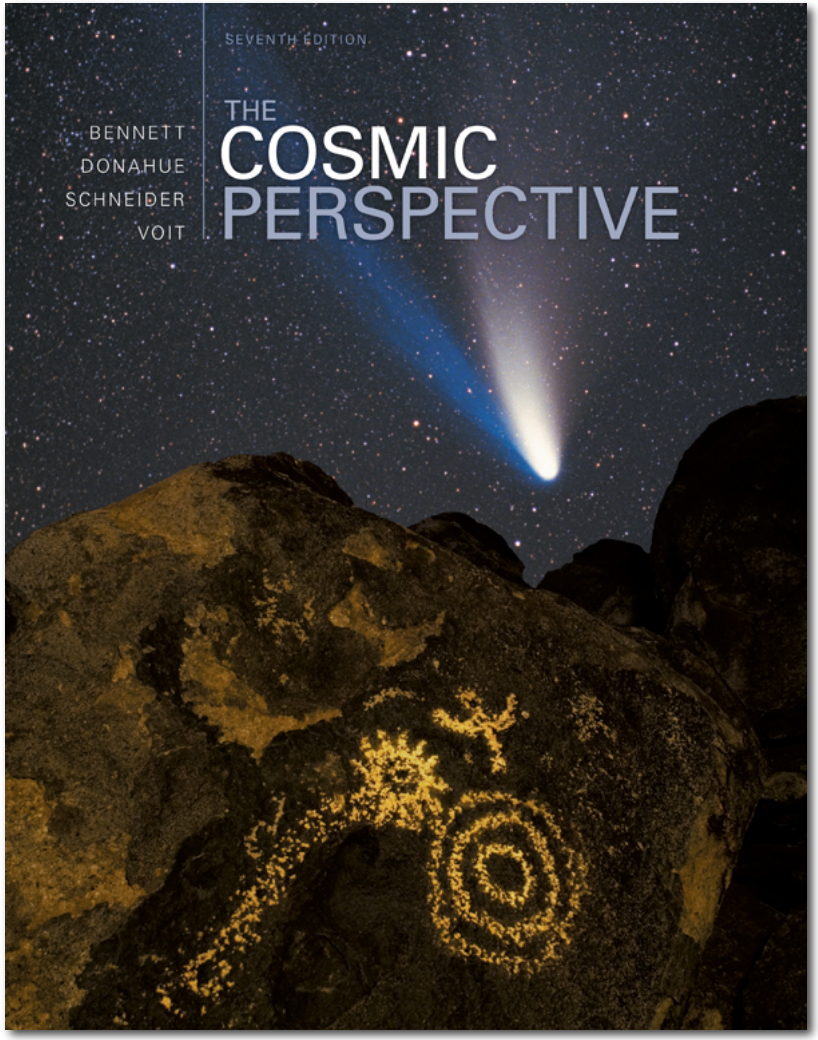
Chapter 7 Lecture

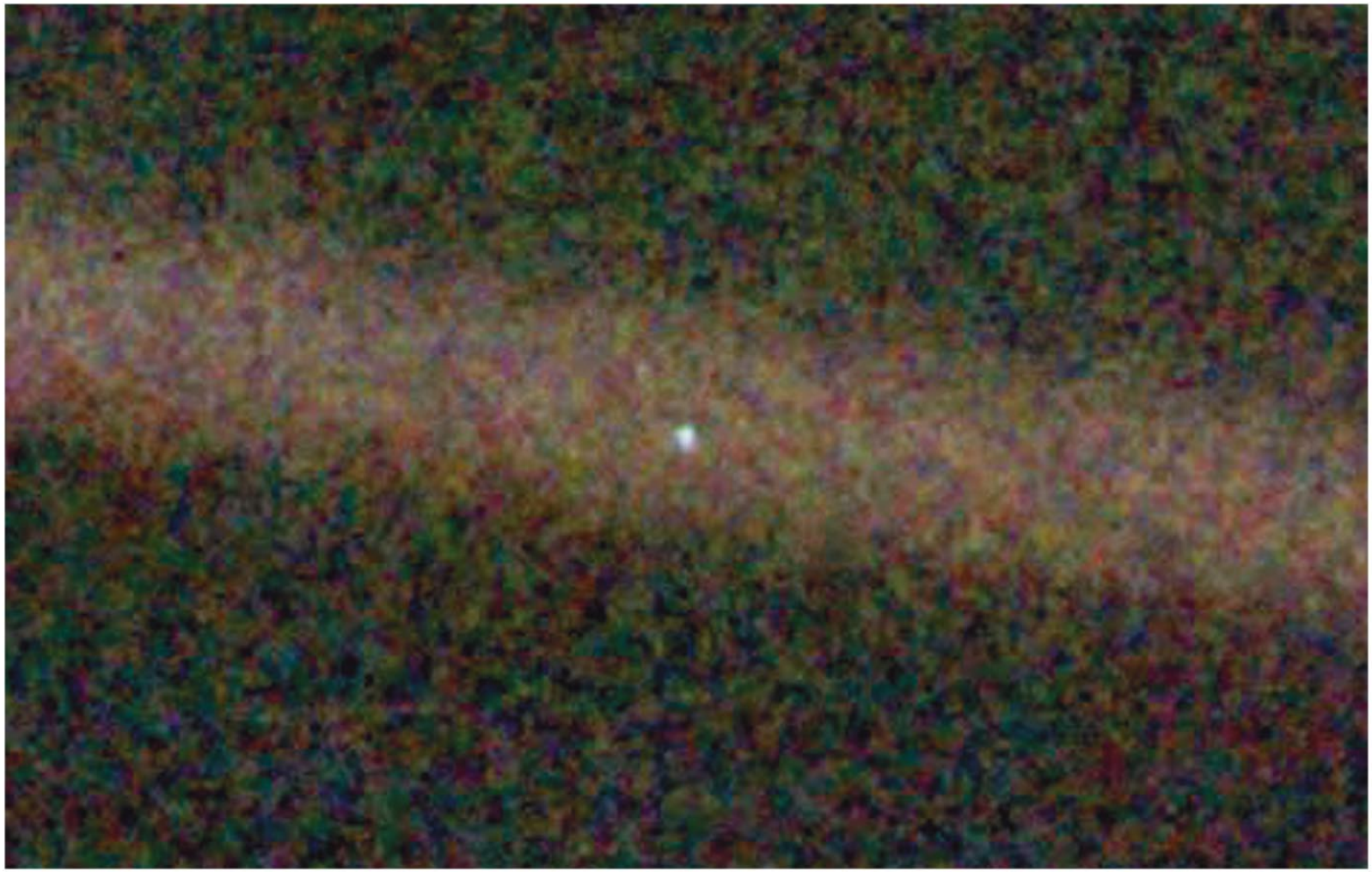
The Cosmic Perspective

Seventh Edition



Our Planetary System

Our Planetary System

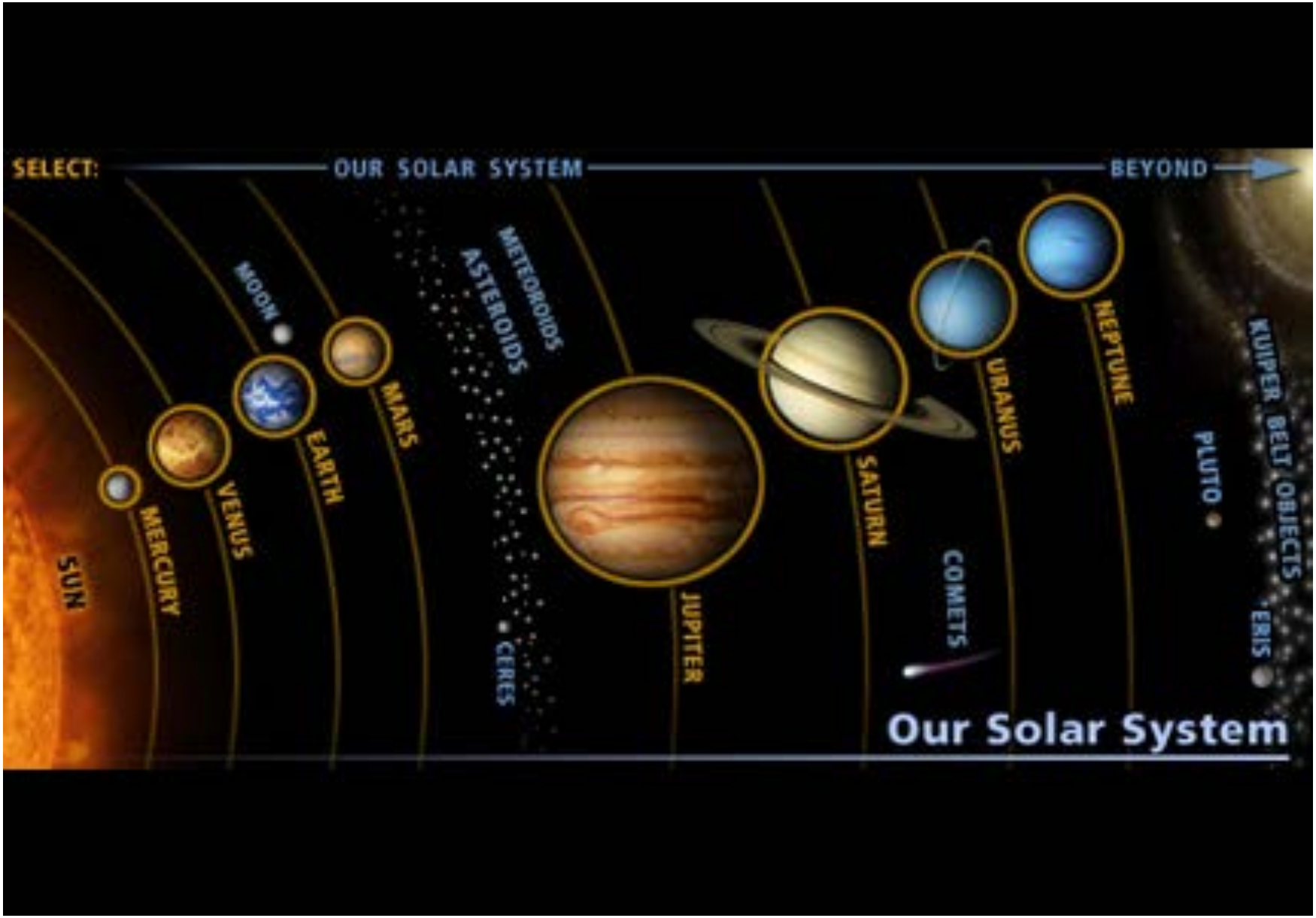


- Earth, as viewed by the *Voyager* spacecraft

7.1 Studying the Solar System

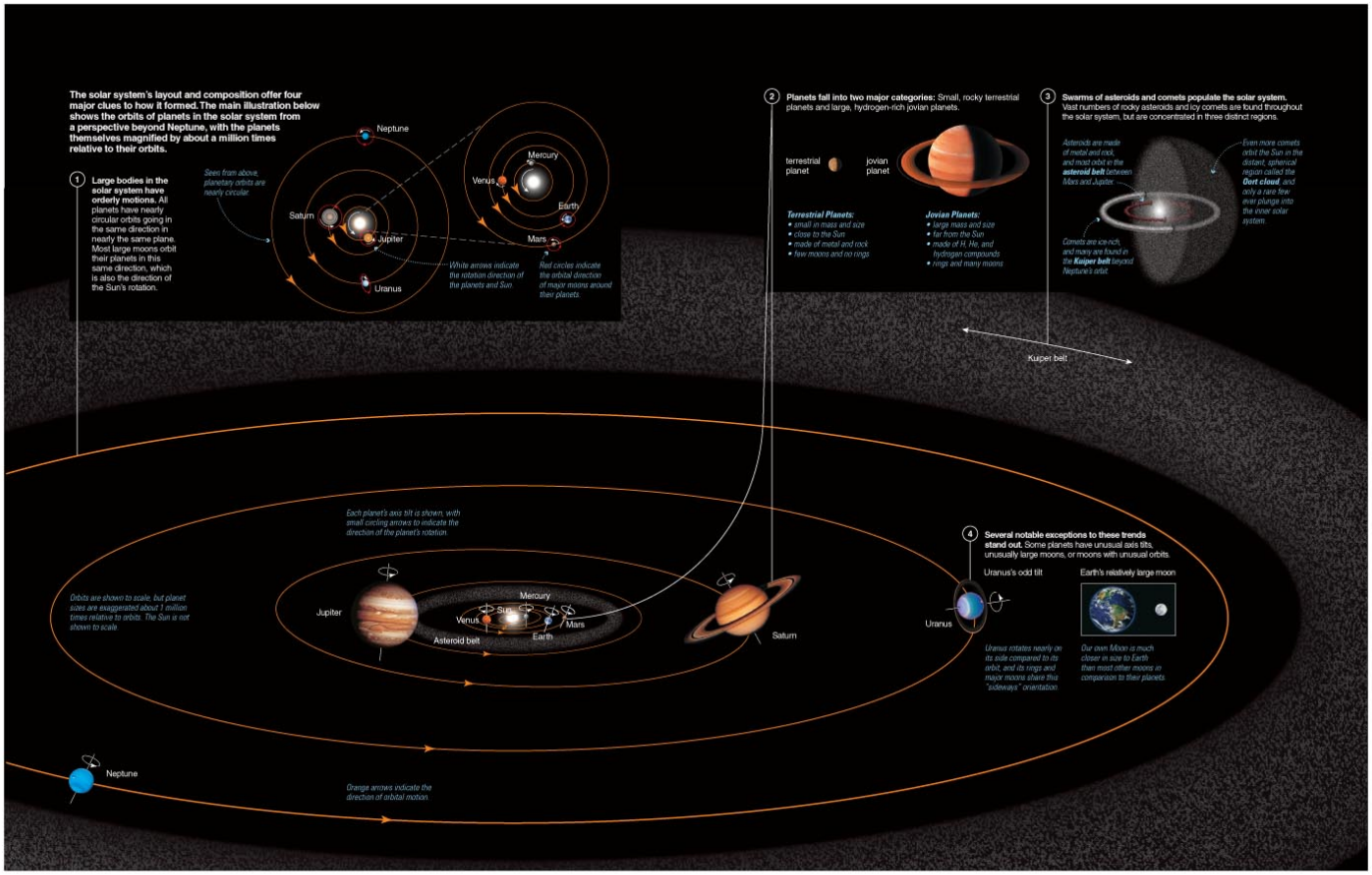
- Our goals for learning:
  - **What does the solar system look like?**
  - **What can we learn by comparing the planets to one another?**

What does the solar system look like?



What does the solar system look like?

- There are eight major planets with nearly circular orbits.
- Dwarf planets are smaller than the major planets and some have quite elliptical orbits.

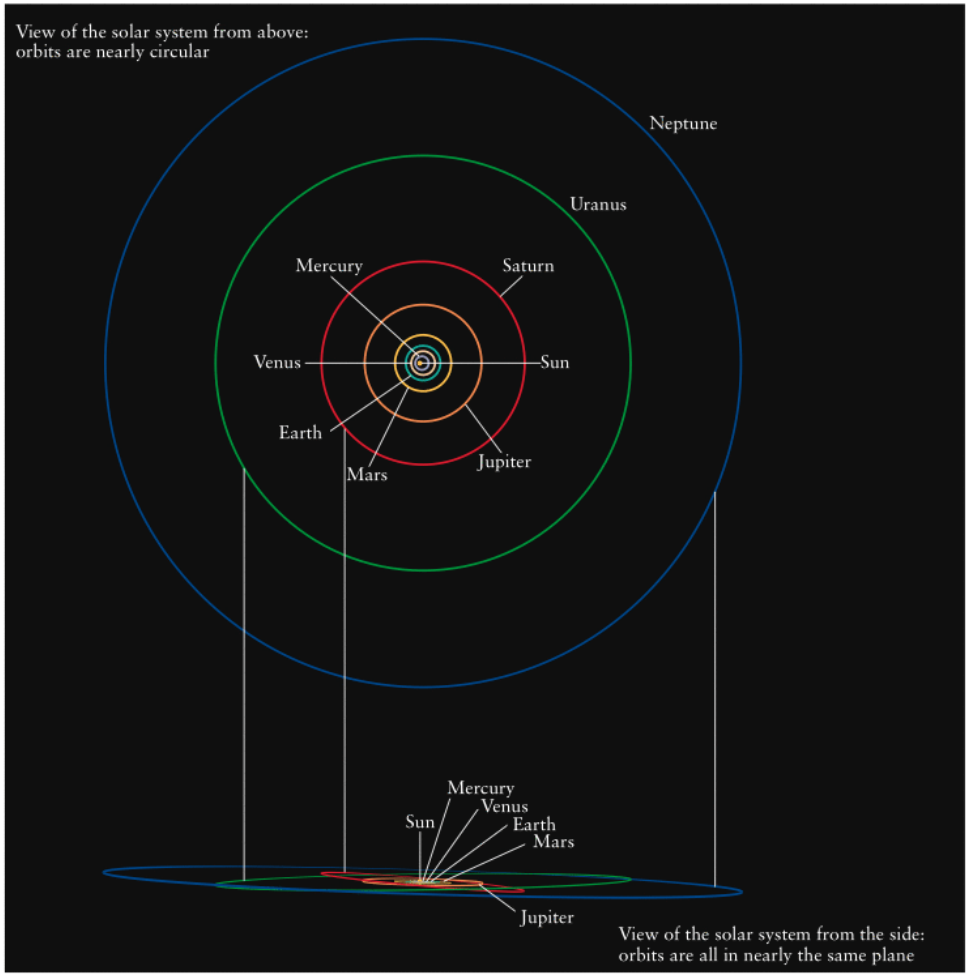


What does the solar system look like?

Viewed from several AU above the Earth's North pole all planets move in the same counterclockwise direction around the sun.

The orbits of the eight planets all lie in nearly the same plane.

The plane of the Sun's equator is very closely aligned with the orbital planes of the planets.



IAU's Planet Definition

The definition of a planet set in 2006 by the International Astronomical Union (IAU) states that in the Solar System 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 neighborhood" around its orbit.

A non-satellite body fulfilling only the first two of these criteria is classified as a dwarf planet. A non-satellite body fulfilling only the first criterion is termed a small solar system body.

Thought Question

How does the Earth–Sun distance compare with the Sun's radius?

a) It's about 10 times larger.
b) It's about 50 times larger.
c) It's about 200 times larger.
d) It's about 1000 times larger.

Thought Question

How does the Earth–Sun distance compare with the Sun's radius?

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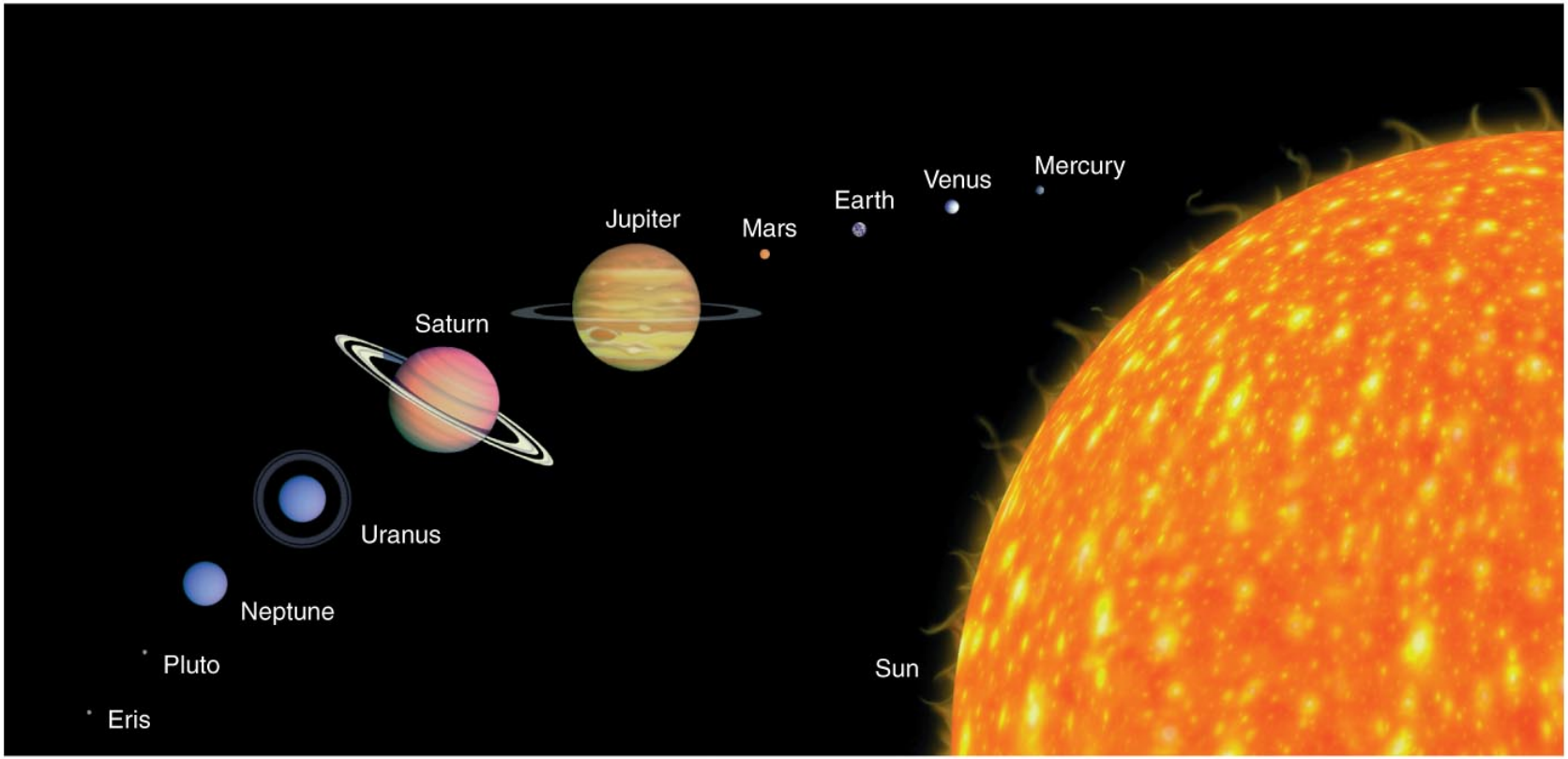
Comparative Planetology

- We can learn more about a world like our Earth by studying it in context with other worlds in the solar system.
- Stay focused on *processes* common to multiple worlds instead of individual facts specific to a particular world.

What are the major features of the Sun and planets?



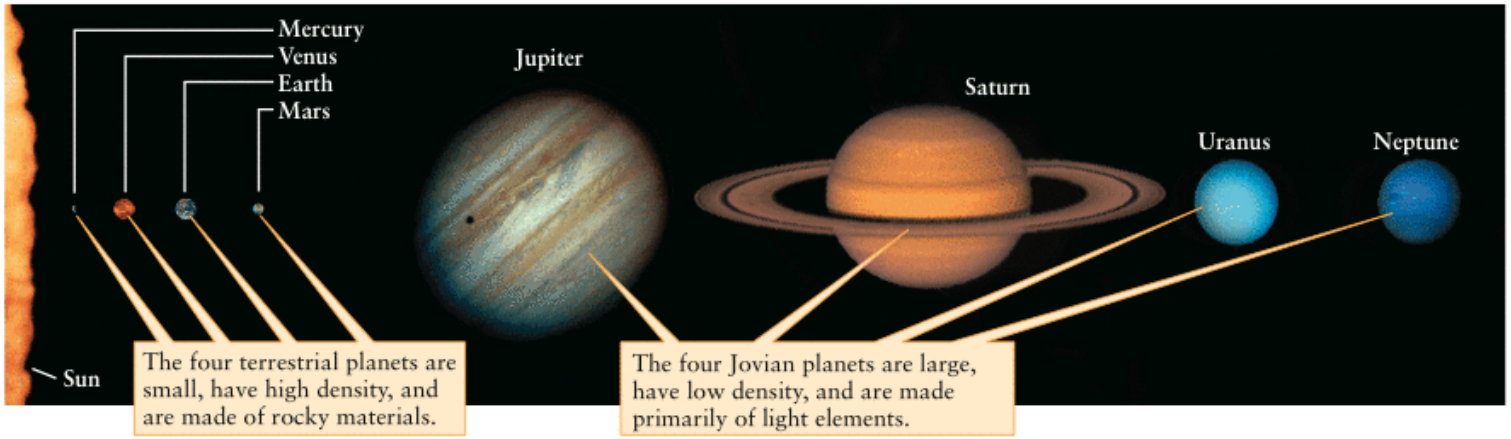
- Sun and planets to scale

Physical Properties of Planets

Terrestrial (resemble Earth): Mercury, Venus, Earth, Mars
Hard, rocky surfaces, craters, valleys and volcanoes

Jovian (resemble Jupiter): Jupiter, Saturn, Uranus, Neptune
These are made of gaseous and/or liquid materials.

The Diameters and Masses of Jovian planets are significantly larger than Terrestrial ones.



Average Density of a Planet

$$\rho = \frac{M}{V}$$

Determine the mass, M, of a planet using Newton's form of Kepler's 3rd Law.

Using the small-angle formula one may determine the diameter of a planet from its observed angular size and its distance from Earth.

Average Density of a Planet

$\rho_{air} \sim 1.2\ kg/m^3$, $\rho_{water} \sim 1000\ kg/m^3$

$\rho_{Saturn(average)} \sim 687\ kg/m^3$, $\rho_{Earth(average)} \sim 5515\ kg/m^3$

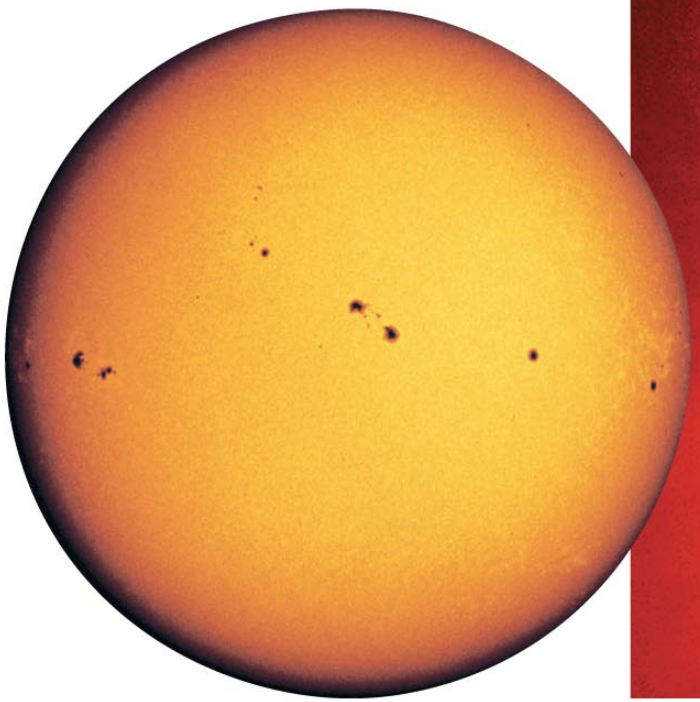
$\rho_{Jovian\ planets} < \rho_{Terrestrial\ planets}$

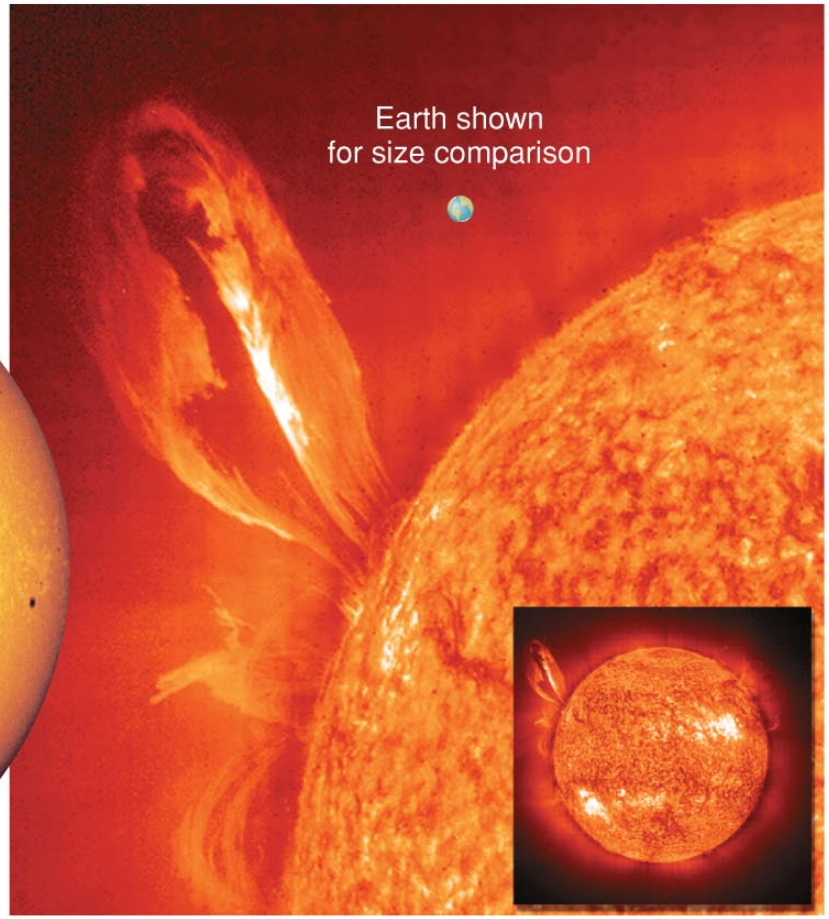
The terrestrial planets are made of rocky materials and have dense iron cores, which gives these planets high average densities.

The Jovian planets are composed primarily of light elements such as hydrogen and helium, which gives these planets low average densities.

Chemical differentiation:
$\rho_{Earth(average)} \sim 5515\ kg/m^3$, $\rho_{Earth(surface\ rock)} \sim 3000\ kg/m^3$

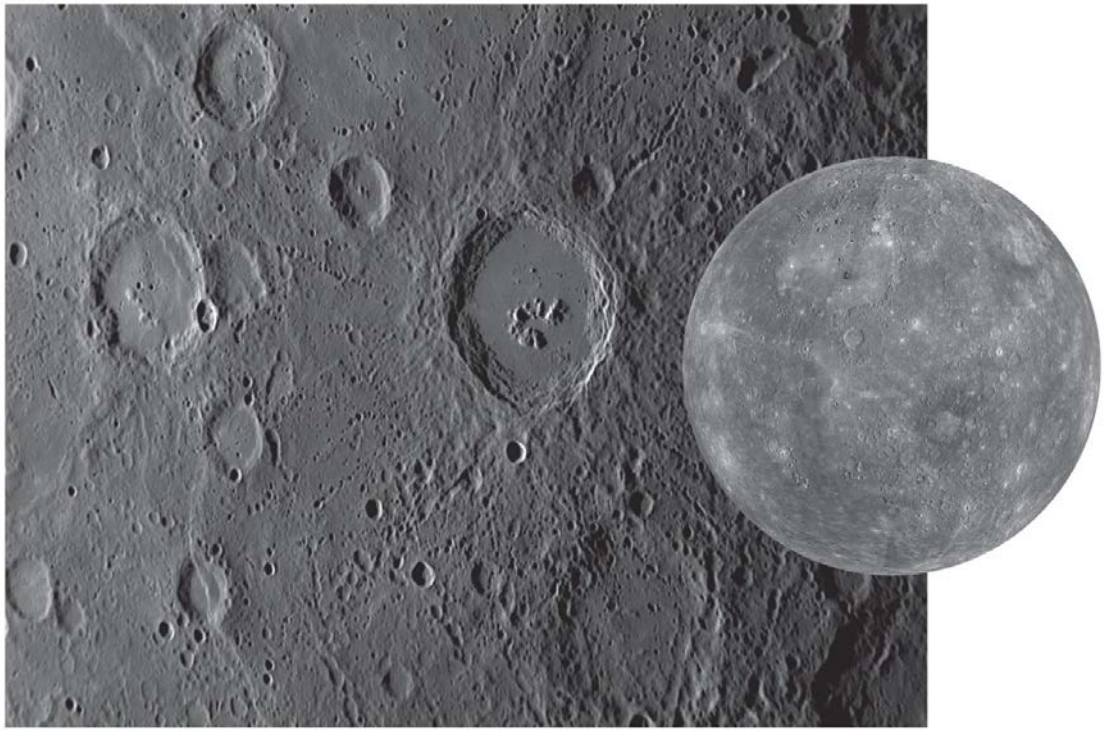
Sun





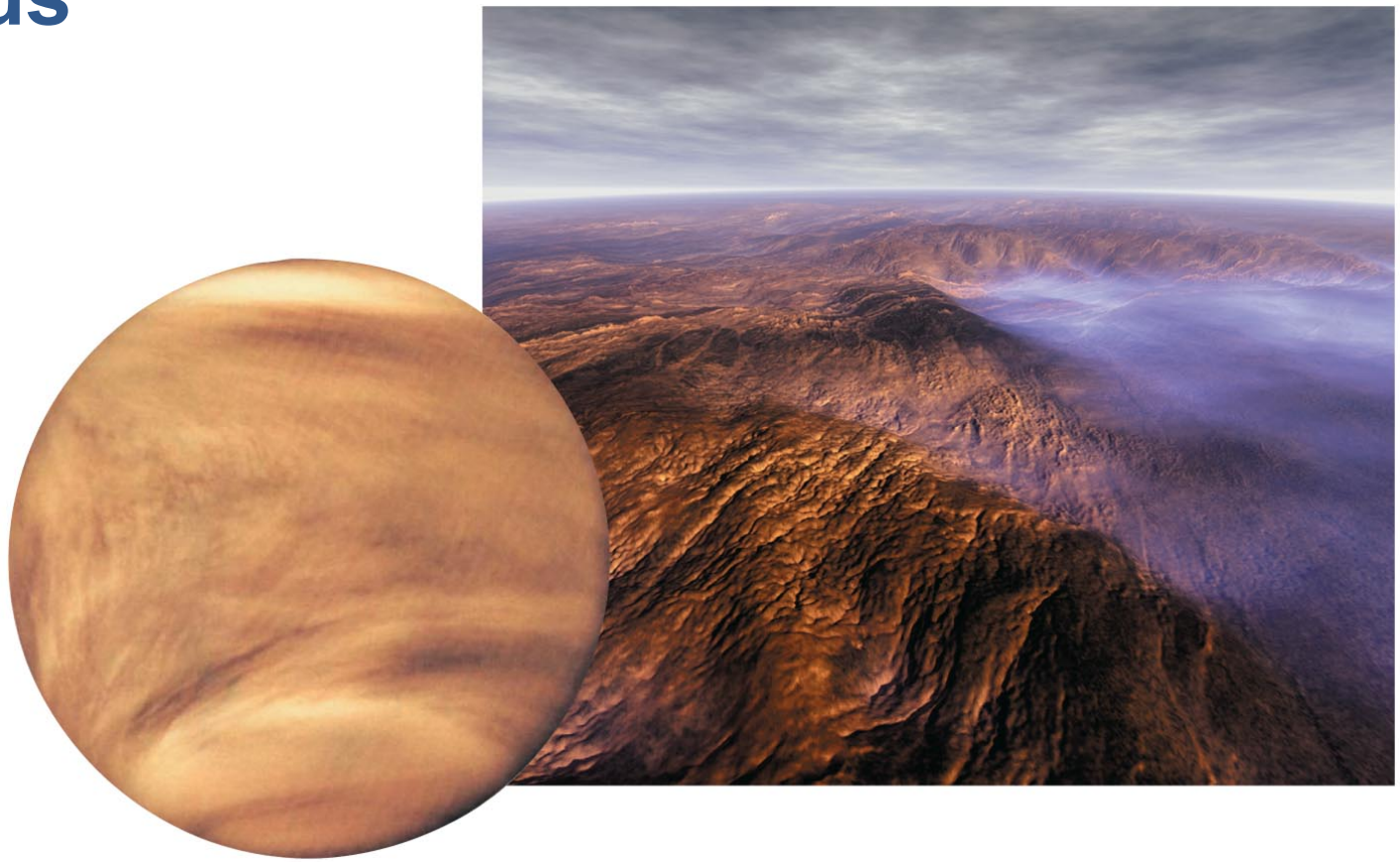
- Over 99.9% of solar system's mass
- ~98% H and He (by mass) and ~2% other elements
- Converts 4 million tons of mass into energy each second
- $R_{Sun} = 108R_{Earth}$

Mercury



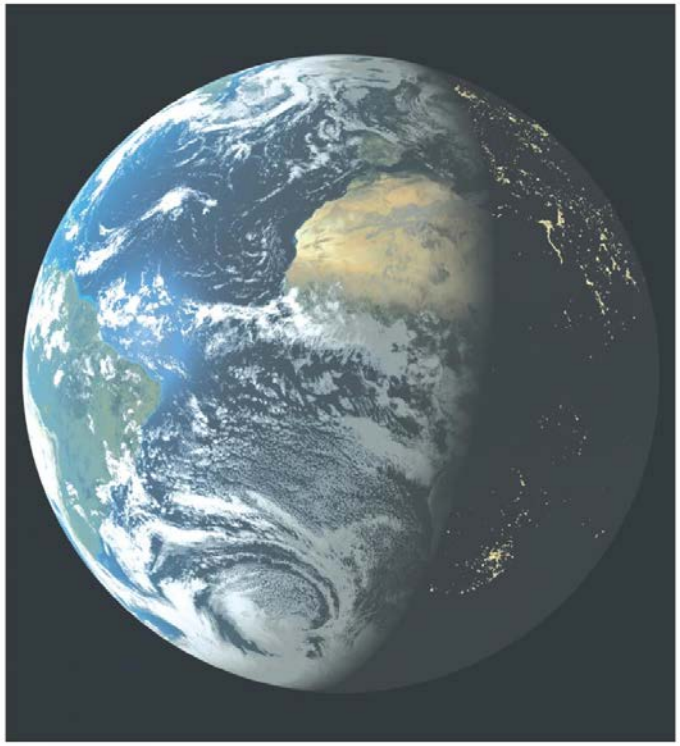
- Made of metal and rock; large iron core
- Desolate, cratered; long, tall, steep cliffs
- Evidence for past geological activity
- Very hot, very cold: 425°C (day), –170°C (night)
- 3-2 Spin-Orbit coupling
- Average density: 5,430 kg/m^3 (very large implying large iron core)

Venus



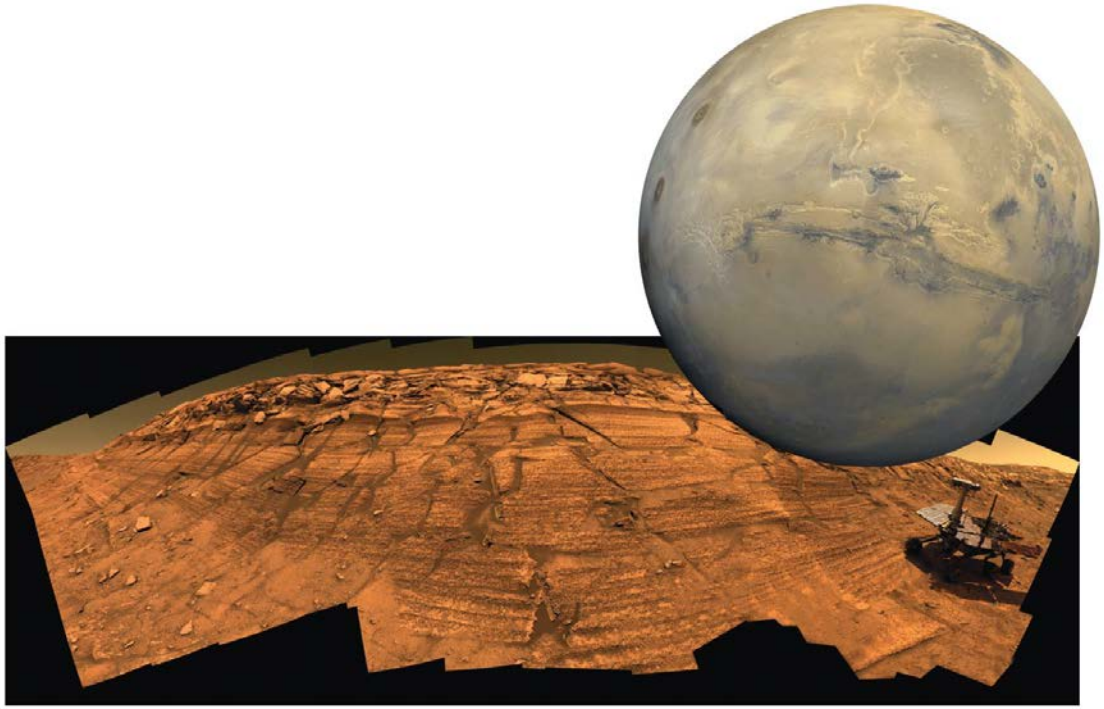
- Nearly identical in size to Earth; surface hidden by clouds
- Hellish conditions due to an extreme **greenhouse effect**
- Even hotter than Mercury: 470°C, day and night
- It rotates slowly around its axis in the opposite direction of Earth

Earth



- An oasis of life
- The only surface liquid water in the solar system
- A surprisingly large moon
- Average density: 5520 kg/m^3
- Only planet with oxygen to breathe and ozone to protect from solar radiation

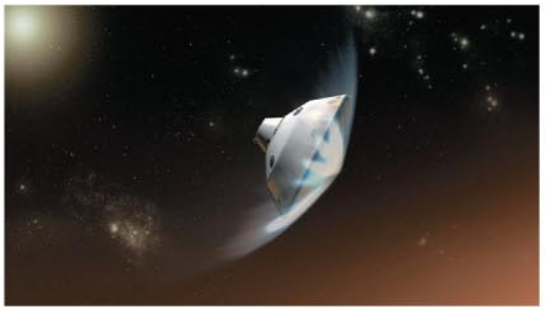
Mars



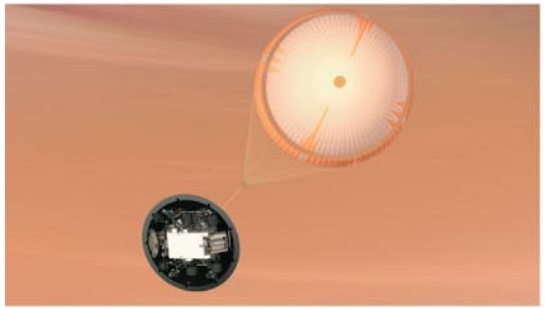
- Looks almost Earth-like, but don't go without a spacesuit!
- Giant volcanoes, a huge canyon, polar caps of frozen CO_2 and H_2O
- Water flowed in distant past; could there have been life?
- Average density 3930 kg/m3
- Two moons: Phobos and Demos, likely captured asteroids
- Many spacecraft have orbited or landed on Mars

Mars

- *Curiosity* rover landed in August 2012.

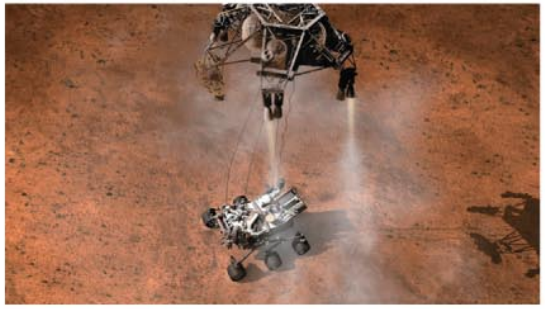


1 Friction slows spacecraft as it enters Mars atmosphere.

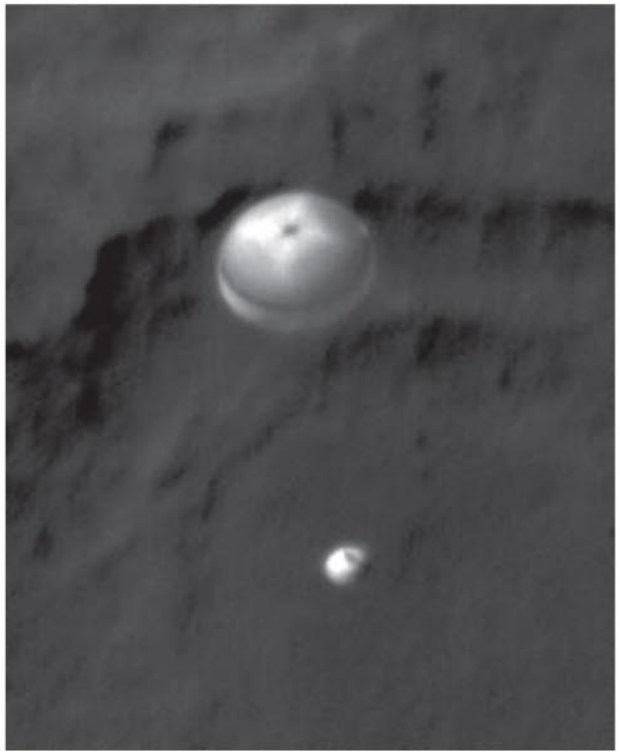


2 Parachute slows spacecraft to about 350 km/hr.

3 Rockets slow spacecraft to halt; "sky crane" tether lowers rover to surface.

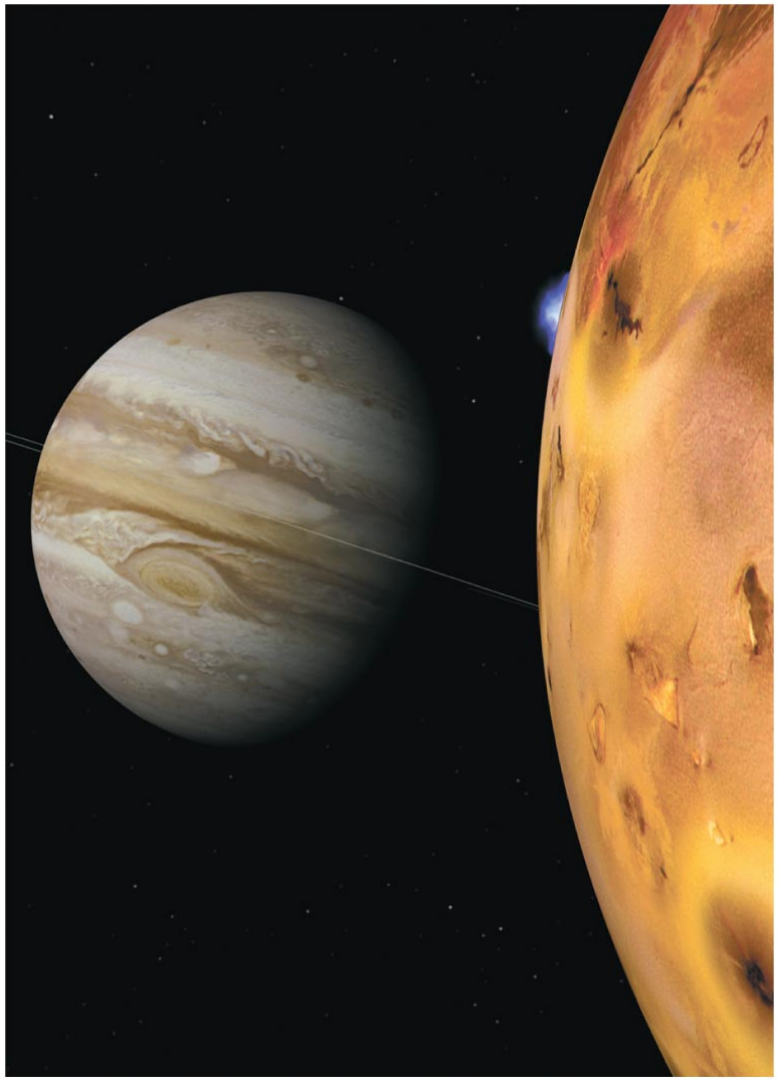


4 Tether released, the rocket heads off to crash a safe distance away.



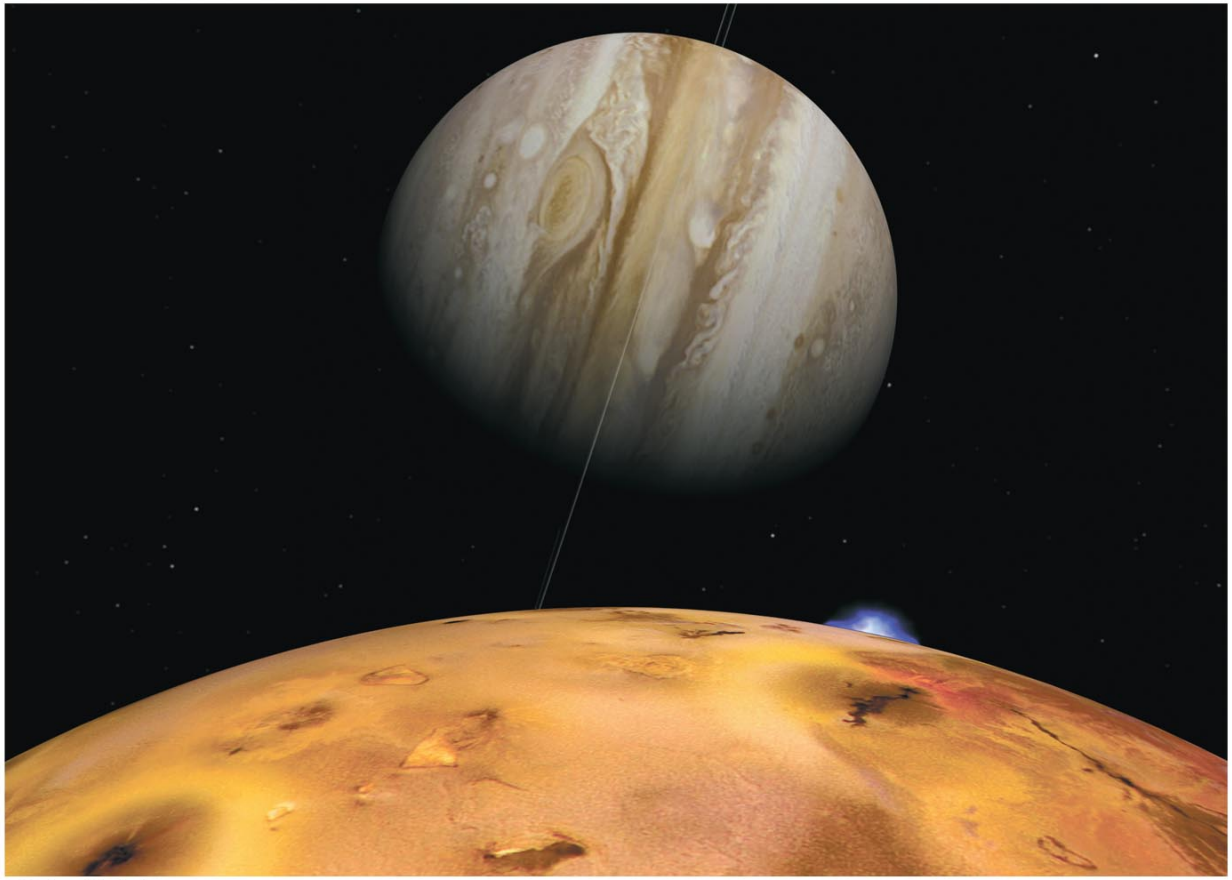
As it flew overhead, the *Mars Reconnaissance Orbiter* took this photo of the spacecraft with its parachute deployed.

Jupiter



- Much farther from Sun than inner planets (~5.2 AU)
- Mostly H/He; no solid surface
- 300 times more massive than Earth
- Many moons, rings
- Average Density=1330kg/m^3
- Great Red Spot (storm)

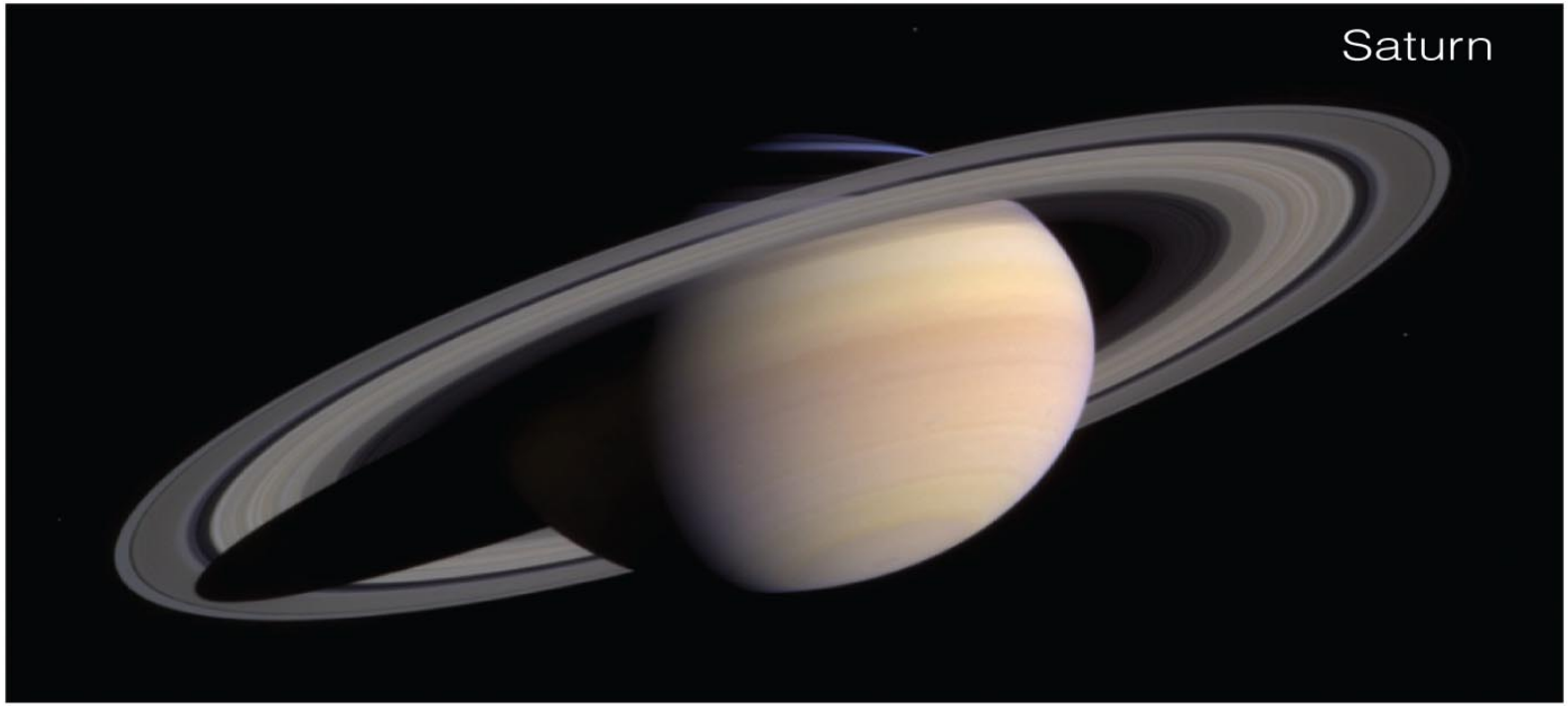
Jupiter



Jupiter's moons can be as interesting as planets themselves, especially Jupiter's four *Galilean moons*.

- Io (shown here): active volcanoes all over
- Europa: possible subsurface ocean
- Ganymede: largest moon in solar system
- Callisto: a large, cratered "ice ball"

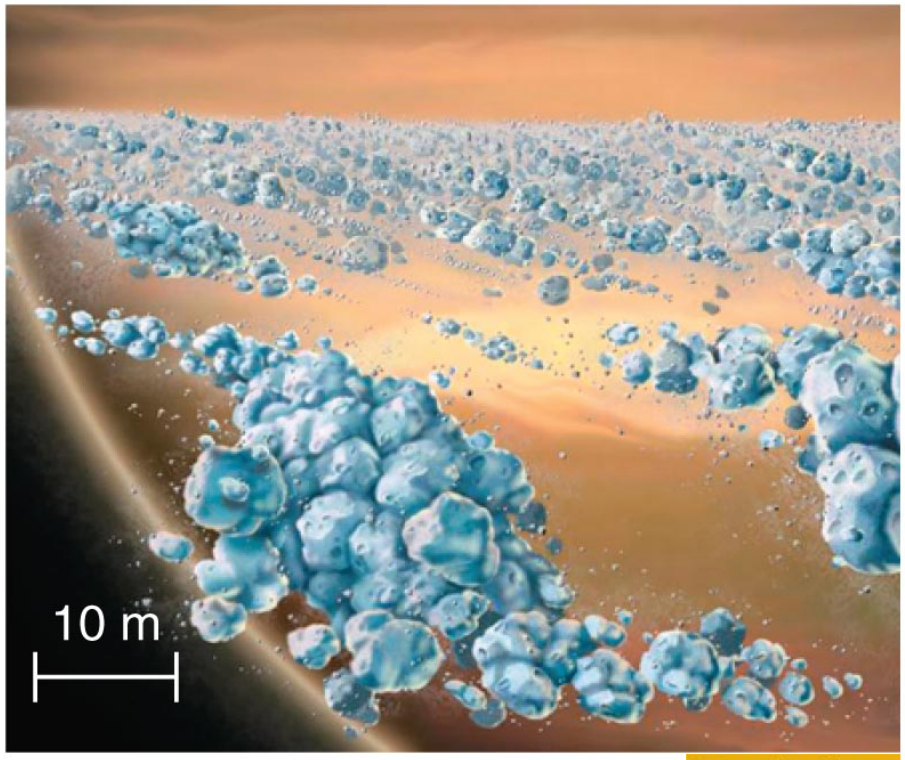
Saturn



- Giant and gaseous like Jupiter
- Spectacular rings
- Many moons, including cloudy Titan and Enceladus
- Average Density: 700 kg/m3
- Average Distance: 9.54AU

Saturn

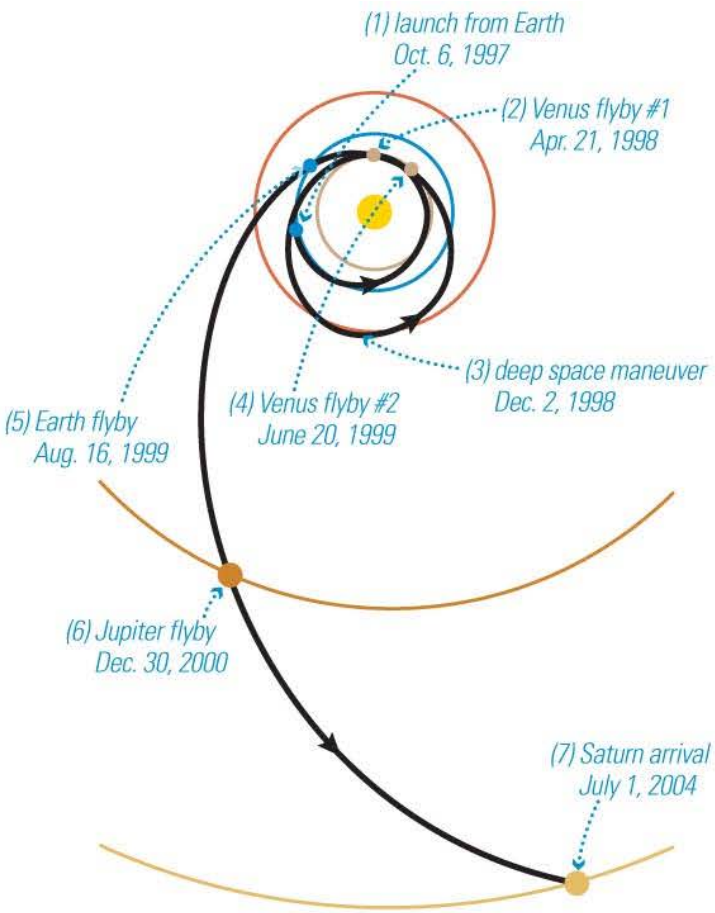
- Rings are NOT solid; they are made of countless small chunks of ice and rock, each orbiting like a tiny moon.



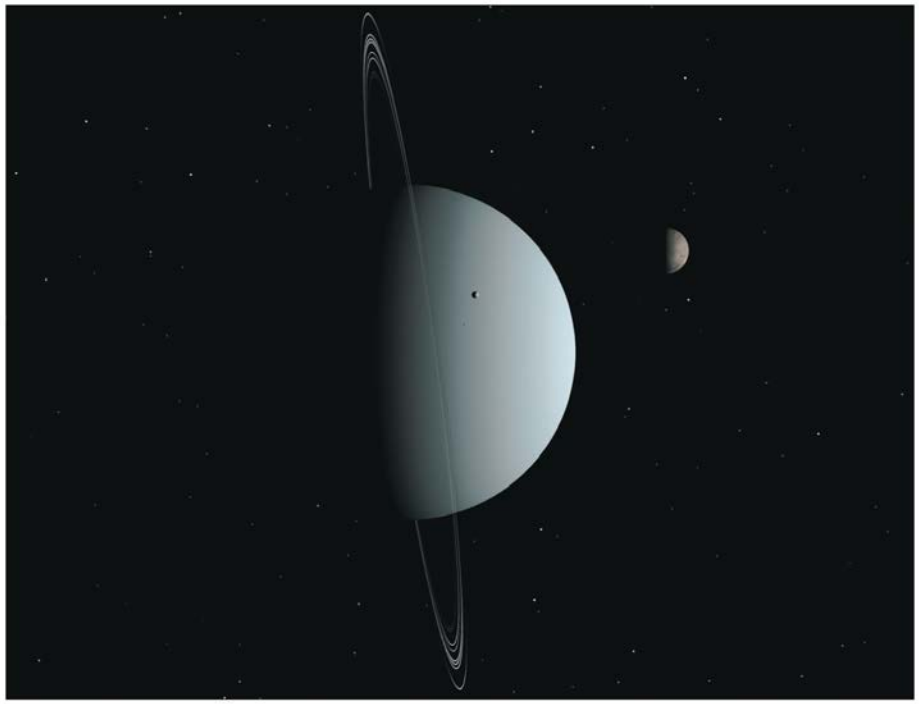
Interactive Figure

Saturn

- *Cassini* probe arrived July 2004 (launched in 1997).

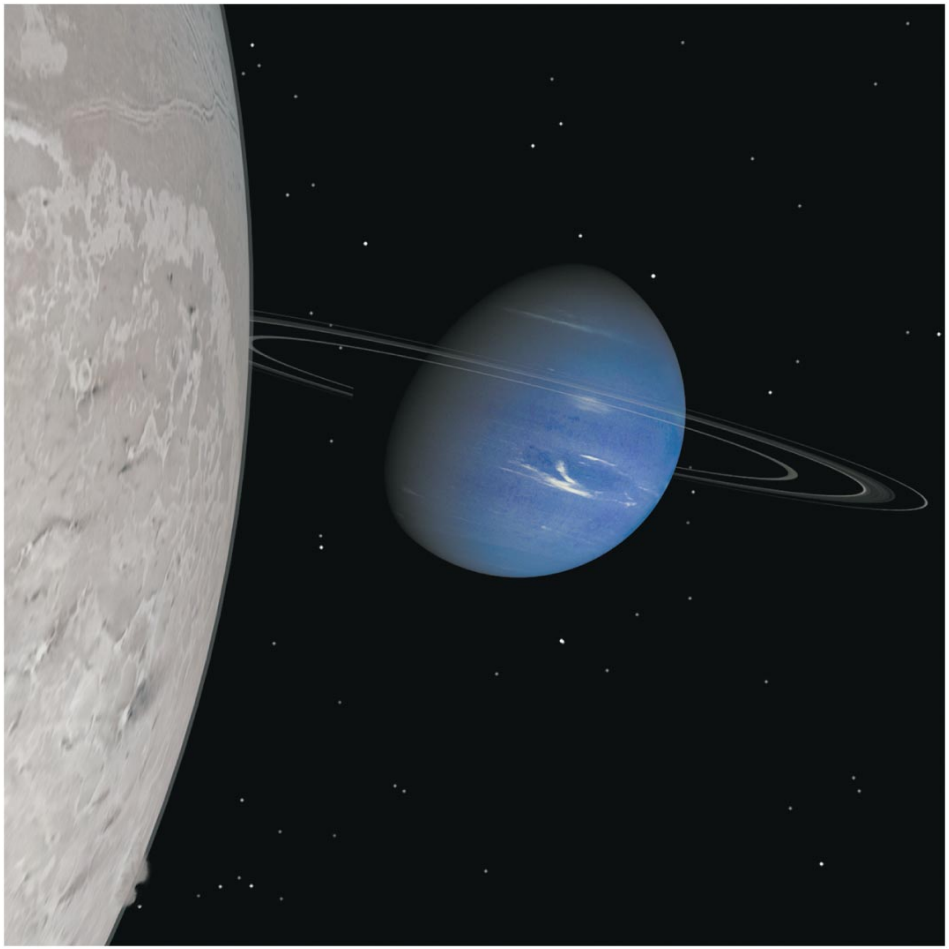


Uranus



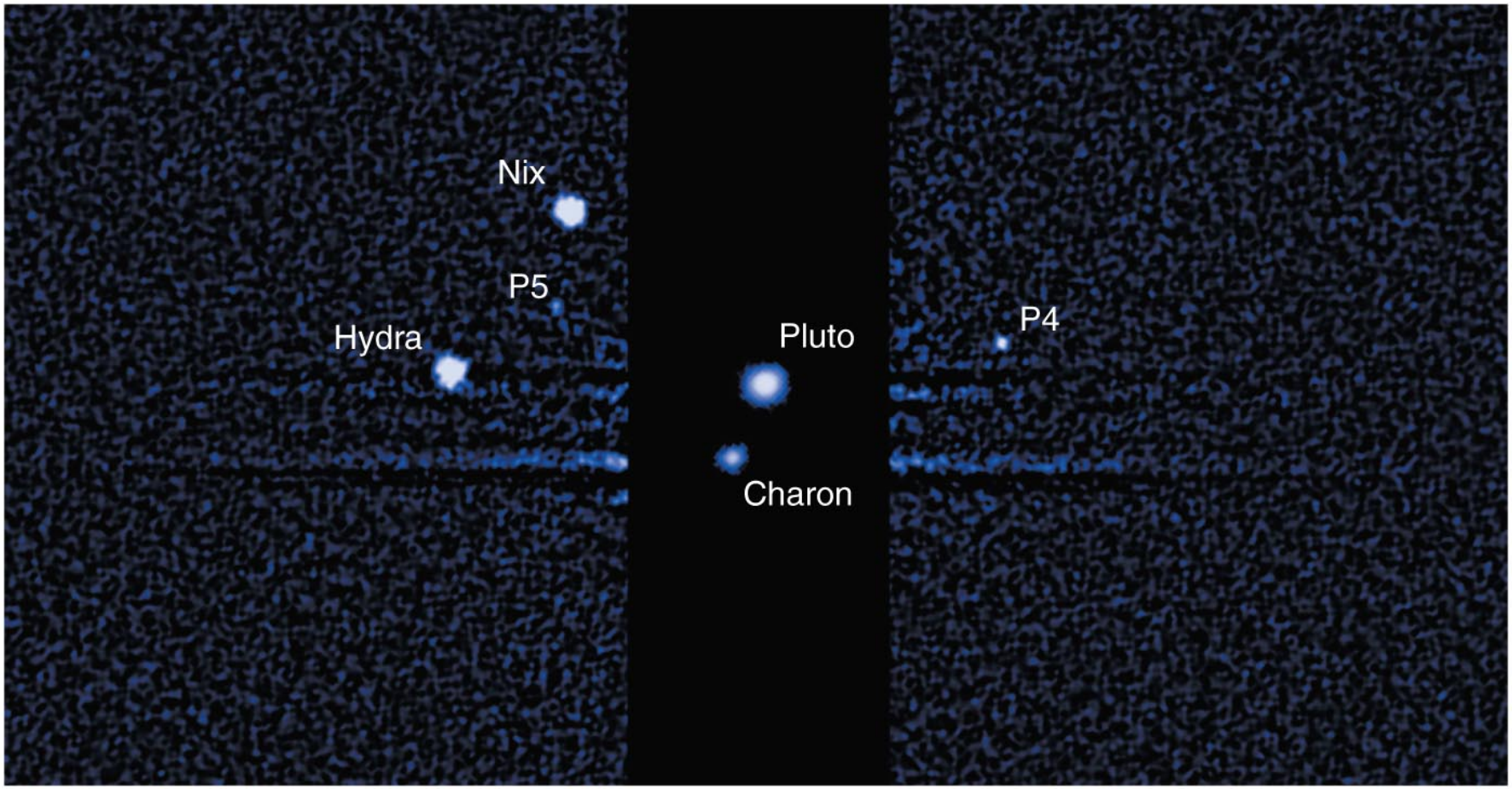
- Smaller than Jupiter/Saturn; much larger than Earth
- Made of H/He gas and **hydrogen compounds** (H_2O, NH_3, CH_4)
- Methane gives it its pale blue-green color
- Extreme axis tilt (collision?)
- Moons and rings
- Average Distance: 19.2 AU

Neptune



- Similar to Uranus (except for axis tilt)
- Many moons (including Triton)
- Average Distance: 30.1 AU

Dwarf Planets: Pluto, Eris, and more



- Much smaller than major planets
- Icy, comet-like composition
- Pluto's main moon (Charon) is of similar size

Table 7.1

TABLE 7.1 The Planetary Data[a]

Photo	Planet	Relative Size	Average Distance from Sun (AU)	Average Equatorial Radius (km)	Mass (Earth = 1)	Average Density (g/cm^3)	Orbital Period	Rotation Period	Axis Tilt	Average Surface (or Cloud-Top) Temperature[b]	Composition	Known Moons (2012)	Rings?
	Mercury	·	0.387	2440	0.055	5.43	87.9 days	58.6 days	0.0°	700 K (day) 100 K (night)	Rocks, metals	0	No
	Venus	•	0.723	6051	0.82	5.24	225 days	243 days	177.3°	740 K	Rocks, metals	0	No
	Earth	•	1.00	6378	1.00	5.52	1.00 year	23.93 hours	23.5°	290 K	Rocks, metals	1	No
	Mars	·	1.52	3397	0.11	3.93	1.88 years	24.6 hours	25.2°	220 K	Rocks, metals	2	No
	Jupiter	●	5.20	71,492	318	1.33	11.9 years	9.93 hours	3.1°	125 K	H, He, hydrogen compounds[c]	67	Yes
	Saturn	●	9.54	60,268	95.2	0.70	29.5 years	10.6 hours	26.7°	95 K	H, He, hydrogen compounds[c]	62	Yes
	Uranus	●	19.2	25,559	14.5	1.32	83.8 years	17.2 hours	97.9°	60 K	H, He, hydrogen compounds[c]	27	Yes
	Neptune	●	30.1	24,764	17.1	1.64	165 years	16.1 hours	29.6°	60 K	H, He, hydrogen compounds[c]	13	Yes
	Pluto	·	39.5	1160	0.0022	2.0	248 years	6.39 days	112.5°	44 K	Ices, rock	5	No
	Eris	·	67.7	1200	0.0028	2.3	557 years	1.08 days	78°	43 K	Ices, rock	1	No

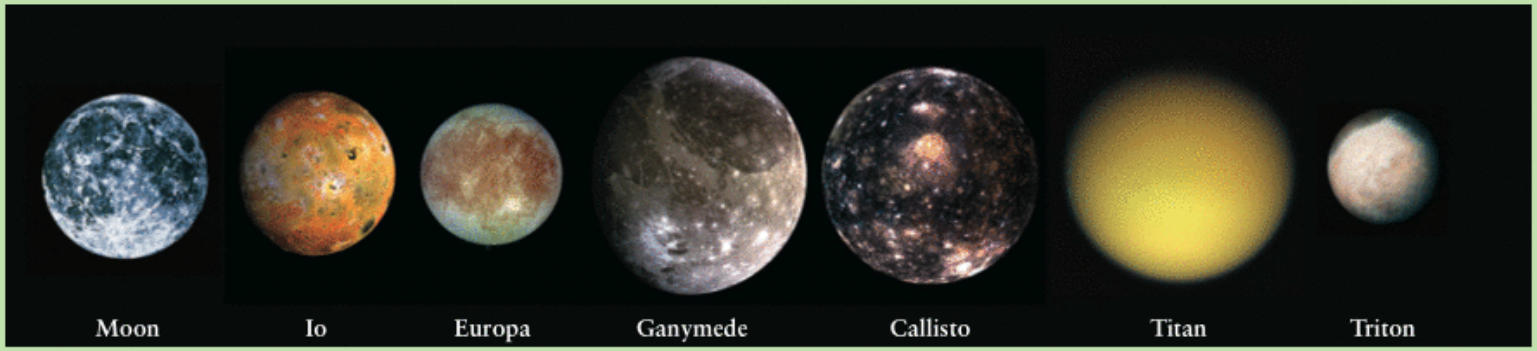
[a]Including the dwarf planets Pluto and Eris; Appendix E gives a more complete list of planetary properties.
[b]Surface temperatures for all objects except Jupiter, Saturn, Uranus, and Neptune, for which cloud-top temperatures are listed.
[c]Include water (H_2O), methane (CH_4), and ammonia (NH_3).

Comparing the Properties of Satellites

WEB LINK 7.3

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)	7.35×10^{22}	8.93×10^{22}	4.80×10^{22}	1.48×10^{23}	1.08×10^{23}	1.34×10^{23}	2.15×10^{22}
Average density (kg/m^3)	3340	3530	2970	1940	1850	1880	2050
Substantial atmosphere?	No	No	No	No	No	Yes	No



RIVUXG
(NASA/JPL/Space Science Institute)

Terrestrial planets have fewer moons than Jovian planets

Lower densities in Ganymede, Callisto, Titan, and Triton implies that they may contain cores made of frozen ice.

Chemical Composition from Spectra

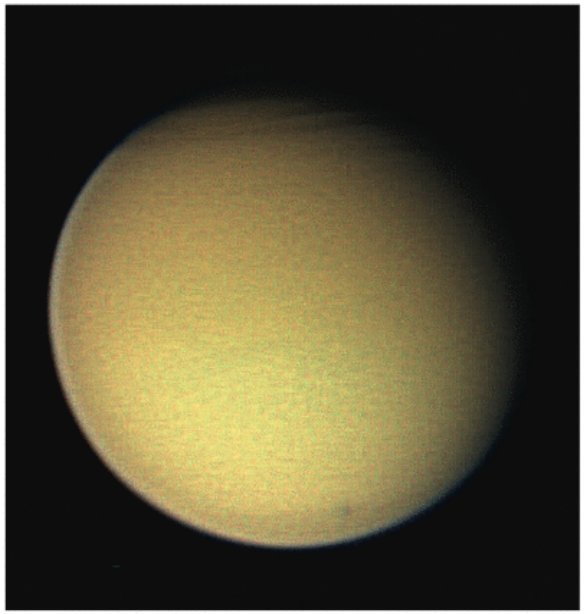
The chemical composition of planets can be obtained from :

1. their average density (rough estimate),

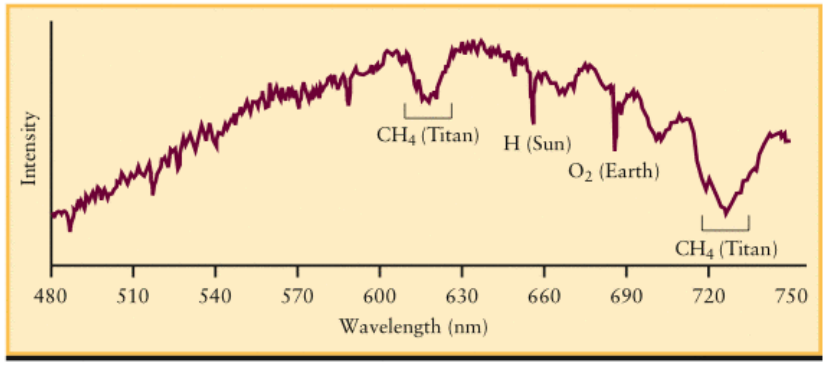
2. the analysis of samples of soil and/or atmosphere (accurate method), and

3. the study of light reflected from the planets and satellites (spectroscopy).

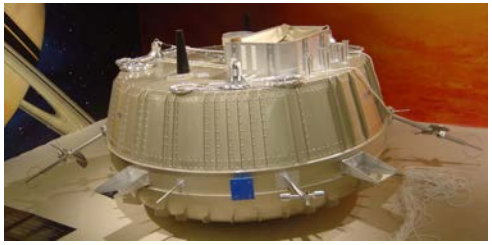
Atmospheric Chemical Composition



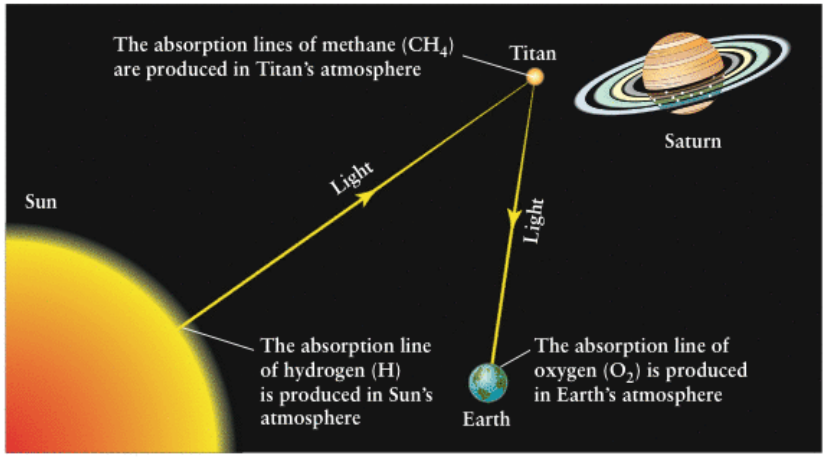
(a) Saturn's satellite Titan



(b) The spectrum of sunlight reflected from Titan



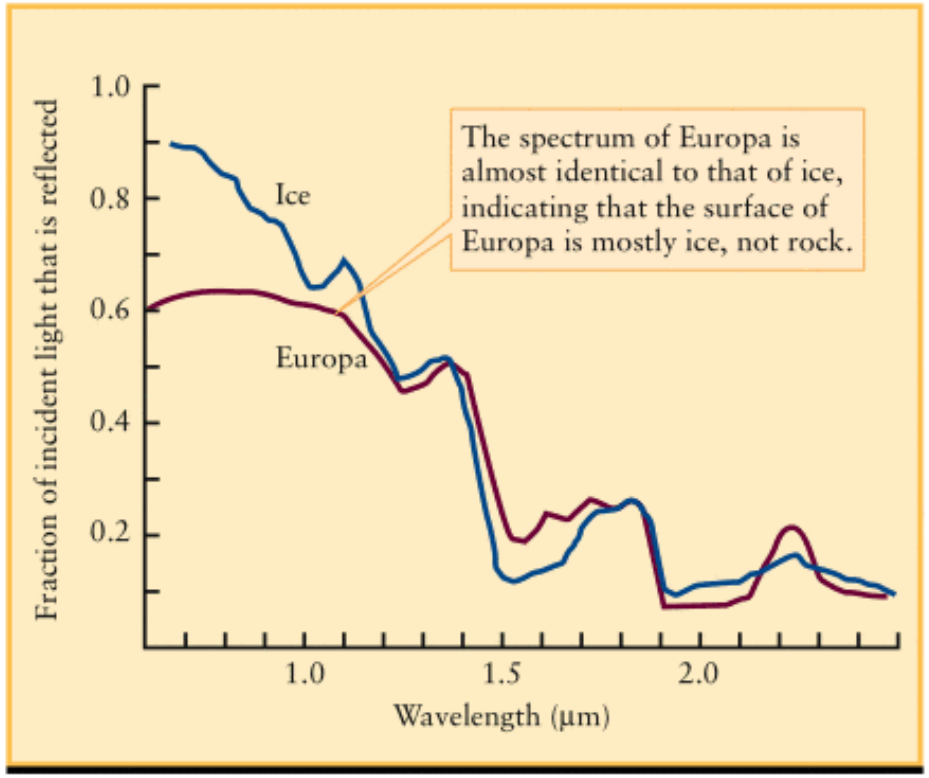
Huygen's Probe landed on Titan



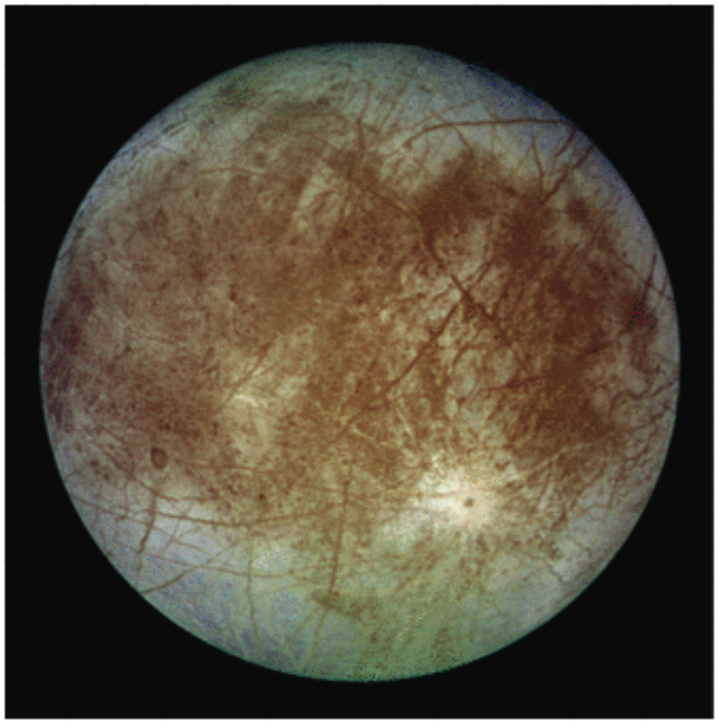
(c) Interpreting Titan's spectrum

Spectrum : The intensity of the electromagnetic radiation of a source as a function of wavelength

Surface Chemical Composition



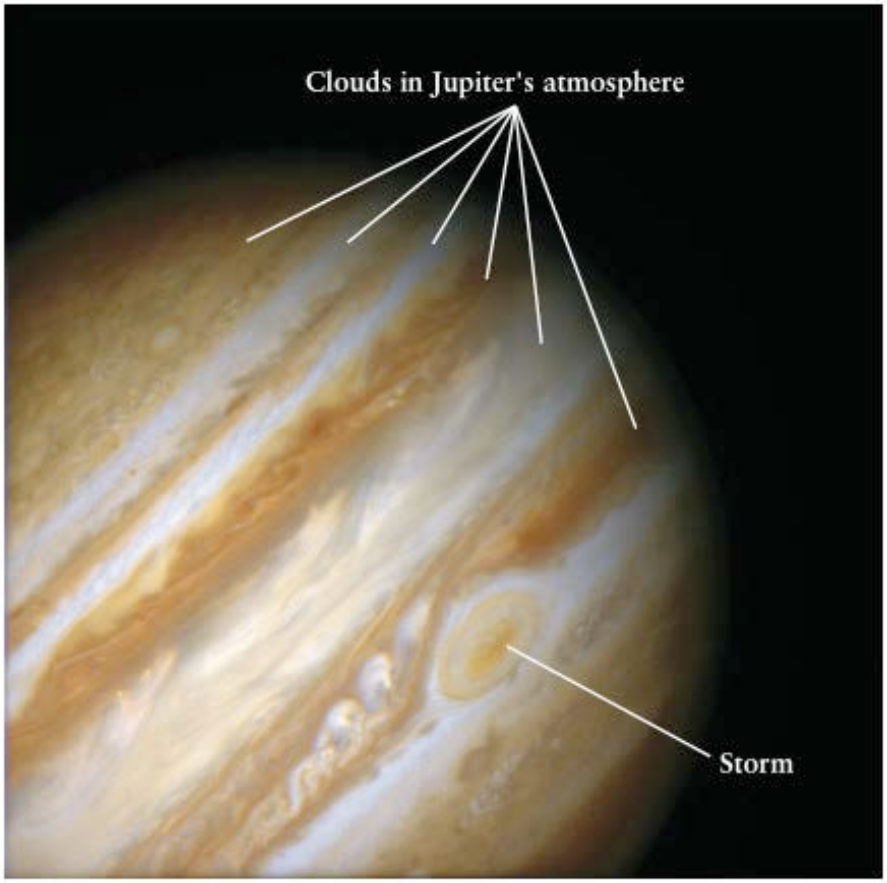
(a) The spectum of light reflected from Europa



(b) Jupiter's moon Europa

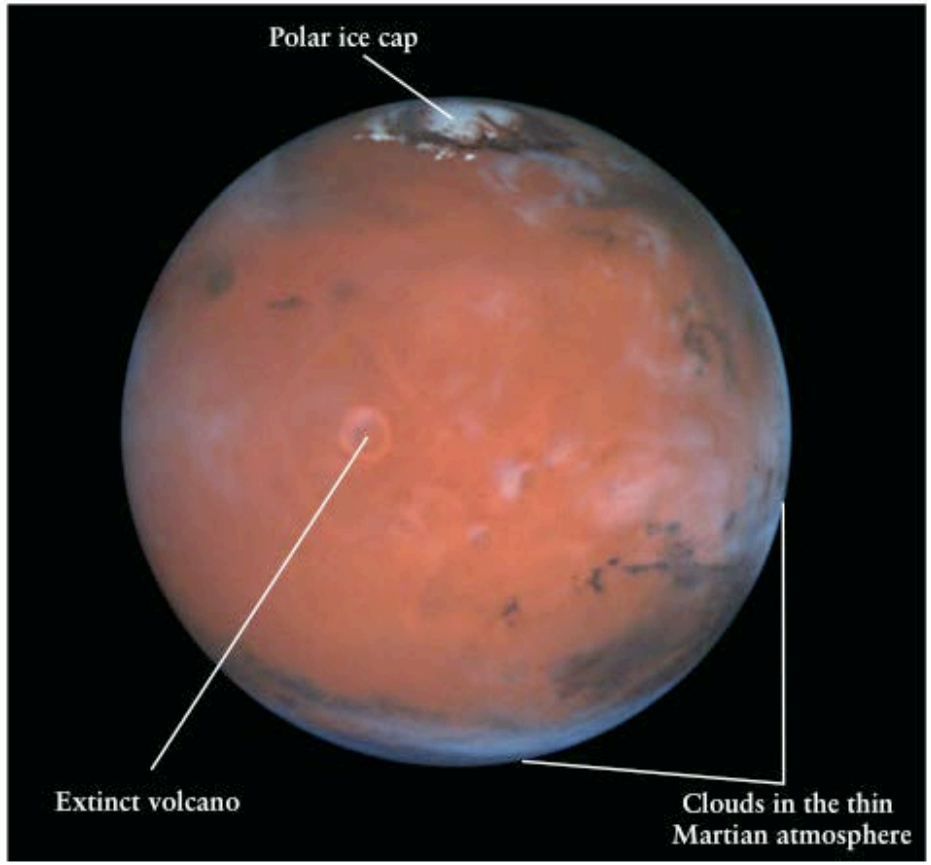
Chemical Composition of Jovian Planets

This Hubble Space Telescope image gives a detailed view of Jupiter's cloud-tops. **Jupiter is composed mostly of the lightest elements, hydrogen and helium.**



Chemical Composition of Terrestrial Planets

Mars is composed mostly of heavy elements such **as iron, oxygen, silicon, magnesium, nickel, and sulfur.**



Thought Question

What process created the elements from which the terrestrial planets were made?

a) the Big Bang
b) nuclear fusion in stars
c) chemical processes in interstellar clouds
d) their origin is unknown.

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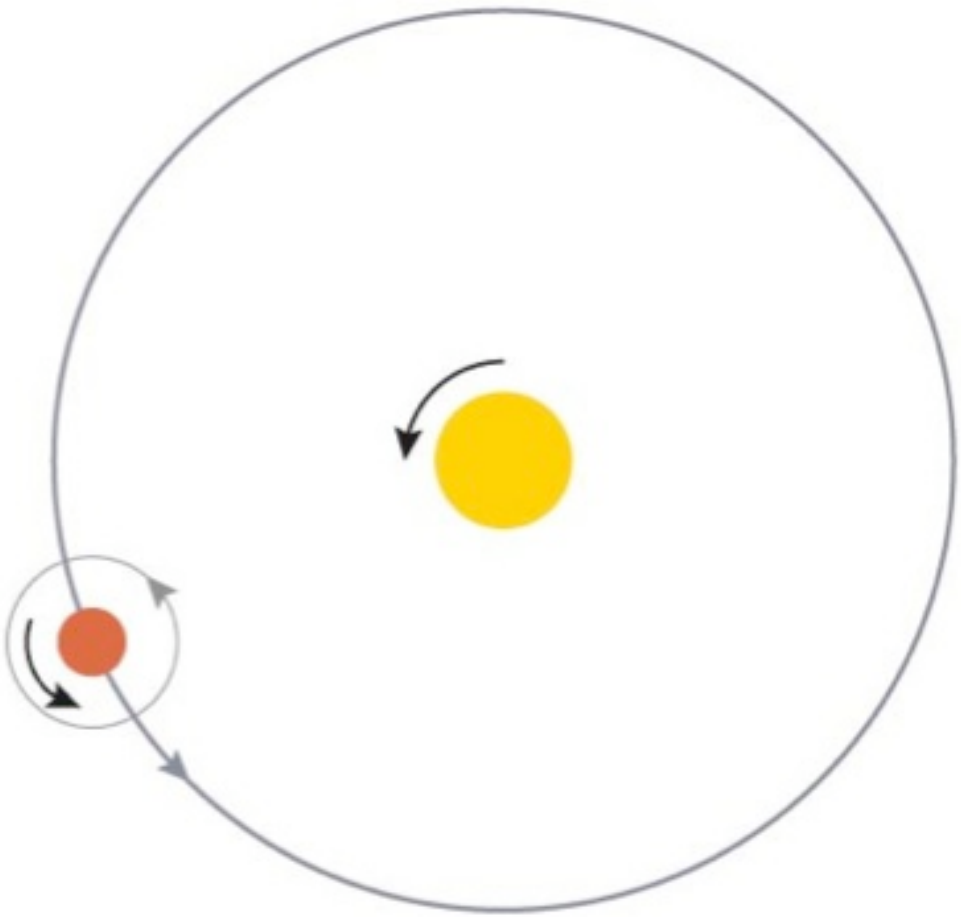
What have we learned?

- **What does the solar system look like?**
  - Planets orbit Sun in the same direction and in nearly the same plane.
- **What can we learn by comparing the planets to one another?**
  - Comparative planetology looks for patterns among the planets.
  - Those patterns give us insight into the general processes that govern planets.
  - Studying other worlds in this way tells us about our own planet.

7.2 Patterns in the Solar System

- Our goals for learning:
  - **What features of our solar system provide clues to how it formed?**

Motion of Large Bodies

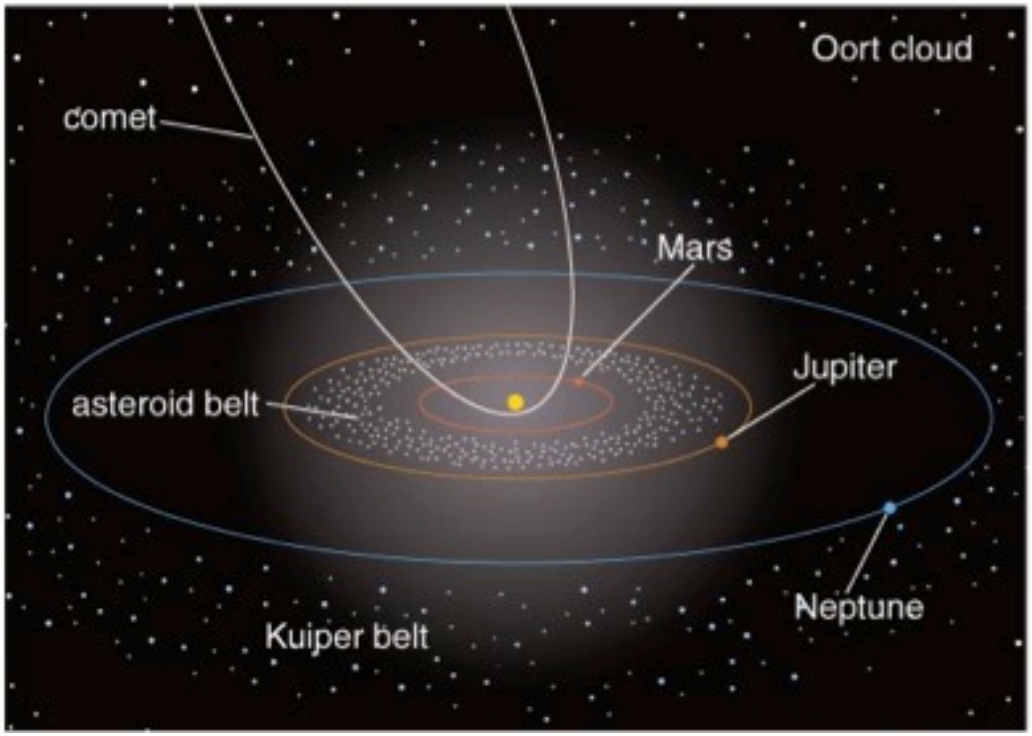


- All large bodies in the solar system orbit in the same direction and in nearly the same plane.
- Most also rotate in that direction.

Two Major Planet Types

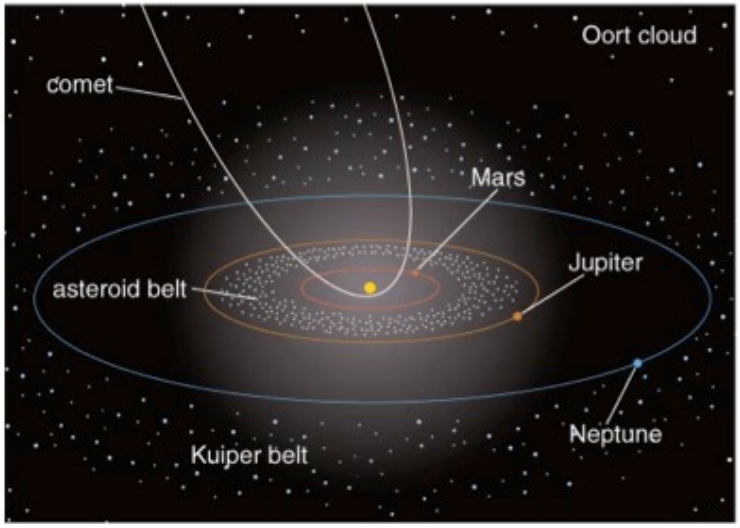
- Terrestrial planets are rocky, relatively small, and close to the Sun.
- Jovian planets are gaseous, larger, and farther from the Sun.

Swarms of Smaller Bodies



- Many rocky asteroids and icy comets populate the solar system.

Swarms of Smaller Bodies



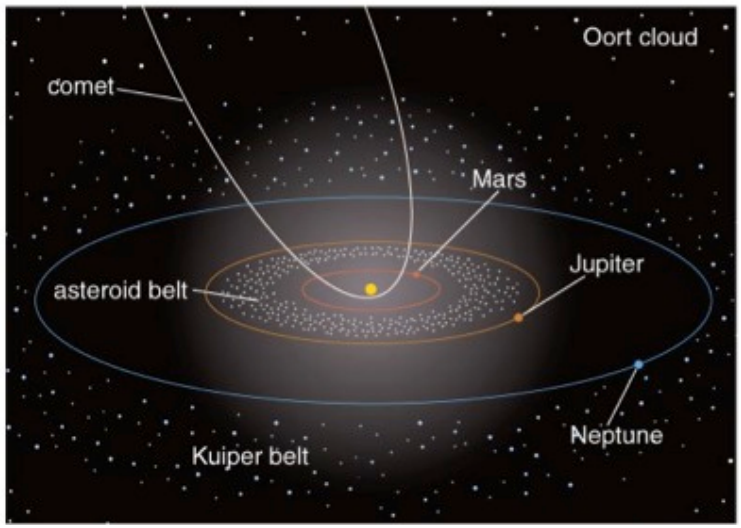
Asteroids are hundreds of thousands of objects composed of rock and metals orbiting the sun between Mars and Jupiter.

According to the IAU definition most asteroids fall in the category of small solar system bodies.

The largest object in the asteroid belt, Ceres, at about 950 km across, has been placed in the dwarf planet category.

Asteroid diameters range from a few meters to 1000 km.

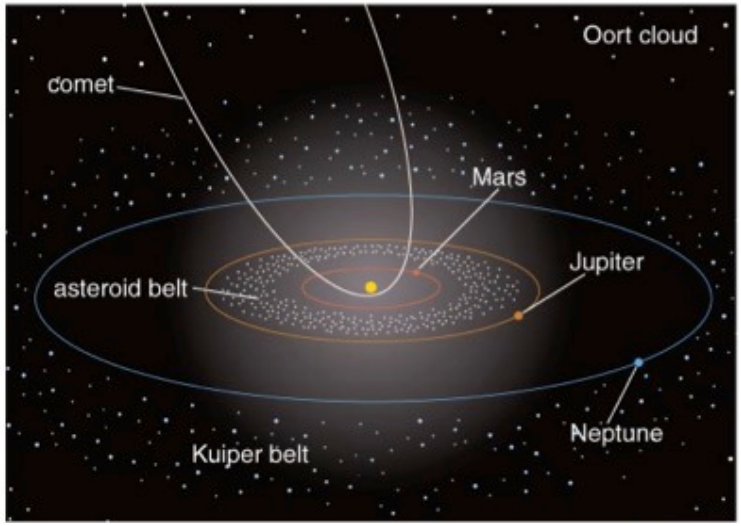
Swarms of Smaller Bodies

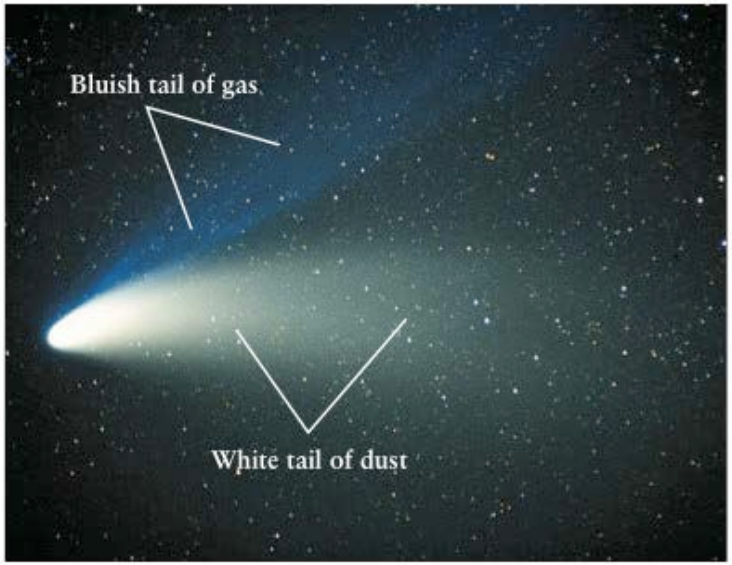


The **Kuiper Belt** is a region of the Solar System beyond the planets extending from the orbit of Neptune (at 30 AU) to ~55 AU from the Sun.

Kuiper Belt objects are composed of frozen methane, ammonia, and water.

Swarms of Smaller Bodies



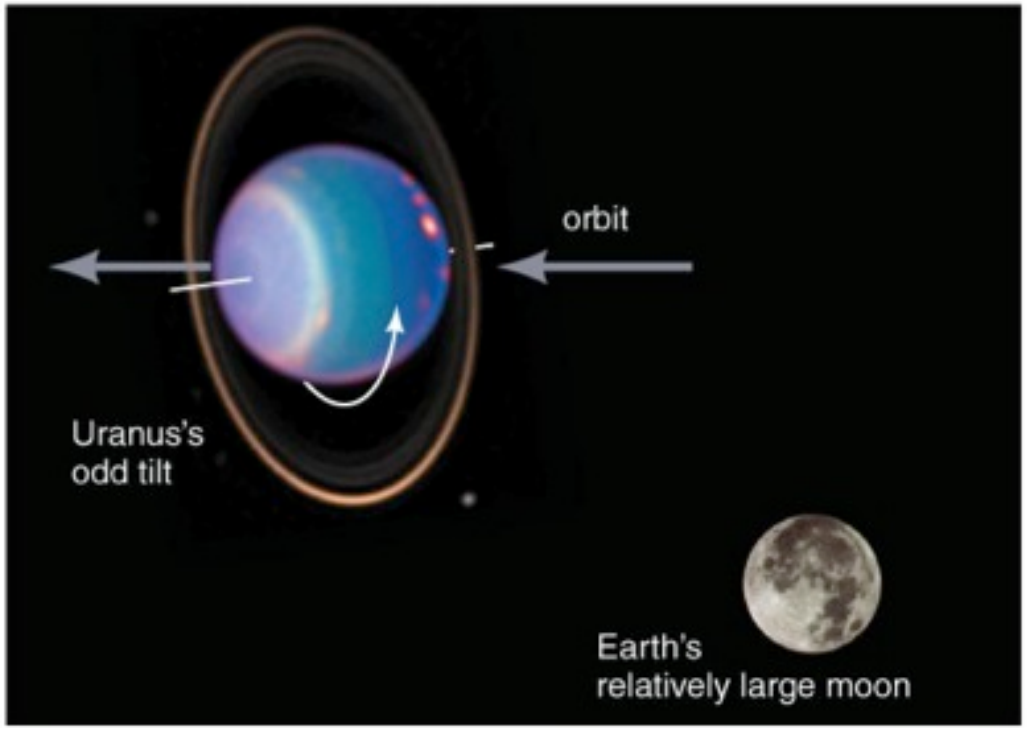


The solid part of a comet is a chunk of dirty ice a few tens of kilometers in diameter.

When a comet passes near the Sun, solar radiation vaporizes some of the icy material, forming a bluish tail of gas and a white tail of dust.

Both tails can extend for tens of millions of kilometers.

Notable Exceptions



- Several exceptions to the normal patterns need to be explained.

Atmospheres of Planets

The average speed v (m/s) of a gas molecule or atom is:

$$v_{particle} = \sqrt{\frac{3kT}{m}}$$

$k = 1.38 \times 10^{-23}$ J/K (Boltzmann constant)

T = temperature of gas, in kelvins

m = mass of atom or molecule in kg

The average speed of the oxygen molecules that you breathe at a room temperature of 20°C is about 0.478 km/s.

Atmospheres of Planets

Derivation of $v_{particle} = \sqrt{\frac{3kT}{m}}$

The temperature of a gas is a direct measure of the average amount of kinetic energy per atom or molecule. The average kinetic energy of a gas atom or molecule is:

$$E_k = \frac{3}{2}kT$$

The kinetic energy of a particle of mass m and velocity v is: $E_k = \frac{1}{2}mv^2$

$$\frac{1}{2}mv^2 = \frac{3}{2}kT \Rightarrow v = \sqrt{\frac{3kT}{m}}$$

Atmospheres of Planets

A good rule of thumb is that a planet can retain a gas if the escape speed is at least 6 times greater than the average speed of the molecules in the gas.

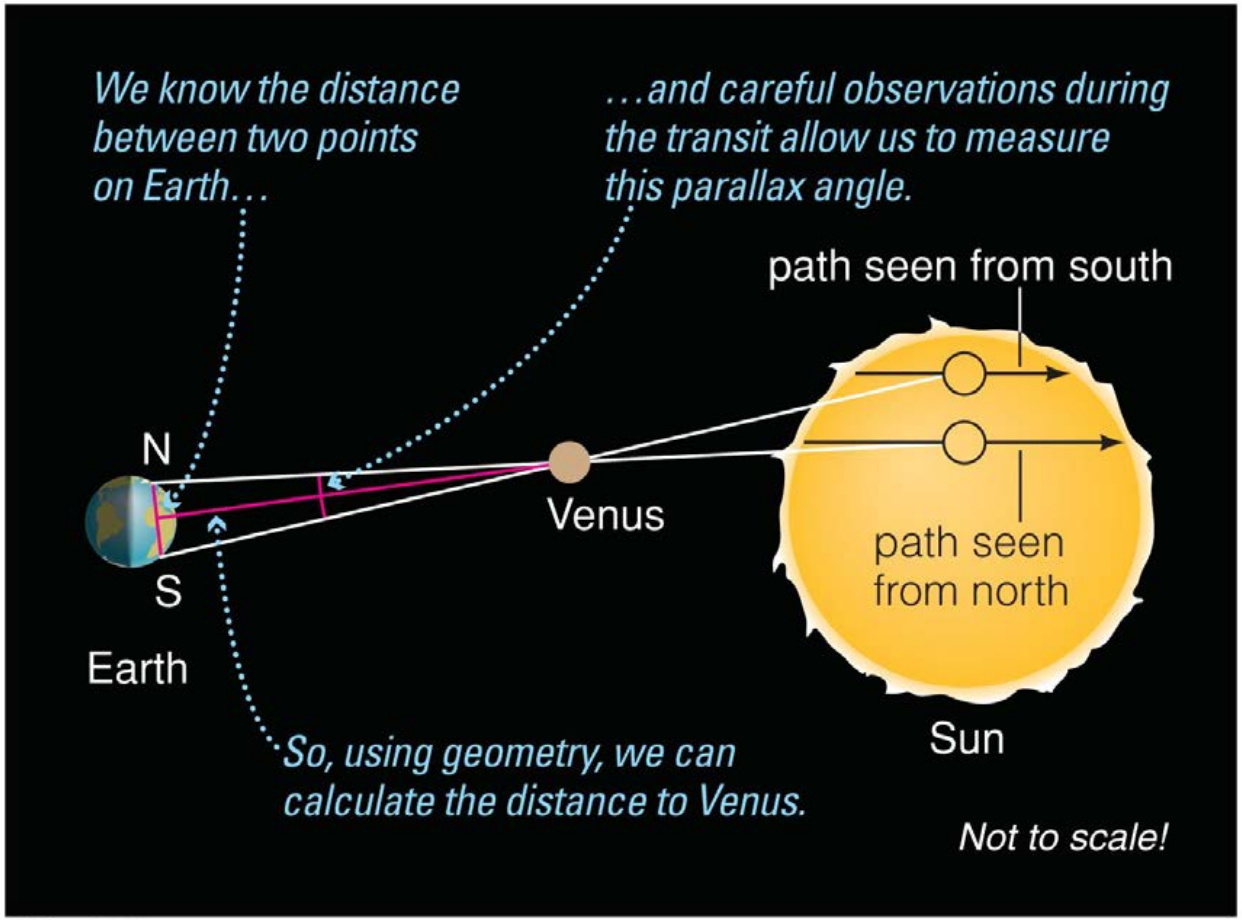
$$v_{escape} \geq 6 \times \bar{v}_{gas}$$

The **atmospheres that surround the terrestrial planets** are composed primarily of more massive, slower-moving molecules such as CO_2, N_2, O_2, and water vapor (H_2O).

On the **four Jovian planets**, low temperatures and relatively strong gravity prevent even lightweight hydrogen and helium gases from escaping into space.

Special Topic:

- How Did We Learn the Scale of the Solar System?

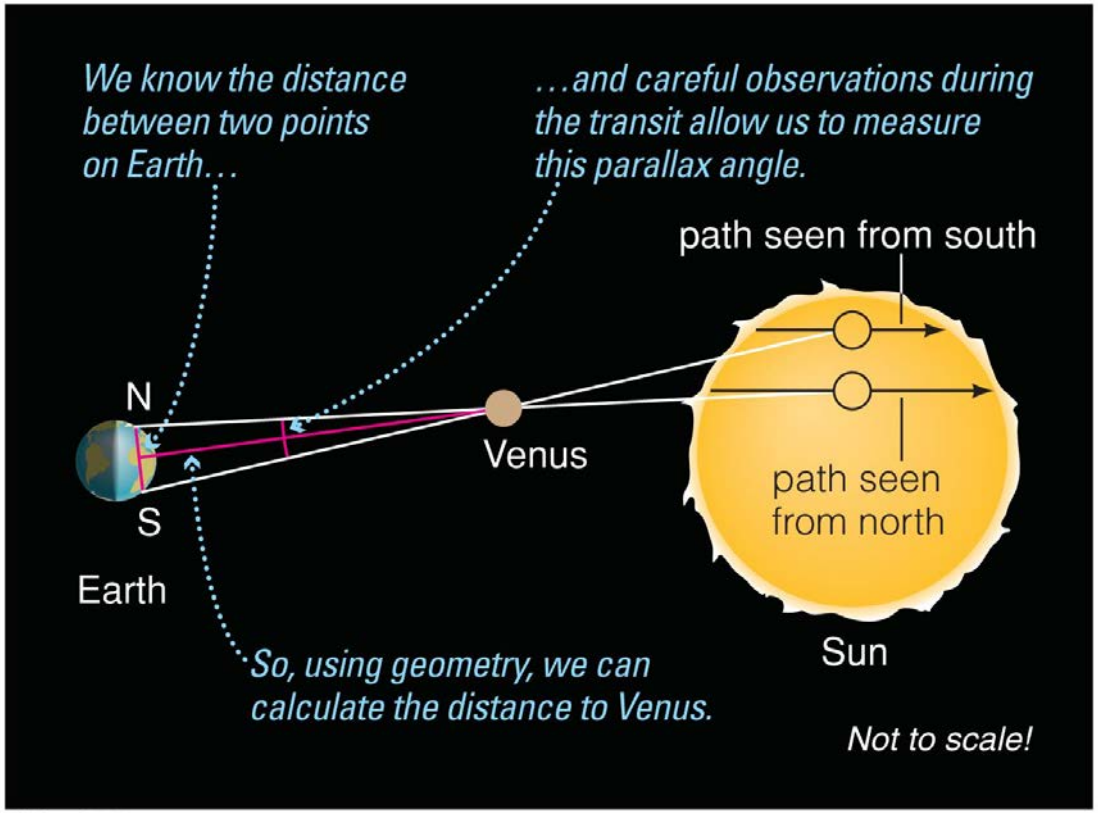


Transit of Venus

Transit of Venus: June 6, 2012

- Apparent position of Venus on Sun during transit depends on distances in solar system and your position on Earth.

Measuring Distance to Venus



- Measure apparent position of Venus on Sun from two locations on Earth
- Use trigonometry to determine Venus's distance from the distance between the two locations on Earth

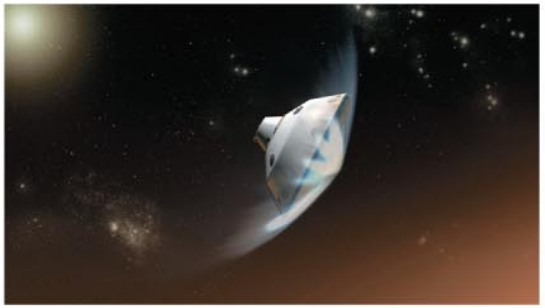
What have we learned?

- **What features of the solar system provide clues to how it formed?**
  - Motions of large bodies: all in same direction and plane
  - Two main planet types: terrestrial and jovian.
  - Swarms of small bodies: asteroids and comets
  - Notable exceptions: rotation of Uranus, Earth's large moon

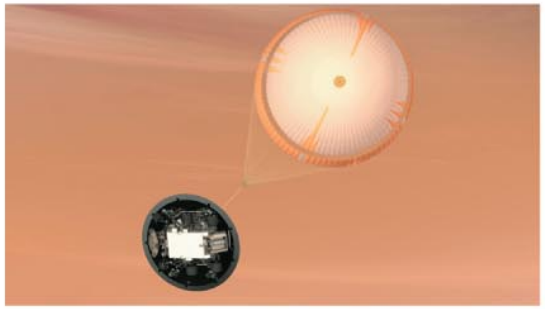
7.3 Spacecraft Exploration of the Solar System

- Our goals for learning:
  - **How do robotic spacecraft work?**

How do robotic spacecraft work?

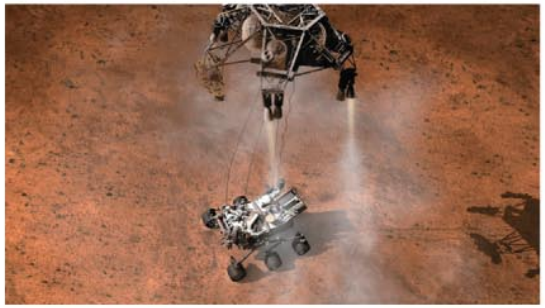


1 Friction slows spacecraft as it enters Mars atmosphere.

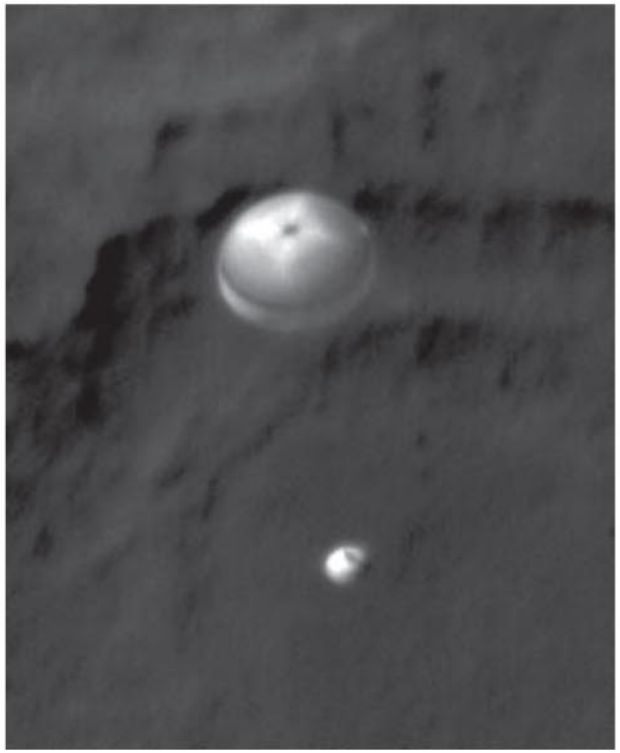


2 Parachute slows spacecraft to about 350 km/hr.

3 Rockets slow spacecraft to halt; "sky crane" tether lowers rover to surface.

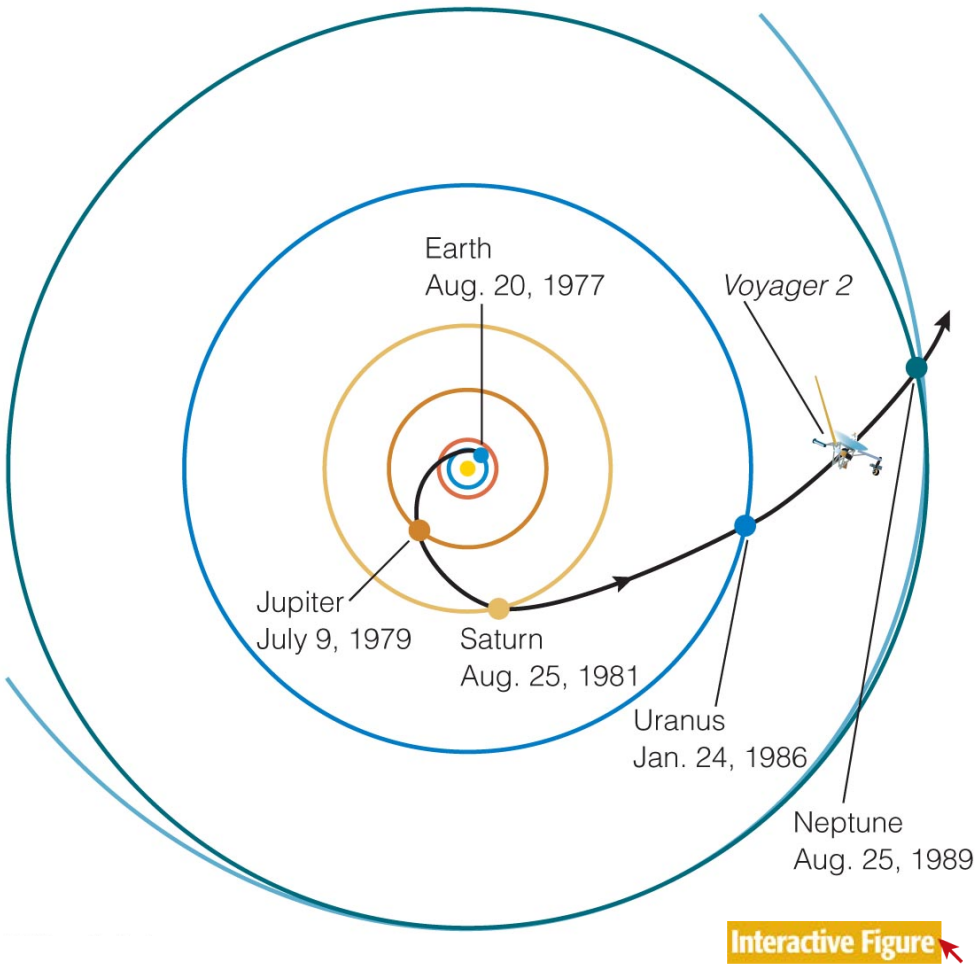


4 Tether released, the rocket heads off to crash a safe distance away.



As it flew overhead, the *Mars Reconnaissance Orbiter* took this photo of the spacecraft with its parachute deployed.

Flybys

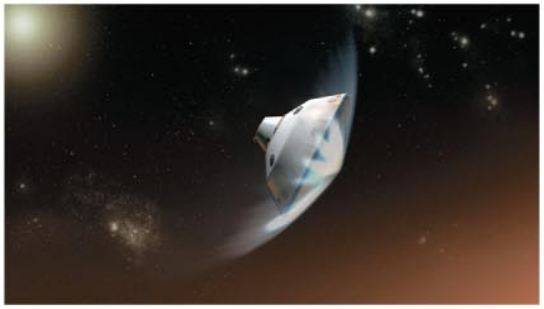


- A flyby mission flies by a planet just once.
- Cheaper than other mission but less time to gather data

Orbiters

- Go into orbit around another world
- More time to gather data but cannot obtain detailed information about world's surface

Probes or Landers



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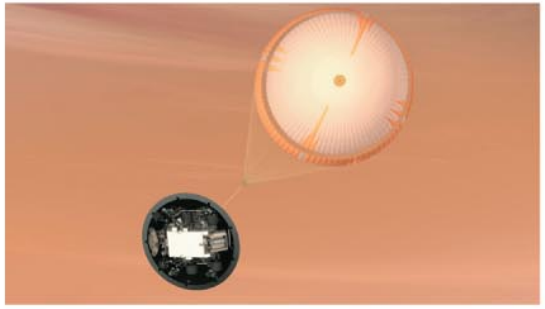

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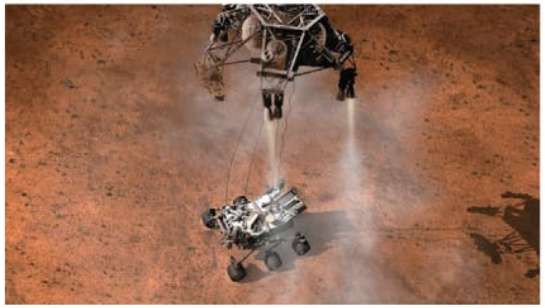

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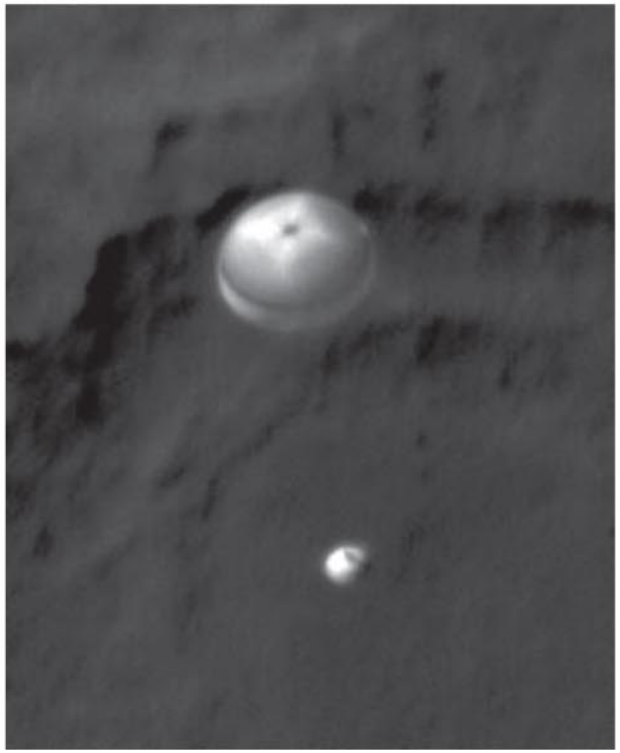


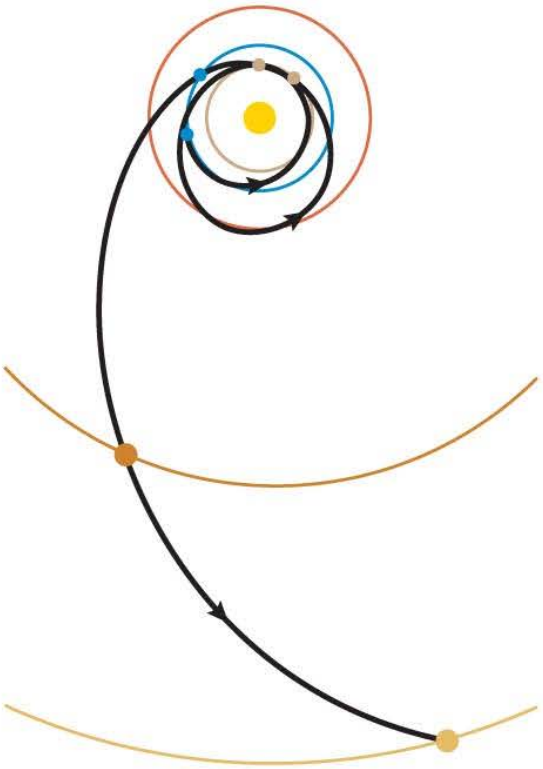
As it flew overhead, the *Mars Reconnaissance Orbiter* took this photo of the spacecraft with its parachute deployed.

- Land on surface of another world
- Explore surface in detail

Sample Return Missions

- Land on surface of another world
- Gather samples
- Spacecraft designed to blast off other world and return to Earth
- *Apollo* missions to Moon are one example, *Hyabusa* to an asteroid is another.

Combination Spacecraft



- *Cassini/Huygens* mission contains both an orbiter (*Cassini*) and a lander (*Huygens*).

What have we learned?

- **How do robotic spacecraft work?**
  - Flyby: flies by another world only once
  - Orbiter: goes into orbit around another world
  - Probe/Lander: lands on surface
  - Sample return mission: returns a sample of another world's surface to Earth