

TELESCOPES

SUPER VIEWS OF SPACE

TELESCOPE CONCEPTS

1 Telescopes collect and detect light, like giant eyes

2 Telescopes' advantages over eyes include:

- larger light-collecting areas
- collecting light for longer periods of time
- the ability to detect wavelengths of light invisible to humans

3 Different telescopes collect different wavelengths of light

4 Telescopes in space avoid interference from the Earth's atmosphere

Find out how telescopes are used to collect light.
Explore these concepts further using the recommended resources mentioned in this reading selection.

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1

Telescopes collect and detect light, like giant eyes

Light is the only source of information astronomers have about stars, planets, nebulae, galaxies, and other distant objects in the Universe. Most of the light from these distant objects is too dim for the human eye to see, so astronomers use telescopes to collect that light. Telescopes can collect much more light than the human eye. They can also detect wavelengths of light the human eye cannot. Using telescopes, astronomers can observe extremely faint light sources they could not see any other way.

On a clear, dark night, you can see thousands of stars. But these are just a tiny, tiny fraction of the hundreds of billions of stars in the Milky Way galaxy — and the Milky Way Galaxy is but one of about 100 billion galaxies in the observable Universe. Only three of these galaxies are visible with the unaided eye; the rest are too faint to see. Without telescopes, we would not know most of these galaxies even existed.

More than Magnification

Many people think of telescopes as giant magnifying glasses. Telescopes can be used to magnify things, but this is not their main purpose in astronomy. The value of telescopes lies not in how much they magnify, but in how much light they collect. Magnification and light-collecting ability are two different things.

Imagine you have two pictures, one dark and blurry, and the other clear and bright. If you magnified the dark, blurry picture, it would still be dark and blurry. Magnifying this picture would not make it any clearer; it would just make it bigger. Magnification cannot add any information that is not already there. The only way to collect more information is to collect more light.

In telescopes, one large lens or mirror is used to collect and focus light, and a separate lens is used to magnify the image the viewer sees. You can attach a variety of magnifying lenses, or eyepieces, to any telescope to magnify its image different amounts. But no matter how much you magnify it, the quality of the image is limited by how much light the telescope collects. Suppose you attached equivalent eyepieces to a small telescope and a large telescope. Their images would be magnified by the same amount, but the larger telescope would provide a brighter image because it collected more light.

For much astronomy research, magnification is completely irrelevant. When studying starlight with a spectroscope, for example, astronomers are interested in learning precisely what wavelengths of light the star is emitting. This information can tell them a great deal about the star, including its chemical composition, its temperature, and even what direction it is moving and how fast. The more light the telescope collects, the clearer the spectral lines will be on the spectroscope. But no image of the star is even created, so there is nothing to magnify.



Holes in Your Eyes

The black pupil in the center of your eye is actually just a hole covered by a clear, protective coating. What looks black is really the darkness inside the eye.

How Telescopes Are Like Eyes

Telescopes and eyes are both tools for collecting and detecting light. In fact, telescopes can be thought of as bigger, more powerful eyes. Eyes have an opening called the pupil where the light enters; a lens to focus the light; and a retina in the back to detect the light. Telescopes also have an opening to let in light; a lens or mirror to focus the light; and a detector to receive and process the light.

In the eye, chemical reactions in the retina convert light into electrical signals, which are processed by the brain. In telescopes, several different kinds of light detectors are used. Some telescopes contain electronic devices that convert light into electrical signals that can be analyzed and stored by a computer. In other telescopes, the light is focused onto photographic film, where the information is recorded as a photograph. In simple backyard telescopes, the light is focused onto the eye of the person looking through the telescope. In this case, the telescope's light detector is a human eye.

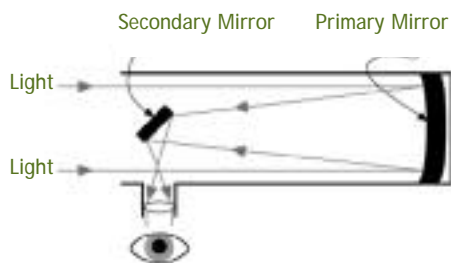
When you look through a telescope, all of the light that enters eventually reaches the back of your eye. Hundreds of times more light enters a small telescope than would normally enter your eye because the telescope's opening (also known as its "aperture") is much bigger than your pupil. The telescope's lens or mirror focuses all of this light so that it fits through your pupil. This is why telescopes let you see objects that do not give off enough light to see by unaided eye alone.



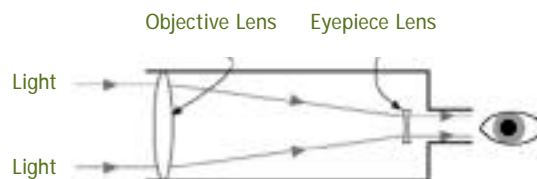
Try this Resource!

Focal Point demonstrates how the primary mirror of a reflecting telescope reflects light to a focal point. This resource is available at https://www.amnh.org/content/download/1896/25293/file/du_u05_refracting.pdf

Reflecting Telescope



Refracting Telescope



2

Telescopes' advantages over eyes

Telescopes have several advantages over eyes, including larger light-collecting areas; collecting light for longer periods of time; and the ability to detect wavelengths of light invisible to humans.

Larger Light-Collecting Areas

When you move from a bright area into darkness, the pupil in your eye can expand from less than $\frac{1}{16}$ inch to more than $\frac{1}{8}$ inch in diameter — becoming sixteen times greater in area — in order to take in more light. Telescopes offer a way to expand the light-collecting area even further, in effect increasing the size of your pupil by hundreds or thousands of times. A simple backyard telescope with a 4-inch-diameter lens can capture 250 times more light than an eye with a $\frac{1}{8}$ -inch-wide pupil, and the Hubble Space Telescope's 94.5-inch mirror captures 143,000 times as much light as a $\frac{1}{8}$ -inch pupil.

Telescopes that capture radio waves look nothing like optical telescopes, but the surface area of the collector still determines how powerful the telescope is. Radio telescopes collect light in “dishes” that resemble satellite TV antennas. The wider the dish, the more powerful the telescope, because a wider dish can capture more light. The radio telescope at the Arecibo Observatory in Puerto Rico has a dish 1,000 feet wide!



Try this Resource!

Building a Simple Refracting Telescope explains how students can construct a simple and inexpensive refracting telescope. This resource is available at http://www.amnh.org/education/resources/rfl/pdf/du_u05_refracting.pdf



If you're visiting the Moveable Museum, you can see for yourselves how changing the size of the aperture where light enters a telescope can affect the brightness of the image. A telescope inside the Museum has an attachment that reduces the size of the aperture to let in less light. Visitors can add this attachment and see what happens when they look through the telescope.



What Lenses Do

Why do eyes and telescopes need lenses? If your eye had no lens, you would see just a big blur of light. The lens focuses the light spreading out from each point onto a single point on the back of your eye. This creates a clear, sharp image on your retina, instead of a blur of light. Telescopes also use lenses or mirrors to create sharp images, as well as to funnel the light onto a small detector.



Bigger Eyes See More

There are two basic kinds of telescopes: **reflectors** and **refractors**. Reflecting telescopes focus light by reflecting it off a mirror. Refracting telescopes focus light by refracting it through a lens. The amount of light a telescope takes in is determined by the size of the lens or mirror collecting the

light. The more surface area it has, the more light can fall on it. If someone mentions a “six-inch lens,” they are not talking about how thick it is, but its diameter. A “ten-foot telescope” is not a tube ten feet long—it is a telescope with a mirror or lens ten feet across!

Collecting Light for Longer Periods of Time

The light detectors in telescopes can gather light from a single source over a long period of time. In some cases, light collected over several hours is used to create a single image. This is something the human eye cannot do. The cells in your retina collect light for just a fraction of a second. Then they repeat the process, essentially taking a new picture about twenty times a second. This enables your eye to keep track of moving objects. If your eye did not constantly update its information about where things are, moving objects would become a blur.

When collecting light from faint objects such as distant galaxies, however, a twentieth of a second is not enough time for your eye to see anything at all, even if you are looking through a large telescope. Astronomers solve this problem by attaching special detectors to telescopes. This lets them point a telescope at a single object for minutes or even hours and combine all the light the camera receives into a single image. The resulting image reveals much more than a person could see with their eyes, even looking through the same telescope.

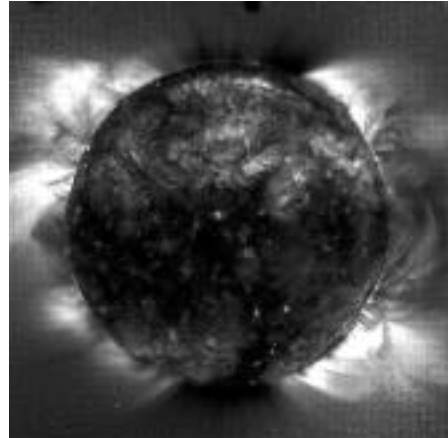
In the past, telescope detectors used photographic film. Though some still use film, most research telescopes now use electronic cameras that store digital images on a computer.

The electronic light detectors used in telescopes are called charged-coupled devices, or CCDs. CCD chips are made of thousands of tiny sensors that convert light into an electrical signal. The amount of electricity that passes through a given spot on the chip reveals how much light struck that point. Computers process the electrical information to make a digital image. The same technology is used in photocopiers, fax machines, video cameras, and bar code readers, all of which convert light signals into electrical signals.

The Ability to Detect Wavelengths of Light Invisible to Humans

Many telescopes are built to detect wavelengths of light your eyes cannot. Light from space comes in many wavelengths, most of which are invisible to the human eye—including gamma rays, X rays, ultraviolet and infrared light, microwaves, and radio waves. Whether visible or invisible, all light contains information about its source. So astronomers use special telescopes to detect wavelengths of light not visible to humans.

An image of the Sun's corona in ultraviolet light taken by the orbiting SOHO Extreme Ultraviolet Imaging Telescope.



SOHO-EIT/ESA-NASA

3

Different telescopes collect different wavelengths

The hotter an object is, the shorter the wavelengths of light it gives off. Because stars are so hot, much of the light they emit is in wavelengths too short for your eyes to see. Pictures of the Sun taken in ultraviolet or X-ray light, for instance, show hot, glowing jets of gas arching out of the Sun. These shapes are always there, but they cannot be seen in visible wavelengths.

Telescopes sensitive to different wavelengths of light are useful in observing different astronomical phenomena.

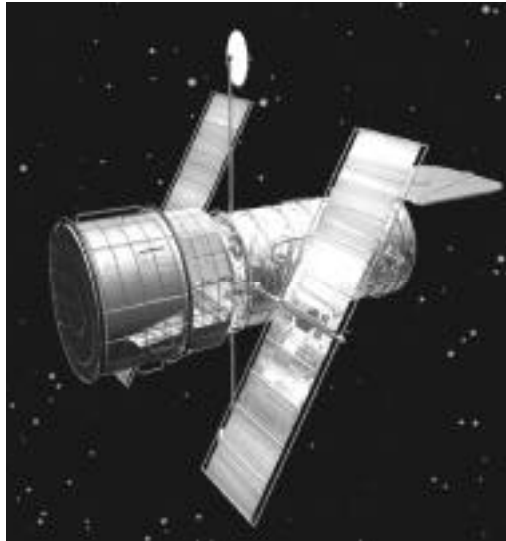
Gamma Ray Telescopes

Gamma rays have the shortest wavelength and contain the most energy of any form of light. They are believed to come from highly energetic processes such as collisions between two black holes, collisions between two neutron stars, or the collapse of hyperstars—giant stars even bigger than the ones that cause supernovas.

The design of a gamma-ray telescope is unique in that the telescope itself is one big detector without any lenses or mirrors. The wavelengths of gamma rays are so small that they pass easily through conventional lenses or mirrors.

X-ray Telescopes

X-ray telescopes are used to observe extremely hot sources, such as the gases around black holes. X-ray telescopes cannot focus X-ray light the same way that ordinary telescopes do, because X-rays go right through most mirrors. Some X-ray telescopes have special mirrors shaped like long, narrow tubes. As X-rays enter the tube, they graze the mirror just enough to reflect gently toward a detector instead of passing through the mirror.



Hubble Space Telescope.

Ultraviolet Telescopes

Ultraviolet (UV) light has shorter wavelengths than visible light. These waves come from very hot stars. Ultraviolet telescopes can also be used to observe the hot gases surrounding the Sun. UV telescopes appear very similar in design to visible light telescopes except they are equipped with specially designed detectors sensitive to UV light.

Visible Light Telescopes

Optical telescopes capture the same kind of light your eyes can see. They reveal how distant objects would look if we were closer to them. Most of the cosmic images we see in magazines and newspapers come from visible light telescopes. Visible light is also a good source of information about average-temperature stars like the Sun.

Infrared Telescopes

Infrared light has fairly long wavelengths that pass through clouds of dust better than light with shorter wavelengths. Infrared telescopes are used to observe objects surrounded by dust, such as young stars being born inside nebulae. Because all warm objects give off infrared light, infrared telescopes are chilled so that they won't detect their own glow. The lifespan of an infrared telescope is limited by how long the telescope can be kept cool.

Microwave Telescopes

Microwaves are used to observe the afterglow of the Big Bang, the ancient explosion that created the Universe. Microwave radiation also reveals the presence of many small molecules, such as carbon monoxide. The design of microwave telescopes is most similar to that of radio telescopes: large metallic “dishes” that collect and focus the longer wavelengths of microwave light.

Radio Telescopes

Radio waves have long wavelengths, from a meter on up to over a kilometer. Extremely large telescope dishes are required to capture these long wavelengths. Radio telescopes can reveal details of distant galaxies and nebulae. Radio telescopes helped astronomers discover “pulsars,” which are collapsed stars that rotate rapidly, emitting pulses of radio waves like the rotating lights on a police car or a lighthouse.

M If you're visiting the Moveable Museum, you can examine a region of the sky through a computer interactive, as observed by different kinds of telescopes to see how space looks in various wavelengths of light.

! **Radio Telescopes Don't Get The Day Off !**
Radio telescopes work almost as well during the day as at night, because radio waves are not drowned out by light from the Sun.



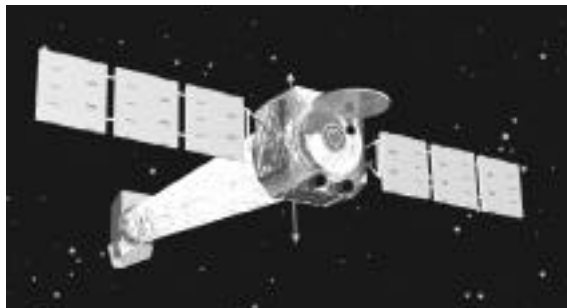
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Telescopes in space avoid interference from the atmosphere

Telescopes on Earth cannot observe many wavelengths of light because the light is absorbed or scattered by the Earth's atmosphere. Short wavelengths—gamma rays, X rays, and UV light—are almost completely blocked. To take pictures in these wavelengths, telescopes must be put into orbit above the Earth's atmosphere.

The Earth's atmosphere does not block all wavelengths, however. Visible light, some infrared light, and radio waves can be observed from Earth, but not without interference. The atmosphere bends these waves, causing images to waver and blur and making stars “twinkle” at night.

To reduce interference from the atmosphere, astronomers want as little atmosphere as possible between their telescopes and space. They also travel to locations where the air is stable, such as remote mountaintops. Astronomers are developing ways to compensate for atmospheric interference, including combining images from several telescope mirrors, and using flexible mirrors that can be adjusted by computer to cancel out the atmosphere's distortion. But the best view of space is still achieved from high above the Earth's atmosphere.



Chandra X-ray telescope.