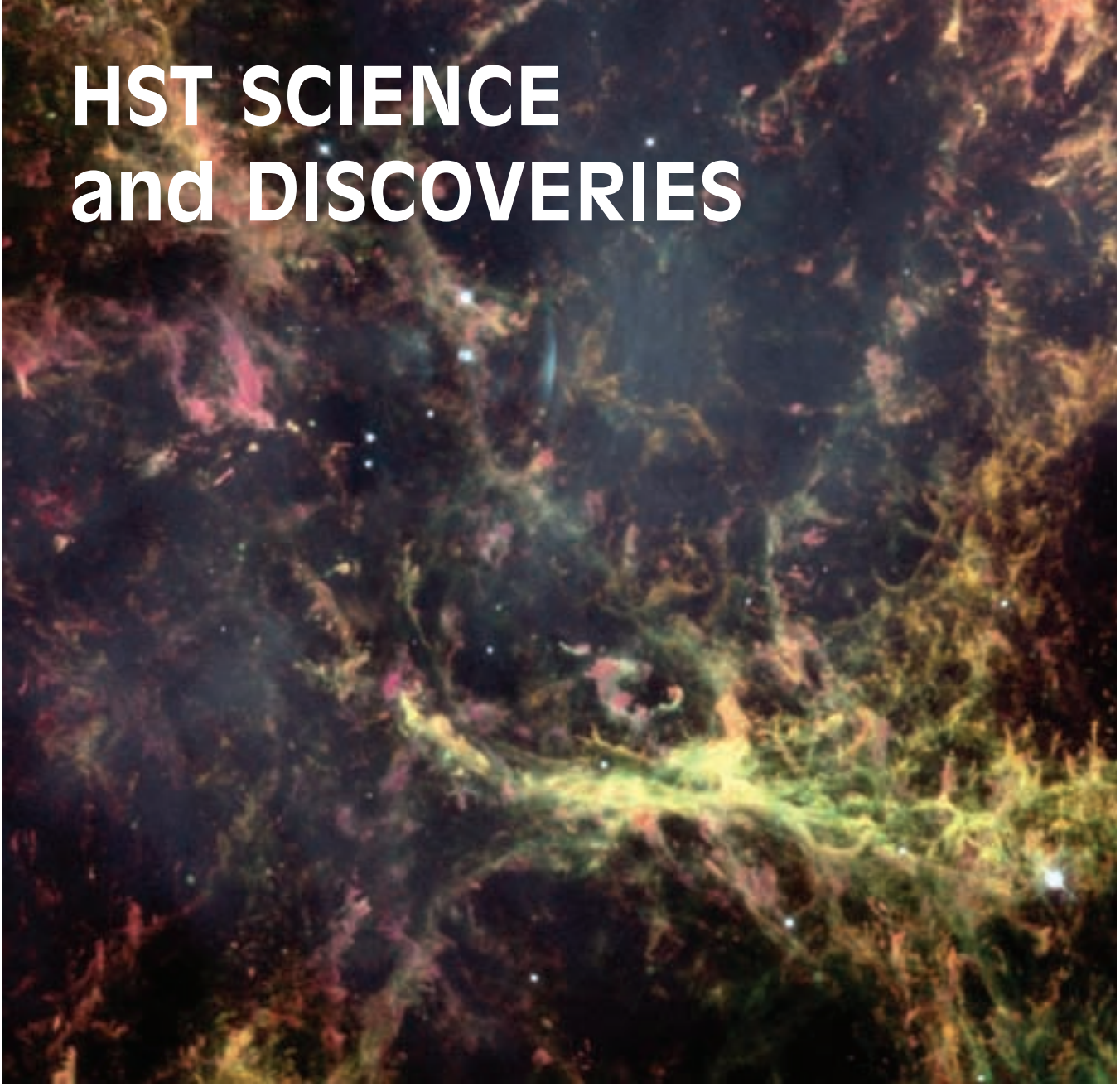
HST SCIENCE and DISCOVERIES



The launch and deployment of NASA's Hubble Space Telescope (HST) ushered in a golden era of space exploration and discovery. For nearly 12 years, Hubble's rapid-fire rate of unprecedented discoveries has invigorated astronomy. Not since the invention of the telescope four centuries ago has our vision of the universe changed so radically in such a short stretch of time.

As the 12.5-ton Earth-orbiting observatory looks into space unburdened by atmospheric distortion, new details about planets, stars and galaxies come into crystal clear view. The Telescope has produced a vast amount of information and a steady stream of images that have astounded the world's astronomical and scientific communities. It has helped confirm some astronomical theories, challenged others and often come up with complete surprises for which theories do not yet exist.

Hubble was designed to provide three basic capabilities:

- High angular resolution—the ability to image fine detail
- Ultraviolet performance—the ability to produce ultraviolet images and spectra
- High sensitivity—the ability to detect very faint objects.

Each year NASA receives over a thousand new observing proposals from astronomers around the world. Observing cycles are routinely oversubscribed by a factor of six.

The Telescope is extremely popular because it allows scientists to get their clearest view ever of the cosmos and to obtain information on the temperature, composition and motion of celestial objects by analyzing the radiation they emit or absorb. Results of HST observations

are being presented regularly in scientific papers at meetings of the American Astronomical Society and other major scientific conferences.

Although Hubble's dramatic findings to date are too numerous to be described fully in this Media Reference Guide, the following paragraphs highlight some of the significant astronomical discoveries and observations in three basic categories:

- Formation and evolution of stars and planets
- Earth's Solar System
- Galaxies and cosmology.

For further information, visit the Space Telescope Science Institute website at http://oposite.stsci.edu.

Evolution of Stars and Planets

It's a cruel world for some fledgling planets. Hubble found an inhospitable neighborhood for embryonic planets in the Orion Nebula, a stellar breeding ground peppered with hot, massive stars whose blistering radiation erodes material around them. The Telescope also hunted for planets in a nearby globular cluster and found none, although up to 50 detections were expected. But Hubble did find a vast stellar nursery in the Large Magellanic Cloud.

Probing the universe since April 24, 1990, Hubble has chased after planets, snapped pictures of the most luminous known star and chronicled the explosive death of a massive star.

Elusive Planets

Scanning 35,000 stars in the tightly packed globular star cluster 47 Tucanae, the Telescope was on the prowl for planets (see Fig. 3-1). Surprisingly, it found none. However, the results do not rule out the possibility that the cluster could contain normal solar systems like ours that the Telescope cannot detect.

Hubble can detect only Jupiter-sized planets orbiting close to their parent stars—closer than the scorched planet Mercury. These star-hugging planets complete an orbit and pass in front of their parent stars every few days. Nevertheless, the finding suggests that the conditions for planet formation and evolution may be fundamentally different in the cluster than in our galactic backyard.

Searching for planets in 47 Tucanae, 15,000 light-years away, was not easy. Planets at that distance are too dim to be seen directly. So astronomers used an indirect method to detect the planets, pushing the

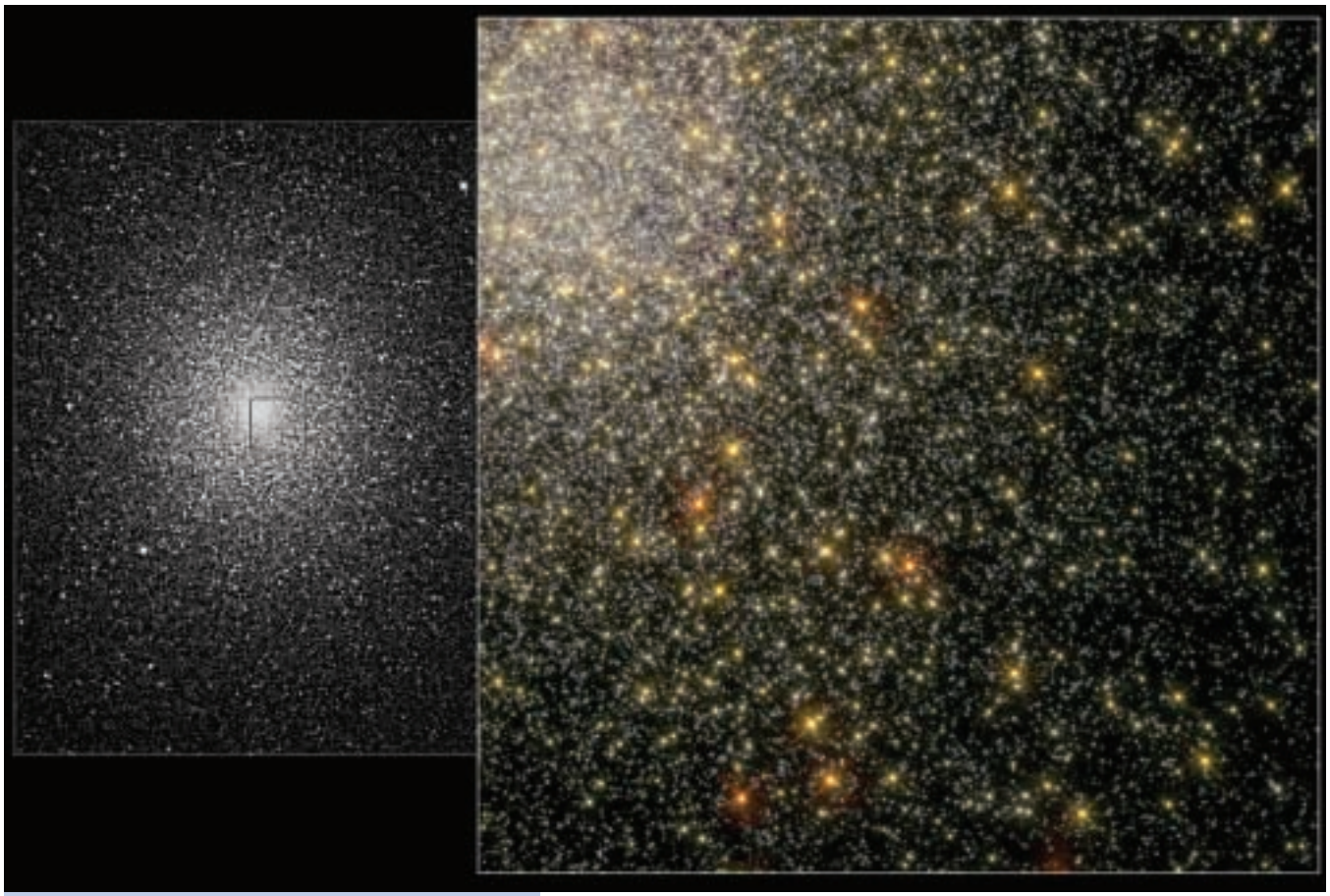


Fig. 3-1 A vast "city" of stars in 47 Tucanae

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Telescope to the limit of its capabilities. Among the 35,000 stars, astronomers looked for a slight dimming of a star due to a planet passing in front of it, an event called a transit. The planet had to be slightly larger than Jupiter, our solar system's largest planet, to block enough light for Hubble to detect it.

Why didn't the Telescope find any Jupiter-sized planets? One reason is that the stars are packed together so tightly that the gravity of nearby stars stripped nascent planets from their parent stars. Another possibility is that a torrent of ultraviolet radiation from the earliest and biggest stars may have boiled away fragile embryonic dust disks out of which planets would have formed.

In a star-forming region a few thousand light-years closer to Earth, planets are playing a life-and-death game of survival. Hubble produced the first direct visual evidence for the growth of planet "building blocks" inside dust disks around dozens of stars in the Orion Nebula (see Fig. 3-2).

Planetary building blocks are large grains, ranging in size from smoke particles to sand grains. To make planets, these grains stick together. Hubble observations show that it may be easy to begin building planets deep inside the star-forming cloud. Reaching adulthood, however, may be a hazardous process. Fledgling planets try to form quickly before they are destroyed by blistering ultraviolet radiation from the nebula's brightest star, Theta 1 Orionis C.

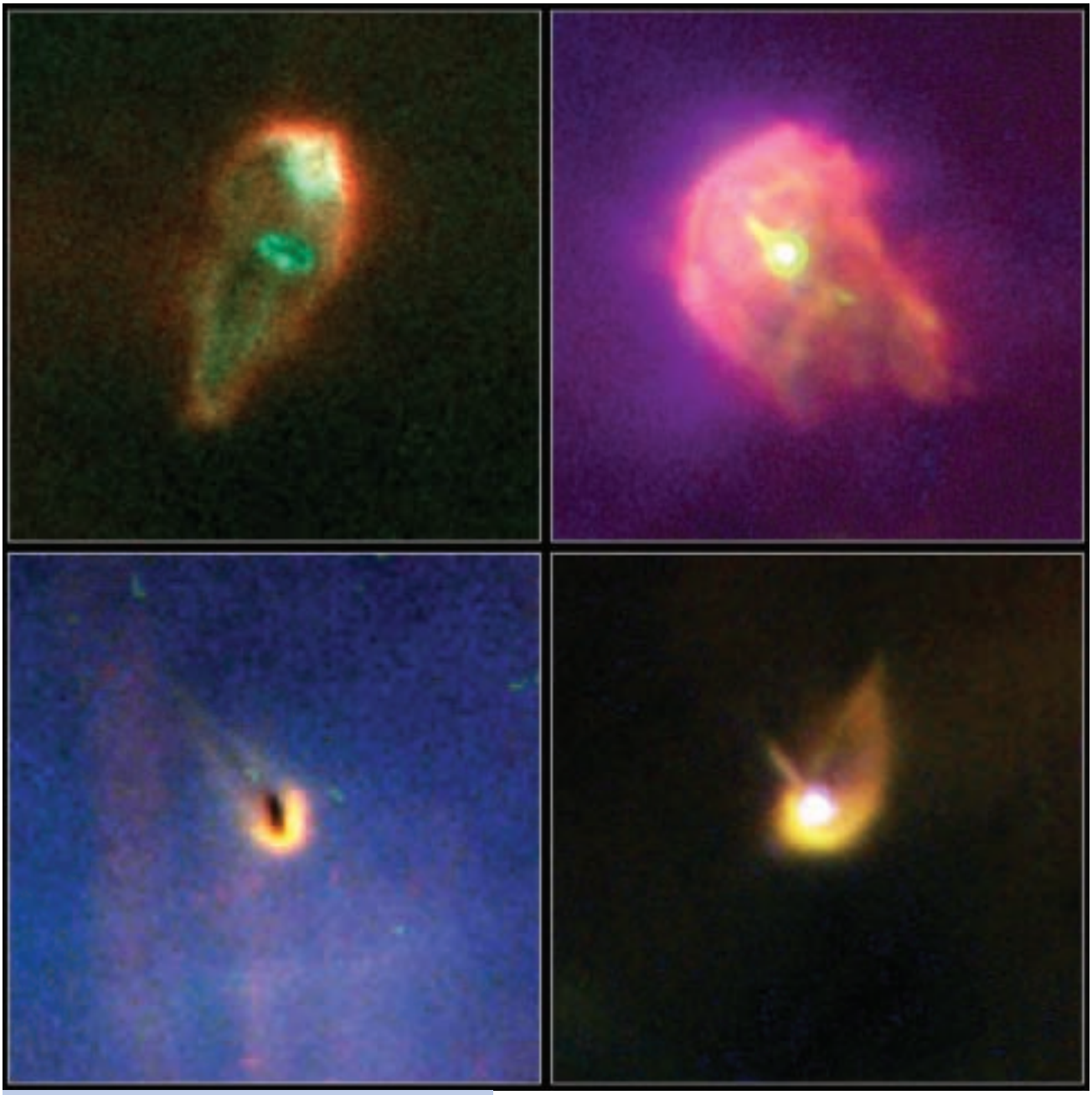

Fig. 3-2 Planetary nurseries under fire in Orion

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Astronomers predict that 90 percent of the youngest disks—which started out being billions of miles across—will be destroyed within 100,000 years. But planet formation will continue in the disks shielded from the deadly radiation. These stars probably will become the parents of a variety of planets.

Stars Under Construction

The telescope has snapped a panoramic portrait of a vast, sculpted landscape of gas and dust where thousands of stars are being born (see Fig. 3-3). This fertile star-forming region, called the 30 Doradus Nebula, has a sparkling stellar centerpiece: the most spectacular cluster of massive stars in our cosmic neighborhood of about 25 galaxies.

The mosaic picture shows that ultraviolet radiation and high-speed material unleashed by the stars in the cluster, called R136 (the large blue blob left of center), are weaving a tapestry of creation and destruction, triggering the collapse of looming gas and dust clouds and forming pillar-like structures that are incubators for nascent stars.

The view offers an unprecedented, detailed look at the entire inner region of 30 Doradus, measuring 200 light-years wide by 150 light-years high. The

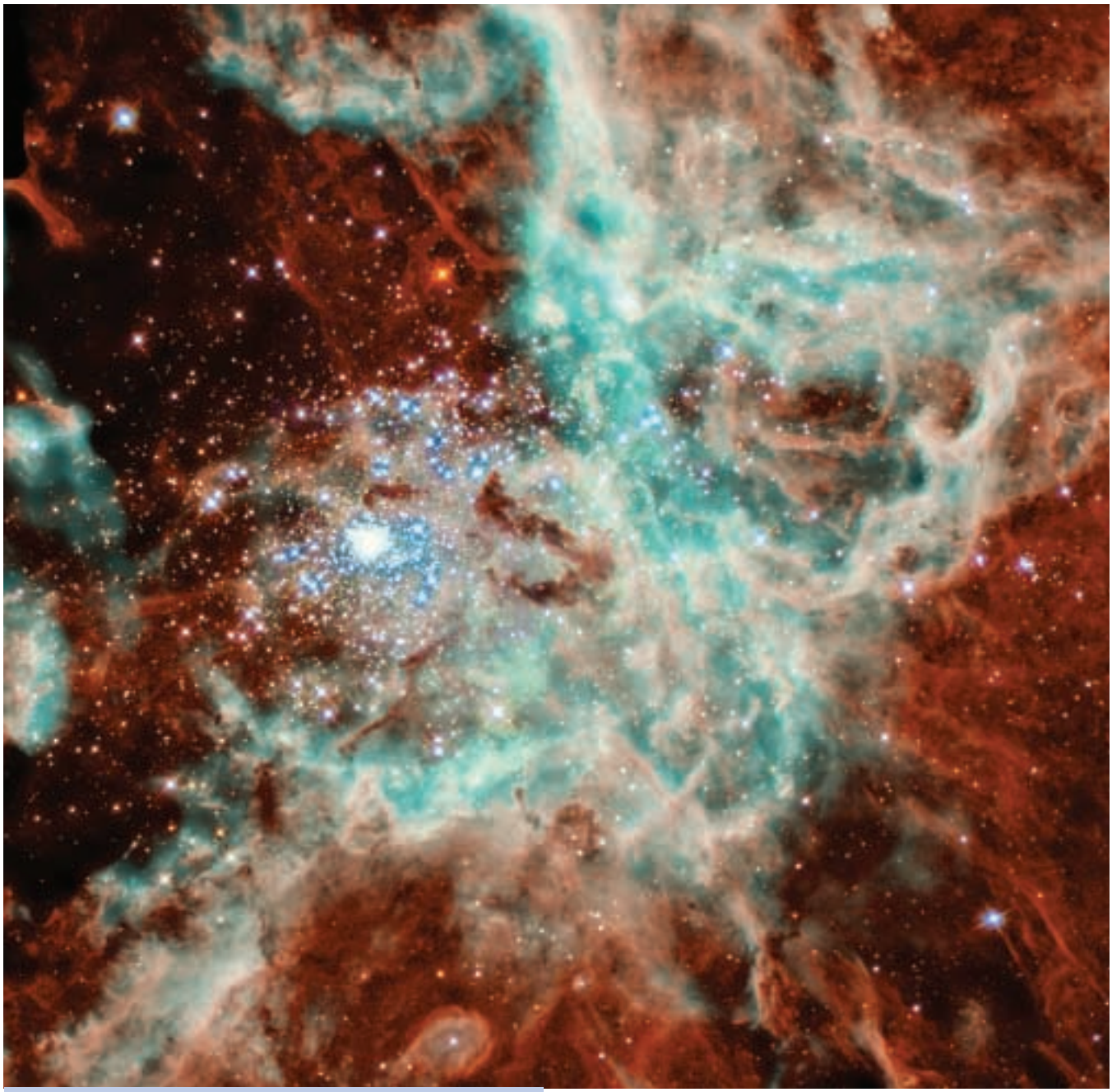

Fig. 3-3 Vast star-forming region in 30 Doradus Nebula

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nebula resides in the Large Magellanic Cloud (a satellite galaxy of the Milky Way), 170,000 light-years from Earth.

Nebulas like 30 Doradus are the "signposts" of recent star birth. High-energy ultraviolet radiation from the young, hot, massive stars in R136 causes the surrounding gaseous material to glow. Previous Hubble telescope observations showed that R136 contains several dozen of the most massive stars known, each about 100 times the mass of the Sun and about 10 times as hot. These stellar behemoths all formed at the same time about 2 million years ago.

Most Luminous Star

Astronomers used Hubble's probing "eye" to find what may be the most luminous known star—a celestial mammoth that releases up to 10 million times the power of the Sun and is big enough to fill the diameter of Earth's orbit. Called the Pistol Star, this stellar behemoth unleashes as much energy in 6 seconds as the Sun does in 1 year (see Fig. 3-4). The image, taken with the Telescope's infrared camera, also reveals a bright nebula, created by extremely massive stellar eruptions. The nebula is so big (4 light-years) it would nearly span the distance from the Sun to Alpha Centauri, the star nearest to Earth's solar system.

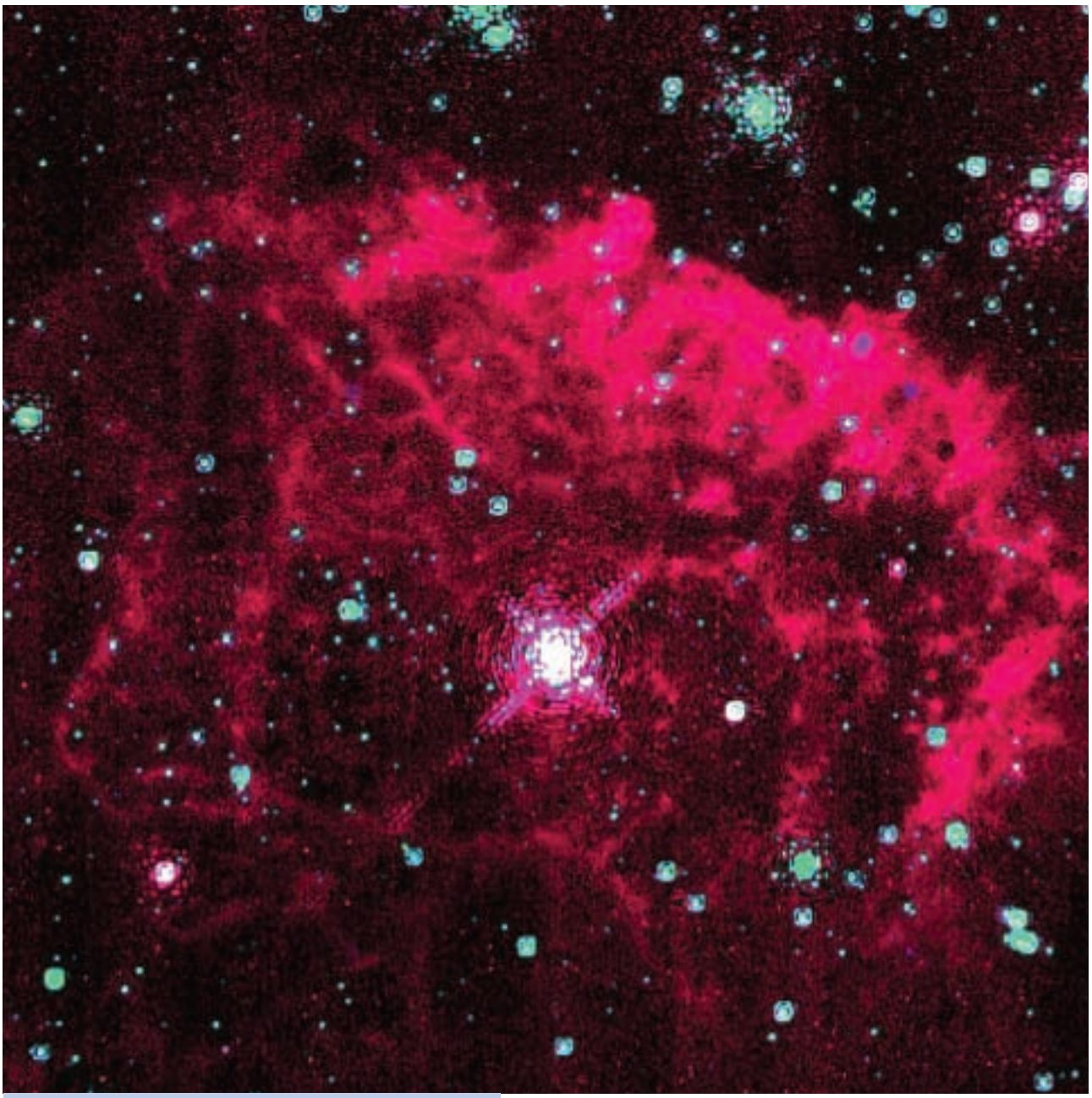

Fig. 3-4 A brilliant star at the Milky Way's core

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When the titanic star formed 1 to 3 million years ago, astronomers estimate that it may have weighed up to 200 times the mass of the Sun before shedding much of its bulk in violent eruptions. The star is approximately 25,000 light-years from Earth near the center of the Milky Way Galaxy.

When massive stars die, they don't go quietly. Instead, they end their lives with mammoth explosions. Hubble has been watching one of these explosions, supernova 1987A. A ground-based telescope first saw the star's self-destruction in February 1987.

In July 1997 Hubble's imaging spectrograph captured the first images of material ejected by the exploding star as they slammed into an inner ring around the dying object. A 100-billion-mile-wide knot of gas in a piece of the ring has already begun to "light up" as its temperature surges from a few thousand degrees to a million degrees Fahrenheit. By analyzing this glowing ring, astronomers may find clues to many of the supernova's unanswered mysteries: What was the progenitor star? Was it a single star or a binary system? The ring was formed 20,000 years ago before the star exploded. What process created it? The supernova is 167,000 light-years away in the Large Magellanic Cloud.

Earth's Solar System

A comet disintegrating as it looped around the Sun.
Another comet slamming into Jupiter.
Auroras on Jupiter and Saturn.
Wacky weather on Mars.

Hubble has kept an "eye" on our solar system.

Death of a Comet

From July to August 2000, the orbiting observatory provided unprecedented close-up views of the demise of Comet LINEAR as the icy body passed around the Sun (see Fig. 3-5). The mountain-sized object broke apart during the summer of 1999. Hubble pictures

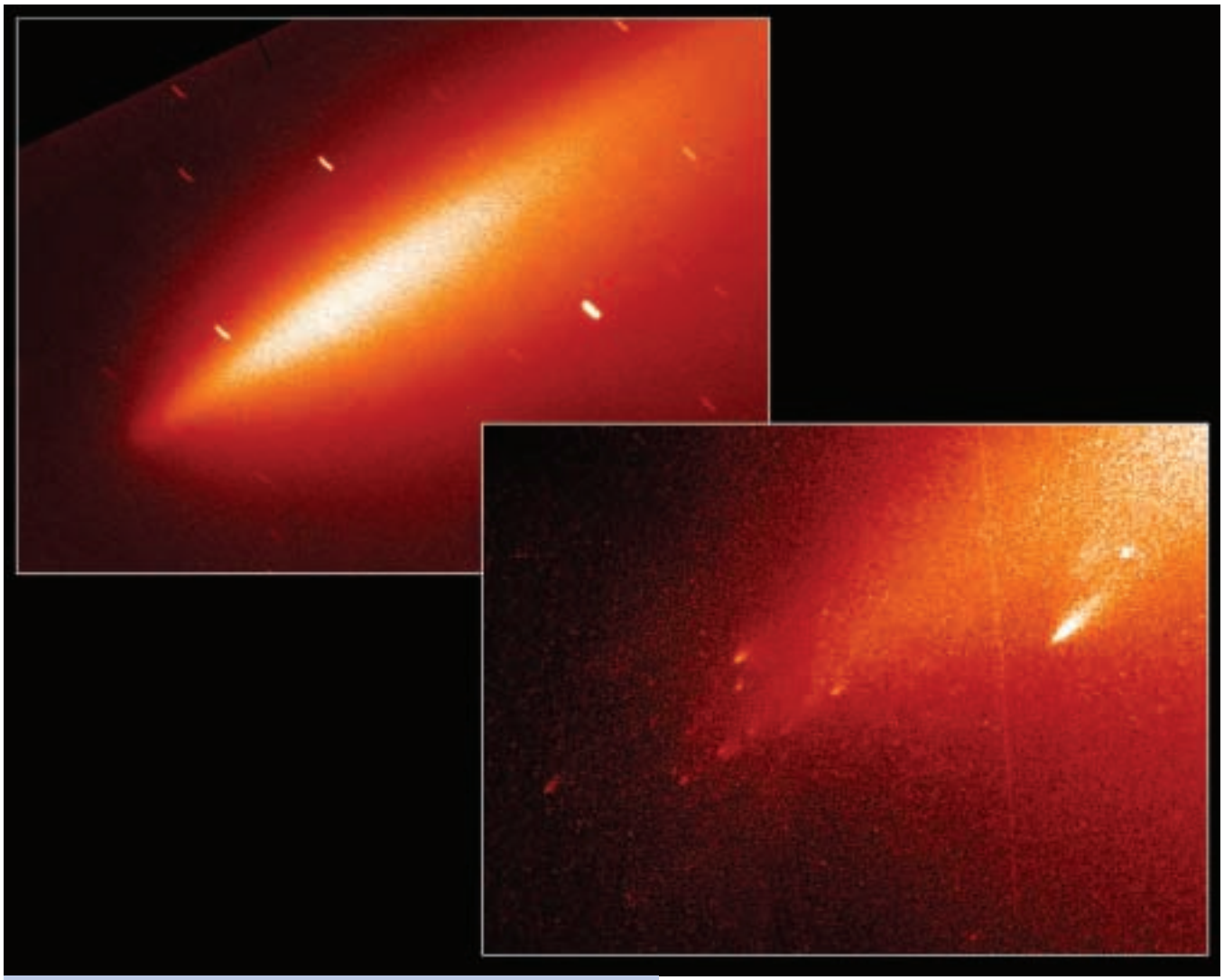

Fig. 3-5 Hubble discovers missing pieces of Comet LINEAR

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support the popular theory that comets are composed of clusters of small, icy bodies called "cometesimals," which date to the early solar system.

In July 2000 the Telescope first noticed the comet falling apart when it fortuitously saw a piece of the icy body blow off and sail along its wispy tail. Following the comet's closest approach to the Sun on July 26, astronomers using ground-based telescopes reported that the comet had vanished. But astronomers employing Hubble discovered that the comet had disintegrated into a cadre of "mini-comets" with tails, each perhaps tens of feet across. The group of objects resembled a shower of glowing balls from fireworks.

Astronomers believe that the Sun's heat caused the comet to distintegrate. By studying how the comet fell apart, astronomers hope to learn how it was put together about 4.6 billion years ago.

Crash on Jupiter

In 1994 the Telescope watched pieces of a comet invade Jupiter. It recorded 21 fragments of Comet Shoemaker-Levy 9 slamming into the giant planet. As each comet fragment crashed into Jupiter, Hubble caught mushroom-shaped plumes along the edge of the planet. The largest fragment impact created an Earth-sized bull's-eye pattern on Jupiter.

The Telescope's probe of the comet's bombardment, combined with results from other space-borne and Earth-based telescopes, sheds new light on Jupiter's atmospheric winds and its immense magnetic field. Hubble's sharp images show that the fragments, the largest of which were probably a few miles across, did not break up catastrophically before plunging into Jupiter's atmosphere. This reinforces the notion that solid, massive bodies produced the comet's atmospheric explosions.

Mars Close-up

In 2001 Hubble captured the best view of Mars ever obtained from Earth (see Fig. 3-6). Frosty white water ice clouds and swirling orange dust storms above a vivid rusty landscape reveal Mars as a dynamic planet.

The picture was taken on June 26 when Mars was approximately 43 million miles (68 million km) from Earth—the closest Mars has been to Earth since 1988. Details as small as 10 miles (16 km) across can be seen. The colors have been carefully balanced to give a realistic view of Mars' hues as they might appear through a ground-based telescope.

Especially striking is the large amount of seasonal dust storm activity seen in the image. One large storm system is churning high above the northern polar cap and a smaller dust storm cloud can be seen nearby. Another large dust storm is spilling out of the giant Hellas impact basin in the Southern Hemisphere.

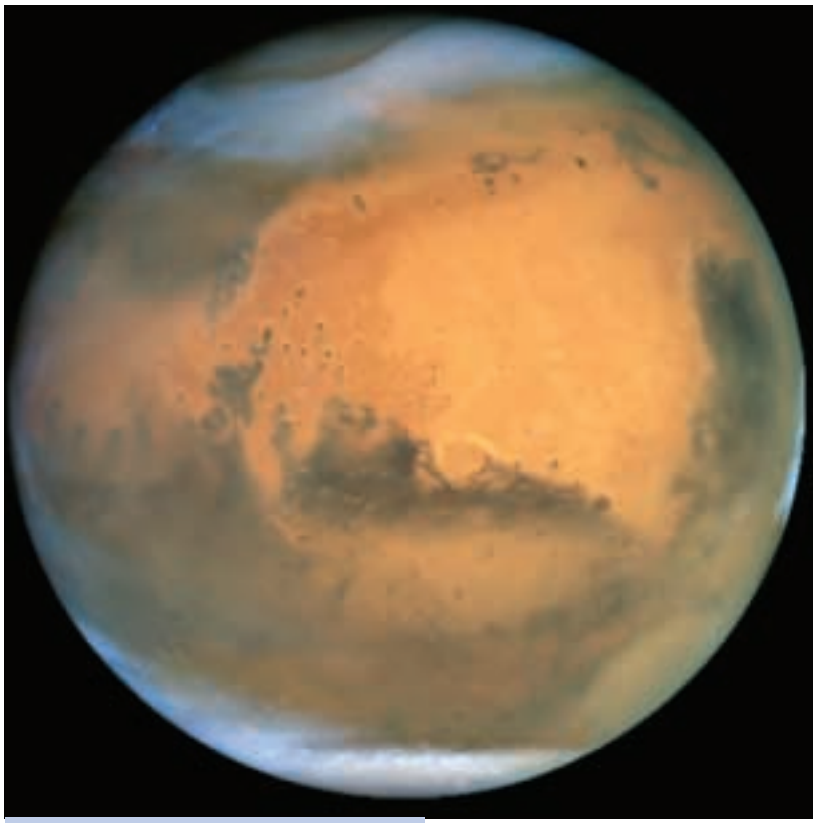

Fig. 3-6 Mars at opposition in 2001

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Hubble has observed Mars before, but never in such detail. The biennial close approaches of Mars and Earth are not all the same. Because Mars' orbit around the Sun is markedly elliptical, the close approaches to Earth can range from 35 million to 63 million miles.

Astronomers study the changeable surface and weather conditions on Mars, in part, to help plan for two NASA missions to land rovers on the planet's surface in 2004. The Mars opposition of 2001 serves as a prelude for 2003 when Mars and Earth will come within 35 million miles of each other, the closest since 1924 and not to be matched until 2287.

Dances of Light

Hubble also studied auroras—curtains of light—that seem to dance above the north and south poles of Saturn and Jupiter. Astronomers used the Telescope's ultraviolet-light camera, the imaging spectrograph, to probe these auroras.

Saturn's auroras rise more than 1,000 miles above the cloud tops. Its auroral displays are caused by an energetic wind from the Sun that sweeps over the planet, much like Earth's aurora. But Saturn's auroras can be seen only in ultraviolet light, which is invisible from Earth. These auroras are primarily shaped and powered by a continual tug-of-war between Saturn's magnetic field and the flow of charged particles from the Sun.

The Telescope took many images of Jupiter's auroras, including some in ultraviolet light. Jovian auroral storms develop when electrically charged particles trapped in the magnetic field surrounding the planet spiral inward at high energies toward the north and south magnetic poles. When these particles hit the upper atmosphere, they excite atoms and molecules there, causing them to glow (the same process that makes streetlights shine). Jupiter's auroras are caused, in part, by particles spewed out by volcanoes on Io, one of Jupiter's moons (see Fig. 3-7).

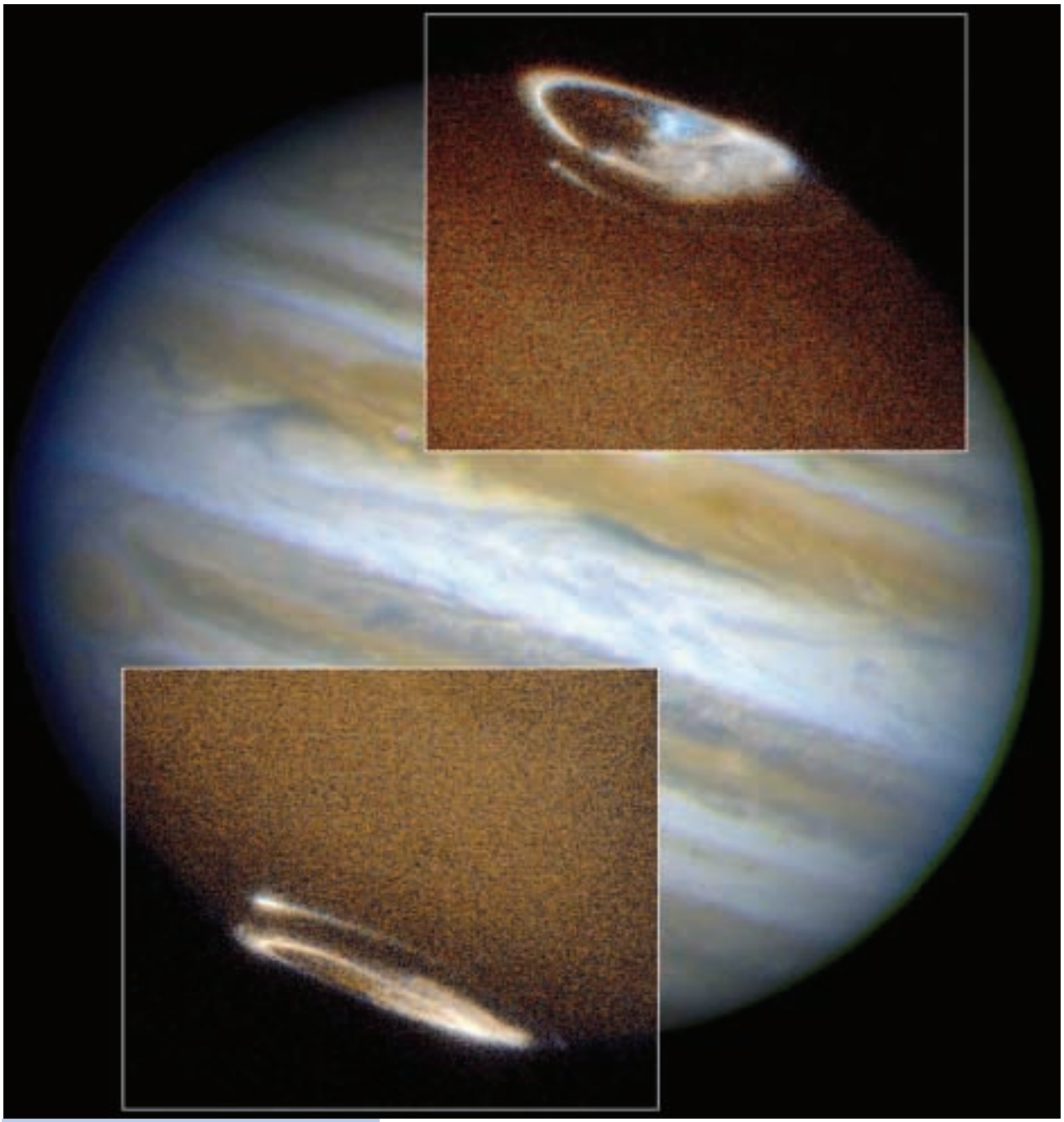

Fig. 3-7 Auroral storms on Jupiter

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Galaxies and Cosmology

To find the most distant exploding star ever seen, Hubble gazed far across the cosmos and discovered a bewildering zoo of galaxies that existed in the early universe. Looking closer to Earth, the Telescope snapped pictures of clusters of young stars born in the wreckage of colliding galaxies and helped astronomers measure the universe's expansion rate by taking pictures of a special class of pulsating star. Using Hubble, astronomers also conducted a census of more than 30 galaxies to study the relationship between galaxies and their black holes. These observations shed light on how the universe behaves and how galaxies were formed.

"Dark Energy"

In 2001 the Telescope's discovery of the farthest exploding star ever found bolstered the case for the existence of a mysterious form of "dark energy" in the universe. The exploding star is a supernova, which erupted in a faraway galaxy 10 billion years ago. The concept of dark energy, which shoves galaxies away from each other at an ever-increasing speed, was first proposed, and then discarded, by Albert Einstein in the early 1900s.

This Hubble discovery also reinforced the startling idea that the universe only recently began speeding up, a finding made in 1998 when the unusually dim light of several distant supernovas suggested the universe is expanding more quickly than in the past. The light from this 10-billion-year-old supernova offered the first tantalizing observational evidence that gravity began slowing down the universe's expansion after the Big Bang. Only later did the repulsive force of dark energy win out over gravity's attractive grip. Astronomers made the discovery by analyzing hundreds of images of ancient galaxies taken by Hubble in infrared and visible light.

Black Holes

Hubble also looked at scores of galaxies to study the relationship between galaxies and their black holes. Using Hubble's Space Telescope Imaging Spectrograph, astronomers conducted a census of more than 30 galaxies. Evidence suggests that monstrous black holes were not born big but instead grew on a measured diet of gas and stars controlled by the host galaxies. The finding supports the idea that a titanic black hole did not precede a galaxy's birth. Instead it co-evolved with the galaxy by trapping about 0.2 percent of the mass of the galaxy's bulbous hub of stars and gas.

This means that black holes in small galaxies went relatively undernourished, weighing in at a few million solar masses. Black holes in the centers of giant galaxies, some tipping the scale at over a billion solar masses, were so engorged with infalling gas that they once blazed as quasars, the brightest objects in the cosmos.

The bottom line is that the final mass of a black hole is not primordial; it is determined during the galaxy formation process. Galaxies are the largest assemblages of stars in the universe: billions of stars bound together by the mutual pull of gravity.

Starburst Galaxies

Most galaxies form new stars at a fairly slow rate, but members of a rare class known as starburst galaxies blaze with extremely active star formation. Scientists using Hubble's WFPC2 are perfecting a technique to determine the history of starburst activity in galaxies by using the colors of star clusters. Measuring the clusters' colors yields information about stellar temperatures. Since young stars are blue and older stars more red, the colors can be related to their ages, similar to counting the rings in a fallen tree trunk in order to determine the tree's age.

Galaxy NGC 3310 is forming clusters of new stars at a prodigious rate (see Fig. 3-8). NGC 3310 has several hundred star clusters, visible as bright blue diffuse objects that trace the galaxy's spiral arms. Each star cluster represents the formation of up to about a million stars, a process that takes less than 100,000 years. Hundreds of individual young, luminous stars also can be seen throughout the galaxy.

Once formed, the star clusters become redder with age as the most massive and bluest stars exhaust their fuel and burn out. Measurements of the wide variation in cluster colors show that they range in age from about 1 million up to more than 100 million years. This suggests that the starburst "turned on" over 100 million years ago, perhaps triggered when a companion galaxy collided with NGC 3310.

Hubble's observations may change astronomers' view of starbursts. They once thought starbursts to be brief episodes, resulting from catastrophic events like a galactic collision. However, the wide range of cluster ages in NGC 3310 suggests that once triggered the starbursting can continue for an extended interval.

Fig. 3-8 Galaxy NGC 3310 ablaze with active star formation

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Stellar Kindergartens

NGC 4013 is a spiral galaxy, similar to the Milky Way, lying some 55 million light-years from Earth in the direction of the constellation Ursa Major. Viewed pole-on, NGC 4013 would look like a nearly circular pinwheel. From Earth, however, it happens to be seen edge-on. Even at 55 million light-years, the galaxy is larger than Hubble's field of view and the image shows only a little more than half of the object, albeit with unprecedented detail (see Fig. 3-9).

Dark clouds of interstellar dust stand out because they absorb the light of background stars. Most of the clouds lie in the plane of the galaxy, forming a dark band about 500 light-years thick, which appears to cut the galaxy in two from upper left to lower right. When light passes through a volume containing small particles (for example, molecules in the Earth's atmosphere or interstellar dust particles in galaxies), it becomes fainter and redder. By studying the color and the amount of light absorbed by these distant clouds in NGC 4013, astronomers can estimate the amount of matter in them. Individual clouds contain as much as 1 million times the amount of mass in the Sun.

Astronomers believe that new stars are formed in these dark interstellar clouds. Later, when the dust disperses, the young stars become visible as clusters of blue stars. NGC 4013 shows several examples of these stellar kindergartens near the center of the image in Fig. 3-9, lying in front of the dark band along the galaxy's equator. (The extremely bright star near the upper left corner is a nearby foreground star belonging to the Milky Way, which lies in the line of sight to NGC 4013.)

The Evolving Universe

Studying galaxies falls into the realm of cosmology, the study of the evolution of the universe on the largest scale. By looking at the distribution of galaxies in

Fig. 3-9 Spiral galaxy NGC 4013 viewed edge-on

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space, Edwin P. Hubble discovered that the universe is expanding. He found that galaxies were rushing away from each other at a rate proportional to their distance: those farthest away were receding the fastest. The measured value for this expansion rate is called the Hubble constant.

Measuring the Hubble constant was one of the three major goals for the Telescope before it was launched in 1990. In May 1999 the Hubble Space Telescope Key Project team announced that it had completed its efforts to measure precise distances to far-flung galaxies, an ingredient needed to determine the age, size and fate of the universe. The team measured the Hubble constant at 70 km/sec/mpc with an uncertainty of 10 percent. This means that a galaxy appears to be moving 160,000 mph faster for every 3.3 million light-years away from Earth.

The team used the Telescope to observe 18 galaxies, some as far away as 65 million light-years. They were looking for Cepheid variable stars, a special class of pulsating star used for accurate distance measurements. Almost 800 were discovered. But the team could only pick out Cepheids in nearby and intermediate-distance galaxies. To calculate distances to far-flung galaxies, they used "secondary" distance measurements, such as a special class of exploding star called a Type Ia supernova.

Combining the Hubble constant measurement with estimates for the density of the cosmos, the team determined that the universe is approximately 12 billion years old if its expansion rate is constant or decelerating somewhat under the influence of gravity. But if the expansion rate is accelerating, as scientists now believe, the universe is older, perhaps 14 billion years. The team also determined that the universe does not have enough bulk to halt the expansion of space.

Summary

The Hubble Space Telescope has established itself as a premier astronomical observatory that continues to make dramatic observations and discoveries at the forefront of astronomy. Following the successful First and Second Servicing Missions, the Telescope has achieved all of its original objectives. Among a long list of achievements, Hubble has:

- Improved our knowledge of the size and age of the universe
- Provided decisive evidence of the existence of supermassive black holes at the centers of galaxies
- Clearly revealed the galactic environments in which quasars reside
- Detected objects with coherent structure (protogalaxies) close to the time of the origin of the universe
- Provided unprecedentedly clear images and spectra of the collision of Comet Shoemaker-Levy 9 with Jupiter
- Detected a large number of protoplanetary disks around stars
- Elucidated the various processes by which stars form
- Provided the first map of the surface of Pluto
- Routinely monitored the meteorology of planets beyond Earth's orbit
- Made the first detection of an ultraviolet high-energy laser in Eta Carinae.

After Servicing Mission 3B, the Telescope will view the universe anew with significantly expanded scientific capabilities from the new ACS and a reactivated NICMOS. These additions, and the upgrades to Hubble's operating hardware, promise other momentous discoveries in the years ahead.