# OPTICAL ODYSSEY

## SUMMER PROJECT 2023

## ASTRONOMY CLUB

IITK

ASTRO IIT KANPUR

# Acknowledgement

We would like to express our heartfelt gratitude to our mentors for guiding us throughout the course of project and making us learn and explore several exciting aspects of Telescopes and related Physics behind them. We would also like to thank the Astronomy Club, IITK and The Science and Technology Council, IITK for helped us expand our knowledge and gain valued experience.


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## 1 Introduction

The Optical Odyssey project under the Science and Technology Council, IIT Kanpur intended to teach the mentees about the optical aspects of Astronomy and the related theory of infamous astronomical telescopes, their very construction, principles applied, and working. The project included many club room sessions and Telescope handling techniques. The final motive of the project was to create a telescope model prototype to better understand the Optical ingredients of Stellar cosmology.

## 2 History

The history of the telescope dates back several centuries, with notable developments and advancements made by various astronomers and scientists. Here's an overview of the significant milestones in the history of the telescope:

The earliest known optical devices used for magnification were simple lenses. These lenses were likely used for decorative purposes rather than astronomical observations. In 1608 a German-dutch spectacle maker invented the earliest telescope called Hans Lippershey Telescope. His telescope had a concave eyepiece which was aligned with a convex objective lens.

In 1609, the Italian astronomer Galileo Galilei constructed a refracting telescope. Galileo's refracting telescopes used lenses to bend or refract light. He uses a concave eyepiece lens and a convex objective lens. The glass was full of little bubbles and had a greenish tinge (caused by the presence of iron impurities). It was also hard to shape the lenses perfectly. The images of stars were blurry, and surrounded by color haloes.

Galileo himself continued to improve his devices until they were over four feet long and could magnify up to thirty times. A variation on the Galilean telescope was suggested by Johannes Kepler in 1611 in his book Dioptrice. He noted that a telescopic device could be built using two convex lenses, but the image it produced would be upside down.

The advantage of this design, according to Kepler, was its larger field of view and high magnification. His recommendation was not immediately taken up by astronomers, however. The Keplerian telescope was not accepted until Christoph Scheiner, a German Jesuit mathematician interested in instruments, published his book Rosa Ursina in 1630. For his study of sunspots, Scheiner experimented with telescopes having only convex lenses. He found that when he viewed an object directly through such an instrument the image was flipped upside down. But it was much brighter and the field of view much larger than in a Galilean telescope, as Kepler had predicted. Since for astronomical observations, an inverted image is no problem, the advantages of what became known as the "astronomical telescope" led to its general acceptance in the science community by the middle of the 17th century.

An even larger "long-focus" telescope was described by the German astronomer Johannes Hevelius in his 1673 book Machinae Coelestis. He made telescopes with focal lengths as long as 150 feet and lenses up to 8 inches in diameter. The Huygens brothers also developed "aerial telescopes." These featured an objective lens mounted in an iron tube at the top of a tall pole. The astronomer raised and lowered this and found the image by trial and error.

Further power increases came, beginning in the mid-17th century, from a new form of telescope - the reflecting telescope. In the 17th century, several astronomers, including Isaac Newton and James Gregory, began experimenting with reflecting telescopes. These telescopes used mirrors instead of lenses to gather and focus light, eliminating some of the chromatic aberration inherent in lenses. Newton's reflecting telescope, known as the Newtonian telescope, became particularly influential and is still widely used today. By the beginning of the 18th century, very long refracting telescopes were rarely used anymore.

In the 18th and 19th centuries, astronomers started building larger aperture telescopes to gather more light and improve their ability to observe faint celestial objects. The size and quality of mirrors improved over time, enabling astronomers to study distant stars, galaxies, and nebulae in greater detail.
Refracting Telescopes with Apochromatic Lenses (19th Century) The development of apochromatic lenses in the mid-19th century significantly reduced chromatic aberration in refracting telescopes. These lenses consisted of multiple elements made from different types of glass to correct color distortion.
Modern Telescope and Technologies: In the 20th and 21st centuries, telescopes have continued to evolve with the introduction of new technologies. Space-based telescopes like the Hubble Space Telescope, launched in 1990, provided unprecedented views of the cosmos unobstructed by Earth's atmosphere.
Radio telescopes and other specialized instruments also expanded our ability to study different wavelengths and phenomena. The 20th century also saw the development of telescopes that worked in a wide range of wavelengths from radio to gamma rays. The first purpose-built radio telescope went into operation in 1937.

Figure 1: Hans Lippershey Telescope

Figure 2: Galilion Telescope

Figure 3: keplerian Telescope

Figure 4: Astronomical Telescope

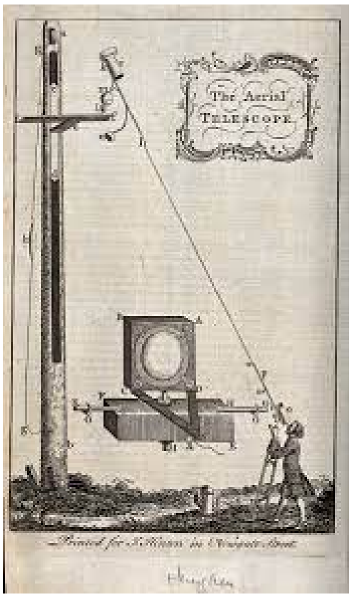


Figure 5: Arial Telescope

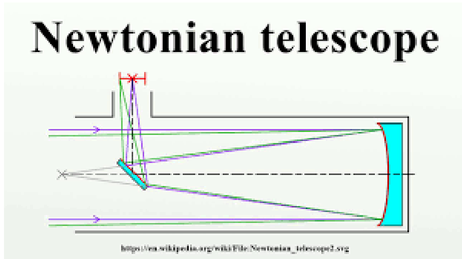


Figure 6: Newtonian Telescope

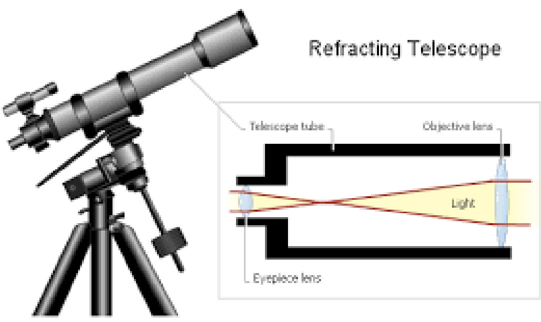


Figure 7: Refracting Telescope

Figure 8: Radio Telescope

# 3 Types of Telescope

## 3.1 Refracting Telescopes

Refracting telescopes use lenses to gather and focus light. They have a long, cylindrical tube with an objective lens at the front that collects and refracts incoming light. The light then passes through an eyepiece at the other end, allowing the viewer to observe magnified images. Refracting telescopes are ideal for observing celestial objects like the Moon, planets, and stars. They are commonly used in amateur astronomy and as terrestrial telescopes.

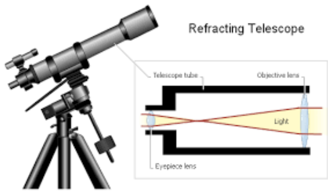


Figure 9: Refracting Telescope

## 3.2 Reflecting Telescopes

Reflecting telescopes use mirrors to gather and focus light. They have a curved primary mirror at the bottom of the telescope that collects incoming light and reflects it to a secondary mirror, which then directs the light to an eyepiece or a detector. Reflecting telescopes are widely used in professional astronomy due to their larger apertures, which allow for greater light-gathering capabilities. They are suitable for observing faint deep-sky objects, galaxies, and nebulae.

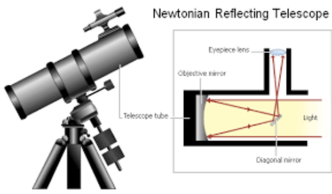


Figure 10: Reflecting Telescope

## 3.3 Catadioptric Telescopes

Catadioptric telescopes combine both lenses and mirrors to gather and focus light. They employ a combination of a corrector plate or lens at the front of the telescope, a primary mirror at the back, and a secondary mirror to reflect the light through a hole in the primary mirror. This design allows for a more compact and versatile telescope. The most common types of catadioptric telescopes are the Schmidt-Cassegrain and the Maksutov-Cassegrain telescopes. They are popular among amateur astronomers due to their portability and versatility.

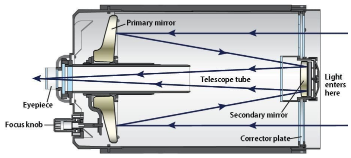


Figure 11: Catadioptric Telescope

### 3.4 Radio Telescopes

Radio telescopes are designed to detect and study radio waves emitted by celestial objects. They use large parabolic dishes or arrays of smaller dishes to collect and focus radio waves onto a receiver. The receiver converts the radio signals into electrical signals, which are then analyzed and processed. Radio telescopes allow astronomers to study phenomena such as pulsars, quasars, and cosmic microwave background radiation.

Figure 12: Radio Telescope

### 3.5 Space Telescope

Space telescopes are observatories placed in orbit around the Earth, allowing them to observe celestial objects without the interference of the Earth's atmosphere. They are equipped with various instruments to study different wavelengths of light, such as visible, ultraviolet, and X-ray. Examples of space telescopes include the Hubble Space Telescope, the Chandra X-ray Observatory, and the Spitzer Space Telescope.

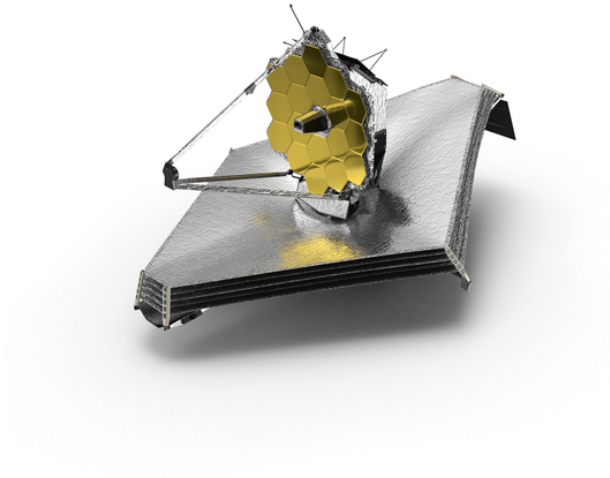

Figure 13: Space Telescope

# 4 Components of Telescope

The main components are as follows:

## 4.1 Aperture

It is a portion of the mirror from which light reflection occurs. The larger the telescope's aperture, the more light it can gather making the image brighter, sharper, and able to produce more details.

## 4.2 Eyepiece

The eyepiece lens magnifies the image formed by the large objective lens and directs the light to your eye.

## 4.3 Finderscope

It assists you in locating objects to observe through the main telescope. It allows the viewer to easily target a specific area for study. Many are equipped with crosshairs to help the user accurately target distant objects.

## 4.4 Telescopic Mounts

### 4.4.1 Equitorial Mount

An equatorial mount is a mount for instruments that compensate for the earth's rotation by having one rotational axis, a polar axis, parallel to the earth's axis of rotation.

### 4.4.2 Azimuthal Mount

A simple two-axis mount for supporting and rotating an instrument about two perpendicular axes – one vertical and the other horizontal. Rotation about the vertical axis varies the azimuth (compass bearing) of the pointing direction of the instrument.

## 4.5 Tripode

The astronomical tripod is a sturdy three-leg stand used to support telescopes or binoculars, though they may also be used to support attached cameras or ancillary equipment. Most tripods have extendable legs. This allows you to vary their height, thereby compensating for uneven terrain.

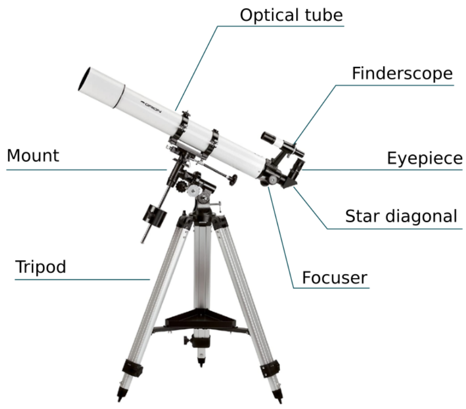


Figure 14: Components of telescope

# 5 Radio Interferometry

Radio interferometry is an advanced technique, developed by professional radio astronomers, that allows using many smaller antennas instead of a too-large one. These groups of antennas together receive the radio waves; with interferometry, radio astronomers can combine the signals from many antennas, and even many telescopes. It allows them to create an image that is much brighter and sharper than what is much brighter and sharper than what is possible from a single antenna dish. Radio interferometers record information about the sky in Fourier space, also called visibility space. The relation between the measurement and the specific brightness distribution of the source is described by the van Cittert-Zernike theorem, which states that the two-point correlation function of the electric field measured by two antennas of the radio interferometer is the Fourier-transformed intensity distribution of the source. As the number of antennas in a radio interferometer array is limited, the sampled Fourier space always remains incomplete. By applying the inverse Fourier transformation to the data, artifacts dominate the reconstructed image.

Figure 15: Radio Interferometer

# 6 HR DIAGRAM

The Hertzsprung-Russell diagram shows the relationship between a star's temperature and its luminosity. It is also often called the H-R diagram or color-magnitude diagram. It is a very useful graph because it can be used to chart the life cycle of a star. We can use it to study groups of stars in clusters or galaxies.

If all stars were alike, all those with the same luminosity would have the same temperature. We might also expect hotter stars to always be brighter than cooler ones. By looking at the chart, we can see this is not the case. There are groups of bright, hot stars and groups of bright, cool stars. There are also groups of dim, hot stars and groups of dim, cool stars.

Most stars, including the Sun, plot in a band that runs from the top-left to the bottom-right of the chart. Stars in this area of the chart are in the main-sequence stage of their lives. We can use the chart to see that the temperature of main-sequence stars increases with brightness. This is because the star's mass controls both its temperature and brightness at this stage.

The turnoff point for a star refers to the point on the Hertzsprung–Russell diagram where it leaves the main sequence after its main fuel is exhausted – the main sequence turnoff.

By plotting the turnoff points of individual stars in a star cluster one can estimate the cluster's age.

## 6.1 Observation from HR diagram

Red giant and red supergiant stars fall in the top-right of the chart. This tells us they are brighter than main sequence stars but also redder and cooler. This is because they expand and cool as they reach the final stages of their lives. However, because of their large size, they remain very bright.

In the bottom-left of the chart, we find hot stars that are dimmer than main-sequence stars. This is because they have small radii but contain a lot of mass. These are white dwarf stars.

Stars tend to spend about 90% of their life in the main-sequence stage. After this, they evolve into giant stars for the remaining 10% of their lives. Finally, they will either explode as a supernova or become white dwarf stars.

## 6.2 HR Diagrams of various Globular Cluster

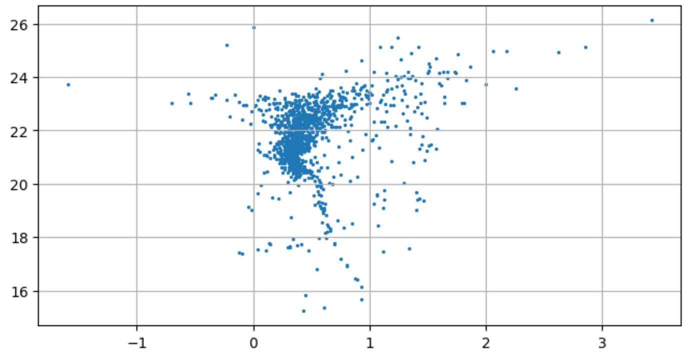


Figure 16: PAL5, Age: 11.5 billion years

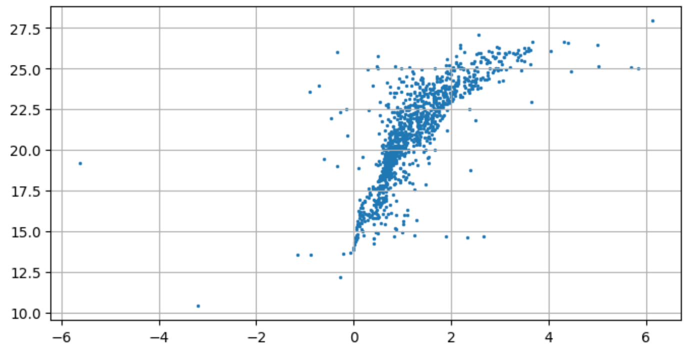


Figure 17: NGC2401, Age:25 million years

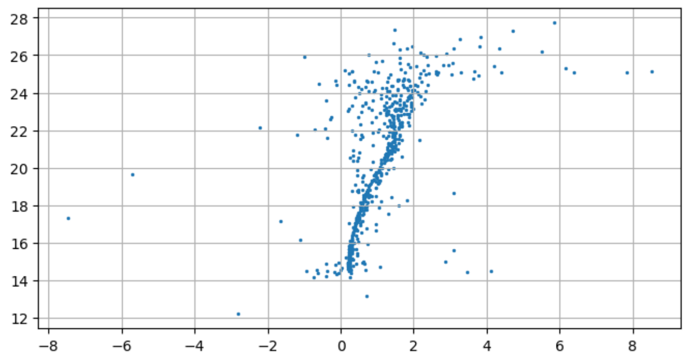


Figure 18: NGC2420, Age: 2.5 billion years

The location of the main sequence turn-off point of each graph determines the age of the globular cluster.

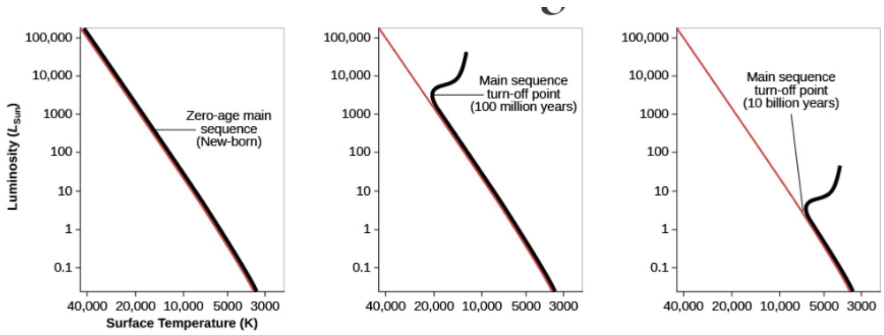


Figure 19: Age of star clusters

# 7 James Webb Space Telescope

## 7.1 Introduction

Launched on 25 December 2021 on an Ariane 5 rocket from Kourou French Guiana, this telescope is the largest space telescope to conduct infrared astronomy. JWST arrived at the Sun-Earth L2 Lagrange point in January 2022. Webb's primary mirror consists of 18 hexagonal mirror segments made of gold-plated beryllium, which combined create a 6.5-meter- diameter (21 ft) mirror, compared with Hubble's 2.4 m (7 ft 10 in). This gives Webb a light-collecting area of about 25 square meters, about six times that of Hubble. Unlike Hubble, which observes in the near ultraviolet and visible (0.1 to 0.8 m), and near-infrared (0.8–2.5 m)[14] spectra, Webb observes a lower frequency range, from long-wavelength visible light (red) through mid-infrared (0.6–28.3 m). Other than that the telescope needs colder temperatures below 50 K (223°C;370°F)such that the infrared light emitted by the telescope itself does not interfere with the collected light. The first Webb image was released to the public via the press. conference on 11 July 2022.

## 7.2 Parts Of JWST

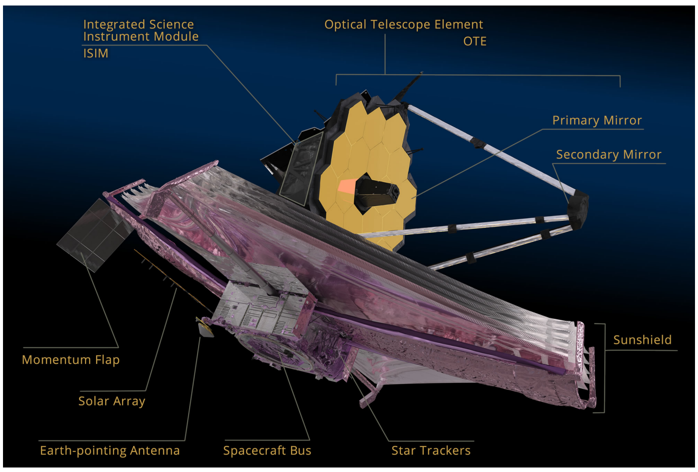


Figure 20: Parts of jwst

### 7.2.1 Sunshield

If we consider the outer then we will observe that there is no convection due to the lack of atmosphere. therefore to manage the radiation and conduction sun shields are provided in the telescopes. sun shields are lightweight and resistant to dehydration from solar radiation It also remains stable across a range of temperatures. If we discuss the structure this has FIVE layers, the first layer is about 0.05m thick, and layers 2- 5 are 0.025mm thick. It is also coated with a layer of aluminum that is about 100nm thick. Also, there is a silicon coating on layers 1 and 2 for high emissivity.

### 7.2.2 Mirrors

Mirrors present in JWST are programmable and each of the 18 segments can be moved to focus the light correctly at the center, further, the curvature of each segment can also be changed. In total, there are 18 hexagonal segments with a diameter of 6.5 m. these mirrors have beryllium plated with gold as their elements are good conductors of electricity and heat and also hold the mirror's shape across the range of temperatures. Gold is used as it is the best reflector of infrared light.

### 7.2.3 Thrusters

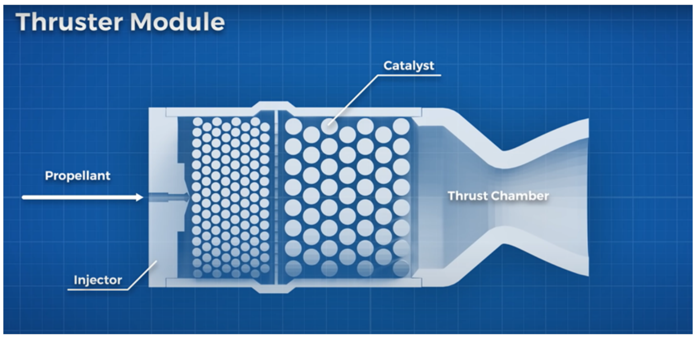


Figure 21: thrusters

The JWST uses two types of thrusters. The Secondary Combustion Augmented Thrusters (SCAT) use hydrazine (N2H4) and the oxidizer dinitrogen tetroxide (N2O4) as propellants. There are four SCATs in two pairs. One pair is used to propel the JWST into orbit, and the other performs station-keeping in orbit. 20 rocket thrusters and 8 modules were used for the movement of the mirrors.

### 7.2.4 The Acoustic cryocooler

JWST is an exquisitely sensitive infrared astronomical observatory. The detectors inside each scientific instrument convert infrared light signals into electrical signals for processing into images, to suppress infrared background noise this needs a significantly cooler temperature, and to solve that purpose this acoustic cooler is provided. Typically, the longer the wavelength of infrared light, the colder the detector needs to be to do this conversion while also limiting the generation of random "noise" electrons.

## 7.3 Integrated Science Instrument Module (ISIM)

The Integrated Science Instrument Module (ISIM) of the James Webb Space Telescope (JWST) is a critical component that houses four scientific instruments. The ISIM was designed and built by NASA's Goddard Space Flight Center in collaboration with several other agencies and institutions. It is one of the most complex and sophisticated scientific instruments ever built, with over 10,000 parts and components. These instruments work together to observe the universe in a wide range of wavelengths, from visible light to mid-infrared. Now we will move to the components of ISIM named as

### 7.3.1 Nircam Instrument

Near Infrared Camera (NIRCam) is designed to capture images of the earliest galaxies in the universe and stars and planets within our own galaxy. The NIRCam operates in the near-infrared spectrum, which allows it to see through dust and gas clouds that obscure visible light. It has two cameras, each with its own set of filters and detectors, allowing for high-resolution imaging and spectroscopy. Another instrument is the,

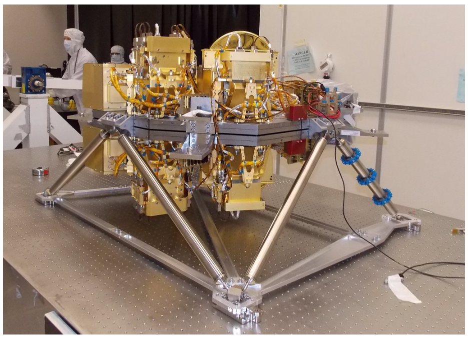

Figure 22: NIRCAM INSTRUMENT

### 7.3.2 Miri Instrument

Mid-Infrared Instrument (MIRI). It is designed to study the formation of stars and planetary systems, as well as the chemical composition of distant galaxies. The MIRI operates in the mid-infrared spectrum, allowing it to detect heat signatures from objects too cold to emit visible light. It has both a camera and a spectrometer, as well as a coronagraph that can block out bright sources of light to reveal fainter objects nearby. Third is,

### 7.3.3 Nirspec Instrument

Near Infrared Spectrograph (NIRSpec) is another scientific instrument housed in the ISIM. It is designed to study the properties of galaxies and stars, including their chemical composition and age. The NIRSpec operates in the near-infrared spectrum and can simultaneously perform high-resolution spectroscopy on up to 100 objects. It also has a built-in micro shutter array that can selectively block out unwanted light sources, allowing for more precise observations. And fourth is,

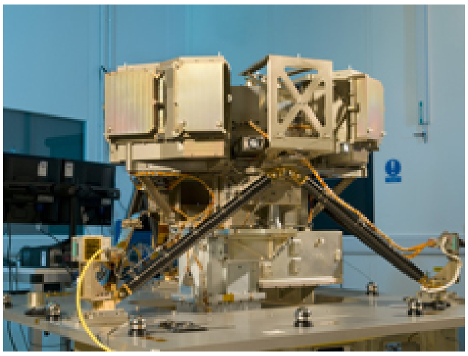

Figure 23: MIRI INSTRUMENT

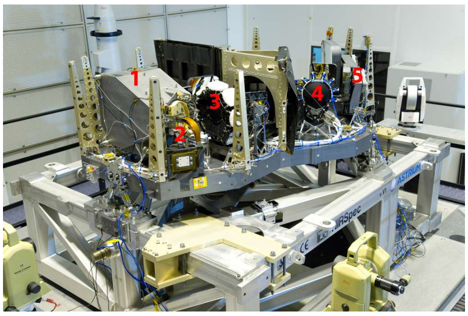


Figure 24: NIRSPEC INSTRUMENT

#### 7.3.4 FGS/NIRISS Instrument

Fine Guidance Sensor/Near Infrared Image and Slit less Spectro graph (FGS/NIRISS) is designed to study exoplanets and their atmospheres, as well as the formation of stars and galaxies. The FGS/NIRISS operates in both visible and near-infrared spectra and has a range of imaging and spectroscopic capabilities. It also has a corona graph for blocking out bright sources of light and a wavefront sensing system for maintaining precise pointing and alignment. .

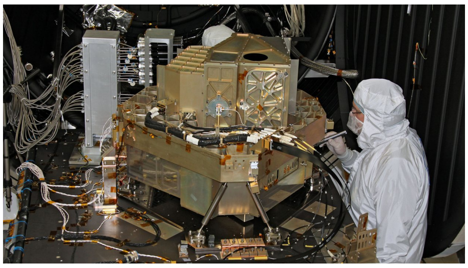

Figure 25: FGS INSTRUMENT

## 7.4 Comparision between JWST and Hubble


Figure 26: Carina Nebula

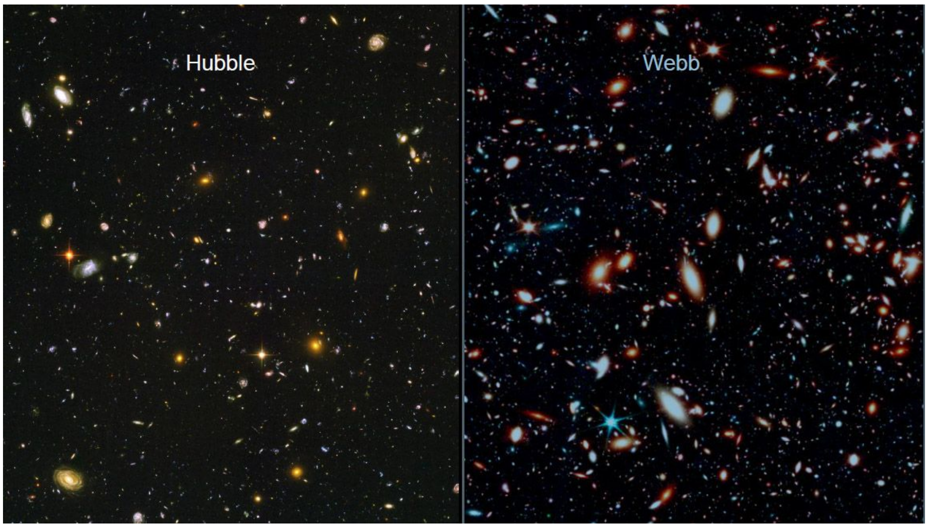


Figure 27: Deep Field Comparison

Figure 28: Mystic Mountain

# 8 Comprehensive study of images of JWST

Hyperlinks are provided to the respective assignment on the detailed study of images taken by James Webb Space Telescope:

- **Carina Nebula**
- **Stephan's Quintet**
- **SMACS 0723**

# 9 Astrophotography

## 9.1 Introduction

Astrophotography, also known as astronomical imaging, is the photography or imaging of astronomical objects, celestial events, or areas of the night sky.Photography using extended exposure-times revolutionized the field of professional astronomical research, recording hundreds of thousands of new stars, and nebulae invisible to the human eye.Today, astrophotography is mostly a subdiscipline in amateur astronomy, usually seeking aesthetically pleasing images rather than scientific data. Amateurs use a wide range of special equipment and techniques.

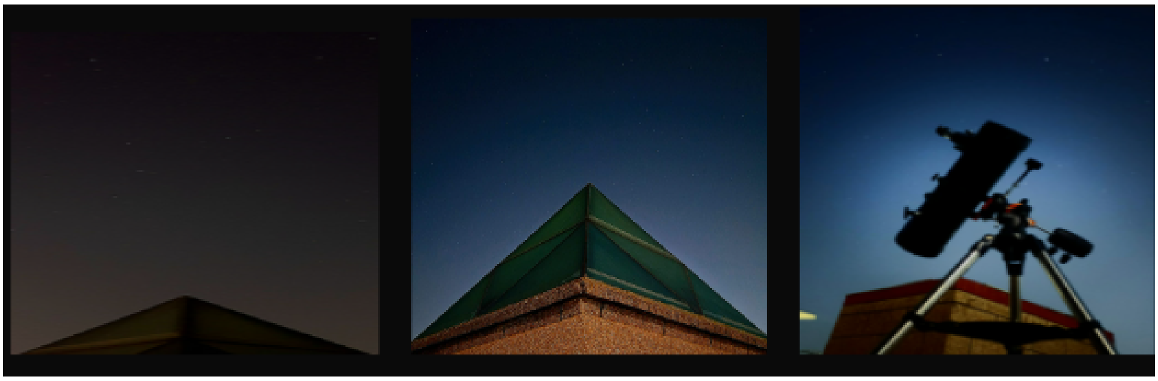

Figure 29: Astrophography

# 10 Experimental setup of JWST

## 10.1 Introduction

The goal of this project is to construct a multiple-mirror light collector similar to the Webb Telescope's primary mirror made up of 7 smaller mirrors. This multiple-mirror assembly is then illuminated using a heat lamp instead of a far-off celestial object. We then develop a "sunshield" for a kitchen thermometer, to protect it from the direct heat of the heat lamp. Having done that, we will learn a good deal about multiple-mirror optics by measuring the intensity of the light reflected from the mirrors as the position of the thermometer is changed. This project illustrates the principles and practice of a multiple-mirror telescope and a cooling sun shield—two engineering features essential to the successful operation of the Webb Telescope.

## 10.2 Materials Required

Heat lamp 250 W, round mirrors, aluminum foil, cardboard, foam board, thermometer, black paint, board pins, ruler, screw, glue gun, cutter, rubber band.

## 10.3 Construction of Setup

Assembling the Optical Bench

1. Cut a piece of 20-by-30-by-1/2-inch foamboard measuring 10 by 30 inches. Attach the foamboard to cardboard of same size.

2. Attach the straight ruler to the top surface of the foam board so that it lies along one edge, and the 0-inch end is 6 inches from one of the short sides (see Figure below).

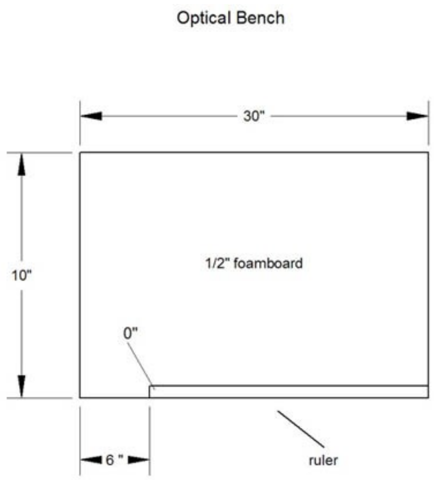


Figure 30: optical bench

3. Next, make the thermometer mount. Start by cutting a 10-by-6-inch section from the 20-by-30-by-1/2-inch foam board.

4. Now we have to create the support of thermometer holder attach a small cardboard with foamboard on one side of the cardboard.

Figure 31: optical bench

5. Now make a small hole in the thermometer holder to insert the thermometer.

6. Place the optical bench on the table so that the ruler is toward you and the 0-inch end of the ruler is to your left. The heat lamp should be mounted on the table at the right end of the optical bench so that the bulb faces to the left, and so that the center of the bulb is about 4 inches above the surface of the optical bench.

7. Place the thermometer mount on the optical bench so that the thermometer probe is positioned in front of the heat lamp.

Creating the Multiple-Mirror Assembly

1. Cut a hexagon of each side 17 inch from the leftover piece of the $\frac{1}{2}$-inch-thick foam board. Mark the placement of the mirrors as shown below in Figure

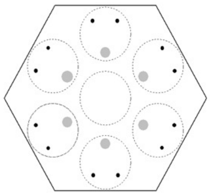

Figure 32: Hexagonal Cardboard

2. Glue the center mirror to the foam board hexagon. Arrange and use valcro dots to attach the surrounding mirrors as shown in Figure. Poke holes where the attachment screws belong.

3. For each of the remaining six mirrors. Use the glue gun to glue a pushpin to the top backside of the mirror.

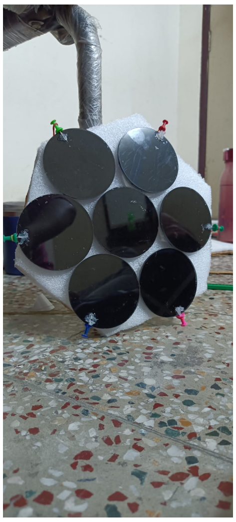

Figure 33: Multiple-Mirror system

4. Using the glue gun, attach the six remaining mirrors to the mirror mount. Put in the adjustment screws. Tie each mirror's pushpin rod to the hexagon mirror mount with a small rubber

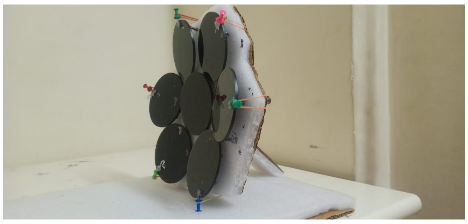

Figure 34: Side view of mirrors

band to hold the mirrors firmly against the adjustment screws. Do not stretch the elastic bands so tight that they pull the pushpin out of the glue holding it.

5. Mount one side of the hexagonal multiple mirror assembly on a base of the remaining 1/2-inch foamboard. Then mount this base on the optical bench as shown in Figure 31

Creating a Thermometer Sunshield

The main measurements taken in this experiment involve measuring the temperature increase caused by the heat lamp's light reflected from the multiple mirrors. However, the thermometer probe will often be closer to the heat lamp than to the multiple mirrors. This means that the thermometer probe must be well shielded from the direct light of the heat lamp. The sun shield for this multiple-mirror experiment needs to protect the thermometer from as much of the heat lamp's direct heat as possible without blocking the mirror assembly.

1. Cut out the pieces of foam board to make the sun shield. The 1/2-inch foamboard with the rectangular opening is called the front plate and enables the probe to detect light reflected from the multiple mirrors. The other two 1/2-inch foamboard pieces are spacer blocks.

2. The 1/2-inch-thick piece is called the back plate and is positioned nearest to the heat lamp. This foamboard is in the form of a rectangle with a central cutout. The bottom of the cutout will be sealed with aluminum foil.

3. Glue aluminum foil to the front and back surfaces of the back plate so that the shiny side of the foil is on the outer surface of the back plate. This piece protects from radiant heat by first reflecting away the heat from the heat lamp, providing an air space that is only heated by the emission of heat from the dull side of the first layer of foil, reflecting the heat that penetrates the air space away from the remainder of the shield. Finally, the shiny surface does not effectively radiate heat absorbed by the front surface foil into the region of the spacer blocks.

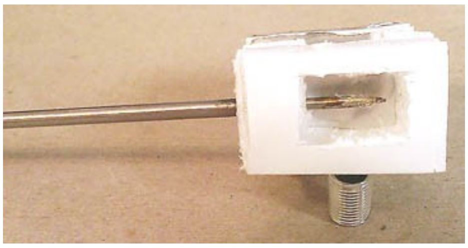

Figure 35: Thermometer sunshied

4. Glue the spacing blocks to one side of the aluminum foil covering the back plate. Position the blocks at the edges of the back plate so that the foil-covered hole in the back plate is not covered by the blocks.

5. Glue the front plate on top of the spacing blocks. Make a central hole in the front spacing block into which the thermometer probe can be inserted. The tip of the thermometer probe should not touch any part of the sun shield so that the warm foam does not heat the thermometer. When completely assembled, the multiple-mirror assembly and optical bench should look like Fig. below.

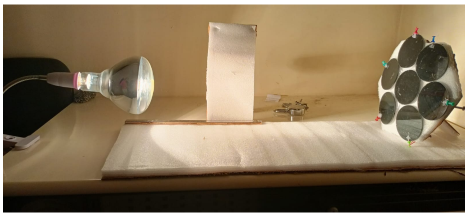

Figure 36: Experimental Setup

## 10.4 Conclusion

We have taken readings without sunshield, with sunshield and with sunshield at 15 degree angle. We observe that the temperature is comparatively higher in case of without sunshield than with sunshield. When the angle of mirror system is kept 15 degree than lights rays converge more so the temperature increases more as a function of time.

**OBSERVED READINGS FROM THE TELESCOPE SETUP**

| Readings without Sunshield (At 0° Angle) | | Readings with Sunshield (At 0° Angle) | | Readings with Sunshield (At 15° Angle) | |
|---|---|---|---|---|---|
| Time (in Mins) | Temperature (°C) | Time (in Mins) | Temperature (°C) | Time (in Mins) | Temperature (°C) |
| 0(R.T) | 32.9 | 0(R.T) | 32.9 | 0(R.T) | 32.9 |
| 0.5 | 39.9 | 0.5 | 34.1 | 0.5 | 34.6 |
| 1 | 42.5 | 1 | 36 | 1 | 36.2 |
| 1.5 | 45.7 | 1.5 | 37.5 | 1.5 | 37.5 |
| 2 | 46.2 | 2 | 38.4 | 2 | 39.5 |
| 2.5 | 46.9 | 2.5 | 38.7 | 2.5 | 41.5 |
| 3 | 47.3 | 3 | 38.9 | 3 | 42 |

Figure 37

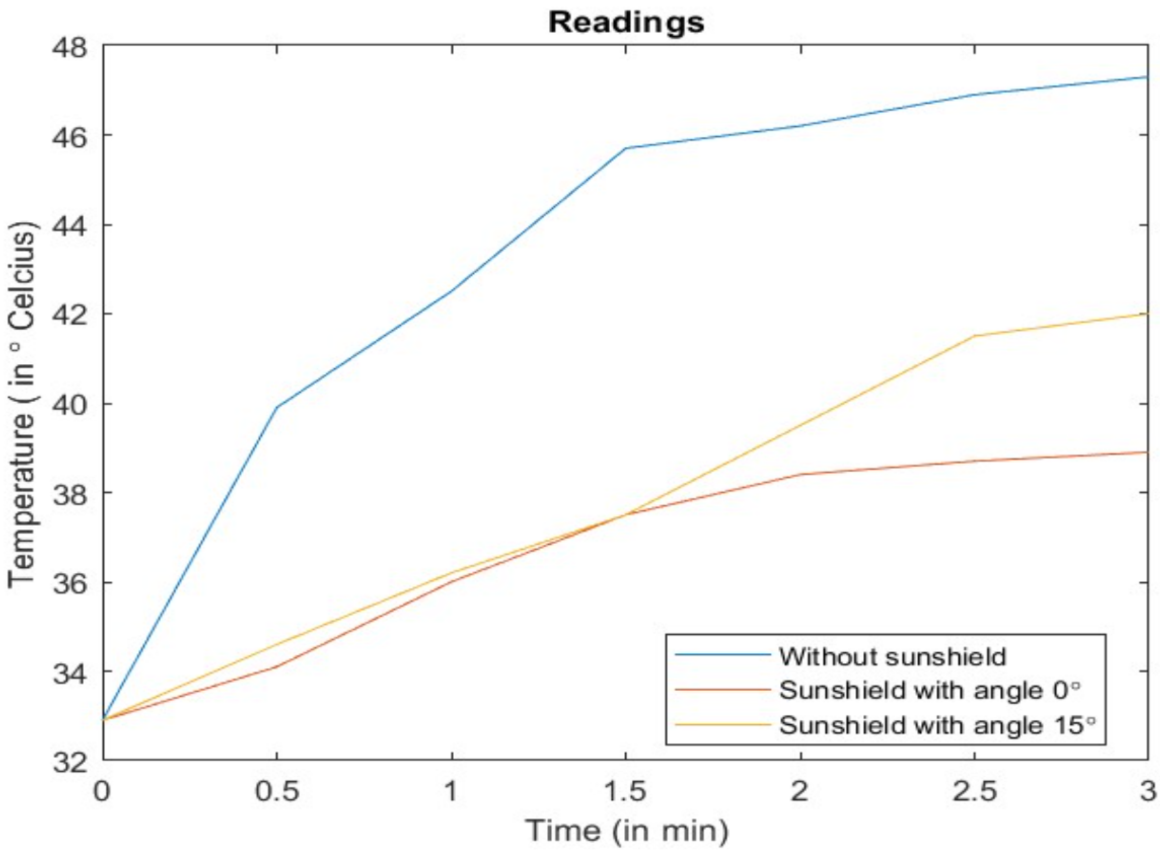
Readings
48
46
44
42
40
38
36
34
32
Temperature ( in ° Celcius)
0
0.5
1
1.5
2
2.5
3
Time (in min)
Without sunshield
Sunshield with angle 0°
Sunshield with angle 15°

Figure 38

## 11 References

[Hyperlinks]


- *Model making*
- *Wikipedia*
- *Radio Telescopes*
- *NASA: James Webb Space Telescope*
- *SLOAN Digital Sky Data*