LESSON 16

Bending Mirrors

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION/PHOTOGRAPH BY CHARLES CONRAD JR.

Curved reflective surfaces, like the one in this astronaut's helmet, produce some strange effects.

INTRODUCTION

So far, your investigations of mirrors have involved flat (plane) mirrors. What if you could somehow bend your mirror? Would it reflect light the same way? Would light striking it follow the law of reflection? How would the *way* and *amount* it was bent affect the way it reflects light? What sort of images would curved mirrors produce? In this lesson, you will bend a mirror and investigate how curved mirrors interact with light. As you progress through your investigation, you may find the answers to some of these questions.

OBJECTIVES FOR THIS LESSON

Observe how images seen in normal flat mirrors change as the shape of a mirror is changed from flat to curved.

Describe the images you observe in curved mirrors.

Identify types of curved mirrors.

Investigate how light rays interact with curved mirrors.

Discuss how the law of reflection can be applied to curved mirrors.

Read about and discuss some uses of curved mirrors.

Getting Started

1. One member of your group should collect the plastic box of materials. Each pair should remove a mirror from the box. Take care not to scratch the mirror or get fingerprints on it.

2. Bend the mirror in different ways for a few minutes. This plastic mirror is flexible, but do not bend it too much or it may break.

   What effect does bending the mirror have on the image that appears in the mirror?

3. Experiment with making different images with your mirror. Here are some suggestions:

   - Try making an image of your face that is upside down.
   - Try making an image of your face that is shorter and fatter than normal.
   - Try making an image of your face that is taller and thinner than normal.

4. Think about what you did to the mirror or how you changed your position in relation to the mirror to make these different images. Discuss with the class how you made these and any other interesting images. Then read "Types of Curved Mirrors."

MATERIALS FOR LESSON 16

For you and your lab partner

- 1 flexible plastic mirror
- 1 wide-slit ray box mask
- 1 no-slit ray box mask
- 1 white screen
- 1 comb

For your group

- 1 ray box
- 1 ray box lid
- 1 60-W clear halogen lightbulb
- 1 extension cord
- 1 bulb holder

Inquiry 16.1
Looking at Convex Mirrors

PROCEDURE

1. Use your flexible mirror to make a convex mirror by bending the top and the bottom of the mirror away from you. Record your observations and responses for this lesson in your science notebook.

A. Describe how the appearance of your reflection changes as you slowly bend the mirror.

2. Hold the mirror in this shape and move it backward and forward in front of your face.

B. Does the image change in any way?

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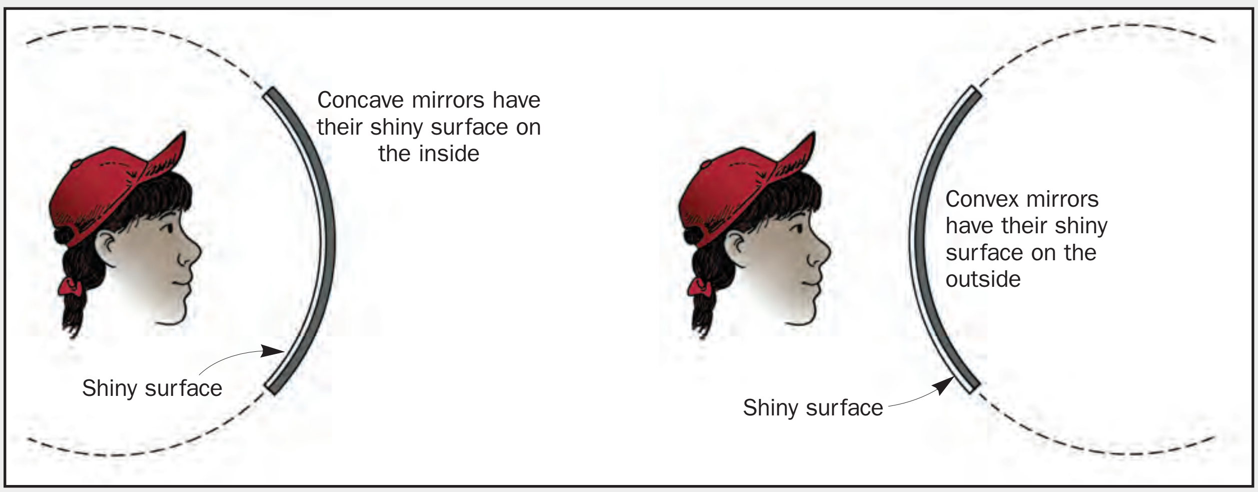
Why is the following statement often written on rearview mirrors: "Objects in the mirror are closer than they appear"? What type of mirrors are they?

Types of Curved Mirrors



There are two main types of curved mirrors. Concave mirrors have a shiny surface that bends toward you—like the inside of a shiny sphere. Convex mirrors have a shiny surface that bends away from you—like the outside of a shiny sphere. Can you remember where else in this module you have seen convex and concave mirrors?

SAFETY TIP

Do not touch the lightbulb. It gets hot and may burn your fingers.

3. Set up the ray box and white screen so that each pair in your group can work at opposite ends of the ray box. Attach the wide-slit ray box mask to the end where you are working and place the comb in front of the wide slit as shown in Figure 16.1. (Make sure that the comb is placed in front of the wide slit so that it produces multiple rays.)

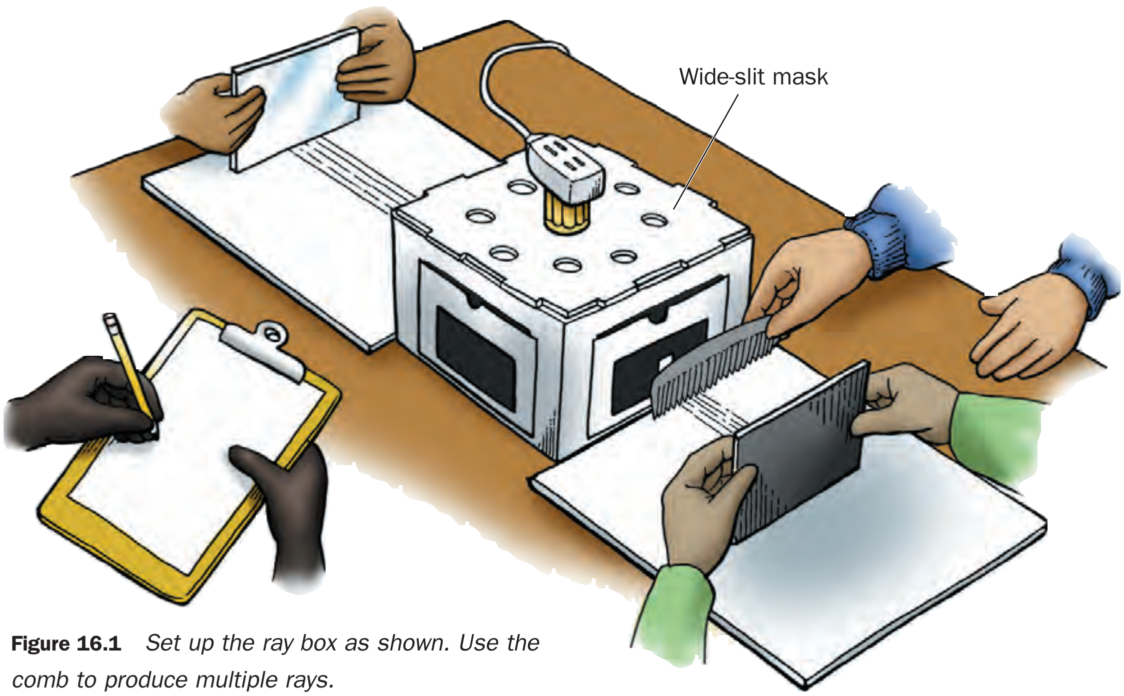


Figure 16.1 *Set up the ray box as shown. Use the comb to produce multiple rays.*

4. Place the mirror in position and then slowly bend its sides away from the comb so that it forms a convex mirror. Make sure the multiple rays fall on the mirror.

C. What do you observe as you bend the mirror?

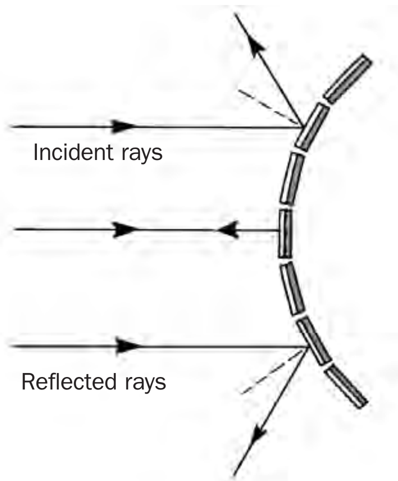
D. Draw a diagram to show what happens when rays from the ray box strike a convex mirror.

EXPLAINING REFLECTION FROM A CONVEX MIRROR

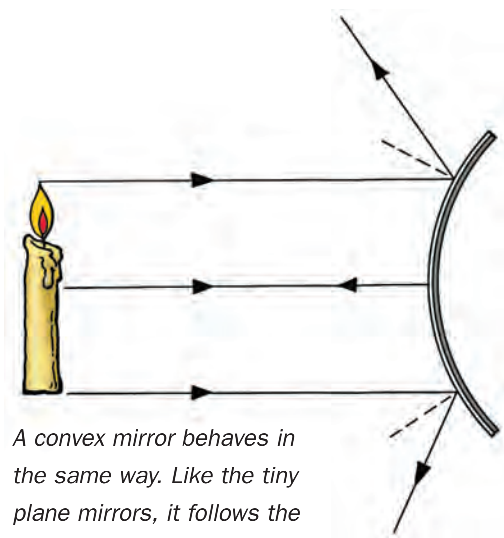
To understand what happens to light when it strikes a convex mirror, it is useful to think of a convex mirror as being a series of tiny plane mirrors connected together, as shown in the top diagram below.

As a ray strikes one of these tiny mirrors, it is reflected. Its angle of incidence equals the angle of reflection. However, because each mirror is tilted differently, the reflected rays go off in different directions. The reflected rays spread out—that is, they diverge.

Where is the image formed in a convex mirror? Use the photograph below and the diagram (bottom left) to decide whether the image is in front of or behind the mirror. How does the image shown in the photographed mirror compare with the object itself? Is it right-side up (upright) or upside down (inverted)? Is it bigger or smaller than the object?



Think of a convex mirror as being made up of many tiny plane mirrors. Each ray that strikes one of these mirrors follows the same law of reflection you studied in Lesson 15.



A convex mirror behaves in the same way. Like the tiny plane mirrors, it follows the law of reflection.

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Is the image in this convex mirror inverted or upright? Bigger or smaller than the object?

Inquiry 16.2
Looking at Concave Mirrors

PROCEDURE

1. Using the materials provided, design a procedure with your partner to investigate reflection from a concave mirror.

   A. Describe your procedure, using diagrams and words.

   B. Record your results and observations. Use diagrams where appropriate.

   C. Write a paragraph that explains how light is reflected from a concave mirror.

2. Discuss how you can use your observations to help you to explain the image(s) you obtained using a concave mirror.

   D. Use words and/or diagrams to record your explanation for the images you obtain.

3. Read "Explaining Reflection From a Concave Mirror."

SAFETY TIP

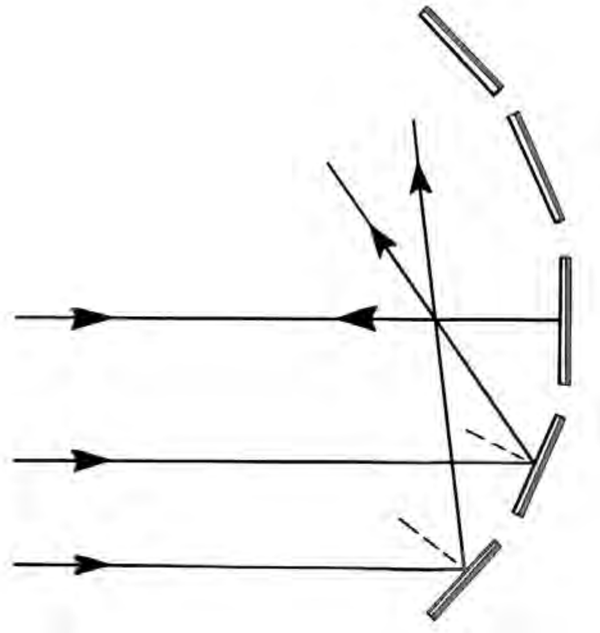
Turn off the ray box immediately after you finish using it. Allow the ray box to cool.

EXPLAINING REFLECTION FROM A CONCAVE MIRROR

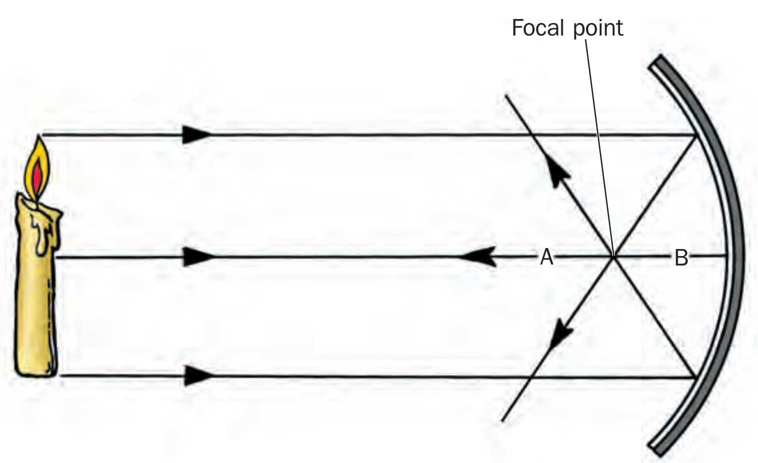
As you have observed, light rays striking the surface of a concave mirror are reflected inward. They are said to converge. Reflection from the surface of a concave mirror, like that from a convex mirror, can be explained by thinking of the surface of the concave mirror as a series of tiny plane mirrors. The angle of incidence equals the angle of reflection of rays for each of these imaginary plane mirrors.

Rays reflected from a concave mirror cross over one another. The point where they cross over is called the focal point of the mirror. This is called the focal point because parallel rays striking the mirror meet at this point—that is, they are focused at that point. The distance from the focal point to the reflective surface of the mirror is called the focal length of the mirror.

What you see in a mirror depends on your position in relation to the focal point. Look at the diagram below. What would be the orientation of the image of the candle—which way would be up—if you were looking at the mirror from point A? What would be the orientation of the image of the candle if you were looking at the mirror from point B?



Reflection from a concave mirror can also be thought of as reflection from a series of tiny plane mirrors. With concave mirrors, as in all forms of reflection, the angle of the incident ray is equal to the angle of the reflected ray.



Predict the orientation of the image of the candle if you were looking at it from point A and then from point B.

The images you observe in a concave mirror depend on the distance of the object from the mirror. Some of these images are upright and others are inverted. Can you guess the point at which the images turn over? Makeup and shaving mirrors are concave mirrors. When you stand close to these mirrors, they provide a magnified image of your face—that is, the image of your face is bigger than it would be in a plane mirror in the same position.

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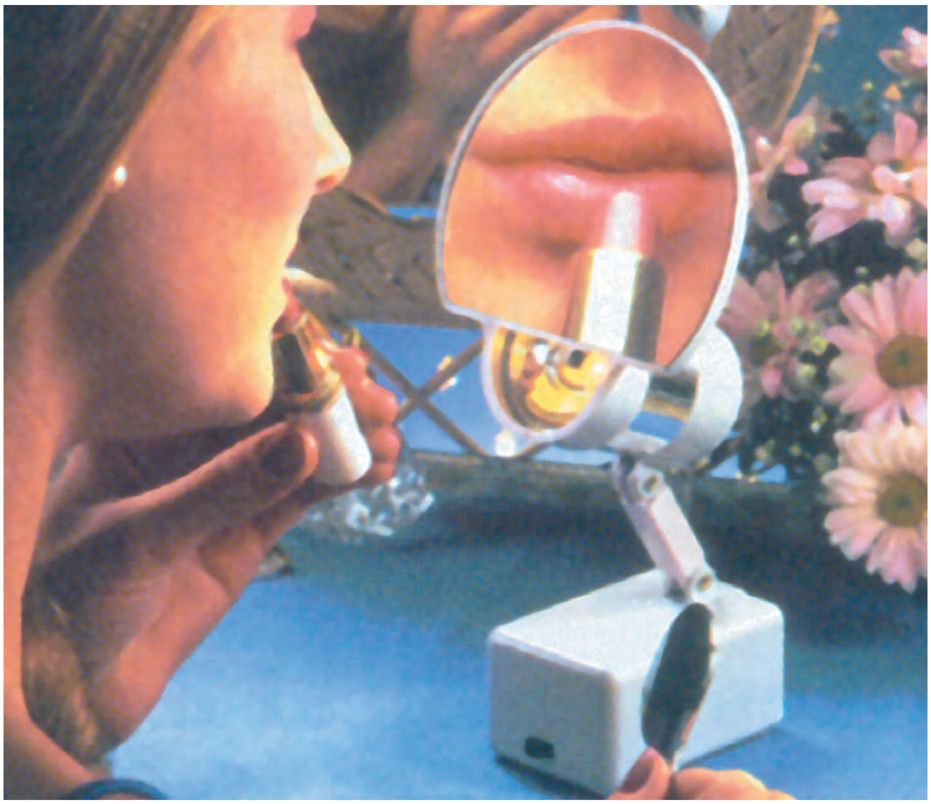
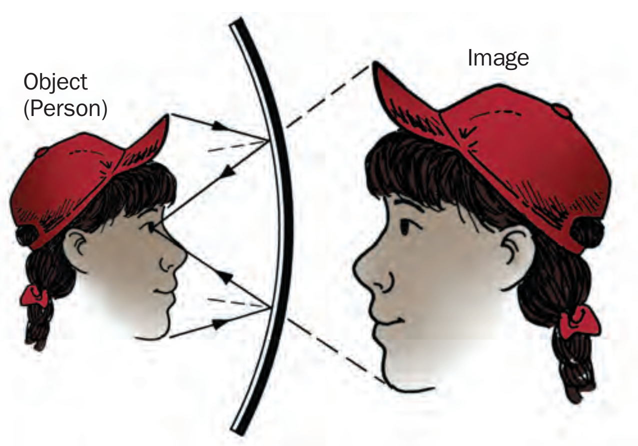


Makeup mirrors are concave. When your face is close to the mirror, it appears magnified and upright. The image of your face is a virtual image.



When an object is within the focal length of a concave mirror, its image is magnified, upright, and virtual. Why is it a virtual image?

REFLECTING ON WHAT YOU'VE DONE

1. Discuss with your group what you have discovered about curved mirrors. Make notes during the discussion.

A. Write a paragraph summarizing what you have learned about curved mirrors.

2. Look at the photograph of a fairground mirror. Where is the surface of the mirror convex? Where is the surface of the mirror concave? Share your ideas with the class.

3. Read "Search and Reflect." Be prepared to explain how mirrors are used as reflectors.

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Mirrors can have concave and convex surfaces, like this "trick" fairground mirror. Looking at the image, can you tell where the surface of the mirror is concave and where the surface is convex?

Search and Reflect

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How were the lives of the German World War II pilots put at risk by concave mirrors?

Reflectors at War

The year is 1940. It's a quiet, very dark night in the city of London, England. Hardly a light can be seen. Thick curtains cover every window. No street lamps are on. Even the few cars on the street have their headlights partly covered. The city is blacked out—because here, light can bring a rain of death. Suddenly, a wail of sirens and the pounding of distant guns shatter the peace. The city of London has become a battlefield. Nazi planes drop their deadly bombs on the city. Another night of the London Blitz has begun.

Light is both friend and foe in this battle. The city tries to hide under its cloak of darkness from the searching eyes of enemy bombers. But some of the heavy, slow German planes, loaded with tons of bombs, find their targets anyway. The city lights up first with the flames of burning buildings, which act as beacons for the German pilots. Then beams of light penetrate upward through the smoke and into the night sky. From the ground, these giant searchlights scan the skies for enemy planes. A searchlight beam picks out one bomber. Before it can drop its deadly cargo of bombs onto the densely populated city, the enemy plane is exposed to merciless gunfire from below.

Searchlights were an important weapon in World War II. Their powerful lamps were focused into a beam of light that could penetrate miles up into the sky. Like a giant flashlight, a concave mirror placed behind the lamp focused the beam.

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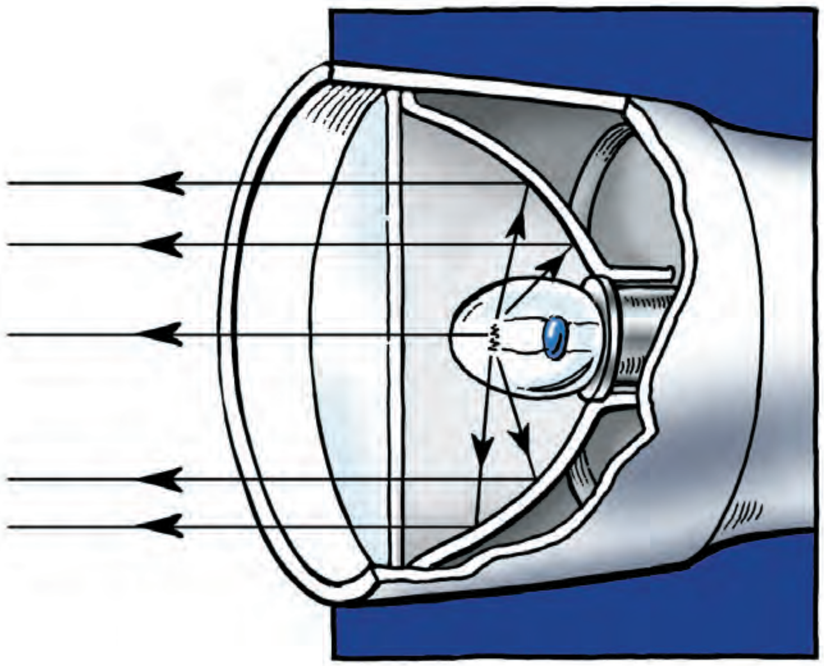
Why was there a concave mirror in this searchlight?

Reflectors Everywhere

Concave reflectors also play an important role in peacetime. Any light designed to provide intense lighting on a limited area contains concave reflectors. By placing the light source (perhaps a lightbulb, a kerosene or gas lamp, or a candle) at the focal point of the concave mirror, light that would have traveled in the opposite direction is reflected forward, making a powerful, highly directional beam of light.

Reflectors are the most common use of concave mirrors. Look at the following pictures of reflectors. Can you think of other places they are used? ☐



Both flashlights and searchlights contain reflectors. These are concave mirrors that focus the light into a beam.

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Searchlights such as these were used to detect night-flying enemy aircraft.

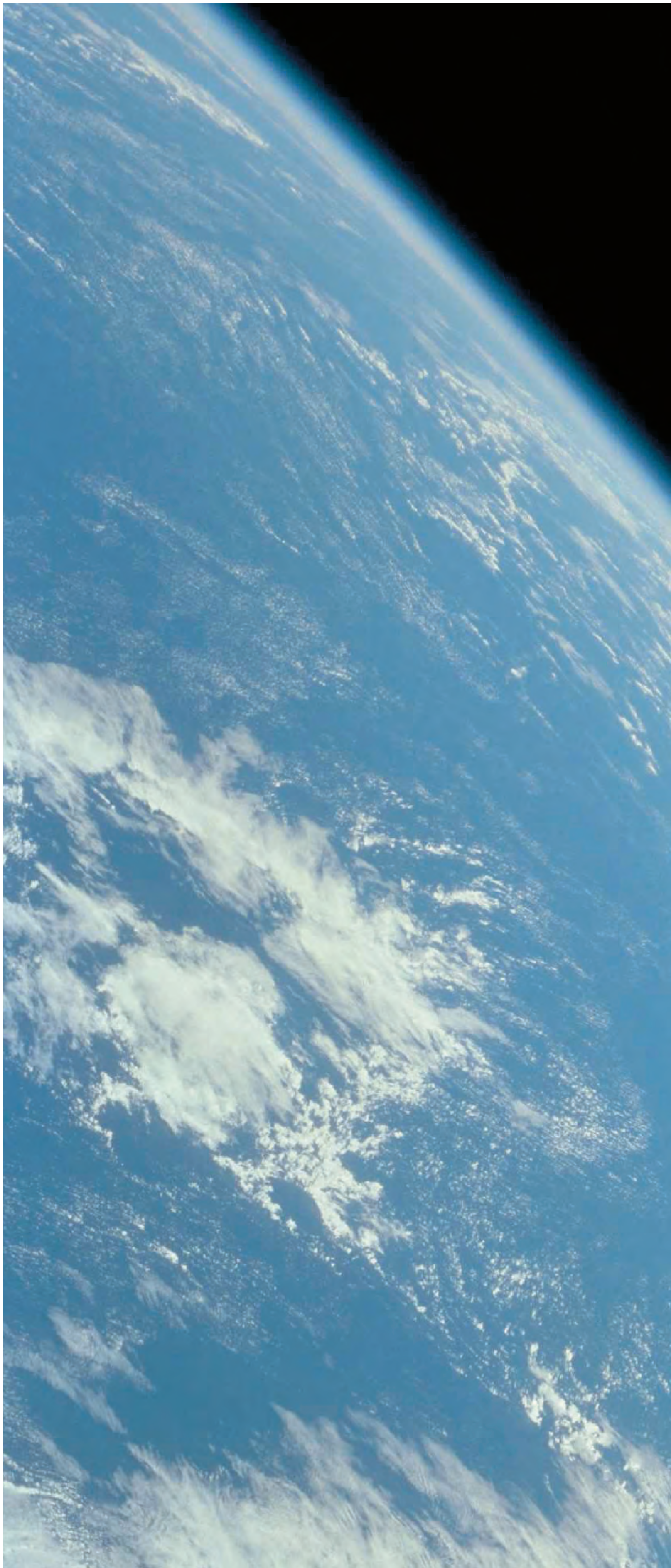
Reflectors are used in headlights of trains, cars, and planes.

Sometimes the reflector is included inside a lightbulb.

Sometimes the reflector takes the form of a reflective lamp shade.

Some types of electromagnetic radiation don’t require shiny mirrors. These giant reflectors collect radio waves from distant stars and galaxies. The reflector focuses the waves onto a receiver at the focal point of the reflector. This reversed use of reflection increases the telescope’s sensitivity to faint radio signals.

The Trouble With Hubble



FIRST LIGHT: MAY 20, 1990

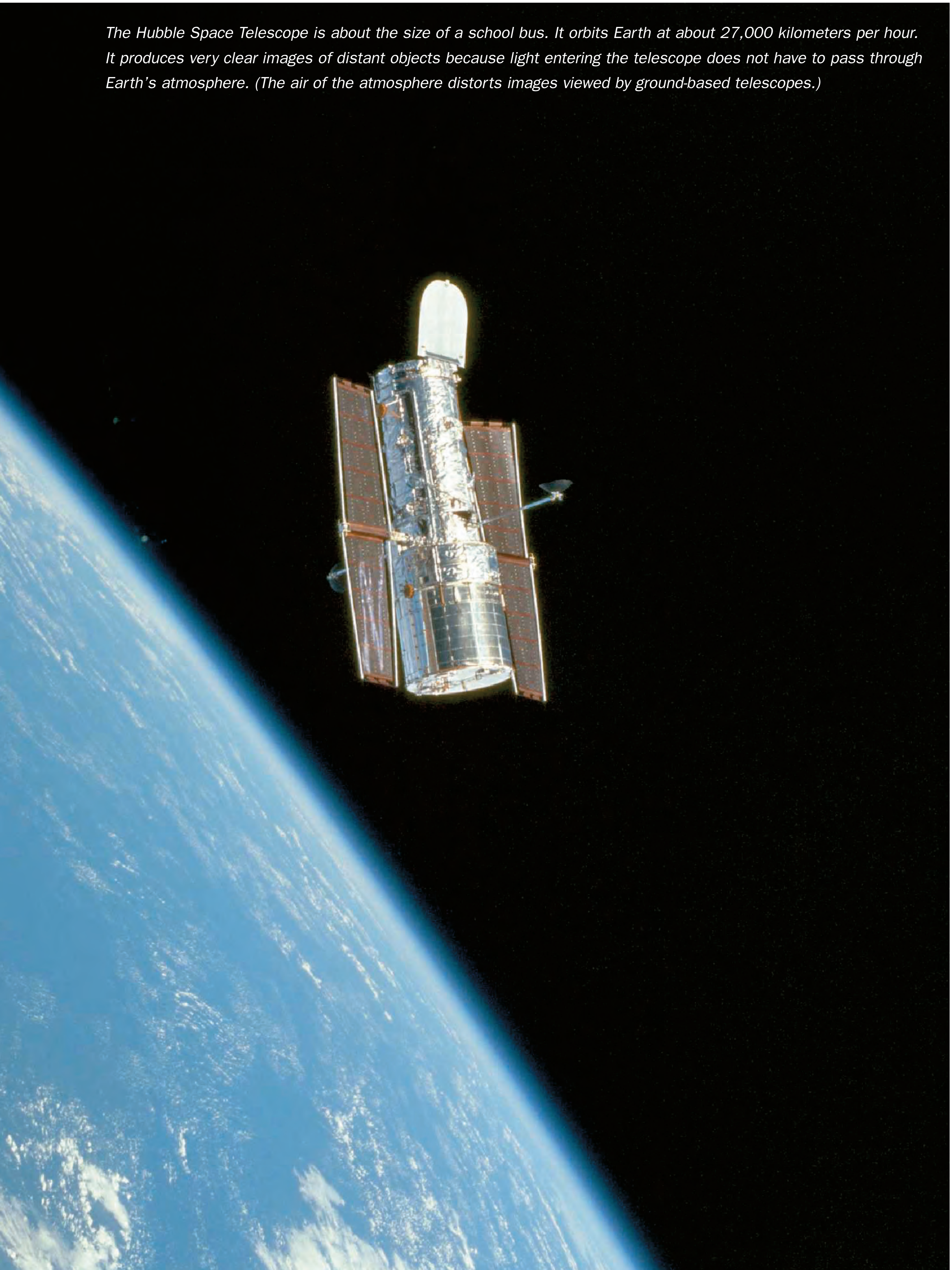
Astronomers around the world held their breath as a drama unfolded 600 kilometers above Earth. The Hubble Space Telescope was about to start working. Scientists had dreamed for decades of being able to see the universe without having to peer through Earth's atmosphere. Now the telescope moved to capture light that left a distant star cluster 1300 years ago. The $1.5 billion telescope was about to get its first test. Astronomers call this test "first light."

As the telescope opened its "eye," a new tool became available to astronomers. They had high hopes. Would Hubble help them unravel many secrets of the universe?

Does Hubble Need Glasses?

With a huge project such as Hubble, nobody expected everything to be perfect. Its designers expected it to go through a shakedown period during which scientists could solve minor problems. And there were problems. For example, the solar panels, which supply the telescope with electricity from sunlight, were

The Hubble Space Telescope is about the size of a school bus. It orbits Earth at about 27,000 kilometers per hour. It produces very clear images of distant objects because light entering the telescope does not have to pass through Earth's atmosphere. (The air of the atmosphere distorts images viewed by ground-based telescopes.)



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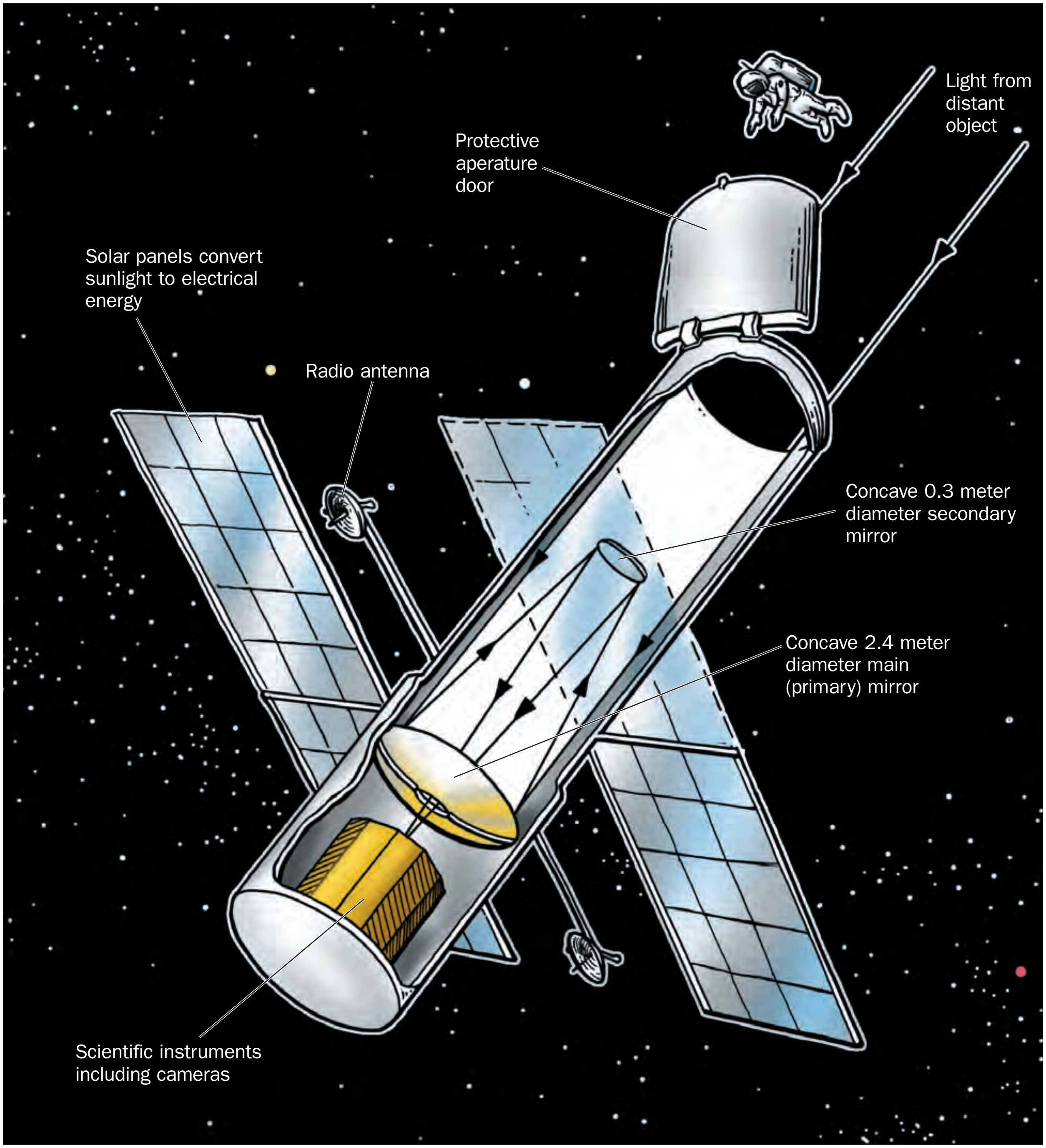

A look inside the Hubble Space Telescope provides a picture of how it works. What is the role of the giant primary concave mirror?

vibrating. This vibration made the telescope shake slightly. But there was a more serious problem. Images from stars should have been clear pinpoints of light. Instead, these images were blurred and surrounded by a halo of light. It was as if Hubble needed glasses. What was causing this problem?

The Hubble Space Telescope is a reflecting telescope. A giant concave mirror collects light and focuses it onto a camera. The mirror must have exactly the right curve to work properly. Even the tiniest error in its curve would put the telescope out of focus. That's exactly what was wrong with Hubble. When the mirror was ground, it was made 0.0002 centimeters too flat at its edges. This small mistake (less than 1/50 of the width of a human hair) made the stars look blurred. How could this problem be fixed?

Scientists and engineers thought of several ways to solve the problem. They could use

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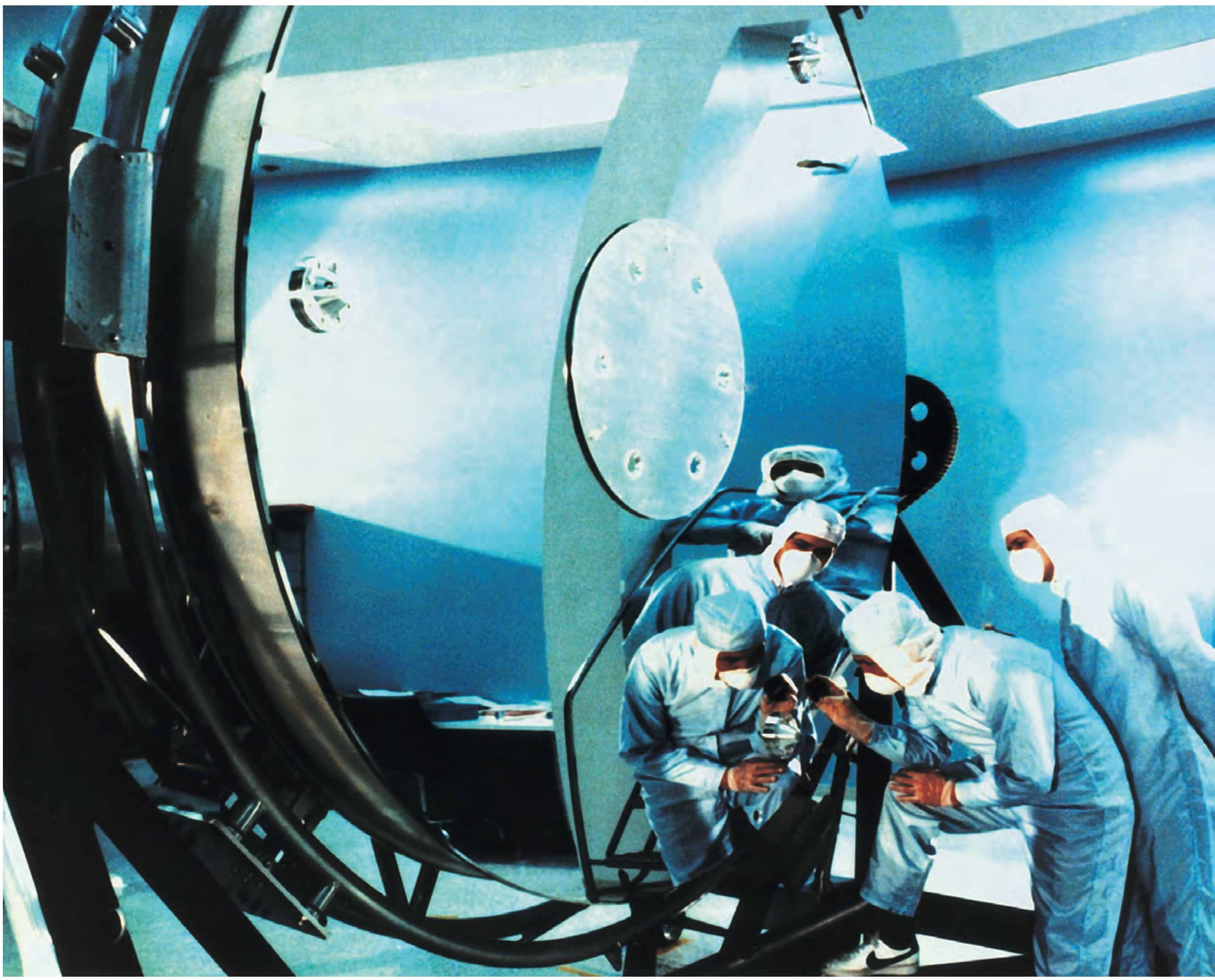
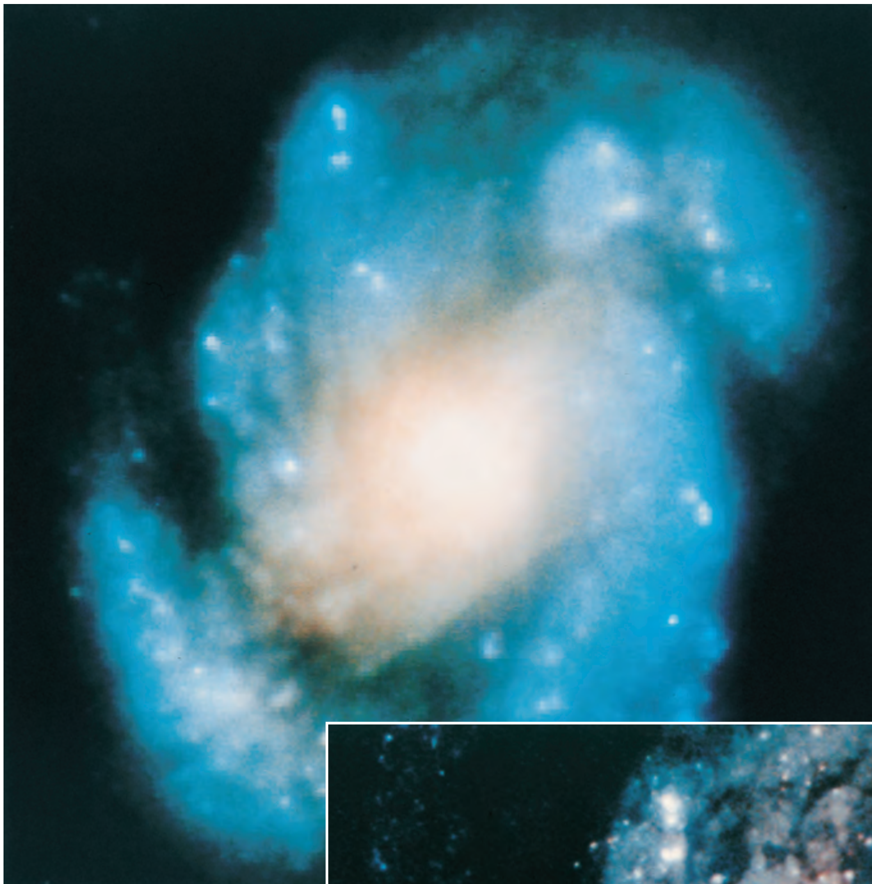


This mirror being inspected is a primary concave mirror of the Hubble Space Telescope. Light that strikes it is reflected into an electronic camera. The image that is detected is transmitted to Earth.



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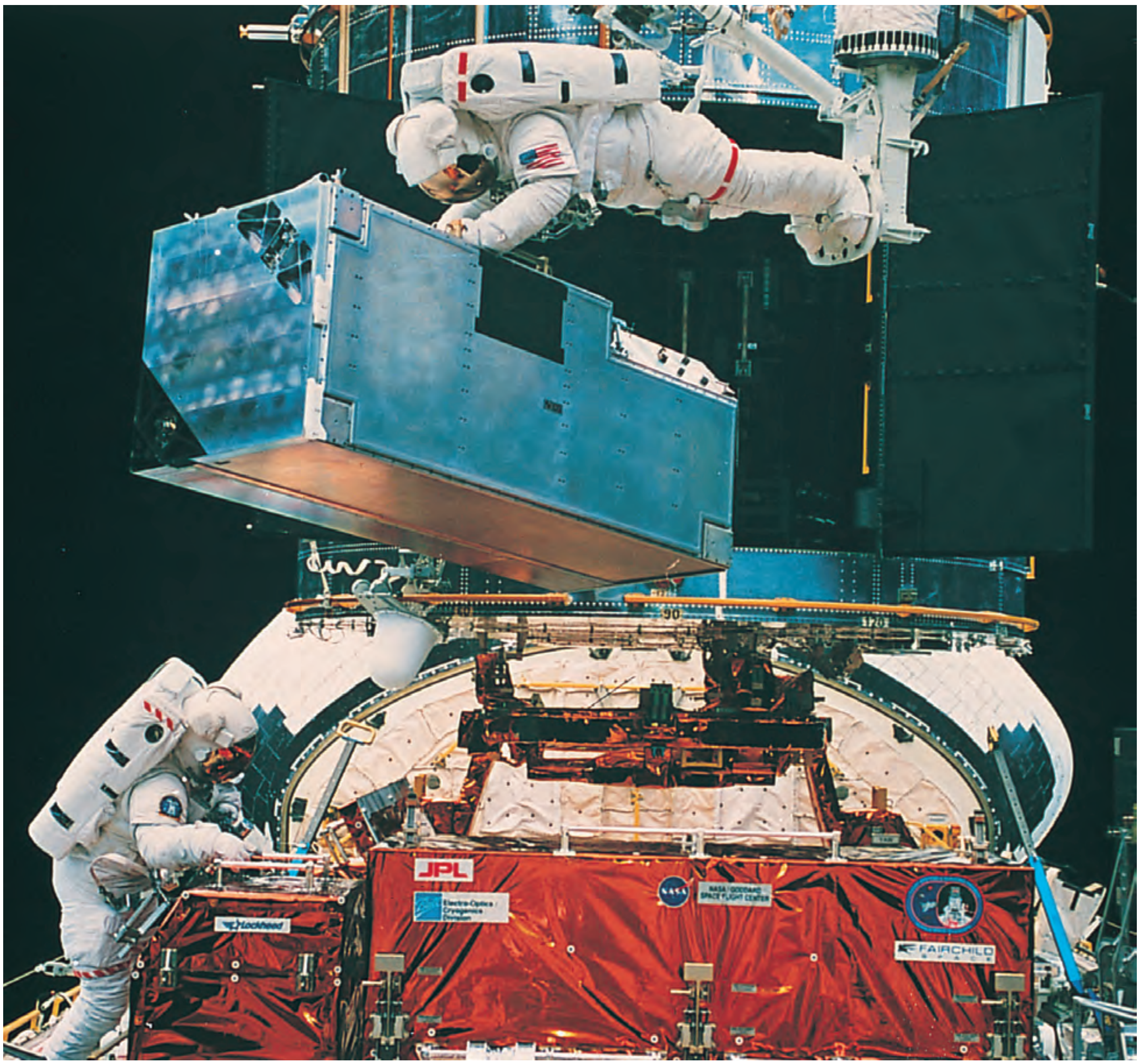
Very small—microscopic, in fact—mistakes in measurements led to errors in the manufacture of the telescope's mirror. Making the mirror too flat at its edges produced a blurring of the image. These pictures show what the same galaxy looked like through the telescope before and after it was repaired.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION/SPACE TELESCOPE SCIENCE INSTITUTE computers to improve the blurred image. The image would be clearer, but some information would be lost in this process. A better idea would be to add lenses to the telescope. The lenses would correct the telescope's "vision," much like glasses correct human vision.

Second Light

The Hubble Space Telescope had been carefully designed. Engineers had predicted it would need maintenance and upgrading while it was still in orbit. However, nobody had predicted such a major repair!

More than 3 years after Hubble was launched, the crew aboard the space orbiter *Endeavor* docked with the space telescope. They had been thoroughly trained for the most complex space repair mission in history. Working in shifts over the next few days, they spent 35 hours in space. They added a new camera and a



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Astronaut Kathryn Thornton unloads the COSTAR *(Corrective Optics Space Telescope Axial Replacement) module from the* Endeavor *orbiter.*

The Cone Nebula is a giant finger of gas and dust about 7 light-years long. The light that made this picture left the nebula 2500 years ago and was captured by recently upgraded cameras in the Hubble Space Telescope.

lens module as big as a telephone booth (called COSTAR) to correct Hubble's faulty vision.

Mission completed, they returned to Earth. Would the space telescope work to its full potential? Had the repairs worked? When the computer screen came on, the astronomers saw pinpoints of light—no halos, just clear stars. The eye in space could now see clearly—Hubble's exploration of the universe could continue.

With the experience of the repair mission firmly under their belts, NASA astronauts gained confidence at working on the space telescope. Scientists thought of new ways to improve the eye in space. A recent space mission to upgrade Hubble's cameras allows the space telescope to send even more spectacular pictures back to Earth. The eye in space sees more clearly than ever. As the Hubble Space Telescope explores the universe, it continues to provide all of us back on Earth with a continuing adventure in space. □

The Flying Telescope

The bigger and higher the telescope, the better. But putting a telescope into space is an expensive business. Why not have one fly first class on its own private jumbo jet instead? Enter SOFIA—not a person, but a telescope. SOFIA stands for Stratospheric Observatory For Infrared Astronomy. SOFIA is designed to look at astronomical objects by capturing the infrared they emit. SOFIA contains a telescope bigger than Hubble. It is designed to cruise at about 800 kilometers per hour (500 miles per hour) 15,000 meters (49,213 feet) above Earth's surface. This puts it above 99 percent of the infrared-absorbing water vapor found in Earth's atmosphere.

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The SOFIA telescope is mounted in a plane and focuses on infrared radiation.