Jupiter and Saturn: Lords of the Planets

Chapter Twelve

Introduction To Modern Astronomy I: Solar System

Introducing Astronomy (chap. 1-6)

Planets and Moons (chap. 7-15)

Sun and Life: Highlights (Chap. 16 & 28)

Ch7: Comparative Planetology I
Ch8: Comparative Planetology II
Ch9: The Living Earth
Ch10: Our Barren Moon
Ch11: Mercury, Venus and Mars

Ch12: Jupiter and Saturn
Ch13: Satellites of Jupiter & Saturn

Ch14: Uranus, Neptune and Beyond
Ch15: Vagabonds of Solar System

Jupiter Data

table 14-1	Jupiter Data
Average distance from Sun:	5.203 AU $= 7.783 \times 10^8$ km
Maximum distance from Sun:	5.455 AU $= 8.160 \times 10^8$ km
Minimum distance from Sun:	4.950 AU $= 7.406 \times 10^8$ km
Eccentricity of orbit:	0.048
Average orbital speed:	13.1 km/s
Orbital period:	11.86 years
Rotation period:	9^h 50^m 28^s (equatorial)
	9^h 55^m 29^s (internal)
Inclination of equator to orbit:	3.12°
Inclination of orbit to ecliptic:	1.30°
Diameter:	142,984 km = 11.209 Earth diameters (equatorial)
	133,708 km = 10.482 Earth diameters (polar)
Mass:	1.899×10^{27} kg = 317.8 Earth masses
Average density:	1326 kg/m^3
Escape speed:	60.2 km/s
Surface gravity (Earth = 1):	2.36
Albedo:	0.44
Average temperature at cloudtops:	−108°C = −162°F = 165 K
Atmospheric composition (by number of molecules):	86.2% hydrogen (H_2), 13.6% helium (He), 0.2% methane (CH_4), ammonia (NH_3), water vapor (H_2O), and other gases

Largest Planet

Saturn Data

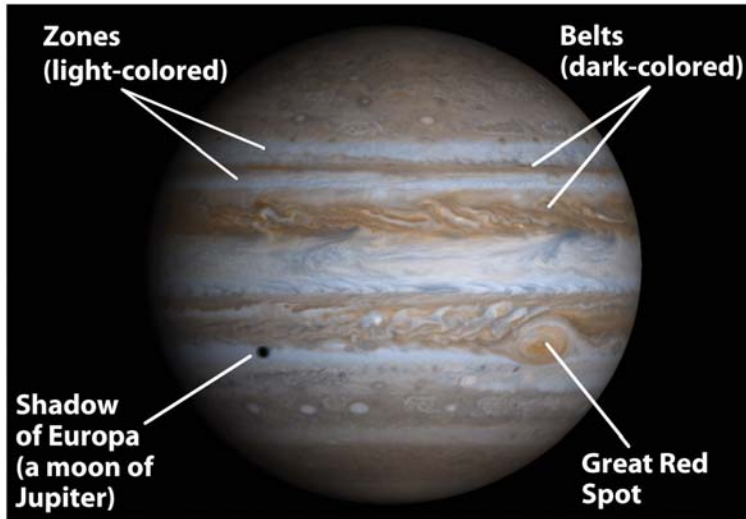| table 14-2	Saturn Data
Average distance from Sun:	$9.572 \text{ AU} = 1.432 \times 10^9 \text{ km}$
Maximum distance from Sun:	$10.081 \text{ AU} = 1.508 \times 3\ 10^9 \text{ km}$
Minimum distance from Sun:	$9.063 \text{ AU} = 1.356 \times 10^9 \text{ km}$
Eccentricity of orbit:	0.053
Average orbital speed:	9.64 km/s
Orbital period:	29.37 years
Rotation period:	$10^h\ 13^m\ 59^s$ (equatorial)
	$10^h\ 39^m\ 25^s$ (internal)
Inclination of equator to orbit:	26.73°
Inclination of orbit to ecliptic:	2.48°
Diameter:	120,536 km = 9.449 Earth diameters (equatorial)
	108,728 km = 8.523 Earth diameters (polar)
Mass:	$5.685 \times 10^{26} \text{ kg} = 95.16$ Earth masses
Average density:	687 kg/m^3
Escape speed:	35.5 km/s
Surface gravity (Earth = 1):	0.92
Albedo:	0.46
Average temperature at cloudtops:	$-180°C = -292°F = 93 \text{ K}$
Atmospheric composition (by number of molecules):	96.3% hydrogen (H_2), 3.3% helium (He), 0.4% methane (CH_4), ammonia (NH_3), water vapor (H_2O), and other gases

Magnificent Rings

Orbital Motion

- Best viewed at opposition

- Jupiter: orbital period ~12 years, distance 5.2 AU
- Jupiter: moves across the zodiac at the rate of one constellation per year
- Jupiter: synodic period ~ 13 months; oppositions of Jupiter occur at intervals of about 13 months

- Saturn: orbital period ~30 years, distance 9.6 AU
- Saturn's oppositions occur at intervals of about one year and two weeks

Apparent Views

Jupiter

- Zones (light-colored)
- Belts (dark-colored)
- Shadow of Europa (a moon of Jupiter)
- Great Red Spot

Saturn

- Zones (light-colored)
- Belts (dark-colored)
- Shadow of Mimas (a moon of Saturn)

- The visible "surfaces" of Jupiter and Saturn are actually the tops of their clouds

- The rapid rotation of the planets (~ 10 hours) twists the clouds into **dark belts** and **light zones** that run parallel to the equator
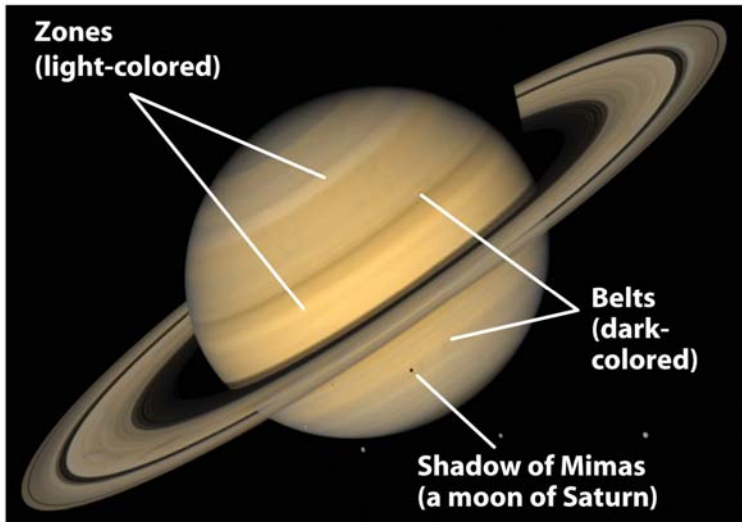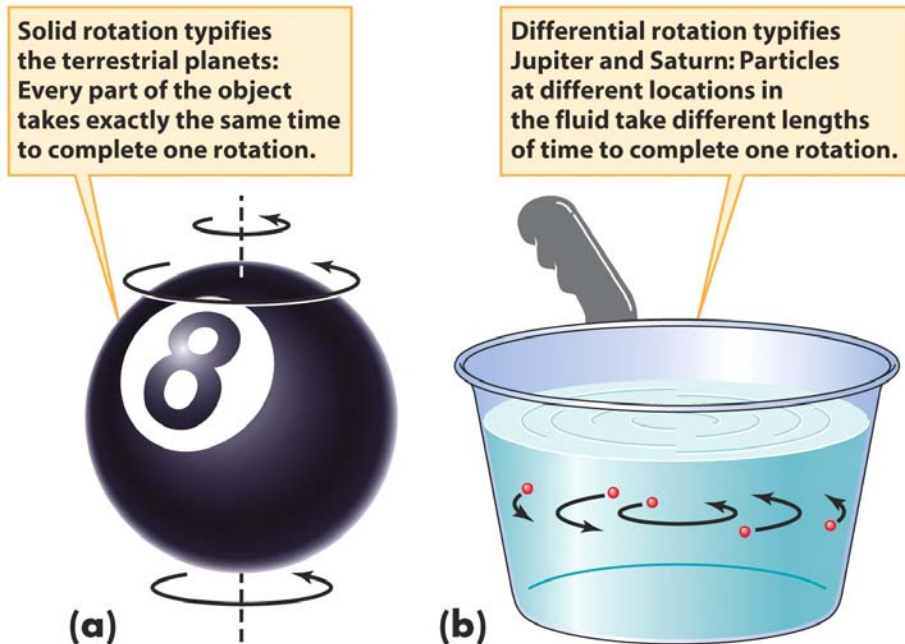
- The **Great Red Spot** in Jupiter is a long-lived stable **storm system** that has lasted for at least 300 hundred years.

Differential Rotation

- **Differential rotation** for Jovian planets
  - Equatorial regions rotate faster than polar regions
  - Jupiter
    - The equatorial region rotates at 9 hours 50 minutes
    - The polar region rotates at 9 hours 55 minutes
  - Saturn
    - The equatorial region rotates at 10 hours 13 minutes
    - The polar region rotates at 10 hours 39 minutes
- **Solid rotation** for terrestrial planets

Solid rotation typifies the terrestrial planets: Every part of the object takes exactly the same time to complete one rotation.

Differential rotation typifies Jupiter and Saturn: Particles at different locations in the fluid take different lengths of time to complete one rotation.

(a)   (b)

Atmosphere: Composition

- **Similar to that of the Sun, from the nebula**
- Jupiter's atmosphere, by the number of molecules, is **86.2% hydrogen (H_2), 13.6% helium (He),** 0.2% methane (CH_4), ammonia (NH_3) and water vapor (H_2O)
- Saturn's atmosphere, by the number of molecules, is **96.3% hydrogen (H_2), 3.3% helium (He),** 0.4% methane (CH_4), ammonia (NH_3) and water vapor (H_2O)
- Compared with Jupiter, **Saturn** has a serious **helium deficiency** in the atmosphere
  - At Saturn's low temperature (-180°C at cloud-top), helium gas forms droplets and falls deeper into the planet
  - Jupiter's temperature is relatively warmer (-108°C at cloud-top), helium does not yet form rain droplets.
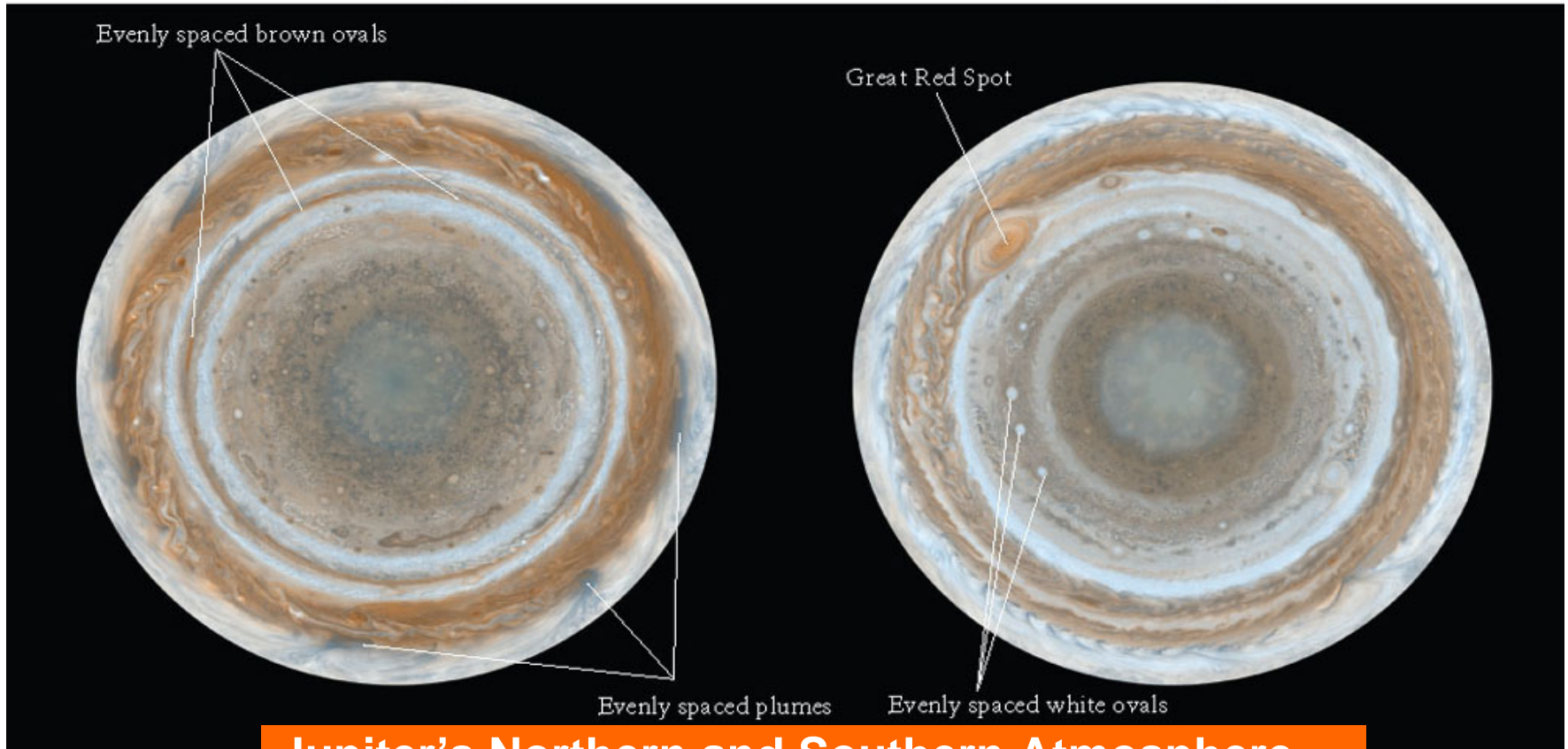
Atmosphere: Activity

- Great Red Spot, Brown ovals and white ovals are **storm systems with circular wind**.
- Different colors due to seeing clouds at different height having different temperature, e.g,. brown seeing deeper
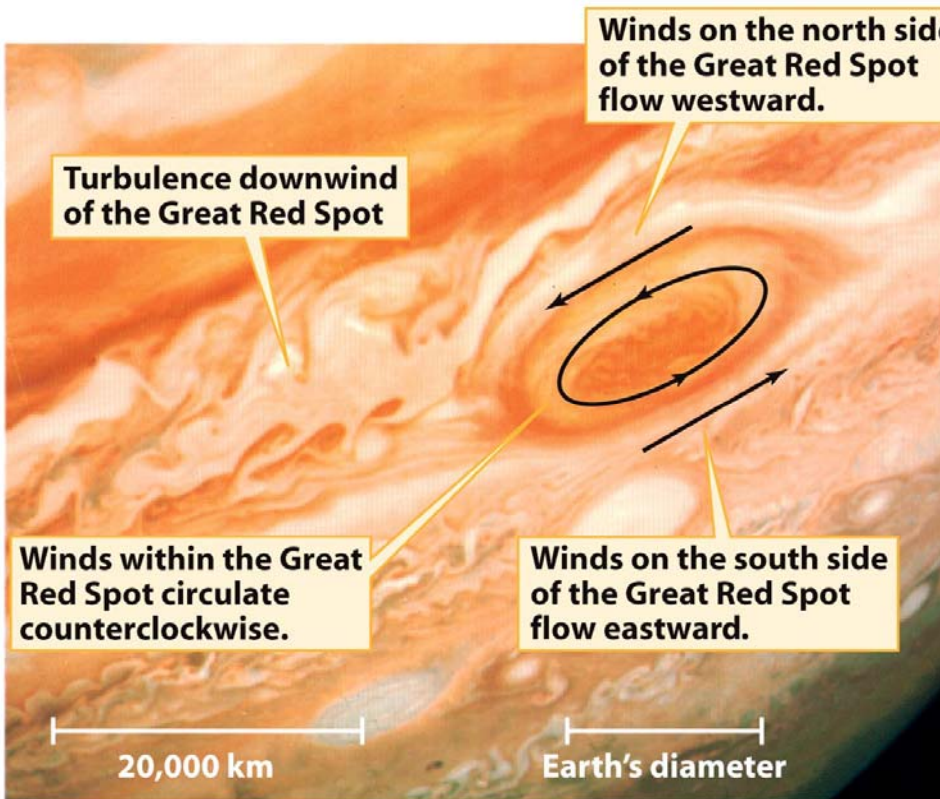

Northern hemisphere

Southern hemisphere

Evenly spaced brown ovals

Great Red Spot

Evenly spaced plumes

Evenly spaced white ovals

Jupiter's Northern and Southern Atmosphere

Atmosphere: Great Red Spot

Winds on the north side of the Great Red Spot flow westward.

Turbulence downwind of the Great Red Spot

Winds within the Great Red Spot circulate counterclockwise.

Winds on the south side of the Great Red Spot flow eastward.

20,000 km   Earth's diameter

- The great red spot was first seen in 1664, but may be much older
- It is larger than the size of the Earth
- The spot rotates counterclockwise with a period of about 6 days
  - Winds on the north flow westward
  - Winds on the south flow eastward
- The spot is red because it is made of clouds at relatively high altitude

Atmosphere: Activity

- Storm systems under development
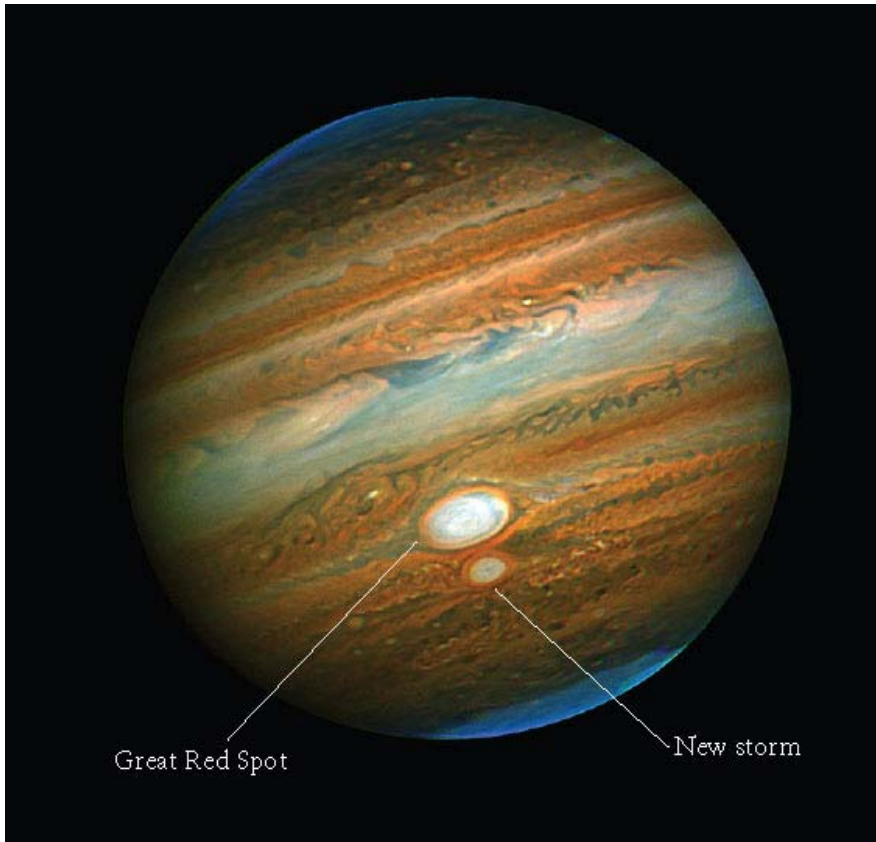
Jupiter's new storm
Gemini North Telescope
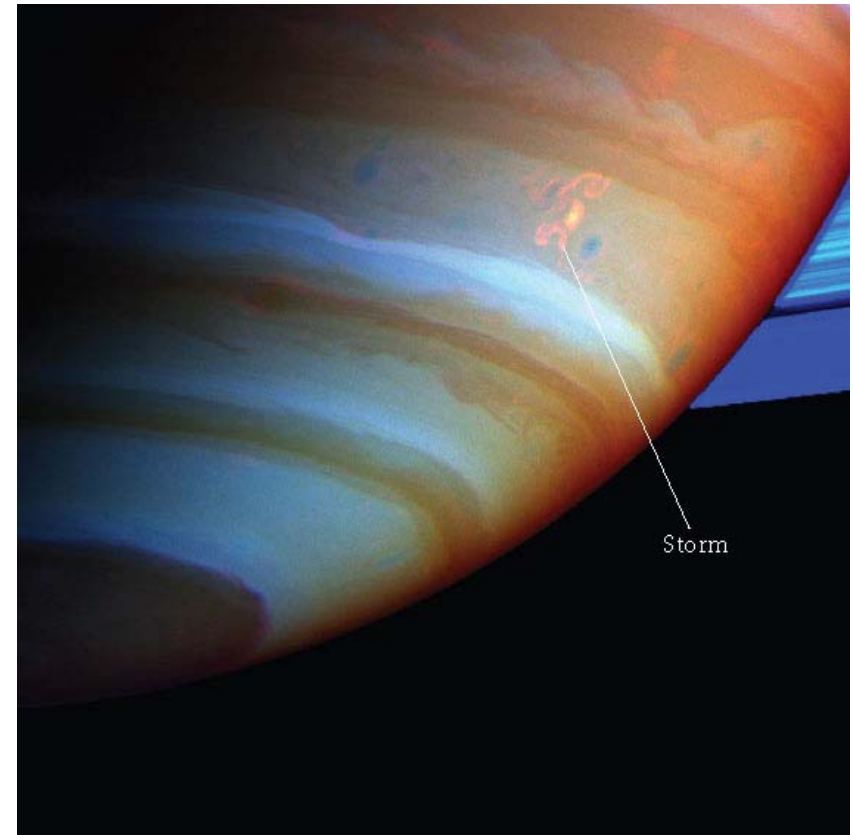
Saturn's new storm
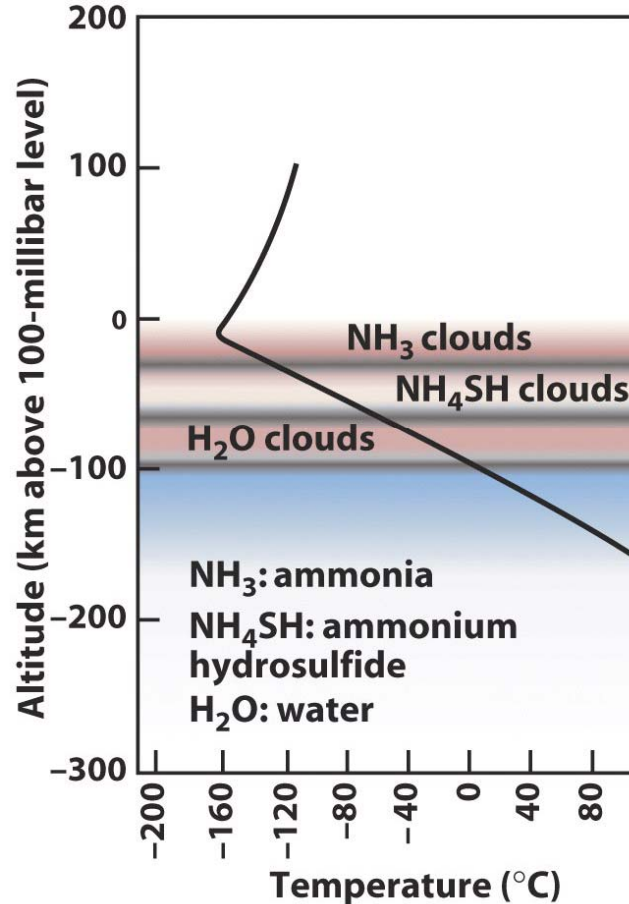Cassini spacecraft, infrared

Internal Heat

- Weather patterns in Earth's atmosphere are powered by sunlight
- Weather patterns in Jupiter and Saturn **are powered mainly by internal heat,** as well as sunlight.
- Jupiter emits twice as much energy as from Sunlight
- **The internal energy comes from the thermal energy left after the initial creation of planets**
- Because of the large size, Jupiter and Saturn has retained substantial thermal energy even after billions of years
- As the result of the continuous heat flow from below, the temperature of the atmosphere increases with increasing depth, causing strong up-down convection.
- Coupled with fast rotation, convection flows in the atmosphere create a global pattern of eastward and westward **zonal winds**, e.g, 500 km/s
- Zonal wind changes direction at the boundary of light zones and dark belts.
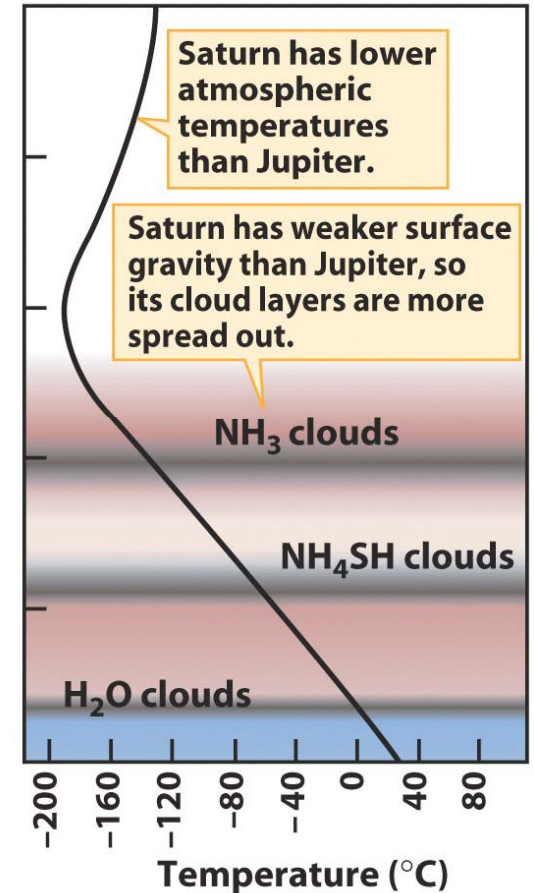
Internal Heat

- The temperature of the atmospheres increases with increasing depth

- Very steeper changes for Jupiter

- The atmosphere may have three layers of clouds

- **Jupiter and Saturn have no solid surface**
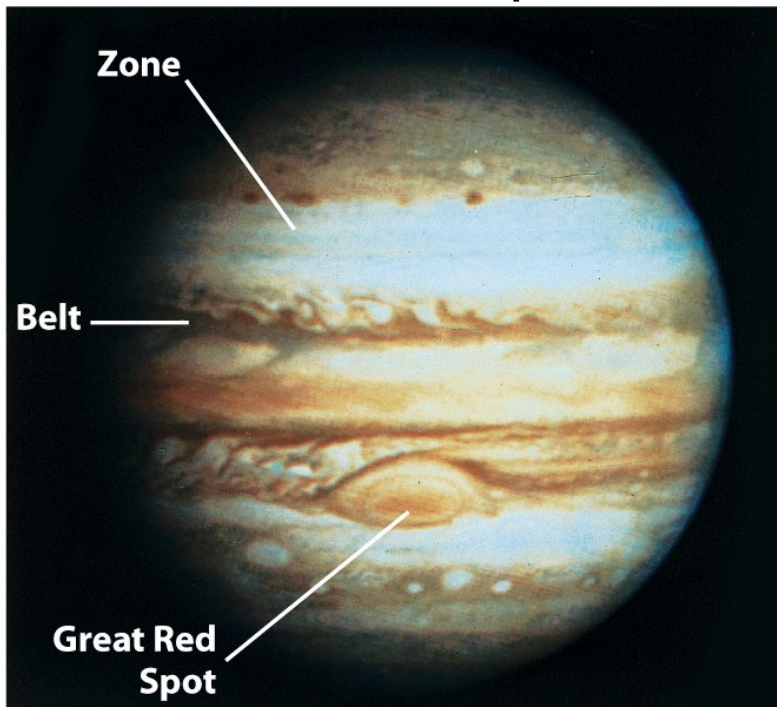
(a) Jupiter's atmosphere

NH$_3$ clouds
NH$_4$SH clouds
H$_2$O clouds

NH$_3$: ammonia
NH$_4$SH: ammonium hydrosulfide
H$_2$O: water

Altitude (km above 100-millibar level)

Temperature (°C)

(b) Saturn's atmosphere

Saturn has lower atmospheric temperatures than Jupiter.

Saturn has weaker surface gravity than Jupiter, so its cloud layers are more spread out.

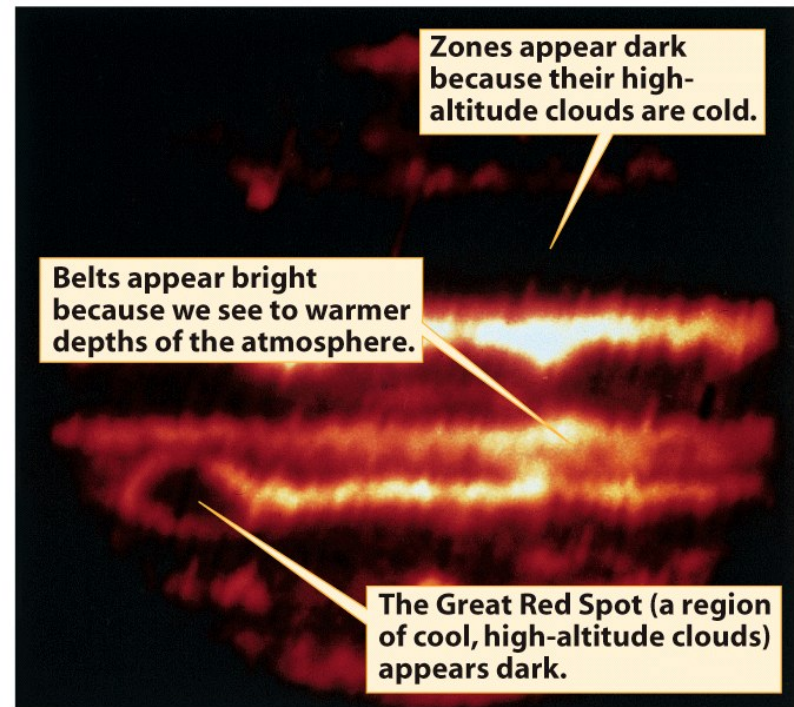NH$_3$ clouds

NH$_4$SH clouds

H$_2$O clouds

Temperature (°C)

Internal Heat

•**Dark belts** are regions we can see into the **atmosphere's lower levels**

•Dark belts appear brighter in infrared images, thus warmer in temperature, and deeper in altitude

•White zones and Great Red Spots are clouds at higher altitude, where temperature is lower.

Zone

Belt

Great Red Spot

(a) Visible-light image

Zones appear dark because their high-altitude clouds are cold.

Belts appear bright because we see to warmer depths of the atmosphere.

The Great Red Spot (a region of cool, high-altitude clouds) appears dark.

(b) Infrared image

Galileo Probe

- The mission continued for 58 minutes

- The probe reached 200 km below the Jupiter's upper cloud layer

- At this depth, temperature has increased to 152°C, and pressure to 24 ATM

- Constant wind at 650 km/s throughout the descent, indicating the energy source is internal heat instead solar heating.
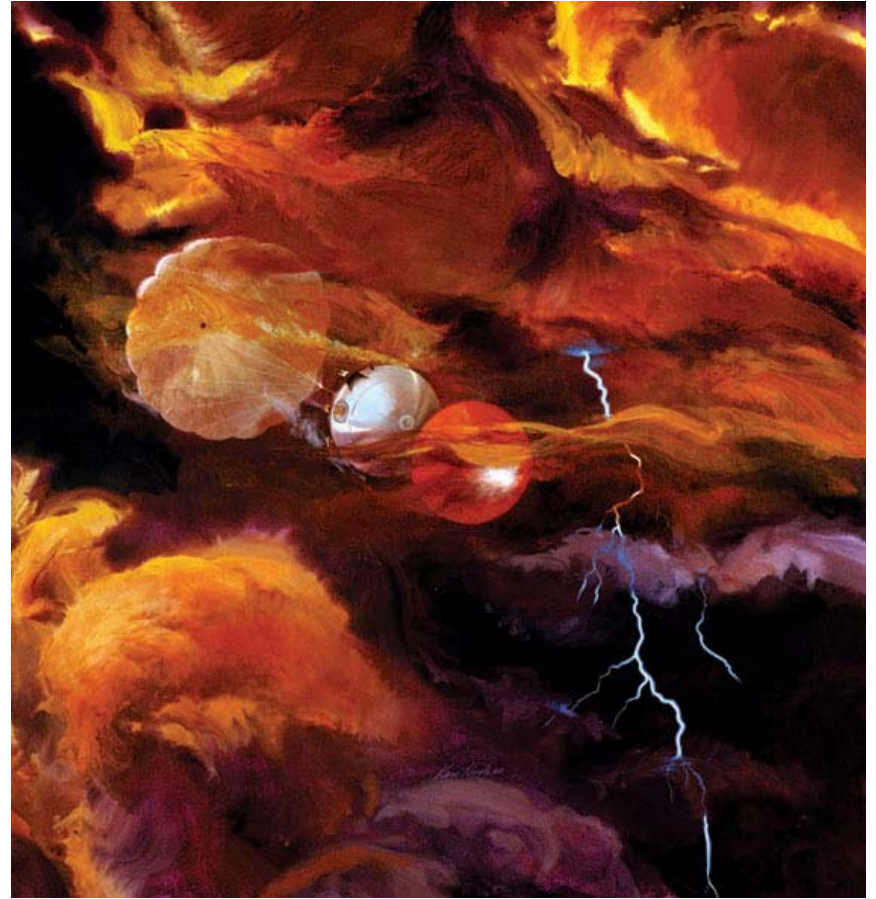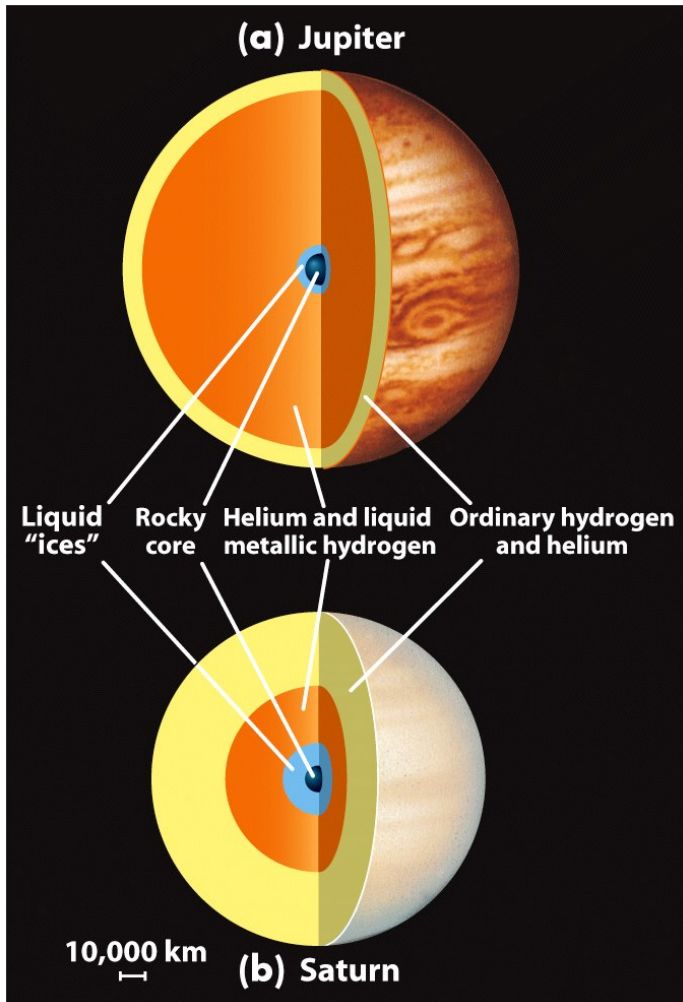

Galileo's Probe Enters Jupiter's Atmosphere
Dec. 7, 1995
(Artist's Impression)

Interior: Oblateness and cores

- Oblateness: sphere is flattened at the pole
- Jupiter: oblateness 6.5%
  - Diameter across the equator is 6.5% larger than its diameter from pole to pole.
- Saturn: oblateness 9.8%
- Earth: 0.3%
- The oblateness depends on (1) planet's rotation rate and (2) the mass distribution over its volume, which can be used to infer the properties of the core

Interior: Oblateness and cores

(a) Jupiter

Liquid "ices"   Rocky core   Helium and liquid metallic hydrogen   Ordinary hydrogen and helium

10,000 km

(b) Saturn

- Jupiter has a rocky inner core
- It is surrounded by an outer core of liquid "ices" (water, ammonia, methane)
- A thick mantle of helium and liquid metallic hydrogen
- An outermost gas layer composed primarily of ordinary hydrogen and helium
- Saturn's internal structure is similar to that of Jupiter, but its core makes up a larger fraction of its volume and its liquid metallic hydrogen mantle is shallower than that of Jupiter

Magnetic Field and Metallic Hydrogen

- Jupiter and Saturn have strong magnetic fields, which should be generated by motion of an electrically conducting fluids in the interior

- **Liquid metallic hydrogen**, instead of liquid iron (in the Earth), plays the role

  - hydrogen becomes a liquid metal when pressure exceeds 1.4 million atmosphere
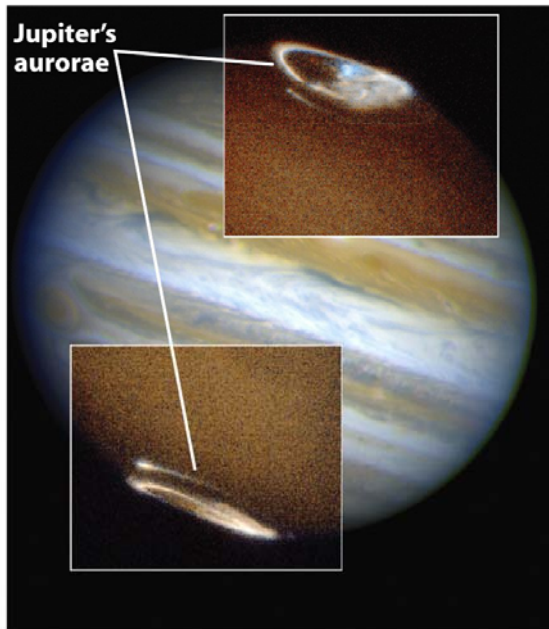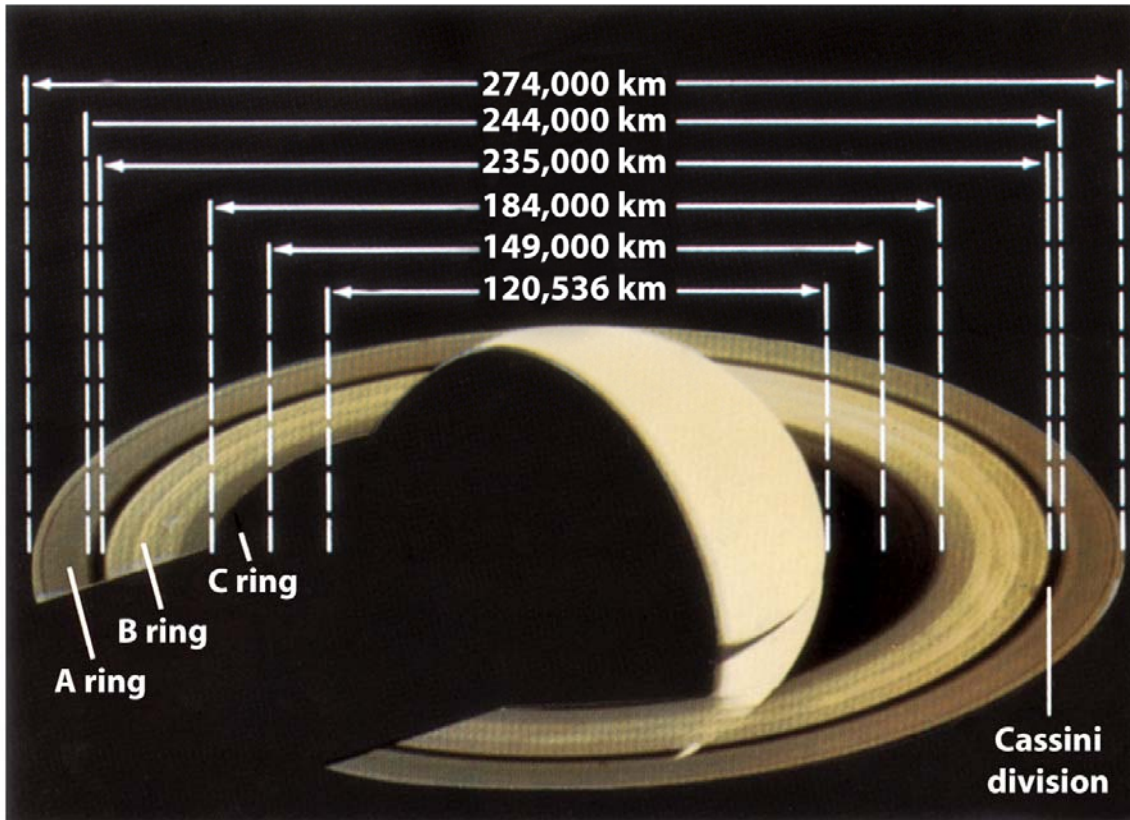

(a) Jupiter
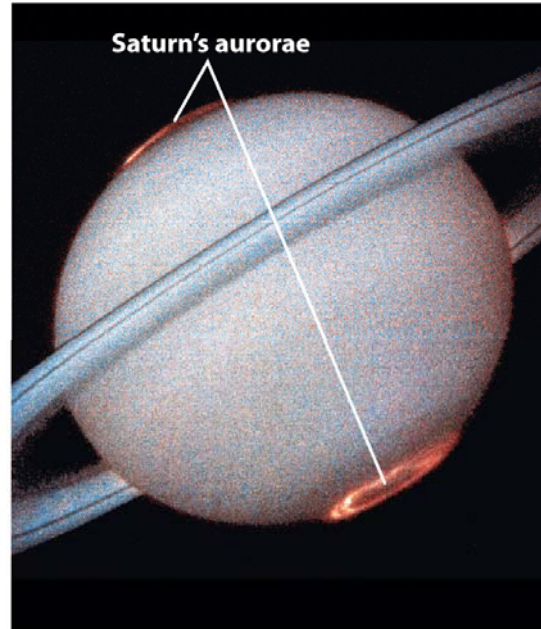
(b) Saturn

Aurorae on Jupiter and Saturn.

Caused by charged particles from the magnetosphere funneled onto the planet's magnetic poles.
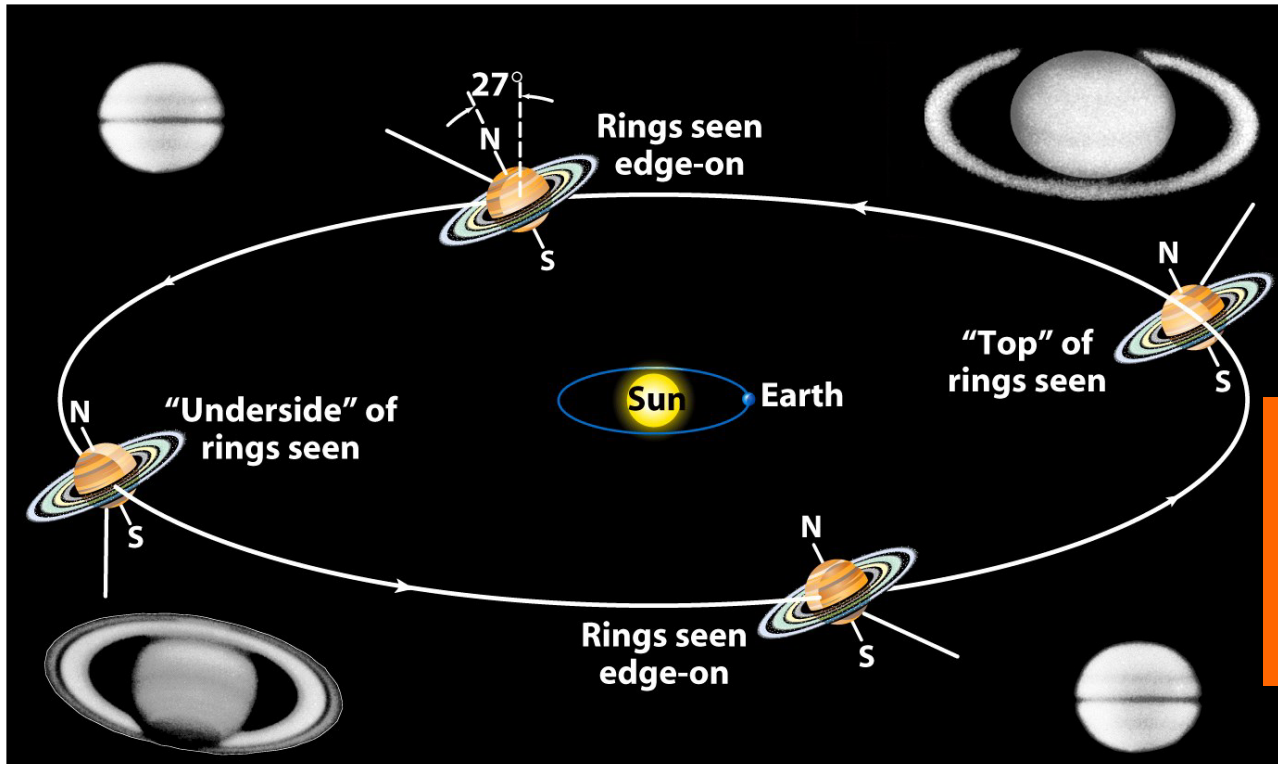
Saturn's Rings

- Saturn is circled by a system of thin, broad rings lying in the plane of the planet's equator

- Largest rings in the system: A ring, B ring, and C ring

- Cassini division is a gap of 4500 km separating A and B ring

Saturn's System of Rings
(Voyager 1 image)

Saturn's Rings

- The ring appears and disappears over years

- The system is tilted away from the plane of Saturn's orbit, which causes the rings to be seen at various angles by an Earth-based observer over the course of a Saturnian year

- The ring disappears when seen edge-on

Movie

1203001.mov

Changing Appearance of Saturn's Ring as Seen from Earth
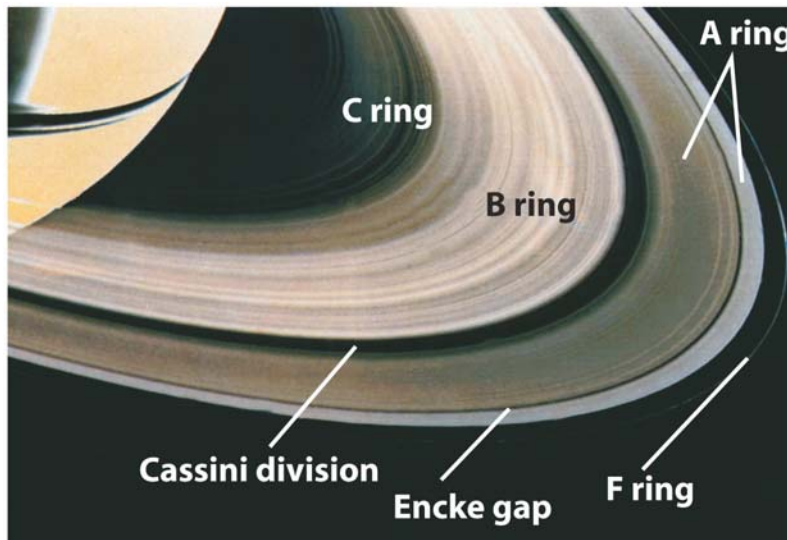
Saturn's Rings: Roche Limit

- Saturn's rings could not be solid sheet of matter.
  - Gravitational tidal force would tear it apart
  - Tidal force tends to keep particles separate.

- **Roche limit:** at this distance from a planet's center, the disruptive tidal force is just as strong as the gravitational force between particles
  - Inside Roche limit, the tidal force overwhelms the gravitational force. Particles can not accrete to form a larger body. Instead, they tend to spread out into a ring around the planet
  - For a planet, Roche limit is ~ 2.4 R (planet radius)

12cc1.swf   **Movie: Roche Limit**

Saturn's Ring: Composition

- Saturn's rings are composed of numerous particles
- The ring particles are ice fragment or ice-coated rocks
- These particles produced thousands of narrow, closely spaced ringlets
- Inner particles move faster than outer particles, in complete agreement with Kepler's third law
- The particles are mostly 10 cm (snowball size) in size; ranging from 1 cm (pebble size) to 5 m cross (boulder size)

A ring

C ring

B ring

Cassini division

Encke gap

F ring

Most of its rings exist inside the Roche limit of Saturn

Saturn's Rings

- The rings are seen as sunlight is reflected by the icy ring particles
- The ring pattern is affected by the gravitational effects of nearby moons.
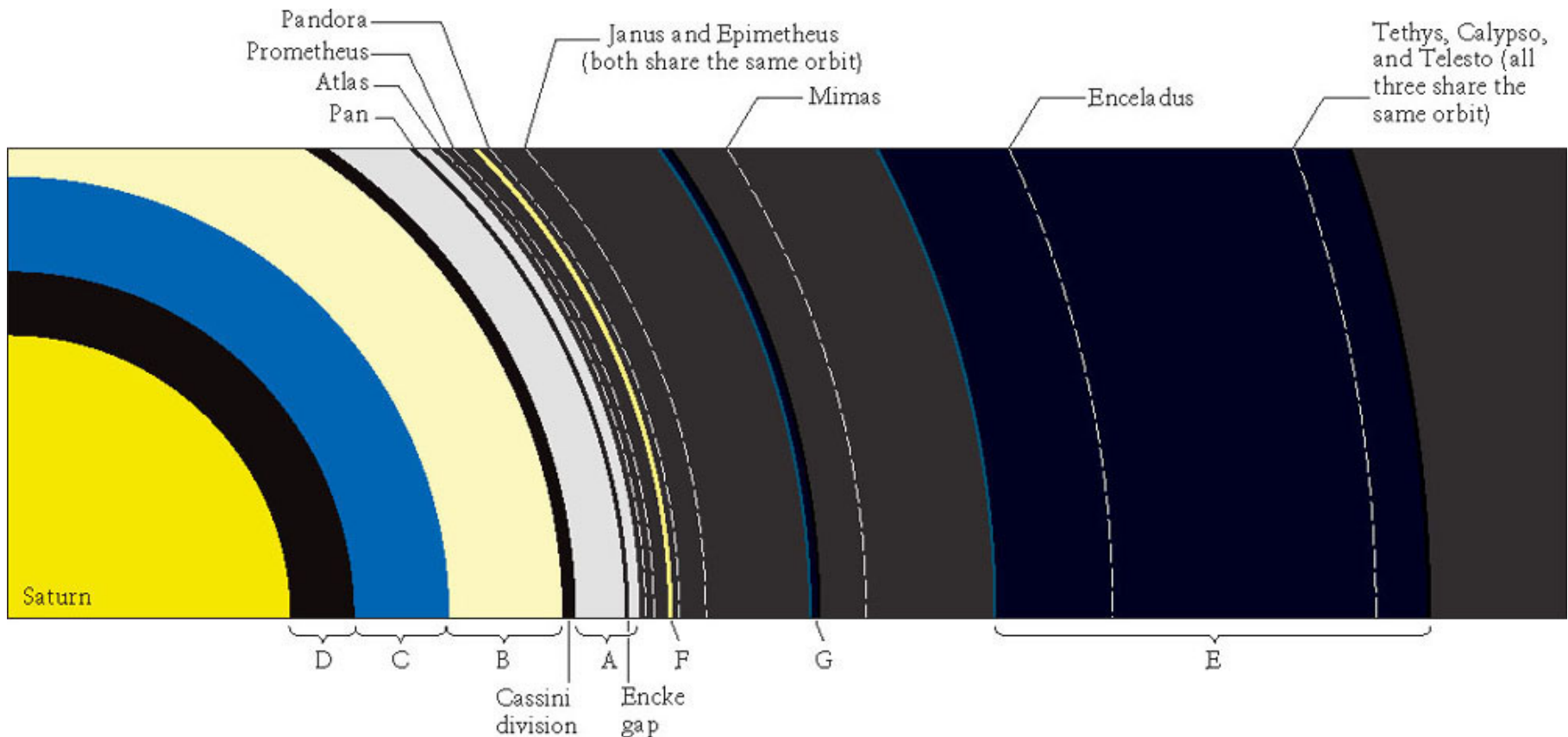
Final Notes on Chap. 12

- There are 11 sections in total.

- The following sections are not covered
  - 12-11 (satellites affect the structure of the ring)

Advanced Question
Chap. 12, Q36 in P326

Jupiter was at oppositon on June 5, 2007. On that date Jupiter appeared to be in constellation Ophiuchus. Approximately when will Jupiter next be at opposition in this same region of the celetial sphere? Explain your answer?