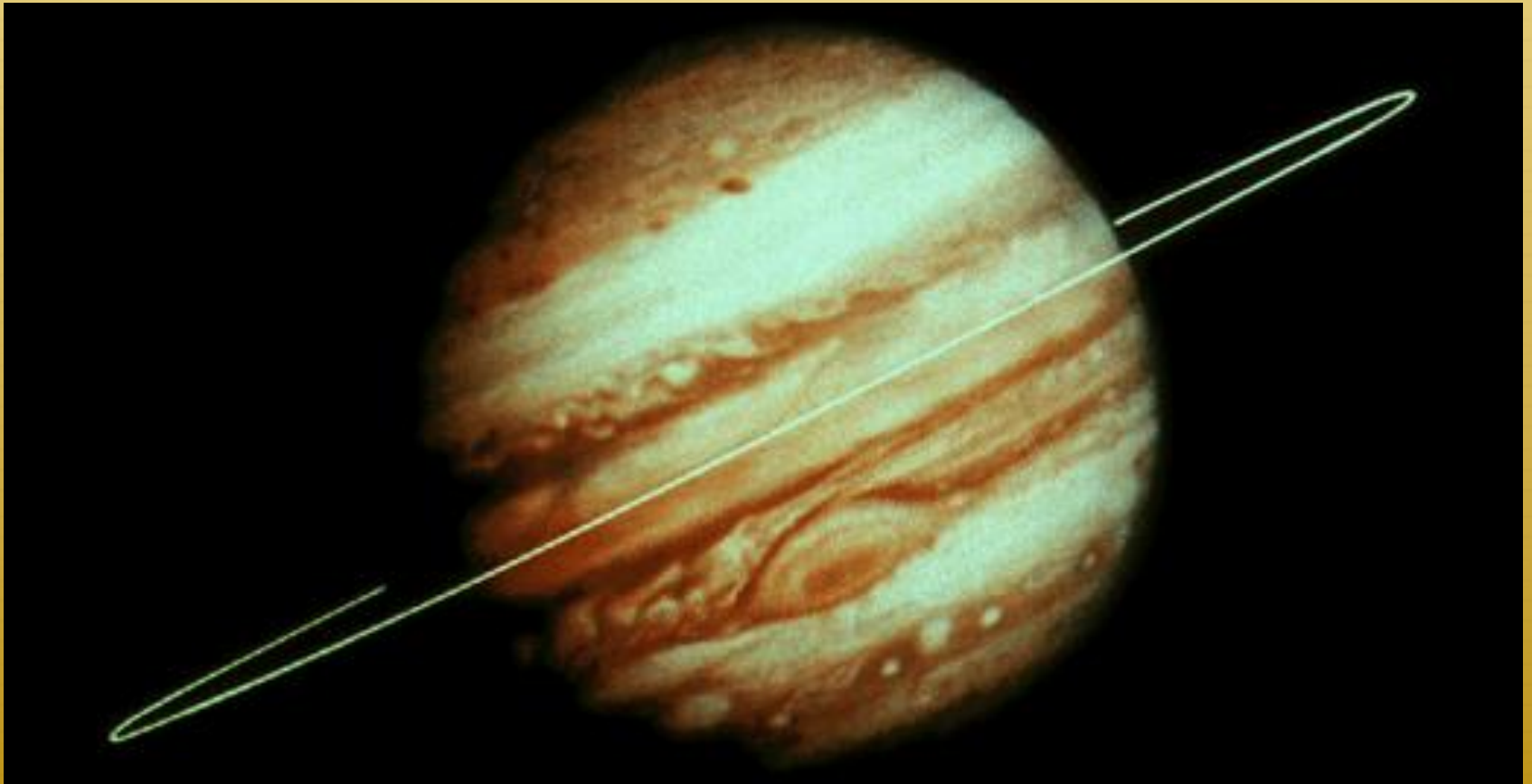
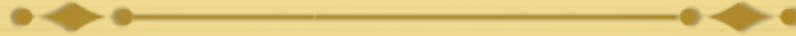




Rings and Inner Moons of Jupiter

Earth-450
April-22nd 2013
Sara Rastegar

Jovian Ring System



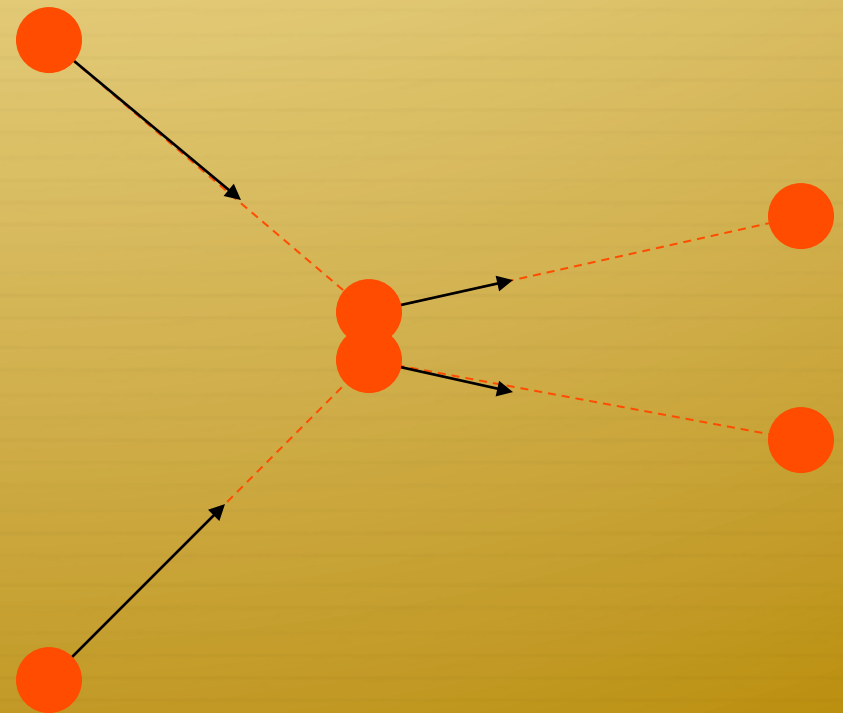
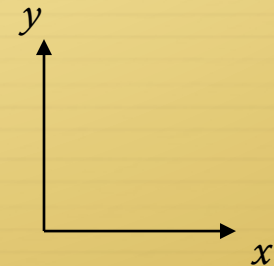
Why are the ring systems so thin?

Collisions of ring particles are **partially inelastic**.

Consider two particles orbiting
e.g. Saturn in orbits which are
slightly tilted with respect to
each other.

Collision reduces difference of
 y components, but has little
effect on x components

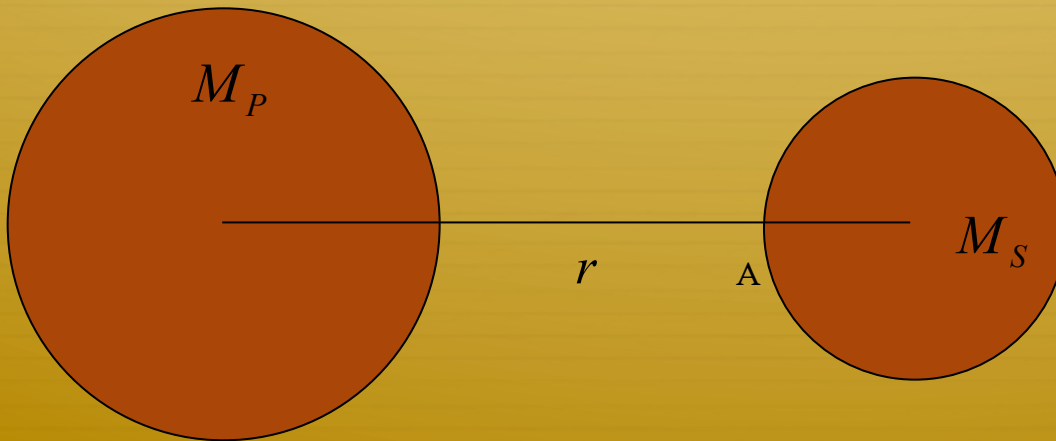
⇒ this thins out the disk of
ring particles



Formation of Ring System

The ring systems of the Jovian planets result from **tidal forces**. During planetary formation, these prevented any material that was too close to the planet clumping together to form moons. Also, any moons which later strayed too close to the planet would be **disrupted**.

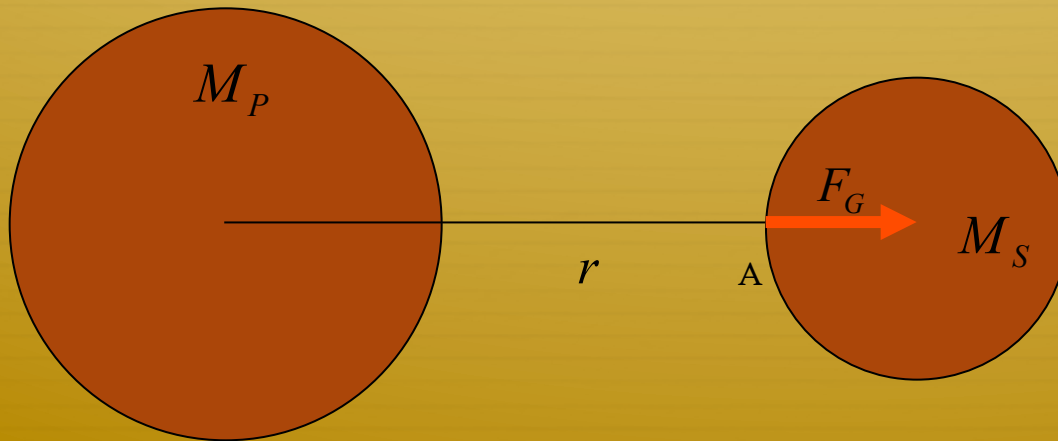
Consider a moon of mass M_S and radius R_S , orbiting at a distance (centre to centre) r from a planet of mass M_P and radius R_P .



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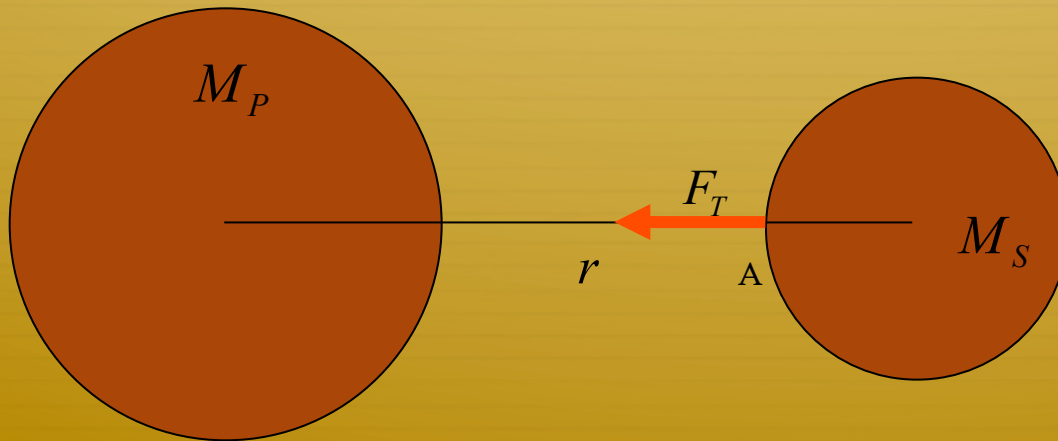
Force on a unit mass at A due to gravity of moon alone is

$$F_G = \frac{G M_S}{R_S^2}$$

Formation of Jovian Rings

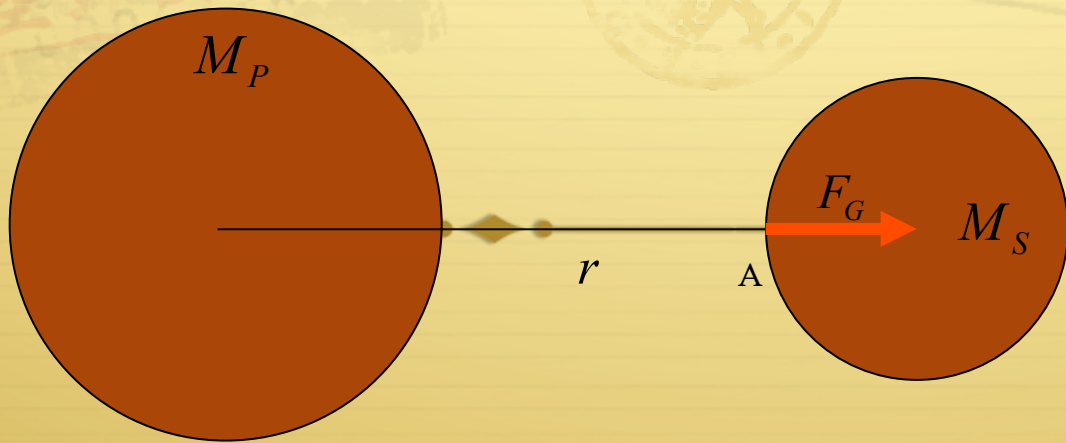
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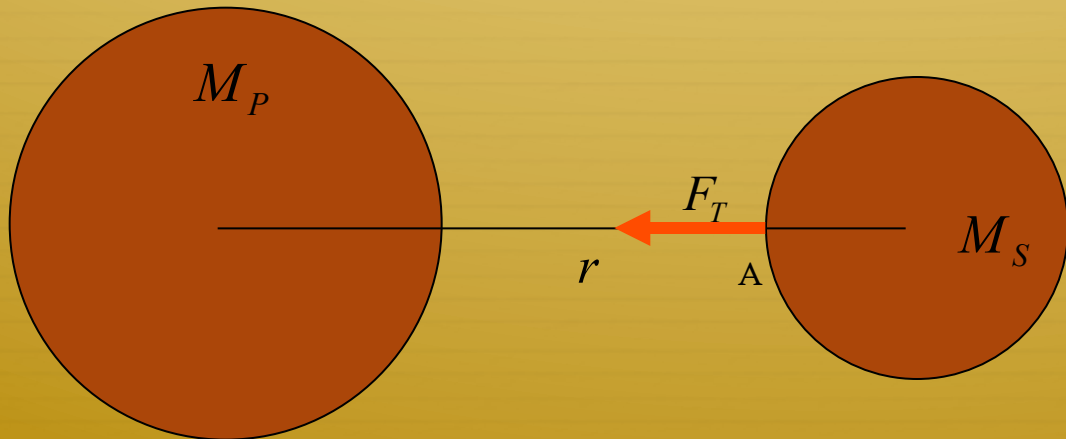
Tidal force on a unit mass at A due to gravity of planet is

$$F_T = \frac{2G M_P R_S}{r^3}$$



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$$F_G = \frac{G M_S}{R_S^2}$$



Tidal force on a unit mass at A due to gravity of planet is

$$F_T = \frac{2G M_P R_S}{r^3}$$

Tidal Disruption of Ring Systems

We assume, as an order-of-magnitude estimate that the moon is **tidally disrupted** if

$$F_T > F_G$$

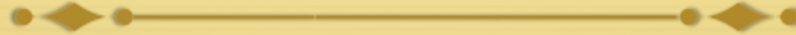
In other words, if

$$\frac{2GM_P R_S}{r^3} > \frac{GM_S}{R_S^2}$$

This rearranges further to

$$r < 2^{1/3} \left(\frac{M_P}{M_S} \right)^{1/3} R_S$$

Tidal Disruption of Ring Systems



We can re-cast the last equation in terms of the *planet's* radius, by writing **mass = density × volume**.

Substituting $M_P = \frac{4\pi}{3} \bar{\rho}_P R_P^3$

$$M_S = \frac{4\pi}{3} \bar{\rho}_S R_S^3$$

So the moon is tidally disrupted if

$$r < 2^{1/3} \left(\frac{\bar{\rho}_P}{\bar{\rho}_S} \right)^{1/3} R_P$$

Roche Stability of Ring Systems

e.g. for **Saturn**, from the Table of planetary data $\bar{\rho}_P \approx 700 \text{ kg m}^{-3}$

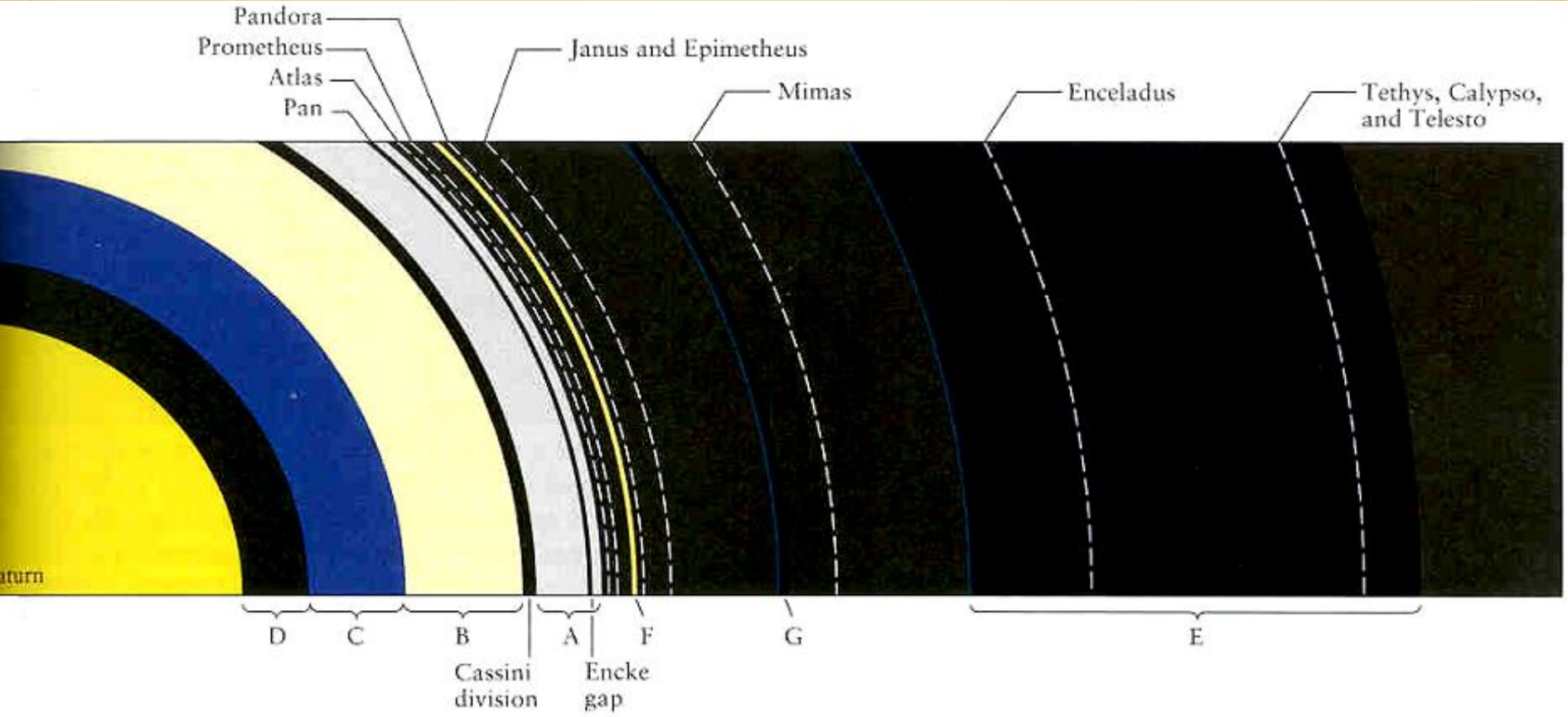
Take a mean density typical of the other moons $\bar{\rho}_m \approx 1200 \text{ kg m}^{-3}$

This implies

$$r_{RL} = 2.456 \times \left(\frac{700}{1200} \right)^{1/3} \times R_P = 2.05 R_P$$

Most of Saturn's ring system *does* lie within this Roche stability limit. Conversely *all* of its moons lie further out!

Roche Stability of Ring Systems



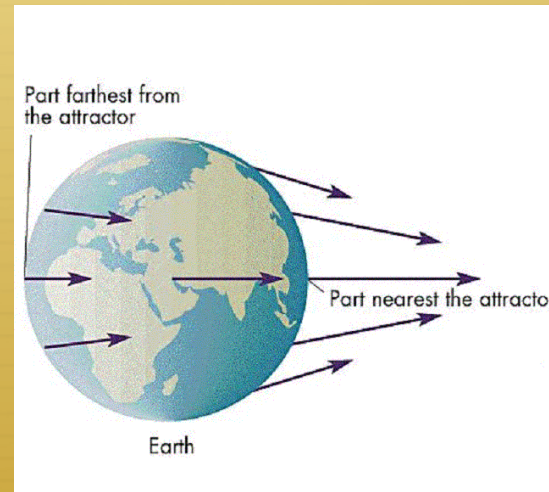
Roche stability limit

More on Tidal Forces

Tidal forces also have an effect (albeit less destructive) *outside* the Roche stability limit.

Consider the Moon's tide on the Earth (and vice versa).

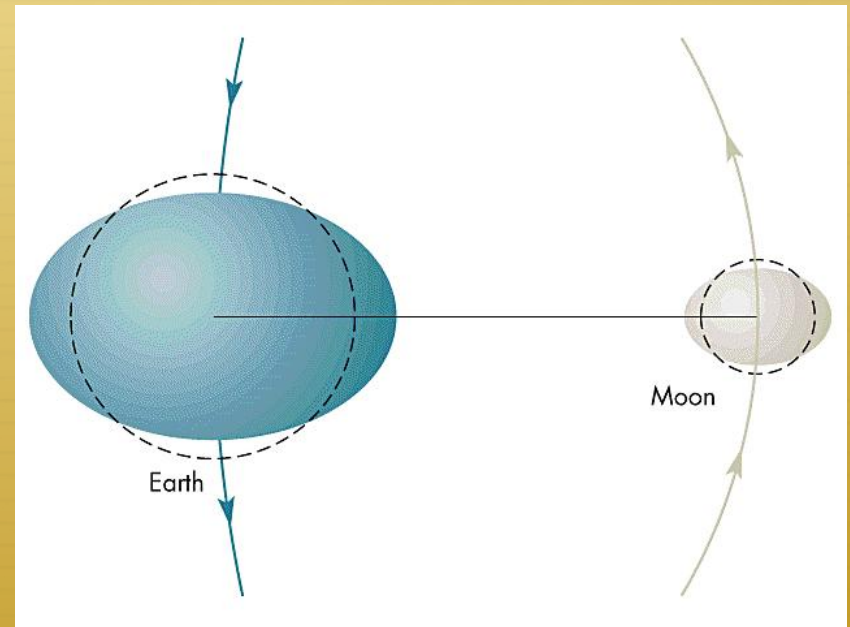
The tidal force produces an oval bulge in the shape of the Earth (and the Moon)



More on Tidal Forces

There are, therefore, **two** high and low tides every ~25 hours.

(Note: not every 24 hours, as the Moon has moved a little way along its orbit by the time the Earth has completed one rotation)



The Sun also exerts a tide on the Earth.

Now, $F_T \propto \frac{M_P}{r^3}$ so

$$\frac{F_{T,\text{Sun}}}{F_{T,\text{Moon}}} = \frac{M_{\text{Sun}}}{M_{\text{Moon}}} \left(\frac{r_{\text{Moon}}}{r_{\text{Sun}}} \right)^3$$

and

$$M_{\text{Sun}} = 1.989 \times 10^{30} \text{ kg} \quad M_{\text{Moon}} = 7.35 \times 10^{22} \text{ kg}$$

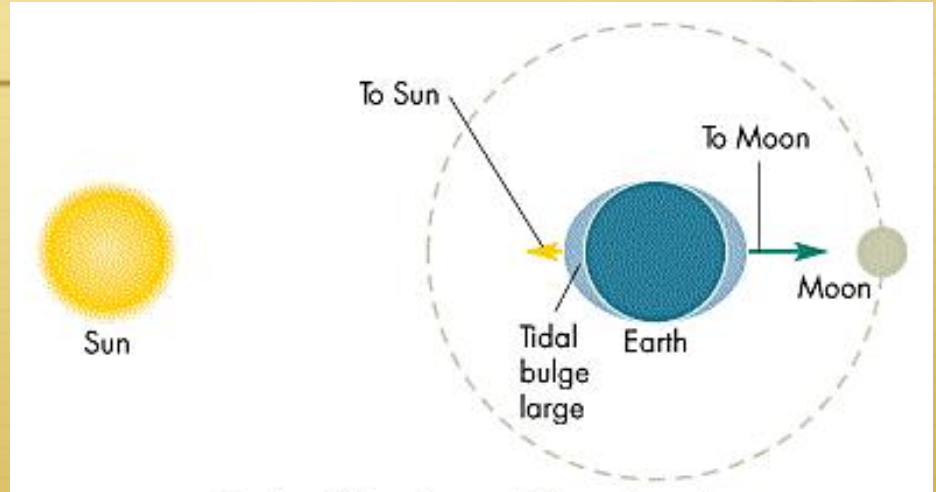
$$r_{\text{Sun}} = 1.496 \times 10^{11} \text{ m} \quad r_{\text{Moon}} = 3.844 \times 10^8 \text{ m}$$

so that

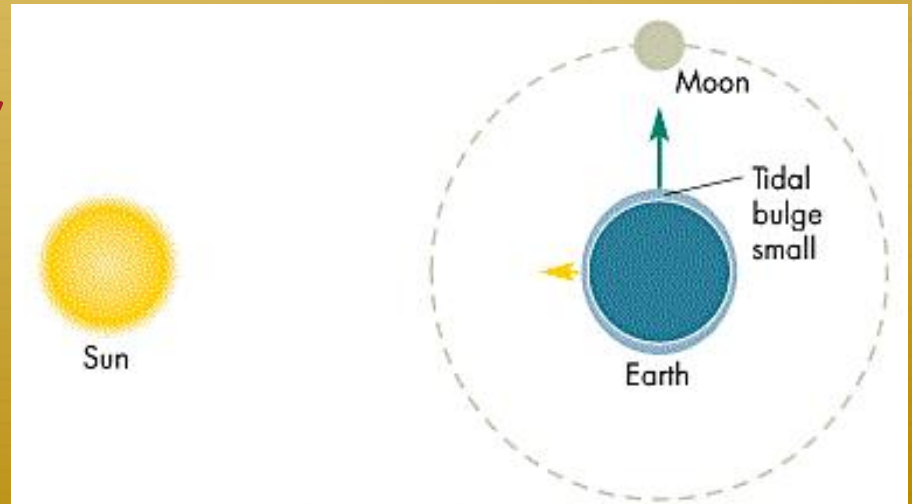
$$\frac{F_{T,\text{Sun}}}{F_{T,\text{Moon}}} = \frac{M_{\text{Sun}}}{M_{\text{Moon}}} \left(\frac{r_{\text{Moon}}}{r_{\text{Sun}}} \right)^3 \approx 0.5$$

The Sun and Moon exert a tidal force similar in magnitude. The size of their combined tide on the Earth depends on their *alignment*.

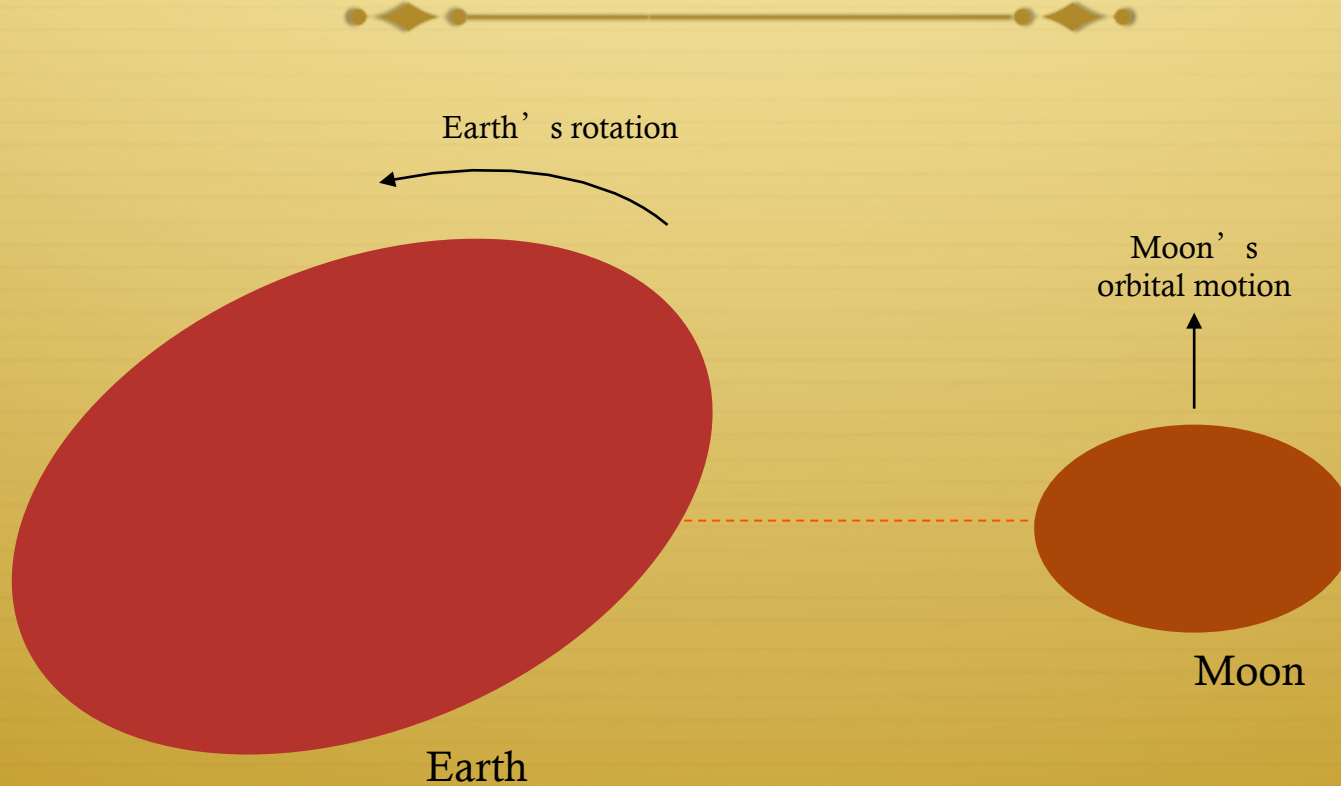
Spring tides occur when the Sun, Moon and Earth are aligned (at Full Moon and New Moon). High tides are much higher at these times.



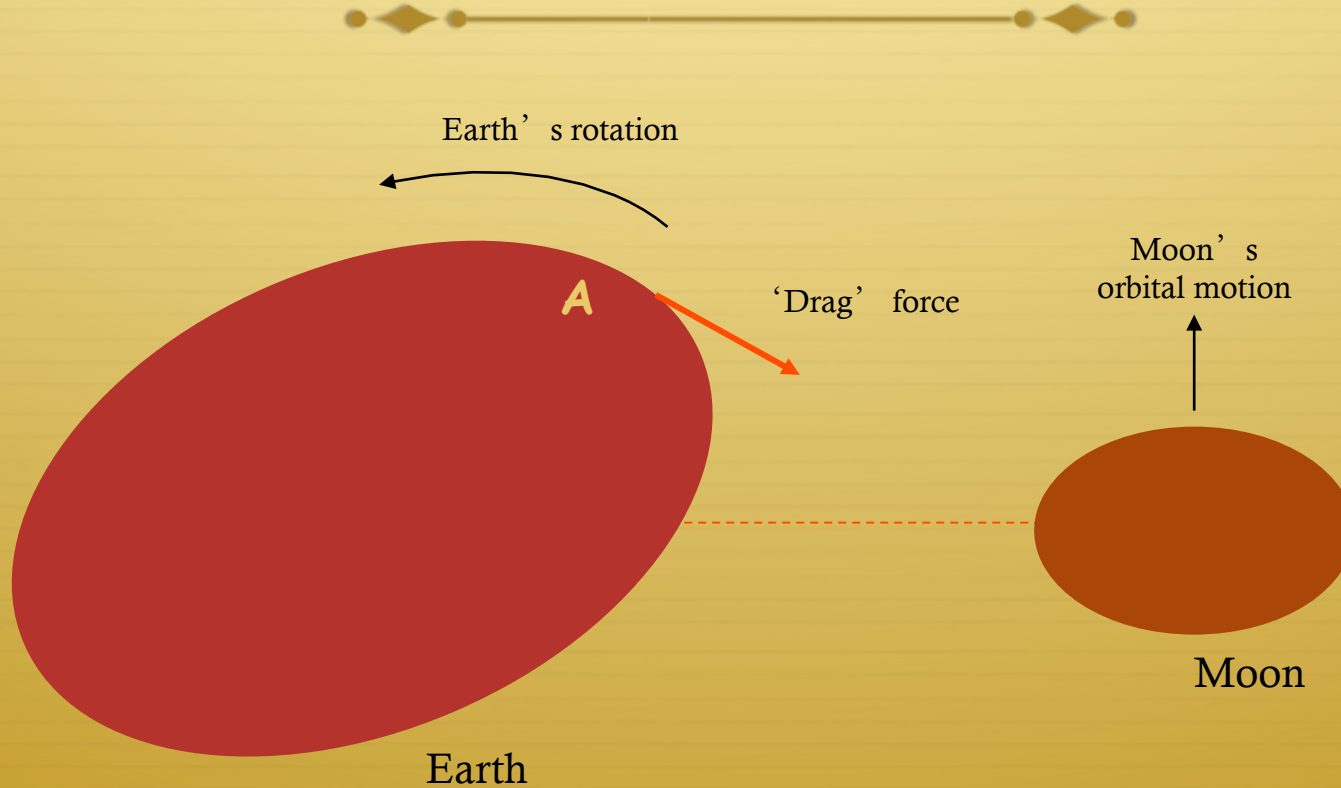
Neap tides occur when the Sun, Moon and Earth are at right angles (at First Quarter and Third Quarter). Low tides are much lower at these times.



The Earth's rotation carries the tidal bulge ahead of the Earth-Moon axis. (The Earth's crust and oceans cannot instantaneously redistribute themselves along the axis due to friction)

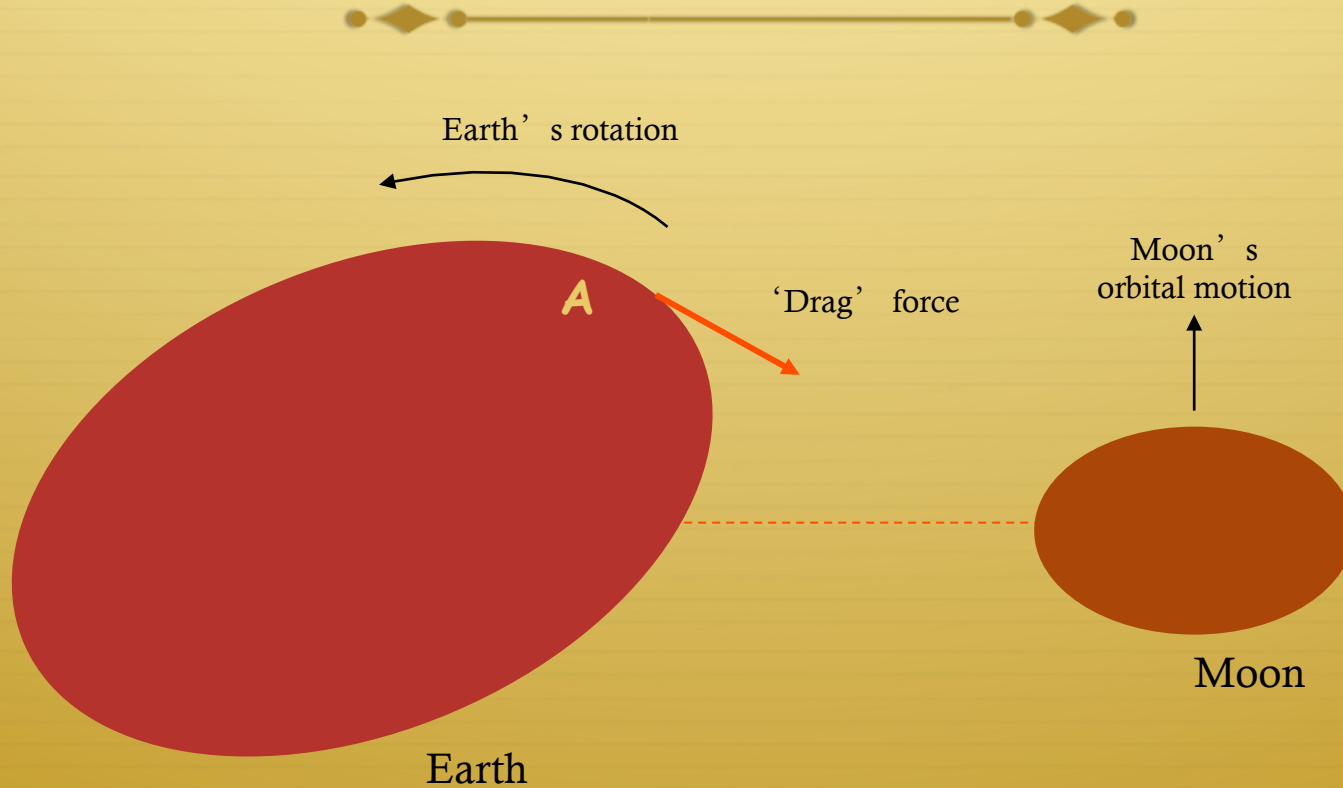


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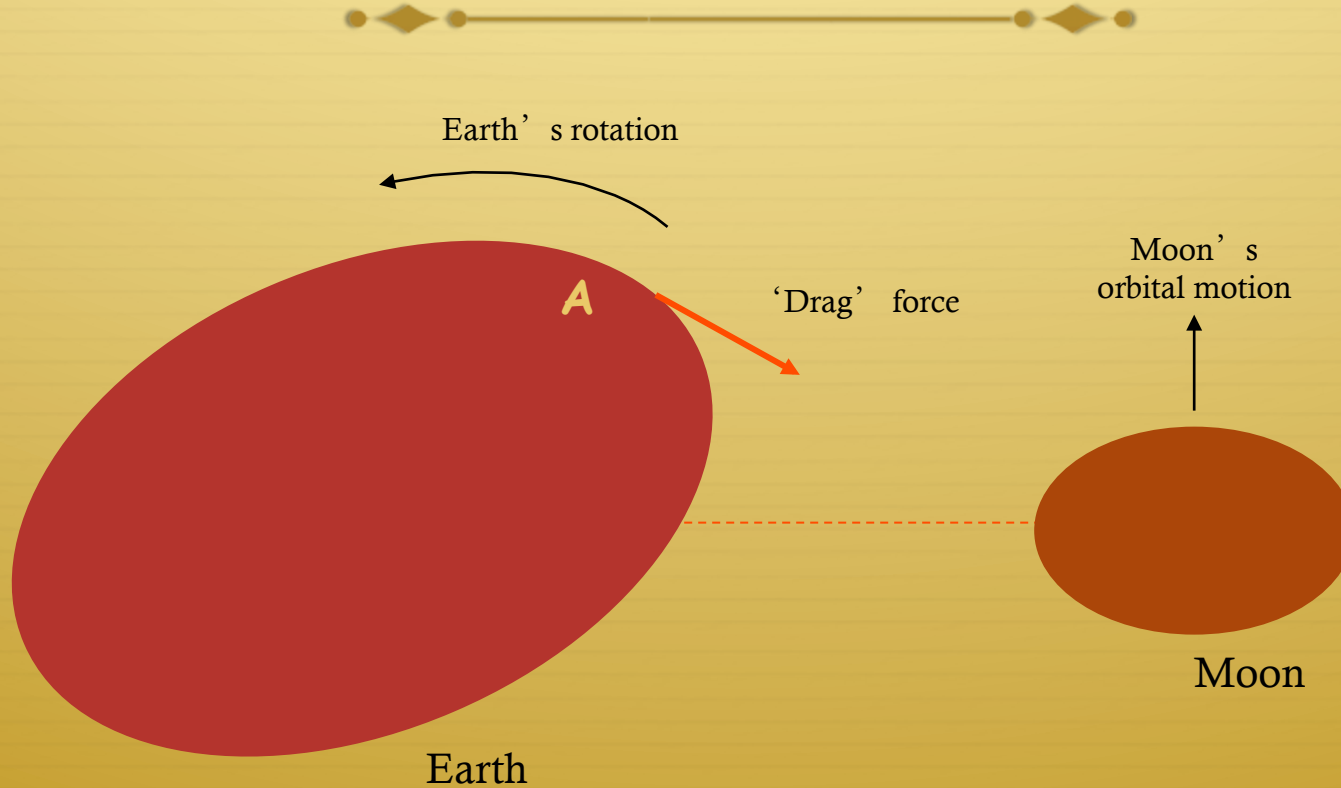


The length of the Earth's day is increasing by 0.0016 sec per century.

At the same time, bulge A is pulling the Moon forward, speeding it up and causing the Moon to spiral outwards. **This follows from the conservation of angular momentum.**



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The Moon's semi-major axis is increasing by about 3cm per year.

Given sufficient time, the Earth's rotation period would slow down until it equals the Moon's orbital period - so that the same face of the Earth would face the Moon at all times.

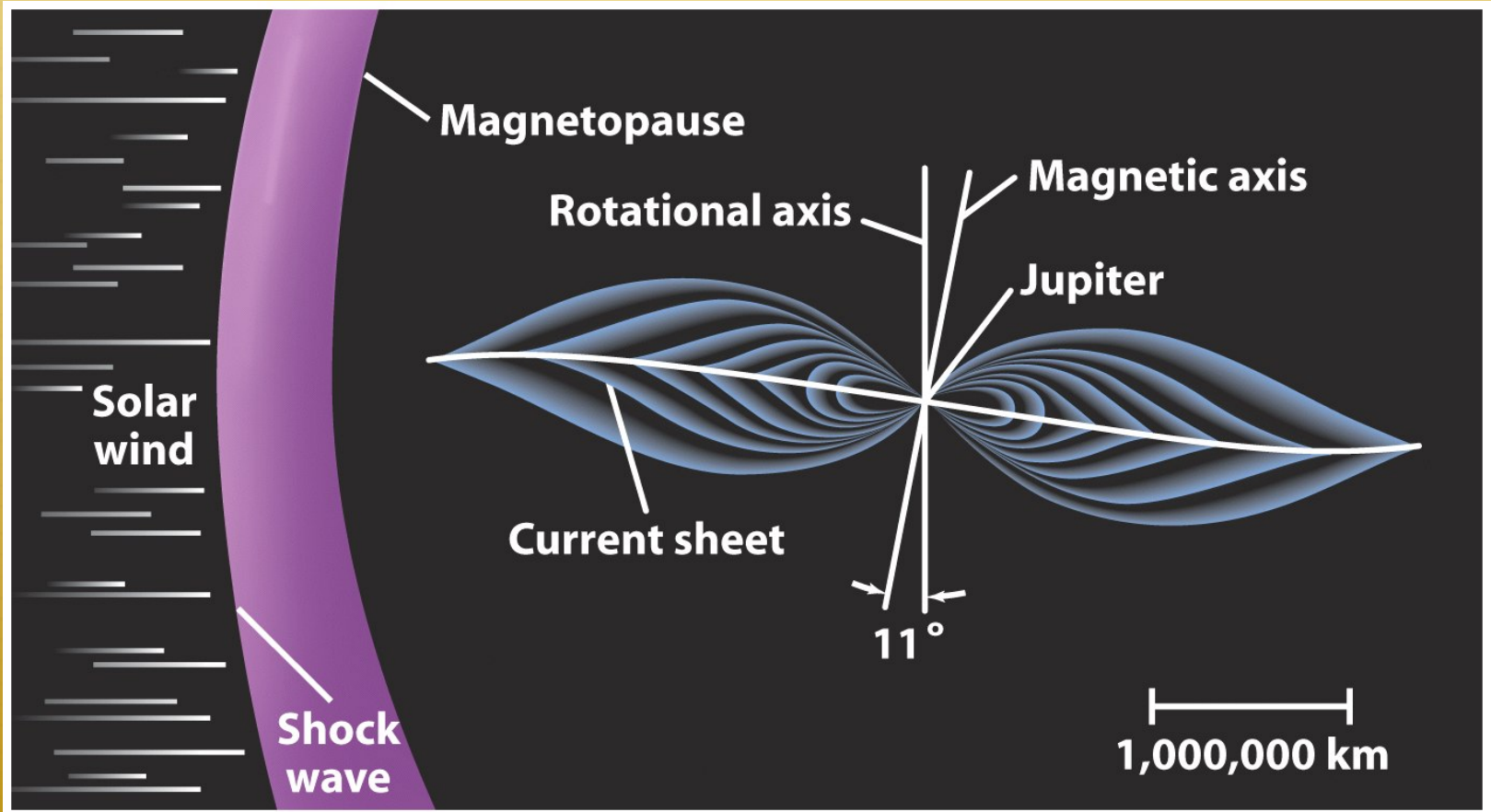
(This will happen when the Earth's "day" is 47 days long)

In the case of the Moon, this has *already happened !!!*

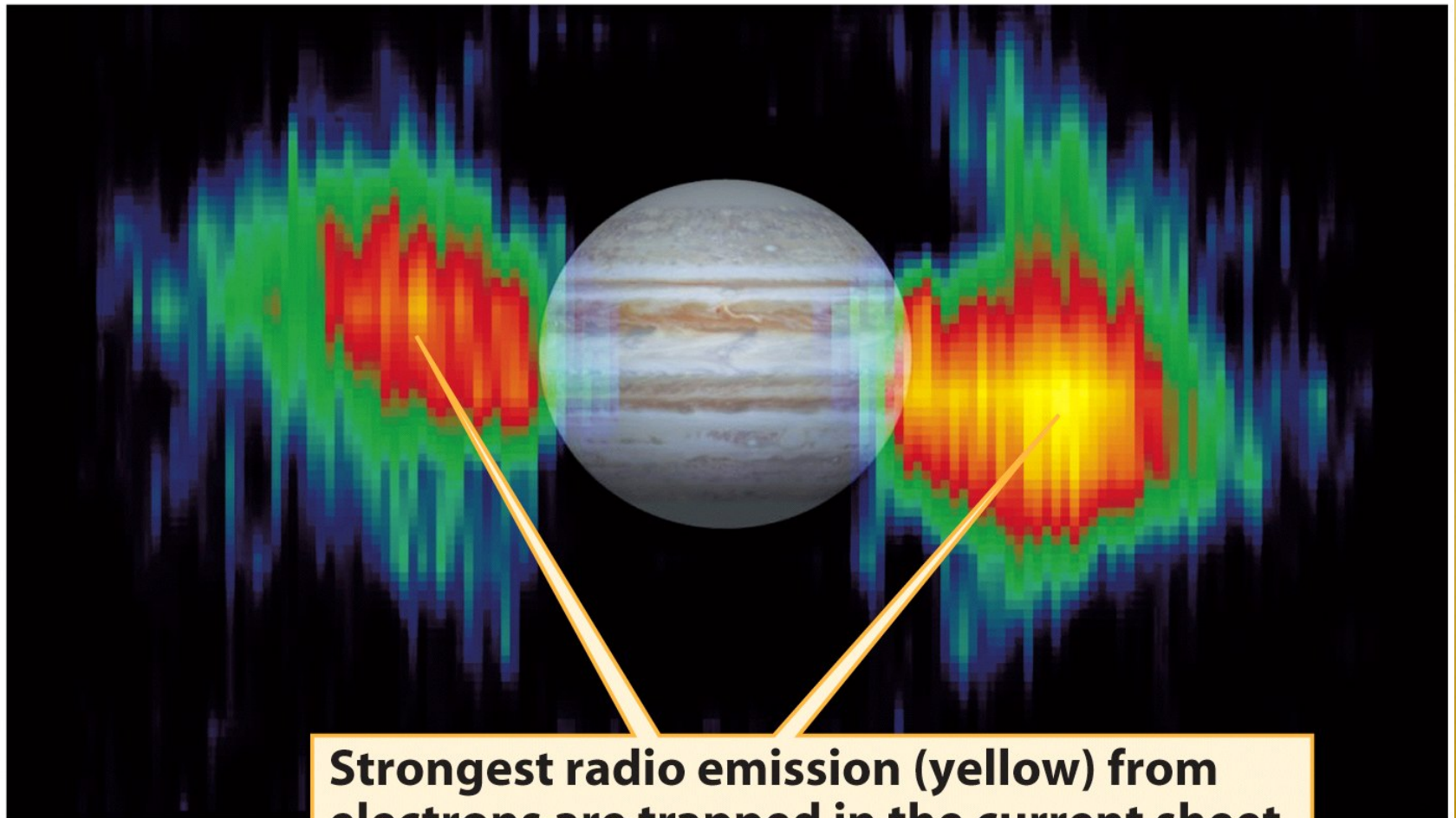
Tidal locking has occurred much more rapidly for the Moon than for the Earth because the Moon is much smaller, and the Earth produces larger tidal deformations on the Moon than vice versa.

The Moon isn't exactly tidally locked. It 'wobbles' due to the perturbing effect of the Sun and other planets, and because its orbit is **elliptical**. Over about 30 years, we see 59% of the Moon's surface.

Jovian Magnetosphere



Synchrotron Radiation



Strongest radio emission (yellow) from electrons are trapped in the current sheet.

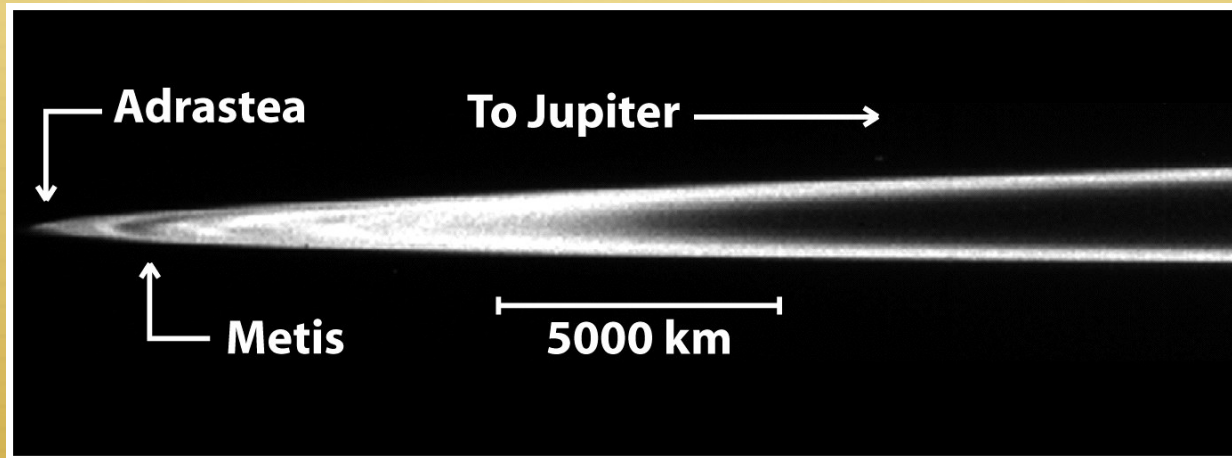
Are *minor* satellites of minor interest?

There is no doubt that the spectacular large Galilean satellites and Titan are of great interest; visually and due to the presence of H_2O and organic molecules which could be precursors to life. Hence they are taking the attention of the Galileo spacecraft and Cassini mission.

Small satellites, if formed with the parent planet, give us information about the heavier elements of the dust and gas nebula from which they formed.

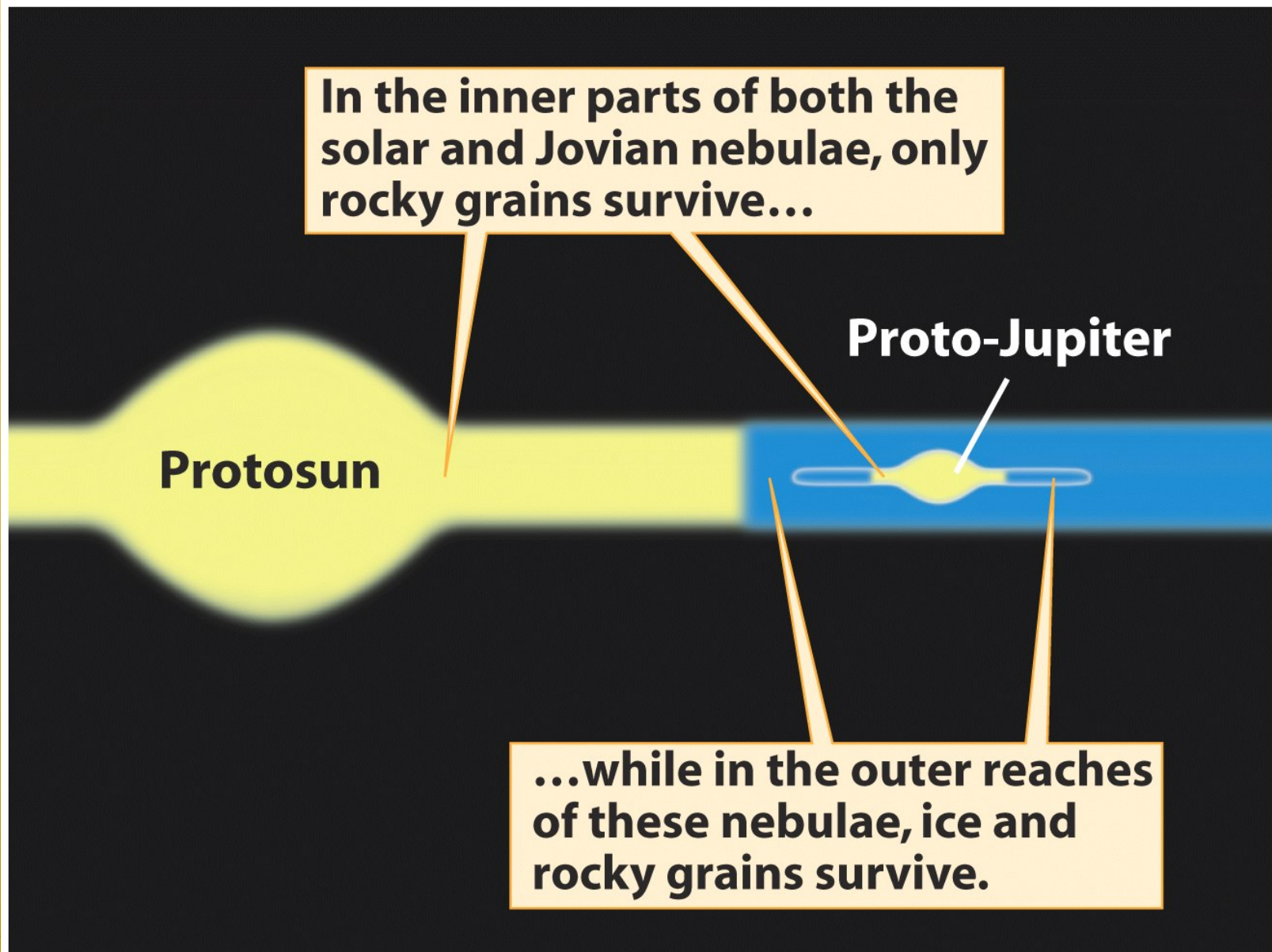
The inner small satellites have a major effect on shaping the ring systems of all the Jovian planets, which, as we shall see, are themselves comprised of tiny satellites which never accreted into larger bodies, or of larger bodies which broke up in the parent planet's gravitational field.

Saturn's rings are composed of numerous icy fragments, while Jupiter's rings are made of small rocky particles



- ✦ The principal rings of Saturn are composed of numerous particles of ice and ice-coated rock ranging in size from a few micrometers to about 10 m
- ✦ Jupiter's faint rings are composed of a relatively small amount of small, dark, rocky particles that reflect very little light

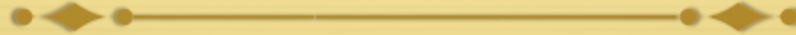
The Galilean satellites probably formed in a similar fashion to our solar system but on a smaller scale



Satellites (moons) are classified into two groups:

1) Regular

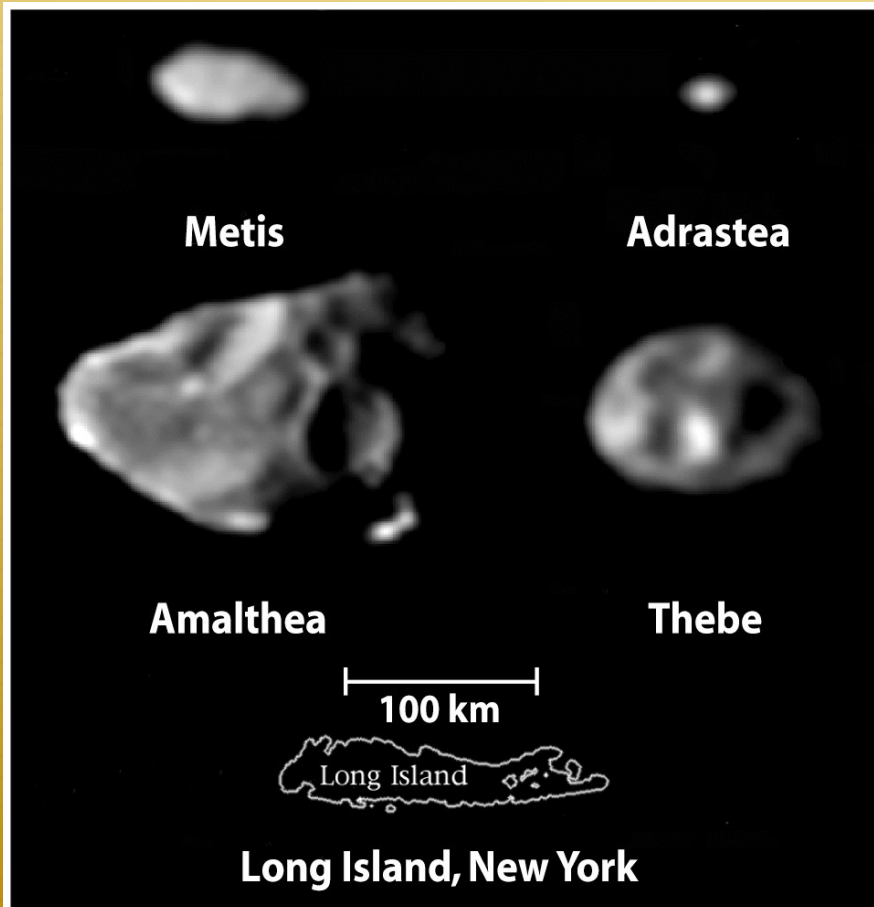
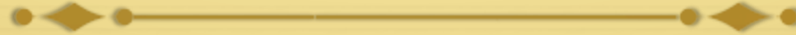
2) Irregular



- The key discriminant is that the REGULAR satellites have orbits which are; *a)* small (in comparison with the total range of gravitational influence of the parent planet), *b)* nearly circular, and *c)* close to the equatorial planes of their planets.
- The IRREGULAR satellites, in contrast, have orbits which are; *a)* large, *b)* eccentric and *c)* inclined relative to the parent planet equatorial plane.

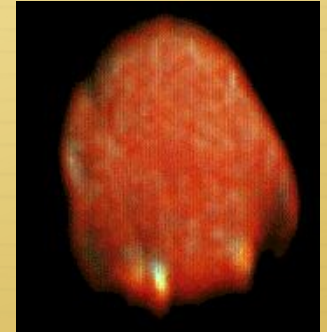
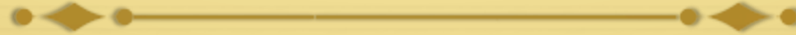
The important difference between the regular and irregular satellites is that the regulars (*may have*) formed by accretion in pre-planetary disks analogous to the disk around the sun from which the planets formed. The irregular satellites cannot have formed in such disks (since they pay little heed to the planetary equators) and instead are thought to have been captured.

Jupiter has dozens of small satellites that have different origins



- ✦ As of early 2011, Jupiter has a total of 63 known satellites
- ✦ In addition to the Galilean satellites, Jupiter has four small inner satellites that lie inside Io's orbit
- ✦ Like the Galilean satellites, these orbit in the plane of Jupiter's equator
- ✦ The remaining satellites are small and move in much larger orbits that are noticeably inclined to the plane of Jupiter's equator
- ✦ Many of these orbit in the direction opposite to Jupiter's rotation

Jupiter's inner minor satellites

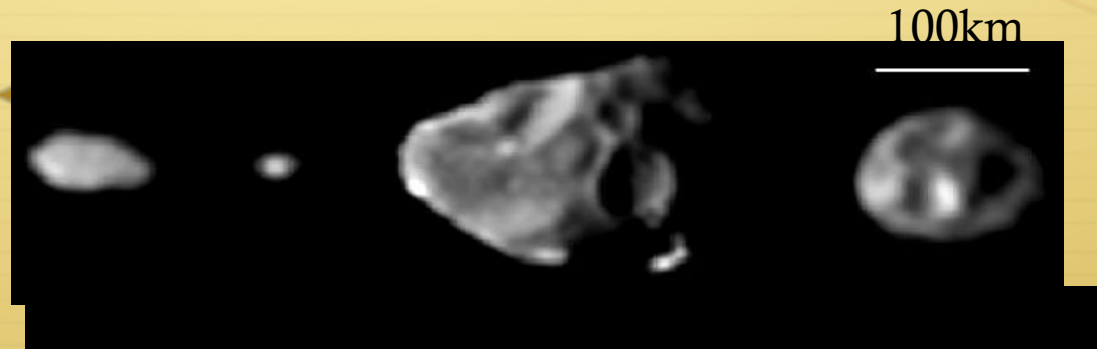


The largest of the inner group of four of Jupiter's minor satellites is **Amalthea**, a remarkable discovery in 1892 considering its orbit is half the size of that of Io and its size is only 270 by 166 by 150 km. In this Voyager 1 image, impact craters can be glimpsed.

Its reddish colour is attributed to sulphur ejected from Io's volcanoes.

Tidal drag has made Amalthea's rotation synchronous with its orbit period.

Galileo spacecraft images of the four inner satellites, to scale

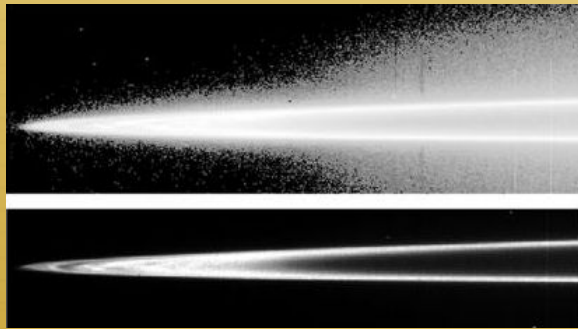


Smaller satellites **Metis** and **Adrastea** have even smaller orbits, and **Thebe** has a slightly larger orbit. Metis and Adrastea orbit in just 7 hours and would thus appear to an observer floating in Jupiter's clouds to set in the *opposite* direction to the Sun.

That their orbits are circular, in Jupiter's equatorial plane and in Jupiter's direction of rotation suggests these bodies may have condensed out of the same material as Jupiter, but were too small to retain lighter elements or to differentiate and take up spherical shapes.

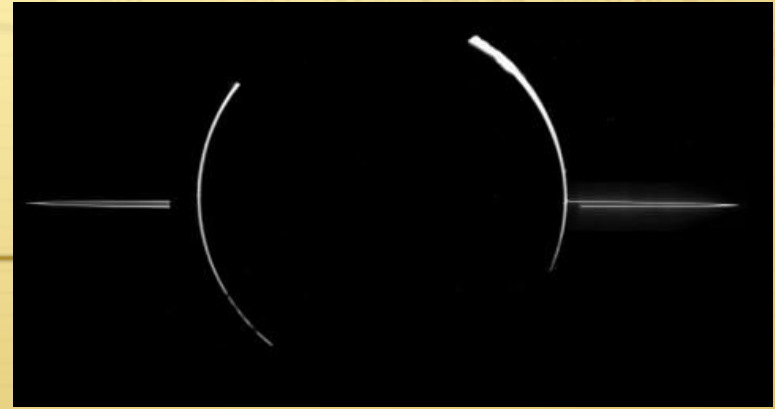
Jupiter's Rings

First discovered as Voyager 1 passed inside the orbit of Amalthea in 1979, Jupiter's rings appear edge-on in this Galileo image with the Sun directly behind Jupiter.



Jupiter was then known to have three dark, thin rings:

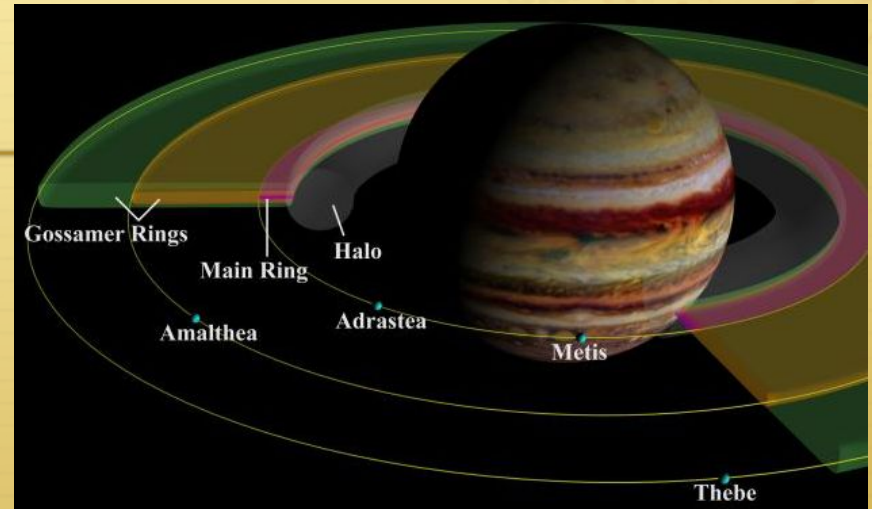
1. the main ring,
2. a halo ring thought to be vertically perturbed by Jupiter's magnetic field, and



3. a faint 'gossamer' ring extending outward from the main ring.

Metis and Adrastea orbit in the main ring. Ring particles are fine, "like reddish soot".

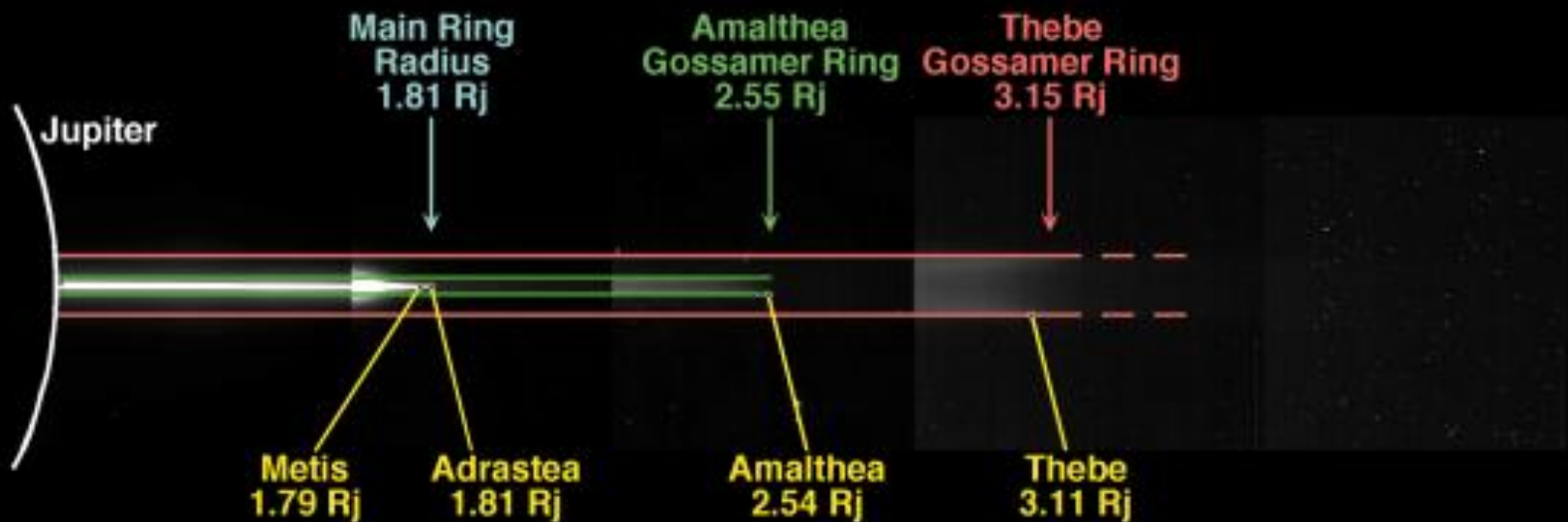
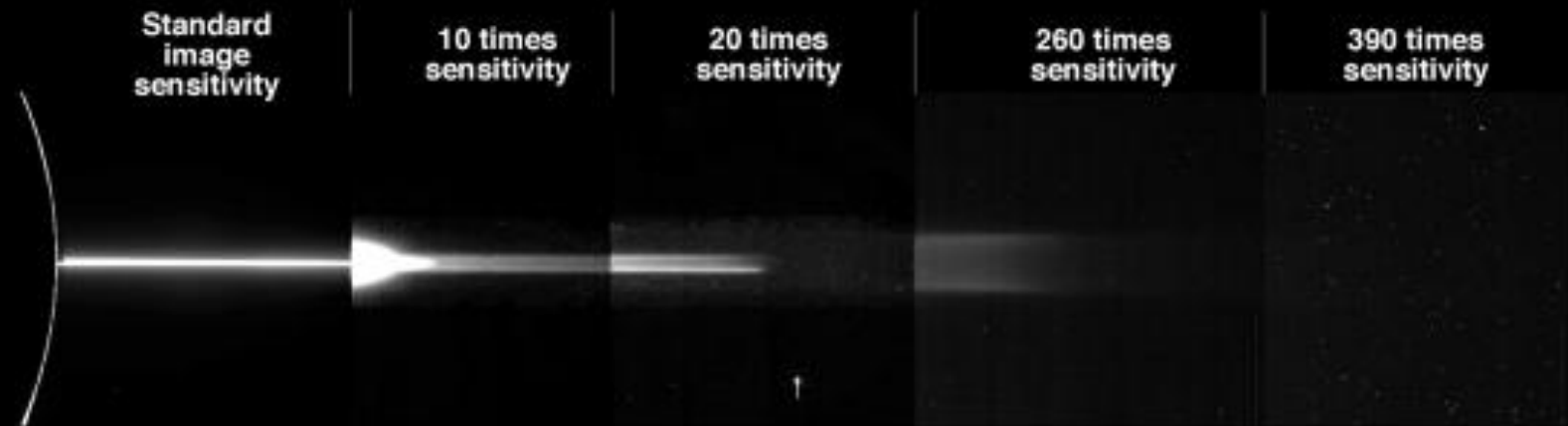
The *Galileo* spacecraft found that the gossamer ring has inner *and* outer components and is composed of fine material observed coming off the reddish surfaces of *Amalthea* and *Thebe* by the impact of incoming small asteroidal bodies. The main ring is similarly produced from *Adrastea* and *Metis*.



“These images provide one of the most significant discoveries of the entire *Galileo* imaging experiment” .

JPL Press Release Information September 15, 1998

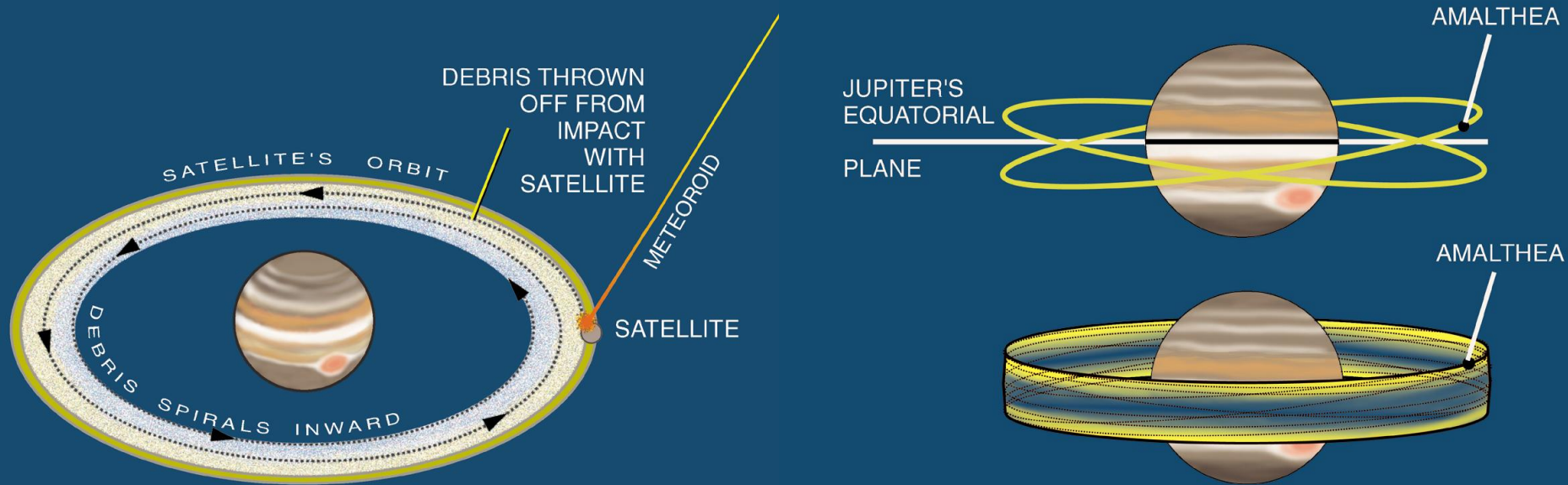




● = Earth for scale

A schematic structure of Jupiter's main and gossamer rings.

The source and the structure of the ring system

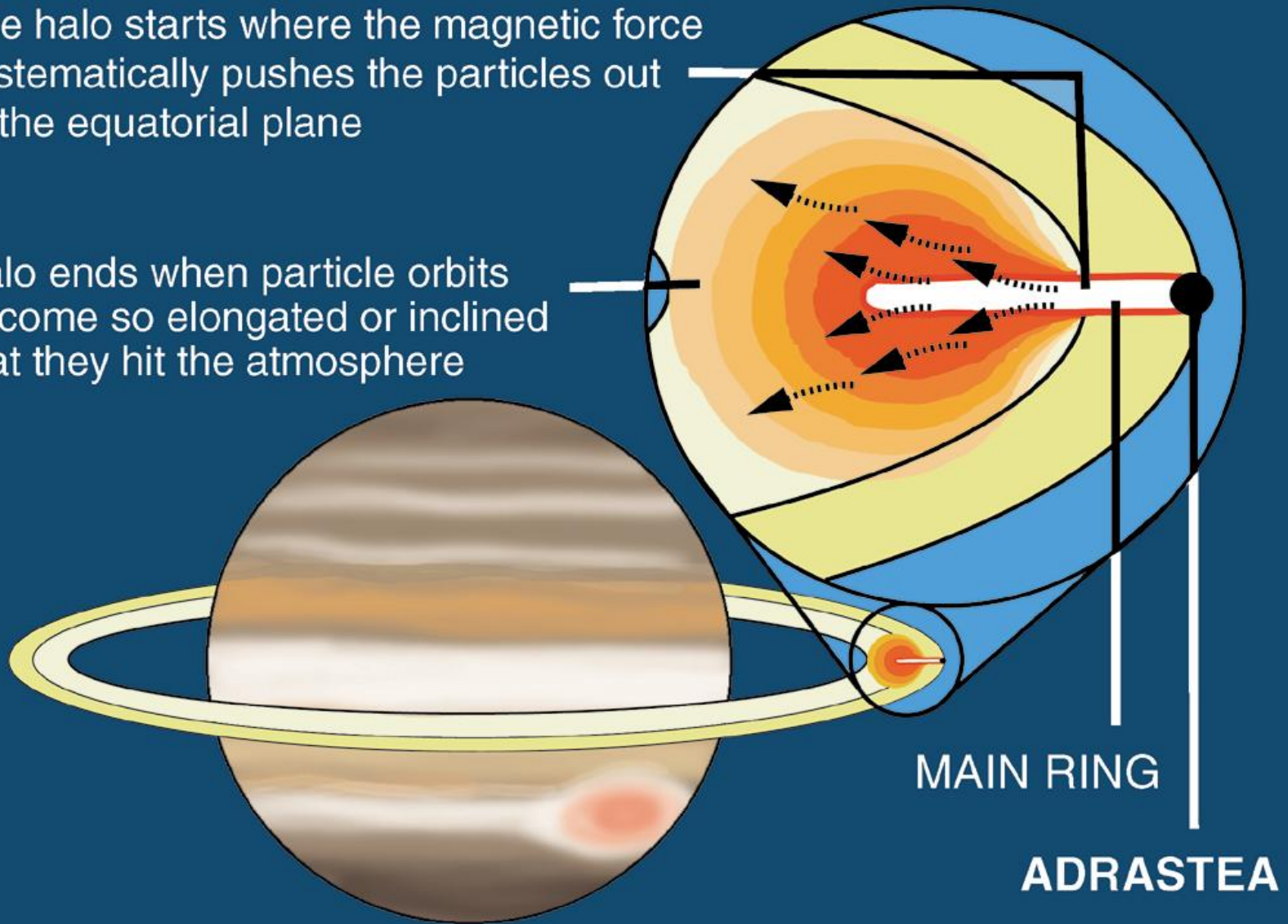


Impacts by small meteoroids (fragments of asteroid-comets) into the two innermost, low-gravity satellites supply the material (dust) for the main ring and halo. Like shepherd moons, the locations of Metis and Adrastea bound the position of the Main ring.

The outer gossamer rings are derived from impacts on the outer small moons, Amalthea and Thebe.

The halo starts where the magnetic force systematically pushes the particles out of the equatorial plane

Halo ends when particle orbits become so elongated or inclined that they hit the atmosphere

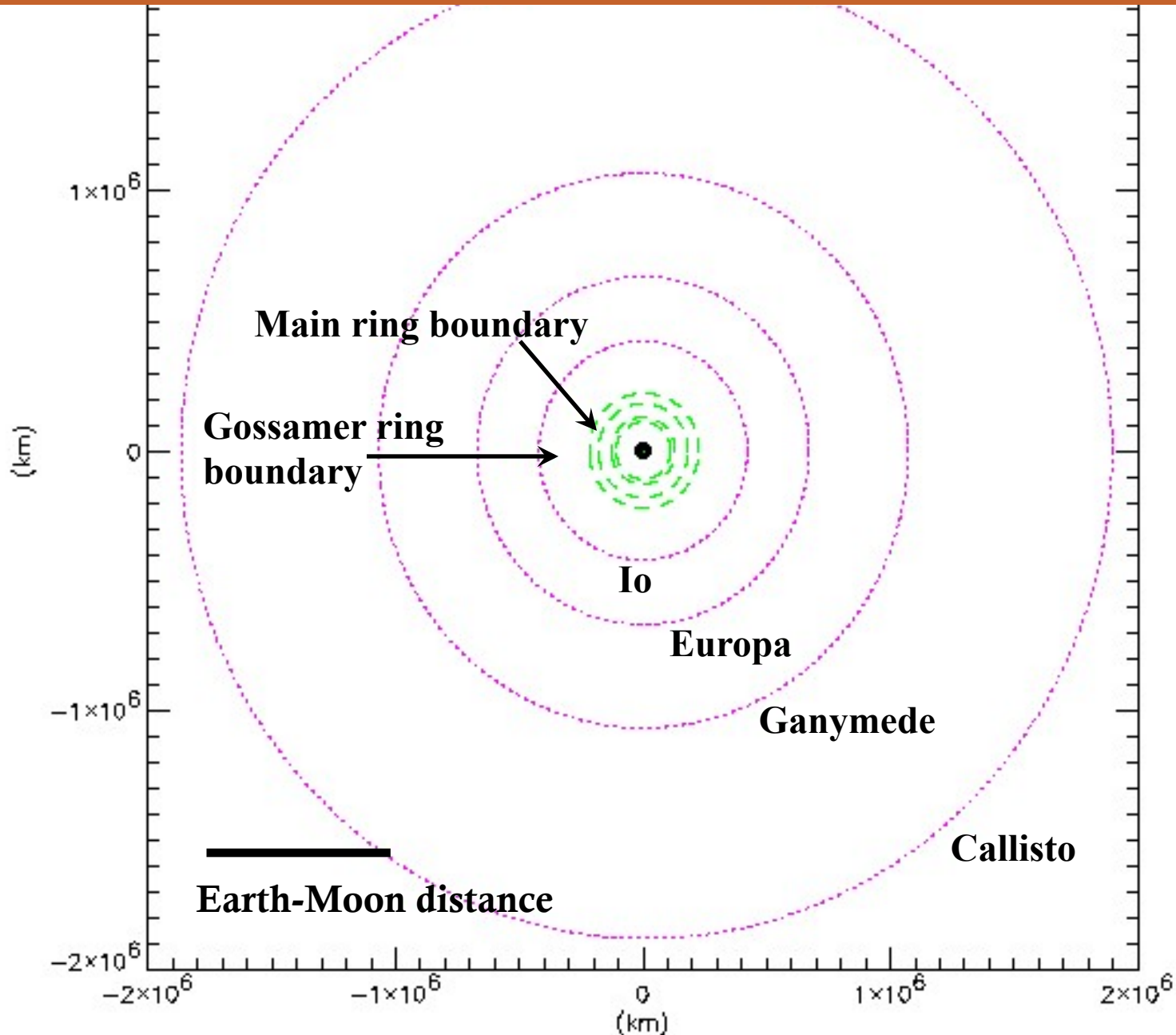


MAIN RING

ADRASTEIA

The halo is created by Jupiter's strong magnetic field which attempts to draw the material out towards the poles.

Relationship of The Rings to the Inner Satellites



Plan view for the orbits of the inner and main satellites of Jupiter also showing the relative extent of the ring system.

Conclusions



“Rings are important dynamical laboratories to look at the processes that probably went on billions of years ago when the Solar System was forming from a flattened disk of dust and gas” .

- Dr. J. Burns, Cornell University, in NASA/JPL Press Release, Sept 15, 1998

At first uninteresting, small misshapen lumps of rock and ice orbiting the gas giants, the minor satellites and rings turn out to be of great interest through their orbit patterns, synchronous rotations for inner satellites, appearance and composition. Puzzling at first, multiple satellites in the same orbit and orbit-swapping satellites are new examples of the variations with which the law of gravity can present us.