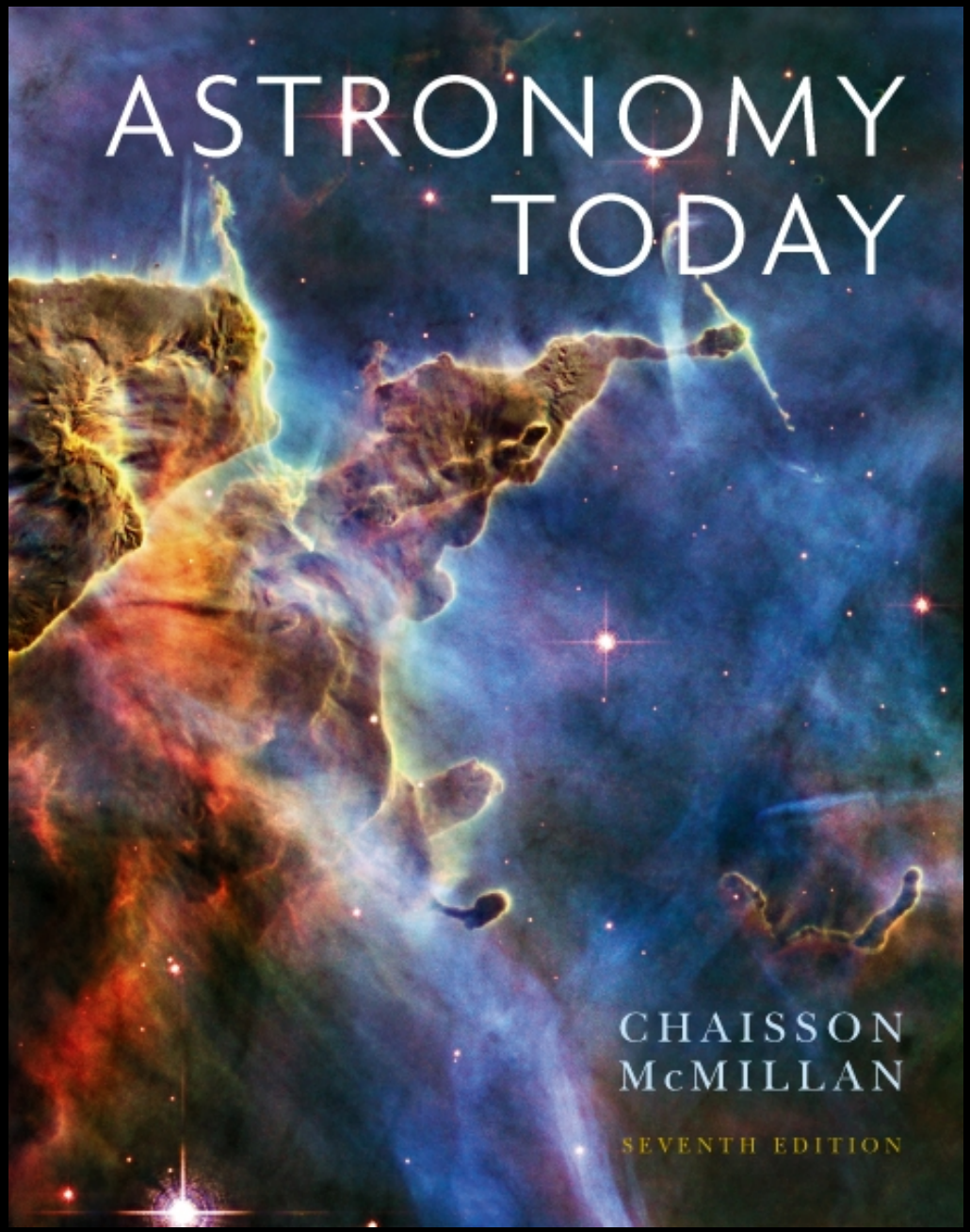


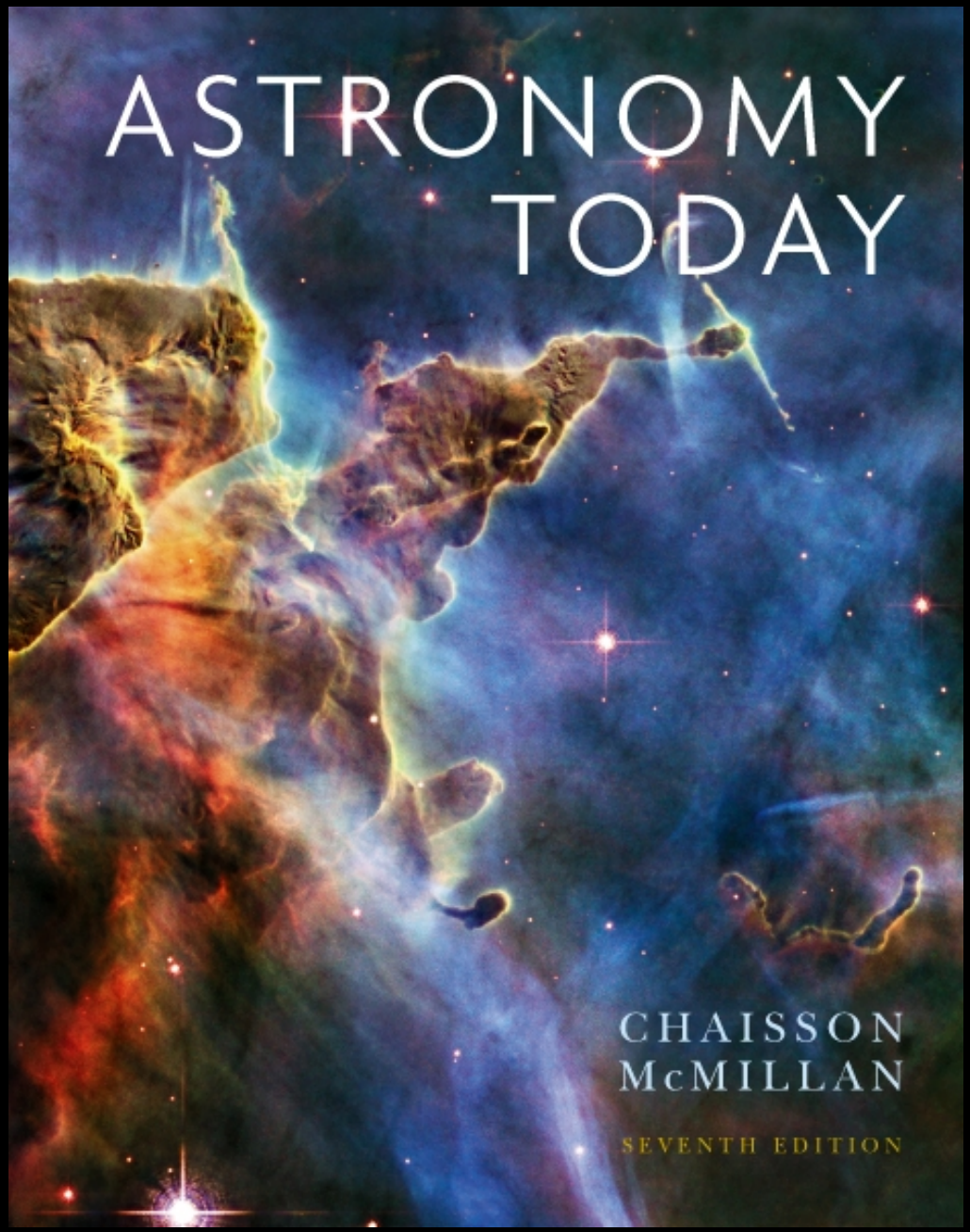
Lecture Outlines

Chapter 11-13

Astronomy Today

7th Edition

Chaisson/McMillan



Lecture Outlines

Astronomy Today

7th Edition

Chaisson/McMillan

Units of Chapter 11-13

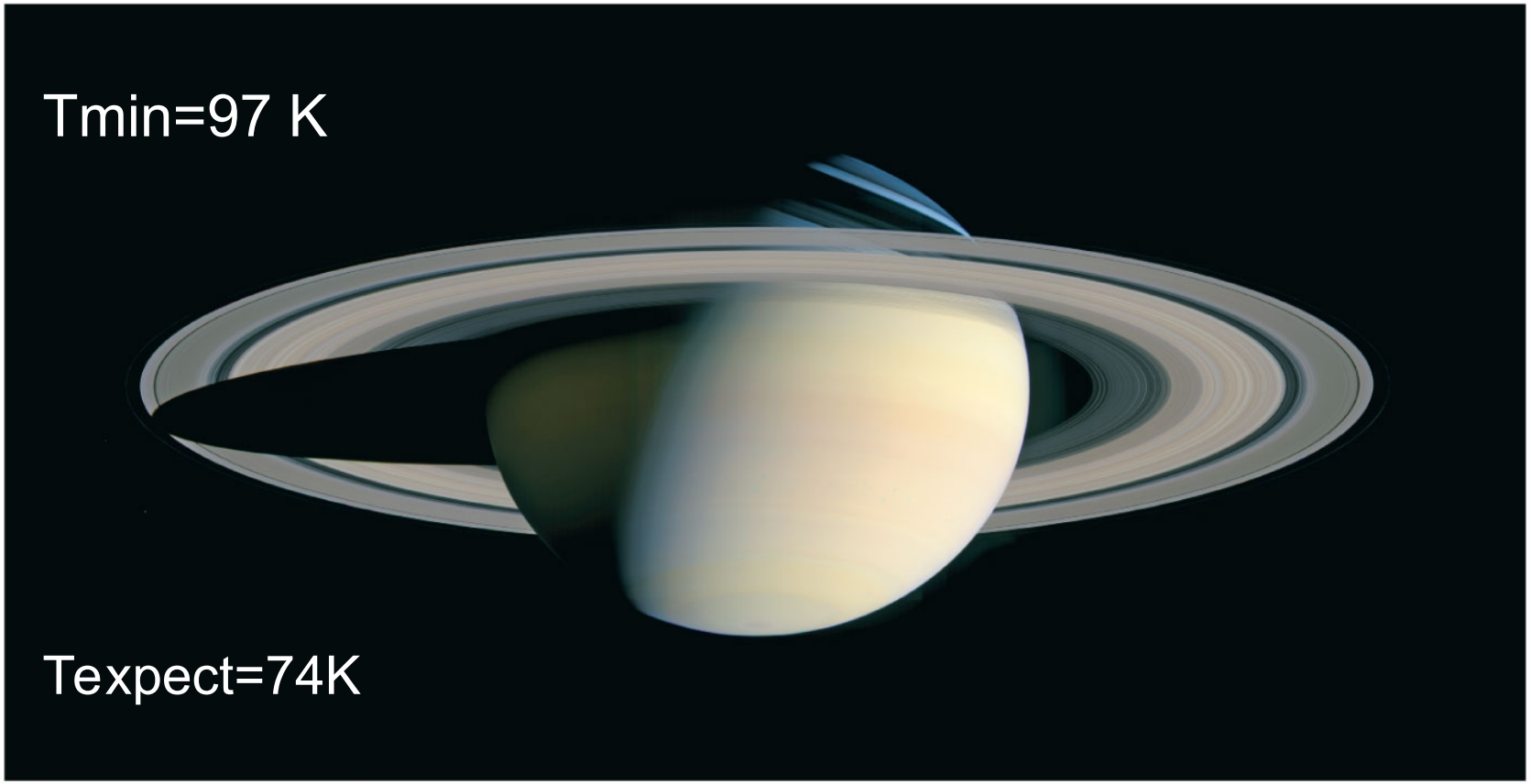
1. Portraits and cloud top temperatures
2. Orbital and Physical Properties skip
3. Compare internal structures light
4. Compare Atmospheres Mostly Jup
5. Compare the Moons Mostly Saturn
6. Compare the Rings Mostly Saturn

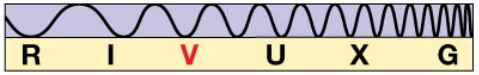
Chapter 11-13
Comparing the Jovians

Tmin=125 K

Texpect=105 K

Chapter 11-13
Comparing the Jovians

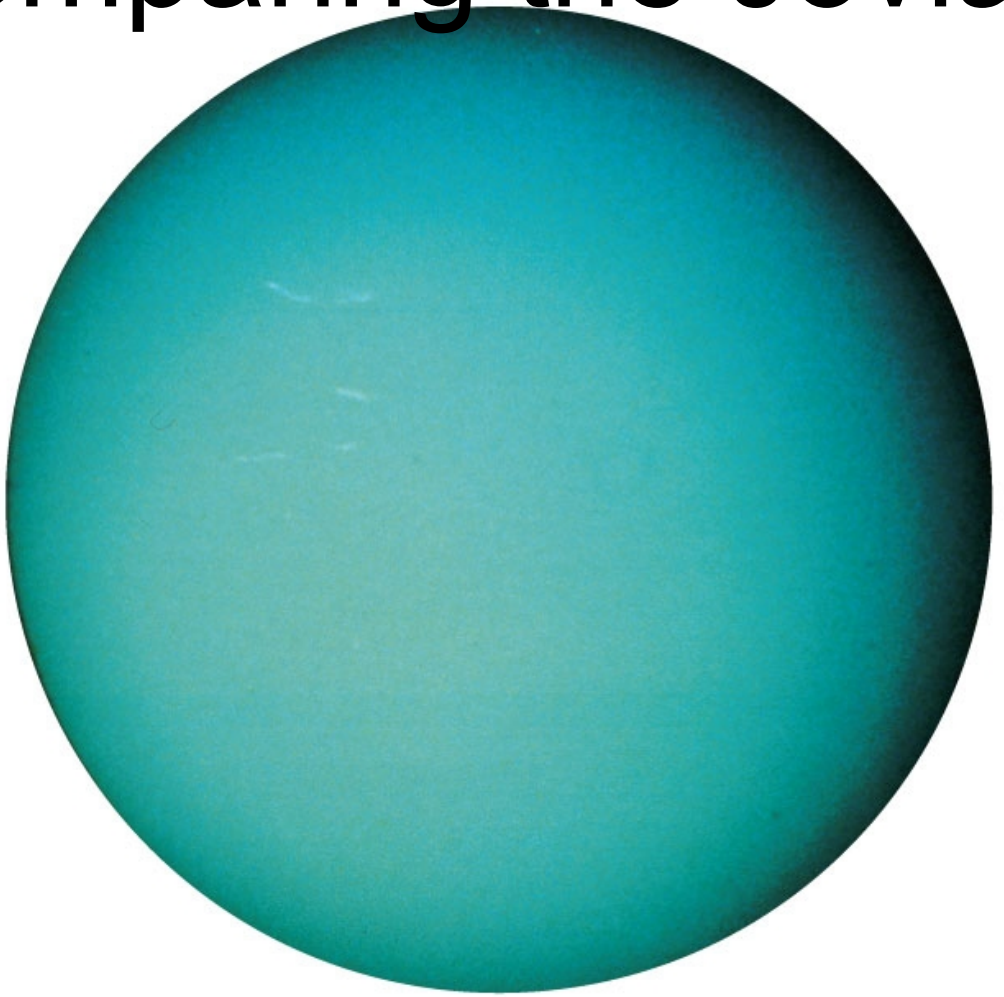


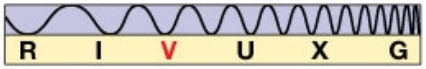


Chapter 11-13
Comparing the Jovians

Tmin=58 K

Texpect=58 K

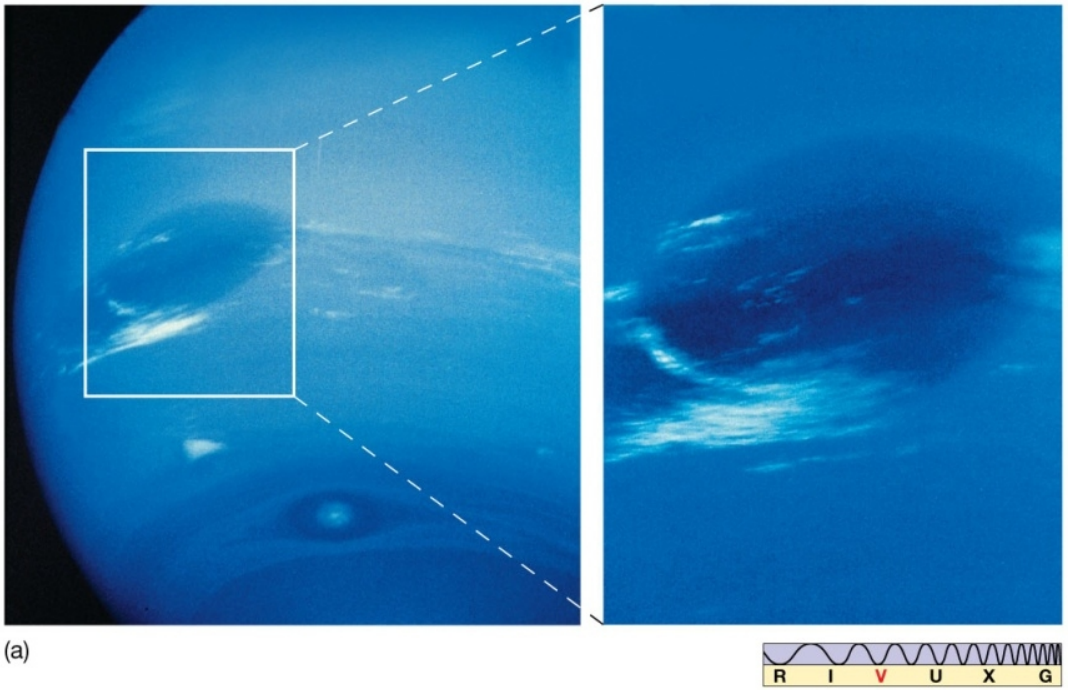


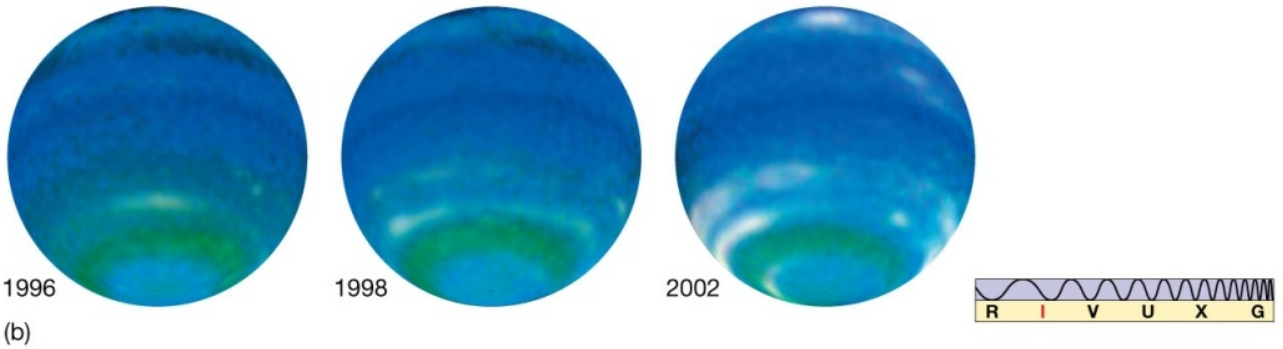


Chapter 11-13
Comparing the Jovians

Tmin=59 K

Texpect=46 K





Condensation and freezing points of gases

T_{BP}=T_boiling = T_condensation. Gas<->liquid.

T_{FP}=T_freezing = T_sublimation/evaporation. Gas<->Solid.

These temperatures assume P=1 atm

Gas	Gas,name	T_{BP} K	T_{BP} ºC	T_{FP} K	T_{FP} ºC	T_{FP} ºF
H_20	Water vapor	373 K	100 ºC	273 K	0 ºC	32 ºF
H_2	Hydrogen	20	-253	14	-259	-434
He	Helium	4	-269	1	-272	-458
N_2	Nitrogen	77	-196	63	-210	-346
O_2	Oxygen	90	-183	55	-218	-360
NH_3	Ammonia	240	-33	195	-78	-126
CH_4	Methane	113	-161	91	-182	-296
NH_4SH	Am.Hydrosulfide	330	57	<195?	?	?

86%
13.8%
Jupiter


= clouds on Jupiter, Saturn, Nept, Uranus


= clouds on Nept, Uranus

Cloud layers of Jupiter

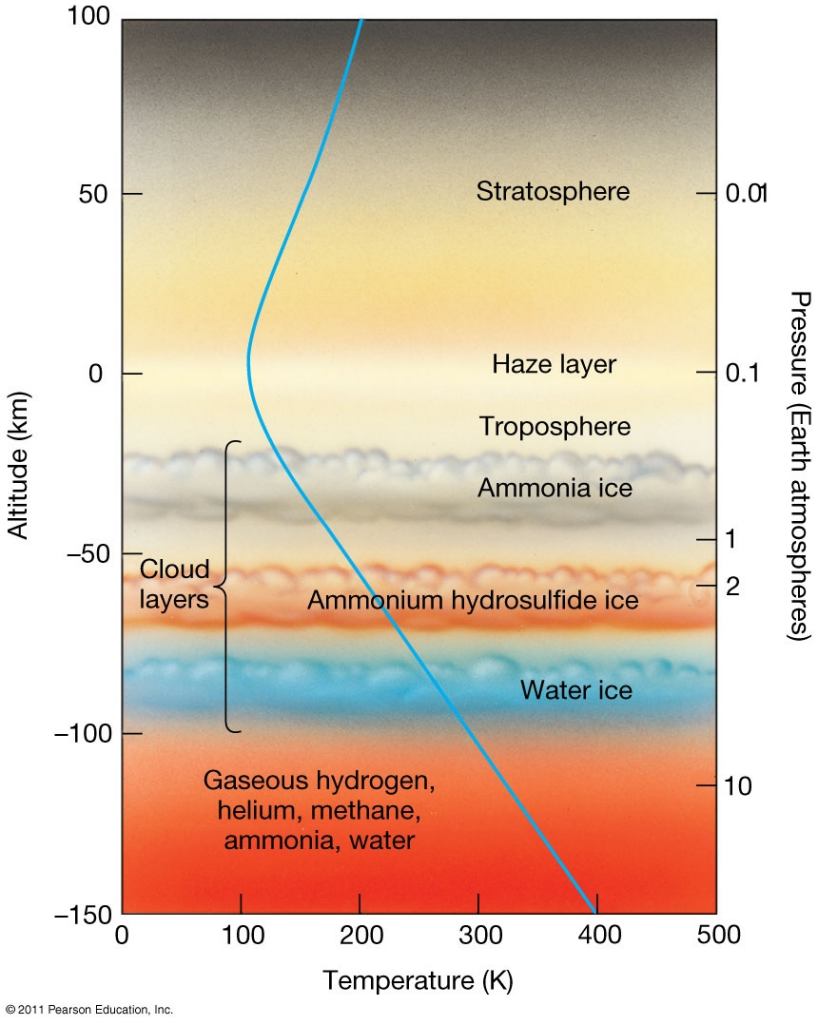
No clouds of H or He.

Methane could form drops (T_{BP} = 113K), but P < 1 atm. CH_4 more important on other Jovians.

White → ammonia ice T_{FP} =195K

Orange → $(NH_4)HS$ T_{FP} <330K

Blue → H_20 ice T_{FP} =273 K



Cloud layers of Saturn

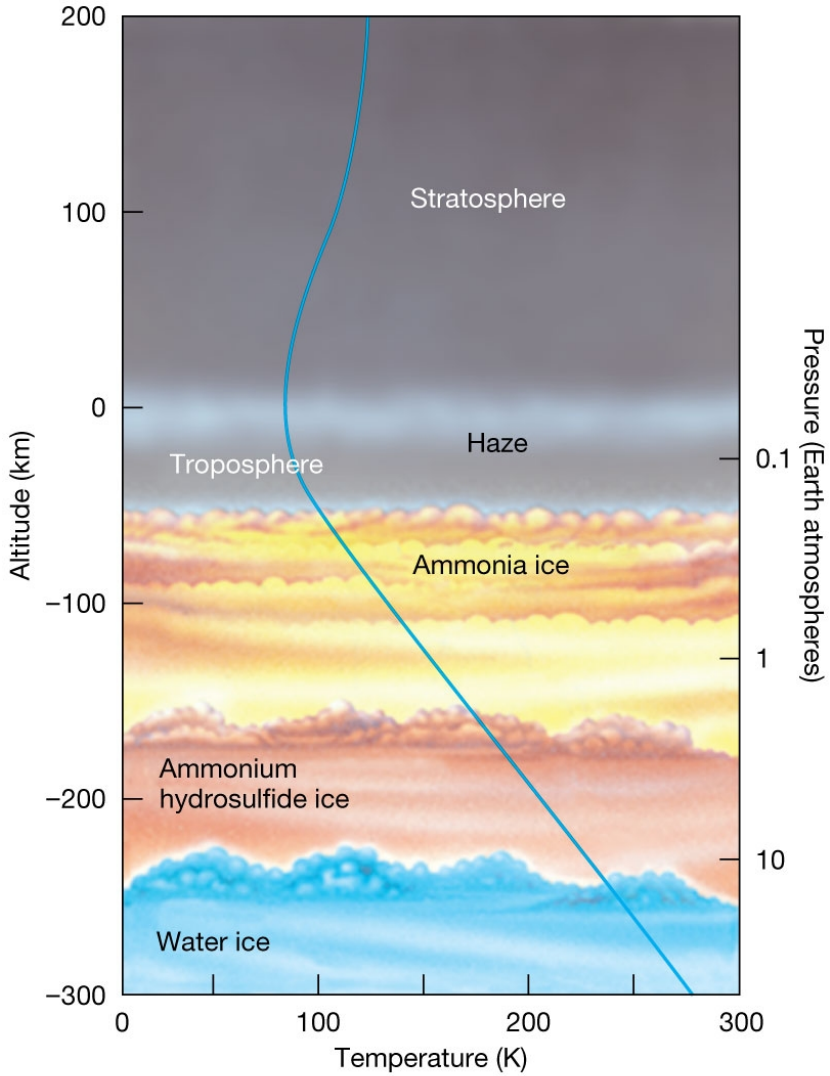
The same types of clouds seen on Jupiter exist on Saturn, but they are more spread out vertically. Why?

Scale height, H=kT/mg, so it's because g is smaller on Saturn.

H_{Jup} = 27 km g=26 m/s^2

H_{Sat} = 60 km g=11 m/s^2

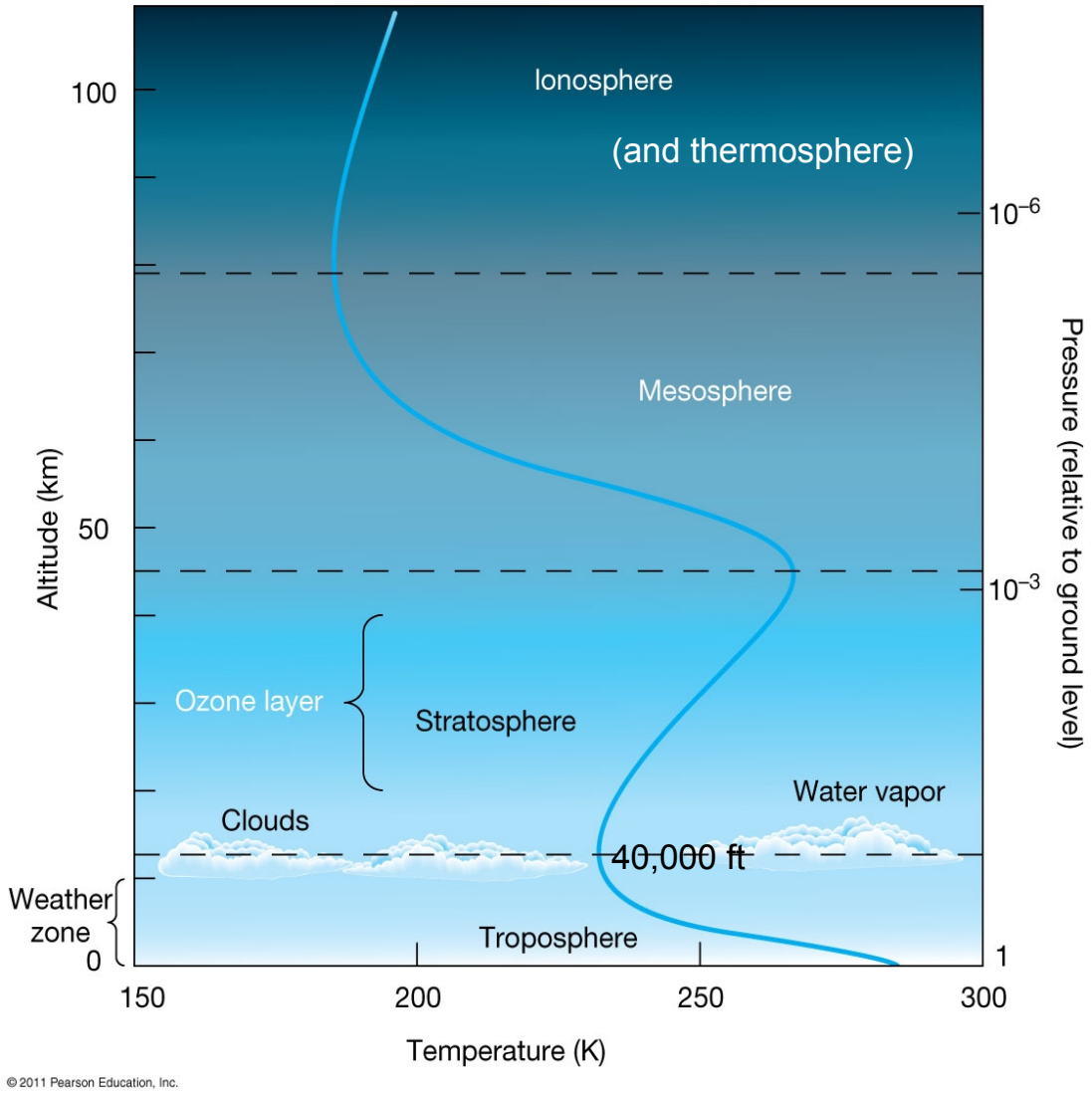
H_{Earth} = 8.5 km g=9.8 m/s^2



7.2 Earth's Atmosphere

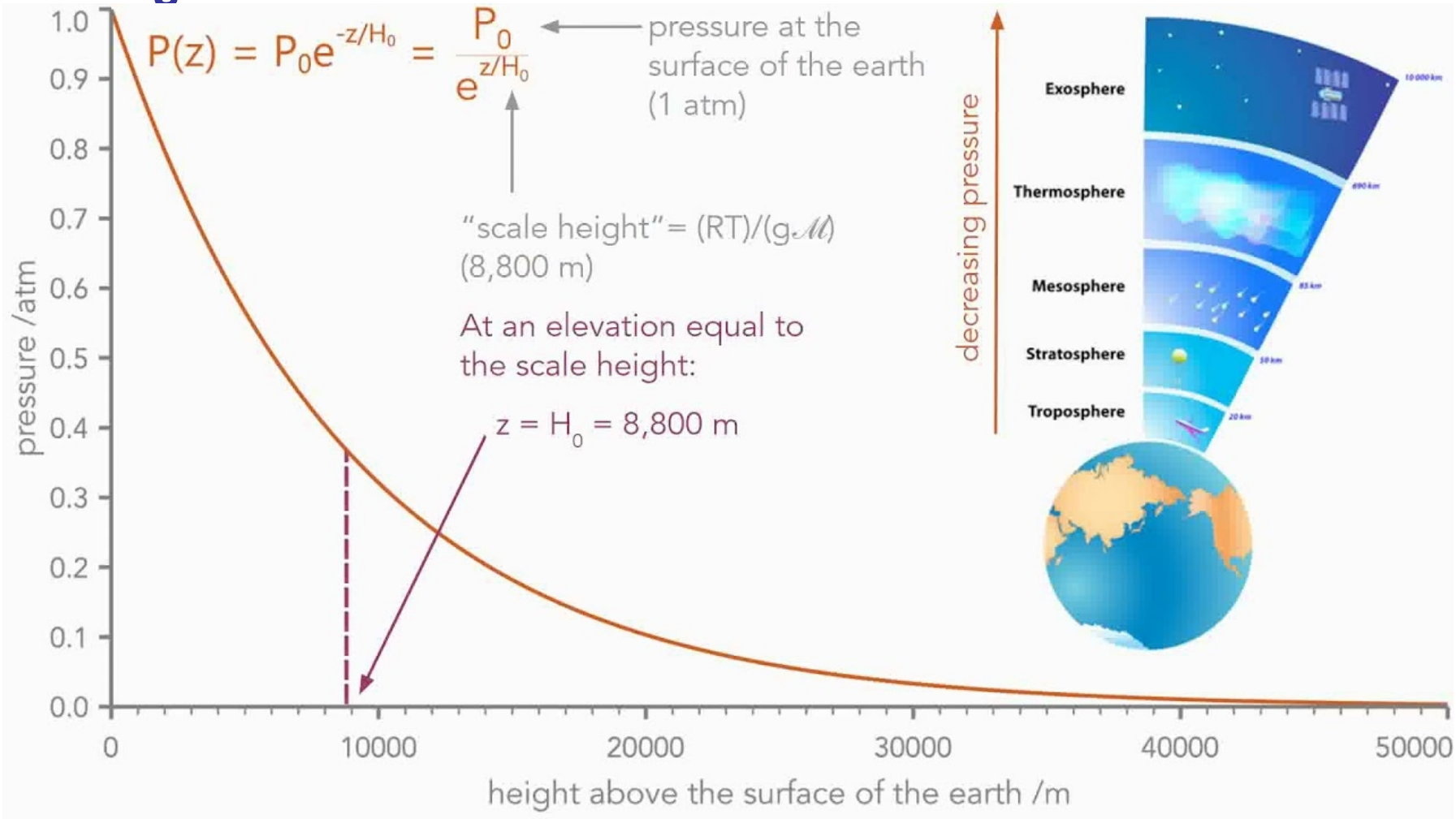
- **Only 12 km tropopause.**

•Scale height of Earth's atmosphere is ~8.5 km.



7.2 Earth's Atmosphere

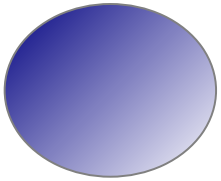
- ***Scale height*** **is the increase in height in an atmosphere that causes the pressure (and density) to decrease to 36.8% of the starting value.**



3. Internal Structures

Although we can't see through the atmospheres of the Jovians, we can use the orbits of our spacecraft to figure out the internal mass density distribution.

They are *oblate spheroids* because of rapid rotation.

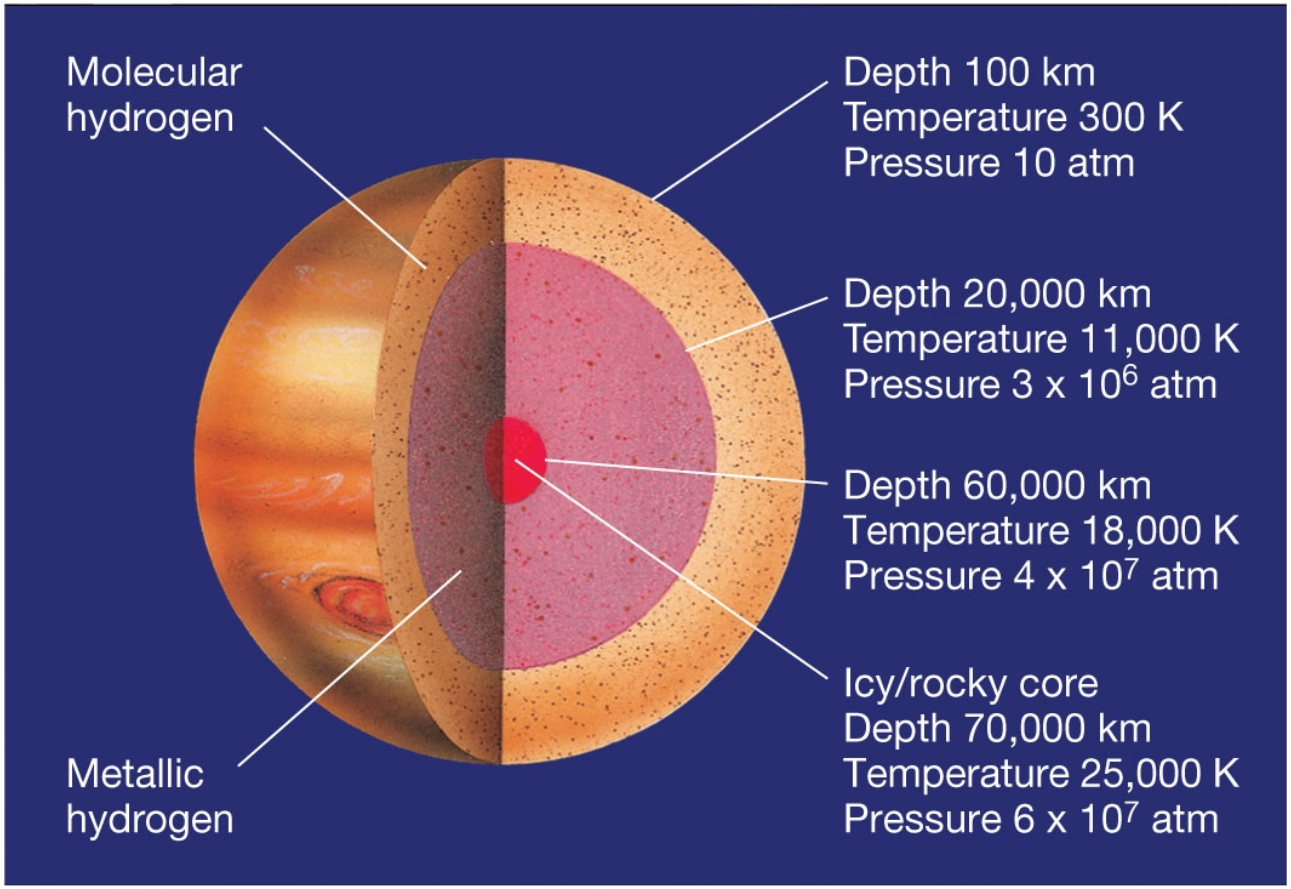


They are generally azimuthally symmetric, but not spherically symmetric. Degree of oblateness suggests denser cores than if made of only H and He.

3. Internal Structures

The internal layers are based on changes in phase and molecular form of hydrogen and helium. (Behavior of H and He known from lab and atomic theory.)
The center is probably a dense "rocky" core.

Jupiter



3. Internal Structure - Jupiter

Jupiter radiates more energy than it receives from the Sun:

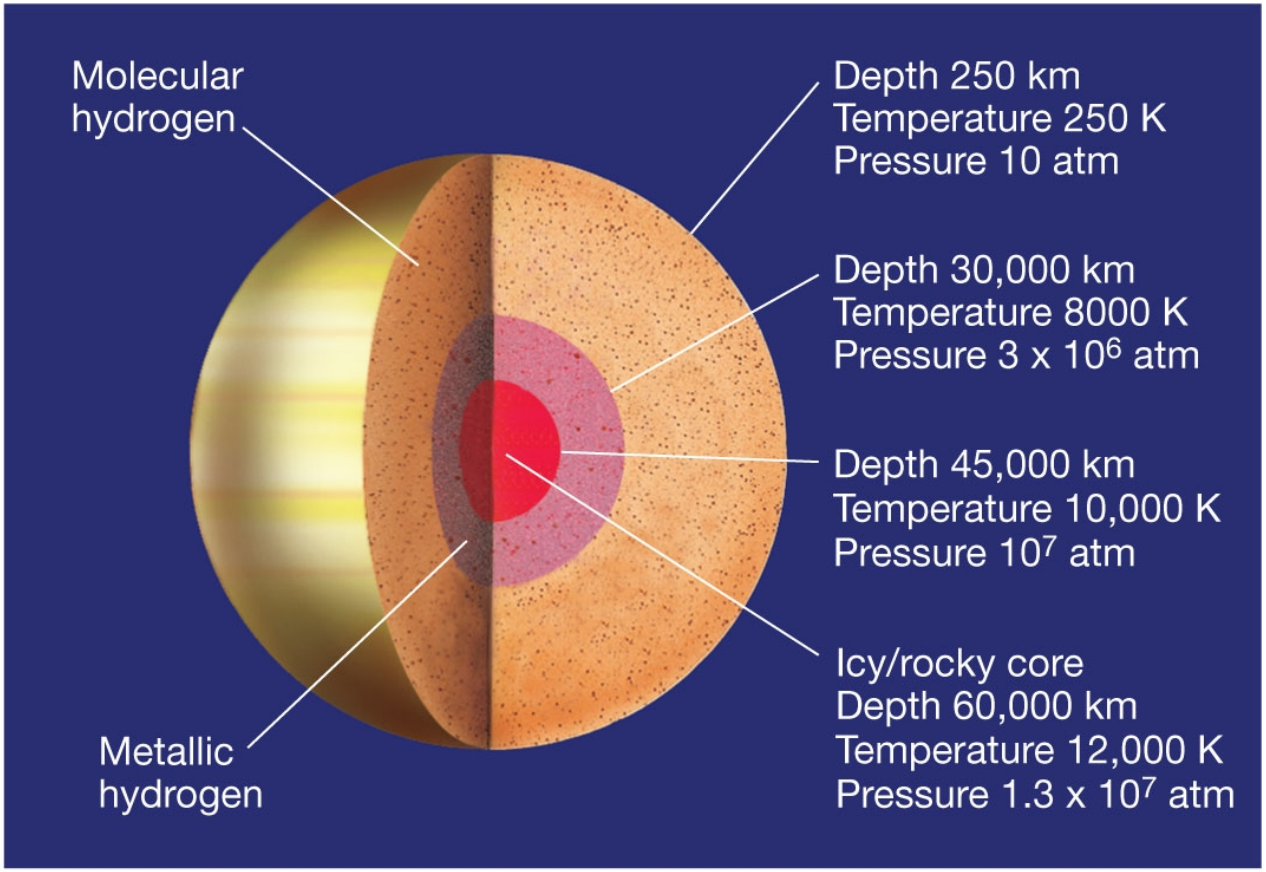
- Core is still cooling off from heat of gravitational contraction

Q: Could Jupiter have been a star?

- No; not dense and hot enough at the core for H fusion. It would need to be about 80 times more massive to be even a very faint star.
- Brown dwarfs have M<~ 0.08 $M_\odot$ - below fusion limit.
- Jupiter has M~0.001 $M_\odot$

3. Internal Structures - Saturn

Interior structure similar to Jupiter's



3. Internal Structure - Saturn

Saturn also radiates more energy than it gets from the Sun, but it's not just the residual heat of collapse. It is ...

Helium rain: helium tends to condense into droplets and then fall.

- Gravitational energy converts into thermal energy as the mass descends and collides with other matter.

- Atmosphere is now noticeably depleted of He.

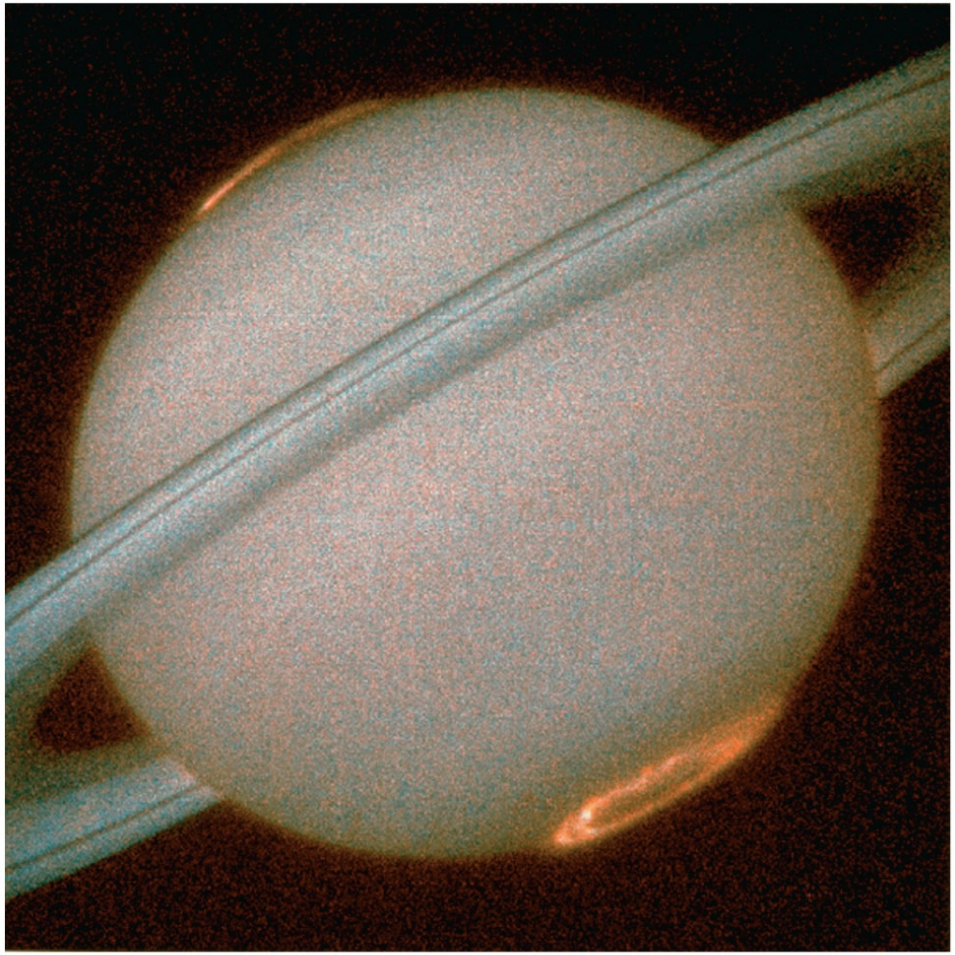
3 Internal Structures - Saturn

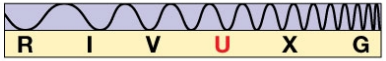
Saturn also has a strong magnetic field, but only 5% as strong as Jupiter's.

Suggests interior rotation of 10^h46^m.

Almost no tilt relative to spin axis.

Creates aurorae.

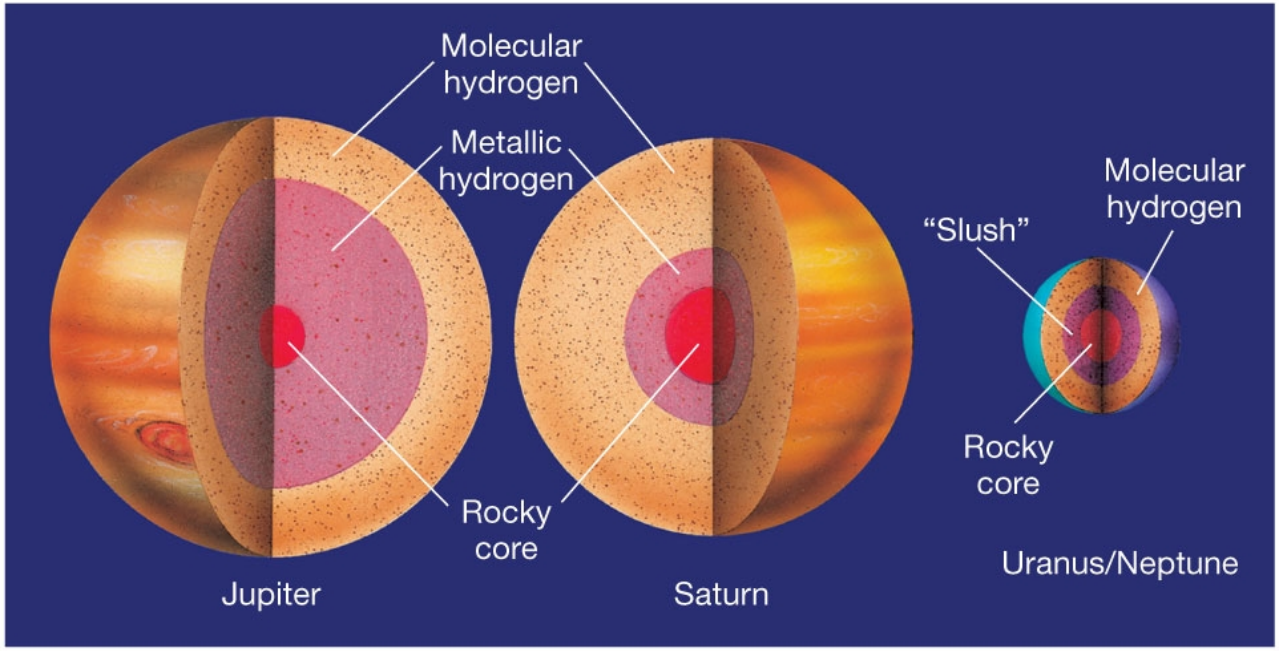




3. Internal Structures - Uranus/Neptune

Magnetic fields of Uranus and Neptune may be produced by dynamos, in the outer slushy layers, not metallic H.

Interior structure of Uranus and Neptune, compared to that of Jupiter and Saturn



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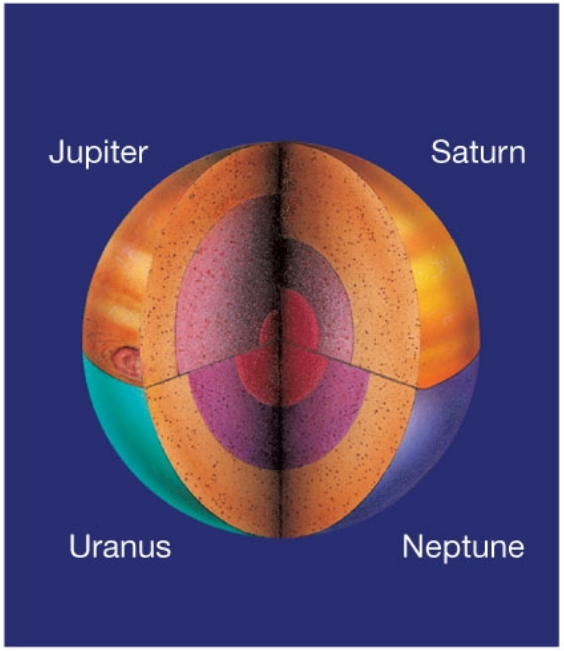

(b)

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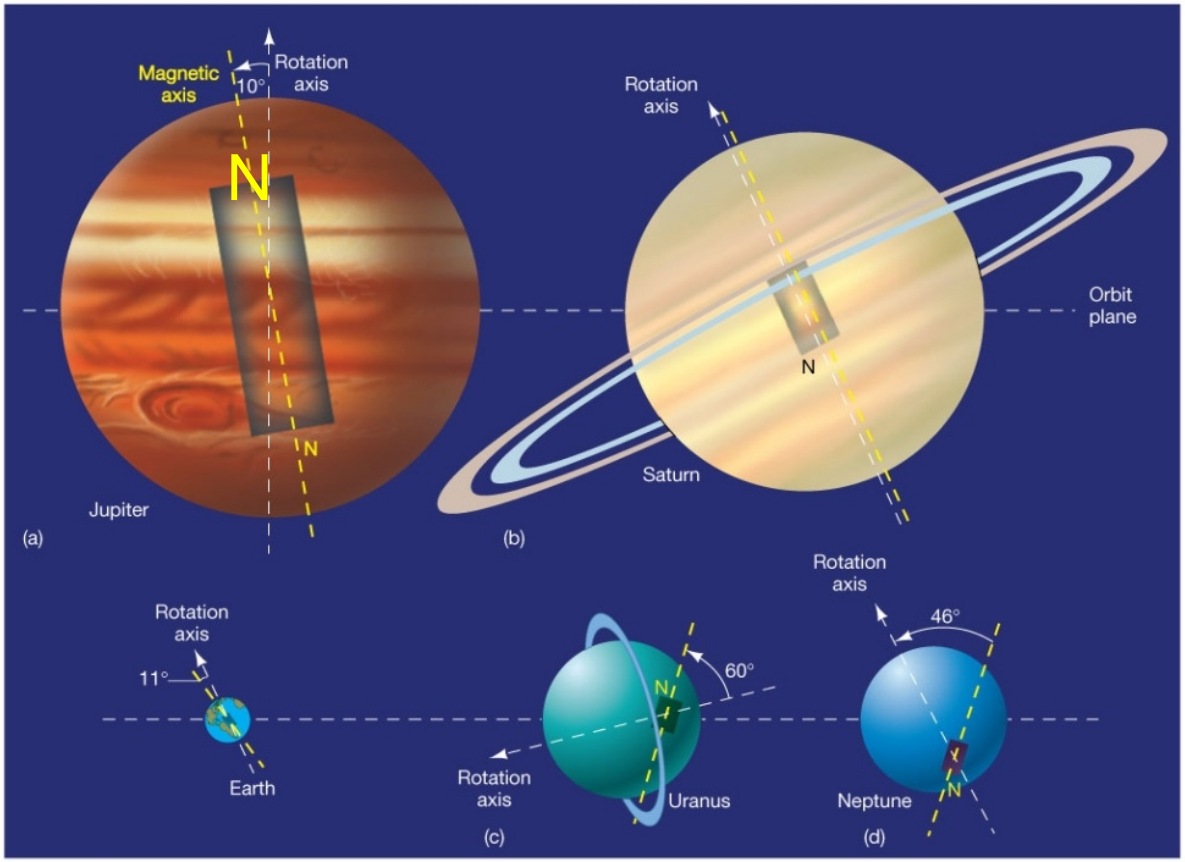
3. Internal Structures (Uranus & Neptune)

Uranus and Neptune both have substantial magnetic fields, but at a large angle to their rotation axes.

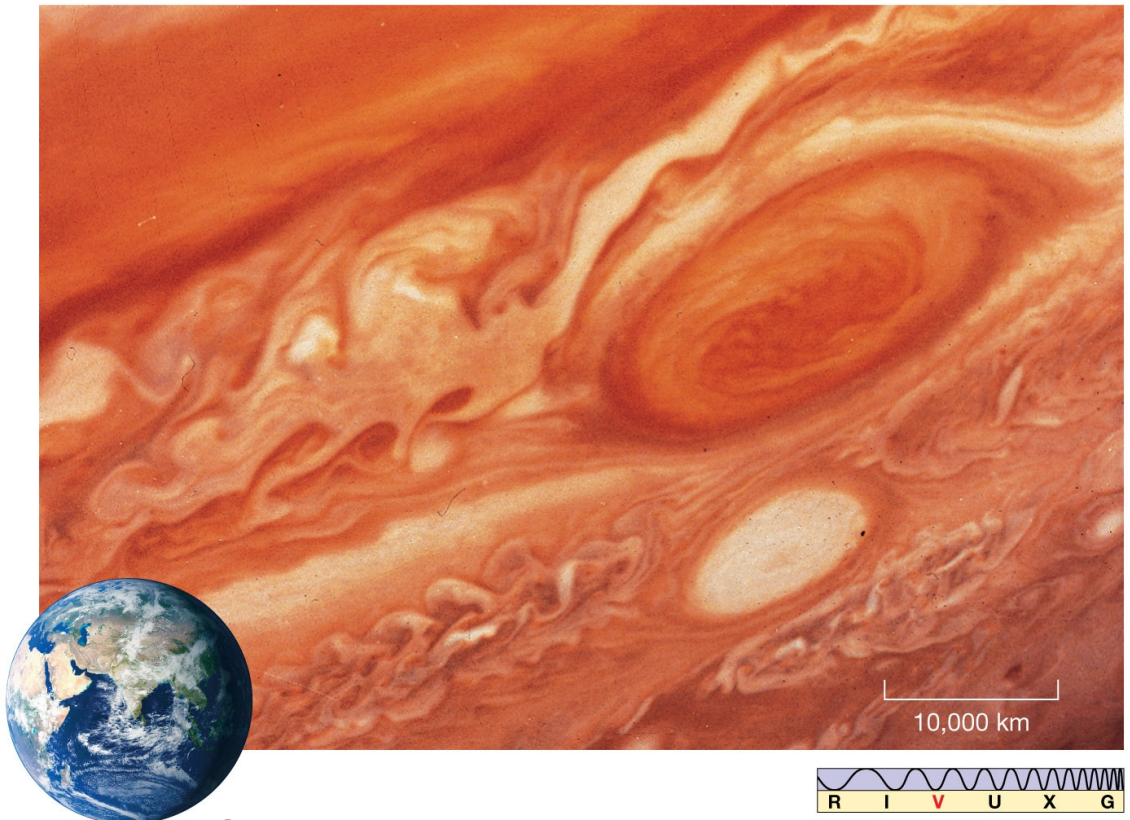
The rectangle within each planet shows a bar magnet that would produce a similar field. Both Uranus' and Neptune's are significantly off center.



4. Atmospheres - Jupiter

Major visible features:

white ovals, brown ovals, Great Red Spot

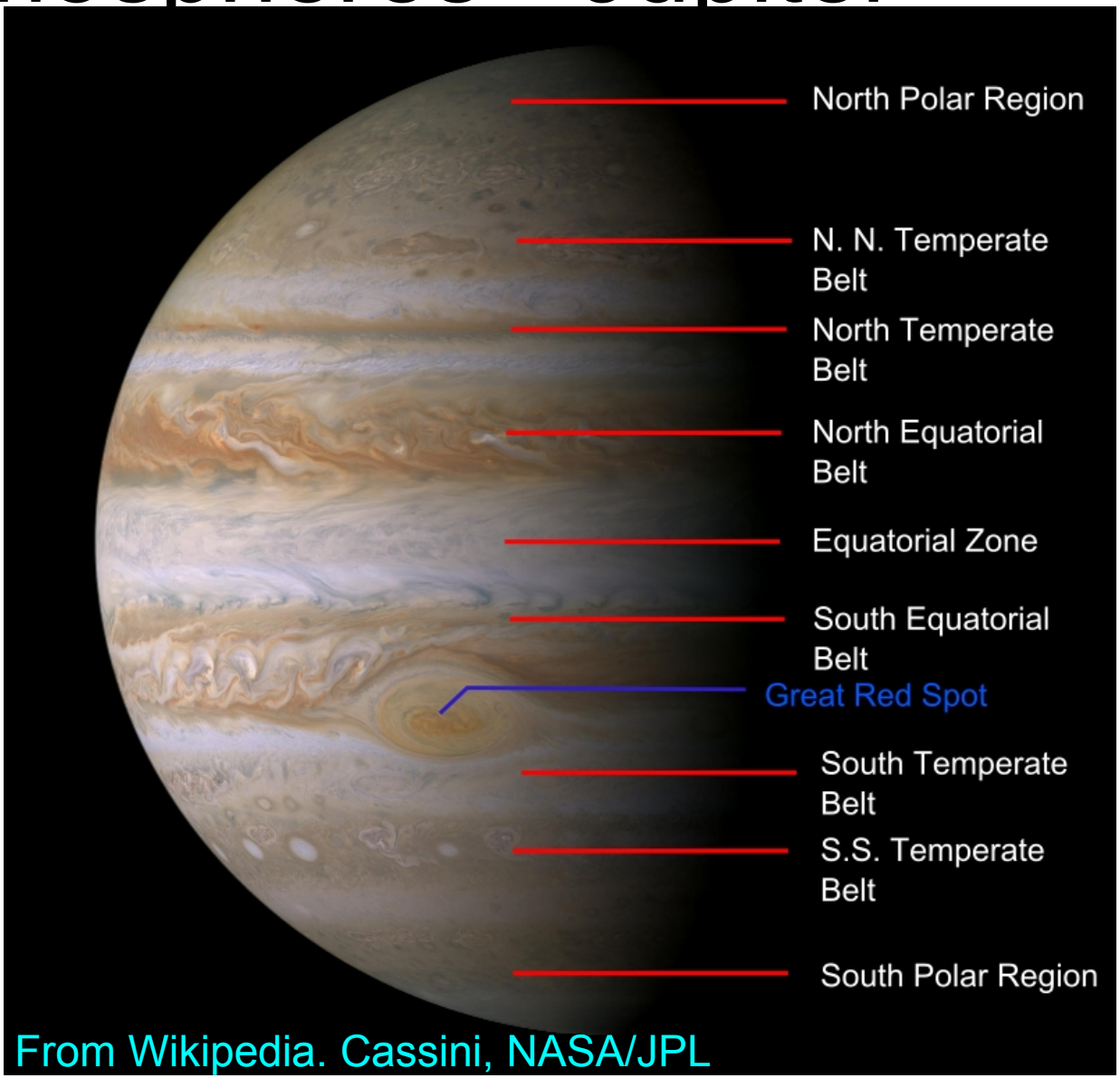


Compare to Kelvin-Helmholtz clouds on Earth...

4. Atmospheres - Jupiter

Belts: dark

Zones: light

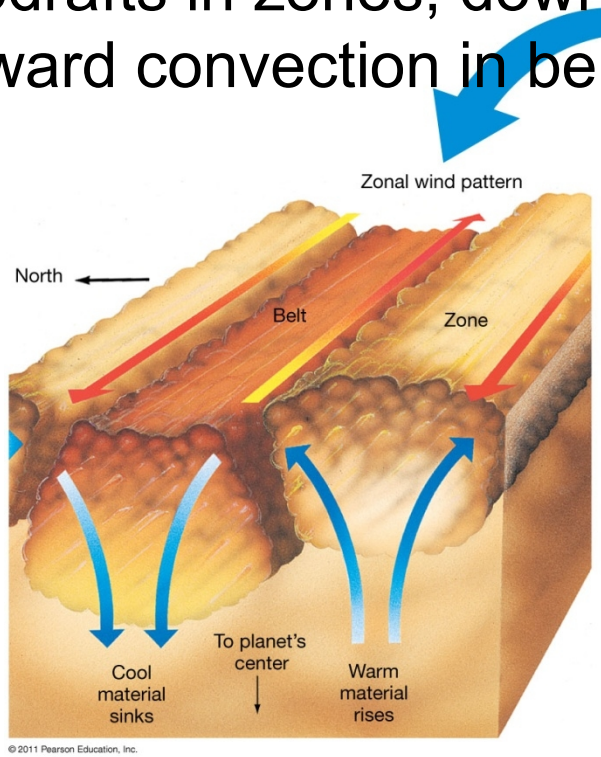


From Wikipedia. Cassini, NASA/JPL

4. Atmospheres - Jupiter

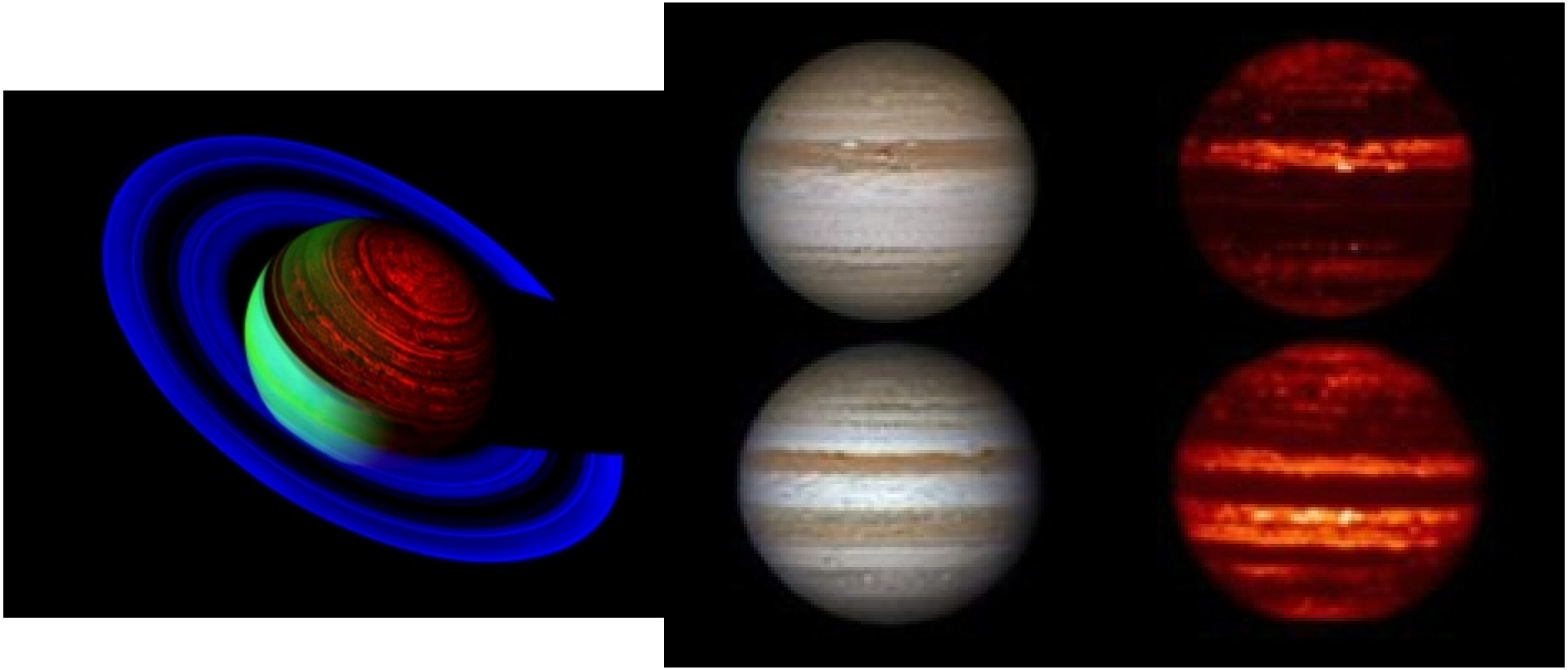
- Atmosphere has bright zones and dark belts
- Zones are cooler, and are higher than belts
- A stable, zonal flow, underlies zones and belts
- Voyager model: updrafts in zones, downdrafts in belts
- Cassini model: upward convection in belts (Juno agrees)

Vertical flow model here is probably wrong!



4. Atmospheres – belts & zones

- Zones are cooler, and are higher than belts
- Infrared images are brighter where we have direct sight of deeper, hot regions
- Visible images: bright=upper cloud decks



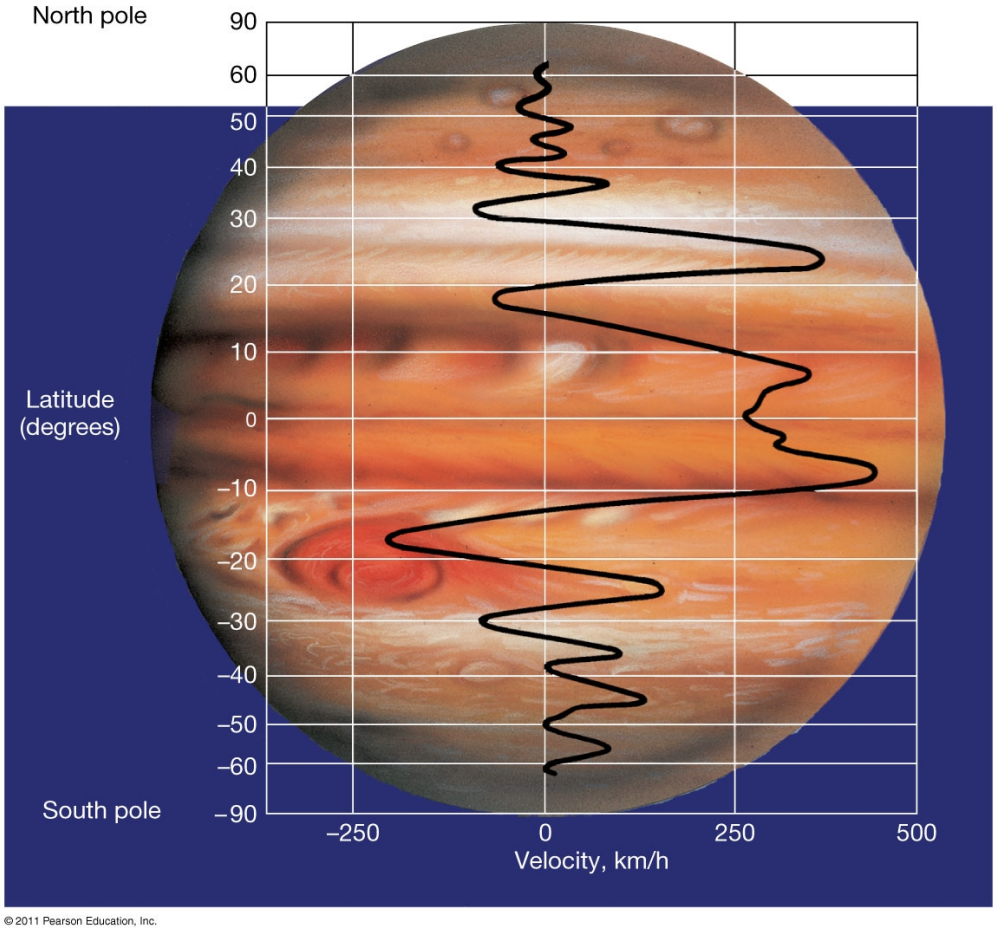
Q: what is strangely missing above?

4. Atmospheres - Jupiter

Zonal Flow: Wind speed with respect to internal rotation rate.

Fast winds to E at equatorial zone and other zones.

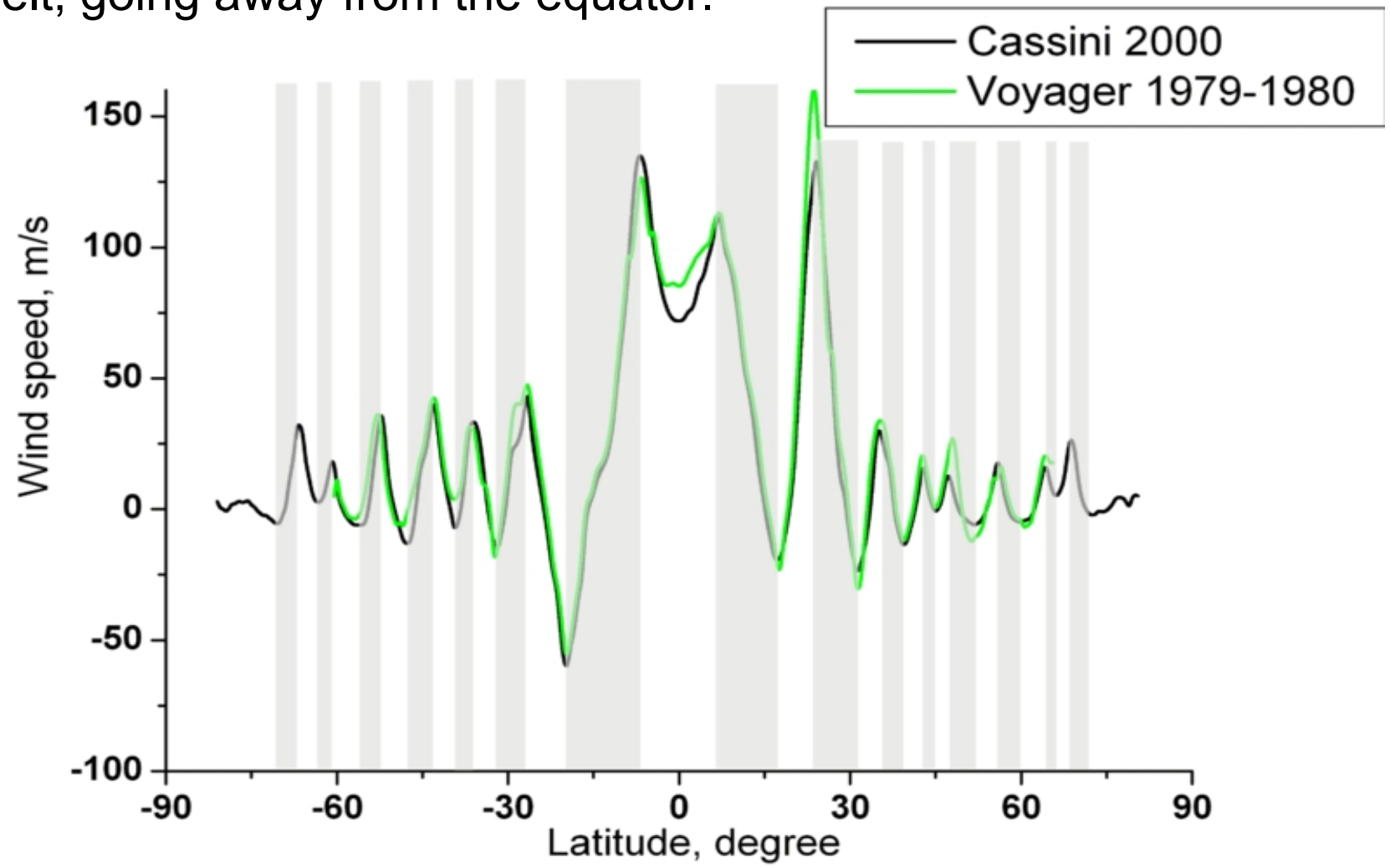
Fast winds to W at S equatorial belt and N equatorial belt.



See animated zonal flow in Wikipedia

4. Atmospheres - Jupiter

Actually, the peak Eastward flows are at transitions from zone to belt, going away from the equator.

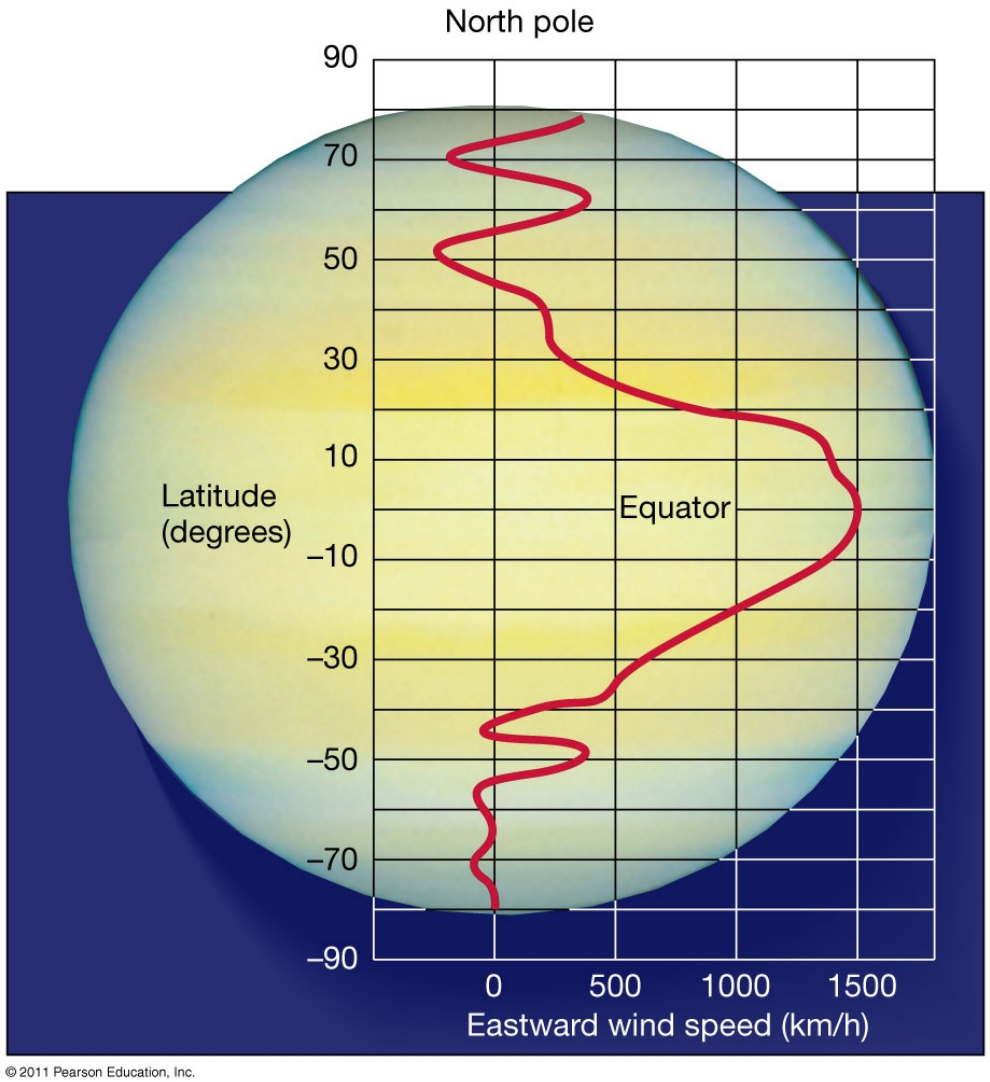


From Wikipedia

4. Atmospheres - Saturn

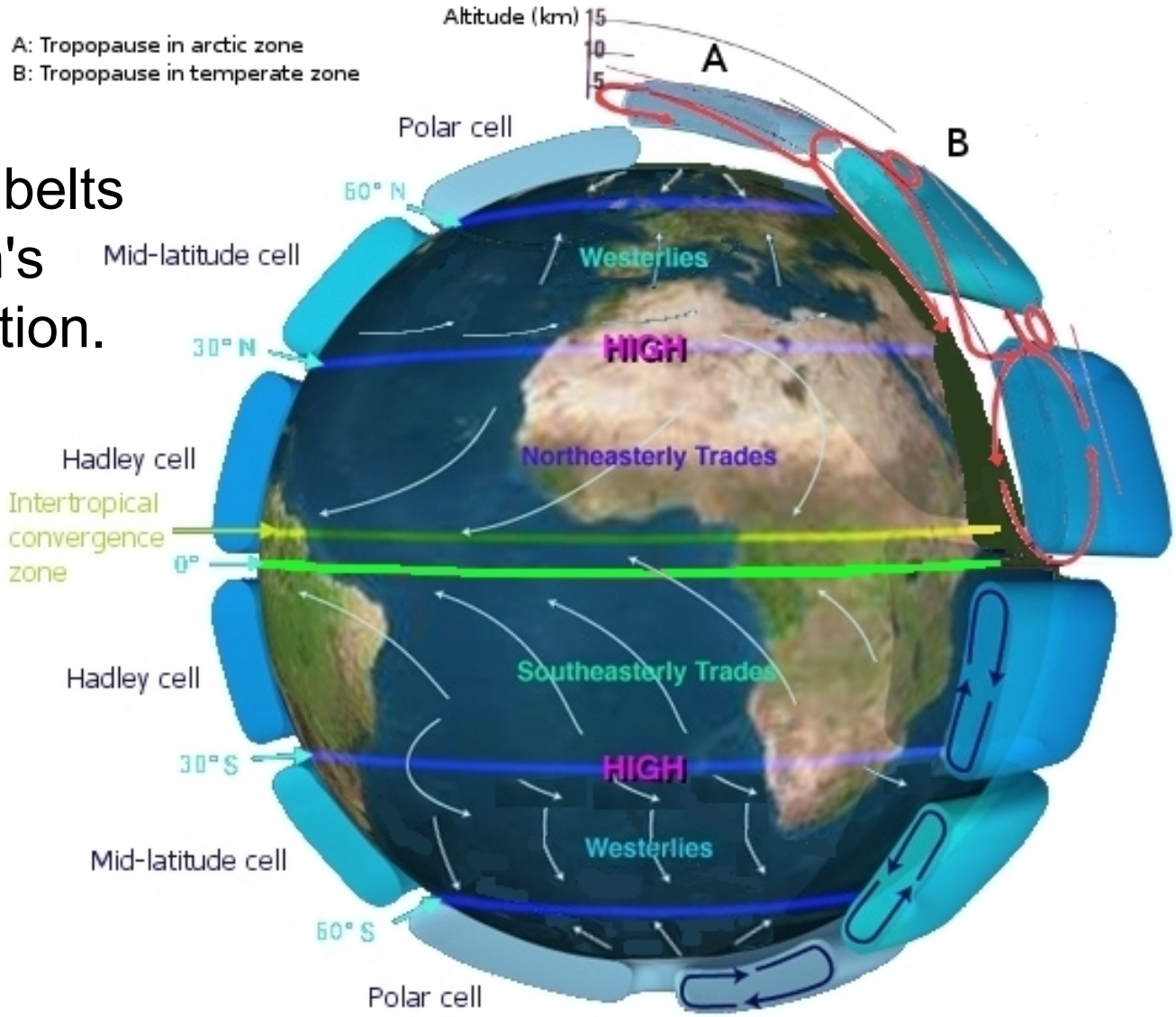
Zonal Flow: Wind speed with respect to internal rotation rate.

Up to 1500 km/s! Broader range of latitudes per zone.



4. Atmospheres - Earth

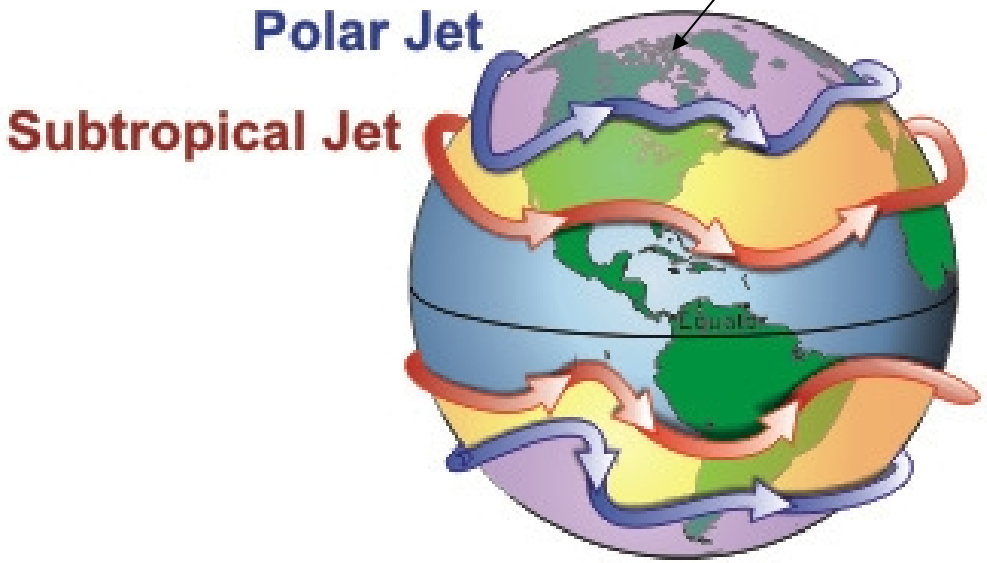
Compare Jupiter's belts and zones to Earth's Hadley Cell circulation.

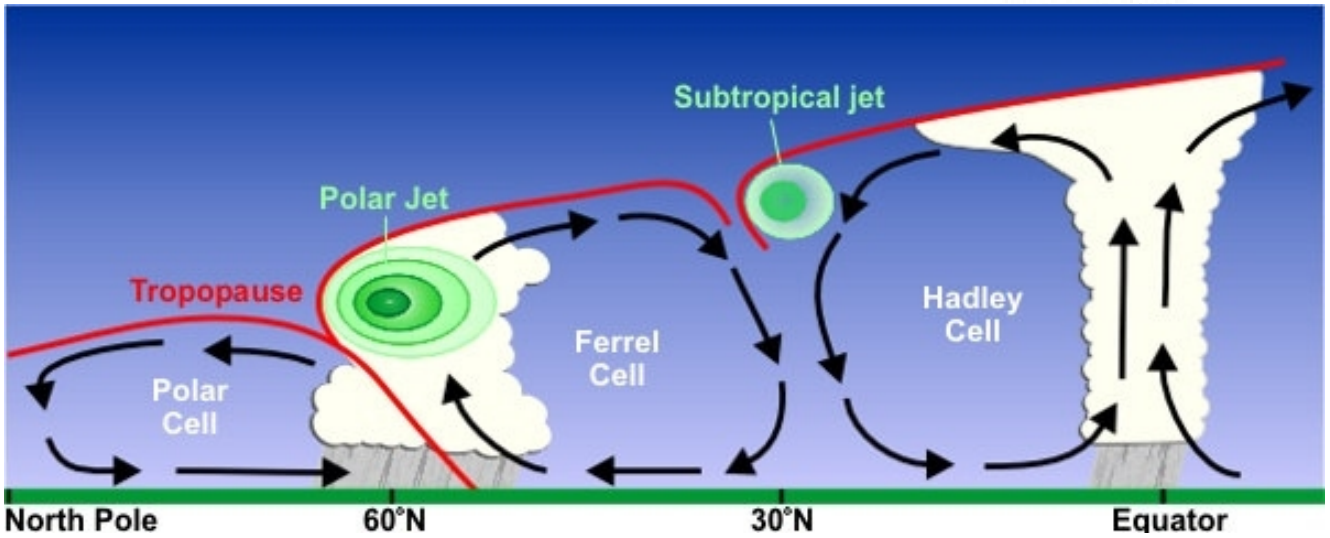


4. Atmospheres - Earth

"polar vortex"

Compare to Earth: Jet Streams





4. Atmospheres - Jupiter

Composition of atmosphere: mostly molecular hydrogen (86%) and helium (14%); small amounts of methane, ammonia, and water vapor

The colors in visible images are probably due to complex chemical interactions,like photolysis. NH_3, CH_4, and C_2H_2 exposed to UV can produce chromophores† (coloring agents). Sulfur compounds, phosphine (PH_3), and organic compounds may also make up some of the chromophores.

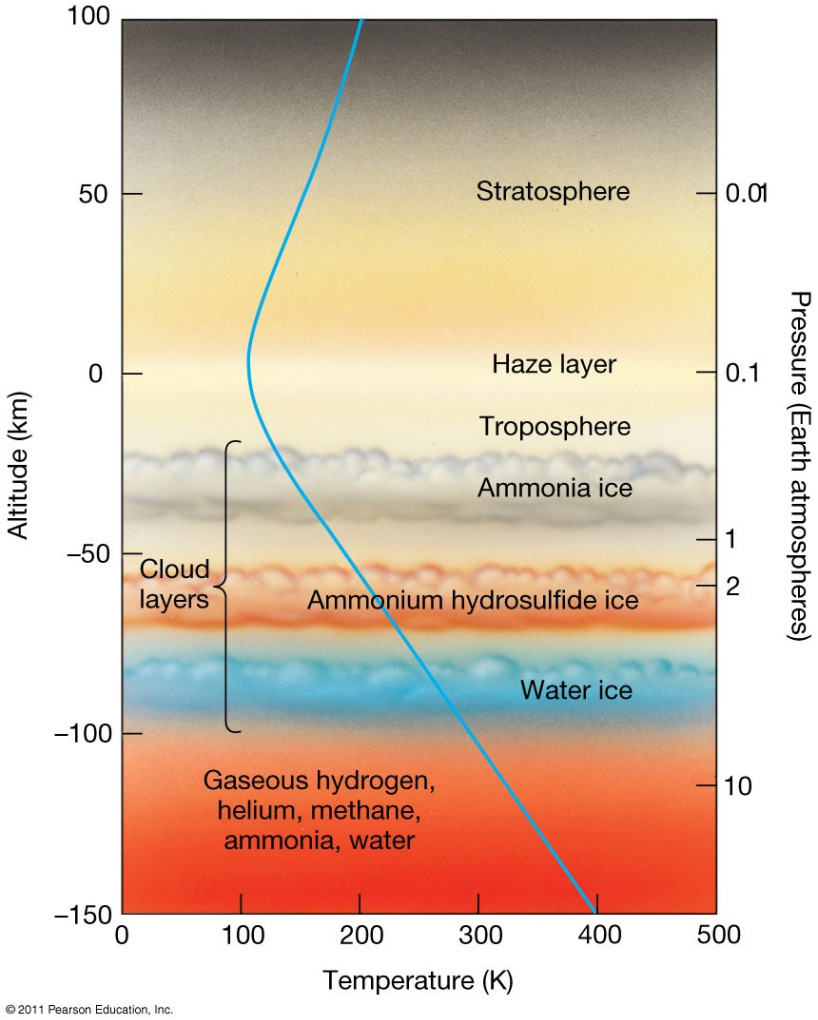
†like aliphatic imines, amines, and nitriles – R. Carlson JPL 2006.

4. Atmospheres - Jupiter

No solid surface; take top of troposphere to be at 0 km

Lowest cloud layer cannot be seen by optical telescopes

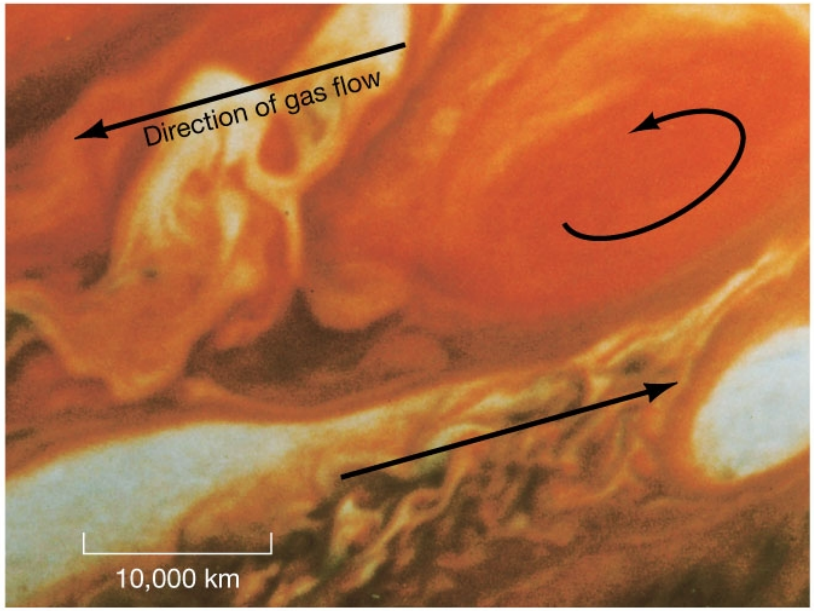
Measurements by Galileo probe show high wind speeds even at great depth—probably due to heating from planet, not from Sun



4. Atmospheres - Jupiter

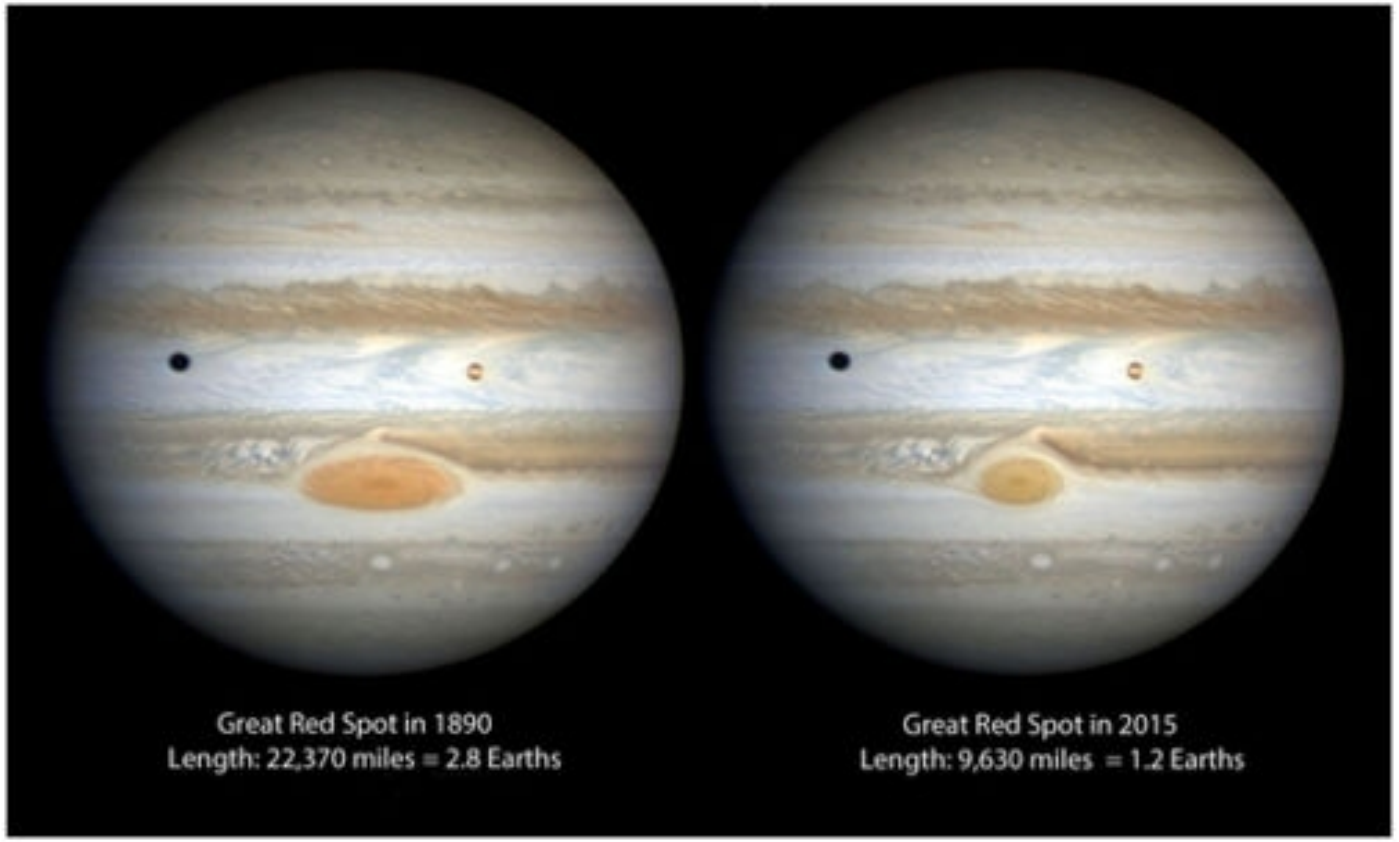
Great Red Spot has existed for at least 120 years, possibly much longer. (R. Hooke discovered in 1664.)

Color and energy source still not understood



4. Atmospheres - Jupiter

Great Red Spot has been shrinking over the last 120 years or so. It has varied in contrast as well.

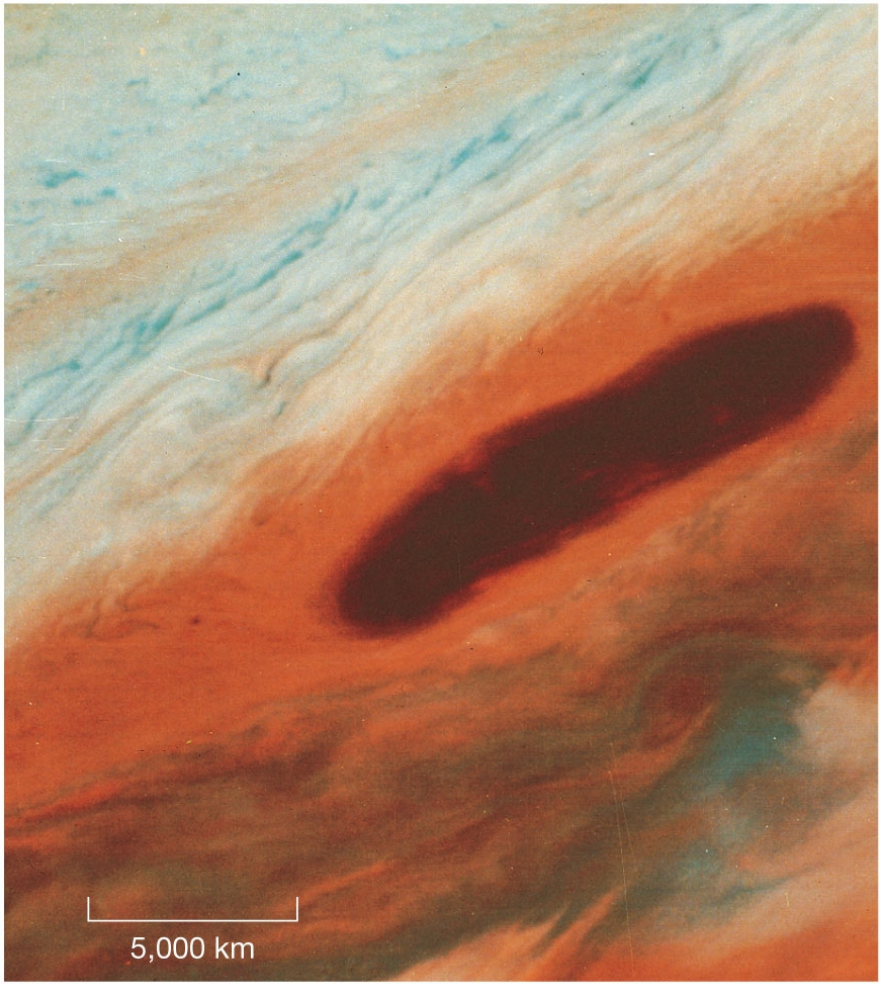


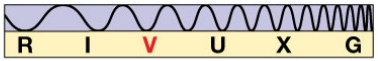
4. Atmospheres - Jupiter

Lightning-like flashes have been seen; also shorter-lived rotating storms

One example: Brown Oval, really a large gap in clouds.

These have only been seen around 20º N latitude, and have cyclonic rotation (CCW in Northern Hem.)





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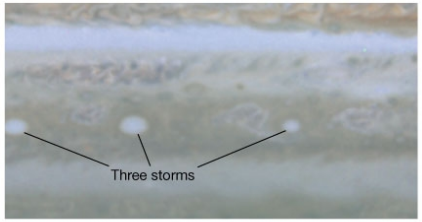
4. Atmospheres - Jupiter

In 2000, three white storms were observed to merge into a single storm, which then turned red. Called “Oval BA” or “Red Spot Jr”.



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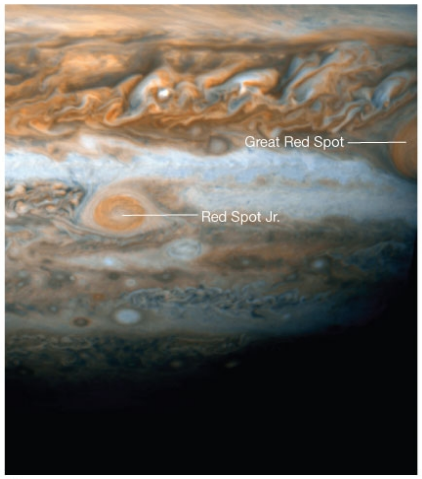

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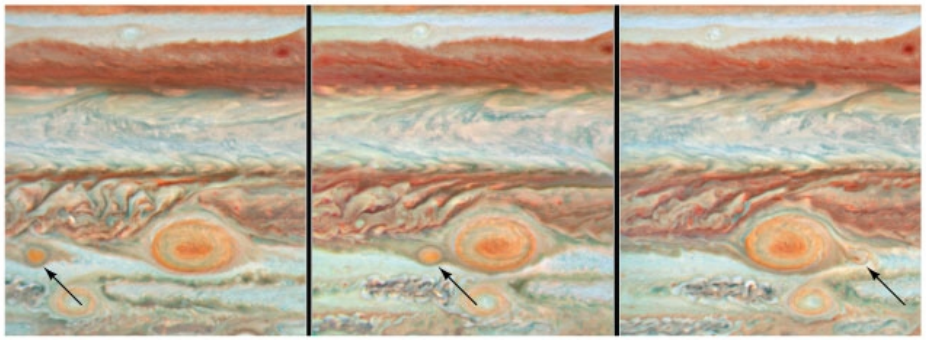
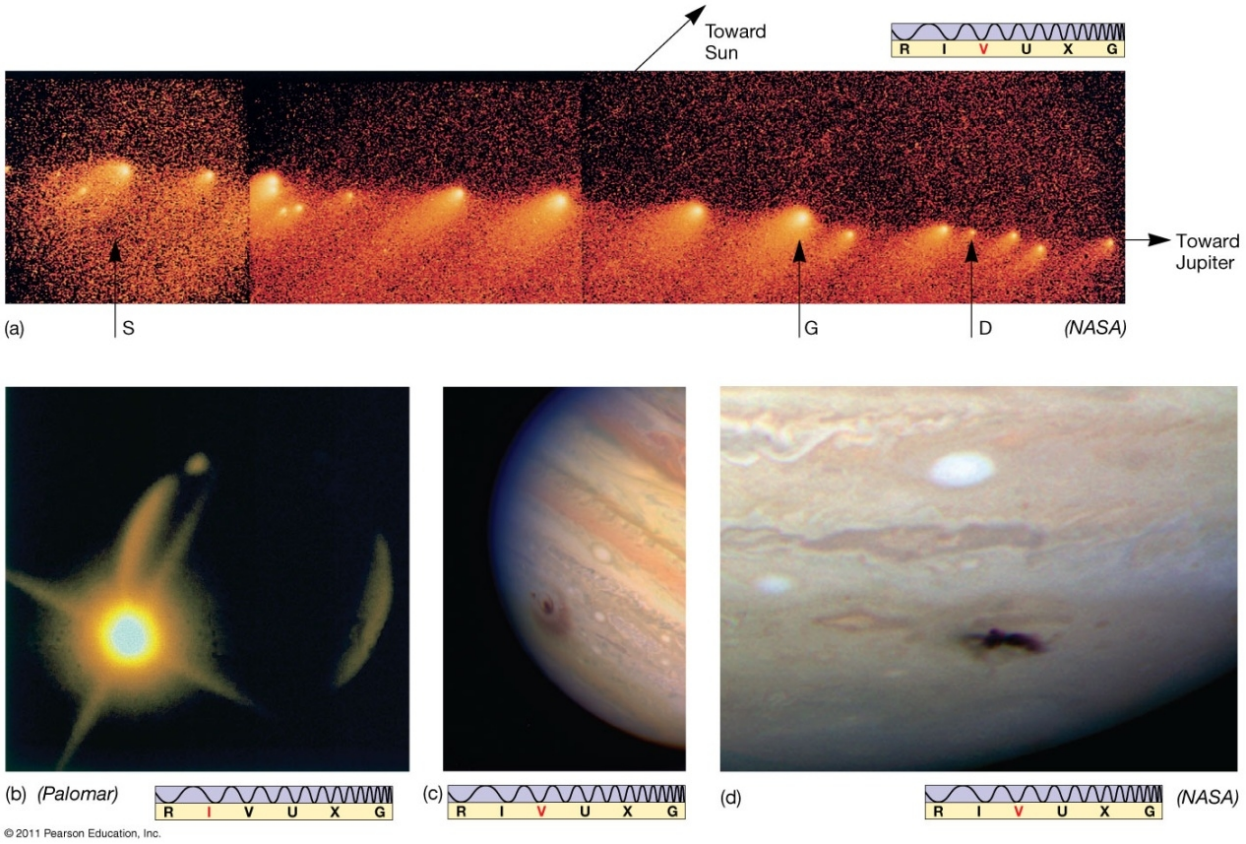


(c)

See video of Jupiter’s zonal flow.

Discovery 11-1: A Cometary Impact

July 1994: Comet Shoemaker-Levy 9, in fragments, struck Jupiter, providing information about high-level winds, and composition.

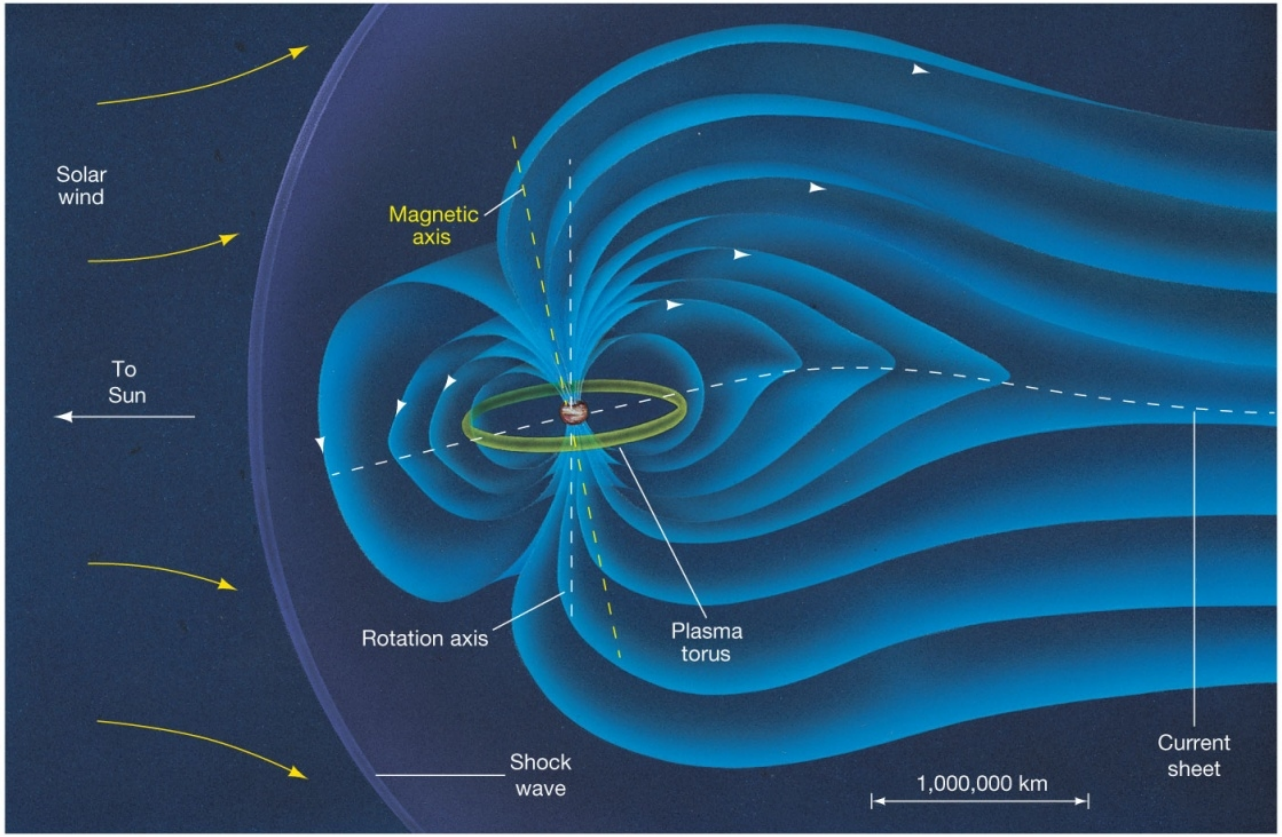


Another object hit Jupiter in 2009!

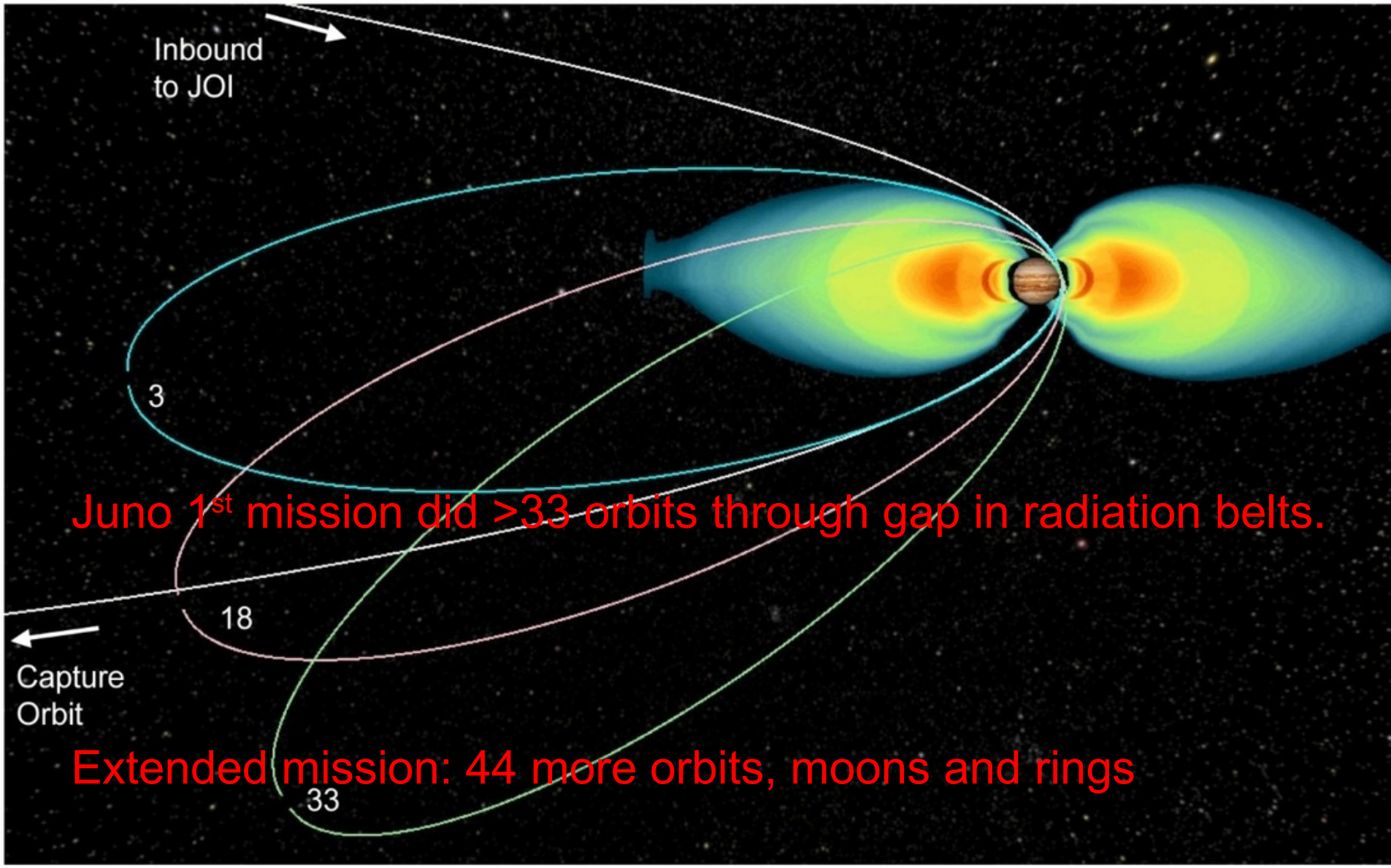
11.4 Jupiter's Magnetosphere

Jupiter is surrounded by belts of charged particles, much like the Van Allen belts but vastly larger

Magnetosphere is 30 million km across



11.4 Jupiter's Magnetosphere



Juno 1st mission did >33 orbits through gap in radiation belts.

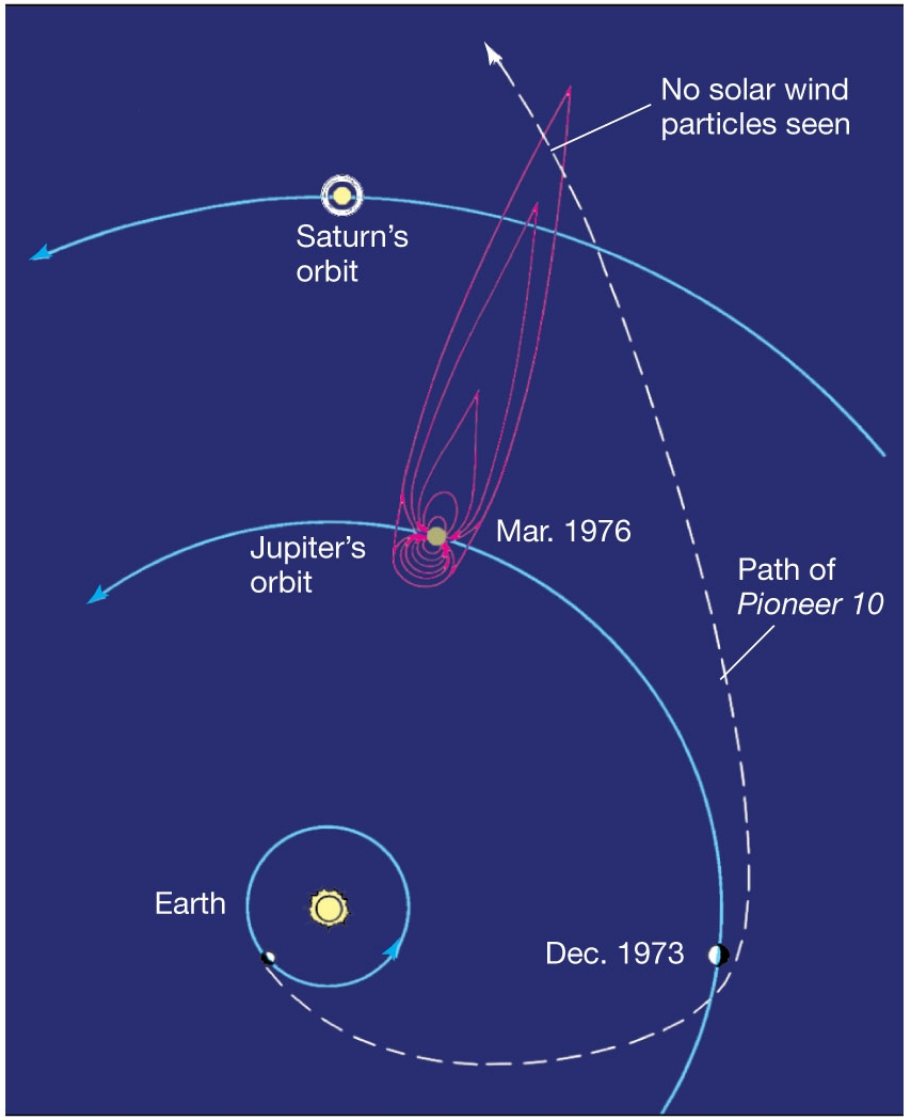
Extended mission: 44 more orbits, moons and rings

11.4 Jupiter's Magnetosphere

Intrinsic field strength is 20,000 times that of Earth.

Volume of magnetosphere is a million times the Earth's.

Magnetosphere tail extends beyond the orbit of Saturn



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11.5 The Moons of Jupiter

95* moons have now been found orbiting Jupiter, but most are very small.

The four largest are the Galilean moons, so called because they were first observed by Galileo:

- Io, Europa, Ganymede, Callisto.

Galilean moons have similarities to terrestrial planets:

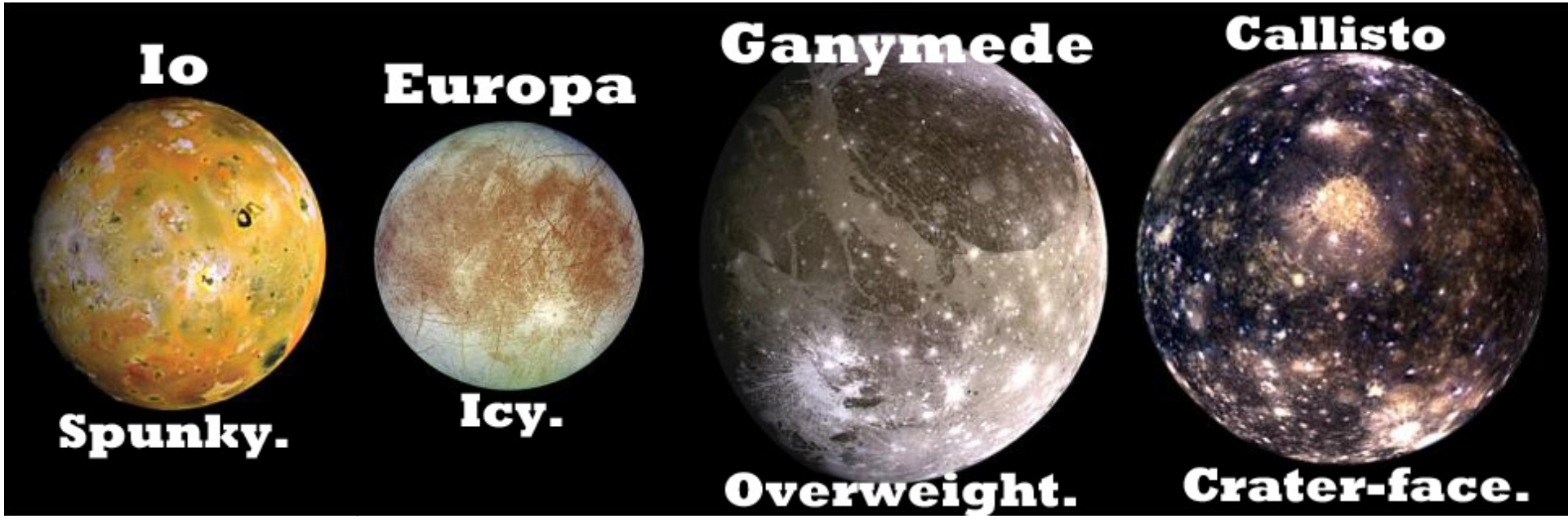
All orbit in same direction, in same plane
Rotate CCW (tidally interlocked like our Moon)
Made of less dense materials as distance increases
Sizes are comparable to the Moon and Mercury

* As of Oct. 2023.

Table 2:

Moon	Distance from Jupiter (km)	Radius (km)	Mass (Earth)	Density (gm/cm^3)	Orbital Period (days)
Io	422,000	1,815	0.0145	3.53	1.77
Europa	671,000	1,569	0.0080	3.03	3.55
Ganymede	1,070,000	2,631	0.0242	1.93	7.16
Callisto	1,883,000	2,400	0.0176	1.79	16.69

Check the ratios of Orbital periods ...



11.5 The Moons of Jupiter

Celestia Gaia Sky animation of the Moon's of Jupiter shows …

1) 4 small moon's closer to Jupiter than Io: Adrastea, Amalthea, Metis, Thebe.
2) Adrastea and Metis almost share an orbit.
3) All moons revolve CCW (seen from N)
4) Zooming in on a Moon often shows it to keep one side facing Jupiter (gravitational interlocking or 1-1 spin:orbit resonance)

11.5 The Moons of Jupiter

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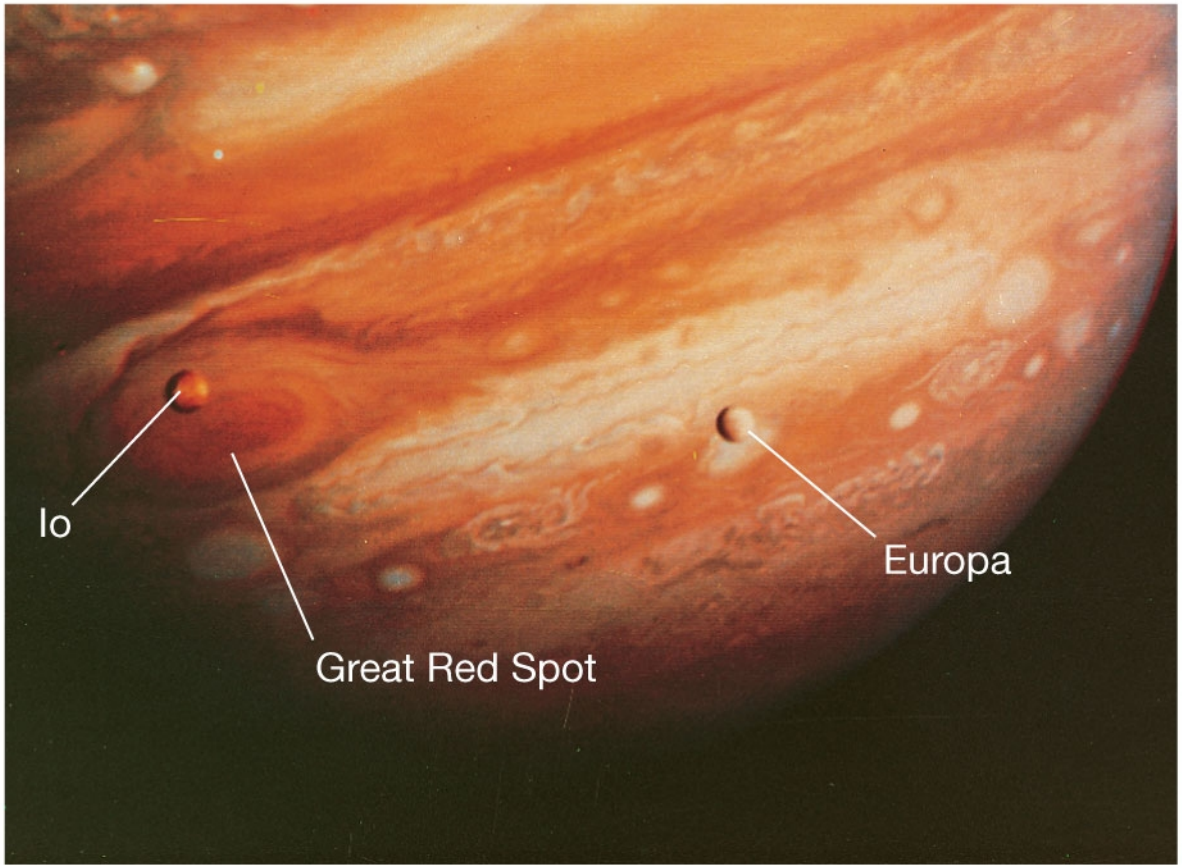
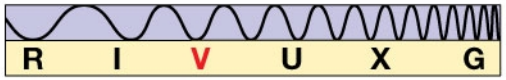
11.5 The Moons of Jupiter

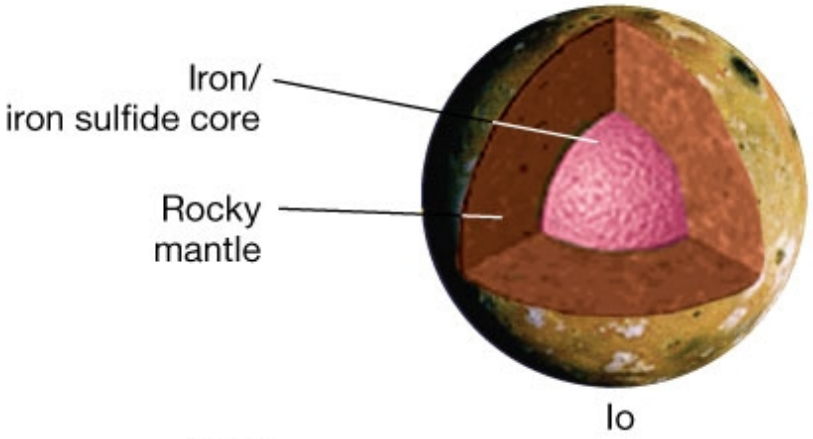
Jupiter with Io and Europa. Note the relative sizes!



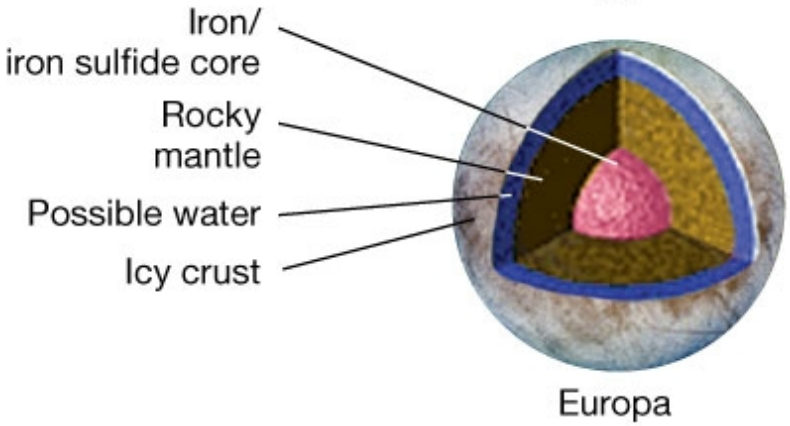


11.5 The Moons of Jupiter

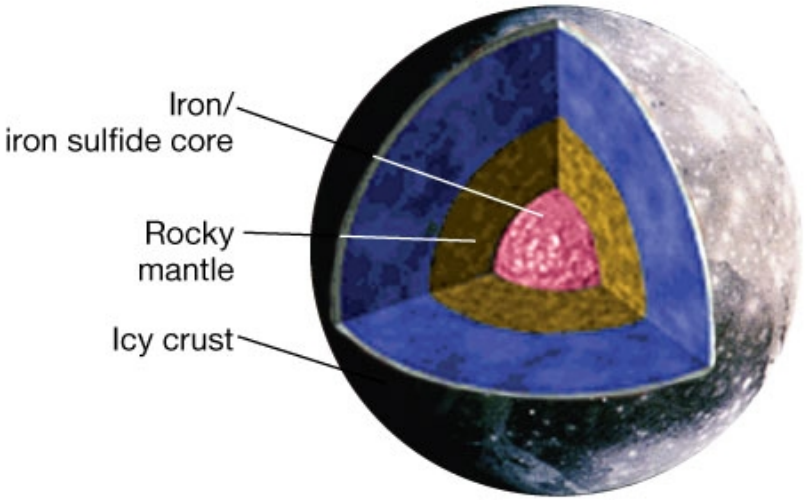
Interiors of the Galilean moons



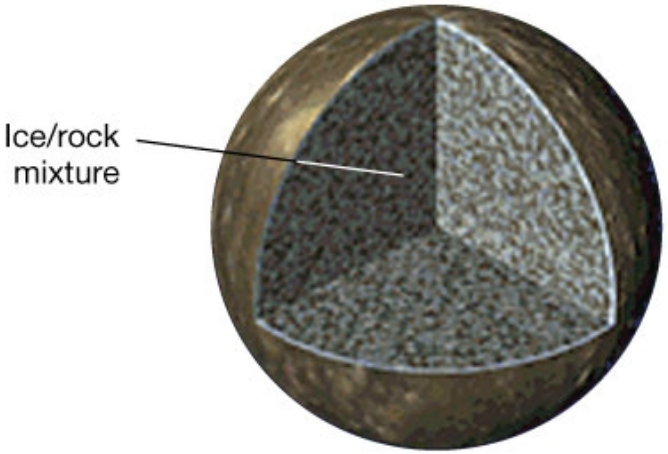
Io



Europa



Ganymede



Callisto

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11.5 The Moons of Jupiter

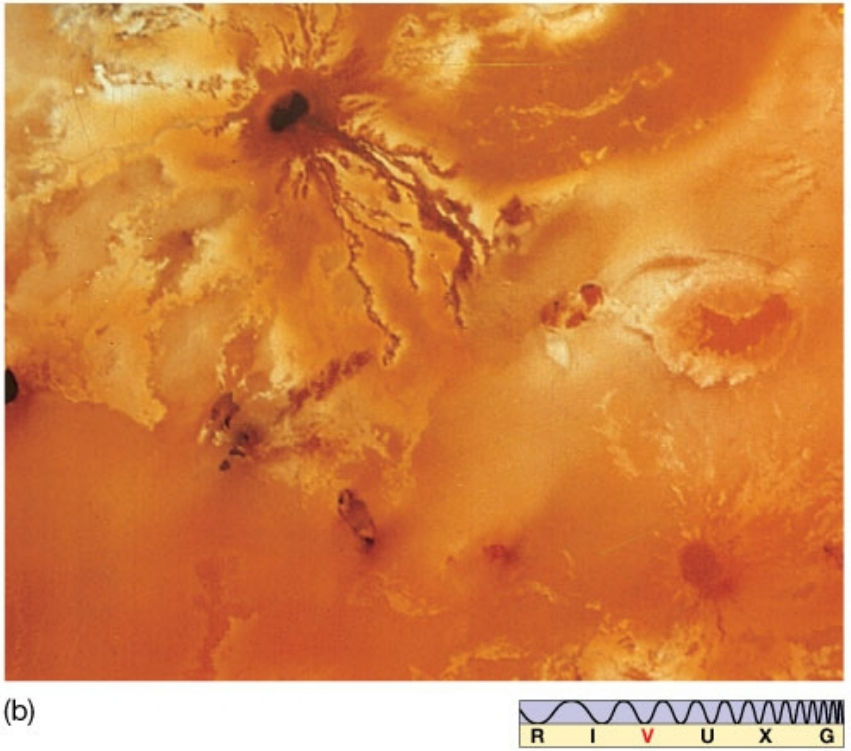
Io is the densist of Jupiter's moons, and the most geologically active object in the solar system:

- Many **active** volcanoes, some quite large
- Can change surface features in a few weeks
- No craters; they fill in too fast—Io has the youngest surface of any solar system object

11.5 The Moons of Jupiter

Orange color is probably from sulfur compounds in the ejecta

(a)

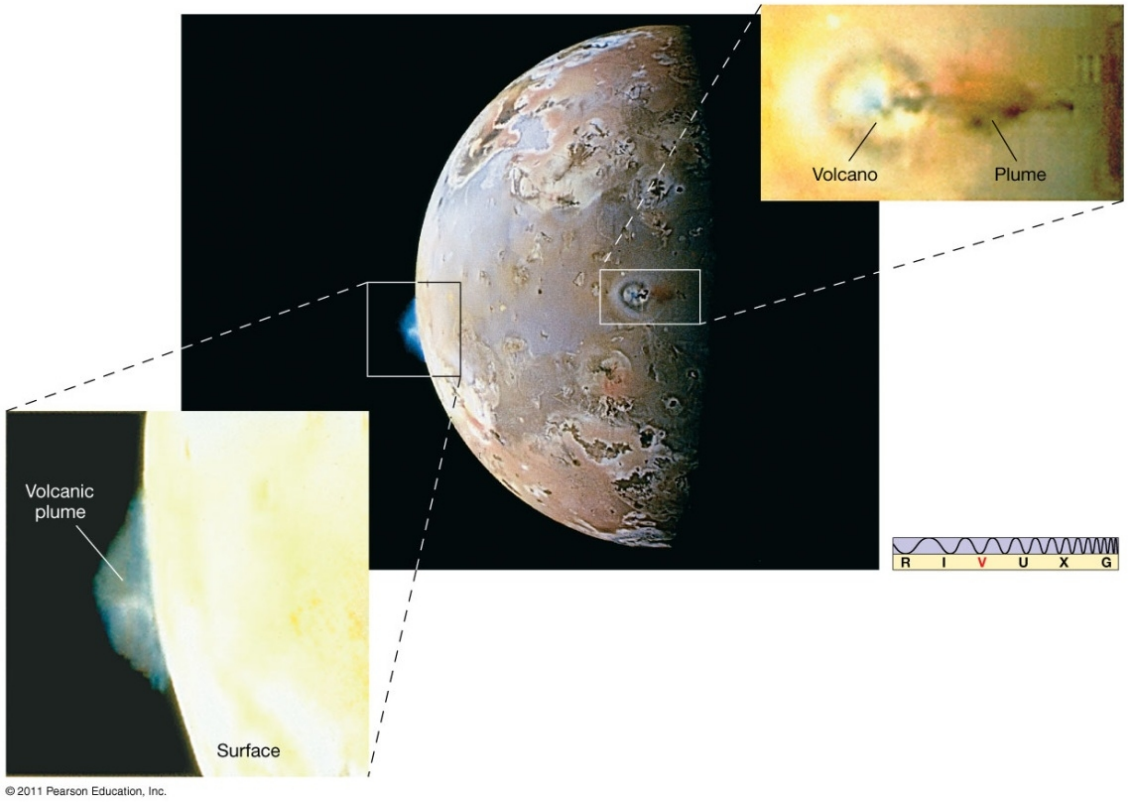


(b)

11.5 The Moons of Jupiter

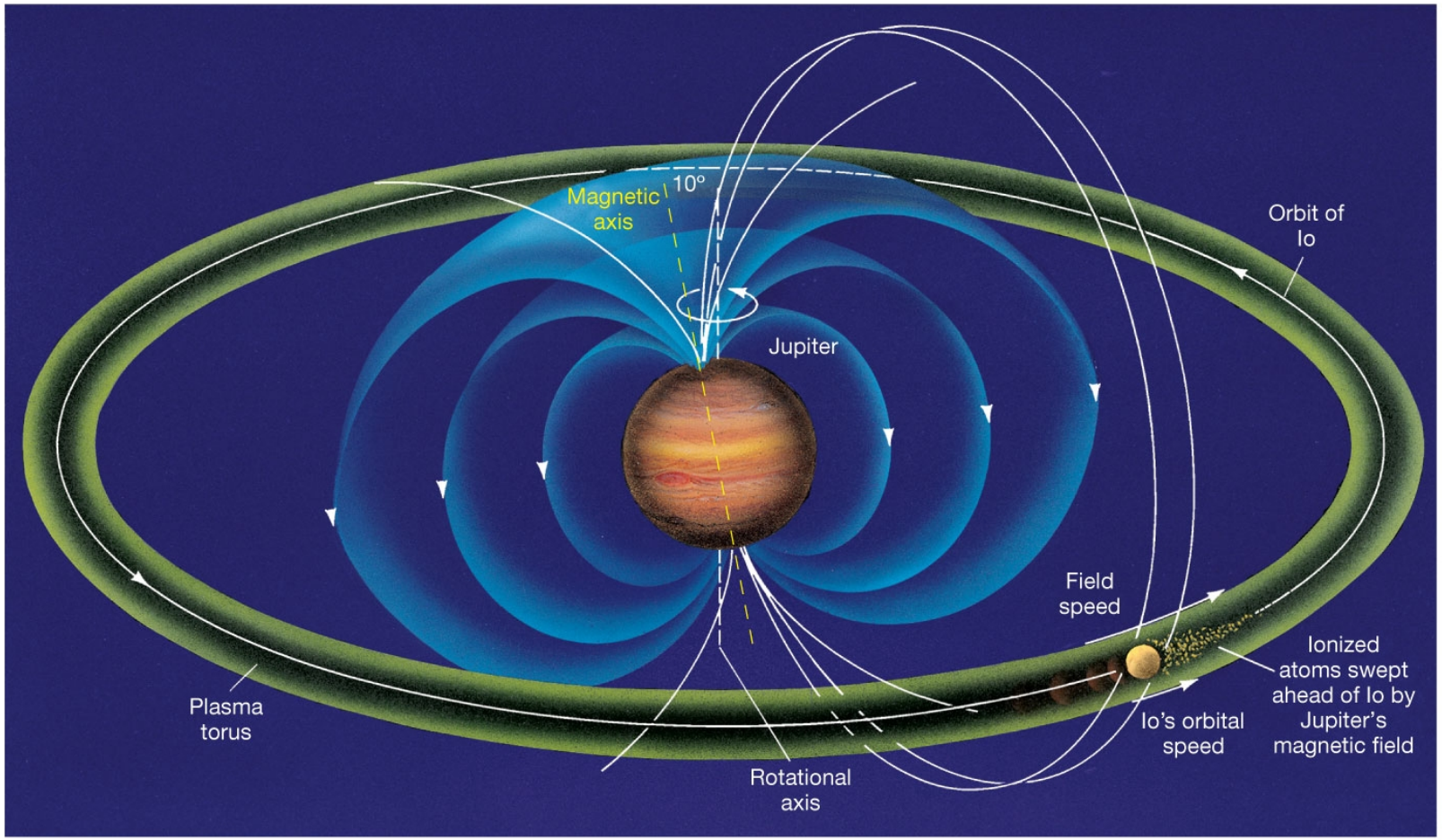
Cause of volcanism: Gravity!

Io is very close to Jupiter so the tidal force is huge. Io passes Europa every 3.6 days and the tug from Europa makes Io quicken and then slow in its orbit. This makes Io librate back and forth relative to Jupiter, so the tidal forces knead Io like bread dough and provide the energy for the volcanoes.



11.5 The Moons of Jupiter

Volcanic eruptions also eject charged particles; these interact with Jupiter's magnetosphere and form a plasma torus

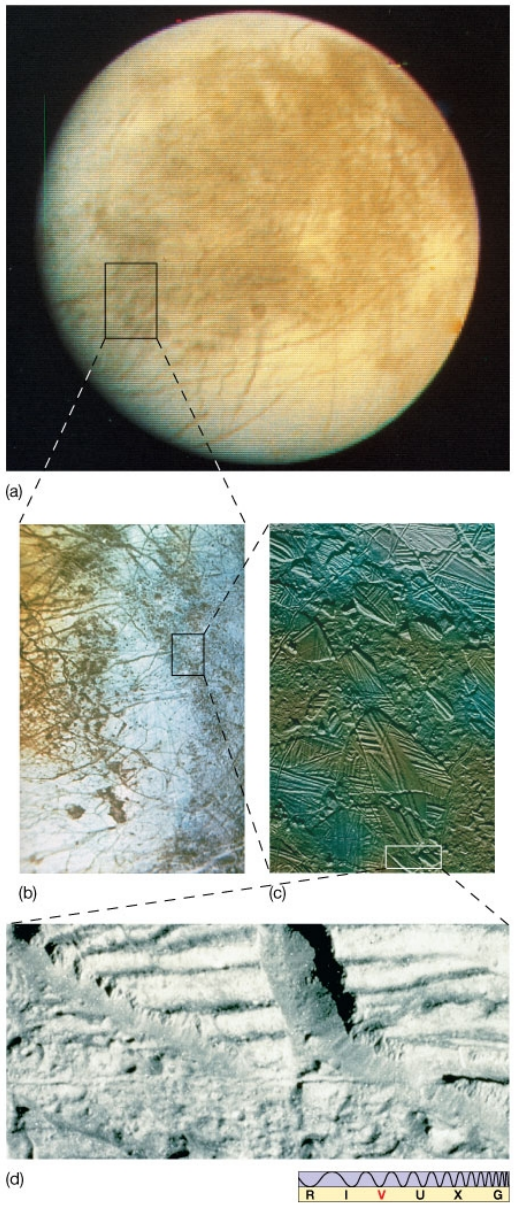


11.5 The Moons of Jupiter

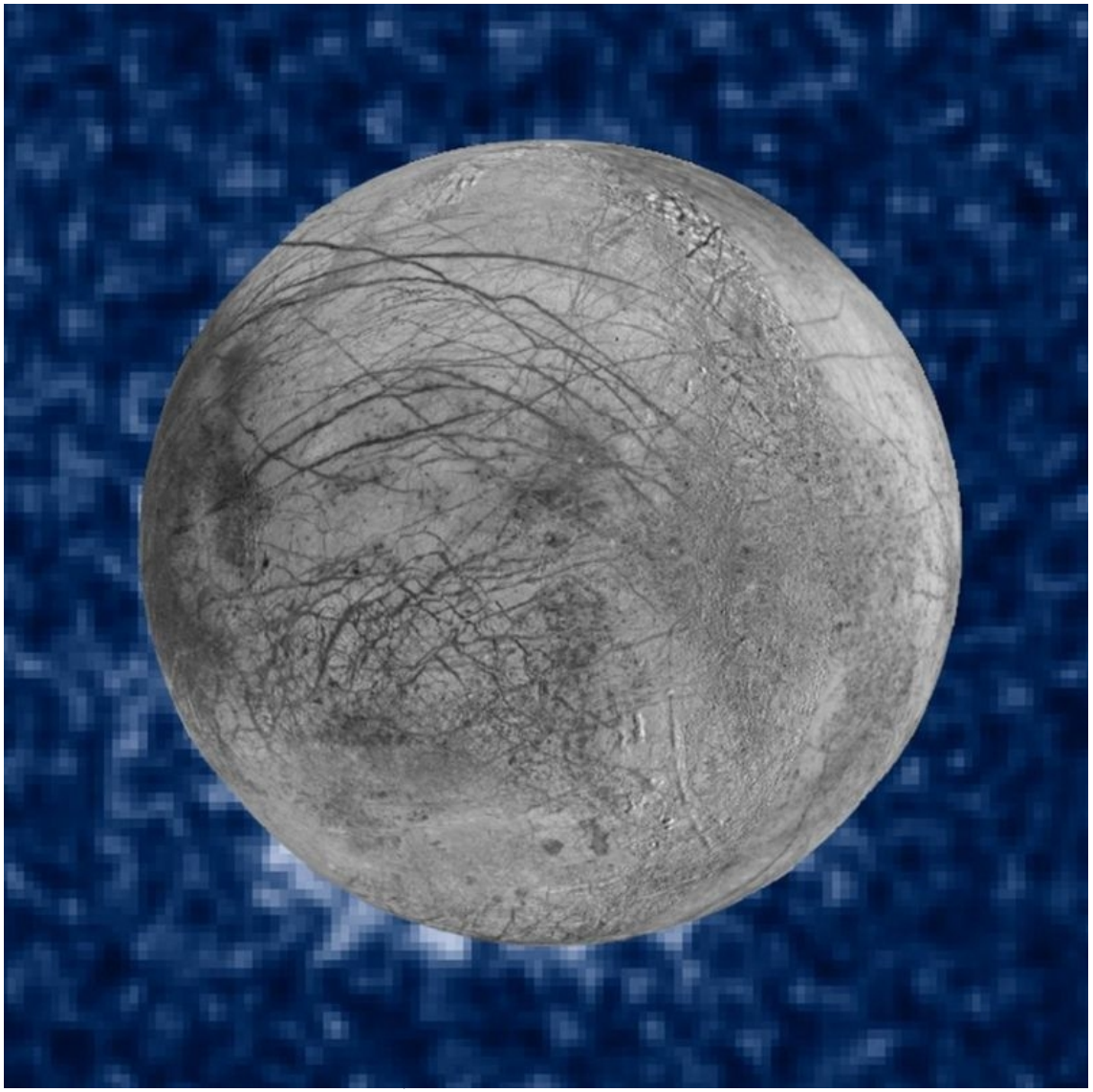
Europa shows few craters; surface is water ice, possibly with liquid water below.

Tidal forces stress and crack ice; water flows, keeping surface relatively flat.

See sci-fi movie “Europa Report”.



11.5 The Moons of Jupiter



Europa: water geysers were detected by HST in 2016 as it passed in front of Jupiter.

ESA and NASA plan a “Europa flyby” mission in 2020’s.

11.5 The Moons of Jupiter

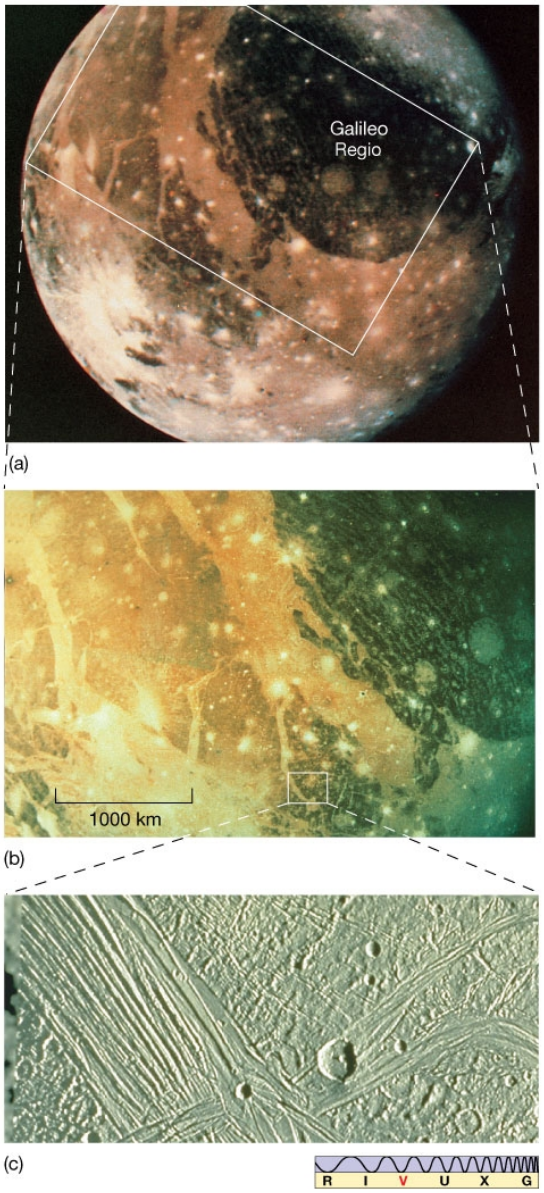
Ganymede is the largest moon in the solar system—larger than Pluto and Mercury

Surface is mostly water ice and a sub-surface ocean is likely.

Dark regions slightly older.

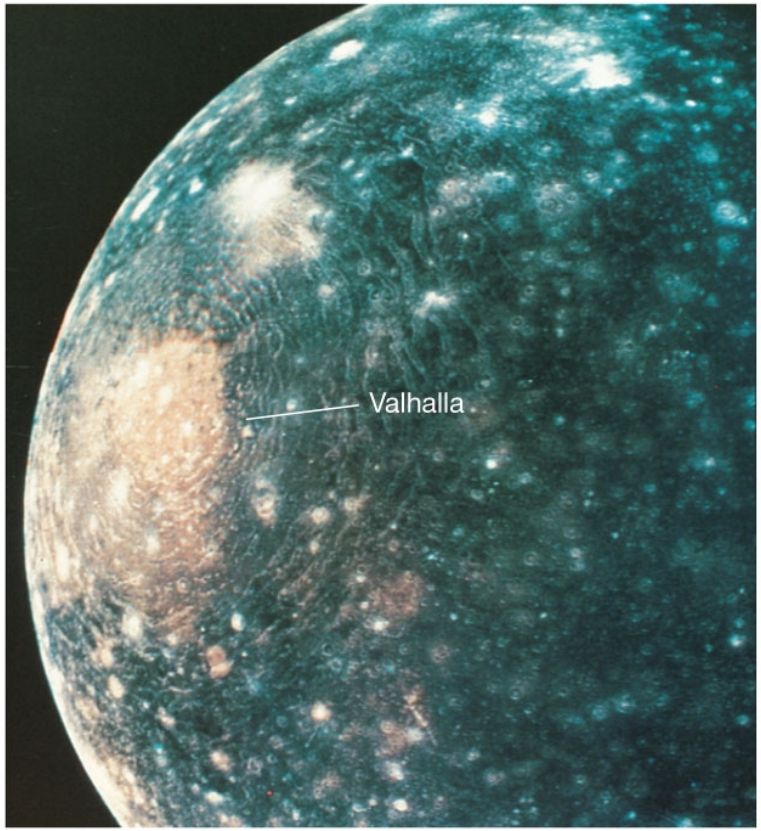
Galileo Regio like maria, but old.

Possible plate tectonics.

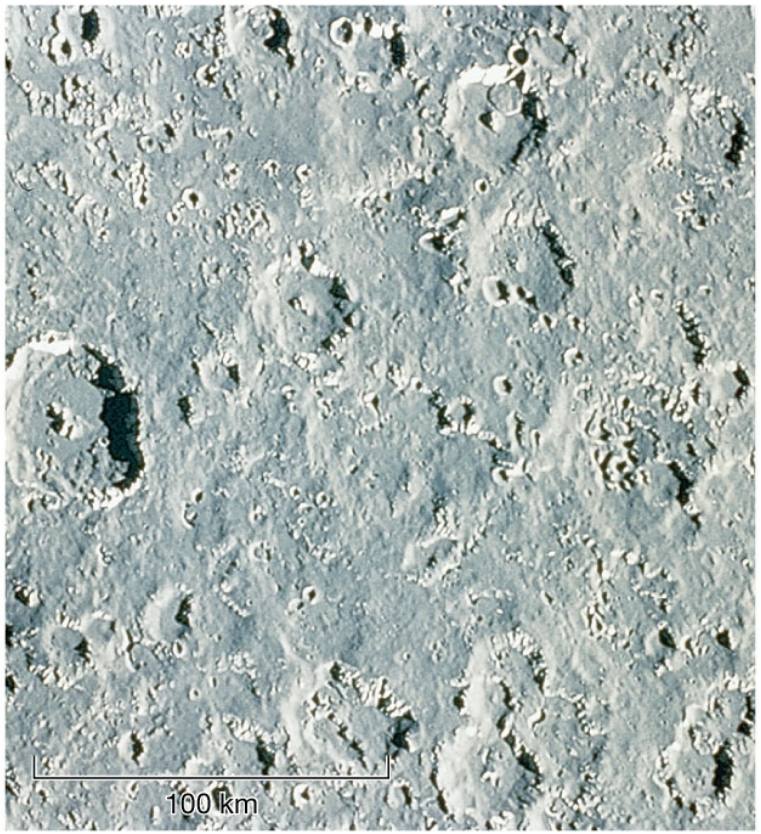


11.5 The Moons of Jupiter

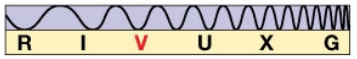
Callisto is similar to Ganymede. No evidence of plate activity; highest crater density; leading edge darker.



(a)



(b)



12.5 The Moons of Saturn

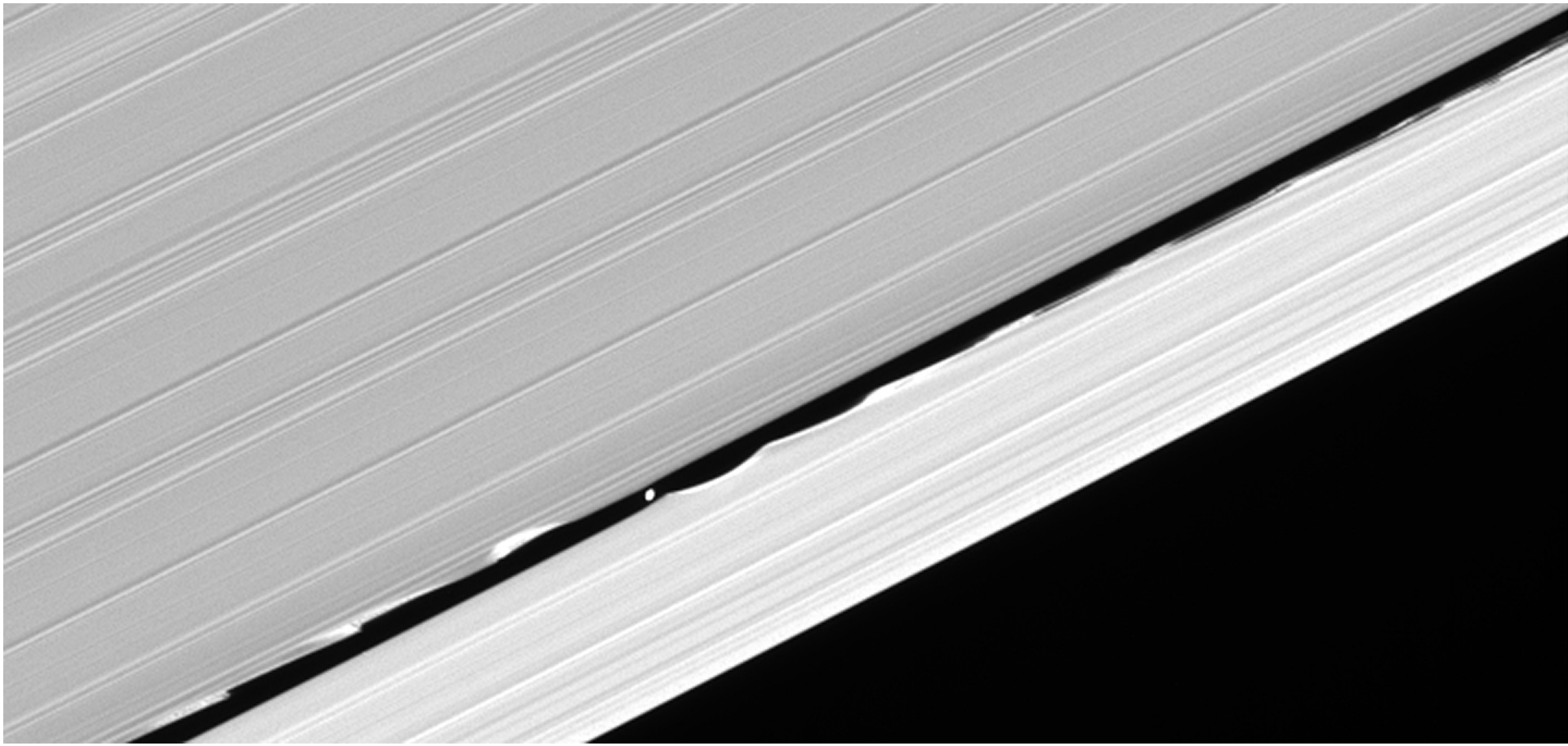
Mnemonic for the larger (>300 km) Moons of Saturn, in order of distance from Saturn:

MET DR THIP

Inspection of orbits of Saturn's moons with *Celestia* reveals:

- Many small (<100 km) moons among rings
- Some *shepherd* moons: Pandora, Prometheus
- "*Moonlets*" in gaps: Daphnis in Keeler Gap, Pan in Encke Gap
- Co-orbital moons: Janus and Epimetheus
- Calypso and Telesto are in Lagrange points ((L4, L5) of Tethys' orbit
- Most big moons tidally locked and orbit CCW in the same plane
- Outer moons (Phoebe) have more eccentric orbits.

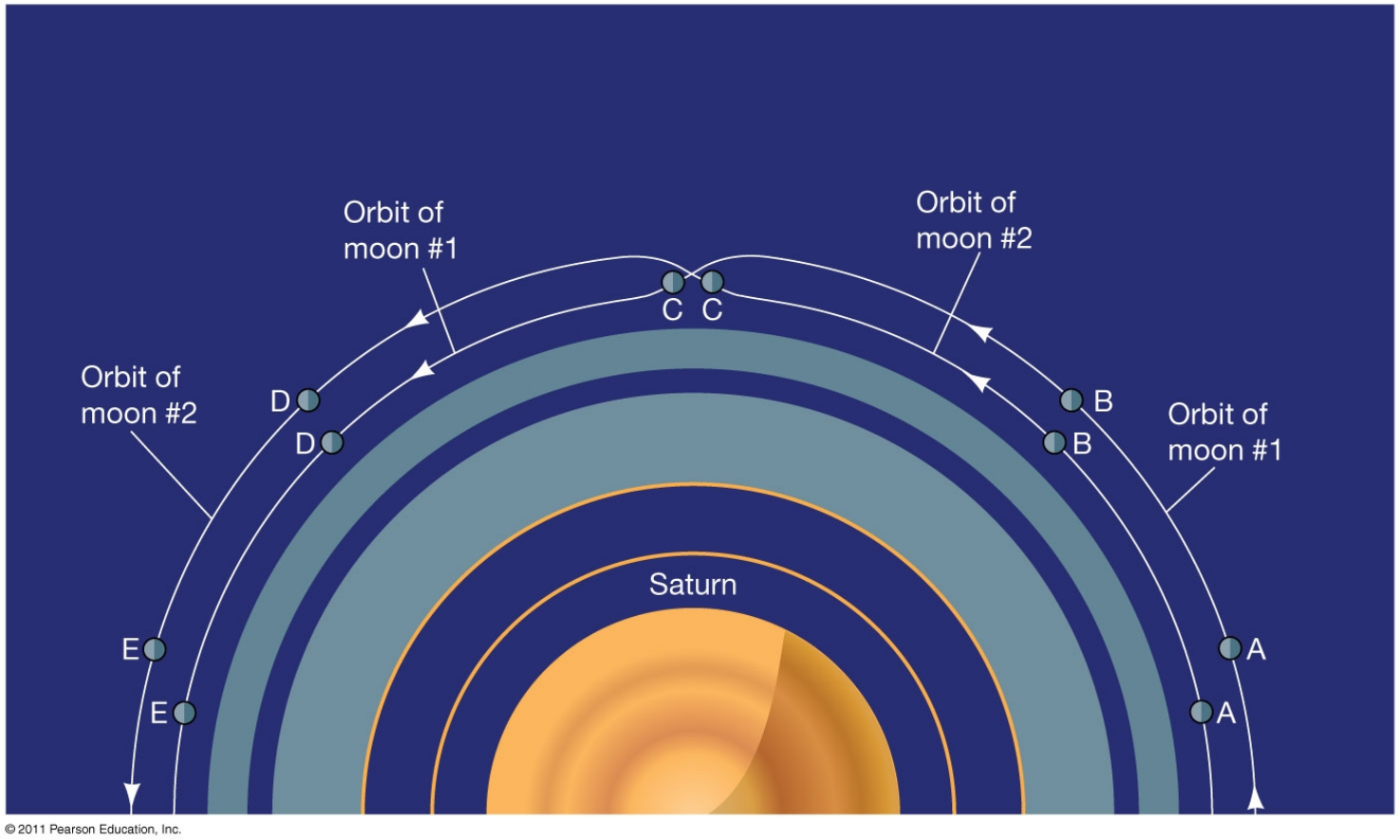
12.5 The Moons of Saturn



Daphnis in the Keeler Gap.

11.5 The Moons of Saturn

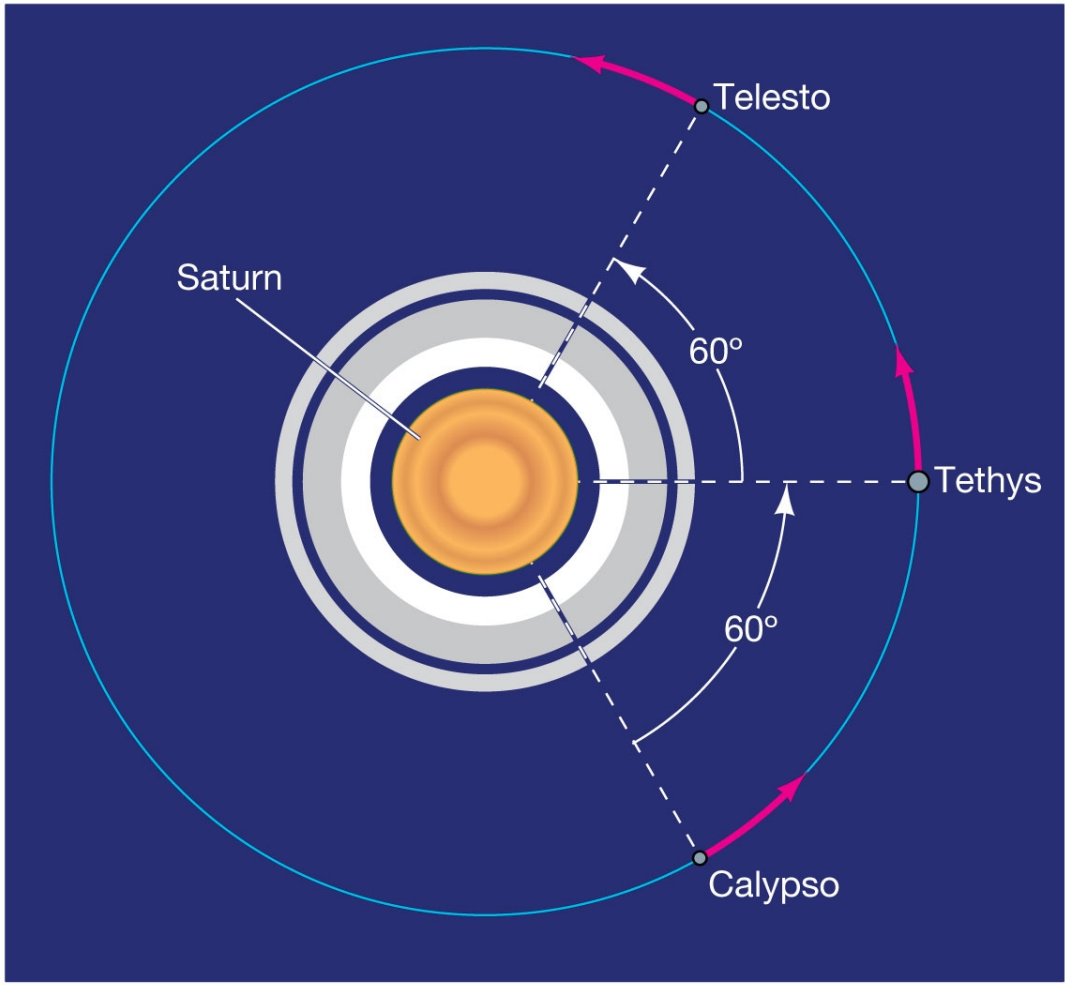
Janus and Epimetheus



Orbital exchange occurs every ~ 4 yrs.

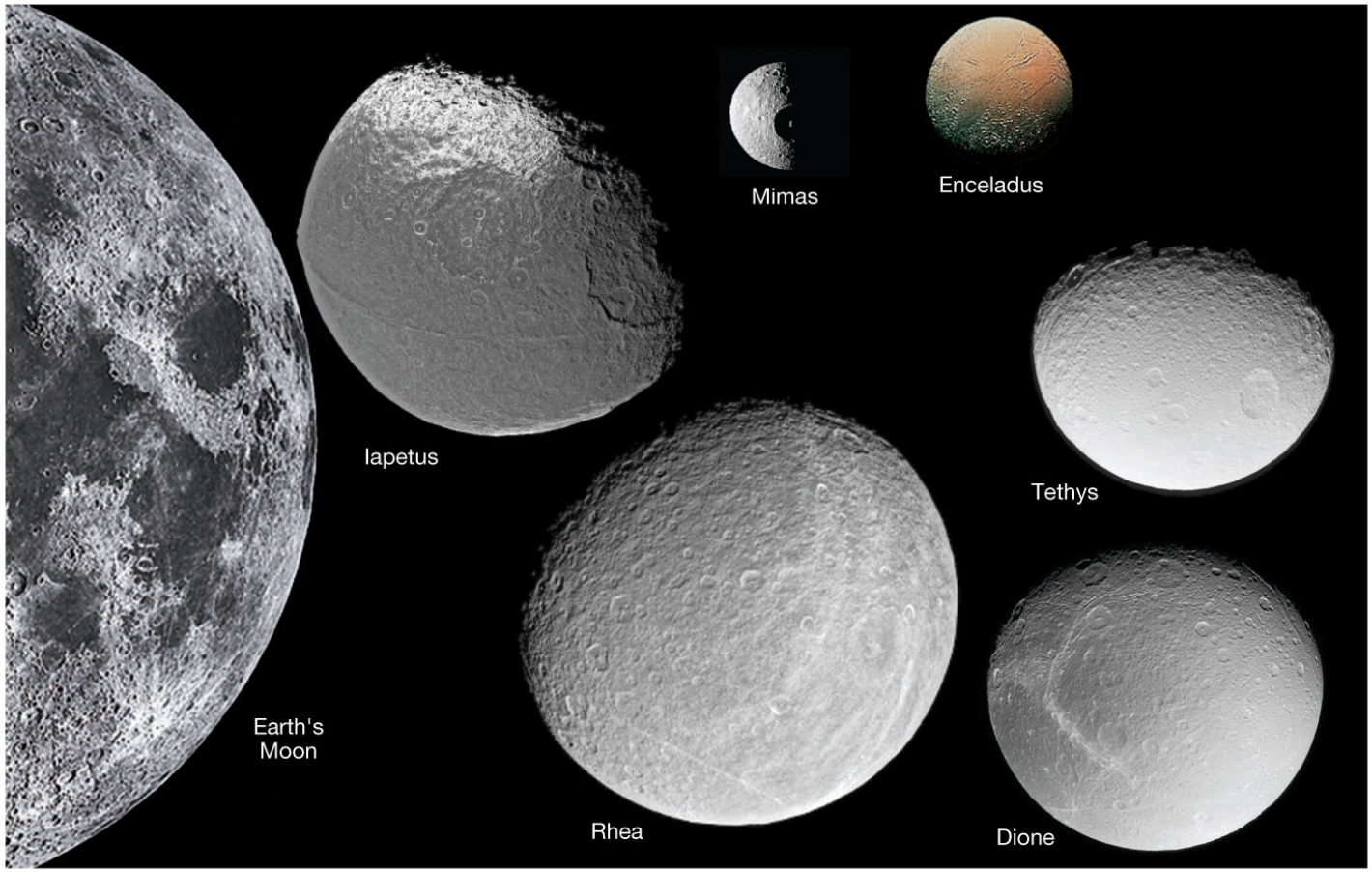
12.5 The Moons of Saturn

Two more moons are at the Lagrangian points of Tethys



12.5 The Moons of Saturn

This image shows Saturn's mid-sized moons

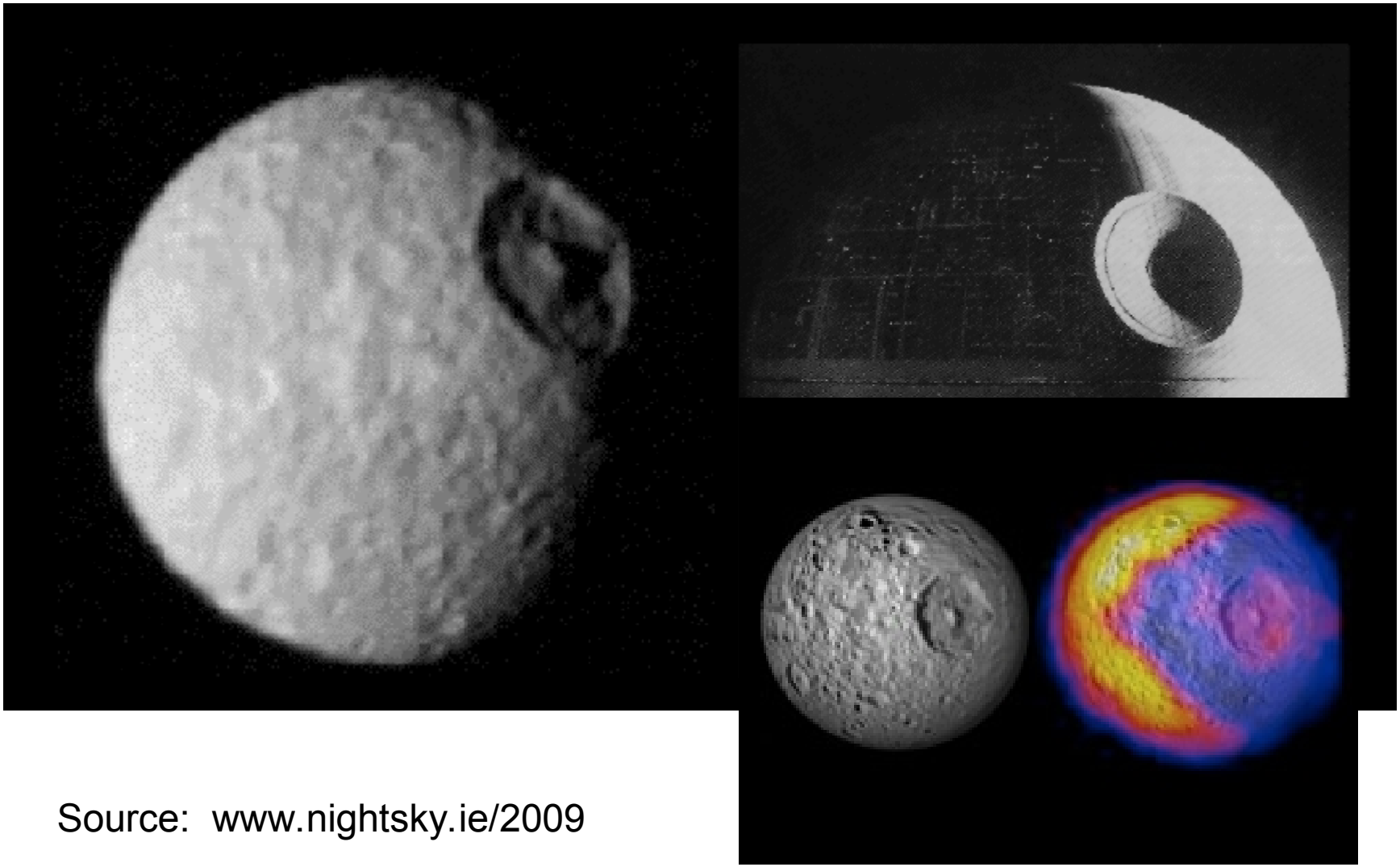


12.5 The Moons of Saturn

- Mimas, Enceladus, Tethys, Dione, and Rhea all orbit between 3 and 9 planetary radii from Saturn, and all are tidally locked—this means they have "leading" and "trailing" surfaces
- Iapetus (the "walnut") orbits 59 radii away and is also tidally locked.
- Mimas = the "death star"
- Tethys = has two "tagalong" moons

12.5 The Moons of Saturn

Mimas – stranger than fiction?



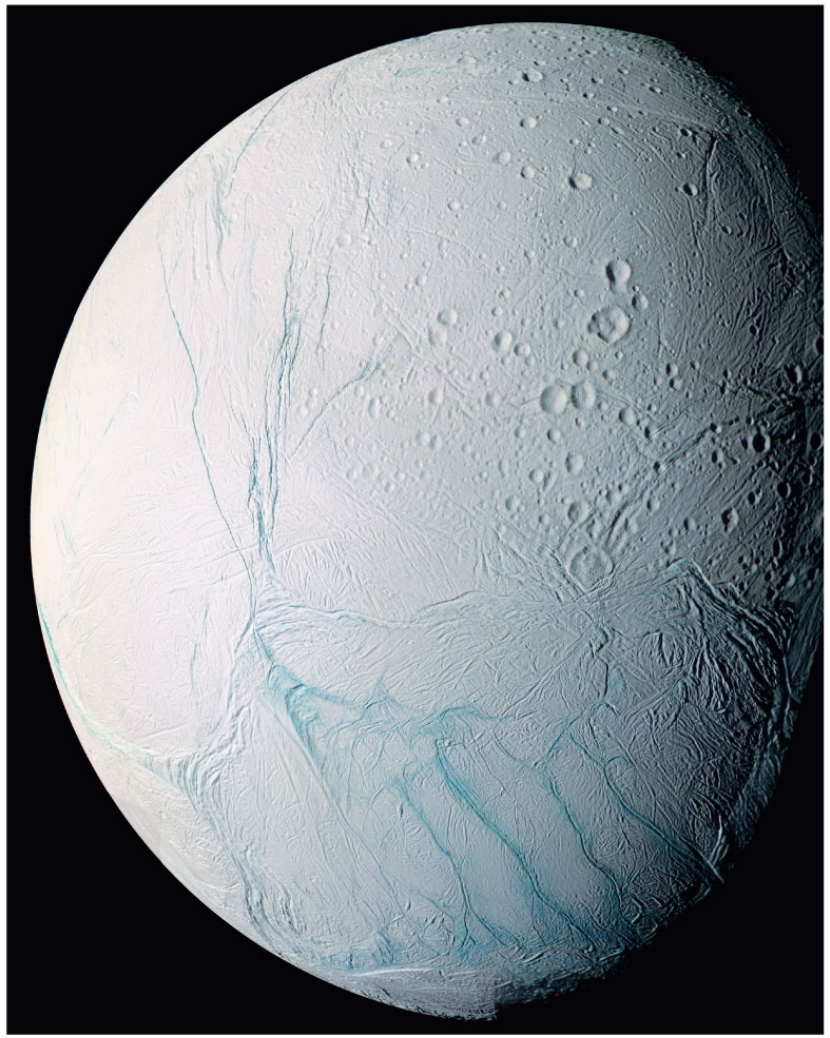
Source: www.nightsky.ie/2009

12.5 The Moons of Saturn

Surface of Enceladus is young near the “Tiger Stripes”.

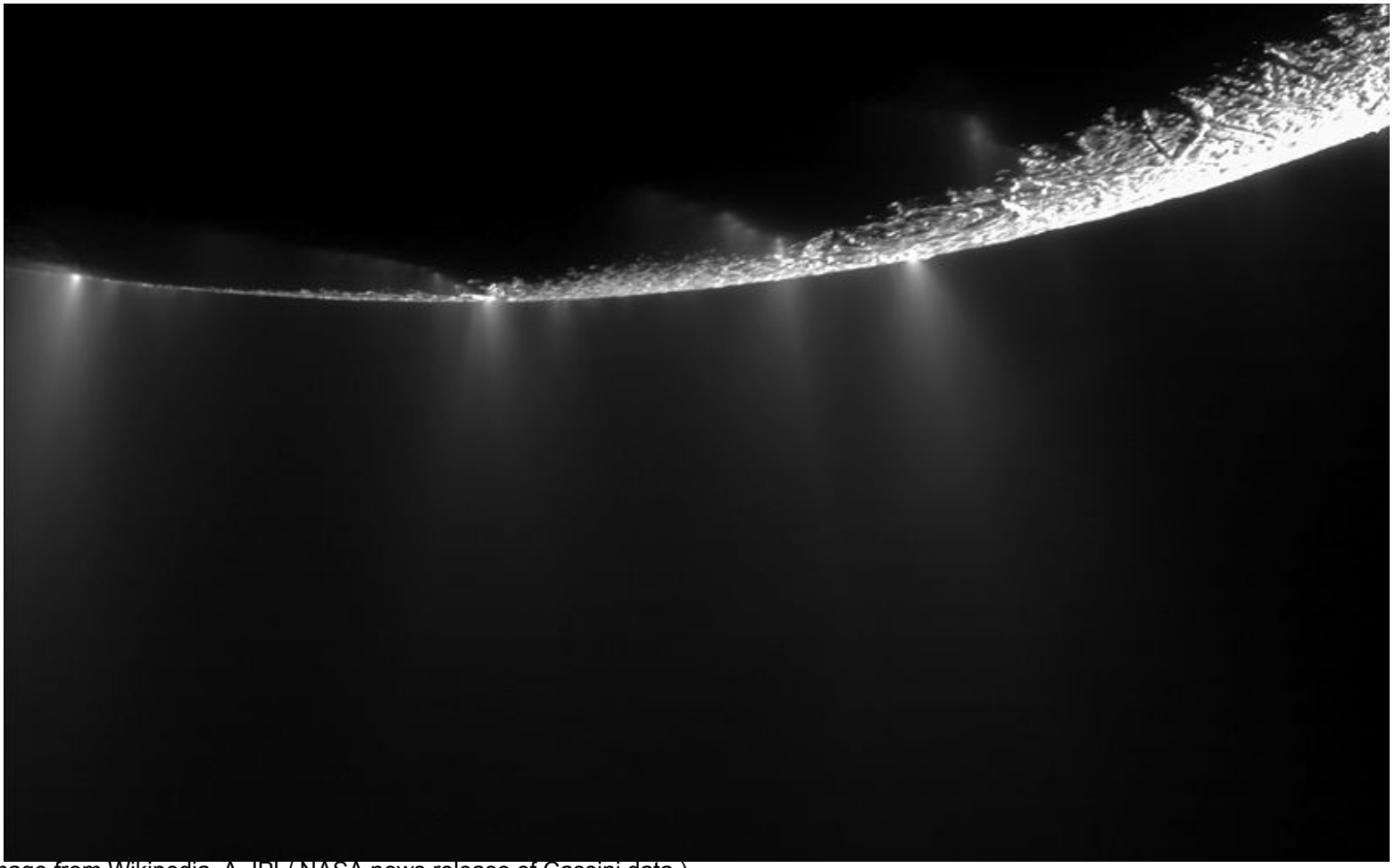
Highest albedo in solar system at 99%.

(Previous collage makes it look more tan colored.)



12.5 The Moons of Saturn

The “Tiger striped” region of Enceladus also produces jets or water geysers. (Likely source of E ring.)



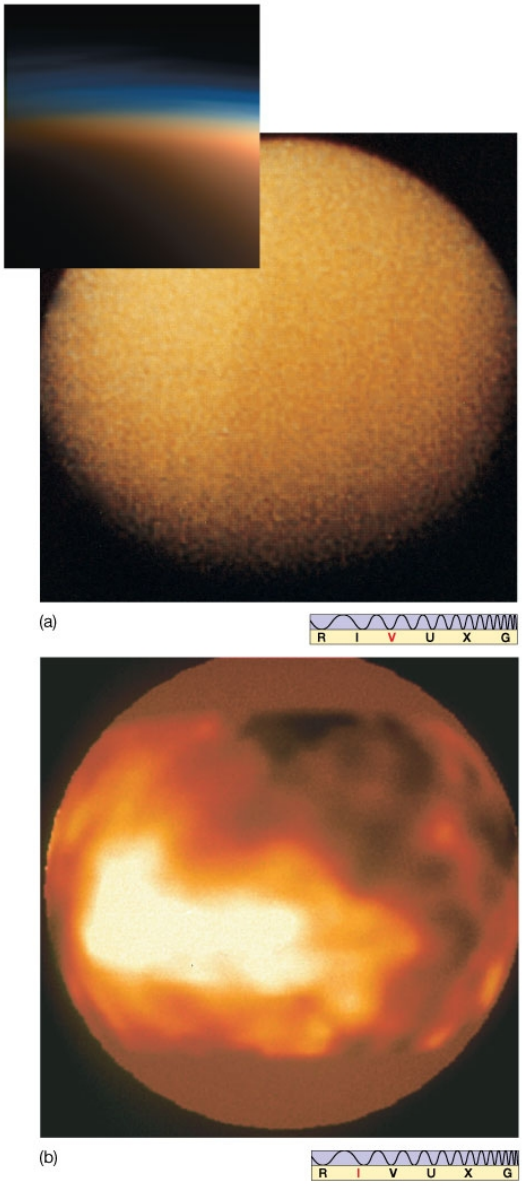
(Image from Wikipedia. A JPL/ NASA news release of Cassini data.)

12.5 The Moons of Saturn

Titan is almost as big as Ganymede.

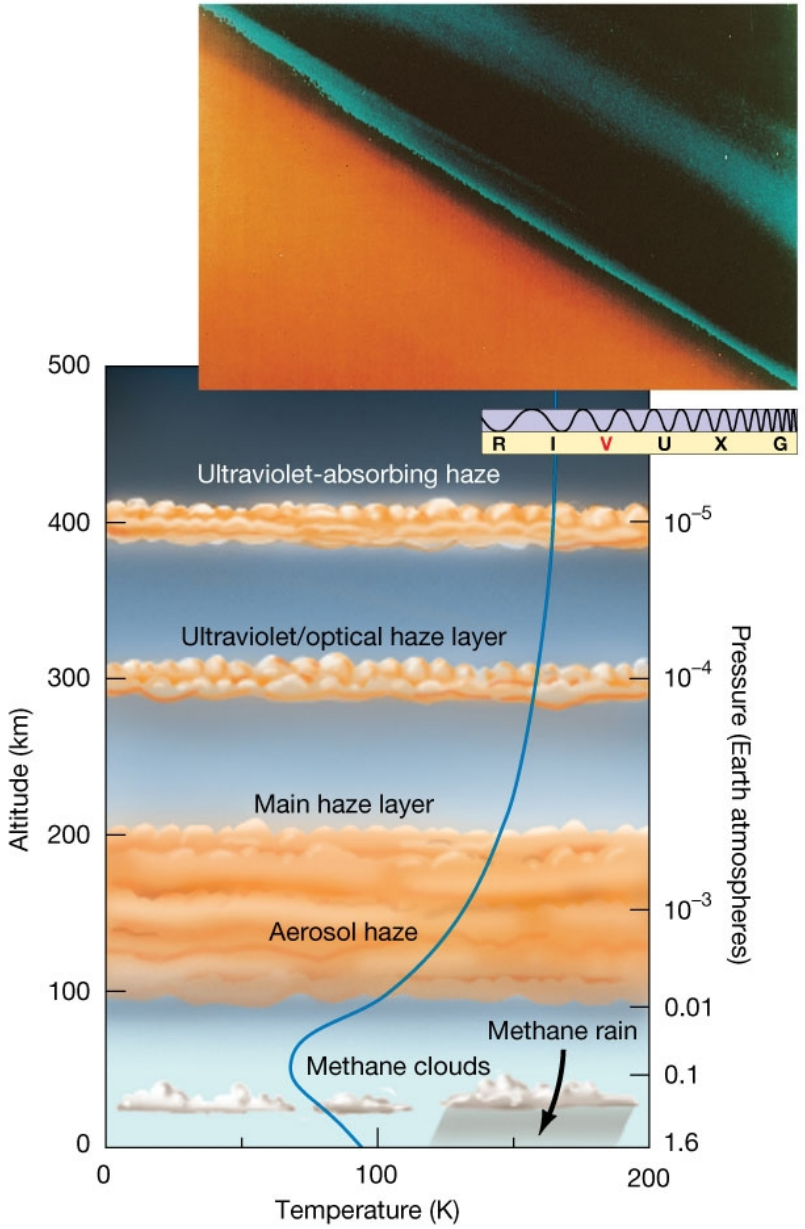
Its atmosphere is thicker and denser than Earth's; mostly nitrogen (96% N_2) and methane (3.5% CH_4)

Need Radio or IR to see deeper details.



12.5 The Moons of Saturn

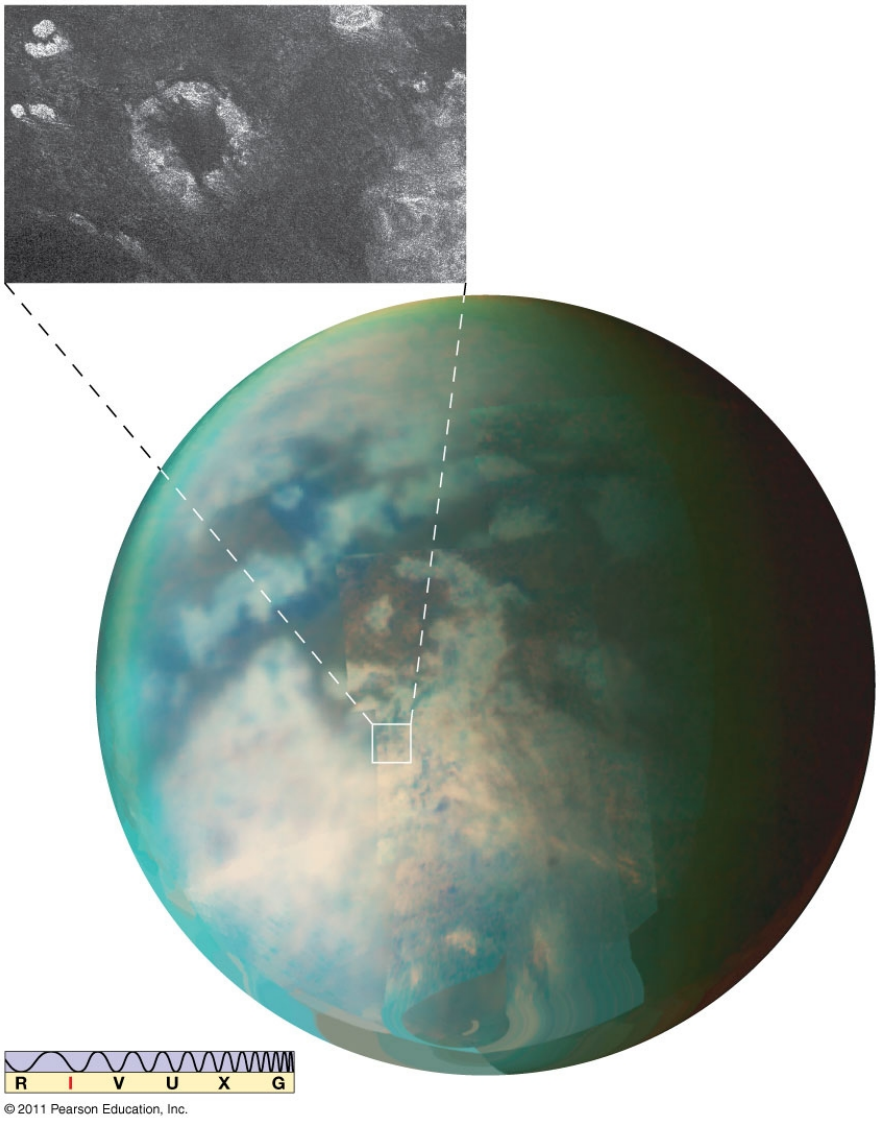
Trace chemicals in Titan's atmosphere make it chemically complex



12.5 The Moons of Saturn

Some surface features on Titan are visible in this *Cassini* infrared image.

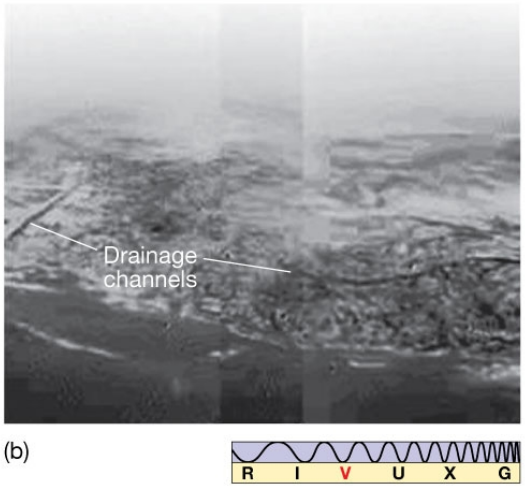
Titan has lakes of liquid hydrocarbons like methane, ethane, propane, and carbon monoxide – organic chemistry!



12.5 The Moons of Saturn

The *Huygens* spacecraft has landed on Titan and returned images directly from the surface

(a)



(b)

(c)

The Moons of Uranus and Neptune

Uranus (discovered by Herschel in 1781) has 4 moons visible in small telescopes.)

It has about 23 other Moons discovered between 1948 and 2008.

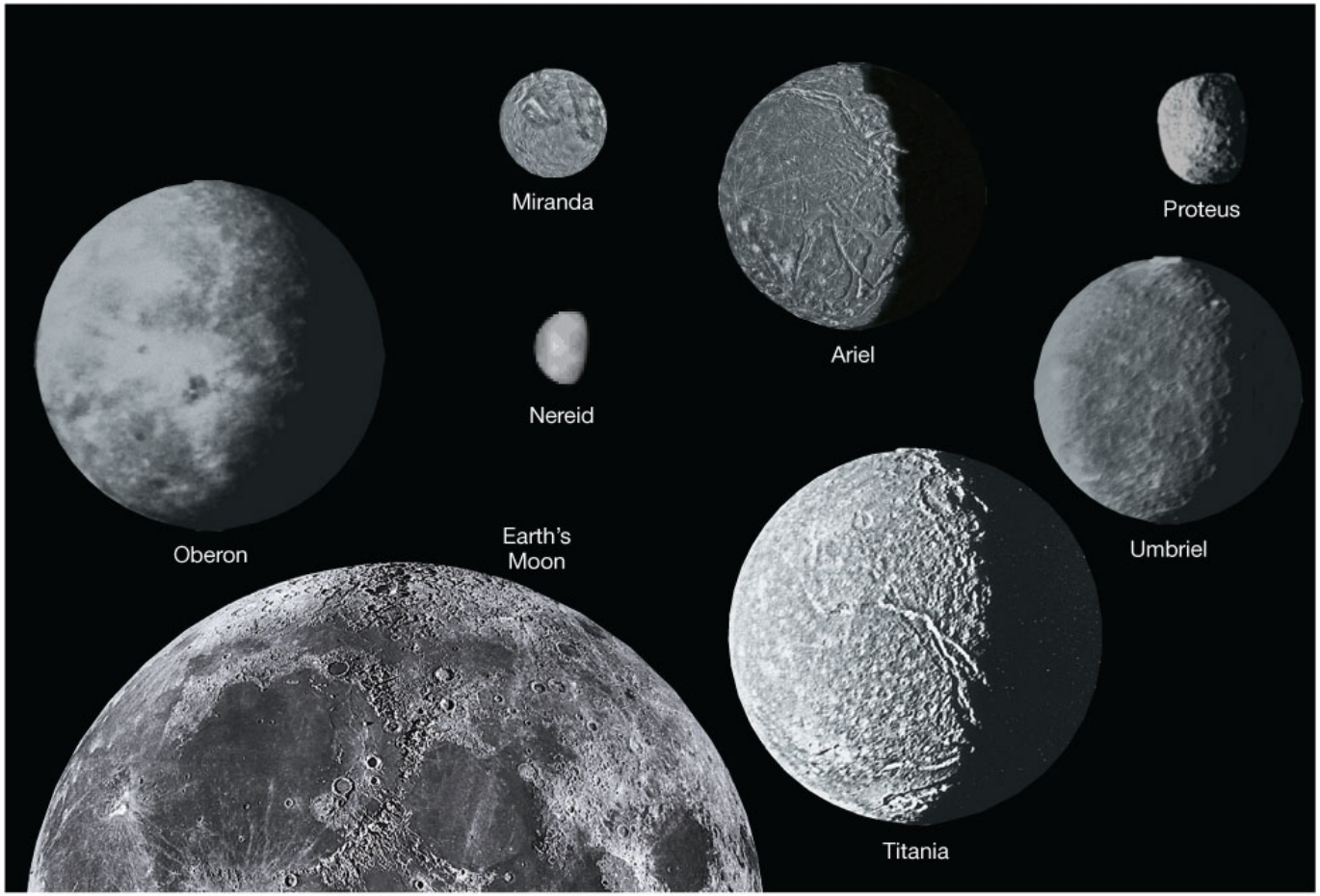
Named after characters in literature of Shakespeare and Pope.

The Moons of Uranus and Neptune

Neptune was discovered in 1846, after analysis of Uranus's orbit indicated its presence

Arrows point to Triton and Nereid.

13.5 The Moon Systems of Uranus and Neptune

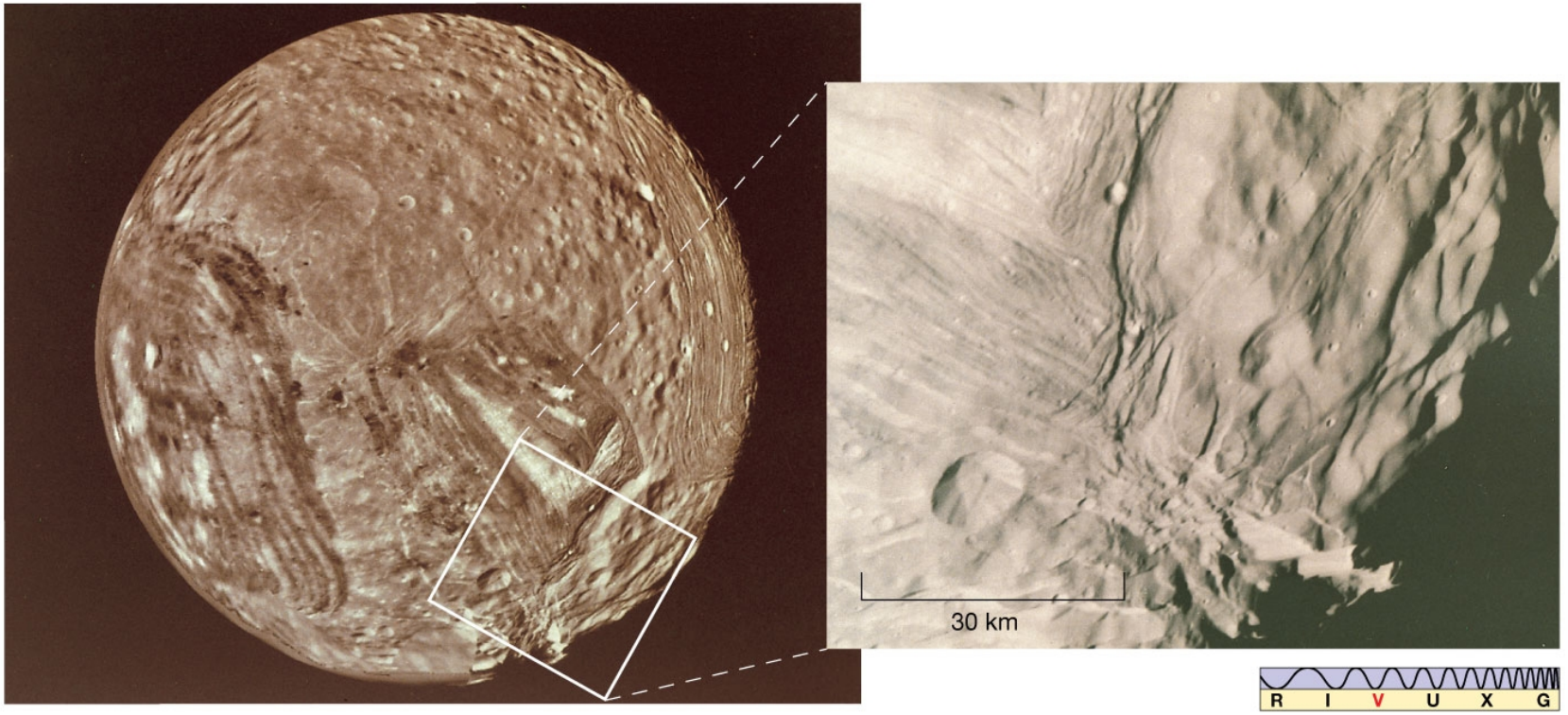


13.5 The Moon Systems of Uranus

- Uranus has 27 moons, five of which are major: Miranda, Ariel, Umbriel, Titania, and Oberon
- Similar to Saturn's medium-sized moons, except that all are much less reflective (Umbriel is the darkest)
- About 9 irregular moons were probably captured
- Orbital resonances, tidal locking, and tidal "kneading" probably occurred with major moons and inner moons.

13.5 The Moon Systems of Uranus and Neptune

Miranda is the most unusual moon of Uranus; origin of the cracks and grooves is uncertain, however ...



Miranda has the most inclined and eccentric orbit of the large Uranian moons. Collision?

13.5 The Moons of Neptune

Neptune has 14 moons, but only two can be seen from Earth: Triton and Nereid

Triton is in a retrograde orbit and is destined to crash onto Neptune (in ~10^8 yrs)

Nereid's orbit is highly eccentric

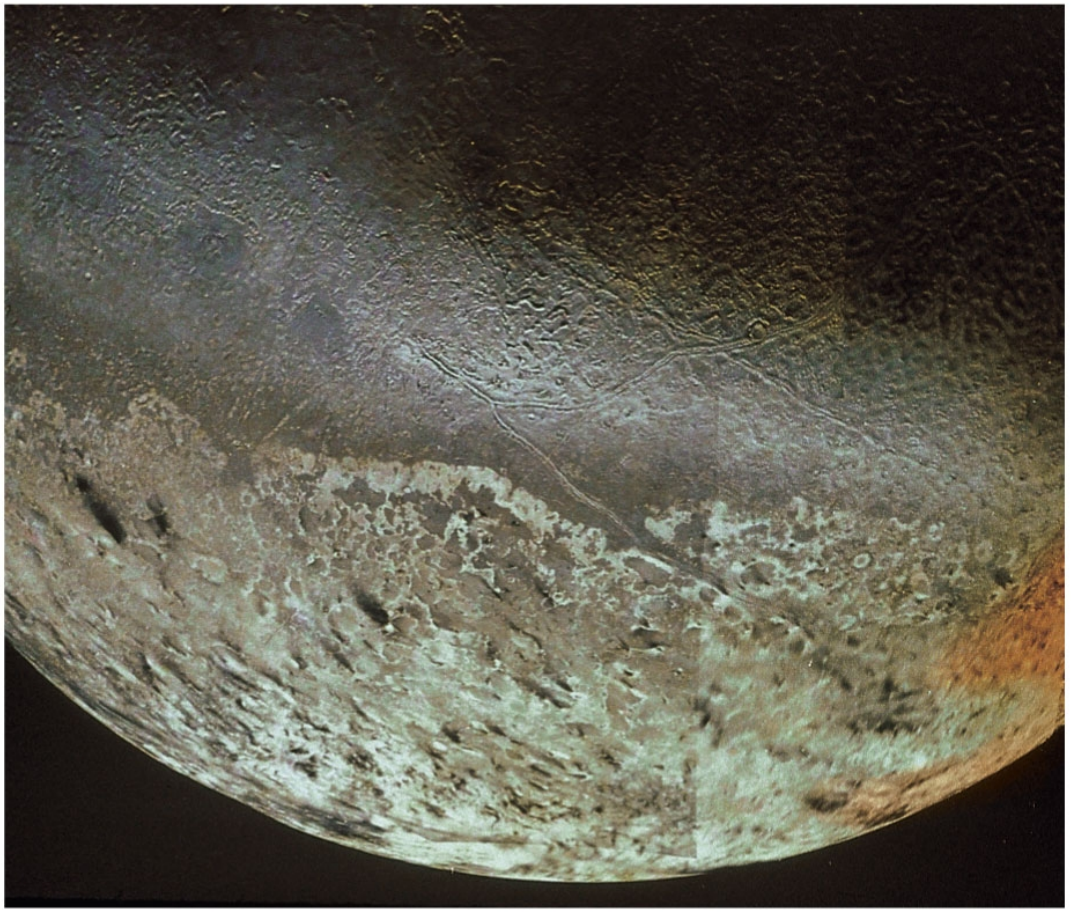
Text: "No dynamically regular moons around Neptune" (Actually, there are 7!)

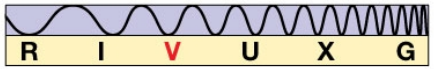
Triton's surface has few craters, indicating an active surface. T~37 K! So Nitrogen ice is present (esp. near poles) along with dry ice, methane ice, etc.

13.5 The Moons of Neptune

Triton – the muskmelon moon.

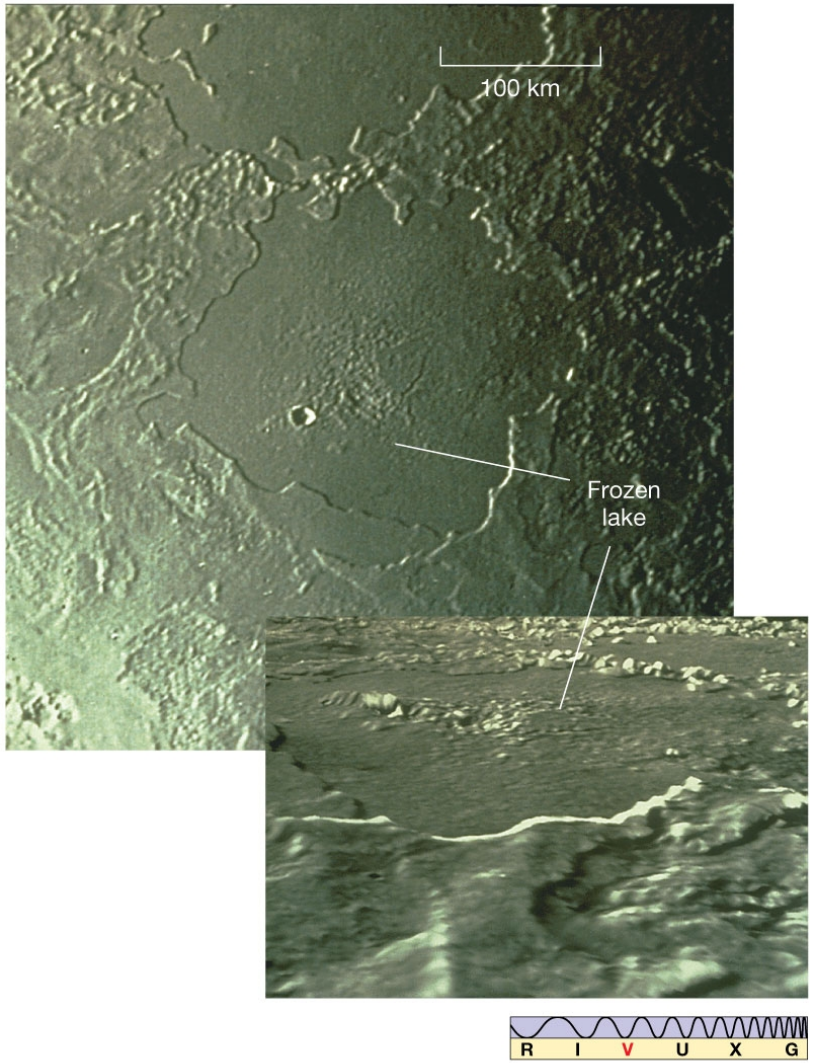
Nitrogen geysers have been observed on Triton, contributing to the surface features





13.5 The Moon Systems of Uranus and Neptune

Also, there appear to be ice volcanoes



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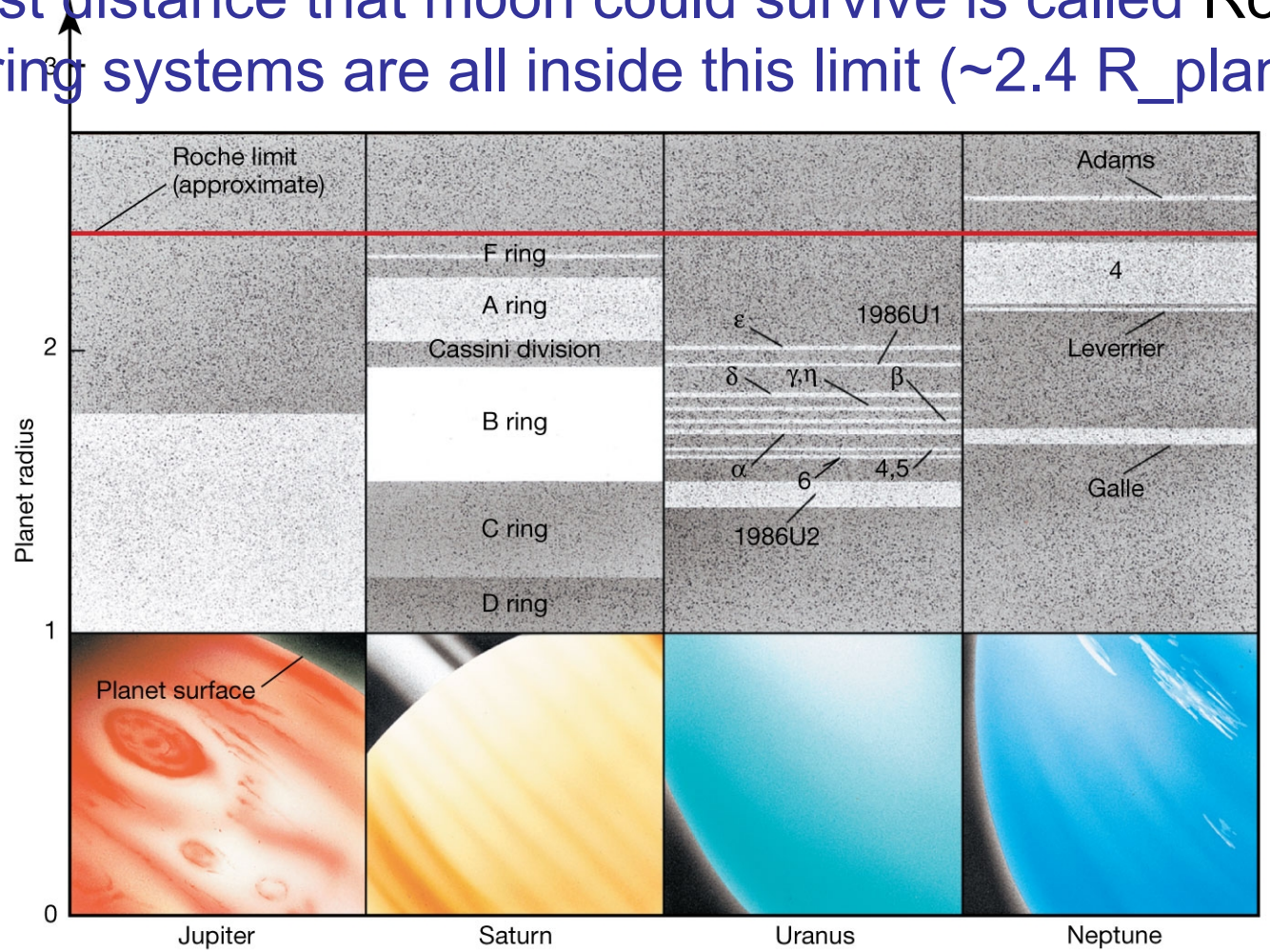
12.4 Saturn's Spectacular Ring System

Closest distance that moon could survive is called Roche limit; ring systems are all inside this limit (~2.4 R_planet)



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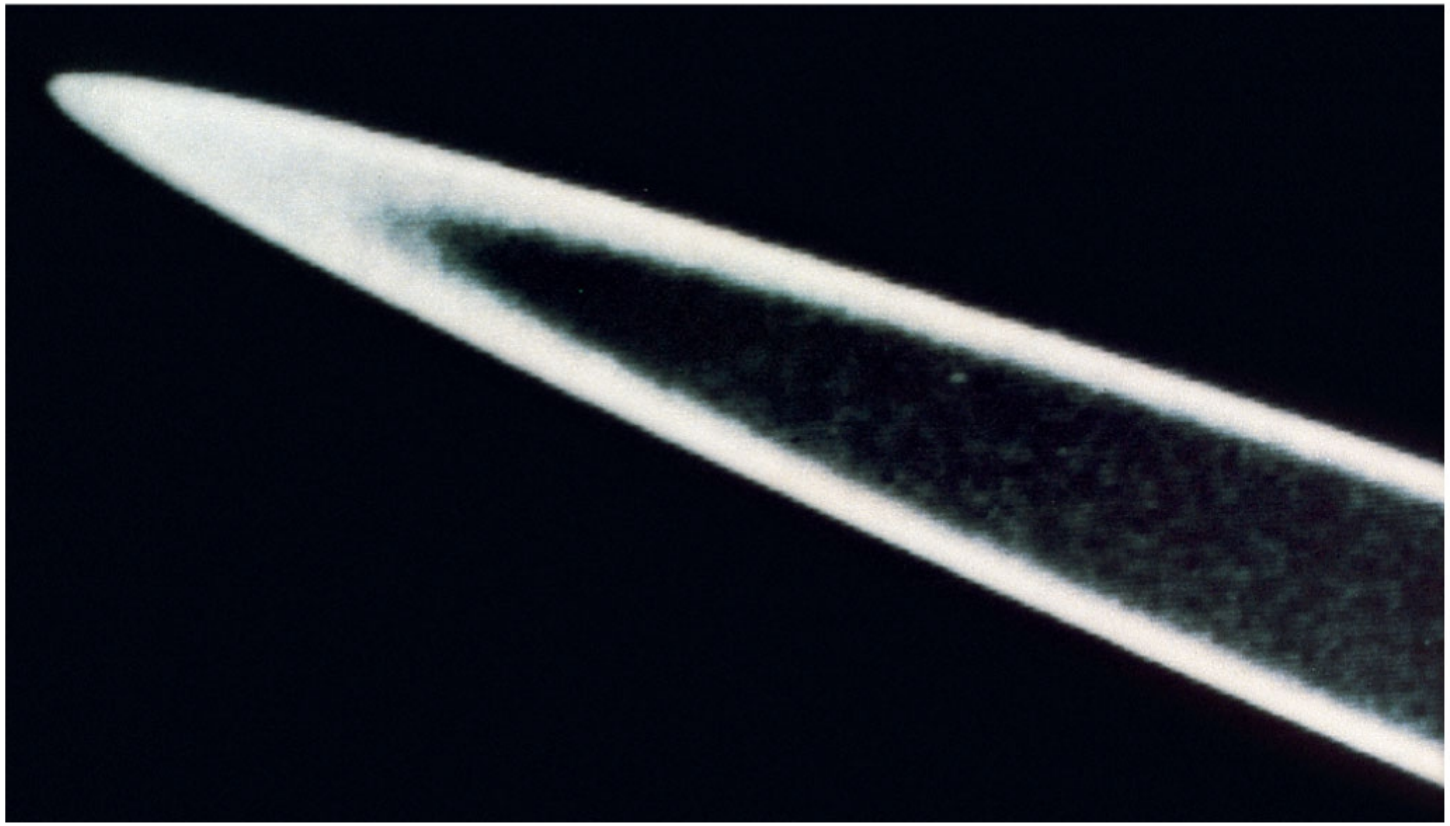
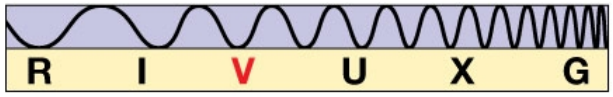
11.6 Jupiter's Ring

Jupiter was found to have a close-in, diffuse ring

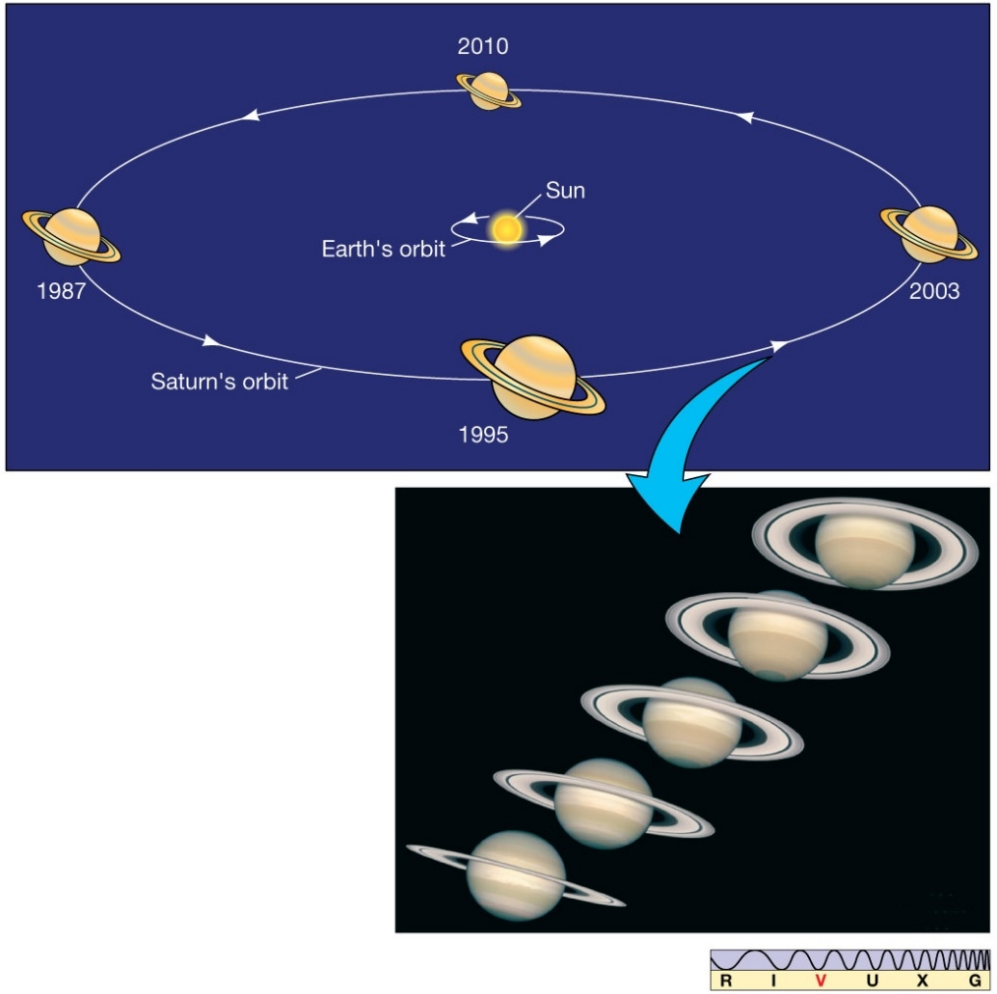




12.4 Saturn's Spectacular Ring System

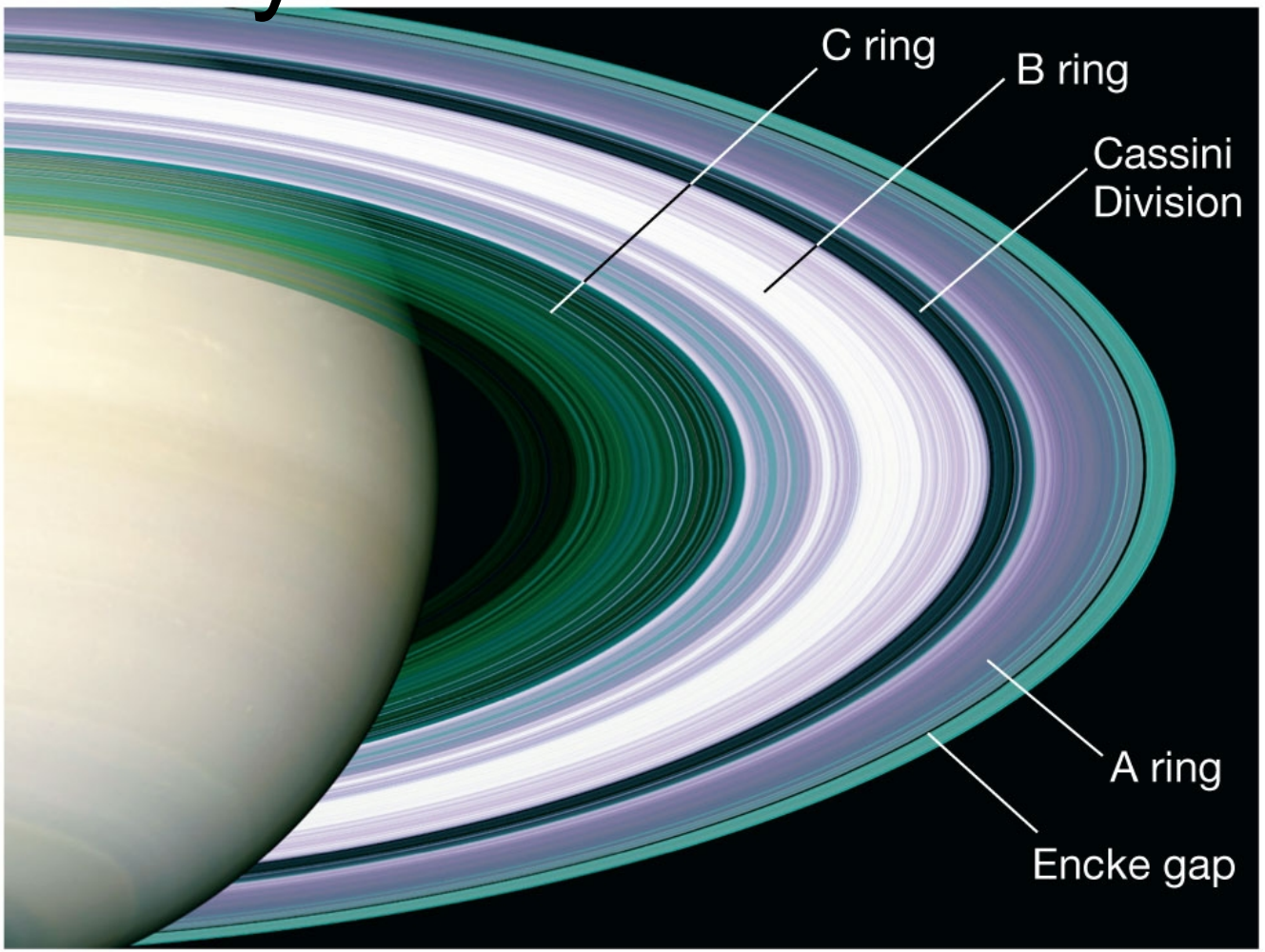
Saturn has an extraordinarily large and complex ring system, which was visible even to the first telescopes.

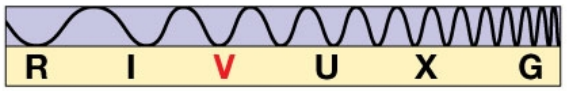
Ring-plane crossings occur every ~15 years.



12.4 Saturn's Spectacular Ring System

Overview of the ring system





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12.4 Saturn's Spectacular Ring System

Ring particles range in size from fractions of a millimeter to tens of meters

Composition: Water ice—similar to snowballs

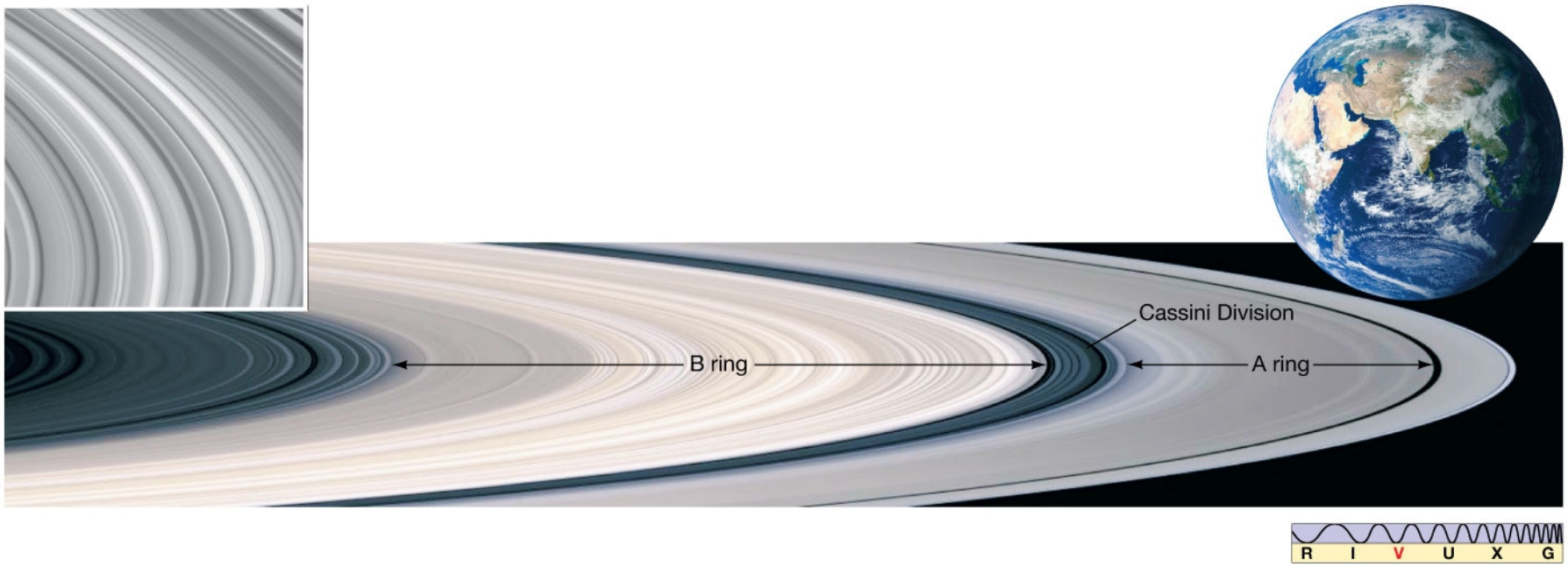
Why rings?

- Too close to planet for moon to form—tidal forces would tear it apart

12.4 Saturn's Spectacular Ring System

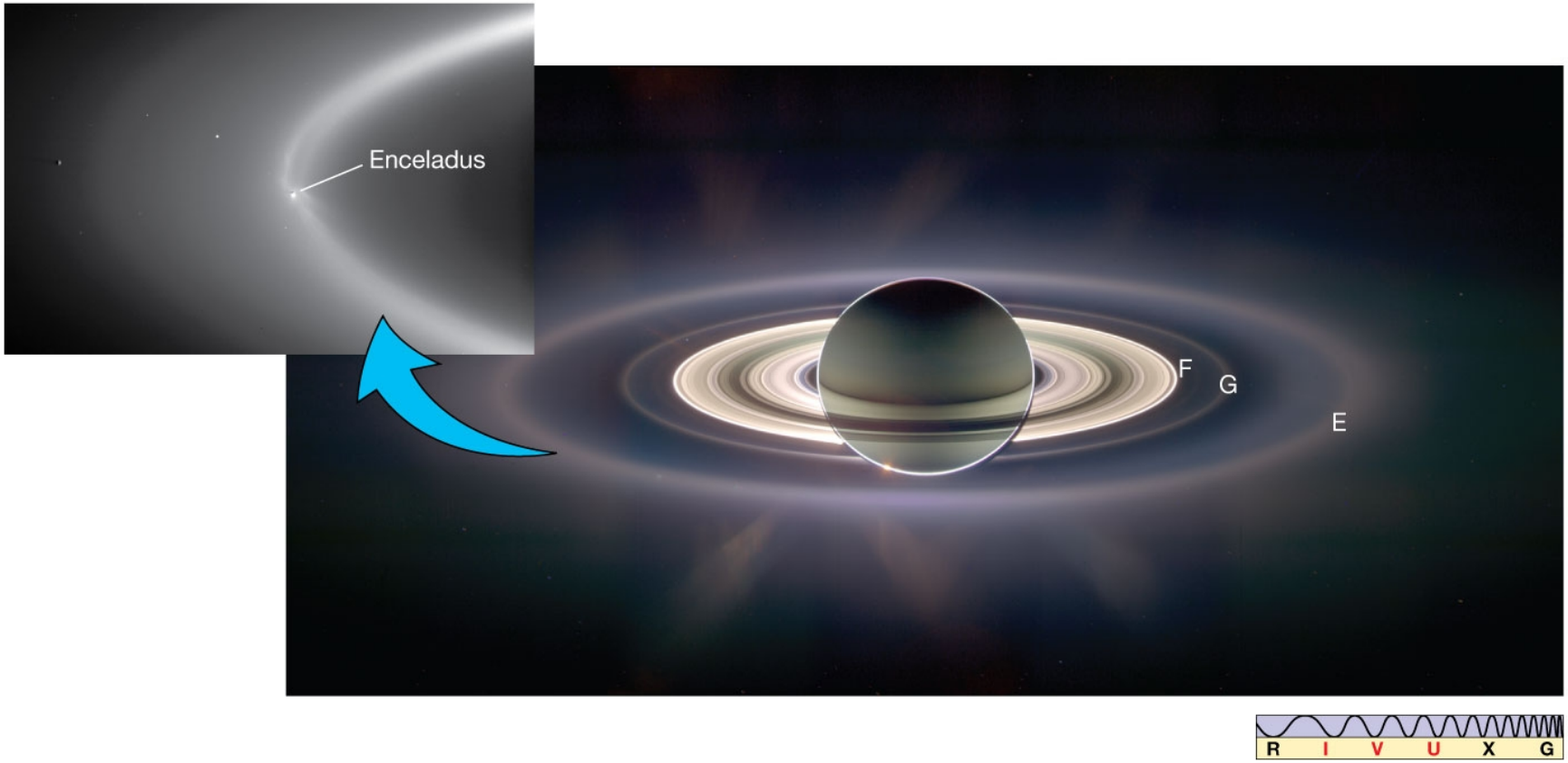
Voyager probes showed Saturn's rings to be much more complex than originally thought

(Earth is shown on the same scale as the rings)

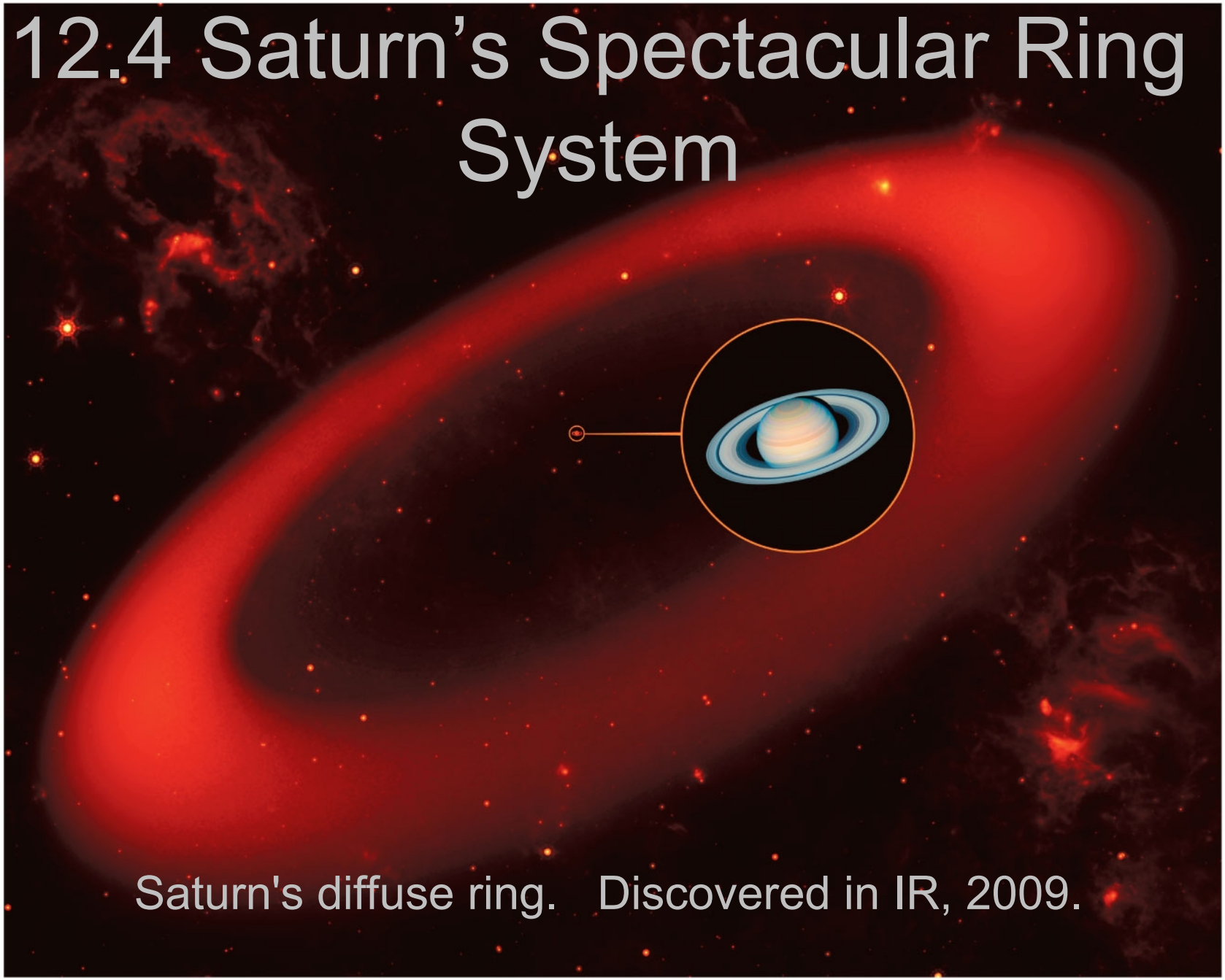


12.4 Saturn's Spectacular Ring System

This backlit view shows the fainter F, G, and E rings



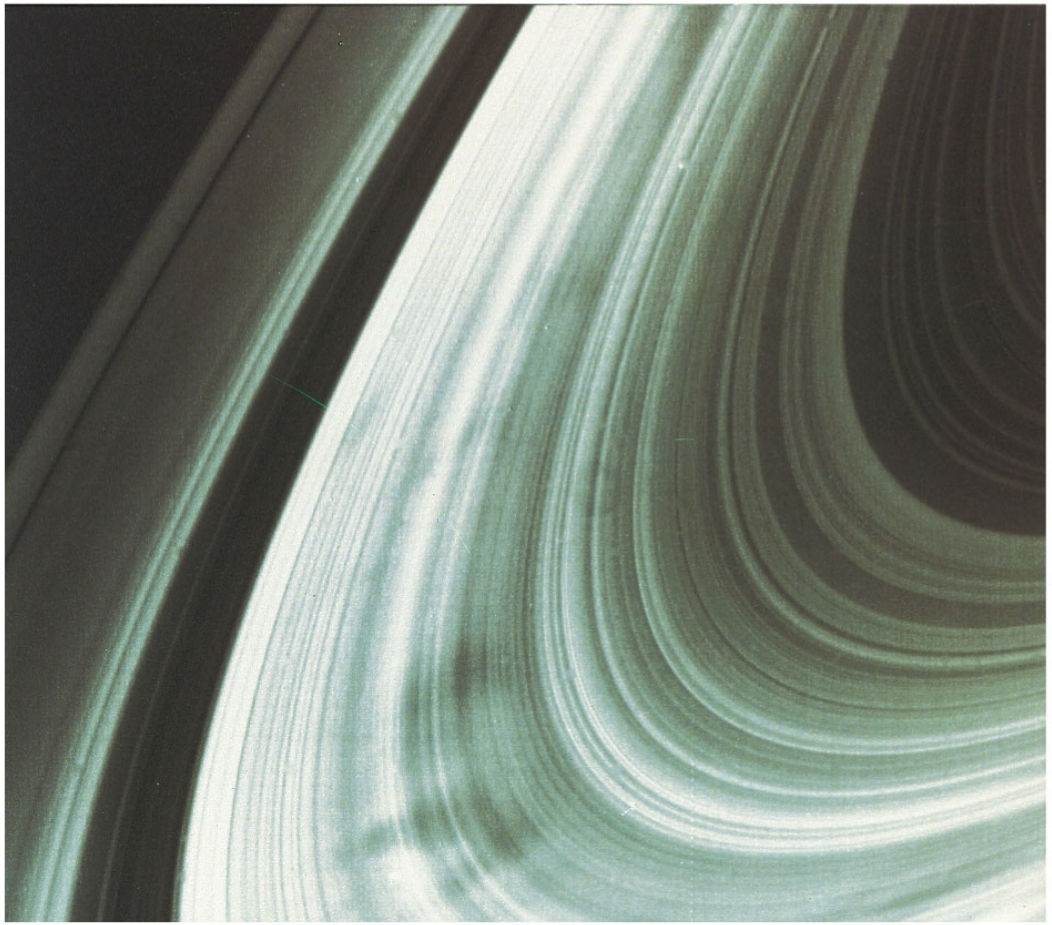
12.4 Saturn's Spectacular Ring System



Saturn's diffuse ring. Discovered in IR, 2009.

12.4 Saturn's Spectacular Ring System

Voyager also found radial "spokes" that formed and then dissipated; this probably happens frequently.

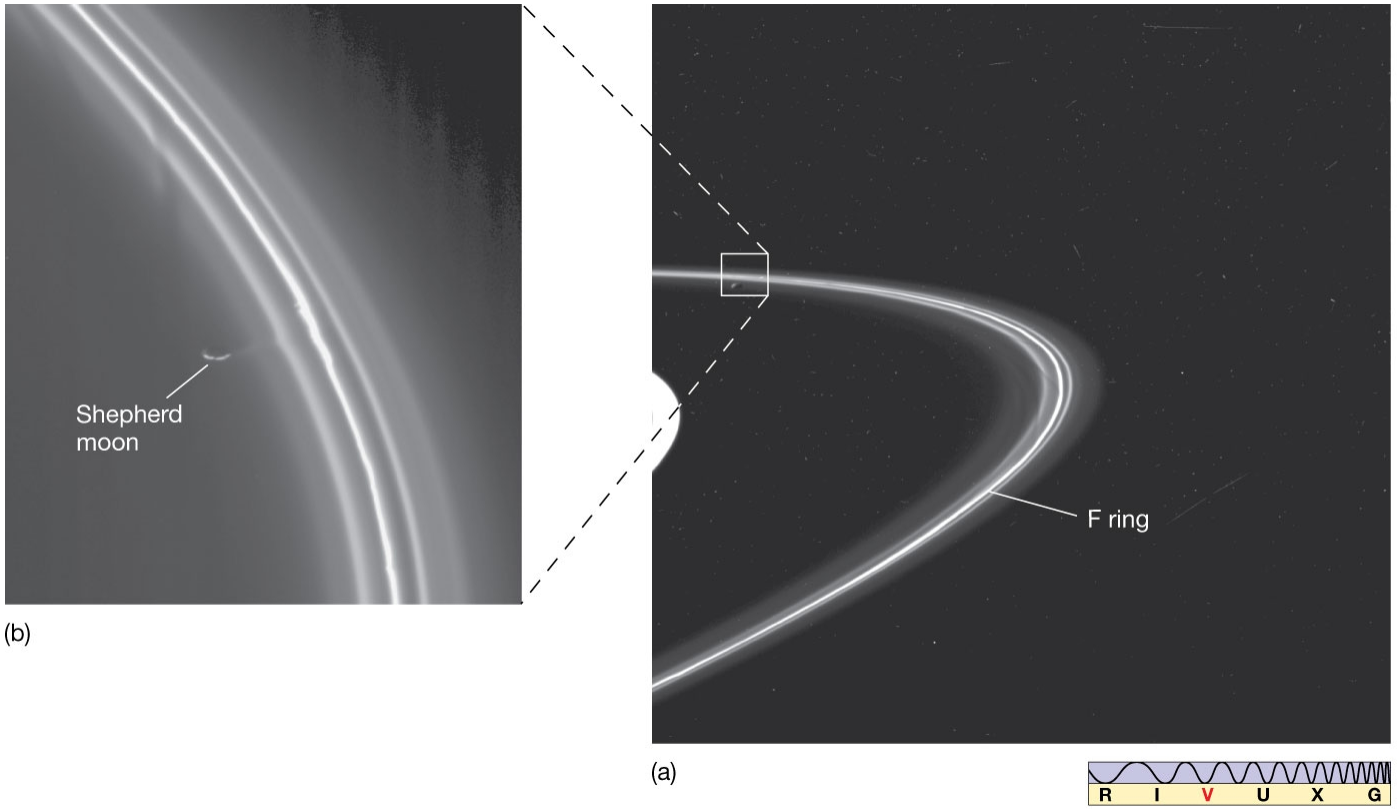


12.4 Saturn's Spectacular Ring System

- Other edges and divisions in rings are also the result of shepherd moons or resonance
- "Shepherd" moon Atlas defines outer edge of A ring through gravitational interactions

12.4 Saturn's Spectacular Ring System

Strangest ring is the F ring; it appears to have braids and kinks. It is just beyond the A ring.



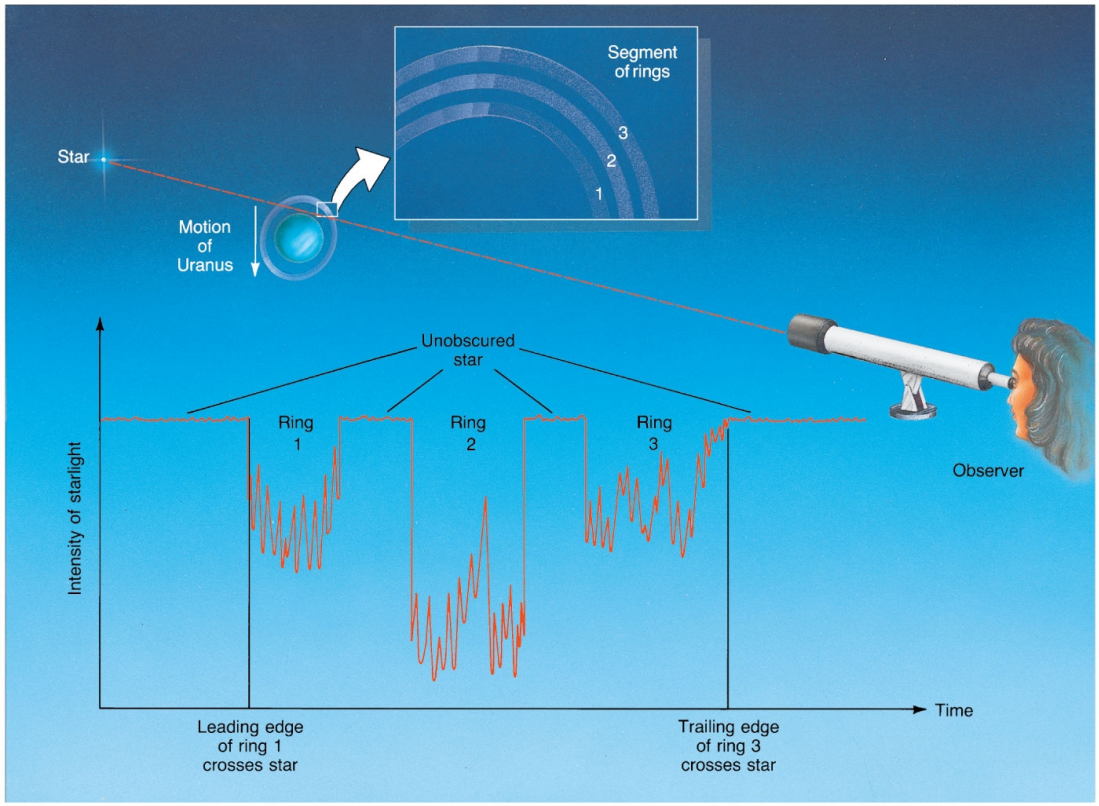
12.4 Saturn's Rings

How and when did they form?

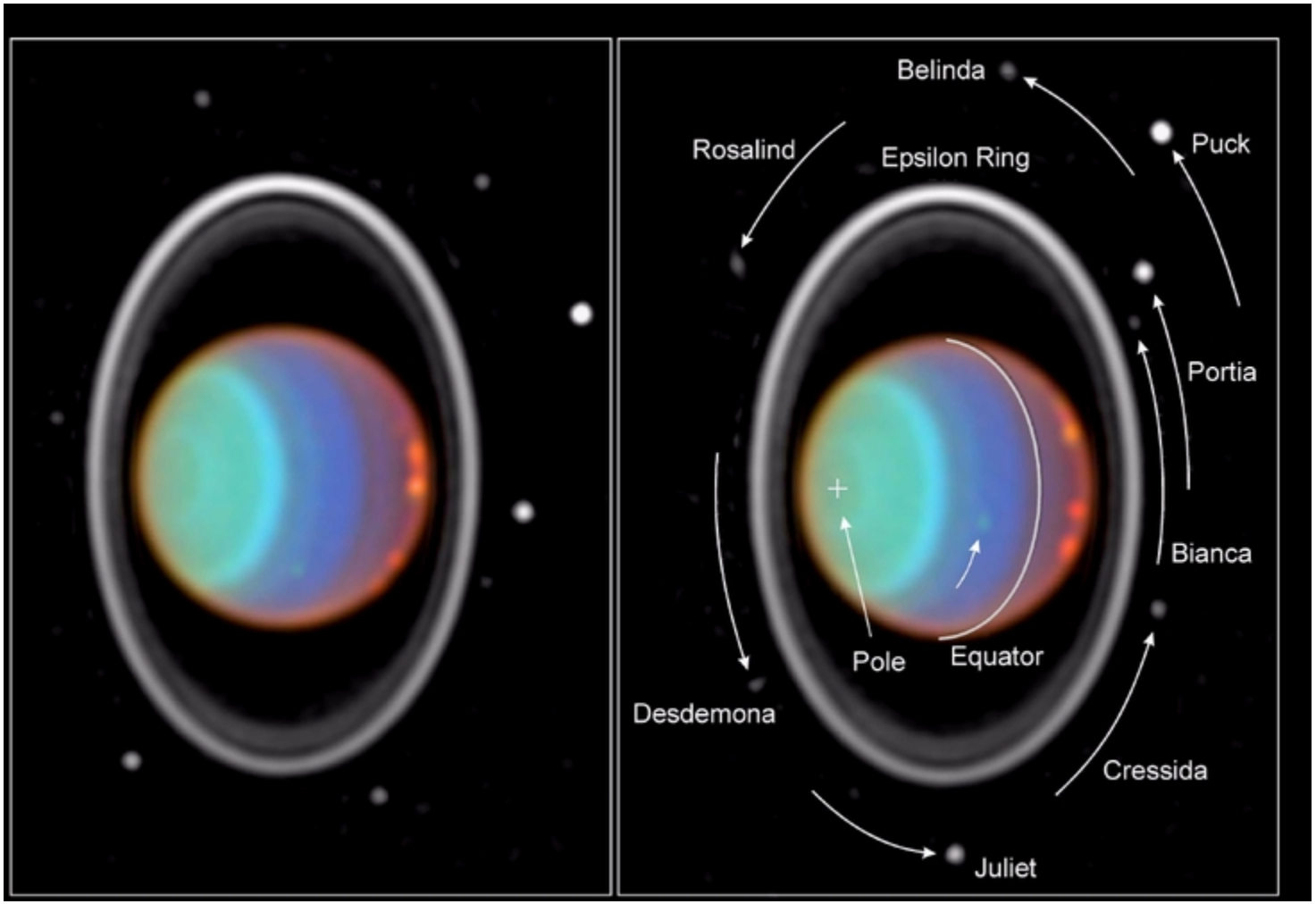
- Probably too active to have lasted since birth of solar system.
- Not all rings may be the same age. B may be very old.
- Either must be continually replenished, or are the result of a catastrophic event.
  - Can you think of a time when a comet or asteroid flew close in too a Jovian planet? What if it hit a moon?

13.6 The Rings of the Outermost Jovian Planets

Uranus and Neptune have faint ring systems, detected during stellar occultations

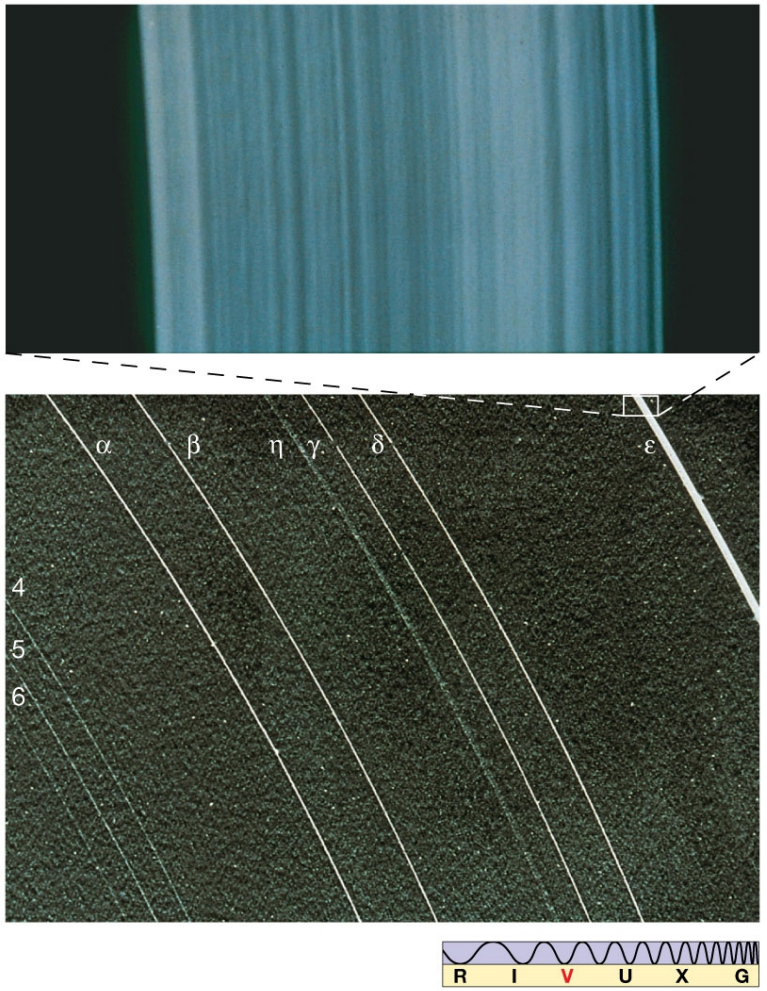


Uranus' Rings (and inner moons)



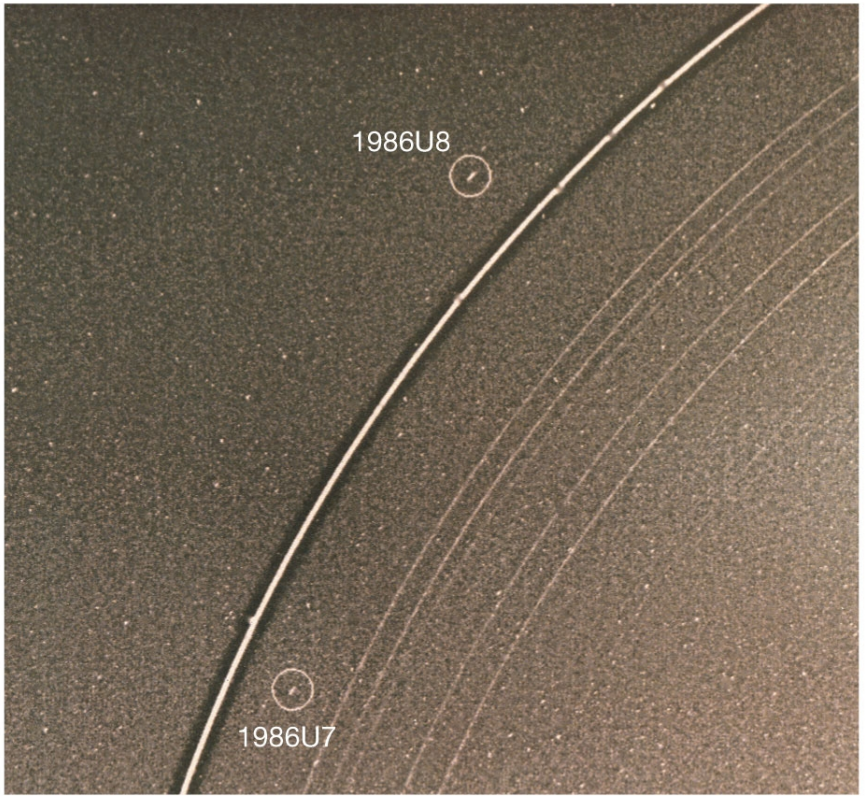
13.6 The Rings of the Outermost Jovian Planets

Uranus's rings are narrow



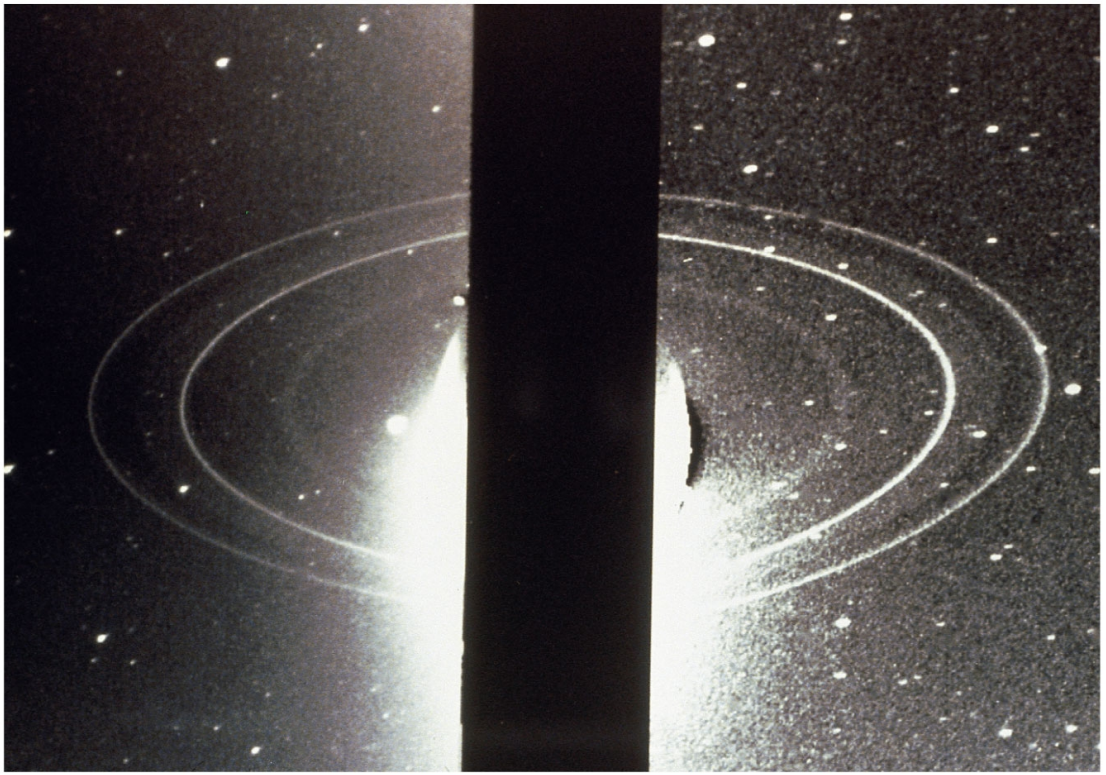
13.6 The Rings of the Outermost Jovian Planets

Two shepherd moons keep the epsilon ring from diffusing



13.6 The Rings of the Outermost Jovian Planets

Neptune has five rings: three narrow and two wide



Summary of Chapter 11

- Jupiter is the largest planet in the solar system
- Rotates rapidly
- Cloud cover has three main layers, forms zone and belt pattern
- Great Red Spot is a very stable storm
- Pressure and density of atmosphere increase with depth; atmosphere becomes liquid and then “metallic”

Summary of Chapter 11 (cont.)

- Relatively small rocky core (but still about 10x size of Earth)
- Still radiating energy from original formation
- 79+ moons, four very large
- Io: active volcanoes, due to tidal forces
- Europa: cracked, icy surface; may be liquid water underneath
- Ganymede and Callisto: similar; rock and ice