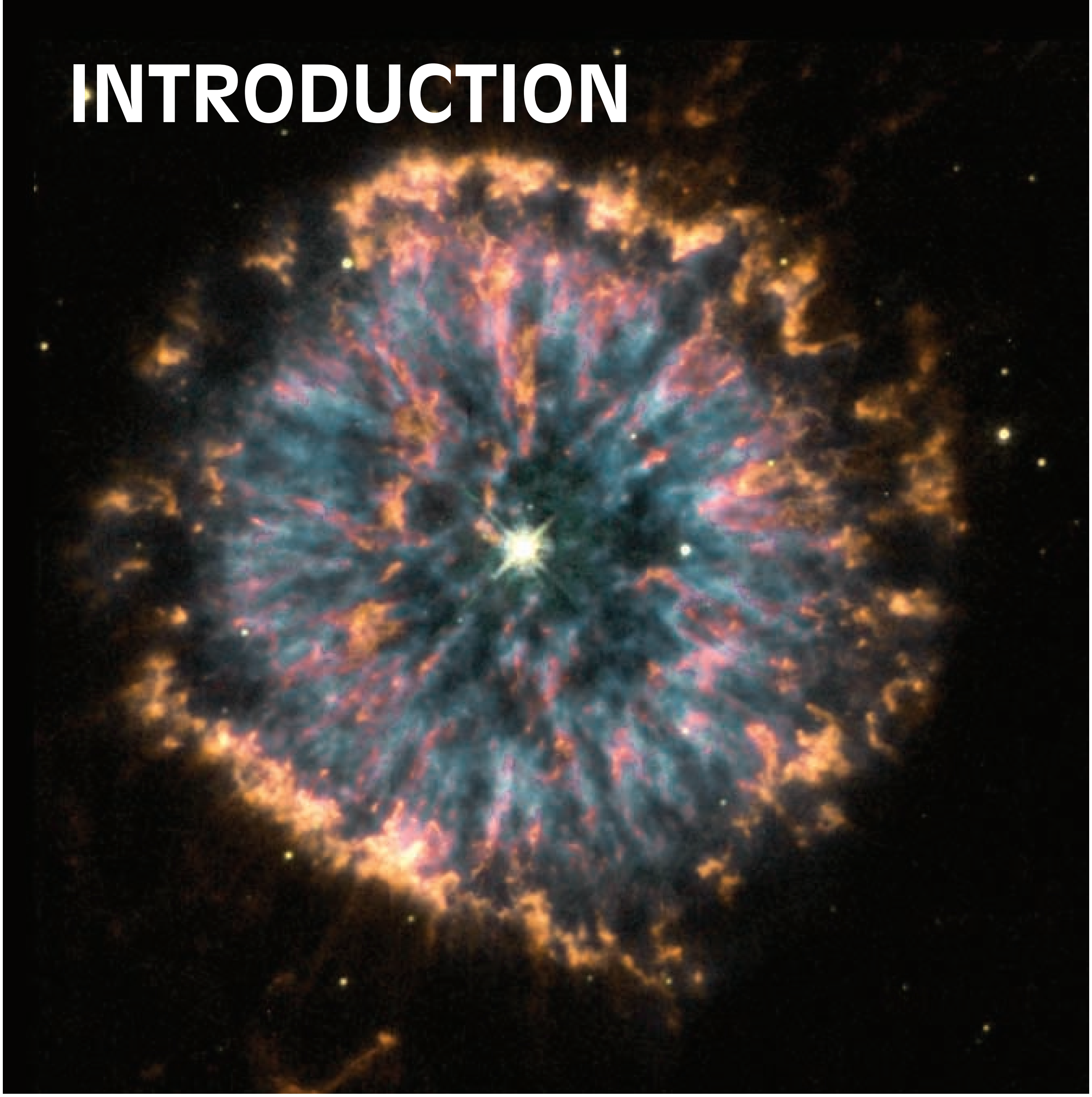
INTRODUCTION



Gazing through his first crude telescope in the 17th century, Galileo discovered the craters of the Moon, the satellites of Jupiter and the rings of Saturn. These observations led the way to today's quest for in-depth knowledge and understanding of the cosmos. And for nearly 12 years NASA's Hubble Space Telescope (HST) has continued this historic quest.

Since its launch in April 1990, Hubble has provided scientific data and images of unprecedented resolution from which many new and exciting discoveries have been made. Even when reduced to raw numbers, the accomplishments of the 12.5-ton orbiting observatory are impressive:

- Hubble has taken about 420,000 exposures.
- Hubble has observed nearly 17,000 astronomical targets.
- Astronomers using Hubble data have published over 3,200 scientific papers.
- Circling Earth every 90 minutes, Hubble has traveled about 1.7 billion miles.

This unique observatory operates around the clock above the Earth's atmosphere gathering information for teams of scientists who study the origin, evolution and contents of the universe. The Telescope is an invaluable tool for examining planets, stars, star-forming regions of the Milky Way, distant galaxies and quasars, and the tenuous hydrogen gas lying between the galaxies.

The HST can produce images of the outer planets in our solar system that approach the clarity of those from planetary flybys. Astronomers have resolved previously unsuspected details of numerous star-forming regions of the Orion Nebula in the Milky Way and have detected expanding gas shells blown off by exploding stars.

Using the Telescope's high-resolution and light-gathering power, scientists have calibrated the distances to remote galaxies to precisely measure the expansion of the universe and thereby calculate its age. They have detected and measured the rotation of dust, gas and stars trapped in the gravitational field at the cores of galaxies that portend the presence of massive black holes.

Hubble's deepest views of the universe, unveiling a sea of galaxies stretching back nearly to the beginning of time, have forced scientists to rethink some of their earlier theories about galactic evolution. (Section 3 of this guide contains additional information on the Telescope's scientific discoveries.)

The Telescope's mission is to spend 20 years probing the farthest and faintest reaches of the cosmos. Crucial to fulfilling this objective is a series of on-orbit manned servicing missions. During these missions astronauts perform planned repairs and maintenance activities to restore and upgrade the observatory's capabilities. To facilitate this process, the Telescope's designers configured science instruments and several vital engineering subsystems as Orbital Replacement Units (ORU)—modular packages with standardized fittings accessible to astronauts in pressurized suits (see Fig. 1-1).

The First Servicing Mission (SM1) took place in December 1993 and the Second Servicing Mission (SM2) in February 1997. Hubble's Third Servicing Mission was separated into two parts: Servicing Mission 3A (SM3A) flew in December 1999 and Servicing Mission 3B (SM3B) is scheduled for an early 2002 launch.

SM3B astronauts will:

- Install a new science instrument, the Advanced Camera for Surveys (ACS).
- Fit Hubble with a new pair of rigid solar arrays.
- Replace the Power Control Unit (PCU).
- Replace a Reaction Wheel Assembly (RWA).
- Retrofit the Near Infrared Camera and Multi-Object Spectrometer (NICMOS).
- Install New Outer Blanket Layer (NOBL) insulation panels.

The ACS consists of three electronic channels and a complement of filters and dispersers that detect light from the ultraviolet to the near infrared (1200 to 10,000 angstroms). This camera will be able to survey a field with 2.3 times the area of the Wide Field and Planetary Camera 2 (WFPC2) currently on Hubble. It will provide four times as much spatial information and up to five times the sensitivity of WFPC2. The ACS will not replace WFPC2, however. WFPC2 will continue with its spectacular observations on the Telescope.

Designed and built by Goddard Space Flight Center (GSFC), the European Space Agency (ESA) and Lockheed Martin Space Systems Company, the new solar arrays will produce 20 percent more power than the current arrays. In addition, they are less susceptible to damage and the extreme temperature swings induced by Hubble's orbit.

The PCU controls and distributes electricity from the solar arrays and batteries to other parts of the Telescope. Although it is still functioning, this PCU has been on the Telescope since 1990 and some of its relays have failed. Replacement will ensure proper operation over the long term.

One of four RWAs will be replaced. The reaction wheels are part of an actuator system that moves the spacecraft into commanded positions. Using spin momentum, the wheels move HST into position and then keep the spacecraft stable. The wheel axes are oriented so that Hubble can operate with only three wheels.

The NICMOS, a dormant instrument, will be retrofitted with a new, experimental NICMOS Cooling System (NCS) to return it to active duty.

If time permits, NOBL insulation panels will be installed to prevent damage to Hubble from sunlight and extreme temperature changes and to maintain the Telescope's normal operating temperature.

Hubble Space Telescope Configuration

Figures 1-2 and 1-3 show the overall Telescope configuration. Figure 1-4 lists specifications for the Telescope. The major elements are:

- Optical Telescope Assembly (OTA)—two mirrors and associated structures that collect light from celestial objects
- Science instruments—devices used to analyze the images produced by the OTA
- Support Systems Module (SSM)—spacecraft structure that encloses the OTA and science instruments
- Solar Arrays (SA).

Optical Telescope Assembly

The OTA consists of two mirrors, support trusses and the focal plane structure. The optical system is a Ritchey-Chretien design, in which two special aspheric mirrors form focused images over the largest possible field of view. Incoming light travels down a tubular baffle that absorbs stray light. The concave primary mirror—94.5 in. (2.4 m) in diameter—collects the light and converges it toward the convex secondary mirror, which is only 12.2 in. (0.3 m) in diameter. The secondary mirror directs the still-converging light back toward the primary mirror and through a 24-in. hole in its center into the Focal Plane Structure, where the science instruments are located.

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Fig. 1-1
The Hubble Space Telescope (HST)—shown in a clean room at Lockheed Martin Space Systems Company – Missiles & Space Operations in Sunnyvale, California, before shipment to Kennedy Space Center—is equipped with science instruments and engineering subsystems designed as Orbital Replacement Units.

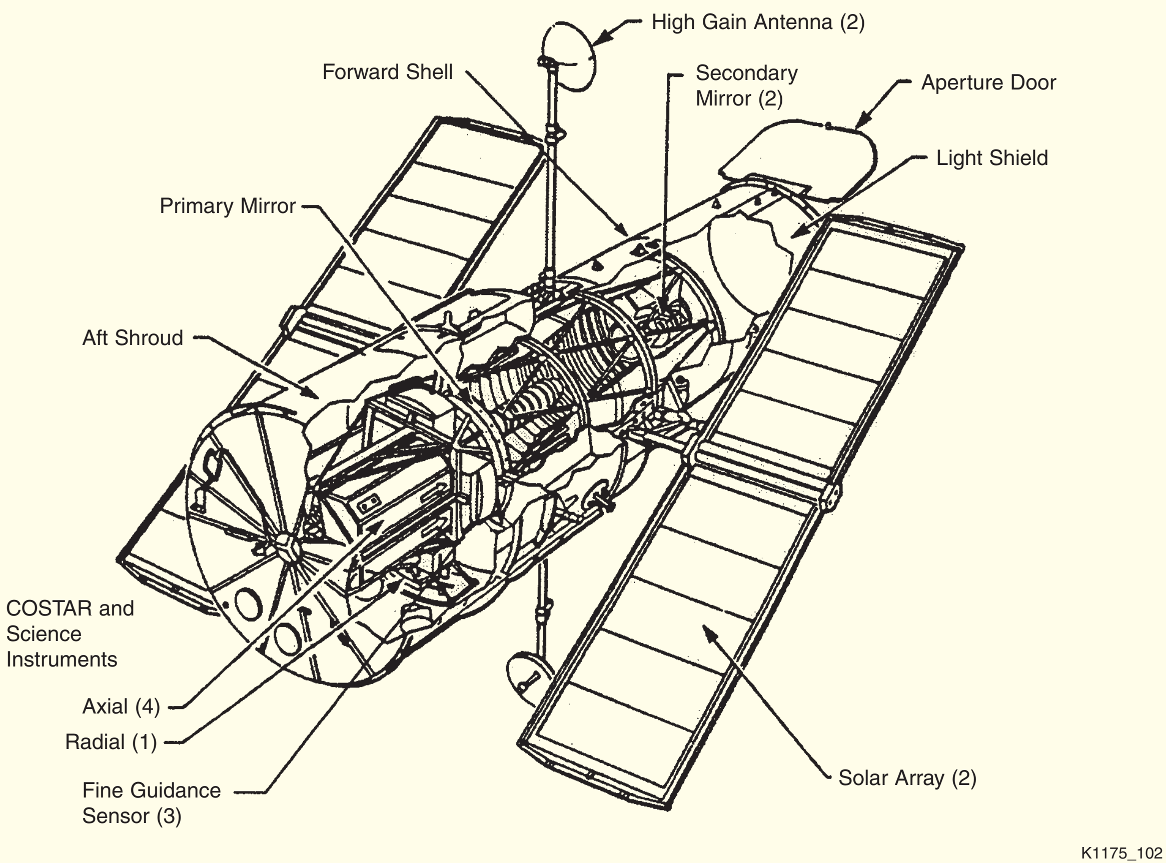

Fig. 1-2 HST overall configuration

Science Instruments

Hubble can accommodate eight science instruments. Four are aligned with the Telescope's main optical axis and are mounted immediately behind the primary mirror. These axial science instruments are:

- Space Telescope Imaging Spectrograph (STIS)
- Faint Object Camera (FOC)
- Near Infrared Camera and Multi-Object Spectrometer (NICMOS)
- Corrective Optics Space Telescope Axial Replacement (COSTAR).

In addition to the four axial instruments, four other instruments are mounted radially (perpendicular to the main optical axis). These radial science instruments are:

- Wide Field and Planetary Camera 2 (WFPC2)
- Three Fine Guidance Sensors (FGS).

Space Telescope Imaging Spectrograph. STIS separates incoming light into its component wavelengths, revealing information about the atomic composition of the light source. It can detect a broader range of wavelengths than is possible from Earth because there is no atmosphere to absorb certain wavelengths. Scientists can determine the chemical composition, temperature, pressure and turbulence of the target producing the light—all from spectral data.

Faint Object Camera. The FOC was decommissioned in 1997 to better allocate existing resources. However, the camera remains turned on and available to scientists if needed. The FOC will be returned to Earth after the ACS is installed in its place during SM3B.

Near Infrared Camera and Multi-Object Spectrometer. Use of this now-dormant instrument will resume after successful installation of NCS during SM3B.

Corrective Optics Space Telescope Axial Replacement. COSTAR was installed on HST in 1993 to fix a flaw in the shape of the primary mirror (a common mirror fabrication defect called spherical aberration) that was detected shortly after Hubble's launch in 1990. Because all the instruments now on the Telescope are equipped with corrective optics, COSTAR no longer is needed, but it will remain on the Telescope until its slot is filled by a new science instrument on SM4.

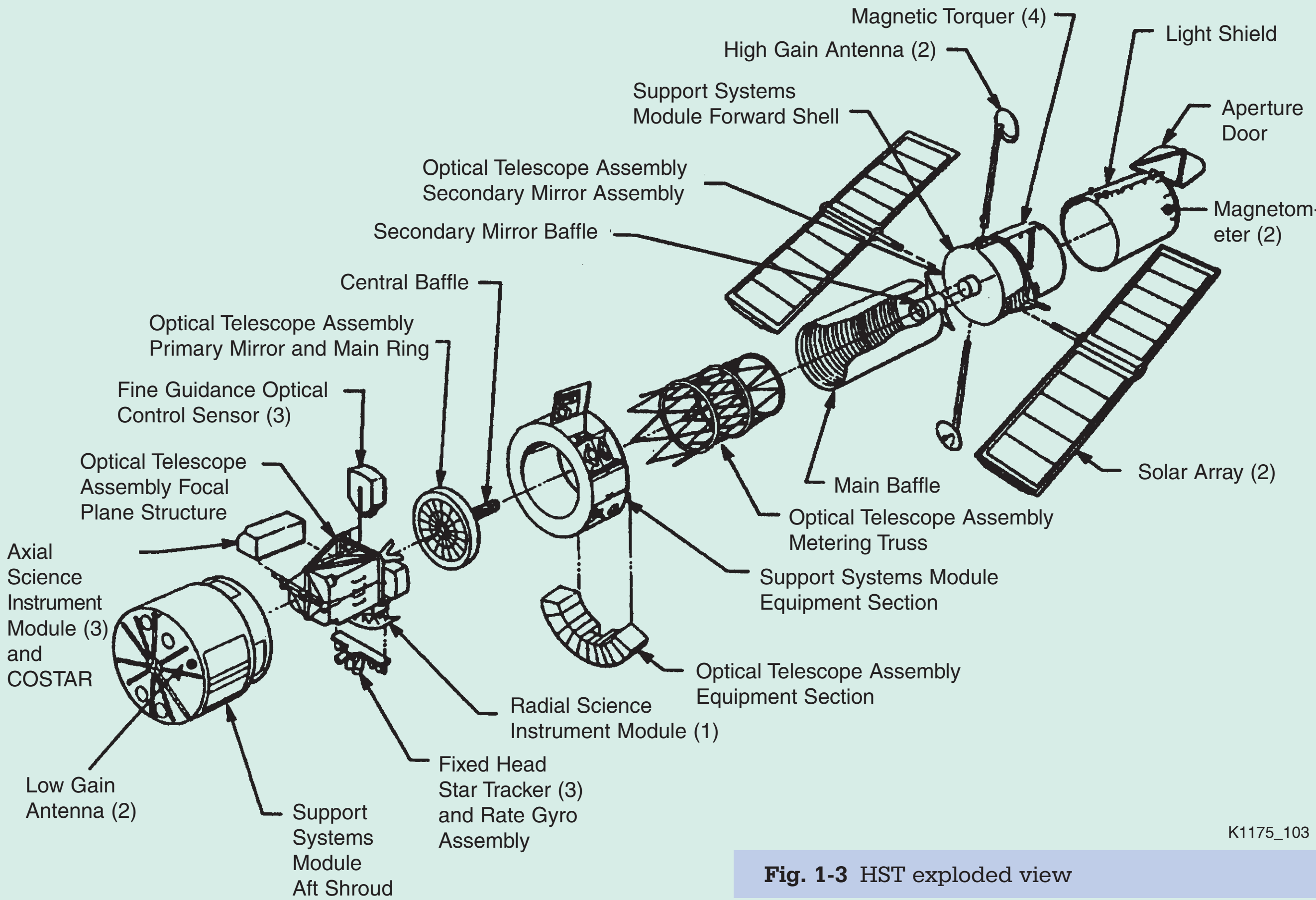

Fig. 1-3 HST exploded view

Hubble Space Telescope (HST)	
Weight	24,500 lb (11,110 kg)
Length	43.5 ft (15.9 m)
	10 ft (3.1 m) Light Shield and Forward Shell
Diameter	14 ft (4.2 m) Equipment Section and Aft Shroud
Optical system	Ritchey-Chretien design Cassegrain telescope
Focal length	189 ft (56.7 m) folded to 21 ft (6.3 m)
Primary mirror	94.5 in. (2.4 m) in diameter
Secondary mirror	12.2 in. (0.3 m) in diameter
Field of view	See instruments/sensors
Pointing accuracy	0.007 arcsec for 24 hours
Magnitude range	5 m_v to 30 m_v (visual magnitude)
Wavelength range	1100 to 24,000 Å
Angular resolution	0.1 arcsec at 6328 Å
Orbit	320 nmi (593 km), inclined 28.5 degrees from equator
Orbit time	97 minutes per orbit
Mission	20 years

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Fig. 1-4 HST specifications

Wide Field and Planetary Camera 2. WFPC2 is an electronic camera that records images at two magnifications. A team at the Jet Propulsion Laboratory (JPL) in Pasadena, California, built the first WFPC and developed the WFPC2. The team incorporated an optical correction by refiguring relay mirrors in the optical train of the cameras. Each relay mirror is polished to a prescription that compensates for the incorrect figure on HST's primary mirror. Small actuators fine-tune the positioning of these mirrors on orbit.

Fine Guidance Sensors. The three FGSs have two functions: (1) provide data to the spacecraft's pointing system to keep HST pointed accurately at a target when one or more of the science instruments is being used to take data and (2) act as a science instrument. When functioning as a science instrument, two of the sensors lock onto guide stars and the third measures the brightness and relative positions of stars in its field of view. These measurements, referred to as astrometry, are helping to advance knowledge of the distances and motions of stars and may be useful in detecting planetary-sized companions of other stars.

Support Systems Module

The SSM encloses the OTA and the science instruments like the dome of an Earth-based observatory. It also contains all of the structures, mechanisms, communications devices, electronics and electrical power subsystems needed to operate the Telescope.

This module supports the light shield and an aperture door that, when opened, admits light. The shield connects to the forward shell on which the SAs and High Gain Antennas (HGA) are mounted. Electrical energy from the SAs charges the spacecraft batteries to power all HST systems. Four antennas, two high-gain and two low-gain, send and receive information between the Telescope and the Space Telescope Operations Control Center (STOCC). All commanding occurs through the Low Gain Antennas (LGA).

Behind the OTA is the Equipment Section, a ring of bays that house the batteries and most of the electronics, including the computer and communications equipment. At the rear of the Telescope, the aft shroud contains the science instruments.

Solar Arrays

The SAs provide power to the spacecraft. They are mounted like wings on opposite sides of the Telescope, on the forward shell of the SSM. The SAs are rotated so each wing's solar cells face the Sun. The cells absorb the Sun's light energy and convert it into electrical energy to power the Telescope and charge the spacecraft's batteries, which are part of the Electrical Power Subsystem (EPS). Batteries are used when the Telescope moves into Earth's shadow during each orbit.

Computers

Hubble's Data Management Subsystem (DMS) contains two computers: the Advanced Computer, installed during SM3A, and the Science Instrument Control and Data Handling (SI C&DH) unit. The Advanced Computer performs onboard computations and handles data and command transmissions between the Telescope systems and the ground system. The SI C&DH unit controls commands received by the science instruments, formats science data and sends data to the communications system for transmission to Earth.

The Hubble Space Telescope Program

Hubble Space Telescope represents the fulfillment of a 50-year dream and 25 years of dedicated scientific effort and political vision to advance humankind's knowledge of the universe. The HST program comprises an international community of engineers, scientists, contractors and institutions. It is managed by 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 Programs and Projects Directorate, under the supervision of the Associate Director/ Program Manager for HST. It is organized as two flight projects: (1) the HST Operations Project and (2) the HST Development Project.

Responsibilities for scientific oversight on HST are divided among the members of the Project Science Office (PSO). The PSO is designed to interact effectively and efficiently with the HST Program and the wide range of external organizations involved with the HST. The senior scientist for the HST and supporting staff work in the Office of the Associate Director/ Program Manager for HST. This group is concerned with the highest level of scientific management for the project. Figure 1-5 summarizes the major organizations that oversee the program.

The roles of NASA centers and contractors for on-orbit servicing of the HST are:

- Goddard Space Flight Center (GSFC)—Overall management of daily on-orbit operations of HST and the development, integration and test of replacement hardware, space support equipment and crew aids and tools
- Johnson Space Center (JSC)—Overall servicing mission management, flight crew training, and crew aids and tools
- Kennedy Space Center (KSC)—Overall management of launch and post-landing operations for mission hardware
- Ball Aerospace—Design, development and provision of axial science instruments
- JPL—Design, development and provision of WFPC1 and WFPC2
- Lockheed Martin—Personnel support for GSFC to accomplish (1) development, integration and test of replacement hardware and space support equipment; (2) system integration with the Space Transportation System (STS); (3) launch and post-landing operations and (4) daily HST operations.

Major subcontractors for SM3B include Goodrich Corporation, Honeywell, Jackson and Tull, Orbital Sciences Corporation, Computer Sciences Corporation, Association of Universities for Research in Astronomy (AURA), Swales Aerospace, QSS, Creare and L-3 Communications.

The HST program requires a complex network of communications among GSFC, the Telescope, Space Telescope Ground System and the Space Telescope Science Institute. Figure 1-6 shows communication links.

The Value of Servicing

Hubble's visionary modular design allows NASA to equip it with new, state-of-the-art instruments every few years. These servicing missions enhance the Telescope's science capabilities, leading to fascinating new discoveries about the universe. Periodic service calls also permit astronauts to "tune up" the Telescope and replace limited-life components.

Organization	Function
NASA Headquarters Office of Space Science Directorate of Astronomy and Physics	• Overall responsibility for the program
Goddard Space Flight Center – Office of the Associate Director/ Program Manager for HST – HST Operations Project – HST Development Project	• Overall HST program management • HST project management • Responsible for overseeing all HST operations
Space Telescope Operations Control Center	• Provides minute-to-minute spacecraft control • Schedules, plans and supports all science operations when required • Monitors telemetry communications data to the HST
Space Telescope Science Institute	• Selects observing programs from numerous proposals • Analyzes astronomical data
Goddard Space Flight Center – HST Flight Systems and Servicing Project	• Responsible for implementing HST Servicing Program • Manages development of new HST spacecraft hardware and service instruments • Manages HST Servicing Payload Integration and Test Program • Primary interface with the Space Shuttle Program at JSC

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Fig. 1-5 Organization summary for HST program operational phase

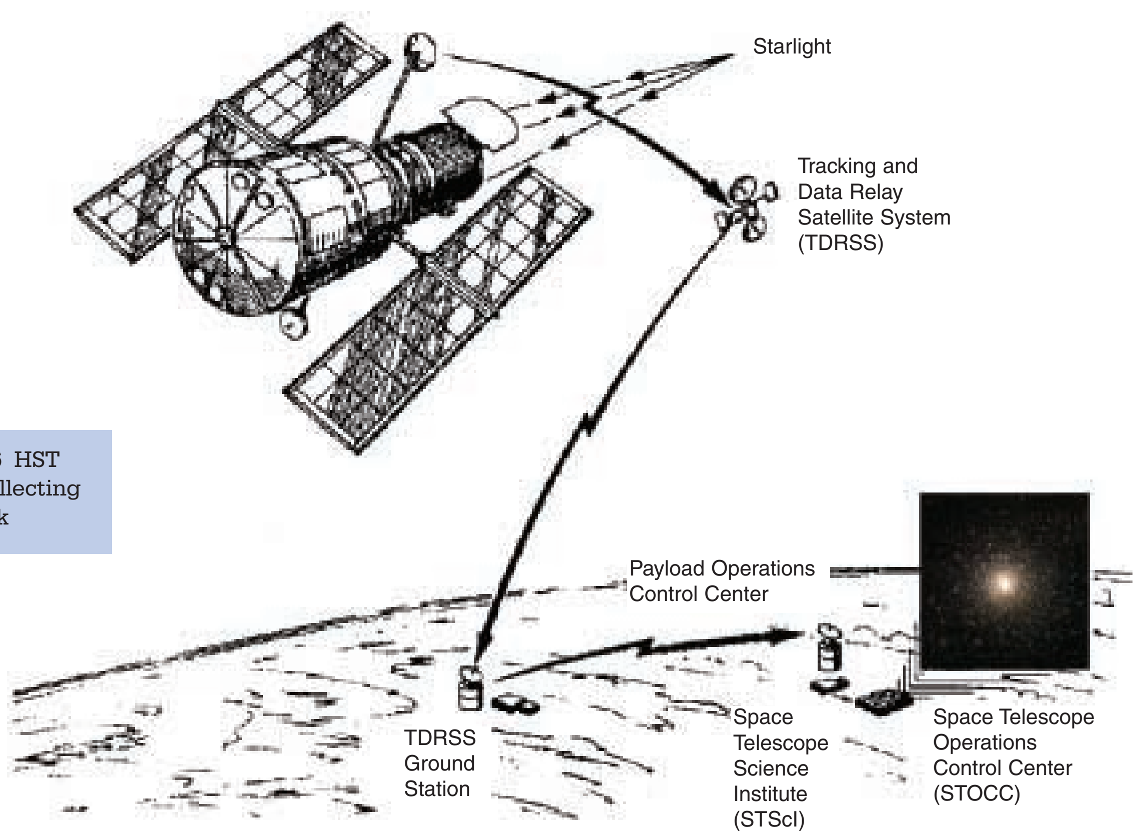

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Fig. 1-6 HST data collecting network