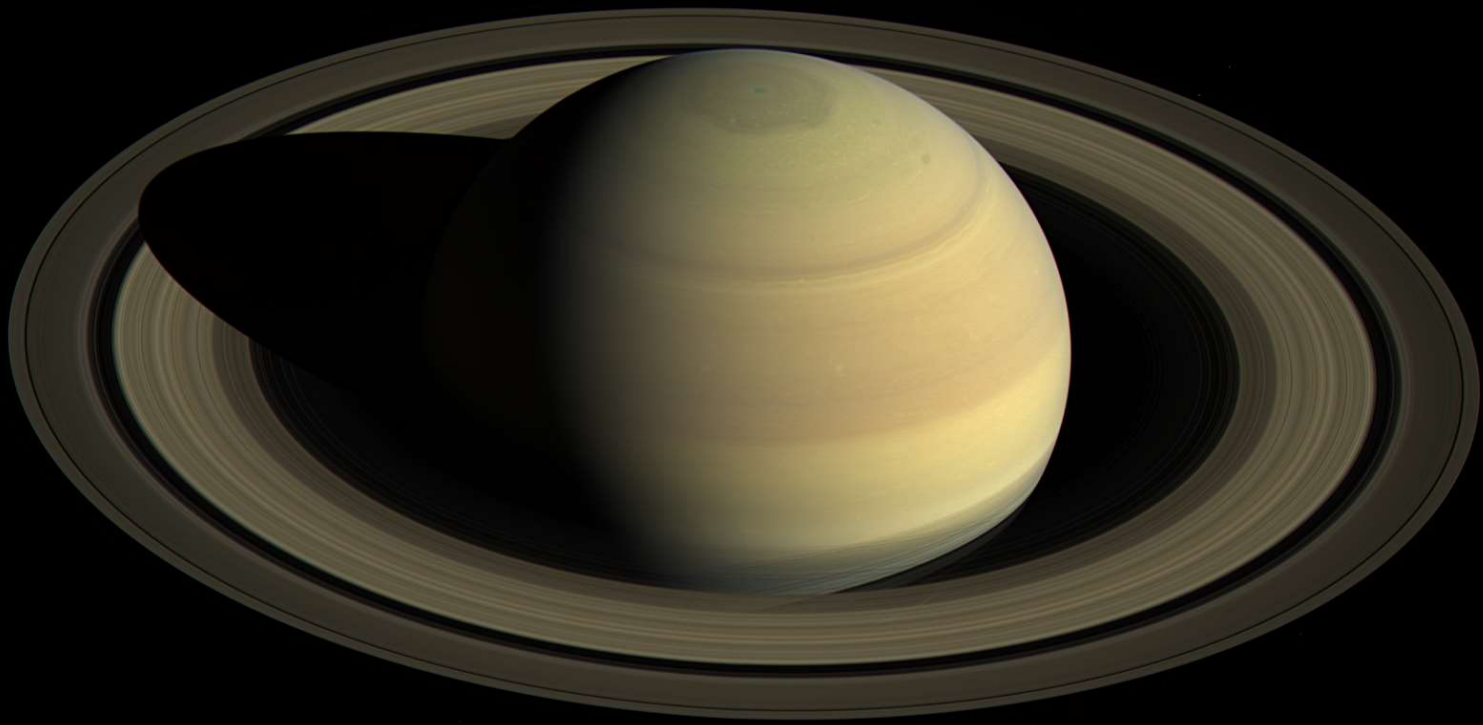
AST 2002
Introduction to Astronomy



A Few Quick Things…

E-mailing me: Must have AST2002 in the subject

Mary Hinkle, Graduate Teaching Assistant:
Office Hours: Mon 1:30-3:00pm. PSB 316

My office hours: Mon 3:00-4:00pm. PSB 308
Tue 3-4 pm. PSB 308

First Mid-term : Will be having more regular homework
Will start going over some of the exam questions…

Next Mid-Term: Wed 7th March

Next Knights Under the Stars Event – Wed 28th Feb 7:30-9:00pm

Mid-Term #1 Solutions

True of False: The star Betelgeuse is 642.5 light years away. We see the star today how it was 642.5 light years ago.

A. True

B. False

Mid-Term #1 Solutions

True of False: The star Betelgeuse is 642.5 light years away. We see the star today how it was 642.5 light years ago.

A. True (~50% answered correctly)

B. False (~50%)

We know that the light must have taken 642.5 years to reach us… *i.e.* the light left the star in ~1375 (middle ages)

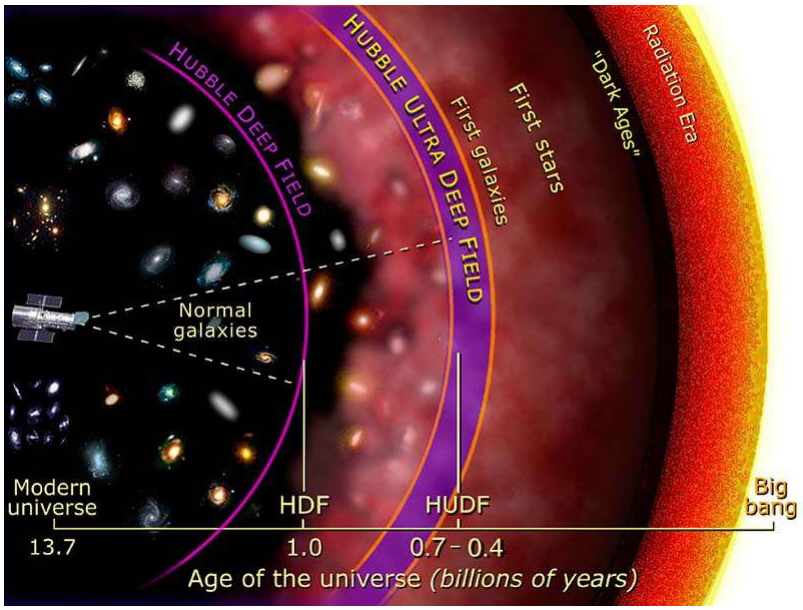
Clarification: Look-Back Time

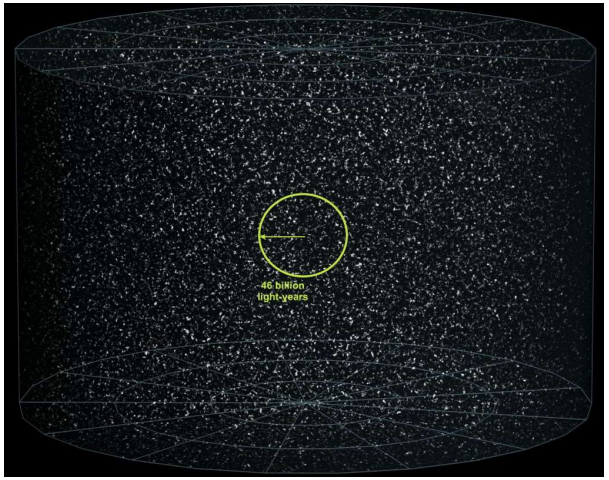
Since distances of objects may be changing, it is easier to speak in terms of the amount of time it has taken an object's light to reach us

- The travel time is called the look-back time, and is usually given in light-years
- Light-years are distances but we also know how long it took light to travel this distance

3.00 x 10^8 meters per second

- We can see further than the age of the Universe due to inflation/expansion



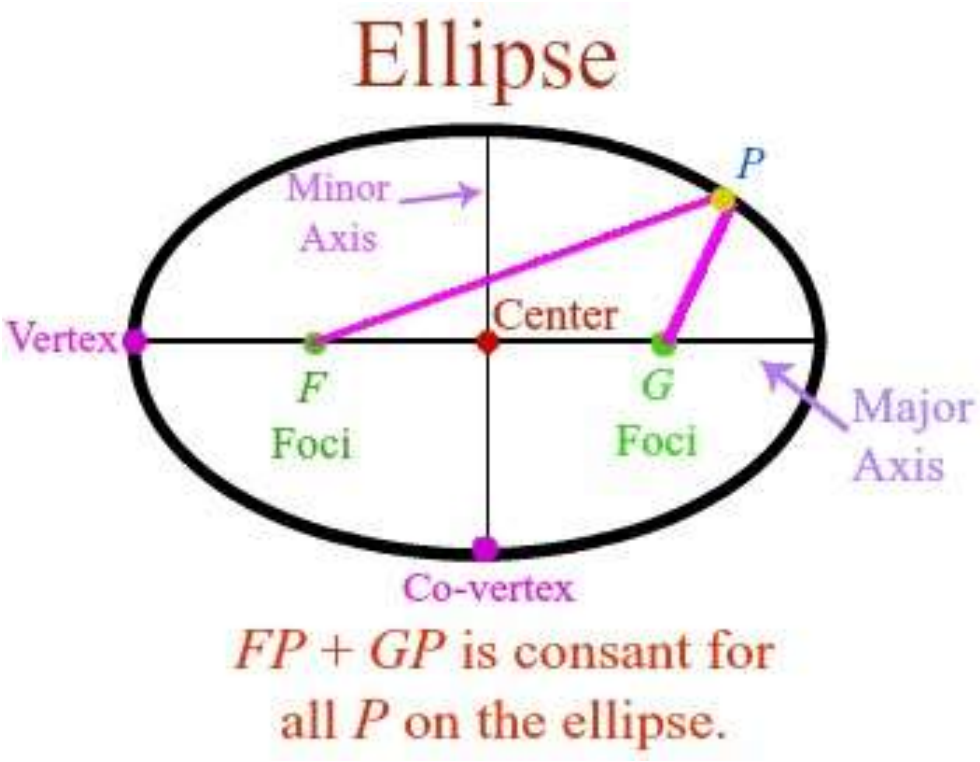


Mid-Term #1 Solutions

True of False: A Circle is a special form of Ellipse.

A. True

B. False

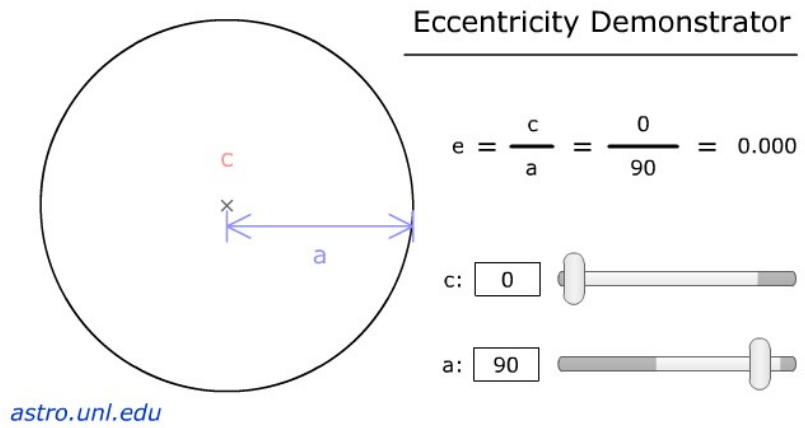


Mid-Term #1 Solutions

True of False: A Circle is a special form of Ellipse.

A. True (62%)

B. False (38%)



"An ellipse is a curve in a plane surrounding two focal points such that the sum of the distances to the two focal points is constant for every point on the curve."

As such, a circle is a special type of ellipse have both focal points at the same location. Covered in Chapter 3.

What is an ellipse?

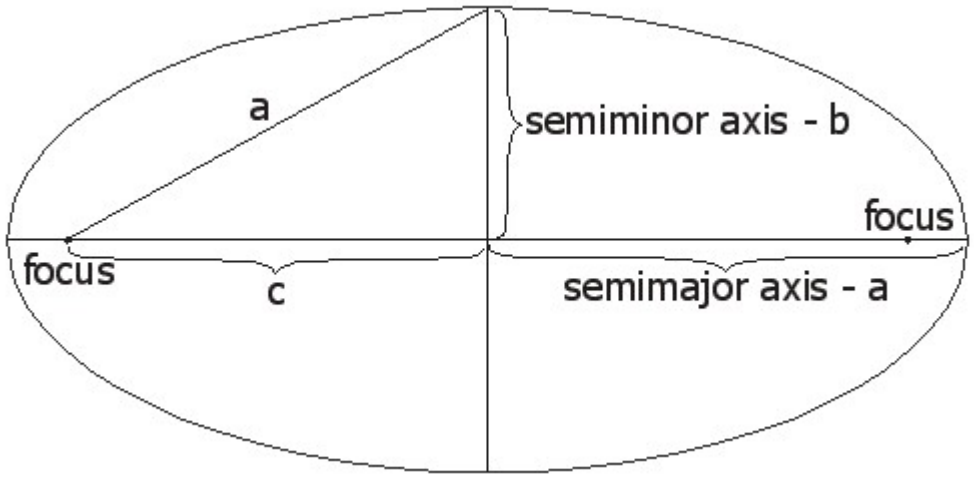
***The size of the ellipse is defined by the Semi-major axis*, a.**

The distance to the focus points is given as c (always a proportion of a)

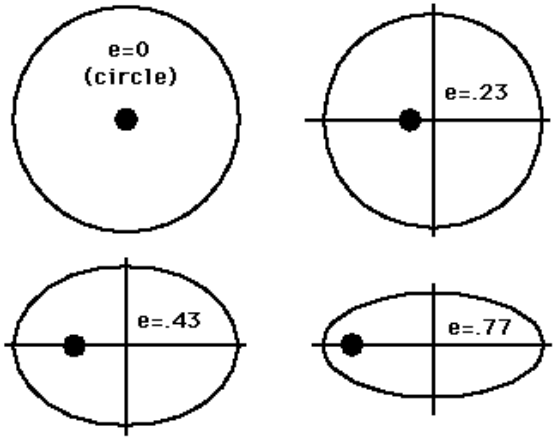
The *eccentricity,* e, is defined as $e = \frac{c}{a}$ (or, equivalently, $c = a \times e$)

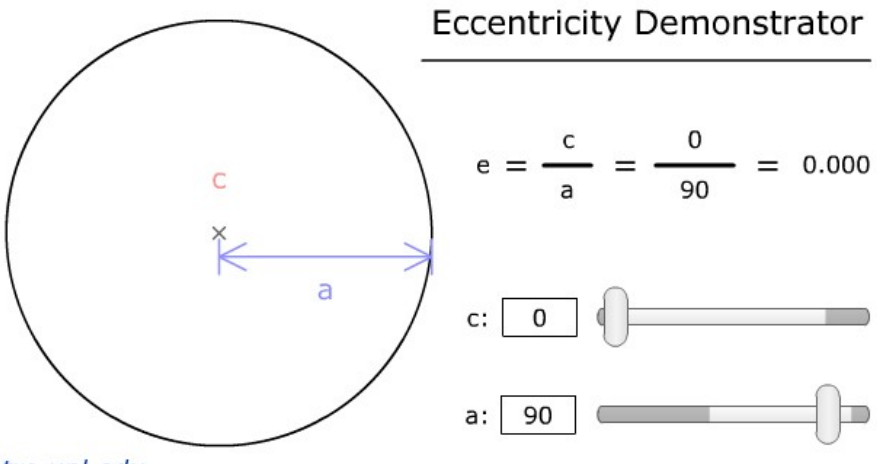
- ***Eccentricity values must lie between 0 (perfect circle) and 1.***

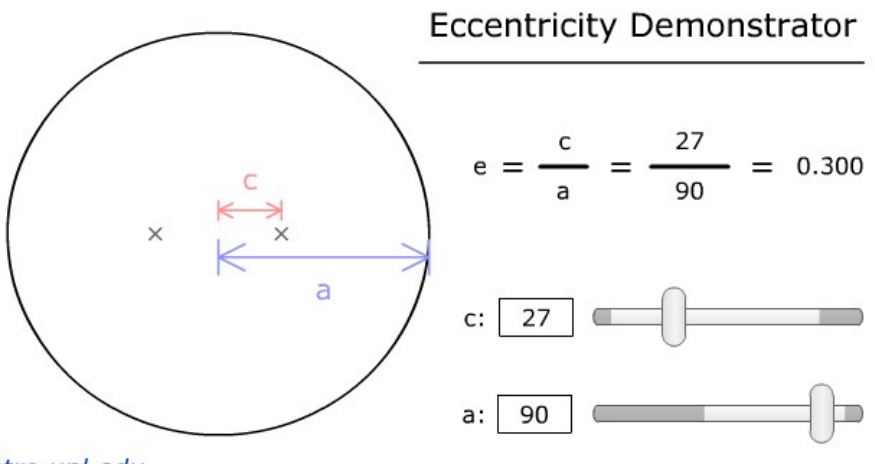
There is also a *semi-minor axis*, b. They can be related by: $b^2 = a^2(1 - e^2)$



In the case of a circle, the two foci lie on top of each other. $c = 0$, therefore $e = 0$



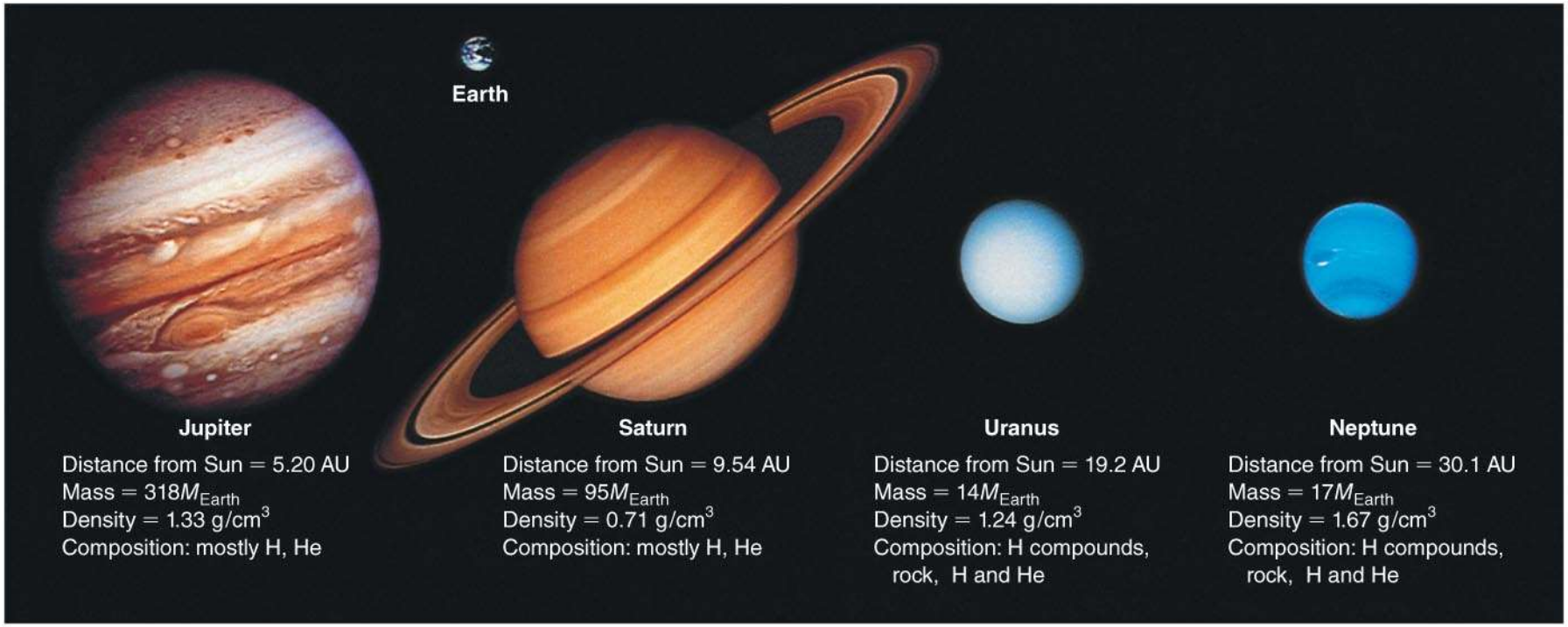




Solar System Data

Celestial Object	Mean Distance from Sun (million km)	Period of Revolution (d=days) (y=years)	Period of Rotation at Equator	Eccentricity of Orbit	Equatorial Diameter (km)	Mass (Earth = 1)	Density (g/cm^3)
SUN	—	—	27 d	—	1,392,000	333,000.00	1.4
MERCURY	57.9	88 d	59 d	0.206	4,879	0.06	5.4
VENUS	108.2	224.7 d	243 d	0.007	12,104	0.82	5.2
EARTH	149.6	365.26 d	23 h 56 min 4 s	0.017	12,756	1.00	5.5
MARS	227.9	687 d	24 h 37 min 23 s	0.093	6,794	0.11	3.9
JUPITER	778.4	11.9 y	9 h 50 min 30 s	0.048	142,984	317.83	1.3
SATURN	1,426.7	29.5 y	10 h 14 min	0.054	120,536	95.16	0.7
URANUS	2,871.0	84.0 y	17 h 14 min	0.047	51,118	14.54	1.3
NEPTUNE	4,498.3	164.8 y	16 h	0.009	49,528	17.15	1.8
EARTH'S MOON	149.6 (0.386 from Earth)	27.3 d	27.3 d	0.055	3,476	0.01	3.3

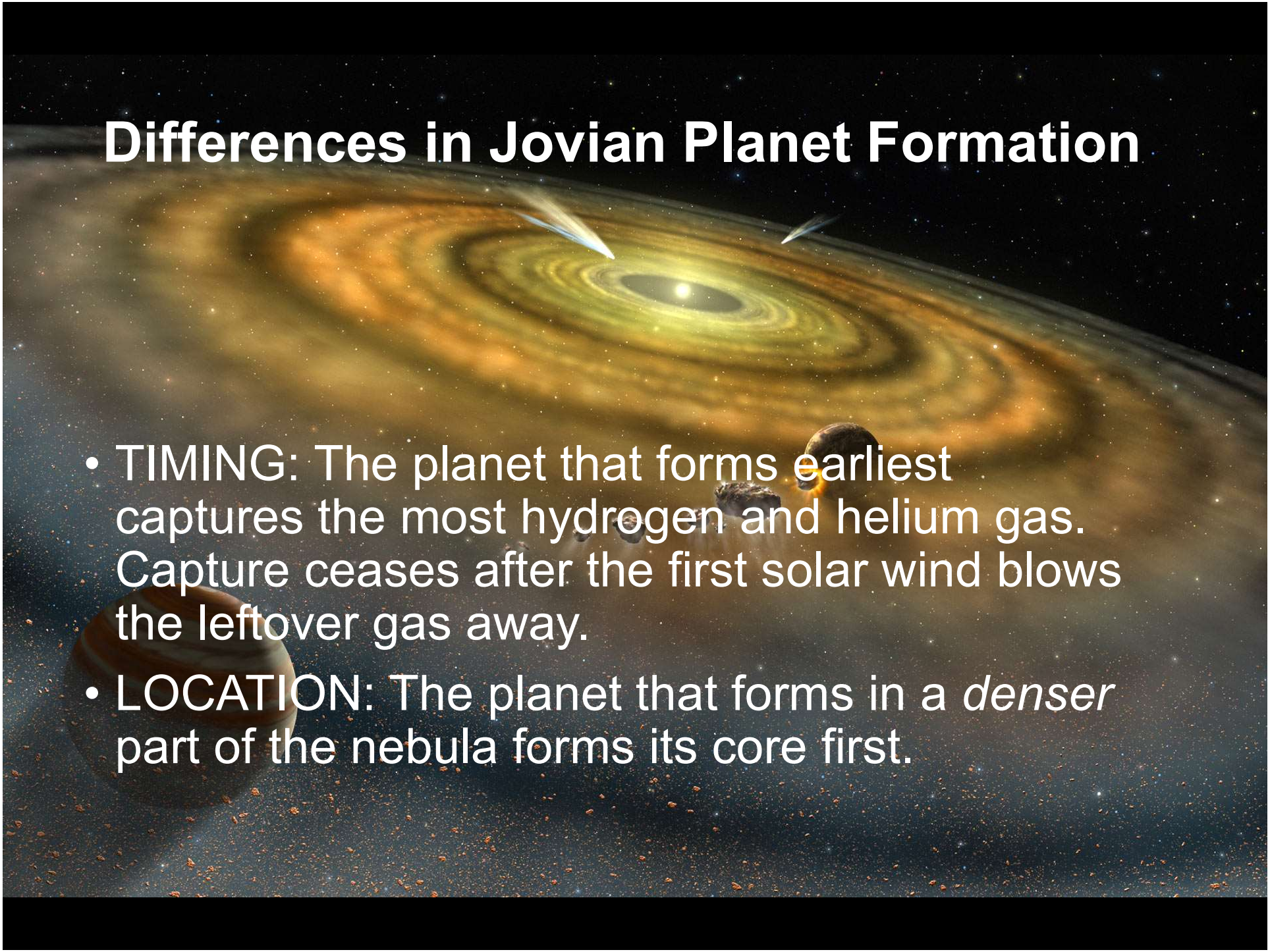
The Jovian Planets



Formed beyond the snow-line where water could condense

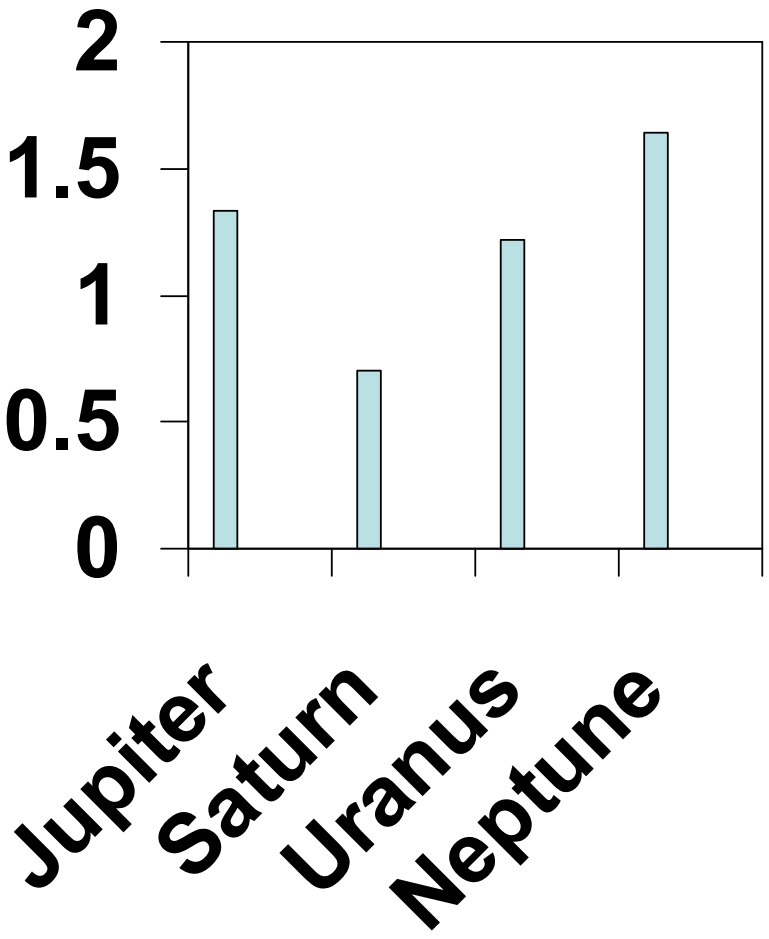
- Bigger and more massive
- Lower density, different composition
- All have rings and Numerous Moons

Differences in Jovian Planet Formation



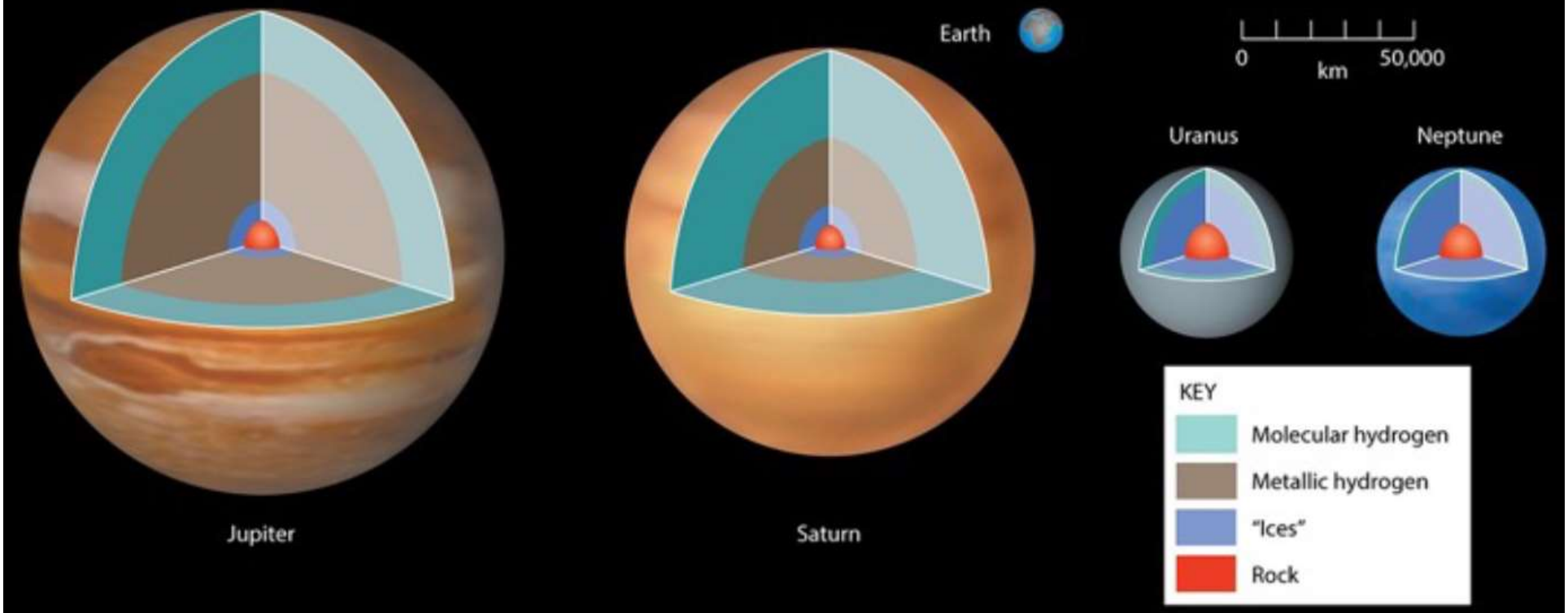
- TIMING: The planet that forms earliest captures the most hydrogen and helium gas. Capture ceases after the first solar wind blows the leftover gas away.
- LOCATION: The planet that forms in a *denser* part of the nebula forms its core first.

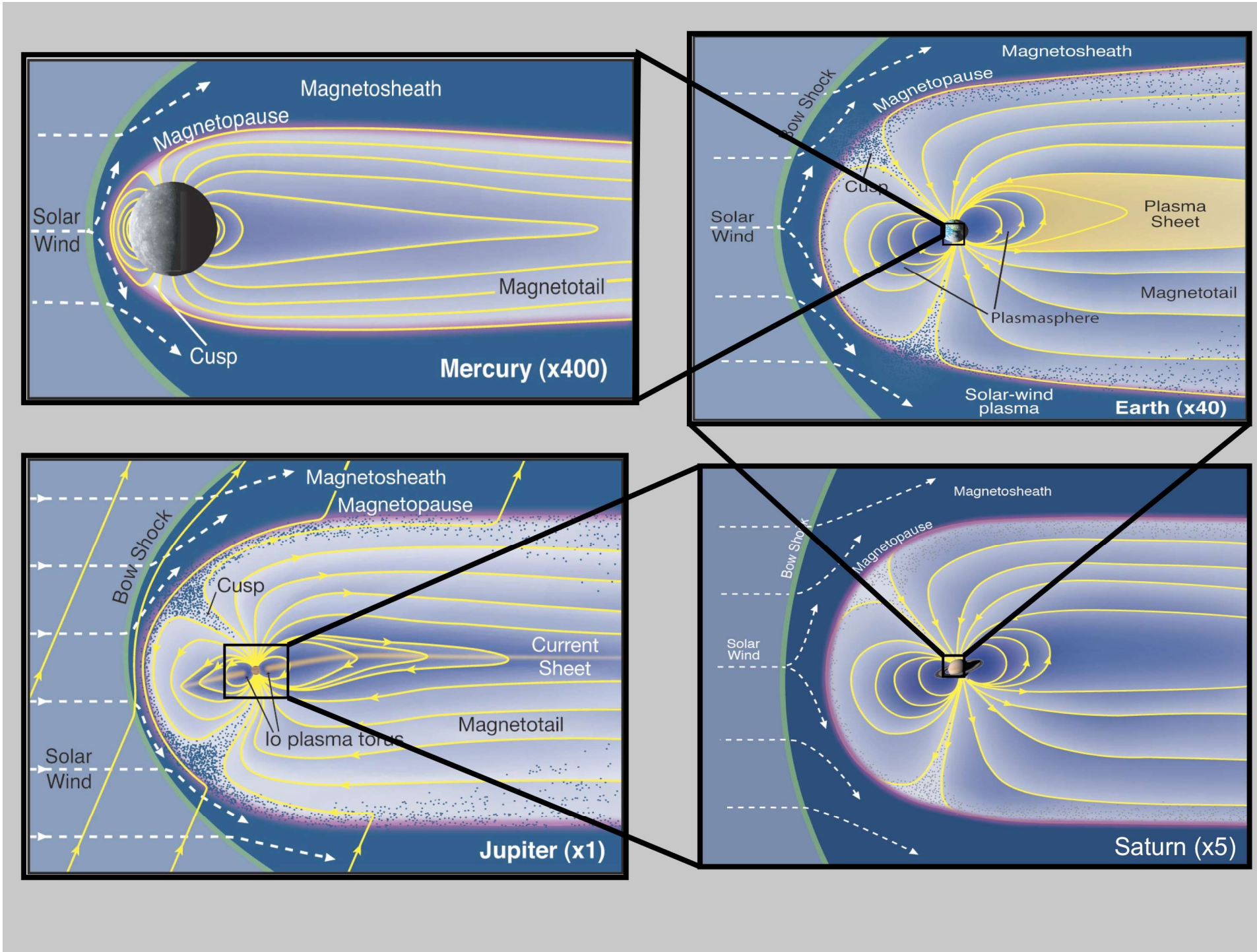
Density Differences



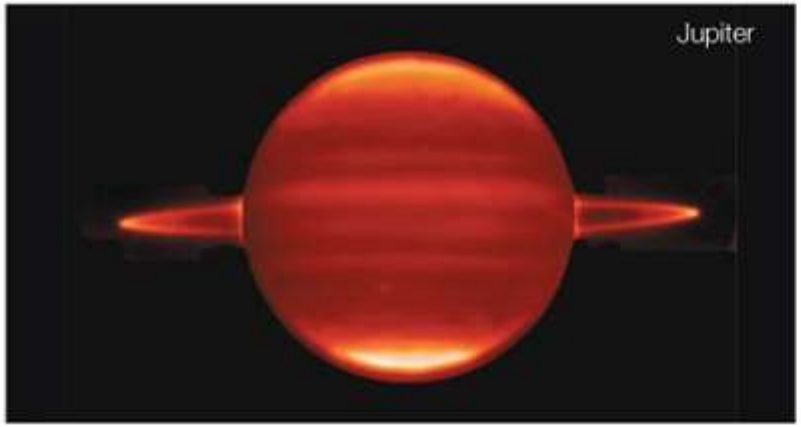
- Uranus and Neptune are denser than Saturn because they have less H/He, proportionately.
- Here, the units are such that the density of water is one.
- *What about Jupiter?*

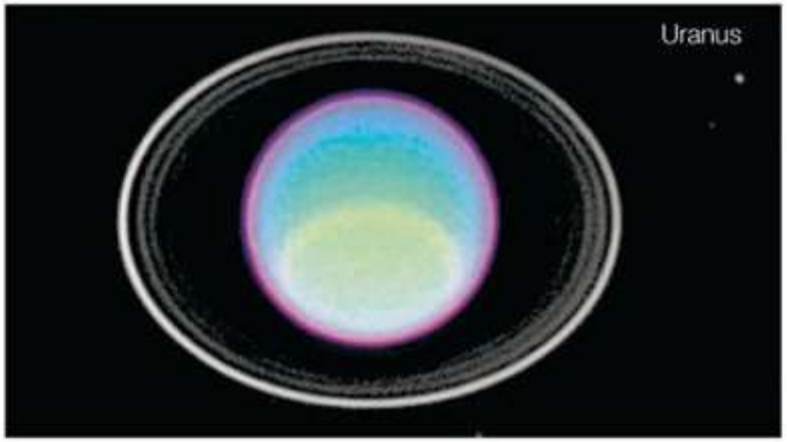
Models of Jovian Interiors

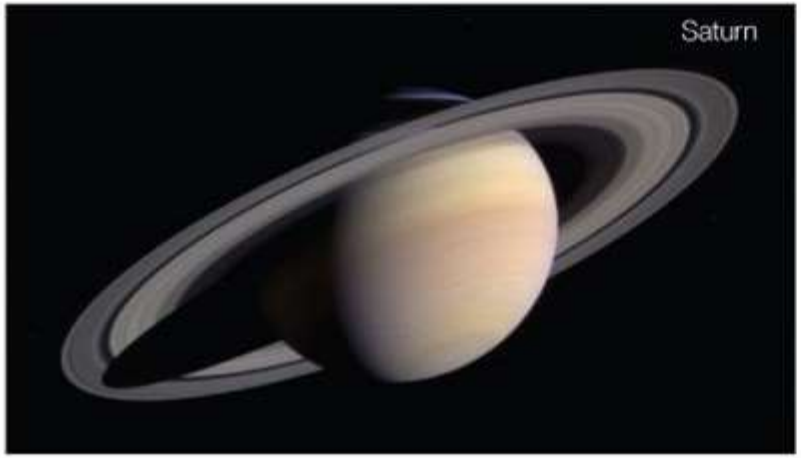


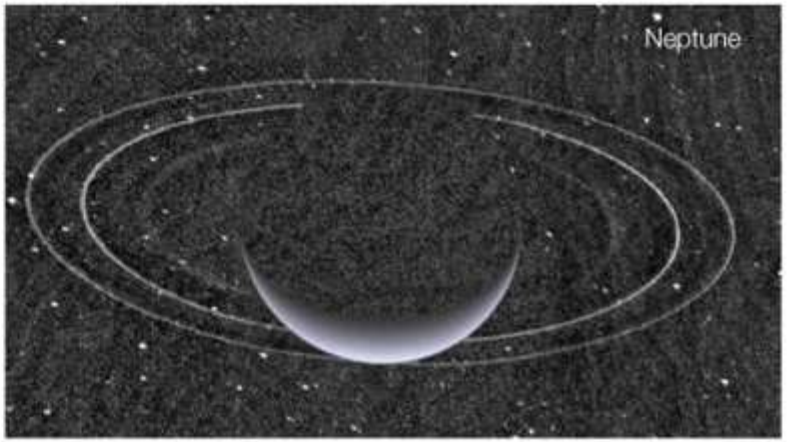

Magnetosheath
Magnetopause
Solar
Wind
Magnetotail
Cusp
Mercury (x400)
Bow Shock
Plasma
Sheet
Plasmasphere
Solar-wind
plasma
Earth (x40)
Current
Sheet
Io plasma torus
Jupiter (x1)
Saturn (x5)

Rings of Jovian Planets



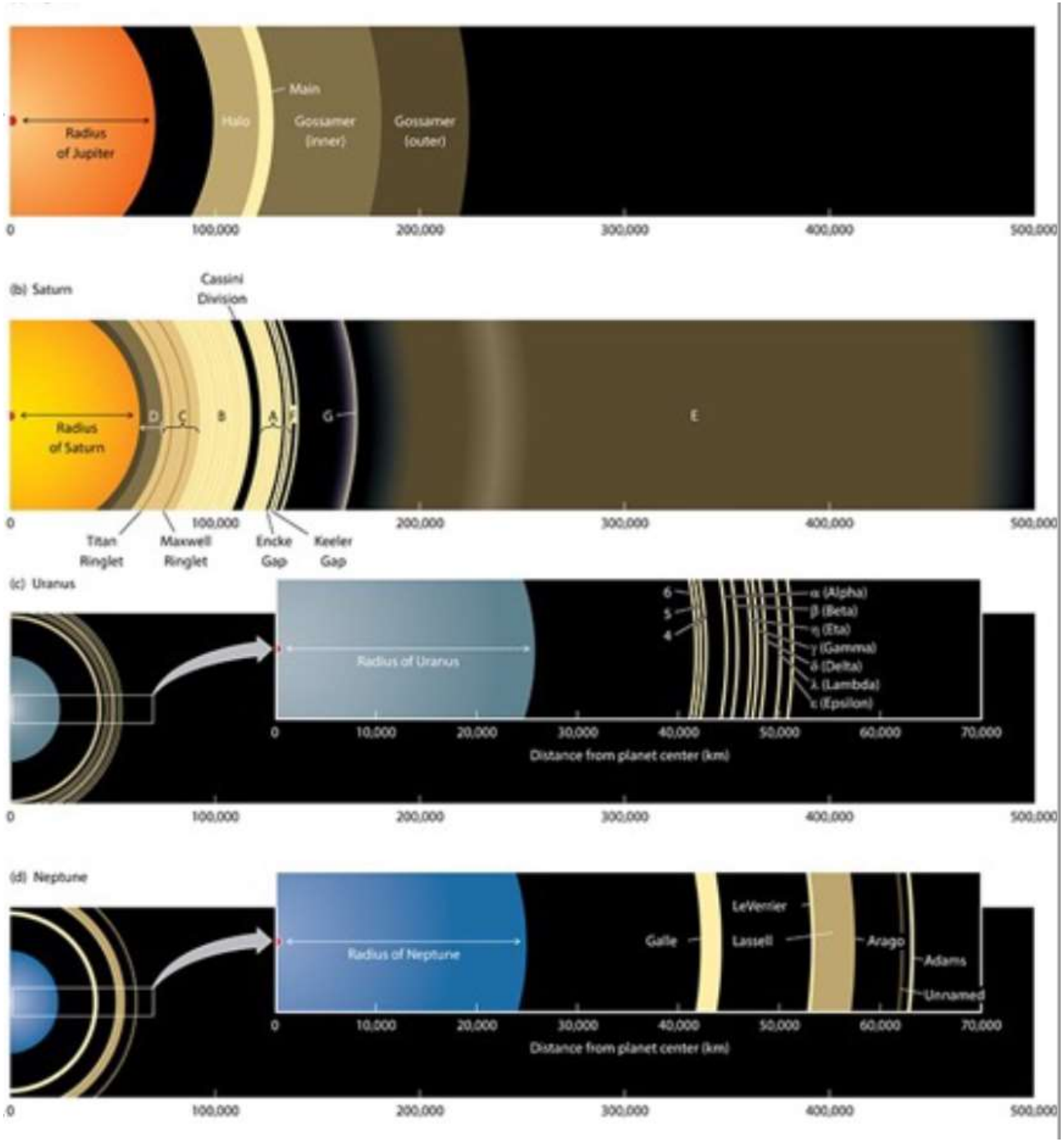






Rings

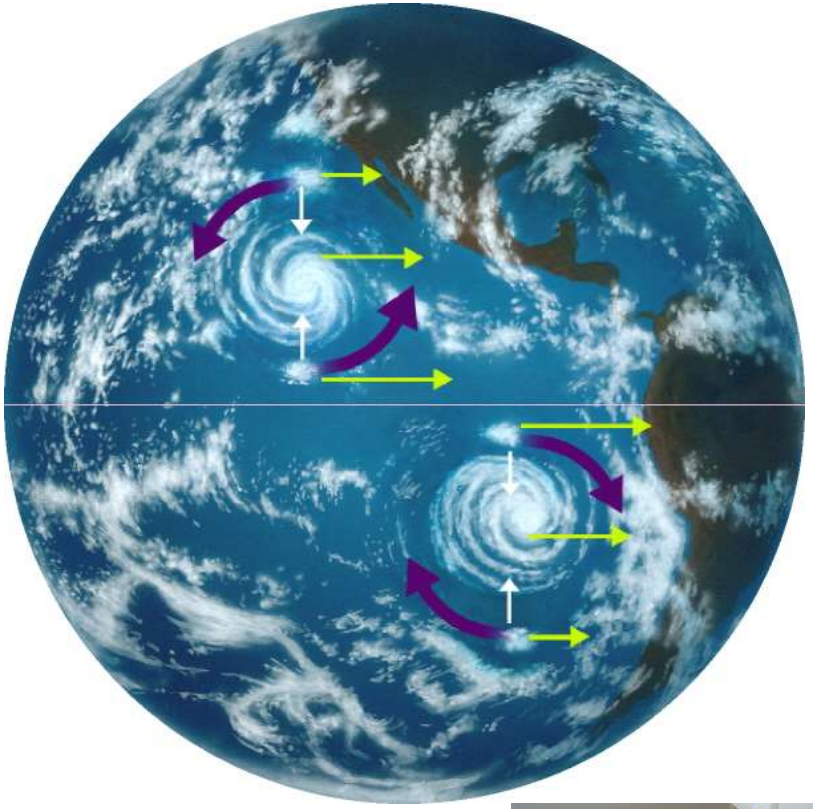
- All four Jovian planets have rings
- Jupiter's rings probably made of silicates with sulfur from Io
- Saturn's rings are made from tiny water ice particles
- Uranus and Neptune have dark rings (organics)



Jupiter's Big Red Spot

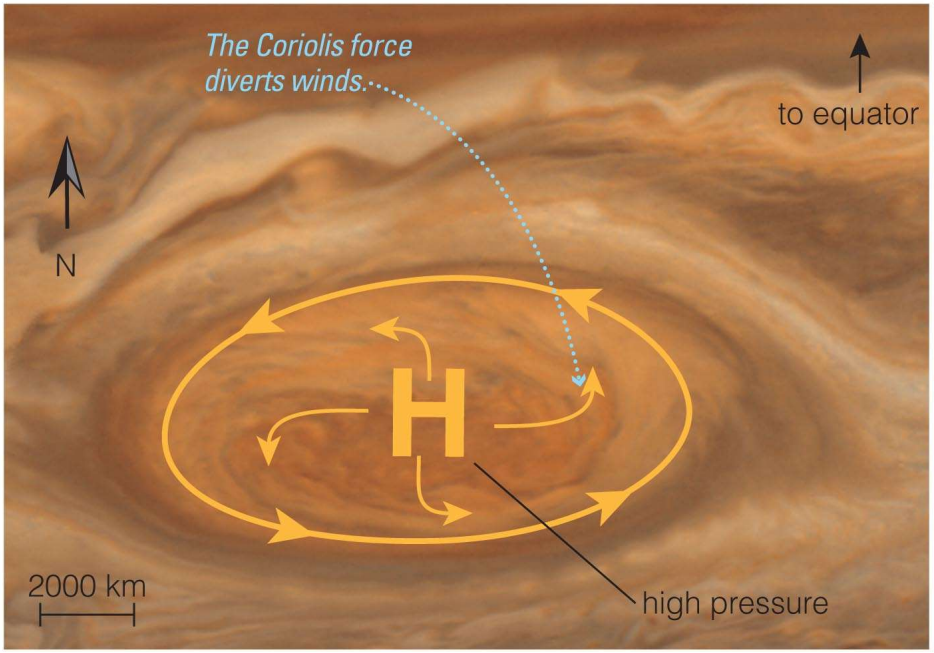
- Storm system that has been active over 300 years
- Could fit 2-3 Earth's inside it

Coriolis Forces

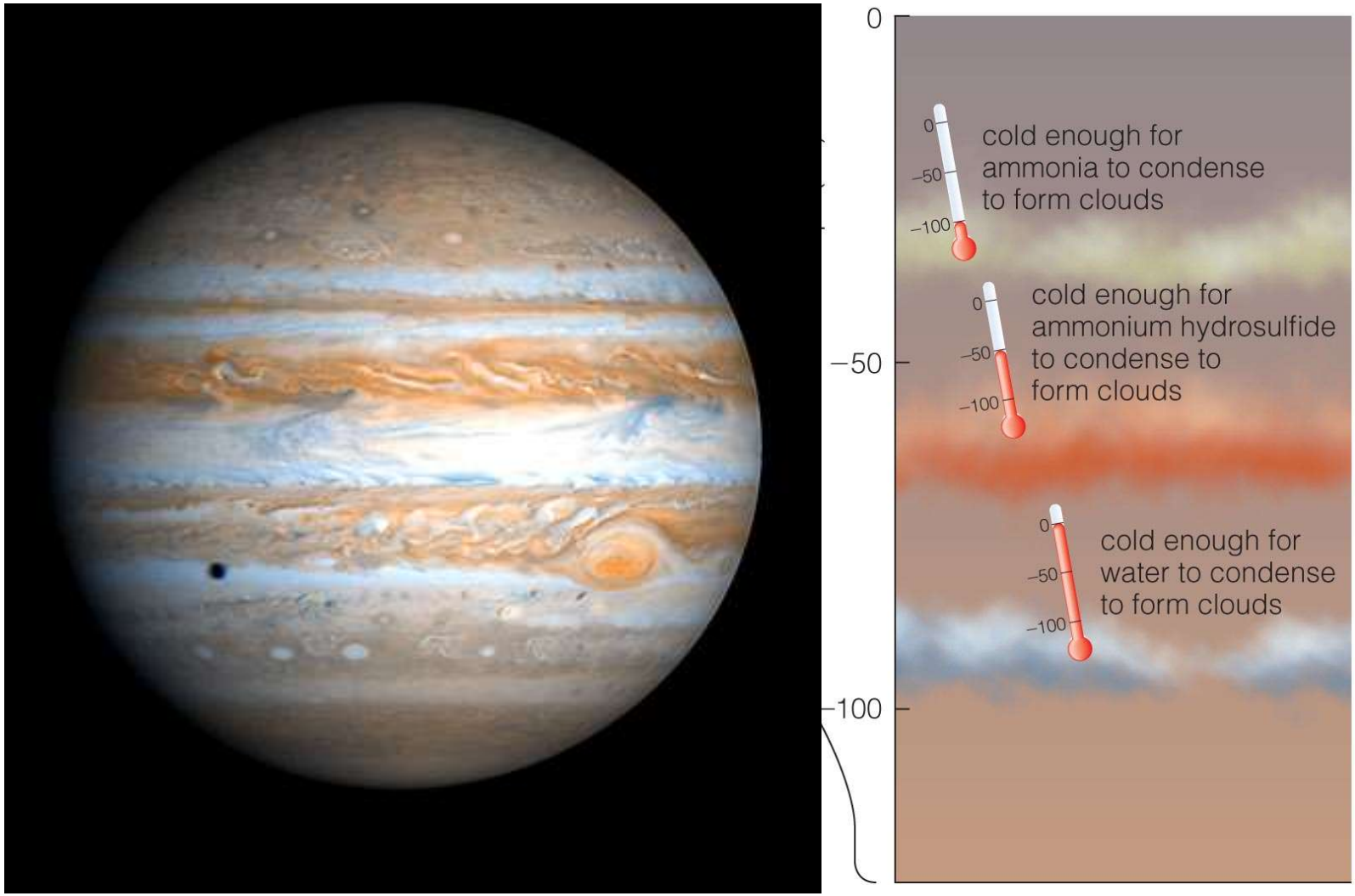


- Caused by the fact that different latitudes of the Earth are traveling at different speeds
- Storms on Earth are due to movement of air from high pressure to low pressure

No. not responsible for toilets flushing in different directions

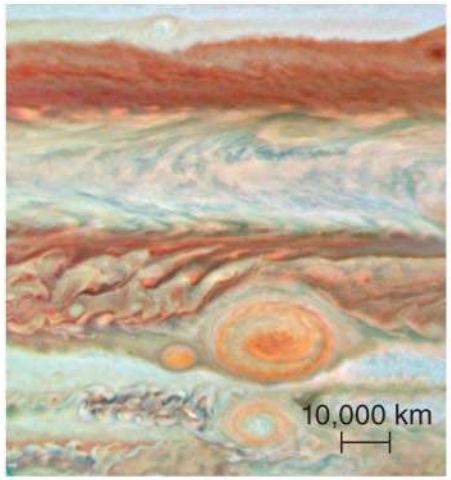


Composition of Jupiter's Bands

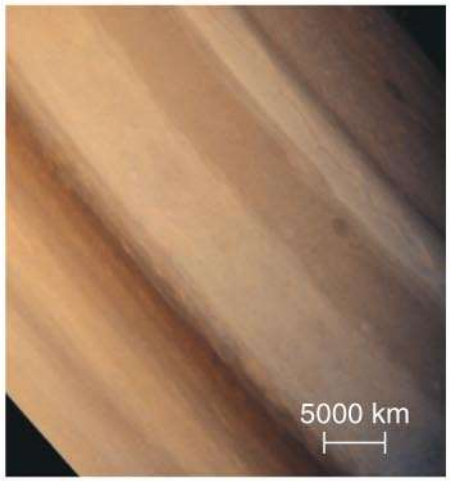


New Slide

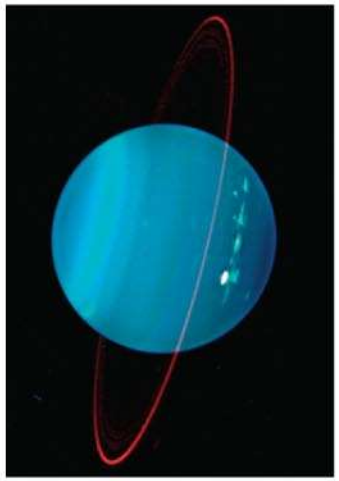
Weather on Jovian Planets



a This Hubble Space Telescope image shows Jupiter's southern hemisphere with the Great Red Spot, "Baby Red" (to its left), and "Red Jr." (below). Baby Red was torn apart by the Great Red Spot a few days later.



b Saturn's atmosphere, photographed by *Voyager 1*. Its banded appearance is very similar to that of Jupiter, but it has even faster winds.

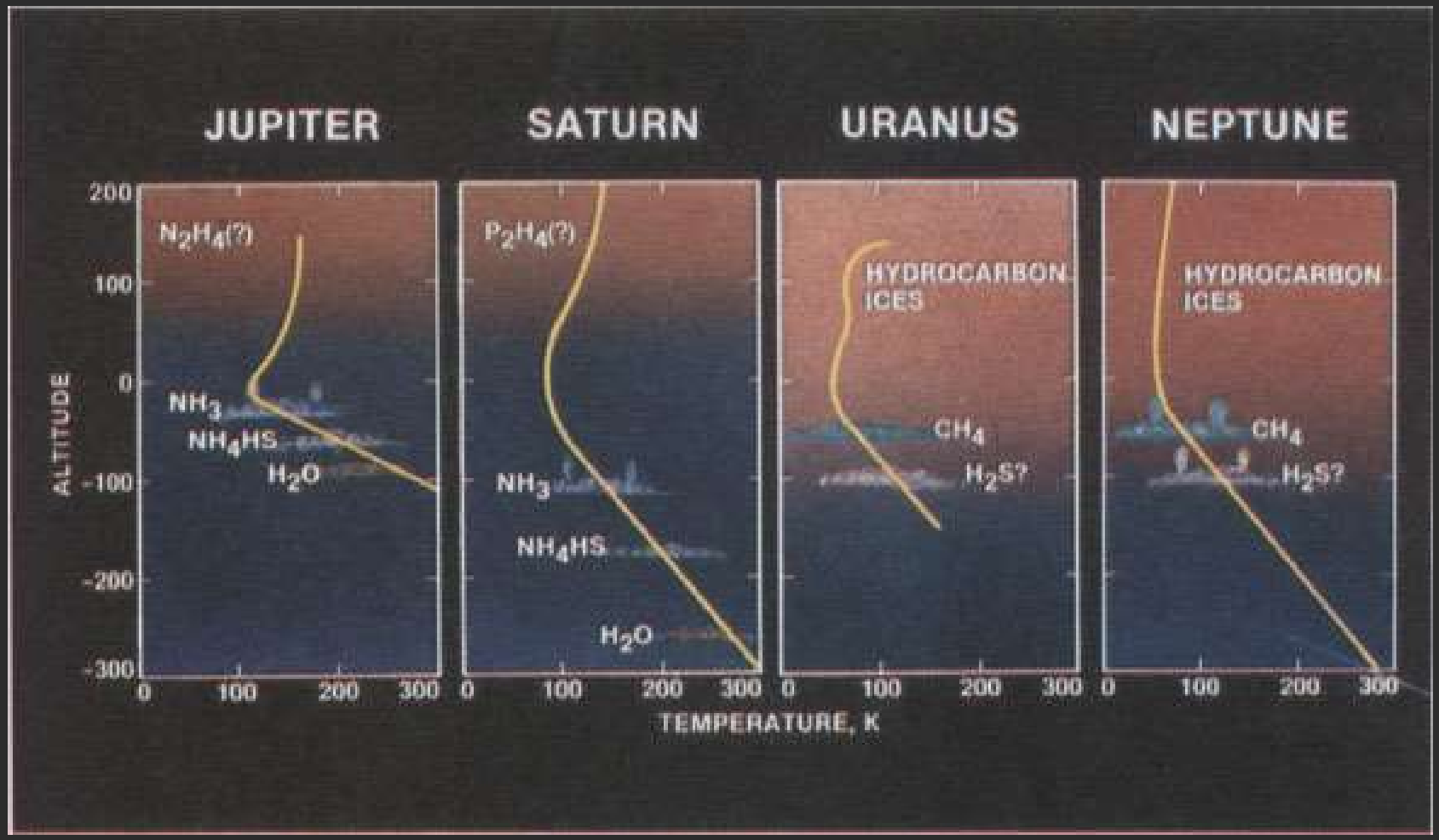


c This infrared image of Uranus from the Keck Telescope shows several storms (the bright blotches) and Uranus's thin rings (red).

d Neptune's atmosphere, viewed from *Voyager 2*, shows bands and occasional strong storms. The large storm (white arrow) was called the Great Dark Spot.

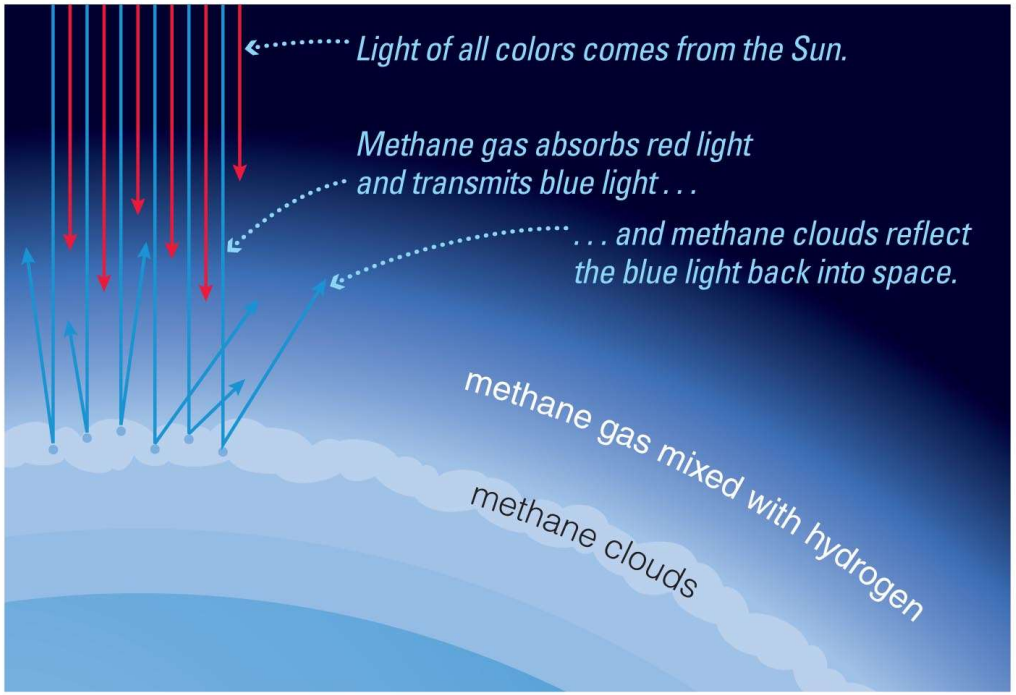
All the jovian planets have strong winds and storms.

Compositions of Jovian Atmospheres



New Slide

Methane on Uranus and Neptune



- **Methane gas** on Neptune and Uranus **absorbs red light** but transmits blue light.
- **Blue light reflects off methane clouds**, making those planets look blue.

What have we covered, and what is next?

Chapter 8: Jovian Planet Systems

8.1. A Different Kind of Planet

- What are Jovian Planets made of?
- What is the weather like on Jovian planets?

8.2. A Wealth of Worlds: Satellites of Ice and Rock

- What kinds of moon orbit the Jovian Planets?
- Why are Jupiter's Galilean moons geologically active?
- What geological activity do we see on Titan and other moons?
- Why are Jovian moons more geologically active than small rocky planets?

8.3. Jovian Planet Rings

- What are Saturn's rings like?
- Why do Jovian planets have rings?

What have we learned?

- What are jovian planets made of?
  - Jupiter and Saturn are mostly made of H and He gas.
  - Uranus and Neptune are mostly made of H compounds.
  - They have layered interiors with very high pressure and cores made of rock, metals, and hydrogen compounds.
  - Very high pressure in Jupiter and Saturn can produce metallic hydrogen.

- What is the weather like on Jovian planets?
  - Multiple cloud layers determine the colors of Jovian planets.
  - All have strong storms and winds.

iClicker Question

Question: Jupiter does *not* have a large metal core like Earth. How can it have a magnetic field?

A. The magnetic field is left over from when Jupiter accreted.

B. Its magnetic field comes from the Sun.

C. It has metallic hydrogen inside, which circulates and makes a magnetic field.

D. That's why its magnetic field is weak.

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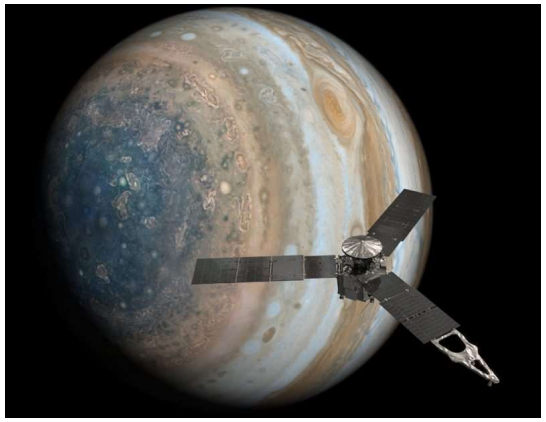
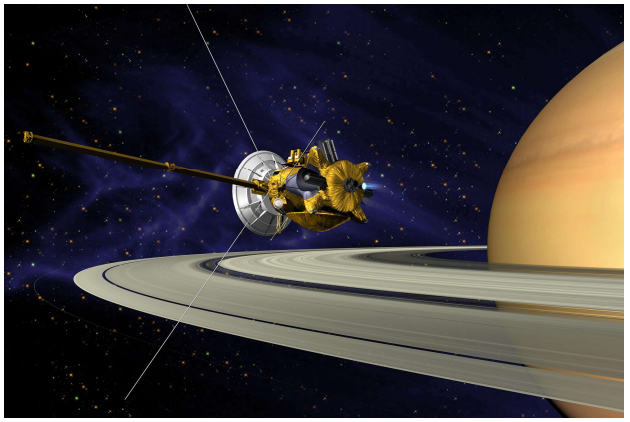
Missions to Outer Planets

- Jupiter has been visited briefly by several spacecraft passing by, or using a gravitational assist (e.g., New Horizons)
- The Pioneer and Voyager spacecraft visited Saturn
- Uranus and Neptune only had a single flyby from Voyager 2

The Galileo Spacecraft studied Jupiter & it's moons from 1995-2003



The Juno Spacecraft is studying Jupiter 2016-

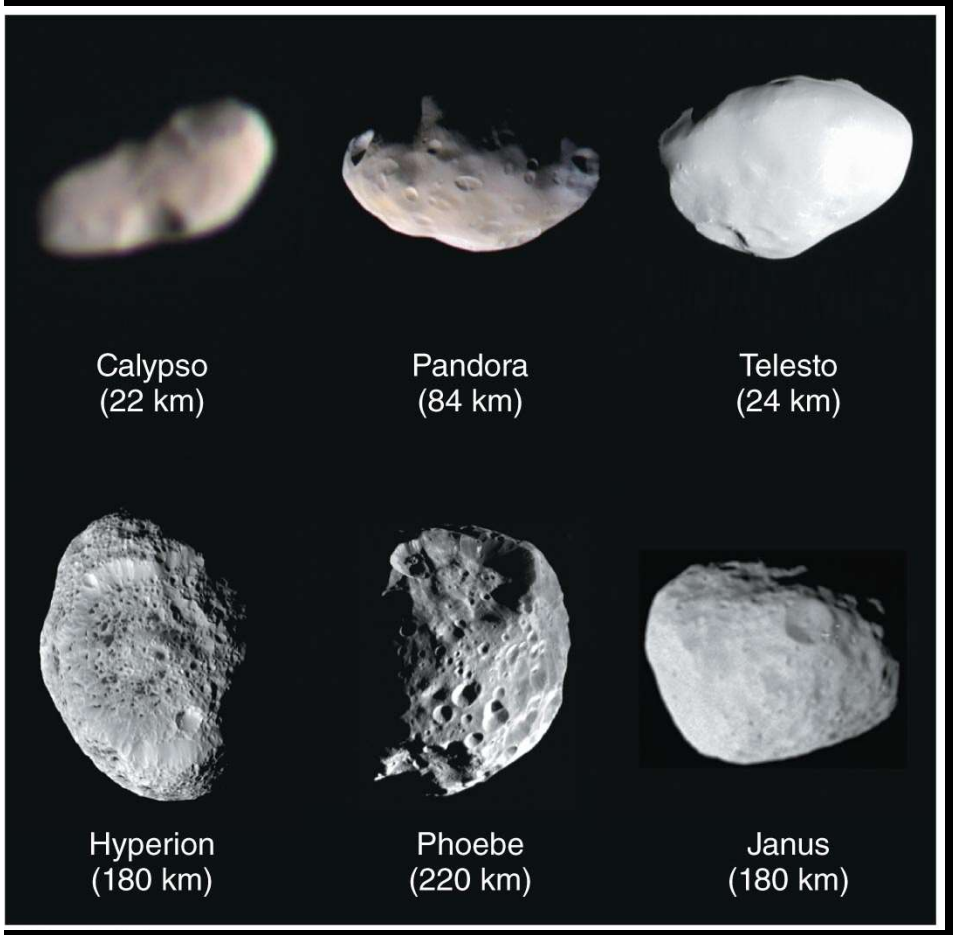


The Cassini Spacecraft studied Saturn & it's moons from 1997-2017

Medium and Large Moons

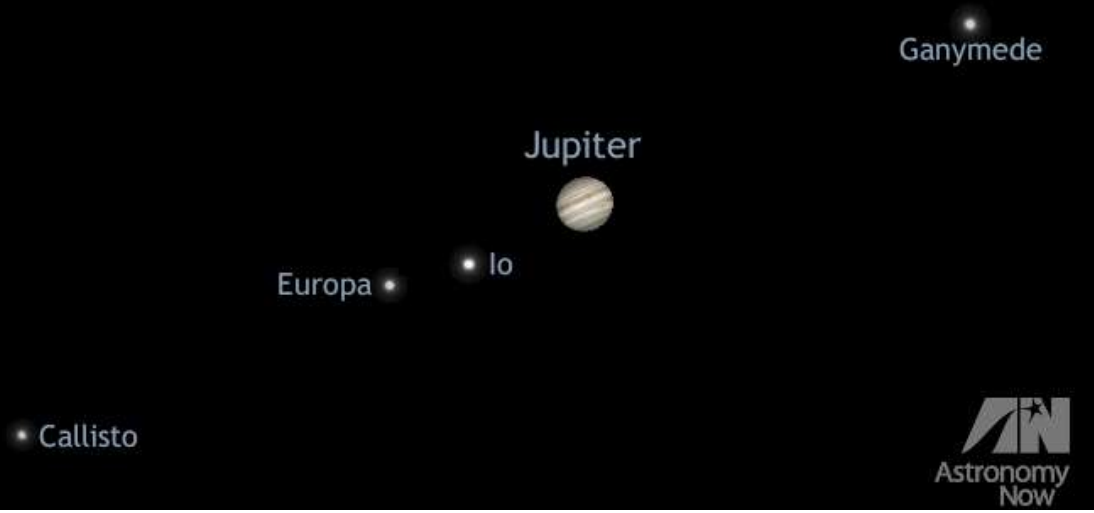
- Medium-sized moons (300–1500 km)
  - Geological activity in past
- Large moons (> 1500 km)
  - Ongoing geological activity
- Enough self-gravity to be spherical
- Have substantial amounts of ice
- Formed in orbit around jovian planets
- Circular orbits in same direction as planet rotation

Small Moons

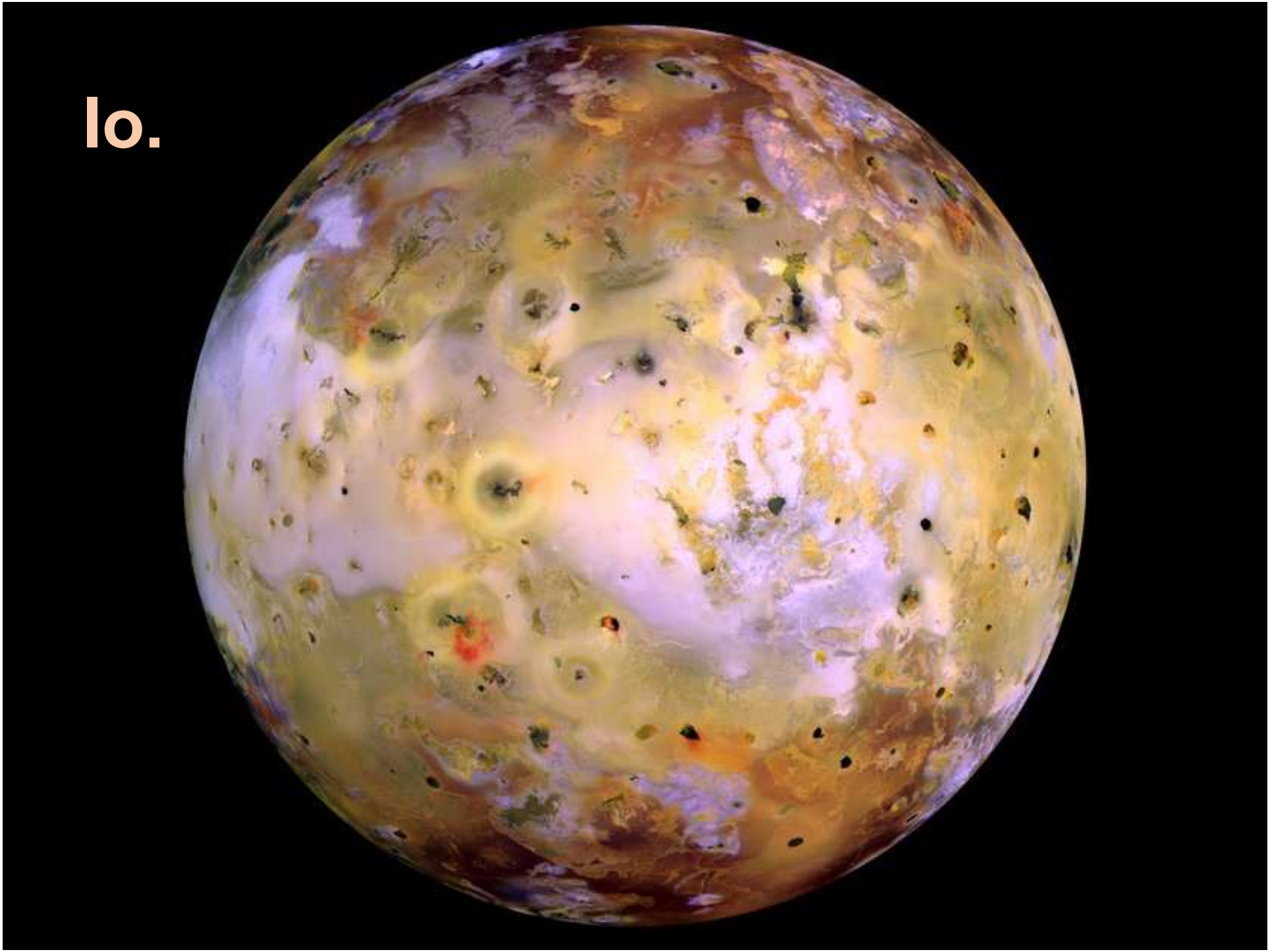


- Small moons (< 300 km)
  - No geological activity
- Far more numerous than the medium and large moons
- Not enough gravity to be spherical: "potato-shaped“
- Most likely captured asteroids/comets/Kuiper Belt Objects

Jupiter's Galilean moons



Io.



Io.

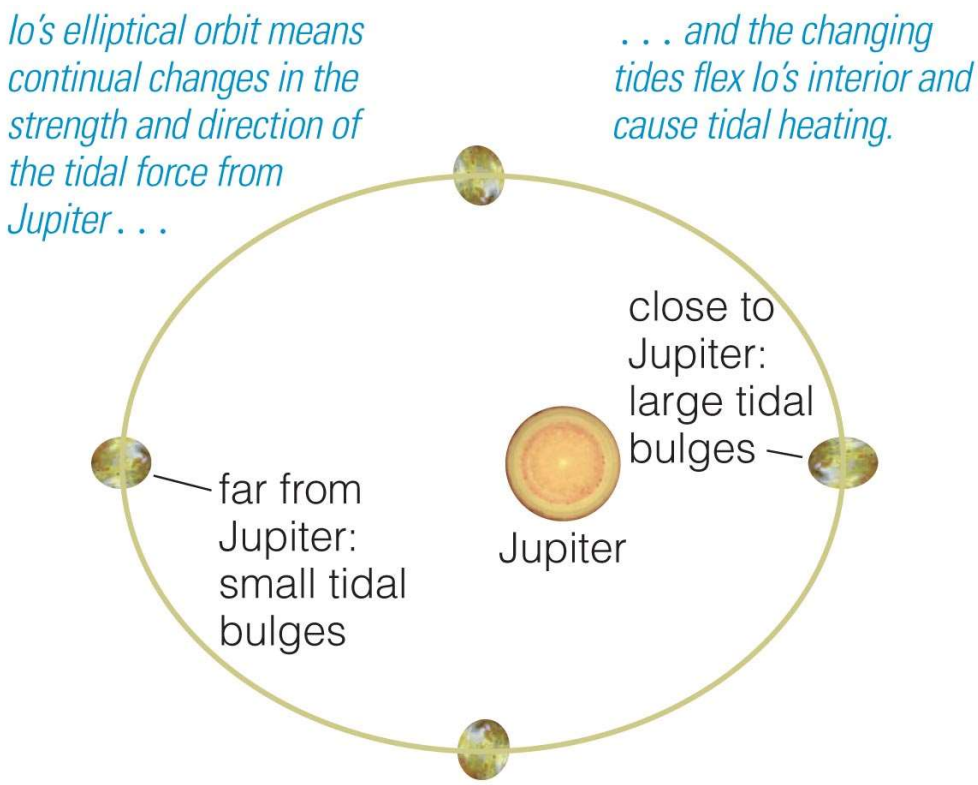
The most volcanically active body in the Solar System

Why is Io so Geologically Active?

Tidal Heating

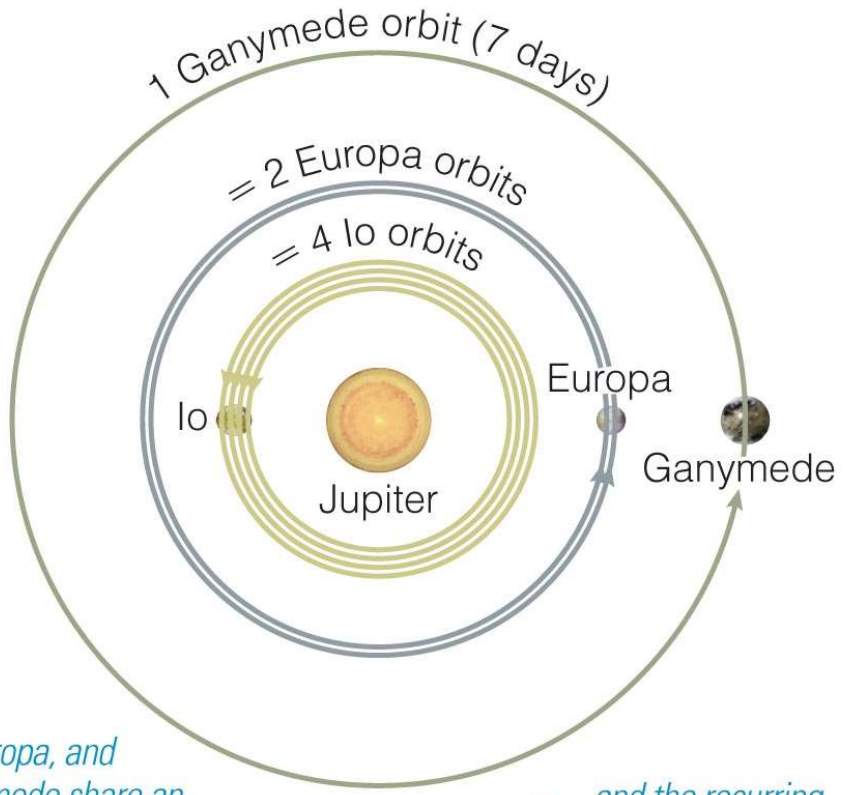
Io is squished and stretched as it orbits Jupiter.

But why is its orbit so elliptical?



a Tidal heating arises because Io's elliptical orbit (exaggerated in this diagram) causes varying tides.

Orbital Resonances



Io, Europa, and Ganymede share an orbital resonance that returns them to the positions shown about every 7 days . . .

. . . and the recurring gravitational tugs make all three orbits slightly elliptical (not shown).

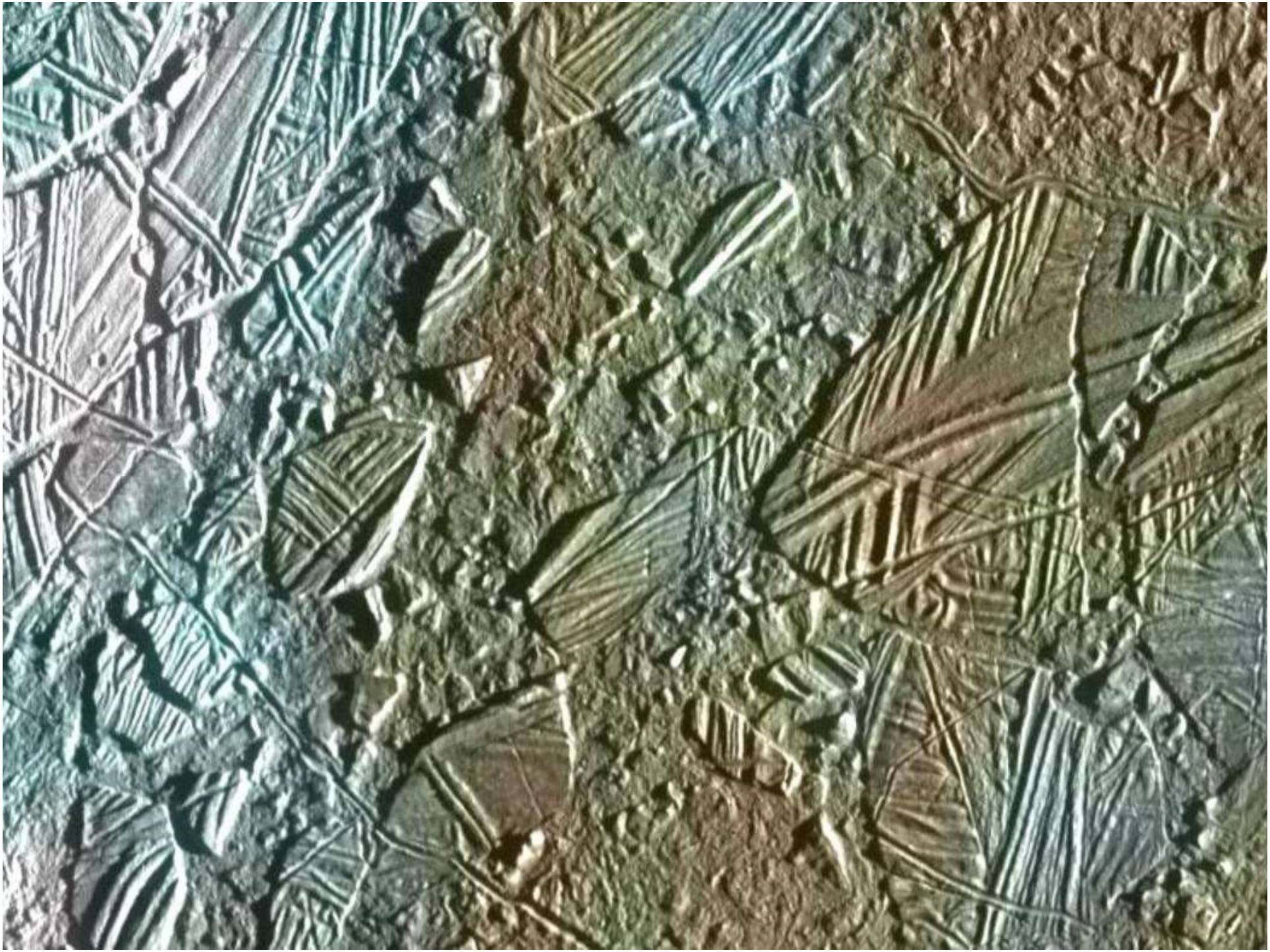
b Io's orbit is elliptical because of the orbital resonance Io shares with Europa and Ganymede.

Every seven days, these three moons line up.

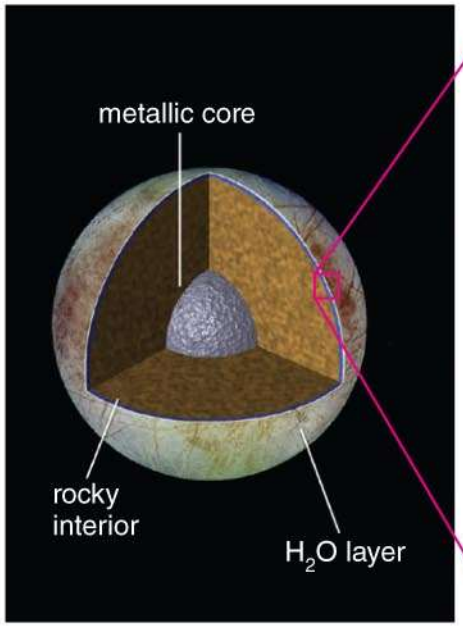
The tugs add up over time, making all three orbits elliptical.

Has strongest effect on Europa (highest eccentricity), but since Io is closer to Jupiter, more tidal forces are felt for Io overall

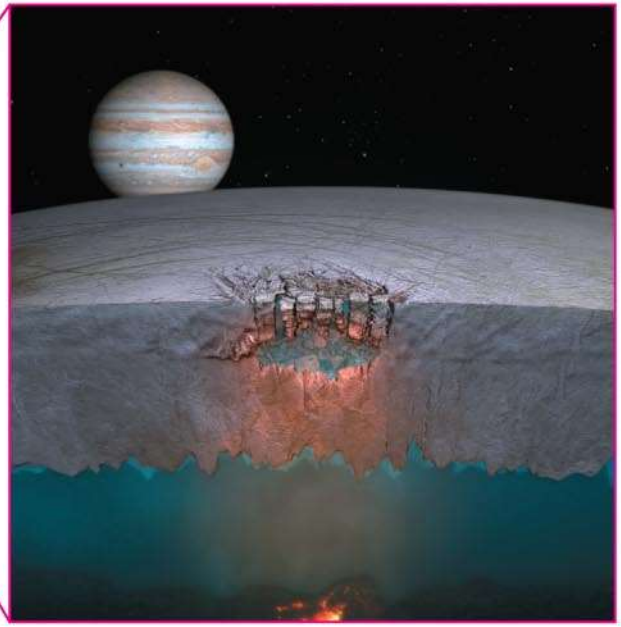
Jupiter's 2nd Moon, Europa



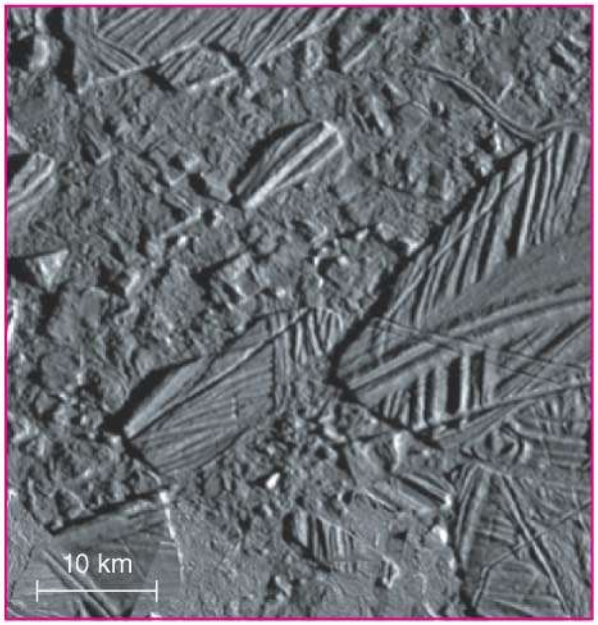
Europa's interior also warmed by tidal heating



Europa may have a 100-km-thick ocean under an icy crust.

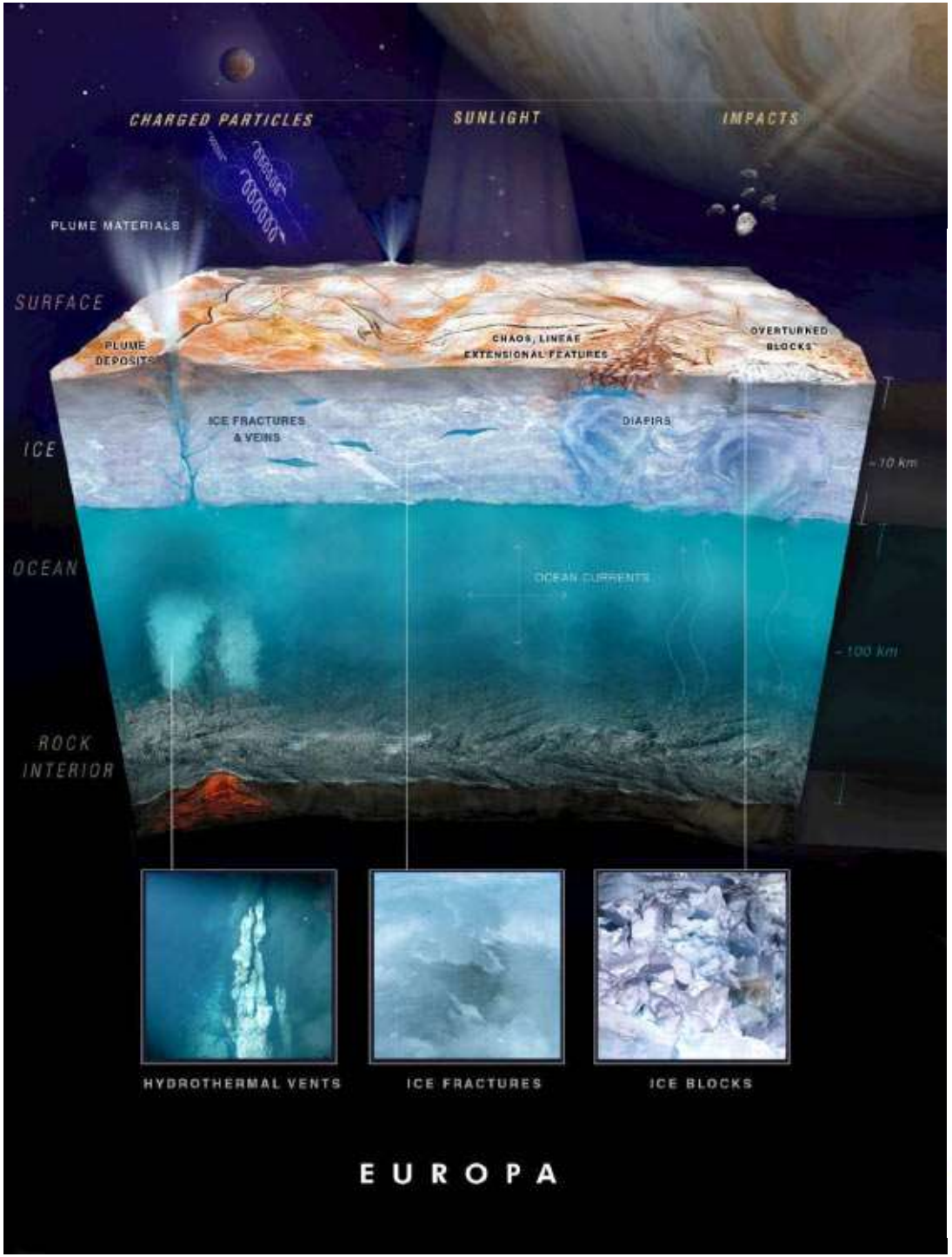


Rising plumes of warm water may sometimes create lakes within the ice, causing the crust above to crack . . .

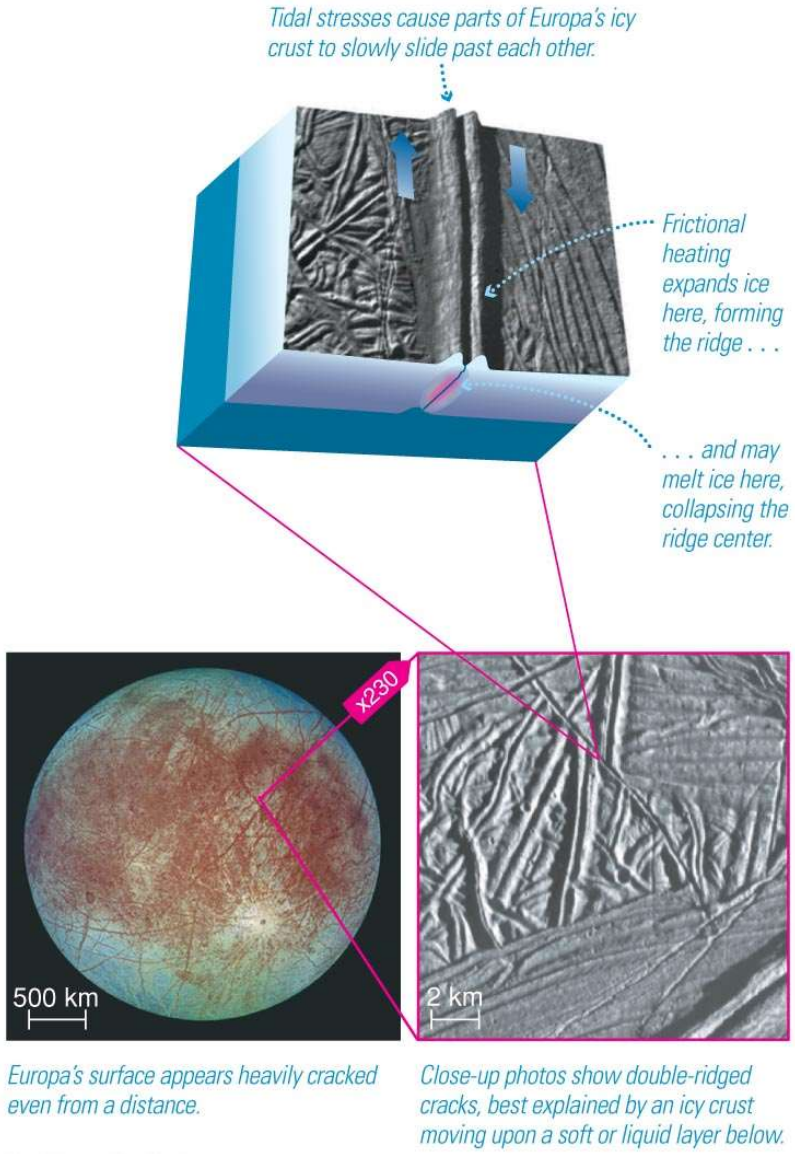


. . . explaining surface terrain that looks like a jumble of icebergs suspended in a place where liquid or slushy water froze.

'Chaos Regions' look as if regions below have melted and some of the floating ice has moved around



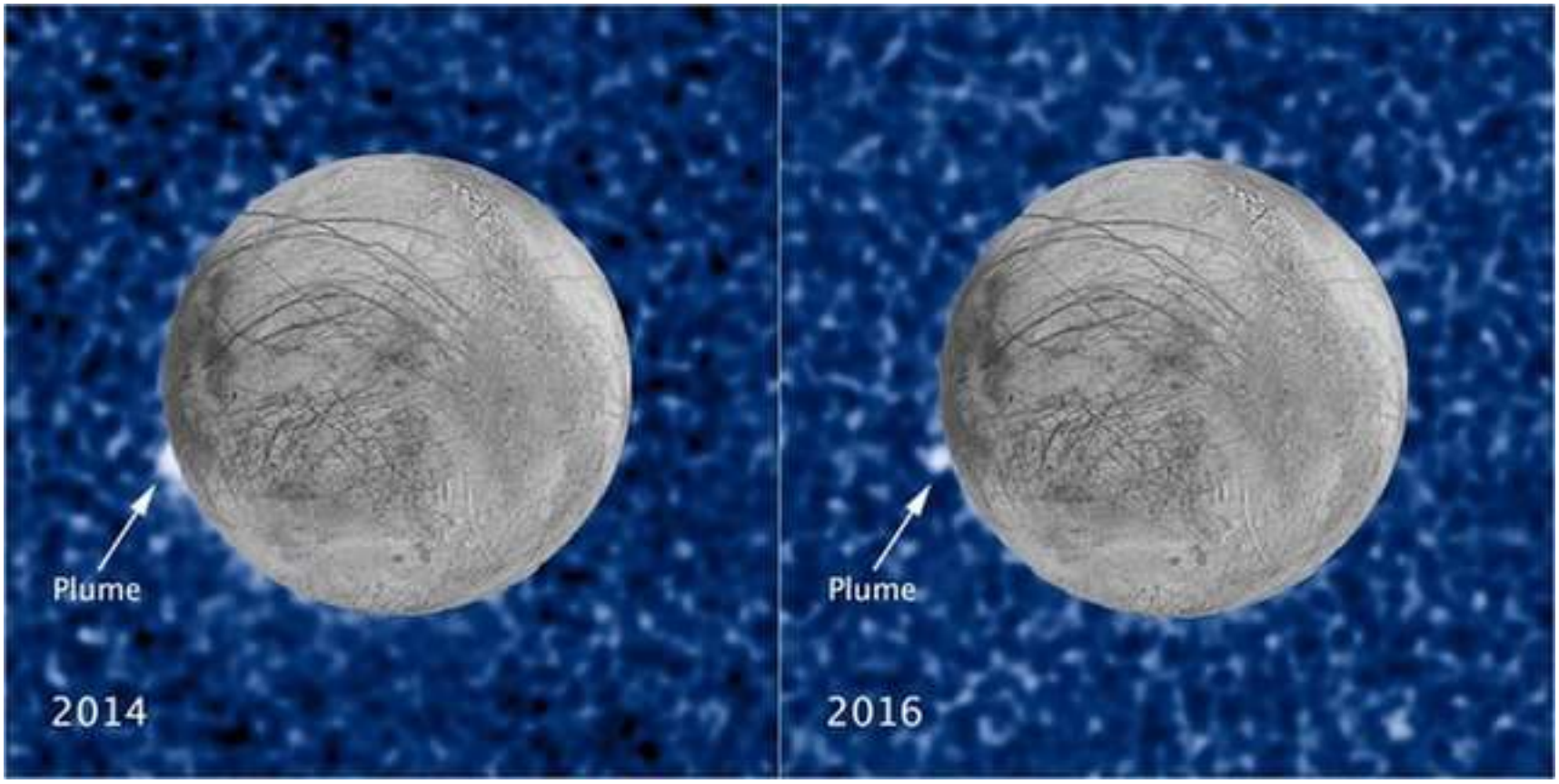
Triple Bands



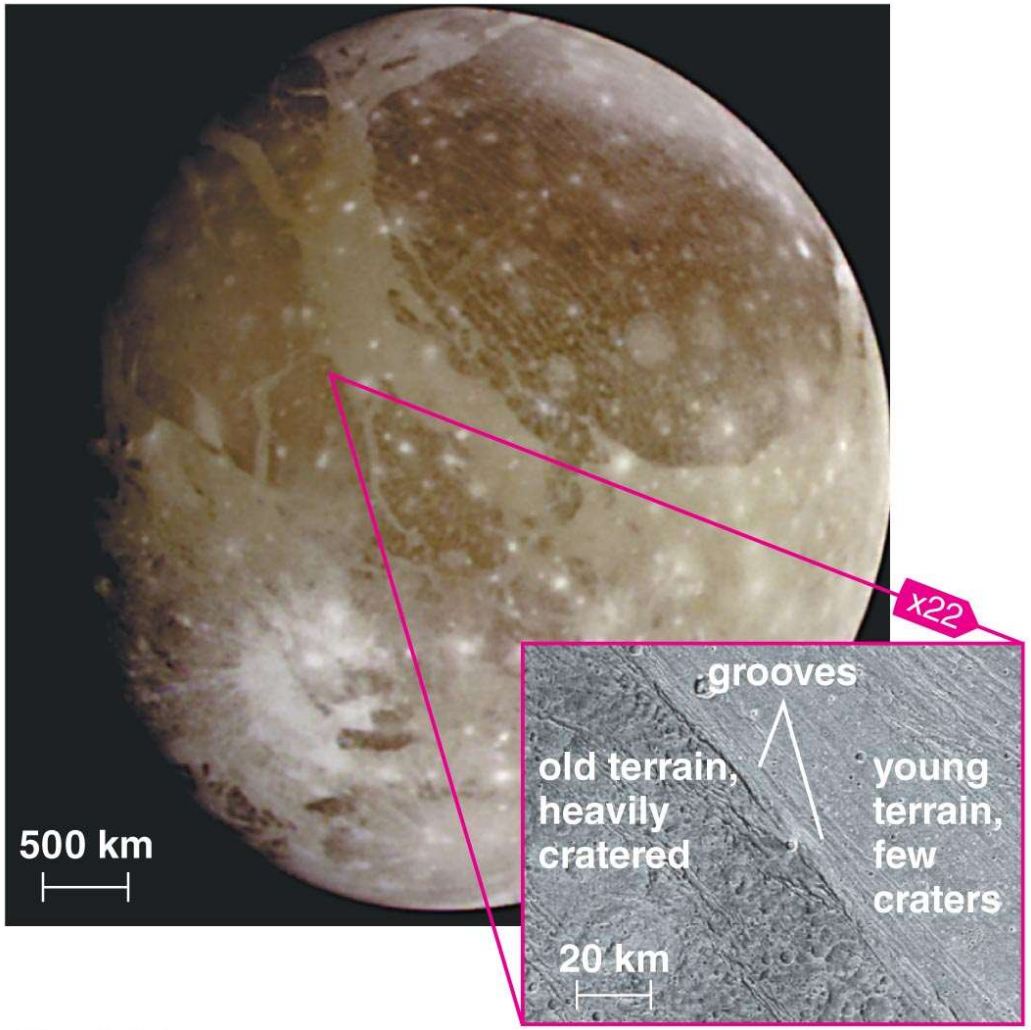
Europa's surface appears heavily cracked even from a distance.

Close-up photos show double-ridged cracks, best explained by an icy crust moving upon a soft or liquid layer below.

Hubble Space Telescope Images Plumes from Europa

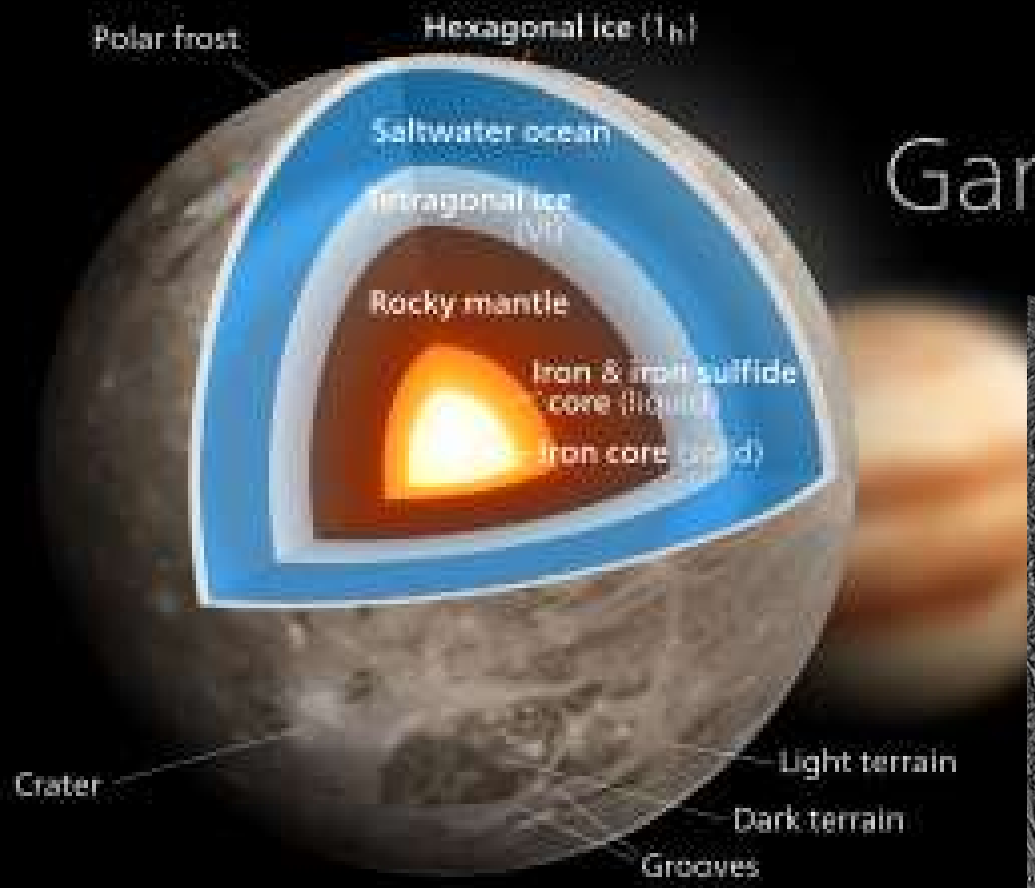


Jupiter's 3rd Moon - Ganymede



- Largest moon in the solar system
- Clear evidence of geological activity
- Tidal heating plus heat from radio-active decay?
- Has a reasonably strong Magnetosphere
- Planetary Dichotomy
  - Half of the surface is young
  - Half of the surface is old

Magnetosphere: Salty Ocean or Liquid Metallic Core?



iClicker Question

Question: What is the correct order of Jupiter's moons from their increasing distance to the Planet?

A. Io, Europa, Callisto, Ganymede
B. Europa, Io, Ganymede, Callisto
C. Ganymede, Callisto, Io, Europa
D. Io, Europa, Ganymede, Callisto

iClicker Question

Question: What is the correct order of Jupiter's moons from their increasing distance to the Planet?

A. Io, Europa, Callisto, Ganymede
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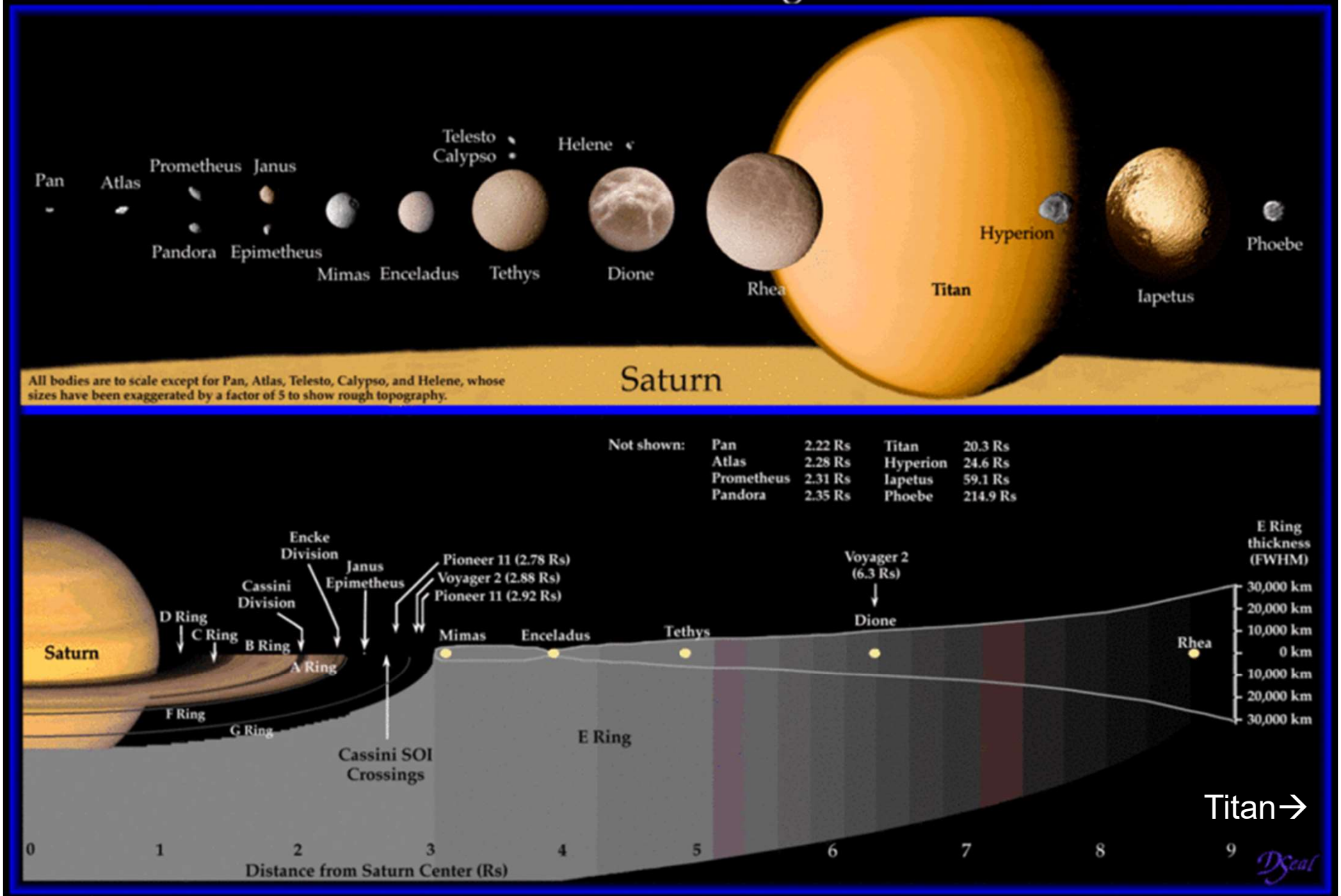
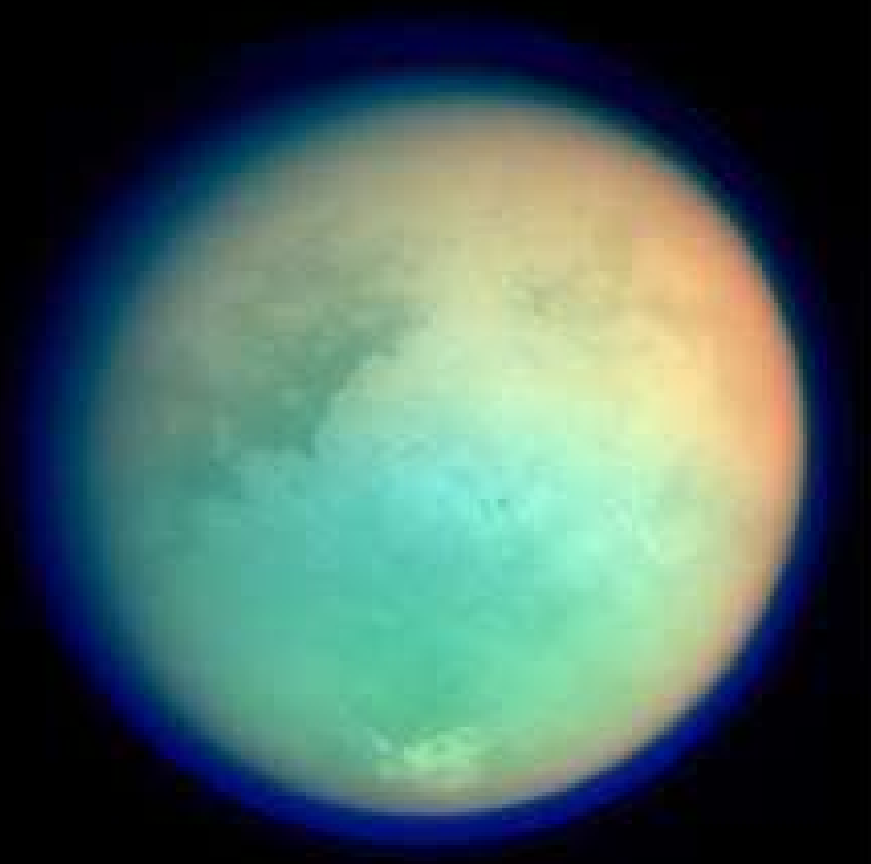
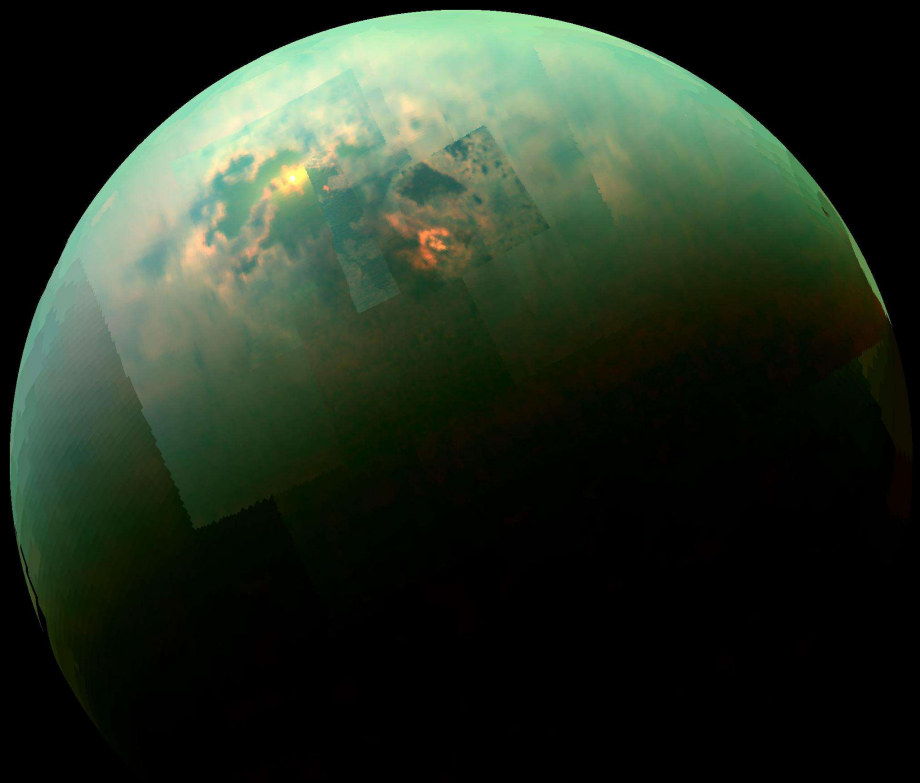
Saturn's Satellites and Ring Structure



This graphic is available in color if required.

Saturn’s Largest Moon - Titan





Titan's Atmosphere

Titan is the only moon with a thick smoggy atmosphere (1.5× Earth)

~95 % N_2 (similar to Earth)

Haze is caused by interaction of UV, solar wind and charged particles interacting with methane (CH_4) clouds to generate larger hydrocarbons such as ethane (C_2H_6), and larger species that contribute to the smog

Clouds indicate rain and lakes may exist on Titan

Thought Question

Where is the best place in the Solar System to fly a drone?

A. Earth
B. Venus
C. Mars
D. Titan

Thought Question

Where is the best place in the Solar System to fly a drone?

A. Earth (not bad, obviously)

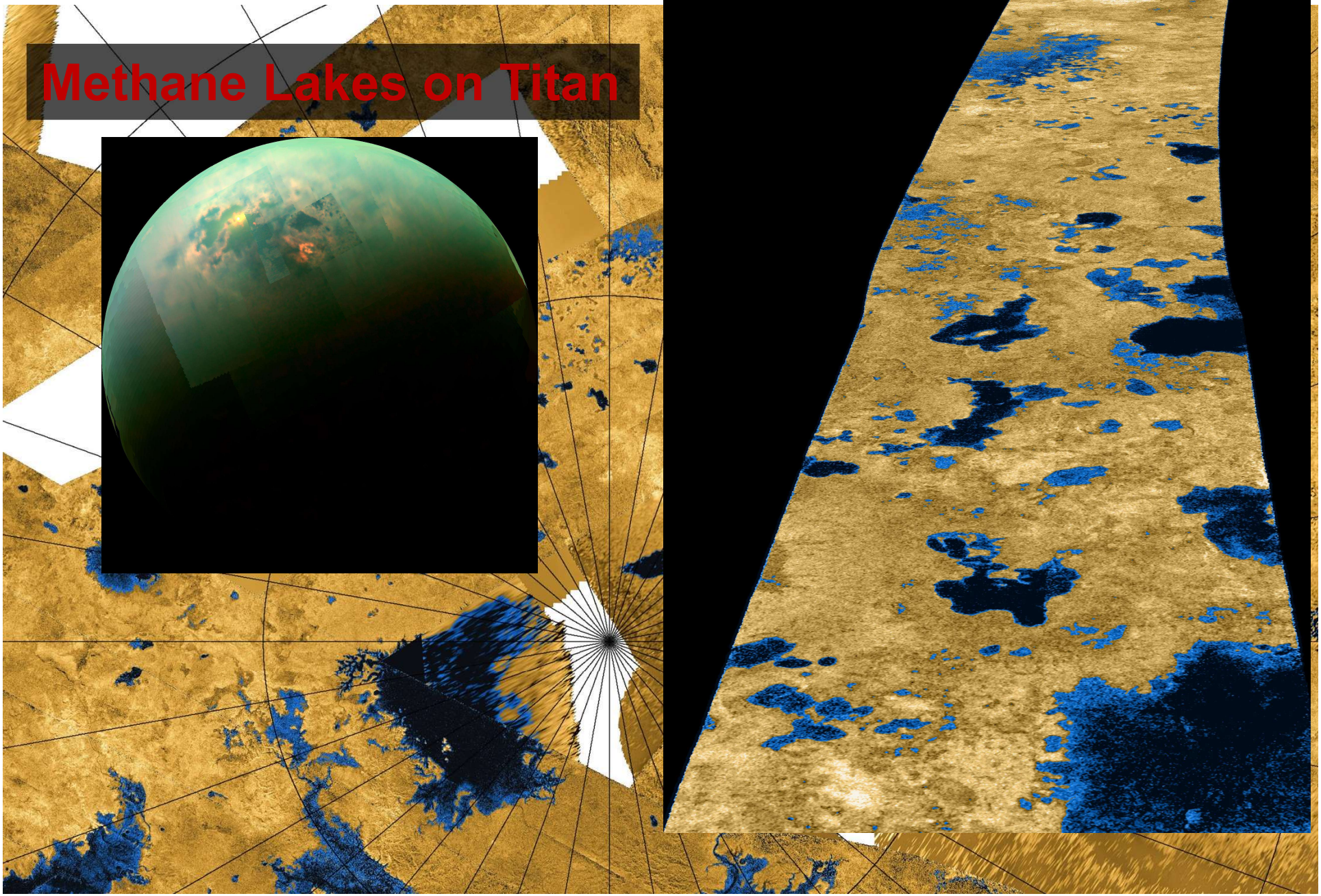
B. Venus (90 atmospheres, 500 °C sulfuric acid)

C. Mars (possible, planned for Mars2020)

D. Titan (1.5 atmospheres, 1/6th the gravity)

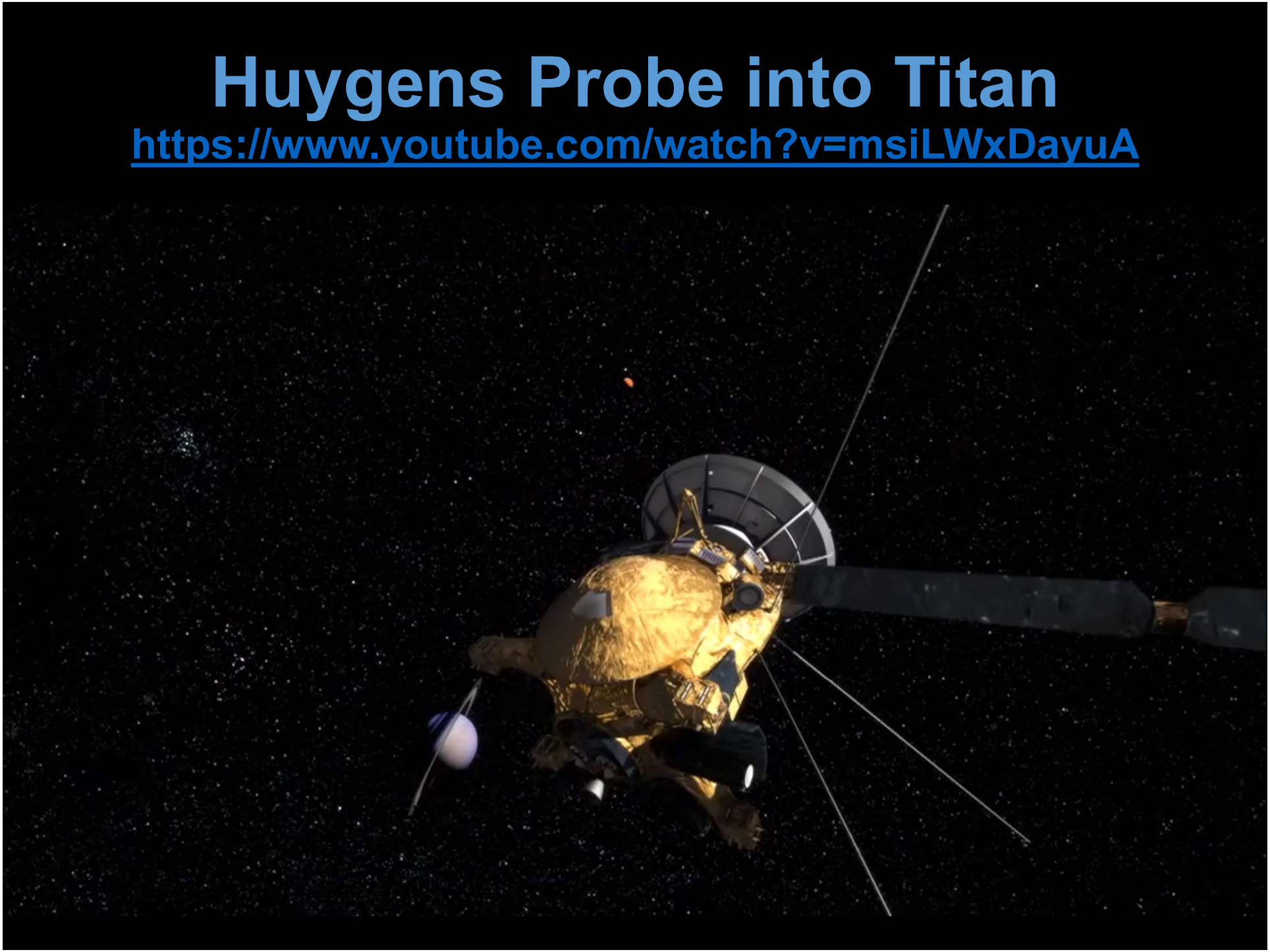

Dragon Fly Mission Concept
(recently selected for further development)

Methane Lakes on Titan

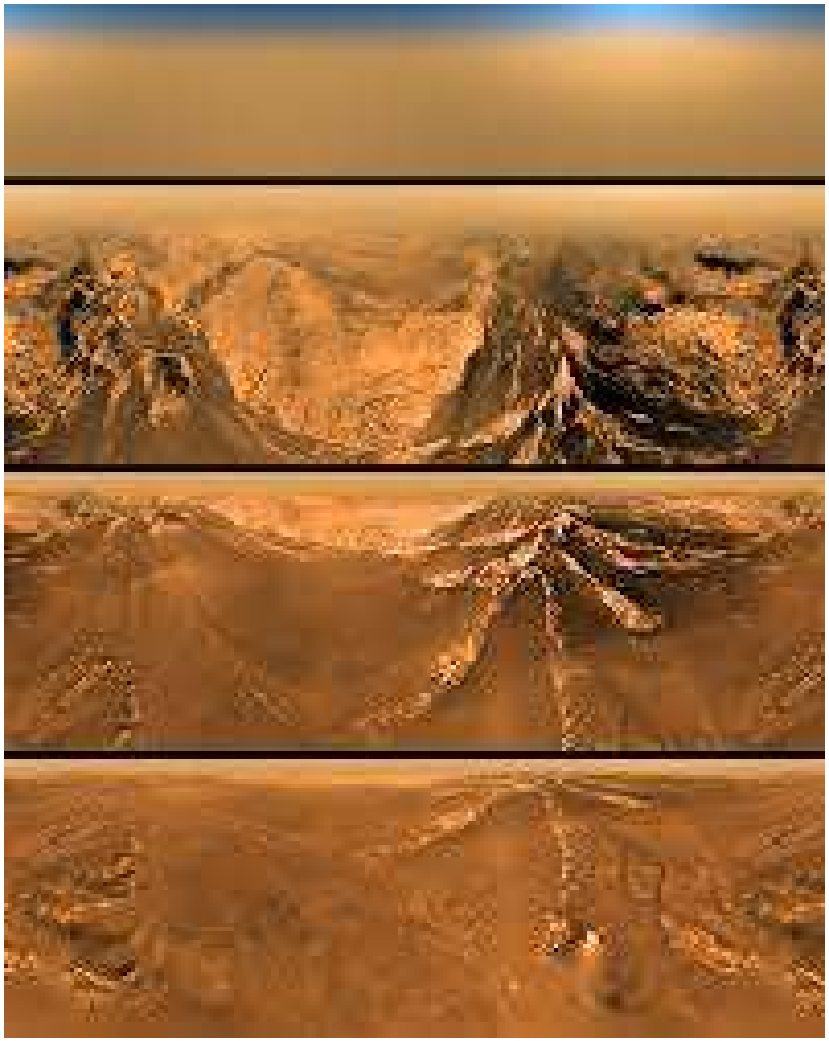


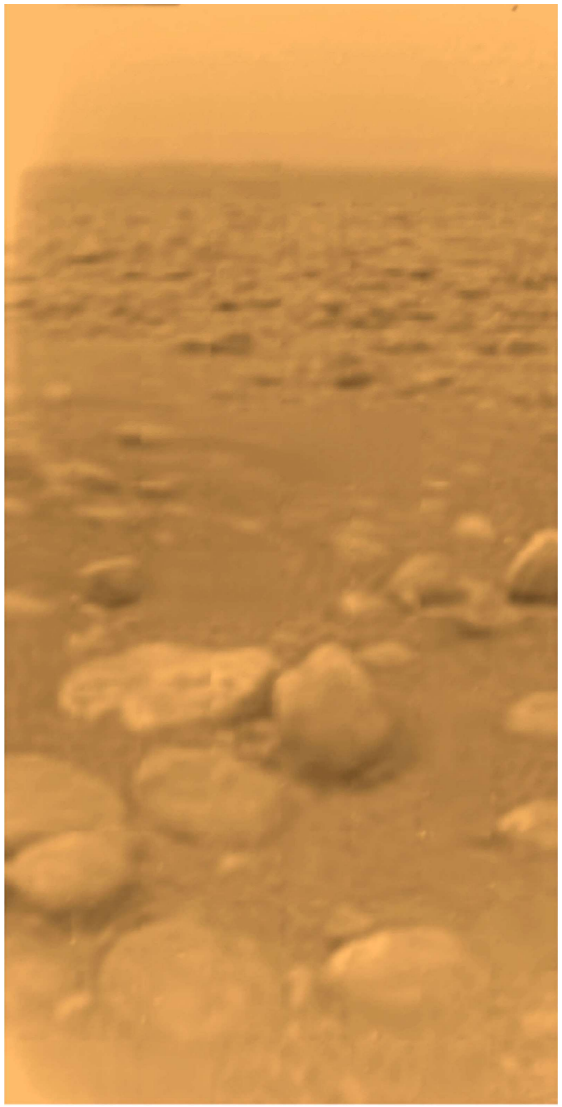
Huygens Probe into Titan

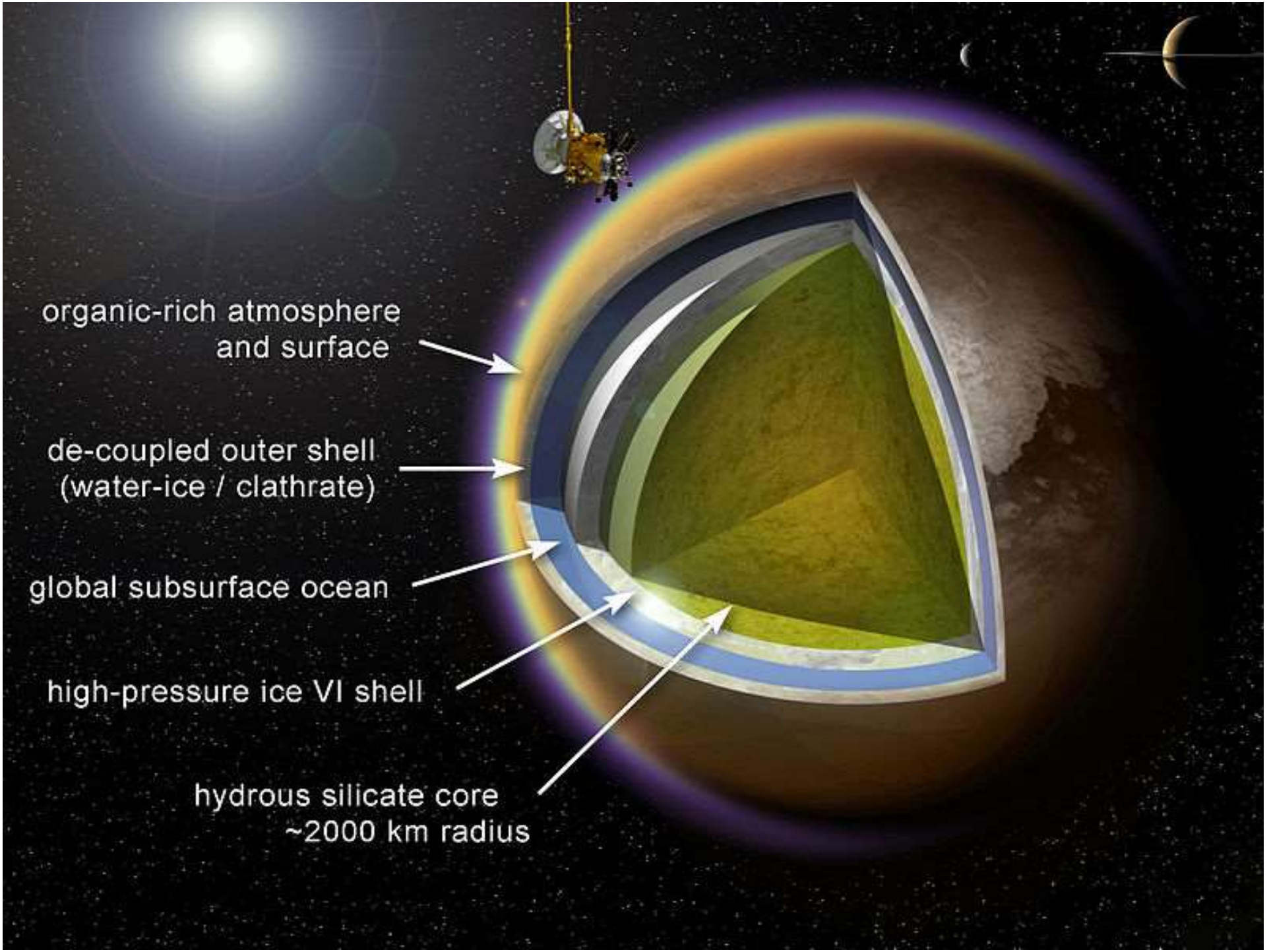
https://www.youtube.com/watch?v=msiLWxDayuA



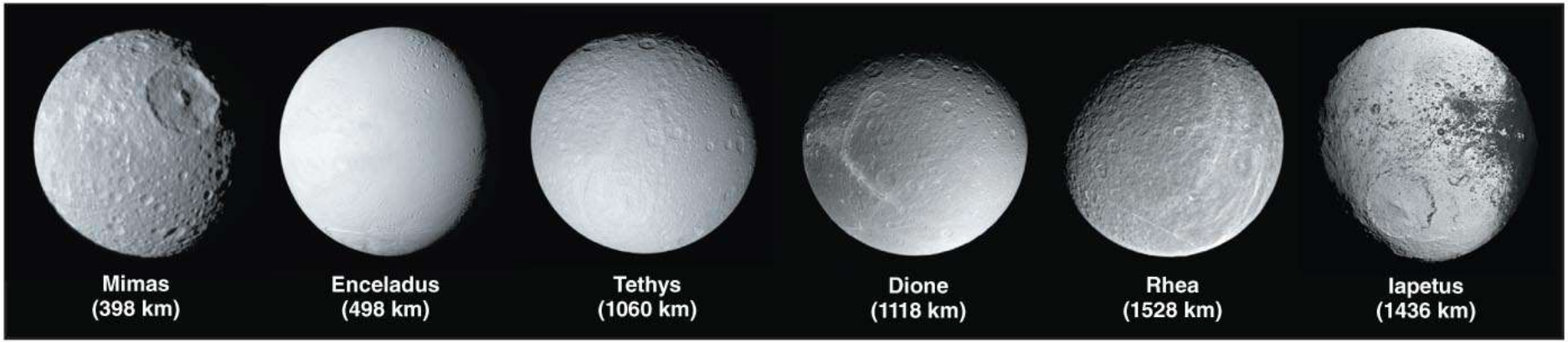
The Surface of Titan





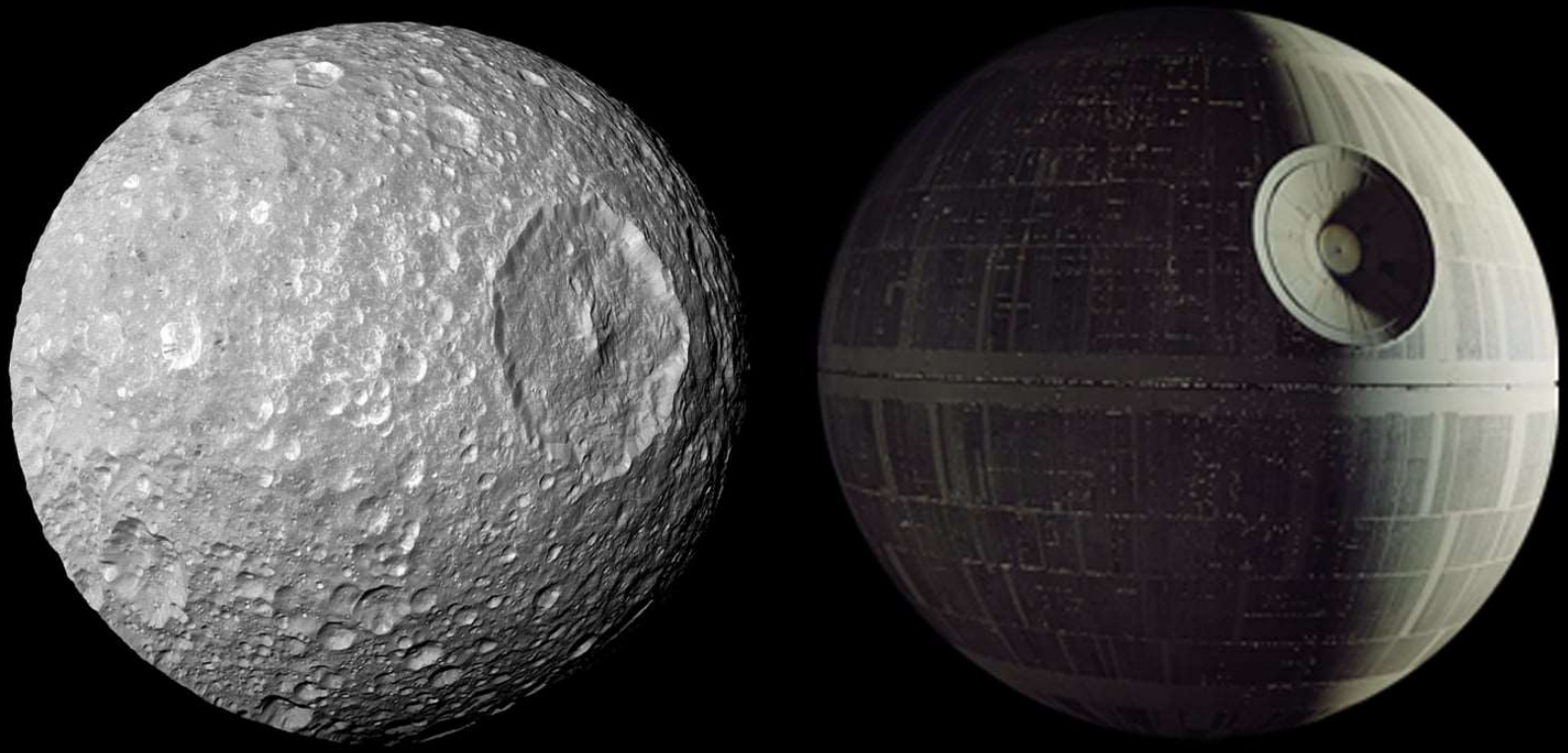

organic-rich atmosphere
and surface
de-coupled outer shell
(water-ice / clathrate)
global subsurface ocean
high-pressure ice VI shell
hydrous silicate core
~2000 km radius

Medium Moons of Saturn

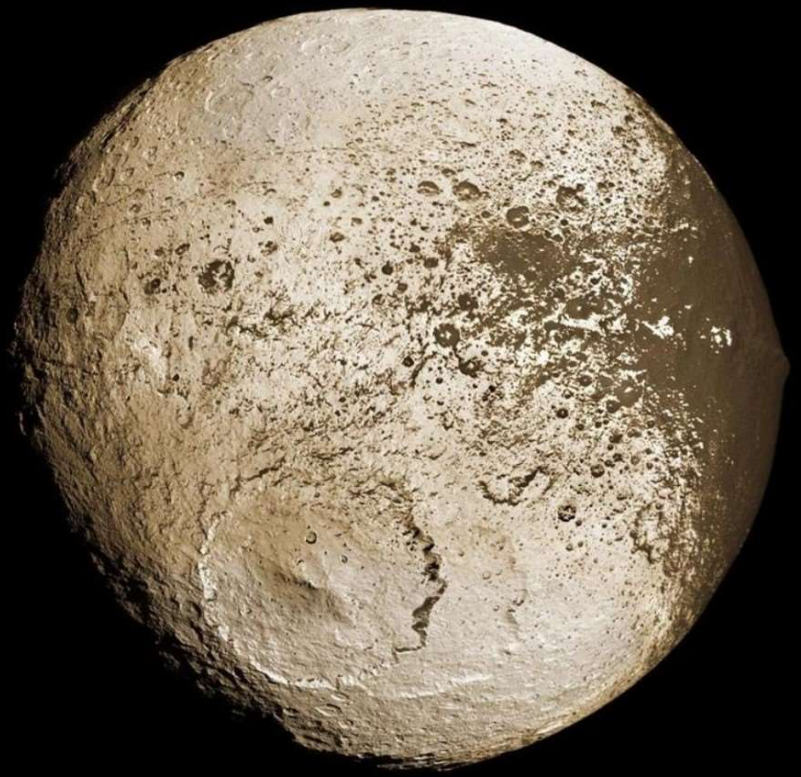


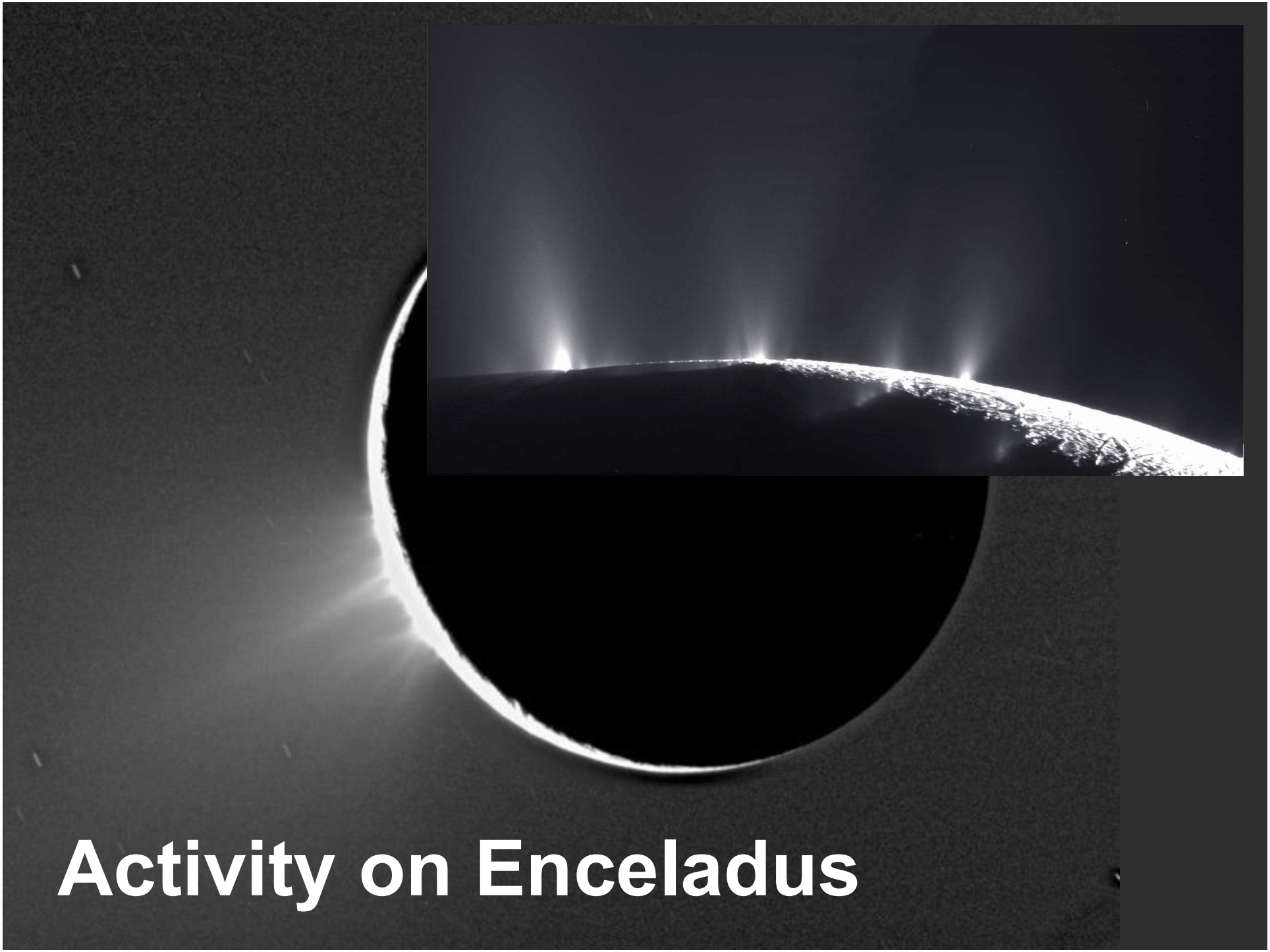
Almost all show evidence of past volcanism and/or tectonics.

Mimas – “That is no moon”



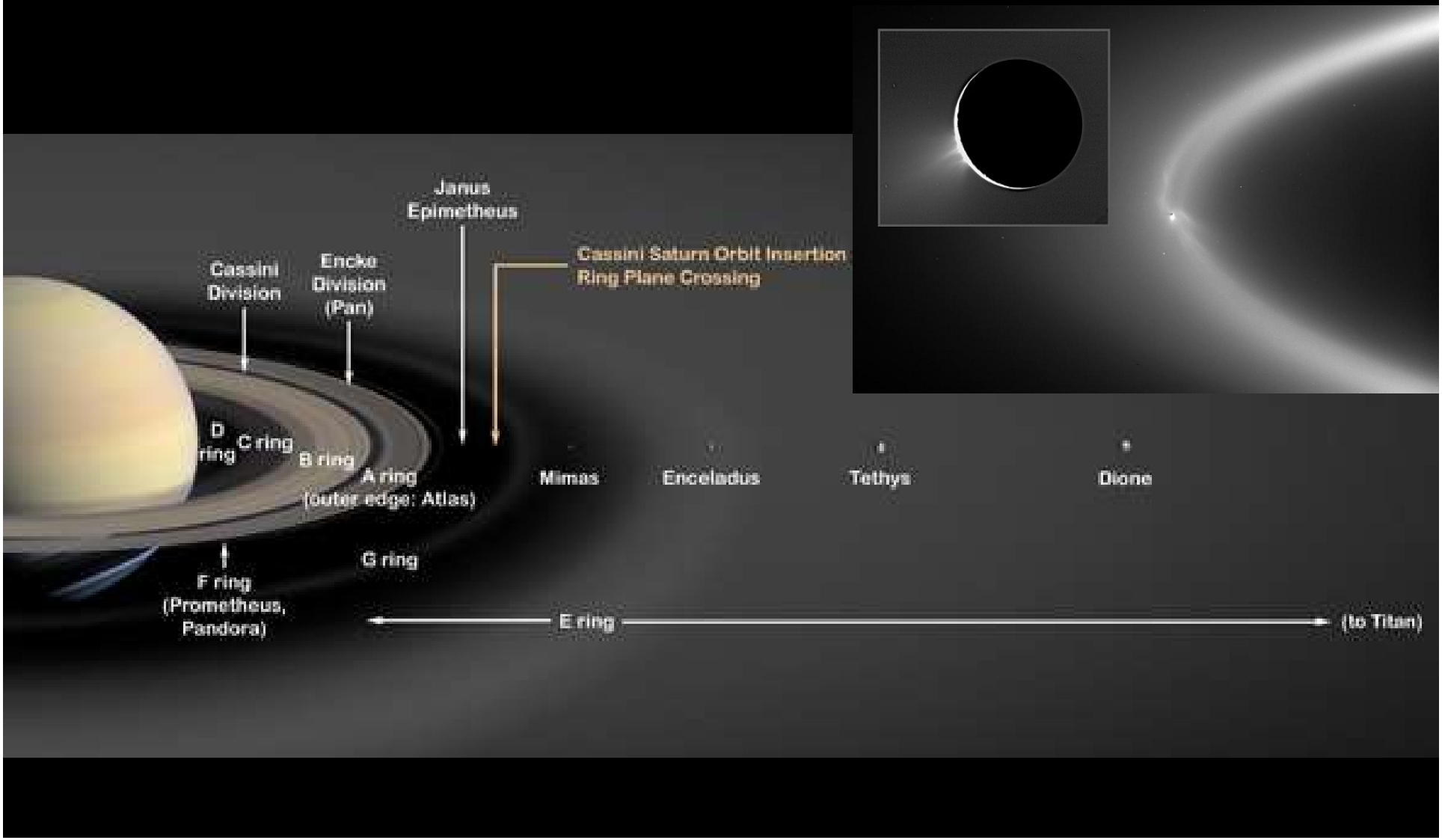
Iapetus – with a 20 km ridge





Activity on Enceladus

Enceladus & Saturn's E-ring

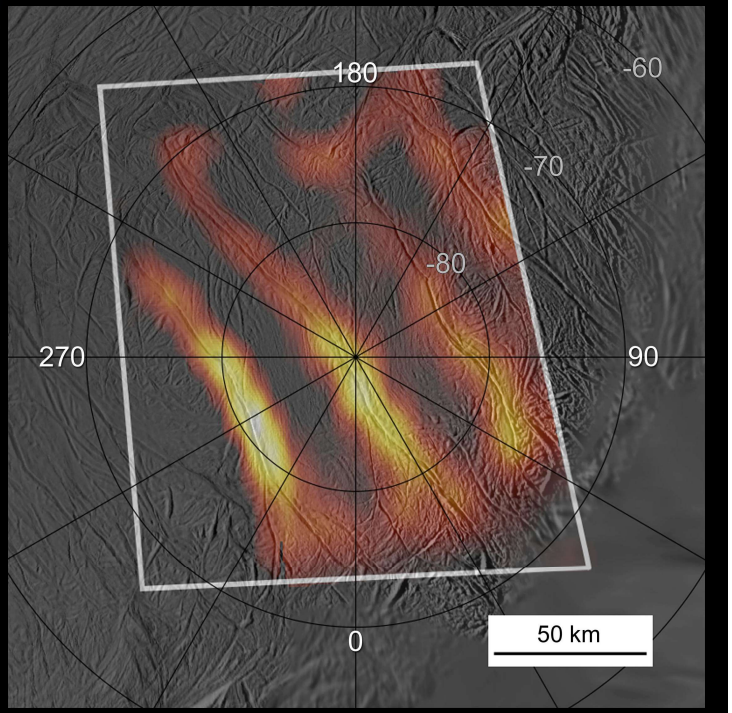


Enceladus

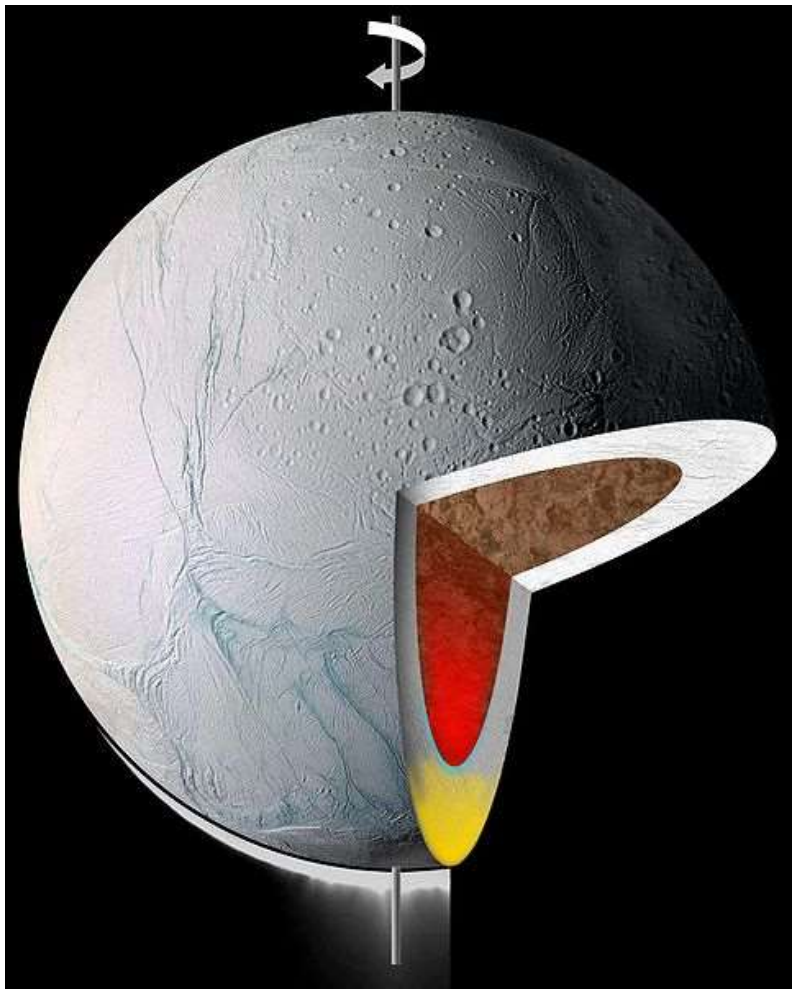
About the size of England

Seems to have geological activity…

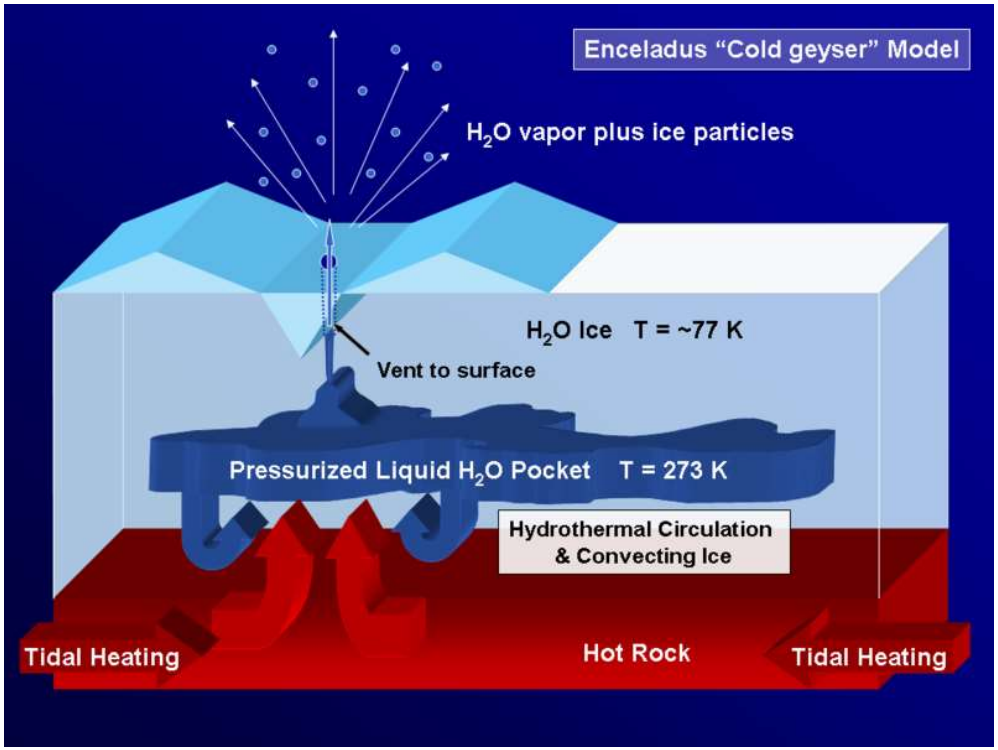
"Tiger Stripes" Region



How is there Activity on Enceladus?

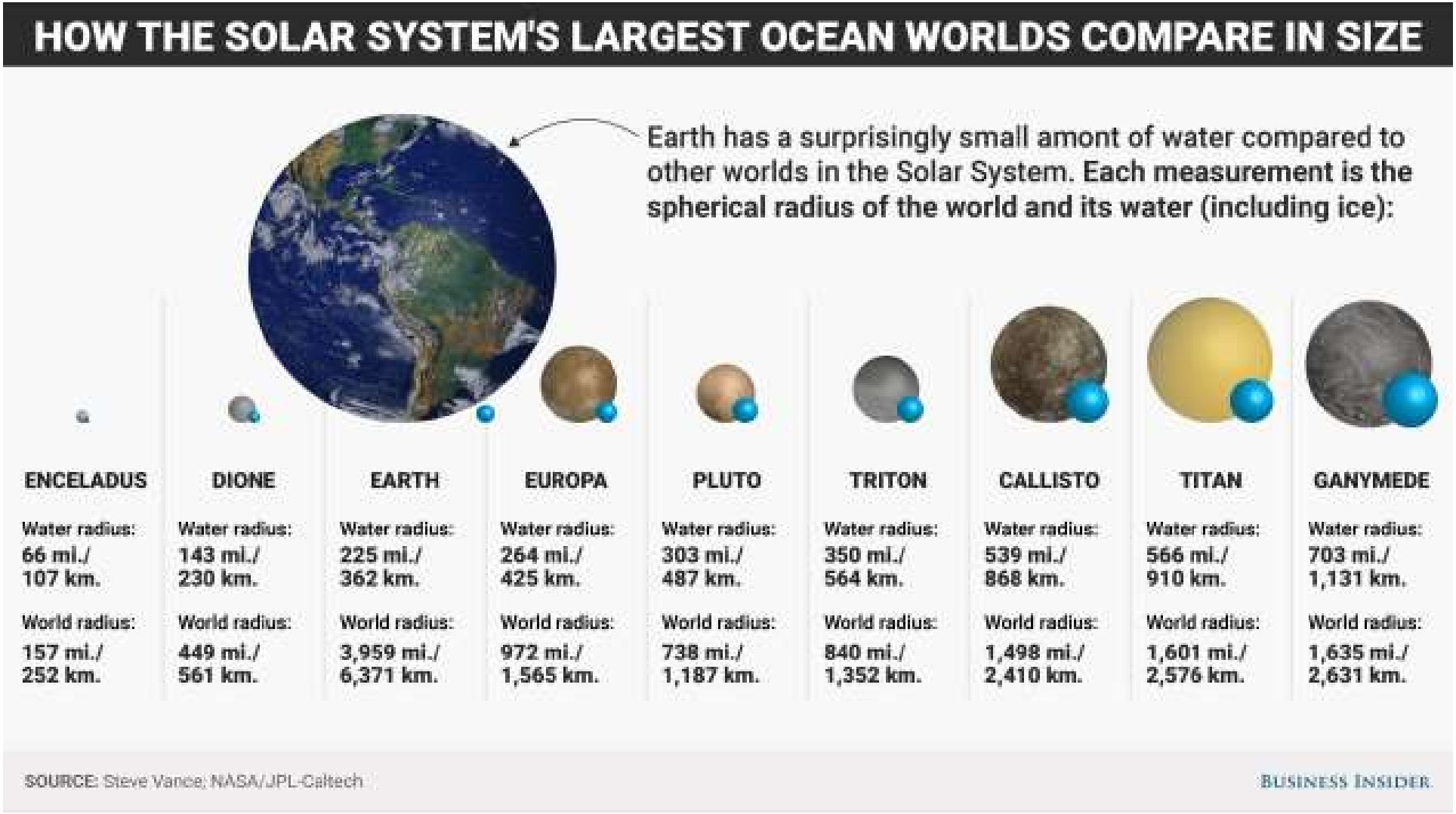


Tidal Heating & Potentially Cryovolcanism…



Icy Water Worlds

Many have more water than Earth!

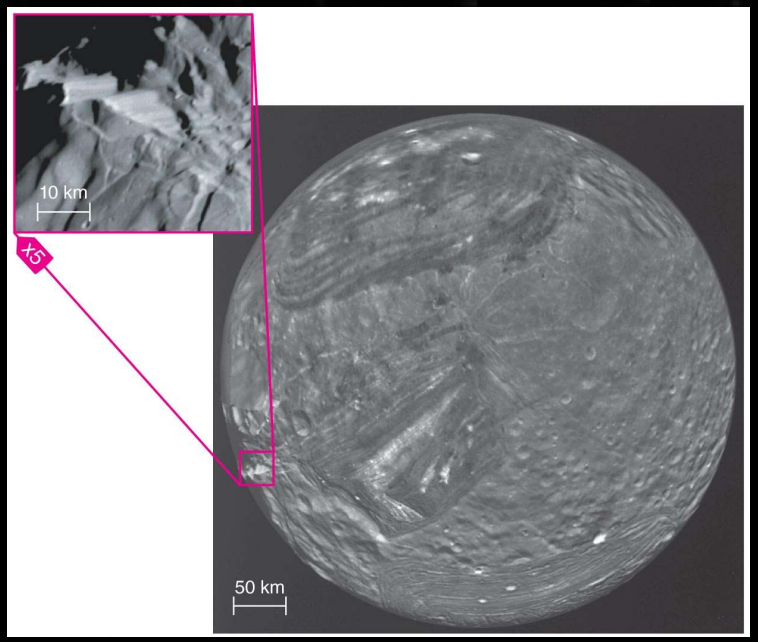


Moons of Uranus

All seem to show evidence of tectonic activity and few craters

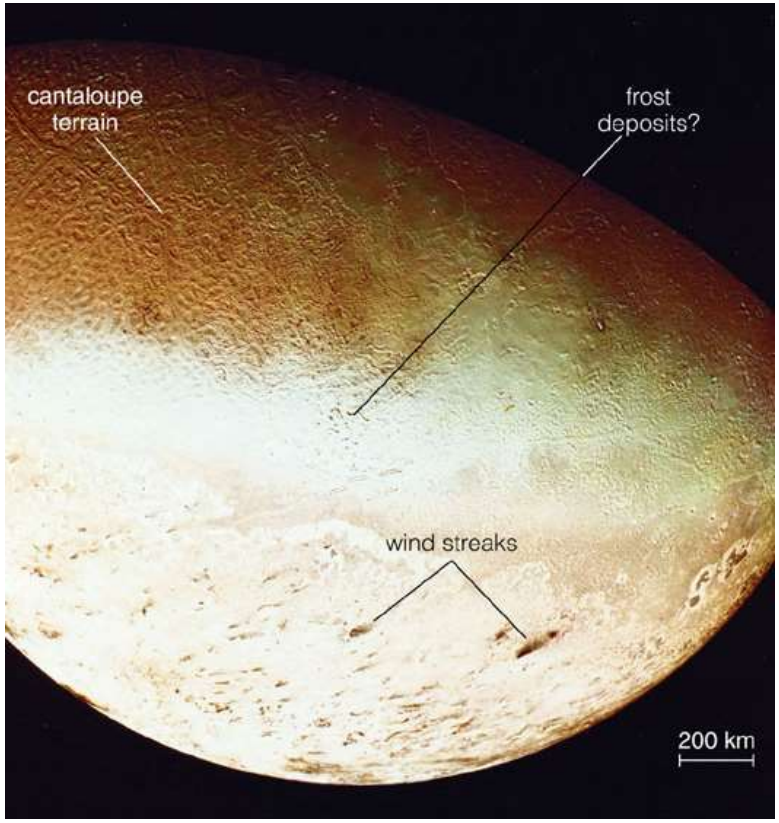
No mission to Uranus currently planed (only have images from Voyager 2 flyby!)

Close-up of Miranda



Neptune only has 1 large moon

Neptune's Moon Triton



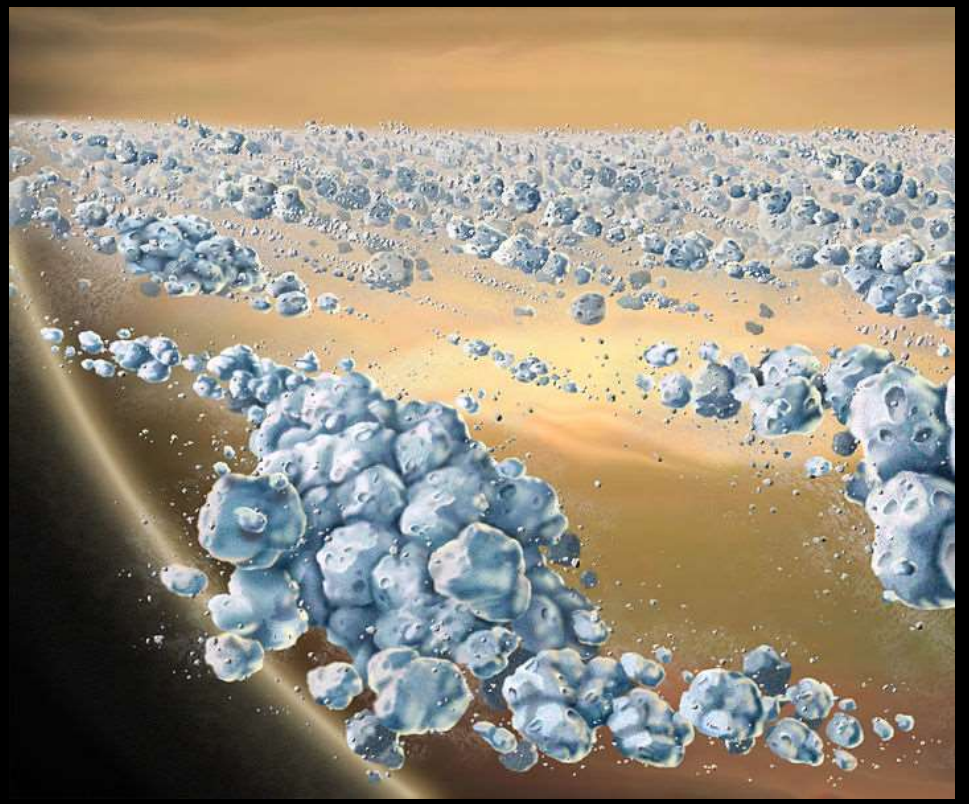
- Probably a captured Kuiper belt object: orbiting Neptune opposite Neptune's direction of rotation.
- Smaller than Earth's Moon, yet has recent geological activity.
- Cryovolcanism?

Geological activity on small moons

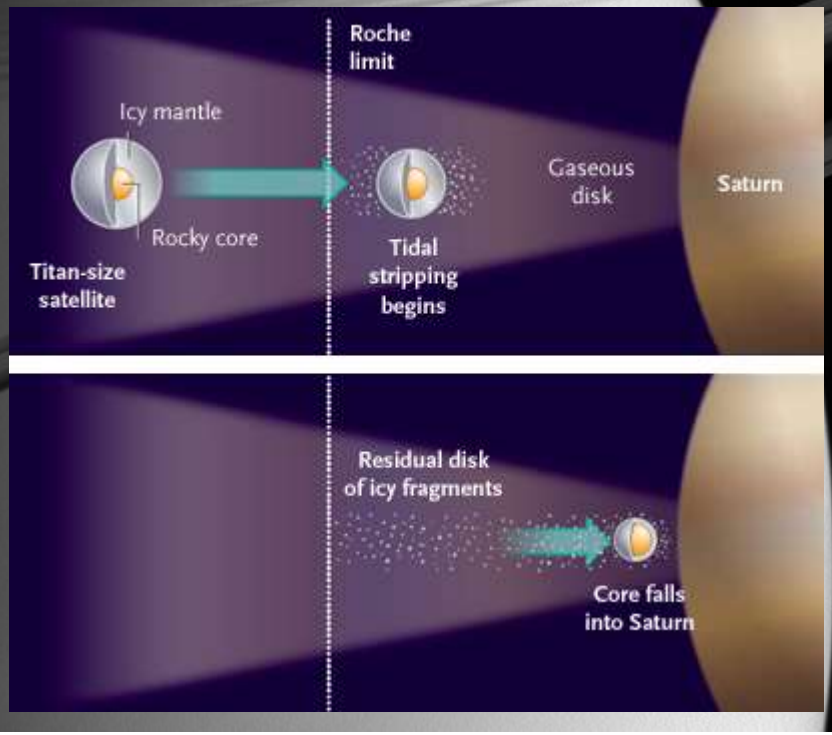
- Hot interiors are necessary for geological activity.
- Tidal heating is not a major energy source for rocky planets.
- In the case of Io, tidal heating is large enough to melt rocky materials.
- *Ice deforms more easily than solid rock, so less internal heat is required, and smaller objects can be geologically active*

A Bit more on Jovian Rings

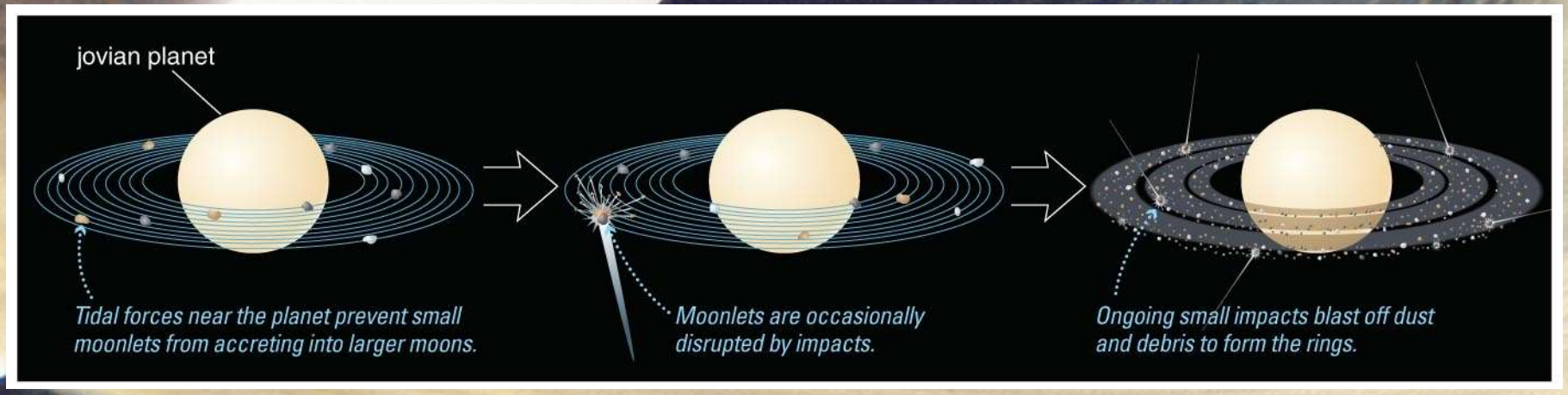
- Huge variations between the rings
- Many gaps are maintained by embedded moons
- Thickness? Upper limits for Saturn's rings are about 150 meters



- Rings aren't leftover from planet formation-- the particles are too small to have survived this long… maybe…
- There must be a continuous replacement of tiny particles…..we think…..
- The most likely source is impacts with the Jovian moons…..maybe….
- Jovian planets have rings because they have <u>lots of Moons</u>!



?



Why do the Jovian planets have rings?

We think they formed from dust created in impacts on moons orbiting those planets

End of Todays Lecture