THE COMPLETE COSMOS

Chapter 22: Hubble's Eye

After astronauts fix its faulty optics, the Hubble Space Telescope peers back through time to the depths of the cosmos.

Outline

Images of the cosmos from the Hubble Space Telescope. In orbit high above Earth's blurring atmosphere, Hubble's pictures are spectacular. Seeing into deep space is do with gathering sufficient light - how it's collected and focused in a telescope, a comparison with the function of the human eye.

The largest telescopes on Earth - like the Keck in Hawaii and the Very Large Telescope (VLT) in Chile - overcome atmospheric distortion. They use clever optical systems to produce pin-sharp images. But for the best observing, there is nowhere like the clarity of space.

Orbital observing began in earnest in 1990 with the launch of the Hubble Space Telescope (HST). It promised pristine and detailed images that would dramatically improve our view and understanding of the Universe. But there was a problem with HST's main mirror. The images were fuzzy. Computer techniques were used to sharpen the images - but it was a make-shift solution.

Then, in December 1993, came the first Hubble Servicing Mission. In a series of spacewalks, Shuttle astronauts undertook the complex task of installing optics to correct the distortion of the main mirror. The mission was a resounding success. Hubble's sight was dramatically restored. Today Hubble fulfils its potential - unveiling the cosmos as never before, from the nearby planets to the farthest reaches of the observable Universe.

Sub-chapters

Collecting Light

- Masterpieces from the Hubble Space Telescope - "Pillars of Creation" in the Eagle Nebula where new stars are born, a dying star shrouded in the beautiful Cat's Eye Nebula, another in the Hourglass Nebula.
- How the human eye collects light and brings it to a focus.
- Seeing deep into space is to do with gathering plenty of light.

Improving the View

- How a large reflecting telescope collects light and brings it to a focus.
- The difficulties of observing space from the Earth - clouds and dust impair the view, atmospheric turbulence causes images to shimmer.
- Today, complex computer-controlled optical systems compensate for much atmospheric distortion at the world's largest Earth-bound telescopes - the Keck Telescopes on Hawaii and the Very Large Telescope (VLT) in Chile.

Hubble Trouble

- For the very best observing there is nowhere like the clarity of space.
- 1990: Launch of the Hubble Space Telescope - positioned in Earth orbit by the robot arm of Space Shuttle. A two-billion dollar eye-in-the-sky, 600 kilometers above the planet.
- Hubble is supposed to see ten-times finer detail than telescopes on Earth and to be 30-times more sensitive to light.

- But there is mirror problem. Hubble's images are blurred. Computer correction helps sharpen them until a repair can be effected in orbit.
- Despite the flaw, Hubble makes a series of discoveries - a supermassive black hole with two jets, the double core of the Andromeda Galaxy suggesting it once consumed another, a suspected black hole in the Whirlpool Galaxy, a supernova remnant.

Repairing Hubble

- Actuality of the first Hubble Servicing Mission in December 1993. Astronauts attempt to correct Hubble's sight.
- Superb photography of spacewalking "repair-men", working half the time under spotlights, performing the most complex fixes ever attempted in orbit.
- They fit new solar arrays, install the corrective optics module, replace the Wide-Field / Planetary Camera, and make numerous minor repairs. Hubble was designed to be serviced in orbit, but this is major reconstruction.
- The mission is a resounding success - Shuttle's finest hour. The distortion of the main mirror is corrected. Hubble's sight is completely restored.

Corrective Optics

- Hubble realizes its potential. The corrective optics bring light to a perfect focus.

The real show can begin.

- Mars in exquisite detail, even remote Neptune has features.
- But Hubble's most outstanding views are of deep space - like a vista of starbirth in the Orion Nebula, clusters of hot young stars, the debris of a supernova called the
- Lagoon nebula, and galaxies in unprecedented detail
- Another mission by Shuttle astronauts sees Hubble fitted with two new instruments, NICMOS and STIS. They reveal the Egg Nebula in visible light and infra-red, and gas jetting from the core of an active galaxy.

New Vistas

* The breathtaking penetration of HST is demonstrated by the Hubble Deep Field. It sees objects four-billion time fainter than can be discerned by the human eye. Hubble reveals galaxies never before seen.

Background

The Hubble Space Telescope

The Hubble Space Telescope is a joint venture of America's National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). The objective is to operate a long-term orbiting observatory for the benefit of the international astronomical community.

HST was dreamt of in the 1940s, designed and built in the 70s and 80s and operated from the 90s onwards. From the start, Hubble was planned a project that would require regular servicing - vital to protect it from instrument and equipment failures.

HST has a 2.4-metre reflecting telescope. It was deployed in low orbit - 600 kilometers above Earth - by the crew of the Space Shuttle Discovery (STS-31) on April 25, 1990. Two months later, however, came the horrifying discovery that the curvature of the 2.4-metre primary mirror was slightly incorrect.

The edge the mirror was too flat by an amount equal to 1/50th the width of a human hair.

This defect - called "spherical aberration" - was caused by the incorrect adjustment of a testing device used in the mirror's manufacture. It meant that light focused by the main mirror was spread over a larger area than intended. This caused a fuzzy halo which slightly blurred the images of planets, stars and galaxies.
Initially, NASA coped with the problem by using advanced computer processing techniques to sharpen Hubble's images. As a result, HST made some dramatic astronomical discoveries. But something had to be done to free-up Hubble's full potential. A mission
was planned for December 1993. The objectives were to properly establish the craft's scientific capabilities, to restore the reliability of its systems, and to validate the on-orbit servicing concept. This first Servicing Mission accomplished all that – and more.

Operating from the Space Shuttle "Endeavour", two pairs of astronauts, working on alternate days, performed a total of five seven-hour spacewalks. They replaced faulty components, fitted two new solar arrays, installed a corrective optics module called
COSTAR in the place of the High-Speed Photometer, and replaced the Wide-Field / Planetary Camera with a completely new version that contained the corrective optics.

The mission was a great success. With its new lenses, HST embarked on some of its most exciting scientific research - programs that required images of the very faintest objects and the finest detail. Hubble has not disappointed. It has delivered an array of breathtaking images that have led to important scientific discoveries.

Responsibility for Hubble's science operations rests with the Space Telescope Science Institute (STScI) at the Johns Hopkins University, Maryland, USA. STScI is run for NASA by the Association of Universities for Research in Astronomy, Inc. (AURA).

Hubble's science instruments include three cameras, two spectrographs, and fine guidance sensors mainly used for astrometric observations. With HST well clear of Earth's atmosphere, these instruments are vastly more effective than most of their terrestrial counterparts. Ground-based telescopes can seldom provide resolution better than 1.0 arc-seconds, except momentarily under the very best observing conditions. HST's
resolution is about ten times better or 0.1 arc-seconds.

HST's Science Instruments
Wide Field / Planetary Camera 2: The original Wide Field / Planetary Camera (WF/PC1) was replaced by WF/PC2 on the STS-61 shuttle mission in December 1993. WF/PC2 was a spare instrument developed in 1985 by the Jet Propulsion Laboratory in California.
Near Infrared Camera and Multi-Object Spectrometer: NICMOS is used for infrared imaging and spectroscopic observations of astronomical targets. It detects light whose wavelengths are between 0.8 and 2.5 micrometers.

Space Telescope Imaging Spectrograph: Light gathered by Hubble is spread out by the spectrograph. It analyses the nature of celestial objects - chemical quantity and composition, temperature, radial velocity, rotational velocity and magnetic fields. STIS studies these objects across a spectral range from ultraviolet (115 nanometers) through the visible red and the near-infrared (1000 nanometers).

NICMOS and STIS replaced the two earlier spectrographs installed on the HST when launched in 1990 - the Goddard High Resolution Spectrograph and the Faint Object Spectrograph. NICMOS and STIS were installed during the second Servicing Mission in February 1997.

Corrective Optics Space Telescope Axial Replacement (COSTAR): COSTAR is not a science instrument. It's a corrective optics package that displaced the High Speed Photometer (installed on the HST at launch) during the first Servicing Mission in December 1993. COSTAR is designed to optically correct the effects of the primary mirror's aberration on the Faint Object Camera (FOC). All the other instruments, installed since HST's initial deployment, were designed with their own corrective optics. When the FOC is replaced by another instrument, COSTAR will no longer be needed.

Faint Object Camera: Built by the European Space Agency, the Faint Object Camera (FOC) has two complete detector systems. Each uses an intensifier tube to produce an image on a phosphor screen 100,000 times brighter than the light received. This phosphor image is then scanned by an electron-bombarded silicon (EBS) television camera. It is so sensitive that objects brighter than 21st magnitude must be dimmed by the camera's filters to avoid saturating the detectors. Even with a broad-band filter, the brightest object that can be accurately measured is 20th magnitude.

HST Mission Operations and Observations
Although it operates around the clock, HST is not observing all the time. Each orbit lasts about 95 minutes with time allocated for "housekeeping" and for observations. Housekeeping includes turning the telescope on to a new target, avoiding the glare of the Sun or the Moon, switching communications antennae and data transmission modes, receiving commands from Earth and downlinking data to Earth - plus calibrating and similar activities.

When the Space Telescope Science Institute (STScI) completes a master observing plan, the schedule is forwarded to Goddard's Space Telescope Operations Control Center (STOCC). There, the science and housekeeping plans are merged into a detailed operations schedule. Each task is translated into a series of commands to be sent to Hubble's onboard computers. Computer loads are uplinked several times a day to keep the telescope operating efficiently.

If possible, two of Hubble's scientific instruments are used simultaneously to observe adjacent targets in the cosmos. For example, while a spectrograph is focused on a chosen star or nebula, the WF/PC (pronounced "wiff-pik") can image a region offset slightly from the main viewing target. During observations the Fine Guidance Sensors (FGS) track their respective guide stars to keep the telescope pointed at the right target.
If an astronomer wants to monitor a Hubble observation, he or she can watch consoles at STScI or at STOCC. These display the images or other data coming in to HST from deep space. If an observation program has been set up for it, a little "real-time" commanding is possible. An astronomer can even control target acquisition or filter changing - but spontaneous guidance from Earth is not yet possible.

Engineering and scientific data from HST, as well as uplinked operational commands, are transmitted through the Tracking Data Relay Satellite (TDRS) and its companion ground station at White Sands, New Mexico, USA. Up to 24 hours of commands can be stored in Hubble's onboard computers. Data can be broadcast immediately from HST to the ground stations or stored on tape for later downlinking.

For a "quick-look" analysis, an observer on the ground can examine Hubble's "raw" images and other data within a few minutes of their transmission from Earth-orbit. Within 24 hours, STOCC formats the data for delivery to STScI which is responsible for data processing - i.e., the calibration, editing, distribution and maintenance of the data for the scientific community.

Competition is keen for Hubble Space Telescope observing time. Only one in ten proposals is accepted.

Links for Further Information

The official Hubble Space Telescope web site at the Space Telescope Science Institute - news, images and links.
http://www.stsci.edu/

A page that includes a graphic image of the HST showing all of its principal components.
http://www.ball.com/aerospace/hst_img08.gif

Images and info from the first Servicing Mission to HST where COSTAR was installed.
http://www.ball.com/aerospace/hstphoto.html

An overview of HST.
http://oposite.stsci.edu/pubinfo/HSToverview.html

Text and images on the various repairs and upgrades to HST.
http://www.skypub.com/news/hstsm2.html

A page that includes HST's image of starbirth in the Eagle Nebula.
http://eis.jpl.nasa.gov/origins/poster/starbirth.html

Questions and Activities for the Curious

1. Why are astronomers constantly campaigning for larger optical telescopes?

2. How does a reflecting telescope collect and focus light?

3. What advantages does the Hubble Space Telescope (HST) have over ground-based telescopes? And what disadvantages?

4. Describe the initial problem with HST's main mirror and how it was corrected.

5. How did computers help in processing the images from the HST before the first Servicing Mission in December 1993?

6. What problems might be encountered by astronauts in servicing the HST in the weightlessness of space?

7. Name some of the discoveries made by the HST. Was the telescope a good investment of resources?

8. If you were given observing time on the HST, which astronomical object(s) would you observe and why?