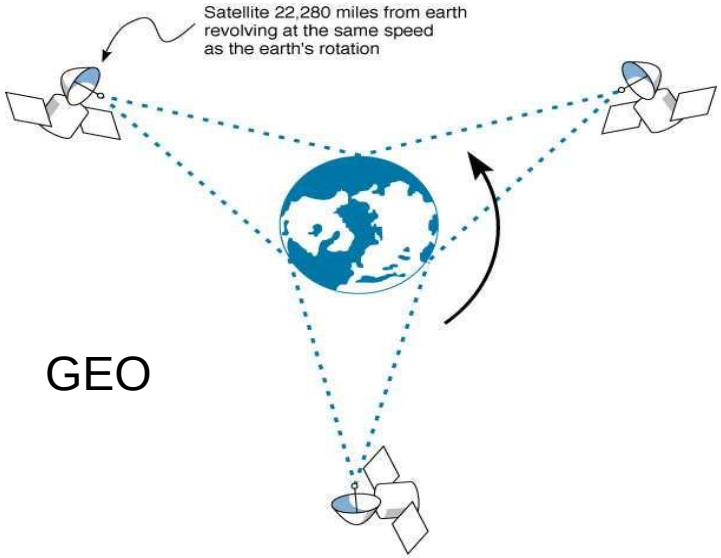
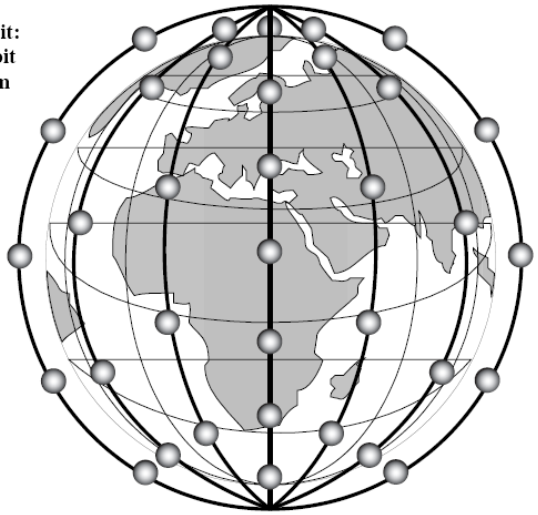
SATELLITE ORBITS



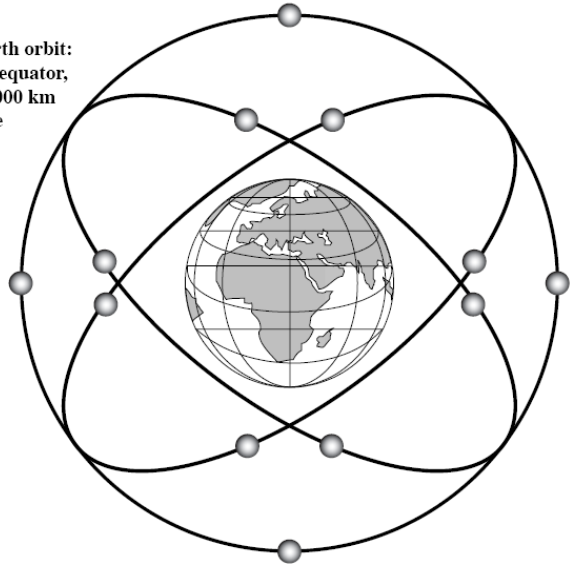
GEO

(a) Low earth orbit: often in polar orbit at 500 to 1500 km altitude



LEO

(b) Medium earth orbit: inclined to the equator, at 5000 to 18,000 km altitude

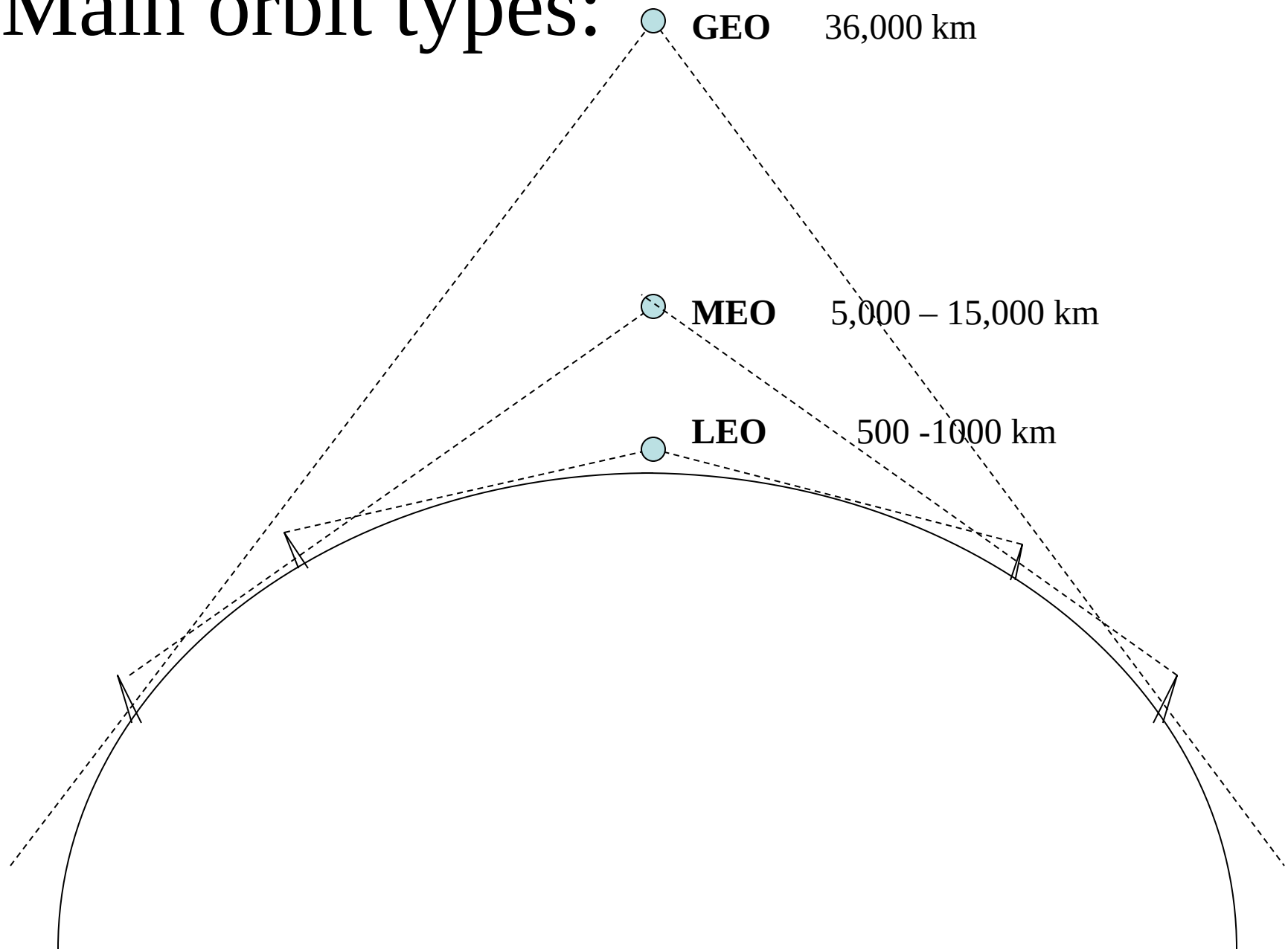


MEO

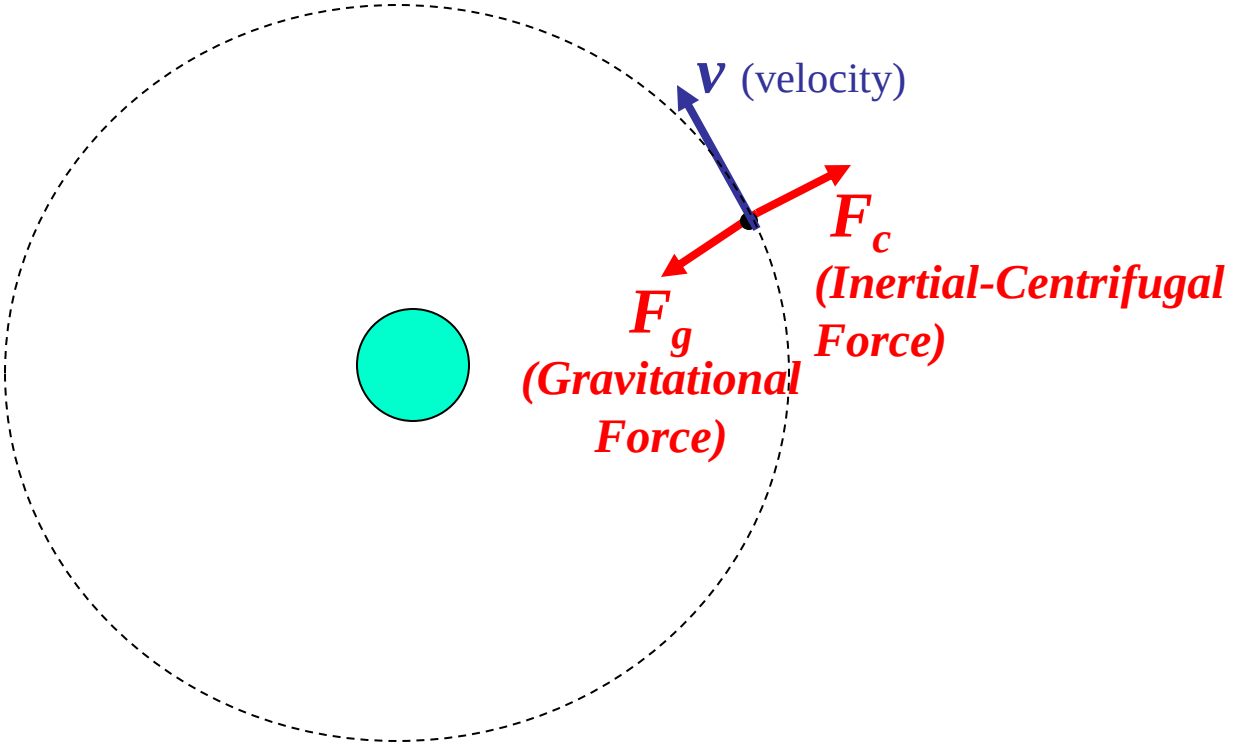
Classification of Satellite Orbits

- Circular or elliptical orbit
  - Circular with center at earth's center
  - Elliptical with one foci at earth's center
- Orbit around earth in different planes
  - Equatorial orbit above earth's equator
  - Polar orbit passes over both poles
  - Other orbits referred to as inclined orbits
- Altitude of satellites
  - Geostationary orbit (GEO)
  - Medium earth orbit (MEO)
  - Low earth orbit (LEO)

Main orbit types:



Why do satellites stay **moving** and in **orbit**?



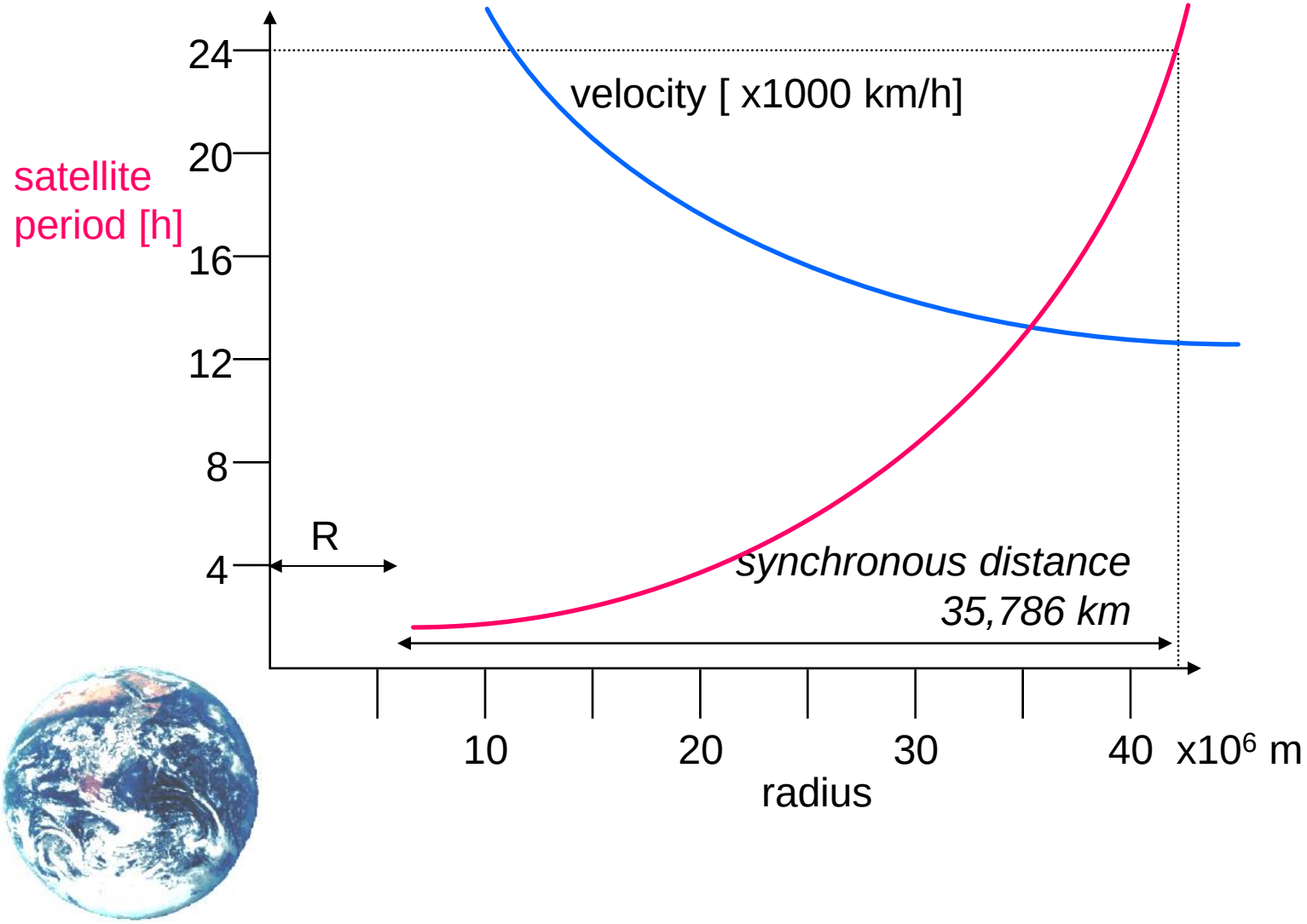
Basics

- Satellites in circular orbits
  - attractive force $F_g = m\ g\ (R/r)^2$
  - centrifugal force $F_c = m\ r\ \omega^2$
  - m: mass of the satellite
  - R: radius of the earth (R = 6370 km)
  - r: distance to the center of the earth
  - g: acceleration of gravity (g = 9.81 m/s²)
  - ω: angular velocity ($\omega = 2\ \pi\ f$, f: rotation frequency)
- Stable orbit

  $F_g = F_c$

$$r = \sqrt[3]{\frac{gR^2}{(2\pi f)^2}}$$

Satellite period and orbits



GEOSTATIONARY ORBIT (GEO)

- In the equatorial plane
- Orbital Period = 23 h 56 min. 4.091 s
  = one ***Sidereal Day*** (defined as one complete rotation relative to the fixed stars)
- Satellite appears to be **stationary** over a point on the equator to an observer
- Radius of orbit, ***r***, = 42,164.57 km

NOTE: Radius = orbital height + radius of the earth

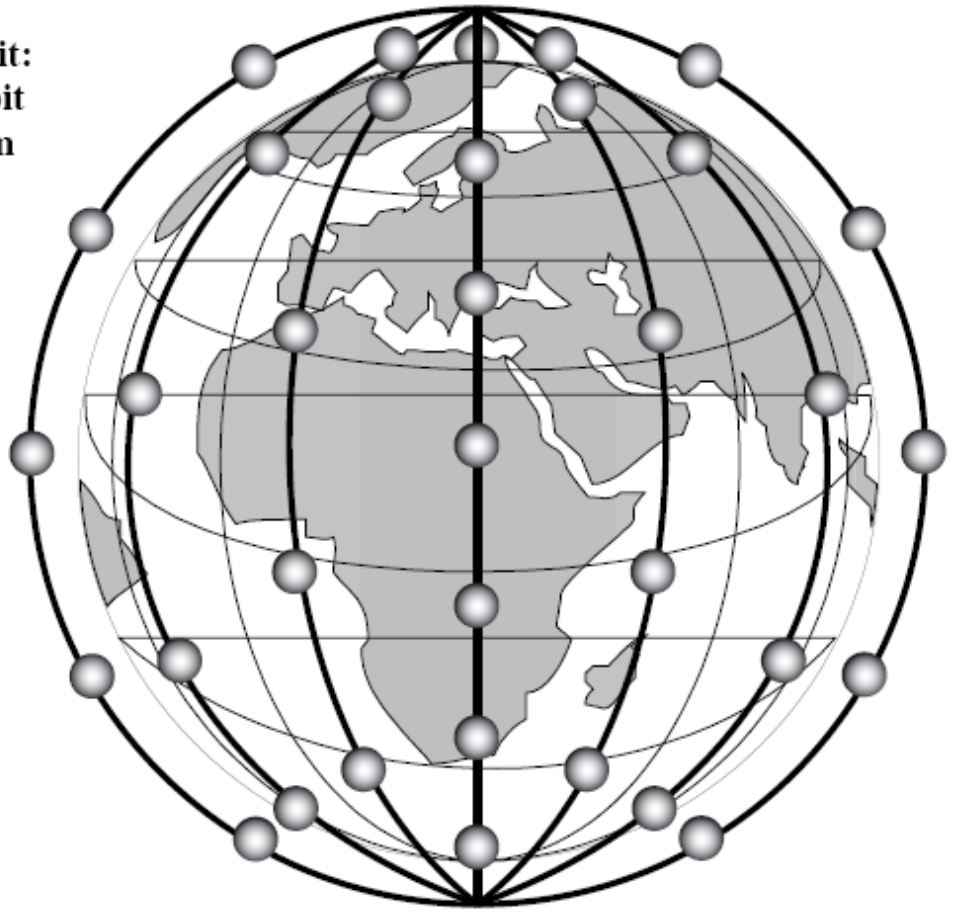
Average radius of earth = 6,378.14 km

GEO Orbit

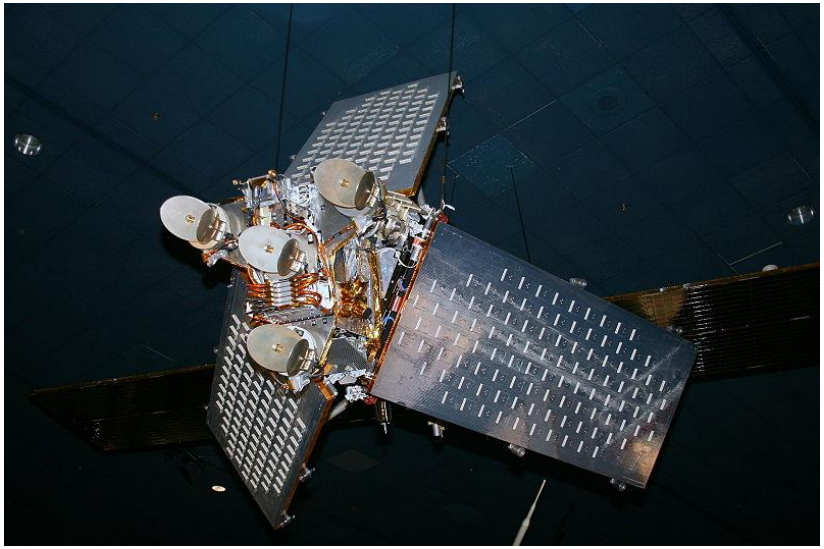
- Advantages of the the GEO orbit
  - satellites typically have a large footprint (up to 34% of earth surface)
  - Tracking of the satellite is simplified
  - fix antenna positions, no adjusting necessary
- Disadvantages of the GEO orbit
  - Weak signal after traveling over 35,000 km
  - Polar regions are poorly served (low elevation angles)
  - Signal sending delay is substantial
  - High transmit power needed

LEO Satellite Characteristics

(a) Low earth orbit: often in polar orbit at 500 to 1500 km altitude



LEO systems
global voice/data



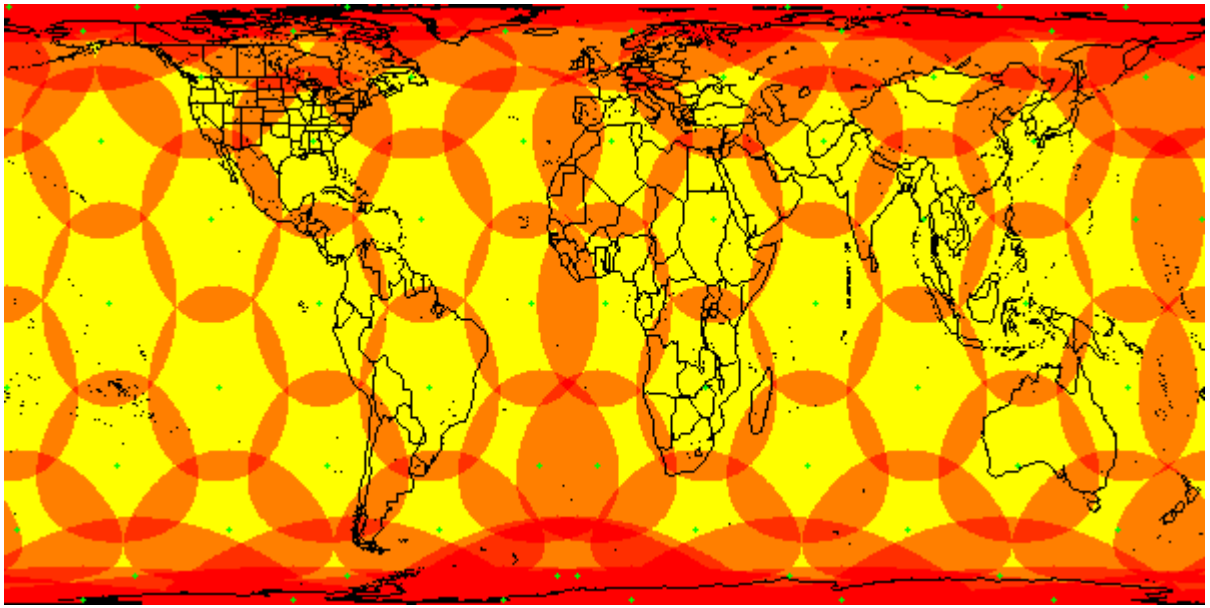
- **Iridium** -66 satellites, 6 orbits
- 750 km – start 1998
- 66 x 48 spot beams
- 2000 cells cover earth
- 1.6 GHz
- Supports 250,000 users

- Globalstar (start 1999, 48 satellites)
  - Customers (2009: 350,000), low stand-by times for mobiles

  Operates at 1.6/2.3 GHz

IRIDIUM EARTH COVERAGE

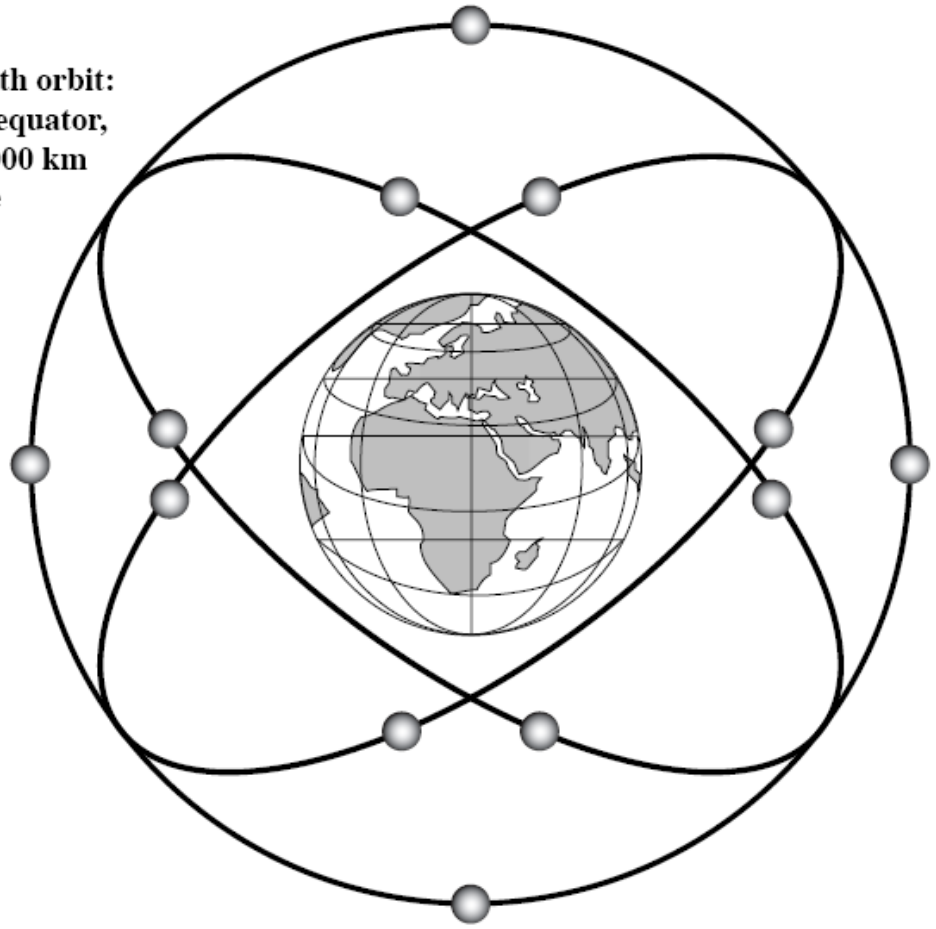
Handles 11,000 phone calls



LEO Satellite Characteristics

- Circular/slightly elliptical orbit under 1000 km
- Orbit period ranges from 1.5 to 2 hours
- Diameter of coverage is about 2000 km – can adopt frequency reuse
- Round-trip signal propagation delay less than 20 ms
- Maximum satellite visible time up to 40 min
- handover necessary from one satellite to another
- many satellites necessary for global coverage
- more complex systems due to moving satellites
- System must cope with large Doppler shifts
- Atmospheric drag results in orbital deterioration

MEO Satellite Characteristics



(b) Medium earth orbit: inclined to the equator, at 5000 to 18,000 km altitude

MEO Satellite Characteristics

- Circular orbit at an altitude in the range of 5000 to 12,000 km
- Orbit period of 6 hours
- Diameter of coverage is 10,000 to 15,000 km
- Fewer satellites than LEO
- More transmitter power than LEO
- Round trip signal propagation delay less than 50 ms
- Maximum satellite visible time is a few hours

ORBIT TIMES

For a circular orbit, time to complete one revolution of the orbit is

$$T = 2\pi\sqrt{\frac{(R_E + h)^3}{GM}}$$

h = height above earth's surface in km

R_E = mean radius of earth in km

G = universal gravitational constant

M = mass of earth

GM = 3.9861352 x 10^5 km^3/s^2

Hence $T = 2.7644 \times 10^{-6}(h + R_E)^{1.5}$

Example: What is h for the geostationary orbit?

T = 23 hours, 56 min, 4.1 sec (1 day)

Coverage Angle: A measure of the portion of the earth surface visible to a satellite taking the minimum elevation angle into account.

$$R/(R+h) = \sin(\pi/2 - \beta - \theta)/\sin(\theta + \pi/2)$$
$$= \cos(\beta + \theta)/\cos(\theta)$$

R = 6370 km (earth's radius)

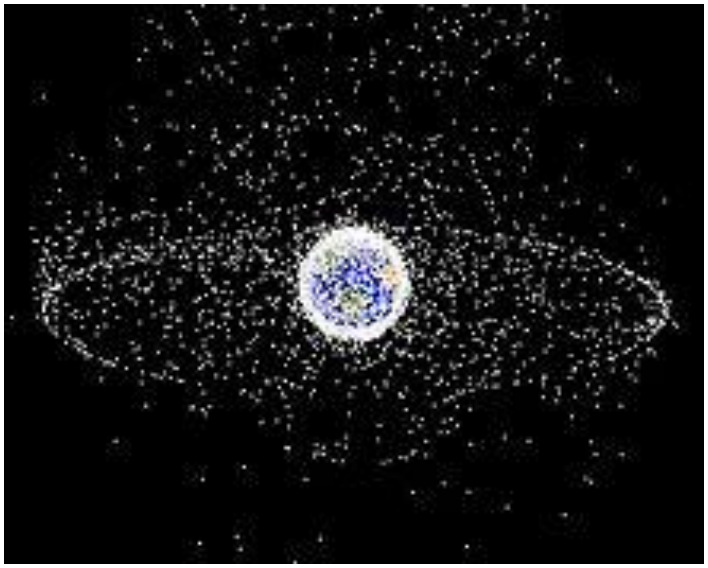
h = satellite orbit height

β = coverage angle

θ = minimum elevation angle

SPACE JUNK

Only one major incident has occurred: the 2009 satellite collision between Iridium 33 and Cosmos 2251.



Space debris populations seen from outside geosynchronous orbit (GEO). Note the two primary debris fields, the ring of objects in GEO, and the cloud of objects in low earth orbit (LEO).