

Reading: , Chap. 4, Sect. 4.6 (Tides); Chap. 12 (all)

Homework #8: On website, due in recitation on Friday/Monday, Nov. 1/4

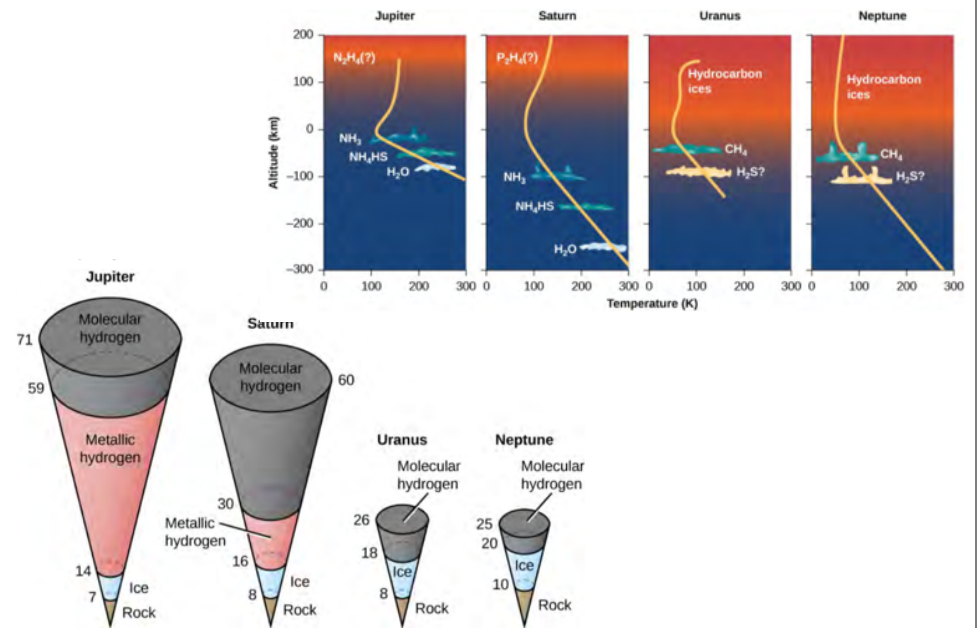
Exam 2 - Two weeks from Today (November 12)

## Last time: The Gas and Ice Giant Planets

- **Jupiter (and Saturn)**
  - Atmosphere Composition (H, He) and cloud coloration
  - Zones, Bands and circulation patterns
  - Interior
- Differences between Jupiter and Saturn
- Uranus and Neptune

## Today: Tides and Rings

- Tidal forces as differential gravitational force (stretch)
- deformation, spin synchronization, orbital changes
- the Roche Distance: tidal breakup
- Planetary Rings: flatness, structure, and resonances
- Ring Systems
  - ways of seeing rings: reflection, transmission, occultation
  - Saturn vs. Uranus, Jupiter, Neptune



## Tidal Forces

Tidal force = differential gravitational force (stretch)

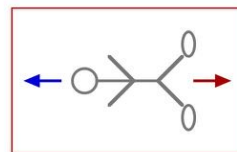
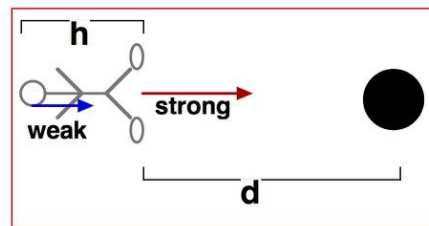
- Gravity

$$F_{\text{grav}} \sim \frac{1}{d^2}$$

- Stretching force

$$F_{\text{tide}} = F_f - F_h \sim \frac{h}{d^3}$$

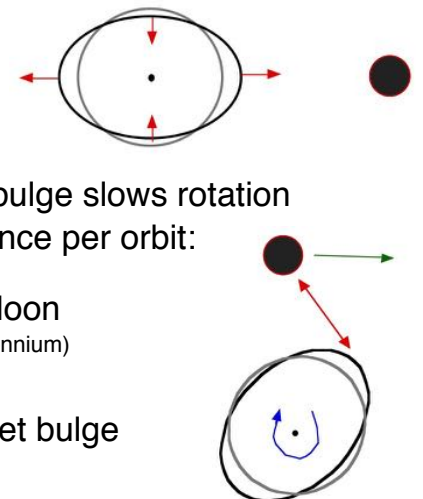
- Increases with decreasing distance
- Increases with increasing size



## Effects of Tidal Forces

- Deforms objects (Stretch+ squeeze)
  - tidal bulge
  - solid body tides (rock/ice)
  - ocean tides
- Spin synchronization:
  - grav. pull on planet/moon bulge slows rotation
  - eventually, moon rotates once per orbit:
    - 1:1 resonance
  - Earth rotation slowed by Moon
    - day gets longer (0.015 second/millennium)
- Orbital changes
  - Moon pulled along by planet bulge
  - orbit spirals outwards
  - month gets longer (0.14 seconds/mill.)

**Synchronous rotation:** rotation period = orbital period



## The Roche Distance: Tidal Breakup

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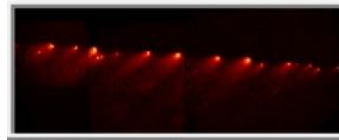
- Satellites are held together by **self-gravity**
- **Tidal force** tries to stretch the satellite ( $F_{\text{tide}} \sim 1/d^3$ )
- How close before  $F_{\text{tide}} >$  **self-gravity**?
- **Minimum Distance: The Roche Distance**

$$D_R = \text{Roche distance} = 2.5 \times R_{\text{planet}}$$

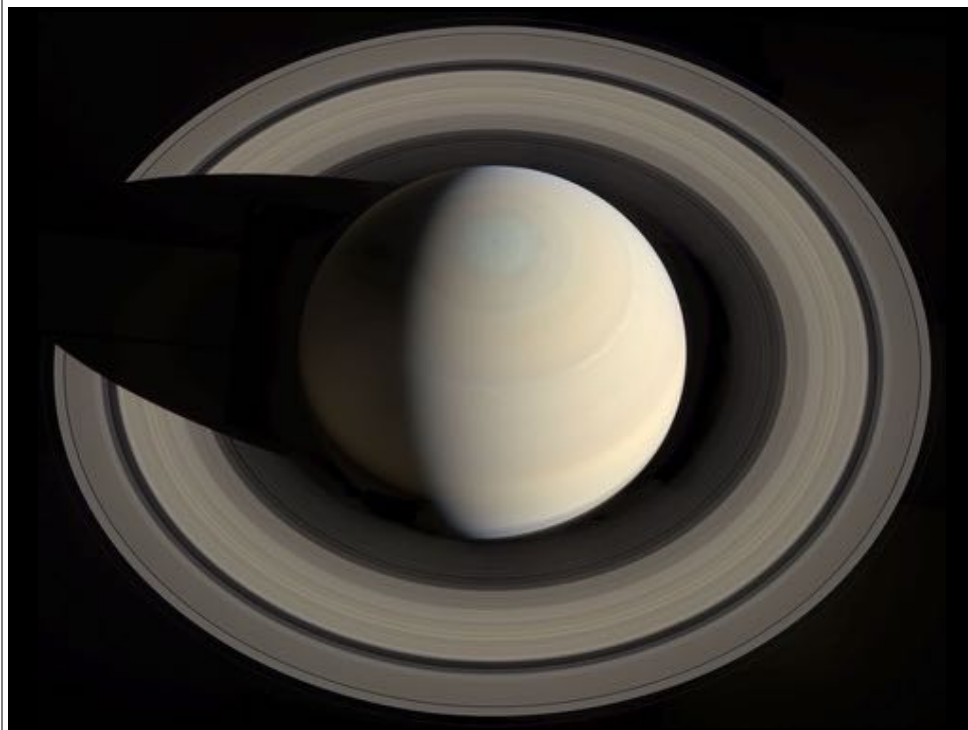
If a satellite strays to within  $D_R$  it may be torn apart by tidal forces

<i>planet</i>	<i>moon</i>	<i>distance</i>
Jupiter	Amalthea	$2.5 R_{\text{ju}}$
Mars	Phobos	$2.8 R_{\text{ma}}$
Saturn	Mimas	$3.1 R_{\text{sat}}$
Uranus	Miranda	$5.1 R_{\text{ur}}$
Earth	Moon	$60 R_{\text{earth}}$

in 1992:

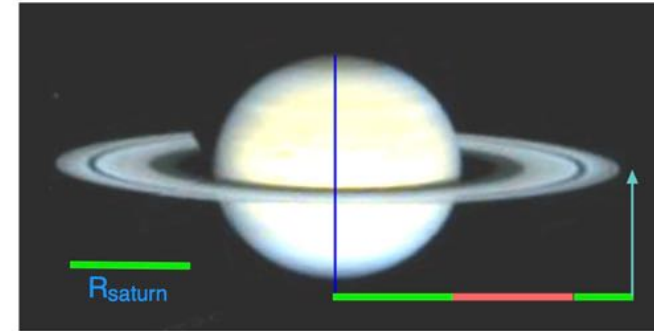


**SL9 – Jupiter**  
**1.34  $R_{\text{Jup}}$**

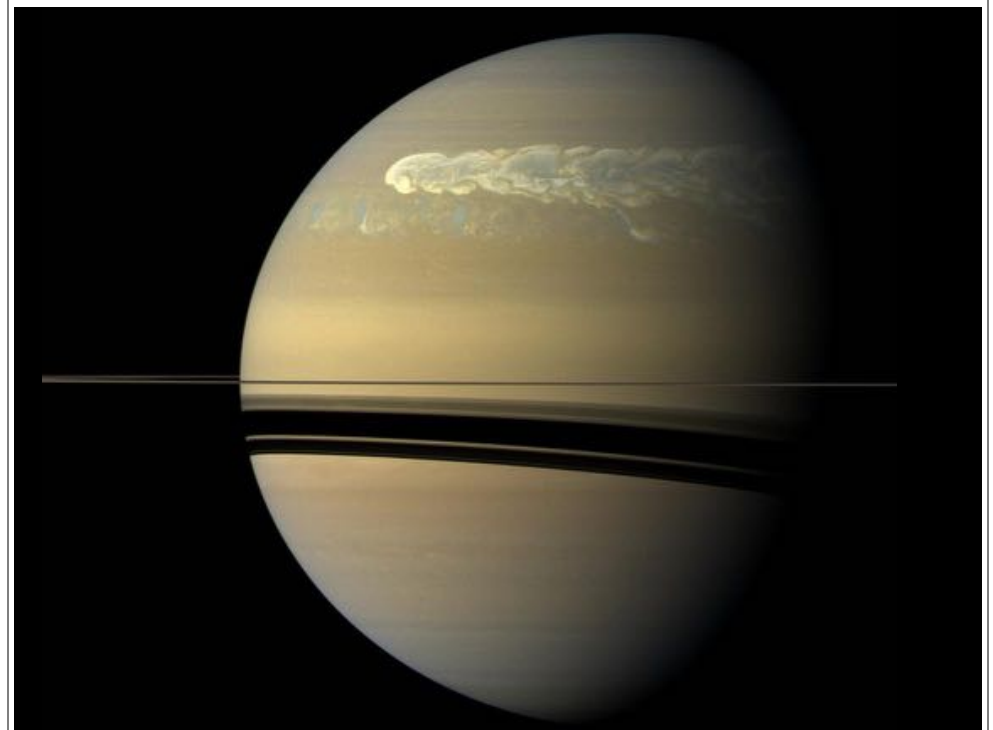


## Planetary Rings

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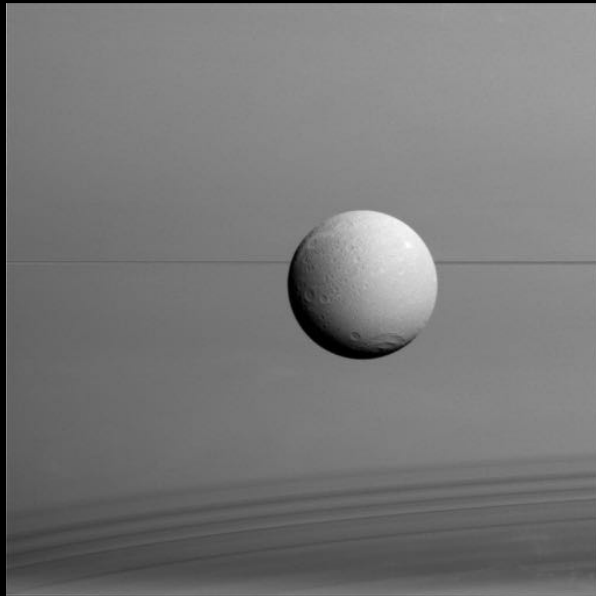


- always found inside the Roche limit
- not solid
- extremely thin
- gappy
- broad and bright (Saturn)
- narrow and dark (Jupiter, Uranus, Neptune)
- origins?



## The rings are very thin!

(Cassini image, August 2015)



Rings, edge on  
Saturn in background

Shadow of rings on  
Saturn cloudtops

<http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA17200>

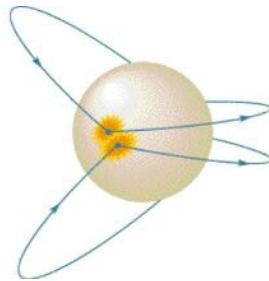


NASA/JPL-Caltech/Space Science Institute

## What are they? Why so flat?

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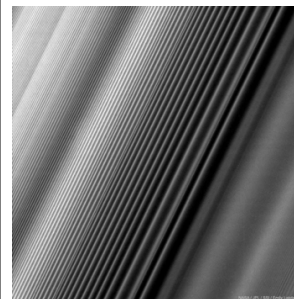
- **Solid sheets? Liquid? What?**
  - extremely thin
  - translucent - stars shine through
  - rotation speed changes with distance from planet
- **Rings made of billions of particles (dust – boulder size)**
- **Dimensions** (Saturn's Rings)
  - 300,000 km across
  - less than 0.15 km (150m) thick
- **Why so flat?**
  - material concentrates in equator
  - more collisions when passing up or down
  - vertical extent continually reduced

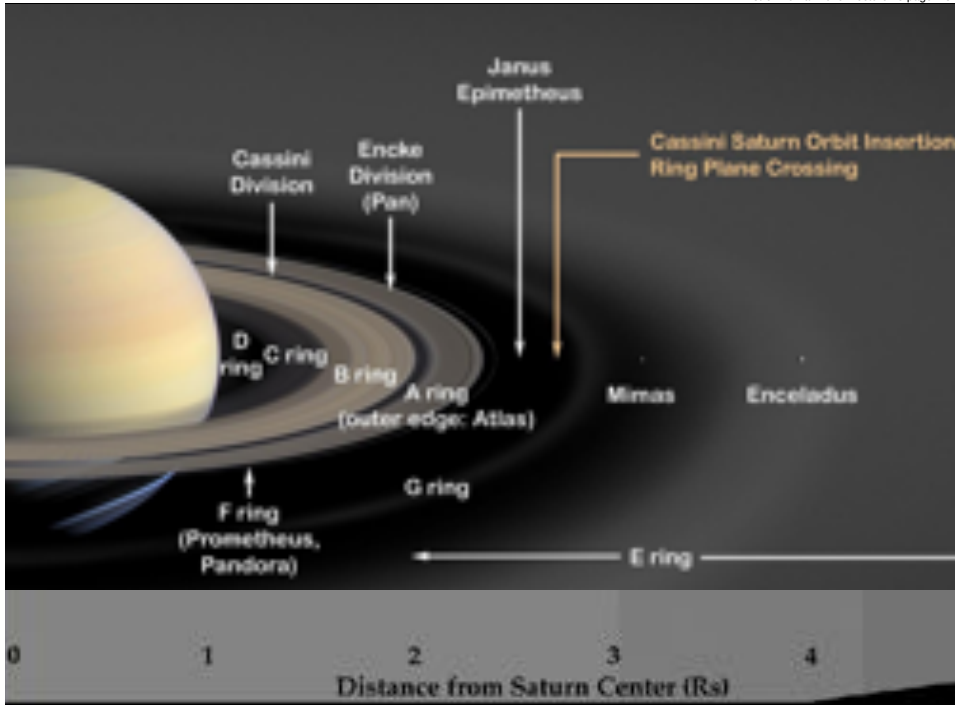


## Structure within the rings

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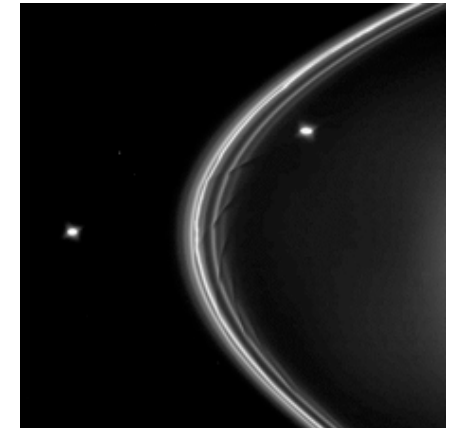
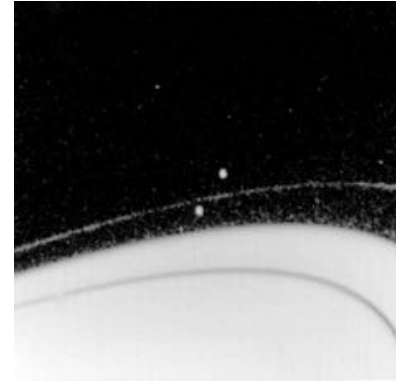
- **Large Gaps**
  - i.e. **Cassini Division** – gap between A and B rings (not empty, but lower density of particles)
- **Multiple rings**
  - broad rings composed of many(!) narrow rings
- **Resonances**
  - orbital period of a **ring region** can be an integer fraction of a **nearby moon's orbital period**
  - ring particle repeatedly tugged by moon
  - resonance “clears gap” at specific place in ring
  - **example: Cassini Division = 2:1 resonance with Mimas**



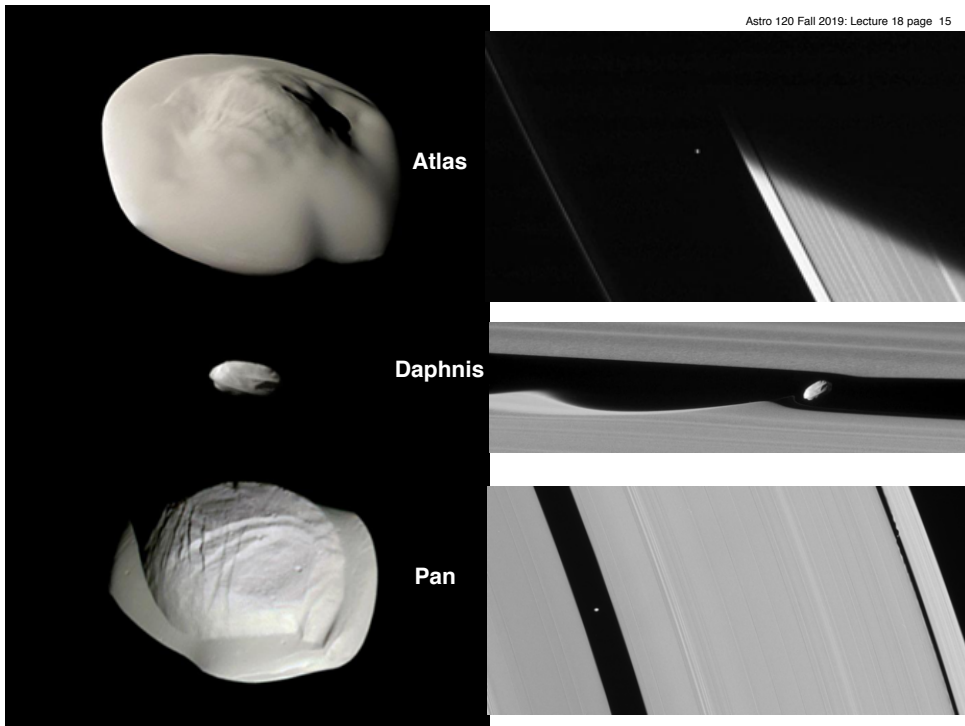


- **shepherding moon(lets) –**

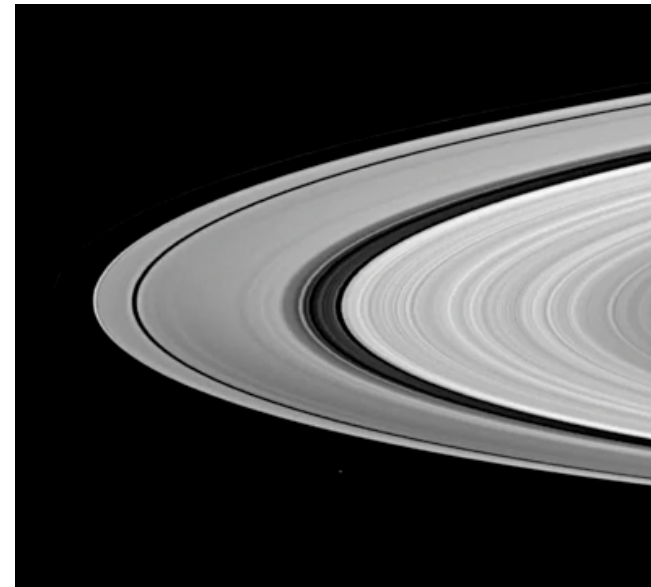
- embedded in rings
- keep rings “in line”



**Complex ring structure slowly becoming understood**



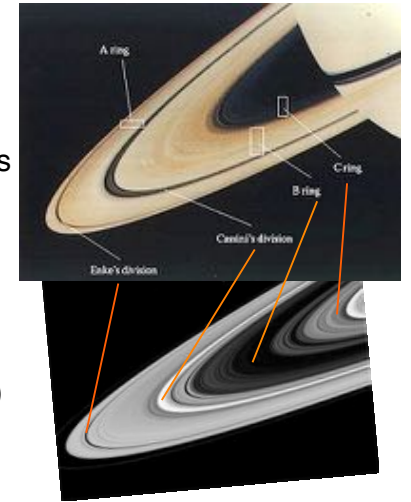
# Cassini Ring Plane Crossing



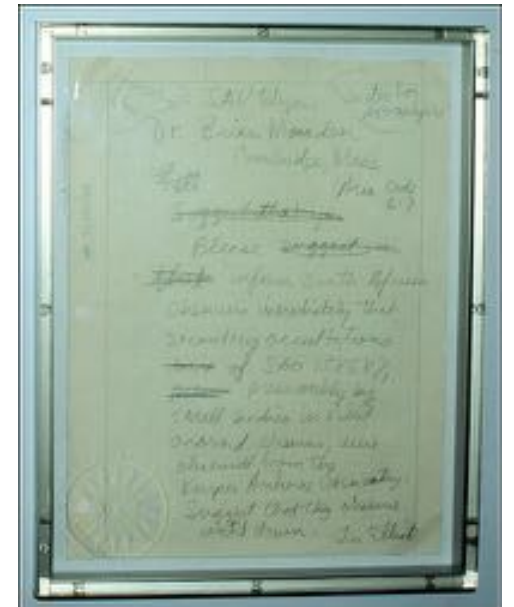
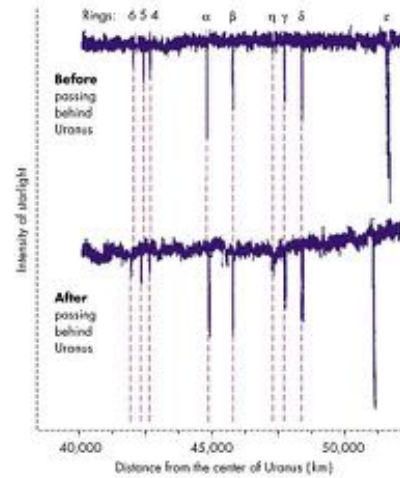
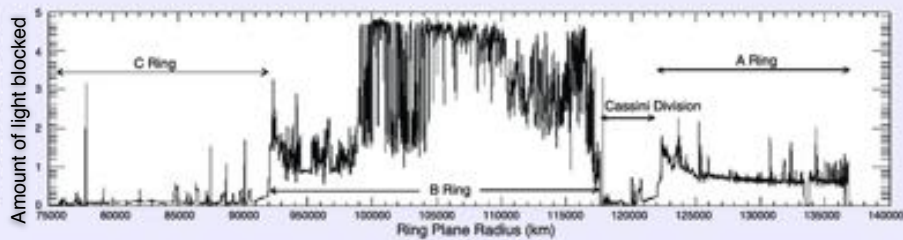


### 3 ways to detect rings:

- reflection
  - large and/or reflective particles (ice, rock)
- transmission
  - small particles (dust)
  - scatters light forward (like fog)
- occultation
  - high particle density blocks starlight



## Saturn ring occultation



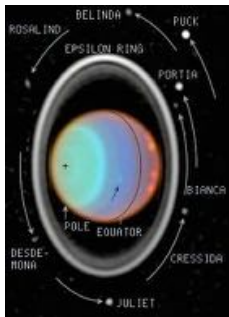
# Ring Systems

## • Saturn

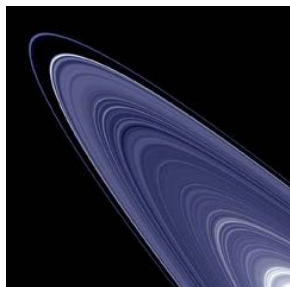
- broad, reflective rings: water-ice particles
- size from dust to boulders
- gaps contain much smaller particles

## • Uranus

- narrow, dark rings discovered by occultation in 1977
- particles of carbon residue from methane ice?
- sharp ring edges caused by shepherding satellites



Uranus Rings (reflection)



Uranus Rings (transmission) Voyager 2

## • Jupiter

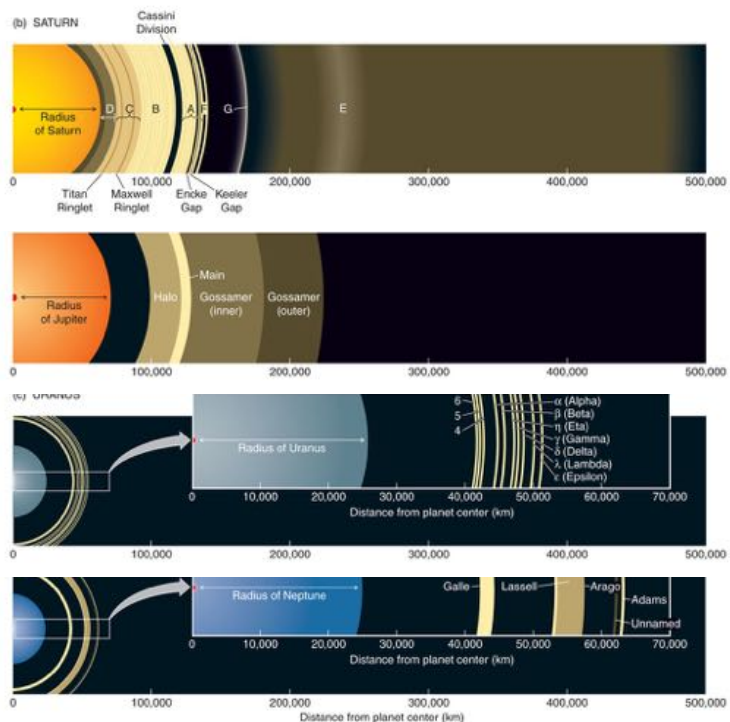


- dark, narrow ring discovered by Voyager in 1979
- bright when viewed by transmission



## • Neptune

- dark, very tenuous rings seen by Voyager in 1989
- bright when viewed by transmission

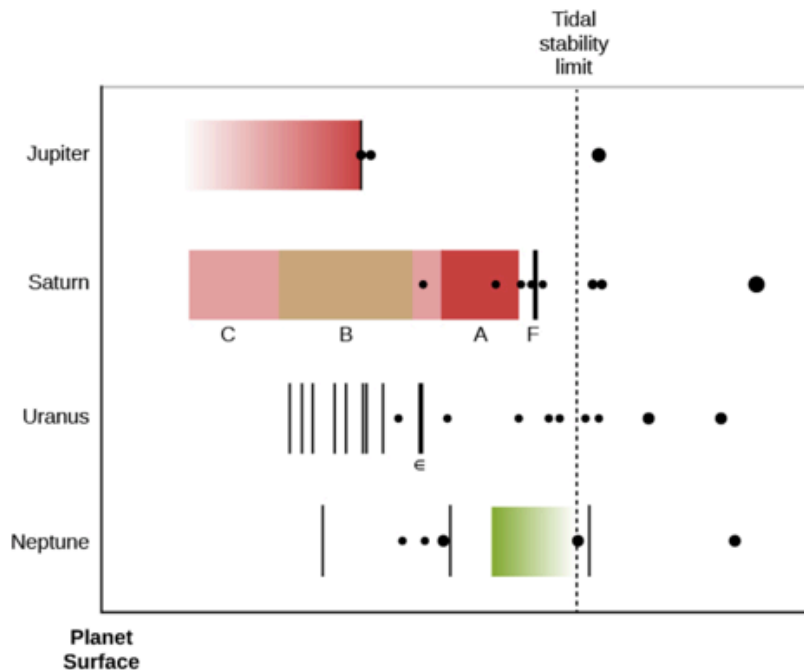


Saturn

Jupiter

Uranus

Neptune



Planet Surface