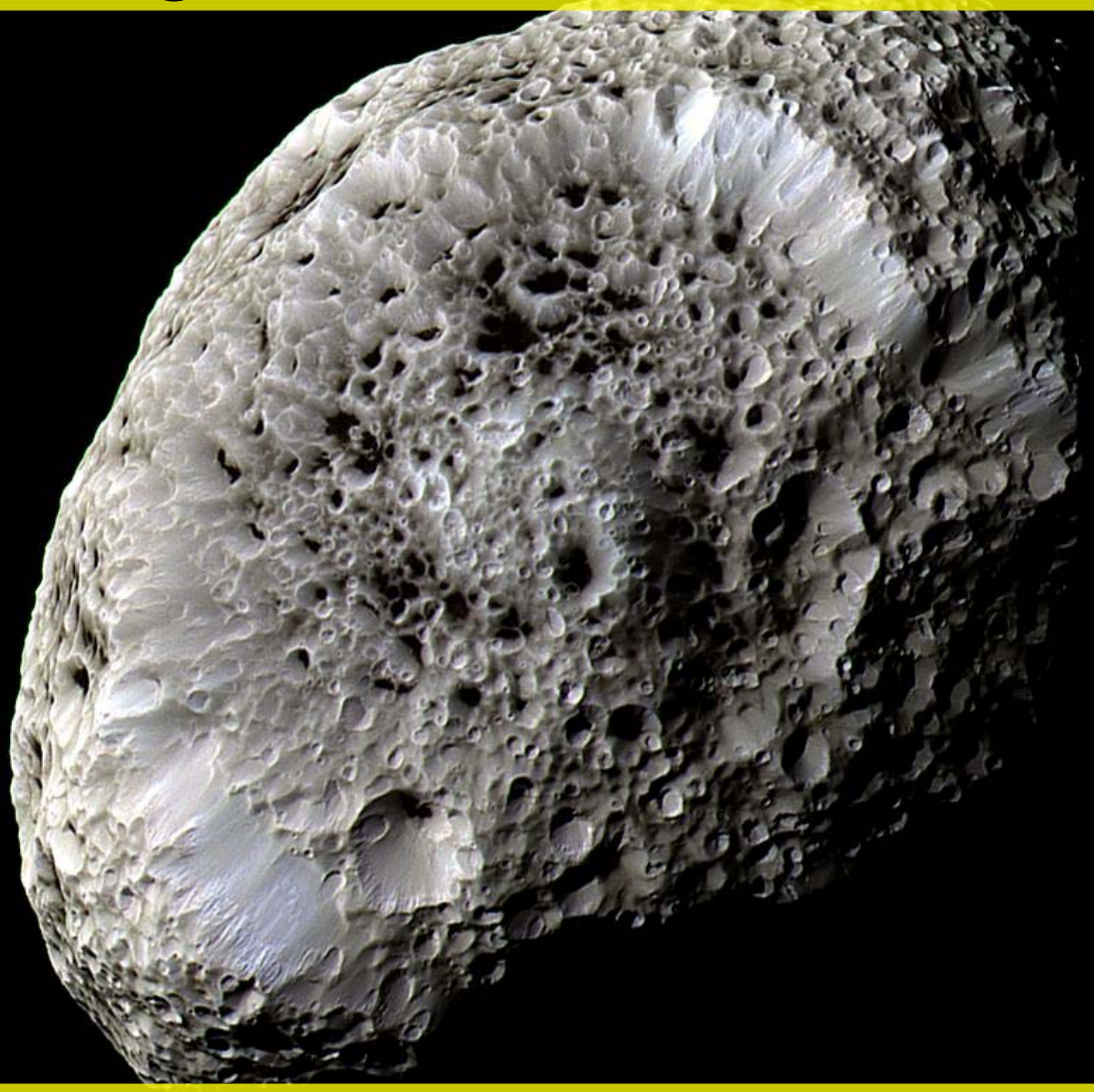
Rings and Moons of Saturn

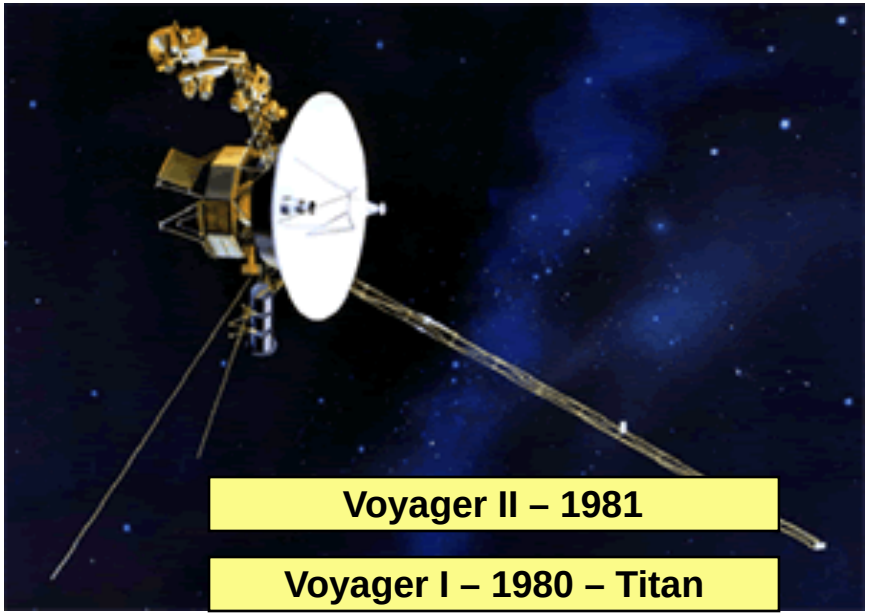


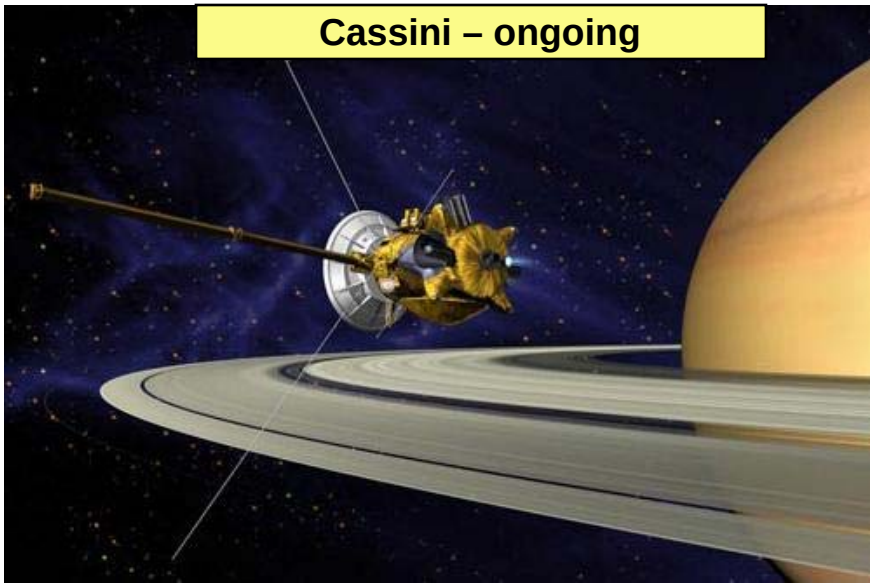
PTYS/ASTR 206 – The Golden Age of Planetary Exploration

Shane Byrne – shane@lpl.arizona.edu

In this lecture…

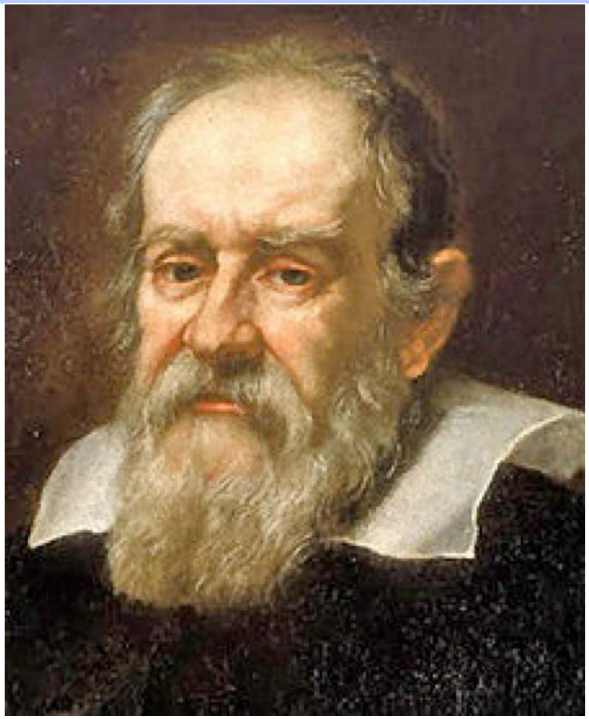
- Rings
  - Discovery
  - What they are
  - How to form rings
    - The Roche limit
  - Dynamics
    - Gaps and resonances
    - Shepherd moons
- Inner moons
  - Tectonics and craters
  - Enceladus – a very special case
- Outer Moons
  - Captured Phoebe
  - Iapetus and Hyperion
    - Spray-painted with Phoebe debris



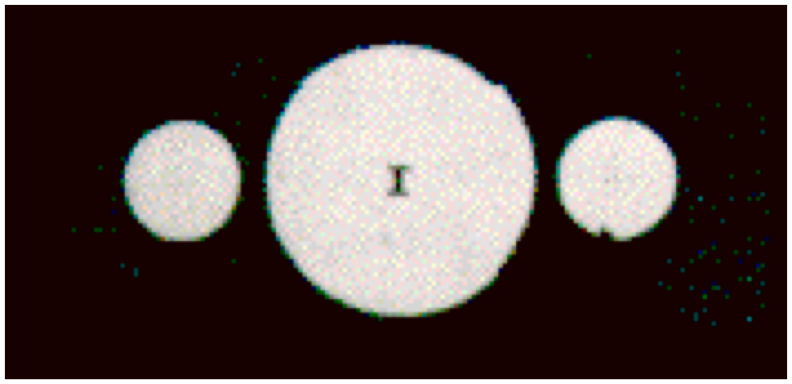


- **We can divide Saturn's system into three main parts…**
  - **The A-D ring zone**
    - **Ring gaps and shepherd moons**
  - **The E ring zone**
    - **Ring supplies by Enceladus**
    - **Tethys, Dione and Rhea have a lot of similarities**
  - **The distant satellites Iapetus, Hyperion, Phoebe**
    - **Linked together by exchange of material**

Discovery of Saturn's Rings



- Discovered by Galileo
- Appearance in 1610 baffled him

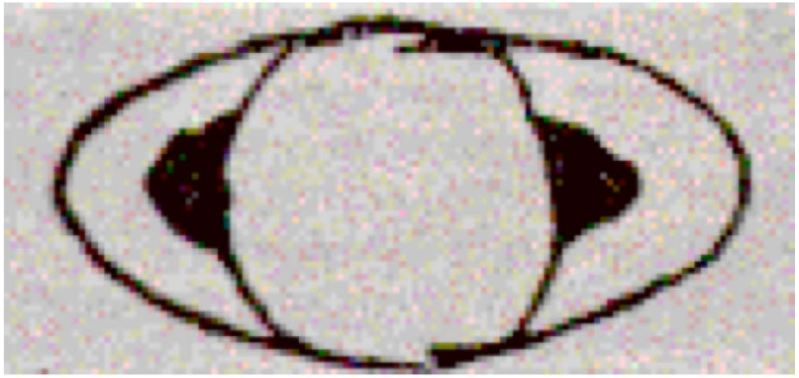


"…to my very great amazement Saturn was seen to me to be not a single star, but three together, which almost touch each other"

- It got more confusing…
  - In 1612 the extra "stars" had disappeared

"…I do not know what to say…"

- In 1616 the extra ‘stars’ were back
  - Galileo’s telescope had improved
  - He saw two “half-ellipses”
  - He died in 1642 and never figured it out

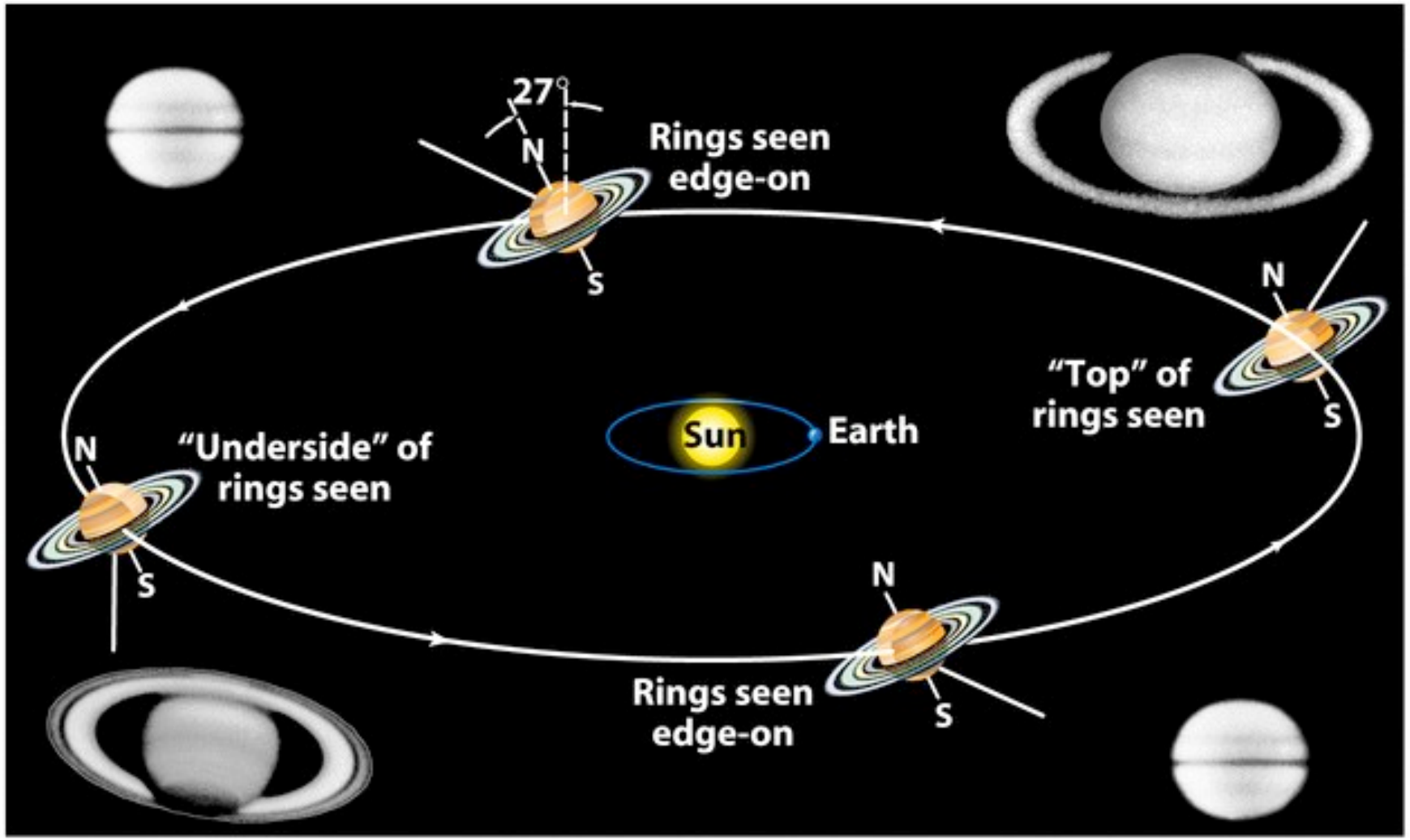


- In the 1650s Huygens figured out that
  - Saturn was surrounded by a flat disk
  - The disk disappears when seen edge on
  - He discovered Saturn’s largest Moon – Titan
  - …but he thought the disk was solid

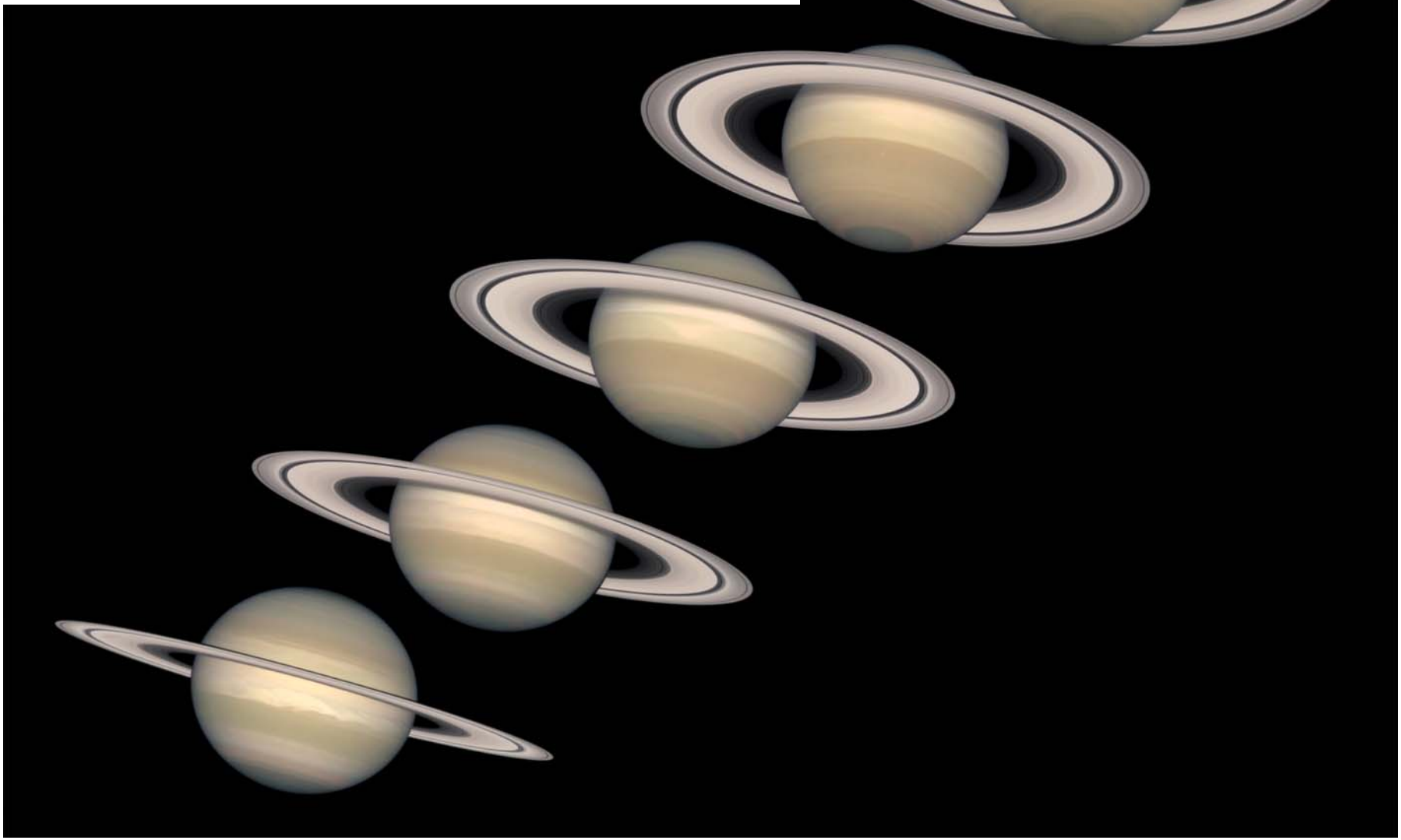
- Other notable contributions
  - Cassini (1676) discovered there is more than one ring
  - Chapelain (1660) and Maxwell (1856) suggest the rings are a swarm of small particles

- **400 years makes a big difference**

- **Ring plane crossings**
  - **Saturn's rings orbit around its equator**
  - **Saturn is inclined to the ecliptic (where the Earth is) by 27°**



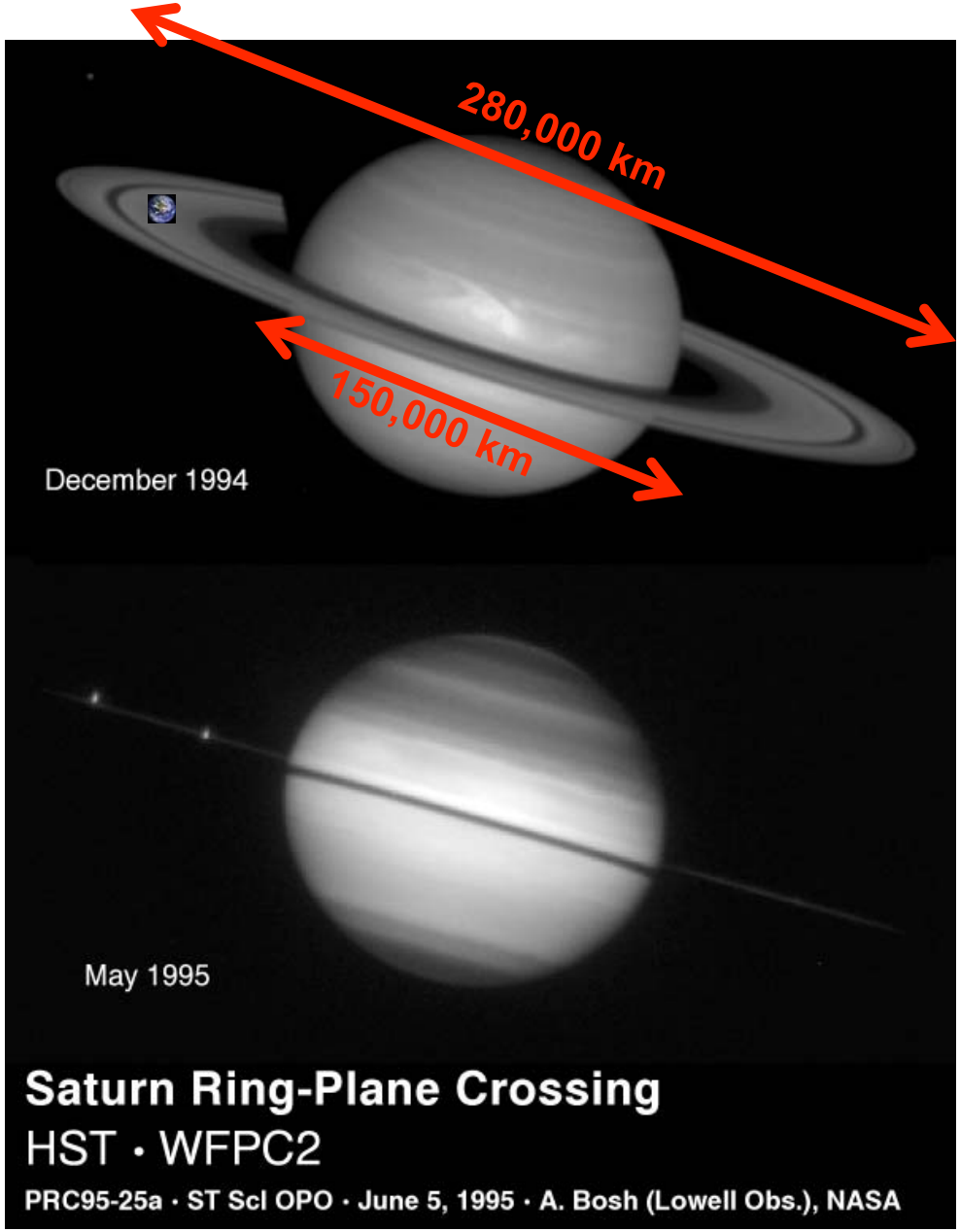
- **This entire cycle takes 29.4 years – Saturn's orbital period**
  - **Saturn's rings seen edge-on every 15 years (including in 2009)**



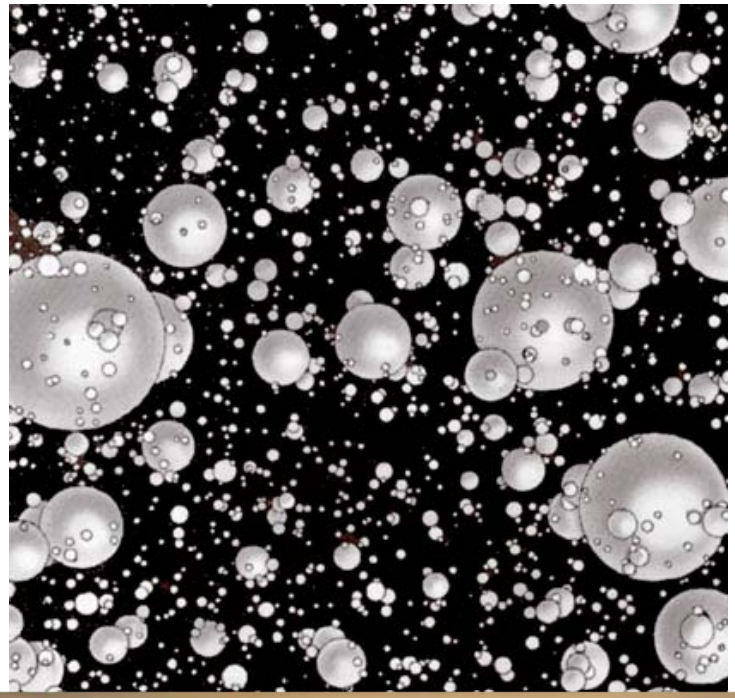
- Moons are easier to see during ring plane crossings

- Rings are **very** thin
  - Less than 200m thick
  - Probably only a few 10s of meters thick
  - …and 280,000 km across!

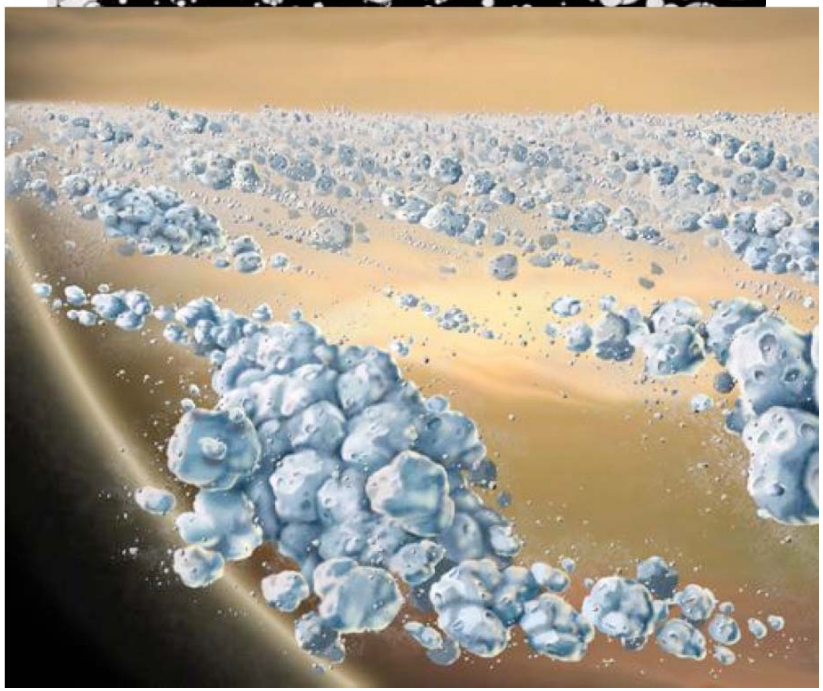
  - Much thinner than a sheet of paper scaled up
  - A standard piece of copier paper scaled up to the size of Saturn's rings would be about 100km thick
  - Rings are 1000 times thinner than this



- Rings are composed of a swarm of small particles
  - Size range 1cm – 5m
  - Power law distribution – smaller particles more numerous than larger ones
    - Just like impact crater sizes
  - Particles are breaking up into smaller pieces due to collisions



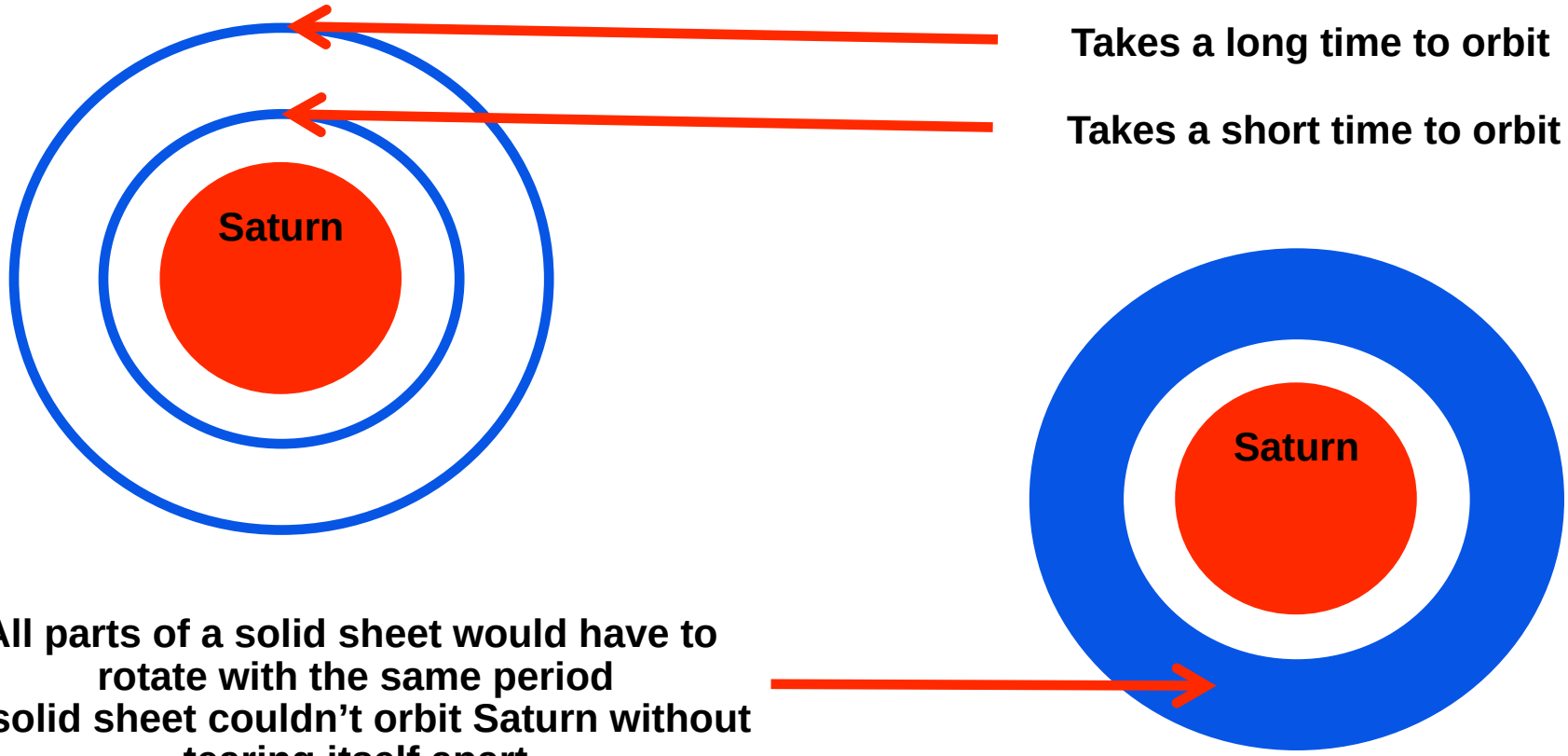
- Spectra show these particles to be water ice



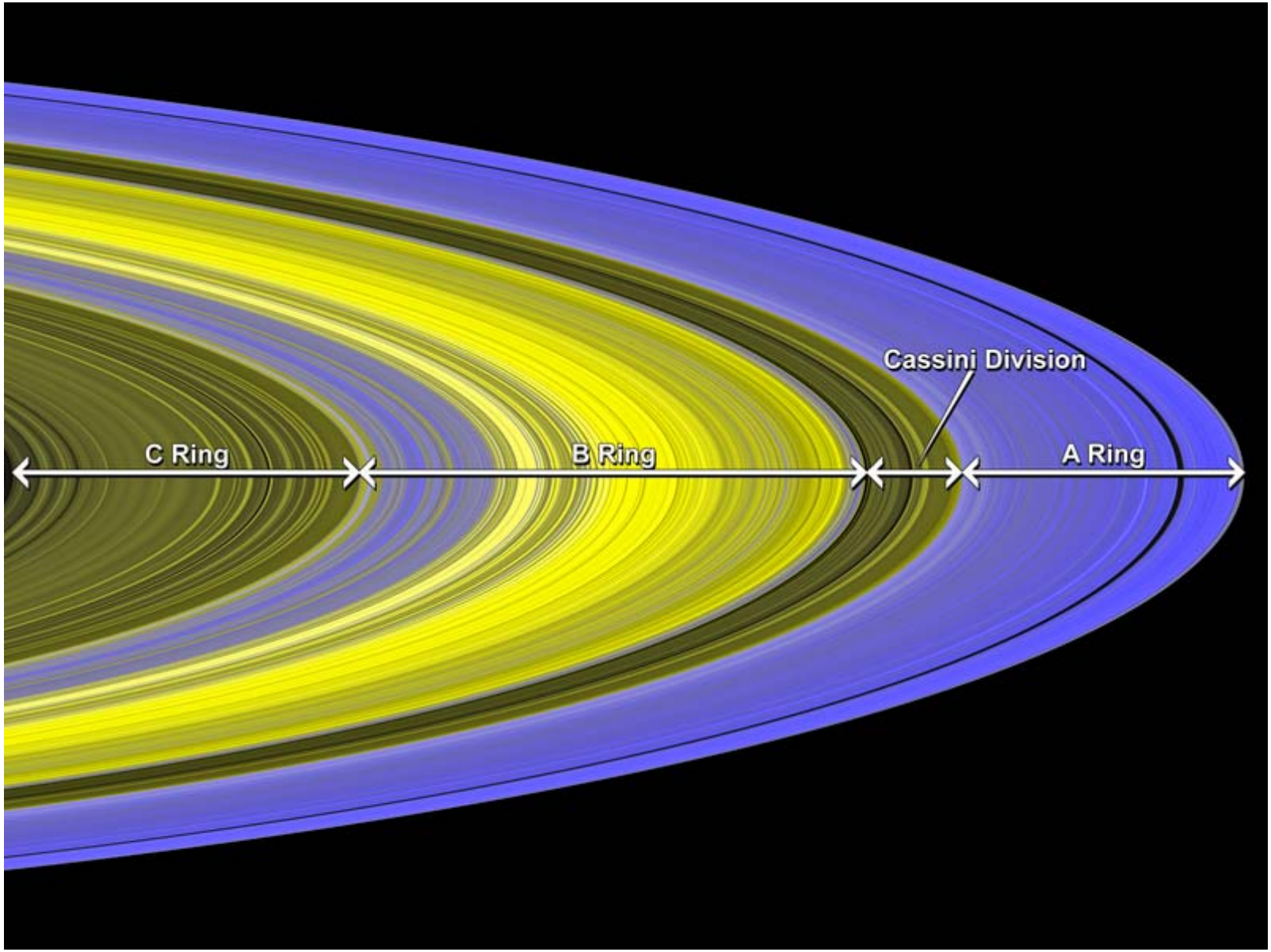
- Small particles can temporarily clump together

- **Why can't Saturn's rings be solid sheets…**
  - **Remember Kepler's 3rd law**
  - **Objects nearer the Sun take less time to orbit**
    - **E.g. Earth takes 1 year, Mars takes 1.9 years**
  - **The same is true for objects orbiting Saturn**

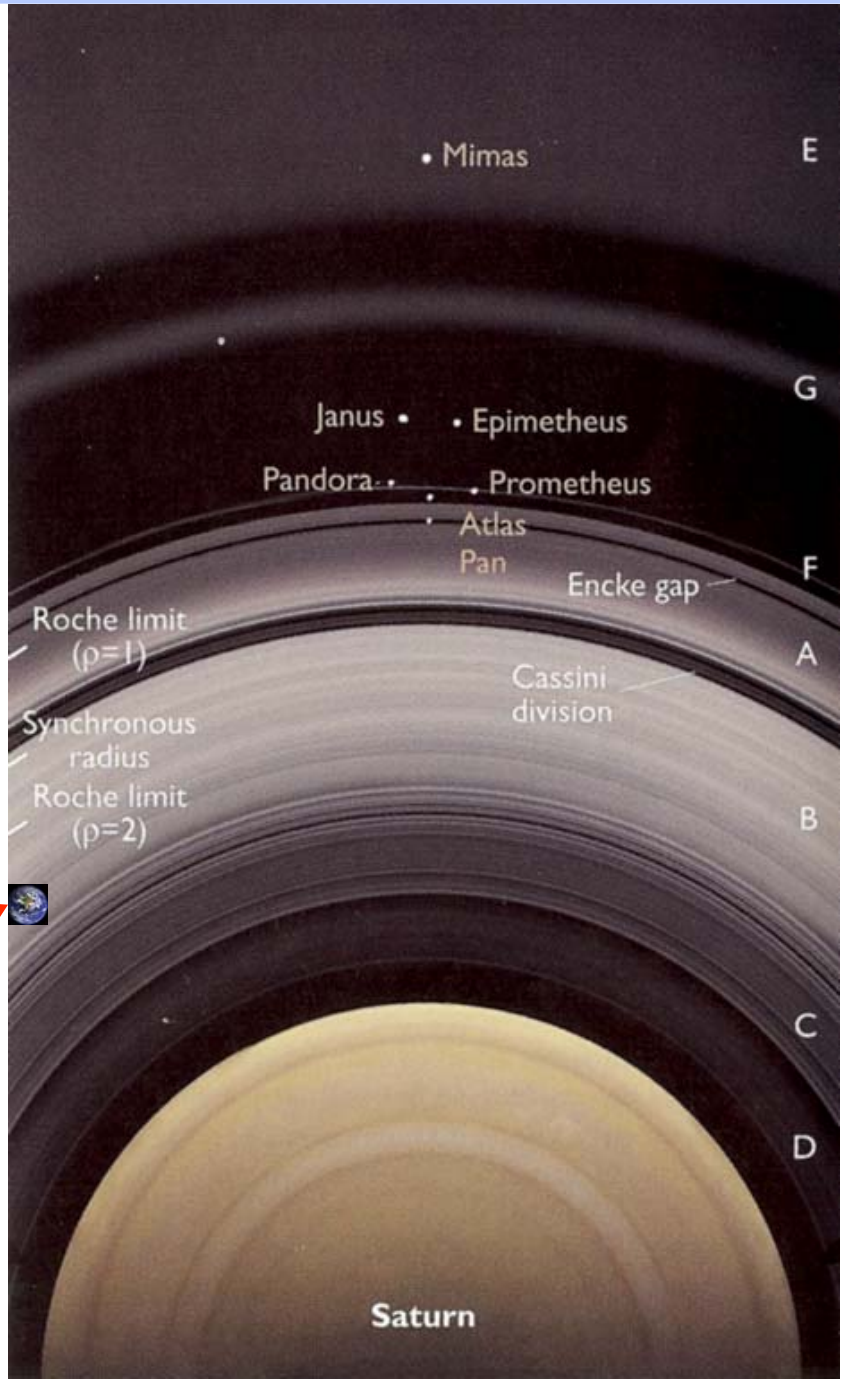
$$P^2 \propto a^3$$



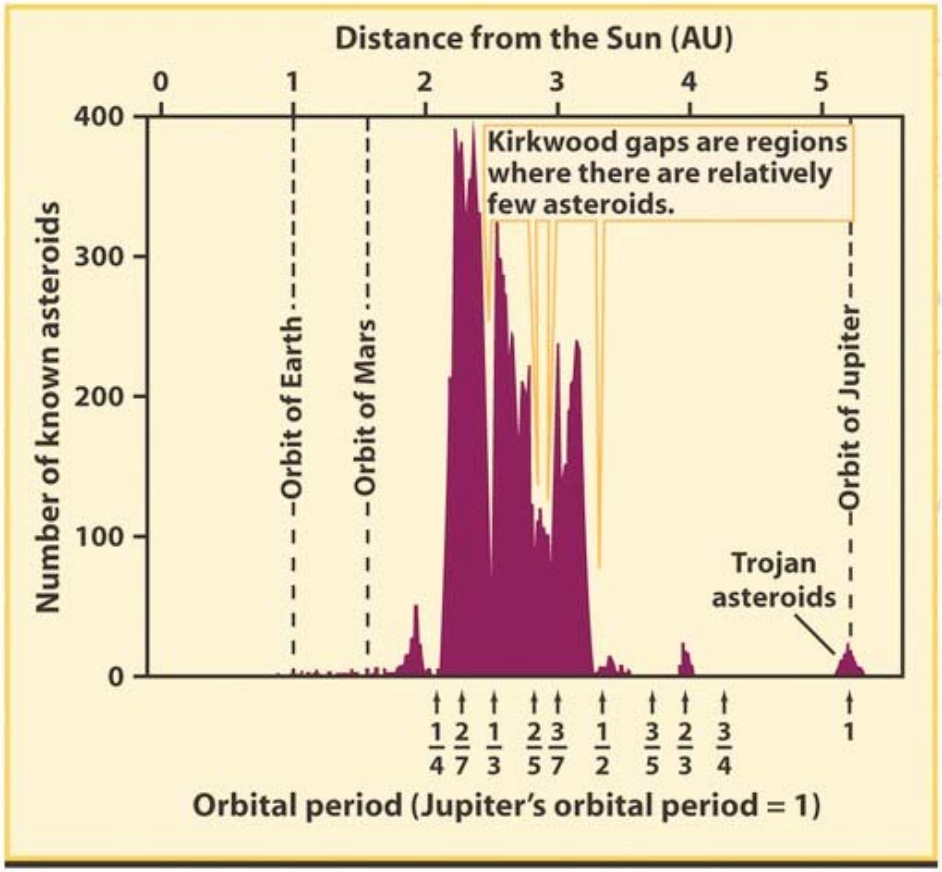
- There's some compositional variation between rings
- Very little mixing of material from ring to ring – i.e. particles have very circular orbits



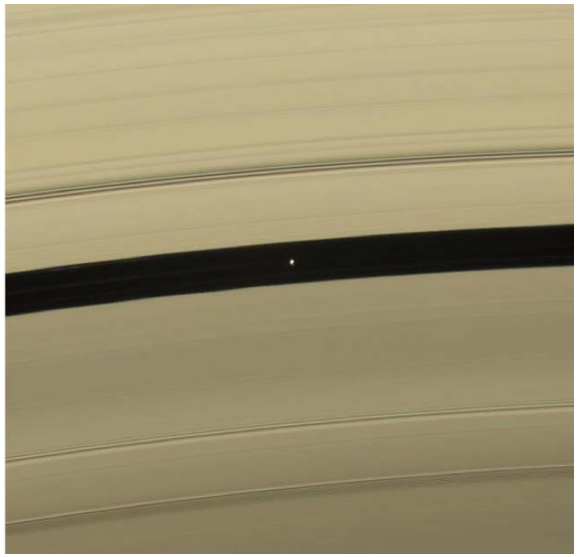
- Rings labeled by letters
  - A ring 200-500 Kg m^2
  - B ring 500-800 Kg m^2
  - C ring 10 Kg m^2
- Total mass of the rings
  - Similar to Mimas, ~400km across
- Separated by gaps
  - The gaps are not totally empty
  - Cassini gap - 100 Kg m^2
- Ring albedo is very high, ~0.8
- Earth for scale



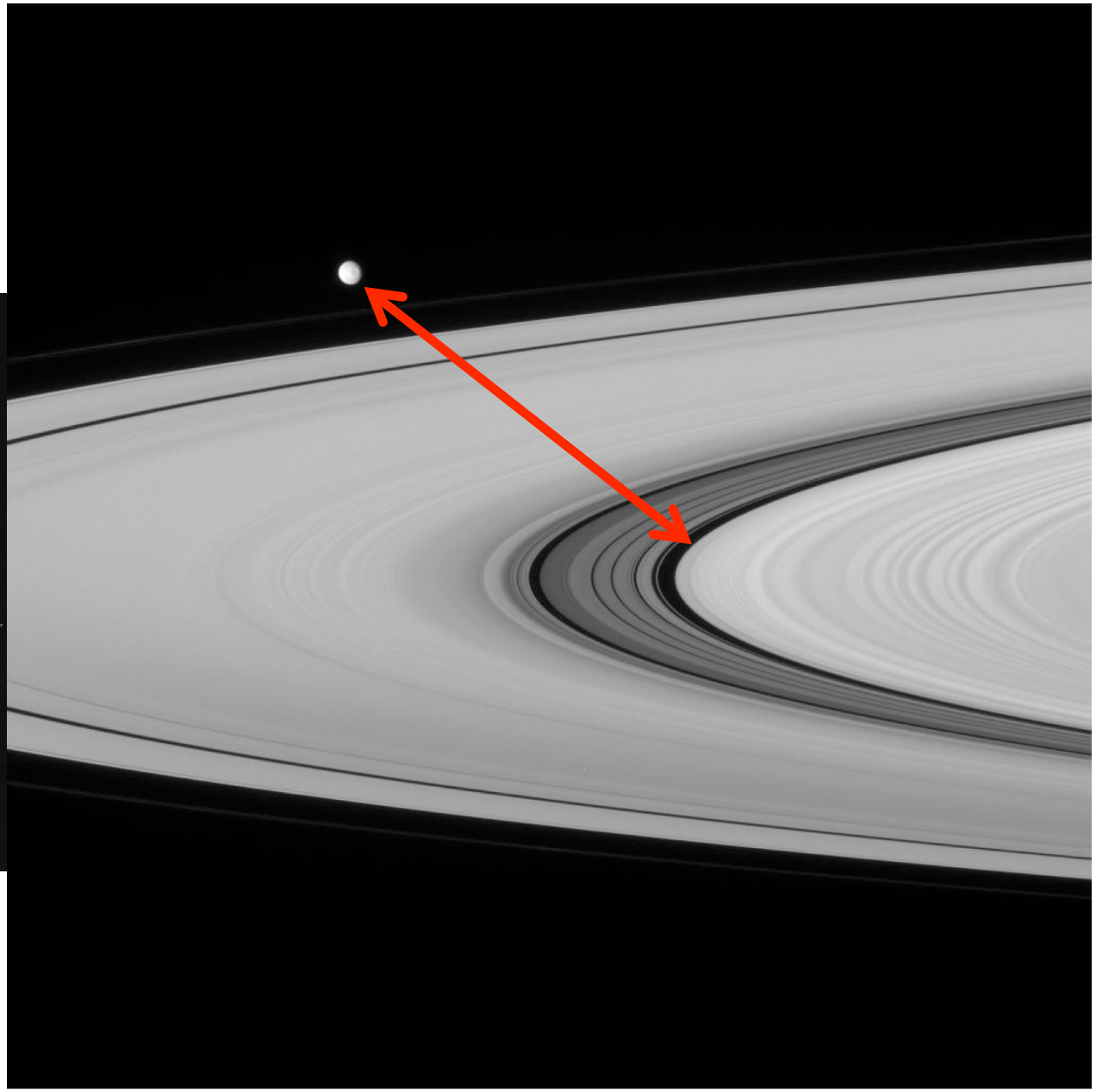
- Gaps in the rings caused by resonances with moons
  - Just like Kirkwood gaps in the asteroid belt – resonances with Jupiter
  - Periods are simple fractions of moon periods



- ...but a little different
  - Asteroid orbits were eccentric
  - Asteroids criss-crossed the Kirkwood gaps
  - Ring particle orbits are very circular
  - Gaps really do look like gaps

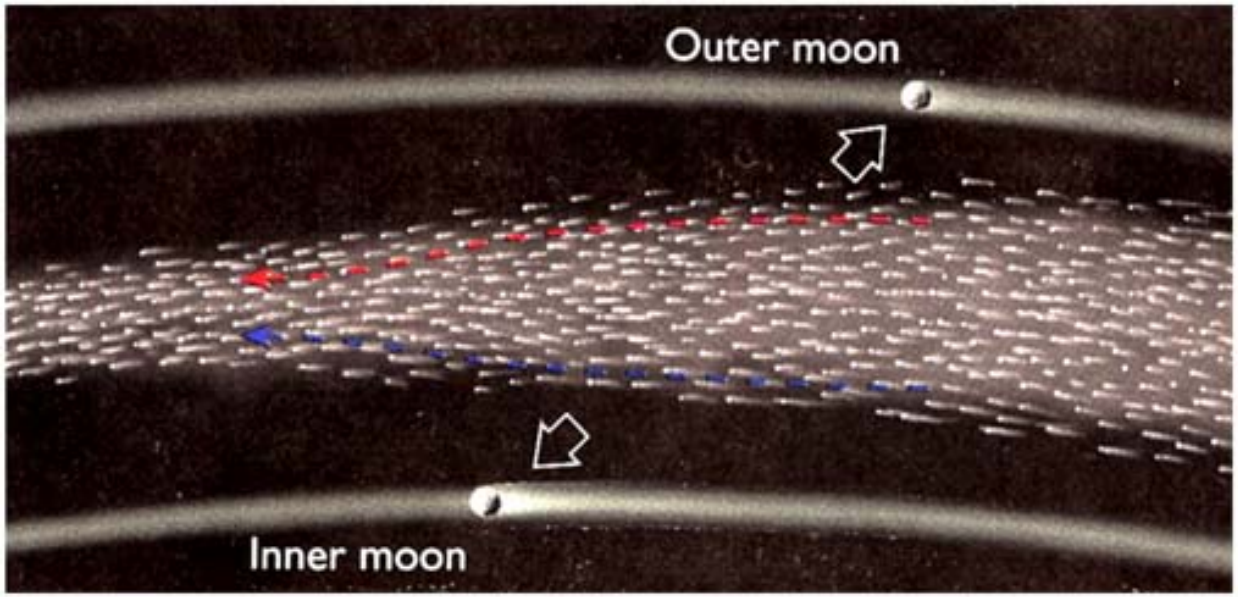


- **Huygens gap**
  - **2:1 resonance with Mimas**
  - **Mimas orbits in ~1 day**

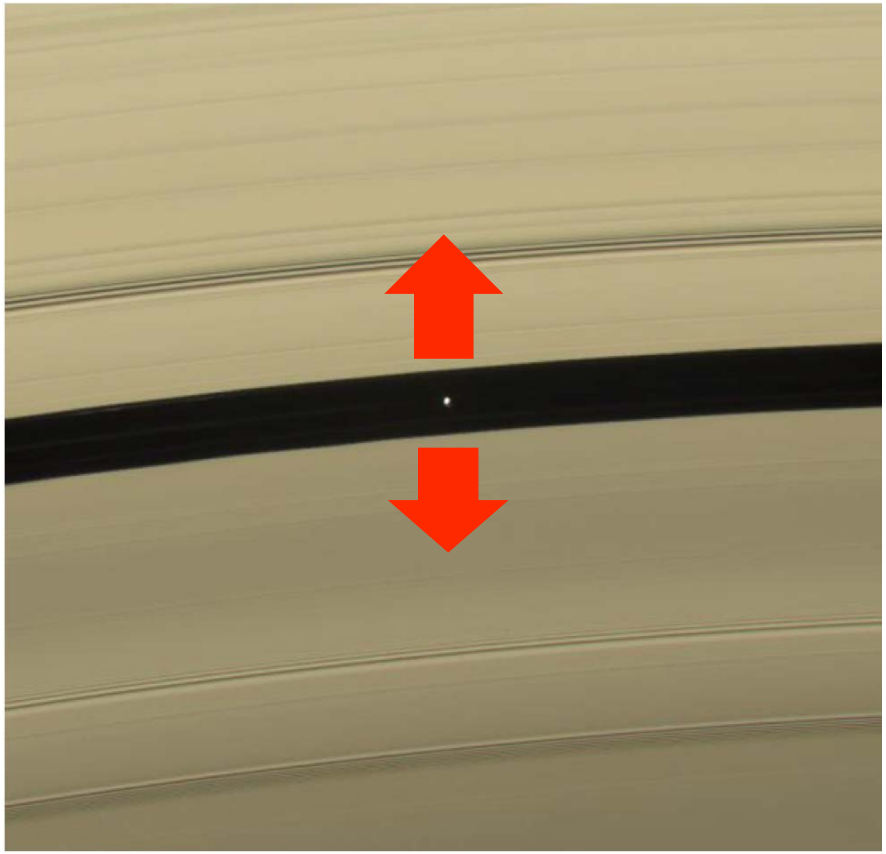


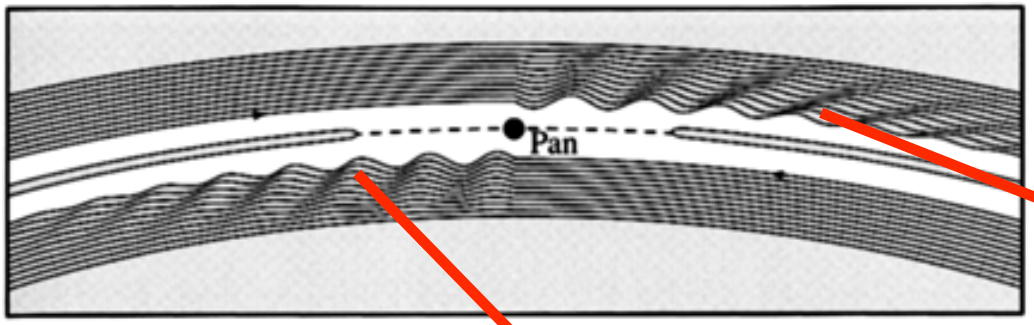
- **Collisions between ring particles should cause the rings to spread out…**
  - **Interactions with Moons can keep the edges sharp**
  - **Swarm of ring particles is ‘herded’ by shepherd moons**

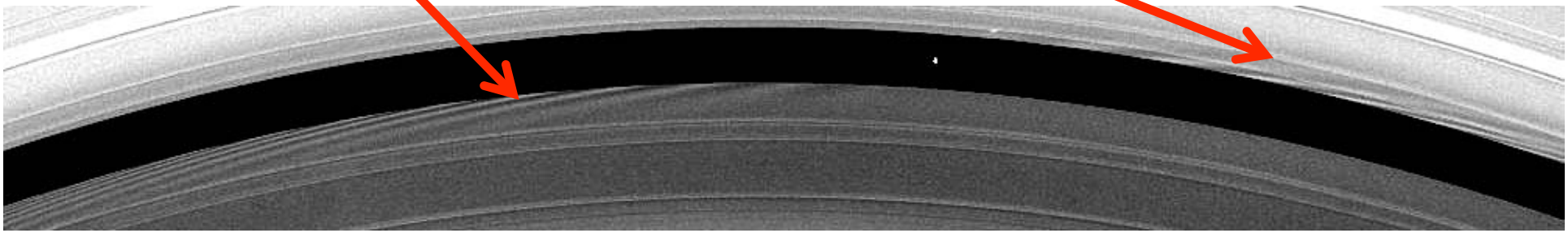
  - **Moon ‘repel’ ring particles**
  - **Moons speed up and slow down passing ring particles causing them to drift outwards/inwards**
  - **Not a totally symmetric process**
    - **Inner moons cause particles to drift outwards**
    - **Outer moons cause particles to drift inwards**



- Two types of shepherding…
- Gaps
  - Encke gap produced by Pan
  - Particles on either side repelled
  - Predicted density waves observed by Cassini







- **Keeler gap is another example**

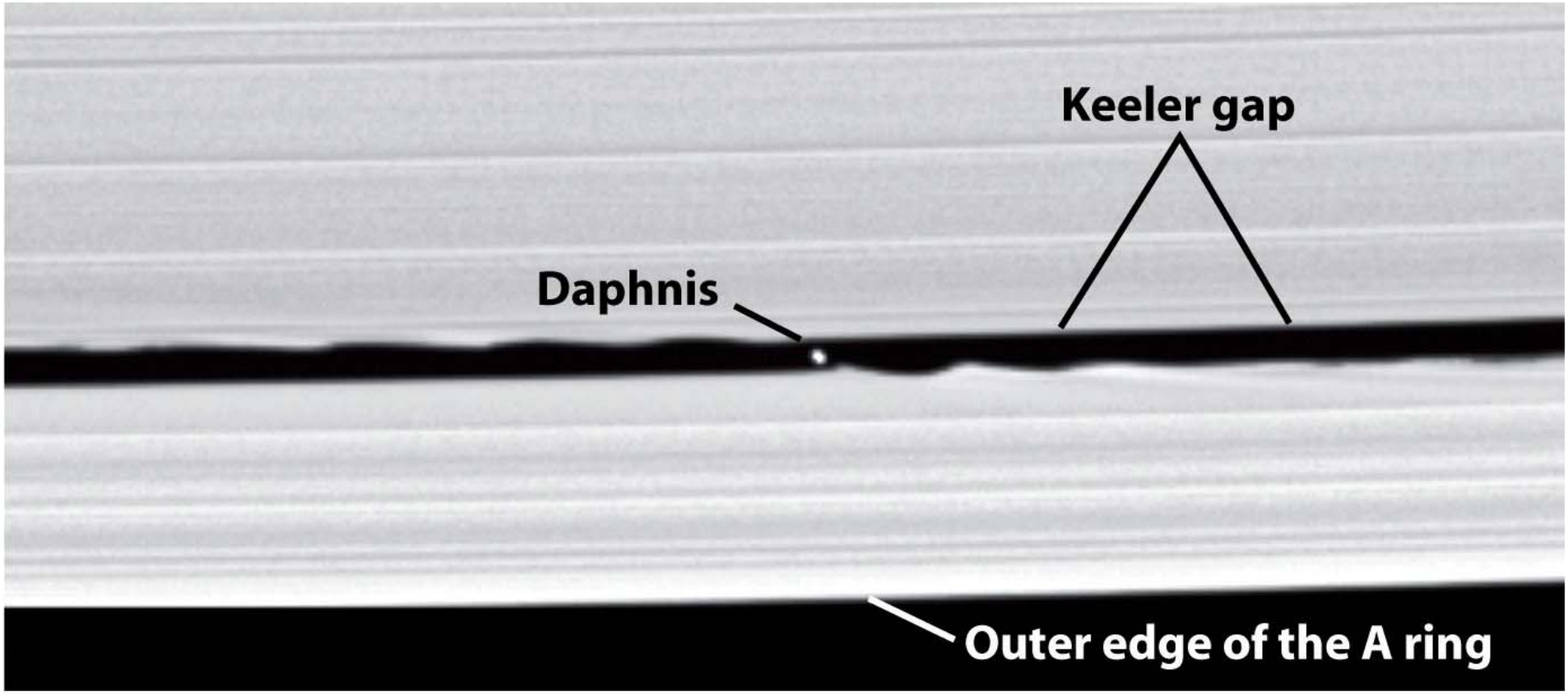
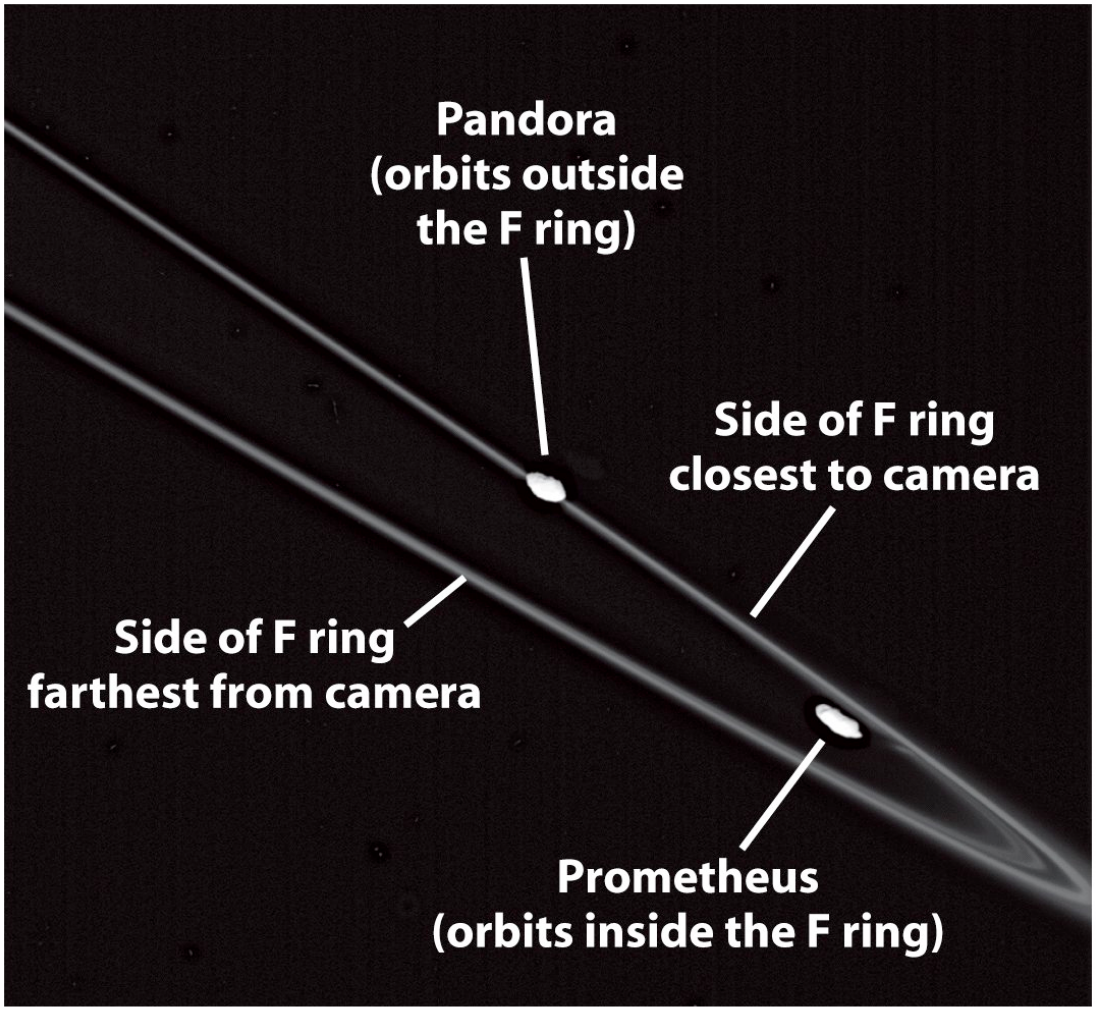
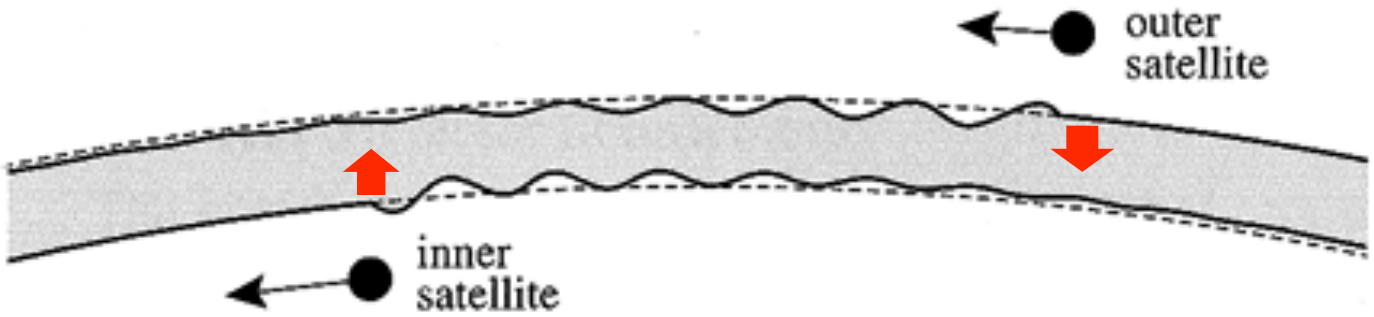
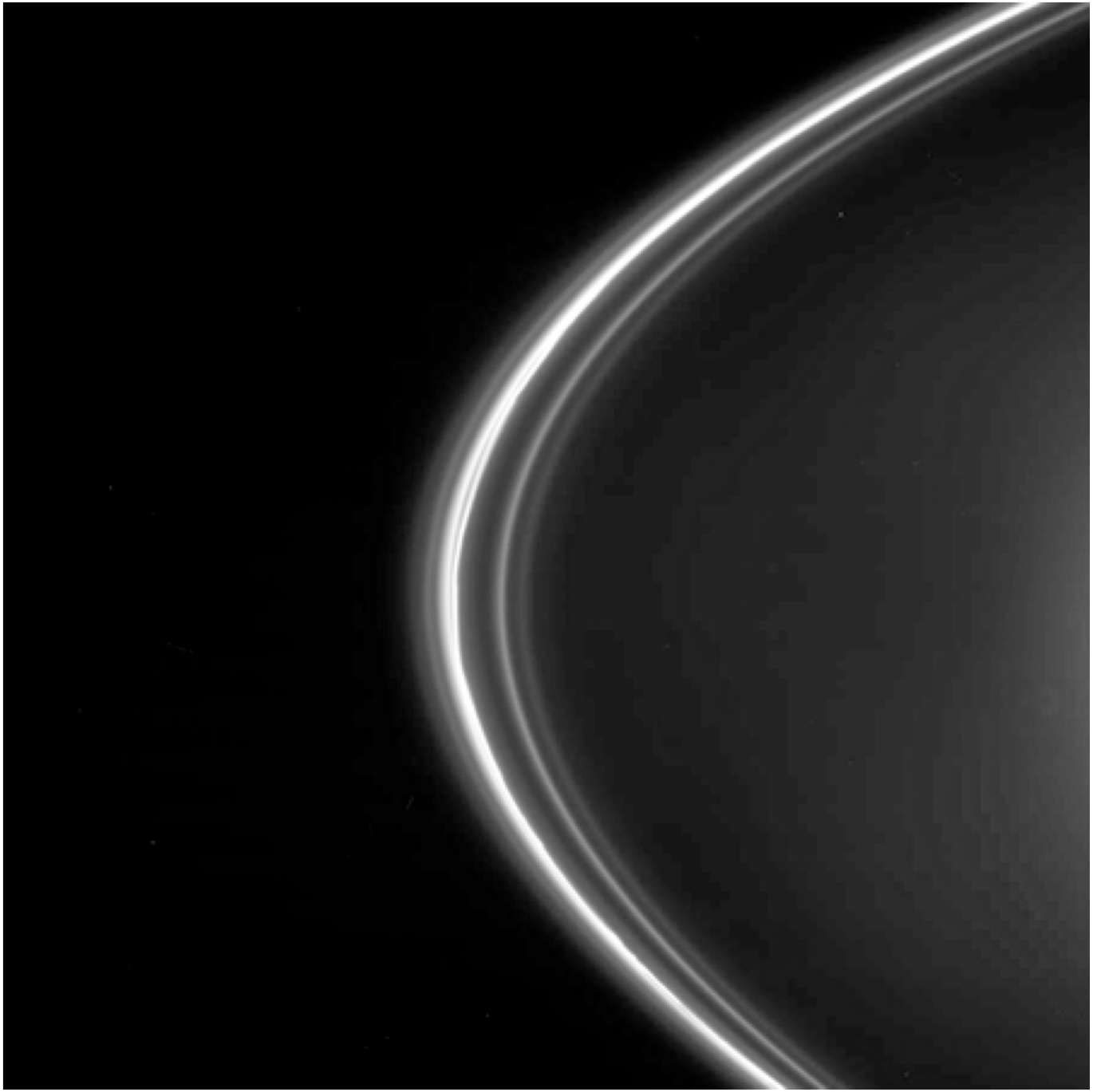


Figure 12-25
Universe, Eighth Edition

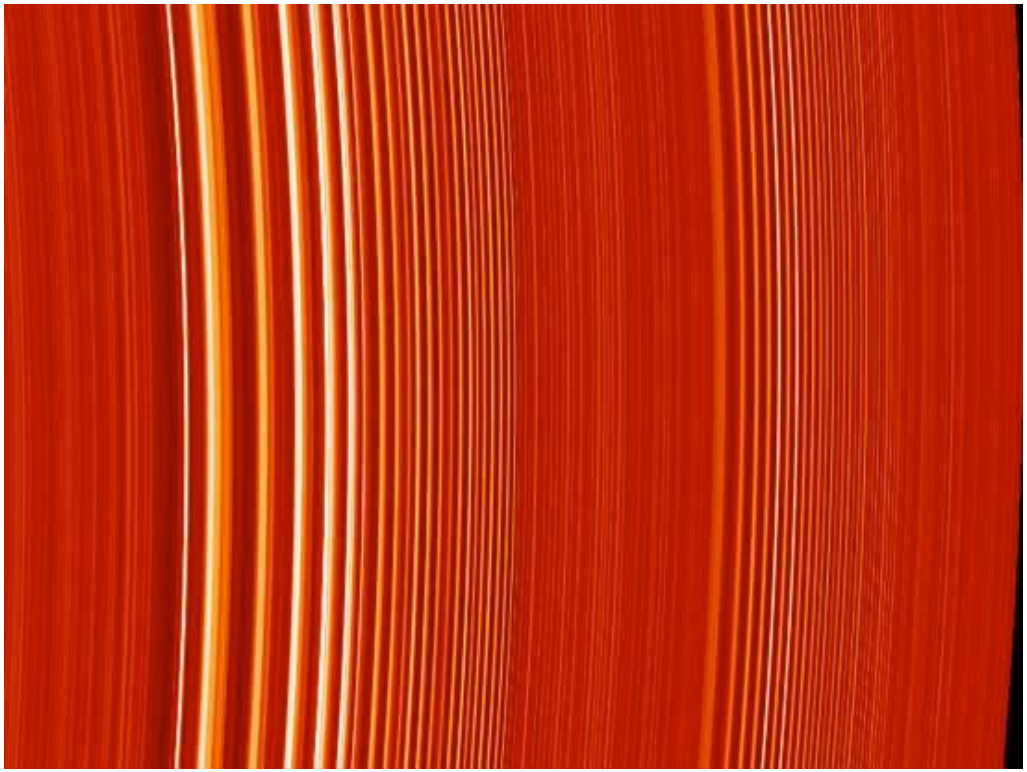
- **Shepherd moons also produce confined rings**
  - **E.g. F ring confined by Pandora and Prometheus**
  - **Pandora pushes particles inwards**
  - **Prometheus pushes particles outwards**
  - **Confines the F ring**

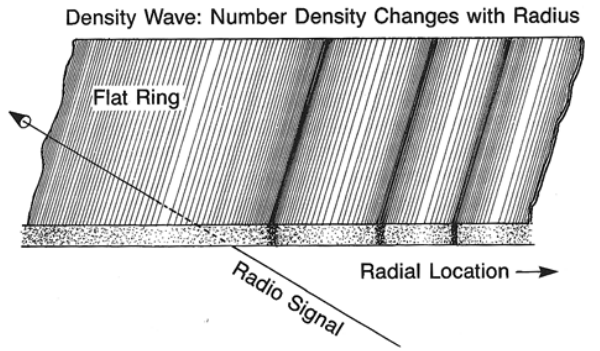


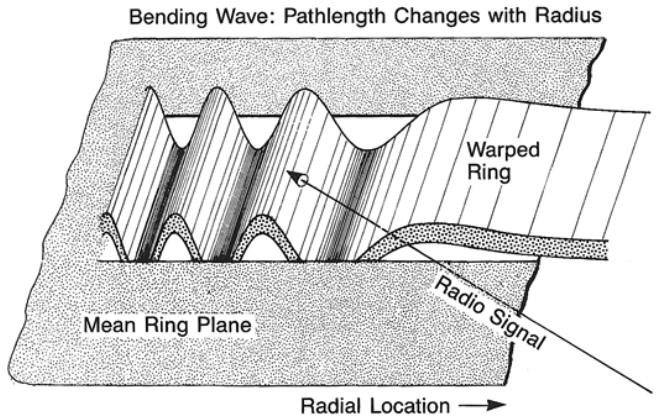


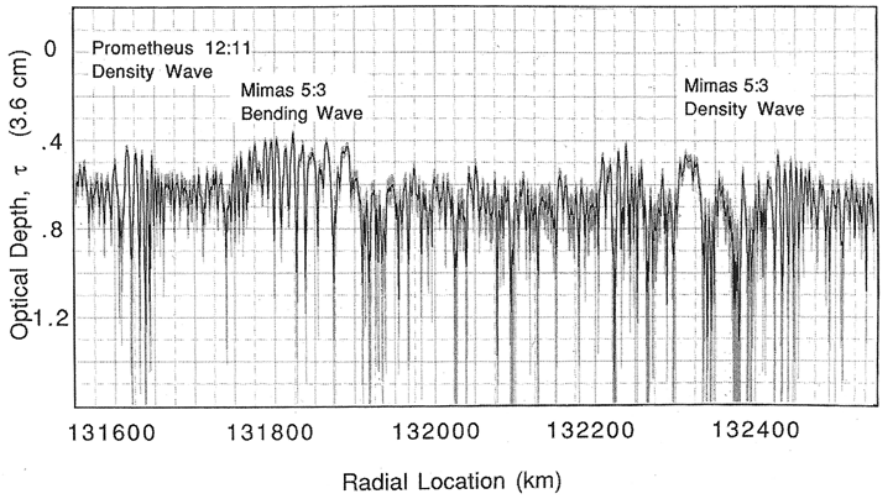


- **Moons set up bending and density waves in the ring plane**
  - **We detect these tracking how the radio signal from the spacecraft is attenuated**
  - **Dips in the signal correspond to dense rings**

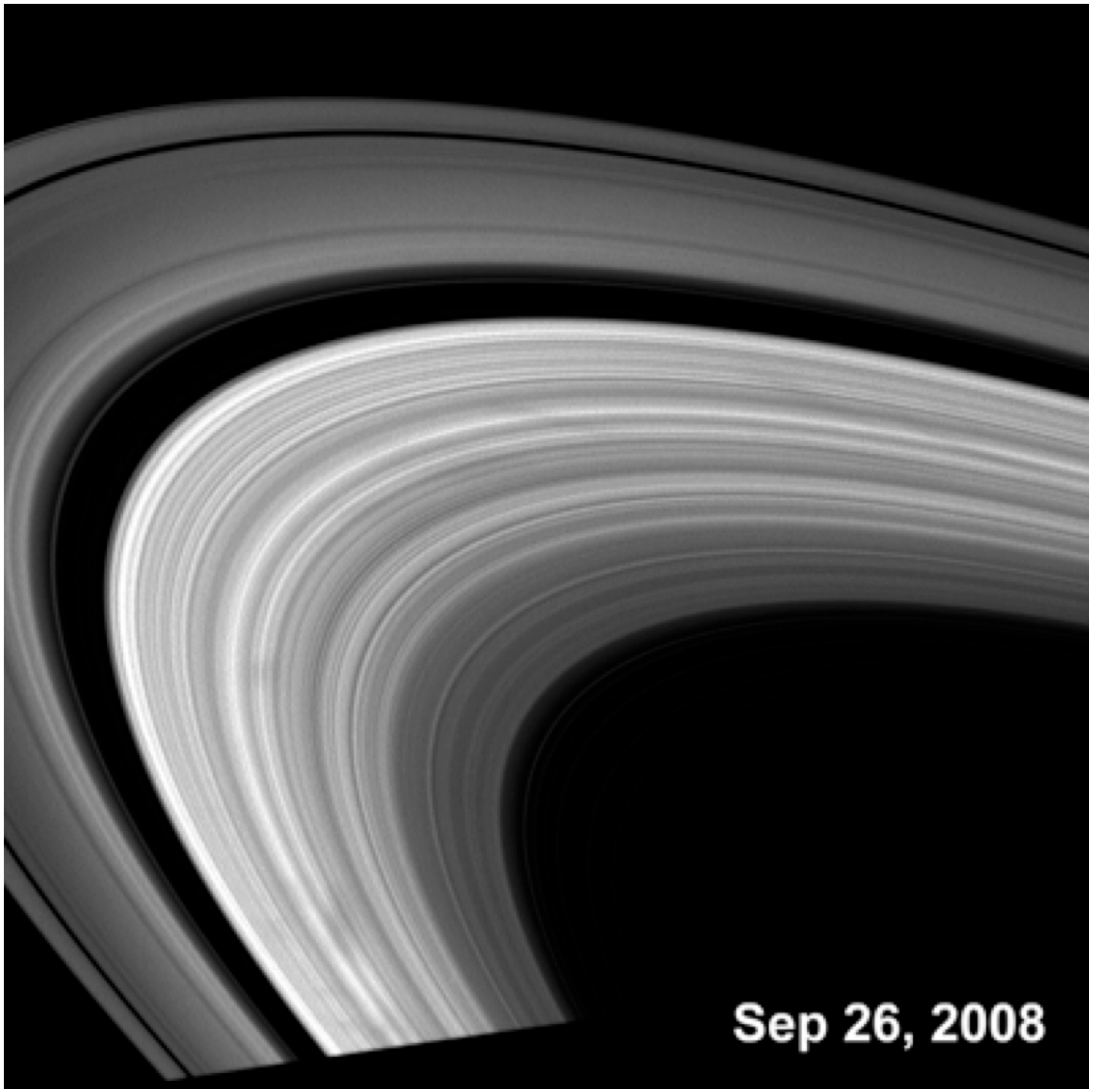




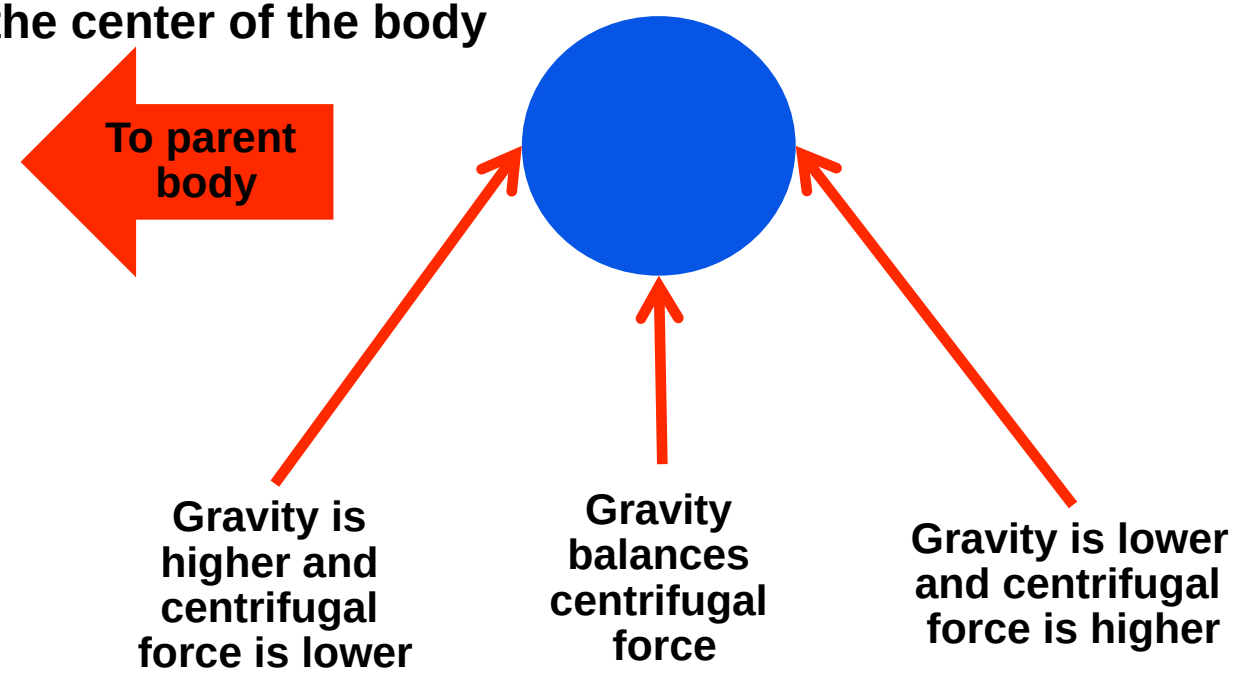




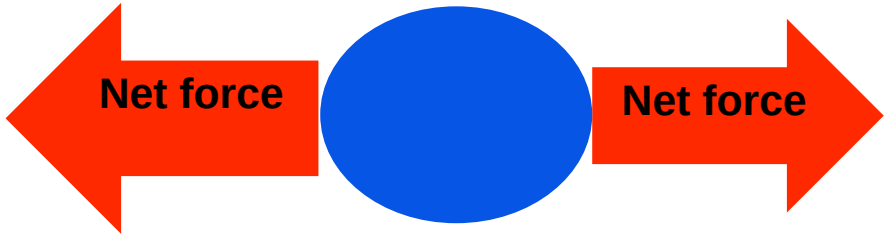
- **Spokes**
  - **Probably electrostatically charged dust-sized particles**
  - **Sweep around with Saturn's magnetosphere**
  - **Visible only at certain seasons**
    - **Near equinoxes – like now**



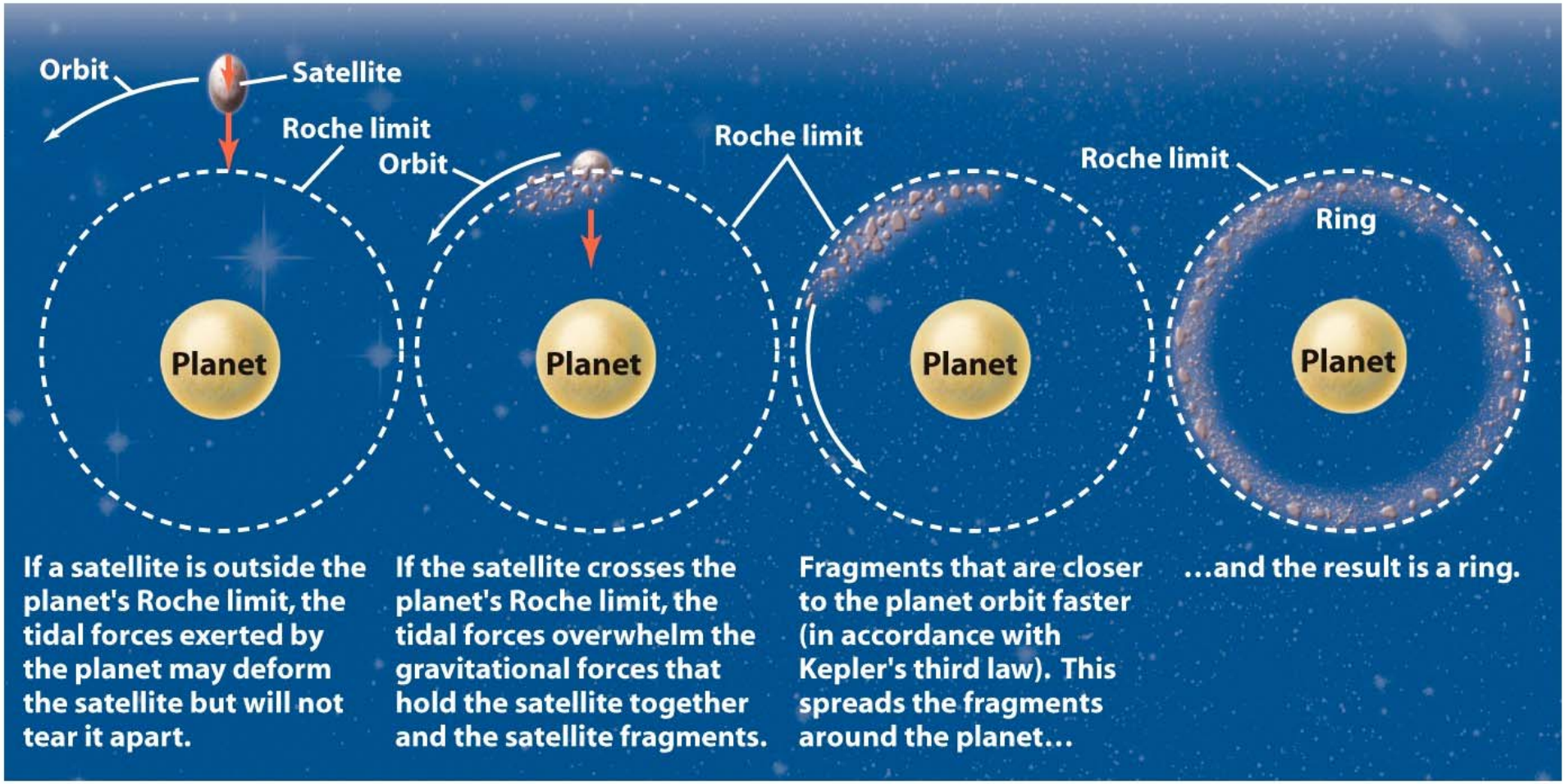
- **Where do the rings come from?**
- **Recap on tides**
  - **A body is in orbit when gravitational forces balance centrifugal**
  - **Only works at the center of the body**



  - **Difference in forces elongates the moon – i.e. raises tides**

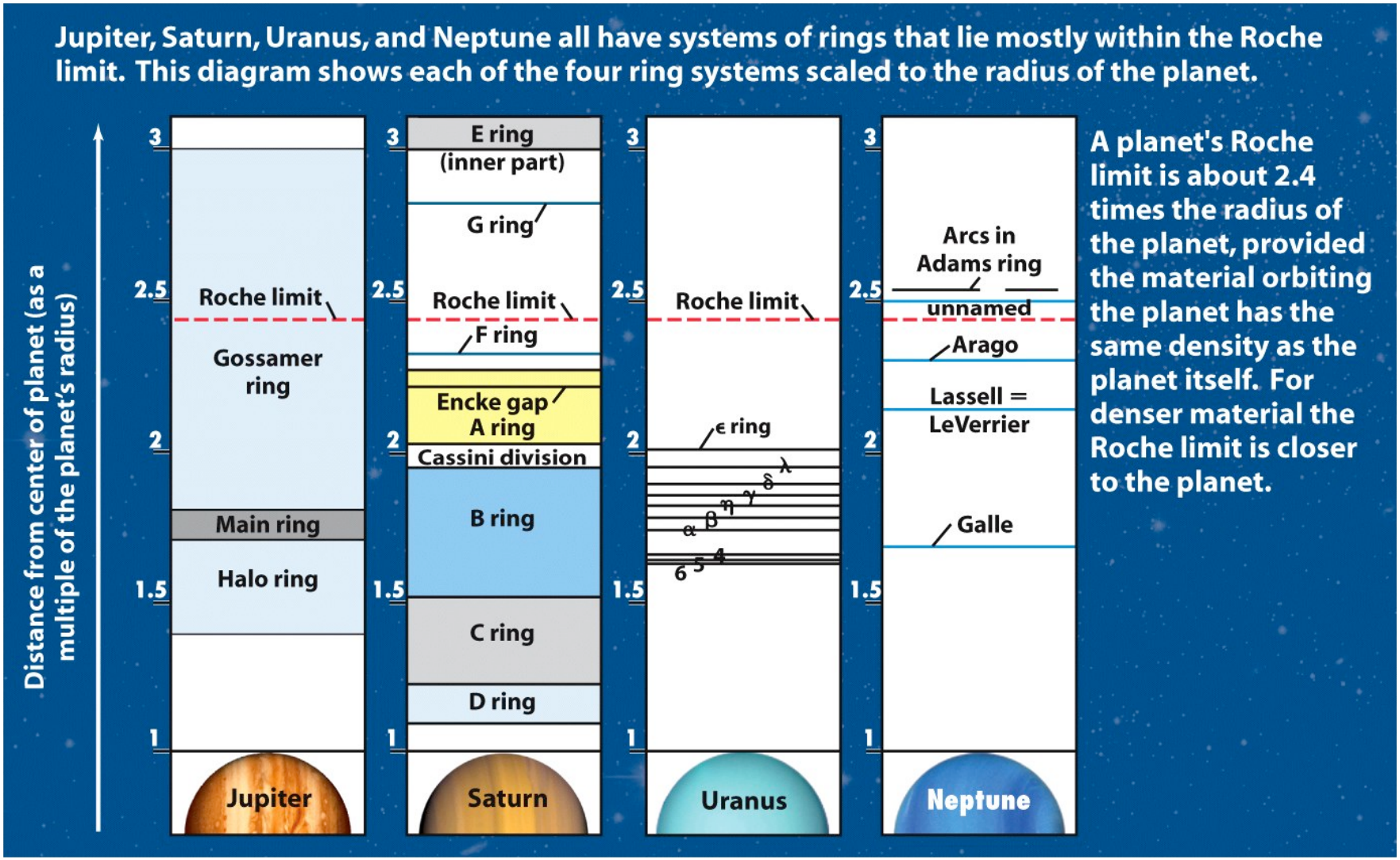


- **What if the tidal force is very strong?**
  - **Stronger than the moon's self-gravity…**
  - **Tidal forces can tear a moon apart**
    - **Much like comet Shoemaker-Levy 9**



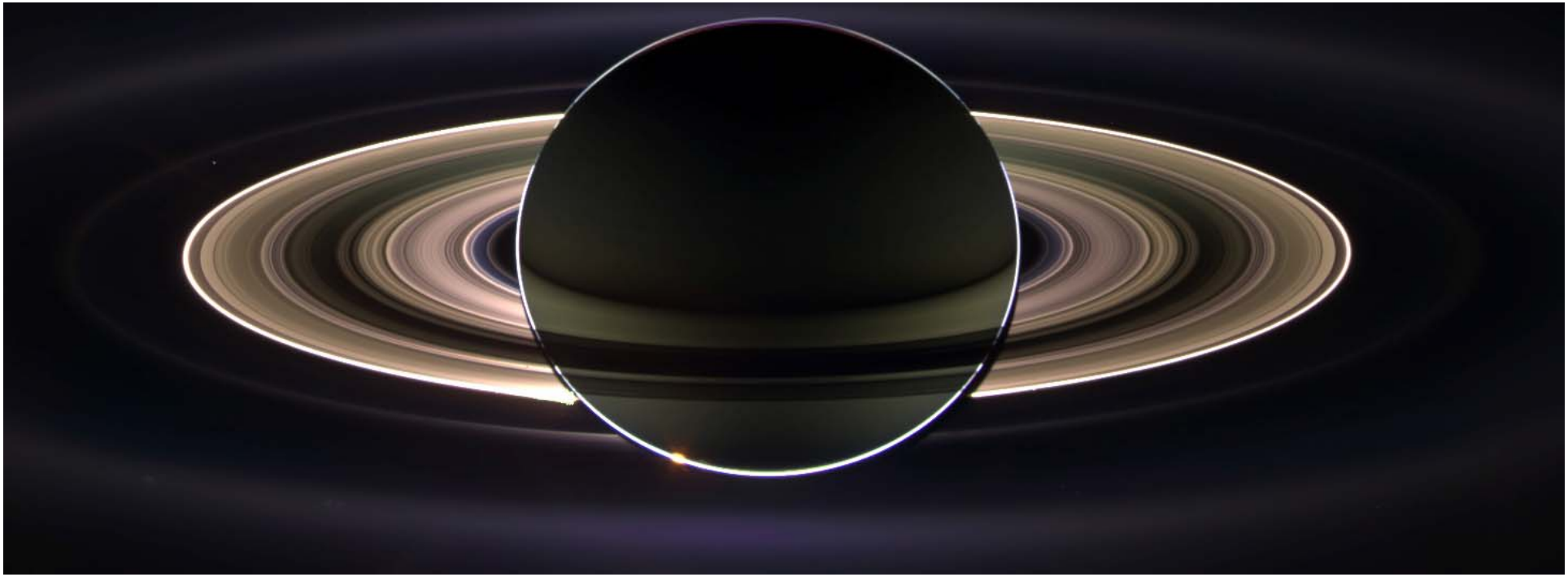
Cosmic Connections 12a
Universe, Eighth Edition

- **Planetary rings are almost all within the Roche limit**
  - **Stops ring particles from sticking together into a bigger moon**



Cosmic Connections 12b
Universe, Eighth Edition

- **Brightness of Saturn's rings indicates that they're young**
  - **<100 million years old**
  - **Probably due to the destruction of a small moon**
- **Rings are short-lived**
  - **Collisions grind down the ring particles to dust**
  - **Probably many sets of rings that have come and gone over the age of the solar system**
- **What a stroke of luck for us….**



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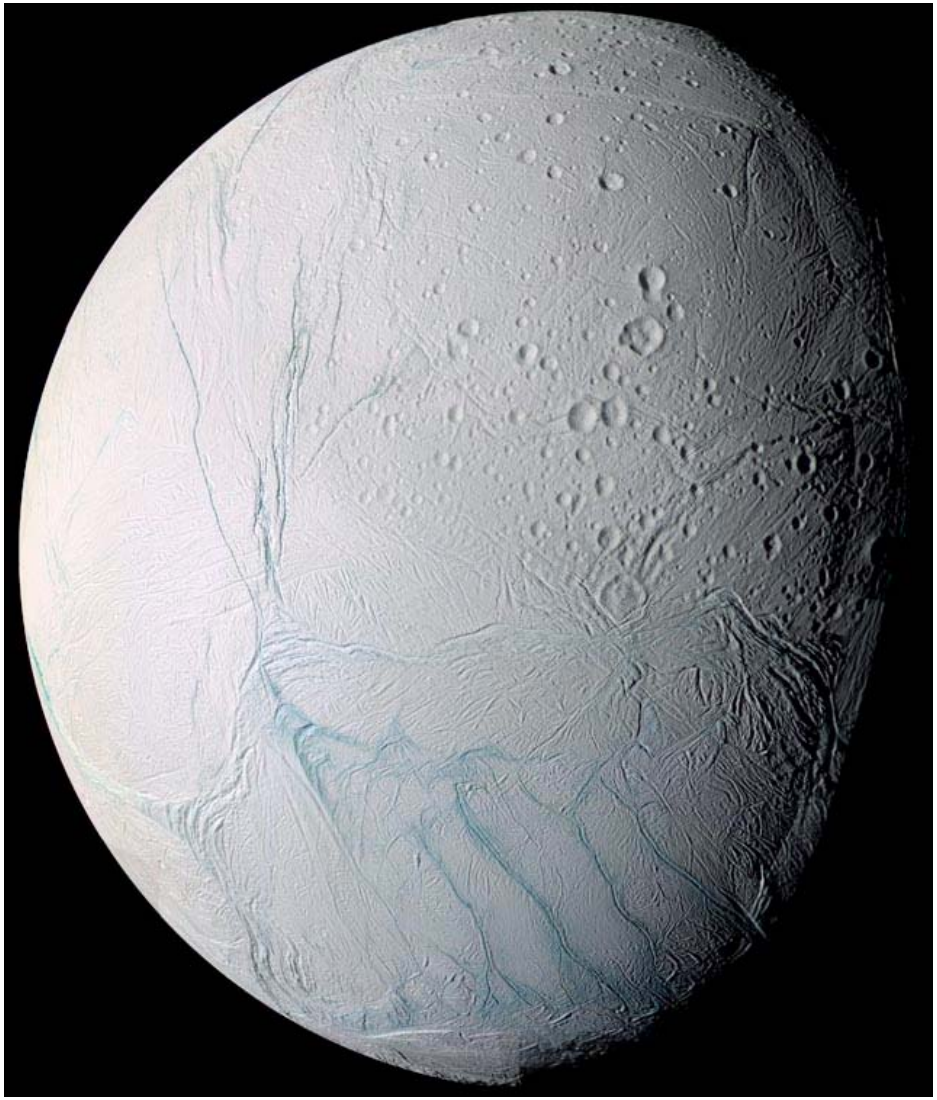
    - **Ring supplies by Enceladus**
    - **Tethys, Dione and Rhea have a lot of similarities**
  - **The distant satellites Iapetus, Hyperion, Phoebe**
    - **Linked together by exchange of material**

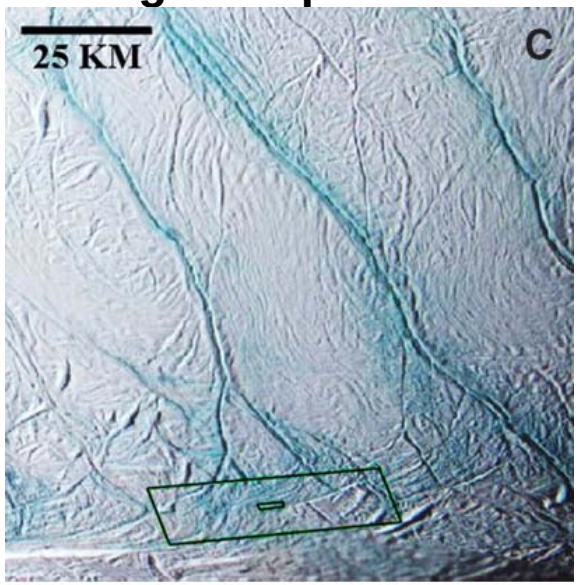
E ring Moons

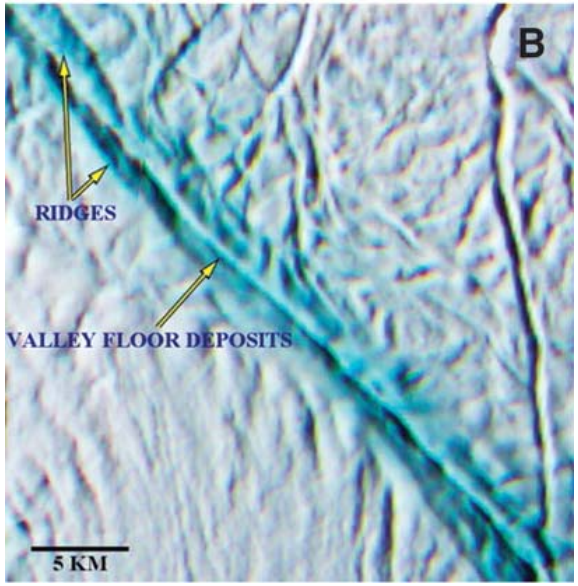
- Source of the E ring is Enceladus
  - Long suspected but now known from Cassini results

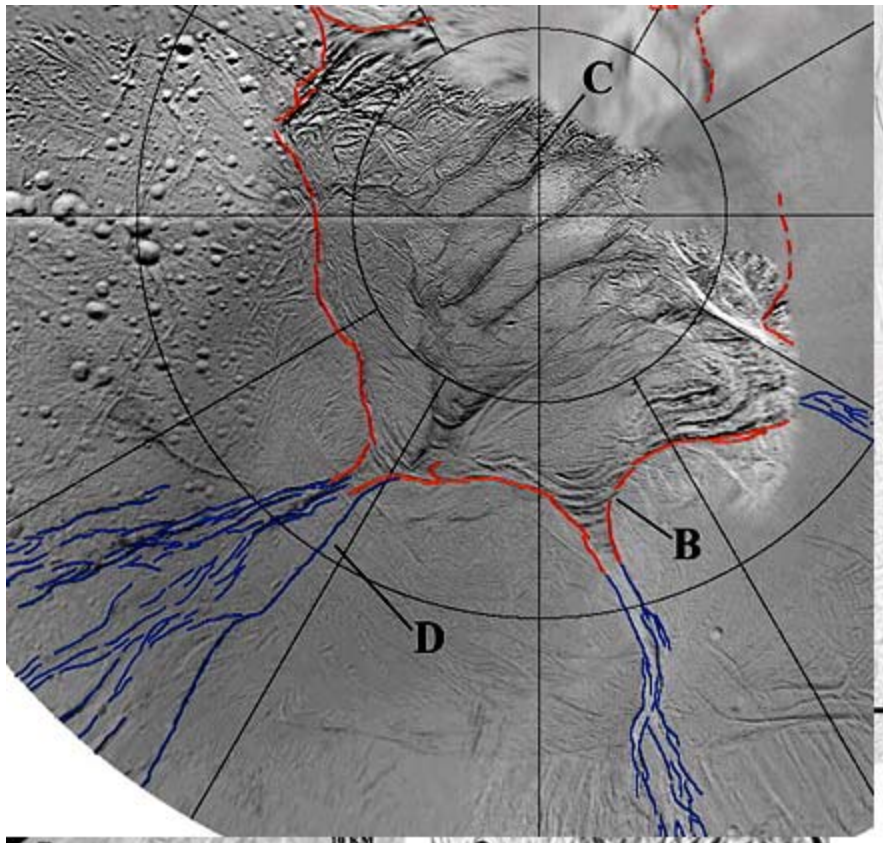
- Enceladus
  - Brightest object in the solar system – albedo ~99%
  - Small – radius 250 km
    - i.e. not much internal heat expected
  - Old terrain – heavily cratered
  - Young terrain
    - Tectonically very active
    - Lots of extension in the south polar area

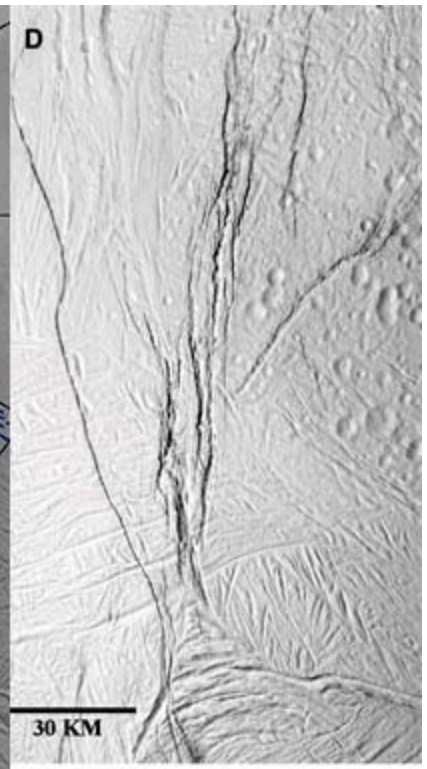


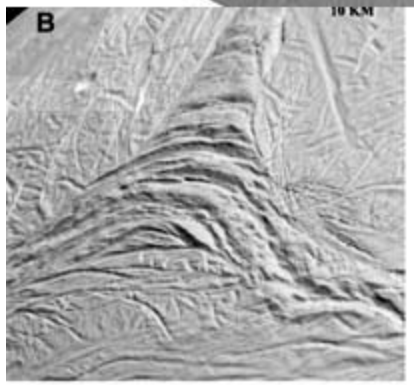
- **South polar terrain**
  - **Tectonically confined**
  - **Tiger stripes**

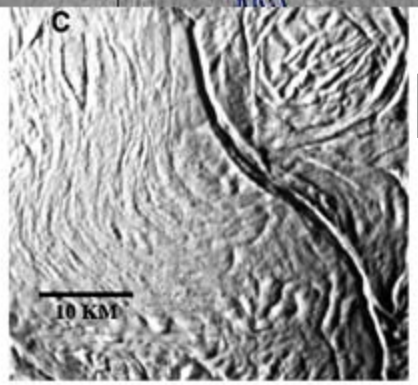






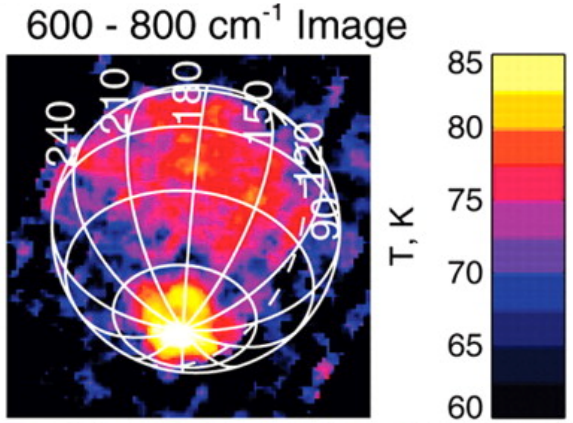


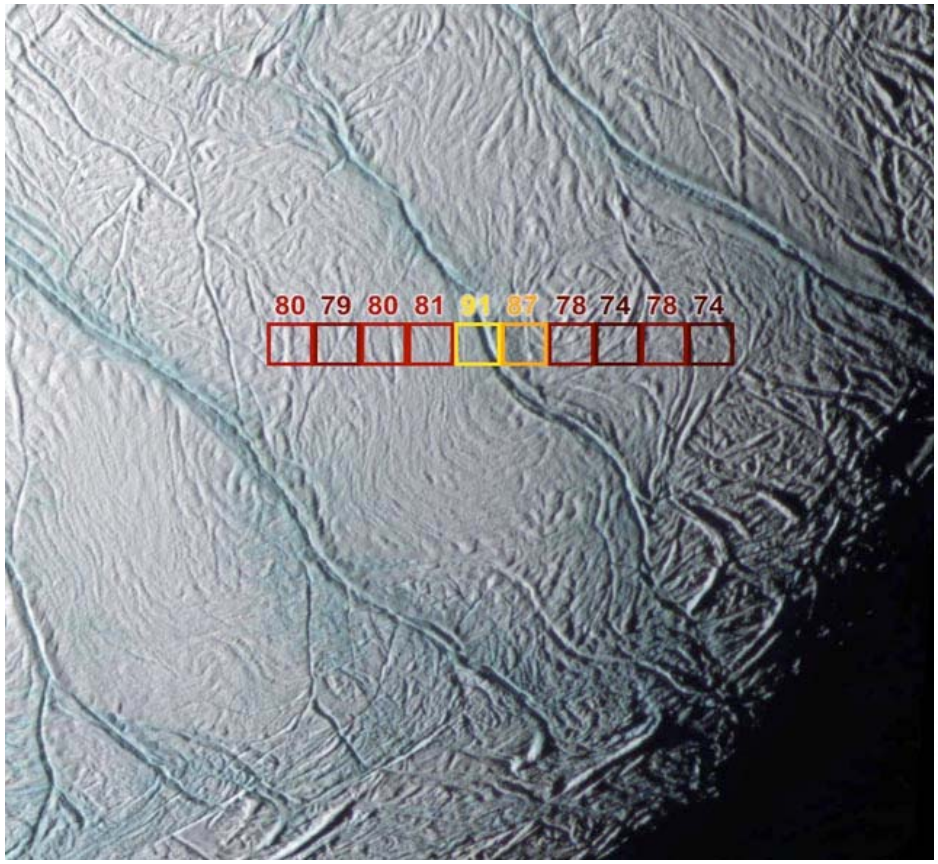


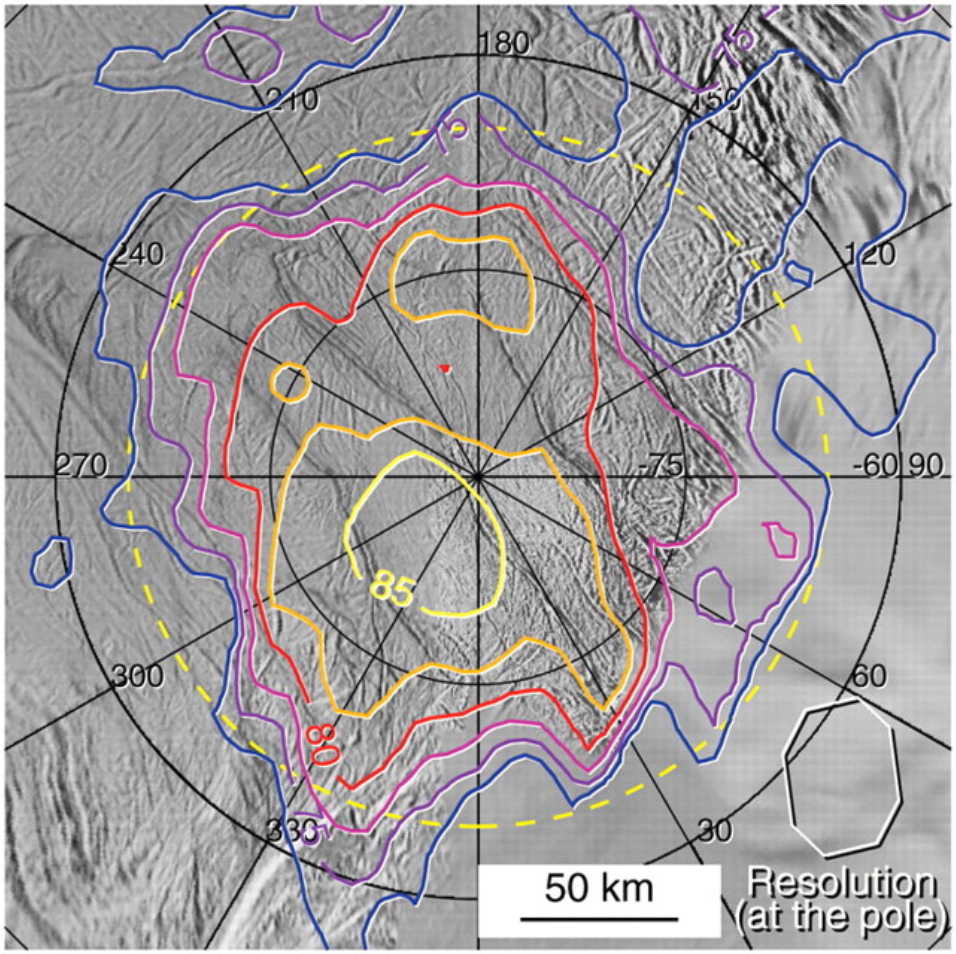


Porco et al., 2006

- **Hot-spot over the south pole**
  - **Highest temperatures over the tiger stripes themselves**







- **Dust impact detector**
  - **Stream of particles emanating from south polar region**
  - **Explains the E ring**
- **Imaging in forward scattered light discovers plumes**
- **UVIS observation of a stellar occultation showed plume had H_2O composition**
- **Magnetometer results indicate liquid water below the surface**

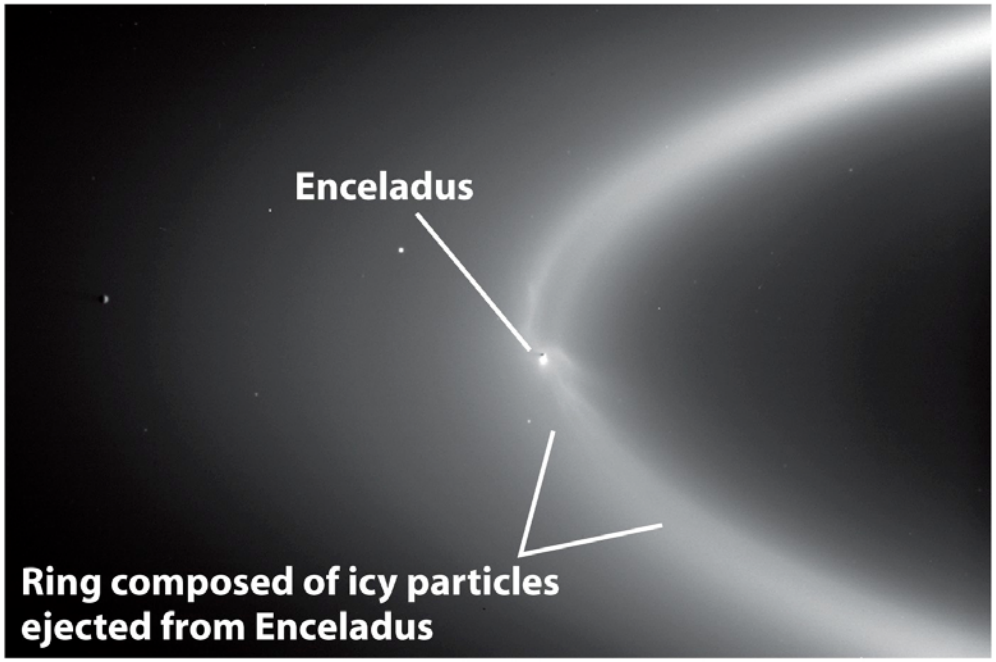
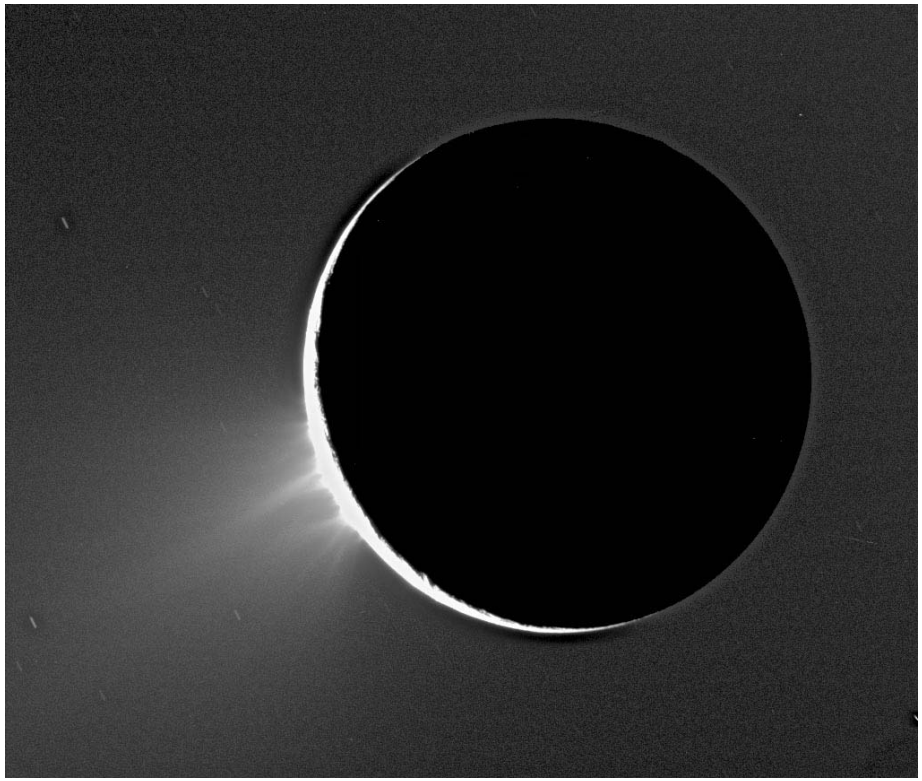
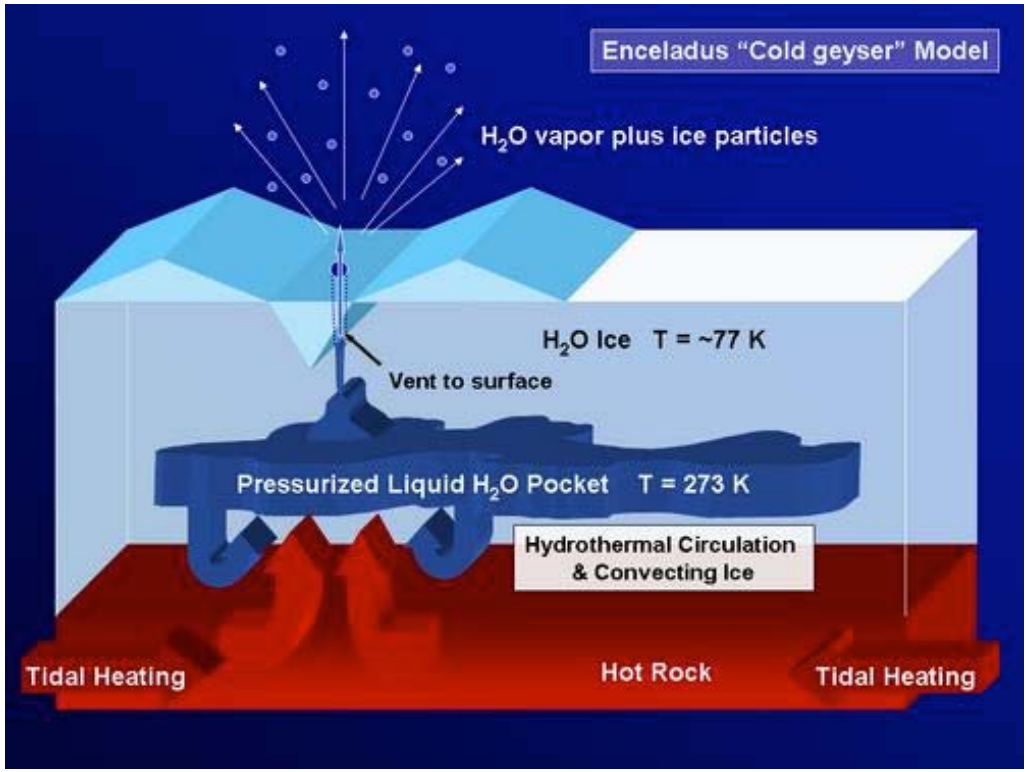
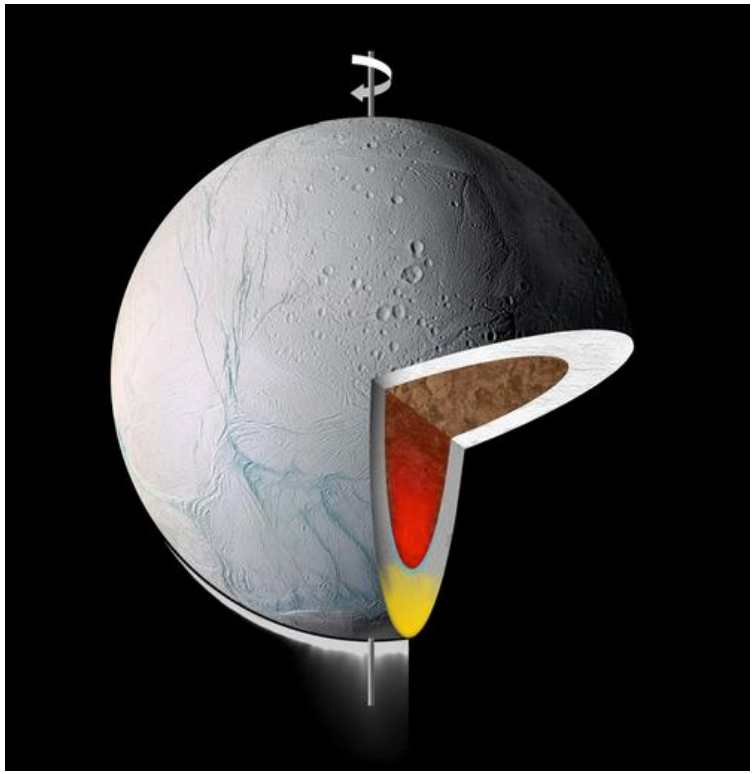


Figure 13-23b
Universe, Eighth Edition

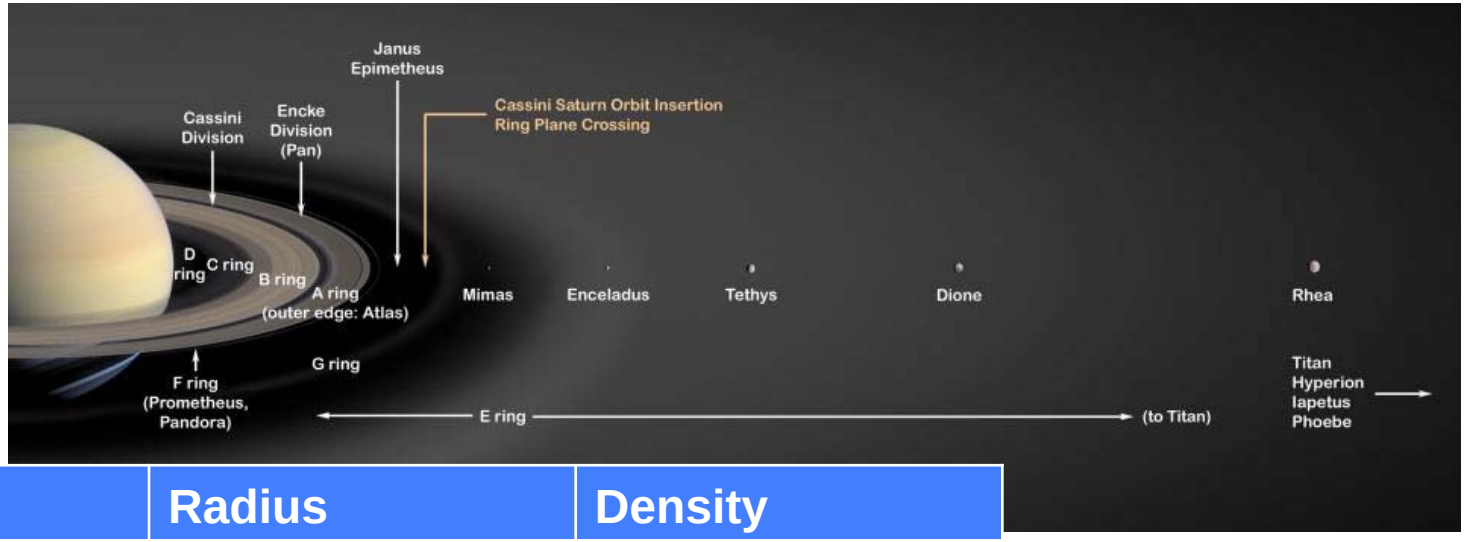


- **Enceladus is in a 2:1 tidal resonance with Dione**
  - **Akin to Io's resonance with Europa**
  - **Tidal heating can only account for about 10% of the energy needed**
  - **Enceladus is still a bit of a mystery**





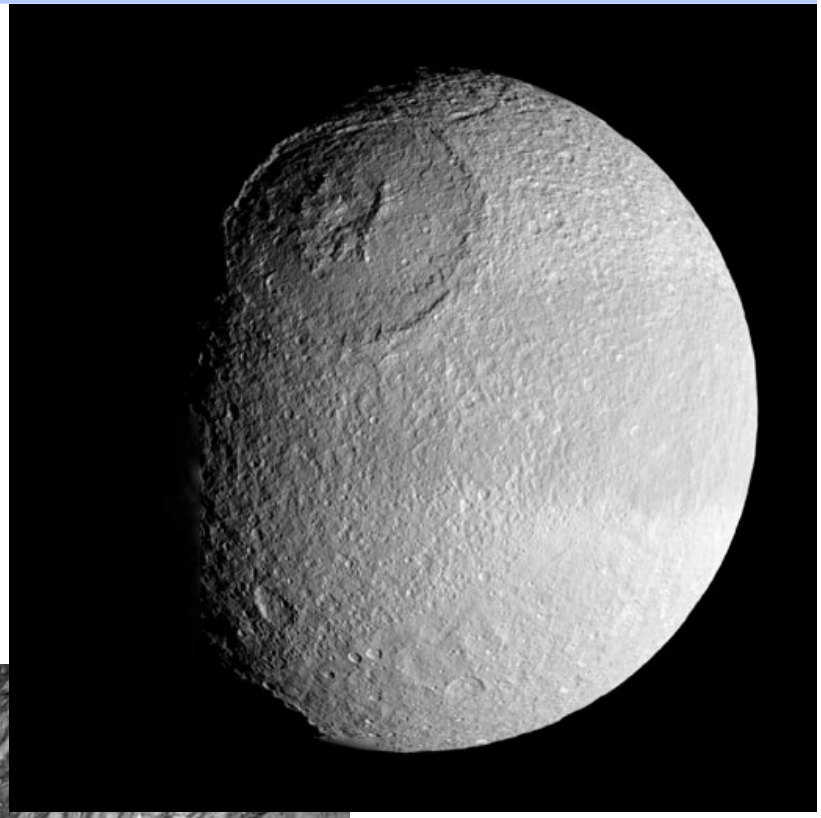
- **Other moons close to the E ring**
  - **Tethys**
  - **Dione**
  - **Rhea**

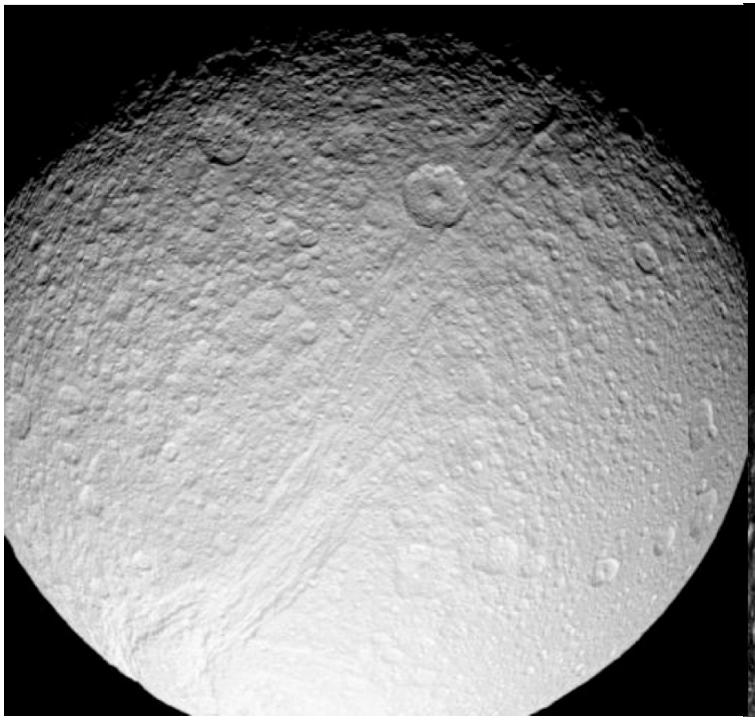


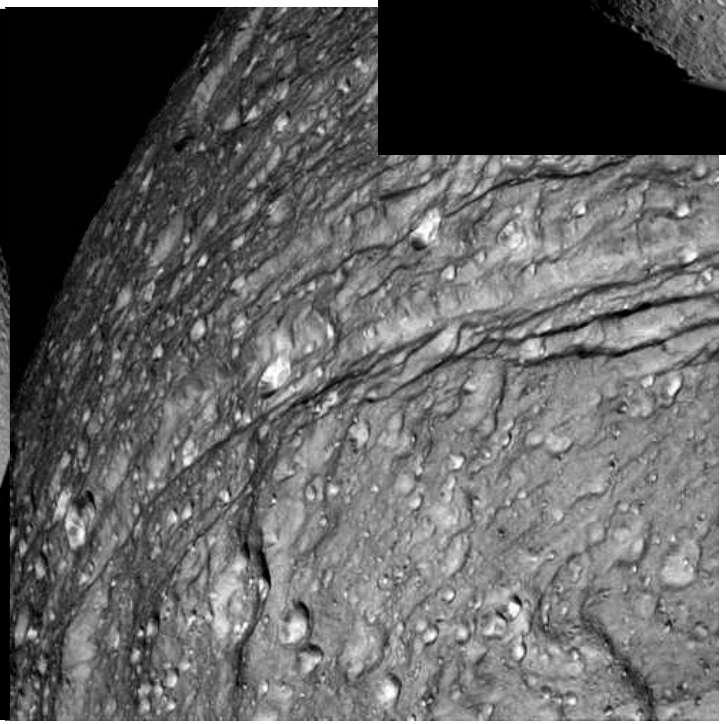
	Radius	Density
Tethys	530 km	970 kg m^{-3}
Dione	560 km	1480 kg m^{-3}
Rhea	764 km	1230 kg m^{-3}

- **Smaller than the Galilean satellites of Jupiter**
  - **Probably no sub-surface oceans here**
- **Less dense & very bright – dominated by water ice composition**
- **All heavily cratered with little geologic activity for billions of years**
- **Tidally locked to Saturn – like our moon is to Earth**

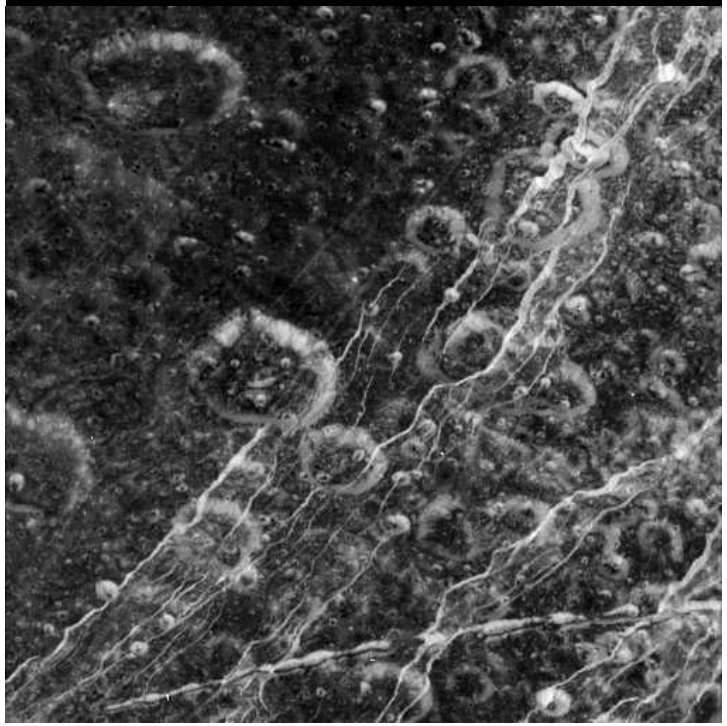
- **Tethys has two major features**
  - **Odysseus**
    - **400km impact basin**
  - **Ithaca Chasma**
    - **A pole-to-pole canyon created by stretching the crust**



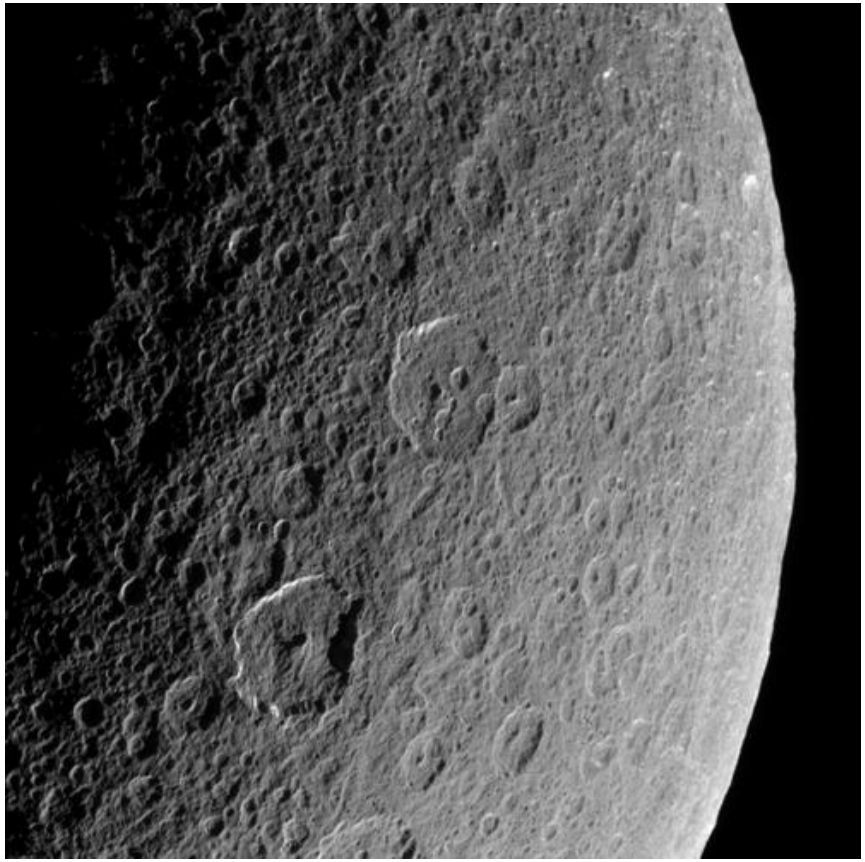


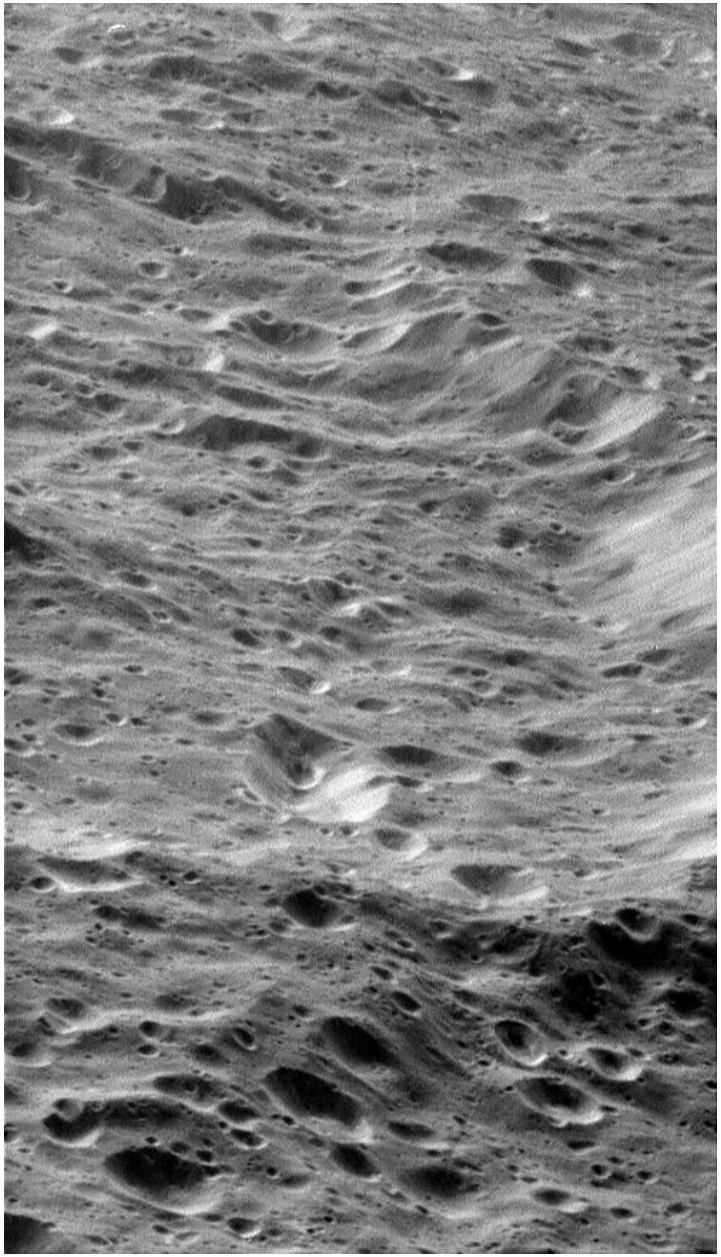


- **Dione**
  - **Density 1430 kg m^{-3} – ⅓ rocky core**
- **Bright wispy features**
  - **Tectonic – many sun-facing scarps**
- **More craters on the trailing hemisphere**
  - **Opposite to that expected**
  - **Leading hemisphere should collect more impacts**
  - **Dione can be spun by craters only 35km in diameter**



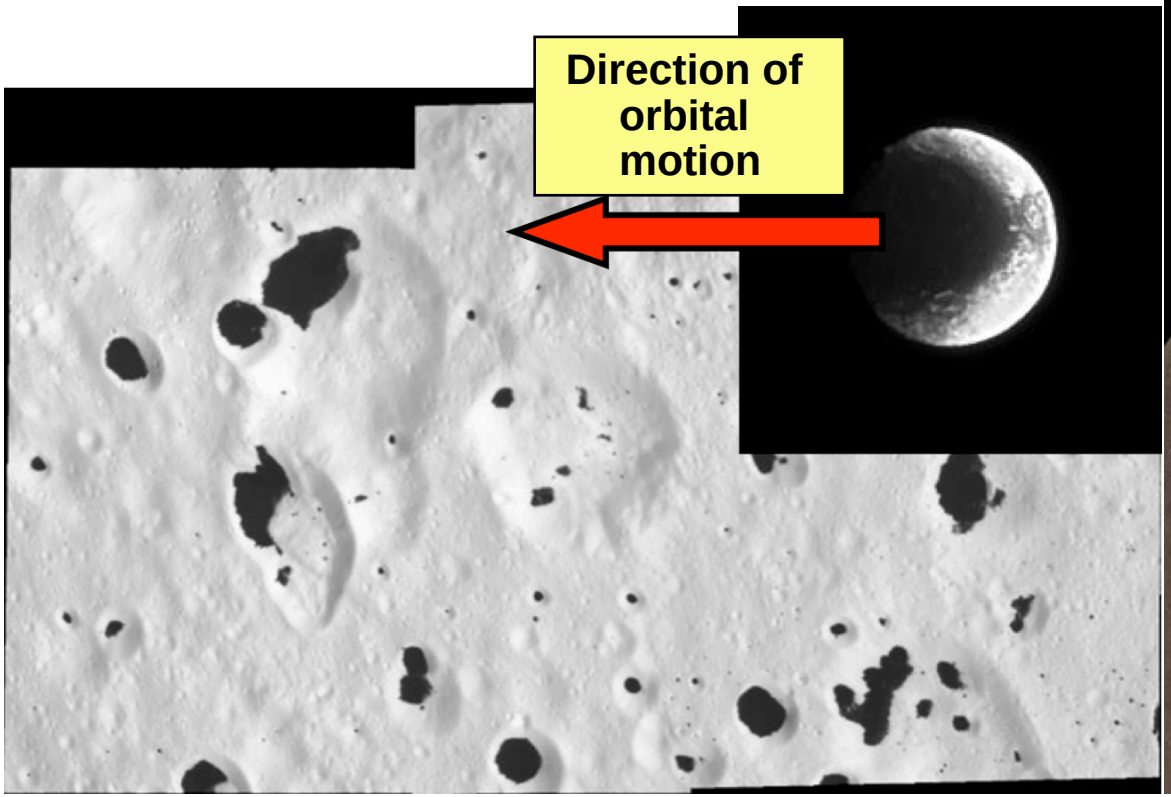
- **Rhea**
  - **Larger than Tethys/Dione**
  - **Further from Saturn**
    - **Less tidal heating**
  - **No surface activity**
  - **Interior probably undifferentiated**
    - **Cassini gravity results**

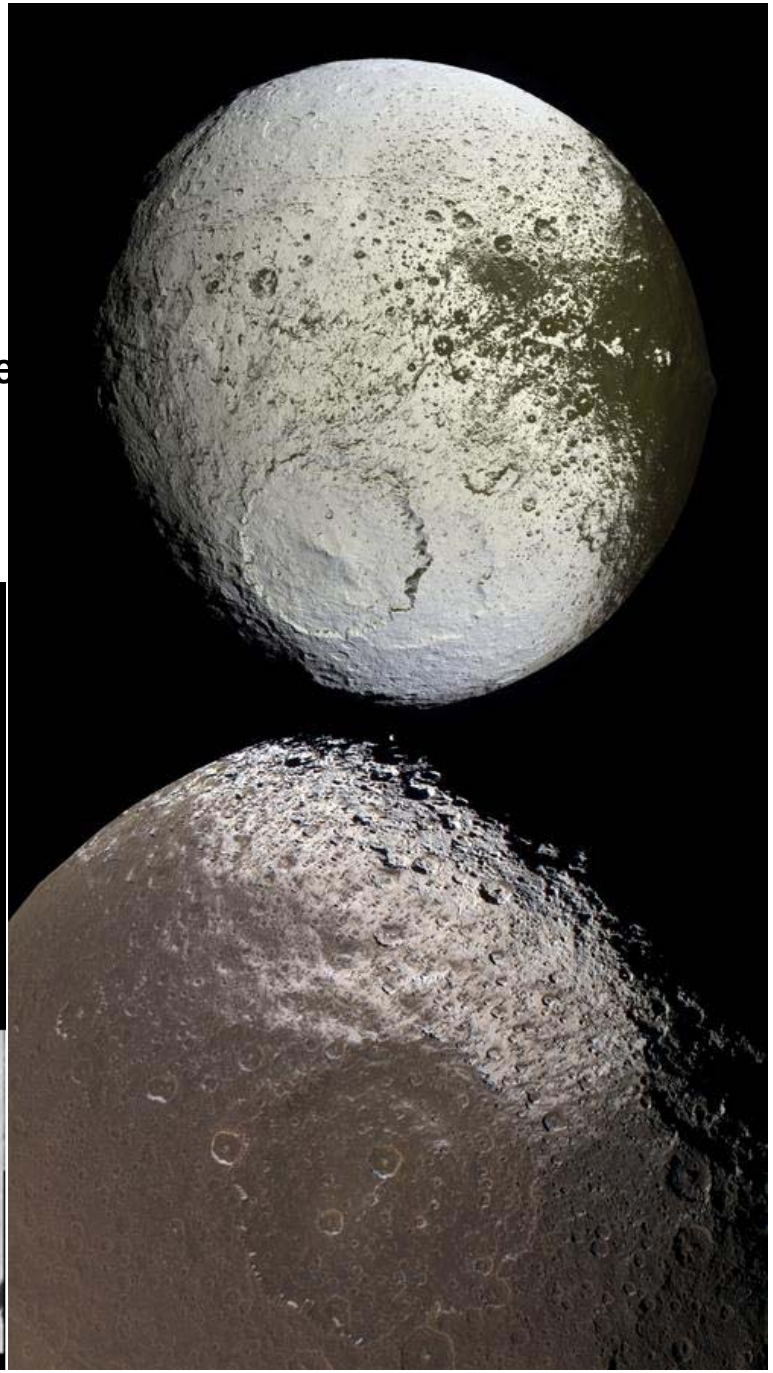




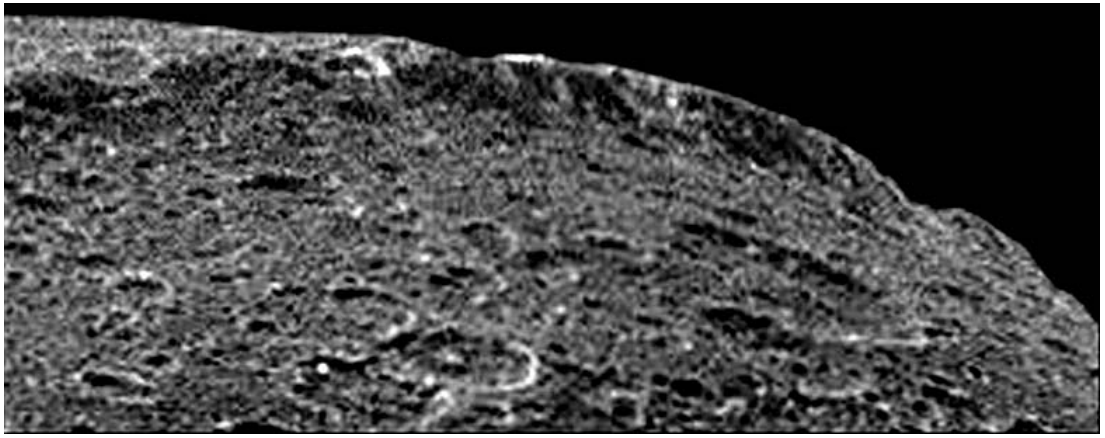
Moons beyond the E ring

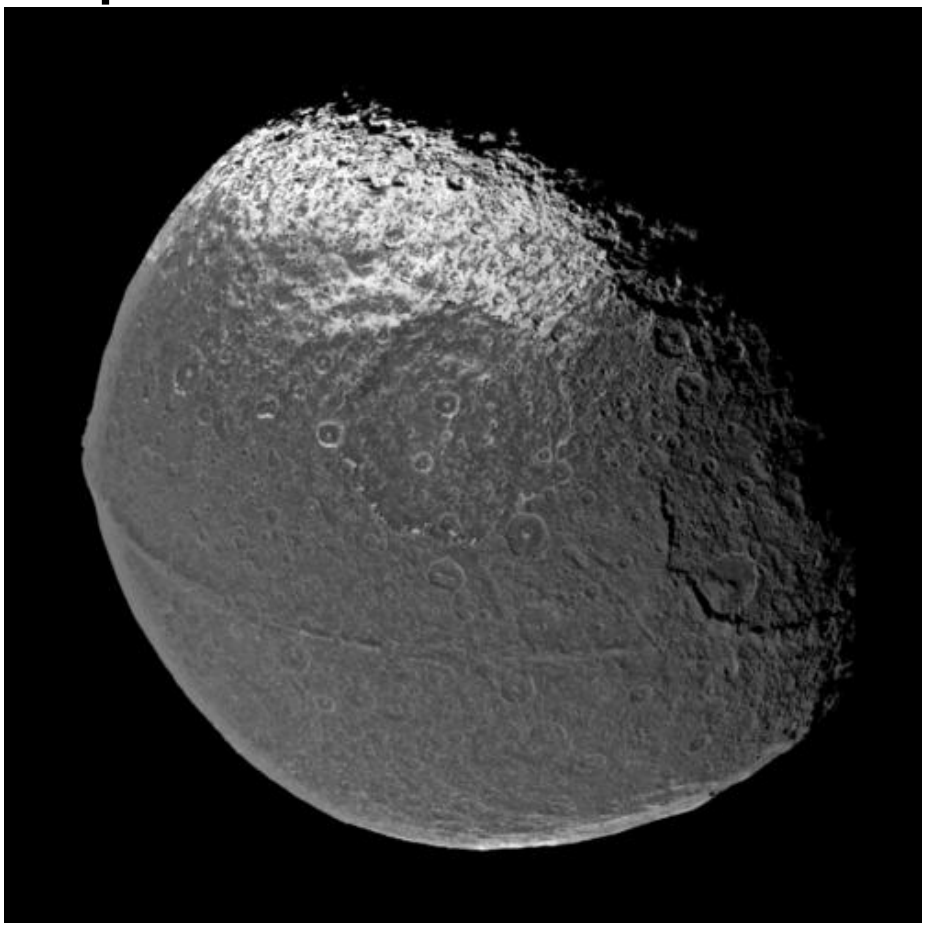
- Iapetus: Two-toned moon
  - Dark organic material ~ 3-4% albedo
  - Bright icy material ~ 50% albedo
  - Radius ~ 720km
- Dark material concentrated on the leading hemisphere
  - Some in floors of dark terrain craters
- Density ~1034 kg m^{-3} indicates icy bulk composition

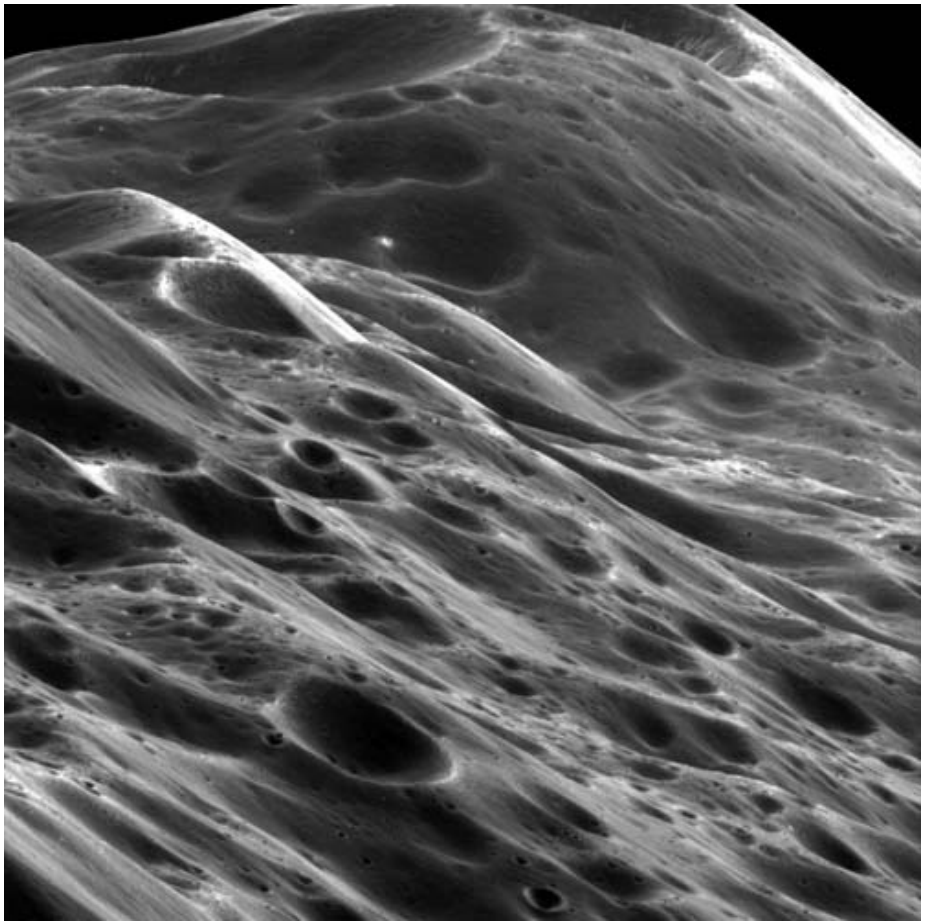




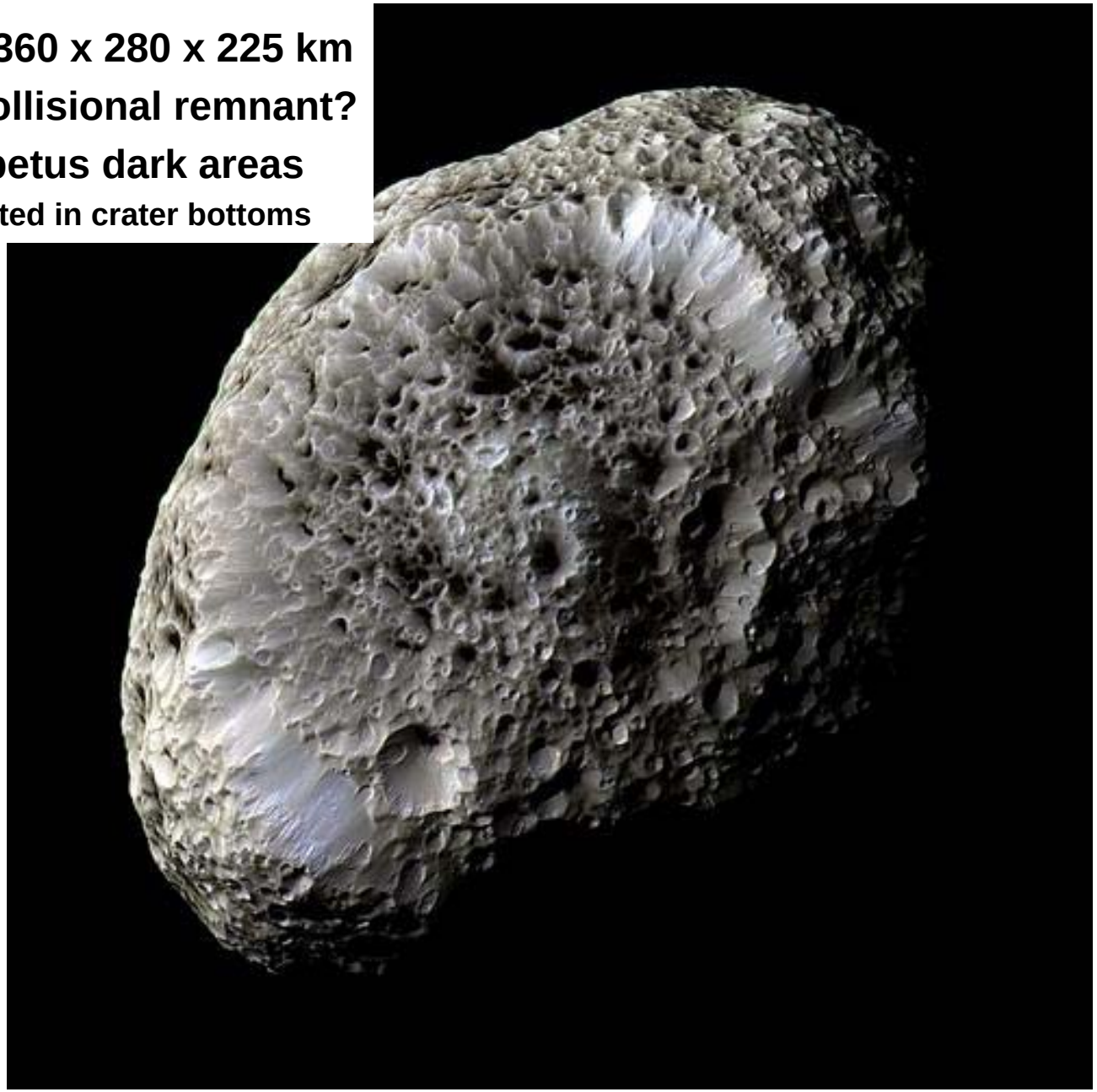
- Ancient equatorial bulge
  - Heavily cratered
  - Covered with dark material
  - Up to 20km in height
- Some sort of change in spin?





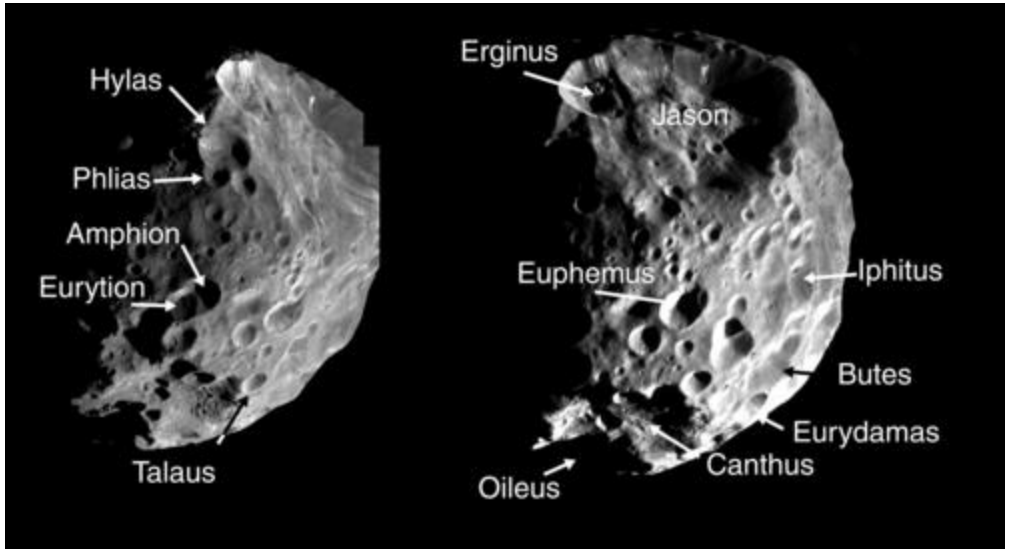


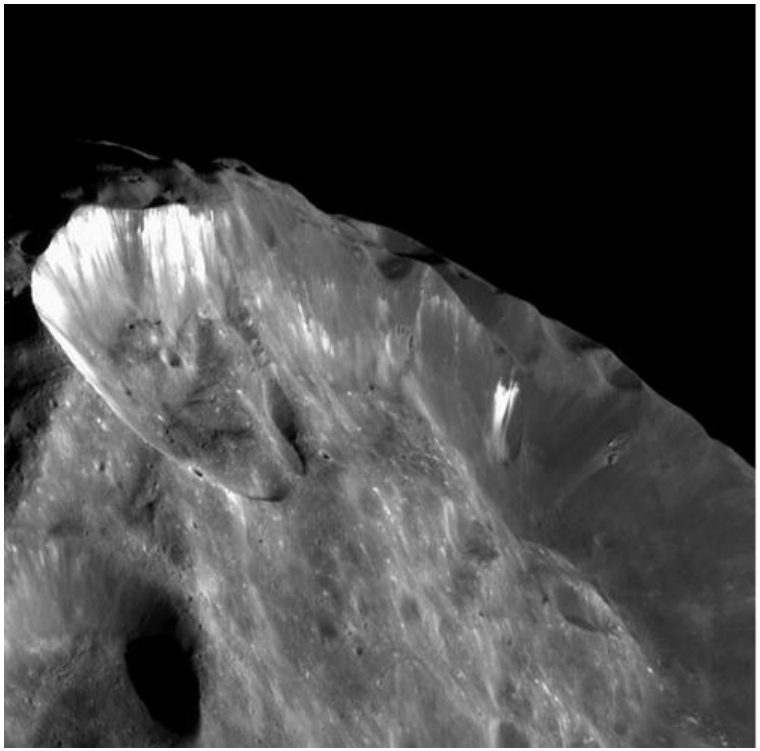
- **Hyperion**
  - **Equatorial diameter: 360 x 280 x 225 km**
  - **Chaotic tumbling – collisional remnant?**
  - **Reddish color like Iapetus dark areas**
    - **Dark material concentrated in crater bottoms**



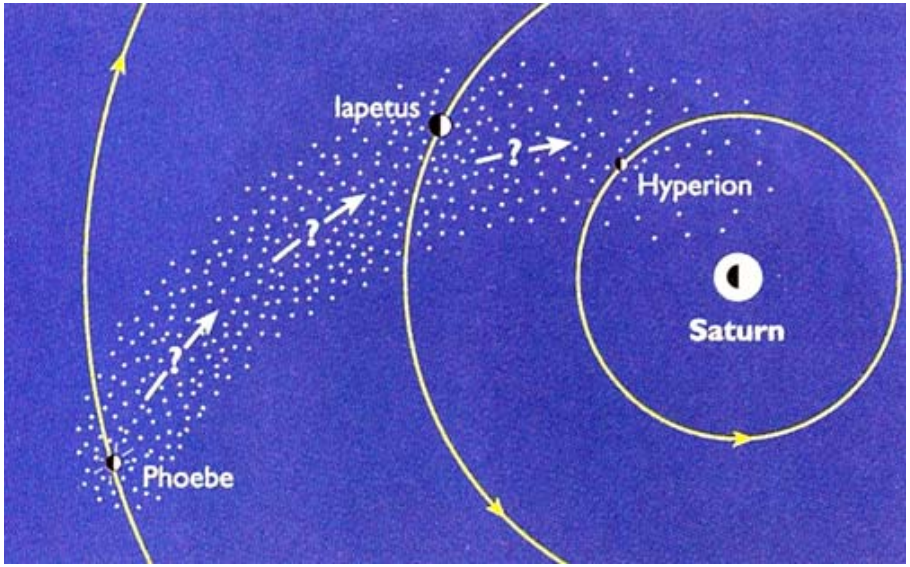
Phoebe

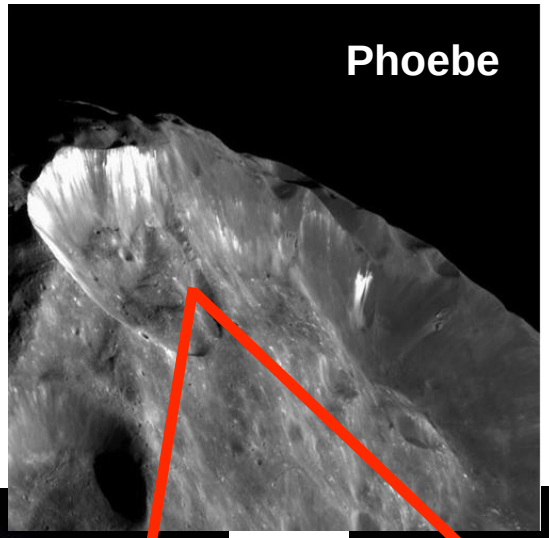
- Retrograde eccentric orbit
  - Implies a captured body
  - Radius ~110 km
- Compositionally distinct
  - Spectrally close to C-type asteroid
  - Minimum density ~1600 kg m^{-3}
  - …but CO_2 detection implies outer solar system origin
- Albedos 7-30%
  - Ice outcrops are not that clean
  - Ice is shallow – but darkens quickly
- Small impacts can eject dark stuff
  - Escape velocity is only ~1 ms^{-1}

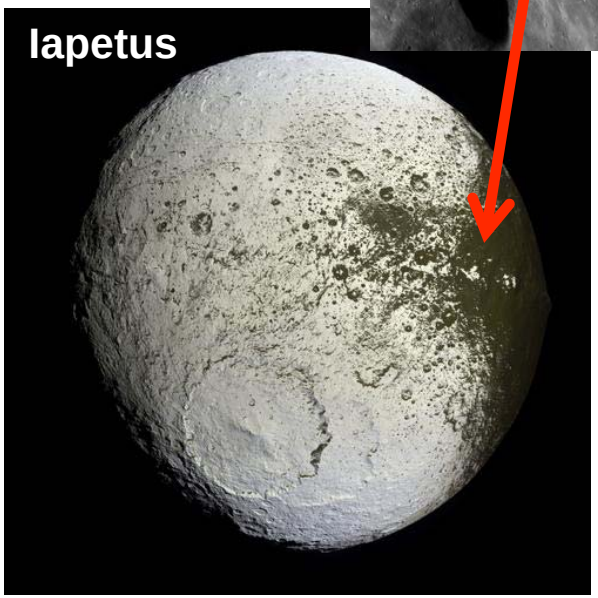


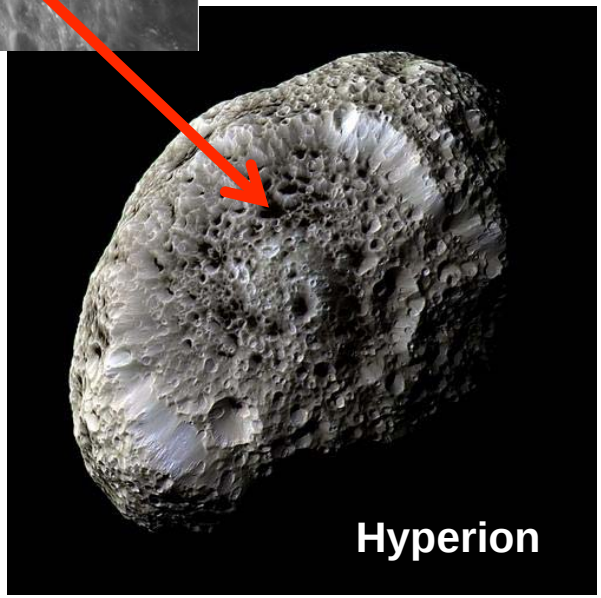


- **Phoebe is the odd one out here**
  - **Dark rocky object among bright icy ones**
  - **Probably supplying the dark material that coats Iapetus and fills craters on Hyperion**









In this lecture…

- Rings
  - A planar swarm of icy particles
  - How to form rings
    - The Roche limit
  - Dynamics
    - Gaps and resonances
    - Shepherd moons
- Inner E-ring moons
  - Mid-size icy satellites: Tectonics and craters
  - Enceladus – water geysers from subsurface liquid!
- Outer Moons
  - Captured Phoebe
  - Iapetus and Hyperion
    - Spray-painted with Phoebe debris

Next: Titan

- Reading
  - Chapter 12 & 13 to revise this lecture
  - Chapter 13,part 8 for next lecture