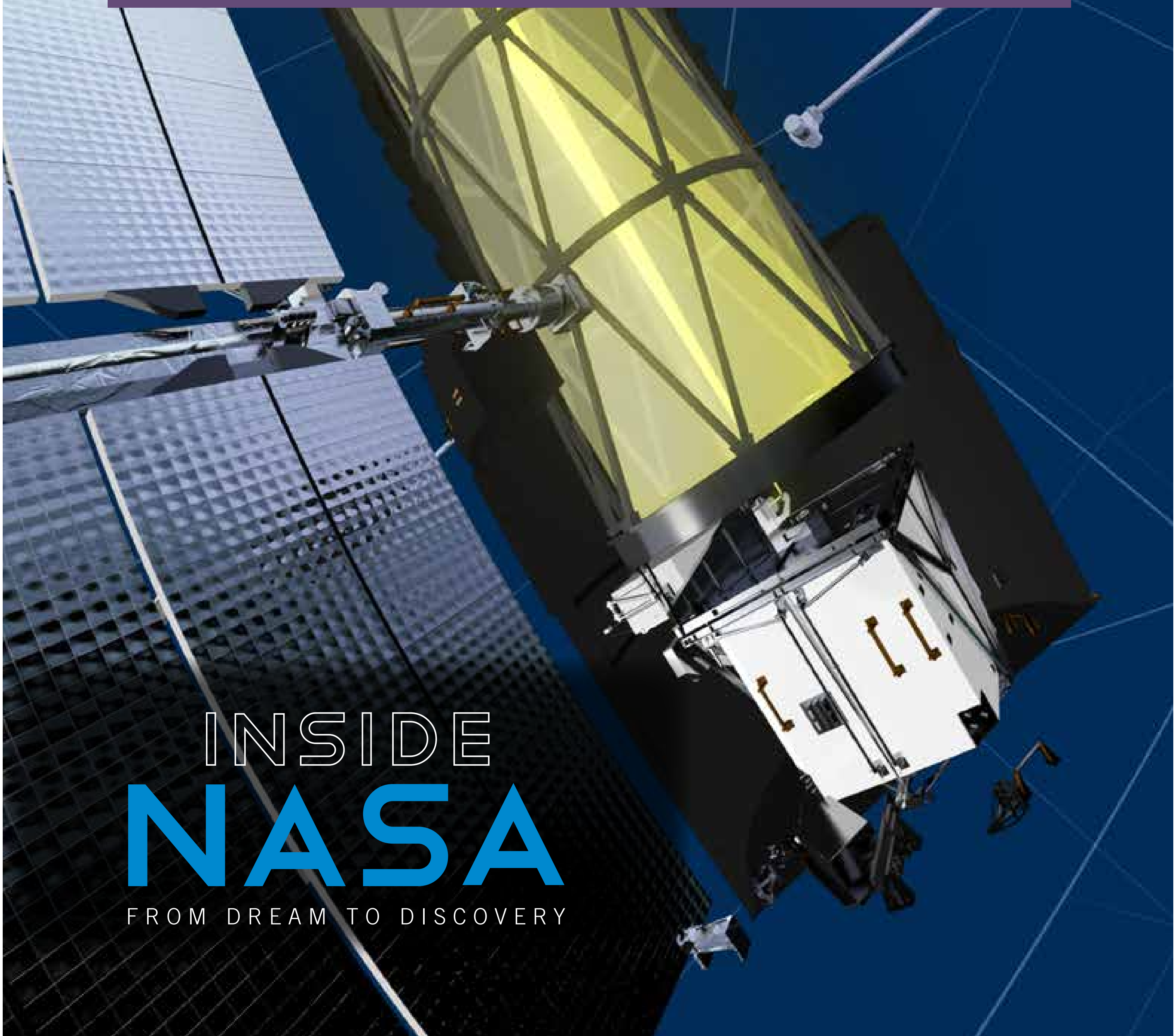
FIXING THE HUBBLE SPACE TELESCOPE

EDUCATOR GUIDE



INSIDE NASA

FROM DREAM TO DISCOVERY

Museum of Science®

Connections to Education Standards

INSIDE NASA FROM DREAM TO DISCOVERY

Next Generation Science Standards:

PERFORMANCE EXPECTATIONS	
4-PS4-2	Develop a model to describe that light reflecting from objects and entering the eyes allows objects to be seen.
3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
MS-PS4-2	Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
HS-ETS1-2	Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Massachusetts Science and Technology/Engineering Standards (2013 Draft)

STANDARDS	
4-PS4-2	Develop a model to describe that light must bounce off an object and enter the eye for the object to be seen.
3-5-ETS1-3	Plan and carry out tests of one or more elements of a model or prototype in which variables are controlled and failure points are considered to identify which elements need to be improved. Apply the results of tests to redesign a model or prototype.
3-5-ETS1-5 (MA)	Evaluate relevant design features that must be considered in building a model or prototype of a solution to a given design problem.
3-5-ETS2-2 (MA)	Describe that technological products or devices are made up of parts. Use sketches or drawings to show how each part of a product or device relates to other parts in the product or device.
MS-PS4-2	Use diagrams and other models to show that both light rays and mechanical waves are reflected, absorbed, or transmitted through various materials.
HS-PS4-1	Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media. Recognize that electromagnetic waves can travel through empty space (without a medium).
HS-ETS1-3	Evaluate a solution to a complex, real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, aesthetics, and maintenance, as well as social, cultural, and environmental impacts.

Connections to Education Standards *(continued)*

INSIDE NASA
FROM DREAM TO DISCOVERY

Massachusetts Science and Technology/Engineering Curriculum Framework (2001)

GRADE LEVEL	SUBJECT	LEARNING STANDARD
3 – 5	Physical Sciences	12: Recognize that light travels in a straight line until it strikes an object or travels from one medium to another, and that light can be reflected, refracted, and absorbed.
9 or 10	Physics	4.5: Interpret and be able to apply the laws of reflection and refraction (qualitatively) to all waves.
9 or 10	Technology/ Engineering	6.2: Explain how information travels through different media, e.g., electrical wire, optical fiber, air, space.

TEACHER TIP

DOWNLOAD FIELD TRIP GUIDES!

Use these handy activity sheets for chaperones and students to make the most of their day at the Museum. Download them before your visit: mos.org/educators.

Bolded words are defined further in the glossary (page 10).

Background

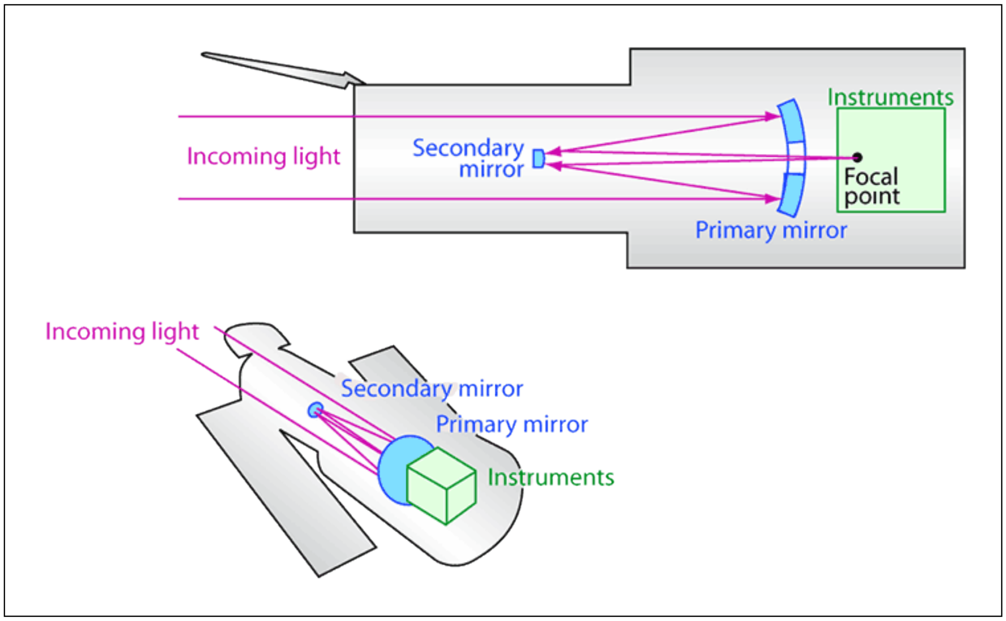
When the Hubble Space Telescope was first launched in 1990, it was designed to see farther and in more detail than any previous telescope. But when scientists and engineers at NASA began receiving the first pictures, it was quickly apparent that something was wrong: the pictures were blurry.

To understand what went wrong, it is helpful to know how telescopes like Hubble work and how the mirrors are made.

Early picture of the galaxy M100. *Image: Hubble/NASA.*

How Hubble's Optics Work

Hubble is a telescope design known as a Cassegrain reflector. It has two mirrors: a primary and a secondary, and the primary is the larger of the two. Light initially enters the telescope tube and hits the **primary mirror**, the main light-collecting surface. The primary mirror then reflects the light to the **secondary mirror**, which is suspended above the primary in the telescope tube. From there, the light reflects off the secondary mirror, through a hole in the primary mirror, and onto the detectors and instruments sitting at the telescope's **focal point**.



Diagrammatic view of light's path inside the Hubble Space Telescope. *Image: Hubble/NASA.*

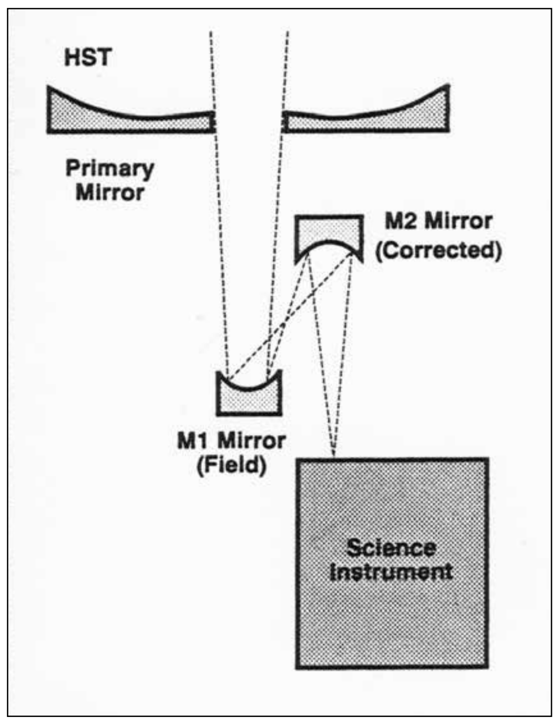
Hubble's Mirror and the Flaw

Hubble's primary mirror was made from a single block of glass, chosen for its ability to perform well at super-cold temperatures. To make the glass reflective, it was coated with a thin layer of aluminum and magnesium fluoride to make it possible to reflect ultraviolet, visible, and near-infrared light well. But before the coating could be applied, the glass needed to be polished to the correct shape.

A company called Perkin-Elmer was commissioned by NASA to shape the surface of Hubble's primary mirror. When polishing a telescope mirror, a special instrument is used to test and measure the curved shape. Unfortunately, in Hubble's case, this instrument was off in its measurement by approximately 1 millimeter. This error caused the mirror to be slightly the wrong shape. While this may not sound critical, it was enough to push the images just out of focus. Because this error was not caught on the ground, it wasn't detected until the first images started coming in.

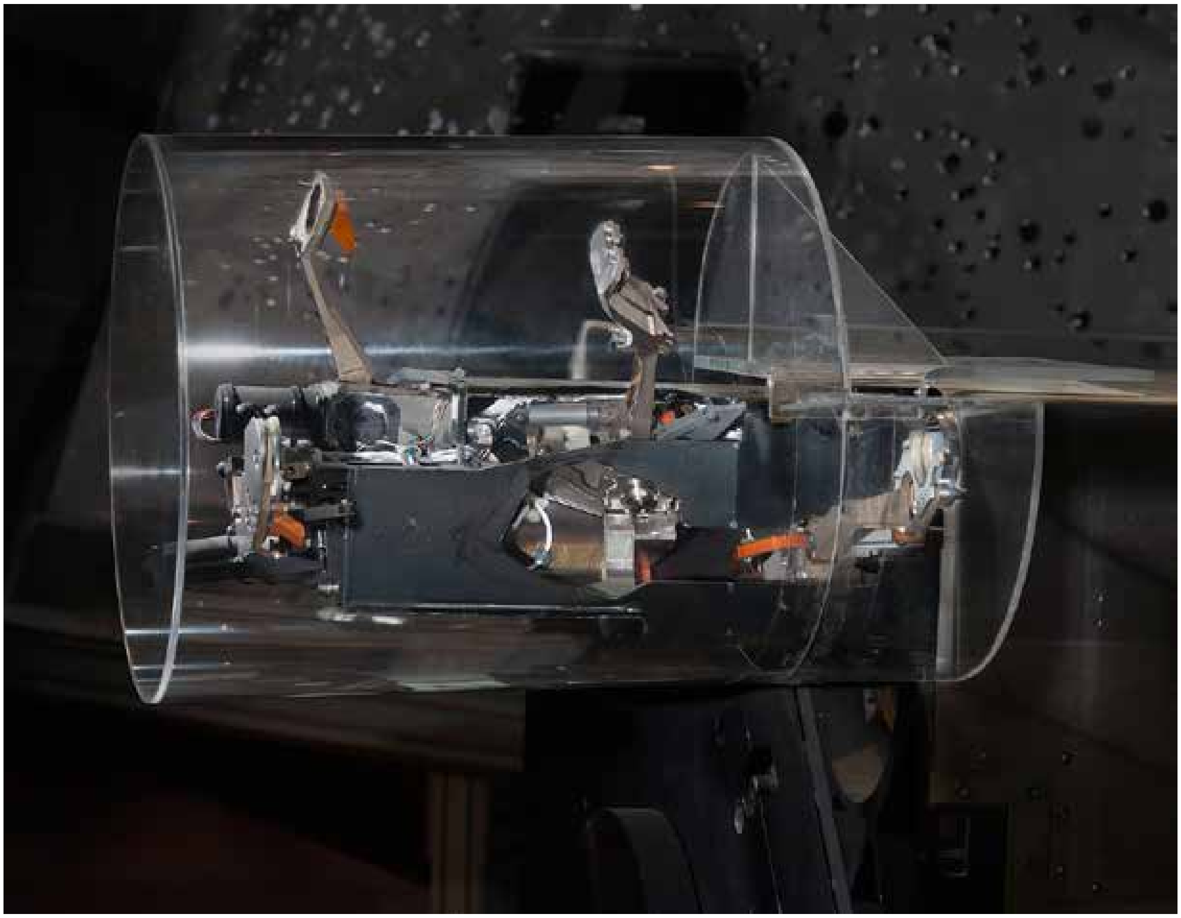
COSTAR: Engineering a Fix

Once it became apparent there was a problem with Hubble's optics, engineers had to design a way to compensate. The mirror itself could not be replaced without returning Hubble to Earth, which would have been too expensive. In order to fix the problem in space, engineers came up with a solution known as **COSTAR** (Corrective Optics Space Telescope Axial Replacement). Because Hubble intentionally had places where instruments could be upgraded and repaired within the structure, COSTAR was designed as a package of small mirrors on an extendable arm. When this arm was deployed, the mirrors would intercept the light being reflected from the secondary mirror before it reached the other instruments and detectors. These tiny mirrors were curved just enough to correct for the blurring caused by the flaw, allowing the images finally picked up by the detectors to be just as clear as originally expected.



Path of light using the additional mirrors provided by COSTAR. Note the two mirrors that intercept the light before finally reflecting it to the science instrument. *Image: NASA/Jeffrey Hoffman.*

COSTAR provided corrective optics for most of Hubble's instruments. Other instruments, such as the Wide Field and Planetary Camera 2 (**WFPC2**), had their own corrective optics built in and replaced their older counterparts on the series of servicing shuttle missions. With upgrades like these, COSTAR slowly became obsolete. In 2009, during the last servicing mission to Hubble, COSTAR was removed entirely and returned to Earth. It is now on display in the National Air and Space Museum in Washington, D.C.



COSTAR today in the National Air and Space Museum. *Image: National Air and Space Museum/Eric Long.*

Servicing Mission 1

Servicing Mission 1, officially known as STS-61, was the shuttle mission during which astronauts delivered and installed COSTAR, as well as updated other equipment, such as WFPC2. It launched on the space shuttle *Endeavour* on December 2, 1993. Considered a very ambitious mission, the timeline consisted of five spacewalks over five days.

The Servicing Mission 1 crew consisted of:

Richard Covey, Mission Commander
Kenneth Bowersox , Pilot
Story Musgrave, Payload Commander
Kathryn Thornton, Mission Specialist
Claude Nicollier, Mission Specialist
Jeffrey Hoffman, Mission Specialist
Thomas Akers, Mission Specialist

The astronauts of Servicing Mission 1. *Image: NASA.*

Over the course of those five spacewalks, Thornton, Hoffman, Musgrave, and Akers performed a variety of tasks, including replacing the telescope's gyroscopes, solar panels, and magnetometers. At the end of the mission, the crew released Hubble from the shuttle's cargo hold, and returned to Earth on December 13, 1993. Within a month, it was announced that the fix to Hubble's optics had been successful.

Servicing Misson 2

Also called STS-82, this mission was launched aboard the space shuttle *Discovery* on February 11, 1997. As well as general equipment upgrades, this mission also replaced the High Resolution Spectrograph with the Space Telescope Instrument Spectrograph (STIS) and replaced the Faint Object Spectrograph with the Near Infrared Camera and Multi-Object Spectrometer (NICMOS).

Servicing Mission 3a

Also called STS-103, this mission launched aboard the space shuttle *Discovery* on December 20, 1999. Servicing Mission 3 was broken up into two separate missions when Hubble was suddenly rendered inoperable by gyroscope failures in late 1999. Hubble possesses six gyroscopes and requires three working ones to function. In 1999, a fourth gyroscope failed, leaving Hubble unable to reorient itself. Servicing Mission 3a was designed to get Hubble working again as soon as possible. The gyroscopes were replaced along with other upgrades, including the telescope's outer insulating blanket.

Servicing Mission 3b

Also called STS-109, this mission launched aboard the space shuttle *Columbia* on March 1, 2002. Along with other work, this mission replaced Hubble's solar panels, updated the NICMOS camera, and used *Columbia* to boost Hubble into a higher orbit. It also removed the last of Hubble's original instruments, the Faint Object Camera (FOC), and replaced it with the Advanced Camera for Surveys (ACS). The FOC was the last instrument for which COSTAR was providing corrective optics, as all subsequent instruments had their own corrective optics built in.

Servicing Mission 4

Also called STS-125, this mission was originally supposed to launch in 2005. When the shuttle fleet was grounded after the loss of *Columbia*, the necessity for another Hubble servicing mission was called into question. It was eventually decided to upgrade Hubble one final time, and STS-125 launched aboard the space shuttle *Atlantis* on May 11, 2009. Since it would be the final servicing mission, it was designed to get Hubble as up-to-date as possible. Among many upgrades, it repaired the ACS and STIS, replaced the Wide-Field Planetary Camera 2 (WFPC2) with the next iteration, the Wide-Field Planetary Camera 3 (WFPC3), and removed the COSTAR corrective optics package and replaced it with the Cosmic Origins Spectrograph (COS). These final updates were designed to keep Hubble functioning until at least 2018. Hubble was released for the final time on May 19, 2009.

Online Learning Tools

Below are links to external websites intended to provide access to further information about the Hubble Space Telescope.

COSTAR

airandspace.si.edu/explore-and-learn/multimedia/detail.cfm?id=2368
Close-up view of the COSTAR package, now on display at the National Air and Space Museum.

Hubble's Amazing Optics

hubblesite.org/the_telescope/nuts_.and._bolts/optics/
A breakdown of how Hubble's optics work.

Hubble Essentials: Quick Facts

hubblesite.org/the_telescope/hubble_essentials/quick_facts.php
A list of quick facts about the Hubble Space Telescope.

Hubble's Instruments: COSTAR

spacetelescope.org/about/general/instruments/costar/
A brief explanation of the COSTAR package.

The Science Instruments

hubblesite.org/the_telescope/nuts_.and._bolts/instruments/
A breakdown of some of the instruments aboard Hubble.

Glossary of Terms

COSTAR A collection of small mirrors on an extendable arm, designed to intercept and correct light reflected from Hubble's secondary mirror, before sending it to the instruments.

Focal point The point at which a telescope focuses incoming light. Generally, the focal point is also the location of the camera or other light detectors.

Primary mirror The largest light-collecting surface on a telescope. In most reflecting telescopes, like Hubble, the primary mirror will reflect light to a small secondary mirror. Therefore the primary mirror is generally curved to best focus incoming light onto the secondary mirror.

Secondary mirror A smaller mirror that receives light reflected from the primary mirror and reflects it in turn onto a telescope's detection instruments.

WFPC2 The Wide Field and Planetary Camera 2 was the successor to the original Wide Field and Planetary Camera and was replaced on Servicing Mission 1 in 1993. It was designed to take images primarily in visible light and was one of the most-used instruments on board Hubble before it was replaced by WFPC3 in 2009.

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