Department of Physics and Astronomy

Astronomy 1X

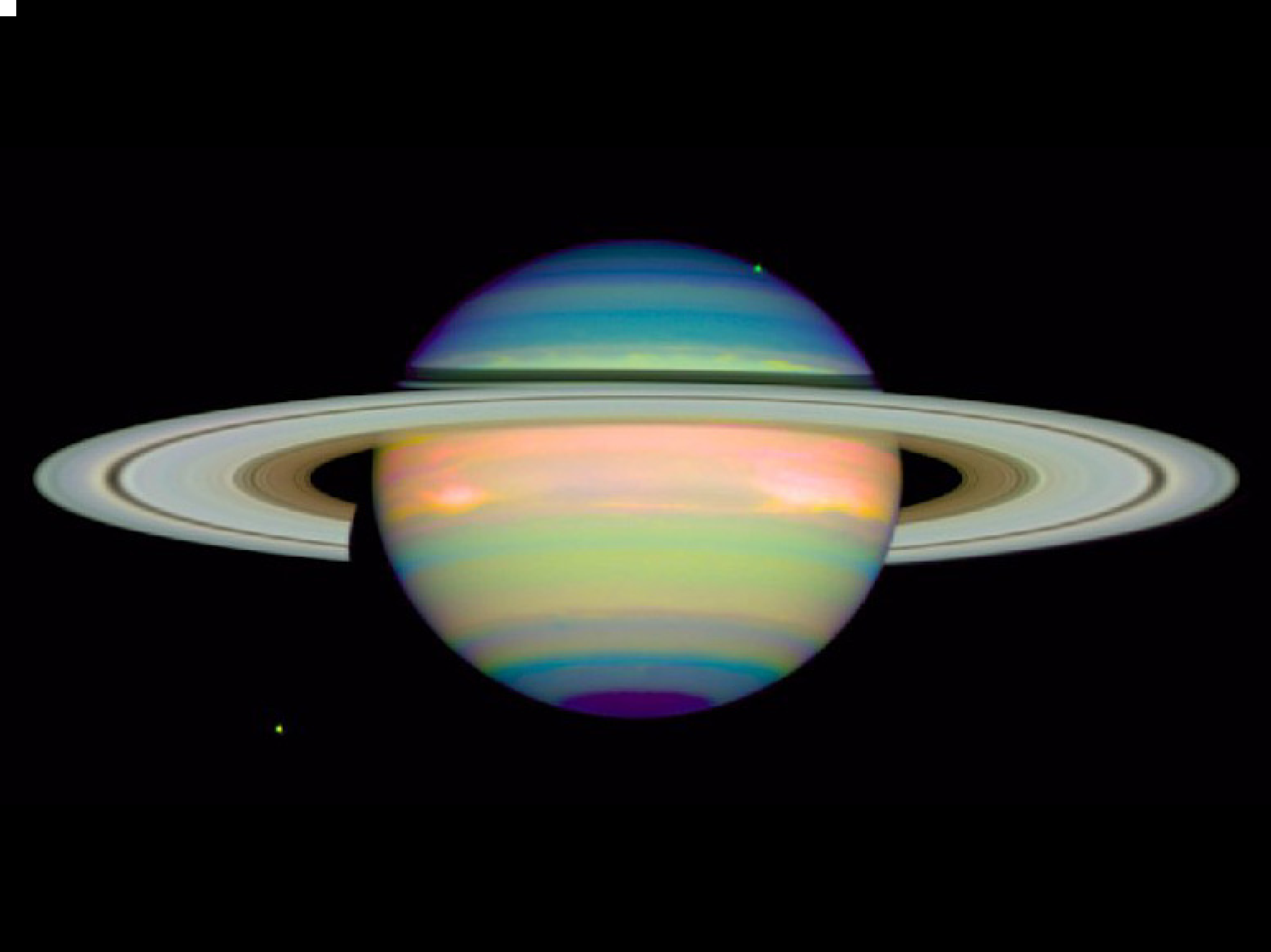
Session 2006-07

Solar System Physics I

Dr Martin Hendry

6 lectures, beginning Autumn 2006

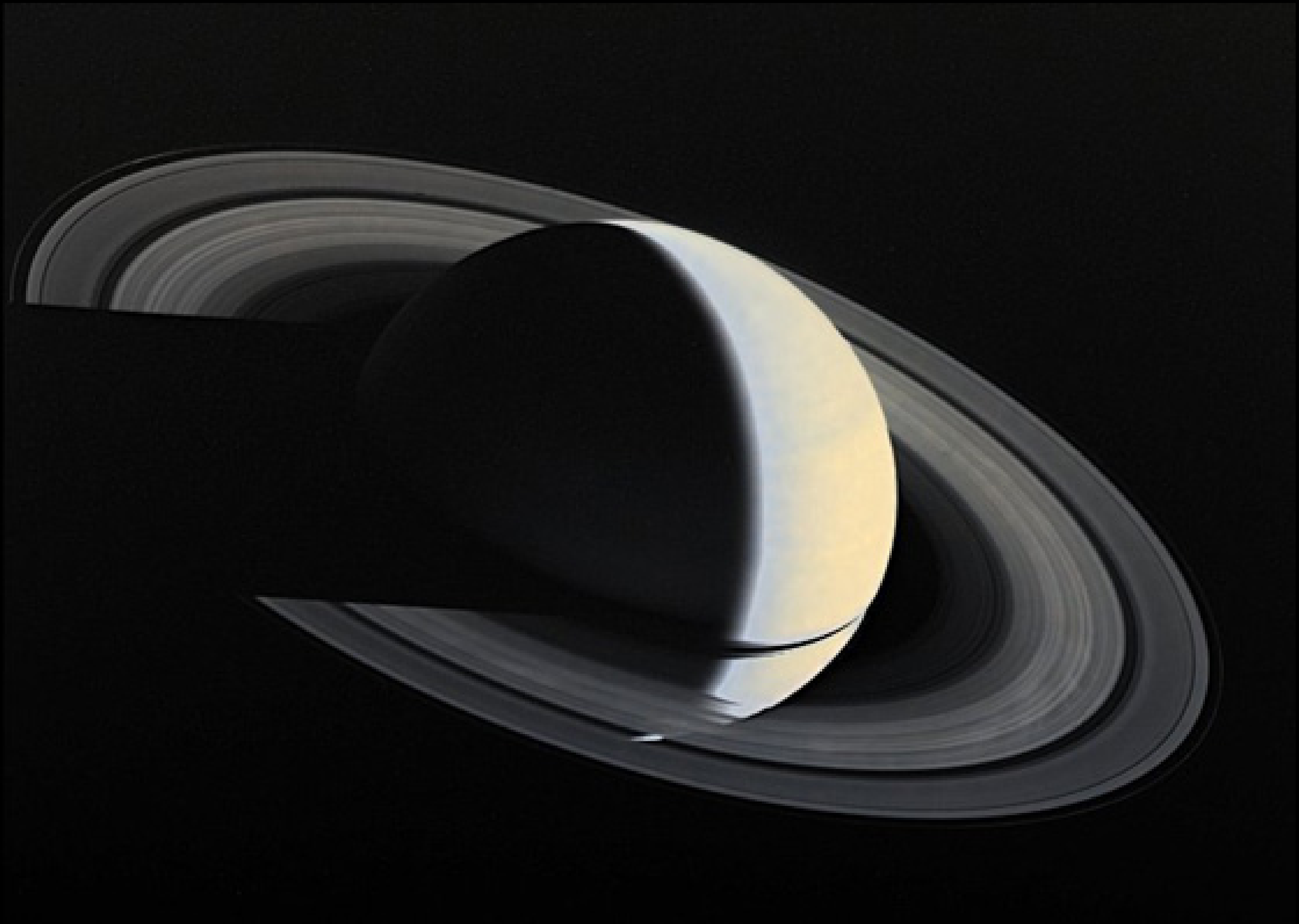
UNIVERSITY of GLASGOW



Ring Systems of the Jovian Planets

All four Jovian planets have **RING SYSTEMS**.

The Saturn ring system is the most impressive: it is easily visible from Earth with a small telescope, and superficially appears like a solid structure



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In 1857 James Clerk Maxwell proved that Saturn's rings couldn't be solid; if they *were* then **tidal forces** would tear them apart. He concluded that the rings were made of 'an indefinite number of unconnected particles'

(see later for more on tidal forces)

Saturn's rings are quite bright; they reflect about 80% of the sunlight that falls on them. Astronomers long suspected that they were made of ice and ice-coated rock, and this was confirmed in the 1970s when **absorption lines** of water were observed in the **spectrum** of light from the rings.

(See A1Y Stellar astrophysics for more on spectra and absorption lines)

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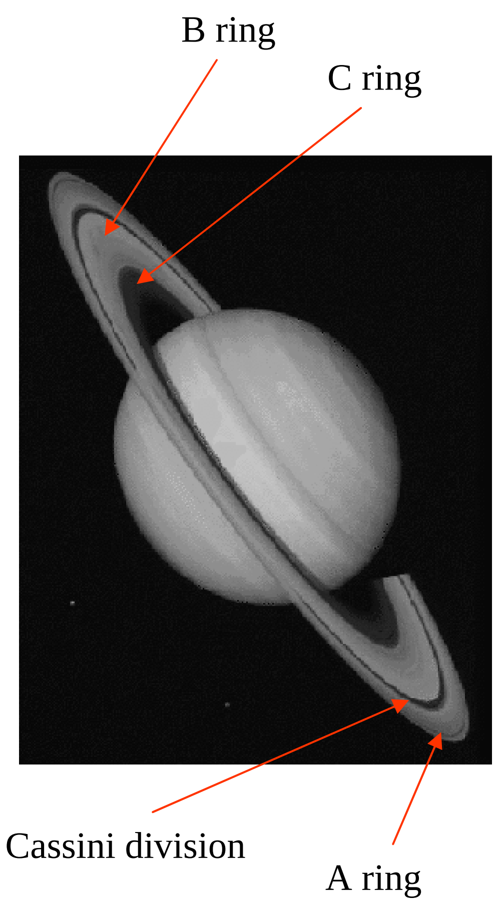

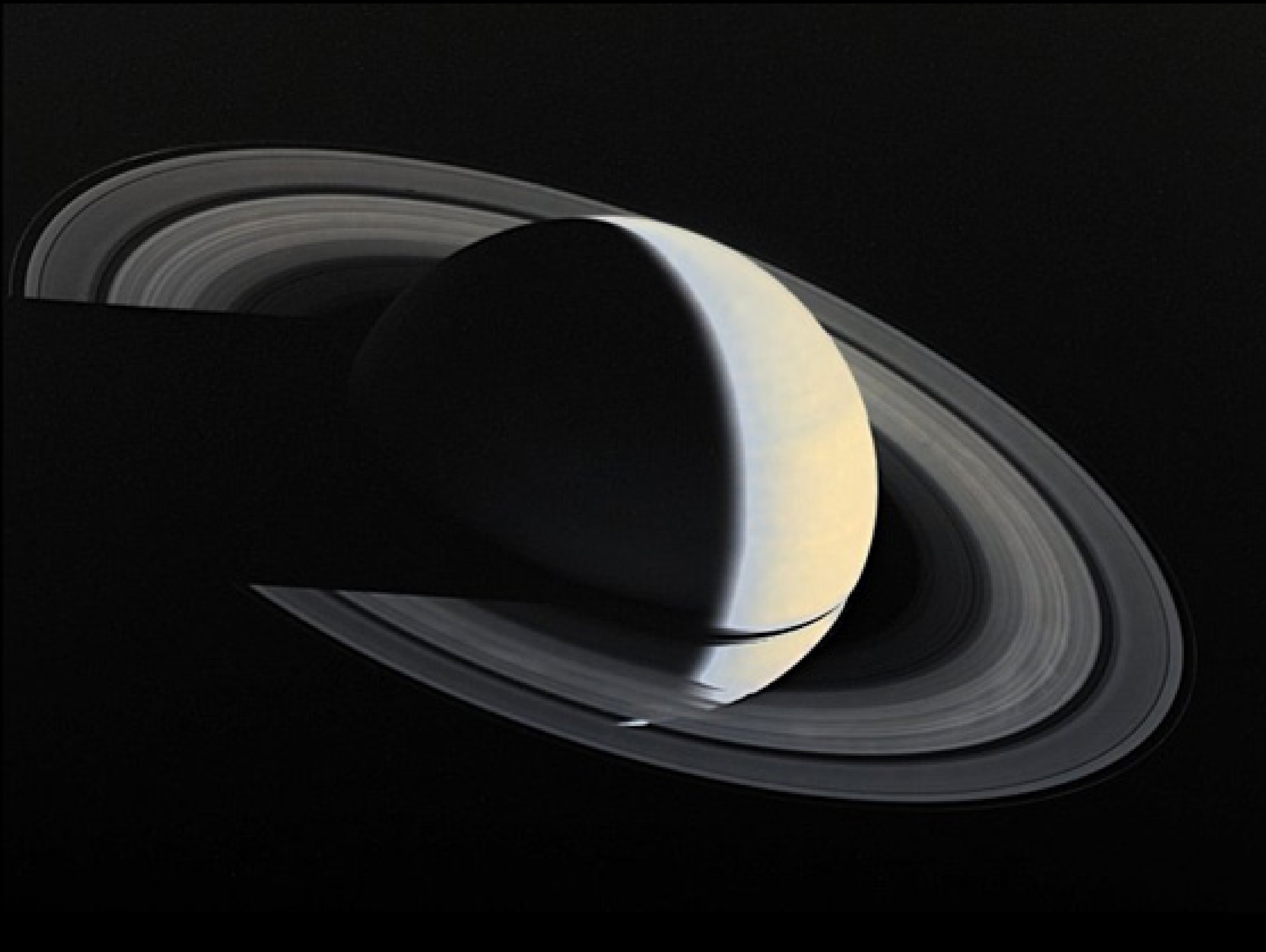

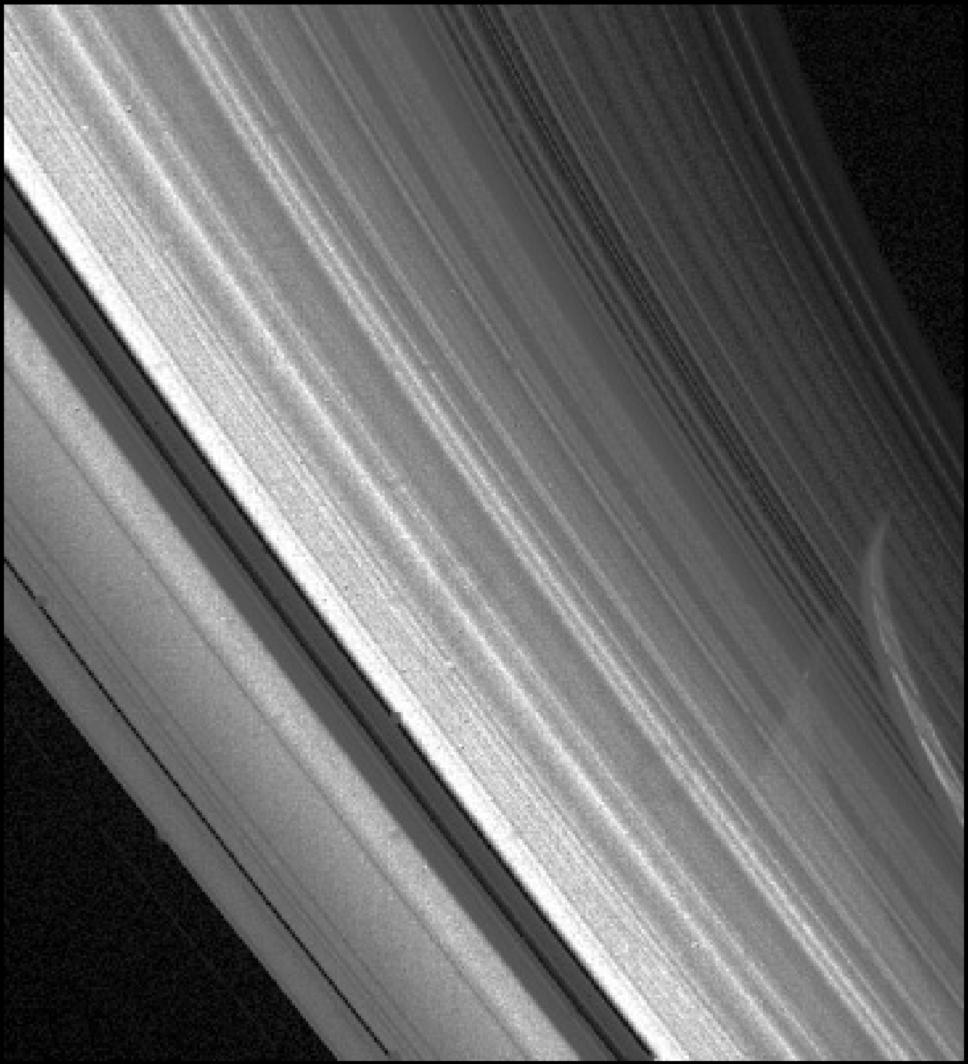
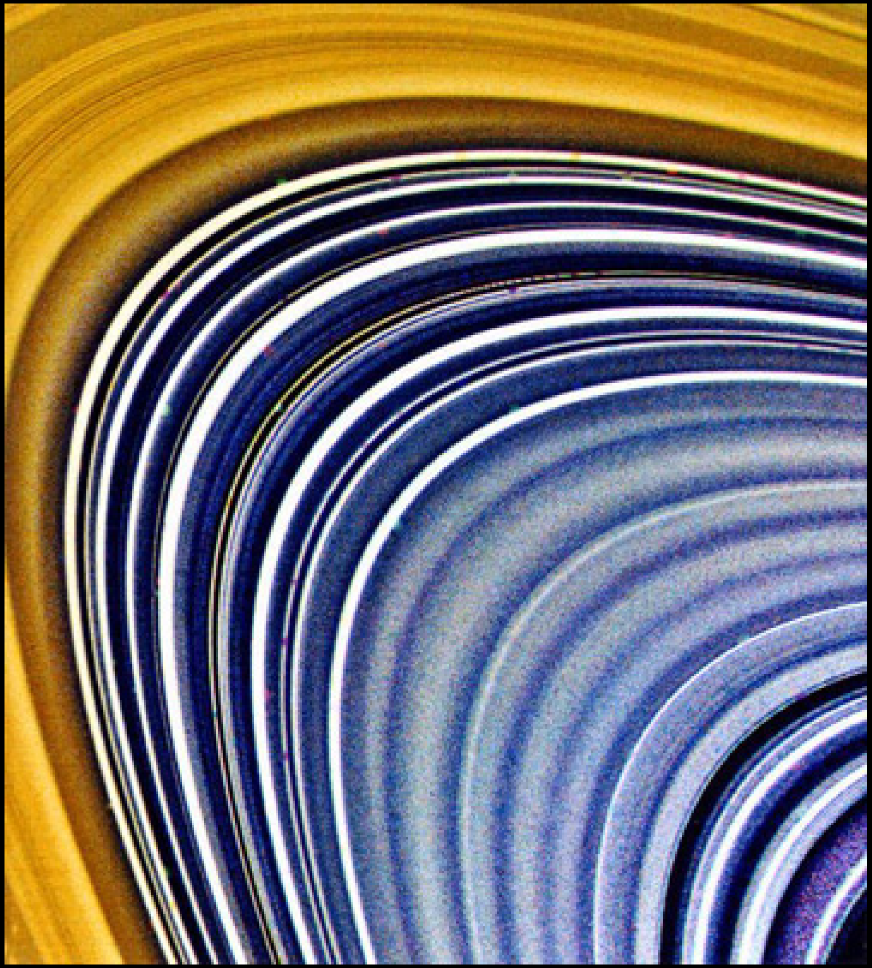

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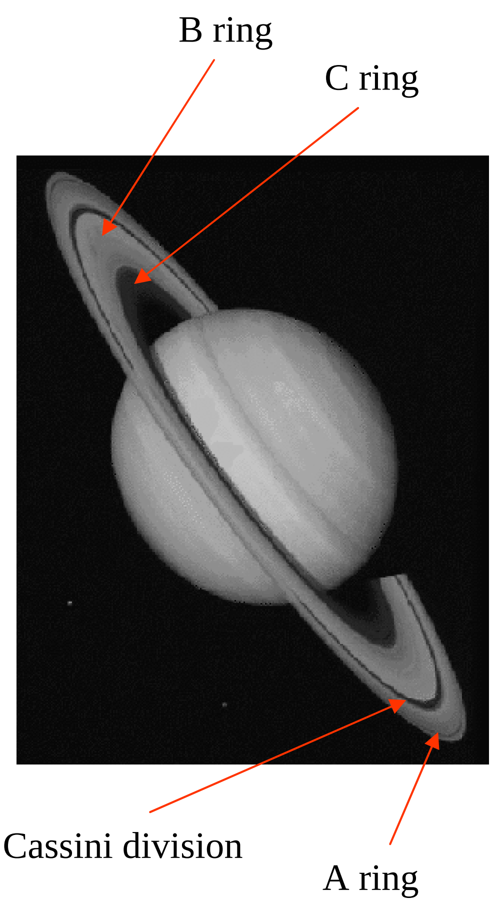

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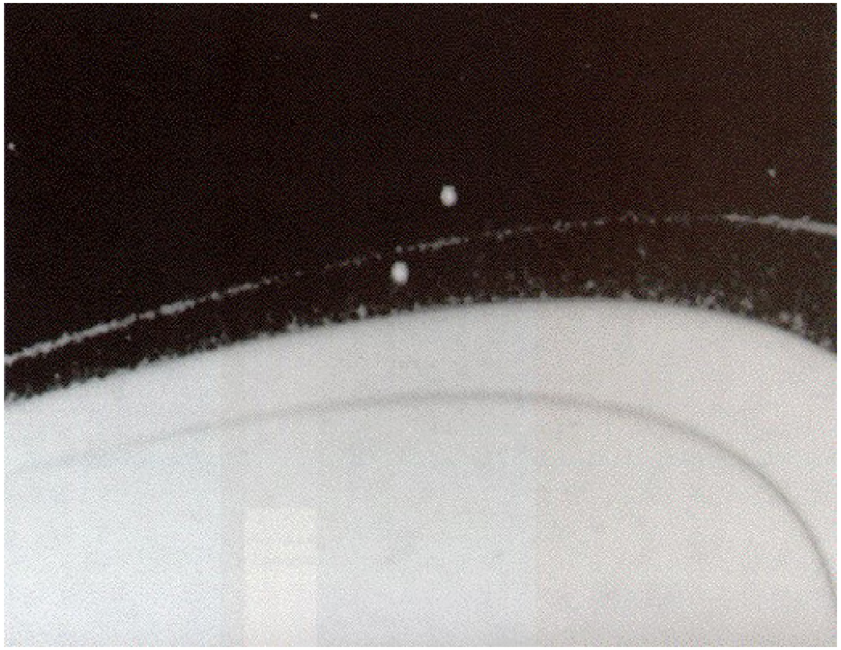
Voyager also discovered a D ring, (inside the C ring), and very tenuous E, F and G rings outside the A ring, reaching out to about 5 planetary radii.

The F ring shows 'braided' structure, is very narrow, and contains large numbers of ~1μm particles

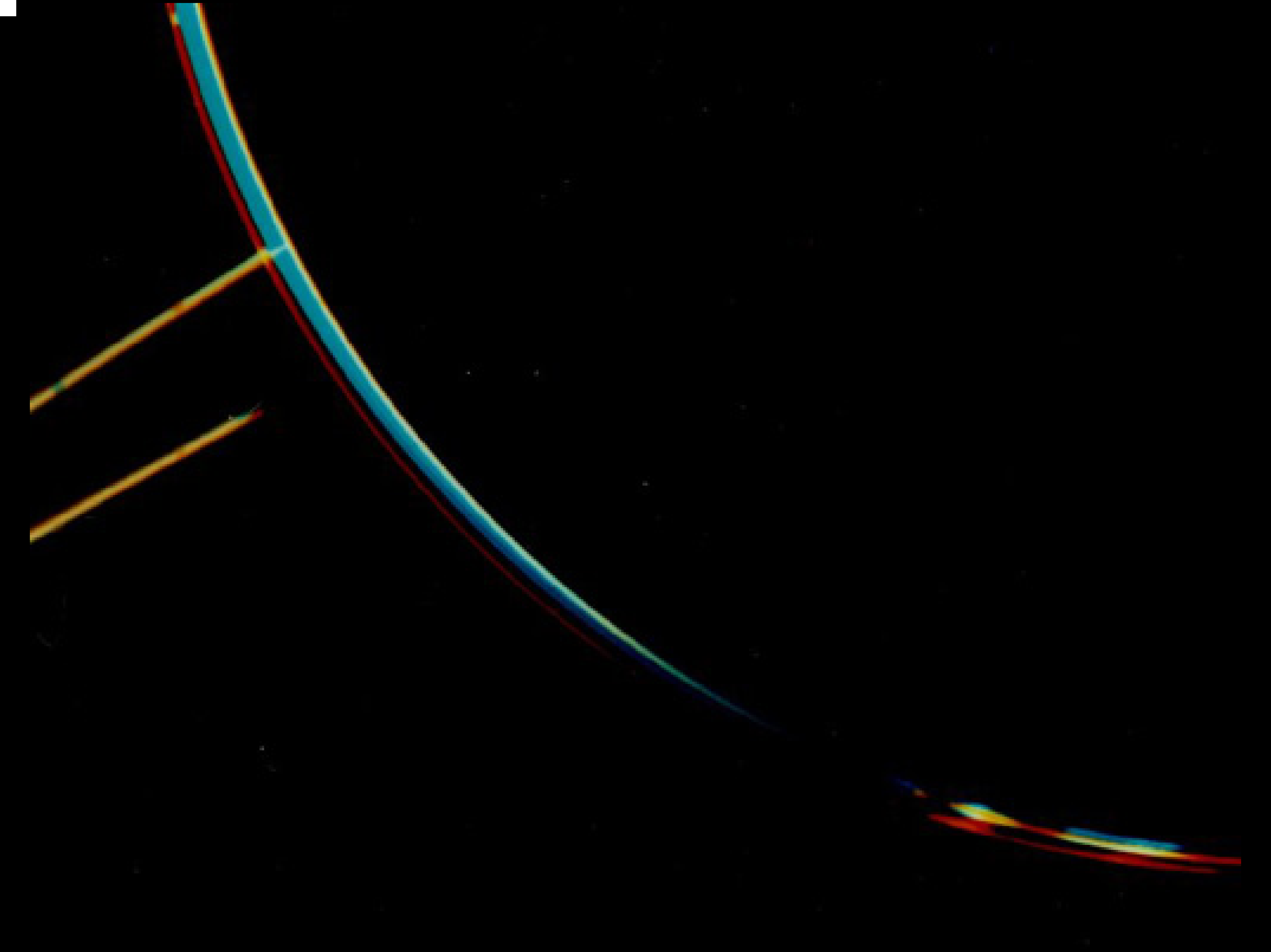
The structure of the F ring is believed to be controlled by the two ‘shepherd moons’ – Pandora and Prometheus – which orbit just inside and outside it. The gravitational influence of these moons confine the F ring to a band about 100km wide



Ring Systems of the other Jovian Planets

- Jupiter's ring system is much more tenuous than Saturn's. It was only detected by the Voyager space probes.

  The ring material is believed to be primarily dust, and extends from near Jupiter to about 3 planetary radii.



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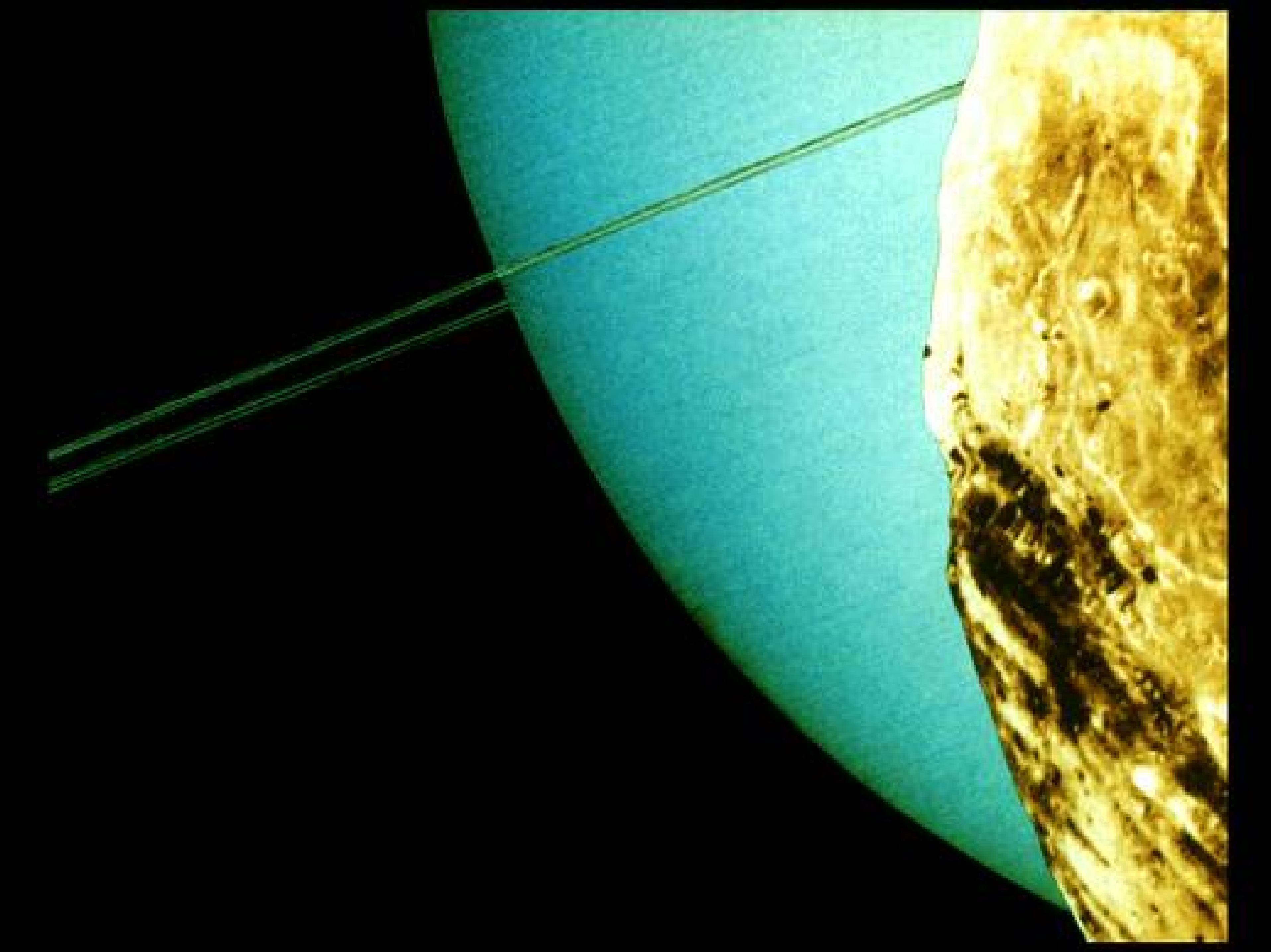
- Uranus' rings were discovered in 1977, during the **occultation** of a star, and were photographed by Voyager 2 in 1986.

  There are 11 rings in total, ranging in width from 10km to 100km. The ring particles are very dark (reflecting only 1% of sunlight) and about 1m across. Some rings are 'braided', and the thickest ring has shepherd moons. There is also a very thin layer of dust between the rings – probably the result of collisions.

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- Neptune's rings were also first discovered from occultation observations, and were photographed by Voyager 2 in 1989. There are 4 rings: two narrow and two diffuse sheets of dust. One of the rings has 4 'arcs' of concentrated material.

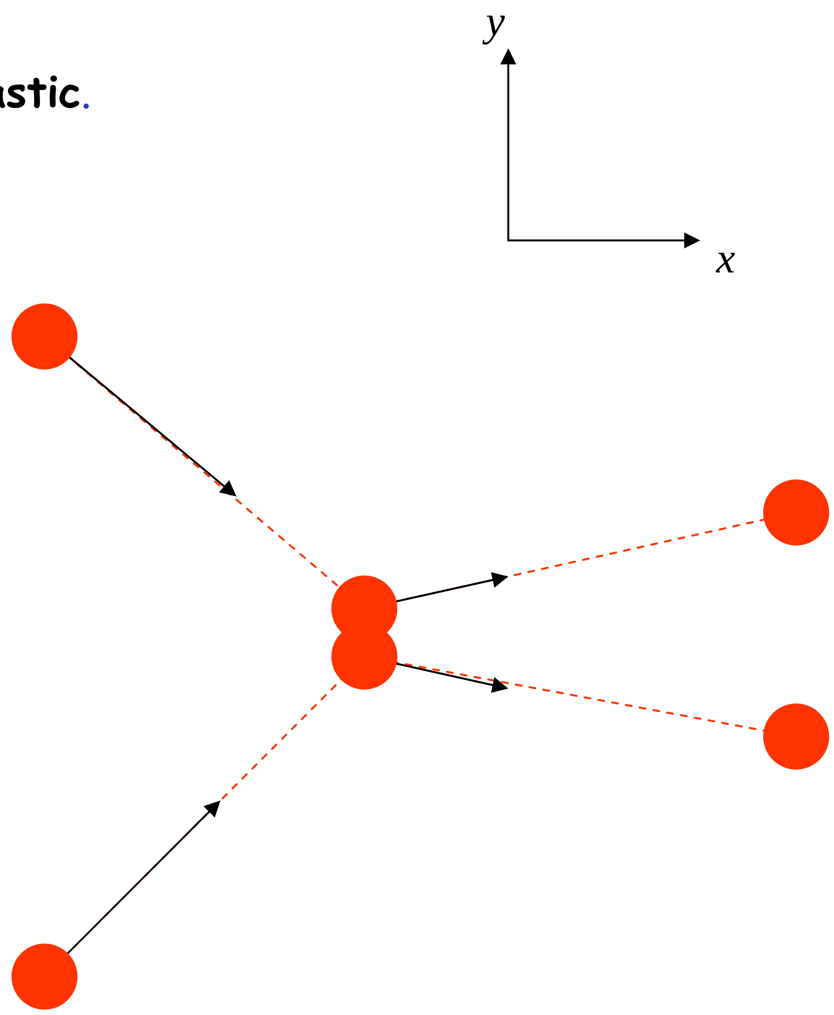
Why are the ring systems so thin?

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

$\Rightarrow$ thins disk of ring particles



How do ring systems form?

The ring systems of the Jovian planets are the result of **tidal forces**. During planetary formation, tidal forces prevented any material (planetesimals) that was too close to the planet clumping together to form moons. Also, any moons formed further out which later strayed too close to the planet would be tidally disrupted.

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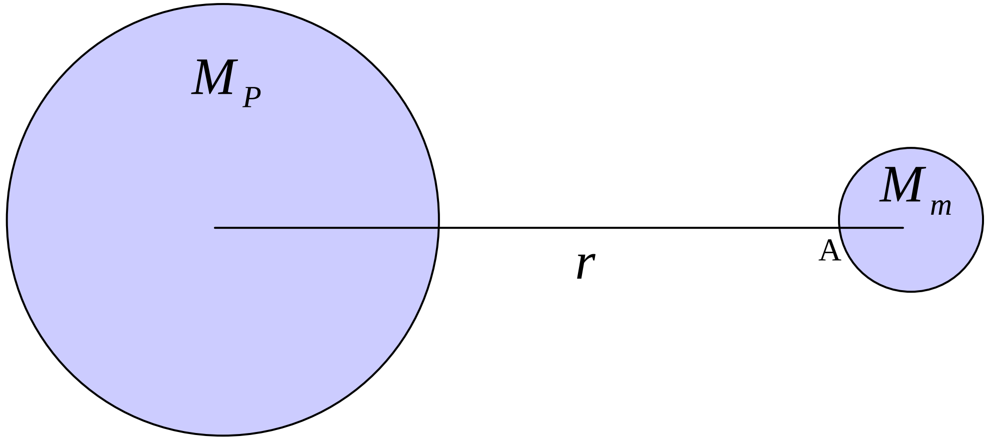
We can estimate the orbital radius at which a moon will break apart, due to tidal forces. Consider a moon, of mass M_m and radius R_m, in a circular orbit of radius r from a planet of mass M_P and radius R_P



Assume for simplicity, spherical planet and moon

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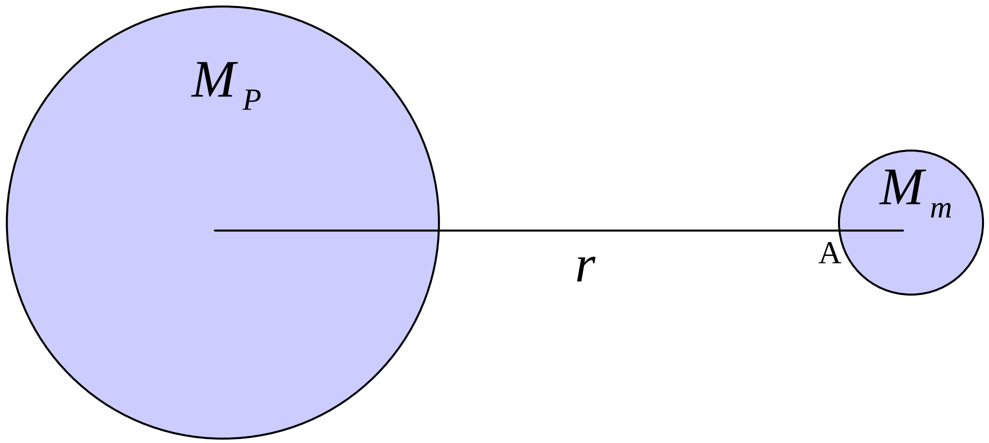
Force on a unit mass at A due to gravity of **moon alone** is

$$F = \frac{G M_m}{R_m^2}$$



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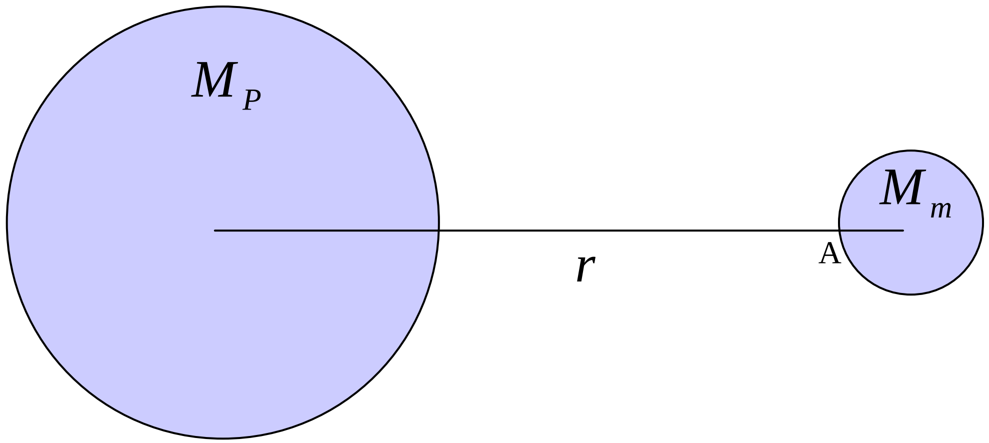

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Tidal force at A due to gravity of **planet** is *

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

* Putting $dr = R_m$

How do ring systems form?

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

$$F_T > F_G$$

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Substituting $M_P = \frac{4\pi}{3}\,\overline{\rho}_P\,R_P^{\;3}$ and $M_m = \frac{4\pi}{3}\,\overline{\rho}_m\,R_m^{\;3}$

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More careful stability analysis

$$r < 2.456\left(\frac{\overline{\rho}_P}{\overline{\rho}_m}\right)^{1/3} R_P \quad = \quad \text{Roche Limit}$$

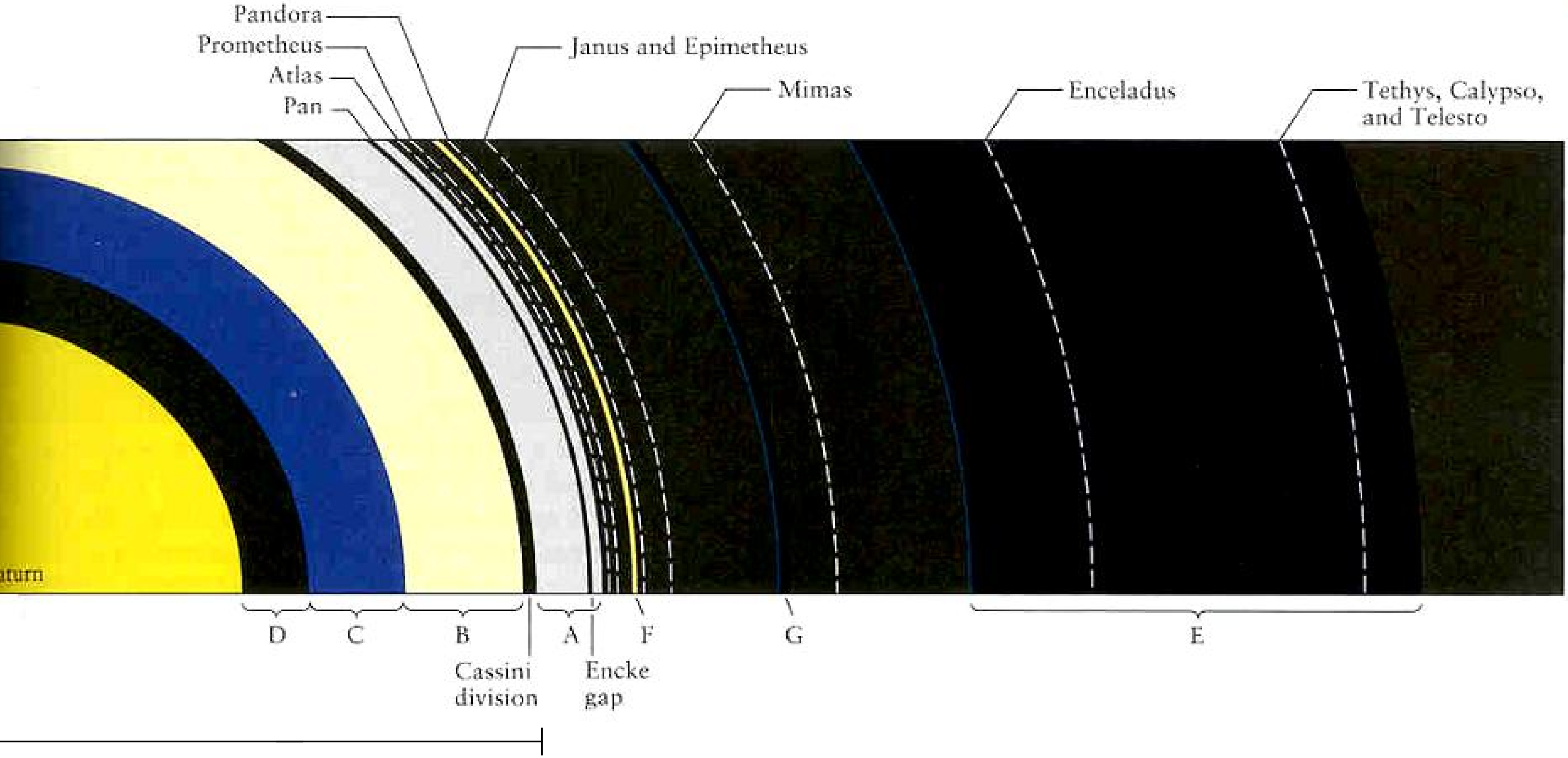
How do ring systems form?

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

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

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

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



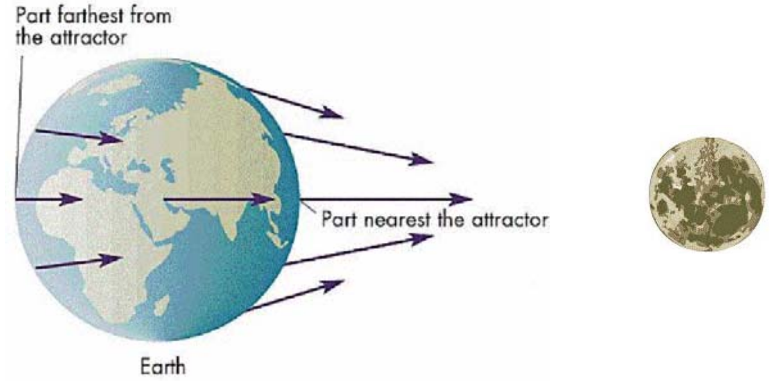
Roche stability limit

More on Tidal Forces

Of course, tidal forces also have an effect (albeit less destructive) *outside* the Roche stability limit.

Consider the effect of 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)



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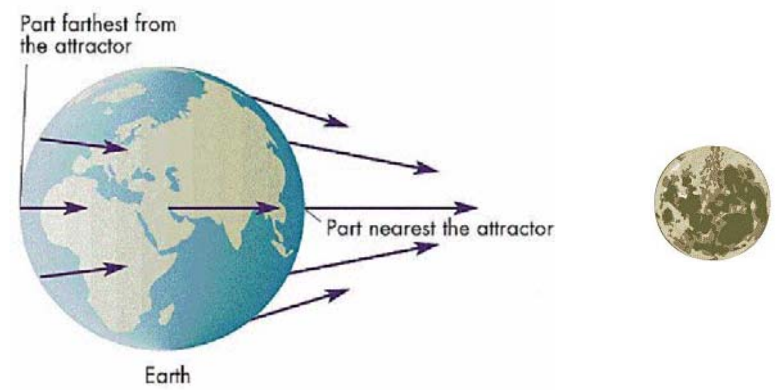

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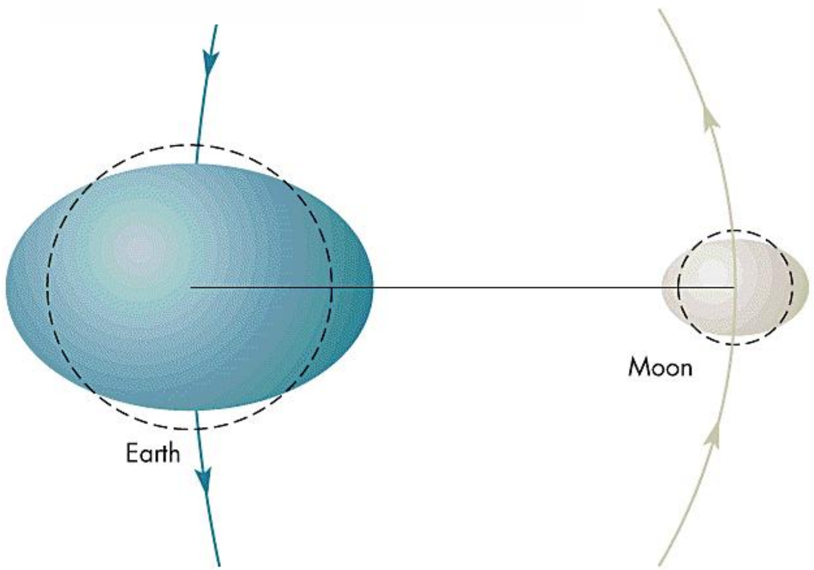
There are, therefore, **two** high and low tides every ~25 hours.



(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. Thus high and low tides are not at the same time each day)

More on Tidal Forces

The Sun also exerts a tide on the Earth.

Now, $F_T \propto \dfrac{M_P}{r^3}$ so $\dfrac{F_{T,\text{Sun}}}{F_{T,\text{Moon}}} = \dfrac{M_{\text{Sun}}}{M_{\text{Moon}}} \left(\dfrac{r_{\text{Moon}}}{r_{\text{Sun}}} \right)^3$

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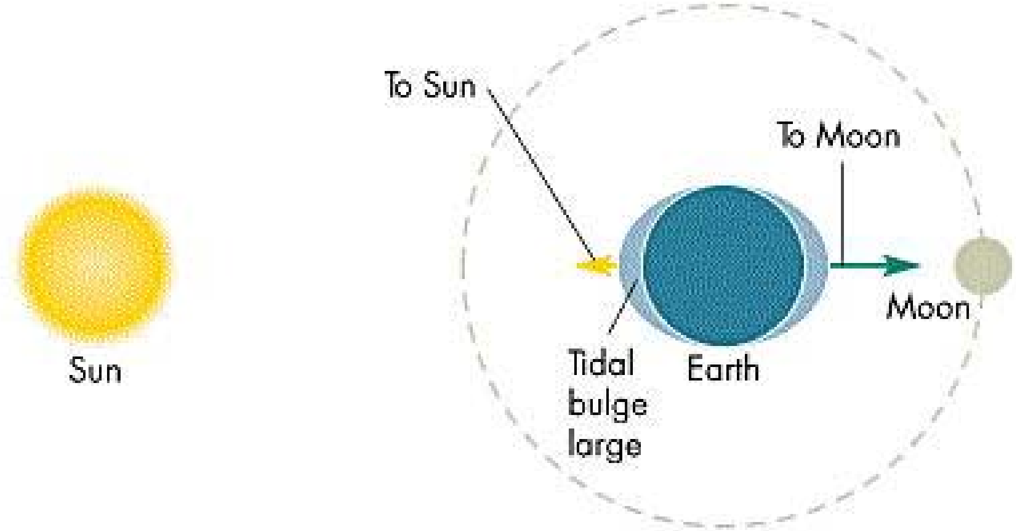
Hence $$\frac{F_{T,\mathrm{Sun}}}{F_{T,\mathrm{Moon}}} = \frac{M_{\mathrm{Sun}}}{M_{\mathrm{Moon}}}\left(\frac{r_{\mathrm{Moon}}}{r_{\mathrm{Sun}}}\right)^3 \approx 0.5$$

i.e. the tidal forces on the Earth due to the Sun and Moon are **comparable**.

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