National Aeronautics and Space Administration

HUBBLE SPACE TELESCOPE

Reshaping Our Cosmic View

Hubble Science Highlights

HUBBLE SPACE TELESCOPE

Introduction

Since its launch in 1990, NASA's **Hubble Space Telescope** has offered us stunning images that capture the overwhelming beauty of the universe, but Hubble is far more than pretty pictures. In its three-plus decades of exploration, Hubble has generated as many questions as it has answered — uncovering new mysteries while expanding our understanding of the universe in ways we never imagined.

Hubble's scientific instruments gather wavelengths of light from ultraviolet, through visible, and into the near-infrared part of the electromagnetic spectrum. Its sensitivity to such a broad range of wavelengths makes it one of the most valuable and productive observatories in the history of astronomy. Hubble exceeds 1.5 million observations, from which astronomers have written more than 20,000 peer-reviewed scientific papers. Publications cited those papers more than one million times — a number that increased over the lifetime of the mission by an average exceeding 100 per day.

Hubble's extensive archive of observations also allows astronomers to study astronomical objects that display subtle changes over time, which help shape our understanding of the very nature and evolution of the universe. Every modern astronomy textbook includes contributions from Hubble.

The stories you find here represent a small sample of Hubble's thought-provoking discoveries and images. Selecting this set from thousands of awe-inspiring observations was difficult, but they serve to highlight some of Hubble's greatest scientific achievements to date.

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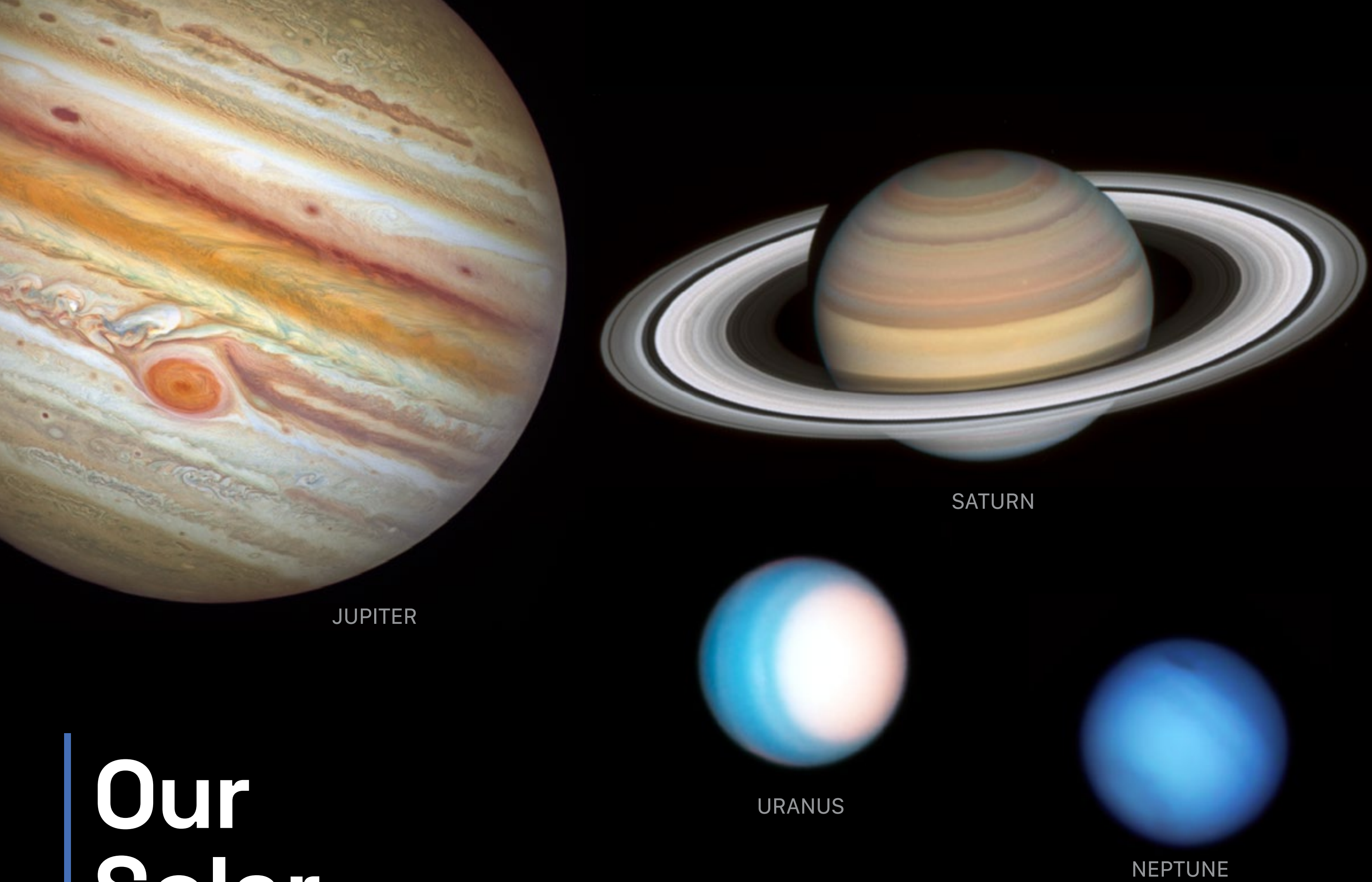


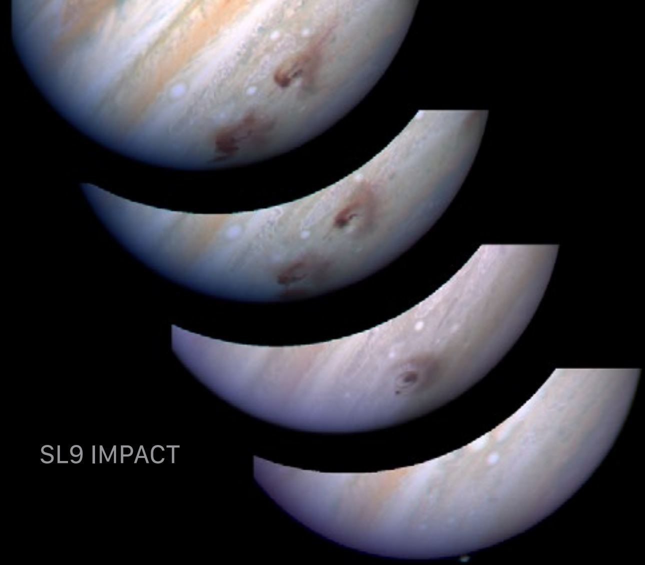
Our Solar System

Studying the Planets and Their Moons

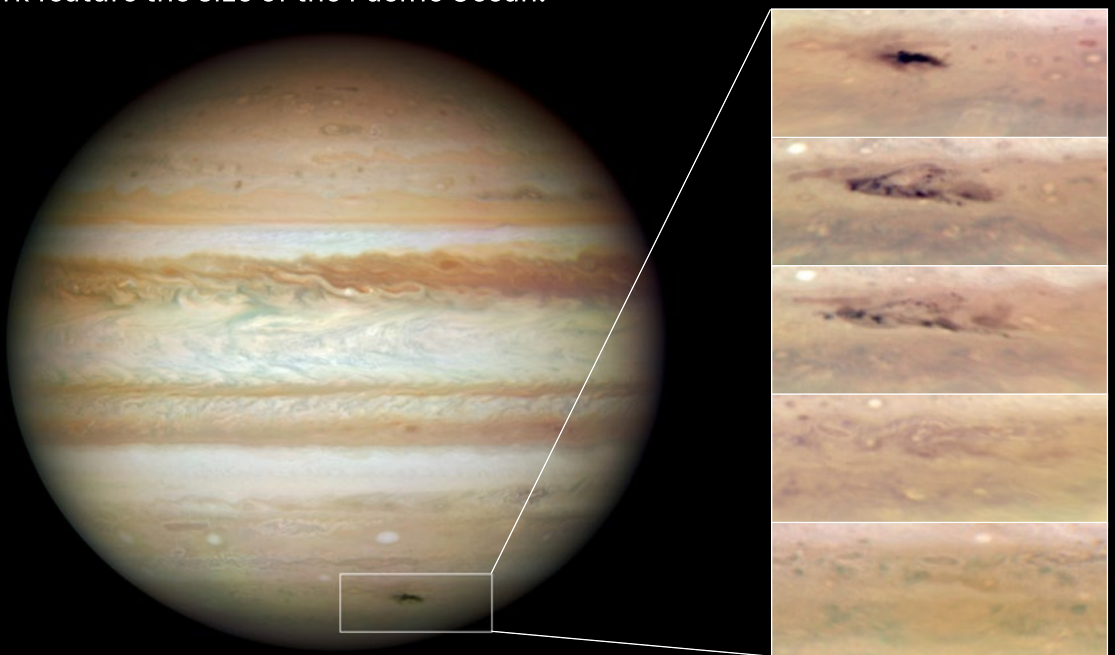
Hubble's long presence in space and regular observations of the planets — Jupiter, Saturn, Uranus, Neptune, and Mars — give planetary astronomers the opportunity to study their ever-changing atmospheres and curious moons, charting the changes of these dynamic systems.

Impacts on Jupiter

In 1994, just four years into its long tenure of collecting data, Hubble watched as 21 fragments of Comet Shoemaker-Levy 9 (SL9) bombarded the giant planet Jupiter with a sequential train of impacts. Each fragment left a temporary black scar that revealed deeper layers of the planet's atmosphere. It was the first time astronomers witnessed such an event. Hubble observed another impact in 2009, when a suspected asteroid plunged into Jupiter's atmosphere and left a temporary dark feature the size of the Pacific Ocean.



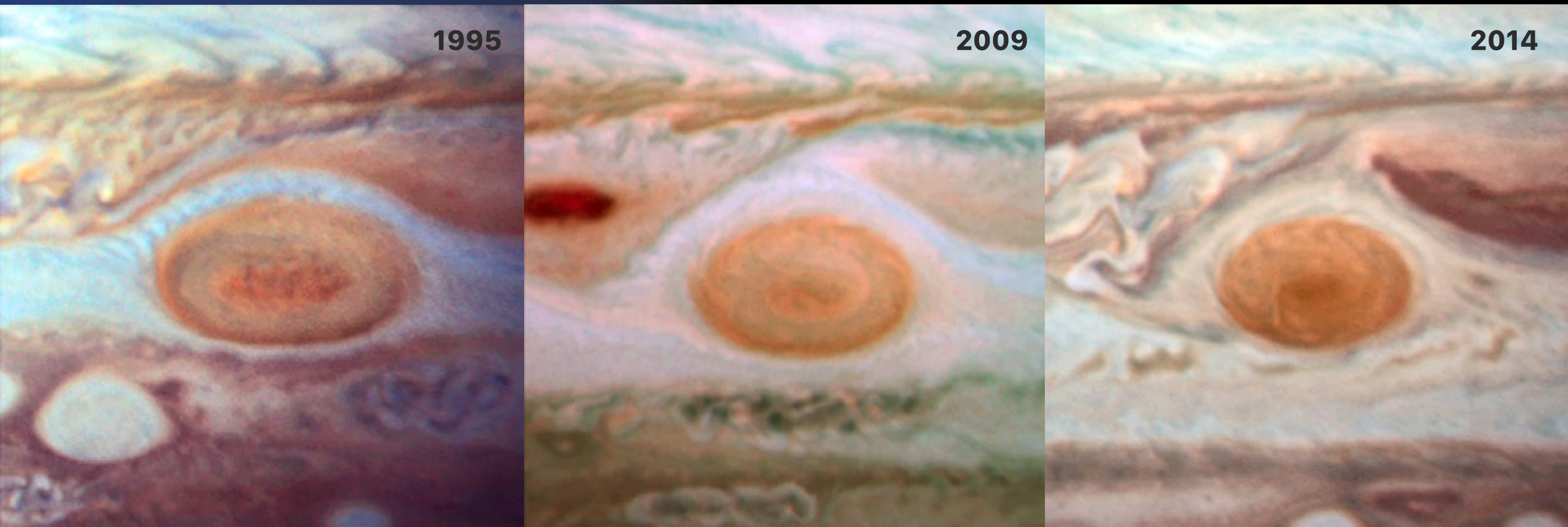
SL9 IMPACT



ASTEROID IMPACT

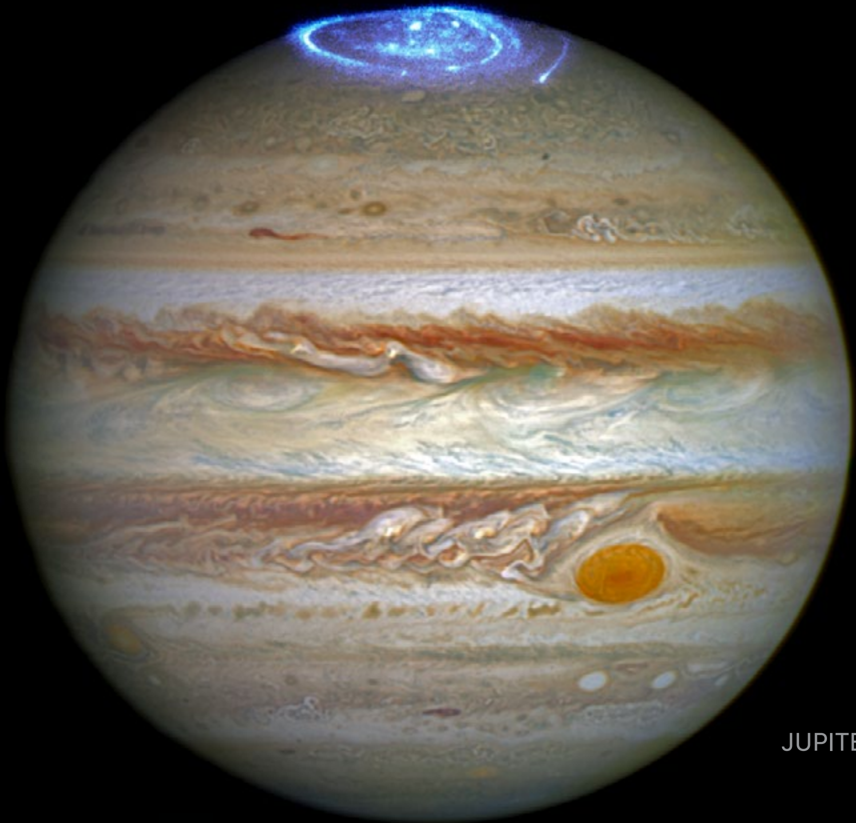
Monitoring Jupiter's Shrinking Red Spot

Using Hubble, astronomers regularly track Jupiter's Great Red Spot, a giant swirling storm slightly larger than Earth. They found that the spot is shrinking and jiggling. Its outer winds are speeding up while moving significantly more slowly toward its center.



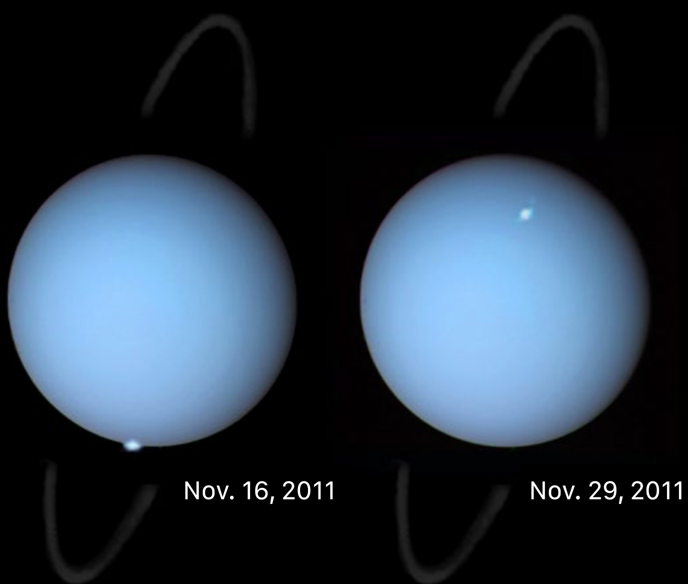
Studying Auroras

Hubble captured brilliant curtains of light, called auroras, on Jupiter, Saturn, and Uranus. Auroras develop when electrically charged particles trapped in a planet's 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 neon light.



JUPITER

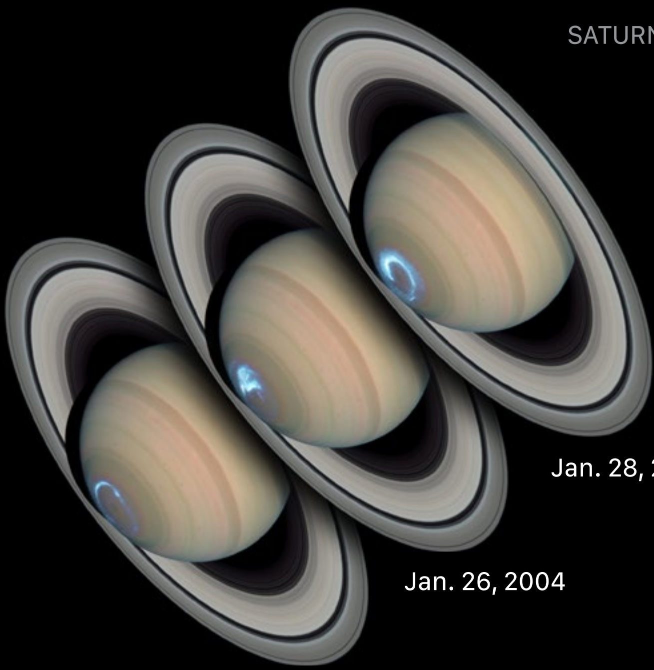
URANUS



Nov. 16, 2011

Nov. 29, 2011

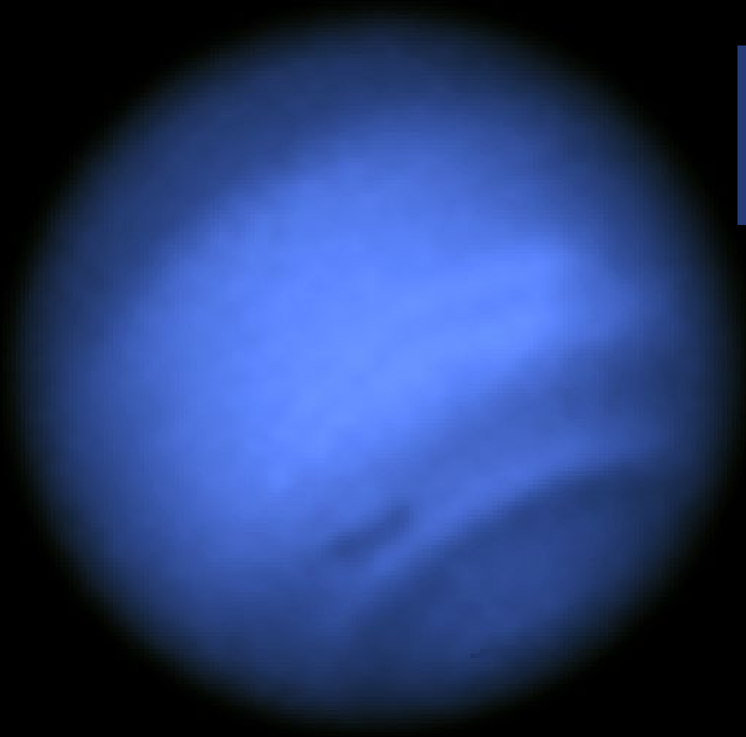
SATURN



Jan. 28, 2004

Jan. 26, 2004

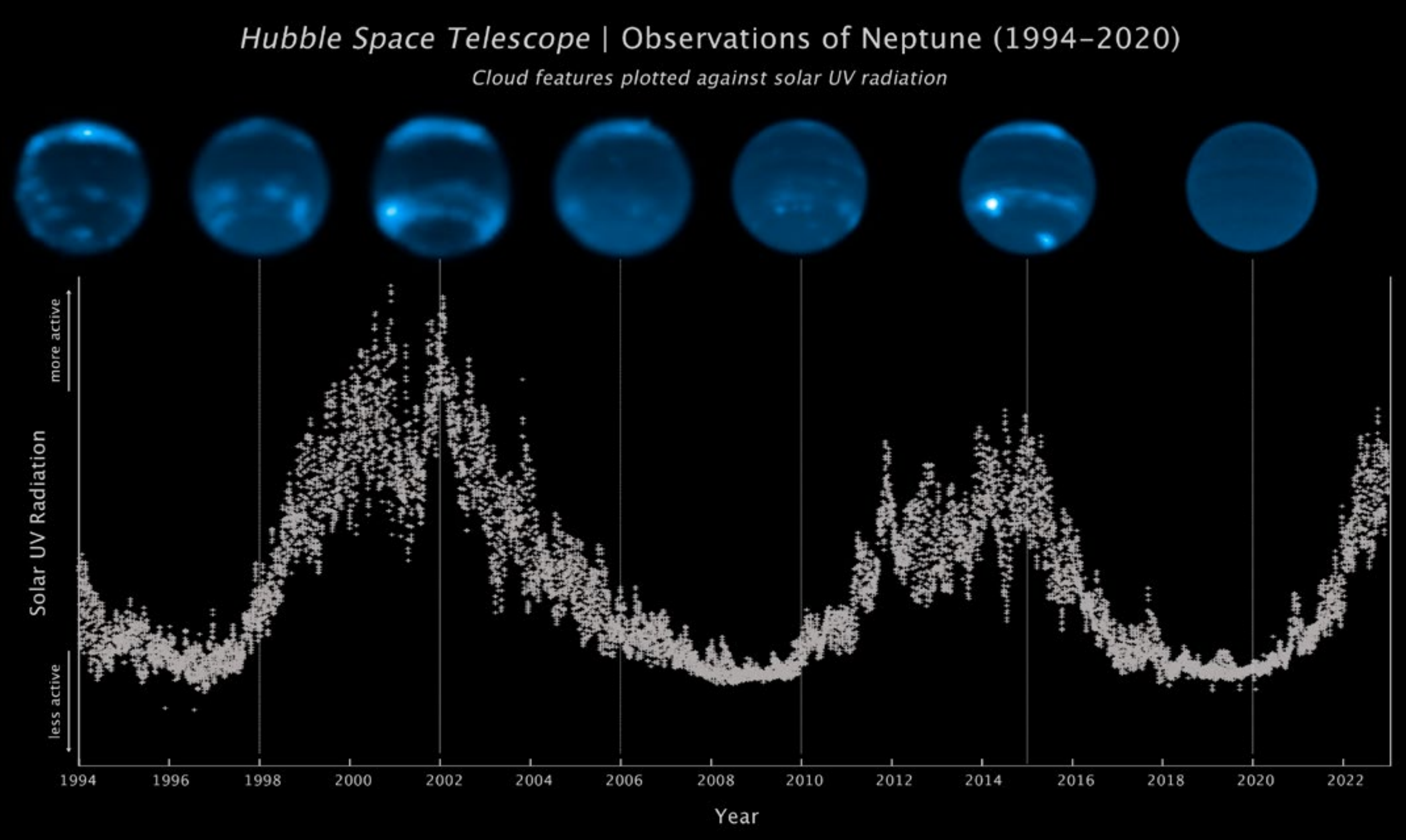
Jan. 24, 2004



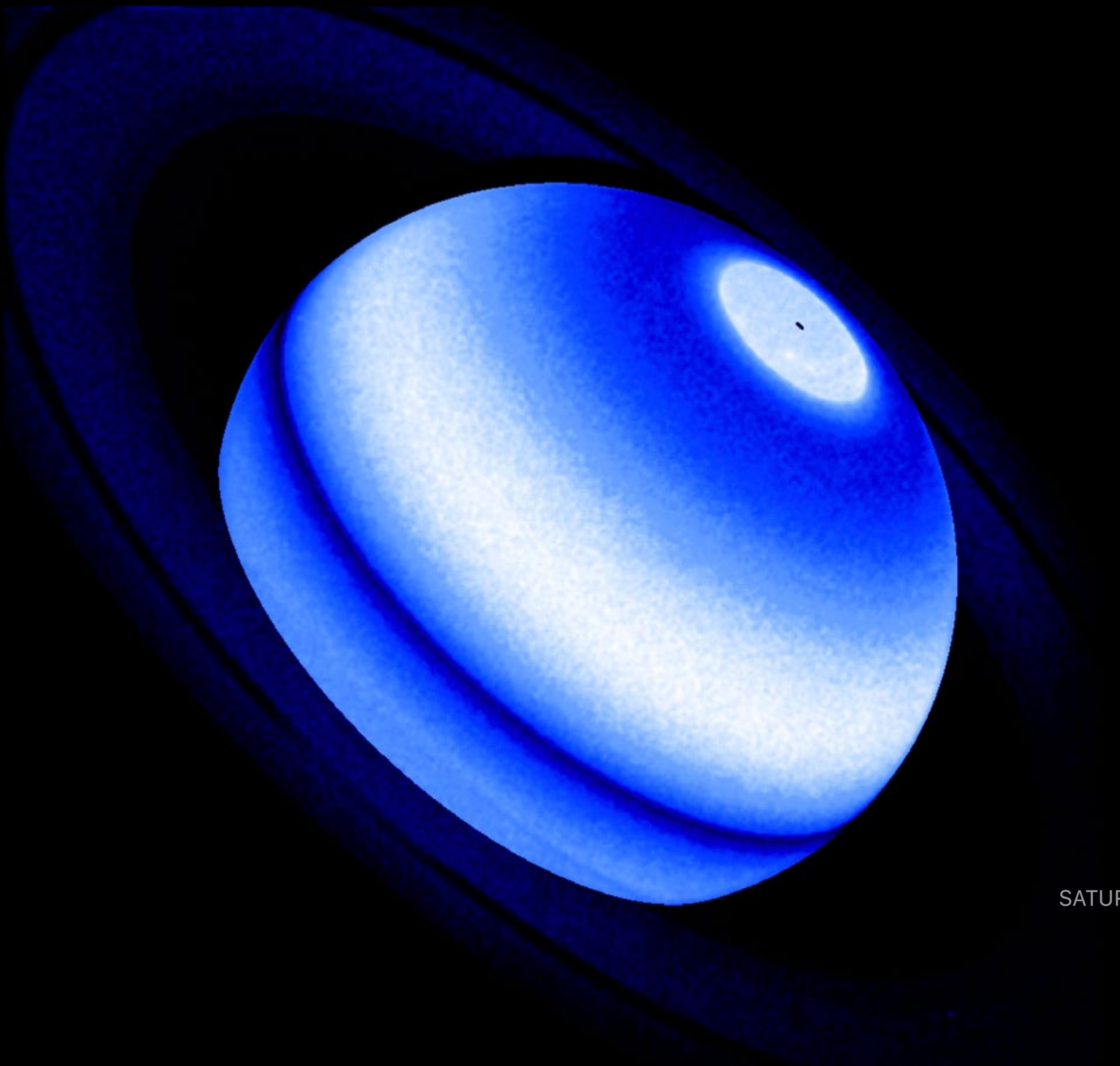
NEPTUNE

Discovering a Link Between Neptune's Clouds and the Sun

Hubble expanded upon NASA's Voyager 2 observations of Neptune and Uranus. It found that Neptune's southern hemisphere 'Great Dark Spot' vanished in 1994, then spotted another dark storm in Neptune's northern hemisphere a year later. Hubble's decades of observations revealed that Neptune's storms last for a few years before vanishing or fading away and that this cycle correlates to the Sun's cycle of activity.



Saturn's Rings Heating Its Atmosphere



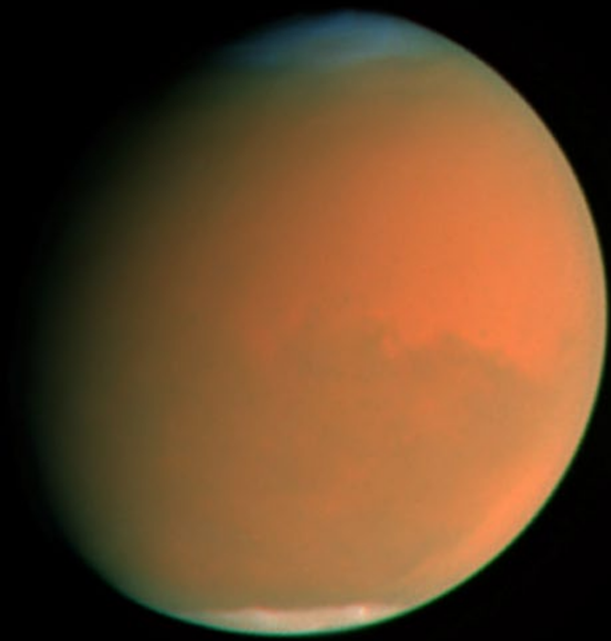
SATURN

Hubble also helped astronomers calibrate archival Saturn data from four separate missions. The precision of Hubble's Space Telescope Imaging Spectrograph (STIS) and its ability to see ultraviolet light allowed researchers to compare STIS UV observations of Saturn to 40 years of UV data from the Voyager and Cassini missions, and the International Ultraviolet Explorer. They discovered that icy ring particles raining on Saturn's atmosphere at specific latitudes and seasonal effects cause atmospheric heating. Researchers are testing to see if this unexpected interaction can help define new ways of examining distant exoplanets for extended Saturn-like ring systems.

Hubble Studies the Dynamic Martian Atmosphere

June 26, 2001

A Partly Cloudy Day on Mars

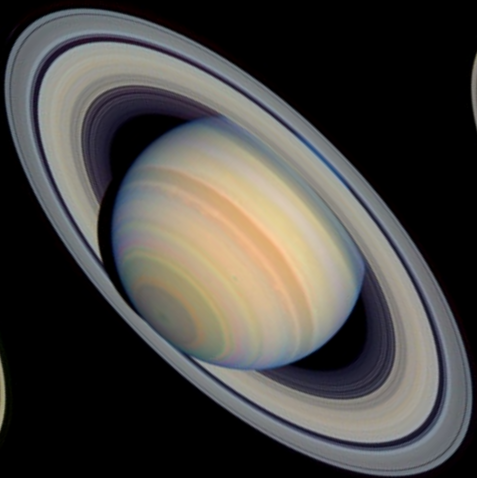


September 4, 2001

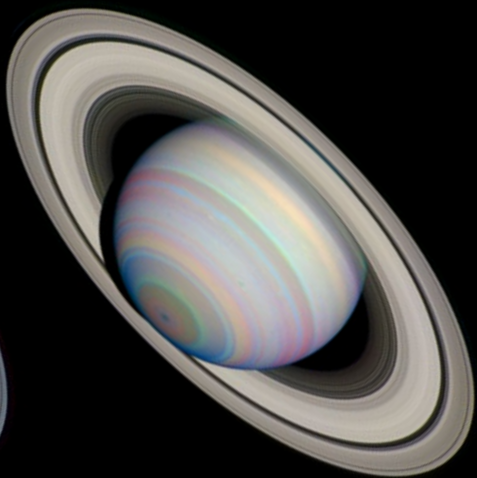
Mars Enshrouded in a Sandstorm

Three Views of Saturn on March 7, 2003

ULTRAVIOLET



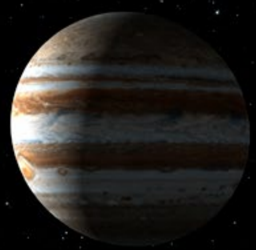
VISIBLE



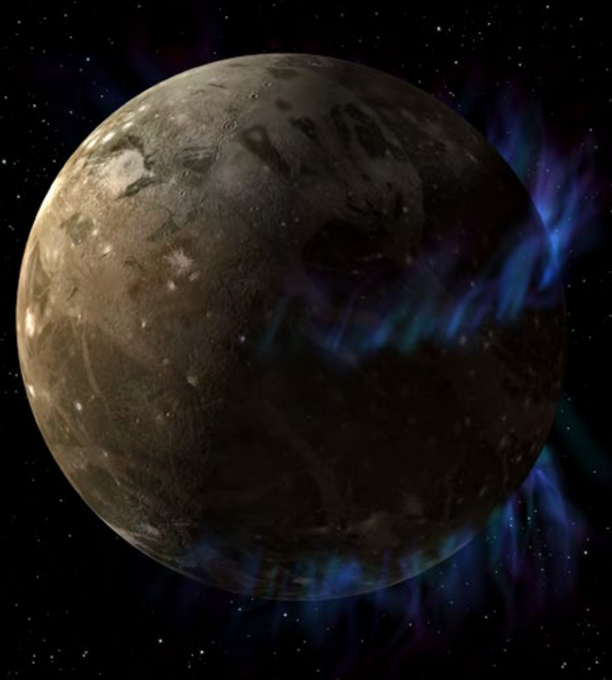
INFRARED

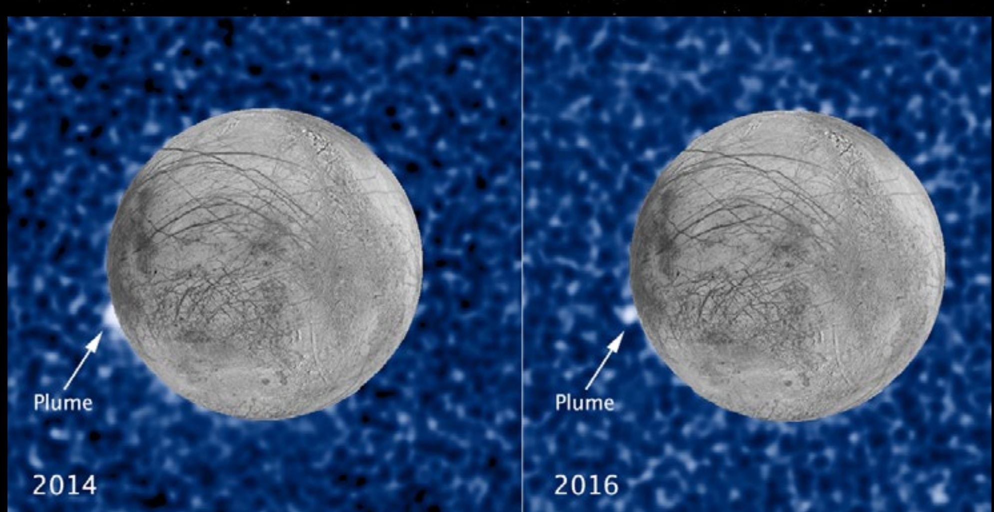
Finding Water on Jupiter’s Moons

ARTIST ILLUSTRATION



Hubble watched changes in auroras on Jupiter and Ganymede and found the best evidence yet for an ocean of saltwater under an ice crust on Ganymede, the largest moon in the solar system. This ocean may have more water than all of Earth’s surface. Hubble also recorded evidence of short-lived changes in the atmosphere above the surface of Jupiter’s moon Europa — the likely result of gas plumes expelled from a subsurface ocean.

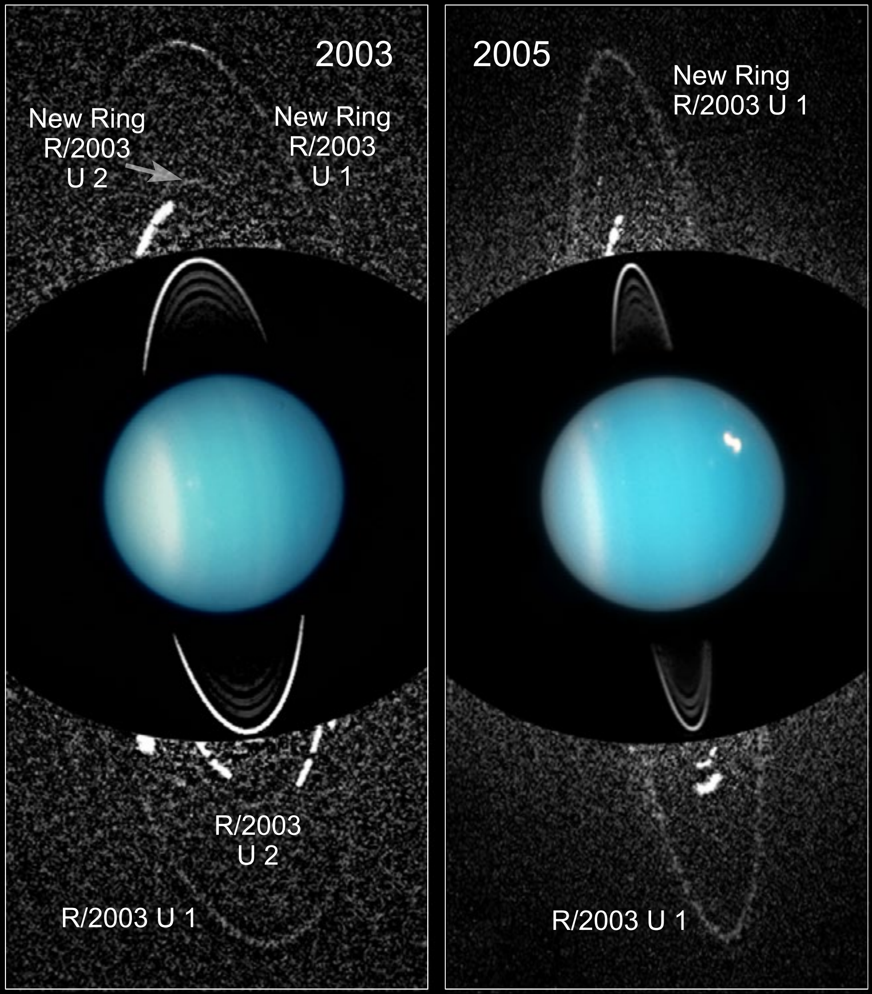




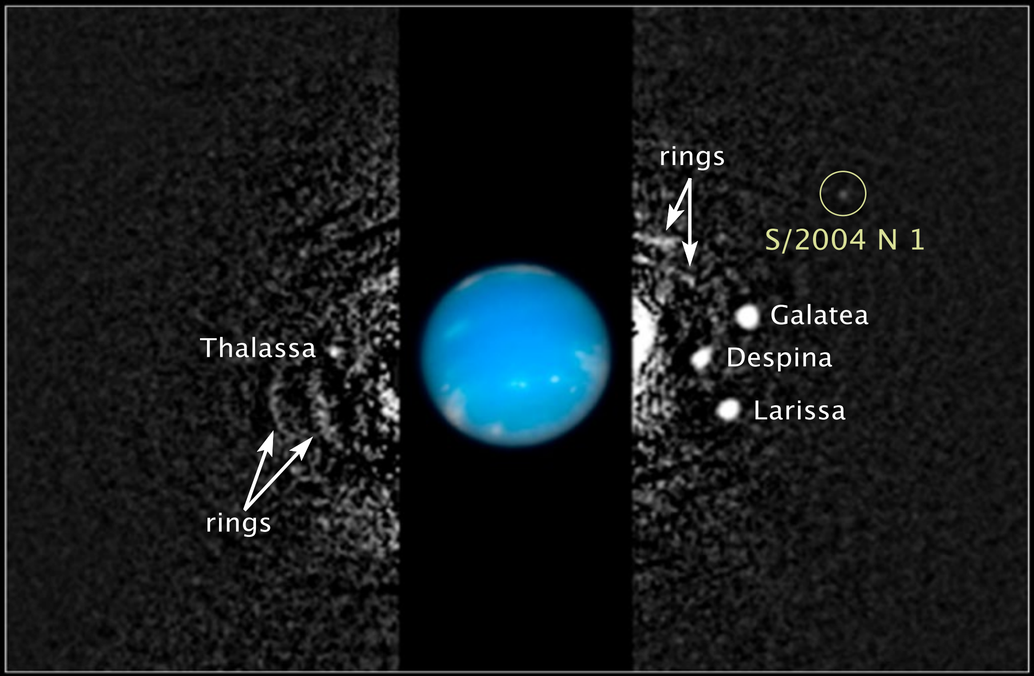
EUROPA

Finding New Moons

In 2003, astronomers using Hubble discovered two small moons around Uranus, called Cupid and Mab. The likely moons are about 8 to 10 miles across (12-16 km), or roughly the size of San Francisco. Hubble also detected two large outer rings around Uranus.

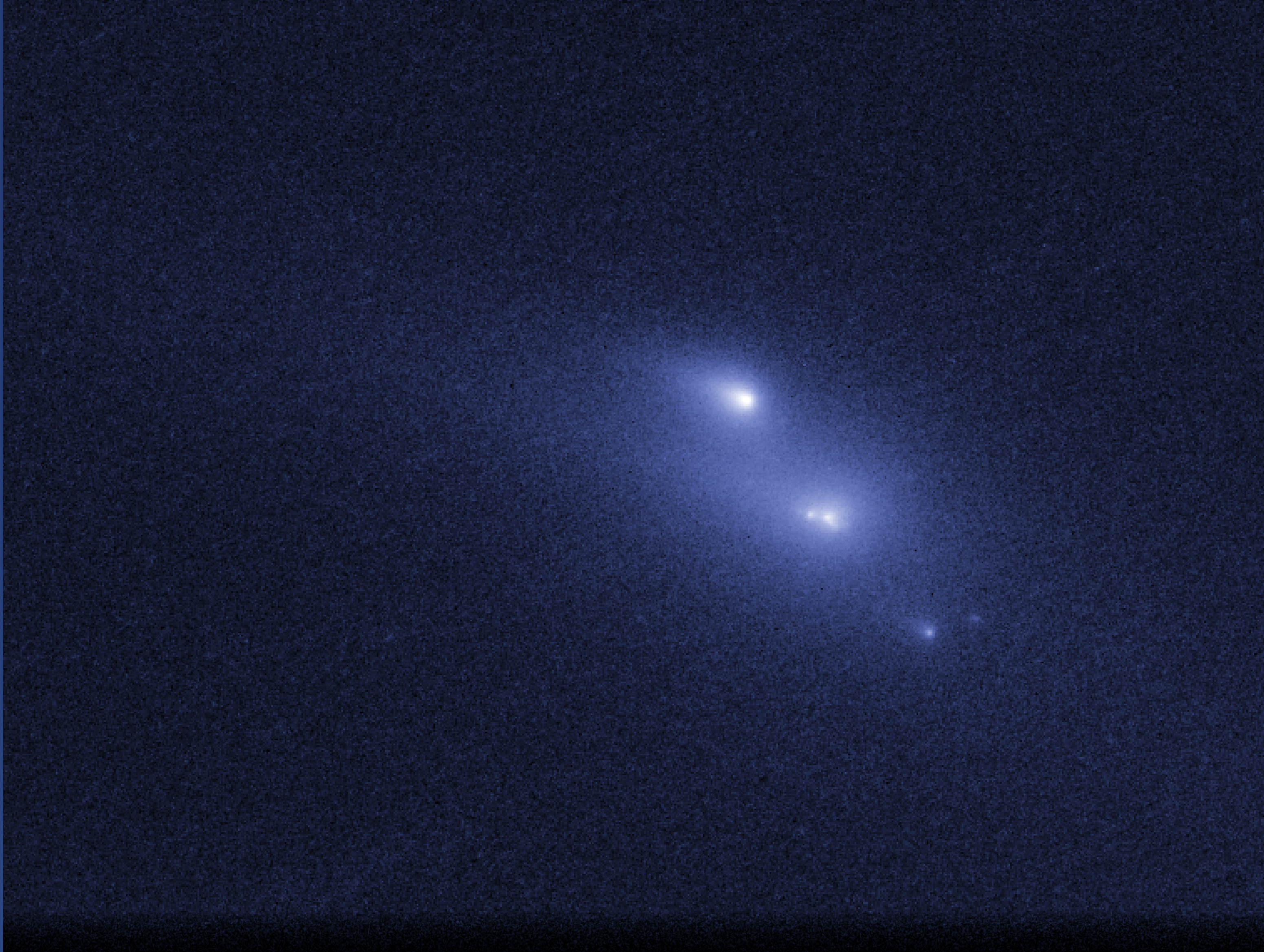


URANUS



NEPTUNE

Ten years later researchers found a small, faint moon called Hippocamp in images Hubble took of Neptune between 2004 and 2009. Astronomers discovered the moon while studying faint ring-arcs around the planet. Then they combed through 150 archived Hubble images of Neptune looking for the moon. Using those Hubble images, they were able to plot Hippocamp's 23-hour orbit around Neptune.



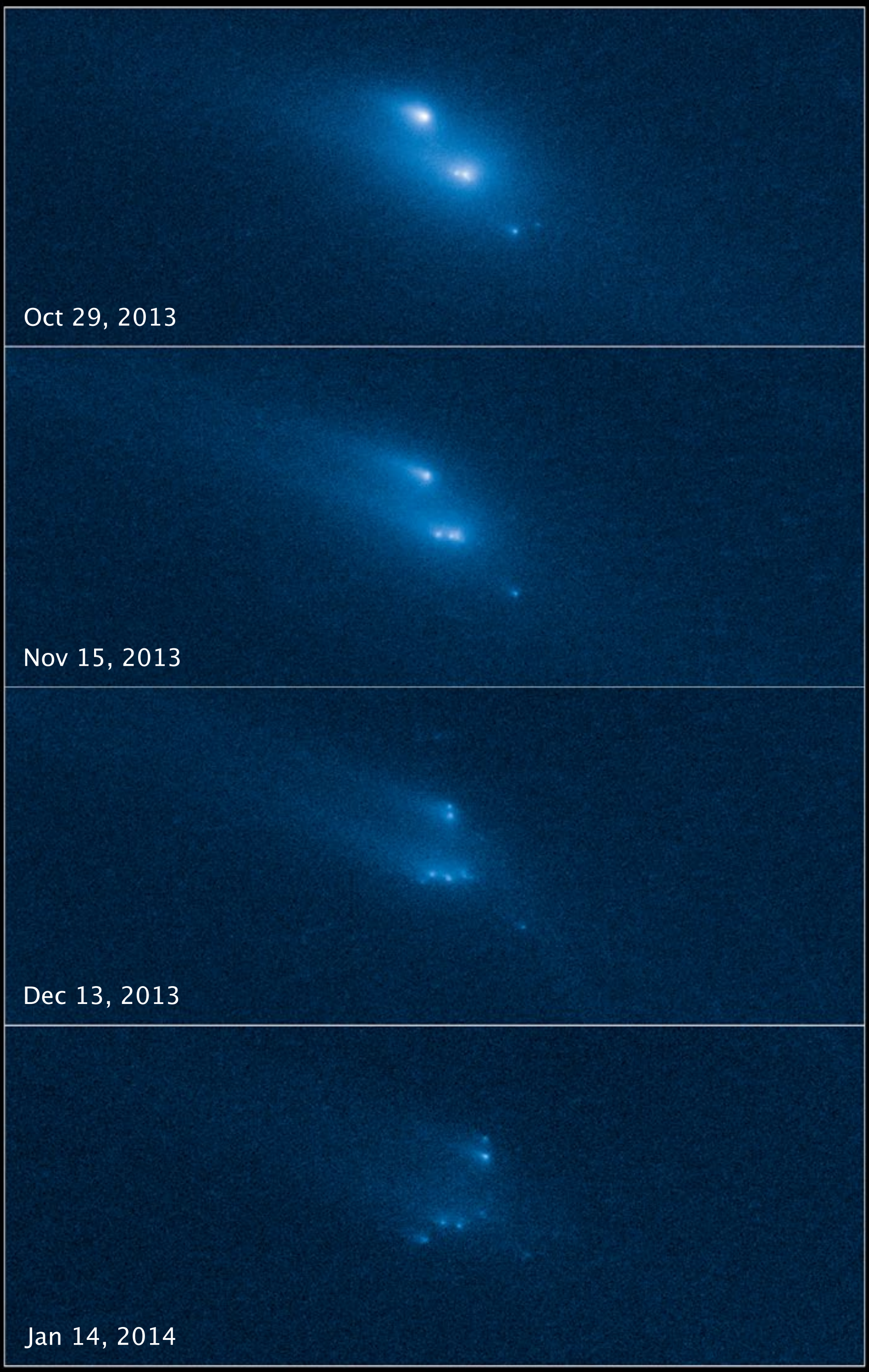
P/2013 R3

Tracking Evolution in the Asteroid Belt

Between the orbits of Mars and Jupiter lies a large concentration of asteroids, which are conglomerates of rock and ice that hold clues to the formation of our solar system. This 'Asteroid Belt' is the rubble left over from the construction of our solar system, and Hubble's observations have helped shape our understanding of their interactions and compositions.

A Fragmented Asteroid

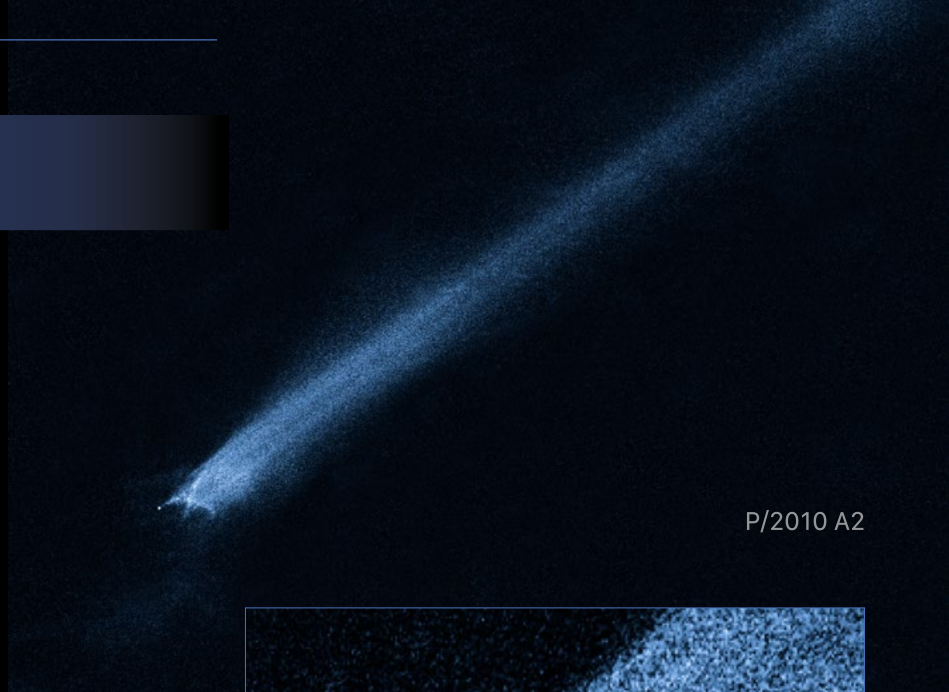
Asteroid P/2013 R3



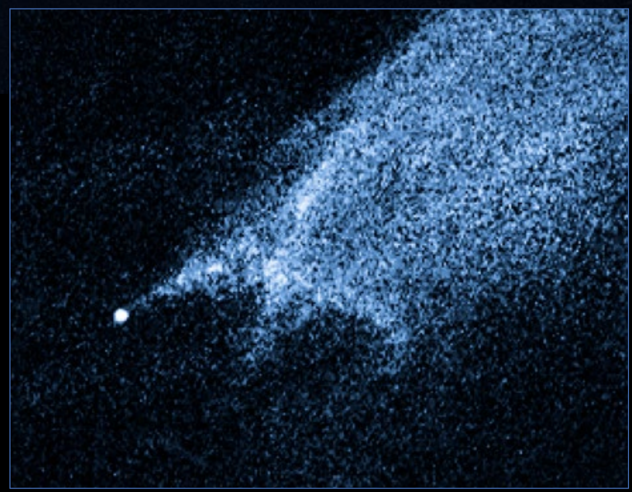
Hubble watched the slow disintegration of asteroid P/2013 R3 into 10 smaller pieces. The Hubble data revealed that the fragments are drifting away from each other at a leisurely one mile per hour — slower than the speed of a strolling human — which suggests the breakup is not the result of a collision.

Asteroid Collisions

Astronomers using Hubble witnessed the impact of two asteroids in the asteroid belt. 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. The observation helped support the idea that the asteroid belt is slowly eroding through collisions.



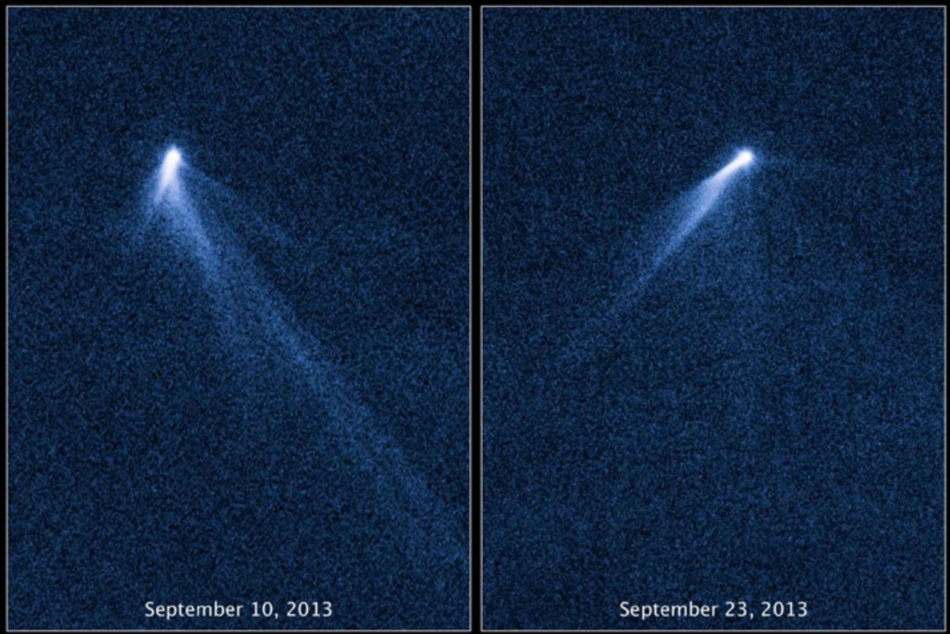
P/2010 A2



P/2010 A2 (zoomed)

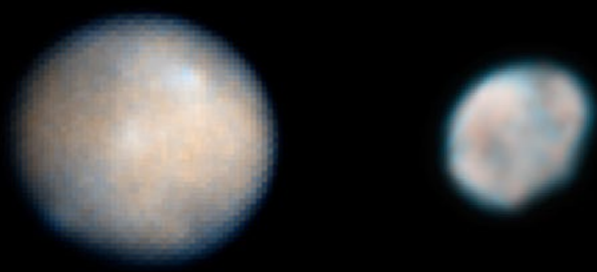
Asteroid or Comet?

In 2013, Hubble observed an asteroid with six comet-like tails of dust radiating from it like spokes on a wheel. 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 the tails may have formed through a series of dust-ejection events.



P/2013 P5

Asteroid Vesta and Dwarf Planet Ceres



Ceres • January 24, 2004
HST ACS/HRC

Vesta • May 14, 2007
HST WFPC2

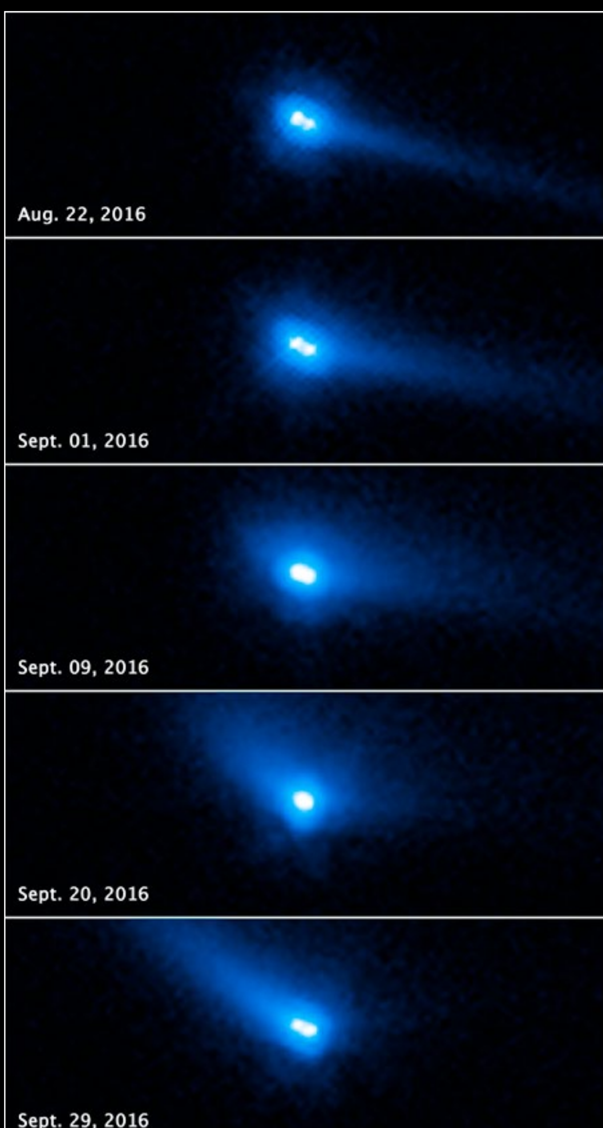
Hubble captured images of the two most massive objects in the Asteroid Belt, Ceres and Vesta, to help NASA better plan the Dawn spacecraft's visit to these two worlds.

Hubble's observations of Ceres revealed bright and dark regions on its surface that could be topographic features, such as craters, and/or areas containing different surface material. Large impacts may have caused some of these features and potentially added new material to the landscape.

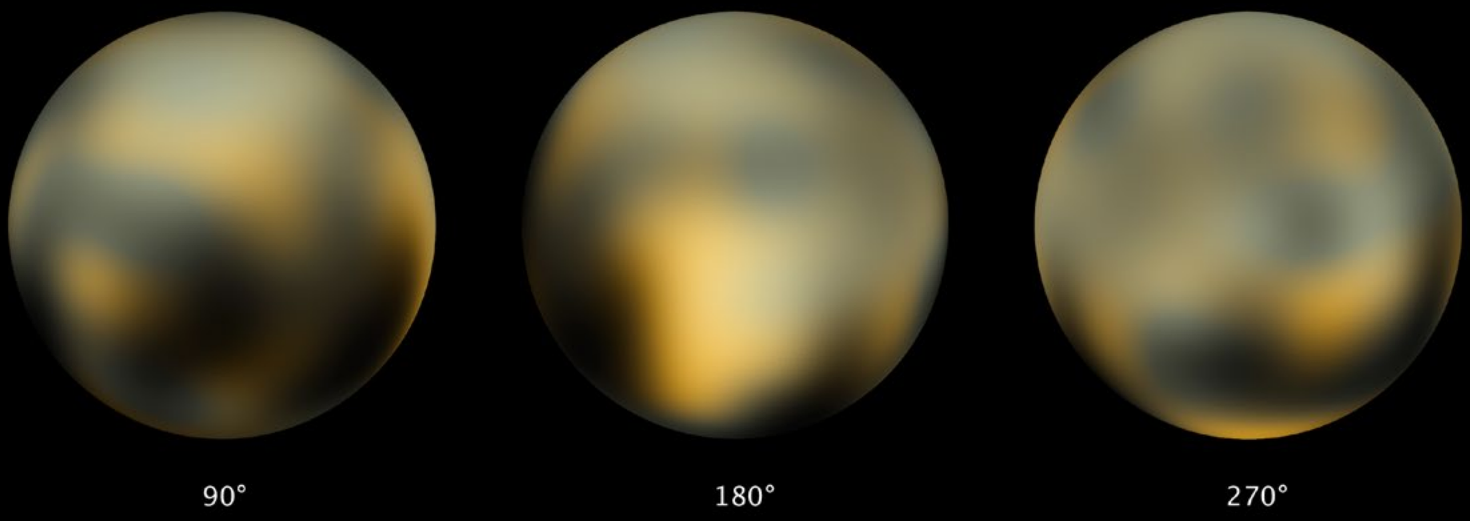
Hubble images of Vesta allowed researchers to map its southern hemisphere, a region dominated by a giant impact basin formed billions of years ago. Hubble discovered the basin and its central peak through observations made in 1997. The basin's width is 95% of Vesta's average diameter and about 12 miles (19 km) deep. Its central peak rises 12-16 miles (19-26 km) and is more than 100 miles (160 km) wide. If Earth had a crater of proportional size, it would fill the Pacific Ocean basin. Hubble's sharp "eye" saw features as small as about 37 miles (60 km) across on Vesta.

A Binary Asteroid

Hubble also observed the first known binary asteroid that also looks like a comet. The asteroid duo orbits each other and has a tail of dust like a comet. The asteroid, called 300163 (2006 VW139), likely broke into two pieces some 5,000 years ago due to its fast rotation.



2006 VW139/288P



PLUTO

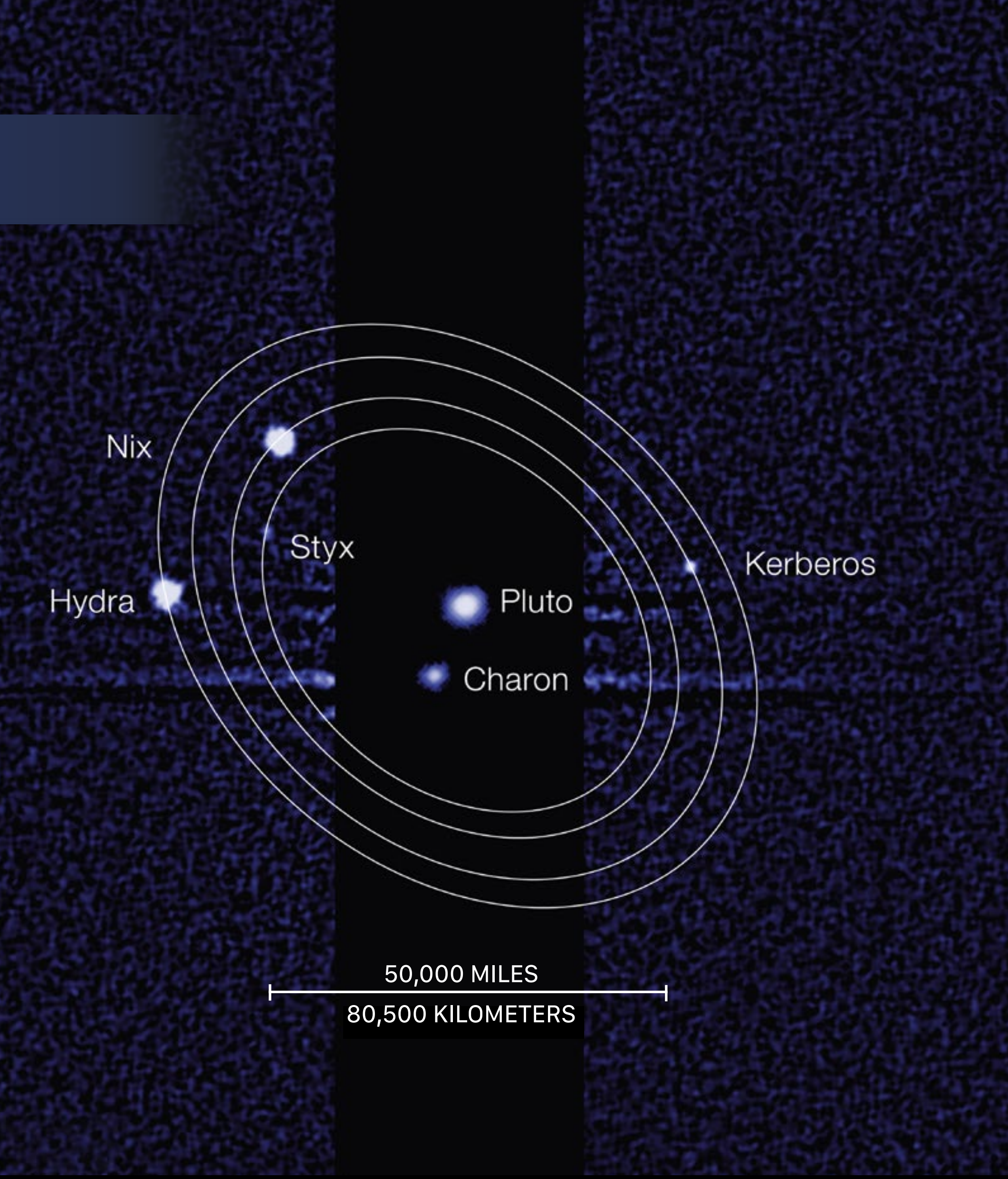
Uncovering Icy Objects in the Kuiper Belt

Hubble observations of the outskirts of our solar system found a moon orbiting Makemake and several new moons around Pluto. These observations played a critical role in helping NASA plan the New Horizons spacecraft's flyby of Pluto and beyond. They allowed the mission's team to refine maps of Pluto's surface in preparation for the rendezvous with Pluto and its moons.

Four New Pluto Moons

Hubble spied four previously unknown moons orbiting icy Pluto. The tiny moons Nix and Hydra were the first ones Hubble spotted, followed by the even tinier Kerberos and Styx. Astronomers later discovered that Nix and Hydra are rotating chaotically and unpredictably as they orbit the dwarf planet.

Hubble also uncovered two potential Kuiper Belt objects that the New Horizons spacecraft could target on its outward journey past Pluto. On Jan. 1, 2019, New Horizons flew past one of these objects — called Arrokoth — capturing up-close imagery that revealed its double-lobed structure in fine detail, complete with fractures and pitting.



Makemake Moon

Hubble also discovered a 100-mile-wide moon in orbit around Makemake, the second-brightest icy dwarf planet in the Kuiper Belt. Makemake is 4.8 billion miles (7.7 billion km) from the Sun and approximately 870 miles (1,400 km) across. Oddly, the moon is as dark as charcoal, while Makemake is as bright as fresh snow.

Our Galaxy

NGC 1977

Exploring the Birth of Stars

Stars form in large clouds of gas and dust called nebulae that scatter the visible wavelengths of light our eyes can see. Hubble’s capability to see ultraviolet, visible, and near-infrared light enables study of several aspects of star formation. Young stars shine brightly in ultraviolet light, while visible light reveals the structure of star-forming clouds, the shock waves induced by jets from forming stars, and colorful ionized gas in the nebulae energized by young stars. Infrared light’s longer wavelengths can pass through the cloud relatively undisturbed. Hubble’s near-infrared instruments and high resolving power can detect this escaping light, revealing deeply embedded regions within these clouds where newborn stars form. These capabilities make it an important tool in the study of developing stars.

Pillars of Star Formation

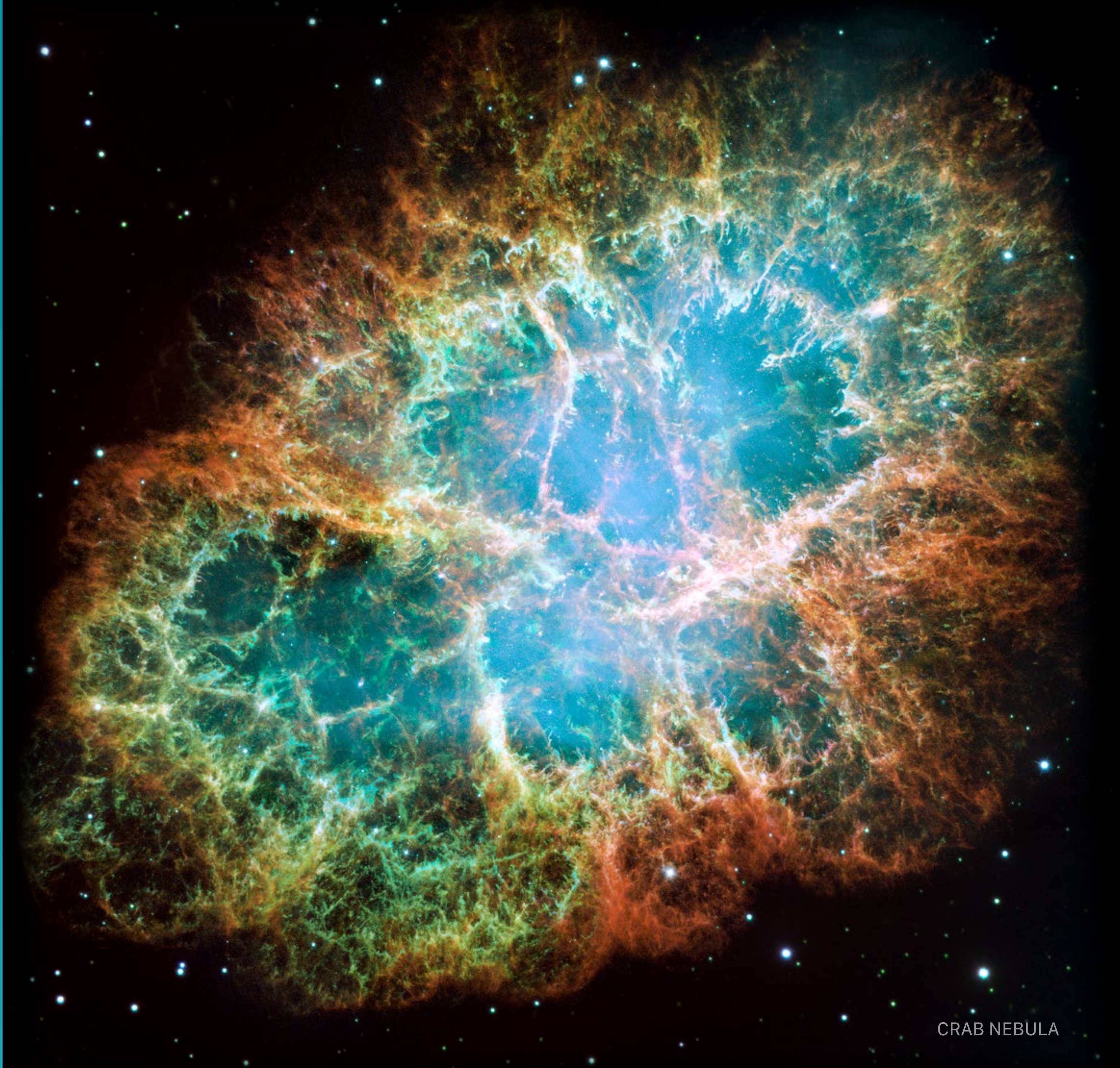
Hubble's observations of nebulae reveal bizarre landscapes sculpted by radiation from young, exceptionally bright stars. The observations reveal the violent process of star birth that produces intense ultraviolet radiation and shock fronts. The radiation clears out cavities in stellar nursery clouds and erodes material from giant gas pillars that are incubators for fledgling stars.

MYSTIC MOUNTAIN

Jets Blasts from Young Stars

Hubble can capture energetic jets of glowing gas from young stars in unprecedented detail. These jets, called Herbig-Haro objects, are a byproduct of gas swirling into newly forming stars. The jets form when the star's magnetic field channels gas toward the spinning star's poles, where it shoots out at supersonic speeds in opposing directions. Hubble's longevity allows astronomers to observe Herbig-Haro objects over time. These observations show us how the jets evolve as they travel through the interstellar medium. Measuring and studying the motions and changes in shape of Herbig-Haro objects helps astronomers untangle the complicated physical processes that form them, while also providing clues about the environment in which newborn stars develop.

HERBIG-HARO JET HH 24



CRAB NEBULA

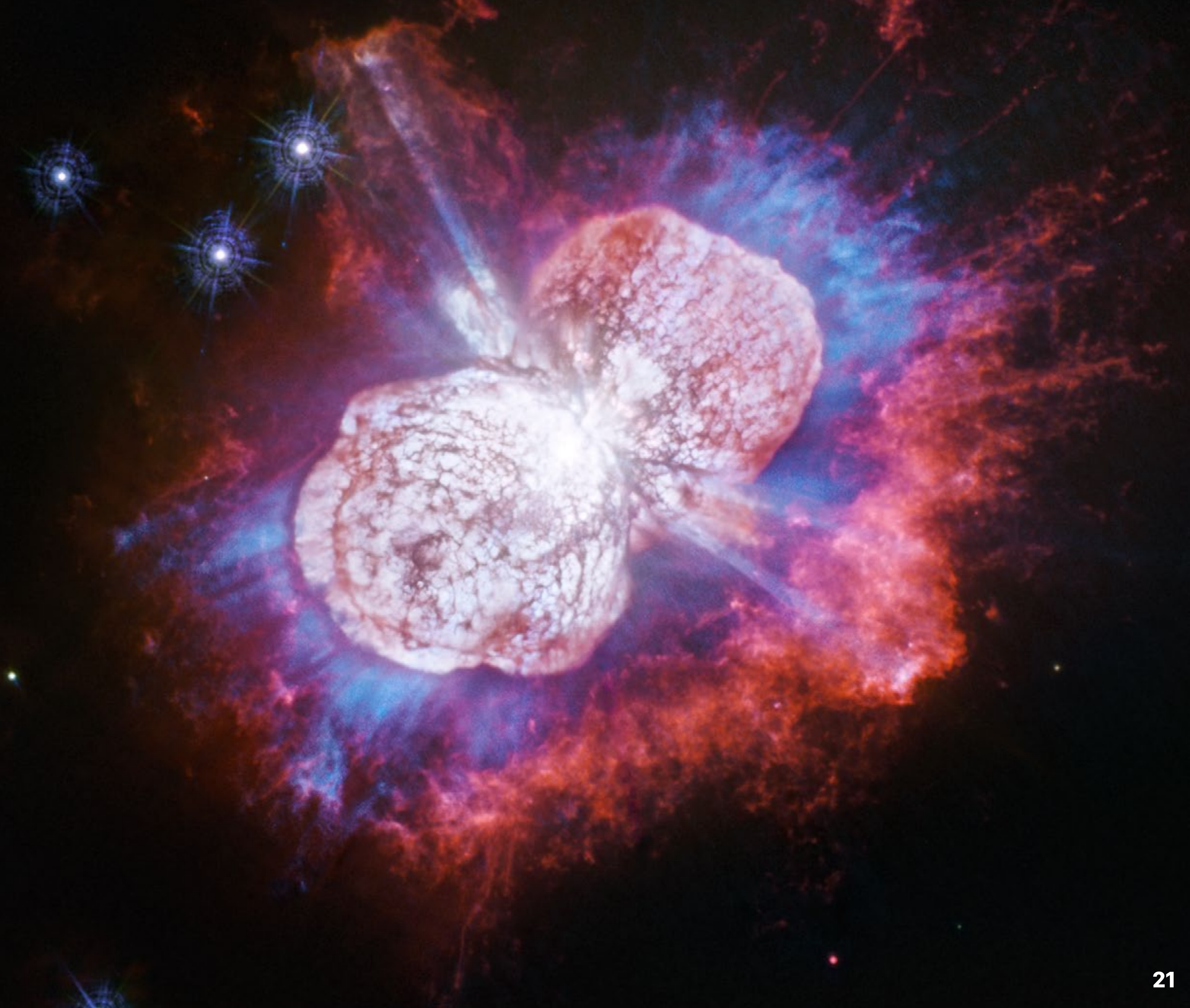
The Death Throes of Stars

When a star runs out of its hydrogen fuel, the path it takes toward death depends on its size. For stars, it's a balance between the radiation pressure of their fuel-burning cores pushing outward, and their gravity pulling inward. When stars run out of fuel, gravity wins this struggle, and the star begins to collapse into a black hole, supernova, neutron star, or white dwarf depending on its size.

The Crab Nebula (previous page) is the result of a massive star's collapsing core that ignited an uncontrolled explosion called a supernova. That explosion was visible during daylight hours on Earth in 1054 CE. The faint remnant we see today is an expanding shell of gas and dust aided by an outflowing wind from a rapidly spinning, highly magnetized neutron star called a pulsar.

Eta Carinae

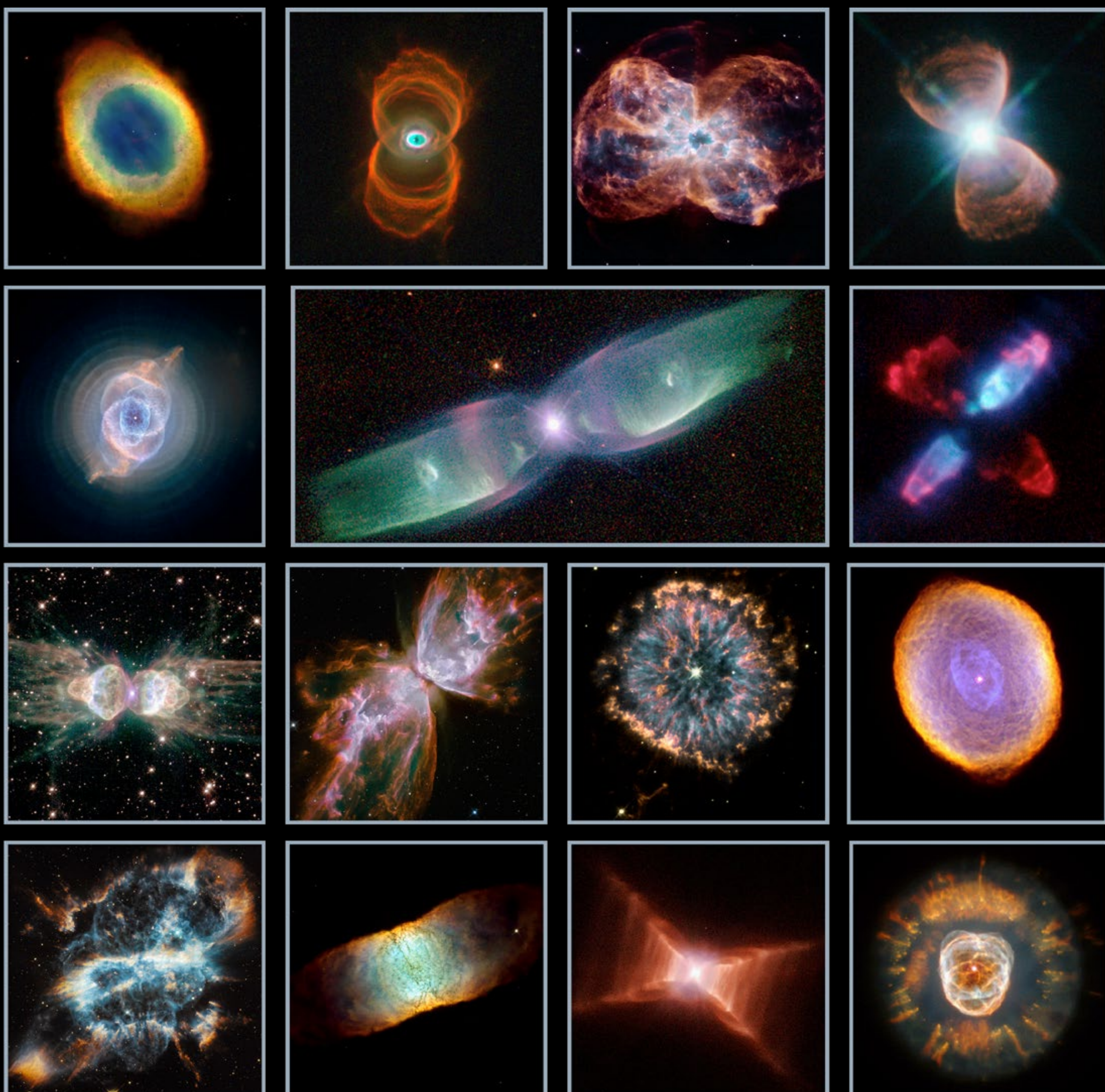
Eta Carinae is another doomed star that will also end its life in a supernova explosion. A regular target for Hubble since its 1990 launch, Eta Carinae is a system with at least two stars. The largest and brightest is an enormous supergiant star about 100 times the mass of the Sun and five million times brighter. This ultraviolet image from Hubble's Wide Field Camera 3 revealed new areas of magnesium embedded in warm gas (blue). The glowing magnesium dwells between the dusty bipolar bubbles and the outer shock-heated, nitrogen-rich filaments (red). The two lobes likely formed during an outburst the star had in the early 1800s.

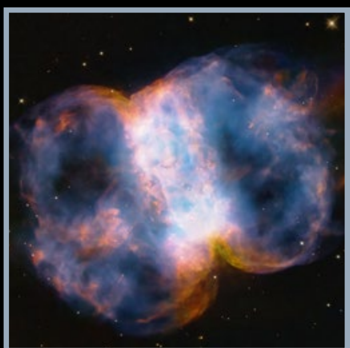


Planetary Nebulae

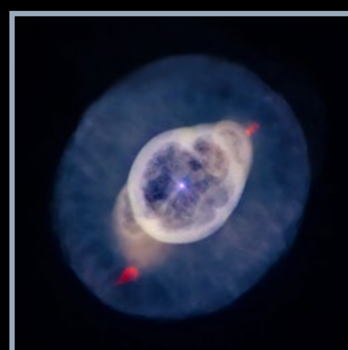
When a medium-sized star begins to die, it sheds its outer layers, forming a shell of gas and dust called a "planetary nebula." Before Hubble, ground-based images suggested that planetary nebulae have simple, spherical shapes. Hubble observations revealed unprecedented details that show they are much more varied and complex. These images offer insights into the complex dynamics that accompany a star's release of its outer gaseous layers before it collapses to form a white dwarf or neutron star.

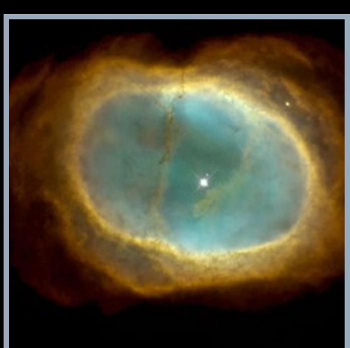
A COLLAGE OF DIFFERENT PLANETARY NEBULAE

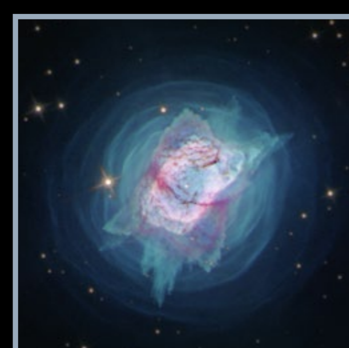




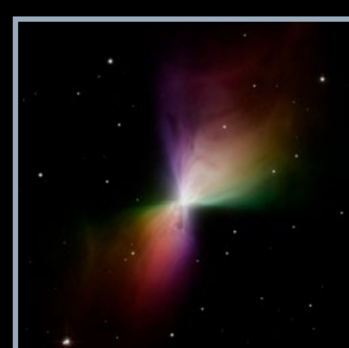








AN ATLAS FEATURING 30 PROPLYDS

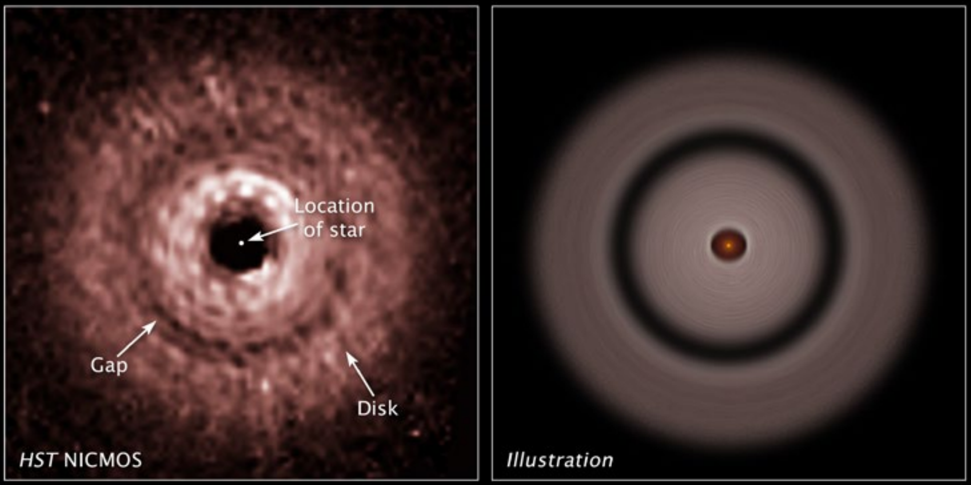
Finding Planetary Construction Zones

In 1992, Hubble was the first telescope to resolve protoplanetary disks (dubbed "proplyds") around stars in the Orion Nebula. Protoplanetary disks are dense gas and dust disks surrounding newly formed stars. Hubble's high resolution and sensitivity, along with the Orion Nebula's proximity, allowed the telescope to image proplyds around nearly 200 stars in the nebula. Proplyds are pancake-like disks of mostly gas and some dust surrounding a young star. They are a prerequisite for the formation of planetary systems.

Hubble also completed the largest and most sensitive visible-light imaging survey of debris disks around stars. Debris disks are belts of dust and rubble that form when objects like asteroids and comets collide. Astronomers use them as "planet detectors." Two particular stars highlight Hubble's observations: TW Hydrae and Beta Pictoris.

TW Hydrae Protoplanetary Disk

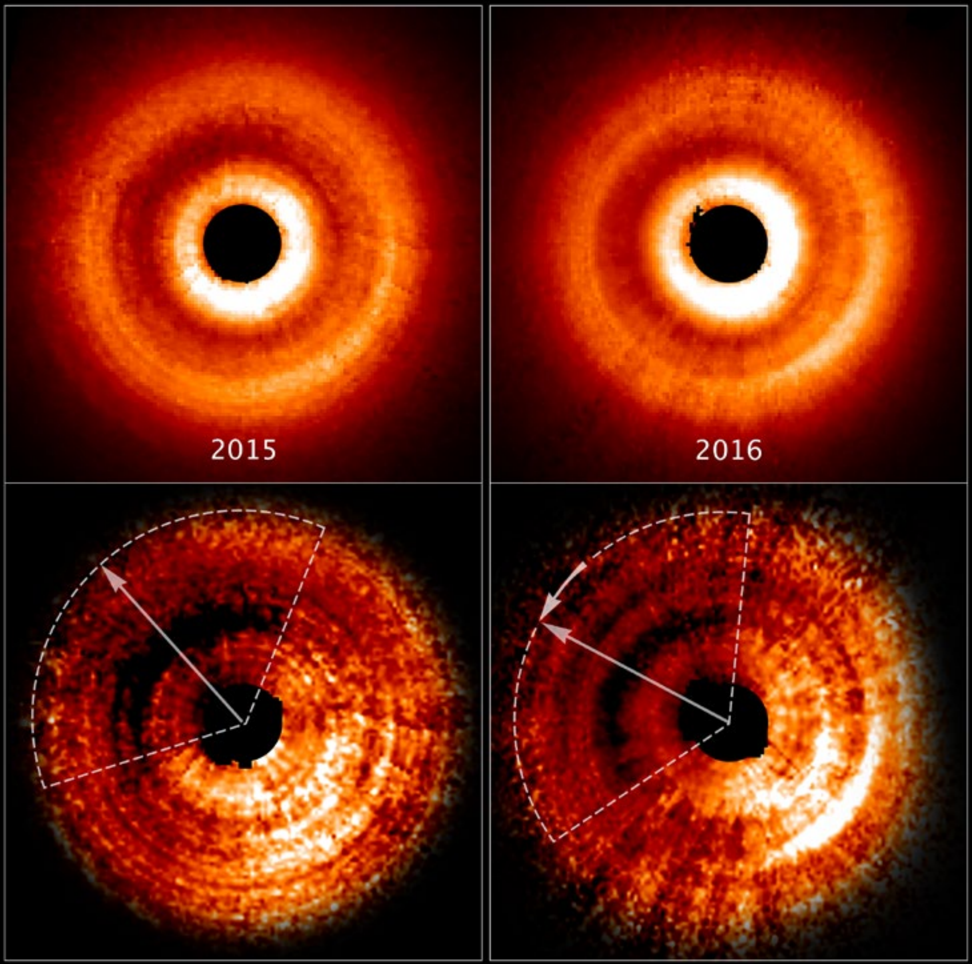
Using a mask to block the star's bright light, Hubble scientists spotted a mysterious gap in a vast protoplanetary disk of gas and dust swirling around the star TW Hydrae. The gap is likely the result of a growing, unseen planet gravitationally sweeping up material and carving out a lane in the disk like a snowplow. The 1.9-billion-mile-wide (3 billion km) gap isn't completely cleared of material yet.



TW HYDRAE DISK

Shadow on TW Hydrae's Disk

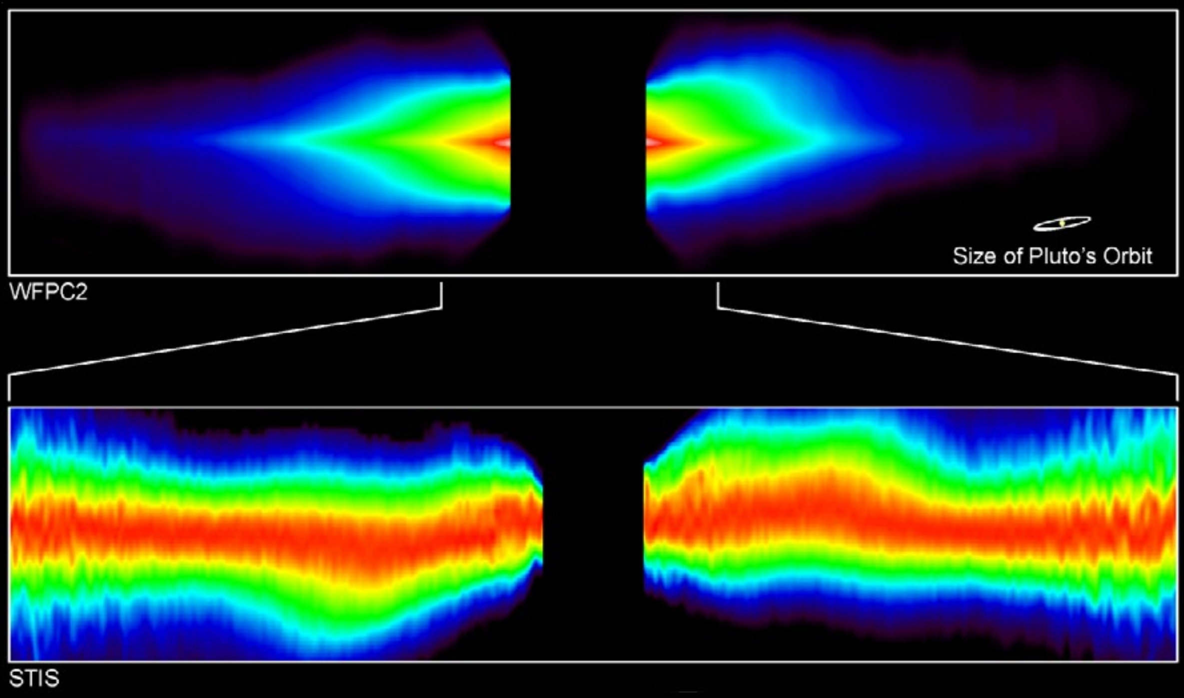
More recently, astronomers using Hubble noticed a change in brightness with position in TW Hydrae's disk. Because Hubble has 18 years' worth of observations of the star, the astronomers could assemble a time-lapse movie of the shadow's rotation. They think an unseen planet in the disk is gravitationally pulling on material near the star and warping the inner part of the disk. The twisted, misaligned inner disk is casting its shadow across the surface of the outer disk.



SHADOW ON TW HYDRAE DISK

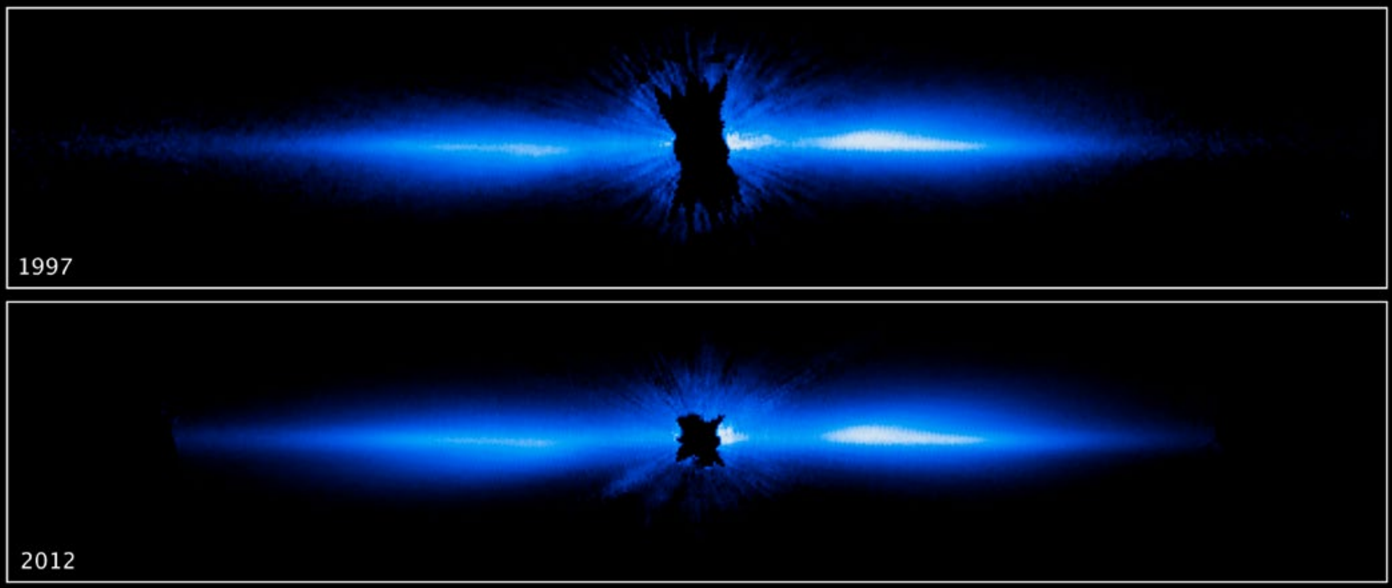
Beta Pictoris Planetary Disk

Hubble's longevity also allowed researchers to chart changes in the disk surrounding the 20-million-year-old star Beta Pictoris. In 1998, Hubble's visible-light views of the edge-on disk revealed undulations that computer models suggested were gravitational evidence of budding planets and possibly a companion brown dwarf or bypassing star. Roughly 10 years after Hubble's observations, astronomers directly imaged a gas giant planet in the disk, still glowing from its recent formation.

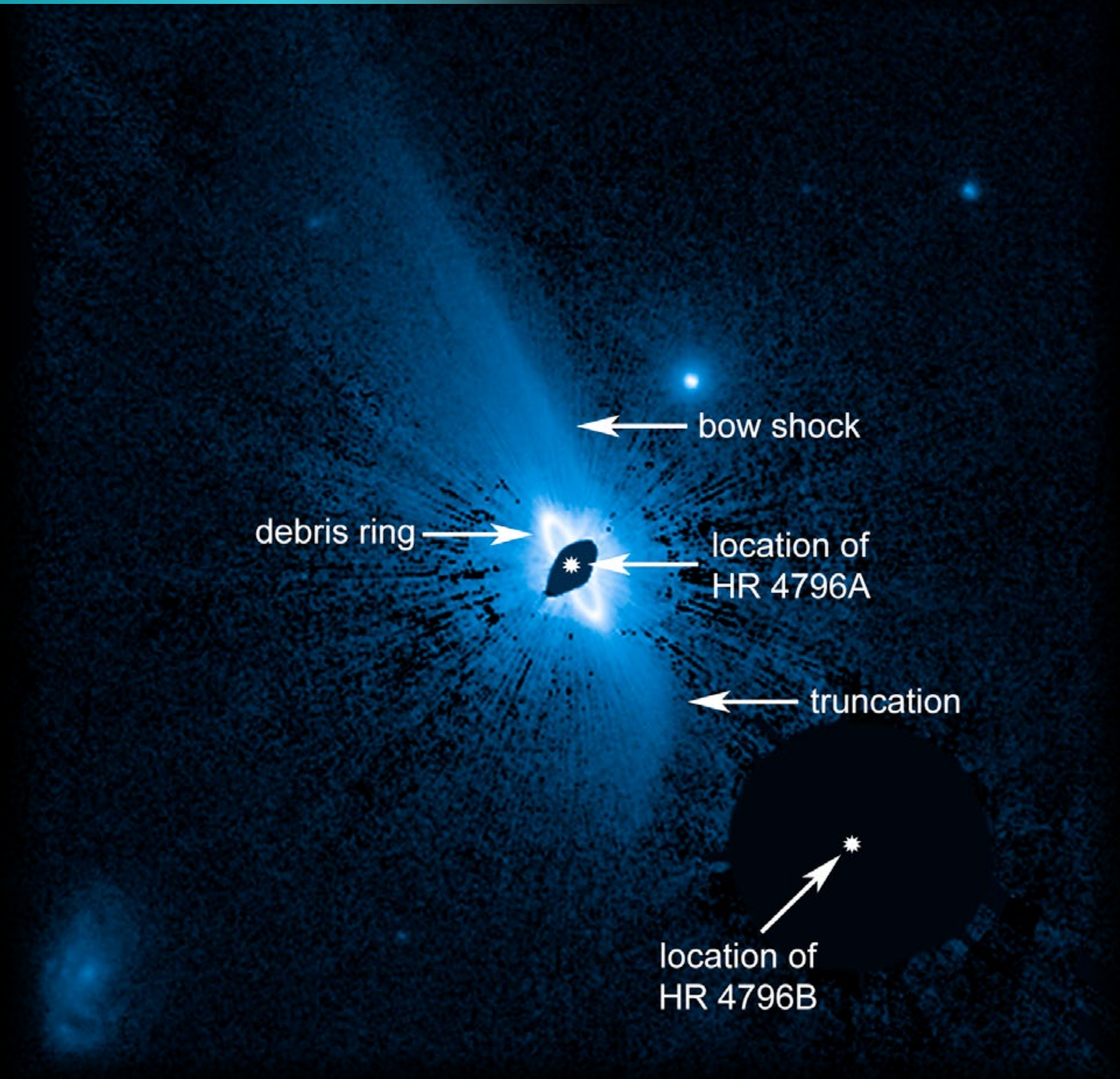


The blue Hubble image traces the disk to within 650 million miles (one billion km) of the star, a distance that would be the radius of Saturn's orbit about the Sun. Astronomers have uncovered at least two young planets around Beta Pictoris, and Hubble's ground-breaking observations of the disk contributed greatly to those discoveries.

BETA PICTORIS DISK



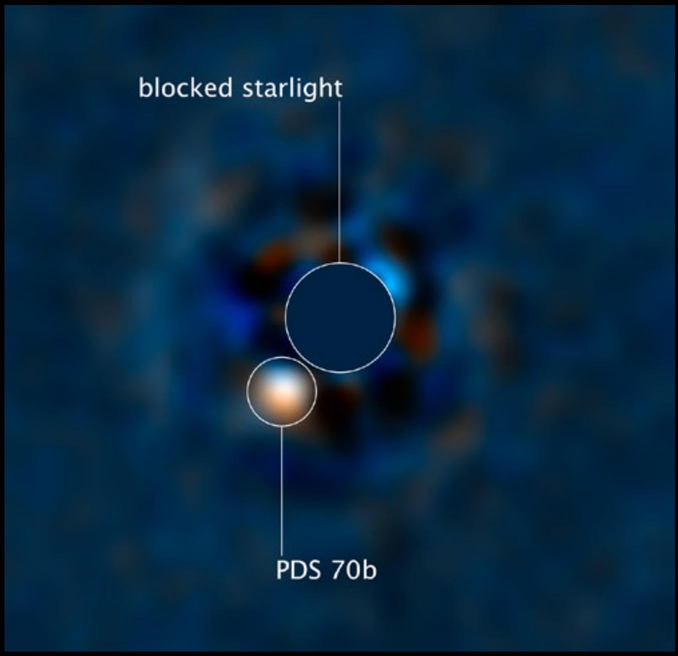
An Asymmetric Dust Disk



Hubble also captured a vast and complex dust structure extending some 150 billion miles (240 billion km) across, enveloping the young, 8-million-year-old star HR 4796A. The bright ring, about 7 billion miles (11 billion km) from the star, is a debris field of very fine dust that is likely the result of developing planets colliding near the star. Light pressure from the star, which is 23 times more luminous than the Sun, expelled the dust far into space. The wider debris field is much more extended in one direction than the other. This may be due to the star's motion through space, or it may be the result of a gravitational tug from the star's binary companion, a red dwarf star (HR 4796B) at least 54 billion miles (87 billion km) from HR 4796A.

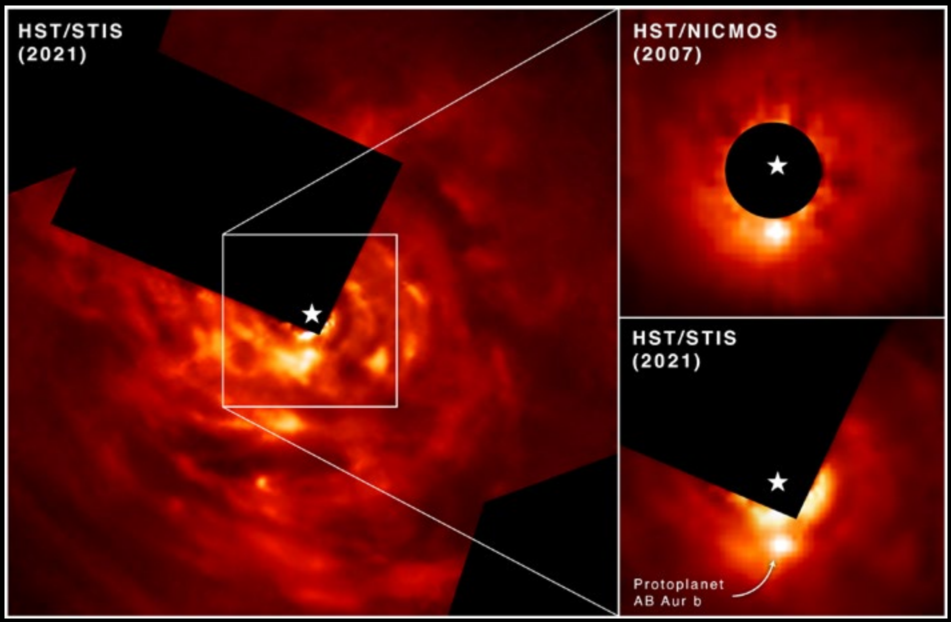
Protoplanet Around PDS 70

Hubble was the first observatory to image a forming planet (PDS 70b) in ultraviolet light (UV). Hubble's unique UV capabilities gave planetary scientists the first opportunity to witness extremely hot gas falling onto the planet. The Jupiter-sized world is slowly accumulating matter, allowing researchers to estimate how fast the planet is gaining mass. Located 370 light-years from Earth, the remote planet took about 5 million years to grow to its present size of up to five times the mass of Jupiter. If PDS 70b's accretion rate remains steady for another million years, the planet would only grow by roughly 1/100th of a Jupiter mass.



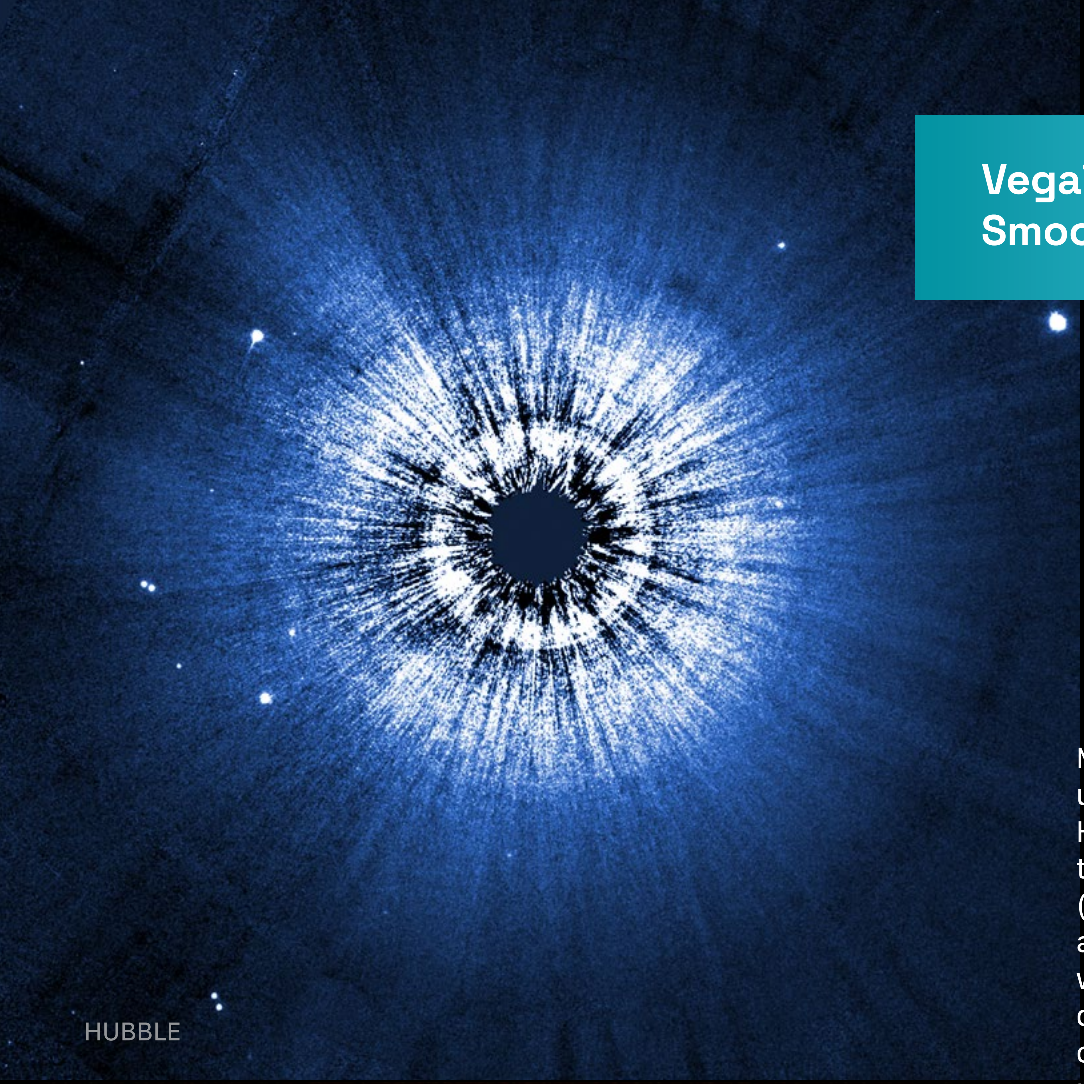
PDS 70

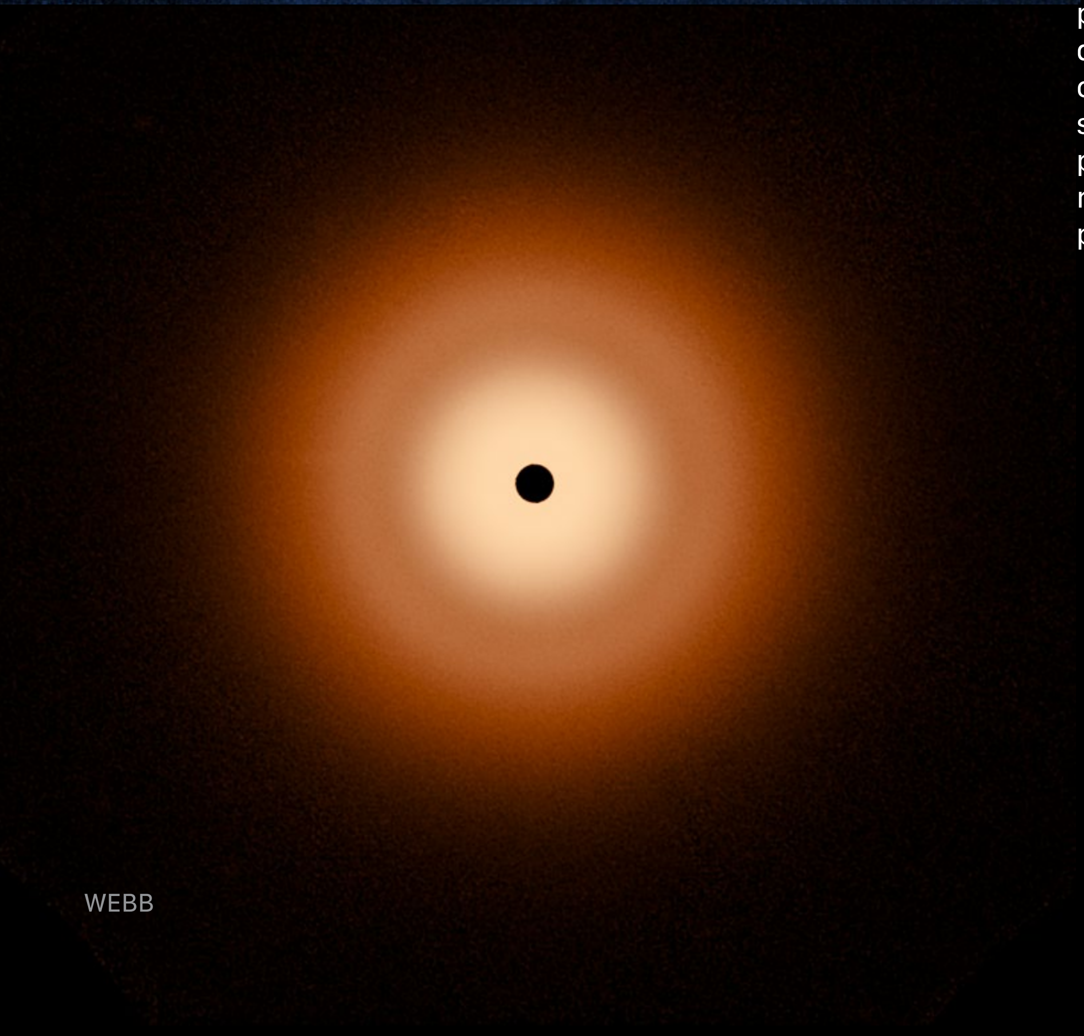
AB Aurigae b



Hubble's longevity and high resolution also came into play when its Space Telescope Imaging Spectrograph (STIS) and its Near Infrared Camera and Multi-Object Spectrograph (NICMOS) directly imaged another forming Jupiter-like protoplanet, called AB Aurigae b, over a 13-year span. Hubble captured the growing exoplanet embedded in a disk that has distinct spiral structures swirling around the young star AB Auriagae. The planet is about nine times more massive than Jupiter and orbits some 8.6 billion miles (13.8 billion km) from the star — over two times farther than Pluto is from the Sun.

Vega's Surprisingly Smooth Dust Disk





More recently, researchers used the combined power of Hubble and Webb to study the 100-billion-mile-diameter (160 billion km) debris field around the star Vega. They were surprised to find Vega's disk looking smooth with no obvious evidence for large planets plowing through the disk, which is common around other young stars. Hubble sees debris the size of smoke particles, and Webb traces roughly sand-grain-sized particles closer to the star.

ARTIST'S IMPRESSION OF "HOT JUPITER" EXOPLANETS

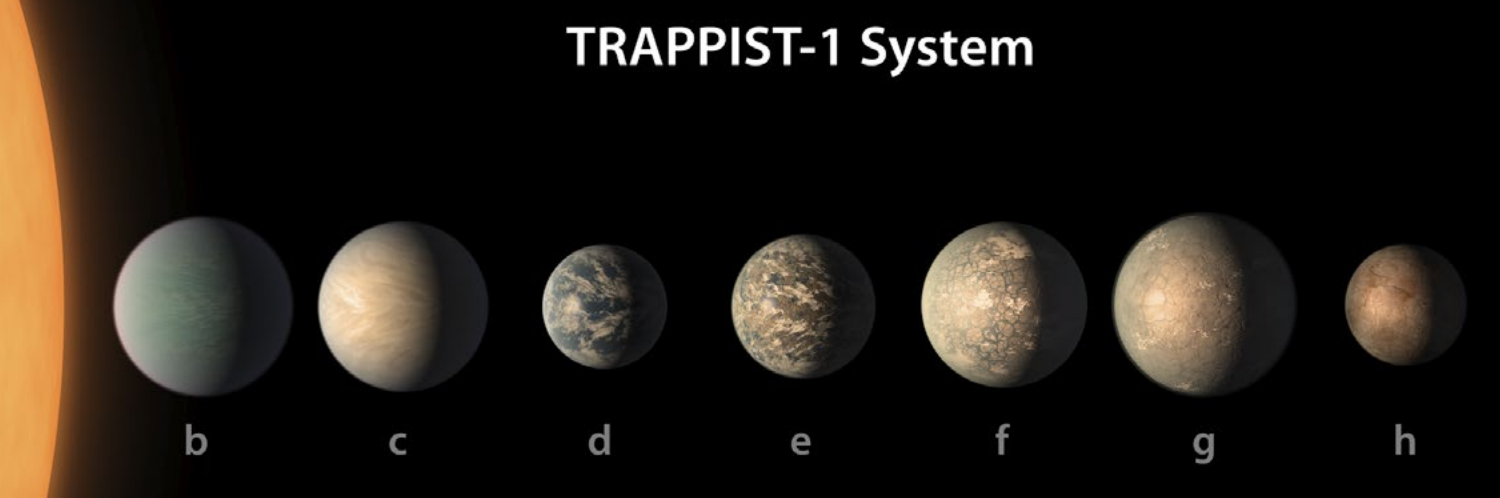
Recognizing Worlds Beyond Our Sun

When Hubble launched in 1990, there were no confirmed planets outside of our solar system. Hubble's unique capabilities allow it to explore planetary systems around other stars. Scientists have since established the existence of more than 5,000 extrasolar planets.

Hubble's unique contributions to the planet hunt include taking the first measurements of the atmospheric composition of extrasolar planets. Its observations have identified atmospheres that contain sodium, oxygen, carbon, hydrogen, carbon dioxide, methane, helium, and water vapor. Hubble observations demonstrate that we can detect and measure the basic organic components for life on planets orbiting other stars.

TRAPPIST-1 System

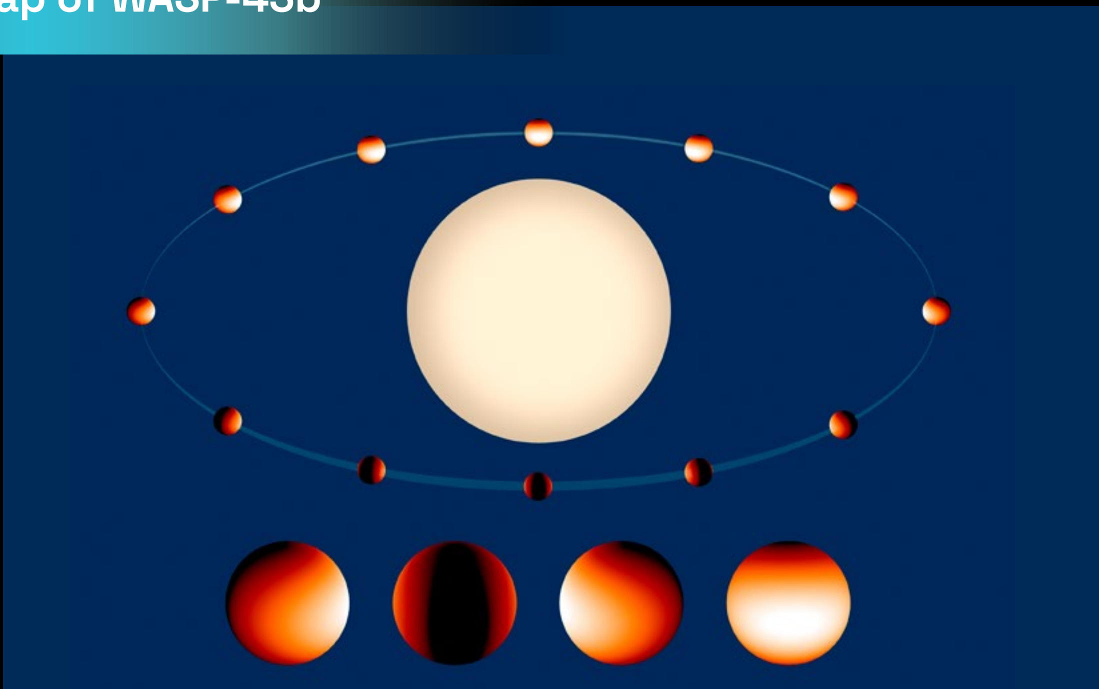
Hubble observed the first known system of seven Earth-sized planets around an ultra-cool dwarf star (TRAPPIST-1) that would allow liquid water to survive on four of the close-orbiting planets. All seven planets orbit closer to their star than Mercury is to our Sun and orbit very close to each other. Hubble observations suggest these planets have more compact atmospheres like those found on Earth, Venus, and Mars.



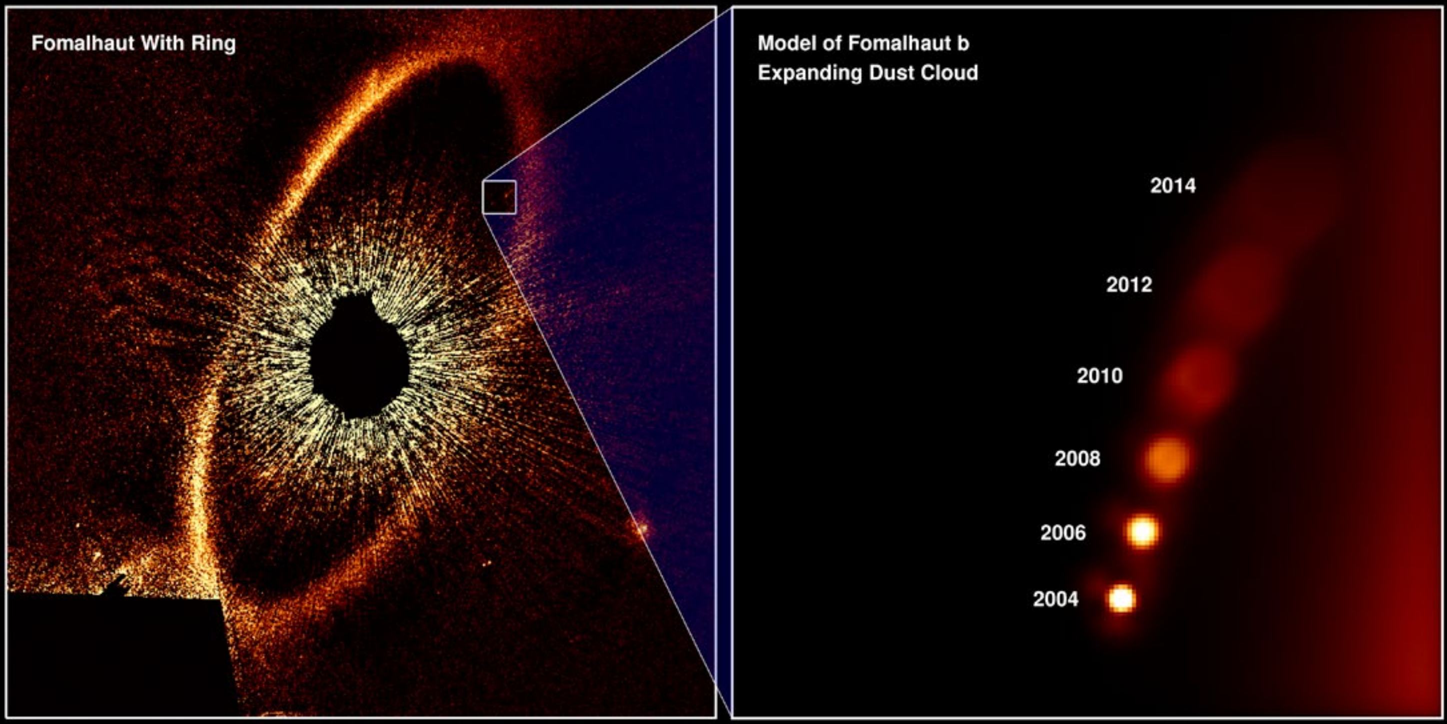
ARTIST'S IMPRESSION OF TRAPPIST-1 SYSTEM

Global Temperature Map of WASP-43b

Astronomers used infrared data from Hubble to make a detailed global map of an exoplanet (WASP-43b) showing the temperatures at different layers in its atmosphere, and the amount and distribution of its water vapor. The white-colored region on the daytime side is 2,800 degrees Fahrenheit (1,540°C). The nighttime-side temperatures drop below 1,000 degrees Fahrenheit (540°C).

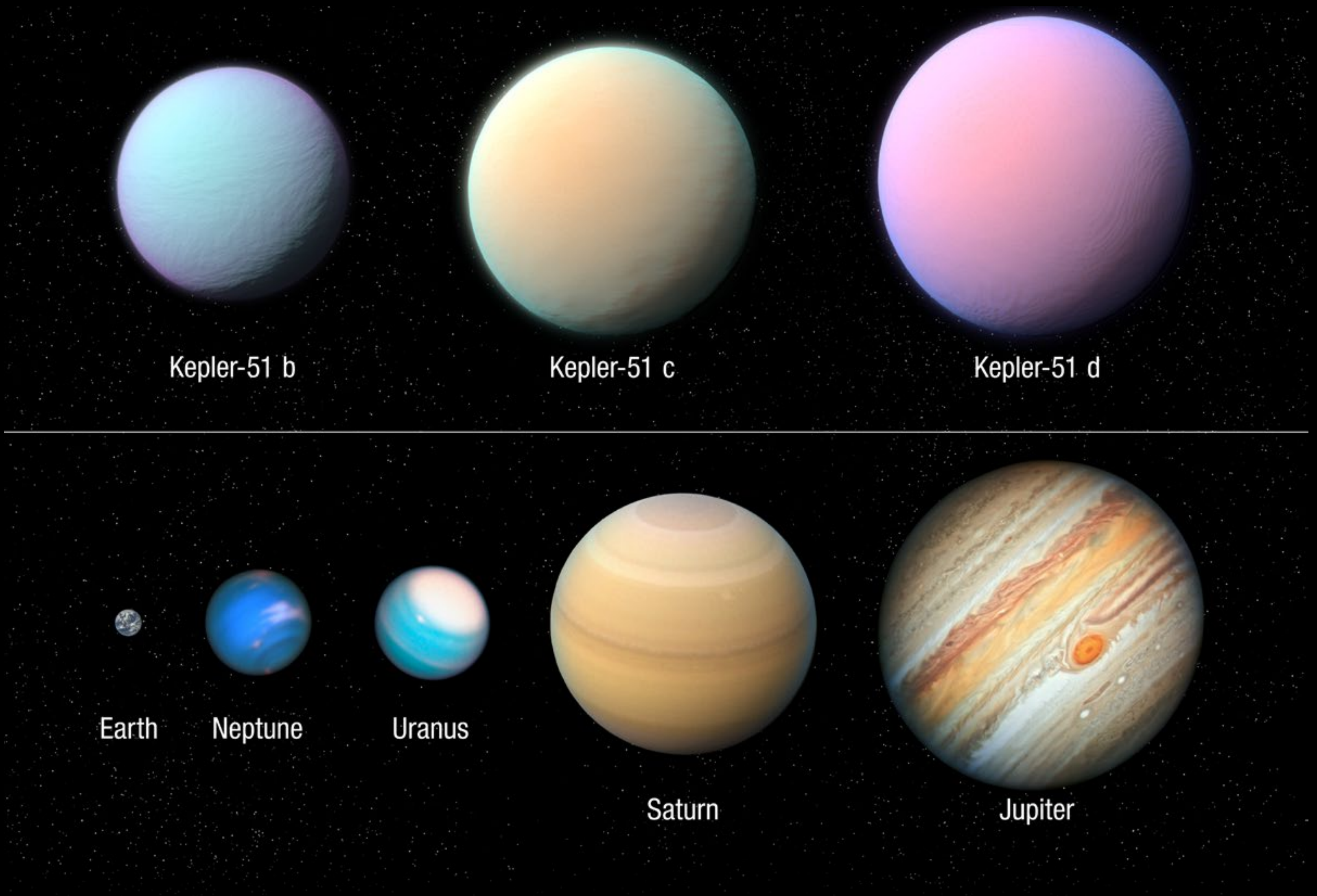


Fomalhaut b Dust Cloud



In 2004, Hubble began regularly observing what astronomers thought might be an extrasolar planet. They studied the suspected planet for 16 years, tracking its movements around the bright nearby star Fomalhaut. However, something strange was happening as the planet appeared to dim with each successive observation. Then, in 2020, it seemed to vanish completely. Further research revealed that the suspected planet may actually be a vast, expanding cloud of dust produced in a collision between two large bodies orbiting Fomalhaut.

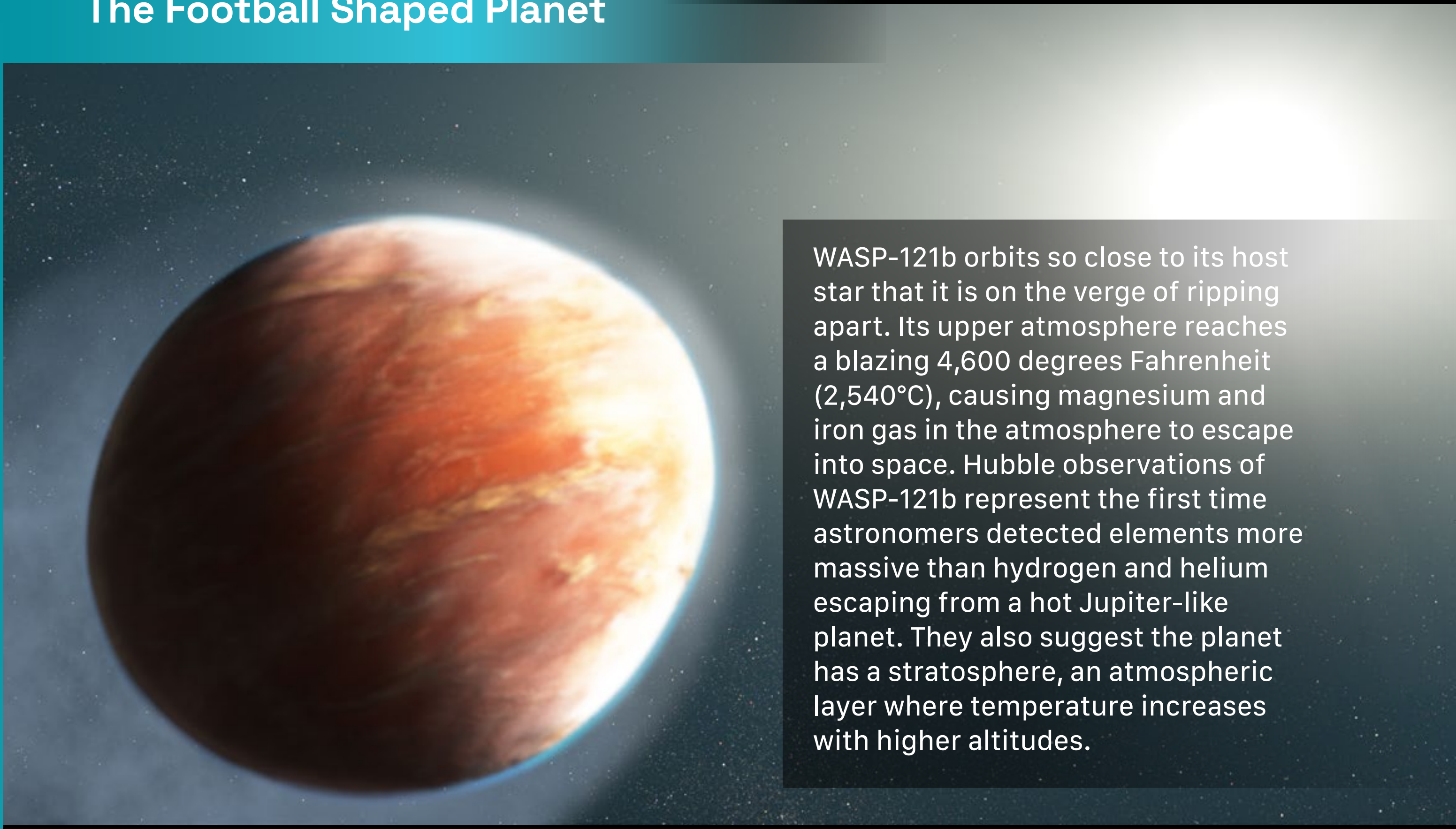
Kepler 51 Planets (artist's impression)



Hubble's exoplanet observations reveal truly strange worlds; including one that absorbs nearly all the light that reaches it. The planet, WASP-12b, is as dark as fresh asphalt. Another, WASP-121b, is an extremely hot, football-shaped world. Hubble observations also confirmed that three super-puffy planets in the Kepler 51 system have extremely low densities. While these planets appear to be as big and bulky as Jupiter, they are actually one hundred times less massive, leading researchers to nickname them 'cotton candy' planets.

The Football Shaped Planet

ARTIST ILLUSTRATION

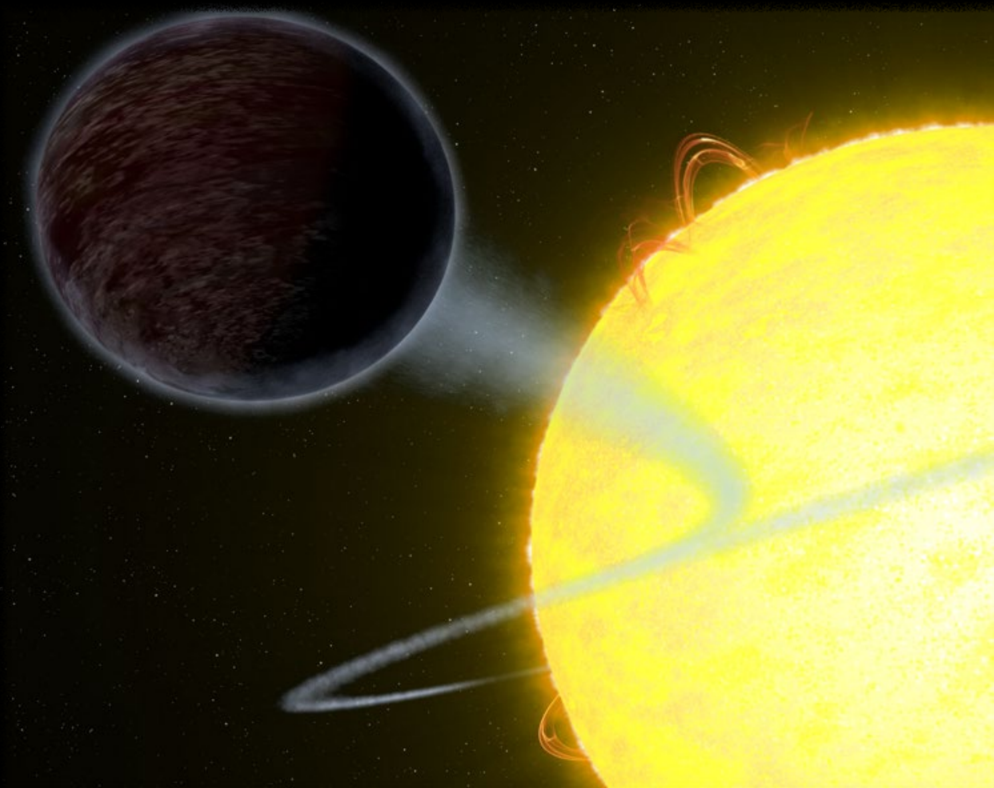


WASP-121b orbits so close to its host star that it is on the verge of ripping apart. Its upper atmosphere reaches a blazing 4,600 degrees Fahrenheit (2,540°C), causing magnesium and iron gas in the atmosphere to escape into space. Hubble observations of WASP-121b represent the first time astronomers detected elements more massive than hydrogen and helium escaping from a hot Jupiter-like planet. They also suggest the planet has a stratosphere, an atmospheric layer where temperature increases with higher altitudes.

A Blistering Pitch-Black Planet

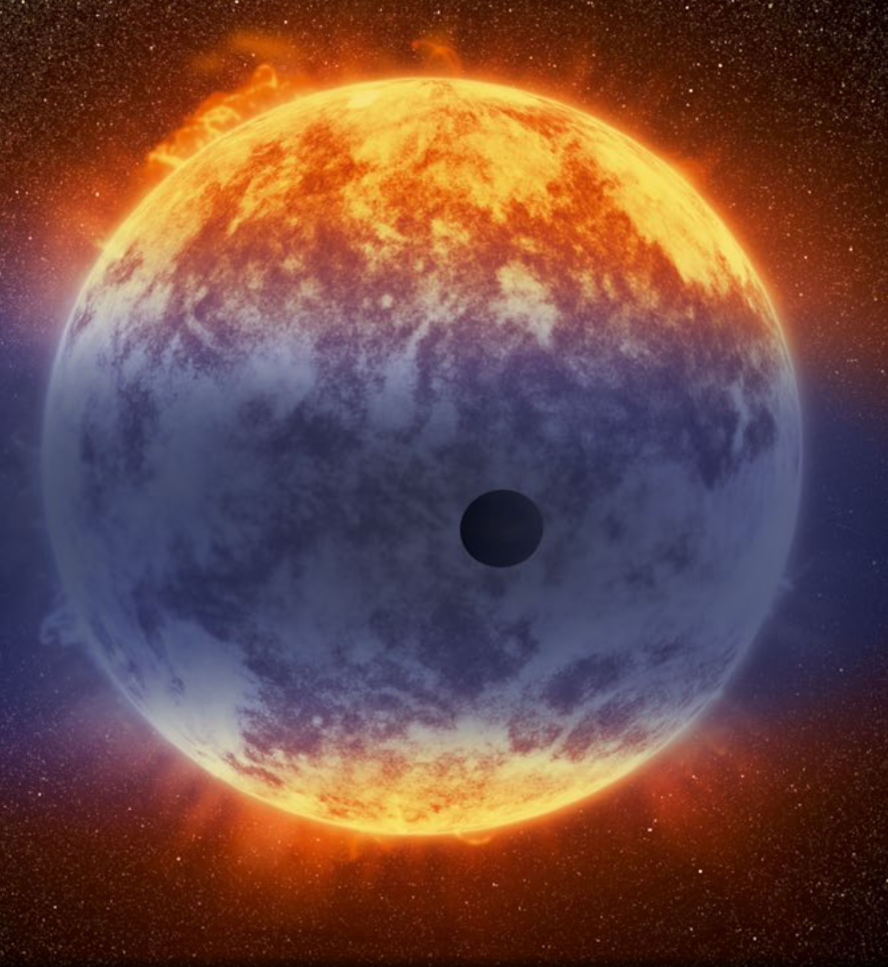
Hubble captured another odd, seething-hot world called WASP-12b located some 1,400 light-years away. This planet is as black as fresh asphalt and is unlike other planets in its class. WASP-12b traps at least 94 percent of the visible starlight falling into its atmosphere, heating it to 4,600 degrees Fahrenheit (2,540°C). The planet is twice the size of any planet in our solar system and orbits so close to its host that it is tidally locked, which means the same side always faces the star. Unlike the day side, the planet's night side is much cooler, some 2,200 degrees Fahrenheit (1,200°C), allowing water vapor and cloud formation. Hubble observations of the day/night boundary detected evidence of water vapor and possibly clouds and hazes in its atmosphere. WASP-12b is about 2 million miles (3 million km) away from its star and completes an orbit once a day.

ARTIST ILLUSTRATION



An Evaporating Planet

ARTIST ILLUSTRATION

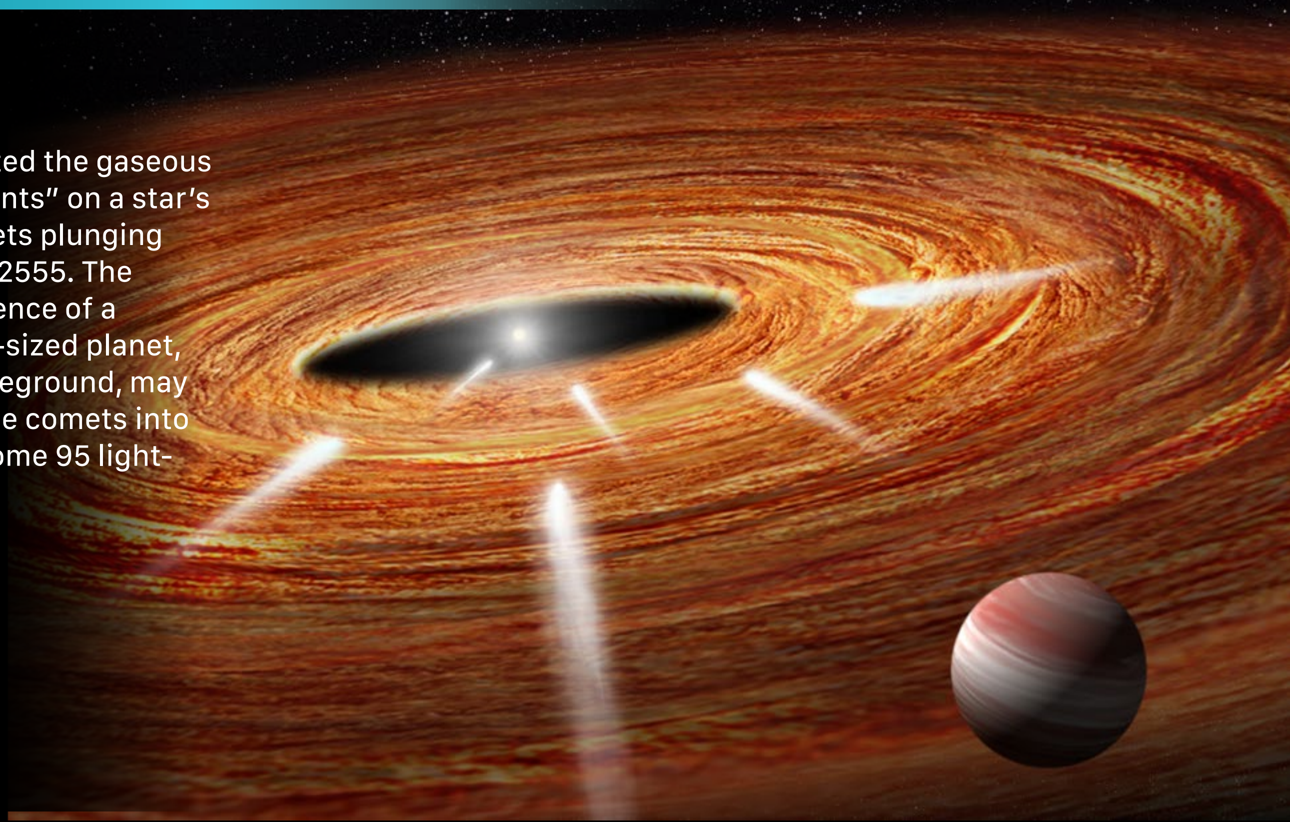


Hubble uncovered yet another odd and elusive planet called GJ 3470b. This Neptune-sized world is roughly 3.7 million miles (6 million km) from its star, about one-tenth the distance between Mercury and the Sun. The planet is so close to its host star that its atmosphere is evaporating. The escaping gas forms a giant cloud around the planet that Hubble's Space Telescope Imaging Spectrograph detected. Researchers estimate that the planet has lost as much as 35 percent of its atmosphere over its lifetime.

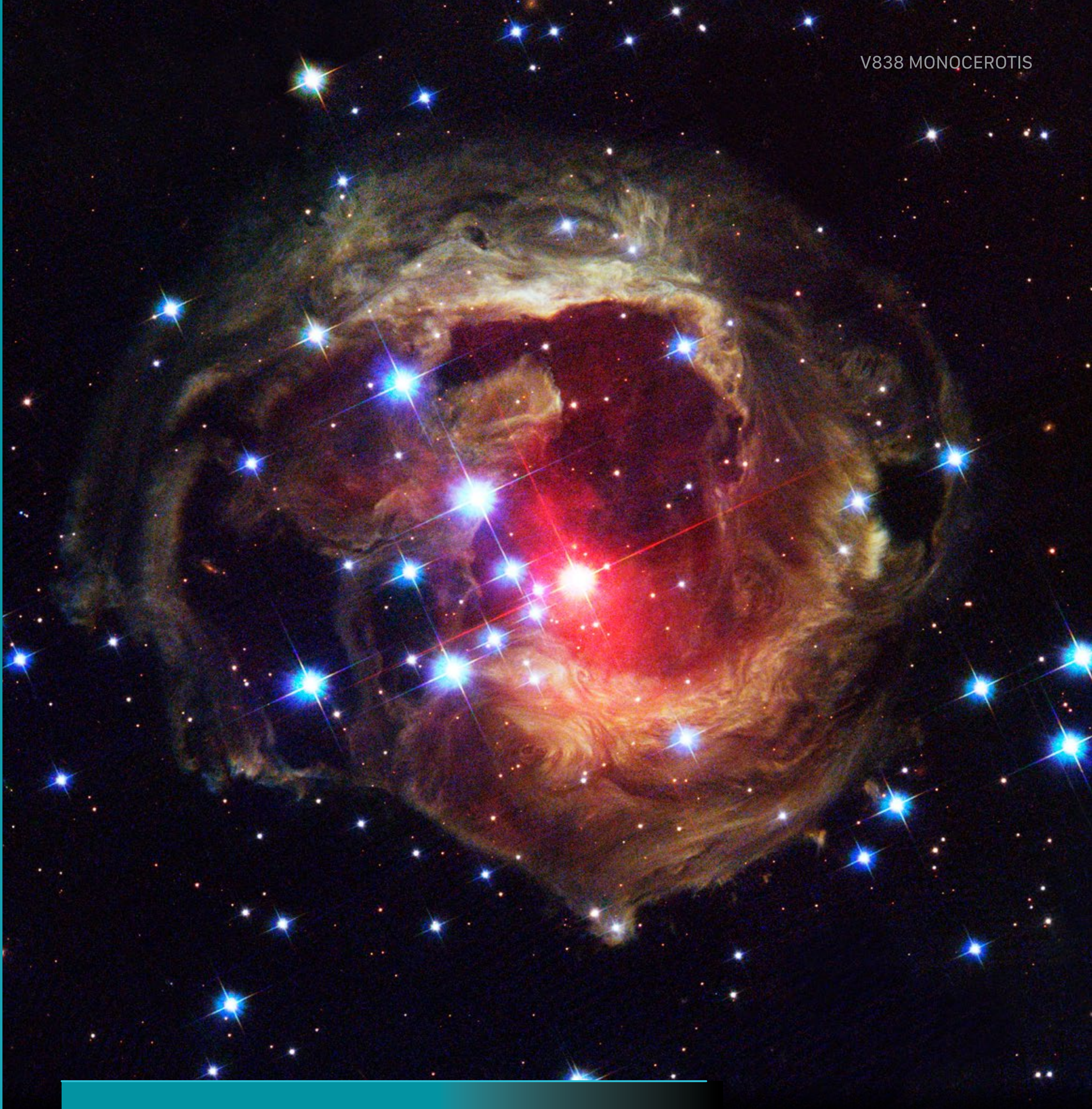
This isn't the first shrinking, warm, Neptune-sized planet Hubble observed. A few years earlier, Hubble found that one of the warmest known Neptunes (GJ 436b) is also losing its atmosphere. These evaporating Neptunes may explain the existence of so-called hot super-Earths, which could form from a similar process that strips away the atmosphere of Neptune-sized planets, exposing their rocky cores.

Exocomets Plunging into a Young Star

ARTIST ILLUSTRATION



Hubble also detected the gaseous spectral "fingerprints" on a star's light of small comets plunging into the star HD 172555. The gravitational influence of a suspected Jupiter-sized planet, depicted in the foreground, may have catapulted the comets into the star, located some 95 light-years from Earth.

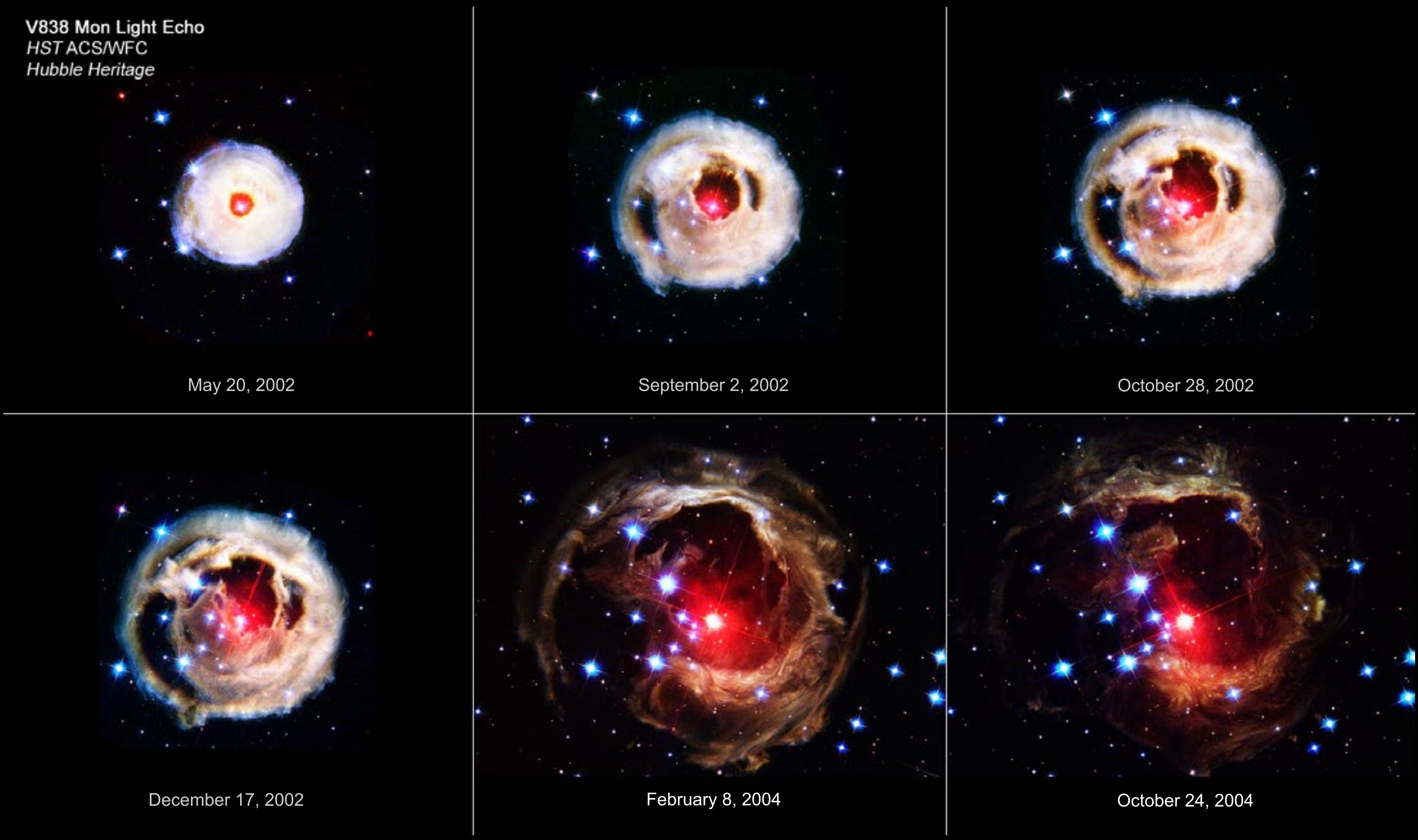


V838 MONOCEROTIS

Seeing Light Echoes

Like ripples on a pond, pulses of light reverberate through cosmic clouds forming echoes of light. Hubble has captured some of the best images of this reverberation of light through space.

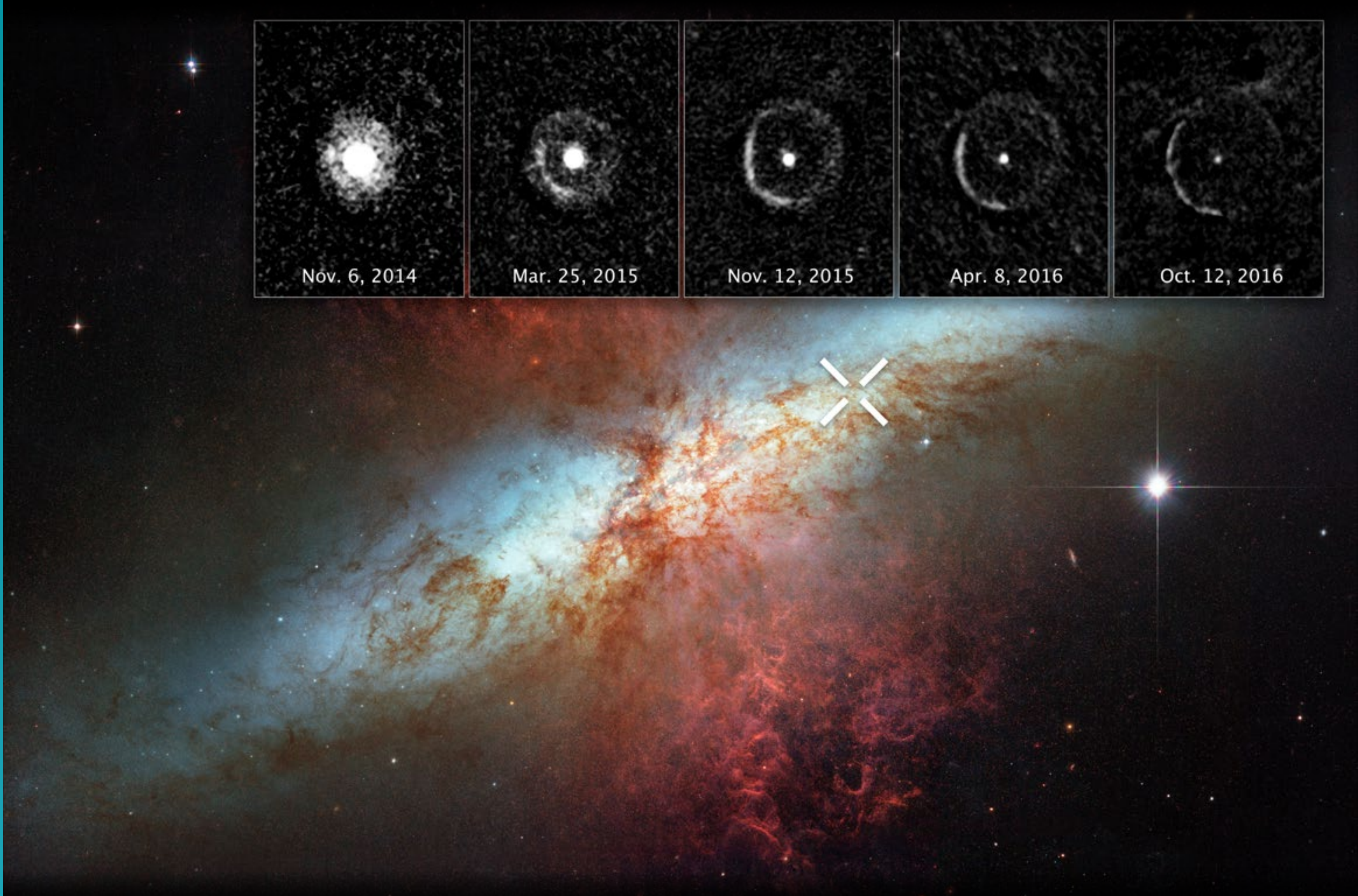
Expanding Light Echo of V838 Monocerotis



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, called a "light echo," is reminiscent of sound waves echoing down a canyon and "revealing" its walls.

View the **V838 Monocerotis movie**.

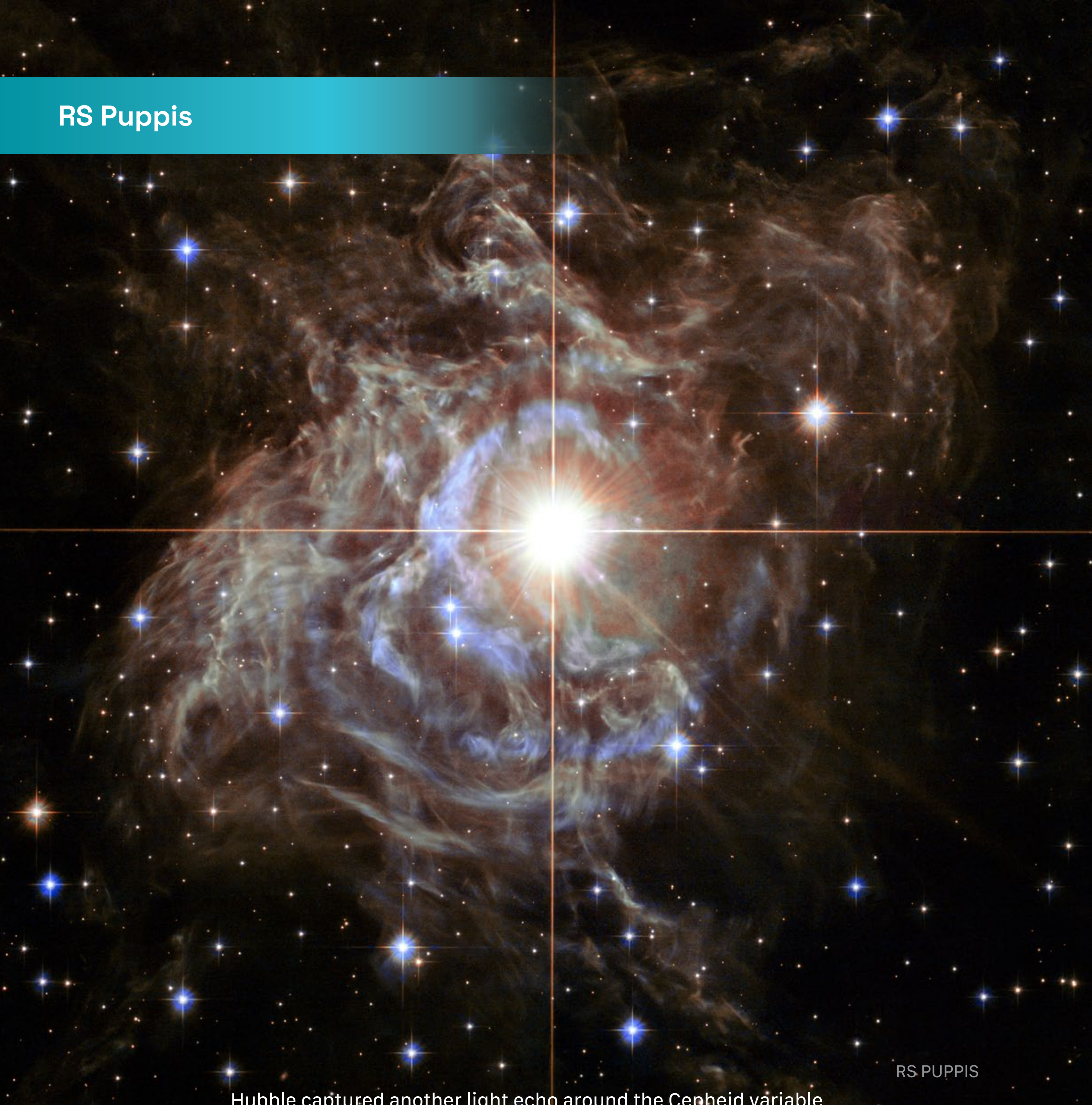
Light Echo Around an Exploded Star



SN 2014J IN M82

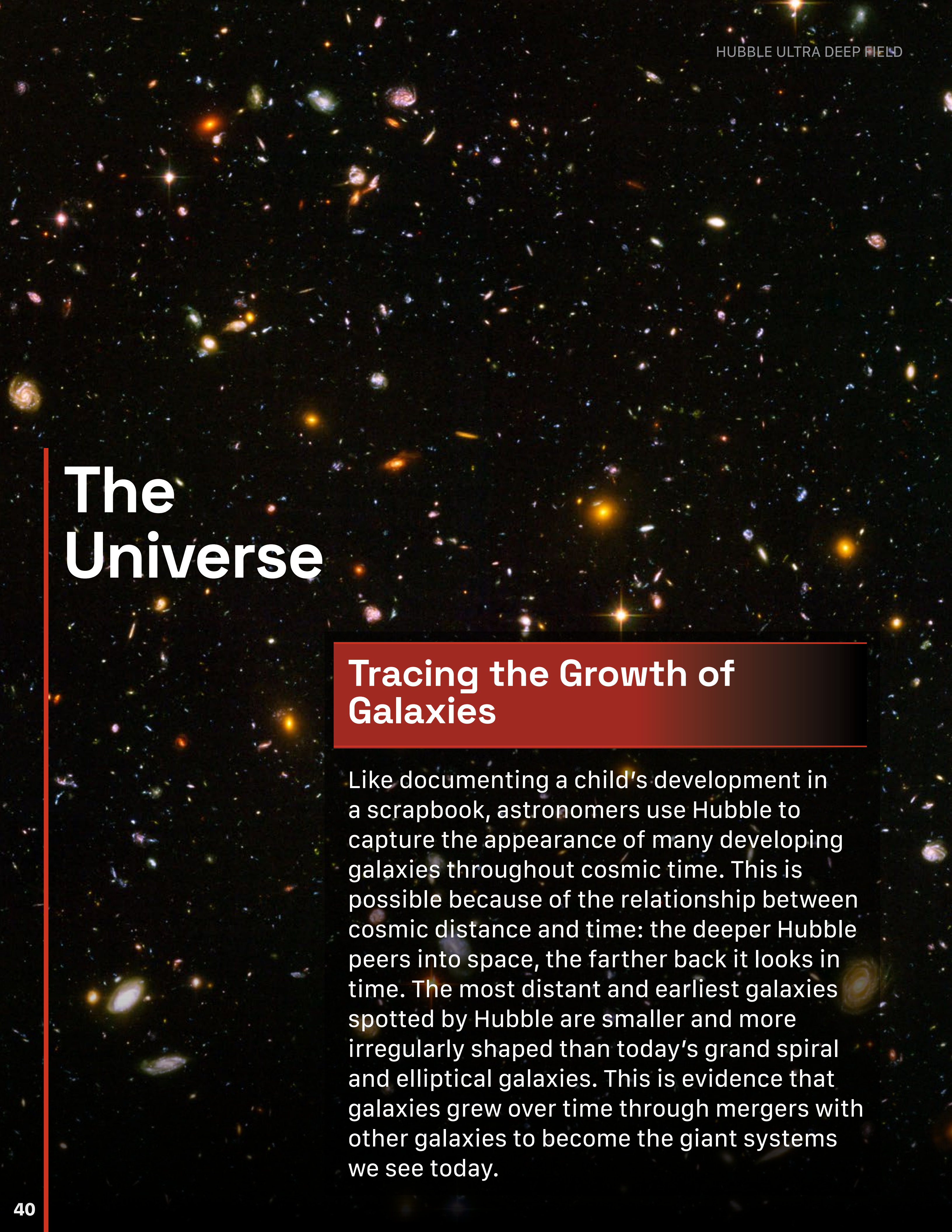
Two years' worth of Hubble images revealed "echoing" light in the expanding shell of an exploded star located some 11.4 million light-years away in the galaxy M82. An "X" marks the spot where astronomers discovered the supernova, called SN 2014J, on Jan. 21, 2014. The inset images along the top reveal the supernova's expanding shell of light as it travels through interstellar space, bouncing off a giant dust cloud that extends 300 to 1,600 light-years from the supernova and reflecting back toward Earth.

RS Puppis



Hubble captured another light echo around the Cepheid variable star RS Puppis in 2013. Each time the star pulsates, it sends another wave of light into the cloud of gas and dust that surrounds it. These rippling light flashes are similar to the ripples produced in a pond after throwing a series of stones into the water. To our eye, they create a ripple pattern that appears to be expanding outward from the star.

View the **RS Puppis Light Echo video**.



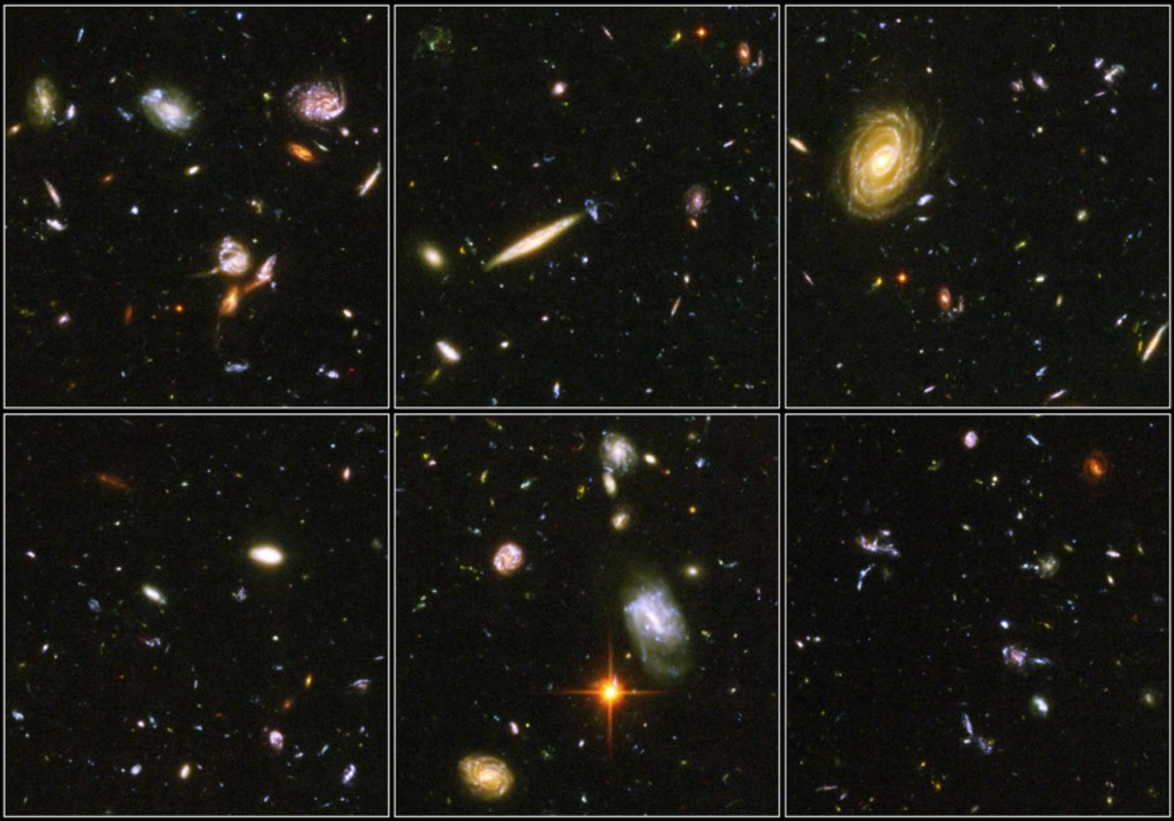
HUBBLE ULTRA DEEP FIELD

The Universe

Tracing the Growth of Galaxies

Like documenting a child's development in a scrapbook, astronomers use Hubble to capture the appearance of many developing galaxies throughout cosmic time. This is possible because of the relationship between cosmic distance and time: the deeper Hubble peers into space, the farther back it looks in time. The most distant and earliest galaxies spotted 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.

Hubble Ultra Deep Field Detail



The Hubble Ultra Deep Field contains an estimated 10,000 galaxies. In ground-based images, the patch of sky in which these galaxies reside (roughly the area of sky seen through the eye of a needle held at arm's length) is largely empty. Hubble's deep field view uncovered a menagerie of galaxy types, shapes, sizes, and ages that help us chart how galaxies evolve over time.

Illustration of the Andromeda Galaxy and the Milky Way Collision

Hubble observations of our neighbor, the Andromeda galaxy (M31), show that the galaxy is moving ever closer to an inevitable collision with our own Milky Way. Andromeda is currently 2.5 million light-years away, but it and the Milky Way are moving toward each other under the mutual pull of gravity between the two galaxies and the invisible dark matter that surrounds them both. The merger will begin about 4 billion years from now and will likely result in the creation of a giant elliptical galaxy.

ARTIST ILLUSTRATION

THE ANTENNAE (NGC 4038, NGC 4039)

Galaxy Details and Mergers

Astronomer Edwin Hubble pioneered the study of galaxies based simply on their appearance and categorized them according to three basic shapes: spiral, elliptical, and irregular. Some 60 years later, the sharp vision of the space telescope named in his honor began seeing unprecedented details in galaxies, revealing intricate, dark dust lanes and glowing knots of star formation. Hubble observations showed galaxies often interact, that mergers are common, and that galaxies grow and evolve by merging.

The Mice
(NGC 4676)

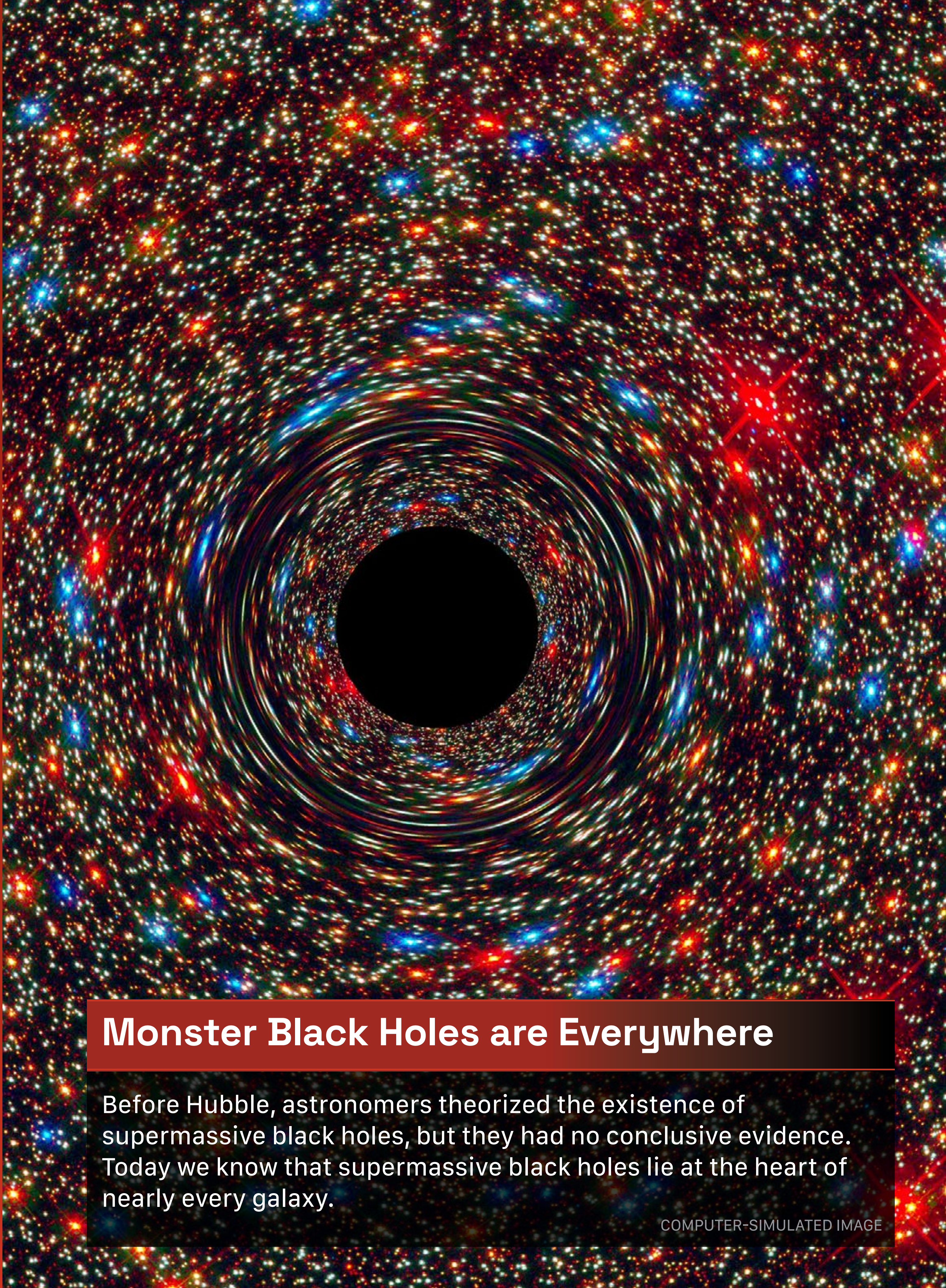
The Hubble telescope captured merging galaxies that look like a "Great Pumpkin," a "Space Triangle," "Antennae," and "Mice." For all their violence, galactic collisions take place at a snail's pace — over timescales that span several hundred million years. Hubble captures a mere snapshot of these mergers.

Hubble images of the "tadpole-like" Antennae and Mice galaxies reveal the gravitational turbulence these galaxies endure. The interacting duo called Arp 143 (the "Space Triangle") holds a pair of distorted, star-forming spiral galaxies. Astronomers think the pair passed through each other, igniting a triangular firestorm of new stars.

Mergers like this preview the coming collision between our own Milky Way and the neighboring Andromeda galaxy 4 billion years from now.

Arp 143

Great Pumpkin
(NGC 2292, NGC 2293)

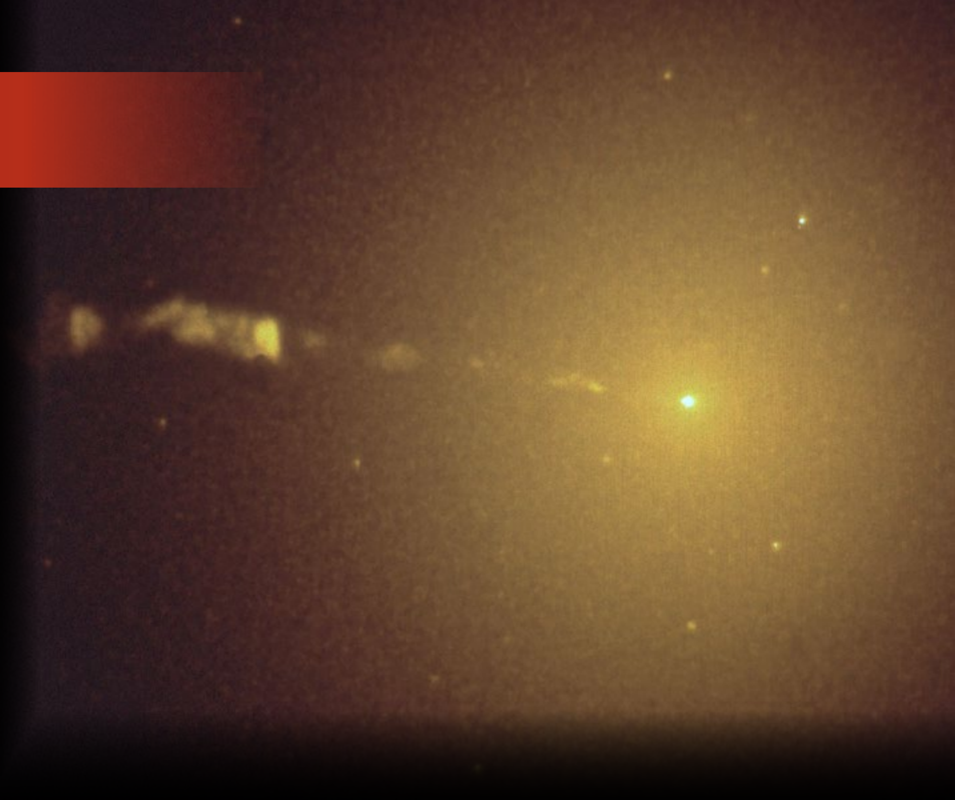


Monster Black Holes are Everywhere

Before Hubble, astronomers theorized the existence of supermassive black holes, but they had no conclusive evidence. Today we know that supermassive black holes lie at the heart of nearly every galaxy.

COMPUTER-SIMULATED IMAGE

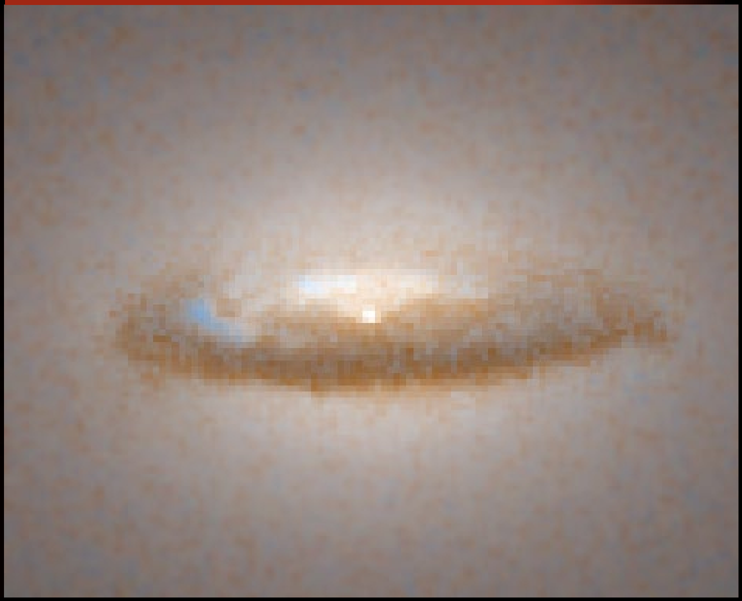
Compact Core of M87



Direct evidence of supermassive black holes didn’t come until 1994 when Hubble’s Faint Object Camera observed the heart of the giant elliptical galaxy M87. Hubble’s observations found a whirlpool of hot, ionized gas orbiting the heart of the galaxy at a speed of about 1.2 million miles per hour (550 km per second). Only a supermassive black hole would have the gravitational power to create a vortex of hot gas at such velocities.

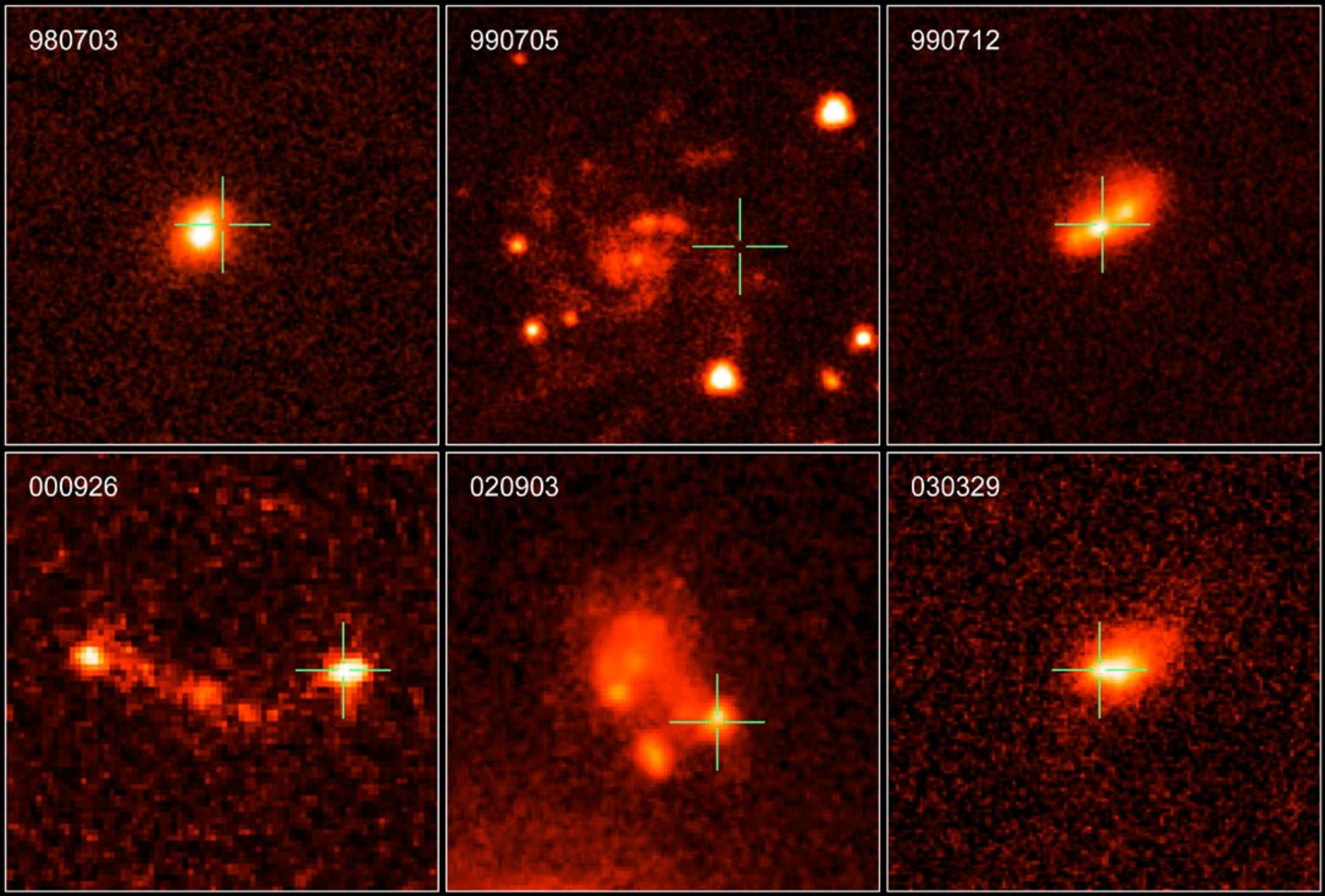
Core of Galaxy NGC 4261

Core of Galaxy NGC 7052



Supermassive black holes are millions to tens of billions of times the mass of the Sun. Hubble images reveal disks of dust that fuel black holes at the centers of galaxies, and a Hubble galaxy census 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 and intrinsically linking the black hole to the galaxy’s evolution.

Black holes aren’t all supermassive and lurking at the cores of galaxies. Astronomers estimate that 100 million black holes roam the stars of our Milky Way alone, and these each have a mass closer to that of a single star. In 2022, two teams using Hubble data measured how a suspected isolated black hole’s gravity acted like a lens, warping and deflecting the light from a background star. Their measurements indicate the lensing object’s size is either a black hole or a compact neutron star.

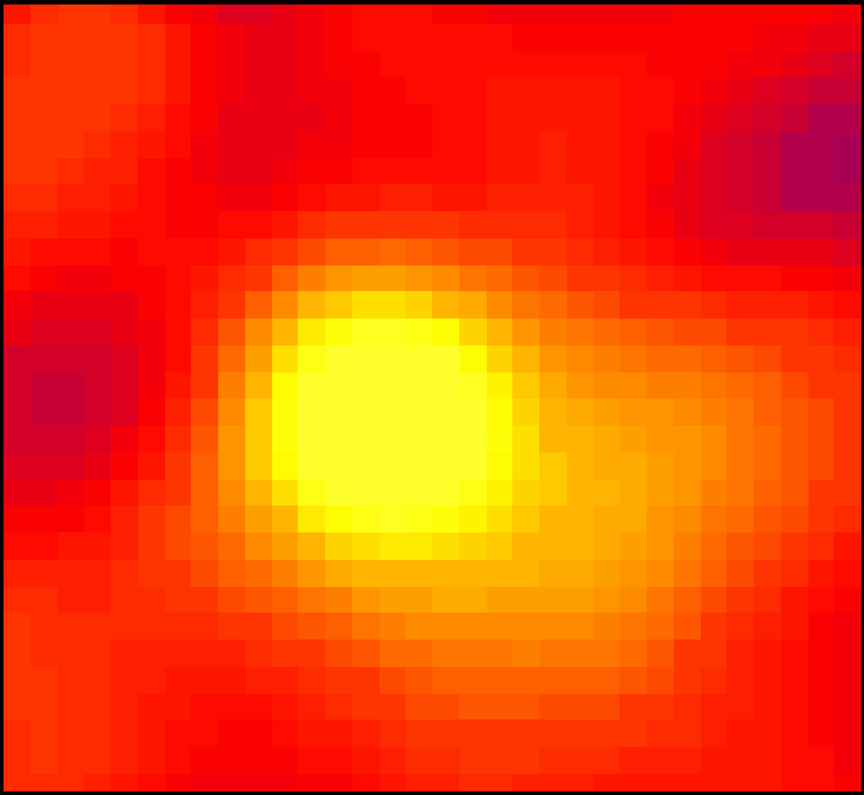


GRB HOST GALAXIES

Homing in on Cosmic Explosions

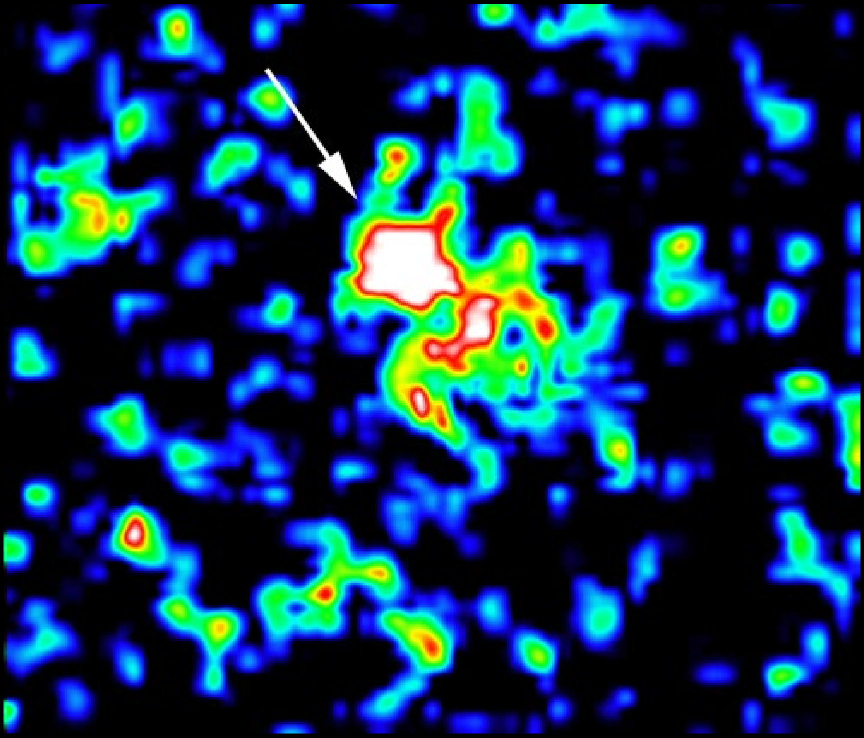
For decades, astronomers pondered the source of one of the most energetic and mysterious events in the universe, gamma-ray bursts (GRB). In a few seconds, GRBs can emit more energy than the Sun over its entire 10-billion-year life. It wasn't until Hubble began observing the visible source of these events that astronomers began to better understand their origins.

GRB 990123



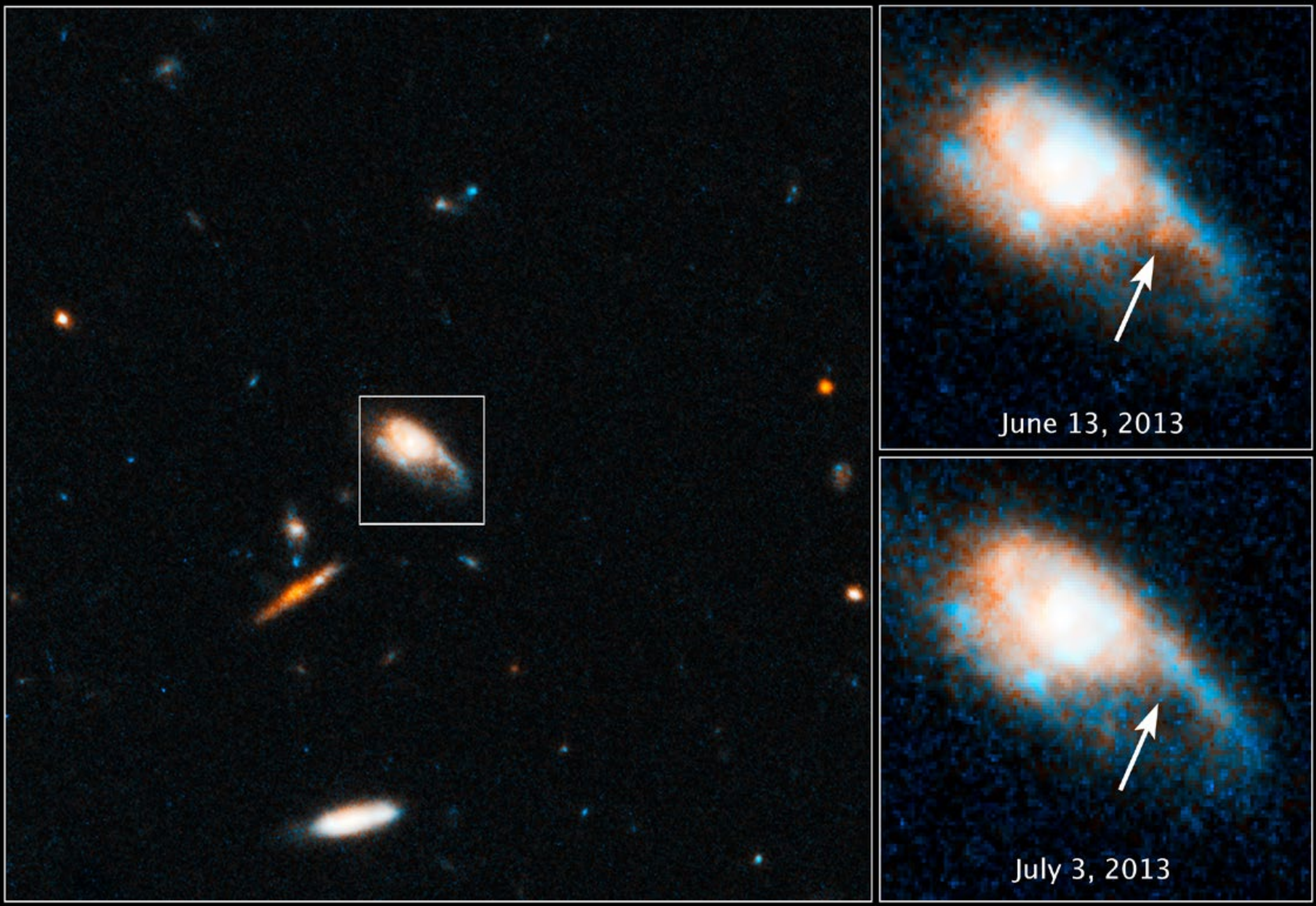
In 1997, astronomers employed Hubble's high resolution and sensitivity to hunt down a rapidly dimming fireball in the region of space that had produced a GRB. The explosive remnant rapidly faded, and ground-based observatories could no longer see it. Hubble observations allowed astronomers to continue following the fading source, and clearly showed that it had two components: a point-like object and an extended feature.

GRB 970228



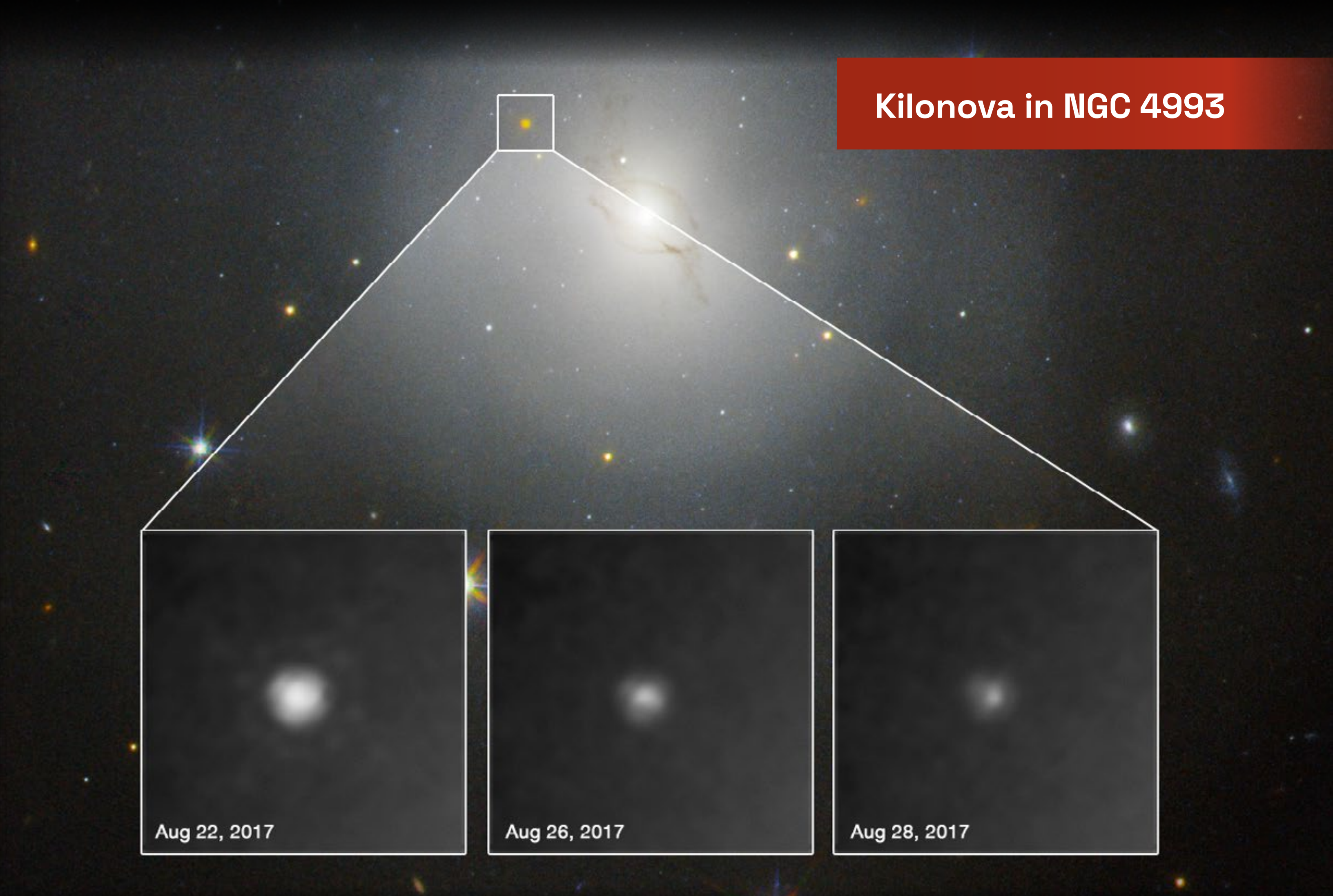
Soon after the GRB 990123 observations, Hubble's Wide Field and Planetary Camera 2 captured the first visible light image that associates a gamma-ray burst source with a potential host galaxy. The bright source was not near the center of the galaxy — which might have suggested it came from a black hole at the galaxy's heart — but on the outskirts.

GRB 130603B



On June 13, 2013, Hubble observed a rapidly fading fireball produced in the aftermath of GRB 130603B, whose initial blast lasted only one-tenth of a second. The Hubble observation revealed a new kind of stellar blast called a kilonova, an explosion that astronomers predicted would accompany short-duration GRBs. This kilonova provided strong evidence that short-duration gamma-ray bursts are the result of a merger of two small, super-dense stellar objects, such as a pair of neutron stars or a neutron star and a black hole.

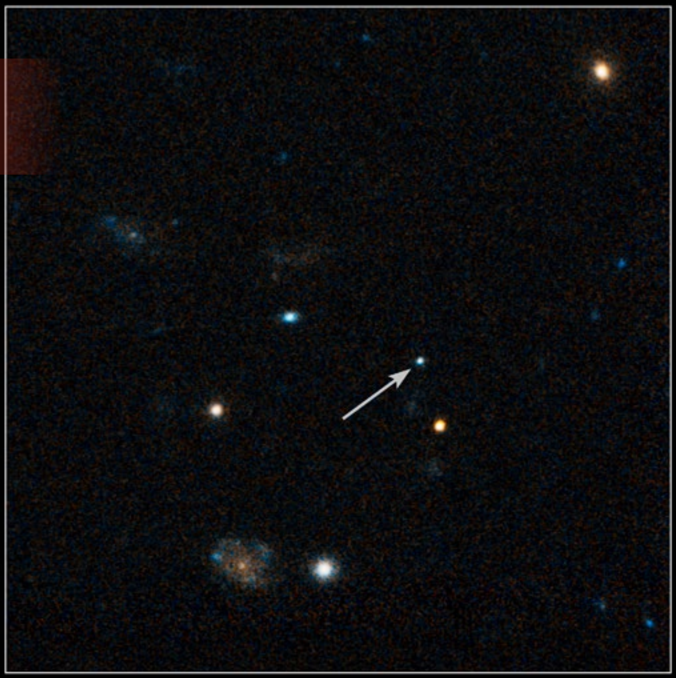
Kilonova in NGC 4993



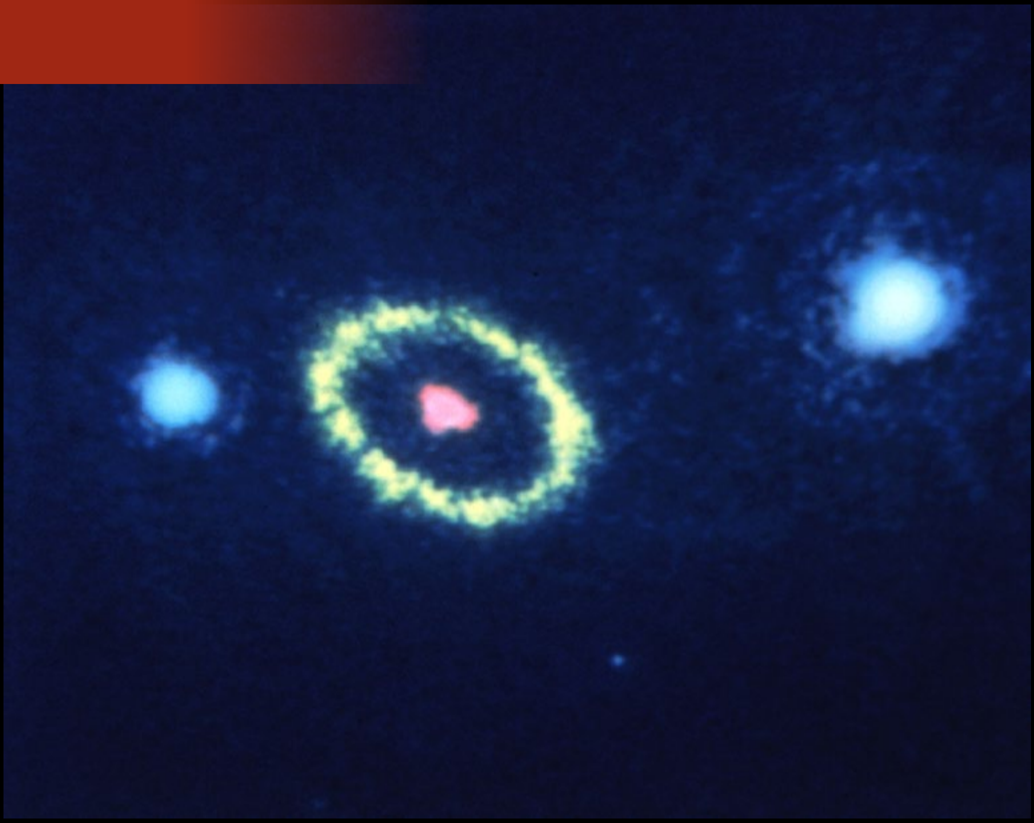
Then, in August 2017, Hubble was part of a team of observatories that observed a kilonova explosion accompanying the merger of two neutron stars and the related gravitational waves. Seventy observatories around the globe observed the merger's aftermath. Hubble's precise measurements allowed astronomers to pinpoint the explosion site and revealed the speed of a jet moving at least 99.97% the speed of light.

GRB 080319B

Today, thanks in large part to Hubble observations, astronomers categorize GRBs into two types: Long GRBs (where the initial burst lasts two seconds or longer) and Short GRBs (where the burst lasts less than two seconds). Short bursts are associated with the collision of either two neutron stars or a neutron star and a black hole. Long bursts stem from the explosive, supernova deaths of massive stars.



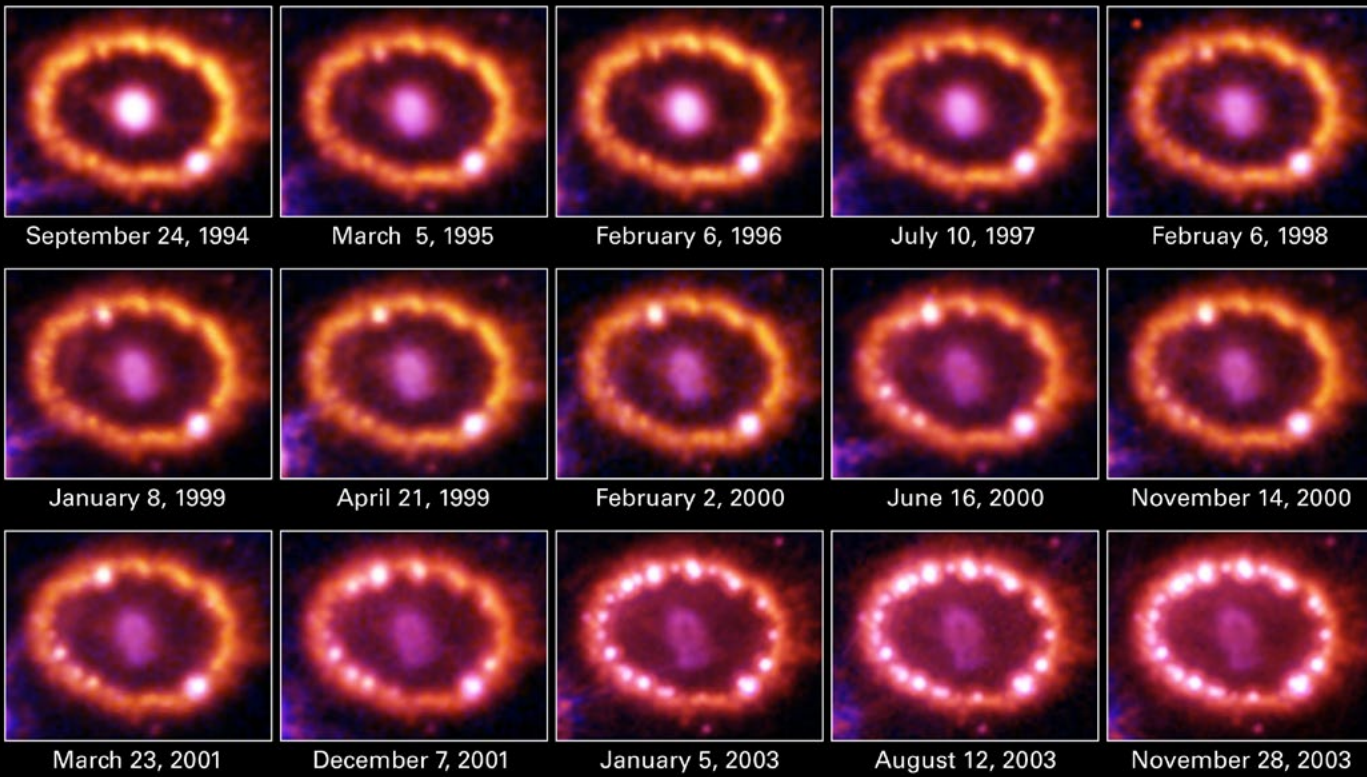
SN1987a
(August 1990)



Hubble's observations of supernovae have also played a key role in our understanding of these explosive star deaths. Its first observations of a supernova came just four months after its launch, when Hubble's Faint Object Camera resolved an elliptical ring of material around the remnants of Supernova 1987A (SN1987A).

SN1987a
(February 1994)

SN1987a
(1994-2003)

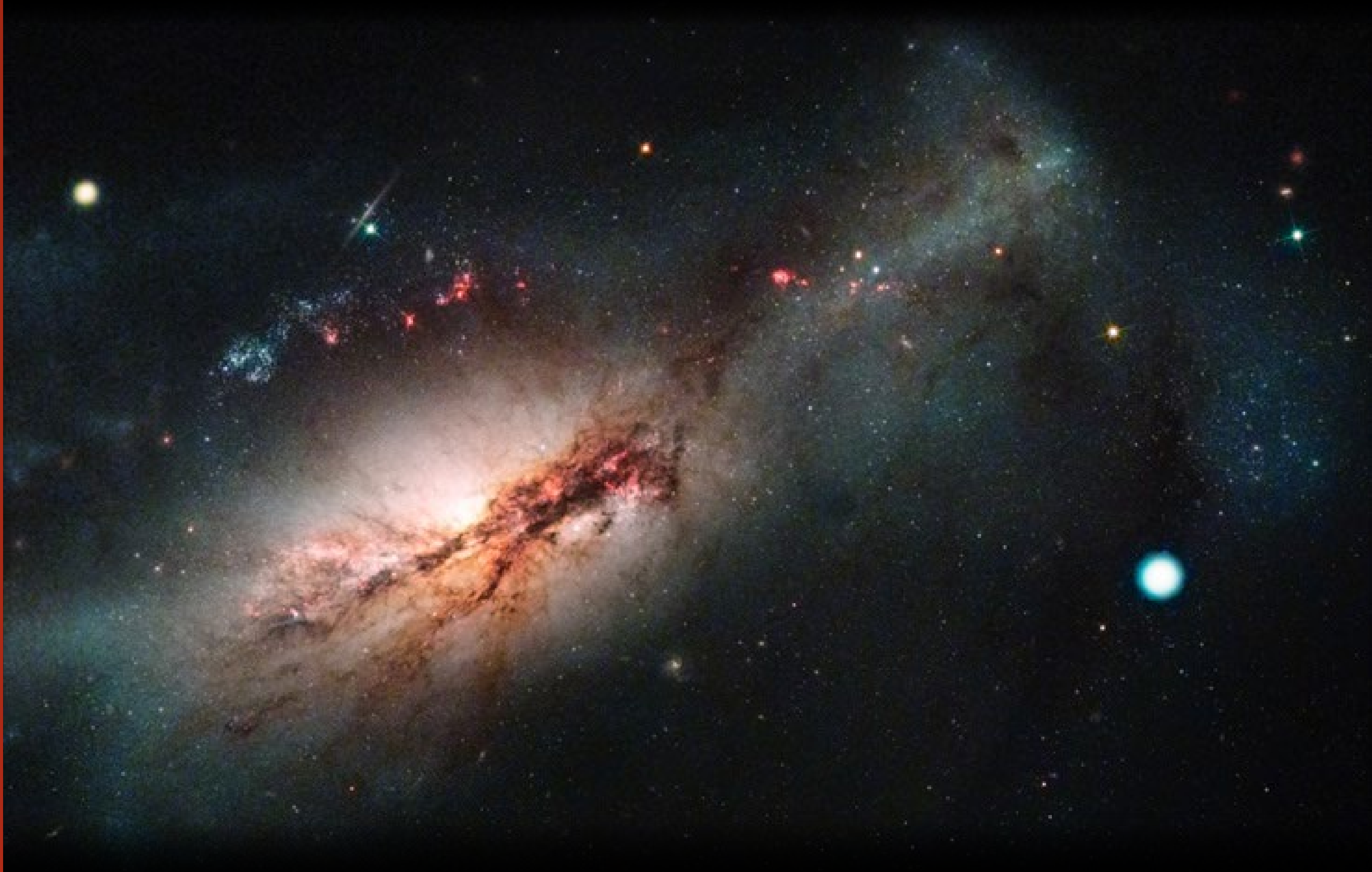


SN1987a
(2017)

SN 1987A was the brightest exploding star astronomers saw in 400 years. Hubble's sensitivity, resolution, and longevity allow it to keep track of SN1987a's evolution, collecting 7,000 data sets for some 250 scientific proposals as of July 2024. This data revealed rings in different planes in 1994. The bright central ring is about one light-year across and existed when the star exploded. The star likely shed the ring thousands of years before it went supernova. Ultraviolet radiation from the exploding star caused it to glow in early Hubble images. As the gas cooled, the ring faded until the blast's shock wave reached the ring causing it to brighten again.

SN 2018zd

COMPOSITE IMAGE



Astronomers found evidence of a hypothesized electron-capture supernova by comparing a Hubble image of the supernova, called SN 2018zd, with earlier Hubble images of the same area of sky. This allowed them to identify the supernova's progenitor star in the galaxy NGC 2146. Stars between eight and 10 times the mass of the Sun theoretically should explode in a different way. Their immense internal pressure would force electrons to fuse with atomic nuclei, causing a sudden drop in electron pressure that triggers the collapse and subsequent explosion of the star's surrounding layers.

SN 2020fqv

In April 2020, astronomers discovered a supernova inside the interacting Butterfly galaxies (NGC 4568). They quickly trained Hubble on the aftermath and got a ringside view of the supernova in the very earliest stage of exploding. Hubble viewed a region very close to the supernova, examining material ejected by the star in the last year of its life. These observations may provide astronomers with an early warning system for other stars on the brink of an explosive death.

Discovering the Runaway Universe

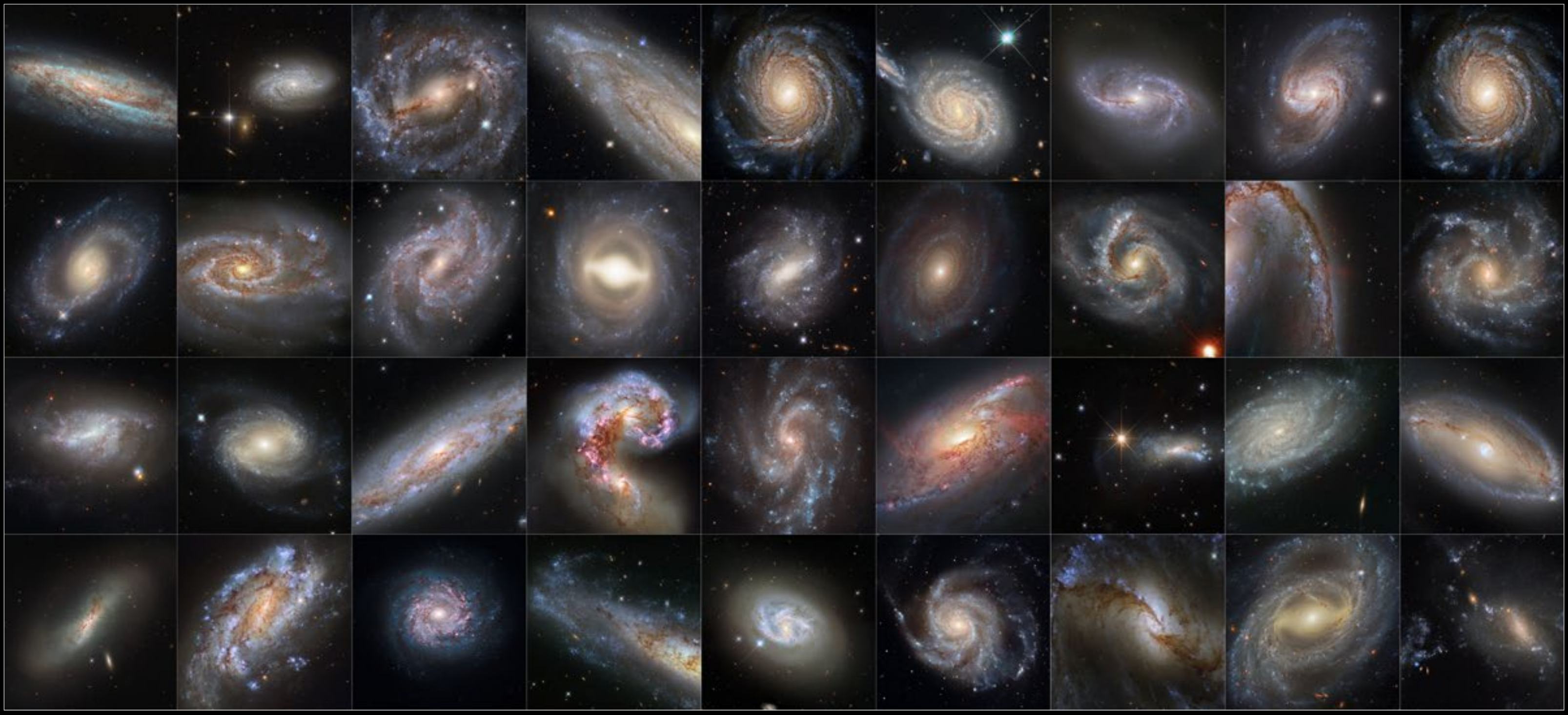
Nearly a century after astronomer Edwin Hubble discovered that the universe is expanding, the telescope named in his honor refined his distance measurements. Astronomers use Hubble to measure distances by comparing the brightness of a known object (like a star or supernova) to that of similar objects in a distant galaxy. They couple those distances with the best galaxy-velocity measurements obtained from other telescopes. After more than three decades of observations, teams using Hubble's extraordinary capabilities have measured the expansion rate (called the Hubble Constant) to a precision of just over 1%, about eight times more precise than they originally anticipated! This value for the Hubble Constant puts the age of the universe at about 13.8 billion years old. However, there is a twist… Our universe is not only growing, but that expansion rate is accelerating.

HUBBLE DEEP UV GOODS-NORTH FIELD

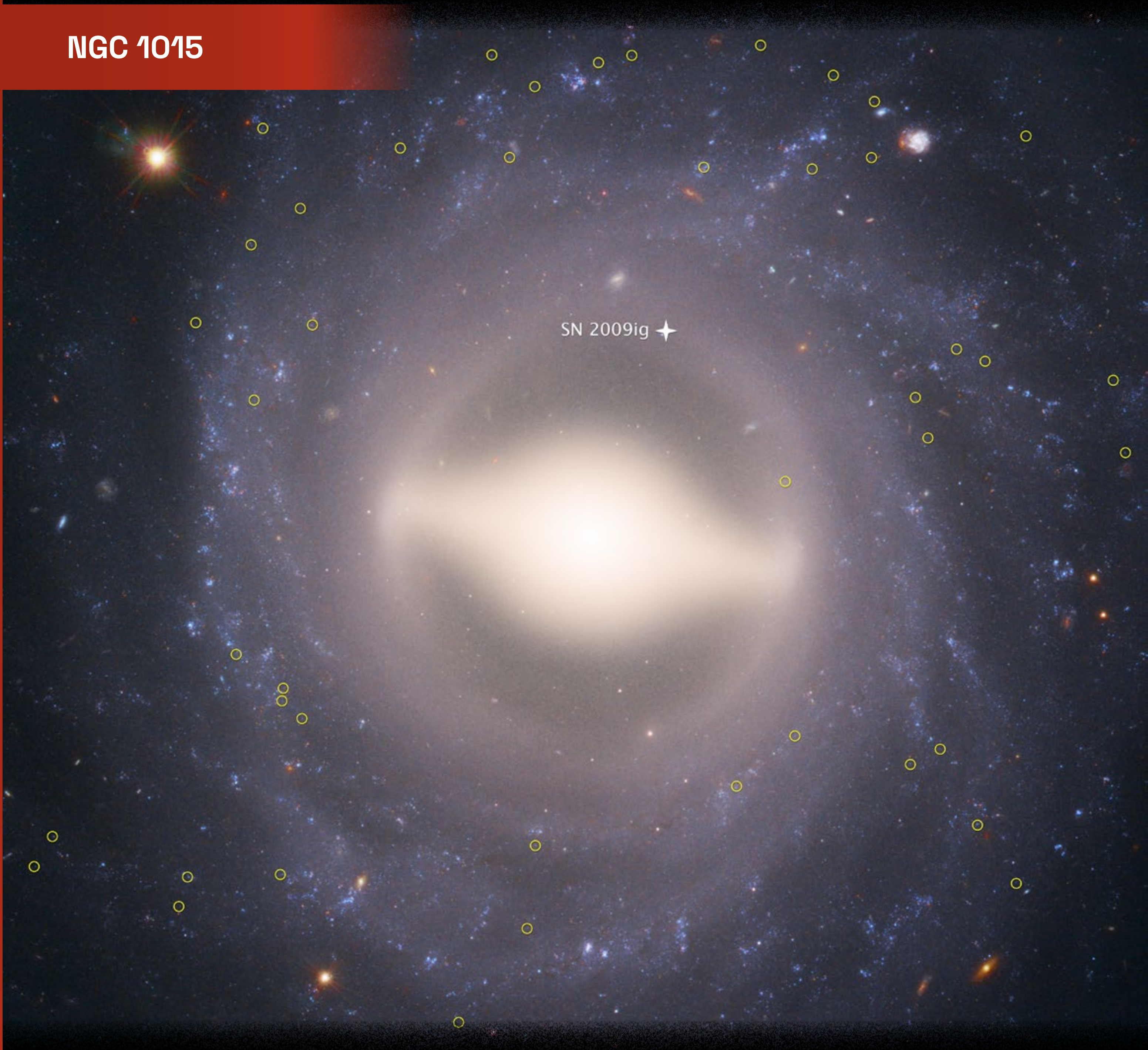
Andromeda Galaxy Cepheid Variable

Hubble observations, along with those of ground-based observatories, surprised astronomers by revealing that the universe is not just expanding but accelerating — a discovery that won the 2011 Nobel Prize in Physics. Astronomers use stars like Cepheid variables and Type Ia supernovae to determine astronomical distances because these types of stars have well-known brightness curves.

Supernova and Cepheid Variable Host Galaxies



NGC 1015

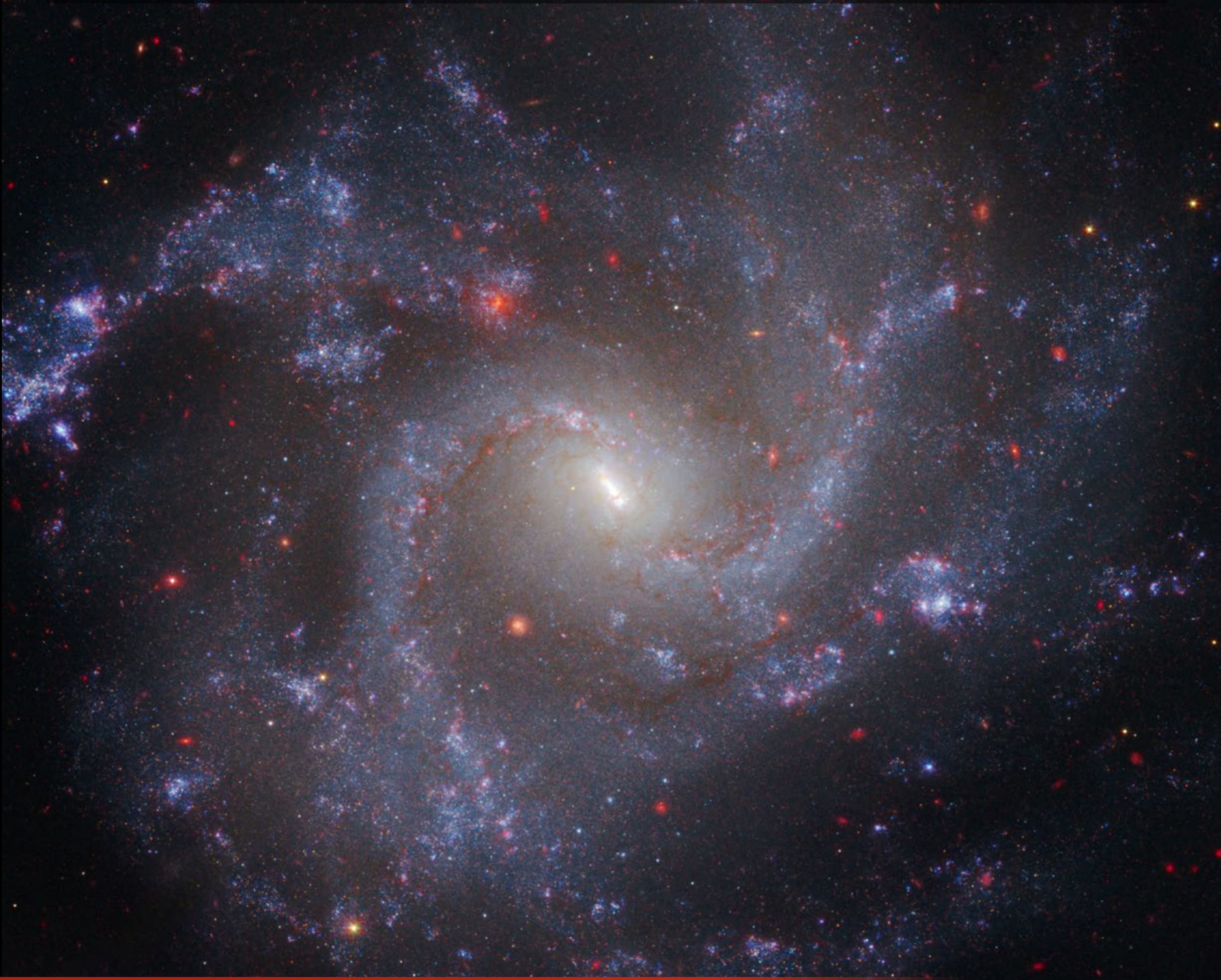


To improve the precision of the Hubble constant, astronomers analyzed Hubble data from 19 galaxies, including NGC 1015. This color-composite of NGC 1015 holds yellow circles that represent the location of Cepheid variable stars. Cepheids are excellent beacons for measuring accurate distances to nearby galaxies because their pulsation rate closely matches their intrinsic brightness.

Type Ia supernovae are also good indicators because they all peak at the same brightness. Astronomers use the difference between the intrinsic peak brightness and how bright it appears to calculate how far away the supernova must be. The small cross-shape near the top of the galaxy denotes the location of a Type Ia supernova.

Comparing both Cepheids and Type Ia supernovae in nearby galaxies allows astronomers to calibrate the brightness of Type Ia supernovae in more distant galaxies, which helps refine their overall measurements of the Hubble Constant.

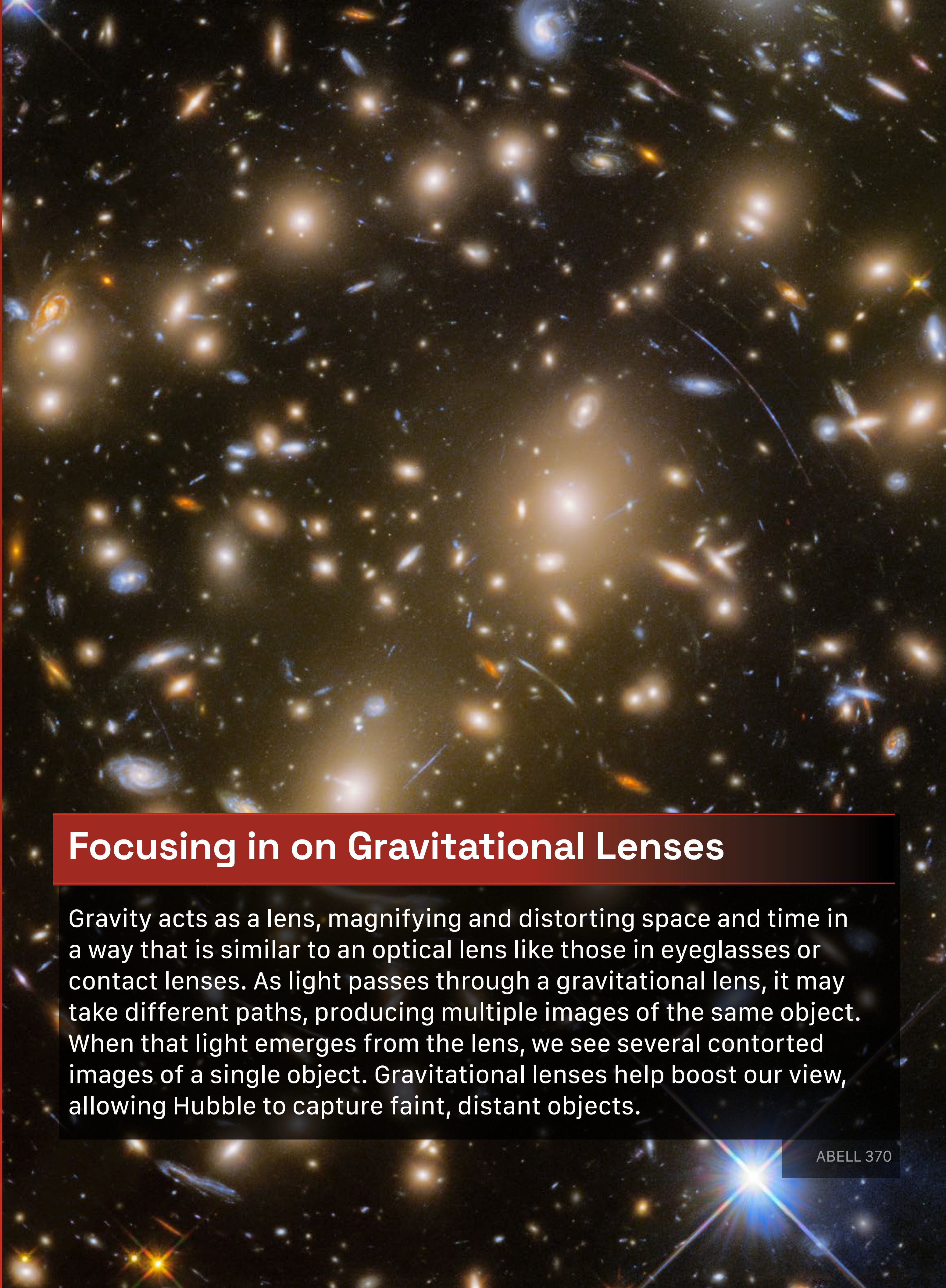
In 2023, to try to eliminate the possibility of measurement errors, researchers used NASA's James Webb Space Telescope to test their Hubble results. Those observations confirmed Hubble's results, leading some scientists to suggest that something else — not measurement errors — is influencing the expansion rate.



Hubble (WFC3) & Webb (NIRCam) Image of NGC 5468

Many scientists believe an invisible force, called "dark energy," causes this acceleration. We can think of dark energy as an "antigravity" or repelling force that pushes galaxies apart by stretching space at an increasing pace. Although current technology does not allow us to directly measure dark energy, we can characterize it by observing its effect on normal matter in the visible universe.

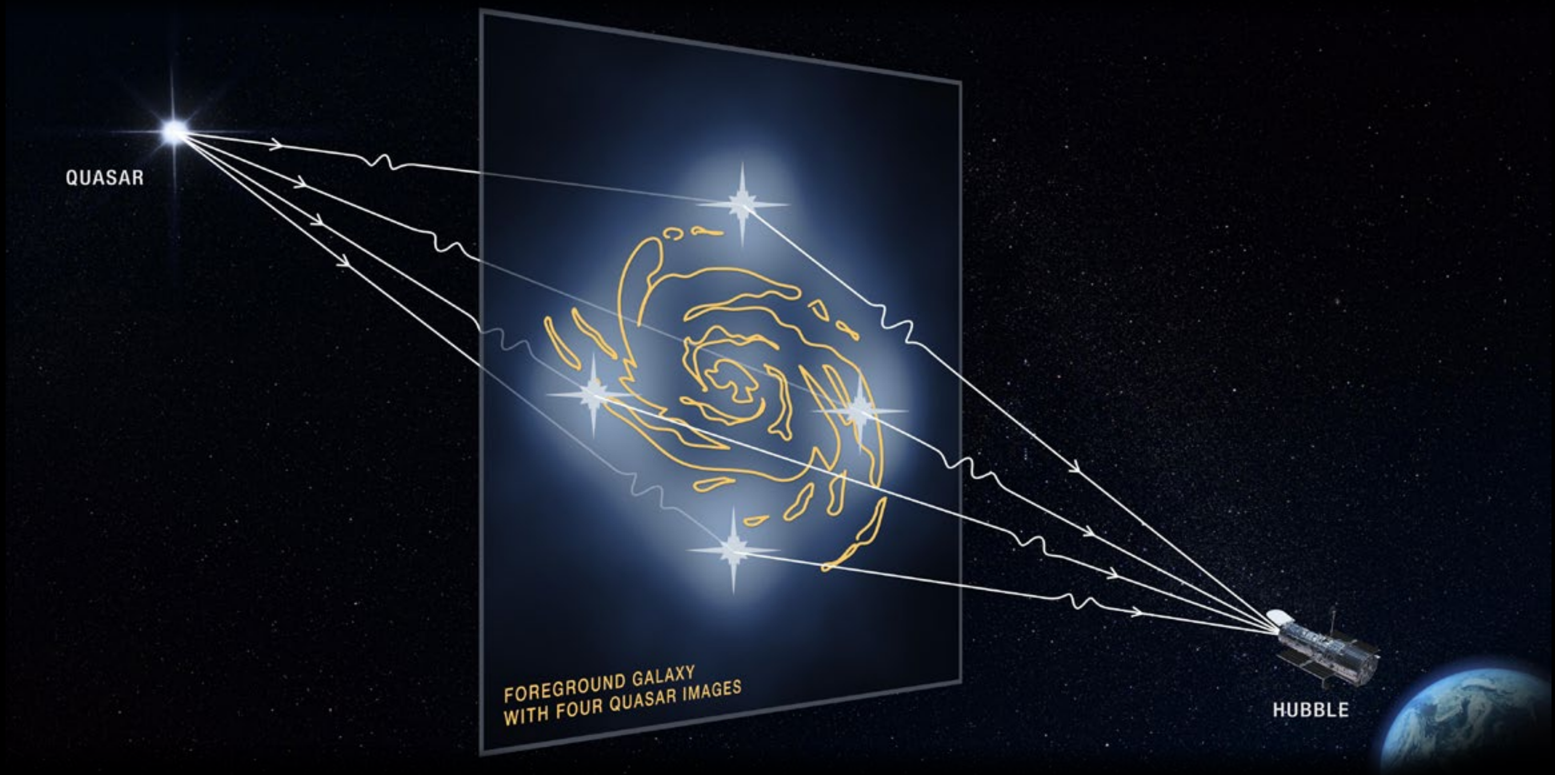
From these observations, scientists estimate that dark energy is about 68%, dark matter is about 27%, while normal matter and energy are only about 5% of the entire universe. By studying how dark energy behaves over time, astronomers hope to gain a better understanding of what it is and how it might affect the future of the cosmos.



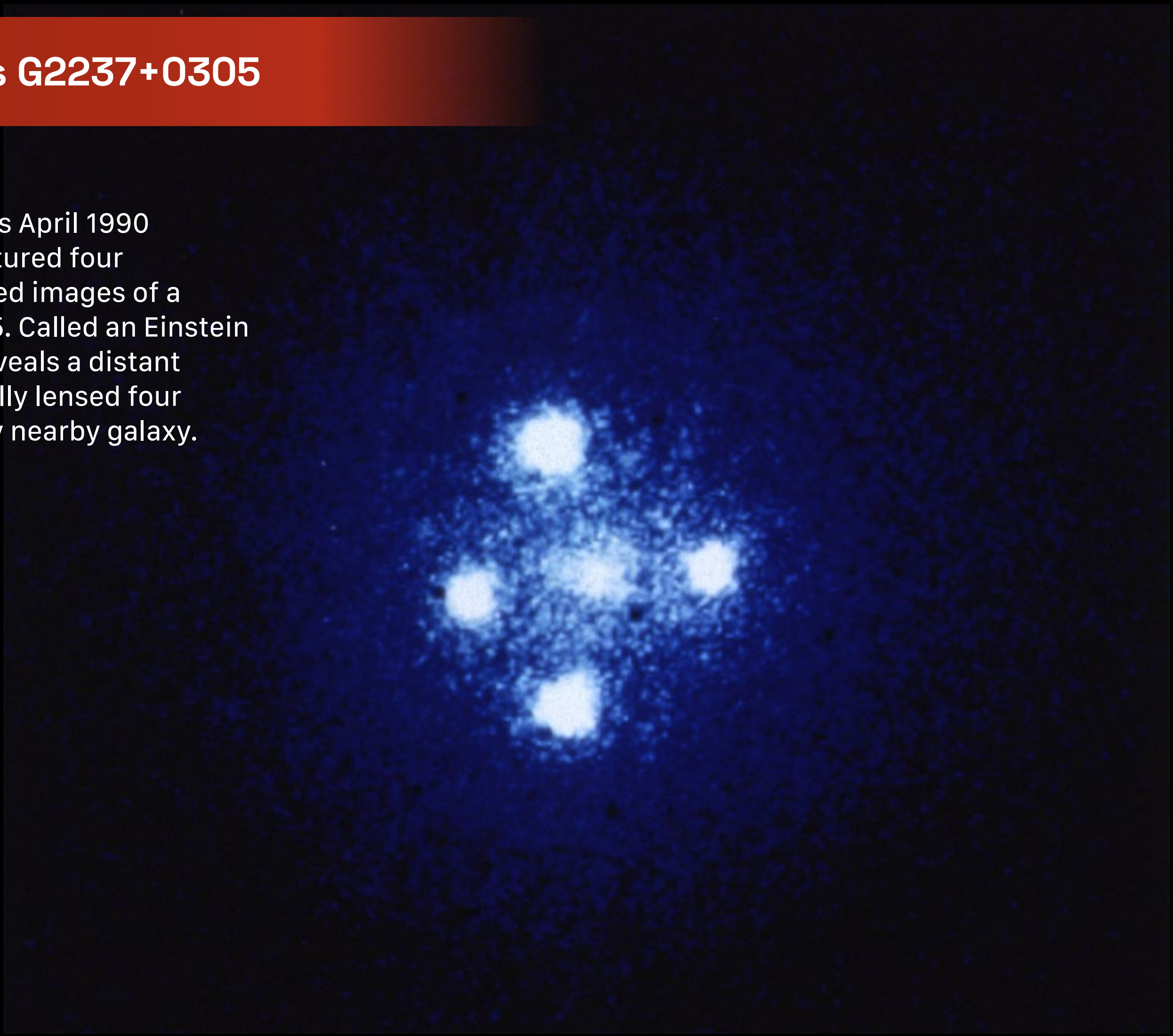
Focusing in on Gravitational Lenses

Gravity acts as a lens, magnifying and distorting space and time in a way that is similar to an optical lens like those in eyeglasses or contact lenses. As light passes through a gravitational lens, it may take different paths, producing multiple images of the same object. When that light emerges from the lens, we see several contorted images of a single object. Gravitational lenses help boost our view, allowing Hubble to capture faint, distant objects.

ABELL 370

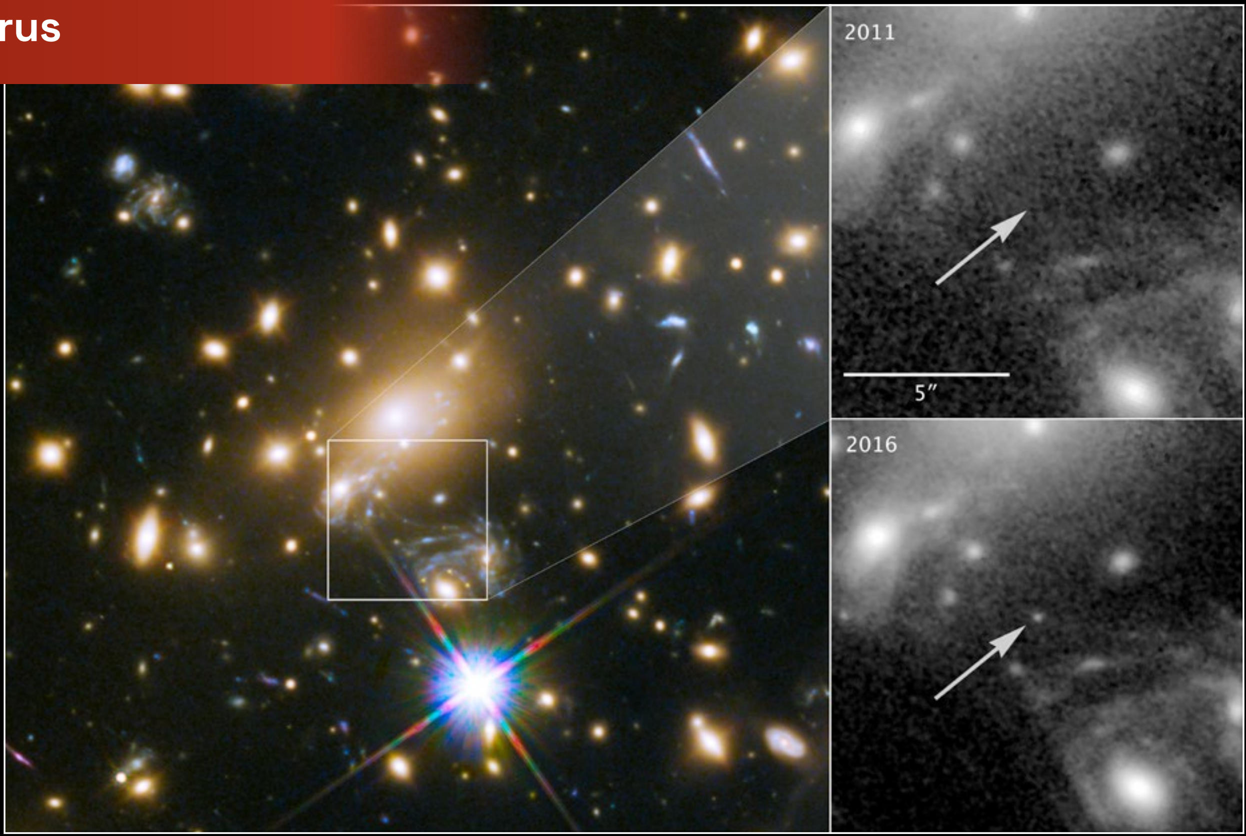


Einstein Cross G2237+0305



Five months after its April 1990 launch, Hubble captured four gravitationally lensed images of a quasar G2237+0305. Called an Einstein Cross, the image reveals a distant quasar gravitationally lensed four times by a relatively nearby galaxy.

Icarus

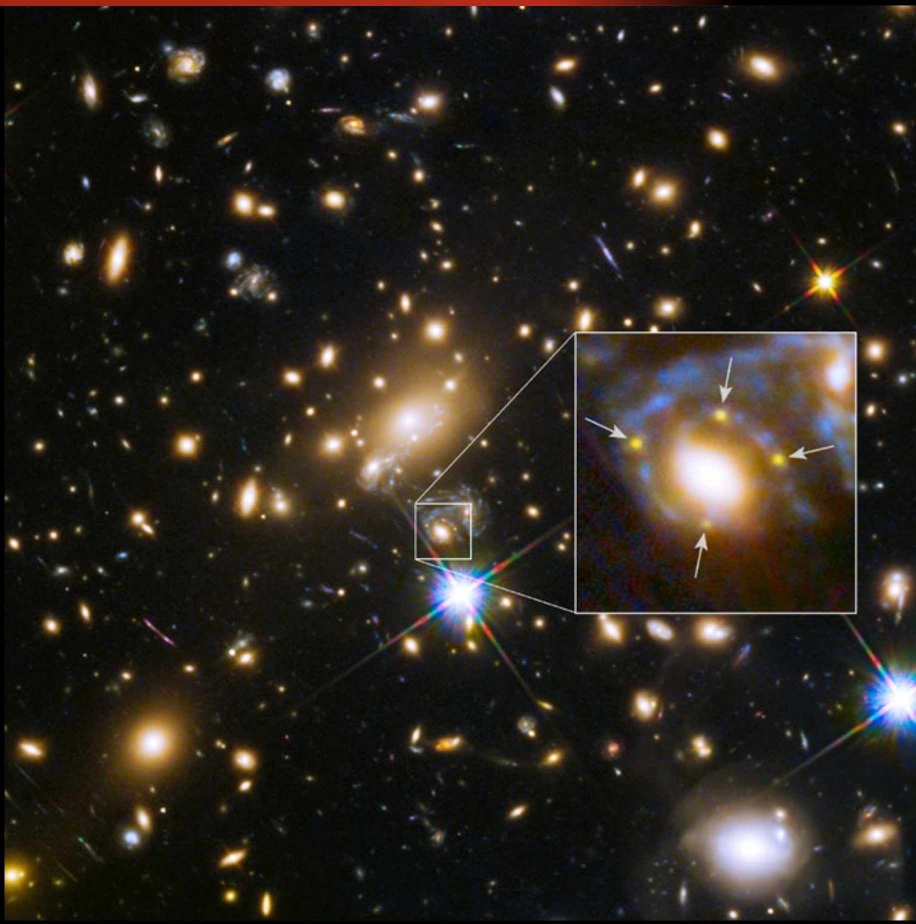


The enormous galaxy cluster MACS J1149.6+2223, located more than 5 billion light-years away, creates a gravitational lens that facilitated two of Hubble's most exciting discoveries using gravitational lenses. The first was Supernova Refsdal. Hubble captured the supernova because the gravitational lens created by a massive galaxy embedded in MACS J1149.6+2223 bent and magnified its light. Refsdal is some 4.3 billion light-years farther than MACS J1149.6+2223 or 9.3 billion light-years from Earth.

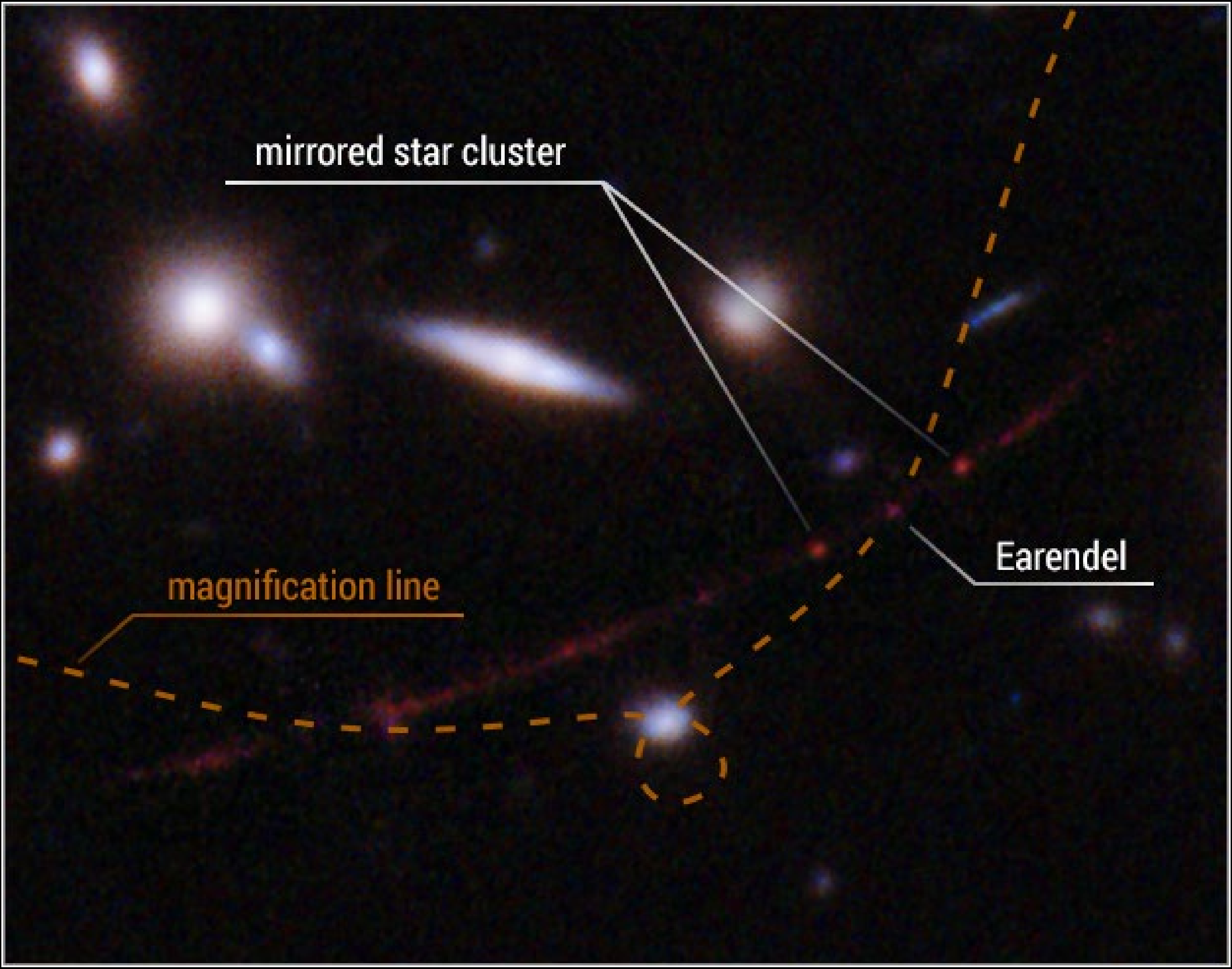
First discovered in 2014, astronomers calculated how Refsdal's light might move through MACS J1149.6+2223's enormous gravitational lens and predicted its reappearance. While looking for and finding the supernova's reappearance, they also found an enormous, distant, blue star they nicknamed Icarus.

Icarus is so far away that its light took 9 billion years to reach Earth. Because the star's light had such a long distance to travel, Hubble's observations captured the star as it appeared when the universe was about 30 percent of its current age.

Supernova Refsdal



Earendel



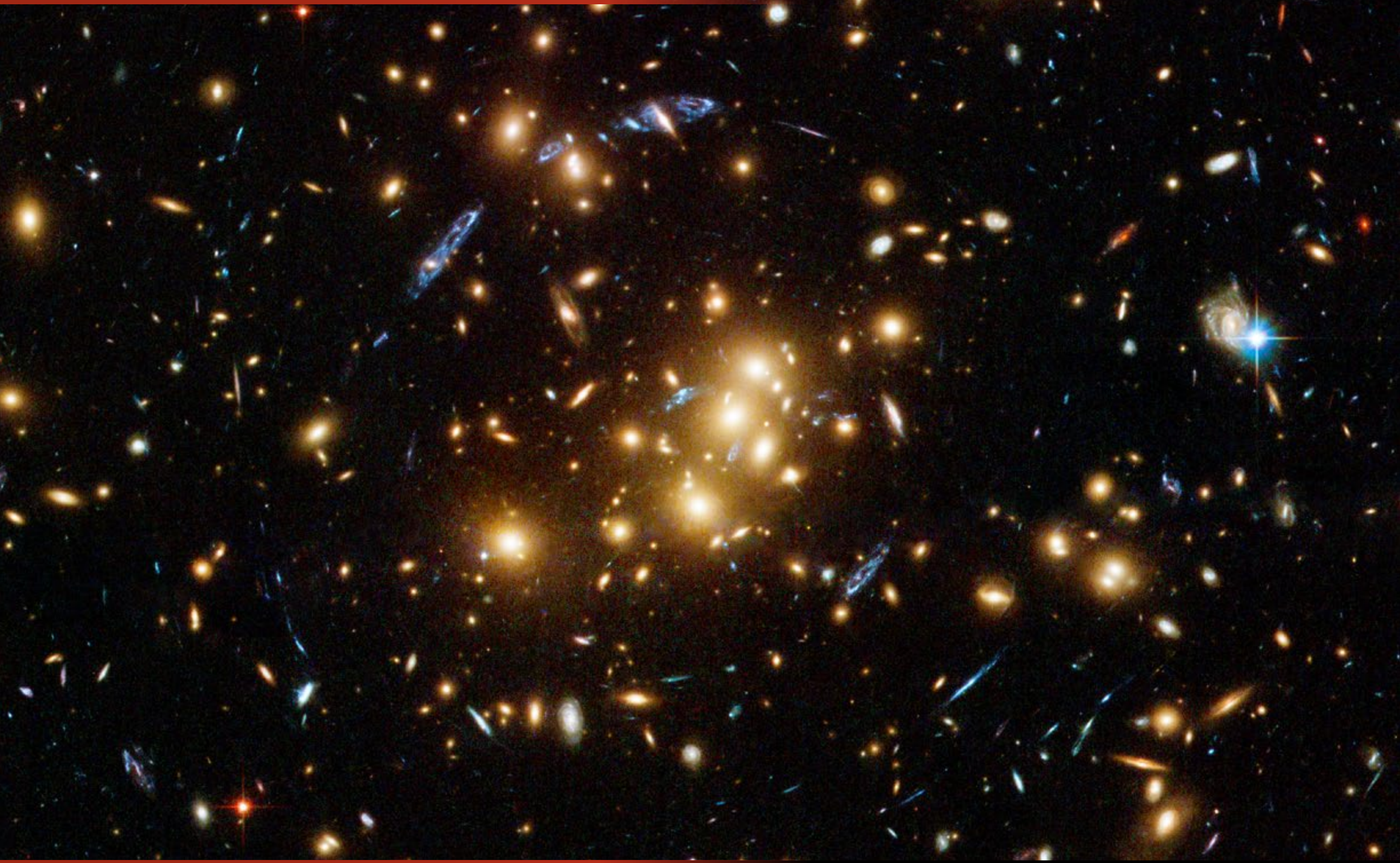
Just four years after the discovery of Icarus, Hubble broke its own record by finding a more distant star, called Earendel, in a gravitational lens created by a huge galaxy cluster called WHL0137-08. The star sits in a ripple of spacetime (indicated by the dotted line) that produces extreme magnification, allowing Earendel to stand out against its host galaxy, which appears as a red arc. It took Earendel's light 12.9 billion years to reach Earth, traveling at 186,000 miles per second (300,000 km per second). Hubble's image captured the star as it appeared when the universe was only seven percent of its current age — within the first billion years after the universe's birth in the big bang — making it the most distant individual star ever seen.

Shining a Light on Dark Matter

More than 80% of the universe is stuff we have never seen. Its gravity drives normal matter (gas and dust) to collect and build up into stars, galaxies, and massive galaxy clusters. Visible matter reveals itself by shining brightly, but astronomers detect dark matter by its gravitational influence on the light we see. By looking at the area around massive galaxy clusters, astronomers can identify warped background galaxies gravitationally lensed by the cluster and reverse-engineer their distortions. Mathematical models of these results shed light on the location and properties of the densest concentrations of matter in the cluster, both visible (normal matter) and invisible (dark matter, indicated by the bluish-purple glow).

ABELL 1689

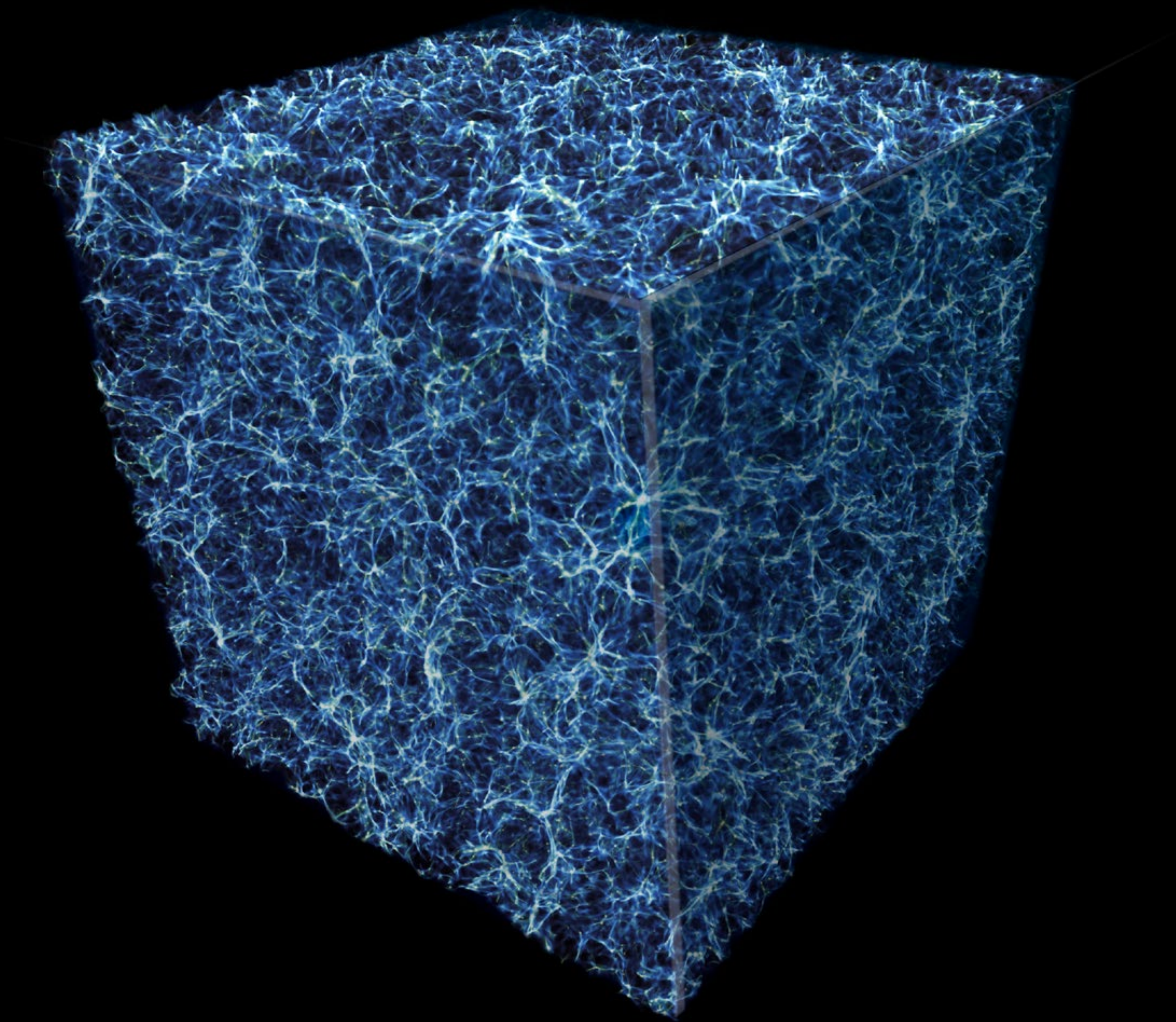
Galaxy Cluster



Galaxy Cluster + Dark Matter

The massive galaxy cluster Cl 0024+17 (ZwCl 0024+1652) reveals the bent and amplified light of gravitationally lensed, distant galaxies. The top view is in visible light with odd-looking blue arcs among the yellowish galaxies. These are the magnified and distorted images of galaxies located far behind the cluster. The right image holds added blue shading that indicates the location of invisible dark matter. The shape and position of the gravitationally lensed galaxies we see in the top image mathematically requires the presence of this dark matter.

COMPUTER SIMULATION OF THE COSMIC WEB



Mapping the Cosmic Web

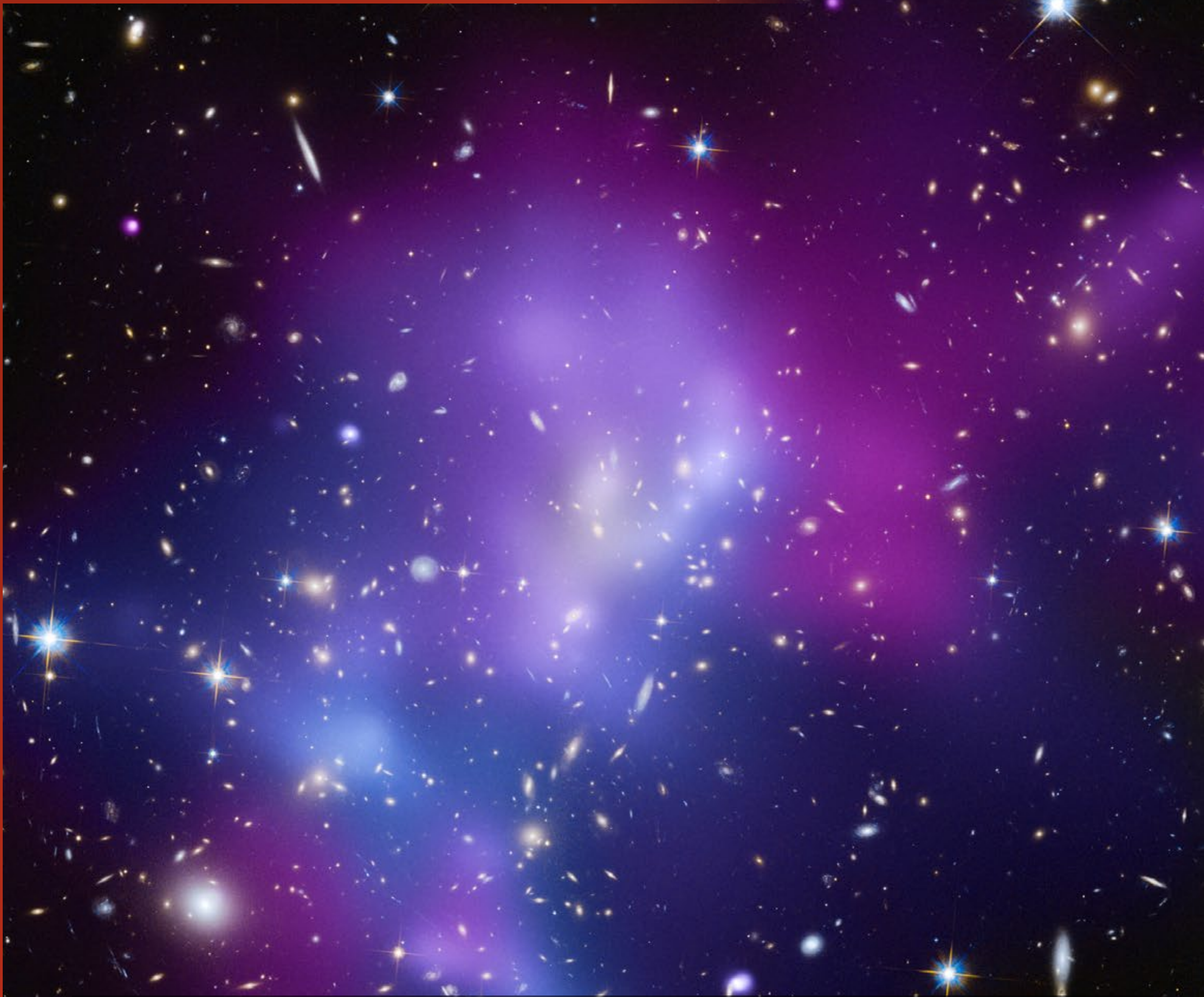
Astronomers theorize that the early universe was very smooth, and that the distribution of matter was uniform with tiny variations in density that grew into a web-like pattern. These areas of slightly higher density also had slightly more gravity to attract more matter. Over time, the universe evolved into a web of filaments and vast sheets, largely made of dark matter, which shape the structure of the universe today.

Galaxy Cluster MACS J0717

Galaxy Cluster MACS J0717 Dark Matter Map

This cosmic web forms the large-scale backbone of the universe. Hubble's high resolution can make detailed observations that spot minute distortions in how light from distant objects bends around a foreground galaxy cluster. Such observations allowed astronomers to make the first map of a filament funneling matter into the massive galaxy cluster MACS J0717. The astronomers expanded Hubble's two-dimensional observations by using data from other observatories that measured distances to the galaxies in the filament.

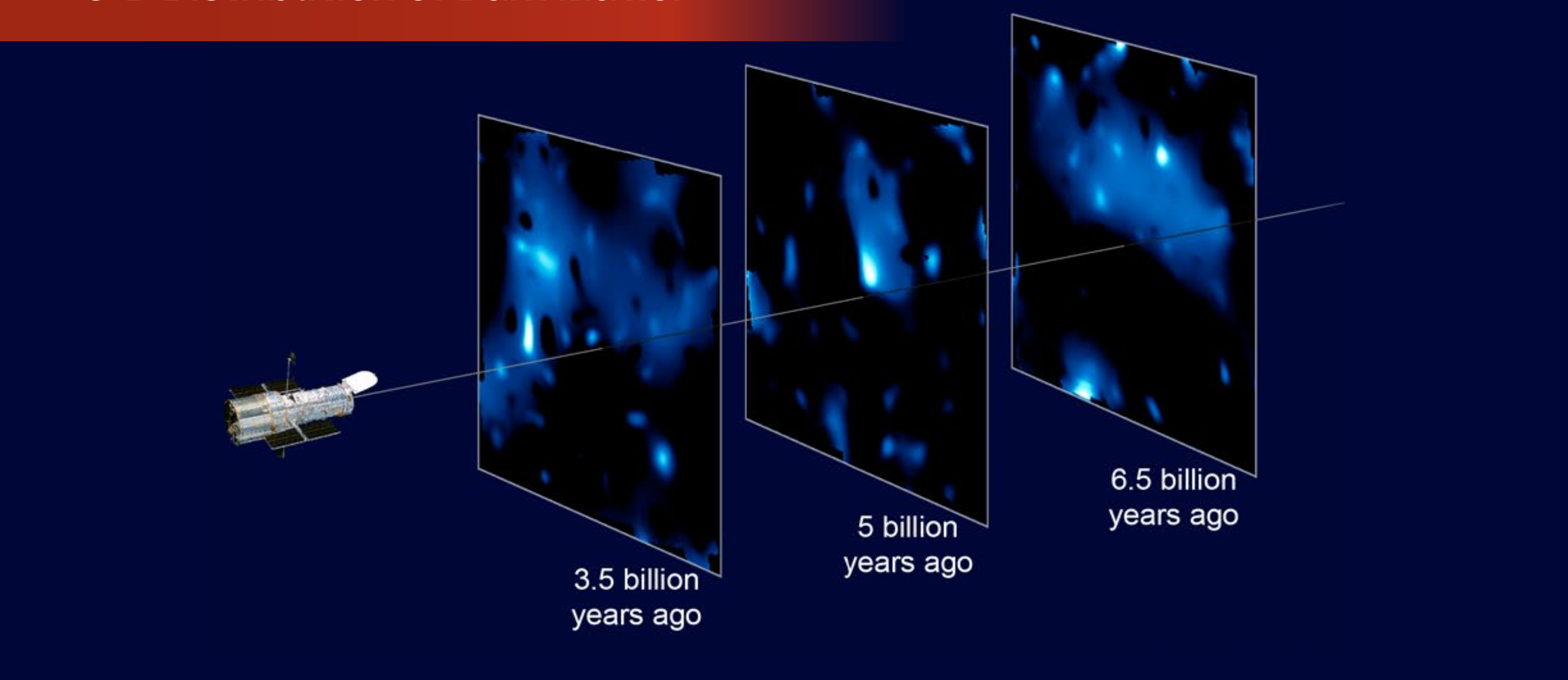
Multiwavelength View of MACS J0717



Hubble observations of MACS J0717 and its filament also revealed the first documented collision of four separate galaxy clusters. The collisions are the result of the 13-million-light-year-long filament of normal and dark matter streaming into a region already full of matter.

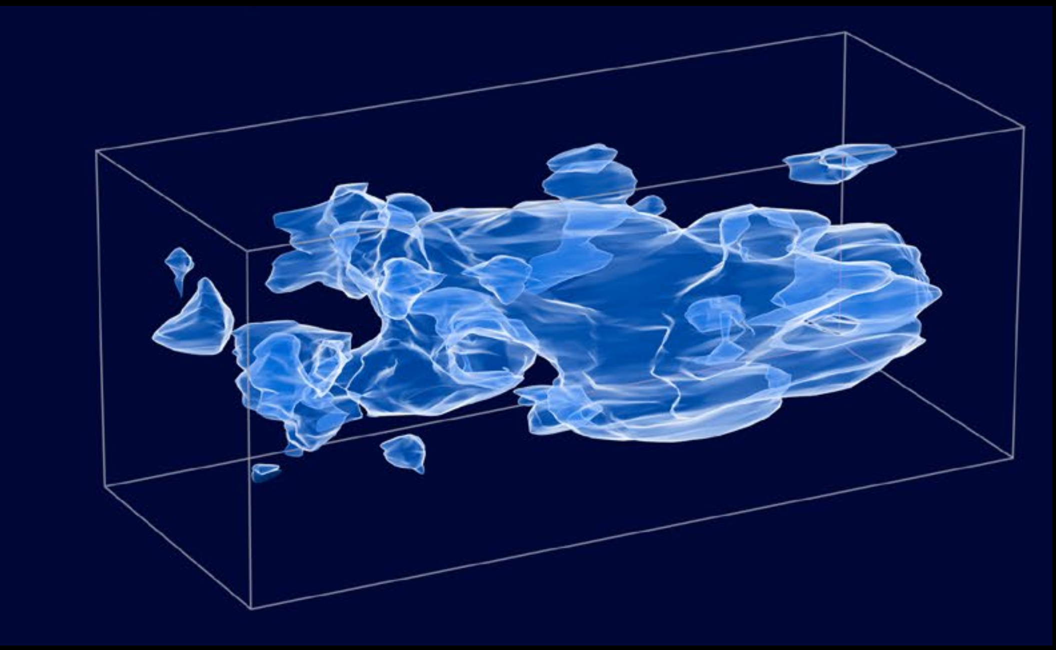
This composite image of visible light data from Hubble and X-ray data from NASA's Chandra X-ray Observatory reveals the hot gas (blue) and cooler gas (reddish-purple). Astronomers can estimate the speed and direction of each cluster's motion — perpendicular to the line of sight — by studying the difference between the average position of the galaxies and the peak in the hot gas. As the filament funnels matter into the cluster, collisions between the gas in two or more clusters causes the hot gas to slow down, dissipating some of its kinetic energy as heat. But the massive and compact galaxies do not slow down as much as the gas does, so they move ahead of it. This allows the researchers to three-dimensionally map the geometry and motion in the system, thereby mapping the large-scale structure of the region located some 5.4 billion light-years from Earth.

3-D Distribution of Dark Matter



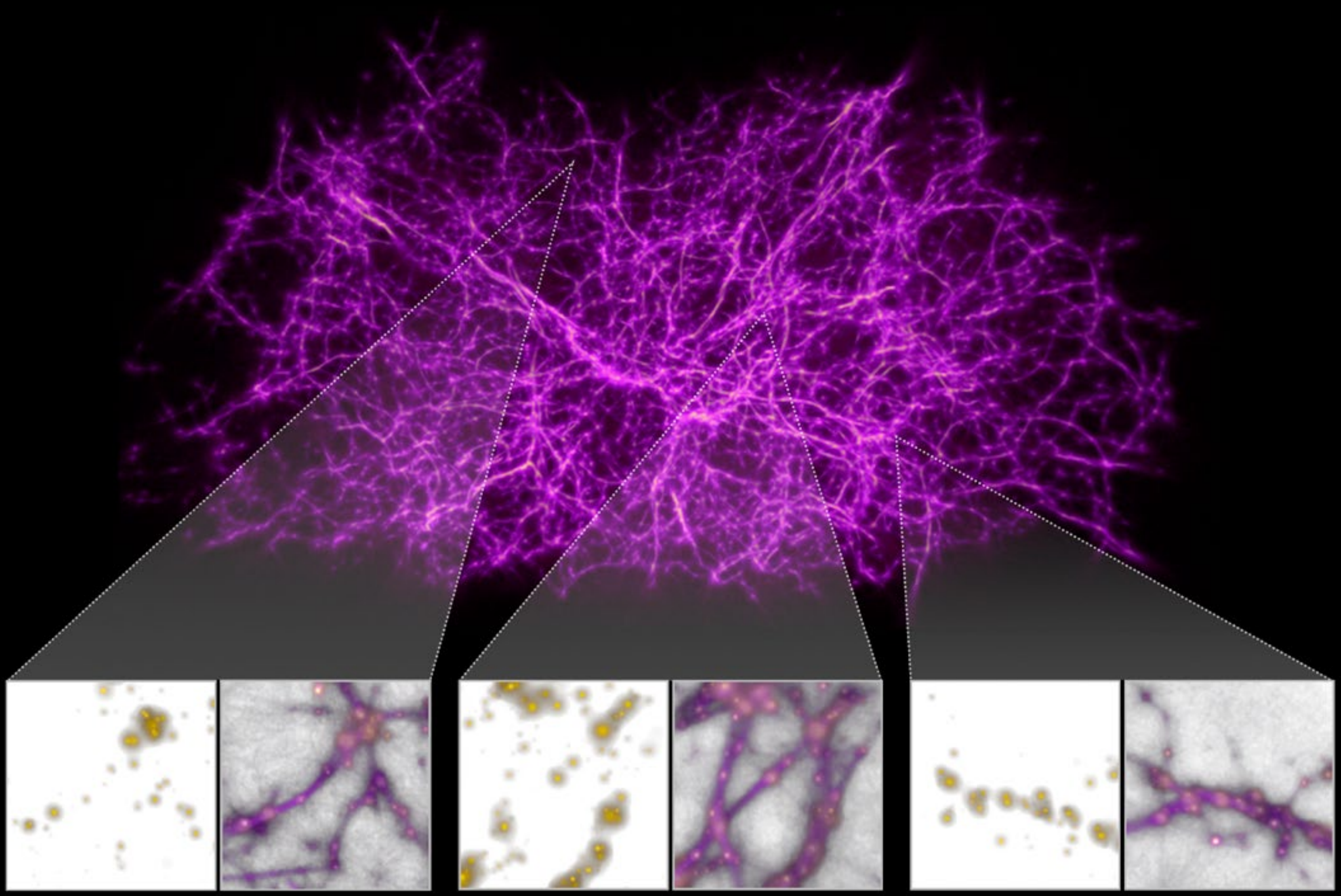
Nearly 1,000 hours of Hubble observations similarly enabled an international team of 70 astronomers to create the first three-dimensional map of the web-like, large-scale distribution of dark matter. The map is comprised of 575 slightly overlapping Hubble images that stretch halfway back in time to the beginning of the universe. They reveal a loose network of dark matter filaments, gradually collapsing and growing clumpier over time under the relentless pull of gravity, confirming theories of how structure formed in our evolving universe.

Each slice reveals the changing distribution of dark matter in a discrete epoch of time. Astronomers calibrated each epoch by measuring the cosmological redshift of the lensing galaxies used to map the dark matter's distribution, placing them into different time/distance "slices."



Astronomers combined the slices to create the three-dimensional map of dark matter over time. The three axes of the box correspond to sky position (right ascension and declination), and distance from Earth increasing from left to right (as measured by cosmological redshift). Note how the dark matter clumping becomes more pronounced, moving right to left across the map, from the early universe to the more recent universe, confirming theories of how the large-scale structure of the universe formed and evolved.

Cosmic Web and Slime Mold



3D COMPUTER MODEL

Recently, simple single-cell organisms that feed on dead plant material became the analogous counterpart to how the large-scale structure of the universe formed. Researchers developed an algorithm that mimics the brainless slime mold's efficiency at building complex filaments to capture new food. They then applied the algorithm to data containing the locations of 37,000 galaxies mapped by the Sloan Digital Sky Survey. The galaxies are analogous to the slime mold's food. The algorithm revealed the striking similarity between how the slime mold builds complex filaments to capture new food, and how gravity constructs the cosmic web filaments between galaxies and galaxy clusters.

After the three-dimensional computer model estimated the location of the cosmic filaments, the astronomers used archival Hubble observations to detect and study the gas permeating the web at points along those predicted filaments. They examined the ultraviolet light from 350 distant quasars in the Hubble Spectroscopic Legacy Archive. Because these quasars are so far from the galaxies, the researchers were able to use the Hubble data to look for the telltale absorption of undetected hydrogen gas in the spectroscopic signature of the quasars and link the gas to the universe's large-scale structure.

The three sets of paired inset images represent galaxies with yellow dots (left). Next to each galaxy snapshot is an image of the galaxies with the cosmic web's connecting strands in purple (right) superimposed on them.

Credits

Cover Image: HP Tau

Cover Caption: The triple-star system, HP Tau, holds a young type of star called a T Tauri star. T Tauri stars are young, variable stars less than about ten million years old. They have yet to begin nuclear fusion in their cores.

Image Credit: NASA, ESA, G. Duchene (Universite de Grenoble I); Image Processing: Gladys Kober (NASA/Catholic University of America)

Learn more about HP Tau.

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MONSTER BLACK HOLES ARE EVERYWHERE ↗

Page 44, Black Hole (Computer-Simulated Image): NASA, ESA, and D. Coe, J. Anderson, and R. van der Marel (STScI)

Page 45, Compact Core of M87: NASA, ESA, Tod R. Lauer (NOAO), Sandra M. Faber (CSC), C. Roger Lynds (NOAO), and the Wide Field/Planetary Camera Imaging Team

Page 45, Core of Galaxy NGC 4261: NASA, ESA, and L. Ferrarese (Johns Hopkins University)

Page 45, Core of Galaxy NGC 7052: NASA, ESA, and Roeland P. van der Marel (STScI), Frank C. van den Bosch (Univ. of Washington)

HOMING IN ON COSMIC EXPLOSIONS ↗

Page 46, GRB Host Galaxies: NASA, ESA, Andrew Fruchter (STScI), and the GRB Optical Studies with HST (GOSH) collaboration

Page 47, GRB 990123: NASA, ESA. STScI

Page 47, GRB 970228: NASA, ESA, K. Sahu, M. Livio, L. Petro, D. Macchetto, STScI

Page 48, GRB 130603B: NASA, ESA, N. Tanvir (University of Leicester), A. Fruchter (STScI), and A. Levan (University of Warwick)

Page 49, Kilonova in NGC 4993: NASA and ESA. Acknowledgment: A.J. Levan (U. Warwick), N.R. Tanvir (U. Leicester), and A. Fruchter and O. Fox (STScI)

Page 49, GRB 080319B: NASA, ESA, N. Tanvir (University of Leicester), and A. Fruchter (STScI)

Page 50, SN1987a (August 1990): NASA, ESA, and STScI

Page 50, SN1987a (February 1994): NASA, ESA, and Dr. Christopher Burrows (ESA/STScI)

Page 51, SN1987a (1994-2003): NASA, ESA, P. Challis, R. Kirshner (Harvard-Smithsonian Center for Astrophysics) and B. Sugerman (STScI)

Page 51, SN1987a (2017): NASA, ESA, Robert P. Kirshner (CfA, Moore Foundation), Max Mutchler (STScI), Roberto Avila (STScI)

Page 52, SN 2018zd (composite): NASA, ESA, and Las Cumbres Observatory; Image Processing: J. DePasquale (STScI)

Page 53, SN 2020fqv: NASA, ESA, Ryan Foley (UC Santa Cruz); Image Processing: Joseph DePasquale (STScI)

DISCOVERING THE RUNAWAY UNIVERSE ↗

Page 54, Hubble Deep UV GOODS-North Field: NASA, ESA, P. Oesch (University of Geneva), and M. Montes (University of New South Wales)

Page 55, Andromeda Galaxy Cepheid Variable: NASA, ESA, and the Hubble Heritage Team (STScI/AURA); Acknowledgment: R. Gendler

Page 55, Supernova and Cepheid Variable Host Galaxies: NASA, ESA, Adam G. Riess (STScI, JHU)

Page 56, NGC 1015: NASA, ESA, A. Riess (STScI/JHU)

Page 57, Hubble & Webb Image of NGC 5468: NASA, ESA, CSA, STScI, Adam G. Riess (JHU, STScI)

FOCUSING IN ON GRAVITATIONAL LENSES ↗

Page 58, Abell 370: NASA, ESA/Hubble, HST Frontier Fields

Page 59, Einstein Cross Illustration: NASA, ESA, and D. Player (STScI)

Page 59, Einstein Cross G2237+0305: NASA & ESA

Page 60, Supernova Refsdal: NASA, ESA, and S. Rodney (JHU) and the FrontierSN team; T. Treu (UCLA), P. Kelly (UC Berkeley), and the GLASS team; J. Lotz (STScI) and the Frontier Fields team; M. Postman (STScI) and the CLASH team; and Z. Levay (STScI)

Page 60, Icarus: NASA, ESA, and P. Kelly (University of Minnesota)

Page 61, Earendel: NASA, ESA, Brian Welch (JHU), Dan Coe (STScI)

SHINING A LIGHT ON DARK MATTER ↗

Page 62, Abell 1689: NASA, ESA, E. Jullo (Jet Propulsion Laboratory), P. Natarajan (Yale University), and J.-P. Kneib (Laboratoire d'Astrophysique de Marseille, CNRS, France); Acknowledgment: H. Ford and N. Benetiz (Johns Hopkins University), and T. Broadhurst (Tel Aviv University)

Page 63, Galaxy Cluster Cl 0024+17 (ZwCl 0024+1652): NASA, ESA, M.J. Jee, and H. Ford (JHU)

Page 63, Galaxy Cluster Cl 0024+17 (ZwCl 0024+1652) + Dark Matter: NASA, ESA, M.J. Jee, and H. Ford (JHU)

MAPPING THE COSMIC WEB ↗

Page 64, Cosmic Web Computer Simulation: NASA, ESA, and E. Hallman (University of Colorado, Boulder)

Page 65, Galaxy Cluster MACS J0717: NASA, ESA, Harald Ebeling(Universitzy of Hawaii at Manoa) & Jean-Paul Kneib (LAM)

Page 65, Galaxy Cluster MACS J0717 Dark Matter Map: NASA, ESA, Harald Ebeling (University of Hawaii at Manoa) & Jean-Paul Kneib (LAM)

Page 66, Multiwavelength View of MACS J0717: NASA, ESA, CXC, C. Ma, H. Ebeling and E. Barrett (University of Hawaii/IfA), et al. and STScI

Page 67, 3-D Distribution of Dark Matter: NASA, ESA, and R. Massey (California Institute of Technology)

Page 68, Cosmic Web and Slime Mold: NASA, ESA, and J. Burchett and O. Elek (UC Santa Cruz)

Eagle Nebula

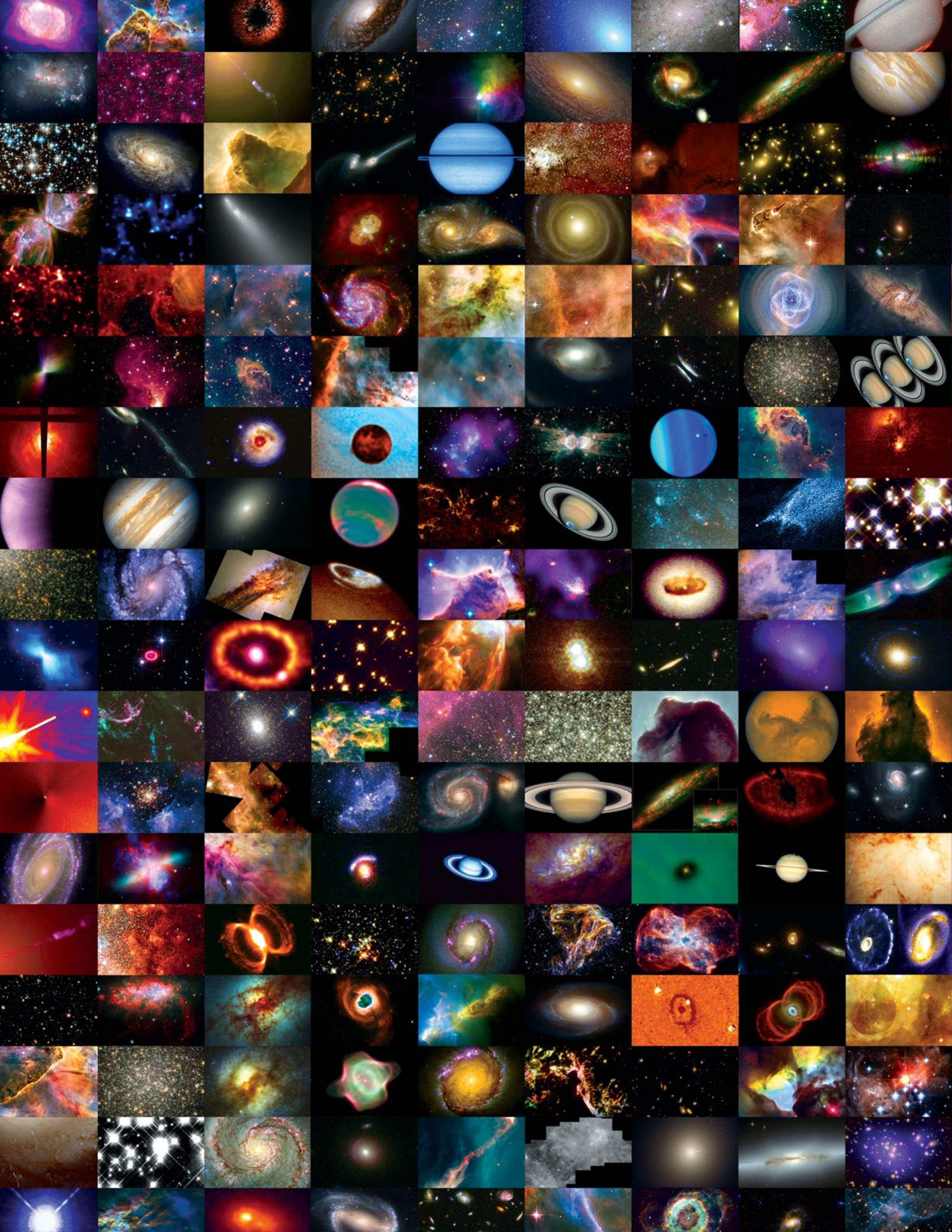
Hubble first imaged this small segment of the Eagle Nebula (Messier 16) in 1995. Dubbed the Pillars of Creation, these new images of the iconic star-forming towers combine several Hubble exposures to provide a wider field of view than the original. The pillars rise about 4 to 5 light-years tall, roughly the distance between the Sun and the nearest star. Yet they represent a relatively small segment of the entire Eagle Nebula, which spans 70 by 55 light-years.

Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

Learn more about the Eagle Nebula

VISIBLE-LIGHT


INFRARED-LIGHT



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