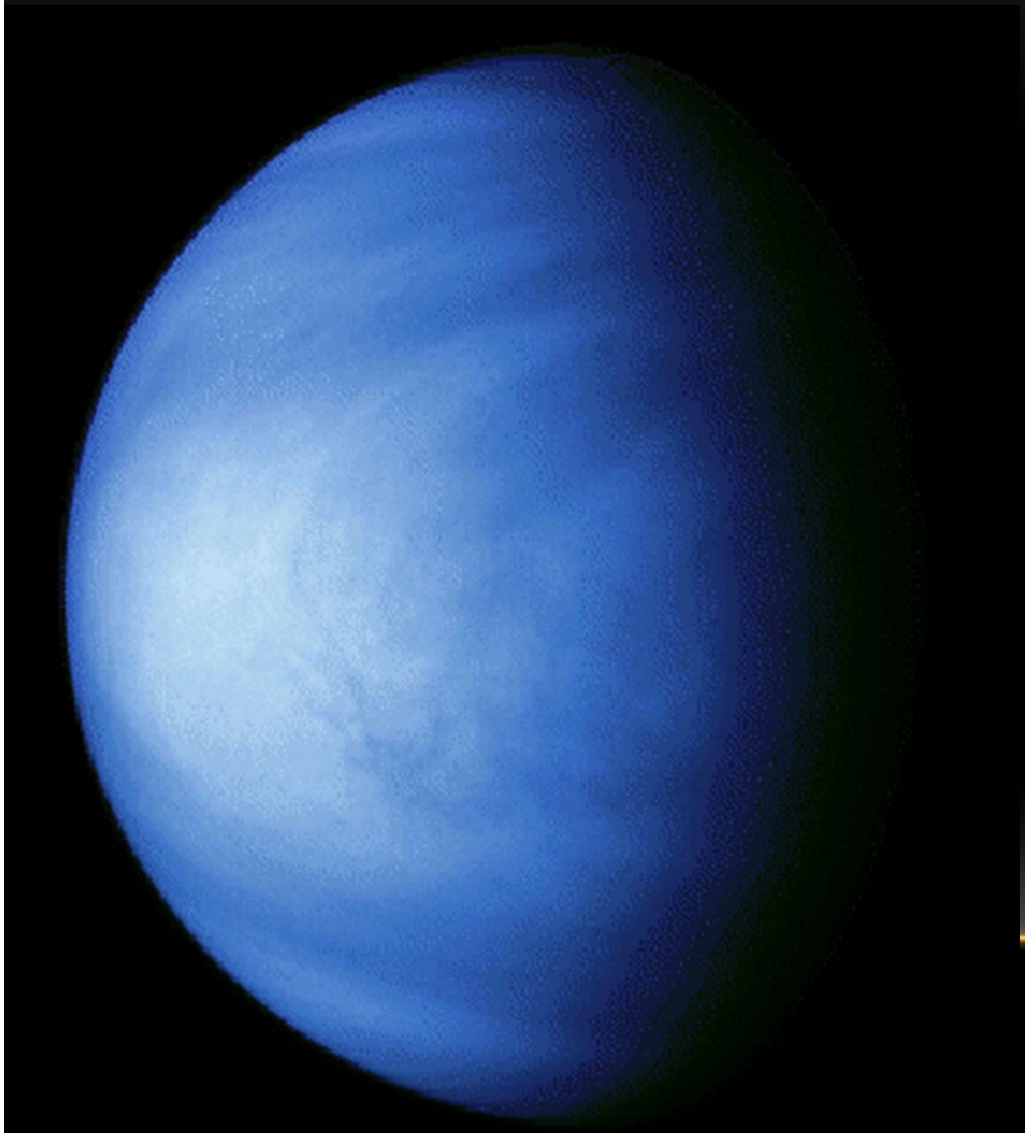
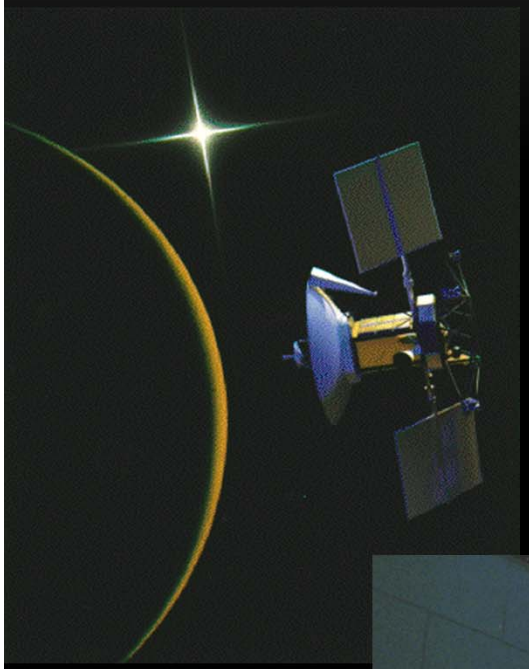
WHAT WE SEE



- Simply the top cloud layer of a very dense atmosphere
- This picture is contrast-enhanced
  - In reality, Venus looks extremely bland!
- …and false-color
  - Really looks just white

SO HOW DO WE OBSERVE IT?



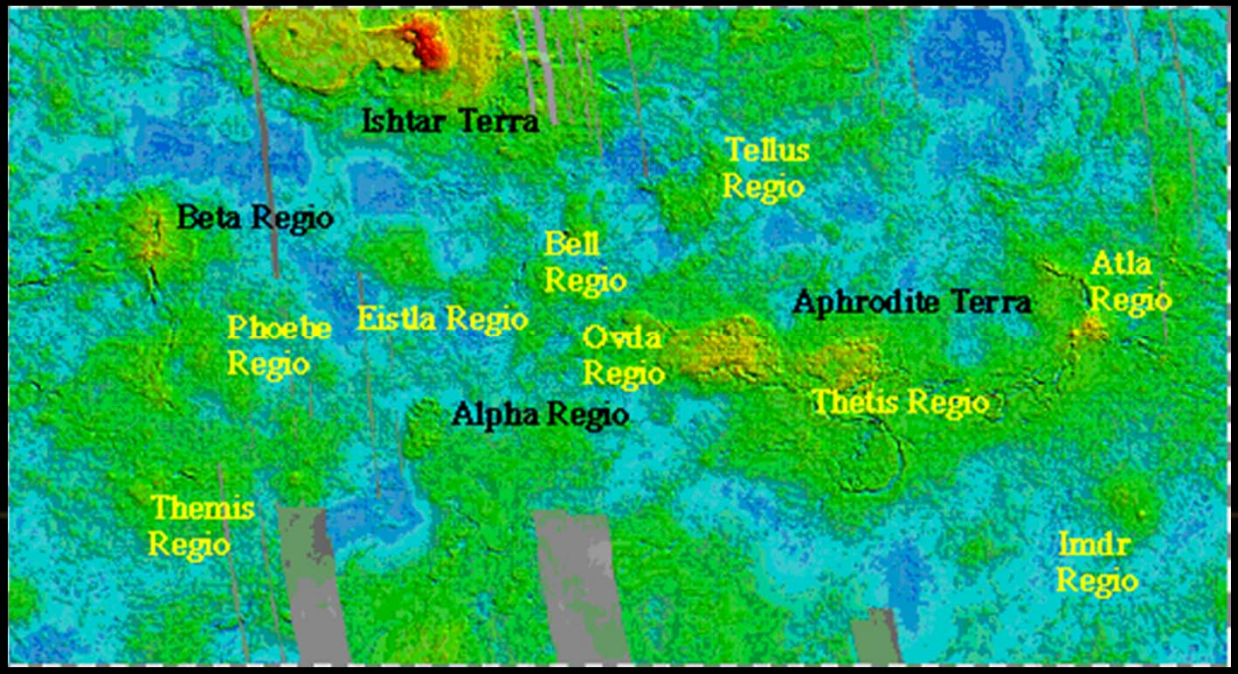
Magellan

- Radar
  - From Earth or Probes
- Many probes sent to Venus
  - US -
    - 3 Mariner flybys
    - 2 Pioneer orbiters
    - Magellan radar mapper
  - Russia -
    - many Venera orbiters, probes, landers
    - 2 Vega landers, orbiters, balloons

Venera 14

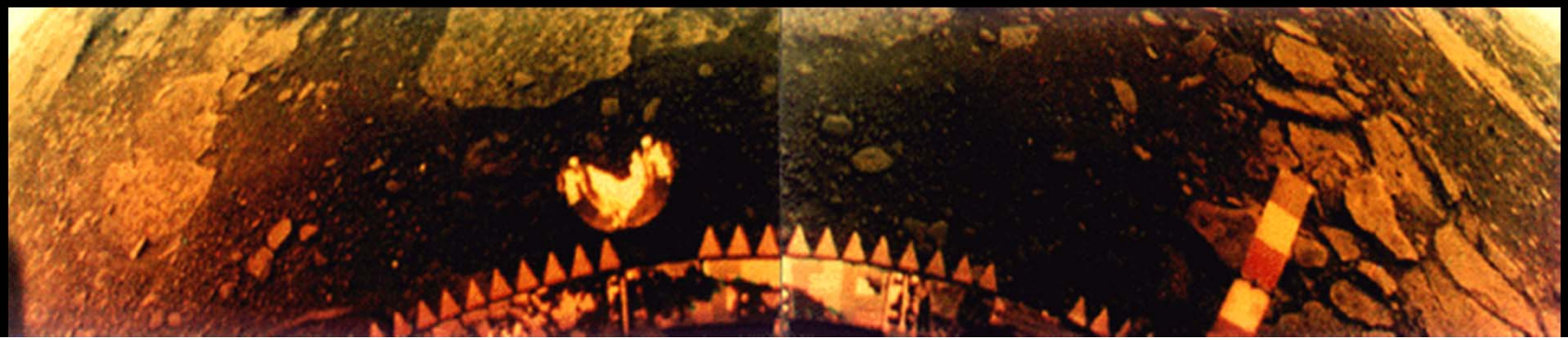
TOPOGRAPHIC MAP

- Mapped out to ~100m by Magellan
- Two large continents , several highlands
- Features named for women
- Lowlands not water filled – this is a radar image

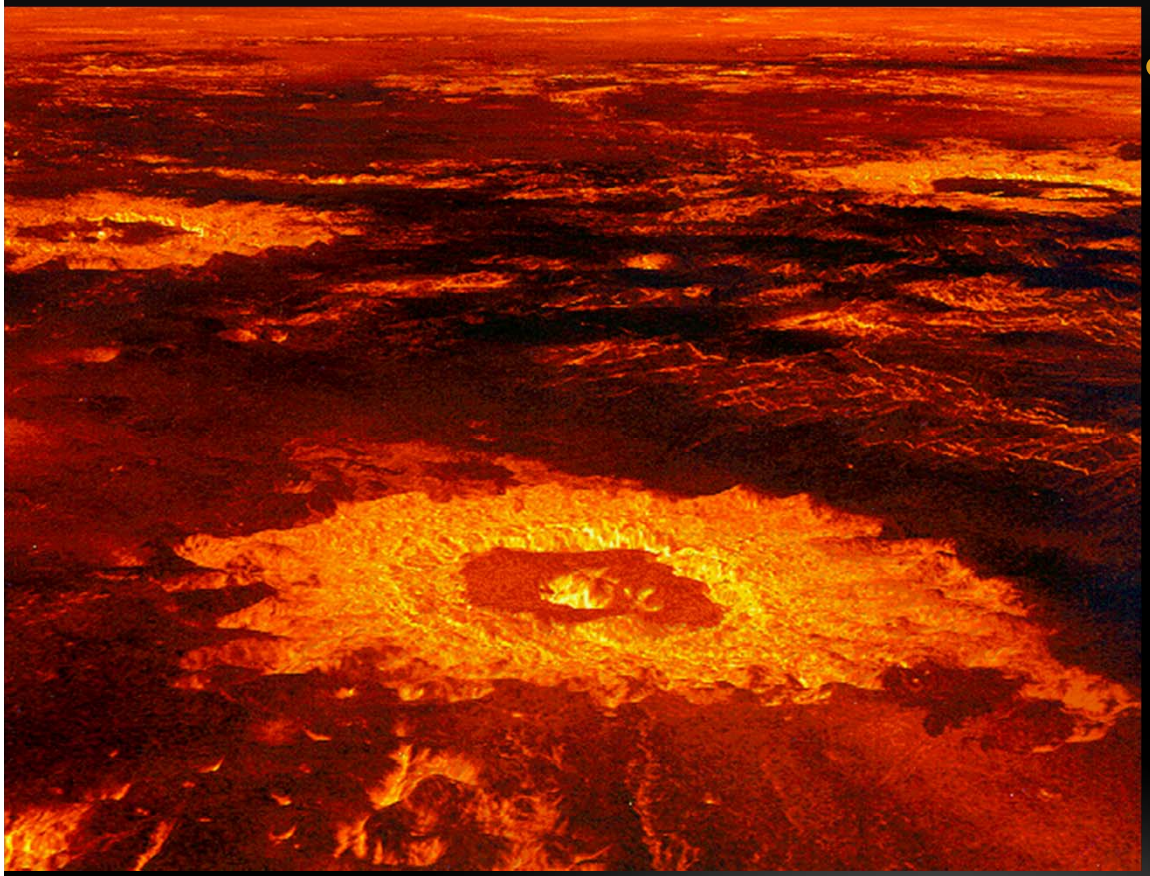


CLOSE UP OF SURFACE

- View from Venera 14 lander (1975)
  - Landers melted after an hour or so
- Many normal rocks
  - Some landers also sampled and analyzed rocks
- No wind at surface
- Intense pressure and heat from thick atmosphere



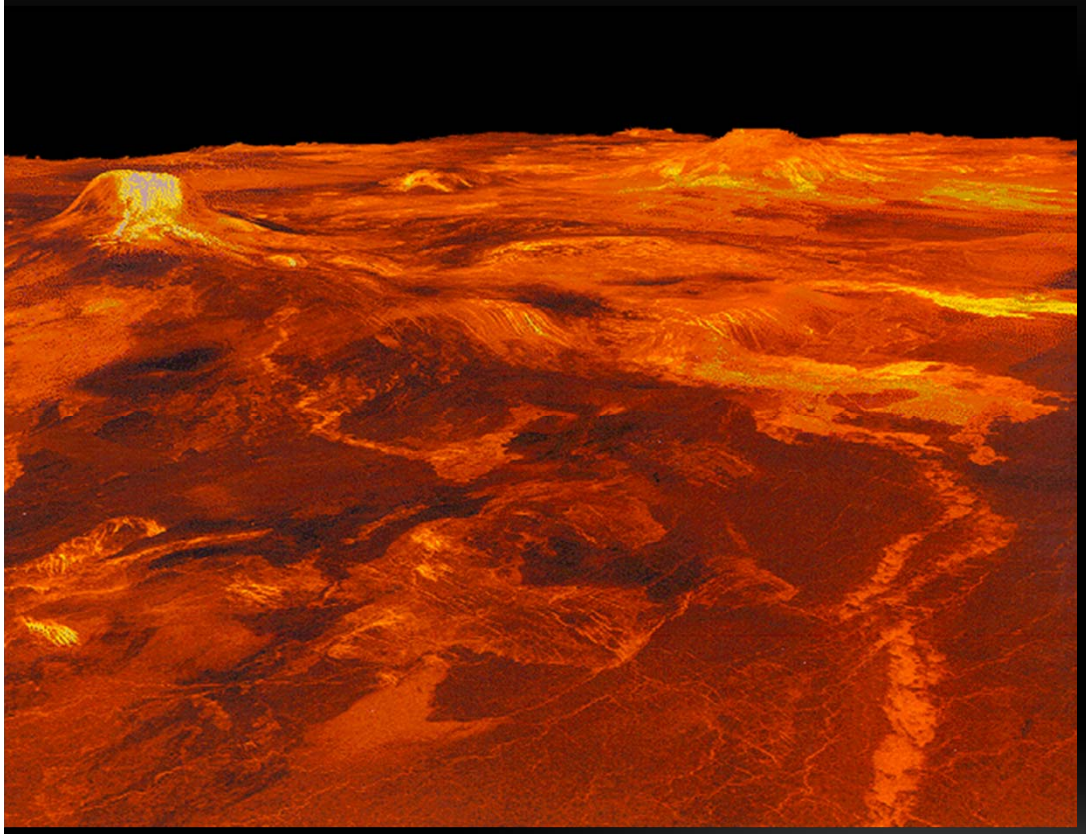
SURFACE FEATURES



Crater Howe
Magellan radar image

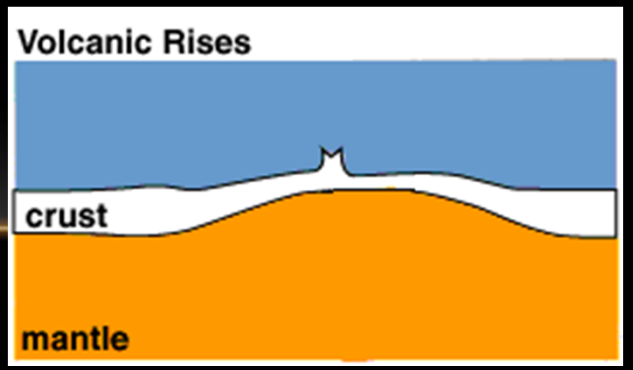
- Some big craters
  - Bottoms lava-filled
  - Area around melted
  - Atmosphere shields from intense cratering & geologic activity erases them
    - Similar to Earth
  - Low winds, no water mean less erosion than Earth

VOLCANIC ACTIVITY



Two shield volcanoes

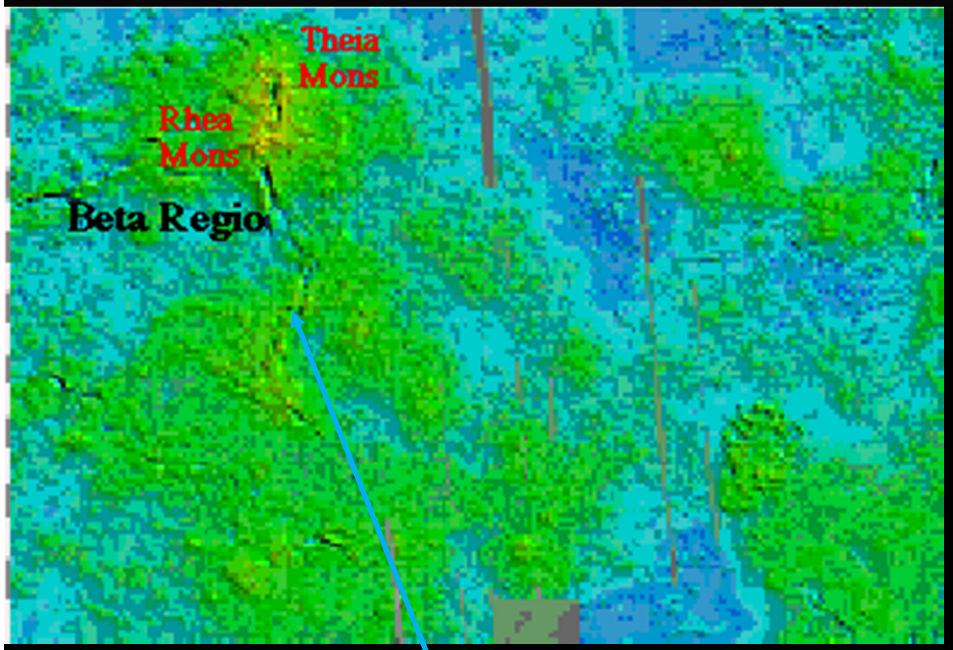
- Volcanic rises
  - Over “hot spots” or “mantle plume” in the crust
  - “Shield Volcanoes” - similar to Hawaii



VOLCANIC DOMES

- Surface over plumes bubbles up, forms a dome
- These domes have “crowned” or collapsed back down

RIFT-TYPE RISES

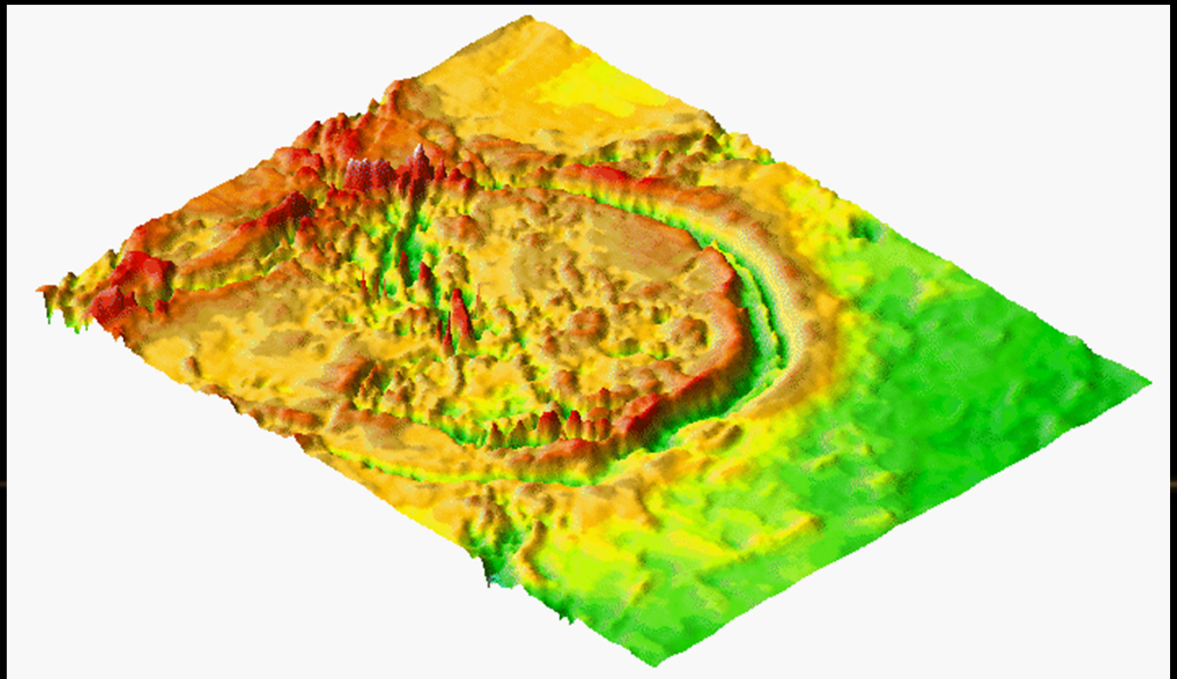


- Another kind of Volcanic Rise is the “rift-type”
- Beta Regio is of this sort
  - > 1000 miles across
  - Cut by rifts bigger than the Grand Canyon
- Caused by crustal motion

A big long rift

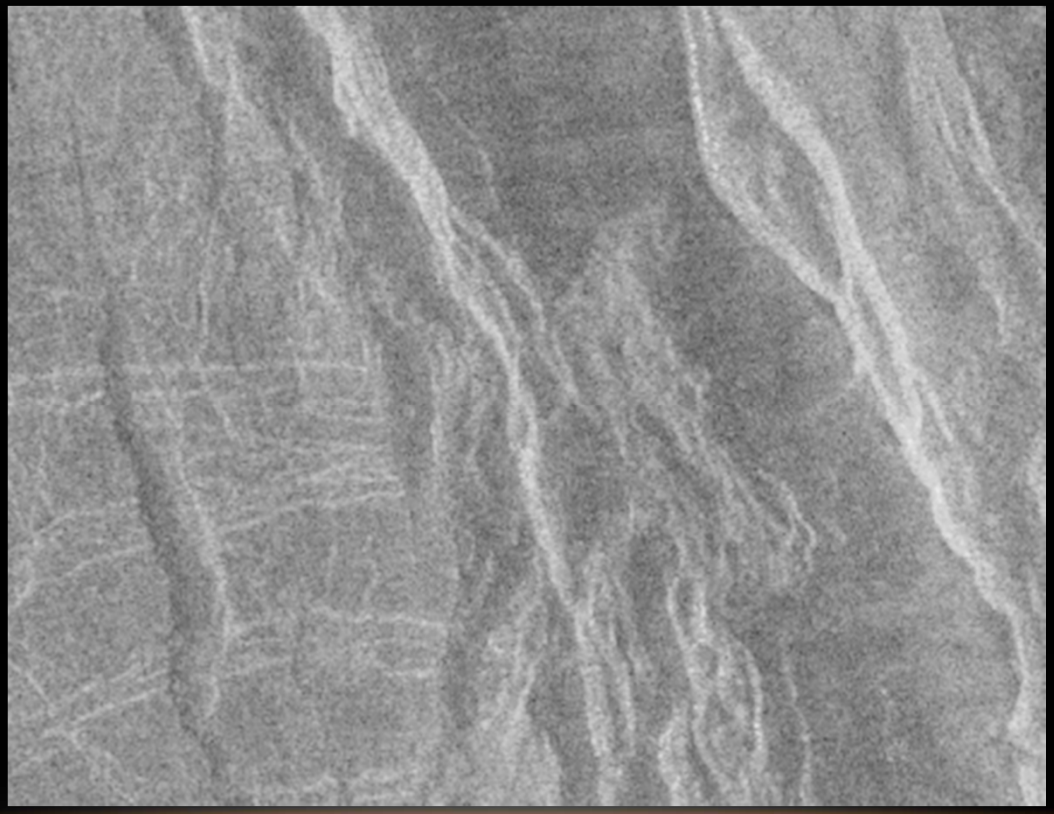
CORONAE

- Corona-type rises are the 3rd sort of volcanic rises
  - Caused by big upwelling from mantle
- Cause trenches around highland plateaus
  - Volcanoes, lava pop out too
- Similar to subduction trenches on Earth

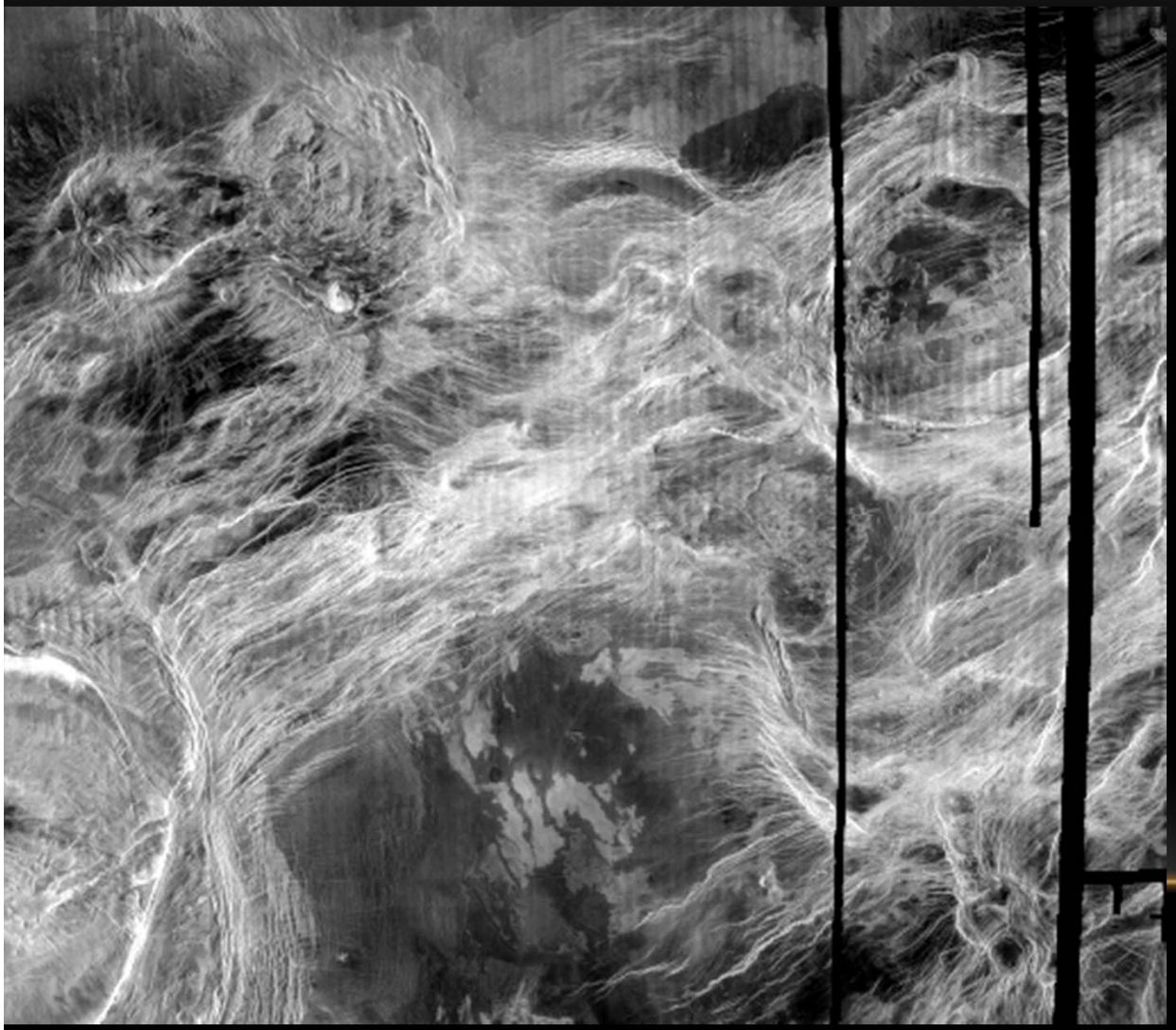


Artemis Chasma, 780 miles across

CLOSE-UP OF GANIS CHASMA



TESSERA

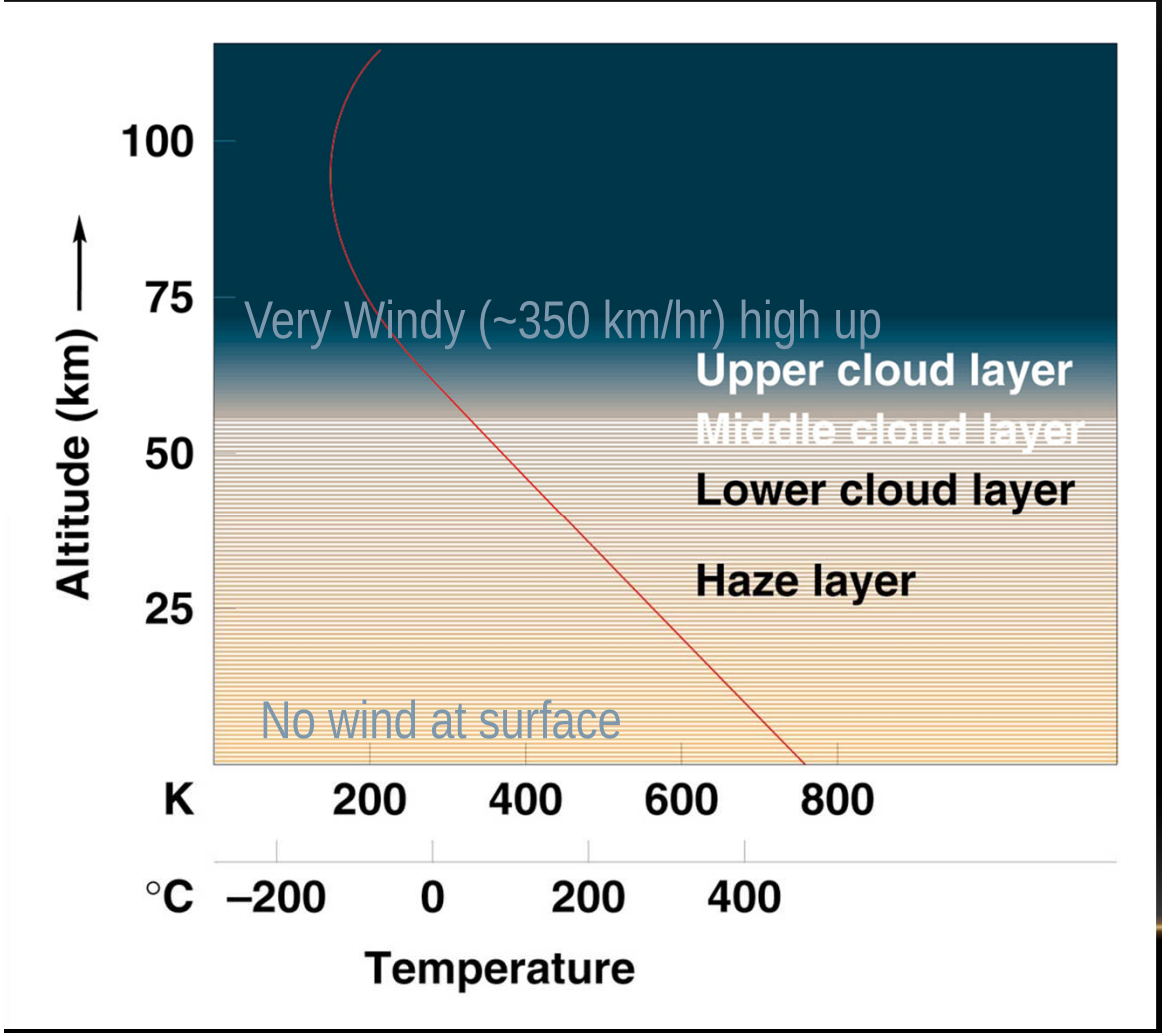


- Complex ridges
  - Found on plateau highlands
- Formed as the crust is pushed together
  - Sort of like some mountain ranges on Earth
  - Tessera are unique to Venus

CRUST IN MOTION

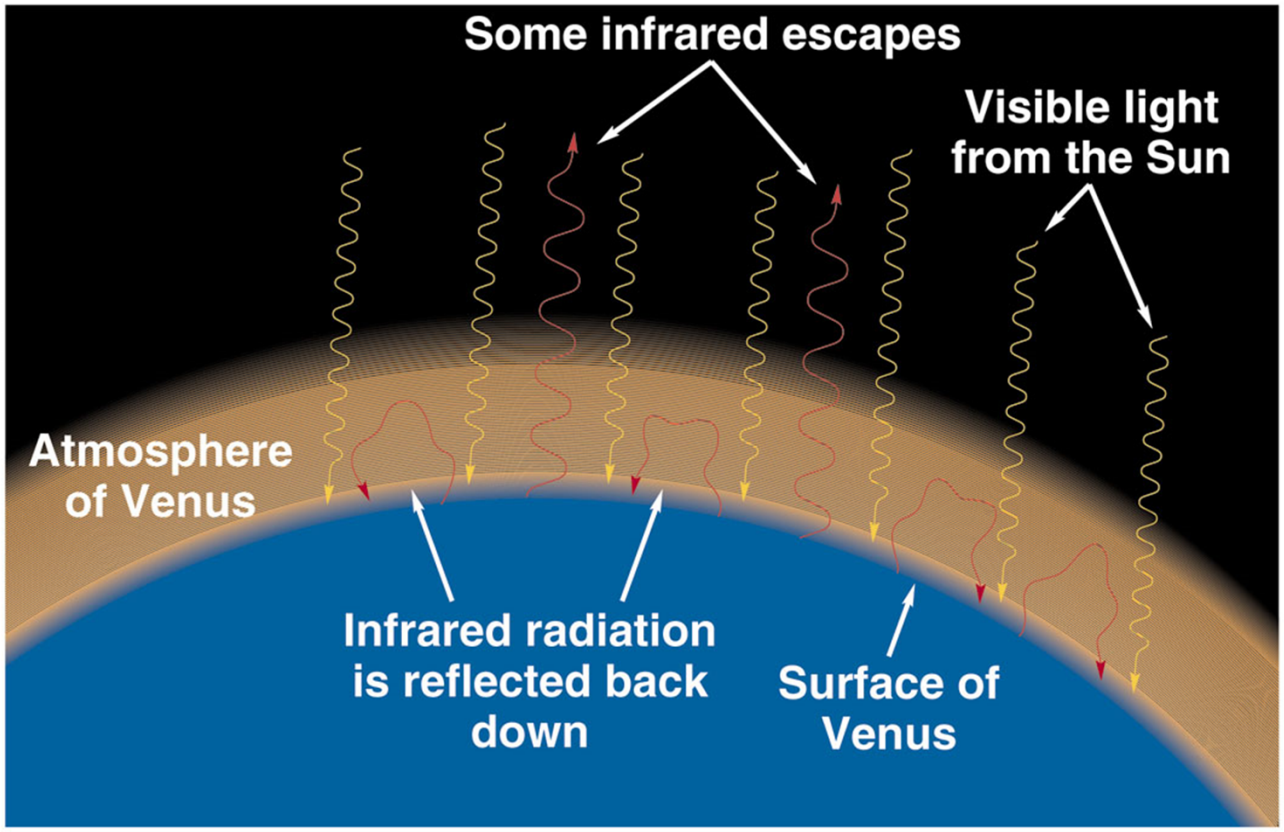
- Venus' crust is obviously in motion
  - Rifts, coronae
  - Tessera
  - Fewer craters than you might expect
- But, it's not like Earth's plate tectonics
  - Thicker crust because slightly smaller planet cools somewhat faster?

VENUSIAN ATMOSPHERE



- Venus' most distinctive trait: stifling atmosphere
- Very thick
  - 90x Earth's pressure at surface
- Very hot
  - That's 870 ºF, lead melts
- 96% CO_2, 3.5% N_2, small amounts of H_2O + sulfuric acid
  - Clouds are acid droplets
  - Makes light look orange

WHY SO HOT?



- Venus is closer to Sun than Earth
  - But not that close!
- Thick atmosphere keeps things warm
  - Greenhouse effect

WHY SO DIFFERENT FROM EARTH?

- On both planets, volcanoes spewed out CO_2 and H_2O to form initial atmospheres
- On Earth –
  - Water condensed out, washed CO_2 into oceans and rocks (“carbon cycle”)
- On Venus, slightly hotter from Sun –
  - H_2O doesn’t condense, but helps trap heat as vapor – things get hotter and hotter
  - UV from sun gradually breaks up airborne H_2O, H escapes planet, O bonds with other stuff (like H_2SO_4)
  - Heat bakes more CO_2 out of rocks

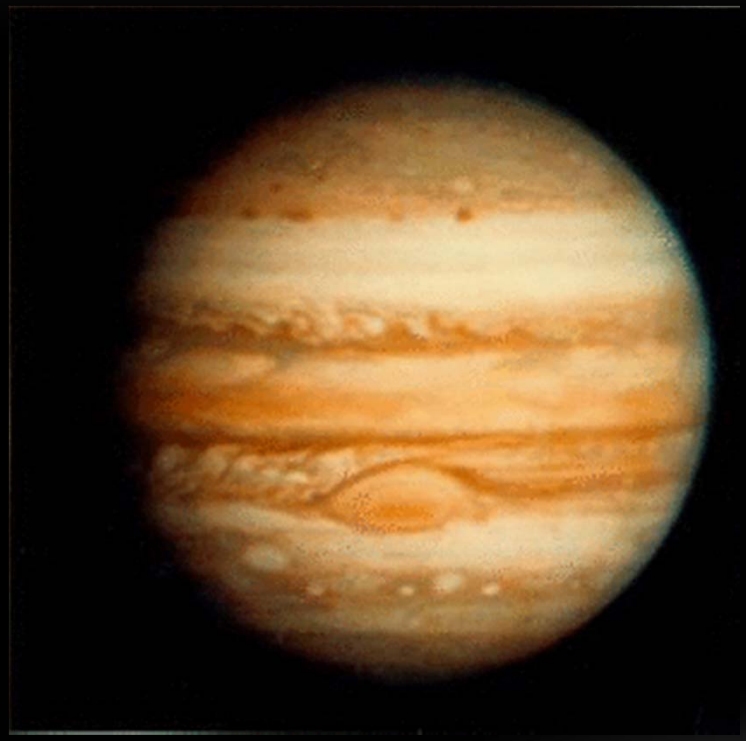
EARTH VS. VENUS

- “Greenhouse Effect” present on both planets
- On Earth, mild form keeps us warm
- On Venus, hot enough to go over the edge
  - Heat makes CO_2 worse
  - “Runaway Greenhouse Effect”
- Where is the “edge”?
  - Something for us to worry about - global warming gone berserk.
  - Probably far from where we are now, but we are headed on the wrong direction

JUPITER 4

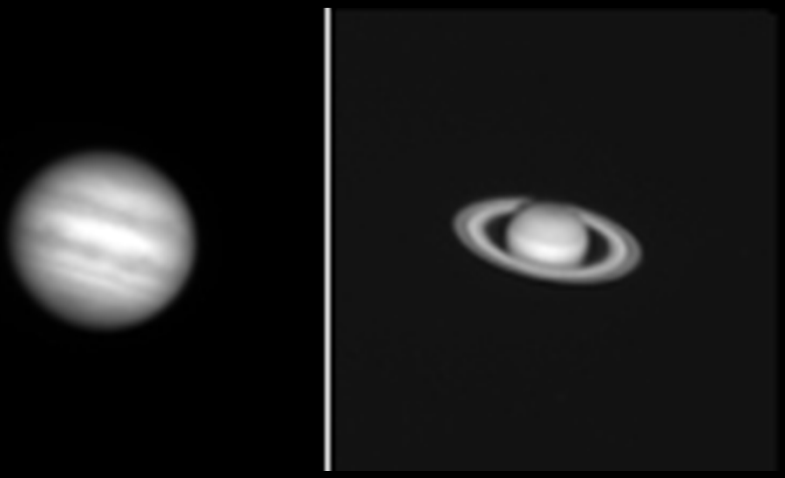
The King of the Planets

JUPITER



- 5th planet from the Sun
- Twice as massive as all other planets put together
- At 5.2 AU
  - So takes 11.9yrs to orbit Sun
- Many moons, plus small ring

VIEW FROM EARTH



Jupiter and Saturn by
Eastbay Astronomical Society
Using a 3” scope (small!)

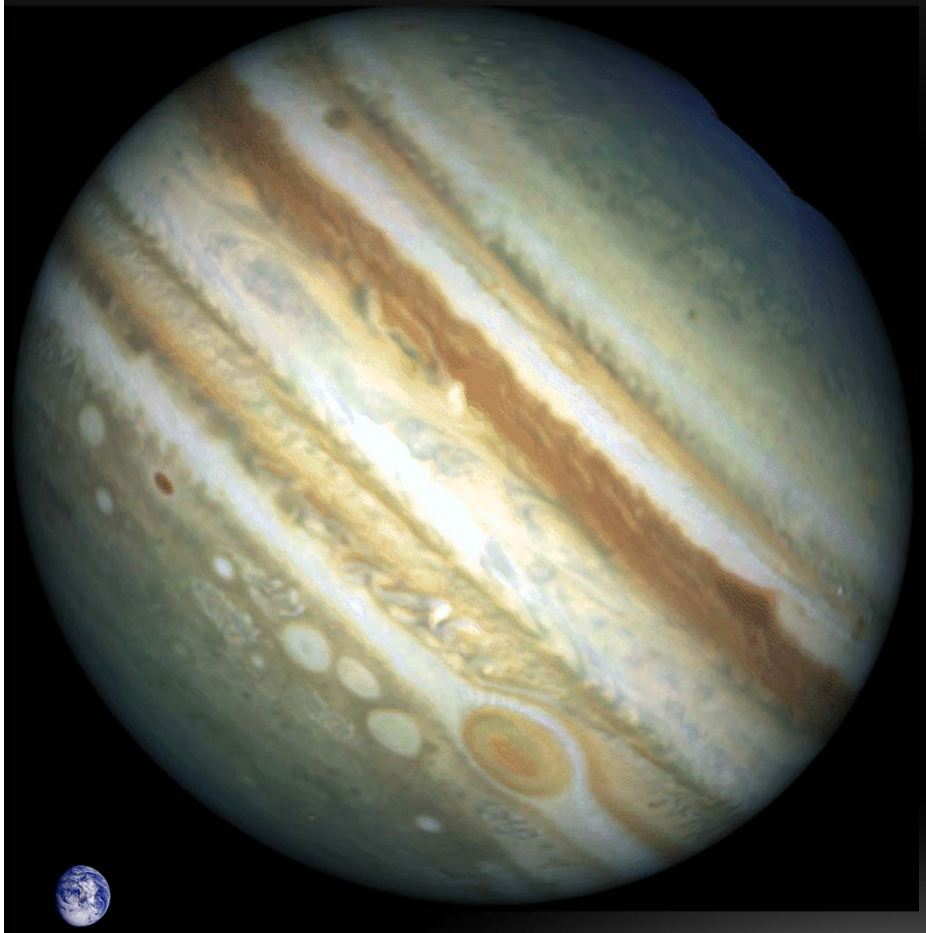
- 3rd brightest thing in the sky
  - After the Moon and Venus
- Easy to find
- Watch the moons
  - Like Galileo
- Watch the clouds

JUPITER'S MOTIONS

23 photos by Tunc Tezel
6/2000-5/2001, bi-weekly

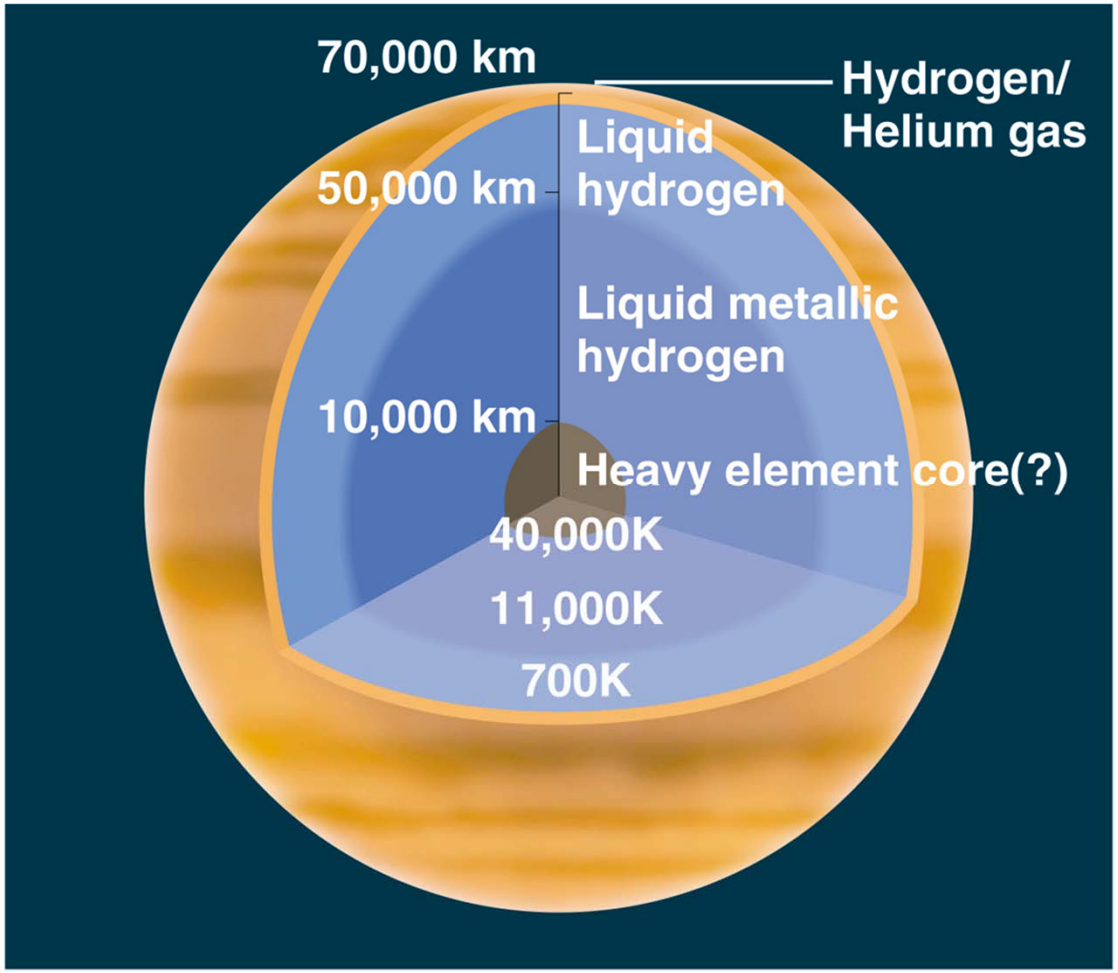
- Superior Planet
  - Opposition
  - Retrograde Motion
    - Picture: Jupiter & Saturn in front of Pleiades, Hyades
  - 11.9 year orbit
- Spins very rapidly
  - 9.9 hour rotation
  - Slightly slower near poles
- Small (3^{o}) axial tilt

SIZE, DENSITY?



- Diameter is 11x Earth
- Mass is 318x Earth
- So avg. density only 1.3 g/cm^3
  - Composition – liquid!
  - Strong gravity, cool temperatures – all gases stuck to Jupiter

ATMOSPHERE

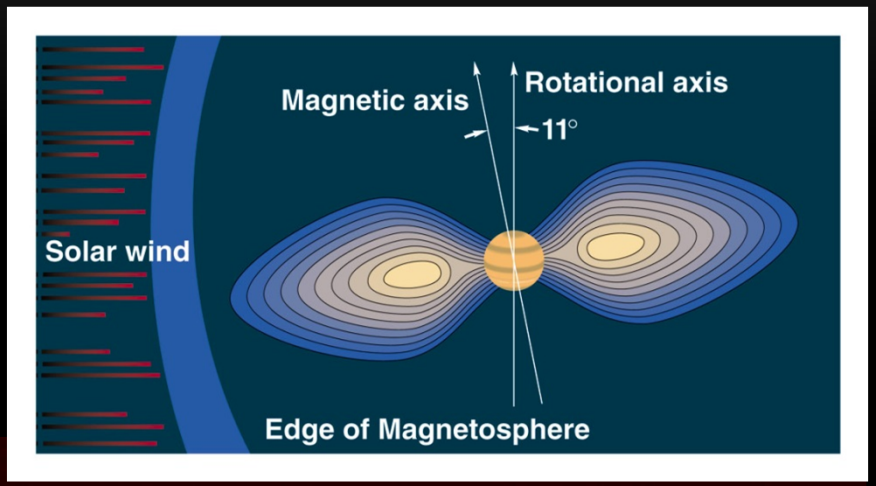


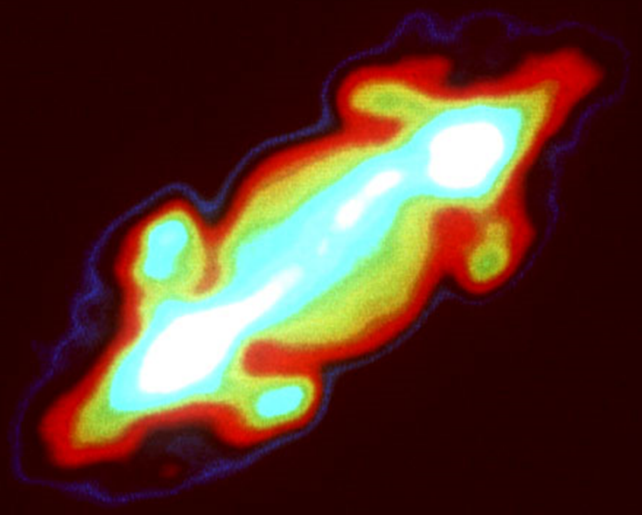
- All atmosphere, no surface
- 90% H, 10% He
  - H_2O, NH_3, CH_4 also present
- Oblate
  - Spinning makes equator 7% fatter
  - But pure gas would be even more oblate
  - So there is likely an ~1 M_{Earth} rocky core

METALLIC HYDROGEN?

- Ok, pressurize Hydrogen gas, get the liquid hydrogen – but a metal?
- If one pressurizes H to 3 million atmospheres, it becomes a liquid metal
  - Seen in very small quantities in labs
  - 20,000km deep on Jupiter will do it too
- Very fast rotator + huge metal core:
  - Giant magnetic field!

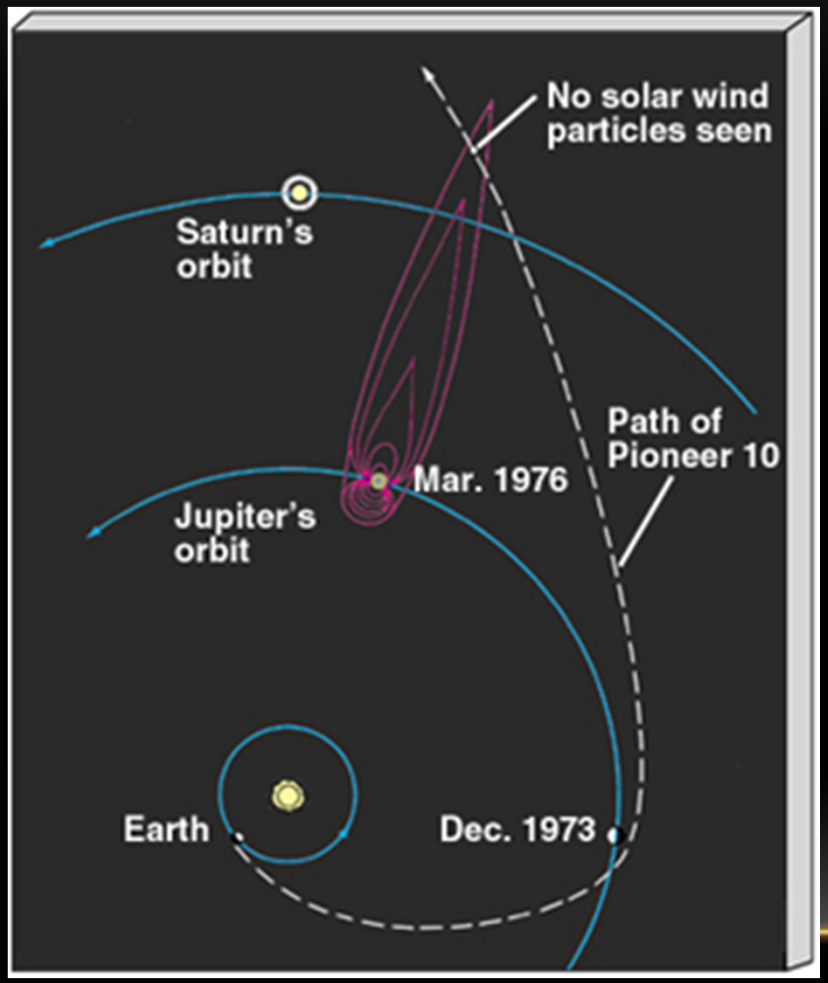
MAGNETOSPHERE





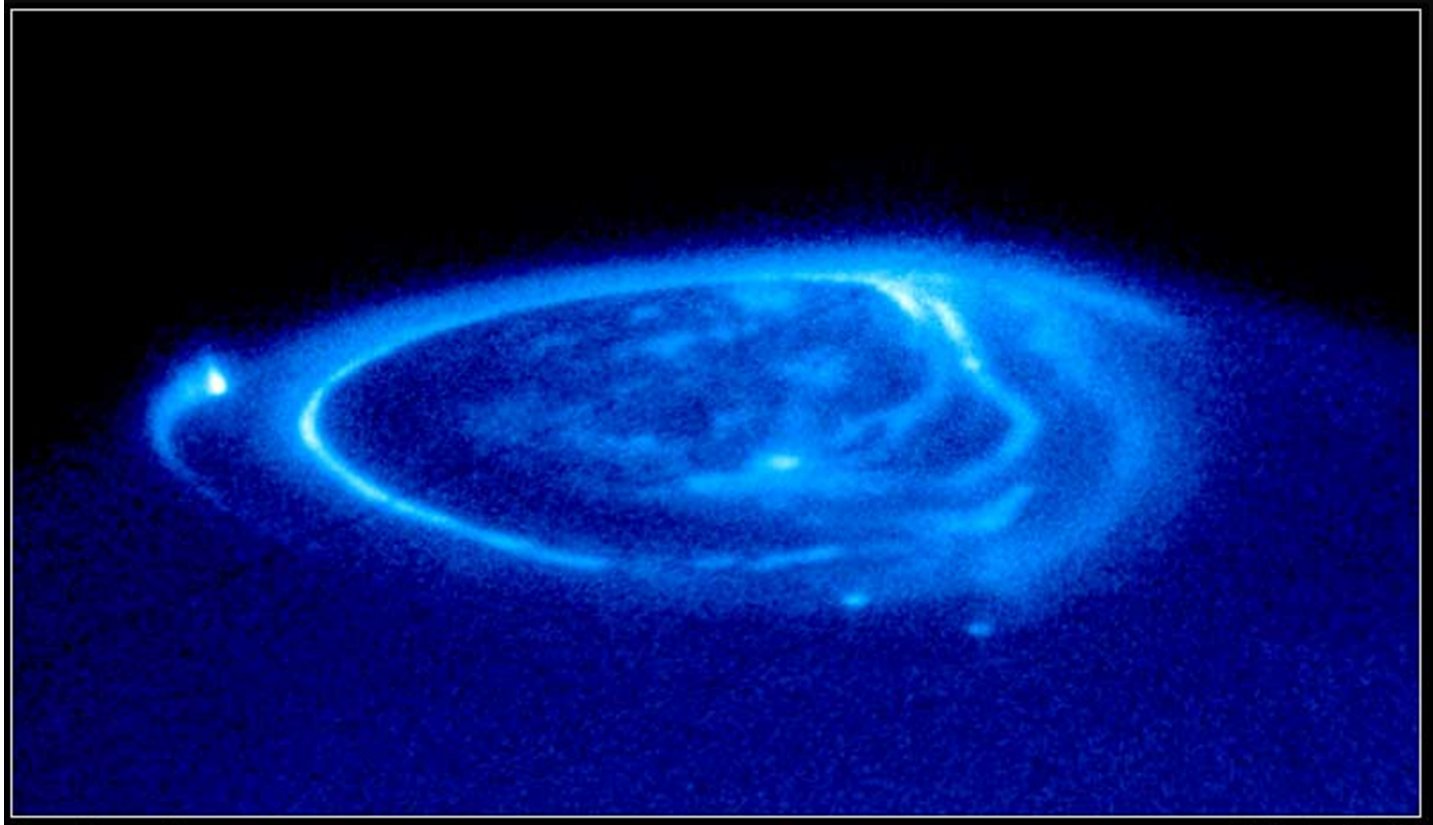
- Magnetic field is 20,000 times Earth's
- All those charged particles swirling about emit radio noise
- Left is a radio image of it

REALLY BIG MAGNETOSPHERE



- Pioneer 10 swung past Jupiter
- It swung through the tail of the magnetosphere again past Saturn!

AURORA

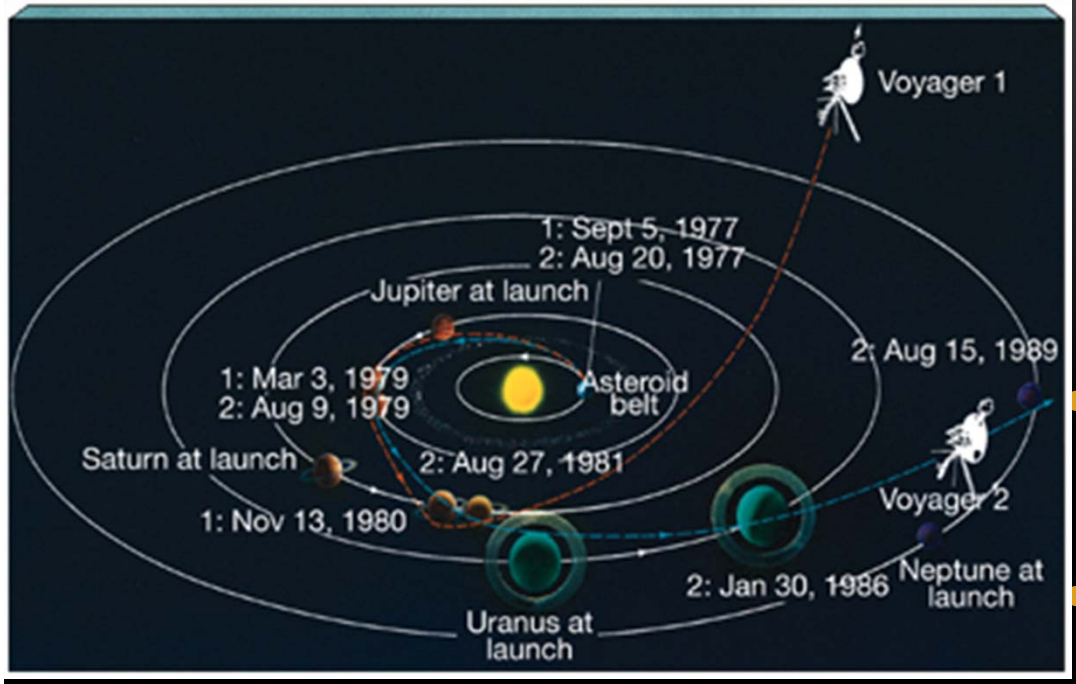


Jupiter Aurora
HST • STIS
NASA and J. Clarke (University of Michigan) • STScI-PRC00-38

- Just like Earth, Solar Wind is channeled to the poles
- Aurora made where it hits the atmosphere

SLOW TO COOL

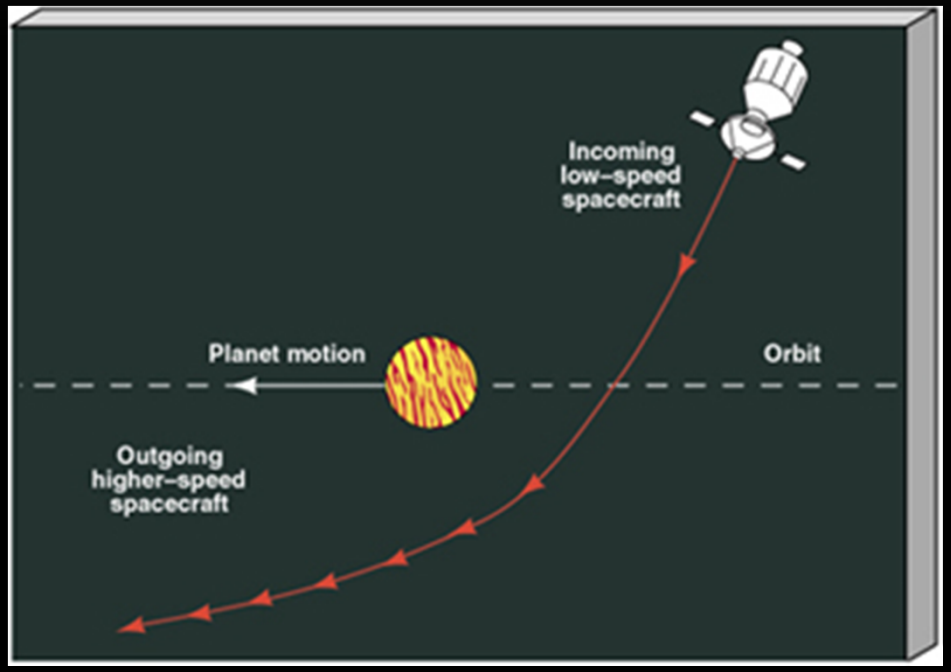
- If a planet takes more time to cool the larger diameter it is, then Jupiter must still be Quite Toasty
- In fact, it emits about twice the heat the Sun shines on it
  - It is a 125 K blackbody
  - Would expect ~105 K from the Sun alone
  - $(125/105)^4$ is about 2 (remember σT^4?)



PROBES

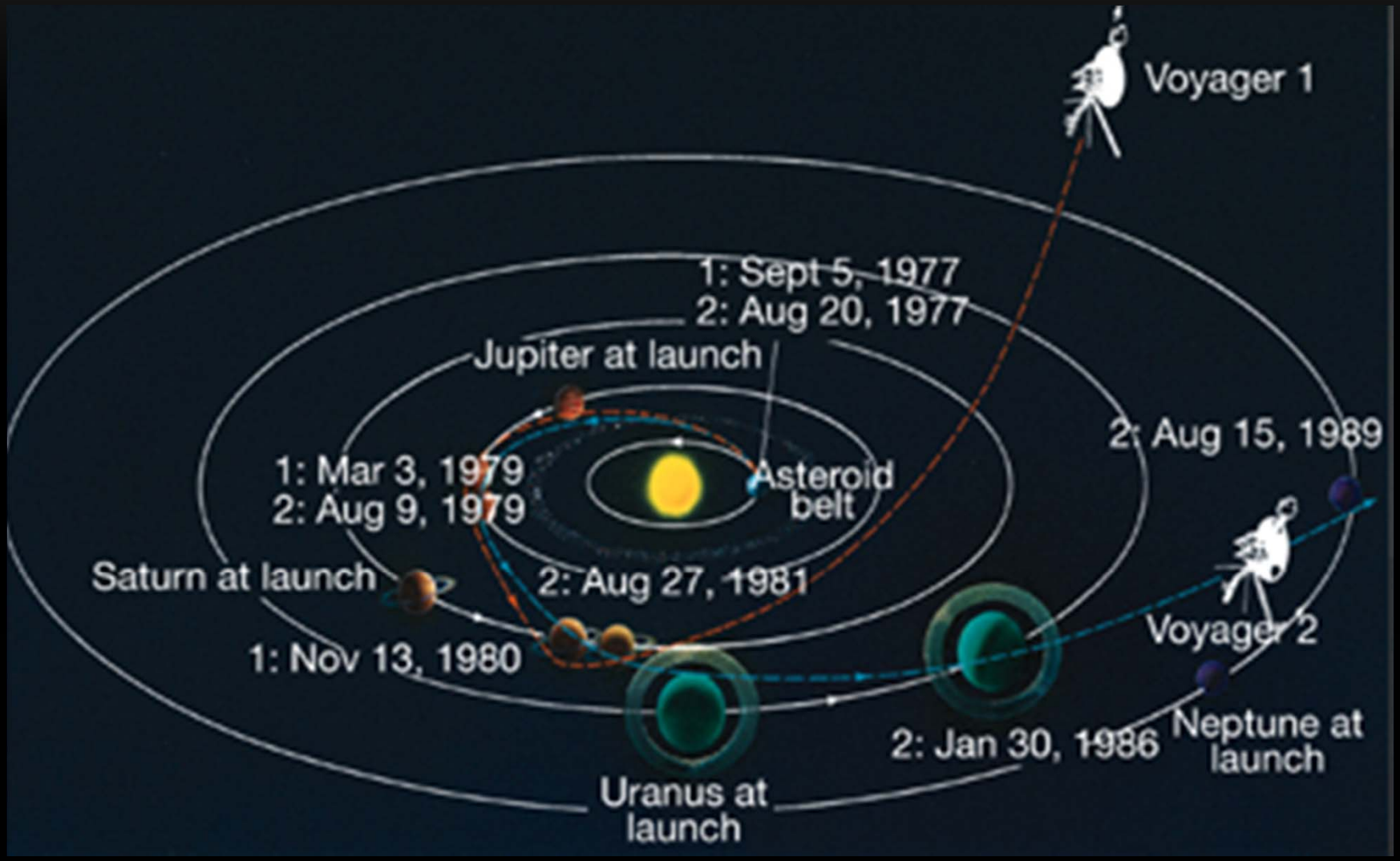
- Pioneer 10, 11 flew by in 1970's
- Voyager 1 & 2 in 1979
- Galileo orbited 1995-2003
  - And dropped probe into the planet
- Cassini flew by on its way to Saturn

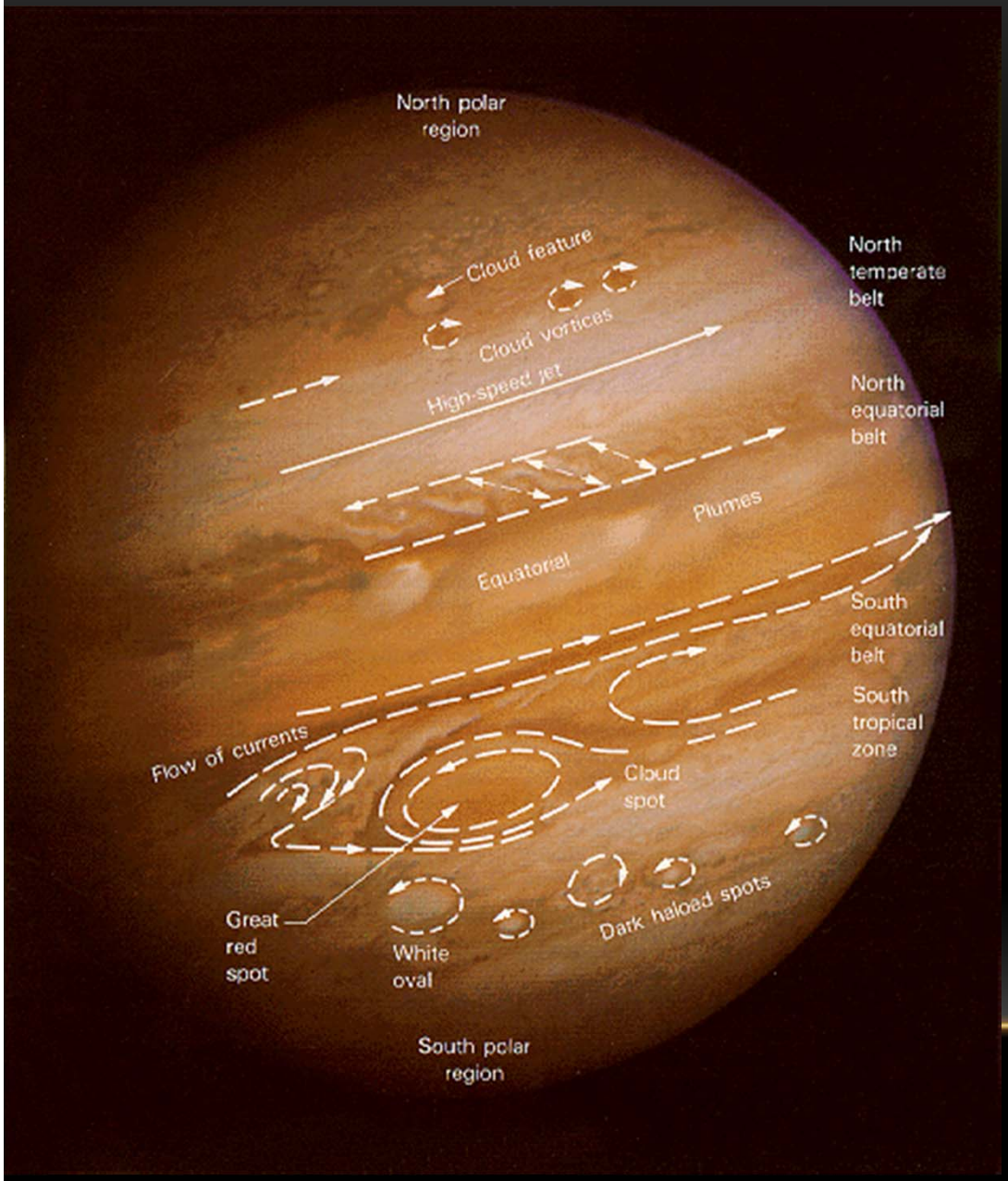
SLINGSHOT



- Spacecraft pass by planets, use their gravity to speed up or slow down
- Approach from behind, speed up
- Approach from the front, slow down
- This is much more efficient than bringing along big rockets

VOYAGER SLINGSHOTS

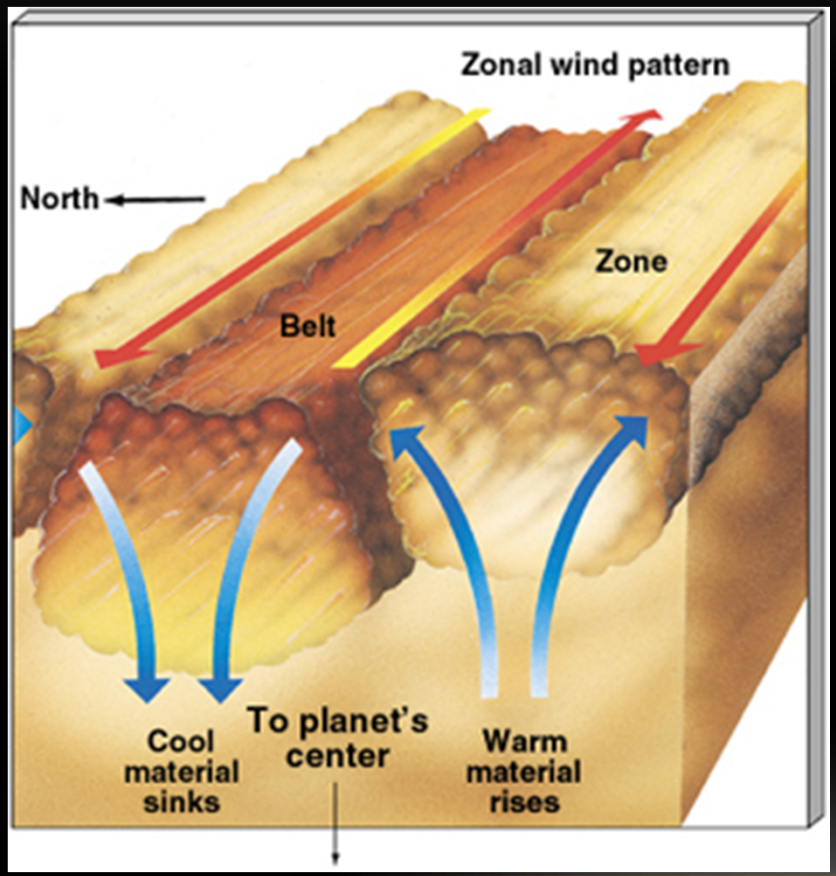




ATMOSPHERE

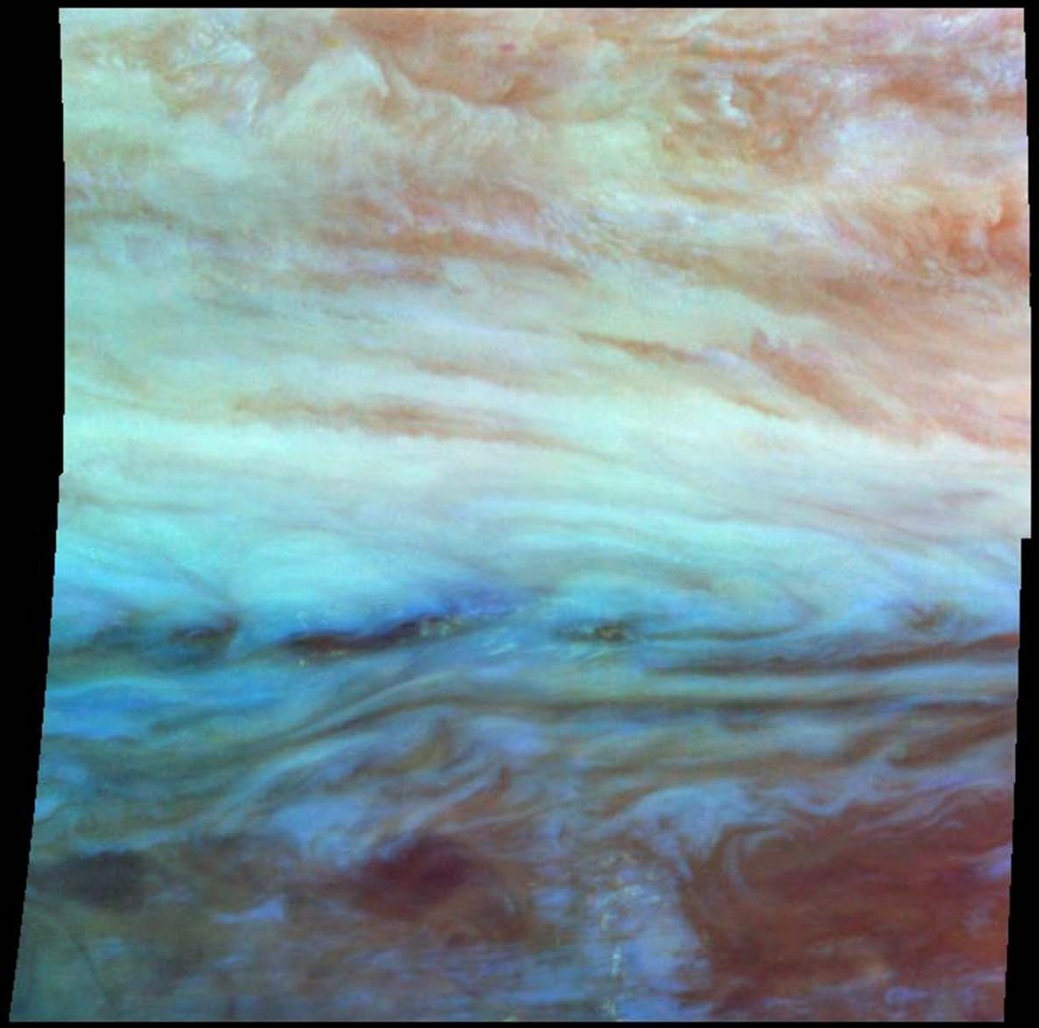
- Well, it's pretty much all atmosphere
- Lots of Weather
- White Zones
- Dark Belts
- Storms –
  - Great Red Spot, white ovals, dark ovals

ZONES & BELTS



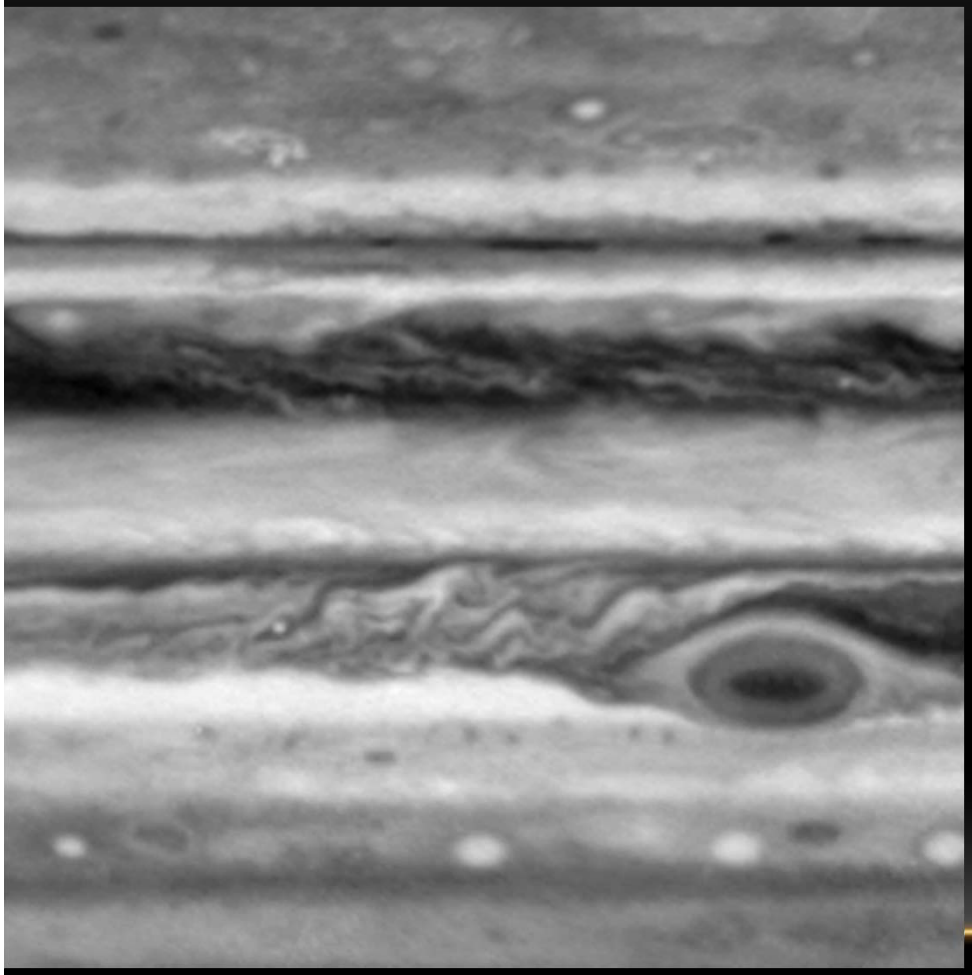
- White Zones are warm upwelling high pressure regions
  - Going westward
  - White generally ammonia ice
- Dark Belts are cool sinking low pressure regions
  - Going Eastward
  - Darker colors are ammonium hydrosulfide ice

SWIRLIES



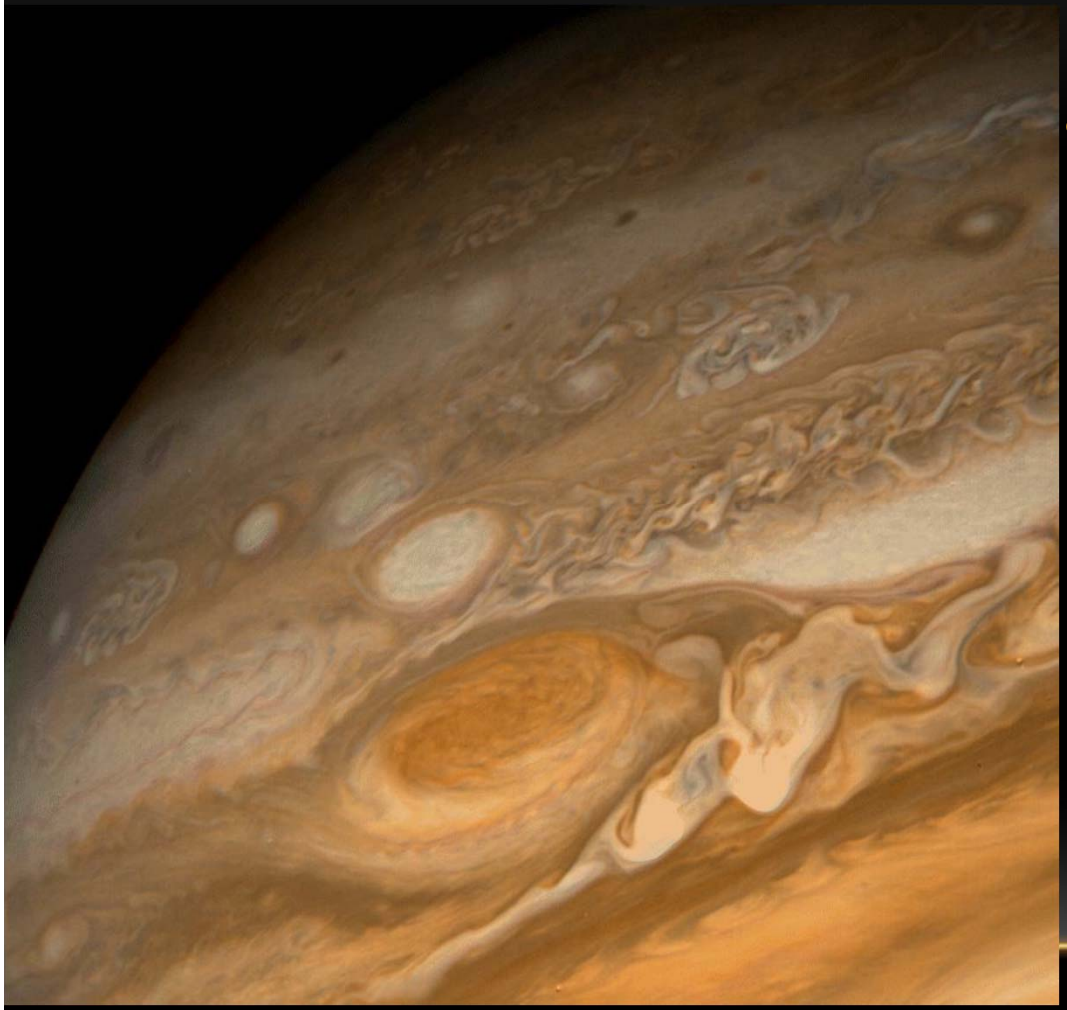
- Where the wind bands rub up against each other, things mix up a bit
- Wind speeds are ~250 mi/hr in opposite directions!

GREAT RED SPOT



- A hurricane you could fit a couple Earths into
- Has been visible since Galileo's time
  - Sometimes weaker or stronger
- Similar to Earthly Hurricane, but with no land to break it up

EDDIES

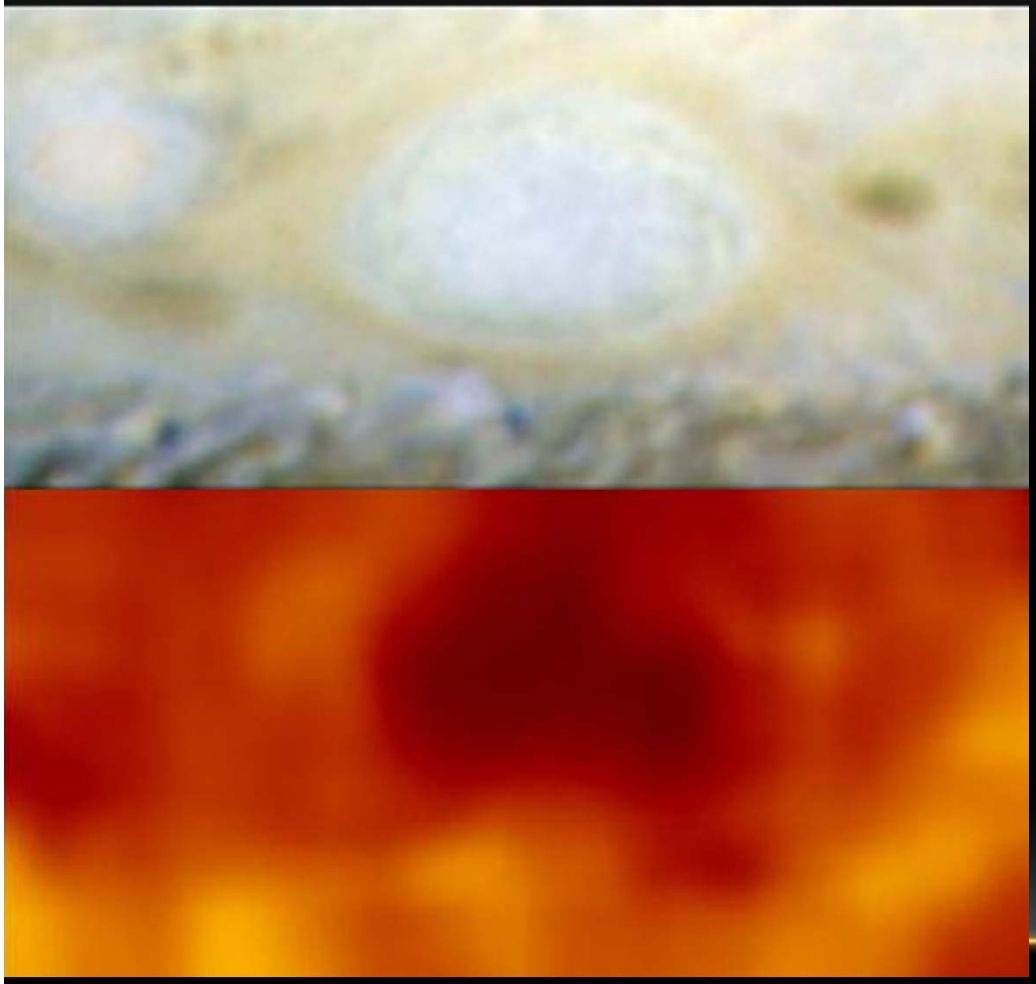


- At the trailing edge of the Great Red Spot, the eddies get large

WHITE OVALS

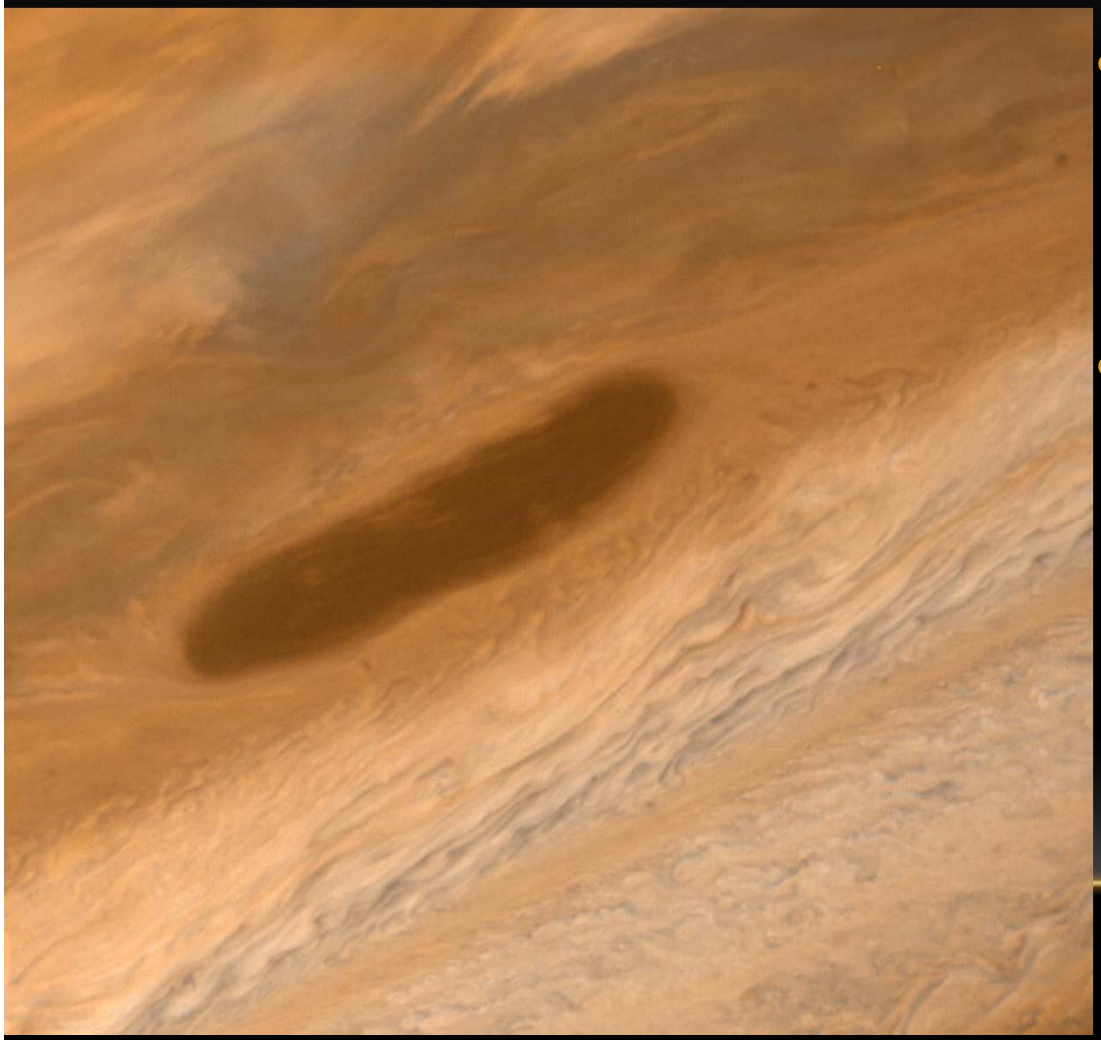
- Other storms are white high-pressure systems
- Sometimes they collide with the Red Spot, and wash it out a bit

WHITE OVALS



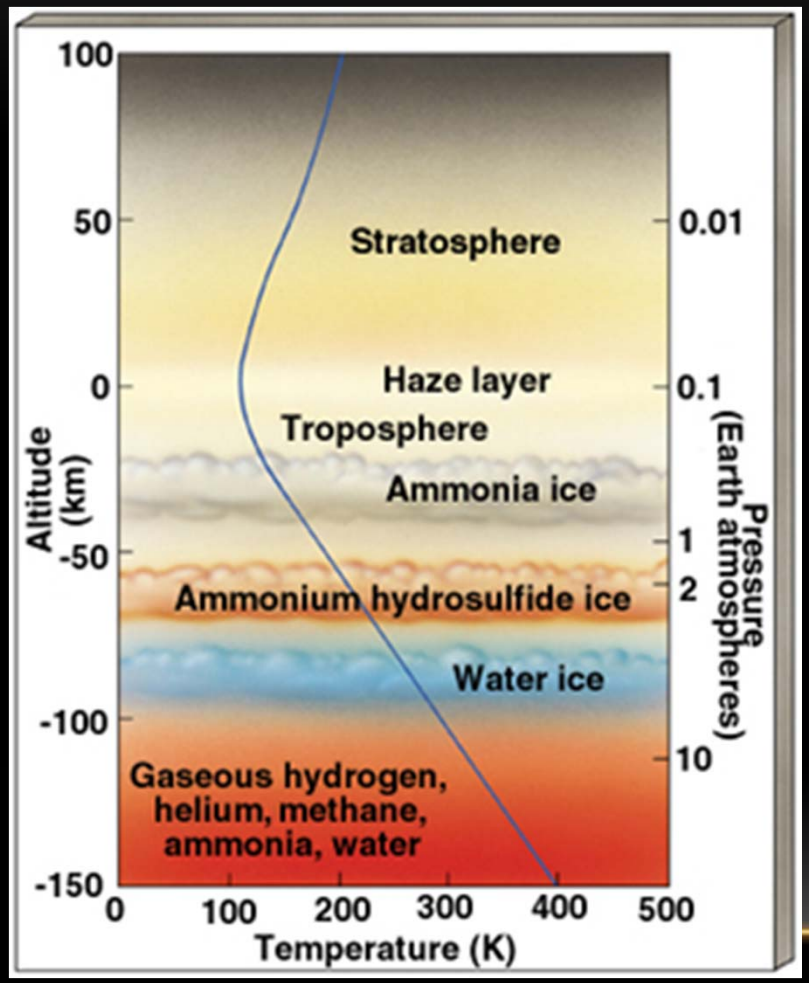
- Sometimes they collide with each other
- Top is HST image of collision aftermath
- Bottom is Galileo temperature profile
  - New storm is cooler

BROWN OVALS



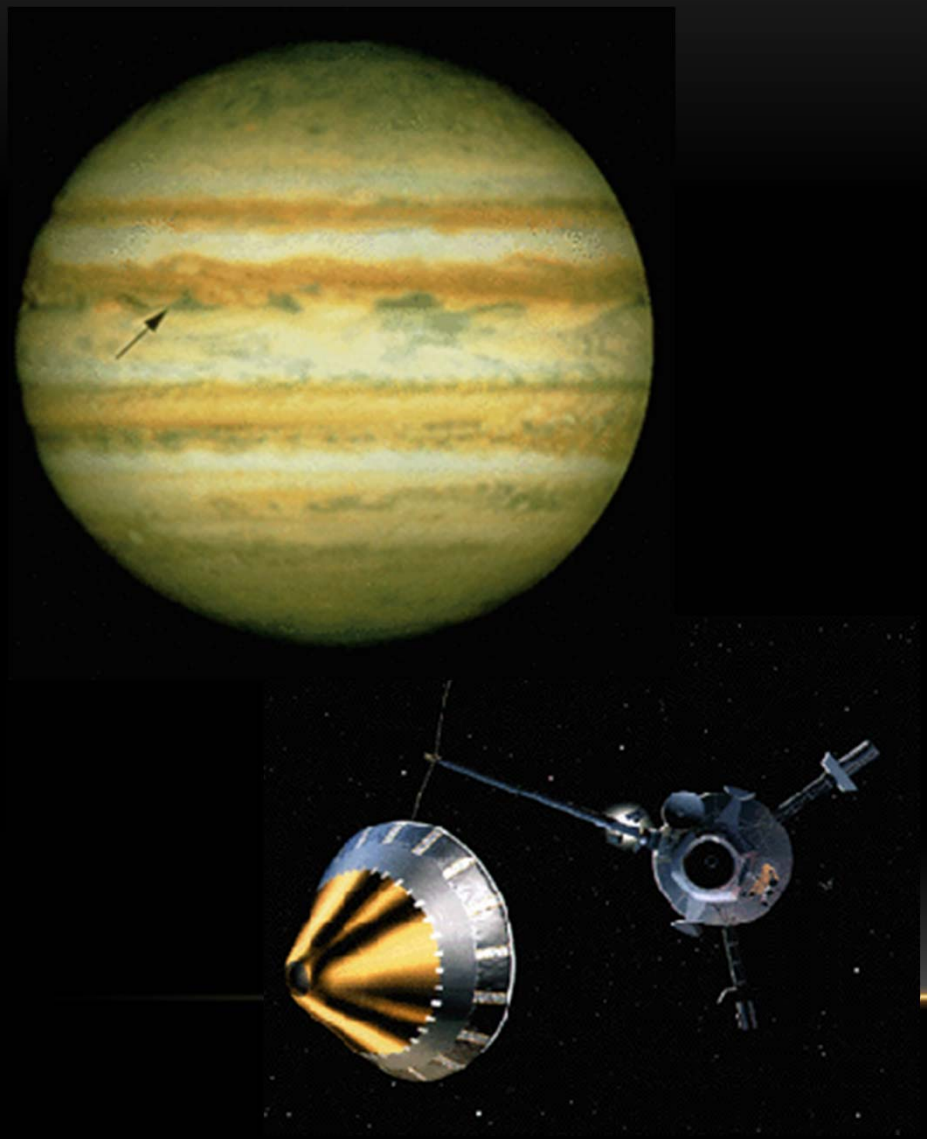
- Brown Ovals are holes in the upper layer of clouds
- You can see down to the next layer of brown clouds
  - Warmer, so white ammonia ice can’t form

CLOUD LAYERS



- If the hazy cloud tops are "0 km"
- The white ammonia ice cloud tops are at –30 km
- At –50 km are brown ammonium hydrosulfide ice clouds
- Water clouds are at –80 km

GALILEO PROBE



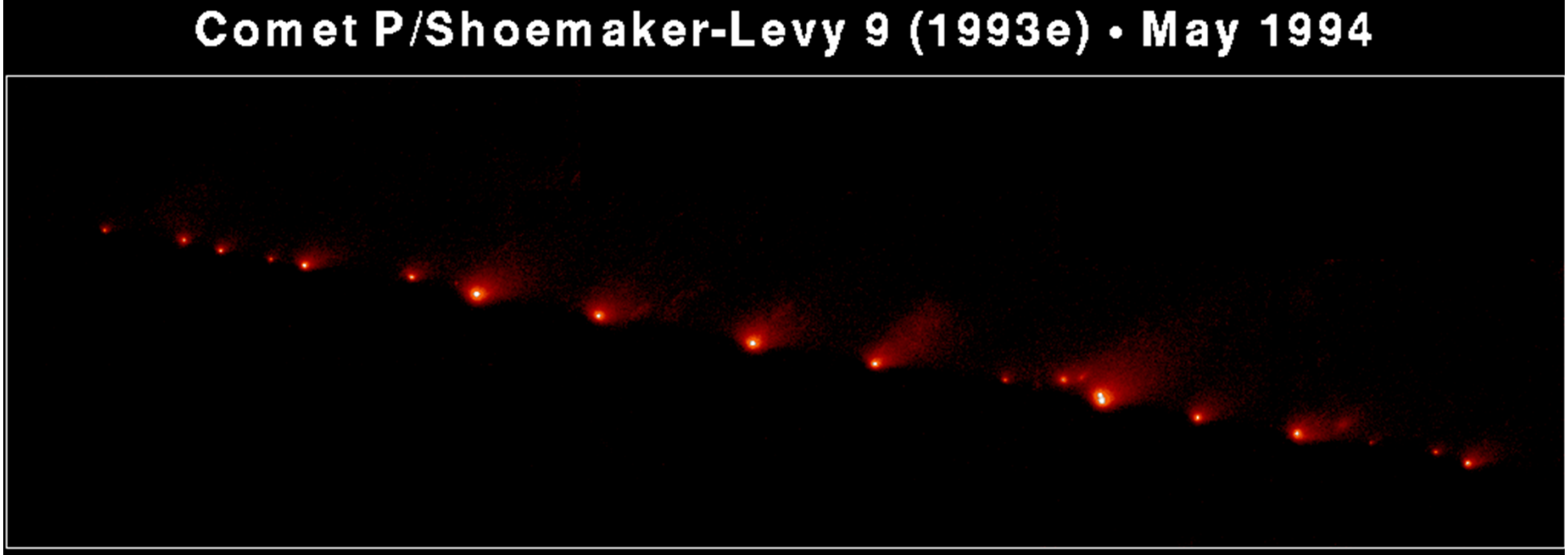
- The Galileo mission dropped a probe into Jupiter
- It descended 150 km before being crushed
- Happened to go through a hole in the clouds

END OF THE GALILEO MISSION

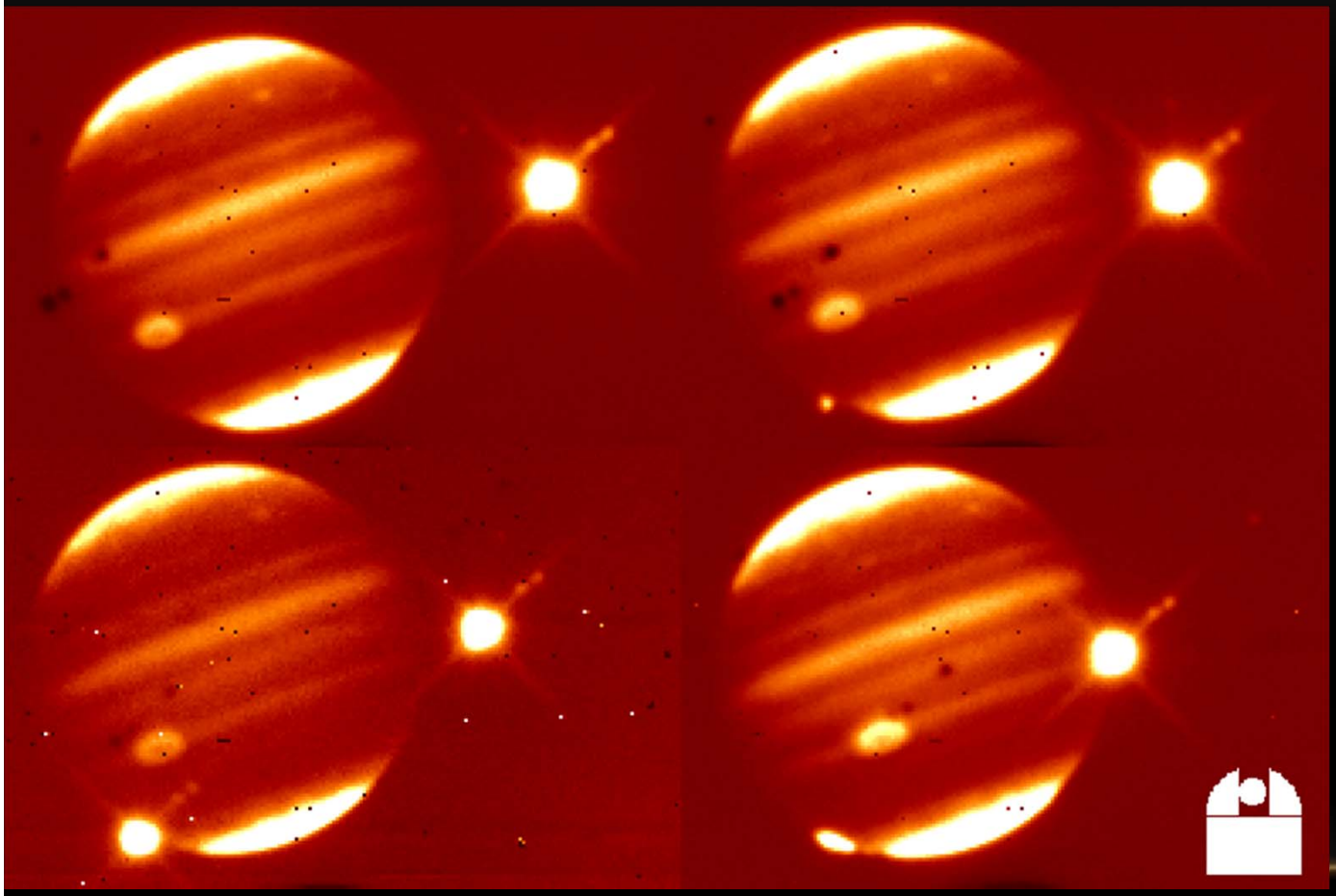
- In 2003 the Galileo spacecraft itself crashed into Jupiter
- Intentional!
  - Was low on gas
  - If left to its own devices, might have crashed into a moon
  - Don’t want to contaminate moons with Earth stuff (they could have their own microbes)

COMET SHREDDED

- A comet got too close to Jupiter, broke up due to tides



COMET IMPACT



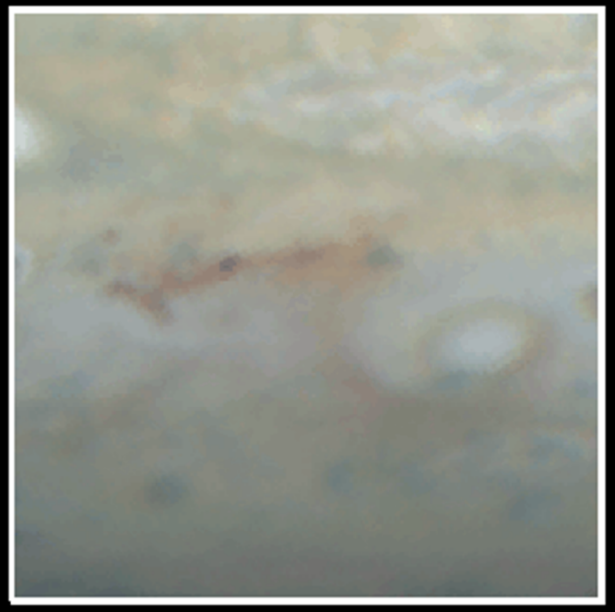
- Infrared sequence showing first chunk hitting Jupiter
  - Lower left
  - Moon Io is bright thing in upper right
- Spectra of fireball gives composition of comet

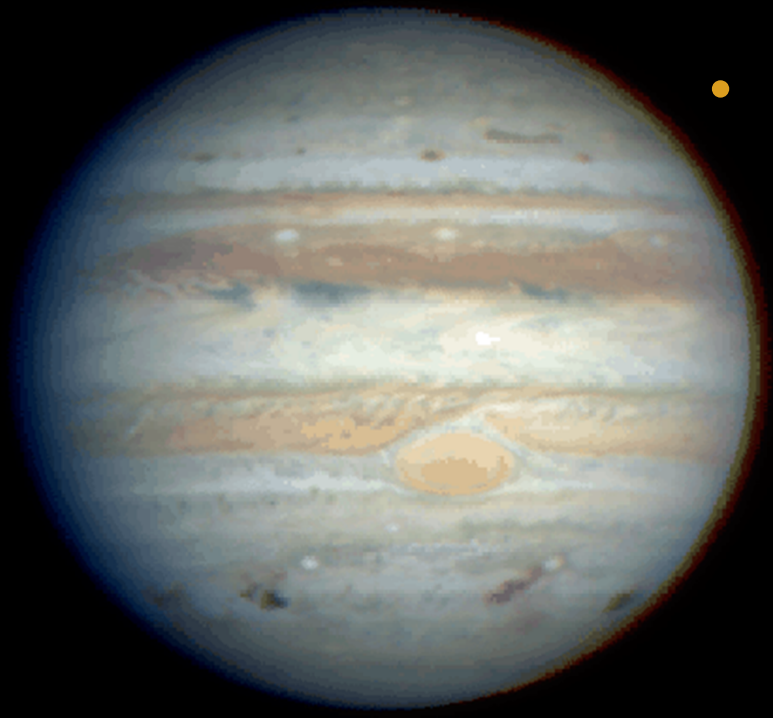
Calar Alto IR Observatory photos, courtesy
Max Planck Inst. fuer Astronomie, Heidelberg.

Jupiter 22 July 1994

ATMOSPHERE STIRRED UP

"A" impact site
after 5.5 days





- Study of impact sites helps us understand Jupiter's atmosphere

Hubble Space Telescope
Wide Field Planetary Camera 2

SATURN 

Rings!

SATURN

- The 6th planet from the sun
- 2nd largest planet
- Spectacular ring system

Feb. 22 2002 occultation
Tom Martinez, Kansas City

SATURN

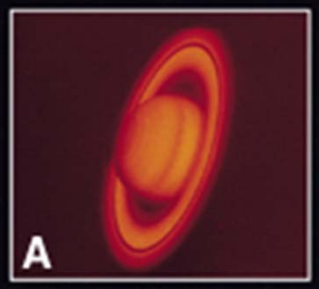
HST Image

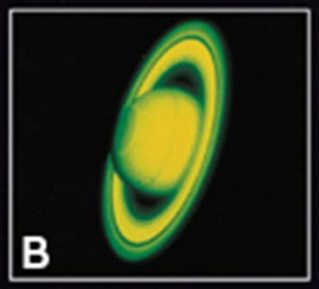
- 9.6 AU from Sun
  - 29.5 year orbit
- Fast rotator
  - 10.7 h
- Slightly smaller diameter than Jupiter
  - 9.5 Earths
- But less than 1/3 Jupiter's mass
  - Only 85 Earths

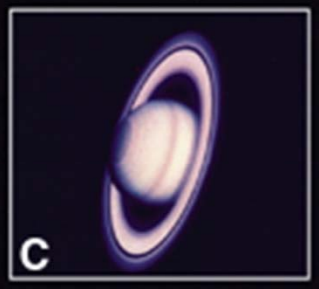
VIEW FROM EARTH

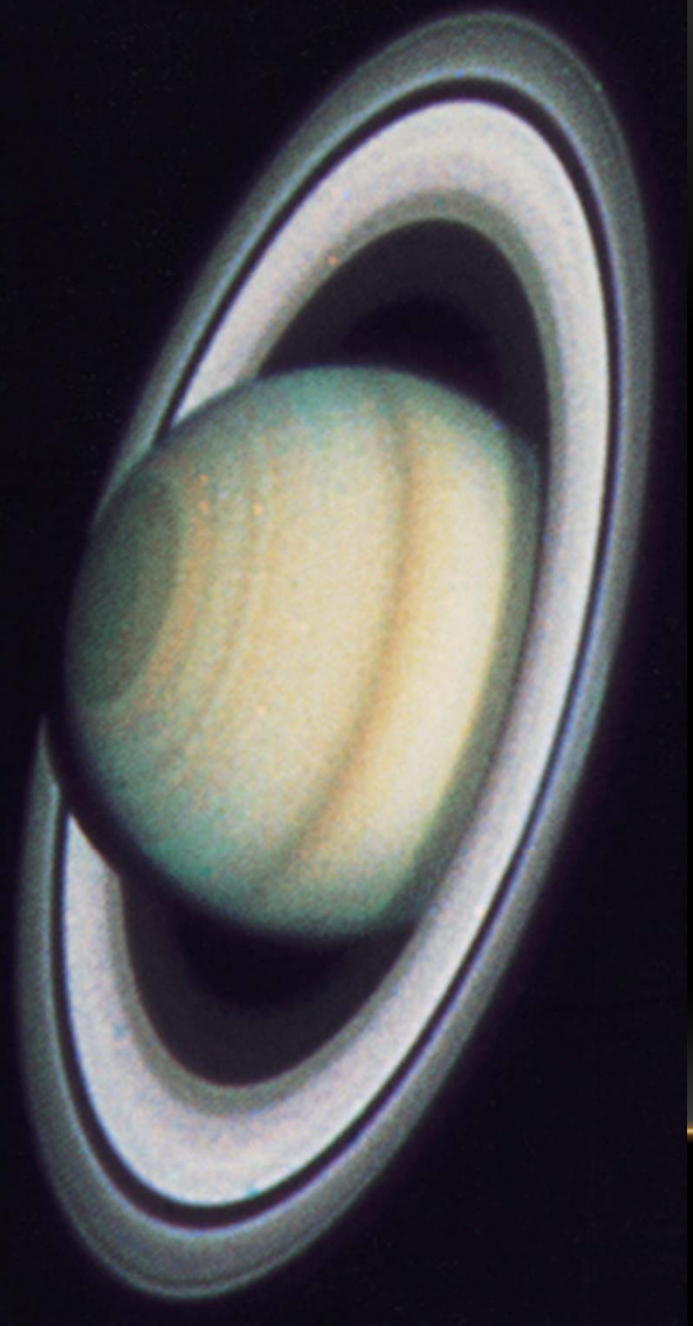
Photo by Robert H Thompson
Using typical 8” backyard scope

- Very much like Jupiter, except
  - Not as bright
  - Butterscotch colored
  - Moves more slowly
- Plain cloud surface
- But tremendous rings!
- Moons visible, but less obvious





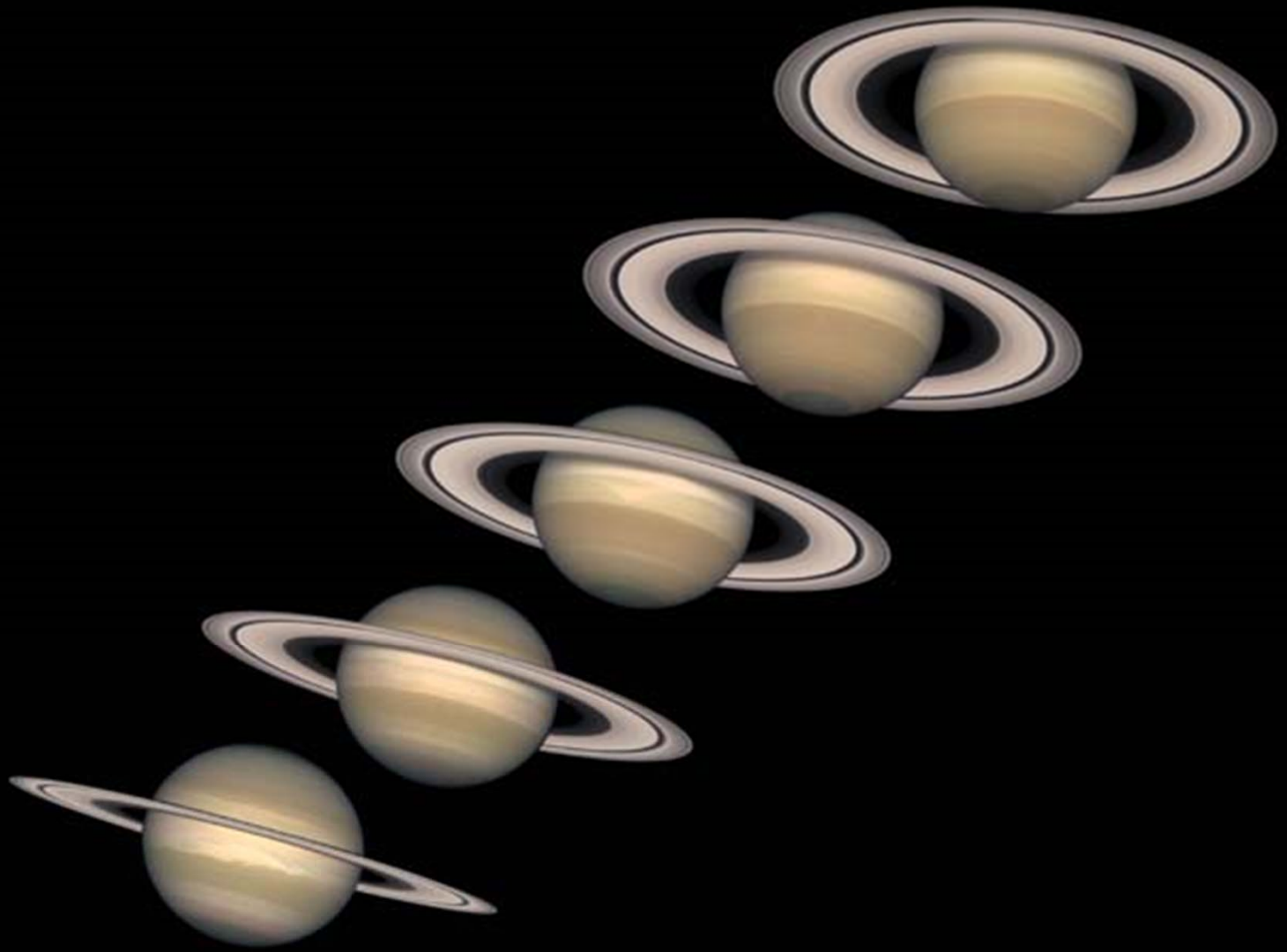




VIEW FROM HST

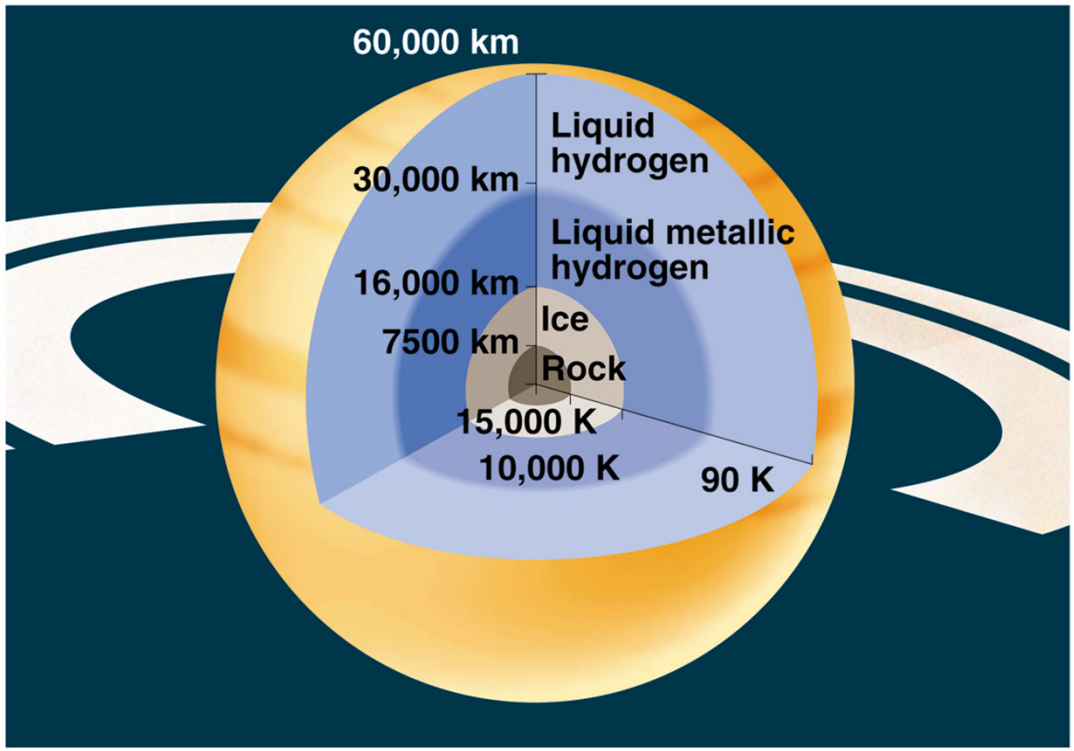
- Hubble has very good resolution (above the messy atmosphere)
- Color pictures are taken by combining 3 single-color filtered photos
  - Red, Green, Blue

SATURNIAN SEASONS



- As seen from the HST
- Saturn has a 27^{o} axial tilt

SIZE, DENSITY?



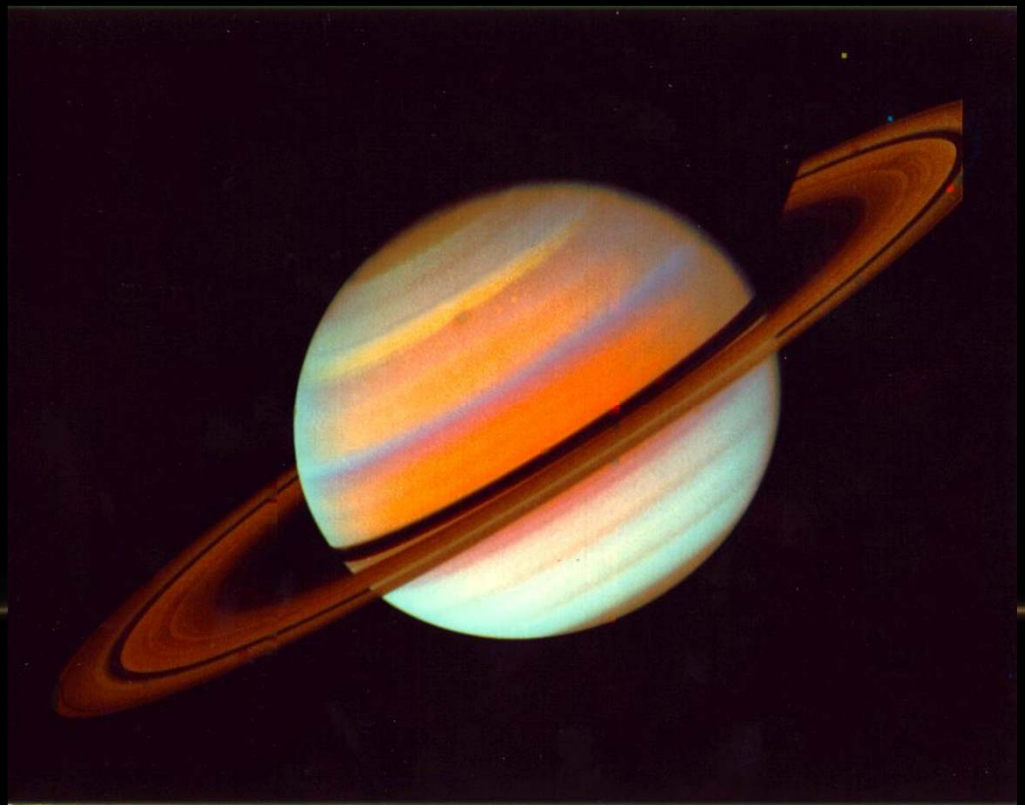
- While Saturn is almost as big around as Jupiter, it has less than 1/3 the mass
- So its density is small – only 0.7 g/cm^3!
- But similar composition
  - Mostly H, He
- Just less compressed
  - Much less of it is metallic Hydrogen!
- Not as oblate as Jupiter
  - Central rocky core likely about 15 M_{Earth}

WEATHER ON SATURN

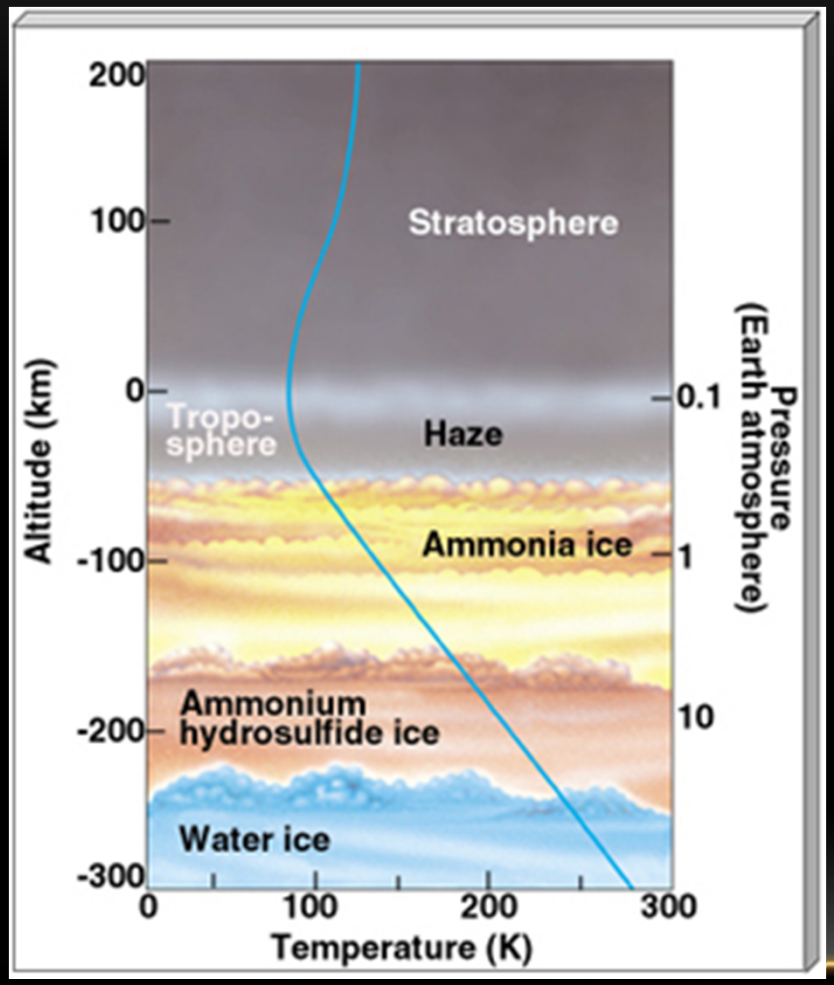
- Fainter bands and zones visible
- But much more boring
- One white oval storm seen, lasted for a couple years
- Why is it different from Jupiter?

WINDS

- Zones, Belts still there -
  - Just fainter – false color image helps to see
  - Even faster winds than on Jupiter



ATMOSPHERIC STRUCTURE



- Same general structure as Jupiter
  - just fluffed out more
- Jupiter's gravity is so strong the layers are compressed
  - Lets us see more of the more colorful, deeper down stuff

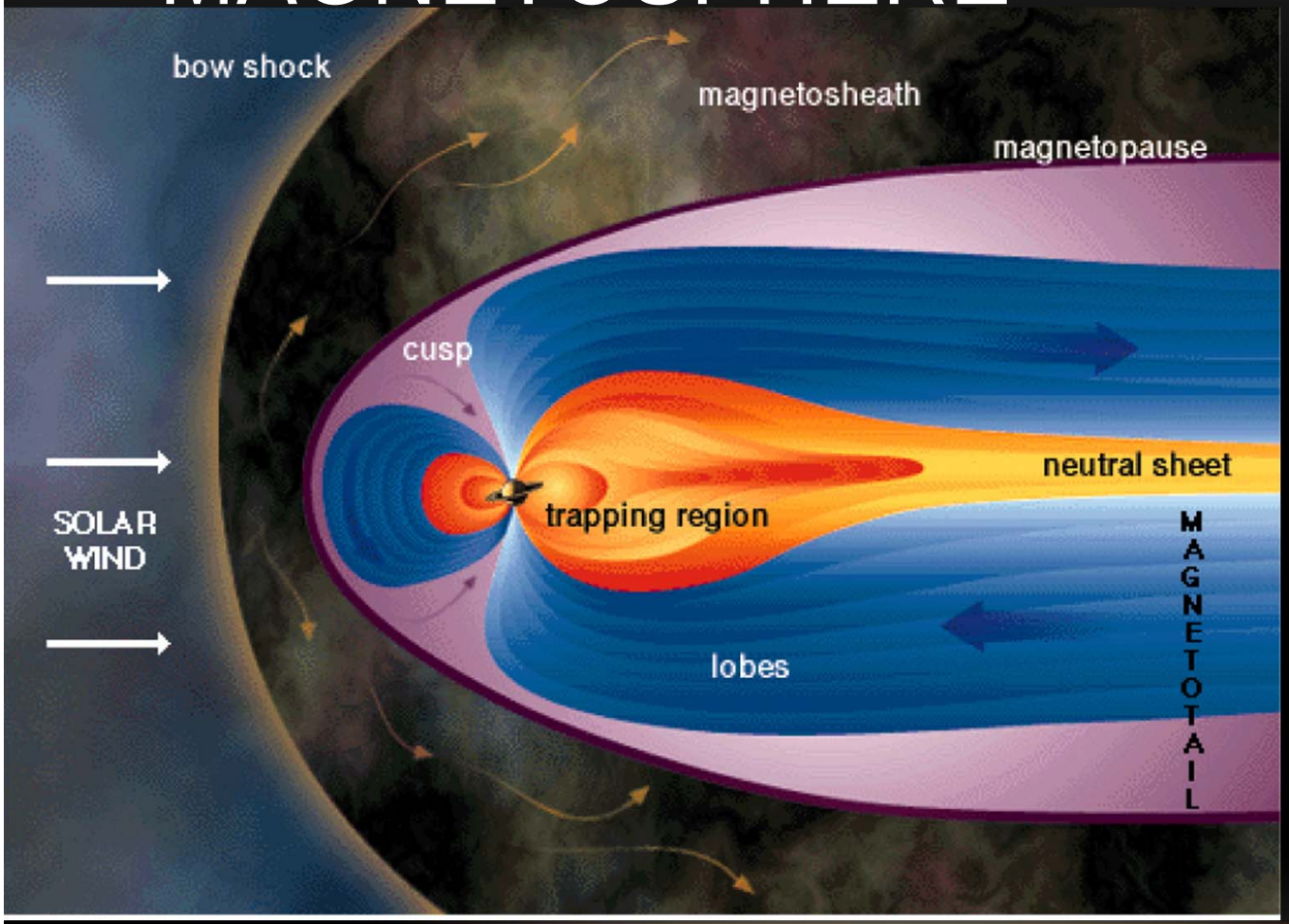
EXCESS ENERGY

- Like Jupiter, Saturn is warmer than expected
  - But by 3x, not just 2x!
  - And Saturn is smaller, so should be cooler
- A clue – Saturn has ½ the “surface” Helium Jupiter does

HELIUM RAIN

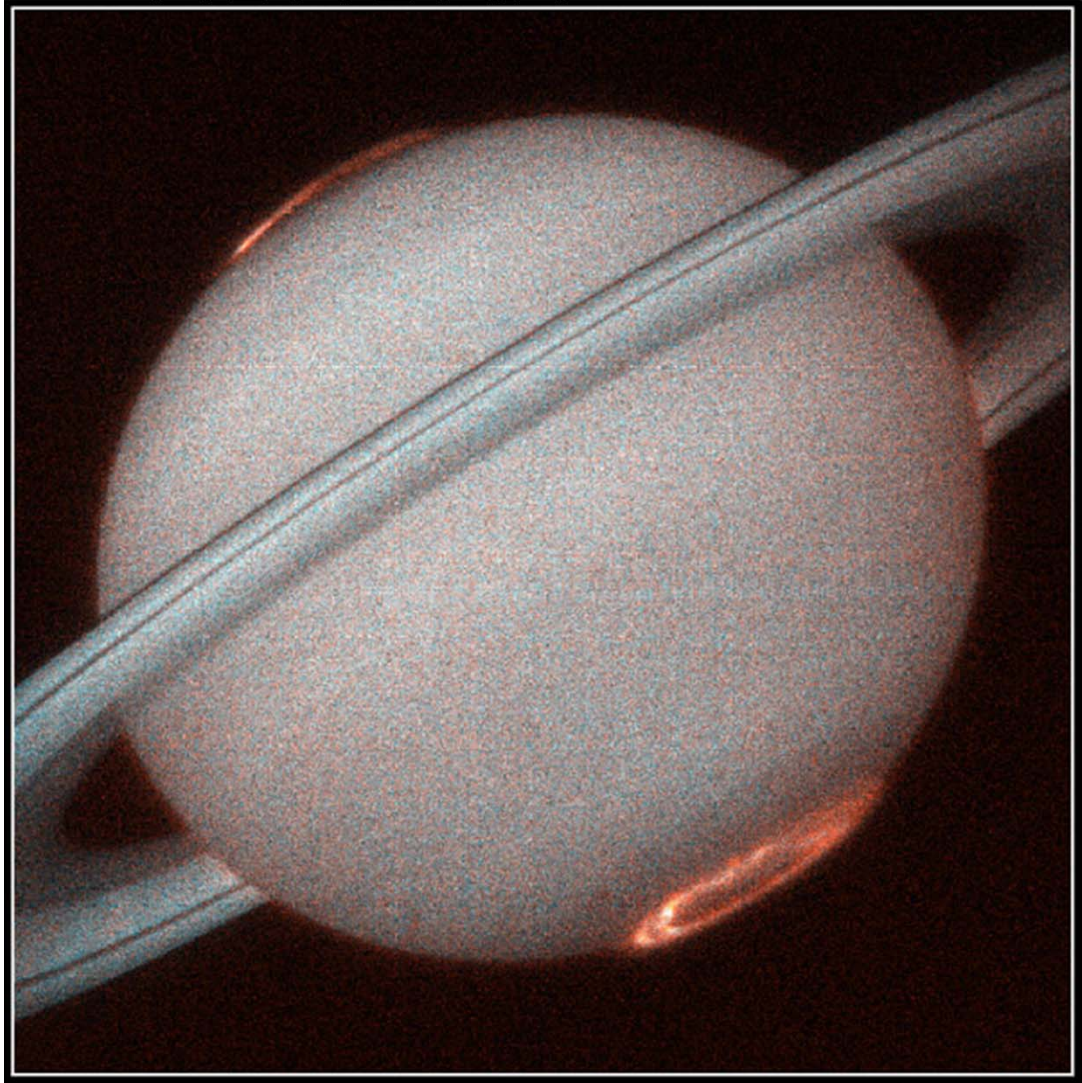
- On Jupiter, it is warm enough that liquid Helium dissolves in liquid Hydrogen
- Too cold for this on Saturn
  - Helium forms droplets
  - Helium heavier than Hydrogen, droplets fall
  - Falling converts gravitational potential energy to heat energy
- So Saturn is warmer than it would be otherwise, due to Helium rain

MAGNETOSPHERE



- Fast rotator
- Metallic liquid hydrogen (just not as much as Jupiter)
- So should have a big magnetic field
- It does!
  - 1/20 Jupiter's
  - 1000x Earth's

AURORA

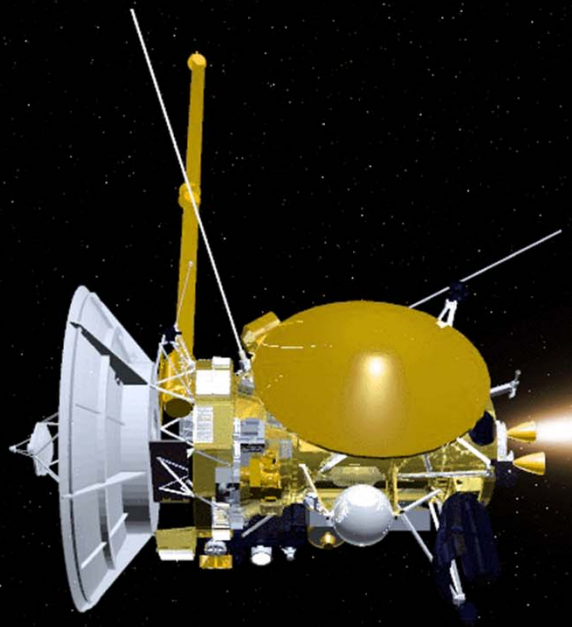


Saturn Aurora HST • STIS
PRC98-05 • ST ScI OPO • January 7, 1998 • J. Trauger (JPL) and NASA

- Aurora too – visible in the UV

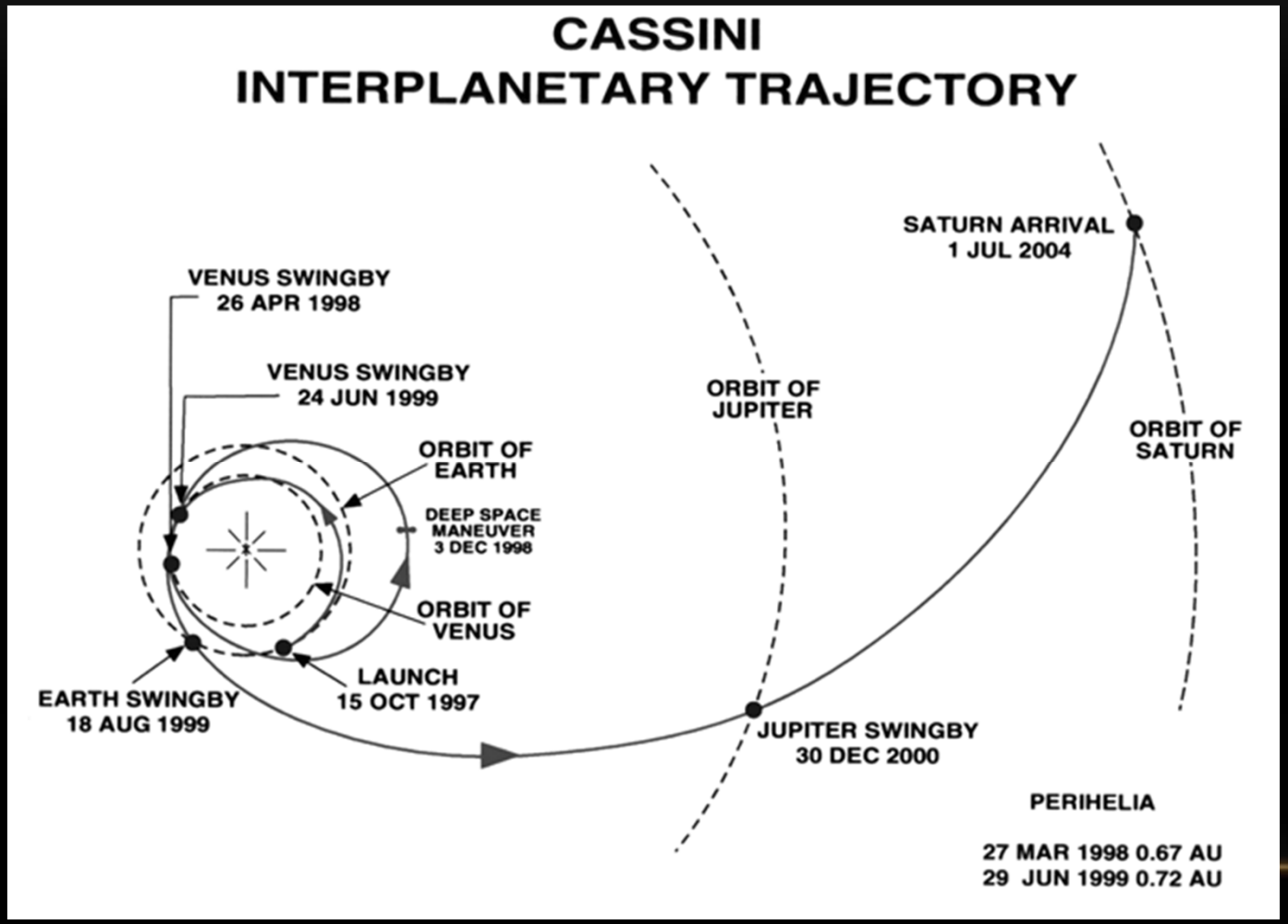
PROBES

- Pioneer 11 (1979)
- Voyager 1 & 2 (`80,`81)
- Cassini orbited 2004-2017



Cassini fires engine to slow down and enter orbit

TAKING THE LONG ROAD



- Two Venus slingshots
- One from Earth
- One from Jupiter

URANUS

Tilted Blue Marble

URANUS

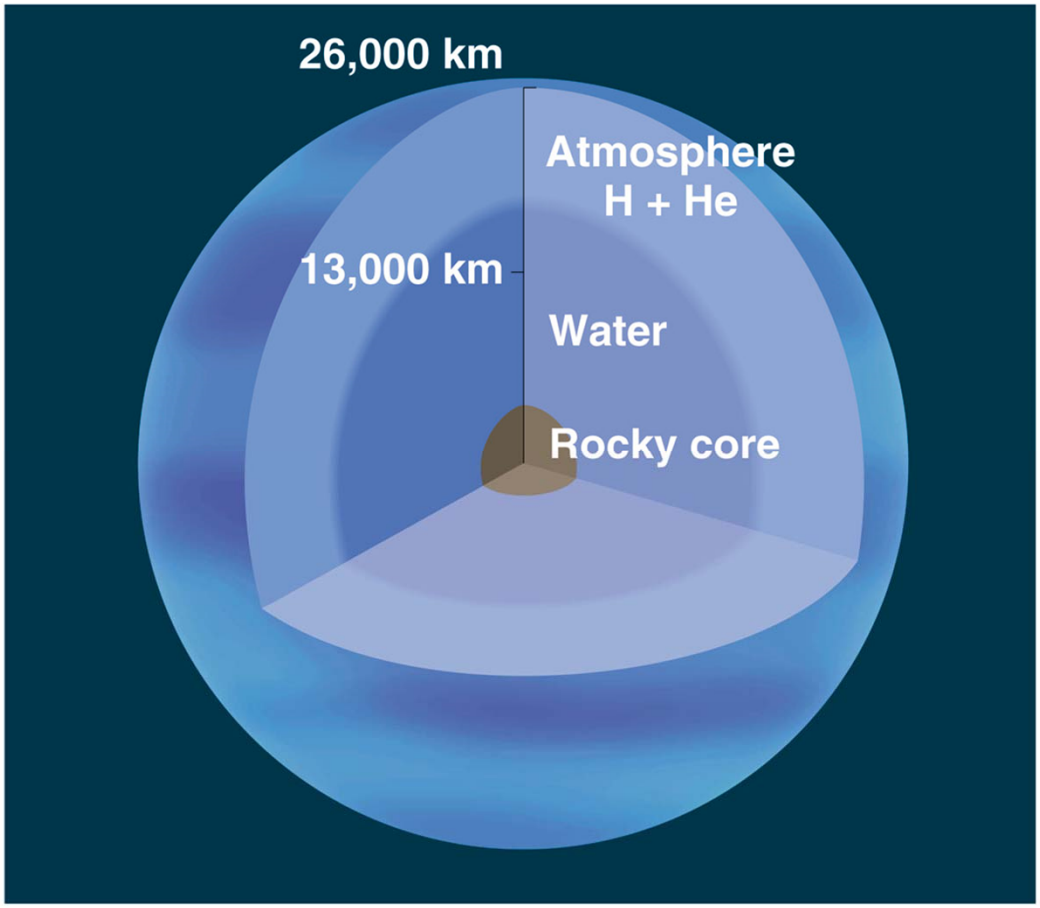
- Discovered 1781 by William Herschel
  - Looking for comets
  - Saw it move
- At the edge of naked-eye visibility

Uranus & Moons
3 Aug 99 5:08 UT

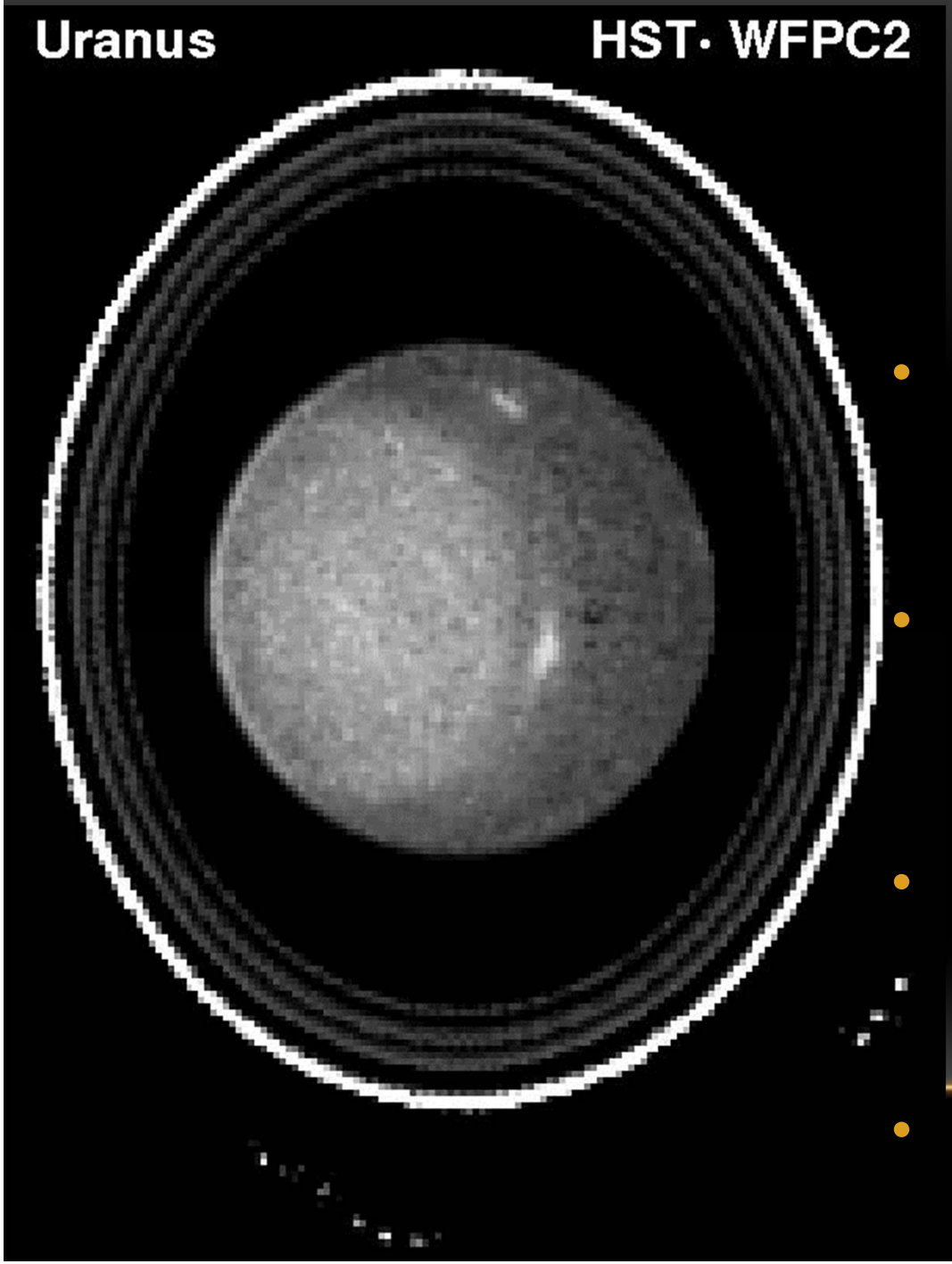
URANUS

- 7^{th} planet out from Sun
  - 19.2 AU
  - 84 year orbit
- 4 Earth-diameters across
- 14.5 Earth-masses
- Density 1.27 g/cm^3

STRUCTURE

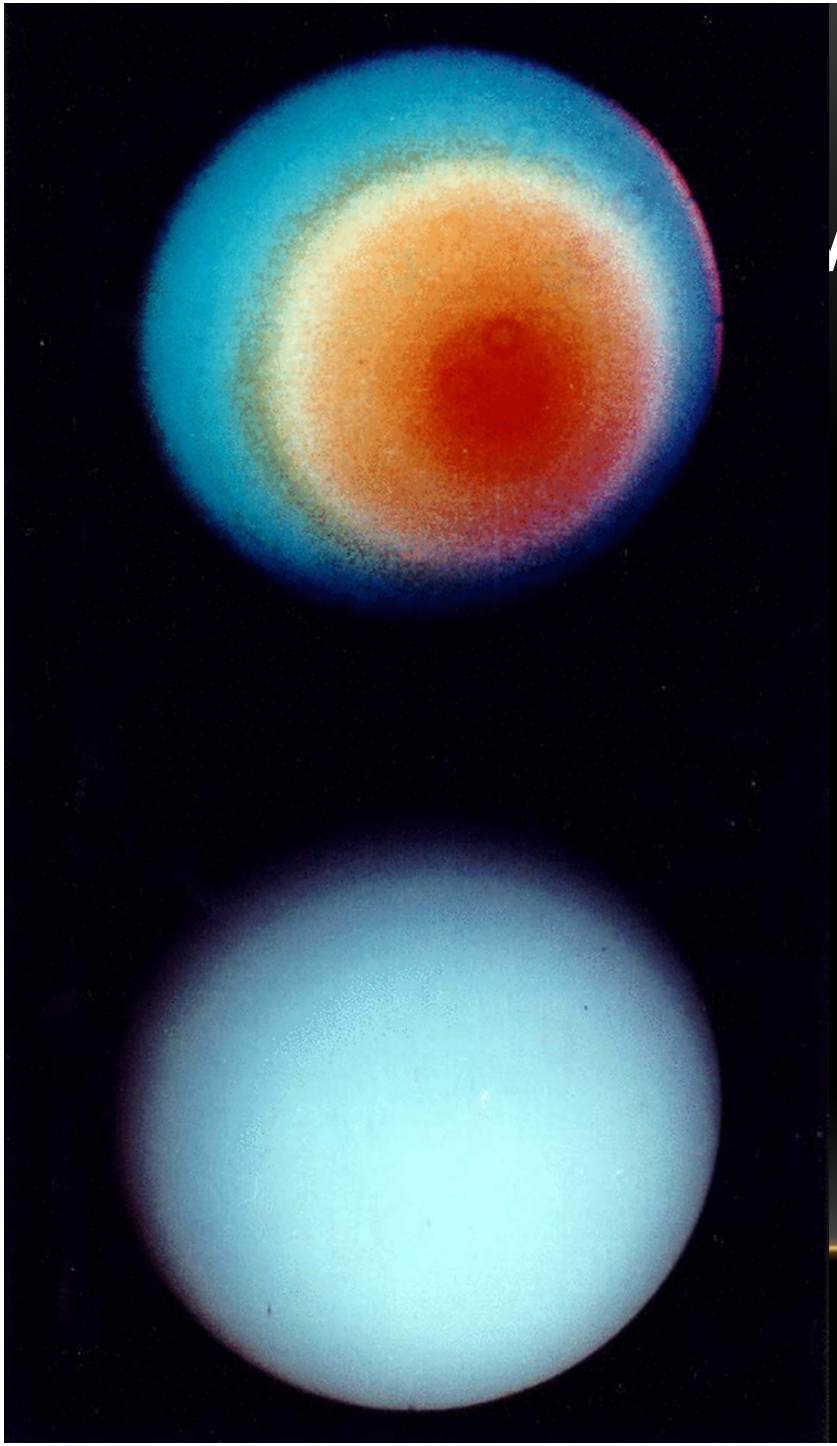


- From density and spectroscopy
- Gas-giant again
- Lower pressures likely mean a lot of liquid water as apposed to liquid hydrogen
- Very small rocky core



ON ITS SIDE

- Uranus rotates once in 17.2 hours
  - Fast rotation
- But on its side
  - 98^{0} tilted axis
  - No good ideas why
- Fast rotation, liquid conducting stuff
  - Magnetic field 100x that of Earth
- Rings present



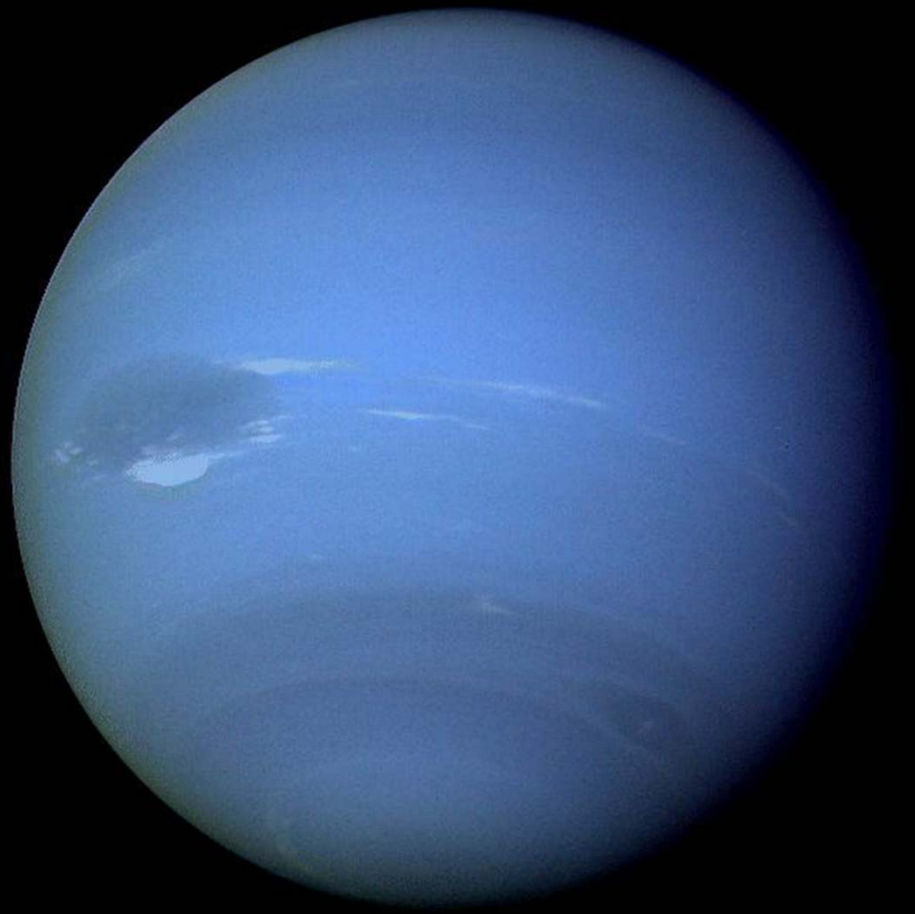
ATMOSPHERE

- Very Jovian
  - 83% H, 15% He
  - 2% Methane, gives it the Blue color
- Striped winds still there
  - Just hard to see unless contrast is enhanced
- Immense seasons
  - But winds distribute heat around planet evenly
- No internal heat source

NEPTUNE

Another Blue Marble

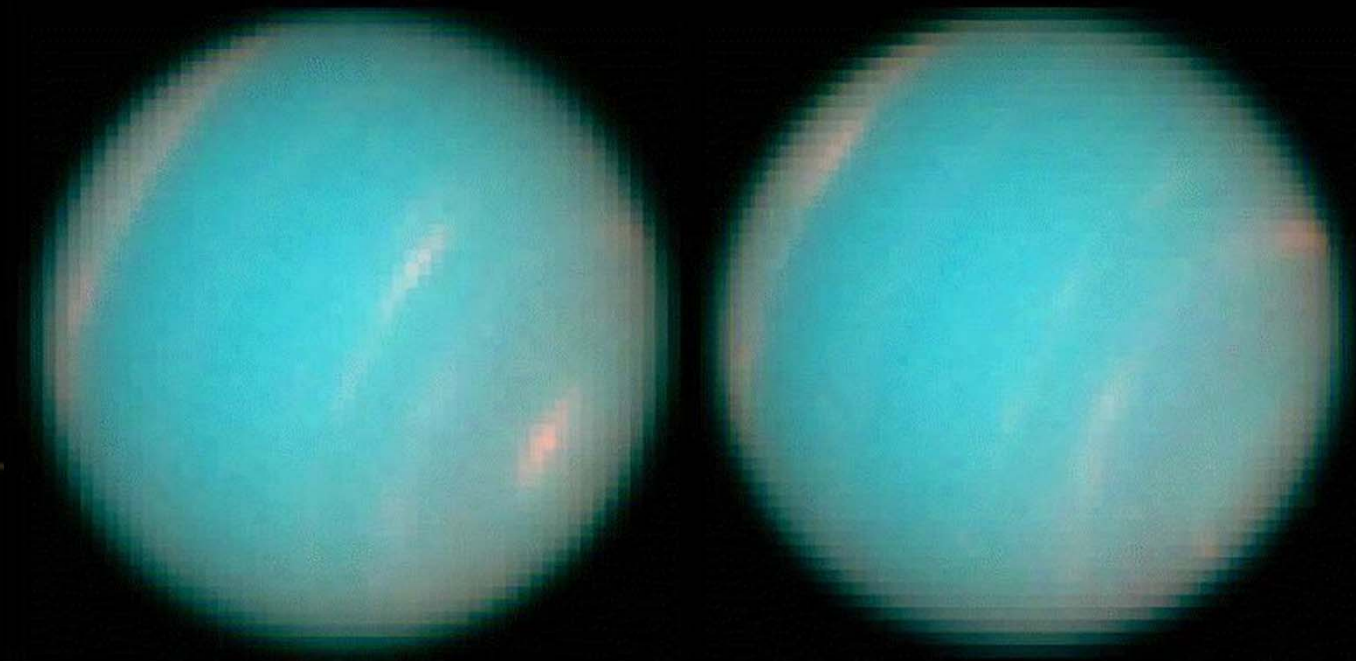
NEPTUNE



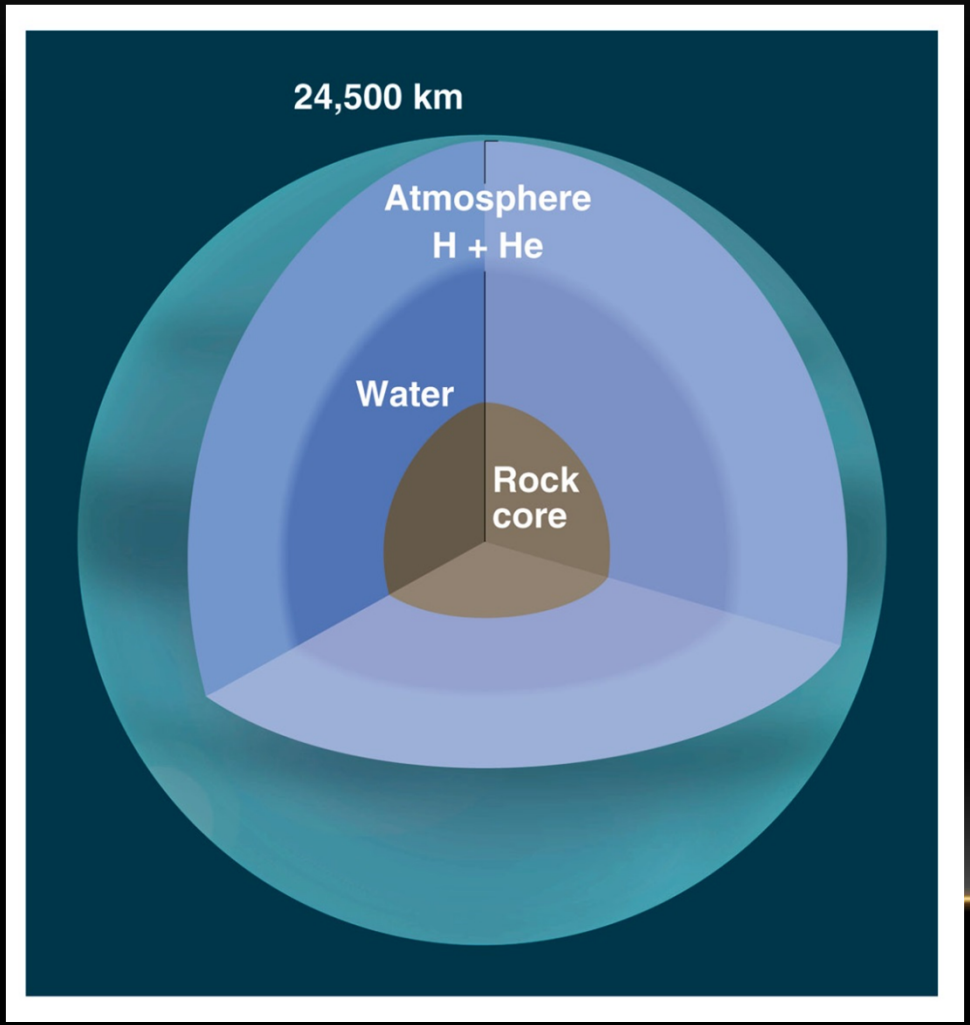
- In 1845, mathematicians John Adams and Urbain LeVerrier analyze Uranus' orbit
  - See irregularities, predict an 8th planet whose gravity is pulling on Uranus
- 1846 – Johann Galle looks there and sees Neptune

NEPTUNE

- 30 AU orbit
  - 165 year long
- HST picture below
  - Most all we know about Neptune comes from Voyager 2 flyby

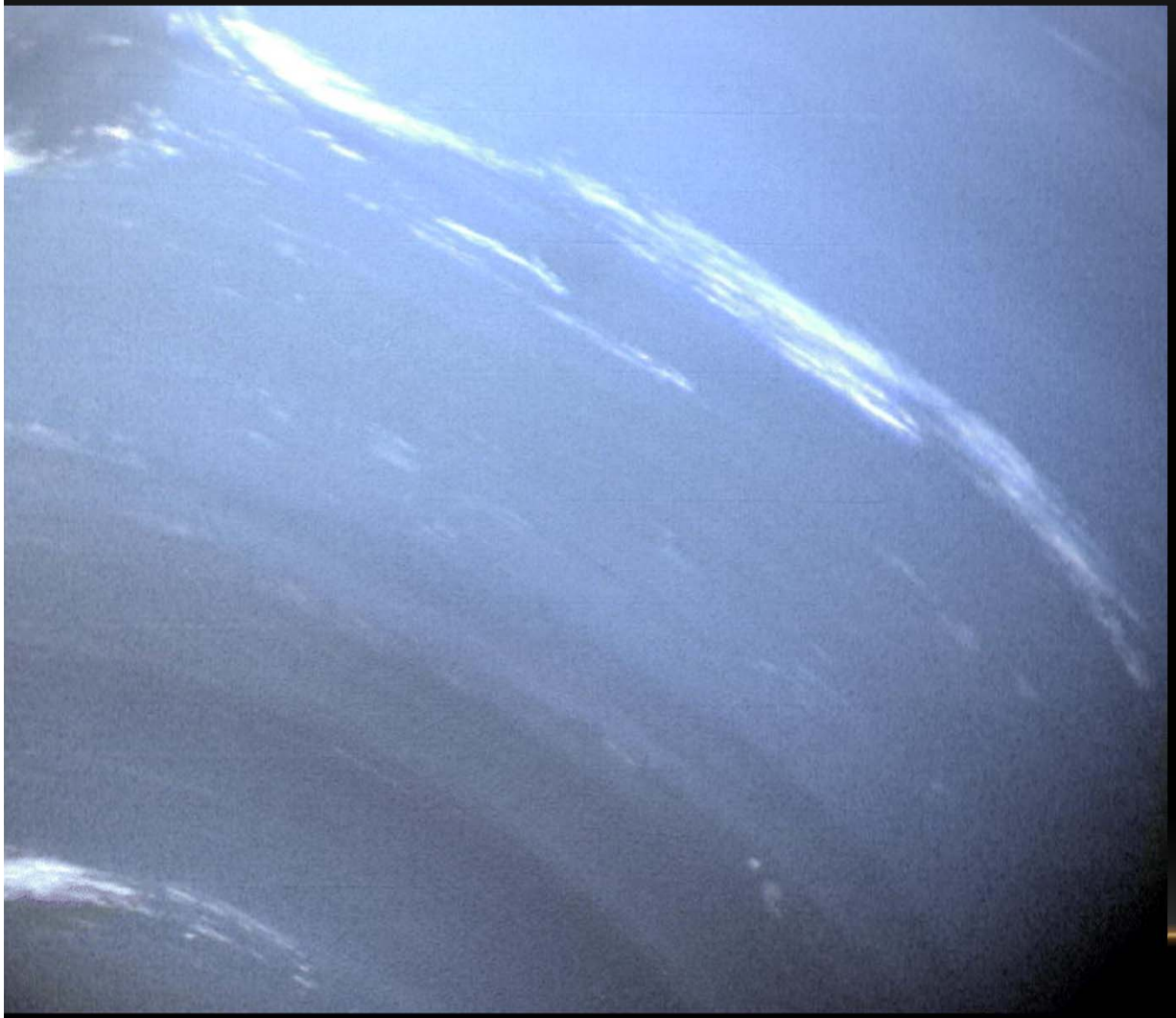


NEPTUNE'S STRUCTURE



- Slightly smaller but more massive than Uranus
  - 3.9 Earth radii
  - 17 Earth masses
- Similar structure
  - Larger rocky core
  - More compact layers
- Same magnetic field as Uranus
  - 100x Earth's

ATMOSPHERE



- Deeper blue
  - Still from methane
  - But light goes deeper into the atmosphere
- Bands more obvious
  - Like Jupiter/Saturn comparison
- Great Dark Spot storm
  - Like Jupiter’s Red Spot
- Cirrus clouds

INTERNAL ENERGY SOURCE

- Atmospheric surface
- Neptune radiates more energy than it receives
  - So similar temperature to Uranus
  - 2.7x more energy!
  - Source still unknown
  - But this probably drives the active atmosphere