Section 9: Ring Systems of the Jovian Planets

All four Jovian planets have **RING SYSTEMS**. e.g. **Saturn's rings** are easily visible from Earth with a small telescope, and appear solid.

The rings consist of countless lumps of ice and rock, ranging from ~1cm to 5m in diameter, all independently orbiting Saturn in an incredibly thin plane – less than 1 kilometre in thickness.

(Diameter of the outermost ring – 274000 km. If Saturn's rings were the thickness of a CD, they would still be more than 200m in diameter!)

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'

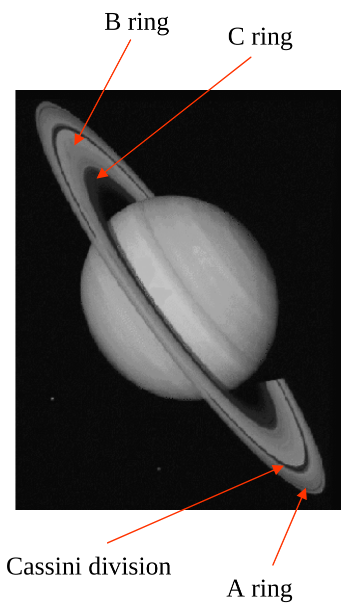
Saturn's rings are bright; they reflect ~80% of the sunlight that falls on them. Their ice/rock composition was confirmed in the 1970s when **absorption lines** of water were observed in the **spectrum** of light from the rings.

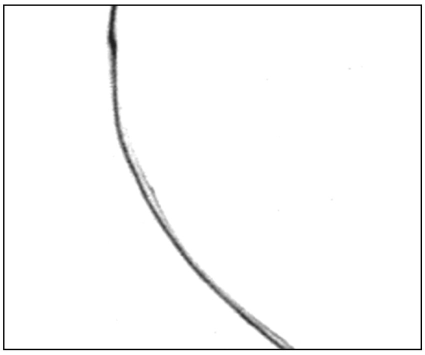
(See A1Y Stellar astrophysics for more on spectra and absorption lines)

Ground-based observations show only the **A**, **B** and **C** rings.

In the 1980s the **Voyager** spacecraft flew past Saturn, and observed thousands of **'ringlets'** – even in the **Cassini Division** (previously believed to be a gap).

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

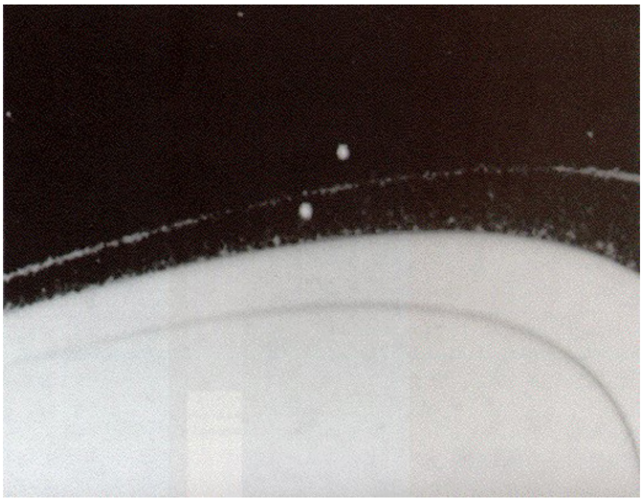




The F ring shows braided structure, is very narrow, and contains large numbers of micron-sized particles.

The structure of the F ring is 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 primarily dust, and extends to about 3 Jupiter radii.

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

  There are 11 rings, ranging in width from 10km to 100km. The ring particles are very dark and ~1m across. Some rings are 'braided', and the thickest ring has shepherd moons. There is a thin layer of dust between the rings, due to collisions.

- **Neptune**'s rings were first 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.

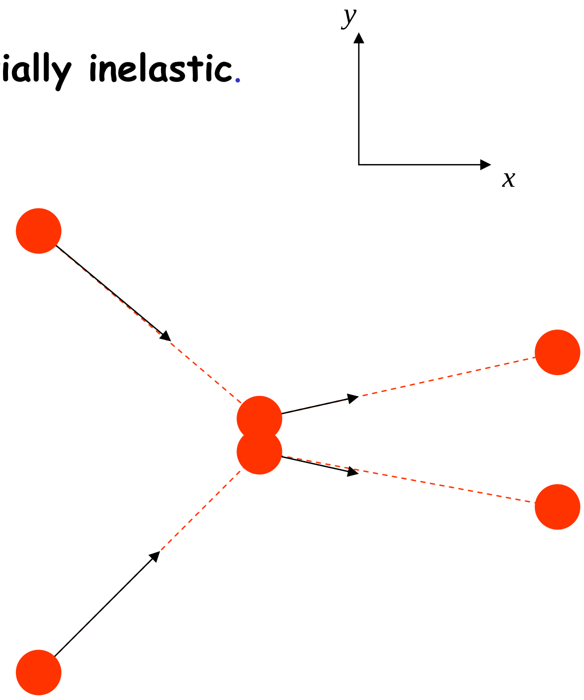
Why are the ring systems so thin?

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

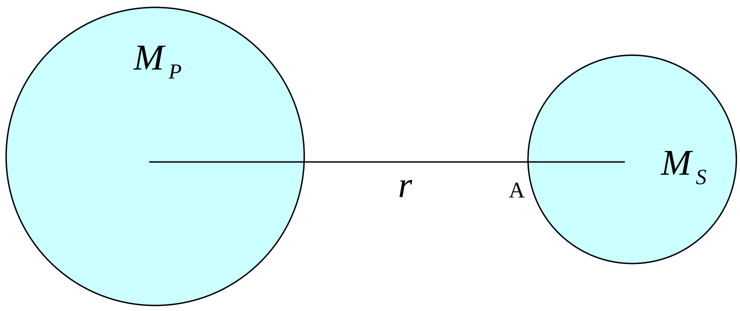
$\Rightarrow$ this thins out the disk of ring particles



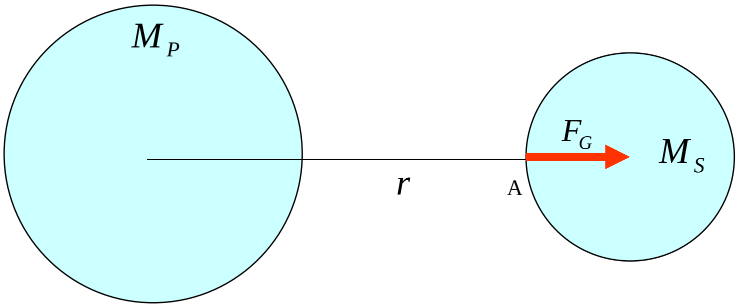
Section 10: Formation of ring systems

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.



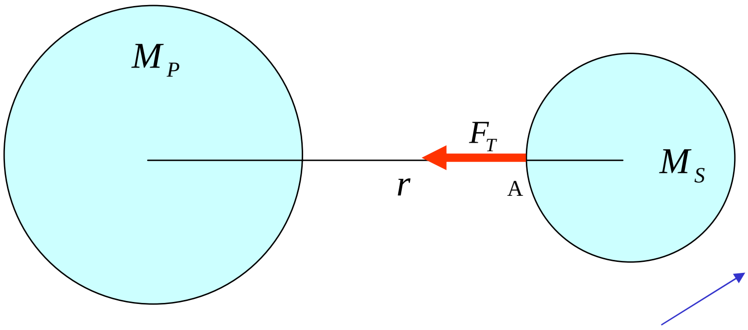
(Assume that the planet and moon are spherical)



(Assume that the planet and moon are spherical)

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

$$F_G = \frac{G M_S}{R_S^{\ 2}} \qquad (10.1)$$



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

$$F_T = \frac{2G M_P R_S}{r^3} \qquad (10.2)$$

This follows from eq. (4.3) putting $\Delta = R_S$

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

$$F_T > F_G \qquad (10.3)$$

In other words, if

$$\frac{2G M_P R_S}{r^3} > \frac{G M_S}{R_S^{\ 2}} \qquad (10.4)$$

This rearranges further to

$$r \ < \ 2^{1/3} \left(\frac{M_P}{M_S} \right)^{1/3} R_S \qquad (10.5)$$

We can re-cast eq. (10.5) in terms of the *planet's* radius, by writing **mass = density × volume**.

Substituting
$$M_P = \tfrac{4\pi}{3}\,\overline{\rho}_P\,{R_P}^3$$

$$M_S = \tfrac{4\pi}{3}\,\overline{\rho}_S\,{R_S}^3$$

So the moon is tidally disrupted if
$$r \;<\; 2^{1/3}\left(\frac{\overline{\rho}_P}{\overline{\rho}_S}\right)^{1/3} R_P \qquad (10.6)$$

More careful analysis gives

the **Roche Stability Limit**
$$r < 2.456\left(\frac{\overline{\rho}_P}{\overline{\rho}_m}\right)^{1/3} R_P \qquad (10.7)$$

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

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

This implies
$$r_{RL} = 2.456 \times \left(\frac{700}{1200}\right)^{1/3} \times R_P \;=\; 2.05\,R_P \qquad (10.8)$$

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