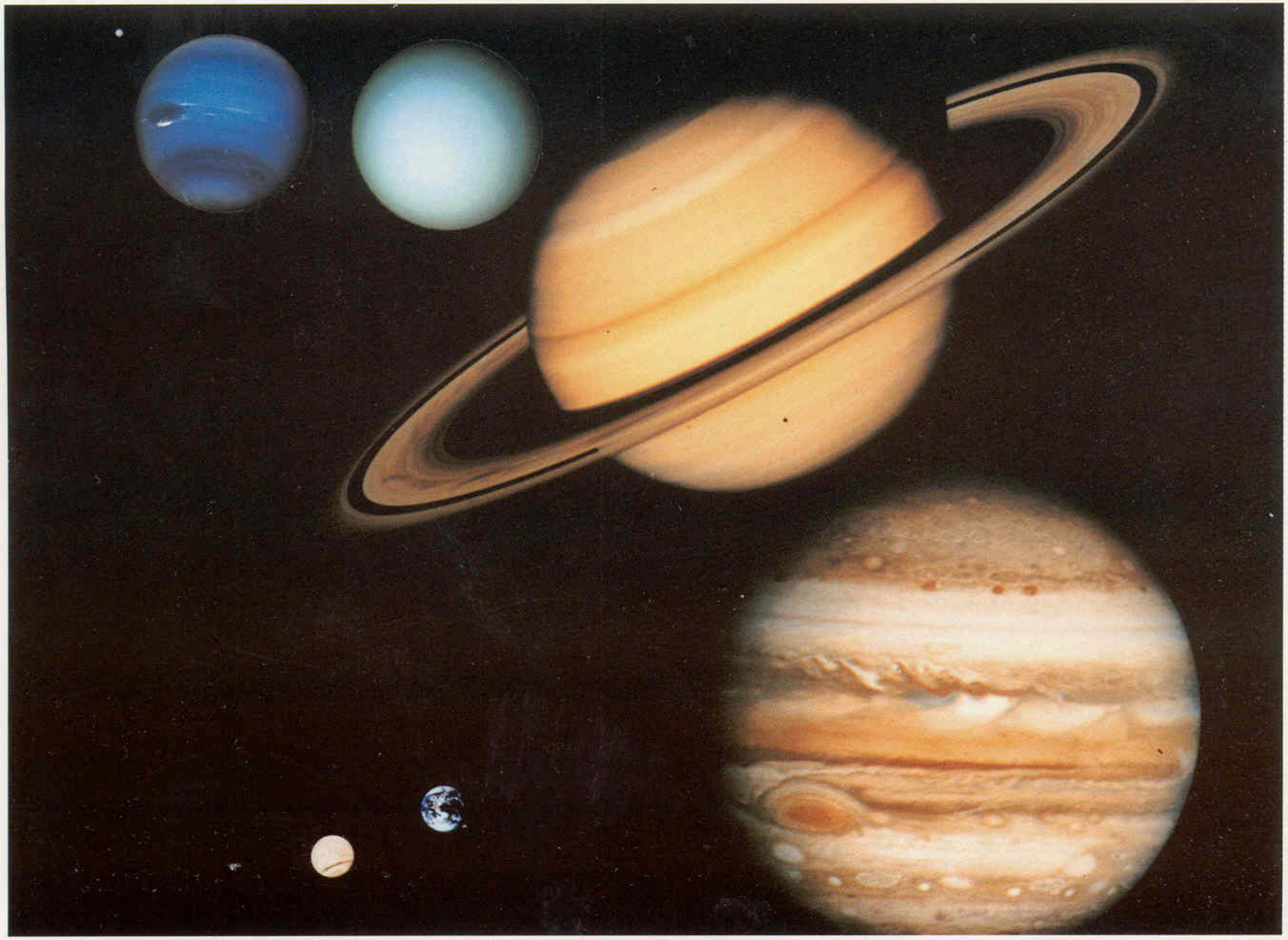
Astr 2310 Thurs. May 3, 2016
Today's Topics

- Chapter 10: The Jovian Planets
  - Jupiter
    - Physical Properties
    - Atmospheric Features
    - Interior
    - Origin
  - Saturn
    - Physical Properties
    - Atmospheric Features
    - Interior
    - Origin
  - Uranus
    - Physical Properties
    - Atmospheric Features
    - Interior
    - Origin
  - Neptune
    - Physical Properties
    - Atmospheric Features
    - Interior
    - Origin

Jovian Planets



A composite of Voyager images showing Jupiter, Saturn, Uranus, and Neptune, scaled to their relative sizes. Earth and Venus are also shown scaled to their relative sizes.

From Encylopedia of the Solar System

Overview of General Properties

Planet	Distance	Period	Dia. (km)	Mass (ME)	Avg. Den.	Rotation
Jupiter	5.2 AU	11.9 yr	142,800	318	1.4 gm/cc	9.9 hr
Saturn	9.5 AU	29.5 yr	120,540	95	0.7 gm/cc	10.7 hr
Uranus	19.2 AU	84.1 yr	51,200	14	1.2 gm/cc	17.2 hr
Neptune	30.1 AU	164.8 yr	49,500	17	1.7 gm/cc	16.1 hr
Pluto	39.4 AU	248.6 yr	2,240	0.002	2.5 gm/cc	153.4 hr

Composition:

Gaseous envelope (mostly H + He) with an icy and silicate (rocky) core. Models imply Jupiter and Saturn have metallic H "mantles."

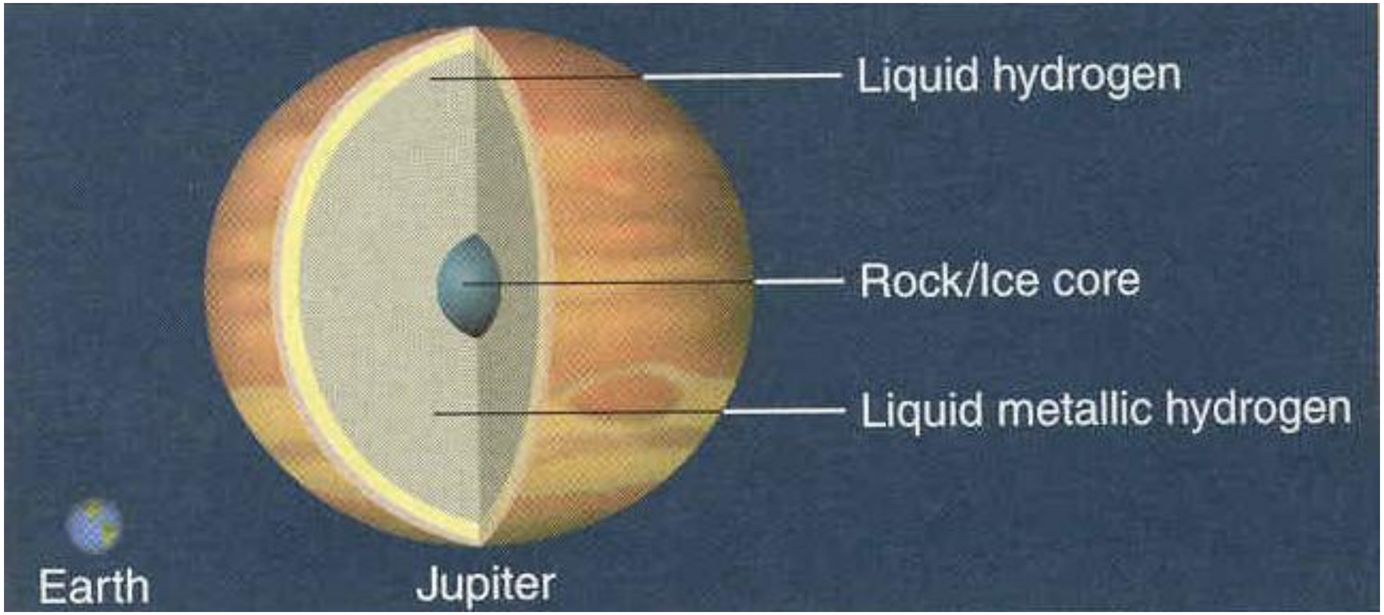
Jovian planets freture "reducing atmospheres – Hydrogen rich (H_2, He, CH_4, NH_3, H_2O)

Terrestial planets feature "oxidizing atmospheres – Oxygen rich (O_2 or CO_2)

Jupiter

- **Exploration:**
  - Galileo's first telescope revealed disk and 4 bright moons. Huygen's discovered Great Red Spot soon after.
  - Voyager 1 & 2 flyby2 (late 1980s) revealed complex cyclonic storms
- **Physical Properties:**
  - Mass: 318 of Earth's
  - Diameter: 142,800 km (more than 11 times Earth's)
  - Avg. Density: 1.33 gm/cc (mostly gas)
  - Rotation: siderial period of 9h 50m (differential rotation!)
- **Interior**
  - Composition: Massive H (75%) and He (24%) atmosphere
  - Models imply that H is liquid or even metallic over most of inerior
  - Models suggest the core is rocky about size of Earth
- **Atmospheric Features**
  - Alternating light and dark bands with light areas cooler (higher). Rapid rotation stretches clouds horizontally.
  - Large cyclonic storms (Great Red Spot)
  - Lots of complex hydrocarbon molecules found in atmosphere
  - Max. winds ~ 300 km/hr
- **Origin**
  - Compositional gradient of moons suggest Jupiter was quite hot an bright at time of formation
  - Strong magnetic field due to differentially rotating liquid metallic H mantle.
  - Internal heat source suggests condensation of He

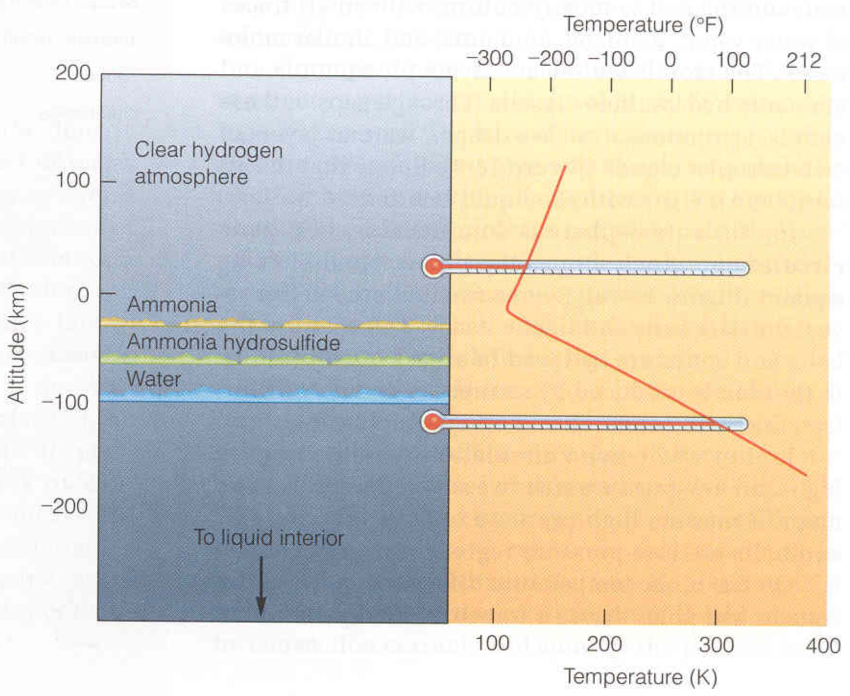
Ice+Rock Core   H+He "Atmosphere"



- Jovian Planets possible because of H_2O condensation
    - With H+O solid, much more material available
    - Solid cores get large enough for gravity to hold H, He gas

- With a miniature gas nebula present you can build a miniature solar system of (giant planet + many moons)

Details of the Atmosphere

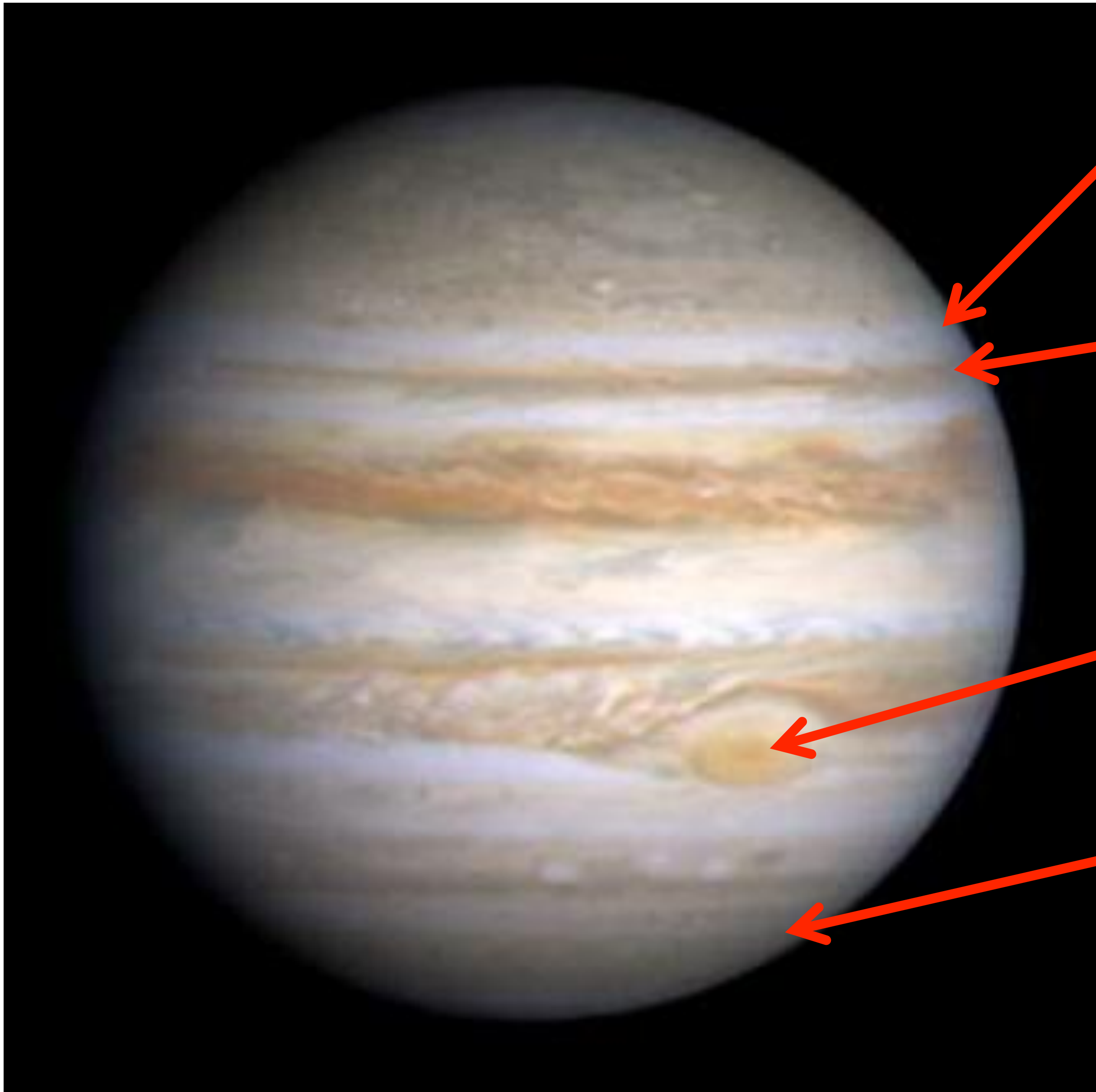


- Mostly made of H, He
- Trace amounts of C, N, O, S
- CH_4 present as gas
- NH_3, NH_4SH, H_2O can condense in colder upper regions ⇒ clouds
- Colors from unknown trace chemicals

- Density of gas smoothly increases with depth till point where it is indistinguishable from liquid
  ⇒ no real "surface"

- At very high temperatures and pressures hydrogen becomes a "metal" and conducts electricity
  ⇒ generates magnetic field

Jupiter as seen by Cassini



Zones:
Light Bands
High NH_3 clouds

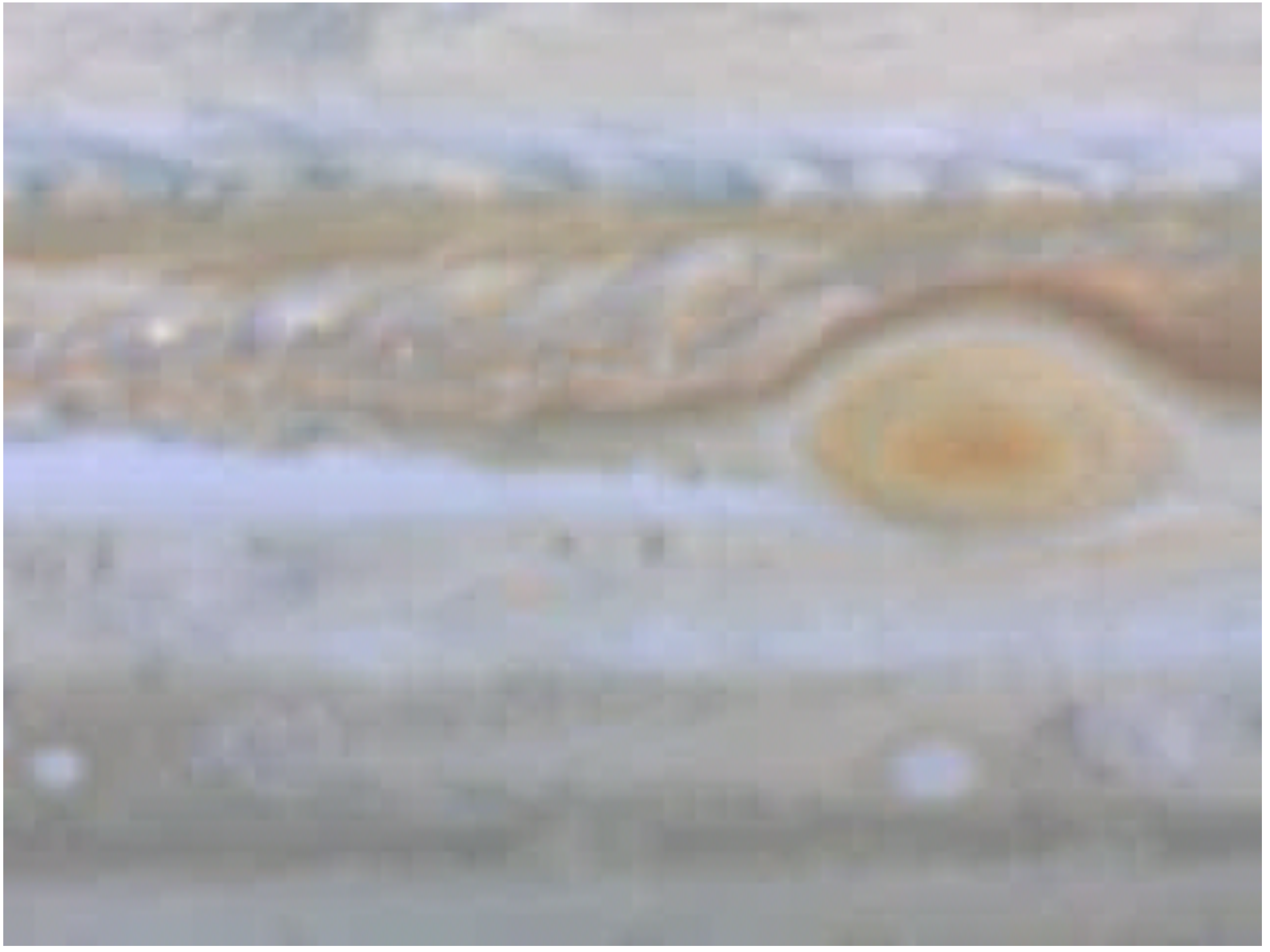
Belts
Dark Bands
Clear to lower layers

Great Red Spot

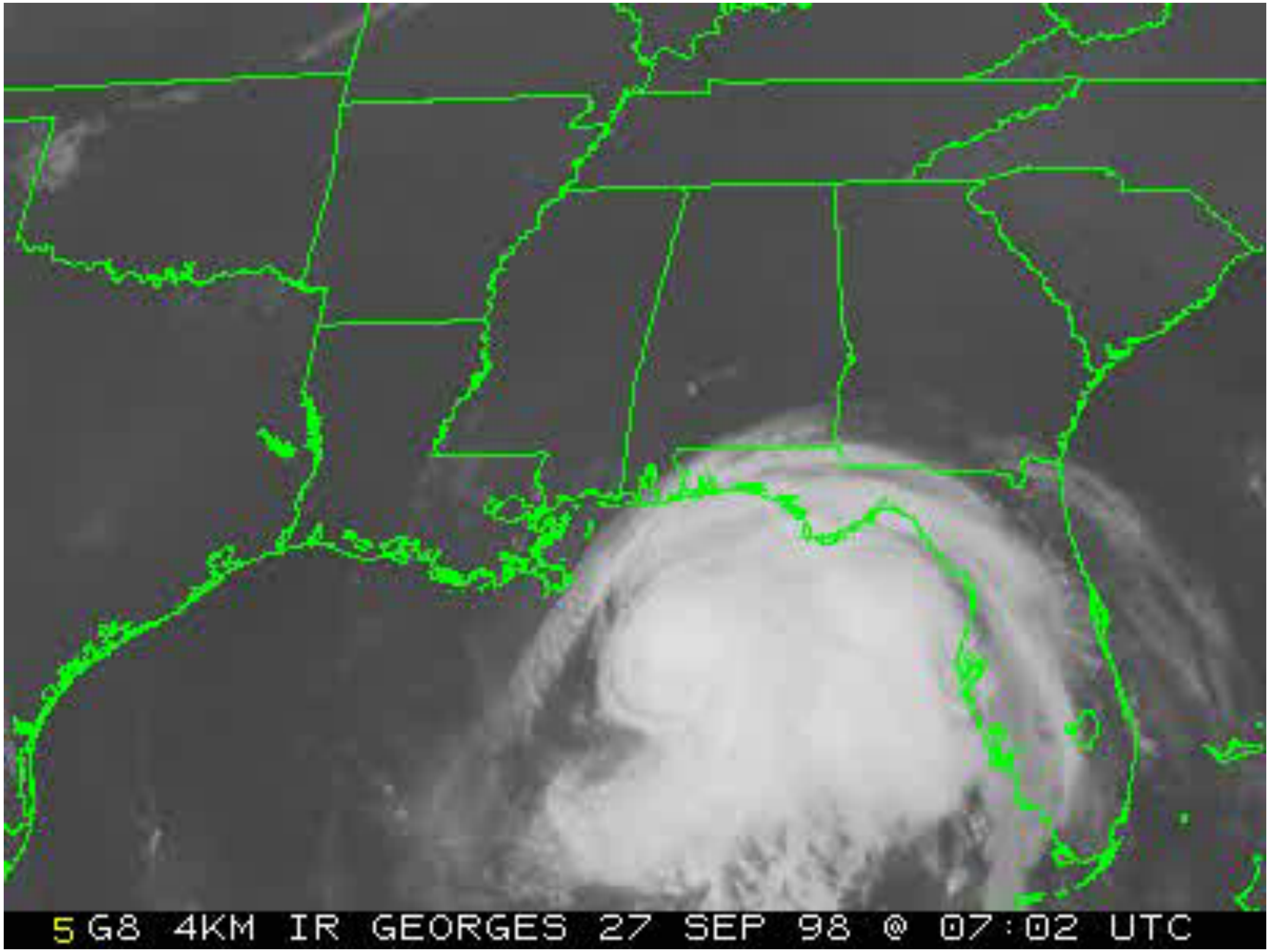
Chaotic pattern at high latitude

Winds on Jupiter

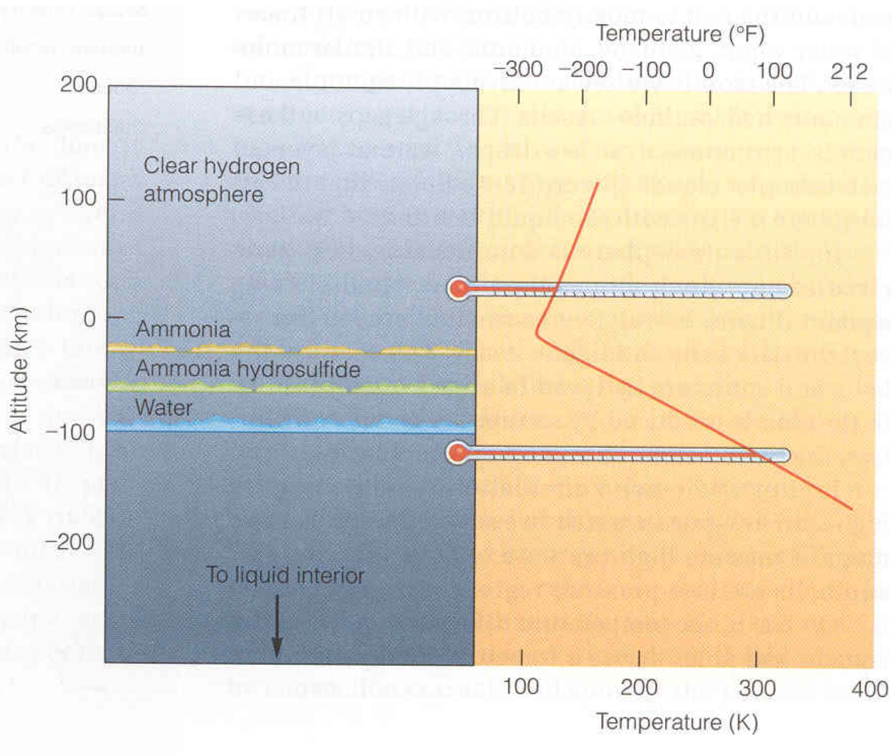
Winds near the Great Red Spot



Hurricanes exist because
Low Pressure trying to turn winds to the left
almost balance
Coriolis Force trying to turn winds to the right.



Jupiter has multiple cloud decks as air rises in low pressure "zones"



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- Trace amounts of C, N, O, S
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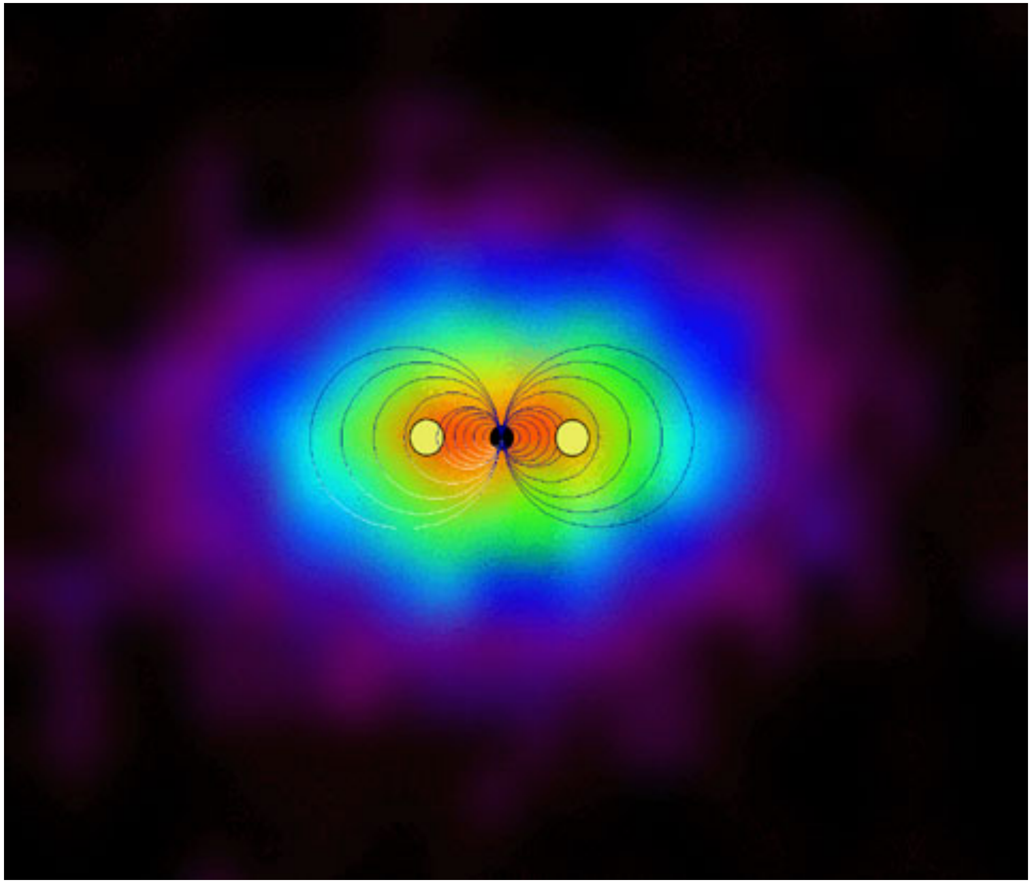
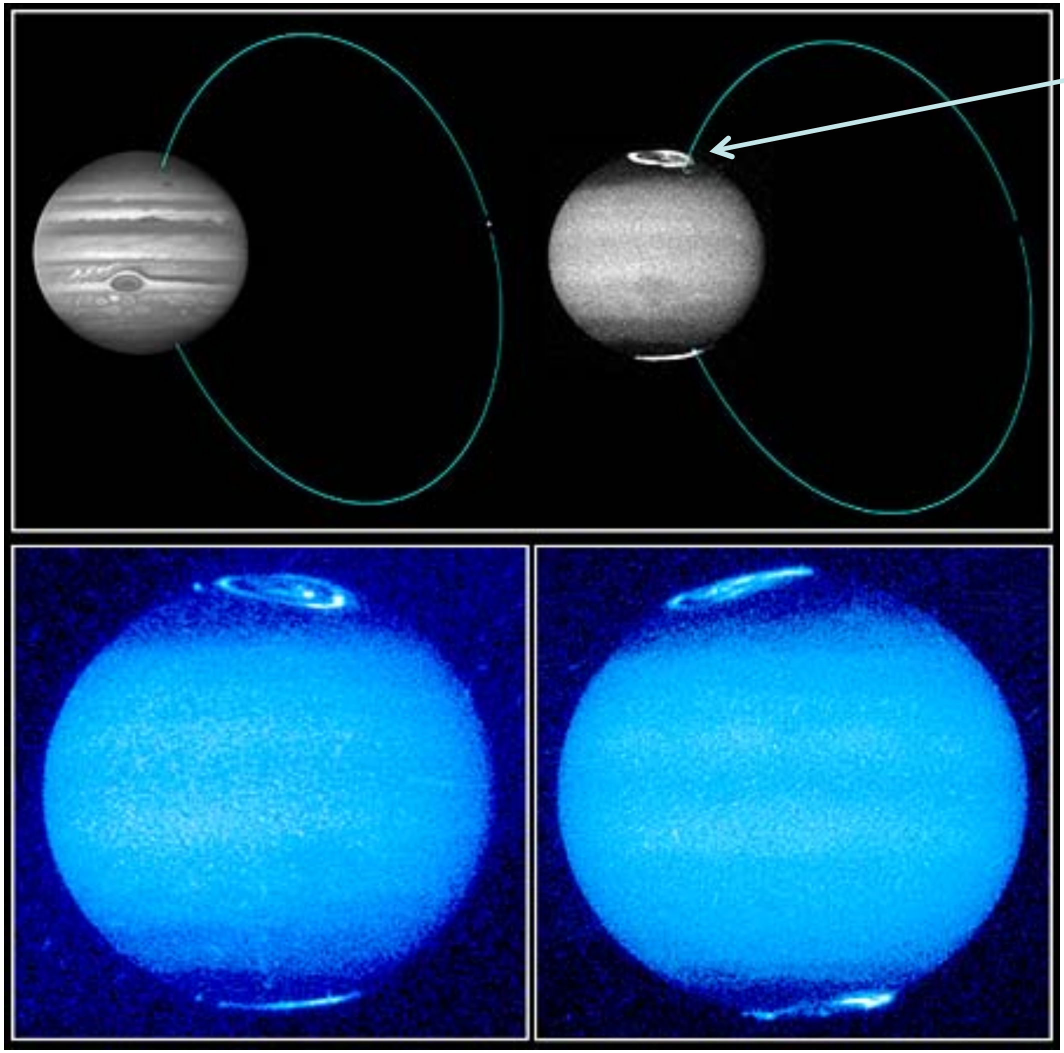
Magnetic fields and trapped particles



Cassini image of magnetosphere from escaping ions

- Magnetic fields favored by
  - Conductive core
    - Earth: Fe
    - Jupiter: Metallic H
  - Fast rotation rate
- Charged particles trapped by magnetic field
  - Come from satellites
  - Cause aurora on Jupiter

Aurora on Jupiter



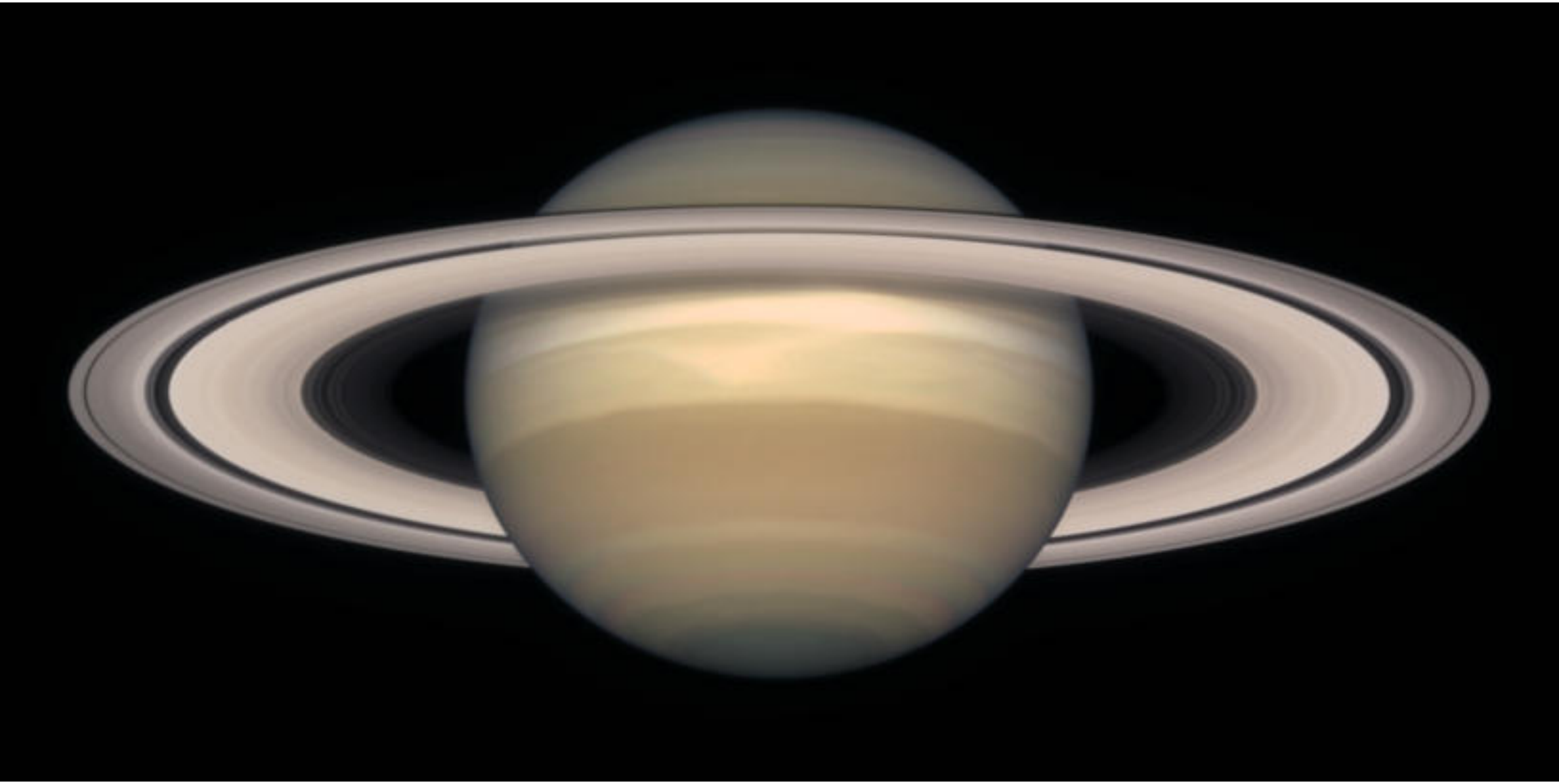
Hubble ultraviolet image, with magnetic field lines drawn in

Aurora caused when some trapped particles “leak” into the atmosphere of Jupiter

Saturn

- **Exploration:**
  - Galileo's first telescope revealed "ears" which Huygen's discovered to be rings
  - Voyager 1 & 2 flyby2 (late 1980s) revealed only weak cyclonic storms but complex ring system
- **Physical Properties:**
  - Mass: 95 times Earth's
  - Diameter: 120,540 km (about 9.4 times Earth's)
  - Avg. Density: 0.68 gm/cc (mostly gas)
  - Rotation: siderial period of 10h 50m (differential rotation!)
- **Interior**
  - Composition: Massive H (75%) and He (24%) atmosphere
  - Models imply that H is liquid or even metallic over most of interior (like Jupiter)
  - Models suggest the core is rocky about size of Earth with some ice (?)
- **Atmospheric Features**
  - Alternating light and dark bands with light areas cooler (higher). Rapid rotation stretches clouds horizontally. Again, like Jupiter but much less dramatic
  - Large cyclonic storms (but nothing like Great Red Spot)
  - Lots of complex hydrocarbon molecules found in atmosphere
  - Max. winds ~ 1300 km/hr
- **Origin**
  - Magnetic field is present but weaker than Jupiter's
  - Origin of rings something of a mystery as lifetime is only a few million years
  - Internal heat source suggests condensation of He

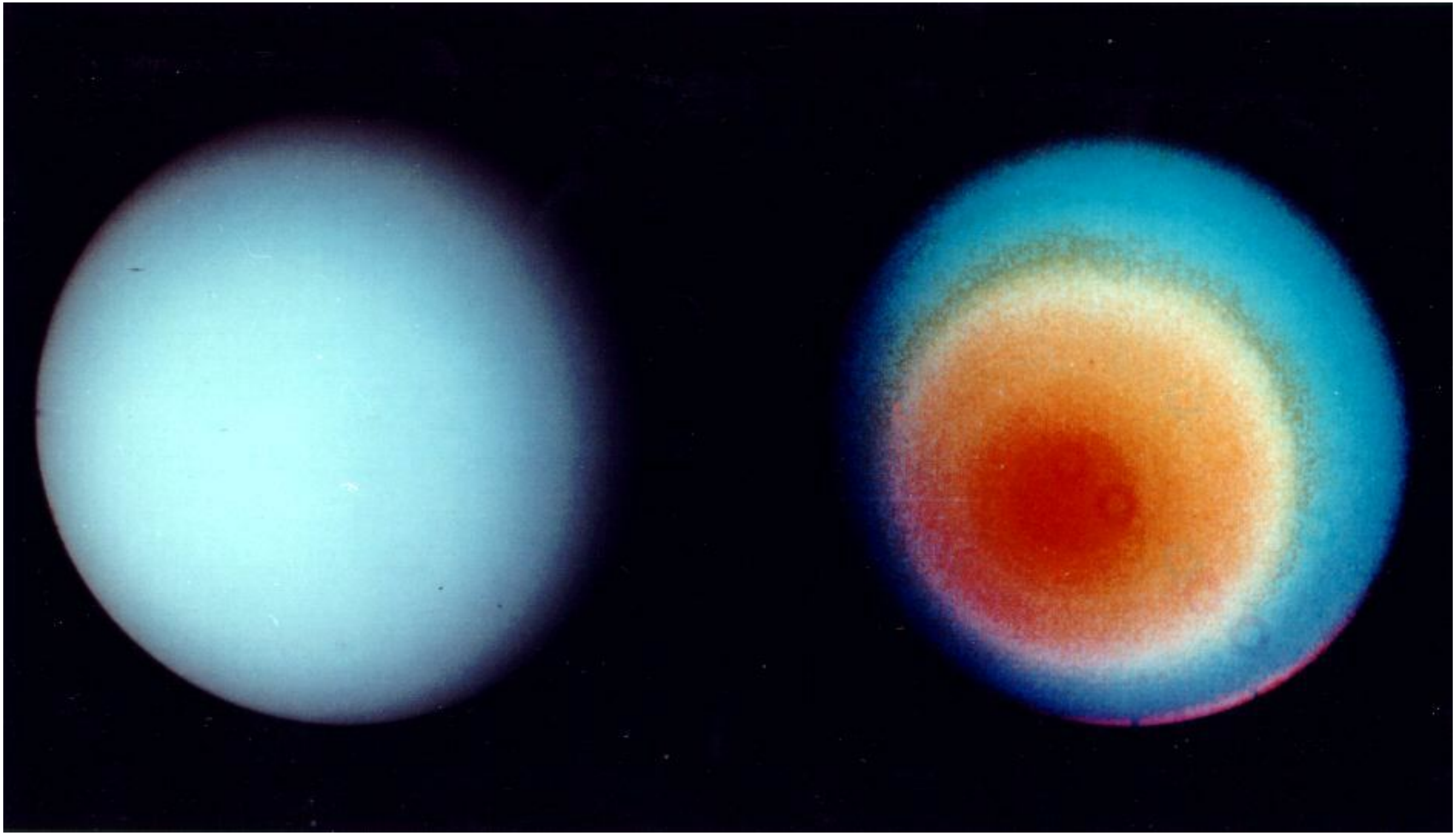
Saturn as seen by the Hubble Space Telescope



Uranus

- **Exploration:**
  - Accidently discovered telescopically by Herchel in 1700s.
  - Voyager 2 flyby2 (late 1980s) revealed essentially featureless atmosphere.
- **Physical Properties:**
  - Mass: 14 of Earth's
  - Diameter: 51,200 km (4.1 times Earth's)
  - Avg. Density: 1.2 gm/cc (mostly gas)
  - Rotation: siderial period of 17h 12m (differential rotation!)
- **Interior**
  - Composition: Massive H (75%) and He (24%) atmosphere
  - Models imply that H is liquid or even metallic over most of inerior
  - Models suggest the core is rocky about size of Earth
- **Atmospheric Features**
  - Essentially featureless atmosphere.
  - Lots of complex hydrocarbon molecules found in atmosphere
  - Max. winds ~ 100 km/hr
- **Origin**
  - Origin of large obliquity is a mystery
  - Weak magnetic field
  - No evidence of an Internal heat source

Uranus



Uranus is nearly featureless with little evidence for major storms.
Note the pole-on view (obliquity > 90^{o})

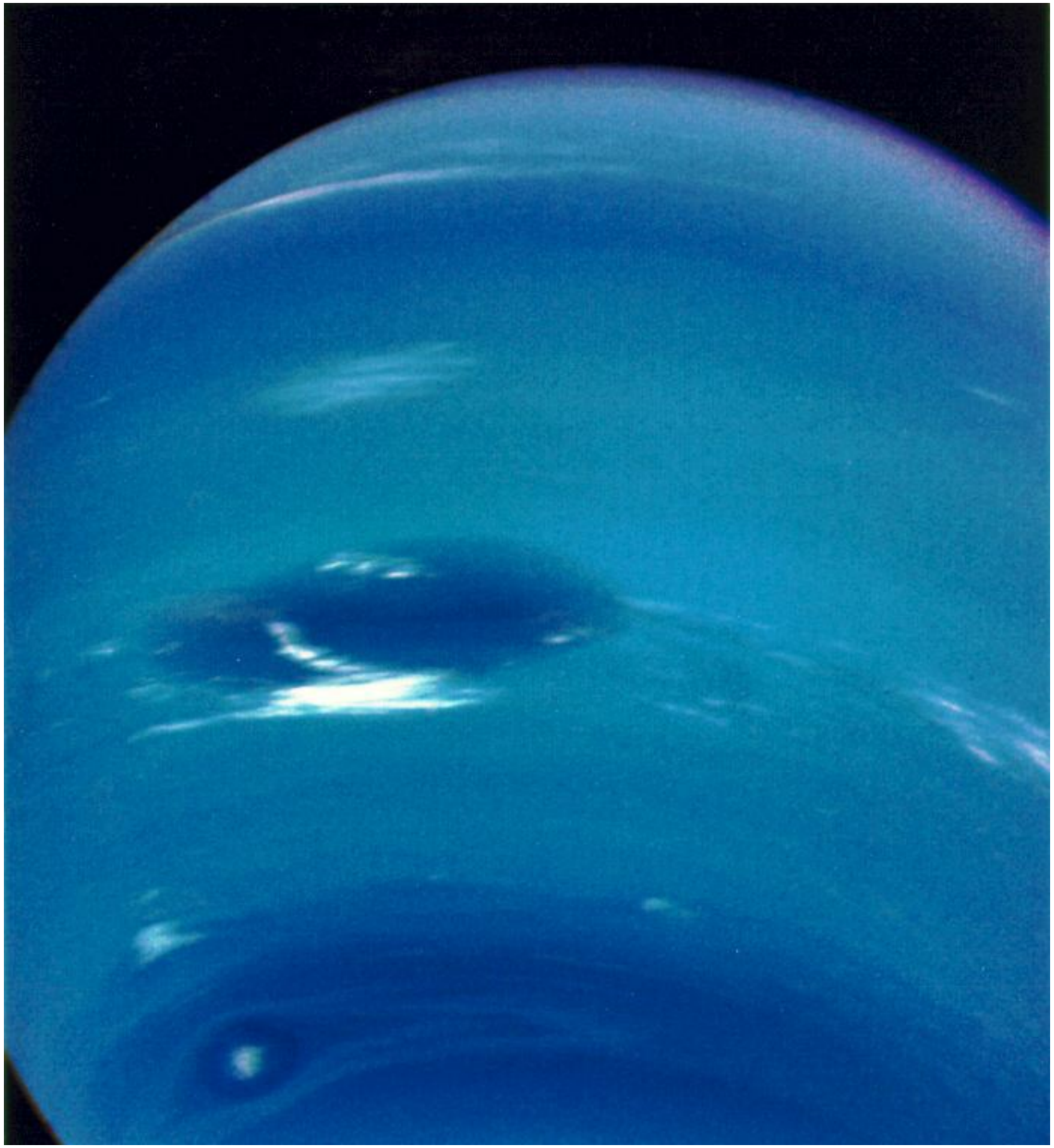
Neptune

- **Exploration:**
  - Galileo's recorded it moving near Jupiter's 4 bright moons but didn't recognize it as a distant planet. Discovered via its perturbation of Uranus.
  - Voyager 2 flyby (late 1980s) revealed complex cyclonic storm and cirrus clouds
- **Physical Properties:**
  - Mass: 17 of Earth's
  - Diameter: 50,400 km (nearly 4 times Earth's)
  - Avg. Density: 1.7 gm/cc   (mostly gas)
  - Rotation: siderial period of 16h 6m (differential rotation!)
- **Interior**
  - Composition: Massive H (75%) and He (24%) atmosphere
  - Models imply that H is liquid or even metallic over most of interior
  - Models suggest the core is rocky about size of Earth
- **Atmospheric Features**
  - Alternating low contrast bands. Rapid rotation stretches clouds horizontally.
  - Large cyclonic storm (Great White Spot) but not as long lived as on Jupiter
  - Lots of complex hydrocarbon molecules found in atmosphere
  - Max. winds ~ 2100 km/hr
- **Origin**
  - Moderately strong magnetic field due to differentially rotating liquid metallic H mantle.
  - Internal heat source suggests condensation of He

Neptune

Large cyclonic storms

High wind shear
(highest winds in solar system

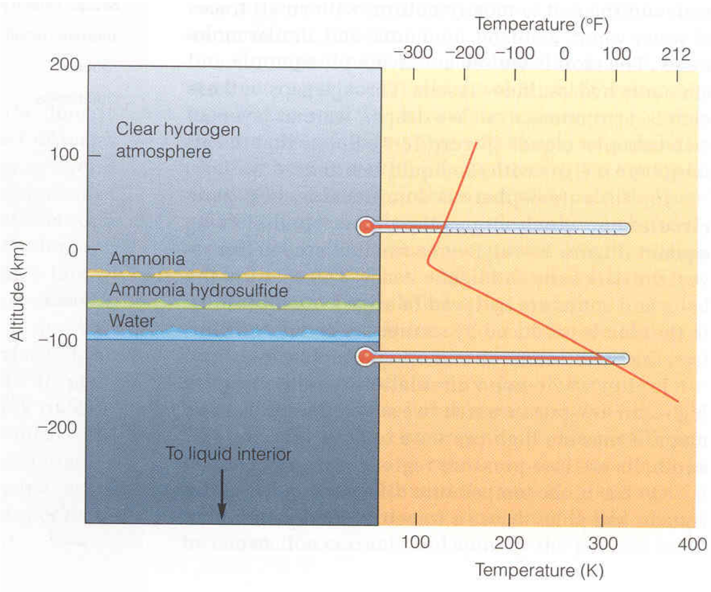


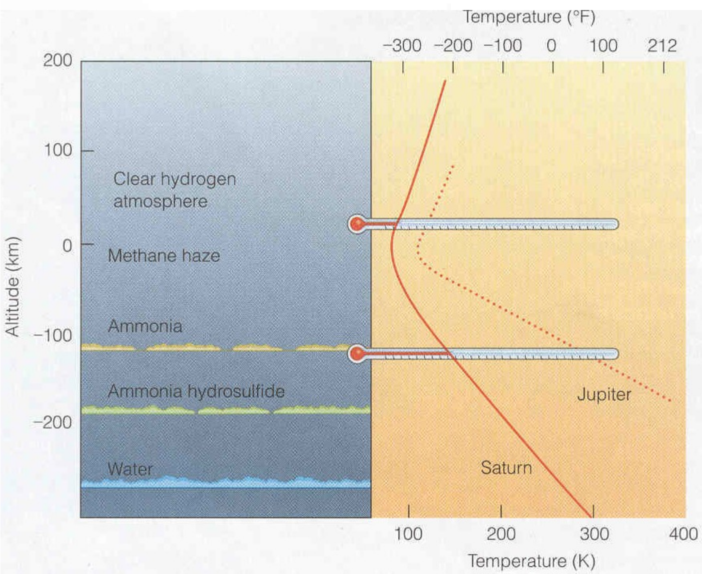
Comparison of Jovian Planets

Planet	a (AU)	P (years)	T (K)	E_{out}/E_{in}	M (M_{earth})	ρ (gm/cm^3)
Jupiter	5.2	12	143	1.7	318	1.34
Saturn	9.5	29	93	1.8	95	0.69
Uranus	19.2	84	53	~1	15	1.29
Neptune	30.1	165	57	2.6	17	1.66

- Variation in distance presumably ultimate causes other effects
  - P: Kepler's third law
  - T: Falloff mostly just result of falling solar energy
    - But Neptune hotter because more internal heat
  - M: Clue to details of solar nebula mode
    - Less material in outer solar system – or perhaps less efficient capture
  - ρ: Should drop with mass because less compression
    - Works for Saturn vs. Jupiter
    - Increase for Uranus, Neptune indicates less H, He and more heavy material

Effects of T (and E) on Atmospheres





Saturn's bands much less distinct than Jupiter's

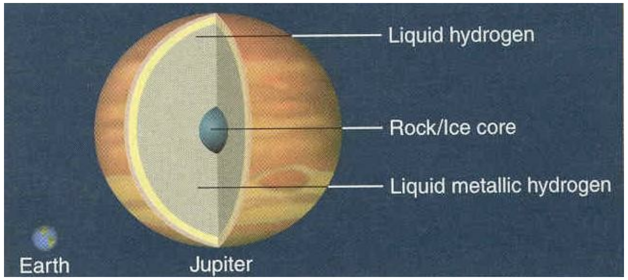
- Temp. lower on Saturn ⇒ cloud condense lower
- Deeper clouds ⇒ markings less visible

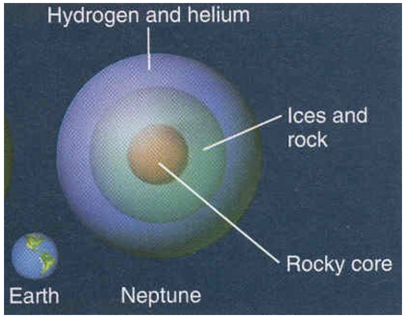
Differences at Uranus and Neptune

- Even colder ⇒ clouds even deeper
- So cold CH_4 can condense
- Little solar energy to drive weather
  - Uranus has strange seasons – tipped on its side
  - Neptune has strong internal heat source, so it still can have weather
- Large amounts of heavy elements compared to amount of H, He on Jupiter, Saturn
  - Large amounts of CH_4 gas absorb red, make planets appear blue

Implications of M, ρ for Solar Nebula

- Relative amount of H, He (compared to heavy elements) drop for Saturn
then drop dramatically at Uranus and Neptune

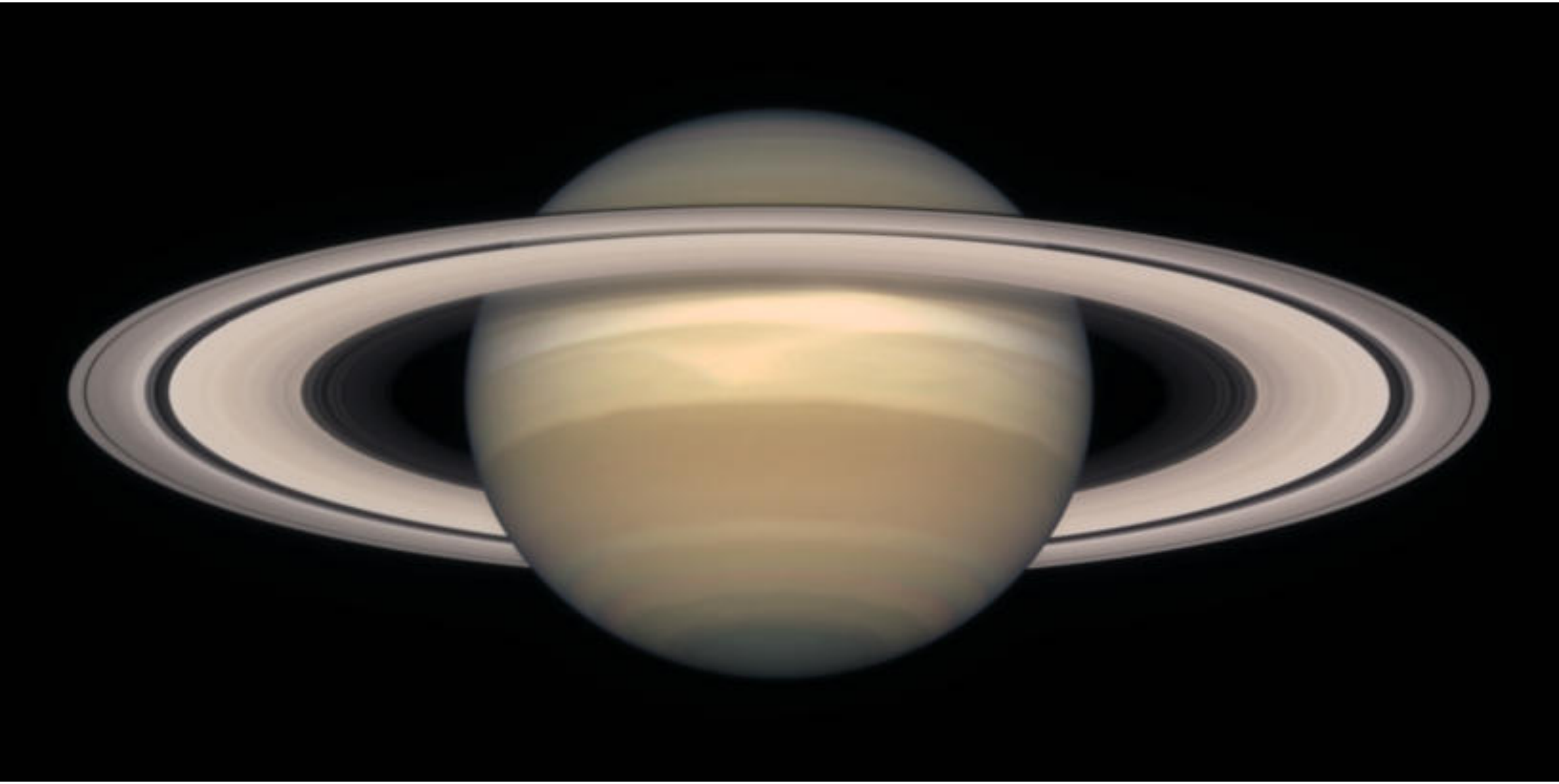




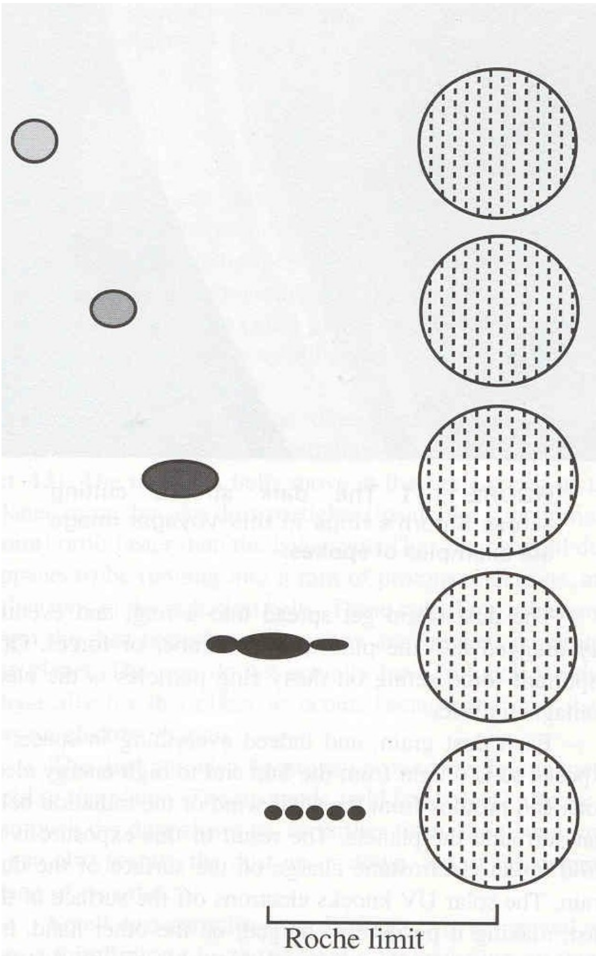
From our text Horizons, by Seeds

- Why were these outer planets so less efficient at capturing H, He?
  - Their mass is still great enough to do this, especially given low temperatures in the outer solar system
- May be a problem of timing
  - Accretion takes longer in the outer solar system because
    - The velocities of all objects there are much less
    - The distances between objects are greater
    - This is the same reason the periods of the orbits are so long
  - Uranus and Neptune may have only started to grow to critical size by the time the H, He gas was being driven out of the solar system

Saturn's Rings as seen by the Hubble Space Telescope



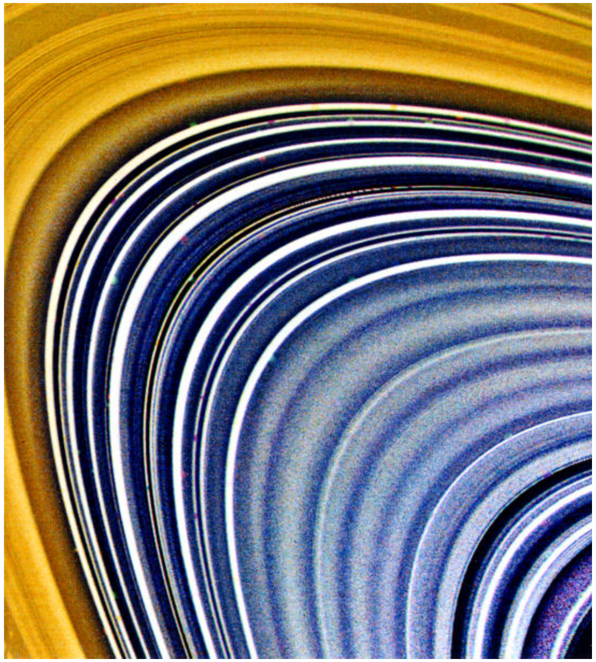
The Roche Limit
When can tides tear a moon apart?



From Worlds Apart by Consolmagno and Schaefer

- **As a planetary body get close to another object, tidal forces distort the body more and more.**
  - **Remember, Earth raises tides on the Moon just like it raises tides on the Earth**
- **If the distortion gets large enough, the moon will be pulled apart**
  - **Happens at "Roche Limit" when moon is ~2.44 × radius of planet away**
  - **At that point, tidal force pulling up on surface of moon is greater than moon's gravity pulling down**
- **Only matters for objects held together by gravity**
  - **Astronaut in orbit <u>will not</u> be pulled apart**
    - **Is held together by much stronger chemical forces**
  - **Astronaut standing on the outside of the shuttle, hoping the shuttle's gravity would hold her there, <u>will</u> be pulled away from the shuttle**

Rings are individual particles all orbiting separately

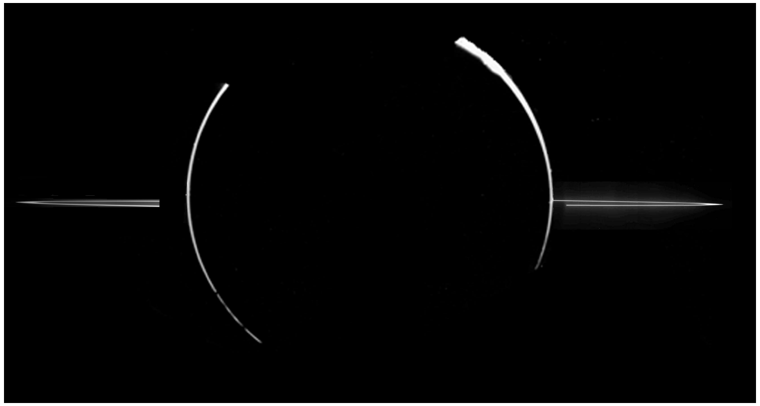


Voyager Image

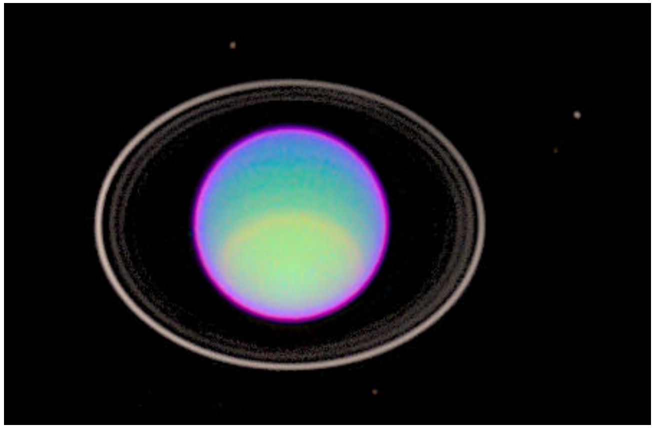
Painting by Bill Hartmann

- **Each particle – dust to golf ball to boulder size – is really a separate moon on its own orbit**
- **Orbit with Keplerian velocities: high in close, slow farther out**
- **Nearby <u>relative velocities</u> are low – so particles just gently bump into each other – slowly grinding themselves up**

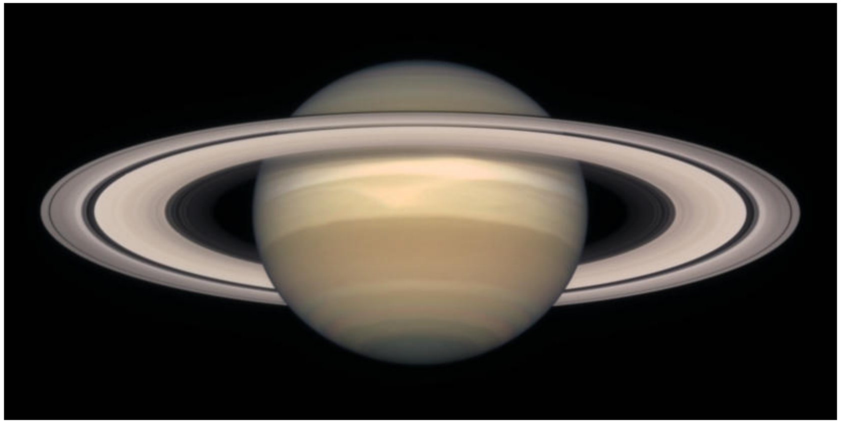
Comparison of Jovian Ring Systems



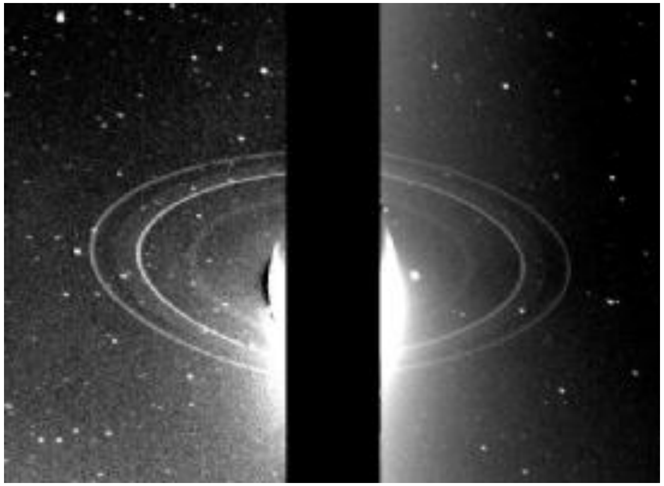
Jupiter



Uranus



Saturn



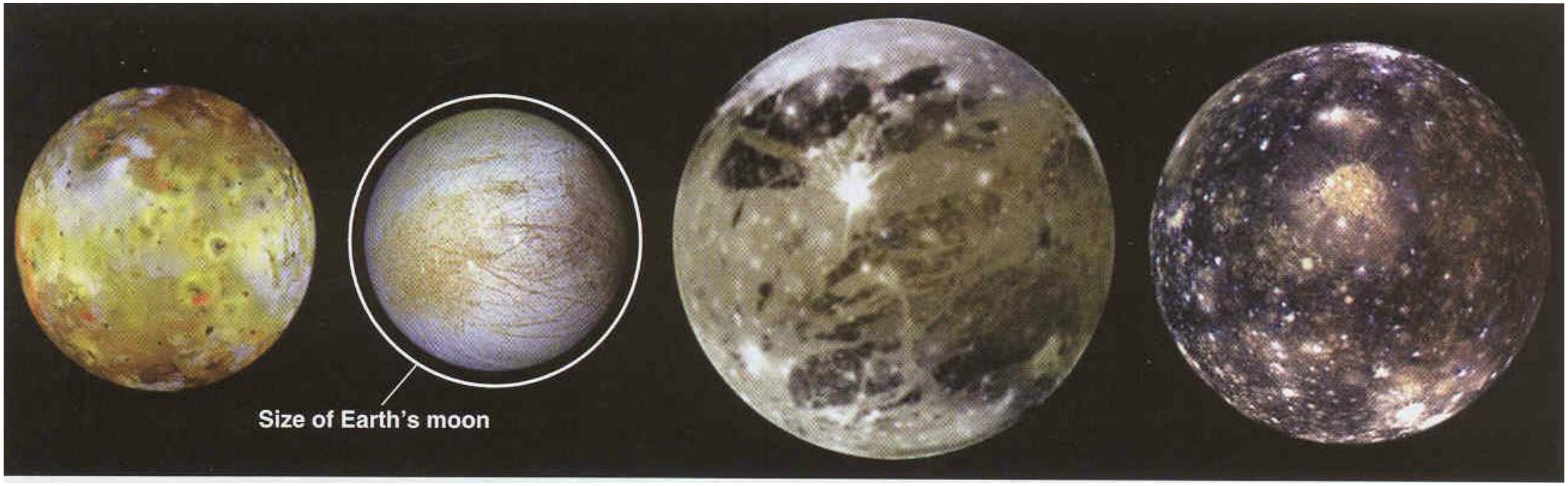
Neptune

- **All within Roche limit**
- **Details controlled by Resonances and Shepard Satellites**

Moons of Jovian Planets

- Physical Properties
  - Largest are similar to Earth's moon in size
  - Most are icy and heavily cratered
- Interior
  - Some of the icy moons show signs of extensive melting and water-ice vulcanism
    - Upwelling of liquid water
    - Resurfacing from water flows now frozen
    - Interior moons of Jupiter show extensive tidal melting
      - Io: extensive volcanoes
      - Europa: liquid H2O oceans beneath icy crust
- Origin
  - Largest moons may be captured from Kuiper belt

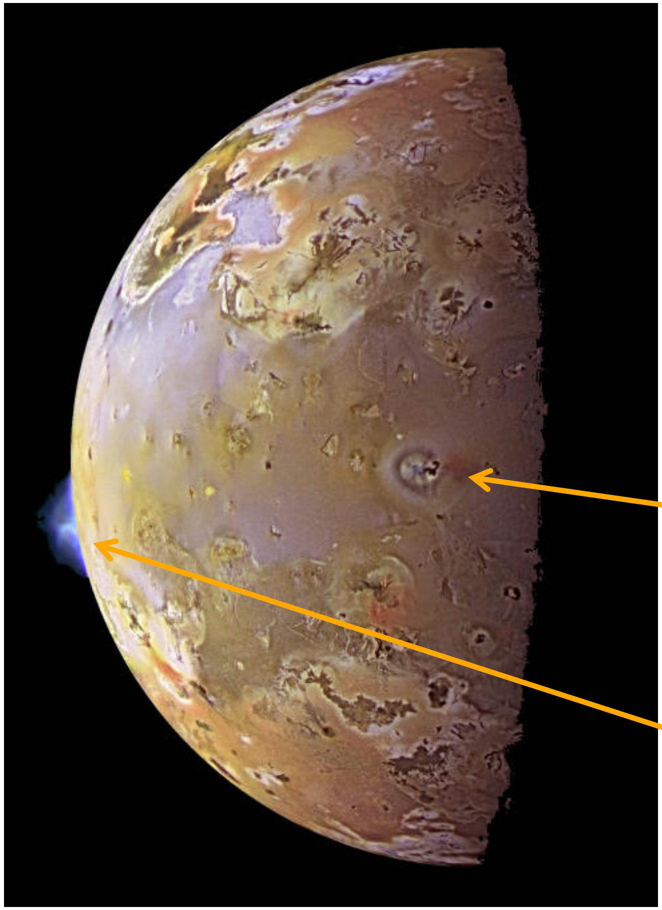
Jupiter as a miniature solar system



- Four large moons (Io, Europa, Ganymede, Callisto)
- Regular (equatorial, circular) orbits
- Pattern of changing density and composition with distance
  - Inner two (Io, Europa) mostly rocky
  - Outer two (Ganymede, Callisto) more icy

Io, Europa break rules about activity

- Io most volcanically active body in solar system
- Europa shows new icy surface with few craters

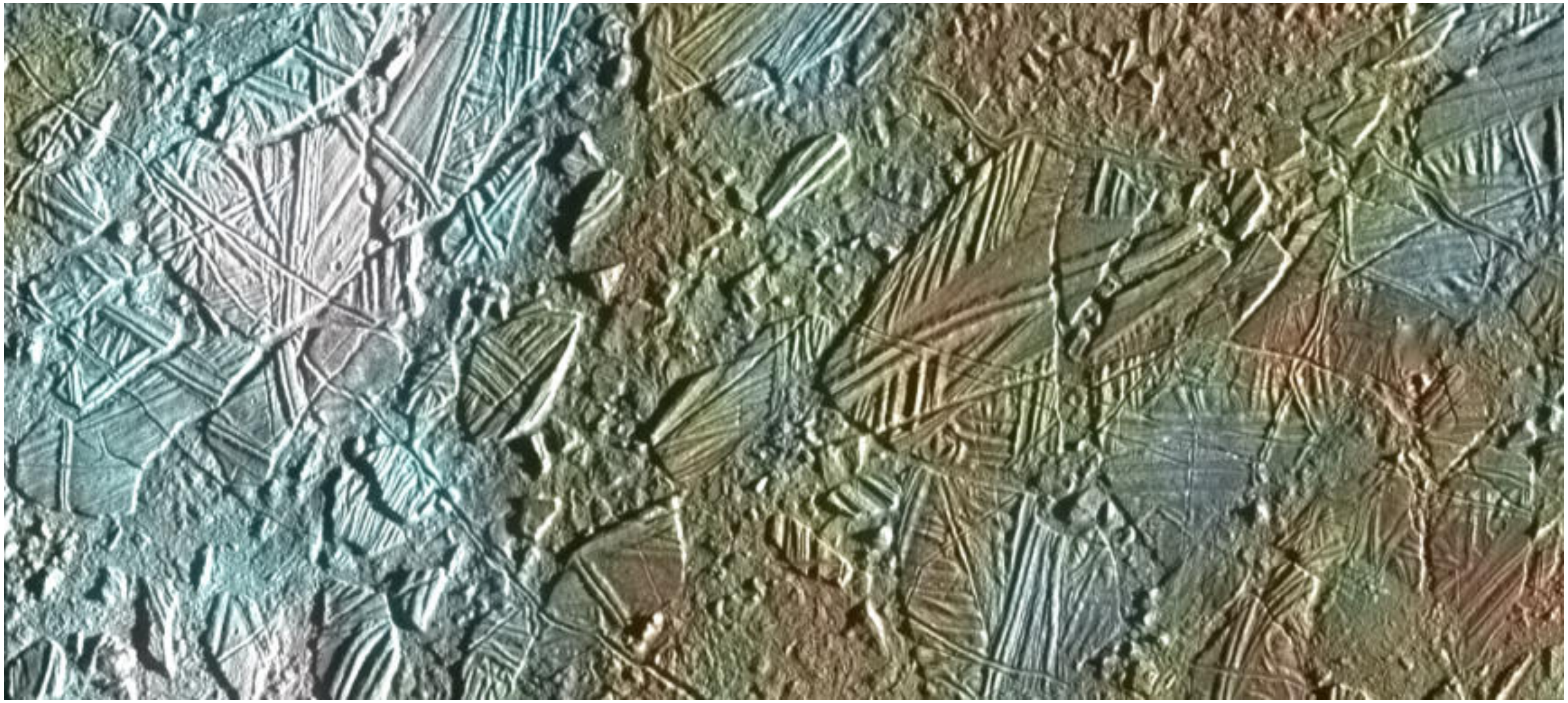


Prometheus plume seen on ground

Plume above Pillan volcano

Io as seen by Galileo

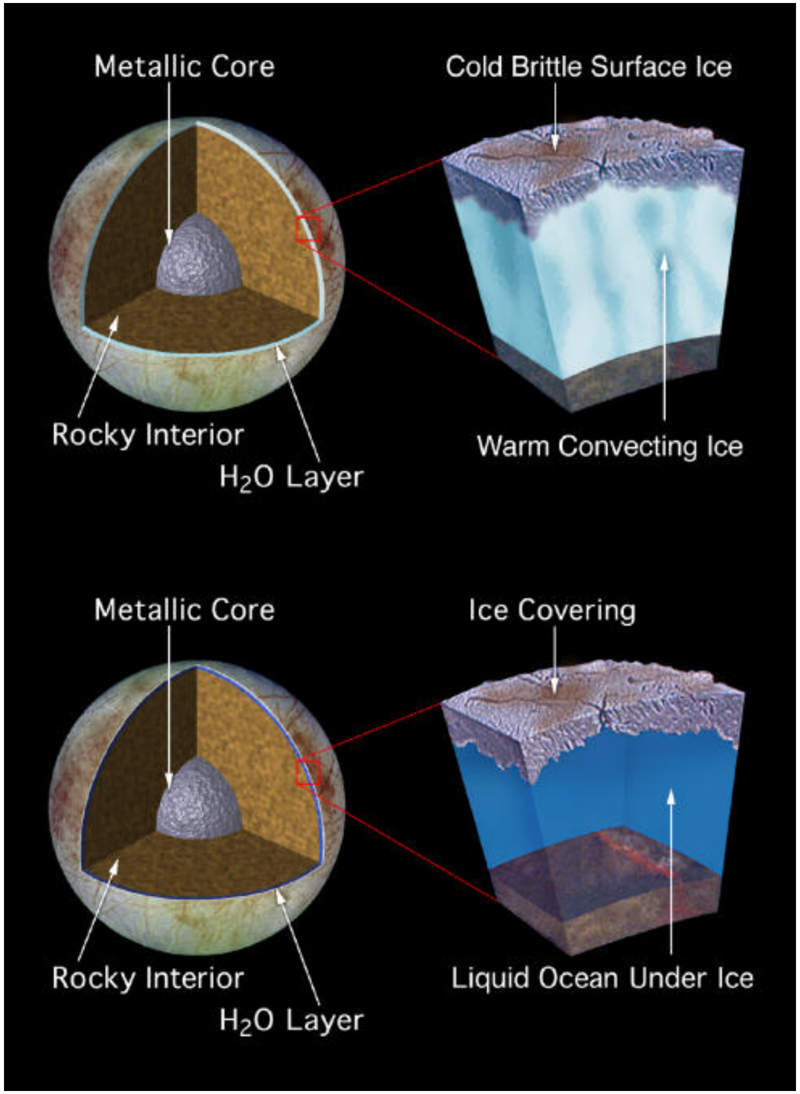
Tidal heating explains activity



Europa image from Galileo: Broken rafts of ice – contaminated by dark non-ice minearls

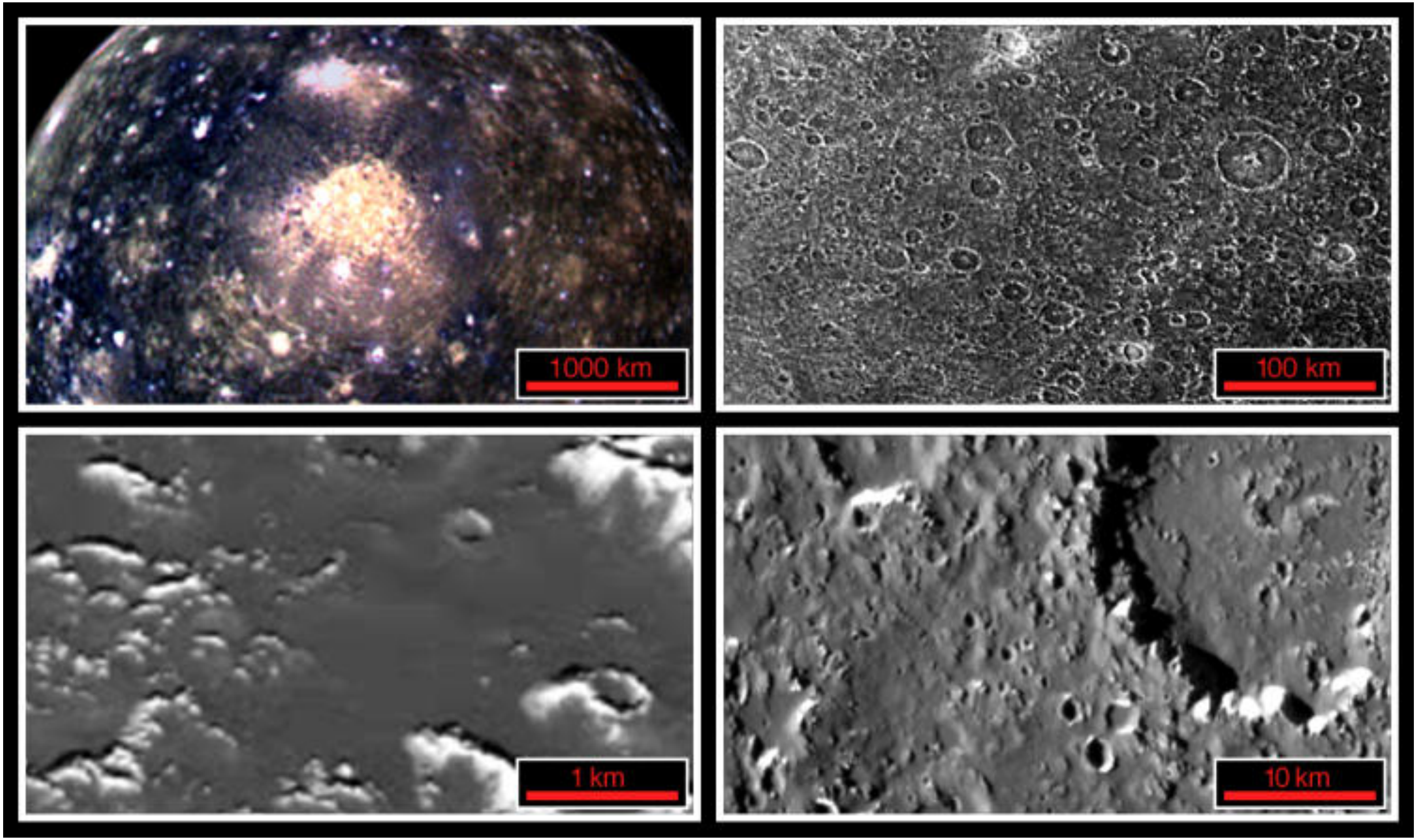
- Large tides from Jupiter flex satellites
- Friction from flexing heats interiors
- Important for Io, Europa, some other outer solar system satellites

Possible H_2O ocean on Europa



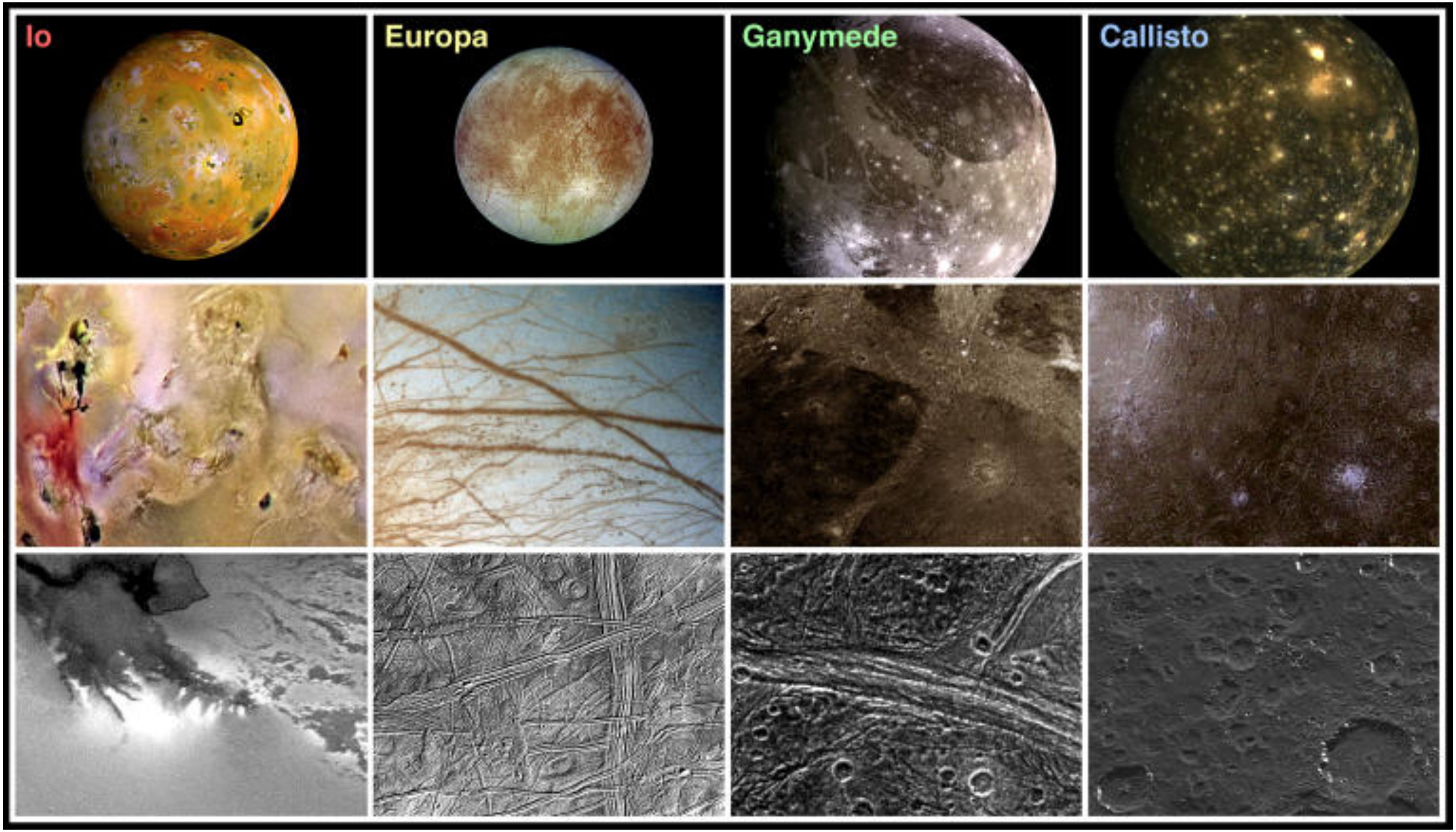
- **Tidal heating may keep H_2O liquid under ice cover**
- **Perhaps a location where life could evolve**
- **"Europa Orbiter" Mission being planned to determine if ocean exists**

Callisto not active



Tides and tidal heating falls off rapidly with distance from Jupiter

Comparison of Satellites



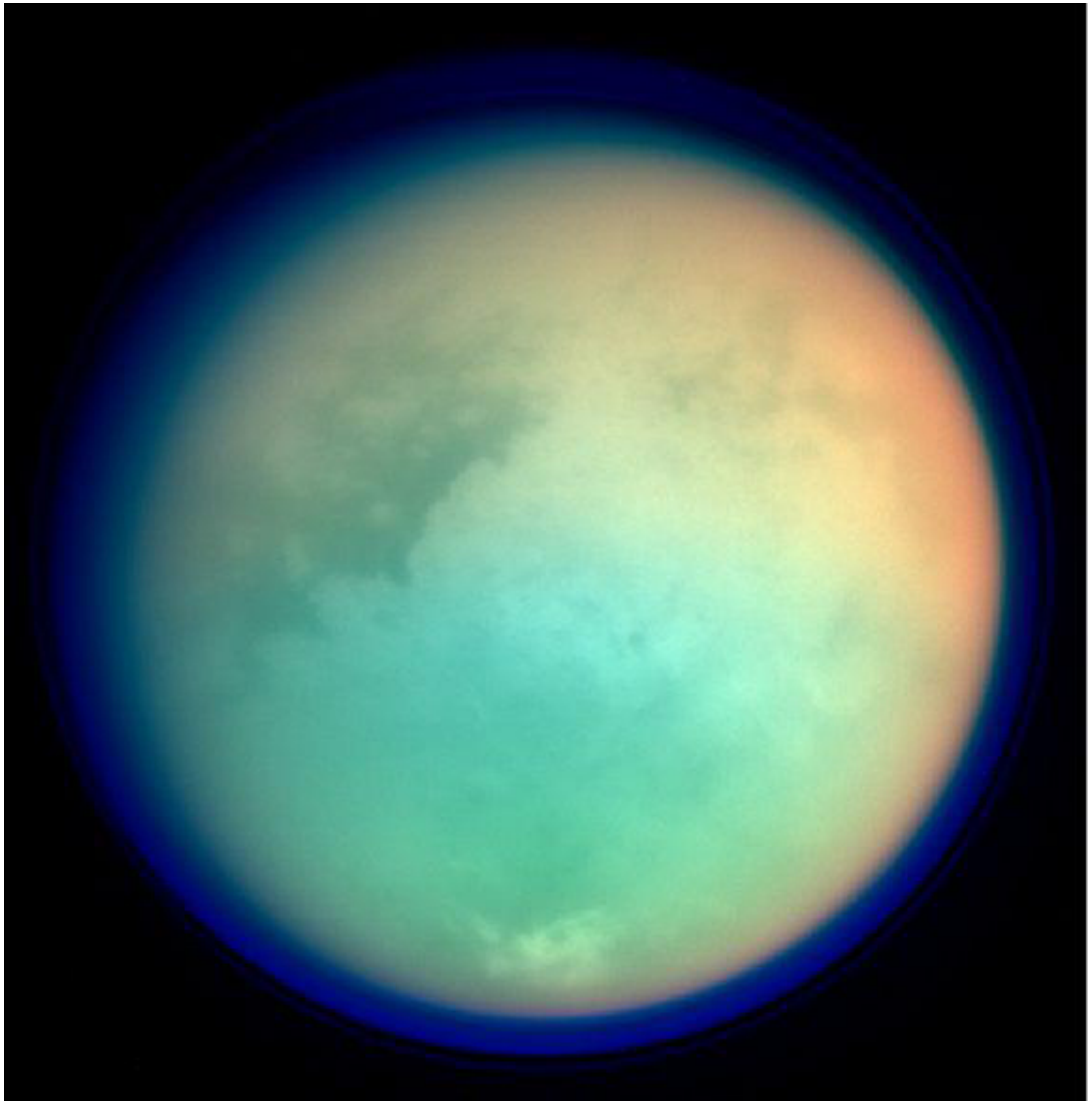
Titan: Largest Moon of Saturn

Largest moon of Saturn

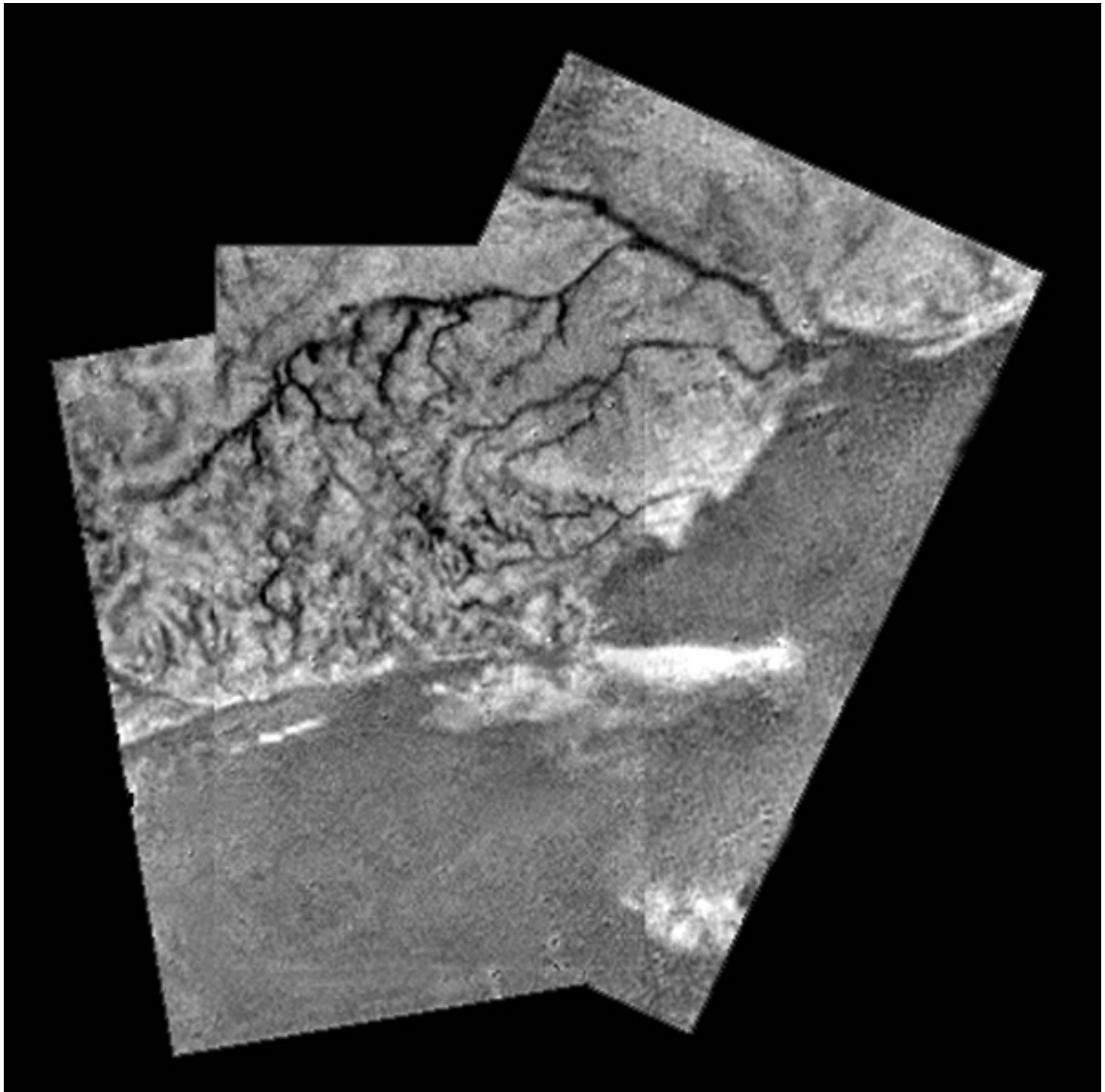
Has thick atmosphere
- Pressure ~ 1 earth atmosphere
- Mostly N2, some CH4
- Gas held because of low T

UV acting on CH4 ⇒ smog
- Ethane produced – Lakes?
- We "see" surface only in IR

Cassini dropped probe in Fall 2004



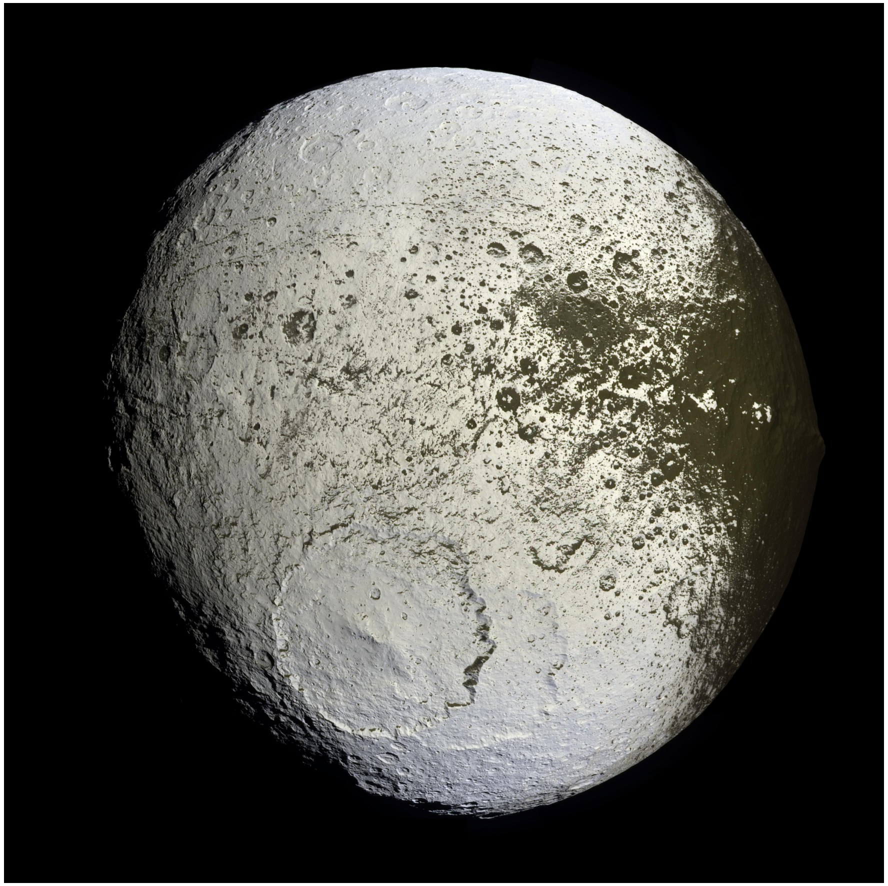
Titan's Surface from Huygens Probe

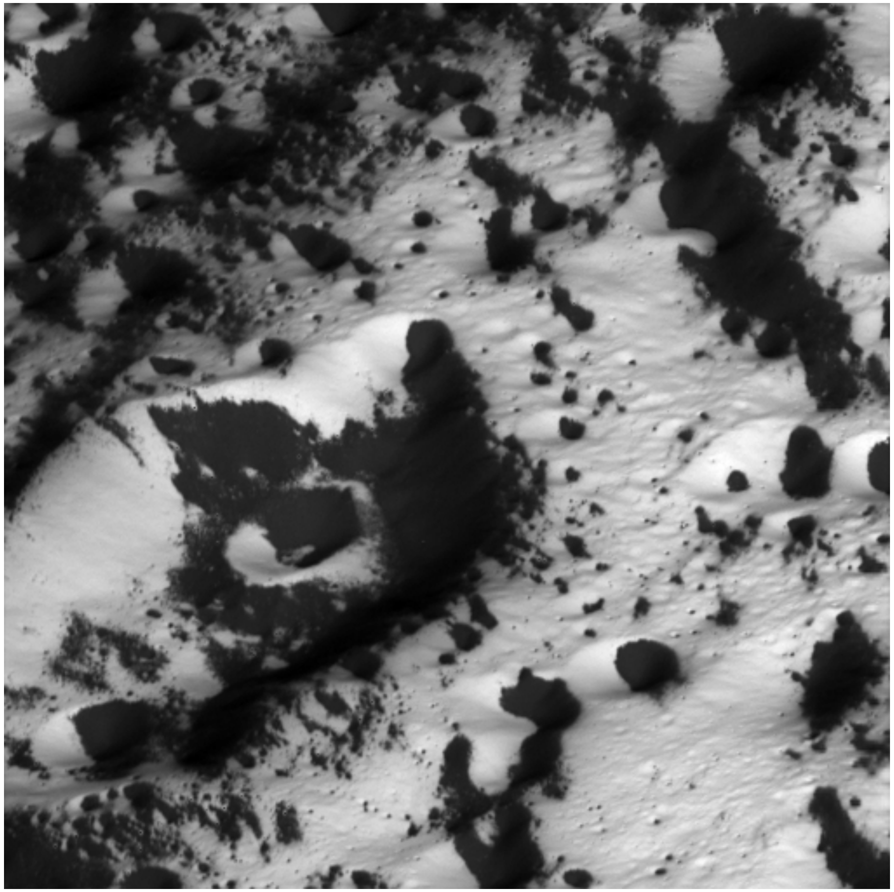


Iapetus – Saturn's Strange Moon

Iapetus: large albedo variations

Most of moon is icy but leading face is covered with very dark, organic (?) material.
Transition regions show clear evidence for deposition of dark material.
Origin is unknown.

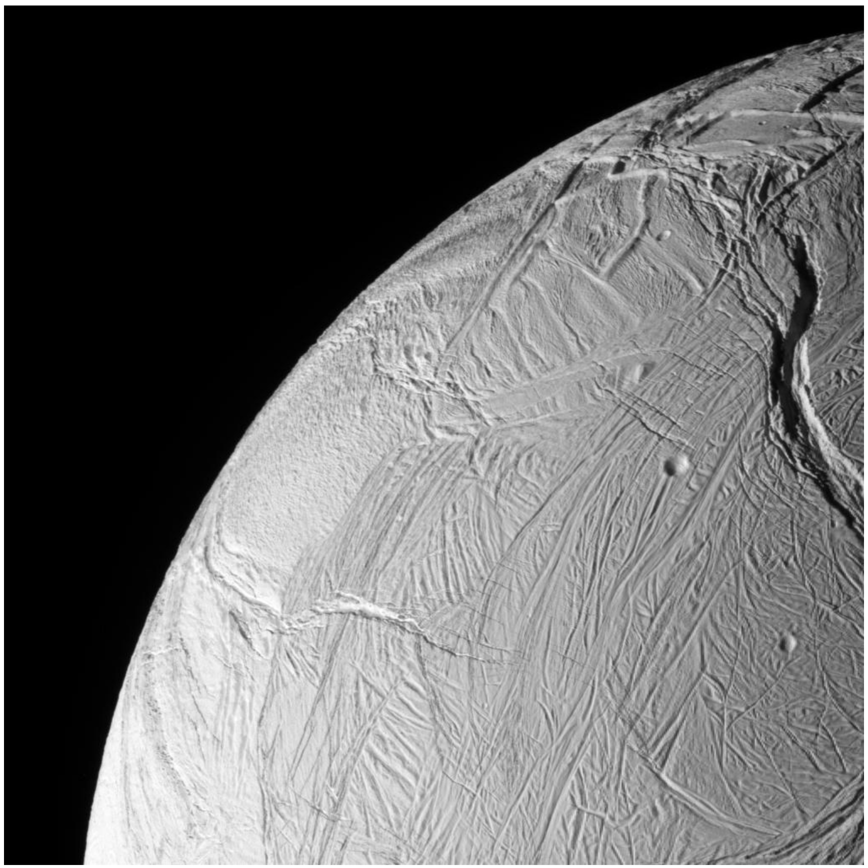


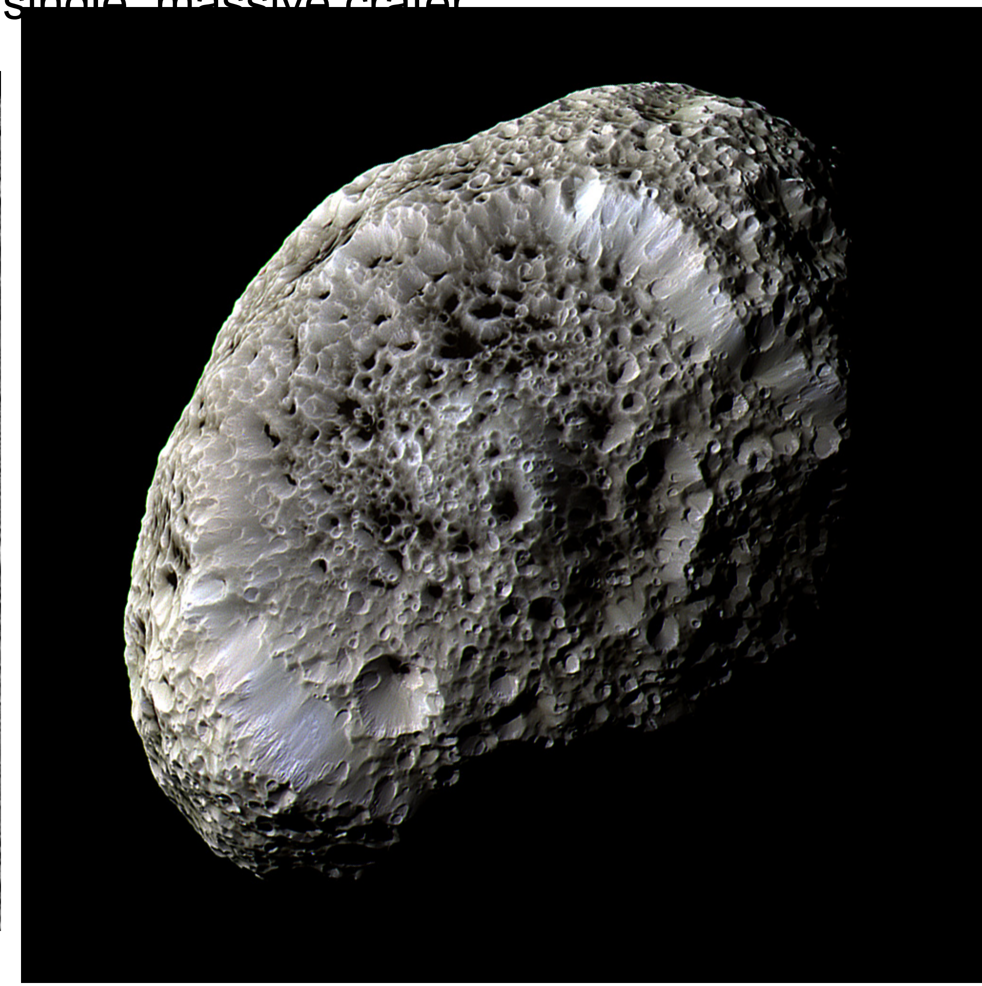


Enceledus and Hyperion

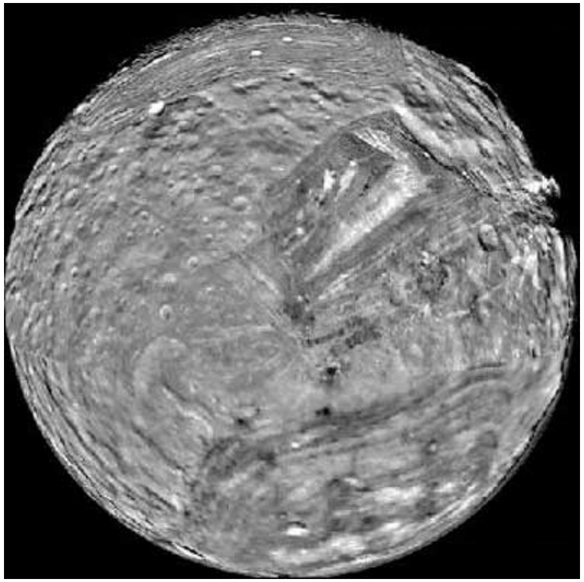
Enceledus: extensively resurfaced, one hemisphere essentially crater-free. Water erases cratered surface.

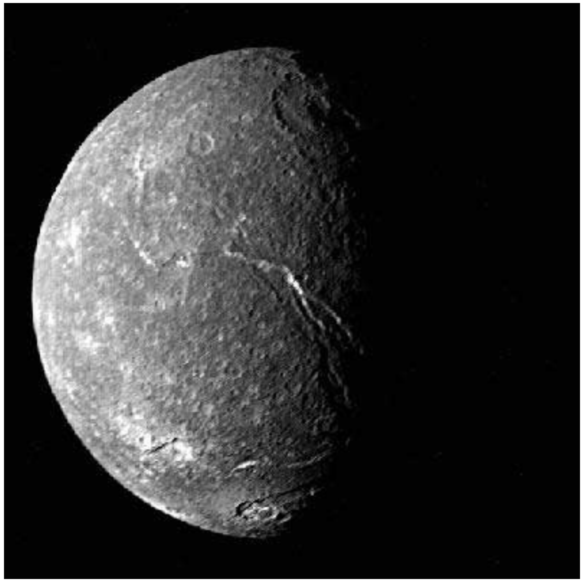
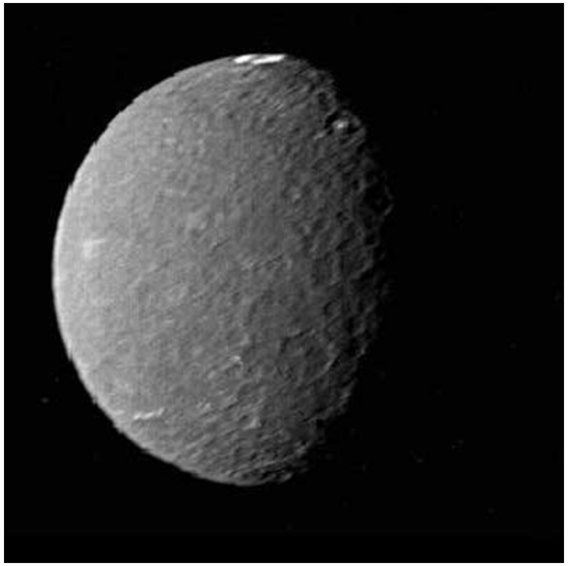
Hyperion: heavily cratered including a single, massive crater





Uranus' Moons



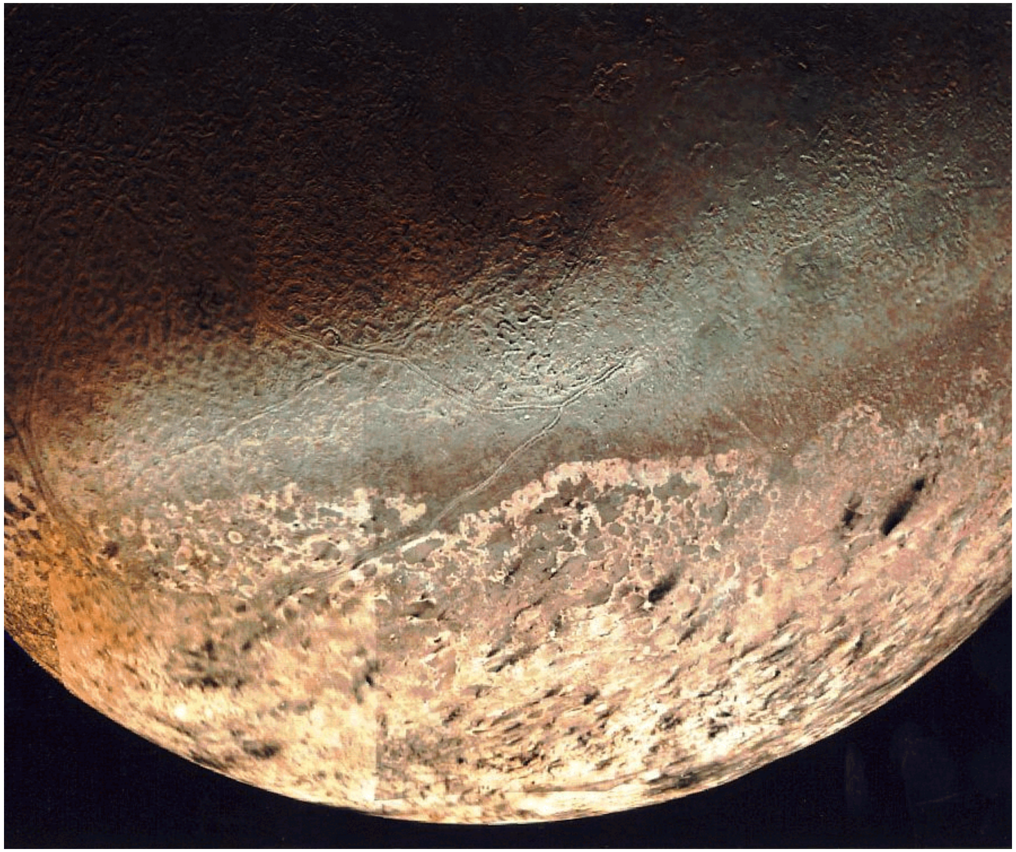




Clockwise from upper left:

Miranda, Ariel, Titania, Umbrial, and Oberon

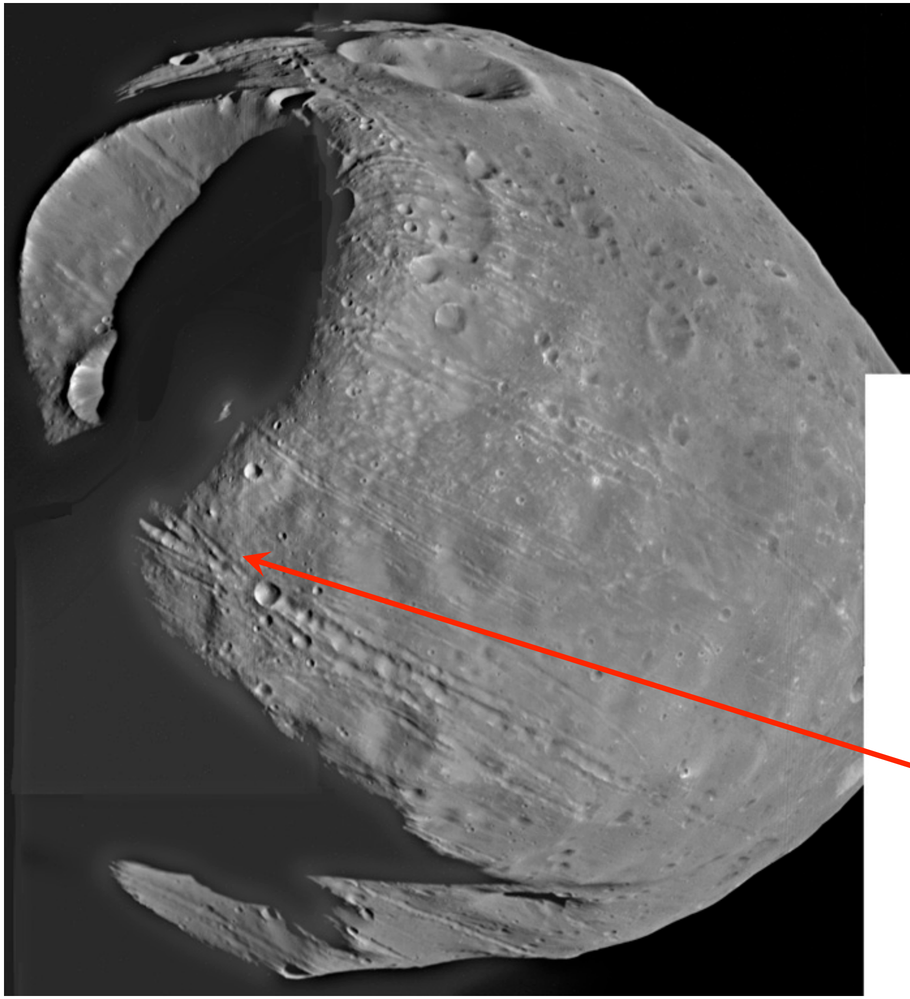
All are icy and heavily cratered. Albedo variations suggest some upwelling of ice

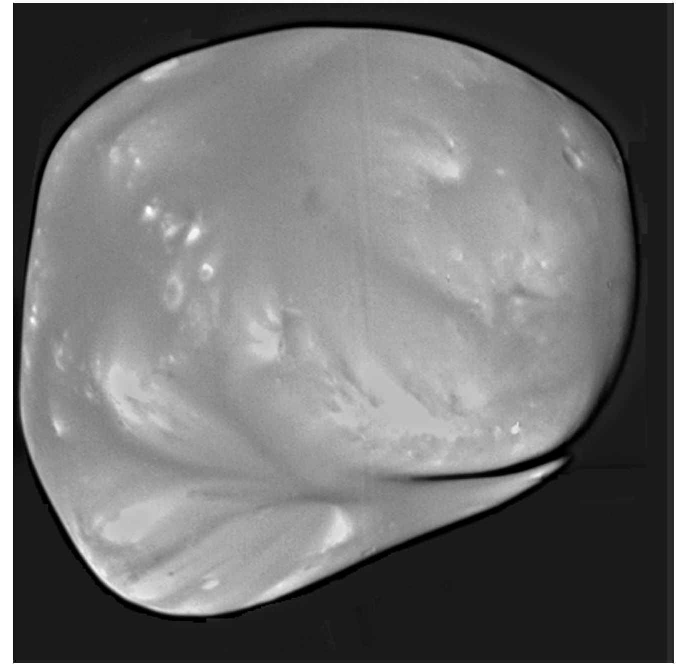
Triton: Neptune's Largest Moon



- Largest moon of Neptune
- In unusual retrograde orbit
  - Probably captured after it formed
  - Tides during capture may have caused heating
- Does have thin atmosphere (N_2)
- Shows recent "activity"
  - Not volcanic – rather volatile related
  - Ices migrate with seasons
  - "Geysers" caused by heated ices

Phobos & Deimos: Two "misplaced" asteroids?





Grooves seem related to the large crater called "Stickney"

- Phobos and Diemos are small (~25 km and ~15 km diam.) moons of Mars
- Look like captured asteroids rather than moons formed in place
- Are "C" class – i.e. dark "Carbonaceous" type "asteroids"