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## on the cover

**Front:** NASA released this Hubble Space Telescope image to celebrate the scope's 30th birthday. *[NASA, ESA, and STScI]*

**Back:** Earth from space shows no borders except those between land and water. *[NOAA/NASA EPIC Team]*

# Hubble's Handlers

The 30th anniversary of the Hubble Space Telescope celebrates both the instrument and the creative people who have kept it going.

**By Steve Murray**

The Hubble Space Telescope berthed in Space Shuttle Columbia's bay during the observatory's fourth servicing mission, in 2002. *[NASA]*

As of April 24, the astonishing Hubble Space Telescope completed 30 years in space (about 164,500 orbits, to be precise). Many astronomers who use Hubble today weren't even born when it was launched. The project's success is owed to three decades of hard work by scientists and engineers who continually push its capabilities and fix its problems. As some of these people look back on Hubble's accomplishments at this anniversary, they're equally excited about what it will achieve in the future.

## The Bix Fix

Robert Williams is a Distinguished Osterbrock Professor at the University of California, Santa Cruz, and Astronomer Emeritus at the Space Telescope Science Institute (STScI) in Baltimore, Maryland. STScI manages the telescope science program while a partnership between NASA Goddard Spaceflight Center in Greenbelt, Maryland, and the European Space Agency (ESA) manages Hubble operations. Williams served as the Institute Director during some critical early years, 1993 to 1998.

His first big decision was whether to even take the job. After all, the telescope had been in space for three years by that time, and its faulty optics were known worldwide. "It was uncertain whether or not it would be successful," says Williams. "Still, it was the premier facility in the world at the time. How could you not want to be involved with it?"

The first Space Shuttle mission to repair Hubble's optics took place just four months into his tenure. With so much riding on its success, it wasn't easy to watch the astronauts from the ground where he had little control on the outcome. "We were all on edge," says Williams. "Some people were so nervous that they left town for the week."

In December 1999, astronauts onboard Space Shuttle Discovery replaced the Hubble Space Telescope's main computer and the observatory's gyroscopes. Hubble wouldn't be the amazing machine it still is if it weren't for the humans involved in the decades-long project. *[NASA/JSC]*

And while the optical system recieved the most attention, other issues were also found soon after launch. As the telescope transitioned between daylight and darkness during each orbit, for example, the solar arrays would buckle or "snap" slightly from the temperature change. That movement would often cause the fine guidance sensors — essential for orienting Hubble in space — to

lose lock on their guide stars. The electronics that drove the guidance sensors weren't sufficiently protected from the radiation of space, either. As Hubble traveled over the South Atlantic Anomaly, where the Van Allen radiation belt comes closest to the Earth's surface, says Larry Dunham, Chief Systems Engineer for Hubble. "You'd get radiation hits that turned ones to zeros and zeros to ones." Fortunately, Hubble ground engineers addressed both problems with software changes until later Shuttle missions installed upgraded equipment.

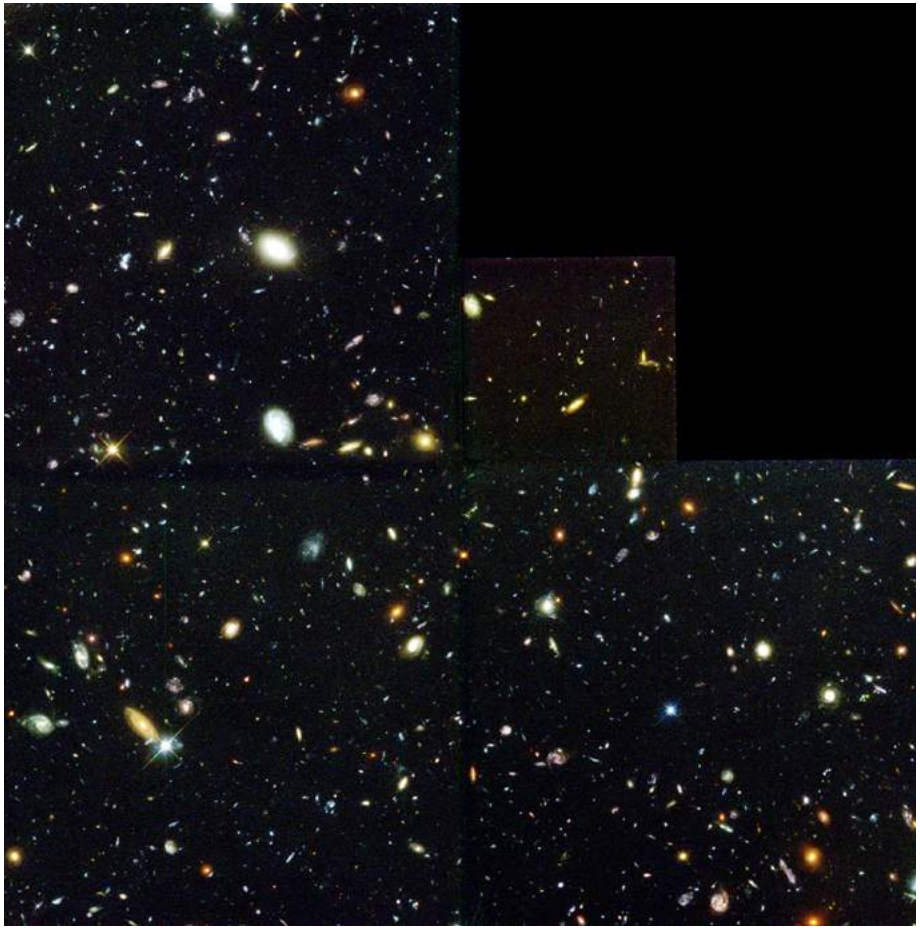
What if that first servicing mission had failed? "I had taken the risk," says Williams, "so I was prepared to be the guy who turned off the lights at the institute if it came to that. Hubble would still have compared well to the best ground-based telescopes, but you don't want to spend $2 billion on an instrument that ends up only 'as good' as ground-based instruments."

## Flexing Hubble's Muscles

The telescope did important science during its first three years, but things (literally) brightened immediately after the first Shuttle repairs, and the telescope soon showed its true potential. Williams used his Director's Discretionary Time (10% of the observing budget, awarded to high-risk projects) to ramp up two Hubble projects that would yield pioneering discoveries in astronomy: a search for the oldest galaxies and a new measure of cosmic expansion.

"Hubble was the premier research telescope in existence," he says. "Someone had to see what it could reveal of the distant universe." But to push what the telescope could do would take days and days of observing time. With astronomers clamoring for that precious resource, it was a controversial decision. Williams took a chance and allowed the telescope to stare for 10 days at a tiny spot in the constellation Ursa Major and built up an image only 2.6 arcminutes on a side. (That's less than one-tenth of the diameter of the Moon.) That image is now famous as the Hubble Deep Field. This tiny, seemingly uncluttered spot actually contains almost 3,000 objects. Most are galaxies; the light from some of the most distant of them has traveled more than 10 billion years to get to Hubble.

The Hubble Space Telescope launched with Space Shuttle Discovery. The next day, astronauts onboard Discovery captured this image of the telescope. *[NASA]*



Hubble stared at a seemingly empty speck of space for 10 days in December 1995. The resulting image, the Hubble Deep Field, revealed thousands of galaxies across cosmic time. *[R. Williams (STScI), the Hubble Deep Field Team and NASA/ESA]*

"Until Hubble came along," Williams explains, "the farthest distance that we'd been able to see galaxies was four billion light years away — only about 25% of the time back to the Big Bang. The faintest objects in that image are more than 90% of the time to the Big Bang, and those galaxies really looked different. They weren't symmetrical; they looked like train wrecks." In the Hubble deep field image, astronomers were seeing how galaxies had evolved, from clumpy young galaxies to the grand spiral and elliptical galaxies of our nearby universe.

That wasn't the only high-risk project Williams led with his discretionary time. He later supported two teams of astronomers trying to better determine the rate of cosmic expansion, known as the Hubble constant ($H_o$). "That was a difficult series of observations that pushed the telescope to its limit," Williams recalls.

Both teams planned to observe exploding stars called supernovas at far distances. Their final results, however, were revolutionary. They expected to measure how cosmic expansion was slowing down but found, instead, that it was speeding up. That meant that a new energy source was involved – today known as dark energy and making up some two-thirds of the universe. "Most people would agree it was the most important result that's come out of the telescope," says Williams. In fact, the discovery also won the three lead researchers the 2011 Nobel Prize in Physics.

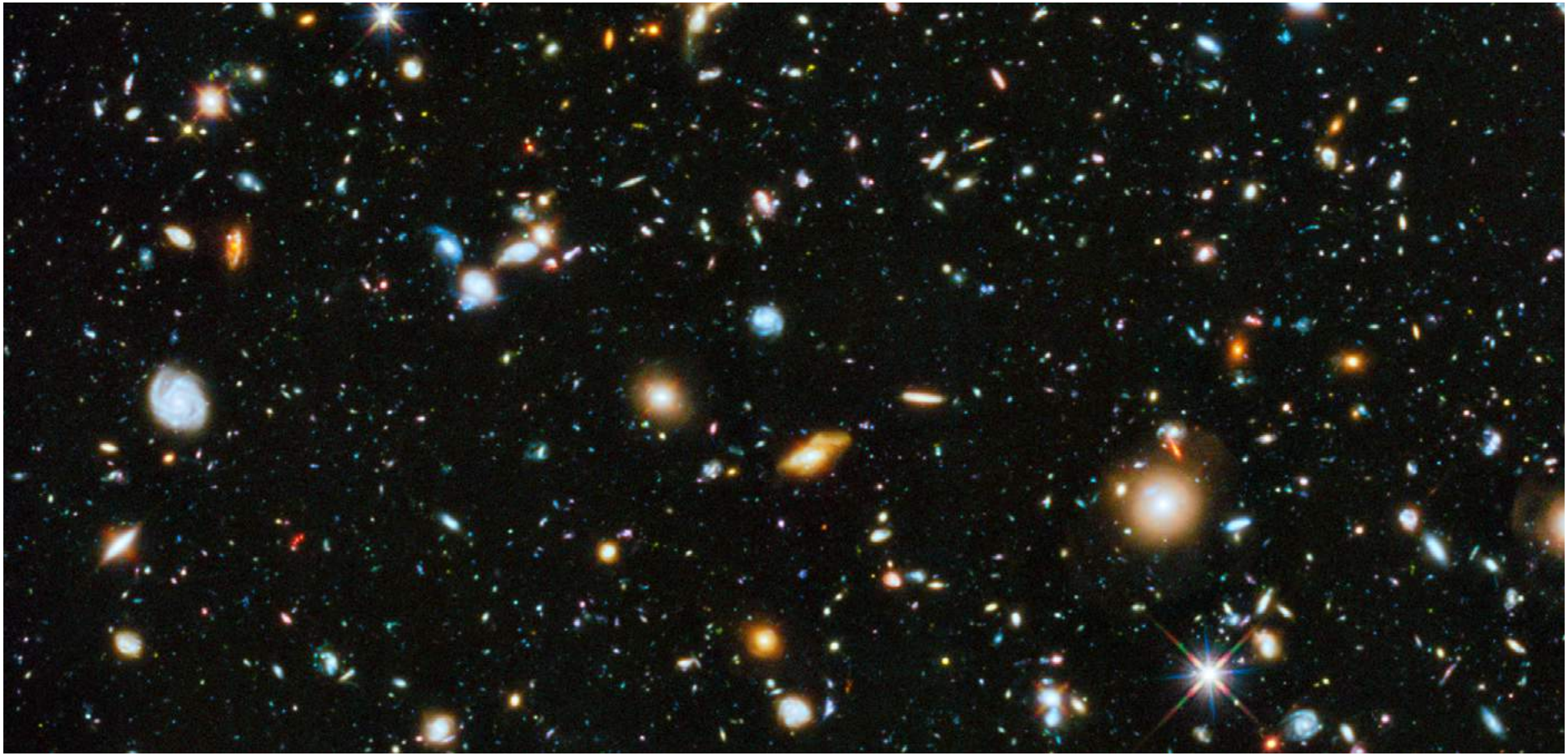
## The Last Mission

In 2009, the last Shuttle servicing mission repaired the Space Telescope Imaging Spectrometer (STIS) and installed Wide Field Camera Three (WFC3), a panchromatic instrument that could see wavelengths from ultraviolet into the near infrared. And as with previous missions, Goddard engineers were online, furnishing real-time assistance to the Shuttle crew. "Probably the most exciting times of my career," says Dunham, "were when the astronauts were up there, and I was down here  trying to support them. Our control room would be packed with 100 people on two different shifts."

Even after five servicing missions, though, anxiety was still a big part of the process. Sometimes it helped to be far away from the

action in the control rooms. "I agreed to give a talk at my daughter's school back in 2009," said Tom Brown, Head of the Hubble Space Telescope Mission Office at the STScI. Brown had worked on STIS after installation and WFC3 during development and test. "As luck would have it, the time they asked me to come was the very morning they installed Wide Field Camera Three." The instrument represented years of work to Brown.

The astronauts had to uninstall the old camera (WFC2) to put the new one in the same slot, but WFC2 was stuck. After repeated failed tries, NASA gave the astronauts permission to crank a release bolt as hard as needed. Everyone held their breath. If it cracked or stripped, that would be it for WFC3 but, happily, the gamble worked. "I got back after talking to the kids, and everyone at work was still kind of hyperventilating," recalls Brown. "I'm really glad I wasn't there to see that!"



In the telescope's 30-year history, the Hubble team has captured more deep-field images. This one is a composite of several of them. *[NASA, ESA, H. Teplitz and M. Rafelski (IPAC/Caltech), A. Koekemoer (STScI), R. Windhorst (Arizona State University), and Z. Levay (STScI)]*


During the final serving mission, in 2009, the Hubble control room was a busy place. During the mission, team members took a break to pose for a photo. *[NASA]*

## Fixes From A Distance

After the Shuttle servicing missions ended more than 10 years ago, technical changes to the telescope could be implemented only from the ground, with software coding as their only tool. NASA Goddard engineers, however, had been doing this kind of remote work for a long time. "There always seems to be something going on with the telescope," says Dunham, "especially with the fine guidance sensors and the [gyroscopes]. We've updated the logic for them several times in the past few years." Deep institutional knowledge also helps to sustain the effort. "We've got a team of 83 people here," he adds, "with an average experience of 22 years." Dunham himself joined the program back in 1982 — a year before the telescope even got the name *Hubble* — and he's been with the telescope full-time longer than anyone else.

Some engineering, of course, tries to anticipate potential future problems, too. "Hubble had six newly installed gyroscopes after the last servicing mission," explains Jennifer Wiseman, Senior Project Scientist for Hubble at NASA Goddard, "but over the years gyroscopes naturally wear out. Since that mission, we've lost three." The telescope can point accurately at targets using three gyroscopes, but, she adds, "our ground team has already developed procedures that use other sensors to complement the working gyros, and keep pointing capability, should we lose any more."

Hubble science processes, as well as Hubble systems, can also be beefed up from the ground. "We're using the gravity of galaxy clusters as lenses to view light from the more distant galaxies behind them," says Wiseman. And one of the innovative things astronomers can do with that lensed light is disentangle the patterns of the distorted light to learn how the invisible dark matter in the intervening galaxy cluster is distributed.

Spatial scanning is another tool developed by STScI astronomers. "That's where we intentionally drag the field of view and smear out all the stars" says Brown. The technique measures an object's motion against background stars, using parallax to determine its distance. "It's terrible for pictures," he adds, "but you get amazingly accurate astrometry perpendicular to the direction you're dragging."

And now Hubble is emerging as a critical player in so-called multi-messenger astronomy, owing to its unique wavelength coverage. "All of the new observatories coming online are going to want to get data with Hubble," Brown says, "particularly in the ultraviolet and optical where Hubble has unique capabilities." While the next large space observatory James Webb Space Telescope (JWST) will do

To replace the previous generation camera with the Wide Field Camera 3 during the final servicing mission, astronauts had to crank hard on a release bolt. *[NASA]*

amazing science, it detects only infrared radiation. Pairing JWST with Hubble can do incredible things.

"Even now, 10 years after the last servicing mission," says Brown, "Hubble is on the bleeding edge of what you can do in astronomy."

## Ultimately, Everything Ends

So far, Hubble has traveled about 4.5 billion miles (7.2 billion km) in its orbit around Earth, and Wiseman is optimistic about its future longevity. "Just from the trending of the health of the components of Hubble," she says, "the probability curves show that it has a great chance of being productive, at least to 2025, and probably many years beyond that." Hubble will almost surely be around in 3.5 years, then, to pass the 5-billion-mile (8-billion-km) mark.

Nevertheless, something important will eventually fail on the telescope. What happens then? A research gap would last until a replacement comes along. LUVOIR, for example, is an infrared-optical-ultraviolet space telescope being evaluated in the National Academy of Sciences Decadal Survey right now. Although recommendations from the survey are expected in six to nine months, however, the telescope still wouldn't be ready to launch before the 2030s or 2040s. These workhorse projects take time. In fact, the National Academy of Sciences recommended the Large Space Telescope, what became Hubble, in 1969.

Williams is philosophical about the situation. "We have to face the fact that there are these gaps, particularly since pioneering facilities are so expensive," he says. "You can only undertake a few of them at any one time." The next couple large space telescopes that NASA is developing will be infrared instruments. "And so when Hubble eventually shuts down," he adds, "there's likely to be a time in which ultraviolet astronomy, at least in the United States, will not be viable." That's because ultraviolet astronomy is not possible from the ground, due to Earth's protective atmsphere.

In the meantime, there's still a lot of work for Hubble to do. "There's no shortage of science that needs to be done with the telescope," says Wiseman. "In fact, the pressure from proposers around the world is as high as ever." As of May, almost 1,100 science proposals had been received for Hubble's next observation cycle.

"There's plenty of discovery space left," she adds. And as long as it's healthy, the Hubble Space Telescope will be in orbit to fill it. ★

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