Twenty-five years of the Hubble Space Telescope

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For the past twenty-five years, the Hubble Space Telescope has been one of the most fruitful and versatile astronomical platforms ever launched into space. For more than 9,000 days, the telescope has provided outstanding scientific data in the near ultraviolet, visible, and near infrared regions of the electromagnetic spectrum on nebulae, globular clusters, galaxies, supernovae, exoplanets, black holes and our own solar system. For a generation, Hubble has inspired and spearheaded a new era of inquiry about the cosmos.

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Hubble was launched on April 24, 1990 on board the space shuttle *Discovery*. It was the first of NASA's Great Observatories to be launched, a constellation of four space telescopes which also includes the Compton Gamma Ray Observatory (de-orbited in 2000), the Chandra X-ray Observatory, and the Spitzer Space Telescope. Each was designed to observe different wavelengths, complementing the others and combining their views into a greater whole. The series has been one of NASA's most successful scientific programs. Every telescope launched (with the exception of Compton) remains in at least partial operation.

Six instruments are used to collect light focused by Hubble's mirrors: Wide Field Camera 3 (WFC3), the Cosmic Origins Spectrograph (COS), the Advanced Camera for Surveys (ACS), the Near Infrared Camera and Multi-Object Spectrometer (NICMOS), the Space Telescope Imaging Spectrograph (STIS) and the Fine Guidance Sensor (FGS). Data is then beamed down to Earth for processing, distribution and study.

Significantly, none of the instruments on the telescope are part of its original equipment. One of the main reasons for launching Hubble by space shuttle was that the instruments on board could be replaced as newer ones became available. Indeed, almost everything on Hubble—scientific instruments, batteries, gyroscopes, solar panels, computers—has been upgraded. Only the original mirrors and the substructure itself remain from the original launch. The final scheduled service mission was in 2009.

While it is a public relations boost for NASA, Hubble's true importance lies in its continued and vast contributions to astronomy. One of its initial goals was to observe a specific class of stars known as Cepheid variables, whose brightness can be determined, and then measure their distance from Earth. This greatly increased the precision in measuring the expansion rate of the universe, reducing the margin of error from fifty percent to ten percent.

A follow-up study, this time observing supernovae in distant galaxies, found that the expansion rate of the universe is increasing, rather than decreasing as expected. Ground-based observations confirmed the existence of the poorly understood force driving the expansion, called "dark energy." Its discovery was awarded the 2011 Nobel Prize for physics.

Hubble's high resolution also made possible the first direct studies of supermassive black holes. These objects were first identified as radio sources in distant galaxies but the source was unclear. Something extraordinarily powerful would have to be generating a great deal of energy to be seen from billions of light years away. After decades of work, it became clear in the 1960s that the only explanation for what astronomers were seeing was the energy emitted from an accretion disk of black holes millions and even billions of times the mass of our Sun.

Here, the Chandra observatory has played a key role in understanding these objects, working in tandem with Hubble to dig deeper into the underlying physics that drives these events. It was Chandra which first discovered that the nearby Andromeda galaxy most likely has two supermassive black holes instead of one. Combined efforts using Hubble, Chandra and other telescopes have since shown that supermassive black holes are common features of galactic nuclei.

Hubble also contributed substantially to our understanding of the mechanics by which giant clouds of gas and dust collapse to form new stars. Its stunning portrait of the Eagle Nebula in 1995 became a popular poster and screen background for millions worldwide. This image captured pillars of dense gas containing even denser cores becoming new stars, simultaneously being evaporated by the young and brilliant stars already formed. A recent image captures motions in the intervening 14 years, measuring a 200 kilometer per second growth of a jet associated with a young star.

Infrared images of the Eagle Nebula were taken by the Spitzer telescope in 2007 to see inside the clouds, complementing Hubble's observations. The most striking feature revealed is the abundance of hot dust, most likely warmed by a nearby supernova from 8,000 to 9,000 years ago. If so, the explosion's blast wave would have toppled the three pillars 6,000 years ago. Since light takes 7,000 years to travel from the Eagle Nebula to Earth, we will see whether or not this prediction is true within a millennium.

Perhaps the most extraordinary science done by the observatory are the deep field images, the first of which was the Hubble Deep Field (HDF) taken in 1995. Focusing on an area of the sky less than 100 times the size of the Moon as viewed from Earth, where only a handful Milky Way stars can be seen, Hubble collected light for eleven days.

In that minute region of space, Hubble revealed to astronomers and the public alike just how large space is. About 3,000 distinct galaxies were observed in the images, each containing tens of billions of stars, with spiral, irregular and elliptical galaxies all present. The study provided the first in-depth look at the early universe, seeing galaxies as far as 12 billion light years away and thus—since light takes time to travel through space—galaxies as they were 12 billion years ago. Astronomers were astonished by the number and variety of young galaxies Hubble revealed.

These images motivated a succession of subsequent "deep field" explorations, created with new generations of improved cameras aboard Hubble. In 2003-2004, the Hubble Ultra Deep Field (HUDF) was taken, focusing on 11 square arcminutes in the constellation Fornax and looking back in time 13 billion years to view 10,000 galaxies forming less than a billion years after the Big Bang. The Hubble eXtreme Deep Field (XDF) was taken in 2012 focusing in on a region of the HUDF. The exposure was taken over twenty-three days, collecting data on galaxies that are ten billion times fainter than the human eye can see. Some of the 5,500 newly discovered galaxies are 13.2 billion years old, the oldest ever observed in visible light. Due in part to this work, astronomers estimate that the observable universe contains 200 billion galaxies.

The first proposal to use a rocket to put a telescope in space was published by the German physicist Hermann Oberth in 1923. In his work *Die Rakete zu den Planetenräumen* ("The Rocket into Planetary Space"), which was previously a doctoral dissertation rejected as "utopian", he suggests that rockets could eventually lift telescopes into Earth orbit. His work, alongside that of Robert Goddard, Konstantin Tsiolkovsky and Oberth's assistant Wernher von Braun founded modern rocketry and paved the way for every space telescope that has flown.

Hubble's origins date back to 1946 when the astronomer Lyman Spitzer published the paper "Astronomical advantages of an extraterrestrial observatory," which first laid out the scientific justifications for putting an observatory above the atmosphere. Spitzer argued that if the best telescopes of the day could have been placed where there is no air, the lack of turbulence would increase the angular resolution of each by at least ten-fold. Moreover, they would also be able to observe infrared and ultraviolet light, which are largely blocked by Earth's atmosphere.

After a series of small-scale instruments designed to show that infrared and ultraviolet astronomy could in fact be successfully done in space, NASA approved the plans for a space-based 3-meter reflecting telescope in 1968. It was provisionally known as the Large Space Telescope (LST) and first slated to launch in 1979.

Though the astronomical community fully backed the creation of the instrument, NASA faced funding hurdles from a recalcitrant Congress and public spending cuts instigated by President Gerald Ford. Now that the geopolitical impetus for space exploration had vanished—after the United States beat the Soviet Union to the Moon—there was little interest in providing money for spaceflight, especially for missions that had no military purpose, only scientific knowledge. Funding for the project was deleted in 1974. It was only after a Herculean effort by astronomers campaigning for the LST that funding was restored, and even then it was four years later at only half the original budget. As a result construction of the primary mirror and other instruments began the year the telescope was originally slated to launch.

Here, NASA ran up against the US military. The company commissioned to build the mirror, Perkin-Elmer, was well known to the US government for its development of the optics used on the Keyhole-9 HEXAGON spy satellites. Soon after it was announced that Perkin-Elmer would be producing the mirrors for LST, the US Air Force demanded that the experience, techniques and personnel involved in making the KH-9 satellites not be used in the development of the LST because those resources were classified. As a result, Perkin-Elmer was forced to develop the team and facilities to design the mirror from scratch, causing the scheduled launch date of 1983 to slip to 1986.

Further delays were caused by the Challenger disaster in 1986, which grounded the shuttle fleet. The newly renamed Hubble Space Telescope, designed to be carried into space by a shuttle, was forced to wait in a clean room purged with nitrogen until its launch could be rescheduled. The cost of the wait was approximately $6 million a month, but it did allow engineers to make improvements such as replacing a possibly failure-prone battery. It also allowed the computer experts to further develop the software needed to control Hubble, which was not ready in 1986 and only just completed when Hubble finally launched in 1990.

Almost immediately, a flaw potentially fatal for the scientific usefulness of Hubble was discovered. The first light images from the telescope were of drastically lower quality than expected. An investigation into the problem indicated that Perkin-Elmer had ground the mirror precisely, but 0.002 millimeters out of shape. This error had actually been caught during mirror development by one of the testing procedures. However, a second test did not show the spherical aberration and that measurement was adopted as the more valid as a cost-cutting management decision.

However, Hubble was designed to be repaired and to have instruments replaced during subsequent shuttle missions. A plan was drafted to bring a corrective mirror to the telescope during Service Mission 1 scheduled for December 1993. During five space walks, clocking in at 35 hours and 28 minutes, astronauts took out the High Speed Photometer and installed the COSTAR device, a robotic assembly of 5,300 parts which deployed six adjustable corrective mirrors in the optical paths of the other scientific instruments.

Astronauts also used the mission to replace wobbly solar arrays and defective gyros as well as install the second generation Wide Field Planetary Camera. On February 21, 1994, the newly repaired Hubble released the most detailed image yet of Pluto and its moon, Charon, beginning a career for which it has become internationally famous.

Despite the colossal success of Hubble, NASA has made plans to end the mission. As the shuttle program was close to ending, the 2009 service mission to the telescope included installing a ring on the outside of Hubble, allowing future missions—manned or robotic—to more easily capture the telescope. The intention is not—as would be logical—to attach a rocket that would boost its orbit in an effort to combat the slow orbital decay caused by atmospheric drag. Instead, in what can only be described as an act of anti-scientific vandalism and a deliberate coup de grâce, NASA plans to attach a rocket to guide Hubble towards the Earth, burning up the telescope during re-entry.

The justification for this is that the next generation James Webb Space Telescope (JWST) will be Hubble's successor. In any scientific sense, this is not true. The JWST will *complement* the Hubble space telescope, looking more towards infrared rather than ultraviolet light. This will allow a greater focus on objects more distant and colder than what Hubble is optimized to study. It is expected to be able to detect stars in the early universe 280 million years older than Hubble.

However, the launch of the JWST has been pushed back from an initial date sometime in 2011 to October 2018. Primary responsibility for this rests with the constant threats by congressional Republicans, particularly those on the House Appropriations Committee, to end the project. In fact, in 2011, they did fully cancel the project, though funding was later restored after an international scientific appeal. For its part, the Obama administration ensures that funding levels remain as low as feasible.

As such, there is no replacement for Hubble. At a cost of $10 billion (a pittance compared to what the US spends on wars abroad or surveillance at home), after two and a half decades of groundbreaking scientific discoveries and a generation of being the fuel for excitement of scientific discovery, Hubble is expected to be forcibly de-orbited in 2024 as its orbital decay brings to a close its scientific observations. JWST, which is not serviceable in orbit, is expected to live only another four years beyond that. No credible plans exist for a successor mission. One begun in earnest right now, developed at the same pace as JWST, would begin observations in 2037.