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SCIENCE

A mirror to space

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In the 20 years of its functioning, the Hubble Space Telescope has revealed hitherto unknown secrets.

NASA/AFP

The Hubble Space Telescope as seen from the space shuttle Discovery in 1997.

THE worldwide astronomical community celebrated the Hubble Space Telescope's (HST) 20th anniversary in space on April 25, 2010. Some argue that this telescope has had as profound an impact on astronomical research as Galileo Galilei's very small telescope 400 years ago.

The HST is a technological wonder of our age that has fascinated millions with its beautiful and awe-inspiring images of the universe. It has revolutionised the science of astronomy, revealing hitherto unknown secrets of planets, stars and galaxies and giving us a perspective on the universe we could never have imagined previously. Apart from capturing stunning close-ups of the planets in our own solar system, Hubble has looked deep into the Milky Way and beyond to take pictures of rare, massive stars a hundred times bigger and a million times brighter than our own sun and star-forming nebulae that extend across dozens of light years. It has allowed scientists to witness some of the most destructive forces in existence when galaxies collide, and the huge amount of energy released when stars reach the end of their lives.

Hubble's Deep Field images are among the most scientifically important images ever taken, showing the most distant and most ancient galaxies in the visible universe. The HST has contributed significantly to essentially all areas of current astronomical research – from planetary science to cosmology.

As of mid-March 2010, the HST has observed 30,322 unique targets, and there are 44.34 terabytes of data in the HST archive. Astronomers have published 8,736 scientific papers to date using HST data, and these papers have generated 323,291 citations. The HST's findings are thus far too numerous to be described even very briefly in one article. Let us have a look at the factors that prompted astronomers to envision having a giant telescope in space.

Origin of the plan

Obtaining information about objects in the sky, up to a point, has been made dramatically easier thanks to advances in mirror and detector technology. Beyond that, astronomers face a barrier: the atmosphere of our earth. Even bigger and more sensitive telescopes have not been able to penetrate this. We are not able to see the universe clearly from the earth because we are looking up through a hazy shroud of gases around our planet.

As light from celestial objects is bent, scattered, and absorbed by passage through our turbulent atmosphere, images are distorted, blurred and dimmed. Placing telescopes on high mountain peaks improves viewing, but the best place for a telescope is in space. To observe the faintest and farthest stars and galaxies in as much detail as possible, we must lift our telescopes into orbit beyond the turbulent, obscuring atmosphere.

PICTURES: BY SPECIAL ARRANGEMENT

A HUBBLE PORTRAIT of the Eagle nebula, never seen before.

The concept of a space telescope has its origins in the writings of Herman Oberth in the 1920s, M.N. Saha in 1937 and Lyman Spitzer in the 1940s. These scientists suggested that astronomy could benefit greatly from a telescope that viewed the universe from above the earth's obscuring atmosphere.

The dream of these scientists was fulfilled on April 24, 1990, when the HST was released into orbit. It is the largest telescope in space to date. It is a reflecting telescope with a primary mirror that is 2.4 metres (94.5 inches) in diameter. It can detect very faint objects since it can look 50 times farther into space than can earth-based powerful telescopes. With its precise optics and its location above the earth's atmosphere, it can resolve details 10 times smaller than can be resolved by any conventional telescope on earth. Every few years, astronauts visit the telescope in orbit and install new instruments. The telescope has thus exceeded its original design criteria.

AN HST IMAGE of the Whirpool galaxy, which is 31 million light years away.

The orbiting observatory was named the Edwin P. Hubble Space Telescope after the scientist who, in the 1920s, discovered that there are other galaxies comparable in scale to our own. Hubble also provided the observations that were interpreted to show that the universe is expanding.

The project cost $2 billion; most of the funds come from the National Aeronautics and Space Administration (NASA), the United States' space research agency. The European Space Agency provided the solar array that supplies power, one of the instruments and some of the staff. The telescope is controlled from the Space Telescope Science Institute (ST ScI) on the campus of Johns Hopkins University in Baltimore, U.S. The HST was originally designed to work for at least 15 years. The telescope's overall dimensions approximate those of a city bus or railroad tank car – 13 m (43 feet) long, 12 m (39 feet) across with solar arrays extended, and 11,000 kg when weighed on the ground. The main mirror is designed to capture optical, ultraviolet and infrared radiation before it reaches the earth's murky atmosphere.

The optical system and scientific instruments aboard the HST are compact and pioneering. The telescope reflects light from its primary mirror back to a smaller, 0.3-m (12-inch) secondary mirror, which in turn sends the light through a hole in the doughnut-shaped main mirror and on to the aft bay of the spacecraft. There, any of six major scientific instruments wait to analyse the incoming radiation. Most of these instruments are about the size of a telephone booth. They include two cameras to image (electronically photograph) various regions of the sky, two spectrographs to split the radiation into its component colours, a photometer to study the intensity of light, and a group of fine guidance sensors to measure the positions of stars in the sky.

Defects in the HST

Soon after the HST was placed in orbit from the space shuttle in 1990, astronomers discovered that the telescope's 2.4-m primary mirror lacked the proper curvature, which caused its star images to be surrounded by a hazy glow. The primary mirror is too flat by about 1/50th the width of a human hair. Hubble's problem was identified as a spherical aberration in the optical assembly – it made the telescope's images fail to come to a sharp focus as expected. In simple terms, light from the inner and outer edges of the primary mirror is not brought to the same focal plane; instead, light from the outer edge comes to focus about 4 cm behind light from the inner edge. This aberration was demonstrated in a series of images taken with the Wide-Field and Planetary Camera over a wide range of focus settings of the secondary mirror. Tests showed that the faulty optical surface was that of the primary mirror.

Then it was noticed that the twin solar-cell wings vibrated intermittently, shaking the telescope. When this happened, stars danced in and out of the instruments' pinhole apertures and high-magnification images got smeared. The solar arrays would expand and contract as the space telescope passed in and out of the earth's shadow during its every 90-minute orbit. But the motion of the array made the telescope jitter and this, in turn, made the images blurred.

Thirdly, defects were noticed with the Rate Sensor Units (RSUs) of the HST. RSUs help point the telescope. They are essentially gyroscopes. The first gyro failed in December 1990, the second in June 1992 and a third developed problems in November 1992. The telescope has six gyros but needs only three to point it. Replacing these units had to be given the highest priority because another failure would have prevented astronomers from pointing the telescope.

DARK MATTER IMAGED from the large galaxy cluster known as the Bullet Cluster. Dark matter does not radiate or absorb light, but the HST can sense how its gravity distorts the shapes of background galaxies by gravitational lensing.

Knowing that the problem was a straightforward spherical aberration of the main mirror made it possible to fix it, just the same way as eyeglasses improve a person's defective vision. The main camera, the Wide Field and Planetary Camera, which makes about half the observations of Hubble, was to be replaced in any case in a servicing mission after about three years. A small mirror in it was reground to correct the spherical aberration of the main mirror. For the other instruments, an ingenious system known as COSTAR (Corrective Optics Space Telescope Axial Replacement) replaced the least-used of the HST's instruments. COSTAR corrected them all by erecting mirrors on movable stalks in front of the other instruments. The replacement camera, now known as Wide Field and Planetary Camera 2 (WFPC2), and the COSTAR were installed by astronauts aboard a space shuttle in 1993. The astronauts also replaced the solar panels, gyroscopes, and other items that needed repair. This first repairing mission was a spectacular success, and the Hubble Space Telescope went into full working order. Images taken with the WFPC2 are of much higher quality than the pre-repair images. It has already taken hundreds of thousands of images.

Another repairing mission in 1997 installed an infrared camera known as NICMOS (Near Infrared Camera/Multi Object Spectrograph), extending Hubble's capabilities to longer wavelengths. A Space Telescope Imaging Spectrograph (STIS) was also installed, which is much more efficient than the earlier spectrographs. This helps the HST discover even the most distant galaxy known to humankind.

A 1999 upgrade mission restored various telescope systems to good health and reboosted the spacecraft into a higher orbit. This servicing mission replaced the transmitter and six gyros. A subsequent upgrade mission in 2002 replaced the Faint Object Camera with the Advanced Camera for Surveys. Unfortunately, the lifetime of NICMOS had been shortened because of a problem that led to increased heat transfer. This mission provided an electronic cooler that restored NICMOS to its earlier functioning mode. The new camera will not only be more sensitive but also have a wider field of view than the older camera, improving Hubble's observing efficiency for surveys by a factor of 10.

The last servicing mission was in May 2009 when WFPC2 was replaced by a more sophisticated camera, Wide Field Camera 3, or WFC3, and COSTAR was replaced by COS (Cosmic Origins Spectrograph). During the mission, astronauts equipped the HST with the largest and most advanced complement of functioning instruments it has ever had. As a result, the telescope seems destined to make many more exciting discoveries. In particular, WFC3 is expected to help us get a better understanding of dark energy. The COS will probably reveal to us the structure and composition of the ‘cosmic web' – the filamentary gas that permeates intergalactic space.

The HST's achievements

HST observations to date have demonstrated three very important points:

a) The transition from cosmic deceleration to acceleration occurred around a redshift of 0.5 (about five billion years ago).

b) Dark energy was already present nine billion years ago, though it was not yet dominant.

c) Dark energy's equation of state (the ratio of its pressure to its density) is consistent with what quantum mechanics predicts for vacuum energy.

IMAGES OF THE core of the spiral galaxy M100 in the Virgo cluster, (left) taken with the Wide Field and Planetary Camera1 and (right) taken with WFPC 2.

The other contributions of the HST to astronomy are as follows:

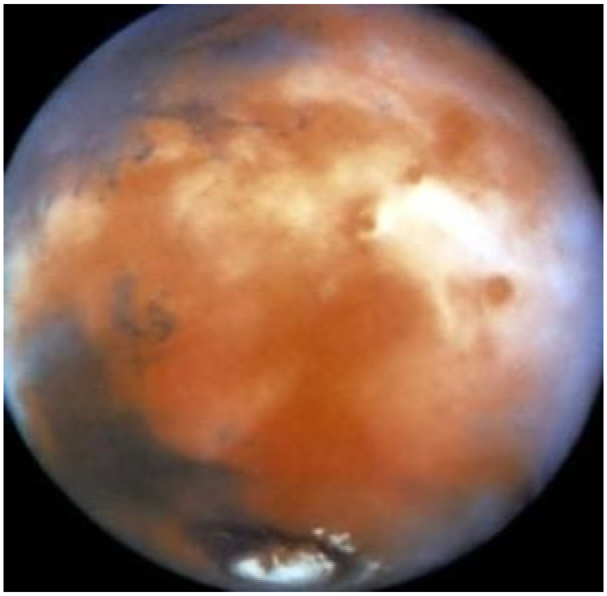
1) HST images of galaxy centres revealed another important fact: not only do most galaxies harbour supermassive black holes but the galaxies and the black holes evolve in intimate connection.

2) The HST observed about 180,000 stars in the Milky Way galaxy's crowded central bulge. These observations led to the discovery of 16 planet candidates. Finally, the HST produced the first direct visible-light image of a planet orbiting another star. The HST has detected the atmospheric composition of at least two exoplanets, and more are sure to follow in the near future.

3) Astronomers have used the HST to observe the dark matter's distribution in the collision of two clusters of galaxies, one seen pole on and the other from a direction perpendicular to the collision axis.

4) The HST acquired the most detailed images after Comet Shoemaker-Lavey's collision with Jupiter in 1994.

5) The HST discovered two moons of Pluto and took the most detailed images of its surface, showing significant changes over time.


AN HST IMAGE of Mars, received in 2003.

6) The HST discovered a Kuiper Belt object only one kilometre across.

7) The HST has provided exquisite images of stellar deaths, including the three-ring structure around Supernova 1987A.

8) The HST mapped the distribution and movement of gas in the nearby galaxies.

9) The HST imaged the host galaxies of dozens of gamma-ray bursts (GRBs) showing that long-duration GRBs are produced mostly in low-metallicity galaxies and they are concentrated in regions with massive stars.

10) The HST discovered that protoplanetary disks around young stars are quite common.

The HST is not just a device for studying objects in the far reaches of space – it is also a time machine capable of looking back into the early history of the universe and uncovering the secrets of cosmic evolution.

Staring into the abyss of intergalactic space and capturing sparse rays of light that left their home galaxies billions of years ago, Hubble has looked further across the cosmos and further back in time than any other telescope. This has helped it map out the evolution and life cycles of both individual galaxies and galaxy clusters and, ultimately, probe the origins of the universe itself.

One thing is certain – that we will have to revisit the list of the HST's achievements when it completes 25 years in space in another five years.

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