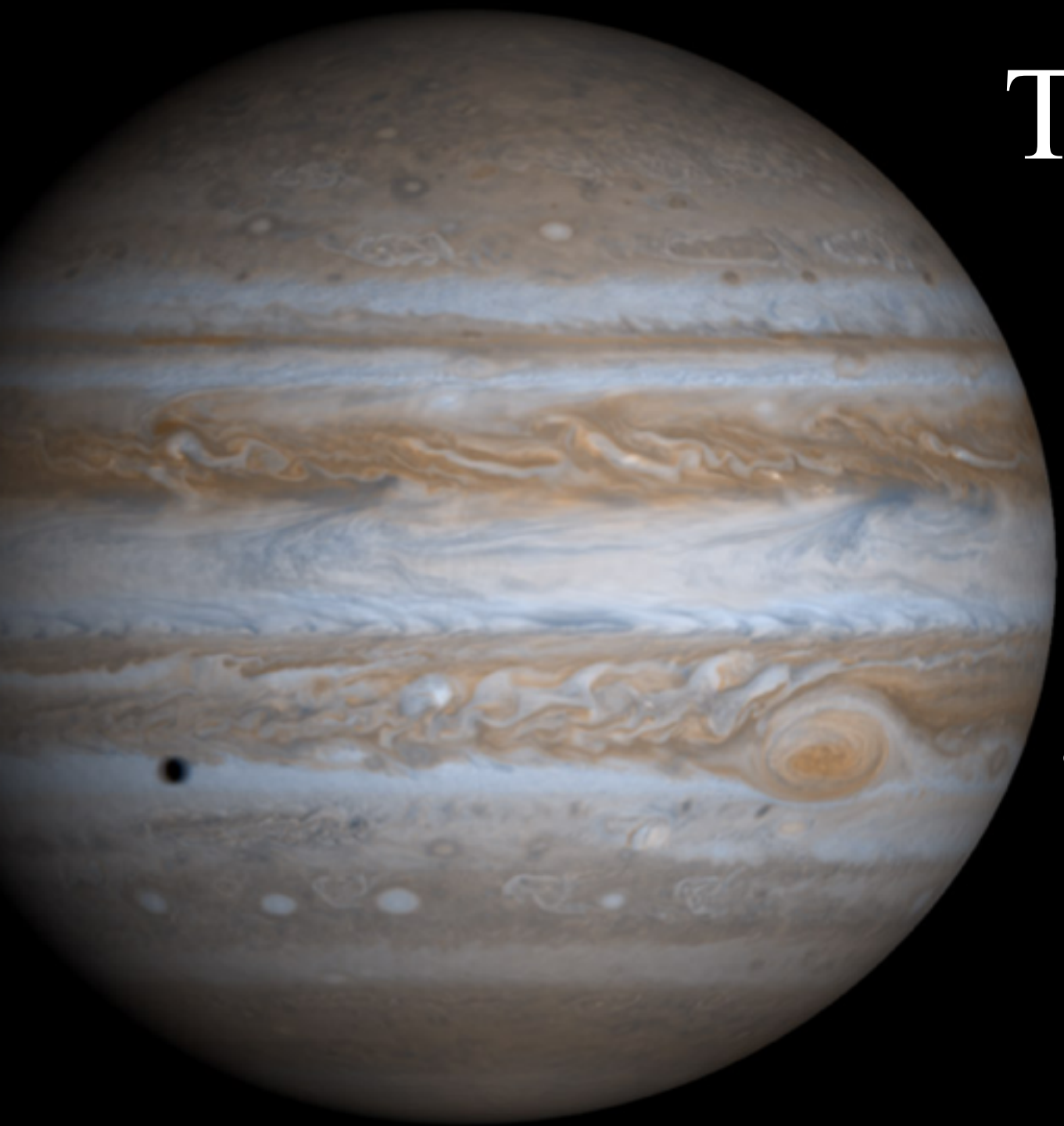


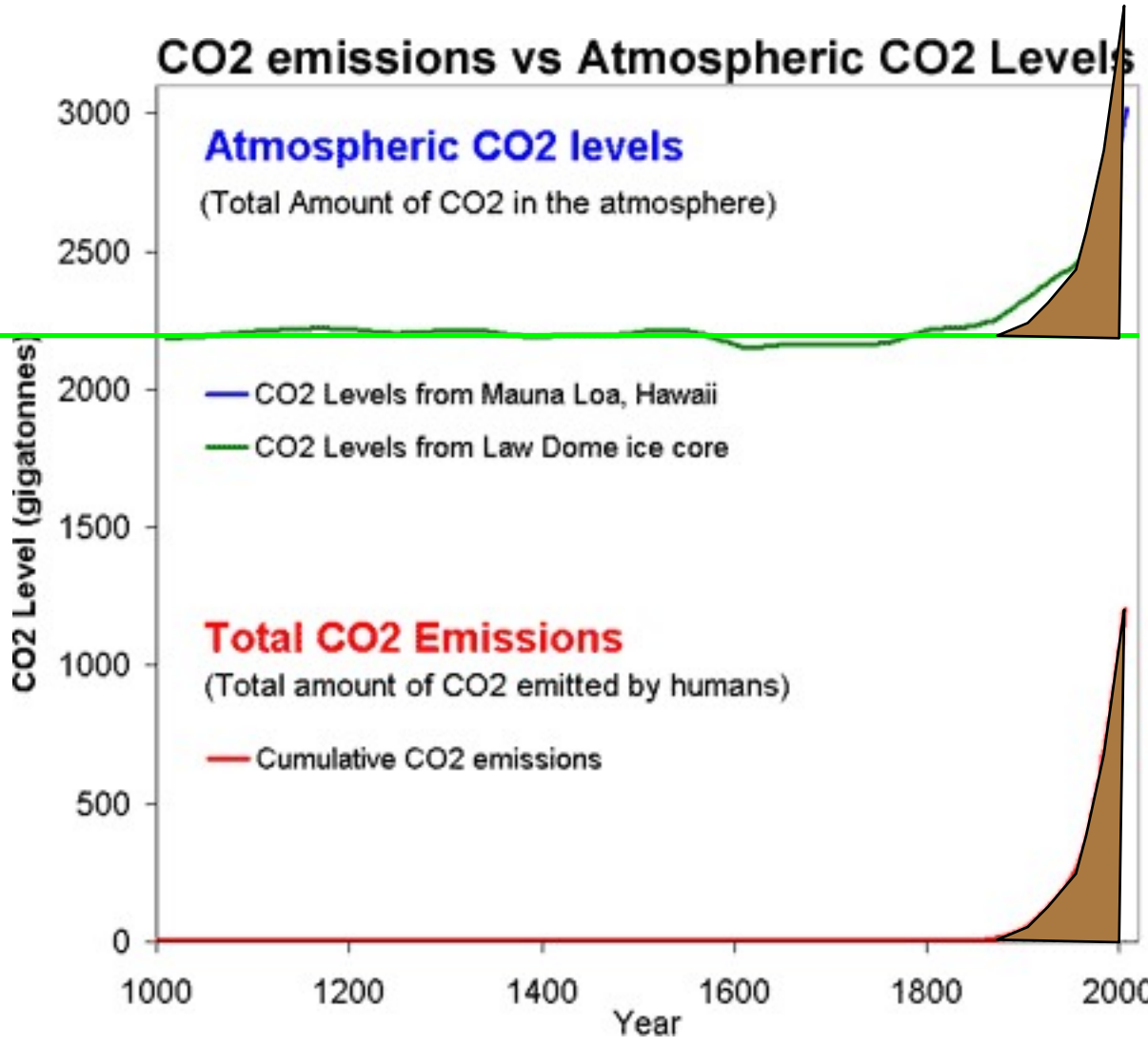
Today

- Jovian planets
- a little more Climate change

Events

- Exam II
  - one week hence

Pre-industrial CO_2 concentration: 280 ppm. Current level: 400 ppm



Pre-industrial CO_2 level

CO_2 added to atmosphere

Human activity

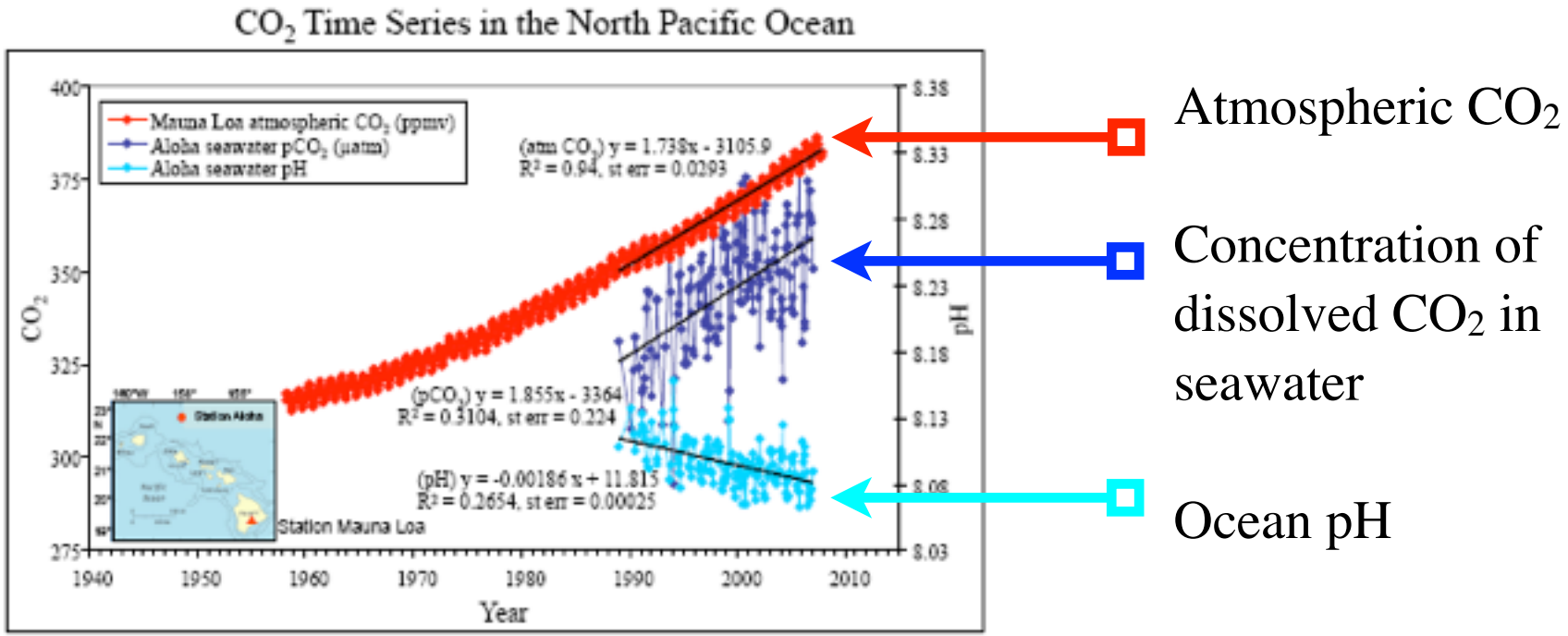
Carbon burned

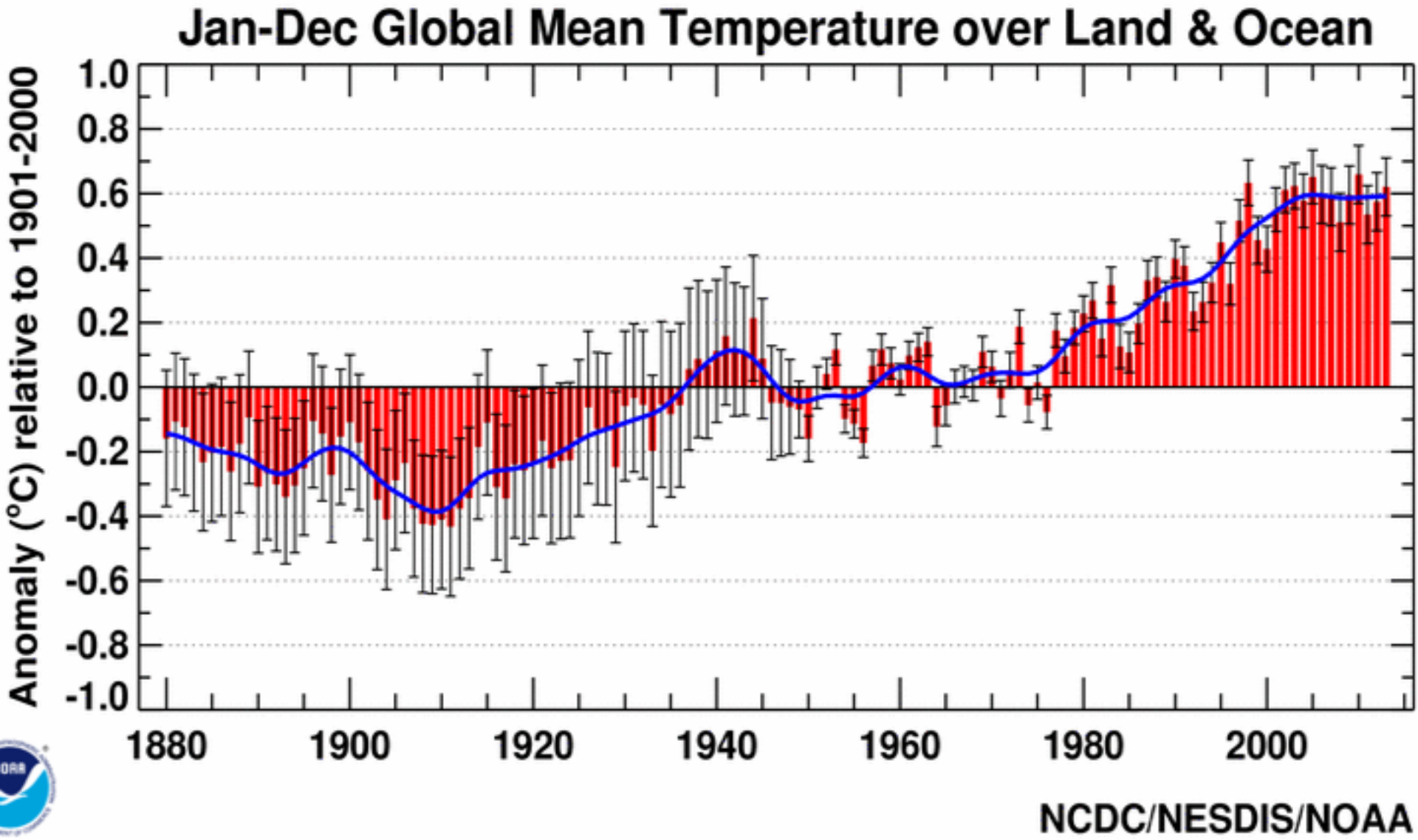
1000

Year (A.D.)

2000

- Should be more CO_2 in atmosphere than there is
  - Some of what we've burned is missing
- Some CO_2 being sequestered in the ocean
  - Ocean acidity up due to increased amounts of CO_2 dissolved in seawater
  - pH = 8.25 to 8.14 over last two centuries



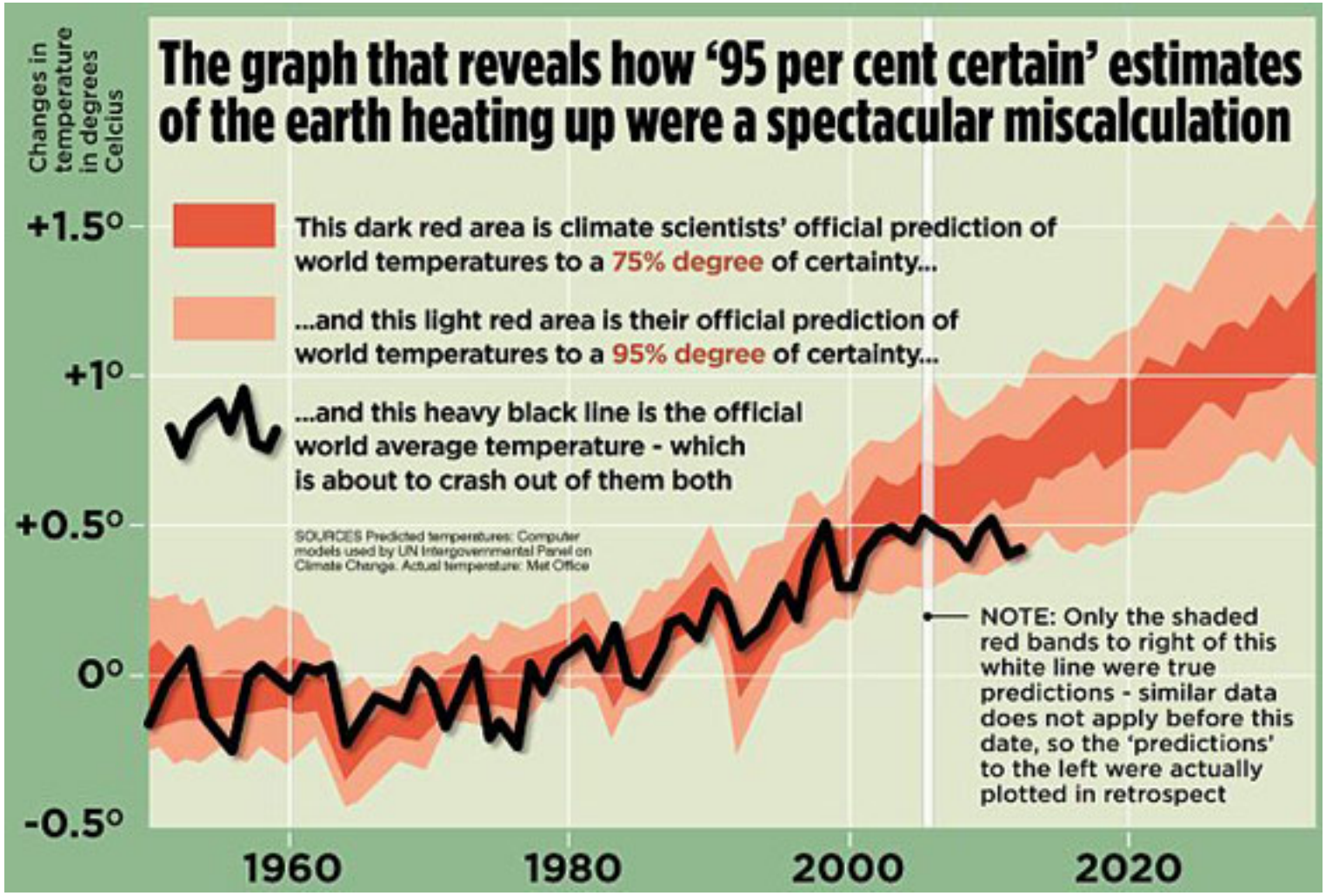

Jan-Dec Global Mean Temperature over Land & Ocean
Anomaly (°C) relative to 1901-2000
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1880
1900
1920
1940
1960
1980
2000
NCDC/NESDIS/NOAA

Basic facts

(non-partisan)

- The globe is warming (measured)
- The concentration of CO2 in the atmosphere is increasing (measured)
- The measured increase is roughly equal to the amount of fossil fuel we've burned (measured)

- Climate change is the *expected* result of adding greenhouse gases to the atmosphere (cf. Venus, Mars)


The graph that reveals how '95 per cent certain' estimates of the earth heating up were a spectacular miscalculation
Changes in temperature in degrees Celcius
+1.5°
+1°
+0.5°
0°
-0.5°
This dark red area is climate scientists' official prediction of world temperatures to a 75% degree of certainty...
...and this light red area is their official prediction of world temperatures to a 95% degree of certainty...
...and this heavy black line is the official world average temperature - which is about to crash out of them both
SOURCES Predicted temperatures: Computer models used by UN Intergovernmental Panel on Climate Change. Actual temperature: Met Office
NOTE: Only the shaded red bands to right of this white line were true predictions - similar data does not apply before this date, so the 'predictions' to the left were actually plotted in retrospect
1960
1980
2000
2020

Climate Change Forecasts

- Gradual increase of average temperature
  - average increase modest but noticeable
  - winter not cancelled by 1° of warming
- More wild swings in weather events
  - Heat waves *and* cold waves more extreme
  - Same for rainfall/snowfall *"Global Weirding"*
- Ocean levels rise
  - 8" since 1880 (measured)
  - 3' forecast by 2100 - mostly thermal expansion *adios, Miami*
- Drought *model dependent*
  - California, southwest dry out (more)
  - due to enhanced evaporation, smaller snowpack

Policy implications

- Basic trend clear but detailed long range forecast challenging.
  - There may be some winners as well as losers
- Probably a bad idea to conduct an uncontrolled experiment on the atmosphere we all breathe & climate we depend on.
  - Earth isn't Venus. But what it will become?
- There is finite energy available in coal, oil, natural gas, uranium...
  - Are we ***NOT*** going to use these resources?

Jupiter

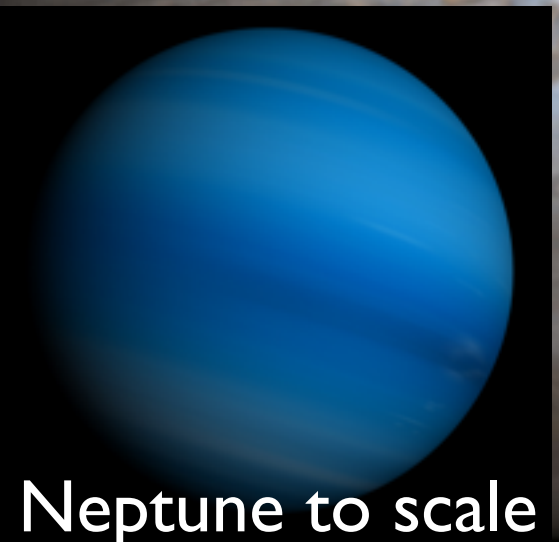
Some astronomers now distinguish between

Gas Giants
Jupiter, Saturn

and

Ice Giants
Uranus, Neptune

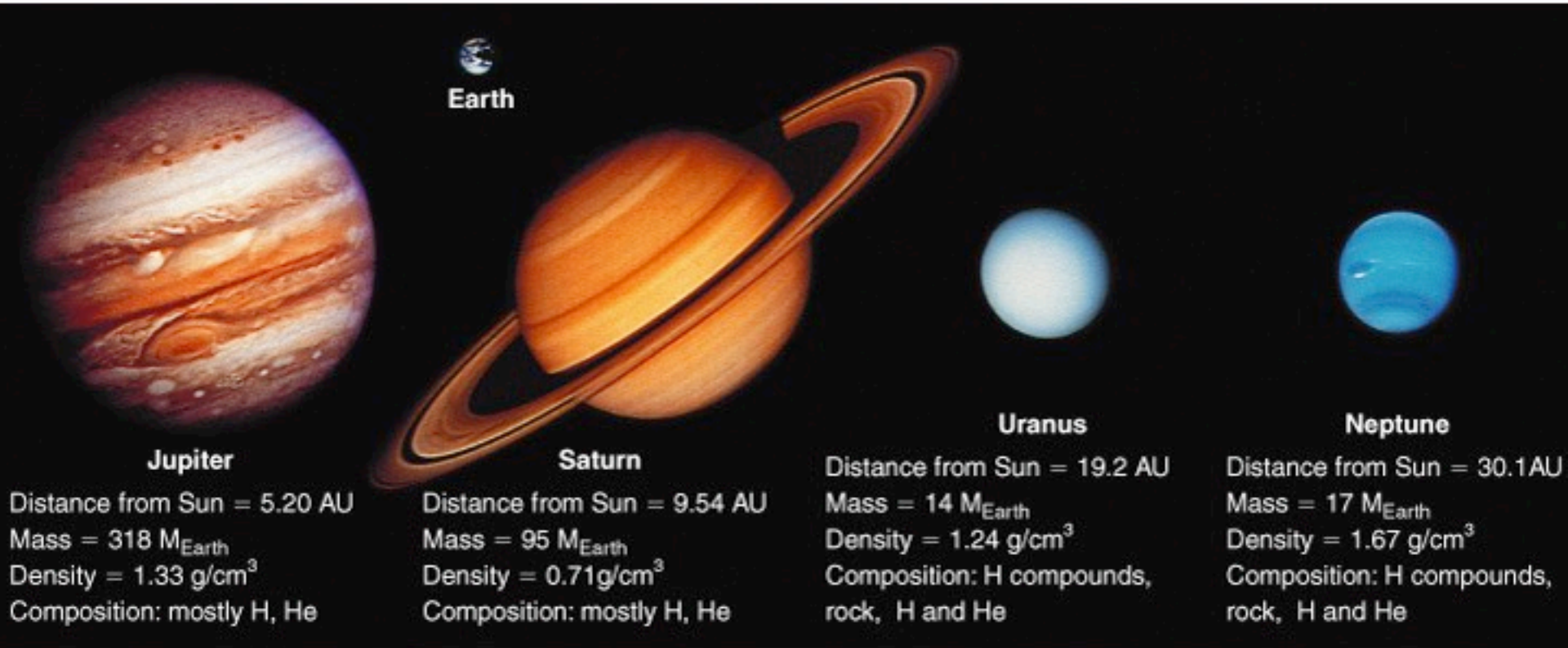
Expect more distinctions with new discoveries



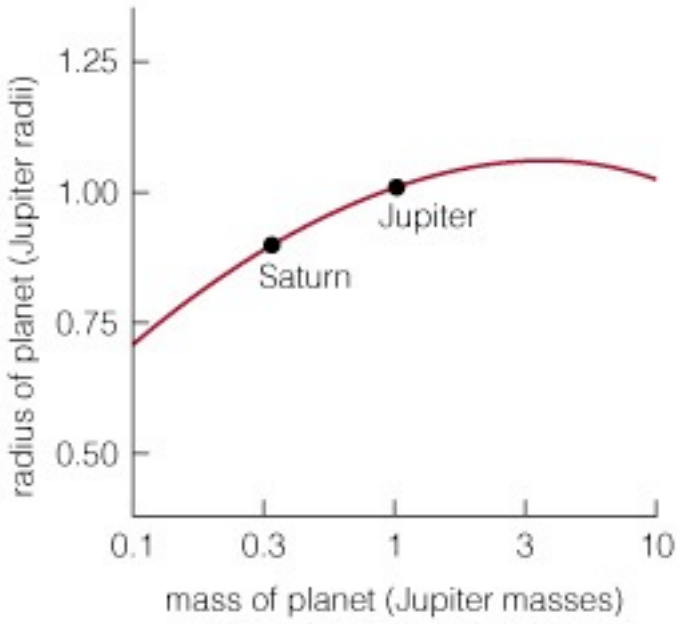
Neptune to scale

Earth to scale

The Jovian planets are *gas giants* - much larger than Earth in size and mass, but lower density



Sizes of Jovian Planets



- Planets get larger as they get more massive
- up to a point...

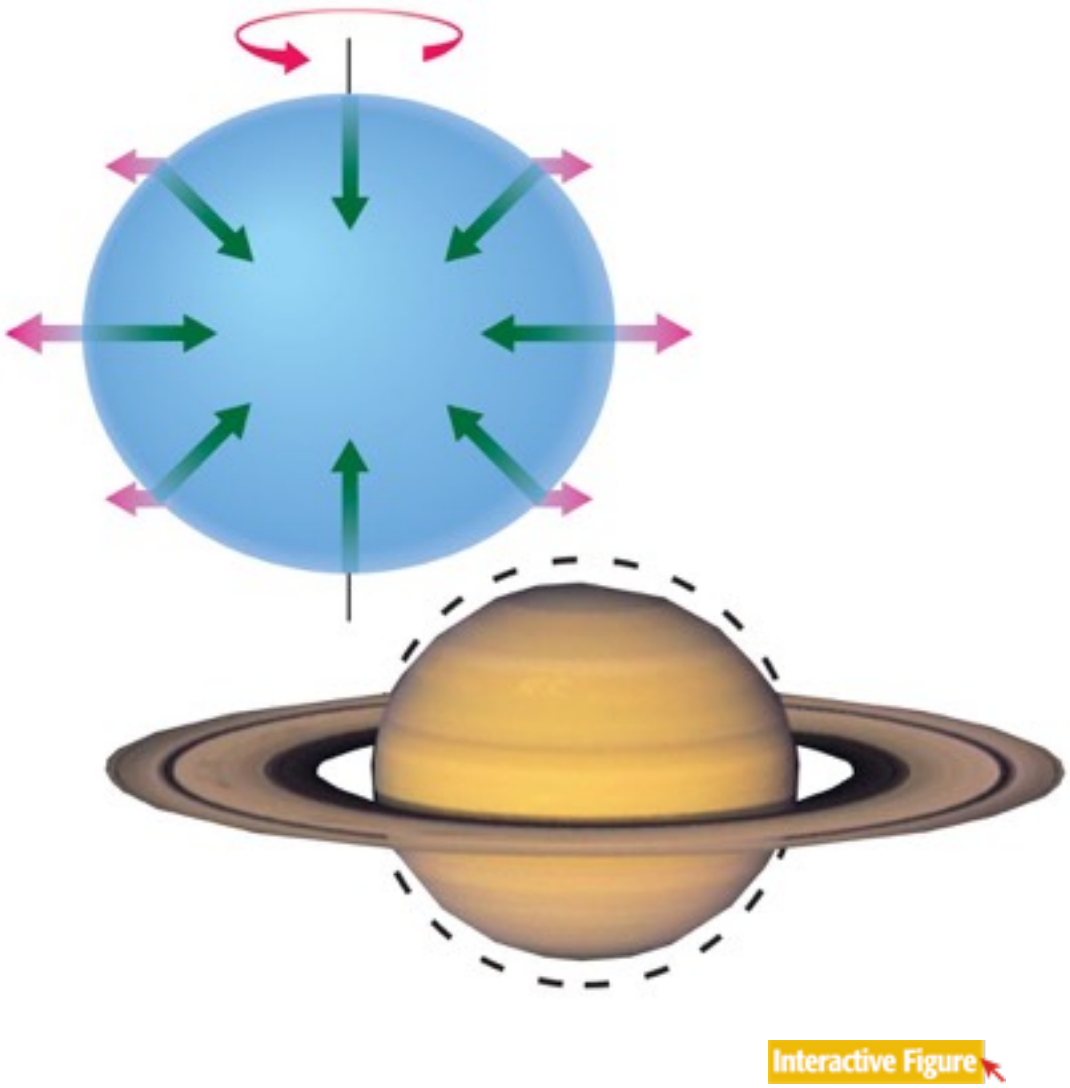
- Planets more massive than Jupiter are expected to *shrink*.
- There comes a point where gravity wins: adding more mass causes *contraction*.

Jovian Planet Composition

- Jupiter and Saturn
  - Mostly H and He gas
    - *these are the most common elements in the Universe*
  - "Gas Giants"

- Uranus and Neptune
  - Mostly hydrogen compounds: water (H_2O), methane (CH_4), ammonia (NH_3)
  - Some H, He, and rock
  - "Ice Giants"

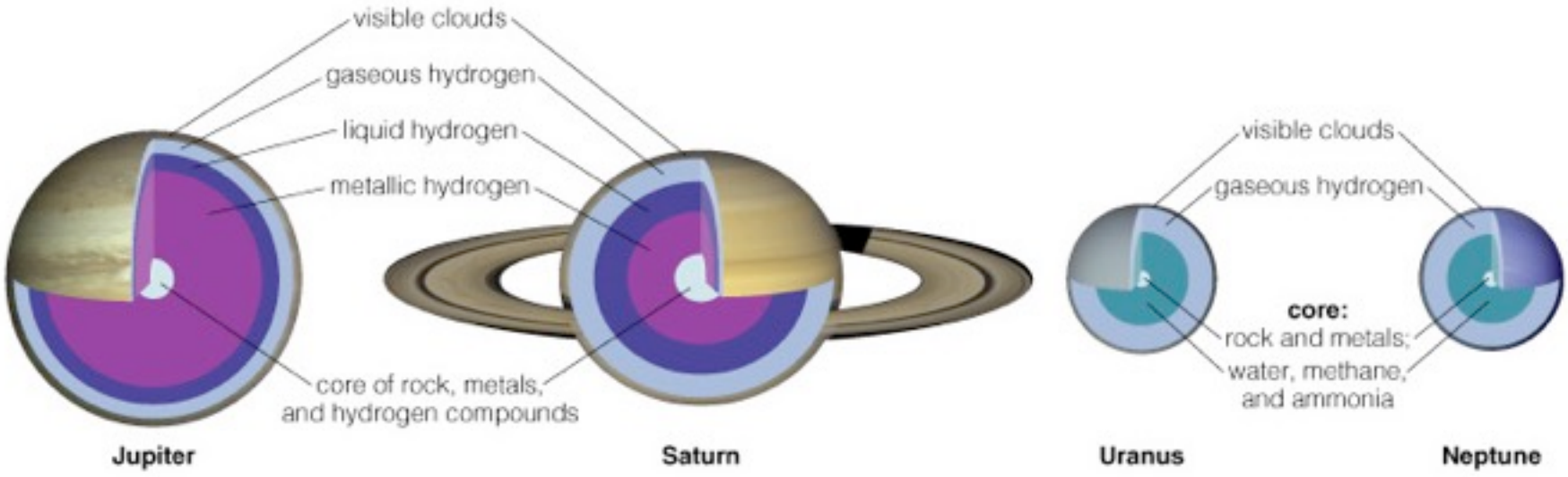
Rotation and Shape



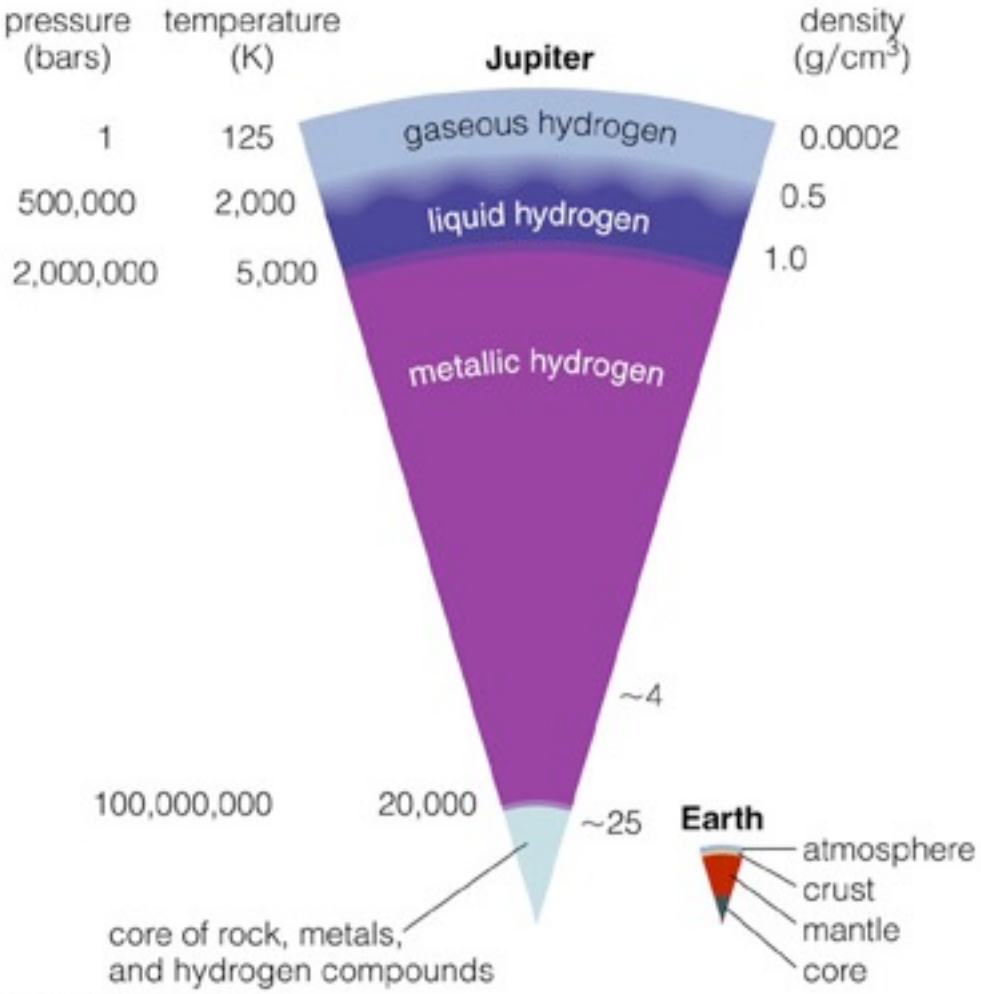
- Jovian planets are not quite spherical because of their rapid rotation.
- "Oblate"

show Jovian Planet shapes

Interiors of Jovian Planets

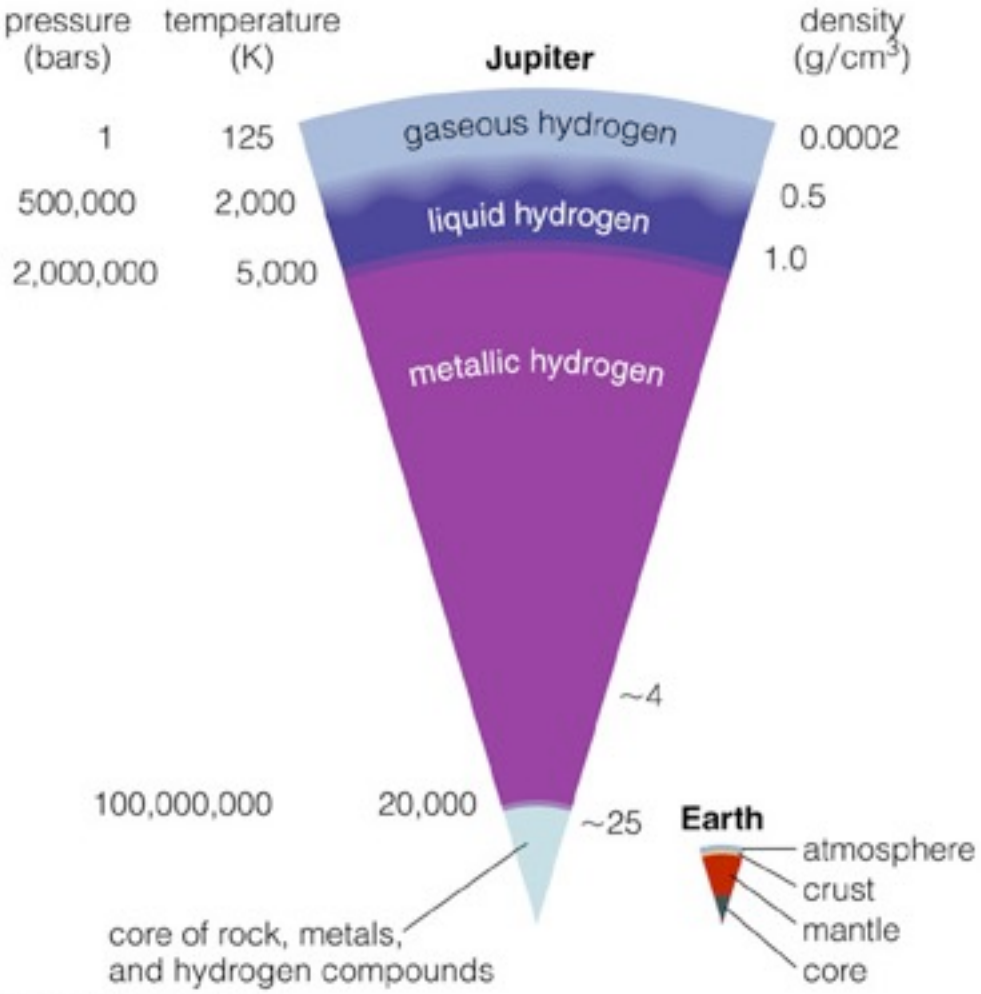


Inside Jupiter



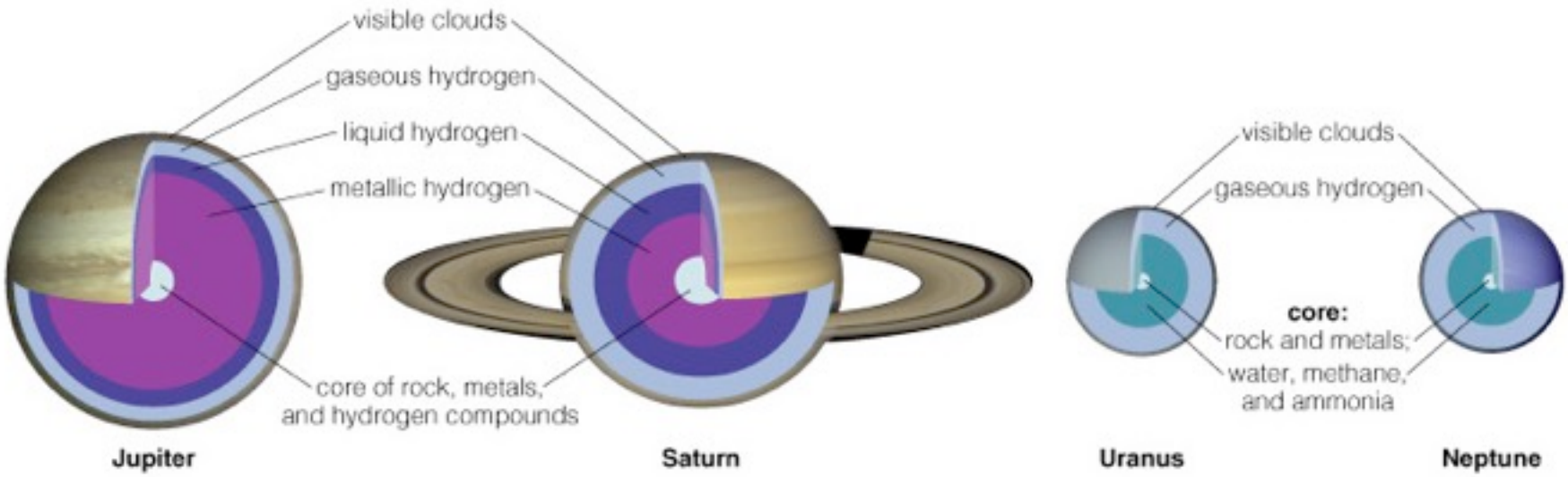
- High pressure inside of Jupiter causes the phase of hydrogen to change with depth.
- Hydrogen acts like a metal at great depths because its electrons move freely.

Inside Jupiter



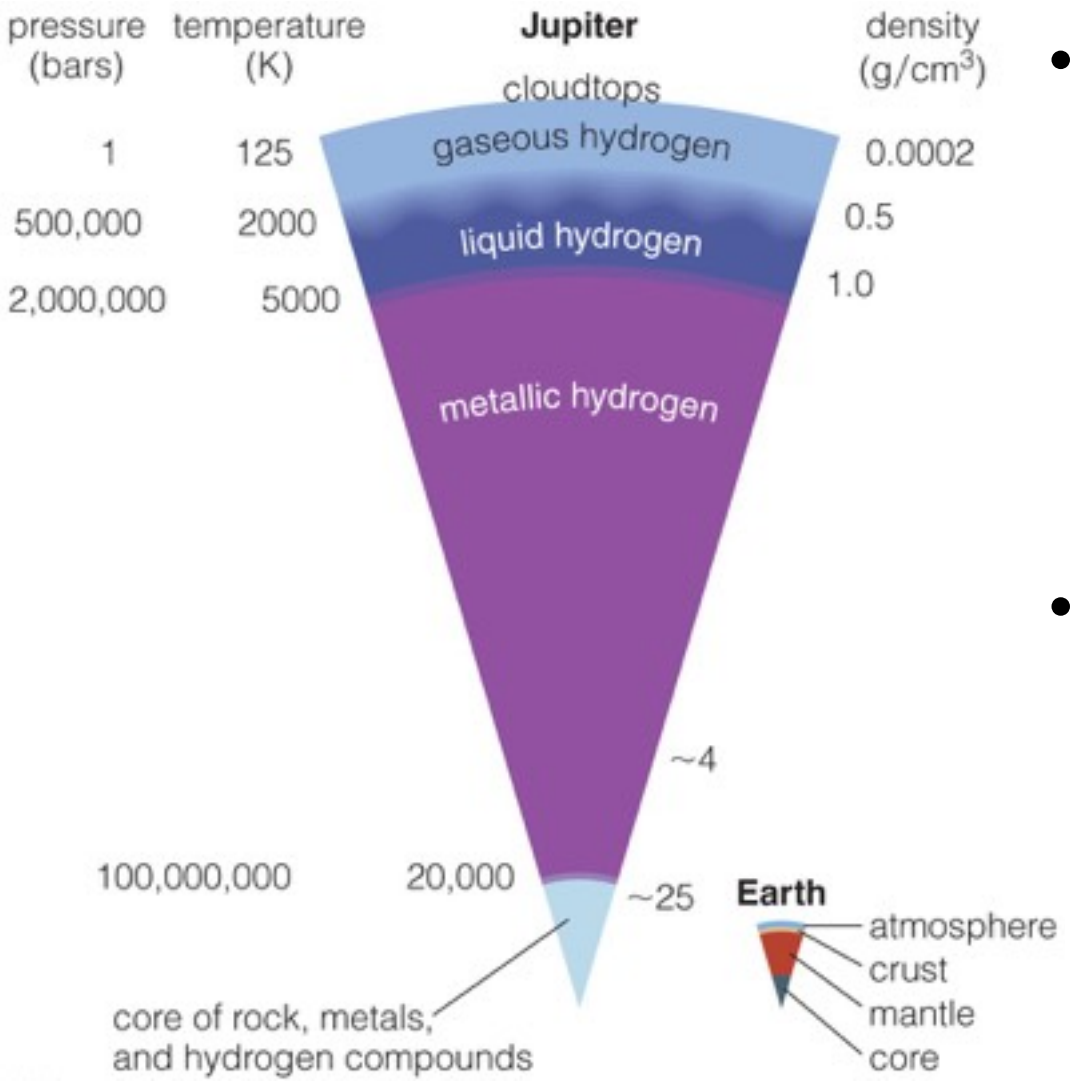
- The core is thought to be made of rock, metals, and hydrogen compounds.
- The core is about the same size as Earth but 10 times as massive.

Comparing Jovian Interiors



- Models suggest that cores of jovian planets have similar composition.
- Lower pressures inside Uranus and Neptune mean no metallic hydrogen.

Jupiter's Internal Heat



- Jupiter radiates twice as much energy as it receives from the Sun.
- Energy comes from the gradual gravitational contraction of the interior (releasing potential energy).

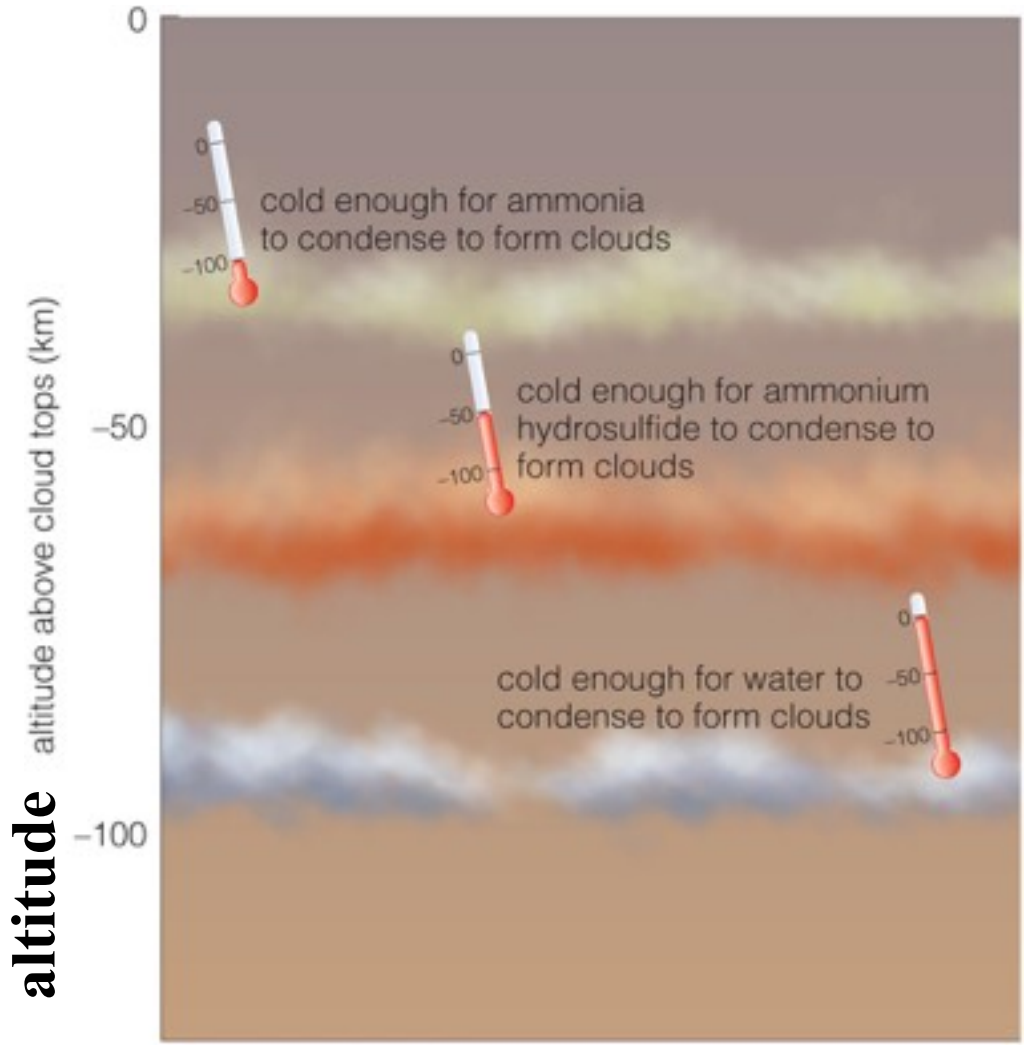
Internal Heat of Other Planets

- **Saturn** also radiates twice as much energy as it receives from the Sun.
  - Energy probably comes from differentiation (helium rain).

- **Neptune** emits nearly twice as much energy as it receives
  - also driven by gravitational contraction, but precise mechanism unclear.

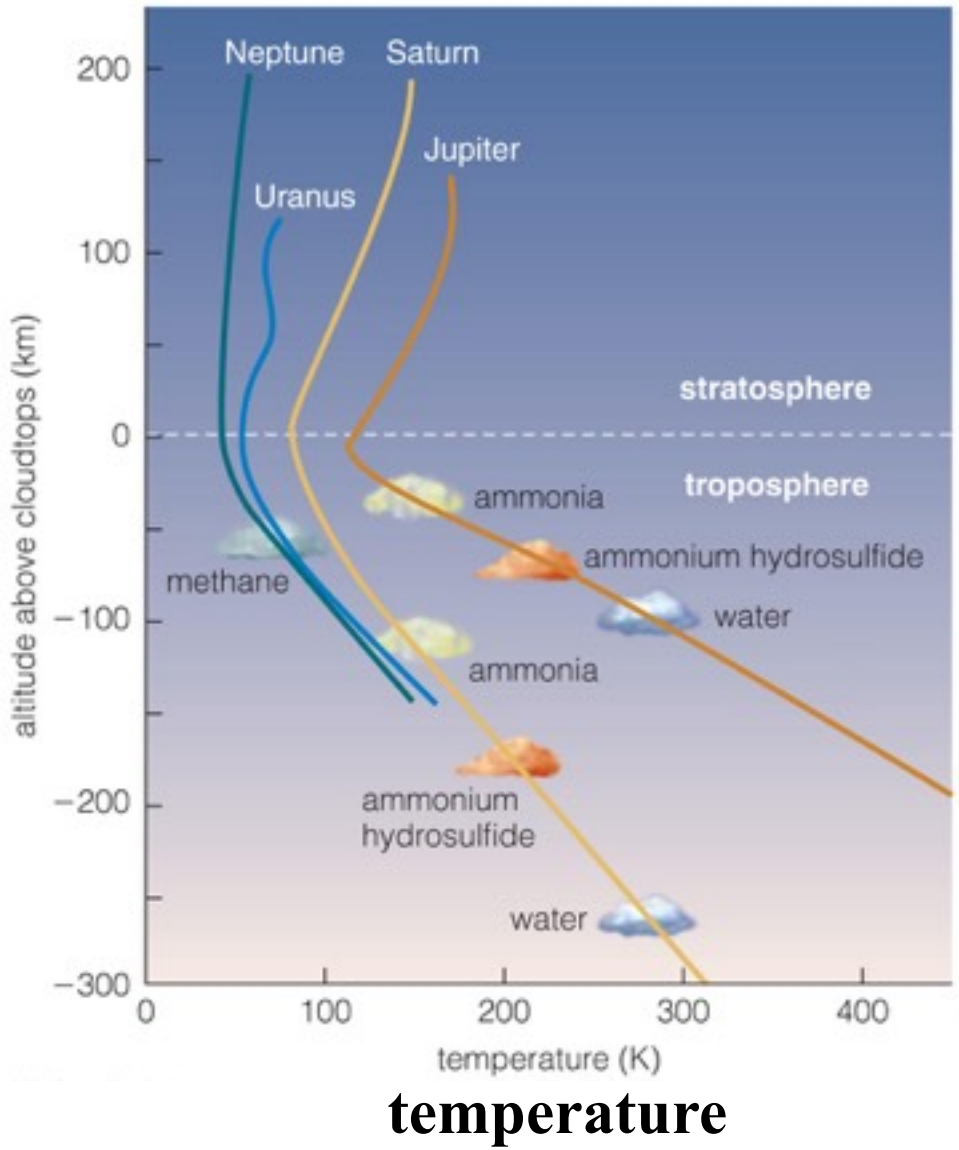
- **Uranus** does not radiate more than it receives.
  - no notable internal heat source
  - lower mass & lower density than Neptune

Jupiter's Atmosphere



- Hydrogen compounds in Jupiter form clouds.
- Different cloud layers correspond to freezing points of different hydrogen compounds.
- Other jovian planets have similar cloud layers.

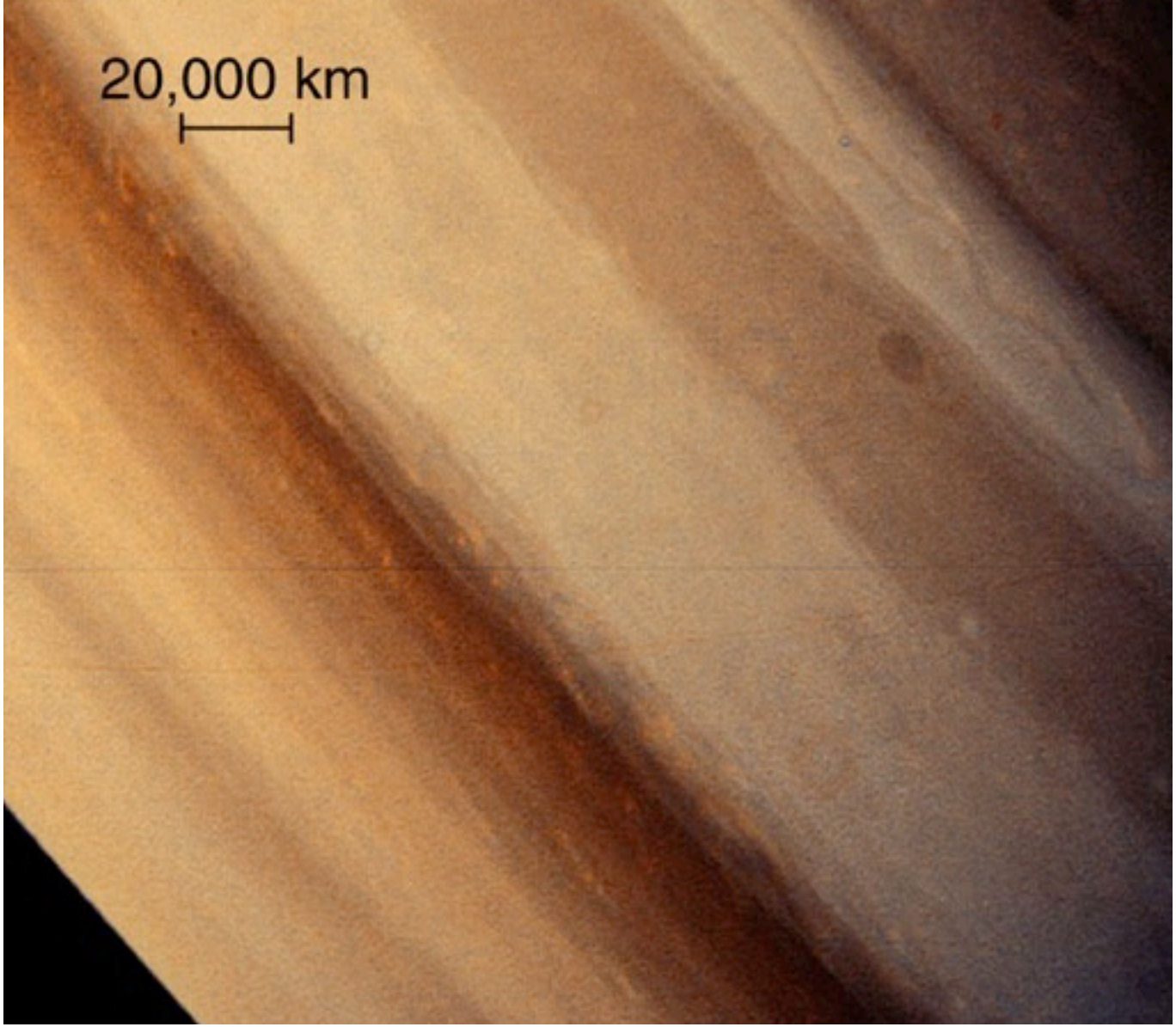
Jovian Planet Atmospheres



- Other jovian planets have cloud layers similar to Jupiter's.
- Different compounds make clouds of different colors.
- Reveal conditions to different depths in each planet

Jupiter's Colors

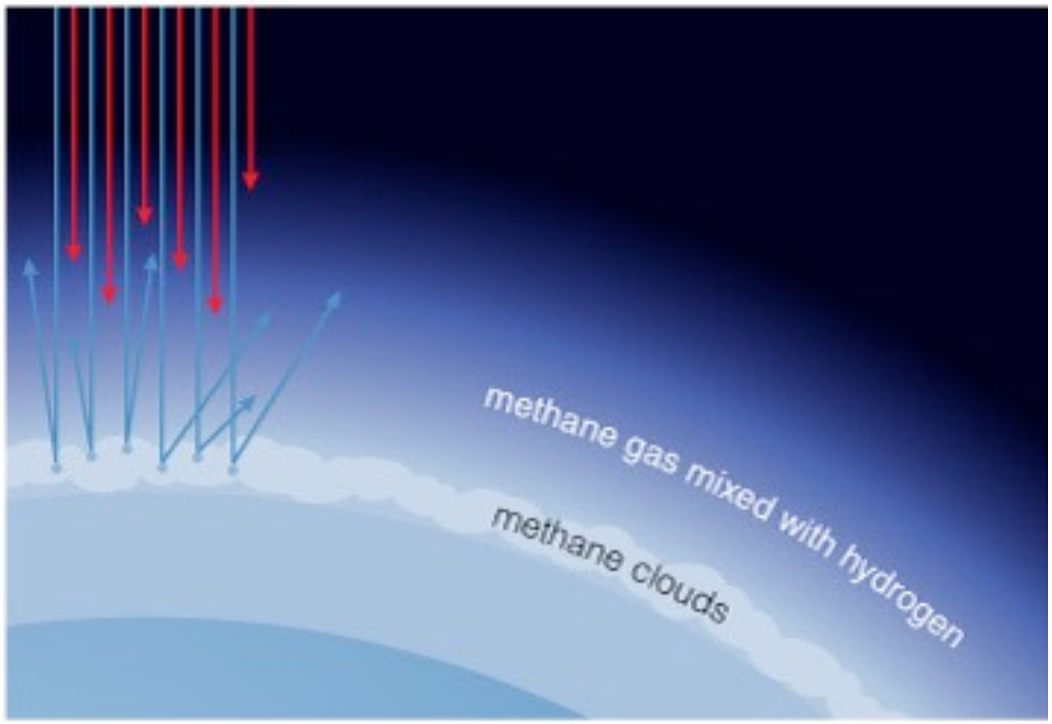
- Ammonium sulfide clouds (NH_4SH) reflect red/brown.
- Ammonia, the highest, coldest layer, reflects white.



Saturn's Colors

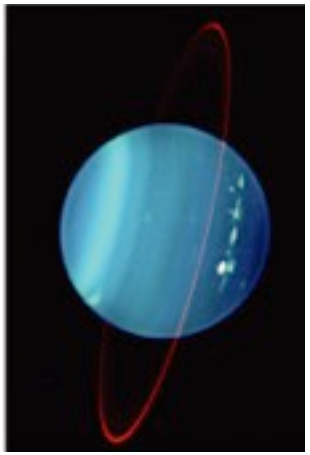
- Saturn's layers are similar but are deeper in and farther from the Sun — more subdued.

Methane on Uranus and Neptune



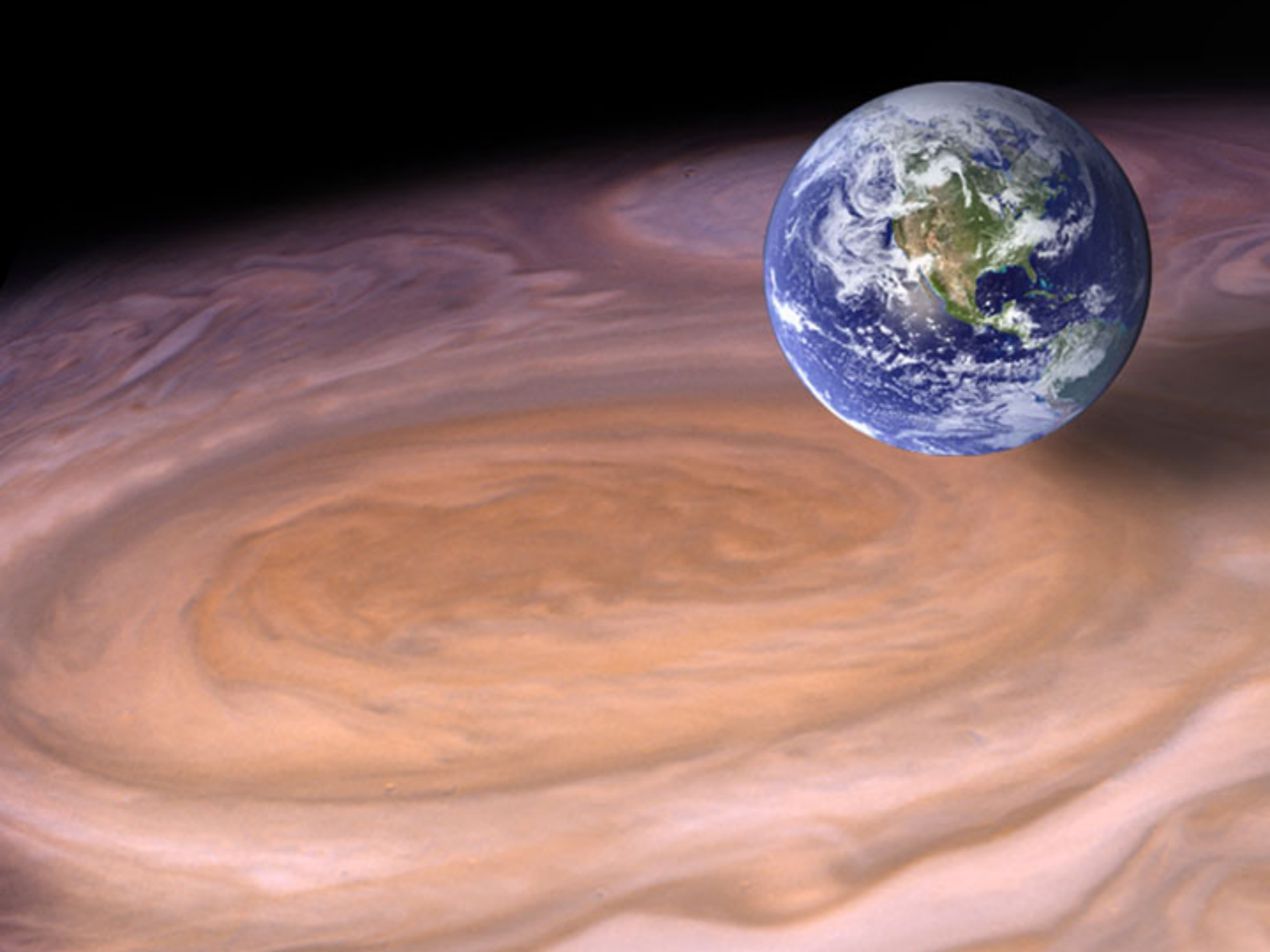
- Methane gas on Neptune and Uranus absorbs red light but reflects blue light.
- Blue light reflects off methane clouds, making those planets look blue.

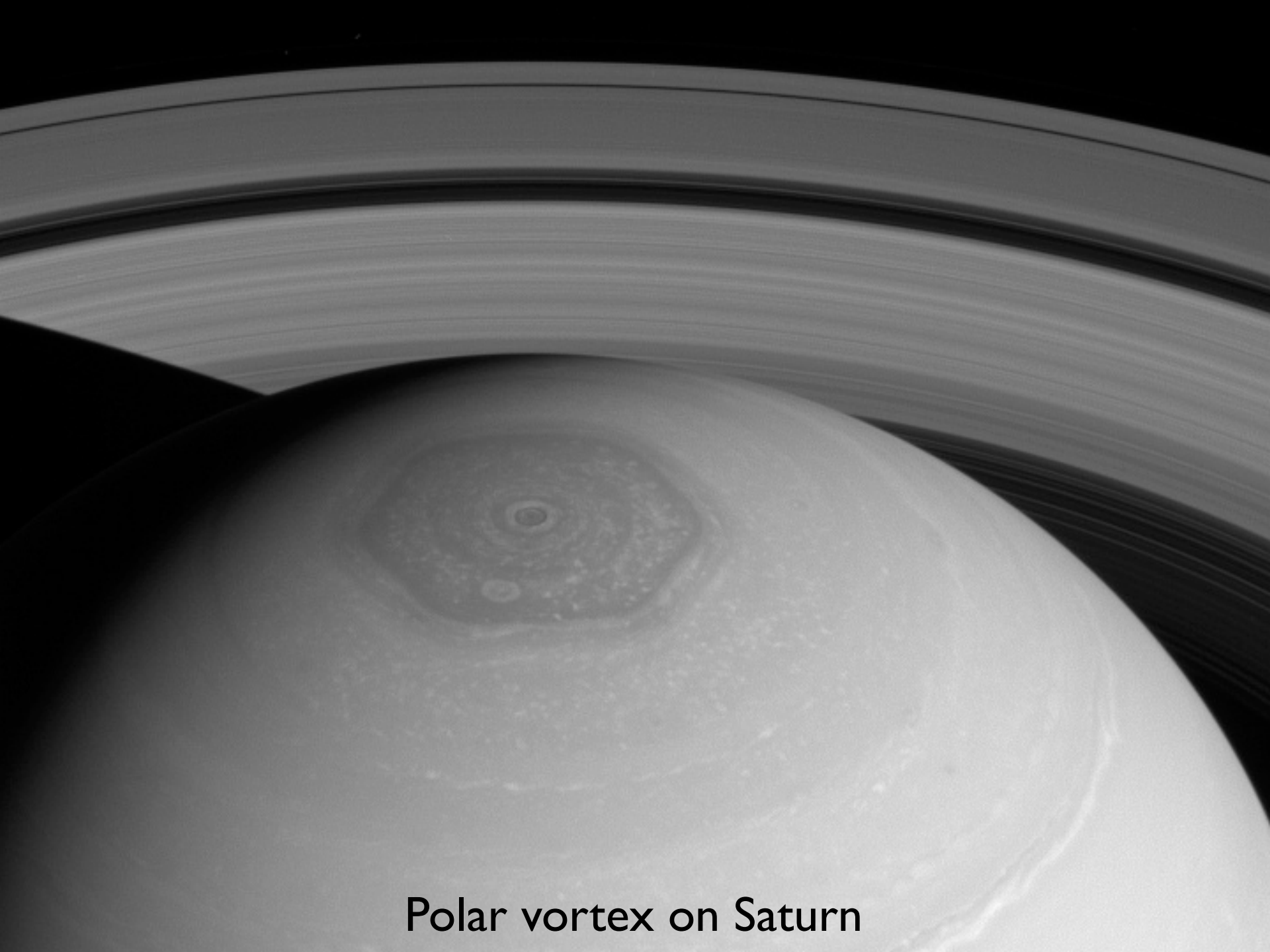
Weather on Jovian Planets



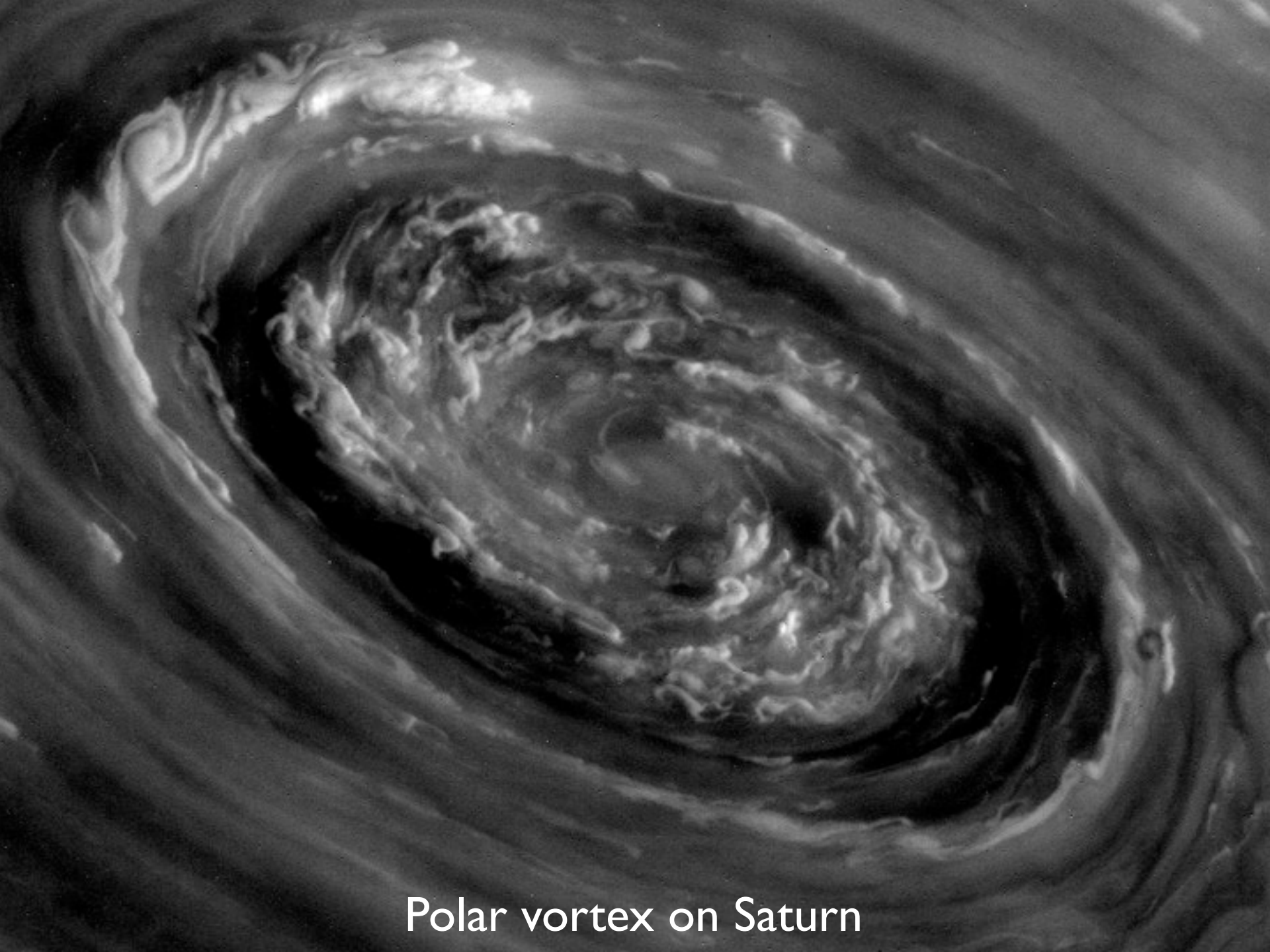
- All the jovian planets have strong winds and storms.

The great red spot on Jupiter is a storm larger than Earth that has persisted for centuries.



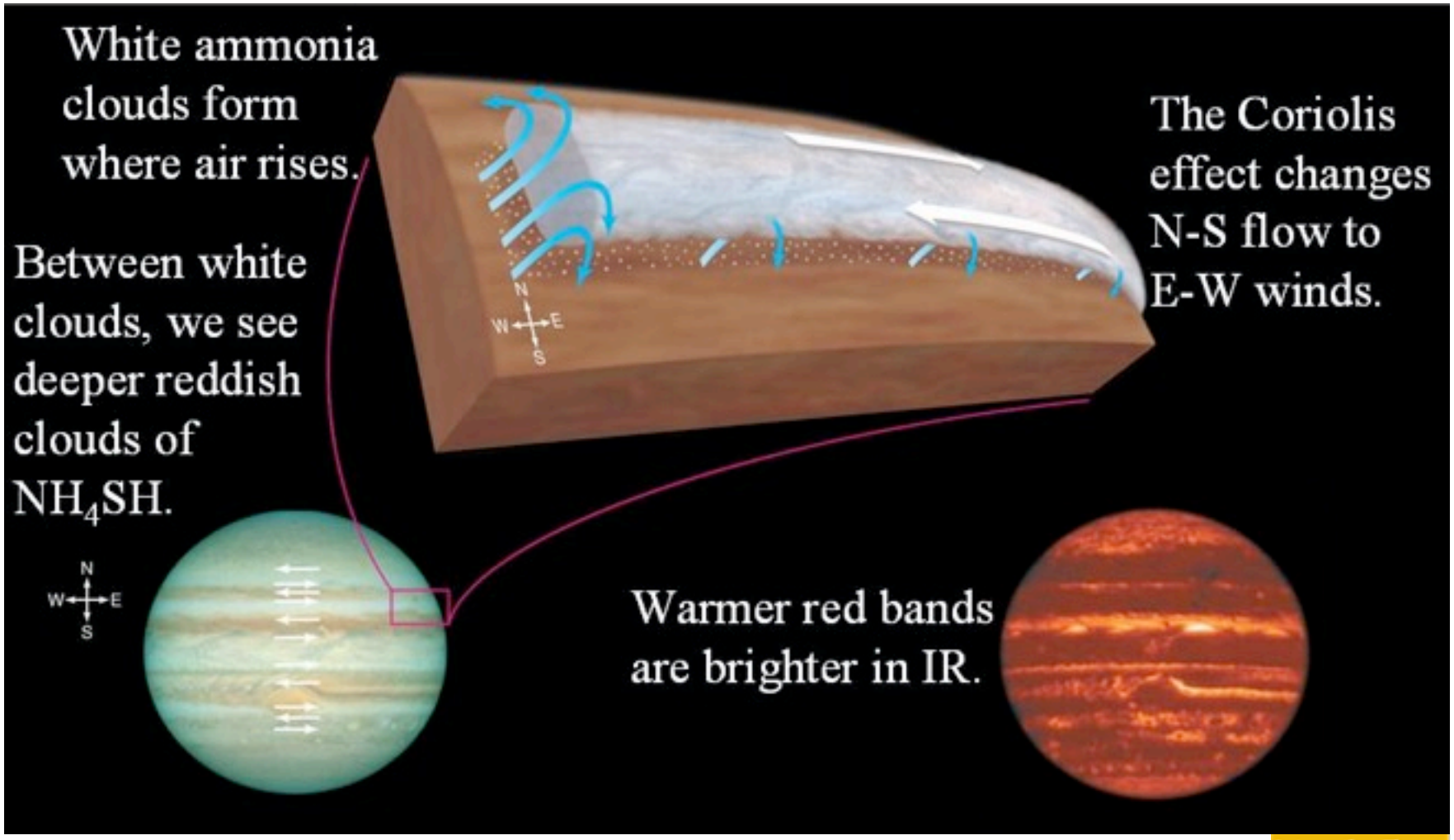


Polar vortex on Saturn



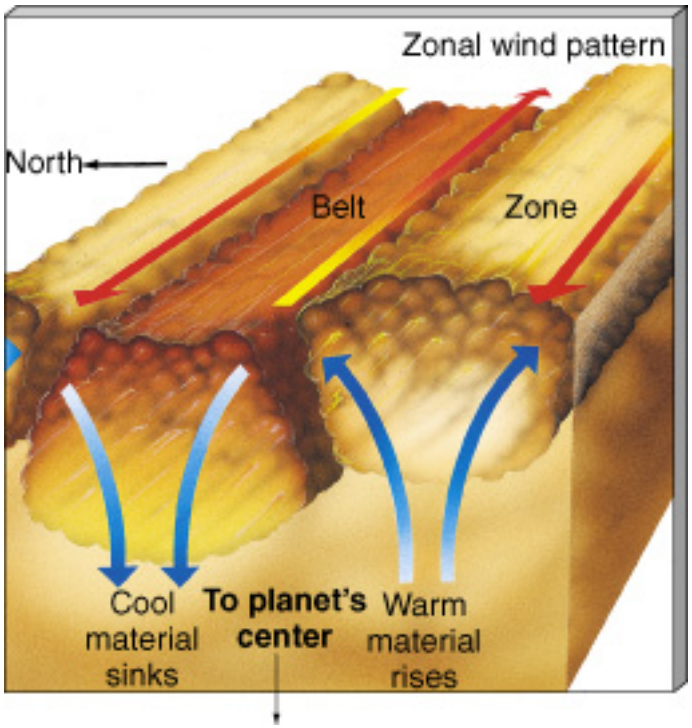
Polar vortex on Saturn

Jupiter's Bands



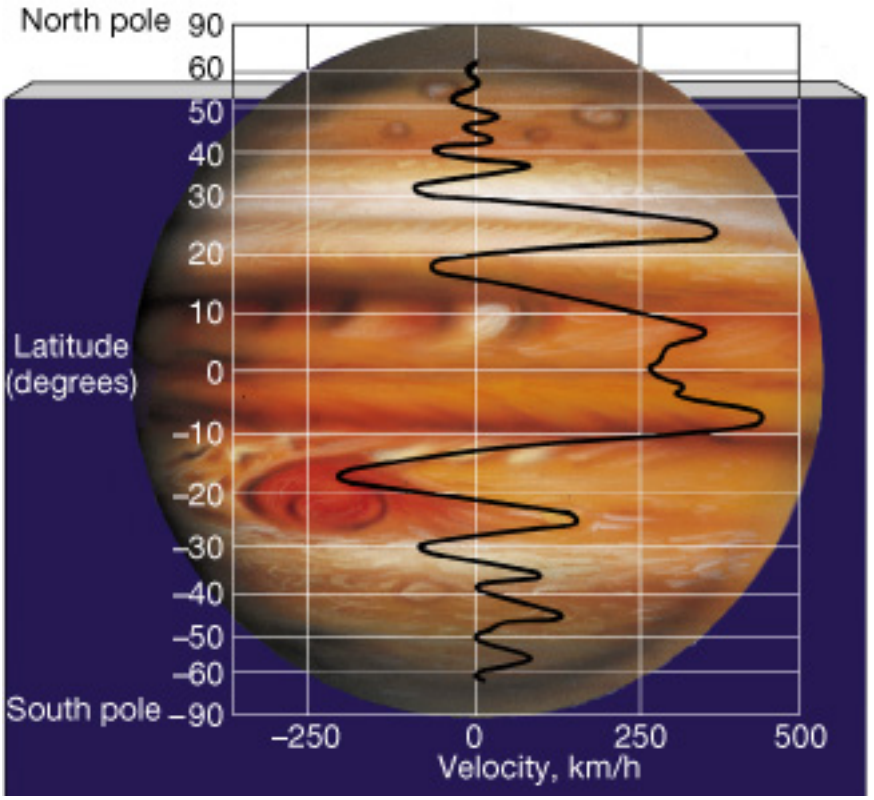
Zonal (band) structure in Jovian planet atmospheres

Zonal wind pattern



Hot rising and cool sinking material segregates into band structure

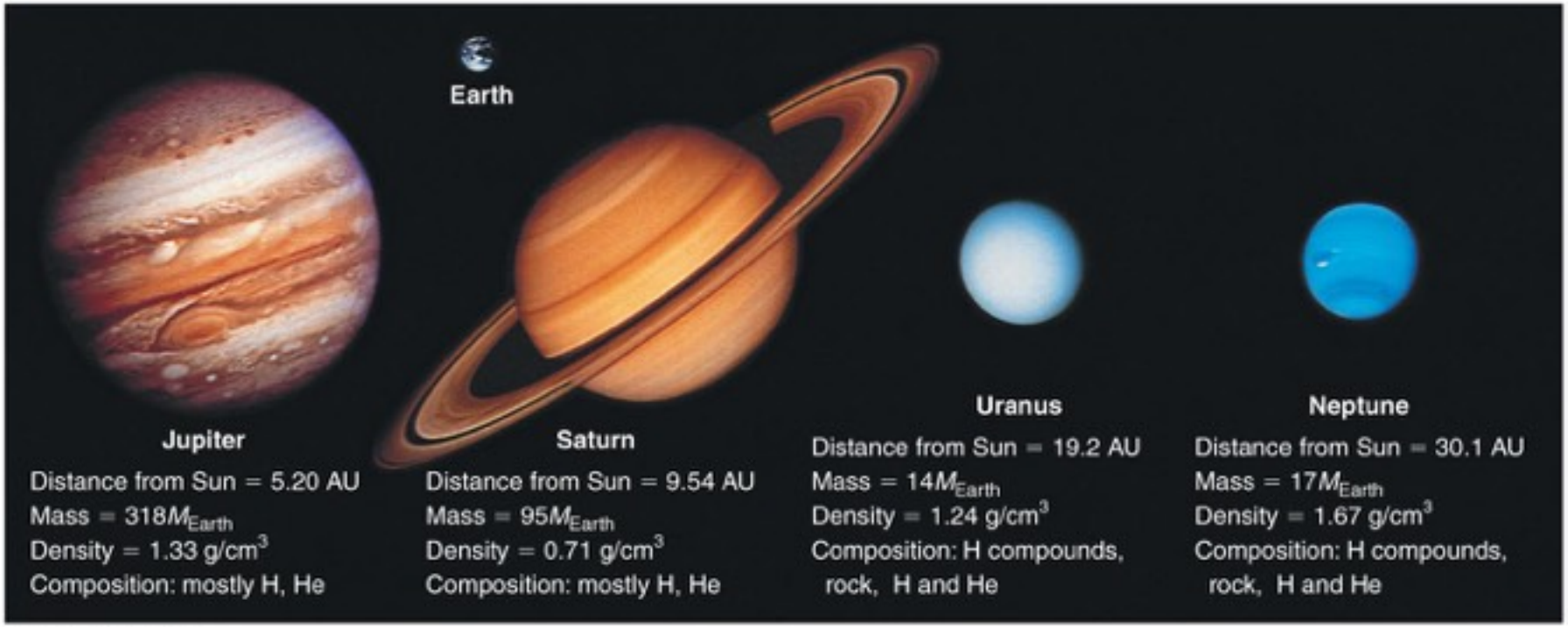
Zonal wind speed



Rapid rotation causes many zones (more than Earth's 3) with high wind speeds

show Jovian cloud layers

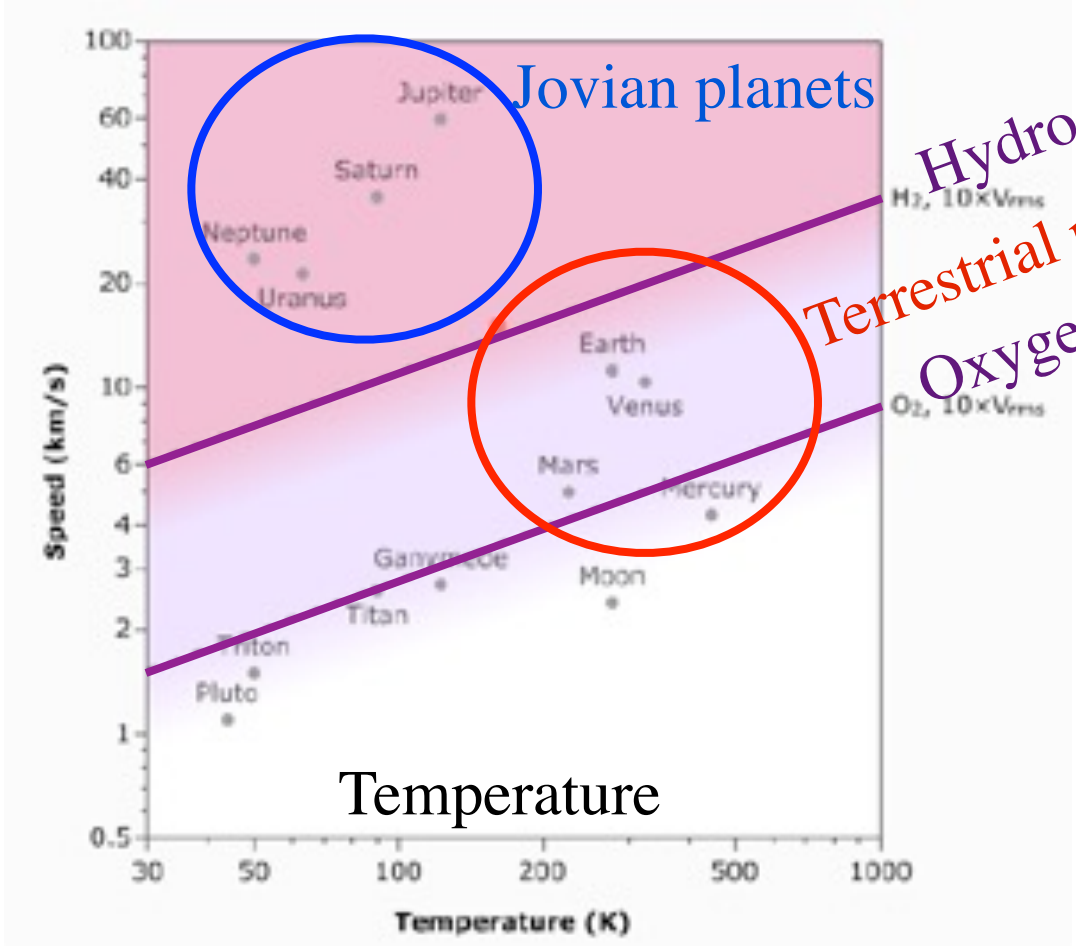
Weather on Jovian Planets



- All the jovian planets have strong winds and storms.

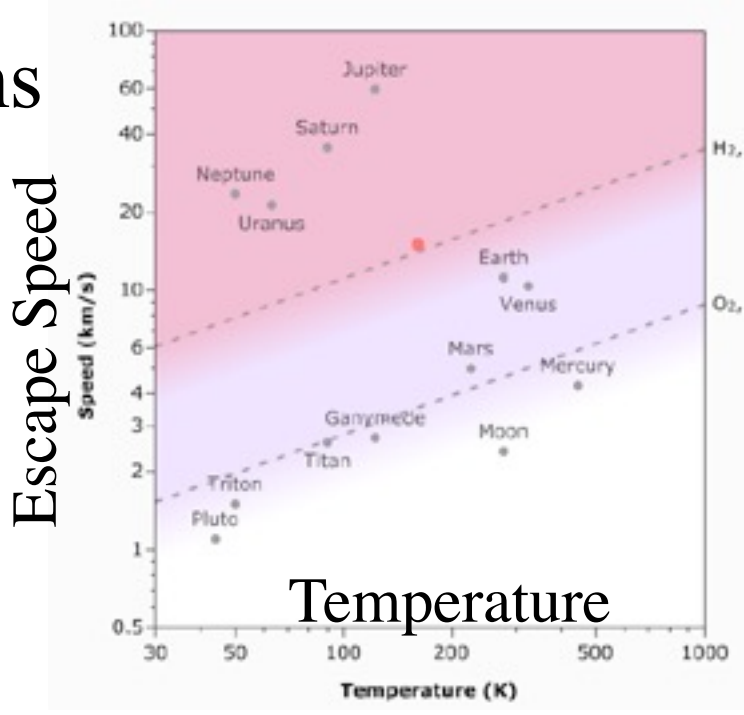
Jovian planets are

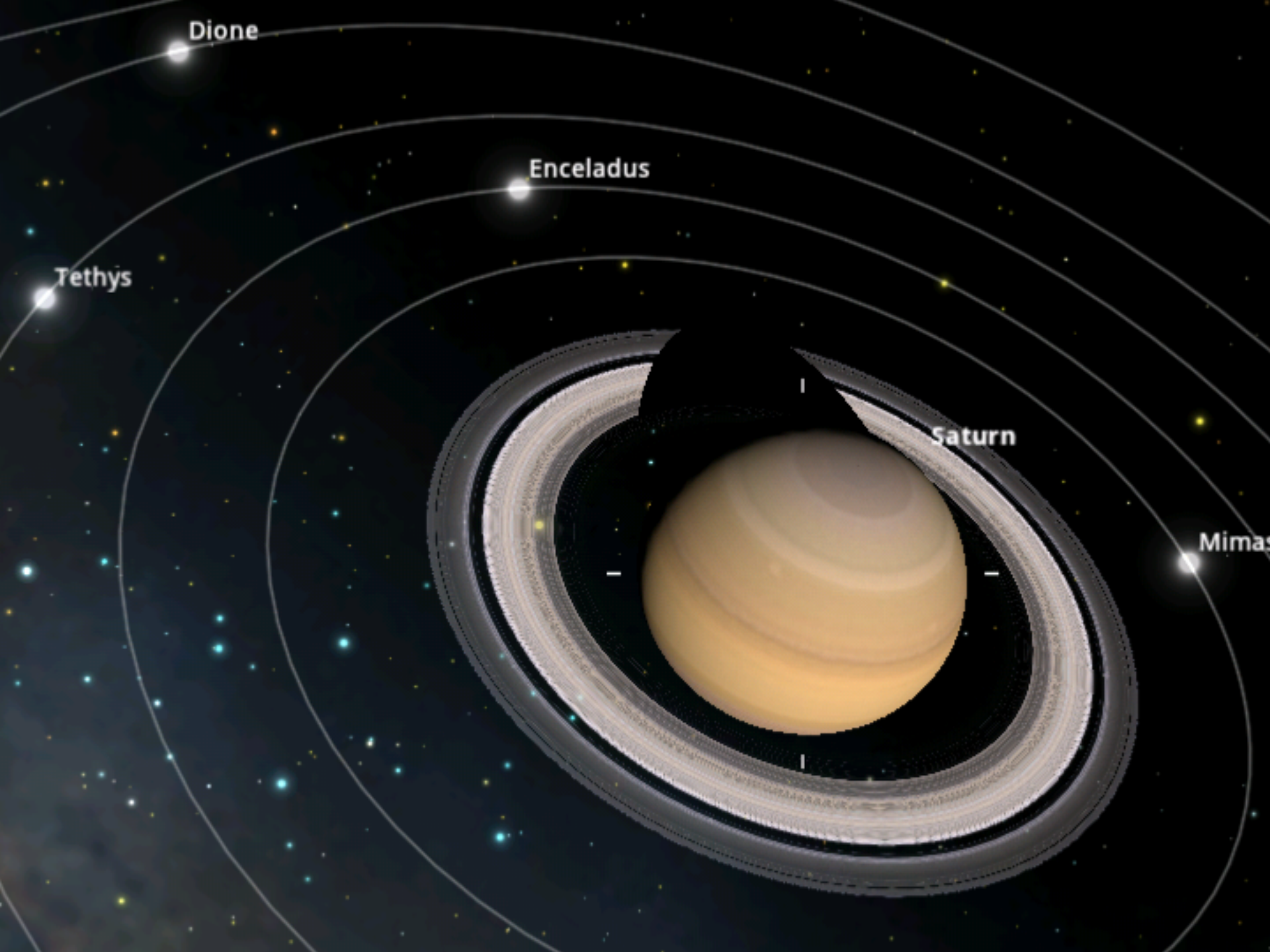
- Big
  - massive and cold, they can retain light elements like hydrogen and helium



Jovian planets are

- Big
  - massive and cold, they can retain light elements like hydrogen and helium
  - their composition is like that of the stars
  - the smaller terrestrial planets are the abnormal planets in terms of composition
- Like miniature solar systems
  - moons
  - rings




Dione
Enceladus
Tethys
Saturn
Mimas