National Aeronautics and Space Administration

Highlights of Hubble's Exploration of the Universe

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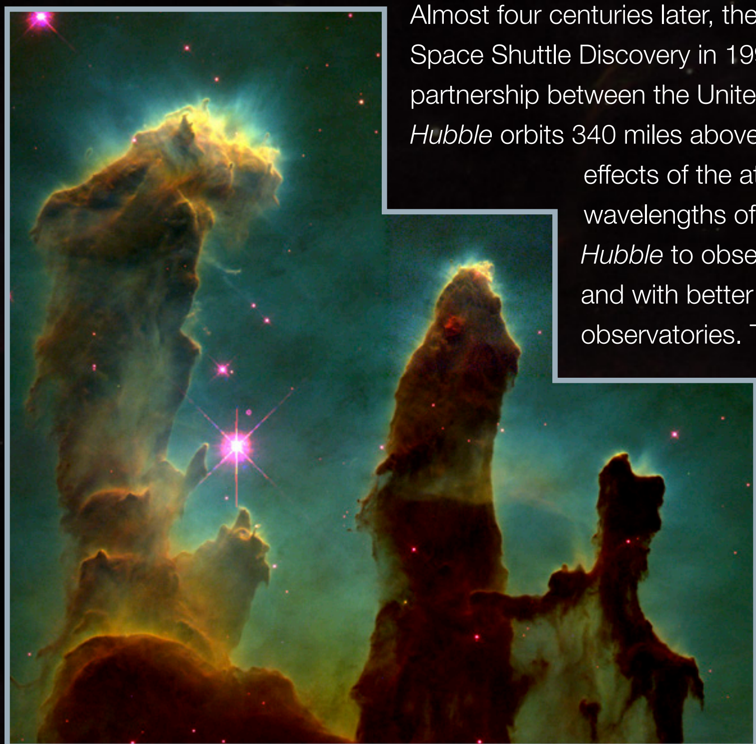
Introduction

In 1609, visionary Italian scientist Galileo Galilei turned the newly invented optical device of his day—the telescope—to view the heavens. His observations conclusively showed that there were celestial bodies (the moons of Jupiter) that did not revolve around the Earth, launching a revolution that forever changed our view of an Earth-centered universe.



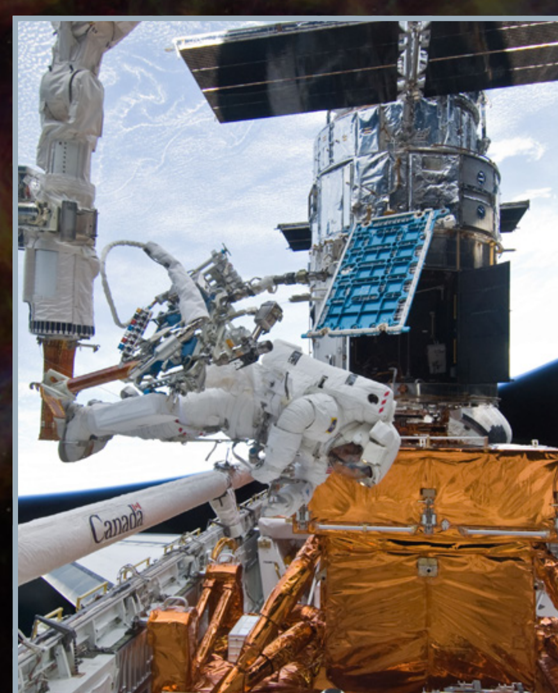
One of Hubble*'s most iconic images is of this portion of the Eagle Nebula (M16). Dubbed the "Pillars of Creation," it shows star birth. Imbedded in the tips of the finger-like protrusions at the top of the columns are dense, gaseous globules within which stars are being born.*

Almost four centuries later, the launch of NASA's *Hubble Space Telescope* aboard the Space Shuttle Discovery in 1990 started another revolution in astronomy. Developed as a partnership between the United States space program and the European Space Agency, *Hubble* orbits 340 miles above Earth's surface. Its gaze outward lies beyond the distorting effects of the atmosphere, which blurs starlight and blocks some important wavelengths of light from reaching the ground. This vantage point allows *Hubble* to observe astronomical objects and phenomena more consistently and with better detail than generally attainable from ground-based observatories. The telescope's sensitive cameras and spectrographs can view objects as nearby and small as the collision of asteroids to distant star-forming galaxies that date back to when the universe was only three percent of its current age. In fact, *Hubble* observations have played a key role in discovering and characterizing the mysterious dark energy that now appears to permeate space. Results like these have changed our fundamental understanding of the cosmos.

Well into its third operational decade, *Hubble* is still extremely productive. The orbiting telescope has taken over a million observations and provided data that astronomers have used to write more than 17,000 peer-reviewed scientific publications on a broad range of topics, from planet formation to gigantic black holes. These papers have been referenced in other publications approximately 900,000 times, and this total increases, on average, by more than 150 per day. Every current astronomy textbook includes contributions from the observatory. Today's college undergraduates have not known a time in their lives when astronomers were not actively making discoveries with *Hubble* data.

Hubble's discoveries and memorable photos have also reinvigorated the public's interest in astronomy. Along with pictures of the telescope and the astronauts who launched and serviced it during six space shuttle missions, certain memorable science images have become cultural icons. They appear regularly on book covers, musical albums, clothing, TV shows, movies, and even ecclesiastical stained-glass windows.

This booklet features thirteen representative topics with eye-catching images and thought-provoking discoveries. Selecting this set from the thousands of amazing *Hubble* observations was difficult, but these serve to highlight some of *Hubble*'s greatest scientific achievements to date. Additional images and information can be found at http://nasa.gov/hubble and http://hubblesite.org.



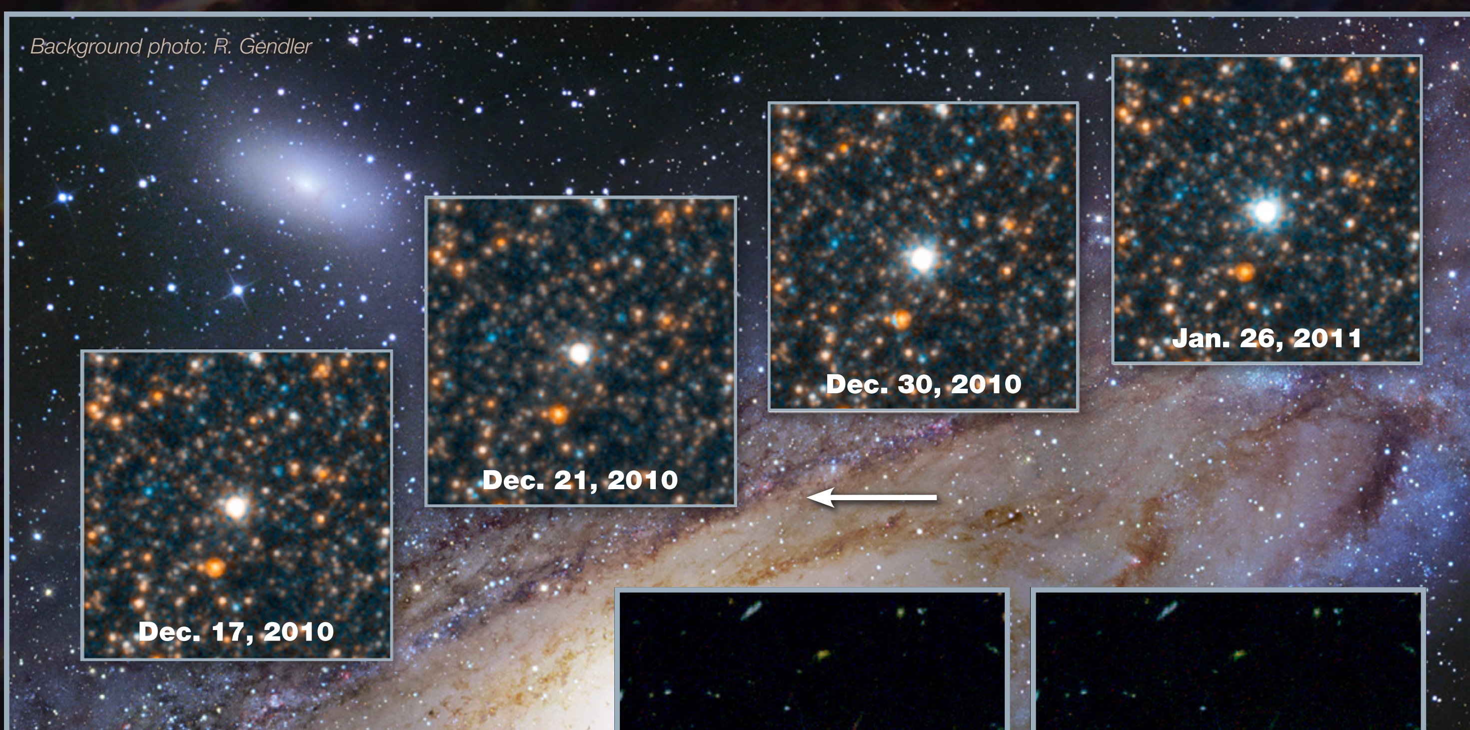
Right: Astronaut Mike Good maneuvers to repair the Space Telescope Imaging Spectrograph during the final Hubble *servicing mission in May 2009. Periodic upgrades have kept the telescope equipped with state-of-the-art instruments, which have given astronomers increasingly better views of the cosmos.*

Cover image: Veil Nebula

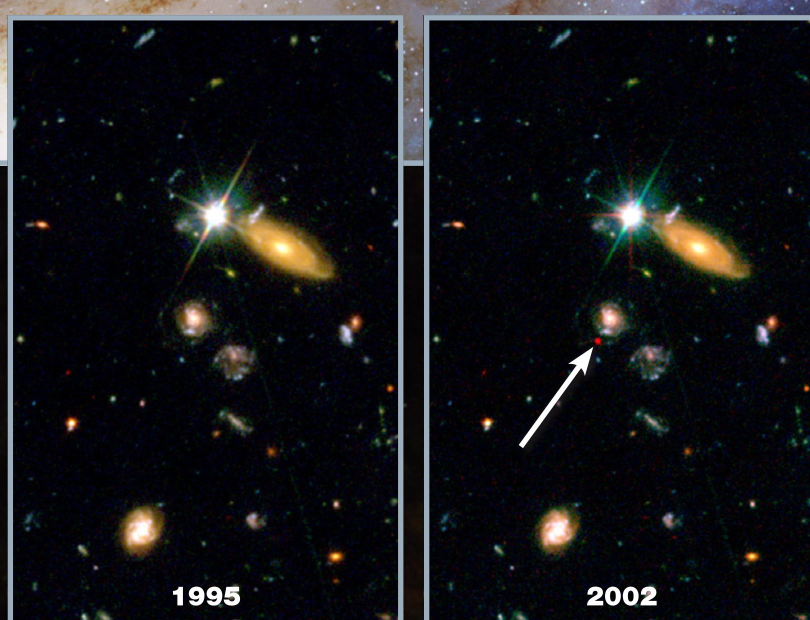
Discovering a Runaway Universe

Our cosmos is getting bigger. Nearly a century ago Edwin Hubble measured the expansion rate of the universe. This value, called the Hubble constant, is an essential ingredient needed to determine the age, size, and fate of the cosmos. Before *Hubble* was launched, the value of the Hubble constant was imprecise, and calculations of the universe's age ranged from 10 billion to 20 billion years. Now, astronomers using *Hubble* have refined their estimates of the universe's present expansion rate and are working to make it more accurate. They do this by getting better galaxy distance measurements from *Hubble* and coupling these values with the best galaxy-velocity measurements obtained from other telescopes. Scientists measure distances by comparing the brightness of a known object in our galaxy (like a star or an exploded star) to that of a similar object in a distant galaxy. With *Hubble*'s refined distance values, calculations currently put the age of the universe as 13.8 billion years.

To the surprise of astronomers, *Hubble* observations along with those of ground-based observatories have also shown that the universe is not just expanding, but accelerating—a discovery that won the 2011 Nobel Prize in Physics. Many scientists believe this acceleration is caused by a "dark energy" that pervades the universe. Dark energy can be thought of as a sort of "antigravity" that is pushing galaxies apart by stretching space at an increasing pace. The nature of this energy is a complete mystery, even though astronomers estimate that it makes up about 70 percent of the mass and energy in the entire universe. Though it cannot be measured directly using current technology, dark energy can be characterized by its effect on matter in the visible universe. By observing how dark energy behaves over time, astronomers hope to gain a better understanding of what it is and how it might affect the future of the cosmos.



Above: Astronomers use cyclical changes in the brightness of Cepheid stars to determine astronomical distances. The arrow points to a Cepheid star in the Andromeda galaxy observed by Hubble *(inset boxes).*



Right: Certain supernovas have a characteristic maximum brightness that can be used to calculate their distances from Earth. Refining celestial distances enables astronomers to better calculate the expansion rate of the universe. The arrow points to a distant supernova discovered in an area of the sky first imaged in 1995 called the Hubble *Deep Field. Astronomers found the supernova when they targeted the same area of sky again in 2002 and saw a change.*

Tracing the Growth of Galaxies

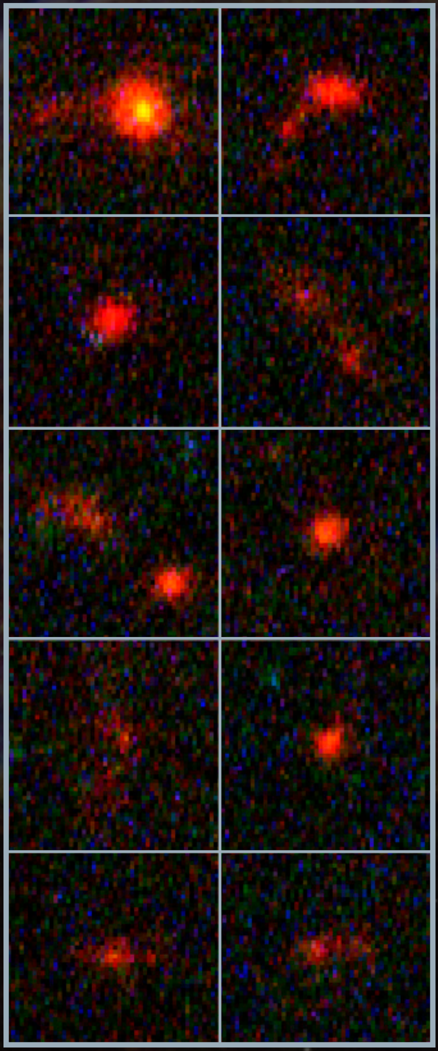
Like documenting a child's development in a scrapbook, astronomers have used *Hubble* to capture the appearance of many developing galaxies throughout cosmic time. This is possible because of the mathematical relationship between cosmic distance and time: the deeper *Hubble* peers into space, the farther back it looks in time. As it happens, the most distant and earliest galaxies spied by *Hubble* are smaller and more irregularly shaped than today's grand spiral and elliptical galaxies. This is evidence that galaxies grew over time through mergers with other galaxies to become the giant systems we see today.

Because the universe was smaller in the past, galaxies were more likely to interact with one another gravitationally. Some of *Hubble*'s cosmic "snapshots" show fantastic stellar streamers pulled out and flung across space by colliding galaxies. They apparently settled over time into the more familiarly shaped galaxies seen closer to Earth and hence nearer to the present time. By carefully studying galaxies at different epochs, astronomers can see how galaxies changed and evolved over time. Among the things they investigate are the relative amounts of stars and gas in galaxies, the types and amounts of identifiable chemical elements present, and star-formation rates.

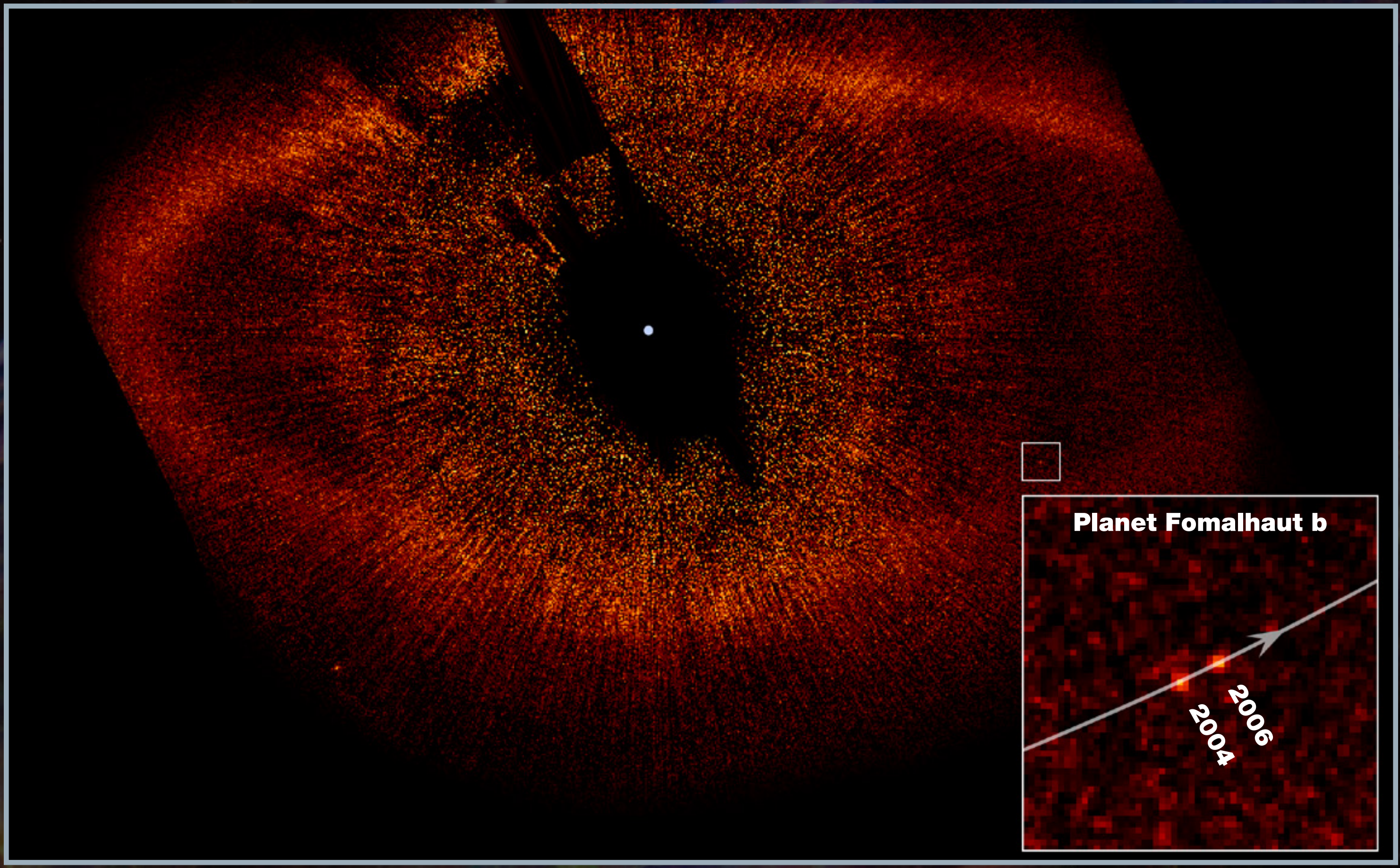
And the evolution continues. *Hubble* observations of our neighboring Andromeda galaxy (M31) have allowed astronomers to predict with certainty that a titanic collision between our Milky Way galaxy and Andromeda will inevitably take place beginning 4 billion years from now. The galaxy is now 2.5 million light-years away, but it is inescapably moving toward the Milky Way under the mutual pull of gravity between the two galaxies and the invisible dark matter that surrounds them both. The merger will likely result in the creation of a giant elliptical galaxy billions of years from now.

Left: Hubble*'s Ultra Deep Field is one of the most distant looks into space ever. The cumulative exposure time needed to capture the image was about a million seconds (11 days).*

Right: A sample of the faintest and farthest galaxies in the Hubble *Ultra Deep Field shows that they were irregularly shaped and frequently interacting in the distant past.*



Recognizing Worlds Beyond Our Sun



Astronomers used Hubble *to take what might be the first-ever visible-light pictures of an extrasolar planet, named Fomalhaut b.*

At the time of *Hubble*'s launch in 1990, astronomers had not found any planets outside our solar system. Scientists have now confirmed the existence of more than 4,000 extrasolar planets, most of them discovered by NASA's *Kepler* space observatory and by ground-based telescopes. *Hubble*, however, has made some unique contributions to the planet hunt.

Astronomers used *Hubble* to make the first measurements of the atmospheric composition of extrasolar planets. *Hubble* observations have identified atmospheres that contain sodium, oxygen, carbon, hydrogen, carbon dioxide, methane, and water vapor. Most of the planetary bodies studied to date are too hot for life as we know it. But the *Hubble* observations demonstrate that the basic organic components for life can be detected and measured on planets orbiting other stars. In one case, astronomers had sufficient data to make a detailed global map of an exoplanet showing the temperature at different layers in its atmosphere, and the amount and distribution of its water vapor.

Hubble's ultraviolet-light capabilities were used to uncover an immense cloud of hydrogen bleeding off a planet orbiting a nearby star. The hydrogen is evaporating from a warm, Neptune-sized planet due to extreme radiation from the star. This planet could explain the existence of so-called hot super-Earths, which might be stripped-down versions of this planet that have exposed a rocky core.

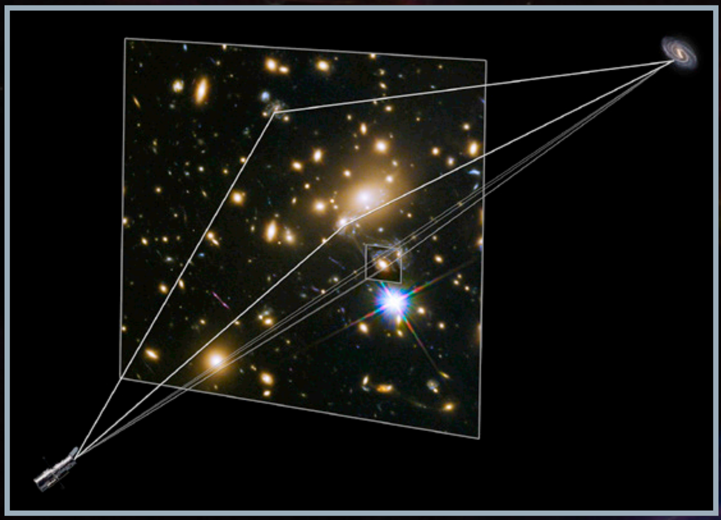
Using another technique called gravitational microlensing, astronomers have also used *Hubble* to confirm the existence of a Saturn-mass planet orbiting two small, faint stars in a tight orbit around each other. Gravitational microlensing occurs when the gravity of a moving foreground star bends and amplifies the light of a background star that temporarily aligns with it along our line of sight. Details in the character of the brightening reveal clues to the nature of the foreground star and any planets it may have.

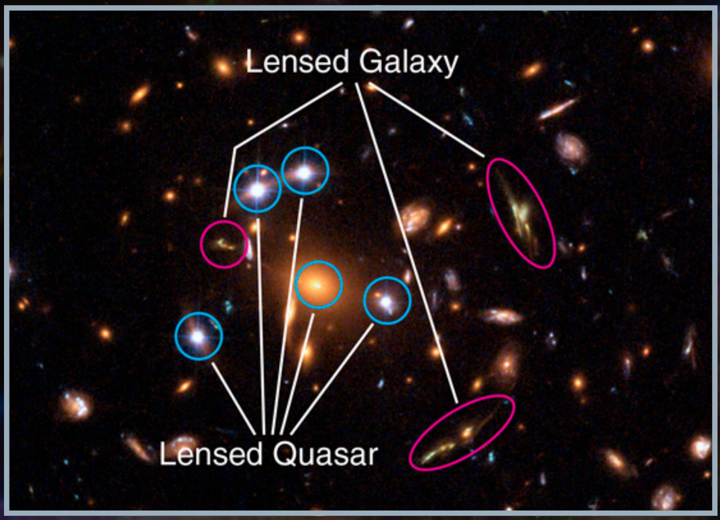
Hubble also captured what might be the first visible-light images of an extrasolar planet. The imaged planet circles the star Fomalhaut, located 25 light-years away. This unusual planet follows a highly elongated orbit near the inner edge of a ring-like disk around Fomalhaut, and is presently about 10 times farther from the star than Saturn is from the Sun.

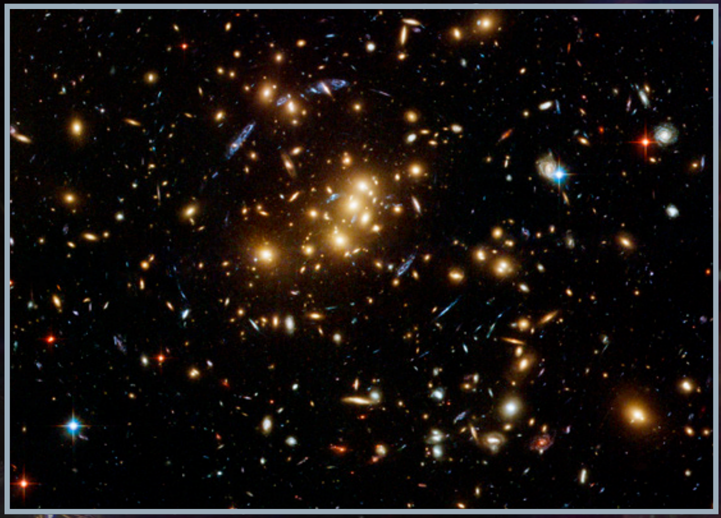
Shining a Light on Dark Matter

Dark matter is an invisible form of matter that makes up most of the universe's mass and creates its underlying structure. Dark matter's gravity drives normal matter (gas and dust) to collect and build up into stars and galaxies. Although astronomers cannot see dark matter, they can detect its influence by observing how the gravity of massive galaxy clusters, which contain dark matter, bends and distorts the light of more distant galaxies located behind the cluster. This phenomenon is called gravitational lensing.

Hubble's uniquely sharp vision allows astronomers to map the distribution of dark matter in space using gravitational lensing. Large galaxy clusters contain both dark matter and normal matter. By observing the areas around massive clusters of galaxies astronomers can identify warped background galaxies and reverse-engineer their distortions to reveal where the densest concentrations of matter lie. Mathematical models of these results shed light on the location and properties of the lensing material, both visible and invisible (dark). The universe appears to have about five times more dark matter than regular matter and seems to be organized around an immense network of dark matter filaments that have grown over time. Massive visible structures, like galaxy clusters, are found at the intersections of these filaments.





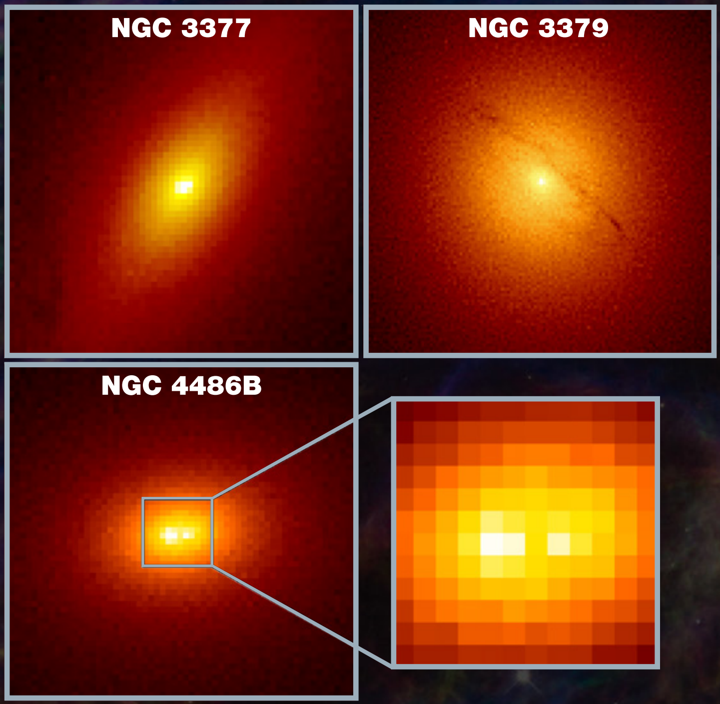


Top left: This sketch shows paths of light from a distant galaxy that is being gravitationally lensed. Top right: Gravitational lensing has created three distorted images of the same background galaxy and five of a background quasar in this image of galaxy cluster SDSS J1004+4112.

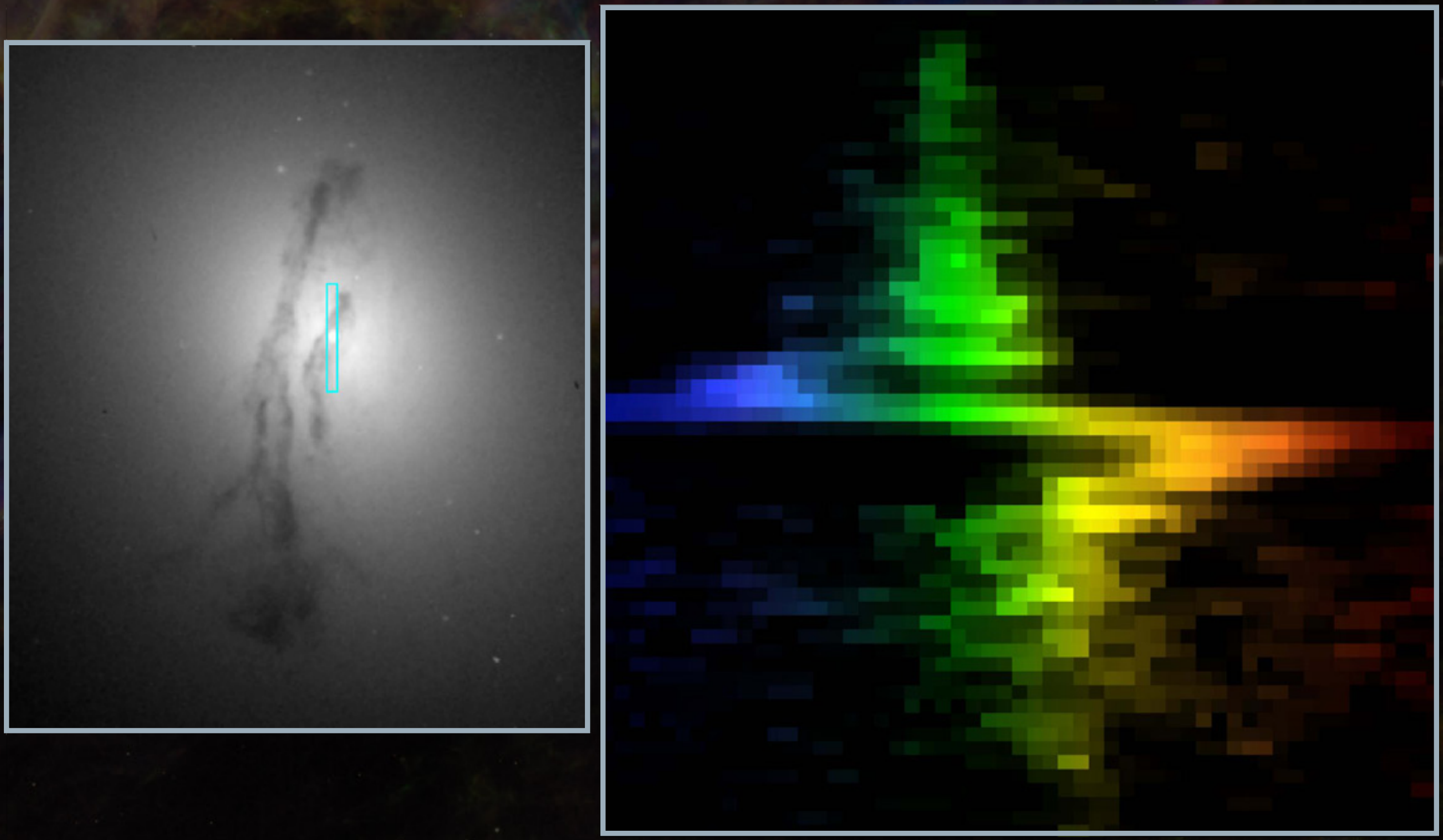
Bottom: These two pictures show a massive galaxy cluster, Cl 0024+17. The visible-light image (left) shows blue arcs among the yellowish galaxies. These arcs are magnified, warped images of galaxies located behind the cluster whose light has been distorted and bent. The blue overlay (right) shows the dark matter density needed to account for the gravitational distortions.

Realizing Monster Black Holes Are Everywhere

Hubble provided decisive evidence that the hubs of most galaxies contain enormous black holes, which have the mass of millions or even billions of stars. Not only are black holes resident in almost every galaxy, but somehow their sizes correspond. A *Hubble* census of galaxies showed that a black hole's mass is dependent on the mass of its host galaxy's central bulge of stars: the larger the galaxy, the larger the black hole. This close relationship may be evidence that black holes grew along with their galaxies, devouring a fraction of the galaxy's mass. *Hubble* also provided astronomers the first-ever views of material encircling black holes in large, flat disks.



Combining images with data from Hubble's *spectrographs, researchers have peered into the center of many galaxies and established the existence of large black holes. In a census performed by* Hubble *in the late 1990s, galaxies NGC 3379 and NGC 3377 were found to have black holes that "weighed in" at 50 million and over 100 million solar masses, respectively, and NGC 4486B was revealed to have a double nucleus at its core.*



Shown here are two Hubble *views of the galaxy M84. Left: This camera view shows the bright core at the center of the galaxy surrounded by a (vertical) dark band of gas and dust. Right: This plot was generated by passing light near the core of the galaxy through a spectrograph. The thin, vertical rectangle in the center of the left panel shows the size and shape of the spectrograph's sampling slit. Spectra taken left and right of the slit's position, which is centered on the core of the galaxy, show a dramatic shift in color to blue or red. Blueshifted light indicates that the emitting light source is moving toward Earth, while redshifted light indicates objects that are moving away. At 880,000 miles per hour, stars and glowing gases nearest to the core of M84 are moving the fastest. They are circling a black hole at the center of the galaxy, and so appear to be moving rapidly toward Earth on the left and receding on the right.*

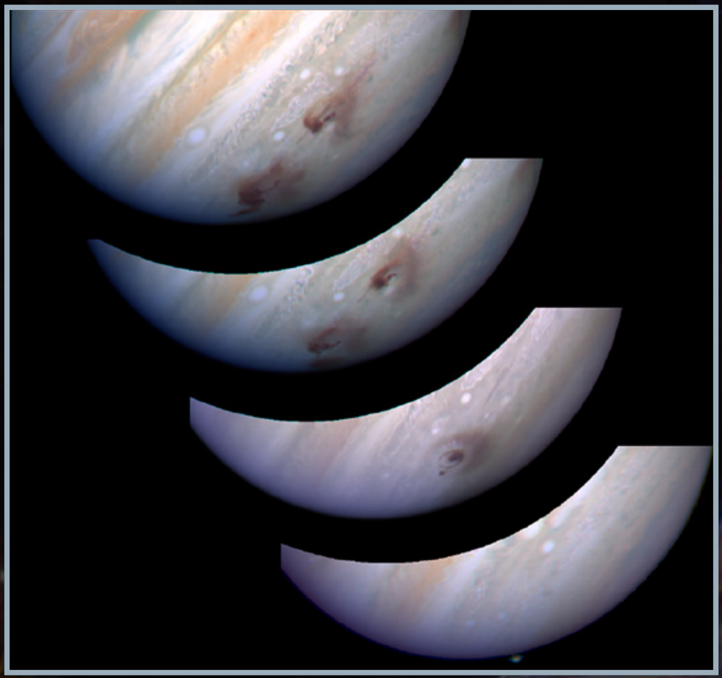
Studying the Outer Planets and Moons

Hubble has witnessed impacts on Jupiter that were produced by minor bodies in the solar system. The latest collision observed by *Hubble* occurred in 2009 when a suspected asteroid plunged into Jupiter's atmosphere, leaving a temporary dark feature the size of the Pacific Ocean. In 1994 *Hubble* watched 21 fragments of Comet Shoemaker-Levy 9 bombard the giant planet sequentially—the first time astronomers witnessed such an event. Each impact left a temporary black, sooty scar within Jupiter's clouds.

Jupiter is well known for its Great Red Spot, a giant storm roughly the size of Earth that has been continuously visible since at least the late 1800s. The mammoth storm has been shrinking in size for at least 80 years. Astronomers now use *Hubble* regularly to measure the Red Spot's size and investigate why it is slowly disappearing.

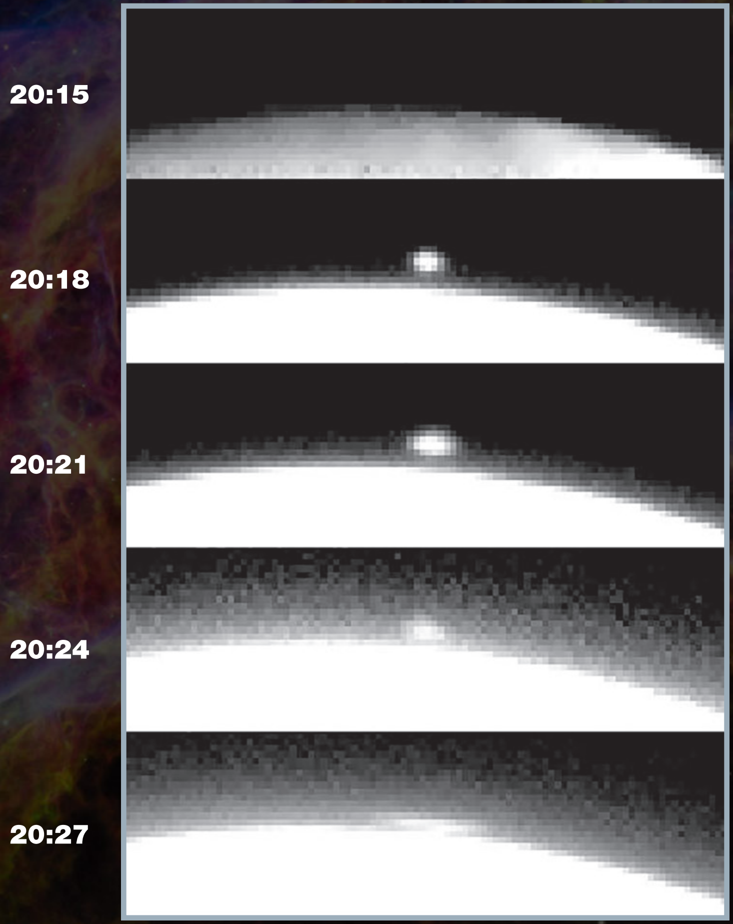
Hubble also made the first images of bright auroras at the northern and southern poles of Saturn and Jupiter. Auroras are brilliant curtains of light that appear in the upper atmosphere of a planet with a magnetic field. They develop when electrically charged particles trapped in the magnetic field spiral inward at high speeds toward the north and south magnetic poles. When these particles hit the upper atmosphere, they excite atoms and molecules there causing them to glow in a similar process to that of a fluorescent light.

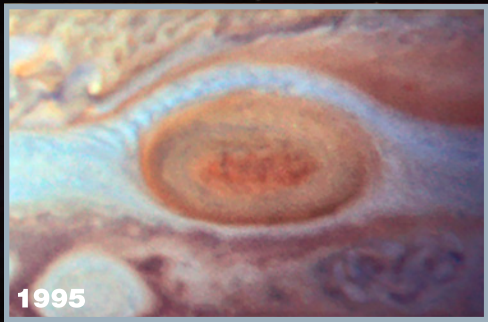
Jupiter's moons also have yielded important clues in the search for life beyond Earth. *Hubble* provided the best evidence yet for an underground saltwater ocean on Ganymede, the largest moon in the solar system, by detecting related activity in Ganymede's own auroras. This subterranean ocean is thought to have more water than all the water on Earth's surface. *Hubble* also recorded evidence of transient changes in the atmosphere above the surface of Jupiter's moon Europa. Astronomers suspect that these disturbances are caused by gas plumes expelled from a subsurface ocean. Identifying liquid water is crucial in the search for habitable worlds beyond Earth and in the quest to find life as we know it.

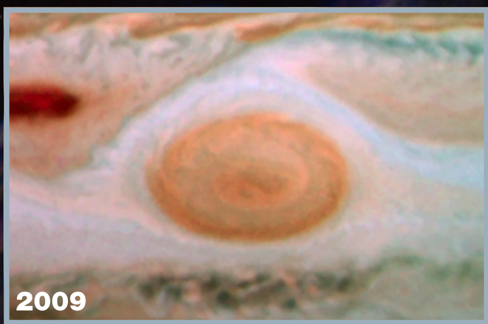


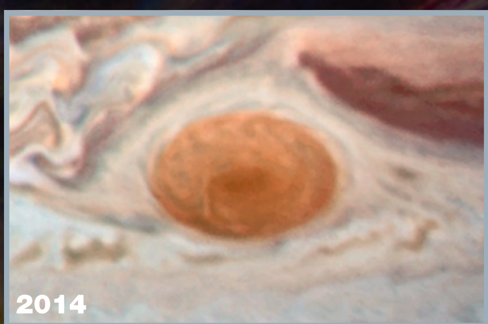
This image series, starting in the lower right corner, shows the darkening of Jupiter's clouds as a result of the impact of Comet Shoemaker-Levy 9.

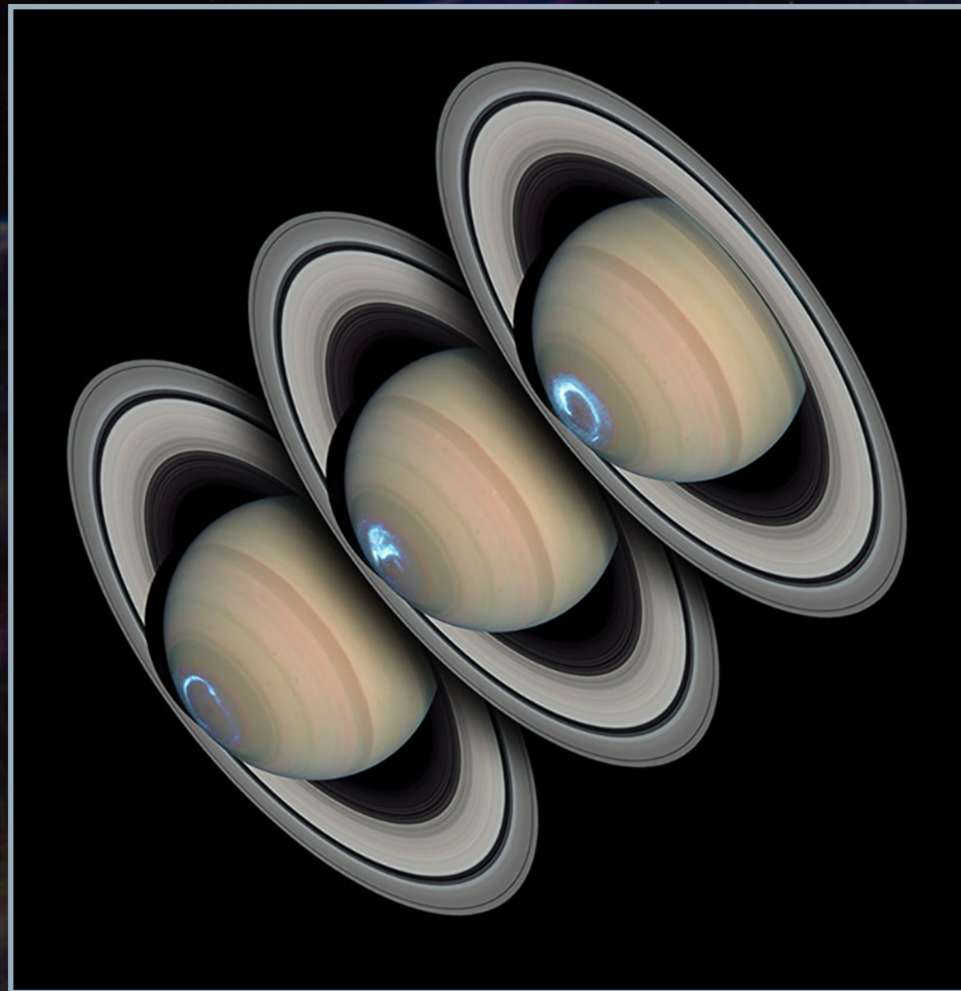
Hubble *captured a colossal plume rising above the limb of Jupiter from the impact of the first large fragment of Comet Shoemaker-Levy 9. (Times along the left side are in hour:minute format.)*

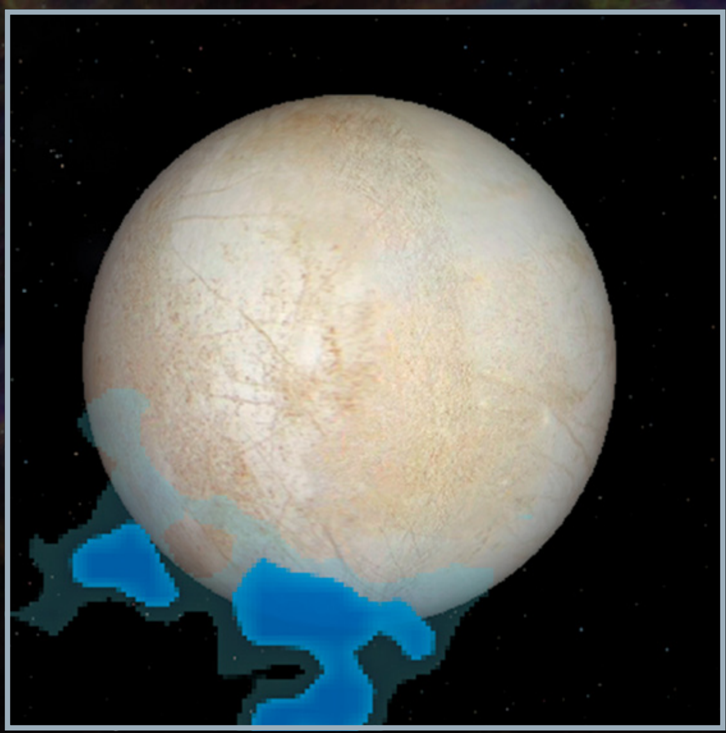


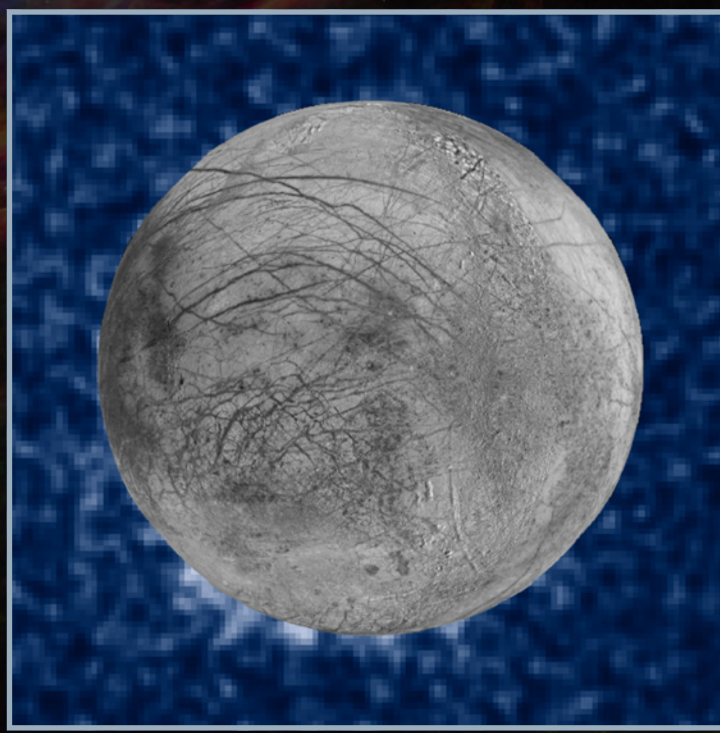










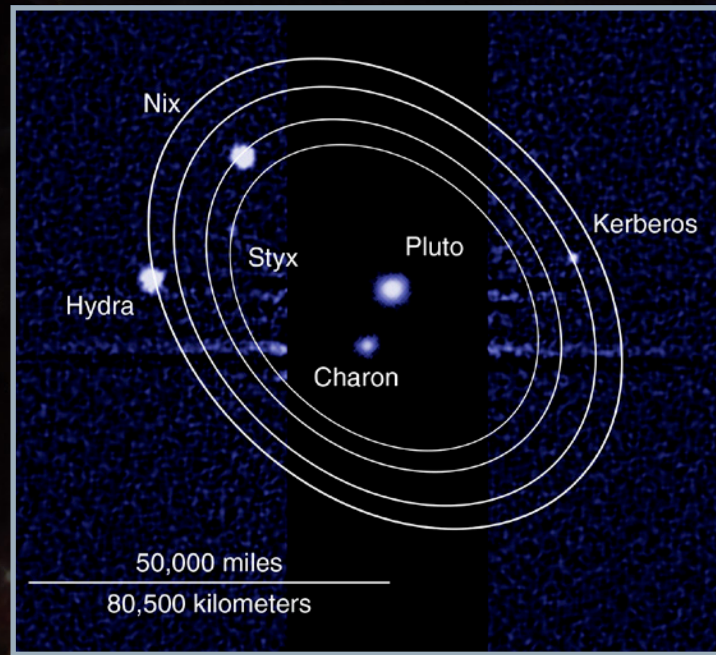


Top left: Jupiter's trademark Great Red Spot—a swirling, 300-mile-per-hour storm—has shrunk to its smallest size ever. Astronomers have followed this gradual downsizing since the 1930s and are now keenly monitoring its shrinkage and investigating its cause with Hubble. *Top right:* Hubble's *ability to capture ultraviolet light revealed a region of glowing auroras over the pole of Saturn. While sharing some features of Earth's auroras and others of Jupiter's, Saturn's auroras are different from both and are likely unique in the solar system. Below left: The blue areas mapped on Jupiter's moon Europa mark spots where* Hubble *found spectroscopic evidence of oxygen and hydrogen—the two elements that form the water molecule. Scientists believe this is most likely the result of water vapor plumes erupting from beneath the surface, with recent visual evidence of these plumes also seen by* Hubble *(below right). The pictures of Europa are a combination of shots gathered by NASA's* Voyager *and* Galileo *missions.*

Uncovering Icy Objects in the Kuiper Belt

While probing the dwarf planet Pluto on the outskirts of our solar system, *Hubble* spied four previously unknown moons orbiting the icy world. The tiny moons Nix and Hydra were the first to be spotted, followed by the even tinier Kerberos and Styx. Astronomers recently discovered that Nix and Hydra are rotating chaotically, that is, unpredictably, as they orbit the dwarf planet.

NASA's *New Horizons* spacecraft shot past Pluto in July 2015, making detailed observations of its surprisingly varied and intriguing surface. *Hubble* played a critical role in helping astronomers prepare for the flyby. With frequent observations of Pluto from the early 1990s to 2010, scientists refined maps of the planet's surface. *New Horizons* personnel used these maps to prepare for the spacecraft's brief but important rendezvous with Pluto and its moons.

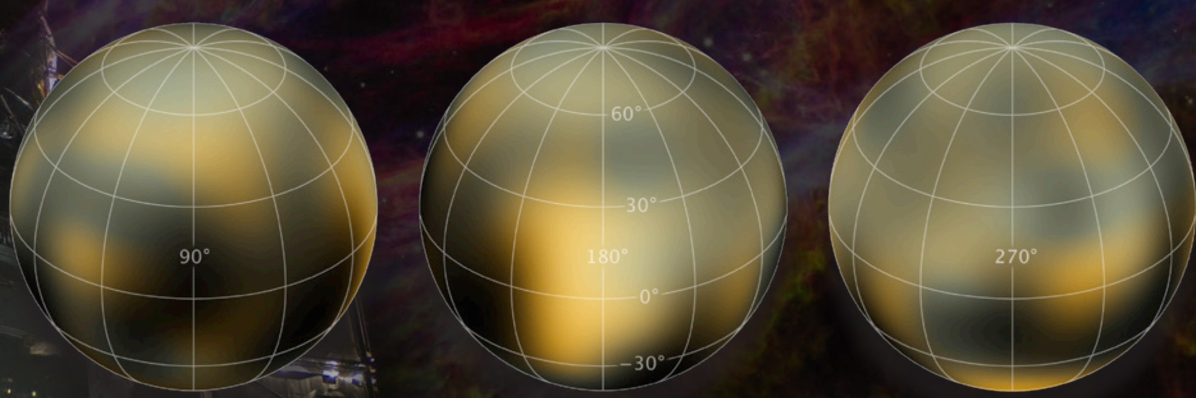


This graphic combines images taken by Hubble *in July 2012. A long exposure (blue areas) captures the tiny moons, while a shorter exposure (vertical black band) shows Pluto and Charon more clearly. (Objects not to scale.)*

Peering out even farther, to the dim outer reaches of our solar system, *Hubble* uncovered two Kuiper belt objects that the *New Horizons* spacecraft could potentially target on its continual outward journey. The *New Horizons* mission chose to focus on a *Hubble* candidate called 2014 MU_{69}. On January 1, 2019, *New Horizons* flew past the object — now named Arrokoth — capturing up-close imagery that revealed its double-lobed structure in fine detail, complete with fractures and pitting.

Hubble also discovered a 100-mile-wide moon in orbit around Makemake, the second brightest icy dwarf planet in the Kuiper belt. At 4.8 billion miles from the Sun, Makemake was discovered in 2005 using the Palomar Observatory and is approximately 870 miles across. Oddly, the moon, nicknamed MK 2, is as dark as charcoal while Makemake is as bright as fresh snow.

Right: Only about 100 miles in diameter, the tiny dot above the dwarf planet Makemake seen in this Hubble *image is its orbiting moon, nicknamed MK 2.*

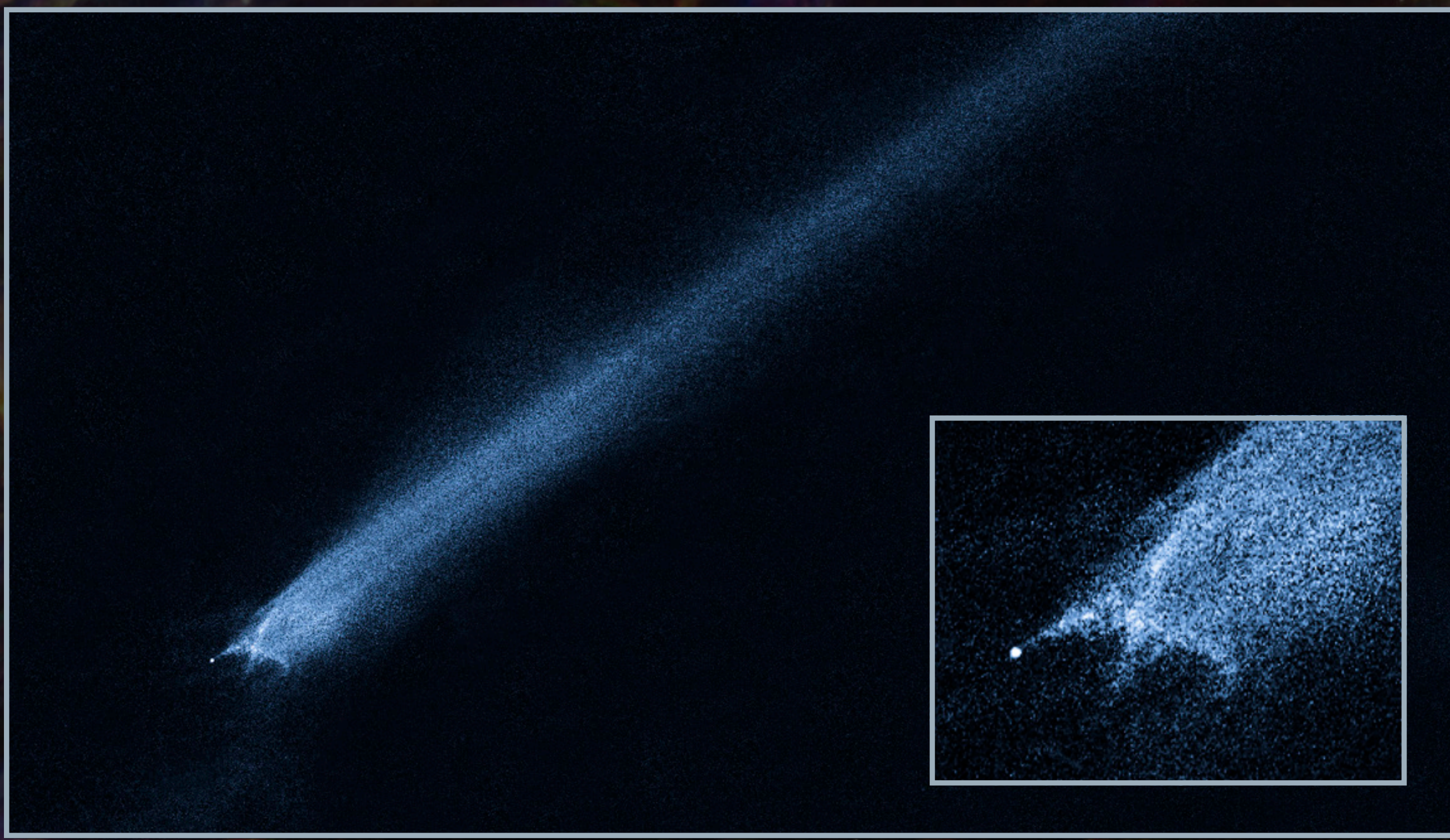


Hubble*'s view of Pluto provided NASA's* New Horizons *mission with the best available information for planning its rendezvous with the dwarf planet.*

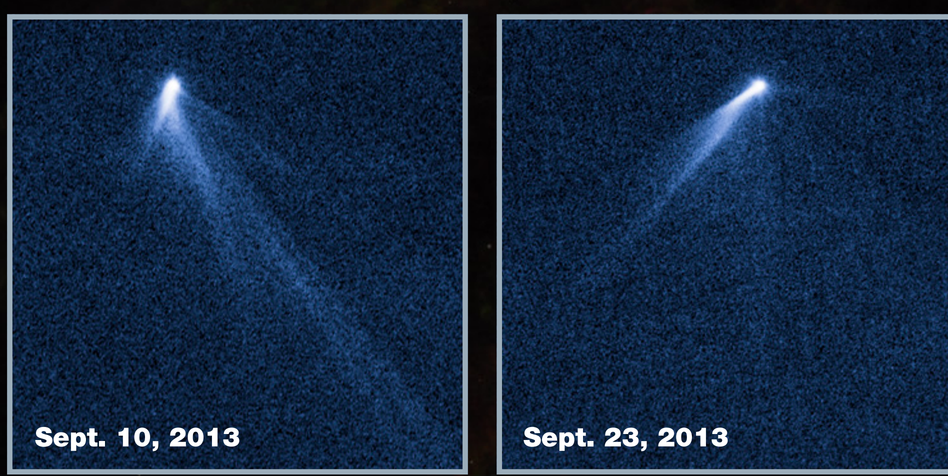
Tracking Evolution in the Asteroid Belt

Asteroids do not just slam into planets like Jupiter or Earth, they also collide with each other. Astronomers using *Hubble* witnessed one such impact in the asteroid belt between Mars and Jupiter, a reservoir of leftover rubble from the construction of our solar system. The *Hubble* observations showed a bizarre X-shaped pattern of filamentary structures near the point-like core of an object with trailing streamers of dust. This complex structure suggested the small body was the product of a head-on collision between two asteroids traveling five times faster than a rifle bullet. Astronomers have long thought that the asteroid belt is being eroded through collisions, but a crash had never been seen before.

Another *Hubble* observation of the asteroid belt revealed a unique object: an asteroid with six comet-like tails of dust radiating from it like spokes on a wheel. Astronomers were surprised by the asteroid's unusual appearance. Unlike all other known asteroids, which appear simply as tiny points of light, this asteroid resembles a rotating lawn sprinkler. Computer models of the object suggest that the tails could have been formed by a series of dust-ejection events.



An odd, X-shaped debris field trailing dusty streamers is believed to be the remnants of an asteroid collision. Scientists think that a small, fast-moving asteroid blasted into a larger and slower-moving one.



Images of asteroid P/2013 P5 revealed it to be like none other, with multiple dust trails radiating in various directions and changing in appearance with time.

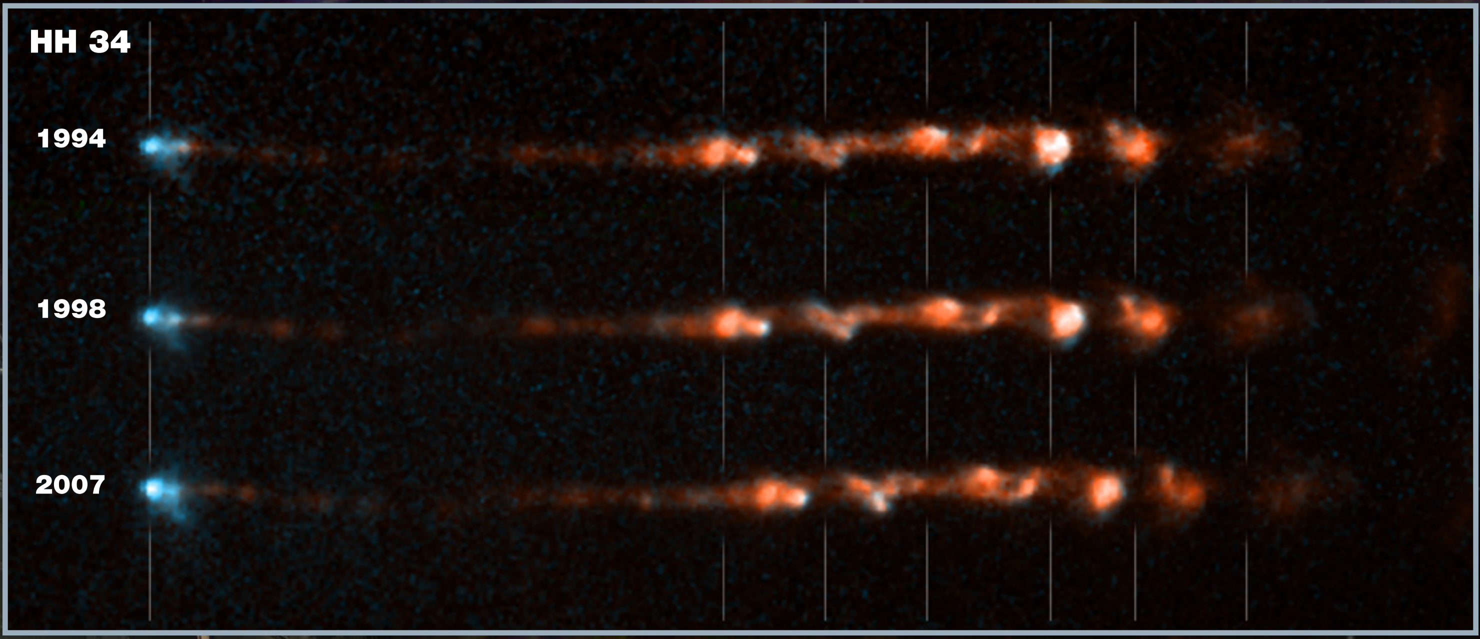
Exploring the Birth of Stars

Hubble's infrared detectors have penetrated gigantic, turbulent clouds of gas and dust where tens of thousands of stars are bursting to life. *Hubble* views of these nebulas reveal a bizarre landscape sculpted by radiation from young, exceptionally bright stars. The observations show that star birth is a violent process, producing intense ultraviolet radiation and shock fronts. The radiation clears out cavities in stellar nursery clouds and erodes material from giant gas pillars that are incubators for fledgling stars.

Hubble has also captured energetic jets of glowing gas from young stars in unprecedented detail. These jets are a byproduct of gas swirling into newly forming stars, some of which gets channeled by magnetic fields and shot from the poles of the spinning stars at supersonic speeds in opposing directions. Because of *Hubble*'s long operational lifetime, astronomers have seen motion and changes in the shapes of these jets over time. Measuring and studying these changes are invaluable in trying to untangle the complicated physical processes that form them and to better understand the environment around newborn stars.

The glowing, clumpy streams of material shown moving left and right in this Hubble *image are the signposts of star birth. Collectively named Herbig-Haro 47, the speedy outflows have been ejected episodically, like salvos from a cannon, from a young star in the center of the image that is hidden by dust. As they move through space, these outflows create bow shocks and ripples as they collide into other clouds of material in the neighborhood of the star.*

This series of observations by Hubble *documents changes in a powerful jet called Herbig-Haro 34 (HH 34) located in the Orion Nebula.*



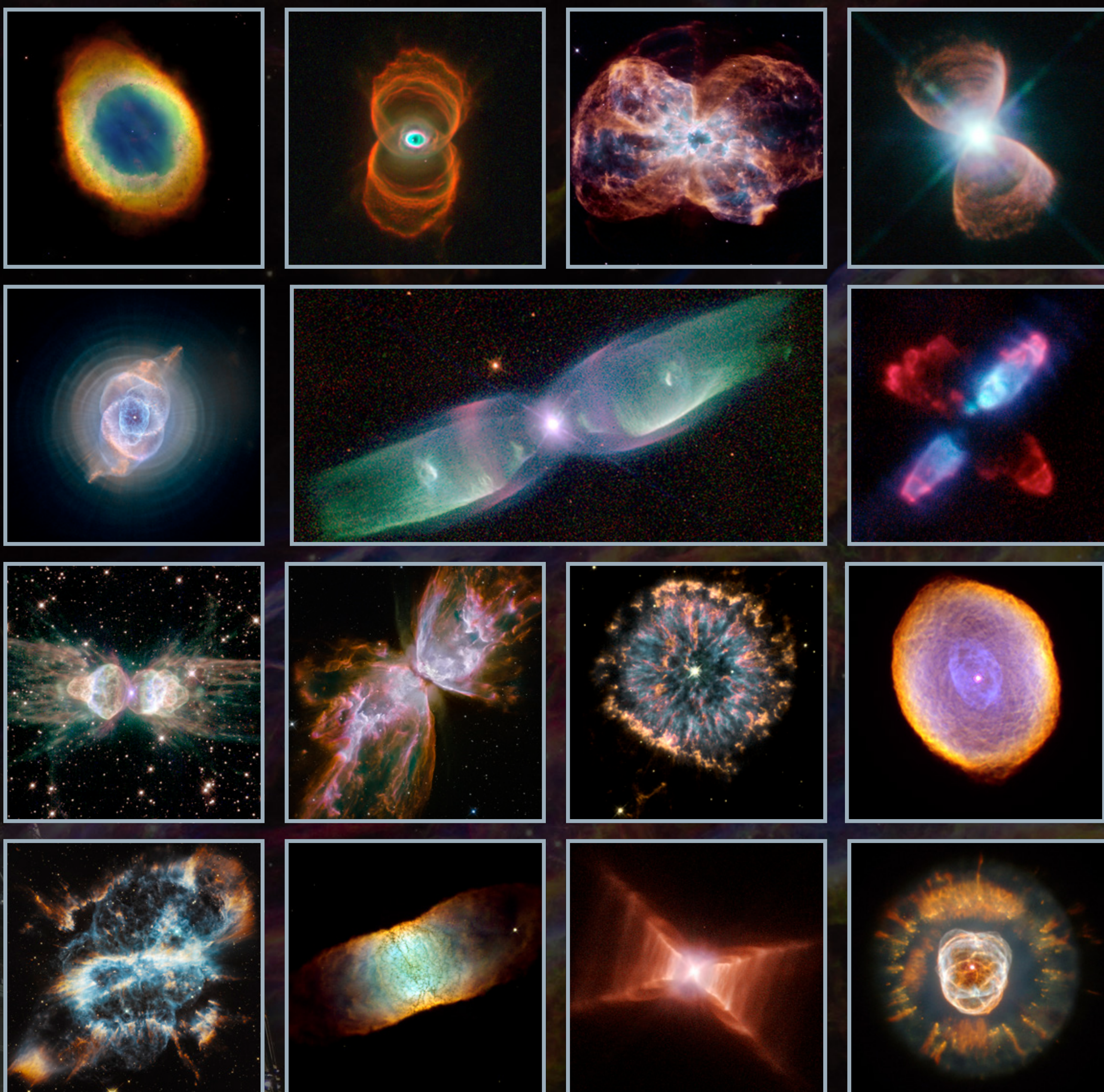
Dubbed "Mystic Mountain," this section of the much more extensive Carina Nebula features jets expelled from stars forming within immense, dusty pillars of gas.

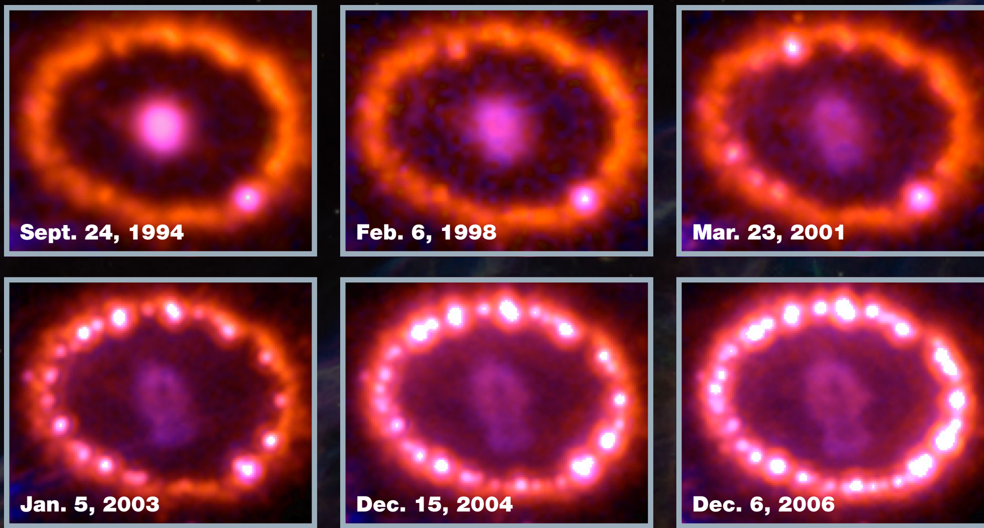
Documenting the Death Throes of Stars

Hubble has revealed unprecedented details in the appearance of Sun-like stars that have entered the death throes of their lives. Ground-based images suggested that many of these objects, called planetary nebulas (though they are unrelated to planets), have simple spherical shapes. *Hubble* has shown, however, that their shapes are much more varied and complex. Some look like pinwheels, others like butterflies, and still others like hourglasses. Such images yield insights into the complex dynamics that accompany a star's release of its outer gaseous layers before it collapses to form a white dwarf.

Turning its sights to the tattered remains of a more massive star's explosive death, *Hubble* observations of Supernova 1987A revealed three mysterious rings of material encircling the doomed star. The telescope also spied bright spots on the middle ring's inner region caused by an expanding wave of matter slamming into it from the explosion. Likewise, *Hubble*'s view of M1, the Crab Nebula, showed details never before seen about this mighty blast and the rapidly spinning pulsar that remains at its core.

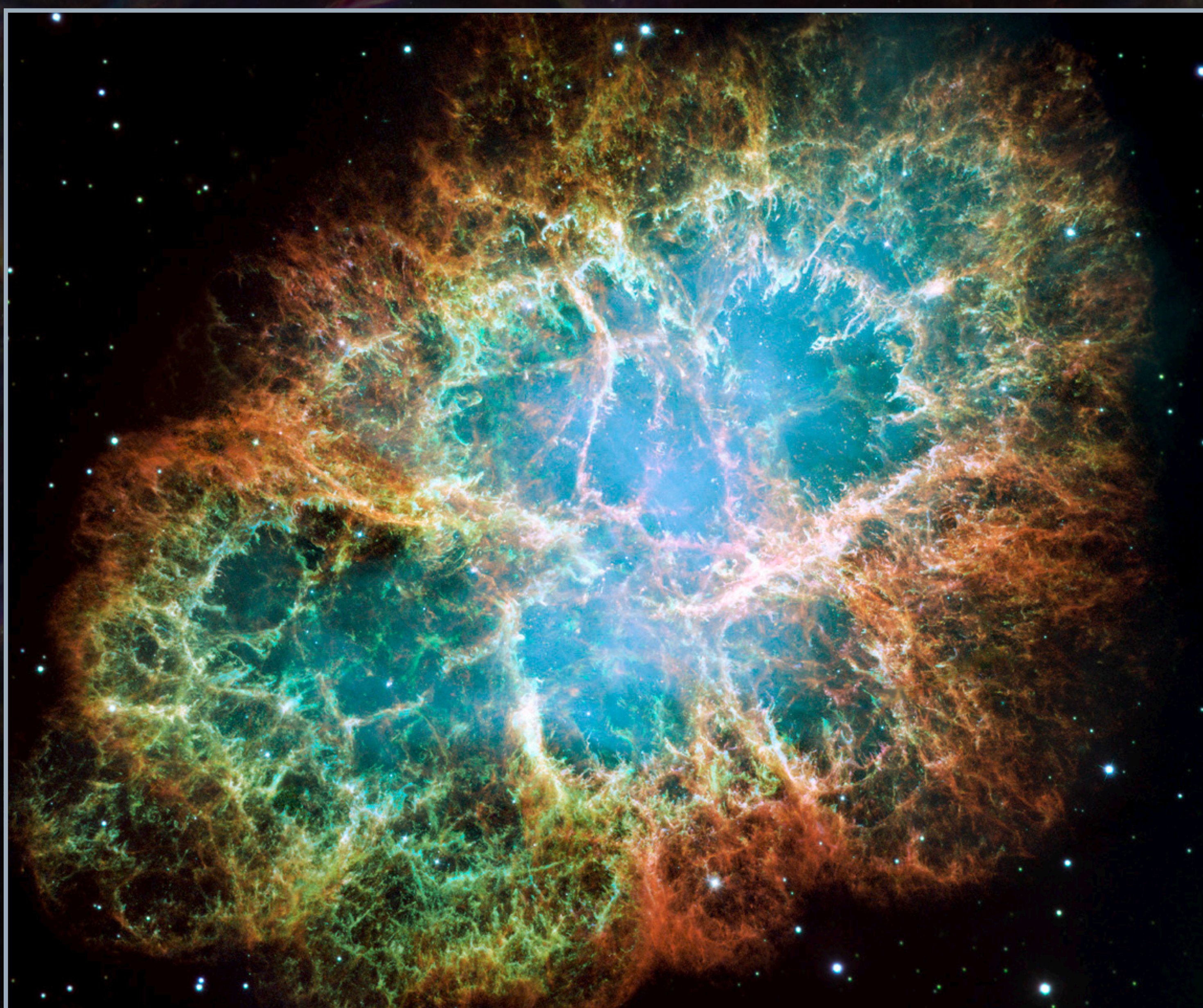
Hubble *has revealed the astounding variety and amazing complexity of planetary nebulas.*





A shock wave of material from the central, exploded star of SN 1987A is slamming into an existing ring of material around the doomed star. As it does, various spots in the ring are heated and begin to glow. The nature of the strangely shaped pink feature in the center of the ring is not well understood.

Supernova 1987A as seen by Hubble *in 1994.*



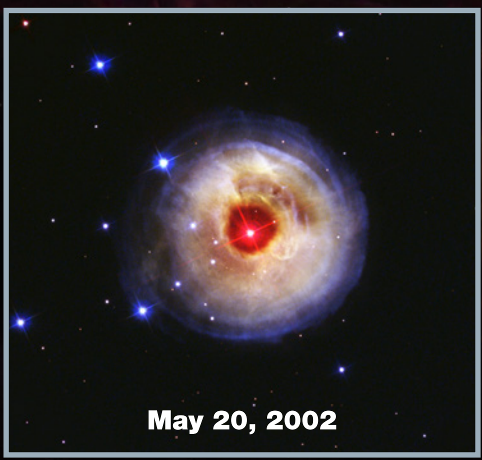
M1, the Crab Nebula, is the remnant of a stellar explosion that was seen in Earth's skies in the year 1054 AD. The colors in the image were assigned to distinguish various chemical elements, which are now all racing into space to enrich new generations of stars.

Seeing Light Echoes

Hubble has captured the best sequence of images of the reverberation of light through space caused by the outburst of a star. In January 2002, an unexplained flash of light from a red supergiant star left what looked like an expanding bubble of debris. In fact, the light was simply illuminating clouds that were already in place around the star. Since light travels at a finite speed, the flash took years to reach the most distant clouds and expose them. This phenomenon is called a “light echo,” as it is reminiscent of sound waves echoing down a canyon and “revealing” its walls.

The red star at the center is an unusual, erupting supergiant called V838 Monocerotis, located approximately 20,000 light-years away. During its outburst, the star’s intrinsic brightness flared to about 600,000 times that of our Sun. The burst may have been triggered by the star swallowing a companion star or planet. The dark gaps around the red star are regions where there are voids in the dust—like empty pockets within Swiss cheese. Light echoes are commonly seen around supernovas, but V838 Mon did not detonate itself; the flash seems to be a unique and little-understood transient phenomenon.

A mysterious flash from the red giant star V838 Mon illuminated the surrounding area in a light echo.



May 20, 2002

September 2, 2002

October 24, 2004

October 28, 2002

December 17, 2002

February 8, 2004

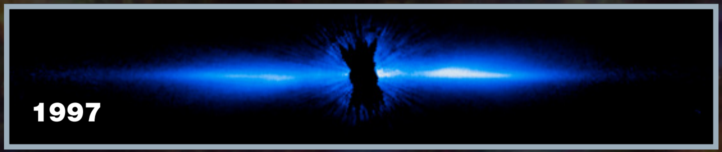
Finding Planetary Construction Zones

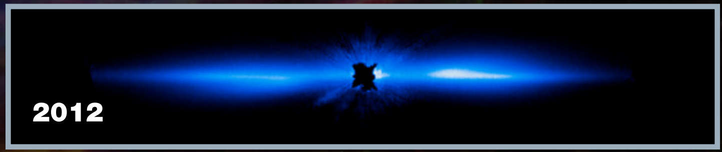
Astronomers used *Hubble* to confirm that planets form in dust disks around stars. The telescope first resolved protoplanetary disks around nearly 200 stars in the bright Orion Nebula. Looking at nearby stars elsewhere in the sky, *Hubble* completed the largest and most sensitive visible-light imaging survey of dusty debris disks, which were probably created by collisions between leftover objects from planet formation.

Two particular stars illustrate these findings: TW Hydrae and Beta Pictoris. Using a mask to block the star's bright light, *Hubble* scientists spotted a mysterious gap in a vast protoplanetary disk of gas and dust swirling around the star TW Hydrae. The gap is most likely caused by a growing, unseen planet that is gravitationally sweeping up material and carving out a lane in the disk like a snowplow. It is 1.9 billion miles wide and not yet completely cleared of material. Researchers have also noted changes in the planetary disk surrounding Beta Pictoris. By masking out the star's light, scientists have studied changes in the orbiting material caused by a massive planet embedded within its dust disk. Astronomers spotted the planet using the European Southern Observatory.

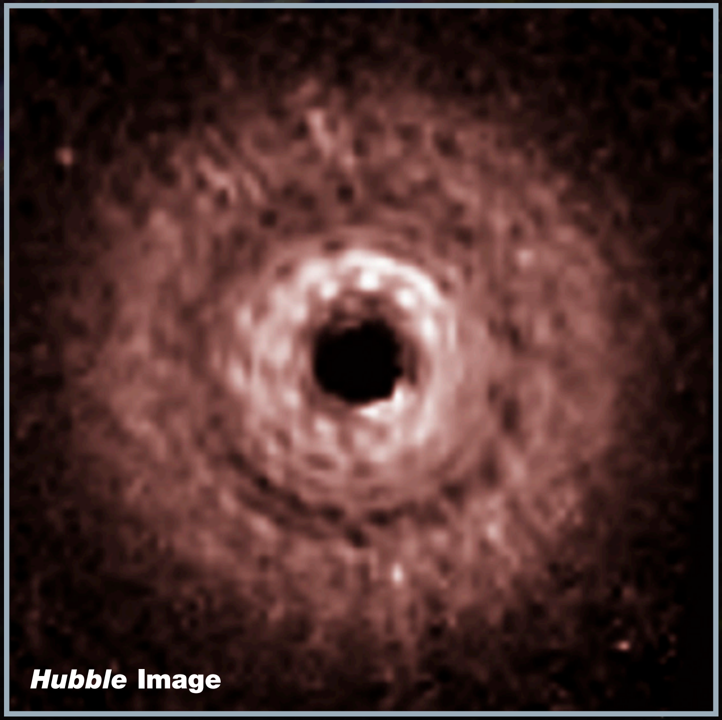
Here are a few of the many protoplanetary disks that were discovered by Hubble *in the large, majestic Orion Nebula. The disks appear as silhouettes, illuminated from behind by the glowing gases of the nebula.*

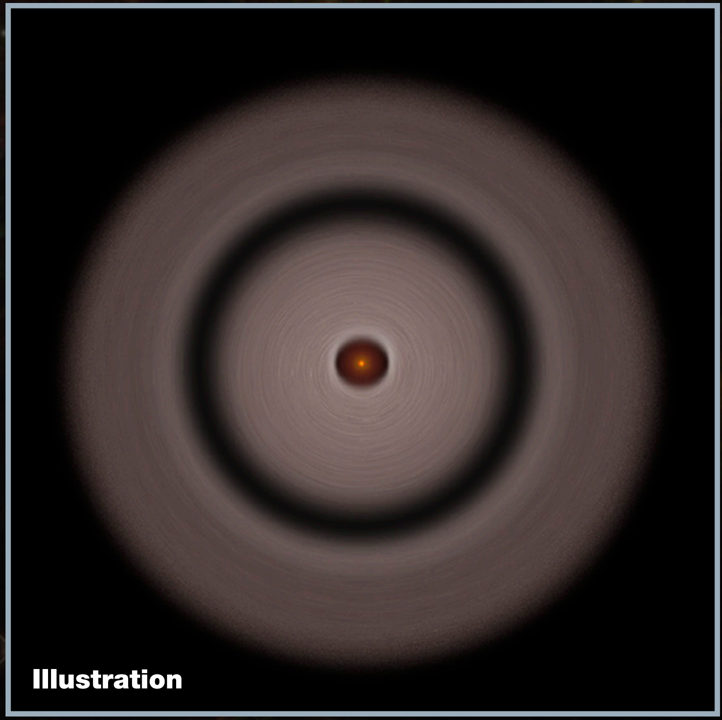
Below left and right: Hubble *has provided detailed pictures showing changes in the large, edge-on, gas-and-dust disk encircling the 20-million-year-old star Beta Pictoris.*





This Hubble *image and illustration show a gap in a protoplanetary disk of dust and gas around the nearby star TW Hydrae. The gap's presence is probably due to the effects of a growing, unseen planet that is gravitationally sweeping up material and carving out a lane in the disk. Astronomers used a masking device within the* Hubble *camera to block out the star's bright light so that the disk's structure could be seen.*



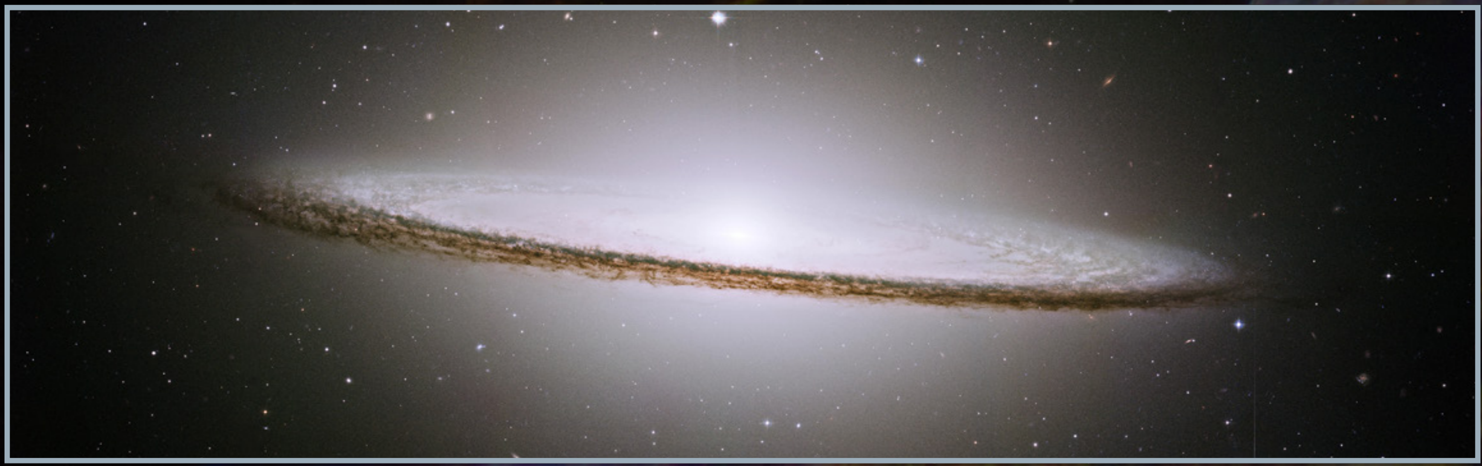


Viewing Galactic Details and Mergers

When Edwin Hubble discovered that the universe was a vast frontier of innumerable galaxies beyond our Milky Way, he categorized them according to three basic shapes: spiral, elliptical, and irregular. Later, the sharp vision of the space telescope named in his honor revealed unprecedented details in such galaxies. In addition, *Hubble*'s images uncovered a plethora of oddball, peculiarly shaped galaxies that are more numerous the farther back into time the telescope looks. This is because the expanding universe was smaller long ago, and galaxies were both younger and more likely to interact since they were closer to one another.

Among this zoo of odd galaxies are "tadpole-like" objects and apparently merging systems dubbed "train-wrecks." For all their violence, galactic collisions take place at a glacial rate by human standards—timescales on the order of several hundred million years. *Hubble*'s images, therefore, capture snapshots of galaxies at various stages of interaction. The merging of galaxies produces turbulence and tides that can induce new vigorous bursts of star formation within their interstellar gas clouds. These observed mergers form a preview of the coming collision between our own Milky Way and the neighboring Andromeda galaxy 4 billion years from now.

Top: Looking like a broad-brimmed Mexican hat, the "Sombrero" galaxy, M104, is a spiral galaxy seen nearly edge-on. Bottom left: Astronomers classify galaxy NGC 1300 as a barred spiral because its arms do not swirl into the center but instead are connected to ends of a straight bar of stars that contains the nucleus. Bottom right: Long streamers of stars and gas appear as tails in this Hubble *image of the gravitationally interacting galaxies NGC 4676, nicknamed "The Mice."*



The "Antennae Galaxies," NGC 4038 and 4039, are spiral galaxies in the process of merging. The bright knots in the bluish areas are massive pockets of young star clusters, whose formation was sparked by the turbulent interaction of the galaxies.

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