Optical telescopes

No 48

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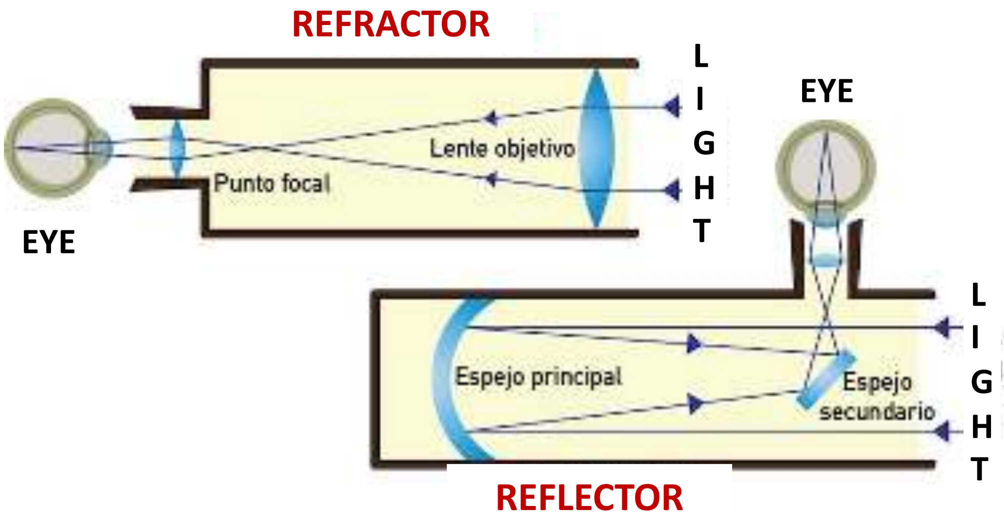
What is a telescope?

A telescope is an optical instrument that receives and concentrates light from distant objects to form enlarged and more detailed images. It uses lenses or mirrors to focus electromagnetic radiation (light). It's an essential tool in astronomy for exploring the Universe.



https://concepto.de/telescopio/

Telescopes collect and focus light from distant stars and galaxies, but the instruments attached to them do the detailed work. They analyze the light, revealing what celestial objects are made of, how they move, and how they change over time. Together, they turn faint traces of light into a clearer picture of how the cosmos works.

First telecopes in history

The first practical telescope was built in 1608 by Hans Lippershey. A year later, Galileo Galilei improved the design and pointed his telescope at the sky. He discovered the four largest moons of Jupiter, the phases of Venus, and mountains on the Moon — findings that changed our understanding of the Cosmos.

Later, Isaac Newton developed the reflecting telescope, using mirrors instead of lenses, to overcome chromatic aberration and improve image quality.

Optical principles

The operation of telescopes is based on several fundamental laws of optics:

- **Reflection**: the angle of incidence equals the angle of reflection, first described by Euclid.

$$\theta_i = \theta_r$$

where θ_i is the angle of incidence and θ_r is the angle of reflection.

- **Refraction**: light changes direction when passing between media with different refractive indices, described by Willebrord Snell and developed further by René Descartes.

$$n_1 \, sin \, \theta_1 = n_2 \, sin \, \theta_2$$

where n_1 and n_2 are the refractive indices of the two media and θ is the angle perpendicular to the interface.

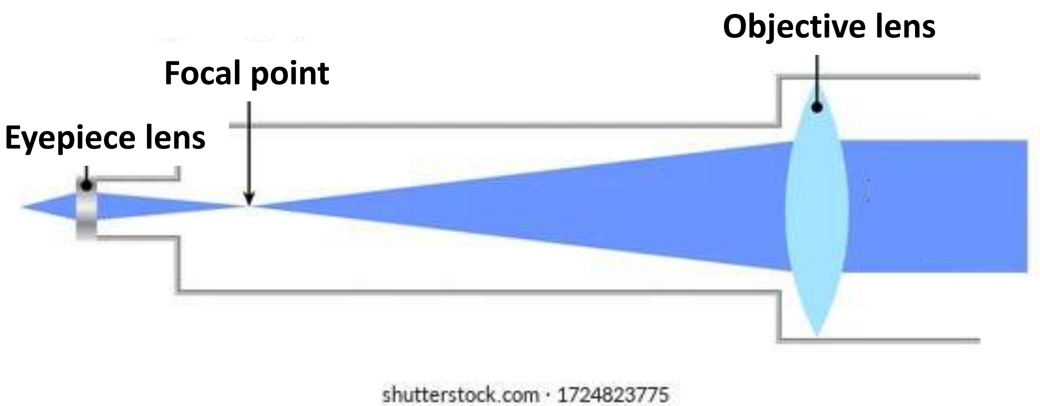
- **Diffraction:** Light acts as a wave and spreads when passing through an aperture. The angular resolution is given by

$$\theta \approx 1.22 \frac{\lambda}{D}$$

where λ is the wavelength and D is the aperture diameter, showing that a larger aperture improves resolution.

Refracting telescope

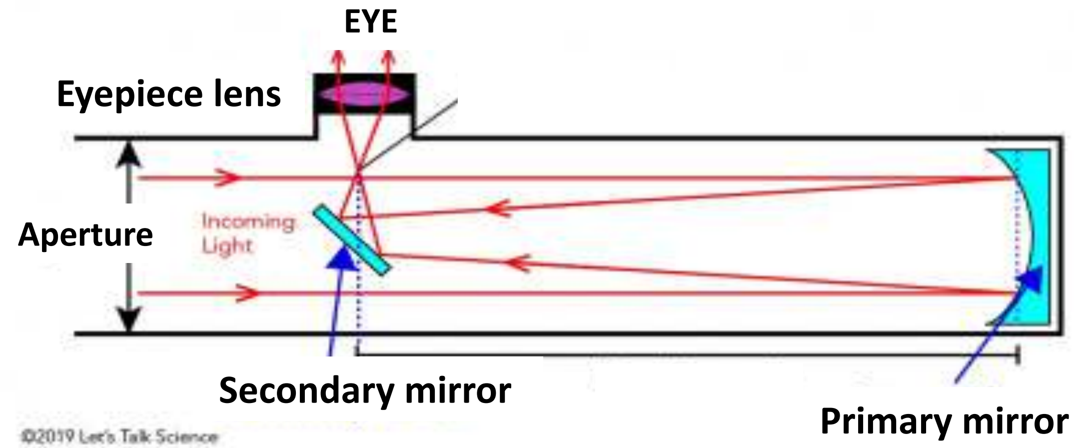
A refracting telescope uses lenses to bend (refract) incoming light and bring it to a focus. The primary lens, called the objective lens, gathers light from a distant object and forms an image at the focal point. An eyepiece lens then magnifies this image for observation.



Refractors produce sharp and high-contrast images, but their size is limited by lens weight and optical aberrations such as chromatic aberration. The materials used to manufacture the lenses of a refracting telescope must be homogeneous and isotropic to ensure high image quality. This requirement arises because light passes through the lens material.

Reflecting telescope

A reflecting telescope uses mirrors instead of lenses to focus light. The primary mirror, typically concave, collects light and reflects it toward a secondary mirror or directly to an eyepiece.



Mirrors avoid chromatic aberration and can be made much larger than lenses, allowing astronomers to observe faint and distant objects. Reflecting telescopes are the favorite of amateur astronomers because they give big, bright views of the sky without costing too much.

Its mirror is made of low-expansion glass or ceramics and coated with a thin reflective layer of aluminum. The surface is also polished with extreme precision, often to within one-eighth of the wavelength of light or better.

The greater the required accuracy, the more complex and demanding the polishing and testing process becomes.

Image magnification

Both refracting and reflecting telescopes magnify images in the same basic way. Light from a distant object is first focused by the objective - a lens in refractors or a mirror in reflectors - forming a real image at the focal plane.

An eyepiece then acts as a magnifier, enlarging this image for the observer. The magnification is given by:

$$M = f_o / f_e$$

where f_o is the focal length of the objective and f_e is the focal length of the eyepiece.

Size and resolution

The aperture of a telescope — the diameter of its primary lens or mirror — determines both its light gathering power and its resolving ability. A larger aperture collects more light, allowing fainter objects to be seen, and improves angular resolution, enabling the telescope to distinguish finer details.

Thus, increasing the aperture improves the telescope's ability to see fine details in distant objects (see page 6).

One variation, called a segmented-mirror telescope, uses many smaller mirrors working together as one. This design makes it possible to build much larger and lighter mirrors than a single solid piece.

Telescope sizes

Refracting telescopes are harder to build than reflectors because large lenses are heavy, difficult to support, and suffer from chromatic aberration—a distortion caused by the different refraction of light colors that produces colored fringes around objects—whereas mirrors can be lighter, free from this effect, and easier to scale up to larger sizes.

The largest refractor ever built is the Yerkes 40-inch telescope (diameter of 1.02 m, left), while the largest segmented reflector is the Gran Telescopio Canarias (diameter of 10.4 m, right). Reflectors are widely used in modern astronomy due to their versatility and superior light-gathering capacity.

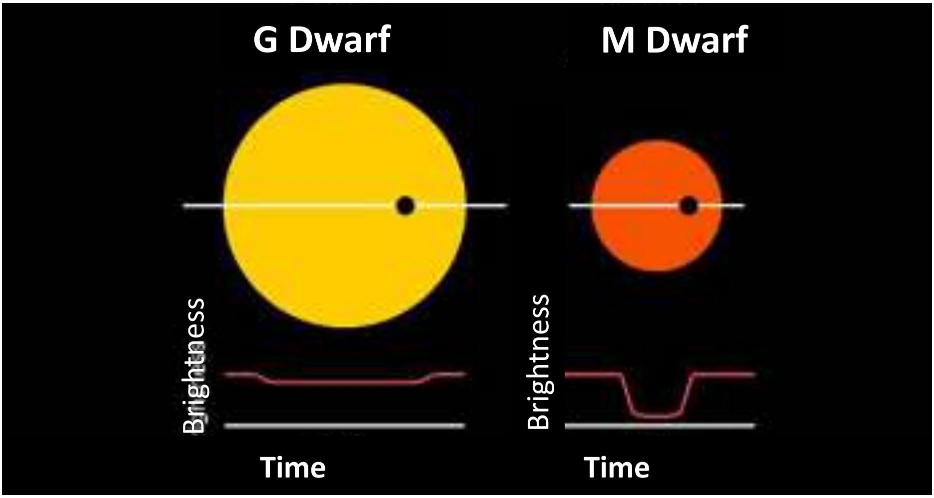
Space telescopes

The Earth's atmosphere distorts and blurs light from celestial objects due to turbulence and temperature variations, a phenomenon known as atmospheric seeing. This limits the resolution of ground-based telescopes and causes stars to twinkle. To minimize these effects, astronomers use adaptative optics to correct distortions in real time, or place telescopes in high-altitude, dry sites, or launch telescopes into space, where there is no atmospheric interference.

The largest space telescope ever built and currently in operation is the James Webb Space Telescope, a segmented-mirror reflector made of up of 18 hexagonal segments working together as a single 6.5-meter mirror.

Instruments: photometry

Telescopes use various instruments to capture and analyze light from the Universe. They help transform what the telescope sees into meaningful data, revealing the hidden details of stars, planets, and galaxies.



Variation in the photometric brightness of two stars during a planetary eclipse (https://astro.unl.edu/).

Photometry is all about measuring how bright celestial objects are and how their light changes over time. Using filters, astronomers can track the flickering of variable stars, the dimming of exoplanet transits, or subtle changes in a galaxy's glow. It's a simple but powerful way to learn about an object's brightness, color, and energy.

Instruments: spectrophotometry

Spectrophotometry goes a step further by splitting light into its different colors, or wavelengths. By looking at how bright each color is, scientists can determine what an object is made of, how hot it is, and even how it's moving through space. It's a bit more complex than simple brightness measurements, but it gives us a much deeper glimpse into the inner workings of stars and galaxies (see tuimp 30).

SPHEREx (Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer, NASA-JPL).

Telescopes used for astronomical research, along with the scientific projects that drive them, are often developed through multi-national and multi-institutional collaborations.

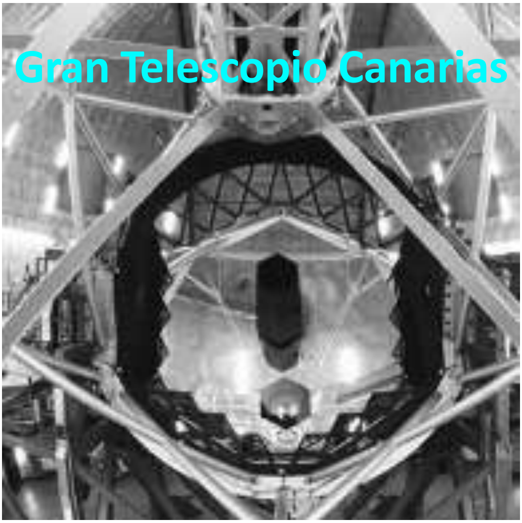
Quiz

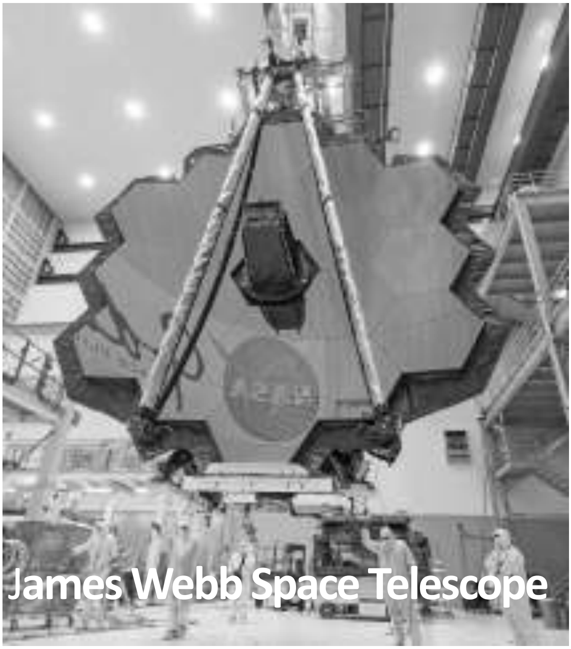
Which one is the Gran Telescopio Canarias (GRANTECAN)?

Answer on overleaf

Answer

These figures show two segmented telescopes; James Webb Space Telescope (JWST, see p.11) and Gran Telescopio Canarias (GRANTECAN see p 10).





The Universe in my pocket no 48

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Cover image: Gran Telescopio Canarias, GTC

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Translation: Stan Kurtz