

# Telescope

Learners' Space



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# PROPERTIES OF LIGHT

Light, an electromagnetic phenomenon, possesses distinct properties that are vital for comprehending the functioning of telescopes. Two essential properties, wave-particle duality, and the electromagnetic spectrum, play a fundamental role in our understanding of light and its interaction with telescopes. Let us explore these properties in further detail:

## 1.1 Wave Particle Duality

Wave-particle duality is a fundamental concept in physics that applies not only to light but also to other particles. It suggests that light can exhibit both wave-like and particle-like behavior, depending on the experimental conditions and observations. To grasp the functioning of telescopes, understanding this concept is of utmost importance. Let's delve into the wave and particle nature of light and their relevance to telescopes:

### 1.1.1 Wave Nature of Light

The wave nature of light refers to its ability to propagate as an electromagnetic wave. This wave-like behavior is characterized by properties such as wavelength, frequency, and amplitude. In the context of telescopes, the wave nature of light plays a crucial role in two key phenomena:

#### Interference

When light waves from different sources or regions overlap and combine, interference occurs. This phenomenon can result in two distinct outcomes: constructive interference and destructive interference. In constructive interference, the overlapping waves reinforce each other, leading to regions of increased brightness in the observed image. Conversely, in destructive interference, the waves cancel each other out, resulting in dark regions. In telescopes, interference phenomena can significantly influence the quality and clarity of the observed images.

#### Diffraction

Diffraction occurs when light waves encounter an obstacle or pass through a small aperture, causing them to spread out and exhibit bending and interference effects. This phenomenon limits the

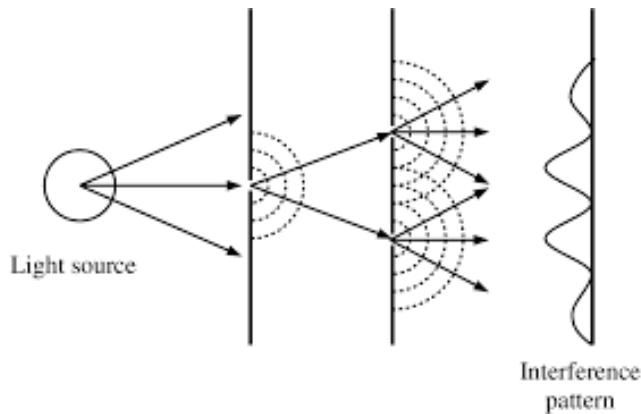


Figure 1.1: Interference of light

achievable resolution of a telescope, as it imposes a fundamental limit on the level of detail that can be resolved in an image.

### 1.1.2 Particle Nature of Light (Photons)

The particle nature of light emphasizes that light can also be described as a stream of discrete particles known as photons. These photons carry energy and momentum and exhibit particle-like behavior. The understanding of light's particle nature, especially demonstrated by the photoelectric effect, has practical implications for telescope technology:

#### Photoelectric Detectors

Telescope technology often incorporates photoelectric detectors, such as CCD (charge-coupled device) sensors. These detectors convert incoming photons into electrical signals, enabling the measurement and recording of light intensity at different wavelengths. In modern telescopes, photoelectric detectors are instrumental in capturing digital images and conducting scientific observations.

The combination of wave and particle properties of light is vital for understanding the behavior of light in telescopes. Telescopes utilize lenses or mirrors to manipulate light waves, focusing them to form clear images. The wave nature of light affects the resolution and quality of these images, while the particle nature of light enables the detection and measurement of light intensity using photoelectric detectors.

## 1.2 The Electromagnetic Spectrum

The electromagnetic spectrum encompasses a vast range of electromagnetic radiation, including radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays. Understanding the electromagnetic spectrum is crucial for comprehending how telescopes operate and the specific range of wavelengths they are designed to observe. Let's further explore the electromag-

netic spectrum in the context of telescope functioning:

### 1.2.1 Optical Telescopes

Optical telescopes, including refracting and reflecting telescopes, are designed to focus visible light. They utilize lenses or mirrors to gather and direct the light onto detectors, such as CCDs (charge-coupled devices), which convert the light into electrical signals for image formation and analysis.

#### Radio Telescope

Radio telescopes are specialized instruments designed to observe radio waves emitted by celestial objects in the universe. Unlike optical telescopes that use lenses or mirrors to focus visible light, radio telescopes collect and detect radio waves using large dish-shaped antennas. Radio telescopes detect and analyze radio waves emitted by astronomical objects. These waves are a form of electromagnetic radiation with longer wavelengths than visible light. Radio telescopes capture incoming radio waves using a large antenna and convert them into electrical signals. Radio telescopes feature large, parabolic-shaped antennas that are specifically designed to collect radio waves. The size of the antenna determines the sensitivity and resolving power of the telescope. The dish-shaped antenna reflects incoming radio waves towards a focal point, where receivers are positioned to capture the signals.

#### Infrared Telescopes

Infrared telescopes employ specialized optics and detectors that are sensitive to infrared radiation. They often use cooled instruments to minimize interference from thermal emissions and achieve higher sensitivity.

#### X-ray and Gamma-ray Telescopes

Telescopes operating in the X-ray and gamma-ray regions cannot utilize traditional lenses or mirrors due to the high energy and penetrating nature of these radiations. Instead, they use grazing incidence mirrors or other advanced technologies to focus the radiation onto specialized detectors, such as scintillation counters or solid-state detectors.

Telescopes are designed and optimized for specific regions of the electromagnetic spectrum to capture and analyze the unique information carried by each type of radiation. By covering a broad range of wavelengths, astronomers can gain a comprehensive understanding of celestial objects and their properties.

## 1.3 Functioning of a Telescope

Telescopes operate by utilizing lenses or mirrors to capture and focus incoming light, facilitating the observation and analysis of remote celestial objects. Here's how the concepts of lenses, mirrors, focal length, and focal point contribute to the functioning of a telescope:

### Light Gathering

The primary purpose of a telescope is to gather as much light as possible from distant objects. Lenses or mirrors with larger apertures (diameter) permit an increased amount of light to enter the telescope, resulting in brighter images and enhanced visibility of faint objects.

### Focusing

The curvature of lenses and mirrors determines their ability to focus incoming light. Convex lenses and concave mirrors bring parallel light rays to a focal point, creating a clear image. The focal length plays a crucial role in determining the degree of light convergence or divergence, consequently impacting the telescope's magnification and field of view.

### Eyepiece or Detector Placement

Within a telescope, the precise location of the focal point of the primary lens or mirror significantly influences the placement of the eyepiece or detector. The eyepiece is positioned precisely at the focal point to magnify the focused image for visual observation. In modern telescopes, detectors such as CCDs (charge-coupled devices) are situated at the focal plane, enabling digital capture and recording of the focused image.

# HISTORY OF TELESCOPES

Here's a fun video that gives a brief history of the Telescope: <https://youtu.be/4ItrMx1jFb4>

## 2.1 Galileo's Telescope and Discoveries

Galileo's telescope allowed him to observe mountains and craters on the moon, challenging the prevailing belief in a perfect celestial realm. He also observed the Milky Way, expanding our understanding of the structure of the galaxy. Galileo's telescope opened a new era of astronomical exploration, providing empirical evidence that supported the Copernican heliocentric model and expanding our knowledge of celestial bodies.

## 2.2 Newtonian telescope

Sir Isaac Newton's invention of the reflecting telescope in the 17th century introduced a design using mirrors instead of lenses, improving image quality and enabling larger telescopes. Telescopes with larger apertures and improved optics allowed astronomers to observe fainter objects, leading to the calculation of stellar distances, the discovery of new celestial bodies, and the study of their properties and behaviors.

## 2.3 Spectroscopy

In the 19th century, the introduction of the spectroscope enabled astronomers to analyze the light emitted by celestial objects, providing valuable information about their composition, temperature, and motion. This led to the development of astrophysics as a separate field of study.

## 2.4 Atmospheric Limitations and the Need for Space Telescopes

Earth's Atmosphere and Visual Distortion: The Earth's atmosphere causes visual distortion, known as atmospheric turbulence, which affects ground-based telescopes. Twinkling stars and blurring of images are the results of this atmospheric interference. Also, Astronomers recognized the limitations imposed by the Earth's atmosphere and envisioned space-based observatories as a solution to overcome these challenges. Space telescopes, such as the Hubble Space Telescope (HST) and the James Webb Space Telescope(JWST), are free from atmospheric distortion and



Figure 2.1: Galileo's telescope

can capture images with exceptional clarity and resolution. They have revolutionized our understanding of the universe and enabled breakthrough discoveries.

**The Hubble Space Telescope (HST):** Collaboration and Deployment: Launched in 1990, the HST is a joint project between the European Space Agency and NASA. It was deployed by astronauts aboard the space shuttle Discovery into an orbit above the Earth's atmosphere. The HST has made significant contributions to various fields of astronomy. It has explored the solar system, provided precise measurements of stellar distances, and observed distant galaxies, revealing the age and size of the universe. The HST's high-resolution images and spectroscopic capabilities have allowed scientists to study the formation and evolution of galaxies, investigate the properties of black holes, and unravel the mysteries of dark matter and dark energy.

**James Webb Space Telescope (JWST):** The James Webb Space Telescope (JWST), is designed to surpass the capabilities of the HST. It observes the universe in the infrared part of the electromagnetic spectrum, allowing scientists to peer deeper into space and further back in time. The JWST's focus on infrared observations is crucial for studying the early universe, as it can detect the faintest and most distant objects. Its instruments are cooled to extremely low temperatures to reduce thermal noise and increase sensitivity.

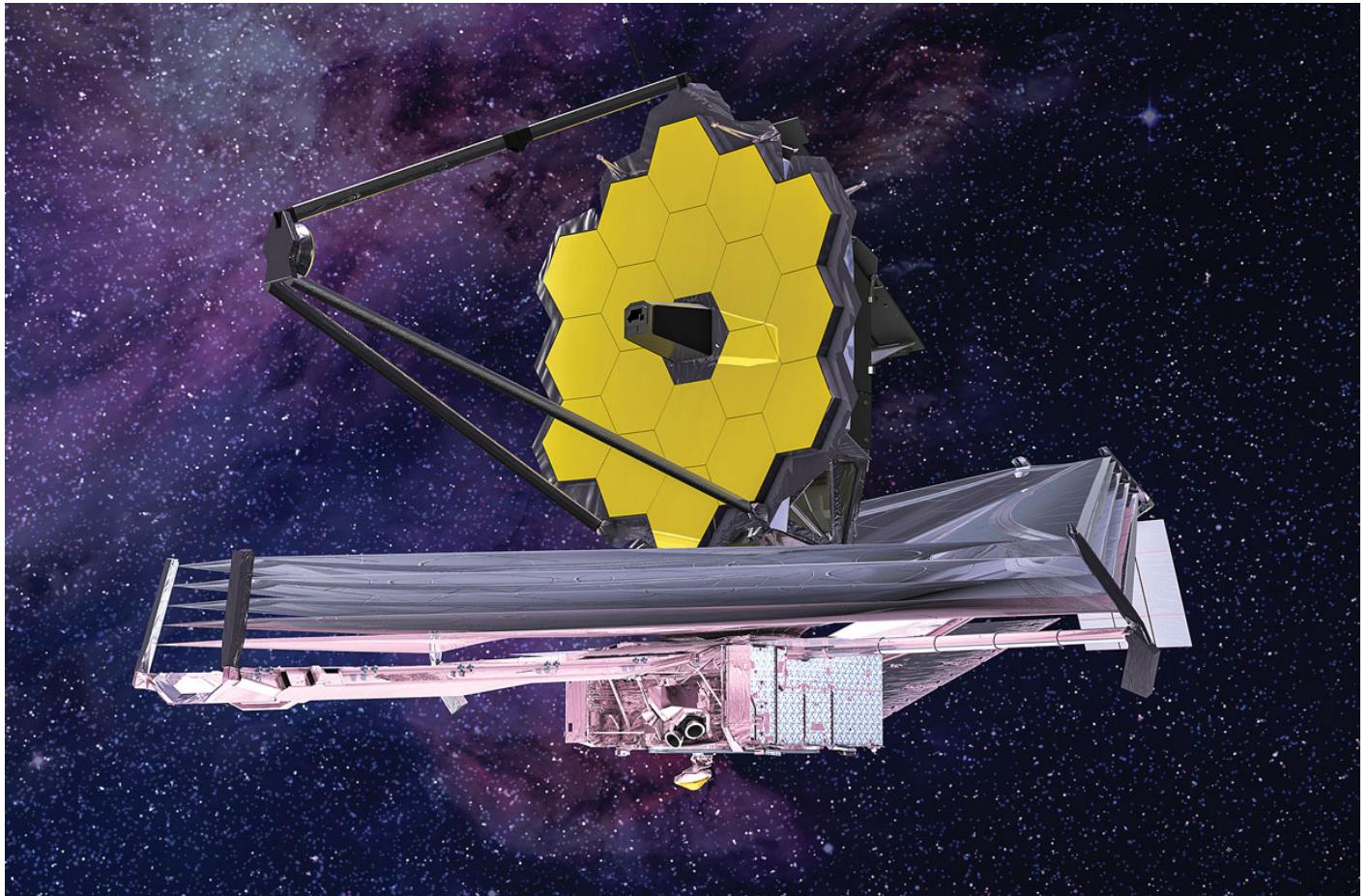


Figure 2.2: The James Webb Space Telescope

# BASIC CLASSIFICATION OF TELESCOPES

Telescopes can be classified into multiple types on different bases. The most fundamental basis for classification would be the optical system employed in the telescope.

Here's a video giving a comparative study on Reflectors, Refractor and Compound telescopes:  
[https://youtu.be/\\_v1RWyzQAng](https://youtu.be/_v1RWyzQAng)

## 3.1 Reflector Telescopes

**Properties:** Reflectors use mirrors to gather and focus light. The primary mirror collects light and reflects it to a secondary mirror, which then directs it to the eyepiece or a camera. Common types of reflectors include Newtonian and Cassegrain telescopes.

**Ranges:** Reflector telescopes are available in various sizes, ranging from a few inches in aperture to several feet. They are suitable for a wide range of astronomical observations, including deep sky objects and planetary viewing. **Functioning:** The primary mirror gathers incoming light and reflects it to the secondary mirror. The secondary mirror redirects the light through a hole in the primary mirror to the eyepiece or imaging equipment. Reflectors are known for their ability to gather more light compared to refractors of the same size, making them ideal for observing faint objects.

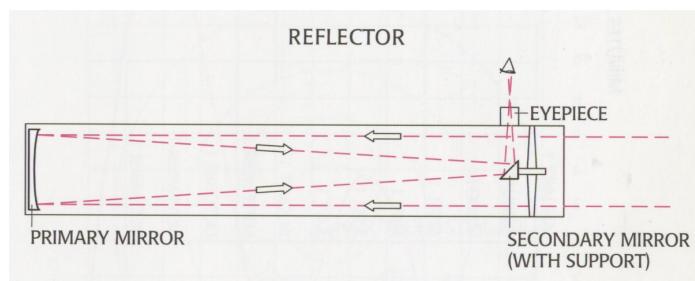


Figure 3.1: Ray diagram of a reflector telescope

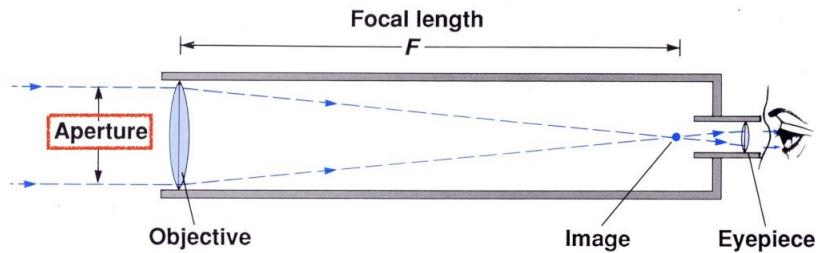


Figure 3.2: Ray diagram of a refractor telescope

### 3.2 Refractor Telescopes

**Properties:** Refractors use lenses to gather and focus light. They have a simple design with an objective lens at the front and an eyepiece at the back. Refractors offer a sealed optical tube, minimizing maintenance requirements.

**Ranges:** Refractor telescopes come in various sizes, typically ranging from a few inches to a few feet in aperture. They are versatile and suitable for a wide range of observations, including lunar, planetary, and terrestrial viewing. **Functioning:** The objective lens gathers and refracts incoming light to form an image at the focal point. The eyepiece magnifies the image for observation. Refractors are popular for their high contrast, and sharp images, making them well-suited for observing the Moon, planets, and terrestrial subjects.

### 3.3 Compound Telescopes

**Properties:** Compound telescopes combine lenses and mirrors in their optical systems. They use a combination of mirrors and lenses to fold the optical path and reduce the overall length of the telescope. Common types of compound telescopes include Schmidt Cassegrain and Maksutov Cassegrain telescopes.

**Ranges:** Compound telescopes are available in various sizes, typically ranging from a few inches to a foot in aperture. They are highly versatile and suitable for a wide range of observations, including planetary, lunar, and deep sky viewing. **Functioning:** Light enters through the front corrector lens, which collects the light and directs it to the primary mirror. The primary mirror reflects the light to the secondary mirror, which then reflects it to the eyepiece or camera. Compound telescopes offer a compact design, allowing for portability while maintaining a large aperture size.

Reflector telescopes can be further classified based on the mirror employed:

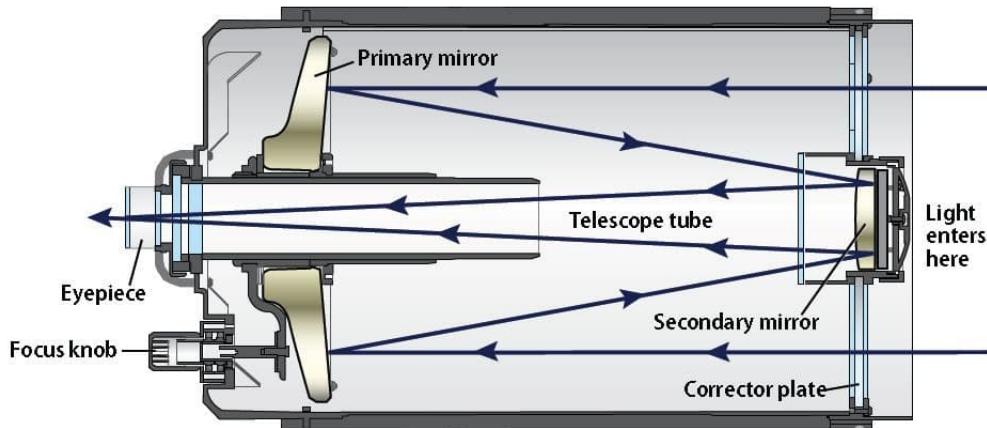


Figure 3.3: Ray diagram of a compound telescope

Did you know that we could make an actual telescope from a spinning liquid? Find out more by checking out this cool video: <https://youtu.be/sOsQYAWSHzU>

### 3.4 Parabolic Telescopes

#### Design

A parabolic telescope employs a primary optical element known as a parabolic mirror. This mirror possesses a concave shape, with its reflecting surface conforming to the curve of a parabola. Parabolic mirrors possess the remarkable ability to converge incoming parallel light rays to a single point, referred to as the focal point. Consequently, these mirrors facilitate precise image formation and enable high-resolution observations.

#### Advantages:

Parabolic mirrors are designed to minimize spherical aberration, an optical aberration responsible for image blurring and distortion. The curvature of the mirror ensures that light rays from various regions of its surface converge at the same focal point, resulting in a sharp and well-defined image. Parabolic telescopes efficiently capture and focus light, rendering them suitable for diverse applications, including visual observation and astrophotography. These telescopes excel in resolving fine details and facilitating the observation of faint celestial objects.

### 3.5 Elliptical Telescopes

#### Design

An elliptical telescope employs an elliptical mirror as its primary optical element. This mirror, characterized by a concave shape, follows the curve of an ellipse. Elliptical mirrors offer a more compact design compared to parabolic mirrors. The elliptical shape allows for a shorter tube length while still maintaining effective light-gathering and focusing capabilities. **Advantages**  
Elliptical telescopes are renowned for their wider field of view when compared to traditional parabolic telescopes. This feature makes them particularly well-suited for observing expansive celestial objects, such as galaxies or star clusters. Elliptical telescopes commonly find application

in wide-field observations where a comprehensive perspective of the sky is desired. They prove valuable in surveys, the search for transient events, and the capture of panoramic views of the cosmos.

Moving on, there's another important factor used to classify telescopes.

The following video provides a comprehensive study of the azimuthal mount and the equatorial mount <https://youtu.be/Ufi0njStt2s>

### 3.6 Mounts

The mount is a sturdy support structure that holds the telescope and enables controlled movement. There are two primary types of mounts:

#### 3.6.1 Azimuthal mount

**Properties:** An azimuthal mount, also known as an alt-azimuth mount, is a type of telescope mount that allows movement in two perpendicular axes: altitude (up and down) and azimuth (left and right). It provides a simple and intuitive way to point the telescope in any direction.

##### Advantages

Azimuthal mounts are easy to operate and require minimal setup time. They are suitable for casual observing, terrestrial viewing, and beginners in astronomy. They are also commonly used in portable telescopes and camera tripods.

##### Usage

Azimuthal mounts are commonly used for visual observations, tracking celestial objects, and casual stargazing. They are well-suited for observing the Moon, planets, and brighter deep-sky objects. They are popular for terrestrial observations, such as birdwatching and landscape viewing.

#### 3.6.2 Equatorial Mount

##### Properties:

An equatorial mount is a telescope mount designed to align with the celestial coordinates of the sky. It consists of two perpendicular axes: Right Ascension (RA) and Declination (Dec). The RA axis is aligned with the celestial pole, while the Dec axis is perpendicular to it. This alignment allows for easy tracking of celestial objects as they appear to move across the sky due to Earth's rotation. Equatorial mounts provide continuous and accurate tracking of celestial objects by aligning with Earth's rotation.

##### Advantages

Equatorial mounts offer precise tracking of celestial objects, making them ideal for long-exposure astrophotography and detailed observations. Once properly aligned, they allow objects to stay centered in the field of view with just one motion.

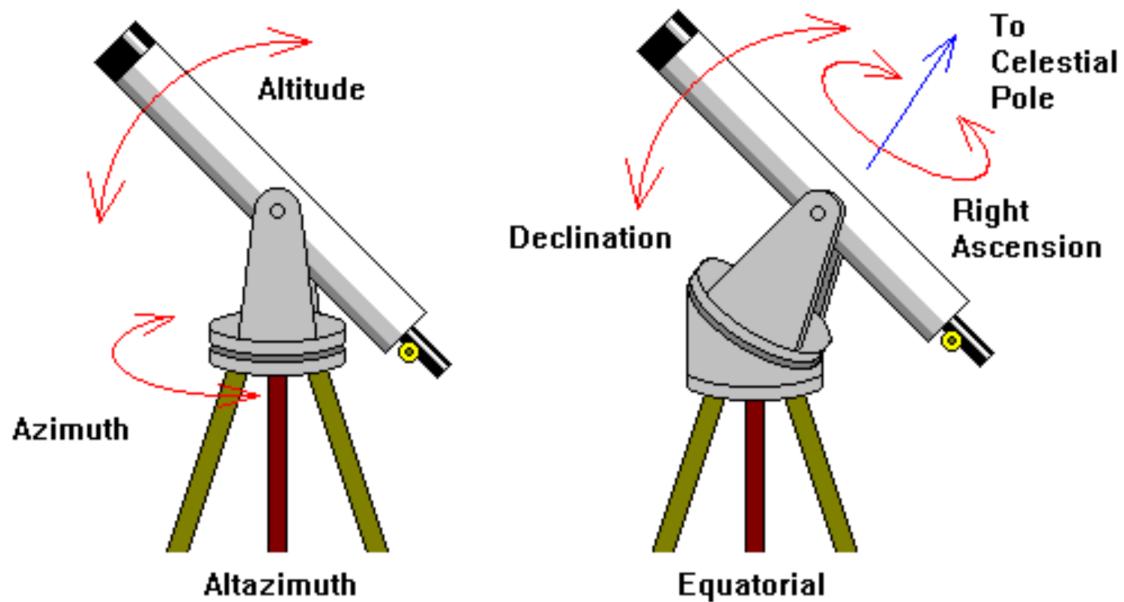


Figure 3.4: Axes of rotation for an azimuthal and equatorial mount

### Usage

Equatorial mounts are commonly used by advanced astronomers, astrophotographers, and researchers. They are well-suited for deep-sky observations, planetary imaging, and astrophotography. Equatorial mounts are popular for tracking and imaging galaxies, nebulae, star clusters, and other faint celestial objects.

# IMAGE QUALITY

Here's a video that evaluates the relation between resolution aperture and wavelength: <https://youtu.be/g0pbXBppUEU>

## 4.1 Diffraction

Diffraction is the phenomenon in which light waves undergo bending or spreading when encountering an obstacle or passing through an aperture.

Diffraction imposes limitations on the resolution of a telescope, which refers to its ability to discern fine details in an image. This limit is known as the diffraction limit or the Rayleigh criterion.

## 4.2 Angular Resolution

Angular resolution is primarily determined by the diameter of the telescope's aperture. It represents the ability of the telescope to distinguish fine details and resolve closely spaced objects. The larger the aperture, the better the angular resolution. This is because a larger aperture allows more light to enter the telescope, resulting in a narrower diffraction pattern and finer details being captured.

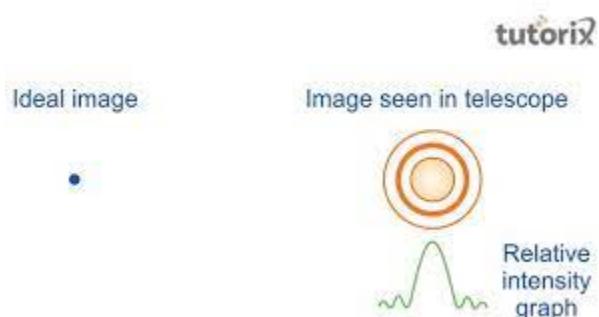


Figure 4.1: Effect of diffraction in a telescope

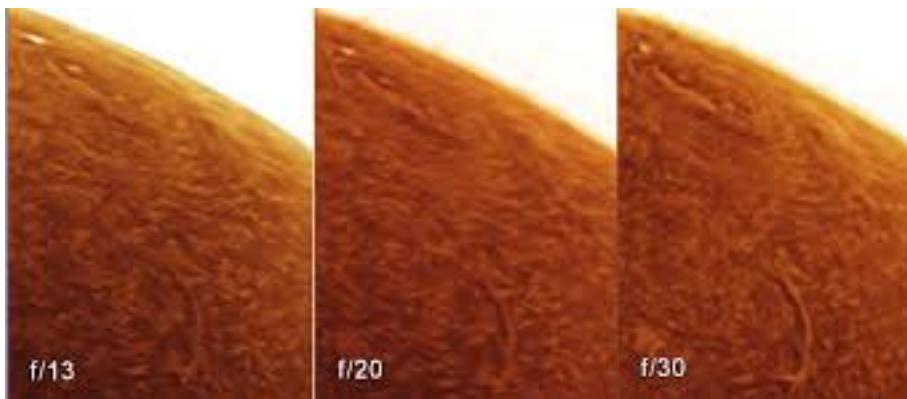


Figure 4.2: Dependence of resolution on f-ratio

### 4.3 Plate Scale

Plate scale refers to the angular size of an object in the sky per unit distance on the telescope's image plane. It is determined by the focal length of the telescope and the size of the detector or image sensor used. A smaller plate scale provides a narrower field of view, resulting in higher magnification and a better image scale for observing smaller and more detailed objects. Conversely, a larger plate scale offers a wider field of view, suitable for observing larger objects or panoramic views of the sky.

The plate scale is intricately linked to the focal length and aperture of the telescope. A longer focal length combined with a larger aperture produces a smaller plate scale, allowing for higher magnification and finer details. Conversely, a shorter focal length or smaller aperture results in a larger plate scale, providing a wider field of view but potentially sacrificing some resolution.

### 4.4 Focal Ratio (f/number)

The focal ratio is the ratio of the telescope's focal length to its aperture diameter. It affects the telescope's light-gathering ability, image brightness, and depth of focus. A lower focal ratio (e.g., f/4) allows more light to enter the telescope, resulting in brighter images. It also provides a shallower depth of focus, which can be advantageous for astrophotography. Higher focal ratios (e.g., f/10) provide a greater depth of focus, which is beneficial for planetary observations where a larger depth of focus helps maintain sharp focus across the planet's disc.

The focal ratio is closely related to the aperture diameter. For a given focal length, a larger aperture results in a lower focal ratio. This means that telescopes with larger apertures can achieve brighter images and potentially shallower depth of focus. However, it's important to balance the focal ratio with other factors, such as the desired field of view and the availability of suitable eyepieces.



Figure 4.3: Aperture and the light gathering power

## 4.5 Aperture

The aperture of a telescope refers to the diameter of its primary lens or mirror. It plays a crucial role in determining the telescope's light-gathering capability, resolving power, and image brightness. A larger aperture collects more light, allowing for brighter and clearer images. It also improves the telescope's ability to resolve fine details and observe faint objects.

The aperture is directly linked to both angular resolution and plate scale. A larger aperture enhances angular resolution by reducing the effects of diffraction and improving the telescope's ability to separate closely spaced objects. Additionally, a larger aperture, combined with a longer focal length, produces a smaller plate scale, allowing for higher magnification and finer details.

## 4.6 Optical Quality

Optical quality refers to the precision and quality of the telescope's optics, including lenses or mirrors and their coatings. It affects image sharpness, contrast, and the overall quality of the observed images. High optical quality ensures minimal optical aberrations, such as chromatic aberration or spherical aberration, resulting in sharper and more accurate images. It also improves contrast and reduces scattered light, enhancing overall image quality.

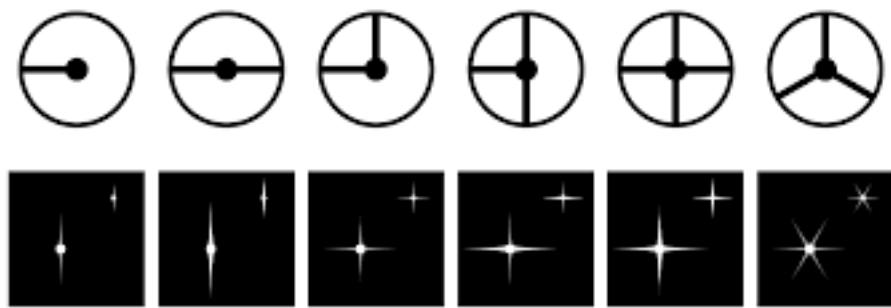


Figure 4.4: Spider vanes causing diffraction

Even a telescope with a large aperture may not deliver optimal image quality if its optics have significant aberrations. Therefore, investing in high-quality optics and maintaining them in good condition is crucial for obtaining the best possible images.

## 4.7 Size of the mirror

Large mirrors hold significant importance in telescopes as they serve the purpose of collecting and focusing light emitted from distant celestial objects. The size of the mirror's surface area directly affects its light-gathering capacity. Consequently, larger mirrors are capable of gathering more light, resulting in brighter and clearer images. As a result, observatories try to make the telescope as big as possible. The radius can get insanely high. The largest visible-light telescope currently in operation is at Gran Canarias Observatory and features a 10.4-meter (34-foot) primary mirror. The Hobby-Eberly Telescope at McDonald Observatory near Fort Davis, Texas, has the world's largest telescope mirror.

Why do stars appear spiky in the images taken by a telescope? Well, let's find out! <https://youtu.be/ipe3NN1yPzM>

## 4.8 Spider vanes

Spider vanes are support structures in telescopes that hold the secondary mirror in place. While their primary purpose is mechanical stability, they can introduce some optical effects due to their presence in the optical path. Spider vanes are typically thin metal or carbon fiber strips that extend from the telescope's central obstruction (caused by the secondary mirror) towards the edges of the primary mirror. The number of spider vanes can vary, with three-vane and four-vane configurations being the most common examples.

Spider vanes can cause diffraction effects that alter the appearance of objects observed through the telescope, particularly bright stars. The vanes create interference patterns that manifest as

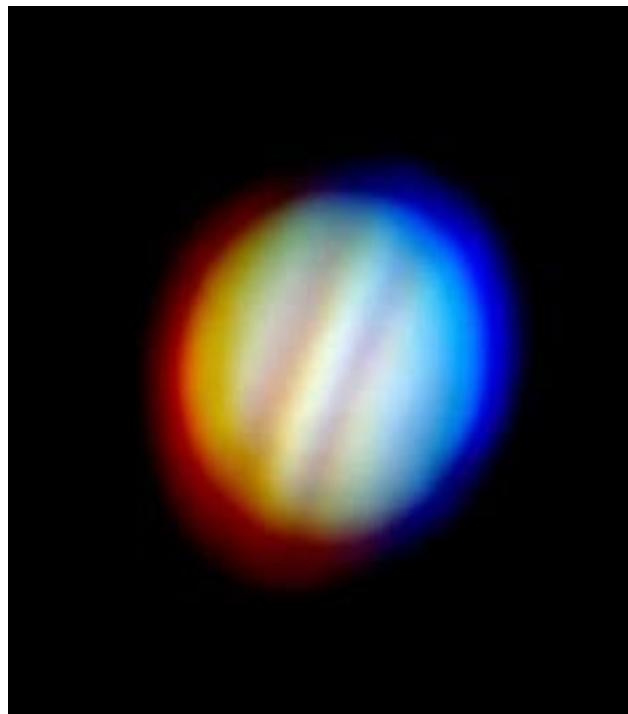


Figure 4.5: Chromatic aberration as seen in an image of Jupiter

spikes radiating from the bright object. The number and thickness of the vanes determine the appearance of the diffraction pattern. Some telescopes employ a secondary mirror cell supported by an optical window. This design eliminates the spider vanes from the optical path, reducing their diffraction effects.

#### 4.9 Chromatic aberration

It is the failure of a lens or lens system to bring all colors to a common focus because the refractive index of glass varies with the wavelength of the light passing through it, resulting in color fringing. It shows as a blue halo around bright stars and as a yellow and blue color cast to the opposite edges of the Moon and the planets. This effect is more pronounced in shorter f-ratio telescopes. The effect can be minimized in scopes that use two glass elements made from different types of glass (historically crown and flint glass).

# DIGITAL IMAGING USING TELESCOPES

Telescopes now, with the introduction of digital imaging have revolutionized the field of astronomy by providing us with ultra-high resolution images of deep space and celestial bodies at a distance never gauged before.

A small video on CCDs <https://youtu.be/wsdmt0De8Hw>

## 5.1 Charge Coupled Devices (CCDs)

**Working Principle:** Charge Coupled Devices (CCDs) are electronic devices utilized in digital imaging. They employ an array of light-sensitive pixels that convert incident light into electrical charge, storing the accumulated charge within each pixel.

**Functioning:** When light strikes a pixel, it generates electron-hole pairs within a semiconductor material, resulting in the accumulation of charge. This charge is subsequently transferred through a sequence of electrodes to a readout node, where it is converted into a digital signal representing the brightness or intensity of the captured light.

**Evolution over Time:** CCD technology has undergone significant advancements since its

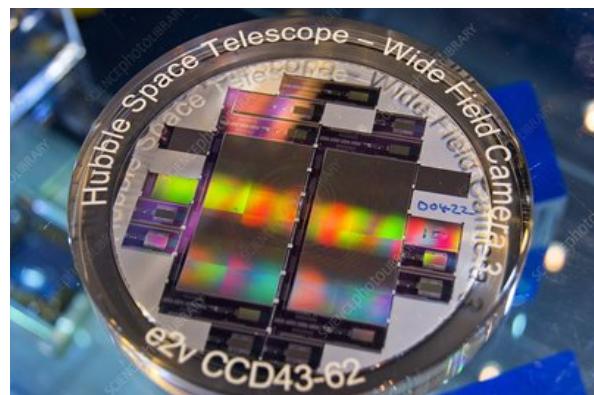


Figure 5.1: A CCD used on the Hubble Space Telescope

inception. Early CCDs possessed relatively lower resolution and found primary application in scientific and astronomical research. However, advancements in fabrication techniques have yielded high-resolution CCDs suitable for diverse imaging purposes.

**Usage and Advantages:** CCDs have revolutionized astrophotography by enabling the acquisition of digital images with high sensitivity and minimal noise. They are extensively employed in astronomical telescopes due to their ability to detect faint light emitted by distant celestial objects. CCDs exhibit excellent quantum efficiency, facilitating efficient light detection across a wide range of wavelengths.

**Resolution:** CCDs are available in varying resolutions, typically measured in megapixels. Higher-resolution CCDs offer finer details in captured images and enable more precise measurements of astronomical objects.

**Differences:** CCDs differ from other types of image sensors, such as CMOS (Complementary Metal Oxide Semiconductor) sensors, in terms of their construction and readout mechanisms. CCDs provide superior image quality, particularly in low-light conditions, owing to their reduced noise levels. However, they may have slower readout speeds compared to CMOS sensors.

**Example:** CCDs find extensive usage in professional observatories and space telescopes. For instance, the Hubble Space Telescope relied on CCD detectors to capture awe-inspiring images of distant galaxies and nebulae.

## 5.2 Basics of Digital Imaging in Telescopes:

**Image Sensors:** Image sensors, including CCDs, form the fundamental components of digital cameras employed in telescopes. They convert incident light into electrical signals, allowing for subsequent processing and storage as digital data. These sensors comprise an array of pixels, with each pixel capturing the light intensity at a specific location.

**Pixel Resolution:** Pixel resolution refers to the number of pixels present in an image sensor. Higher pixel resolution yields enhanced image detail and enables larger prints or closer examination of digital images. However, higher resolution necessitates greater storage capacity for the captured images.

**Capturing Astronomical Images:** In telescopes, astronomical images are obtained by exposing the image sensor to light emitted by celestial objects. The duration of the exposure varies depending on the desired level of detail and the object's brightness. Longer exposures are typically employed to capture faint objects, whereas shorter exposures are suitable for brighter objects.

**Processing Astronomical Images:** Once captured, astronomical images undergo various processing techniques to enhance their quality and extract meaningful scientific information. These techniques encompass noise reduction, image stacking, color balancing, and image calibration to eliminate artifacts and improve image clarity.

**Example:** Modern amateur astrophotographers employ CCD cameras and dedicated astronom-



Figure 5.2: The penetration of different components of the electromagnetic spectrum into the earth's atmosphere

ical imaging software to capture and process stunning images of planets, galaxies, and nebulae from their observation setups.

# SPACE TELESCOPES

Space telescopes are super fascinating and have helped us make groundbreaking discoveries and got us closer than ever to uncovering the secrets of the universe. And we have just the right person with us to tell y'all all there's to know about space telescopes. Neil deGrasse Tyson on space telescopes: <https://youtu.be/7aGJ69u76vA>

## 6.1 Revolutionizing Astronomy Beyond Earth's Atmosphere

### Introduction

Space telescopes have revolutionized the field of astronomy by providing unparalleled views of the universe unobstructed by Earth's atmosphere. These remarkable instruments have enabled scientists to observe celestial objects with unprecedented clarity, revealing insights into the cosmos that were once inaccessible from the ground. In this comprehensive account, we will explore the origins of space telescopes, the efforts to counter atmospheric effects, their advantages over terrestrial telescopes, and their functioning, and highlight a few important space telescopes that have made significant contributions to our understanding of the universe.

### Origins of Space Telescopes

The idea of placing telescopes in space originated in the mid-20th century as astronomers recognized the limitations imposed by Earth's atmosphere. Atmospheric turbulence and distortion blur the images captured by ground-based telescopes, severely limiting their resolution and sensitivity. The concept gained momentum with the advent of space exploration and the technological advancements that made it possible to launch instruments into orbit around Earth.

### Countering Atmospheric Effects

The primary motivation behind space telescopes is to overcome the adverse effects of Earth's atmosphere on astronomical observations. The atmosphere distorts light through phenomena such as atmospheric turbulence, light pollution, and absorption by atmospheric gases. By placing telescopes above the atmosphere, astronomers can capture clearer, sharper, and more detailed images of celestial objects.

### Advantages of Space Telescopes

1. Unobstructed Observations:

Space telescopes are not affected by atmospheric turbulence, allowing them to capture sharper and more detailed images.

### 2. Full Spectrum Coverage:

Space telescopes can observe the entire electromagnetic spectrum, including ultraviolet, X-ray, and gamma-ray wavelengths that are absorbed by Earth's atmosphere.

### 3. Long Observing Time:

Unlike ground-based telescopes limited by daylight and atmospheric conditions, space telescopes can continuously observe celestial objects without interruptions.

### 4. Stable Environment:

In space, telescopes are not subjected to the vibrations, temperature fluctuations, and light pollution experienced by terrestrial telescopes, providing a more stable observing environment. **Functioning of Space Telescopes**

Space telescopes consist of several essential components: 1. Optics: High-quality mirrors or lenses collect and focus incoming light. 2. Detectors: Advanced detectors, such as charge-coupled devices (CCDs), record the captured light and convert it into digital signals. 3. Instrumentation: Additional instruments onboard space telescopes, such as spectrographs and cameras, analyze and enhance the captured data. 4. Power and Communication: Solar panels provide power, while communication systems transmit the collected data back to Earth for analysis.

## Important Space Telescopes

### 1. Hubble Space Telescope (HST):

Launched in 1990, the Hubble Space Telescope is one of the most iconic space observatories. It has provided breathtaking images and made numerous scientific discoveries across various fields of astronomy.

### 2. Chandra X-ray Observatory:

Launched in 1999, Chandra is dedicated to studying X-ray emissions from high-energy celestial sources, such as black holes, supernovae, and galaxy clusters.

**3. Spitzer Space Telescope:** Launched in 2003, Spitzer was specifically designed to observe the universe in the infrared portion of the electromagnetic spectrum, unveiling hidden celestial objects like dusty star-forming regions and exoplanets.

### 4. James Webb Space Telescope (JWST):

Set to launch in late 2021, JWST is the highly anticipated successor to the Hubble Space Telescope. It promises to revolutionize our understanding of the early universe, exoplanets, and more.

## Space Telescopes vs. Terrestrial Telescopes

While both space and terrestrial telescopes play crucial roles in astronomy, space telescopes have distinct advantages:

### 1. Image Quality:

Space telescopes offer significantly higher image quality due to the absence of atmospheric distortion.

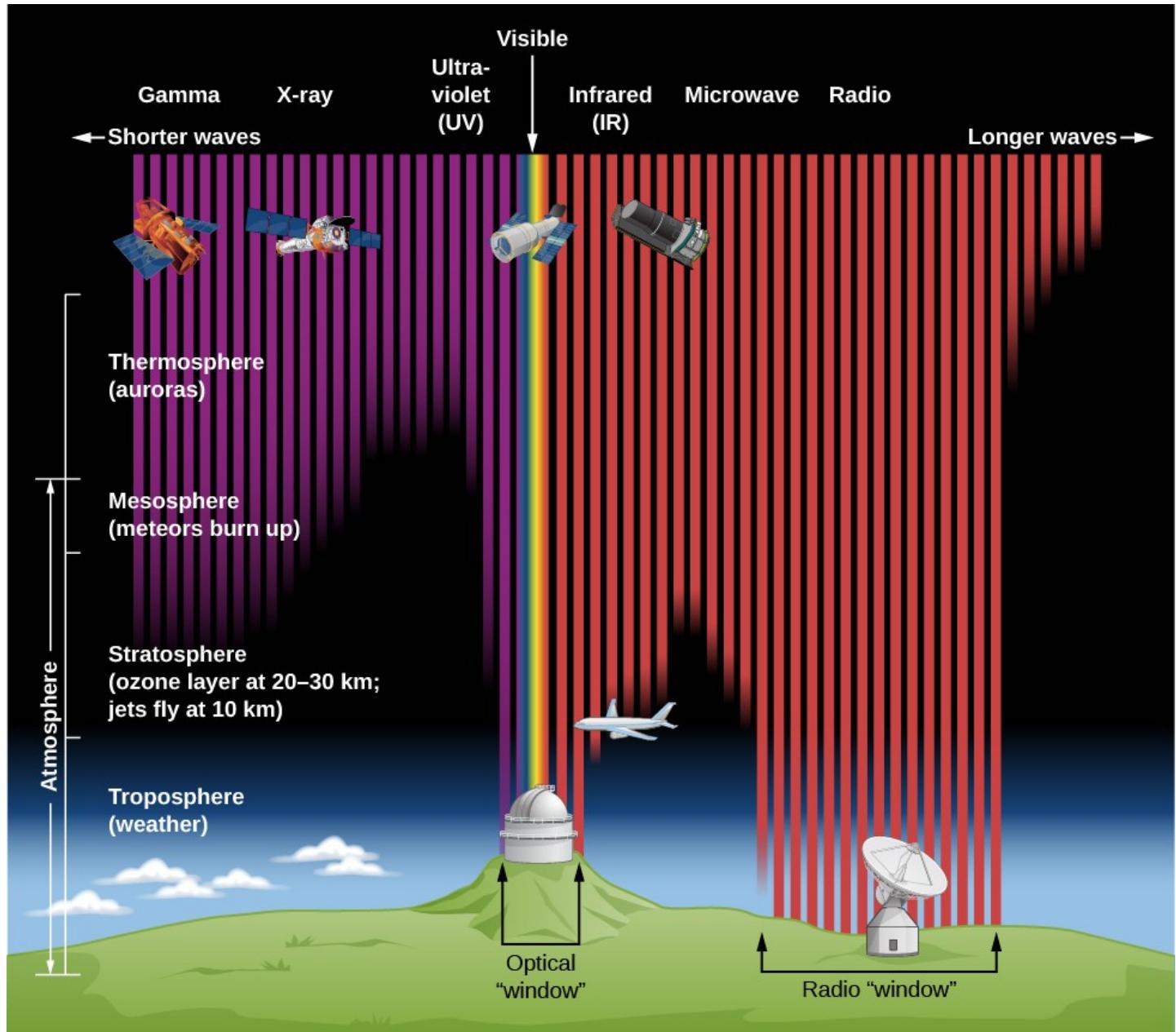


Figure 6.1: The penetration of different components of the electromagnetic spectrum into the earth's atmosphere

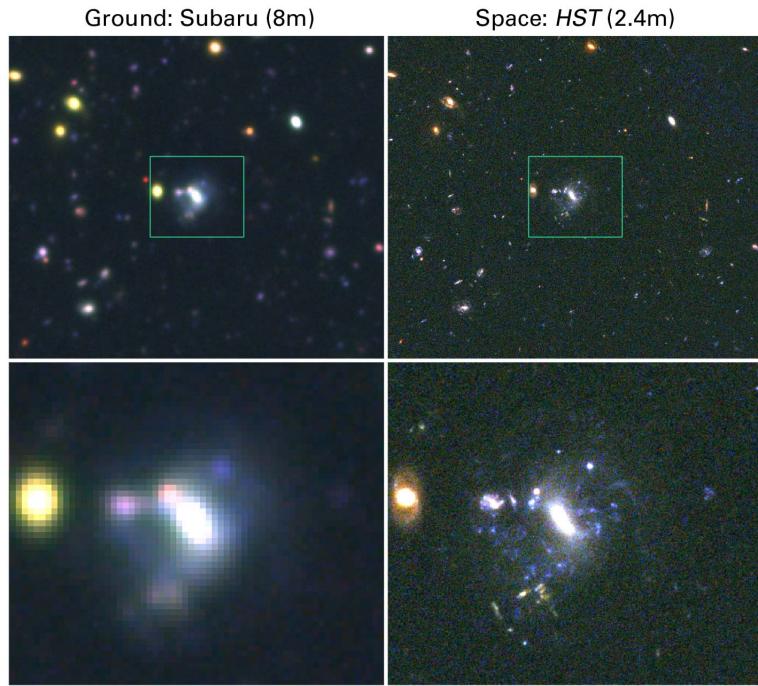


Figure 6.2: A comparison between images captured by a ground telescope and a space telescope

#### 2. Observing Range:

Space telescopes can observe a broader range of wavelengths, including those absorbed by Earth's atmosphere.

#### 3. Continuous Observation:

Space telescopes can observe continuously without being limited by daylight or atmospheric conditions.

#### 4. Stability:

Space telescopes operate in a stable environment, free from vibrations, temperature fluctuations, and light pollution.

## 6.2 The Hubble Space Telescope

Here's a fascinating story about an image captured by the Hubble that ended by changing astronomy: <https://youtu.be/95Tc0Rk2cNg>

The Hubble Space Telescope (HST) is one of the most iconic and influential astronomical observatories ever launched into space. Launched in 1990, the HST has transformed our understanding of the universe, delivering breathtaking images and groundbreaking scientific discoveries. In this comprehensive account, we will explore the history, achievements, capabilities, and impact of the Hubble Space Telescope.

### History and Launch

The concept of a space-based telescope was conceived in the 1940s, but it wasn't until the 1970s that concrete plans for the HST began to take shape. The development and construction of the telescope involved collaboration between NASA and the European Space Agency (ESA). The HST was finally launched aboard the Space Shuttle Discovery on April 24, 1990.

### Achievements and Scientific Discoveries

The Hubble Space Telescope has made numerous groundbreaking scientific discoveries across various fields of astronomy. Some of its notable achievements include:

#### 1. Determining the Age of the Universe:

The HST's observations of distant galaxies helped refine estimates of the age of the universe to be approximately 13.8 billion years.

#### 2. Probing Dark Matter:

By studying the effects of gravitational lensing, Hubble contributed to our understanding of dark matter, an elusive substance that makes up a significant portion of the universe's mass.

#### 3. Measuring the Expansion Rate of the Universe:

Hubble's observations of distant supernovae provided evidence for the accelerated expansion of the universe, leading to the discovery of dark energy.

#### 4. Mapping Exoplanet Atmospheres:

Hubble observed the atmospheres of exoplanets, providing insights into their composition and potential habitability.

#### 5. Unveiling Star Formation:

Hubble's observations of nebulae and star-forming regions have shed light on the processes involved in the birth and evolution of stars.

### Capabilities and Instruments

The Hubble Space Telescope is equipped with several state-of-the-art instruments that enable a wide range of observations across the electromagnetic spectrum. Its primary instruments include:

#### 1. Wide Field Camera 3 (WFC3):

This versatile instrument captures images in ultraviolet, visible, and infrared light, allowing scientists to study distant galaxies, star clusters, and nebulae.

#### 2. Advanced Camera for Surveys (ACS):

ACS is designed for high-resolution imaging and spectroscopic observations, contributing to various research areas, including galaxy evolution and the study of dark matter.

#### 3. Cosmic Origins Spectrograph (COS):

COS is primarily used for ultraviolet spectroscopy, providing insights into the composition and dynamics of celestial objects.



Figure 6.3: The Hubble Space Telescope



Figure 6.4: An image captured by the Hubble Space Telescope

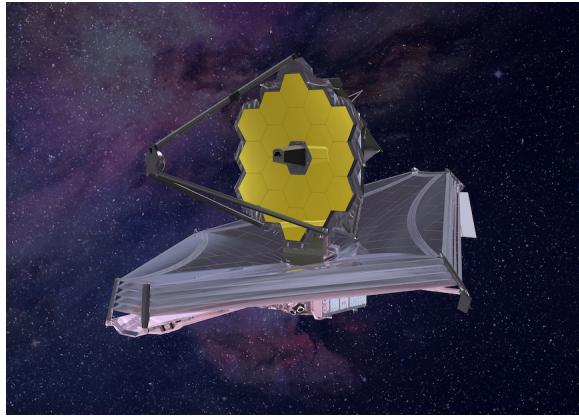


Figure 6.5: The James Webb Space Telescope



Figure 6.6: An image captured by the James Webb Space Telescope

### 6.3 The James Webb Space Telescope

Here's all the engineering you need to know behind the James Webb Space Telescopes: <https://youtu.be/aICaAEXDJQQ>

The James Webb Space Telescope (JWST) is the highly anticipated successor to the Hubble Space Telescope, set to be launched in late 2021. JWST represents a significant leap forward in technological capabilities, promising to revolutionize our understanding of the early universe, exoplanets, and other key areas of astronomical research. In this comprehensive account, we will explore the history, design, capabilities, and expectations surrounding the James Webb Space Telescope.

#### History and Development

The idea for the JWST emerged in the 1990s as astronomers recognized the need for a successor to Hubble. A collaboration between NASA, ESA, and the Canadian Space Agency (CSA), the project was named in honor of James E. Webb, NASA's administrator during the Apollo era. The development of JWST faced significant technical challenges, including the design of a large segmented mirror and the need for advanced cooling systems. **Design and Instrumentation** The James Webb Space Telescope boasts several groundbreaking features that set it apart from its predecessors. Key design elements and instruments include:

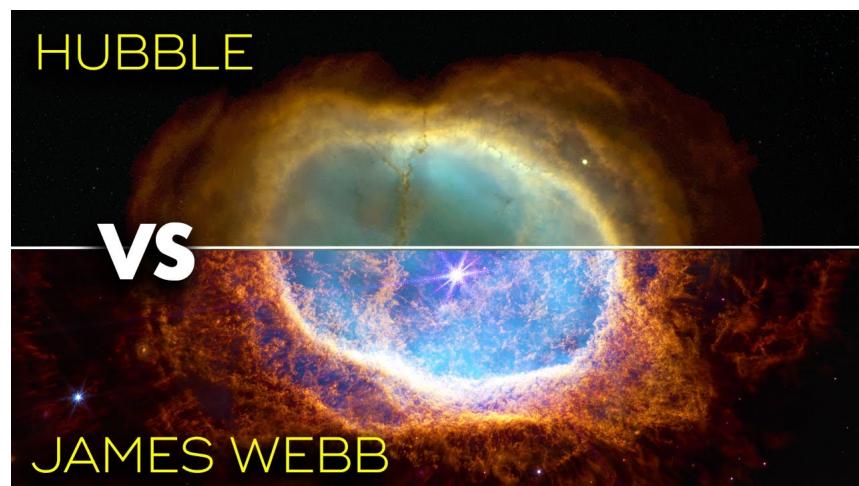


Figure 6.7: Comparing the image captured by the HST with the image captured by the JSWT

1. Large Segmented Mirror:

The primary mirror of JWST consists of 18 hexagonal segments, allowing for a large collecting area of 6.5 meters in diameter. This enables unprecedented sensitivity and resolution in infrared observations.

2. Infrared Focus:

JWST is optimized for observations in the infrared portion of the electromagnetic spectrum, as this wavelength range offers unique insights into the early universe, exoplanets, and the formation of stars and galaxies.

3. Advanced Cooling System:

To observe faint infrared signals, JWST requires extremely low temperatures. It is equipped with a sun shield that blocks sunlight and keeps the telescope's instruments and optics at cryogenic temperatures.

**Scientific Objectives:**

The James Webb Space Telescope is designed to address key scientific questions and advance our understanding of the universe. Some of its primary scientific objectives include:

1. Observing the First Galaxies:

JWST aims to observe the formation and evolution of the first galaxies, shedding light on the early universe and the processes that led to the emergence of cosmic structures.

2. Characterizing Exoplanet Atmospheres:

By studying the atmospheres of exoplanets, JWST will provide valuable insights into their composition, potential habitability, and the conditions necessary for life.

3. Investigating Star and Planet Formation:

JWST will observe protoplanetary disks and young stars, allowing scientists to study the formation and evolution of stars and planetary systems.

#### 4. Probing the Origins of Life:

By analyzing the organic molecules and chemical processes in regions of star formation, JWST aims to contribute to our understanding of the origins of life on Earth and the potential for life elsewhere in the universe.

### Achievements of the JWST

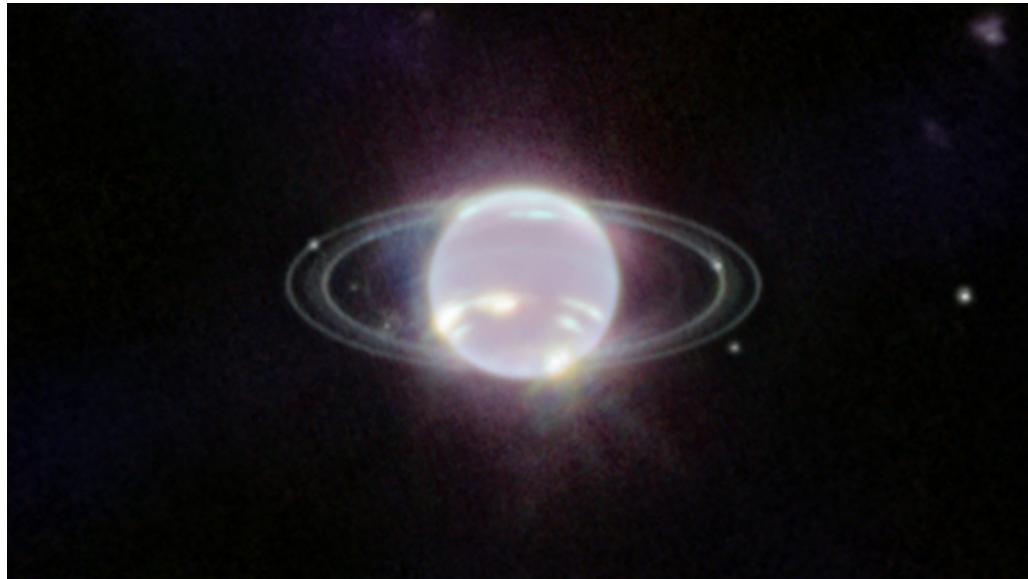


Figure 6.8: Neptune captured by the JSWT

1. Clearest view of Neptune: In October 2022, the James Webb Space Telescope released the clearest view of Neptune and its rings seen in decades. Some of these rings have not been detected since 1989, and some have never been seen at all. The image depicts the planet's bright rings and fainter dust bands.
2. In October 2022, Webb captured a Wolf-Rayet star known as WR-140. The star is a dust-forming double star system or binary. Notably, the image shows the star as being surrounded by at least 17 concentric rings that researchers believe to be dust shells. Each ring was created when the two stars came close together and their stellar winds interacted.
3. Imaging Exoplanets: Exoplanets are famously difficult to capture. The JWST has been able to take images of exoplanets with never-before-seen sensitivity which is pivotal for their research



Figure 6.9: The Wolf-Rayet star

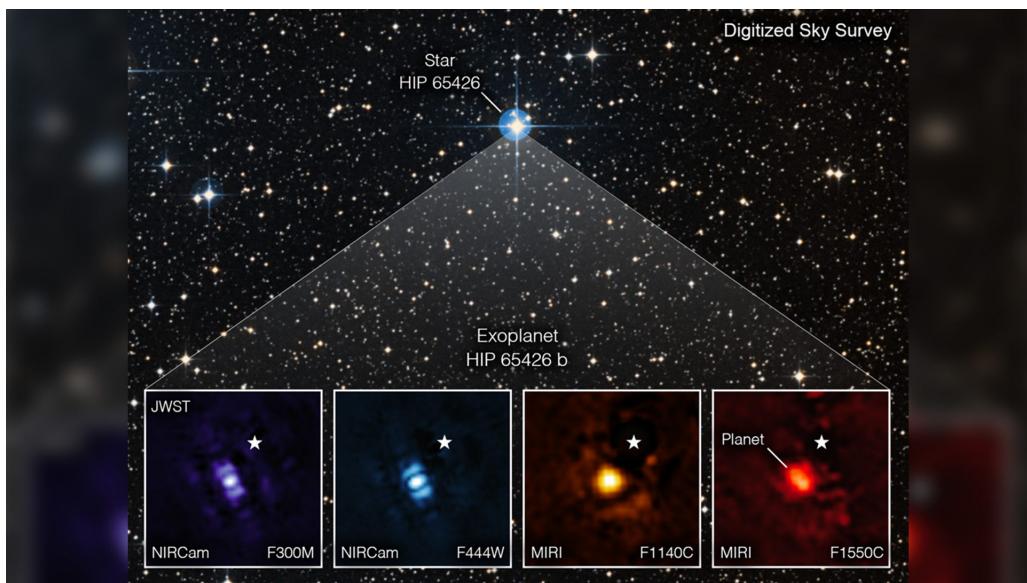


Figure 6.10: Pictures of exoplanets