Tides are Important

Roche Limit -

The closer a moon is to a planet, the stronger the tidal forces it will feel (I.e. the stronger the differential gravity will be between the surface nearest the planet and that felt at the center of the moon). Within the Roche limit the differential gravity felt by the moon (or planet in the case of orbiting the Sun) will be stronger than its self-gravity and the object will be torn apart.

Examples include:

Formation of rings around large planets at small radial distances

Tearing apart of comets that pass close to stars/large planets**

Massive gas giants orbiting close to their stars.

Tides are Important

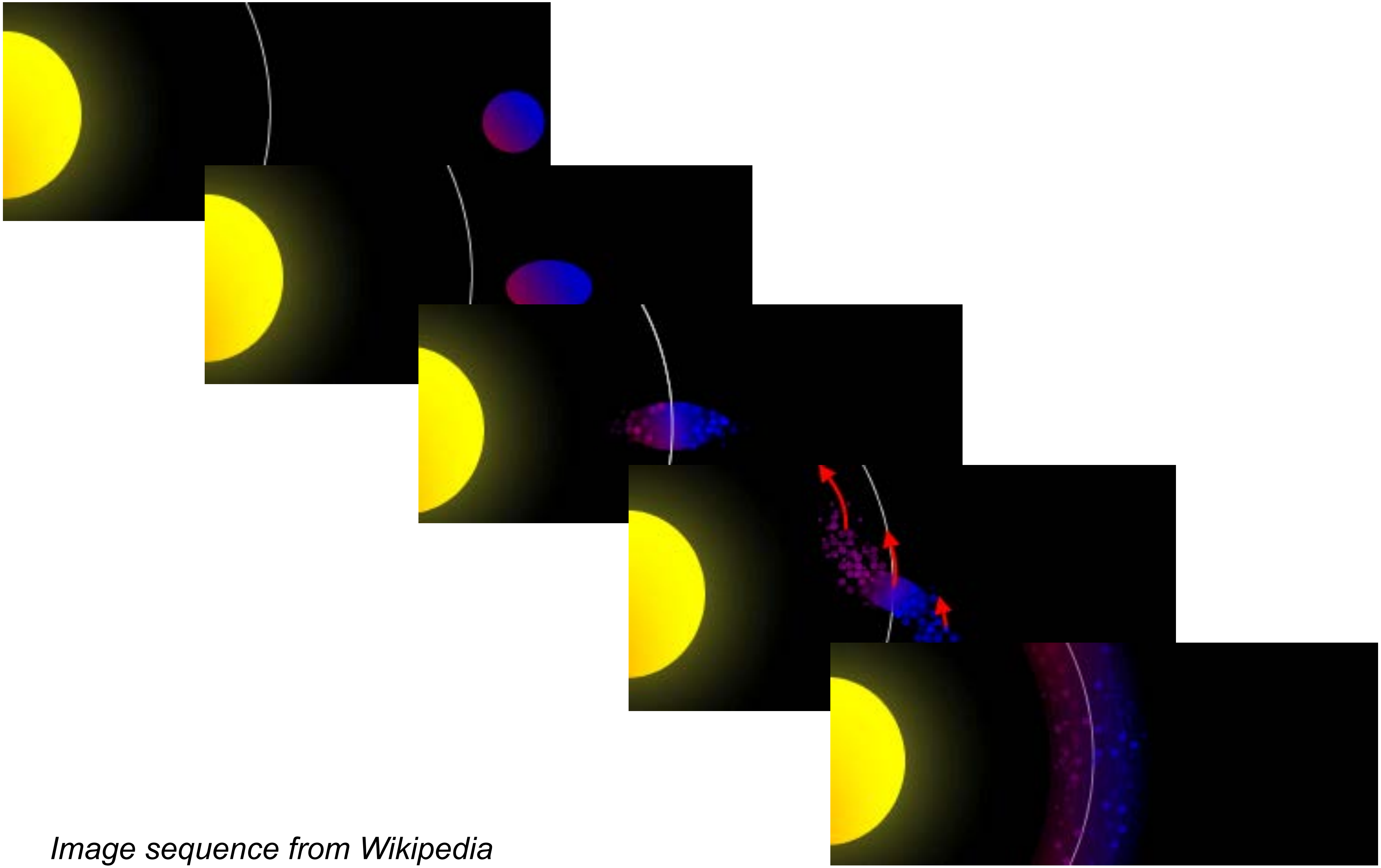
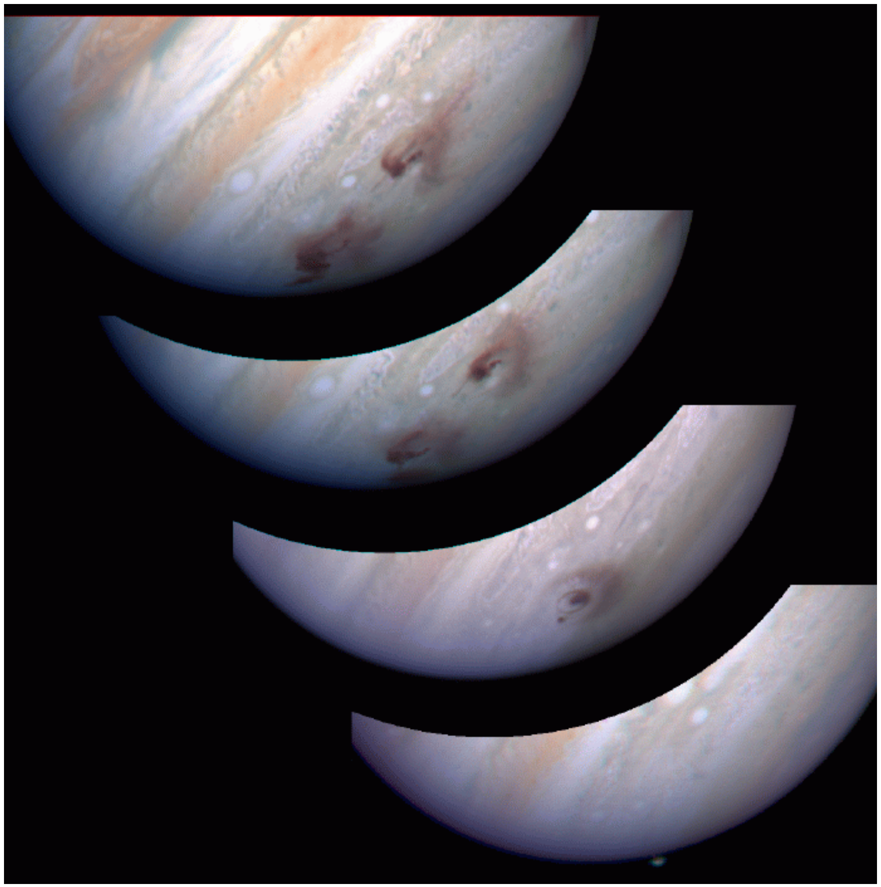


Image sequence from Wikipedia

Tides are Important

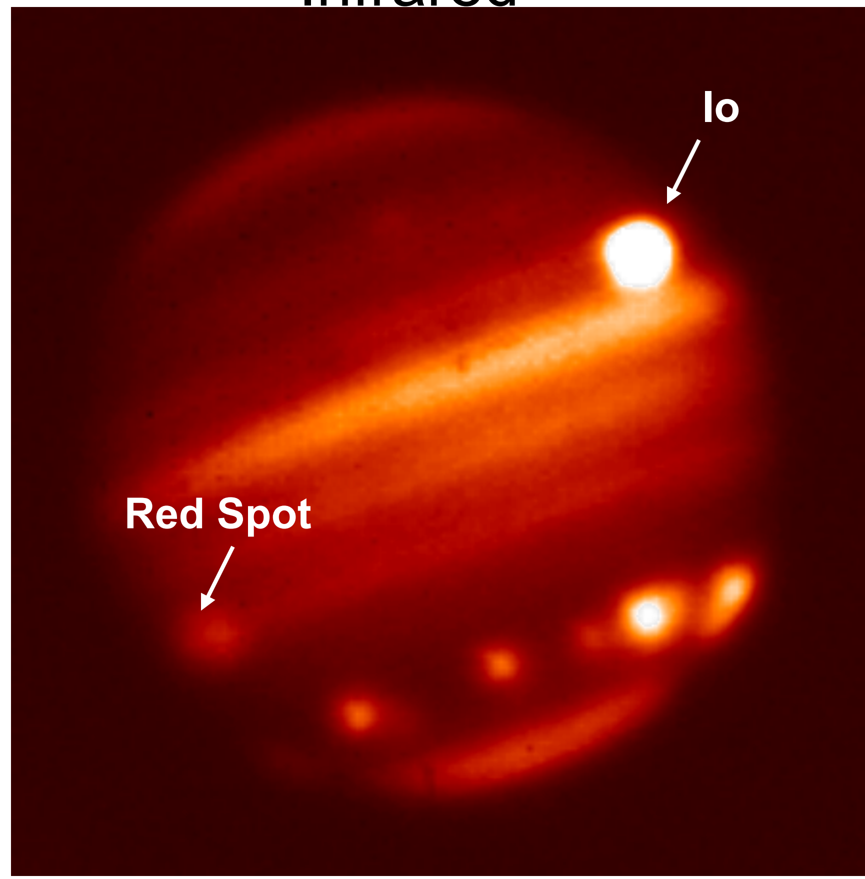
Comet Shoemaker-Levy 9 Impact of Jupiter

time



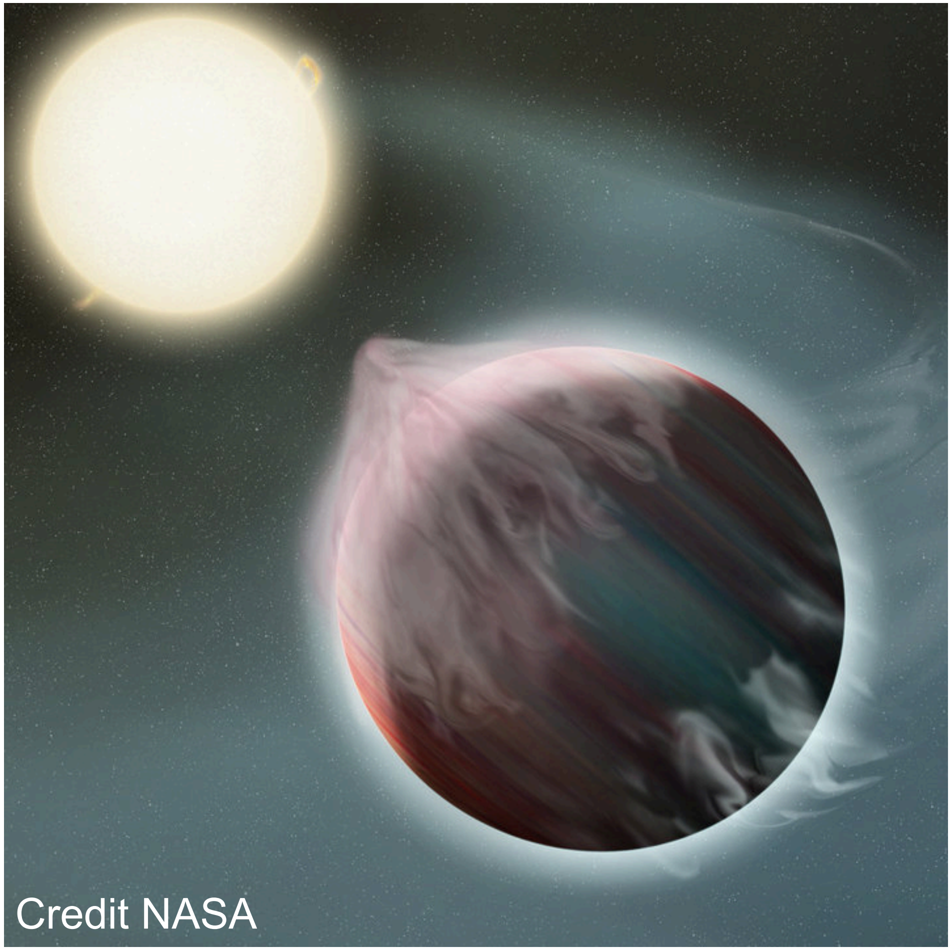
Courtesy HST Comet Science Team

Infrared



Courtesy NASA IRTF Comet Science Team

Victims of Tidal Forces

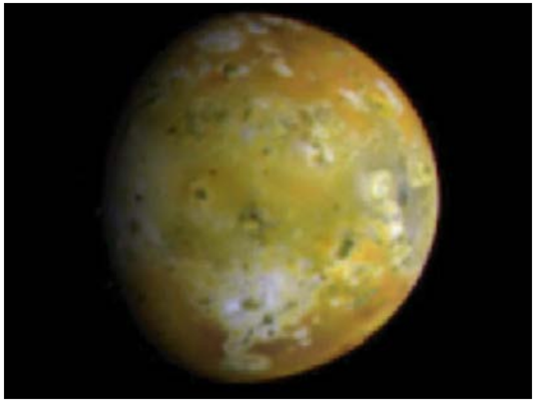
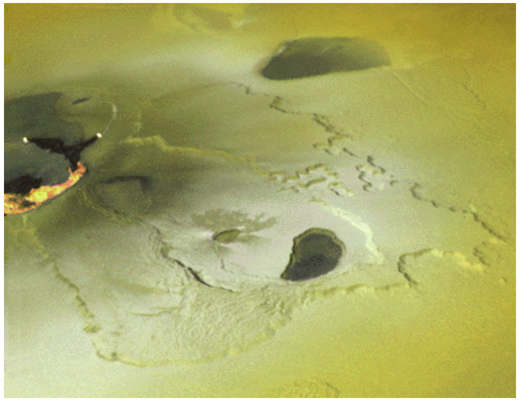
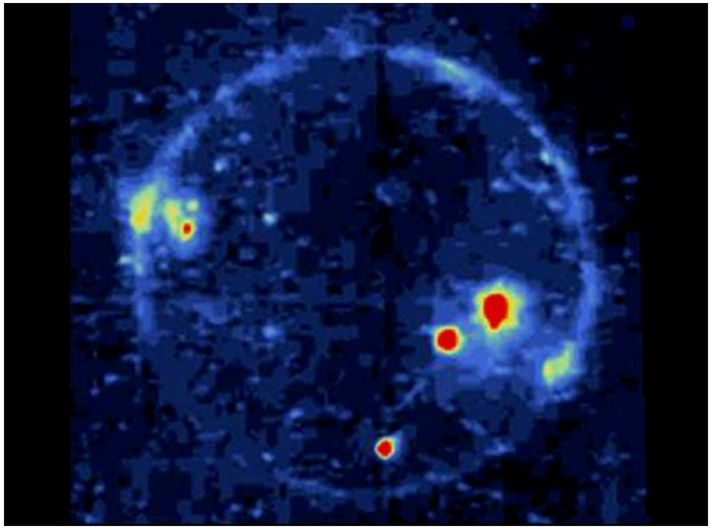


‘Hot Jupiters’ may be more difficult to find in more mature stellar systems due to the gravity of their nearby stars. -- ApJ 2010

Tidal Heating

Temporal variations in tidal forces can also lead to internal heating of a planet or moon. This occurs due to the fact that planets are not perfectly rigid or perfectly fluid…

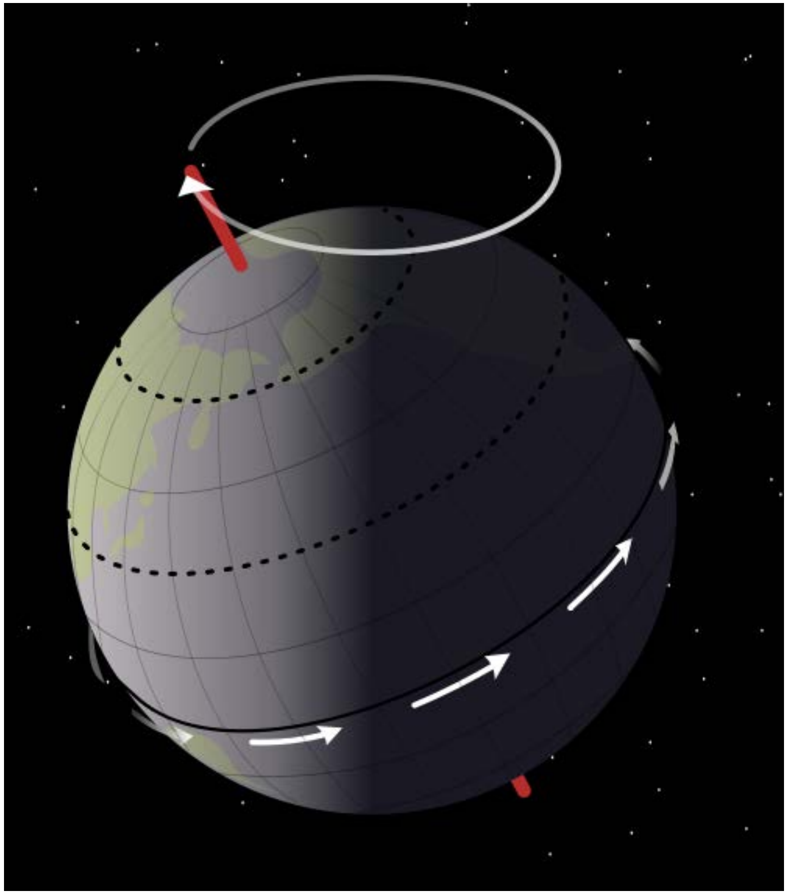
Thus tidal forces cause the object to change shape, but since the response is not perfect or instantaneous this leads to energy being dissipated as heat as the object changes shape.

Torque on Oblate Planets

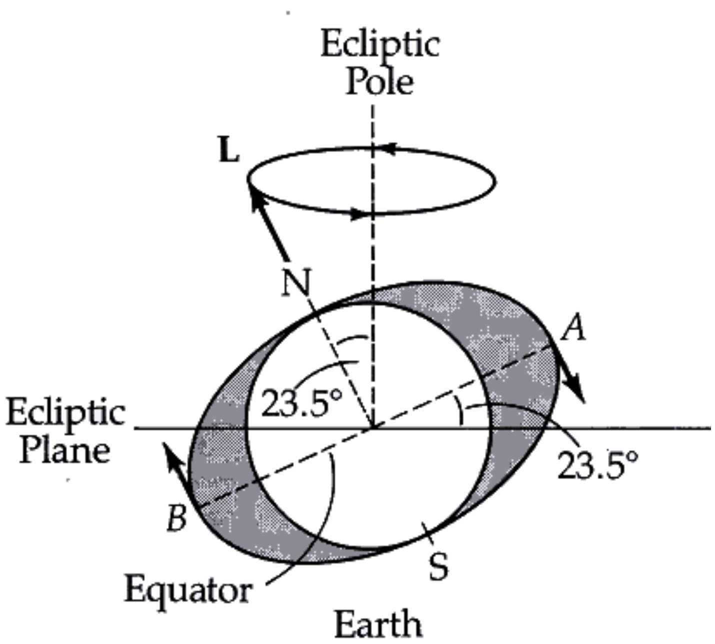
These forces are a result of nonspherical mass distribution. Solar torque on a given planet causes precession of the rotation axis, and can lead to a different length in orbital period and varied periodicity between the seasons (called the Milankovich Cycle).

Earth's obliquity is somewhat stabilized by our Moon.

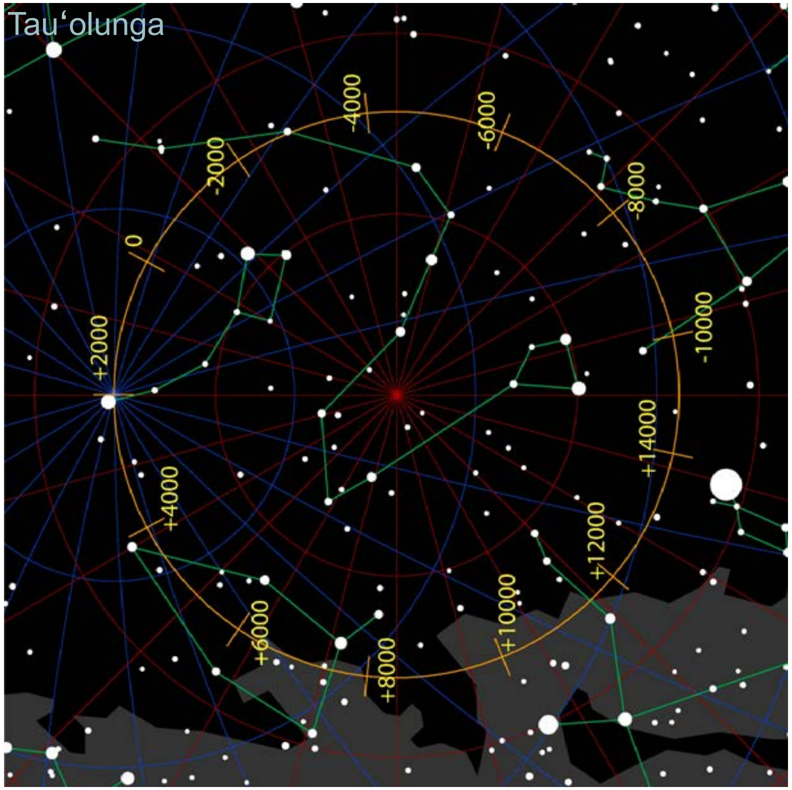


Torque on Oblate Planets

Generally the strongest torques on oblate planets come from the Sun. The period of Earth's rotational axis precession is ~26,000 years.



Figures modified from UOregon



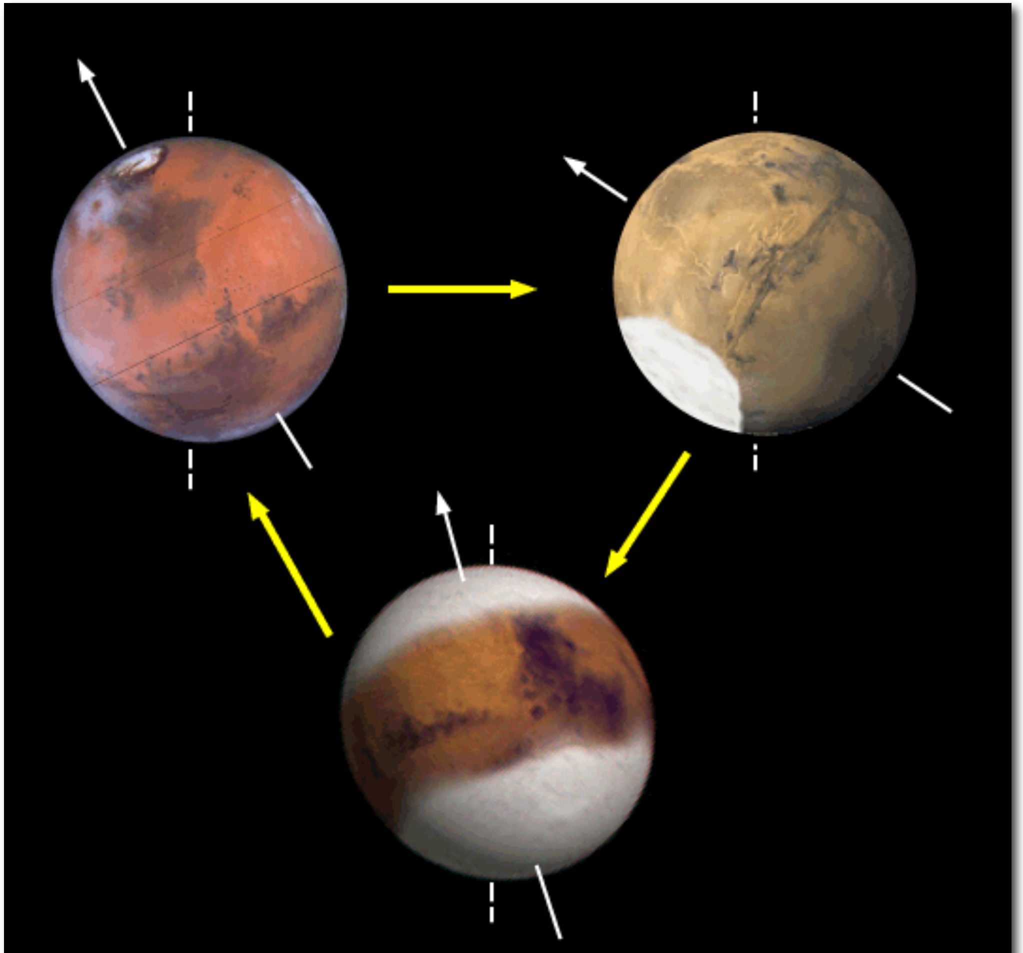
Migration of the 'North' star

Obliquity?

Defined as the angle of the rotation axis. Planets like Neptune and Uranus have significant obliquity, with Mars' obliquity ranging widely over solar system timescales. Without the stabilizing moon, we could potentially experience much greater and unpredictable seasonal variability (Mars).

Consider the rapid change in seasons Mars would experience when it undergoes a > 60º obliquity change…

Mars Obliquity?

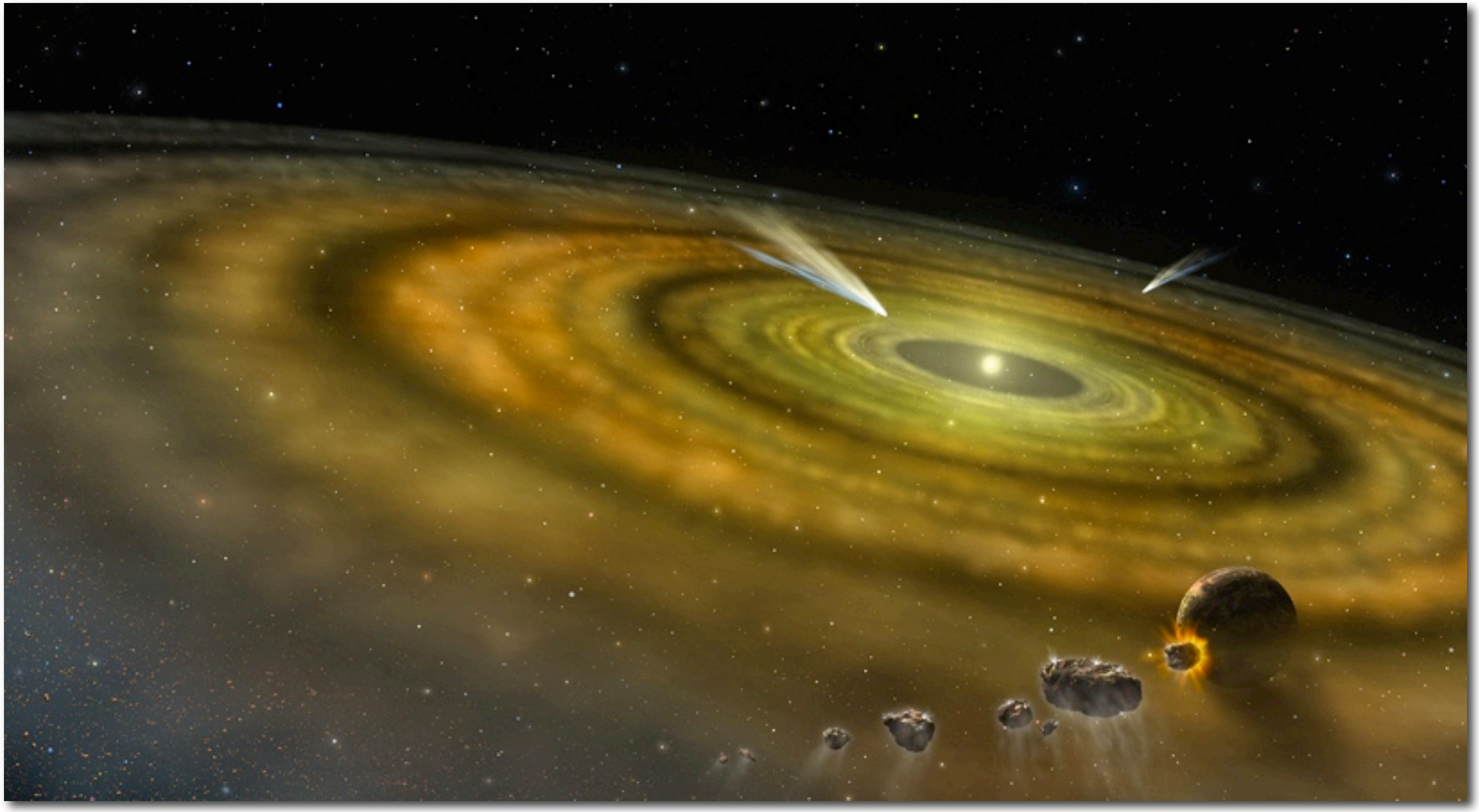


ASD/IMCCE-CNRS

Martian obliquity (25° today) has ranged up to 45° over tens of Ma, and varied between ~15 and 35° during the last 5 Ma, with a "periodicity" close to 120,000 years.

Recap of Dissipative Forces

Forces due to solar radiation, solar wind and gas drag can act to modify the orbit of smaller objects in the solar system.



NASA/FUSE/Lynette Cook

Recap of Dissipative Forces

Solar Radiation Effects:

- Radiation Pressure (μm)
- Poynting-Robertson Drag (cm)
- Yarkovsky Effect (m to 10 km)
- YORP Effect (up to 20 km)

Solar Wind Drag or Corpuscular Drag (< μm dust)

Gas Drag (Solar System formation, and extended atmosphere interactions with rings)

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Gas Drag (Solar System formation, and extended atmosphere interactions with rings)

The Curious Case of Iapetus

a.k.a. why even planetary surface geologists care about P-R drag

Leading hemisphere

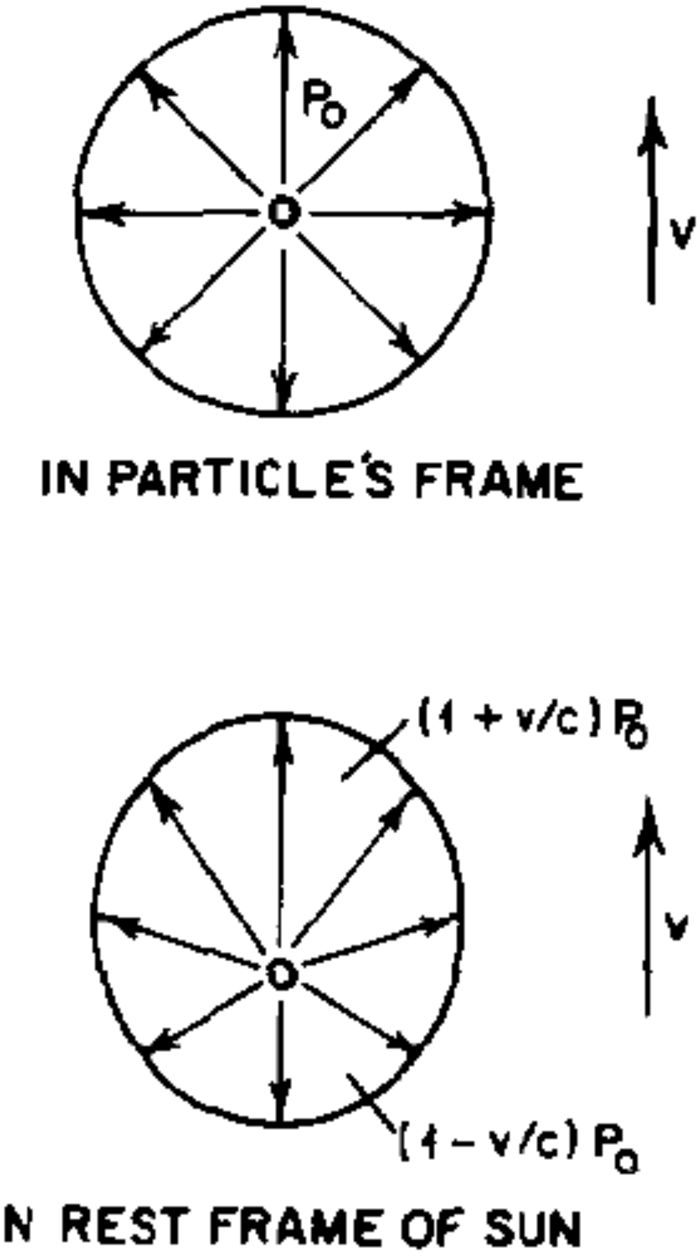
Trailing hemisphere

Poynting-Robertson Drag

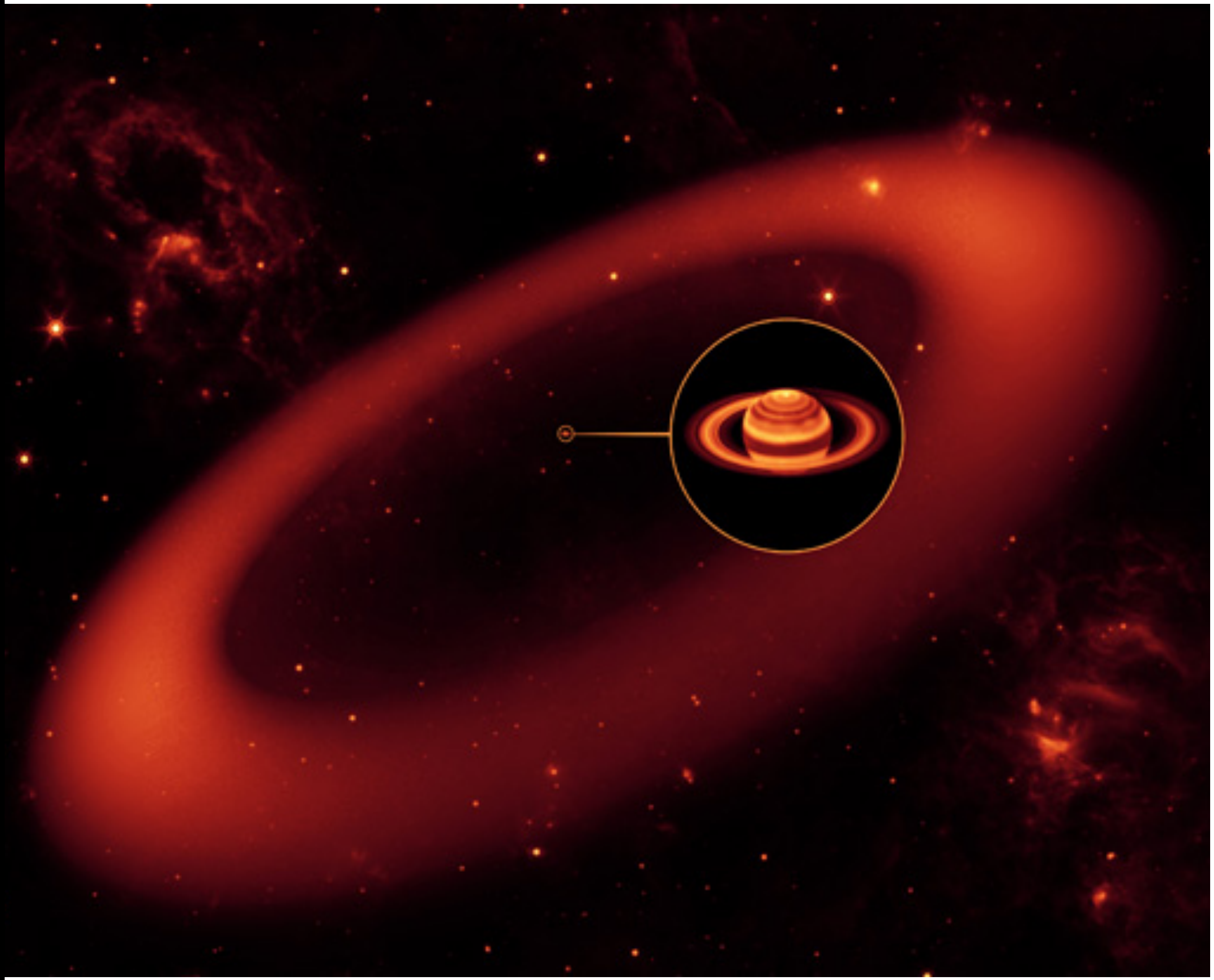
A Relativistic Effect

Gradual angular momentum loss leads to orbital decay over timescale

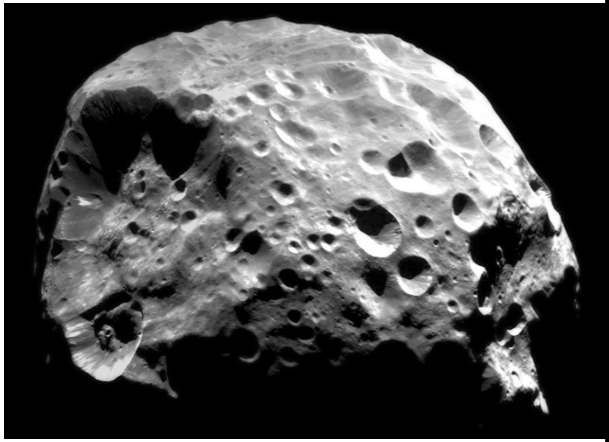
$$t_{PR} \approx 400 r_{AU}^2 / \beta$$



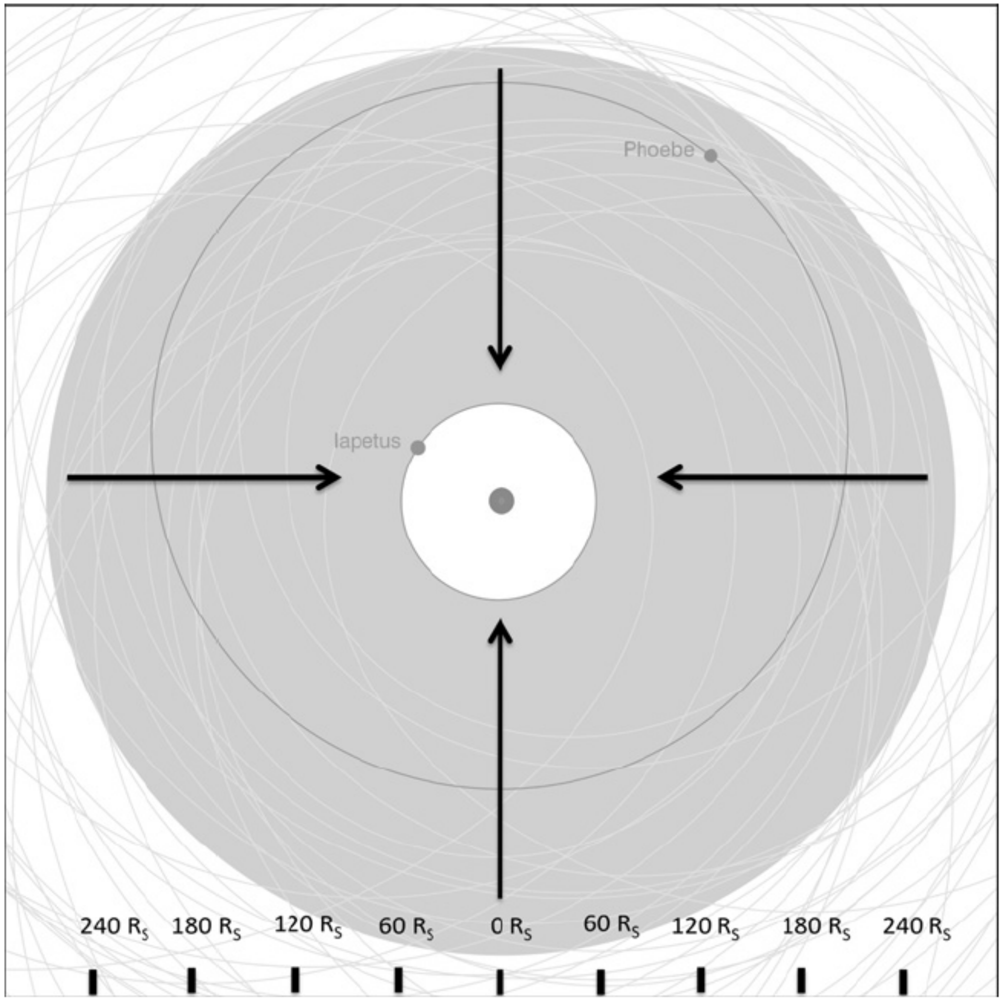
Source of Small Particles: The Phoebe Ring



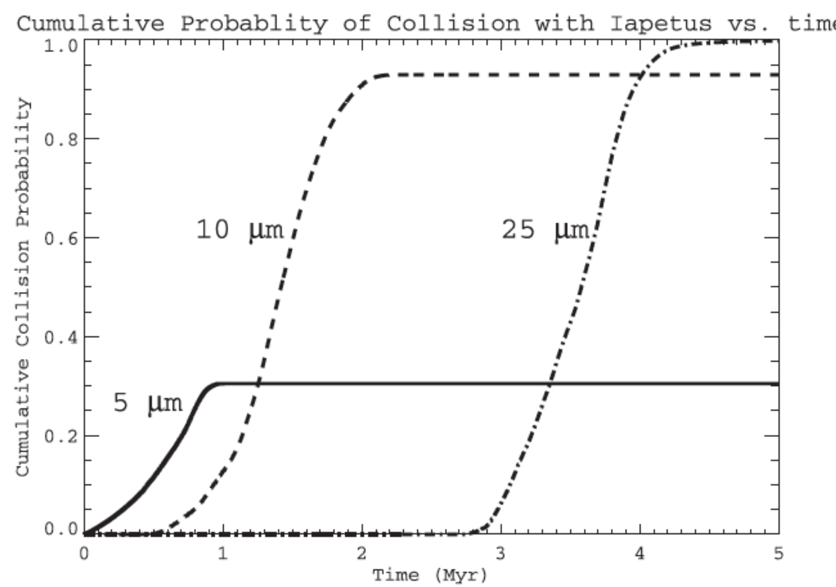
Phoebe is a dark satellite with a retrograde orbit



P-R Drag
for Phoebe ring grains



Tamayo et al. (2011)



Comets

Yarkovsky-like effects due to heterogeneous outgassing