Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

MIN-Fakultät
Fachbereich Informatik
Arbeitsbereich SAV/BV (KOGS)

IP2: Image Processing in Remote Sensing
2. Orbits, Acquisition Constraints and Missions

Summer Semester 2014

Benjamin Seppke

Agenda

- Orbital Computations
- Space borne Earth Observation
  - Orbits
  - Exemplary satellites
- Acquisition Constraints
  - Spatial and Temporal Coverage
  - Task-dependent Affordances
- Missions

Ikonos

Orbital Computations (1)

- Shape:
  - Computations are based on semi-major axis a and semi-minor axis b
  - If the shape is given w.r.t. Apogee Ap and Perigee Pe:

    $a = \frac{1}{2}(Ap + Pe)$ arithmetic mean

    $b = \sqrt{Ap \cdot Pe}$ geometric mean

- Attention:
  - If altitudes are given for the orbits, the Earth's radius/ diameter needs to be added!

Orbital Computations (2)

- Orbital period T:

  $$T = 2\pi\sqrt{a^3 (GM)^{-1}}$$

  with $GM \approx 398600.4419\ km^3 s^{-2}$

- Velocities for an Orbit with semi-major a and eccentricity e
  - Max speed (at Perigee)

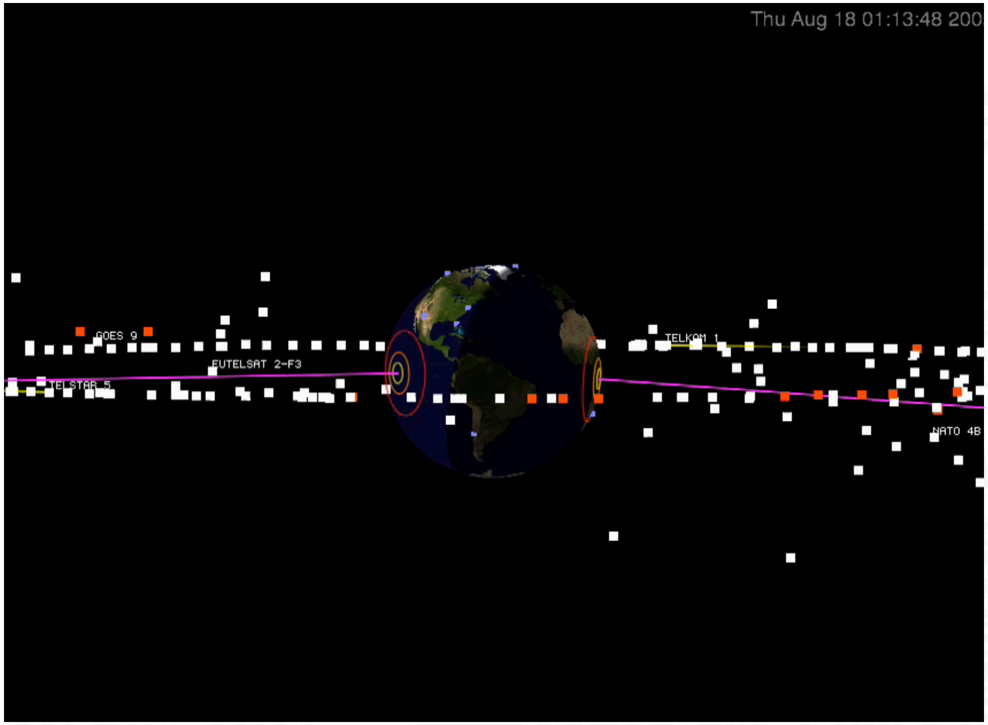
    $$v_{\max} = \sqrt{\frac{(1+e)GM}{(1-e)a}}$$

  - Min speed (at Apogee)

    $$v_{\min} = \sqrt{\frac{(1-e)GM}{(1+e)a}}$$

Orbits of EO Satellites

- Geostationary
- Geosynchronous
- Molniya
- Sun synchronous
- GPS
- Altrimetric



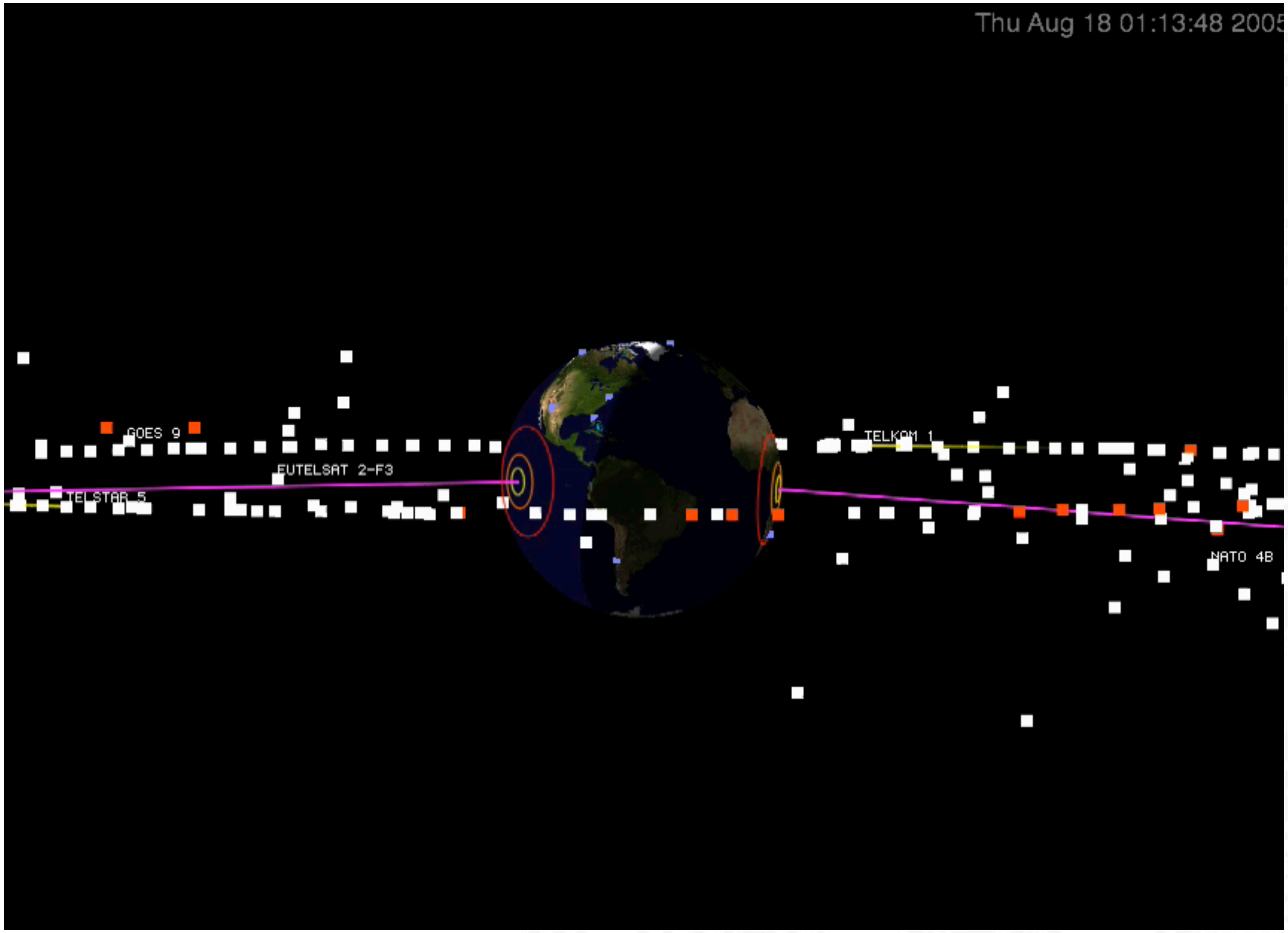
Geostationary Orbits

- Satellite stays over a fixed point above the equator. Used for:
  - Communication Satellites
  - Weather Satellites

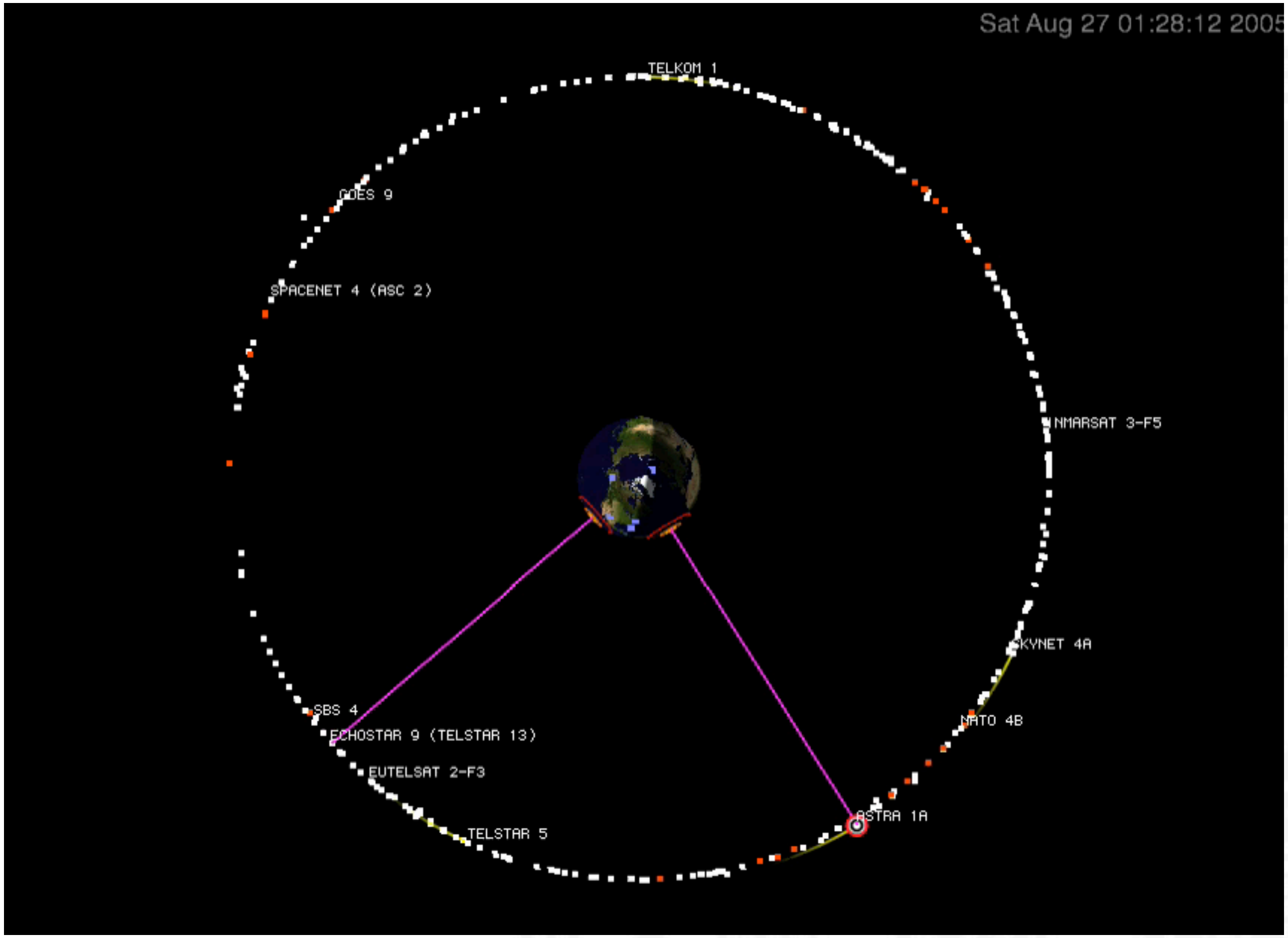
Orbital Period of the Satellite needs to be equal to the Rotation Period of the Earth: $P_E = 86164$ s.

➡ $a = 42170$ km, 35800 km above the equator

Satellites on Geostationary Orbits (1)



Satellites on Geostationary Orbits (2)



Disadvantages of Geostationary Obits

- High orbital altitude → large distance to Earth, low resolution.
- Restricted to equatorial regions, poles cannot be monitored
- Typical radii of the observation circle are between 55°- 65°).

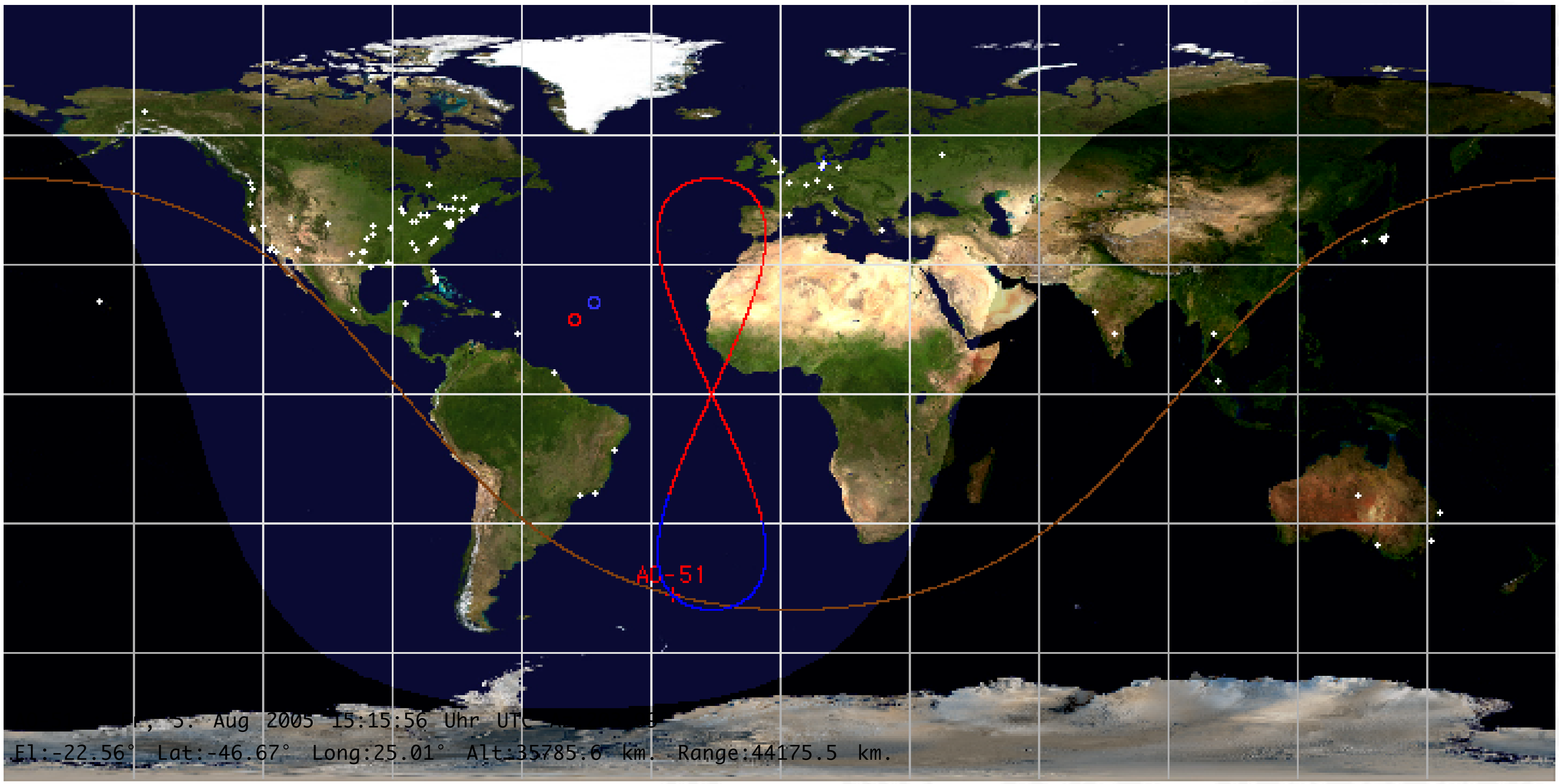
Geosynchronous Orbit

- Similar to geostationary orbit, but with an oribtal inclination w.r.t. the equator.
- Orbital period of the satellite is still equal to the rotation period of the Earth: $P_E = 86164\ s$.

  ⇒ $a = 42170\ km,\ 35800\ km$ above the equator

- Geosynchronous satellites can monitor polar regions, since they meander between Northern and Southern Hemisphere of the Earth periodically.

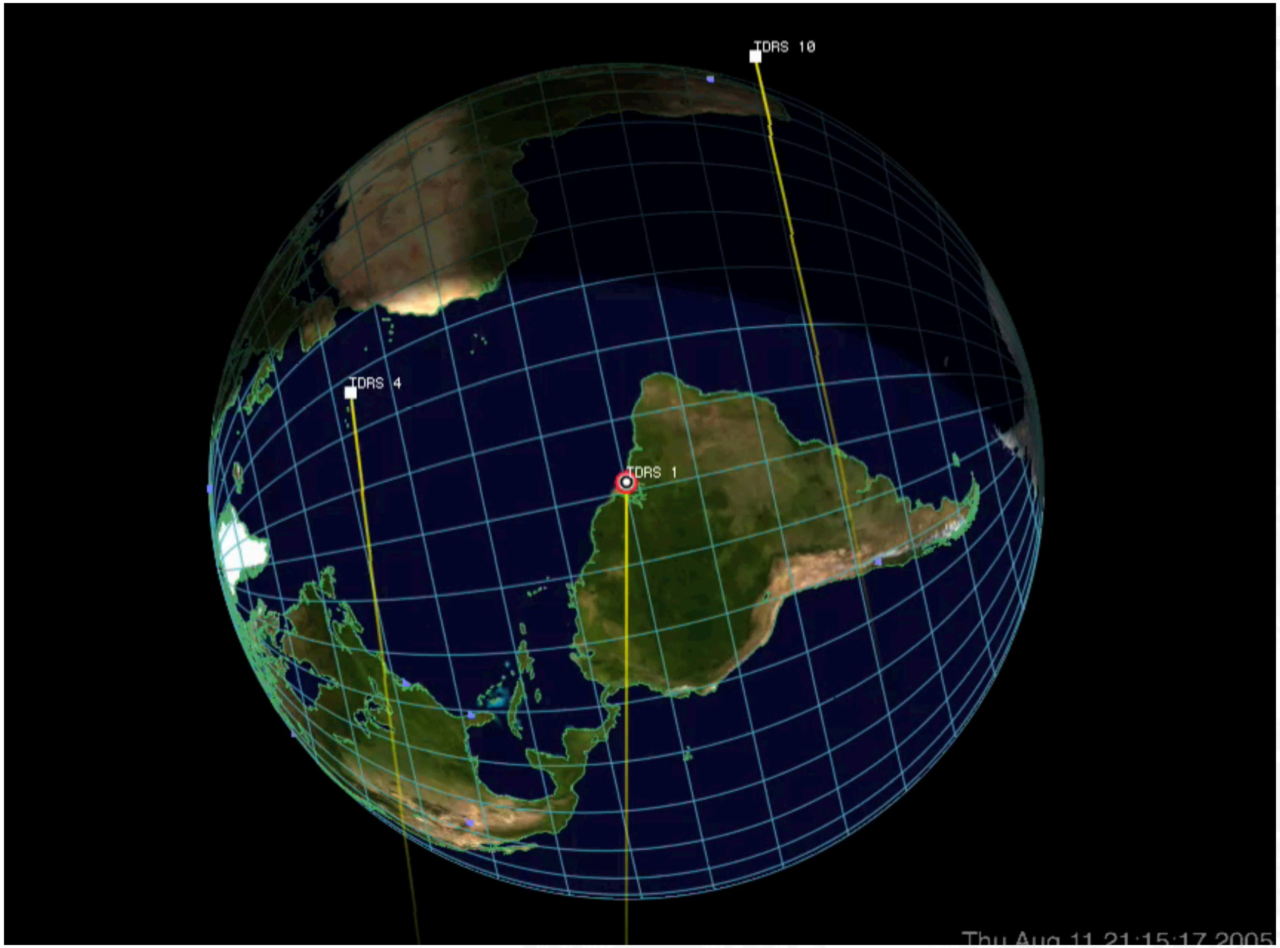
Ground-Track of a geosynchronous Satellite



Example of Geosynchronous Satellites:
Tracking and Data Relay Satellite System (TDRSS)

- Consists of:
  - 3 geosynchronous satellites, (2 active, 1 reserved)
  - Distance by means of longitude ≥ 120°.
- Operation purpose:
  - Telemetry applications
  - Relay stations for other satellites, particularly Landsat.

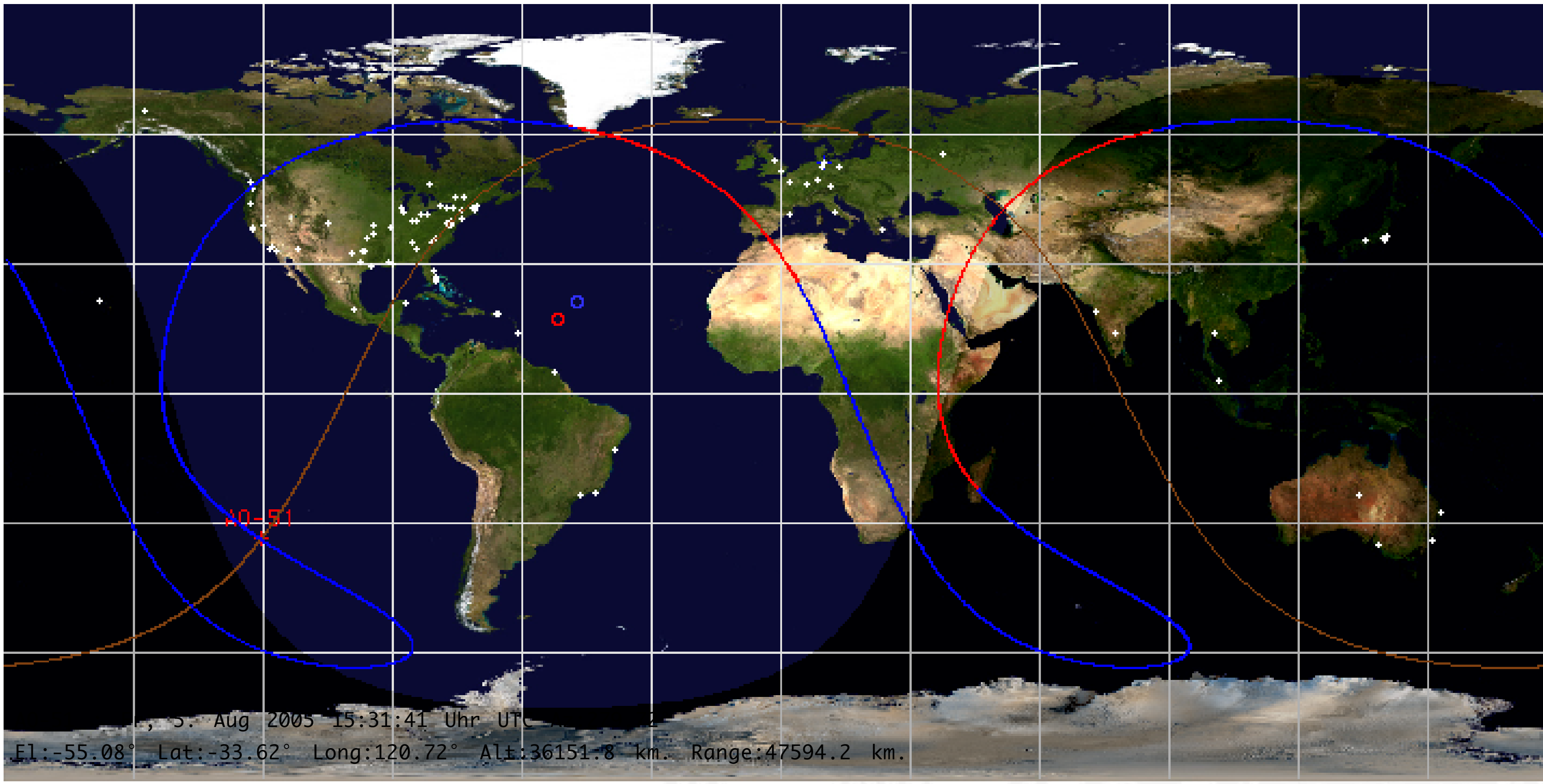
TDRSS Satellites in Orbital Motion



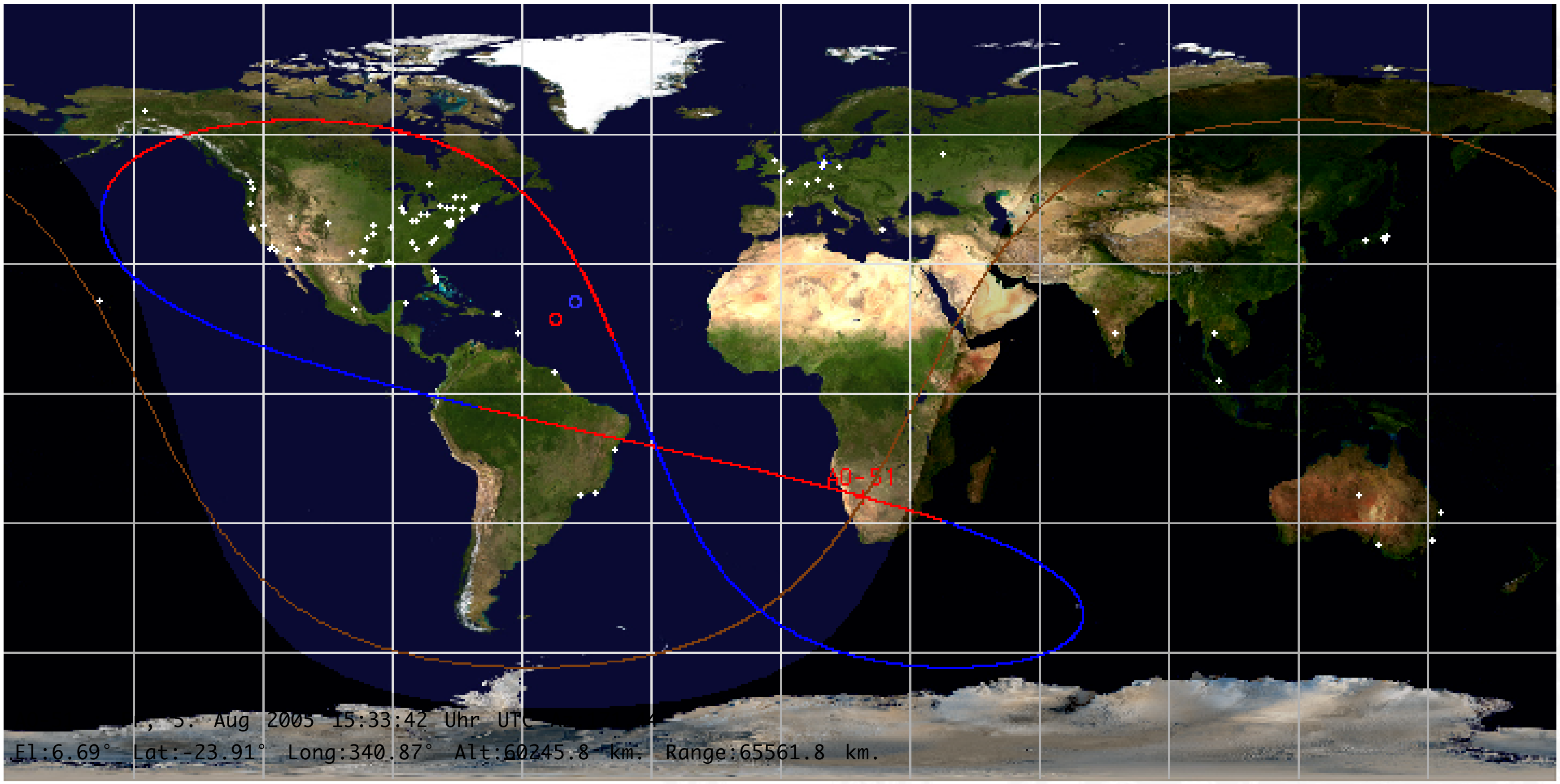
Molniya-Orbits

- From Russian: МОЛНИЯ, Flash
- Orbits for satellites to observe certain latitudes longer than others.
- Particularly used for communication satellites, military satellites like early-warning systems.
- Properties:
  - High eccentricity
  - Apogee above latitude to be monitored
  - Perigee above "uninteresting" latitudes

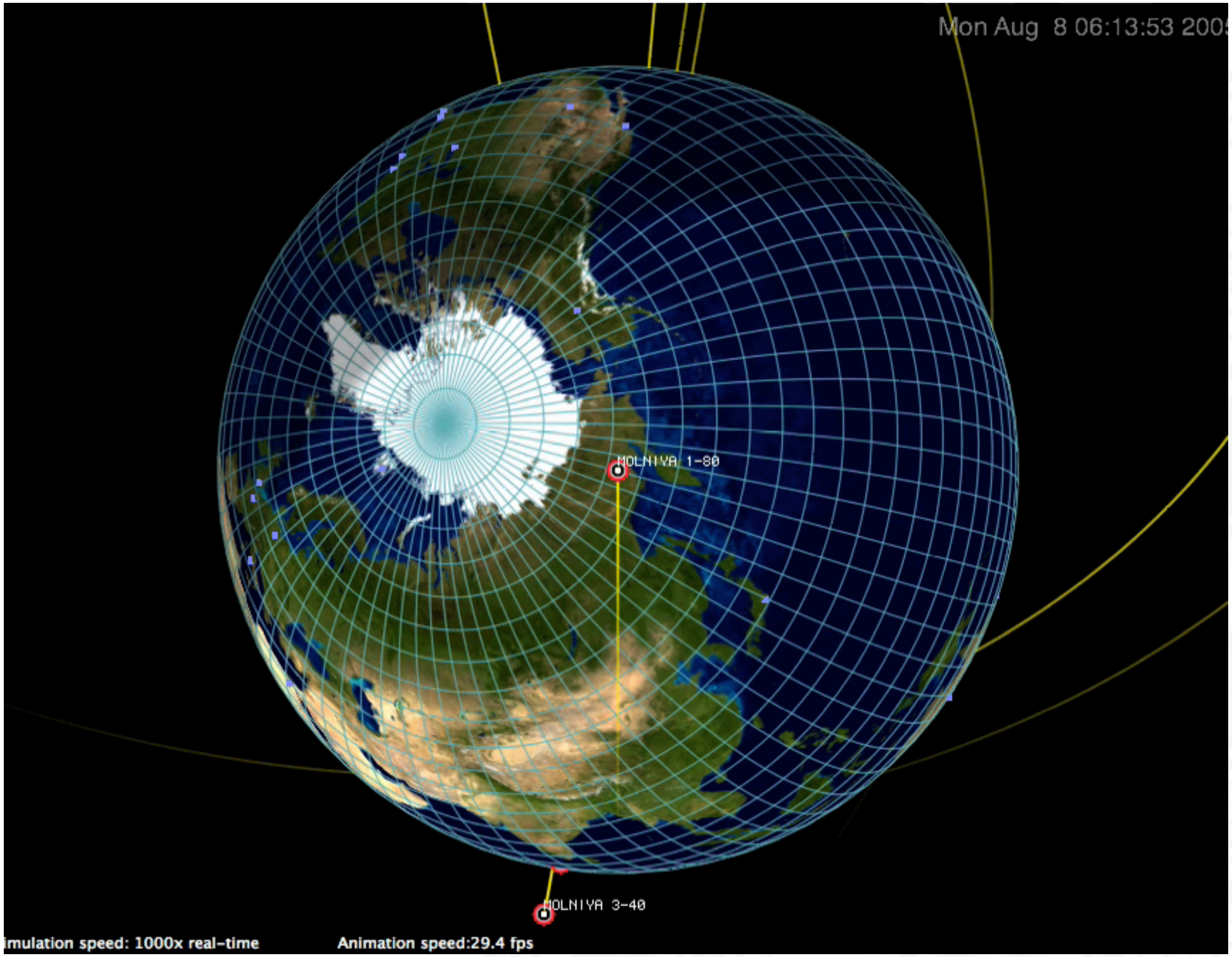
Molniya Orbit, P=1/2 day



Molniya Orbit, P=1 day (geosynchronous)



Orbital Motion of a Molniya Satellite



Non-rotating Orbit

- If the apogee shall stay on the same (geographic) Latitude, than the length of the Perigee needs to be:

$$\omega = 0$$

$$\Rightarrow \quad \omega = \Omega \frac{1 - 5\cos^2(i)}{2\cos(i)}$$

$$\Rightarrow \quad \cos(i) = \frac{1}{\sqrt{5}}$$

$\Rightarrow$ Non-rotating Orbits have inclination angles of:
$i = 63.4°$ or $i = 116.6°$

Sun Synchronous Orbits

Motivation: Similar illumination on each visit of an area on the Earth's surface. Examples:

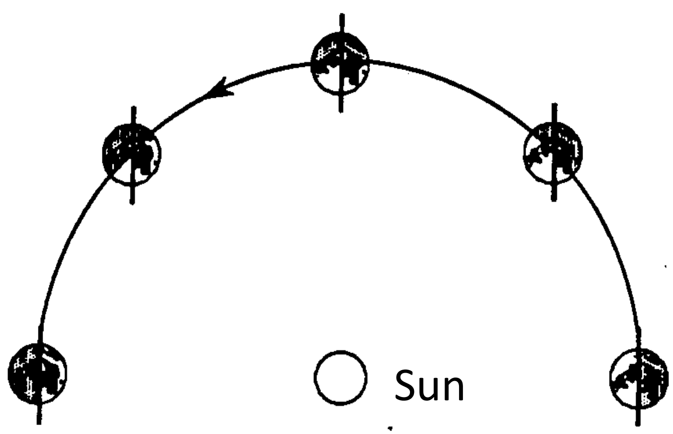
Light direction:

- From behind: Images without shadows
- From side, in front: high contrasts, use of shadows as indictor for the measurement of heights (e.g. mountain peeks)

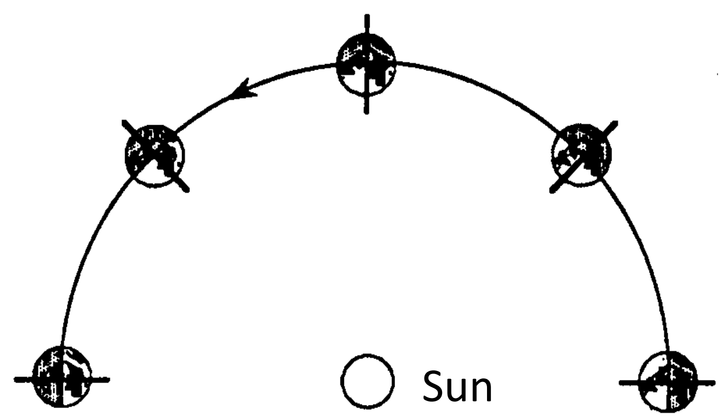
Classification

- Same sun illumination makes observations comparable
- Easier image fusion (might be) sufficient

Sun Synchronous Orbits



not sun synchronous



sun synchronous

Preconditions for Sun Synchronous Orbits

- Apparent angular velocity of the Sun ☼:
  scheinbare Winkelgeschwindigkeit

$$\Omega_{ss} = 360° / year = 1.991 \times 10^{-7} s^{-1}$$

- Precession of the ascending node must be equal to the apparent angular velocity of the Sun
- Holds, if semi-major of the orbit a_{ss} fulfills:

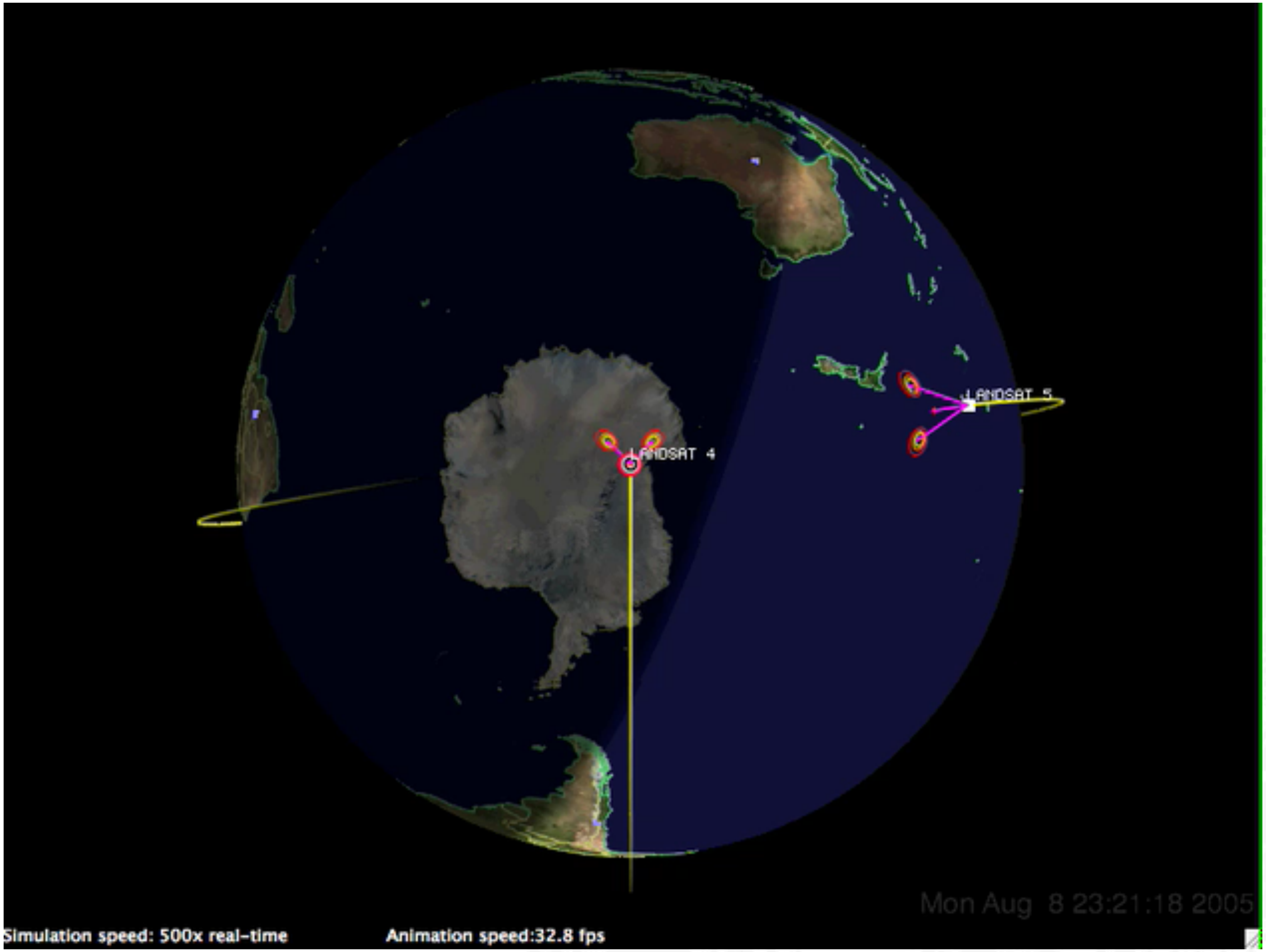
$$\left(\frac{a_{ss}}{1000\ km}\right)^{\frac{7}{2}} = -6624.6 \cdot \frac{\cos(i)}{\left(1-e^2\right)^2}$$

- E.g. $a_{ss} = 7878$ km, $e = 0$, $i = 102°$
- Generally: Inclination ≥ 96°
  → also called: Polar Orbits

Sun Synchronous Satellite: Landsat 4

- Altitude: ca. 705 km,
- Inclination: 99.2°
- Sensors:
  - Thematic Mapper (7-Band, TM)
  - Multi Spectral Scanner (4 Band, MSS)
- Crosses the equator at 9:30 a.m. local time
- Civil Earth Observation:
  - Monitoring of Forests
  - Vegetation
  - Geology etc.

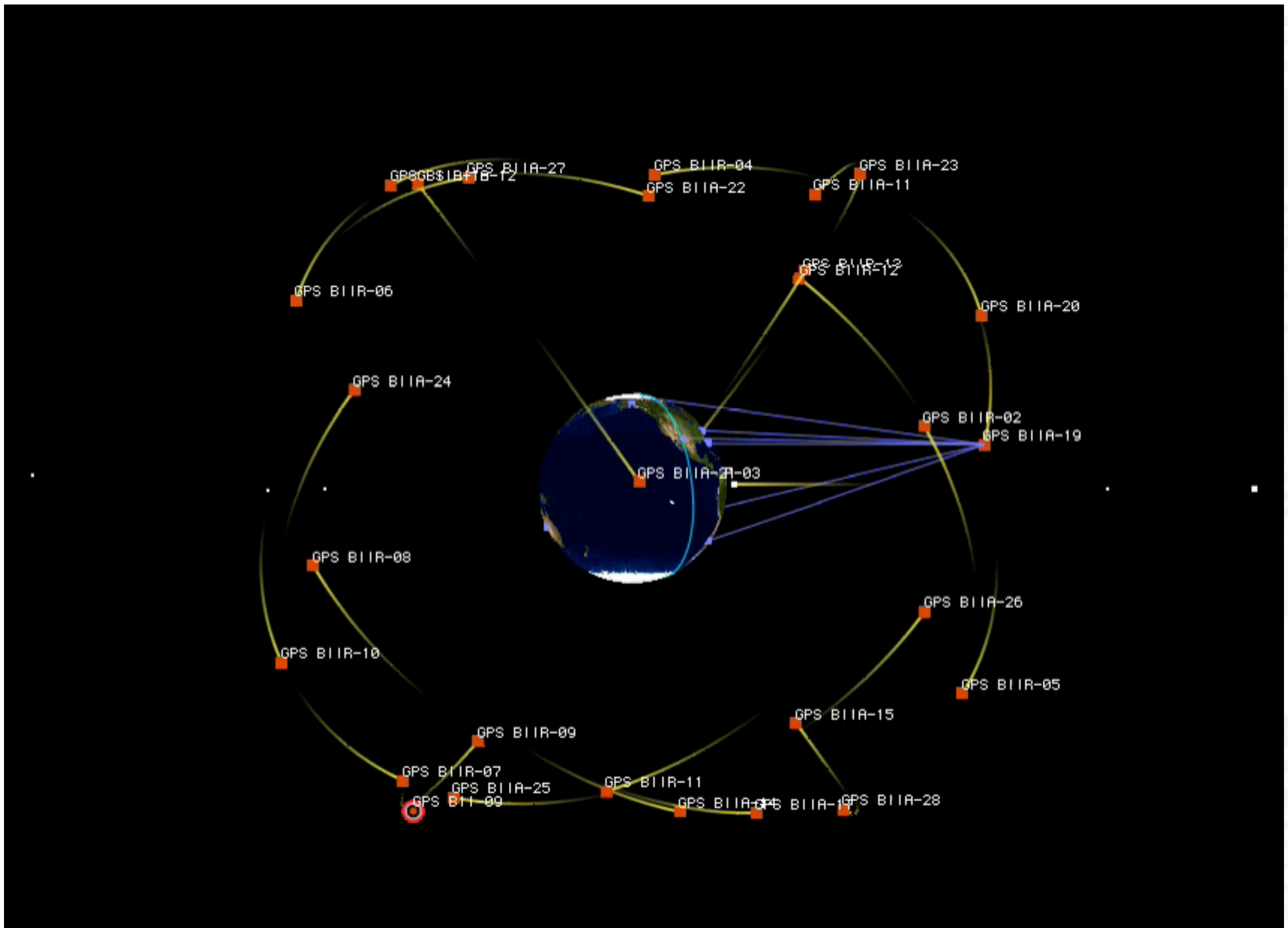
Landsat Ensemble: Sun Synchronous Orbits



GPS Orbits

- Setup:
  - 24 Satellites
  - 6 levels of altitudes, 4 satellites per levels
  - Inclination: 55°
  - (Lowest) altitude: 20200 km.
- Each Satellite is equipped with:
  - 2 Cesium clocks
  - 2 Rubidium clock
  - Detectors for nuclear explosions.
  - 710 Watt solar panel (Diameter 5.3 m)
- Planned lifetime: 7.5 years per satellite

GPS Ensemble: Orbital Motion



Requirements for EO tasks

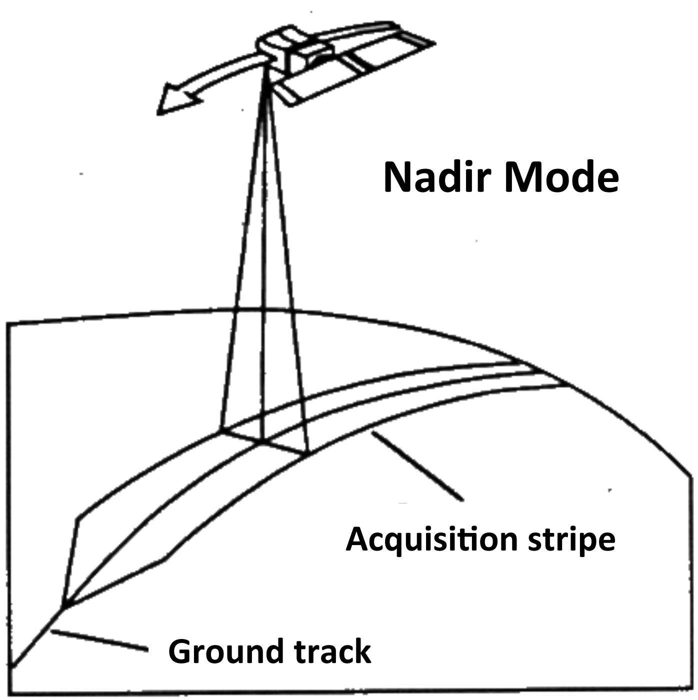
Different earth observation tasks may need special:

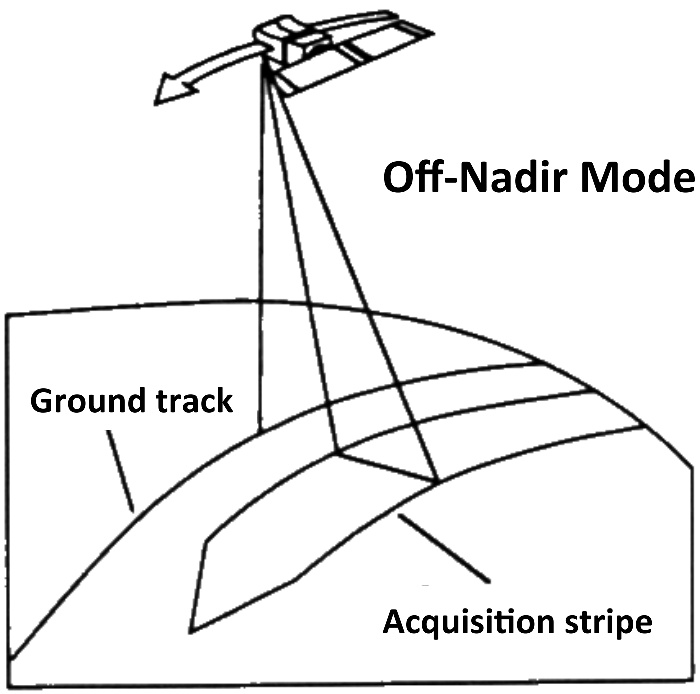
- resolution,
- Acquisition stripe

  Überdeckungsstreifen
- Repetition rates

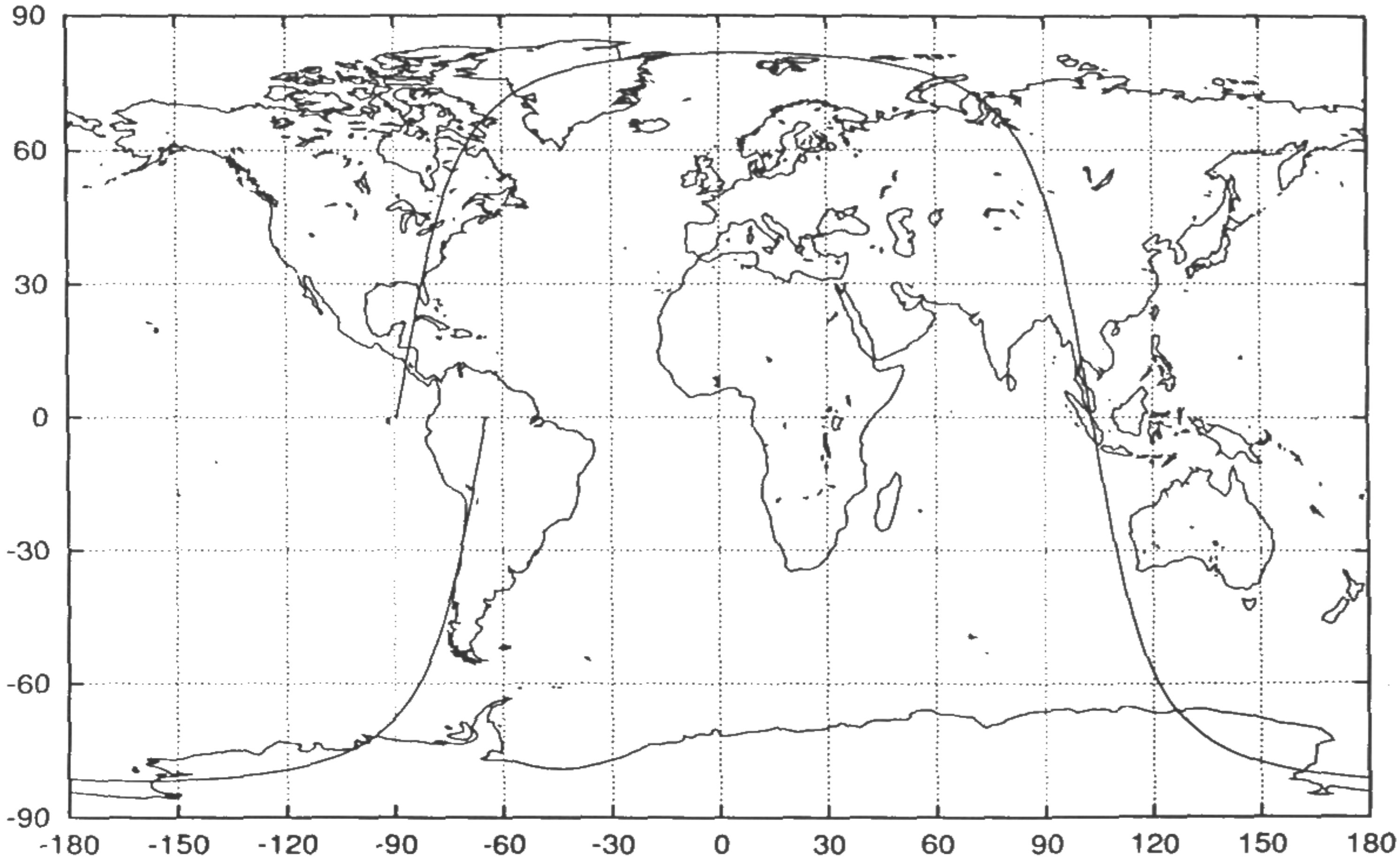
  Wiederholrate
- Sampling
- Crossing angles of ground tracks

Nadir and Off-Nadir Mode

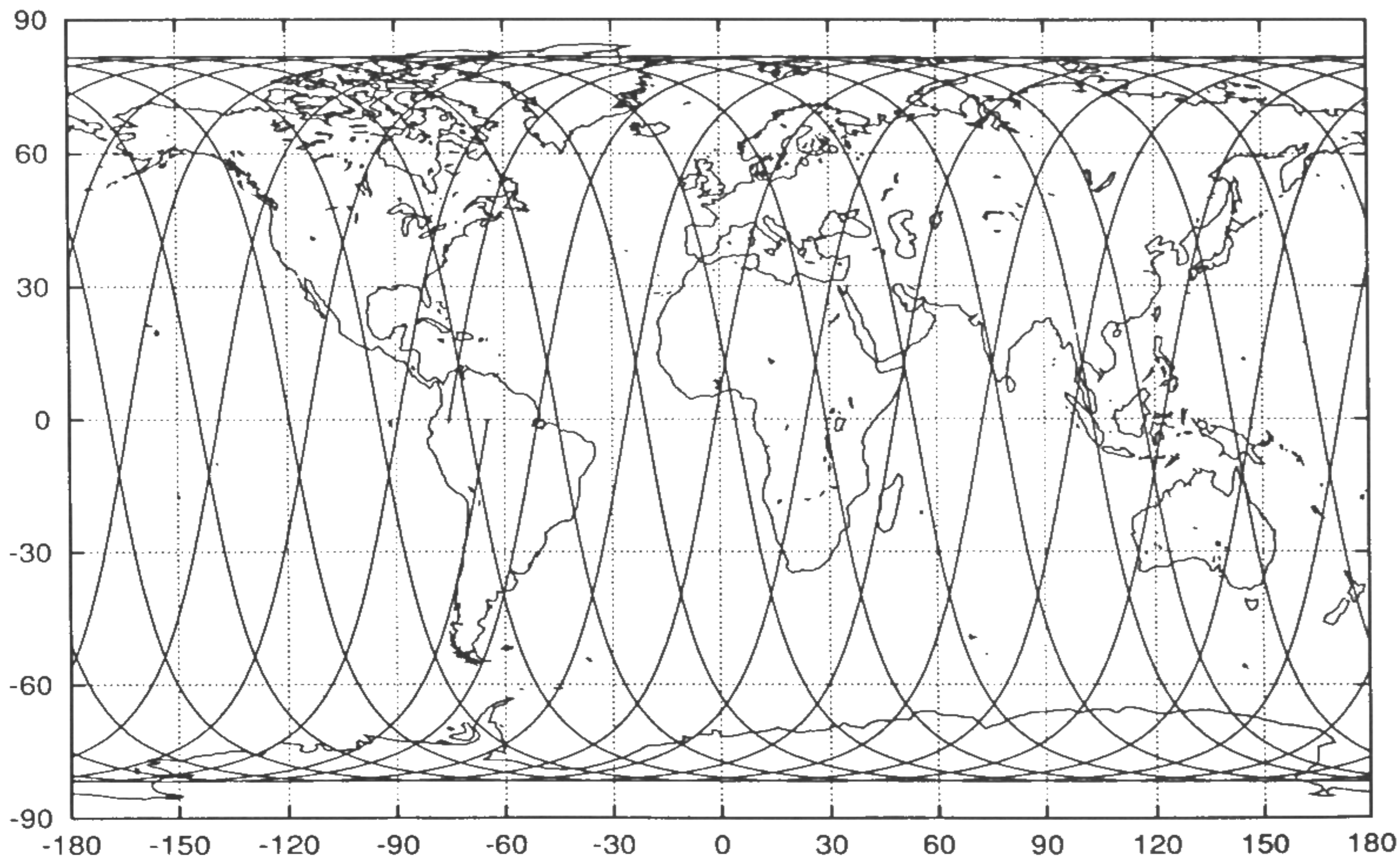




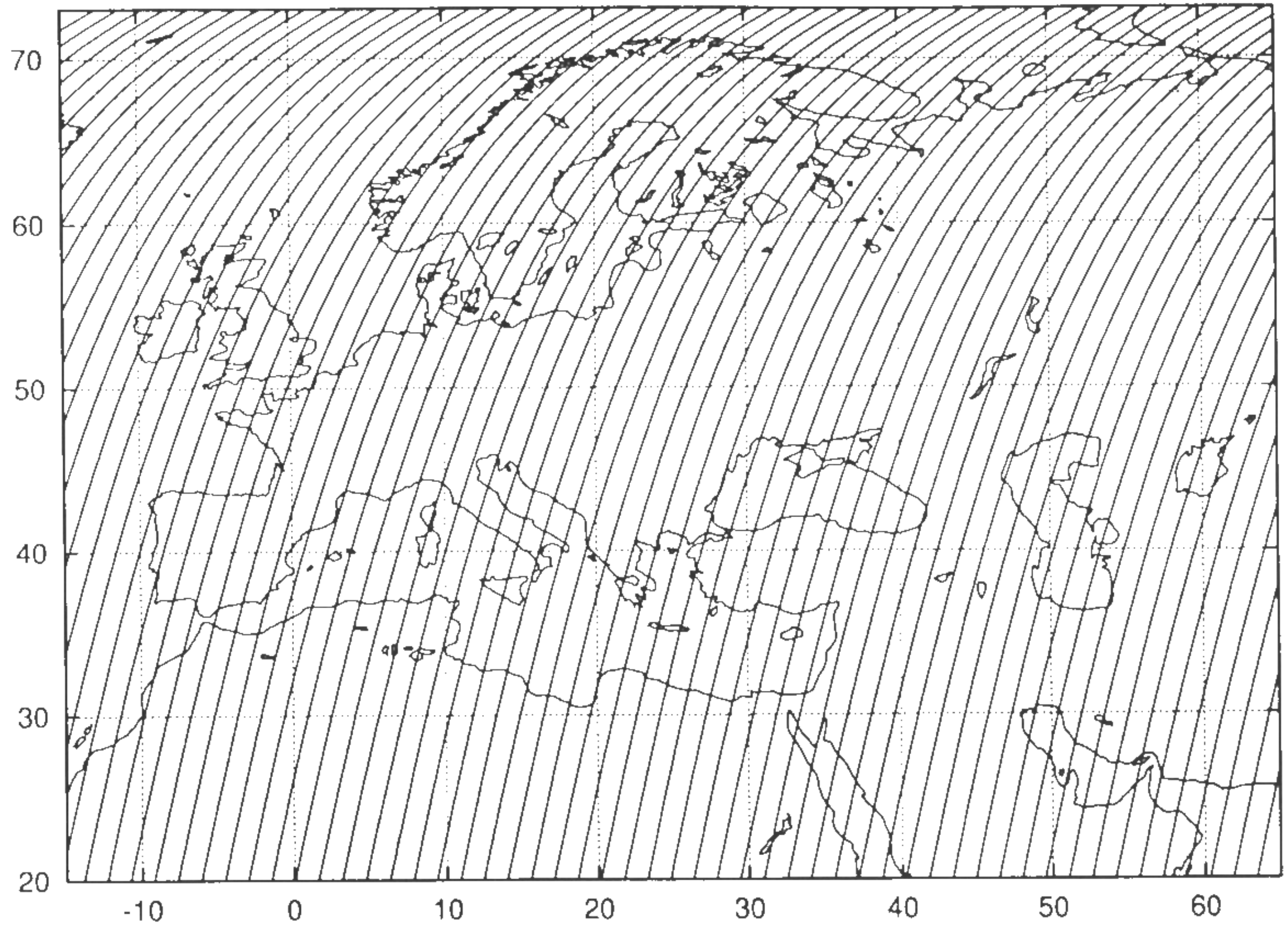
Landsat 4,5: Ground Track of one Orbit



Landsat 4,5: Ground Track of one Day



Landsat 4,5: All Ground Tracks of a Cycle



Exact Orbit Repetition

- If a certain location shall be monitored periodically, we will need an exact repetition of the ground track:

$$P_N\left(\Omega_e - \Omega\right) = 2\pi \frac{n_1}{n_2}$$

$\Omega_e = \frac{2\pi}{P_E}$ Rotation velocity of the earth,

$\Omega = \frac{2\pi}{P}$ Rotation velocity of the satellite

n_1 Revisit time,

n_2 Orbit count between two (re-)visits

n_1, n_2 Coprime natural numbers,

Teilerfremd

Example: ERS 1

$$a = 7153135\,m, e = 0.00117, i = 98.5227°$$

$$\Omega = 1.997 \times 10^{-7} s^{-1}$$

$$P_N(\Omega_e - \Omega) = 6027.9\,s$$

$$\frac{n_1}{n_2} = 0.06977 = \frac{3}{43}$$

$\Rightarrow$ n_1=3, n_2=43

- ERS-1 visits a given location each third day, after 43 Orbits
- “Neighbored” ground tracks are spaced by 360°/43 = 8.4°.
  - At equator: 930 km,
  - At 60° latitude: 460 km
- The acquisition stripe needs to have a width of at least 930 km to monitor the complete earth from that orbit.

Altrimetric Orbits

Altrimetrische Orbits

- To generate height measurements from space, the orbits of the (used) satellites should cross each other over the location to measure in a right angle:

$$\cot\left(\frac{\chi}{2}\right) = \cot(i) - \frac{2\pi\sqrt{a^3(GM)^{-1}}}{P_E \sin(i)}$$

- Example: $\chi = 90° \Rightarrow i = 40°$ or $i = 130°$
- One should also take the revisit time into account! Particularly if the measured subject is periodically varying: e.g. sea surface height (tidal change)

→ Shannon's Sampling-Theorem

Space Missions

- Rockets and energy requirement
- Data transmission/acquisition:
  - Ground stations,
  - Relay satellites
- Lifetime
- Big vs. small satellites

Rockets, Energy Requirements and Launch

- Rocket Equation (at vacuum, without gravity):

$$\Delta V\left(m_i, m_f\right) = U \ln\left(\frac{m_i}{m_i - m_f}\right)$$

with

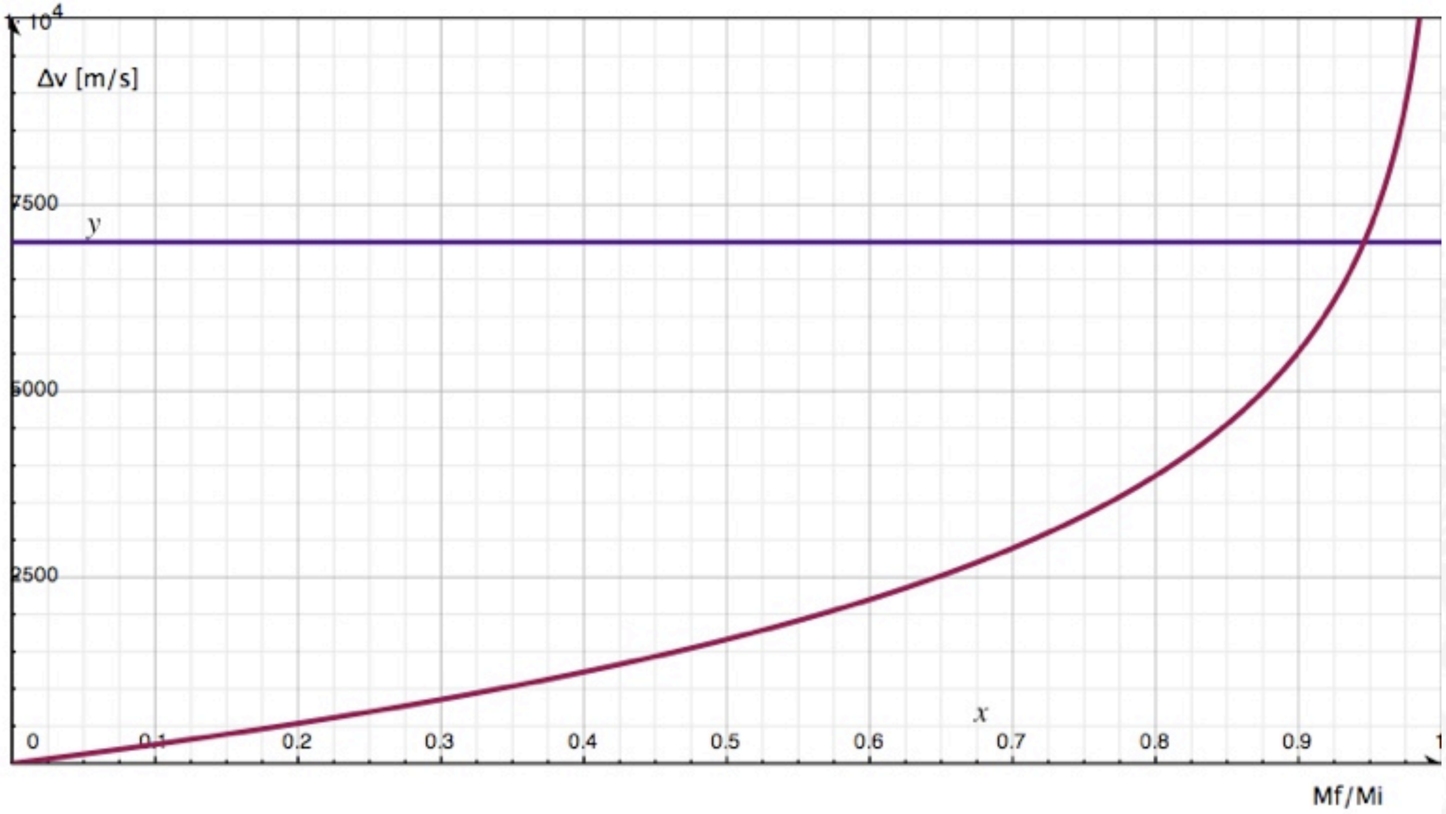
m_i: (Overall) rocket mass

m_f: Burned fuel

ΔV: velocity acceleration

U: exit velocity of fuel

Rocket Equation



- Typical velocity in low altitude orbits 7km/s, U=2.4km/s,
- Rocket mass has to consist of fuel by 95%!

Example: Ariane 1

European Rocket for geosynchronous orbit launches with 7° inclination:

- First Start: 24.12.1979
- Launch costs: $ 32 Mil (1985)
- Development costs: 2 Bil € (1986)
- Payload: 1850 kg
- 4 Stages:

Stage	Gross mass [kg]	Empty mass [kg]	Thrust [kgf]	Burn Time [s]	Length [m]
1	160 000	13 000	282 660	145	18.4
2	37 130	3625	73 518	132	11.5
3	9 687	1 457	6 289	563	10.2
4	369	34	1 978	50	1.1

Lifetime of Satellites

- The lifetime of a satellite is restricted by:
  - Energy requirements:

    If not all necessary energy can be produced by the solar panels
  - Orbital Altitude

    Atmosphere may slow down the satellite's velocity (highest effect at perigee)
  - Flexibility w.r.t. orbital maneuvers

    Each Orbit change vector costs valuable and finite fuel
- Plus: Other unexpected effects, like sun storms, particle/objects collisions etc.

Altitude Loss per Orbit Cycle: $\delta(a)$

$$\delta(a) = \frac{4\pi A a^2}{M} \rho(a)$$

with:

- a: semi-major axis of the orbit
- A: Effective cross section
  - *Wirkungsquerschnitt*
- M: Satellite's mass
- $\rho(a)$: Atmospheric density

Approximate Lifetime: τ

- Lifetime τ is assumed to be proportional w.r.t. M and A for a given orbit:

$$\tau = \frac{M\, f(h,e)}{A}$$

with:

h: Perigee height

e: Eccentricity

A: Effective cross section

Wirkungsquerschnitt

M: Satellite's mass

Fig. 9.12. Approximate behaviour of the function $f(h,e)$