Scope It Out!
A Flash game about telescopes.

Opening Screen shows levels 0-4 and pictures of the James Webb Space Telescope and Hubble Space Telescope.

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Level Zero

The two basic kinds of telescopes are the reflector and the refractor. Select a telescope to see the path light takes as it travels.

Left hand choice:

A refracting telescope works similarly to a magnifying glass. Light enters the end of the telescope where it is bent and focused by a convex (curved outward) glass lens. The light travels to the end of the tube where it is magnified by a concave (curved inward) lens in the eyepiece. For viewing ease, many modern telescopes have what is called a “diagonal” mirror at the end of the telescope that simply angles the light toward the eyepiece.

Link: Who invented This?

The first refracting telescopes appeared in the Netherlands around 1608. Since Galileo improved the design and popularized the telescope in 1609, he gets much of the credit! Galileo was the first to use a telescope to study space – in fact, he discovered Jupiter's four largest moons!

More about refractors:

You might be most familiar with a refractor telescope, at least partly because their design allows them to be very simple, compact, and portable. Astronomers as far back as Galileo have used refractors to make important discoveries. But refractors have their limits. For one thing, it’s a challenge to use lenses when building bigger and more powerful telescopes because big, powerful lenses need to be thick. (Think eyeglass lenses for very poor eyesight!) A big, thick lens is also heavy and would need to be flawless to allow light to travel through it. Additionally, refractors have a flaw called chromatic aberration, which happens when a lens doesn’t correctly focus all colors (wavelengths) of light to the same point. Reducing this effect requires increasingly long telescope tubes, allowing for a longer focal length for the telescope. What is the alternative to a refractor? Enter the reflecting telescope!

[Replay animation?] [Continue?]

Right-hand choice:

[Animation: The girl fades out, the light path plays, the mirror locations are highlighted.]

Light enters the top of a reflecting telescope and hits the primary mirror (located at the bottom end of the tube), where it is reflected and focused. The angled secondary mirror, near the eyepiece, reflects the light to where it can be easily seen by the observer. The eyepiece contains a magnifying lens to enlarge the image.

Link: Who invented this?

Though reflecting telescopes have been around since 1616, Sir Isaac Newton's design from 1668 was the first practical one. He added an angled secondary mirror that allowed the observer to more easily view the image created by the telescope. Newton's design is what you see here, which is why this is called a Newtonian Reflector. We will see more of another design, called a Cassegrain Reflector, later. Its arrangement of mirrors differs slightly from Newtonian Reflector, and thus it reflects light slightly differently.

More about reflectors:

Building large, powerful refractor telescopes can be a challenge, which is why the reflecting telescope has increased in popularity for astronomical research. Unlike a powerful lens, which would need to be thick, a mirror can be very thin. Making a large, near-perfect mirror surface is easier than creating a large, perfect lens, and because only one side of the mirror has to be reflective, they are easier to clean and polish. Because mirrors can be thin and light, they are much easier to launch into space than lenses are, which is why nearly all space telescopes are reflecting telescopes. (Reflectors also do not have the issues that refractors do with chromatic aberration, which happens when a lens doesn’t correctly focus all colors (wavelengths) of light to the same point.)

[Replay animation?] [Continue?]

Though these telescopes differ in how they collect and focus the light from objects in space, they look like large tubes.

But do all telescopes need tubes?   Let’s find out!

Level One:

Let’s compare our simple Newtonian reflecting telescope to the James Webb Space Telescope. The Webb doesn’t have a tube, it’s true – but it’s still a reflecting telescope, and as such, it has many of the same components. Try to figure out the major components of our simple reflecting telescope, which is shown on the left side of the screen. (Hint: There are seven of them!) Just select the part of the drawing that you think might be one of these seven components. If you guess right, you will be shown a picture of that component as well as the matching component of the Webb.

Telescope Tube – Sunshield

The tube of a reflecting telescope not only holds the mirrors in place, it keeps ambient light out. The tube also protects the mirrors from fingerprints and scratches.

The sunshield on the Webb serves a similar purpose. Webb will observe primarily infrared light, often from very faint and distant objects. The sunshield will keep infrared light (or heat) from the Sun/ EarthMoon, as well as the spacecraft itself, from reaching the mirror and the instruments.

Primary Mirror – Primary Mirror

The primary mirror is the main light-gathering surface on a reflecting telescope. Traditionally, telescope mirrors are created by covering a precisely curved piece of glass with a reflective coating. A very large glass mirror would be very heavy and expensive to launch into space. Instead of glass, Webb's primary mirror is made of beryllium, a very lightweight and strong material. Webb's primary mirror is very large – it is over six times larger in area than the Hubble's glass primary mirror. The mirror is made up of 18 hexagonal segments that work together as a single mirror.

Fun Fact: To make the mirrors even lighter, much of the backside of each segment is cut away, leaving just a thin "rib" structure. The ribs are only about one millimeter thick. Although most of the metal is gone, the ribs are enough to keep the segment's shape steady.

Secondary Mirror – Secondary Mirror

A secondary mirror is the second light-gathering surface in a reflecting telescope. When light enters a telescope, such as the Newtonian reflector that we are showing here, it is gathered by the primary mirror and then reflected towards the secondary mirror, which then directs the light to where the observer can view it.

The Webb also has a secondary mirror that directs the light from the primary mirror to where it can be collected by the Webb's instruments. The path the light takes is slightly different for the Webb than for a Newtonian reflector.

Observer/Eyepiece – "ISIM"

Instead of a person with their eye to a magnifying eyepiece, Webb has instruments that sit right behind the primary mirror. They are contained in a box-like structure, called the "Integrated Science Instrument Module" (ISIM). The instruments are what receive the collected light and process it, just like your eye and your brain would!

Focus Knob – Mirrors

Though the Webb doesn't have an eyepiece with a focus knob, it can still be focused. Webb's secondary mirror is moveable and can be adjusted to focus the telescope. In addition, all but one of the instruments have internal focusing mechanisms for fine adjustments. Each segment of Webb's 18-section primary mirror is also adjustable so that the segments can be focused and aligned relative to each other.

Viewfinder – Startrackers

To locate astronomical objects in the sky, many telescopes have an attached viewfinder. A viewfinder is really a small simple refracting telescope with lenses - the magnification isn't very high, so it will allow you to easily zero in on the object you wish to observe. If you center your object in the viewfinder, it should be in the center of the field of view of your telescope.

The Webb has star trackers that are used to coarsely point the telescope. During an observation, the Fine Guidance Sensor (FGS), which is located in the same box as the instruments, is used for fine adjustments.

Tripod – Backplane

The telescope tube may hold the mirrors in place, but the tripod serves as a steady base structure for the telescope and its components. On the Webb, the mirror segments are held in place by a special backplane structure, built to keep the telescope mirrors steady. On the backside of the backplane, the ISIM box containing the instruments are attached.

Level Two

In Level One we showed you which parts of a simple Newtonian reflecting telescope corresponded to parts of the James Webb Space Telescope. Now, try and match them yourself!

Select one of the seven components of our reflecting telescope on the left and then drag the component over the Webb Telescope to the right. Line the component up with the part of Webb you think matches, and then let go. Keep going until you have found all seven matches!

Telescope Tube – Sunshield

The tube of a telescope has many of the same functions as the sunshield of the Webb. Both serve as protection for their mirrors, and keep ambient light out. In the case of the Webb, the sunshield shields the telescope and instruments from infrared light (in the form of heat) given off by the spacecraft bus electronics and from the heat of the sun. Faint infrared light coming from the first stars and galaxies that formed in the early Universe, can be lost in the glare if other sources of infrared light affect the telescope. The mirror and instruments themselves are even cooled cryogenically to about 50 Kelvin (-223° C or -370° F).

Primary Mirror – Primary Mirror

Both telescopes have primary mirrors. The Webb's is built in 18 separate hexagonal pieces, which act together as one large mirror, thanks to its wavefront sensing and control subsystem, which can adjust the pieces as needed. Having a segmented mirror allows it to be bigger while still being lightweight enough to launch into space.

Webb's primary mirror makes it a powerful telescope. It has the angular resolution to see details the size of a US penny at a distance of about 24 miles (38.6 km), or a regulation soccer ball at a distance of 340 miles (550 km)!

Secondary Mirror – Secondary Mirror

Both telescopes have secondary mirrors. (Reflector telescopes can actually even have tertiary mirrors – Webb has one.)

Webb's mirror set up differs a bit from our simple Newtonian reflector. The Webb is actually a type of Cassegrain reflector. In a Cassegrain, the light is still gathered by the primary mirror and directed towards the secondary mirror. But then the light is directed by the secondary mirror back towards a focal point behind and through the center of the primary mirror.

This is where Webb's tertiary mirror directs the light to a flat "fine steering mirror," where it is then reflected into the science instruments. The science instruments are located in the box attached to the back of the primary mirror.

Observer/Eyepiece – "ISIM"

The Webb's instruments take the place of a human's eye to an eyepiece. The instruments are all contained in the "Integrated Science Instrument Module" or ISIM. Each of them has a different capability. The Near Infrared Camera (NIRCam) is Webb's primary imager. The Mid Infrared Instrument (MIRI) has a camera to produce images and a spectrograph to provide spectroscopy of mid-infrared sources. The Near Infrared Spectrograph (NIRSpec) can take more than 100 spectra of faint near infrared objects at once! The Fine Guidance Sensor and Near Infrared Imager and Slitless Spectrograph (FGS/NIRISS) is a combination instrument. The FGS allows Webb to point precisely, so that it can obtain high-quality images. NIRISS is a spectrograph.

Focus Knob – Secondary Mirror

How a telescope focuses actually varies depending on what kind of telescope it is. Our Newtonian reflector (on the left) uses a knob to adjust the eyepiece to focus the telescope. Both mirrors are stationary. A simple Cassegrain reflector has a moveable primary mirror that allows the user to adjust the telescope's focus.   Webb is a Cassegrain-type telescope, but it is actually the secondary mirror that is moved to focus the telescope. Adjustments can also be made by changing the alignment of the individual segments of the primary mirror with respect to each other. All but one of the instruments have an internal focus adjustment as well.

Viewfinder – Star Trackers

The Webb's star trackers work similarly to a viewfinder.   They are used to coarsely point the telescope so that the target appears in the field of view of the intended instrument. Once an observation is started, the Fine Guidance Sensor (located in the ISIM with the instruments) can compensate for small drifts in the observatory's alignment and help the telescope maintain its good pointing.

Tripod – Backplane

The backplane of the Webb Telescope serves as the base structure for the mirrors and instruments. The backplane had to be specially designed to withstand the cold temperatures that the mirror is kept at – and to keep the mirror segments very steady. It also needs to withstand the temperature fluctuations from launch to deployment. The ISIM, which holds the instruments, is attached to the back of the backplane.

Level Three

Let's compare our simple Newtonian reflecting telescope to the Hubble Space Telescope. The Hubble has many of the same parts and functionality.

Find the major components of the simple reflecting telescope on the left side of the screen, and you will be shown the matching component of the Hubble Space Telescope on the right. (Hint: There are seven of them!) Just select the part of the drawing that you think might be one of these components.

Telescope Observer – Hubble Instruments

The Hubble doesn't have an eyepiece for an observer to put their eye up to – instead it has a suite of instruments that perform this function, and these are located behind the primary mirror. In a Cassegrain-style telescope like Hubble, the light collected by the primary mirror is sent forward to the secondary mirror, which then directs it back through a hole in the center of the primary. Behind the primary mirror, the light is focused onto an area called the focal plane. The science instruments are located in different portions of the Hubble's focal plane and either receive the light from the mirrors directly or have it redirected to them.

Telescope Tripod – Hubble Optical Telescope Assembly

Our simple telescope has a tube to contain its mirrors, but still needs the tripod and mount to serve as a steady base structure. The Hubble has a complicated structure to hold its optics in place. The Optical Telescope Assembly, which includes the mirrors and focal plane structure, has a support truss (or skeleton) made of graphic epoxy. This substance, used for golf clubs, bicycles, and tennis racquets, is strong and lightweight and it doesn't easily expand or contract, making it ideal for supporting the mirrors.

Telescope Tube – Hubble Housing

The tube of a simple reflecting telescope corresponds to what is called the "housing" of the Hubble Space Telescope. Both protect the mirrors contained within, and both keep out ambient light, allowing the mirrors to collect only the light from the objects being observed. The Hubble's housing also contains multiple layers of insulation to protect the mirrors from extreme temperatures. To keep the mirror from warping, it is kept at around room temperature (70 degrees F) all the time. Inside the housing are aluminum baffles that further help eliminate stray light. There are three baffles: a main one that lines the tube, one around the secondary mirror, and one in the center of the primary mirror to help channel the light through to the focal plane.

Telescope Focus Knobs – Hubble Instruments

Our simple telescope has a knob that adjusts the position of the eyepiece, while other types of telescopes will allow the observer to move the primary mirror. In Hubble's case, the secondary mirror can be moved to adjust the focus. In addition, each instrument can perform some internal adjustments to ensure accurate focus. This is necessary because the instruments are removable – and it's not possible to install them with the accuracy needed to guarantee their images will be perfectly focused. Thus all the instruments are fine-tuned for focus after installation.

Telescope Viewfinder – Hubble Startrackers

It can be hard to find tiny and distant objects with a high-powered telescope, which typically has a small field of view. Many telescopes have viewfinders, which are simply small telescopes with low magnification but large fields of view, to make it easier to find the object or region you wish to observe.

The Hubble has star trackers on its side - they are used to view large areas of the sky to help the Hubble determine its orientation in space. This is similar to a viewfinder helping you to orient your telescope in the sky.

Telescope Secondary Mirror – Hubble Secondary Mirror

The Hubble is a reflecting telescope, and so like our simple model also has a secondary mirror. Light takes a slightly different path in the Hubble than it does in the simple reflector because of the kind of reflecting telescope it is. The Hubble is a Cassegrain telescope, which means that the secondary mirror directs the light to a focal point which is behind the primary mirror. The primary mirror has a hole in the center to allow the light to pass through to the focal point.

Telescope Primary Mirror – Hubble Primary Mirror

Our simple reflecting telescope's primary mirror is set at the bottom of the telescope tube. Similarly, Hubble's primary mirror is located inside, toward the back of the telescope's housing, with the secondary mirror in front of it.

Hubble's mirrors are made of glass and are polished to be incredibly smooth. The primary mirror is so smooth that if it were scaled up to the diameter of the Earth, the biggest bump would be only six inches tall! The mirror is also coated with very thin layers of reflective substances (aluminum and magnesium fluoride).

Level Four

In Levels One and Two, we showed you which parts of a simple reflecting telescope corresponded to parts of the James Webb Space Telescope. In Level Three we showed you which parts corresponded to parts of the Hubble. Now try to match the parts of the Hubble to those of the Webb!

Select one of the six components of the Hubble on the left and drag the component over to the Webb Telescope on the right. Line it up with the part of the Webb you think it matches, and then let go. Keep going until you have found all six matches!

Hubble Housing – Webb Sunshield

The housing of the Hubble performs a similar job to the Webb's sunshield. The Hubble's housing contains many layers of insulation to protect its mirrors from extreme temperatures. The Webb's five-layered sunshield helps to keep its mirrors and scientific instruments cool by protecting them from both the heat of the sun and the warm spacecraft bus electronics. The Webb does not need a tube, because the only stray light at its location comes from the sun, and is blocked by the sunshield.

HST Primary Mirror – Webb Primary mirror

The mirrors on these two telescopes are a study in contrasts. Hubble's mirror is 2.4 meters in diameter, while Webb's will be 6.5 meters. This gives Webb over six times more collecting area than Hubble! If Webb had a traditional mirror like Hubble's it would be enormously heavy. Hubble's mirror weighs 1825 pounds – nearly a ton! Can you imagine how heavy this would make Webb's much larger mirror? To solve this, Webb's mirror is made up of 18 hexagonal segments made of ultra-lightweight Beryllium. The segments will act together as a single mirror.

Hubble Secondary Mirror – Webb Secondary Mirror

Hubble's secondary mirror is within the telescope's housing, positioned in front of the primary mirror, so it can redirect light back through the hole in the center of the primary focal area. Though Webb doesn't have a tube, it has a similarly positioned secondary mirror and the light is directed in the same manner. This type of a telescope is called a Cassegrain reflector.

The secondary mirrors on both Hubble and Webb are adjustable. Their distances away from their primary mirrors can be altered, so that the telescopes can be properly focused.

Hubble Instruments – Webb ISIM

Neither space telescope has an observer with their eye to an eyepiece – instead there are instruments to collect and record data from the sources being observed. The instruments are located behind the primary mirrors of both satellites. Hubble has optical and infrared cameras and two spectrographs. Webb's instruments are in a box called the ISIM or "Integrated Science Instrument Module" and include several cameras, each sensitive to a different region of the infrared region of the electromagnetic spectrum, and two spectrographs. Webb's instruments will be extremely sensitive.

Hubble Startrackers – Webb Startrackers

Both satellites have startrackers to help them to orient the telescopes in the sky and to coarsely point them. Both also have Fine Guidance Sensors for finer pointing.

Hubble Assembly – Webb Backplane

Both telescopes need a way to support their mirror assemblies. Since Hubble is tubular, it has a tubular structure inside the housing which includes a strong, lightweight graphite epoxy truss. The Webb doesn't have a tube encasing its primary mirror. Instead the primary mirror is supported by a backplane structure. The backplane has the added task of keeping each mirror segment firmly and steadily in place to allow the segments to act as a whole mirror.