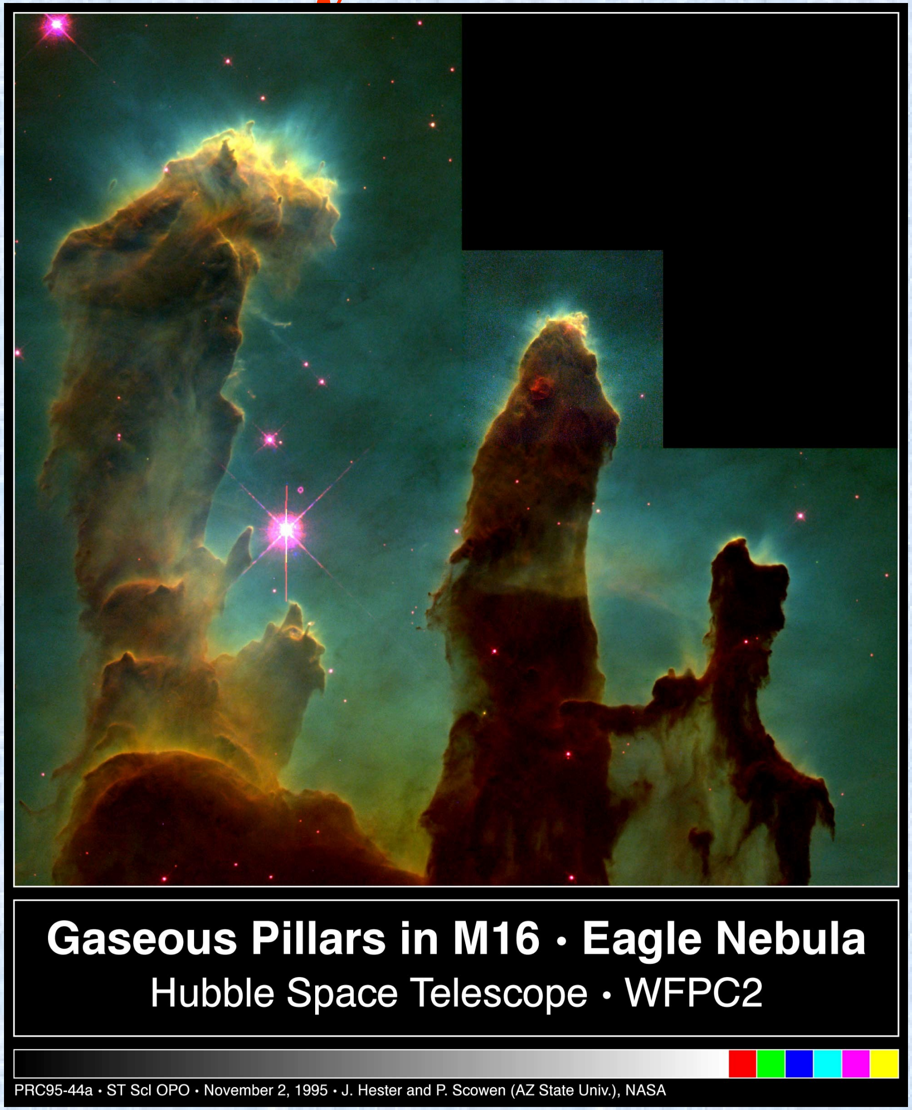
# Astronomy 1 – Winter 2011




Lecture 10; January 28 2011

# Previously on Astro-1

- **A most valuable tool: the Doppler effect**
  - The discovery of extrasolar planets
- **Telescopes: astronomers' tools of the trade**
  - Basic optics
  - Refractors
  - Reflectors
  - Light gathering power and resolution
- **Telescopes and the atmosphere**
  - Space Telescopes

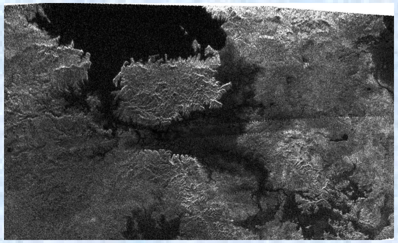
# Today on Astro1

- A tour of the solar system
- Terrestrial Planets
- Jovian Planets
- Satellites/Moons
- Trans-Neptunian objects
- Asteroids and comets

# The Solar System is a diverse place…

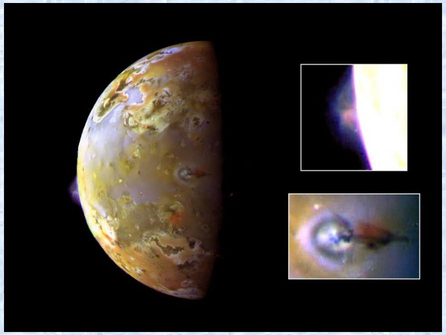
Barren, cratered landscapes

Sulfuric acid clouds

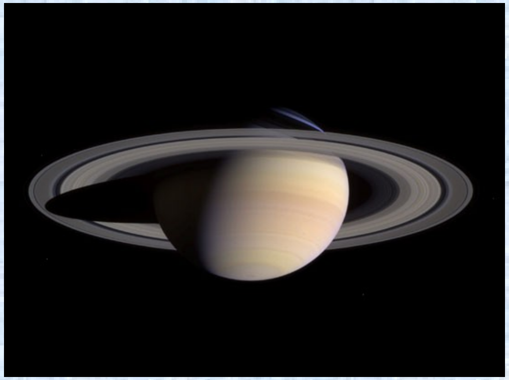


Hydrocarbon lakes

Exotic volcanoes



Desolate deserts

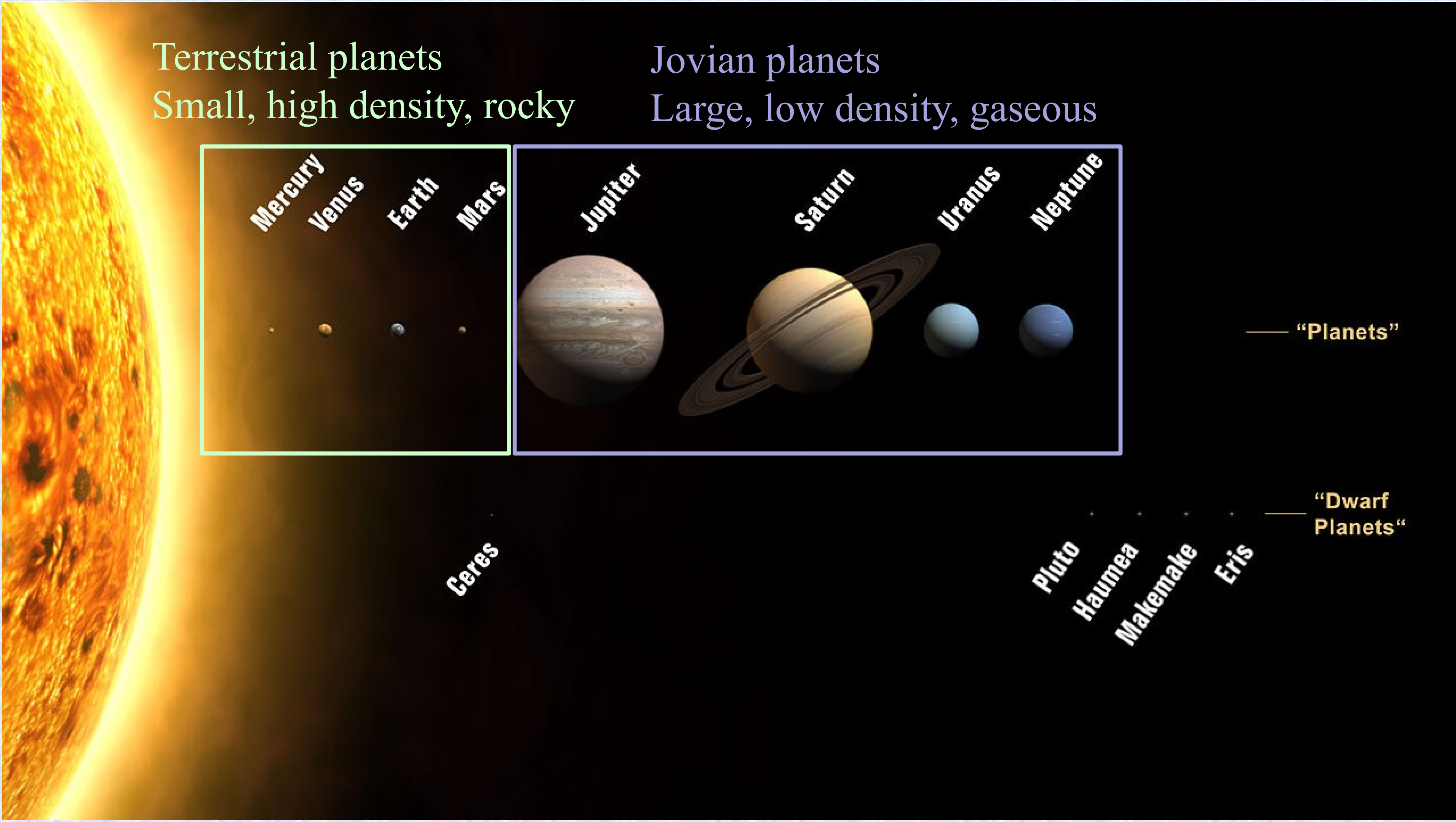


Gas giants

Frozen ice-balls


Why does it look the way it does?

# Planets in our Solar System



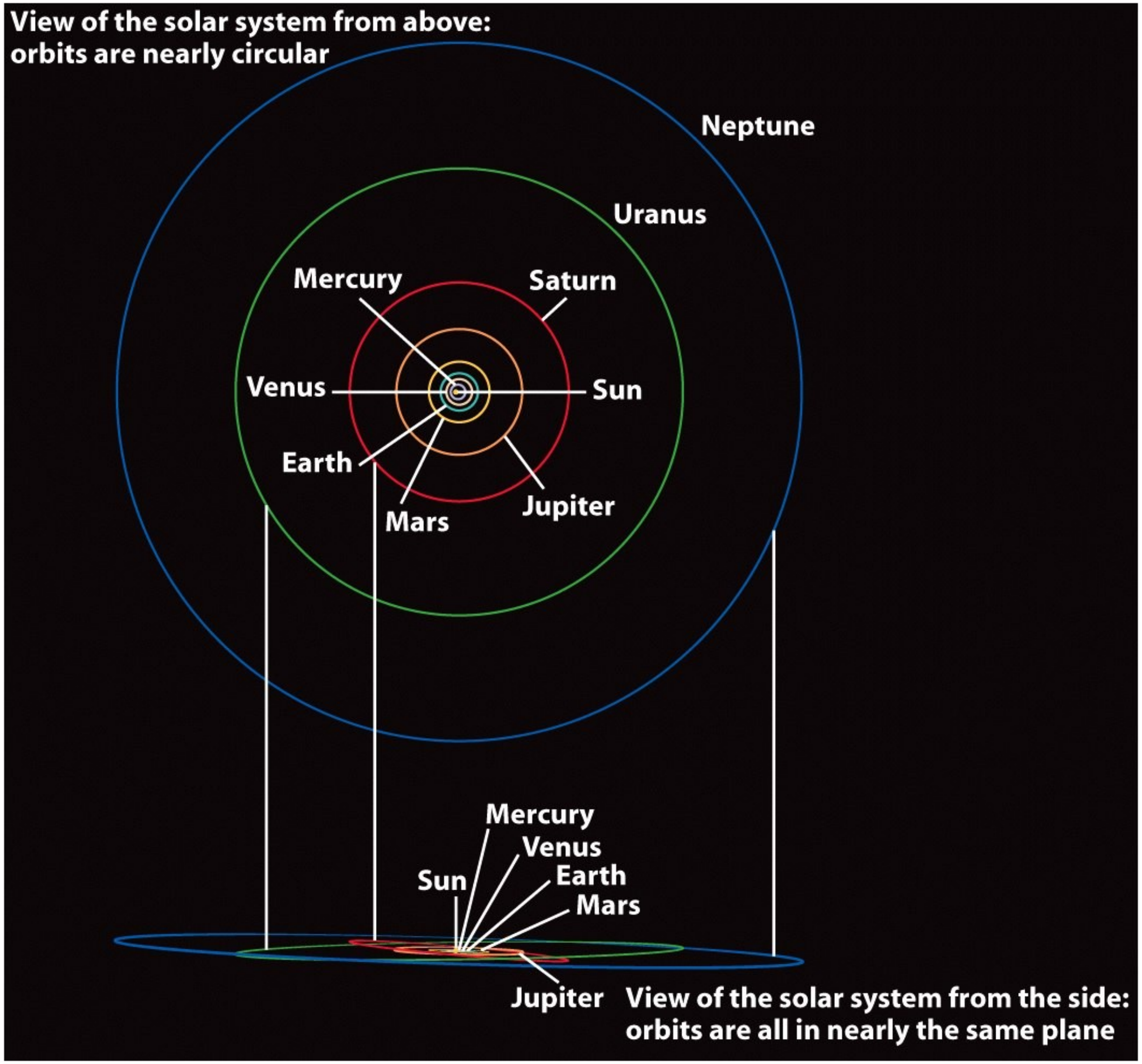



Figure 7-1
*Universe, Eighth Edition*


- Orbits not random
- In nearly same plane
- Orbit in same direction (nearly all also rotate in that direction)

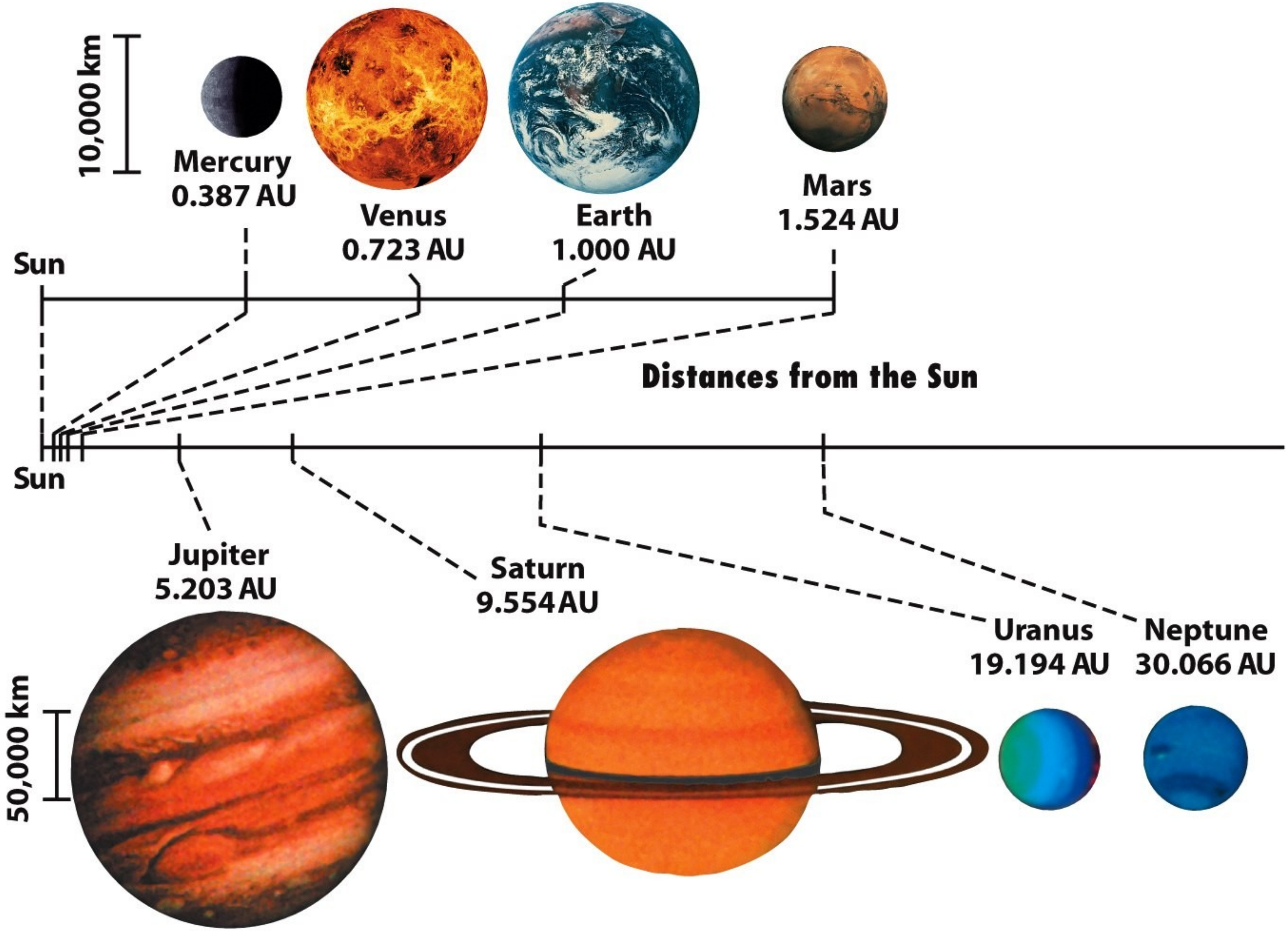



Table 7-1 illustration
*Universe, Eighth Edition*

# Four inner (Terrestrial) Planets

Small, low mass, high density, rocky

**Table 7-1 Characteristics of the Planets**

| | The Inner (Terrestrial) Planets | | | |
|---|---|---|---|---|
| | **Mercury** | **Venus** | **Earth** | **Mars** |
| Average distance from Sun ($10^6$ km) | 57.9 | 108.2 | 149.6 | 227.9 |
| Average distance from Sun (AU) | 0.387 | 0.723 | 1.000 | 1.524 |
| Orbital period (years) | 0.241 | 0.615 | 1.000 | 1.88 |
| Orbital eccentricity | 0.206 | 0.007 | 0.017 | 0.093 |
| Inclination of orbit to the ecliptic | 7.00° | 3.39° | 0.00° | 1.85° |
| Equatorial diameter (km) | 4880 | 12,104 | 12,756 | 6794 |
| Equatorial diameter (Earth = 1) | 0.383 | 0.949 | 1.000 | 0.533 |
| Mass (kg) | $3.302 \times 10^{23}$ | $4.868 \times 10^{24}$ | $5.974 \times 10^{24}$ | $6.418 \times 10^{23}$ |
| Mass (Earth = 1) | 0.0553 | 0.8150 | 1.0000 | 0.1074 |
| Average density ($kg/m^3$) | 5430 | 5243 | 5515 | 3934 |

Table 7-1 part 1
*Universe, Eighth Edition*

# Four outer (Jovian) Planets

Large, high mass, low density, gaseous
Visible "surface" = cloud formations

**Table 7-1 Characteristics of the Planets**

| | The Outer (Jovian) Planets | | | |
|---|---|---|---|---|
| | Jupiter | Saturn | Uranus | Neptune |
| Average distance from Sun ($10^6$ km) | 778.3 | 1429 | 2871 | 4498 |
| Average distance from Sun (AU) | 5.203 | 9.554 | 19.194 | 30.066 |
| Orbital period (years) | 11.86 | 29.46 | 84.10 | 164.86 |
| Orbital eccentricity | 0.048 | 0.053 | 0.043 | 0.010 |
| Inclination of orbit to the ecliptic | 1.30° | 2.48° | 0.77° | 1.77° |
| Equatorial diameter (km) | 142,984 | 120,536 | 51,118 | 49,528 |
| Equatorial diameter (Earth = 1) | 11.209 | 9.449 | 4.007 | 3.883 |
| Mass (kg) | $1.899 \times 10^{27}$ | $5.685 \times 10^{26}$ | $8.682 \times 10^{25}$ | $1.024 \times 10^{26}$ |
| Mass (Earth = 1) | 317.8 | 95.16 | 14.53 | 17.15 |
| Average density ($kg/m^3$) | 1326 | 687 | 1318 | 1638 |

Table 7-1 part 2
*Universe, Eighth Edition*

# How do we know?

Distance: Kepler's Third Law ($P^2/a^3$=constant)

Size: observed angular size and distance

Mass: if satellite – Kepler's Third Law
flyby by spacecraft, gravitational pull, deflects path

Density: mass/volume

# Question 10.1 (iclickers!)

- Suppose that in the near future a series of extrasolar planets are discovered with the following characteristics: spherical solid surfaces; mean densities about four times that of water; radii about 4000 km; low density atmospheres. How would these planets be classified in terms of our solar system
  - A) Jovian Planets
  - B) Cometary nuclei
  - C) Asteroids
  - D) Terrestrial Planets

# Satellites

**Table 7-2 The Seven Giant Satellites**

| | Moon | Io | Europa | Ganymede | Callisto | Titan | Triton |
|---|---|---|---|---|---|---|---|
| Parent planet | Earth | Jupiter | Jupiter | Jupiter | Jupiter | Saturn | Neptune |
| Diameter (km) | 3476 | 3642 | 3130 | 5268 | 4806 | 5150 | 2706 |
| Mass (kg) | $7.35 \times 10^{22}$ | $8.93 \times 10^{22}$ | $4.80 \times 10^{22}$ | $1.48 \times 10^{23}$ | $1.08 \times 10^{23}$ | $1.34 \times 10^{23}$ | $2.15 \times 10^{22}$ |
| Average density ($kg/m^3$) | 3340 | 3530 | 2970 | 1940 | 1850 | 1880 | 2050 |
| Substantial atmosphere? | No | No | No | No | No | Yes | No |


R I V U X G

(NASA/JPL/Space Science Institute)

Table 7-2
*Universe, Eighth Edition*


- Seven large satellites almost as big as terrestrial planets
- Comparable in size to Mercury
- Remaining satellites (>140 known today!) much smaller

**Saturn's satellite Titan**

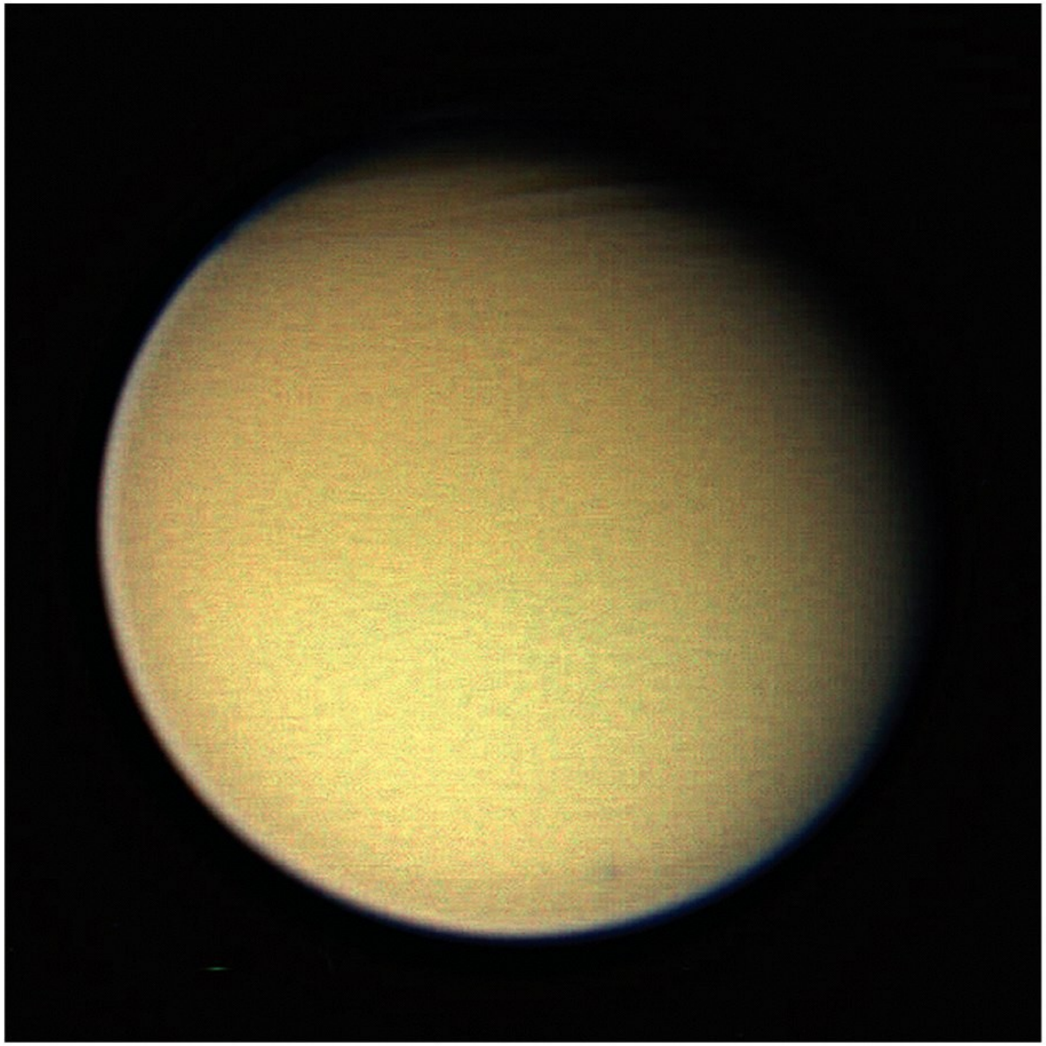
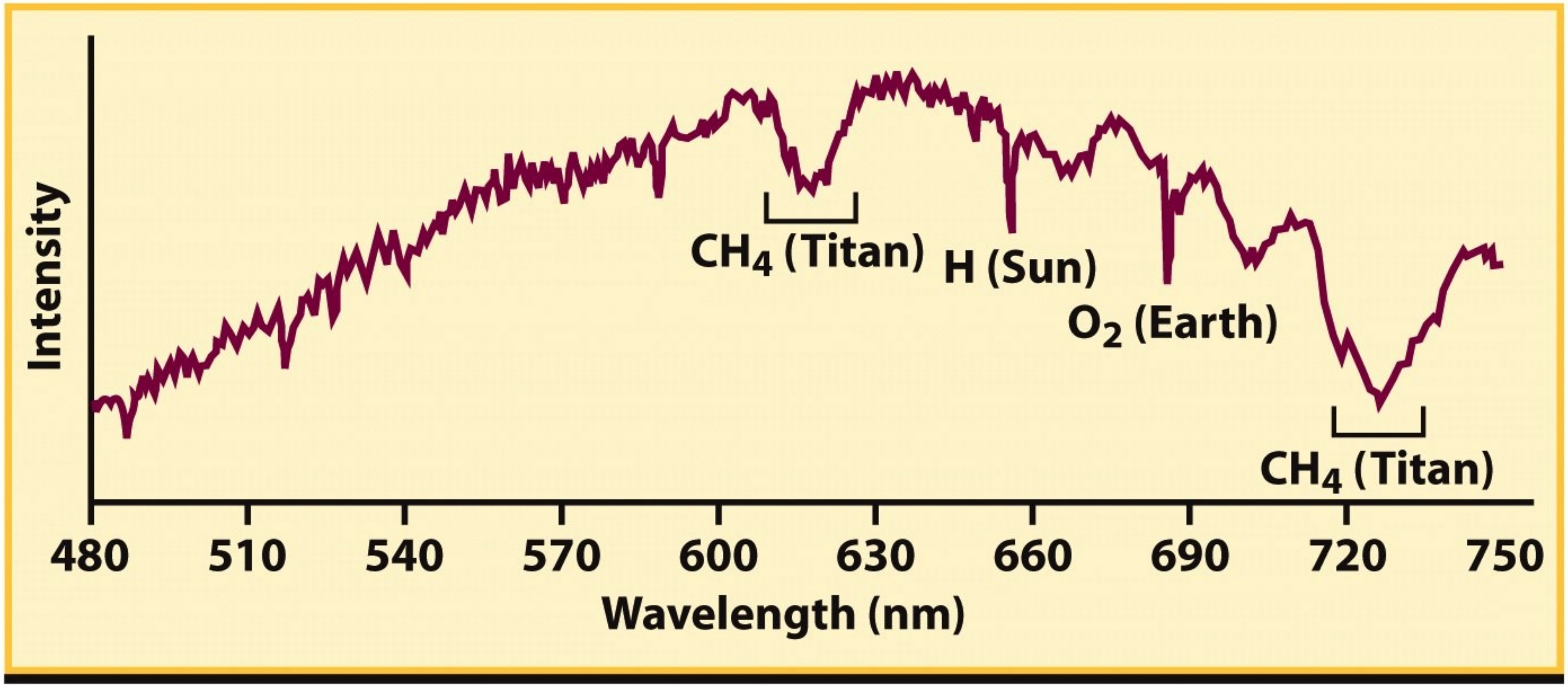


**Figure 7-3a**
***Universe, Eighth Edition***


Titan: only satellite with a substantial atmosphere

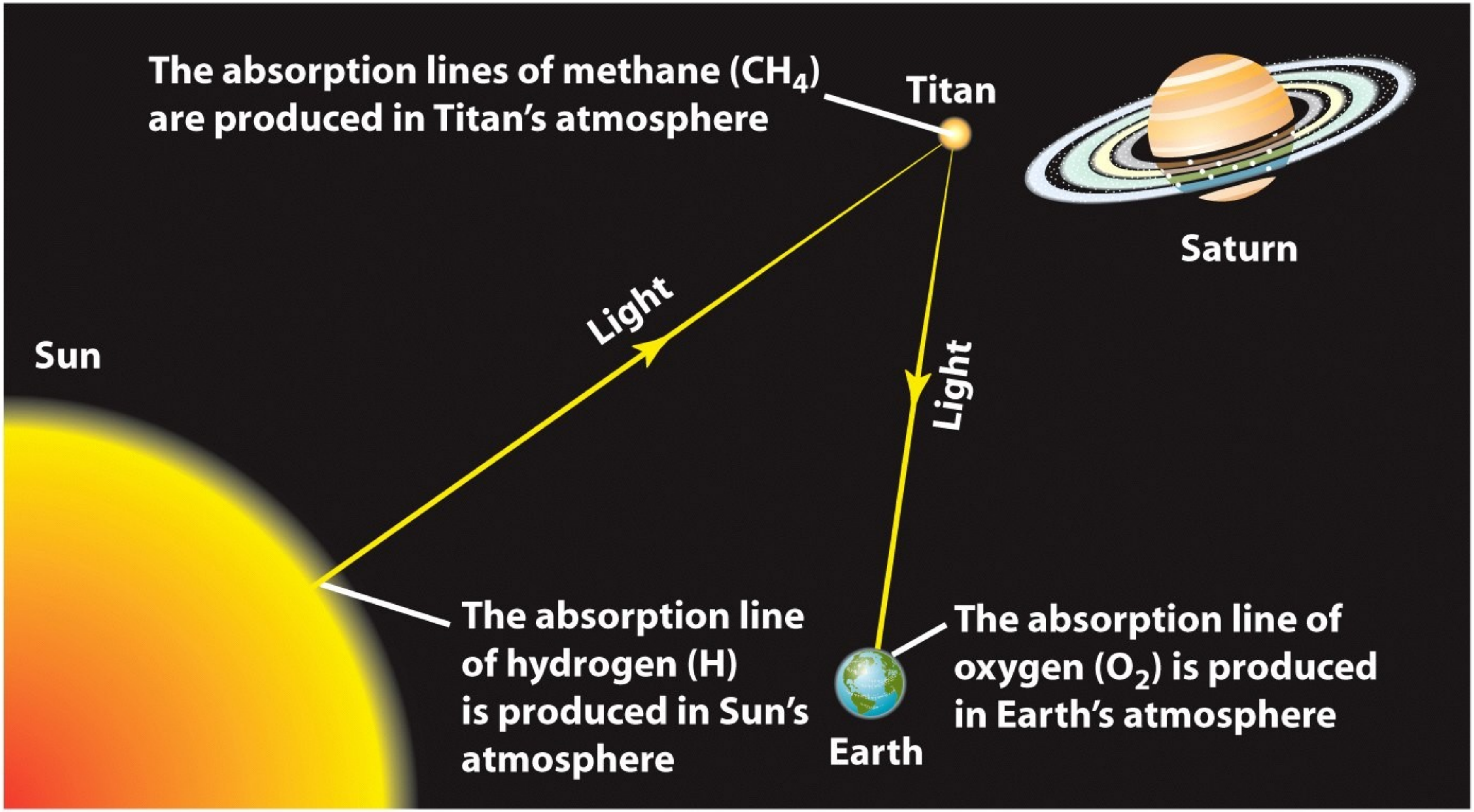
# Chemical composition




**The spectrum of sunlight reflected from Titan**

**Figure 7-3b**
***Universe, Eighth Edition***


- Dips: due to absorption by hydrogen atoms (H), oxygen molecules ($O_2$), and methane molecules ($CH_4$)
- Only methane actually present in Titan's atmosphere




## Interpreting Titan's spectrum

**Figure 7-3c**
***Universe, Eighth Edition***

Jupiter's moon Europa

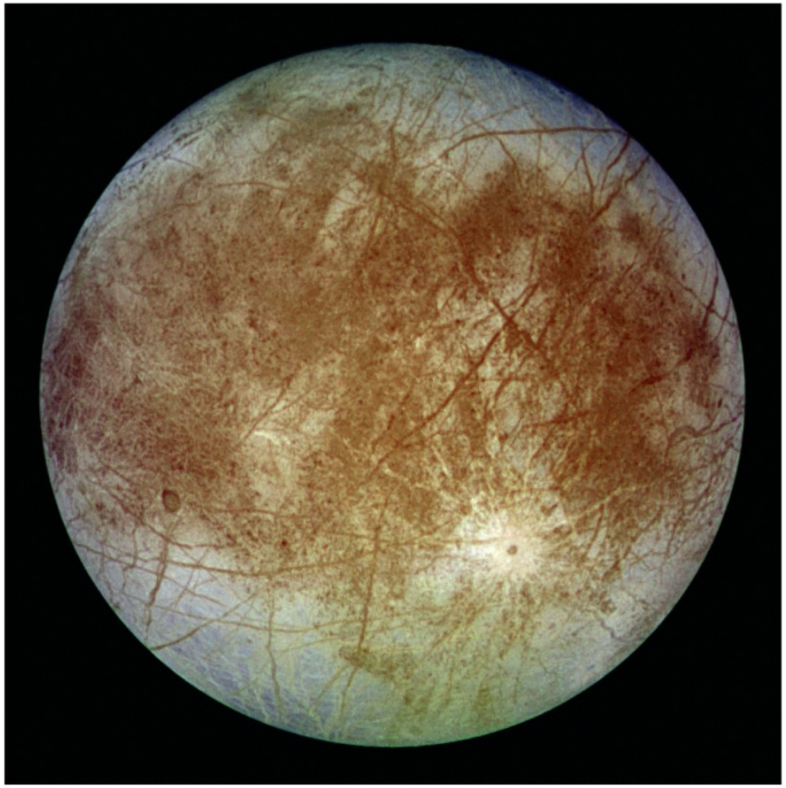
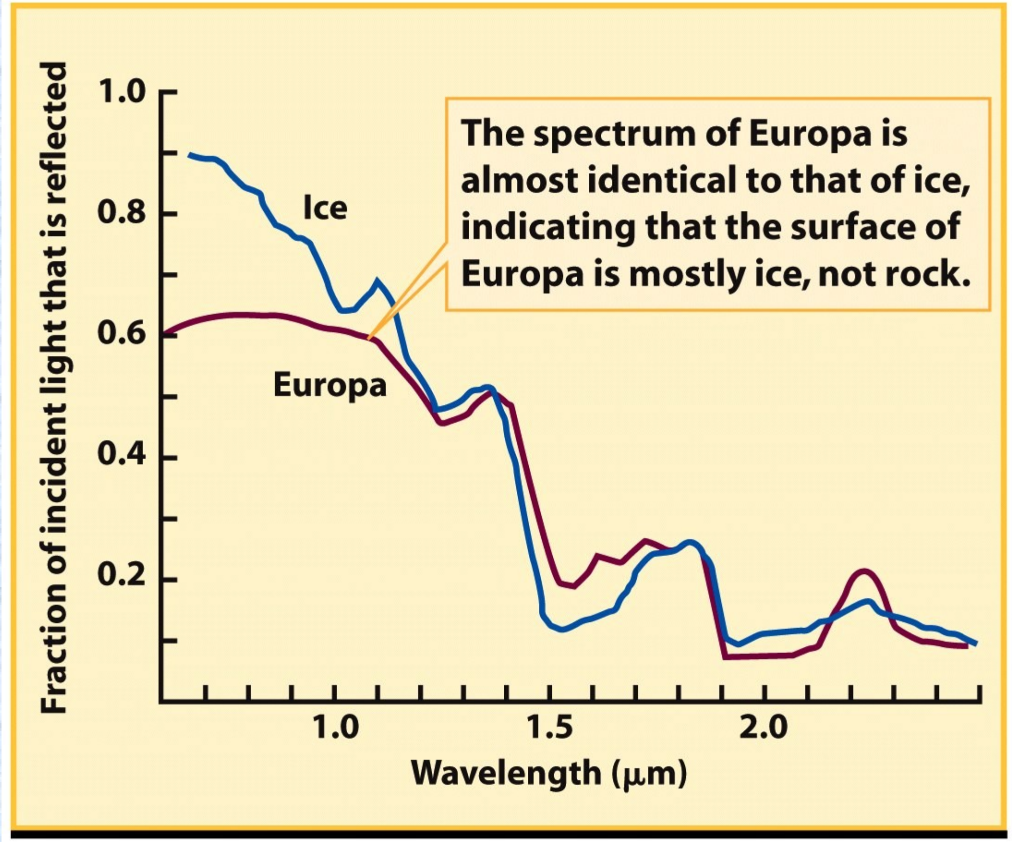


Figure 7-4a
*Universe, Eighth Edition*


The spectum of light reflected from Europa

Figure 7-4b
*Universe, Eighth Edition*


Europa:
- No atmosphere
- Sun light reflected from surface

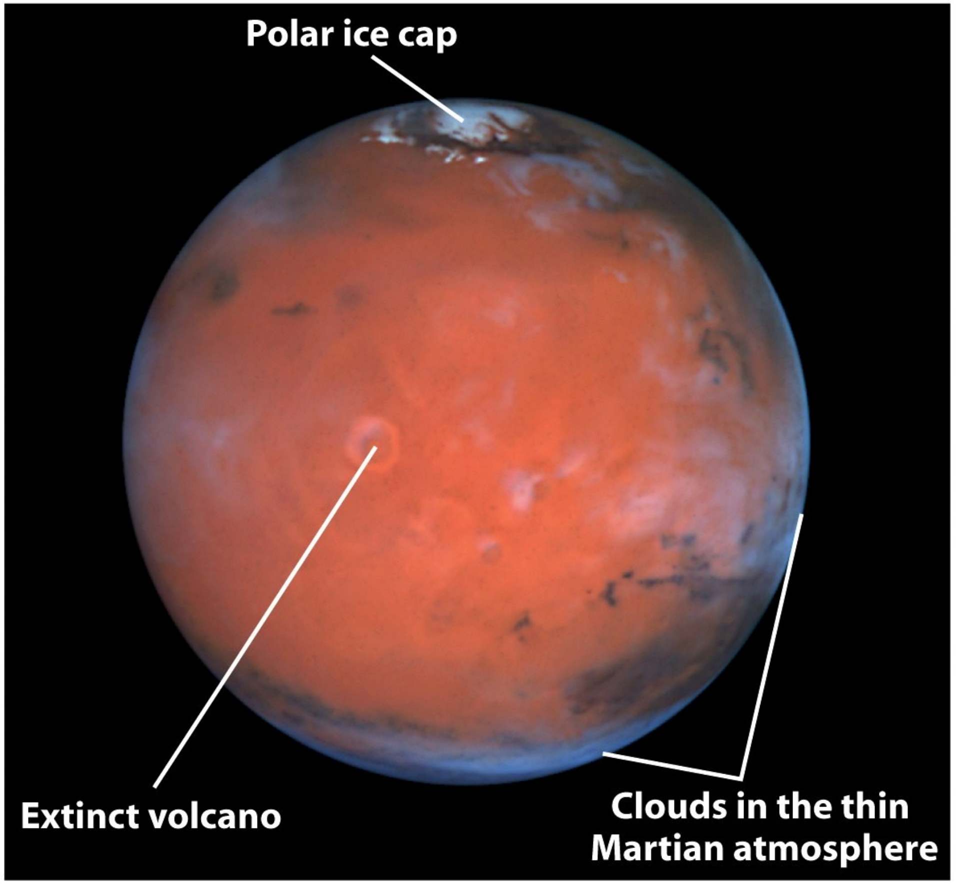


Figure 7-6
*Universe, Eighth Edition*


Mars:
- Composed mostly of heavy elements
  (iron, oxygen, silicon, magnesium, nickel, sulfur) → red surface
- Atmosphere thin, nearly cloudless
- Olympus Mons = extinct volcano, nearly 3 times height of Mount Everest

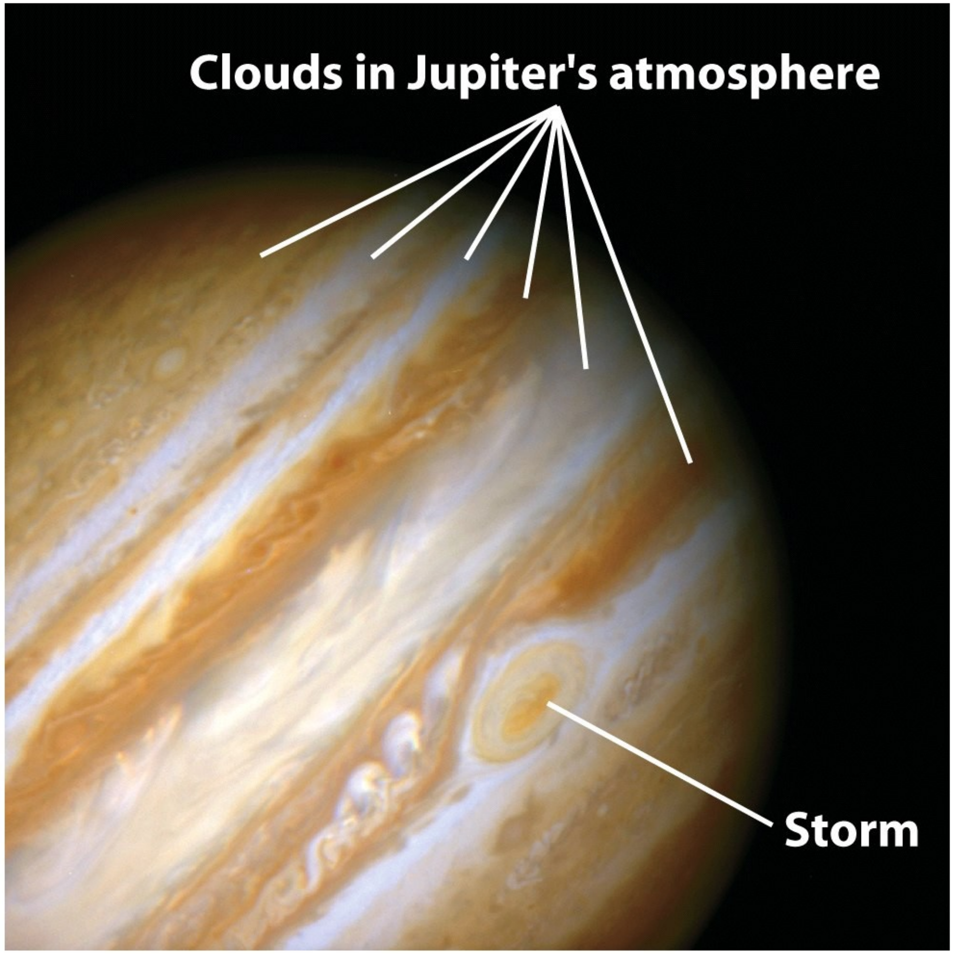



**Figure 7-5**
***Universe, Eighth Edition***


Jupiter:
- Composed mostly of lightest elements (hydrogen, helium), colorless
- Colors: trace amounts of other substances
- Giant storm = Great Red Spot, >300 years old

## How do we know?

Chemical composition: soil probes (Venus, Earth, Moon, Mars)
spectroscopy
average density
color

# Table 7-3 Comparing Terrestrial and Jovian Planets

| | Terrestrial Planets | Jovian Planets |
|---|---|---|
| Distance from the Sun | Less than 2 AU | More than 5 AU |
| Size | Small | Large |
| Composition | Mostly rocky materials containing iron, oxygen, silicon, magnesium, nickel, and sulfur | Mostly light elements such as hydrogen and helium |
| Density | High | Low |

Table 7-3
*Universe, Eighth Edition*

# Question 10.2 (iclickers!)

- A ground based telescope is pointed at the atmosphere of Titan and a spectrum is obtained. The spectral lines observed in this spectrum:
  - A) Can only be features of Titan
  - B) can be characteristic of the Earth's atmosphere as well as Titan's atmosphere
  - C) Can be characteristic of the cooler outer layers of the Sun's atmosphere as well as of Titan's atmosphere
  - D) can be characteristic of the atmosphere of Titan and the Earth and also of the cooler outer layers of the Sun's atmosphere.

# The Surface of Terrestrial Planets and the Moon: Impact Craters

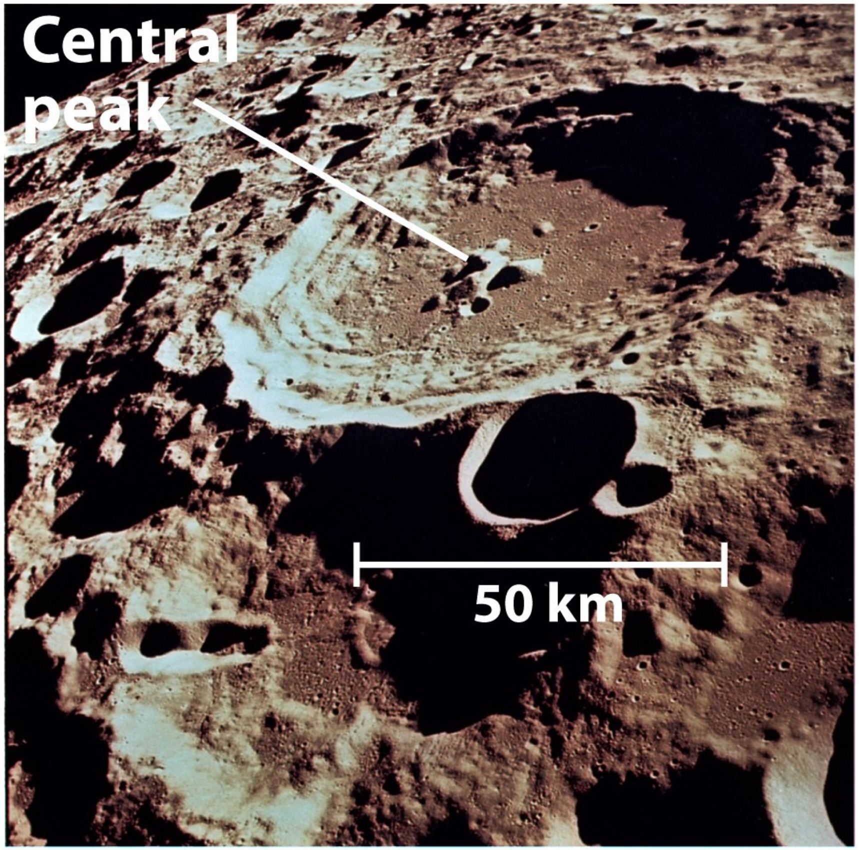



Figure 7-10a
*Universe, Eighth Edition*


- Asteroids/Comets on elongated orbits, can collide with planet/satellite
- Jovian planets: swallowed by atmosphere
- Terrestrial planets: impact crater (central peak!)

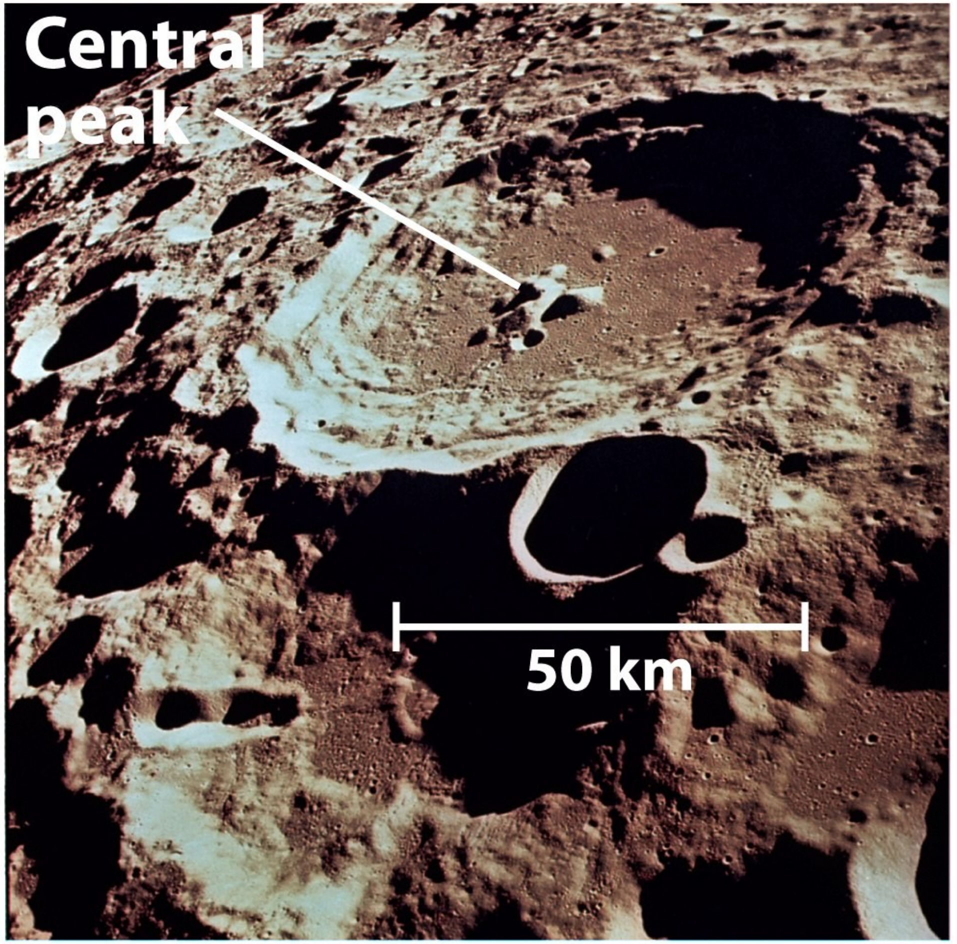



Figure 7-10a
*Universe, Eighth Edition*


Moon:

- Surface with craters of all sizes
- Large crater equal to length of San Francisco Bay

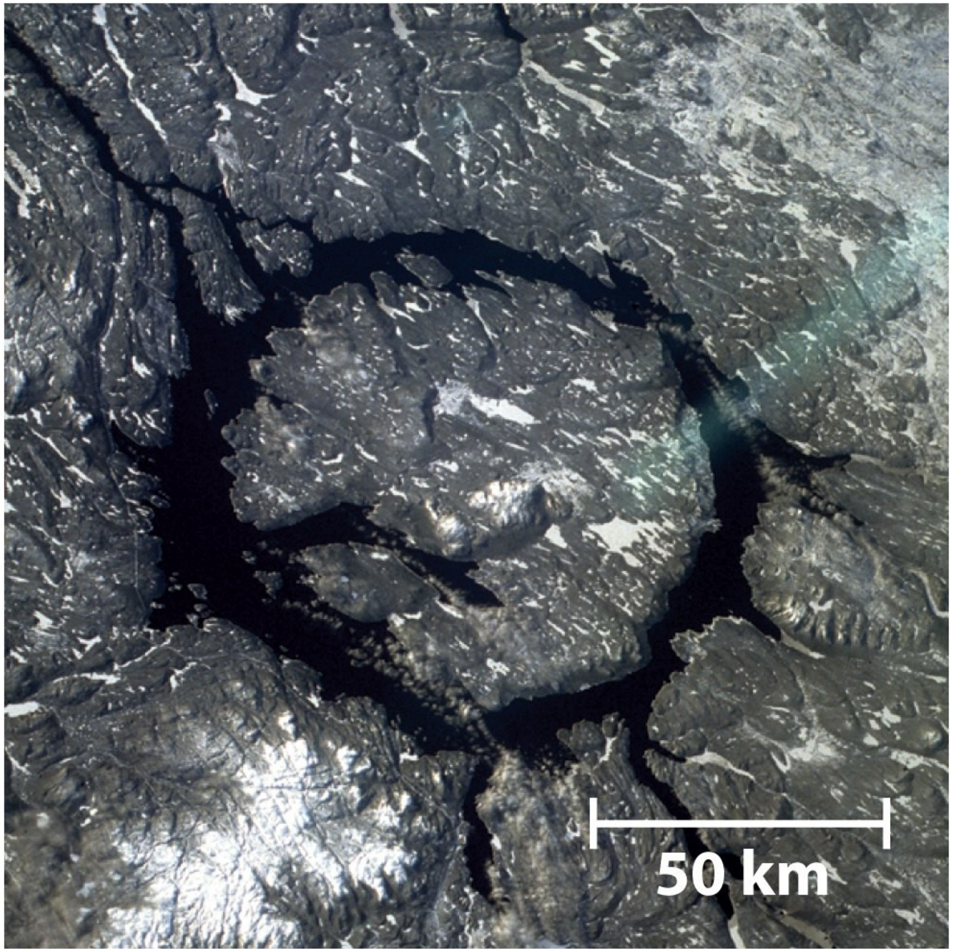



Figure 7-10b
*Universe, Eighth Edition*


Earth:
- Only < 200 craters
- Manicouagan Reservoir in Quebec
- Relic of a crater formed >200 million years ago; eroded by glaciers


**Figure 7-10c**
***Universe, Eighth Edition***


Mars:
- Lowell Crater in the southern highlands, 201 km (125 miles) across
- Craters on top of craters
- Light-colored frost: condensation of carbon dioxide from atmosphere

# Observations:

- SMALLER worlds (the Moon, Mercury, Mars) have more craters than larger worlds (Earth, Venus)

- LARGER worlds have more geological activity (volcanoes, faults, etc.)

- **What's the connection?**

**Geological activity erases craters**

Figure 7-11
*Universe, Eighth Edition*

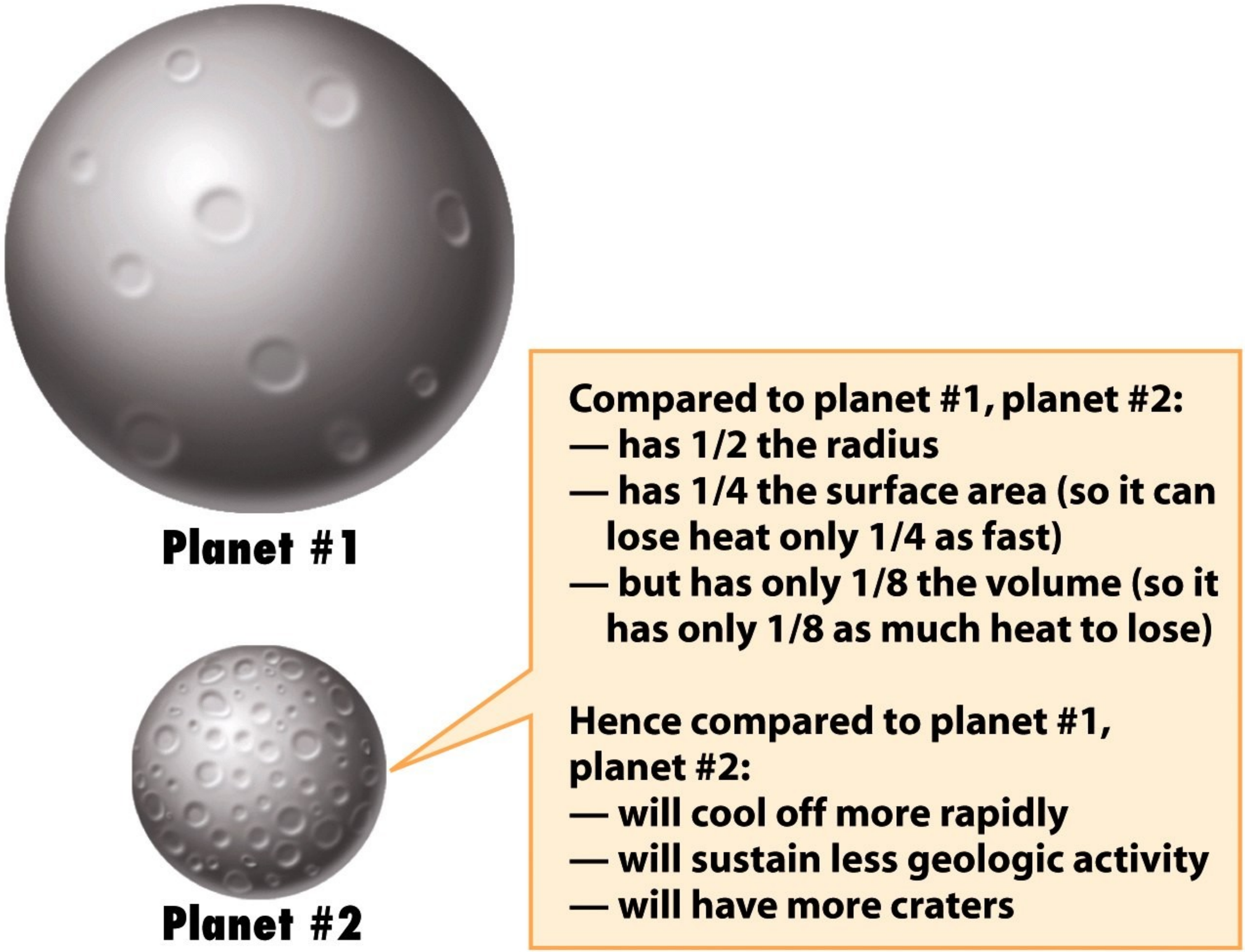



**Figure 7-11**
***Universe, Eighth Edition***

## How do we know?

Geological activity: number of craters

Inner core: if geologically active → at least partially molten

## The Inner (Terrestrial) Planets Close to the Sun - Small diameter, small mass - High density

| | Mercury | Venus | Earth | Mars |
|---|---|---|---|---|
| Average distance from Sun (AU) | 0.387 | 0.723 | 1.000 | 1.524 |
| Equatorial diameter (Earth = 1) | 0.383 | 0.949 | 1.000 | 0.533 |
| Mass (Earth = 1) | 0.0553 | 0.8150 | 1.0000 | 0.1074 |
| Average density ($kg/m^3$) | 5430 | 5243 | 5515 | 3934 |

Cosmic Connections 7a
*Universe, Eighth Edition*


## The Outer (Jovian) Planets Far from the Sun - Large diameter, large mass - Low density

| | Jupiter | Saturn | Uranus | Neptune |
|---|---|---|---|---|
| Average distance from Sun (AU) | 5.203 | 9.554 | 19.194 | 30.066 |
| Equatorial diameter (Earth = 1) | 11.209 | 9.449 | 4.007 | 3.883 |
| Mass (Earth = 1) | 317.8 | 95.16 | 14.53 | 17.15 |
| Average density ($kg/m^3$) | 1326 | 687 | 1318 | 1638 |

Cosmic Connections 7c
*Universe, Eighth Edition*

# Measuring Magnetic Fields

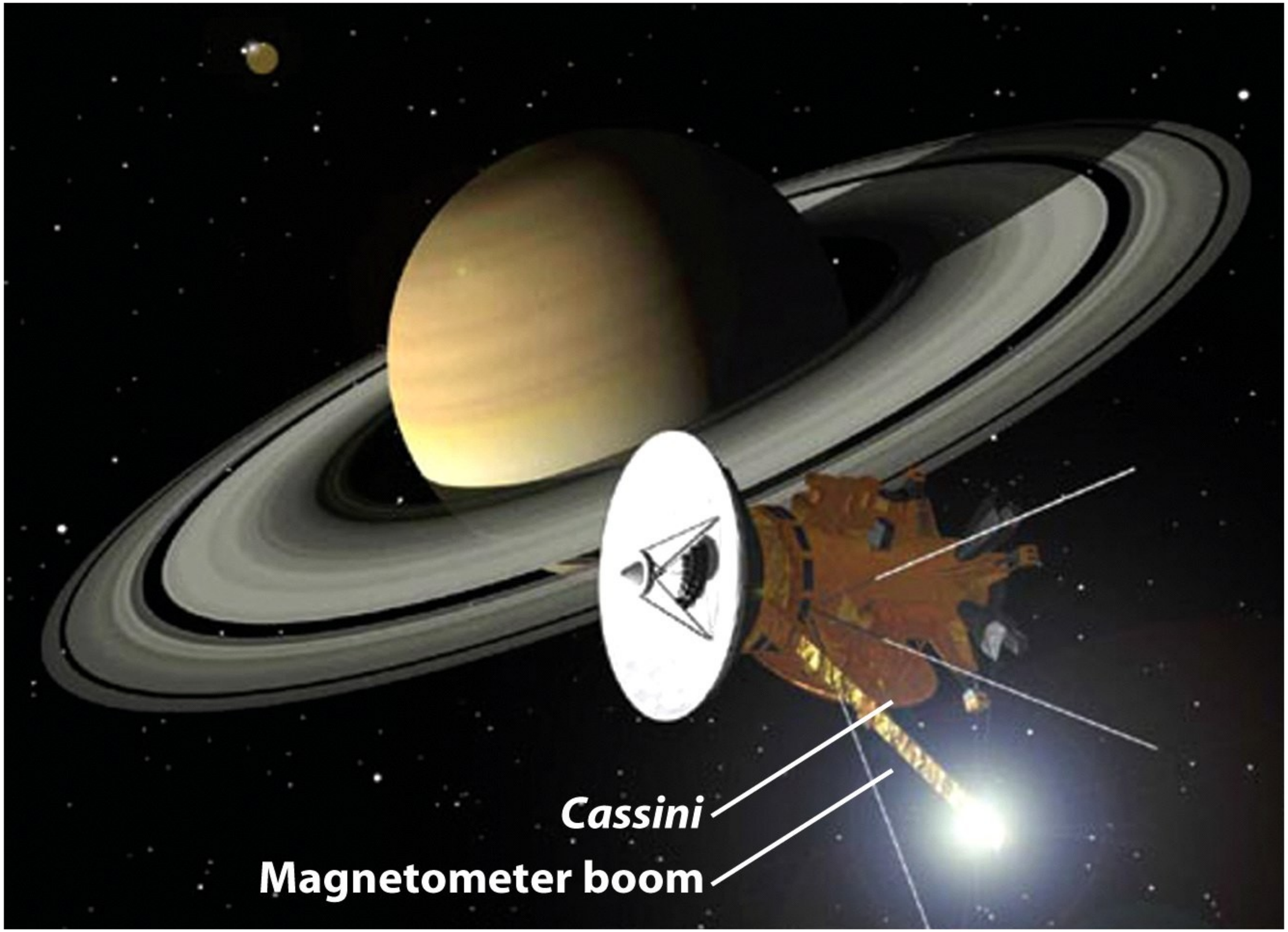
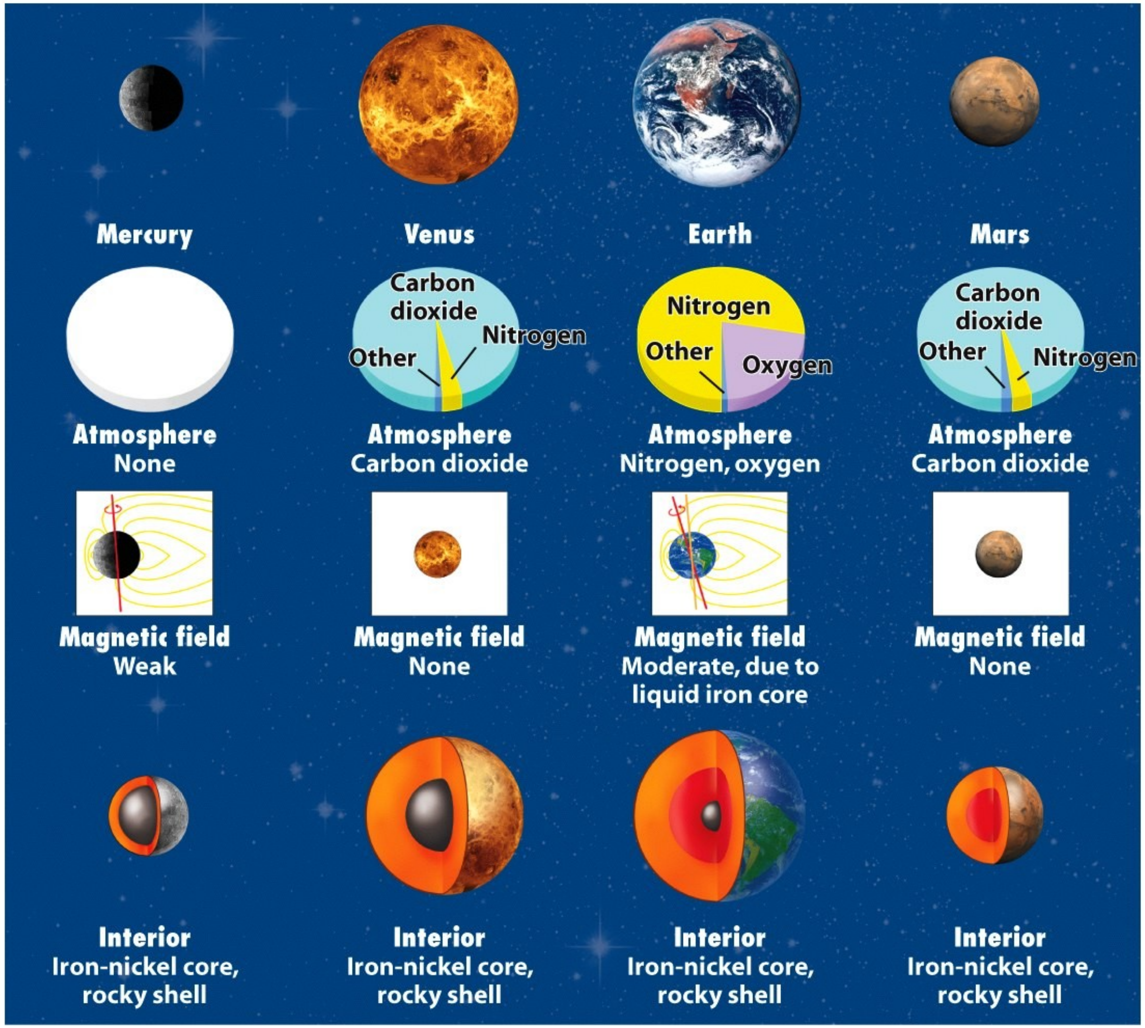



Figure 7-14
***Universe, Eighth Edition***

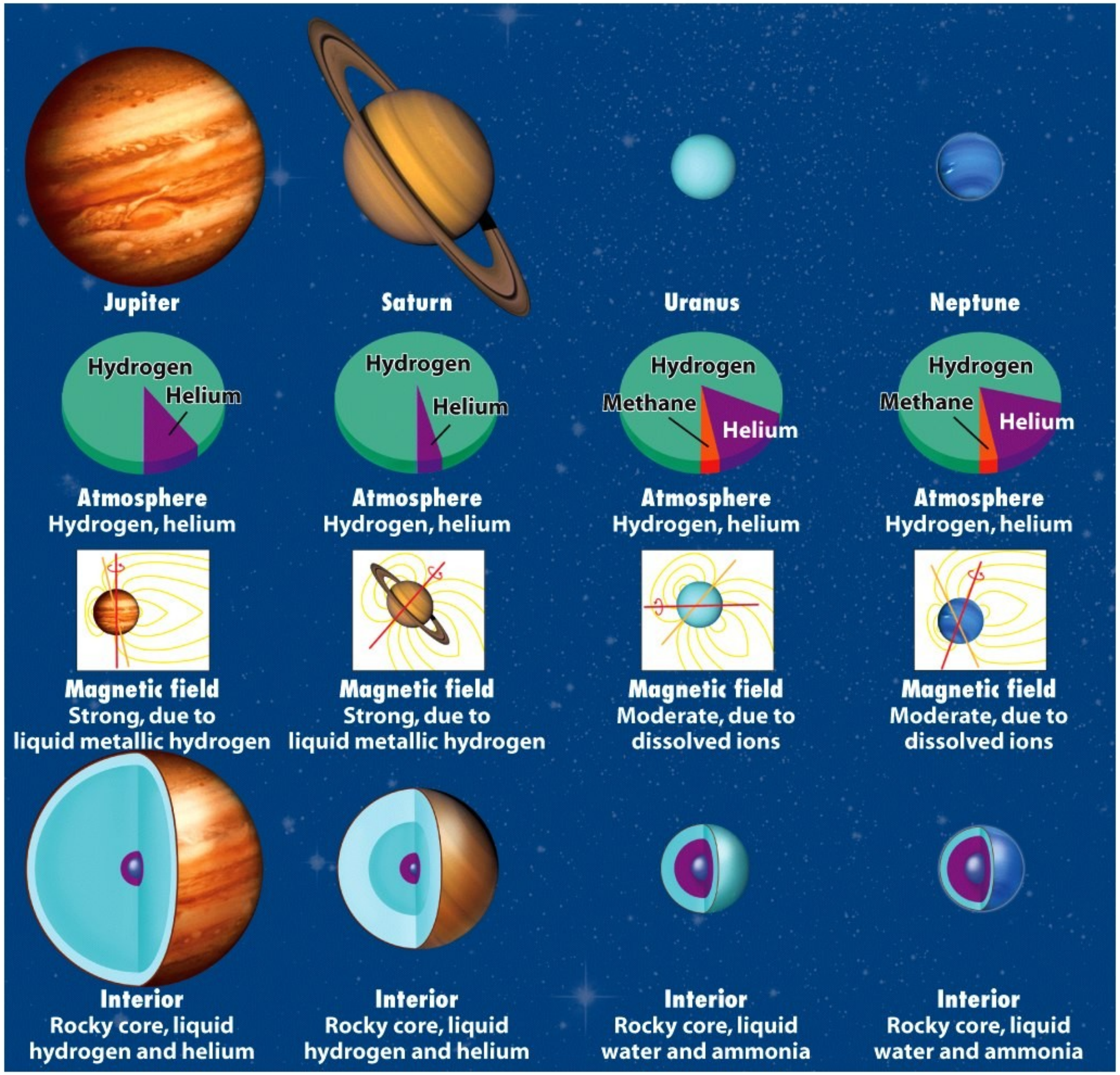
# Terrestrial Planets




**Cosmic Connections 7b**
***Universe, Eighth Edition***


- High atmospheric temperatures (close to sun)
- H2 and He light elements, fast, escape
- CO2, N2, O2, H2O remain

# Jovian Planets



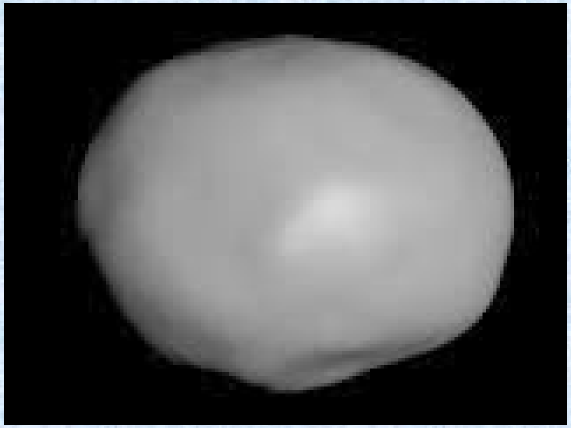

Cosmic Connections 7d
*Universe, Eighth Edition*


- Low temperatures (far from sun)
- Massive, strong gravity, can hold H, He

# Official International Astronomical Union definition of a planet

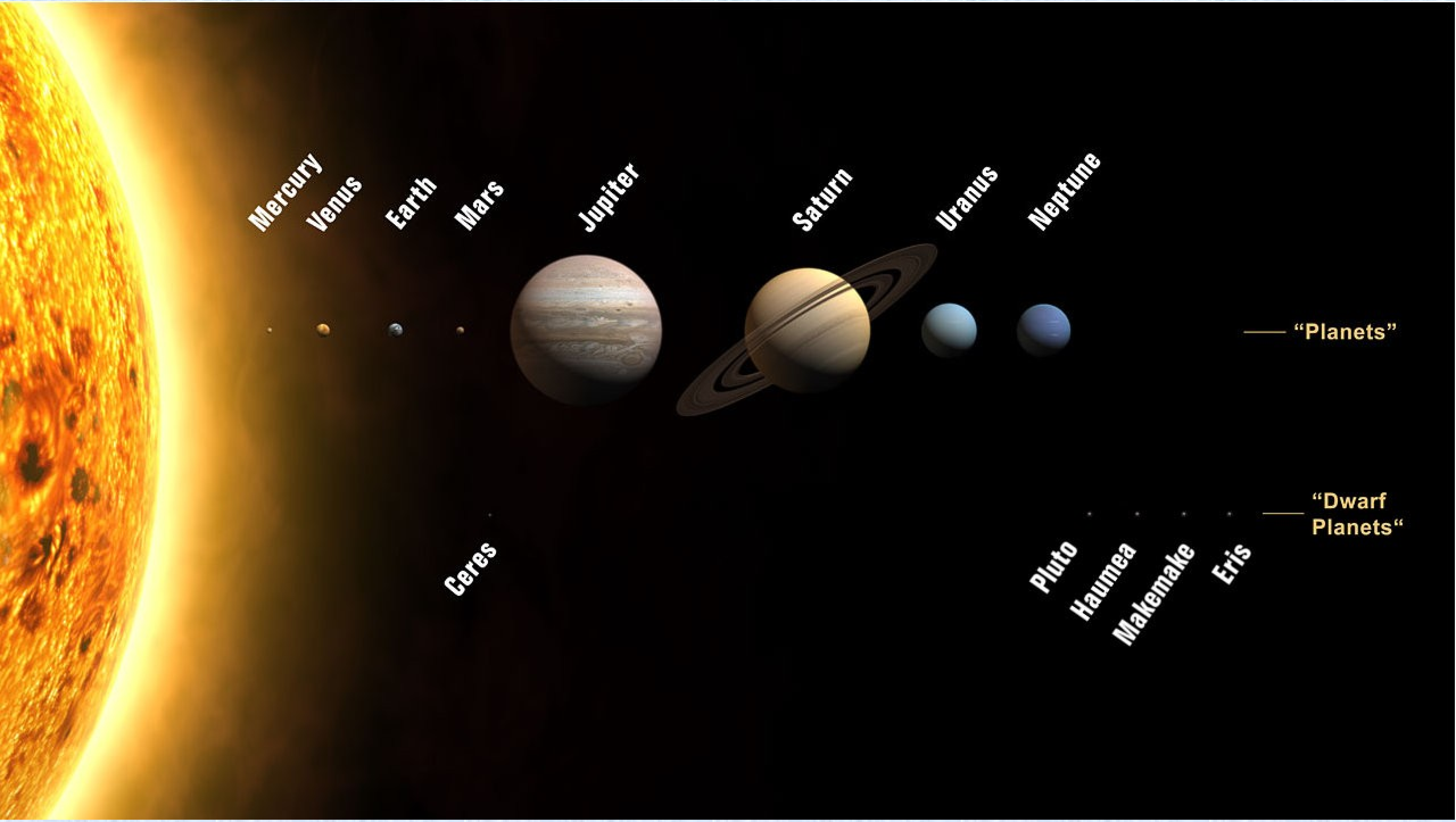
A planet is a celestial body that:

1. is in orbit around the Sun,
2. has sufficient mass to assume hydrostatic equilibrium (a nearly round shape), and
3. has "cleared the neighbourhood" around its orbit.

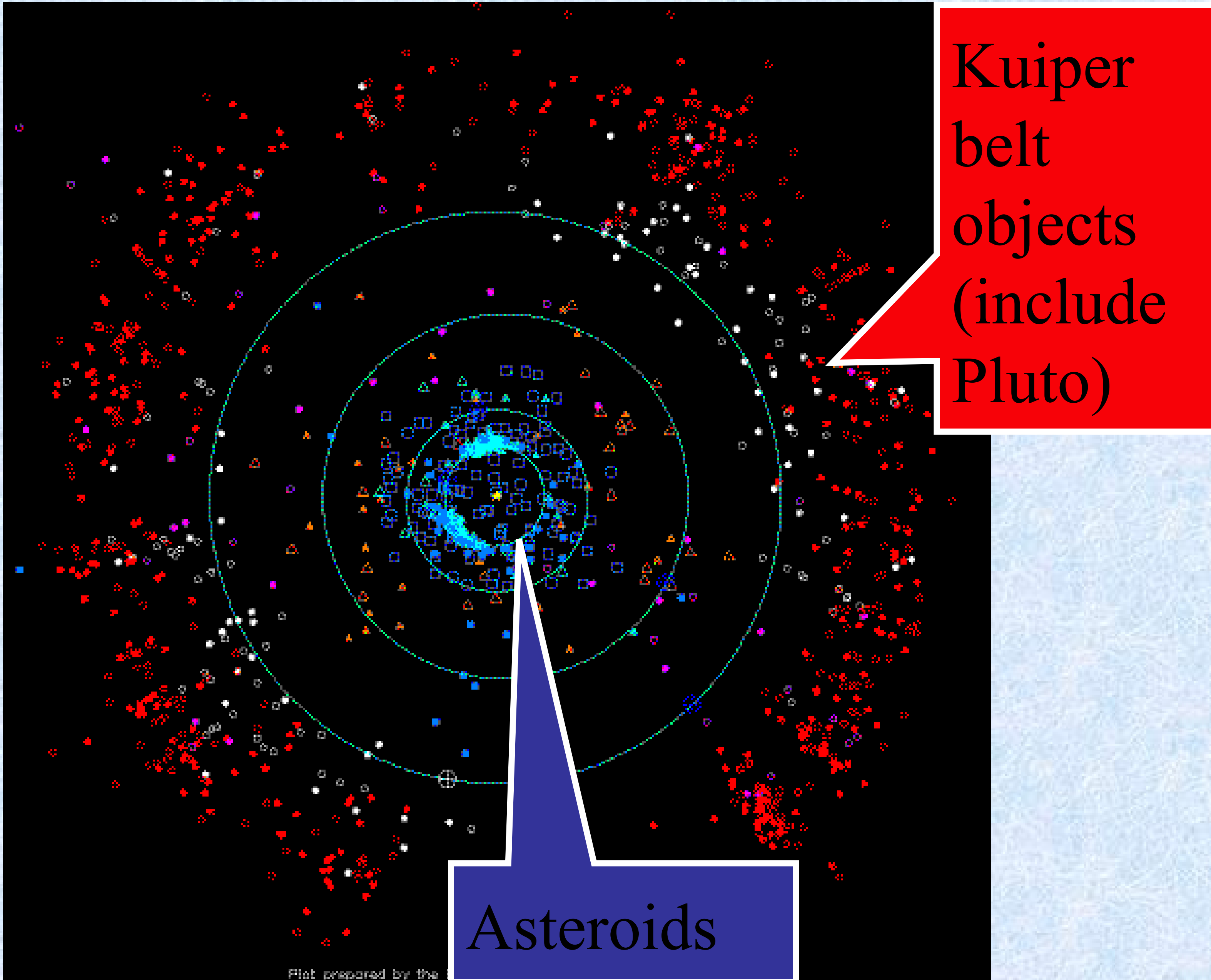


The second-largest asteroid, Vesta

If a solar system body only meets the first two criteria (and is not a satellite) it is called a “dwarf planet”.
All others: “small solar system bodies”.


Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
“Planets”
Ceres
Pluto
Haumea
Makemake
Eris
“Dwarf Planets“

# Small bodies in the solar system



# Asteroids

**Figure 7-7**
***Universe, Eighth Edition***


- Rocky objects between Mars and Jupiter in "asteroid belt"
- Left-overs that did not form a planet
- Combined mass < Moon

# Asteroids

Figure 7-7
*Universe, Eighth Edition*


433 Eros:

- 33 km (21 mi) long and 13 km (8 mi) wide
- Gravity too weak to have pulled it into a spherical shape
- Image taken March 2000 by *NEAR Shoemaker,* first spacecraft to orbit around and land on an asteroid.

# Question 10.3 (iclickers!)

- In general small bodies in the solar system are less likely than large bodies to possess a planet-wide magnetic field. Why should we expect size and magnetism to be correlated?
  - A) A small body cools more rapidly and is less likely to possess a molten liquid interior.
  - B) Small bodies are more likely to be heavily cratered and such impacts can destroy the mechanism that produces the magnetic field
  - C) Magnetic fields are produced by the entire volume of a body. Smaller bodies have smaller volumes and therefore smaller magnetic fields
  - D) Small bodies necessarily rotate more slowly and a rapid rotation rate is one requirement for a planet wide magnetic field

# Trans-Neptunian Objects (TNOs) = Kuiper Belt Objects (KBOs)

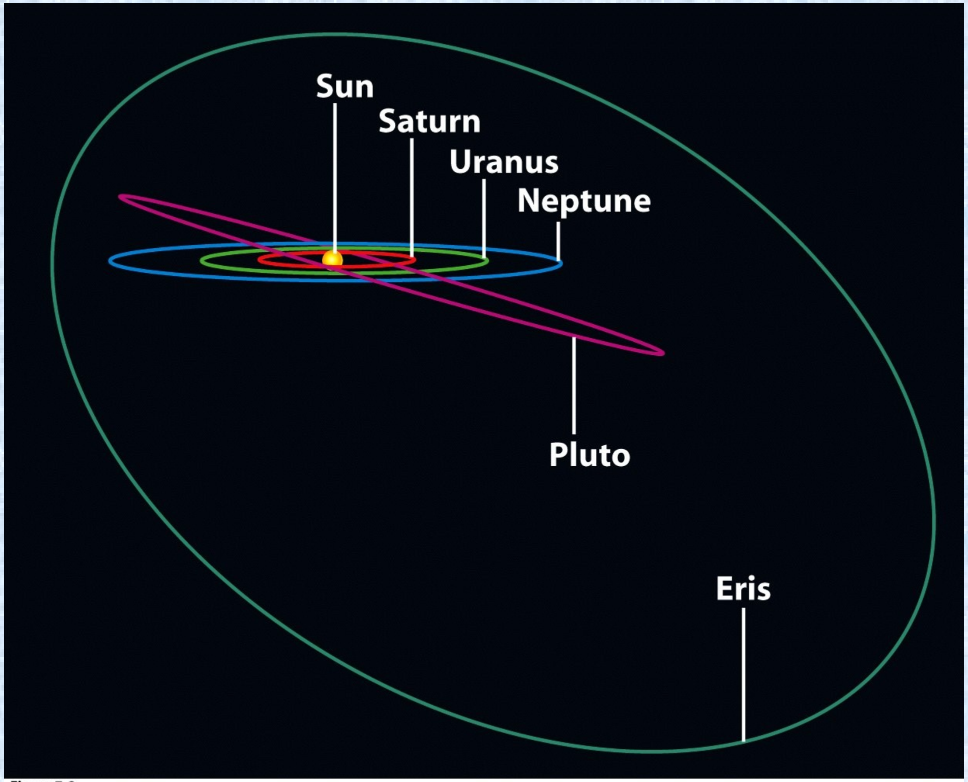



Figure 7-8
*Universe, Eighth Edition*


- Rocky & icy objects beyond Neptune (> 900 known; maybe up to 35,000?)
- High eccentricities
- Pluto is first discovered TNO (1930) and second biggest
- Reside in Kuiper belt (30-50 AU from sun)
- Debris left over from formation of solar system

# Trans-Neptunian Objects (TNOs) = Kuiper Belt Objects (KBOs)

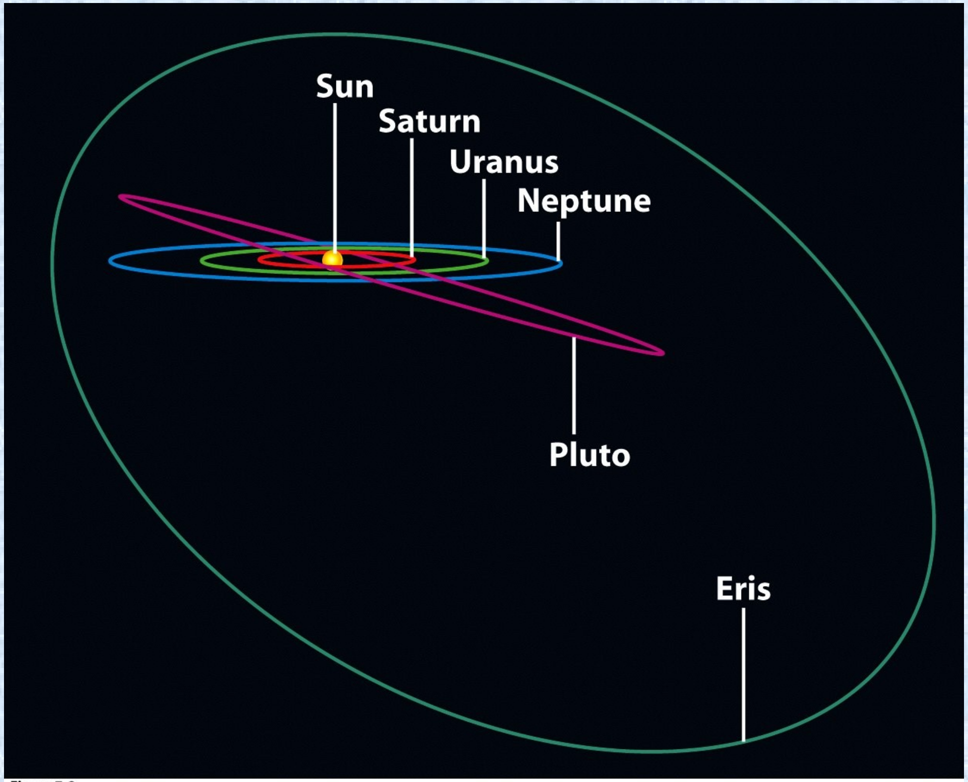



Figure 7-8
*Universe, Eighth Edition*


Pluto and Eris (2003 UB313):
- Two largest Trans-Neptunian Objects
- Orbits steeply inclined to the ecliptic

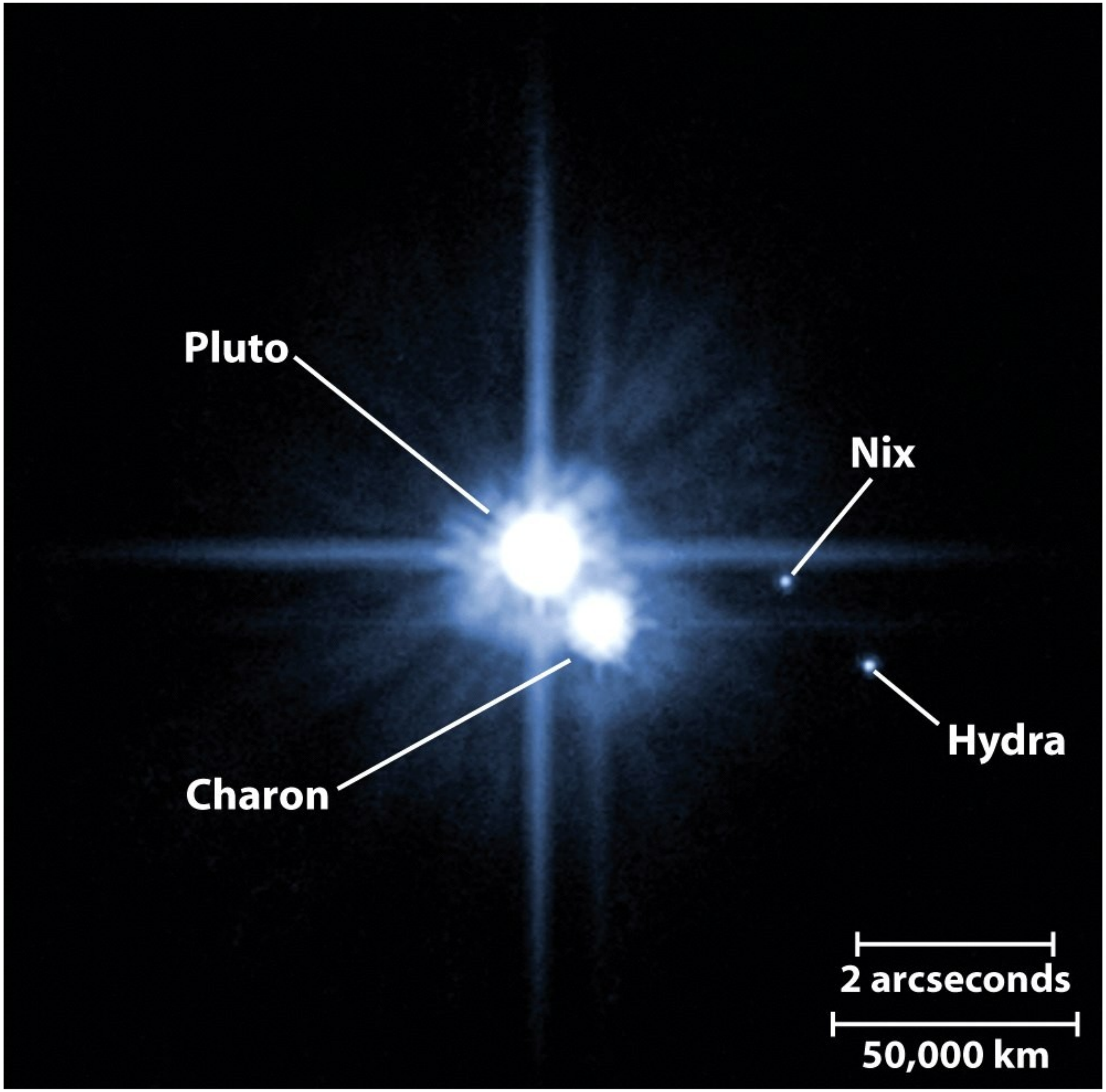
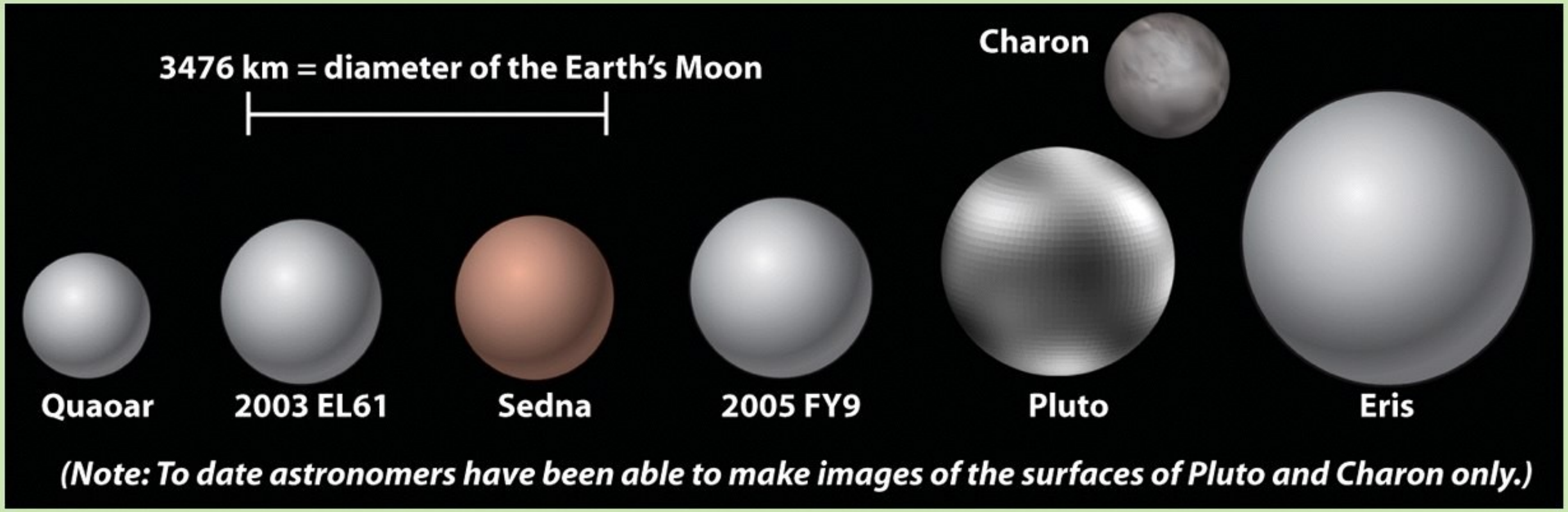



**Figure 14-19**
***Universe, Eighth Edition***

## Table 7-4 Seven Large Trans-Neptunian Objects

| | Quaoar | 2003 EL61 | Sedna | 2005 FY9 | Pluto | Charon (satellite of Pluto) | Eris |
|---|---|---|---|---|---|---|---|
| Average distance from Sun (AU) | 43.54 | 43.34 | 489 | 45.71 | 39.54 | 39.54 | 67.67 |
| Orbital period (years) | 287 | 285 | 10,800 | 309 | 248.6 | 248.6 | 557 |
| Orbital eccentricity | 0.035 | 0.189 | 0.844 | 0.155 | 0.250 | 0.250 | 0.442 |
| Inclination of orbit to the ecliptic | 8.0° | 28.2° | 11.9° | 29.0° | 17.15° | 17.15° | 44.2° |
| Approximate diameter (km) | 1250 | 1500 | 1600 | 1800 | 2274 | 1190 | 2900 |




R I V U X G

(Images of Pluto and Charon: Alan Stern, Southwest Research Institute; Marc Buie, Lowell Observatory; NASA; and ESA)

Table 7-4
*Universe, Eighth Edition*

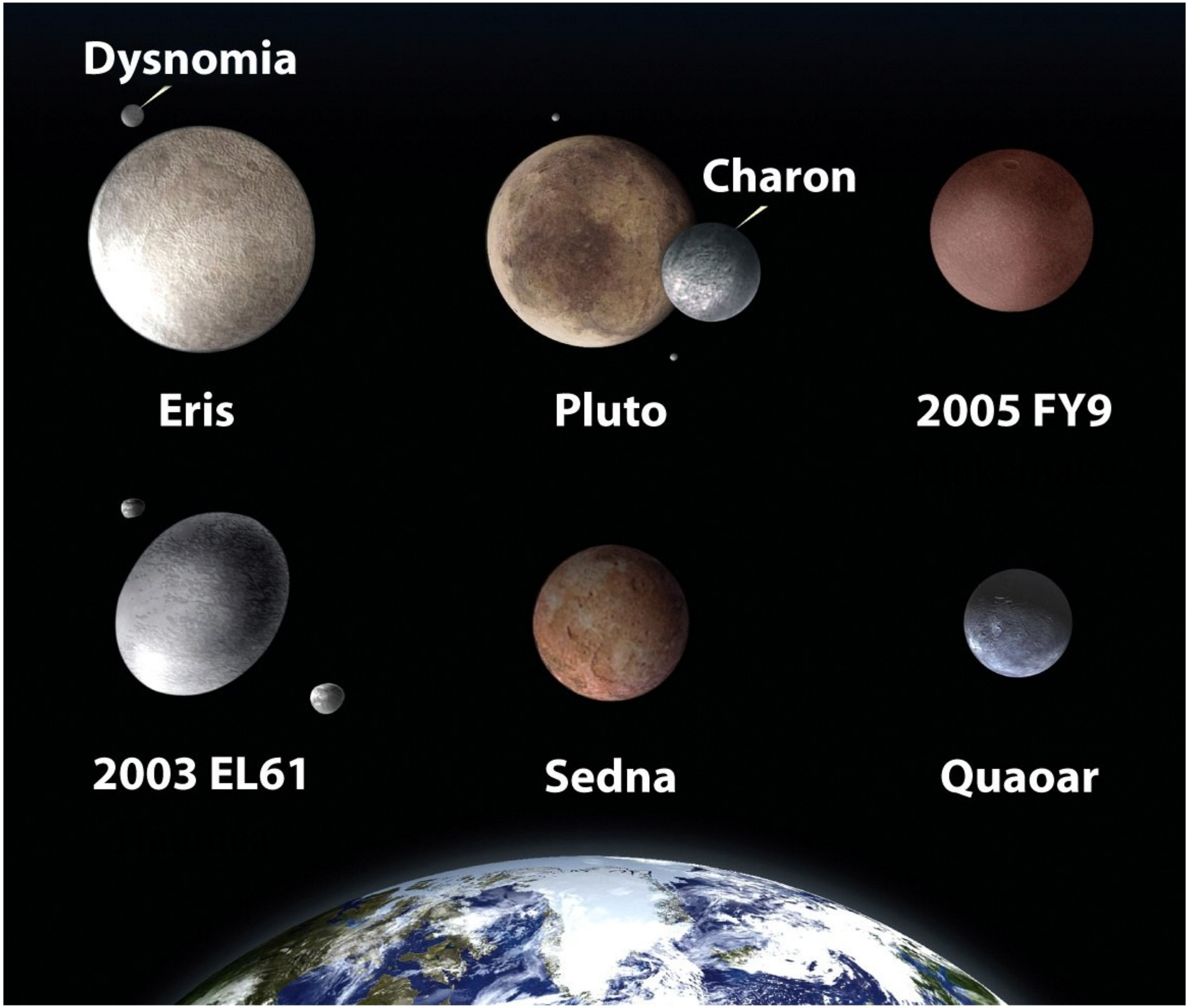
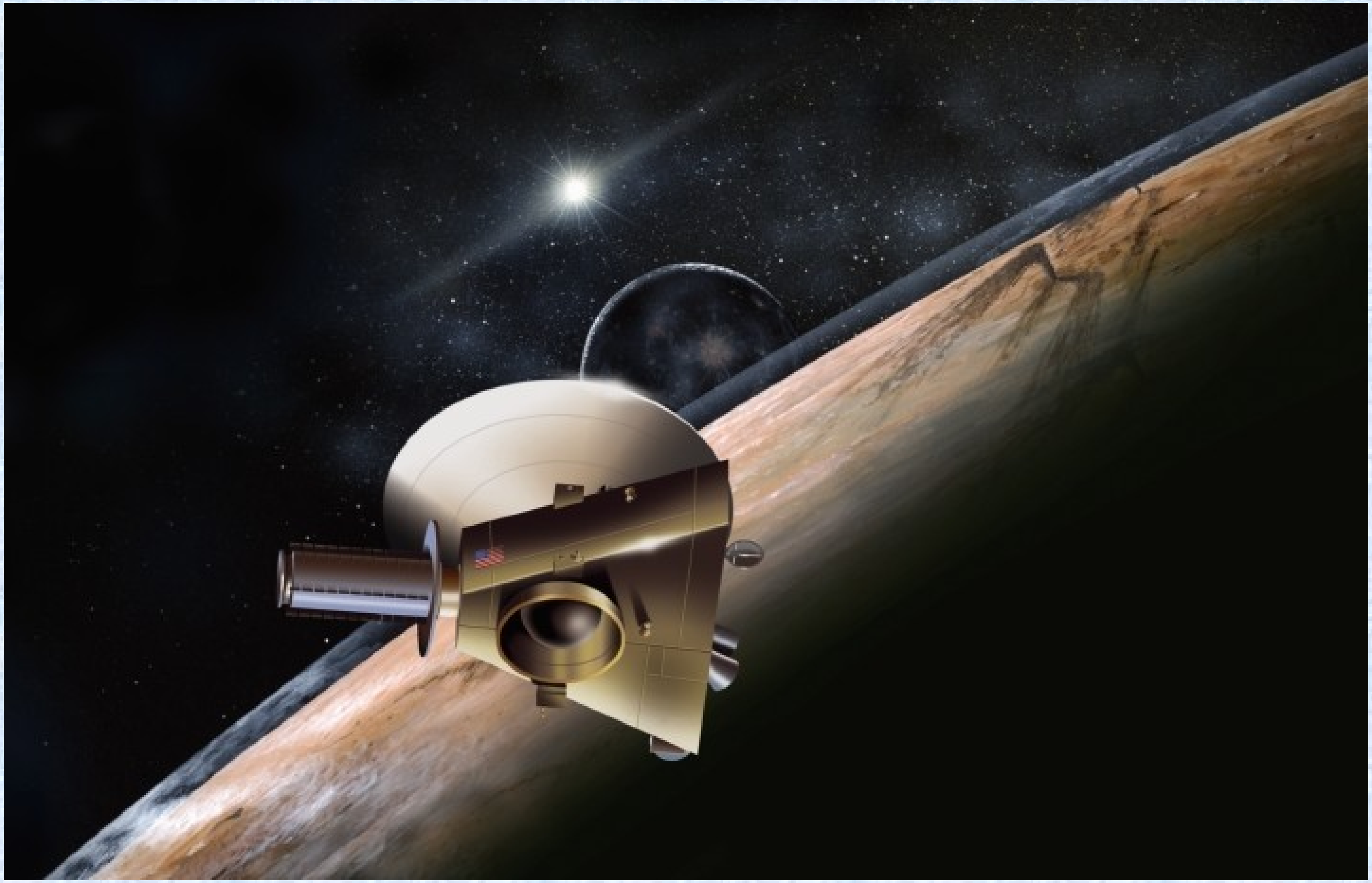


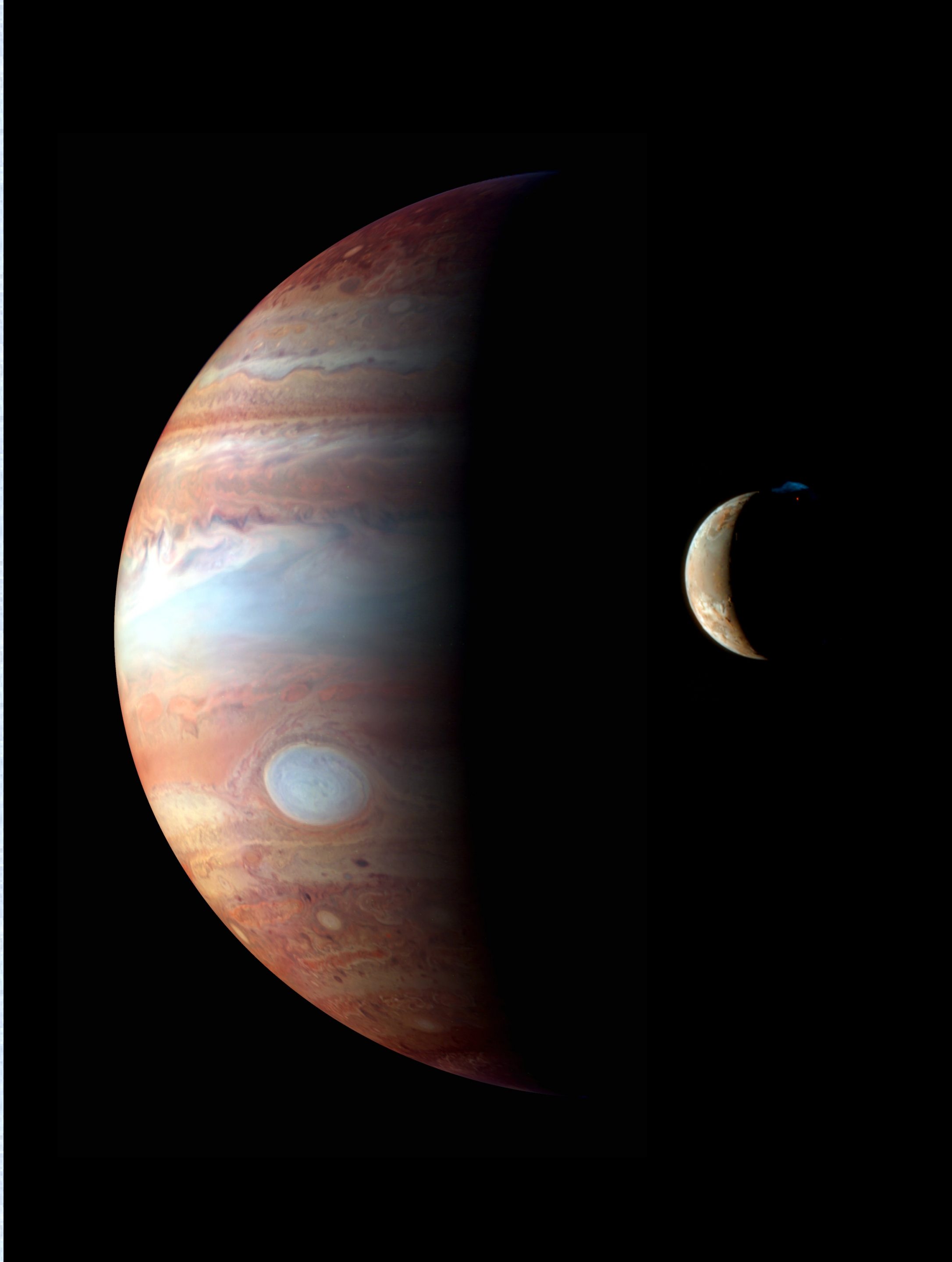

**Figure 14-20**
***Universe, Eighth Edition***

# *New Horizons* spacecraft

- Launch 2006
- Pluto/Charon flyby in 2015, then flyby of at least one (other) Kuiper belt object



• Picture of Jupiter and Io



# Comets ("Dirty Snowballs in Space")

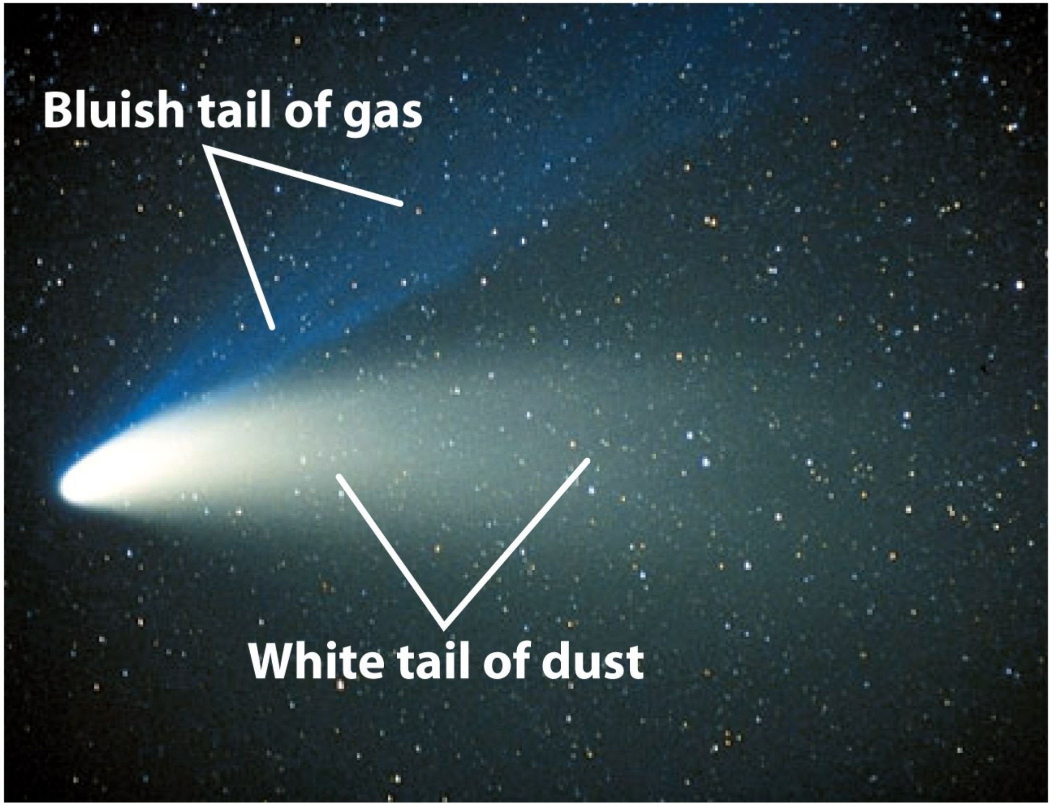



Figure 7-9
*Universe, Eighth Edition*


- Rocky & icy objects on eccentric orbits that come close to sun.
- Few tens of km in diameter
- From Kuiper Belt or even further out (Oort Cloud; 50,000 AU)
- e.g. if collision of two KBOs, a fragment can be knocked off and diverted into elongated object, brings it close to sun

# Comets

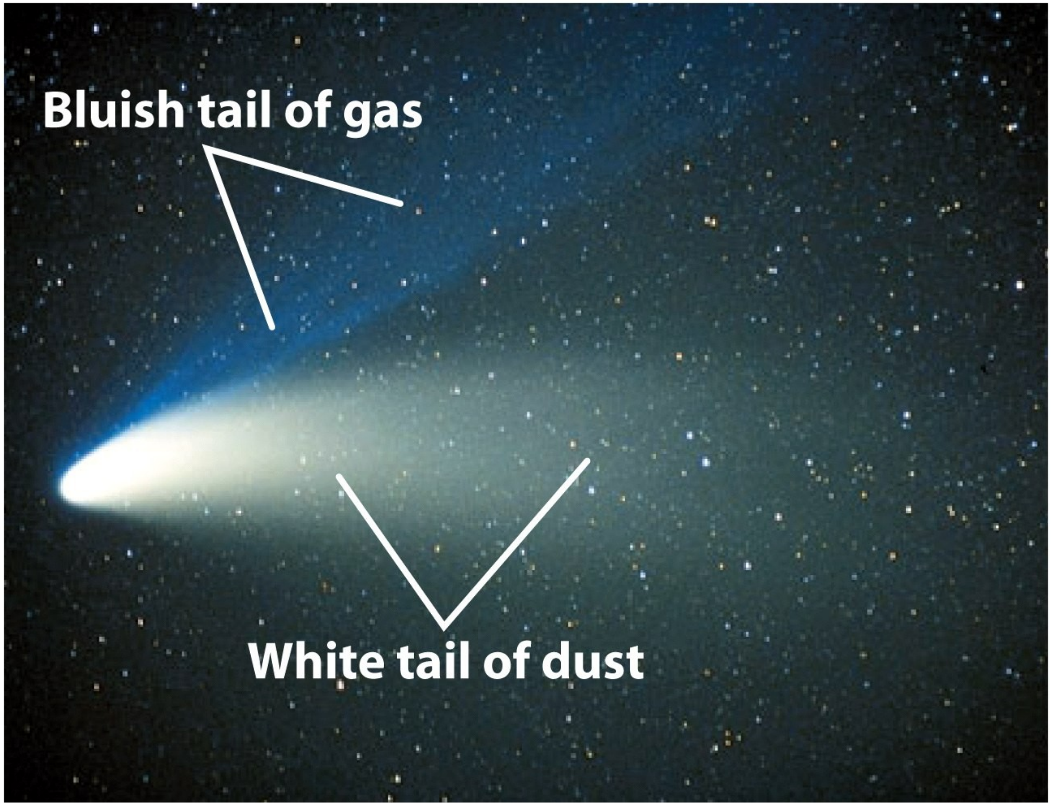



Figure 7-9
*Universe, Eighth Edition*


Hale-Bopp: (April 1997)
- Near Sun: solar radiation vaporizes some icy material
- Bluish tail of gas,  white tail of dust
- Tails can extend for tens of millions of kilometers

# Summary

- **Properties of the Planets:**
  - Orbits in the same plane and direction
  - Inner (terrestrial) planets are small and made of heavy elements
  - Outer (Jovian) planets are big and made of light elements
- **Other bodies in the Solar system**
  - There are seven large satellites (like the moon)
  - Asteroids in Asteroid Belt between Mars and Jupiter
  - Outer solar system is populated by TNO and comets
- **How do we learn about solar system bodies?**
  - We send probes
  - Spectroscopy reveals the composition of atmospheres
  - Craters and magnetic fields reveal the presence of a liquid melted core

# The End