
April 2010
AEROSPACE
AMERICA
20
HUBBLE at
Reflections on the universe…
and ourselves
A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

REFLECTIONS ON THE UNIVERSE

HUBBLE AT 20

by Leonard David
Contributing writer

Since its launch in 1990, the remarkable Hubble Space Telescope has become an icon of astronomical exploration—seeing more, seeing farther, seeing deeper. But arriving at that lofty position and attaining such capability has not come easily.

Hubble's scrutiny of the surrounding universe far surpasses that of ground-based telescopes. The orbiting observatory has won the cosmic staring contest hands down, showcasing its ability to help resolve the age of the universe, identify quasars and scope out the existence of dark energy.

As one of NASA's most successful and long-lasting science missions Hubble is also, quite literally, a tangible symbol of human dexterity, staying power and resolve. On-orbit service calls by a succession of shuttle crews to change out instruments and replace life-limiting items have ensured Hubble's endurance as a 21st-century machine of breakthroughs and breathtaking discoveries.

Its successor, the James Webb Space Telescope now in development, has a planned launch in 2014. As a large infrared telescope with a 6.5-m primary mirror, it will be the premier observatory of the next decade—building upon the Hubble's lasting legacy.

Liberation from Earth's atmosphere

The idea of parking a telescope in space has been credited to an early founder of rocketry, German scientist Hermann Oberth, who wrote of the possibility in the 1920s. Some 20 years later U.S. astrophysicist Lyman Spitzer Jr. authored a seminal report for Project RAND, titled *The Astronomical Advantages of an Extraterrestrial Observatory.* In that September 1946 paper, the scientist suggested that a space-based telescope—liberated from the blurring of Earth's atmosphere and its distortion of light streaming in from stars—could "uncover new phenomena not yet imagined," and perhaps "modify profoundly our basic concepts of space and time."

Spitzer shouldered decades of work to make the space telescope a reality. In 1965, the Princeton University astronomer headed a National Academy of Sciences committee to define the scientific objectives for a proposed large space telescope. The idea did not find universal support among astronomers, who

...AND OURSELVES

FROM THE PEAKS OF EXCITEMENT DURING ITS 1990 LAUNCH TO DESPAIR AFTER DISCOVERY OF WHAT SEEMED A FATAL FLAW, THE HUBBLE SPACE TELESCOPE HAS EMERGED TRIUMPHANT, CONTINUING TO PROVIDE DAZZLING IMAGES AND HISTORIC BREAKTHROUGHS IN OUR UNDERSTANDING OF THE UNIVERSE.

On the first servicing mission, STS-61 astronaut Story Musgrave, anchored to the end of the remote manipulator arm, prepares to be elevated to the top of the towering HST to install protective covers on magnetometers. Astronaut Jeffrey Hoffman assisted Musgrave with the final servicing tasks.

feared that its high price tag would lessen support for ground-based efforts.

Undaunted, Spitzer began an aggressive campaign to persuade both the scientific community and Congress of the great value of placing a large telescope into space. His diligent advocacy helped spur NASA to approve the Large Space Telescope project in 1969.

In the mid-1970s, NASA and ESA took up the idea and outlined a 3-m space telescope—a facility that was "descoped," in both size and the number of instruments, because of budget considerations. Funding began to flow for the project in 1978; a few years later the telescope was named after U.S. astronomer Edwin Powell Hubble. It was Hubble who confirmed an "expanding" universe and was first to understand the true nature of galaxies. Indeed, it is Hubble's Law that provides the foundation for the Big Bang theory of the beginning of the universe.

Work began on the Hubble Space Telescope (HST), an observatory carrying a 2.4-m mirror and interchangeable instruments to perform its visible, infrared and ultraviolet light astronomical duties. It would be placed in orbit by NASA's space shuttle, which was still unfinished, and either be returned to Earth for repairs and replacement instruments, or be serviced in space.

The HST began to take physical shape as contractors, universities and NASA centers plunged into the effort. Marshall would handle design, development and construction of the telescope and its support systems. Goddard would see to the design, development and construction of the science instruments, and would also perform ground control.

Perkin-Elmer was given the task of fabricating the HST assembly, including the mirrors and fine guidance sensors required to point and direct the telescope. Lockheed Missiles—now Lockheed Martin—was contracted to build the structure and supporting systems, and to assemble and test the telescope.

By 1979, astronauts were fully immersed in training on a telescope mock-up, conducting underwater tank work to simulate the working conditions induced by microgravity.

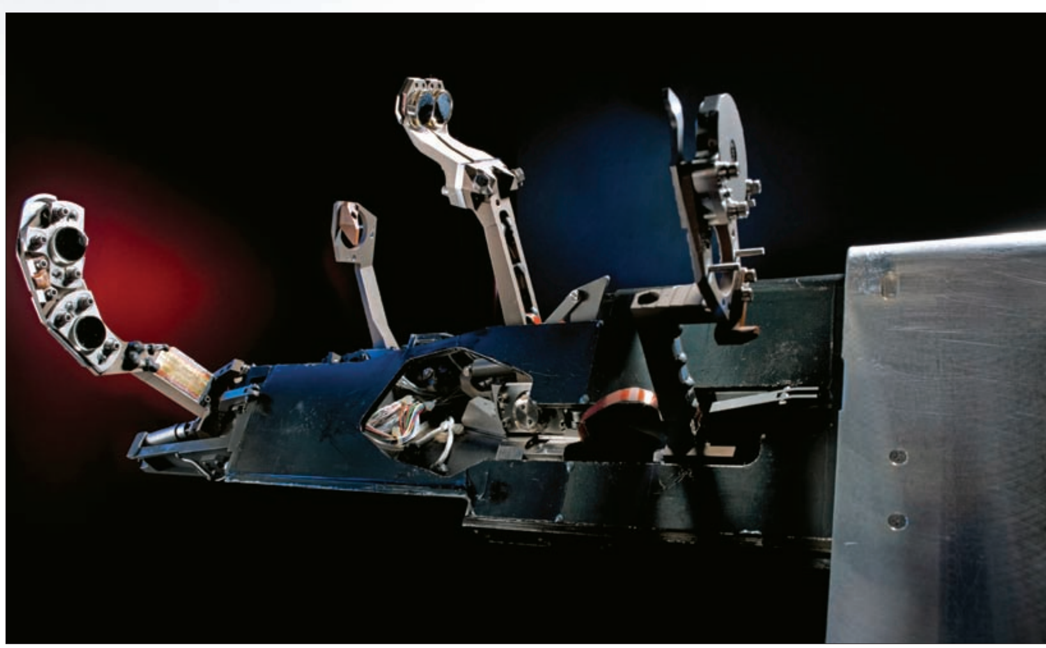
Hubble's shuttle sendoff had been slated for October 1986, but the tragic Challenger accident earlier that year had led to a two-year stoppage of shuttle missions. On April 24, 1990, on its STS-31 mission, space shuttle Discovery roared skyward, later to deploy HST into a circular orbit 600 km above the Earth, inclined at 28.5 deg to the equator.

Some 70 years had passed since an orbiting observatory had first been proposed. But as Hubble's aperture door swung open to soak in its first views, the telescope's history-making potential became more a focal point of disappointment.

Baltimore…we have a problem!

Shortly after the HST began functioning in orbit, James Crocker, then head of the programs office at the Space Telescope Science Institute in Baltimore, Md., heard the words "spherical aberration" used in connection with Hubble. He was told by a colleague: "There's a fundamental flaw with the mirror. It can't be fixed. You can't focus it out."

The blurry imagery was the result of Hubble's primary mirror having been precisely ground to the wrong shape. Later investigation found that a main null corrector—a device used to verify the exact shape of the mirror—had been incorrectly assembled. During polishing, Perkin-Elmer specialists had scrutinized the large mirror's surface with two other null correctors, both of which correctly found



Soon after its launch, scientists realized that the HST's large primary mirror was flawed. Shuttle crews installed this corrective optics package, called COSTAR, in 1993. The hardware was later returned to Earth and is now on display at the National Air and Space Museum. Photo by Eric Long, courtesy of the Smithsonian Institution.

that, indeed, the mirror suffered from spherical aberration. However, those test results were considered less accurate than the primary device, which was reporting that the mirror was perfectly configured.

The mirror's slightly wrong shape caused the light that bounced off the center to focus in a different place than the light bouncing off the edge. The tiny flaw—about 1/50th the thickness of a sheet of paper—was enough to distort the view.

Edward Weiler, NASA's associate administrator for the Science Mission Directorate, recalls that Hubble's spherical aberration "was like death by a thousand duck bites." In his role at the time, Weiler was the HST chief scientist, serving as prime scientific spokesperson for the program from 1979 until 1998. Given the telescope's eyesight woes, he says, "It was hopeless at that point. To describe it as a roller-coaster ride is an underestimate."

Then-director Charles Pellerin of NASA's Astrophysics Division writes in his book, *How NASA Builds Teams,* that after 15 years and $1.7 billion spent, Hubble became a national disaster, permeating popular culture and seen as a technological dud analogous to the Hindenburg on fire or the Titanic sinking.

A leadership failure had caused the flaw, a review board later reported. The board, notes Pellerin, found that NASA's hostile management of its Perkin-Elmer contractor caused the company to become wary of reporting technical problems if they could rationalize them. Managerial failings and quality control shortcomings on both sides, coupled with schedule slips and cost overruns, had conspired to produce the imperfect mirror.

The fix is in

For James Crocker, now vice president and general manager of Sensing and Exploration Systems at Lockheed Martin Space Systems, a slice of good news was that the tool used, the null corrector, was found in bonded storage at Perkin-Elmer. He tells *Aerospace America*: "While we didn't have Hubble's eyes…we had the tool that was used to make the Hubble wrong. We had the prescription. We knew what the error was. And if I can measure your eyes, I can make glasses for you."

Financially backed by Pellerin's Astrophysics Division, a crack team of specialists from NASA, ESA, industry and academia were brought together to brainstorm a fix for Hubble—an expert team that included Crocker. "No idea was too stupid…but some were pretty wacky," he recalls.

Bruce McCandless, a crewmember on STS-31, was also a member of that brainstorming group. "There were weird ideas," he says, a number of which ground control officials would never support, for safety reasons.

"Could an astronaut be sent down inside the telescope to spray something on the mirror to change its curvature? There was thought about thickening the outer edges of the mirror, then resilver it in place. There was no lack of imagination," says McCandless, now a Colorado-based aerospace consultant.

A first-order nonstarter was bringing Hubble back to Earth. "There was a belief, which I subscribed to as well, that if we ever brought it down, the likelihood of getting it relaunched was fairly remote," McCandless says. "So the decision was to do everything possible to fix it in place and in the meantime

HOUSE CALLS TO HUBBLE

Following its deployment in 1990, the HST has been shuttle serviced on five separate occasions.

The repairs that have been done on Hubble "are really leading edge for human spaceflight," says Mark LaPole, the Hubble mission program manager for Ball Aerospace in Boulder, Colo. "When you talk to the astronaut crew that gets assigned to Hubble, the energy that comes out of their pores is just phenomenal," he says.

Ball Aerospace has been involved in building Hubble instruments since June 1978, having built seven so far. Following the May 2009 servicing mission, all the instruments aboard the observatory are Ball-built. Probably more than 50% of the company has touched Hubble, LaPole adds.

"There's not much left to replace, because everything has been replaced," he says. "Every piece of electronics… batteries, solar arrays. Everything is new…and it could be new again."

Servicing Mission 1, December 1993

•Installation of two new devices, the wide field and planetary camera 2 and the corrective optics space telescope axial replacement, both designed to compensate for the primary mirror's incorrect shape.
•New solar arrays attached to reduce "jitter" caused by excessive flexing of the solar panels during the telescope's transit from cold darkness into warm daylight.
•New gyroscopes that help point and track the telescope, along with fuse plugs and electronic units.

Servicing Mission 2, February 1997

•Installation of the near-infrared camera and multiobject spectrometer and the space telescope imaging spectrograph.
•A refurbished fine guidance sensor, a solid state recorder and a renovated, spare reaction wheel assembly.

Servicing Mission 3A, December 1999

•Replacement of six gyroscopes, one fine guidance sensor and a transmitter.
•Installation of an advanced central computer, a digital data recorder, an electronics enhancement kit, battery improvement kits and new outer layers of thermal protection.

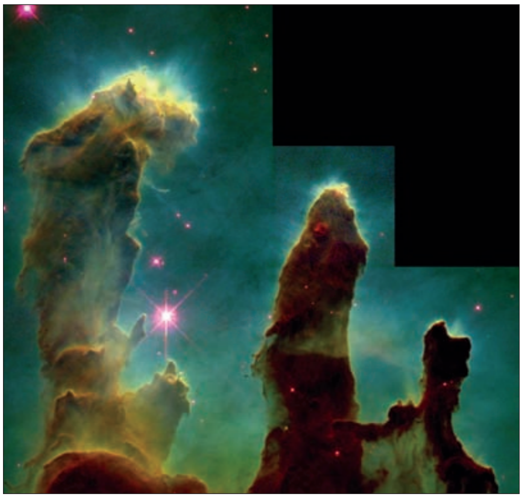
Servicing Mission 3B, March 2002

•A new science instrument called the advanced camera for surveys.
•A solar array panel swap-out with smaller, more powerful units and replacement of an outdated power control unit.
•Installation of a new cooling system for the near-infrared camera and multiobject spectrometer.
•Replacement of one of the four reaction wheel assemblies.

Servicing Mission 4, May 2009

•Considered Hubble's most challenging servicing mission, featuring installation of a new wide field camera 3 and the cosmic origins spectrograph, as well as extraction of COSTAR.
•Installation of the spare science instrument command and data handling unit.
•On-site repairs of nonworking advanced camera for surveys and the space telescope imaging spectrograph. Requirement for spacewalkers to access the interior of the instruments, switch out components and reroute power.

These eerie, dark pillar-like structures are columns of cool interstellar hydrogen gas and dust that are also incubators for new stars. They are part of the Eagle Nebula, a nearby star-forming region 7,000 light-years away in the constellation Serpens. The picture was taken on April 1, 1995, with the WF/PC 2.



get as much data as we could with the unit as it existed."

Still, even with the best image enhancement software available, Hubble's myopic condition—as well as its embarrassing techno-turkey status in the public eye—was intolerable. Furthermore, beyond the needed optical fix, the telescope was also experiencing solar array twang, among other teething issues.

Crocker is noted for conceiving the idea of the corrective optics space telescope axial replacement (COSTAR) and leading the Ball Aerospace team that developed it. This was a eureka solution, he relates, one that came to him while he was taking a shower, as he stared at a sliding shower head.

COSTAR was a series of small mirrors used to intercept the light reflecting off Hubble's mirror, correct for the flaw, and bounce the light to the telescope's array of science instruments. The device could be installed in place of one of the telescope's other instruments; Hubble's high-speed photometer was sacrificed.

Astronauts could also replace the wide field and planetary camera with a new version (WF/PC 2) that contained small mirrors to correct for the aberration. This was the first of Hubble's instruments to have built-in corrective optics.

Bolstered by nearly a year of training, the crew of Endeavour headed for Hubble on December 2, 1993. Following five days of spacewalks and repairs, the telescope received its first makeover, revitalized and reshaped into the powerful observatory that had been originally promised.

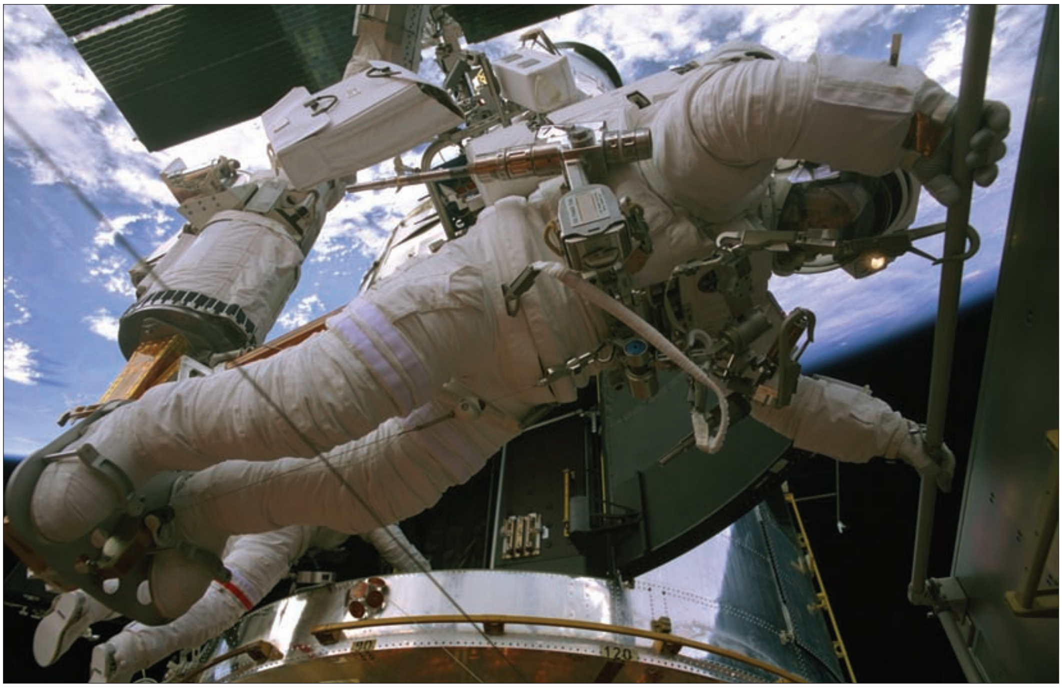
Beyond the grandeur of the universe revealed by the rejuvenated telescope, Crocker concludes, Hubble's story is a classic American saga of snatching victory from the jaws of defeat, "with brave astronauts launching into space to save the day—damn the torpedoes, full speed ahead—and overcoming adversity."

On seeing the first image from the transformed Hubble on the night of December 18, 1993, Weiler recollects: "All I can describe is vindication. That was the emotion. We had been dumped on; we had been ridiculed for three years. That was the true birth of Hubble. That's the anniversary that counts."

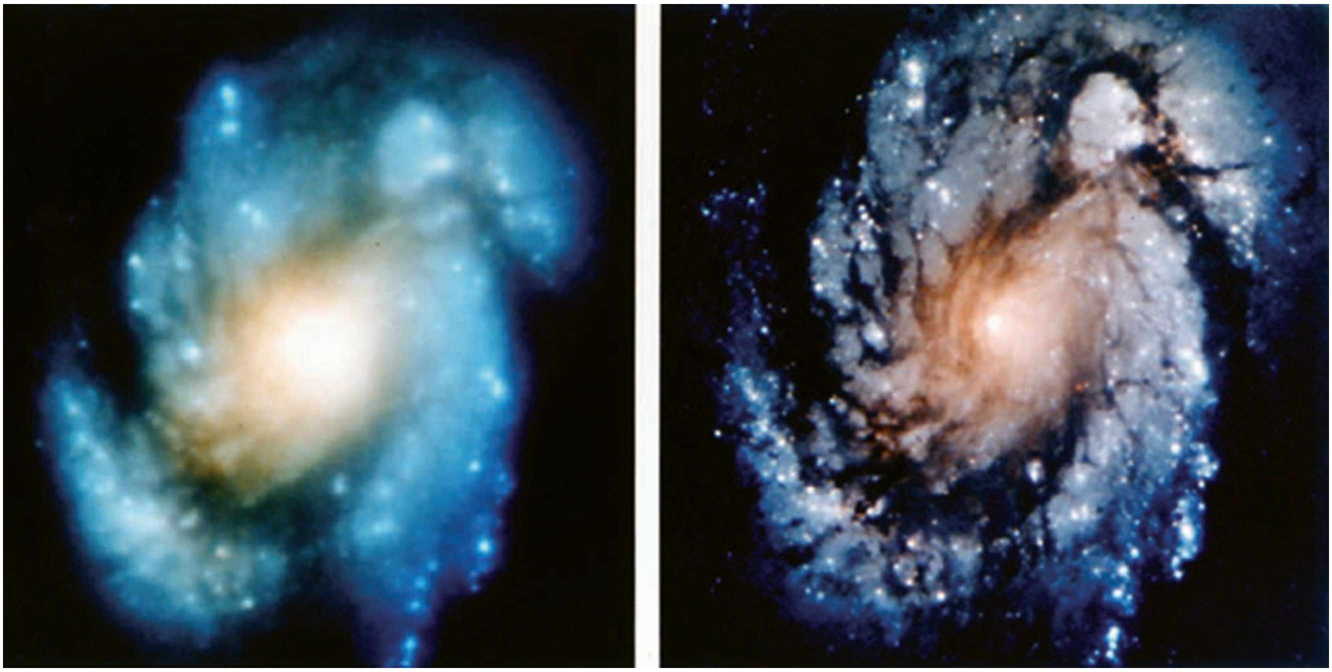
Hubble's vision was successfully repaired. In the first test of the telescope's advertised capability to be serviced and repaired in orbit, it passed in a full spectrum of flying colors.

The human factor

Since its 1990 launch into Earth orbit, five shuttle servicing missions have flown to Hubble. There has been a steady progression from



Captured by the IMAX 3D cargo bay camera, Astronaut Andrew Feustel transfers the COSTAR unit from the telescope to its temporary stowage position in the Atlantis cargo bay.



Side-by-side images of the core of the galaxy M100 show the dramatic improvement in the HST's view of the universe after the first servicing mission. The new image, taken withWF/PC-2, demonstrates that the camera's corrective optics compensate fully for the optical aberration in the primary mirror. Credit: NASA/STScI.

routine work to a reboosting of the facility to extend its useful lifetime.

The disastrous loss of the shuttle Columbia and its crew on February 1, 2003, nixed a scheduled HST visit that following year, sparking heated debate over the safety risk to humans, even spurring a major look into robotic servicing of the observatory.

That intense debate eventually subsided and led to the spectacular May 2009 "final" servicing mission to enhance Hubble's health and augment its observational skills at least into 2014 and perhaps beyond. During that last human stopover, Hubble was outfitted with a soft capture and rendezvous system to enable the telescope's safe disposal by either a future crew or robotic system.

Originally blueprinted for a 15-year service life, the telescope's performance continues, without question, to be truly stellar. But Hubble also represents a bridge-building between two communities: space science and human spaceflight.

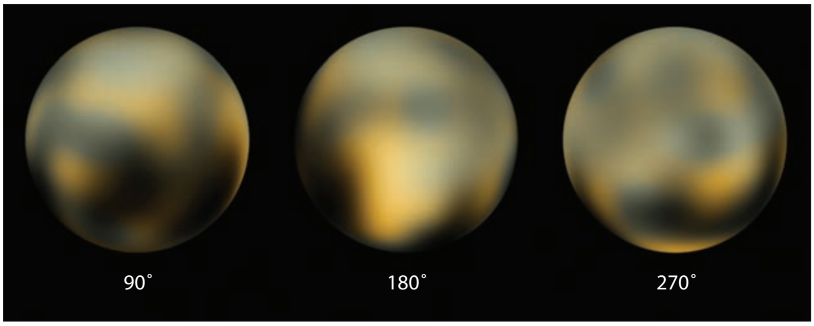
"Hubble is the shining star in the merger of science and the human space program. Hubble was designed from day one to be serviced…with astronauts in mind," Weiler tells *Aerospace America.* Indeed, if it were not for the human space program, he continues, "it would already have made one hell of a light show reentering."

John Grunsfeld, newly appointed deputy director of the Space Telescope Science Institute, has often been called the chief HST repairman—an unabashed "Hubble hugger." As a NASA astronaut he participated in three flights to service the telescope: STS-103 in December 1999, STS-109 in March 2002, and most recently, STS-125 in May 2009. He also served on two other shuttle flights.

There have been many twists and turns that make Hubble an incredible story, far beyond what an engineer could ever devise, Grunsfeld suggests. "It would take the likes of an Ernest Hemingway to really create a story with this much intrigue, politics…probably love stories buried in there somewhere. Certainly we have love for the telescope. It's a story about humans struggling and striving to do great things. And the best part of it…we don't know how it ends."

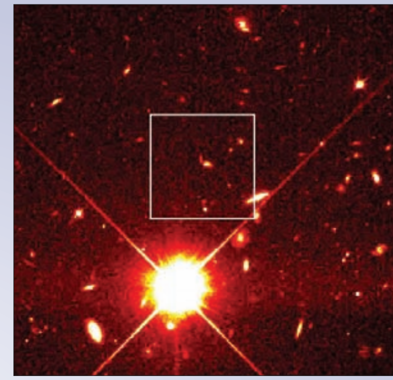
If Hubble had not been serviced by astronauts, Grunsfeld wonders, would it have remained in the public eye as much as it has?

The most detailed and dramatic images ever taken of the distant dwarf planet Pluto, released in February 2010, show an icy, mottled, dark molasses-colored world undergoing seasonal surface color and brightness changes. Credit: NASA, ESA, and M. Buie/SRI.



REFLECT ON THIS! HUBBLE'S MAJOR SCIENTIFIC FINDINGS

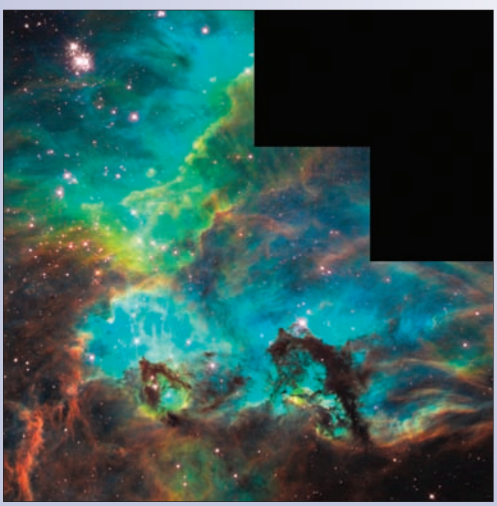
Over the last two decades, the Hubble Space Telescope has been an astronomical anchor for scientific study of the surrounding universe. The observatory's workhorse findings have had a major impact in every area of astronomy, with thousands of technical publications reporting on the facility's sharp-shooting productivity. Herewith, a "Top 10" summary of some of Hubble's major scientific results:



The accelerating universe and dark energy. *Hubble's ability to detect faint supernovae contributed to the discovery that the expansion rate of the universe is accelerating, indicating the existence of mysterious "dark energy" in space.* ➤

◀ ***The distance scale and age of the universe.*** *Observations of Cepheid variable stars in nearby galaxies were used to establish the expansion rate of the universe to better than 10% accuracy.*

The evolution of galaxies. *The Hubble Deep Field provided a deep view into the distant past of the universe, allowing scientists to reconstruct how galaxies evolve and grow by swallowing other galaxies.* ➤



◀ ***The birth of stars and planets.*** *Peering into nearby regions of star birth in the Milky Way galaxy, Hubble has revealed flattened disks of gas and dust that are the likely birthplaces of new planets.*

Stellar death. *When Sun-like stars end their lives, they eject spectacular nebulae. Hubble has revealed the enigmatic details of this process.* ➤

On the other hand, it has provided a flood of images that time and time again elicit expressions of awe and fascination.

"It has been a long-term love affair, if you will, with the public. The visibility of the images, the Eagle Nebula, the Hubble Deep Field…they show the public that the universe is much more interesting than ever imagined, not just a bunch of stars and points of light."

Spirit of discovery

The public hungers for human space exploration. Moreover, people want to see an effective use of the nation's investment in such activity, says Frank Cepollina, the manager of NASA's Hubble Space Telescope Development Project at Goddard.

"The fact that we put these great scientific machines up…that's significant for a few days," Cepollina says. "It's even more significant when you see humans for a few weeks working on those machines in space…and then they see the result of that work."

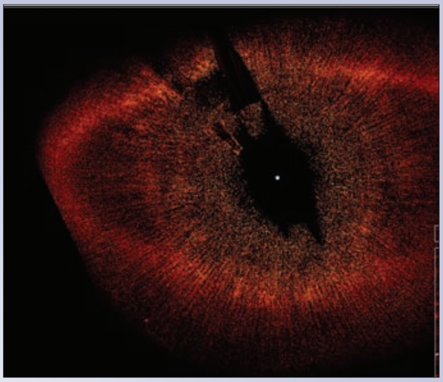
Cepollina is widely regarded as the "father" of repairing and upgrading satellites, designing the tools and technologies that enable astronauts to perform intricate tasks difficult to do even on the ground. He has been responsible for carrying out the on-orbit servicing that has maintained Hubble in peak condition, leading the charge on hardware that has allowed the observatory to stay on the cutting edge of technology throughout its long life.

Scientists making use of Hubble are direct beneficiaries of the near-term application of a new Moore's Law in orbit, an evolution of capability, says Cepollina. (Moore's Law refers to the observation—in computer parlance—that the number of transistors that can be placed on a computer chip roughly doubles every two years.)

"The new equipment has much better sig-

Stellar populations in nearby galaxies. Deep images by Hubble that resolve individual stars in other galaxies have revealed the history of star formation.

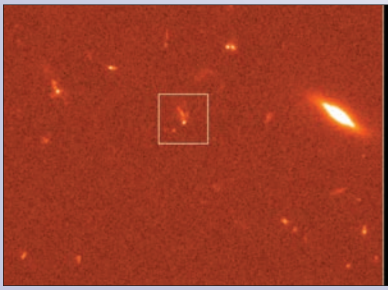
Planets around other stars. Hubble made detailed measurements of a Jupiter-sized planet orbiting a nearby star, including the first detection of the atmosphere of an extrasolar planet.

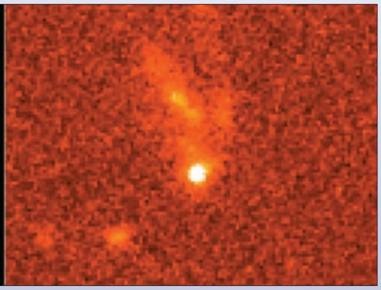


The impact of comet Shoemaker-Levy 9 on Jupiter. The explosive collision of the comet with Jupiter in 1994 was observed by Hubble, providing Earthlings with a cautionary tale of the danger posed by cometary impacts.

Black holes in galaxies. Hubble observations have shown that monster black holes, with masses millions to billions of times the mass of our Sun, inhabit the centers of most galaxies.

Gamma-ray bursts. Hubble has played a key role in determining the distances and energies of gamma-ray bursts, showing that they are the most powerful explosions in the universe other than the Big Bang itself.





With special thanks to the Space Telescope Science Institute.

nal-to-noise ratios, far fewer disturbances. There are these immediately observable improvements. They are getting much better imagery. It is not a new telescope, but it has brand-new scientific instruments," Cepollina says. "And that's what satellite servicing does in the big picture…progressively change out the scientific instrumentation so that you can continuously improve your return."

Over the years there has also been a progressive evolution of astronaut capability in orbit. Much, but not all, of that, Cepollina says, is due to more intelligent tools that can take on the brunt of a spacewalker's workload. "Let the batteries and self-powered devices do the work for them. Use their intelligence more keenly than in the past, where we relied on their brute force, skill and endurance."

What Hubble represents, he believes, is the human spirit of fostering discovery using the least costly approach possible, given the human and hardware assets already financed by U.S. taxpayers.

In saluting Hubble and what it has taught, Cepollina advises that scientific discovery becomes a direct function of our ability to provide Moore's Law every four or five years to orbit. When you do that, he adds, the products are tremendous leaps in information flow and discovery potential.

Barring a life-ending Hubble event, have we seen the last servicing mission to the esteemed orbiting facility?

Cepollina is quick to respond. "No, because I think the value of a machine like Hubble—as long as it demonstrates that it can keep making scientific advancements—we have not seen the end of it. Hubble represents a spirit of discovery. And as long as discoveries keep coming, we should do everything in our power to keep it upgraded and innovated with new technology."