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# HST Project Science Office


# Program Overview

- [HST Servicing Missions]
- [HST Instruments]
- [Frequently Asked Questions]
- [Historical Timeline]

The Hubble Space Telescope (HST) is a unique astronomical observatory. From its vantage point 620 km above the surface of the Earth, it looks out into space with a 2.4 meter primary mirror which provides unprecedented image resolution from 120 nm (near-ultraviolet) to 2500 NM (near-infrared). The near vacuum of space affords the HST with an unfair advantage over ground-based observatories. The Earth's atmosphere absorbs a great deal of ultraviolet and infrared radiation, and distorts visible light images as well. In the upper reaches of the atmosphere, the HST is able to capture images and spectra from distant stars which would be difficult or impossible to obtain from the ground.

### HST Optics

The HST optics are among the finest ever made. They are so precise that at wavelengths greater than approximately 300 NM, the image quality is limited only by the laws of physics. The light collected by the HST Optical Telescope Assembly (OTA) is directed through an aperture in the primary mirror to a suite of instruments which lie behind it. The light gathered by the primary mirror is brought to a focus at a surface called the "focal plane". Light from this plane is sent to the science instruments (SI's) for measurement and analysis.

### Spacecraft Design

The HST was designed to be serviced and maintained in orbit. It was understood that any world-class observatory must be periodically upgraded in order to keep pace with technological advances, otherwise the HST would not continue to enjoy its world-class status. The HST program was intended to last for 15 years (now 20 years), much longer than any other space program at that time. As a result, the Scientific Instruments and many other spacecraft parts were made to be replaced by astronauts quickly and easily. These replaceable parts are called Orbital Replacement Units (ORU's) and Orbital Replacement Instruments (ORI's).

HST has 8 ORI bays that hold its complement of science instruments. The instruments are classified as "radial" or "axial" depending on position and instrument shape. The radial bays, which house the three Fine Guidance Sensors (FGS), and one Radial Scientific Instrument, have pie-shaped enclosures. They are located above the aft shroud and encircle the focal plane. The aft shroud can be seen in the HST Internal Layout.

The axial bays, which lie in the aft shroud of the spacecraft and behind the focal plane, house the four Axial Science Instruments. These instruments have "telephone booth" sized rectangular enclosures.

The three FGS's are used for extremely fine measurements of stellar positions, and also for the guidance and pointing of the telescope, and are replaced only by other FGS's. The remaining Radial SI and the four Axial SI's constitute the five main science instruments of the observatory. The Focal Plane History chart shows the usage of the focal plane area throughout the history of the observatory. For each diagram, the red outlines represent the apertures of instruments which were replaced during the previous servicing mission.

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Web Site Last Updated: January 2000
Contact: Webmaster , Global Science & Technology, Inc.

# HST Project Science Office


## About the Project Science Office

**Web Site Overview**

**Project Science Office Organization Chart**

Welcome to the web site for the Hubble Space Telescope Project Science Office.

The HST is NASA's first orbiting space observatory. It has been remarkably successful for many reasons. One of the most important reasons is that the HST is the first spacecraft specifically designed to benefit from on-orbit astronaut servicing. This radically different approach enables the periodic maintenance and upgrade missions to HST that have substantially improved its scientific performance since it was launched in 1990. For more information about the HST Program, see our Program Overview and The Hubble Space Telescope Project Site.

The HST is unique. As the only space observatory of its kind in existence, the HST's management, maintenance, and operations all require unique and innovative approaches. It is our hope that some of the excitement and enthusiasm we have for our work will be conveyed to you through this site.

**Project Science:**
The role of the Project Scientist in any NASA mission is to ensure that the mission meets its scientific potential. For the HST, the responsibilities for scientific oversight are divided up among the members of the Project Science Office (PSO). The PSO is designed to interact effectively and efficiently with the HST flight project and the wide range of external organizations involved with the HST. The members of the PSO team are organized according to the groups they advise:

**The Office of the Associate Director of Flight Projects for the HST**.
The Senior Scientist for the HST and his staff work in the Office of the Associate Director of Flight Projects for HST. This group is concerned with the highest level of scientific management for the Project. Examples of their activities include budgetary oversight for the HST scientific activities, the organization of major scientific reviews and presentations to the Project, and outreach planning. For more information, please contact Dr. David Leckrone, NASA/GSFC Code 440, Greenbelt, MD 20771, 301-286-5975, e-mail david.leckrone@gsfc.nasa.gov.

**Operations and Ground Systems**.
The Project Scientist for Operations and Ground Systems (O&GS) works with the Project Manager for O&GS to optimize HST operations for

scientific excellence. This includes monitoring the operations infrastructure for ensuring a safe and productive spacecraft, while also considering the highest levels of scientific planning, scheduling, and budgeting for the scientific research done with HST. The Space Telescope Science Institute, located in Baltimore, MD, is managed within the HST O&GS Project. For more information, please contact Dr. Ken Carpenter, NASA/GSFC Code 681, Greenbelt, MD 20771, 301-286-3453, e-mail kenneth.carpenter@gsfc.nasa.gov.

**Flight Systems and Servicing.**
The Project Scientist for Flight Systems and Servicing (FS&S) works with the Project Manager for FS&S to ensure that the hardware development and servicing activities for the HST are providing the best scientific return possible. This includes Science Instrument development activities, and spacecraft maintenance and upgrades. All flight hardware for the HST is developed within this organization. For more information, please contact Dr. Edward Cheng, NASA/GSFC Code 685, Greenbelt, MD 20771, 301-286-5038, e-mail edward.cheng@gsfc.nasa.gov.

The PSO works as a team to ensure that all aspects of the HST Program work together so that the HST produces the best scientific results possible.

The HST mission is all about science, and the PSO has the job of making sure that science comes first!

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# Programmatic Information

The Hubble Space Telescope Program is managed by the **NASA/Goddard Space Flight Center** (GSFC) for the Office of Space Science (OSS) at NASA Headquarters .

The program falls under the Search for Origins and Planetary Systems scientific theme. Within GSFC, the Program is in the Flight Projects Directorate (Code 400), under the supervision of the Associate Director of Flight Projects for HST (Code 440). The HST Program is organized as two flight projects, the HST Operations and Ground Systems Project(O&GS, Code 441) and the HST Flight Systems and Servicing Project (FS&S, Code 442).

- NASA Headquarters/HST Project Organization
- HST Project Organization Chart
- Project Science Office Organization Chart
- HST Level 1 Requirements

# HST Project Science Office


# Staffing

[David S. Leckrone]

[Malcolm Niedner]

[Edward S. Cheng]

[Kenneth G. Carpenter]

[David A. Cottingham]

[David E. Lynch]

[Barry Kirkham]

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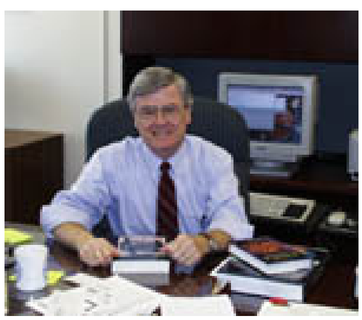


**David S. Leckrone**
Senior Scientist for the Hubble Space Telescope Project
NASA, Goddard Space Flight Center
Code 440
Greenbelt, MD 20771
301-286-5975


**Biography and Research:**

Dr. David S. Leckrone is a career NASA scientist, having worked at the Goddard Space Flight Center since 1969. He holds a B.S. degree in Physics from Purdue University, M.A. and Ph.D. degrees in Astronomy from the University of California at Los Angeles, and an M.A.S. degree in Management from the Johns Hopkins University. He is a veteran space astronomer, specializing in the ultraviolet spectroscopy of hot stars and the abundances of the chemical elements. He has been a frequent observer with space instruments, including the Orbiting Astronomical Observatory (OAO-2), the Copernicus Satellite, the International Ultraviolet Explorer and the Goddard High Resolution Spectrograph on the Hubble Space Telescope. He leads an international team of astrophysicists and atomic physicists mapping the abundances of the elements in chemically peculiar stars with the HST/GHRS and is the author of approximately 70 scientific publications.

Dr. Leckrone has worked on the Hubble Space Telescope Project since 1976, first as Scientific Instruments Project Scientist, then as Deputy Senior Project Scientist. In 1992 he was appointed Senior Project Scientist for HST. In this capacity he provides scientific leadership for all aspects of the Hubble Project, including management, operations, development of flight instruments and on-orbit servicing. He was the lead Project Scientist at JSC Mission Control during the highly successful Hubble servicing missions in 1993 and 1997.

Dr. Leckrone was awarded NASA's Exceptional Scientific Achievement Medal in 1992 and the NASA Outstanding Leadership Medal in 1994. In May, 1996, he received an honorary Doctor of Philosophy degree in Mathematics and Natural Sciences from the University of Lund in Sweden.

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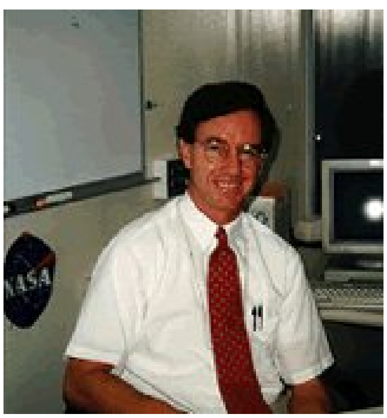


**Malcolm B. Niedner, Jr.**
Deputy Senior Scientist for the Hubble Space Telescope Project
NASA, Goddard Space Flight Center
Code 681
Greenbelt, MD 20771
301-286-5821

**Biography and Research:**

Education: A.B., Physics, Brown University, 1971 MA, Astronomy, Indiana University, 1976 Ph.D., Astronomy, Indiana University, 1979.

Current Position: Astrophysicist, Laboratory for Astronomy and Solar Physics (since 2/80) Deputy Senior Project Scientist, Hubble Space Telescope (since 2/93) Former positions/titles: Discipline Specialist of Large-Scale Phenomena, International Halley Watch (1982-90) Guest Investigator, Astro-Halley (1983-86) Comet Scientist, ICE mission to Comet G-Z (1984-1985) Past research interests and the subjects of various refereed publications include cometary plasma tails, their interactions with the solar wind, and the inference of solar-wind & interplanetary magnetic field conditions out of the ecliptic plane by using comets as natural probes. Currently Dr. Niedner is shifting his focus to the high-redshift Universe: intergalactic absorption, UV background radiation, young galaxies, etc.

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**Kenneth G. Carpenter**

**Biography and Research:**

Dr. Kenneth Carpenter is currently the Project Scientist for Hubble Space Telescope Operations and Ground Systems and splits his time between those duties and scientific research. Previously, Dr. Carpenter was a Co-Investigator on the Goddard High Resolution Spectrograph (GHRS) Investigation Definition Team. He received his Ph.D. from Ohio State University in 1983, worked for several years at JILA/University of Colorado, as a Postdoctoral Research Associate, then as a Research Scientist for the GHRS Project at CASA/University of Colorado and NASA/GSFC.

In 1988 he joined NASA, and several years later assumed his current duties within the HST Project. His research interests include studies of the chromospheres, transition regions, winds and circumstellar shells of cool stars, as well as the calculation of model atmospheres and synthetic spectra and investigations of line fluorescence processes. Hardware interests include development and operations of UV spectroscopic instruments, such as the GHRS and STIS.

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**Edward S. Cheng**
Hubble Space Telescope Project
NASA, Goddard Space Flight Center
Greenbelt, MD 20771 Code 685
Greenbelt, MD 20771 301-286-5038

**Biography and Research:**

Ed Cheng is Project Scientist for the Hubble Space Telescope/Flight Systems and Servicing Project. He earned his Doctorate at Princeton University developing one of the earlier balloon-borne measurements of the Cosmic Microwave Background Radiation anisotropy. He has been at GSFC since 1989, during which time he has also served as Deputy Project Scientist for the Cosmic Background Explorer (COBE). In his spare time, he develops new experiments for measuring the Cosmic Microwave Background as a member of the Infrared Astrophysics Branch in the Laboratory for Astronomy and Solar Physics.

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**David A. Cottingham**
Principal Scientist
Global Science and Technology, Inc.
6411 Ivy Lane, Suite 300
Greenbelt, MD 20770
301-286-0872

**Biography and Research:**

Dr. David A. Cottingham is an astrophysicist specializing in instrument design and experimental cosmology. He earned his BS and M.S. degrees in physics from Yale University, and his Ph.D. in physics from Princeton University. He subsequently worked at the Massachusetts Institute of Technology and the University of California, Berkeley on various experiments related to the cosmic microwave background.

Dr. Cottingham came to Goddard in 1991, initially as a visiting scientist working on COBE. In 1993 he moved to Global Science and Technology, Inc., and began work with the HST Project Science Office for Flight Systems and Servicing. At the same time he has been a collaborator with the MSAM/Tophat program of balloon-borne far-infrared telescopes.

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**David E. Lynch**
Senior Scientist
Global Science and Technology, Inc.
6411 Ivy Lane, Suite 300
Greenbelt, MD 20770
301-474-9696

**Biography and Research:**

David Lynch is a physicist working in ultraviolet polarimetry of interacting binary stars. He earned a BS and MS in physics from the University of Maryland, College Park and is currently working toward a Ph.D. at UM. Mr. Lynch began working at Goddard in 1991 for the HST Project Scientist for Operations and Ground Systems. He began working with Global Science and Technology in 1992 and continued his support of HST Project Science.

Mr. Lynch's research is largely on spectropolarimetric data obtained with the Faint Object Spectrometer, which was a first generation HST instrument. He also has been teaching Mathematics at Prince George's Community College for 14 years.

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**Dr Barry Kirkham**

Senior Engineer, TRW Inc,
NASA Goddard Space Flight Center, Code 440.8,
Greenbelt, MD 20771
301 286 6936

**Biography and Research:**

Barry Kirkham supports the project science office primarily on the operations side of HST. He has worked on HST since the early planning days, including the design and development of the original TRW-provided ground software used at STScI. He earned his Ph D at University College London, London University, in 1975. His thesis work was in experimental UV interstellar spectroscopy, especially in absorption lines of Mg. He later worked on design and laboratory measurements for a solar Ly-alpha coronagraph at Harvard College Observatory.

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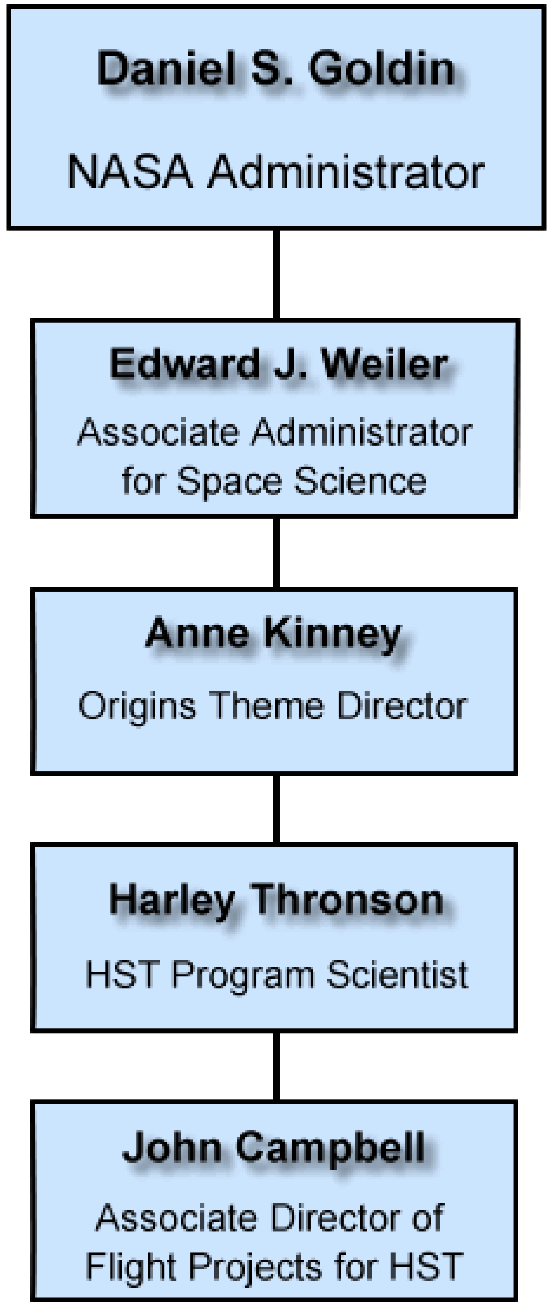
Contact: Webmaster , Global Science & Technology, Inc.

# HST Project Science Office


## NASA Headquarters: HST Reporting



# HUBBLE SPACE TELESCOPE PROGRAM
# CODE 440

**HST PUBLIC INFORMATION**
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(130)

**HST PROGRAM MANAGER**

**Associate Director/Program Manager for HST**
Preston M. Burch *

Buswell - Project Secretary

**DEPUTY PROGRAM MANAGER**

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David M. Scheve

Buswell - Project Secretary

**DEPUTY PROGRAM MANAGER**

**Deputy Program Manager/Technical for HST**
Michael L. Weiss *

**HST BUSINESS LEAD**

Gloria J. Goodman

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Jim Mannion

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**SENIOR SCIENTIST FOR HST**
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**DEPUTY SENIOR SCIENTIST FOR HST**
Dr. Malcolm B. Niedner
(684.1)

**SYSTEMS ASSURANCE**
**Manager**
Robert A. Sticka +
(303)

B. Dedalis - Project Safety Mgr (302)

| AREAS OF SUPPORT (CODE 500) | | |
|---|---|---|
| DISCIPLINE SUPPORT | OPERATIONS & GROUND SYSTEMS (CODE 441) | FLIGHT SYSTEMS & SERVICING (CODE 442) |
| **CONTAMINATION** C. Lorentson (545) | | X |
| **FABRICATION LEAD ENGR** W. Alexander (548.3) | | X |
| **OPTICS LEAD ENGR** Dr. H. J. Wood (551) | X | X |
| **POINTING CONTROL SYSTEM** L. Purves (571) | X | X |
| **THERMAL SYSTEM** G. Ousley (545) | | X |
| **STRUCTURAL** J. Metzger (543) | | X |

* = acting
\+ = shared between HST offices

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Pattison - PSS HST Info. Systems
Vacant - Project Support Specialist

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Cover - Contracting Officer
Davis - Procurement Technician
Petkoff - Contract Specialist
J. Jones - Contract Specialist
Kramer - Contracting Officer
Stevens - Contracting Officer
Square - Contract Specialist

***Original Signed By***

**Preston M. Burch, Acting, Associate Director/Program Manager for HST** **Date**

**February 15, 2001**

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**DEPUTY PROGRAM MANAGER**

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Square - Contract Specialist

***Original Signed By***

**Preston M. Burch, Acting, Associate Director/Program Manager for HST** **Date**

**February 15, 2001**

# HST Project Science Office


The Project Science Office is staffed by scientists from the Laboratory for Astronomy and Solar Physics (Code 680) and contractors. It serves as an advisory forum to the Office of the Associate Director for Flight Projects for the HST.

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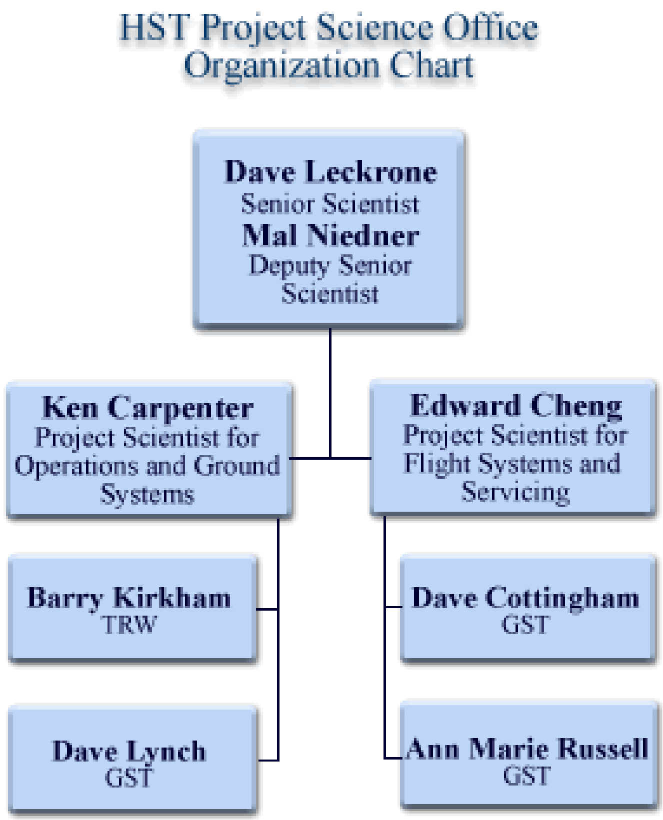

STR-78
BASELINE ISSUE
February 29, 1996

# HUBBLE SPACE TELESCOPE

## LEVEL I REQUIREMENTS

## FOR THE OPERATIONAL PHASE

## OF THE HUBBLE SPACE TELESCOPE PROGRAM

This Level 1 requirements document for the Hubble Space Telescope is a merging of requirements as defined in the approved 1983-85 and the 1989 Level 1 Requirements documents, as amended by approved waivers and Critical Decision Items (CDI's). The intent of this formal release is to present the complete Level 1 requirements in a single integrated document. As such, it supersedes and replaces all previous Level 1 requirements documents.


**Office of Space Science**

**Astrophysics Division**

**National Aeronautics and Space Administration**
**NASA Headquarters**
**Washington, DC**


**February 29, 1996**

# HUBBLE SPACE TELESCOPE

LEVEL I REQUIREMENTS
FOR THE OPERATIONAL PHASE
OF THE HUBBLE SPACE TELESCOPE PROGRAM

## CONCURRENCE

George Albright
Program Manager
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Mark Nolan
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HST Flight Systems & Servicing

Kenneth Ledbetter
Division Director
Astrophysics

Dr. Edward Weiler
HST Program Scientist

## APPROVAL

Dr. Wesley J. Huntress, Jr.
Associate Administrator
Office of Space Science

National Aeronautics and Space Administration
NASA Headquarters
Washington, DC

**February 29, 1996**

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**HUBBLE SPACE TELESCOPE**
**LEVEL I REQUIREMENTS**
**FOR THE OPERATIONAL PHASE**

## 1. SCOPE

This document combines and updates the original Hubble Space Telescope (HST) Level I Requirements document dated December 23,1983, the amendment dated October 29,1985, and the Level 1 Requirements operational phase augmentation document dated May 17,1989. Approved waivers and approved Critical Decision Items (CDI's) have been incorporated as required. The requirements herein cover the operational phase of the HST program. The performance requirements provided in this document represent the minimum performance levels to be used in assessing the need for on-orbit servicing or upgrade and for ground system modifications.

The mission of the HST Project is to provide a space observatory for use by the international astronomy community to increase the sensitivity and resolving power and extend the spectral range of astronomical observations decisively beyond those achievable from earth observatories.

The normal operations and condition of the HST will be maintained by NASA, including the command, control, and communications system. Within broad policy generated by NASA, the HST science program will be managed by the Space Telescope Science Institute (STScI) to maximize the scientific usefulness of the observatory and to bring the user community into direct contact with and control of the science that is done.

The European Space Agency (ESA) has provided two sets of solar arrays and one scientific instrument (the Faint Object Camera) for the Hubble Space Telescope and personnel for the STScI. In return, scientists from ESA member nations are guaranteed at least 15 percent of the HST observing time on the average through May 2001. ESA participation is defined in a Memorandum of Understanding.

### 1.1 Control

This document shall be controlled at Level I by NASA Headquarters, Office of Space Science (OSS), which carries the primary responsibility for fulfillment of these requirements.

## 2. OVERALL PROGRAM REQUIREMENTS

The goal of the HST program during the operational phase is to maximize the scientific productivity of the Observatory. To meet this goal, NASA shall operate, maintain and enhance the HST spacecraft and supporting ground systems while the Space Telescope Science Institute (STScI), in accordance with NASA policy guidance and oversight, shall conduct the HST science program.

**2.1 Operational Life [1]**

A high level of scientific productivity, using acquisition methods and strategies in conjunction with instrumentation selected through peer review, shall be maintained to the extent possible, and/or practical, for 15 years, or longer.[2] The measures to be taken to achieve this will include:

a. operational work-arounds such as procedural and software changes,
b. orbital replacement of malfunctioning spacecraft equipment,
c. orbital replacement of scientific instruments,
d. orbital replacement of limited-life equipments or units, at the appropriate mission life points,
e. development of Space Support Equipment (SSE) to support maintenance missions,
f. maintenance and upgrade of the supporting ground system, and
g. reboost as required to maintain a satisfactory orbital altitude.

**2.2 Servicing Mission Authorization**

The execution of all servicing missions requires approval by the NASA Administrator.

**2.3 Scientific Capabilities**

A scientific measurement capability is provided through a complement of up to four axial scientific instruments, one radial scientific instrument, and three Fine Guidance Sensor. [3] This capability shall be maintained and enhanced through the acquisition and on-orbit installation of replacement scientific instruments and Fine Guidance Sensors, and the maintenance and modification of the supporting ground system. The HST shall be able to accommodate a cryogenically-cooled infrared SI, including provision for the removal of evaporated cryogen from the aft shroud.

**2.4 Space Transportation**

The Space Shuttle shall provide the basic transportation for all phases of the HST program including deployment, on-orbit servicing, and reboost or return to earth.

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**1** Per CDI-049.

**2** Per CDI 054.

**3** GSFC Waiver #11 points out that the first servicing mission installation of the corrective optics package COSTAR left HST one short of the five SI's called for in the original wording. The wording of this sentence has been modified to make it more flexible in terms of instrument complement.

**2.5 Communications**
All normal forward and return link data transmission shall be via the NASA Communications Network (NASCOM) and the Space Network (SN). In situations where there is an outage of the normal communication service, the remaining or replacement elements of the Deep Space Network (DSN) 26 meter subnet or the Goddard Space Flight Tracking and Data Network (GSTDN) shall provide tracking, command, and engineering telemetry for health and safety communications support.

**2.6 Mission Termination**
At the completion of the useful operational life of the HST, as determined by NASA Headquarters, the HST shall be either placed in a long-term stable orbit or safely deorbited.

## 3. OBSERVATORY PERFORMANCE

The purpose of this section is to define the minimum acceptable performance capabilities for the Observatory. These shall serve as criteria for planning and initiating orbital servicing activities. It is expected that some flight subsystems will degrade with time, e.g., the HST exterior thermal coatings, which cannot be refurbished or replaced and whose degradation cannot be circumvented by ground system work-arounds.

### 3.1 Image Quality

The optical system shall consist of a f /24 Ritchey-Chretien telescope with a 2.4-meter diameter primary mirror and corrective optics. The optical image, including effects of optical-wave front error, pointing stability, and scientific instrument to OTA alignment, should satisfy the following on-axis requirements at 6328 Angstroms and be a design goal at ultraviolet wavelengths: 70%[4] of the total energy of a stellar image must be contained within a radius of 0.10 seconds of arc; the resolution of the image using the Rayleigh criterion for contrast shall be at least 0.10 seconds of arc; and the full-width half-intensity diameter of the image shall be no more than 0.10 seconds of arc. After correction for astigmatism, these specifications shall apply to the image quality over the entire usable HST field.

The HST shall be capable of collecting and imaging radiant energy in a broad spectral band from 1216 Angstroms to 10 micrometers. Specifically, the OTA optical throughput, which includes the combined reflectivity of both the primary

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**4** GSFC Waiver #2 requested the 70% figure to be changed to 60% at 6328A and 35% at 1216 However, the original Level I requirement was met or exceeded following 1993 servicing mission, so the requirement has not been modified.

and secondary mirrors and the central obscuration effect, shall be no less than 38 percent at 1216 Angstroms and 55 percent at 6328 Angstroms.[5]

The overall system must be capable of measuring unresolved objects appreciably fainter than those accessible from the ground; i.e., at least 27 $m_V$ with a signal-to-noise ratio of 10 in 4 hours of observing time.[6]

The overall system must be capable of measuring extended sources of surface brightness 25 $m_V$ per square seconds of arc with a signal-to-noise ratio of 10 in 10 hours, with a resolution of at least 0.25 seconds of arc.[7]

**3.1.1 Image Stability**

The image jitter due to all causes shall be less than 0.012 arcsec R.M.S. over a period of 24 hours. The optical image quality, as defined in 3.1. shall be simultaneously maintained at the apertures of up to four axial scientific instruments[8], one radial scientific instrument, and three Fine Guidance Sensors for elapsed periods of 24 hours allowing up to 4 hours for thermal stabilization after thermally worst-case slews.

**3.1.2 Target Positioning** [9]

The HST shall contribute an error no greater than 0.03 arc seconds during the acquisition and positioning of a fixed or moving target within any instrument aperture.

**3.1.3 Guide Star Acquisition & Tracking** [10]

The HST must be able to acquire and track on guide stars in at least 75% of randomly selected targets located at the galactic poles when using the stellar statistics of "Guide Star Probabilities", NASA Contractor Report 3374, January 1981.

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**5** GSFC Waiver #19 requested waiver based on reduced throughput that would result with incorporation of COSTAR. However, the original Level 1 requirement was met or exceeded following 1993 servicing mission, so the requirement has not been modified.

**6** GSFC Waiver #3 wanted to reduce this requirement. The original Level I requirement was met or exceeded following 1993 servicing mission, so the requirement has not been modified.

**7** GSFC Waiver #4 requested a 10% reduction in the requirement for extended object sensitivity. The original Level I requirement was met or exceeded following 1993 servicing mission, so the requirement has not been modified.

**8** GSFC Waiver #11 points out that the first servicing mission installation of the corrective optics package COSTAR left HST one short of the five SI's called for in the original wording. The wording of this sentence has been modified to make it more flexible in terms of instrument complement.

**9** Per CDI-057.

**10** Per CDI-058.

**3.1.4 Solar System Object Tracking** [11]

Tracking errors for moving targets shall remain less than 0.03 arcsec. r.m.s., for tracking rates less than 0.02 arcsec/sec, and less than 0.04 arcsec, r.m.s., for tracking rates between 0.02 and 0.20 arcsec/sec, over 3 arcmin apparent displacement.

**3.1.5 Stray Light Performance**

The scattered light surface brightness must be less than 23 $m_V$ per square seconds of arc except within 50 degrees of arc of the sun or 30 degrees of arc of the moon or 90 degrees of arc of the bright earth limb.[12]

**3.2 Scientific Observational Capabilities**

The scientific productivity of the HST requires that certain core observational capabilities be maintained throughout its operational lifetime. Loss of any of these capabilities shall justify instrument replacement at the earliest planned servicing mission.

**3.2.1 Core observational Capabilities**

Allocation of time and details of observing programs are based on scientific merit. In the long term, a stable observational capability shall be provided to enable the following:

a. Visible photometric imaging at high spatial resolution for science and target acquisition support.

b. Ultraviolet spectrophotometry at medium to high spectral and spatial resolution.

c. Near infrared spectrophotometry (> 1 micron) and imaging with high resolution. This capability is to be available for at least five years of HST lifetime, and should be instituted as soon as possible after launch.[13]

High spatial resolution is intended to mean roughly 2 samples per cycle at a 50% value of the Optical Telescope modulation transfer function. Medium and high spectral resolutions are intended to mean 1000 and 30,000, respectively. The minimum fields of view for the UV/visible and IR imaging shall be approximately 90 and 10 arcsec, respectively. Performance degradation below any of the levels stipulated - but not total loss - does not constitute justification for immediate instrument replacement, but shall be a factor in prioritizing replacement in service mission planning. The capability of conducting parallel observations, i.e., concurrent operation of any two science instruments on a noninterference basis, is a general core capability.

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**11** CDI-063 waived this requirement for launch, but required implementation by March 1991. In 1993, GSFC requested a further waiver, which was denied.

**12** Revised from 80 degrees to 90 degrees per CDI-055.

**13** Per CDI-066.

**3.2.2 Additional Observational Capabilities.**
In addition to the core capabilities, a versatile observational capability shall be maintained to support, at any time, at least several of the following:

a Wide field of view (approx. 2 arcmin) visible imaging
b. Imaging at UV wavelengths
c. Faint object (approx. $m_V$= 20.5) visible spectroscopy at high spatial resolution
d Faint object UV spectroscopy
e. Very high resolution (approx. $10^5$) UV spectroscopy
f. High speed (approx. 20 microsec) photometry.

**3.3 Spacecraft Subsystems Performance** In general, unacceptable subsystem performance is that which compromises the observational capabilities specified in Section 3.2 or results in operational impacts which degrade science productivity. Specific requirements, which are particularly relevant to the maintenance of adequate support for science mission operations, follow.

**3.3.1 Power** [14]
The electrical power system shall provide adequate energy to maintain the scientific operational capabilities stated in paragraphs 3.2 and 3.2.1. In addition, the batteries shall maintain sufficient storage capability to enter safemode or gravity gradient mode (164 amp-hours). A servicing mission will be required prior to the time that the battery storage capability is projected to be less than 164 amp-hours or the solar array capability is projected to be less than that required to maintain scientific operational capabilities in paragraphs 3.2 and 3.2.1.

**3.3.2 On-Board Data Storage**
The flight system shall provide at least 100 Mbytes of science and engineering data storage.

**3.3.3 Data Quality**
The system shall provide a bit error rate not worse than $2.5x10^{-5}$ without Reed - Solomon encoding for all telemetry and $1x10^{-7}$ for end-to-end data flow for all data processed by the SI C&DH with Reed-Solomon encoding.

**3.3.4 Time/Frequency**
The system shall provide a clock signal to the science instruments with a 1 microsecond resolution relatable to Universal Time Code (UTC) to within 10 milliseconds. Frequency stability of the on-board frequency signal shall be at least $lX10^{-9}$ over 24 hours.

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14 Per CDI-053

### 3.3.5 Data Management

The on-board system shall manage and communicate a long term average of 300 Mbytes of science data per day. It shall be capable of supporting approximately a twofold growth in this average data volume due to advanced instrument requirements.

## 4. GROUND SYSTEM REQUIREMENTS

The ground system required to support the HST program shall support Observatory and science management, the former performed by the Goddard Space Flight Center (GSFC) and the latter, under contract to GSFC, by the Space Telescope Science Institute (STSCI).

### 4.1 General Functional Capabilities

The ground system shall provide the following general routine functional capabilities in support of mission operations:

a. Spacecraft and scientific instrument command and control.

b. Performance monitoring and engineering trend analysis.

c. Science and mission planning and scheduling, including parallel science data acquisition and parallel event scheduling.

d. Capture and processing of engineering and science data.

e. Science data analysis and general observer selection and support.

f. Archiving and distribution of science data and archival research support.

g. Support for spacecraft subsystem and science instrument maintenance, replacement and refurbishment.

h. Orbit and attitude data collection and processing.

### 4.2 Observatory Operations

The ground system shall be capable of supporting HST operations on a continuous basis. Availability for all mission critical facilities shall be at least 99.8% with a mean time to repair of less than 1 hour. The availability for off-line support systems shall be greater than 97.5% with a mean time-to repair of 8 hours. Routine maintenance shall be performed without disruption of flight operations support. The observatory operations project organization shall ensure that sufficient and appropriate hardware equipments and software programmers-developers and key hardware and software maintenance skills are available to support expected life-cycle activities, including the incorporation of efficiency and capabilities enhancements and upgrades and problems resolution.

### 4.2.1 On Line Operations

The following on-line operational capabilities, normally used to support realtime transactions, shall be provided:[15]

a. Generation, uplink, and logging of command loads and real-time commands.
b. Monitoring of all flight systems and science instruments in order to assure their health, safety, and data quality.
c. Generation and uplink of commands to adjust pointing and maintain tracking.
d. Attitude determination and sensor calibration in support of pointing control.
e. Monitoring and recording of the performance, runtime, and any anomalies in the flight and ground systems.

### 4.2.2 Planning and Scheduling

The ground system shall provide the following capabilities:

a. Planning and scheduling, accounting for all constraints, in order to maximize efficient use of the Observatory. The goal is to achieve an annual average of 35% on-target time (OTT). OTT is defined to be the period which begins with the initiation of the Fine Guidance Sensor (FGS) acquisition process and ends with the release of the telescope pointing control each orbit (e.g., the HST is released to slew to the next target). In achieving this 35% goal, the intent is to minimize the amount of "on target' time spent for acquisition while maximizing the actual amount of target exposure time. If an observation can be accomplished on gyro control only, then OTT begins with commencement of science data collection or with any instrument-peculiar target acquisition procedures (e.g., shutter open) and ends with release of spacecraft pointing control each orbit.
b. Planning maneuvers and housekeeping activities to maintain the amount of dark time available for scientific observing at or above 20 minutes per orbit averaged over the precession cycle.
c. Timeline re-planning and scheduling for observing targets of opportunity within 24 hours of authorization.
d. Concurrent operation of two scientific instruments (parallel science) plus the use of a Fine Guidance Sensor for astrometry.[16]
e. Preparation of schedules and command loads for 24 clock-time hours of HST operation, including scheduling of parallel activities, in less than 12 working

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**15** Interactive selection and execution of alternative preplanned mission sequences (referred to as branching) for up to 20% of the total activity" was formally waived via CDI-062 and GSFC Waiver #16.
**16** Per CDI-059, waived for launch but to be implemented by March '91.

hours as a goal, and including the ability to reschedule 5% of these activities in response to mission needs.[17]

f. Maintaining reference materials and procedures to enable acquisition, tracking and observation of moving targets as per Section 3.1.4.

**4.2.3 Servicing Mission Planning**

The ground system, to support planning for servicing missions, shall provide reliability forecasting, mission simulations, mission operations and post-mission data processing and analysis.

**4.2.4 Simulation and Test**

The capability shall be provided to simulate the operation of the HST to support building or modifying hardware and software over the full life cycle of HST, test operational procedures and commands, assist in fault diagnostics, verify compliance of new subsystems against interfaces, and train new operators. The system shall be capable of testing new or revised flight software before installation without undue disturbance of ongoing normal orbital operations.

**4.3 Data Acquisition**

The ground system shall maintain and upgrade its data capture and processing throughput capability commensurate with advanced science instrument requirements.

**4.3.1 Data Rates**

The ground system shall be capable of simultaneously receiving data at rates of 1.024 Mbps and 32 or 4 or 0.5 Kbps.

**4.3.2 Data Volume**

The ground system shall be capable of capturing a peak maximum data volume of 900 Mbytes in a 24 hour period and of processing, on a long term average, 300 Mbytes daily for transmission to the STScI within 24 hours after receipt.

**4.3.3 Data Storage**

The ground system shall provide a minimum of 30 days of fail-safe storage of captured (unedited) data.

**4.3.4 Data Dissemination**

After a one year proprietary period, HST data shall be made accessible to the general scientific community. Archived data shall be periodically transferred to the HST European Coordination Facility and other facilities as authorized by the Associate Administrator, Office of Space Science.

**4.4 Science Operations**

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[17] Per CDI-061-Rl.

The STScI has been established for the purpose of conducting and managing the science operations of the HST program. Its primary functions include:

a. Establishment of science program guidelines.
b. Selection of HST general observers and archival researchers, providing them technical assis tance with their research programs, and managing grants to selected U.S. general observers.
c. Developing operational procedures and science observing schedules, including parallel science and parallel events scheduling.
d. Providing applications utilities and calibration data for analysis of HST data.
e. Processing, archiving and publicizing HST science data and results.
f. Evaluating Observatory and scientific instrument performance.
g. Maintaining the Guide Star Selection System.

**4.4.1 Research Management**
The ground system shall provide for the management and selection of research proposals, tracking associated resource requirements, and maintaining resulting products of the research throughout the life of the program.

**4.4.2 Observing Support** [18]
The ground system shall have the capability to support two general observers concurrently in the conduct of their observing programs involving such functional areas as target acquisition, acquisition verification, and quick-look data analysis.

**4.4.3 Science Data Processing and Products**
Calibrated standard data products shall be available to observers within five days of their acquisition. Uncalibrated data in SOGS format[19] shall be available to observers 24 hours after receipt by the STScI Calibration algorithms, tables, and files shall be made available to authorized observers within thirty days of the request. Transportable versions of the data analysis software shall be maintained for use by observers who have access to compatible computers.

**4.4.4 Data Archive**
The capability shall be provided to archive, search and retrieve all the edited and calibrated science and related engineering data. The system shall support the access and distribution needs of up to 1000 archival researchers per year. A minimum of 3 years of current data shall be maintained on-line to facilitate automatic real-time interactive access. The remainder shall be permanently archived and retrievable, within a reasonable time, on request ("reasonable" defined as seconds to minutes if requested by an online user, and 1-2 weeks if by mail). The system shall accommodate both local and remote users via electronic

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**18** GSFC Waiver #18 eliminated branching as a requirement.
**19** Per CDI-064.

access, restrict access to only authorized users, and prevent against inadvertent loss or destruction of data, accidental or malicious.

## 5. SERVICING SUPPORT REQUIREMENTS

Over the operational lifetime of the HST, a capability must be maintained for onorbit servicing in order to restore, wherever possible, original levels of performance and to enhance the science capability. Assuring this involves the timely development of replacement scientific instruments; Space Shuttle Program support; servicing mission planning; timely availability of Orbital Replaceable Units (ORUs); the development and maintenance of supporting test equipment, ORU delivery systems, spare components, and the Space Support Equipment (SSE); and a ground logistics system. Two classes of missions may be needed: Planned Service Missions (PSM) and Contingency Service Missions (CSM). Although both types require planning, the CSM launch preparation is triggered by a critical event, whereas the PSM occurs on a schedule related to forecasted maintenance need. A PSM is used to restore or upgrade the Observatory and scientific instrument performance (cf. Section 3.0). It is also used to reboost the spacecraft. The CSM corrects a failure which leaves a single point failure mode in a mission critical subsystem. A CSM may also be utilized to reboost the Observatory.

The program infrastructure shall maintain the capability to return the HST from orbit. The capability to return the HST from orbit shall not be maintained for every HST servicing mission, but instead will be provided only if so specified in the mission call-up instructions. That is, the hardware, software, procedures, etc., necessary for returning the HST from orbit shall be developed, verified, etc., on a schedule that permits the recovery of the HST by the Space Shuttle from orbit on any mission so desired, provided that recovery capability is specifically ordered up prior to mission initiation. Specific hardware capability does not, however, have to be planned for nor carried on every servicing mission, thus optimizing the use of the Space Shuttle lift capability to better support HST servicing missions where there is no identified imminent need for returning the HST.

### 5.1 Initiation Criteria

The decision to perform a servicing mission will be made by the Administrator in response to an Office of Space Science request. The request for a CSM will be initiated as soon as a justifying condition or pending condition is established. The need and requirements for a PSM shall be reviewed at least every six months and, under normal circumstances, confirmed at least 18 months prior to the scheduled launch.

A CSM will be requested whenever there is a loss of an ORV(s) which leaves the HST with a potential single point mission failure. A mission failure condition is one in which the Observatory is no longer in communication with the ground or commandable, cannot be safely retrieved for servicing or reboost, is unable to support any science operations, or has lost the scientific payload. Potential failure of any one of the five major subsystems - power, thermal, pointing control, command and data handling, communications - is justification for initiating the CSM process.

The criteria considered in planning and requesting a PSM are the forecast of:

a. Orbital decay to an altitude such that science operations become constrained or mission duration is imperiled.
b. Loss of core observational capability as specified in Section 3.2.1
c. Subsystem performance degradation below levels specified in Section 3.
d. Availability of advanced instruments.

Activities supporting conduct of a CSM ‘will require major mobilization of effort across NASA in order to effect rapid repair of the HST. The basic purpose or such a call-up will of course be to repair the HST before it sustains further failure which could then result in irreversible damage to or loss of the Observatory. For planning purposes, the maximum allowable Space Shuttle response time - that is, time from call-up of the CSM by the Administrator to achieving launch readiness status - is assumed to be no greater than 12 months.

If resources and the situation allow, routine servicing activities and/or replacement of scientific instruments may be accomplished during a CSM.

**5.2 Planning Support**

The servicing support system shall:

a Maintain a long term schedule of servicing missions including best estimate of launch dates, the most likely complements of subsystems and scientific instruments, and associated procurement schedules and activities.
b. Provide a reliability model of the HST, updated periodically with flight data, for use in decision support and logistics management.
c. Account for all ORUs through a logistics data system covering reliability parameters, inventory status, and EVA timeline activities and tool requirements.
d. Maintain trend analyses on sub-system performance, orbital decay and relevant geophysical models.

**5.3 ORU Requirements**

An inventory of critical Orbital Replaceable Units (ORUs) shall be provisioned and maintained to ensure support of a CSM call-up at any time. The inventory shall also include those ORUs which need to be replaced on PSMs based on current forecasts of need dates. To the extent the budget permits, an inventory of desirable ORU changeouts, i.e., those which will result in enhancements, shall also be supported.

**5.4 Orbital Replacement Instrument Requirements**

In order to meet the scientific performance requirements established in Section 3.2 or to upgrade FIST science return, additional scientific instruments will be acquired for installation on PSMs. These Orbital Replacement Instruments (ORIs) shall:

a. Be fully compatible with the flight and ground data management and communication systems, as they currently exist or are expected to be upgraded.
b. Meet operational phase thermal, mechanical and electrical interface specifications.
c. Have as a design goal an operational lifetime of at least 5 years.
d. Use, to the maximum extent practicable, on-orbit replaceable subsystems.

Algorithms shall be provided along with the ORIs to permit on- orbit support and instrument-unique ground data processing.

**5.5 Space Support Equipment**

A baseline set of reconfigurable Space Support Equipment (SSE) shall be maintained to support servicing missions. This baseline includes:

a. The Flight Support System (FSS) to provide the mechanical and electrical interface between HST and the Space Shuttle.
b. Orbital Replacement Unit Carrier(s) to provide mounting, power, environmental protection and load isolation for the ORUs and ORIs.
c. EVA crew aids and tools.

On a single mission, the capability shall exist to carry into orbit a full set of replacement batteries, a set of solar arrays, at least one radial and one axial module, and multiple ORUs as required. The actual servicing mission equipment mix for a given mission will be determined by Observatory performance and trend analyses, space support equipment considerations, available EVA capability, Space Shuttle performance capabilities, and other considerations determined relevant at the time.

**5.6 Technical Information Management**

An automated information management system shall be maintained which provides:

a. Management and resource control data.
b. Technical design and test data.

## 6. SAFETY AND EQUIPMENT RELIABILITY

### 6.1 Crew Safety

The design of the SSE, ORUs and ORIs shall assure that the Space Shuttle Orbiter or crew safety shall not be compromised at any time under either normal or contingency modes of operation. These modes include all phases of mission activity, i.e., rendezvous, capture,, on-orbit maintenance, redeployment, reboost and earth return.

### 6.2 Equipment Reliability

The HST and SSE shall meet the requirement that no single failure or operator error result in damage to the Space Shuttle. Any deployment or extension which could prevent payload bay door closure must be controlled by independent primary and backup methods, and the combination must be two-failure tolerant. Payload equipment which could interfere with the closing of the payload bay doors shall be jettisonable without EVA.

The HST shall have no single point failure that will jeopardize recovery of the HST or affect Space Shuttle crew safety. Nor shall a single point failure within the HST subsystems cause a permanent loss of command capability, engineering telemetry, or scientific data. HST structures shall be designed with adequate factors of safety to meet these requirements.

# HST Project Science Office

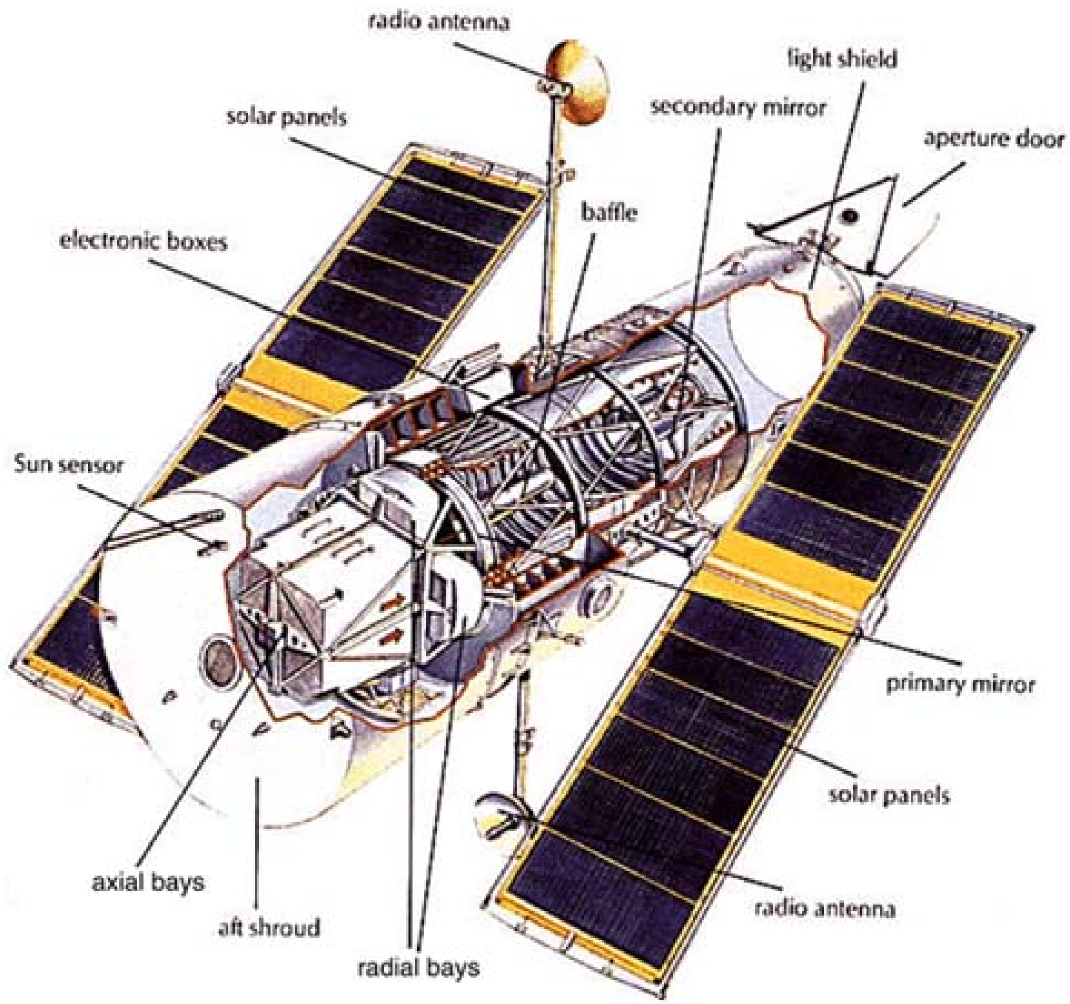

## Web Site Overview

These pages provide a top-level view of the HST observatory and its scientific goals. We also provide information on the Project's activities which are of general public interest. Please visit the excellent site at the Space Telescope Science Institute for detailed scientific results, images and data from the HST. Internal GSFC users can access detailed Project working information, on the Goddard restricted project site (MIMS).

For general HST Project information, check out the GSFC Web site, and the specific Code 440/441/442 pages.

# HST Project Science Office


## Hubble Space Telescope Layout



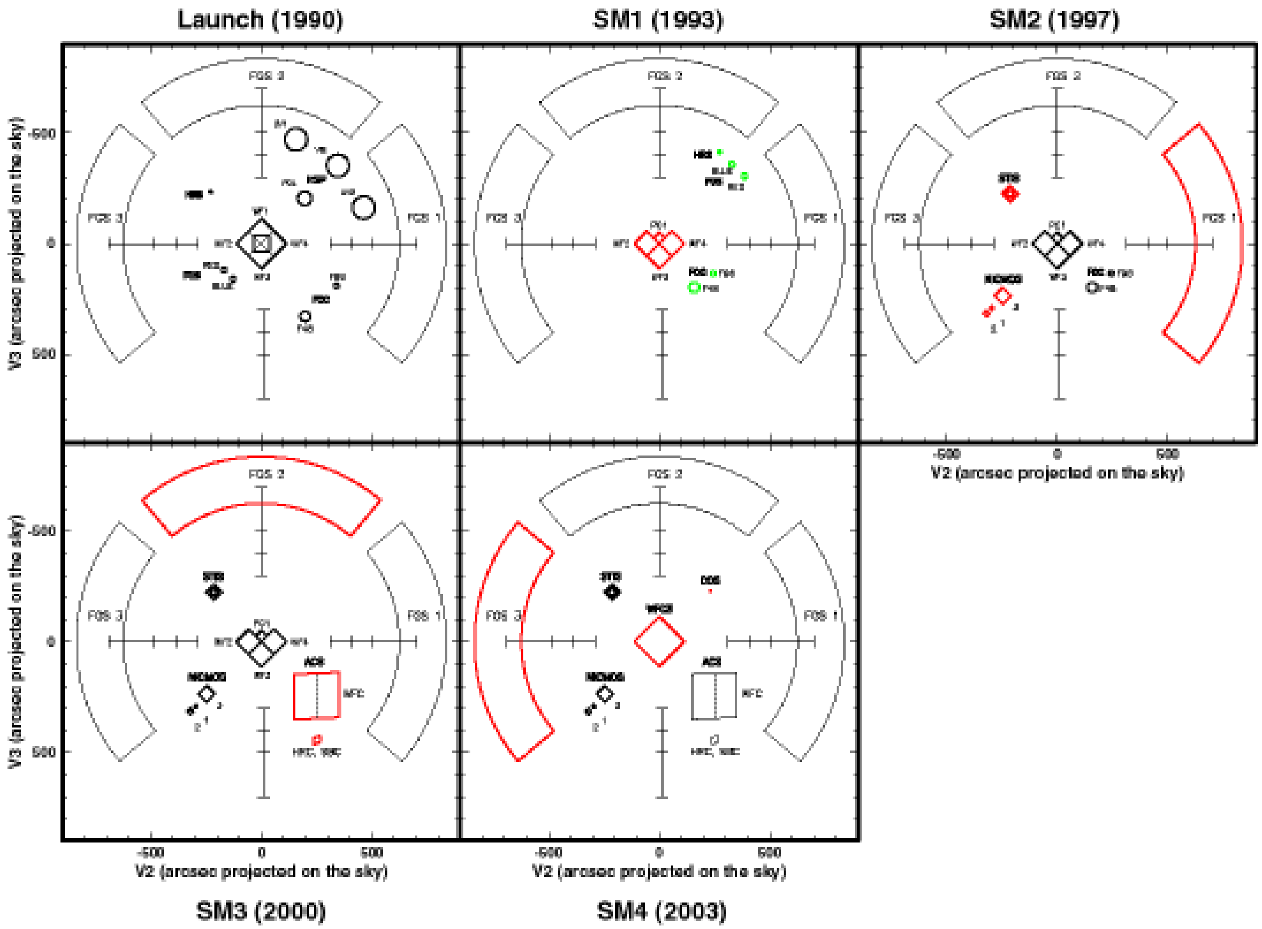
# HST Project Science Office

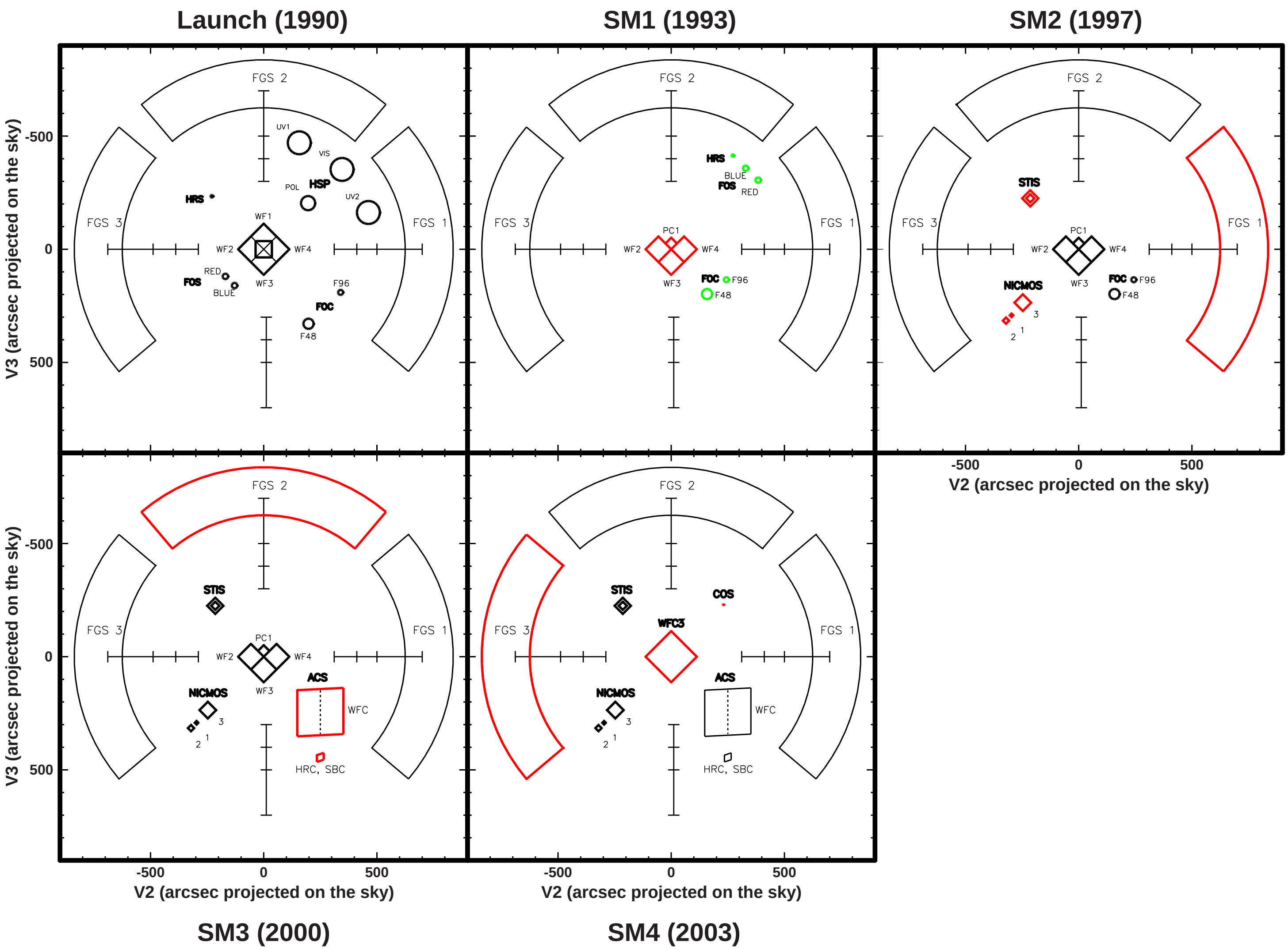

## Focal Plane History Chart

To understand the Field of View of the HST, we can diagram the sections of the Focal plane belonging to each instrument. While the HST gathers light from the entire circular area, the instruments each only sample a small section of this circle.

The placement of the apertures of each instrument are shown as are their relative sizes. You will notice that the different instruments are actually looking at different parts of the field of view at any time. The three circular sections belonging to the FGS's are referred to as 'pickles', which are the most distinctive part of the diagram. The entire field of view is about the size of the letter 'O' on a dime held at arms length.

click here for a pdf version of this file.


Launch (1990)
SM1 (1993)
SM2 (1997)
SM3 (2000)
SM4 (2003)
FGS 1
FGS 2
FGS 3
STIS
NICMOS
ACS
WFC
HRC, SBC
WFC3
COS
FOC
V3 (arcsec projected on the sky)
V2 (arcsec projected on the sky)
-500
0
500


Launch (1990)
SM1 (1993)
SM2 (1997)
SM3 (2000)
SM4 (2003)
FGS 1
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FGS 3
UV1
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F96
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WF3
WF4
PC1
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V2 (arcsec projected on the sky)
-500
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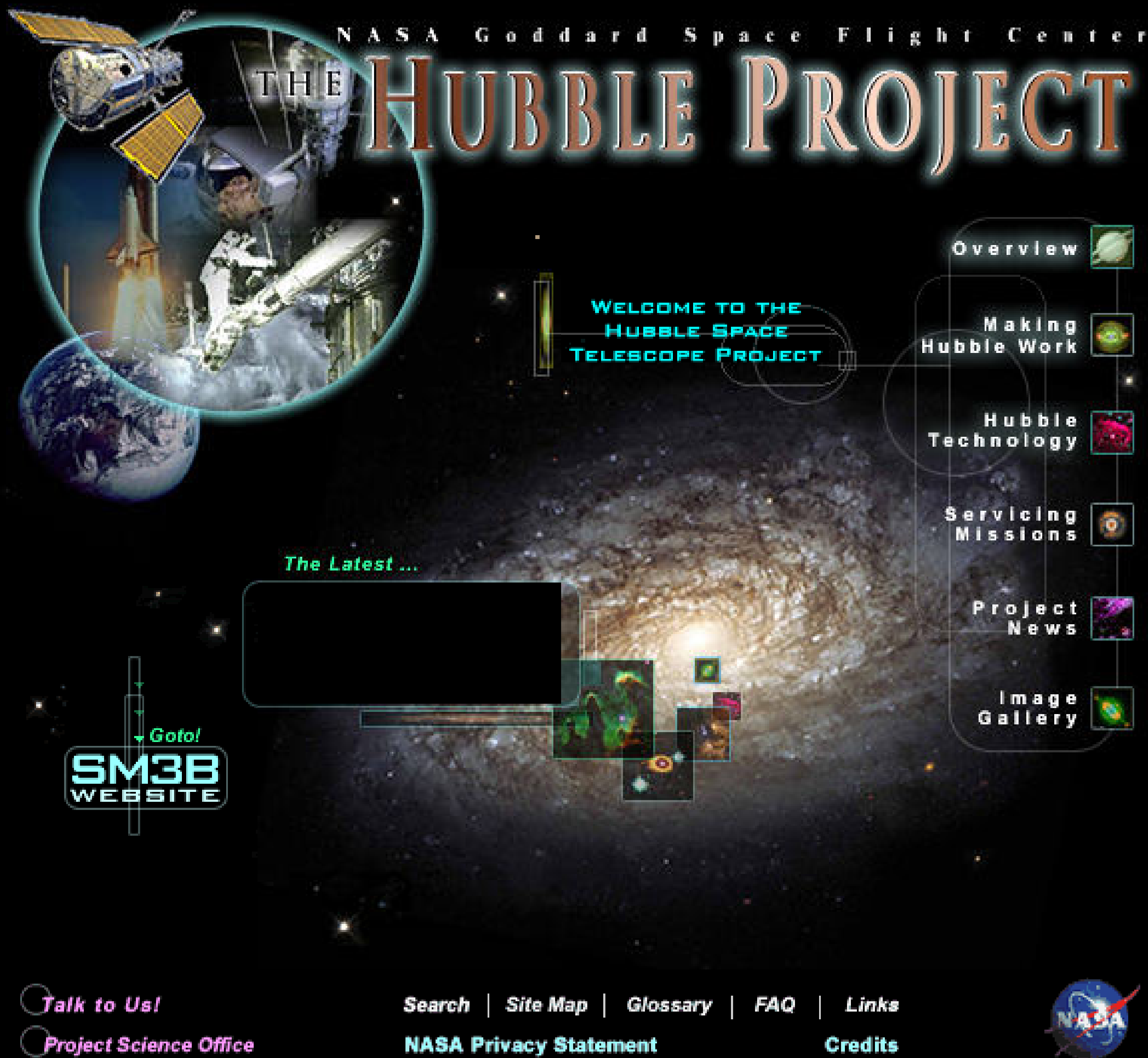
NASA Goddard Space Flight Center
THE HUBBLE PROJECT
Welcome to the Hubble Space Telescope Project
Overview
Making Hubble Work
Hubble Technology
Servicing Missions
Project News
Image Gallery
The Latest ...
Goto!
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# Servicing Missions



Every few years, a team of astronauts carries a full manifest of new equipment on the Space Shuttle for the ultimate "tune-up" in space.

From the beginning, Hubble was designed to be modular and astronaut-friendly. This design allows NASA to equip Hubble with new, state-of-the-art scientific instruments every few years, giving the telescope exciting new capabilities with each servicing mission.

Each new instrument placed on Hubble increases its scientific power by a factor of 10 or greater. In addition, during each servicing mission, the astronauts replace limited-life components with systems incorporating the latest technology.

With every servicing mission Hubble becomes, in effect, a new state-of-the-art observatory, at a fraction of the cost of building one "from scratch."



Contact: webmaster@hubble.gsfc.nasa.gov, Global Science & Technology, Inc.
Page Last Updated: October 29, 2001

# Hubble's Science Instruments

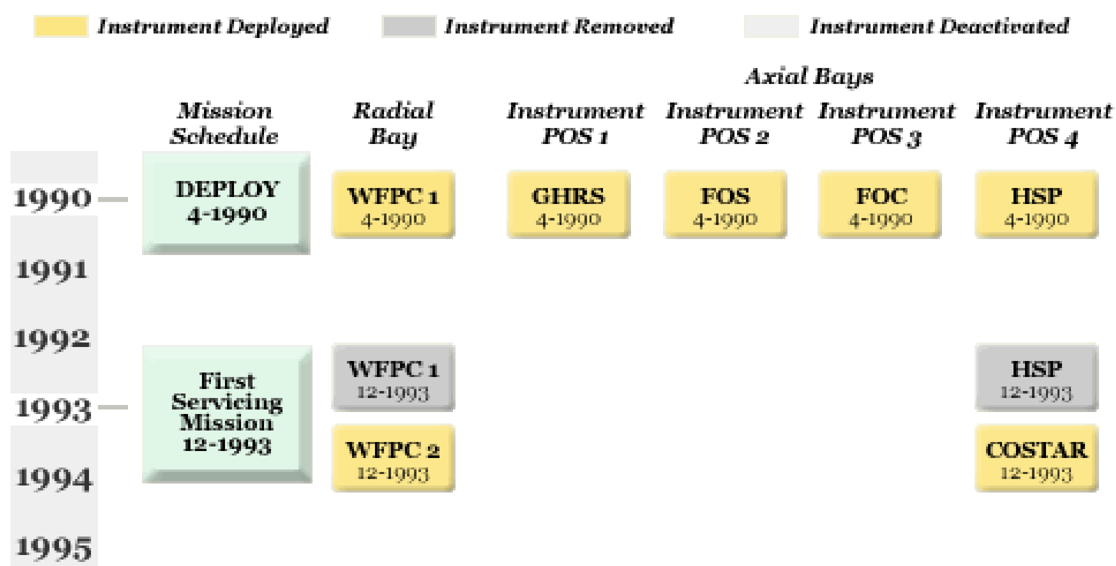


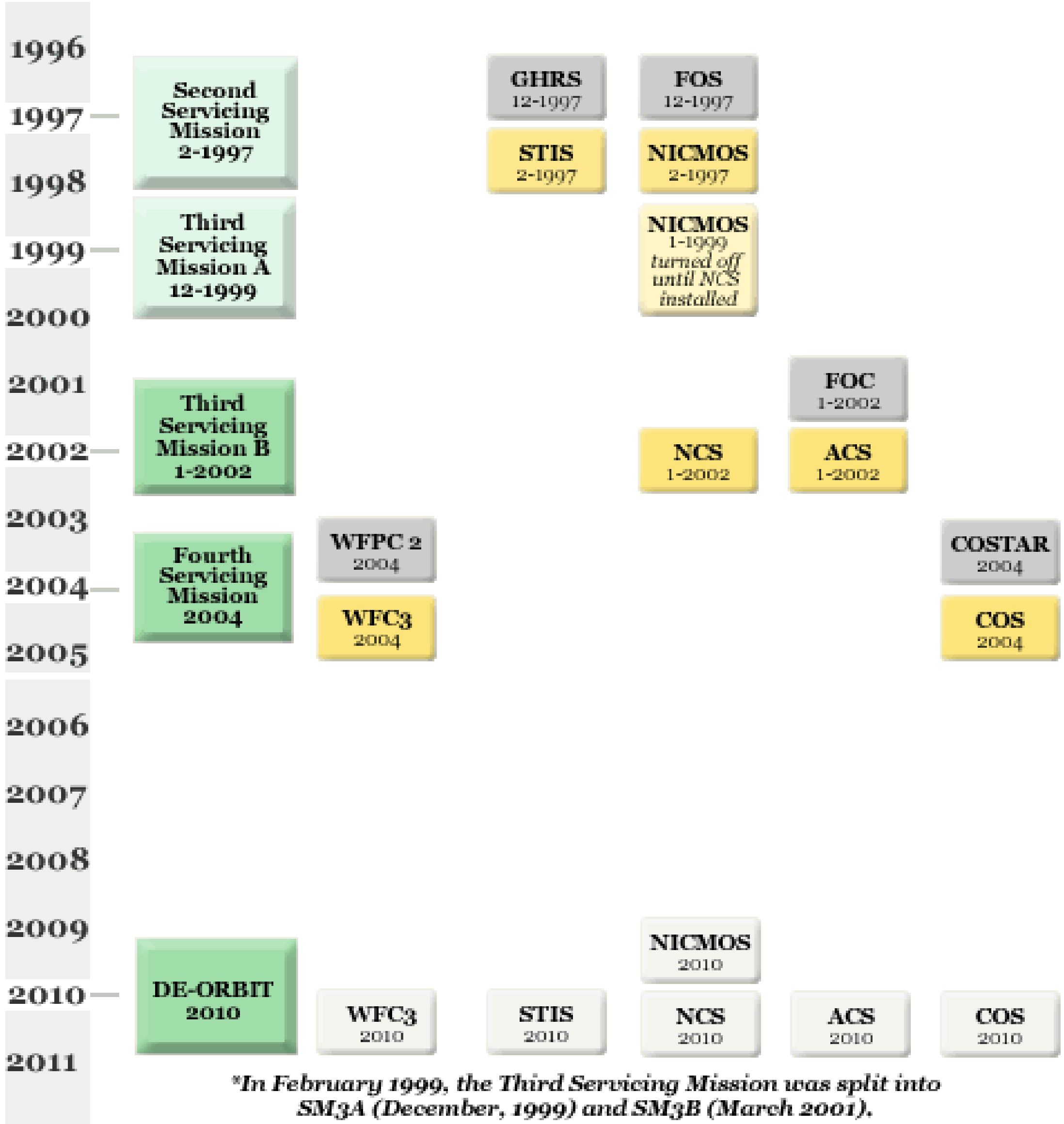


Over the course of Hubble's 20 year mission, new and improved instruments are periodically installed in order to bring the most advanced instrument technologies to the observatory.

This figure shows how the complement of instruments aboard Hubble is evolving over the life of the observatory.

**Below the chart is a short description of each instrument.**






## Alphabetical Instrument Listing

### 1990 Initial complement at deployment:

- **WFPC (1)** - Wide Field/Planetary Camera I - First Generation Imaging camera. WFPC (1) operated in either Wide Field mode, capturing the largest images, or Planetary mode with higher resolution.

- **GHRS** - Goddard High Resolution Spectrograph - First Generation Spectrograph. GHRS was used to obtain high resolution spectra of bright targets.

- **FOS** - Faint Object Spectrometer - First Generation Spectrometer. FOS was used to obtain spectra of very faint or far away sources. FOS also had a polarimeter for the study of the polarized light from these sources.

- **FOC** - Faint Object Camera - First Generation Imaging camera. FOC is used to image very small field of view, very faint targets. This is the final, first generation instrument still on Hubble.

- **HSP** - High Speed Photometer - First Generation Photometer. This instrument was used to measure very fast brightness changes in diverse objects, such as pulsars.

- **FGS** - Fine Guidance Sensors - Science/Guidance instruments. The FGS's are used in a "dual-purpose" mode serving to lock on to "guide stars" which help the telescope obtain the exceedingly accurate pointing necessary for observation of astronomical targets. These instruments can also be used to obtain highly accurate measurements of stellar positions

## 1993 Servicing Mission 1:

- **WFPC2** - Wide Field Planetary Camera II - Second Generation Imaging camera. WFPC2 is an upgraded version of WF/PC (1) which includes corrective optics and improved detectors.

- **COSTAR** - Corrective Optics Space Telescope Axial Replacement - Second Generation Corrective Optics. COSTAR is not an actual instrument, it consists of mirrors which refocus the abbreviated light from Hubble's optical system for first generation instruments. Only FOC utilizes its services today.

## 1997 Servicing Mission 2:

- **STIS** - Space Telescope Imaging Spectrograph - Second Generation Imager/Spectrograph. STIS is used to obtain high resolution spectra of resolved objects. STIS has the special ability to simultaneously obtain spectra from many different points along a target.

- **NICMOS** - Near Infrared Camera/Multi-Object Spectrometer- Second Generation Imager/Spectrograph. NICMOS is Hubble's only Near Infrared (NIR) instrument. To be sensitive in the NIR, NICMOS must operate at a very low temperature, requiring sophisticated coolers. Problems with the solid Nitrogen refrigerant have necessitated the installation of the NICMOS Cryocooler (NCC) on SM3B to continue operations.

## 2002 Servicing Mission 3B:

- **NCS** - NICMOS Cooling System - Like COSTAR, NCS is not a separate instrument but rather a device which will allow NICMOS to continue operations by providing mechanical cooling for the NICMOS detectors. Results from the HOST mission indicate that the NCS will allow NICMOS to operate for up to 5 years beyond SM3B.

- **ACS** - Advanced Camera for Surveys - The Advanced Camera for Surveys (ACS) is a third-generation Imaging Camera. This camera is optimized to perform surveys or broad imaging campaigns.

## 2003 Servicing Mission 4:

- **WFC3** - Wide Field Camera 3- Fourth Generation Imaging camera. This camera will supplement ACS and guarantee imaging capability for Hubble after the Fourth Servicing Mission.

- **COS** - Cosmic Origins Spectrograph - Fourth Generation Spectrometer. COS is an ultraviolet spectrograph optimized for observing faint point sources with moderate spectral resolution.



Contact: webmaster@hubble.gsfc.nasa.gov, Global Science & Technology, Inc.
Page Last Updated: November 28, 2001

# Frequently Asked Questions

Goto SM3B WEBSITE

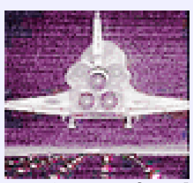
### Where can I find images taken by Hubble?

The archive of Hubble images is maintained by the Space Telescope Science Institute.

### When is the end of Hubble's mission?

The current plan is to operate Hubble until 2010. We anticipate a mission to Hubble will be required in 2010 either to return it to the ground, to raise it to a higher orbit (possibly with the aid of an attached booster), or to guide it into a controlled re-entry.

### How many servicing missions remain?



SM3A (December, 1999) will be followed by SM3B (early 2002) and SM4 (currently scheduled for July, 2003). No further missions to Hubble are planned until the final "closeout" mission in 2010.

The primary science payload for SM3B is the Advanced Camera for Surveys (ACS), a camera with high sensitivity to visible and ultraviolet light. ACS will exceed our current camera (WF/PC2) in "discovery power" by a factor of 10.

On SM4 we'll be installing the Cosmic Origins Spectrograph (COS), the most sensitive ultraviolet spectrograph ever flown on Hubble, and the Wide Field Camera 3 (WFC3), the first truly "panchromatic" camera on Hubble.

## What's a Hubble ?

### What does Hubble weigh and how big is it?

Hubble weighs about 24000 lbs on Earth. That would be about 11000 kg. It is about the size of a big tractor-trailer truck. To be more precise: The length is 13.2 meters (43.5 ft.) and the maximum diameter is 4.2 meters (14 ft.)

You can compare this to a car, which weighs around one or two tons (roughly 1000 to 2000 kg). Thus, Hubble weighs as much as six to twelve cars (depending on their size). It's not really phenomenally heavy. To get really heavy stuff, look at big aircraft carriers and monster skyscrapers!

### How can I see Hubble pass over my area?

Check for Hubble sightings in your area at NASA Sky Watch.

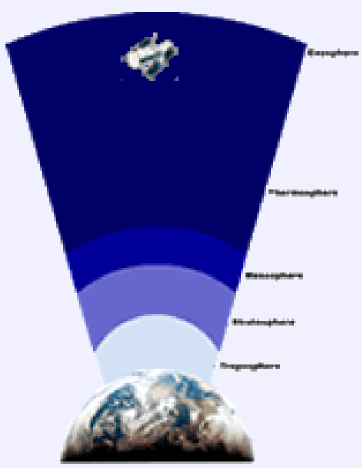
### How fast does Hubble travel?

At its current altitude, Hubble orbits the earth every 100 minutes, with a speed of approximately 17,000 mi/hr or 27,200 km/hr.

### How high up is Hubble?

The Hubble Space Telescope is a Low Earth Orbiting (LEO) satellite.

It is located about 320 nautical miles (375 statute miles, 600 km) above the surface of the earth.



### Who was Edwin Hubble?

Hubble, Edwin Powell (1889-1953), an American astronomer, was born in Marshfield, Missouri. As a staff member (from 1919) at Mt. Wilson Observatory, Hubble used the 100-in. (254-cm) telescope there to discover that there are large-scale galaxies beyond the Milky Way and that they are distributed almost uniformly in all directions.

In what is now known as Hubble's Law, he was the first to offer observational evidence supporting the theory of the expanding universe.

### What are the main objectives of the Hubble Program?

The Announcement of Opportunity for The Hubble Space Telescope, dated March 1977, cites that the main scientific objectives for Hubble are to determine:

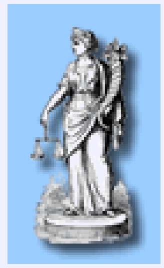
**A.** The constitution, physical characteristics, and dynamics of celestial bodies.

**B.** The nature of processes which occur in the extreme physical conditions existing in and between astronomical objects.

**C.** The history and evolution of the universe.

**D.** Whether the laws of nature are universal in the space-time continuum.

### What is Hubble's Law?



Hubble's law is a statement that the greater the distance between any two galaxies, the greater is their relative speed of separation. In other words, the universe is expanding roughly uniformly. This empirical finding is more consistent with the big bang theory of the universe's origin than with the steady state theory.

The law was first proposed in 1929 by Edwin Hubble, who observed that the more distant a galaxy, the greater is its red shift, and hence its velocity relative to our galaxy.

### How much did Hubble cost to put in orbit?

Hubble was put into orbit in 1990 from the Space Shuttle Discovery. Built 1978-90 at a cost of $1.5 billion, the telescope (named for astronomer E.P. Hubble) was expected to provide the clearest view yet obtained of the universe.

A flaw in Hubble's 94.5-in (2.4-m) light-gathering mirror, discovered after the telescope was in orbit, initially limited its effectiveness. In 1993, however, astronauts repaired the telescope, replaced critical instruments, and added corrective optics while in orbit.

### Can Hubble see objects on the moon?

There are three problems with HST viewing things on the moon:

1. Size: An object on the moon 4 meters across, viewed from HST, would be about 0.002 arcsec in size. The highest resolution instrument currently on HST is the FOC, at 0.014 arcsec. So anything we left on the moon cannot be resolved in any HST image. It would just appear as a dot -- except see next point.

2. Motion of the moon: The HST pointing system is designed to hold it quite motionless relative to the distant stars -- but the Moon isn't. In 1 second of time, the moon moves over 0.5 arcsec. The shortest exposure time any of the HST instruments offers is 0.1 sec -- so an object we left on the Moon would appear as a streak.

3. Too much light: This one you can probably work around, but the Moon when illuminated by the Sun is far too bright for any HST instrument to take a picture of -- the detectors would saturate in much less than the shortest exposure time. So the picture would have to be taken when the Sun wasn't illuminating the area in question -- just lit up by Earthshine.



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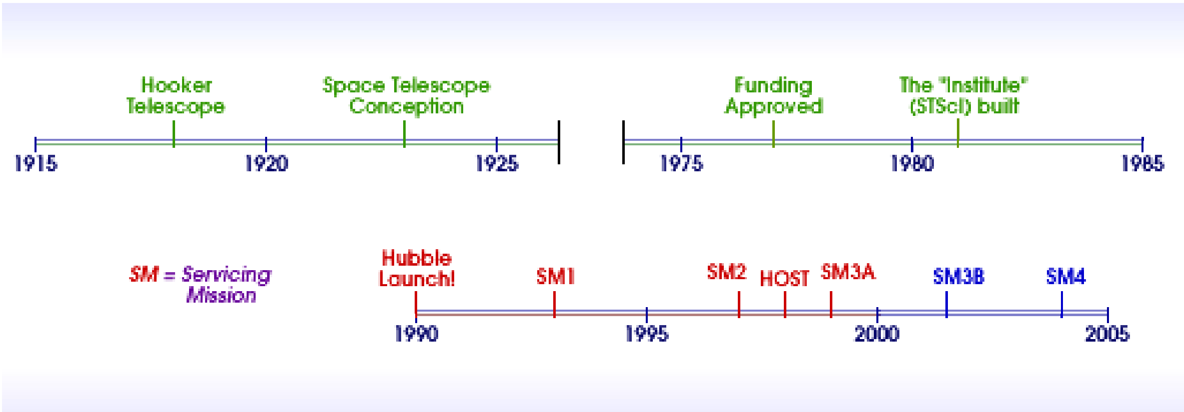
Page Last Updated: March 7, 2002

# Historical Timeline








## 2004

### Servicing Mission 4 (SM4)

- Installation of WFC3.
- Installation of COS.

## 2002

### Servicing Mission 3B (SM3B)

- February 2002:Planned for Shuttle Columbia.
- Installation of ACS.
- Installation of NCS.
- Replace SA2 with SA3 (solar arrays).

1999

### Servicing Mission 3A (SM3A)

- December 9, 1999: (STS-103) Launch of Shuttle Discovery.
- Replacement of RSU (Rate Sensing Units containing gyroscopes).
- Install new computer.
- General maintenance.

*November 13, 1999: Hubble placed in safe mode after the failure of a fourth gyroscope.*

1998

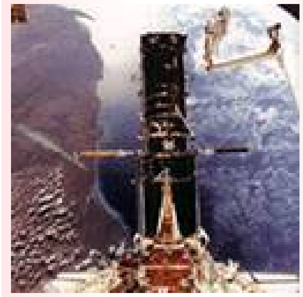
### HST Orbital Systems Test (HOST)

- October 29, 1998: (STS-95) Launch of Shuttle Discovery.
- The HOST mission was flown to test new technologies for installation into Hubble during servicing missions 3A and 3B.

1997

**Servicing Mission 2 (SM2)**

- February 11, 1997: (STS-82) Launch of Shuttle Discovery.
- STIS replaced FOS.
- NICMOS replaced GHRS.



1993

**Servicing Mission 1 (SM1)**

- December 2, 1993: (STS-61) Launch of Shuttle Endeavour
- COSTAR corrective optics installed, replacing HSP.
- WFPC2 replaced WFPC.

1990

**Hubble Space Telescope (HST) Deployed**

- April 24, 1990: (STS-31) Launch of Shuttle Discovery.
- April 25, 1990: Hubble Telescope deployed into orbit.
- June 25, 1990: Spherical aberration discovered in Hubble's primary mirror
- COSTAR Approved: the creation of a complex packaging of five optical mirror pairs which would rectify the spherical aberration in Hubble's primary mirror.

1981

**Space Telescope Science Institute (STScI)**

Operations begin in Baltimore, Maryland. The STScI was built as the astronomical research center for the Hubble Space Telescope.

1977

**Congress approves funding for The Hubble Space Telescope**

NASA names its largest, most complex, and capable orbiting telescope in honor of Edwin Hubble.

1923

**Conception of a space telescope**

Famed rocket scientist Herman Oberth publishes an article speculating on telescopes in Orbit.

Space pioneer Hermann Oberth was considered by many to be the most famous mentor of the late Dr. Wernher von Braun, the first director of the NASA Marshall Space Flight Center in Huntsville, Alabama.

1918

## The Hooker Telescope and Edwin Hubble

The 2.5 meter (100 inches) Hooker Telescope begins operations at Mt. Wilson Observatory in Pasadena, California.

With this telescope in the 1920's, astronomer Edwin Hubble measured the distances and velocities of galaxies, work which led to today's concept of an expanding Universe.



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Page Last Updated: October 29, 2001

# What is the Origins Program?


Have you ever looked up at the night sky, marveling at the vastness of the Universe and your own connection to it?

It's hard to communicate the full sense of wonder that floods through us at such a moment, but we all understand. At least once, the dimly glittering night sky has stopped us in our tracks, bringing quiet contemplation of how the Universe came to be and what our relationship is to everything within it.

## The Origins Program's Two Defining Science Questions

NASA's Origins Program seeks to answer two enduring human questions that we once considered around ancient campfires, yet still keep alive in today's classrooms:

**Where do we come from?**
**Are we alone?**

Knowing "where we come from" means understanding how the great chain of events unleashed after the Big Bang culminated in us and in everything we observe today. It is the story of our cosmic roots, told in terms of all that precedes us: the origin and development of galaxies, stars, planets, and the chemical conditions necessary to support life.

Knowing our uniqueness--"whether we're alone" in the cosmos--depends on our search for life-sustaining planets and on our understanding of its glorious diversity here on Earth. Only by seeing the innumerable possibilities on our home planet can we be sure that we'll recognize life if and when we find it somewhere else.

## The Origins Legacy

Over the course of the next two decades, the Origins Program will develop the sophisticated telescopes and technologies that will bring us the information we seek. While the questions are challenging, our generation is privileged to have the technological ability to reveal the possibilities for the first time. Just as the Greeks were known for democracy, the Egyptians for pyramids, and the Romans for roads, our civilization may well be remembered for discovering life beyond our own planet, forever changing our perception of the Universe and our place within it.


An Introduction to the Origins Program in sounds and pictures

Planet Quest: the Search for Another Earth In-depth information about planets outside our solar system

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Last Updated: 13-February-02

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***Last revised:*** Feb 20, 2002

Curators: Webmaster
Responsible NASA Official: Cecilia Czarnecki

# Hubble Space Telescope - Code 440

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Mission Statement
Projects
HST Observatory
Management
Links

# HST Operations Project: Code 441

Return to Code 440

## Current Management

Project Manager: Preston M. Burch
Deputy Project Manager: Edward O. Ruitberg
Deputy Project Manager/Resources: Susan M. Sparacino

## HST Operations Project Mission:

The HST Operations Project is responsible for conducting all HST operations and for the maintenance and operation of the ground systems. Within the Operations Project, there are three major elements: Systems Development, Science Management, and Operations. Responsibilities include developing and maintaining ground system facilities and all flight and ground software; operating the Space Telescope Operations Control Center (STOCC); and safely and productively operating the HST Observatory (including the scientific instruments) and its flight systems. The Operations Project oversees the activities of the STScI, operated by the Association of Universities for Research in Astronomy (AURA) for NASA, which implements the HST Science Research Program under contract to NASA. Major STScI responsibilities include soliciting observation proposals, allocating telescope time, implementing observations, and creating processed data products. The STScI also operates and maintains portions of the mission operations ground system.

The Primary objectives of the Operations Project are to conduct all HST Observatory science operations, missions operations and the maintenance and operations ground system for at least 15 years.

The objectives relating to science operations are as follows:

- Prepare and issue Announcements of Opportunities (AOs) for new research programs
- Select HST observers and archival researchers, and provide direct technical support to observers before, during and after observations
- Process, archive, and publicize the scientific data derived from HST, and make this data accessible to other researchers
- Sponsor HST-related research necessary for efficient use of the HST Observatory

The objectives relating to mission operations are as follows:

- Maintain the health and safety of the HST Observatory
- Perform normal and contingency HST Observatory operations
- Provide systems engineering trend analysis and evaluation of the HST Observatory performance
- Support preparations and conduct operations for servicing activities
- Maintain and enhance ground systems and flight software to accomplish mission objectives

---

**Last Modified:** *August 29, 2000*

# HST Development Project: Code 442

Return to Code 440

## Current Management

Project Manager: Frank J. Cepollina
Deputy Project Manager: E. Michael Kienlen
Deputy Project Manager/Resources: Richard C. King, Jr.

---

## HST Development Project Mission:

The HST Development Project is responsible for planning, managing, and directing the HST orbital servicing program. It also develops the detailed mission requirements and plans and is responsible for all Space Shuttle interfaces with the HST Observatory and shuttle servicing equipment. In addition, The Development Project is responsible for the design, development, fabrication, integration, testing, calibration (except for science instruments), and maintenance of the following:

- Observatory components that can be replaced in orbit
- Future generations of HST scientific instruments
- Flight hardware and ground support equipment

necessary to maintain the HST Observatory
- Associated data base required to support periodic servicing missions

## Launch and Servicing Mission Dates:

- HST Launch April 24,1990
- HST SM1 December 2, 1993
- HST SM2 February 11, 1997
- HST SM3A December 19, 1999
- HST SM3B November 2001
- HST SM4 November 2003

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**Last Modified:** *August 29, 2000*

# Overview



Not since Galileo turned his telescope towards the Heavens in 1610 has any event so changed our understanding of the Universe as the deployment of the Hubble Space Telescope.

Hubble orbits **600 Kilometers (375)** above Earth, working around the clock to unlock the secrets of the Universe. It uses excelllent pointing precision, powerful optics, and state-of-the-art instruments to provide stunning views of the Universe that cannot be made using ground-based telescopes or other satellites. (Track Hubble's path in orbit!)

Hubble was originally designed in the 1970s and **launched in 1990**. Thanks to on-orbit service calls by the Space Shuttle astronauts, Hubble continues to be a state-of-the-art, model year 2001 space telescope.

Hubble is the first scientific mission of any kind that is specifically designed for routine servicing by spacewalking astronauts. It has a **visionary, modular design** which allows the astronauts to take it apart, replace worn out equiptment and upgrade instruments. These periodic service calls make sure that Hubble produces first-class science using cutting-edge technology. See technology highlights. Each time a science instrument in Hubble is replaced, it increases Hubble scientific power by a factor of 10 or greater!

## Hubble's Accomplishments

Hubble's accomplishments are extraordinary. Before Hubble, distances to far-off galaxies were not well known. Questions such as how rapidly the Universe is expanding, and for how long, created great controversy.

***Hubble data has changed all of that.***

Every day, Hubble archives 3 to 5 gigabytes of data and **delivers between 10 and 15 gigabytes** to astronomers all over the world. See science highlights. As of March 2000, Hubble has:

- Taken more than 330,000 separate observations.
- Observed more than 25,000 astronomical targets.
- Created a data archive of over 7.3 terabytes (thatís like completely filling a PC every day for 10 years).
- Provided data for more than 2,663 scientific papers.
- Traveled about 1.489 billion miles - nearly the distance from Earth to Uranus. It circles the Earth about every 97 minutes.
- Received more than 93 hours of on-orbit improvements in three successful servicing missions.



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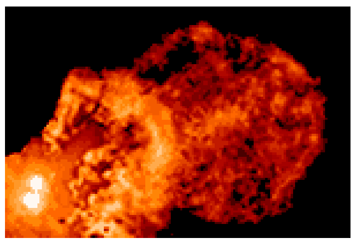
# Making Hubble Work

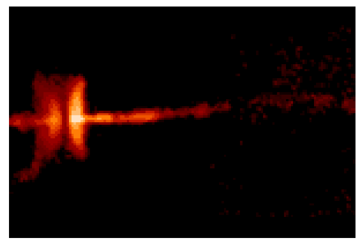




The Hubble Space Telescope orbits far above the distorting effects of the atmosphere, about **600 Kilometers above the Earth.** This perch gives astronomers with their clearest view ever, but it also prevents them from looking directly through the telescope. Instead, **astronomers use Hubble's scientific instruments as their electronic eyes.**



XZ Tauri



HH 30

**Movies from Hubble Show the Changing Faces of Infant Stars**

These instruments include **cameras and spectrographs**. Hubble's cameras do not use film; they collect light with electronic detectors similar to those in home video cameras. The spectrographs separate starlight into a rainbow of colors, just as a prism splits sunlight. By carefully studying the colors, astronomers can decode a star's temperature, motion, composition and age.

Hubble **uses mirrors to focus and magnify light.** Its 8-foot-diameter main mirror is tucked inside a long, hollow tube that blocks the glare from the Sun, Earth, and Moon. Wing-like solar panels collect sunlight and convert it into electricity.

**Radio antennas** allow Hubble to **communicate with its flight controllers** at the Goddard Space Flight Center in Greenbelt, Md. Controllers send detailed instructions several times a day. This information is converted into a code that the spacecraft's main computer can understand.

Imagine pointing a laser on a dime 200 miles away, and holding it steady for hours or days. This is the precision of Hubble's sophisticated pointing control system. Once Hubble locks onto an object, its sensors check for movement 40 times a second. If movement occurs, constantly spinning wheels change speeds to smoothly bring the telescope back into position.

As Hubble observes celestial targets, its computers turn the information into long strings of numbers. This digital data travels as radio signals to a communications satellite, which beams the information to Goddard. From there, it travels by landline to the Space Telescope Science Institute in Baltimore, Md., where is turned back into pictures and astronomical data.

Hubble's daily downloads are stored on optical computer disks, which provide a unique resource for current and future astronomers. **The observations from a single day would fill an encyclopedia.**

Top

# Hubble Technology



From detector technology to astronaut tools, the Hubble team is always looking for ways to make performance better.

Now 10 years old, the telescope is basically a new machine. Upgrades and maintenance keep Hubble operating in top condition to give us the greatest scientific data possible.

Since Hubble's modular design allows for these on-orbit instrument and equipment upgrades, the astronauts are also able to bring back the equipment that is being replaced. The ability to refurbish the returned science instruments has proven to be a cost-effective way to enhance the telescope with the latest technology. By installing the new technology in recycled modules, NASA avoids "reinventing the wheel" and reduces the overall cost of science data.

From manufacturing to medicine, the creative designs and innovative re-uses are some of the many Hubble improvements which translate into benefits for us all.



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Page Last Updated: October 29, 2001

# Servicing Missions



Every few years, a team of astronauts carries a full manifest of new equipment on the Space Shuttle for the ultimate "tune-up" in space.

From the beginning, Hubble was designed to be modular and astronaut-friendly. This design allows NASA to equip Hubble with new, state-of-the-art scientific instruments every few years, giving the telescope exciting new capabilities with each servicing mission.

Each new instrument placed on Hubble increases its scientific power by a factor of 10 or greater. In addition, during each servicing mission, the astronauts replace limited-life components with systems incorporating the latest technology.

With every servicing mission Hubble becomes, in effect, a new state-of-the-art observatory, at a fraction of the cost of building one "from scratch."



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# Project News

Hubble Newsfeed
Press Releases
Project Reports
Incident Reports
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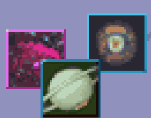
- **Catch up with the online Hubble Newsfeed**
- **Read the latest Incident Reports**
- **Follow Hubble's spectacular Press Releases**
- **Research our Project Reports**

Hubble related news stories have included overviews of **Hubble's advanced technologies**, insights into Astronaut servicing and Hubble's **amazing scientific discoveries.**

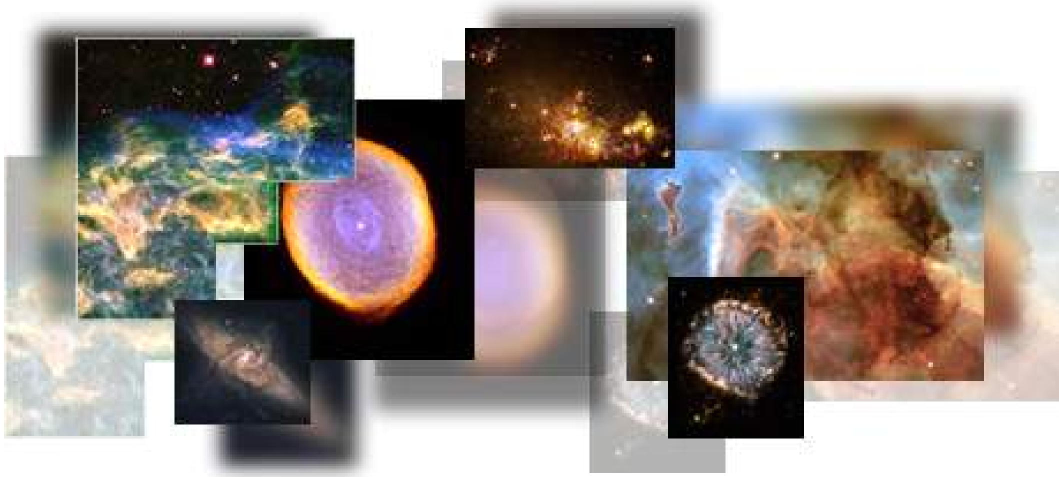
From its **spectacular launch** and dramatic repairs to its **regular revelations about our Universe**, Hubble has been making the headlines for the the past decade.

# Image Gallery









- View Hubble's **Exciting Images.**
- Check out Hubble hardware construction with our **live interactive webcam.**
- Look at Hubble **servicing images** from the past decade.
- Live **NASA Cams**.
- Watch **Space Station construction** in action.

**... and much more!**



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Page Last Updated: December 22, 2001

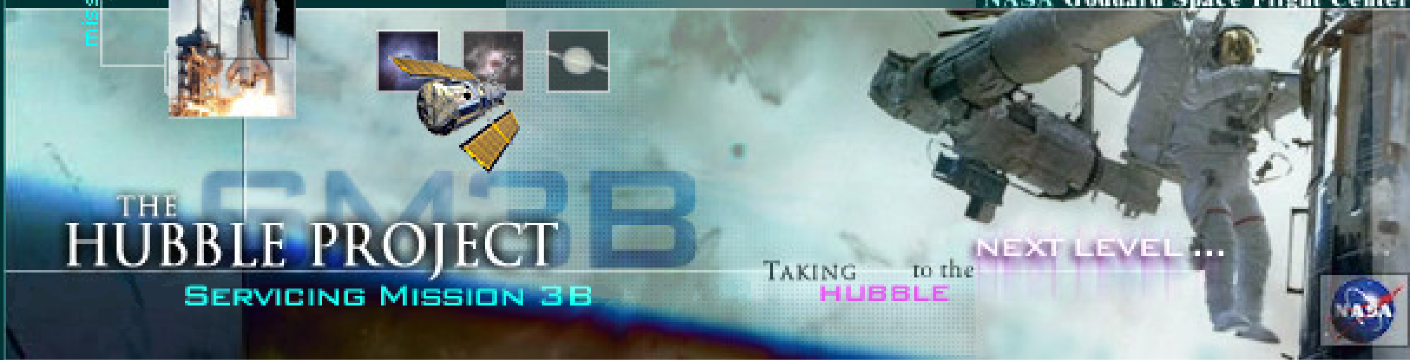
11 days 22:10:00

mission time

Launch **3.01.02** :: Landing **3.12.02**

SEARCH

NASA Goddard Space Flight Center

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# Glossary and Acronyms

Goto SM3B WEBSITE

## Hubble Space Telescope Acronyms List

**ACS** — Advanced Camera for Surveys
This will consist of three electronic cameras and a complement of filters and dispersers that detect light from the ultraviolet at 1200 angstroms to the near infrared at 10,000 angstroms, with 10 times the efficiency of current instruments; to be installed during SM3B in 2002.

**ASLR(K)** — Aft Shroud Latch Repair (kits)
This kit will fix door latches in the aft shroud area of the telescope that have been damaged by extreme temperature changes and high torques.

**BAPS** — Berthing and Positioning System
This is the unit that holds and maneuvers HST while it is berthed to the orbiter. The BAPS can orient the telescope at a variety of angles and can rotate the HST a full 360 degrees to bring any part of HST within the reach of the astronauts and the RMS, or robot arm.

**BPS** — BAPS Support Post
This post is installed to keep the BAPS immobile during activities which generate high torques on the HST, for example reboost.

**C-5**
A heavy logistics global transport aircraft designed to provide massive strategic airlift and express delivery of padded or oversized cargo as well as passengers; transported HST flight hardware and personnel to and from GSFC and KSC.

**COS** — Cosmic Origins Spectrograph
Fourth Generation Spectrometer. COS is an ultraviolet spectrograph optimized for observing faint point sources with moderate spectral resolution.

**COSTAR** — Corrective Optics Space Telescope Axial
Second Generation Corrective Optics. COSTAR is not an actual instrument. It consists of mirrors which refocus the abberated light from the HST optical system for first generation instruments. Only FOC utilizes its services today.

**DF-224**
Onboard Digital Fixed Point 2's complement 24-bit word Rockwell computer module. This was originally the main computer which controls the attitude (orientation) of the Hubble Space Telescope. It has since been repaced by a new computer based on the Intel 80486 microchip.

**ESA** — European Space Agency

**EVA** — Extravehicular activity
outside the spacecraft; activity in space conducted by suited astronauts. This is also known as a spacewalk.

**FGS** — Fine Guidance Sensor
Science/Guidance instruments. The FGS's are used in a "dual-purpose" mode serving to lock on to "guide stars" which help the telescope obtain the exceedingly accurate pointing necessary for observation of astronomical targets. These instruments can also be used to obtain highly accurate measurements of stellar positions.

**FOC** — Faint Object Camera
First Generation Imaging camera. FOC is used to image very small field of view, very faint targets. Last first generation instrument on HST.

**FOS** — Faint Object Spectrograph
First Generation Spectrometer. FOS was used to obtain spectra of very faint or far away sources. FOS also had a polarimeter for the study of the polarized light from these sources.

**FSS** — Flight Support System (Structure)
This is the name for the structure which holds HST and provides power and computer interfaces while it is berthed to an Orbiter during servicing.

**GHRS** — Goddard High Resolution Spectrograph
First Generation Spectrograph. GHRS was used to obtain high resolution spectra of bright targets.

**GSFC** — Goddard Space Flight Center
Greenbelt, Maryland. The HST Project is run from here.

**HOST mission** — Hubble Space Telescope Orbital Systems Test (1998)
This mission tested several pieces of equipment in preparation for SM3A and SM3B.

**HST** — Hubble Space Telescope

**KSC** — Kennedy Space Center, Cape Canaveral, FL
KSC is responsible for launches.

**MLI** — Multi-layer insulation
This is the highly reflective material which is attached to spacecraft to act as a thermal barrier. It consists of many sheets of 25 µm thick polyester or polyamide layers sewn together. It is often silver or gold in color.

**NASA** — National Aeronautics and Space Administration

**NCS** — NICMOS Cooling System
This mechanical cooler was tested during the HOST mission and will be installed during SM3B will allow NICMOS to resume science operations.

**NICMOS** — Near Infrared Camera and Multi-Object Spectrometer
Second Generation Imager/Spectrograph. NICMOS is HST's only NIR instrument.

**NIR** — Near Infrared
Near Infrared light is not visible to human eyes, but many celestial objects shine brightly with this light. Typically associated with heat, NIR images show the presence of molecules and complex compounds.

**NOBL** — New Outer Blanket Layer
The NOBL are stainless steel panels covered with a protective thermal coating. These panels fit over existing, degraded insulation on Hubble's exterior surface, to control Hubble's internal temperature. In 1997, astronauts on Servicing Mission 2 discovered damaged areas of insulation and performed temporary repairs. The NOBL will be permanently mounted.

**OCE-EK** — Optical Control Electronics Enhancement Kit

**ORU/ORI** — Orbital Replacement Unit / Orbital Replacement Instrument
Since HST was designed to be serviced on-orbit, many of the systems, and all of the instruments were designed and built as replaceable units.

**ORUC** — Orbital Replacement Unit Carrier
Special boxes which isolate the delicate instruments and other ORUs from the forces and vibrations of launch and ascent to orbit.

**RSU** — Rate Sensor Unit
Hubble houses three RSU's and each RSU contains two gyroscopes. The gyroscopes are part of Hubble's pointing system. The gyroscopes work by comparing Hubble's motion relative to the axis of the spinning masses inside the gyroscopes. In the absence of external forces, these axes remain stable relative to the fixed stars in the sky. By keeping Hubble fixed relative to these axes, Hubble stays stable relative to the stars.

**SM1** — HST Servicing Mission 1, (December 1993)

**SM2** — HST Servicing Mission 2, (February 1997)

**SM3A** — HST Servicing Mission 3A, (December 1999)

**SM3B** — HST Servicing Mission 3B, (planned for February 2001)

**SSAT** — S-band Single-Access Transmitter
This replacement transmitter uses radio waves to send data to the ground. The older unit it replaces will be returned to Earth and refurbished for a later flight.

**SSDIF** — Spacecraft Systems Development and Integration Facility
This building is located at GSFC. The SSDIF is a 7,989 $m^2$ (86,000 $ft^2$) facility designed to provide support for the integration and testing of spacecraft hardware. It is unique in the fact that it contains a 36,816$m^3$ (1.3M $ft^3$) horizontal, unidirectional flow cleanroom. Additional features include: Automated Data Processing Area, Shipping/Receiving Area, Flight Hardware Storage Area,

and Precision Cleaning facilities.

**SSR** — Solid State Recorder
Hubble's original data recorders were mechanical, reel-to-reel tape recorders with many moving parts that wear out over time. The digital SSR has no moving parts or tape to break, so it is much more robust. This next-generation recorder is faster and more reliable, and it can store 10 times as much data as a mechanical recorder.

**SSRF** — Shell/Shield Repair Fabric
Sheets of flexible, aluminized Teflon® fabric that fit over the original multi-layer insulation on Hubble's forward shell and light shield to add thermal protection. In 1997, astronauts on Servicing Mission 2 discovered damaged areas of insulation and performed temporary repairs. The SSRF will be permanently mounted over these temporary coverings.

**STIS** — Space Telescope Imaging Spectrograph
Second Generation Imager/Spectrograph. STIS is used to obtain high resolution spectra of resolved objects. The special ability of STIS is to simultaneously obtain spectra from many different points along the target.

**STOCC** — Space Telescope Operations Control Center
Located at Goddard Space Flight Center, the STOCC is where all commanding to the HST originates from.

**STS** — Space Transportation System
This is the formal name of the Space Shuttle Program.

**STScI** — Space Telescope Science Institute
This institute, located at Johns Hopkins University, is the home of the HST Scientists. The STScI is responsible for allocating observing time and for calibration, data storage, retrieval, and distribution of science data. STScI also provides software tools for manipulating the data.

**USAF** — United States Air Force

**USN** — United States Navy

**USS** — United States Ship

**VEST** — Vehicle Electrical Systems Test
Hubble high-fidelity mock-up trains astronauts on installation and removal of flight hardware components.

**VIK** — Voltage/Temperature Improvement Kit
These protect Hubble's batteries from overcharging and overheating when in safe mode.

**WFC3** — Wide Field Camera 3
Fourth Generation Imaging camera. This camera will supplement ACS and guarantee imaging capability for HST after Servicing Mission 4.

**WFPC** — Wide Field/Planetary Camera
The camera currently in use is the second-generation instrument WFPC2, installed during the First Servicing Mission in December 1993. It replaced WFPC1 and was built with optics to correct for the spherical aberration of the primary mirror.



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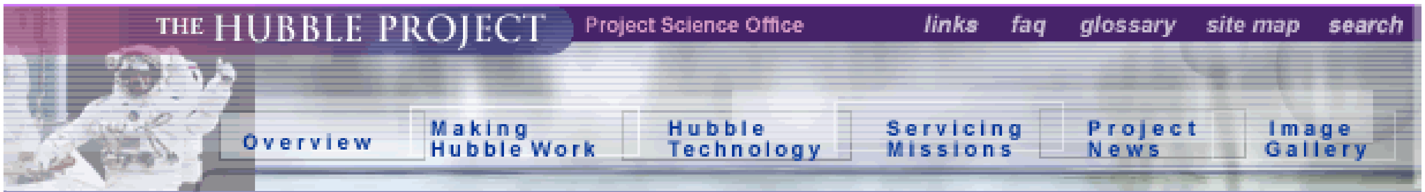
Page Last Updated: January 15, 2002

Talk to Us!

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- Hubble News Overview
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    - Sign Our Guestbook
    - WebChats
        - Russ Werneth Bio
        - Dr. H. John Wood Bio
- The Hubble Space Telescope Project Science Office

# Talk to Us!





**We want to know what you think.**

**Hubble Webchats**
Find out the inside scoop on Hubble from the experts.

**Hubble Guestbook**
Read comments and leave your own.

**E-mail us!**
webmaster@hubble.gsfc.nasa.gov



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# Overview

Historical Timeline
2000 and Beyond
Capturing Images
Hubble's Goals
Science Highlights
Technology Highlights

Goto SM3B WEBSITE

Not since Galileo turned his telescope towards the Heavens in 1610 has any event so changed our understanding of the Universe as the deployment of the Hubble Space Telescope.

Hubble orbits **600 Kilometers (375)** above Earth, working around the clock to unlock the secrets of the Universe. It uses excelllent pointing precision, powerful optics, and state-of-the-art instruments to provide stunning views of the Universe that cannot be made using ground-based telescopes or other satellites. (Track Hubble's path in orbit!)

Hubble was originally designed in the 1970s and **launched in 1990**. Thanks to on-orbit service calls by the Space Shuttle astronauts, Hubble continues to be a state-of-the-art, model year 2001 space telescope.

Hubble is the first scientific mission of any kind that is specifically designed for routine servicing by spacewalking astronauts. It has a **visionary, modular design** which allows the astronauts to take it apart, replace worn out equiptment and upgrade instruments. These periodic service calls make sure that Hubble produces first-class science using cutting-edge technology. See technology highlights. Each time a science instrument in Hubble is replaced, it increases Hubble scientific power by a factor of 10 or greater!

## Hubble's Accomplishments

Hubble's accomplishments are extraordinary. Before Hubble, distances to far-off galaxies were not well known. Questions such as how rapidly the Universe is expanding, and for how long, created great controversy.

***Hubble data has changed all of that.***

Every day, Hubble archives 3 to 5 gigabytes of data and **delivers between 10 and 15 gigabytes** to astronomers all over the world.
See science highlights. As of March 2000, Hubble has:

- Taken more than 330,000 separate observations.
- Observed more than 25,000 astronomical targets.
- Created a data archive of over 7.3 terabytes (thatís like completely filling a PC every day for 10 years).
- Provided data for more than 2,663 scientific papers.
- Traveled about 1.489 billion miles - nearly the distance from Earth to Uranus. It circles the Earth about every 97 minutes.
- Received more than 93 hours of on-orbit improvements in three successful servicing missions.

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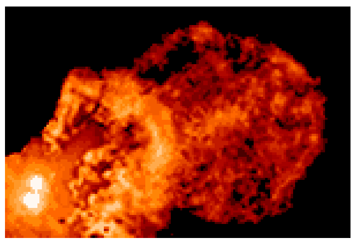
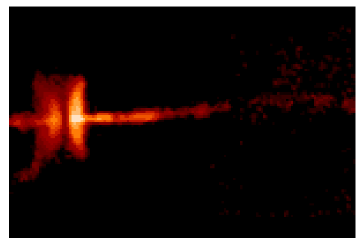
# Making Hubble Work



The Hubble Space Telescope orbits far above the distorting effects of the atmosphere, about **600 Kilometers above the Earth.** This perch gives astronomers with their clearest view ever, but it also prevents them from looking directly through the telescope. Instead, **astronomers use Hubble's scientific instruments as their electronic eyes.**



XZ Tauri



HH 30

**Movies from Hubble Show the Changing Faces of Infant Stars**

These instruments include **cameras and spectrographs**. Hubble's cameras do not use film; they collect light with electronic detectors similar to those in home video cameras. The spectrographs separate starlight into a rainbow of colors, just as a prism splits sunlight. By carefully studying the colors, astronomers can decode a star's temperature, motion, composition and age.

Hubble **uses mirrors to focus and magnify light.** Its 8-foot-diameter main mirror is tucked inside a long, hollow tube that blocks the glare from the Sun, Earth, and Moon. Wing-like solar panels collect sunlight and convert it into electricity.

**Radio antennas** allow Hubble to **communicate with its flight controllers** at the Goddard Space Flight Center in Greenbelt, Md. Controllers send detailed instructions several times a day. This information is converted into a code that the spacecraft's main computer can understand.

Imagine pointing a laser on a dime 200 miles away, and holding it steady for hours or days. This is the precision of Hubble's sophisticated pointing control system. Once Hubble locks onto an object, its sensors check for movement 40 times a second. If movement occurs, constantly spinning wheels change speeds to smoothly bring the telescope back into position.

As Hubble observes celestial targets, its computers turn the information into long strings of numbers. This digital data travels as radio signals to a communications satellite, which beams the information to Goddard. From there, it travels by landline to the Space Telescope Science Institute in Baltimore, Md., where is turned back into pictures and astronomical data.

Hubble's daily downloads are stored on optical computer disks, which provide a unique resource for current and future astronomers. **The observations from a single day would fill an encyclopedia.**

# Servicing Mission 1

Servicing Mission 1
Servicing Mission 2
HOST Mission
Servicing Mission 3A
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Servicing Mission 4

Goto SM3B WEBSITE

(Shuttle Mission: STS-61)
Servicing Mission 1, launched in December 1993, was the first opportunity to conduct planned maintenance on the telescope. In addition, **new instruments were installed** and the optics of the flaw in **Hubble's primary mirror was corrected.**

**COSTAR**
After Hubble's deployment in 1990, scientist realized that the telescope's primary mirror had a flaw called spherical aberration. The outer edge of the mirror was ground too flat by a depth of 4 microns (roughly equal to one fiftieth the thickness of a human hair). This aberration resulted in images that were fuzzy because some of the light from the objects being studied was being scattered.

COSTAR (the Corrective Optics Space Telescope Axial Replacement) developed as **an effective means of countering the effects of the flawed shape of the mirror**. COSTAR was a telephone booth sized instrument which placed 5 pairs of corrective mirrors, some as small as a nickel coin, in front of the Faint Object Camera, The Faint Object Spectrograph and the Goddard High Resolution Spectrograph.

**Costar Animation (Realplayer)**

**SM1 Images**

WFPC2 in the Enclosure

**Wide Field Planetary Camera 2 (WFPC2)**

WFPC2 **significantly improved ultraviolet performance** over WFPC1, the original instrument. In addition to having more advanced detectors and more stringent contamination control, it also incorporated built-in correction optics.

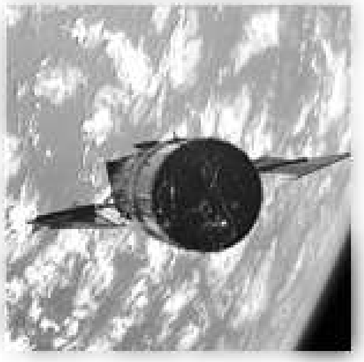

Image of solar arrays
prior to capture

In addition, SM1 included the installation and replacement of other components including:

- **Solar Arrays**
- **Solar Array Drive Electronics (SADE)**
- **Magnetometers**
- **Coprocessors for the flight computer**
- **Two Rate Sensor Units**
- **Two Gyroscope Electronic Control Units**
- **GHRS Redundancy Kit**



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# Servicing Mission 2

Servicing Mission 1
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Goto SM3B WEBSITE

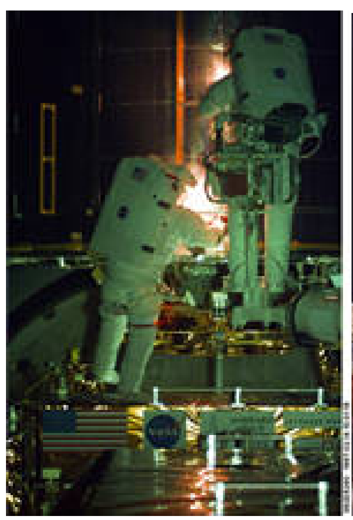
(Shuttle Mission: STS-82)

The Second Servicing Mission, launched February 11, 1997, greatly improved Hubble's productivity. The installation of new instruments extended Hubble's wavelength range into the near infrared for imaging and spectroscopy, allowing us to probe the most distant reaches of the universe. The replacement of failed or degraded spacecraft components increased efficiency and performance.

SM2 Images

Three categories of items made up the mission payload:

- **Science Instruments to enhance science productivity**
- **Primary spacecraft maintenance items**
- **Secondary spacecraft maintenance items.**



**New Science Instruments**

- **The Space Telescope Imaging Spectrograph (STIS)** provides Hubble with **unique and powerful spectroscopic capabilities**. A spectrograph separates the light gathered by the telescope into its spectral components so that the composition, temperature, motion, and other chemical and physical properties can be analyzed.

STIS's two-dimensional detectors have allowed the instrument to gather 30 times more spectral data and 500 times more spatial data than the previous spectrographs on Hubble. These were capable of only looking at one place at a time.

One of the greatest advantages to using STIS is in the **study of supermassive black holes**. STIS searches for massive black holes by studying the star and gas dynamics around galactic centers. It measures the distribution of matter in the universe by studying quasar absorption lines. it also uses its high sensitivity and spatial resolution to study star formation in distant galaxies and perform spectroscopic mapping of solar system objects.

- **The Near Infrared Camera and Multi-Object Spectrometer (NICMOS)** has let us gain valuable new information on the dusty centers of galaxies and the formation of stars and planets. NICMOS consists of three cameras. It is capable of both infrared imaging and spectroscopic observations of astronomical targets.

NICMOS gave astronomers their **first clear view of the universe at near-infrared wavelengths** between 0.8 and 2.5 micrometers - longer wavelengths than the human eye can see. (The expansion of the universe shifts the light from very distant objects toward longer red and infrared wavelengths.)

NICMOS's near infrared capabilities have provided **views of objects too distant for research by previous Hubble optical and ultraviolet instruments**. NICMOS's detectors also perform more efficiently than previous infrared detectors. With its cryogenics depleted, NICMOS is now dormant and awaiting the installation of a new cooling system in SM3B.

**Primary Spacecraft Hardware replacements included the following:**

- **Refurbished Fine Guidance Sensor (FGS).**
  Hubble uses this optical sensor provide pointing information for the spacecraft and as a scientific instrument for astrometric science. The modification to this FGS spare added the capability for ground-controlled alignment corrections.

- **The addition of an Optical Control Electronics Enhancement Kit (OCE-EK)**
  The OCE-EK provided the electronic pathway for commanding the alignment mechanisms.

- **The Solid State Recorder (SSR)**

This recorder replaced one of Hubble's three Engineering Science Tape Recorders (ESTR). The SSR provides much more flexibility than an ESTR, which is a reel-to-reel recorder and can store ten times more data. One of the other ESTRs was also replaced, but with a spare ESTR unit. During SM3A mission the reel-to-reel units were replaced with solid state recorders.

- **Reaction Wheel Assemblies (RWA)**
  One of Hubble's four RWA's was replaced by a refurbished spare. The RWA is part of Hubble's Pointing Control System. Spin momentum in the wheels moves the telescope to a target and maintains it in a stable position.

- **Secondary Spacecraft Hardware**
  Four Data Interface Units (DIU) on Hubble provide command and data interfaces between the spacecraft's data management system and the other HST subsystems. DIU-2 was replaced with a spare unit that has been modified and upgraded to correct for failures that occurred in the original unit.

- **The Solar Array Drive Electronics (SADE)**
  This controls the positioning of the solar arrays. Hubble has two SADEs of which one was replaced during the first servicing mission. The unit that was returned from orbit has been refurbished to correct for problems that resulted in transistor failures has been will be used to replace the second unit, SADE-2. The SADEs are provided by the European Space Agency, NASA's partner in the Hubble program.

The crew has taken more than 150 other crew aids and tools on this mission. They range from a simple bag for carrying some of the smaller tools to sophisticated, battery-operated power tools.

**Doing the Job**

A seven-member crew took part in this mission. Four astronauts conducted the planned spacewalks: Mark Lee, Gregory Harbaugh, Steven Smith and Joseph Tanner were part of the extravehicular activity crew. Kenneth Bowersox was the commander, Scott Horowitz was the pilot, and Steven Hawley was the Remote Manipulator System Operator.



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# Hubble Orbital Systems Test (HOST)

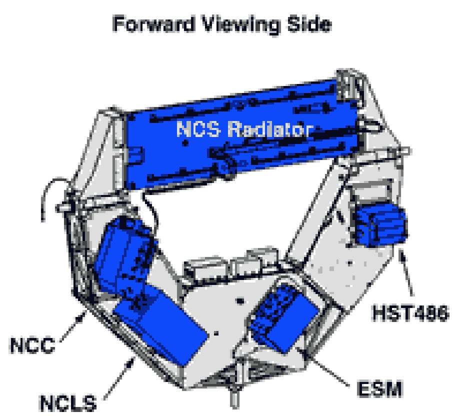


(Shuttle Mission: STS-95)

In October 1998, the Hubble Team conducted the HST Orbital Systems Test (HOST) on board STS-95 ("The John Glenn Mission"). This Space Shuttle mission provided a unique opportunity to test key pieces of new Hubble hardware before they would be installed in the telescope. By flying in an orbit similar to Hubble's, the Shuttle allowed engineers to determine how the new equipment on HOST would perform on the telescope.

HOST engineers monitored the effects of radiation on Hubble's new hardware, including an advanced computer, digital data recorder, and cryogenic cooling system. All the new technologies on the HOST platform performed up to expectation. In 1999, during Servicing Mission 3A, astronauts installed the new computer and data recorder on Hubble. The cryogenic equipment will become part of the telescope in 2001.

Full view of the payload bay, showing the white, rectangular SPACEHAB at the top, SPARTAN in the middle, HOST immediately below it, and the IEH at the bottom (truncated).




The HOST Payload

# Servicing Mission 3A

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- **Hubble SM3A Web Site**
- **SM3A Images**
- **Post-Servicing Science Images**
- **SM3A Media Guide**
- **SM3A Fact Sheets**

(Shuttle Mission: STS-103)

The Hubble Space Telescope is alive and well and back on duty after a successful December, 1999 Servicing Mission (SM3A). To prove it, NASA released two stunning images taken by Hubble just two weeks after Discovery's Christmas-time service call. Discovery's seven-member crew included two Hubble Servicing Mission veterans.

What was originally conceived as a mission of preventive maintenance turned more urgent on November 13, 1999 when the fourth of six gyros failed and Hubble temporarily closed its eyes on the Universe. Unable to conduct science without three working gyros, Hubble entered a state of dormancy called safe mode. Essentially, Hubble "went to sleep" while it waited for help.

NASA decided to split the Third Servicing Mission (SM3) into two parts, SM3A and SM3B, after the third of Hubble's six gyroscopes failed. In accordance with NASA's flight rules, a "call-up" mission was quickly approved and developed and executed in a record 7 months!

The Hubble team has left the telescope far more fit and capable than ever before. The new, improved, and upgraded equipment included six fresh gyroscopes, six battery voltage/temperature improvement kits, a faster, more powerful, main computer, a next-generation solid state data recorder, a new transmitter, an enhanced fine guidance sensor, and new insulation.

The second part of the mission, SM3B, is scheduled for early 2002.

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# Servicing Mission 3B

Servicing Mission 1
Servicing Mission 2
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Goto SM3B WEBSITE

Click here to visit the SM3B website.
Live webcams, images, updates... !

Goto SM3B WEBSITE

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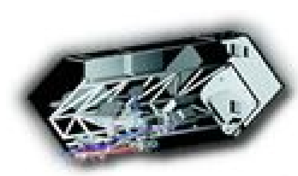
**Preliminary Launch Date: Mid-February, 2002**
Orbiter (shuttle): Columbia STS-109


The Third Planned servicing mission, (part B) will see a **new science instrument**: the **Advanced Camera for Surveys (ACS)**. Several other activities listed below, are planned over 5 Extra Vehicular Activity (EVA) days.

**SM3B EVA Timeline**
**SM3B Images**
**Click here for NASA Space Shuttle Simulation!**

**ACS Installation:**



With its wide field of view, superb image quality, and exquisite sensitivity, Hubble's newest science instrument, the Advanced Camera for Surveys (ACS) will have **10 times more discovery power** than the camera it replaces. In other words, ACS can produce 10 times as many science results in the same amount of time.
*(click for larger picture)*

ASC sees in wavelengths ranging from **visible to far ultraviolet**. It is actually a team of three different cameras with specialized capabilities. The high resolution camera will take extremely detailed pictures of the inner regions of galaxies and search neighboring stars for planets and planets-to-be. The solar blind camera blocks visible light to enhance ultraviolet sensitivity. Among other things, it will be used to study weather on planets in our own solar system. With a field of view twice the size of Hubble's current surveyor, ACS's wide field camera will conduct new surveys of the Universe. Astronomers will use it to study the nature and distribution of galaxies in order to **understand how our Universe evolved.**
*(click for diagram of parts)*

**Solar Array 3 (SA3) Installation:**
Four large flexible solar array (SA) panels (wings) provide power to the observatory.

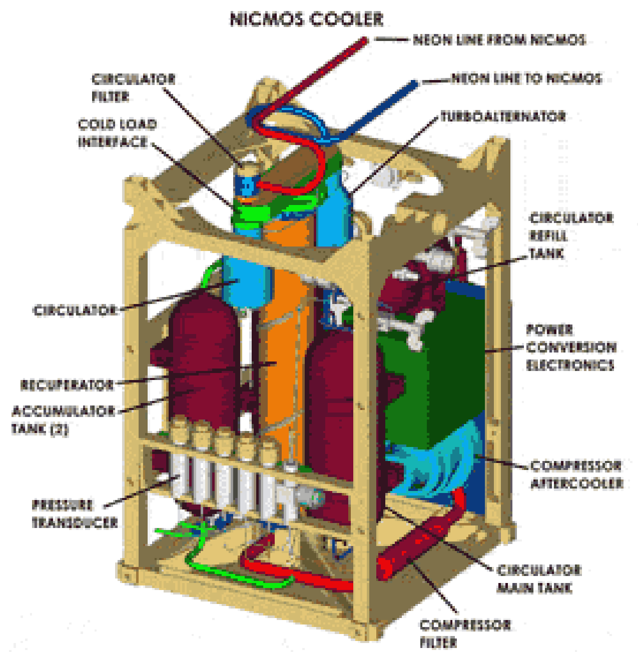
During SM1, the original arrays were replaced by SA2 and have powered Hubble for over 8 years. **Radiation and debris take their toll on sensitive electronics,** which will be replaced to ensure uninterrupted service for the remainder of the mission.

The new solar arrays (SA3) are rigid arrays, which do not roll up and therefore are more robust. **Hubble gets a brand new look with its latest set of solar wings. Although one-third smaller than the first two pairs, they will produce 30 percent more power.** They are less susceptible to extreme temperatures and their smaller sized will reduce the effects of atmospheric drag on the spacecraft. *(see dimensions of solar panel array)*

**Power Control Unit (PCU):**
As Hubble's power switching station, the PCU controls and distributes electricity from the solar arrays and batteries to other parts of the telescope. Replacing the original PCU, which has been on the job for 11 years, will **require the Hubble to be completely powered down for the first time since its launch in 1990**. Hubble's new PCU will allow astronomers to take full advantage of extra power generated by the new solar arrays.

**NICMOS Cryocooler (NCC) Installation:**
Astronauts will retrofit an existing but dormant instrument called the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) with a new, experimental cooling system to return it to active duty. NICMOS was placed on Hubble in 1997 but became inactive two years later, after depleting the ice it needed to cool its infrared detectors. By fitting NICMOS with the experimental cryogenic system, NASA hopes to re-cool the detectors to -334°F (-203°C or 70 K) **revive its infrared vision, and extend its life by several years.**

The super-quiet cooler uses ultra-high speed microturbines, the fastest of which spins at over 200,000 rpm (over 50 times the maximum speed of a typical car engine). Hubble's engineering team successfully demonstrated this technology in 1998 aboard STS-95 in the first on-orbit test of a high-performance, high-efficiency, mechanical cryocooler.




**Orbit Reboost:**
Although the atmosphere is quite thin at satellite altitudes, it is not a perfect vacuum. Over time, all Low Earth Orbiting (LEO) **satellites feel the effects of atmospheric drag and lose altitude**. If the altitude is not restored, then the satellite will eventually re-enter (deorbit). Hubble has no on-board propulsion, so the only way to **restore lost altitude is by the creative use of shuttle jets**. If necessary, before the last EVA, Hubble's altitude will be increased. This was done on both SM1 and SM2. (*See plot of Hubble's orbital history.*)

**STS-109 Crew Info: NASA Astronaut Bios**
Four astronauts are training for **five scheduled spacewalks** to upgrade and service the Hubble Space Telescope during the STS-109 mission in early 2002. Three veteran astronauts, John M.Grunsfeld, James H. Newman, and Richard M. Linnehan, are joined by Michael J. Massimino, who will be making his first space flight.

Grunsfeld has flown three times, STS-67 in 1995, STS-81 in 1997, and STS-103 in 1999 when he performed two spacewalks to service the Hubble Space Telescope. Newman, veteran of three space flights, STS-51 in 1993, STS-69 in 1995, and STS-88 in 1998, has conducted four previous spacewalks. Linnehan flew on STS-78 in 1996 and STS-90 in 1998. Massimino is a member of the 1996 astronaut class.

They will be joined by Scott Altman, (Cmdr., USN), a two-time shuttle veteran, will command the STS-109 mission. He will be joined on the flight deck by pilot Duane Carey, (Lt. Col., USAF), making his first space flight, and flight engineer Nancy Currie (Lt. Col, USA, Ph.D.). Currie has three previous space flights to her credit.

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# Servicing Mission 4

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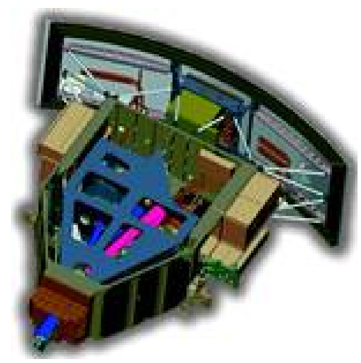
Goto SM3B WEBSITE

**Preliminary Launch Date: July 2003**

Plans for SM4 are very preliminary at this time, but two Science Instruments are in development for the Fourth Servicing Mission.

**WFC3**:



Wide Field Camera Three (WFC3) will be the last main imaging camera to be installed. Everyone has seen the **amazing pictures** generated by the Wide Field Planetary Cameras (1 and 2). WFC3 will replace WFPC2 which was installed during the 1993 Servicing Mission and will be 10 years old by SM4. The new instrument will become Hubble's workhorse.

Since 1993, CCD technology and optical coatings technology have progressed significantly. WFC3 will use the latest CCD technology and will maintain good imaging capabilities throughout the life of Hubble's mission. The WFC3 project represents an **innovative approach** to instrument management and development. Through reuse of key portions of WFPC1 and WFPC2 hardware, designs, and even personnel, WFC3 is being developed in a very cost-effective way.

**COS:**

The Cosmic Origins Spectrograph (COS) will replace COSTAR, which will no longer be necessary after removal of FOC, the last instrument to use its services. COS is a medium resolution spectrograph specifically designed to **observe into the near and mid ultraviolet**. The ultraviolet region is particularly interesting for observing high energy activities such as those found in new hot stars and Quasi Stellar Objects (QSO's). It is also a good region for viewing the composition and character of the Interstellar Medium (ISM).



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Skip Intro

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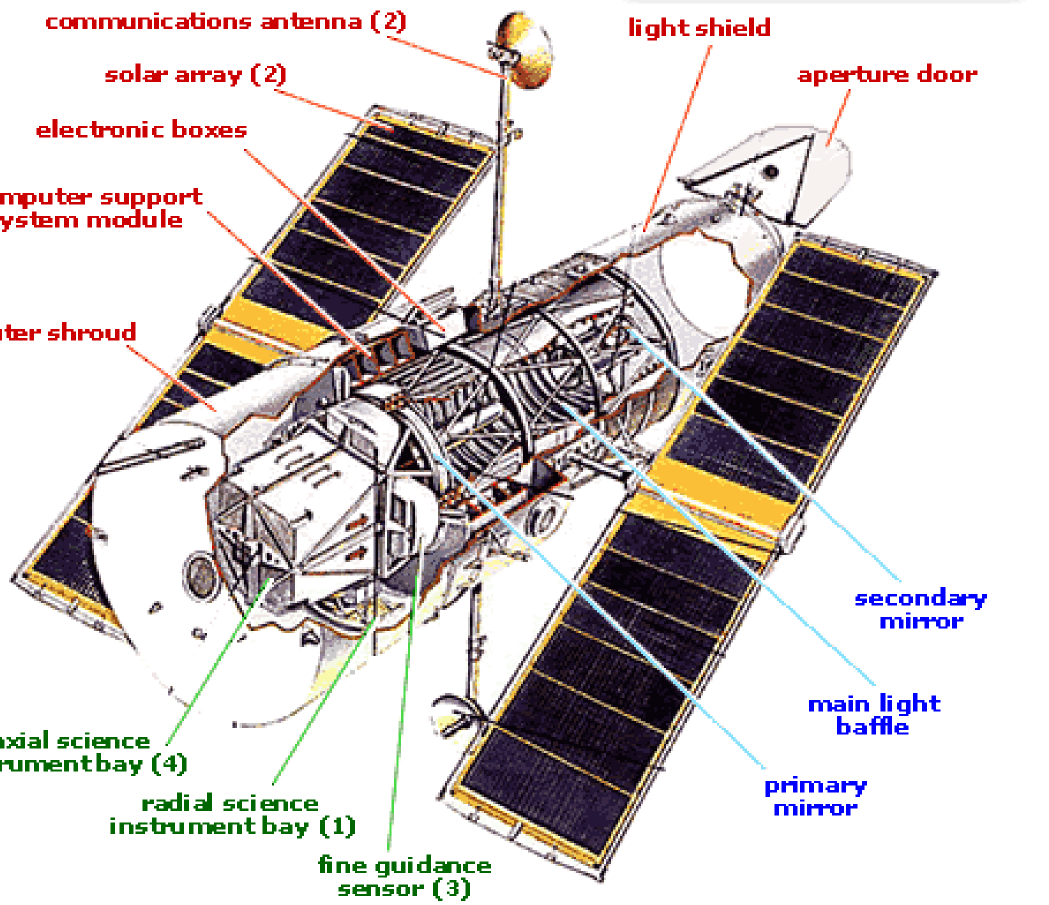
# Hubble's Parts



Rollover labels and click for more info.

KEY
--- Spacecraft Systems
--- Optical Assembly
--- Science Instruments




## Spacecraft Systems and Outer Structure

Several spacecraft support systems are required to keep Hubble functioning smoothly in space. These systems are located around the body of the spacecraft and encompassed by the outer hull.

| | |
|---|---|
| **solar arrays (2)** | 40 foot (12 m) panels that convert sunlight into 2400 watts of electricity in order to power the telescope. |

| | |
|---|---|
| **communications antennae (2)** | Transmit Hubble's information to communications satellites called the Tracking & Data Relay Satellite System (TDRSS) for relay to ground controllers at the Space Telescope Operations Control Center (STOCC) in Greenbelt, Maryland. |
| **computer support systems modules** | Contains devices and systems needed to operate the Hubble Telescope. Serves as the master control system for communications, navigation, power management, etc. |
| **electronic boxes** | Houses much of the electronics including computer equipment and rechargeable batteries. |
| **aperture door** | Protects Hubble's optics in the same way a camera's lens cap shields the lens. It closes when Hubble is not in operation to prevent bright light from hitting the mirrors and instruments. |
| **light shield** | Light passes through this shaft before entering the optics system. It blocks surrounding light from entering Hubble. |
| **pointing control system** | This system aligns the spacecraft to point to and remain locked on any target. Click for more... |

## Optical Assembly

Hubble's opticaltelescope assembly consists of two mirrors, support trusses, and the focal plane structure. This system is a Ritchey-Chretien design, in which two aspheric mirrors serve to form focused images over the largest possible field of view.

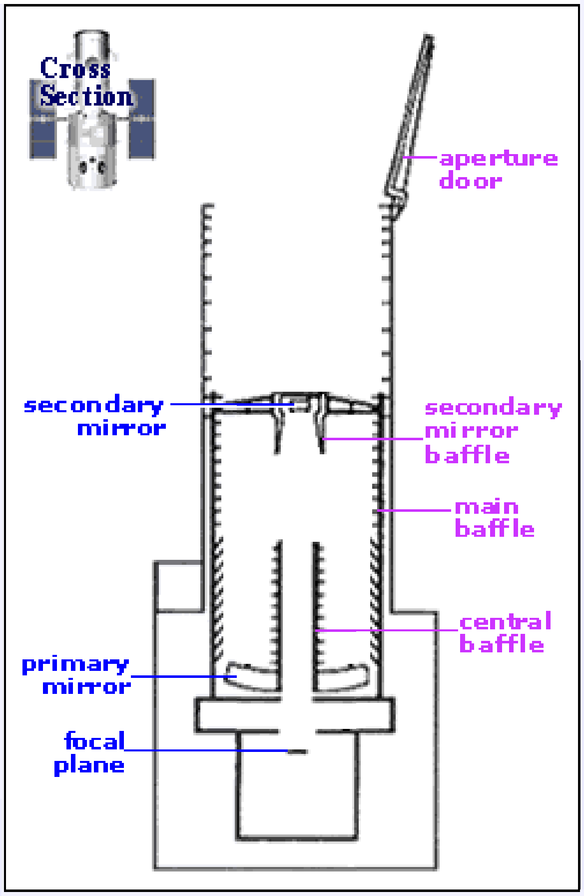
**Rollover** text boxes **to view light path.**

Light enters Hubble's **aperture** and travels down the **main baffle.** A baffle is a surface which eliminates stray light. **1**

Light is reflected by the **primary mirror** which measures about 7 feet (2.4 meters) in diameter. Because of the concave shape, the primary mirror converges the light to the secondary mirror through a **secondary baffle.** **2**

The **secondary mirror,** measuring about 1 foot (0.3 m) in diameter receives the light. It in turn reflects the still-converging light back to the primary mirror through a **central baffle.** **3**

The light travels through a hole in the primary mirror, to reach the **focal plane,** where the science instruments examine the light. **4**




## Scientific Instruments

Hubble's scientific instruments work either together or individually to bring us stunning images from the farthest reaches of space. Presently, Hubble can accommodate five scientific instruments and three fine guidance sensors. (More on instruments...)

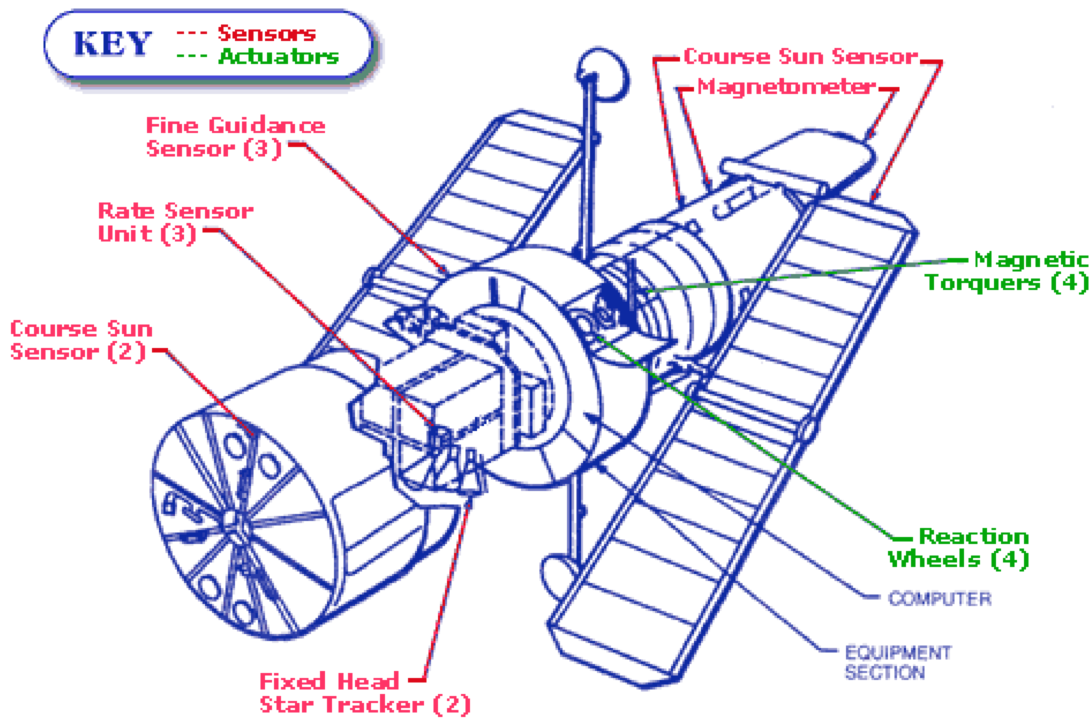
| | |
|---|---|
| **axial bays (4)** | Four instruments are aligned with the main optical axis and are mounted just behind the primary mirror. As of the year of 2000 they consists of:<br><br>**COSTAR:** contains corrective optics for spherical aberration in the primary mirror.<br><br>**FOC** (Faint Object Camera): takes the most detailed images in a small field. |

| | |
|---|---|
| | **NICMOS** (Near Infrared Camera and Multi-Object Spectrometer): Infrared instrument that is able to see through interstellar gas and dust. |
| | **STIS** (Space Telescope Imaging Spectrograph): separates light into component wavelengths, much like a prism. |
| **radial bay (1)** | Presently, **Wide Field/Planetary Camera II** is housed here. Taking images that most resemble human visual information, Wide Field is responsible for taking nearly all of Hubble's famous pictures. |
| **fine guidance sensors (3)** | The sensors lock onto guide stars and measure relative positions. This has two functions. First to provide data to the spacecraft's targeting system. Second, as a scientific instrument to gather knowledge on the distance and motions of stars. |

# Pointing Control System (PCS)



The PCS aligns Hubble so that the telescope **points to, and remain locked on a target**. The PCS is designed for pointing to within .01 arcsec and is capable of holding a target for up to 24 hours while Hubble continues to orbit the Earth at 17,500 mph. If the telescope were in Los Angeles, it could **hold a beam of light on a dime** in San Francisco without the beam straying from the coin's diameter.




| Sensors | |
|---|---|
| Hubble employs a variety of sensors to detect it own orientation and position. All work in tandem to send the correct information to the actuators to adjust Hubble's position on command. | |
| **Fine Guidance Sensor (3)** | These sensors are locked onto two guide stars to keeps Hubble in the same relative position of these stars. |

| | |
|---|---|
| **Coarse Sun Sensors (2)** | Measure Hubble's orientation to the sun. Also assist in deciding when to open and close the aperture door. |
| **Magnetic Sensing System** | Measure Hubble position relative to Earth's magnetic field. |
| **Rate Sensor Unit** | Two rate sensing gyroscope measure the attitude rate motion about its sensitive axis. |
| **Fixed Head Startrackers (3)** | An electro-optical detector that locates and tracks a specific star within its field of view. |

## Actuators

Receiving information from the sensors, the actuators physically adjust Hubble's position and orientation so that Hubble can view the required celestial bodies.

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| **Reaction Wheel Actuators (4)** | The reaction wheels work by rotating a large flywheel up to 3000 rpm or braking it to exchange momentum with the spacecraft which will make Hubble turn. |
| **Magnetic Torquers (4)** | The torquers are used primarily to manage reaction wheel speed. Reacting against Earth's magnetic field, the torquers reduce the reaction wheel speed, thus managing angular momentum. |

# Novel Technology



## Hubble's Latest Technology Improvements

- Computer Processing Improvements
- Super Lightweight Interchangeable Carrier
- Data Storage Capability
- The HST Lubricant Applicator
- Detector Technology
- Lithium Ion Battery
- Cryogenic Cooler
- Diamond-Hard Carbon Coating
- Solar Arrays

### Computer Processing Improvements

During Servicing Mission 3A (SM3A), astronauts replaced Hubble's original main computer, a DF-224/coprocessor combination, with a completely new computer based on the Intel 80486 microchip.

The new computer is 20 times faster and has six times as much memory as the one it replaced. Commercially developed, commonly available equipment was used to build a new computer at a fraction of the price it would have cost to build a computer designed specifically for the spaceflight environment.

The greater capabilities of the new computer are increasing Hubble's productivity. The computer software also uses a modern programming language, which decreases software maintenance costs.

## Data Storage Capability

With the addition of a second Solid State Recorder (SSR) on SM3A, Hubble's data storage capability dramatically increased. The science data archiving rate is now more than ten times greater than 1993 rates.

Prior to SM2, Hubble used three reel-to-reel tape recorders designed in the 1970s. In February 1997, astronauts replaced one of the mechanical recorders with a digital SSR. In 1999, SM3A astronauts removed a second mechanical recorder and installed another digital SSR.

Unlike the reel-to-reel recorders they replace, the SSRs have no reels, no tape, and no moving parts that can wear out and limit lifetime. Data is stored digitally in computer-like memory chips until Hubble's operators command its playback. Although an SSR is about the same size and shape as the reel-to-reel recorder, it can store ten times as much data: 12 gigabits of data instead of only 1.2 gigabits. This greater storage capacity allows the second generation of Hubble's advanced-technology scientific instruments to be fully productive.

## Detector Technology

Hubble's state-of-the-art detector technology allows the telescope to capture and process faint amounts of light from the far reaches of space.

Charge-coupled device (CCD) detectors are commonly referred to as the "film" of digital cameras, but that description hardly does justice to this incredibly useful technology.

Modern CCD detectors match the resolution of film, but they surpass film in several key performance areas. For example, they are capable of operating over a much wider wavelength range: a single CCD detector can record data from the infrared to the x-ray energy band, making this technology extremely adaptable. Their sensitivity to light is far superior to film over these large wavelength ranges.

In addition, images can be read-out of a CCD in seconds, much faster than film can be developed. Most importantly, CCDs record images digitally, allowing the information to be stored and manipulated by a computer. These versatile qualities have lead to the rapid transfer of CCD technology into industrial, medical, and consumer applications. The CCD is now the "detector of choice" in products ranging from automotive quality control monitors to breast biopsy systems to video cameras.

The accelerated progress in CCD development over the past two decades is due in large measure to the efforts of the Hubble Project, which has continuously driven the leading edge of this technology. Hubble scientists realized early on that the broad wavelength sensitivity, coupled with the ease of digital data analysis, made CCD detectors ideal for astronomy. CCDs were aboard the Hubble Space Telescope when it launched in 1990.

Successive generations of science instruments pioneered CCD technology enhancements. These efforts have led to the production of larger format, more sensitive, and more reliable detectors, which enable Hubble to deliver its outstanding science.

The following new Hubble Instruments are taking advantage of the latest advances in CCD technology:

- ***Advanced Camera for Surveys (ACS)***
  The Advanced Camera for Surveys, to be launched on Servicing Mission 3B, employs two state-of-the-art, 8-million pixel CCDs with an advanced performance-enhancing coatings. These coatings allow the detectors to absorb up to 85% of the photons that strike it. The combination of large field of view and superior sensitivity will improve Hubble's scientific discoveries by a factor of ten. The Advanced camera CCD program also targets specific process enhancements, which reduces image artifacts and improves manufacturing yield.

- ***Wide Field Camera 3 (WFC3)***
  Wide Field Camera 3 is an instrument planned for launch on Servicing Mission 4. This dual-channel instrument will provide an unprecedented, wide-spectral range view of the Universe. Its two-detector system spans the near ultraviolet to the near infrared. The Hubble Program is focusing its efforts on developing a CCD with high sensitivity over both the visible and ultraviolet spectrum. This would provide a new capability in the near-ultraviolet for both astronomical and earthbound uses. Building upon the advances made by ACS, these detectors would provide higher sensitivity and lower noise than ever achieved in detectors of this size. For the long wavelength (infrared) channel, the technological advance is in operating the detector using thermoelectric cooling exclusively. This reduces cost and complexity when compared with the traditional implementations, which use cryogens or other cryogenic cooling systems.

- ***Cosmic Origins Spectrograph (COS)***
  In 2003, astronauts will begin a new era in ultraviolet spectroscopy when they install the Cosmic Origins Spectrograph (COS) instrument into Hubble. One of its major goals is to measure the distribution of matter in the almost empty space between galaxies. This is a major puzzle as we complete our census of where all the matter in the Universe resides. Because most of this matter is in the form of Hydrogen gas, measurements in the ultraviolet are key because this gas has unique signatures in this wavelength region. This innovative instrument uses a simple and elegant optical design, coupled with advanced ultraviolet detectors, to achieve a factor of 10 improvement in sensitivity levels compared with previous instruments. Using this new capability, Hubble scientists hope to better understand the characteristics of the matter between and within stars and galaxies.

### Cryogenic Cooler

Astronauts installed the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) on Hubble in 1997. Its infrared vision allowed scientists to probe dark, dusty, never-before-seen regions of space. NICMOS used solid nitrogen ice to keep cool and so that it could conduct infrared science. In 1999, with its supply of ice exhausted, NICMOS became dormant. On SM3B, astronauts will retrofit NICMOS with a new cooling system that will return it to active duty. The heart of this system is the NICMOS Cryogenic Cooler (NCC).

The NCC is a state-of-the-art, mechanical cryocooler that will potentially increase NICMOS's life span from 1.8 years to more than 5 years. It uses rapidly rotating microturbines, the fastest of which spins at over 200,000 revolutions per minute (over 50 times the operating speed of a typical car engine). It will cool the infrared detectors to below -315 ° F (-193 ° C or 80 K). The NCC operates with virtually no mechanical vibration. Such vibration would cause Hubble to shake and affect image quality, much as a shaky camera affects picture quality.

The Hubble Project successfully demonstrated this new technology aboard STS-95 in 1998. This was the first on-orbit test of a high performance, high efficiency, mechanical cryocooler. The test took place less than 20 months after cryocooler development beganóan extremely short time for bringing a new technology into the space applications portfolio.

Installing a new cryocooler will triple the lifetime of the instrument, ensuring a greater scientific return on the original investment. This revolutionary technology paves the way for exciting advances in infrared astronomy on both Hubble and the Next Generation Space Telescope.

### Solar Arrays

The addition of new, rigid solar arrays on SM3B will provide Hubble with increased electrical power-generating capability. This will enhance science productivity by allowing up to four science instruments to operate simultaneously. Advancements in solar cell technology make it possible for these new arrays to produce 30 percent more power than the current set, which was installed on Hubble in 1993 during SM1 (*see schematic of solar array*).

The rigid arrays are one-third smaller than the set they replace. The smaller size decreases on-orbit drag and slows Hubble's rate of orbital decay. These smaller, stiffer arrays also are easier for the astronauts to work around during servicing missions (*see diagram of solar array dimensions*).

The panel supports on the arrays are made of lithium-aluminum, which is stronger, lighter and tougher than the type of aluminum commonly used in spacecraft construction. These supports are much less sensitive to the extreme temperature changes of Hubble's orbit. (Within each 97-minute orbit, the temperature outside Hubble spans about 299 degrees Celsius (600 degrees Fahrenheit).

The Hubble Program bought solar panels from the production line of a commercial system of communications satellites. By purchasing off-the-shelf panels, the Program saved considerable time and expense.

**The Super Lightweight Interchangeable Carrier (SLIC)**

*Click here for PDF file of the SLIC*

The Super Lightweight Interchangeable Carrier (SLIC) is a state-of-the-art cradle that will ride on the Space Shuttle and carry new equipment to Hubble in Servicing Mission 4. Lighter and stronger than its predecessors, SLIC will be built of composite material and will incorporate a more structurally efficient design. The weight saved by SLIC's innovative design can be used to carry extra science equipment or fuel. With modular construction and a removable top deck, SLIC can be customized for different types of missions, including on-orbit satellite retrieval and repair, and supply and science missions to the International Space Station.

**The HST Lubricant Applicator**

During the first and second servicing missions, the astronauts discovered that a number of the bolts that keep the large Aft Shroud doors closed, exhibited high running torques during operation. In an effort to solve this problem, the Hubble Program developed a tool to apply a thin film of lubricant to the threads of these door bolts. While a simple task here on Earth, applying a viscous fluid in the vacuum of space had never been performed before. Care had to be taken to avoid getting the grease on the astronaut's gloves or the rest of the highly sensitive spacecraft. In response to this challenge, the innovative Hubble team developed the HST Lubricant Applicator. With this new tool, the astronauts were able to apply a small amount of grease on the threads at each location without contaminating themselves or the spacecraft. Although the tip of the tool was designed specifically for applying grease to the Hubble's door bolts, it can easily be modified to fit almost any feature of any other space structure.

### Lithium Ion Battery

A prototype Lithium Ion (Li-Ion) battery pack for NASA's Power Ratchet Tool (PRT) was flown in support of SM3A. The PRT is a power tool developed at Goddard Space Flight Center, and was used previously by the astronauts in space to service Hubble.

NASA teamed with the Air Force Research Labs, Wright-Patterson AFB, and SAFT America Inc., to develop and certify this new cutting-edge battery technology for human space flight. The Li-Ion battery chemistry as compared to nickel cadmium (NiCad) provides superior energy density, over 50% higher voltage, excellent charge retention and high cycle life. This 10-cell battery pack could fit in a small portable 12-volt commercial power drill, yet supplies over 40 volts. While 24-volt power drills are currently available, their battery packs are bulky and heavy, making them hard to hold for long periods of time and difficult to operate when working in tight spaces.

The Li-Ion battery will reduce overall logistics and maintenance costs for NASA, compared to the current PRT silver zinc batteries. Those batteries require special handling and must be discarded after each flight. Unlike silver zinc batteries, the Li-Ion is a sealed cell design, ready for use. It can be reused over and over again, and NASA plans to make it rechargeable on orbit.

Both the USAF and NASA are looking at a wide variety of applications for this type of battery chemistry including backup power systems for F-16 and F-22 Fighters, the Space Shuttle, and for new high power, compact tools to help build the International Space Station (ISS).

### Diamond-Hard Carbon Coating

A revolutionary, diamond-hard coating will cover tiny parts on a cryogenic cooler scheduled to fly on Hubble Space Telescope in 2001. Called UltraC DiamondTM, this film-like, patent-pending coating is tough, slippery and approximately 1/100th the thickness of a human hair. Experts foresee widespread applications and enormous benefits for NASA and private industry.

During normal operation, the cryocooler's tiny circulator shaft will spin at a speed of 90,000 rpm. To minimize friction and wear, the circulator shaft and bearings need a very thin, hard, slippery coating. The Hubble team looked at various other coatings, and UltraC DiamondTM met their rigorous requirements.

Unlike other coatings, UltraC DiamondTM can be deposited on a wide range of materials, including titanium, ceramics and polymers. Coated surfaces are scratch and chip resistant and can be polished to precise optical flatness and finish.

UltraC DiamondTM virtually stops wear debris from forming and can be applied at relatively low temperatures. It functions in a wide thermal range, from extremely low to moderately high. The coating's microscopically uniform structure and the way it is applied enable its use on very small parts with just millionths of an inch between them. The coating dramatically extends a part's lifetime and saves energy otherwise lost to heat from friction.



Contact: webmaster@hubble.gsfc.nasa.gov, Global Science & Technology, Inc.
Page Last Updated: December 18, 2001

# Re-using Space Hardware



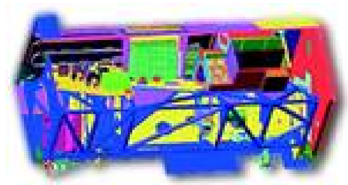


When Hubble astronauts replace instruments and equipment during servicing missions, the used hardware is brought back to Earth. However the usefulness of this equipment is far from over.

The ability to refurbish the returned science instruments and hardware, has proven to be **a cost-effective way to enhance the telescope with the latest technology**. NASA also avoids "reinventing the wheel" by installing the new technology in recycled modules.

Some of the innovative ways in which the Hubble Program reuses instruments and equipment:

**Cosmic Origins Spectrograph (COS): Optical Bench Reuse**



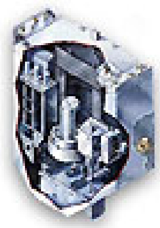
In 2003, astronauts will fit the Hubble Space Telescope with COS, **a new ultraviolet instrument**. However, its optical bench - the frame that holds the instrument's powerful optics and detectors - has flown on Hubble before. COS will be reusing the bench from one of Hubble's original science instruments, the Goddard High Resolution Spectrograph (GHRS). After its launch aboard Hubble in 1990, GHRS successfully fulfilled its mission and was returned to Earth by Space Shuttle astronauts in 1997.

NASA and the Hubble industry team conducted rigorous testing and determined that the 20-year old optical bench could be reused in the new COS instrument. Ultrasonic and x-ray inspections showed that the bench was still structurally sound. In fact, it was in virtually the same condition as when it was delivered to NASA in 1981.

**Wide Field Camera 3 (WFC3)**

WFC3 is a fourth-generation instrument for Hubble. It is designed to **replace the Wide-Field Planetary Camera 2 (WFPC2)**, which was installed in Hubble during SM1 in 1993.

The First Wide Field instrument, the Wide Field Planetary Camera 1 (WFPC1) was returned following SM1 and many of its assemblies are available for reuse. Flight spares of optical components are also available and can be used in WFC3 at minimal cost. WFC3 will reuse the WFPC1 SOFA filter mechanisms. This will provide up to 48 filter slots. The filters for WFC3 will consist of some of the most popular filters from WFPC1 & WFPC2 and ACS.



### Refurbishing Fine Guidance Sensors (FGSs)

During SM3A in 1999, astronauts replaced one of the three fine guidance sensors (FGSs), which are part of Hubble's pointing control system. Hubble's FGSs are undergoing **a systematic program of refurbishment and upgrading.**

In "round-robin" fashion, one FGS per servicing mission is being replaced, returned to the ground, disassembled and refurbished. It is then taken back to Hubble on the next servicing mission to become the replacement unit for the next FGS to be serviced. By the conclusion of SM4, all three FGSs will have been brought up to optimum condition.

This refurbishment process is a most effective reuse of space assets and **the best way to save valuable resources**. By renewing existing hardware, NASA has saved millions of dollars.

### Recycled Equipment Carriers Take Hubble Hardware to Orbit

**Getting new equipment to Hubble** is at least as challenging as installing it. How and where all this hardware including the advanced camera, solar arrays, cooling system and thermal blankets rides to orbit, **is critical to mission success**. Four specialized pallets, called carriers, fit into the Shuttle's payload bay to hold this precious cargo for its trip to orbit. These carriers are the Second Axial Carrier (SAC), the Rigid Array Carrier (RAC), the Flight Support System (FSS), and the Multi-Use Lightweight Equipment Carrier (MULE).

These carriers are excellent examples of recycling valuable NASA hardware; each has flown in space several times before. The SAC flew Hubble's SM1 and SM2 servicing missions. The bottom half of the RAC comes from the Spacelab Program. The FSS was first used for the 1984 Solar Maximum repair mission, and it also flew on SM1, SM2, and SM3A. The MULE is a refurbished cradle originally flown on the Upper Atmosphere Research Satellite (UARS) mission, STS-48, and again on the STS-95 HOST mission.

During servicing, the FSS functions as Hubble's lifeline and temporary home. In addition to bringing new hardware to Hubble, the other carriers act as temporary parking places for the instruments and other equipment being replaced. They also provide storage space and protection for this hardware during its journey back to Earth.

# The Clean Room

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Hubble Clean Room
Select...

The Clean Room, formally known as the T**he Spacecraft Systems Development and Integration Facility** (SSDIF), is an 86,000 square foot (7989.4 square meter) building used to integrate and test space hardware. Located at Goddard Space Flight Center in Greenbelt, MD, this facility houses the 1.3 million cubic foot (36,811.76 cu meters) High Bay Clean Room. **This building is the largest of its kind anywhere**, and plays an important role in Hubble servicing.

Everyone entering this room must wear a "bunny suit"-these are special coveralls, hoods, boots, gloves and masks. This gear helps protect the sensitive flight hardware from particles that could impede performance.

The STS-103 astronauts trained in this room-as did the crews from the two previous Hubble servicing missions. Using the clean room's very precise mechanical and electrical simulators, they practiced installing the actual Hubble hardware. This is where the Shuttle platform resides that is used to anchor Hubble. It is also home to the Shuttle carriers that take new Hubble instruments, tools and other hardware to orbit. If something unexpected happens during the mission, the clean room could become a hub of activity as Hubble engineers work to solve the problem.

Technician standing in front of the Clean Room door

Technician standing beside HiFi (High Fidelity Mechanical Simulator)

**Clean Room Facts**

- At 125 feet (38.1 meters) long, 100 feet (30.48 meters) wide and 89 feet (27.13 meters) high, it can simultaneously hold the entire contents of two Shuttle cargo bays.
- It is 1,000 times cleaner than a hospital operating room.
- One whole wall is made up of HEPA filters that remove particles smaller than a red blood cell.
- Air constantly circulates through the filters, across the room, out of tiny holes in the opposite wall, over the ceiling and back through the filters.
- Two 35-ton cranes are suspended 69 feet (21.03 meters) and 80 feet (24.38 meters) above the floor.
- A computerized system monitors and controls the environment 24 hours a day, 365 days a year.
- Only properly trained, "bunny-suited" people may enter.
- For easy identification, astronauts are the only people who wear blue hoods.

# The Neutral Buoyancy Lab

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To prepare for a Hubble servicing mission, astronauts spend many hours training underwater. This allows them to experience how their suits, science instruments, tools, crew aids and other equipment respond to movement in a space-like environment. In the water, astronauts wear small weights on their space suits to make themselves "neutrally buoyant." This means they neither sink nor rise, but hover suspended, as they would in space. By practicing their servicing tasks underwater, the spacewalkers learn to work swiftly and efficiently in orbit.

Click on thumbnails for larger image.

# Science Instrument Links

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Science Instruments
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Goto SM3B WEBSITE

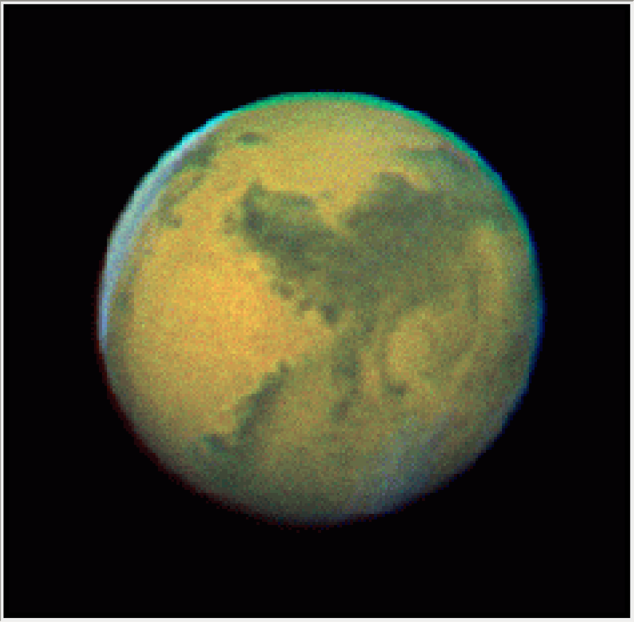
| Instrument Description Links | Instrument Site Links |
|---|---|
| ACS | Advanced Camera for Surveys |
| COS | Cosmic Origins Spectrograph |
| COSTAR | Corrective Optics Space Telescope Axial Replacement |
| FGS | Fine Guidance Sensors |
| FOC | Faint Object Camera |
| FOS | Faint Object Spectrometer |
| GHRS | Goddard High Resolution Spectrograph |
| HSP | High Speed Photometer |
| NCS | NICMOS Cooling System |
| NICMOS | Near Infrared Camera/Multi-Object Spectrometer |
| STIS | Space Telescope Imaging Spectrograph |

| | |
|---|---|
| **WF/PC (1)** | **Wide Field / Planetary Camera** |
| **WFPC2** | **Wide Field Planetary Camera II** |
| **WFC3** | **Wide Field Camera 3** |



Contact: webmaster@hubble.gsfc.nasa.gov, Global Science & Technology, Inc.

Page Last Updated: October 29, 2001



# WIDE-FIELD/PLANETARY CAMERA 1

**These pages contain instrument-specific information about the Wide-Field Planetary Camera 1 (WF/PC-1) and are maintained by the WF/PC-1 Group in the Science Instruments Branch at the Space Telescope Science Institute (STScI). The WF/PC-1 was used from April 1990 to November 1993, to obtain high resolution images of astronomical objects over a relatively wide field of view and a broad range of wavelengths (1150 to 11,000 Angstroms).**

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- ## WF/PC-1 Calibration Products

**Includes links to memos, cdbsfiles, meeting viewgraphs, and archive of old news.**

- ## Frequently Asked Questions

- ## Manuals and Reports

**Includes links to the WF/PC-1 Instrument Handbook, Instrument Science Reports, WF/PC-1 Instrument Definition Team Status Reports, meeting viewgraphs, and more.**

# GHRS
## Goddard High Resolution Spectrograph

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Here you will find instrument specific information about the Goddard High Resolution Spectrograph (GHRS), built by the Instrument Definition Team. GHRS was used to make finely detailed spectroscopic observations of ultraviolet sources, but was removed from HST in February 1997.

**Advisories** *Last Updated:* 02 Dec 98

Everyone should read these!

**Calibration Resources** *Last Updated:* 26 Sep 97

Information, software and files related to the calibration of the GHRS.

**Documents** *Last Updated:* 22 Oct 97

Access to recent Instrument Science Reports , the GHRS Instrument Handbook, HST Data Handbook, and the GHRS Space Telescope Analysis Newsletter.

**Frequently Asked Questions** *Last Updated:* 4 Dec 97

**Proposal Resources** *Last Updated:* 19 Oct 96

Information on proposal preparation or existing proposal information,

**Yellow Pages** *Last Updated:* 02 Feb 98

Advice on who to contact when you are lost.

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STScI Home Page -|- Instruments

*HST Spectrographs Group*

*Updated: 02/06/98*

# FOS

# Faint Object Spectrograph

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The Faint Object Spectrograph (FOS) was one of the original 4 axial instruments on the Hubble Space Telescope (HST). The FOS, which was removed from HST during the Second Servicing Mission in February 1997, was used to make spectroscopic observations of astrophysical sources from the near ultraviolet to the near infrared (1150-8000 Angstroms).

ST-ECF Post Operational HST Archives

The Post-Operational Archives (POA) branch of the Space Telescope - European Coordinating Facility (ST-ECF) has taken over the main responsibility of FOS (re-)calibration. Their web pages contain all of the information that was previously on the STScI FOS pages, supplemented with more recent FOS news including a new and improved version of the FOS calibration pipeline (POA_CALFOS), which replaces CALFOS in the standard IRAF/STSDAS FOS calibration. We invite you to check out their web pages.

# Glossary

A - B - C - D - E - F - G - H - I - J - K - L - M - N - O - P - Q - R - S - T - U - V - W - X - Y - Z

**ACS -** Advanced Camera for Surveys (See Instruments).

**Arc minute (am) -** See arcsecond.

**Arcsecond** (as) **-** For the measurement of small angles, degrees are too large. 1 Degree = 60 arc minutes ; 1 arc minute = 60 arc seconds. Further divisions are possible by using the SI prefixes e.g. mas = milli arc second or 1/1000th of 1 arc second. The "arc" in arc second assures that this is a measure of angle, not time.

**Axial Instrument -** Science Instruments for HST are classified according to their shape and how they are mounted in the telescope. Axial instruments are about the size and shape of a telephone booth. There are a total of four of these instruments in HST at any one time. Currently the four axial instruments are: STIS, NICMOS, FOC and COSTAR. Axial instruments are mounted in the rear of the telescope along the optical axis. Light from the telescope's mirrors enters these instruments directly.

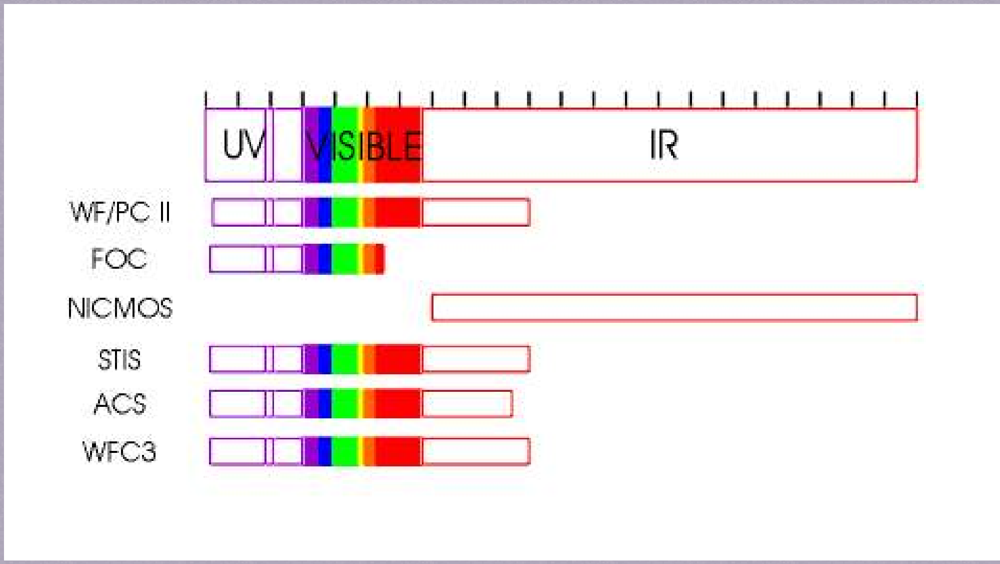
**Charge Coupled Device (CCD**) **-** Charge coupled devices are the detectors used in modern video cameras and in digital cameras. Like all electronic photosensors, they turn light (photons) into electric charges (electrons). CCD's have many characteristics which are desirable for astronomy. A good CCD has a better dynamic range than film, enabling a CCD based camera to record many levels of light and dark. CCD's are linear over much of their range, meaning that the intensity of the image may be measured. They are fast, and respond to a wide range of wavelengths (see Electromagnetic Spectrum).

**COS -** Cosmic Origins Spectrograph (See Instruments).

**COSTAR-** Corrective Optics Space Telescope Axial Replacement (See Instruments).

**Electromagnetic Spectrum -** Light is an electromagnetic wave. Different colors of light correspond to different wavelengths. The Hubble Telescope has instruments which can see wavelengths from Near Ultra-violet (NUV) to the Near Infra-Red (NIR).

**FGS -**Fine Guidance Sensors (See Instruments).



**Field of View (FOV) -** The field of view of an astronomical instrument is the angular size of an image. Although the WFC3 instrument will have a large field of view, this is large compared to other instruments. The entire field of view of the Hubble telescope is comparable to the "O" in "One Dime" held at arm's length. Although this seems like a small area, images from astronomical targets are frequently smaller than this.

**FOC -** Faint Object Camera (See Instruments).

**Focal Plane -** The imaginary surface at which the light to all of the HST instrument is focused. Also the diagram which shows how each of the instruments see the sky. The HST Focal Plane is a familiar sight to many.

**FOS -** Faint Object Spectrometer (See Instruments).

**GHRS -** Goddard High Resolution Spectrograph (See Instruments).

**Instruments -** The Hubble Space Telescope Program uses many instruments to probe the heavens. The past, present, and future instruments are:

- **ACS -** Advanced Camera for Surveys **-** The Advanced Camera for Surveys (ACS) is a third-generation Imaging Camera. ACS Website.
- **COS -** Cosmic Origins Spectrograph **-** Fourth Generation Spectrometer. COS is an ultraviolet spectrograph optimized for observing faint point sources with moderate spectral resolution COS Website.
- **COSTAR -** Corrective Optics Space Telescope Axial Replacement **-** Second Generation Corrective Optics. COSTAR is not an actual instrument, it consists of mirrors which refocus the abberated light from the HST optical system for first generation instruments. Only FOC utilizes its services today.
- **FGS -** Fine Guidance Sensors **-** Science/Guidance instruments. The FGS's are used in a "dual-purpose" mode serving to lock on to "guide stars" which help the telescope obtain the exceedingly accurate pointing necessary for observation of astronomical targets. These instruments can also be used to obtain highly accurate measurements of stellar positions.
- **FOC -** Faint Object Camera **-** First Generation Imaging camera. FOC is used to image very small field of view, very faint targets. Last first generation instrument on HST.
- **FOS -** Faint Object Spectrometer **-** First Generation Spectrometer. FOS was used to obtain spectra of very faint or far away sources. FOS also had a polarimeter for the study of the polarized light from these sources.
- **GHRS -** Goddard High Resolution Spectrograph **-** First Generation Spectrograph. GHRS was used to obtain high resolution spectra of bright targets.
- **HSP -** High Speed Photometer **-** First Generation Photometer. This instrument was used to measure very fast brightness changes in diverse objects.
- **NICMOS -** Near Infrared Camera/Multi**-**Object Spectrometer. Second Generation Imager/Spectrograph. NICMOS is HST's only NIR instrument.
- **STIS -** Space Telescope Imaging Spectrograph **-** Second Generation Imager/Spectrograph. STIS is used to obtain high resolution spectra of resolved objects. The special ability of STIS is to simultaneously obtain spectra from many different points along the target. STIS Website.
- **WF/PC (1) -**Wide Field / Planetary Camera - First Generation Imaging camera. WF/PC operated in either Wide Field mode, capturing the largest images, or Planetary mode with higher resolution.
- **WFPC2 -** Wide Field / Planetary Camera II **-** Second Generation Imaging camera. WFPC2 is an upgraded version of WF/PC (1) which includes corrective optics and improved detectors. WFPC2 Website.
- **WFC3 -** Wide Field Camera 3. Fourth Generation Imaging camera. This camera will supplement ACS and guarantee imaging capability for HST after the fourth

Servicing Mission.

**Near Infrared (NIR) -** See Electromagnetic Spectrum.

**Near Ultra-Violet (NUV) -** See Electromagnetic Spectrum.

**Nanometer (nm) -** Wavelengths of light are extremely small. Units like nanometers (billionths of meters) are frequently used. Visible light is 400-700 nm.

**Radial Instrument -** Science Instruments for HST are classified according to their shape and how they are mounted in the telescope. Radial instruments are mounted above the axial instruments and to the side. Radial instruments receive light by use of "pickoff mirrors" which redirect the light path into the instrument, rather than directly like axial instruments. There are a total of four radial instruments on HST. Three of the radial instruments are the FGS's and the fourth is WFPC2. WFC3 will replace WFPC2.

**Selectable Optical Filter Assembly (SOFA) -** This is the name of the carousel which was removed form WF/PC (1) and which held the filters used on orbit in this instrument. By re-using legacy equipment in this way, development costs are held down for WFC3.

**Servicing Mission (SM) -** A servicing mission is a Space Shuttle flight during which repairs and upgrades are performed on the Hubble Space Telescope. There have been two Servicing Missions to date, and three more are planned.

**Spectrum -** If white light is passed through a prism, it is broken into many colors, like a rainbow, called a spectrum. The spectrum of a star or luminous source can tell us many things about it, like temperature, composition, and velocity. See Electromagnetic Spectrum.

**STScI -** Space Telescope Science Institute **-** The STScI is located in Baltimore, Maryland at the John's Hopkins University. The STScI maintains all operations for the telescope including proposal selection, scheduling, data calibration, distribution, and archiving. Their website can be found here.

**WF/PC** (1) **-**Wide Field / Planetary Camera (See Instruments).

**WFPC2-**Wide Field / Planetary Camera II (See Instruments).

**WFC3 -**Wide Field Camera 3 (See Instruments).

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FOC Home
What's New!
News and Advisories
Calibration Resources
Documentation
Frequently Asked Questions
Yellow Pages

Here you will find instrument calibration and data analysis information about the Faint Object Camera (FOC), one of the 4 axial instruments on the Hubble Space Telescope (HST). FOC is used to make high-resolution observations of faint sources at UV and visible wavelengths.

See what's new in the FOC WWW pages.

Advisories *Last Updated:* 7 April 1997

Important information, new documentation, and new products for the FOC. Everybody should read these!

Calibration Resources

References to all the calibration products available for the FOC are available, along with the FOC simulator(FOCSIM), for calculating FOC exposure times and source count rates, and the Image Orientation Calculator form.

Documentation *Last Updated:* 7 April 1997

The FOC Instrument Handbook, recent Instrument Science Reports, TIPS presentations, HST Data Handbook, and other reports are available.

Frequently Asked Questions

Yellow Pages *Last Updated:* 3 Jan 96

When all else fails and you need to know whom to call...

*The FOC Instrument Group*

05 Aug 1998

# High Speed Photometer

The High Speed Photometer (HSP) was one of the four original axial instruments on the Hubble Space Telescope (HST). The HSP, which was removed from HST during the First Servicing Mission in December, 1993, was used to make very rapid photometric observations of astrophysical sources in a variety of filters and passbands from the near ultraviolet to the visible.

**Advisories and Instrument Status**: (last updated 24 December 1997)

- HSP WWW page established.
- Subset of HSP documents now online - includes some ISRs, Instrument Handbook, and IDT reports.

Documentation (last updated 31 December 1997)

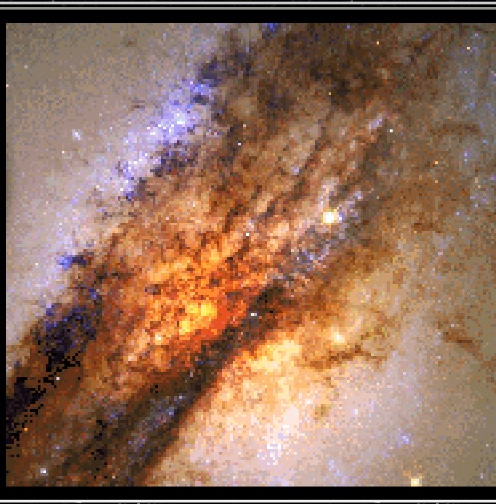
Access Instrument Science Reports, the last version of the HSP Instrument Handbook, HST Data Handbook, and other HSP publications and IDT reports.

User Support

HSP user support is limited, please contact the STScI Help Desk.



*31 December 1997*



SPACE TELESCOPE SCIENCE INSTITUTE

# WIDE FIELD PLANETARY CAMERA 2

**These pages contain instrument-specific information about the Wide-Field Planetary Camera 2 (WFPC2) and are maintained by the WFPC2 Group in the Science Support Division at the Space Telescope Science Institute (STScI). The WFPC2 is used to obtain high resolution images of astronomical objects over a relatively wide field of view and a broad range of wavelengths (1150 to 11,000 Å).**

**A WFPC2 Site Guide is available to help users easily find major items of interest.**

- ## ADVISORIES:

  **Important information, new documentation, and new products for the WFPC2. *Everyone should read this!* (Last update: 20 February 2002.**

- ## Documentation:

  **Includes the WFPC2 Instrument Handbook, Calibration Status Reports, Instrument Science Reports, WFPC2 Instrument Definition Team Status Reports, and more.**

- ## WFPC2 Software Tools:

  **Direct access to the most popular WFPC2 Tools, such as the Exposure Time Calculator, the Linear Ramp Filter Calculator, and the WFPC2 PSF Search Tool.**

- ## User Support:

  **The WFPC2 Group provides many services to assist users of HST with data reduction, visiting the Institute, and answer general questions.**

- ## Frequently Asked Questions:

  **A list of Frequently Asked Questions about WFPC2, ranging from proposal preparation to data analysis.**

**Ball Aerospace built the Corrective Optics Space Telescope Axial Replacement (COSTAR), which corrected a spherical aberration in the Hubble Space Telescope's primary mirror.**

The aberration inhibited Hubble's ability to properly focus light. Known as the "eyeglasses for Hubble," COSTAR restored the imaging capabilities for the axial instrument and corrected the telescope's imaging capabilities to near the theoretical limit.

After Hubble's servicing mission in 2002, COSTAR's mission will be complete. New instruments will incorporate an internal correcting optical system based on the COSTAR's successful design. COSTAR will be removed from Hubble during the final servicing mission in 2004.

Instrument Design
Apertures
Filters
Gratings
Detectors
Performance
Image Quality
Spectral Resolution
Throughput
Sensitivity
Background
Accuracy
Anomalies
Observing Strategy
Target Acquisition
Spectroscopy
Imaging
Pushing the Limits
Proposing
Phase 1
Phase 2
Program Status

## Welcome

The Space Telescope Imaging Spectrograph (STIS) was installed in HST on Feb 14, 1997, replacing the GHRS spectrograph. STIS provides spectra and images at ultraviolet and visible wavelengths, probing the Universe from our solar system out to cosmological distances. This site provides information needed to craft a Phase 1 proposal, design a Phase 2 observing plan, and analyze archival data. Feedback or requests for more information should be sent to help@stsci.edu.

## Cycle 11 Phase II Update for STIS

STIS has been operating with some significant changes in its performance since the release of the STIS Instrument Handbook (IHB) version 5.1 (July 2001). This update provides the latest information regarding STIS performance and policies which are relevant to the preparation of Cycle 11 Phase II proposals.

The items presented here include:

- Update on Charge Transfer Inefficiency of the STIS CCD
- CCD Side 2 Read Noise
- CCD Sensitivity Revisions
- Enhanced FUV-MAMA Dark Current
- Positional Accuracy of Moving Targets

Get the full update in our "New in the Last 45 Days" list below.

Shortcuts

Spectroscopic ETC
Imaging ETC
Target ACQ ETC
Instrument Handbook
Data Handbook
Call for Proposals
HST Primer
Phase 2 Instructions
ISRs

## New in the Last 45 Days

STAN - March 2002

Invitation to the HST user community to provide suggestions for additional STIS calibrations.

C. Proffitt 10 Mar 2002 (html)

STIS Data Handbook

Contains the STIS Data Handbook in PDF and html formats.
Spectrographs Group 19 Feb 2002 (html)

STAN - February 2002

Update G140L low order flats, and CALSTIS V2.12 & 2.12A Release Notes

Spectrographs Group 08 Feb 2002 (html)

# NICMOS




- NICMOS

Instrument Design
Coronagraph
Detectors
Dewar
Filters
Grisms
NCS
Polarizers
History
Performance
Anomalies
Background
Coronagraphy
Focus
Image Quality
Photometry
Plate Scale
Polarimetry
Sensitivity
Spectroscopy
Proposing
Phase I
Phase II
Observing Strategies
Calibration
Advisories
Reference Files
Tutorial
Visiting STScI
Software Tools
Document Archive


The Near Infrared Camera and Multi-Object Spectrometer (**NICMOS**) provides imaging capabilities in broad, medium, and narrow band filters, broad-band imaging polarimetry, coronographic imaging, and slitless grism spectroscopy, in the wavelength range 0.8-2.5 microns. NICMOS has three adjacent but not contiguous cameras, designed to operate independently, each with a dedicated array at a different magnification scale. (See the Instrument Handbook for more details).

## Cycle 11 News

**Welcome to the New NICMOS Website** We have redesigned the structure and navigation of this website.
More...

**Post-SAA Darks** Automatic post-SAA DARKs planned for use in removal of persistent cosmic ray images.
More...

**New Pattern Structure - Phase II** New Phase II syntax implemented for pattern specification.
More...

**New URL for the ETC** Update your bookmarks! The URL for the NICMOS ETC has been changed.
More...

## Shortcuts


Instrument Handbook
Data Handbook
Advisories
Anomalies
NICMOS ETC
Dark Generator
Flat Generator


## New in the Last 45 Days

NICMOS ISR 2002-002: NICMOS Cycle 10 Interim Calibration Plan
This document describes the NICMOS calibration activities for cycle 10 which will execute after the completion of the SMOV3b program and before the start of the routine Cycle 11 calibration program.
NICMOS Group 14 Mar 2002 (pdf)

NICMOS Data Handbook v5
NICMOS Data Handbook Version 5 NICMOS Group 19 Feb 2002 (html)

# NICMOS Cooling System

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The HOST mission on board Space Shuttle Discovery, STS-95, has demonstrated the zero-gravity operation of the reverse turbo-Brayton cycle cryocooler in the NCS. As a result of this successful demonstration, this system will be used to cool the NICMOS instrument after SM3B (2000).

These cryogenic coolers allow longer operational lifetimes than is presently possible with expendable cryogenic systems. It is expected that with the NCS installed on HST, NICMOS's operational life will be extended by at least five years beyond SM3B. The NCS works using three fluid loops. The first loop is the circulator loop. When installed in the HST, gas will be circulated in this loop between the cooling system and the inside of the NICMOS cryostat. This carries heat away from the cryostat and keeps the detectors at their operating temperature (73 Kelvin or -200 C). For the HOST mission, the NICMOS cryostat was replaced by a simulator that contains an exact replica of the plumbing and interfaces in the NICMOS. This device is called the NICMOS Cooling Loop Simulator (NCLS).

**NICMOS Cryocooler**

The second loop is the primary cooling loop. It contains a compressor, a turboalternator, and two heat exchangers. This loop implements a reverse-Brayton thermodynamic cycle, and provides the cooling power for the entire system. It is the heart of the NICMOS cryocooler.

In generating this cooling power, a significant amount of heat is also generated (up to 500 Watts). This heat is carried away from the primary cooling loop by the third loop in the NCS, called the Capillary Pumped Loop. This loop connects the main heat generating component, the compressor, with the external radiator, which radiates the heat into space. The heat is carried by evaporating ammonia on the hot end, and recondensing it at the cold end of the CPL.**NICMOS Radiator**

The Electronics Support Module (ESM) controls the major functions of the NCS. It contains an 8051 microprocessor, which implements the control laws for cooler functions including compressor, turboalternator and circulator speed. It also controls the CPL reservoir temperatures, regulating the quantity of heat transported to the radiator by the CPL. In the background, it collects and monitors critical NCS telemetry as well as general housekeeping telemetry, and relays commands to the NCS subsystems.

# Hubble Space Telescope

# Orbital Systems Test (HOST)

**OFFICIAL KSC LAUNCH DATE/TIME: Oct. 29 at 2:19:34 p.m.**

**OFFICIAL KSC LANDING DATE/TIME: Nov. 7 at 1:04 p.m.**

**MISSION DURATION: 8 days, 22 hours and 44 minutes**


Space Shuttle Discovery Image Gallery

Home

Mission Overview

Additional Mission Information

Mission Updates

Image Gallery

Mission Results NEW

NASA Shuttle Web

Press Information

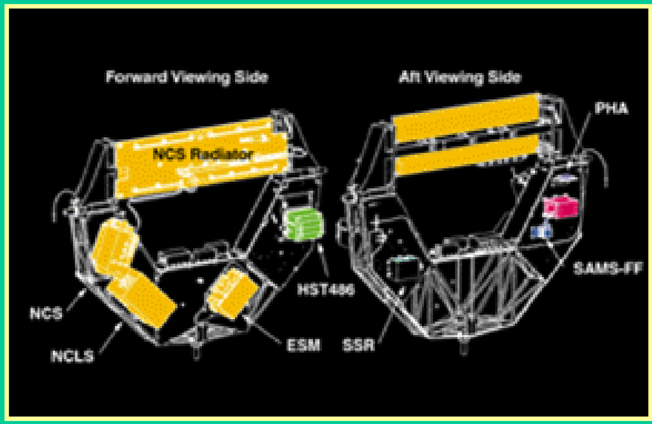
As part of working towards Servicing Mission 3 (SM3, scheduled for the spring of 2000), the Hubble Space Telescope (HST) team has done double duty with the flight of the Hubble Space Telescope Orbital Systems Test (HOST) platform in 1998 on the Space Shuttle Discovery.

As NASA's premier orbiting astronomical observatory, the HST provides its unprecedented scientific contributions through the four planned Servicing Missions, two of which have already been completed. In 2010, when the HST is currently planned to be brought back to Earth, it would have had four generations of scientific instruments spanning two decades of technology.

The HOST mission is a new paradigm in bringing advanced technologies to the observatory by providing an on-orbit test bed for key pieces of hardware. It shortens development time for flight hardware by providing early flight experience to minimize the risk of using new technologies in a valuable international resource. In shortening the time from technological readiness to on-orbit use, we are able to use newer and more capable technologies to maximize scientific return.

The HOST mission was a primary payload aboard Discovery during the 9-day STS-95 mission which began on October 29, 1998 at 2:19 p.m., (Eastern Time).

Next to Mission Overview




## Key Hardware Elements

Mission Overview

486 Computer

Solid State Recorder (SSR)

**Fiber Optics Flight Experiment (FOFE)**

**Pulse Height Analyzer (PHA)**

**NICMOS Cooling System**

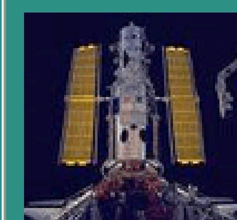
**The Space Acceleration Measurement System for Free Flyers (SAMS-FF)**

For comments or questions regarding this site, please contact **webmaster@hstsci.gsfc.nasa.gov.**

Curator: Tammy Eskin, Global Science & Technology, Inc.



GSFC Internal



Space Telescope Science Institute

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Instrument
- archive
- calibration
- coronagraph
- detectors
- filters
- overview
- photo gallery
- publications
  - handbook

Science
- archive
- gallery
- overheads
- pipeline
- programs
- team members

General
- about this site
- computing
- employment
- press releases
- server statistics
- team only
- useful links

The Advanced Camera for Surveys (ACS) was installed in the Hubble Space Telescope (HST) during Servicing Mission 3B, launched aboard the Space Shuttle *Columbia* (STS-109) 1 March, 2002 6:22 am EST. The ACS will increase the discovery efficiency of the HST by a factor of ten. It will consist of three electronic cameras and a complement of filters and dispersers that detect light from the ultraviolet to the near infrared (1200 - 10,000 angstroms).

· ACS is alive and well in orbit!

· (STS-109 mission status)

· ACS Launched ! (STS-109)

· HST Mission Control at GSFC (LIVE!)

· 6 Dec - ACS has completed ground calibration and is ready for launch!

· 27 Nov - ACS has shipped to Kennedy Space Center

· Weekly project status (team-only)

collaborators

The ACS science and engineering team is concentrated at the Johns Hopkins University and the Space Telescope Science Institute, but includes scientists from major universities in the United States and Europe. The ACS Principal Investigator and leader of the science team is Holland Ford, a professor in the Department of Physics and Astronomy and an astronomer at the Space Telescope Science Institute.

# WIDE FIELD CAMERA 3

NASA/GODDARD HUBBLE SPACE TELESCOPE

JPL • J&T • SAI • BALL • STScI • MANTECH • OMEGA • TINSLEY • GST • MTech • RSC • MEGA • LM • OSC • BARR • RITSS

Private Pages (Authorization required)

The Hubble Space Telescope Project

ITAR Compliance

Detector Characterization Laboratory



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For more information or to report problems with this website please contact: webmaster@wfc3.gsfc.nasa.gov

[Instrument Development](#)

[Science](#)

[Publications](#)

[Related Missions](#)

[Public Outreach](#)

[CASA](#)

[CASA-ARL](#)

[COS Spectral Simulator](#)

# The Hubble Space Telescopes'

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# Cosmic Origins Spectrograph

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The Cosmic Origins Spectrograph (COS) is a new instrument for the Hubble Space Telescope that will be installed in 2004. It is designed for high throughput, medium resolution (R=20,000) spectroscopy of point sources, allowing the efficient observation of numerous faint extragalactic and galactic ultraviolet (1150-3000 Å) targets. The primary science objectives of the mission are the study of the origins of large scale structure in the universe, the formation and evolution of galaxies, and the origin of stellar and planetary systems and the cold interstellar mediume. The instrument has been designed with maximum effective area as the primary constraint, and will provide more than an order of magnitude gain in sensitivity over previous HST instruments in this wavelength region. COS will complement and extend the suite of HST instruments, ensuring that HST maintains a powerful UV spectroscopic capability from 2004 until the end of its mission.

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[Instrument Development] [Science] [Publications] [Related Missions] [Public Outreach] [Contacts]
[CASA] [CASA-ARL] [COS Spectral Simulator]

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# 2000 and Beyond



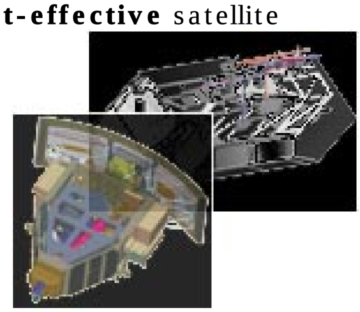



**The Team**

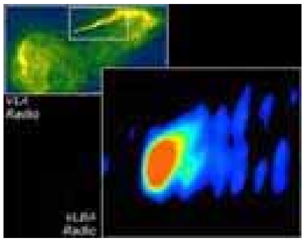
Hubble's exciting accomplishments are possible because of the ingenuity and perseverance of the entire Hubble team, **from NASA, ESA, industry and education**. The commitment of all the members of the Hubble Program remains as strong as when Hubble was launched a decade ago. These dedicated people, from welders, to scientists, programmers to model makers, are dedicated to ensuring Hubble's health and cutting-edge performance well into the 21st Century.

**The Technology**

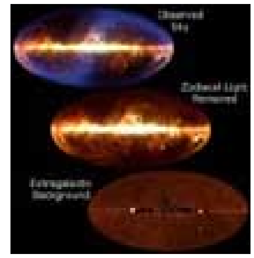
Hubble's design has proven that human presence in space is a success, Shuttle astronaut servicing keeps Hubble operating at peak performance on a continuing basis. Hubble continues to be the most **productive, cost-effective** satellite mission ever launched. Hubble's visionary, **modular design** allows the telescope to be fitted with new instruments and components at substantial cost savings. New Solar arrays, new batteries, new computers and more, all assure us that Hubble will fulfill its mission into the next decade.



**The Science**



Hubble’s place in history as a pathfinder for new scientific discoveries is assured. The telescope's future looks bright as well. Continued servicing of Hubble’s systems assure the telescope’s peak performance. The installation of new instruments, including the **Advanced Camera for Surveys**, **Cosmic Origins Spectrograph** and **Wide Field Camera 3**, offer limitless possibilities of unexpected insights into our Universe throughout the next decade.



Each time we send a mission into space to enhance Hubble's abilities, we are proclaiming our desire to take another step closer to answering these universal questions.

**How did the Universe Begin?**

**What is our place in it?**

**Is there anyone else out there?**

Our desire for exploration has found a special partner in the Hubble Space Telescope. Our unique human connection with Hubble allows each of us here on Earth to feel the magic of discovery for ourselves.

# How Hubble Captures Images

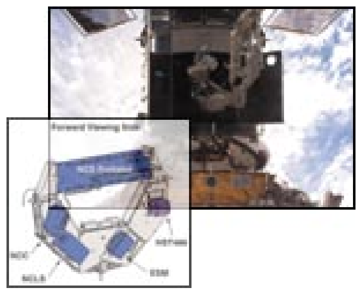
Historical Timeline
2000 and Beyond
Capturing Images
Hubble's Goals
Science Highlights
Technology Highlights
Goto SM3B WEBSITE

# Hubble's and NASA's Goals



The **NASA Strategic Plan** is a major step toward **shaping the Space Science program of the 21st century**. Guided by this plan, the space science community can continue to change the way we think about our place in the Universe.

Hubble's unique and original design meets the challenges set forth by NASA. Hubble is also an integral part of **NASA's Origins Program**, which is designed to aid us in obtaining knowledge of our cosmic roots. Throughout its first decade, Hubble has maintained a standard of excellence in exploring the development of space and human enterprise, researching and developing advanced technologies, and advancing and communicating scientific knowledge.



Hubble and its continuing servicing missions are central to the implementation of the science goals for NASA and the Origins Program:

Hubble has provided information crucial to understanding the structure of our Universe.

Hubble continually tests physical theories and reveals new phenomena throughout the Universe, especially through the investigation of extreme environments.

Hubble helps scientists understand how both dark and luminous matter determine the geometry and fate of the Universe.

Hubble instruments have helped us understand the dynamic and chemical evolution of galaxies and stars and the exchange of matter and energy among stars and the interstellar medium.

Hubble has expanded our knowledge of how stars and planetary systems form together.

Hubble has provided detailed images that assist us in understanding the nature and history of our solar system, and what makes Earth similar to and different from, its planetary neighbors.



Contact: webmaster@hubble.gsfc.nasa.gov, Global Science & Technology, Inc.
Page Last Updated: October 29, 2001

# Science Highlights

Historical Timeline

2000 and Beyond

Capturing Images

Hubble's Goals

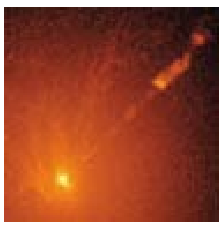
Science Highlights

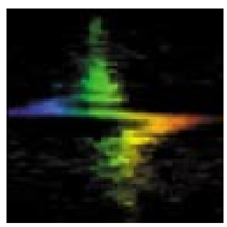
Technology Highlights

Goto SM3B WEBSITE

**The Best View of Mars**

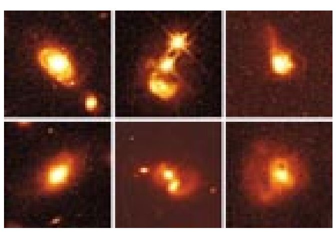
Hubble captured the best view of Mars ever obtained from Earth. Frosty white water ice clouds and swirling orange dust storms above a vivid rusty landscape reveal Mars as a dynamic planet in this sharpest view ever obtained by an Earth based telescope. The Earth-orbiting Hubble telescope snapped this picture on June 26, when Mars was approximately 43 million miles (68 million km) from Earth -- its closest approach to our planet since 1988. Hubble can see details as small as 10 miles (16 km) across.





**Proof of Black Holes**

Hubble was the first optical telescope to provide convincing proof of a black hole several billion times the mass of the Sun. Now it is demonstrating that supermassive black holes are at the core of most, if not all, galaxies.

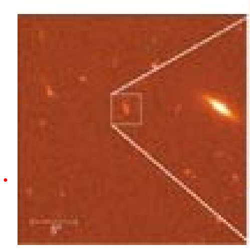


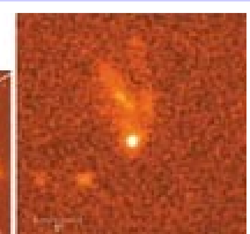
**Quasars**

Hubble cleared up the mystery of quasars. It confirmed that quasars are actually active galactic nuclei in distant galaxies and are powered by black holes.

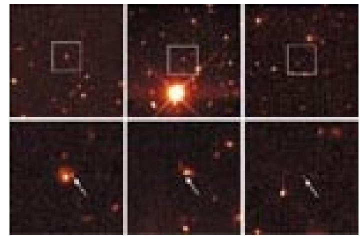
**Gamma Rays Origins**

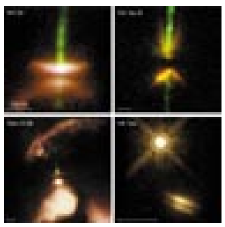
Until Hubble, scientists could not determine if mysterious, intense bursts of gamma rays originated in our own galaxy, far across the Universe, or somewhere in between. The telescope traced these bursts to the outskirts of faint, distant galaxies in the early Universe.



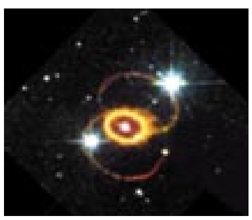


**The Expanding Universe**
Hubble teamed with ground-based telescopes to observe exploding stars in galaxies whose light was emitted when the Universe was half its present age. The preliminary result, if confirmed, will be one of the most important scientific discoveries of our time—that the expansion of the Universe is accelerating, driven by an unknown force.

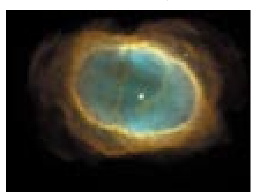




**The Birth of Stars**
Hubble's unprecedented views of star birth reveal the diverse and complex processes that influence star formation. They show that planet-forming dust disks surrounding young stars are common throughout the galaxy. Hubble was the first telescope to reveal the internal structures of these disks, which suggest the presence of newly formed planets.

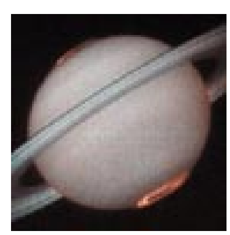


**The Death of Stars**
The telescope's exquisite images of dying stars help scientists understand the death process and how it is influenced by each star's specific circumstances. Only Hubble can chronicle the spectacular changes as the blast debris expands over time.



**Comet Collision**
Hubble provided spectacular views of Comet Shoemaker-Levy/9's collision with Jupiter, the first detailed images of Pluto and its satellite Charon, and new understanding of the atmospheres of Uranus and Neptune.

**Auroras and Electricity**
Hubble revealed stunning views of the northern and southern lights on Jupiter, Saturn and Ganymede, as well as imagery of the dynamic electrical interactions between Jupiter and its satellite Io.



Contact: webmaster@hubble.gsfc.nasa.gov, Global Science & Technology, Inc.
Page Last Updated: October 29, 2001

# Technology Highlights





*Hubble has been a driving force behind numerous technological leaps in space engineering. Following are just some of Hubble's innovations.*

## Deployment (1990)

The Hubble Program innovated a **unique pointing and control system**, which is extraordinarily stable and precise. This system achieves a level of stability and precision that is comparable to standing in Washington D.C. and steadily focusing a laser beam on a dime atop the Empire State Building in New York City, approximately 200 miles (322 Kilometers) away.

Hubble is the first spacecraft designed with handrails, easily replaceable equipment and other astronaut-friendly features.

## Servicing Mission 1 (1993)

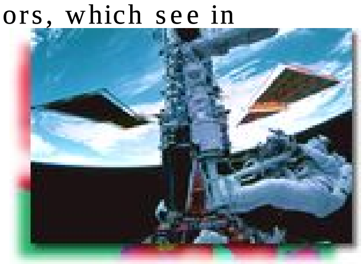
The 1993 servicing mission saw **the first use of a computer-controlled space tool**, the Power Ratchet Tool (PRT).

Hubble's huge **solar wings**, replaced in SM1 (1993) and SM2 (1997), hold the record for the **largest structures ever replaced in orbit**.

## Servicing Mission 2 (1997)

The Pistol Grip Tool (PGT), used to service Hubble in 1997 and again in 1999, was the **first cordless power tool** in space.

Hubble is the first spacecraft to use **ultraviolet Multi-Anode Microchannel Array** (MAMA) detectors, which see in ultraviolet but are blind to sunlight and other visible light. These detectors are part of the Space Telescope Imaging Spectrograph (STIS), which was installed in 1997, and the Advanced Camera for Surveys (ACS), which will become a part of Hubble in 2002.



The 1997 servicing mission was the **first to use magnetic shock absorbers**, called isolators, in space. They flew aboard a pallet in the Shuttle's payload bay that was used for transporting equipment to and from Hubble.

### HST Orbital Systems Test (1998)

The Hubble program achieved a first by successfully demonstrating the capabilities of the NICMOS Cryocooler during the STS-95, John Glenn mission.

### Servicing Mission 3A (1999)

Astronauts on the 1999 mission became the first to use highly efficient Lithium Ion batteries in a space tool.

They also installed the **first extremely radiation-resistant, Intel-based, 486 computer ever placed in orbit**.

### Servicing Mission 3B (2001)

Hubble will employ the first-ever high-tech refrigeration device, which will cool and restore life to the now-dormant Near Infrared Camera and Multi-Object Spectrometer (NICMOS) using a new technology called a **Reverse Brayton-Cycle Cryocooler** which uses microturbines spinning at over 400,000 revolutions per minute (over 100 times the maximum speed of a typical car engine). It provides 10 watts of maximum cooling at a temperature of around -200°C in order to reduce the noise of the NICMOS detectors and enable them to make scientific observations again.



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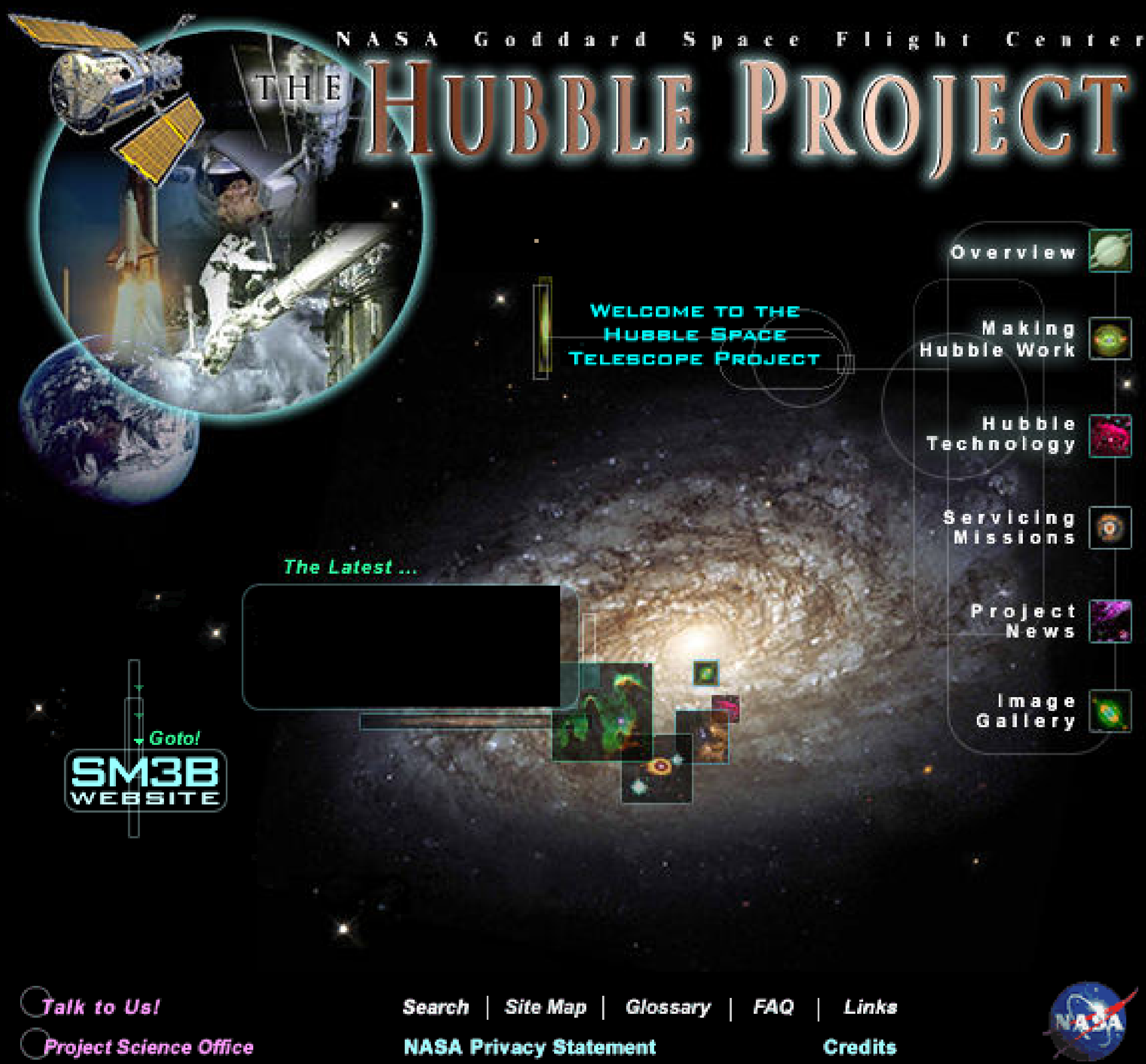
NASA Goddard Space Flight Center
THE HUBBLE PROJECT
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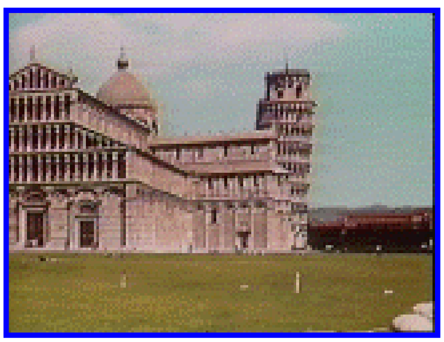
# Galileo

## Part I: The Early Years

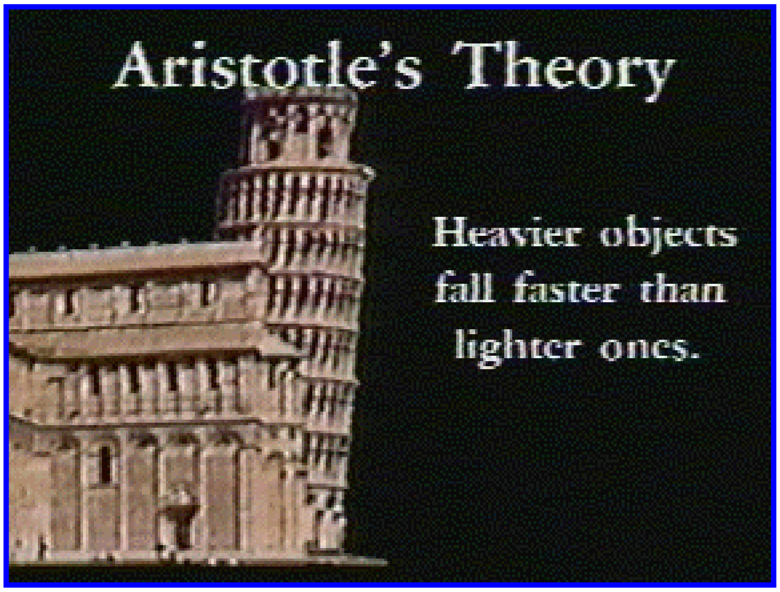
Galileo Galilei was born near Pisa in 1564 -- the same year in which Shakespeare was born and the year in which Michelangelo and Calvin died.

After studying at the University of Pisa, he was appointed to the chair of mathematics -- but as this picture of Pisa reminds us,



it was a Pisa, of course, that the famous leaning tower might well have suggested Galileo's most famous experiment.

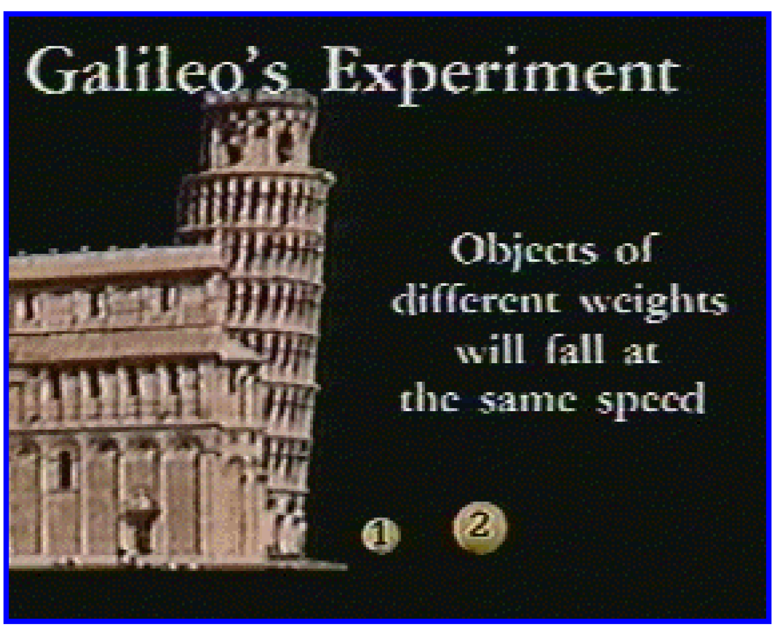
The computer animation linked to this picture, illustrates what Galileo's demonstration would have shown.




First of all the theory which virtually everyone accepted at the time was the traditional theory of Aristotle, who believed that heavier objects fall more quickly than lighter ones.

Consider, for example, two objects -- one twice as heavy as the other. Imagine Aristotle at the top of the leaning tower of Pisa, dropping off two cannonballs, one twice as heavy as the other. According to Aristotle, it should fall twice as fast. If it were four times heavier, it should fall four times faster.

But in fact, what the leaning tower of Pisa type of experiment demonstrates, when actually performed,

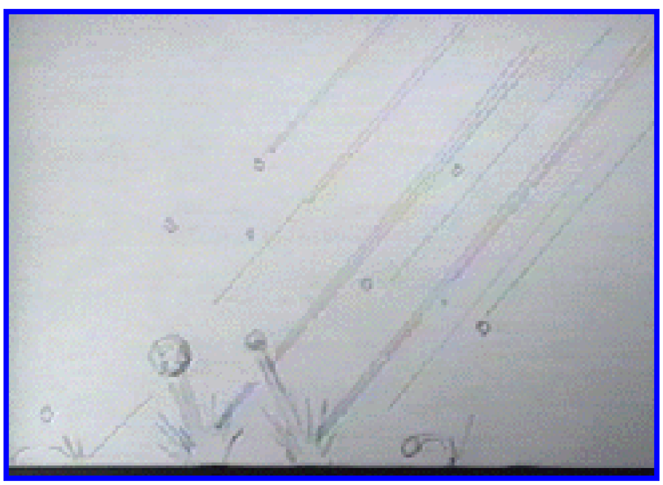


is that Aristotle was wrong, that no matter what the difference in weight, two heavy objects will fall simultaneously at virtually the same speed.

Recently it has been fashionable to question whether or not Galileo ever dropped anything off the campanile -- or leaning tower -- of the Duomo in Pisa. If he did so, it certainly could not have been an "experiment" in the modern sense of the word -- can you imagine running up and down the leaning tower of Pisa -- trying to drop objects of different weights simultaneously, from the edge of the tower, at the very same time, which is not easy to do, and then observe how quickly they fall, especially when the time elapsed would only have been a matter of seconds -- and nothing like the stop watch or any other convenient device -- had been invented yet?

Actually, whether or not Galileo ever performed his famous experiment on the leaning tower hardly seems to matter -- a similar experiment-demonstration had already been published by Benedetti Giambattista in 1553, and the test had also been made and published by the Flemish engineer Simon Stevin in 1586.

As for Galileo's interest in disproving Aristotle's Theory about falling objects, years later he said that he had first thought about this during a hailstorm, when he notice that both large and small hailstones hit the ground at the same time.



If Aristotle were right, this could only happen if the larger stones dropped from a higher point in the clouds -- but at virtually the same time -- or that the lighter ones started falling earlier than the heavier ones -- neither of which seemed very probable to Galileo. Instead, the simplest explanation was simply that heavy or light, all hailstones fell simultaneously with the same speed.

Go to the next section: Galileo II: Heavenly Bodies

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| click on craft ----------------> refresh information | Weather by INTELLICAST |
| ctrl + click on craft ----------> toggle on/off ground trace | |
| click and hold on map ------> when Hubble will fly over location | |

- Hubble whirls around Earth at 5 miles per second or 18,000 mph. A road trip from Los Angeles to New York City would take only 10 minutes.
- Hubble completes one full orbit every 97 minutes.
- In nearly 10 years, Hubble has traveled over 1 billion miles.
- In an average orbit, Hubble uses about the same amount of energy as 24 100-watt light bulbs.



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# Driving Hubble Through Space

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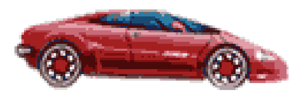
## Hubble's Amazing Journey...



Imagine going on a 20-year space adventure with Hubble as your vehicle. To begin, you'll need a road map and a driver. It's a long trip, so you'll take good care of your vehicle and give it regular servicing. You'll even "soup it up" along the way.

### Driving Hubble Through Space

Like any vehicle, Hubble needs a driver. Actually, Hubble has a team of drivers. They are the spacecraft engineers and operations people who drive the telescope from "Hubble Mission Control" at NASA's Goddard Space Flight Center.

Your car, with its 1000 parts and a single computer, needs only one operator. With over 100,000 parts and seven computers, Hubble needs three operators backed by dozens of engineers and scientists.

Hubble's four flight control teams work in shifts. Together, they operate the telescope 24 hours a day, seven days a week, every day of Hubble's 20-year life.

During servicing missions, Hubble Mission Control becomes a much busier place. Extra teams of engineers monitor Hubble's vital signs as the astronauts install new instruments and make other improvements.

### Mapping the Journey

- While orbiting the Earth, Hubble's powerful optics view destinations near the edge of the Universe and the beginning of time.

• Hubble receives more than 1000 requests for observing time each year and accepts about 300.

• The telescope averages three observations per hour.

• Each observation requires more than 100 computer functions.

• Hubble can perform two observations simultaneously by using different instruments.

## Steering the Telescope

• Operators send more than 100,000 instructions to Hubble each week.

• Hubble generates more than 10 billion bits of scientific data each week.

• The telescope orbits the Earth at 17,000 mph.

• Hubble can hold steady on a target for 24 hours to an accuracy of .007 arcseconds—the same as holding a laser beam on a dime 322 Kilometers away.

• Hubble can move 90 degrees in 15 minutes—as fast as the minute hand on a clock.

**Monitoring Hubble's Systems and Driving Safely**

Imagine using an ordinary personal computer to view the inner workings of Hubble. This is how engineers monitor Hubble, using a super-secure, user-friendly interface. Authorized users can view Hubble's vital signs from anywhere in the world with a standard, off-the-shelf computer and an Internet or modem connection.

This powerful, streamlined system includes an on-line archive of engineering data. These are like your car's mileage and maintenance records.

**Watching the Gauges**


• Operators monitor 6,800 different engineering indicators on Hubble, including temperature and pointing.

• Engineers can view conditions in real time and monitor how they change.

• Using Hubble's secure user interface, they can quickly diagnose problems from anywhere in the world. This is especially valuable during servicing missions.

**Troubleshooting Problems**

• Operators check more than 100 warning alerts each week.

•Artificial intelligence assists in monitoring and troubleshooting.

# Hubble in Cruise Control

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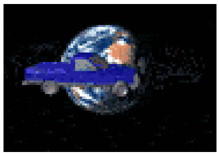

- Communications
- Radiation
- Power
- Temperature
- Orbit Decay
- Hubble and Safe Mode
- Meteors
- Track Hubble's Path in Orbit

## The Ins and Outs of a Spacecraft in Orbit

**After a successful spacecraft deployment, many factors are involved in keeping a spacecraft operating while in orbit. Communications, temperature, radiation, and much more, all must be taken into consideration.**

### Communications

Satellites communicate with the ground in order to receive commanding and to transmit data. This is done through RF (radio frequency) communications. In order to open communications, a satellite must be visible from its receiver on the ground. The time that a satellite is visible to a ground station and available for communications is called a "contact time". These occur several times a day, but typically last only for a short time for most Low Earth Orbiting (LEO) satellites.

Special satellites at very high altitudes can remain in contact with a ground station at all times by orbiting the Earth once per day. These satellites don't appear to move, and are called "Geostationary" satellites. A set of these satellites are used to relay data from other satellites. These make up the Tracking and Data Relay Satellite System (TDRSS). The Hubble Space Telescope communicates with TDRSS and data and commands are relayed.

### Orbit Decay

Hubble is a Low Earth Orbiting (LEO) satellite. It is located about 320 nautical miles (375 Statute miles, 600 km) above the surface of the earth. At its current altitude, Hubble orbits the earth approximately every 97 minutes, with a speed of about 17,000 mi/hr or 27,200 km/hr. Hubble's orbit around Earth is inclined towards the equator at an angle of 28.5 degrees.

Contrary to popular belief, Hubble does move through the Earth's atmosphere. It's orbit lies in a region known as the thermosphere, or upper atmosphere. In this region, the atmosphere is extremely thin, but some atmospheric gasses are still present. Satellites in this region feel the effects of the atmosphere in the form of aerodynamic drag. Over the course of years, this drag slowly removes energy from the orbit and the satellite falls to a lower altitude. As the altitude is lowered, the density of the atmosphere increases and the drag rises. Eventually, if the altitude loss is not restored, the satellite will reenter and "deorbit". This is referred to as Orbital Decay.

Since the drag force on a satellite is stronger for lower altitude satellites than for higher ones, the force can be minimized by placing a satellite in an orbit as high as possible. To further complicate matters, the atmospheric density also depends on heating from the sun.

The Sun's output runs from low to high levels in cycles, which last on average 11 years. The time when the sun's output reaches its peak value is referred to as "solar maximum". During solar maximum, the densities at all altitudes are enhanced, and the drag effects on satellites are much larger than during times of solar minimum. Solar output can be measured in a variety of ways, the most familiar being sunspot counts and 10.7 cm radio emissions (solar flux). The density increase is related in a complicated way to these measures and altitude.

The Hubble Project is very sensitive to the dangers posed by Orbital Decay, and closely monitors both the solar output, and the satellite orbit. If a satellite loses altitude, then it must be moved back to a higher position. For some satellites, specialized jets are used to increase altitude. Hubble has no jets or engines of any kind for propulsion, so the only way to restore the altitude is to grab it and move it. This can be done by the Space Shuttle Orbiter during a servicing mission. This is called a "reboost". Hubble was given a reboost during both the first and second servicing missions. A future reboost is planned for servicing mission 3B in 2001.

### Power

By far the most common means of powering a spacecraft in earth orbit is through solar cells. Arrays of these cells collect the radiant energy from the sun and convert it into useable electricity for the spacecraft systems. The more power required by a satellite, the more solar cells it needs. For this reason, spacecraft systems must be designed to be as power efficient as possible. In order to keep a spacecraft fully powered, the solar cells must be facing the sun. Hubble has solar arrays which can be steered and rotated so that regardless of the orientation of the telescope, the arrays can always receive full direct sunlight.

### Radiation

Radiation in space comes in many forms. These include high-energy particles, x-rays and Gamma Rays among others. The atmosphere does a good job of filtering out most of the harmful radiation before it gets to the Earth's surface, but a satellite is subjected to high levels of these. Computers and other electronics must be manufactured especially for space so that they will stand up to the harsh environment. When a chip is made to withstand these radiation effects, it is termed "Rad-Hard".

## Temperature

Without the insulating protection of an atmosphere, a satellite experiences dramatic temperature changes over the course of a day. A satellite day (at Hubble's altitude) lasts about 97 minutes and temperatures can range from -300 degrees Fahrenheit to +300 degrees Fahrenheit. During the passage from orbital day to orbital night, there is almost no twilight, and so the temperatures change suddenly. Spacecraft and materials must sustain both the extremes as well as the quick changes to operate properly in space.

## Hubble and Safe Mode

***What is Safe Mode?***

Almost all modern spacecraft have on-board computers that control their operation as well as monitor the status of various spacecraft subsystems. Hubble is no exception.

During normal operation, the computer executes the commands that cause it to perform its intended tasks. If, for some reason, the computer determines that one of the subsystems shows unusual behavior, the computer can revert to an operating mode which does no work, but which preserves the safety of the spacecraft.

These are called "safe modes". Such modes are entered without intervention from ground controllers, since communication may not be available at the time the unusual event occurs. These can be thought of as the "self preservation" instincts of the spacecraft. When a spacecraft is in a safe mode, it is said that it is in "safe hold." The most important function of safe modes is to preserve spacecraft power and communications.

***When is Safe Mode used?***

Hubble has three broad classes of safe modes, each at a more serious level of spacecraft distress.

**1.** If the computer is functional, then the computer remains in control.

Normal operations stop and the spacecraft is positioned so that its solar arrays are pointing to the Sun (to maintain power). This crude pointing can be done using simple Sun sensors (in case of gyroscope failure). This level of safe mode is relatively benign, and can be thought of as the spacecraft taking a "nap."

**2.** If the computer has a problem, or if the nature of the problem could potentially interfere with the operation of the computer, then the computer is shut down. Because the computer is no longer operating, many subsystems are turned off when the spacecraft is in this state.

Control is handed over to a dedicated control system with its own set of special gyroscopes. This dedicated system again has the job of orienting the spacecraft to maintain power from the solar panels. This level of safe mode is analogous to the spacecraft being in a light coma.

**3.** If for some reason the dedicated control system is not functioning properly, the spacecraft is shut down one more level, and enters a mode where tidal forces in orbit keep the spacecraft aligned in a predictable orientation.

This is called "gravity gradient" mode. Because normal levels of power cannot be ensured in this mode (the panels sometimes point away from the Sun), significant portions of the spacecraft, including heaters, need to be turned off to ensure the ability to recover. In this mode, the level of risk is analogous to the spacecraft being in a deep coma. Some level of permanent damage to some spacecraft subsystems or instruments is possible in this safe mode.

**Recovery from Safe Mode**

Recovery from all safe modes requires intervention from ground controllers. Typically, we first diagnose the problem causing the safe mode entry by using spacecraft data prior to entering safe mode. Special commanding (such as activating redundant systems) is then set up to work around these problems. A controlled "wake up" is then executed with the special commanding, placing the spacecraft in an operational state. This procedure gets more intricate with deeper levels of safe hold.

Hubble last experienced safe mode in November 1999, when the fourth of Hubble's six gyroscopes failed. This was a level 2 safe mode. Hubble was brought out of safe mode when astronauts replaced its gyroscopes on December 20, 1999.

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# Maintaining Hubble

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## Hubble's Pit Crew: Maintenance, Repair and Upgrades

With guidance from engineers on the ground, teams of space-walking astronauts give Hubble fresh, new instruments and components and get it back into tiptop shape, during each servicing mission.

• All instruments and more than 90 spacecraft components are designed to be replaced by Space Shuttle astronauts.

• More than 1000 different procedures guide Hubble's operators during servicing missions.

• As new technology becomes available, Hubble is "souped up" with high performance equipment.

• Each next-generation instrument is far more powerful than its predecessor. For example, the Advanced Camera for Surveys (ACS) will be installed in 2002. It is 10 times more powerful than the camera it replaces.

## Tools to Keep Hubble Running Smoothly

Hubble's caretakers use various tools to keep Hubble in peak condition.

• Testing—The team performs thousands of hours of tests on hardware and software before it becomes a part of Hubble's system.

• Contingency Planning—Engineers and astronauts practice endless "what if?" scenarios to prepare for surprises. It's much like asking yourself: What if my engine overheats? What if it snows? What if I run out of gas? What if I turn

here instead of there? By working out the answers before the problems arise, the Hubble team tries to be prepared for anything.

• Training—Astronauts, engineers, and the entire mission control team train together for hundreds of hours to prepare for each Hubble servicing mission.

• Diagnostic Tools—Engineers use hundreds of tools to quickly pinpoint both software and hardware problems.

• Servicing Missions—Regular, scheduled maintenance and replacement of limited-life components keep Hubble operating at peak efficiency.

• On-Orbit Tools—Astronauts use more than 150 special tools and crew aids to service Hubble.

**Major Spacecraft Systems**


• Pointing Control

• Electrical Power

• Thermal Control

• Communications

• Data Management

• Telescope

• Astronomical Instruments

• Safekeeping

# Hubble's "Mission Control" (STOCC)

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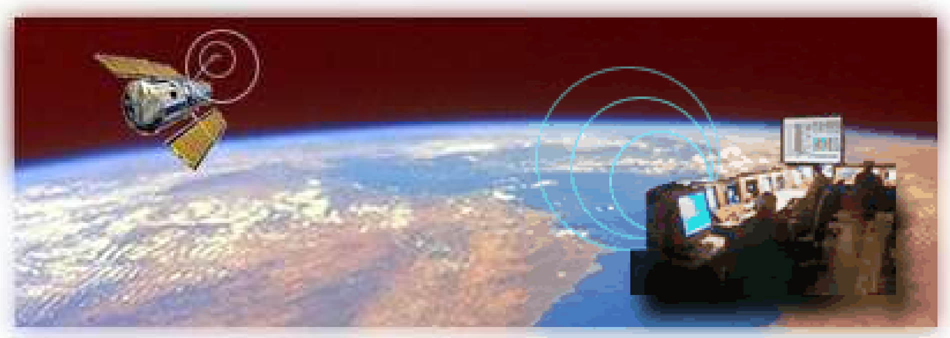
Hubble's flight controllers are headquartered at NASA's Goddard Space Flight Center in Greenbelt, Md. From the Space Telescope Operations Control Center (STOCC), these engineers and technicians "drive" the telescope 24 hours a day, seven days a week, every day of Hubble's 20-year life.

Each of Hubble's four flight control teams consists of three operators backed by dozens of engineers and scientists. The teams work in seamless shifts to keep the telescope healthy, productive and running smoothly. Using Hubble's Control Center System (CCS), they send more than 100,000 instructions to Hubble each week.



Track Hubble's path in Orbit.

The STOCC is "Hubble Mission Control"-the focal point of all Hubble Space Telescope operations. Controllers carry out routine operations in one section, while another section supports preparations for servicing missions, including testing and simulations. In an adjacent section, engineers perform in-depth subsystem analysis, conduct simulated subsystem tests, integrate new databases and validate new ground software and updates to flight software.

**During Hubble Servicing**

During an on-orbit servicing mission, Hubble Mission Control becomes a much busier place. Extra teams of engineers monitor Hubble's vital signs as the astronauts install new instruments and make other improvements.

Like the astronauts, Hubble's controllers train extensively for their critical mission roles. Shortly after a servicing mission shuttle launch, this team prepares Hubble for the on-orbit service call. They begin by transitioning the telescope from normal science operations to a "ready for servicing" condition. Controllers command Hubble to its capture attitude and configure it for rendezvous with the Space Shuttle. To prepare for capture and berthing, they command Hubble to close its aperture door and stow its high gain antennas.

After the new equipment is installed, Hubble's ground controllers run tests on the newly installed items. These tests are done immediately after installation, with the crew positioned at a safe location, to determine whether more astronaut activity is required. While the crew sleeps, the ground team performs more detailed functional checkouts of the new equipment.

After all the servicing tasks are complete, Hubble and the Space Shuttle are configured for battery charging. The Shuttle crew transfers the Telescope to internal power, disconnects the power feed and uses the robotic arm to position Hubble for deployment. The telescope's controllers command Hubble to deploy its high gain antennas and open its aperture door. They reactivate and check out all equipment that was powered off for servicing. Hubble is then released. The ground team begins the telescope's operational re-commissioning, and normal science operations resume.





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# The Hubble Team





## World Class Teamwork...

The Hubble Team is a **diverse group** united in a **common goal**: To keep Hubble healthy and producing breakthrough science. Like an orchestra performing a symphony, the Hubble Team melds its varied talents, strengths and expertise to function as a single entity.

From astronauts to accountants, and scientists to secretaries, every member of the Hubble team plays a vital role. Mission success requires the **close coordination of many, many individuals**, as well as collaboration with other institutions, including Kennedy Space Center, Johnson Space Center, NASA Headquarters, the Space Telescope Science Institute and the European Space Agency. Industrial and educational partners from across the nation and around the globe are essential members of Hubble's science and engineering teams.

Hubble's "core team" is the Project's backbone. The Team uses its extensive expertise in the following areas to choreograph Hubble's successful missions:

- Astronomy
- Astrophysics
- Engineering
- Ground system operations
- Software development
- Logistics
- Integration and testing
- Administration
- Resources
- Procurement
- Fabrication

- Configuration management
- Scheduling
- Property control
- Documentation
- Photo and video documentation
- Graphic arts
- Technical writing
- Presentation support
- Technology transfer
- Outreach

This partnership of **scientific expertise and technological excellence** allows the Hubble Space Telescope to continue as one of the "crown jewels" of NASA - year after year, mission after mission.

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# The Neutral Buoyancy Lab

Parts and Definitions
Science Instruments
Pointing System
Novel Technology
Re-using Hardware
Hubble Cleanroom
Neutral Buoyancy Laboratory
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To prepare for a Hubble servicing mission, astronauts spend many hours training underwater. This allows them to experience how their suits, science instruments, tools, crew aids and other equipment respond to movement in a space-like environment. In the water, astronauts wear small weights on their space suits to make themselves "neutrally buoyant." This means they neither sink nor rise, but hover suspended, as they would in space. By practicing their servicing tasks underwater, the spacewalkers learn to work swiftly and efficiently in orbit.

Click on thumbnails for larger image.

# Hubble Orbital Systems Test (HOST)

Servicing Mission 1
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HOST Mission
Servicing Mission 3A
Servicing Mission 3B
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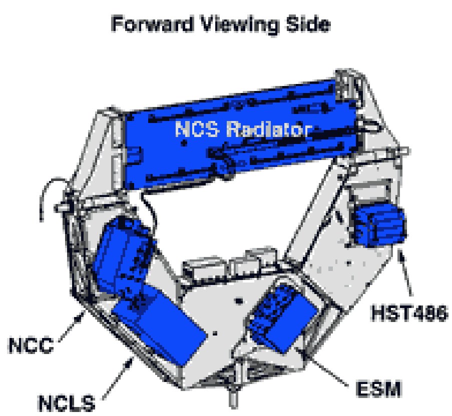
(Shuttle Mission: STS-95)

In October 1998, the Hubble Team conducted the HST Orbital Systems Test (HOST) on board STS-95 ("The John Glenn Mission"). This Space Shuttle mission provided a unique opportunity to test key pieces of new Hubble hardware before they would be installed in the telescope. By flying in an orbit similar to Hubble's, the Shuttle allowed engineers to determine how the new equipment on HOST would perform on the telescope.

HOST engineers monitored the effects of radiation on Hubble's new hardware, including an advanced computer, digital data recorder, and cryogenic cooling system. All the new technologies on the HOST platform performed up to expectation. In 1999, during Servicing Mission 3A, astronauts installed the new computer and data recorder on Hubble. The cryogenic equipment will become part of the telescope in 2001.

Full view of the payload bay, showing the white, rectangular SPACEHAB at the top, SPARTAN in the middle, HOST immediately below it, and the IEH at the bottom (truncated).




The HOST Payload

# Servicing Mission 3A

Servicing Mission 1
Servicing Mission 2
HOST Mission
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Servicing Mission 4

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- **Hubble SM3A Web Site**
- **SM3A Images**
- **Post-Servicing Science Images**
- **SM3A Media Guide**
- **SM3A Fact Sheets**

(Shuttle Mission: STS-103)

The Hubble Space Telescope is alive and well and back on duty after a successful December, 1999 Servicing Mission (SM3A). To prove it, NASA released two stunning images taken by Hubble just two weeks after Discovery's Christmas-time service call. Discovery's seven-member crew included two Hubble Servicing Mission veterans.

What was originally conceived as a mission of preventive maintenance turned more urgent on November 13, 1999 when the fourth of six gyros failed and Hubble temporarily closed its eyes on the Universe. Unable to conduct science without three working gyros, Hubble entered a state of dormancy called safe mode. Essentially, Hubble "went to sleep" while it waited for help.

NASA decided to split the Third Servicing Mission (SM3) into two parts, SM3A and SM3B, after the third of Hubble's six gyroscopes failed. In accordance with NASA's flight rules, a "call-up" mission was quickly approved and developed and executed in a record 7 months!

The Hubble team has left the telescope far more fit and capable than ever before. The new, improved, and upgraded equipment included six fresh gyroscopes, six battery voltage/temperature improvement kits, a faster, more powerful, main computer, a next-generation solid state data recorder, a new transmitter, an enhanced fine guidance sensor, and new insulation.

The second part of the mission, SM3B, is scheduled for early 2002.

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# Up-to-the-Minute Hubble & Science News!

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Press Releases
Project Reports
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1/8/2002

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The deepest views of the cosmos from the Hubble Space Telescope yield clues that the very first... (more)

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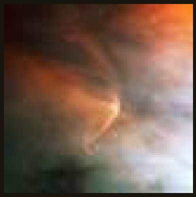
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### A Bow Shock Near a Young Star

The Hubble Space Telescope continues to reveal various stunning and intricate treasures that reside... (more)

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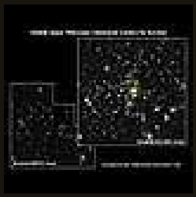
2/15/2002

### New Instrument Package to Expand Space Telescope's Vision

NASA's Servicing Mission 3B for the Hubble Space Telescope will give the orbiting observatory a... (more)

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2/7/2002

### Hubble Reveals "Backwards" Spiral Galaxy

Astronomers have found a spiral galaxy that may be spinning to the beat of a different cosmic drummer.... (more)

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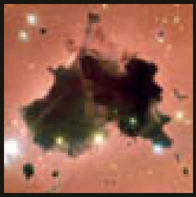
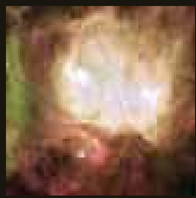

1/3/2002

### Thackeray's Globules in IC 2944

Strangely glowing dark clouds float serenely in this remarkable and beautiful image taken with the... (more)



*12/19/2001*

## Hubble Sends Season's Greetings from the Cosmos to Earth

Looking like a colorful holiday card, this image from NASA's Hubble Space Telescope reveals a vibrant... (more)

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| **Exotic phenomena** (24) | **2000** (35) |
| **Galaxies** (55) | **1999** (43) |
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| **Star clusters** (36) | **1995** (49) |
| **Stars** (87) | **1994** (12) |

# Hubble Project Reports



| | |
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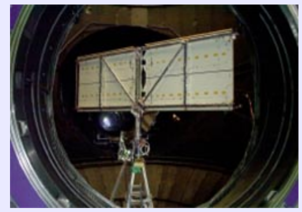
|  |  |
| The Hubble Biennial Report 1999-2000. (pdf)<br>A comprehensive report of Hubble read by our government representatives. | The Quest for More Power Bridges Two Continents:<br>Hubble Project News, Dec. 2000. |



Contact: webmaster@hubble.gsfc.nasa.gov, Global Science & Technology, Inc.
Page Last Updated: October 29, 2001

# Incident Reports

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**July 6 , 2001 -Update**
Space Telescope Imaging Spectrograph science instrument.

Another significant step toward recovery of STIS operations using side 2 was taken successfully earlier today. Over the past few days, the revised software load for the side 2 control section 386 processor was uplinked, a multi-hour process. After confirming that all the various checksums and memory compares were correct, the operations team proceeded this morning to command STIS into the MECH OPERATE state.

In this state, the 386 went from its BOOT state to the OPERATE state, using the new software load. In addition the MAMA Interface Electronics were powered, as well as the Mechanism power converter. In the initialization process for the mechanisms, several of the simple shutters were exercised and have been confirmed to operate on their redundant motor windings (Cal Insert Mechanism, Mode Isolation Shutter, Echelle Blocker). In addition, the slit wheel went into its continuous feedback control mode using the side 2 position resolver. All of this activity completed successfully. STIS was commanded back to the SAFE state about an hour ago. It will be brought up via stored commanding innext week's SMS.

The following side 2 items have not yet been exercised, but will be in next week's mini-Orbital Verification activities: the side 2 power converters for the thermo-electric cooler, CCD electronics box, and cal lamps, and the side 2 windings of the Mode Select Mechanism drive motors (the MSM was already in its home position and therefore did not have to move during the mechanism initialization).

The MAMA tubes have also not yet been ramped up to High Voltage, but that process does not involve any additional side 2 electronics -- the MAMA tubes are non-redundant components that are known not to be the site of the side 1 fault.

An issue with the slit wheel operation during today's test was traced to the wrong designator being burned into the side 2 PROM code back before launch. This purely descriptive telemetry parameter has no influence on the actual operation of the mechanism -- it properly is controlling about the side 2 "home" position as read by the side 2 position resolver.

---

**June 20 , 2001 -Update**
Space Telescope Imaging Spectrograph science instrument.

The STIS instrument has been in safe mode because of a power system anomaly that blew a fuse on the main power bus providing power to the instrument. We ran an engineering test today that is designed to characterize the nature of the anomaly. This test uses power from an alternate power bus (Bus C) to provide power to the instrument on the same power converters and electronics that have been used in the past.

Analysis of the previous failure showed that there was a chance that the failure was transient and was caused by a short circuit from a "tin whisker". The results today show that this explanation is probably not correct, and they will be used for further analysis.

The STIS instrument will be put back into operation using its redundant side (a duplicate set of power converters and electronics) as soon as software modifications are completed. This redundant side is believed to be fully operational.

All the blown fuses from this test and from the initial anomaly will be replaced during the upcoming SM3B Servicing Mission, currently planned for late-January 2002.

---

**May 16, 2001, approximately 1:52 am EDT**
**LOCATION OF INCIDENT:**
Space Telescope Imaging Spectrograph science instrument.

**DESCRIPTION OF INCIDENT:**
On May 16, 2001, the Space Telescope Imaging Spectrograph (STIS) onboard the Hubble Space Telescope (HST) experienced a sudden drop in electrical voltage, and was autonomously placed into safehold by the computers and software onboard HST. "Safing" is just what the name implies–putting an instrument into a non-observing, safe state when anomalous and possibly harmful conditions are detected. An entry into safehold protects the instrument, and gives engineers time to diagnose the cause of the anomalous condition and to propose options for bringing the instrument back "on-line" in a cautious manner.

STIS is currently receiving enough power from a redundant power supply line to operate its heaters, and to remain above its temperature "survival limit." Engineers are presently attempting to isolate the cause of the power drop within STIS. It is known that no current is flowing through a fuse and electrical relay in the "power distribution unit" (PDU) which supplies power to STIS, but it is not known with certainty whether this was caused by a situation inside or outside of the instrument. Plans for future tests are being evaluated which could help to isolate the problem area.

HST and its instruments were designed to provide redundancy against situations such as this, and a parallel effort has commenced to make changes to the onboard software which will allow STIS to run on its back-up power supply line (referred to as "side 2"). It will take at least several weeks to make these changes and to test them, and in the meantime the engineers analyzing the cause of the power drop will hopefully have more understanding of the original problem.

HST will continue with its science program, as the Wide-Field and Planetary Camera-2 (WFPC2) was unaffected by the STIS power anomaly. Next week’s schedule of science observations is being modified accordingly, and WFPC2 will pick up the slack produced by STIS's safemode entry. HST Project hopes to have STIS back on-line as soon as possible, consistent with the need to proceed cautiously and to protect this very important science instrument.

---

**April 30, 2001 Update:**
On April 28, 2001, at approximately 4:15 pm EDT, Hubble entered Zero-Gyro Sun Point safemode due to a anomaly affecting gyro 5. Resumption of the HST science program occured at approximately 8:00pm EDT, April 29, 2001.

**April 28, 2001 @ 20:15 GMT (4:15 pm EDT)**
**LOCATION OF INCIDENT:**
HST Pointing Control System-Gyro 5

**DESCRIPTION OF INCIDENT**:
The gyro 5 motor current increased from 0.210 Amps to 0.330 Amps causing the motor current safemode limit test to fail. The flight software autonomously took the gyro off-line and placed Hubble into Zero-Gyro Sun Point since fewer than 3 gyros were operationally active. The 0.330 Amp level and no gyro rate output indicate that gyro 5 had stalled.

Earlier this week, gyro 5 experienced 2 events that caused elevated motor current levels. In the second event, the motor current peaked at 0.260 Amps. The nominal operating level is approximately 0.130 Amps.

The MOSES spacecraft subsystem engineers and the Space Telescope Science Institute verified that all spacecraft subsystems are operating nominally. Hubble's subsystems' performance will continue to be closely monitored.

Hubble's safemode recovery procedure is in progress. Resumption of the HST science timeline is scheduled to begin April 29, 2001 at 8:00 pm EDT.

**IMPACT ON PROGRAM/PROJECT AND SCHEDULE:**
The entry in Zero-Gyro Sunpoint safemode and the recovery operation has resulted in approximately 28 hours of HST science downtime.

**CORRECTIVE ACTION:**
The following corrective actions are being taken:

1) Reconfigure the HST gyros for operation using gyros 2, 3, and 4 for vehicle pointing control.

2) Recover the HST from Zero-Gyro sunpoint utilizing approved safemode recovery procedures.

3) Resume the HST science program on April 29, 2001 at 8:00pm EDT. **Completed**.

4) Assess gyro 5 performance data and determine what action is necessary.

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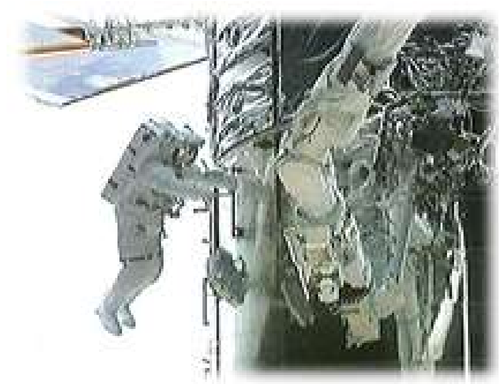
# Servicing Mission Images





- Servicing Mission 1
- Servicing Mission 2
- Servicing Mission 3A
- Servicing Mission 3B
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# Index of Animations

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**Star Birth in the Trifid Nebula**
*STScI PR99-42*

QuickTime 4

QuickTime 3

**Huge Spring Storms Rouse Uranus from Winter Hibernation**
*STScI PR 99-11*

Rotation of Uranus *(18.04MB)*

Rotation of Uranus *(3.90MB)*

**Vast Stellar Disks Set Stage for Planet Birth in New Hubble Images**
*STScI PR 99-05*

Model of Stellar Disk and Planet Formation *(8.26 MB)*

**Gap In Stellar Dust Disk May Be Swept Out By Planet**
*STScI PR 99-03*

Cornagraph Demonstration *(1.57 MB)*

**The Universe "Down Under" Is The Target of Hubble's Latest Deep-View**

*STScI PR 98-41*

Animation showing Hubble Space Telescope Telescope pointing at HDF North and South targets *(2.53 MB)*

The Hubble Space Telescope is pointing north at a blank patch of sky above the Big Dipper *(39.21 MB)*

Zoom" into the Hubble Deep Field from a wide view of the sky *(2.31 MB)*

**Hubble Provides A Moving Look At Neptune's Stormy Disposition**

*STScI PR 98-34*

Neptune's Weather: Animation made from images of Neptune *(17.25 MB)*

**NASA Selects Home For Next Generation Space Telescope**

*STScI PR 98-20*

*(4.43 MB)* *(3.13 MB)*

NASA Administrator Dan Goldin makes the official announcement

*(10.39 MB)* *(6.91 MB)*

Maryland Senator Barbara Mikulski comments on placing NGST's operations at STScI

*(5.54 MB)* *(2.53 MB)*

The Senator and Administrator unveil the poster commemorating the announcement

**Hubble Takes First Image of a Possible Planet Around Another Star and Finds a Runaway World**

*STScI PR 98-19*

False color image of two gas giant protoplanets that have formed quickly in a disk of gas and dust *(3.69 MB)*

*(1.94 MB)* *(1.03MB)*

Zoom-In/Visualization of TMR-1C Planet

**Gamma-Ray Burst Found to be Most Energetic Event in Universe**

*STScI PR 98-17*

Animation of Gamma Ray Burst *(2.63 MB)*

**Hubble Provides Multiple Views of How to Feed a Black Hole**

*STScI PR 98-14*

Simulation of a merger between an elliptical and a spiral galaxy that may have shaped Centaurus A *(5.24 MB)*

HST/NICMOS image with superimposed diagram *(5.69 MB)*

Centaruas A Feeding a Black Hole *(4.76 MB)*

Zoom Sequence: Ground-based image of Centaurus A *(12.93 MB)*

**Shock Wave Sheds Light on Fading Supernova**

*STScI PR 98-08*

*(2.57 MB)*

Animation of Super Nova 1987A

**Hubble Reveals Stellar Fireworks Accompanying Galaxy Collisions**

*STScI PR 97-34*

Zoom into the Antennae Galaxies *(3.9 MB)*

Computer Simulation of Galaxy Collision *(2.2 MB)*

Artist's Concept of Hypothetical Collision of the Milky Way with the Andromeda Galaxy *(2.2 MB)*

Galaxy Merger Evolution Sequence *(1.3 MB)*

**Hubble Reveals Huge Crater on the Surface of the Asteroid Vesta**

*STScI PR 97-27*

Asteriod Vesta Animation *(1.49 MB)*

**Hubble Probes Inner Region Of Comet Hyakutake**

*STScI PR 96-14*

Animated star chart showing path of Comet Hyakutake *(2.81 MB)*

**Hubble Finds Thousands of Gaseous Fragments Surrounding a Dying Star**

*STScI PR 96-13*

Animation showing formation of the Helix Nebula *(1.13 MB)*

**Warped Disk in Beta Pictoris**

*STScI PR 96-02*

Animated model of star with disk and planet *(522KB)*

**The Hubble Deep Field**

*STScI PR 96-01*

Animation of HDF Zoom in *(1.81 MB)*

## The Orion Nebula

STScI PR 95-45

MPEG Mosiac Of Orion Nebula *(475 KB)*

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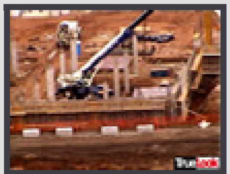

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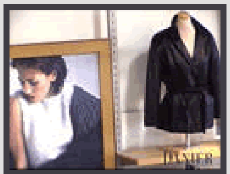

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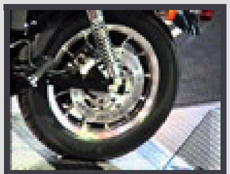

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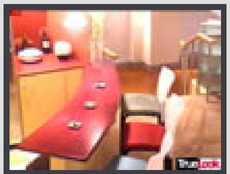

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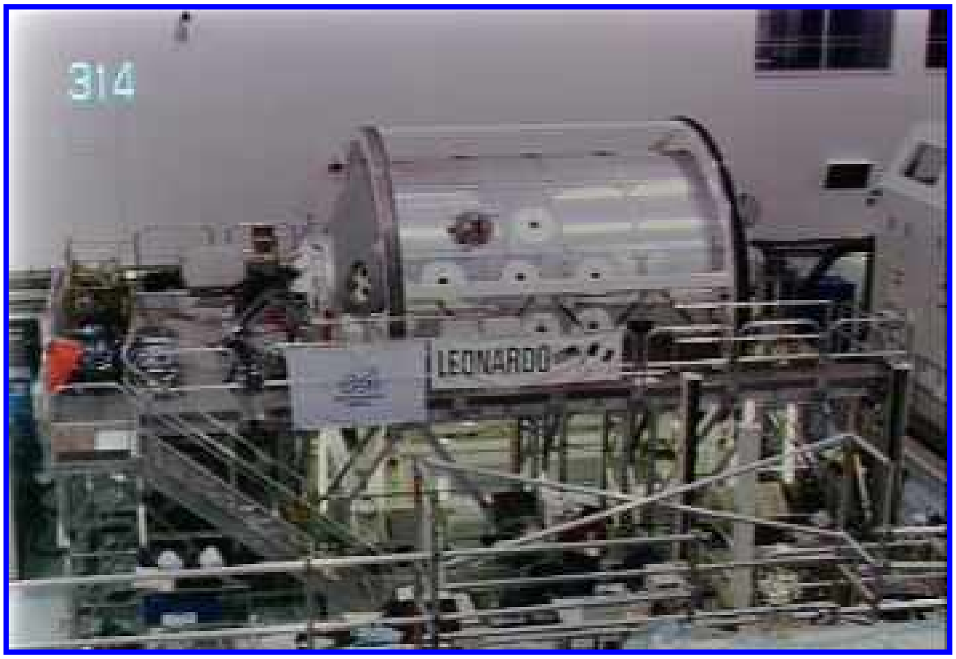

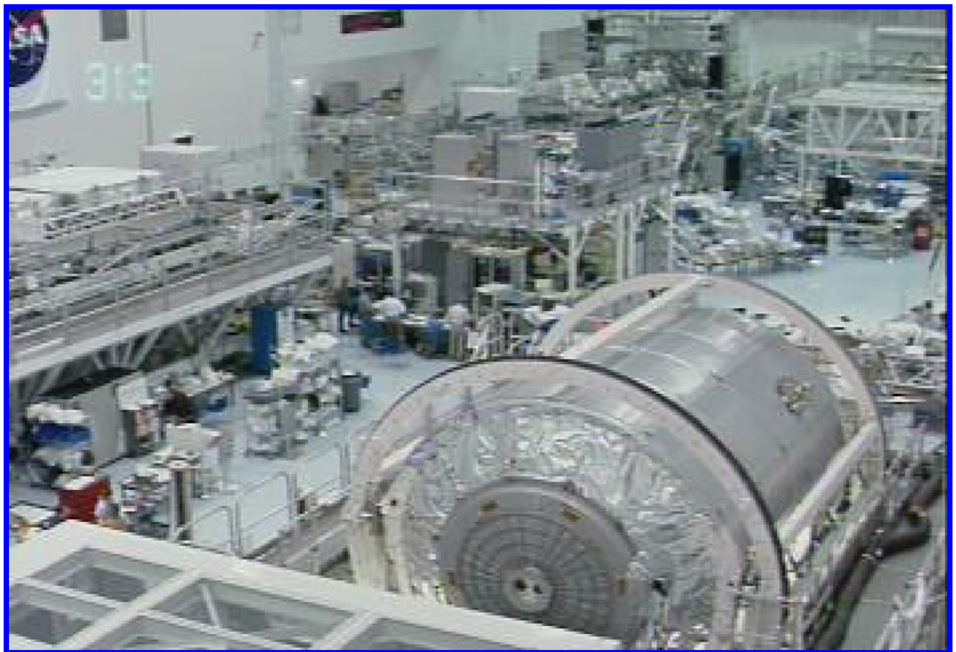

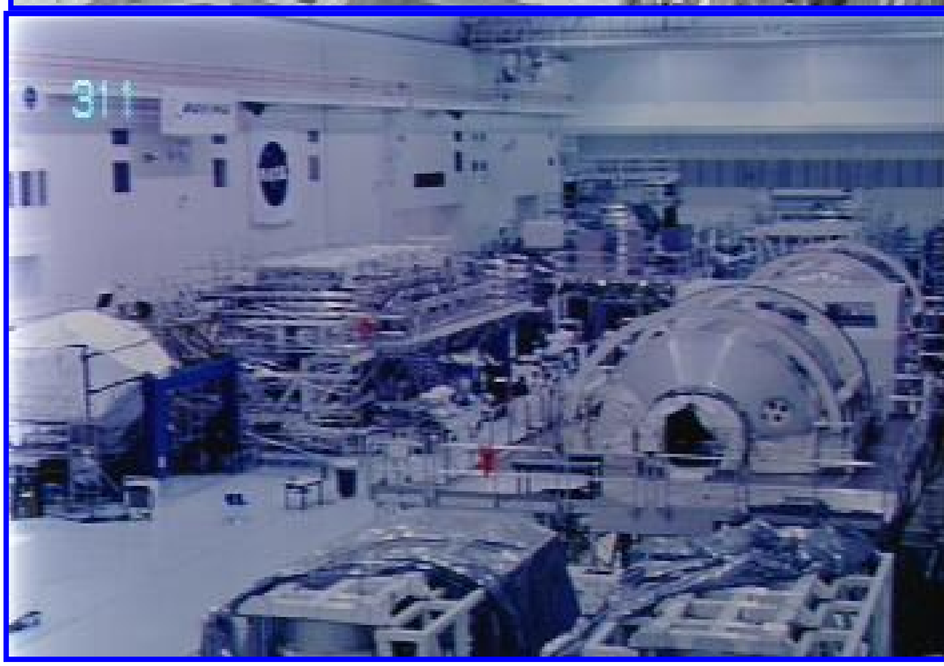
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Space Station Processing Facility High Bay

Replay Z1 Truss Turnover Ceremony - 7/31/00 12:30 EST

MEIT Testing Video Feed

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- Other KSC Live Video Feeds
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**Last Revised:**Wednesday, March 7, 2001 08:12:00 EST (J. Dumoulin)

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Page Last Updated: March 8, 2002

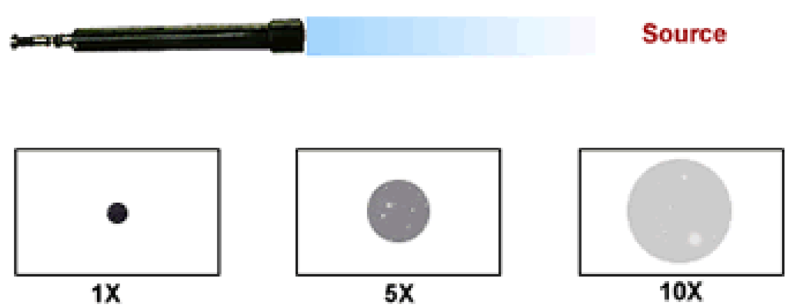
# Hubble and Light



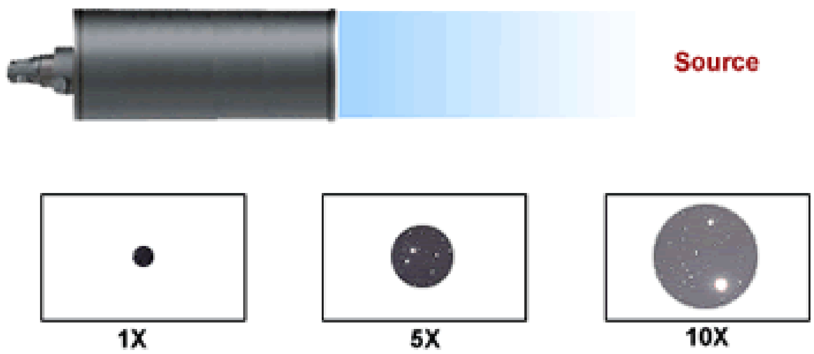
## How Hubble Captures Images

In order to understand what Hubble sees, it is necessary to understand what astronomical telescopes do, and how they differ from the ones on the ground.

All telescopes collect light and magnify it. When an image is magnified, it gets dimmer. This is because the light coming from the object is spread out over a larger area. If we try to magnify the image too much, it gets so dim when we look through the telescope we don't see anything at all.




Astronomers have come up with several creative ways to obtain more light and make their images brighter. One way astronomers get around this problem is to make the telescope larger. A larger telescope will collect more light from the object, so the image is brighter too.




Another way is to use a recording device instead of the human eye. Recording devices can be photographic films or electronic detectors. Unlike the human eye, these methods have an advantage in that exposures of faint objects can made over a very long time. The exposures can be as long as 45 minutes per image. The images can then be added together to add up to exposure times of up to 38 hours for each filter. The longer an exposure is, the more light falls on the film. As long as the image is held very still, eventually an image of the faint target will appear. Another advantage of recording devices is that a permanent copy of the observation is obtained.

Hubble looks at objects which are so distant and faint, that even with highly sensitive CCD detectors (which are many times more sensitive than the human eye) it must expose for long periods of time. These exposures can be for 30 minutes or more. Sometimes hundreds of half-hour exposures are added together to produce one very long exposure. Observations using CCD detectors can also be added together, which is something that cannot be done with photographic film.

# Hubble and Meteor Showers

Driving Hubble
Cruise Control
Maintaining Hubble
Mission Control
The Hubble Team
Goto SM3B WEBSITE

**On Nov. 18, 2001, sky watchers will see a dazzling storm of Leonid meteors. Click here for times and more details.**

*Several times a year sky watchers are treated to spectacular nighttime displays of "shooting stars". These "shooting stars" are actually meteor showers. Many showers are familiar to sky-watchers, as they occur year after year.(Image: NASA/ESA)*

- 1998 Leonids images
- The Leonids and HST
- What are Meteor Showers
- The Leonids and the Space Shuttle
- All About the Leonids
- Leonids Links
- How do the Leonids Affect Us?

**What Are Meteor Showers?**

Meteors are actually chunks of rock and dust, left by passing comets. When the Earth travels along its orbit, it runs into clouds of this debris. Due to the high relative speed between the Earth and the meteors, they glow brightly as they burn up high in the Earth's atmosphere.

**All About the Leonids**

In mid November, there is an annual meteor shower called the Leonid Meteor Shower, or simply, The Leonids. The Leonid shower gets its name because the meteors appear to be coming from the constellation Leo. The comet responsible for the Leonid meteor shower is the comet Temple-Tuttle, which passed close by the Earth in 1998.

Temple-Tuttle travels in a highly elongated ellipse around the Sun with a period of 33 years. As the comet gets close to the Sun, ice is boiled off, leaving dust and bits of rock along its path. This debris continues to follow the same orbital path as the comet, and eventually spreads out over the entire orbit.

Every year in November the Earth passes near the comet's orbit and encounters the ice and the rock. This gives rise to the Leonid shower. Naturally, this debris is most plentiful close to, and behind the comet. For one or two years after perihelion, the point where the comet is closest to the Sun, the showers are especially strong. Exceptionally strong showers are called "storms." The strength of the meteor shower or storm is indicated by the rate that particles are observed in the sky.

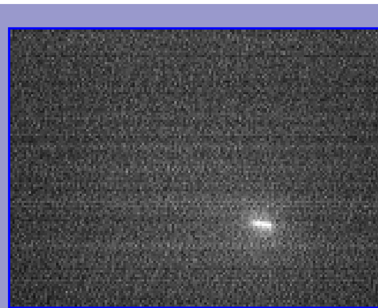


Image above is one frame of meteor recorded from a NASA balloon flight. (approx 3:32 a.m. CST Nov 17).
**Click for 131KB animated gif**

Movie highlights from the balloon over Alabama.

Balloon view of Leonids (Realplayer)
Credit NASA/Marshall Space Flight Center

Typical meteor showers provide between five and 10 "shooting stars" per hour. Storms are much stronger and have counts in the hundreds. The strongest recorded Leonid meteor storm, in 1966, provided over 150,000 counts per hour for about three hours.

### How do the Leonids Affect Us?

The incoming rain of particles is not a concern to anyone on the Earth, since the particles burn up high in the atmosphere. Orbiting satellites and spacecraft, however, can be affected by meteor impacts during a shower or storm. Although each particle is very small, typically about the size of a grain of sand, it is moving extraordinarily fast, about 155,000 mph. At this speed a typical grain of sand could have the same impact as a .22 caliber bullet. This impact is enough to damage sensitive spacecraft parts.

### The Leonids and the Space Shuttle

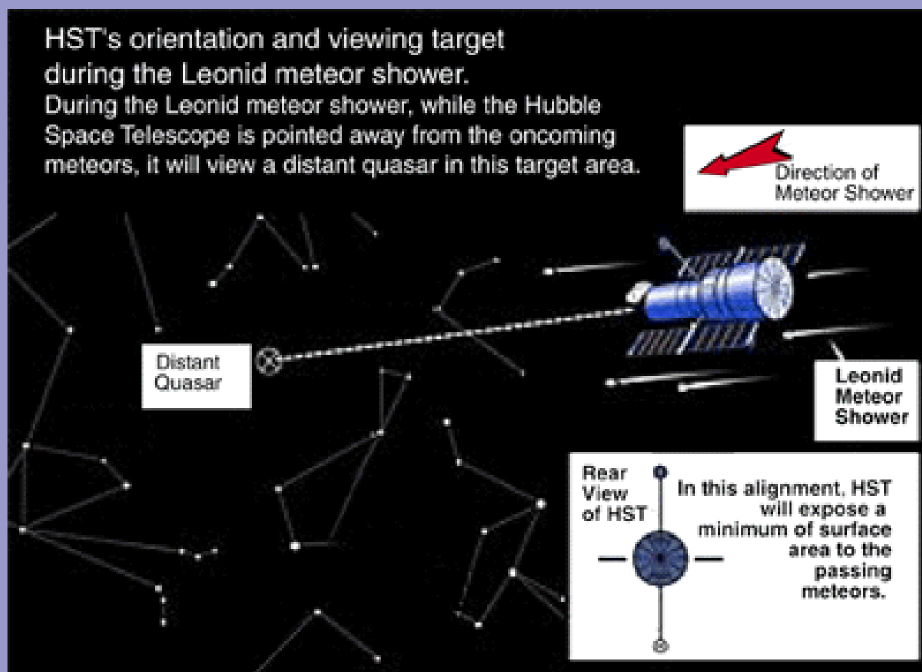
Because of these reasons, precautions are taken to avoid, or minimize damage during strong showers or storms. As a general precaution, no shuttle flights are scheduled during the major meteor showers, including the Leonids. Although meteor strikes are very unlikely, the potential damage from even a single hit to the shuttle could be severe.

### Hubble and The Leonids

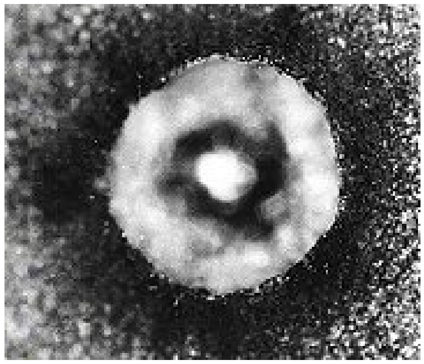
Satellites must also take precautions and are oriented so as to minimize the likelihood of impacts to any vital systems. The operations of the Hubble Space Telescope are designed to protect its sensitive spacecraft instruments and systems during this period. During the current safe mode, Hubble's orientation is being reassessed.

**In past years, Hubble was oriented directly away from the incoming stream of particles.**

**In this configuration, Hubble presents the smallest possible cross-section (or target) for the particles to hit. In addition, the solar arrays, which are the only power source on telescope, will be oriented parallel to the meteors' path so that the meteors will see them "edge-on".**




The largest target Hubble presents in this orientation is the aft end of the telescope, which is the most protected and least damageable part of the telescope. Hubble has also be uploaded with a modified safe-mode program. In the event of equipment failure during the Leonids, the new program allows the telescope to maintain the safest orientation with respect to the meteor shower, and also remain in a stable configuration until corrections can be made.



**A 900 micron impact crater found on the HST WF/PC1 camera radiator in 1994, after it was removed from the HST and returned to Earth.**

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**Leonids Links**

**NASA's Space Academy**
**BadAstronomy**
**Leonids Photo Atlas**
**STScI 1998 Web page covering HST operations during Leonids**
**Sky and Telescope 1998 Leonid Page**
**1998 NASA Space Science News Article**
**The Upcoming Leonid Meteoroid Storm and its Effect on Satellites**
**Testimony to the U.S. House of Representatives May 21, 1998**
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# STOCC Team



Just as the astronauts are training extensively for the next servicing mission, so too is Hubble's Flight Operations Team in the Space Telescope Operations Control Center (STOCC). Shortly after a servicing mission shuttle launch, this team will prepare Hubble for the on-orbit service call.

They will begin by having the telescope transition from normal science operations to a "ready for servicing" condition. The team will command Hubble to its capture attitude and configure it for rendezvous with the Space Shuttle. They will command Hubble's aperture door to close and the high gain antennas to be stowed in preparation for capture by the Shuttle's robotic arm and berthing in the payload bay. The solar arrays will remain deployed however following berthing, Hubble's power will be provided by the Shuttle. To aid astronauts in their servicing tasks, the Telescope will then be rotated to several different positions on its berthing platform to allow easy access to the equipment bays.

**STOCC Team SM3A Images**

After the new equipment is installed, STOCC ground controllers will command tests on the newly installed items. These tests will be done immediately after installation, with the crew positioned at a safe location, to determine if the installed equipment will require any further astronaut activity. Later, while the crew sleeps, the STOCC team will perform more detailed functional checkouts of the installed equipment to determine if further work is necessary. After all servicing is completed, Hubble and the shuttle will be configured for battery charging. The Shuttle crew will then transfer the telescope to internal power, disconnect the power feed, and using the robotic arm, position Hubble for deployment. The STOCC will command the deployment of the high gain antennas and opening of the aperture door. All equipment powered off for servicing will be reactivated and checked out. Hubble will then be released. Operational re-commissioning of the telescope will take place, and normal science operations will resume.


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# STOCC Positions



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- Mission Support Room (MSR)
- Mission Operations Manager (MOM)
- System Engineering and Evaluation Room (SEER)
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- STOCC "Back Room" Positions
- HST Systems Engineering Specialists
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- Mission Operations Room (MOR)
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## Servicing Mission Operations Room (SMOR)

The Servicing Mission Operations Room (SMOR), is used to support preparation, testing and simulations for Hubble's servicing missions while routine operations are conducted simultaneously at the Mission Operations Room (MOR). The SMOR and MOR can quickly be configured to support routine operations or any other Hubble spacecraft support activity.

**The SMOR consists of the following positions:**

Mission Operations Manager (MOM)
HST Systems
HST Systems Engineering Specialists

## Mission Operations Manager (MOM)

The MOM is the controlling authority for all STOCC operations. The MOM coordinates with the Servicing Mission Manager (SMM) and Systems Manager for all nominal mission operations, contingency operations, and Command Plan (CP)/ Servicing Mission Integrated Timeline (SMIT) replan activities. The MOM Informs the Servicing Mission Manager of operational status, coordinating all "GO/NO GO" calls for the mission.

## HST Systems

The HST Systems personnel interface with Johnson Space Center Payload Systems. They provides HST systems engineering and analysis support to the Systems Manager and coordinates all operational activities with STOCC Control, HST Systems Support, HST Engineering Analysis Support, the Extravehicular Activities (EVA) Specialist, and Space Support Equipment (SSE) Systems.

## HST Systems Engineering Specialists

***HST Systems Engineers consists of the following positions:***

**Data Management Systems (DMS)** - The DMS engineer is responsible for the engineering and analysis support for the Data Management System. The DMS is Hubble's "nervous system" . It routes commands received from the ground or generated onboard to the various devices on the spacecraft. The DMS also receives data from these devices and formats it for transmission to the ground.

**Electrical Power Systems (EPS)** This includes the solar panels that convert solar energy into electrical power and batteries that provide power when the sun is behind the earth. During a servicing mission, power is primarily supplied by the Shuttle. The EPS also includes hardware to route the power to various devices on the telescope and includes fuses and other protection against electrical problems.

**Instrumentation and Communication (I&C)** - This position manages Hubble Spacecraft communications during all flight phases throughout the mission.

**Mechanical System (MS)** - The mechanical system position is responsible for verifying all Hubble's mechanical activity, including solar array movement, and providing the analysis of mechanical activity. The position is in direct support of MOM.

**Pointing Control System (PCS)** -The PCs engineer is responsible for the engineering and analysis support for the Pointing Control System (also known as the Attitude Control System). The PCs includes sensors such as gyroscopes, star trackers, and the fine guidance sensors. These determine where Hubble is pointing and how fast it is moving, and make corrections to hold it very stable. The PCs use reaction wheels and magnetic torquers to move Hubble from one part of the sky to the other.

**Orbital Replacement Unit System Engineers** - These positions change over the course of the mission depending on which system on board Hubble is being worked on. These positions include:

**Optical Telescope Assembly (OTA)** - The OTA includes the main telescope optics, including the 2.4 meter diameter primary mirror. The three fiine guidance sensors are also the responsibility of the OTA engineer.

**Safing Engineer (SAF)**- The Safing engineer is responsible for the engineering and analysis support for the onboard safing systems. A telescope as sophisticated as Hubble requires constant vigilance to ensure all of its systems are operating safely and as expected. The safing system includes programs that run in two separate computers, checking on Hubble's performance.

**Scientific Instruments systems (SI)** - the subsystem responsible for the instruments on-board that are used for observations

## Mission Operations Room (MOR)

The MOR is used to control and monitor Hubble flight operations, engineering and science activities. It contains the operational workstations and displays required to monitor the health and safety of the spacecraft. It also provides the system capability to command the spacecraft and monitor all engineering and science activities.

***The MOR consists of the following positions:***

**STOCC Operations (STOCC OPS) -** The STOCC OPS provides a direct interface to the Johnson Space Center Payload Operations position. STOCC OPS coordinates the operational application of the Command Plan (CP) within the Servicing Mission Integrated Timeline (SMIT) scenario and coordinates all STOCC operations and mission scheduled events and/or activities.

**Shift Supervisor (SS) -**The SS is the lead controller for the flight operations team. The SS issues all commands to Hubble and is responsible for the configuration of the ground system. This includes implementing planned activities, maintaining Hubble's health, controlling STOCC commanding, and coordinating the transfer of data from the Mission Control Center (MCC) at Johnson Space Center, to the STOCC.

**STOCC Operations Support Team -**The STOCC Operations Support Team is responsible to STOCC Control for overall Hubble subsystem status. (The members of this team who reside in the MOR, are also members of the HST Servicing Mission Flight Control Team (FCT)). The team is comprised of the following console engineer (CE) positions:

- **CCS Support -** CCS is an acronym for Control Center System that is the computers and programs used by all controllers and engineers in the STOCC. The CCS Support position helps solve problems and assist users with CCS questions.
- **Data Management/Communications/Power System Controller (DMS/I&C)** - The DMS controller evaluates the status of the data management system, which processes commands and formats, records, and plays back data for transmission to the ground. DMS is also responsible for the communications system and the power system that includes the solar panels and batteries.
- **Mission Support Analyst (MSA)** -The MSA is the STOCC timeline expert. Hubble servicing mission operations are conducted primarily according to two key documents, the Servicing Mission Integrated Timeline (SMIT) and the Command Plan. The MSA ensures that operations are following the plan. The MSA is a member of the planning team that updates these plans during the mission on a daily basis or more often if required.
- **Pointing Control/Science Instruments/Mechanisms Controller (PCs)** - The PCs controller is responsible for evaluating the status of the pointing control system that stabilizes the HST and moves it to point at a specific target. He/she is also responsible for the five science instruments and the mechanical devices onboard the vehicle.
- **Sensor Analysis and Calibration Controller (SAC)** - The SAC controller runs the computer programs used to very accurately calibrate the onboard pointing control system hardware, such as the Fine Guidance Sensors, gyroscopes, and reaction wheels. SAC also produces computer loads for the onboard computers, such as ephemeris loads.

Each Console Engineer is responsible to the STOCC Control for the execution, completion, and verification of real-time command activities involving their subsystems, continuous monitoring of their subsystems, and if necessary, alerting both STOCC Control and the SS of spacecraft anomaly recognition.

**Ground System Manager -**The Ground Systems Manager (GSM) is the focal point for all ground system activities. The role of Ground System Managers is to support the Servicing Mission through their experience and expertise with the Control Center System (CCS) ground system, data flows, networking, and overall HST/JSC/Orbiter operations. During Servicing Mission simulations and the mission itself, STOCC OPS will assign the GSM to assist ground system and network troubleshooting efforts specific to the Mission Operations Room (MOR) and Servicing Mission Operations Room (SMOR).

## Mission Support Room (MSR)

The MSR directly supports day-to-day flight operations and engineering activities by providing off-line mission planning functions and data processing. MSR personnel perform engineering data processing and mission analysis. They also support problem assessments and resolutions.

## System Engineering and Evaluation Room (SEER)

The SEER is used by the HST subsystem engineers to perform in-depth subsystem analysis; to conduct simulated subsystem tests; to integrate new databases; and to validate new ground software and updates to flight software. This room has the same capabilities as the MOR and also can be configured as a backup operations control room.

## STOCC "Back Room" Positions

**Thermal Subsystem**
The Thermal Control Subsystem engineers must carefully monitor the temperatures of the telescope and the new replacement hardware. During servicing, internal components normally heated and protected by the insulated doors, are exposed to the extreme thermal environments ( deep space pointing is coolest, direct sun is hottest).

**Engineering Support System (ESS)**
The ESS team has access to all of the historical telemetry data from Hubble since deployment in 1990. They have the ability to retrieve and plot voltages, temperatures, currents, speeds, torques, switch positions, and other values.

**Anomaly Response Manager (ARM)**
The Anomaly Response Manager team is called into action to resolve problems which arise during the mission. They act as systems engineering to coordinate a multidisciplinary analysis and response for any trouble.

**Servicing Mission Planning and Replanning Tool (SM PART)**
A servicing mission requires the coordination of hundreds of engineers and controllers, two spacecraft, communications relay satellites, and astronauts. The SM PART team prepares and revises a time-line and command plan that depicts every detail of this servicing symphony.

**Simulation Team (SIM TEAM)**
Training is key to ensuring mission success. The year leading up to the mission is spent simulating the mission. The simulation team crafts clever failures to present to the operations teams.

**Electronic Data Control Center (EDOCS)**
Documentation for technical reference and dissemination of tactical data and plans requires real time response. "Real time" means fast. The EDOCS team created and maintains an intranet site with all of the information needed to plan and execute the servicing mission.

**Data Operations Control (DOC)**
"Behind every successful console, there is a server", You may now be familiar with engineers and controllers huddled over their consoles analyzing spacecraft performance. The team at the DOC operates all of the computer equipment which processes Hubble's data and prepares commands.

**Network**
The HST network is essential to tie together all the control computers. The network team had assembled a high speed, high reliability network to fulfill the servicing mission requirements.

**Video Imaging and Photographic Requirements (VIPR)**
This group maintains the electronic Video Imaging and Photographic Requirements (VIPR) This group maintains the electronic imaging system and database for the Hubble project. During the mission, the VIPR locates

images in real time to assist with the evaluation of anamolies and to plan for off-nominal tasks. The VIPR also works with Shuttle crew members to capture specific video images of the newly replaced hardware in Hubble so we can photographically document the modifications. This also helps the EVA community on the ground to assess the task and ensure everything has been successfully accomplished.

## MET (Mission Elapsed Time) Clock

The Clock shows the time in four different ways.

| | |
|---|---|
| **Line 1**: | Greenwhich Mean Time (GMT) |
| **Line 2**: | Mission Elapsed Time (MET) (the time elapsed since the start of the mission) |
| **Line 3**: | Variable Time (this time is set to either a particular phase of the mission or to MET) |
| **Line 4**: | Spacecraft Time (this is the time as it is displayed by the space shuttle and should be the same at the MET) |



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# Hubble's Ground System

Driving Hubble
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The Hubble Team

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Mission Control
Select...

Imagine using an ordinary personal computer to view the inner workings of the world's premiere observatory in space. This is now possible for Hubble engineers, thanks to the new, super-secure, user-friendly ground system.

The ground system is the central hub for controlling the telescope's day-to-day operations and the support of on-orbit servicing missions. With this new system, Hubble engineers are no longer tied to their workstations. They can view the telescope's vital signs from anywhere in the world with a standard, off-the-shelf computer and an internet or modem connection.

The system may be operated in either a small, single server mode at a user facility or in a high performance multi-server mode, the configuration used in Hubble Mission Control. This newly redesigned control system has dramatically improved overall Hubble performance and drastically reduced the cost of operations and systems maintenance.

Users can customize their databases to suit their particular application, including:
• Operations.
• Servicing mission simulations.
• Payload and spacecraft flight software development.
• Operator training.
• Procedure development and verification.
• Software maintenance and testing.
• New spacecraft hardware testing and integration.
• Science instrument development.

**Architecture**: The new system consolidates the functions of the five original systems into a single, streamlined system that provides the full spectrum of spacecraft control, analysis, data management, command management, and subsystem calibration.

**Security**: A highly secure design based on concentric networks provides controlled transmission of data among the networks while absolutely protecting the telescope and its operating systems, command functions, and databases from unauthorized use or change.

**Efficiency and Flexibility**: Hubble engineers can directly access engineering data from anywhere in the world. Prior to this new system, users had to be located at the data source. It now allows quicker response to spacecraft anomalies, decreased travel expenses, and improved team interaction.

**Information Access**: Users have nearly instantaneous access to Hubble data, including the vast warehouse of archived information. (Hubble generates the information equivalent of a standard set of encyclopedia, i.e., about 600 Mbytes, each and every day.) Operators can request data in real time and monitor conditions as they change. They can obtain visual displays of any requested telemetry, and they can produce graphs and perform analysis in real-time at the consoles.

**Automation**: Engineering telemetry management is now automated and merges real
time and stored spacecraft data. This reduces the delay in obtaining data for analysis and trouble shooting from 648 hours to 8 hours. In the past, this process has involved as many as sixteen people. That number is now reduced to zero. The process for collecting and merging real-time and spacecraft-recorded data is now fully automated.

**Speed**: Users can now make very rapid, complex queries over wide time spans with excellent performance.

**Monitoring**: The system is designed to monitor itself at the network, hardware and software application levels, reducing maintenance and operations costs.

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# The Hubble Team



Hubble Teams
Select...

## World Class Teamwork...

The Hubble Team is a **diverse group** united in a **common goal**: To keep Hubble healthy and producing breakthrough science. Like an orchestra performing a symphony, the Hubble Team melds its varied talents, strengths and expertise to function as a single entity.

From astronauts to accountants, and scientists to secretaries, every member of the Hubble team plays a vital role. Mission success requires the **close coordination of many, many individuals**, as well as collaboration with other institutions, including Kennedy Space Center, Johnson Space Center, NASA Headquarters, the Space Telescope Science Institute and the European Space Agency. Industrial and educational partners from across the nation and around the globe are essential members of Hubble's science and engineering teams.

Hubble's "core team" is the Project's backbone. The Team uses its extensive expertise in the following areas to choreograph Hubble's successful missions:

- Astronomy
- Astrophysics
- Engineering
- Ground system operations
- Software development
- Logistics
- Integration and testing
- Administration
- Resources
- Procurement
- Fabrication
- Configuration management
- Scheduling
- Property control
- Documentation
- Photo and video documentation
- Graphic arts
- Technical writing
- Presentation support
- Technology transfer
- Outreach

This partnership of **scientific expertise and technological excellence** allows the Hubble Space Telescope to continue as one of the "crown jewels" of NASA - year after year, mission after mission.

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# Hubble and Education

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The Hubble Team

Goto SM3B WEBSITE

Hubble Teams
Select...

- **Hubble and Innovative Science Education**
- **Hubble Engineering Competition**
- **PCs in Space Educational Software**
- **Hubble Science Programs**
- **Educational Outreach at the Space Telescope Science Institute**

Hubble science and outreach activities are an integral part of science education around the world. Students, universities and research organizations all over the world use Hubble data to learn critical research methods.

The Hubble Program uses the telescope's amazing images and discoveries to create public outreach activities for an entire generation of school children. These future leaders and explorers will have the benefit of a view of the Universe that was a figment of the imagination just a decade ago.

The NASA Strategic Plan mandates that we involve the education community in our endeavors to inspire America's students, create learning opportunities, enlighten inquisitive minds, and communicate widely the content, relevancy, and excitement of NASA's missions and discoveries. Educational programs such as Hubble's help ensure that a continuing supply of scientists, engineers, and technologists will be available to meet the needs of the 21st century.

**Hubble and Innovative Science Education**

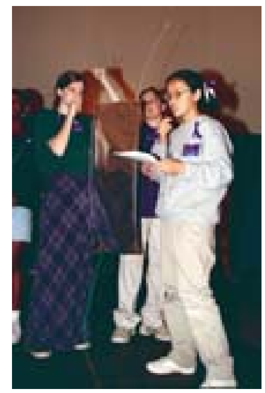
Each year over 7000 school groups visit the Hubble Integration Facility. Among them is the SUNBEAMS program (Students United with NASA Becoming Enthusiastic about Math and Science).

The program is designed to encourage positive and enthusiastic attitudes towards

math and science among middle school students.

Students visit the Hubble testing and integration facilities, are allowed to handle materials in the Thermal Systems Support Lab where Hubble's thermal blankets are sewn, and interact with Hubble staff. This unique, hands-on opportunity creates an immediate connection between Hubble's breathtaking images and the people and skills necessary to make the telescope work.

**Hubble Engineering Competition**



A Hubble Space Telescope engineering competition, sponsored by the Hubble Program, the GSFC Education Office and the GSFC Public Affairs Office (PAO) Contractor Consortium, was held with the regional participation of middle school students (Grades 6-8). The competition involved integrated disciplines such as engineering, science, and mathematics. This outreach event focused on school teams learning and utilizing the engineering process to solve real-life or potential real-life issues encountered by engineers working with Hubble.

The competition was a valuable education initiative supporting the development of higher-level thinking skills and problem-solving skills for all students who participated. The use of the engineering process at the middle school level enhances students' ability to practice critical thinking skills in a team environment while providing a background for some career choices in engineering. This type of competition is more challenging than the typical science fair because contestants must use their scientific knowledge to devise a creative solution within a relatively short period of time.

**Educational Outreach at the Space Telescope Science Institute**

At the Space Telescope Science Institute (STScI), where Hubble's images are processed and analyzed, education plays a major role in outreach. STScI supports teachers of grades K-12 by providing web-based and printed materials that promote science, math, and technology skills. The award-winning Amazing Space website provides interactive lessons and activities, which are based on national educational standards. Amazing Space modules are developed by teams of scientists, teachers, graphic artists, web programmers, curriculum specialists, and education evaluators. STScI also provides posters, trading cards, lithographs, bookmarks, and information specifically designed for teachers and students without access to the Web.

STScI also supports science museums and planetaria. They provide Hubble expertise, multimedia shows, and exhibit materials tailored to the needs of each venue. STScI has partnered with Goddard and the Smithsonian to develop an extensive, traveling Hubble exhibit, which debuts at Chicago's Adler Planetarium in June of 2000. Over the next five years, a large and small version of this exhibit will travel to museums and planetaria across the country. These exhibits, along with STScI's other educational outreach products, bring the excitement of Hubble science closer to us all.

**PCs in Space Educational Software**

NASA teams with industry partners and educators to create interactive, educational software showcasing Hubble images to inspire students around the world. PCs in Space, Jackson and Tull's free software, is an innovative program available through the internet. The educational material incorporates Hubble's latest discoveries into existing curricula, enhancing the overall educational experience. This enormously successful program has reached 4.5 million students in the past five years, sparking enthusiasm for space science among a new generation.

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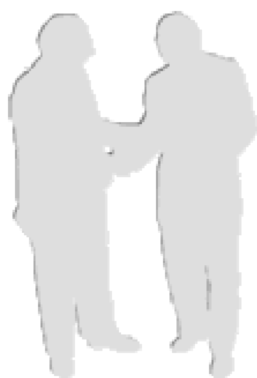
# Hubble and Industry



## Partners in Innovation

See List of Partners





No enterprise as complex as Hubble can be successful without the dedication and support from a wide range of technical disciplines. These are provided through Hubble's industry partners, bringing the most advanced and cost-effective solutions to the unique challenges of creating, operating, and strengthening the world's most powerful observatory.

Hubble's industry partners include companies from all over the United States and the world. They make everything from lubricants to solar arrays. They work side by side with their government partners to maintain and operate the telescope 24 hours a day, 7 days a week. In the end, it is the staff of all these Hubble organizations who routinely make the personal sacrifices when necessary, to keep our observatory operating flawlessly.



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# List of Industry Partners

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AASC
ACI Electronics Corporation
Advanced Circuit Technologies
Alatec Products
Alliant Techsystems, Inc.
AlliedSignal
Almag Plating
AMP Inc.
Apnet
Arrow Zeus Electronics
Associated Spring
Astrium Ltd.
Astrium GMBH
Astro Instrument Corporation
Atlantic Science and Technology
AURA
Aviation Equipment
Avnet Inc.

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BAE Systems
Ball
Bally Ribbon Mills
Barden Precision
Barr Associates, Inc.
BD Systems
Bechdon
BEI Sensors and Systems Company
Boeing
Bradley Enterprises
Brush Wellman

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C-S Metals
CalTech
Cannan
Capstone Electronics
Castrol Inc.
CDA InterCorp
Ceramic to Metal Seals
CES
Clement Engineering
Climax Specialty Metals
Coastal Optical Systems
Conexant
Contravis Space
Copper & Brass Sales
Courtaulds Performance Films
CSA Engineering, Inc.
CSC
CYTEC-FIBERITE

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Denton Vacuum, Inc.
E.V. Roberts
Eagle Precision
Eastern Plating
EER
Energy Solutions International, LLC
Epner Technology
Fastener Depot
Fry Steel

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General Dynamics
Genesis Engineering Co., LLC
Global Science & Technology
Hardware Specialty Co.
Helicoflex Co.
Hernandez
HISCO
Honeywell Technical Solutions
Hypertronics Corporation
Indium Corp of America
Industrial Retaining Ring
Interface Welding
ISI

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Jackson & Tull
Jodin Yvon-Spex

Kaydon Custom Bearings
K R ANDERSON
Kenig Aerospace
Kyocera America, Inc.
Lake Shore Cryotronics
Litchfield Precision
Lockheed Martin
Lockwood Software
LSEI

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M & D Machine
ManTech
Marconi Applied Technologies
Marlow Industries
Maryland QC
Max Levy & Associates
Maxwell Technologies
McMaster Carr
Mega
Melles Griot
Minco Products, Inc.

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Nanonics Corporation
Newark Electronics
Newport Corporation
Nusil Technology
Oceaneering Space Systems
OerliKon Contravis AG
Omitron
Omnetics
Optical Filter Corporation
Optical Research Associates
Orbital Science Corporation

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Pacific Coast Technology
Penn Camera
Photo Chemical
PNE
PRO-PAC
Raytheon
Research Devices, Inc.
Research Electro Optics
Robert C. Byrd Institute
Rockwell Science Center

SAES Getters
SAFT America, Inc.
Samson Metals
SAVA Industries
Sea Wire & Cable
SGT
Sheldahl Co.
Sherburn Electric Corporation
Southwest Products Company
Spacecraft System Engineering Services
Space Systems Integration
Specialty Manufacturing
Spectrum Laser
Stern and Stern
SUMATECH
Surmet
SVG Tinsley Laboratories
Swales Aerospace

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Tifco-Spline
Titanium Industries
Tomas & Betts
TOPER Manufacturing
Toshiba America
Total Plastics
TFE
TTI, Inc.
TW METALS
Tyco Engineered Systems

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Unisys
United Supertek, Inc.
University of Arizona
University of California
USA
Vantage Systems
Washington Valve
Wolcott Park
Yellow Springs Instruments
Zeus West

# The Engineering Team




Hubble's engineering team spans scores of specialties and at least as many locations. Its ranks include some of the finest minds in Government, industry and education. From detectors and optics to, thermal control and contamination - and everything in between - Hubble's engineering team blends its talents seamlessly to achieve mission success.

**Planning Hubble's Spacewalks**
The group in charge of spacewalks, or extravehicular activity (EVA), designates an expert with "ownership" for each item planned for change-out. Early in the design process, this EVA expert works with the hardware design engineers to ensure success on orbit.

**Designing Instruments and Equipment**
To develop Hubble hardware, engineers start with a requirement. Then they brainstorm to develop alternate design concepts. For flight hardware and on-orbit work, the engineering process is built around feedback, refinement and expecting the unexpected. The philosophy is to design for success, but always be prepared for failures and surprises. "What if?" plays a starring role in the design process.

Design engineers train in the Neutral Buoyancy Laboratory (NBL), a 6.2-million gallon pool that simulates zero gravity. The NBL includes mock-ups of Hubble, the Shuttle's cargo bay, and the instruments being changed out. Working underwater in pressurized astronaut suits, the designers practice moving with and operating tools and changing out instruments. They can then apply their understanding of movement, visibility, and pressurized suit and glove operations to the design process.

The equipment is assembled, tested and prepared for shipment to the launch site in the world's largest clean room at the Goddard Space Flight Center in Greenbelt, Maryland. This is where the astronauts train with actual Hubble flight hardware. The crew also trains extensively for each mission at Johnson Space Center in Houston, Texas. At Kennedy Space Center, Fla., the combined Hubble/Shuttle team continues integration, testing and final preparations for launch.

**Expecting the Unexpected**

The ground and astronaut crews practice intense and detailed mission simulations to train for possible real-life anomalies. This tests team readiness and helps the engineers develop and validate procedures and hardware. It prepares the entire team for anything reality might throw at them during the actual mission.



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# Hubble and the European Space Agency (ESA)



## International Cooperation

Over the next 10 years European scientists plan to use Hubble as one of their prime research tools, and they also expect to benefit from synergy between Hubble and the ground-based 8-meter class telescopes that are becoming available to scientists in Europe.

ESA astronauts have taken part in two of Hubble's 3 servicing missions to date. Claude Nicollier (Switzerland) worked with American colleagues on the First Servicing Mission, when Hubble's initial optical problems were repaired. On the latest, Servicing Mission 3A, both Claude Nicollier and Jean-François Clervoy (France) were members of the crew.


Jean-François Clervoy


Claude Nicollier

The partnership agreement between ESA and NASA was signed on October 7, 1977. ESA has provided, among other items, two pairs of solar panels and one of Hubble's scientific instruments (the Faint Object Camera). 15 European scientists are contributing to the science operation of the Hubble Observatory and are currently working at the Space Telescope Science Institute in Baltimore (STScI). In return for this contribution, European astronomers have guaranteed access to 15% of Hubble's observing time.

Scientific operation of the Hubble Observatory is the responsibility of the Space Telescope Science Institute, which is run for NASA by the

Association of Universities for Research in Astronomy (AURA).

The Space Telescope European Coordinating Facility (ST-ECF), hosted by the European Southern Observatory (ESO) in Garching near Munich, Germany, provides support to European Hubble users. ESA and ESO jointly operate ST-ECF.

The Hubble Space Telescope is an international cooperation project between NASA and ESA.

# Science Instrument Links



| Instrument Description Links | Instrument Site Links |
|---|---|
| ACS | Advanced Camera for Surveys |
| COS | Cosmic Origins Spectrograph |
| COSTAR | Corrective Optics Space Telescope Axial Replacement |
| FGS | Fine Guidance Sensors |
| FOC | Faint Object Camera |
| FOS | Faint Object Spectrometer |
| GHRS | Goddard High Resolution Spectrograph |
| HSP | High Speed Photometer |
| NCS | NICMOS Cooling System |
| NICMOS | Near Infrared Camera/Multi-Object Spectrometer |
| STIS | Space Telescope Imaging Spectrograph |

| | |
|---|---|
| **WF/PC (1)** | **Wide Field / Planetary Camera** |
| **WFPC2** | **Wide Field Planetary Camera II** |
| **WFC3** | **Wide Field Camera 3** |



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# Clean Room Images

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Re-using Hardware
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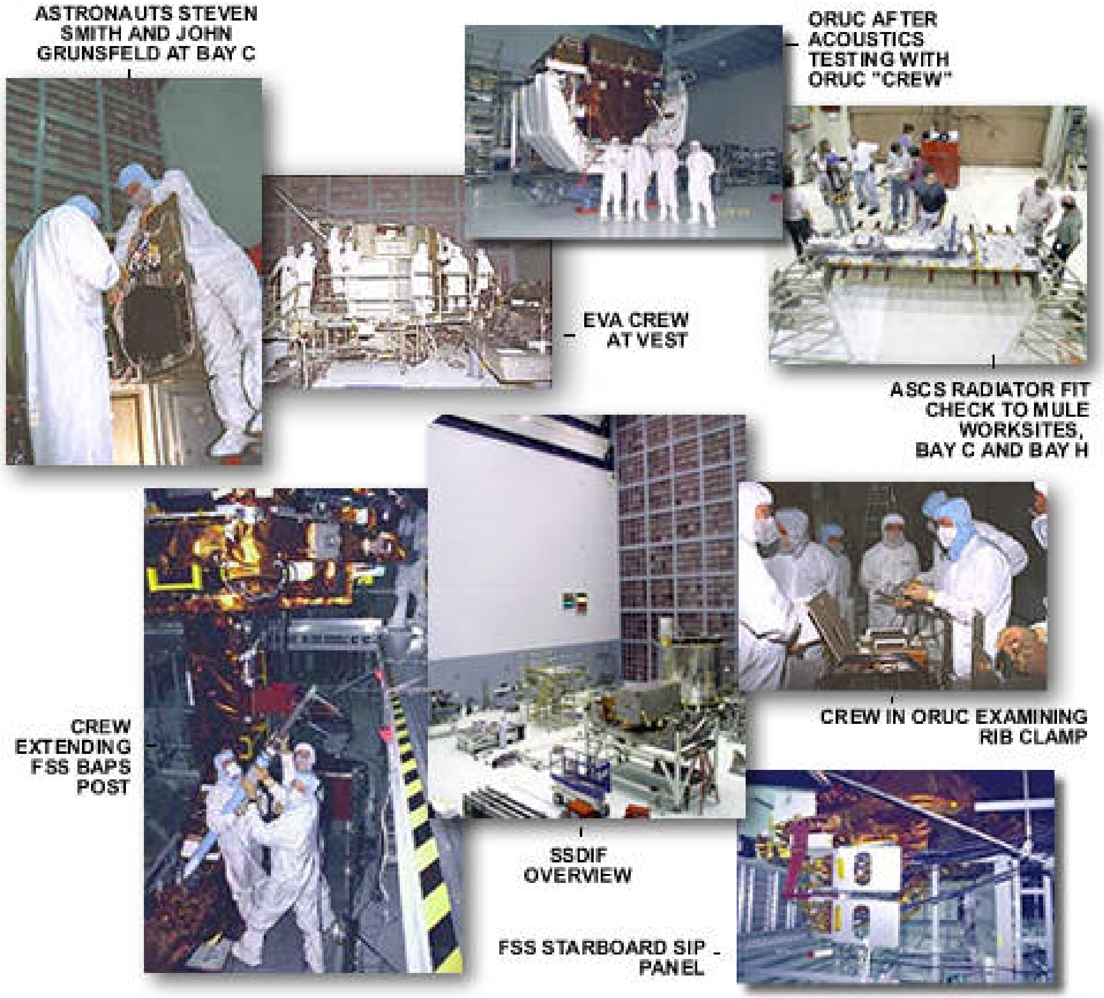
Neutral Buoyancy Laboratory
Goto SM3B WEBSITE

Click on thumbnails for larger image.

Hubble Clean Room
Select...



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# Clean Room Panorama

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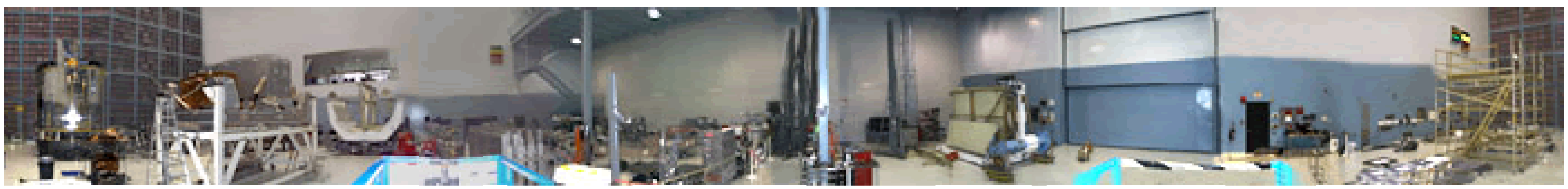
Hubble Clean Room
Select...

**This is a 360 degree panoroma of the cleanroom.**
**Move over image to see captions.**





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Page Last Updated: October 29, 2001

# Servicing Mission 1 Images

Science Images

Servicing Mission Images

Live Webcams

Science Animations

NASA TV

Goto SM3B WEBSITE

**See COSTAR Animation (Realplayer)**

*WF/PC2 in the Enclosure*

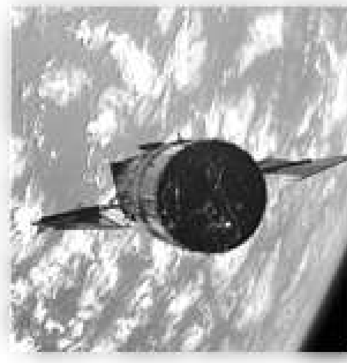
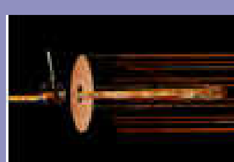
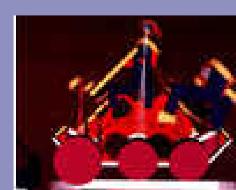
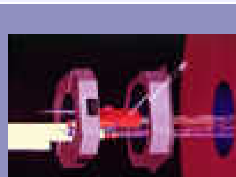
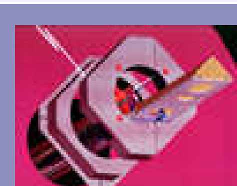


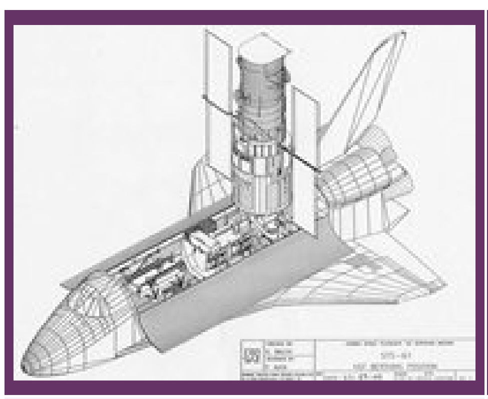
*Image of solar arrays prior to capture*

## COSTAR Images

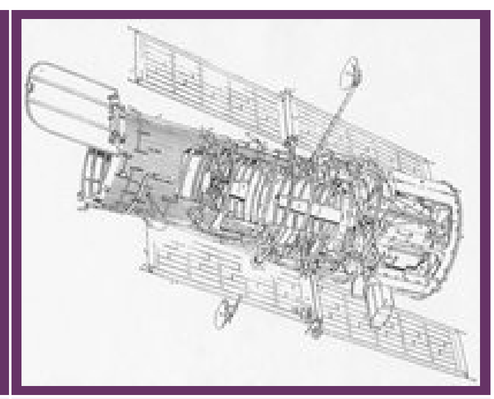
| | | |
|---|---|---|
|  |  |  |
| The Cassegrain Optical system of the Hubble Space Telescope shown feeding light-ray bundles to the COSTAR and WFPC2. | The Cassegrain Optical system of the Hubble Space Telescope shown feeding light-ray bundles to the COSTAR and WFPC2. | View from inside the optical bench of COSTAR from behind the three spheres for the two spectrographs. GHRS is on the left. |
|  |  |  |

| | | |
|---|---|---|
| View of the entire HST focal plane showing the pick-off mirror of WFPC2 in the center and the COSTAR mirrors surrounding it. | The support arm for the WFPC2 pick-off mirror showing the actuator motors for tip/tilt of the mirror platform. | View from behind the HST primary mirror showing COSTAR and the associated ray bundles. The white Z-shaped bundle is for the WFPC2. |
| |  | |
| | The same hardware and ray bundles as in Figure 6 above seen from the side. | |

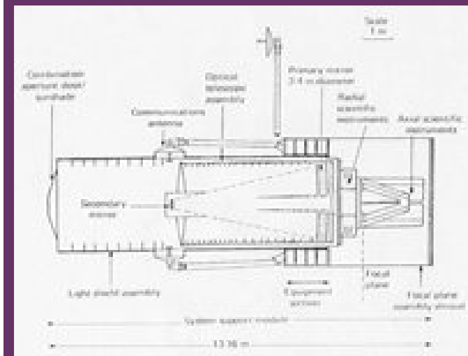
## Hubble Engineering Drawings



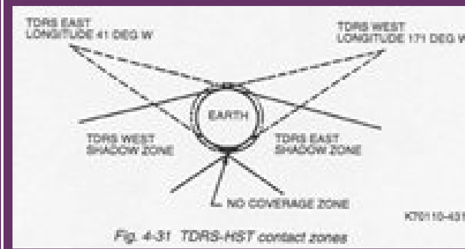
HST in the Shuttle Bay



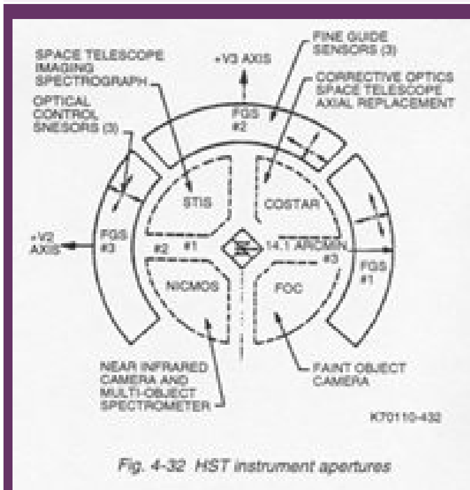
HST Layout



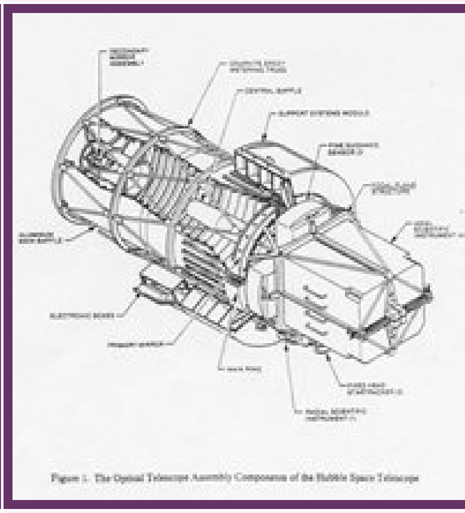
System Support Module



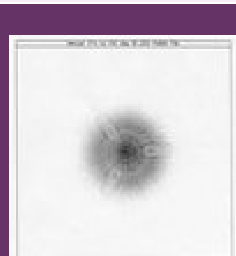

TRDS-HST Contact Zone



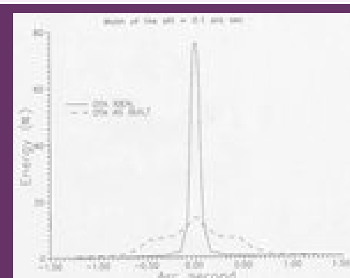

HST Instrument Apeture



Optical Assembly Components



Manual Fit to the FOC



Width of the Slit

Top

# Sevicing Mission 2 Images



Launch of STS-82, Space Shuttle Discovery

The Hubble Space Telescope in Discovery's Payload Bay

Astronauts Servicing Hubble

Hubble Floating in Orbit





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# Image Gallery

## Hubble's Post Mission Pictures

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Flight Day 5 Images
Flight Day 5 Movies (Quicktime)
Flight Day 4 Activities - Crew Pictures
Flight Day 4 Movies(Quicktime)
Flight Day 4 Images
Flight Day 3 Images
Flight Day 3 Movies(Quicktime)
Flight Day 2 Images
Space Shuttle Discovery in Orbit, Flight Day 2, 12/20/99

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### Space Shuttle Discovery and Crew at Kennedy Space Center

Images from the Launch of Discovery - 12/19/99
Launch Movies (Quicktime)
Launch Movies (Realplayer)
Space Shuttle Discovery, Ready to Go - 12/16/99
Discovery Roll-Back at the Pad - 12/16/99
Discovery on the Launch Pad - 12/9/99
Discovery Crew Arrives at Kennedy - 12/6/99

Discovery Rolls out to the Launch Pad - 11/14/99

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## Hubble Team Pictures

The Hubble Space Telescope Servicing Mission 3A began with the spectacular launch of the space shuttle Discovery on December 19, 1999 at 7:50 pm EST.This mission has taken on a new sense of urgency - the world's most productive scientific observatory suspended operations several weeks ago because of a gyroscope failure.

This mission is needed to restore Hubble's ability to keep itself still enough to take scientific observations. This flawless launch shows that the hard work and thoroughness of the launch team over the past six months has paid off. The Hubble Space Telescope Project now stands ready to work with the flight operations team to restore the telescope to perfect operating condition. This will happen through 10 days of detailed and meticulous work, 24 hours a day, throughout the holiday season.

Here are some pictures of the dedicated team that makes the Hubble Space Telescope possible. Their personal sacrifices and the understanding of their families and friends are what make this project one of the most unique and successful human endeavors ever undertaken. We hope you enjoy seeing some of these "faces of Hubble."

**Christmas Pictures**

More Christmas at JSC - 12/26/99
Hubble's Christmas Elves at the STOCC - 12/25/99
Hubble JSC Team on Christmas Day- 12/25/99
Have a Hubble Holiday! The Hubble JSC Team at work - 12/24/99
A Christmas Gift - 12/21/99

Post-Deployment at JSC - 12/25/99
Hubble Management Team on its way to Johnson Space Center - 12/19/99
Hubble JSC Team hard at work
Hubble Team members in the MOSB at Kennedy Space Center - 12/18/99
Hubble STOCC Operations Team Images
Hubble Prelaunch Reception at Kennedy Space Center
Hubble Team Members & Discovery - 12/16/99

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## Prelaunch Images

Neutral Buoyancy Testing
HST Hardware in the Cleanroom
Cleanroom Panorama
Serving Mission PreLaunch Walkdown

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**HST EVA Animations** - Updated Dec.6,1999

Download latest Quicktime

Download latest RealPlayer

EVA Day1 (25,970 KB) (431 KB)
EVA Day2 (23,730 KB) (412 KB)
EVA Day3 (12,910 KB) (231 KB)
EVA Day4 (20,810 KB) (349 KB)

## HST Interactive SM3A Model

user system requirements

## HST SM3A Panoramic Animations

HST Animations Instructions
user system requirements

This is a composite model of the SM3A and SM3B mission. Solar panels shown are scheduled to be installed on SM3B.

## Artists Renderings of the HST during Servicing Mission 3A

## HST Animation Sequences

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*Last Updated: 1/5/99*
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*Webmaster Global Science & Technology, Inc.*

# Servicing Mission 3B Images

Science Images
Servicing Mission Images
Live Webcams
Science Animations
NASA TV
Goto SM3B WEBSITE

**Equipment Schematics**
**Crew Fam Visit**
**Neutral Buoyancy Training**
**The Goddard Cleanroom**

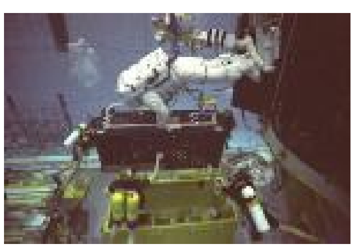
Preparations for servicing missions start long before launch. Here are just some of the things the shuttle crew and the Hubble team need to do in order to be ready for the upcoming mission.

## Training in the Neutral Bouyancy Lab

John Grunsfeld assisting the installation of ACS.

John Grunsfeld using the Pistol Grip Tool to release ACS.

John Grunsfeld installing the Nicmos Cooling System radiator. Rich Linnehan assisting with the alignment of the radiator.



Linneham, Massimino and Newman.

Jim Newman on the Remote Manipulator System (RMS).

Rich Linnehan on the RMS Inspecting the installation of ACS

Jim Newman with the new outer layer blanket (NOBL)

Jim Newman disengaging several bolts.

Hubble Personnel getting ready at the NBL.

Hubble Personnel getting ready at the NBL.

The NBL control room.

**At Goddard Space Flight Center.**

The Advanced Camera for Surveys (ACS)

The crew in front of the new solar panels.

The crew evaluating the NICMOS cryocooler (NCC).

John Grunsfeld using a ratchet that he will be using during a spacewalk

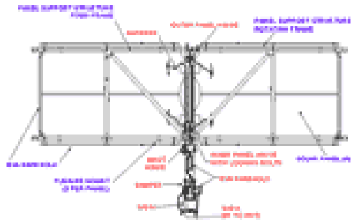
Crew in front of the High Fidelity Mechanical Stimulator.

Crew orientation in the High Bay.

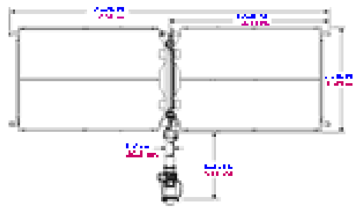
Crew members Rich Linnehan, Jim Newman and Michael Massimino.

EVA crew has photo op with Ken Olson (who is suited up for NBL run).

**Schematics for New Equipment.**



Replacement solar panel arrays for Hubble. Labeled parts.



Replacement solar panel arrays for Hubble. Dimensions.



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Return to KSC Home Page


Space Shuttle Simulation 1.3.0

Enter the Shuttle Simulation

If you have any questions or comments regarding this simulation,
please contact KSC webmaster Spaceport Services

Web Development: JBOSC Web Development Team

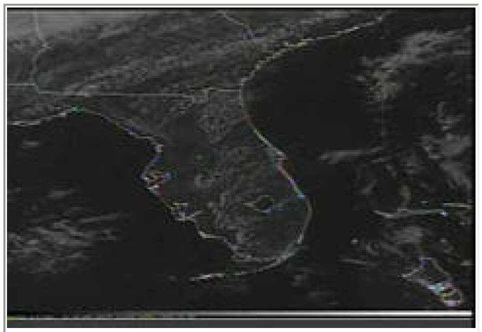
A Service of the NASA/KSC External Relations and Business Development Directorate

JoAnn H. Morgan, Director

**08/03/00**

# NASA - KSC Video Feeds

| **Streaming NASA Television** | |
|---|---|
| RealPlayer Stream<br>Windows Media - (In Browser)<br>RealPlayer 5.0 Stream<br>RealPlayer (Audio Only) | KSC Payload Processing Feed<br>Live JAVA Shuttle Countdown/Video Monitor NEW<br>Text Shuttle Countdown Clock<br>ELV Select TV 1 \| ELV Select TV 2 |



Channel 1
KSC Weather


Channel 2
NASA TV

Channel 3
View from LC-39A

Channel 4
Hubble Servicing Mission processing in VPF

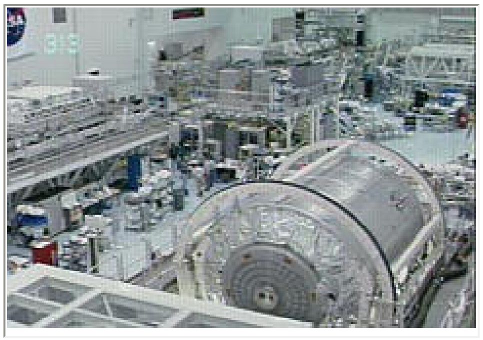

Channel 5
ISS processing in SSPF

Channel 6
View of LC 39-A

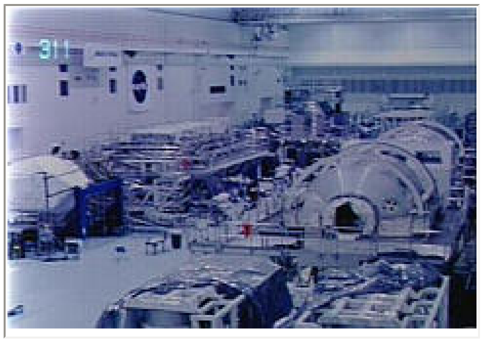

Channel 7
Station processing in SSPF


Channel 8
ISS Truss in O&C Building


Channel 9
Station processing in SSPF Highbay



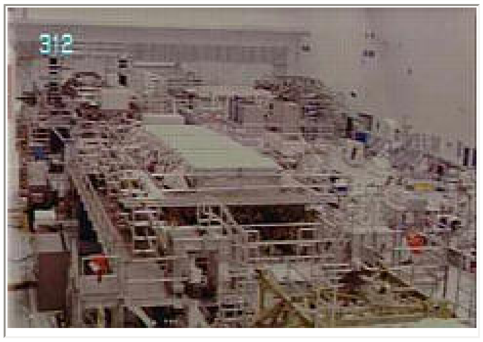
[Channel 10](#)
Station processing in SSPF




Channel 11
ISS processing in SSPF

Channel 12
ELV Select Video


Channel 13
View from Pad 39-A




Channel 14
View from SSPF


Channel 15
O&C High Bay (Streaming Feed)

## Control Panel

**Current Mode: 90 seconds - Medium**

Image Size: Small - Large 2 X 7 - Large 3 X 5

Refresh Time: No Refresh - 45-seconds - 60-seconds - 120-seconds - 180-seconds

*Note: To view medium and large images your browser must support inline JPEGs*

The following sites "may" be broadcasting live Real Audio/Video of NASA TV:
RealVideo NASA TV (NASA KSC)
RealAudio NASA TV (NASA KSC)

The RealPlayer is available free of charge from: RealNetworks.



---

**Author:** Michael Downs, NASA Internet Systems Lab
**Last Updated:** Wed Mar 13 13:38:21 EST 2002 (J. Dumoulin)

# Newspaper References

Hubble Newsfeed
Press Releases
Project Reports
Incident Reports
Goto SM3B WEBSITE

**Each month The Hubble Space Telescope is mentioned in News Articles and Magazine Features all across the nation and the world.**

**Highlights from the more than 100 news articles from September - November 2000:**

| Date | Publication | Headline |
|---|---|---|
| November 11, 2000 | The Times (London) | *"Relax, it's just a star hurtling to Earth"* |
| November 11, 2000 | The Herald (Glasgow) | *"Wayward star just 200 light years away; Supernova explosion left behind object with density of the sun"* |
| November 9, 2000 | THE HINDU | *"Black Hole in Nearby Galaxy"* |
| October 17, 2000 | The New York Times | *"Hubble Unveils an Ancient Cataclysm"* |
| October 12, 2000 | The Christian Science Monitor | *"Astronomers Zoom in on the Birth of Stars"* |
| October 8, 2000 | The Columbus Dispatch | *"Gushing-Star Videos Inspire Awe"* |
| October 3, 2000 | THE ARIZONA REPUBLIC | *"A Star is Born, and Burns Out"* |
| October 2, 2000 | The Irish Times | *"Nebula IC 418"* |
| September 26, 2000 | The New York Times | *"Q & A; Birth and Death of Stars"* |
| September 23, 2000 | The Straits Times (Singapore) | *"Hubble Captures Bubbles in Space"* |

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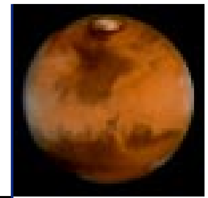
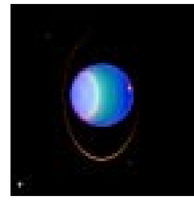
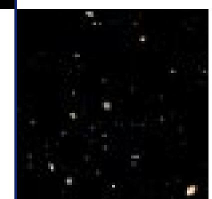
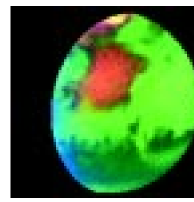
1999
Hubble Space Telescope
2000
Biennial
Report

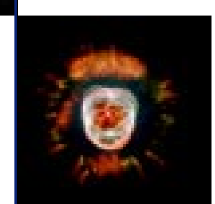
*"Discoveries in basic science drive the engine of technological advance, which keeps raising our national standard living and creates new jobs. One cannot predict the long term effects of scientific discoveries. The U.S. space exploration program has itself spawned new products and new industries ... there at least resides hope for future benefits for our country and for mankind -- and jobs."*

***Lester Ageloff***
***Letter to the Editor***
***Florida Herald-Tribune***

# Contents



# I. A Decade of Excellence

Not since Galileo turned his telescope toward the heavens in 1610 has any event so changed our understanding of the Universe as the Hubble Space Telescope. With its unprecedented power and clarity, Hubble is leading an exciting, new revolution in astronomy and breaking ground in on-orbit servicing.

1. Crewmembers of STS-82; 2. Spiral galaxy captured with the Hubble Space Telescope

Orbiting 370 miles above Earth, Hubble works around the clock to unlock the secrets of our Universe. With its exquisite pointing precision, powerful optics, and state-of-the-art instruments, Hubble provides views of the Universe simply unattainable from ground-based telescopes or other satellites. Hubble is in high demand as astronomers compete for observing time. Only one in six proposals is accepted.

Even when reduced to raw numbers, Hubble's accomplishments are extraordinary. Every day, Hubble archives 3 to 5 gigabytes of data and delivers between 10 and 15 gigabytes to astronomers all over the world. As of July 2000, Hubble has:

- Taken more than 347,000 separate observations.
- Observed more than 30,000 astronomical targets.
- Created a data archive of over 7.7 terabytes (that's like completely filling a PC every day for 10 years).
- Provided data for more than 2,785 scientific papers.
- Traveled about 1.539 billion miles—nearly the distance from Earth to Uranus. HST circles the Earth about every 97 minutes.
- Received more than 93 hours of on-orbit improvements in three successful servicing missions.

Hubble yields images of amazing complexity, diversity and beauty as it unlocks the mysteries of the Universe. In revealing the first clear views of deep space, Hubble helps astronomers understand how galaxies and stars formed in the early Universe. Before Hubble, distances to far-off galaxies were not well known and a great controversy existed over how rapidly the Universe is expanding and how long the expansion has been occurring. The telescope fulfilled its promise to accurately measure the size, rate of expansion, and age of the Universe.

The second decade promises to be as exciting as the first. New, more powerful instruments will be installed on Hubble during the final two servicing missions. The new instruments will be 10 to 20 times more powerful than the existing instruments and they promise to provide new opportunities for scientific discovery.

## Hubble Science & Technology: at the Forefront

Although designed in the 1970s and launched in 1990, Hubble is a state-of-the-art, model year 2000 space telescope—thanks to on-orbit servicing. Hubble is the first scientific mission of any kind specifically designed for routine servicing by spacewalking astronauts. Its visionary, modular design allows servicing crews to perform periodic improvements, ensuring that Hubble produces first-class science using cutting-edge technology.

The following scientific and technological achievements are just some of the highlights of Hubble's illustrious career.

- Hubble was the first optical telescope to provide convincing proof of a black hole several billion times the mass of the Sun. Now it is demonstrating that supermassive black holes are at the core of most, if not all, galaxies.
- Hubble cleared up the mystery of quasars, which until recently were among the least understood objects in the Universe. It confirmed that quasars are actually active galactic nuclei in distant galaxies and are powered by black holes.
- Until Hubble, scientists could not determine if mysterious, intense bursts of gamma rays originated in our own galaxy, far across the Universe, or somewhere in between. The telescope traced these bursts to the outskirts of faint, distant galaxies in the early Universe.
- Hubble teamed with ground-based telescopes to observe exploding stars in galaxies whose light was emitted when the Universe was half its present age. The preliminary result, if confirmed, will be one of the most important scientific discoveries of our time—that the expansion of the Universe is accelerating, driven by an unknown force.
- Hubble's unprecedented views of star birth reveal the diverse and complex processes that influence star formation. They show that planet-forming dust disks surrounding young stars are common throughout the galaxy. Hubble was the first telescope to reveal the internal structures of these disks, which suggest the presence of newly formed planets.
- The telescope's exquisite images of dying stars help scientists understand the death process and how it is influenced by each star's specific circumstances. Although many telescopes have observed Supernova 1987A, only Hubble can chronicle the spectacular changes as the blast debris expands over time.
- Hubble provided spectacular views of Comet Shoemaker-Levy/9's collision with Jupiter. These violent explosions served to reinforce how volatile our Universe is and how fragile and tenuous our own existence is on Mother Earth. Hubble also provided the first detailed images of Pluto and its satellite Charon, and new understanding of the atmospheres of Uranus and Neptune.
- Hubble revealed stunning views of the northern and southern lights on Jupiter, Saturn and Ganymede, as well as imagery of the dynamic electrical interactions between Jupiter and its satellite Io.

- Hubble is the first spacecraft designed with handrails, easily replaceable equipment, and other astronaut-friendly features. Three fully successful servicing missions have kept Hubble healthy and updated, and two more missions will take place before the end of Hubble's career.
- The 1993 servicing mission saw the first use of a computer-controlled space tool, the Power Ratchet Tool (PRT). The first cordless power tool in space, the Pistol Grip Tool (PGT), was used to service Hubble in 1997 and 1999.
- Astronauts on the 1999 mission became the first to use the highly efficient Lithium Ion batteries in a space tool. They also installed the first extremely radiation-resistant, Intel-based 486 computer in orbit.
- Hubble is the first spacecraft to use ultraviolet Multi-Anode Microchannel Array (MAMA) detectors, which see in ultraviolet but are blind to sunlight and other visible light. These detectors are part of the Space Telescope Imaging Spectrograph (STIS), which was installed in 1997, and the Advanced Camera for Surveys (ACS), which will become part of Hubble in 2001.
- Hubble innovated a unique pointing and control system, which is extraordinarily stable and precise. It is designed to point to within 0.01 arcsec (an arcsec is the width of a paperclip wire viewed from the distance of two football fields). It holds the telescope in that orientation with 0.007-arcsec stability for up to 24 hours while Hubble orbits the Earth at 17,500 mph. This level of stability and precision is comparable to standing in Washington D.C. and steadily focusing a laser beam on a dime atop the Empire State Building in New York City, approximately 200 miles away.
- Hubble's huge solar arrays, replaced in 1993 and 1997, hold the record for the largest structures ever replaced in orbit.
- The 1997 servicing mission was the first to use magnetic, eddy current shock absorbers in space. This technology was a great success for Hubble and has been employed in commercial applications.
- In 2001, Hubble will employ the first-ever high-tech refrigerator, which will cool and restore life to the now-dormant Near Infrared Camera and Multi-Object Spectrometer (NICMOS). The system is the first space use of a new technology called a Reverse Brayton-Cycle Cryocooler. It is powered by a compressor capable of running at up to 450,000 rpm with a tiny turbine generator turning at up to 300,000 rpm. In 1998, the Hubble program achieved another first by successfully demonstrating the capabilities of this system during the STS-95 mission.

These exciting accomplishments reflect the ingenuity and perseverance of the entire Hubble team, which is dedicated to ensuring the telescope's health and optimal performance well into the 21$^{st}$ Century. With powerful new instruments scheduled for installation, we have every reason to believe the best is yet to come.

# II. Hubble and Servicing

## Science on the Cutting Edge

Accelerated innovation through human intervention in space is a core concept of Hubble's design. One of the most important features of the Hubble Space Telescope is its ability to be maintained and upgraded on orbit. These human activities allow the observatory to produce the best astronomical data humankind has ever collected over a two-decade period. Hubble's revelations have already rewritten scientific textbooks, putting us on the path of discovering the most intimate secrets of our Universe.

STS-103 spacewalk

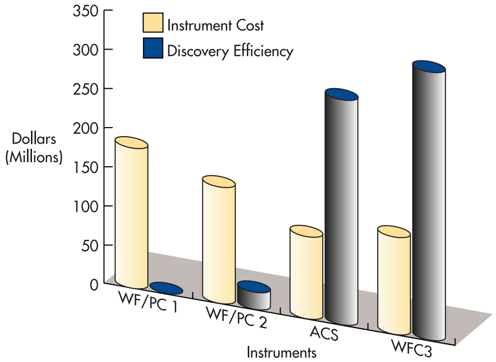
Every few years, a team of astronauts carries a full manifest of new equipment on the Space Shuttle for the ultimate "tune-up" in space. The telescope was being designed as the Space Shuttle was being readied for its first flights. NASA realized that if a shuttle crew could service Hubble, it could be upgraded and maintained indefinitely, representing risk management at its best. So from the beginning, Hubble was designed to be astronaut-friendly. Its modular design allows NASA to equip Hubble with new, state-of-the-art, scientific instruments every few years, giving the telescope exciting new capabilities with each servicing mission. Each new instrument increases Hubble's scientific power by a factor of 10 or greater.

**Instrument Cost:** The development cost of the instrument up to the end of the test period in space.

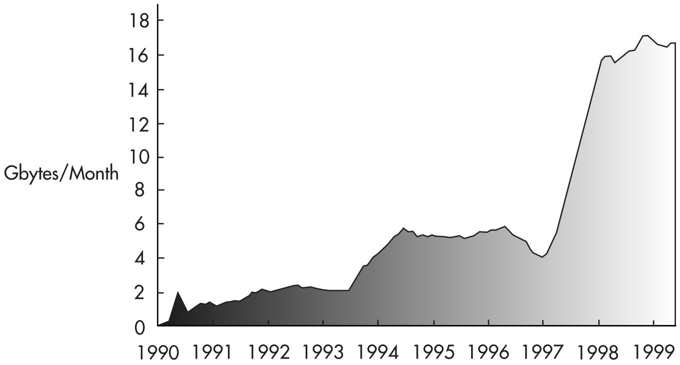
**Discovery Efficiency:** The figure-of-merit that estimates how well an imaging instrument can make new discoveries

In addition to science upgrades, the servicing missions permit astronauts to replace limited-life components with systems incorporating the latest technology. This further improves telescope performance and ensures continued mission success. With each servicing mission, Hubble essentially becomes a new state-of-the-art observatory. This is achieved at a fraction of what it costs to build a series of space observatories "from scratch." The science instruments developed are 10 to 20 times more powerful and cost half as much as the earlier science instruments.

**Discovery Efficiency vs. Instrument Cost**




**Science Data Production**



## Hubble Servicing Mission-3A: Now Better Than Ever

The Hubble Space Telescope is alive and well and back on duty after a successful December 1999 Servicing Mission (SM3A). "Better than new," is how Dr. Ed Weiler, NASA Associate Administrator for Space Science, described Hubble. To prove it, NASA released two stunning images Hubble took just two weeks after Discovery's Christmas-time service call.

NASA decided to split Hubble's Third Servicing Mission (SM3) into two parts, SM3A and SM3B, after the third of Hubble's six gyroscopes failed. In accordance with NASA's flight rules, a "call-up" mission was quickly developed and approved. The second part of the mission, SM3B, is scheduled for late 2001.

What was originally conceived as a mission of preventive maintenance became more urgent on November 13, 1999 when the fourth of six gyros failed and Hubble temporarily closed its eyes on the Universe. Unable to conduct science without three working gyros, Hubble entered a state of dormancy called safe mode. Essentially, Hubble "went to sleep" while it waited for help.


The crew of STS-103 preparing to board Space Shuttle Discovery.

The Hubble team developed and executed the SM3A mission in record time, leaving the telescope far more fit and capable than ever before. SM3A represented the first time that NASA ever planned and executed a complex mission in only seven months. The new, improved, and upgraded equipment included six fresh gyroscopes, six battery voltage/temperature improvement kits, a faster, more powerful main computer, a next-generation solid state data recorder, a new transmitter, an enhanced fine guidance sensor, and new insulation.

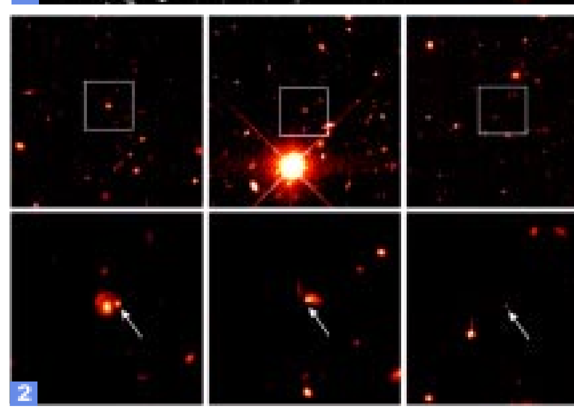
As NASA Administrator Dan Goldin told the crew, "Everyone on this planet is going to share the fruits of what you have done. You've done all of us proud."

# III. The 10 Greatest Hubble Discoveries of the Past Decade

With its extremely sensitive detectors and precise optics, the Hubble Space Telescope yields images of awesome complexity, diversity, and beauty. Its vision, which ranges from ultraviolet to near-infrared, provides explanations to long-pondered astronomical puzzles. Hubble also delivers unimagined surprises and raises at least as many new questions as it answers. With each new instrument installed during its periodic servicing missions, Hubble's capabilities grow tenfold. What follows is a description of Hubble's greatest accomplishments over the past decade.

## Distant Galaxies and Galaxy Evolution

Before Hubble, little was known about galaxies outside our immediate cosmic neighborhood. Hubble's powerful instruments allow scientists to peer deep into space, to a time when our Universe was very young. Providing the first clear view of deep space, Hubble helps astronomers understand the evolution of galaxies and the rate of star formation in the early Universe. The telescope reveals that the early Universe was populated by structures that were much smaller and more irregularly shaped than galaxies in the modern Universe. These smaller structures, made up of young stars and primordial gases, are believed to be the building blocks from which the more familiar spiral and elliptical galaxies formed. (Figure 1)



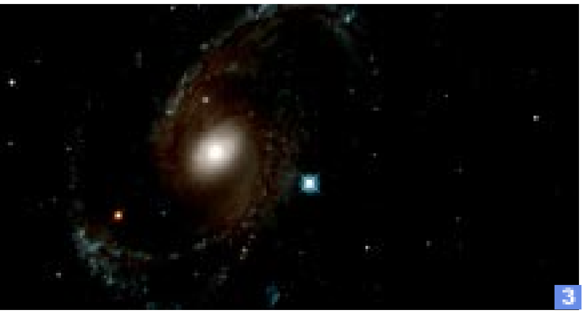
**1.** The Hubble Deep Field. **2.** Three distant supernovae.

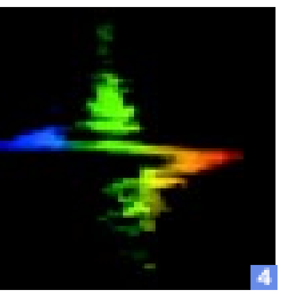
## Our Accelerating Universe

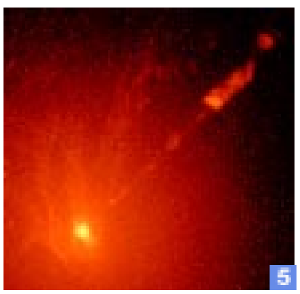
Hubble teamed with ground-based telescopes to observe supernovae in galaxies whose light was emitted when the Universe was half its present age. Only Hubble could accurately measure the brightnesses of the most distant supernovae in the sample. From these measurements, astronomers were able to accurately calculate the galaxies' distances. By combining these distances with the rate at which the galaxies were receding, astronomers determined the rate at which the Universe itself was expanding far back in time. The result was remarkable, providing the first tentative clue that the expansion of the Universe is accelerating—driven by an unknown repulsive "force" strong enough to overcome gravity. Einstein anticipated this possibility by adding a "cosmological constant" to his equations of general relativity. In the next few years Hubble will lead the way by extending these measurements even farther across the Universe and farther back in time. (Figure 2)

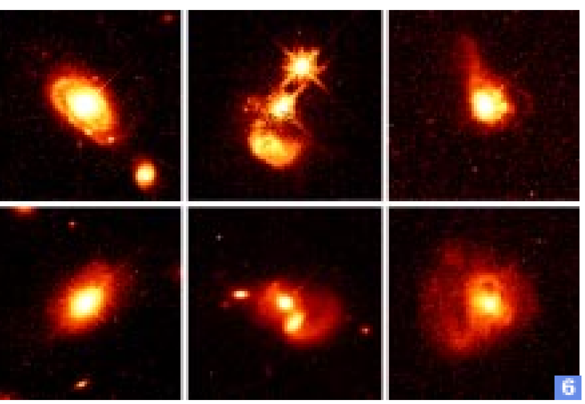
## MEASURING THE UNIVERSE

Before Hubble, distances to far-off galaxies were not well known, and a great controversy existed over how rapidly the Universe is expanding and how long the expansion has been occurring. Hubble fulfilled its promise to accurately measure the size, rate of expansion and age of the Universe. (Figure 3)









Hubble was the first telescope capable of resolving the "standard candle" Cepheid variable stars and using them to obtain very accurate distances to a large number of moderately distant galaxies. Astronomers used these measurements to recalibrate other standard distance indicators by which they measure galaxies at much greater distances. These calculations resulted in a much more accurate measurement of the rate at which the Universe is expanding (the Hubble Constant) and a determination that the Universe is younger than many astronomers had believed it to be. Before Hubble, scientists placed the age of the Universe at anywhere between 10 and 20 billion years; now they agree that approximately 12 to 15 billion years have elapsed since the Big Bang.

## CONFIRMING SUPERMASSIVE BLACK HOLES

Prior to Hubble's launch, ground-based telescopes hinted at the existence of large concentrations of mass at the very centers of galaxies. Although astronomers suspected these might be the massive black holes predicted theoretically as early as the 1930s, no earthbound optical telescopes could resolve these galaxy centers. Hubble was the first optical telescope capable of probing deeply into the center of a galaxy. It provided the first convincing proof of a black hole several billion times the mass of the Sun. With a "demographic" survey of central black holes now underway, Hubble is demonstrating that supermassive black holes are at the core of most—or perhaps all—galaxies. Ultimately, Hubble will help explain the role these "monsters" play in the formation and evolution of galaxies. (Figures 4 & 5)

**3.** Spiral galaxy NGC 4603, the most distant galaxy in which Cepheid variables have been found. **4.** The signature of a black hole in the center of galaxy M84. **5.** Massive black hole at the heart of active galaxy M87. **6.** Quasars at the center of a normal spiral galaxy.

## THE NATURE OF QUASARS

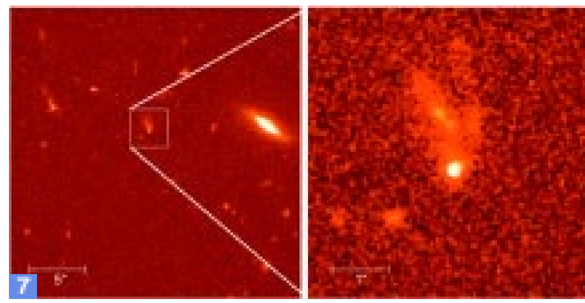
When quasi-stellar radio sources, commonly known as quasars, were discovered in the 1960s, they were recognized as the most distant and energetic objects known in the Universe. They were also the least understood. Hubble has cleared up much of the mystery surrounding quasars, confirming that they are very distant, active, galactic nuclei in the early universe, undergoing especially intense outbursts of activity, powered by black holes. (Figure 6)

Hubble also reveals that a variety of different types of galaxies play host to quasars. Scientists were surprised to learn that a large portion of these quasar-hosting galaxies are colliding and merging with other galaxies. Galaxy collisions, which Hubble determined were common in the early Universe, may provide the extra "fuel" to feed a host galaxy's central black hole and generate a quasar's enormous energy output.

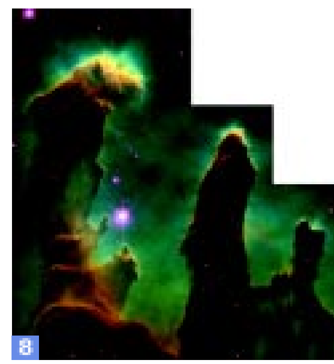
## The Origin of Gamma Ray Bursts

Military satellites first detected intense, mysterious bursts of highly energetic gamma radiation from unknown cosmic sources. Later, the Compton Gamma Ray Observatory (GRO) observed thousands of these bursts and found them to be uniformly distributed over the sky. But the source of these bursts remained a mystery, and scientists could not determine if they originated in our own galaxy, far across the Universe, or somewhere in between.

**7.** The most famous of all planetary nebulae: the Ring Nebula (M57). **8.** Towers of sculpted gas in the Eagle Nebula. **9.** Hubble sees disks around young stars.

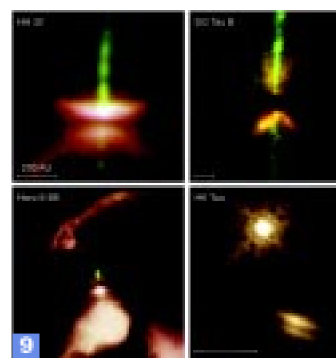


A joint Italian-Dutch satellite called Beppo-Sax was designed to spot gamma ray bursts very quickly and to locate their positions accurately, so that other telescopes could be trained on them while the bursts were still bright. The Hubble Space Telescope's exquisite resolution and sensitivity allowed astronomers to locate the sources of the gamma ray bursts in faint, distant galaxies at random distances from their centers. By following the sources to very faint levels, Hubble provided important information about the stellar "catastrophes" that produce these extraordinarily intense and rapid bursts of energy. (Figure 7)



## The Birth of Stars

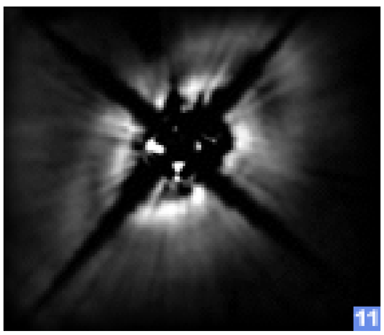
Hubble's resolution and sensitivity allow unprecedented views of the diverse and complex processes of star formation. The telescope captures collisions of galaxies, which stimulate the birth of large populations of young, massive stars and star clusters. Hubble also observes that intense radiation from a massive star can compress interstellar gas and trigger the formation of smaller stars nearby. In supernovae explosions, Hubble views radiation and ejected material that enrich and compress the interstellar gas and dust from which new stars can form. The telescope shows that in large, dense clouds of molecular hydrogen and dust, radiation from nearby hot stars limits the masses of forming stars by eroding away material. Hubble also confirms that a star's formation always seems to be governed by an accretion disk of material falling onto the protostar and by bipolar jets carrying material away from the "construction site." (Figures 8 & 9)

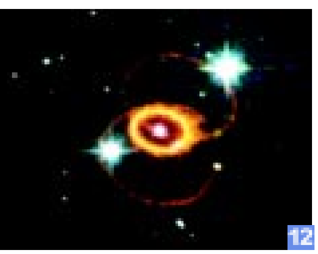


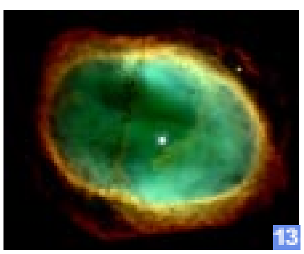
## The Formation of Planets

For centuries, astronomers have believed that a disk of dust was the precursor to our own solar system, providing the raw material from which the planets were constructed. Before Hubble, infrared satellites inferred the presence of dust disks around a small number of young stars. One such disk, around Beta Pictoris, had been directly imaged with a ground-based, coronagraphic instrument. (Figures 10 & 11)

The Hubble Space Telescope revolutionized observational astronomy by revealing the abundance of such disks. Hubble finds that about half the young stars in the Orion Nebula are surrounded by gas and dust structures, many of which are clearly disks. High-resolution, near-infrared Hubble images of other star-forming regions show protoplanetary disks forming and evolving. These disks, which appear to be common throughout our galaxy, contain enough material to form entire planetary systems equivalent to our solar system. For the first time in history, Hubble revealed the internal structures of protoplanetary disks and of the debris left behind by prior planet formation. Thus, Hubble has opened up the empirical study of the structure and evolution of protoplanetary systems.







**10.** Dust ring around star offers new clues into planet formation.
**11.** Gap in stellar dust disk may be swept out by planet.
**12.** Supernova 1987A
**13.** The "Eight-Burst" or the "Southern Ring" Nebula

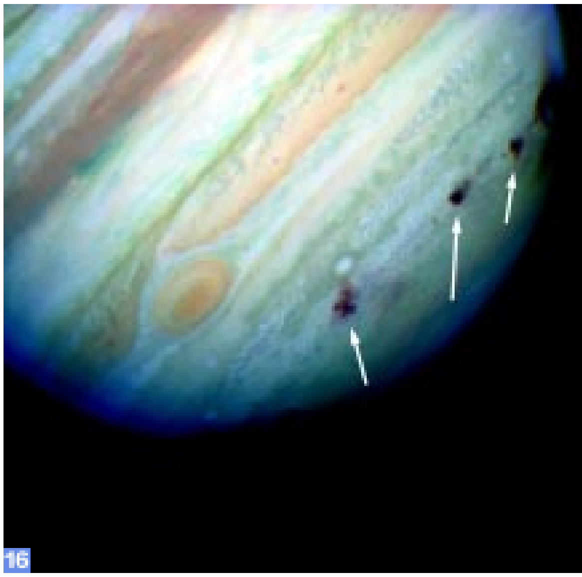
## The Death of Stars

Dying stars shed material into interstellar space, sometimes gently and episodically, sometimes in explosive catastrophes. In either case, the ejected material is enriched in chemical elements produced in the interior, nuclear furnaces of these stars. This material "seeds" the interstellar gas and dust with the basic building blocks from which new stars, planets, and life may originate. Hubble's breathtaking images of dying stars provide a remarkably detailed understanding of the events preceding star death, how material is shed, and how that material interacts with the surrounding environment. The telescope also shows how the death process is influenced by each star's individual circumstances, such as a companion star, the presence of planets, a magnetic field, and rapid rotation. (Figures 12 & 13)

Perhaps the most spectacular example is Supernova 1987A, the nearest supernova seen in the last 400 years. An armada of telescopes has observed the supernova since its detection in February 1987. However, only Hubble has the resolution to trace, at sub-light-year scale, the evolving changes in both the fireball debris and the circumstellar ring of enriched gas. For the first time ever, Hubble observed the delicate ring structures left over from the pre-explosion evolution of the dying star. It also witnessed the blast debris from the supernova explosion expanding outward over time. Now, using Hubble, astronomers are seeing the innermost ring "light up" as the blast material collides with it.

# Our Dynamic Solar System

Within our own solar system, the Hubble Space Telescope provides fascinating details about our neighboring planets. Hubble captured the first images of Pluto and its satellite Charon that were detailed enough to enable measurement of their masses and crude mapping of their surfaces. The telescope also showed that the atmospheres of the giant, gaseous outer planets, Uranus and Neptune, once thought to be bland and nearly featureless, actually possess very dynamic climates. Hubble treated scientists to stunning views of the northern and southern lights on Jupiter, Saturn, and Ganymede, as well as of the dynamic electrical interactions between Jupiter and its satellite Io. In 1995, Hubble afforded astronomers the rare opportunity to view Saturn's rings edge-on. The telescope's sharp resolution led to the discovery of an atmosphere surrounding the rings, the discovery of several new moons, and the observation of known moons in unexpected positions. The telescope has also monitored the weather on Mars and provided extraordinary images of seasonal changes at the Martian poles. (Figures 14 & 15)



In 1994, Hubble witnessed the collisions of the 21 fragments of Comet Shoemaker-Levy/9 with the upper atmosphere of Jupiter. These uniquely clear pictures revealed the enormous fireballs created when fragments entered the Jovian atmosphere at 140,000 mph and heated the atmospheric gases up to 50,000º F, cooking them into a stew of "soot" and organic molecules. Hubble tracked the movement of this "soot" over several weeks, allowing scientists to monitor the upper atmospheric winds. The telescope's observations of the impact sites provided new information about the composition and density of Jupiter's atmosphere. Hubble's Comet Shoemaker-Levy/9 campaign reminds humanity of our vulnerability and motivates us to remain vigilant of the space environment in which we exist. (Figure 16)

**14.** Saturn's aurora

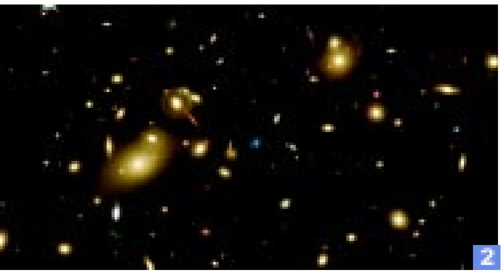
**15.** Jupiter's aurora

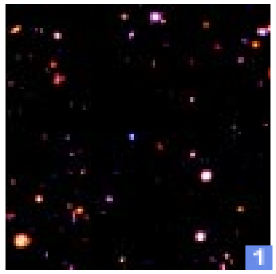
**16.** Impact of Shoemaker-Levy/9 on Jupiter

**17.** Scientists awaiting the first images of the Shoemaker/Levy impact

# IV. Hubble Continues to Expand Our Universe

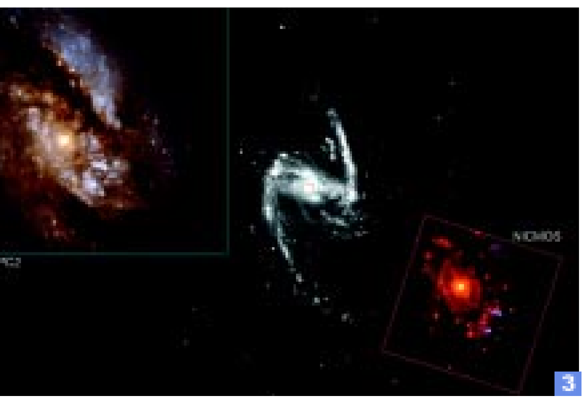
As the Hubble Space Telescope enters its second decade, its discoveries continue to make front page news. The following are recent examples of how Hubble broadens our knowledge of the Universe in which we live.





## Most Ancient Galaxies Ever Seen

With its infrared vision, Hubble has uncovered the oldest, faintest galaxies ever seen. Some may be over 12 billion light-years away, making them the farthest objects ever imaged in the Universe. (Figure 1)




## A Cosmic Magnifying Glass

Hubble captures an image of a massive cluster of galaxies that act as a zoom lens in space. Called Abell 2218, this cluster's strong gravitational field magnifies the light of remote galaxies far behind it and works as a deep probe of the very distant Universe. (Figure 2)

## Getting to the Heart of the Galaxy

A galaxy's central bulge holds secrets to how and when a galaxy is formed. Using Hubble's visible light and infrared cameras to penetrate deep into the cores of the galaxies, astronomers untangle the stars' true colors — a measure of age — from their apparent colors, which are made redder by interstellar dust. (Figure 3)

## Lone Black Holes Work as Lenses

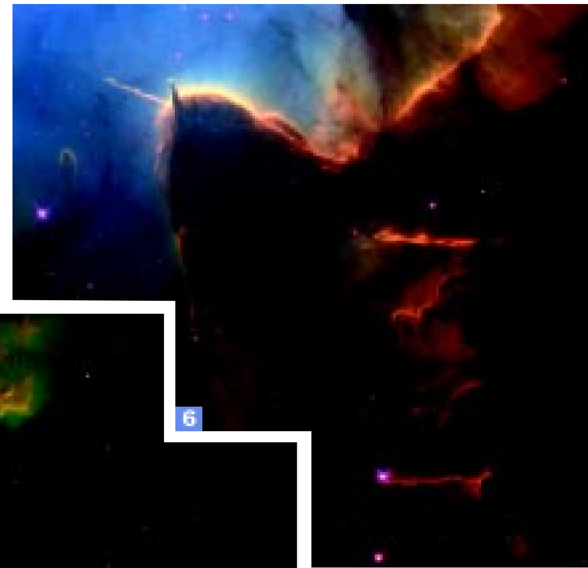
Hubble helps confirm the existence of isolated, stellar-mass black holes adrift in our galaxy. The telescope also shows how gravity from these black holes bends light like a powerful lens in space. (Figure 4)

## A Galactic Ballet

Hubble's high resolution captures the details of the strange and beautiful dance near the constellation Canis Major. Strong tidal forces from Galaxy NGC 2207 have distorted the shape of Galaxy IC 2163, flinging out stars and gas into long streamers that stretch out 100,000 light-years. Trapped in orbit around each other, these galaxies will eventually merge into a single, more massive galaxy. (Figure 5)

## Doomed Stellar Nursery in the Trifid Nebula

Within the Trifid Nebula, Hubble reveals a stellar nursery being torn apart by radiation from a nearby, massive star. The embryonic stars are forming within an ill-fated cloud of dust and gas, which are destined to be eroded away by the glare of a massive neighbor. This stellar activity shows how the life cycles of stars like our Sun are intimately connected with their more powerful siblings. (Figure 6)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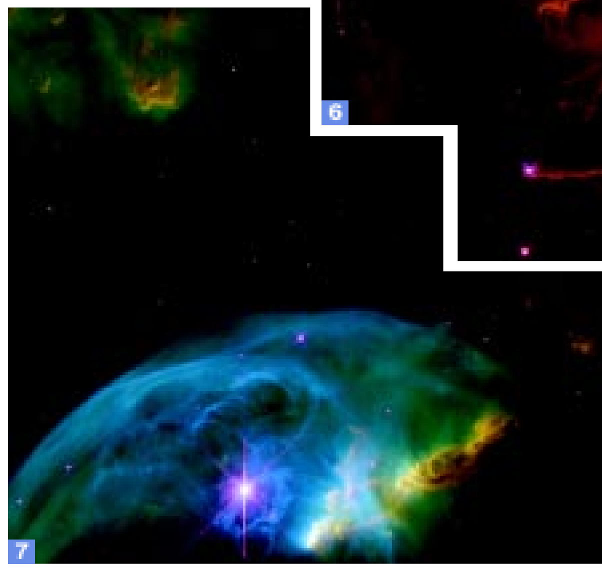
## A Bubble in Space

Hubble reveals loops and arcs in the Bubble Nebula (NGC 7635) that have never been seen before. The origin of this curious bubble within a bubble may be due to a collision of two distinct stellar winds, but its origin is currently unknown. (Figure 7)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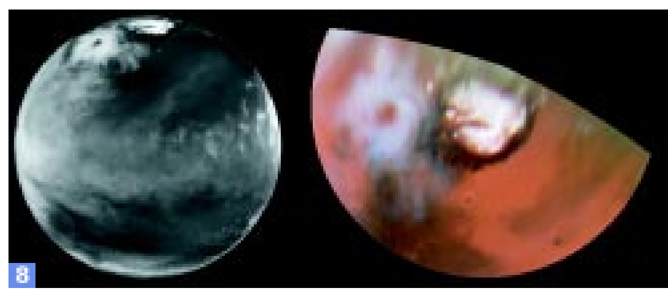
## Giant Cyclone Near Martian North Pole

Using Hubble, astronomers have discovered an enormous cyclone raging in the northern, polar regions of Mars. Nearly four times the size of Texas, the storm is composed of water ice clouds like the storm systems on Earth, rather than of the dust typically found in Martian storms. (Figure 8)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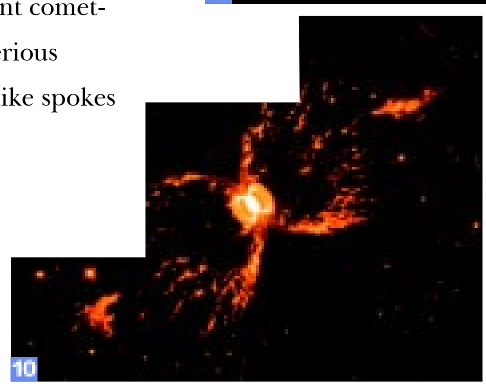
## The Eskimo Nebula

Hubble's sharp sight reveals that the "parka" of the Eskimo Nebula is really a disk of material with a ring of giant comet-like structures in the "fur." The tails of these mysterious objects all point away from the star's center, much like spokes on a wheel. (Figure 9)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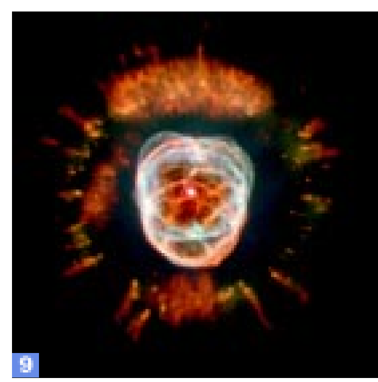
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## Star Pair Creates Unique Hourglass Shapes

Hubble reveals new details about the tempestuous relations between an unlikely pair of stars, a red giant and a white dwarf. Interactions between this pair may have sparked episodic outbursts creating an oddly shaped, gaseous nebula called the Southern Crab Nebula. Ground-based telescopes show a larger, hourglass-shaped nebula, but Hubble reveals another small, bright hourglass nestled in the center of the larger one, suggesting that separate outbursts occurred several thousand years apart. (Figure 10)

THE WHITE HOUSE

WASHINGTON

April 7, 2000

Warm greetings to everyone gathered at the NASA Goddard Space Flight Center to celebrate the 10th anniversary of the Hubble Space Telescope.

It was ten years ago this month that Dr. Steven Hawley eased the Hubble Space Telescope out of the space shuttle's cargo bay and gently placed it into orbit 380 miles above the surface of the Earth, thus beginning the remarkable tenure of the world's most famous telescope. The world anxiously awaited the first images from Hubble, and, while they were not as clear as we had hoped, these images were better than any previous telescope had ever produced. Four years later, following an extraordinary servicing mission that earned its management team the prestigious 1994 Collier Trophy, an improved Hubble Space Telescope continued the quest to unlock the secrets of our universe.

The HST has helped scientists see farther, clearer, and deeper into the past than we ever imagined. Over the past decade, HST images — some of which are now being immortalized as postage stamps — have been splashed across our newspapers and magazines. Textbooks have been rewritten as new images replaced old and as hypotheses have been converted into truths. HST images have aided scientists in the calibration of a cosmic measuring stick, the measurement of the expansion rate of our universe, the detection and measurement of black holes, and the exploration of the nature of quasars, the birth and death of stars, and the beginnings of new planetary systems.

These achievements alone have surpassed the expectations of the visionaries who developed the HST. And, owing to the foresight of NASA and its partners who designed the HST to be serviced on-orbit, newer and different instruments are fitted to Hubble on each servicing mission, enabling the HST to evolve as technology advances. As we celebrate this milestone, I salute the men and women responsible for designing, building, operating, and servicing the Hubble Space Telescope as well as the many scientists who continue to astound us with their discoveries. You have each played an important role in making the Hubble Space Telescope one of NASA's brightest stars.

Best wishes for a memorable anniversary celebration.

Bill Clinton

## V. Hubble Captures the World's Attention

Over the past decade, the Hubble Space Telescope has captivated the world with its story of human resolve and exploration. Halfway through its 20-year mission, the telescope has become an international, cultural icon and part of the fabric of our lives. An entire generation of children has never known a world without Hubble.

Routine upgrades by Shuttle astronauts strengthen the unique bond between humans and Hubble. The relationship is dynamic and interactive: human interaction has enabled Hubble to evolve, providing cutting-edge discoveries for over a decade. Hubble's scientific productivity exceeds that of all other astronomical observatories, providing crucial training and insights for the next generation of innovators and explorers. It engages the ordinary citizen, with its ties running especially deep in industry and education.

President and Mrs. Clinton watching the launch of STS-95, October 1998.

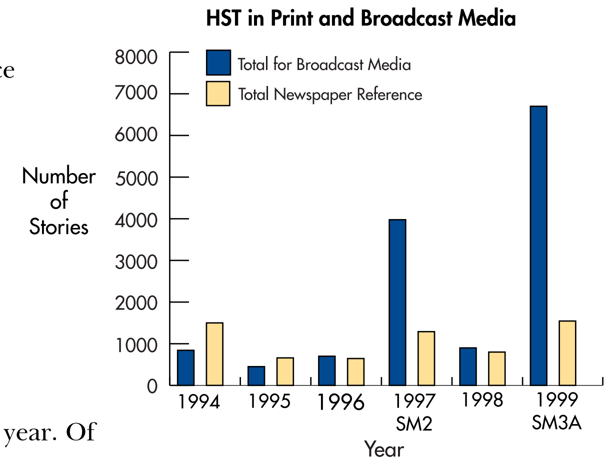
### Hubble in the News

"Hubble's rate of discovery is simply unprecedented for any single observatory," says Dr. Ed Weiler, Associate Administrator for Space Science. "But what may be even more important in the long term is what Hubble has given to just about everyone on Earth. Hubble's spectacular images and discoveries of black holes, colliding galaxies, and bizarre objects at the edge of the Universe have been brought into millions of homes by newspapers, television, and the Internet."

From its spectacular launch and dramatic repair to its regular revelations about our Universe, Hubble is in the news more consistently than any other topic in space science. In addition to stories in the standard broadcast media, Hubble has maintained an ever-expanding presence on the World Wide Web.

## Hubble in Print and Broadcast Media

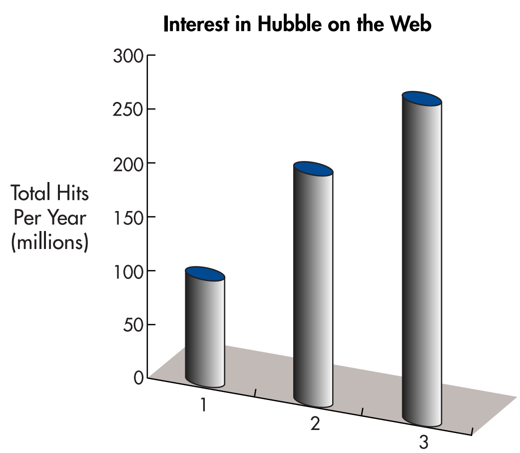
From the moment Congress made Hubble a reality, the public has been fascinated by the Telescope's progress, its seemingly insurmountable difficulties, and ultimately, its overwhelming success. In particular, the interaction of Hubble and its Space Shuttle servicing crews sparks the imagination of the public and the media.



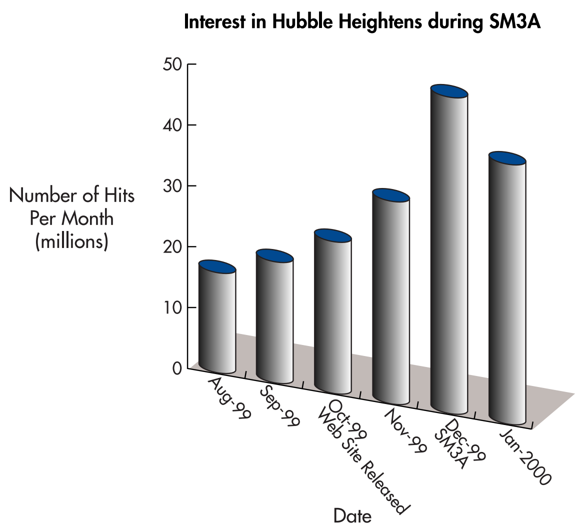

While many scientific satellites have captured the public's attention, none has rivaled Hubble in maintaining a consistent presence in the media and in popular imagination year after year. Of NASA's major science missions, the Hubble Space Telescope maintains the largest sustained presence in the news.

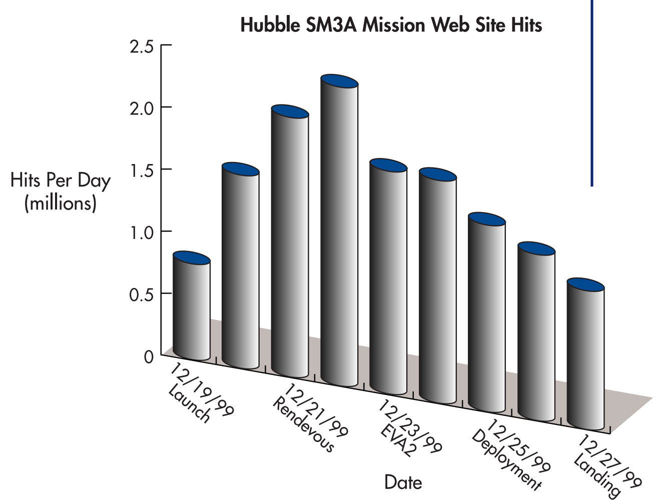
## Hubble on the Web

The World Wide Web provides a unique way for people around the world to stay connected to the Hubble Space Telescope. Statistics from the official Hubble websites at the Space Telescope Science Institute and Goddard Space Flight Center (GSFC) show an ever-increasing interest in Hubble images, science, and related news. These sites averaged 18 million hits per month during the non-servicing time periods in 1999.



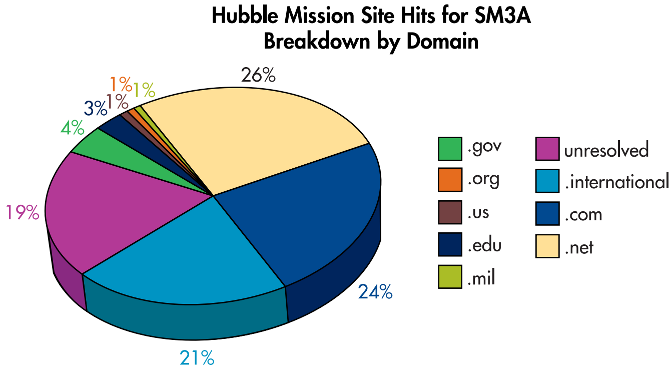

Servicing heightens interest in Hubble. Web site statistics graphically show the increased level of public interest during the SM3A servicing mission. Visits to the public Hubble Mission web site peaked at over 2 million hits per day during spacewalks, with the combined Hubble sites averaging six times more visitors than in non-servicing mission periods.




## THE HUMAN CONNECTION

Interest in Hubble comes from around the globe. Visitors to the Hubble mission web site are a diverse representation of age, occupation, and geographic location. The audience breakdown shows that interest in Hubble is not limited to members of government or the scientific community, but includes access from businesses, educational institutions, and international addresses, as well as individuals across the United States, as shown in the chart below.



## Excerpts from the Hubble SM3A Mission Web Site Guestbook Show Overwhelming Support for NASA and the Hubble Program

- "Thank you for bringing space travel to us. Watching the liftoff of Discovery on NASA TV tonight was amazing. I am a teacher and I am currently involved in the Mars Millennium Project with my students. Watching the liftoff still leaves me in wonder. I can remember watching when man made his first steps on the moon. I look forward to the day when we take our first steps on Mars. Thank you to Congress for the continued funding to the space program. Thank you for bringing the adventure and education to us. Our prayers are with you."

- "Nothing lasts forever without repair. Robots can't do this work. Have successful and safe mission."

The STS-103 Crew on their way to the launch pad

- "Greetings from Holland. Please forward the following message towards the crew: Have a safe blast off, a very successful mission AND last but not least a very successful return to the base. Looking forward to see the progress on this site."

- "Thanks for the experience of being a part of the launch, it's great for the mind. Also, Thank you, Congress for the funding."

- "Excellent work. The universe is ours, thanks to all your hard work guys."

- "...know how important this instrument is to us, though we may be bricklayer, accountant, or teacher. It is our sharp eye on the universe, our window on creation, and our time machine. Thank you NASA ... CONGRATULATIONS!"

- "Greetings, this just boggles the mind as to what is out there. And all we can do is look, but without you doing what you do best, we couldn't even do that. This Earth is such a small place, why can't people learn to get along with one another."

# VI. Hubble Partners: Taking the Initiative

Industrial and educational partners from across the nation and around the globe play critical roles on Hubble's science and engineering teams. In addition to performing scientific observations and analysis, these partners team with NASA on hardware design, fabrication, and integration and testing, as well as spacecraft operations and information technology. This partnership of scientific expertise and technological excellence allows the Hubble Space Telescope to continue as one of the "crown jewels" of NASA year after year, mission after mission.

Hubble Team Meeting

## Hubble and Industry - Partners in Innovation

No enterprise as complex as Hubble can be successful without the dedication and support from a wide range of technical disciplines. These are provided through Hubble's industry partners, bringing the most advanced and cost-effective solutions to the unique challenges of creating, operating, and strengthening humankind's most powerful observatory. This combined Hubble team routinely makes the personal sacrifices necessary to keep our observatory operating flawlessly.

## Industry Partners

AASC
ACI Electronics Corporation
Advanced Circuit Technologies
Alatec Products
Alliant Techsystems, Inc.
AlliedSignal
Almag Plating
AMP Inc.
Apnet
Arrow Zeus Electronics
Associated Spring
Astrium GMBH
Astrium Ltd.
Astro Instrument Corporation
Atlantic Science and Technology
AURA
Aviation Equipment
Avnet Inc.
BAE Systems
Ball
Bally Ribbon Mills
Barden Precision
Barr Associates, Inc.
BD Systems
Bechdon
BEI Sensors and Systems Company
Boeing
Bradley Enterprises
Brush Wellman
C-S Metals
CalTech
Cannan
Capstone Electronics
Castrol Inc.
CDA InterCorp
Ceramic to Metal Seals
CES
Clement Engineering
Climax Specialty Metals
Coastal Optical Systems
Conexant
Contravis Space
Copper & Brass Sales
Courtaulds Performance Films
CSA Engineering, Inc.
CSC
CYTEC-FIBERITE
Denton Vacuum, Inc.
Eagle Precision
Eastern Plating
EER
Energy Solutions International, LLC
Epner Technology
E.V. Roberts
Fastener Depot
Fry Steel
General Dynamics
Genesis Engineering Co., LLC
Global Science & Technology
Hardware Specialty Co.
Helicoflex Co.
Hernandez
HISCO

Honeywell Technical Solutions
Hypertronics Corporation
Indium Corp of America
Industrial Retaining Ring
Interface Welding
ISI
Jackson & Tull
Jodin Yvon-Spex
Kaydon Custom Bearings
K R ANDERSON
Kenig Aerospace
Kyocera America, Inc.
Lake Shore Cryotronics
Litchfield Precision
Lockheed Martin
Lockwood Software
LSEI
M & D Machine
ManTech
Marconi Applied Technologies
Marlow Industries
Maryland QC
Max Levy & Associates
Maxwell Technologies
McMaster Carr
Mega
Melles Griot
Minco Products, Inc.
Nanonics Corporation

Newark Electronics
Newport Corporation
Nusil Technology
Oceaneering Space Systems
OerliKon Contravis AG
Omitron
Omnetics
Optical Filter Corporation
Optical Research Associates
Orbital Science Corporation
Pacific Coast Technology
Penn Camera
Photo Chemical
PNE
PRO-PAC
Raytheon
Research Devices, Inc.
Research Electro Optics
Robert C. Byrd Institute
Rockwell Science Center
SAES Getters
SAFT America, Inc.
Samson Metals
SAVA Industries
Sea Wire & Cable
SGT
Sheldahl Co.
Sherburn Electric Corporation
Southwest Products Company

Spacecraft System Engineering Services
Space Systems Integration
Specialty Manufacturing
Spectrum Laser
Stern and Stern
SUMATECH
Surmet
SVG Tinsley Laboratories
Swales Aerospace
Tifco-Spline
Titanium Industries
Tomas & Betts
TOPER Manufacturing
Toshiba America
Total Plastics
TFE
TTI, Inc.
TW METALS
Tyco Engineered Systems
Unisys
United Supertek, Inc.
University of Arizona
University of California
USA
Vantage Systems
Washington Valve
Wolcott Park
Yellow Springs Instruments
Zeus West

## Hubble and Education - Investing in Our Future

The scientific enterprise of Hubble draws upon an international group of universities and research organizations. The students at these institutions learn critical research methods using the data from Hubble. They convert it from raw numbers into our civilization's most accurate and detailed view of the physical Universe. Public outreach activities convey the excitement of Hubble's discoveries to an entire generation of school children. These future leaders and explorers will have the benefit of a view of the Universe that was speculation and conjecture just a decade ago.

### Hubble and Innovative Science Education

Each year, over 7000 school groups visit the Hubble Integration Facility. Among them is the SUNBEAMS program (Students United with NASA Becoming Enthusiastic about Math and Science). The program is designed to encourage positive and enthusiastic attitudes towards math and science among middle school students. Hubble is so well known to students through their schools and through the media that it is uniquely suited to illustrating the connection between real-life skills and the abstract concepts of science. Students visiting the Hubble testing and integration facilities can interact with Hubble staff and handle materials in the Thermal Systems Support Lab, where Hubble's protective blankets are sewn. This unique, hands-on opportunity engages students directly, creating an immediate connection between Hubble's breathtaking images and the people and skills necessary to make the telescope work. Hubble's very real human connection opens children's minds to a world of possibilities for the future. (Figure 1)

### Hubble Engineering Competition

An engineering competition, sponsored by the Hubble Program, the GSFC Education Office, the GSFC Public Affairs Office (PAO), and the GSFC PAO Contractors Consortium, was held with the regional participation of middle school students. The competition involved integrated disciplines such as engineering, science, and mathematics. This outreach event focused on school teams learning and utilizing the engineering process to solve the real-life or potential real-life issues encountered by engineers working with Hubble. (Figure 2)

**1.** Presentations at the Hubble Engineering Competition
**2.** SUNBEAMS students touring Hubble facilities

The competition was a valuable education initiative encouraging the development of higher-level thinking skills and problem-solving skills. The use of the engineering process at the middle school level enhanced students' ability to practice critical thinking in a team environment. At the same time, it provided a background for career choices in engineering. This type of competition is more challenging than the typical science fair because contestants must use their scientific knowledge to devise a creative solution within a relatively short period of time.

The NASA Strategic Plan mandates that we involve the education community in our endeavors to inspire America's students, create learning opportunities, enlighten inquisitive minds, and communicate widely the content, relevancy, and excitement of NASA's missions and discoveries. Educational programs such as Hubble's help ensure that a continuing pool of scientists, engineers, and technologists will be ready to meet the needs of the 21st century.

## The Hubble Team Goes to School

As part of the Hubble tenth anniversary commemoration, Hubble personnel created a presentation program and visited schools across the Washington, DC metro area and in Virginia, Maryland, Connecticut, and California. These school visits were designed to inspire students to excel in math and science by communicating Hubble's accomplishments over the past decade. In the Washington D.C. area alone, between mid-April and late-May of 1999, nearly 19,000 students in 300 schools were reached.

## Educational Outreach at the Space Telescope Science Institute

At the Space Telescope Science Institute (STScI), where Hubble's images are processed and analyzed, education plays a major role in outreach. STScI supports teachers of grades K-12 by providing web-based and printed materials that promote science, math, and technology skills. The award-winning *Amazing Space* web site provides interactive lessons and activities, which are based on national educational standards. *Amazing Space* modules are developed by teams of scientists, teachers, graphic artists, web programmers, curriculum specialists, and education evaluators. STScI also provides posters, trading cards, lithographs, bookmarks, and information specifically designed for teachers and students without access to the Web.

PCs in Space is used nationwide


In addition, STScI supports science museums and planetaria. It provides Hubble expertise, multimedia shows, and exhibit materials tailored to the needs of each venue. STScI partnered with Goddard and the Smithsonian to develop an extensive, traveling Hubble exhibit, which debuted at Chicago's Adler Planetarium in June 2000. Over the next five years, a large and small version of this exhibit will travel to museums and planetaria across the country. These exhibits, along with STScI's other educational outreach products, bring the fun of math and science to our children through the awesome power of Hubble's images.

## PCs in Space Educational Software

NASA teams with industry partners and educators to create interactive, educational software showcasing Hubble images to inspire students around the world. *PCs in Space*, Jackson and Tull's free software, is an innovative program available through the Internet. The educational material incorporates Hubble's latest discoveries into existing curricula, enhancing the overall educational experience. This enormously successful program has reached 4.5 million students in the past five years, sparking enthusiasm for space science among a new generation.

## Partners in Higher Education

In 1999, these institutions were awarded merit-based research grants to analyze Hubble data:

Arizona State University
Australian National University
Boston University
Bowling Green State University
California Institute of Technology
Canadian Military College
Carnegie Institute of Washington
Carnegie Mellon University
Case Western Reserve University
Catholic University of America
Centre d'Etudes de Saclay (CEA Saclay)
Clarkson University
Columbia University
Copenhagen University Observatory
Cornell University
Crimean Astrophysical Observatory
Dartmouth College
Dublin Institute For Advanced Studies
Ecole Normale Superiure de Lyon
Georgia State University Research Foundation
Harvard University
Harvard-Smithsonian Center for Astrophysics
Haverford College
Herzberg Institute of Astrophysics
Imperial College of Science Technology and Medicine
Indiana State University South Bend
Indiana University System
Institute For Advanced Study
International School for Advanced Studies
Konkoly Observatory
Kyiv University
Leiden Observatory
Liverpool John Moores University
Louisiana State University
Lowell Observatory
Lund University
Macalester College
Massachusetts Institute of Technology
McMaster University
Michigan State University
Middlebury College
New Mexico State University
Northern Arizona University
Northwestern University
Observatoire de Geneve
Observatoire de Grenoble
Observatoire de Marseille
Observatoire de Paris
Observatoire Midi-Pyrenees
Observatorio Astronomico Nacional
Ohio State University
Oxford College of Emory University
Paul Scherrer Institute
Princeton University
Queen's University
Rice University
Royal Greenwich Observatory
Royal Observatory Edinburgh
Ruhr-Universitat Bochum
Rutgers the State University of New Jersey
San Francisco State University
Skidmore College
Smith College
South Carolina State University
Southwest Research Institute
St. Mary's University
State University of New York at Stony Brook
Sternwarte der Universitaet Bonn
Sterrewacht Leiden

Stockholm University
Technion-Israel Institute of Technology
Tel Aviv University
The Academy of Art & Science
The Johns Hopkins University
The Pennsylvania State University
The Queen's University of Belfast
The University of Virginia
Towson State University
Universidad Autonomia de Madrid
Universidad de Chile
Universidad de Concepcion
Universidad Nacional Autonoma de Mexico
Universidade de Sao Paulo
Universidade Federal de Santa Catarina
Universidade Federal do Rio Grande do Sul
Universita degli Studi di Bologna
Universita degli Studi di Catania
Universita degli Studi di Milano
Universita di Firenze
Universita di Pisa
Universitaet Erlangen-Nurenberg
Universitaet Potsdam
Universitat Basel
Universitat Bonn, Astronomische Institute, Sternwarte
Universitat Hamburg, Hamburger Sternwarte
Universitat Heidelberg
Universitats-Sternwarte Gottingen
Universitats-Sternwarte Munchen
Universite de Liege
Universite Laval
Universite Paris XI
Universiteit van Amsterdam
Universities Space Research Association
University College London
University of Alabama
University of Arizona
University of Bristol
University of British Columbia
University of Calgary
University of California - Berkeley
University of California - Davis
University of California - Los Angeles
University of California - San Diego
University of California - Santa Barbara
University of California - Santa Cruz
University of Cambridge
University of Central Lancashire
University of Chicago
University of Cincinnati Main Campus
University of Colorado at Boulder
University of Delaware
University of Denver
University of Durham
University of Edinburgh, Institute of Astronomy
University of Florida
University of Guam
University of Hawaii
University of Hertfordshire
University of Illinois at Urbana - Champaign
University of Keele
University of Kentucky
University of Leicester
University of Manchester
University of Maryland
University of Massachusetts
University of Melbourne
University of Michigan
University of Minnesota - Twin Cities
University of Montreal
University of Nevada - Las Vegas
University of New South Wales
University of North Carolina at Charlotte
University of North Carolina at Raleigh
University of Nottingham
University of Oklahoma Norman Campus
University of Oregon
University of Oslo
University of Oxford
University of Padova
University of Pennsylvania
University of Pittsburgh
University of Rhode Island
University of Sheffield
University of Southern California
University of St. Andrews
University of Sussex
University of Sydney
University of Texas at Austin
University of Texas at El Paso
University of Toledo
University of Toronto
University of Utrecht
University of Victoria
University of Virginia
University of Wales, College of Cardiff
University of Washington
University of Waterloo
University of West Virginia
University of Wisconsin - Madison
University of Wyoming
Valparaiso University
Villanova University
Wellesley College
Wesleyan University
Western Kentucky University
Western Michigan University
Whitman College
Yale University
York University

## VII. Hubble and NASA's Strategic Goals

The NASA Strategic Plan is a major step toward shaping the Space Science Program of the 21st century. Guided by this plan, the space science community can continue to change the way we think about our place in the Universe.

Hubble's unique and original design meets the challenges set forth by NASA. Hubble is also an integral part of NASA's Origins Program, which is designed to aid us in obtaining knowledge of our cosmic roots. Throughout its first decade, Hubble has maintained a standard of excellence in exploring the development of space and human enterprise, researching and developing advanced technologies, and advancing and communicating scientific knowledge.

Hubble and its continuing servicing missions are central to the implementation of the science goals for NASA and the Origins Program:

- Hubble has provided information crucial to understanding the structure of our Universe.
- Hubble continually tests physical theories and reveals new phenomena throughout the Universe, especially through the investigation of extreme environments.
- Hubble helps scientists understand how both dark and luminous matter determine the geometry and fate of the Universe.
- Hubble instruments have helped us understand the dynamic and chemical evolution of galaxies and stars and the exchange of matter and energy among stars and the interstellar medium.
- Hubble has expanded our knowledge of how stars and planetary systems form together.
- Hubble has provided detailed images that assist us in understanding the nature and history of our solar system, and what makes Earth similar to and different from its planetary neighbors.

We can utilize the knowledge provided by HST, including the development of cutting-edge technologies to advance our knowledge and to improve the quality of life on Earth.

*"I am honored to be the leader of an organization that has this Hubble team."*

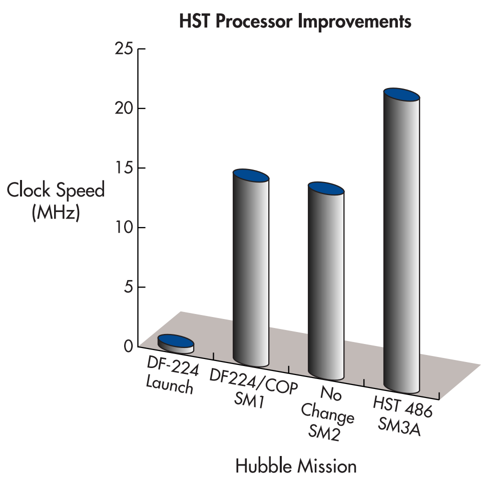
— Daniel S. Goldin, NASA Administrator

# VIII. Hubble and Advanced Technologies

From detector technology to astronaut tools, the Hubble Program is continually seeking to optimize performance. The 10-year-old telescope is essentially a new machine. Upgrades, maintenance, and creative innovations maximize Hubble's scientific return and ultimately benefit many aspects of our everyday life. From manufacturing to medicine, these numerous technological advances enhance the U.S. economy and our standard of living, making Hubble a valuable investment for our future.

## Computer Processing Improvements

During Servicing Mission 3A, astronauts replaced Hubble's original main computer, a DF-224/coprocessor combination, with a completely new computer based on the Intel 80486 microchip. The new computer is 20 times faster and has six times as much memory as the one it replaced. In a good example of NASA's goal of "faster, cheaper, better," commercially developed, commonly available equipment was used to build a new computer at a fraction of the price it would have cost to build a computer designed specifically for the spaceflight environment.

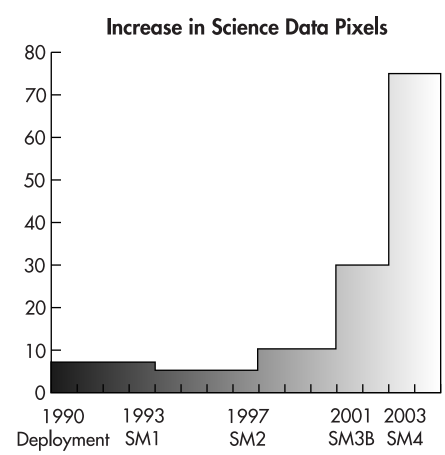



The greater capabilities of the new computer are increasing Hubble's productivity. The computer software also uses a modern programming language, which decreases software maintenance cost.

## Data Storage Capability

With the addition of a second Solid State Recorder (SSR) on SM3A, Hubble's data storage capability dramatically increased. The science data archiving rate is now more than ten times greater than 1993 rates.

Prior to SM2, Hubble used three mechanical reel-to-reel tape recorders designed in the 1970s. In February 1997, astronauts replaced one of these recorders with a digital SSR. In 1999, SM3A astronauts removed a second mechanical recorder and installed another digital SSR.



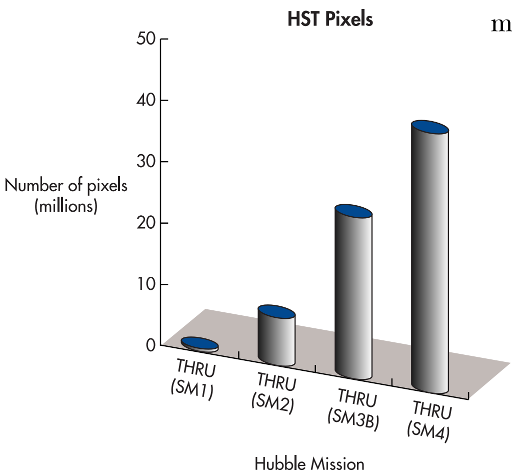

Unlike the reel-to-reel recorders they replace, the SSRs have no reels, no tape, and no moving parts that can wear out and limit lifetime. Data is stored digitally in computer-like memory chips until

Hubble's operators command its playback. Although an SSR is about the same size and shape as the reel-to-reel recorder, it can store ten times as much data: 12 gigabits of data instead of only 1.2 gigabits. This greater storage capacity allows the second generation of Hubble's advanced-technology scientific instruments to be fully productive.

## DETECTOR TECHNOLOGY

Hubble's state-of-the-art detector technology allows the telescope to capture and process faint amounts of light from the far reaches of space.

Charge-coupled device (CCD) detectors are commonly referred to as the "film" of digital cameras, but that description hardly does justice to this incredibly useful technology. Modern CCD detectors match the resolution of film, but they surpass film in several key performance areas. For example, they are capable of operating over a much wider wavelength range. A single CCD detector can record data from the infrared to the x-ray energy band, making this technology extremely adaptable. Their sensitivity to light is far superior to film over these large wavelength ranges.

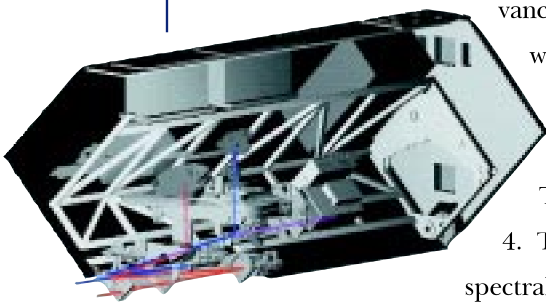



In addition, images can be read out of a CCD in seconds, much faster than film can be developed. Most importantly, CCDs record images digitally, allowing the information to be stored and manipulated by a computer. These versatile qualities have lead to the rapid transfer of CCD technology into industrial, medical, and consumer applications. The CCD is now the "detector of choice" in products ranging from automotive quality control monitors to breast biopsy systems to video cameras.

The accelerated progress in CCD development over the past two decades is due in large measure to the efforts of the HST Program, which has continuously driven the leading edge of this technology. Hubble scientists realized early on that broad wavelength sensitivity, coupled with the ease of digital data analysis, makes CCD detectors ideal for astronomy. CCDs were aboard the Hubble Space Telescope when it launched in 1990. Successive generations of science instruments pioneered CCD technology enhancements. These efforts have led to the production of larger format, more sensitive, and more reliable detectors, enabling Hubble to deliver exceptional scientific data.

## Advanced Camera for Surveys (ACS)

The Advanced Camera for Surveys, to be launched on Servicing Mission 3B, employs a 16-million pixel focal plane (consisting of two state-of-the-art, 8-million pixel CCDs) with advanced, performance-enhancing coatings. These coatings allow the detectors to absorb up to 85 percent of the photons that strike them. The combination of the instrument's large field of view and superior sensitivity will improve Hubble's scientific capabilities by a factor of ten. The Advanced Camera CCD program also targets specific process enhancements, which reduce image artifacts and improve manufacturing yield.

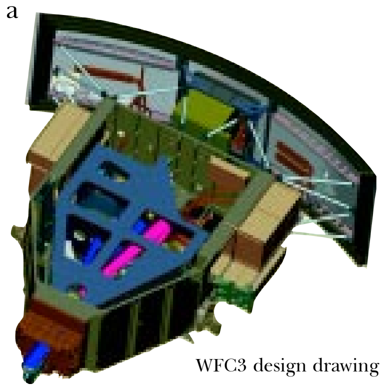


ACS design drawing

## Wide Field Camera 3 (WFC3)

The Wide Field Camera 3 is planned for launch on Servicing Mission 4. This dual-channel instrument will provide an unprecedented, wide-spectral range view of the Universe. Its two-detector system spans the near-ultraviolet to the near-infrared. The Hubble program is focusing its efforts on developing a CCD with high sensitivity over both the visible and ultraviolet spectrum. This would provide a new capability in the near-ultraviolet for both astronomical and earthbound uses. Building upon the advances made by ACS, these detectors would provide higher sensitivity and lower noise than ever achieved in detectors of this size. For the long wavelength (infrared) channel, the technological advance is comprised of an IR detector system that is cooled exclusively by a thermal electric cooler to -120º C (150 Kelvin). This reduces cost and complexity when compared with the traditional methods, which use cryogens or other cryogenic cooling systems. WFC3 will improve Hubble's scientific capabilities by a factor of twelve.

The science community is eagerly anticipating the discoveries that will be made with these new highly efficient instruments. In the meantime, Hubble's CCD efforts are already paying off on Earth. Each new development broadens the applications for, and improves the performance of, these detectors.



WFC3 design drawing

## Cosmic Origins Spectrograph (COS)

In 2003, astronauts will begin a new era in ultraviolet spectroscopy when they install the Cosmic Origins Spectrograph (COS) instrument into Hubble. One of its major goals is to measure the distribution of matter in the almost empty space between galaxies. This is a major puzzle as we complete our census of where all the matter in the Universe resides. Most of this matter is in the form of hydrogen. Measurements in the ultraviolet are key since this gas has unique signatures in this wavelength region. This innovative instrument uses a simple and elegant optical design, coupled with advanced ultraviolet detectors. It improves sensitivity levels by a factor of ten compared with previous instruments. Using this new capability, Hubble scientists hope to better understand the characteristics of the matter between and within stars and galaxies.

## Cryogenic Cooler

Astronauts installed the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) on Hubble in 1997. Its infrared (IR) vision allowed scientists to probe dark, dusty, never-before-seen regions of space. Solid nitrogen ice kept NICMOS cool and allowed it to conduct infrared science. In 1999, with its supply of ice exhausted, NICMOS became dormant. On SM3B, astronauts will retrofit NICMOS with a new cooling system that will return it to active duty. The heart of this system is the NICMOS Cryogenic Cooler (NCC).

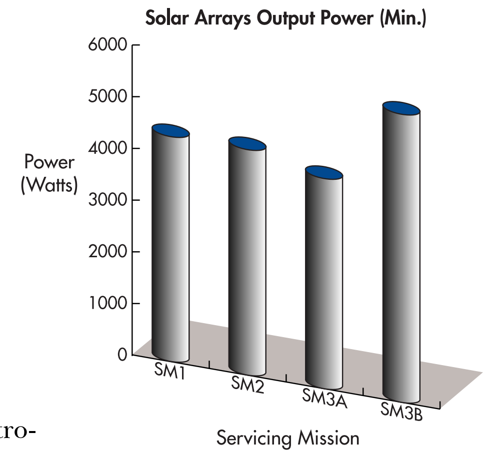
The NCC is a state-of-the-art, mechanical cryocooler that will potentially increase NICMOS's life span from 1.8 years to more than 5 years. It uses rapidly rotating microturbines, the fastest of which spins at over 400,000 rpm (over 100 times the maximum speed of a typical car engine). It will cool the infrared detectors to -200º C, or 70 Kelvin. The NCC operates with virtually no mechanical vibration. Such vibration would cause Hubble to shake and affect image quality, much as a shaky camera affects picture quality.

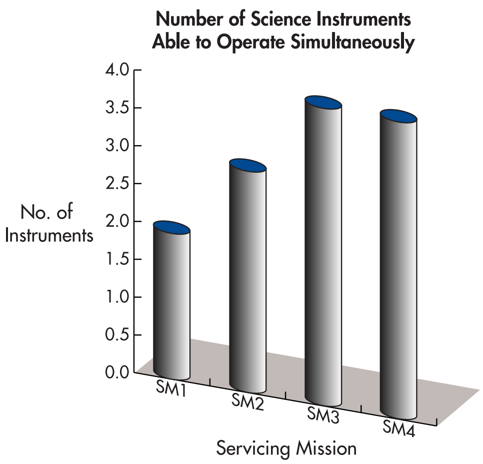
The Hubble Project successfully demonstrated this new technology aboard STS-95 in 1998. This was the first on-orbit test of a high-performance, high-efficiency, mechanical cryocooler. The test took place less than 20 months after cryocooler development began—an extremely short time for bringing a new technology into the space applications portfolio.

The cost to develop and install the NCC is approximately $19 million, while the cost of NICMOS was $120 million. Installing a new cryocooler will triple the lifetime of the instrument, ensuring a greater scientific return on the original investment. This revolutionary technology paves the way for exciting advances in IR astronomy on both Hubble and the Next Generation Space Telescope.

## Solar Arrays Increase Simultaneous Science Capabilities

The addition of new, rigid solar arrays on SM3B will provide Hubble with increased electrical power-generating capability. This will enhance science productivity by allowing up to four science instruments to operate simultaneously. Advancements in solar cell technology make it possible for these new arrays to produce 20 percent more power, even though they are 30 percent smaller than the current set, which was installed on Hubble during SM1.




The smaller size decreases on-orbit drag and slows Hubble's rate of orbital decay. These smaller, stiffer arrays also are easier for the astronauts to work around during servicing missions.

The panel supports on the arrays are made of lithium-aluminum, which is stronger, lighter, and tougher than the type of aluminum commonly used in spacecraft construction. These supports are much less sensitive to the extreme temperature changes of Hubble's orbit. (Within each 97-minute orbit, the temperature outside Hubble spans about 149º C (300º F).

The Hubble Program bought solar panels from the production line of a commercial system of communications satellites. Purchasing off-the-shelf panels saved considerable time and expense.

## The HST Lubricant Applicator

The Lubricant Applicator in use.

During the first and second servicing missions, the astronauts discovered that several bolts keeping the large Aft Shroud doors closed were exhibiting high running torques during operation. In an effort to solve this problem, the Hubble team developed a tool to apply a thin film of lubricant to the threads of the door bolts. While a simple task here on Earth, applying a viscous fluid in the vacuum of space had never been performed before. Care had to be taken to avoid getting the grease on the astronaut's gloves or the rest of the highly sensitive spacecraft. In response to this challenge, the innovative Hubble team developed the HST Lubricant Applicator. With this new tool, the astronauts were able to apply a small amount of grease on the threads at each location without contaminating themselves or the spacecraft. Although the tip of the tool was designed specifically for applying grease to the Hubble's door bolts, it can easily be modified to fit almost any feature of any other space structure.

## Lithium Ion Battery

A prototype Lithium Ion (Li-Ion) battery pack for NASA's Power Ratchet Tool (PRT) was flown during Servicing Mission 3A. The PRT, a power tool developed by GSFC, is used to service Hubble. This was the LiIon battery's first test in space.

NASA teamed with the Air Force Research Labs, Wright-Patterson AFB, and SAFT America Inc., to develop and certify this new, cutting-edge battery technology for human space flight. The Li-Ion battery chemistry as compared to nickel cadmium (NiCad) provides superior energy density, over 50% higher voltage, excellent charge retention, and high cycle life. This ten-cell battery pack could fit in a small, portable, 12-volt commercial power drill, yet supplies over 40 volts. While 24-volt power drills are currently available, their battery packs are bulky, making them hard to hold for long periods of time and difficult to operate when working in tight spaces. The Li-Ion battery will reduce overall logistics and maintenance costs for NASA, compared to the current technology because each one will be used on multiple missions.

NASA contimues to develop this technology for use in its next generation power tool. Our goal is to get the same power in a smaller, more compact battery.

## Diamond-Hard Carbon Coating

A revolutionary, diamond-hard coating will cover tiny parts on the NICMOS cryogenic cooler. Called UltraC Diamond™, this film-like coating is tough, slippery, and approximately 1/100th the thickness of a human hair. This is its first space use on titanium and the first time any hard, carbon coating will be used on such small, complex, and precise machinery.

During normal operation, the cryocooler's tiny circulator shaft will spin at 90,000 rpm. To minimize friction and wear, the shaft and bearings need a very thin, hard, slippery coating. The Hubble team looked at various other coatings, but only UltraC Diamond™ met their rigorous requirements. The coating is a prime example of the economic value-added benefits of Hubble technology. It was developed by Surmet Corporation, and the Hubble Program funded the extensive testing required to qualify it for flight.

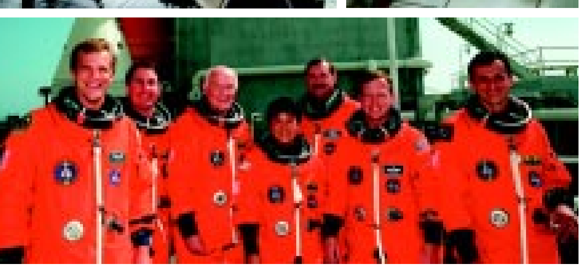
Experts foresee widespread applications and enormous benefits for NASA and private industry. This tough and nearly frictionless coating is ideal for applications such as semiconductor manufacturing, high-speed micromachines, miniaturized satellites, and prosthetics. It is also well suited for use in power plant turbines, air conditioners, and automobile engines.

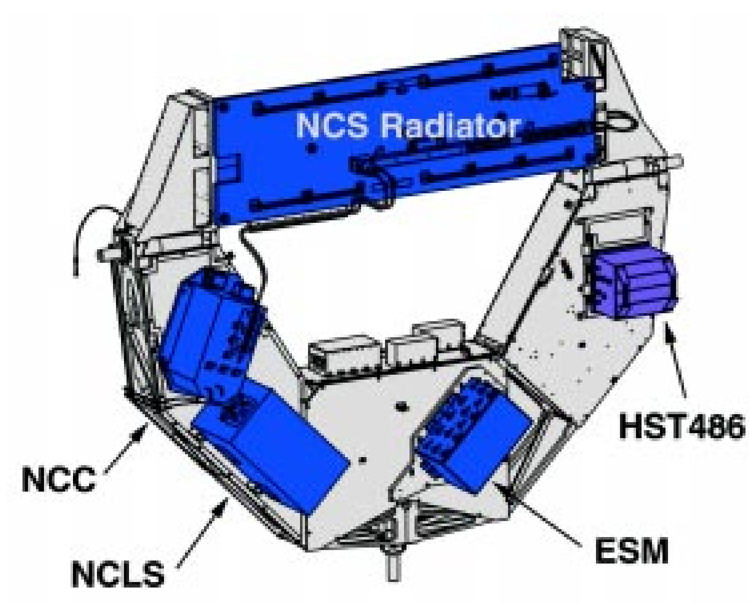
## Hubble and the Shuttle Program – A Test Bed in Space Adds Scientific Value

In October 1998, the Hubble Team conducted the HST Orbital Systems Test (HOST) on board STS-95 ("The John Glenn Mission"). HOST provided an on-orbit test bed for key pieces of new Hubble hardware, including a new, main computer (HST486), NICMOS Cryogenic Cooler (NCC), and digital data recorder. By flying in an orbit similar to Hubble's, HOST helped engineers determine how the new equipment would perform on Hubble.

HOST engineers monitored the effects of radiation on Hubble's new hardware. All the new technologies aboard HOST performed optimally. In 1999, astronauts installed the new computer and data recorder on Hubble. The cryogenic equipment will become part of the telescope in 2001.

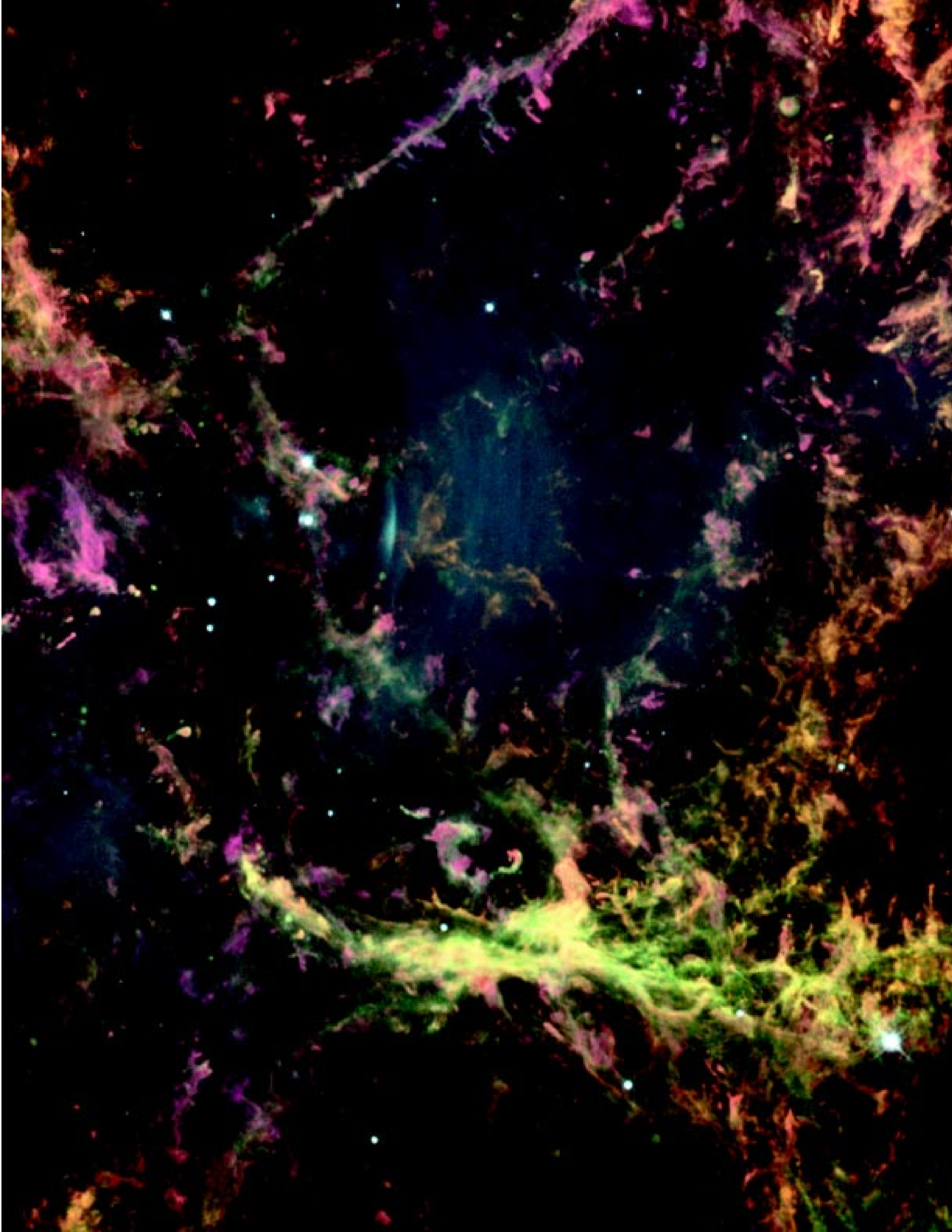
The success of the HOST mission underscores the value of the Shuttle and humans in space. It also illustrates the Hubble Program's philosophy of using new and advanced technology to maximize science return.






**HST Orbital Systems Test Platform**

The NICMOS Crogenic Cooler (NCC), NICMOS Cooling Loop Simulator (NCLS), Electronic Support Module (ESM) and NCS Radiator worked together to test the operation of the revolutionary NICMOS Cooling System (NCS).



# IX. Vision 2000: The New Hubble Control Center System (CCS)

Imagine something remarkably new and remarkably powerful, right at one's own fingertips. It's the Hubble Control Center System (CCS) and it opens the window to the world of Hubble Space Telescope operations. Imagine using an ordinary personal computer to view the inner workings of Hubble, and monitor its actions as operations are run. This is the new CCS. It is how spacecraft engineers and flight operations personnel now fly the telescope from "Hubble Mission Control" at the Goddard Space Flight Center.

CCS software is the central hub for controlling the telescope's day-to-day operations and supporting servicing mission upgrades and repairs. The radical re-engineering of the CCS flight and ground systems, which began in 1996, demonstrates the Hubble Program's commitment to using the latest technology to improve efficiency and cut costs. The redesigned CCS has dramatically improved overall Hubble performance and drastically reduced the cost of operations and systems maintenance. Compared against the original goal for Vision 2000, the new CCS era is proving to be a huge success. The ongoing operations and maintenance costs have more than eclipsed the 60 percent savings benchmark. The CCS has successfully supported routine spacecraft operations since February 1999, including the flawless servicing mission in December 1999.

Spacecraft subsystem engineers use CCS to control and monitor HST operations during SM3A in the Space Telescope Operations Control Center at Goddard

By establishing an integrated Product Development Team (PDT), in which civil servants and contractors were melded into a single, badgeless team, the Hubble Program was able to successfully complete this massive restructuring under an extremely tight schedule. This integrated team delivered eight major releases in approximately three years, demonstrating the benefits that come from a highly motivated, co-located team.

The CCS redesign went well beyond replacing outdated software and hardware. It streamlined flow, eliminated redundant systems, and provided a user-friendly interface for the operators and spacecraft engineers. With CCS, engineers are no longer tied to their workstations. They can access CCS functions from anywhere in the world with a standard, off-the-shelf computer and an Internet or modem connection.

The CCS Graphical User Interface (GUI) software developed for Hubble is so user friendly and successful that it was commercialized and is now being used by Lockheed Martin on the Globalstar telecommunications program.

## Architecture

The improved CCS greatly reduced architectural complexity and will reduce future maintenance costs. It consolidated the functions of the five original systems into a single, streamlined system that provides the full spectrum of spacecraft control, analysis, data management, command management, and subsystem calibration. Its highly scalable client-server architecture supports single computers as well as multi-processor strings. This is especially useful for servicing where CCS is tailored to different sizes to meet varied requirements. These range from single-computer, flight hardware ground testing systems to the large scale real-time servicing mission operational system.

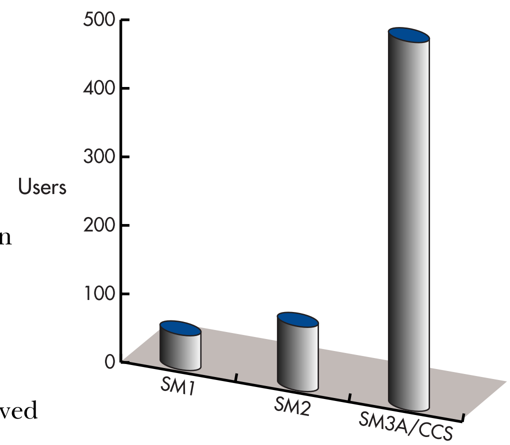
## Security

CCS design and development have been security-conscious from the start. The current design is based on concentric networks, which are linked by up-to-date security features. This design provides controlled transmission of data among the networks while absolutely protecting the telescope and its operating systems, command functions, and databases from unauthorized use or change.

## Efficiency and Flexibility

The Hubble Program decided in early 1995 that the then-emerging, web-related technologies would become a key architectural component in creating an efficient data delivery system. CCS is now capable of delivering engineering data directly to the user, regardless of geographic location. This stands in sharp contrast to the former practice of requiring that the user be located at the data source. CCS allows quicker response to spacecraft anomalies, decreased travel expenses, and improved team interaction. It also enables easier and quicker setup of the remote NASA control centers at Johnson Space Center and Kennedy Space Center, which play vital roles in Hubble's servicing missions.

**Increased Accessibility of Hubble Engineering Data with the New CCS**




## Information Access

A wealth of spacecraft information now available to Hubble personnel proved invaluable during SM3A. Users can define data requests in real time and are able to monitor conditions that have changed on the spacecraft. The previous system, used during SM1 and SM2, only allowed users to access limited real-time spacecraft telemetry information from a handful of custom workstations located at a few facilities.

## AUTOMATION

The process for collecting and merging real-time and spacecraft-recorded data has been fully automated in CCS. The engineering data is kept online for 30 days, then rolled off to a large, robotic tape archive and a data warehouse archive. This process and the source of the data are transparent to the user. Eventually, CCS data archives will hold all of Hubble's engineering data since deployment.

## SPEED

CCS now enables users to make very rapid, complex queries over wide time spans. The new data warehouse technology stores the data using schemes that combine complex query capabilities with excellent performance. For a systems engineer using the self-service features of CCS, the average response time for data delivery was cut by a factor of six.

## MONITORING

CCS has been designed to monitor itself at the network, hardware, and software application levels, further reducing maintenance and operations costs.

The Hubble Program has achieved its goals of improving user productivity, and reducing maintenance and operations costs with this new system. CCS provides a secure, highly distributed command and control system that will ensure the success of Hubble's operations throughout its second decade.

## PRODUCTIVITY INCREASES

***CCS reduces:***

- staff for spacecraft operations by 50%
- science planning by 10%
- data processing by 40%

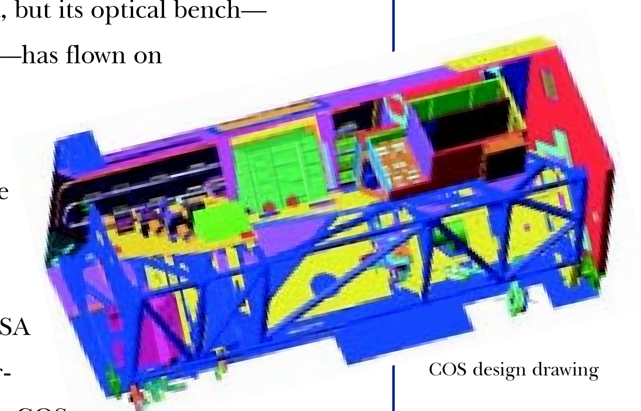
| Task | Before CCS | After CCS | Improvement |
|---|---|---|---|
| Observing Hours per Year | 2400 | 4815 | 2X |
| Target of Opportunity Lead Time | 2 wks. | 24 hrs. | 14X |
| Time from Proposal to Data Receipt | 19 wks. | 7 wks. | 3X |
| Reference Database Change | 14 wks. | 1 hr. - 2 wks. | 7X |
| Average Response Time | 6 hrs. | 1 hr. | 6X |

# X. Hubble And Space Assets: Servicing Adds Economic Value Through Reuse

Hubble's modular design allows for on-orbit instrument upgrades during planned servicing calls. The ability to refurbish the returned science instruments has proven to be a cost-effective way to enhance the telescope with the latest technology. By installing the new technology in recycled modules, NASA avoids "reinventing the wheel" and reduces the overall cost of science data. Future Hubble instruments will have 10 to 20 times more capability at half the cost of previous instruments.

## Cosmic Origins Spectrograph (COS): Optical Bench Reuse

In 2003, astronauts will fit Hubble with a new ultraviolet instrument, but its optical bench—the frame that holds the instrument's powerful optics and detectors—has flown on Hubble before.


COS design drawing

The Cosmic Origins Spectrograph (COS) reuses the bench from one of Hubble's original instruments, the Goddard High Resolution Spectrograph (GHRS). This instrument successfully fulfilled its mission and was returned by Space Shuttle astronauts in 1997. NASA and the Hubble industry team conducted rigorous testing and determined that the 20-year-old optical bench could be reused in the new COS instrument. Ultrasonic and x-ray inspections showed that the bench was still structurally sound. In fact, it was in virtually the same condition as when it was delivered to NASA in 1981. By reusing the GHRS bench, the Hubble Program saved $1.3 million and hundreds of work hours. This is the first-ever refurbishing of a Hubble science instrument.

COS will allow scientists to observe faint, ultraviolet targets both inside and outside of distant galaxies. It will help astronomers understand the interstellar medium, the formation and evolution of galaxies, and the origins of stellar and planetary systems. COS will provide Hubble with ultraviolet spectroscopic capability from 2003 to the end of its 20-year mission.

## Wide Field Camera 3 (WFC3)

WFC3 is a fourth-generation instrument for Hubble. It is designed to replace the Wide-Field Planetary Camera 2 (WFPC2), which was installed in Hubble during SM1 in 1993. WFC3 will have greater throughput and sensitivity than WFPC2. The WFC3 project is designed to take advantage of much of the hardware, software, and experience from the previous instruments.

By virtue of Hubble servicing, WF/PC1 was returned on Servicing Mission 1. As a result, approximately 30 percent of its assemblies can be re-flown on the WFC3 instrument. This significantly lowers the cost of WFC3. A prime example of the savings generated by this approach is the Selectable Optical Filter Assembly (SOFA). This previously flown, highly complex mechanism, with its 48 filter slots, will be refurbished and tested prior to flight. Thus, the costly design and development cycle is eliminated. In addition, the mission risk associated with flying a new mechanism design for the first time is mitigated.

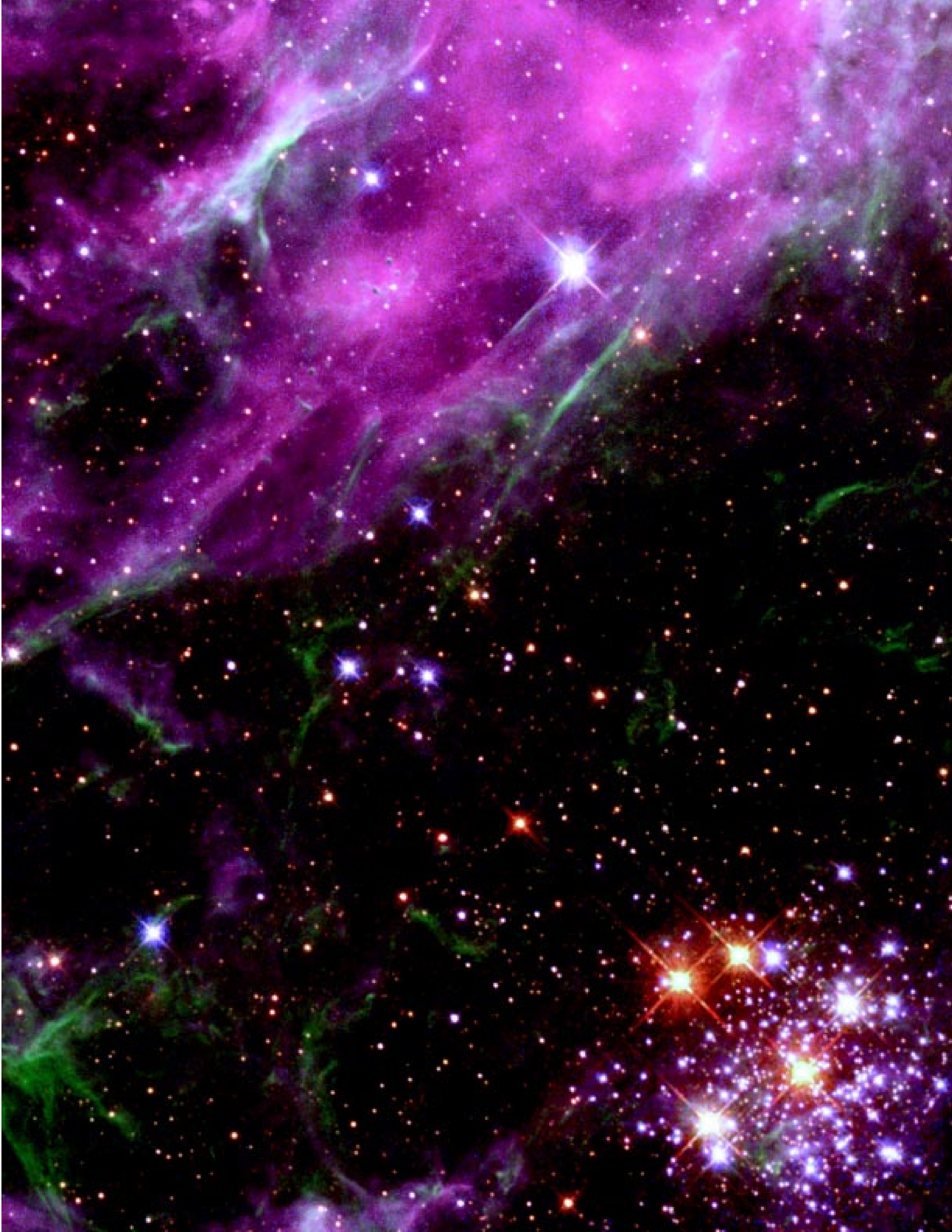
Wide-Field Planetary Camera being removed on-orbit during the first Servicing Mission.

The filters for WFC3 will consist of the most popular filters from WF/PC1, WFPC2, and ACS. In addition, as new detector technologies become available, these are being incorporated into the instrument design to maximize the instrument's scientific productivity. The NASA, industry, and university teams who worked to successfully build WF/PC1 and WFPC2 are working together again to bring us WFC3, leveraging their expertise and experience to provide a superior instrument at modest cost.

## Refurbishing Fine Guidance Sensors (FGSs)

During SM3A in 1999, astronauts replaced one of the three fine guidance sensors (FGSs), which are part of Hubble's pointing control system. Hubble's FGSs are undergoing a systematic program of refurbishment and upgrading. In "round-robin" fashion, one FGS per servicing mission is being replaced, returned to the ground, disassembled, and refurbished. It is then taken back to Hubble on the next servicing mission to become the replacement unit for the next FGS to be serviced. By the conclusion of SM4, all three FGSs will have been brought up to optimum condition.

This refurbishment process is the most effective use of these space assets and the best way to save valuable resources. Each refurbishment of a previously flown FGS costs $10 million. If purchased new, each would cost NASA—and ultimately the American taxpayers—$70 million apiece. If NASA purchased new FGSs instead of refurbishing existing units, three replacement FGSs would cost $210 million. By renewing existing hardware, the cost for three FGSs drops to $30 million—which represents $180 million in cost savings.



# XI. 2000 and Beyond

World class teamwork
World class technology
World class science

Hubble's return on investment for tangible and intangible benefits should please Hubble's main investors, the American public. The design of the Hubble Space Telescope has proven that human intervention in space is a resounding success, keeping Hubble operating at peak performance throughout this decade. Hubble continues to be the most productive, cost-effective satellite mission ever launched. Hubble's visionary, modular design allows the telescope to be fitted with new instruments and components at substantial cost savings. The dedication of all members of the Hubble Program from NASA, ESA, industry, and the scientific community remains as strong as when Hubble was launched a decade ago.

Hubble's place in history as a pathfinder for new scientific discoveries is guaranteed. The telescope's future looks bright as well. Continued servicing of Hubble's systems ensure the telescope's optimal performance. The installation of new instruments, including the Advanced Camera for Surveys, Cosmic Origins Spectrograph, and Wide Field Camera 3, offer limitless possibilities of unexpected insights into our Universe throughout the next decade.

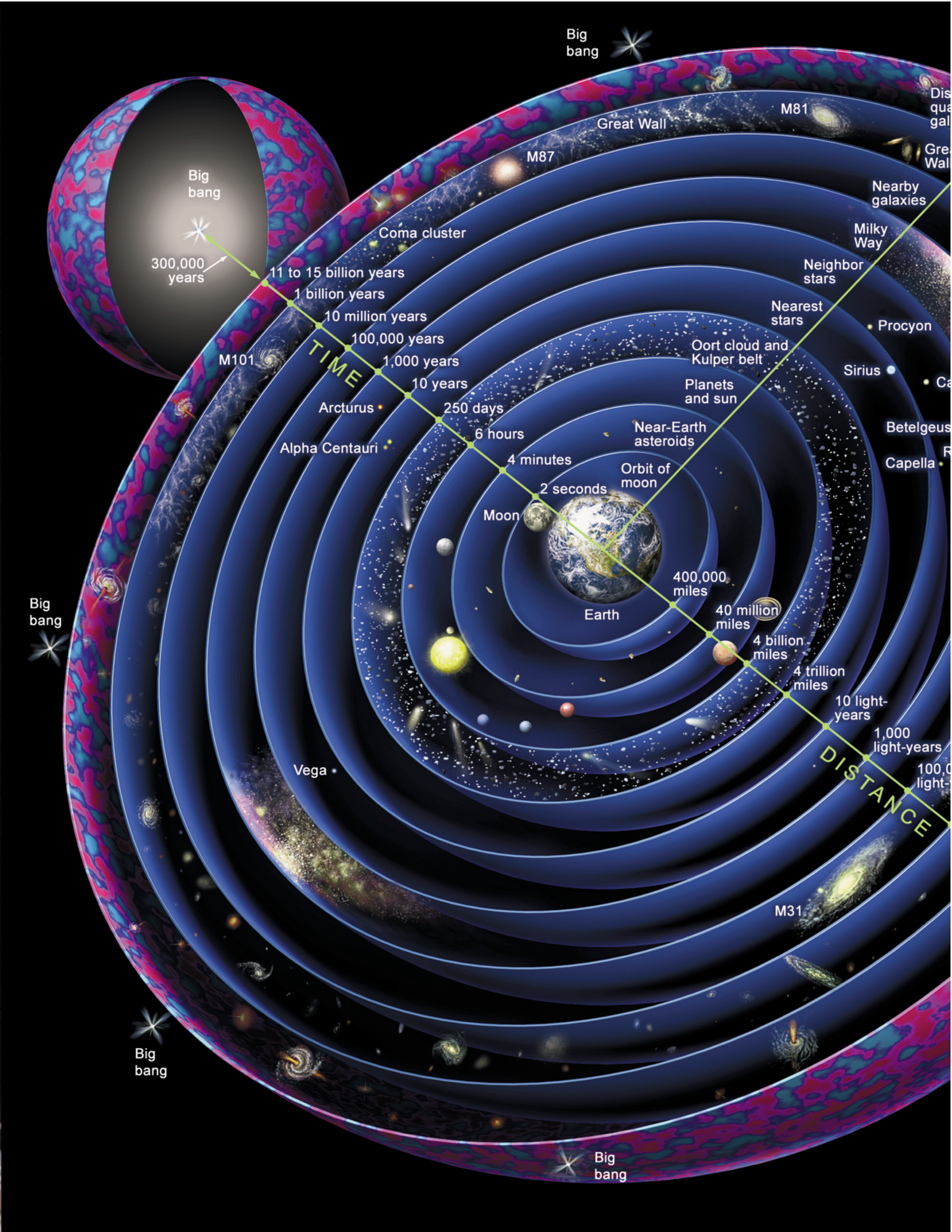
We have begun to scratch the surface of the mystery that is our Universe, and through Hubble's innovations and technical advances we have made significant strides. However, the age-old questions of mankind still remain:

Astronaut Steve Smith giving a "thumbs up" during STS-103.

***How did the Universe begin?***
***What is it made up of?***
***What is our place in it?***
***How does it all work?***
***Is there anyone else out there?***

It is the possibility of shedding light on these fundamental questions that launched the Hubble Program and that continue to motivate the Hubble team and capture the imagination of the world.

The human desire for exploration has found a special partner in the Hubble Space Telescope. We have now had one decade to get to know each other, and we can look forward to at least one more. Each time we send a mission into space to enhance Hubble's abilities, we are proclaiming our desire to take another step closer to answering these universal questions. This unique human connection allows each of us here on Earth to feel the magic of discovery for ourselves.



Big bang
Big bang
300,000 years
11 to 15 billion years
1 billion years
10 million years
100,000 years
1,000 years
10 years
250 days
6 hours
4 minutes
2 seconds
TIME
Coma cluster
M87
Great Wall
M81
Nearby galaxies
Milky Way
Neighbor stars
Nearest stars
Procyon
Oort cloud and Kulper belt
Sirius
Planets and sun
Betelgeus
Near-Earth asteroids
Capella
Orbit of moon
Moon
Earth
M101
Arcturus
Alpha Centauri
400,000 miles
40 million miles
4 billion miles
4 trillion miles
10 light-years
1,000 light-years
DISTANCE
Vega
M31
Big bang
Big bang
Big bang
Big bang

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*"I think there is no better proof than these pictures that NASA's capability to send humans into space to work on Hubble has had a vital role in space science and the renaissance in astronomy we're now seeing,"*

**- Dr. Ed Weiler**
**NASA Associate Administrator for Space Science.**

# Project Report: Dec 2000





## The Quest for More Power Bridges Two Continents

**by Ann Jenkins and Tom Griffin**
*reprinted from the HST Newsletter, Dec. 2000*

In October 2000, a team from NASA and the European Space Agency (ESA) partnered to perform a unique and important test on one of Hubble's new solar wings. These new solar cell panels, Hubble's third set will be installed by astronauts in 2001. The advanced arrays will provide the increased electrical energy needed to power the telescopeís newest generation of science instruments.

The goal of the Solar Array 3 (SA3) Disturbance Verification Test (DVT) was to collect measurements of the dynamic forces produced within the solar array due to Hubbleís extreme thermal space environment. These measurements will verify that any forces transmitted to Hubble will not impact science operations.

Hubble teammates took one of the new solar wings to Sea's European Space Research and Technology Center (ESTER) in Noordwijk, The Netherlands, to conduct the disturbance test. Because of the unique features of ESTEC's Large Space Simulator (LSS), as well as the solar array's size and ESAís longstanding experience with Hubble's solar arrays, ESTEC is the only place in the world the test could be performed.

This test is just the latest chapter in a longstanding, international partnership-Hubble Space Telescope is a project of international cooperation between NASA and ESA. ESA provided Hubble's first two sets of solar arrays, and it built and tested the motors and electronics for the new set. Additionally, ESA built and provides science operations support for the Faint Object Camera, the last of Hubble's original science instruments.

### Hubble's Harsh Environment

During its 90-minute orbit, Hubble cycles through searing sunlight followed by frigid darkness. In this environment, parts of the solar cell panels fluctuate up to 137° C each and every orbit. These dramatic, repeated changes can cause tiny vibrations, creaks and crackles to be generated within a spacecraftís solar arrays. If these dynamic events are transferred to the observatory, they might affect Hubble's sensitive pointing control instruments and interfere with science observations. This was the case with Hubble's first set of solar arrays, which was replaced in 1993 with a much more stable pair.

This is a view of the backside of the Solar Array Wing. The wing is mounted inside the LSS chamber (the ring of the chamber surrounds the wing). This chamber is the only known one in the world that can accommodate our Solar Array Wing both because of its size and because of the space environment it simulates.

ESA's LSS simulates Hubble's harsh thermal environment. This world-class test facility features a huge thermal vacuum chamber containing a bank of eighteen extremely bright, collimated lights. These lights uniformly illuminate the test article and realistically simulate the Sun's intensity-including sunrise and sunset.

By exposing the solar wing to the light and temperature extremes of Hubble's orbit and measuring the interface forces, engineers should be able to verify how the new arrays will act in space. "It's important to prove that the solar arrays will not suffer thermal shock from the constant day/night cycles and impact Hubble's excellent performance," explains Keith Chamberlin, HST Solar Array Manager.

**Moving Day**

After months of preparation at Goddard Space Flight Center, Hubble's new solar array finally arrives in The Netherlands on October 18, 2000, aboard a United States Air Force transport plane. The C5 cargo plane, carrying two trailers loaded with the array and associated test equipment, leaves the U.S. from Andrews Air Force Base and lands at Schiphol Airport in Amsterdam. At Schiphol, NASA's tractor drives the trailers drive off the C5 cargo plane.

After being detached from the tractor, these trailers are modified into "European vehicles," hooked up to the Dutch tractors, and escorted in a convoy to ESA's facility in Noordwijk, about 15 miles away. The NASA/ESA transportation team's thorough and professional planning allow this process to be executed with clockwork precision. [In particular, NASA's Jimmy Barcus (Code 442) and Jean Manell (Cortez Engineering), as well as their ESA counterpart, Mr. Herman Thoma, deserve special recognition for their flawless coordination.]

The DVT test team, which has been preparing ESTEC's test facility for the solar array's arrival, is ready and waiting when the convoy arrives. They inspect the weatherproof, protective crates for damage. Finding everything in order, they carefully roll Hubble's solar array into the test facility. Now the long process of unpacking, cleaning, setting up, and pre-test verification begins.

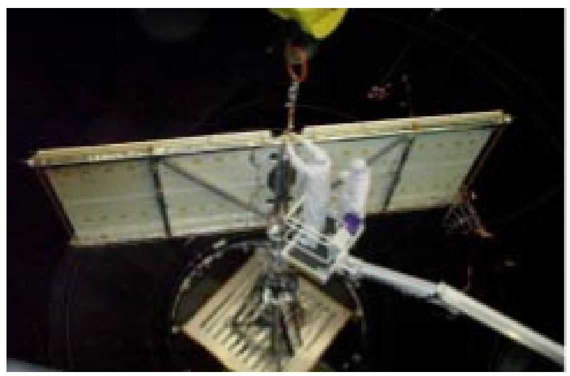
**The Right Connections**

After the solar array and support pedestal are placed in the Large Space Simulator, engineers and technicians methodically connect the test instrumentation wiring to the computers in the payload test area established just outside the chamber. About 200 instrumentation lines, thermocouples, force gauges, and accelerometers, instruments that measure temperature and movement, will monitor the Solar Array during the test.

The wires for all these instrumentation gauges must be connected and routed from the chamber to the data acquisition system computers outside the chamber. Since all these instrumentation channels are monitored individually, the team takes great care to verify the accuracy of the electrical connections.

**The Main Event**

After the long and arduous process of verification, the chamber doors are closed, the vacuum of space is established, and bakeout begins. During the contamination bakeout, the chamber's temperature is increased to remove contaminants such as water, oil and residue that may be present on the solar array, the support hardware or chamber itself.



Riding in a "cherry picker," two technicians prepare for the removal of the Solar Array Wing from the chamber.

Finally, on October 30, after eighteen orbit simulation runs over four days, the Disturbance Verification Test is complete. Preliminary analysis indicates that no disturbances were observed which were large enough to cause the Hubble Space Telescope to lose a "lock" on a focused object. Back at Goddard, engineers are completing a full, detailed analysis on the test results. The HST Solar Array Manager calls this ambitious test a complete success, and he credits the efficiency and professionalism of the entire team. "ESA provided a top-notch group that helped us in any way they could," says Chamberlin. "Even last minute requests. They took care of anything we needed. And our Goddard team did an excellent job.

**"A Wonderful Machine"**

From the ESA point of view, the test provided an opportunity to work outside the normal and relatively small European space community. As Mr. Andrea Cotellessa, the ESA Test Conductor for the DVT, observed, "Working with the NASA team was an extremely valuable opportunity for all of us at ESTEC.We at ESA are relatively young in the space business.Working along side our NASA counterparts has taught us much about NASA's longstanding and professional approach to spacecraft testing."

Mr. Anton Linssen, the ESA HST SM3B Project Manager, proudly announced, "The HST solar array is the first NASA Payload to be tested at ESTEC. All of the DVT team members should be congratulated for their dedication to realize this successful conclusion of an extremely ambitious and important test. Most importantly, this test was good for the Hubble Observatory."

Once again, the power of Hubble brought together talented and dedicated people from both sides of the Atlantic in support of a common and universal goal. Two comments caught in passing at Schiphol Airport summarize the positive impact of this test. As the trailers were being reloaded into the C5 for the trip home, USAF Master Sergeant Timkoff remarked, "We are excited to be working with NASA and ESA. This trip not only provides us a dynamic training opportunity but allows us to actively contribute to Hubble's success." The second observation came from an anonymous and surprised Schiphol Airport fireman. "This payload will become a part of Hubble? And it was brought here to Holland to be tested? Then the test performed must be very important because the Hubble is a wonderful machine!"

::: Talk to Us!



# Sign in Guestbook

Webchats

Guestbook

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Credits

Goto SM3B WEBSITE

Welcome to the Hubble Project Guestbook!

View Guestbook comments by clicking right here!

- Be a part of the Guestbook! Let the world know you were here and let us know how we are doing!
- Name: [ ]
- E-mail Address (optional): [ ]
- Now type your message into the textbox below:

[ ]

☐ Please check if you would like to receive e-mail from our Hubble Project News mailing list.

[Submit Information] [Reset]

# Webchats





## Upcoming Chats

| Event | Date | Time |
|---|---|---|
| | | |

## Archived Chats

| Event | Date | Time |
|---|---|---|
| *On-line Deep Space QuestChat with* ***Russell Werneth***<br><br>*See Archived Chat*<br>Russell Werneth is responsible for training astronauts to use special tools and conduct extravehicular activities (EVAs) in order to maintain the Hubble Space Telescope (HST) during servicing missions. | Friday November 17, 2000 | 10 AM to 11 AM Pacific |
| *On-line Deepspace QuestChat with* ***Dr. H. John Wood***<br><br>*See Archived Chat*<br>Dr. H. John Wood is part of a team that has helped solve the Hubble's viewing problems. He discusses how Hubble is able to see far into the universe. *See More Info*. | Thursday October 12, 2000 | 1 PM to 2 PM Eastern |



Contact: webmaster@hubble.gsfc.nasa.gov, Global Science & Technology, Inc.
Page Last Updated: October 29, 2001

# Russell Werneth



**Position:** Extra Vehicular Activity (EVA) Manager for the Hubble Space Telescope (HST) Project

**Location:** NASA Goddard Space Flight Center (GSFC) Greenbelt, Maryland

**Education**
BSME, University of Maryland; MSME, University of Maryland; MEngrAdmin, George Washington University

**Current responsibilities**
Hubble Space Telescope EVA & Crew Systems Manager: Responsible for the development of astronaut tools, requirements, and procedures and for the initial training of the EVA (spacewalking) astronauts for Hubble Servicing Missions.

**Previous responsibilities/careers**
Formerly taught mechanical engineering at the University of Maryland at College Park, and robotics at the Naval Postgraduate School in Monterey, California.

Formerly Combat Systems Engineer and Robotics Engineer at the Naval Surface Warfare Center in White Oak, Maryland.

**Personal information**
Recipient of many awards from NASA (including the Silver Snoopy Astronaut Award) and the University of Maryland (Outstanding Volunteer Award, College of Engineering Centennial Award to the top 100 engineering graduates).

Mid-Atlantic District Director for Tau Beta Pi, the national engineering honor society. Formerly Tau Beta Pi national vice president.



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# H. John Wood





## Astronomer - NASA Goddard Space Flight Center

Dr. H. John Wood is an astronomer and serves as an optical engineer for the Optics Branch at Goddard Space Flight Center. Since June 1990, he has been Optics Lead Engineer on the Hubble Space Telescope (HST) Project. He led the team which successfully determined the prescription of HST while on orbit. He then led NASA's effort to develop and test the corrective optics for HST. In addition to his work on Hubble, he currently manages the Instrument Synthesis & Analysis Laboratory for new instrument engineering design at Goddard.

A graduate of Swarthmore College, Dr. Wood earned the M.A. and Ph.D. in Astronomy from Indiana University. He has been at Goddard Space Flight Center for 16 years. In addition to the Hubble Project, he has been Lead Optical Engineer on other Goddard projects: the Mars Observer Laser Altimeter and the Diffuse Infrared Background Experiment aboard the Cosmic Background Explorer (COBE). Earlier he was assistant to the director at Cerro Tololo Interamerican Observatory (Chile) for two years. He held a Fulbright Research Fellowship for two years at the University Observatory in Vienna, Austria. He also served five years as a staff astronomer at the European Southern Observatory in Chile. His career began with six years on the astronomy faculty of the University of Virginia at Charlottesville.

Winner of the 1992 NASA exceptional service medal and the 1994 NASA exceptional achievement medal for his work on COBE and HST, he is the author of 50 research papers in astronomy and space optics. He was invited to edit special editions of Applied Optics and Optics and Photonics News on the HST first servicing mission. He was co-chair of the HST Independent Optical Review Panel which was charged with the determination of the optical parameters for the HST while on orbit.

Dr. Wood currently serves as the Chair of the Optical Technology Division of the Optical Society of America. Although his career has comprised astronomical research as well as the building and testing of scientific instruments, Dr. Wood has given talks and presentations to thousands of elementary and middle school students and their teachers. He has been technical officer and science editor on the "PCs in Space" software development program of Jackson & Tull. This interactive software enables children in grades 3 - 9 to learn about Astronomy, Physics, Mathematics, Geology and Earth Science using images from orbiting satellites.