Introduction to Astronautics

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Astronautics

- The branch of aerospace engineering that deals with flight outside the atmosphere is termed as astronautics.
- Astronautics involves the basic concepts of space flight, space stations, orbit determination as well as rocket propulsion.
- Astronautics can be analyzed in three parts

  - Ascent through the atmosphere

  - Mission in space

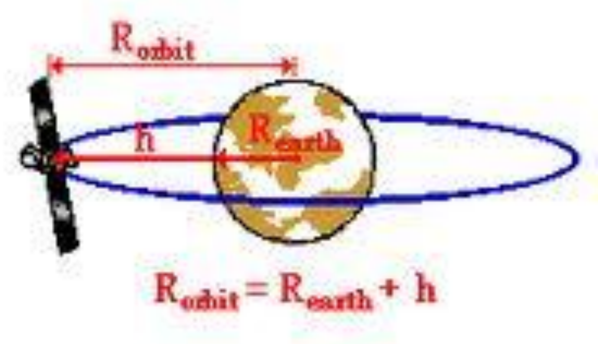
  - Planetary entry

Definitions and Terminology

- For any object to be placed in an orbit around the Earth, it is essential for it to have a minimum velocity of 7.9 km/ sec
- If you want to have a mission to the moon or beyond, or if you need to go beyond the gravitational attraction of earth, you will need to obtain a minimum speed of 11 km/sec
- Once you get out of Earth's gravity, you will continue to travel at that speed until you enter the gravitational attraction of another body.

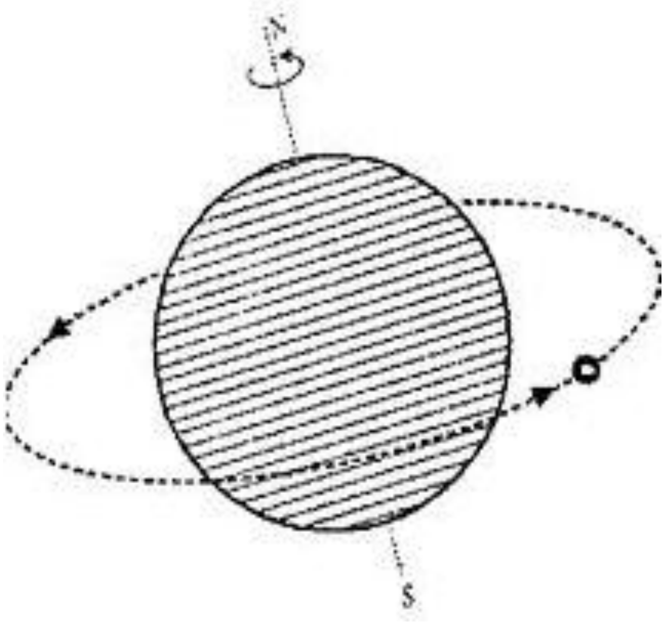
Definitions and Terminology

- When you are out in space, there will be no atmosphere to create any drag effects on your space vehicle
- In order to escape Earth's atmospheric effects, you have to be higher than 1000 km altitude.
- The time taken by a satellite to execute one complete orbit is called the period and it is shown by **τ**



Period of a Satellite

- The time taken by a satellite to execute one complete orbit is called the period and it is shown by **τ.** Hence, if a satellite rotates one orbit in 3 hours, then its period is 3 hours



Definitions and Terminology

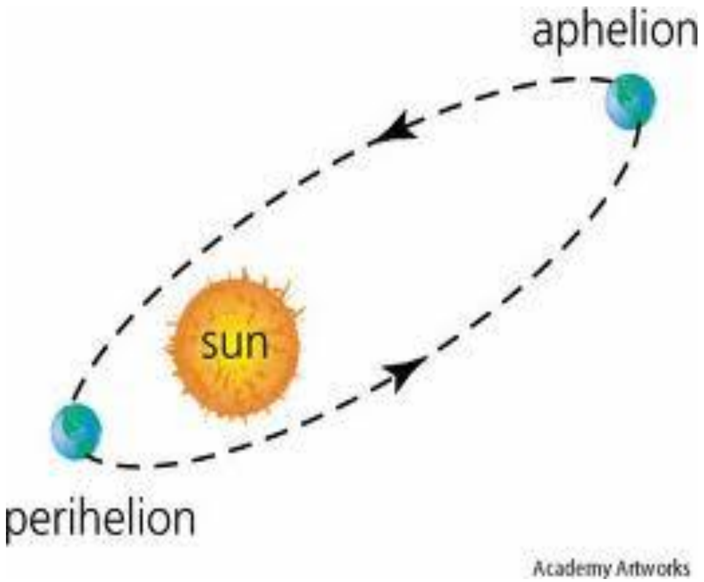
- When you are out in space, there will be no atmosphere to create any drag effects on your space vehicle
- International treaties state that altitude above 100 miles (160 km) is considered space as flying below this altitude requires that country's permission.

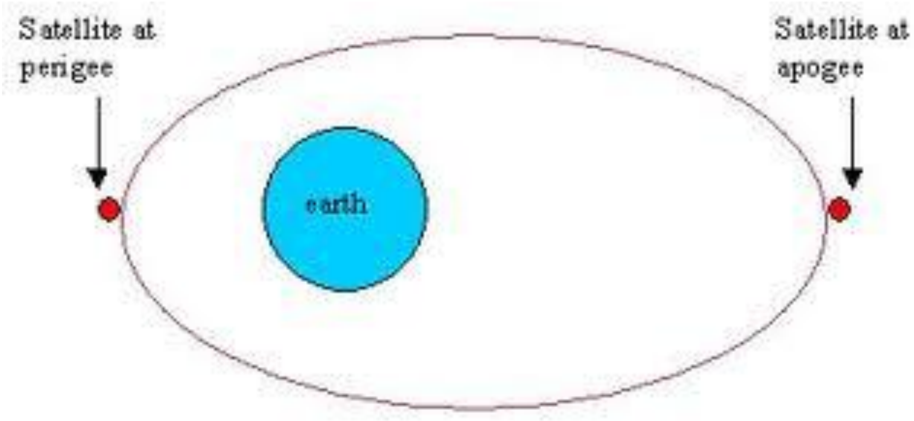
- Most satellites are placed above 400 km of altitude in orbit
- In order to fully escape Earth's atmospheric effects, you have to be higher than 1000 km altitude.

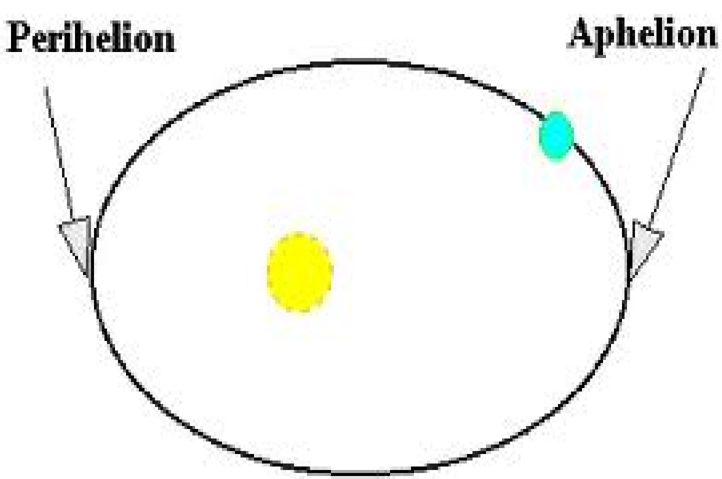
Definitions and Terminology

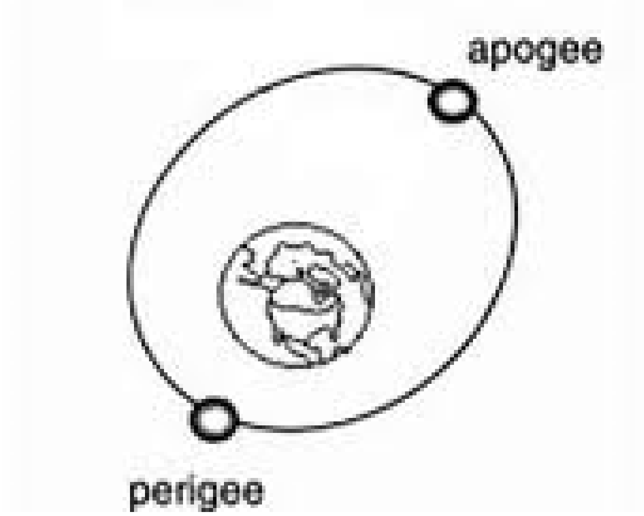
- **Apogee** is the highest altitude or point in an orbit around the Earth
- **Perigee** is the lowest altitude or point in an orbit around the Earth
- **Aphelion** is the highest point in an orbit of an object around the sun (far from the sun)
- **Perihelion** is the lowest point in an orbit of an object around the sun (close to sun)

Apogee – Perigee – Aphelion - Perihelion









Types of Orbits

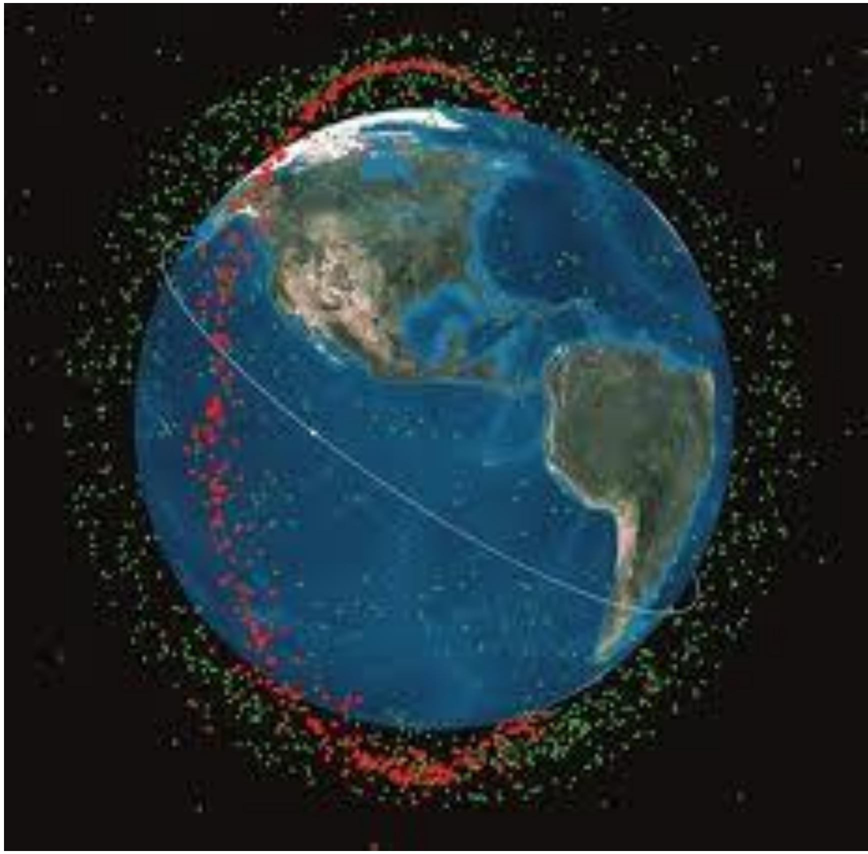
- **Geostationary orbit** is when the satellite or spacecraft is stationary in a single position relative to the Earth
- **Polar Orbit** is an orbit in which your spacecraft or your satellite crosses the orbits in a longitudinal fashion. In a polar orbit, you can circle the Earth several times.
- **Highly Elliptical Orbit**: When the satellite passes Earth quickly and stays away from Earth fixed in a distant location.

LEO MEO HEO

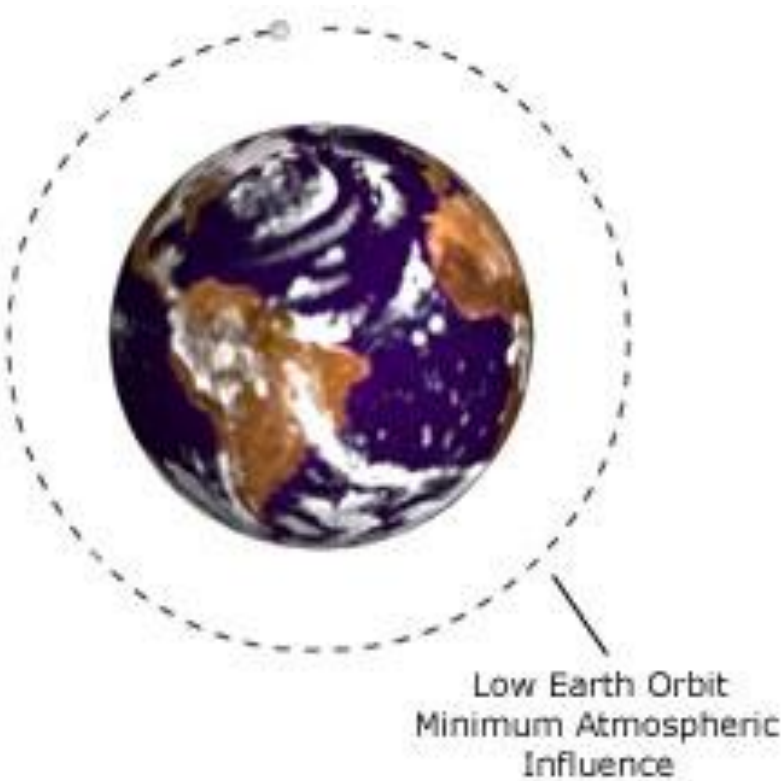
- LEO is orbit with less then 1000 km altitude
- MEO is above 1000 KM to 10000 km
- HEO is above 10000 KM

LEO

- LEO is Low Earth orbit and it is considered as 160 km to 1000 km of altitude. Technically, in Low Earth orbit, the drag effects will always hinder operations.
- For example, ISS is in LEO (around 386 km – 460 km) and it needs its orbit readjusted by the Space Shuttle or by its own thrusters every 6 months or it will fall down
- Satellites in LEO will have very high speeds around 18,000 miles per hour



Types of Orbits



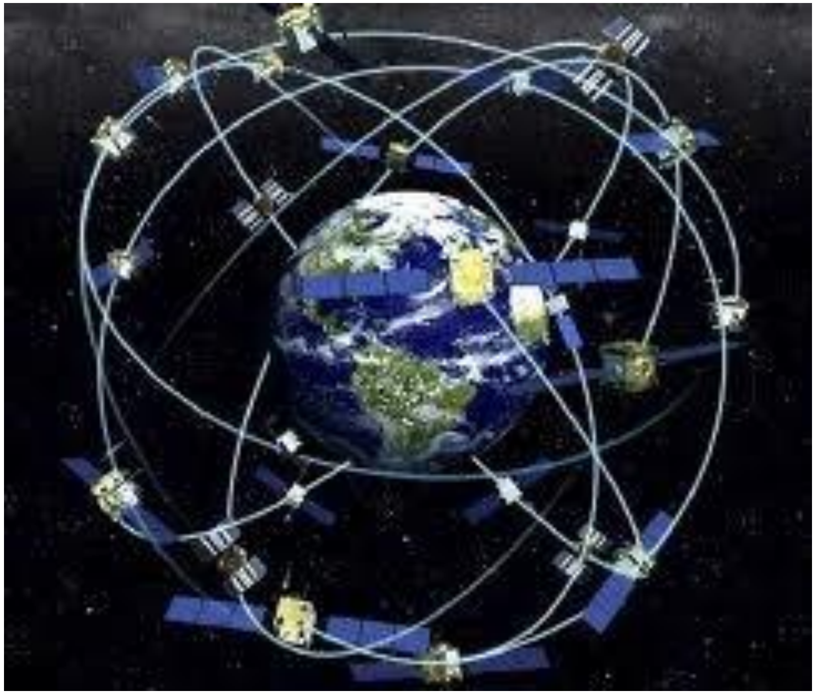
Low Earth Orbit is used for things that we want to visit often with the Space Shuttle, like the Hubble Space Telescope and the International Space Station. This is convenient for installing new instruments, fixing things that are broken, and inspecting damage. It is also about the only way we can have people go up, do experiments, and return in a relatively short time

Low Earth Orbit Disadvantages

- The first disadvantage is that there is still some atmospheric drag. Even though the amount of atmosphere is far too little to breath, there is enough to place a small amount of drag on the satellite or other object. As a result, over time these objects slow down and their orbits slowly decay
- The second disadvantage has to do with how quickly a satellite in LEO goes around the Earth. As you can imagine, a satellite traveling 18,000 miles per hour or faster does not spend very long over any one part of the Earth at a given time

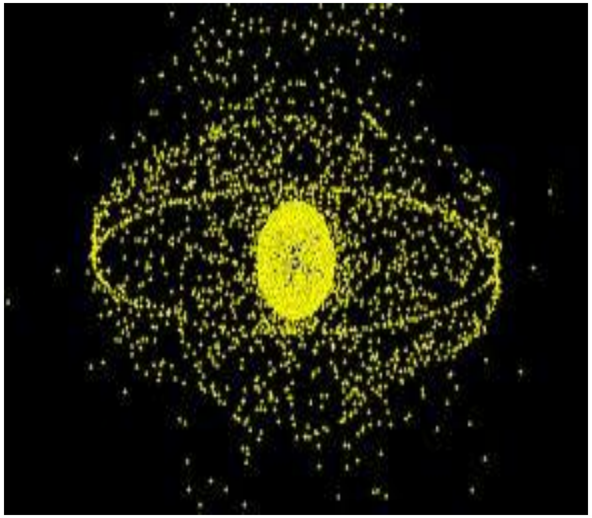
MEO

- MEO is Middle Earth Orbit is a special orbit that is beyond LEO.
- MEO is usually defined as 1001 Km – 10000 Km in most literature. However, previously it was defined as high as 10,000 km

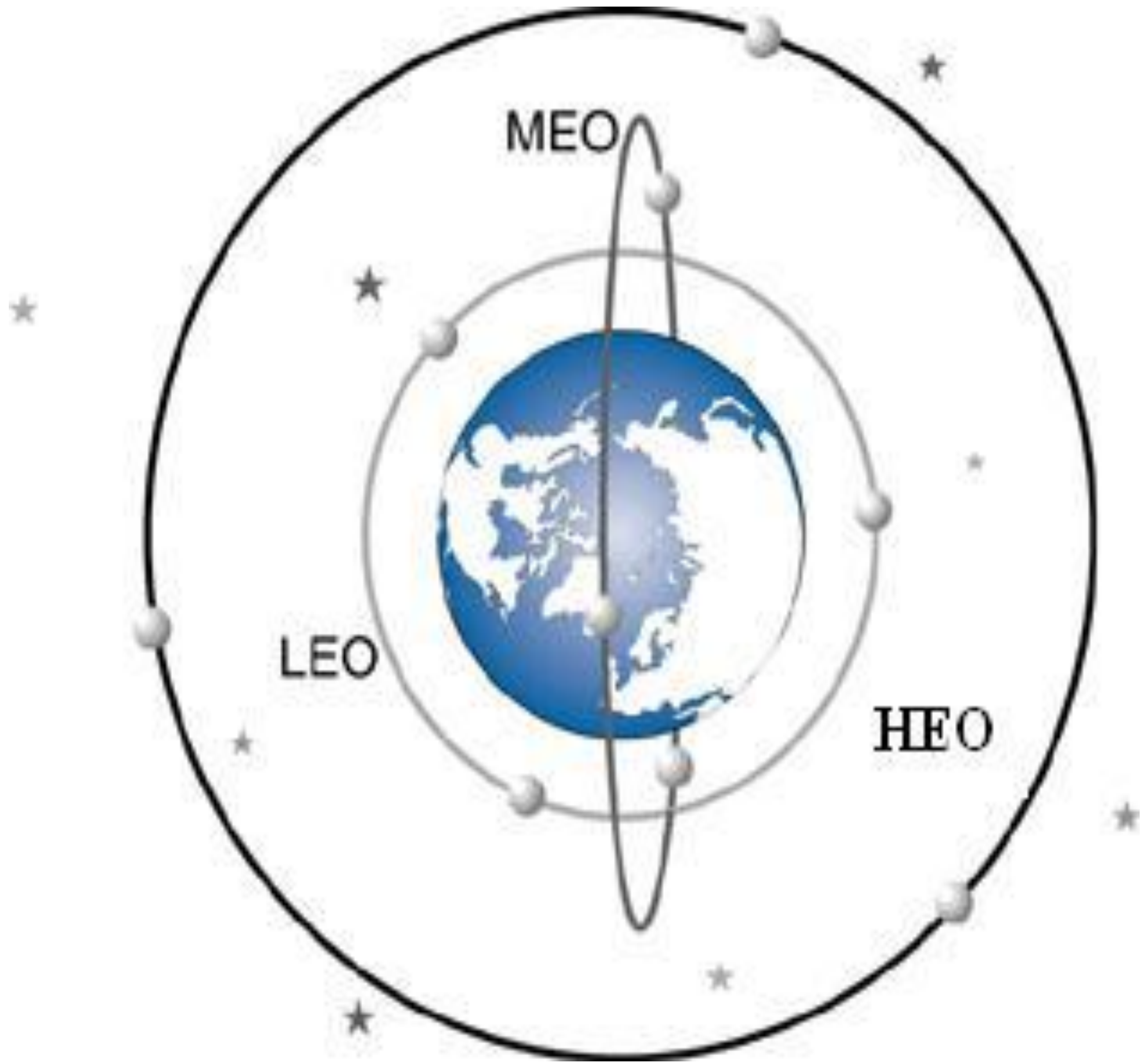


HEO

- HEO is High Earth orbit
- HEO is defined as orbit above 10000 km in most literature. It extends to 40,000 km altitude.
- Mostly in HEO, the drag effects would be non existent. Hence, HEO will have a more stable orbit free from atmospheric effects, but also it will require much more energy to put there

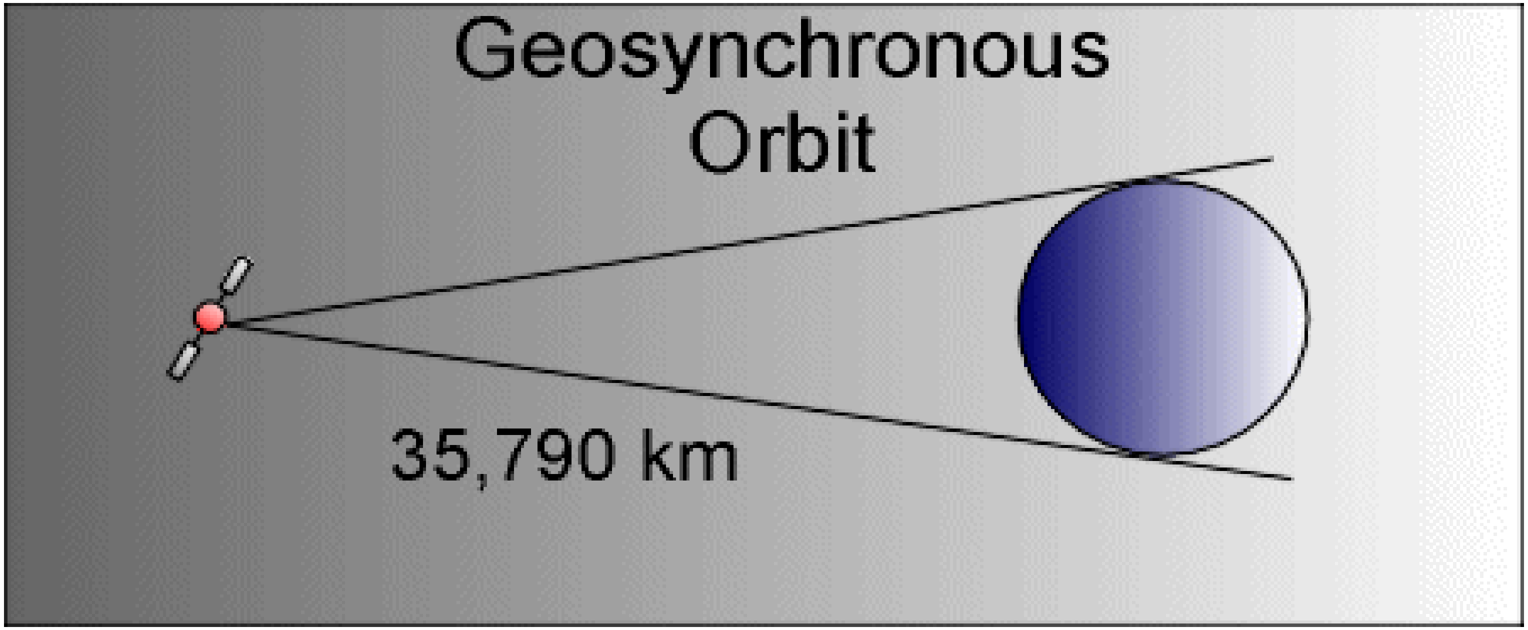


LEO – MEO - HEO



Geosynchronous/ Geostationary Orbit

- Satellite has to be placed approximately 22,000 miles (36,000 km) away from the surface of the Earth in order to remain in a GEO orbit

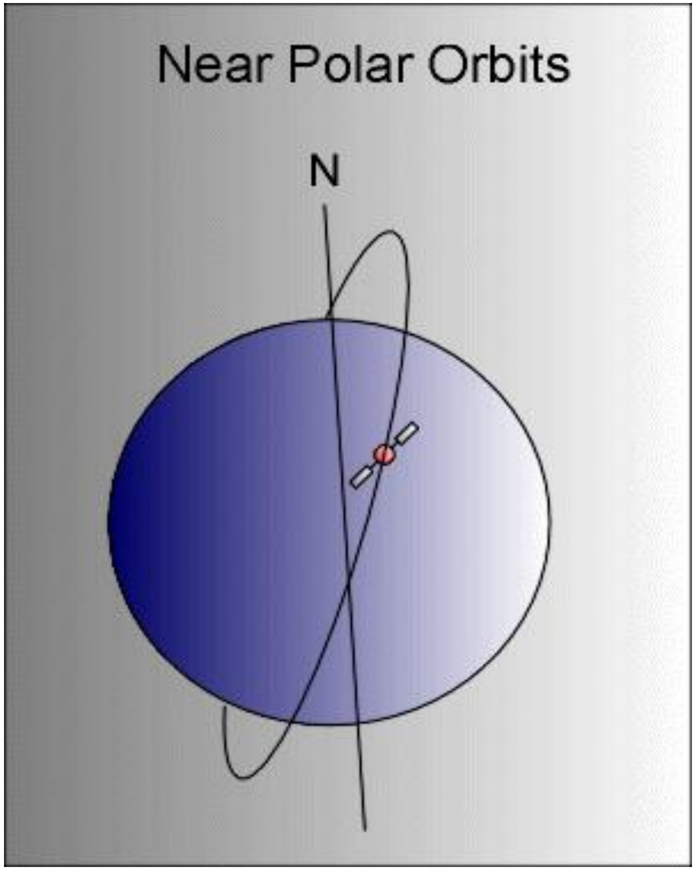


Geosynchronous/Geostationary Orbit

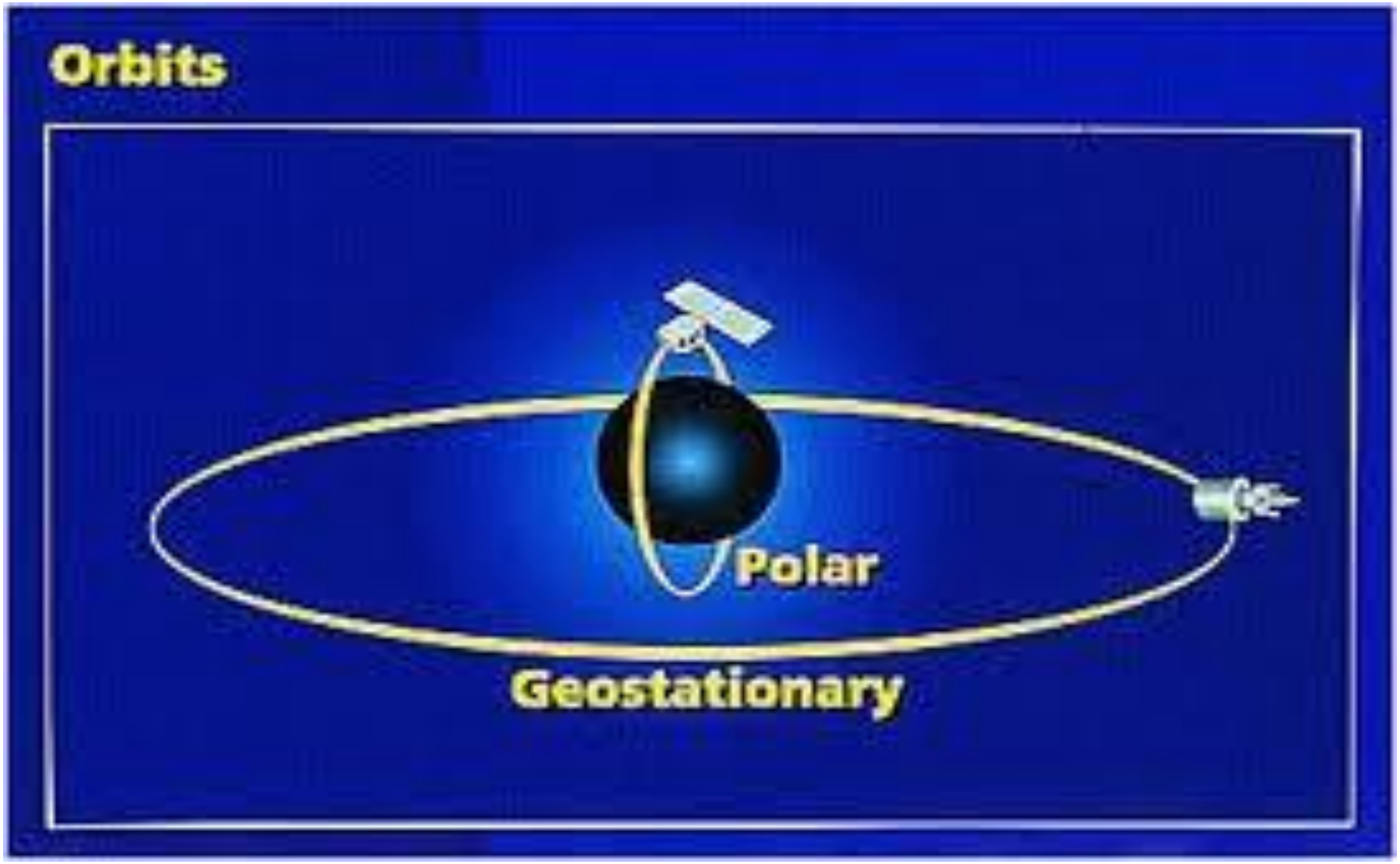
- By positioning a satellite so that it has infinite dwell time over one spot on the Earth, we can constantly monitor the weather in one location, provide reliable telecommunications service, and even beam television signals directly to your house
- The down side of a geosynchronous orbit is that it is more expensive to put something that high up and not possible to repair it from the shuttle
- So you only put something in GEO if you really need to have it in the same location in the sky at all times.

Polar Orbit

- These orbits have an inclination near 90 degrees. This allows the satellite to see virtually every part of the Earth as the Earth rotates underneath it. It takes approximately 90 minutes for the satellite to complete one orbit.

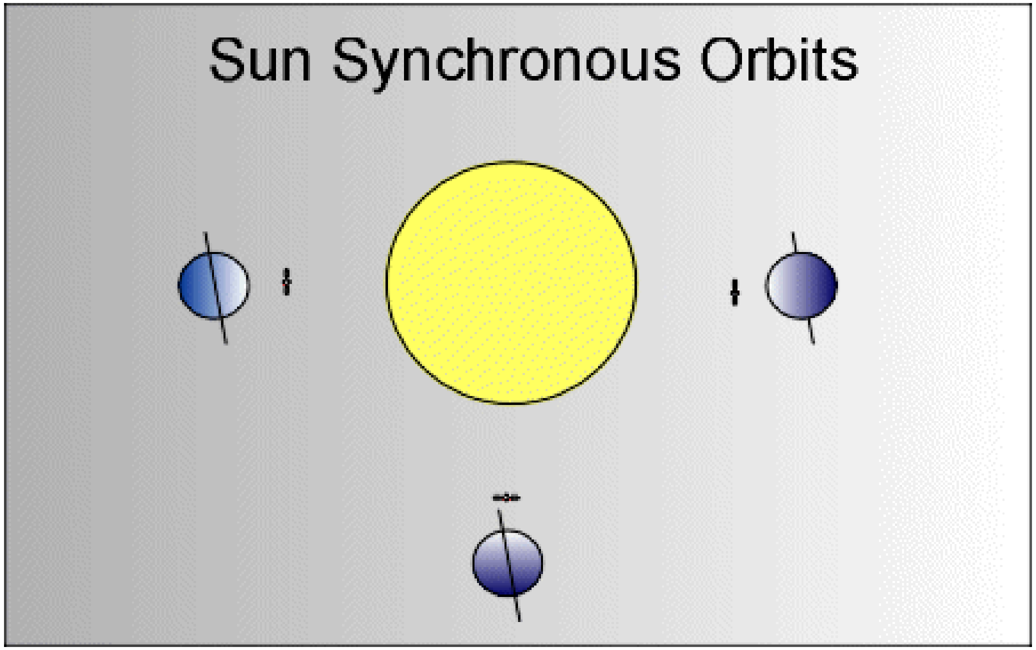


Polar / Geostationary Orbit



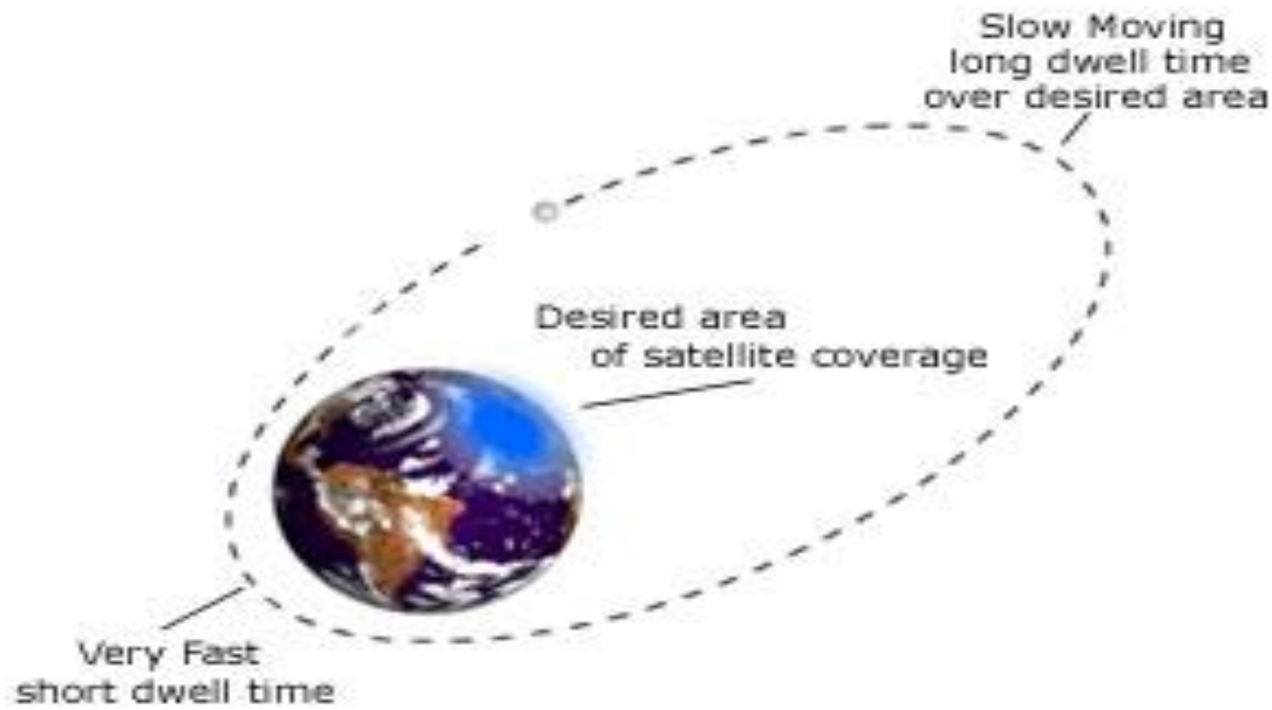
Heliosynchronous Orbit

- These orbits allows a satellite to pass over a section of the Earth at the same time of day. Since there are 365 days in a year and 360 degrees in a circle, it means that the satellite has to shift its orbit by approximately one degree per day. These satellites orbit at an altitude between 700 to 800 km
- These orbits are used for satellites that need a constant amount of sunlight

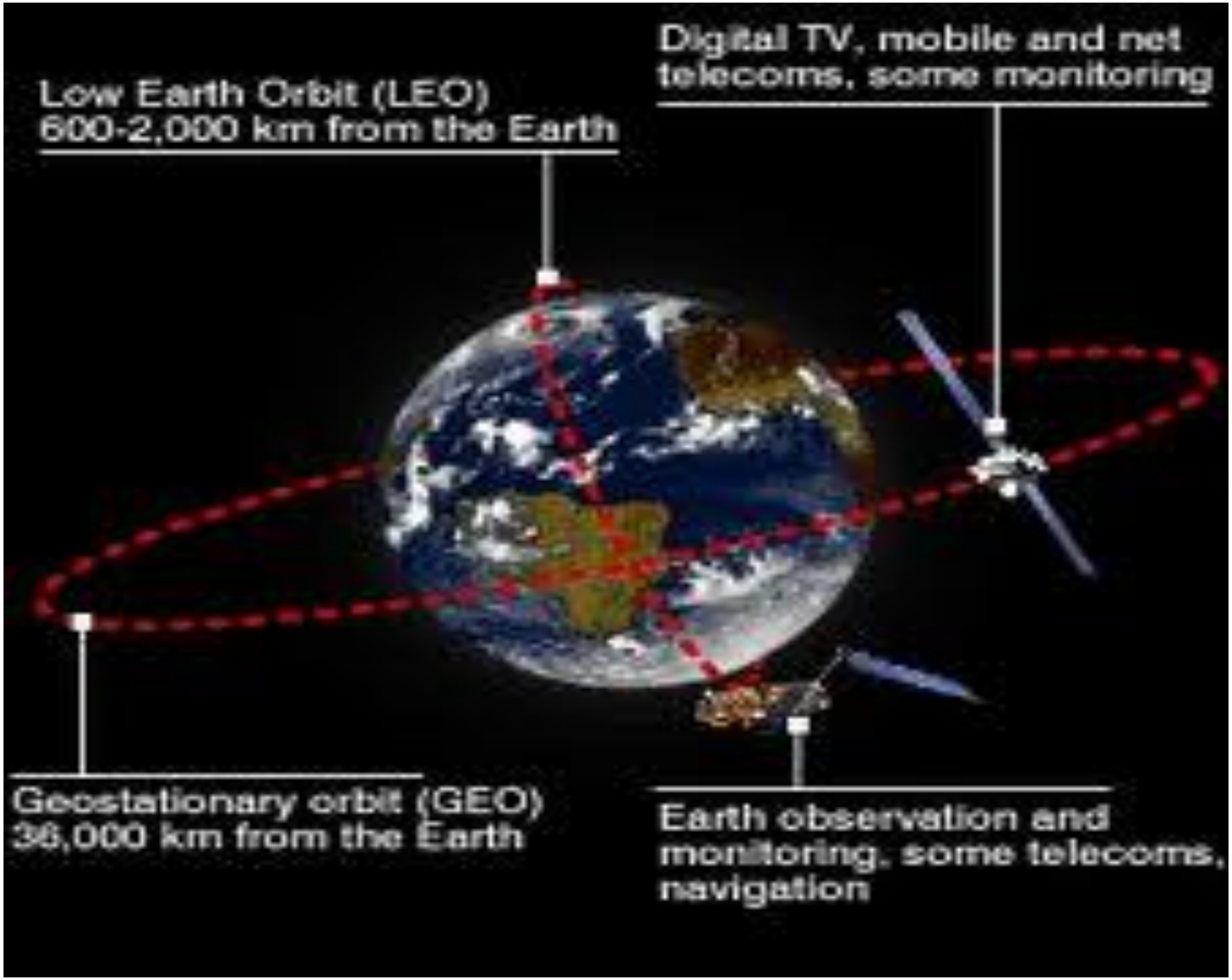


Highly Elliptical Orbit

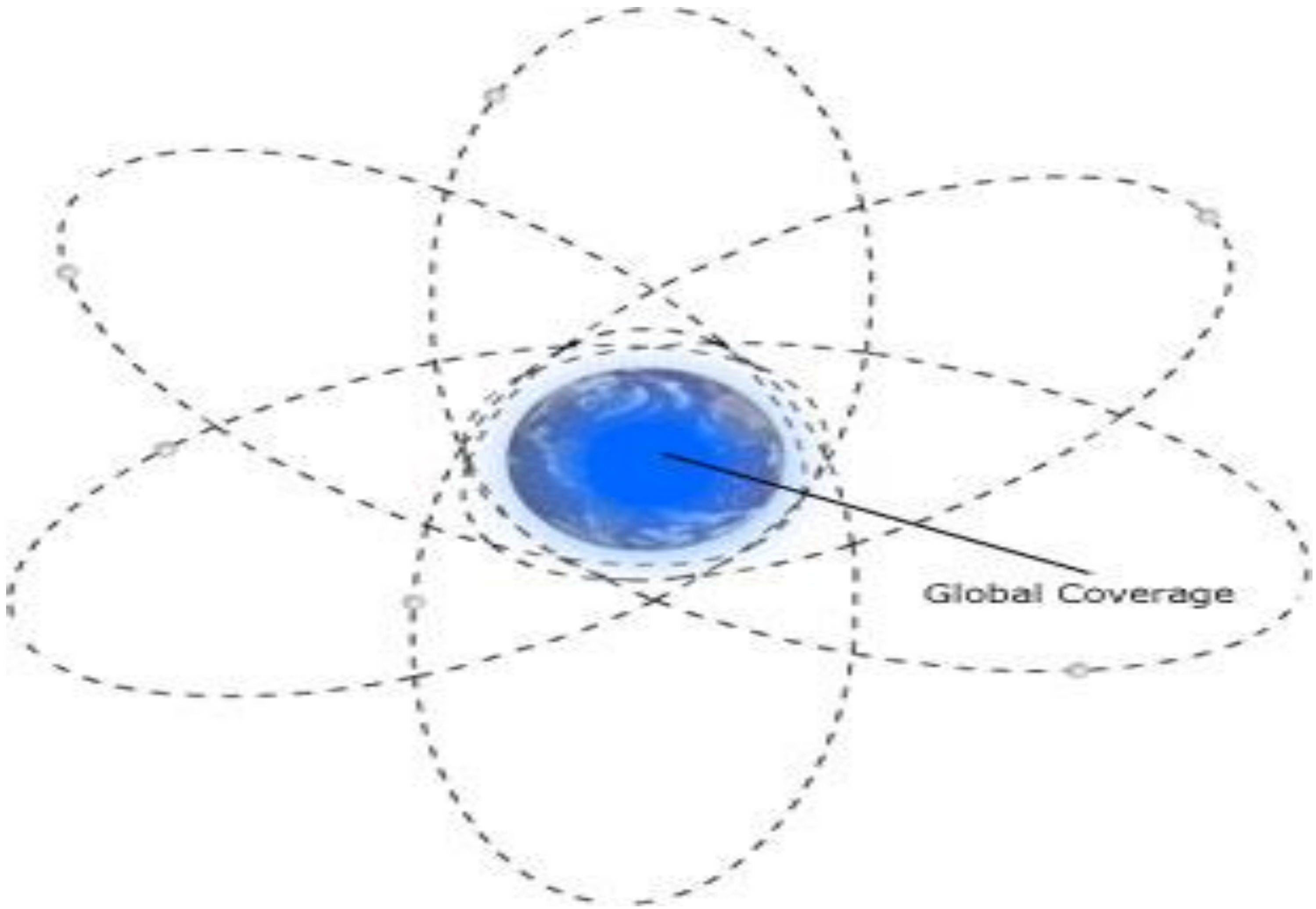
- An object in orbit about Earth moves much faster when it is close to Earth than when it is farther away.
- If the orbit is very elliptical, the satellite will spend most of its time near apogee (the furthest point in its orbit) where it moves very slowly.



Various Satellite Orbits



GPS Satellite Coverage

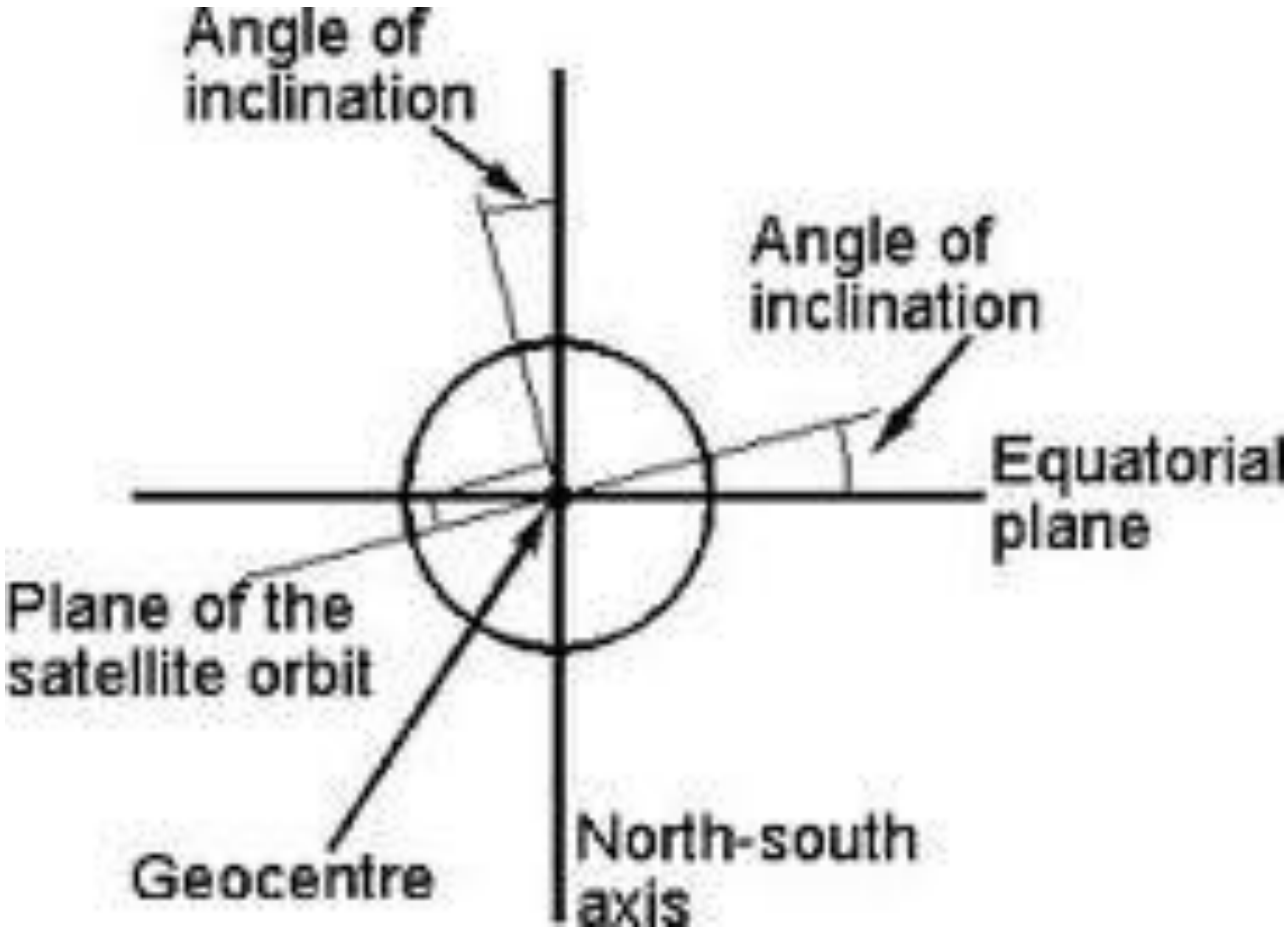


Types of Satellites

- Weather Satellites
- Communications Satellites
- Observation Satellites
- Navigation / GPS Satellites
- Military Satellites
- Nanosatellites / Microsatellites
- Remote Sensing Satellites

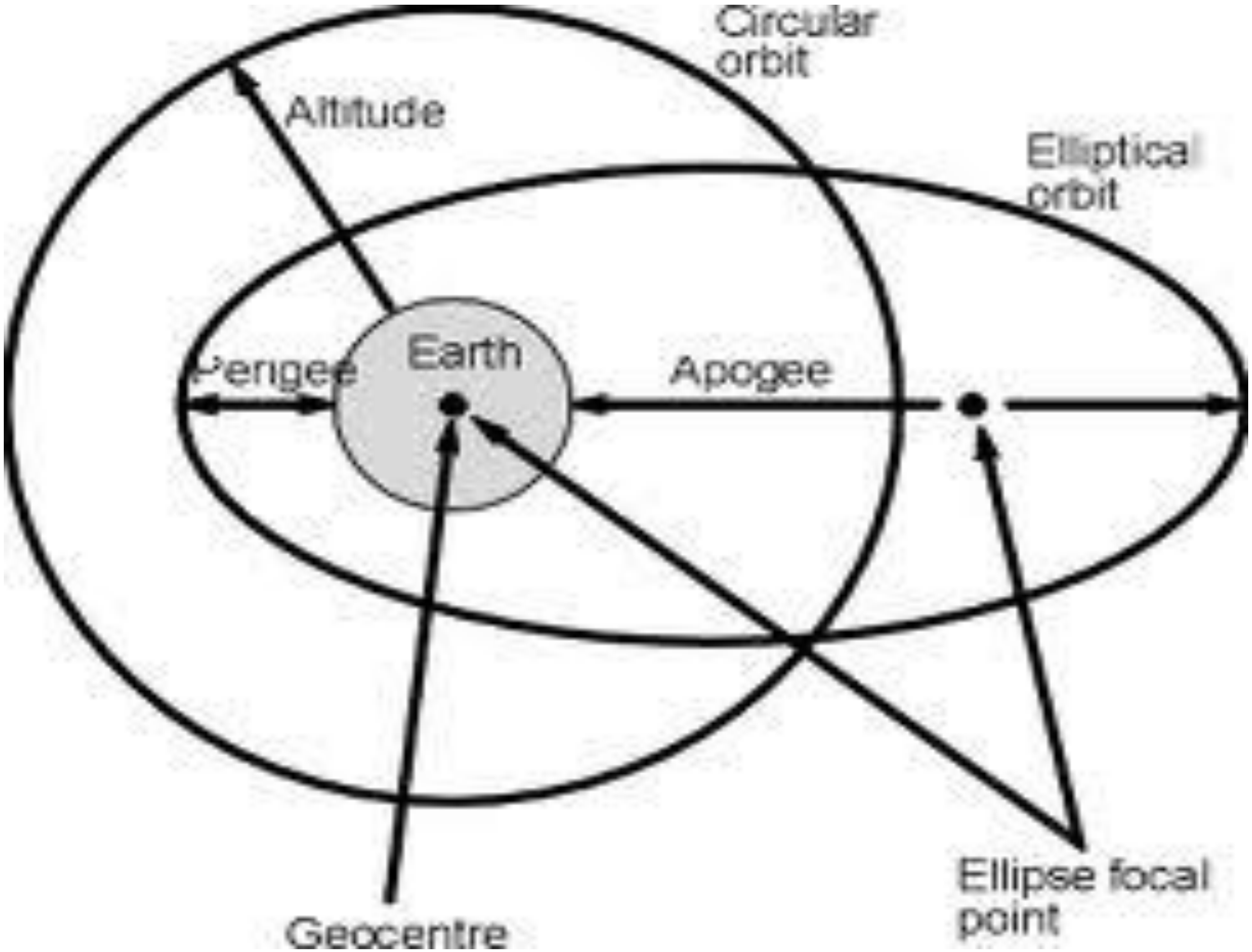
Angle of Inclination

- Angle of inclination is the angle that the satellite makes against the Earth's axis



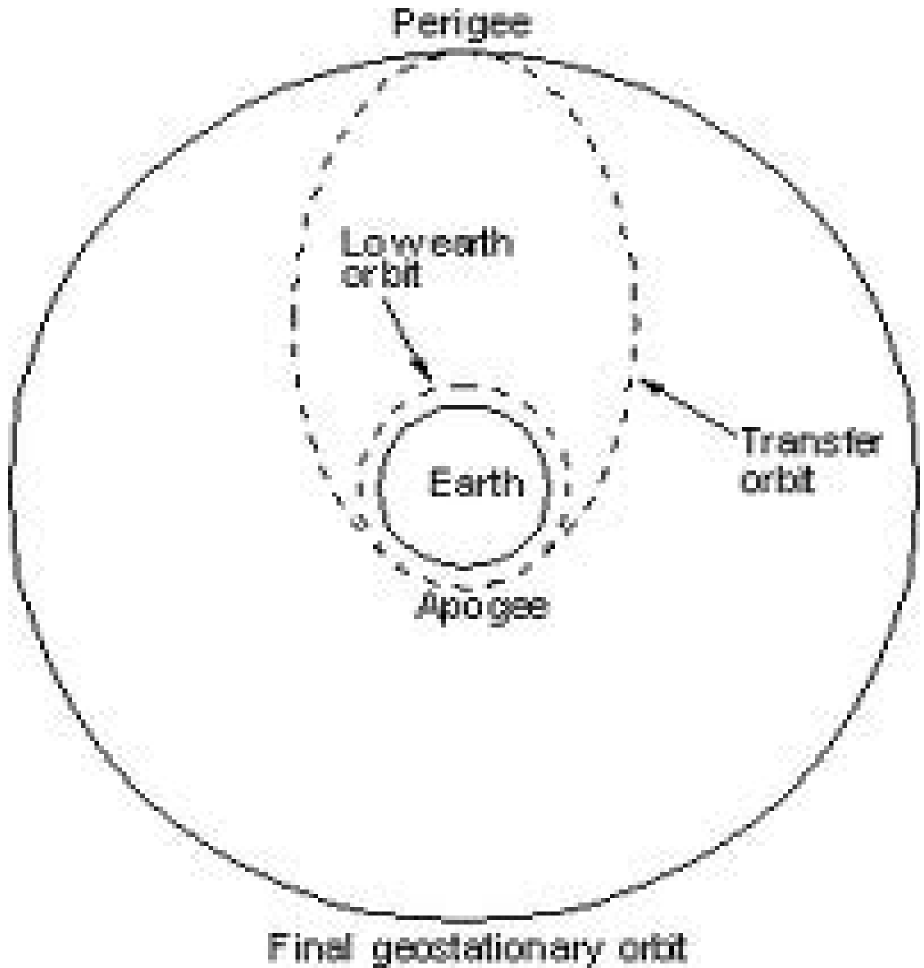
Angle of Inclination

Satellite Orbits



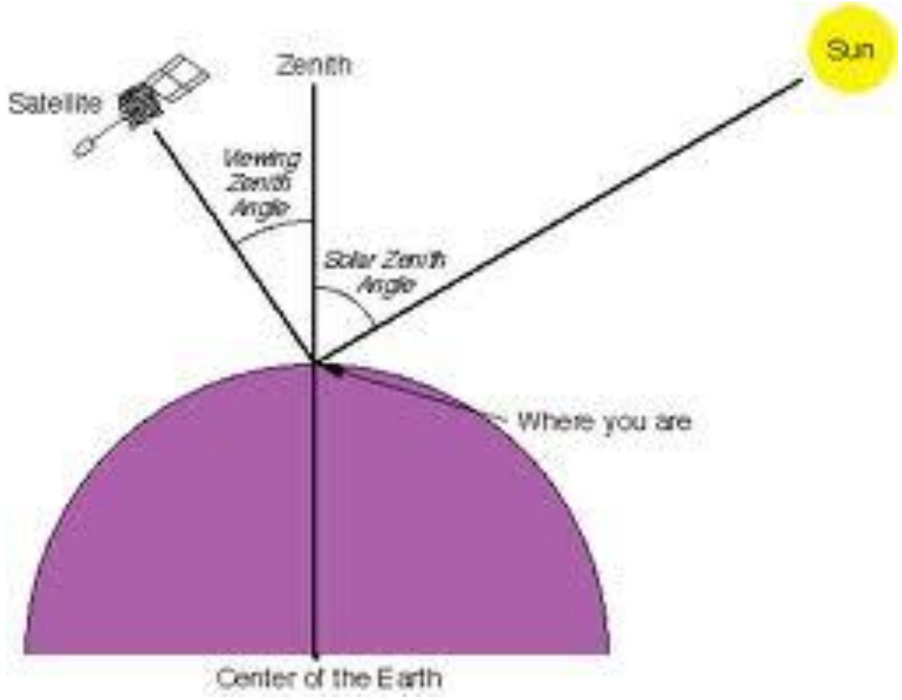
Transfer Orbits

- The type of orbit that is used to transfer the satellite from one orbit to another



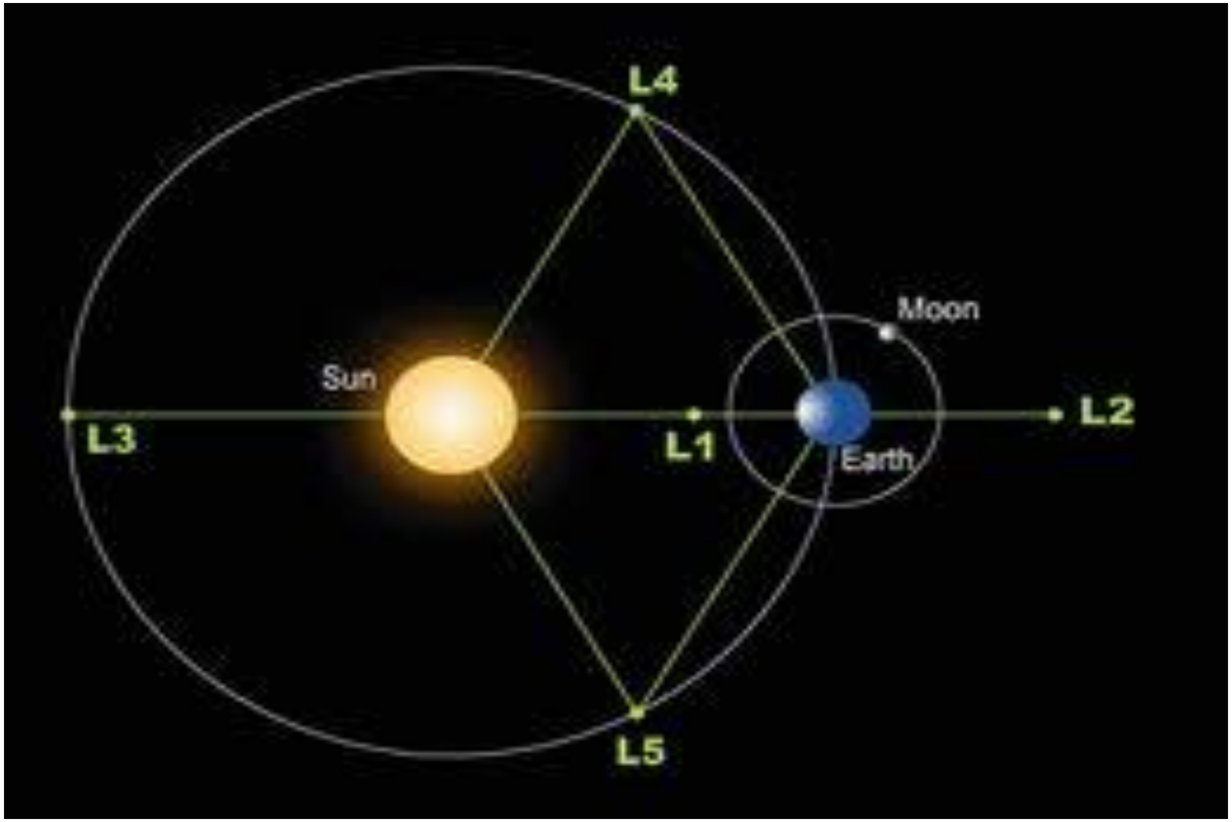
Zenith and Nadir

- Zenith is the direction toward the satellite
- Nadir is the direction toward Earth



Lagrange Points

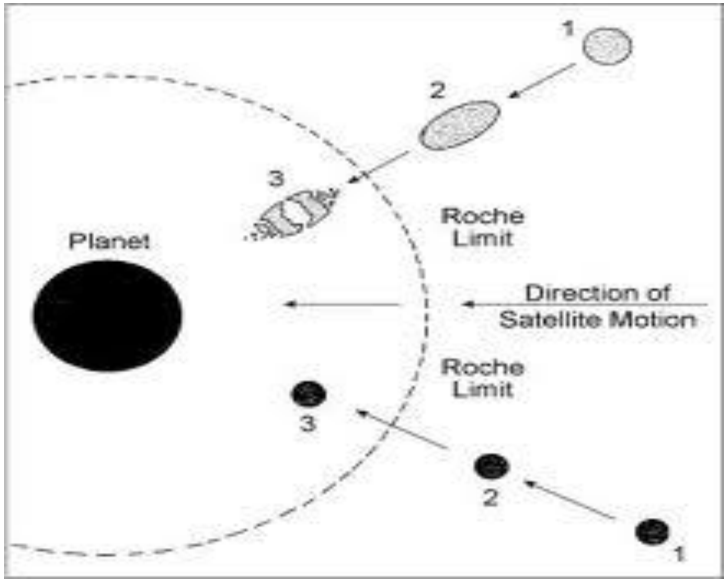
- Lagrange points are locations in space where gravitational forces and the orbital motion of a body balance each other

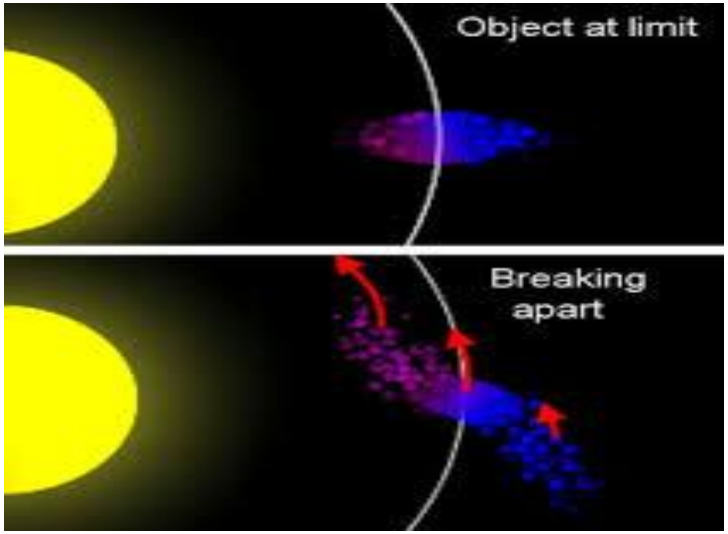


Roche Limit

- The **Roche limit** sometimes referred to as the **Roche radius**, is the distance within which a celestial body, held together only by its own gravity, will disintegrate due to a second celestial body's tidal forces exceeding the first body's gravitational self-attraction.
- Typically, the Roche limit applies to a satellite's disintegrating due to tidal forces induced by its *primary*, the body about which it orbits L_R is the Roche limit, from the planet's center
- R_P is the planet's radius
- L_R is the Roche limit, from the planets center.

$$L_R = 2.44\left(\frac{\rho_P}{\rho_S}\right)^{1/3} R_P$$





Problem

- For the Earth-Moon system, what is the Roche Limit if R = 6,378 km, ρM = 5.5 gm/cm3 and ρm = 2.5 gm/cm3?
- ANSWER

$d = 2.4xR\,(\rho_M/\rho_m)^{1/3}$

with R = 6,378 km, $\rho_M = 5.5\ gm/cm^3$ and $\rho_m = 2.5\ gm/cm^3$

$d = 2.4 \times 6{,}378\,(5.5/2.5)^{1/3}$

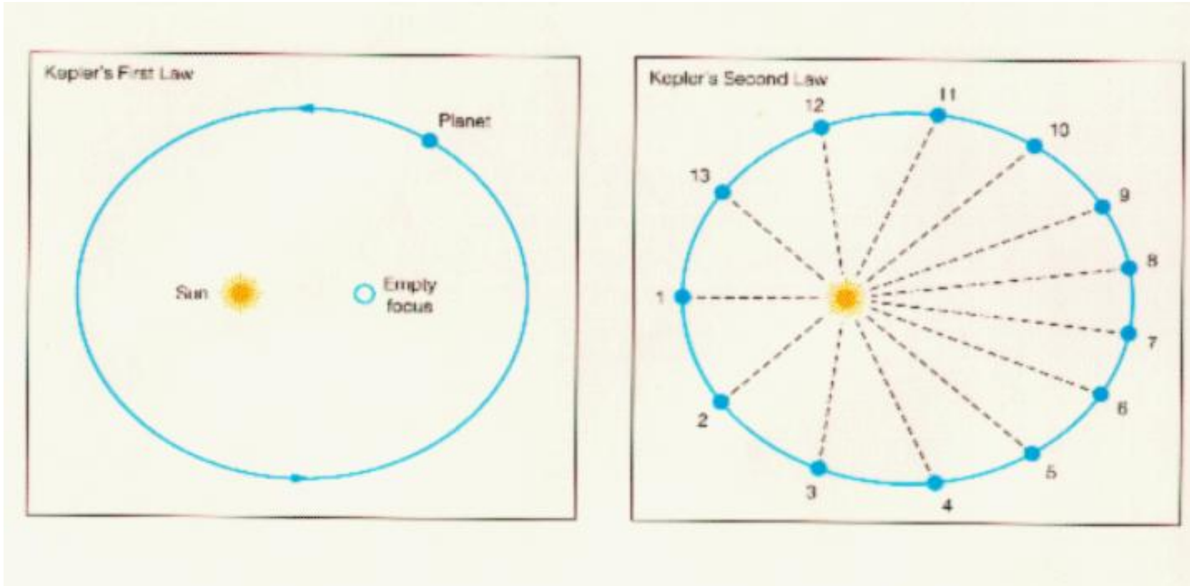
d = 19,900 km.

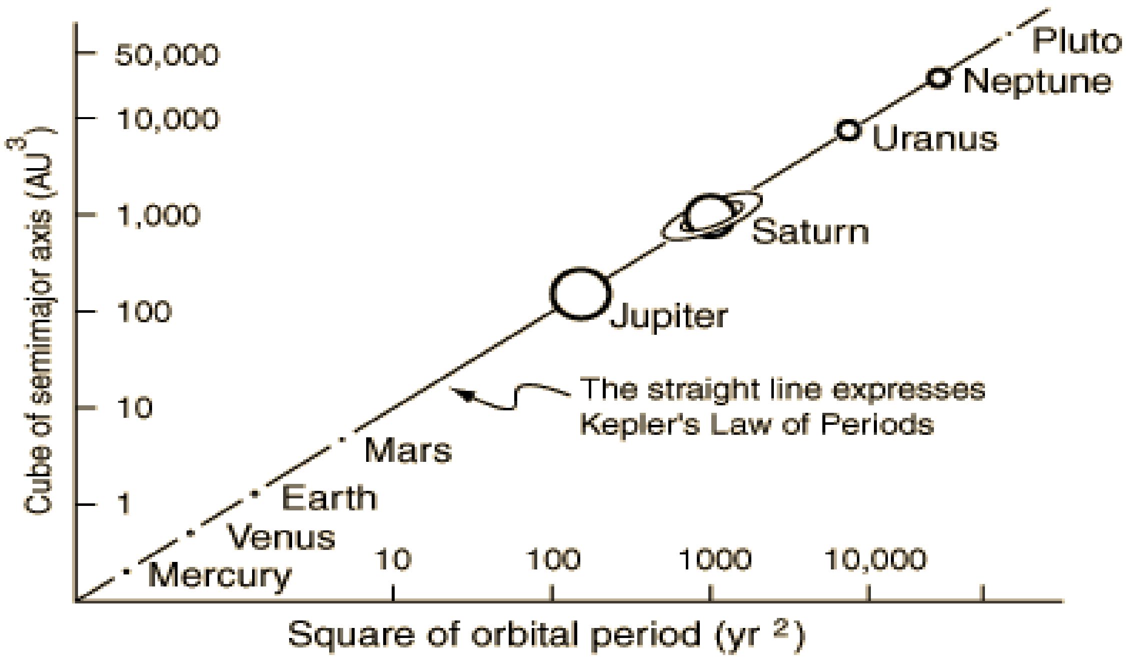
Fortunately our moon is at a distance of 363,000 km (perigee) and is steadily moving farther away by 3 centimeters per year

Kepler's Laws

- Kepler's Law holds for any satellite or natural body in orbit
- **A Satellite will have an elliptical path around its center of attraction**
- In equal times, the areas swept by the radius vector of a satellite are the same. (**As a satellite moves near its parent object, it will move faster**)
- The periods of any two satellites around the same planet are related to their semimajor axis. (**As a satellite has a larger orbit, it will move more slowly**)

Kepler Laws





$$\frac{P^2}{a^3} = \text{constant}$$

Gravitational Force on a Object

- The Law of Universal Gravitation was discovered by Isaac Newton which states that the gravitational force between two masses varies inversely as the square of the distance between their centers.
- Where G is the Universal Constant in

  G = 6.67 x 10^-11 m^3/kgs^2

$$F = \frac{GmM}{r^2}$$

Newton’s Laws

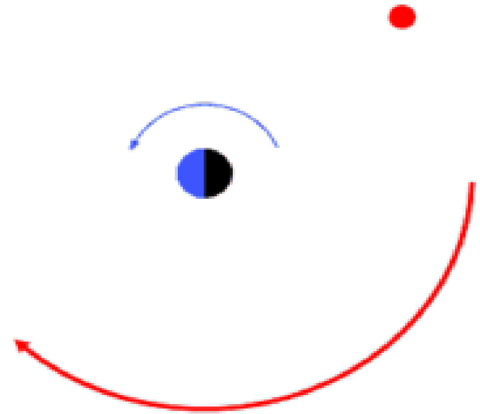
- **Newton's First Law:** A body will remain at rest or in motion in a straight line unless acted upon by a force.
- **Newton's Second Law:** Change in motion is proportional to the applied force and parallel to it.
- **Newton's Third Law:** To every action there is an equal and opposite reaction.

Sample Satellite Orbits

- Intelsat : 35,786 km : 3.07 km/s : 24 hours
- ICO: 10,255 km : 4.8954 km/s : 5 hr 56 min
- Iridium: 780 km : 7.46 km/s : 1 hr 40 min

Prograde and Retrograde Orbit

- *Prograde orbit* is in the same direction as the primary's rotation
- *Retrograde orbit* is one in which a satellite moves in a direction opposite to the rotation of its primary



Reentry of a Spacecraft

- A spacecraft orbiting around the Earth will have a very large kinetic energy and a corresponding high velocity if 8500 m/sec
- These speeds correspond to very high Mach numbers of 30 or more as they enter the atmosphere
- Hence, a spacecraft on reentry will have a large reentry speed causing problems with stability as well as heating of the body

Types of Reentry Paths

- **Ballistic Entry** where the vehicle has little or no aerodynamic lift. The impact point is predetermined by the conditions at first reentry point. The pilot has no control over the landing position. Besides the space shuttle all other spacecraft reenter on a ballistic path.
- **Skip Entry** in which the spacecraft skips like a stone
- **Glide Entry** in which the spacecraft comes in high with 30 or 4o degrees of angle of attack. The vehicle can be piloted. The best example is the space shuttle.

Concerns for Reentry

- Aerodynamic Heating
- Maximum Deceleration
- For safety of the occupants, the maximum deceleration should not exceed 10 gs or 10 times the acceleration of gravity
- The aerodynamic heating of the vehicle should be low enough to maintain tolerable temperatures inside the spacecraft

THANK YOU

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