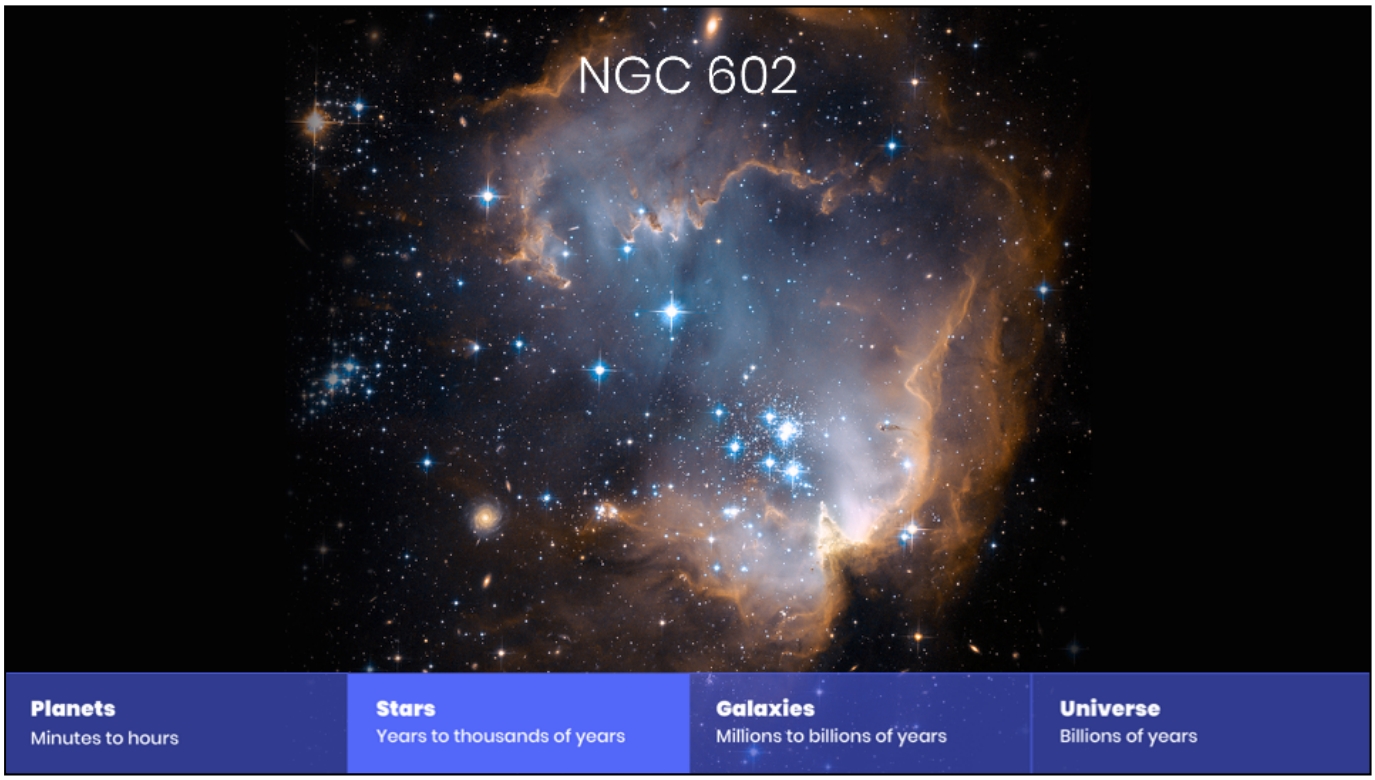


At the heart of this star-forming region lies star cluster NGC 602. It is a cluster of newly formed stars that are blowing a cavity in the center of a star-forming region in the Small Magellanic Cloud, a companion galaxy to our own Milky Way. The high-energy radiation blazing out from the hot young stars 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.

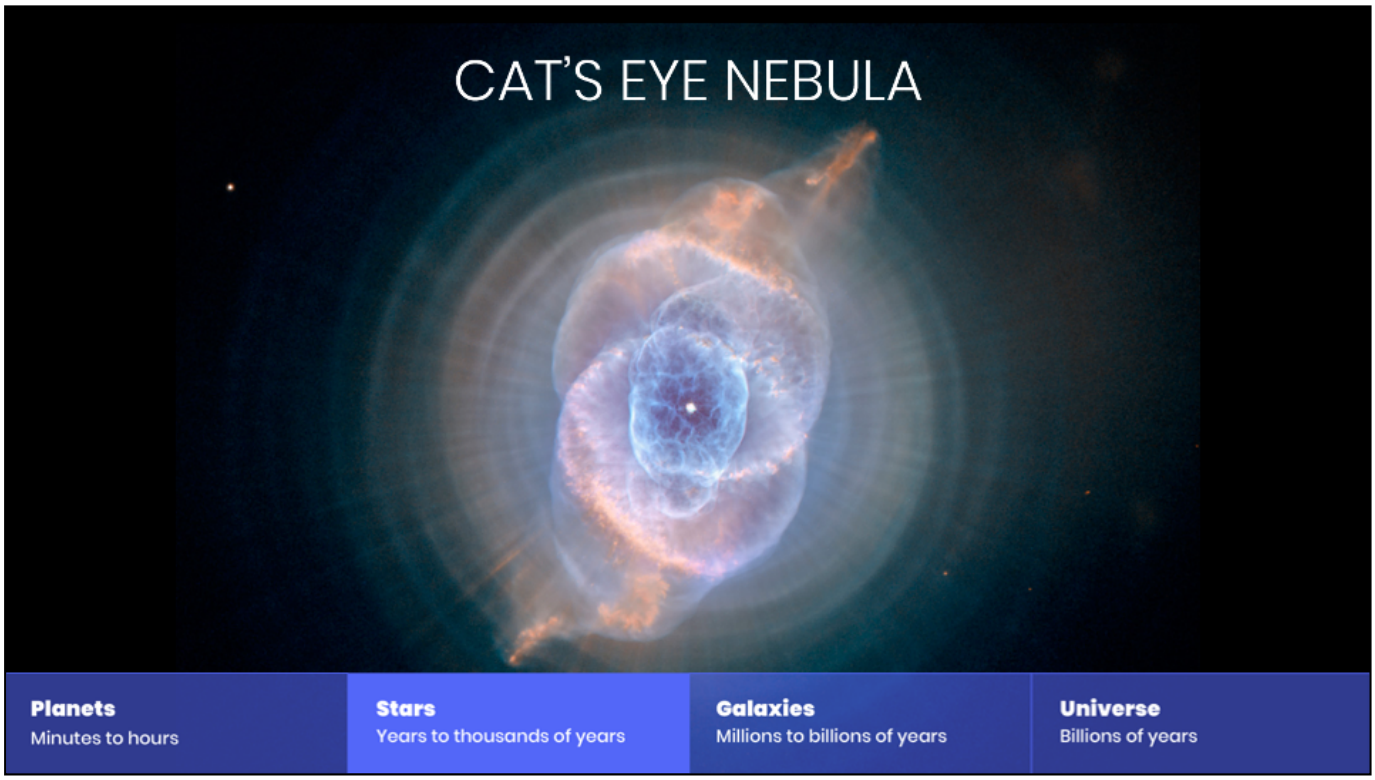
Ridges of dust and gaseous filaments are seen surrounding the cluster. Elephant trunk-like dust pillars point towards the hot blue stars and are telltale signs of their eroding effect.

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.

https://hubblesite.org/contents/news-releases/2007/news-2007-04.html

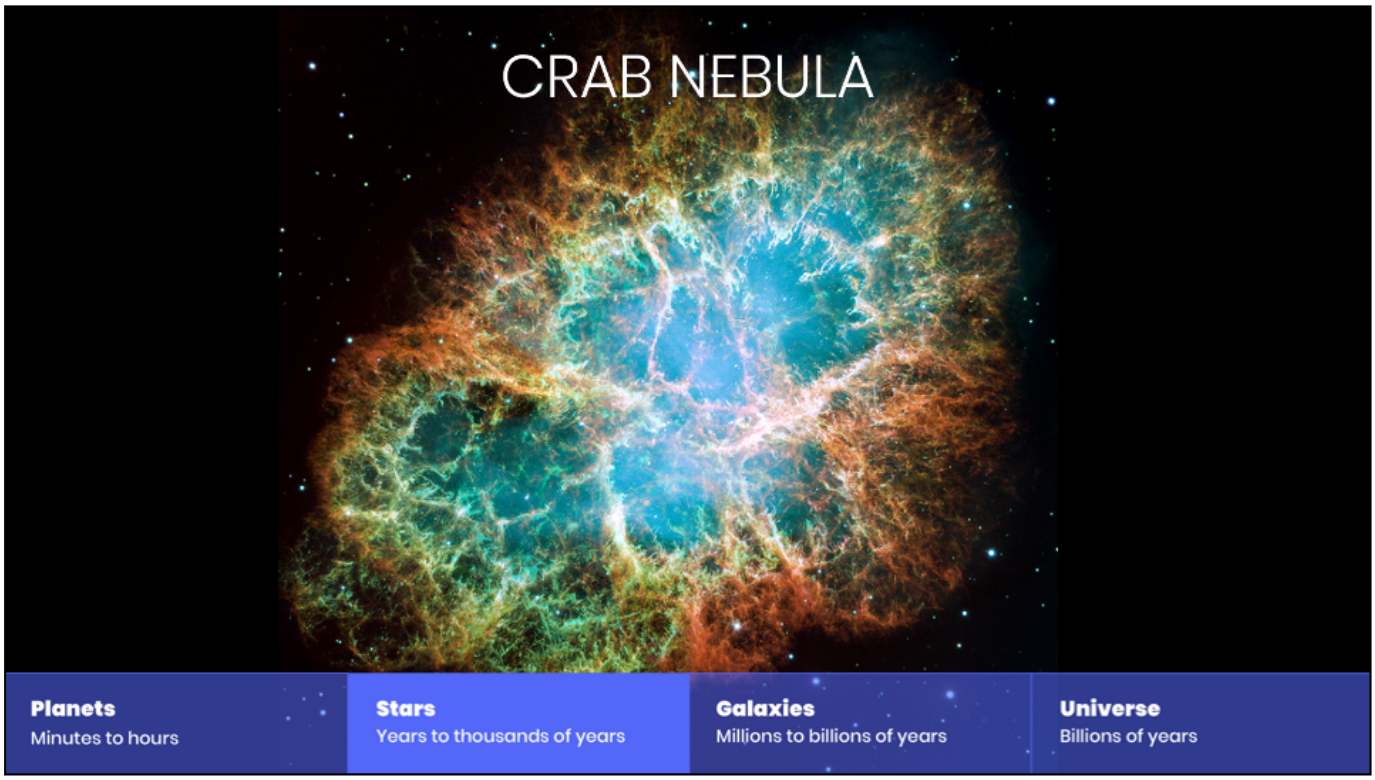
X-ray from Chandra plus Hubble observations:
https://hubblesite.org/contents/media/images/2013/17/3177-Image.html



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.

https://hubblesite.org/contents/news-releases/2004/news-2004-27.html



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.

https://hubblesite.org/contents/news-releases/2005/news-2005-37.html

A multi-wavelength image released in 2017 of the nebula combines data from

five different telescopes: the VLA (radio); Spitzer Space Telescope (infrared); Hubble Space Telescope (visible); XMM-Newton (ultraviolet); and Chandra X-ray Observatory (X-ray).

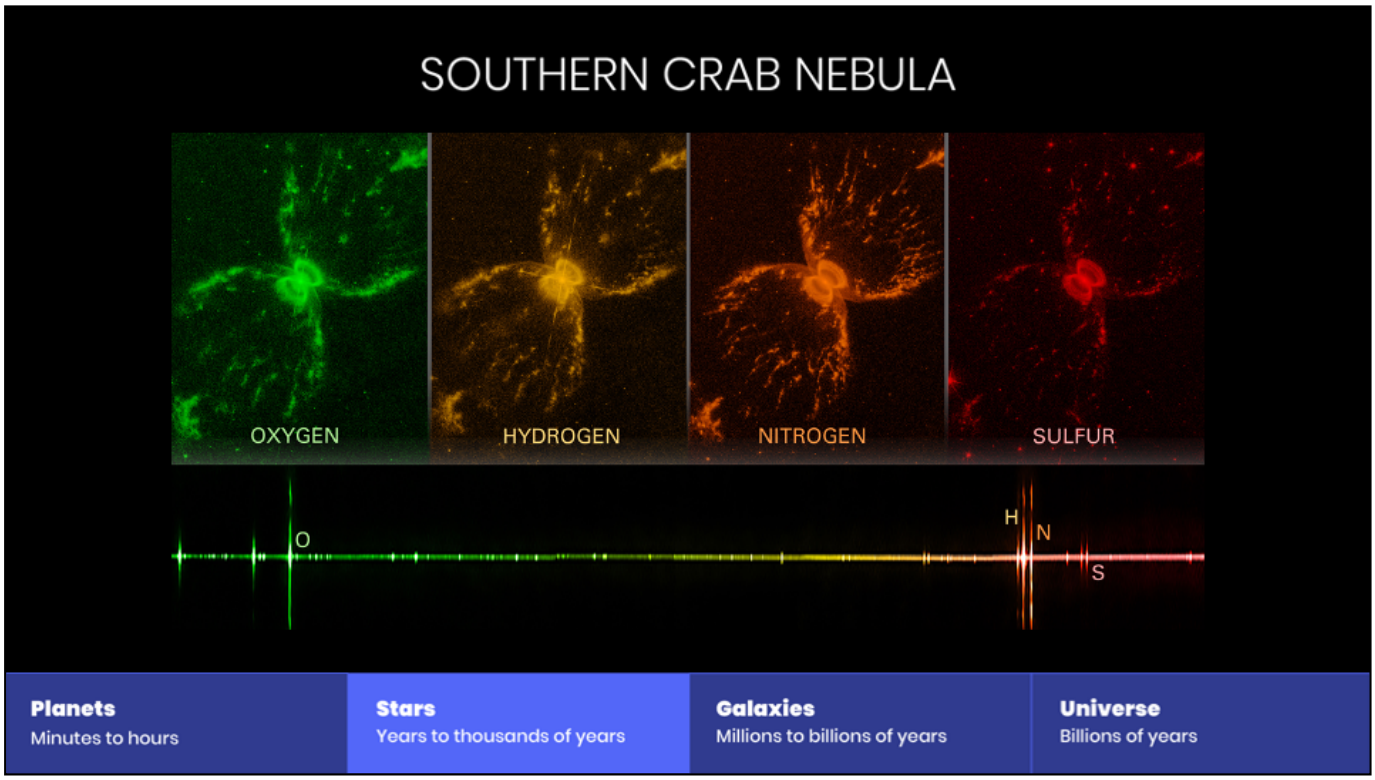
https://hubblesite.org/contents/media/images/2017/21/4027-Image.html

This visualization features a three-dimensional multiwavelength representation of the Crab Nebula, looking into the heart of the nebula, home to its rapidly spinning crushed stellar core, called a pulsar. The torrential outflow of radiation from this magnetic dynamo illuminates the nebula. The visualization is based on images from NASA's three Great Observatories: the Chandra X-ray Observatory and the Hubble and Spitzer space telescopes. Observing the nebula across its wide spectrum of energies provides a holistic view of its complex structure.

https://hubblesite.org/contents/media/videos/2020/03/1271-Video.html

Supplemental movie: Crab Pulsar Wind

https://hubblesite.org/contents/news-releases/2002/news-2002-24.html



This Hubble image shows the results of two stellar companions in a gravitational waltz, several thousand light-years from Earth in the southern constellation Centaurus. The stellar duo, consisting of a red giant and white dwarf, are too close together to see individually in this view. But the consequences of their whirling about each other are two vast shells of gas expanding into space like a runaway hot air balloon. Both stars are embedded in a flat disk of hot material that constricts the outflowing gas so that it only escapes away above and below the stars. This apparently happens in episodes because the nebula has two distinct nested hourglass-shaped structures. The bubbles of gas and dust appear brightest at the edges, giving the illusion of crab legs. The rich colors correspond to glowing hydrogen (red), sulfur (green), nitrogen (orange), and oxygen (blue). This image was taken to celebrate Hubble's 29th anniversary since its launch on April 24, 1990.

https://hubblesite.org/contents/news-releases/2019/news-2019-15.html

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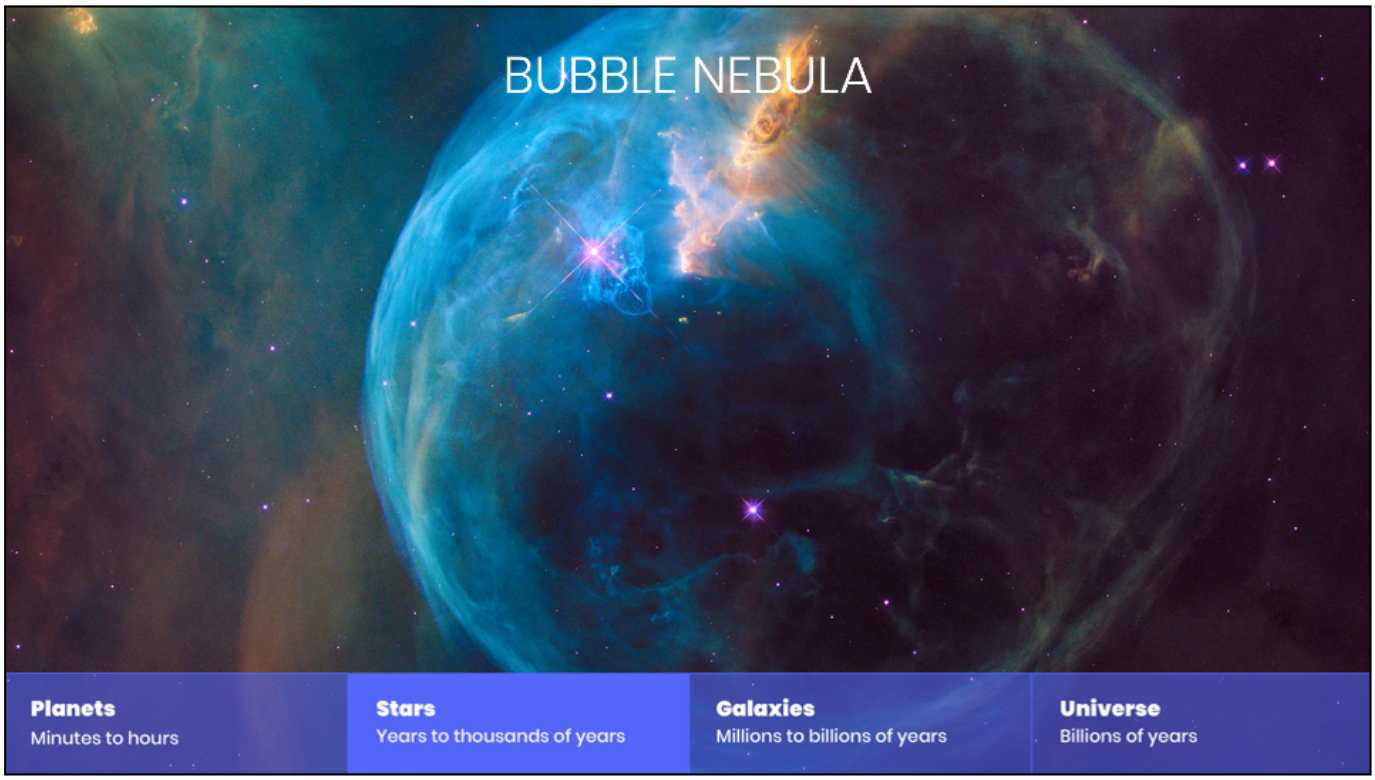
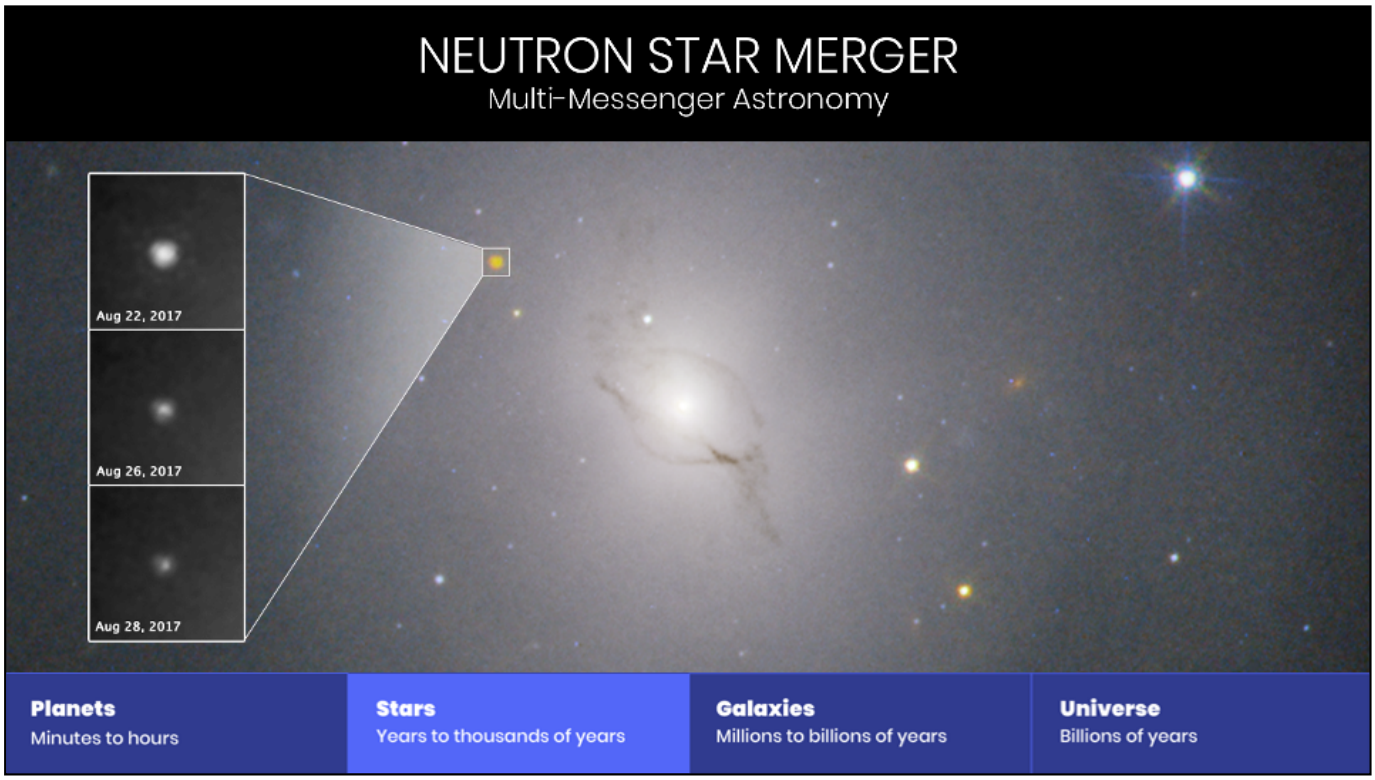
chemical properties of distant objects by studying these spectra.

You can learn more about spectra here:
https://hubblesite.org/contents/articles/spectroscopy-reading-the-rainbow
https://hubblesite.org/contents/articles/the-electromagnetic-spectrum



In 2016, the Hubble Space Telescope photographed an enormous, balloon-like bubble being blown into space by a super-hot, massive star. This colorful feature is called the Bubble Nebula, or NGC 7635. The bubble is 7 light-years across – about one-and-a-half times the distance from our sun to its nearest stellar neighbor, Alpha Centauri. The Bubble Nebula lies 7,100 light-years from Earth in the constellation Cassiopeia.

https://hubblesite.org/contents/news-releases/2016/news-2016-13.html



On August 17, 2017, weak ripples in the fabric of space-time known as gravitational waves washed over Earth. Unlike previously detected gravitational waves, these were accompanied by light, allowing astronomers to pinpoint the source. NASA's Hubble Space Telescope turned its powerful gaze onto the new beacon, obtaining both images and spectra. The resulting data will help reveal details of the titanic collision that created the gravitational waves, and its aftermath.

The Laser Interferometer Gravitational-Wave Observatory (LIGO) detected gravitational waves at 8:41 a.m. EDT on August 17. Two seconds later, NASA's Fermi Gamma-ray Space Telescope measured a short pulse of gamma rays known as a gamma-ray burst. Many observatories, including space telescopes, probed the suspected location of the source, and within about 12 hours several spotted their quarry.

In a distant galaxy called NGC 4993, about 130 million light-years from Earth, a point of light shone where nothing had been before. It was about a thousand times brighter than a variety of stellar flare called a nova, putting it in a class of objects astronomers call "kilonovae." It also faded noticeably over 6 days of Hubble observations.

The source of all three was the collision of two neutron stars, the aged remains of a binary star system. A neutron star forms when the core of a dying massive star collapses, a process so violent that it crushes protons and electrons together to form subatomic particles called neutrons. The result is like a giant atomic nucleus, cramming several Suns' worth of material into a ball just a few miles across.

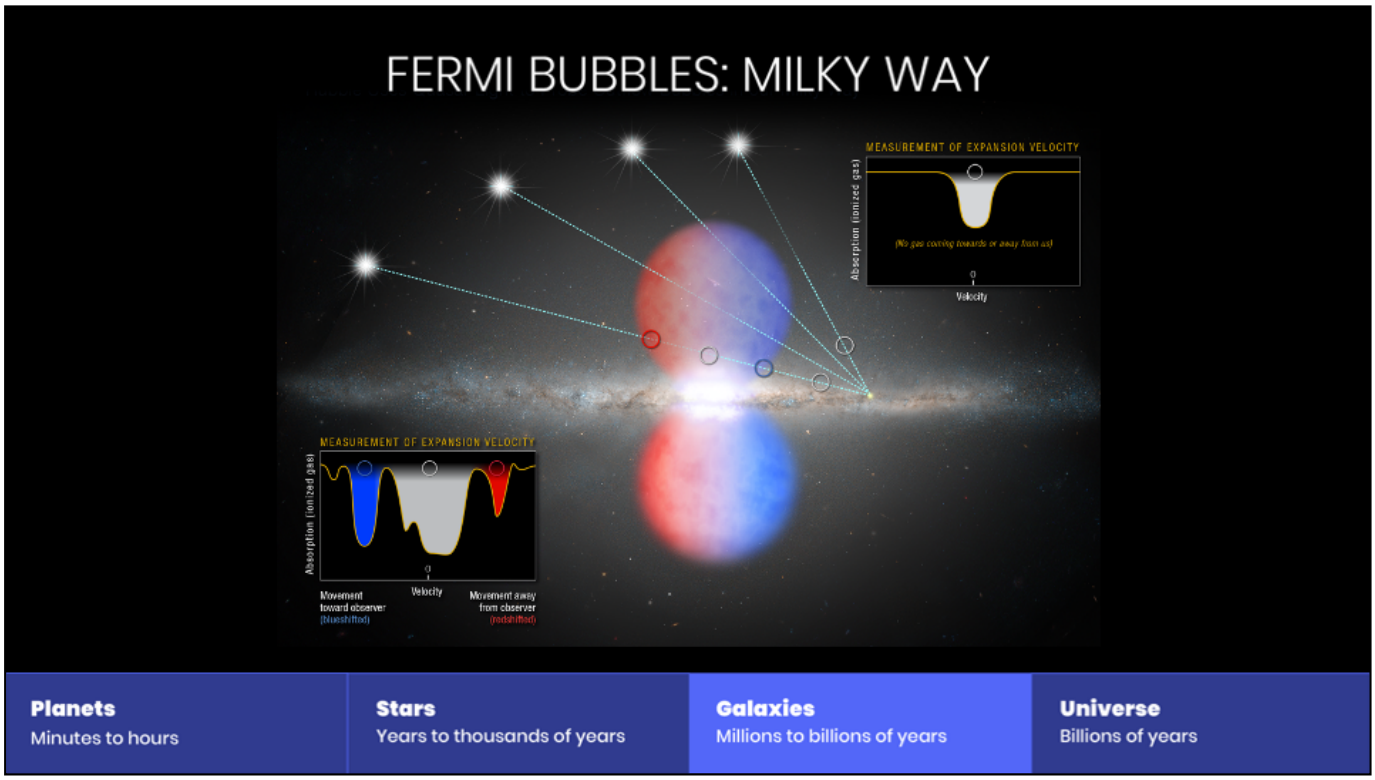
NASA's Hubble Space Telescope imaged the kilonova and captured its near-infrared spectrum, which revealed the motion and chemical composition of the expanding debris.

"The spectrum looked exactly like how theoretical physicists had predicted the outcome of the merger of two neutron stars would appear," said Andrew Levan at the University of Warwick in Coventry, England, who led one of the proposals for Hubble spectral observations. "It tied this object to the gravitational wave source beyond all reasonable doubt."

https://hubblesite.org/contents/news-releases/2017/news-2017-41.html

Information on the LIGO result can be found at:
https://www.ligo.org/detections/GW170817.php

This combination of observations represents a first in multi-messenger astronomy—a term used to describe the different ways that astronomers can study an object in a coordinate way to deepen the understand of the phenomenon—through light, gravitational waves, and particles.



Two giant balloon-like lobes of plasma known as the Fermi Bubbles straddle the center of the Milky Way. They are each almost 30,000 light-years in height, and may be related to the super-massive black hole at the Galactic Center. These Bubbles were discovered in 2010 using NASA's Fermi gamma-ray satellite. They also exhibit enhanced infra-red, radio, and X-ray emission. Using the Cosmic Origins Spectrograph (COS) on Hubble, astronomers were able for the first time to identify the spectroscopic signature of the gas venting into the Fermi Bubbles at ultraviolet wavelengths. They examined how the light of a distant quasar was modified by passing through the northern Fermi Bubble. By analyzing absorption lines seen in the quasar spectrum produced by COS, they detected both the near-side (blueshifted) and the far-side (redshifted) of the outflow, and inferred an outflow velocity of 900-1000 km/s, or more than 2 million miles per hour!

https://hubblesite.org/contents/news-releases/2015/news-2015-03.html

A follow-on study also using (COS) analyzed ultraviolet light from 47 distant quasars. Quasars are bright cores of distant active galaxies. Imprinted on the quasars' light as it passes through the Milky Way bubble is information about the speed, composition, and temperature of the gas inside the expanding bubble. The COS observations measured the temperature of the gas in the bubble at approximately 17,700 degrees Fahrenheit. Even at those sizzling

temperatures, this gas is much cooler than most of the super-hot gas in the outflow, which is 18 million degrees Fahrenheit, seen in gamma rays. The cooler gas seen by COS could be interstellar gas from our galaxy's disk that is being swept up and entrained into the super-hot outflow. COS also identified silicon and carbon as two of the elements being swept up in the gaseous cloud. These common elements are found in most galaxies and represent the fossil remnants of stellar evolution. The cool gas is racing through the bubble at 2 million miles per hour. By mapping the motion of the gas throughout the structure, the astronomers estimated that the minimum mass of the entrained cool gas in both bubbles is equivalent to 2 million suns. The edge of the northern bubble extends 23,000 light-years above the galaxy.

https://hubblesite.org/contents/news-releases/2017/news-2017-10.html

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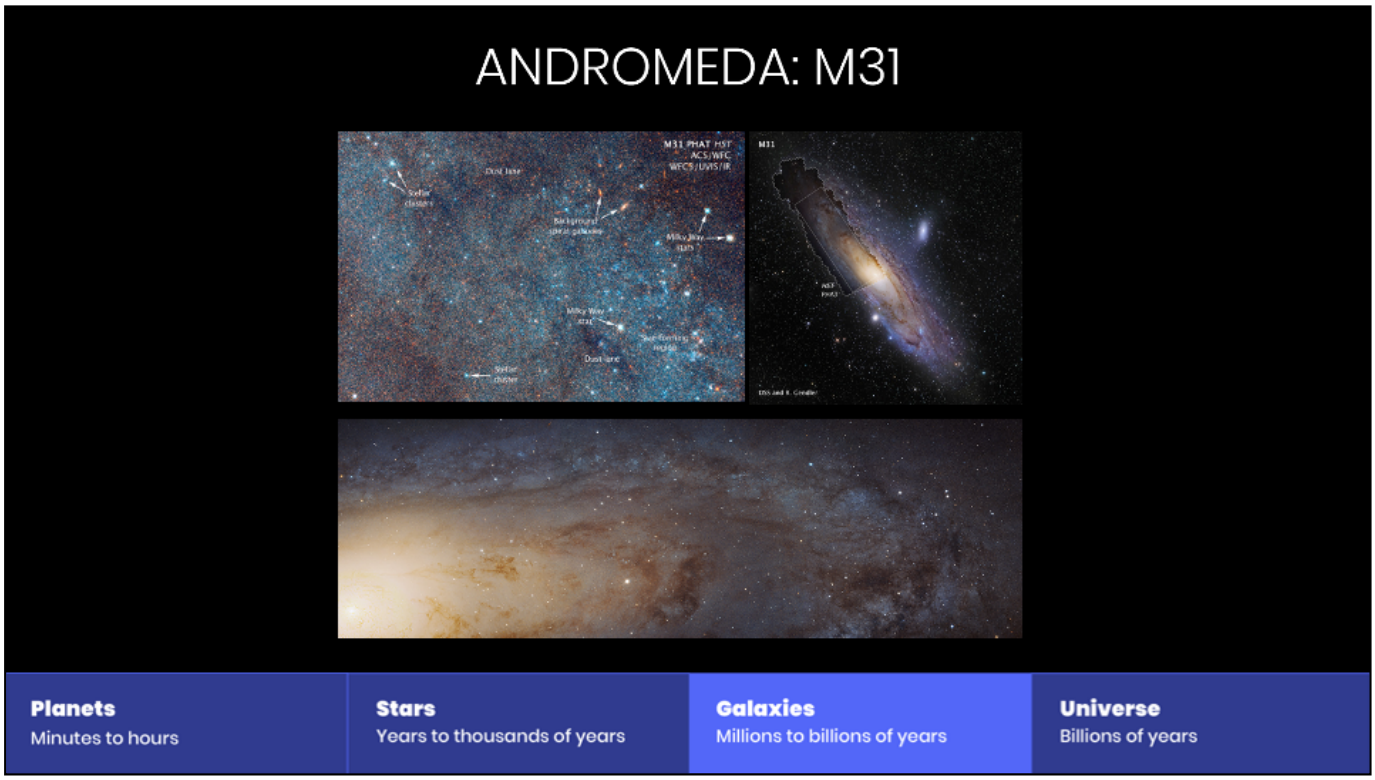
https://hubblesite.org/contents/articles/the-electromagnetic-spectrum



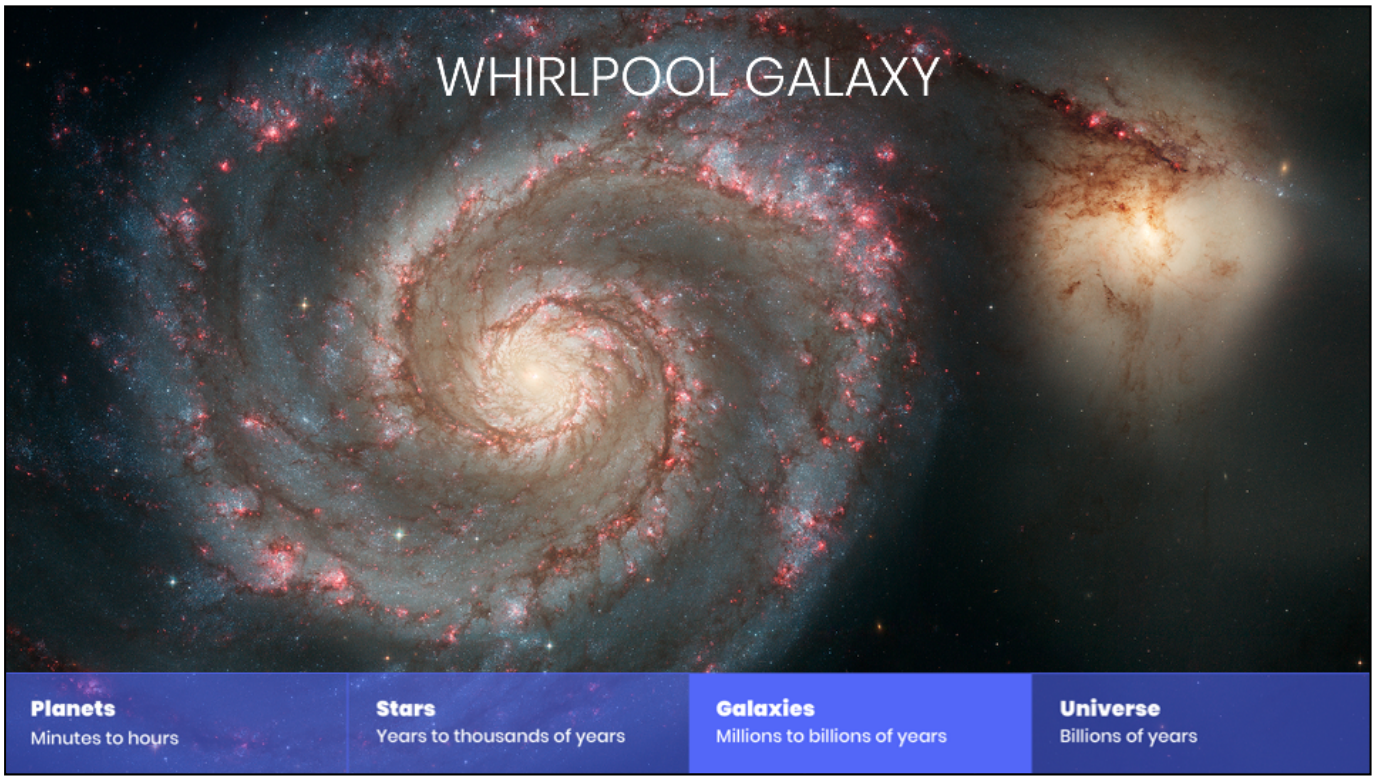
The largest Hubble Space Telescope image ever assembled, this sweeping view of a portion of the Andromeda galaxy (M31) is the sharpest large composite image ever taken of our galactic neighbor. Though the galaxy is over 2 million light-years away, Hubble is powerful enough to resolve individual stars 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.

https://hubblesite.org/contents/news-releases/2015/news-2015-02.html

Supplemental movies: Three movies on the PHAT survey

https://hubblesite.org/resource-gallery/videos?keyword=phat



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).

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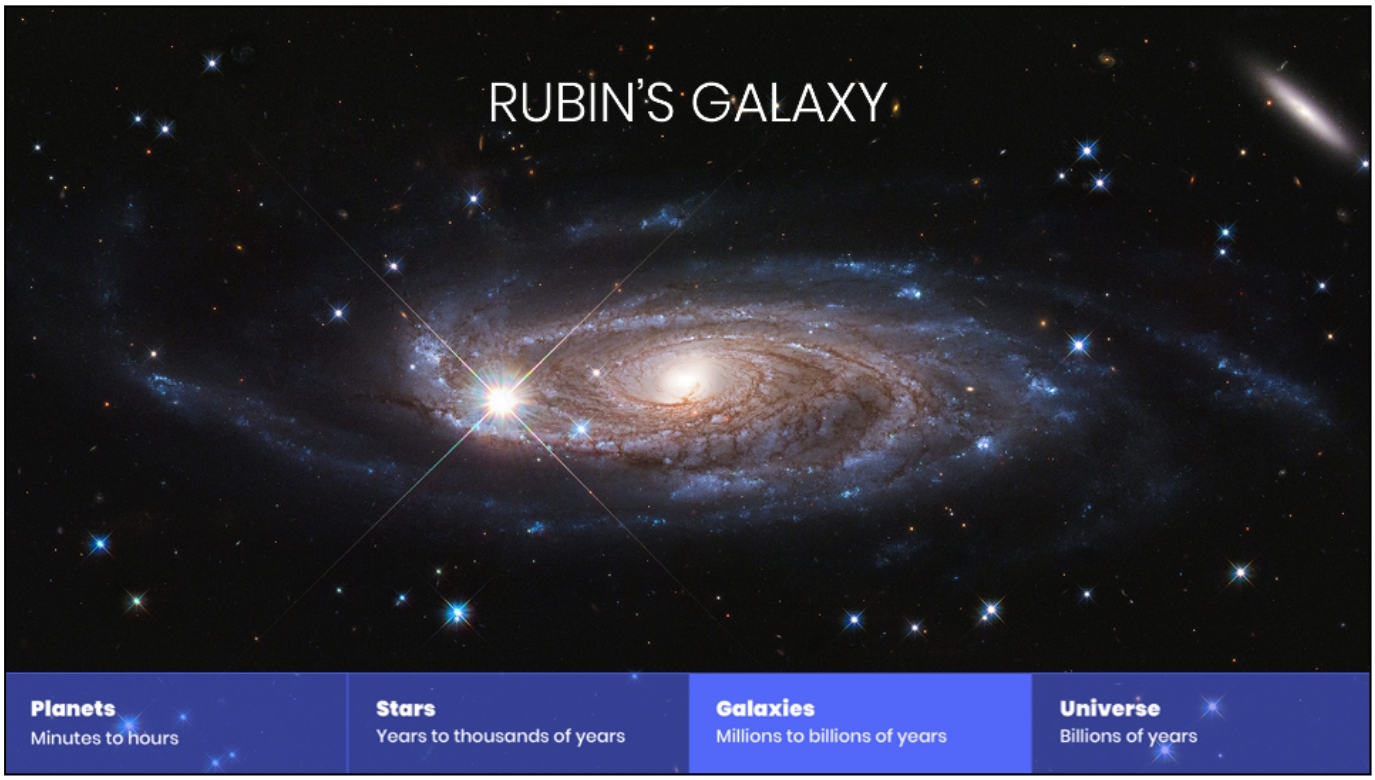
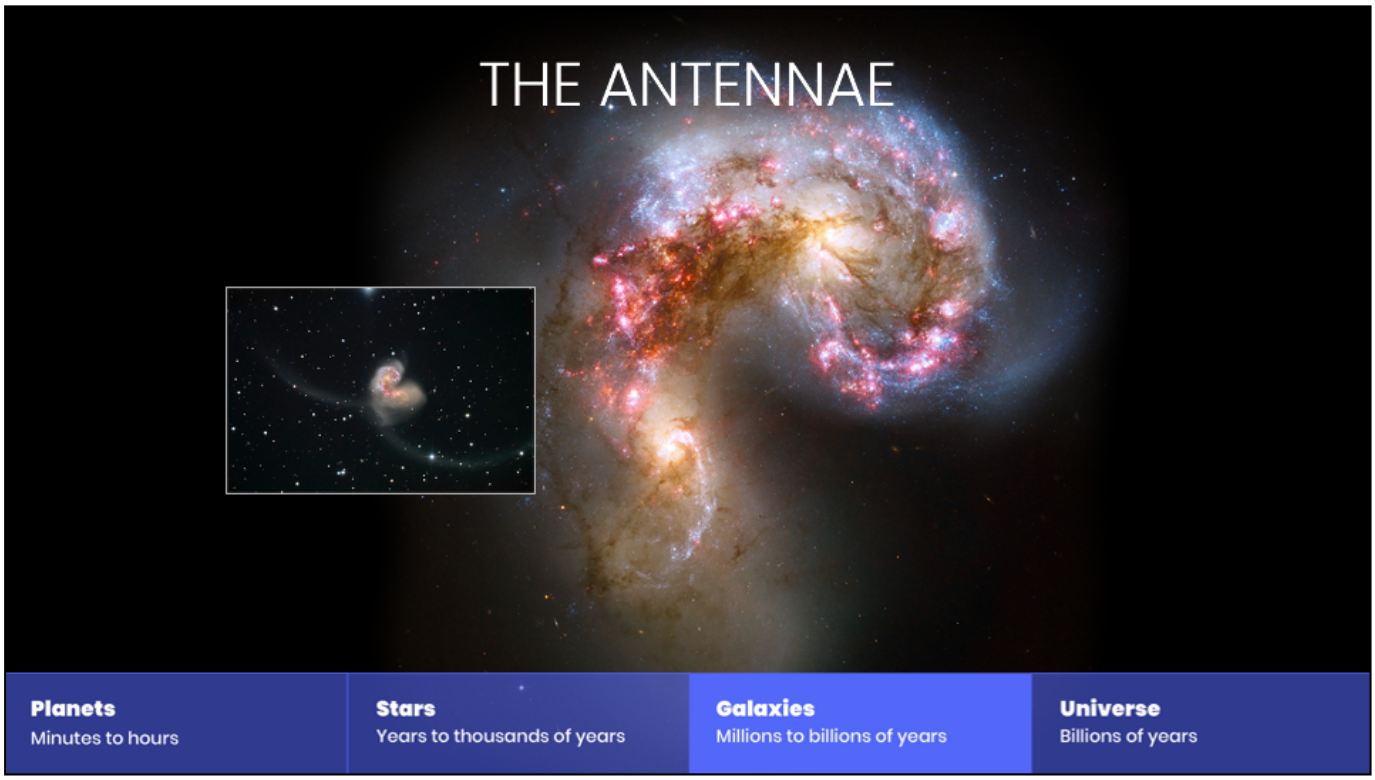
https://hubblesite.org/contents/media/videos/1191-Video.html



Galaxies are like snowflakes. Though the universe contains innumerable galaxies flung across time and space, no two ever look alike. One of the most photogenic is the huge spiral galaxy UGC 2885, located 232 million light-years away in the northern constellation, Perseus. It's a whopper even by galactic standards. The galaxy is 2.5 times wider than our Milky Way and contains 10 times as many stars, about 1 trillion. This galaxy has lived a quiescent life by not colliding with other large galaxies. It has gradually bulked up on intergalactic hydrogen to make new stars at a slow and steady pace over many billions of years. The galaxy has been nicknamed "Rubin's galaxy," after astronomer Vera Rubin (1928 – 2016). Rubin used the galaxy to look for invisible dark matter. The galaxy is embedded inside a vast halo of dark matter. The amount of dark matter can be estimated by measuring its gravitational influence on the galaxy's rotation rate.

NASA's upcoming James Webb Space Telescope could be used to explore the center of this galaxy as well as the globular cluster population. NASA's planned Wide Field Infrared Survey Telescope (WFIRST) would give an even more complete census of this galaxy's cluster population, especially that of the whole halo.

https://hubblesite.org/contents/news-releases/2020/news-2020-01.html



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.

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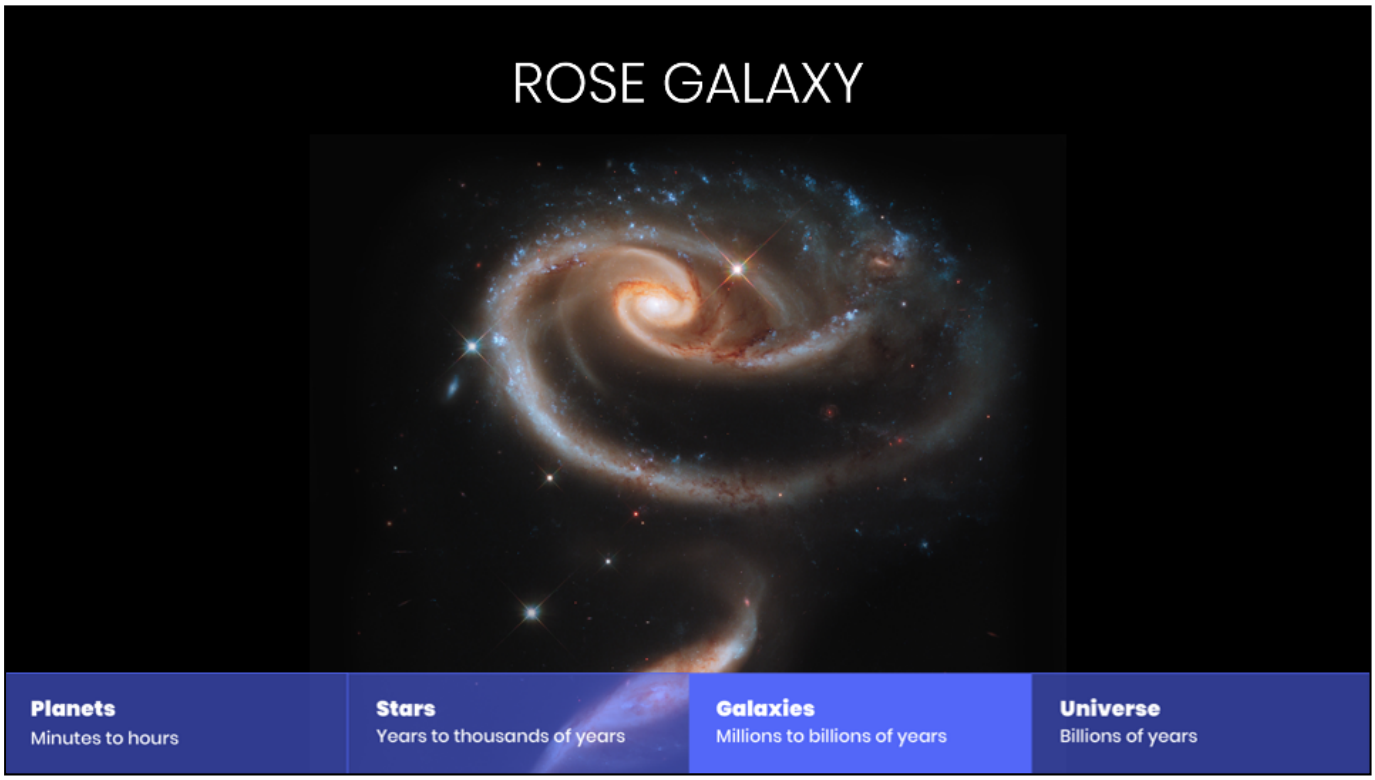
https://hubblesite.org/contents/news-releases/2006/news-2006-46.html



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.

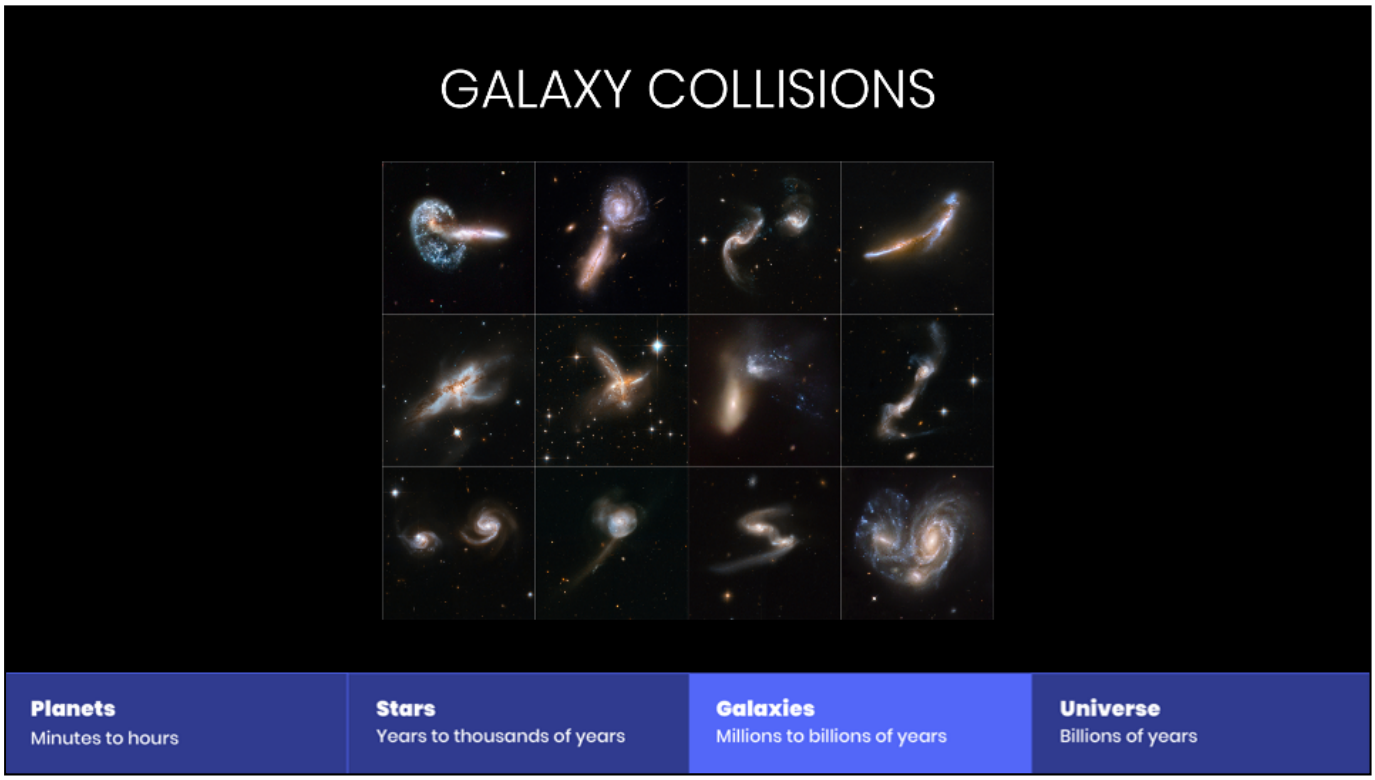
https://hubblesite.org/contents/news-releases/2011/news-2011-11.html

Supplemental animation: Arp 273 Zoom in

https://hubblesite.org/contents/media/videos/2011/11/659-Video.html

3D animation:
https://hubblesite.org/contents/media/videos/2011/11/658-Video.html

Scientific visualization of galaxy collisions:
https://hubblesite.org/contents/media/videos/2011/11/660-Video.html

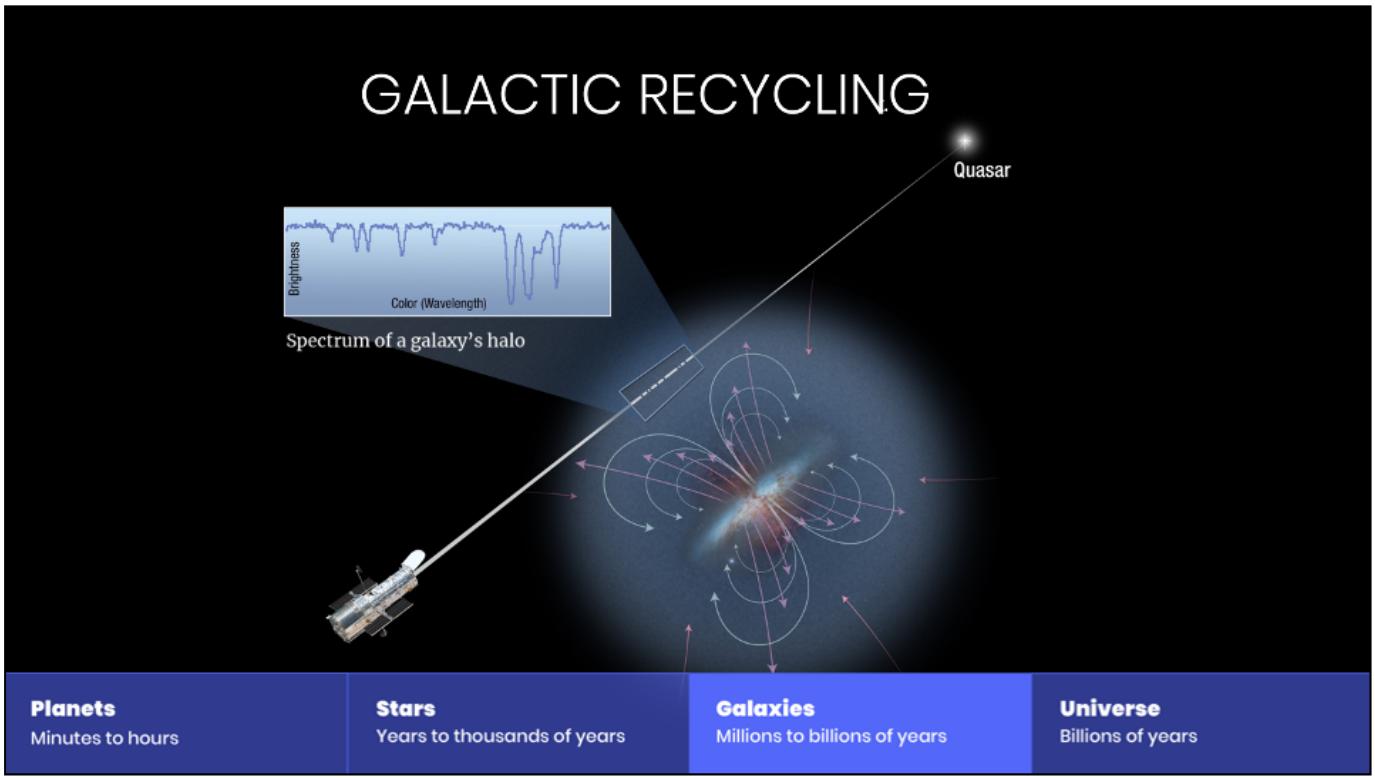


Astronomy textbooks typically present galaxies as staid, solitary, and majestic island worlds of glittering stars. But galaxies have a dynamical side. They have close encounters that sometimes end in grand mergers and overflowing sites of new star birth as the colliding galaxies morph into wondrous new shapes.

https://hubblesite.org/contents/news-releases/2008/news-2008-16.html

The Hubble Space Telescope has observed galaxies in various states of dynamical interaction that match very well with our expectations of how galaxies may interact via computer simulations that model the forces of nature, like gravity.

https://hubblesite.org/contents/media/videos/2008/16/17-Video.html?keyword=galaxy%20collisions



Hubble observations flexed the special capabilities of the Cosmic Origins Spectrograph (COS) to detect otherwise invisible mass in the halo of our Milky Way and a sample of more than 40 other galaxies. Galaxies learned to "go green" early in the history of the universe, continuously recycling immense volumes of hydrogen gas and heavy elements to build successive generations of stars stretching over billions of years. In other words they are more fuel efficient than any hybrid car on the road. This ongoing recycling keeps galaxies from emptying their "fuel tanks" and therefore stretches out their star-forming epoch to over 10 billion years. The catch is that those galaxies that crank up the rate of star formation can blow away their remaining fuel, essentially turning off further star-birth activity. But galaxies like our Milky Way that frugally pace the rate of star birth can go on building new stars at least one billion years into the future.

In the above schematic, Hubble observes the light of a distant quasar shining through the invisible gaseous halo of a foreground galaxy. By examining the brightness of the light at different wavelengths, as shown in the inset spectrum, astronomers can determine how much mass resides in these galactic halos and what chemical elements are present. The gas detected by Hubble's spectrograph in these galaxy halos is far too wispy and diffuse to be imaged with its cameras – it can only be detected spectroscopically.

https://hubblesite.org/contents/news-releases/2011/news-2011-37.html

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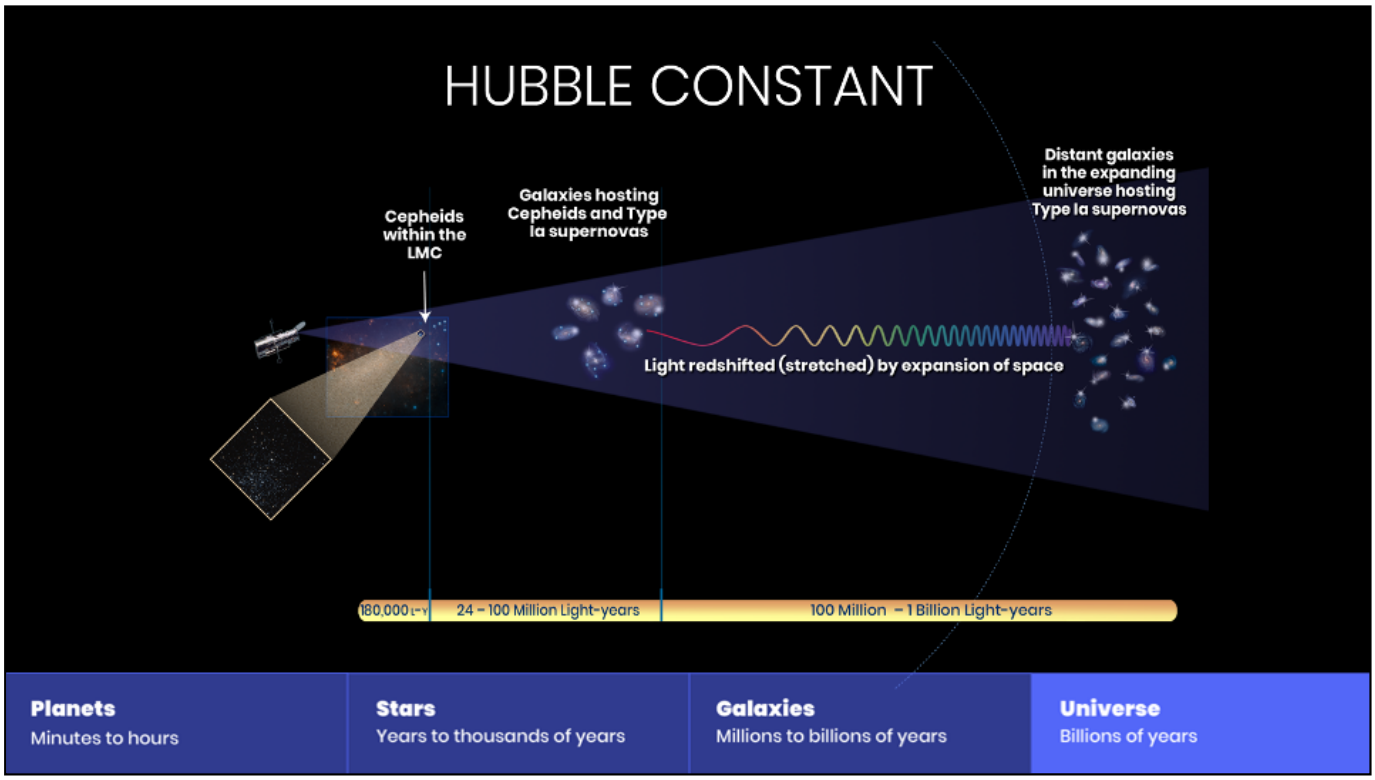

In 1924, American astronomer Edwin Hubble announced that he discovered galaxies outside of our Milky Way by using the powerful new Hooker telescope perched above Los Angeles. By measuring the distances to these galaxies, he realized the farther away a galaxy is, the faster it appears to be receding from us. This was incontrovertible evidence the universe is uniformly expanding in all directions. For nearly a decade Albert Einstein refused to accept the observational evidence. His theory of general relativity described a static universe. But this could only be accomplished by invoking a "cosmological constant," which he described as repulsive property of space that would counterbalance the pull of gravity and prevent the universe from imploding. The expansion rate is the basis of the Hubble constant. It is a sought-after value because it yields clues to the origin, age, evolution, and future fate of our universe.

For nearly the past century astronomers have worked meticulously to precisely measure the Hubble constant. Before the Hubble Space Telescope was launched in 1990, the universe's age was thought to lie between 10 and 20 billion years, based on different estimates of the Hubble constant

Accurately measuring the Hubble Constant, or the present-day expansion rate

of the universe, was one of the original science goals for the Hubble Space Telescope when it launched in 1990. Hubble measurements suggest a faster expansion rate in the modern universe than expected, based on how the universe appeared more than 13 billion years ago. These measurements of the early universe come from the European Space Agency's Planck satellite. This discrepancy has been identified in scientific papers over the last several years, but it has been unclear whether differences in measurement techniques are to blame, or whether the difference could result from unlucky measurements.

The latest Hubble data lower the possibility that the discrepancy is only a fluke to 1 in 100,000. This is a significant gain from an earlier estimate, less than a year ago, of a chance of 1 in 3,000.

These most precise Hubble measurements to date bolster the idea that new physics may be needed to explain the mismatch.

https://hubblesite.org/contents/news-releases/2019/news-2019-25.html

About the Image:

This illustration shows the three basic steps astronomers use to calculate how fast the universe expands over time, a value called the Hubble constant.

All the steps involve building a strong "cosmic distance ladder," by starting with measuring accurate distances to nearby galaxies and then moving to galaxies farther and farther away.

This "ladder" is a series of measurements of different kinds of astronomical objects with an intrinsic brightness that researchers can use to calculate distances.

Among the most reliable for shorter distances are Cepheid variables, stars that pulsate at predictable rates that indicate their intrinsic brightness. Astronomers recently used the Hubble Space Telescope to observe 70 Cepheid variables in the nearby Large Magellanic Cloud to make the most precise distance measurement to that galaxy.

Astronomers compare the measurements of nearby Cepheids to those in galaxies farther away that also include another cosmic yardstick, exploding stars called Type Ia supernovas. These supernovas are much brighter than Cepheid variables. Astronomers use them as "milepost markers" to gauge the distance from Earth to far-flung galaxies.

Each of these markers build upon the previous step in the "ladder." By extending the ladder using different kinds of reliable milepost markers, astronomers can reach very large distances in the universe.

Astronomers compare these distance values to measurements of an entire galaxy's light, which increasingly reddens with distance, due to the uniform expansion of space. Astronomers can then calculate how fast the cosmos is expanding: the Hubble constant.

NASA's Wide Field Infrared Survey Telescope (WFIRST) will help astronomers address the disagreement in the Hubble constant value by tracing the expansion history of the universe. The mission will also use multiple techniques, such as sampling thousands of supernovae and other objects at various distances, to help determine whether the discrepancy is a result of measurement errors, observational technique, or whether astronomers need to adjust the theory from which they derive their predictions.

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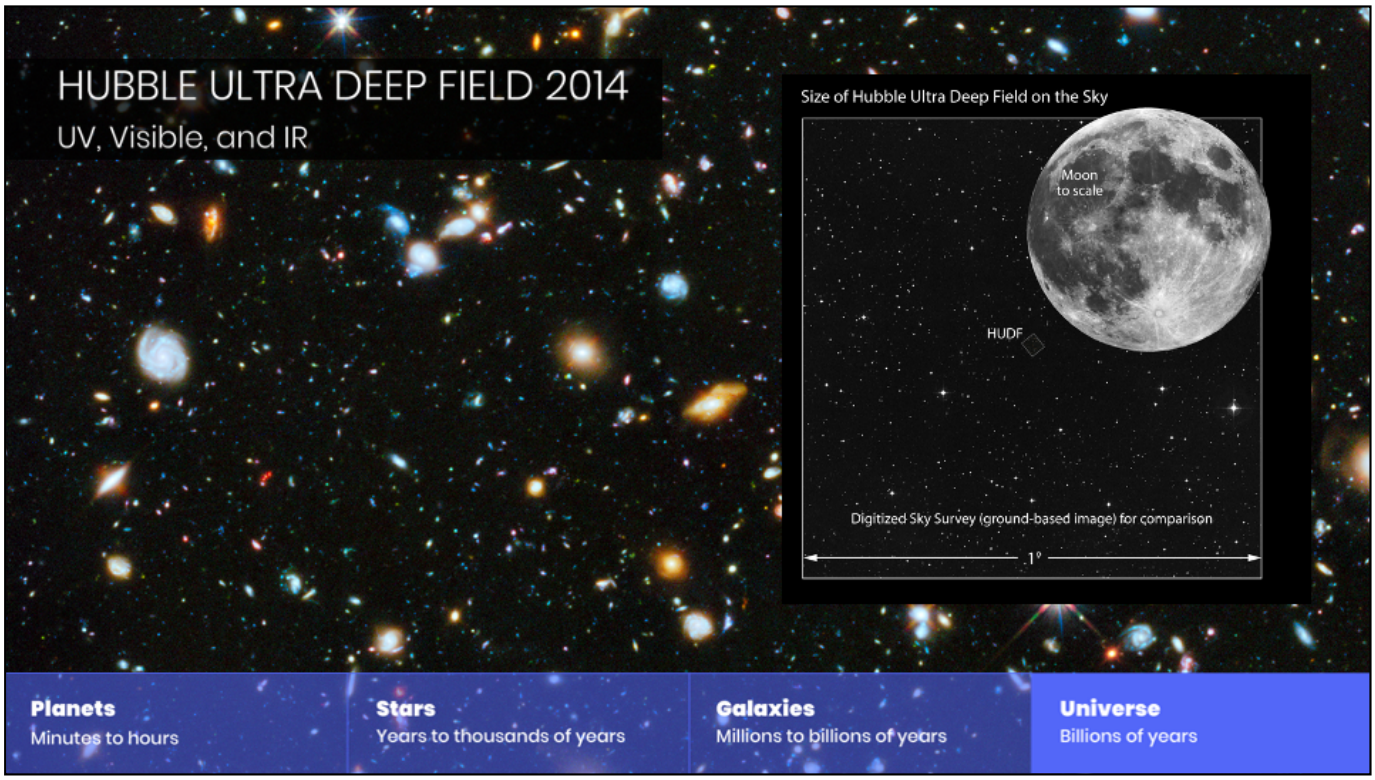
https://hubblesite.org/contents/news-releases/2019/news-2019-28.html



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 UV-HUDF image. 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.

https://hubblesite.org/contents/news-releases/2014/news-2014-27.html
https://hubblesite.org/contents/media/videos/2014/27/766-Video.html
https://hubblesite.org/contents/media/videos/2012/37/715-Video.html

This region of the sky has been observed by Hubble for multiple observing programs, including the Hubble Ultra Deep Field program. All of Hubble's data is stored on the Mikulski Archive for Space Telescopes (MAST). The latest effort in the science of Hubble's deep fields has been to combine all of the deep field data of this region of the sky into one catalog on MAST. This is known as the Hubble Legacy Field. The Hubble Legacy Field will be a tremendous resource for astronomers to compare with data from other telescopes that have observed this region, like the Chandra X-ray

Observatory, and future telescopes that will observe the deep universe in new and powerful ways, like the James Webb Space Telescope and the Wide Field Infrared Survey Telescope (WFIRST).

https://hubblesite.org/contents/news-releases/2019/news-2019-17.html

Another 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 spent multiple years peering at six massive clusters of galaxies that are such lenses in Hubble's Frontier Fields program (2013-2017). With the boost from such natural "zoom lenses" found in space, Hubble's Frontier Fields observations uncovered 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 looked 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 proposed these observations in order to 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 peered deep into the fields, imaging them at X-ray wavelengths to 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 370 is a very efficient lens located about 4 billion light years away at a redshift of z=0.375.

https://hubblesite.org/contents/news-releases/2017/news-2017-20.html

https://hubblesite.org/contents/news-releases/2018/news-2018-39.html

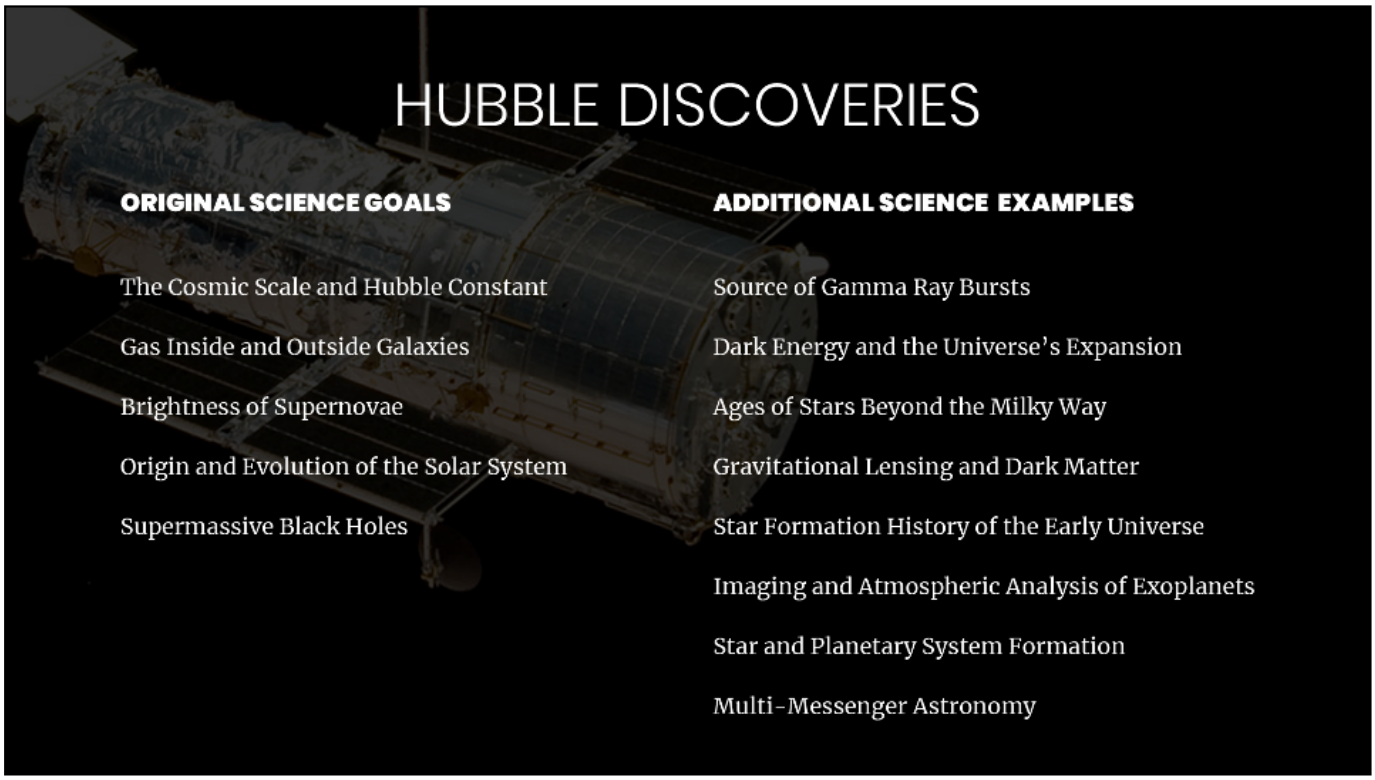
Archived Frontier Fields blog, with additional information, images, and videos

https://frontierfields.org/

Illustration of a black hole visiting Baltimore Harbor

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

https://hubblesite.org/contents/media/videos/2003/01/25-Video.html



Hubble has made tremendous discoveries in the past 30 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_o), 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.

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.

•Coordinated observations with other observatories using light, gravitational waves, and particles to do multi-messenger astronomy

Barbara A.
MIKULSKI
ARCHIVE FOR
SPACE
TELESCOPES

Maximizing scientific accessibility and productivity of astronomical data.

The Mikulski Archive for Space Telescopes (MAST) is a NASA funded project that provides a variety of astronomical data archives focused on scientific data sets in the optical, UV, and near and Fred parts of the spectrum.

MAST contains the data of 25 missions and data collections

http://archive.stsci.edu/

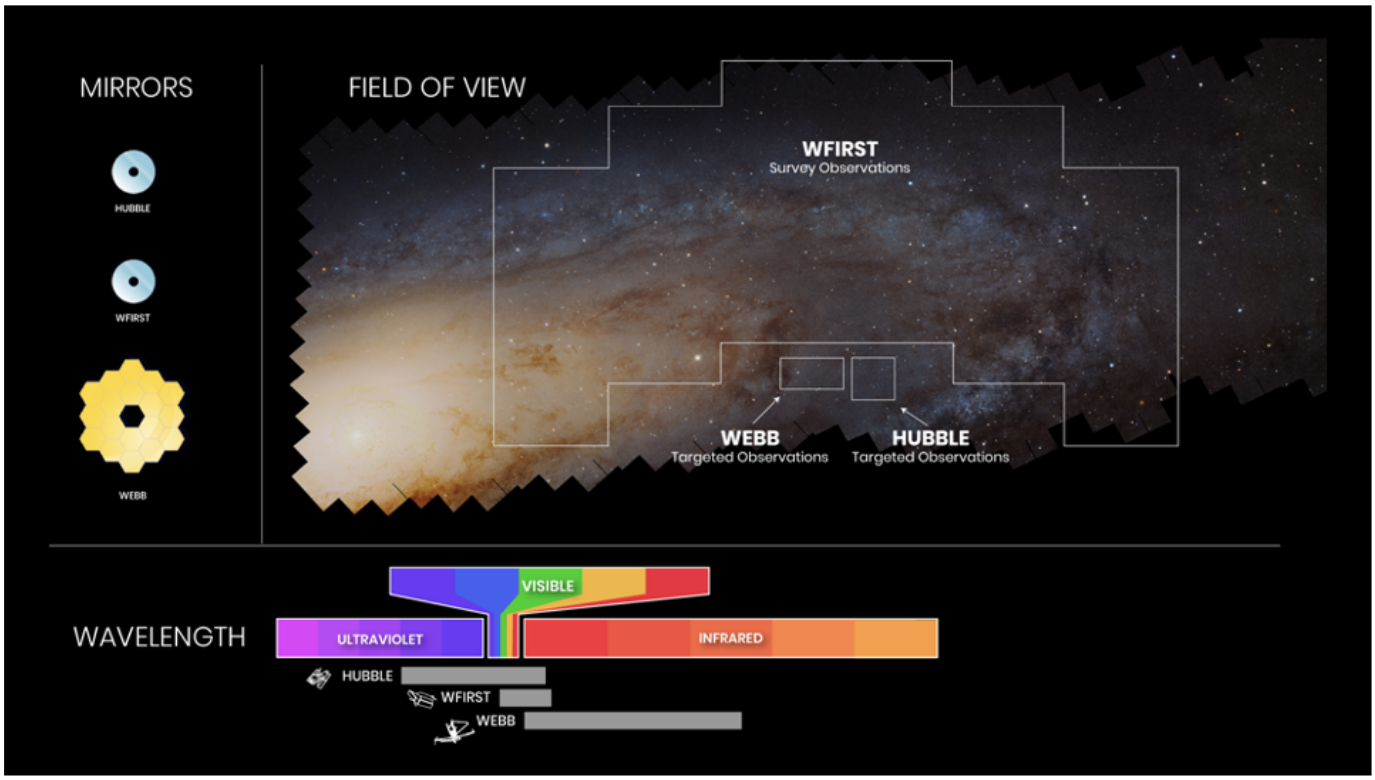
Besides providing engaging imagery and science results, what is Hubble's "Return on Investment" for the public?

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

Mission outreach provides resources for learners, educators, developers, and other professionals in museums, planetariums, nature centers, observatory & park visitor centers, and other free-choice learning venues. Find materials that span from the beginning of Hubble's mission to the innovative science it is enabling today.

http://www.stsci.edu/communications-and-outreach

https://hubblesite.org/resource-gallery/learning-resources



What is next?

The power of Hubble as demonstrated in the previous slide deck lays in its coverage of the electromagnetic spectrum, spectacular high-resolution images, and targeted observations of objects. For the foreseeable future, Hubble will be the only space-based, high-resolution instrument capable of seeing into the ultraviolet (UV) universe. This is a powerful capability that is being leveraged in the ULLYSES project. Hubble is unique in its ability to perform spectroscopy studies in wavelengths ranging from UV to visible to near infrared (IR). Coupled with its powerful camera that provide among the highest resolution of images of any current and future planned space-based observatories, Hubble is a premier telescope that set the bar as the first Great Observatory.

In the future, Hubble will partner with NASA's next generation observatories, the James Webb Space Telescope and the Wide Field Infrared Survey Telescope (WFIRST). These observatories will expand and deepen our understanding of the universe, and their infrared vision will provide insights into celestial objects near and far.

Details of the comparisons

Mirrors: The space telescope mirrors determine the light collecting power of the telescope. A large mirror can collect more light, hence able to see fainter objects. The thin gold plating on the Webb mirror segments additionally makes it more sensitive to collecting infrared light. Mirror size is determined by engineering and science constraints. Webb's mirror is made up of 18 smaller mirror segments that can be individually controlled in order to properly focus the telescope after launch.

Field of View (FOV): The field of view is the extent that can be viewed at any given time. The optical system in a telescope determines its field of view. This includes the primary mirror, secondary mirror, any additional lenses and mirrors in the instrument, and the size of the detector. A larger mirror does not indicate a larger field of view.

Wavelength: Telescopes can observe in different wavelengths of light based on the instrument sensors. Spectrometers usually work best for a limited range of wavelengths. Wavelengths for a telescope are decided on based on the scientific needs of the mission.

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JWST

Built in partnership with the European and Canadian Space Agencies, NASA's James Webb Space Telescope (sometimes called JWST or Webb) will be the world's premier infrared space observatory, serving thousands of astronomers worldwide. Scheduled to launch in 2021, the telescope represents an important step forward in technology, science capability, and potential discoveries.

Webb has the amazing resolution of Hubble and the ability to detect light wavelengths into the mid-infrared range, like the Spitzer Space Telescope. Like Hubble, Webb will take targeted observations of celestial objects and will use its powerful spectrographs to obtain detailed information about the composition of objects near and far. It will study every phase in the history of our universe, from the earliest and most distant galaxies to the current state of our local solar system, and everything in between.

As shown in the illustration on this slide, Webb has a much larger, segmented mirror compared to Hubble's. (Webb: 6.5 meter; Hubble: 2.5 meter). This gives

Webb the sensitivity it needs at infrared wavelengths to probe deeper into the universe as well as to see faint objects and exoplanet systems in sharp detail.

Webb will complement the Hubble Space Telescope, providing simultaneous and/or follow-up observations at infrared wavelengths. Webb will also combine forces with Hubble's unique capabilities in ultraviolet and visible light to give us a new, more comprehensive view of the universe.

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

Supplemental movies, many covering all topics regarding JWST: https://webbtelescope.org/resource-gallery/videos, http://jwst.nasa.gov/videos.html

See the time lapse of the JWST sunshield deployment: http://jwst.nasa.gov/videos/JWSTSunshieldDeployment.wmv

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WFIRST

WFIRST (the Wide Field Infrared Survey Telescope) will be NASA's next large space observatory after JWST. This survey mission touches upon nearly every class of astronomical object, environment and distance, and will help astronomers explore some of the greatest mysteries of the cosmos, including why the expansion of the universe seems to be accelerating.

Unlike Hubble and Webb that conduct targeted observations, WFIRST will be a survey telescope. It will provide a panoramic field of view that is 100 times greater than Hubble's, leading to the first wide-field maps of the universe with the same sharp space-based resolution achievable by Hubble at near-infrared wavelengths. The main image on this slide shows a high-resolution view of our nearest galactic neighbor, the Andromeda galaxy. Astronomers took 400 distinct pointings with Hubble and connected them to build a wide-field mosaic. The large white outline shows the enormous footprint of WFIRST superimposed on this Hubble mosaic. It would take just two WFIRST pointings to cover the entire region explored by Hubble in this mosaic at the same depth and image clarity.

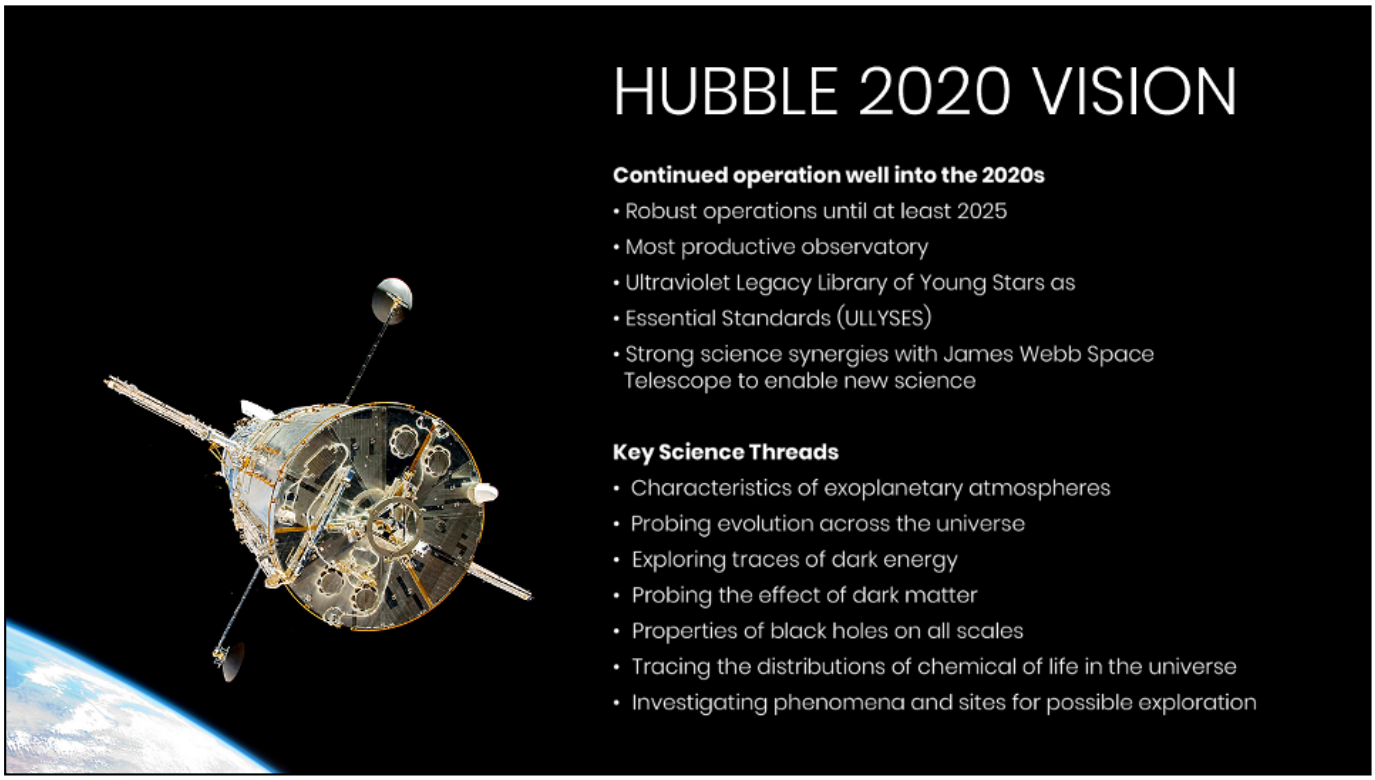
WFIRST will contribute to all areas of astrophysics. It will survey billions of galaxies and catch the light of stellar explosions to better understand the enigmatic dark energy. Its scans of the sky will uncover thousands of exoplanets beyond our solar system. Beyond these goals, WFIRST will enable

investigations of additional astrophysical topics, ranging from stars in neighboring galaxies, supermassive black holes in faraway galaxies, cosmic nurseries where stars and planets form, and small bodies in our solar system. WFIRST will also image our own galaxy, measuring its structure, and finding telltale signs of smaller galaxies torn apart by interactions with the Milky Way. WFIRST's spectrographs will determine the distances to tens of millions of galaxies, turning WFIRST's wide-field images into three dimensional maps and measuring the expansion of the universe.

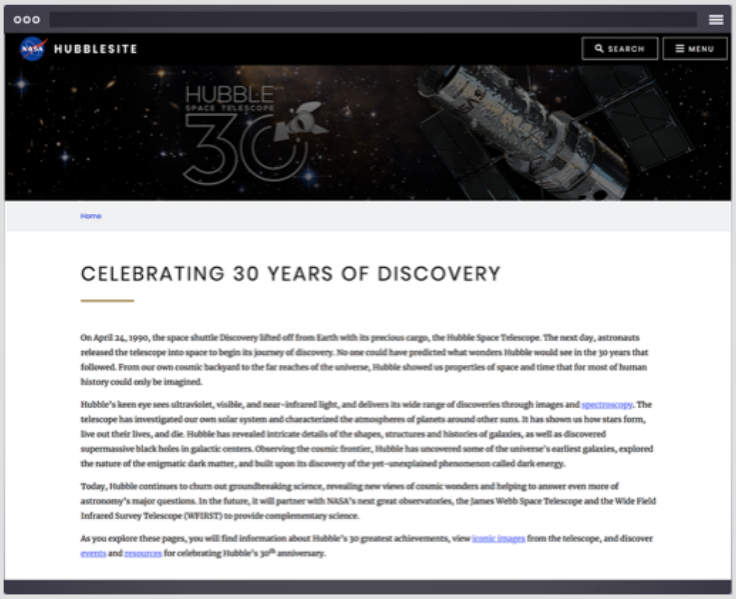
WFIRST also has a technology demonstration instrument – The Coronagraphic Instrument – which will further our progress towards building next generation coronagraphs capable of imaging Earth-sized exoplanets at Earth-Sun distances. Coronagraphs operate as an artificial eclipse, blocking out the bright light of a star so nearby, faint objects are visible.

WFIRST will complement Webb and Hubble. WFIRST surveys will discover rare astronomical objects that can be followed up by targeted deep infrared observations with JWST, optical and ultraviolet observations with Hubble, and other powerful telescopes being built in the 2020s.

General information can be found at: https://wfirst.gsfc.nasa.gov/index.html, http://www.stsci.edu/wfirst



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 scienitifc 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.



https://hubblesite.org/30

https://hubblesite.org/30 has resources for Hubble's anniversary. There are many links to supplemental materials. Visit the main website https://hubblesite.org/ for even more material.