Space Technology

Artifical Earth-orbiting satellites

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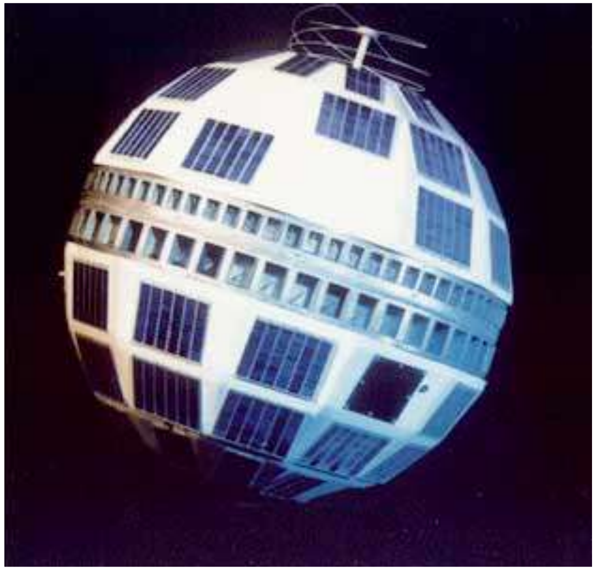
The first satellites in orbit

Sputnik-1(1957)

Vostok-1 (1961)
Jurij Gagarin

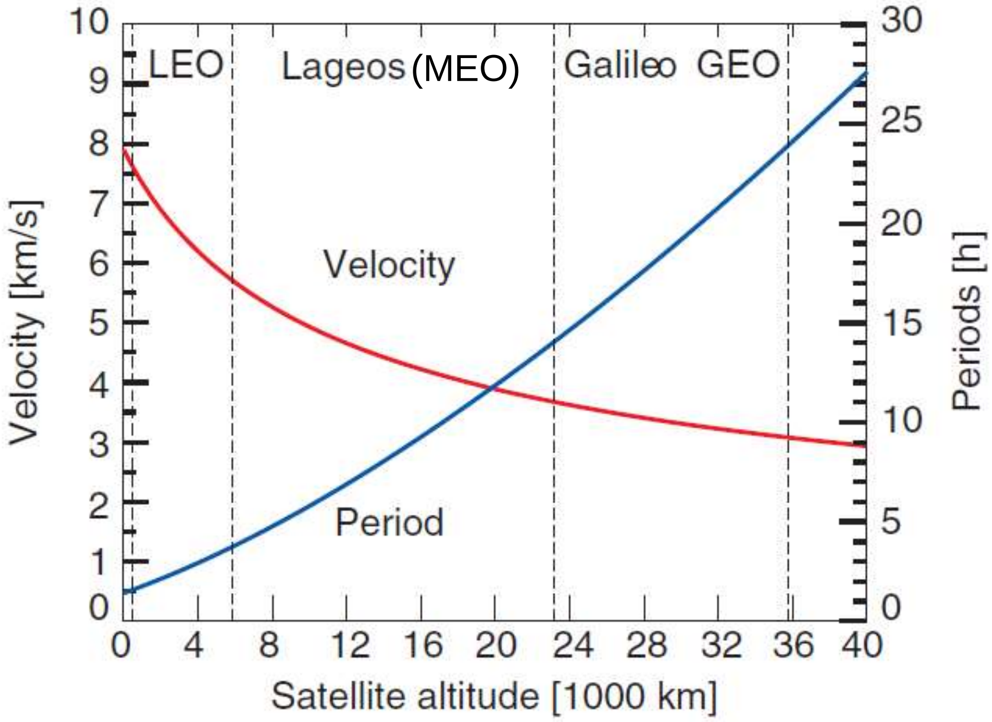


Telstar-1 (1962)

Kepler orbits

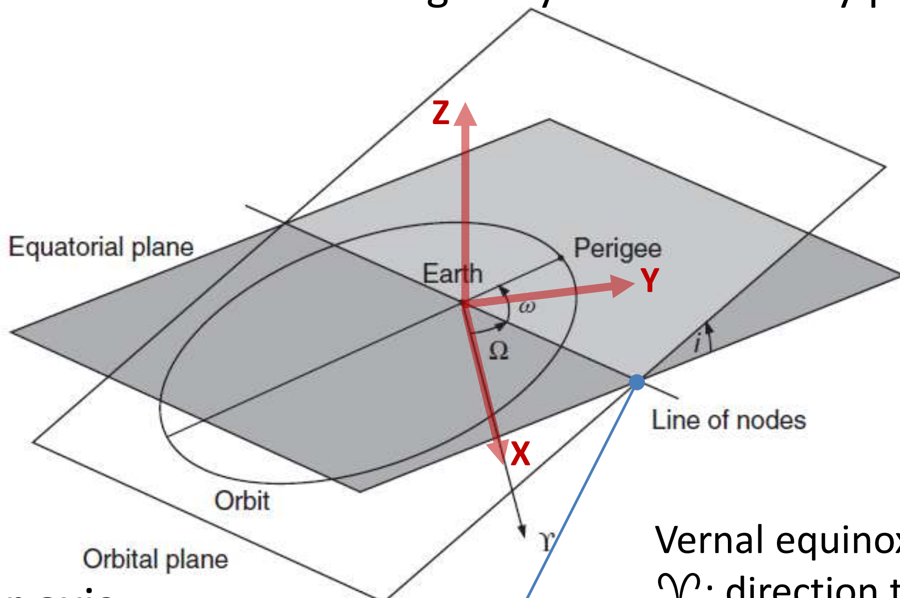
Kepler's laws (Johannes Kepler, 1571-1630) applied for satellites:

1.) The orbit of a satellite around the Earth is an ellipse, one focus of which coincides with the center of the Earth.
2.) The radius vector from the Earth's center to the satellite sweeps over equal areas in equal time intervals.
3.) The squares of the orbital periods of two satellites are proportional to the cubes of their semi-major axis: a^3/T^2 is equal for all satellites



Kepler orbits: equatorial coordinates

The Keplerian elements: uniquely describe the location and velocity of the satellite at any given point in time using equatorial coordinates $\boldsymbol{r} = (x, y, z)$
(to solve the equation of Newton's law for gravity for a two-body problem)

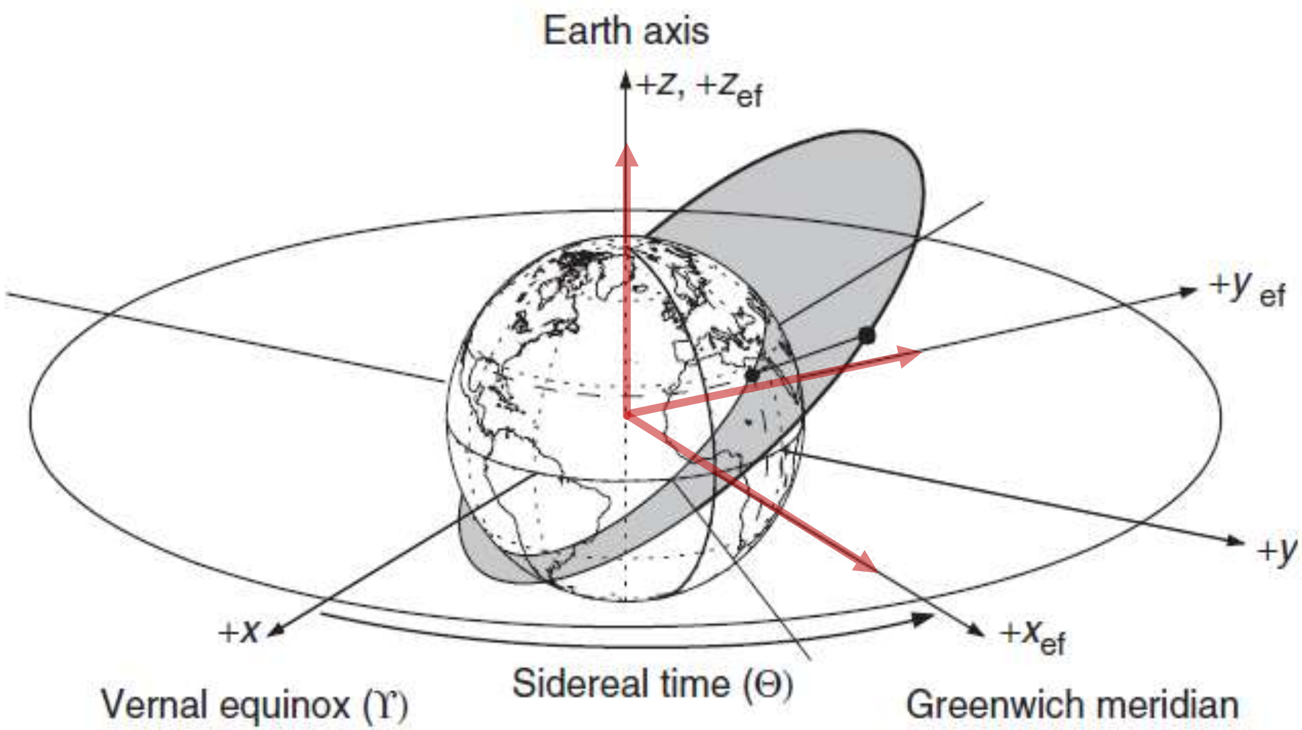


Vernal equinox:
♈: direction to the Sun at the beginning of spring
(length of day==length of night)

Elements:

a	Semi-major axis
e	Eccentricity
i	Inclination
Ω	Longitude of the ascending node
ω	Argument of perigee
M	Mean anomaly
	(angle difference of a fictitious circular vs. true elliptical orbit)

Earth-centered orbits



Sidereal time: Earth rotation vs. fixed stars

One **sidereal** (astronomical) day:

one complete Earth rotation around its axis (~4min shorter than a normal day)

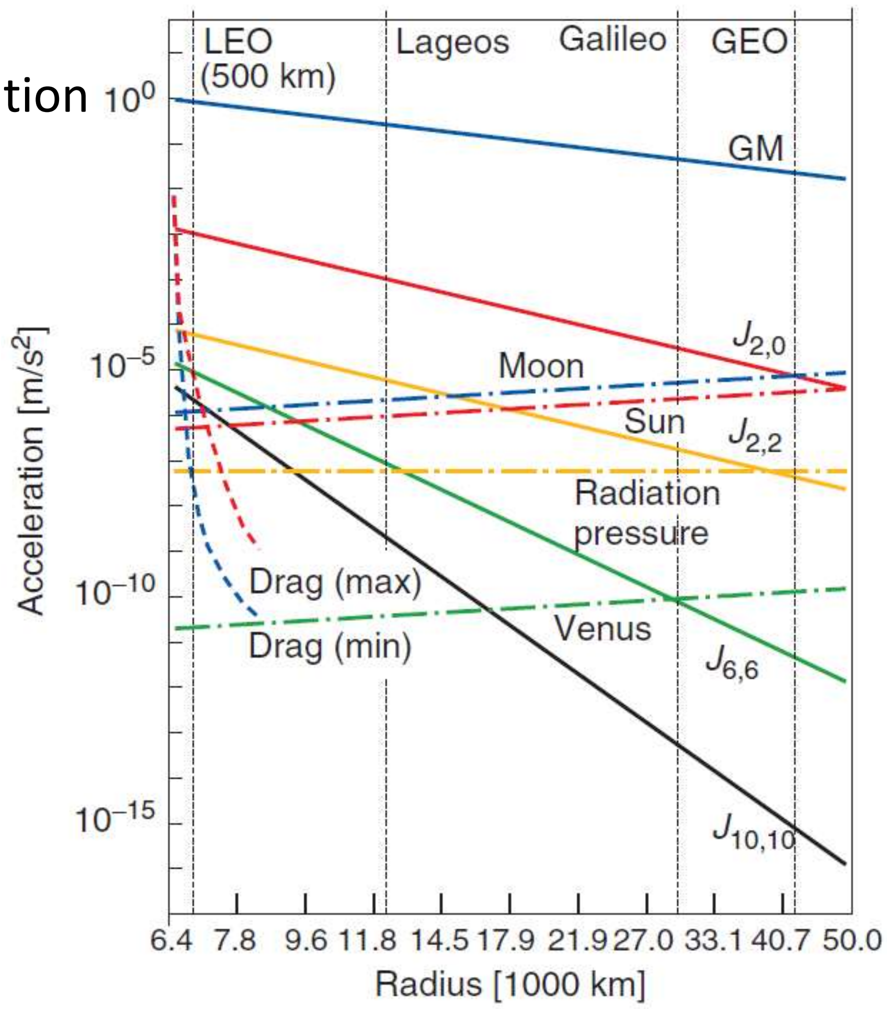
Coordinated universal time (**UTC**):

- derived from atomic clocks

leap second, leap year

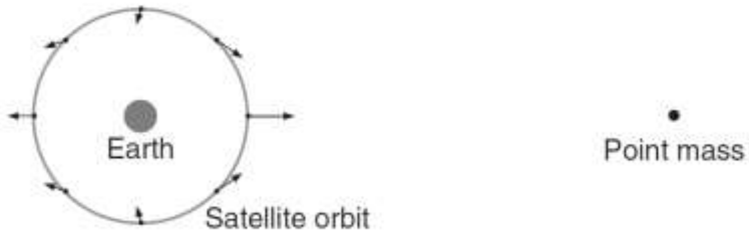
Perturbations 1.

- ❑ The Earth's radius at the poles are 20km smaller (flattening)
- ❑ The effects of the Earth's atmosphere
- ❑ Gravitational perturbations caused by the Sun and Moon
- ❑ Other:
  - inhomogeneous Earth mass distribution
  - radiation pressure
  - rise of the tide (oceans)
  - relativistic effects

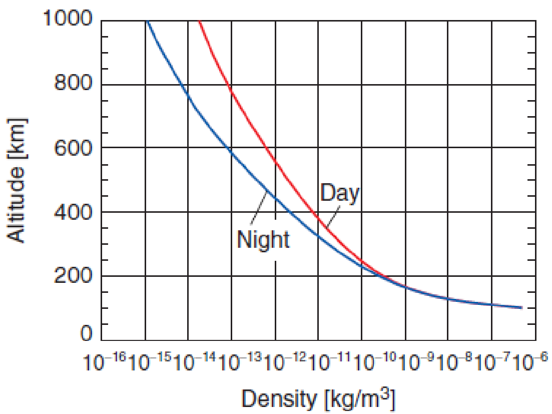


Perturbations 2.

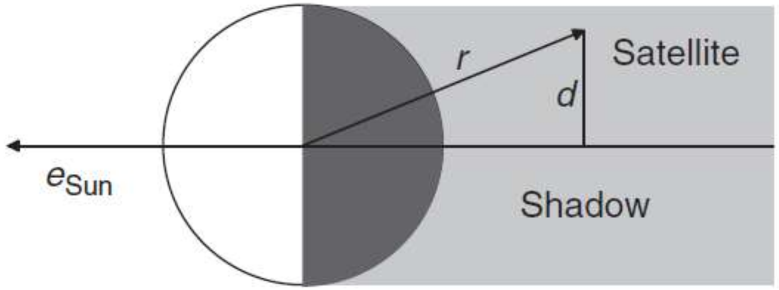
- Gravitational field models (CHAMP and GRACE missions)
- Sun and Moon gravity:



- Air drag; the atmosphere density variations:

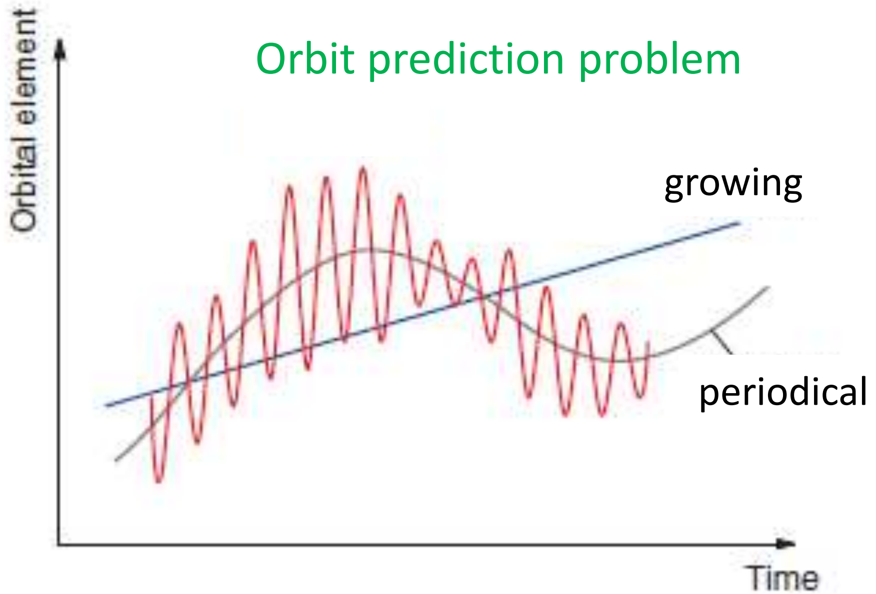


- Radiation pressure of the Sun:



Orbit models 1.

- Variation of the Kepler's orbital elements:
  - semi-major axis, orbital inclination and mean anomaly
  - small temporal orbital elements variations
    - Gaussian variational theory
    - perturbation theory



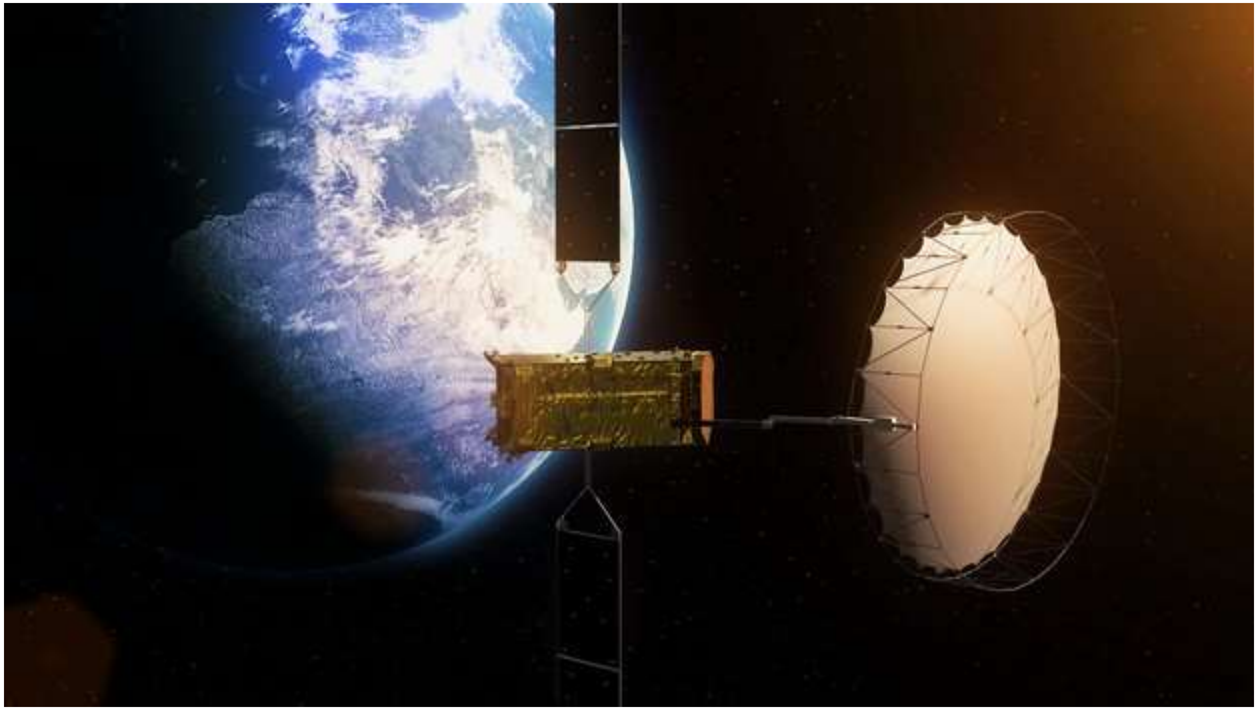
Orbit models 2.

- Simplified General Perturbations Model No. 4 (SGP4).
- Originally developed for North American Aerospace Defense Command (NORAD) for continuous monitoring of near-Earth objects.

Orbit models 3.

- The NORAD orbital elements are published in a two-line data format, or two-line elements: TLEs

ALPHASAT
1 39215U 13038A   16181.24794345 .00000000 00000-0 10000-3 0 9994
2 39215   1.3480 32.2103 0001229 65.4771 294.1841 1.00272954 10777



TLE line 1.

Field	Columns	Content	Example
1	01–01	Line number	1
2	03–07	Satellite number	25544
3	08–08	Classification (U=Unclassified)	U
4	10–11	International Designator (Last two digits of launch year)	98
5	12–14	International Designator (Launch number of the year)	067
6	15–17	International Designator (piece of the launch)	A
7	19–20	Epoch Year (last two digits of year)	08
8	21–32	Epoch (day of the year and fractional portion of the day)	264.51782528
9	34–43	First Time Derivative of the Mean Motion divided by two (rev/day^2)	−.00002182
10	45–52	Second Time Derivative of Mean Motion divided by six (rev/day^3)	00000-0
11	54–61	BSTAR drag term (ballistic coefficient; aerodynamics)	-11606-4
12	63–63	Ephemeris type (orbital model) Always 0	0
13	65–68	Element set number. Incremented when a new TLE is generated for this object.	292
14	69–69	Checksum (modulo 10)	7

TLE line 2.

Field	Columns	Content	Example
1	01–01	Line number	2
2	03–07	Satellite number	25544
3	09–16	Inclination (degrees)	51.6416
4	18–25	Longitude of the ascending node (degrees)	247.4627
5	27–33	Eccentricity (decimal point assumed)	0006703
6	35–42	Argument of perigee (degrees)	130.5360
7	44–51	Mean Anomaly (degrees)	325.0288
8	53–63	Mean Motion (revolutions per day)	15.72125391
9	64–68	Revolution number at epoch (revolutions)	56353
10	69–69	Checksum (modulo 10)	7

Determination of orbit parameters

- Direction measurements (e.g. with antennas; transmitter on the satellite is required)
- Distance measurements (transponder on the satellite is required)
- Measure the change of distance (Doppler shift)
- Laser ranging (for accurate distance measurement)
- GPS-based position measurements on LEO satellites

Orbit design, lauch, maneuvers

Alphasat Launch, 25 July 2013, Ariane 5

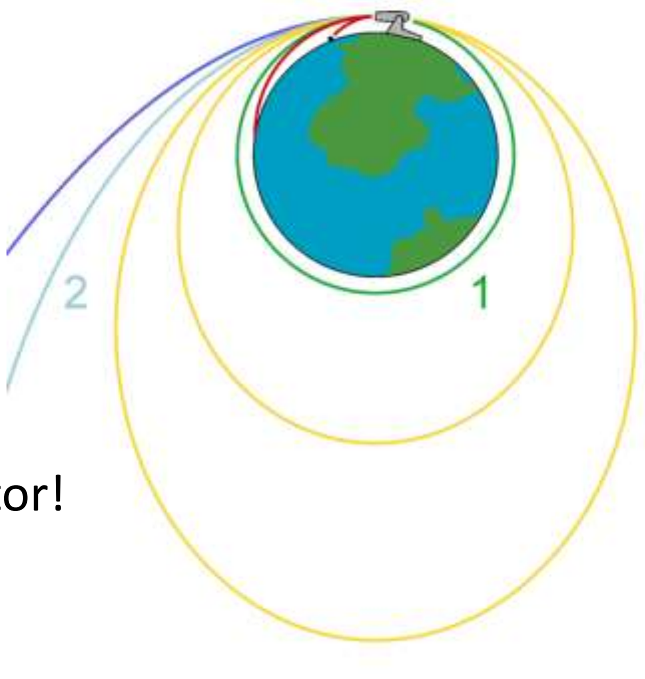
Cosmic velocities

- First cosmic speed: speed required to arrive an orbit around a celestial body

$$v_1 = \sqrt{\frac{GM}{R}}$$

G: universal gravitational constant ($G = 6.67 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$)
M: mass of the celestial body
R: radius of the celestial body

- velocity on Earth ≈7.91km/s
- atmospheric friction is not taken into account
- for satellites at 200km: 7.78km/s



- The rotation of Earth may help: launch at equator!

Escape velocity

- Escape velocity: the object's kinetic energy ≥ gravitational potential energy

$$v_e = \sqrt{\frac{2GM}{R}}$$

G: universal gravitational constant
M: mass of the body to be escaped
R: radius of the celestial body

- escape velocity on Earth ≈11.19km/s
- atmospheric friction is not taken into account
- this is an elliptical orbit around the Sun

- Third cosmic velocity: to leave the Solar System

$$v_3 = \sqrt{\frac{2GM}{D}}$$

M: mass of the Sun
D: Sun-Earth distance

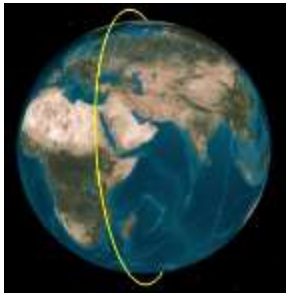
v_3=42.3km/s

- Fourth cosmic velocity: to leave the Milky Way ~130km/s

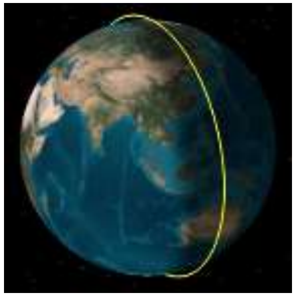
Orbits 1: LEO (Low Earth Orbit)

- ❑ Height: 300-1500km
- ❑ Nearly round orbit; 80-120min

1. Non-polar LEO°; inclination<70
   (ISS, Hubble)

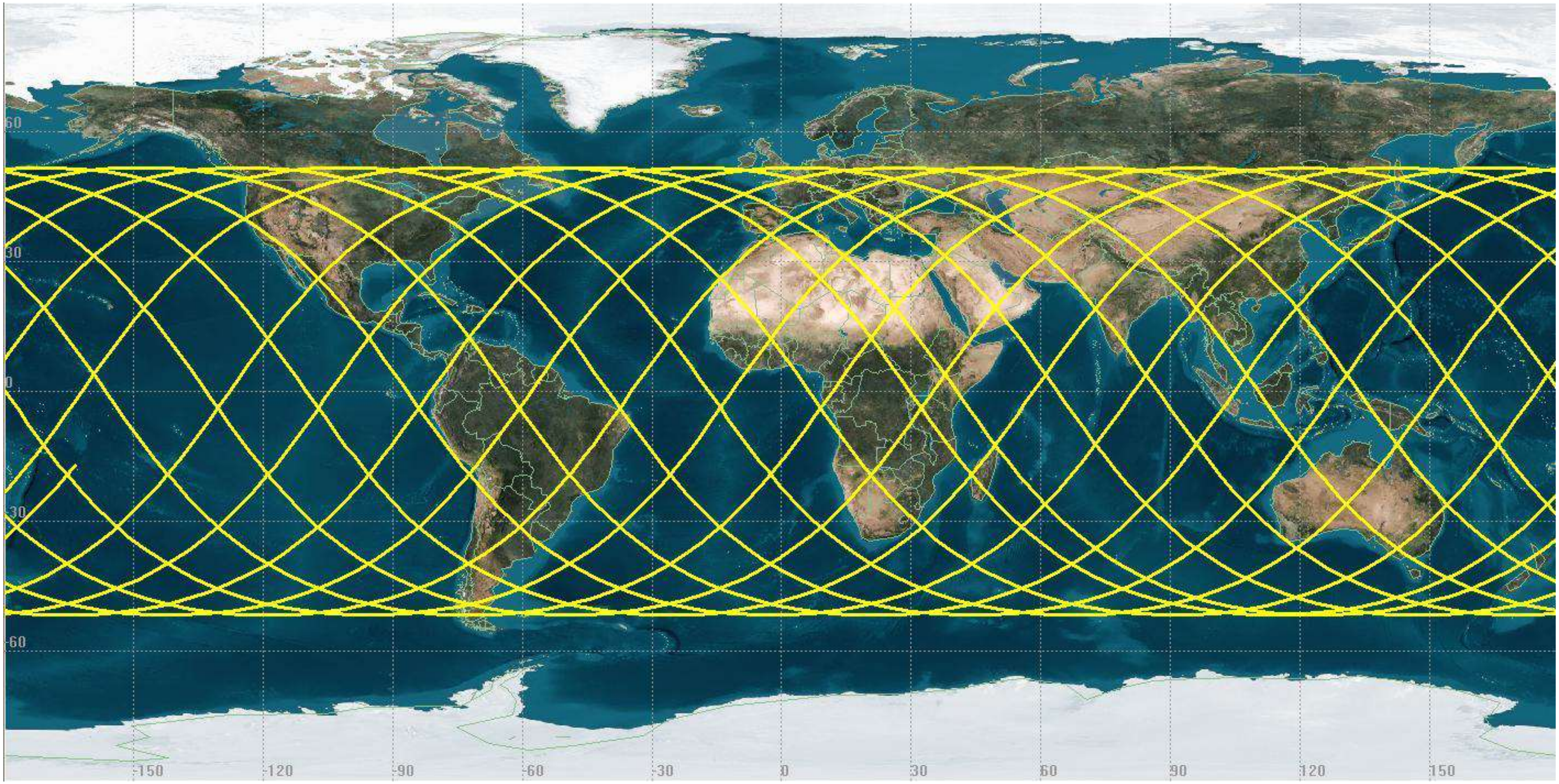


2. Polar, Sun-synchronous; inclination ~90°
   (remote sensing, ESEO)
   Transit above a specific point: always at the same time
   7-16 orbits/day



3. Polar, non Sun-synchronous
   (METEOR series, GOCE)

LEO ground track



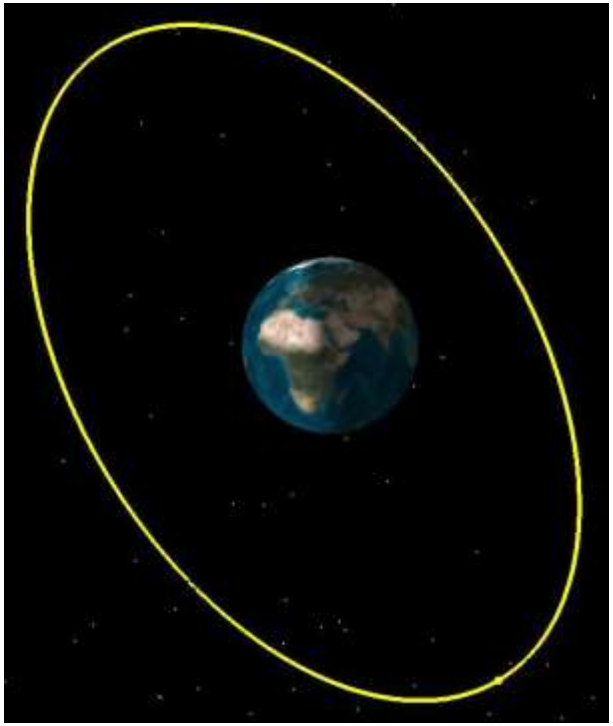
Orbits 2: MEO (Medium Earth Orbit)

- ❑ Height: 2000-36000km
- ❑ Orbiting period: 2-24hr
- ❑ Van-Allen belt!

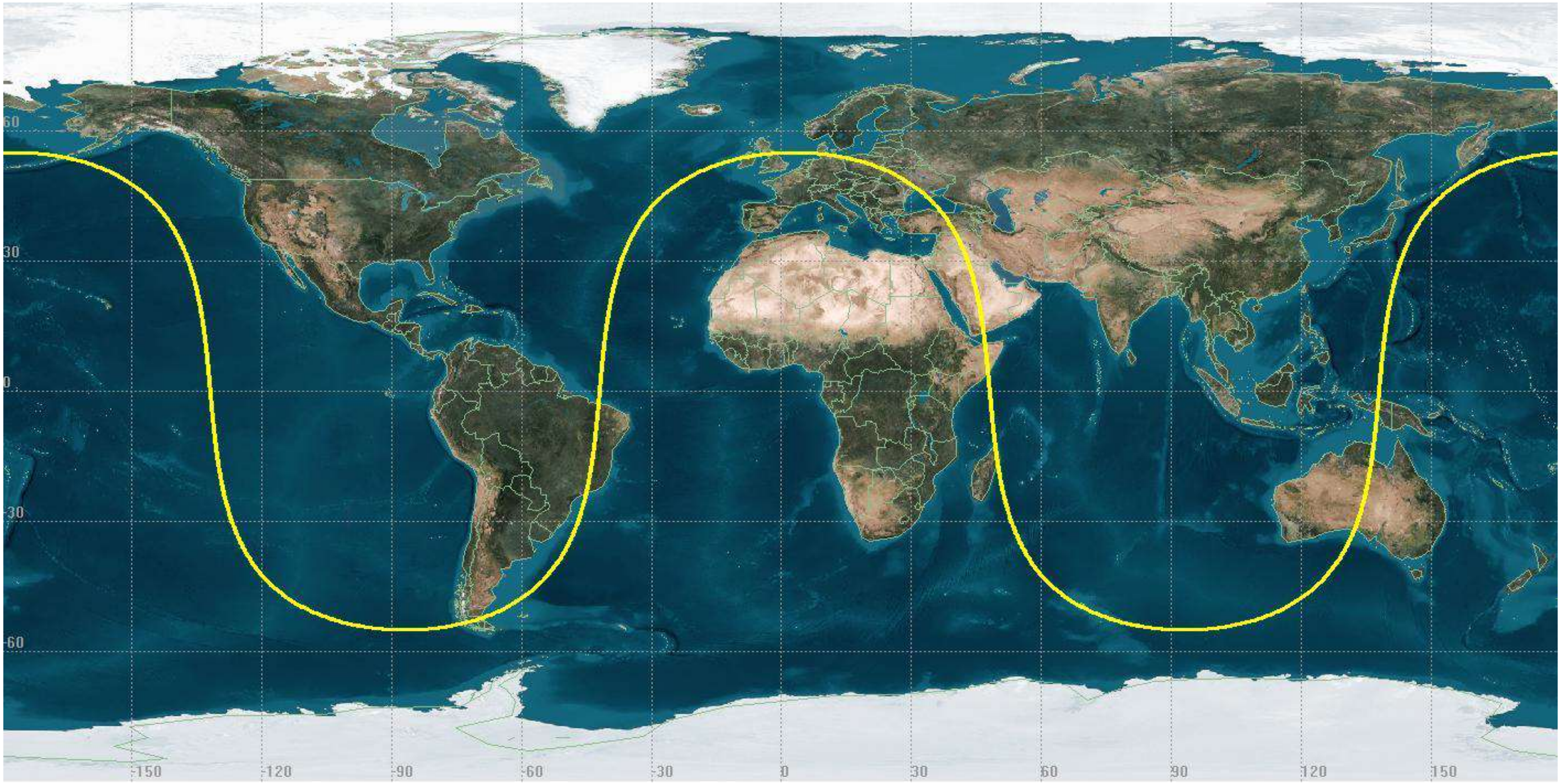
1. Navigation satellites
   (GPS, Galileo)

2. Communication satellites
   (Telstar)

3. Satellites for geodesy and space environment
   (Lageos)

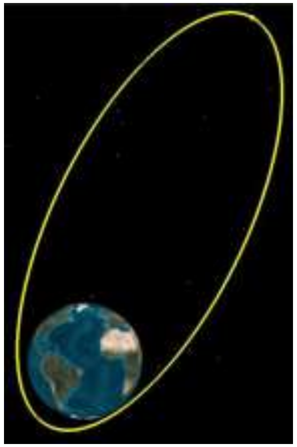


MEO ground track

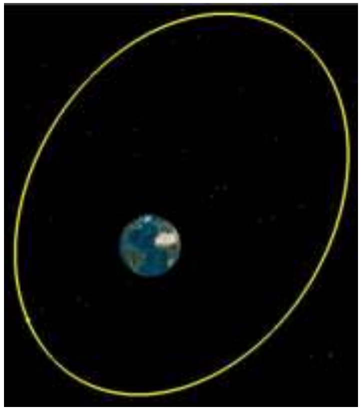


Orbits 3: HEO (Highly Elliptical Orbit)

- ❑ Apogeum > 36000km, Perigeum ~1000km
- ❑ Inclination: 50-70°

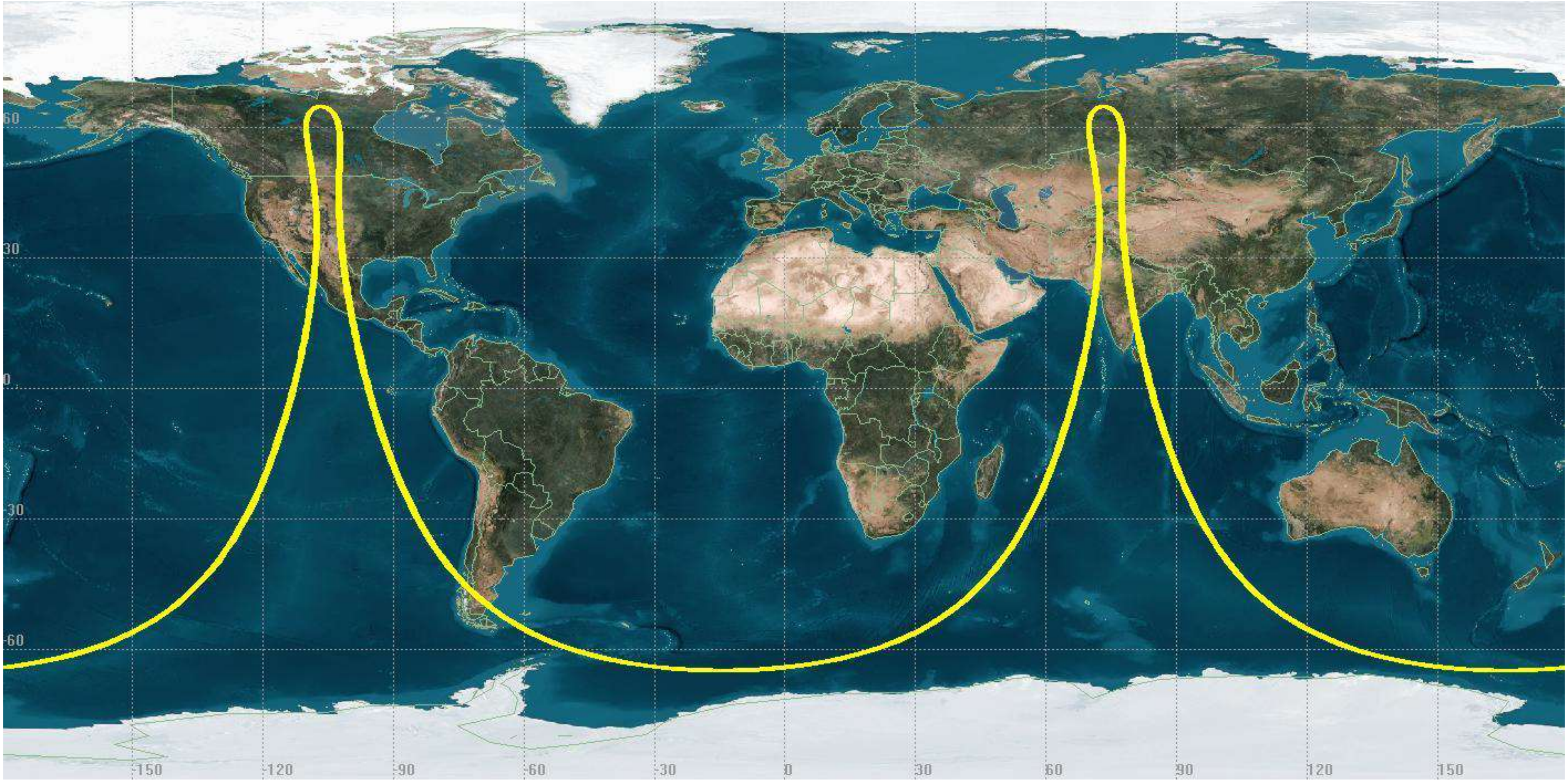


1. Molniya orbit
   500/40000km
   long visibility, 12hr period



2. Tundra orbit
   24500/47000km
   period=1 sidereal day

HEO ground track



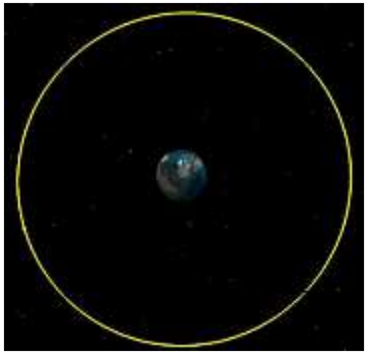
Orbits 4: GEO orbits

- Orbital period: exactly 24hr

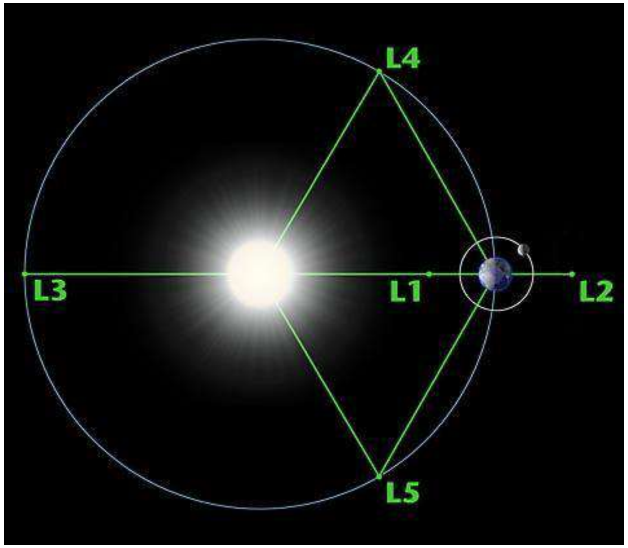
1. Geostationary
   inclination=0°
   35786km
   period=1 sidereal day
   (Meteosat)

2. Geosynchronous orbit
   inclination≠0°
   tracking required
   period=1 sidereal day
   (Alphasat)

3. Lagrange points
   stable: L4,L5
   unstable: L1,L2,L3



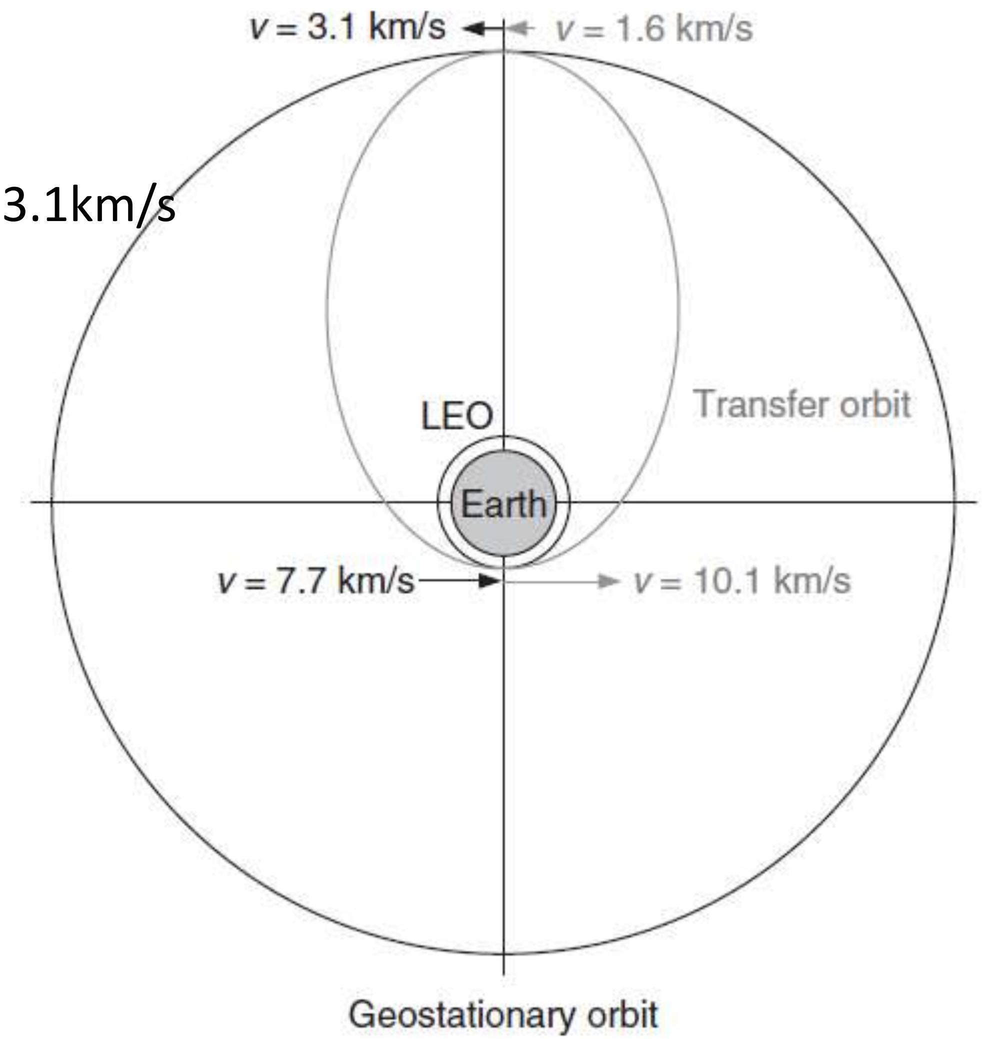
Sun's analemma



Orbital maneuvers 1.

- Moving between two circular orbits:
  Hohmann transfer (most energy efficient transfer)

1. LEO orbit
2. increase velocity to 10.1km/s
3. at 36.000km decrease velocity to 3.1km/s

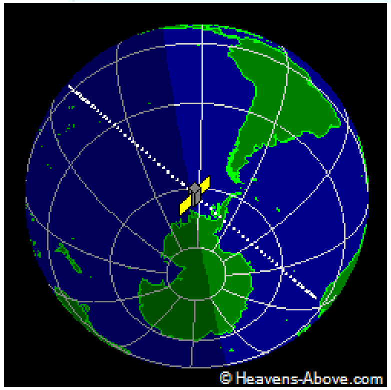


Orbital maneuvers 2.

- LEO satellite for remote sensing

1. The orbital period is synchronized with the Earth's rotation
2. After a certain period of time the satellite flies over the same ground track (repeat orbit)
3. Ensure that lighting conditions vary as little as possible between different exposures of the same area (Sun-synchronous orbit)
4. Correction maneuvers are required regularly to compensate orbital perturbations

	ALOS	Landsat 5	ENVISAT	SPOT	IRS-1A
Altitude (a)	692 km	705 km	800 km	832 km	904 km
Orbital period (T)	98.5 min	99 min	100.6 min	101 min	103.2 min
Inclination (i)	98.16°	98.2°	98.55°	98.7°	99°
Repeat period (K days)	46	16	35	2	22
Orbits per repeat period (N)	671	233	501	369	307
Local time of the node transit	10:30	09:30	10:00	10:30	10:00

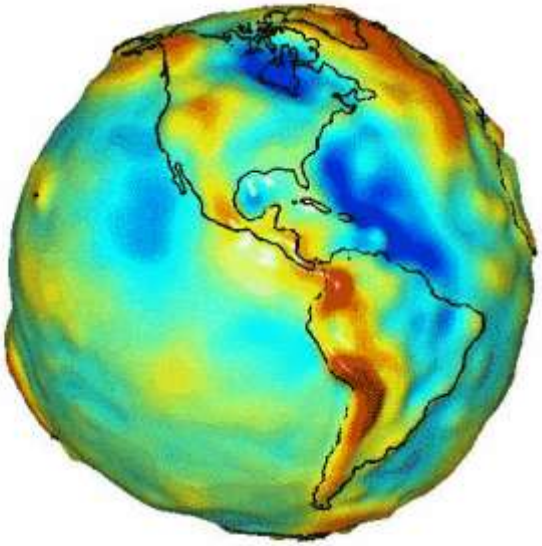


Masat-1:
repeat period was not integral

Orbital maneuvers 3.

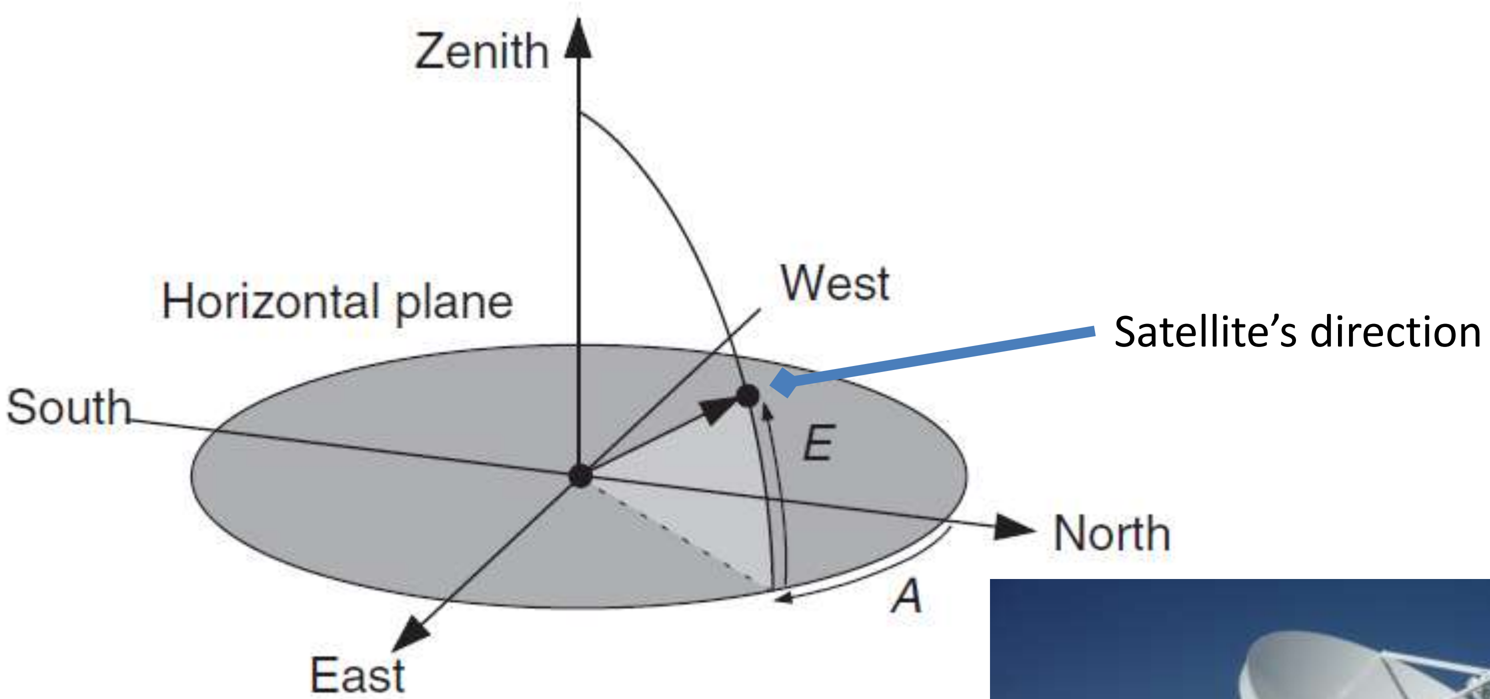
- Geostationary satellites

1. Semi-major axis = 42 164.3 km
2. Perturbations:
   - The irregular form of the Earth
   - Gravitational perturbations
   - Inclination vector drift (Sun and Moon effects)
3. Geographical longitude and latitude may not exceed ±0.1°/150x150km
4. Regular orbital control maneuvers are required about in every two weeks



Animation created with data from the GRACE spacecraft, shows the variances in Earth's gravity field
NASA / University of Texas Center for Space Research

Azimuth and elevation

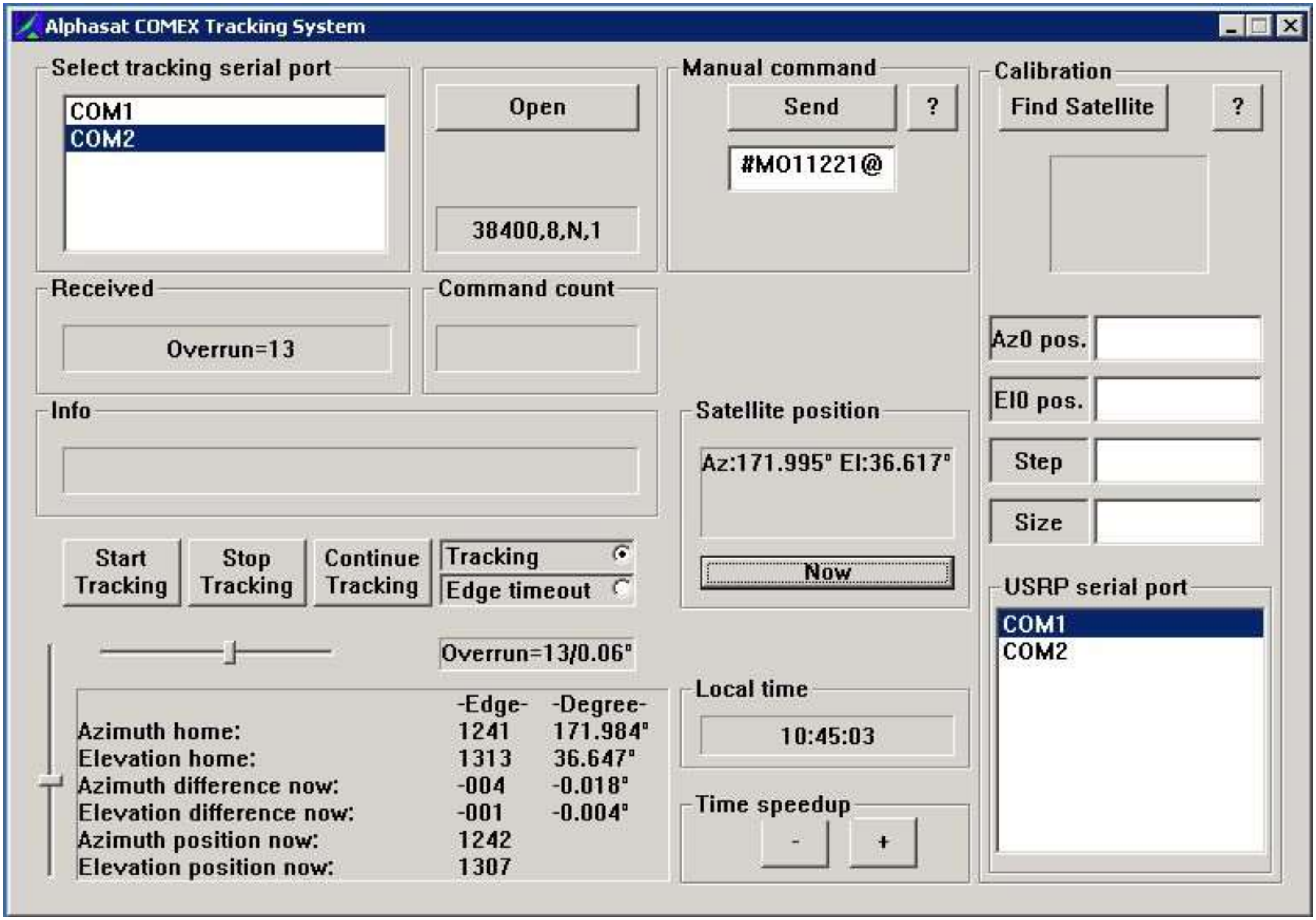


Tracking systems 1.

Tracking systems 2.

Tracking systems 3.

Tracking systems 4.



Sources:

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  Principles of Communications Satellites
  Wiley, ISBN: 978-0-471-55796-8
- Wilfried Ley, Klaus Wittmann and Willi Hallmann (ed):
  Handbook of Space Technology
  Wiley, ISBN: 978-0-470-69739-9

Main topics / questions

- ❑ **Kepler's laws**
- ❑ **Role of the Keplerian elements**
- ❑ **Perturbation effects that influencing Earth orbiting satellites**
- ❑ **The TLE orbital element set (only the role and a summary)**
- ❑ **Orbit types (LEO,MEO,HEO,GEO)**
- ❑ **The Hohmann transfer (figure)**
- ❑ **Azimuth and elevation degrees (figure)**