Astro Instruments 101

SnT Council

Summer Project 2022

Astronomy Club IITK

Handbook

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Contents

1 History of Astronomy

1.1 Introduction

Astronomy has been practiced for as long as humans have been looking at the sky and wondering what it all means. Early astronomers, in different civilizations, used the observed motion of the stars, the Sun, Moon and planets as the basis for clocks, calendars and a navigational compass. The Greeks developed models to account for these celestial motions. The Greeks named the stars and plotted their positions. Tycho Brahe was Astronomys first true observer.

The real renaissance of astronomy began with Nicholas Copernicus, who advanced the idea that the Sun is in the center of the Solar System. Armed with the excellent naked-eye observations of Tycho Brahe, Johannes Kepler formulated his Three Laws of Planetary Motion, which, for the first time, correctly described the way the planets move through the Solar System. Galileo Galilei was the first person to use a telescope to look at celestial bodies (though he did not invent the telescope) and discovered the four brightest moons of Jupiter, proving that there are things in the Solar System that don't revolve around the Sun.

Since Galileo's time, astronomy has made great strides, and many amazing instruments were discovered/invented. Some of them include Sundials, Gyroscopes, Antikythera Mechanism, Sextant etc.

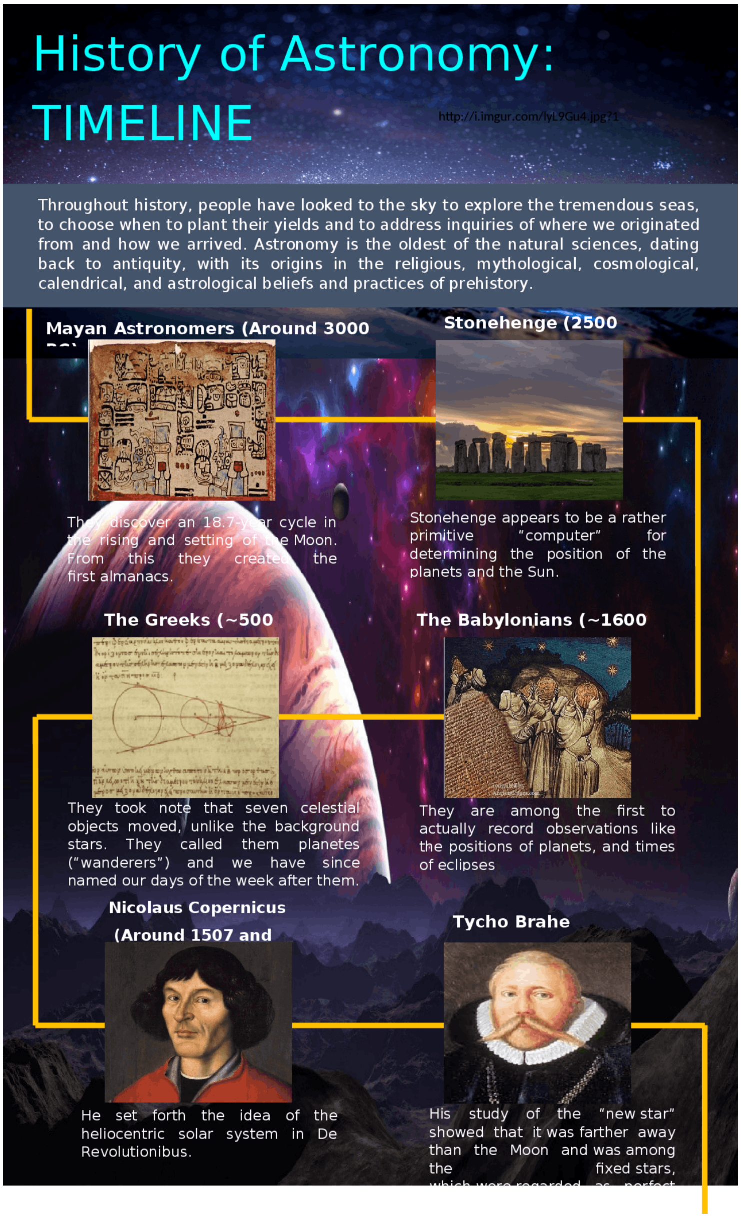


Figure: A brief Timeline of Ancient Astronomy

1.2 Early Astronomical Observations and Records

Early astronomical observations were recorded on metal discs, like the Nebra Sky Disc, which has observations like the Sun/full moon, lunar crescent, a cluster of stars etc. embedded on it; or on rocks, like petroglyphs, which have embedded star patterns or likewise. Astronomical Records such as the Stonehenge have been found.

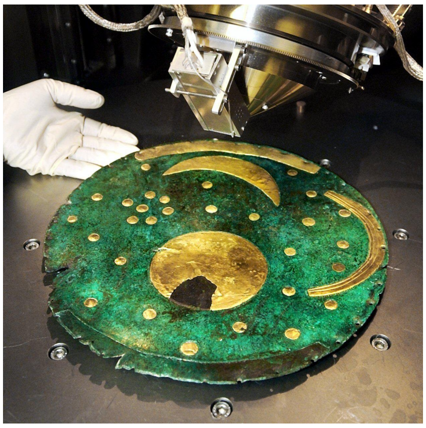


Figure: Nebra Sky Disc

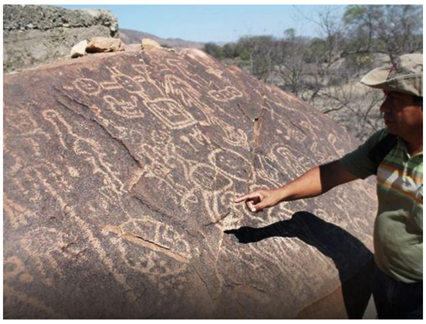


Figure: A Petroglyph

1.3 Spherical Earth or Flat Earth?

From many years, there had been beliefs that the Earth is not a Spherical but a Flat disc. These beliefs were shunted to some extent by Ferdinand Magellan, who sailed through the circumference of the Earth and returned to the same point. Also, he didn't fall down at the edge of the disc. Some events like the Shadow of Earth on Moon's surface during a Lunar Eclipse also push towards the fact that the Earth has a spherical surface.

1.4 Eratosthenes

Eratosthenes was a ancient Greek observer, He calculated the circumference of the Earth by using the basic concepts of Geometry and without knowing the radius of the Earth.

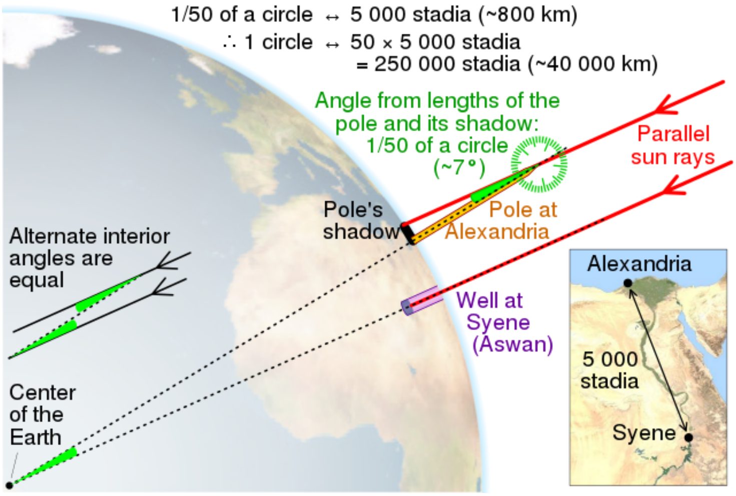


Figure: Eratosthenes' calculations

1.5 Geocentric vs Heliocentric models of the Solar System

1.5.1 Geocentric Model: Ptolemy

Geocentric model, in astronomy, is a concept that describes that the Earth is the centre of the Universe. In other words, this is a suspended description of the Universe with Earth at the centre. Under this model, the Sun, moon, stars, and other planets orbit around the Earth. This was the predominant description of the cosmos in many ancient civilizations. Many great people including Aristotle in Classical Greece accepted this model as the correct description of the cosmos. Two major observations that were used in developing this model were:

1. The Sun appears to revolve around the Earth once per day when observing from anywhere on Earth.
2. An earthbound observer sees no movement of Earth because it feels solid, stable and stationary.

1.5.2 Heliocentric Model: Copernicus

Heliocentric model in astronomy is an astronomical model in which the Earth and planets move around the Sun at the centre of the Solar system. This model is quite opposite to the geocentric model. The concept of Earth revolving around the Sun was developed as early as the 3rd century BC by Aristarchus of Samos. However, a proper mathematical heliocentric model was not proposed until the 16th century. It was presented by the mathematician, astronomer, and Catholic cleric Nicolas Copernicus. This was named as Copernicus revolution. This development led to the following introduction of elliptical orbits by Johannes Kepler and supporting observations made using a telescope by Galileo Galilei.

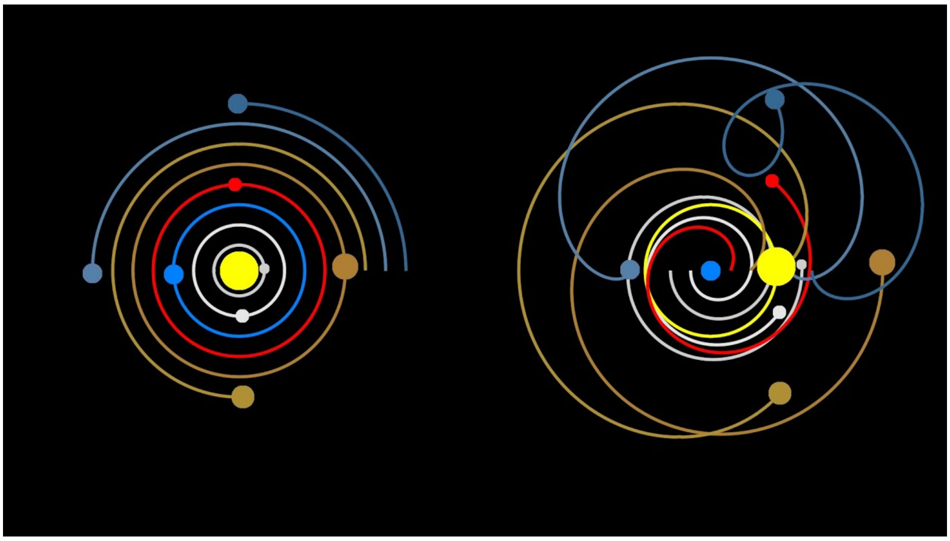


Figure: Geocentric vs Heliocentric Models

1.6 Galilean Findings

Galileo was a great astronomer. He is called the Father of Modern Astronomy. He discovered various astronomical objects and phenomenon, some of which, as we know, helped prove the heliocentric model of the solar system. Some of his observations were:

- Jupiter and its four moons
- Phases of Venus
- Mountains and Seas (Craters) on the Moon
- Spots on the surface of the Sun

2 Ancient Astronomical Instruments

Our Ancestors were curious about the night sky, and they built various devices to study that. These instruments (like the Sextant) were extensively used for measurements, computation and demonstration by ancient observers (like Tycho Brahe). Some of the devices made by them are:

2.1 Star Chart

A Star Chart is a map of the night sky. They are used to identify and locate constellations, galaxies, stars, nebulae, etc. Other instruments like Astrolabe and Planisphere also utilize star charts.

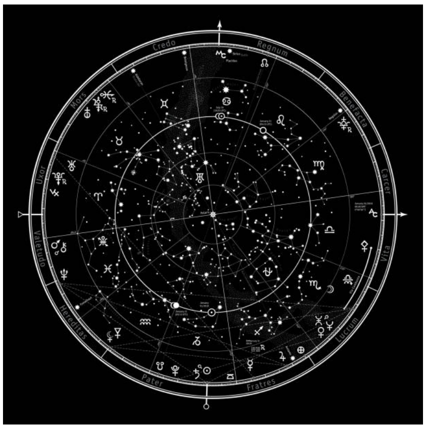


Figure: Starchart

2.2 Astrolabe

Astrolabe is an astronomical instrument for taking the altitude of the sun or stars and for solution of other problems in astronomy and navigation used by astronomers from the Middle Ages until superseded by the sextant.It is like a 2D model of the celestial sphere. The device employed a disk with 360 degrees marked on its circumference. Users took readings from an indicator that pivoted around the suspended device's center like a clock's hand.

Figure: 1) Astrolabe 2) Parts of Astrolabe

It serves various functions like finding the Position of Celestial Objects, measuring time, computing what part of the sky is visible at any time, etc.

2.3 Planisphere

A Planisphere is a simple hand-held device that shows a map of which stars are visible in the night sky at any particular time. Rotating a wheel shows how stars move across the sky through the night and how different constellations are visible at different times of the year. Its design is very similar to that of Astrolabe and is the successor of that.

Figure: Planisphere

2.4 Armillary Sphere

An armillary sphere is a model of objects in the sky consisting of a spherical framework of rings centered on Earth or the Sun representing lines of celestial longitude, latitude, and other astronomically important features. It follows the geocentric model. Using an armillary sphere, someone can calculate the position of something in the sky relative to an observer on Earth. This model can also be used to show people how the celestial sphere works visually.

Figure: Armillary Sphere

2.5 Orrery

An orrery is a mechanical model of the Solar System that shows the relative positions and motions of the planets and moons according to the heliocentric model. It is driven by a clockwork mechanism that simulates the motion of planets around the earth.

Figure: Orrery

2.6 Gyrotheodolite

A Gyrotheodolite is an instrument composed of a gyrocompass mounted to a theodolite. It is used to determine the orientation of the true north. It is the main instrument for orientation in mine surveying and in tunnel engineering, where astronomical star sights are not visible, and GPS does not work.

Figure: Gyrotheodolite

2.7 Gyroscope

A gyroscope is used to measure or maintain orientation and angular velocity. It is a spinning wheel or disc in which the axis of rotation (spin axis) is free to assume any orientation by itself. It contains a wheel mounted in a set of rings so that its axis of rotation is free to turn in any direction: when the wheel is spun rapidly, it will keep the original direction of its rotation axis no matter which way the ring is turned.

Figure: Gyroscope

2.7.1 Mechanics of gyroscope

The working principle of the gyroscope is based on gravity and is explained as the product of angular momentum experienced by the torque on a disc to produce a gyroscopic precession in the spinning wheel. This process is termed gyroscopic motion or gyroscopic force and is defined as a rotating object's tendency to maintain its orientation.

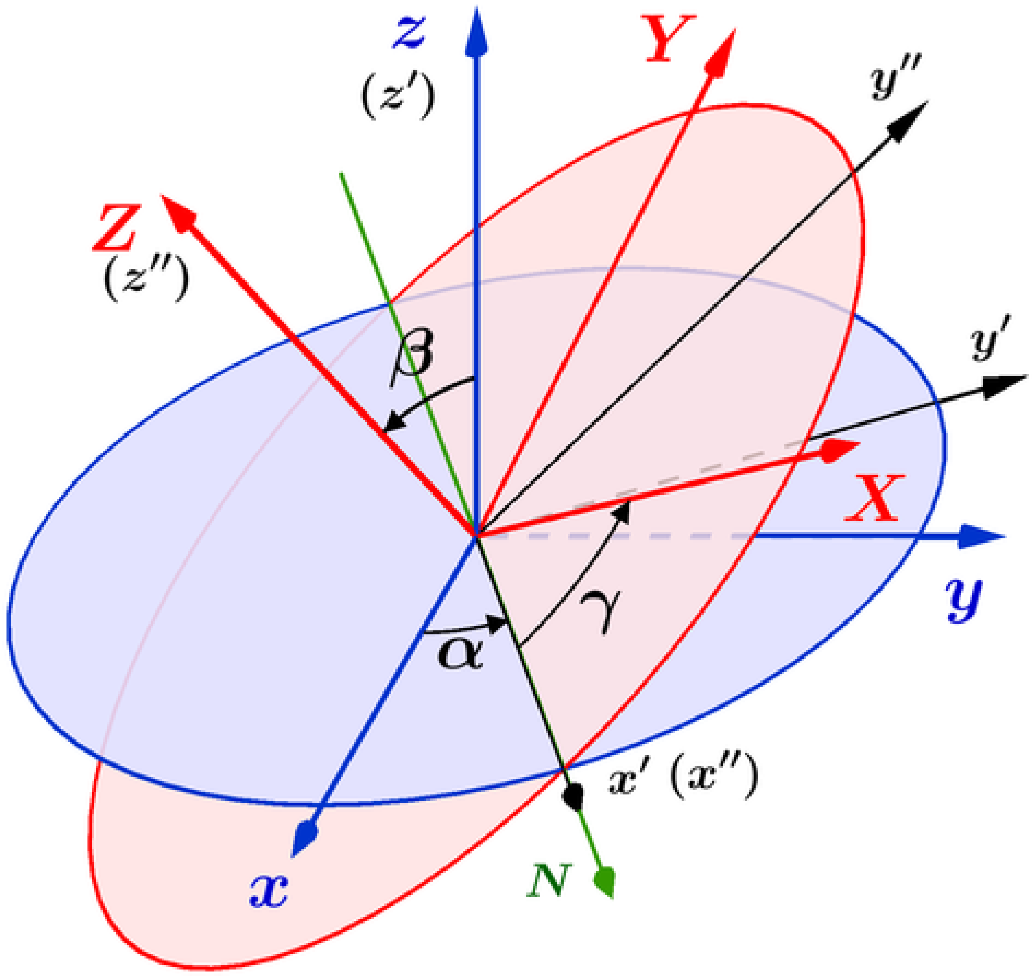


Figure: Euler angles of spinning top

angular momentum, respectively we get:

$$\Sigma F = ma_G \tag{2.1}$$

$$M^G = \omega^\beta.(I^G\omega^\beta) + I^G\alpha^\beta \tag{2.2}$$

And We also have Euler equations which are as follows:

$$M_1 = I_1.\omega_1(I_2 I_3).\omega_2.\omega_3 \tag{2.3}$$

$$M_2 = I_2.\omega_2(I_3 I_1).\omega_1.\omega_3 \tag{2.4}$$

$$M_3 = I_3.\omega_3(I_1 I_2).\omega_1.\omega_2 \tag{2.5}$$

Along with this, we have some assumptions:

1. **Symmetric Rotor-**
$$I_1 = I_2 \neq I_3 \tag{2.6}$$

2. **Steady Precision-**
$$\dot{\theta} = \ddot{\theta} = 0 \tag{2.7}$$

3. **High Spin-**
$$|\dot{\phi}| = |\dot{\psi}| \tag{2.8}$$

with the above assumptions, we following equations:

$$\dot{\psi} \approx \omega_3^0 = constant \tag{2.9}$$

$$\dot{\psi}^2 \ll |\omega_3^0 \dot{\phi}| \Rightarrow \dot{\phi} \approx mgl/I_3\dot{\psi} = constant \tag{2.10}$$

From the above equations and assumptions, we get the values of M_1, M_2, M_3 :
$\mathbf{M_1 = mgLsin\theta cos\psi}$
$\mathbf{M_2 = -mgLsin\theta cos\psi}$
$\mathbf{M_3 = 0}$

2.7.2 Applications of gyroscope

- In spacecraft, the navigation of the desired target is done with the help of a gyroscope. The spinning center of the gyroscope is used as the orientation point.
  Generally, $I_1 = I_2 = I_0 \leq I3$, and we have $s = pcos\theta_0(I0 - I3)/I3$

  Here **p** is **precession** and **s** is **spin**
  So, spacecraft has s and p are opposite in direction, which is called Retrograde motion.
  But for the rockets we have, $I1 = I2 = I0 \geq I3$ therefore S and p will be in the same direction, which is called prograde motion.

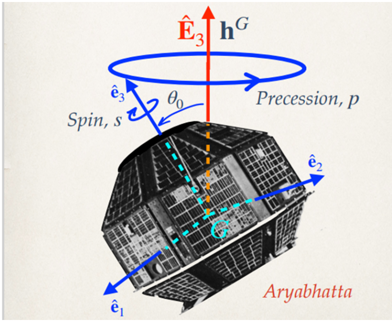


Figure (a): Retrograde motion

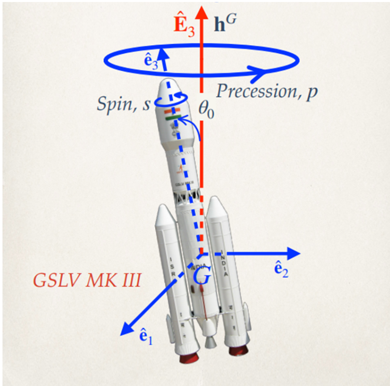


Figure (b): Prograde motion

- If you mount two gyroscopes with their axles at right angles to one another on a platform and place the podium inside a set of gimbals, the platform will remain completely rigid as the gimbals rotate in any way they please. This is the basis of inertial navigation systems (INS).
- The effect of all this is that once you spin a gyroscope, its axle wants to keep pointing in the same direction. If you mount the gyroscope in a set of gimbals so that it can continue pointing in the same direction, it will. This is the basis of the gyro-compass.

2.8 Sundial

A sundial is the earliest type of timekeeping device, which indicates the time of day by the position of the shadow of some object exposed to the suns rays. As the day progresses, the sun moves across the sky, causing the shadow of the object to move and indicating the passage of time.

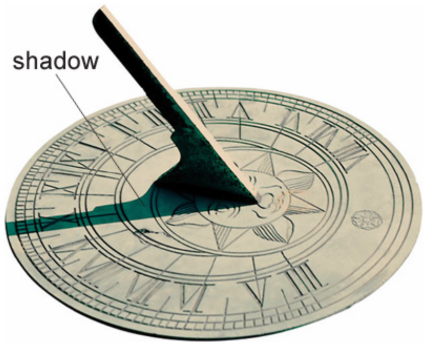


Figure: Sundial

2.8.1 Types of Sundial

Horizontal sundial: This is the type found commonly on pedestals in gardens. The dial plate is horizontal. The gnomon (which casts the shadow) makes an angle e the msallqual to the latitude of the location for which it was designed.

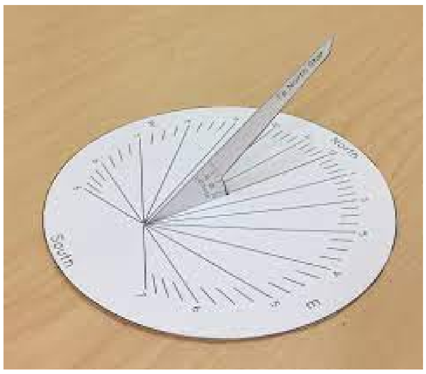


Figure: Horizontal Sundial

by horizontal sundial we calculate Hour angle(H) with the following formulae:

$$H = arctan(tan(T).sin(L)) \tag{2.11}$$

where L is angle gnomon makes an with the horizontal,
T is the hour angle measured from the northsouth line around the equatorial dial
H is the projected hour angle on the ellipse of the horizontal dial

Vertical sundial: This is the type found on the walls of churches and other buildings. Vertical sundials may bedirect south dials if they face due south (in which case the gnomon will be at an angle equal to the co-latitude of the place, and the hour lines, if delineated for local time at the place, will be symmetrical about the vertical noon line).

Figure: Vertical Sundial

by vertical sundial we calculate Hour angle(H) with the following formulae:

$$H = arctan(tan(T).cos(L)) \tag{2.12}$$

where L is angle gnomon makes an with the horizontal,
T is the hour angle measured from the north-south line around the equatorial dial
H is the projected hour angle on the ellipse of the vertical dial

Equatorial dial: It has the dial plate fixed in the plane of the equator. The gnomon is perpendicular to the dial plate. The hour lines are spaced equally at 15-degree intervals. The armillary sphere is a development of this idea and consists of a series of rings in the planes of the equator and the meridian and a rod parallel to the earth's axis and passing through the center of the rings.

Figure : Equatorial Sundial

Reference material for the mathematical derivation of hour angle for horizontal and vertical sundials: The mathematics of sundials, Jill Vincent

2.9 Making of Ancient Instruments by the mentees

2.9.1 Construction of Planisphere

- **Step 1-** In order to fit together, the pieces must be of the same scale. For your present location of Kanpur, we recommend a planisphere kit designed for latitude 26.45°N.
- **Step 2-** You should have the star wheel and the body of the planisphere on two separate sheets of paper, or more preferably, on a thin card. If you have any transparent plastic to hand, e.g., acetate sheets for use on overhead projectors, you should have the altitude/azimuth grid onto a sheet of plastic. If you do not have any acetate to hand, don't worry your planisphere will work fine without it!
- **Step 3-** Carefully cut out the star wheel and the body of the planisphere. Also, cut out the shaded grey area of the planisphere's body, and if you have it, the grid of lines which you have onto transparent plastic. If you are using cardboard, you may wish to carefully score the body of the planisphere along the dotted line to make it easier to fold it along this line later.
- **Step 4-** The star wheel has a small circle at its center, and the planisphere's body has a matching small circle at the bottom. Make a small hole (about 2mm across) in each. If you have a paper drill to hand, these are ideal, but otherwise, you can use a compass point and enlarge the hole until it is around 2mm across by turning the point in a circular motion.

- **Step 5-** Slot a split-pin fastener through the middle of the star wheel, with the head of the fastener against the side of the star wheel. Then slot the body of the planisphere onto the same fastener, with the side facing the back of the fastener. Fold the fastener down to secure the two sheets of cardboard together.

- **Step 6(optional)-** If you have the altitude/azimuth grid onto a sheet of plastic, you should now stick this grid of lines over the viewing window which you cut out from the body of the planisphere.

- **Step 7-** Fold the body of the planisphere along the dotted line so that the front of the star wheel shows through the window which you cut in the body.

Figure: Planisphere Made by mentees

2.9.2 Construction of Sundial

- **Step 1:** Cut the rectangle which is the base of the sundial.

- **Step 2:** Using the calculator on the website.

- **Step 3:** Using a protractor draw the degrees on the template for each hour between 6am and 6pm. (note: reversal of hours, 6am on right hand side, for southern hemisphere) Angles are measured from the base line (6 - 6) pm 6 5 4 3 2 1 12 6 9 11 10 8 7 6 am.

- **Step 4:** Create a gnomon triangle, the gnomon angle needs to be specific to the latitude of the area in which the sundial is being used, i.e., Kanpurs latitude is 25ř so the angle in the triangle would be 25ř.
- **Step 5:** Tape the triangle to the middle line of the sundial face (from point a to b) making sure the x angle is closest to a (where x = degree specific to latitude) This will create the shadow casting onto the face of the dial. To hold the gnomon vertically a small bracket can be made.

Figure: Sundial made by mentees

Modern Astronomical Instruments

3

3.1 Introduction

Approach in astronomy has been changed from ancient times with the use of electromagnetic waves and its properties and astronomical tools have become sophisticated and advanced with time . A few of them are:

3.2 Spectroscope

A spectroscope, is a device for detecting and analyzing wavelengths of electromagnetic radiation. A Spectroscope is used in astronomy to study spectrum of various heavenly bodies. By doing that scientists can analyse the composition of the star, galaxy etc.

Figure : Spectroscope

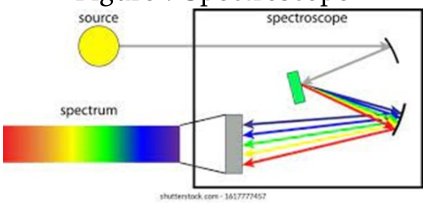


Figure :Working of spectroscope

3.3 Polarimeter

A Polarimeter is a scientific instrument used to measure angle of rotation caused by passing polarized (uni -directional) light through an optically active substance. Polarimetry, a technique to measure the polarisation of light, is a powerful tool that allows astronomers to infer information about celestial objects, from passing comets to distant galaxies, that can not be obtained using other techniques.

Figure: Polarimeter

3.4 Coronagraph

A coronagraph is a telescopic attachment designed to block out the direct light from a star so that nearby objects which otherwise would be hidden in the star's bright glare can be resolved.

Figure:coronagraph at wendelstein observatory

3.5 Interferometer

They are called interferometers because they work by merging two or more sources of light to create an interference pattern, which can be measured and analyzed; hence 'Interfere-o-meter', or interferometer.

Figure: Complete Interferometer

Astronomical interferometers can produce higher resolution astronomical images than any other type of telescope. At radio wavelengths, image resolutions of a few micro-arcseconds have been obtained, and image resolutions of a fractional milliarcsecond have been achieved at visible and infrared wavelengths.

3.6 LIGO

LIGO stands for "Laser Interferometer Gravitational-wave Observatory". It is the world's largest gravitational wave observatory . Comprising two enormous laser interferometers located 3000 kilometers apart, LIGO exploits the physical properties of light and of space itself to detect and understand the origins of gravitational waves (GW).

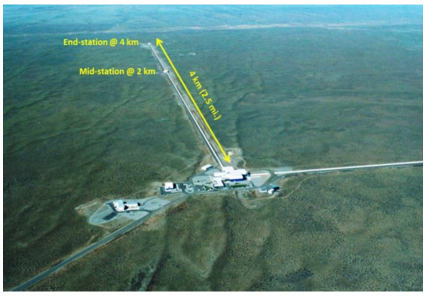


Figure: LIGO

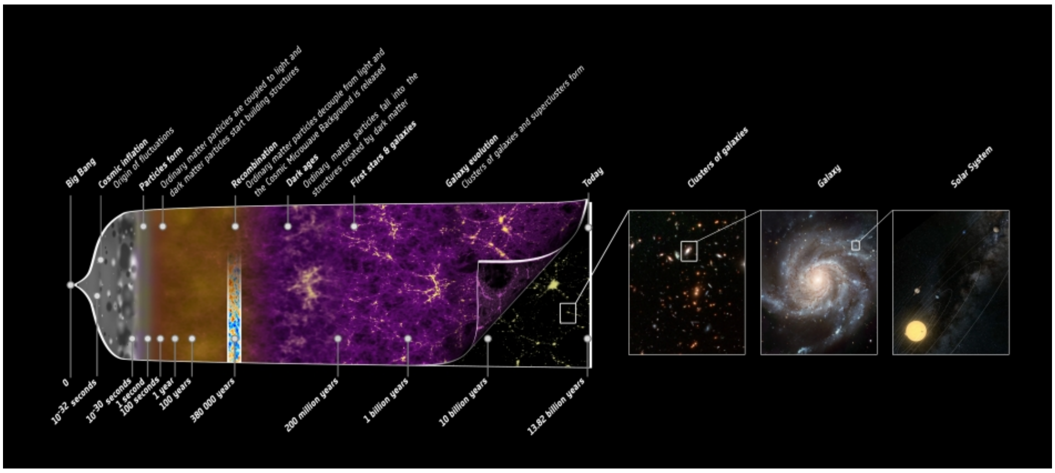
3.7 Radio Astronomy

Radio astronomy is a subfield of astronomy that studies celestial objects at radio frequencies.The discovery of the cosmic microwave background radiation ,regarded as evidence of the Big Bang Theory ,was made through radio astronomy. Astronomers around the world use radio telescopes to observe the naturally occurring radiowaves that come from stars, planets, galaxies, clouds of dust, and molecules of gas. Most of us are familiar with visible-light astronomy and what it reveals about these objects.

Figure: Radio Astronomy

4 Evolution of The Universe

4.1 Introduction



The domain of **Astronomical Instrumentation** which is constantly being researched upon is very much driven by the goal to find several answers related to the origin of universe. Isn't it?

The universe is everything. It includes all of space, and all the matter and energy that space contains. It even includes time itself and, of course, it includes you. Earth and the Moon are part of the universe, as are the other planets and their many dozens of moons.

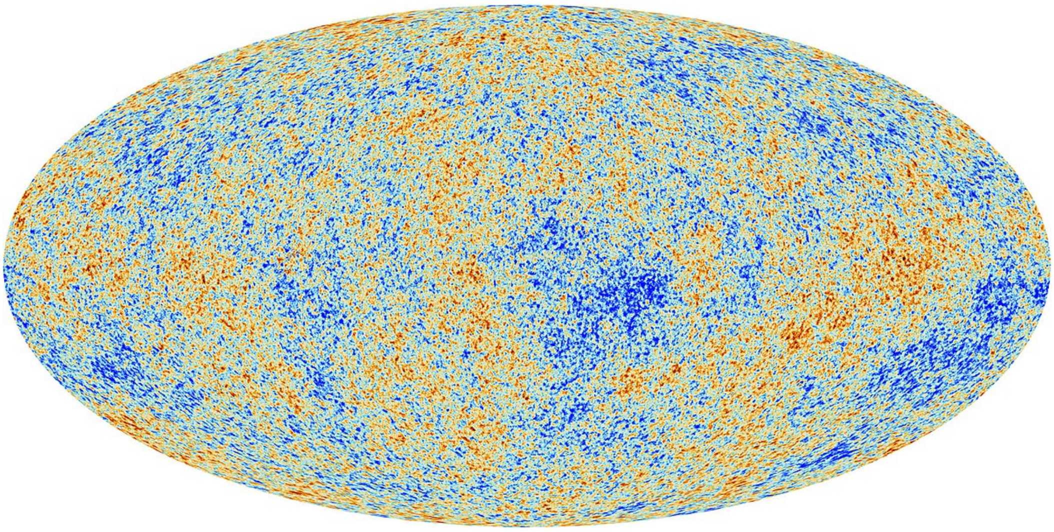
Along with asteroids and comets, the planets orbit the Sun. The Sun is one among hundreds of billions of stars in the Milky Way galaxy, and most of those stars have their own planets, known as exoplanets. The Milky Way is but one of billions of galaxies in the observable universe all of them, including our own, are thought to have supermassive black holes at their centres. All the stars in all the galaxies and all the other stuff that astronomers cant even observe are all part of the universe.

4.2 The Big Bang

The universe as we know it was created in a massive explosion that not only created the majority of matter but the physical laws that govern our ever-expanding cosmos. This is known as The Big Bang Theory. The Big Bang hypothesis states that all of the current and past matter in the Universe came into existence at the same time, roughly 13.8 billion years ago. At this time, all matter was compacted into a very small ball with infinite density and intense heat called Singularity. Suddenly, the Singularity began expanding, and the universe as we know it began.

4.3 Plank Epoch

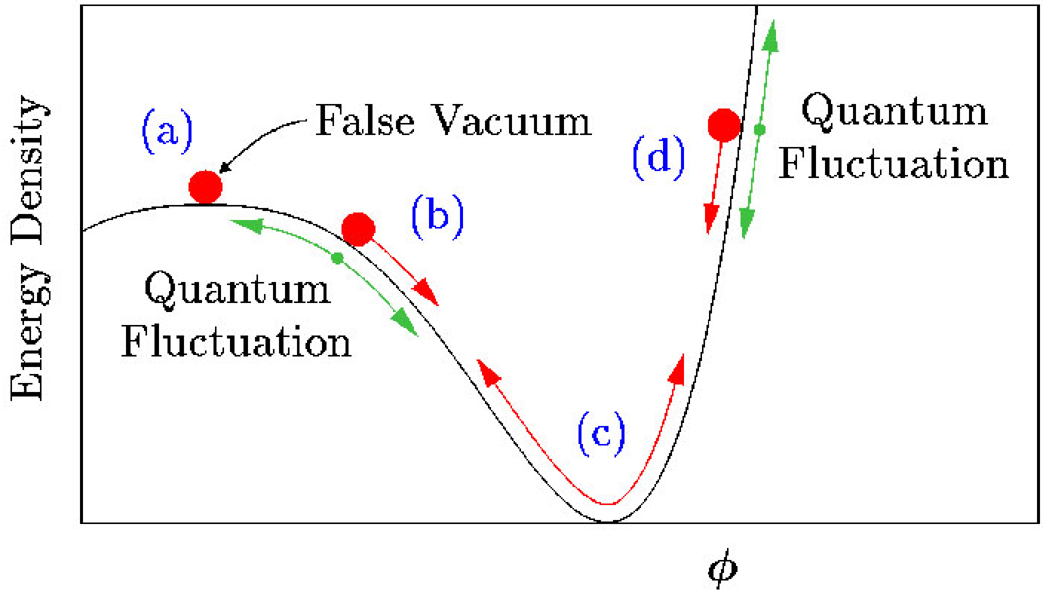
With the creation of the first fundamental forces of the universe, the Inflation Epoch began, lasting from 10-32 seconds in Planck time to an unknown point. Most cosmological models suggest that the Universe at this point was filled homogeneously with a high-energy density and that the incredibly high temperatures and pressure gave rise to rapid expansion and cooling.



This began at 10-37 seconds, where the phase transition that caused for the separation of forces also led to a period where the universe grew exponentially. It was also at this point in time that baryogenesis occurred, which refers to a hypothetical event where temperatures were so high that the random motions of particles occurred at relativistic speeds.

4.4 Cosmic Inflation

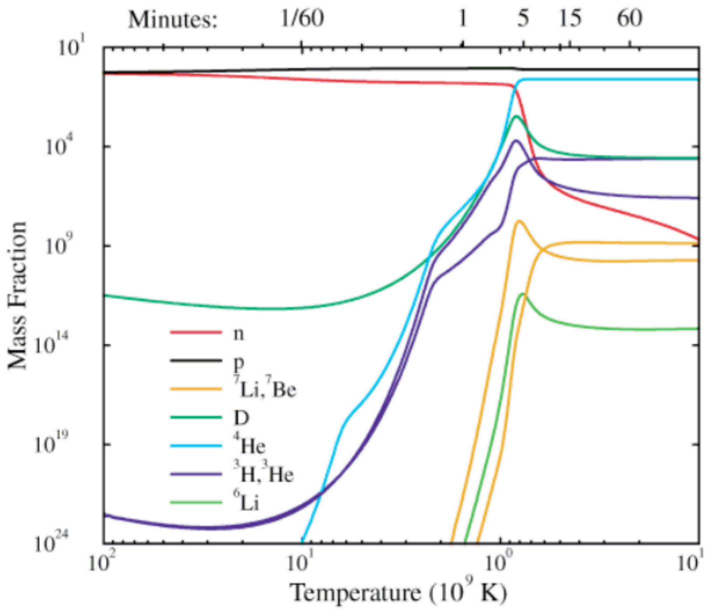
Cosmic inflation is a faster-than-light expansion of the universe that spawned many others. Inflation was invented to explain a couple of features of the universe that are really hard to explain without it. The first is that Einsteins general theory of relativity famously makes mass bend space and time.



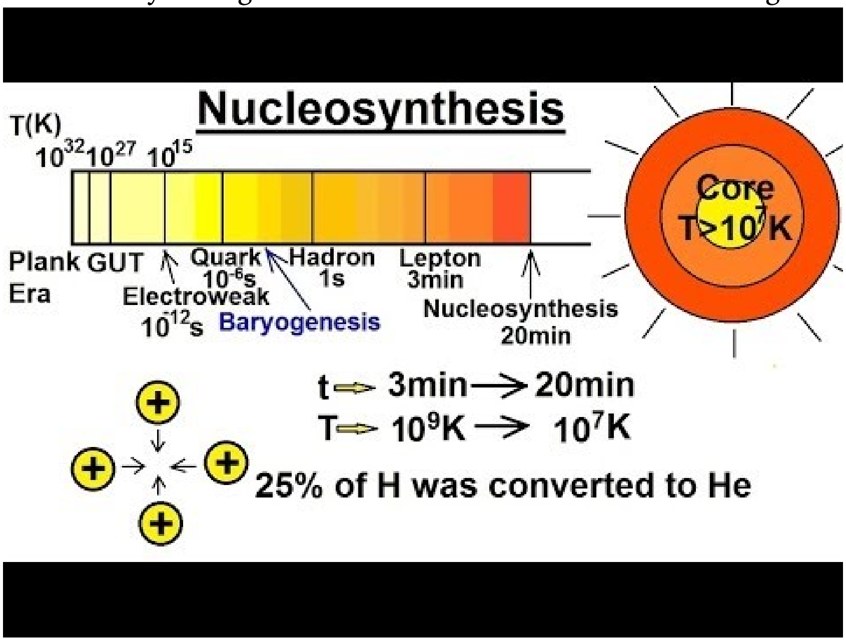
But the reality is that it is flat. Not only that, but even bits of it far off in different directions as observed from Earth have roughly the same temperature, although in an expanding universe, there wouldn't have been time for heat to pass between them to even things out. That seems a naked assault on the laws of thermodynamics. Cosmic inflation solves these problems at a stroke. In its earliest instants, the universe expanded faster than light.

4.5 Big Bang Nucleosynthesis

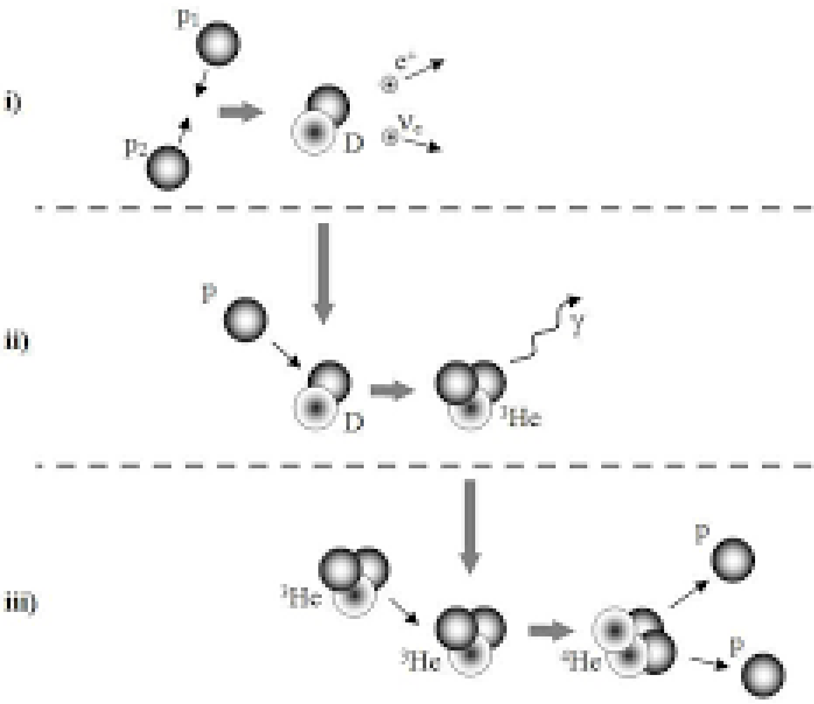
The Big Bang Nucleosynthesis theory predicts that roughly 25 percent of the mass of the Universe consists of Helium. It also predicts about 0.01 percent deuterium and even smaller quantities of lithium. The important point is that the prediction depends critically on the density of baryons (i.e., neutrons and protons) at the time of nucleosynthesis. Furthermore, one value of this baryon density can explain all the abundances at once. In terms of the present-day critical density of matter, the required density of baryons is a few percent. This relatively low value means that not all dark matter can be baryonic.



The fact that helium is nowhere seen to have an abundance below 23 percent mass is very strong evidence that the Universe went through an early hot phase.



4.6 Nuclear Fusion



The light and heat from stars are made by a process called nuclear fusion. Fusion happens when 2 atoms are forced together to form a heavier atom. This creates a lot of energy. However, fusion can only occur at the incredibly high temperatures and pressures found in the center of stars.

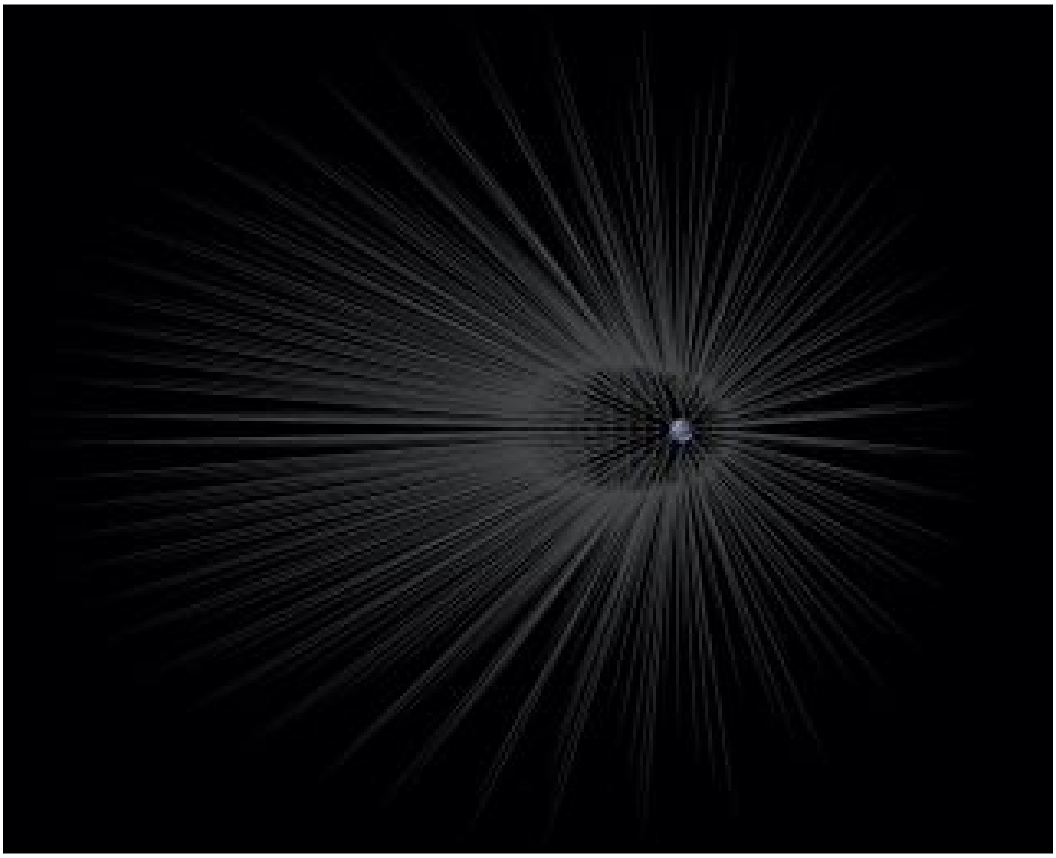
All the elements in the Universe heavier than hydrogen and helium were made in stars through nuclear fusion. When the star dies these elements are then emitted into space. They move into nearby gas clouds, or nebula, and form the building blocks for a new generation of stars. Our Sun and all the planets in the Solar System contain these elements. Elements are produced inside the very first stars.

4.7 Recombination

In cosmology, recombination refers to the epoch at which charged electrons and protons first became bound to form electrically neutral hydrogen atoms. Recombination occurred about 370,000 years after the Big Bang.

4.8 Dark Matter

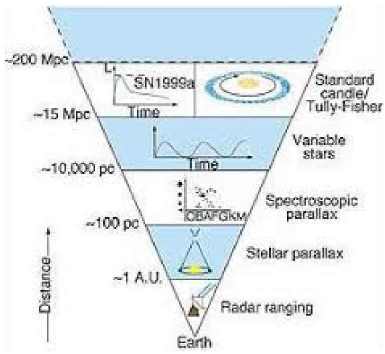
Most of the mass energy, about 95 percent, in the universe is dark. By dark, we mean that it does not emit any form of electromagnetic radiation. The existence of Dark Matter is inferred indirectly by its gravitational effect.



Dark Matter makes up 23 percent of the total mass-energy density of the universe. The dominant contributor is Dark Energy, and a small amount is due to atoms or baryonic matter.

5 Celestial Mechanics

5.1 The Cosmic Distance Ladder



5.1.1 Distances

Particular objects with specific properties let astronomers measure distances in a certain way that may be unique to the object or rely on other(relatively closer) methods for its measurement. This hierarchy of distances, when put together, gives us the cosmic distance ladder.

1. The first part of the ladder involves using precise geometry and trigonometry to deduce the distance of nearby objects like the sun, moon, planets etc.
2. Distances from the nearby stars can be worked out by the parallax method.
3. For stars much far away, we can use inverse square law to determine their distance by using the apparent brightness(observed by photography) and the absolute brightness (observed by spectrography).
4. Galactic and extragalactic distances are measured with the help of the cepheid variable, pulsating stars with varying diameters and temperatures (changing brightness).
5. Tully-Fisher relation gives the relation between the intrinsic luminosity of a galaxy and its rotational velocity(measured through spectrography).

5.1.2 Hubbles law

$$v = H_o D$$

Hubbles law is an observational statement that states that the velocity of recession(with respect to Earth) is proportional to the object's distance from the Earth. Hubbles law was the first observational basis of the expanding universe.

5.2 The Newton's and Kelper's Laws

5.2.1 Kepler's law of planetary motion

Kepler's laws of planetary motion given by **Johannes Kepler** in the 1600's, are observational laws much based on the observations done by Tycho Brahe, that describe the motion of planets around the Sun.
The Three Kepler's laws are:

1. The orbit of a planet is an ellipse with the Sun at one of the two foci.
2. A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time.
3. The square of a planet's orbital period is proportional to the cube of the length of the semi-major axis of its orbit.

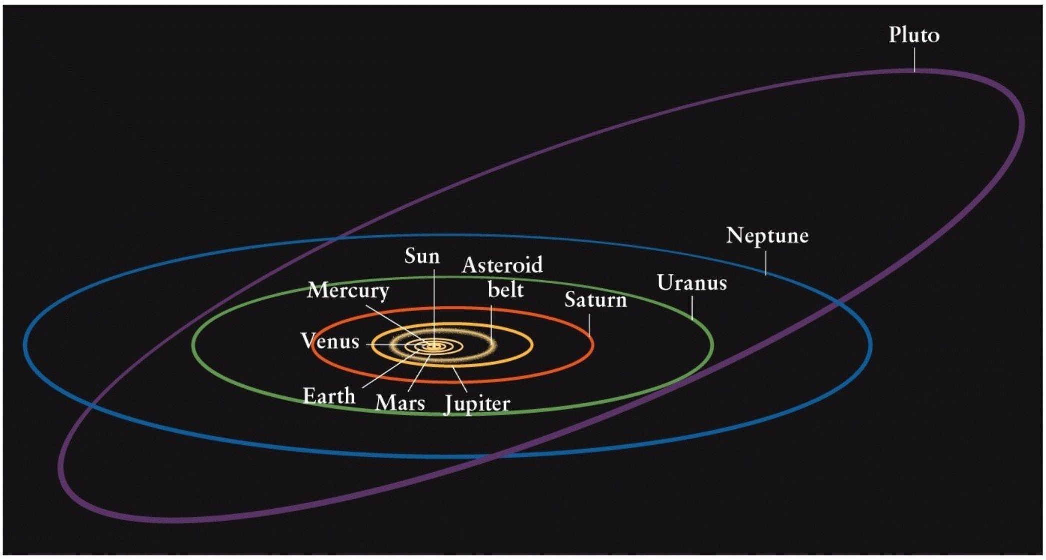
5.2.2 Newton's Laws

Published in the late 1600's by **Sir Isaac Newton**, Newtons three laws of motion quantitatively describe the most of the mechanical dynamic systems.
Newton's laws of motion are:

1. A body remains at rest, or in motion at a constant speed in a straight line, unless acted upon by a force.
2. When a body is acted upon by a force, the time rate of change of its momentum equals the force.
3. If two bodies exert forces on each other, these forces have the same magnitude but opposite directions.

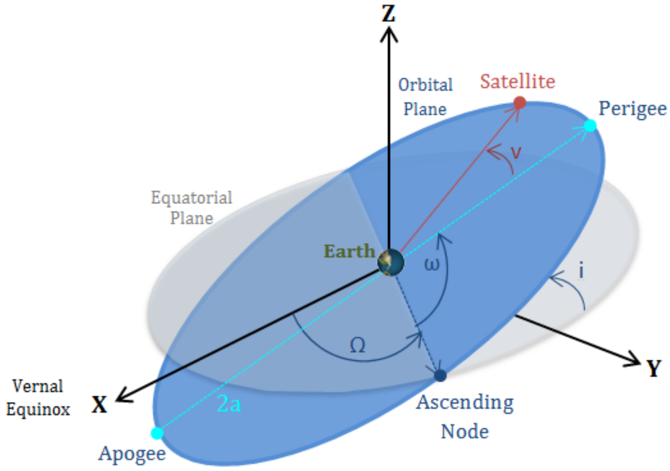
Kepler's laws, which are formulated on the basis of observational data are very much the same as newton's when applied to planetary systems.

5.3 Orbits



An object's curved path or trajectory around a major celestial entity like a planet, star, etc., is in orbit. Depending upon how was the object initially realized,it follows a circular, elliptical, parabolic or hyperbolic path due to the other objects gravitational field.
Six parameters can fully describe the orbit of, say, a satellite around the Earth.

1. a, length of the semi-major axis
2. eccentricity, e
3. Inclination
4. Right ascension of the ascending node
5. Argument of perigee
6. Time of the perigee passage



5.3.1 Perturbation theory

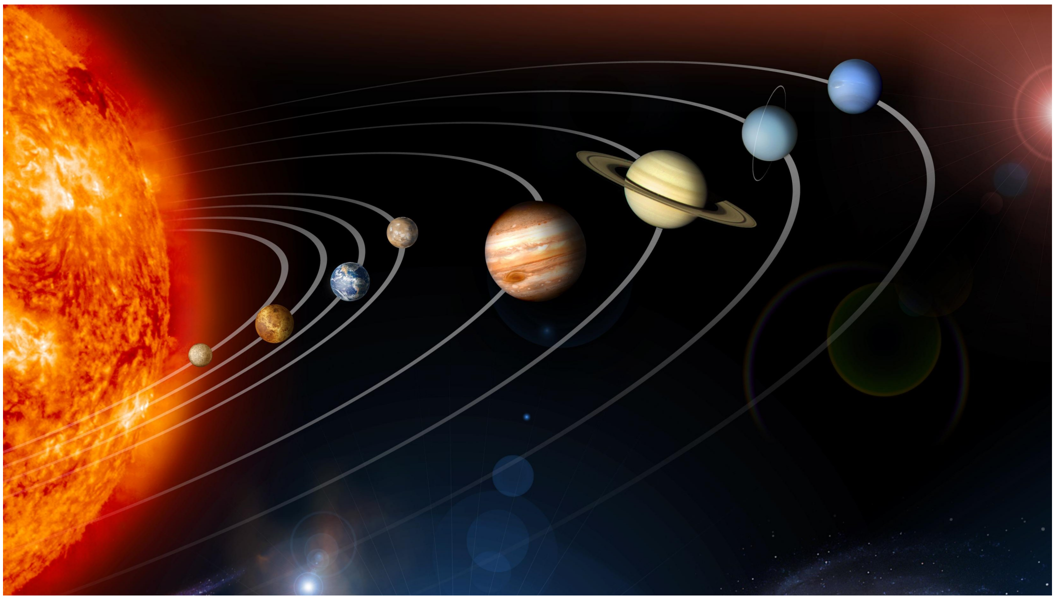
The divergence from an ideal calculated orbit due to the gravity of other celestial objects (like the planets and asteroids in our solar system) is known as an orbital perturbation, the study of which is of much importance for precise satellite works.

5.4 Motion of Planets around the Sun

All the planets in the solar system revolve around the Sun, through its gravitational field.

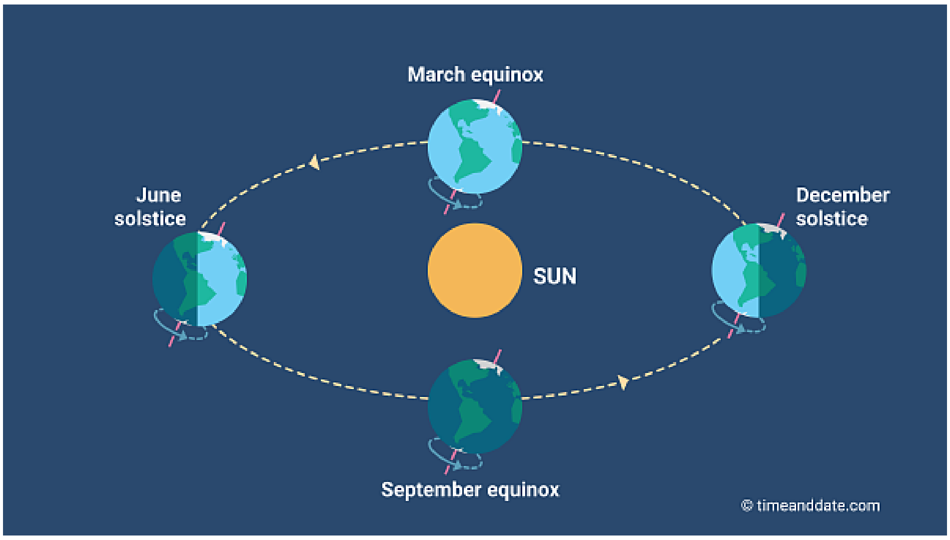
$$V(r) = \frac{-GM_s}{r}$$

All of the Planets follow a elliptical trajectory with the sun at a foci and all of them move in a anticlockwise sense. This is due to the persisted initial rotation of the system of gas that got transformed to what are now the planets and the Sun.
The closer the planet the smaller is its radius and the higher is it's amount of rotation. Hence the closest planet, Mercury takes about 88 days to complete its revolution, where as Neptune, the farthest takes about 165 earth years to complete one revolution.



5.5 Motion Related to Earth

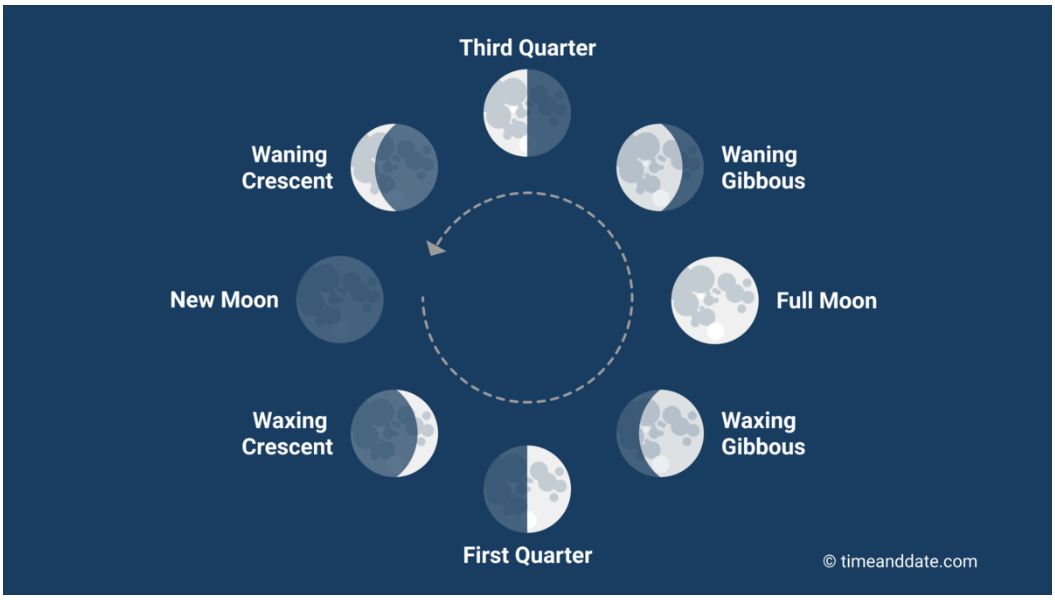
5.5.1 The Earth and Sun System



The tilted axis of rotation of the Earth causes the seasons to occur. At around June, the upper side is tilted towards the sun, causing summer in the Northern Hemisphere. The exact opposite happens in December when the Southern Hemisphere experiences summer.

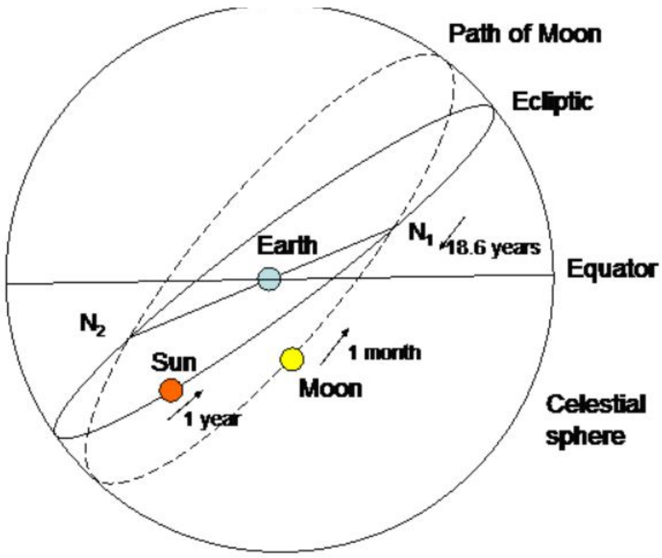
5.5.2 The Earth and Moon System

The Different Phases of the Moon



As the moon revolves around the Earth, the area of reflection of the sun's rays through the Moon as seen from the Earth causes the different lunar phases.

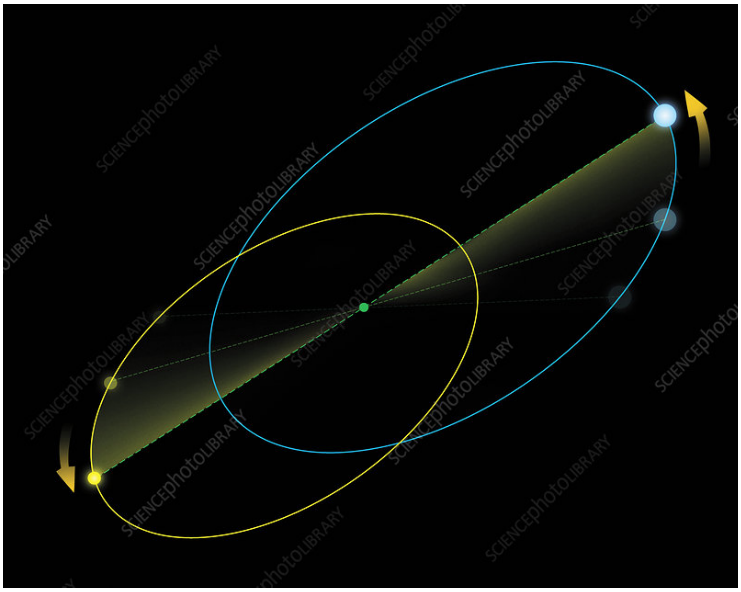
Eclipses



The lunar orbit's inclination itself undergoes periodic change and it so happens that nearly every 2 years, the new moon is completely aligned with the sun and the Earth, causing a solar eclipse.
Similarly, a lunar eclipse occurs when the Earth is is aligned in between the Sun and the Moon, casting a shadow on the Moon's Surface.

5.6 Multi Star Systems

5.6.1 Binary Star System



A system of two stars under the influence of each other's gravitational field is a binary star system.
How do we detect them?

1. Visible Binary: binary stars that can be observed through common observation.
2. Spectroscope Binary: A periodic change in the velocity (determined through spectroscopy) may imply the existence of a binary star system.
3. Eclipsing Binary: Two close star binary systems in which light from one can at times be hidden behind the other.
4. Non-eclipsing Binary: some can be detected using photometry.

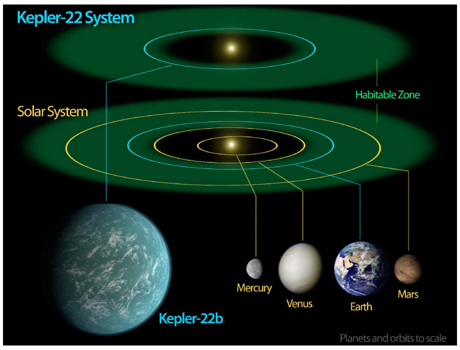
5. Astrometric Binary: A binary star system in which a single star seems to curl around. The other star may be too dim to be seen or may be hidden in the glare of the prime star.

5.6.2 Examples of Multi star systems

Multi-star systems are a very common phenomenon in the outer space. Some notable examples include

1. Sirius, the brightest star in the night sky, is part of a binary star system.
2. Polaris and alpha Centauri both belong to a triple star system.

5.7 Zone of Habitability



The zone of habitability is an area or zone around a star where it is not too hot and not too cold for liquid water to exist.

5.8 Cosmic Rays and Space Weather

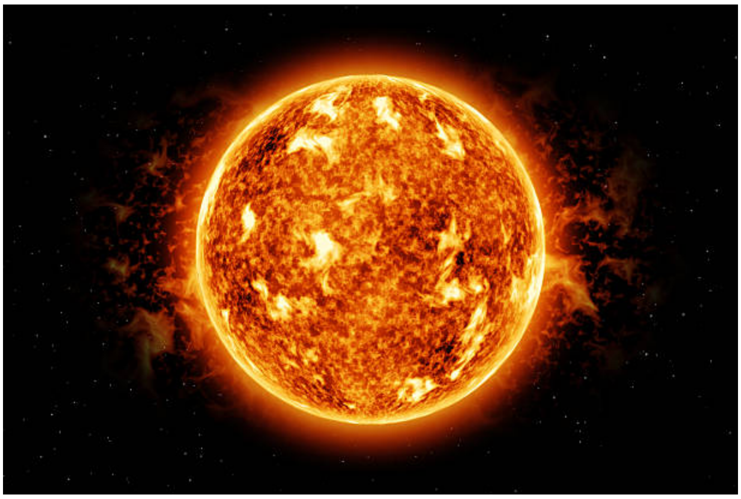
5.8.1 Cosmic Rays

Cosmic Rays are a very high energy (short wavelength) radiation that originates from outside our solar system. They were discovered in the early 1900s and helped in the discoveries of many particles like positron, and muon before the advent of particle accelerators.

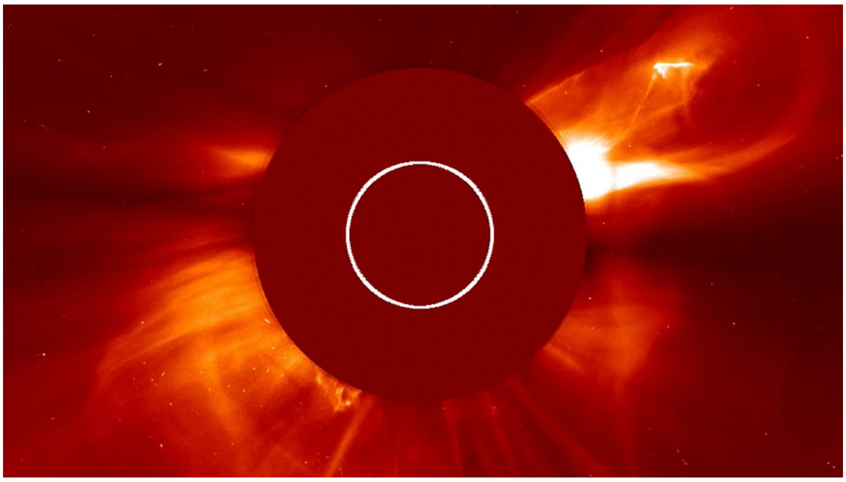
5.8.2 Space Weather

Like Earth's weather, space has seasons that arise due to the variation of the Suns solar activity. The sun develops active regions revealing areas of full field line, which give rise to solar flares and coronal mass ejections.

1. A solar flare is a tremendous amount of energy realized due to the twisted magnetic field on the suns surface.



2. Coronal mass ejections are large ejections of plasma and magnetic fields from the Suns corona.



These solar events pose a constant threat to satellites and astronauts. These events on an extreme scale can even disturb the Earths magnetic field.

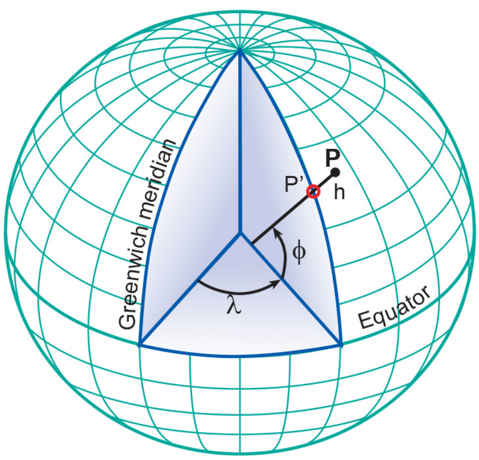
6 Astronomical Coordinate Systems

6.1 Introduction

Astronomical coordinate systems are organized arrangements for specifying positions of satellites, planets, stars, galaxies, and other celestial objects relative to physical reference points available to a situated observer (e.g. the true horizon and north cardinal direction to an observer situated on the Earth's surface). Coordinate systems in astronomy can specify an object's position in three-dimensional space or plot merely its direction on a celestial sphere, if the object's distance is unknown or trivial.There are specifically five types of coordinate systems including Geometrical,Equatorial,Alt-Azimuth,Ecliptic and Galactic coordinate system

6.2 Geometrical Coordinate System

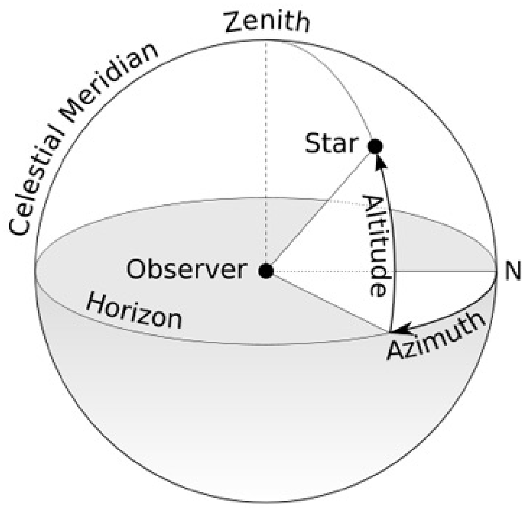
A geographic coordinate system is a system that uses a three-dimensional spherical surface to determine locations on the Earth.



Any location on Earth can be referenced by a point with longitude and latitude coordinates. The geographic coordinate system is appropriate for global data sets and applications, such as satellite imagery repositories.

6.3 Equatorial Coordinate System

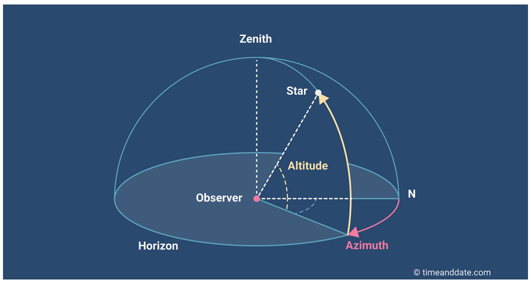
The equatorial coordinate system is probably the most widely used celestial coordinate system. It is also the most closely related to the geographic coordinate system because they use the same fundamental plane and poles.



The projection of the Earths equator onto the celestial sphere is called the celestial equator. Similarly, projecting the geographic poles onto the celestial sphere defines the north and south celestial poles.

6.4 Alt-Azimuth Coordinate System

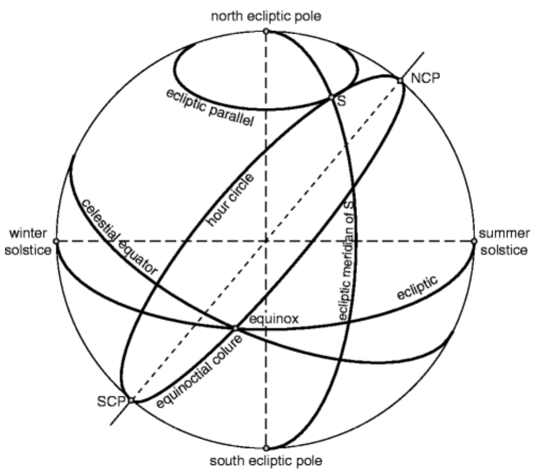
The astronomical coordinate system in which the position of a body on the celestial sphere is described relative to an observer's celestial horizon and zenith.



The coordinates of a body in this system are its altitude and azimuth. Altitude is measured from the celestial horizon along the vertical circle through the body and the zenith of the observer. Azimuth is measured along the celestial horizon from the observer's south point (the point on the horizon directly south of him) to the point where the body's vertical circle intersects the horizon. Because the earth rotates on its axis, the altitude and azimuth of a celestial body are constantly changing.

6.5 Ecliptic Coordinate System

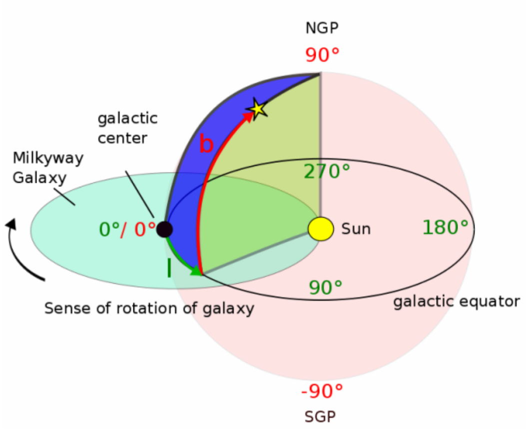
An astronomical coordinate system in which the principal coordinate axis is the ecliptic, the apparent path of the sun through the heavens.



The ecliptic poles are the two points at which a line perpendicular to the plane of the ecliptic through the center of the earth strikes the surface of the celestial sphere. The north ecliptic pole lies in the constellation Draco.

6.6 Galactic Coordinate System

The galactic coordinate system has latitude and longitude lines, similar to what you are familiar with on Earth.



In the galactic coordinate system, the Milky Way uses the zero degree latitude line as its fundamental plane. The zero degree longitude line is in the direction of the center of our galaxy. The latitudinal angle is called the galactic latitude, and the longitudinal angle is called the galactic longitude. This coordinate system is useful for studying the galaxy itself.

6.7 Ephimeris

In astronomy and celestial navigation, an ephemeris is a book with tables that gives the trajectory of naturally occurring astronomical objects as well as artificial satellites in the sky, i.e., the position (and possibly velocity) over time. Historically, positions were given as printed tables of values, given at regular intervals of date and time. The calculation of these tables was one of the first applications of mechanical computers. Modern ephemerides are often provided in electronic form. However, printed ephemerides are still produced, as they are useful when computational devices are not available.

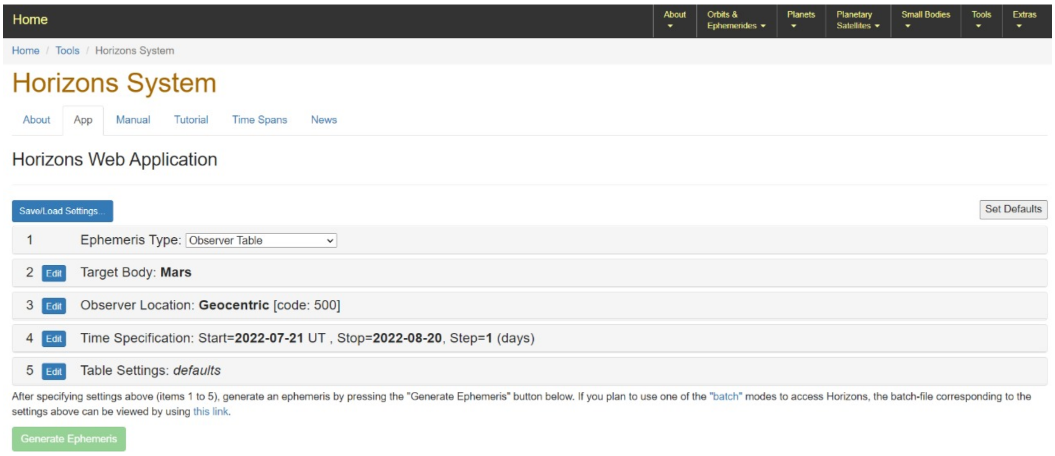
SEPTEMBER 2012 **00:00 UT**

Day	Sid.t	☉	☽	☿	♀	♂	♃	♄	♅	♆	♇	☊	☊	⚸	⚷
S 1	22 42 15	8♍57'57	14♓ 4	29♌48	24♋ 0	5♏24	14♊35	26♎15	7°R38	1°R32	7°R 2	29°R37	0♐ 4	28♉46	7°R15
S 2	22 46 11	9°56'00	27° 1	1♍44	25° 4	6° 3	14°41	26°20	7♈36	1♓31	7♑ 1	29♏25	0° 0	28°53	7♓12
M 3	22 50 8	10°54'04	9♈40	3°41	26° 7	6°42	14°47	26°26	7°34	1°29	7° 1	29°15	29♏57	29° 0	7° 9
T 4	22 54 5	11°52'11	22° 3	5°38	27°11	7°22	14°53	26°32	7°32	1°28	7° 0	29° 8	29°54	29° 6	7° 6
W 5	22 58 1	12°50'19	4♉11	7°35	28°16	8° 1	14°59	26°38	7°29	1°26	7° 0	29° 3	29°51	29°13	7° 3
T 6	23 1 58	13°48'30	16° 8	9°32	29°20	8°41	15° 4	26°44	7°27	1°24	7° 0	29° 0	29°48	29°19	7° 1
F 7	23 5 54	14°46'42	27°57	11°28	0♌25	9°21	15° 9	26°50	7°25	1°23	6°59	29°D 0	29°44	29°26	6°58
S 8	23 9 51	15°44'56	9♊45	13°24	1°30	10° 0	15°14	26°56	7°23	1°21	6°59	29° 0	29°41	29°33	6°55
S 9	23 13 47	16°43'13	21°36	15°18	2°35	10°40	15°19	27° 2	7°21	1°20	6°59	29°R 0	29°38	29°39	6°52
M10	23 17 44	17°41'31	3♋37	17°12	3°41	11°20	15°24	27° 8	7°19	1°18	6°58	28°59	29°35	29°46	6°49
T11	23 21 40	18°39'51	15°51	19° 5	4°46	12° 0	15°29	27°14	7°16	1°16	6°58	28°55	29°32	29°53	6°46
W12	23 25 37	19°38'14	28°24	20°58	5°52	12°40	15°33	27°20	7°14	1°15	6°58	28°50	29°29	29°59	6°43
T13	23 29 34	20°36'39	11♌19	22°49	6°58	13°21	15°37	27°27	7°12	1°13	6°58	28°42	29°25	0♊ 6	6°41
F14	23 33 30	21°35'05	24°37	24°39	8° 5	14° 1	15°41	27°33	7°10	1°12	6°58	28°32	29°22	0°13	6°38
S15	23 37 27	22°33'34	8♍19	26°28	9°11	14°42	15°45	27°39	7° 7	1°10	6°57	28°21	29°19	0°19	6°35
S16	23 41 23	23°32'04	22°20	28°16	10°18	15°22	15°49	27°46	7° 5	1° 9	6°57	28°11	29°16	0°26	6°32
M17	23 45 20	24°30'37	6♎37	0♎ 3	11°25	16° 3	15°53	27°52	7° 3	1° 7	6°57	28° 2	29°13	0°33	6°30
T18	23 49 16	25°29'11	21° 4	1°49	12°32	16°44	15°56	27°59	7° 0	1° 6	6°D57	27°55	29° 9	0°39	6°27
W19	23 53 13	26°27'47	5♏35	3°34	13°39	17°24	15°59	28° 5	6°58	1° 4	6°57	27°50	29° 6	0°46	6°24
T20	23 57 9	27°26'25	20° 4	5°17	14°47	18° 5	16° 2	28°12	6°55	1° 3	6°57	27°48	29° 3	0°52	6°22
F21	0 1 6	28°25'04	4♐26	7° 0	15°55	18°46	16° 5	28°18	6°53	1° 2	6°57	27°D48	29° 0	0°59	6°19
S22	0 5 3	29°23'45	18°40	8°42	17° 2	19°27	16° 7	28°25	6°51	1° 0	6°57	27°49	28°57	1° 6	6°16
S23	0 8 59	0♎22'28	2♑43	10°23	18°10	20° 9	16°10	28°32	6°48	0°59	6°58	27°R49	28°54	1°12	6°14
M24	0 12 56	1°21'13	16°35	12° 3	19°19	20°50	16°12	28°38	6°46	0°57	6°58	27°48	28°50	1°19	6°11
T25	0 16 52	2°19'59	0♒16	13°41	20°27	21°31	16°14	28°45	6°44	0°56	6°58	27°45	28°47	1°26	6° 9
W26	0 20 49	3°18'47	13°45	15°19	21°36	22°13	16°16	28°52	6°41	0°55	6°58	27°39	28°44	1°32	6° 6
T27	0 24 45	4°17'36	27° 3	16°56	22°44	22°54	16°17	28°59	6°39	0°53	6°58	27°32	28°41	1°39	6° 4
F28	0 28 42	5°16'28	10♓ 8	18°32	23°53	23°36	16°19	29° 5	6°36	0°52	6°59	27°23	28°38	1°46	6° 2
S29	0 32 38	6°15'21	23° 0	20° 8	25° 2	24°18	16°20	29°12	6°34	0°51	6°59	27°14	28°35	1°52	5°59
S30	0 36 35	7♎14'16	5♈39	21♎42	26♌11	24♏59	16♊21	29♎19	6♈31	0♓50	6♑59	27♏ 5	28♏31	1♊59	5♓57

The astronomical position calculated from an ephemeris is often given in the spherical polar coordinate system of right ascension and declination, together with the distance from the origin if applicable. Some of the astronomical phenomena of interest to astronomers are eclipses, apparent retrograde motion/planetary stations, planetary ingresses, sidereal time, positions for the mean and true nodes of the moon, the phases of the Moon, and the positions of minor celestial bodies such as Chiron.

6.8 NASA JPL Horizons

The JPL Horizons on-line solar system data and ephemeris computation service provides access to key solar system data and flexible production of highly accurate ephemerides for solar system objects (1,217,865 asteroids, 3,810 comets, 211 planetary satellites includes satellites of Earth and dwarf planet Pluto, 8 planets, the Sun, L1, L2, select spacecraft, and system barycenters). Horizons is provided by the Solar System Dynamics Group of the Jet Propulsion Laboratory.


Home
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App
Manual
Tutorial
Time Spans
News
Horizons Web Application
Save/Load Settings...
Set Defaults
1 Ephemeris Type: Observer Table
2 Edit Target Body: Mars
3 Edit Observer Location: Geocentric [code: 500]
4 Edit Time Specification: Start=2022-07-21 UT , Stop=2022-08-20, Step=1 (days)
5 Edit Table Settings: defaults
After specifying settings above (items 1 to 5), generate an ephemeris by pressing the "Generate Ephemeris" button below. If you plan to use one of the "batch" modes to access Horizons, the batch-file corresponding to the settings above can be viewed by using this link.
Generate Ephemeris

7 Telescopes

7.1 Introduction

A telescope is an optical instrument using lenses, curved mirrors, or a combination of both to observe distant objects, or various devices used to observe distant objects by their emission, absorption, or reflection of electromagnetic radiation.

7.2 History of Telescope

Hans Lippershey which is a maker of sunglasses comes from Middleburg, Netherlands. on October 2nd, 1608 created the first instrument called a telescope. This telescope has the ability to magnify objects that were observed up to five times. A year later in 1609, Galileo Galilei created the first telescope used in astronomy, which can magnify up to 20 times, so in 1610 he confirmed the theory of "sun-centered universe. In 1668, Isaac Newton created a new telescope is a telescope that uses mirrors as a lens. So this discovery is a turning point in the history of science. Then in the mid 17th century, Havelius, an astronomer who came from Germany to make a telescope lens having a skeleton made of wood as high as 46 meters. Furthermore, Huygens which is an astronomer from Dutch using a telescope with different lenses. Telescopes also do not use a tube and only consist of two lenses. In 1897, in the Gulf Williams, United States, was made sebuat Yerkes telescope with a diameter of 101 cm, making it the largest lens telescope in the world at that time. Until now, the largest telescope Keck telescope which is made at the summit of Mauna Kea volcano in Hawaii, this telescope has the ability to view an area eight times larger than any other telescope.

Some Pre-Telescopic observatories: **Machu Picchu** and **Stonehenge**

Figure: Machu Picchu

Figure: Stonehenge

7.3 Components of Telescope

1. Telescope Tube, the aperture of a telescope, the diameter of its main optical component can be of 6,8,10,12 or 14 inches. The primary mirror of the scope is located at the lower end of the tube as in a reflector.
2. Finderscope is a small auxiliary telescope mounted atop the main astronomical telescope and points in the same direction. Finder usually has a smaller magnification then the main telescope can provide and therefore can see more of them sky. This helps in locating the desired astronomical object in the sky.
3. Eyepiece is used to focus the light captured by the scope and magnify it for the eye to observe the object.
4. Telescope mount, a mechanical structure is required to support the telescope tube firmly so that the objects can be viewed and photographed without vibrations and allow a smooth and controlled movement to precisely point an object in the sky. There are two major types of the mount in the astronomical telescope: Alt-azimuth mount(better known as alt-az) and Equatorial mount. There is also a Dobsonian mount which is a newer and a modified version of Alt-azimuth mount.
5. Tripod, as an accomplice to place telescope on a surface
6. Half Pillar, to raise the mounting position, so as to set the tripod hit the pole ballast when the telescope is in use. Functions of a telescope
   - Gathering as much light radiation as possible coming from astronomical source
   - Increasing an angular separation between objects
   - Creating a focused image of an object

More the aperture (light collecting area), more the amount of light entering.

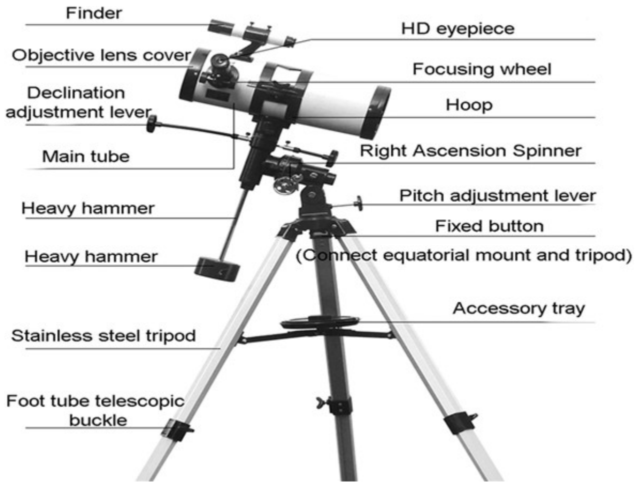


Figure: Components of telescope

7.4 Priciple of working of Telescope

The light from a source reaches the primary lens (or primary mirror), converging at a focal point of a system. Depending on the design, the light either enters the eyepiece (refractors) or is reflected outside a main tube towards the ocular lens (reflectors). The angular resolution is defined by the diameter of the main lens or mirror, which is referred to as an aperture D, measured in millimeters. For the visible light this limit is described by the following formula:

$$sin\alpha = 138/D, \tag{7.1}$$

Where a is the limit resolution measured in arcseconds.
As mentioned before, the bigger the aperture, more light the optics can gather. More light enters the telescope, the fainter objects can be viewed. Limiting magnitude of magnification a telescope can be found according the following formula:

$$M \approx 2.7 + 5logd \tag{7.2}$$

Where d is the aperture diameter in millimeters. Focusing distance is the distance required by lenses or mirrors to direct light at the focal point The field of view is

the area of the sky or the area that can be seen and observed through a telescope
Magnification of a Telescope(M)

$$M = fo/fe \tag{7.3}$$

where, fo is the focal length of the objective and fe is eyepiece's focal length.
Resolution is the closest distance between two objects can still be seen as two separate objects.It refers to precision of details present in image.It depends on size of telescope; Large apertures produce sharper images.

7.5 Optical Defects

The quality of the views produced by optical telescopes is limited by optical defects - aberrations. Refractors suffer from chromatic aberration more than from other deviations. This is the result of the difference of the speed of light of various wavelengths in medium. Red light is refracted more than blue one.
As the consequence of this effect, a star is rounded by colorful concentric rings of light. A corrective lens is placed on top of the primary objective to reduce chromatic aberration.Other types of aberrations are monochromatic. They are spherical, coma, astigmatism, distortion and field curvature. Spherical aberration results from the special spherical surface feature - it focuses on a line, not a point. Therefore, rays from the center of a mirror focus farther from it than rays from the edges. This is fixed by employing parabolic mirrors.
The rest of aberrations are off-axis, they depend on the field angle.

7.6 Types of telescopes

7.6.1 Refracting Telescope

Refracting telescopes are the long, tube-shaped telescopes which you might imagine Galileo using. Refractors use lenses to refract (bend) incoming light through a tube to a focal point. Refractors typically have two lenses. The objective lens is the lens at the front of the telescope through which the light passes. The eyepiece or lens is the lens, which magnifies the image.

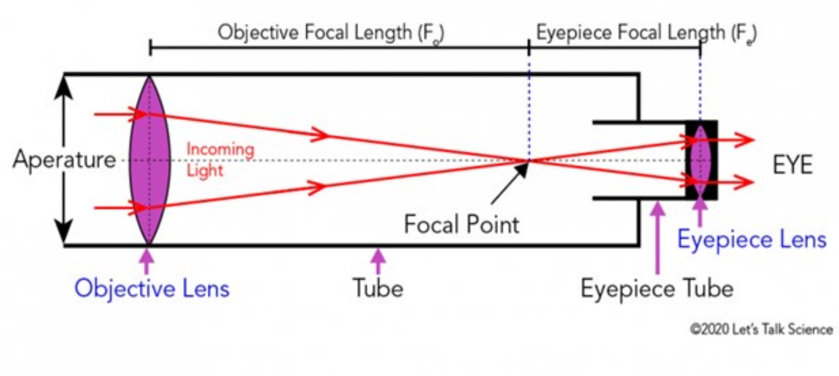


Figure: Refracting Telescope

7.6.2 Reflecting Telescope

Reflecting telescopes use mirrors instead of lenses to reflect light to a focal point. Reflectors have two mirrors. The primary mirror is the big curved mirror at the back that starts to focus the light. The secondary mirror is the smaller mirror at the front that redirects the light towards your eye. Reflectors also have eyepiece lenses.

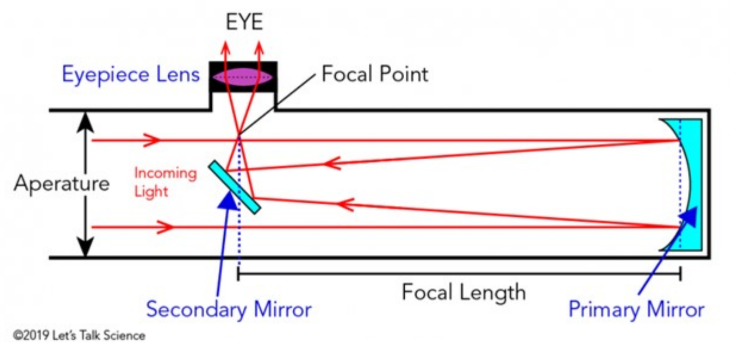


Figure: Reflecting Telescope

Reflecting type telescope is preferred over astronomical (refracting type) because it has following advantages:

1. In reflecting type, objective is not lens hence image formed is free from chromatic aberration.
2. Spherical aberration can also be minimized by using parabolic mirrors in the place of concave mirrors.
3. Concave spherical mirrors of large aperture can be easily manufactured.

4. It has high resolving power.

5. As the mirrors weigh less as compared to the lenses, the mechanical support required for the reflecting type telescope is comparatively less.

7.6.3 Cadiatropic Telescope

Optical telescopes combine specifically shaped mirrors and lenses to form an image. This is usually done so that the telescope can have an overall greater degree of error correction than their all-lens or all-mirror counterparts, with a consequently wider aberration-free field of view.

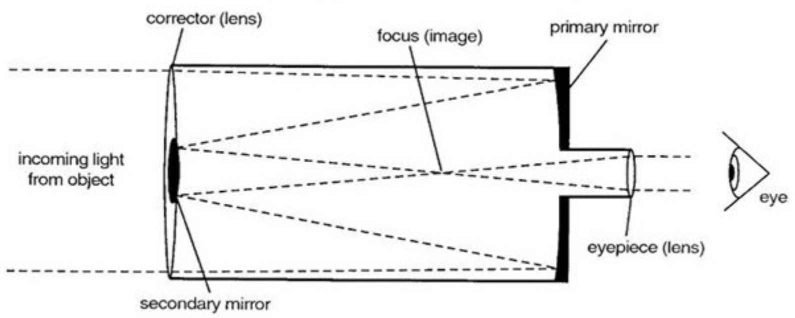


Figure: Cadiatropic Telescope

7.6.4 Radio Telescopes

Radio waves are not something that can be heard They can produce current in conductors (metal antenna or something similar)
Radio waves are reflected by conducting surfaces
A radio-reflecting telescope consists of a concave metal reflector (called a dish),a radio receiver, and an antenna system that is used to detect radio-frequency radiation between wavelengths of about 10 meters and 1 mm. The radio waves collected by the dish have reflected a focus, where they can then be directed to a receiver and analyzed Furthers methods like interferometry can be applied.

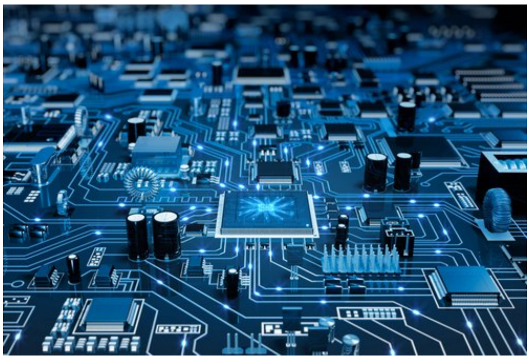
Figure: Radio Telescope

7.7 Characterisitics of Good telescope

1. The key characteristic of a telescope is the aperture of the main mirror or lens.
2. Magnification is not one of the criteria on which to base your choice of a telescope. The magnification of the image is done by a smaller eyepiece, so the magnification can be adjusted by changing eyepieces
3. A sturdy and stable mount is essential

8 Electronics and Instrumentation

Ground-based telescopes reached their size limits around the early 20th century, still, space exploration needed to be expanded further. New technologies had to be discovered and developed to overcome these limitations. They had to be focused on improving Detectors, Imaging, Photography, etc.

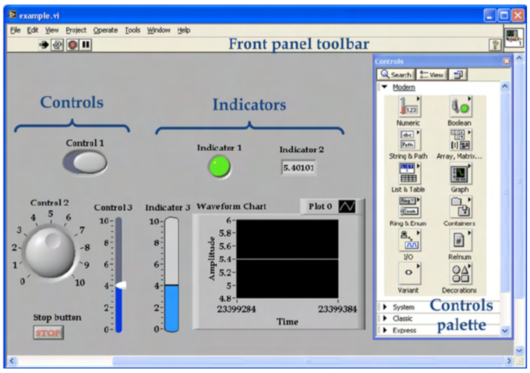


8.1 Electronics

The amazing combination of sophisticated electronics and precise instruments brought about a revolution in astronomy, which can be called an electronic revolution. Dome Automation, CCDs, Spectrographs, GPUs, Microcontrollers and so many more countless inventions have given a great boost to Astronomy and Space Exploration. Electronic Imaging, Photometry, Spectroscopy, Polarimetry, Detectors, Interferometry and many more types of branches have propped up, and the electronics and instruments developed from them have greatly helped the researchers.

8.2 Instrumentation

Virtual Instrumentation, which is the use of customizable software and modular hardware, proves very effective due to its many advantages, like, User defined measurement system, Compatibility, Portability, and Versatility (due to easy customization), etc. Software like LabVIEW has been a great help in the easy development and analysis of sensors, detectors, etc.



8.2.1 LabVIEW

In the project, LabVIEW resources were shared and taught by the mentors. Various concepts learned in the project were implemented in LabVIEW. We also have done some examples related to that; some are:

1. **Thermometer simulator:** Mentees made this simulator which converts temperature in degrees Celcius to degrees Fahrenheit

2. **Projectile simulator:** For a given projection velocity and angle of projection, this simulator gives the time of flight, maximum height and total range using the mathematical formulae:

$$R = u^2 sin2\theta/g \tag{8.1}$$

$$H = u^2 sin^2\theta/2g \tag{8.2}$$

$$T = 2usin\theta/g \tag{8.3}$$

where T is the time of flight,
H is maximum height,
R is the total range,
u is projection velocity,
θ is angle of projection.

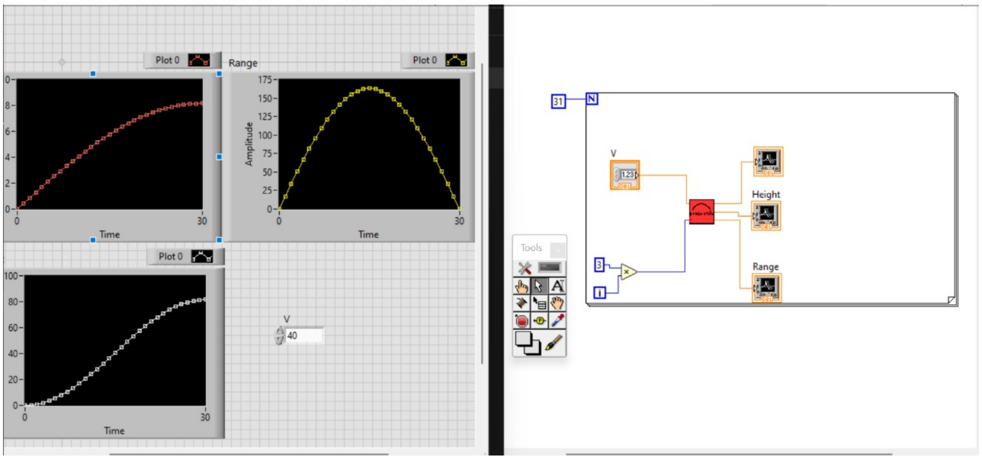


Figure: Projectile simulator

3. **Dice simulator:** This simulator works as a virtual dice; every time on running the program you will get output from 1,2,3,4,5,6 like an actual dice.

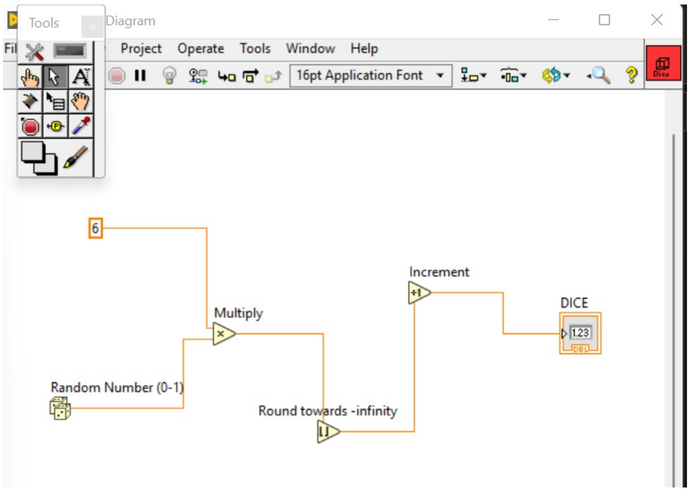


Figure : Dice Simulator block diagram

4. **Sundial Calculator**| It calculates the hour angle H using the following mathematical relation:

$$H = arctan(tan(T).sin(L)) \tag{8.4}$$

where T and L have usual meanings,

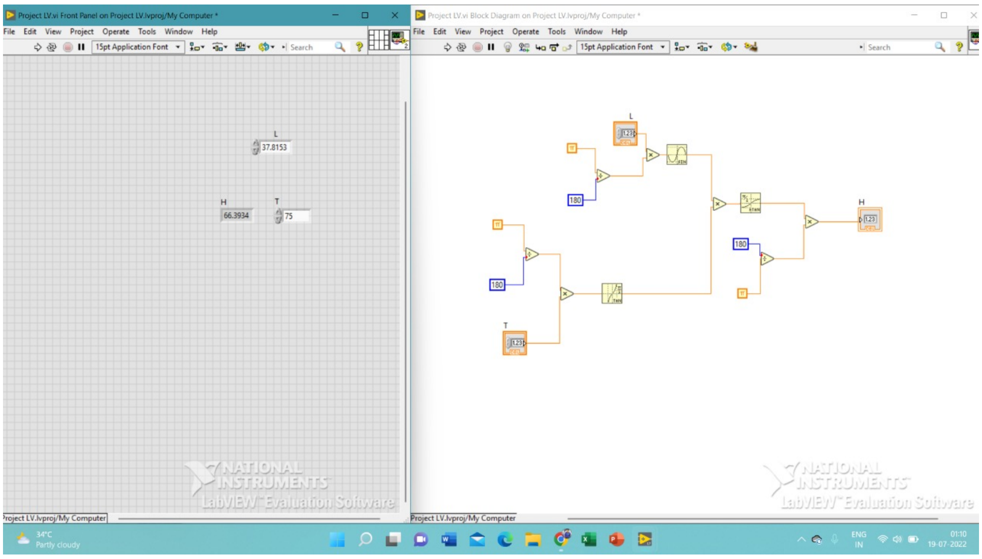


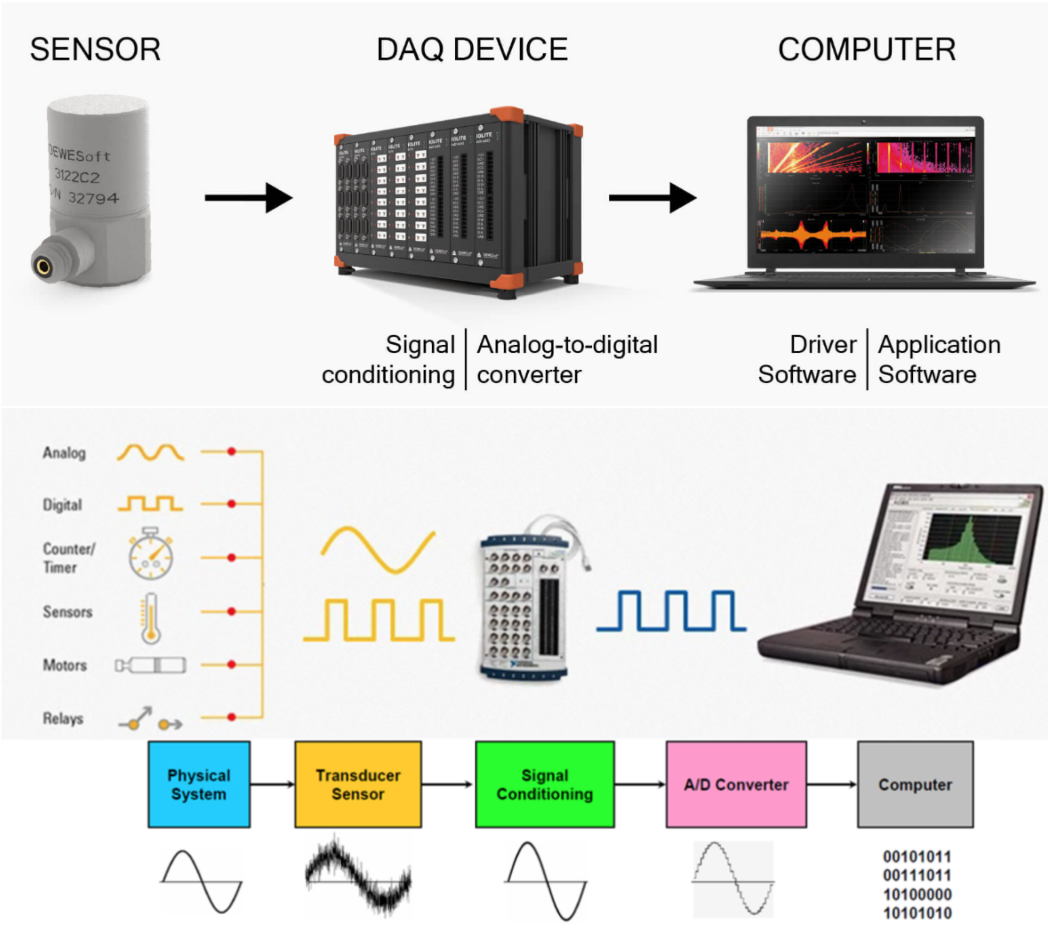
Figure: Sundial Calculator

Data Acquisition

9

9.1 Introduction

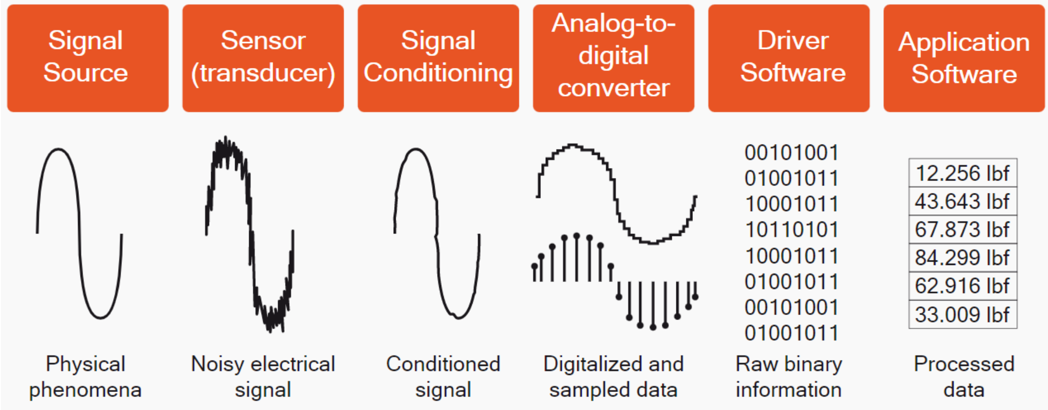
It is the process of sampling signals that measure real-world physical phenomena and converting them into a digital form that can be analyzed and monitored by the software. Its components include Sensors, Signal Conditioning, DAQ Hardware, Software, PC etc.



Sensors detect change in the physical environment, Transducers convert physical quantity or energy into electrical signals, Actuators convert electrical signals into physical form of energy, i.e., they take input from the system and give output to the environment.

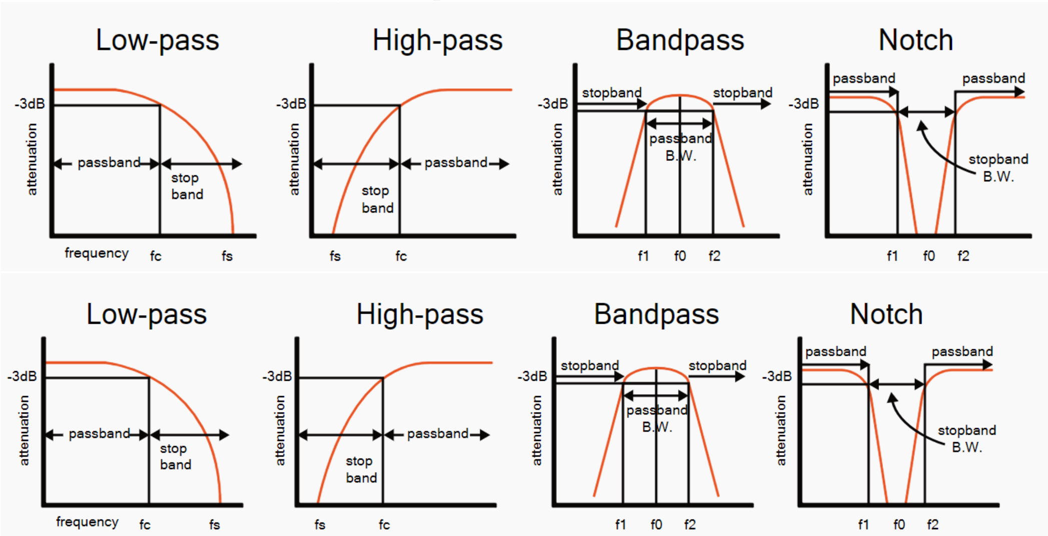
9.2 Signal Conditioning

Signal Conditioning is the manipulation of digital signals to prepare them for digitizing. In it, output is taken from analog sensors and prepared to be sampled digitally. It involves amplification, filtering, linearization, transducer excitation, isolation etc.



9.3 Filtering

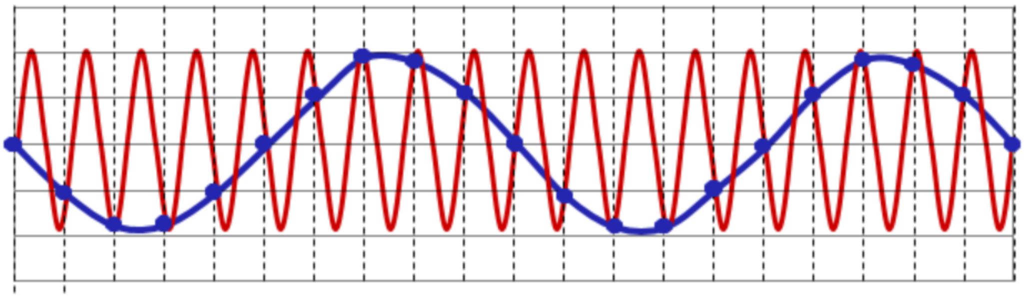
Filtering in Data Acquisition basically means allowing only those waves/observations to be retained which satisfy some particular set of conditions.



Basic filter types

9.4 DAQ Hardwares

DAQ Hardware devices/hardware contain signal conditioning and analog to digital converter. Users need to set the sampling rate and provide for precise timing for computer system data analysis. Sampling considerations include Device range, resolution, code width, sampling rate etc.

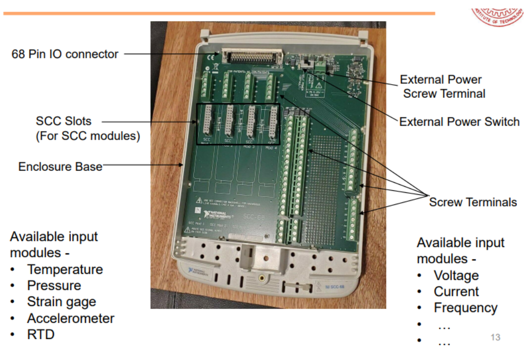


Aliasing is an effect that causes distortion of the sampled signal to the sampling rate being too low to capture the frequency content.

9.5 Nyquist Sampling theorem

Nyquist Sampling theorem states that the sampling rate should at least be twice the maximum frequency component of the signal of interest.

Some of the highly useful multipurpose DAQ hardware are BNC 2120 and SCC-68.



10 Orbital Mechanics

10.1 Kepler's Laws of Motion

The Kepler's laws of planetary motion describes the orbit of the planets around Sun, which can be mathematically derived from Newton's laws. These can be formulated as follows:

Figure 46: Hoffmann Transfer Orbit 54 Chapter 9 Orbital Mechanics

1^{st} law: No edgings can be there on any planetary orbit. So possible smoothened orbit can be parabolic, hyperbolic, elliptic, circular(special).

From Newtonian law of Gravitation,

$$F = -\frac{GMm}{r^2} = -mA \tag{10.1}$$

$$A = -\frac{\mu}{r^2} \tag{10.2}$$

where,

A = acceleration of m caused by the gravitational force F of M

μ = GM = standard Gravitational Parameter

The equation of orbit under $\frac{1}{r^2}$ attractive force is given by

$$r\left(\theta\right) = \frac{p}{1 + ecos\theta} \tag{10.3}$$

$$p = a\left(1 - e^2\right) \tag{10.4}$$

$$e = \sqrt{1 + \frac{2EL^2}{m\mu^2}} \tag{10.5}$$

where,

a = semi-major axis

p = semi-latus rectum

e = eccentricity of conic-section

E = total energy of moving planetary body

L = angular momentum of moving body

Thus, depending on the value of e, the orbit can be circular, elliptic, parabolic or hyperbolic.

	Energy	Orbit
e = 0	E < 0	Circular
0 < e < 1	E < 0	Elliptic
e = 1	E = 0	Parabolic
e > 1	E > 0	Hyperbolic

Figure 45: Planetary Orbit

Total energy of planets moving around the Sun is negative and thus planets move in an elliptic orbit around the Sun.

NOTE: During Mission-

From a circular orbit, thrust applied in a direction opposite to the satellite's motion changes orbit to elliptical; the satellite will descend and reach the lowest orbital point (the periapse) at 180 degrees away from the firing point; then it will ascend back. Thrust applied in the direction of the satellite's motion creates an elliptical orbit with its highest point (apoapse) 180 degrees away from the firing point.

2^{nd} law: The radius vector of a planet sweeps out area at a constant rate.

$$\frac{dA}{dt} = \frac{L}{2m} = constant \tag{10.6}$$

where,

A = area vector

3^{rd} law: Square of Time Period of body is moving directly proportional to third power of inter-body distances between them.

$$T^2 \propto a^3 \tag{10.7}$$

10.2 Escape Velocity

The specific energy (energy per unit mass) of any space vehicle is composed of two components, the specific potential energy and the specific kinetic energy. The specific potential energy associated with a planet of mass M is given by

$$PE(specific) = \frac{GM}{r} \tag{10.8}$$

while the specific kinetic energy of an object is given by

$$KE(specific) = \frac{v_2}{2} \tag{10.9}$$

and so the total specific orbital energy is

$$TE = KE + PE = \frac{v_2}{2} - \frac{GM}{r} \tag{10.10}$$

Since energy is conserved, TE cannot depend on the distance, r from the center of the central body to the space vehicle in question, i.e. v must vary with r to keep the specific orbital energy constant. Therefore, the object can reach infinite r only if this quantity is nonnegative, which implies:

$$v \geq \sqrt{\frac{2GM}{r}} \tag{10.11}$$

10.3 Hoffmann Transfer Orbit

In orbital mechanics, the Hohmann transfer orbit is an elliptical orbit used to transfer between two circular orbits of different radii around a central body in the same plane. The Hohmann transfer often uses the lowest possible amount of propellant in traveling between these orbits and thus is highly fuel efficient.

Calculation:

The total energy of the orbiter is the sum of its kinetic energy and potential energy, and this total energy also equals half the potential at the average distance a (the semi-major axis):

$$E = \frac{mv^2}{2} - \frac{GMm}{r} = -\frac{GMm}{2a} \tag{10.12}$$

$$\Rightarrow v^2 = \mu\left(\frac{2}{r} - \frac{1}{a}\right) \tag{10.13}$$

where,

v = speed of orbiter

μ = GM, the standard gravitational parameter of the primary body, the Sun

r = distance of orbiter from primary focus

a = semi-major axis

Therefore, the delta-v (Δv) required for the Hohmann transfer can be computed as follows,

$$\Delta v_1 = \sqrt{\frac{\mu}{r_1}}\left(\sqrt{\frac{2r_2}{r_1 + r_2}} - 1\right) \tag{10.14}$$

$$\Delta v_2 = \sqrt{\frac{\mu}{r_2}}\left(1 - \sqrt{\frac{2r_1}{r_1 + r_2}}\right) \tag{10.15}$$

where,

$$a = \frac{r_1 + r_2}{2} \tag{10.16}$$

r_1 = radius of the departure circular orbit corresponding to the periapsis of the Hohmann elliptical transfer orbit

r_2 = radius of the arrival circular orbit corresponding to the apoapsis of the Hohmann elliptical transfer orbit

Δv_1 = Delta-v required to enter the Hohmann transfer orbit from the lower orbit

Δv_2 = Delta-v required to enter the higher Orbit from the Hohmann transfer orbit

Thus,

$$\Delta v_{total} = \Delta v_1 + \Delta v_2 \tag{10.17}$$

And the time taken to transfer between the orbits by the Kepler's third law,

$$t = \frac{1}{2}\sqrt{\frac{4\pi^2 a^3}{\mu}} = \pi\sqrt{\frac{r_1 + r_2}{8\mu}} \tag{10.18}$$

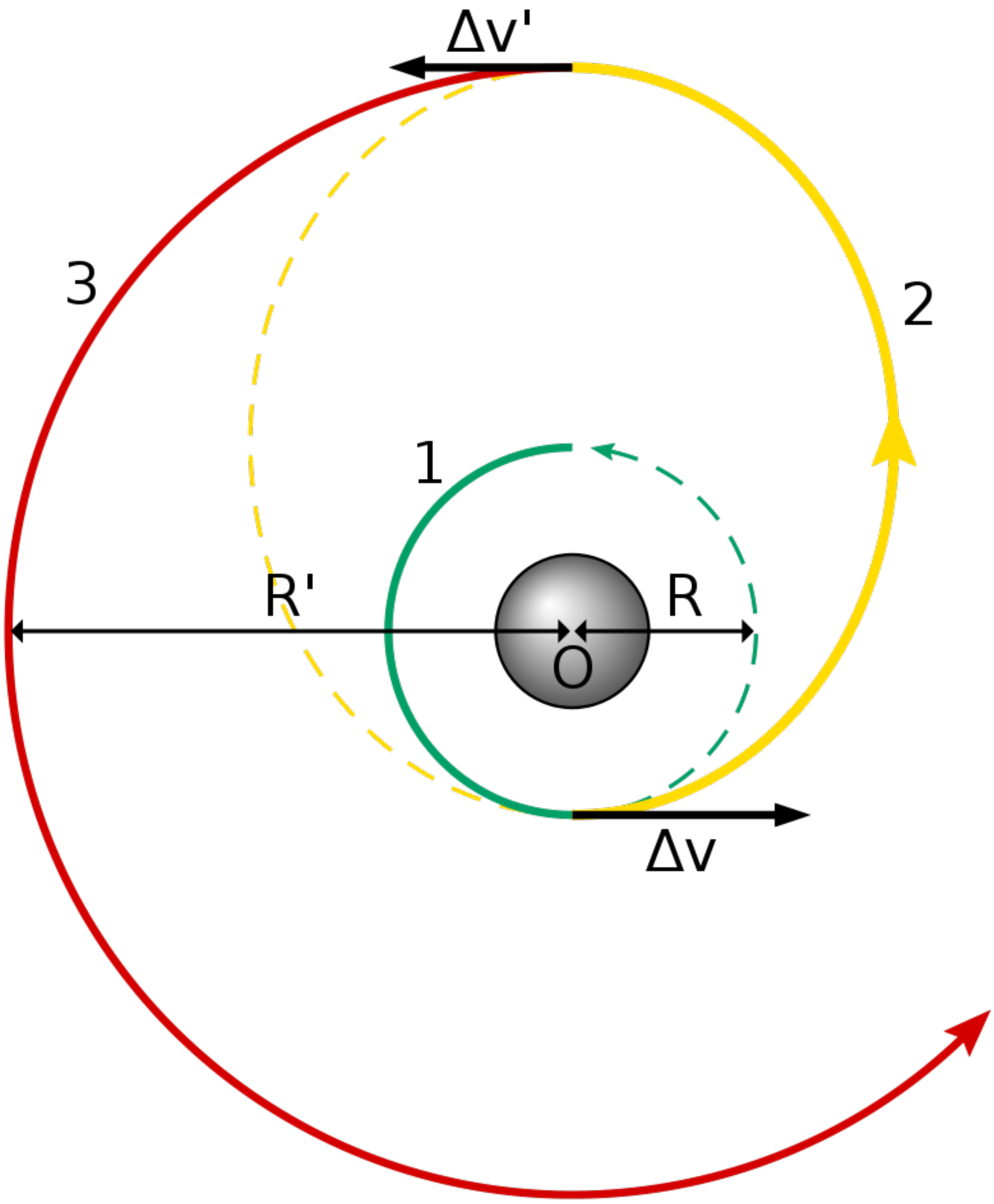
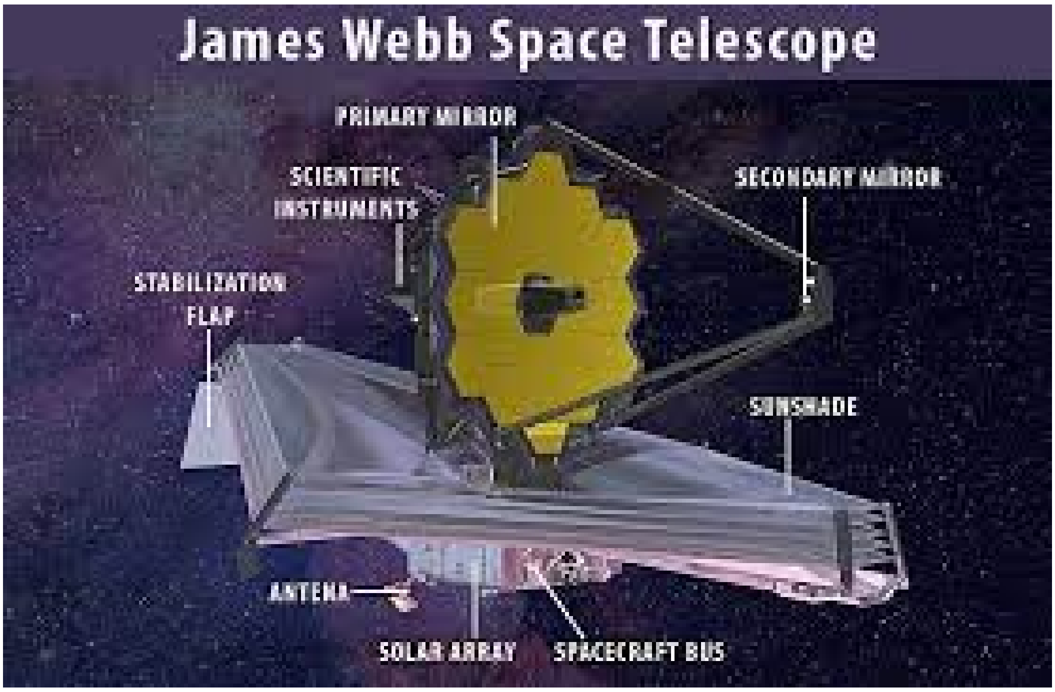


Figure 46: Hoffmann Transfer Orbit

11 Case Studies: Space Telescopes

11.1 James Webb Space Telescope

On the 25th of December 2021, The James Webb Telescope set sailed from ESA's launch site at Kourou in French Guiana, beginning a historic program that took nearly 20 years of immense hard work and ambition to complete and 10 billion dollars worth of capital. The JWST is a collaborative program led by the National Aeronautics and Space Administration (NASA) with the European Space Agency(ESA) and the Canadian Space Agency(CSA), intended to succeed NASA's Hubble Space Telescope.



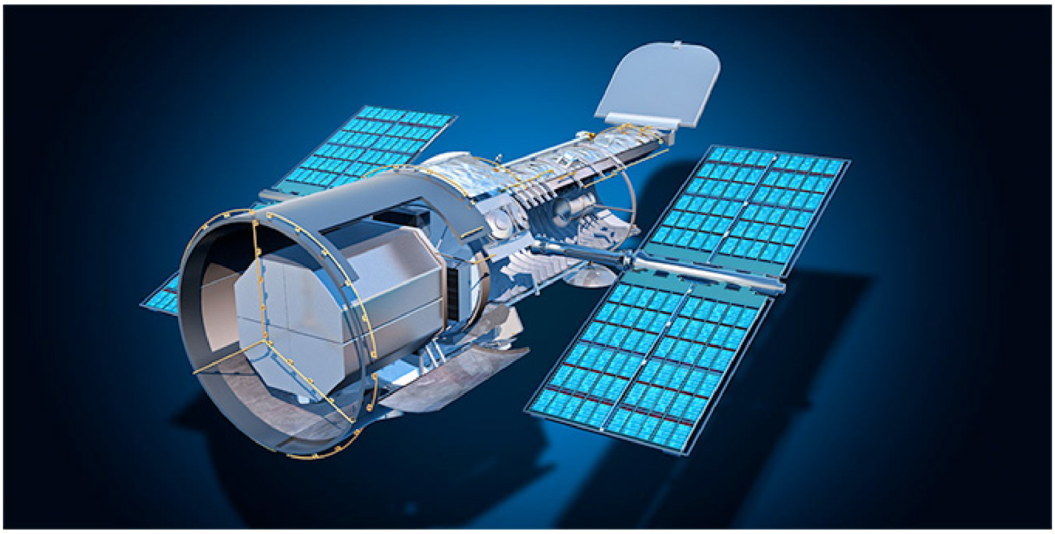
11.2 O

nboard Instrument: -Infrared Camera (NIRCam): The camera will operate in the near-infrared region and detect the earliest stars and galaxies in the process of formation, the population of stars in nearby galaxies, as well as young stars in the Milky Way and Kuiper Belt objects. -Infrared Spectrograph(NIRSpec): The spectrometer would also operate in the Near-Infrared region and would study the properties such as composition, age, and temperature of an object.

Mid-Infrared Instrument(MIRI): The instrument contains a camera and a spectrograph and operates at an even longer wavelength in the mid-infrared region.

Fine Guidance Sensor/Near Infrared Imager And Slitless Spectrograph (FGS/NIRISS): The FGS allows Webb to point and focus precisely on the target. The NIRISS will help in light detection, exoplanet detection and its characterisation, and exoplanet transit spectrography.

11.3 Hubble Space Telescope



The Hubble Space Telescope was designed as a general purpose observatory, meant to explore the universe in visible, ultraviolet and infrared wavelengths. To date, the telescope has studied more than 40,000 cosmic objects, providing views astronomers were unable to capture from the ground Hubble features a 2.4 m (7 ft 10 in) mirror, and its five main instruments observe in the ultraviolet, visible, and near-infrared regions of the electromagnetic spectrum. Hubble's orbit outside the distortion of Earth's atmosphere allows it to capture extremely high-resolution images with substantially lower background light than ground-based telescopes. It has recorded some of the most detailed visible light images, allowing a deep view into space. Many Hubble observations have led to breakthroughs in astrophysics, such as determining the rate of expansion of the universe.. The purpose of Hubble, the most complex and sensitive optical telescope ever made, is to study the cosmos from a low Earth orbit. By placing the telescope in space, astronomers are able to collect data that is free of Earth's atmosphere. Hubble detects objects 25 times fainter than the dimmest objects seen from Earth and provides astronomers with an observable universe 250 times larger than is visible from ground-based telescopes, extending our view more than 13 billion light-years away. Hubble views galaxies, stars, planets, comets, planet formation in other solar systems, and even unusual phenomena such as quasars, with 10 times the clarity of ground-based telescopes.

We also tried to make a CAD model of Hubble Telescope.

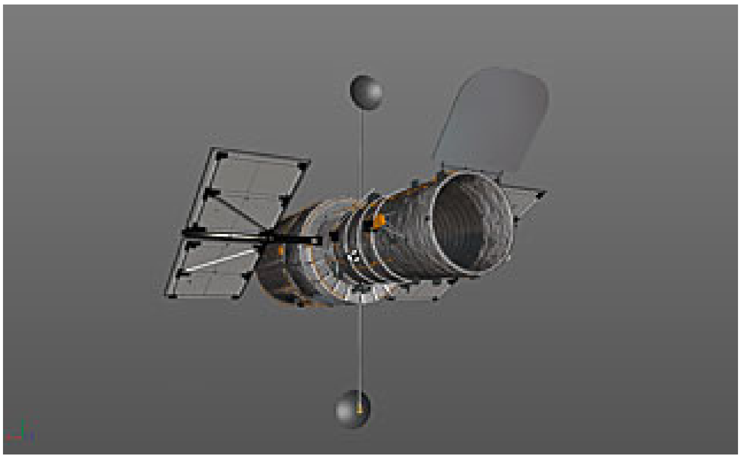


Figure: Trial CAD model for Hubble Telescope

12 References

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