Planetary exploration: tools and missions

3.1. Mission design

To go where? To do what?

Space environment - Power and communications

3.2. Orbital mechanics

From Earth to space

On site: orbit insertion and other movements

Lagrange points and Hill spheres

3.3. Magellan exploration of Venus

Exploration context

Magellan spacecraft

Mapping Venus: radar and gravity

3.4. Cassini-Huygens at Saturn and Titan

Exploration context

Cassini spacecraft

Huygens probe

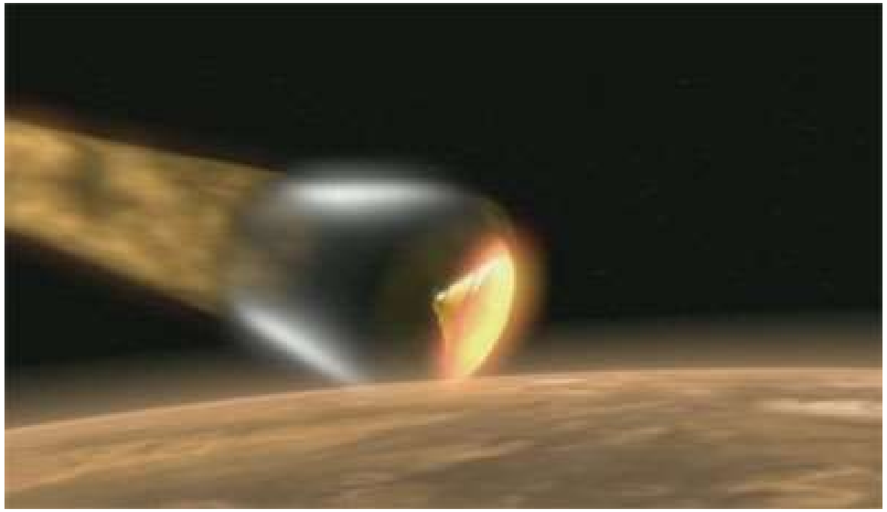
Mapping Saturn and its satellites - Landing on Titan

3.1. Mission design

Define target(s): planetary system(s), orbiting and/or landing, local conditions

Define instruments needed for each task. Prune down to sustainable power / time.

Define mission duration (transit + study itself).
Constrains power/communication options



Space environment is very harsh:

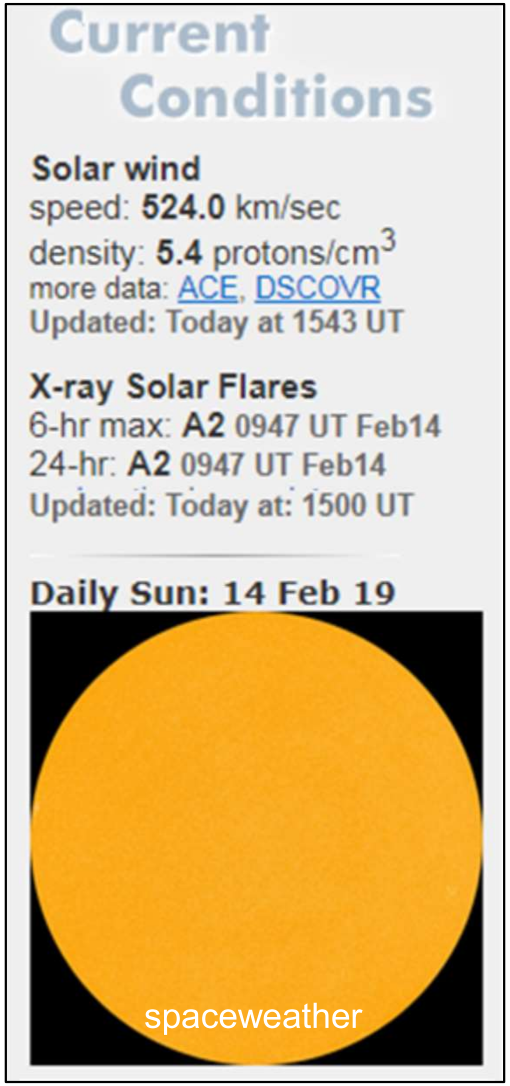
launch (high *g*, high vibrations)

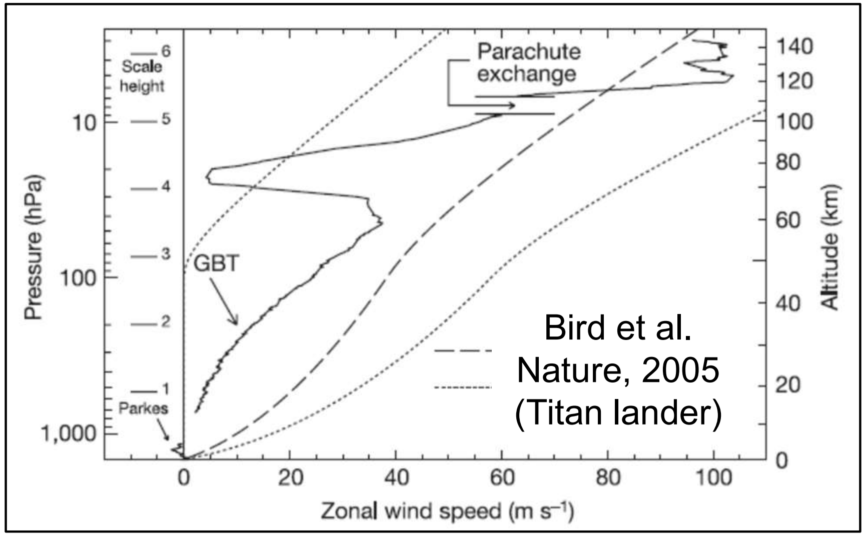
solar radiation
cosmic rays
interplanetary dust

near planets:
magnetic fields
more particles (e.g. near rings)

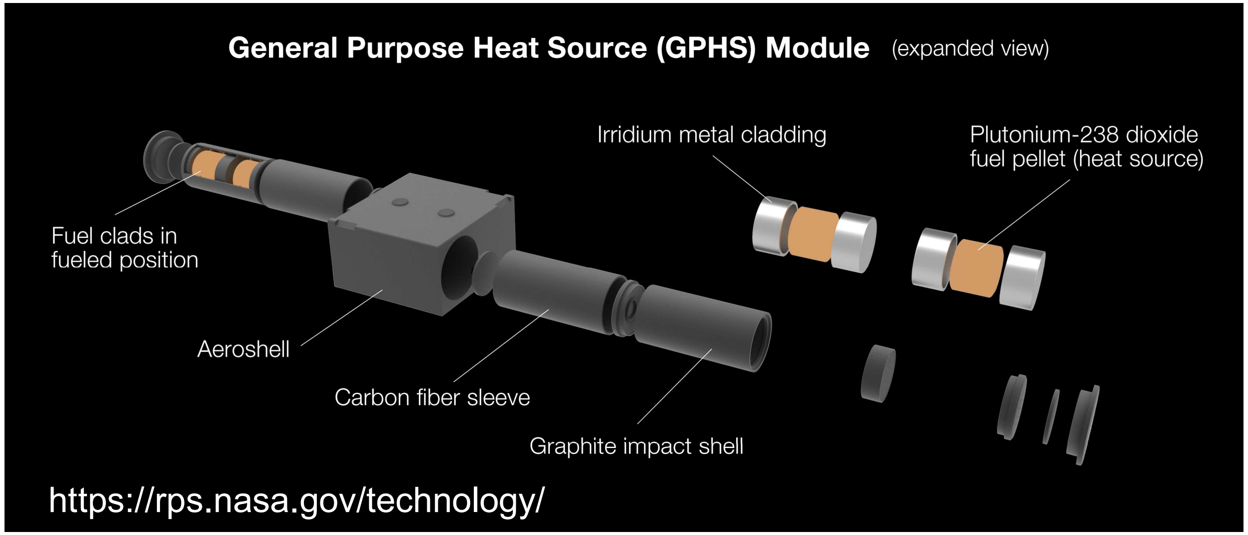
on planets:
atmospheres (corrosive? winds?)
gravity
temperatures

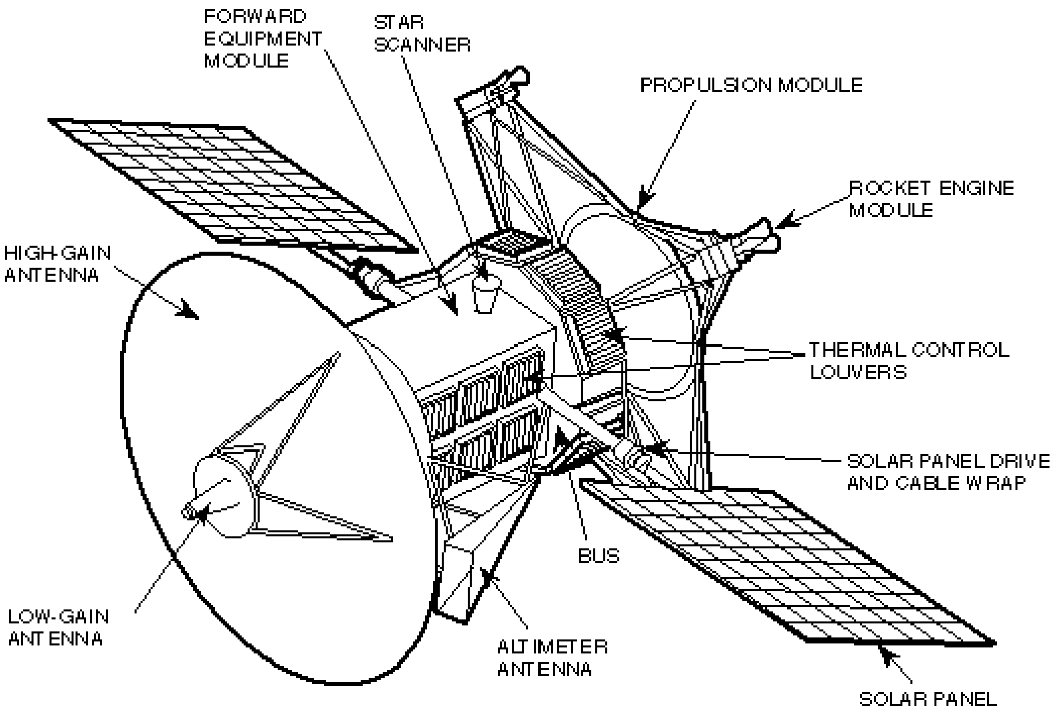
Spacecraft software and hardware (e.g. electronics) need hardening





Power





Radio-isotope generator

Output decreases with time, but useful far from Sun

best source, but limited legal uses due to danger associated with takeoff => u don't want to put radioactive material in the atmosphere

Solar panels ← soluto

Example:

5. 8 m long
28 V ~ not as great
NiCd batteries
1 kW nominal power

have issues with

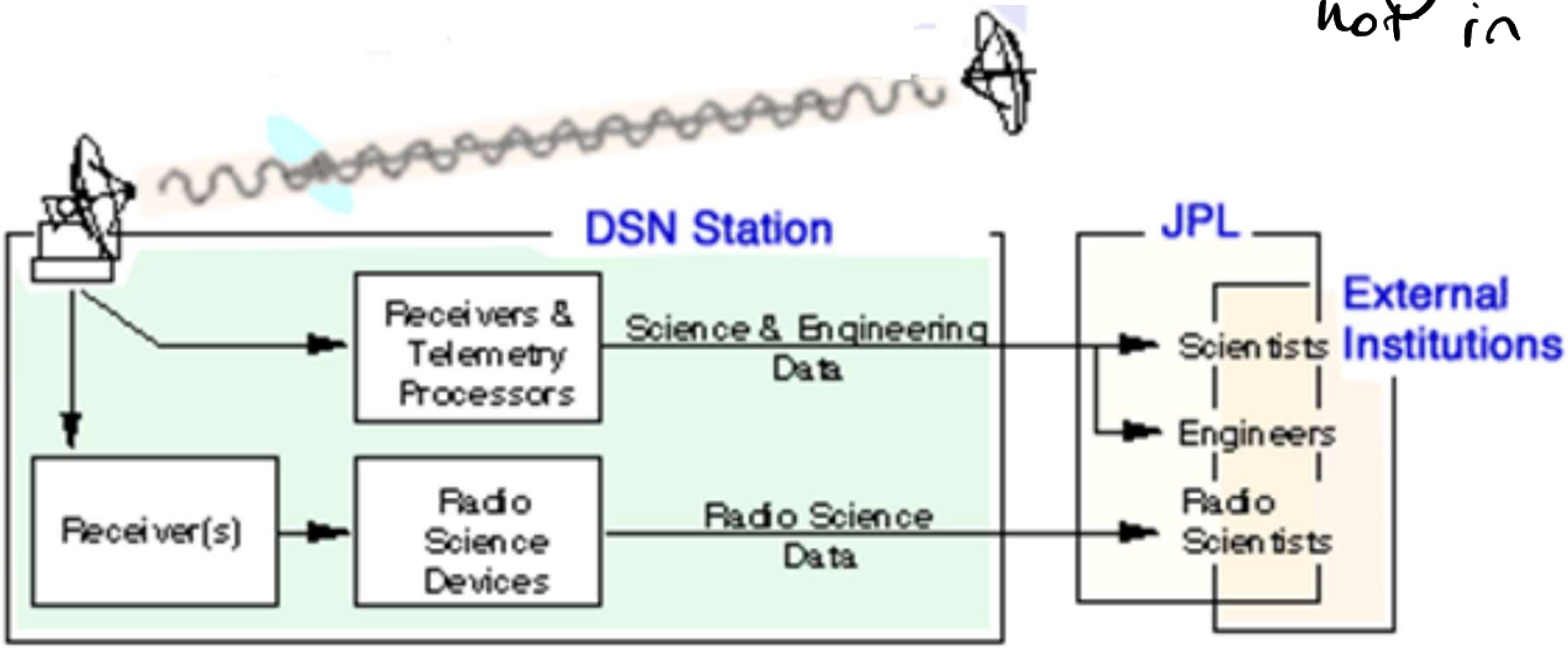
Communications

om

(very big)

Sand

landing needs to be not in the shadows

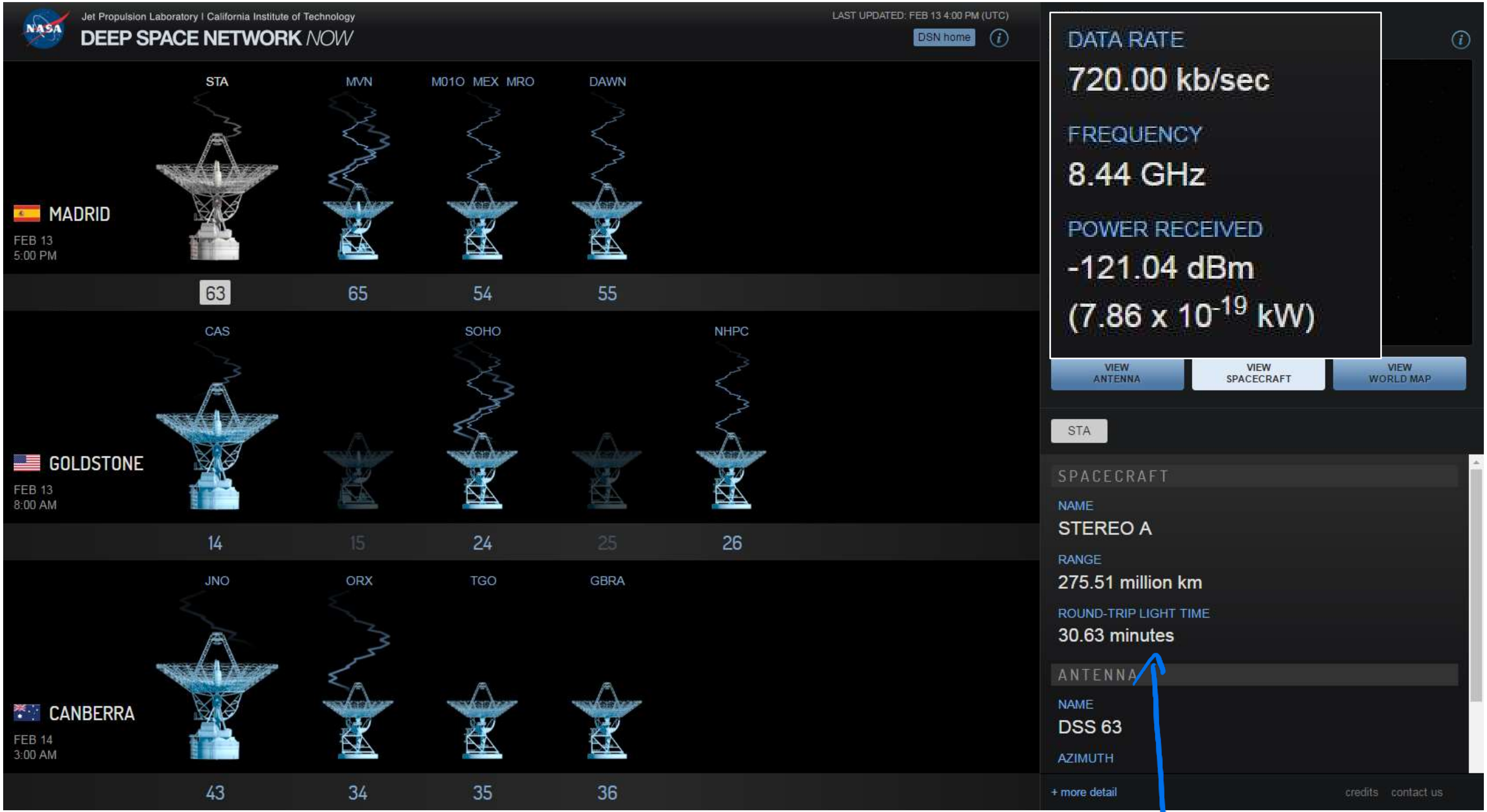


DSN (Deep-Space Network)

Typical radio power: 20 W (e.g. for Voyager)

Typical bandwidth: 100's kilo**bits**/second

Several nodes: accounts for Earth rotation



Spacecraft can receive information at fixed data rates
(usually small – varies with spacecraft radio and power constraints)

Signals sent/received are attenuated by the very large ranges

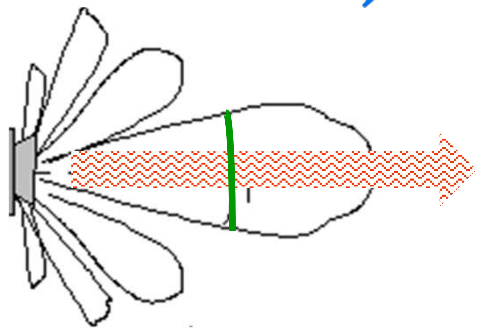
limited by communication times

U need to add "intelligence" to the sots

The beam pattern shows how much of the target is within the radio beam.

It shows the power variations with angles:

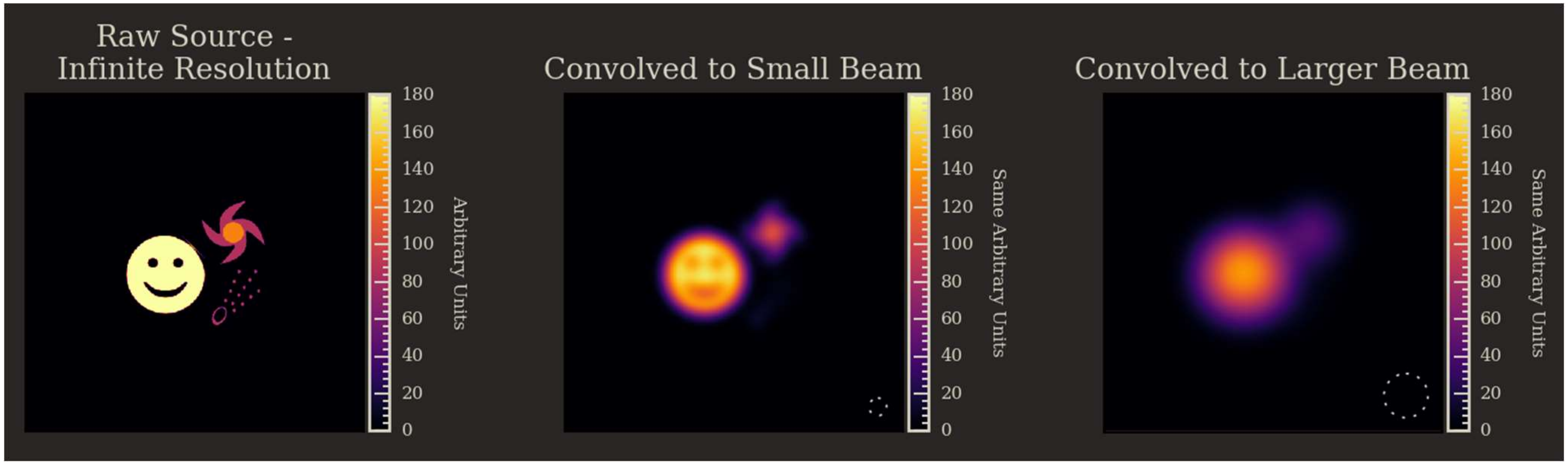
$$x_{dB}(\theta) = 20\log_{10}\frac{P(\theta)}{P_{max}}$$



It is usually defined by its half-power beam width

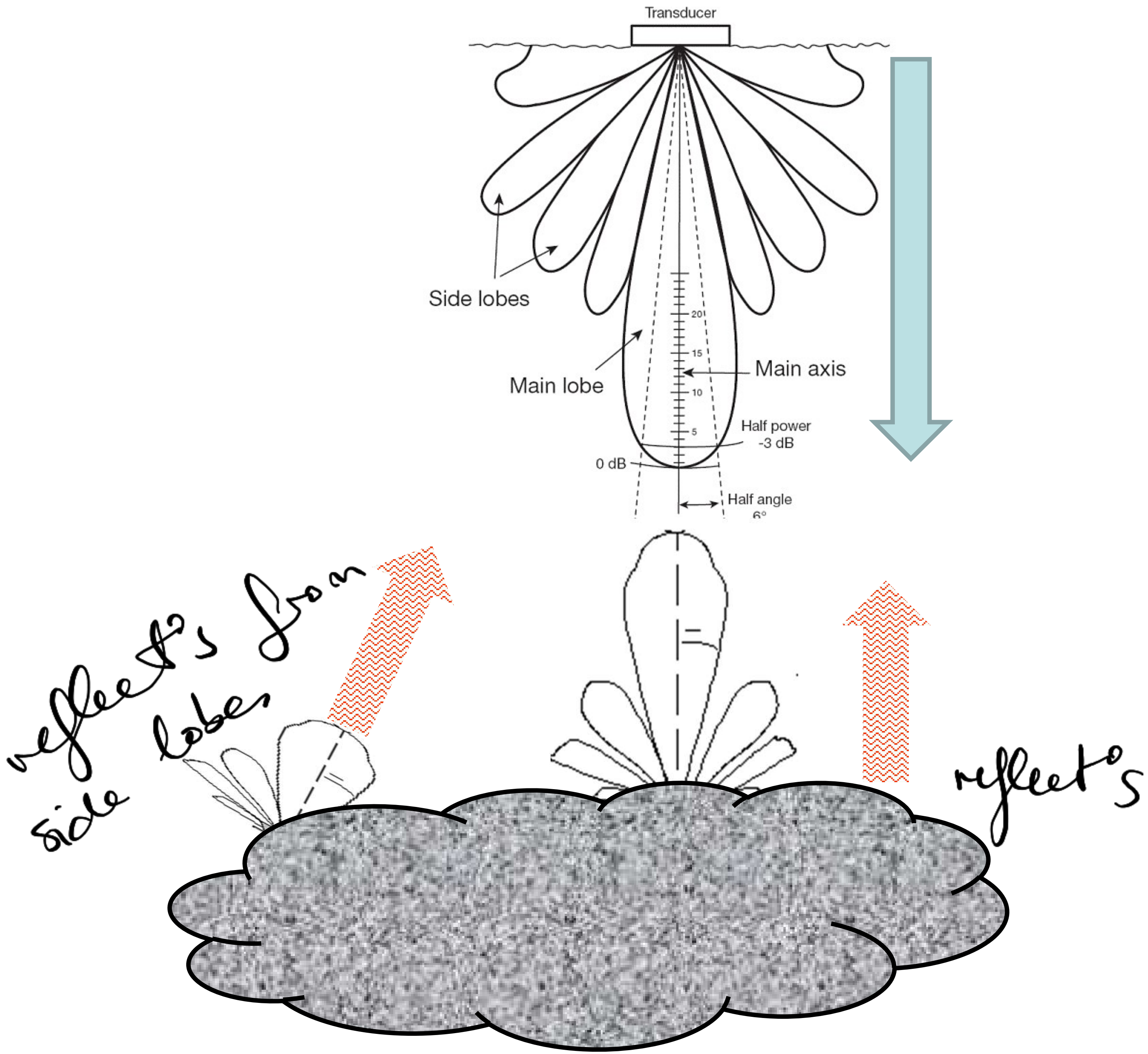
Signals need to have small sidelobes

Need to deconvolve raw signal with beam pattern to get real image



Beam widths are important for radio communication and for imaging

They constrain where the data comes from and how it can be interpreted …



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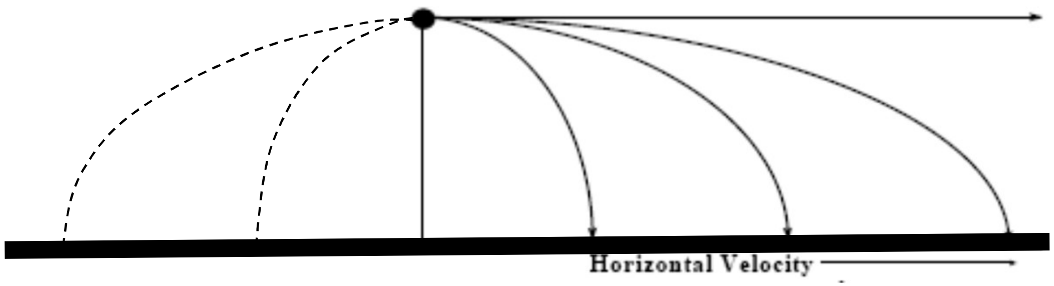
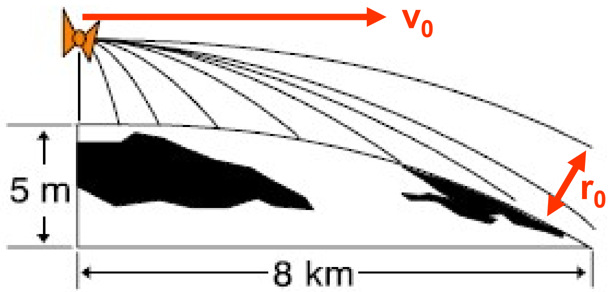
3.2. Orbital Mechanics

After launch, a satellite reaching speed v_0 and left to itself will fall back.
How far it falls will depend on v_0:





(numerical values correspond to Earth's curvature)

The first "escape velocity" v_1 is that needed to lift the satellite in low circular orbit:

On this circular orbit, of radius r_0, the amplitude of the acceleration is $\frac{v_1^2}{r_0}$

The satellite, of mass *m*, experiences gravity: $G\frac{mM_{Earth}}{r_0^2}$

Therefore: $G\frac{mM_{Earth}}{r_0^2} = m\frac{v_1^2}{r_0}$ gravity = mass x centripetal acceleration

$$\boxed{v_1 = \sqrt{\frac{GM_{Earth}}{r_0}}}$$

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Example:

M_{Earth} = 5.98 x 10^{24} kg

130 km orbit + Earth radius (6,370 km): r_0 = 6,500 km

The resulting velocity is: $v_1 = 7.83\ \mathrm{km/s}$

But this does not account for the Earth's rotation …

Let us note *u* the velocity of the launch point at the surface of the Earth.

It is maximum at the Equator:

$$u_{Max} = \omega\, r = \frac{2\pi}{24 \times 3600} \times 6.5 \times 10^6 = 0.47\ \mathrm{km/s}$$

The new speed v_1' is smaller if all vectors are colinear and in the same direction:

$v_1' = v_1 - u$

For this 130-km orbit, v_1' = 7.36 km/s

The initial velocity should be in the direction of *u*, i.e. Eastwards.

The launch site should be as close to the Equator as possible.

The escape velocity v_2 allows the satellite to escape Earth's attraction.

The total energy of the satellite is: $$E = \frac{1}{2} m v^2 - G \frac{M_{Earth} m}{r}$$

Moving away from Earth: $r \to +\infty$ (the 2nd term reduces to 0)

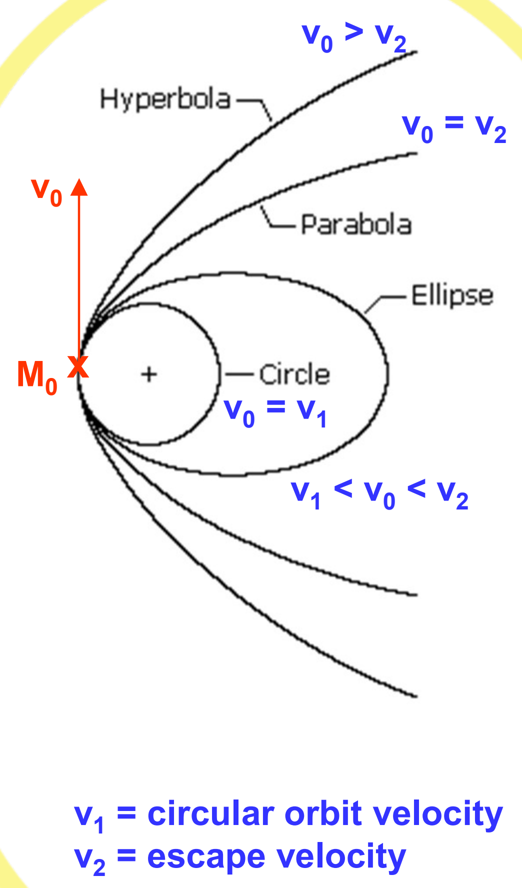
At launch, we must have:

$$E = \frac{1}{2} m v_0^{\,2} - G \frac{M_{Earth} m}{r_0} \geq 0 \Leftrightarrow v_0^{\,2} \geq \frac{2 G M_{Earth}}{r_0}$$

The minimal escape velocity is therefore:

$$\boxed{v_2 = \sqrt{\frac{2 G M_{Earth}}{r_0}}}$$

For Earth: $v_2 \cong 11$ km/s

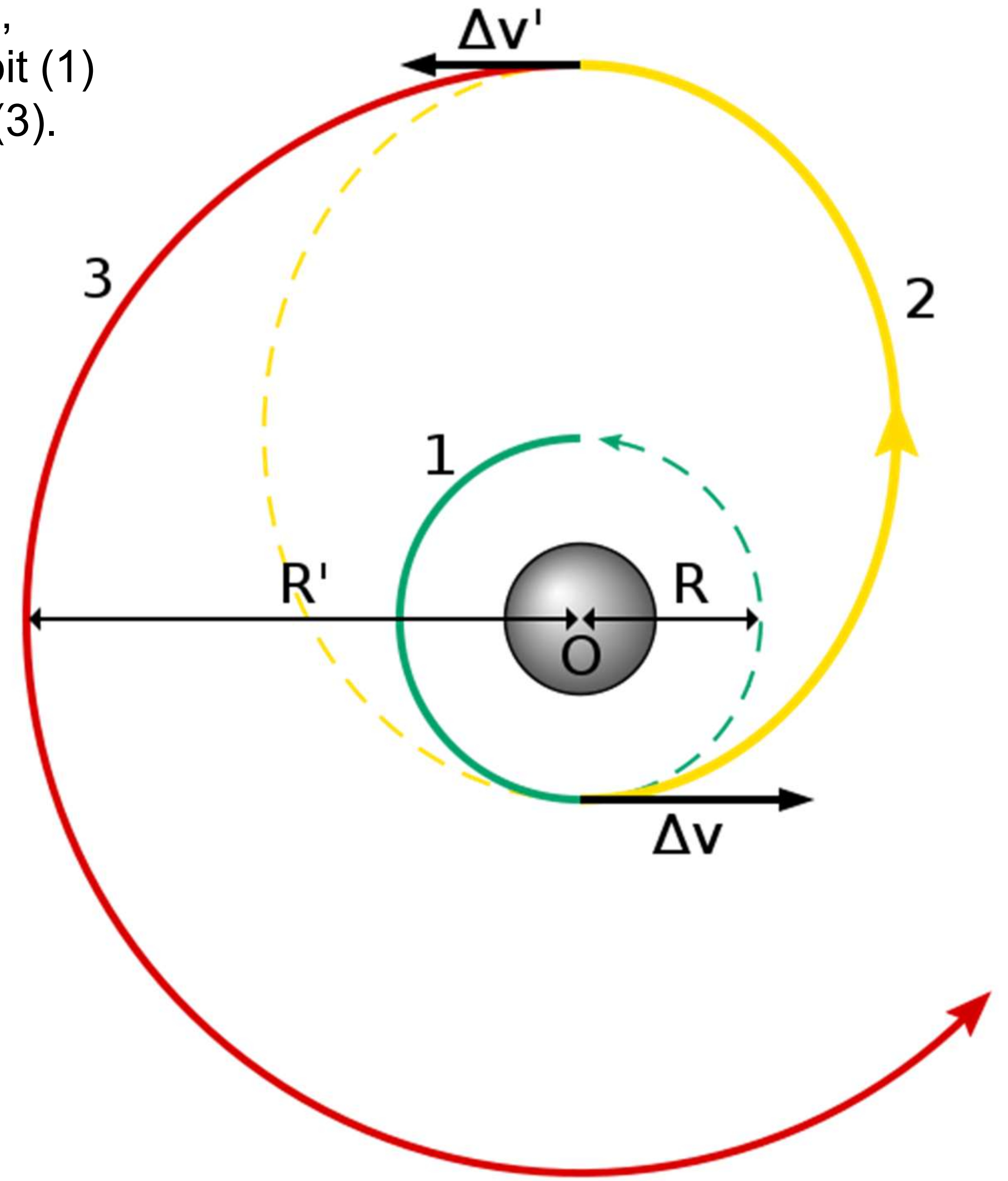


Changing Orbits

Hohmann transfer orbit: part of elliptic orbit, between initial orbit (1) and desired orbit (3).

Transfer (2): changing velocity/direction by firing thruster(s) at beginning and end (to make new orbit circular).

Used to move between orbits or for orbit insertion



Requires delta-v (calculated from kinetic and potential energies):

Changing Orbits

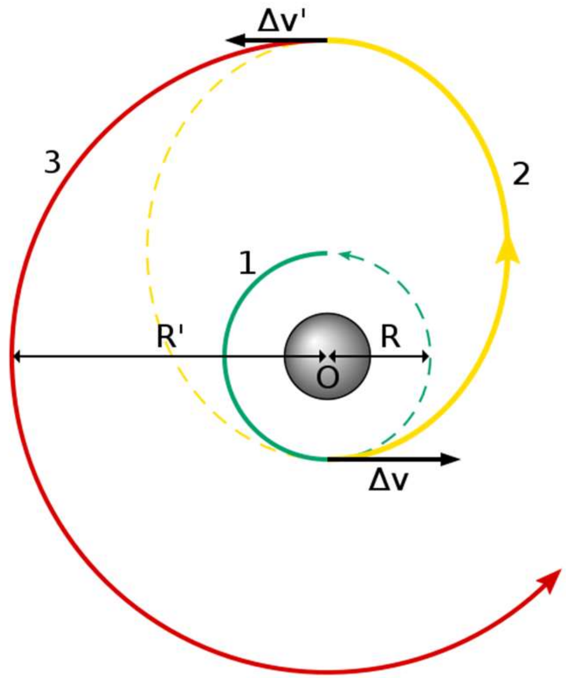
Requires delta-v (calculated from kinetic and potential energies):

At stage (1):

$$\Delta v = \sqrt{\frac{G M_{planet}}{r_1}} \times \left(\sqrt{\frac{2 r_2}{r_1 + r_2}} - 1 \right)$$

At stage (2):

$$\Delta v' = \sqrt{\frac{G M_{planet}}{r_2}} \times \left(1 - \sqrt{\frac{2 r_1}{r_1 + r_2}} \right)$$

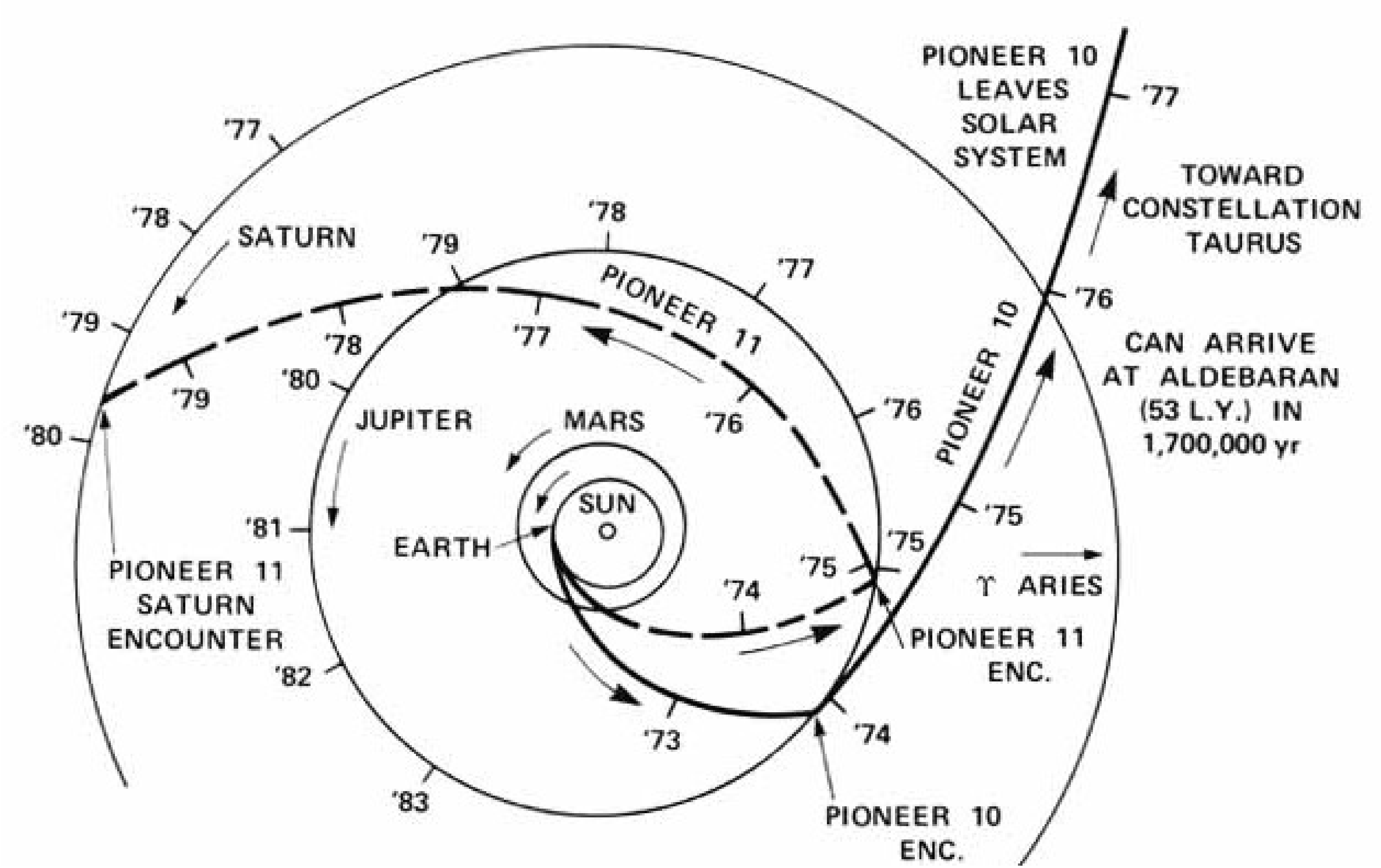


Using Kepler's 3rd law, the time taken for orbit transfer is:

$$t_H = \pi \sqrt{\frac{(r_1 + r_2)^3}{8 G M_{planet}}}$$

(you don't need to remember these equations – if you are asked to use them, they will be provided)

Example: leaving the Solar System (Pioneer 10), using “gravity assist”



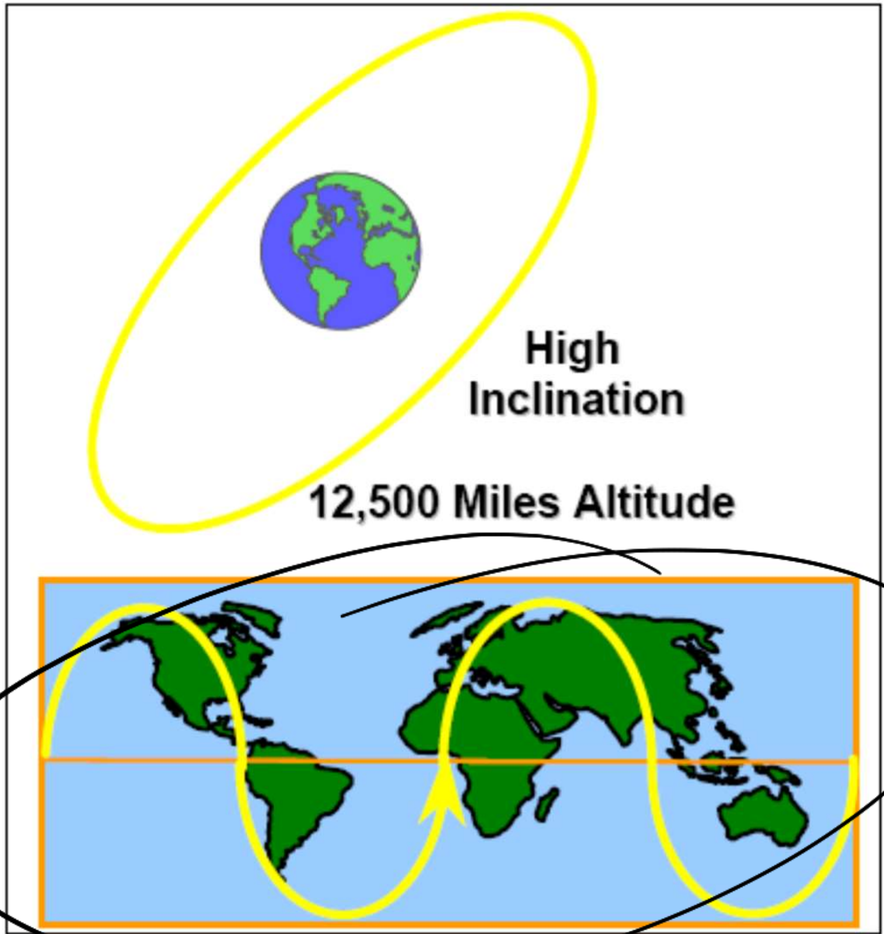
Need to use planetary configurations in the best way

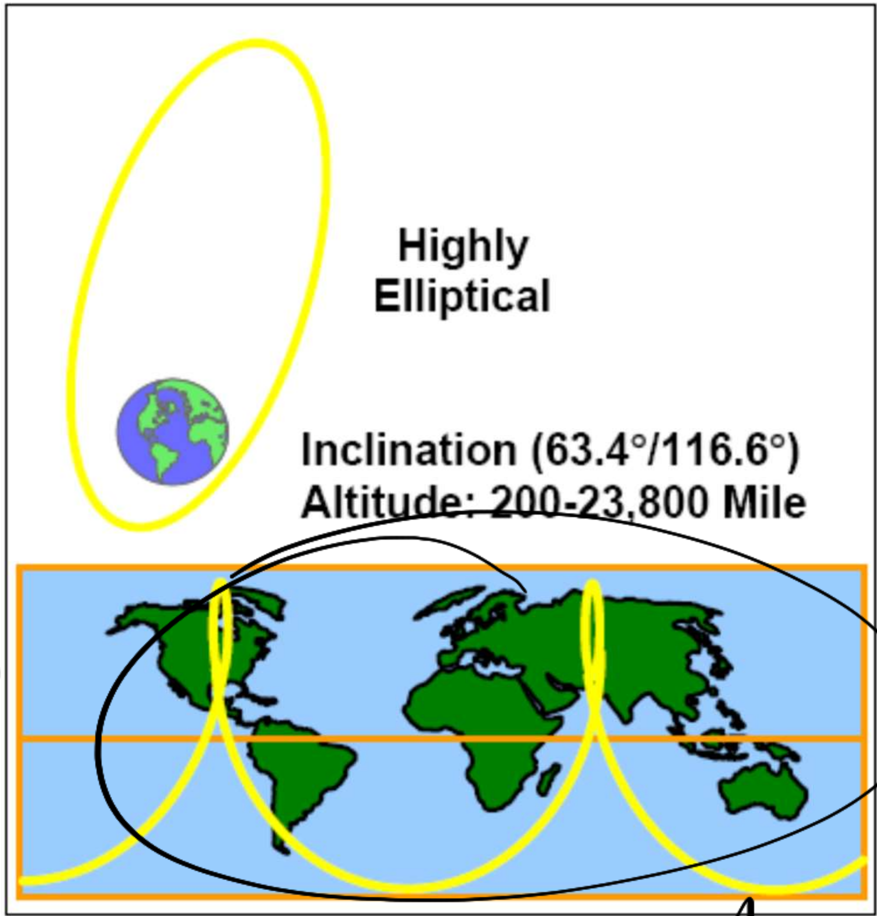
⇒ concept of “launch window”

Planetary Orbits

Insertion into orbit: choice of “right” parameters enables different mapping patterns

Depends on planet rotation (if any) and distance/eccentricity of orbit.





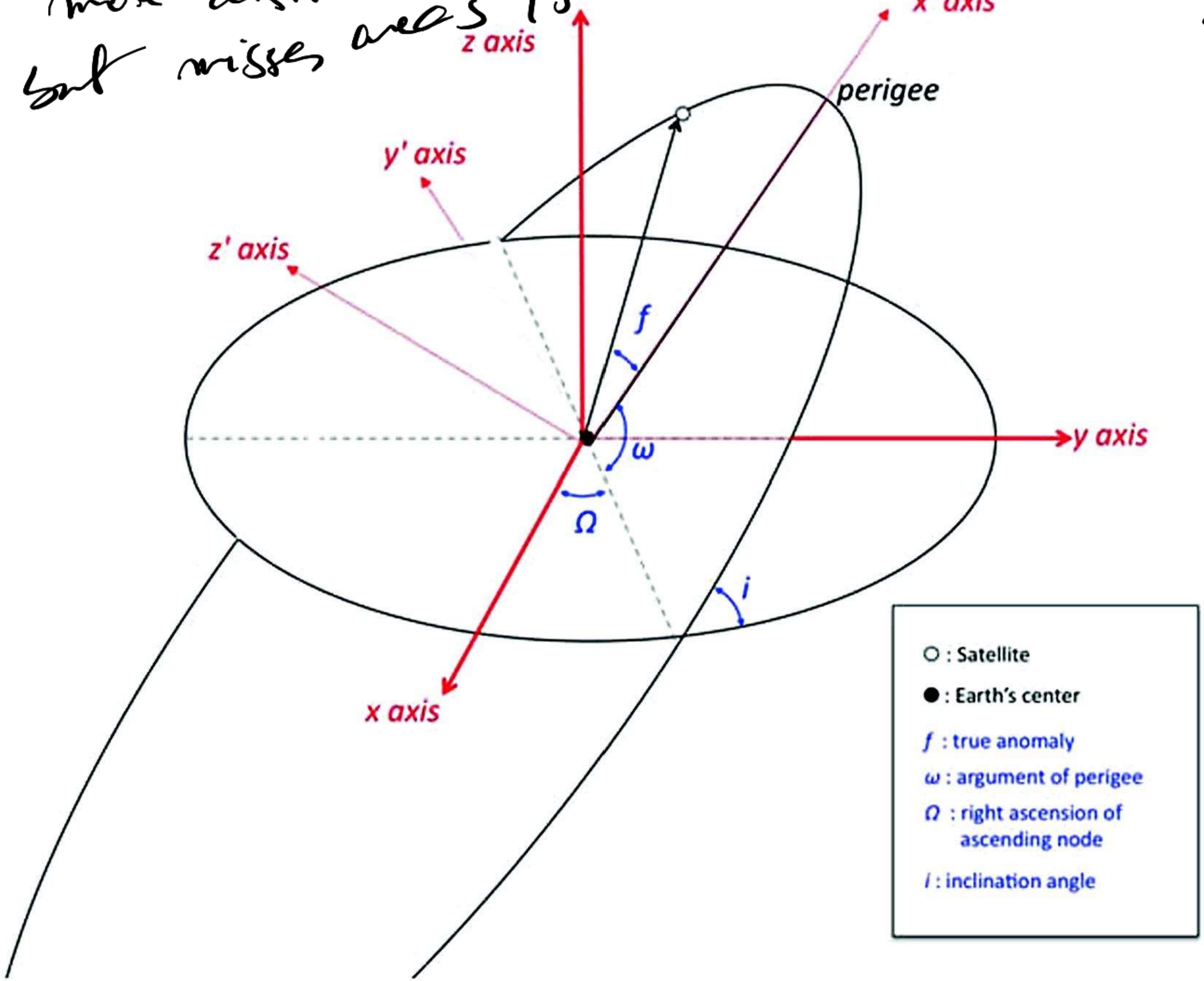
From US Air Force document, space.au.af.mil (2010)

Orbit inclination relative to the equatorial plane (close to ±90° for polar orbits)
Direction: prograde (rotates like the primary, e.g. East on Earth) or retrograde
Eccentricity: 0 (circular) to 1 (elliptical)

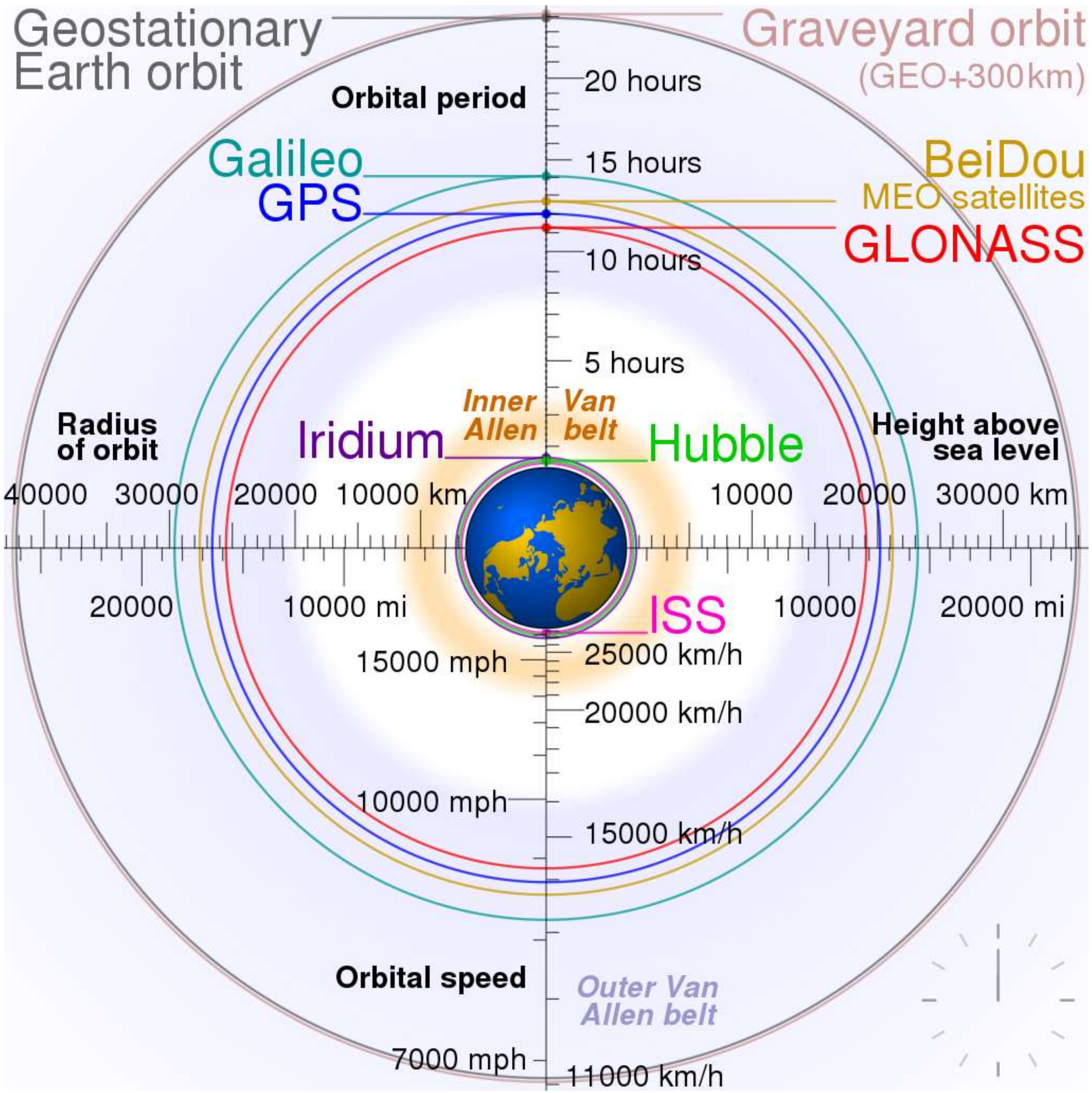
would give more

more distributed (so does the others are)
but misses areas

info about
the poles



From [Mesoscale Meteorological Modeling](#)
Roger A. PielkeSr., in [International Geophysics](#), 2013



https://en.wikipedia.org/wiki/List_of_orbits#/media/File:Comparison_satellite_navigation_orbits.svg

Different orbits for different parts of the mission

Example: Psyche (2023 – 2030) - first asteroid made fully of metal

Could be used to fuel the space economy

Approach: (100 days) Dangers & gravity relat° with Earth

- Optical navigation and instrument calibration, hazard assessment
- Psyche spin axis and rotation period determination

Orbit A: Characterization: 40 days (29 orbits)

- Nadir mapping for preliminary shape determination, global color mapping, magnetic field detection, and gravity science

Orbit B: Topography: 50 days (90 orbits)

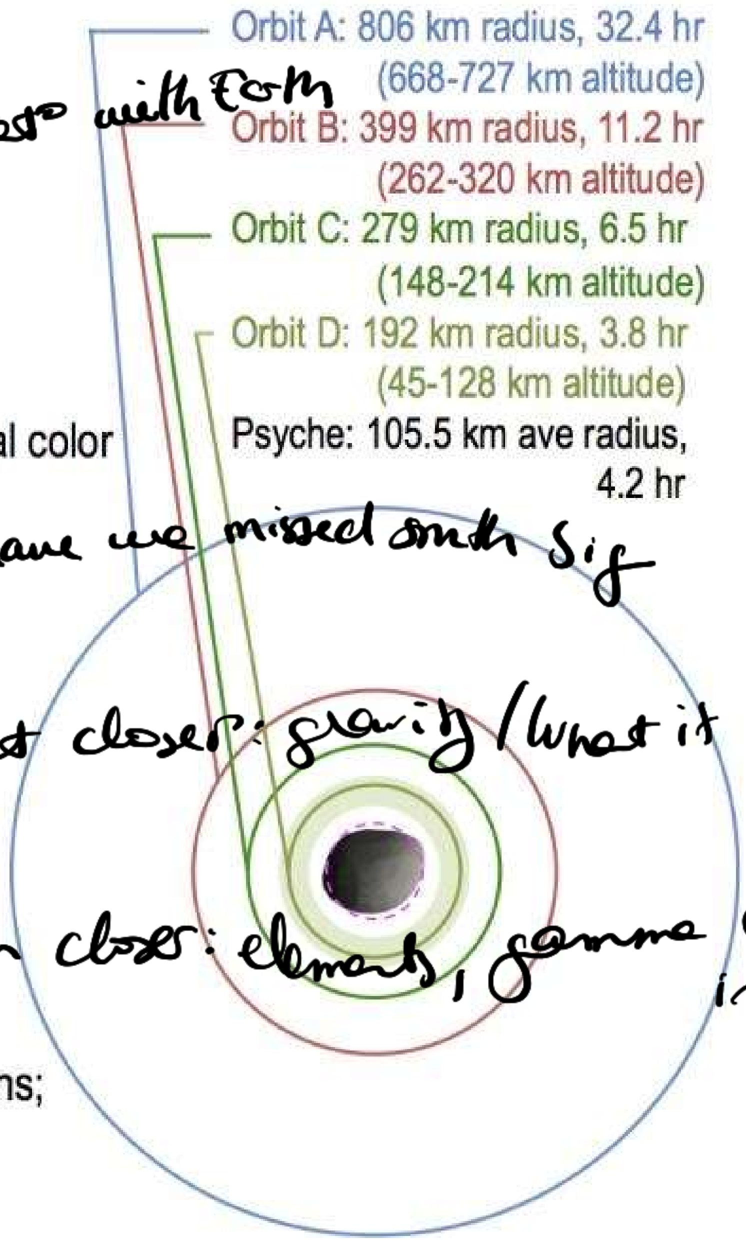
- Nadir and 4 off-nadir imaging cycles for topography
- Global color maps, gravity science, and preliminary magnetic field characterization

Orbit C: Integrated Science: 100 days (369 orbits)

- Gravity science, magnetic field mapping, crater age determination, and preliminary neutron mapping

Orbit D: Elemental Mapping: 70 days (442 orbits)

- Map elemental composition with gamma rays and neutrons; improved imaging, gravity, and magnetic field mapping

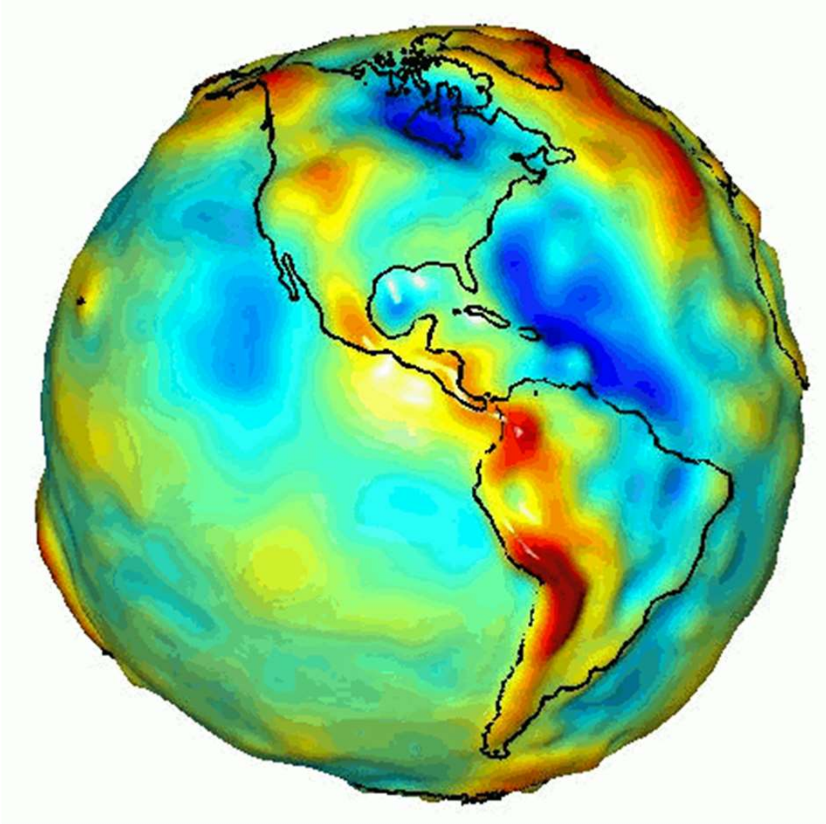


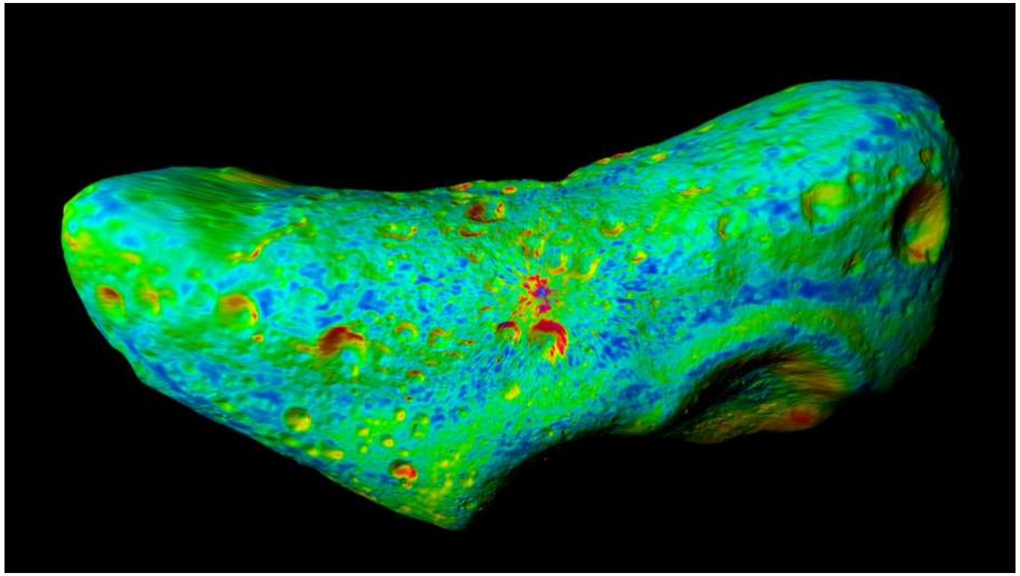
Have we missed smth sig

↑ get closer: gravity / what it is made of

even closer: elements, gamma rays interact°

Even large, spherical bodies can show strong gravity variations





Asteroid Eros

Directly affects orbits (ranges, stability)

1 Gal = 0.01 m s^{-2}

big mountains have great roots
& strong gravity

Orbital mechanics should also consider changes in rotation period (if any)

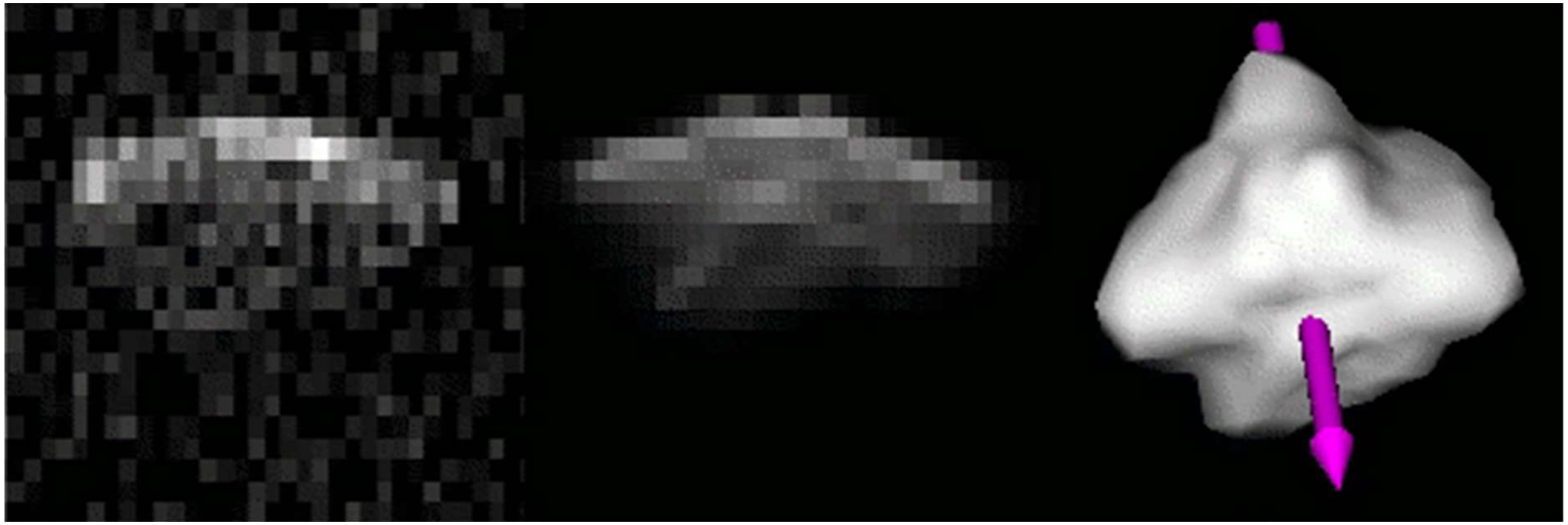
For small bodies: Yarkovsky effect becomes noticeable

Solar radiation on small body carries off momentum as well as heat

(theorised in 19th century, validated 21st century)

Spin caused by sun radiation

Also called YORP effect (Yarkovsky–O'Keefe–Radzievskii–Paddack)



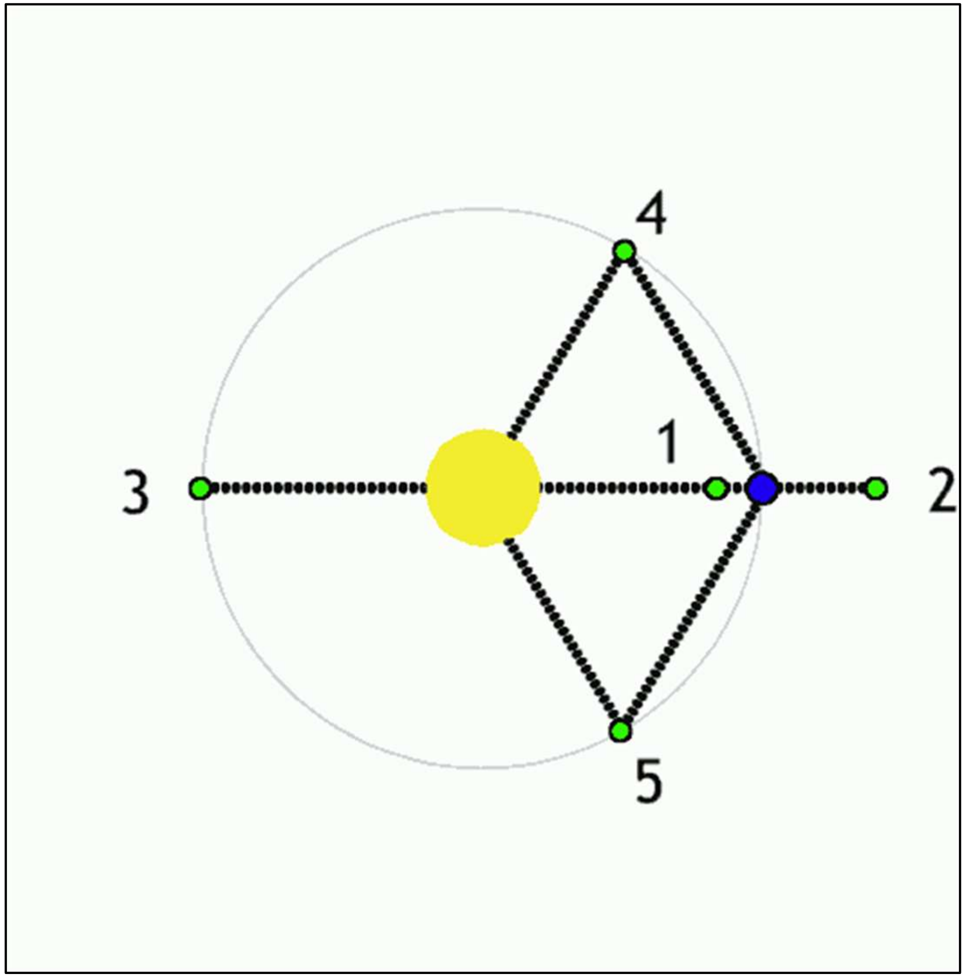
happens with satellites too

solar panels start acting as sails

Radar image and 3D model of asteroid 54509 YORP (formerly 2000 PH)

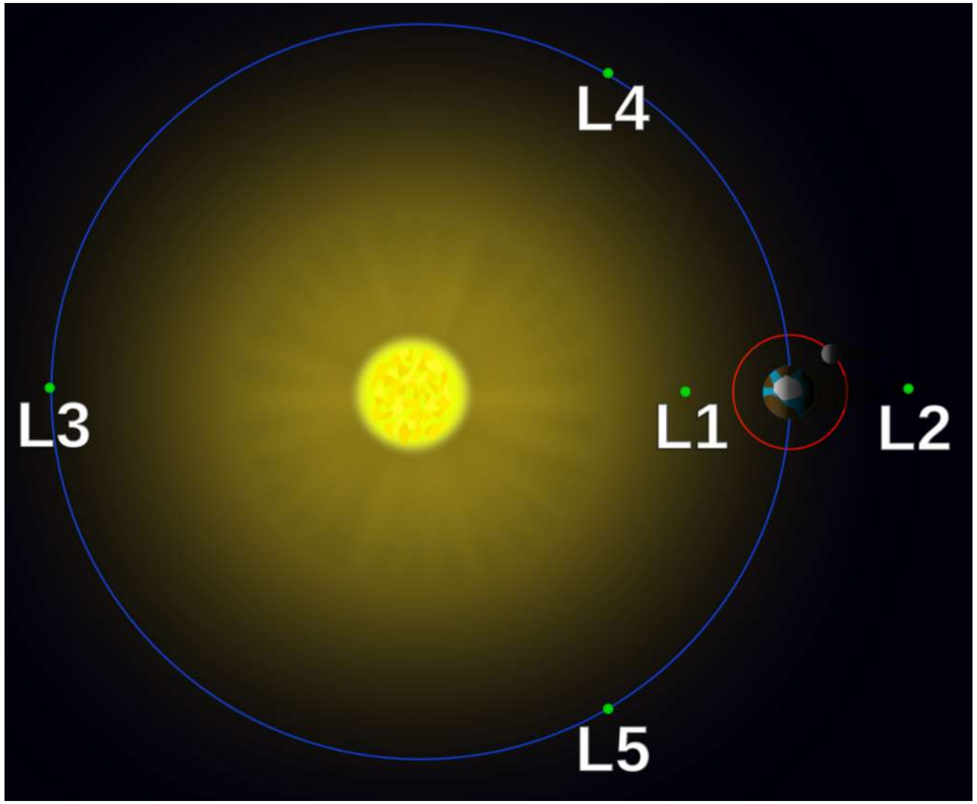
Orbital mechanics can also combine the gravity from several objects

Satellites can be put in equilibrium between two bodies (like the Earth and the Sun)
These are the **Lagrange points** (also called L-points or libration points)



Lagrange point - Wikipedia

points where sun & earth
gravity counteract each
other
⇒
stay in place (without fuel)
useful for sun observat°
or
telescopes



Lagrange point - Wikipedia

Lagrange points are good for satellites (need for “halo orbits” around $L_{1\text{-}3}$).
They are also good for natural objects.

In the Sun-Earth system:

L_1 (1.5×10^6 km from Earth, 0.01 AU)
Solar and Heliospheric Observatory (SOHO)
Other solar observation satellites

L_2 (same as L_1)
Herschel Space Telescope (2009-2013)
James Webb Space Telescope (tbc)
Good for stable temperature (50 K)

L_3
Unstable point but space-weather satellites planned (halo orbit, 7-day warning of solar eruptions)

L_4 and L_5
Interplanetary dust, “trojan” asteroid

L_1, L_2

Closer to the Earth: need to account for gravitational field of the Moon recently seen that it doesn't work that well in other sids of the sls system

First calculated by É. Roche in 1848

Roche limit: disintegration of a small body *m* orbiting a much heavier body *M* of radius *R*

(tidal forces)

inner gravity not enough to counteract larger body gravitational pull

$$d_{Roche} = R\left(2\frac{M}{m}\right)^{\frac{1}{3}}$$

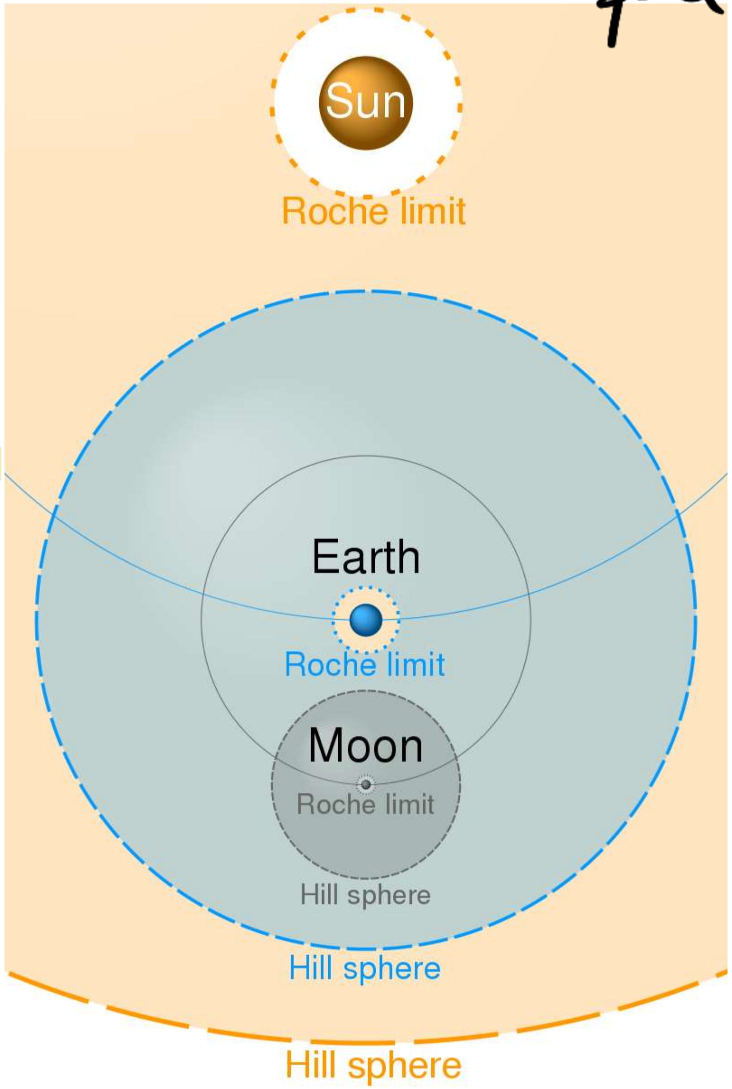
Roche limit = where things are expected to disintegrate

Hill sphere: region in which *M's* gravity dominates

$$d_{Hill} = \frac{d_{Roche}}{\sqrt[3]{\frac{3\,M}{m}}}$$

big body gravity dominates (sun)

Simplified: $$d_{Hill} = R \times \sqrt[3]{\frac{2}{3}}$$



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