INTRODUCTION

Gazing through the 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 a decade 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 259,000 exposures.
- Hubble has observed nearly 13,000 astronomical targets.
- Astronomers using Hubble data have published over 2,400 scientific papers.
- Circling Earth every 90 minutes, Hubble has traveled about 1.425 billion miles, which is nearly the distance from Earth to Uranus.

This unique observatory operates around the clock above the Earth's atmosphere gathering information for teams of scientists who study virtually all the constituents 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 Voyager flybys. Astronomers have resolved previously unsuspected details of 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. They have detected and measured the rotation of cool disks of matter trapped in the gravitational field at the cores of galaxies that portend the presence of massive black holes.

Spectroscopic observations at ultraviolet wavelengths inaccessible from the ground have given astronomers their first opportunity to study the abundance and spatial distribution of intergalactic hydrogen in relatively nearby regions of the universe – and forced scientists to rethink some of their earlier theories about galactic evolution. (Section 4 of this guide contains additional information on the Telescope's scientific discoveries.)

The Telescope's purpose 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. The First Servicing Mission (SM1) took place in December 1993 and the Second Servicing Mission (SM2) was flown in February 1997.

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).

Hubble's Third Servicing Mission has been separated into two parts: Servicing Mission 3A (SM3A) will fly in Fall of 1999 and Servicing Mission 3B (SM3B) is planned for 2001.

The principal objective of SM3A is to replace all six gyroscopes that compose the three Rate

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

Sensor Units (RSU). In addition, space-walking astronauts will install a new Advanced Computer that will dramatically increase the computing power, speed, and storage capability of HST. They will change out one of the Fine Guidance Sensors (FGS) and replace a tape recorder with a new Solid State Recorder (SSR). The Extravehicular Activity (EVA) crew also will install a new S-band Single-Access Transmitter (SSAT), and Voltage / Temperature Improvement Kits (VIK) for the Telescope's nickel-hydrogen batteries. Finally, they will begin repair of the multilayer insulation on Hubble's outer surface.

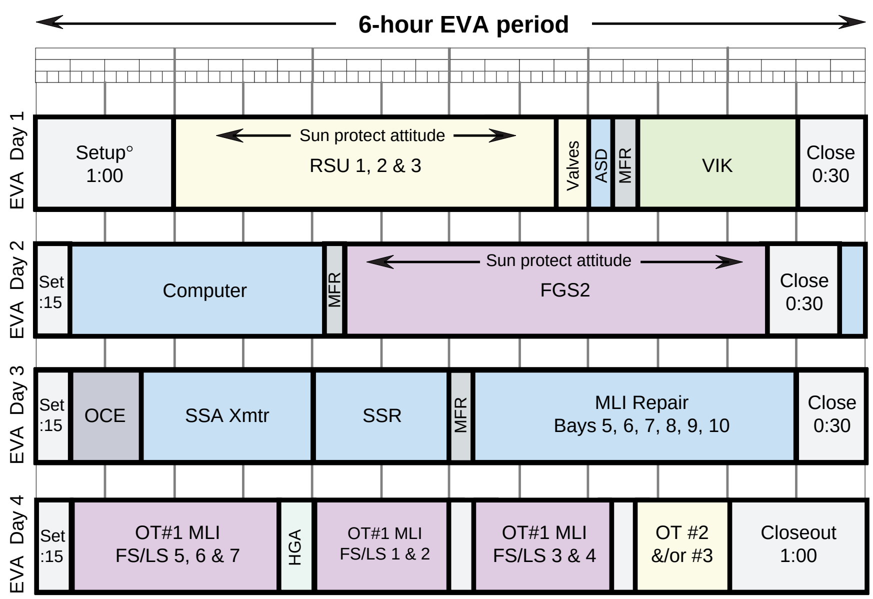
During SM3B astronauts will install a new science instrument, the Advanced Camera for Surveys (ACS), and an Aft Shroud Cooling System (ASCS) for the other axial science instruments. They will attach a new cryogenic cooler to the Near-Infrared Camera and Multi-Object Spectrometer (NICMOS). They also will replace the HST flexible Solar Arrays with new high-performance rigid arrays designed and built by the Goddard Space Flight Center (GSFC), the European Space Agency (ESA) and Lockheed Martin Missiles & Space. Additionally, they will complete repair of the multilayer surface insulation begun on SM3A.

Figure 1-2 shows the SM3A activities as scheduled at press time. Section 2 provides more details of SM3A.

Since 1979 the HST team has overcome enormous technical obstacles to successfully develop and launch the orbiting observatory. The Third Servicing Mission continues this tradition. Its two challenging flights promise to upgrade the Hubble Space Telescope with the latest technology hardware for spacecraft systems and to incorporate advanced instruments that will significantly expand Hubble's scientific capabilities.

1.1 Hubble Space Telescope Configuration

Figures 1-3 and 1-4 show the overall Telescope configuration. Figure 1-5 lists specifications for



Priority	Task Times (stand-alone)
1. RSUs (RSU-1, -2, -3)	1:55 ea
2. VIK	1:10
3. Advanced Computer	1:50
4. FGS (FGS-2)	3:00
5. SSAT (SSAT-2)	1:30
6. SSR (ESTR-3)	1:15
7. Bay 5-10 MLI Repair	2:25 total
8. NICMOS valves open	0:20

Optional Tasks & Priorities

OT#1. FS/LS MLI Repair	3:07
OT#2. Handrail Covers Bays A & J	
OT#3. ASLR for +V2 Doors	

Required Setup	Task Times
Setup	1:00 (1st day)
	0:15 (nth day)
Closeup	0:30 (nth day)
	1:00 (last day)

° = Includes BAPS Post installation
ASD = Aft Shroud Door latch contingency
MFR = crew change positions in Manipulator Foot Restraint
HGA = High Gain Antenna deployment

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Fig. 1-2 Schedule of extravehicular activities 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).

1.1.1 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.

Shortly after launch in 1990, a spherical aberration of the primary mirror was detected. An investigation revealed the specific errors that caused the fault. This knowledge allowed

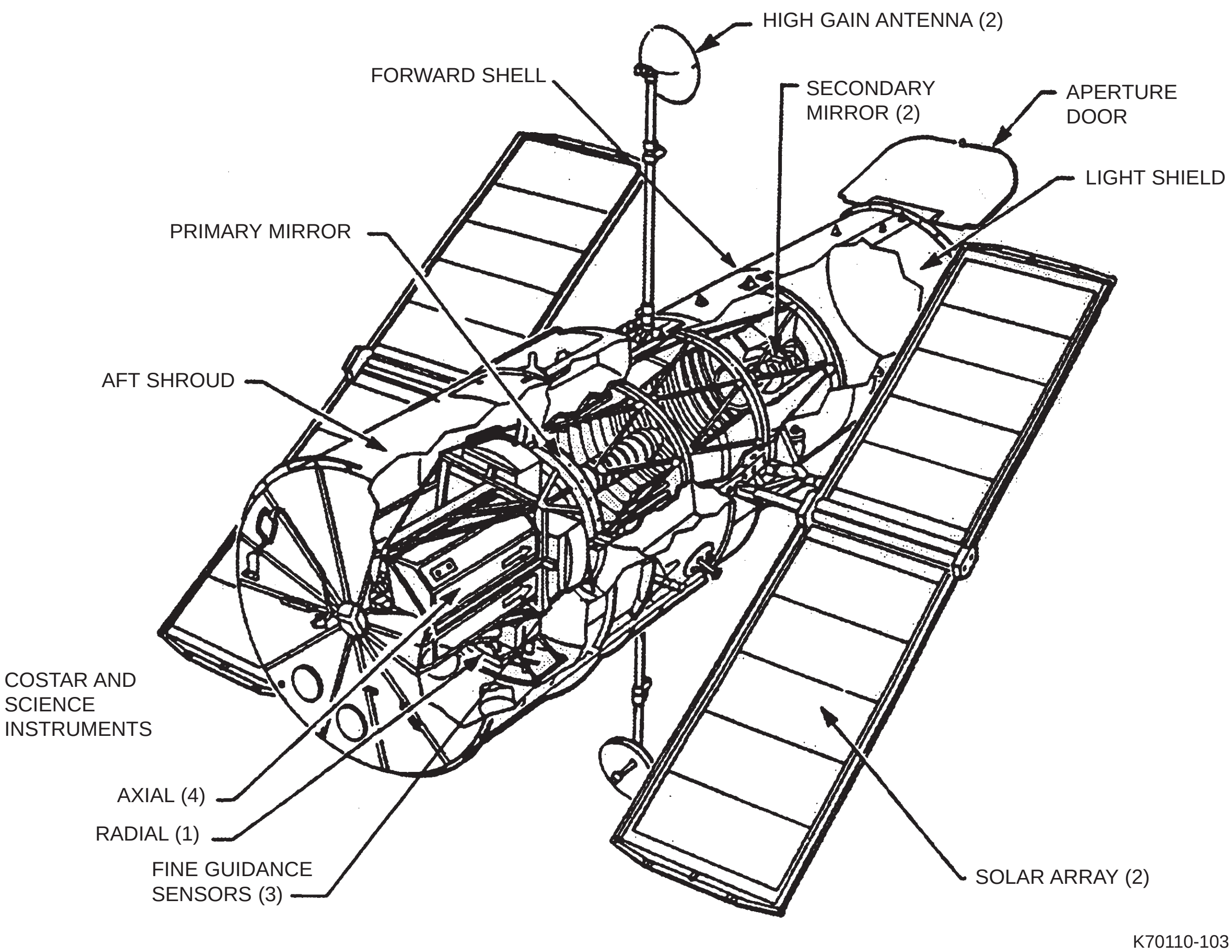

Fig. 1-3 HST overall configuration

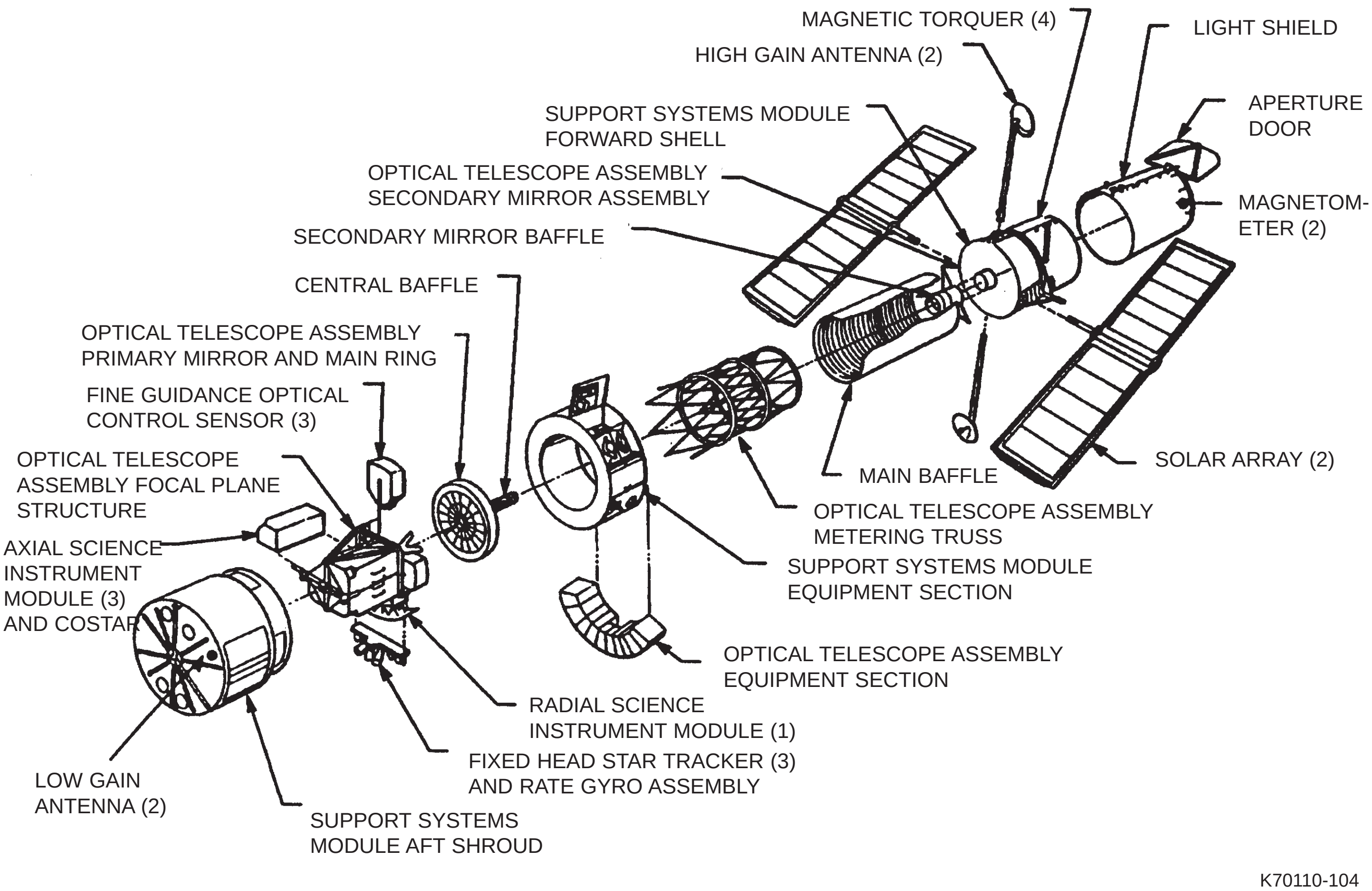

Fig. 1-4   HST exploded view

optical experts to design and fabricate small pairs of corrective mirrors that successfully refocused the light reflected from the primary mirror before it entered the axial science instruments.

The Corrective Optics Space Telescope Axial Replacement (COSTAR) was installed on HST in December 1993. In addition, WFPC2, a radial instrument with corrective optics incorporated, was installed on the same mission. The subsequent increase in optical performance helped to restore the Telescope's capability to original expectations.

All new instruments installed after 1993 correct for spherical aberration internally within their own optical systems.

1.1.2 The 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. The current suite of *axial* science instruments consists of:

- Space Telescope Imaging Spectrograph (STIS)
- Faint Object Camera (FOC) *{decommissioned}*
- Near Infrared Camera and Multi-Object Spectrometer (NICMOS) *{dormant}*
- Corrective Optics Space Telescope Axial Replacement (COSTAR) *{not currently in use}*.

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

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 29 m_v (visual magnitude)
Wavelength range	1100 to 11,000 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. 1-5 Hubble Space Telescope specifications

- 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.

STIS also provides a two-dimensional capability to HST spectroscopy. The two dimensions can be used for “long-slit” spectroscopy, where spectra of many different points across an object are obtained simultaneously, or in a mode that obtains more wavelength coverage in a single exposure. In addition, STIS can produce visible or ultraviolet (UV) images and can provide objective prism spectra in the intermediate UV region of the spectrum. STIS also has a coronagraph capability and a high time-resolution capability in the UV. A team at GSFC manages the STIS instrument and its observations.

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.

1.1.3 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 40-ft (12-m) 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.

1.1.4 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. Each array stands on a mast that supports a retractable wing of solar panels 40 ft (12.2 m) long and 8.2 ft (2.5 m) wide.

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.

Shortly after launch in 1990, it was determined that as the Telescope orbited in and out of direct sunlight, the resulting thermal gradients caused oscillation of the SAs, inducing jitter in the Telescope's line of site. This in turn caused some loss of fine lock of the FGSs during science observations. New SAs with thermal shields over the array masts installed during SM1 minimized the effect.

1.1.5 Computers

Hubble's Data Management Subsystem (DMS) contains two computers: the DF-224 flight computer and the Science Instrument Control and Data Handling (SI C&DH) unit. The DF-224 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.

During SM1 astronauts installed a coprocessor to augment the DF-224 capacity. The new 386-co-processor increased flight computer redundancy and significantly enhanced on-orbit computational capability.

During SM3A astronauts will replace the DF-224 and its co-processor with an Advanced Computer. It will assume all of the DF-224 functions while running 20 times faster and providing six times as much onboard memory.

1.2 The Hubble Space Telescope Program

Hubble Space Telescope represents the fulfillment of a 50-year dream and 23 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 Projects Directorate, under the supervision of the associate director of Flight Projects for HST.

The HST program is organized as two flight projects: (1) the HST Operations and Ground Systems Project and (2) the HST Flight Systems and Servicing 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 flight project 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 of Flight Projects for HST. This group is concerned with the highest level of scientific management for the project.

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 SM3A include Raytheon Optical Systems, Inc., Allied Signal, Jackson and Tull, Orbital Sciences Corporation, Odetics, Honeywell, ETA, and Hughes STX.

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 summarizes the major organizations

Organization	Function
NASA Headquarters	• Provides overall responsibility for the program
Goddard Space Flight Center – Office of the Associate Director of Flight Projects for HST – HST Operations and Ground Systems Project	• Overall HST Program Management • HST Project Management • Responsible 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. 1-6 Organization summary for HST program operational phase that oversee the program. Figure 1-7 shows communication links.

1.3 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.

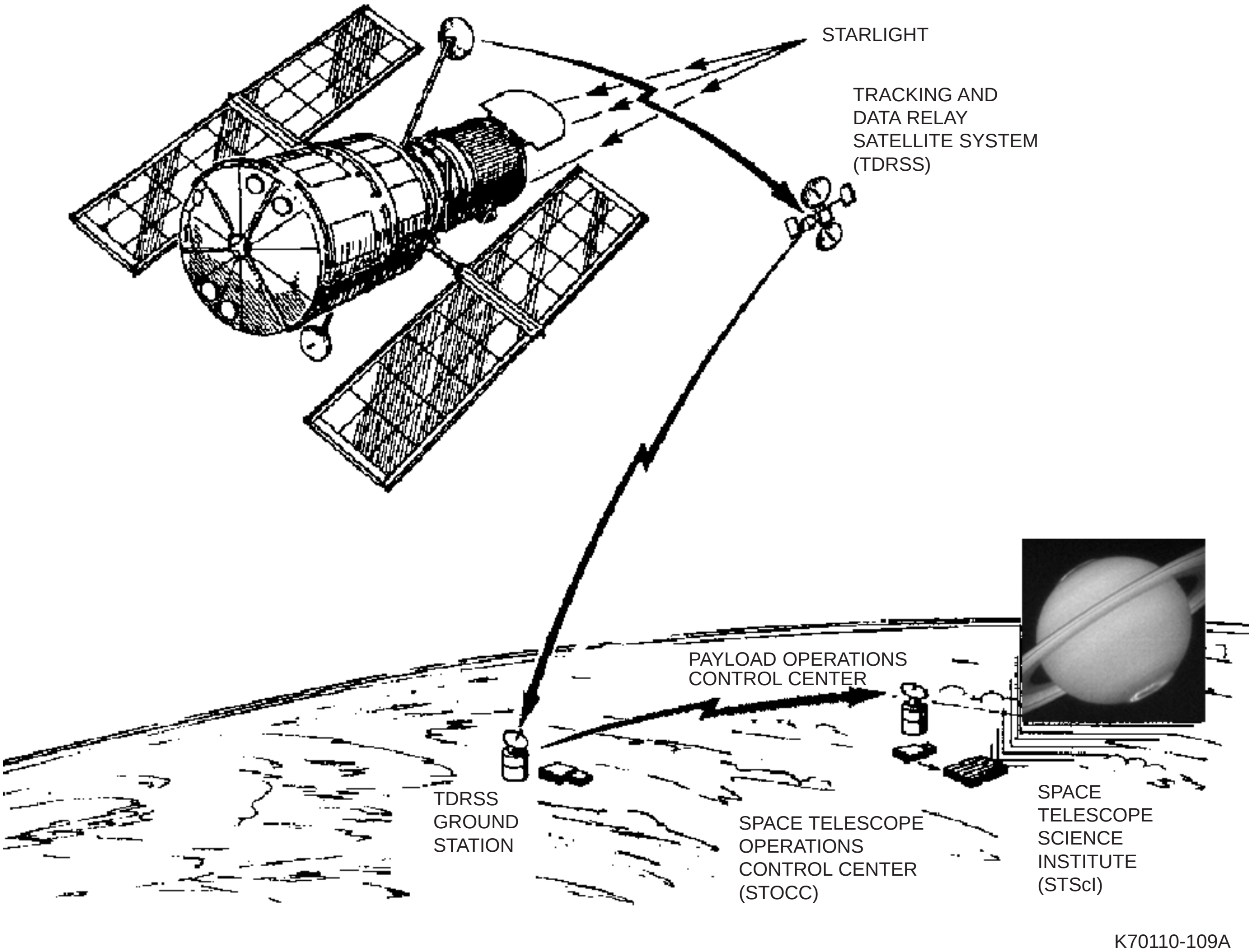

Fig. 1-7 HST data collecting network