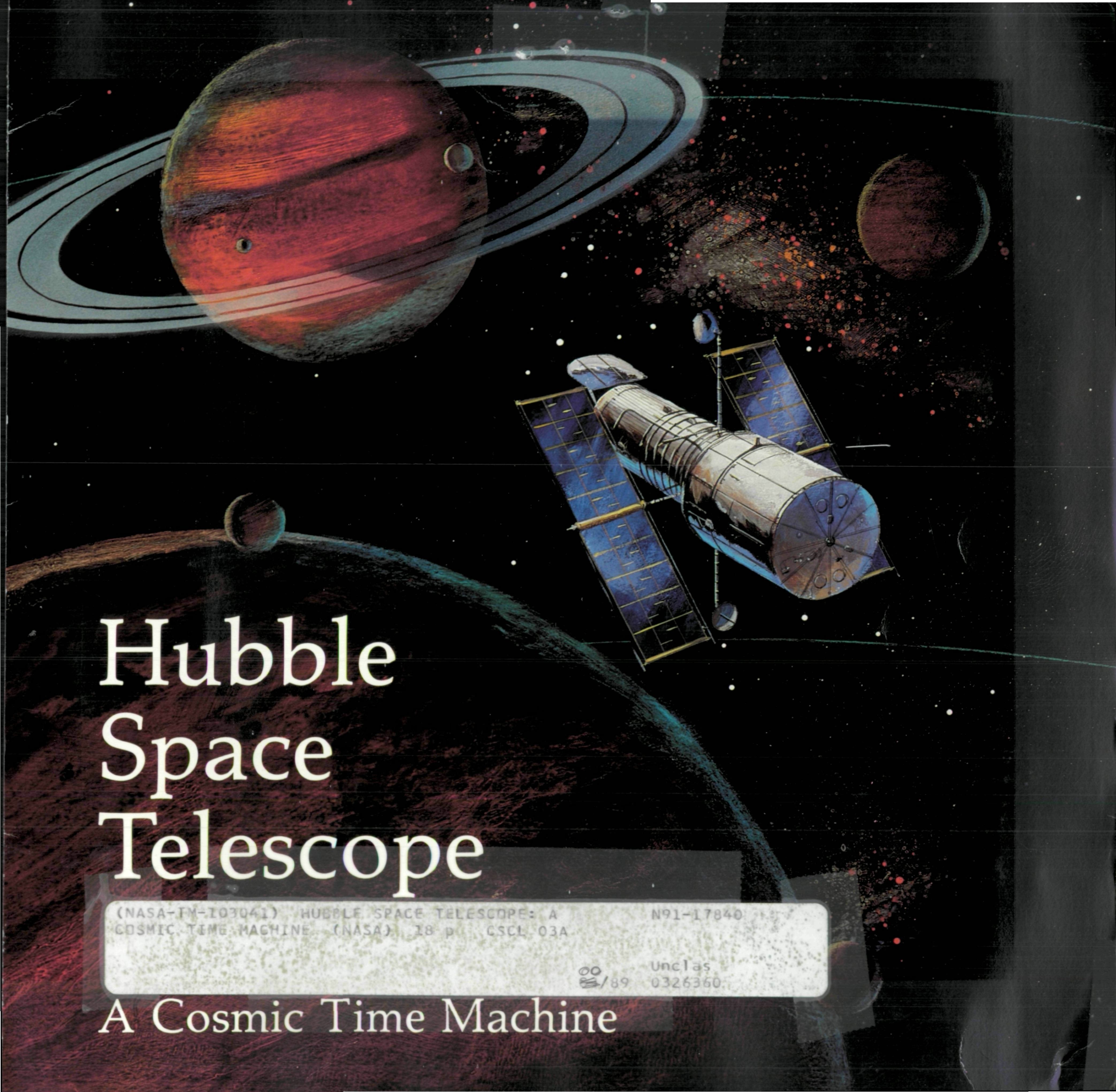


Hubble Space Telescope

A Cosmic Time Machine

. . . Even though the details of astronomical knowledge change as new discoveries are made, there are three major themes that have guided the astronomer's quest for knowledge for several decades. The same themes will continue to express the aims of astrophysics for the foreseeable future. These are to understand the following:

— the origin of the universe,
— the laws of physics governing the universe, and
— the birth of stars and planets and the advent of life.

The goals are vast in scope, challenging in their complexity, and profound in their implication. . . .

Thomas Donahue, chairman
Space Science Board

Mission Directive

Twenty years in the planning and the making, the Hubble Space Telescope is ready to breach Earth's murky atmosphere and show us the universe with such clarity that we will see almost to the beginning of time.

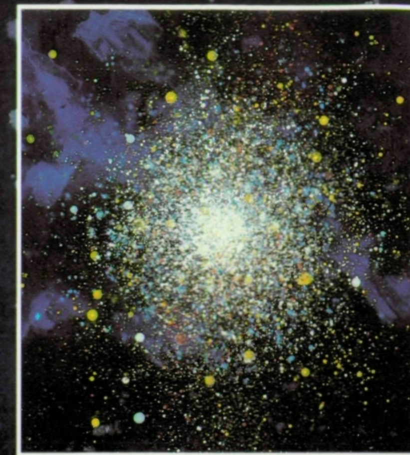
The telescope, orbiting 380 miles above the Earth and beyond the distorting effects of our atmosphere, will look five times more deeply into space, detect objects 50 times fainter, and view them with 10 times finer detail than earthbound observatories—expanding the visible universe by 125 times.

With this telescope, a cosmic time machine, we will see light that is 14 billion years old, light that started hurtling toward us shortly after the explosion that set in motion the evolution of our universe.

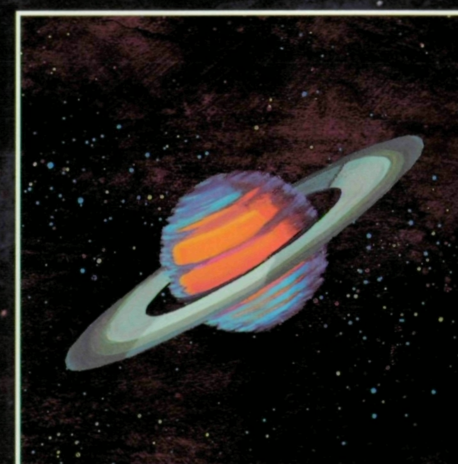
The telescope is named for Edwin Powell Hubble, the astronomer who, in the 1920's, first identified galaxies outside our own Milky Way and determined that most are speeding away from us. On his work is based the idea that our universe is expanding from an original "big bang" 15 to 20 billion years ago.

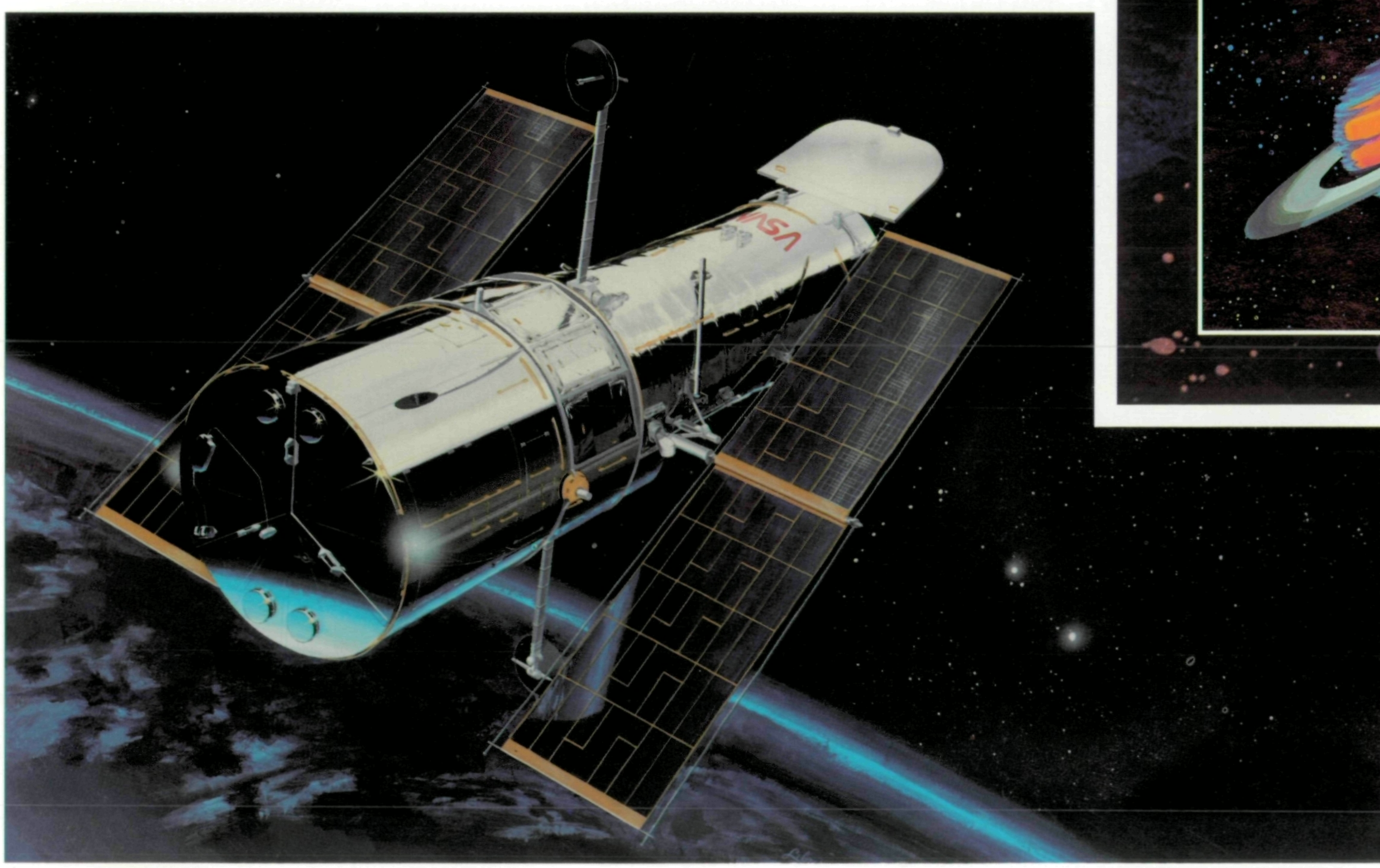
The mission of the Hubble Space Telescope is to explore our expanding and evolving universe. To enlighten us about the age of our universe and its past, present, and future, the telescope will be fixed not only on the most distant celestial objects, like the newly discovered quasar, 14 billion light-years

Globular cluster in the Milky Way



Saturn



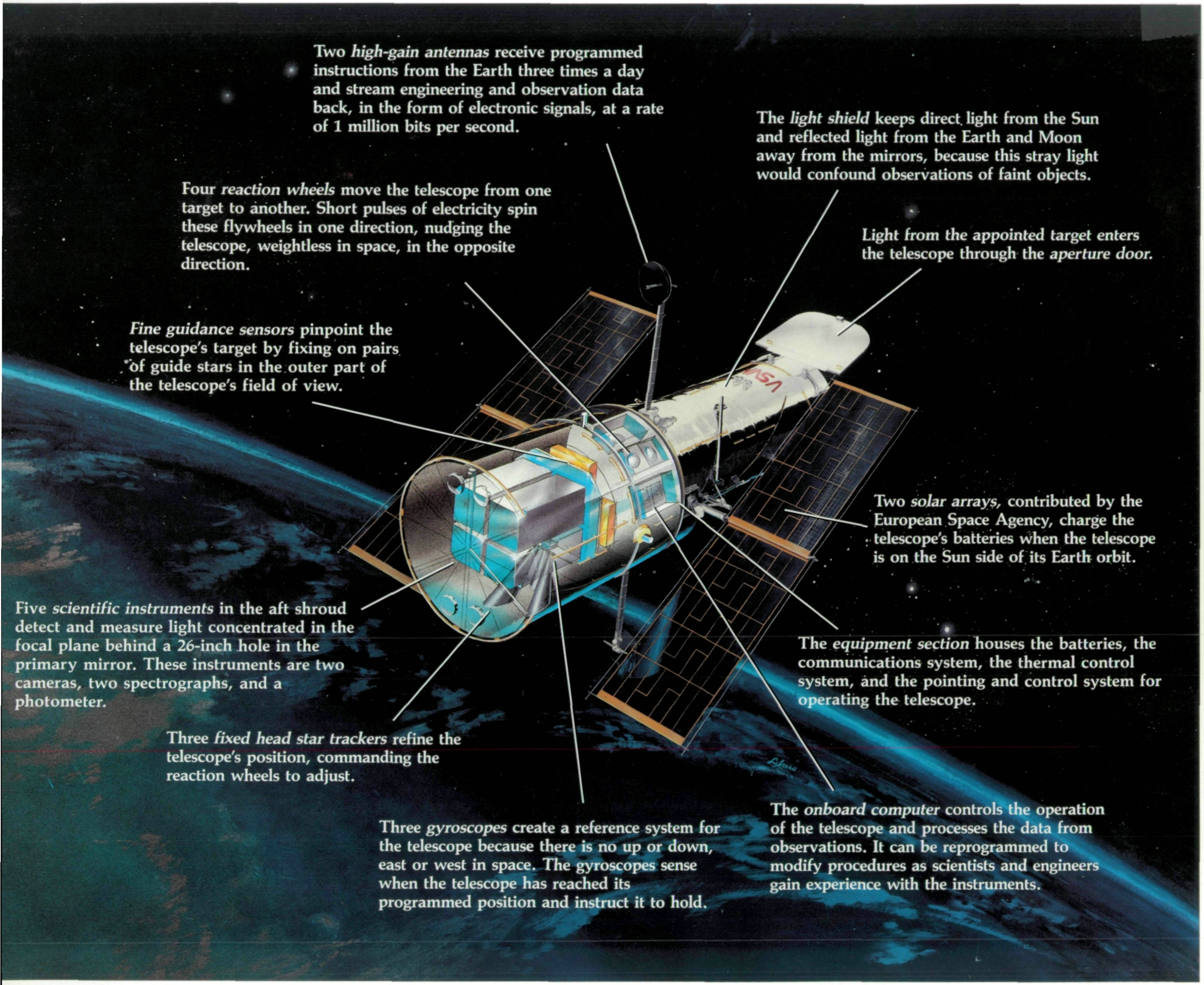


away in the constellation Ursa Major, but also on closer objects.

During 3,000 operating hours every year for the next 15 years or more, scientists will use the Hubble Space Telescope to study

— galaxies, especially active galaxies and radio galaxies with very bright centers
— pulsars, rapidly spinning neutron stars, like the one in the Crab Nebula
— globular clusters, spherical groups of stars that orbit the center of our galaxy and may have black holes at their centers
— neighboring stars where planets may be forming, like one in the constellation Cygnus
— supergiant stars outside our galaxy
— binary star systems in which one star loses mass to the other
— condensing gas clouds and their chemical composition
— the rings of Saturn and the swirling ultraviolet clouds of Venus.

From their clearer, finer observations of these and other known points of light, scientists expect to learn about the birth and death of stars and galaxies. And when, in the words of a NASA announcement from the 1970's, "in conscious expectation of the unexpected," they aim the telescope into the empty regions between, they may learn even more from the darkness.


Two *high-gain antennas* receive programmed instructions from the Earth three times a day and stream engineering and observation data back, in the form of electronic signals, at a rate of 1 million bits per second.
The *light shield* keeps direct light from the Sun and reflected light from the Earth and Moon away from the mirrors, because this stray light would confound observations of faint objects.
Four *reaction wheels* move the telescope from one target to another. Short pulses of electricity spin these flywheels in one direction, nudging the telescope, weightless in space, in the opposite direction.
Light from the appointed target enters the telescope through the *aperture door.*
Fine guidance sensors pinpoint the telescope's target by fixing on pairs of guide stars in the outer part of the telescope's field of view.
Two *solar arrays,* contributed by the European Space Agency, charge the telescope's batteries when the telescope is on the Sun side of its Earth orbit.
Five *scientific instruments* in the aft shroud detect and measure light concentrated in the focal plane behind a 26-inch hole in the primary mirror. These instruments are two cameras, two spectrographs, and a photometer.
The *equipment section* houses the batteries, the communications system, the thermal control system, and the pointing and control system for operating the telescope.
Three *fixed head star trackers* refine the telescope's position, commanding the reaction wheels to adjust.
The *onboard computer* controls the operation of the telescope and processes the data from observations. It can be reprogrammed to modify procedures as scientists and engineers gain experience with the instruments.
Three *gyroscopes* create a reference system for the telescope because there is no up or down, east or west in space. The gyroscopes sense when the telescope has reached its programmed position and instruct it to hold.
NASA

Spacecraft Equipment Systems

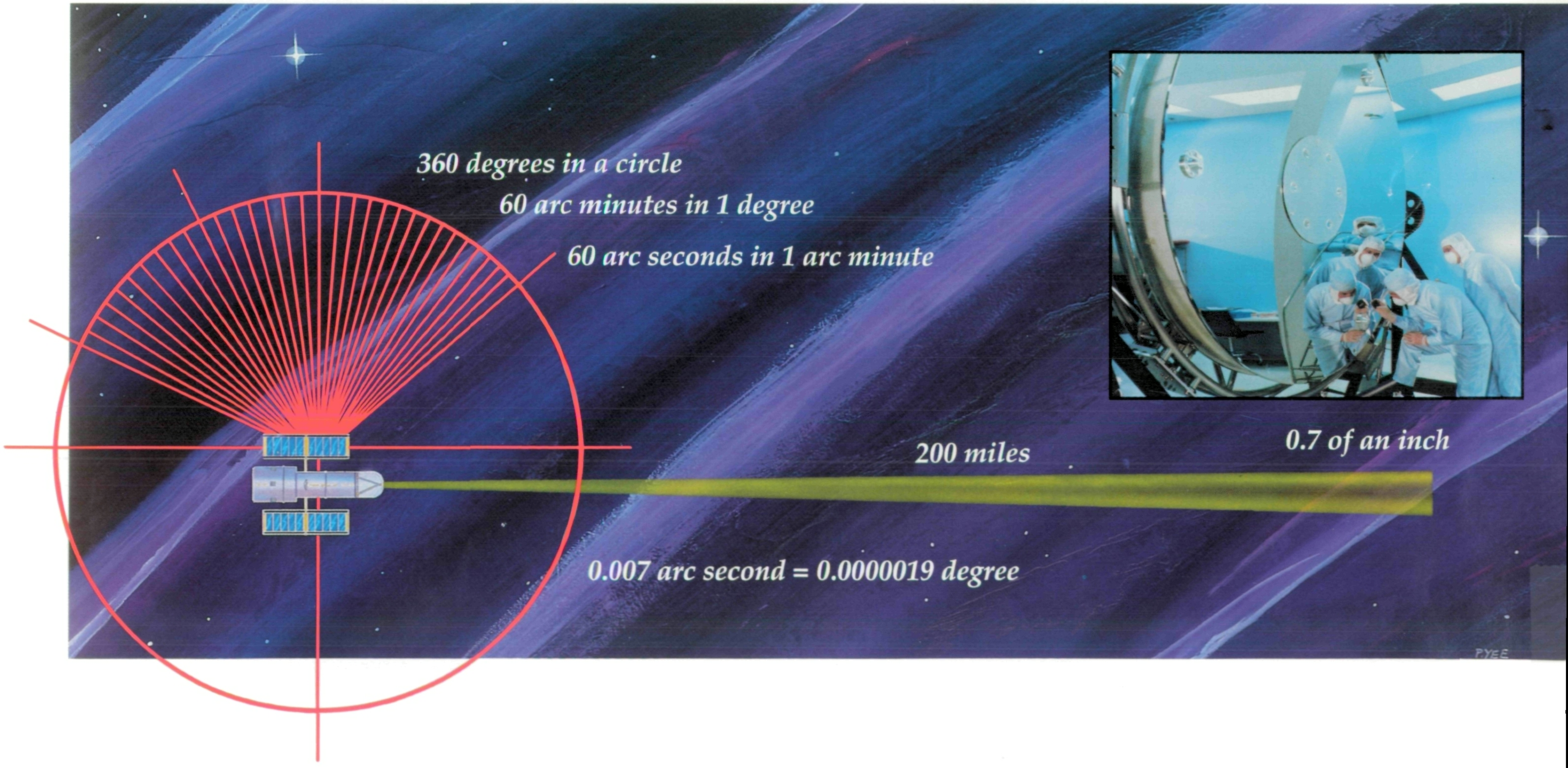
Fit for its ambitious mission, the Hubble Space Telescope is an impressive machine—a reflecting telescope carrying the support systems it needs to work automatically in space. At 43.5 feet long, 14 feet in diameter, weighing 25,500 pounds, the Hubble Space Telescope is the largest astronomical observatory ever placed in orbit.

The major technological achievements at the heart of the telescope are its nearly perfect mirrors and its precise guidance system of rate gyroscopes, reaction wheels, star trackers, and fine guidance sensors.

The primary mirror, 94 inches across, is so smooth and so close to its perfect shape that, if it were the size of the Earth, the peak of its greatest irregularity would be no more than 3 inches high. To make the surface this smooth, 200 pounds of glass were polished away, and to make the glass a mirror, it was coated with aluminum so thin that, peeled away, it would float in the air like a mist.

But to achieve the clarity of image this extraordinary mirror is capable of, the telescope must point accurately and stay on target while it collects light from very faint objects. The guidance system is so accurate and so stable that it pinpoints its target within 0.007 arc second and can stay there for more than 10 hours. This accuracy is equivalent to hitting a dime with a laser beam from 400 miles.

When the target is fixed, the primary mirror collects light in the entire spectrum from ultraviolet to infrared and reflects it to the 13-inch secondary mirror 15 feet in front of it. The secondary mirror reflects the light back through the 26-inch hole in the primary mirror to the five scientific instruments arrayed behind it.



Scientific Instruments

Light—from forming galaxies now mature, from exploding stars now spent—focused by the Hubble Space Telescope's nearly perfect primary and secondary mirrors, is beamed by pickoff mirrors to the five scientific instruments.

For the clearest information from the most sources, these instruments were chosen from among a dozen proposals solicited from the scientific community by the Goddard Space Flight Center.

The Hubble Space Telescope carries two cameras; two spectrographs, the basic tool of modern astronomy; and a photometer.

The wide field and planetary camera, from the California Institute of Technology and the Jet Propulsion Laboratory, is one instrument with two functions. It surveys vast areas of deep space, and it takes vivid pictures of planets and other features of our Solar System.

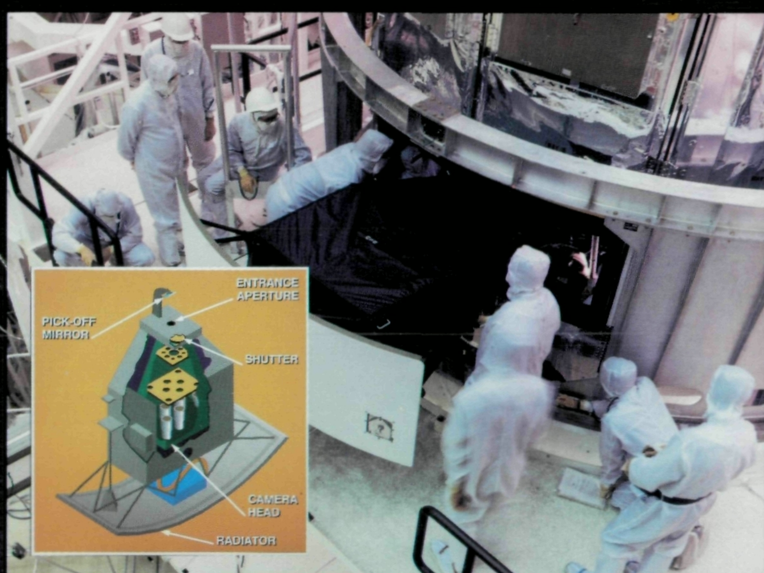
The faint object camera, from the European Space Agency, detects the faintest objects visible to the space telescope.

The high-resolution spectrograph, developed at Goddard and built by Ball Aerospace, observes only ultraviolet light. Its sensors are deliberately insensitive to visible light.

The faint object spectrograph, developed by scientists at the University of California at San Diego and built by Martin Marietta Corporation, will be one of the busiest instruments. It observes the spectra of extremely faint light sources and registers rapid variations in them.

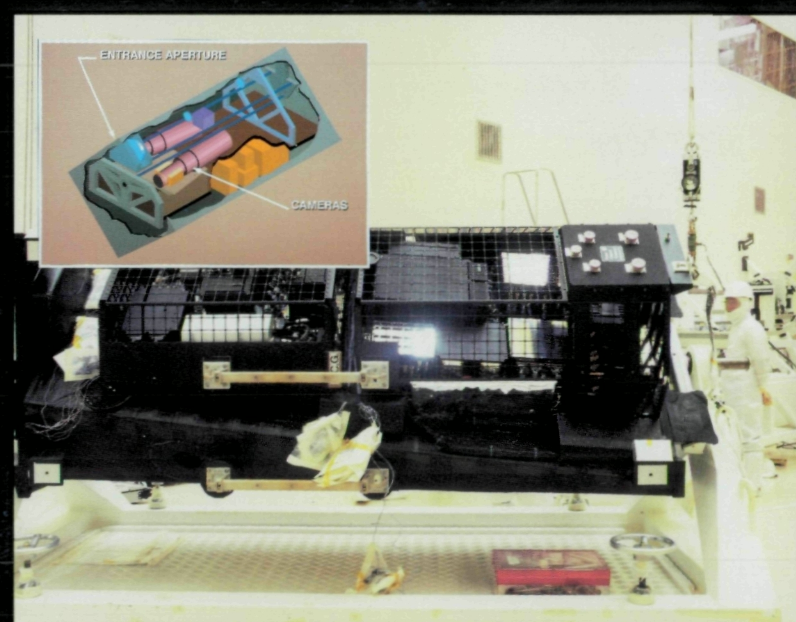
The high-speed photometer, contributed by the University of Wisconsin, detects the smallest objects that can be observed with any of the five instruments. It measures the intensity of light from sources in space and can register changes in brightness that occur as rapidly as every 10 microseconds.

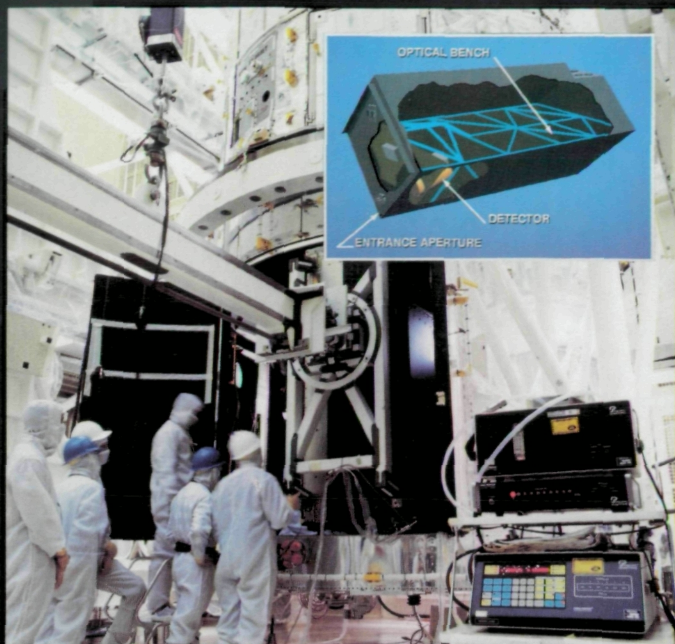
With these carefully chosen instruments, scientists will study light, old and faint, from across space and time.



Wide Field and Planetary Camera
Scientists will use this instrument to study the nature of quasars. A quasar emits 100 times more energy than a galaxy of 10 billion stars, and scientists want to know why. Some theories suggest that quasars are galaxies in a "sick" stage of evolution. As a wide field camera, this instrument may prove this theory by showing that these bright points are surrounded by the dimmer stars of a galaxy.

Faint Object Camera
The faint object camera will detect white dwarf stars in the globular clusters that orbit the center of the Milky Way. White dwarfs are stars that have cooled and collapsed. Studying them will shed light on the evolution of stars.



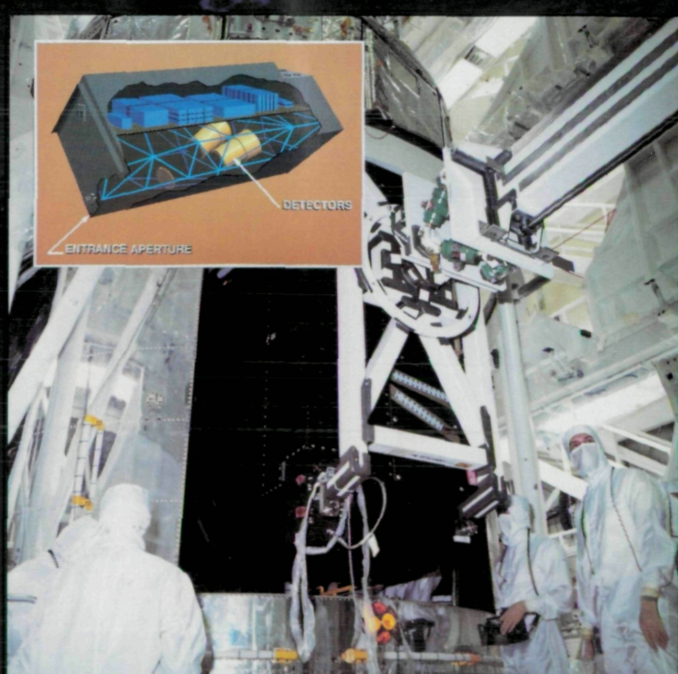


Goddard High-Resolution Spectrograph

With this instrument, scientists will study the faint ultraviolet emissions from very bright objects, such as the nuclei of active galaxies, supernovas, and exploding galaxies. This spectrograph may also reveal interstellar gas in regions where it has not yet been detected; if it does, scientists will use this information to test current models of cosmic evolution.

High-Speed Photometer

This instrument may prove the existence of black holes. Theoretically, matter falling into a black hole will orbit the black hole very quickly, emitting bursts of radiation in a characteristic way. With the photometer, scientists may be able to measure these bursts and prove that black holes exist.



Faint Object Spectrograph

Spectrograms of very distant galaxies taken with this instrument will show the chemical composition of matter at an early stage in the evolution of the universe and reveal how galaxies were formed.

Integration and Test

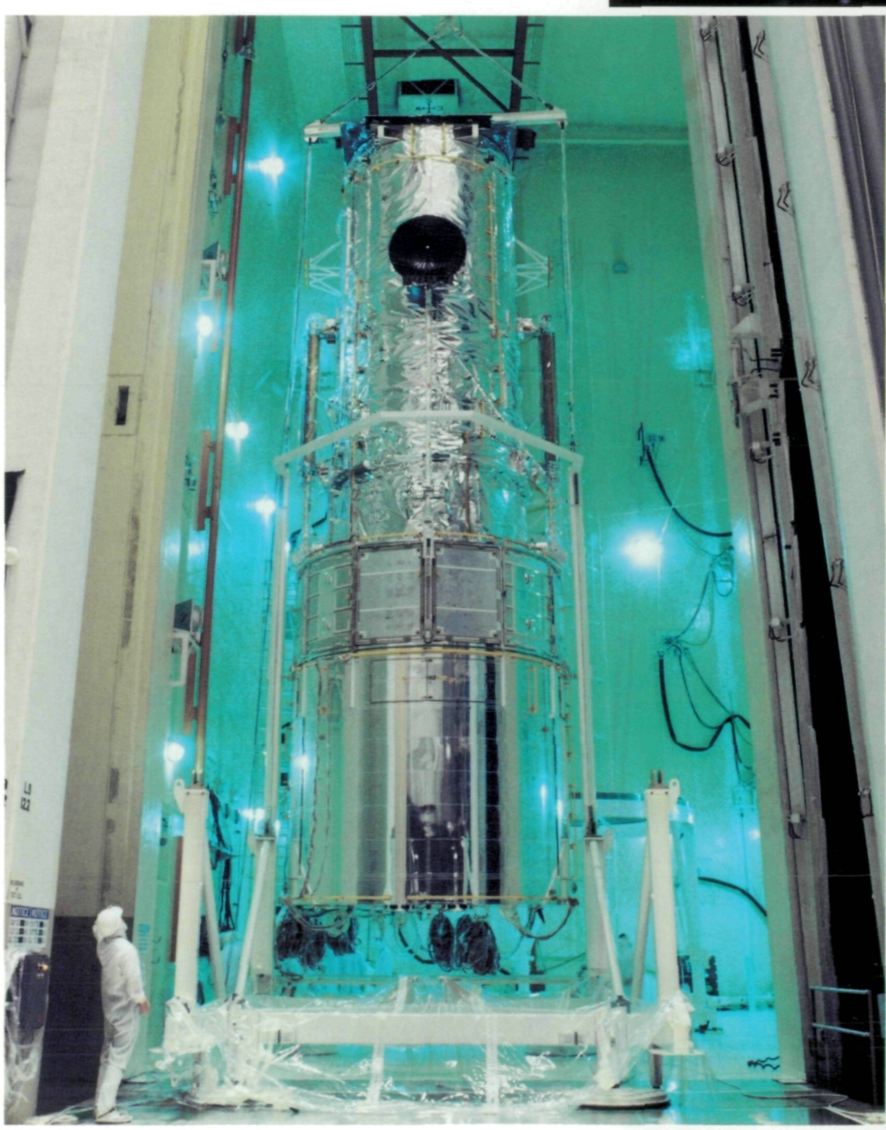
Mirrors and fine guidance sensors from Perkin-Elmer, solar arrays from the European Space Agency, scientific instruments from their separate contributors—these critical pieces, and more, were fit together into one spacecraft by Lockheed Missiles & Space Company.

To protect the mirrors from dust that could scratch them, engineers and technicians, dressed like surgeons, assembled the telescope in a facility far cleaner than a hospital operating room. In the Vertical Assembly and Test Area, a class 10,000 clean room, the air recycles completely every 90 seconds so that it contains no more than 10,000 dust particles per cubic meter.

During assembly, not only had the mirrors to be protected from contamination, but their graphite epoxy support structure had to be kept as dry as possible to preserve its delicate alignment. For the clear images required of the space telescope, its secondary mirror must be aligned precisely in relation to the large primary mirror. However, earthbound materials give off traces of water vapor when they enter the vacuum of space, a phenomenon called outgassing that subtly alters their size and shape. To limit the effects of outgassing on the size and shape of the support structure and, therefore, on the alignment of the mirrors, the support structure was baked dry during its construction. And it was protected from absorbing water vapor during the assembly of the space telescope by a method of continuous dry purging. This dry purging during assembly makes the telescope more stable for its observations.

Fully integrated, the Hubble Space Telescope has been tested under conditions that simulate launch and the space environment. In Lockheed's thermal vacuum chamber, the telescope endured the extremes of hot and cold it will experience in its orbit, flying from day into night every 95 minutes: +50 to −150 degrees Fahrenheit. And it survived the acoustic tests that simulate the stresses of launch.

The Hubble Space Telescope, outfitted for its mission to explore the evolving universe, is ready for its launch from the Space Shuttle Discovery.



The acoustic test simulator subjects the space telescope to the vibrations of launch.

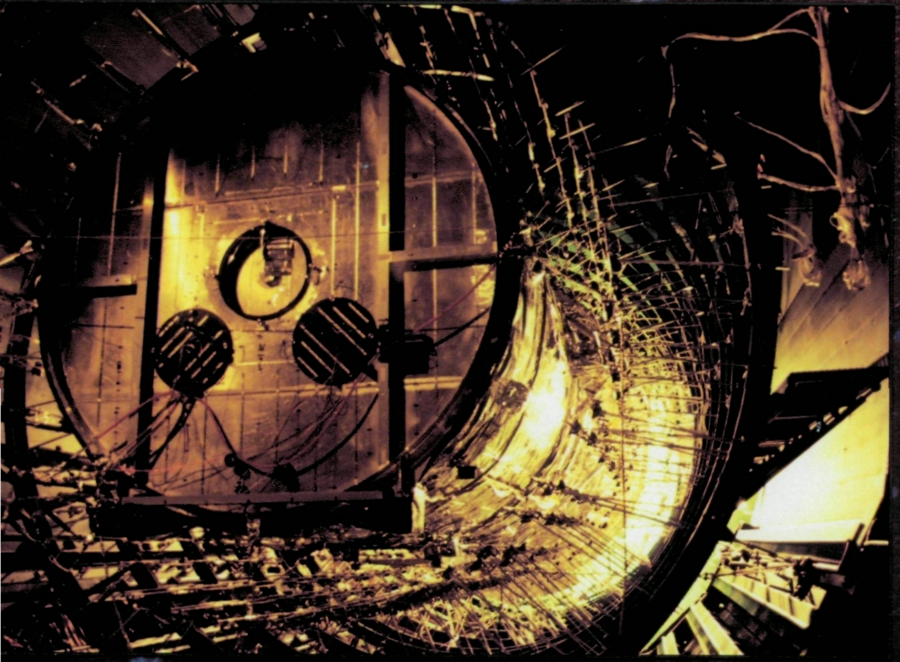
Loren J. Shriver (USAF)
Commander
Colonel Shriver holds a BS in Aeronautical Engineering and an MS in Astronautics. He was a test pilot at Edwards AFB when he was selected to be an astronaut. Colonel Shriver flew as pilot on a previous Space Shuttle mission. As commander on this mission, he is responsible for all aspects of the flight and telescope deployment.

Charles F. Bolden (USMC)
Pilot
Colonel Bolden's education includes a BS in Electrical Science and an MS in Systems Management. He is also a graduate of the U.S. Naval Test Pilot School and served as combat pilot in Vietnam. Colonel Bolden, pilot on a previous Space Shuttle mission carrying scientific instruments, is pilot for the Hubble Space Telescope mission.

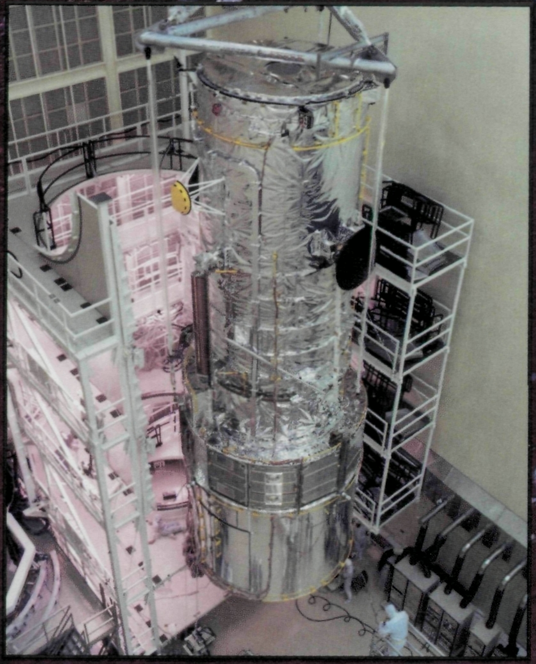
Kathryn D. Sullivan
Mission Specialist
Dr. Sullivan has a BS in Earth Sciences and a doctorate in Geology. The first woman to perform an EVA, Dr. Sullivan is an EVA specialist on this mission.

Bruce McCandless, II (USN)
Mission Specialist
Captain McCandless has a BS from the U.S. Naval Academy and an MS in Electrical Engineering from Stanford University. He was backup pilot for Skylab 2 and, as a mission specialist on another Shuttle flight, he performed the first free-flight EVA. On this mission, he is an EVA specialist.

Steven A. Hawley
Mission Specialist
Dr. Hawley holds a BA in Physics and Astronomy and a doctorate in Astronomy. Experienced as a mission specialist on two previous flights, Dr. Hawley will operate the Shuttle's mechanical arm to deploy the Hubble Space Telescope.

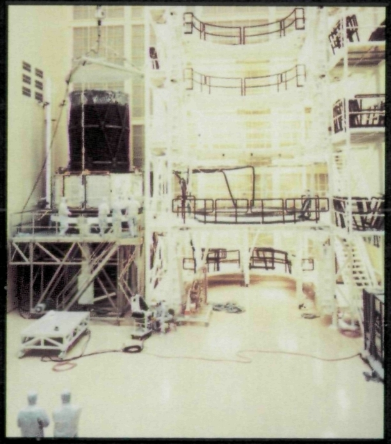


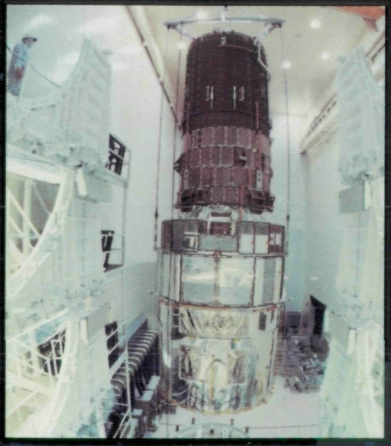
he thermal vacuum chamber simulates the pace environment



The Vertical Assembly and Test Area is a class 10,000 clean room

he Hubble Space Telescope was ssembled on a spacecraft built y Lockheed Missiles & Space ompany

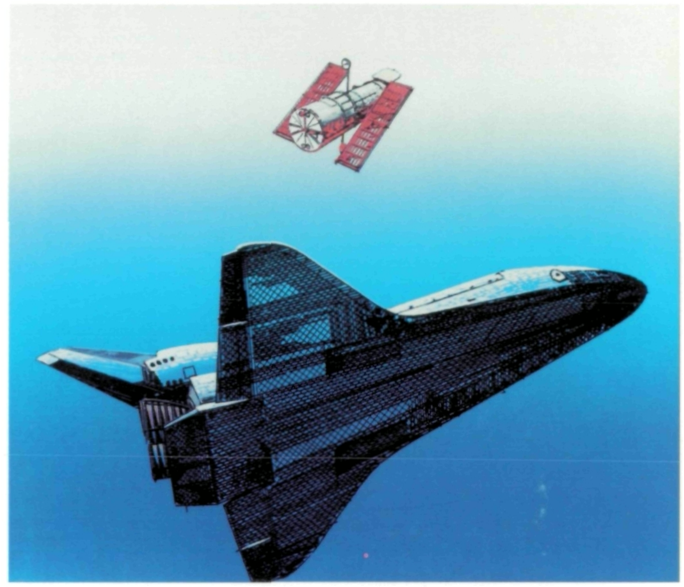


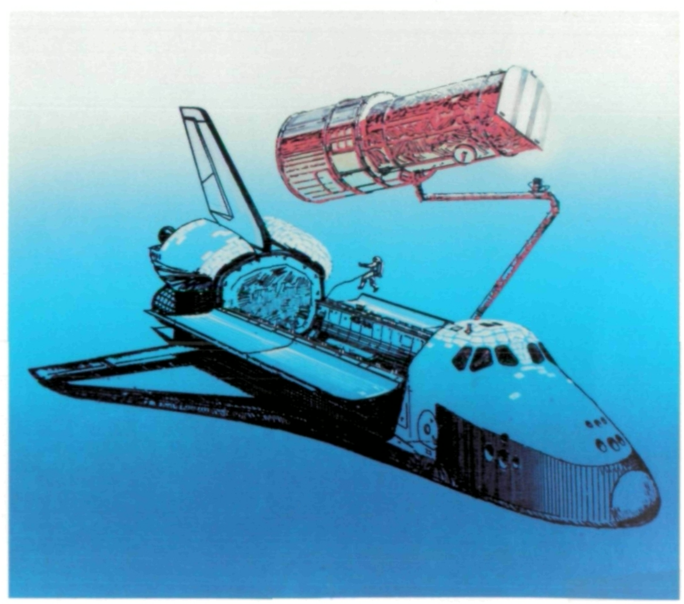


Space Shuttle Operations

At 380 miles above the Earth, the pilot will maneuver the Space Shuttle into proper position, the cargo bay doors will open, and the Shuttle's mechanical arm will raise the 43-foot telescope upright in the bay. Specially trained astronauts will power up the telescope and check its systems. Mission specialists, wearing space suits, may go out into the cargo bay to make final adjustments to the telescope's systems. Then the arm will swing the telescope into space and release it.

The solar arrays will unfold, the antennas will extend. Nearby, the Space Shuttle will keep station for two orbits until ground control at Marshall Space Flight Center determines that the telescope is working properly. Then the Shuttle will leave and the Hubble Space Telescope will begin collecting its first light.





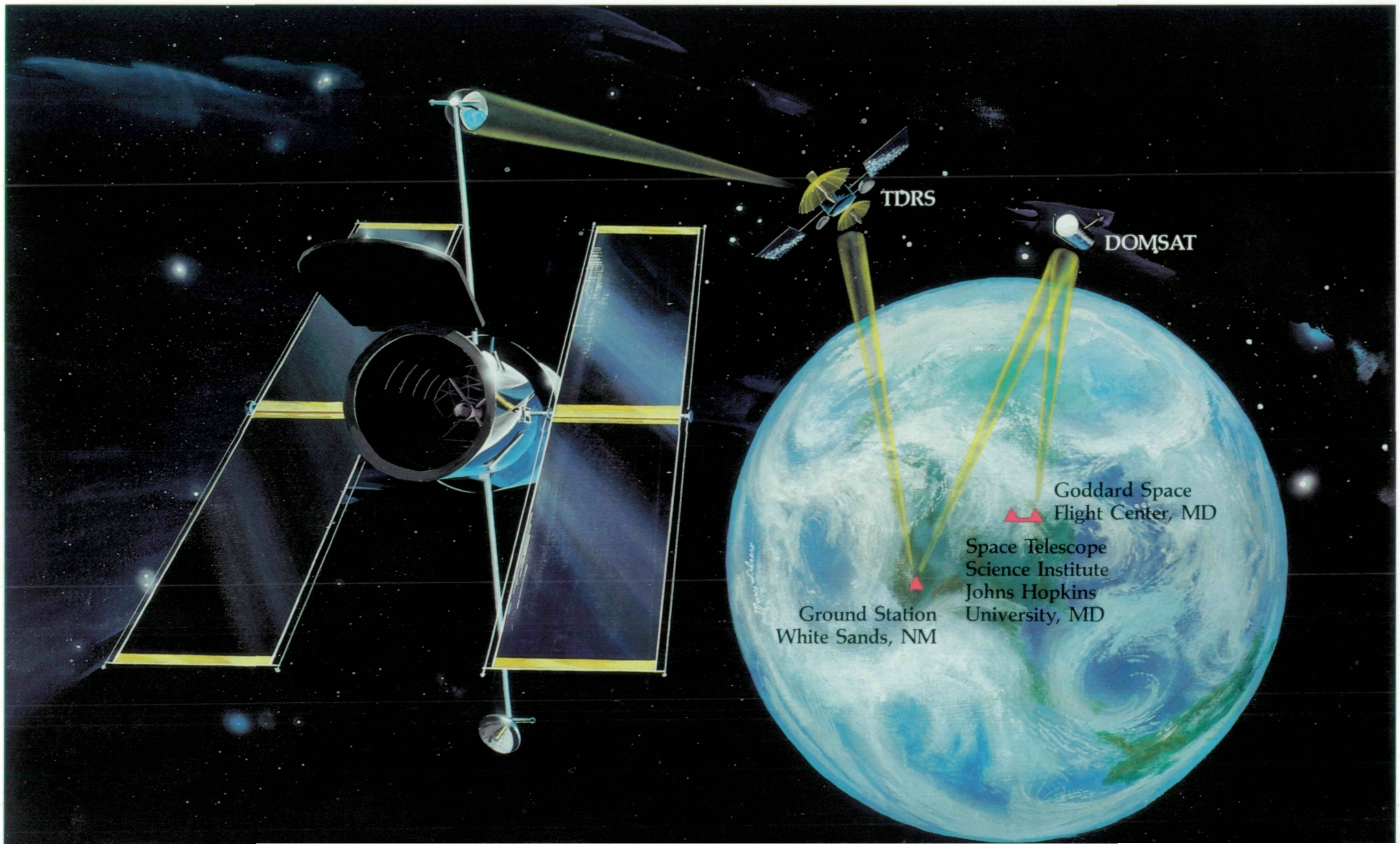
Mission Operation and Data Flow

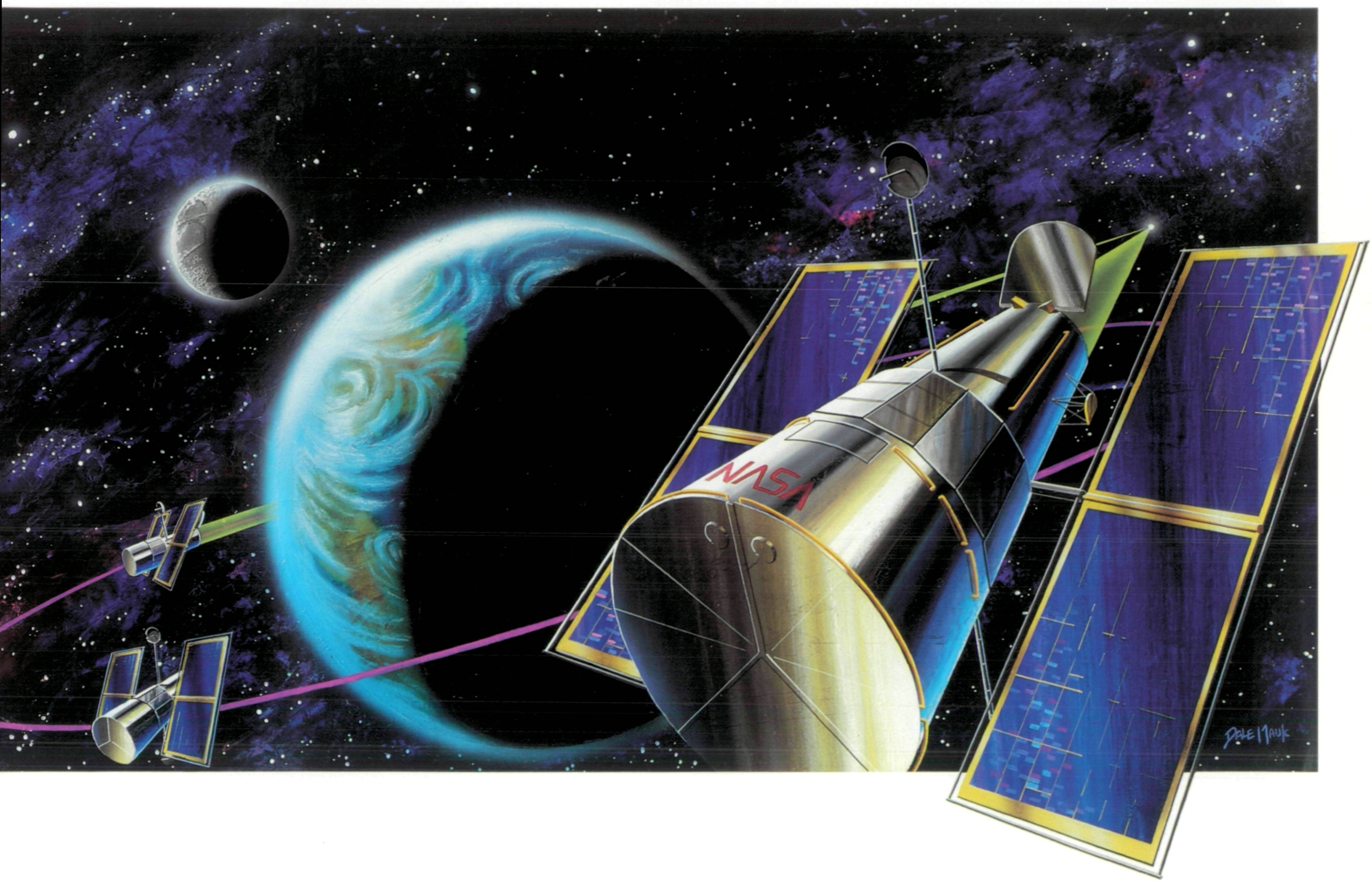
With planets and their moons and comets in our Solar System, with 200 billion stars in our galaxy, with at least 100 billion galaxies in the universe, decisions must be made—where will the Hubble Space Telescope look and when? For the telescope's first year in operation, the Space Telescope Science Institute (STScI) in Baltimore, Maryland, has approved time for 162 observations from among 556 proposals.

To use the telescope most efficiently, STScI computers produce a long-range calendar that schedules every approved observation. After an observation is scheduled, for example, of the site of a 1961 supernova, computer programmers write the second-by-second instructions that point the telescope and keep it on target and that turn on and operate the scientific instruments. Observing time must be planned carefully and programmed pointing instructions must be precise because the telescope moves constantly, orbiting the Earth every 95 minutes.

At Goddard Space Flight Center, controllers transmit the instructions to a Tracking and Data Relay Satellite (TDRS), which relays them to the space telescope's onboard computer.

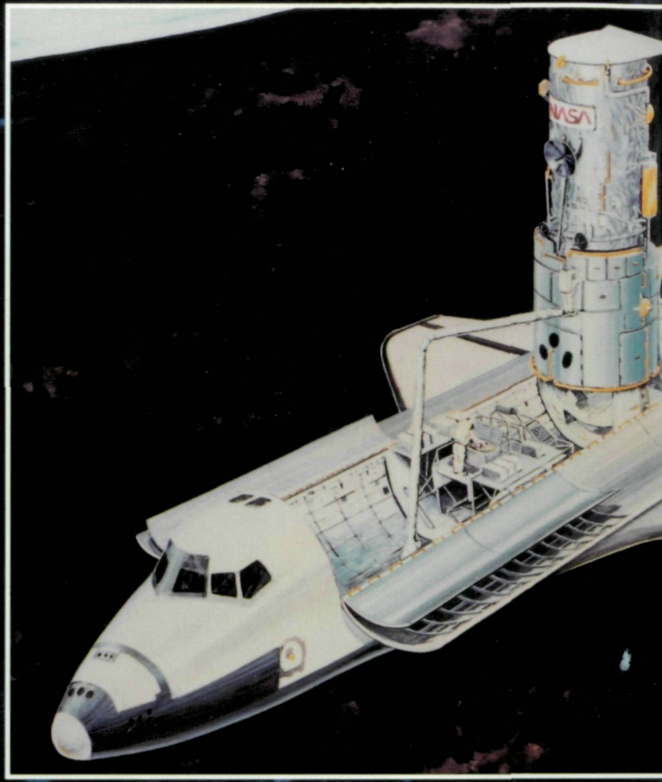
After the telescope has pinpointed the target, the mirrors have adjusted for clearest focus, and the cameras and spectrographs have registered the light from the appointed source, observations, in the form of electronic signals, follow the same path back to Earth—from telescope to relay satellite to ground. A ground station at White Sands, New Mexico, receives all data and sends it by satellite relay to Goddard Space Flight Center in Maryland. After Goddard ground controllers make certain that data has not been lost or corrupted, they send it on to the STScI where it is translated into formats that scientists can use. On a typical day, the STScI will receive enough data on the light from distant space to fill an encyclopedia.



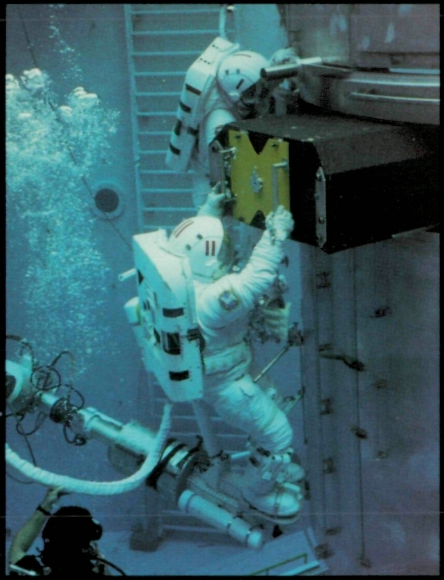

NASA

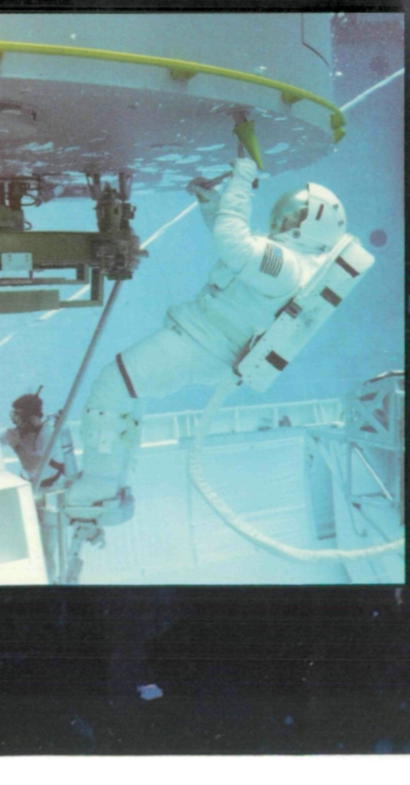
Maintenance and Refurbishment

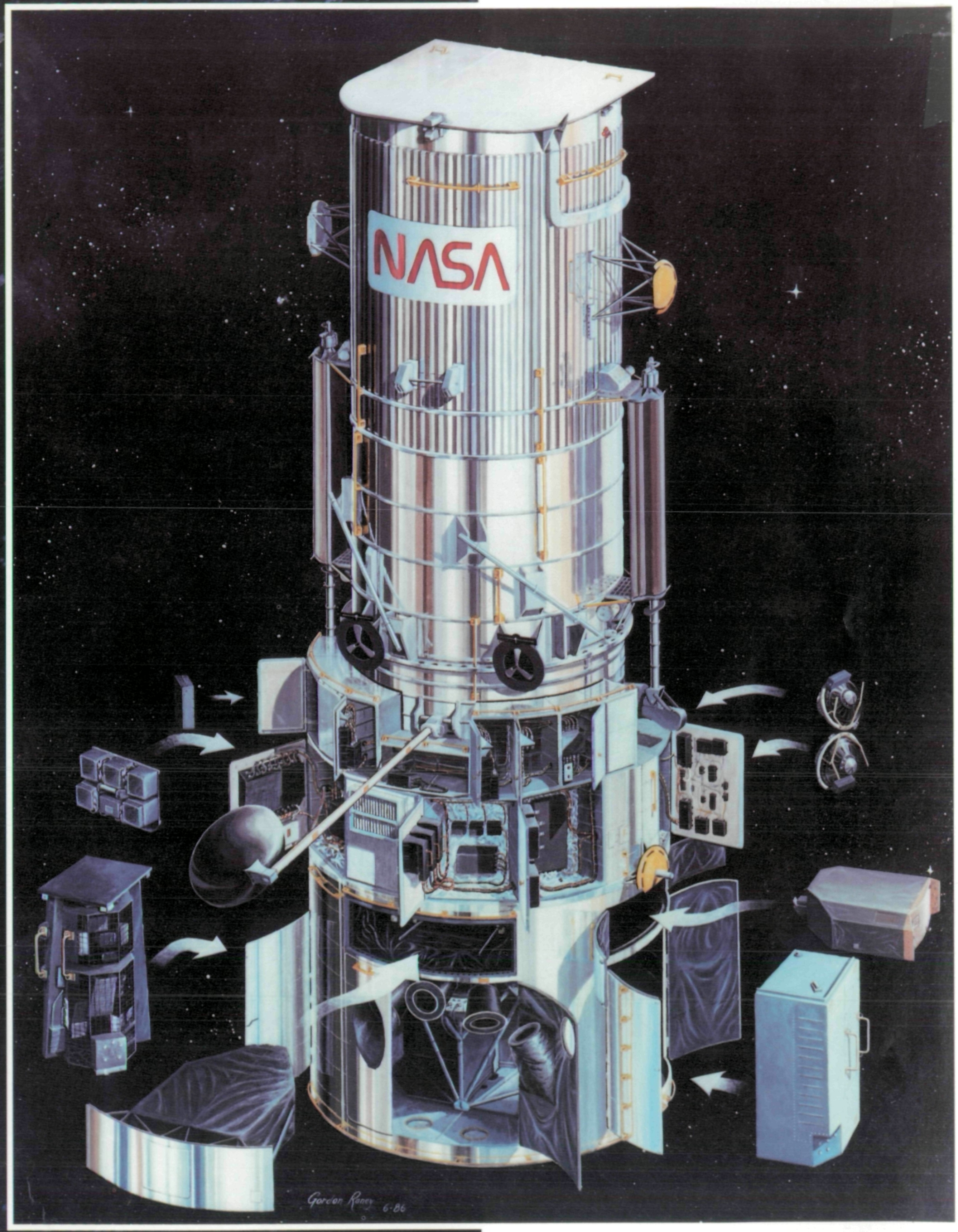
Specially designed to be maintained and refurbished in orbit, the Hubble Space Telescope will be visited by the Space Shuttle every 5 years for routine service calls. The telescope has 225 feet of handrails and 31 foot restraints on its surface for the astronauts to use during extravehicular activities (EVAs), and it has 70 parts, called orbital replacement units (ORUs), that astronauts can replace in space. These include batteries, fine guidance sensors, and solar arrays, which engineers expect to wear out in normal use, and the scientific instruments, which may be replaced with more advanced ones during the Hubble Space Telescope's 15-year mission to observe the evolving cosmos.

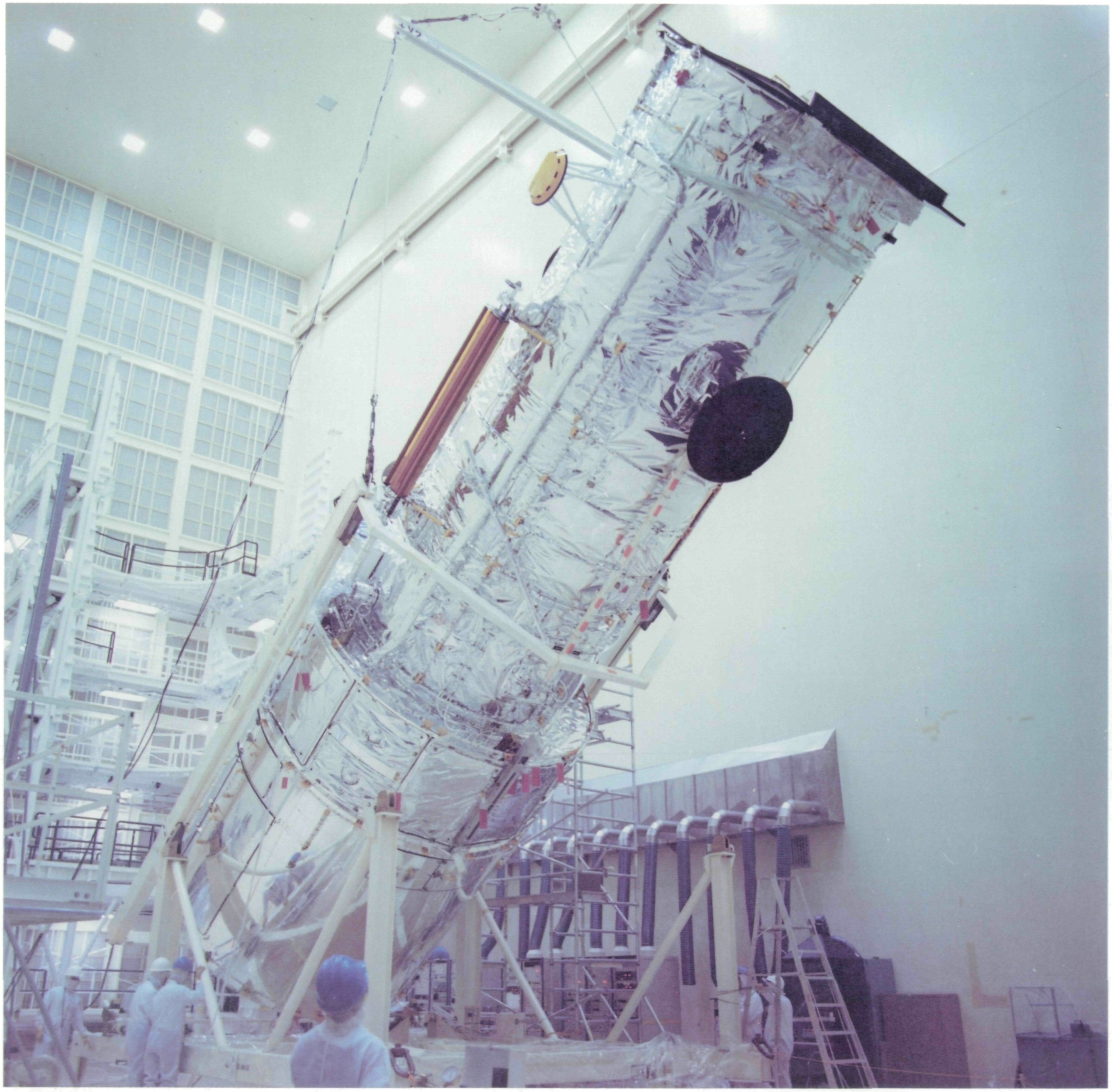


The crew members use simulators to practice rendezvousing with the telescope, retrieving it, stowing it in the Shuttle cargo bay, and redeploying it. In 1-g ground simulations, they also practice replacing telescope hardware while the Hubble Space Telescope is in orbit. To simulate the weightlessness they experience during EVAs, they train underwater with mockups of the telescope and the ORUs.






NASA
Gordon Raney 6-86



At Lockheed Missiles & Space Company in Sunnyvale, California, the Hubble Space Telescope is lowered during final preparation for shipment to Kennedy Space Center.

The Hubble Space Telescope Team

NASA

The Office of Space Science and Applications, responsible for overall program direction
Marshall Space Flight Center, responsible for overall HST project management, design and development overview, and preparation for Hubble Space Telescope maintenance and refurbishment mission
Goddard Space Flight Center, responsible for scientific instruments, mission operations, and the Space Telescope Science Institute (STScI), which is operated by the Association of Universities for Research in Astronomy at Johns Hopkins University
Johnson Space Center, responsible for the Space Shuttle and flight crew operations
Kennedy Space Center, responsible for Space Shuttle launch operations
European Space Agency, providing one scientific instrument and the solar arrays and participating in the STScI

Space Telescope Contractors

Lockheed Missiles & Space Company, responsible for the design and development of the support systems module, for Hubble Space Telescope systems integration, and for systems engineering for Marshall Space Flight Center; and prime contractor for the Mission Operations Control Center for Goddard Space Flight Center in Greenbelt, Maryland
Perkin-Elmer, providing the optical telescope assembly

Scientific Instruments

Wide field and planetary camera
Principal investigator
Prof J. A. Westphal
California Institute of Technology
Contractor
Jet Propulsion Laboratory

Faint object spectrograph
Principal investigator
Dr. R. J. Harms
University of California, San Diego
Contractor
Martin Marietta

Goddard high-resolution spectrograph
Principal investigator
Dr. J. C. Brandt
Goddard Space Flight Center
Contractor
Ball Brothers

High-speed photometer
Principal investigator
Dr. R. C. Bless
University of Wisconsin
Contractor
University of Wisconsin

Faint object camera
Principal investigator
Dr. F. D. Macchetto
European Space Agency
Contractors
Dornier Systems, Matra, British Aerospace

Astrometry
Dr. W. H. Jefferys
University of Texas


Lockheed Missiles & Space Company