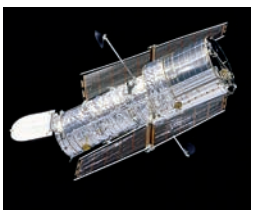
Eye on the Universe

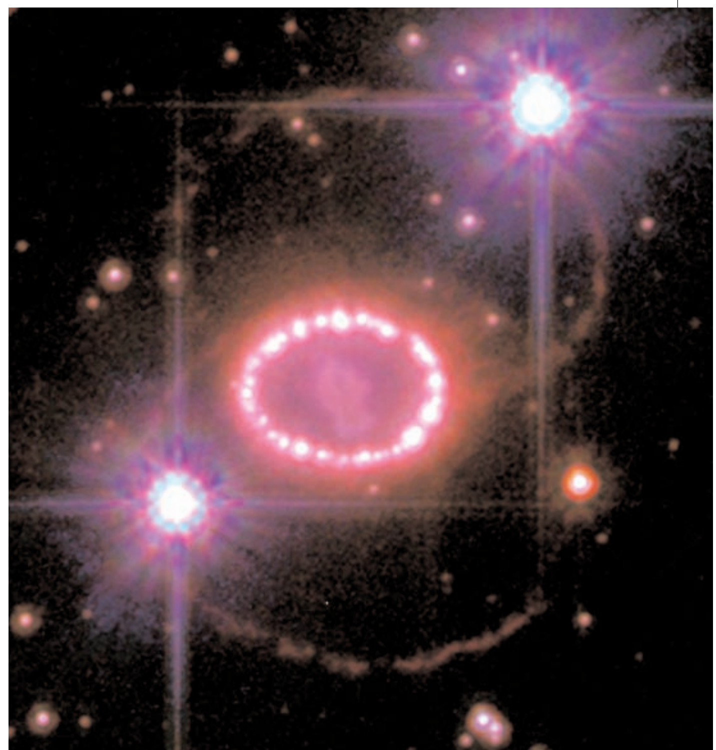
The cosmic drama, as seen from a vantage in space

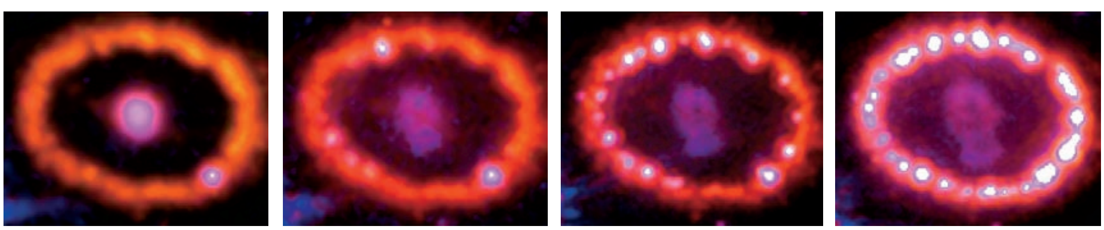


This fall, astronauts aboard the space shuttle *Atlantis* will pay a final visit to the Hubble Space Telescope (HST). They will install new instruments enabling it to peer deeper into space than ever before, and replace aging gyroscopes and batteries to keep it running until at least 2013. For nearly two decades, the orbiting telescope has radioed back to Earth images that have altered our understanding of the universe. The Hubble helped confirm the existence of dark matter: mass that we cannot see, but which nevertheless makes its gravitational influence visible by bending light itself. It proved the existence of black holes, previously a theoretical concept, and enabled the study of star formation and destruction—supernovae—as never before. The Hubble captured the first evidence that planet formation is common during the birth of stars, and has detected life-forming gas on extrasolar planets. It has provided dramatically improved estimates of the age of the universe, and led scientists to the inescapable conclusion that an unknown force—dark energy—is causing the universe to expand at an accelerating rate.

These achievements are remarkable given the telescope's ignominious debut, when a misground mirror seemed destined to be a fatal flaw. Blurred and anomalous images initially made the Hubble project appear a $1.5-billion boondoggle. But unlike its predecessors, the HST was designed to be serviced in space. A 1993 shuttle mission—including astronaut Jeffrey Hoffman, Ph.D. '93—was able to install compensatory mirrors, carefully calibrated to cancel the error. (Special software had provided a temporary "fix" until then). Since then, images produced by the Hubble have played a key role in helping Harvard astronomers make fundamental discoveries about the cosmos. This magazine asked a few of them to choose their favorite images, photographs that have been important to advancing humanity's scientific understanding of the universe. Many of the selections are also beautiful. Herewith the choices of John Huchra, Doyle professor of cosmology; Christopher W. Stubbs, professor of physics and astronomy; David Aguilar, director of public affairs at the Harvard-Smithsonian Center for Astrophysics (HSCA); HSCA astronomer Peter M. Challis; and postdoctoral fellow Anil Seth of the Harvard College Observatory. Hundreds more Hubble images appear at www.hubblesite.org.

~Jonathan Shaw and Jennifer Carling





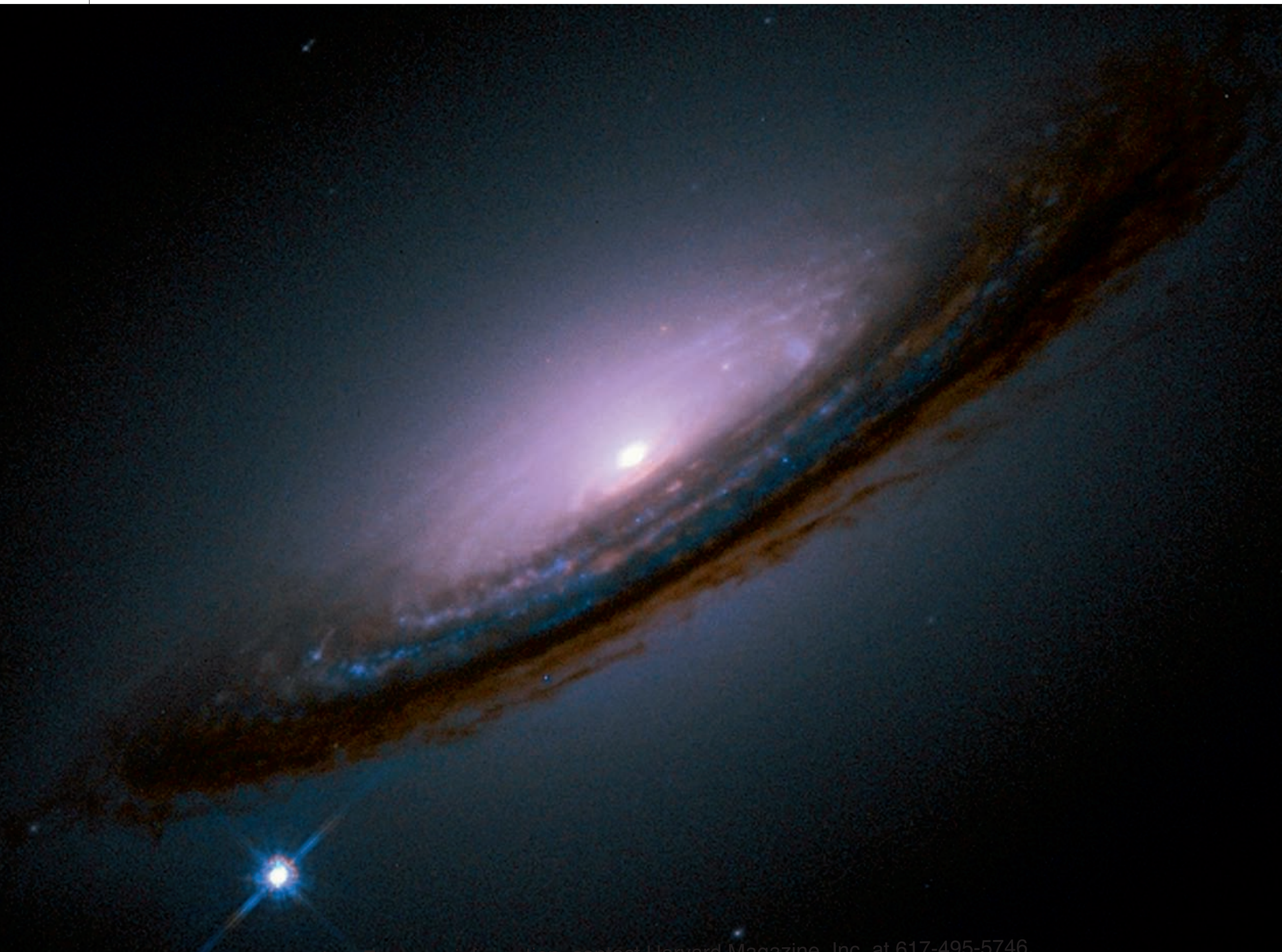
Top: In a 2006 image, a shock wave emanating from an exploding star illuminates a ring of gas shed at least 20,000 years earlier. When observers on Earth 21 years ago first spotted Supernova 1987A, it shone with the brightness of a hundred million suns. The Hubble began making a time series of images in 1990 that show the progression of the blast debris through the ring and the dissipation of the core. Images (left to right) taken in 1994, 2001, 2003, and 2006 have helped "rewrite the textbooks on exploding stars," says Clowes professor of science Robert Kirshner. He and HSCA astronomer Peter M. Challis are part of an international group studying the star's demise.

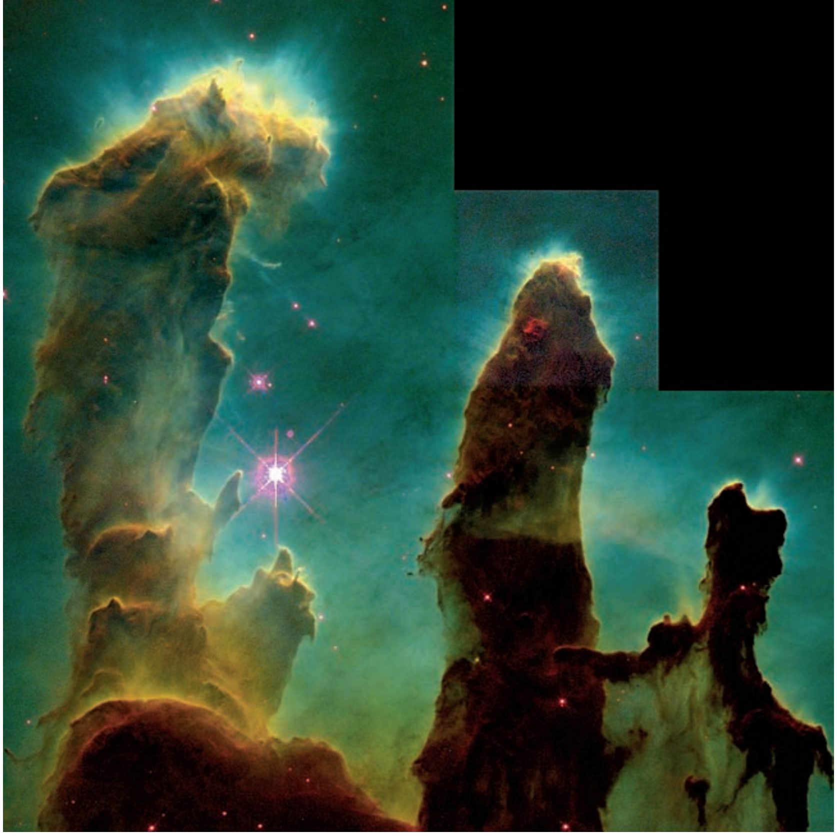
Facing page: One of the most detailed astronomical images ever produced, this panoramic view of the Orion Nebula—just 1,500 light years from our own solar system and on the same spiral arm of the Milky Way galaxy—is a composite made from many exposures over several months. Stars are born in nebulas like this one, as clouds of hydrogen gas coalesce into progressively denser and hotter clusters that eventually ignite in a fusion reaction. More than 3,000 stars appear in this image, including hundreds of young ones, allowing the systematic study of the various stages in this extraordinary process. The Hubble's views of the nebula also enabled astronomers to see protoplanetary disks, the stuff from which planets are thought to form and, for the first time, "brown dwarfs," failed stars that were not dense or hot enough to sustain fusion.

Images courtesy of NASA/STSci

Right: Located in the constellation Circinus about 7,000 light years from Earth, NGC 5315 is the remains of a dying star, the aftermath of stellar apocalypse. "What we are witnessing is the possible future of our own sun," says David Aguilar, of the Harvard-Smithsonian Center for Astrophysics (HSCA). This "planetary nebula"—so called because of its shape, not because it has anything to do with planets—"is a briefly visible cosmic tombstone that will shine for a mere 10,000 years before it disappears."

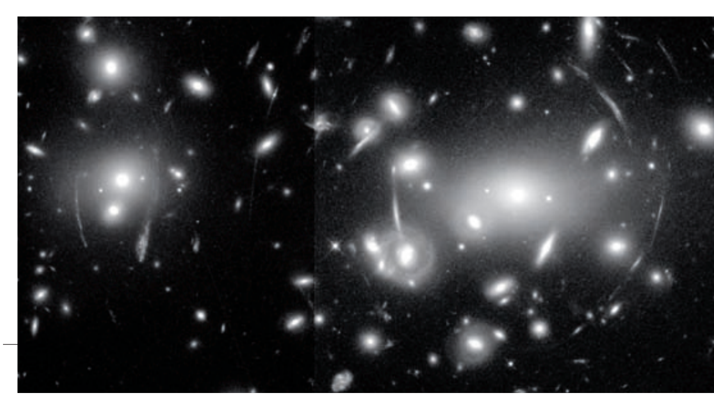
Below: HSCA's Peter M. Challis captured this supernova (1994D), an exploding star that detonated in the outer regions of the galaxy. "Supernovae," says professor of physics and astronomy Christopher M. Stubbs, "are bright enough to be detected halfway across the visible universe, and serve as beacons with which we can measure the history of the expansion of the cosmos." Hubble observations allowed astronomers to peg the age of the universe at 13.7 billion years, but its images of supernovae also drove them, reluctantly, to an astounding conclusion: the universe is expanding at an increasing rate. A force known as "dark energy," they theorize, exerts a steady, repulsive power. In the early universe, when objects in space were closer together, gravity partly counteracted dark energy's influence, slowing the expansion. But over time, the weakening of gravitational forces is causing the expansion to accelerate.



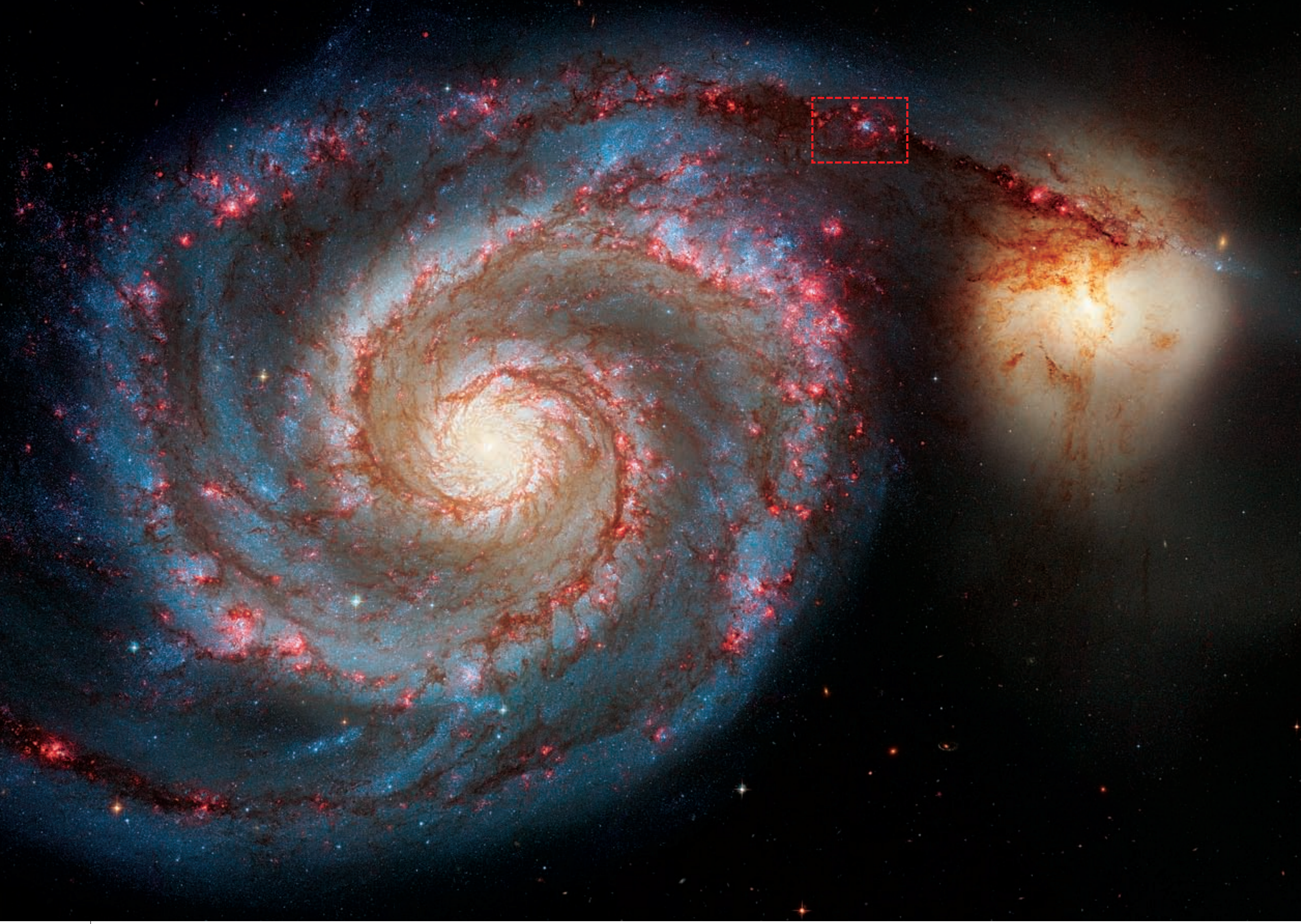


Left: The "Pillars of Creation" may be the most iconic Hubble photograph ever taken. "Located in the Eagle Nebula, the pillars are clouds of molecular hydrogen, light years in length, where new stars are being born," says Aguilar. "However, recent discoveries indicate these pillars were destroyed by a massive nearby supernova some 6,000 years ago. This is a ghost image of a past cosmic disaster that we won't see here on Earth for another thousand years or so—and a perfect example of the fact that everything we see in the universe is history." It was in the Eagle Nebula that proplyds, dusty protoplanetary disks that only the Hubble telescope's high-resolution optics can detect, were observed for the first time. (This photograph was stitched together from shots taken by four cameras. One of the cameras takes a magnified view of its quadrant, which—when shrunk to fit the scale of the other three—leaves dark space in the upper right corner.)

Below: Galaxy Cluster Abell 2218. "The arcs in this image arise from background galaxies whose shapes are distorted by gravitational lensing from the cluster of galaxies in the foreground," says Stubbs. "The strength of this gravitational lens"—which actually bends the path of the light reaching Earth—"allows astronomers to estimate the total mass in the foreground galaxy cluster," he explains. "The total amount of mass is about a factor of 10 higher than the stars we can see. The composition of the rest—the 'dark matter'—is one of the major unsolved problems in modern astrophysics."



The Hubble can detect wavelengths of light far beyond the spectrum visible to the human eye, but it can't see in color. All Hubble images begin as shades of gray, ranging from black to white. Color is added by taking multiple exposures of the same object, adding a particular hue to each one, and then combining them to create a single composite image. "Natural colors," based on the actual wavelengths of light emitted, show the object as it would appear to the human eye, as above. "Representative colors" help scientists visualize wavelengths of light they could not normally see, such as the infrared range of the spectrum. "Enhanced colors" are used to help reveal structural details that might otherwise be lost. For example, sulfur and hydrogen atoms in the "Pillars of Creation" both emit red light. Making the hydrogen green distinguishes it from the sulfur.



Above: The Whirlpool Galaxy, M51, and its smaller companion. Interactions between galaxies can lead to mergers and transformations of shape and appearance, says postdoctoral fellow Anil Seth. "Here, the gravitational influence of the smaller galaxy is creating a burst of star formation across the disk of the larger galaxy. The dense gas from which stars are forming is opaque, creating the brownish dust lanes visible across the image. When the stars first form, they light up the gas around them, creating the red nebulae that trace the spiral arms. Recently formed bright stars are mostly found clumped together in beautiful star clusters and associations. The proximity of the Whirlpool Galaxy to us, combined with the amazing resolution provided by the Hubble Space Telescope, allows us to see this burst of star formation in amazing detail."

Left: The "grand design" spiral galaxy M81. "Because it is tilted at an oblique angle to our line of sight," says Doyle professor of cosmology John Huchra, who headed the team that took the photograph, "we get a 'birds-eye view' of the spiral structure." The galaxy is similar to our home, the Milky Way, he says, but the angle of view from Earth provides a better picture of the typical "global" architecture of spiral galaxies.

Left: Hubble images contain extraordinary detail. In this enlargement of the boxed area on the opposite page, the formation of star clusters is clearly visible.

Below: This Huchra team image of M100, a galaxy in the Virgo cluster, played a key role in determining the expansion rate of the universe, known as the Hubble Constant. "This was the first real science image taken after the fix of the optics back in 1993," recalls Huchra, "and was the first of a series of images the team took to find Cepheids in order to determine the distance to the galaxy." When astronomers want to know the distance in light-years to a given galaxy, they first look for Cepheids, pulsing stars whose brightness varies predictably with the period of the pulse. Because a Cepheid's period tells scientists what its brightness should be at one light-year's distance, they can compare this known baseline to the star's brightness as it actually appears here on Earth, and thereby calculate the distance to the star. "The HST observations of M100 pinned down the distance to the Virgo cluster"—56 million light years away, far too distant for detection of Cepheids by Earth-based telescopes—"and provided the first solid evidence in the long chain of data that led to our determination of" the Hubble Constant, Huchra says. "It ain't as pretty as some of the later images," he admits, "but it's perhaps the most significant of its kind."