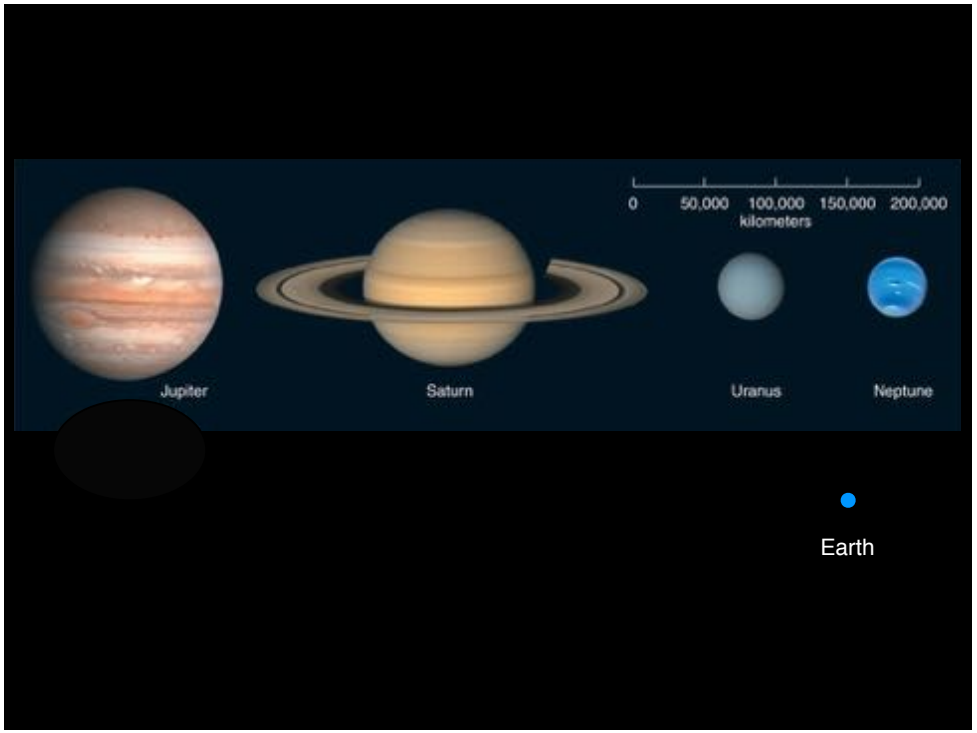
Reading: Chap. 11, Chap. 4, Sect. 4.6, Chap.12, Sect. 12.1-12.5
Homework #7: Due in recitation Friday/Monday (Oct. 25/28)
Homework #8: On website, due in recitation on Nov. 1/4

Last time: **Planetary Atmospheres**

- Survey of Planetary Atmospheres
- Primary Atmosphere, Secondary Atmosphere alteration
- Atmospheric Pressure and Temperature
  - Pressure vs. height: Hydrostatic Equilibrium; T vs. height: thermal equilibrium
- Earth's Atmosphere
- The Greenhouse Effect

Today: **The Gas and Ice Giant Planets**

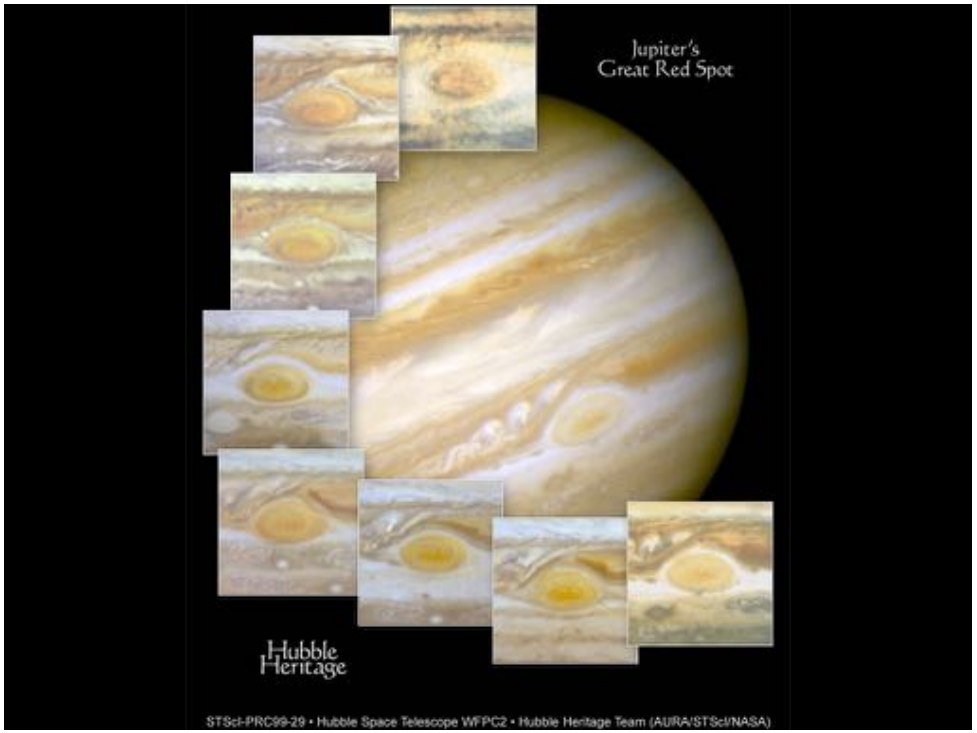
- Jupiter (and Saturn)
  - Atmosphere Composition (H, He) and cloud coloration
  - Zones, Bands and circulation patterns
  - Interior
- Differences between Jupiter and Saturn
- Uranus and Neptune



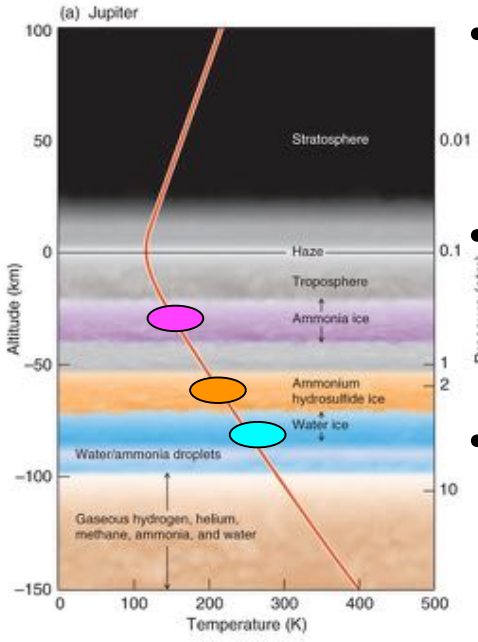
Jupiter

- **The Basics:**
  - Mass = 318 x Earth
  - Diameter = 11.2 x Earth
  - "Surface" Gravity = 2.53 x Earth
  - Moons: 4 major, many minor
  - Rotation: very fast: P ~ 10 hours
  - view from Earth: cloud belts, no surface
  - visits:
    - flybys: Pioneer 10, 11 (1973), Voyager 1, 2 (1979)
    - orbiter: Galileo (1995-2003), Juno (2016- 2018+)
    - atmosphere probe: Galileo (1995)


View through small telescope

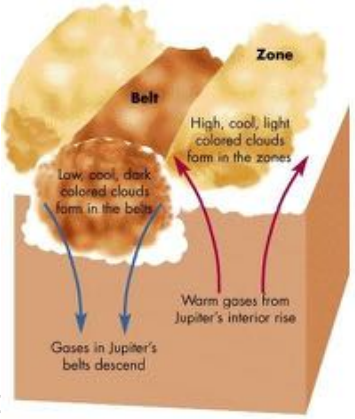


The Jovian Atmosphere



- 75% Hydrogen, ~25% Helium
- trace compounds (all H rich):
  - ammonia (NH_3)
  - methane (CH_4)
  - water vapor
- composition of clouds:
  - ammonia (high level)
  - ammonium hydrosulfide ice (middle level)
  - water ice (low)
- colors of clouds: only small amt. needed.
  - high white clouds (ammonia)
  - lower clouds are dark (amm. hydrosulfide)
  - other coloring agents still unknown, complex organics?!

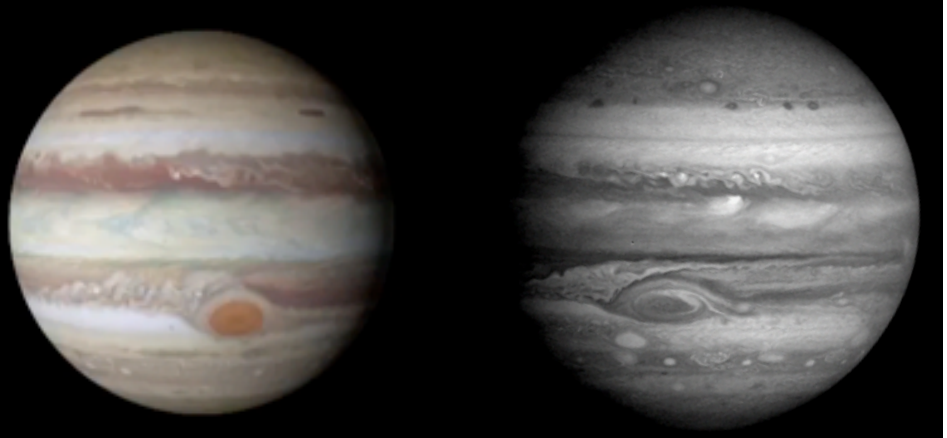
Atmospheric Features



- Zones:
  - upwardly moving material
  - high, cool cloud bands
- Belts:
  - falling gasses
  - low, warm, and dark
- Spots:
  - updrafts: white spots
  - holes in cloud decks: dark spot
- Winds and Circulation: Zonal Winds:
  - belts and zones rotate at different rates
  - lots of shear from band to zone (+/– 360 km/hr!)
  - circulation at interfaces

Example: the Great Red Spot

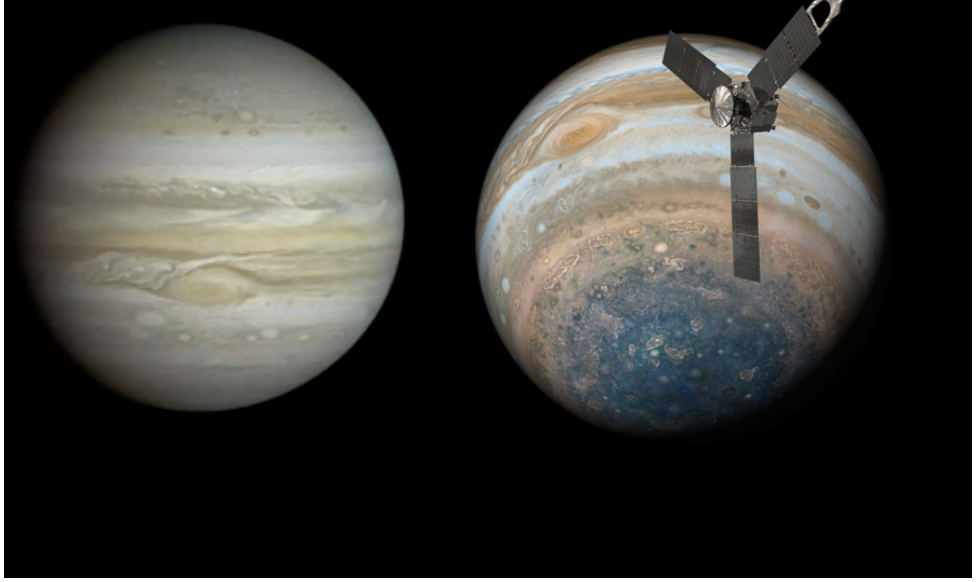
Atmospheric circulation - belts and zones



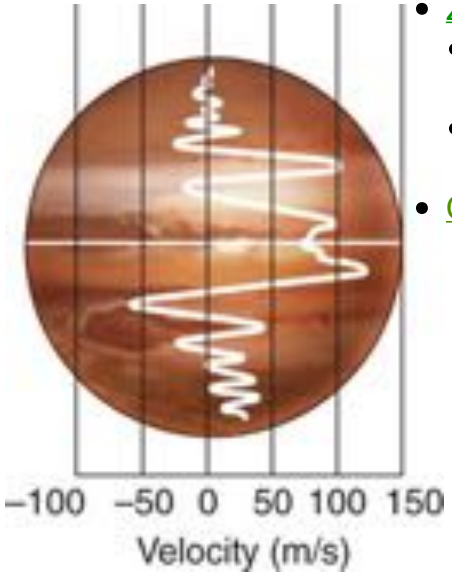
Hubble Space Telescope
January 2015

Voyager 1 flyby - 1979
rotation removed

Atmospheric circulation - belts and zones



Winds and Circulation



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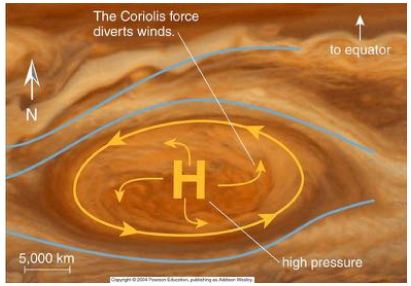
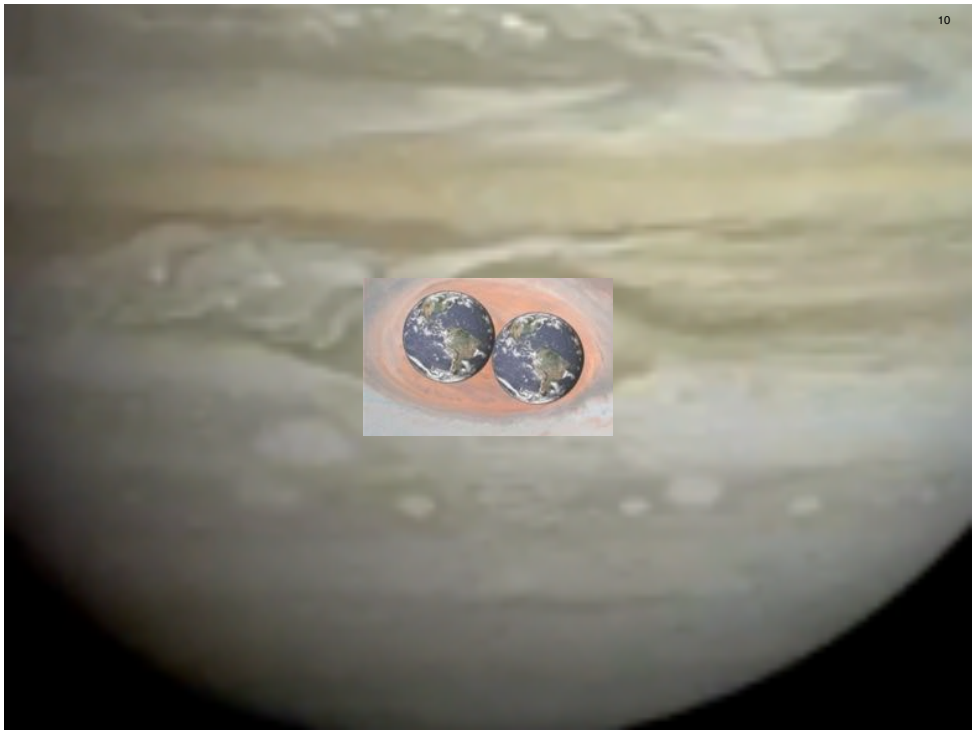
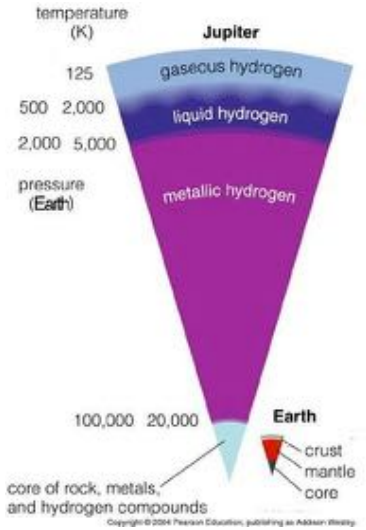




The Jovian Interior

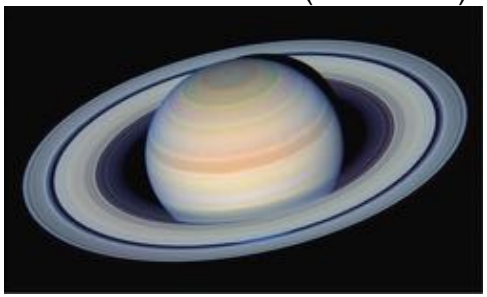


- Clouds and atmosphere
  - temperature increases with depth
  - pressure increases with depth
- Deeper, pressure liquifies hydrogen
  - liquid molecular hydrogen "mantle"
- metallic liquid hydrogen below (electrons free to roam)
  - starts where P ~ 2-3000 x Earth's
  - root of Jovian magnetic field
- A rocky core (M~15xEarth)
  - T ~ 20,000K, P ~ 100,000 x Earth

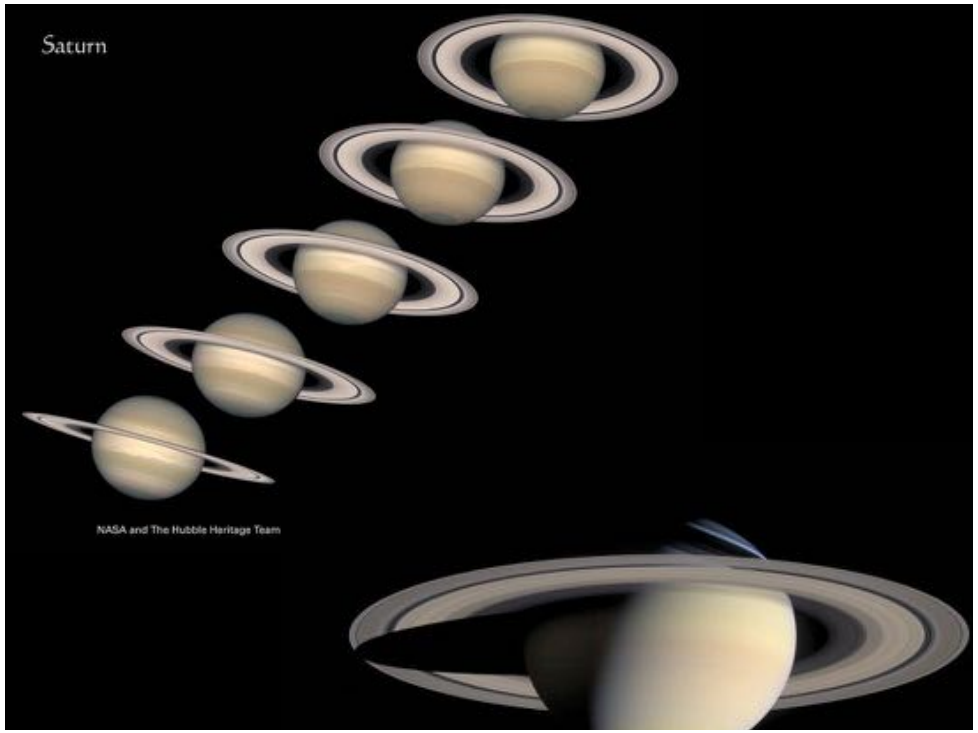
Saturn

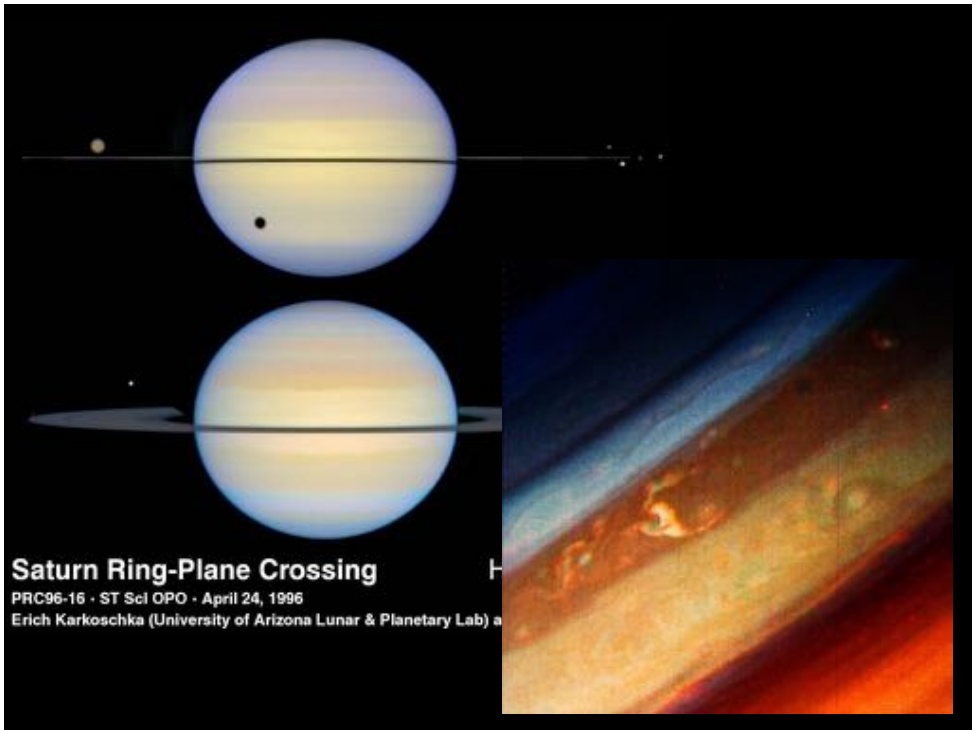
- **The Basics:**
  - Mass = 95 x Earth
  - Diameter = 9.5 x Earth
  - "Surface" Gravity = 1.07 x Earth
  - Moons: 5 major, many minor
  - Rotation: very fast: P ~ 10.6 hours
  - visits:
    - flybys: Voyager 1, 2 (1981)
    - orbiter: Cassini (2004-2017)

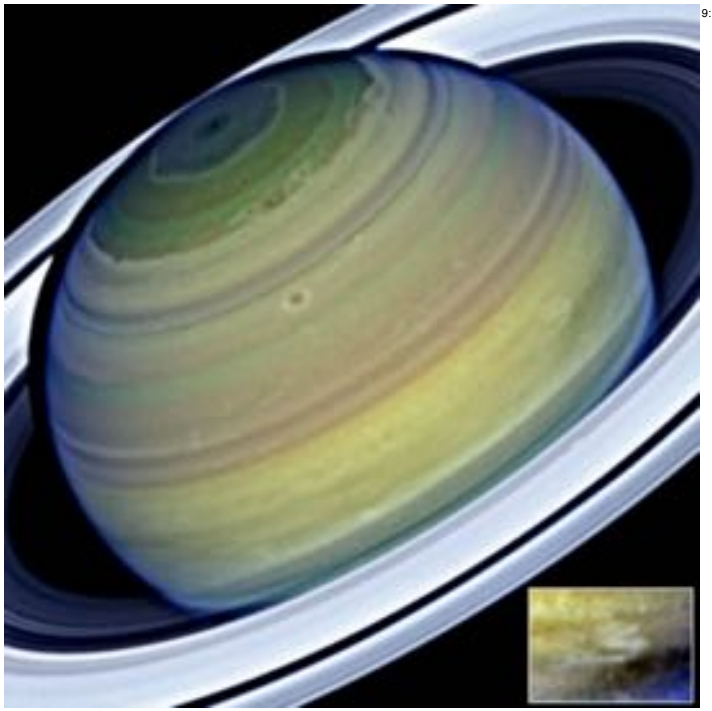
small telescope view



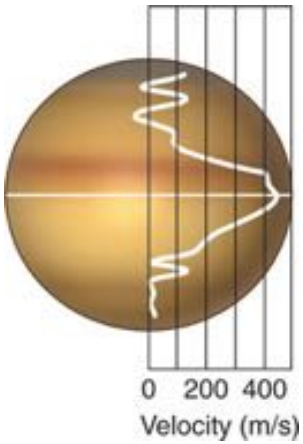
Looking back from Saturn to the Earth...



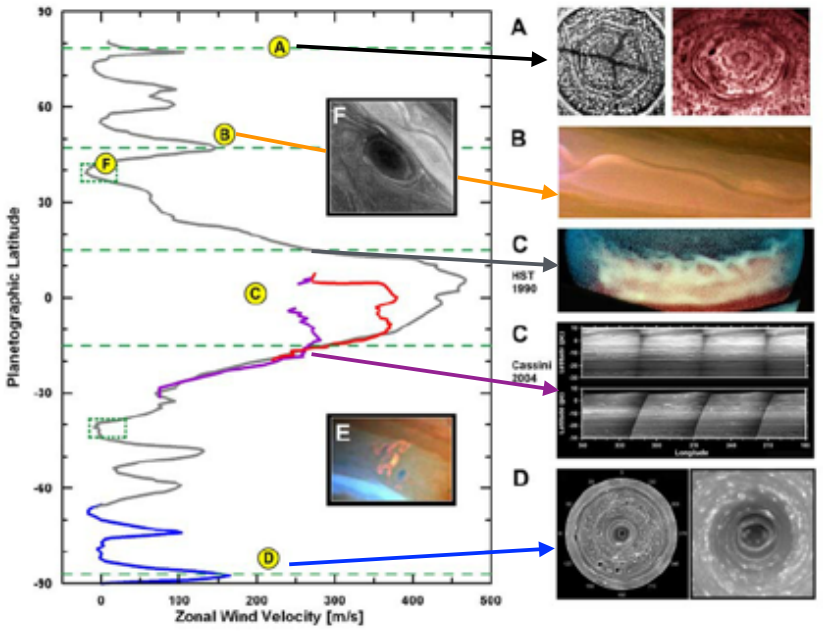




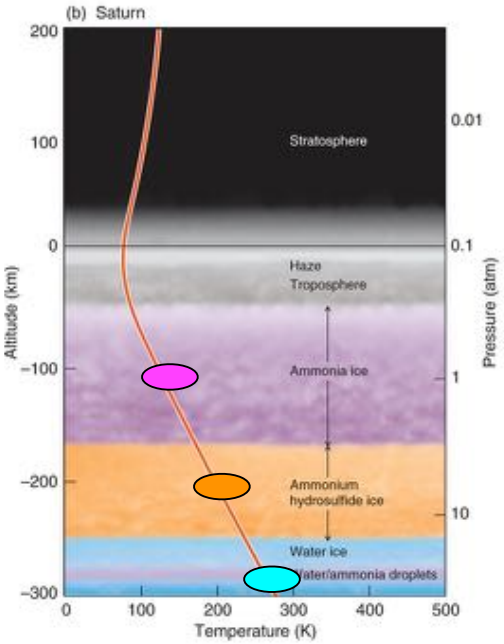
Saturn Atmosphere

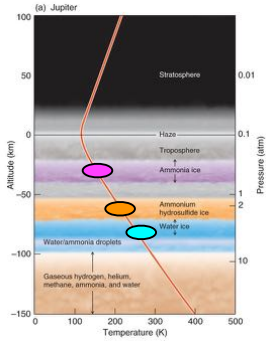


- less vivid coloration than Jupiter
- stronger zonal winds:
  3 x higher than Jupiter
- deeper cloud layers
- less helium than Jupiter
  - helium sinks down in cooler atmosphere
  - Jupiter too hot; Helium stays up



Clouds on Saturn (and Jupiter)

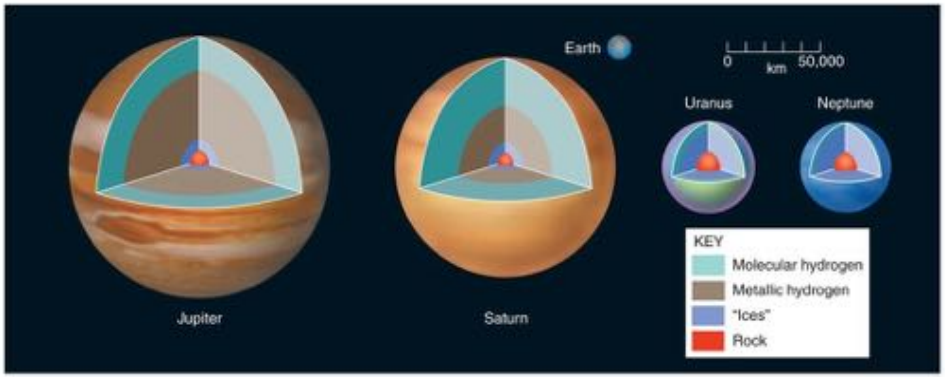




Jupiter's clouds are higher
- warmer close to the sun

Saturn's Interior

- thicker liquid molecular H "mantle"
- smaller metallic H interior
- similar rocky core (to preserve mean density)



Uranus and Neptune

The Basics:

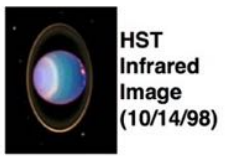
Mass = 14.5 x Earth
Diameter = 4.0 x Earth
Surface Gravity = 0.90 x Earth
Rings: several thin dusky rings
Moons: 5 major, ~10 minor
view from Earth:
- dusky blue disk
- discovered in 1781

visit: flyby: Voyager 2 (1986)

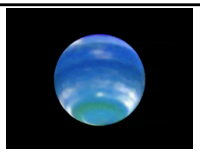
The Basics:

Mass = 17.1 x Earth
Diameter = 3.9 x Earth
Surface Gravity = 1.12 x Earth
Rings: several partial ring arcs
Moons: 1 major, ~7 minor
view from Earth:
- dusky blue disk
- discovered in 1846

visit: flyby: Voyager 2 (1989)

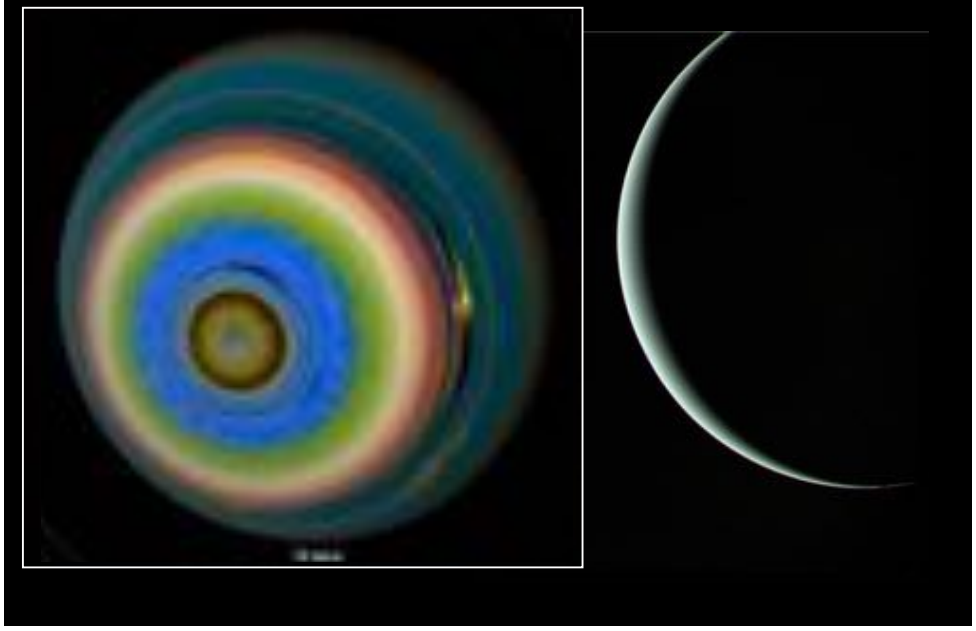


HST Infrared Image (10/14/98)

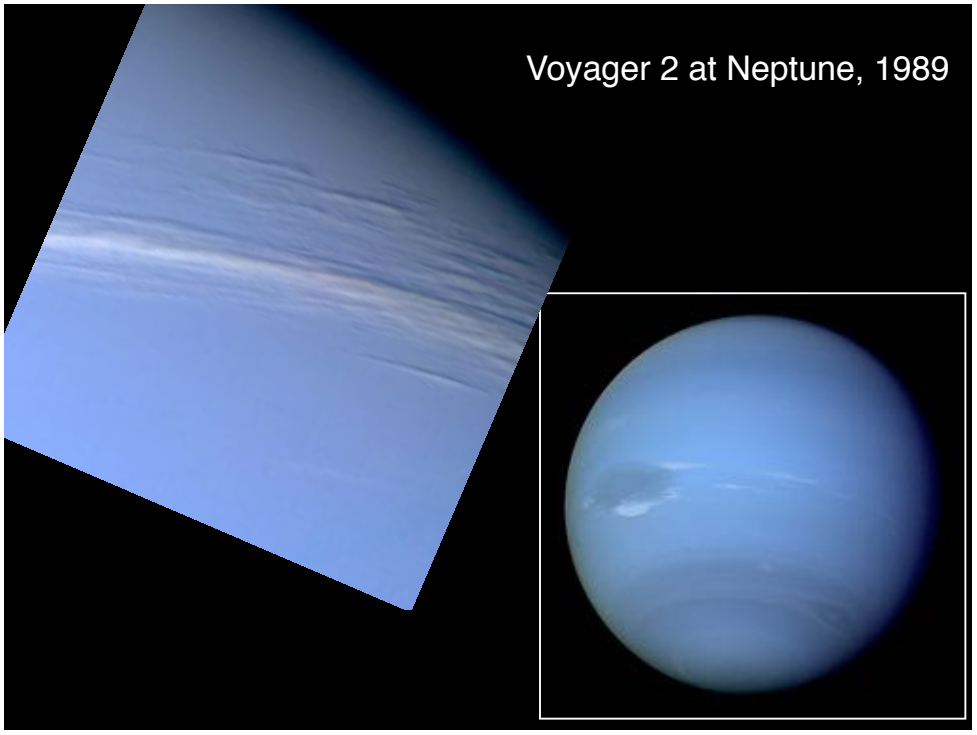


HST IR Images

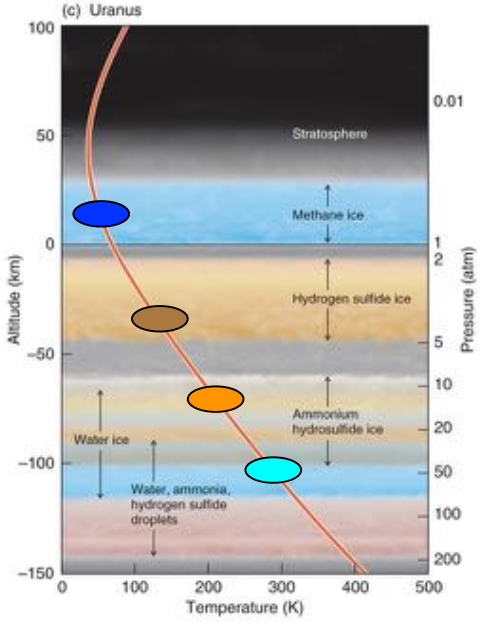
Voyager 2 at Uranus, 1986



Voyager 2 at Neptune, 1989

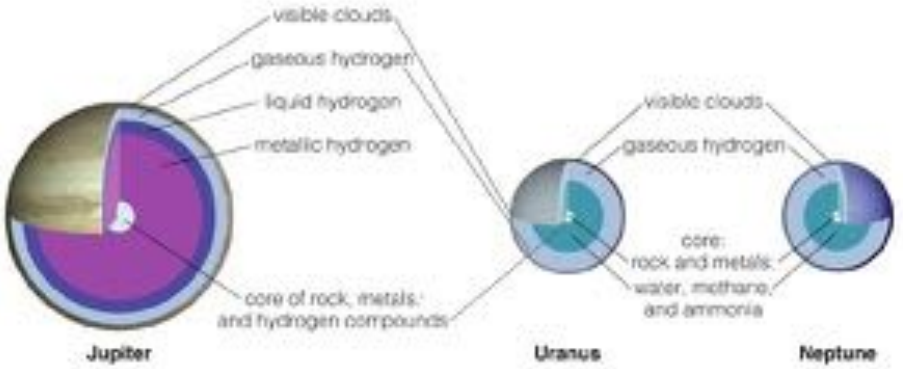


Uranus / Neptune Clouds



- Much farther from the Sun
- Colder
- upper atmosphere cold enough for methane to freeze
- blue cloudtops
- deeper, warmer layers:
  - hydrogen sulfide
  - ammonium hydrosulfide
  - water

Possible Interior Structure of Uranus and Neptune



Outer planets, compared