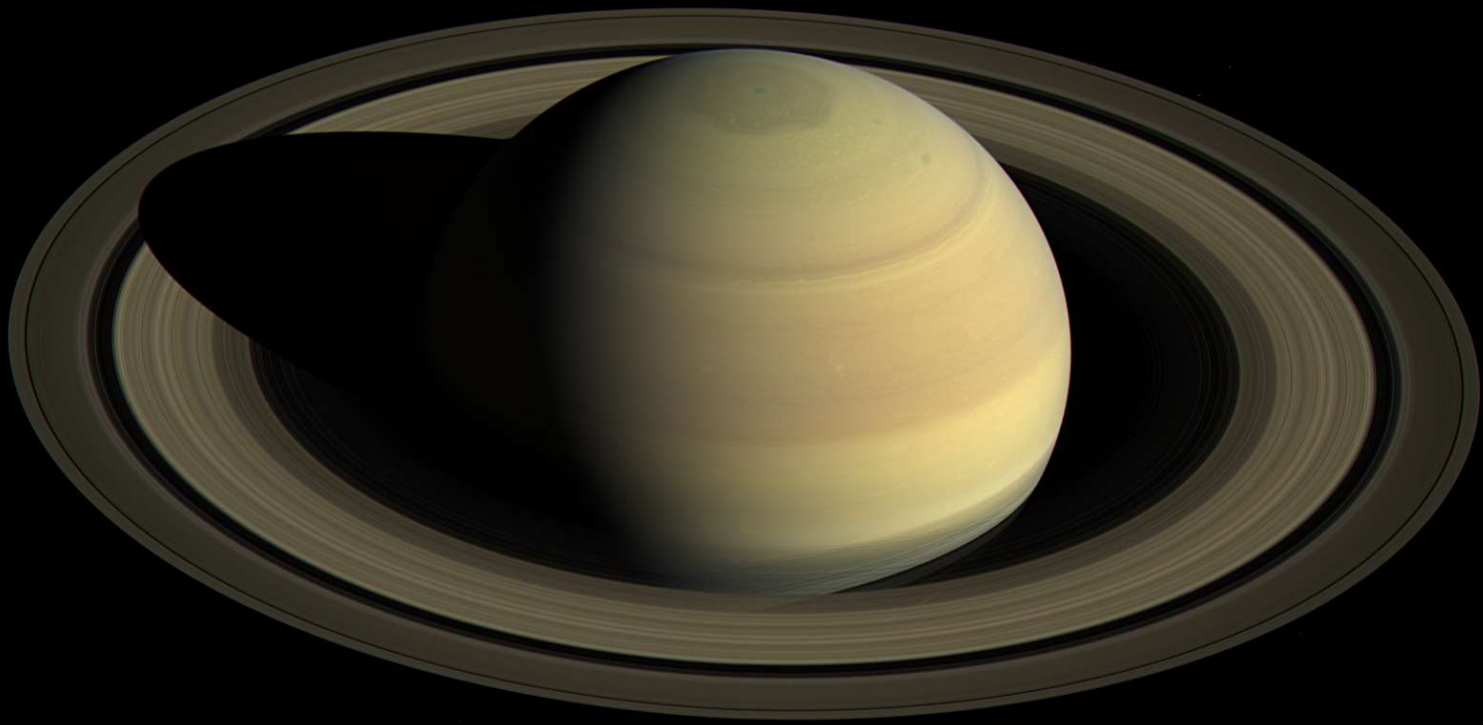
AST 2002
Introduction to Astronomy



A Few Quick Things…

E-mailing me: Must have AST2002 in the subject

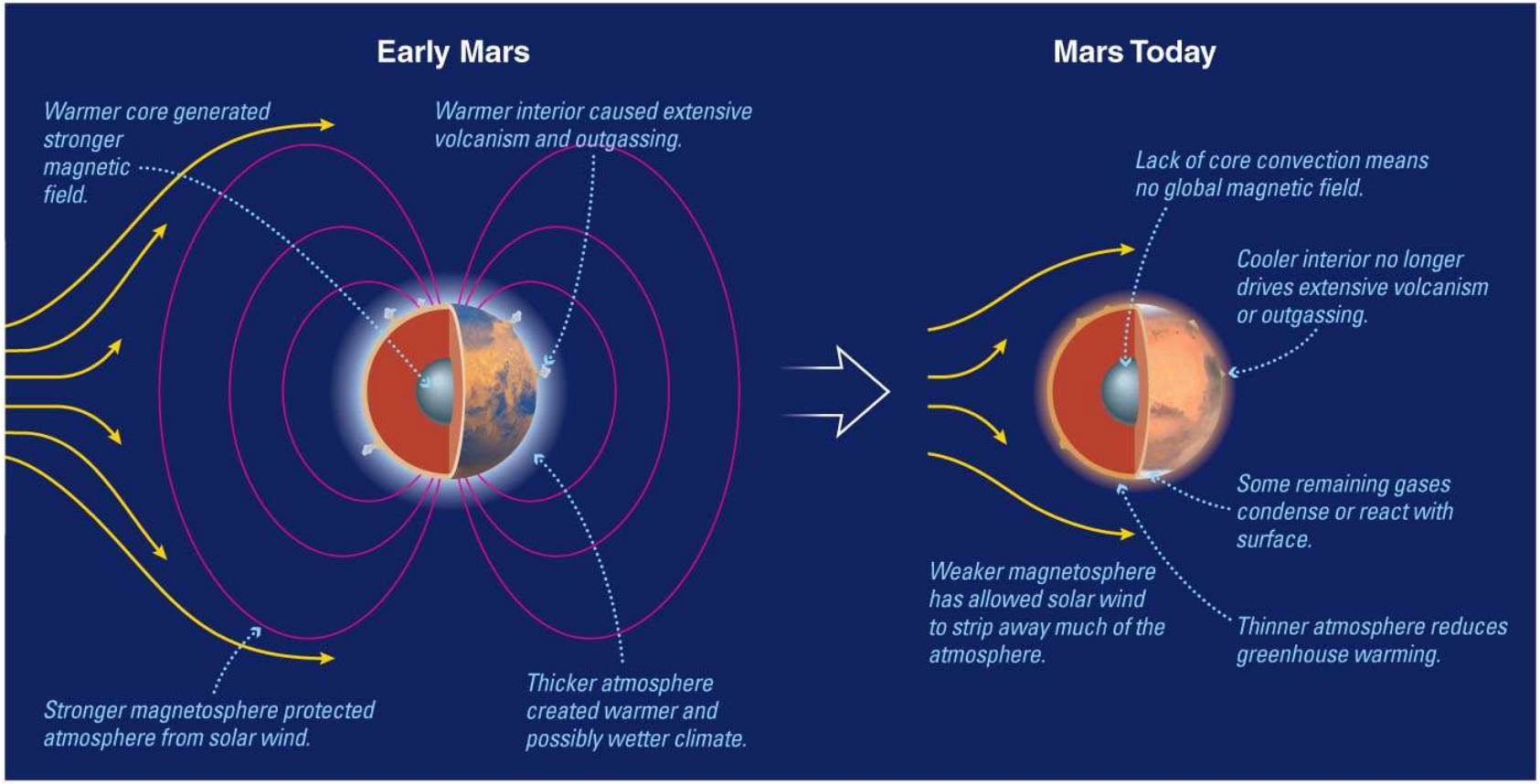
Mary Hinkle, Graduate Teaching Assistant:
Office Hours: Mon 1:30-3:00pm. PSB 316

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 Knights Under the Stars Event – Wed 28th Feb 7-8:30pm

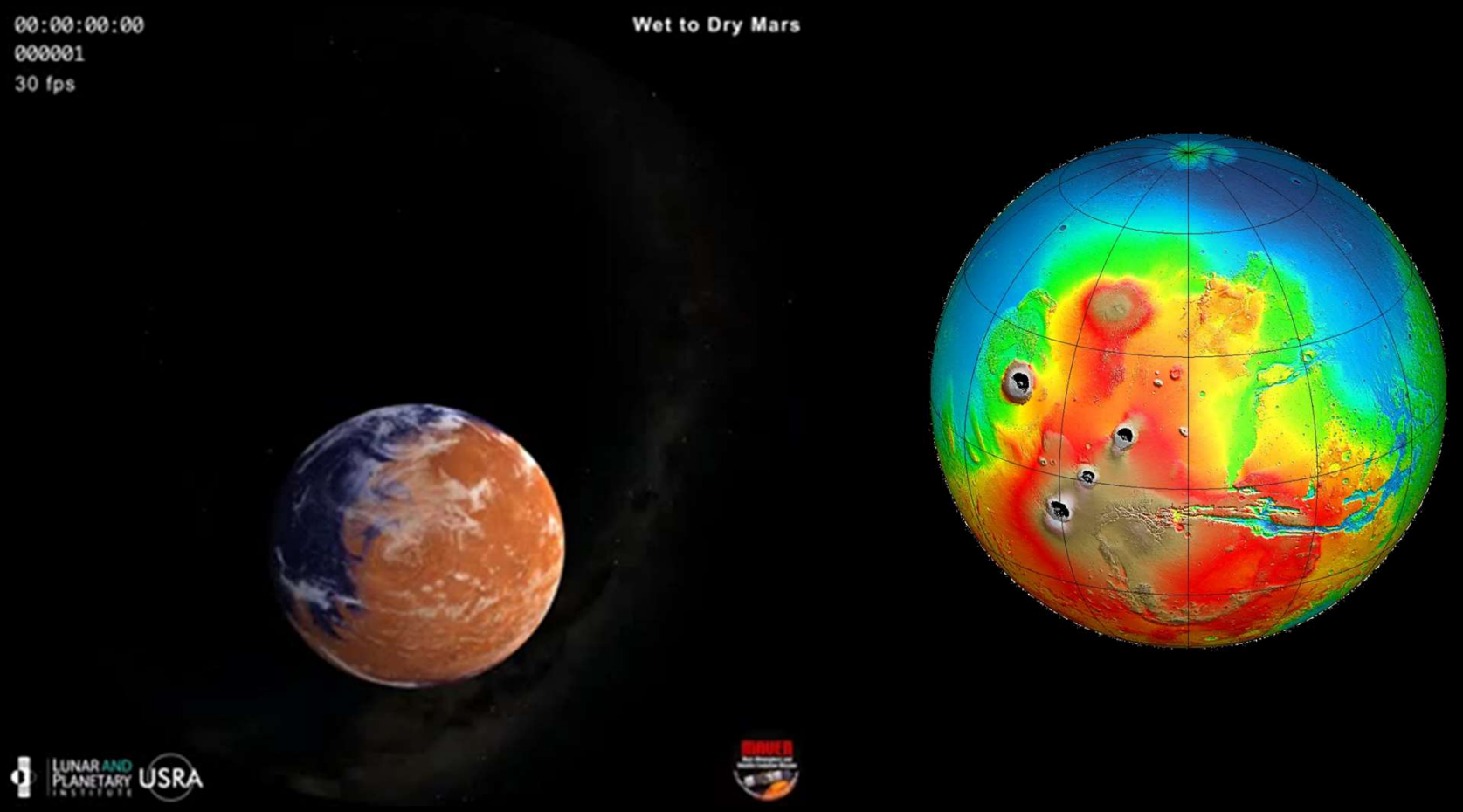
Mars Lost its Magnetosphere



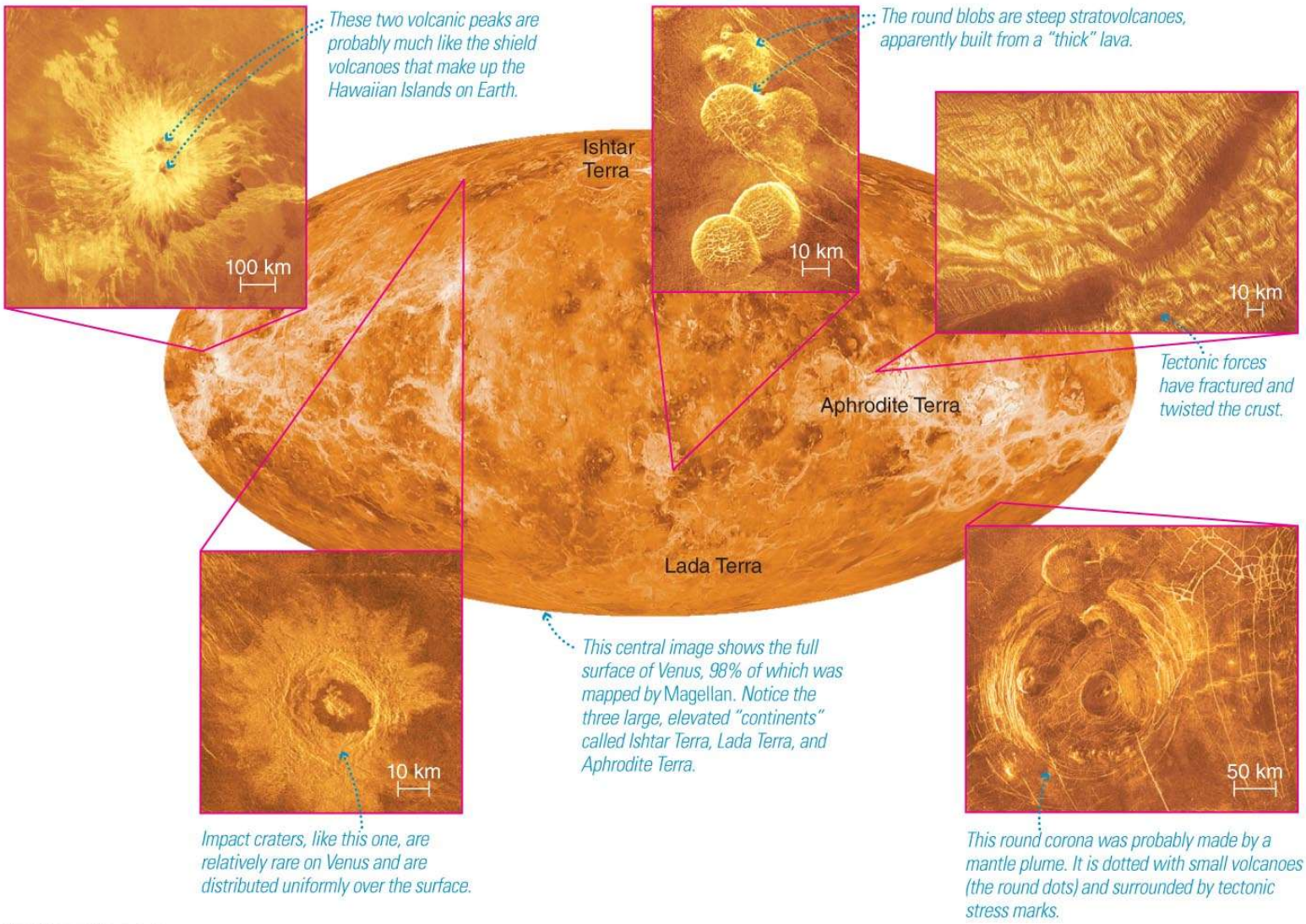
- Somehow Mars lost most of its atmosphere.
- Magnetic field may have preserved early Martian atmosphere.
- Solar wind may have stripped atmosphere after field decreased because of interior cooling.

Transition from Wet to Dry Mars

https://www.youtube.com/watch?v=nFBVBG5nEpw



Is Venus geologically active?



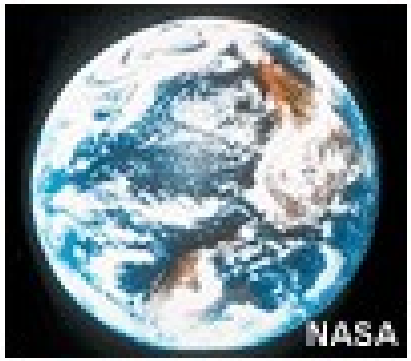
Why is Venus so hot?

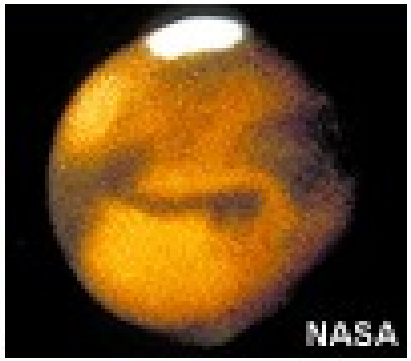
- Venus has reflective sulfuric acid clouds
  - **HIGHER ALBEDO**
- Receives less heat from sunlight than Earth

- The greenhouse effect on Venus keeps its surface temperature at 470°C.
- But why is the greenhouse effect on Venus so much stronger than on Earth?
- Venus has a very thick carbon dioxide atmosphere with a surface pressure 90 times that of Earth.
- Thick carbon dioxide atmosphere produces an extremely strong greenhouse effect. (Runaway Greenhouse Effect)
- Too hot for liquid water…

→ On Earth, carbon dioxide dissolves in water, and can react to form carbonates, slowly removing it from the atmosphere

The Atmospheres of Venus & Mars



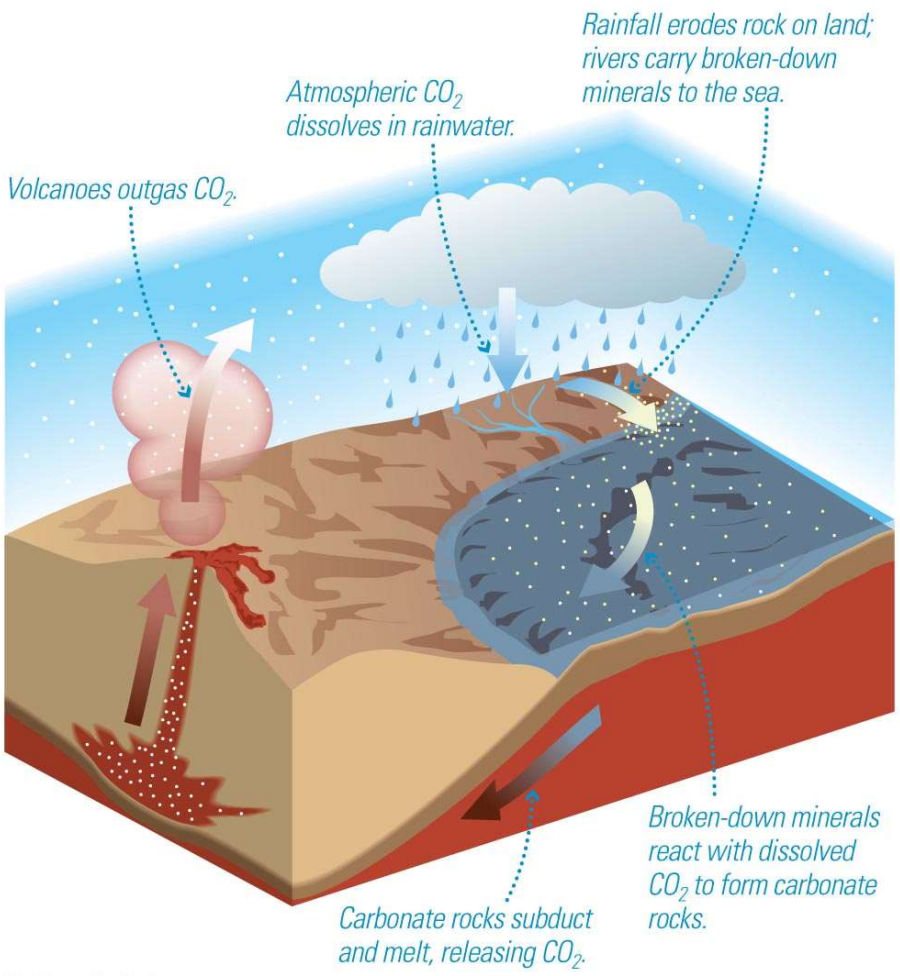


	Venus	Earth	Mars
Surface pressure relative to Earth (bars)	90	1	0.007
Major greenhouse gases (GHG)	CO_2	H_2O, CO_2	CO_2
Temperature if no GHG (°C)	-46	-18	-57
Actual temperature (°C)	477	15	-47
Temperature change due to GHG	+523	+33	+10

What unique features of Earth are important for life?

1. **Surface liquid water**
2. **Atmospheric oxygen**
3. **Plate tectonics**
4. **Climate stability**

The Carbon Dioxide Cycle

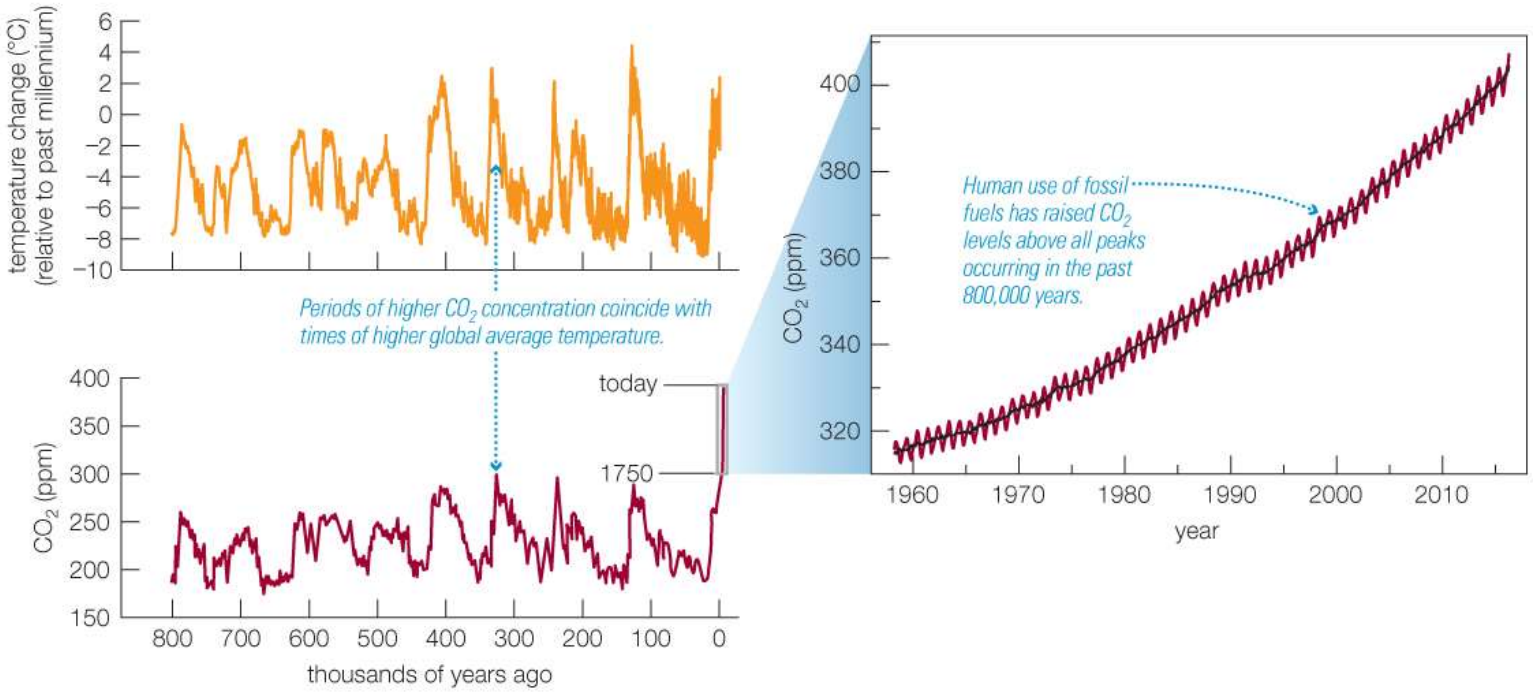


1. Atmospheric CO_2 dissolves in rainwater.
2. Rain erodes minerals that flow into the ocean.
3. Minerals combine with carbon to make carbonate rocks on ocean floor.
4. Subduction carries carbonate rocks down into the mantle.
5. Rock melts in mantle and outgases CO_2 back into atmosphere through volcanoes.

Tectonics makes a very slow feedback loop possible…

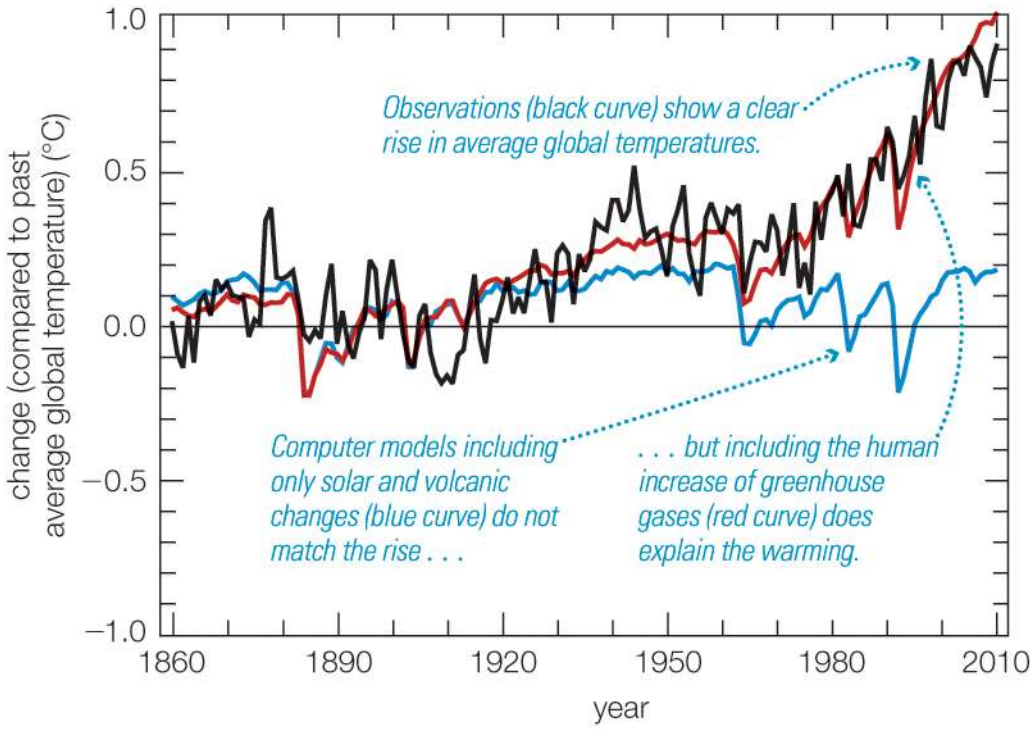
More heat = More rainfall

CO_2 Concentration



- Global temperatures have tracked CO_2 concentration for the last 500,000 years.
- Antarctic air bubbles indicate the current CO_2 concentration is at its highest level in at least 500,000 years.

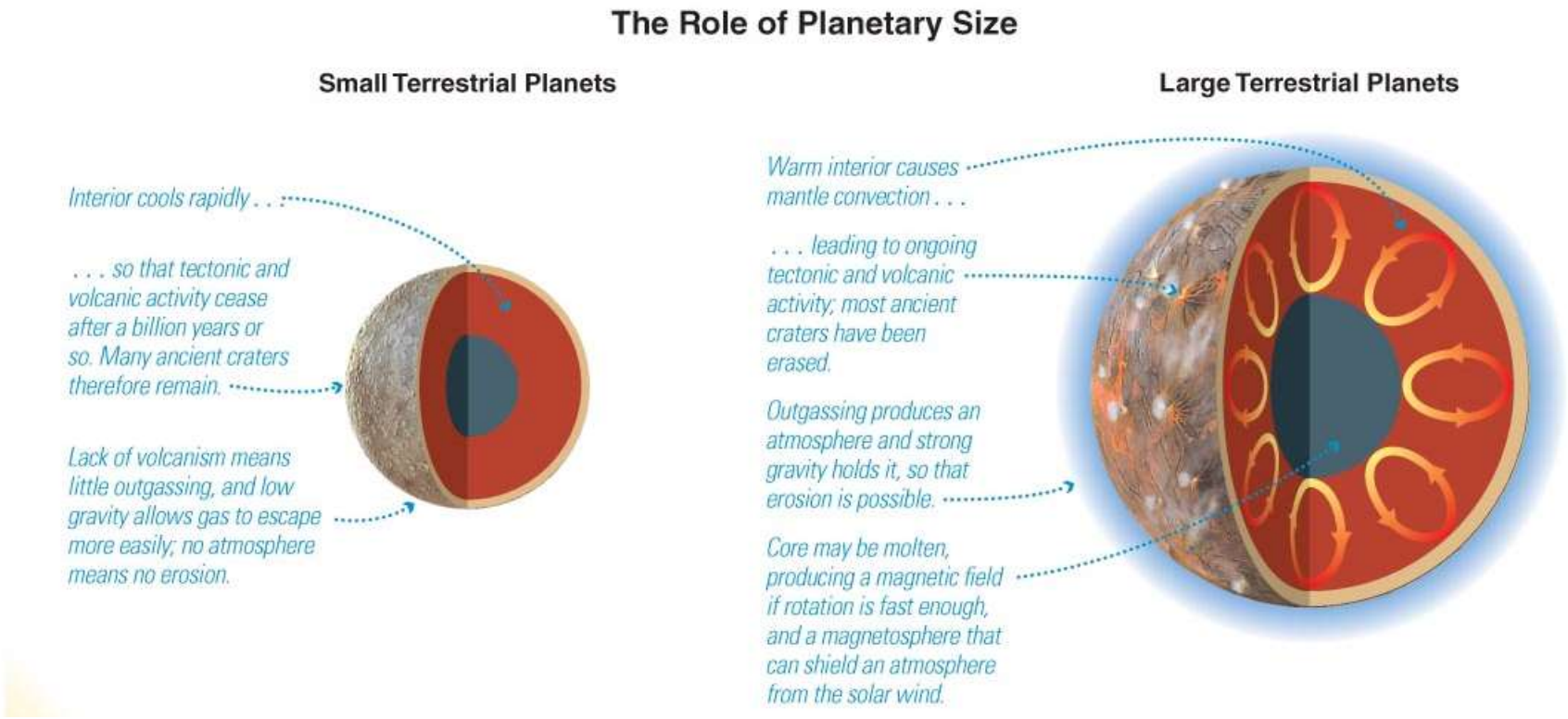
Modeling of Climate Change



- Models of global warming that include human production of greenhouse gases are a better match to the global temperature rise.
- *Models don't work without greenhouse gas contributions*
- Increased by 0.5°C in the past 50 years.

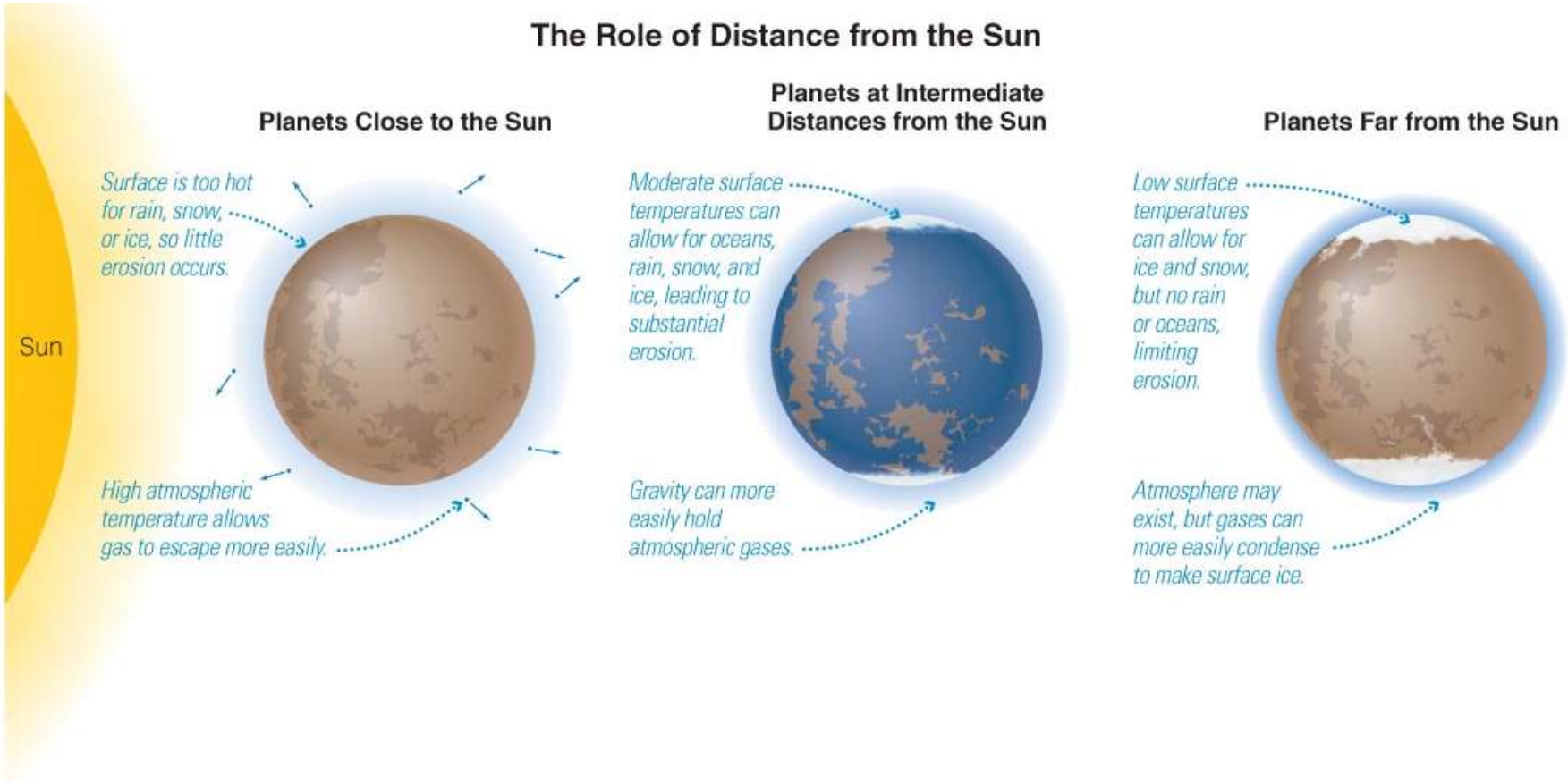
- The concentration of CO_2 is rising rapidly.
- An unchecked rise in greenhouse gases will eventually lead to global warming.

What makes a planet habitable?



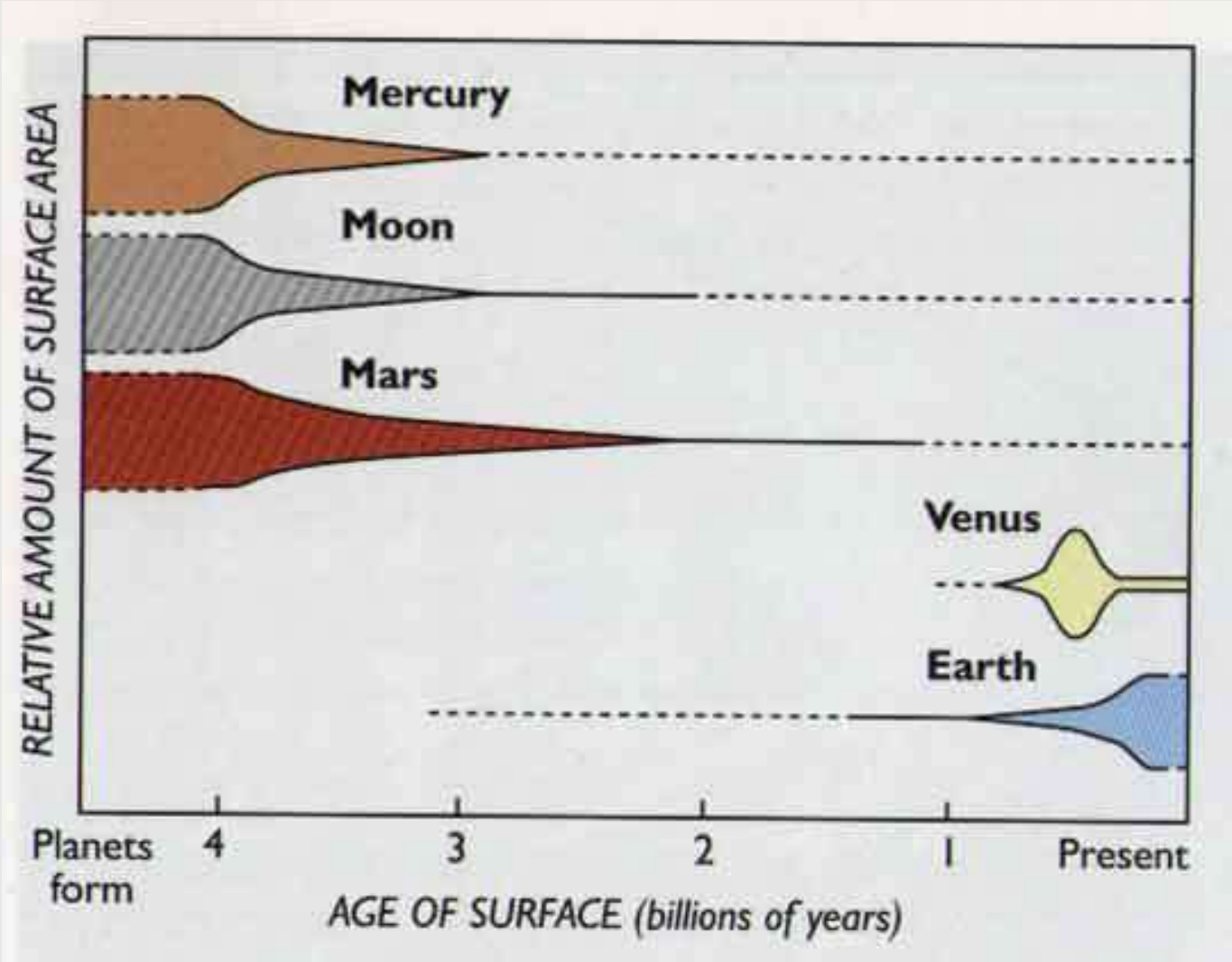
- Must be large enough for geological activity to release and retain water and atmosphere

What makes a planet habitable?

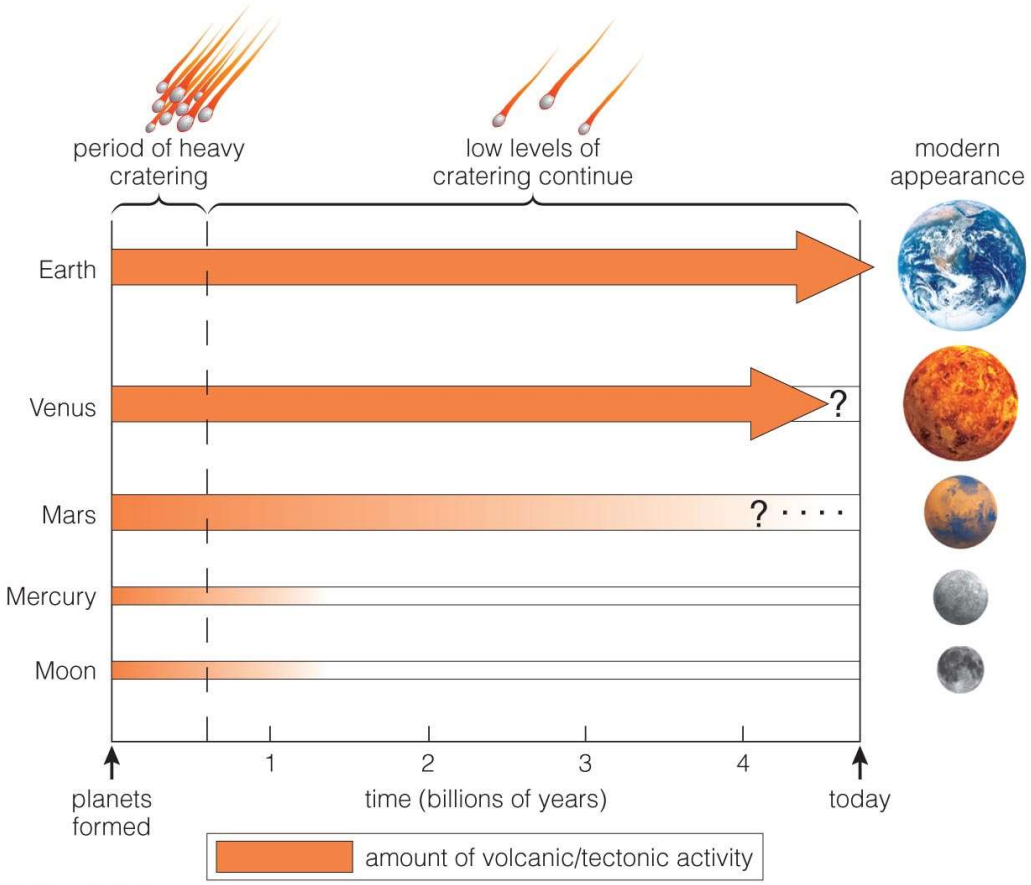


- Must be located at an optimal distance from the Sun for liquid water to exist = *Habitable Zone (Goldilocks Zone)*

Comparative Surface Ages of Terrestrial Worlds



Planetary Destiny



Earth is habitable because it is large enough to remain geologically active, and it is at the right distance from the Sun so oceans could form.

Summary of Last Time

Chapter 7: Earth and the Terrestrial Worlds

- Earth as a Planet
  - Why is Earth geologically active?
  - What processes shape Earth's surface
  - How does Earth's atmosphere affect the planet?
- The Moon and Mercury: Geologically Dead
  - Was there ever geological activity on the Moon or Mercury?
- Mars: A Victim of Planetary Freeze-Drying
  - What geological features tell us that water once flowed on Mars
  - Why did Mars change?
- Venus: A Hothouse World
  - Is Venus Geologically Active?
  - Why is Venus to Hot?
- Earth as a Living Planet
  - What unique features of Earth are important for life?
  - How is human activity changing our planet?
  - What makes a planet habitable?

iClicker Question

Question: What is the source of Earth's magnetic field?

A. Magnetic rocks

B. Magnetized iron in Earth's crust

C. Magnetized iron in Earth's core

D. Molten metal circulating in Earth's outer core, moving like electrons in a wire

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iClicker Question

Question: Why are smaller terrestrial bodies such as Mercury or the Moon “geologically dead”?

A. They don’t have volcanoes
B. They cooled off faster than Earth did
C. They don’t have erosion
D. They were hit by fewer meteorites
E. They are made of different materials than Earth

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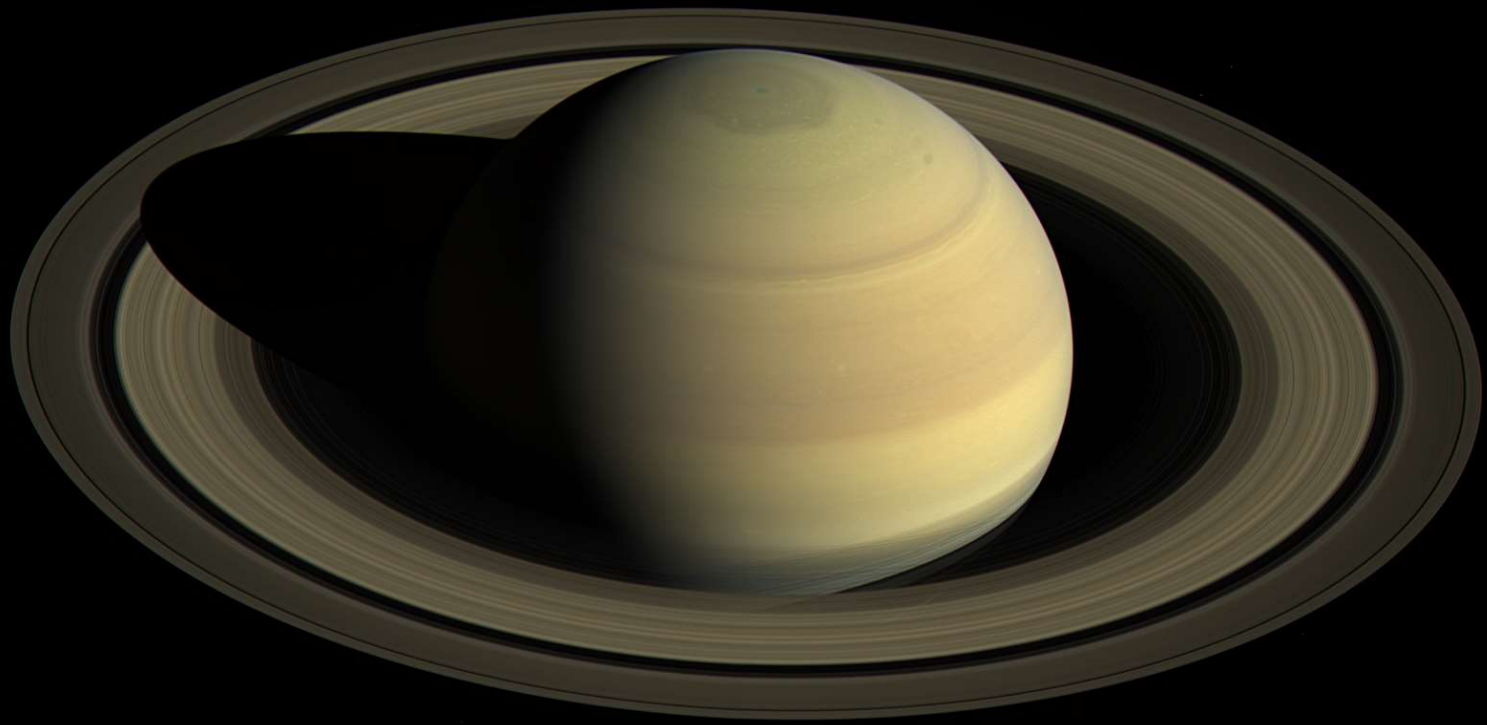
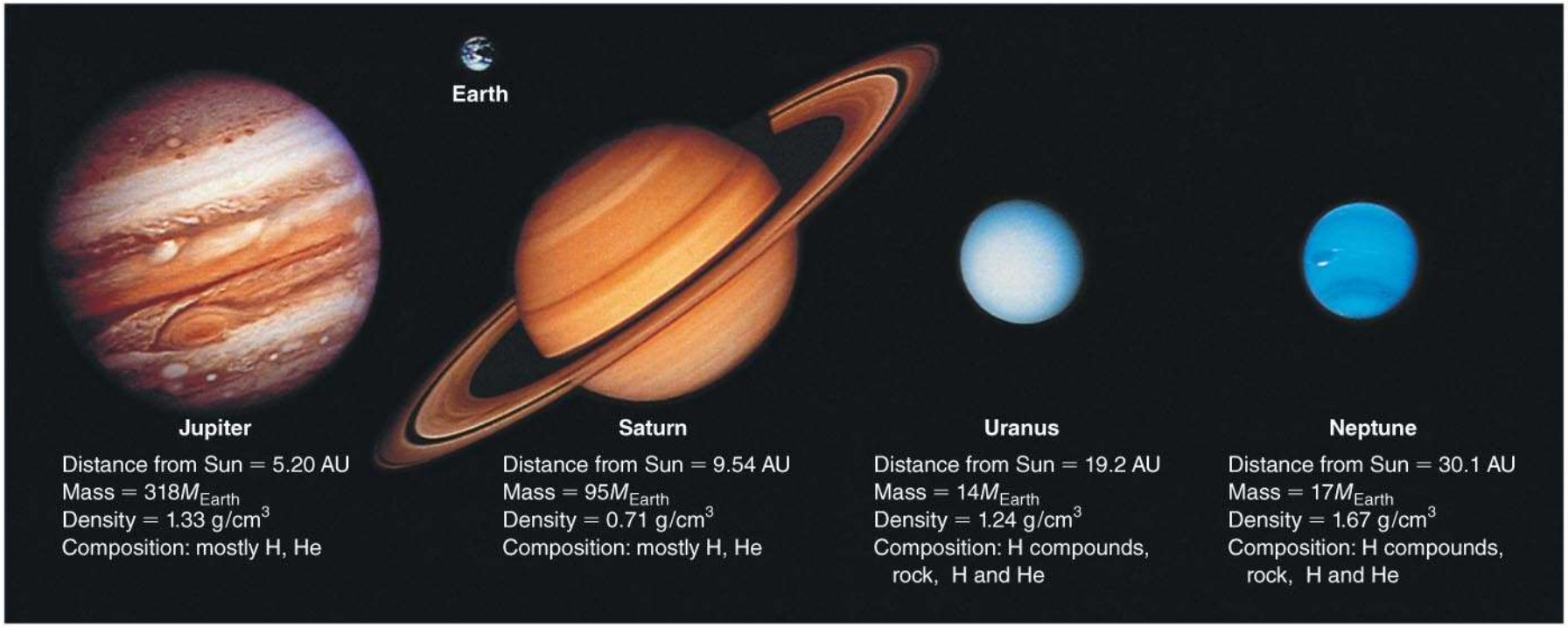


Chapter 8

The Jovian Planets



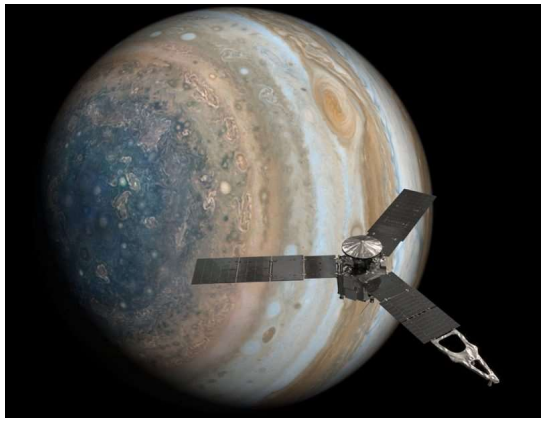
Formed beyond the snow-line where water could condense

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

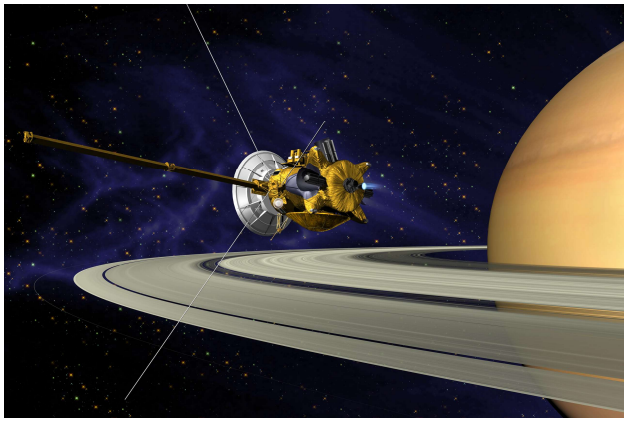
Missions to Outer Planets

- 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

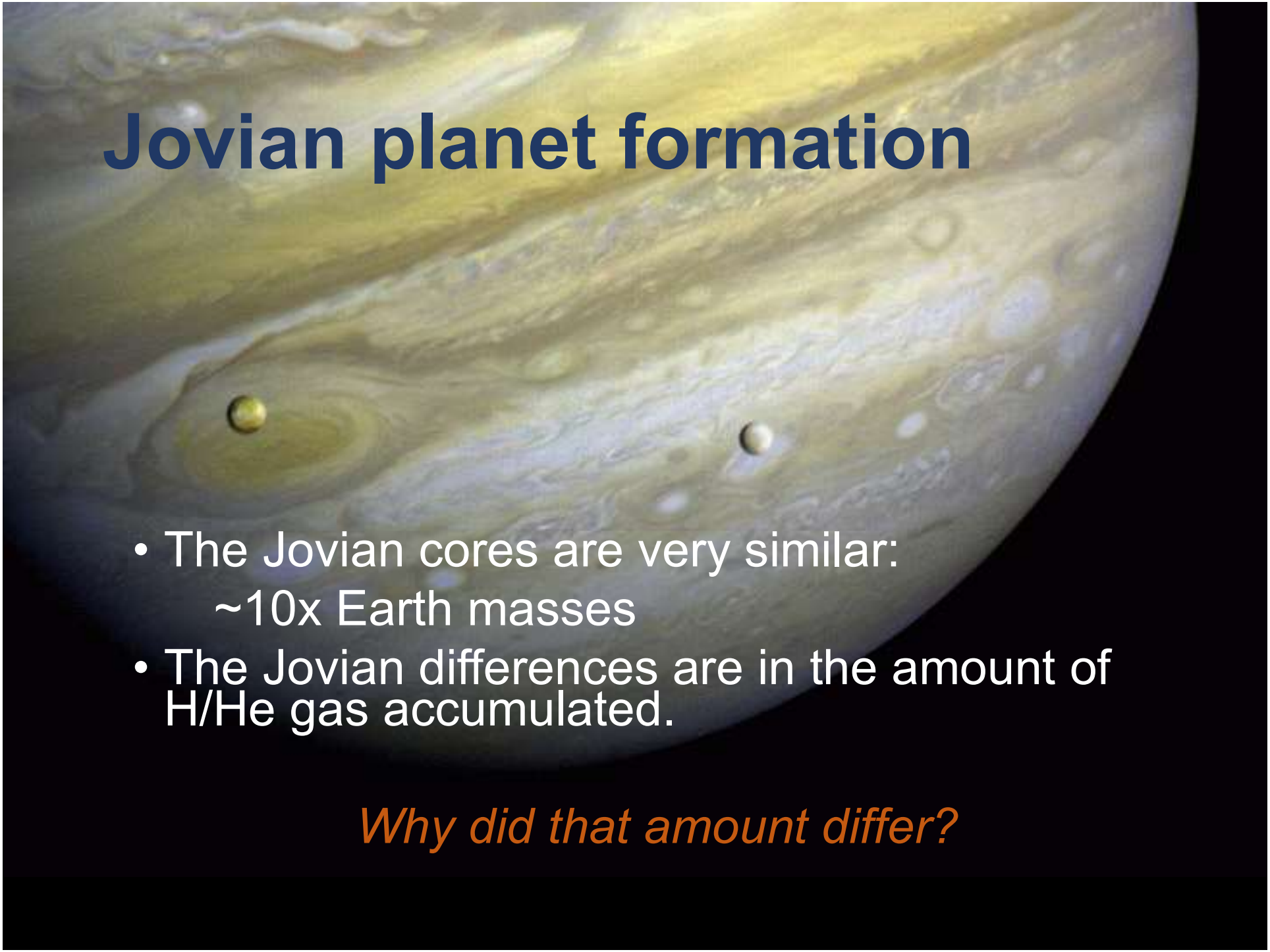


The Juno Spacecraft is studying Jupiter 2016-



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

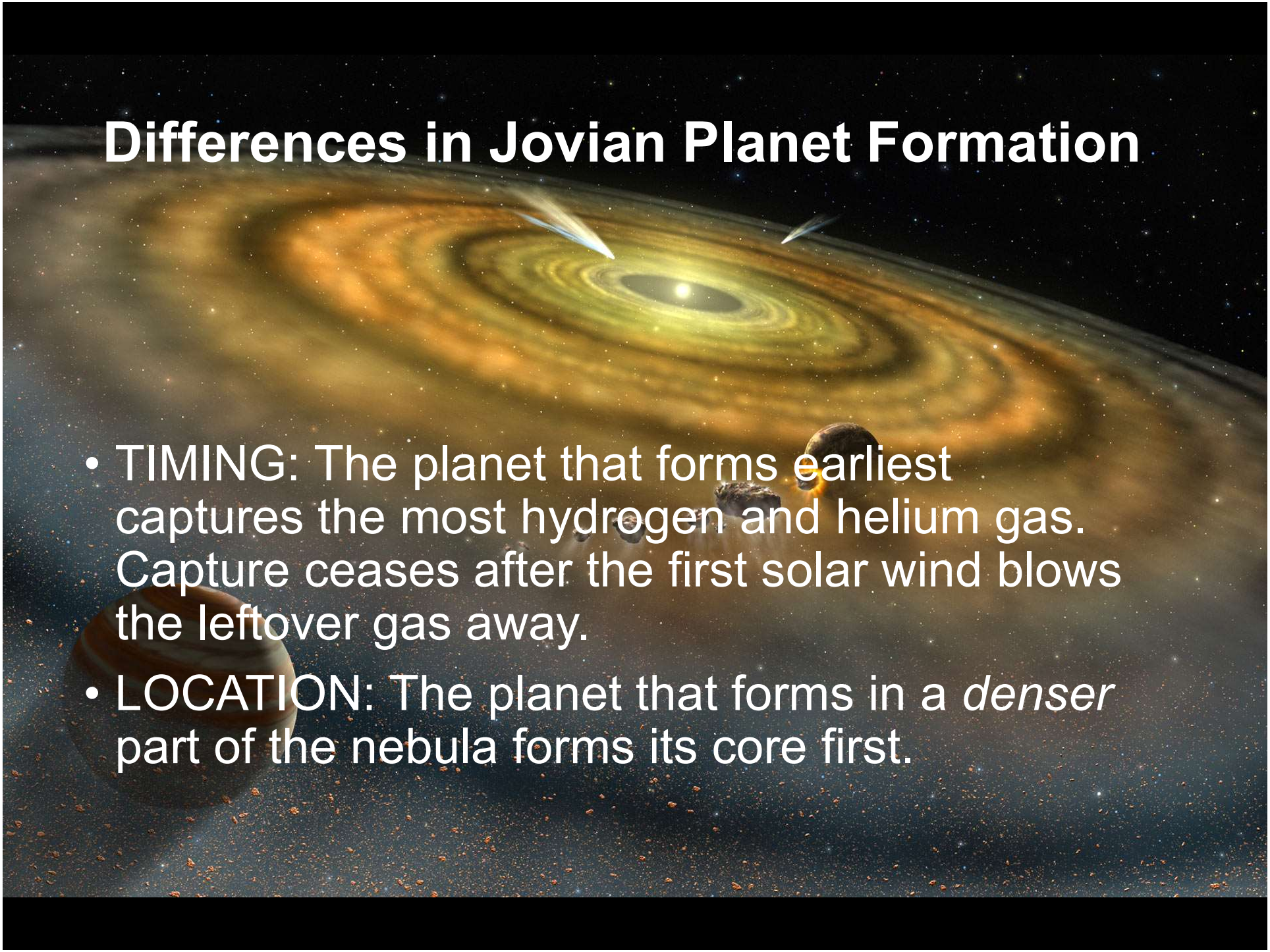
Jovian planet formation



- The Jovian cores are very similar:
  ~10x Earth masses
- The Jovian differences are in the amount of H/He gas accumulated.

Why did that amount differ?

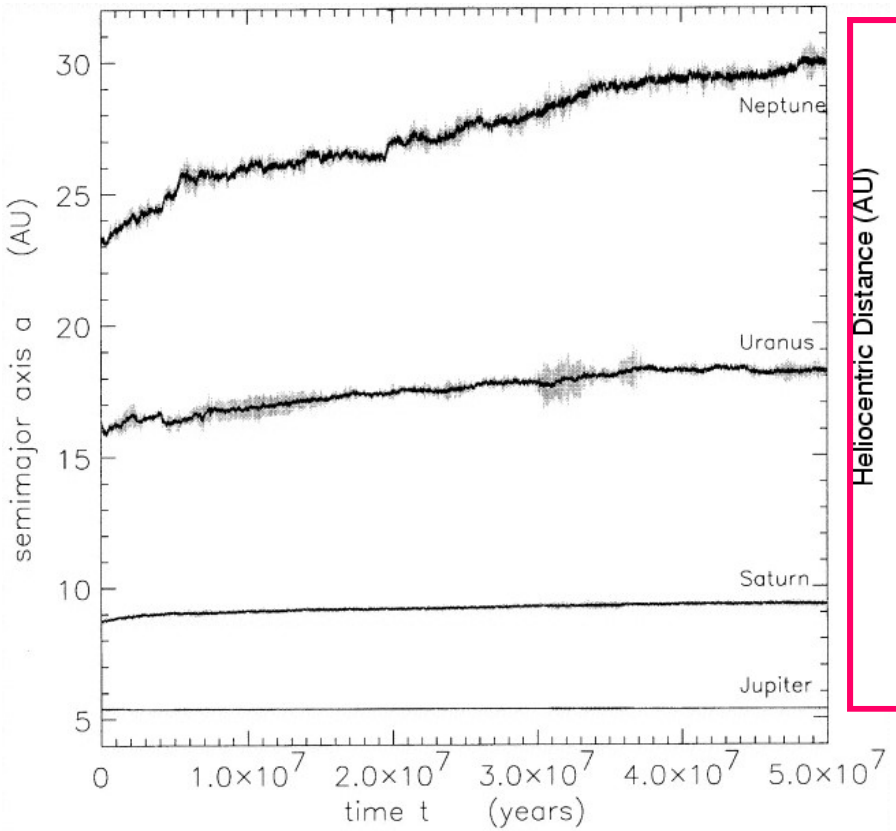
Differences in Jovian Planet Formation

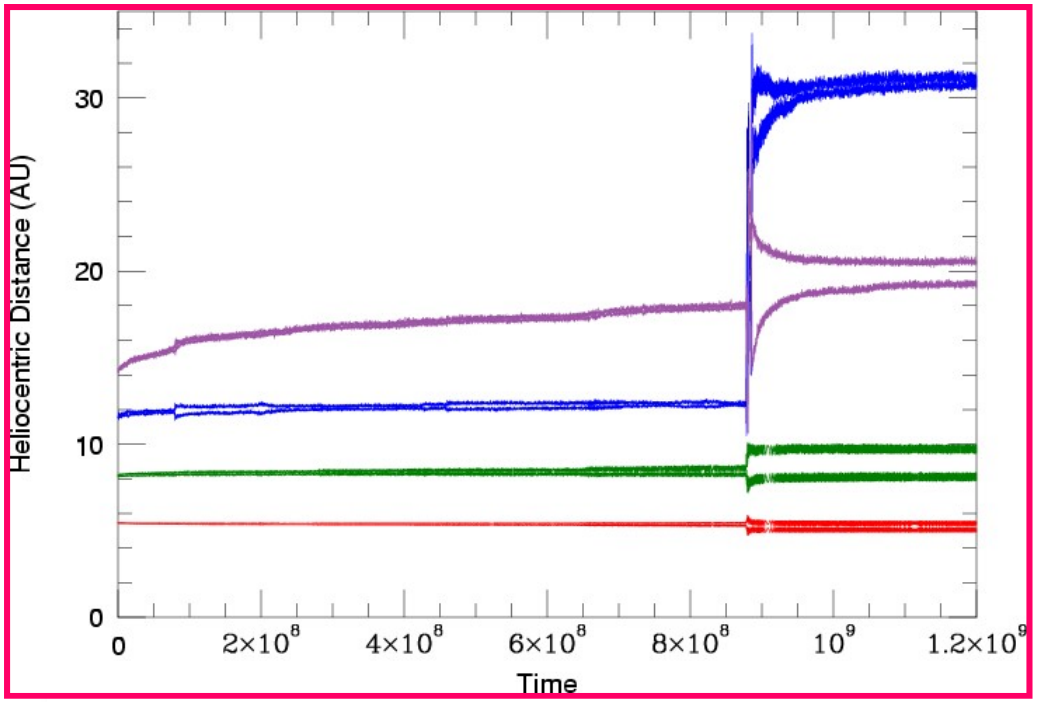


- TIMING: The planet that forms earliest captures the most hydrogen and helium gas. Capture ceases after the first solar wind blows the leftover gas away.
- LOCATION: The planet that forms in a *denser* part of the nebula forms its core first.

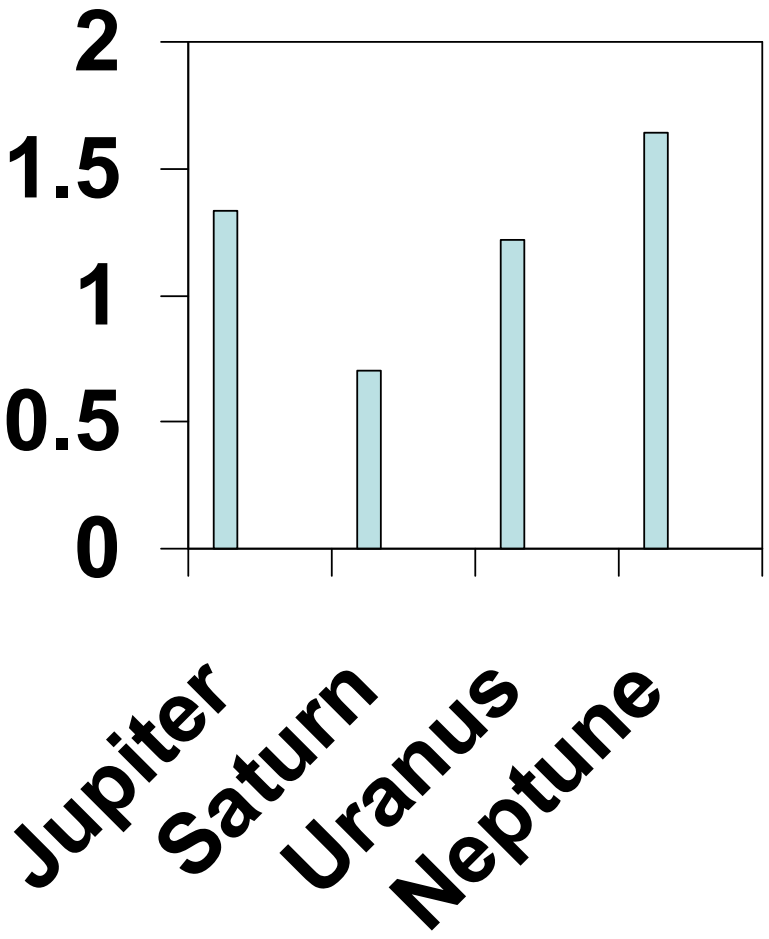
Planetary Migration?

- Current models favor the idea that the Jovian planets formed closer to the Sun
- Then migrated outwards. Also possible that Uranus & Neptune switched
  - Predicted by the *Nice model* - Jupiter and Saturn come into 2:1 resonance



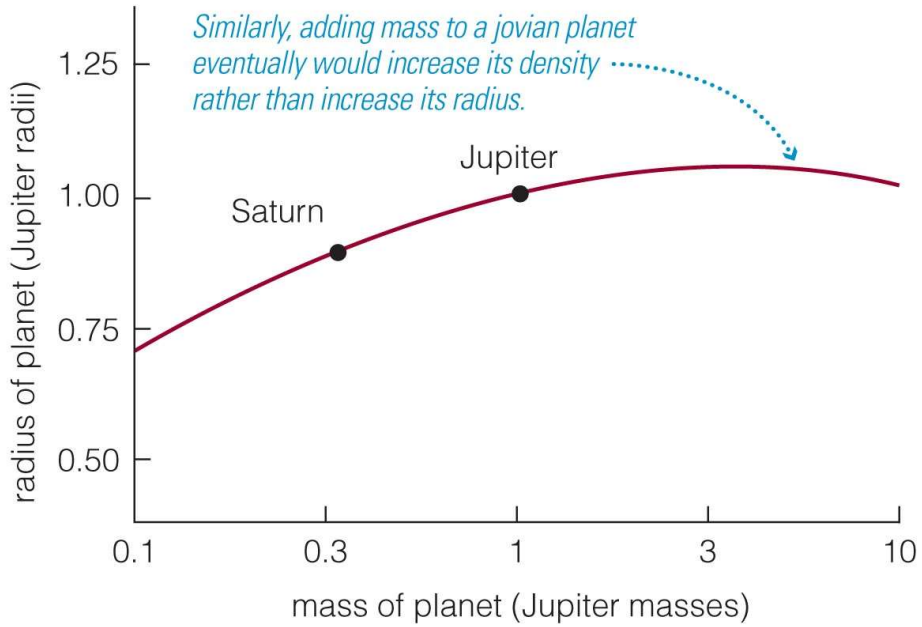


Density Differences



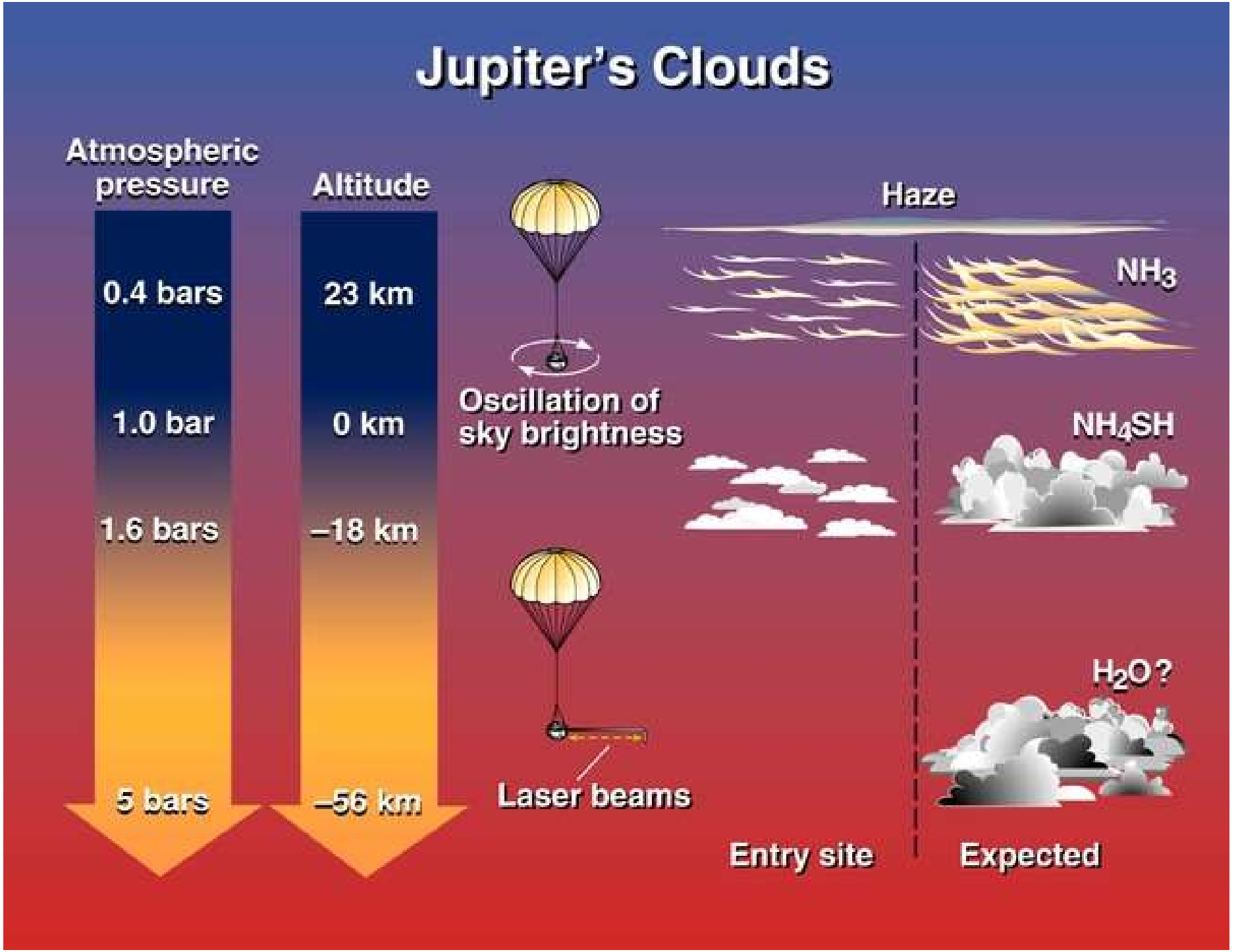
- Uranus and Neptune are denser than Saturn because they have less H/He, proportionately.
- Here, the units are such that the density of water is one.
- *What about Jupiter?*

Sizes of Jovian Planets

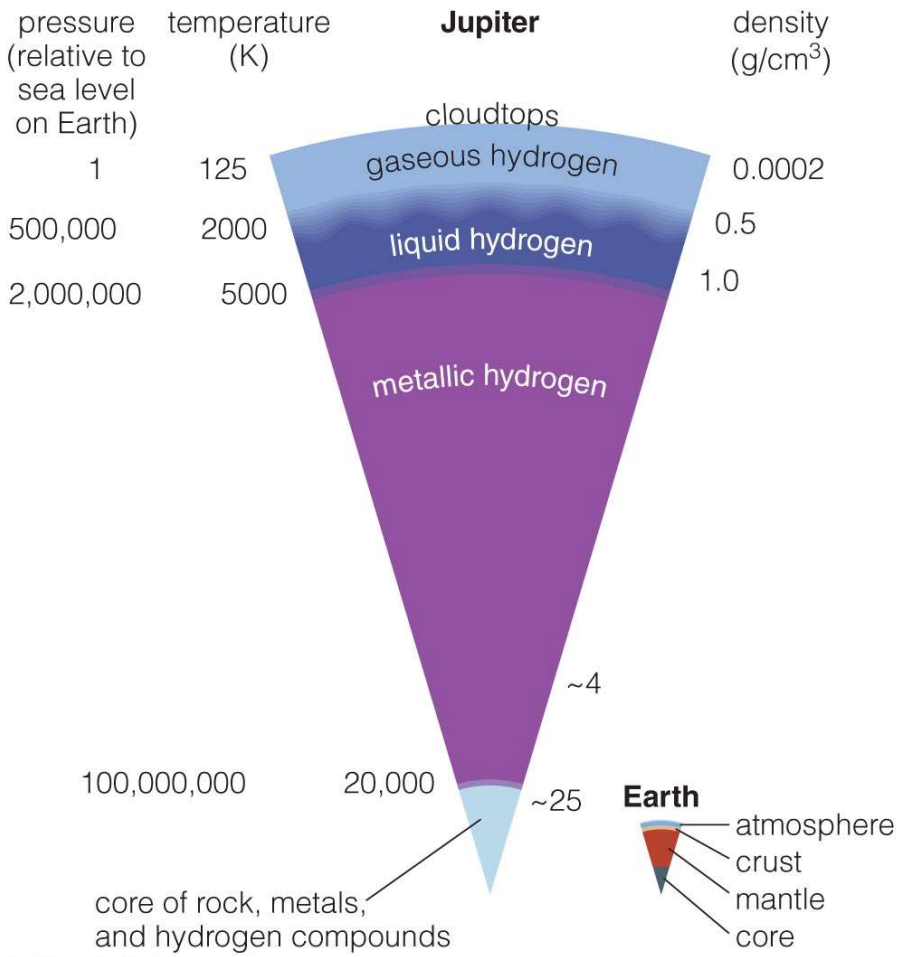


b This graph shows how radius depends on mass for a hydrogen/helium planet. Notice that Jupiter is only slightly larger in radius than Saturn, despite being three times as massive. Gravitational compression of a planet much more massive than Jupiter would actually make its radius smaller.

- As you add more mass, you compress the underlying gas layers
- Greater compression is why Jupiter is not much larger than Saturn, even though it is three times more massive.
- Jovian planets with even more mass can be smaller than Jupiter.

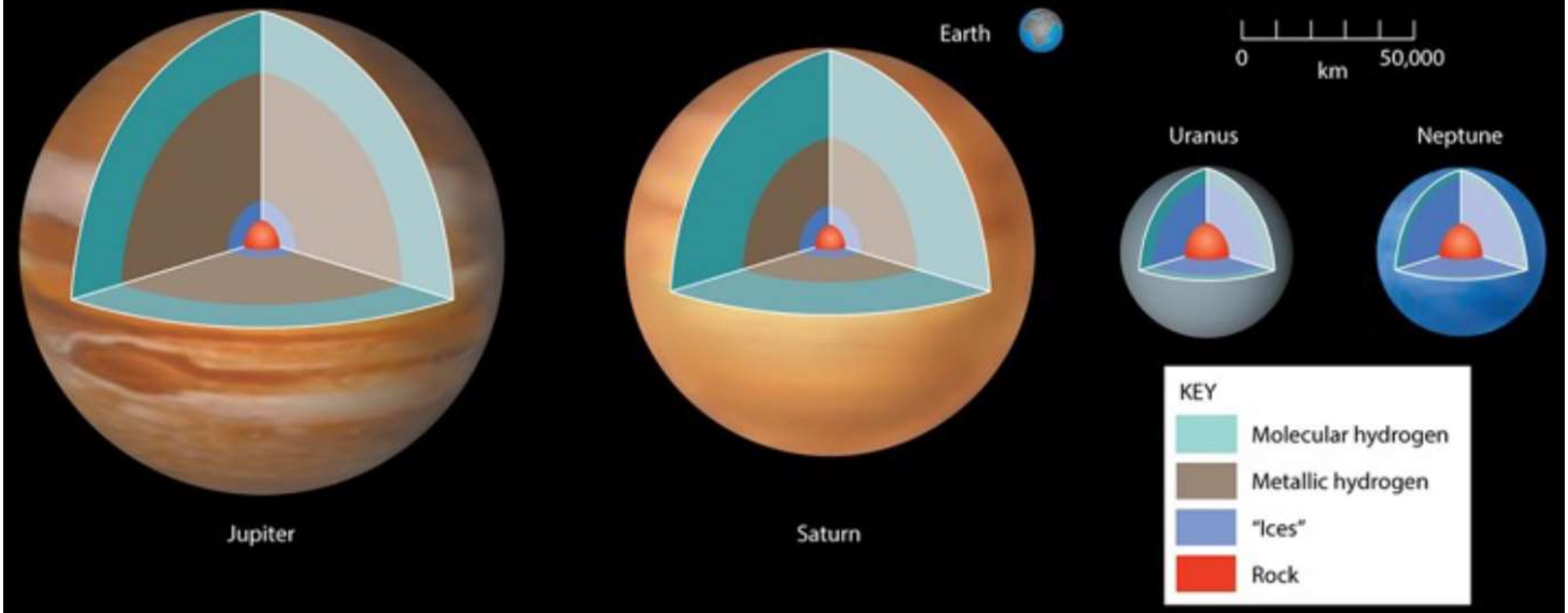

Jupiter's Clouds
Atmospheric pressure
Altitude
0.4 bars
23 km
1.0 bar
0 km
1.6 bars
–18 km
5 bars
–56 km
Oscillation of sky brightness
Laser beams
Haze
NH_3
NH_4SH
H_2O?
Entry site
Expected

Models of Jupiter's Interior



- High pressure inside of Jupiter causes the phase of hydrogen to change with depth.
- Hydrogen acts like a metal at great depths because its electrons move freely.
- ~30x the pressure of Earth's core & 4x the temperature

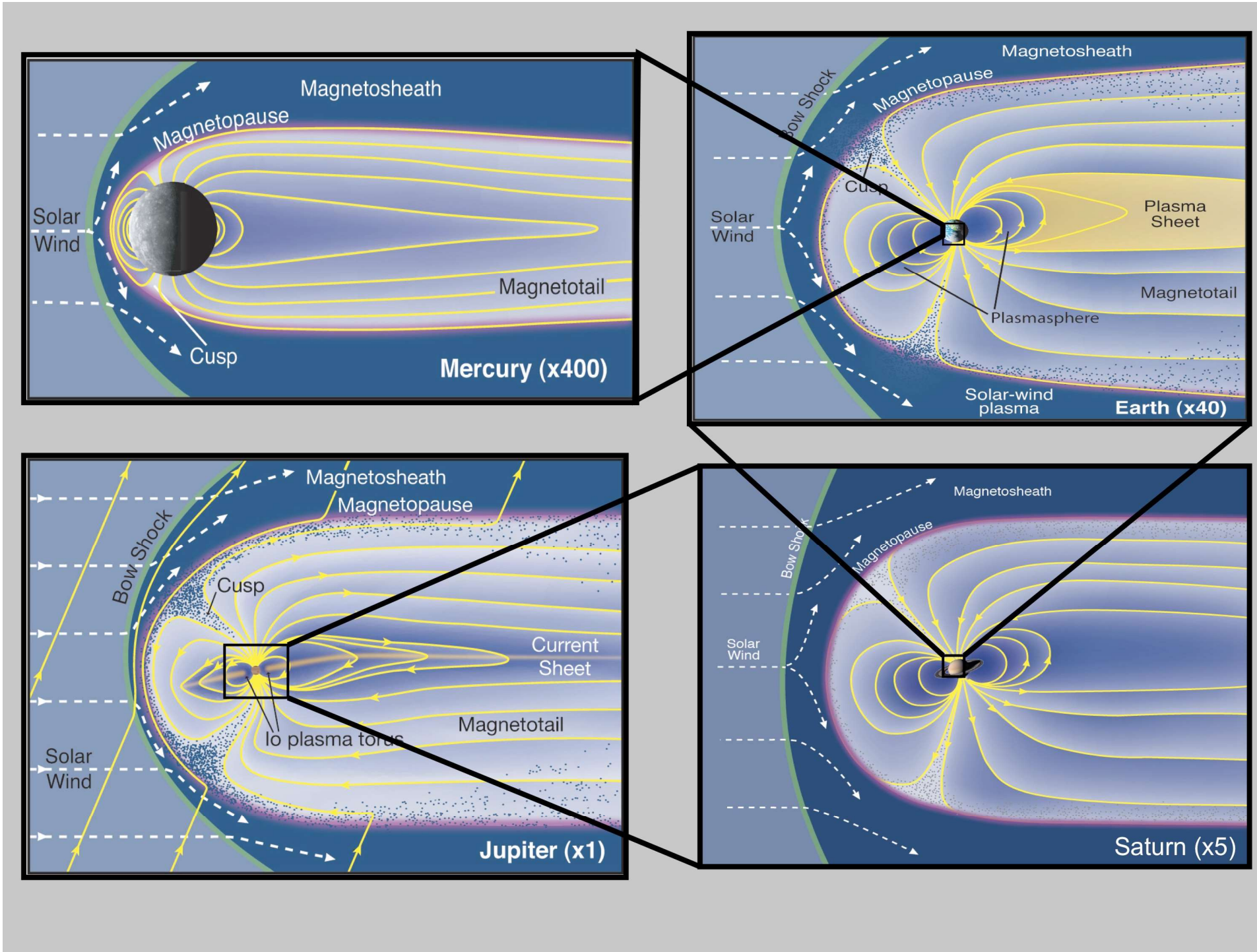
Models of Jovian Interiors



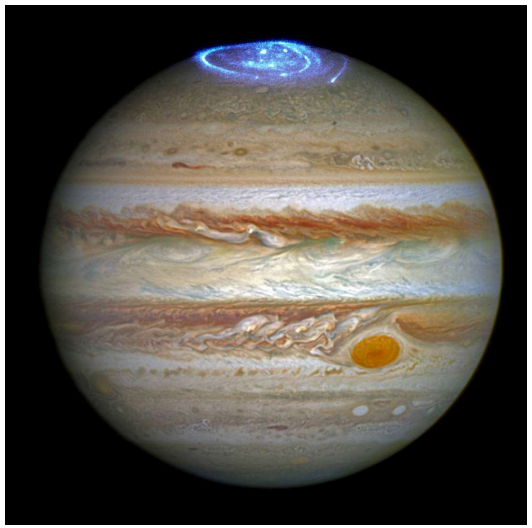
Thought Question

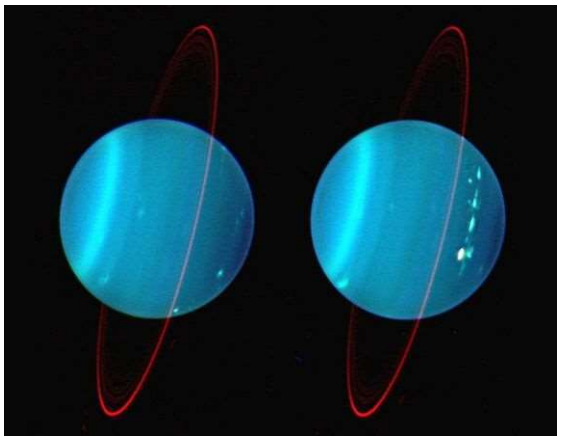
If Jupiter & Saturn have large amounts of liquid, metallic hydrogen, and are spinning very fast, what does that imply?

They have huge, very powerful magnetospheres

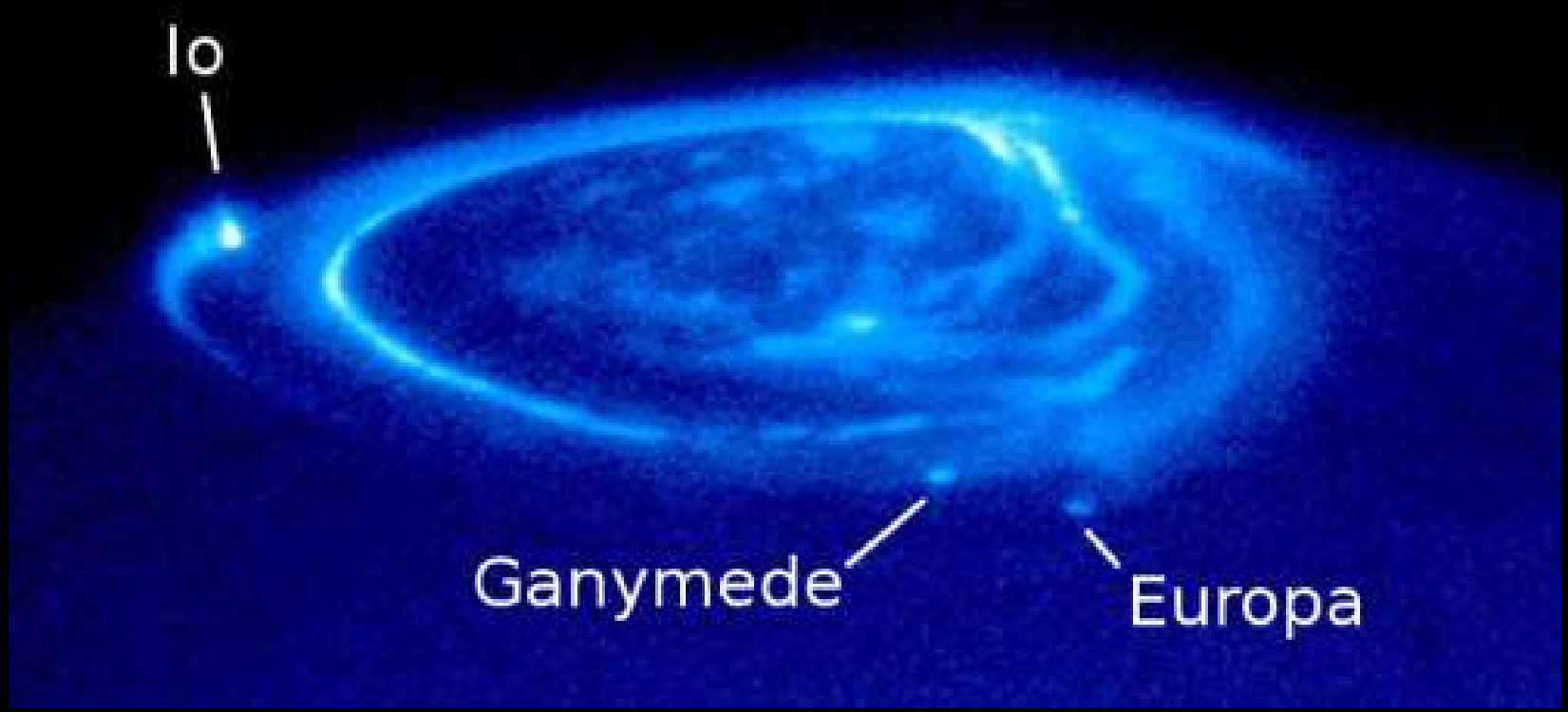

Magnetosheath
Magnetopause
Solar
Wind
Magnetotail
Cusp
Mercury (x400)
Bow Shock
Plasma
Sheet
Plasmasphere
Solar-wind
plasma
Earth (x40)
Current
Sheet
Io plasma torus
Jupiter (x1)
Saturn (x5)

Aurora's on the Jovian Planets

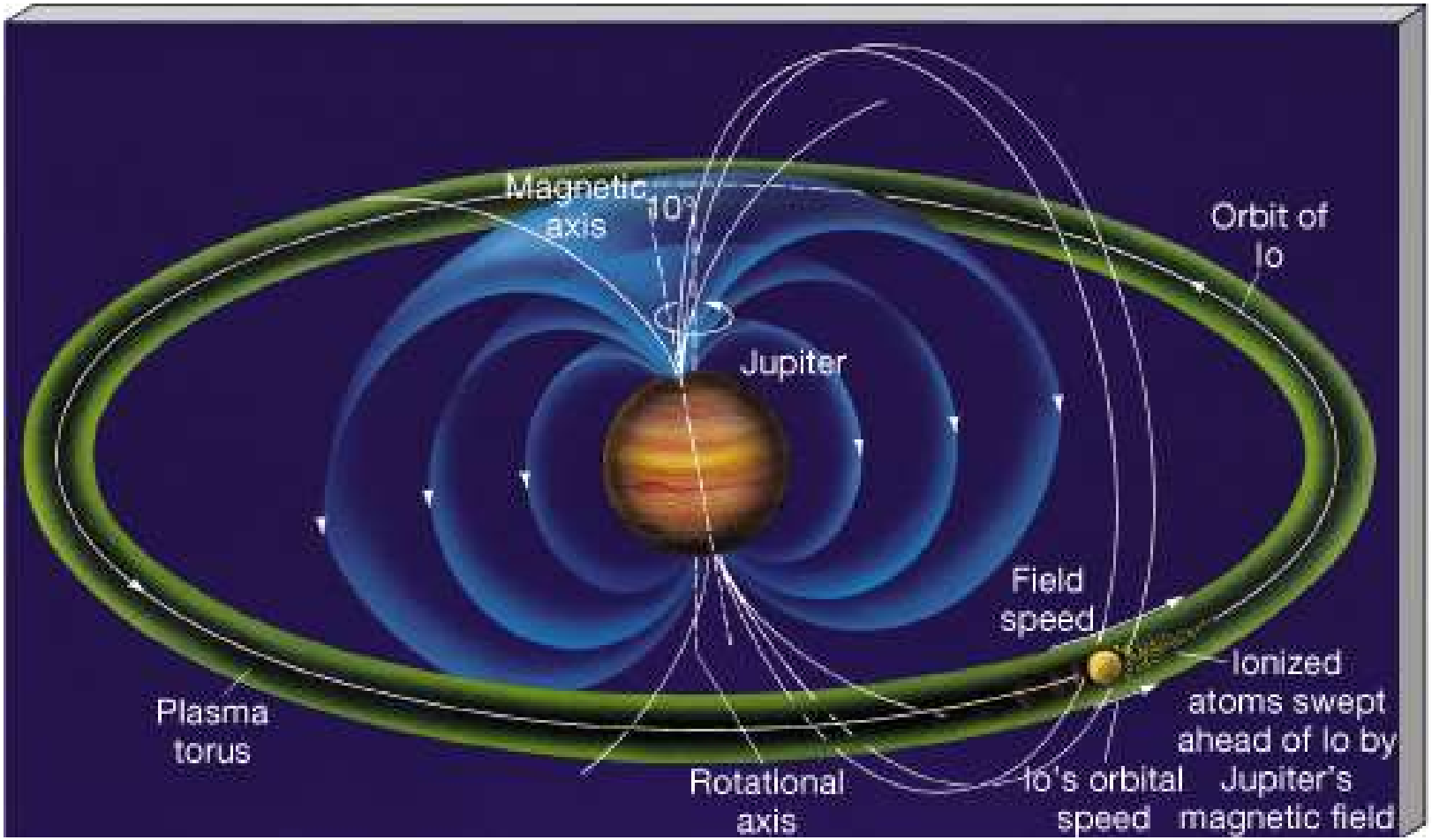




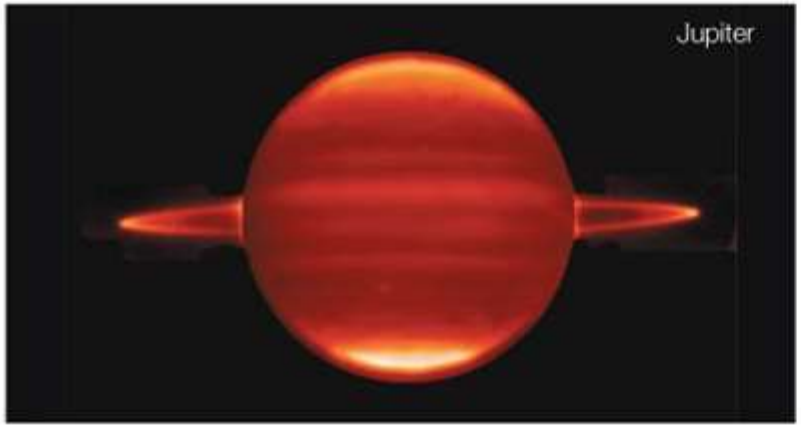
Jupiter's Aurora: A Closer Look

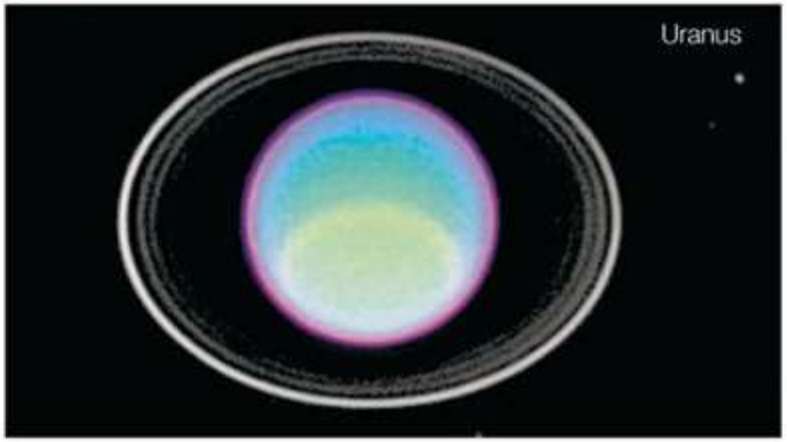


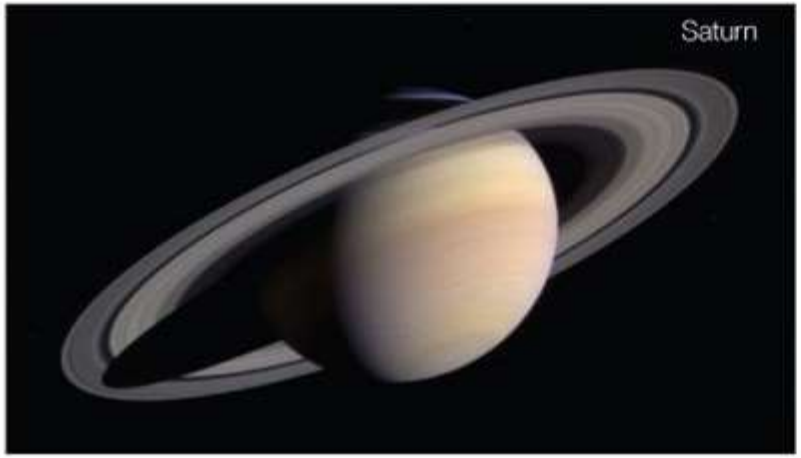
The Connection Between the Magnetosphere and The Galilean Satellites

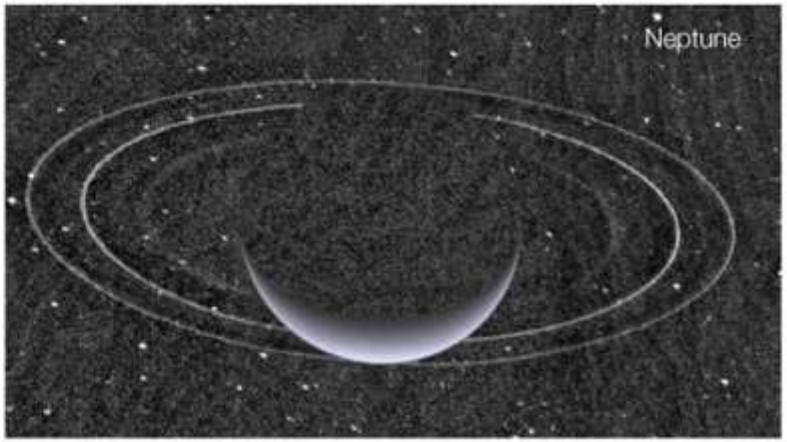


Rings of Jovian Planets



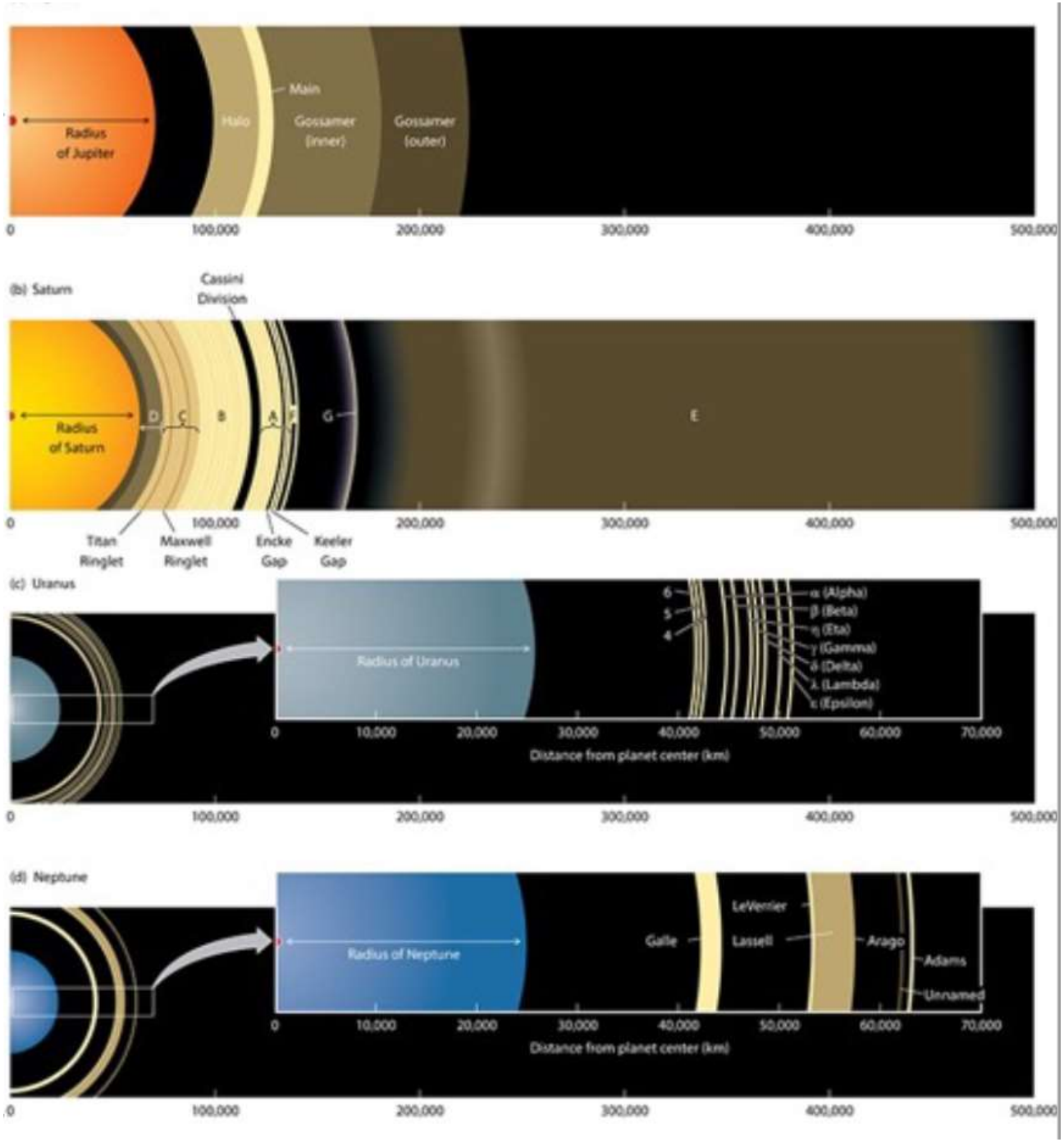






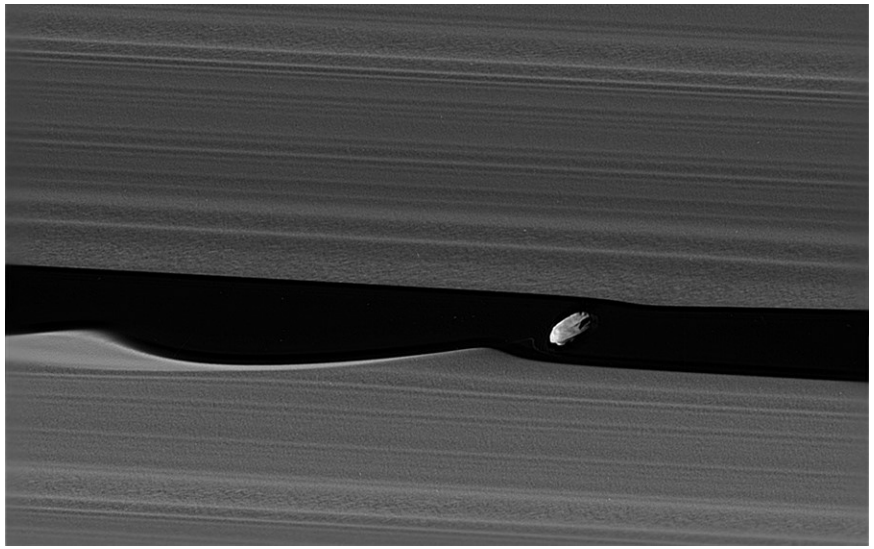
Rings

- 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)



Saturn's Rings are VERY Thin

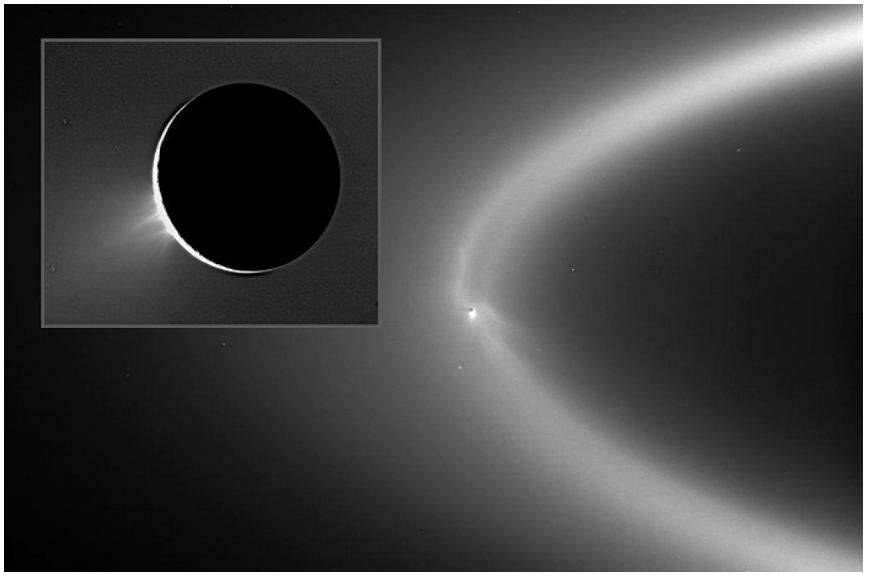
Shepherd Moons & Enceladus



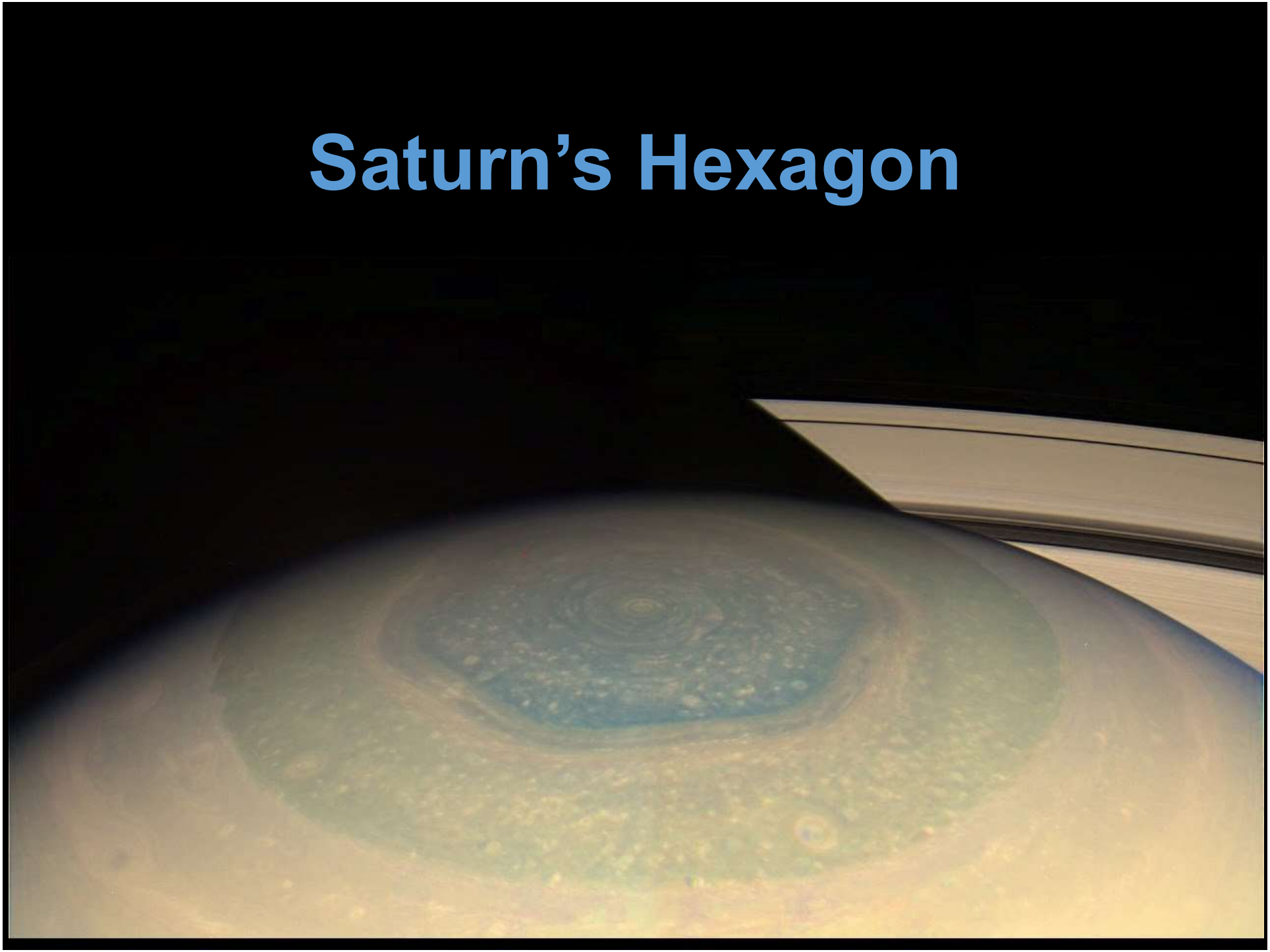
Some gaps are caused by Shepherd moon's

(Here Daphnis)

The diffuse E-ring is formed from plumes coming from Enceladus



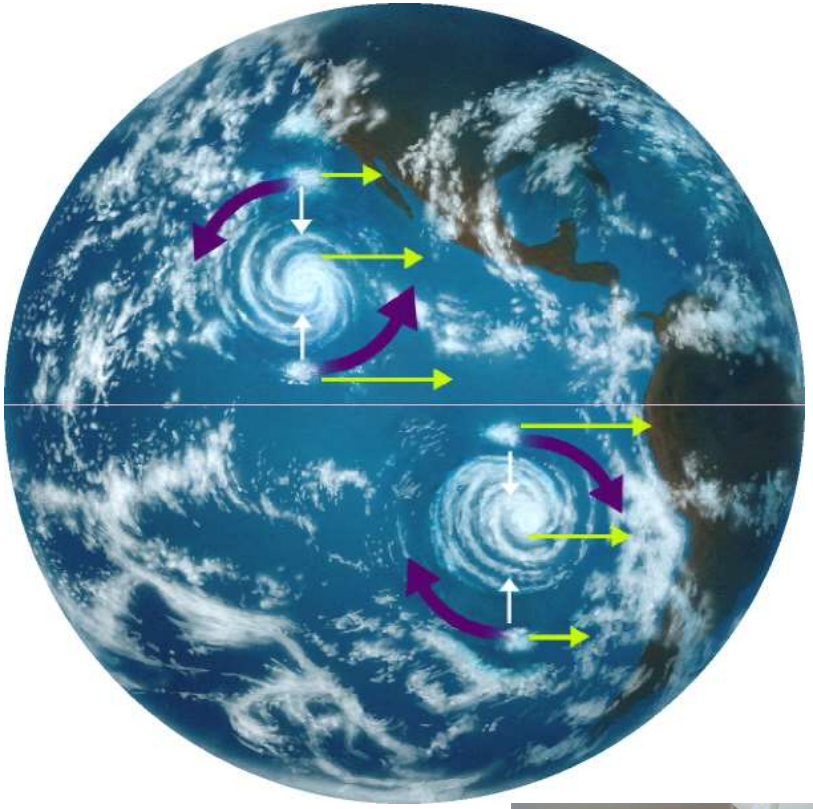
Saturn's Hexagon



Jupiter's Big Red Spot

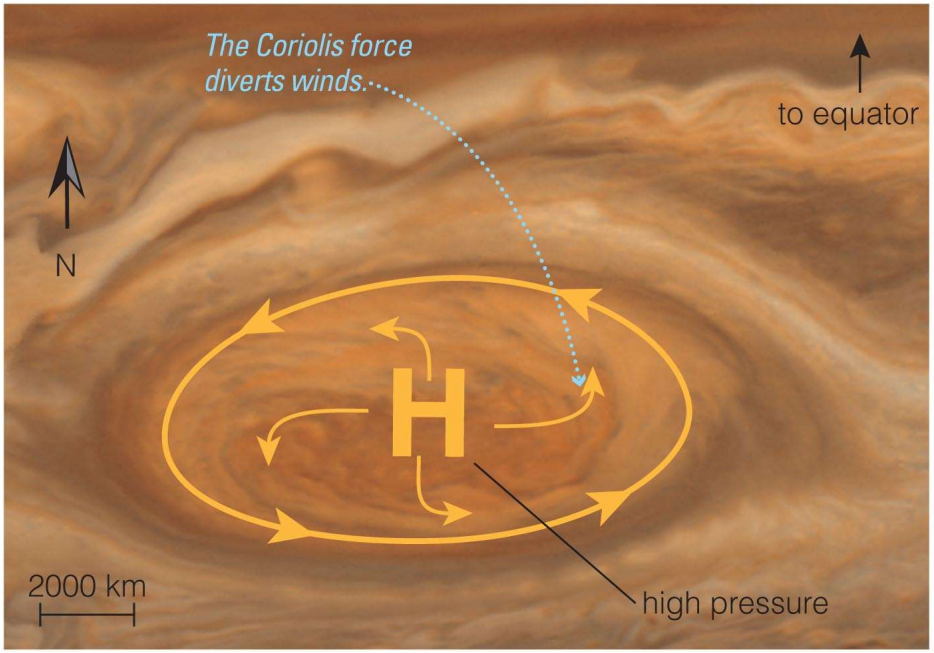
- Storm system that has been active over 300 years
- Could fit 2-3 Earth's inside it

Coriolis Forces

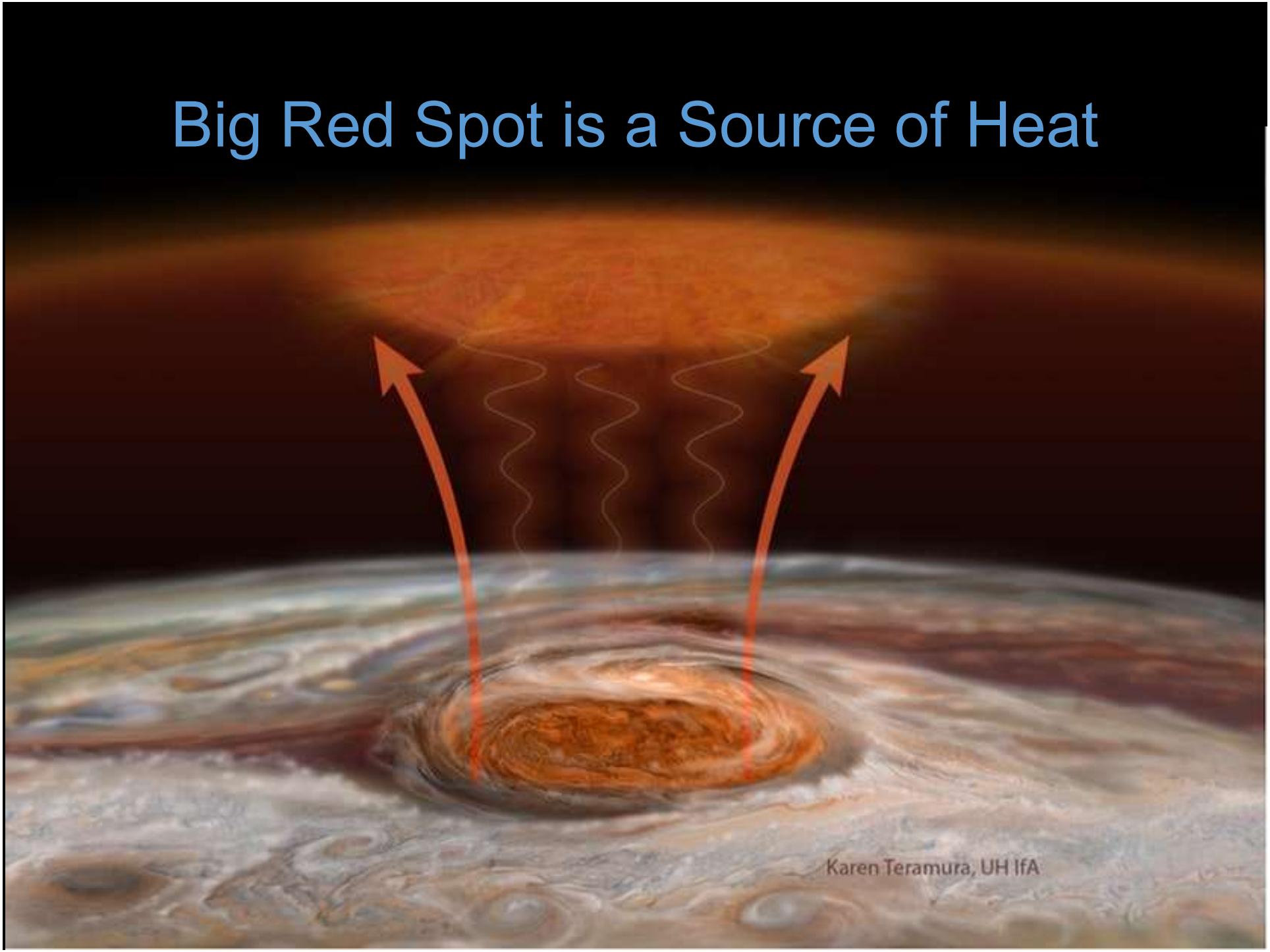


- Caused by the fact that different latitudes of the Earth are traveling at different speeds
- Storms on Earth are due to movement of air from high pressure to low pressure

No. not responsible for toilets flushing in different directions

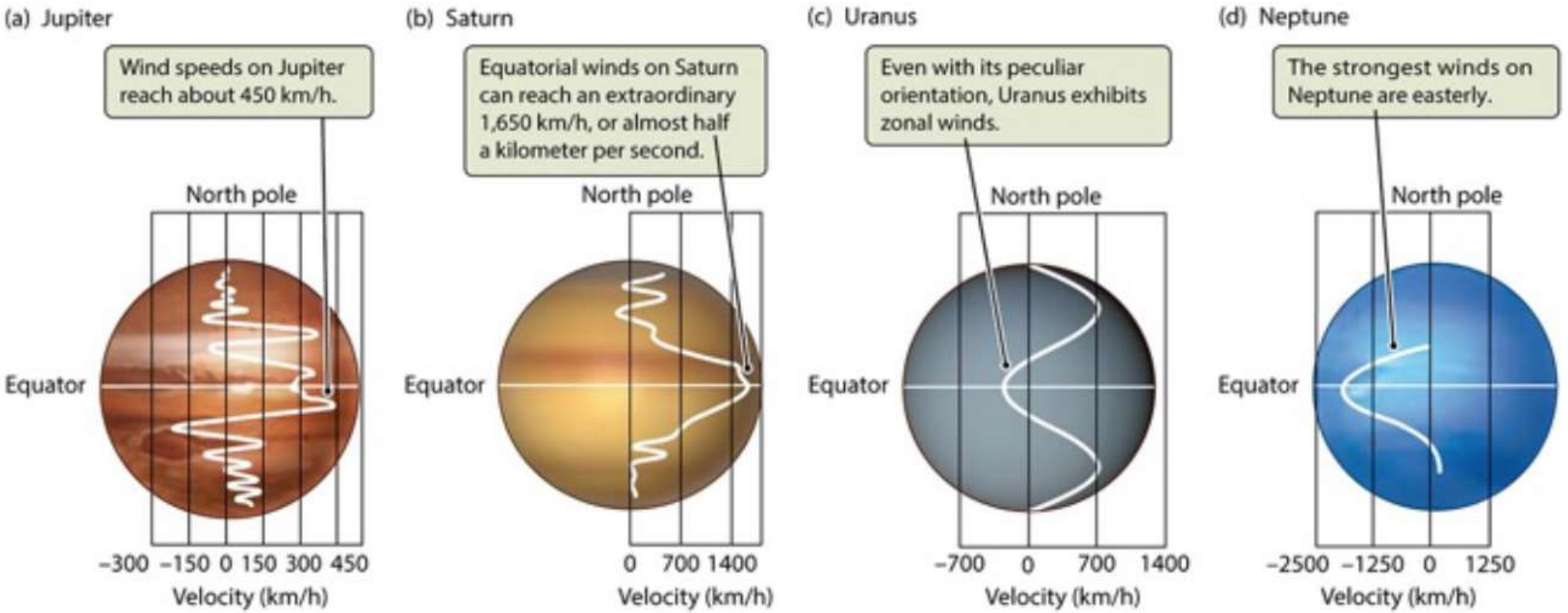


Big Red Spot is a Source of Heat

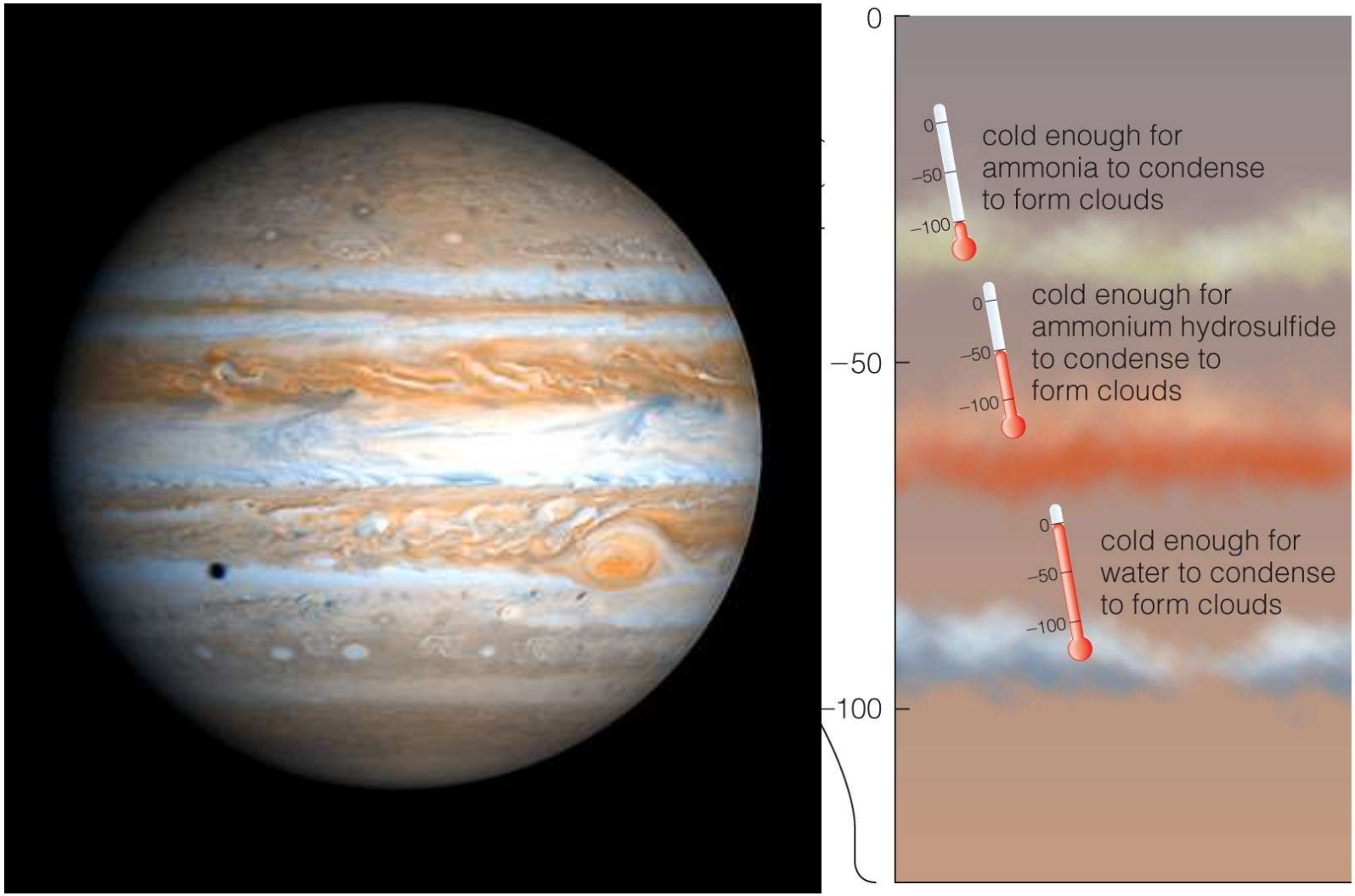


Jovian Planets: Extreme Wind Speeds

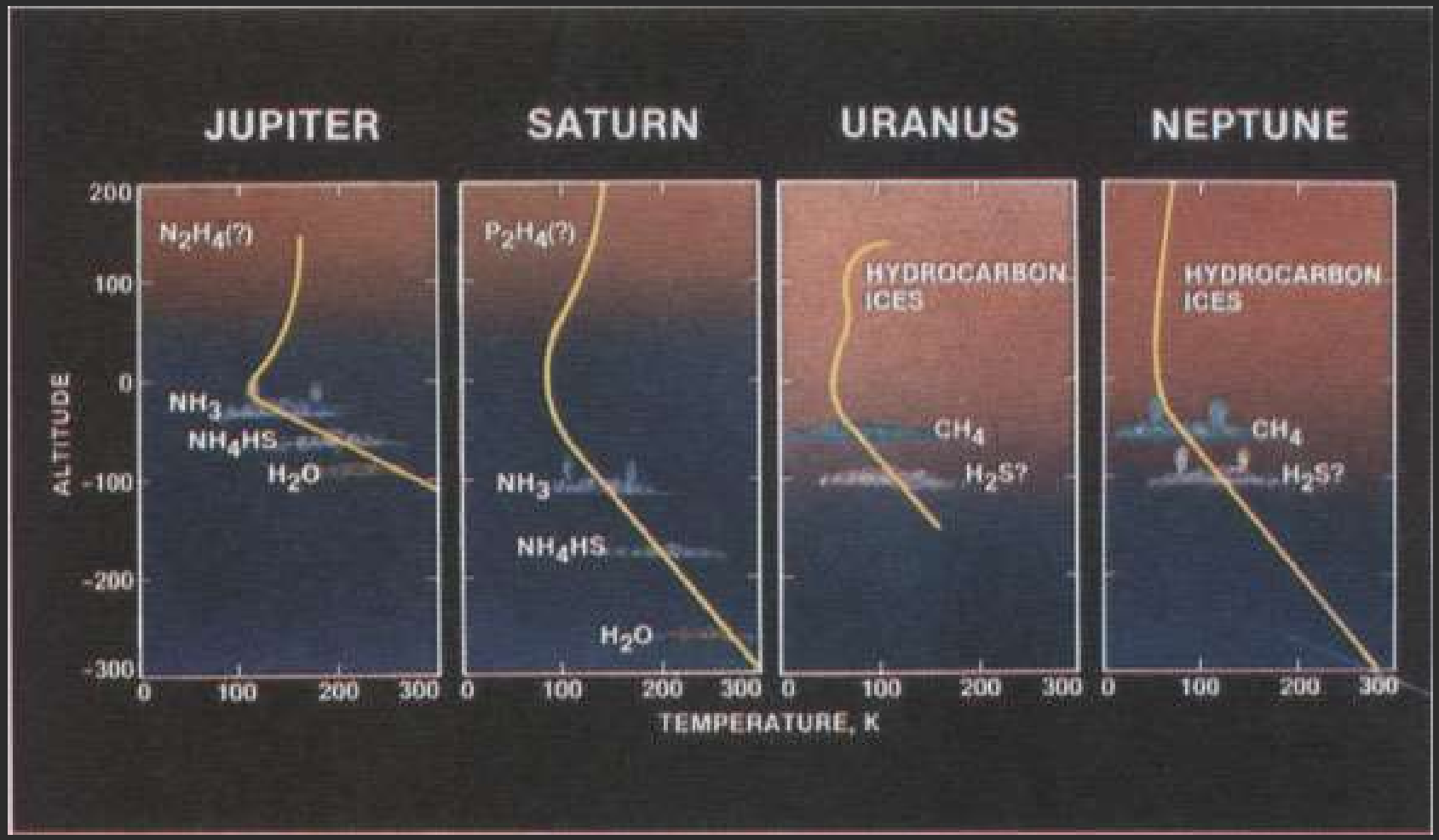
- These planets all rotate VERY fast
- Winds observed can be over 1600 km/hr



Composition of Jupiter's Bands



Compositions of Jovian Atmospheres



The latest images of Jupiter from Juno are stunning!

End of Todays Lecture