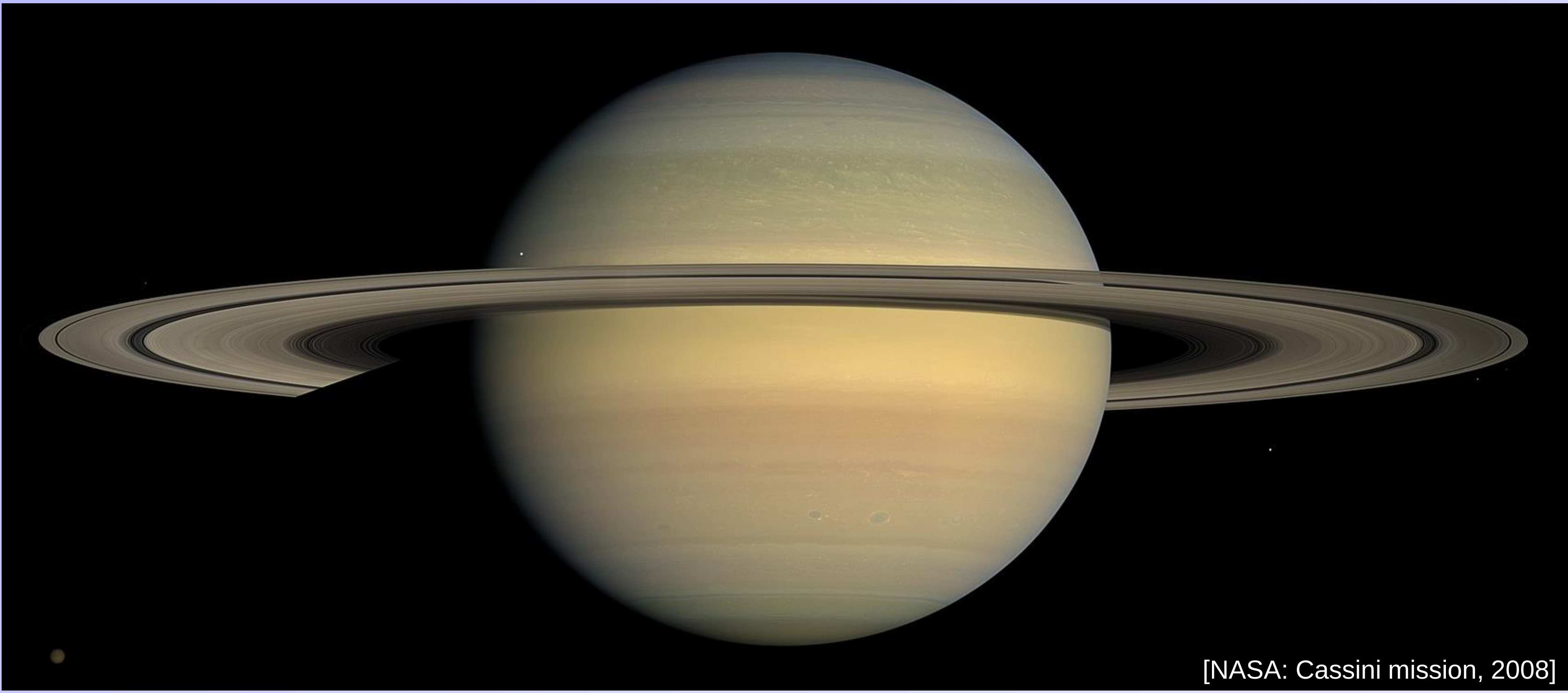
Today’s Topics

Monday, October 28, 2019 (Week 9, lecture 23) – Chapters 11, 12, 13.

1. Saturn
2. Uranus
3. Neptune
4. Dwarf planets
5. Asteroids & Comets

Saturn: "Lord of the Rings"



[NASA: Cassini mission, 2008]

- "Lightweight Jupiter" with rings.
  - → $M_{Saturn} \approx 0.3\ M_{Jupiter}$.
  - → R_{Saturn} = 58,500 km $\approx 0.84\ R_{Jupiter}$.
- Almost twice as far as Jupiter.
  - → Semimajor axis: 9.5 AU (J: 5.2 AU).
  - → Orbital period: T = 29.5 yrs (J: 11.9 yrs).

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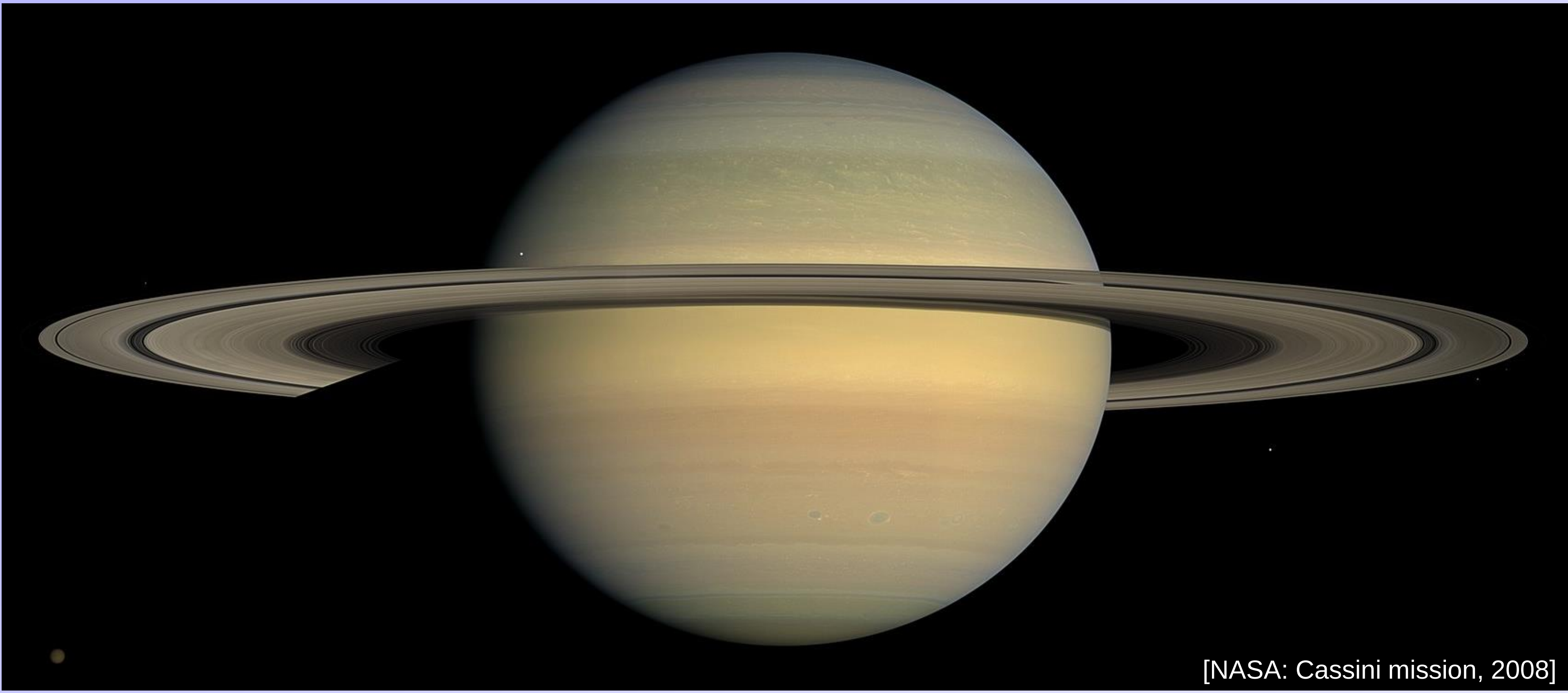

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  → Semimajor axis: 9.5 AU (J: 5.2 AU).
  → Orbital period: T = 29.5 yrs (J: 11.9 yrs).
- Rotates quickly: $T_{rotation}$ = 10.6 hrs.
- At least 82 moons.
  → Only moon in Solar System with an atmosphere: **Titan**.
- Giant rings.
- Large magnetosphere.

The Rings I

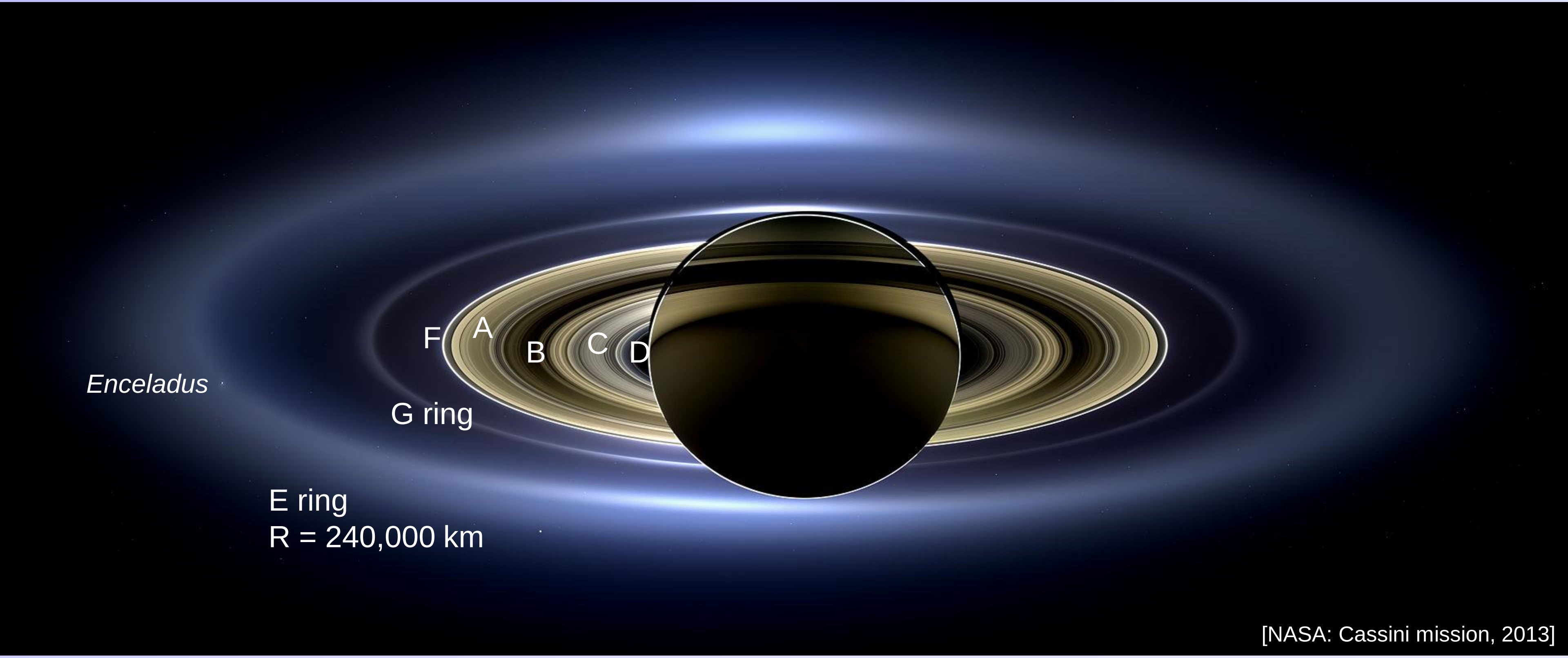
7 distinct ring families

→ A, B, C are the most visible.

→ B is the brightest (not in photo).

→ D, F, G, and E are very faint.

Outer radius of A = 137,000 km
Inner radius of C = 74,500 km

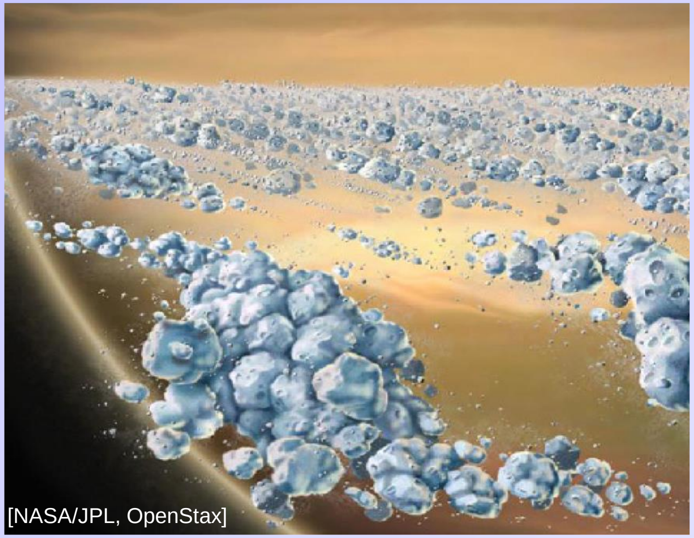


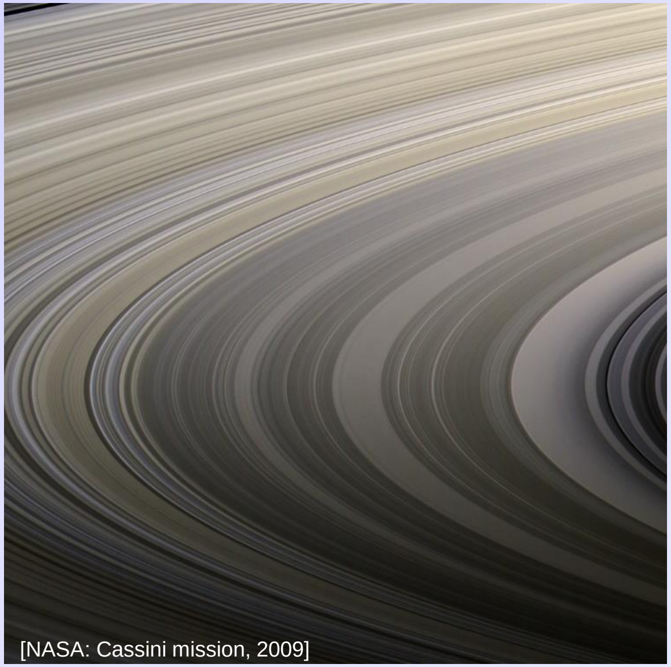
Enhanced image of Saturn's rings (Sun is eclipsed by Saturn)

The Rings II

Ring Properties

- Mostly **water ice** (99.9%).
- Some silicates
- “Particle” size range: 1 cm to 10 m.
- Ring particles **clump together**.
  (mostly multi-meter scale, but up to 10 km in size)
- Thickness of rings: 10-100 m.
- Rings slowly falling into Saturn as **“ring rain.”**
  → *Rings may be gone in 100s of millions of years.*


[NASA/JPL, OpenStax]


[NASA: Cassini mission, 2009]

Saturn’s B ring

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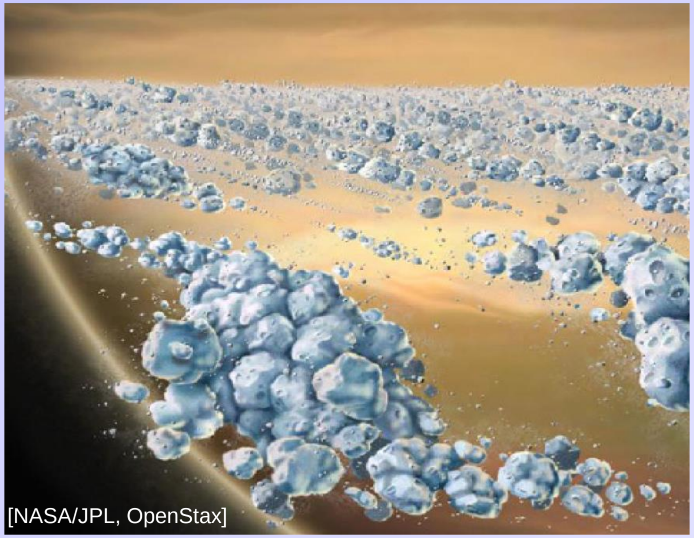
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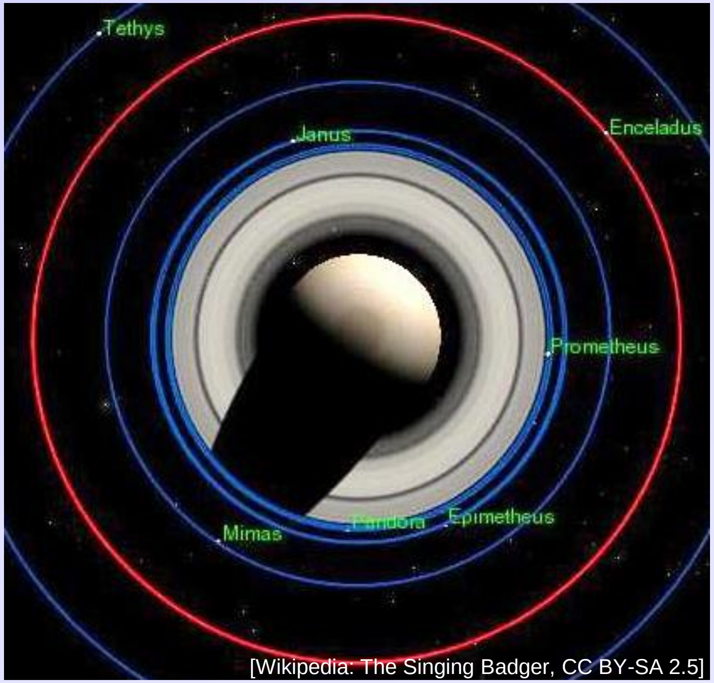
Shepherd moons

- Moons help to keep the rings from spreading out.
  → *Prometheus, Daphnis, Pan, Janus, and Epimethus.*
- Moonlets within the rings also act as **shepherds**.
- **Cryogeisers on Enceladus** feed the E ring.



[Wikipedia: The Singing Badger, CC BY-SA 2.5]

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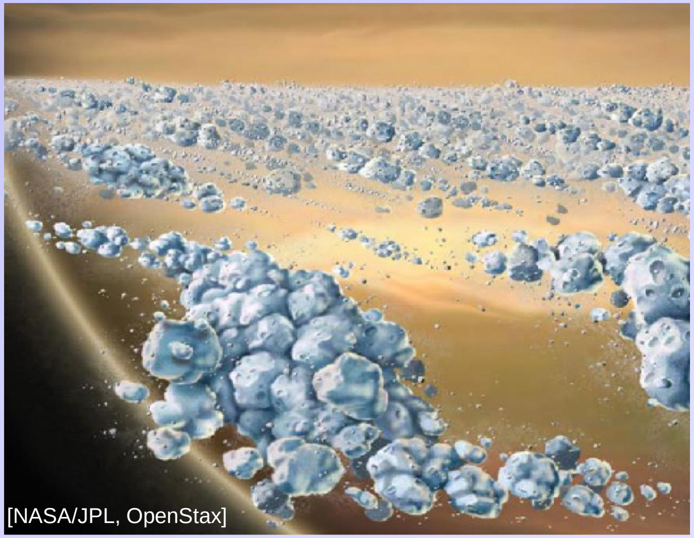
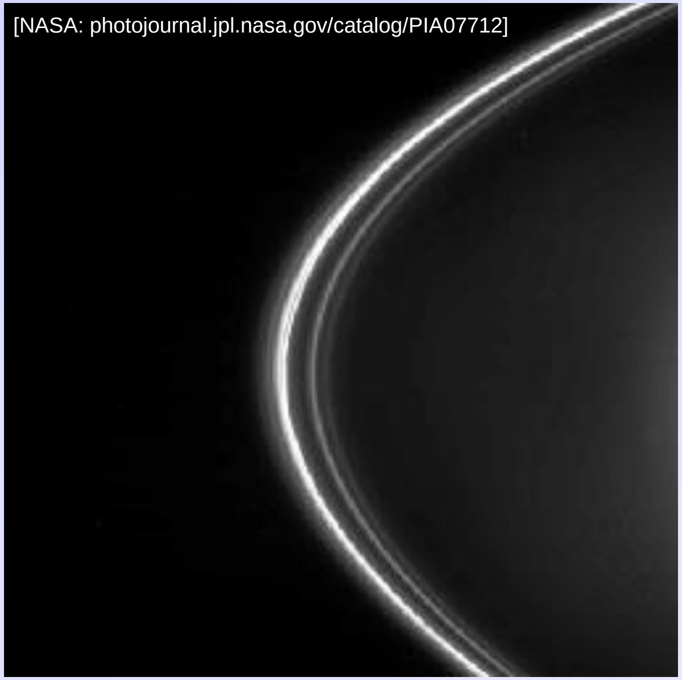
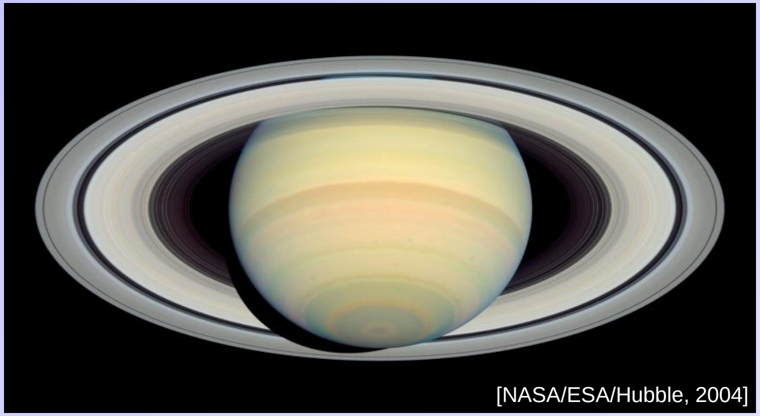




Pandora *Prometheus*

Origin of the Rings

The origin and age of the rings is not well understood (i.e. open question).


[NASA/ESA/Hubble, 2004]

Hypothesis A: *Old rings*

The rings are the remnant of the **formation** of the mini "solar system" of Saturn.

→ Rings are very old: about as old as the Solar System, i.e. ~ 4.4 billion years old.

Hypothesis B: *Young rings*

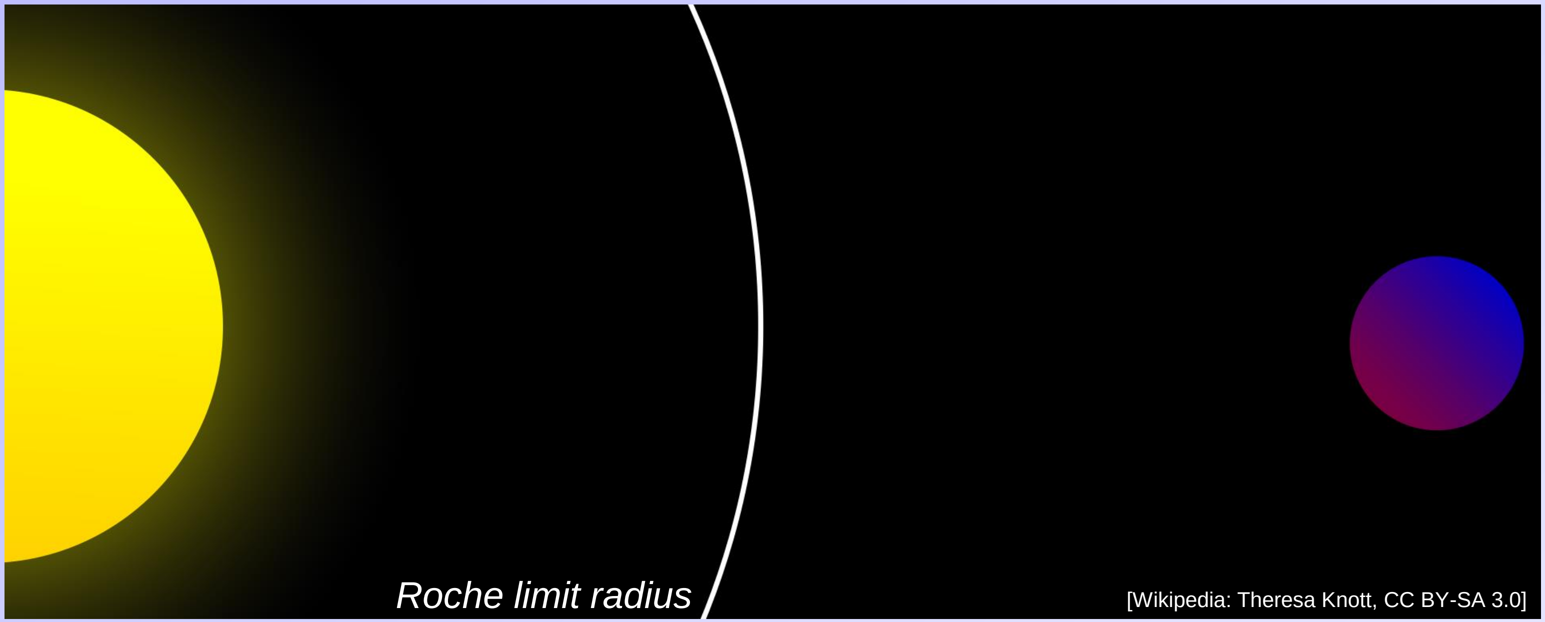
The rings were formed when two icy moons **collided** or when a moon got too close to Saturn (**Roche limit**) and was pulled apart by **tidal forces**.

→ Rings are relatively young: perhaps 100s of millions of years old.

The Roche Limit

The Roche limit is the orbital radius at which a gravitational bound object will be **pulled apart** by the **tidal force** from the central mass (i.e. Sun, Saturn, etc).
(gravity gradient)

→ The Roche limit depends on nature of body (solid, fluid, density).
→ Proposed by Eduard Roche in 1848 (French astronomer).



Far outside the Roche limit radius, the tidal force and deformation are **weak**.

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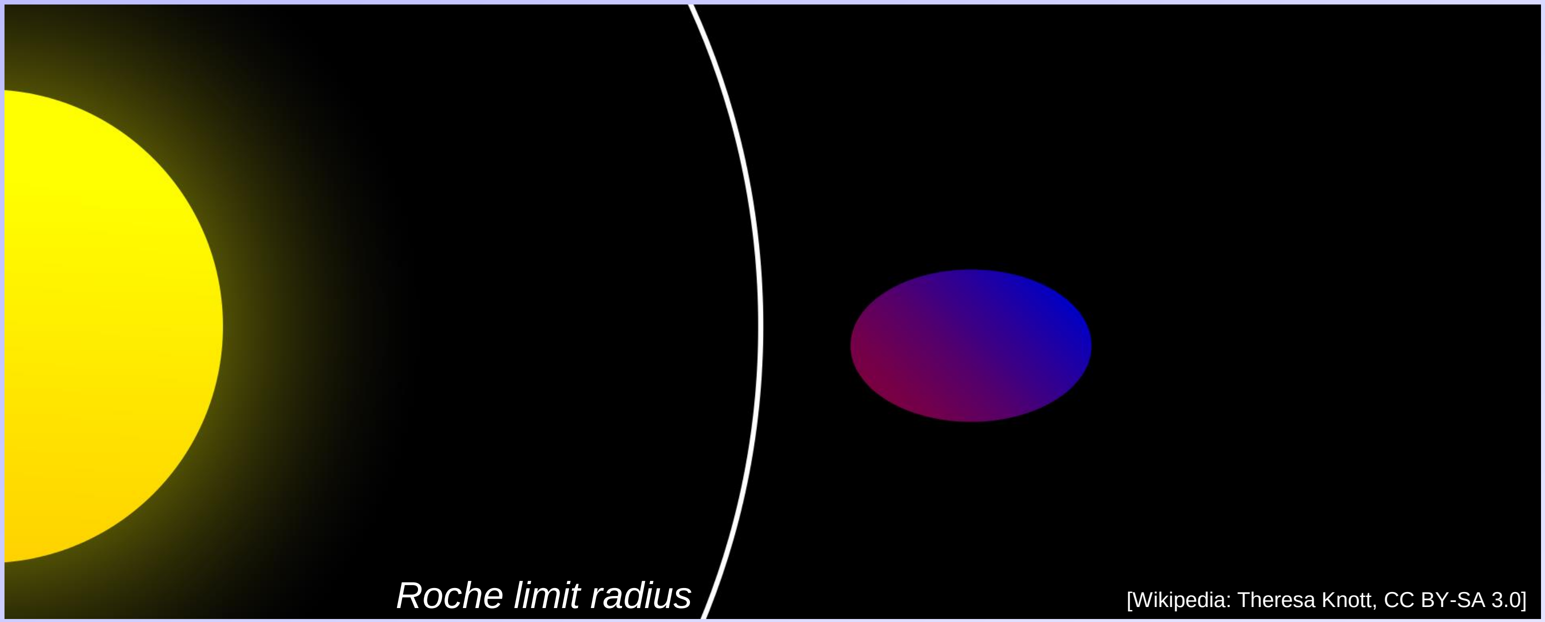

Close to the Roche limit radius, the tidal force and deformation are **strong**.

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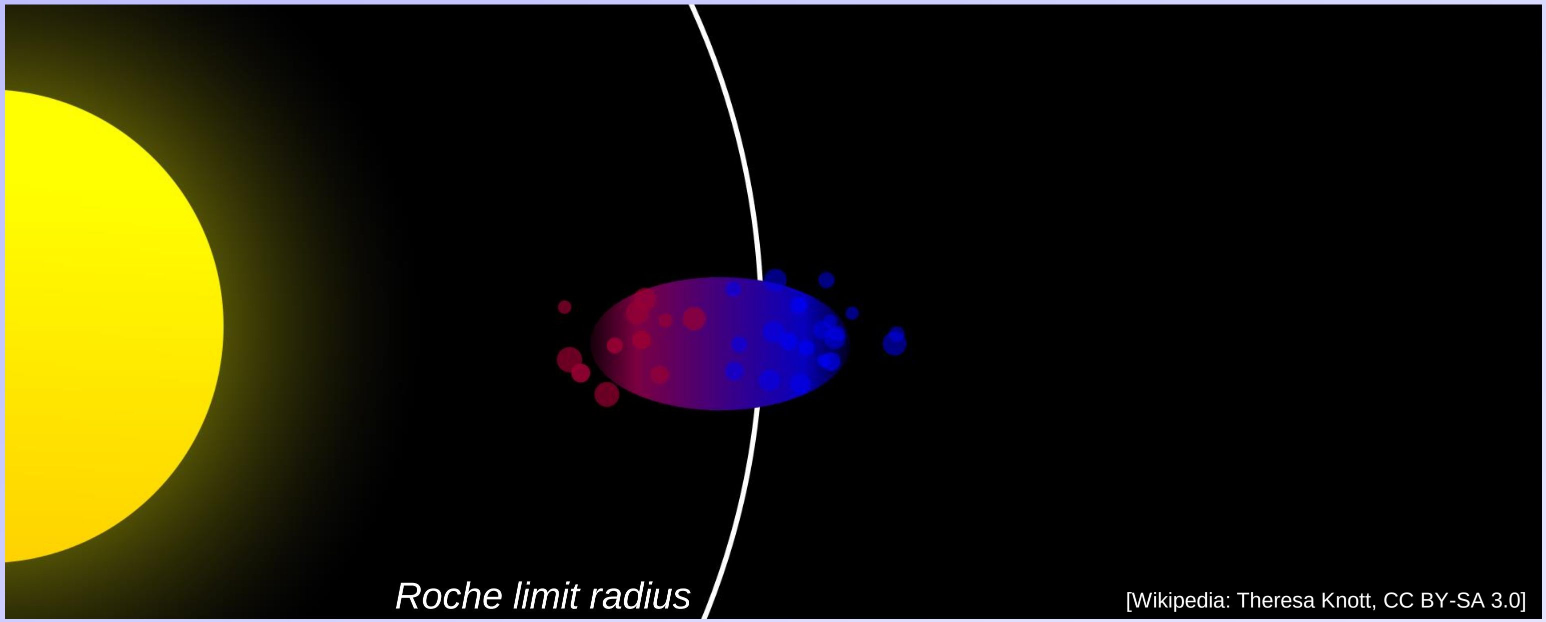

At the Roche limit radius and within it, the tidal force and deformation **pull the planet/moon apart**.

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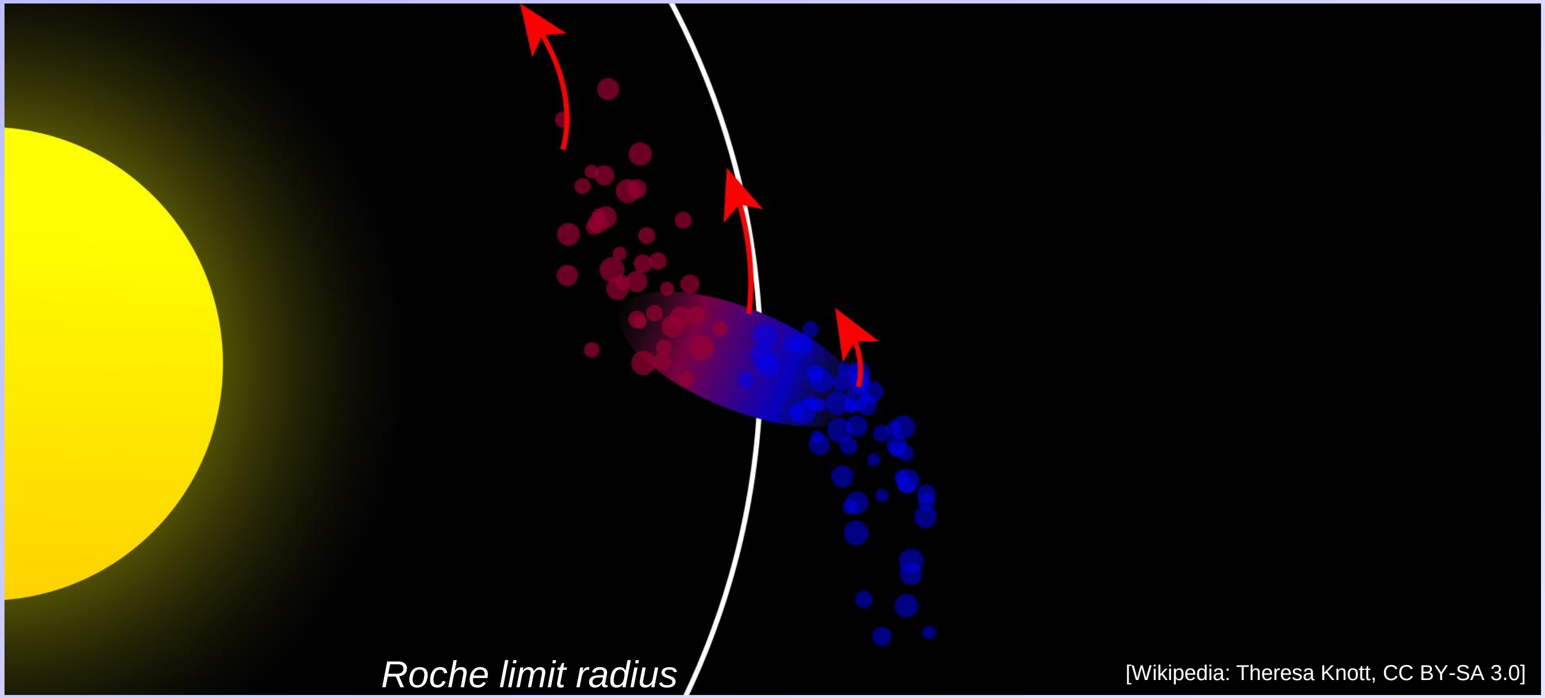

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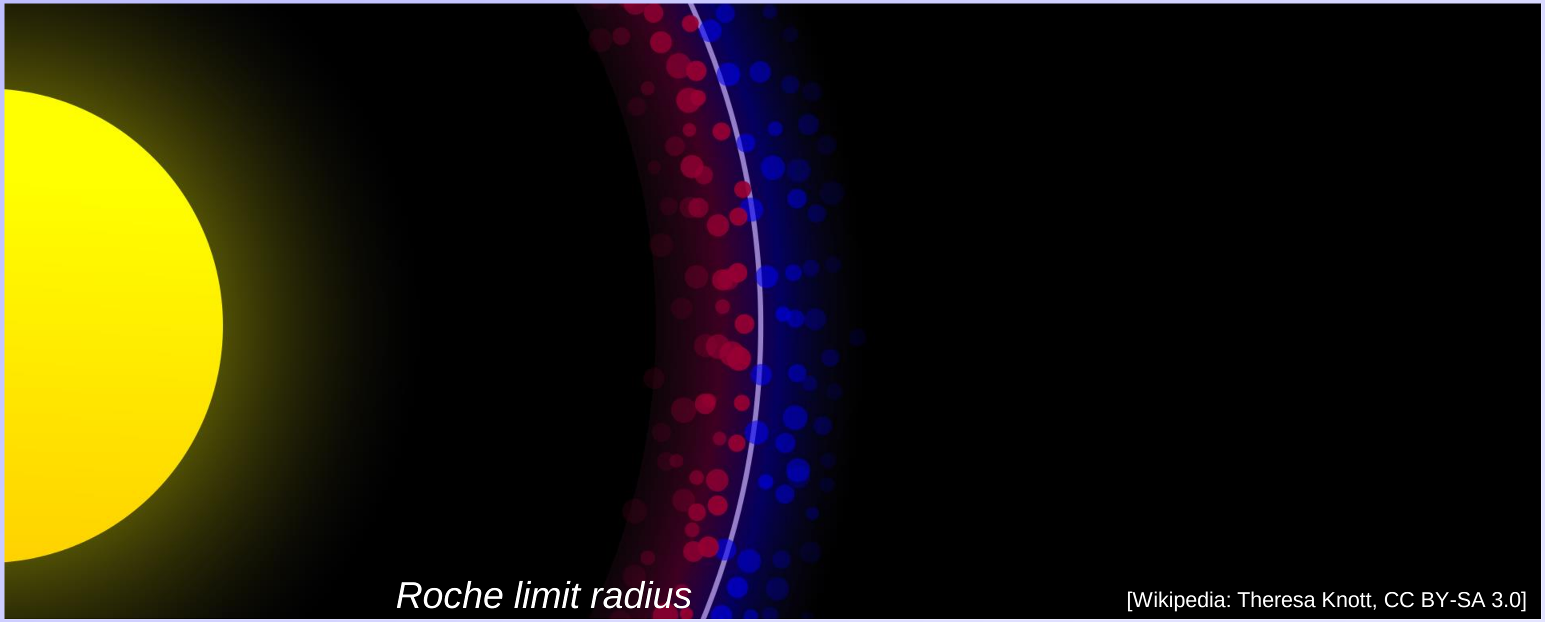
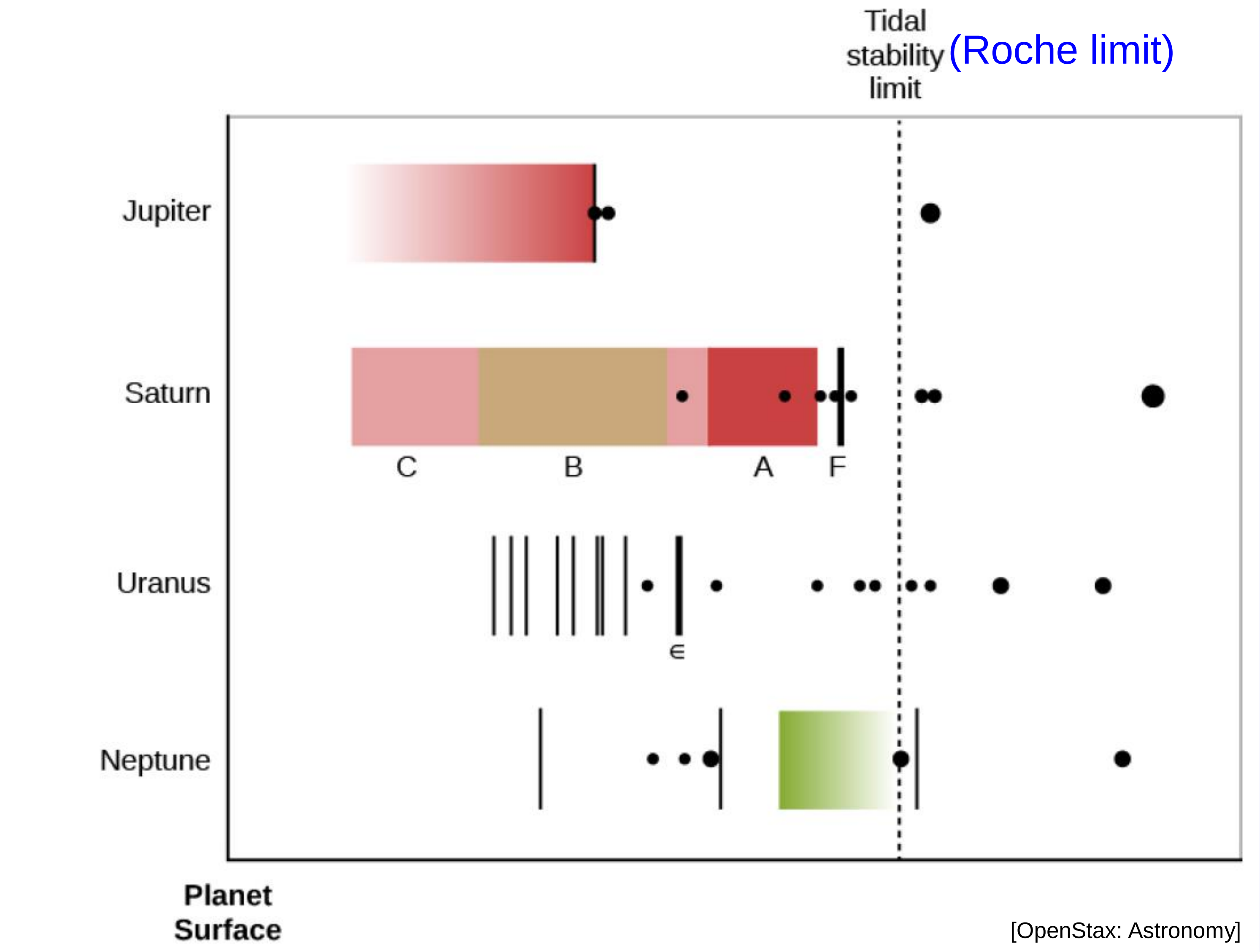


Within the Roche limit radius, planets/moons are pulled apart, and they also cannot form.

→ *The accretion process from planetesimals/rock piles cannot happen.*
→ *Saturns rings are unlikely to become moons (Roche limit ≈ 75,000-150,000 km).*

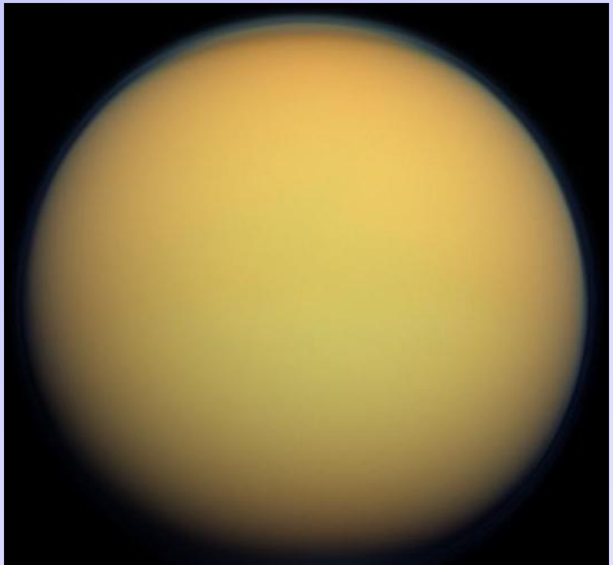
Roche Limit and the Icy Gas Giant



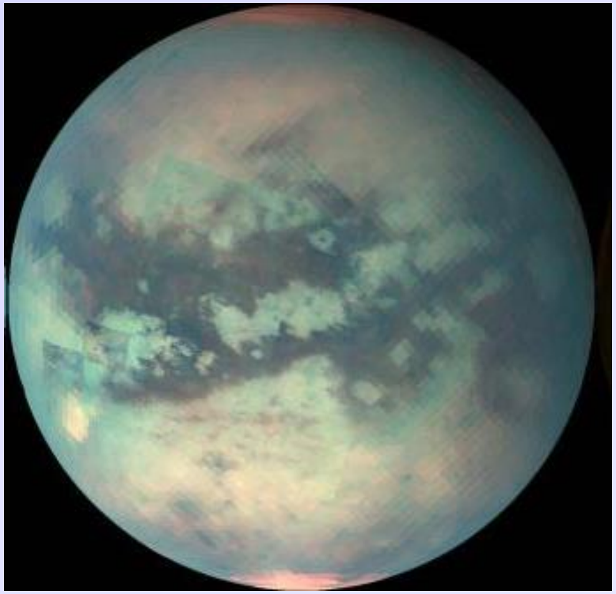
Note: Small moons can survive within the Roche limit.

Titan

- Second largest moon in Solar System.
- **Thick atmosphere:** surface pressure ~ 1.5 bar.
  Nitrogen (N_2): 95-98%.
  Methane (CH_4): 2-5%.
  Other hydrocarbons: trace.
- Temperature: 94 K (surface), i.e. -179° C.
  → **Greenhouse effect** from methane.
  → Anti-greenhouse effect from reflecting smog.



[NASA: Cassini mission, 2012, visible light]



[NASA: Cassini mission, 2005, infrared 1.6-5 μm]

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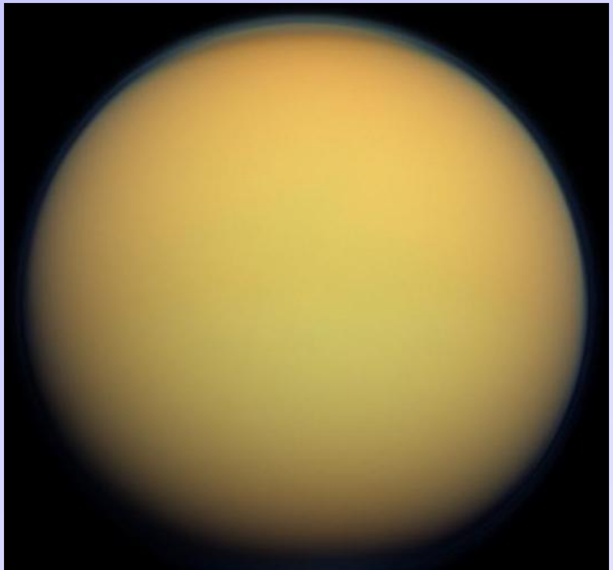
  } ΔT = 12 K
- **Clouds:** Methane, ethane, other hydrocarbons.
  → Methane rain.
  → Cloud cover: 1-8%.
- Not many craters: Geologically young surface or weathered surface.
  → Surface: Water ice and hydrocarbon ice "rocks".
  → Interior should be rocky.
- **Hydrocarbon lakes, rivers, seas.**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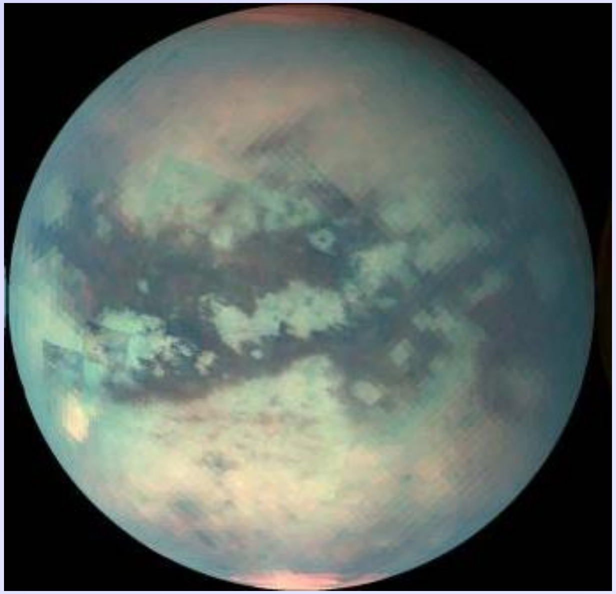
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Surface of Titan, 2005 (Huygens lander).

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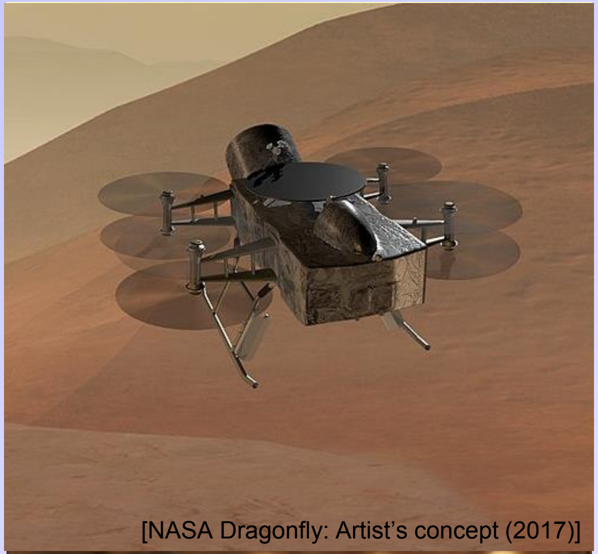
- Target for **astrobiology** mission.
  → Dragonfly (NASA/JHU), launch: 2026, arrive: 2034.



[NASA Dragonfly: Artist's concept (2017)]

[NASA Cassini mission: ESA Huygens lander, 2005]

Surface of Titan, 2005 (Huygens lander).

Uranus (“discovered” by William Herschel, 1781)

- **Orbit properties**
  Semimajor axis = 19.2 AU.
  Orbital period = 84 years.

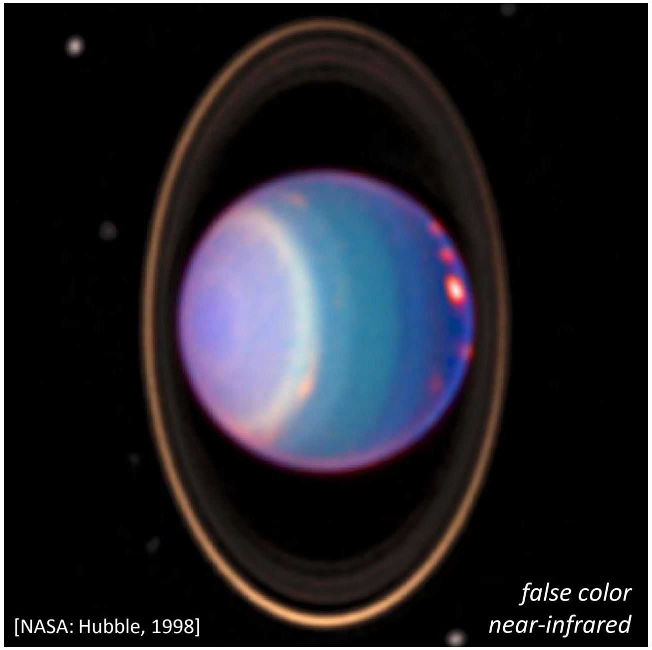
- Several times larger than Earth.
  → $M_{Uranus} = 14.5\ M_{Earth}$
  → $R_{Uranus} \approx 4\ R_{Earth}$

- **Coldest atmosphere** in Solar System: ~ 49 K.

- Atmosphere: H_2 (83%), He (15%), CH_4 (2%).

- Rotation period $T_{rotation}$= 17 hrs.

[NASA: Voyager 2, 1986] *visible light appearance*



[NASA: Hubble, 1998] *false color near-infrared*

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  → *“Planet is on its side.”*

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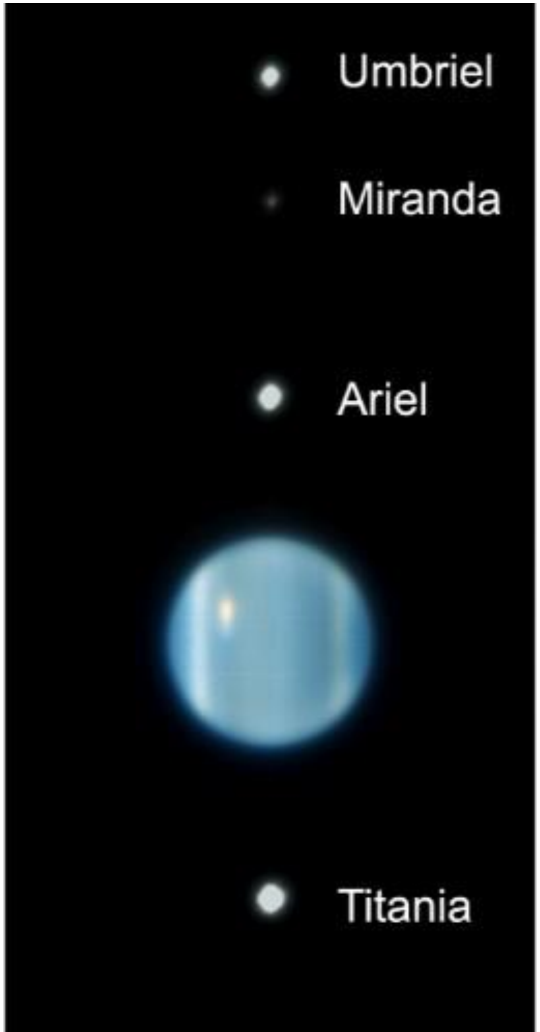

[ESO: Very Large Telescope, 2007]

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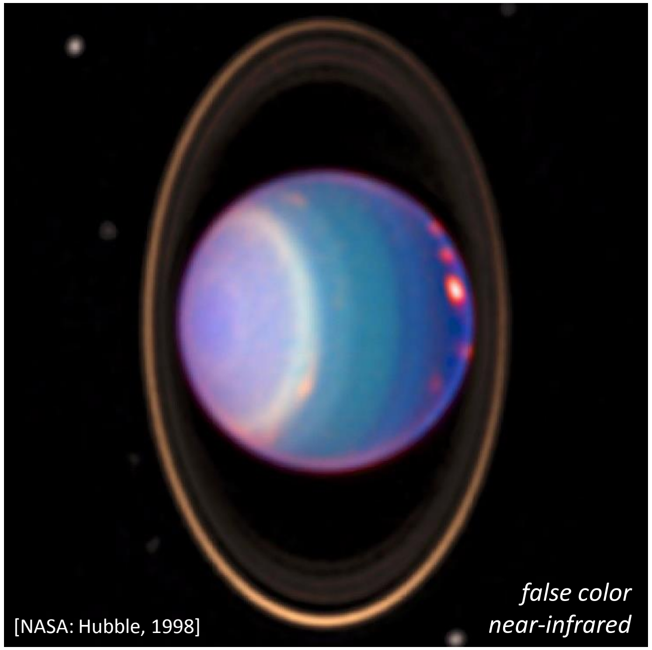

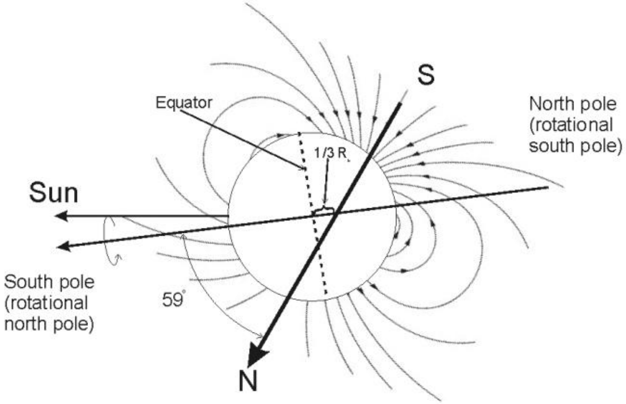

[Wikipedia, based on Voyager 2 data]

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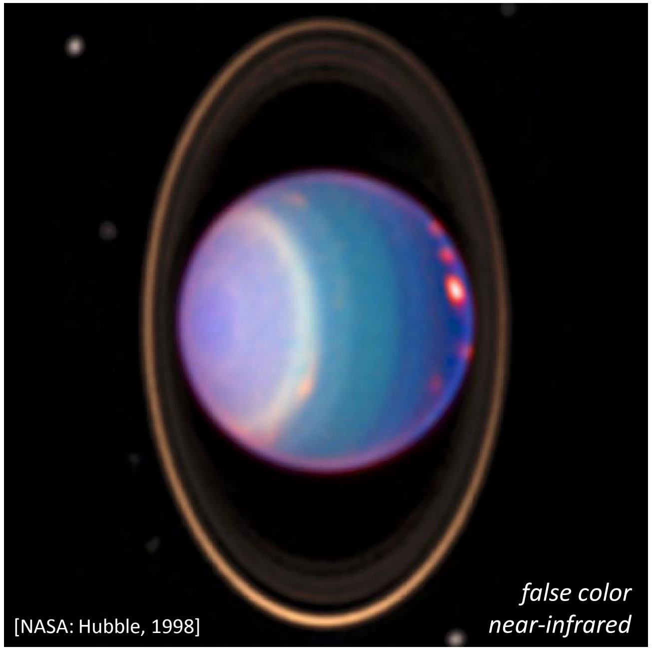
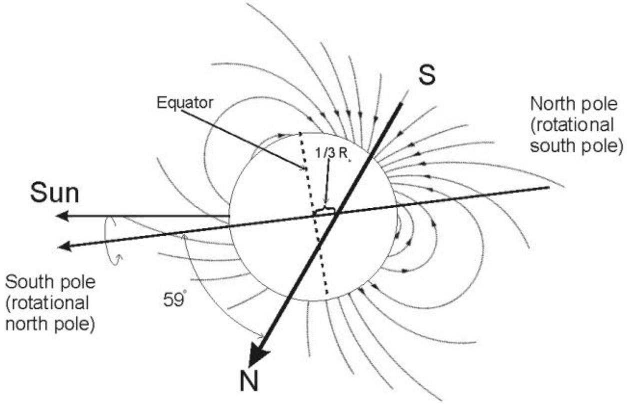
Uranus’s strange orientation is thought to be due to a collision with an Earth-sized protoplanet during formation of Solar System.





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Neptune

Neptune was “discovered” theoretically from its gravitational effect on Uranus’s orbit.

- Probably observed by **Galileo** 1612-13 (retrograde).
- **Alexis Bouvard** noticed irregularities in Uranus’s motion (1820’s).
- **Urbain Le Verrier** and **John Couch Adams** independently predict location of Neptune (1845-46).
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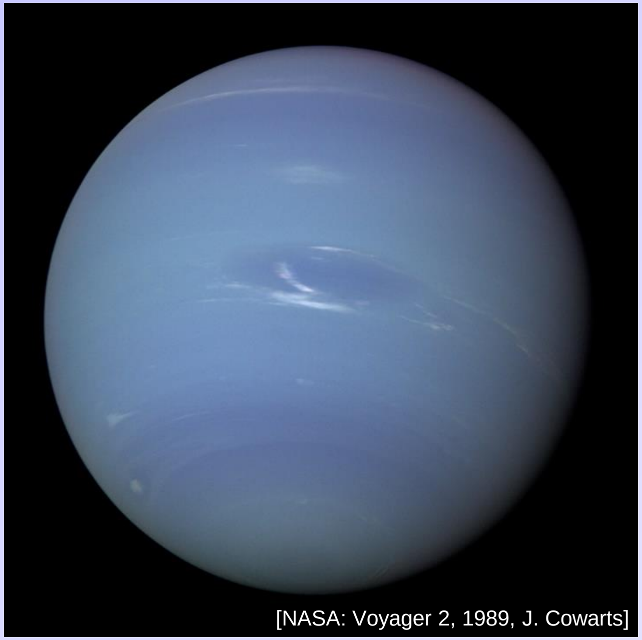

[NASA: Voyager 2, 1989, J. Cowarts]

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➢ Semimajor axis = 30 AU, orbital period = 165 yrs.

➢ 14 moons. Largest is Triton (retrograde orbit).

➢ **Similar** in size and composition **to Uranus.**

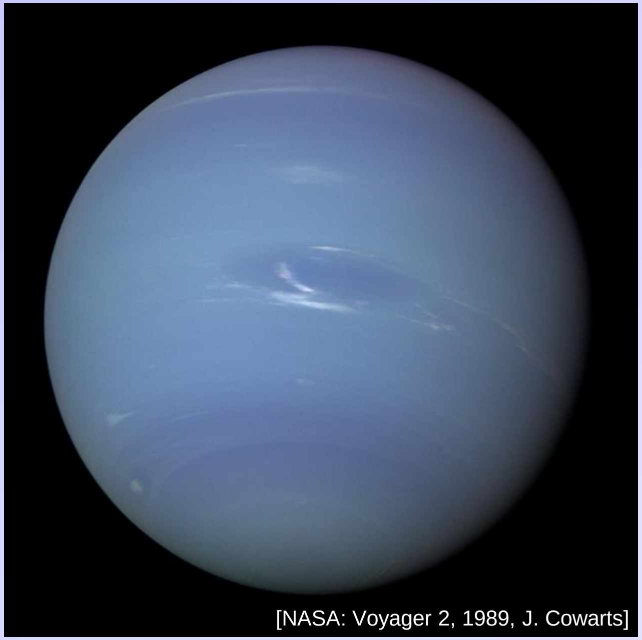
→ $M_{Neptune} = 1.2\ M_{uranus}$

→ $R_{Neptune} = 0.97\ R_{uranus}$

→ Rotation: $T_{rotation} = 16$ hrs $= 0.93\ T_{Uranus}$

→ Atmosphere: H_2 (80%), He (19%), CH_4 (1.5%).

→ Temperature: 55 K (a tad warmer than Uranus).



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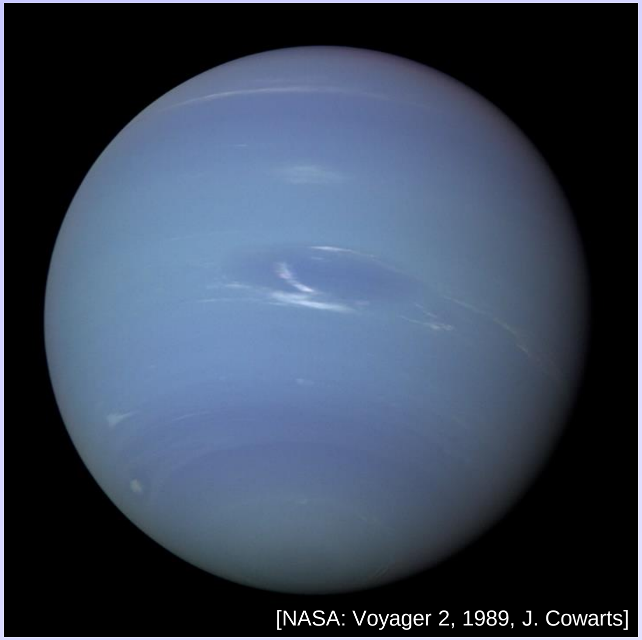
- Planet’s axis is tilted 28°, but **magnetosphere is tilted 47°** to this axis and also off center.



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Dwarf Planets

Definition of a planet (International Astronomical Union 2006)

Body **orbiting the Sun** with sufficient self-gravity to be **spherical-like**, and massive enough to have **cleared its orbital neighborhood**.

Generally not satisfied by dwarf planets.

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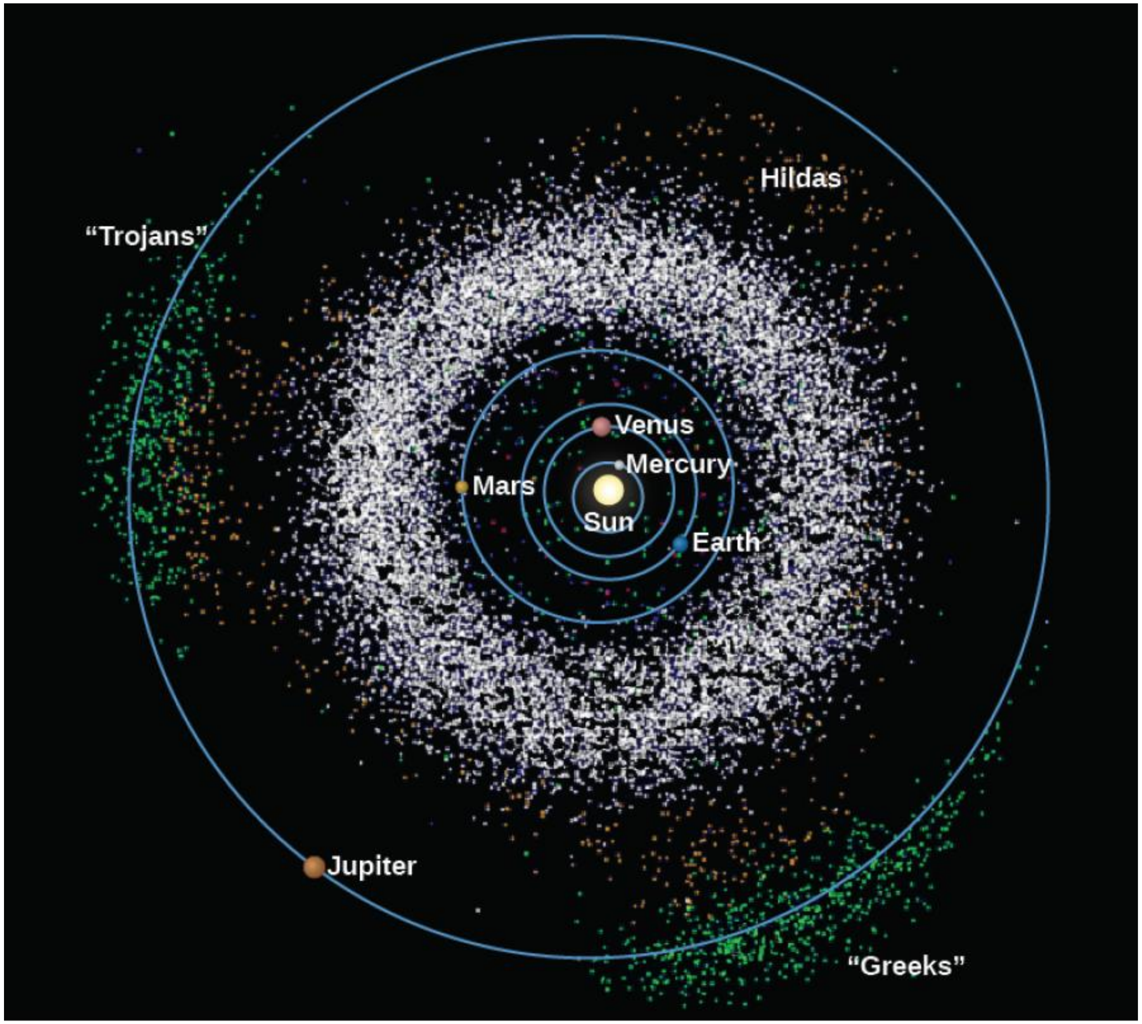
asteroid belt

Kuiper belt

Well-Studied Dwarf Planet	Semimajor Axis (AU)	Orbital Eccentricity	Inclination of Orbit to Ecliptic (°)	Diameter (Earth = 1)	Mass (Earth = 1)	Mean Density (g/cm^3)
Ceres	2.77	0.08	11	0.07	0.0002	2.2
Pluto	39.5	0.25	17	0.18	0.0024	1.9
Haumea	43.1	0.19	28	0.13	0.0007	3
Makemake	45.8	0.16	29	0.11	0.0005	2
Eris	68.0	0.44	44	0.18	0.0028	2.5

Asteroids & Ceres

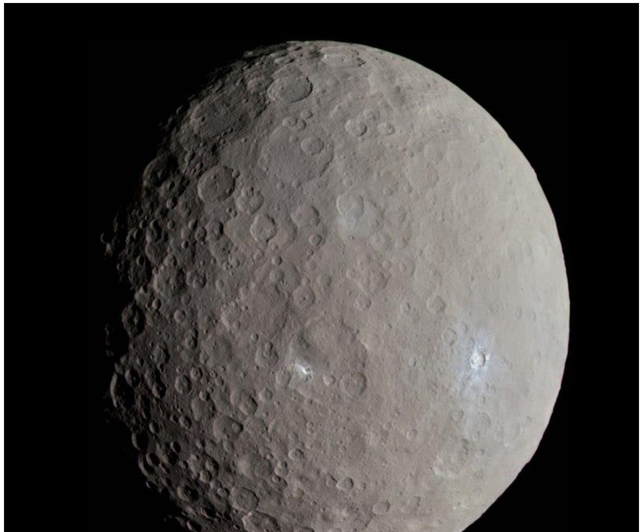
- Asteroids orbit the Sun primarily between Mars and Jupiter.
- Relatively rocky: ~ 2 g/cm^3 (up to 5 g/cm^3)
- Left over from formation on Solar System.
- Some are hard bodies, others are rubble piles.



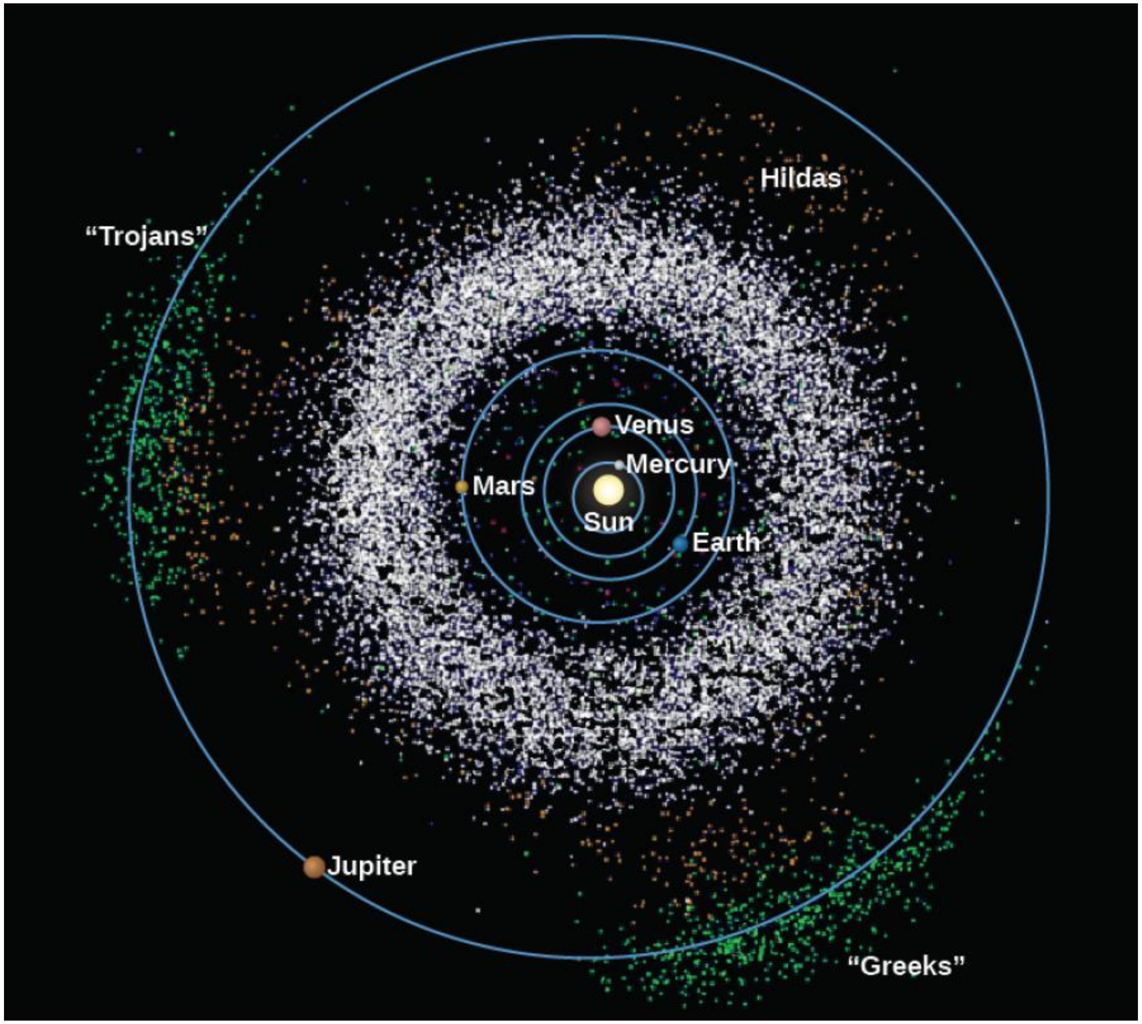
[OpenStax: Astronomy]

Asteroids & Ceres

- Asteroids orbit the Sun primarily between Mars and Jupiter.
- Relatively rocky: ~ 2 g/cm^3 (up to 5 g/cm^3)
- Left over from formation on Solar System.
- Some are hard bodies, others are rubble piles.



Ceres
asteroid/Dwarf plane [NASA: Dawn mission, 2015]



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Lagrange Points

Gravity from Sun and planet + centripetal motion generate a somewhat attractive point