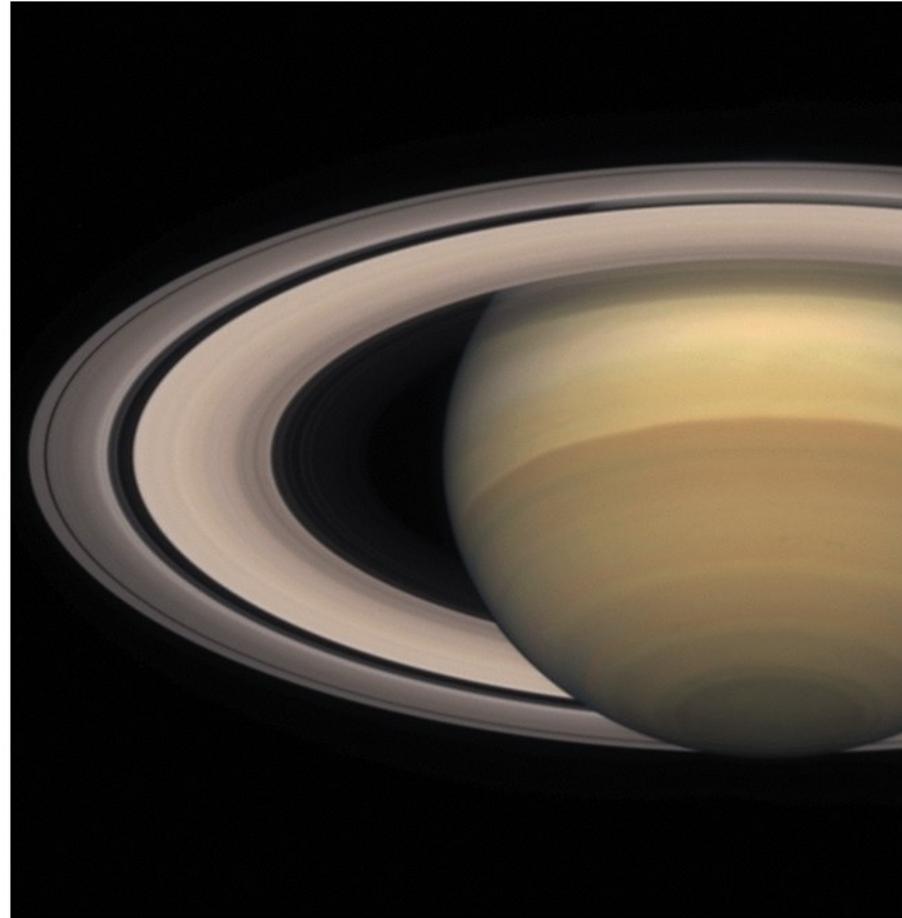
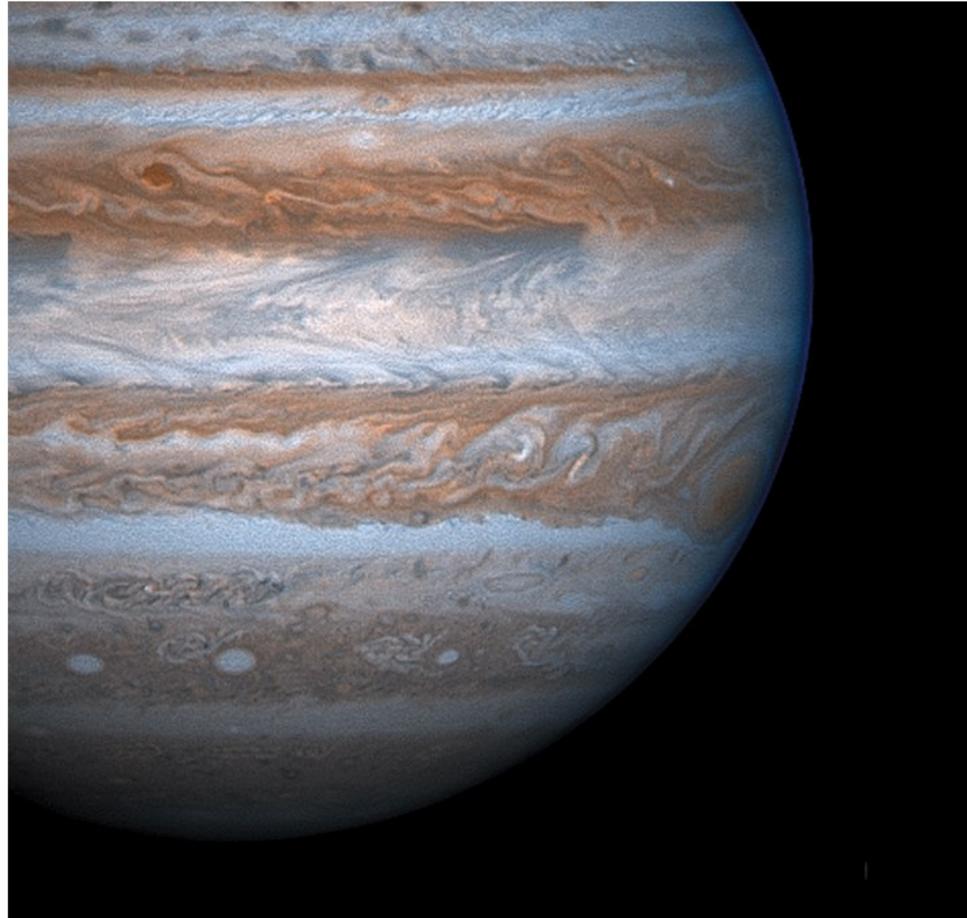


Jupiter and Saturn: Lords of the Planets



Chapter Fourteen

Introduction To Modern Astronomy I

Introducing Astronomy
(chap. 1-6)

Planets and Moons
(chap. 7-17)

Ch7: Comparative Planetology I
Ch8: Comparative Planetology II
Ch9: The Living Earth
Ch10: Our Barren Moon
Ch11: Sun-Scorched Mercury
Ch12: Cloud-covered Venus
Ch13: Red Planet Mars

Ch14: Jupiter and Saturn
Ch15: Satellites of Jup. & Saturn

Ch16: Outer World
Ch17: Vagabonds of Solar System

Guiding Questions

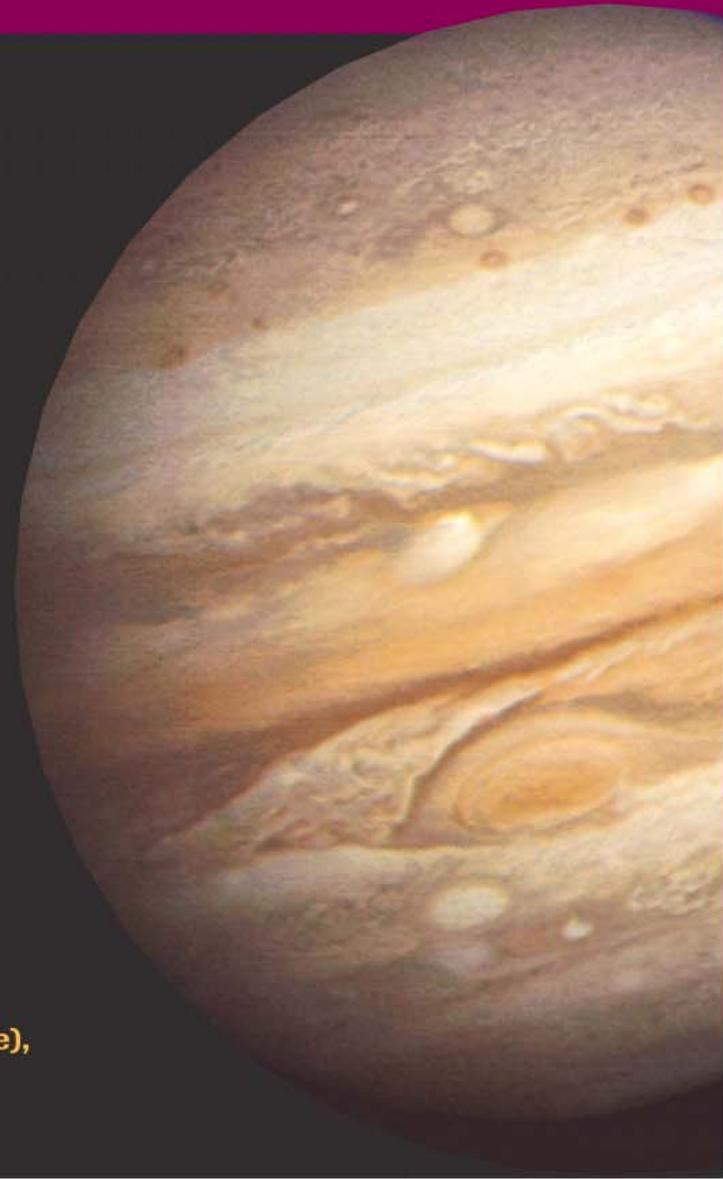
1. Why is the best month to see Jupiter different from one year to the next?
2. Why are there important differences between the atmospheres of Jupiter and Saturn?
3. What is going on in Jupiter's Great Red Spot?
4. What is the nature of the multicolored clouds of Jupiter and Saturn?
5. What does the chemical composition of Jupiter's atmosphere imply about the planet's origin?
6. How do astronomers know about the deep interiors of Jupiter and Saturn?
7. How do Jupiter and Saturn generate their intense magnetic fields?
8. Why would it be dangerous for humans to visit certain parts of the space around Jupiter?
9. How was it discovered that Saturn has rings?
10. Are Saturn's rings actually solid bands that encircle the planet?
11. How uniform and smooth are Saturn's rings?
12. How do Saturn's satellites affect the character of its rings?

Jupiter Data

table 14-1

Jupiter Data

Average distance from Sun:	5.203 AU = 7.783×10^8 km
Maximum distance from Sun:	5.455 AU = 8.160×10^8 km
Minimum distance from Sun:	4.950 AU = 7.406×10^8 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 ₂ O), and other gases



Saturn Data

table 14-2

Saturn Data

Average distance from Sun:	9.572 AU = 1.432×10^9 km
Maximum distance from Sun:	10.081 AU = 1.508×10^9 km
Minimum distance from Sun:	9.063 AU = 1.356×10^9 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:	5.685×10^{26} kg = 95.16 Earth masses
Average density:	687 kg/m³
Escape speed:	35.5 km/s
Surface gravity (Earth = 1):	0.92
Albedo:	0.46
Average temperature at cloudtops:	-180°C = -292°F = 93 K
Atmospheric composition (by number of molecules):	96.3% hydrogen (H₂), 3.3% helium (He), 0.4% methane (CH₄), ammonia (NH₃), water vapor (H₂O), and other gases



Orbital Motion

- Outer planets are best viewed at their opposition
- Orbital period of Jupiter is about 12 years
- Jupiter moves across the zodiac at the rate of approximately one constellation per year
- Oppositions of Jupiter occur at intervals of about 13 months
- Orbital period of Saturn is about 30 years
- Saturn's oppositions occur at intervals of about one year and two weeks

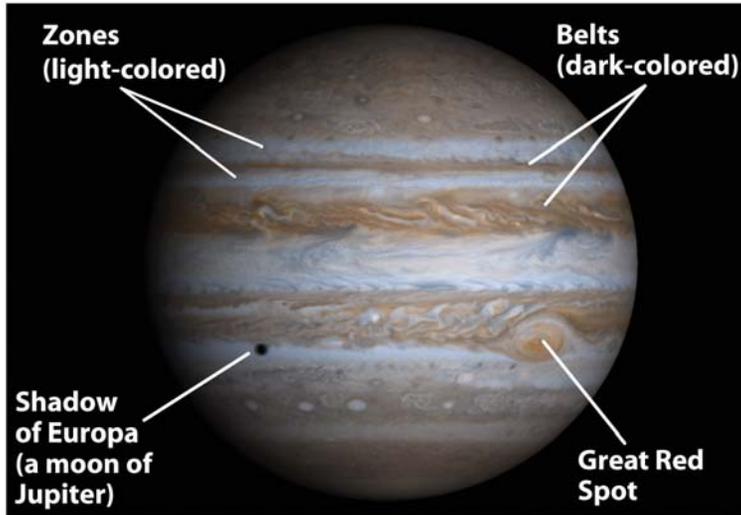
table 14-4 Oppositions of Saturn, 2004–2008

Date of opposition	Earth-Saturn distance		Angular diameter (arcsec)
	(AU)	(10 ⁶ km)	
2005 January 13	8.08	1208	20.6
2006 January 27	8.13	1216	20.5
2007 February 10	8.20	1227	20.3
2008 February 24	8.29	1240	20.1

table 14-3 Oppositions of Jupiter, 2004–2008

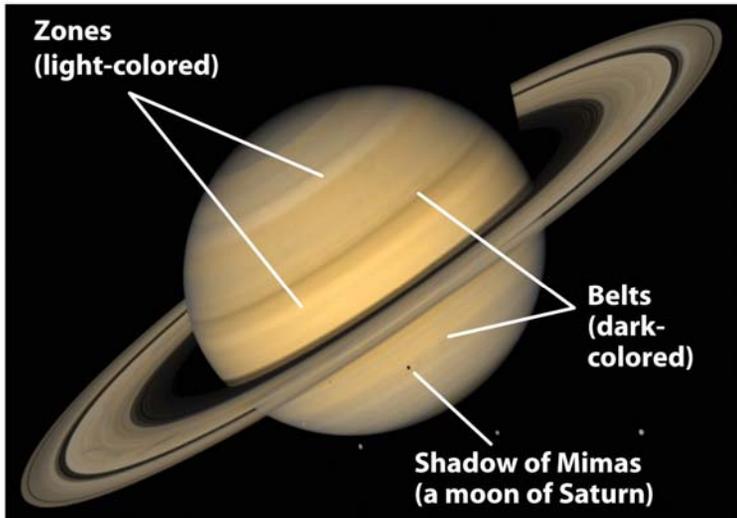
Date of opposition	Earth-Jupiter distance		Angular diameter (arcsec)
	(AU)	(10 ⁶ km)	
2004 March 4	4.43	662	44.5
2005 April 3	4.46	667	44.2
2006 May 4	4.41	660	44.6
2007 June 5	4.30	644	45.7
2008 July 9	4.16	622	47.3

Atmosphere: Cloud-Top



Jupiter

- 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

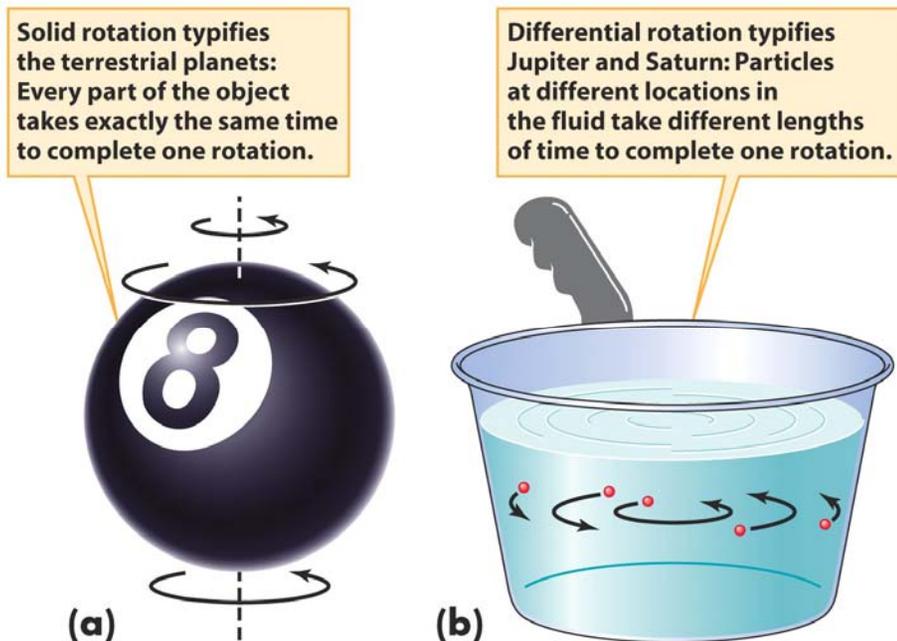


Saturn

- The **Great Red Spot** in Jupiter is a long-lived stable **storm system** that lasted for at least 300 hundred years.

Atmosphere: Differential Rotation

- **Differential rotation** in the outer atmosphere
 - 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



Atmosphere: Composition

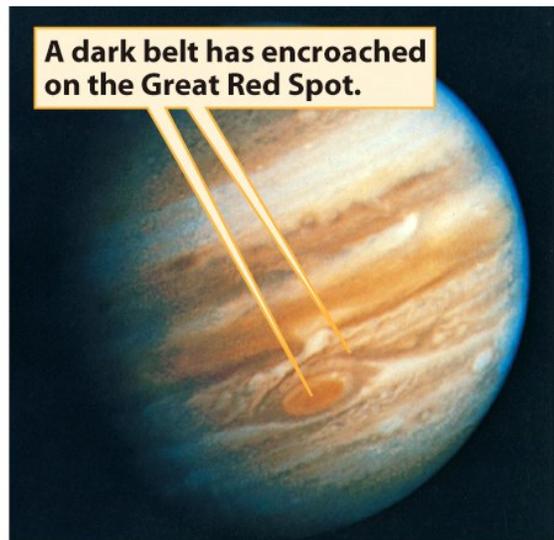
- Jupiter's atmosphere, by the number of molecules, is **86.2% hydrogen (H₂)**, **13.6% helium (He)**, 0.2% methane (CH₄), ammonia (NH₃) and water vapor (H₂O)
- Saturn's atmosphere, by the number of molecules, is **96.3% hydrogen (H₂)**, **3.3% helium (He)**, 0.4% methane (CH₄), ammonia (NH₃) and water vapor (H₂O)
- 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 form rain droplets.

Atmosphere: Activity

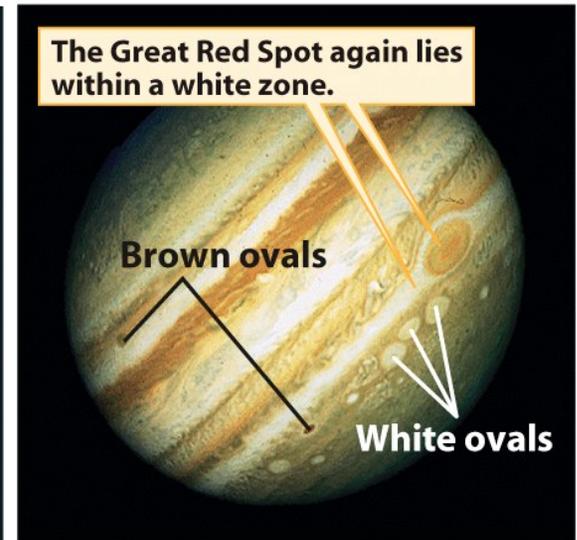
- There are stable, large scale weather patterns in both Jupiter and Saturn's atmospheres
- There are dynamic changes on small scales
- White zones and dark belts change positions, e.g., relative to the position of Great Red Spot
- Great Red Spot, Brown ovals and white ovals are storm systems with circular wind.



(a) *Pioneer 11*, December 1974

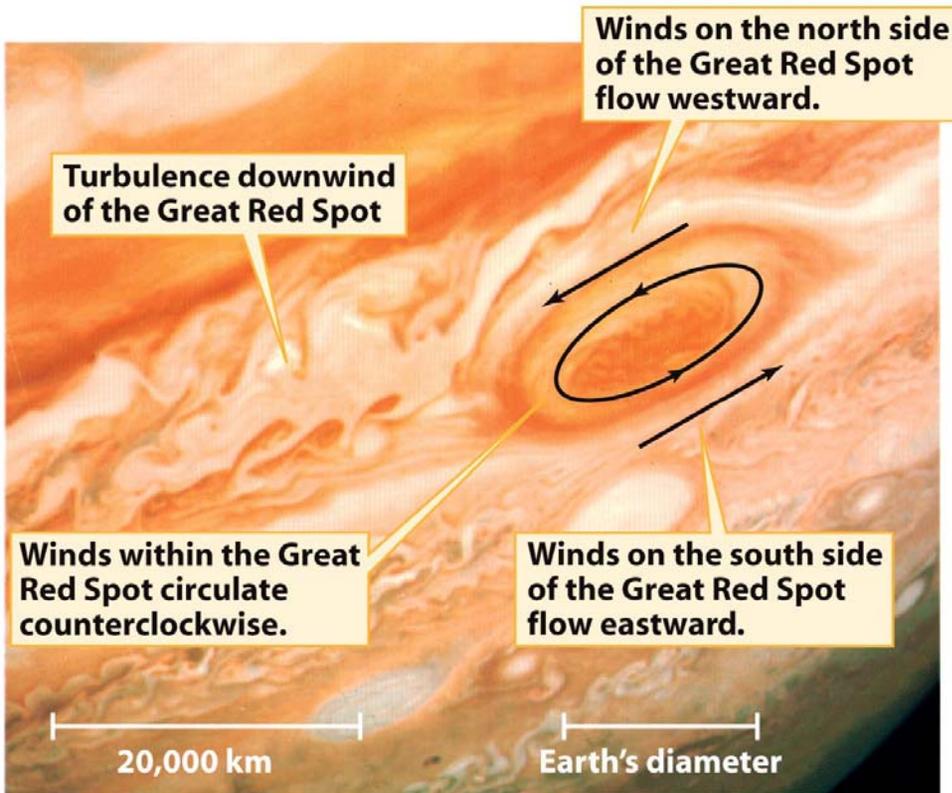


(b) *Voyager 2*, July 1979



(c) *HST*, February 1995

Atmosphere: Great Red Spot



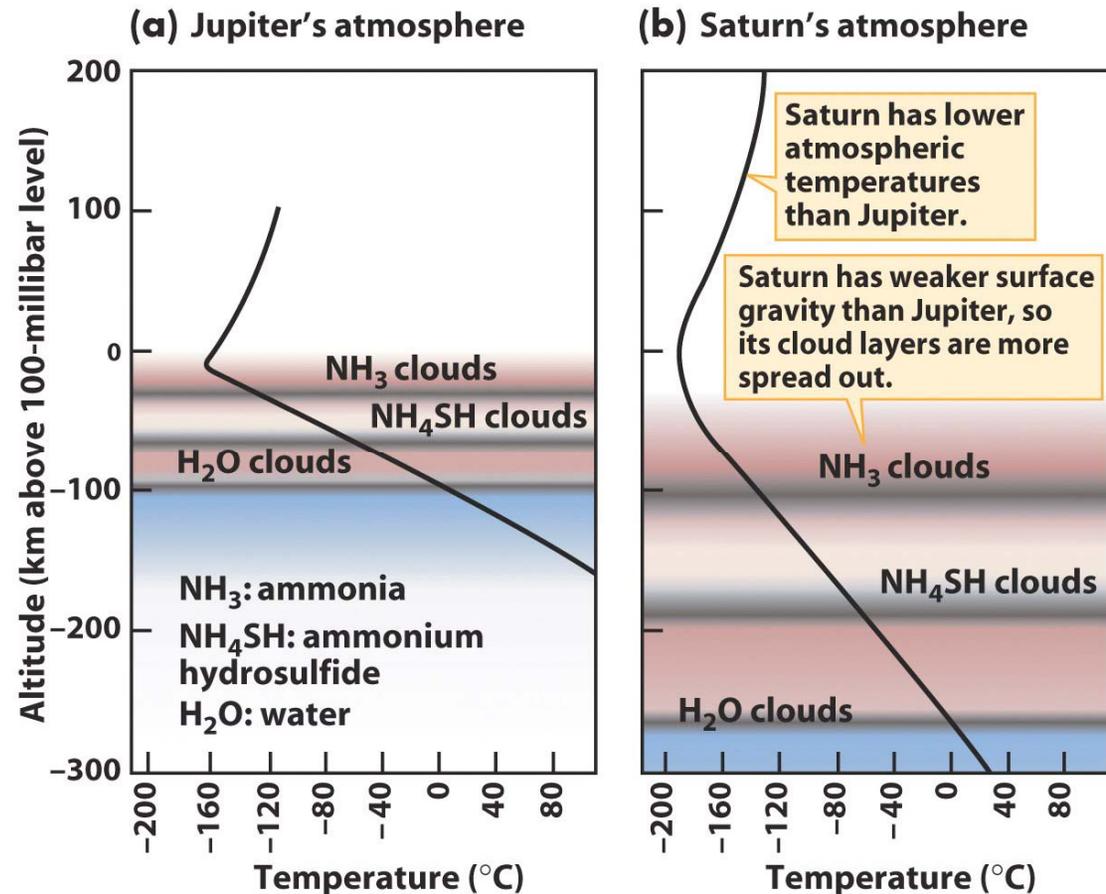
- The great red spot was first seen in 1664, but may be much older
- It is larger than the size of the Earth
- The spot rotates counterclockwise with a period of about 6 days
 - Winds on the north flow westward
 - Winds on the south flow eastward
- The spot is made of clouds at relatively high altitude

Atmosphere: Energy Source

- Weather patterns on Earth are powered by sunlight
- Weather patterns on Jupiter and Saturn **are powered by sunlight as well as internal heat**
- Observations show that Jupiter emits twice as much energy as it absorbs 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 heat flow from below, the temperature of the atmosphere increases with increasing depth

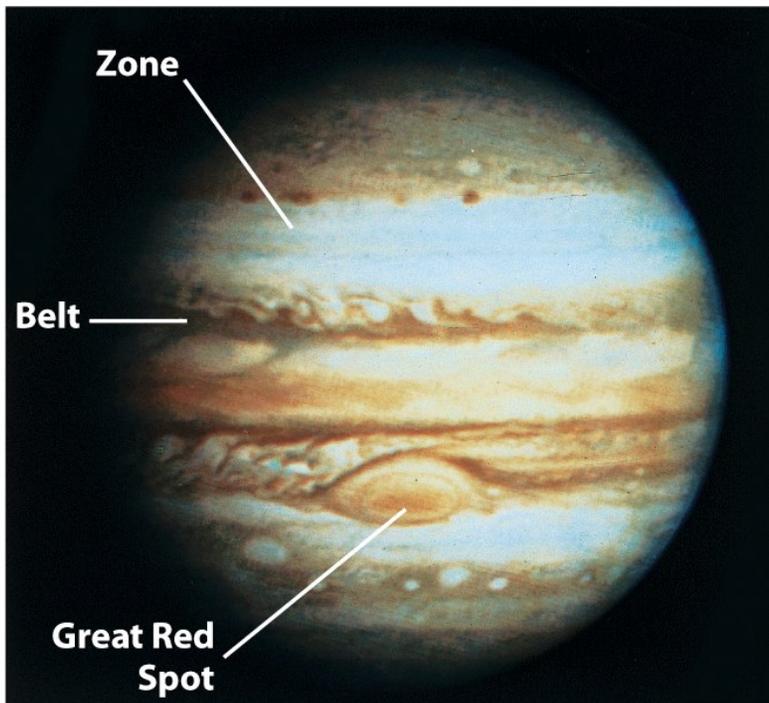
Atmosphere: Energy Source

- The temperature of the atmospheres increases with increasing depth
- The atmosphere may have three layers of clouds
- **Jupiter and Saturn have no solid surface**

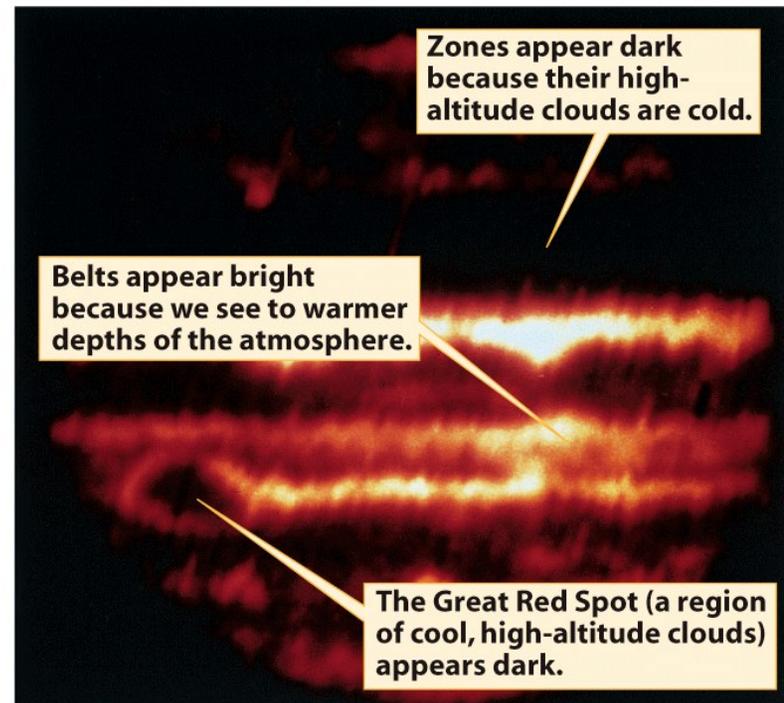


Atmosphere: Energy Source

- **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



(a) Visible-light image

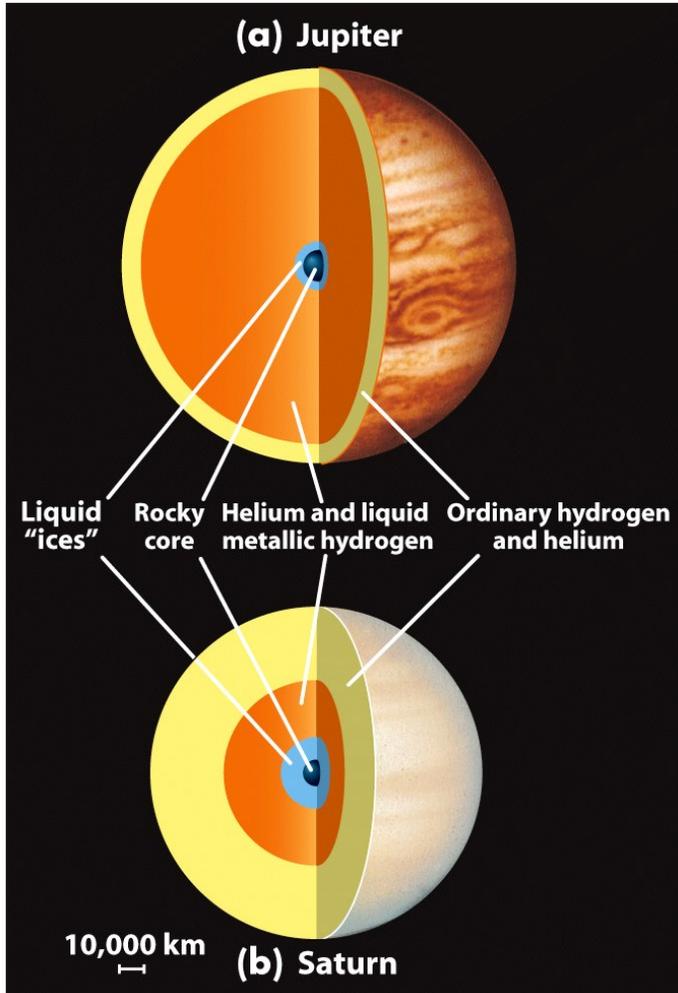


(b) Infrared image

Interior: Oblateness and cores

- Jupiter: oblateness 6.5%
- Saturn: oblateness 9.8%
- Earth: 0.3%
- The oblateness depends on planet's rotation and the mass distribution over its volume
- Scientists used the oblateness, as well as other data, to calculate the internal structure of Jupiter and Saturn
- The core of Jupiter and Saturn is made of rocky material.
- The present core is presumably the “rocky seed”, onto which hydrogen and helium gases were accreted when Jupiter and Saturn were initially formed.

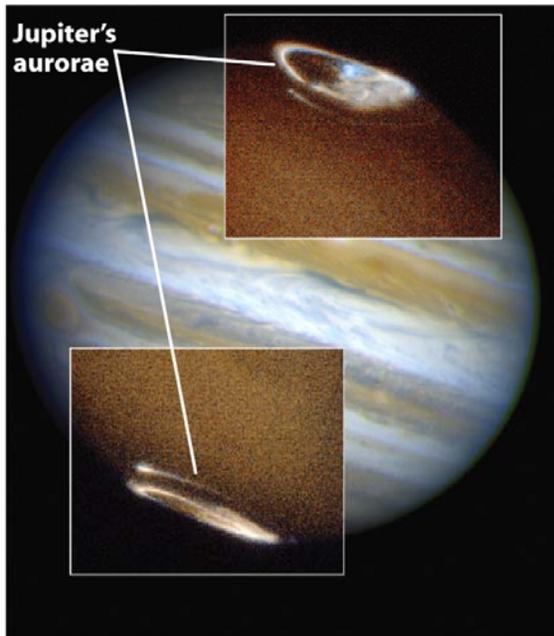
Interior: Oblateness and cores



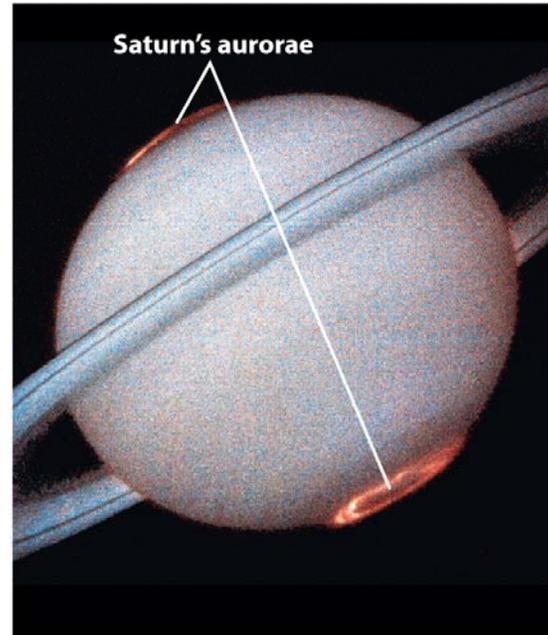
- Jupiter has a rocky core several times more massive than the Earth
- The core is surrounded by a layer of liquid "ices" (water, ammonia, methane)
- On top of this is a layer of helium and liquid metallic hydrogen and an outermost layer composed primarily of ordinary hydrogen and helium
- Saturn's internal 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

- Jupiter and Saturn have strong magnetic fields
- Liquid metallic hydrogen: hydrogen becomes a liquid metal when pressure exceeds about 1.4 million atmosphere
- The magnetic field is caused by the rotational motion of the liquid metallic hydrogen



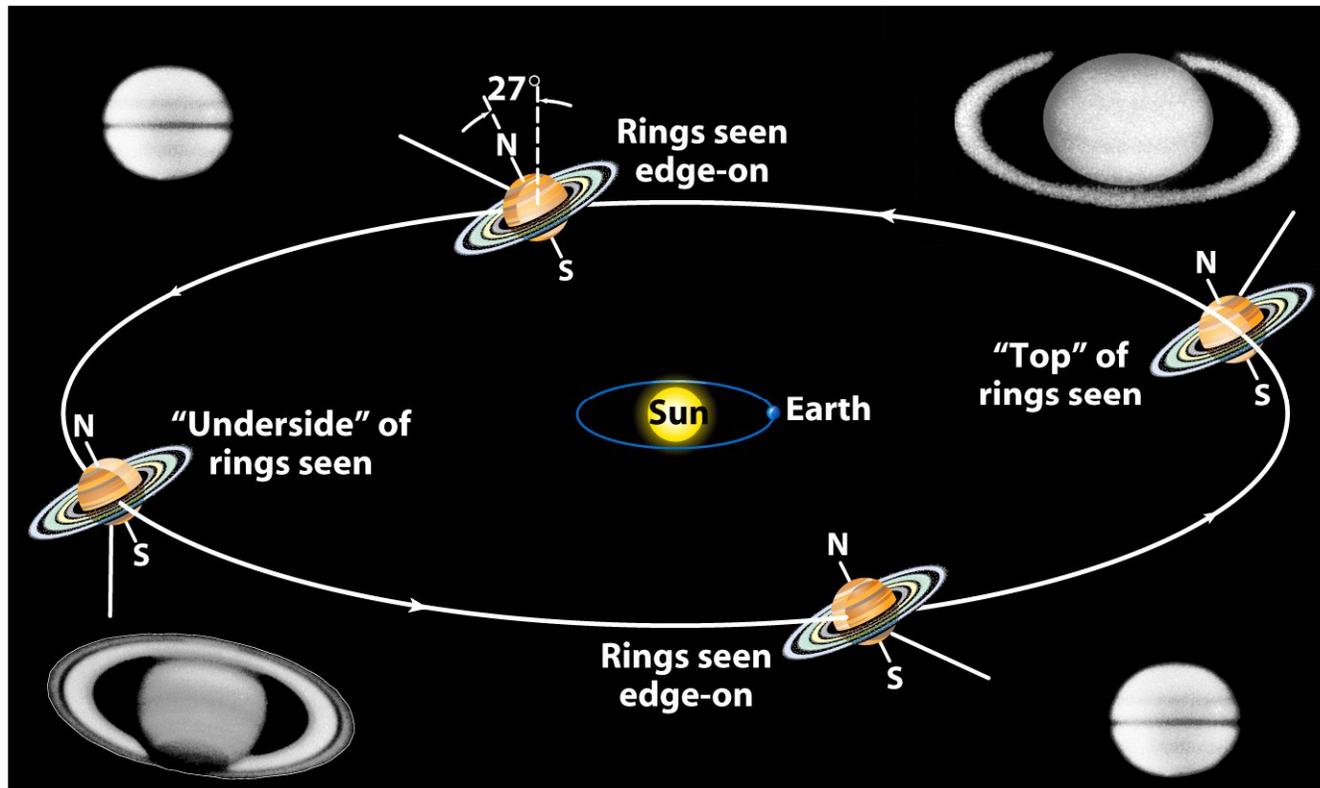
(a) Jupiter



(b) Saturn

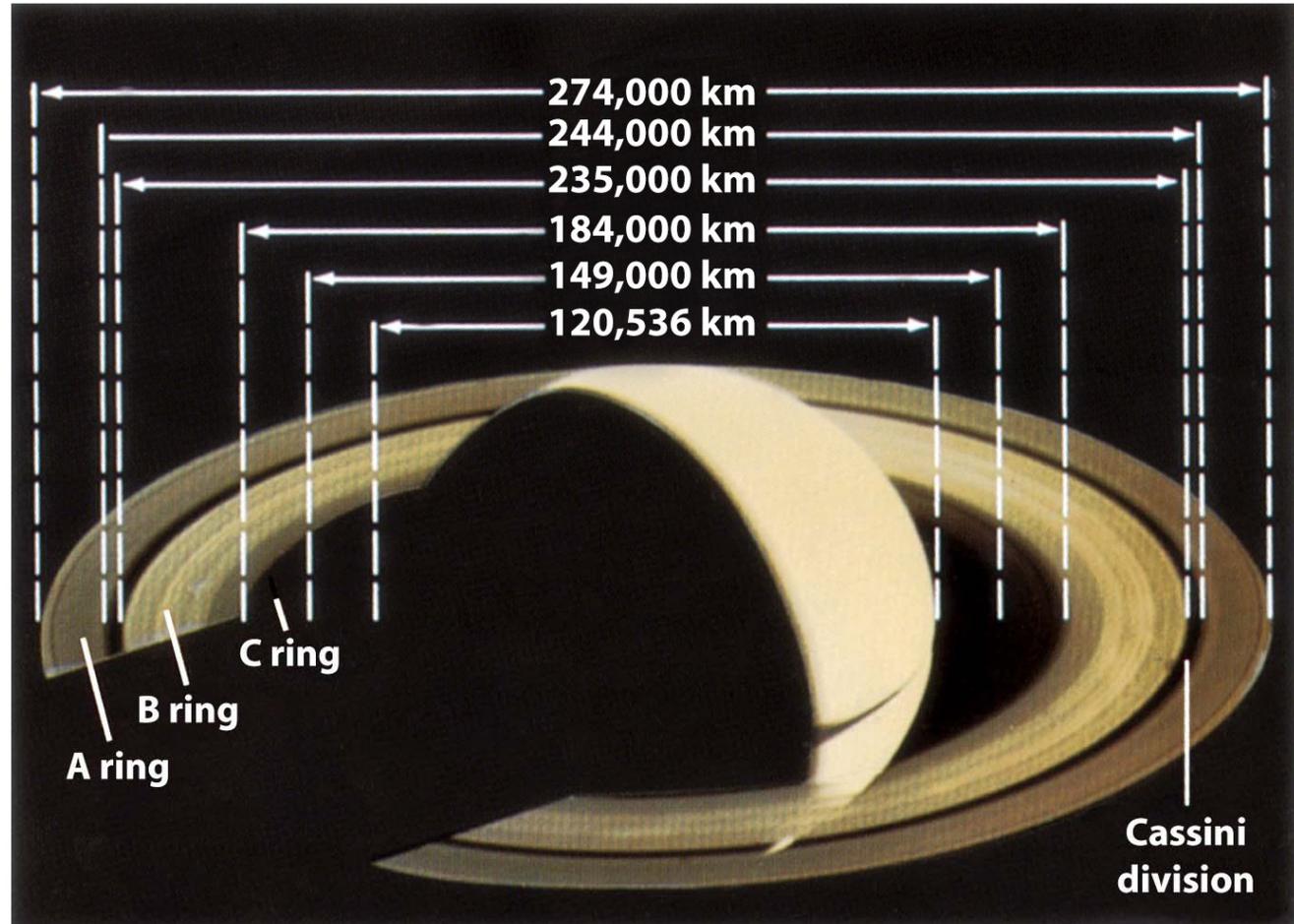
Saturn's Ring: Appearance

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



Saturn's Ring: Ring System

- Saturn's ring is a system of rings
 - A ring, B ring, and C ring
 - Cassini division is a gap of 4500 km separating A ring and B ring

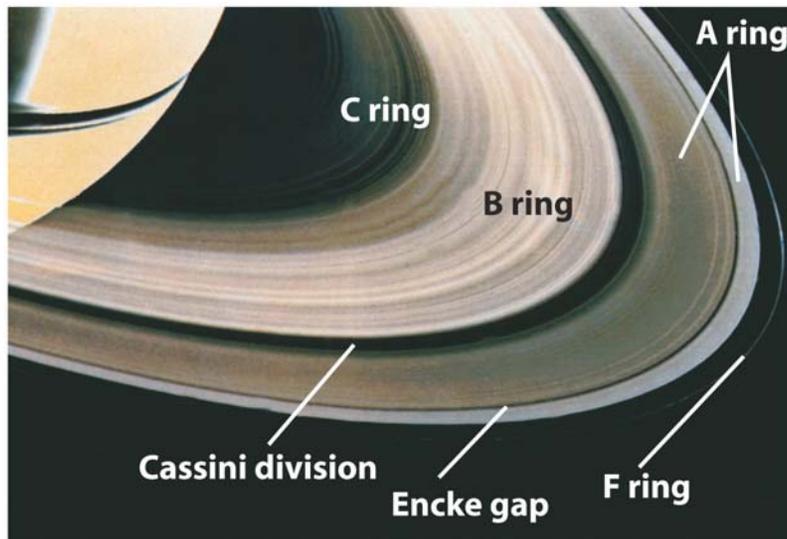


Saturn's Ring: Roche Limit

- Saturn's rings could not be solid sheet of matter.
 - Gravitational tidal force would tear it apart
- **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

Saturn's Ring: Composition

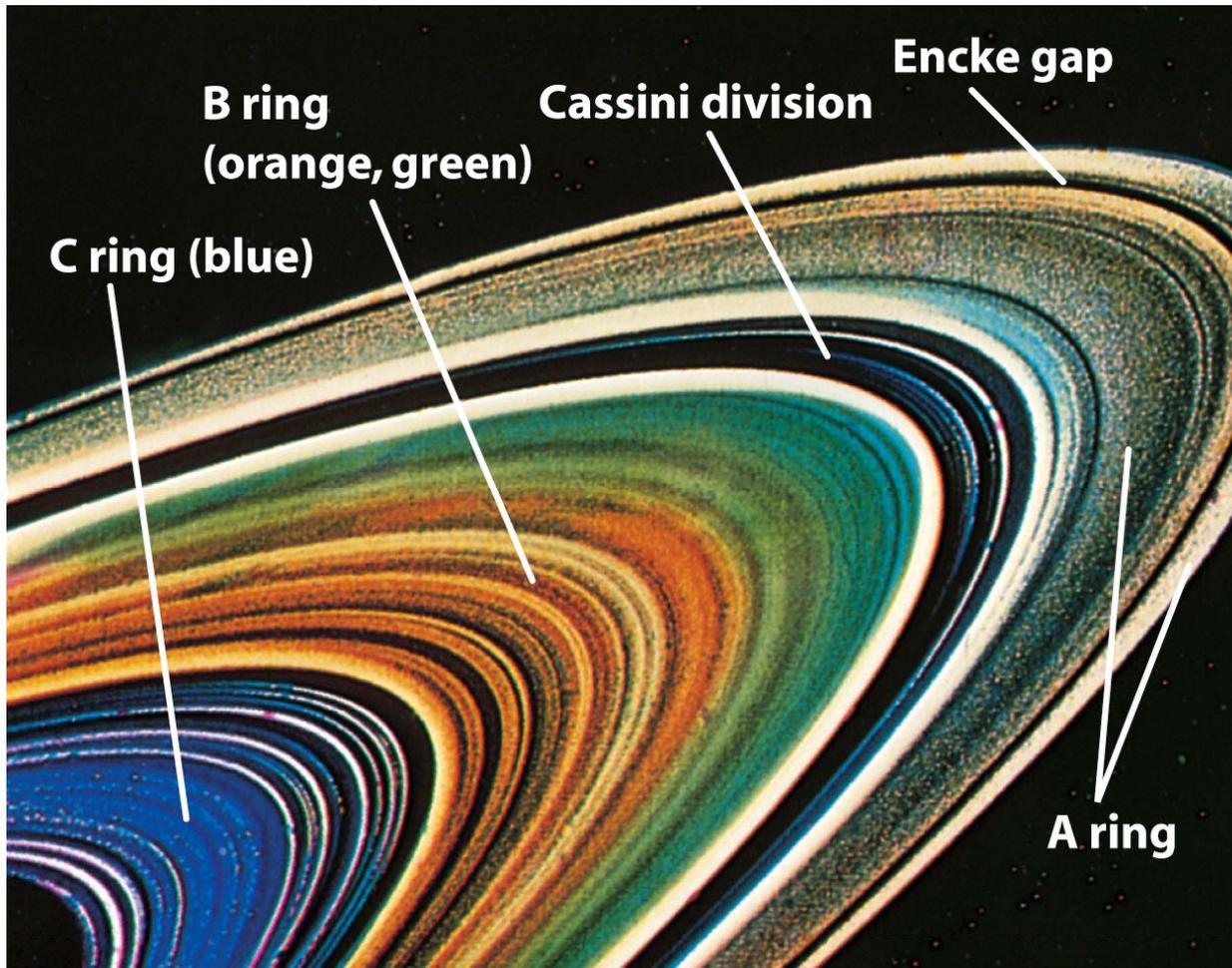
- The principal rings of Saturn are composed of numerous particles, or “moonlets”
- Inner particles move faster than outer particles, in complete agreement with Kepler’s third law
- The particles are mostly 10 cm (snowball size), ranging from 1 cm (pebble size) to 5 m cross (boulder size)
- The ring particles are ice fragment or ice-coated rocks



**Most of its rings exist
inside the Roche
limit of Saturn**

Saturn's Rings: structure

- Each of Saturn's major rings is composed of thousands of narrow, closely-spaced ringlets



Final Notes on Chap. 14

- There are 12 sections in total.
- The following sections are not covered
 - 14-5 (on Galileo Probe and trace gases)
 - 14-8 (on magnetosphere)
 - 14-12 (on satellites' influence on rings)