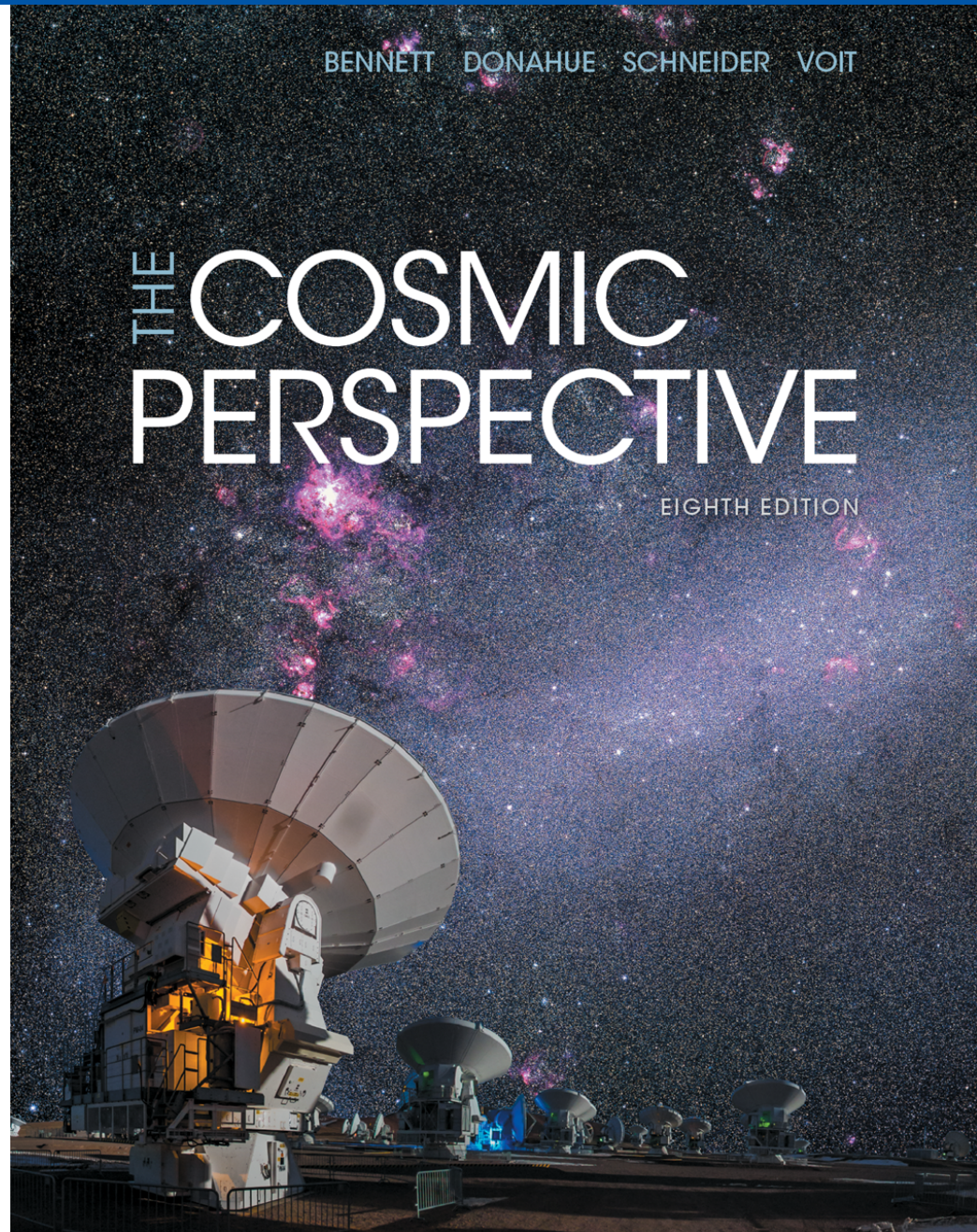
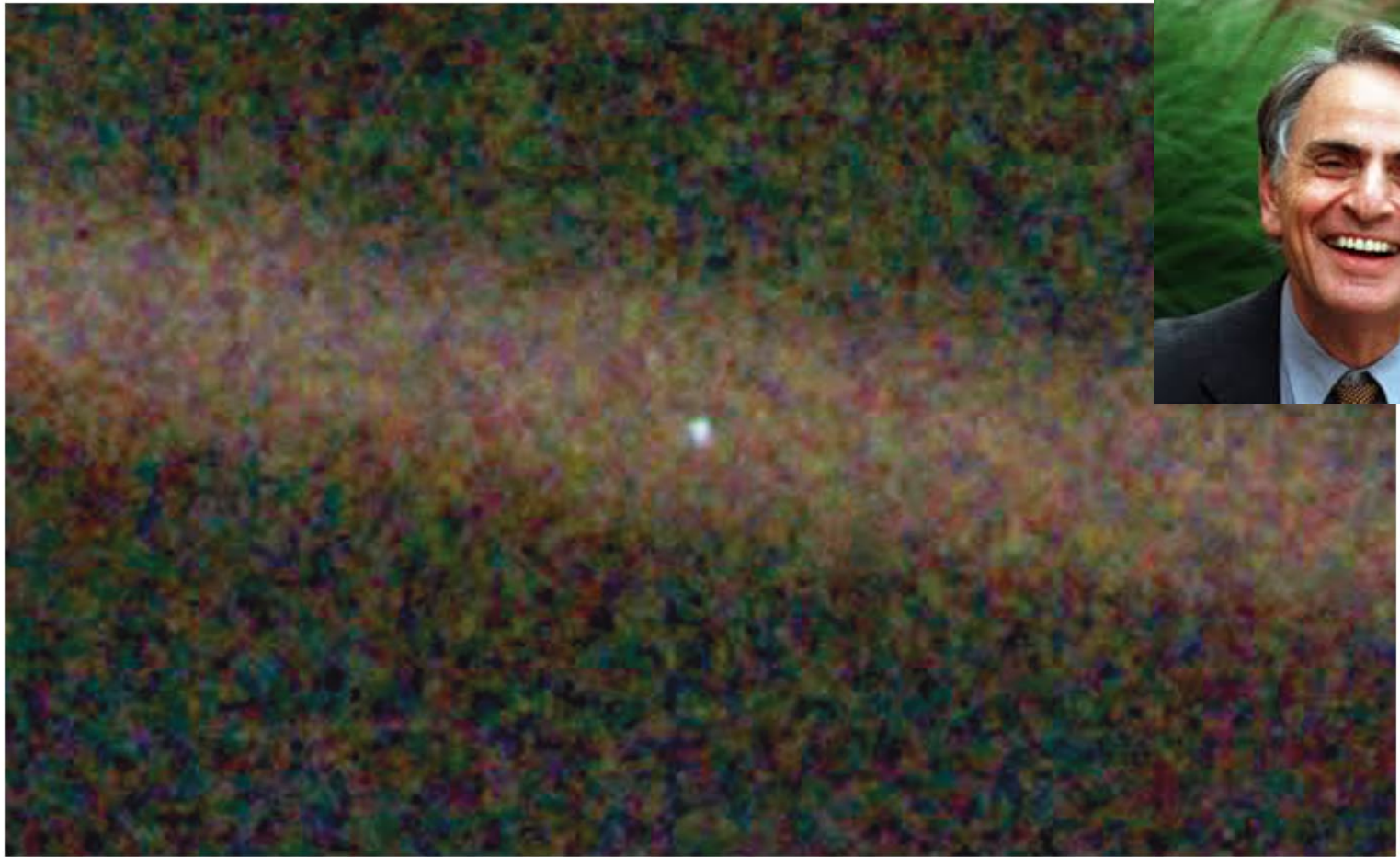


Chapter 7: Our Planetary System



Our Planetary System



- Earth, as viewed by the *Voyager* spacecraft – Carl Sagan's 'pale blue dot'

7.1 Studying the Solar System

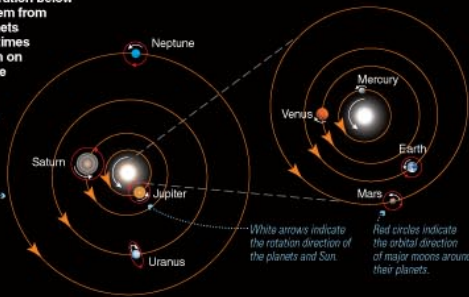
- Our goals for learning:
 - **What does the solar system look like?**
 - **What can we learn by comparing the planets to one another?**

What does the solar system look like?

The solar system's layout and composition offer four major clues to how it formed. The main illustration below shows the orbits of planets in the solar system from a perspective beyond Neptune, with the planets themselves magnified by about a thousand times relative to their orbits. (The Sun is not shown on the same scale as the planets; it would fill the page if it were.)

1 Large bodies in the solar system have orderly motions. All planets have nearly circular orbits going in the same direction in nearly the same plane. Most large moons orbit their planets in this same direction, which is also the direction of the Sun's rotation.

Seen from above, planetary orbits are nearly circular.



White arrows indicate the orbital direction of the planets and Sun. Red circles indicate the orbital direction of major moons around their planets.

2 Planets fall into two major categories: Small, rocky terrestrial planets and large, hydrogen-rich jovian planets.

terrestrial planet

jovian planet



Terrestrial Planets:

- small in mass and size
- close to the Sun
- made of metal and rock
- few moons and no rings

Jovian Planets:

- large mass and size
- far from the Sun
- made of H, He, and hydrogen compounds
- rings and many moons

3 Swarms of asteroids and comets populate the solar system. Vast numbers of rocky asteroids and icy comets are found throughout the solar system, but are concentrated in three distinct regions.

Asteroids are made of metal and rock, and most orbit in the **asteroid belt** between Mars and Jupiter.

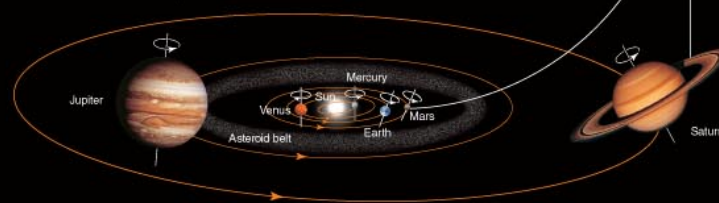
Even more comets orbit the Sun in the distant, spherical region called the **Oort cloud**, and only a few ever plunge into the inner solar system.

Comets are ice-rich, and many are found in the **Kuiper belt** beyond Neptune's orbit.

Kuiper belt

Orbits are shown to scale, but planet sizes are exaggerated about 1000 times relative to orbits. The Sun is not shown to scale; its size is exaggerated only about 50 times relative to the orbits.

Each planet's axis tilt is shown, with small circling arrows to indicate the direction of the planet's rotation.



Asteroid belt

4 Several notable exceptions to these trends stand out. Some planets have unusual axis tilts, unusually large moons, or moons with unusual orbits.

Uranus's odd tilt

Earth's relatively large moon



Uranus rotates nearly on its side compared to its orbit, and its rings and major moons share this "sideways" orientation.

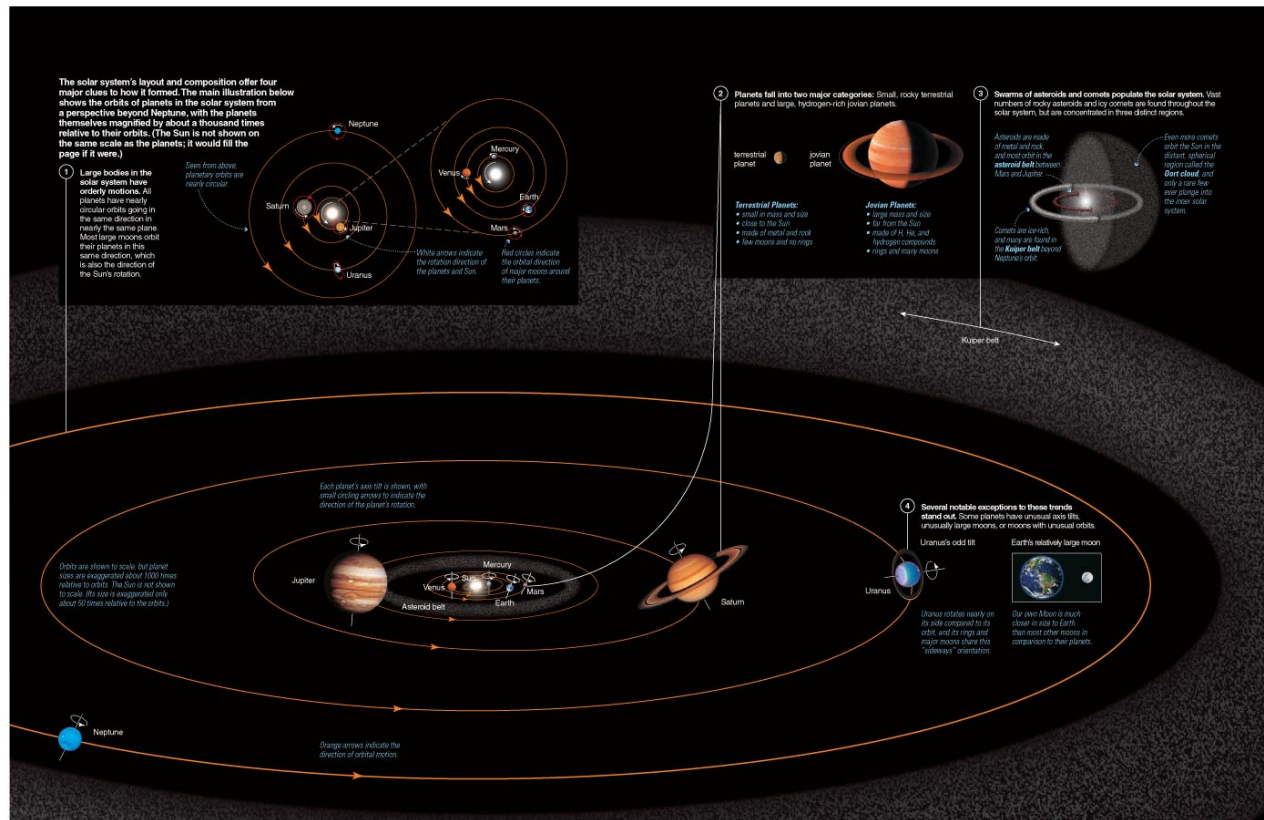
Our own Moon is much closer in size to Earth than most other moons in comparison to their planets.

Orange arrows indicate the direction of orbital motion.

Neptune

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?

- Planets all orbit in same direction and nearly in same plane.

Thought Question

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

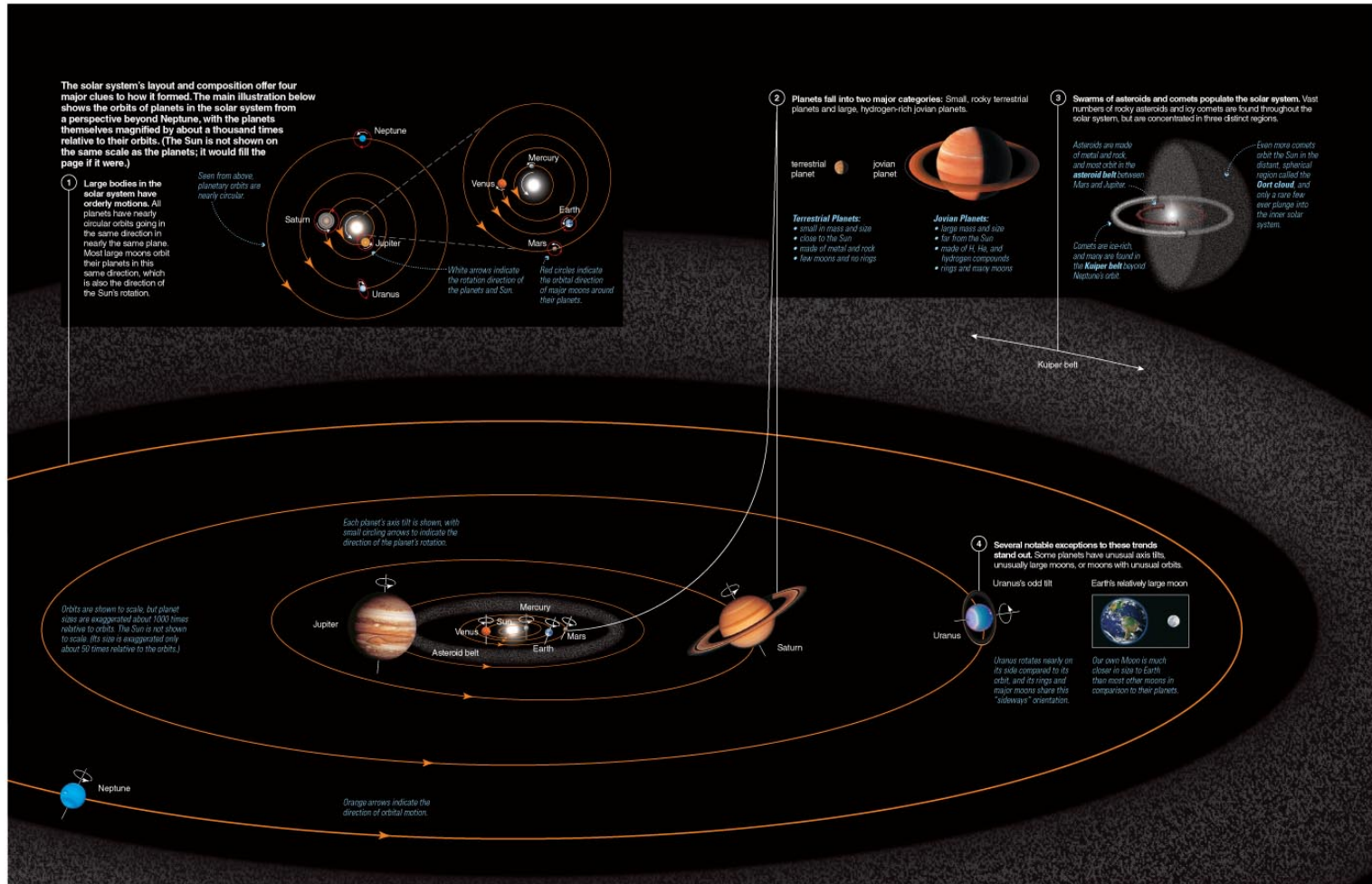
- a) It's about 10 times larger.
- b) It's about 50 times larger.
- c) It's about 200 times larger.
- d) It's about 1000 times larger.

Thought Question

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

- 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.

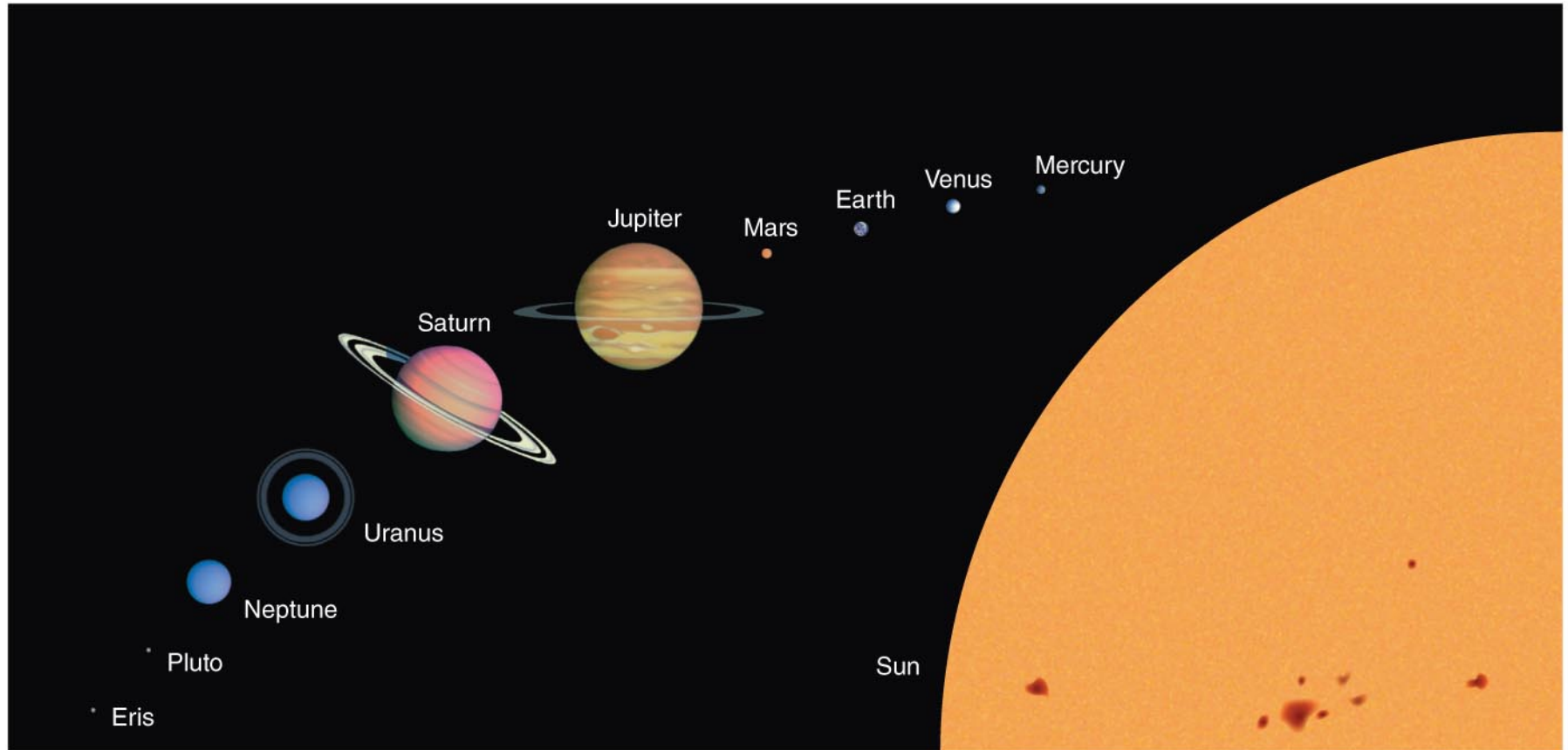
What can we learn by comparing the planets to one another?



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.
- Comparing the planets reveals patterns among them.
- Those patterns provide insights that help us understand our own planet.

What are the major features of the Sun and planets?

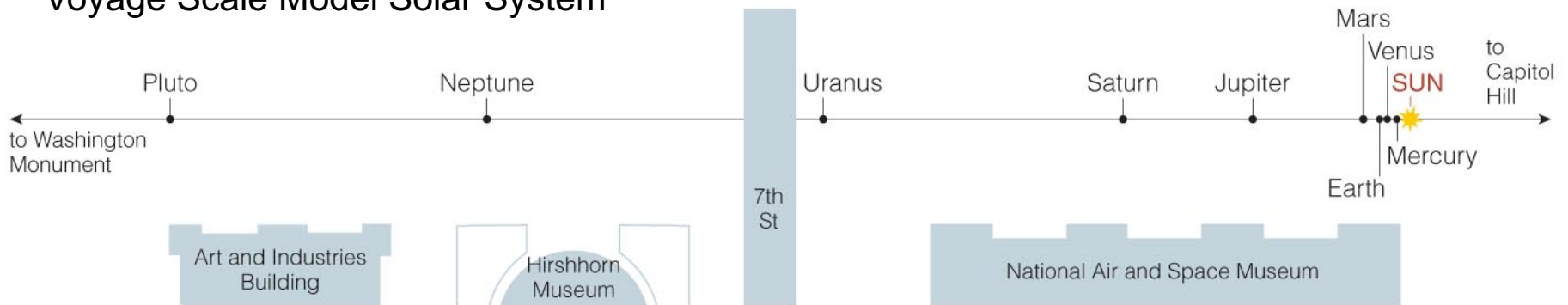


- Sun and planets to scale

Planets are very tiny compared to distances between them.

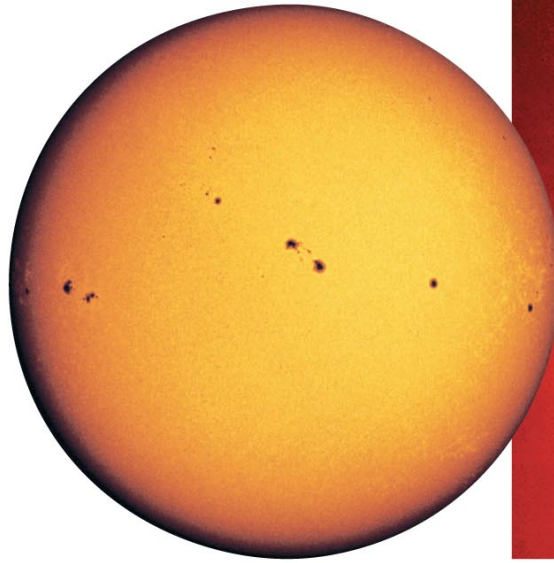


Voyage Scale Model Solar System

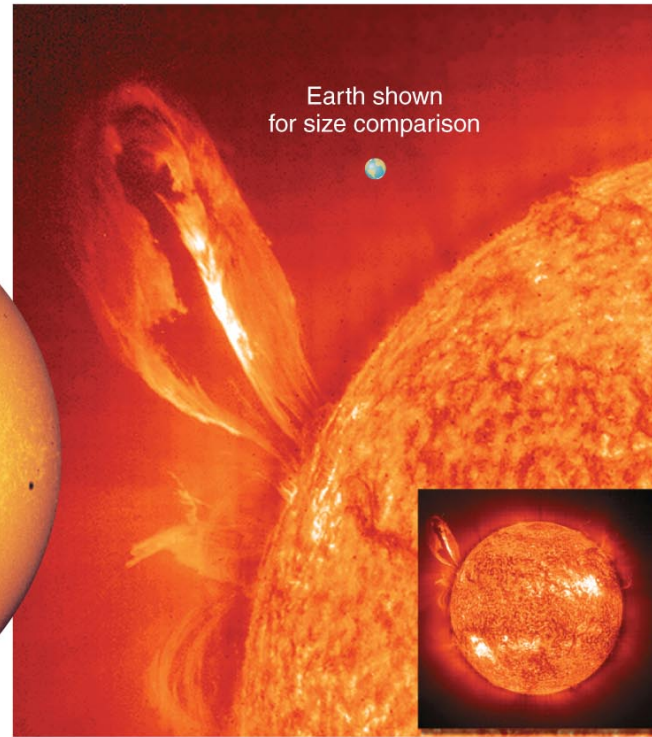


b Locations of the Sun and planets in the Voyage model (Washington, D.C.); the distance from the Sun to Pluto is about 600 meters (1/3 mile). Planets are lined up in the model, but in reality each planet orbits the Sun independently and a perfect alignment never occurs.

Sun



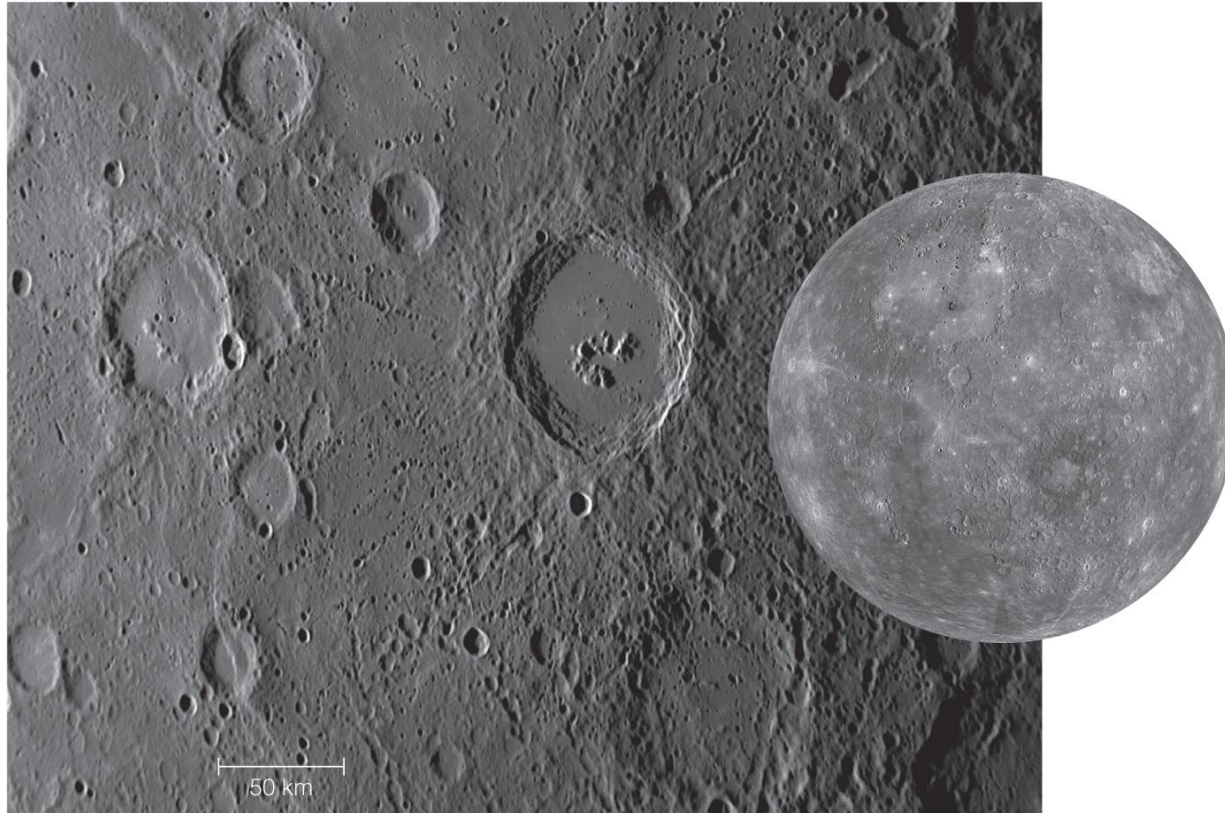
a A visible-light photograph of the Sun's surface. The dark splotches are sunspots—each large enough to swallow several Earths.



b This ultraviolet photograph, from the *SOHO* spacecraft, shows a huge streamer of hot gas on the Sun.

- Over 99.9% of solar system's mass
- Made mostly of H/He gas (plasma)
- Converts 4 million tons of mass into energy each second –
how do we come up with this number?

Mercury

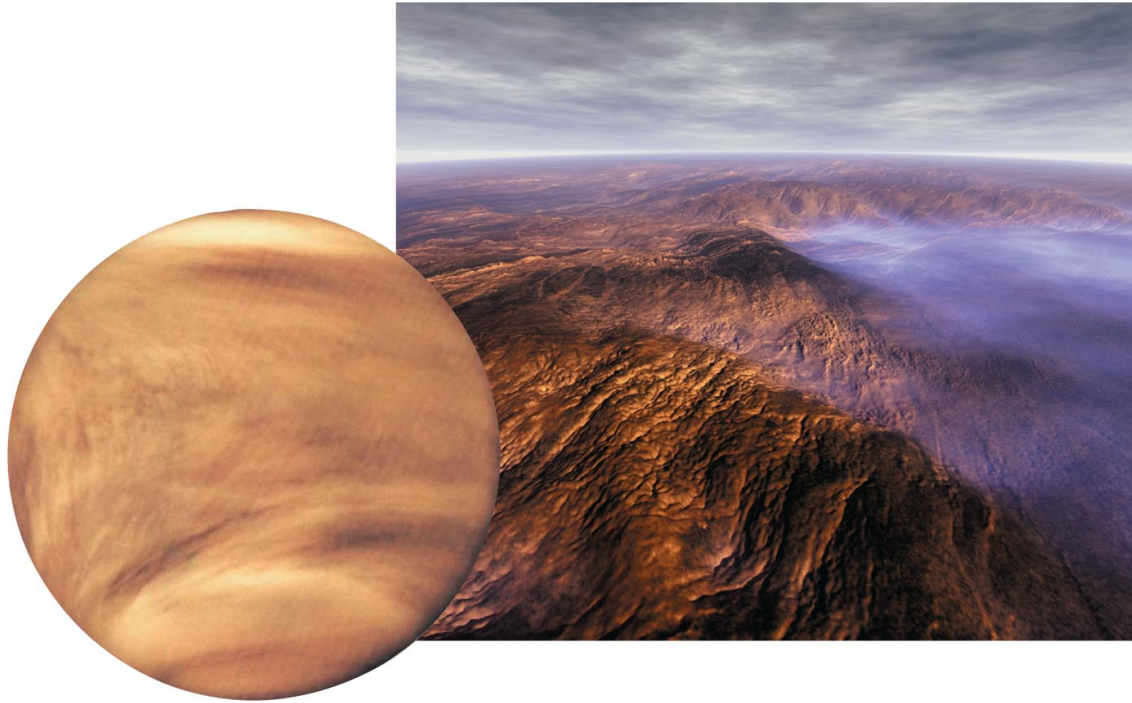


- Made of metal and rock; large iron core
- Desolate, cratered; long, tall, steep cliffs
- Very hot, very cold: 425°C (day), -150°C (night)

727°F

-238°F

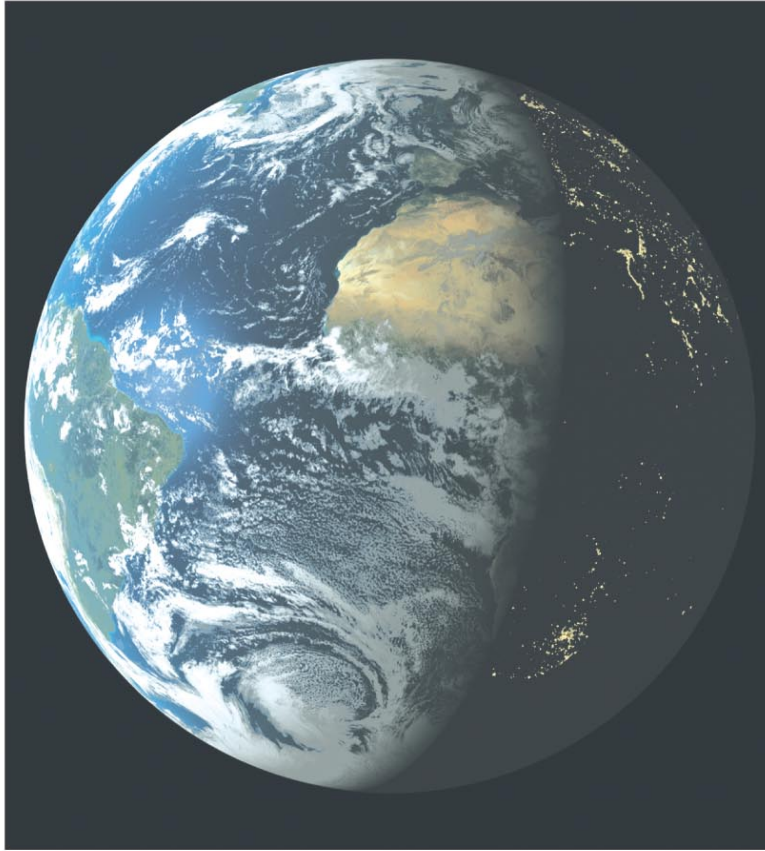
Venus



- 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

878° F

Earth



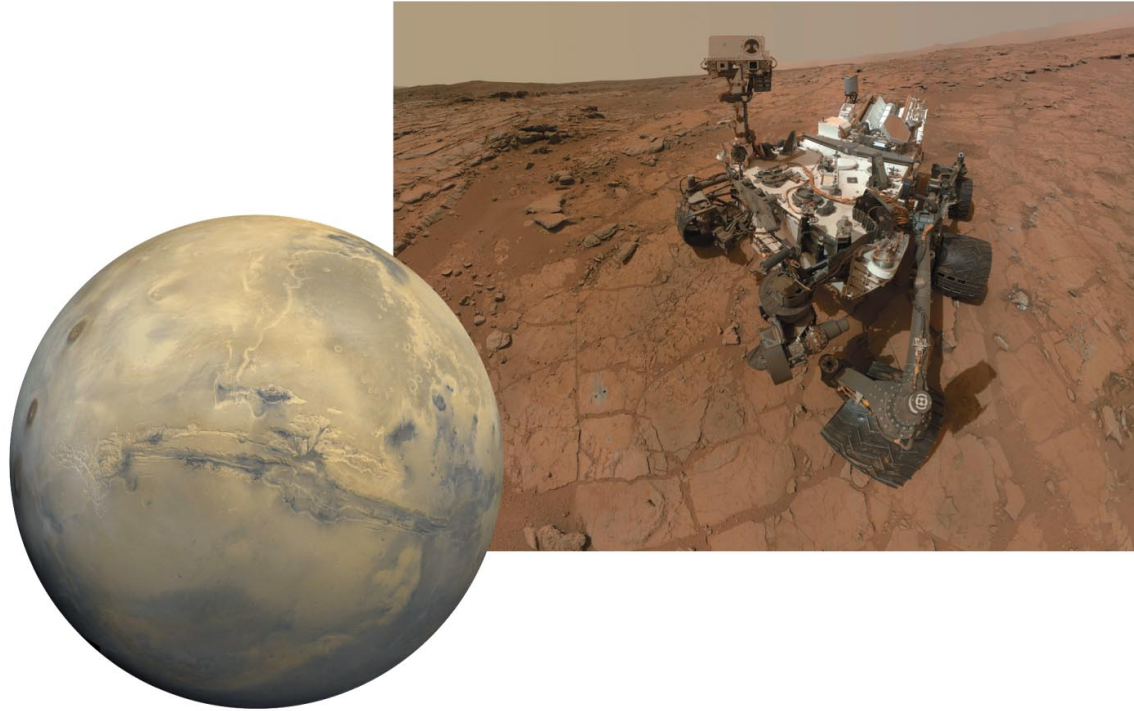
a This image (left), computer generated from satellite data, shows the striking contrast between the day and night hemispheres of Earth. The day side reveals little evidence of human presence, but at night our presence is revealed by the lights of human activity. (From the Voyage scale model solar system, developed by the Challenger Center for Space Science Education, the Smithsonian Institution, and NASA. Image created by ARC Science Simulations © 2001.)



b Earth and the Moon, shown to scale. The Moon is about $\frac{1}{4}$ as large as Earth in diameter, while its mass is about $\frac{1}{80}$ of Earth's mass. To show the distance between Earth and Moon on the same scale, you'd need to hold these two photographs about 1 meter (3 feet) apart.

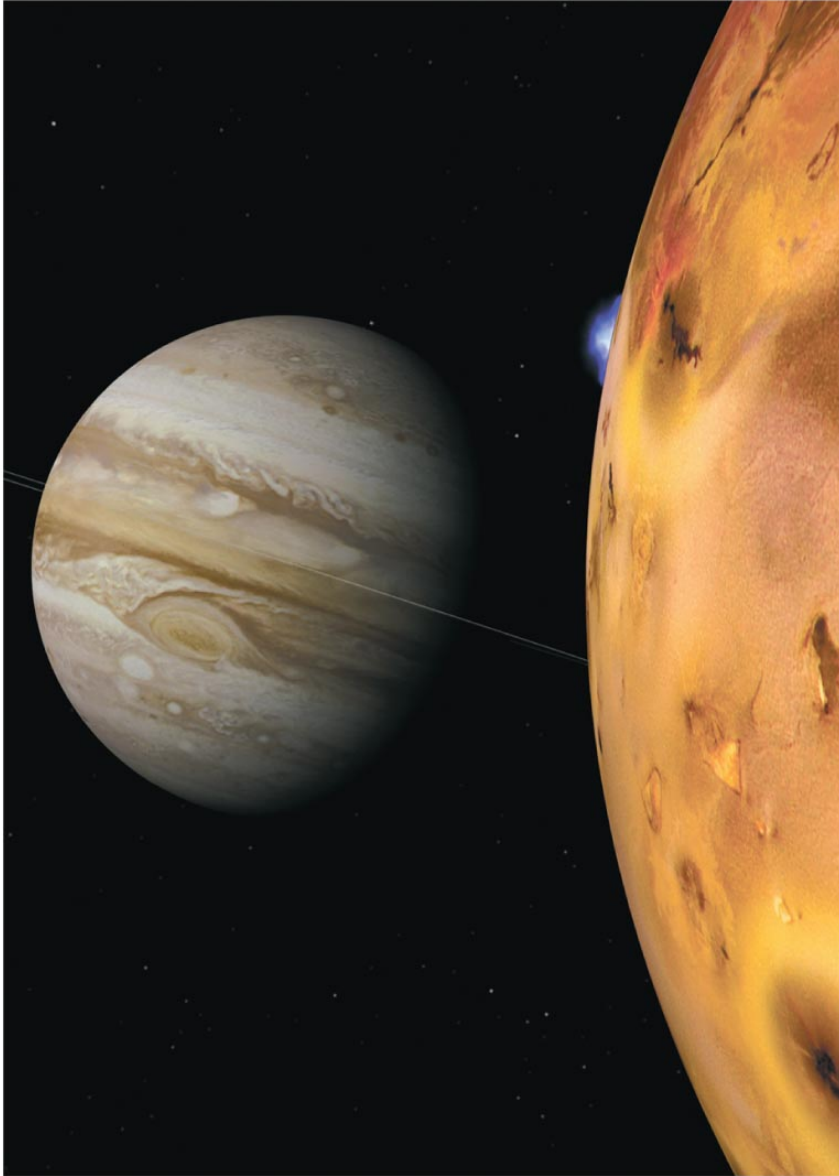
- An oasis of life
- Oceans and ice caps
- A surprisingly large moon

Mars



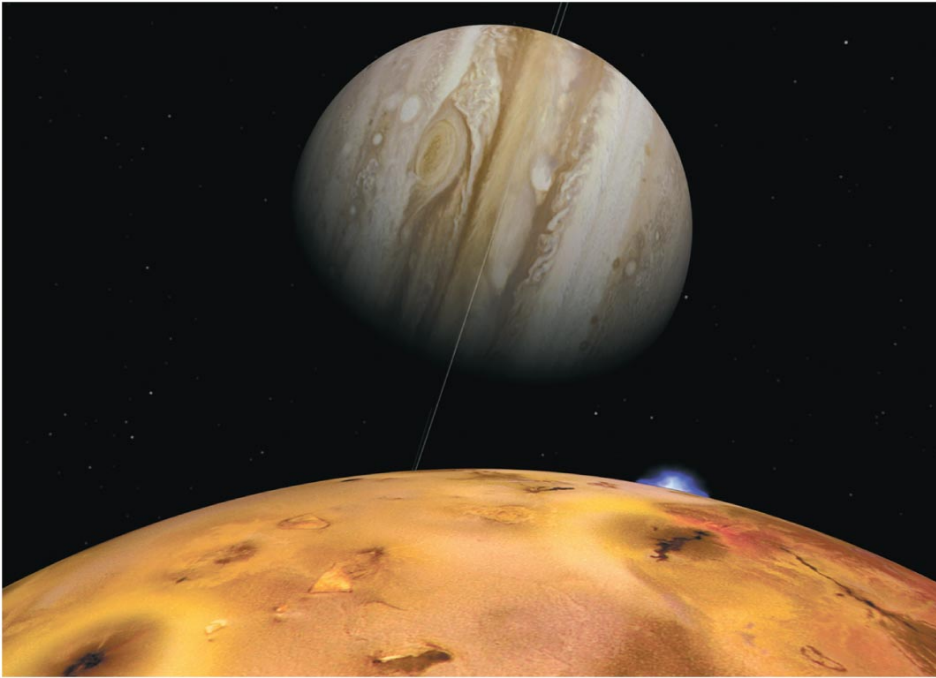
- Looks almost Earth-like, but don't go without a spacesuit!
- Giant volcanoes, a huge canyon, polar caps, more
- Water flowed in distant past; could there have been life?

Jupiter



- Much farther from Sun than inner planets
- Mostly H/He; no solid surface
- 300 times more massive than Earth
- Many moons, rings

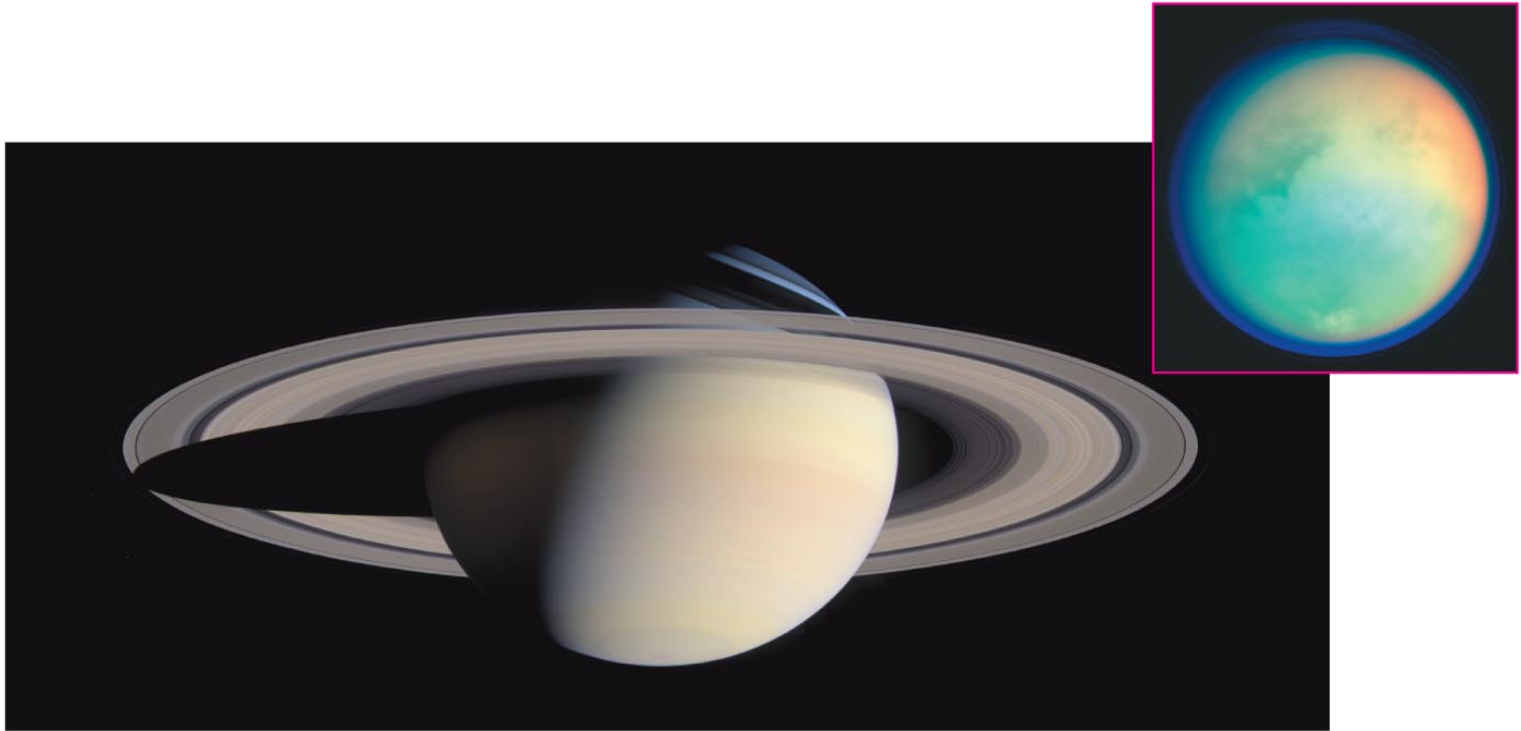
Jupiter



- 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"

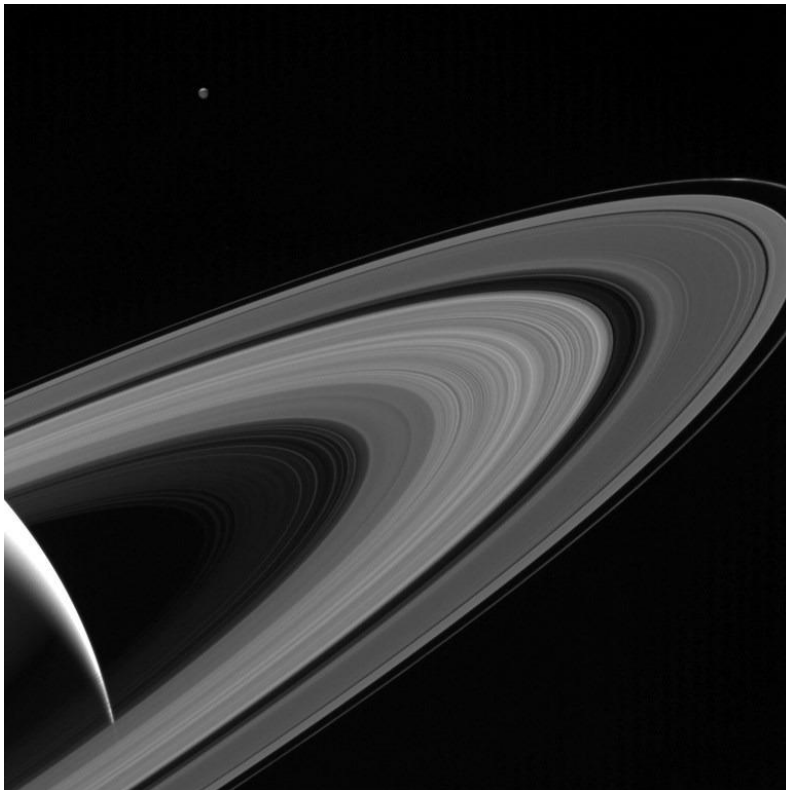
Saturn



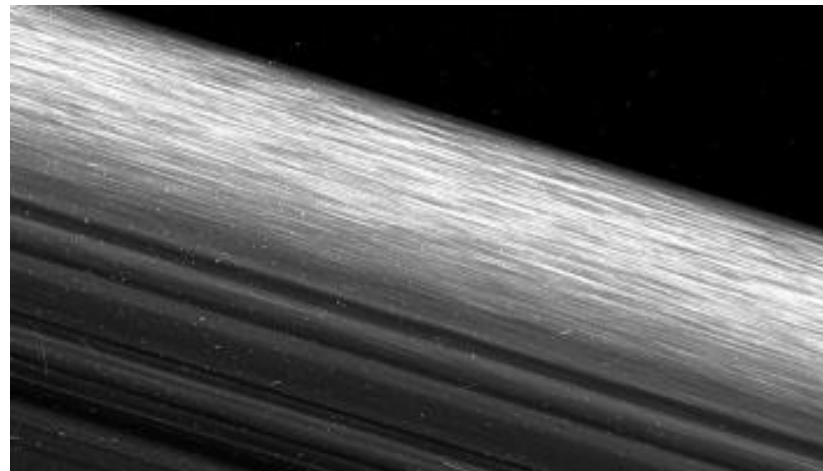
- Giant and gaseous like Jupiter
- Spectacular rings
- Many moons, including cloudy Titan

Saturn

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

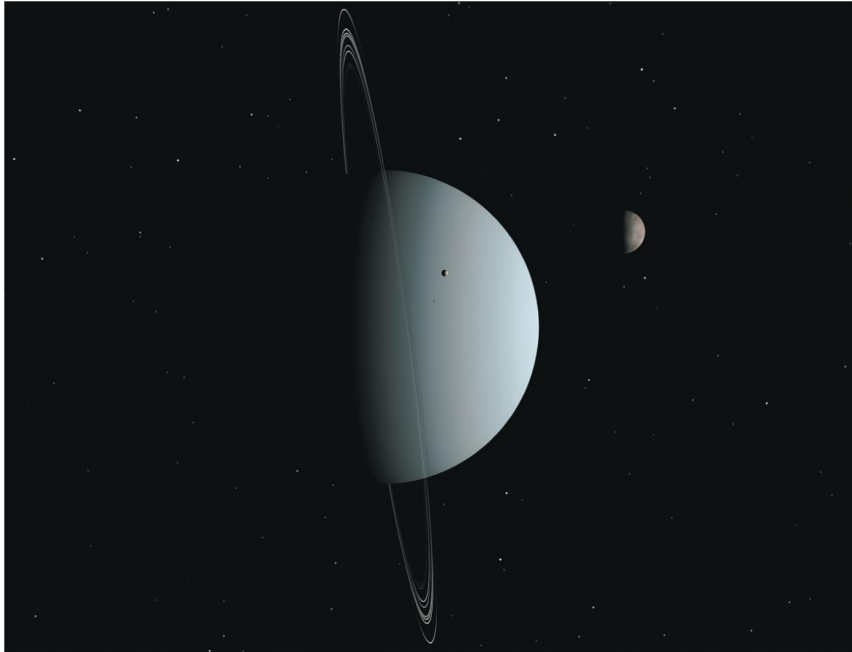


Source: NASA / Cassini



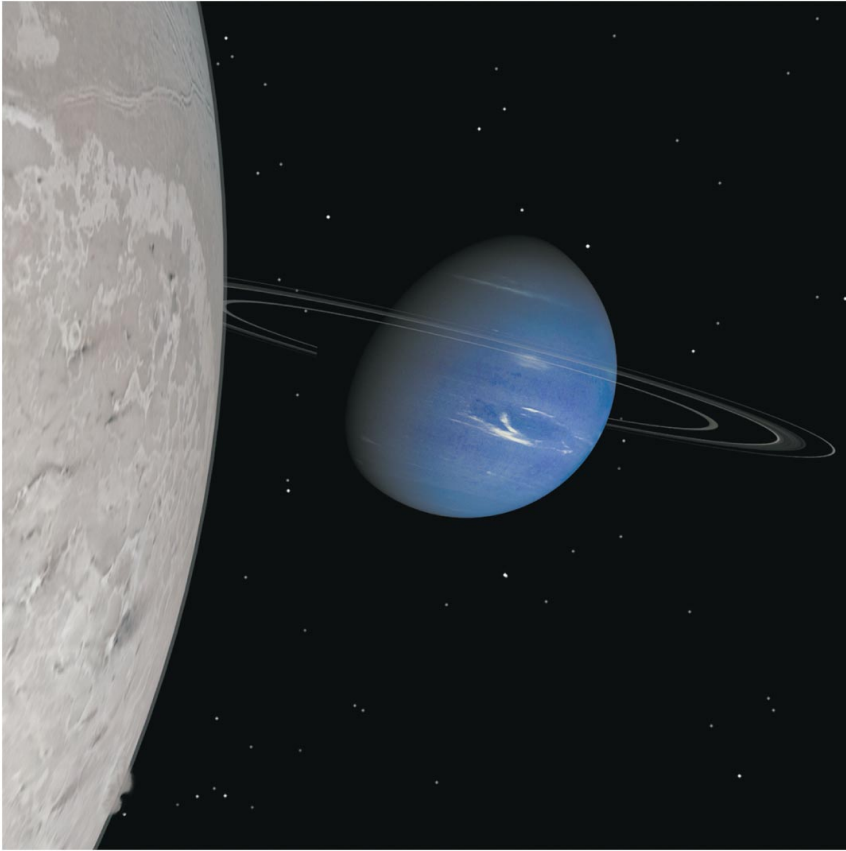
Saturn rings in ultra-high (angular) resolution

Uranus



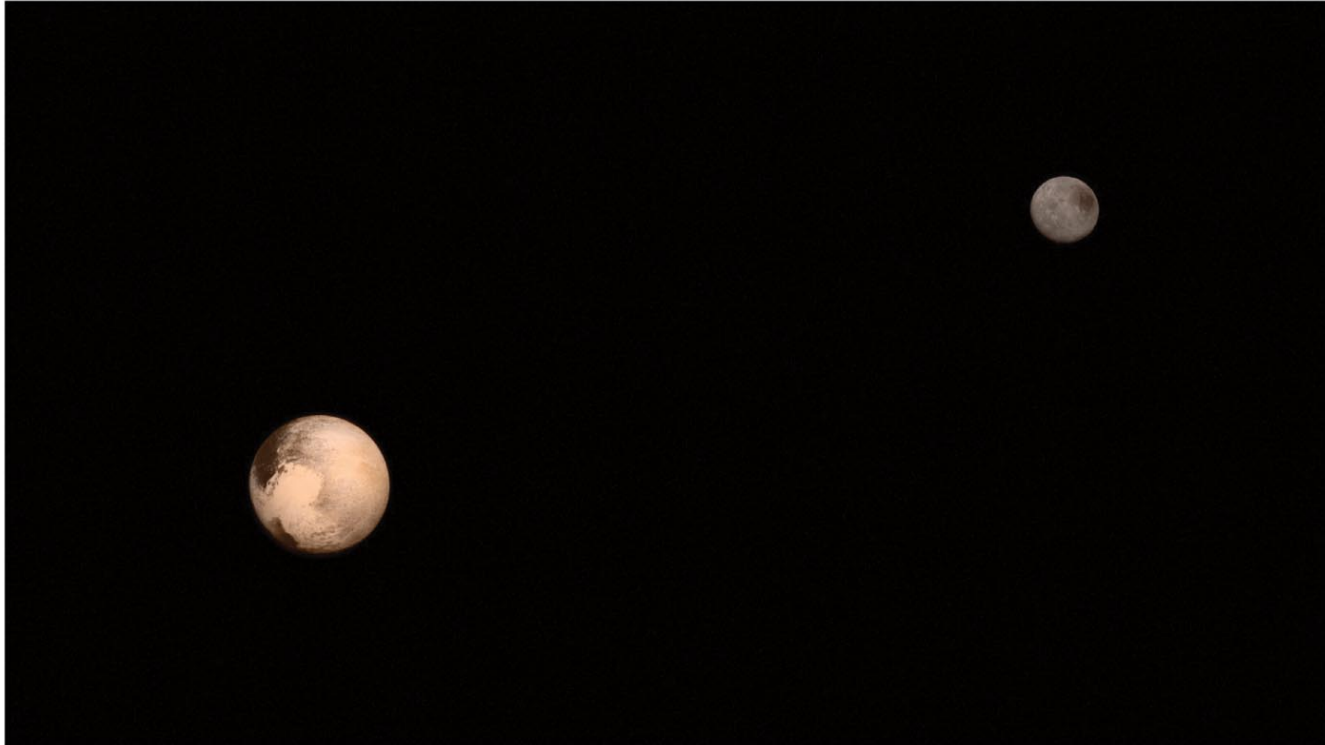
- Smaller than Jupiter/Saturn; much larger than Earth
- Made of H/He gas and **hydrogen compounds** (H_2O , NH_3 , CH_4)
- Extreme axis tilt
- Moons and rings

Neptune



- Similar to Uranus – also has rings (except for axis tilt)
- Many moons (including Triton)

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 (2015)	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	14	Yes
	Pluto	•	39.5	1185	0.0022	1.9	248 years	6.39 days	112.5°	44 K	Ices, rock	5	No
	Eris	•	67.7	1168	0.0028	2.3	557 years	1.08 days	78°	43 K	Ices, rock	1	No

^aIncluding the dwarf planets Pluto and Eris; Appendix E gives a more complete list of planetary properties

^bSurface temperatures for all objects except Jupiter, Saturn, Uranus, and Neptune, for which cloud-top temperatures are listed

^cInclude water (H₂O), methane (CH₄), and ammonia (NH₃)

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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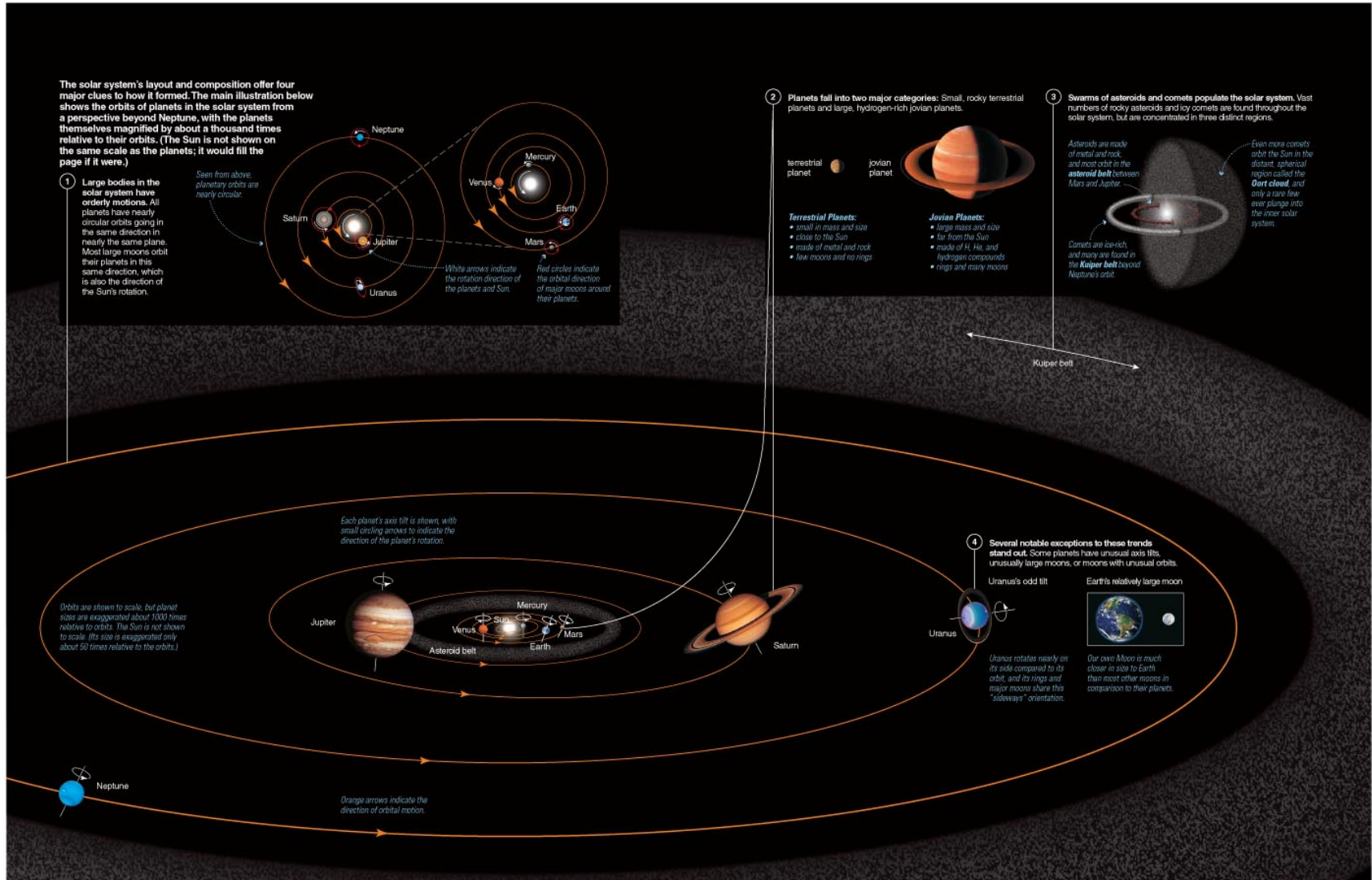
What have we learned?

- **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?**

What features of our solar system provide clues to how it formed?

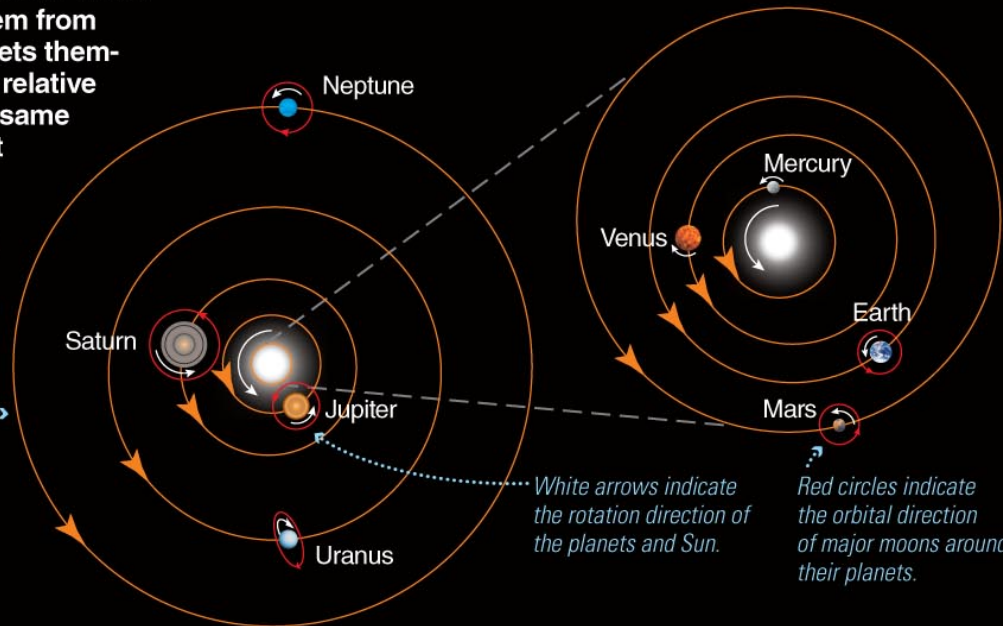


Motion of Large Bodies

The solar system's layout and composition offer four major clues to how it formed. The main illustration below shows the orbits of planets in the solar system from a perspective beyond Neptune, with the planets themselves magnified by about a thousand times relative to their orbits. (The Sun is not shown on the same scale as the planets; it would fill the page if it were.)

- 1 **Large bodies in the solar system have orderly motions.** All planets have nearly circular orbits going in the same direction in nearly the same plane. Most large moons orbit their planets in this same direction, which is also the direction of the Sun's rotation.

Seen from above, planetary orbits are nearly circular.



- 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.

2 Planets fall into two major categories: Small, rocky terrestrial planets and large, hydrogen-rich jovian planets.

terrestrial planet  jovian planet 

Terrestrial Planets:

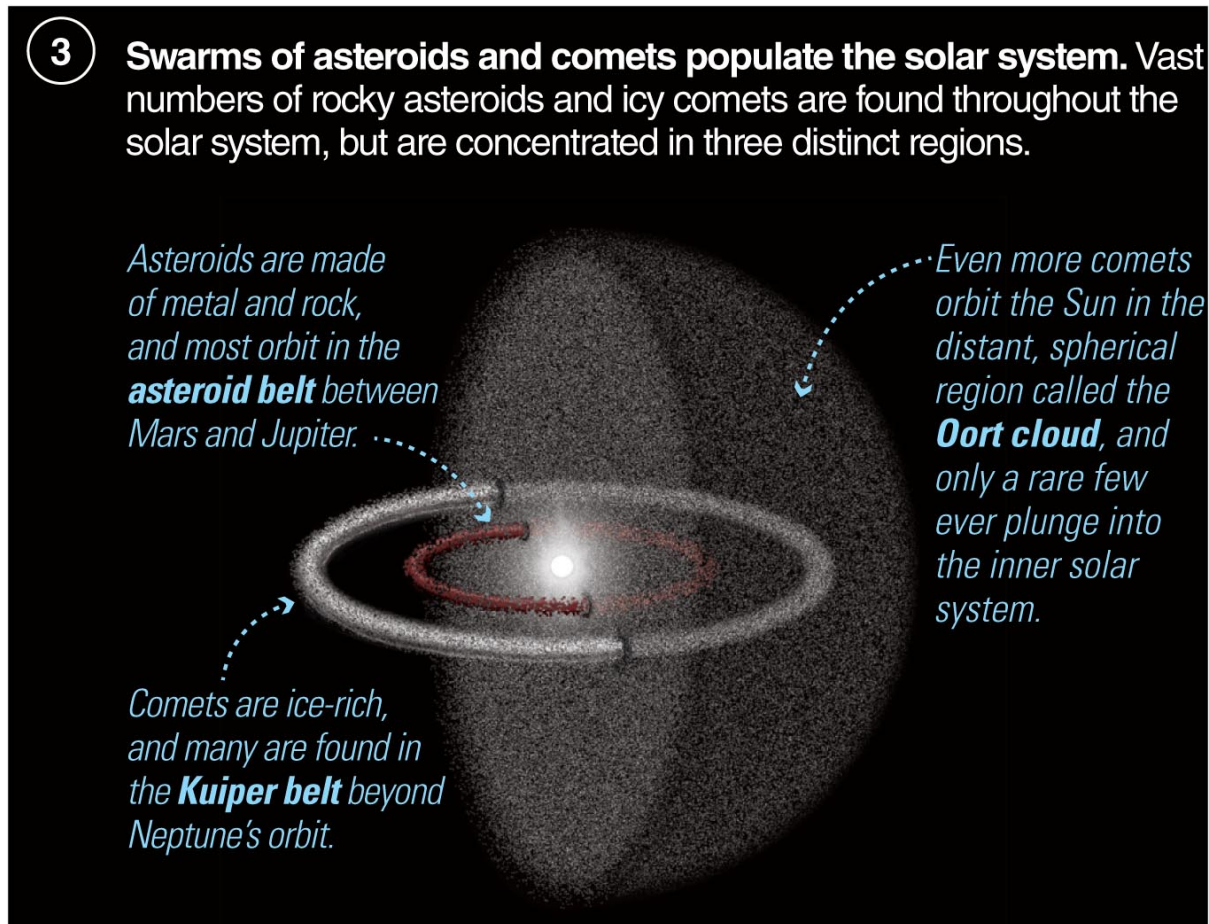
- small in mass and size
- close to the Sun
- made of metal and rock
- few moons and no rings

Jovian Planets:

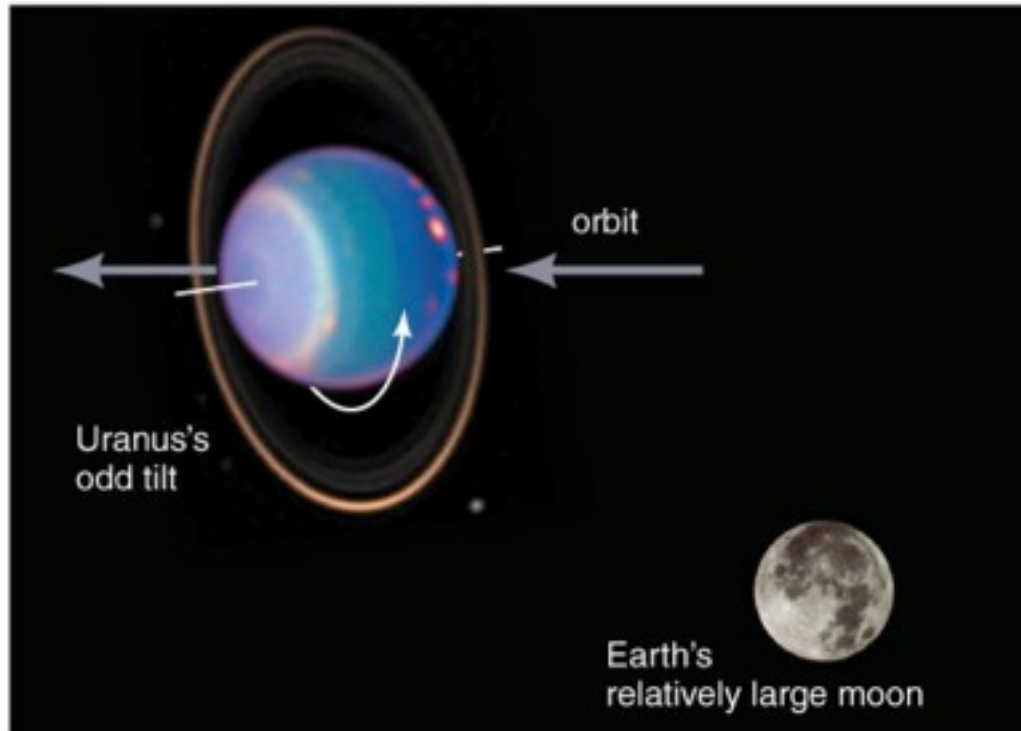
- large mass and size
- far from the Sun
- made of H, He, and hydrogen compounds
- rings and many moons

Swarms of Smaller Bodies

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

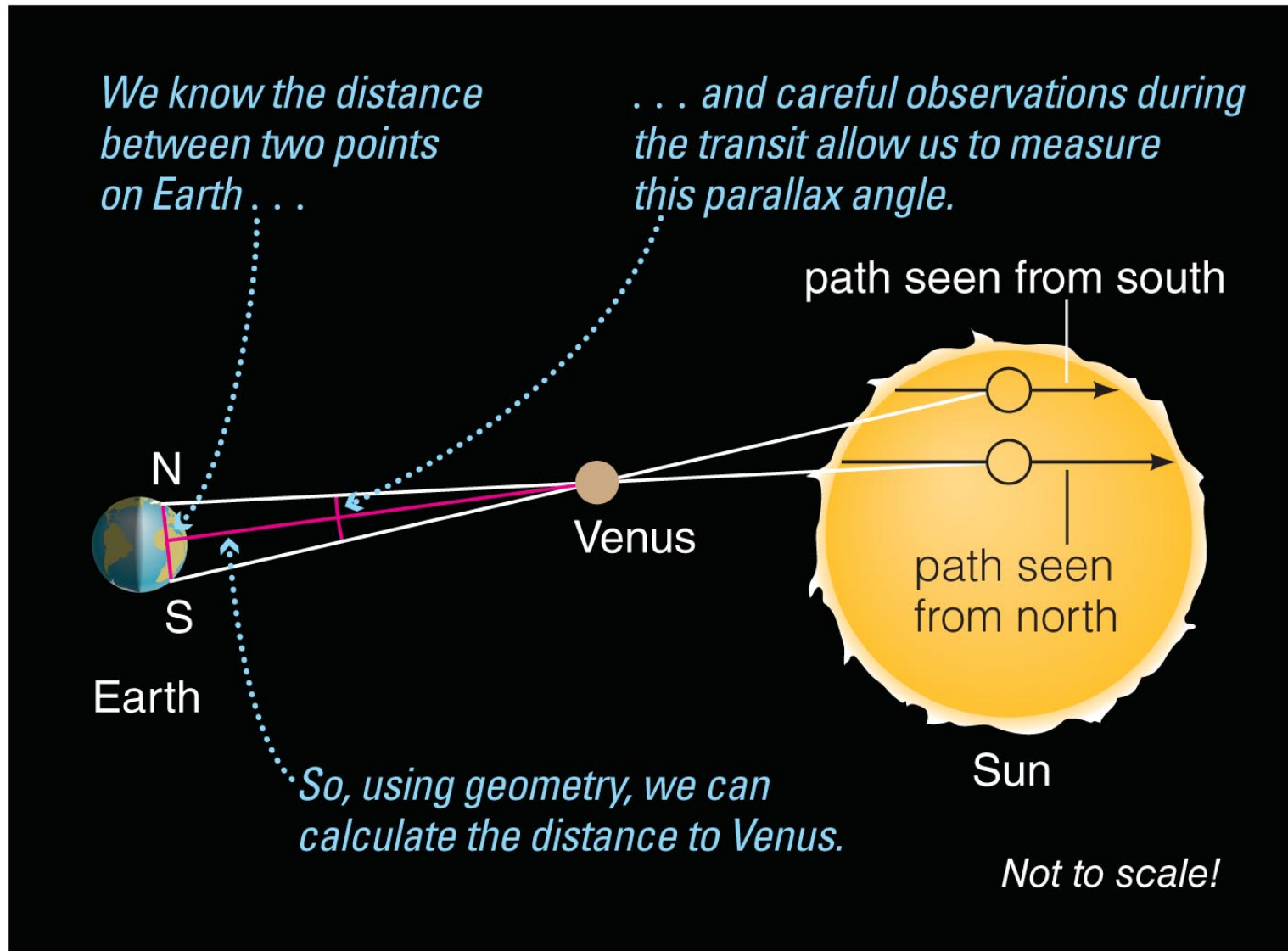


Notable Exceptions



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

Special Topic: How Did We Learn the Scale of the Solar System?



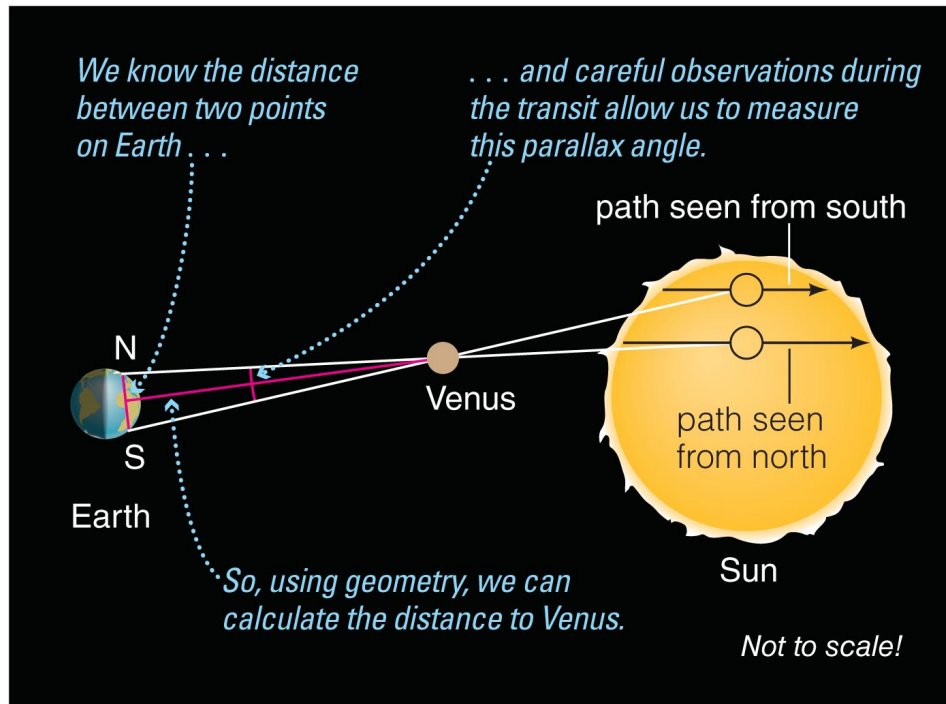
Transit of Venus



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

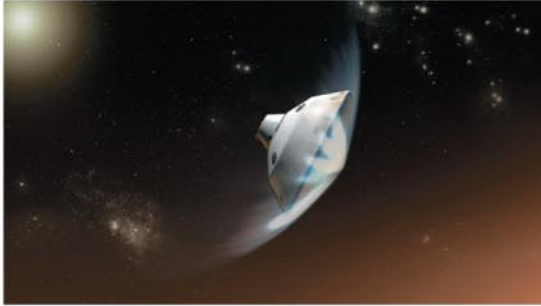
What have we learned?

- **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

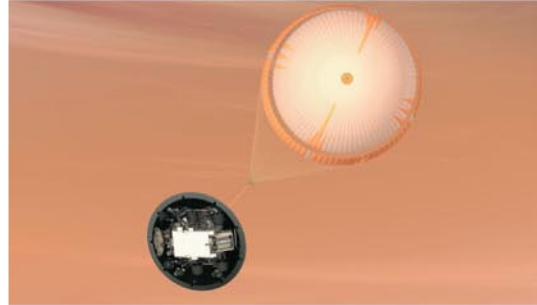
7.3 Spacecraft Exploration of the Solar System

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

How do robotic spacecraft work?



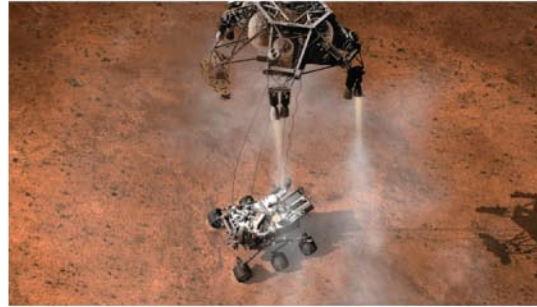
1 Friction slows spacecraft as it enters Mars atmosphere.



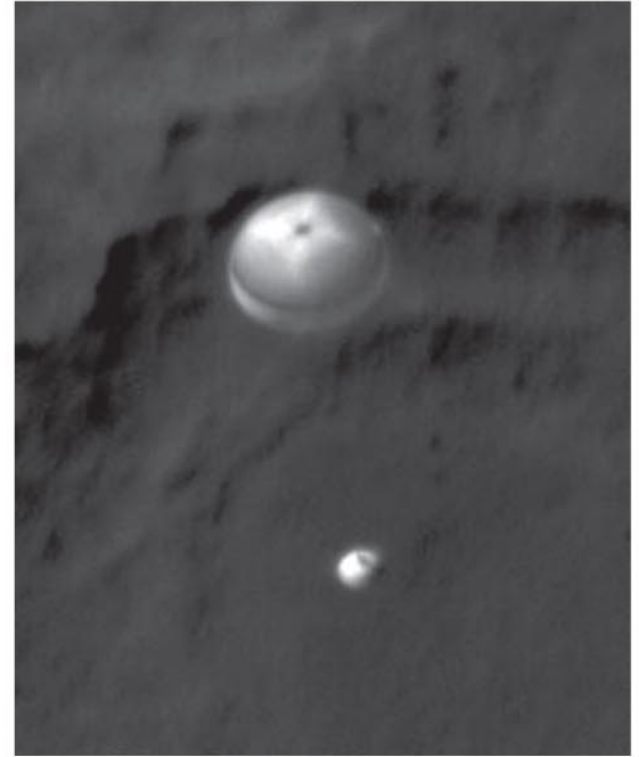
2 Parachute slows spacecraft to about 350 km/hr.



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

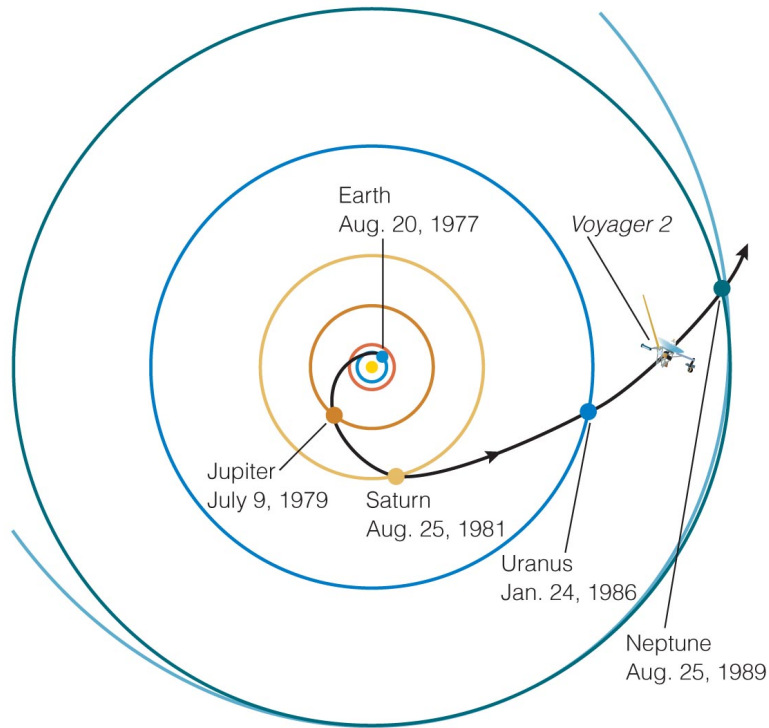


4 Tether released, the rocket heads off to crash a safe distance away.



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

Flybys

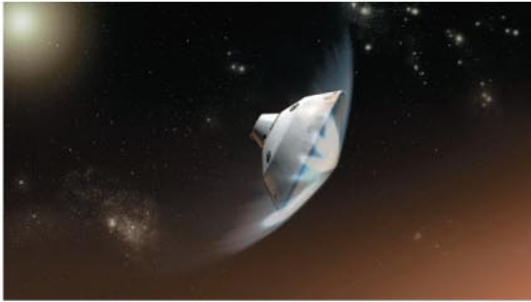


- A flyby mission flies by a planet just once.
- Cheaper than other mission but less time to gather data

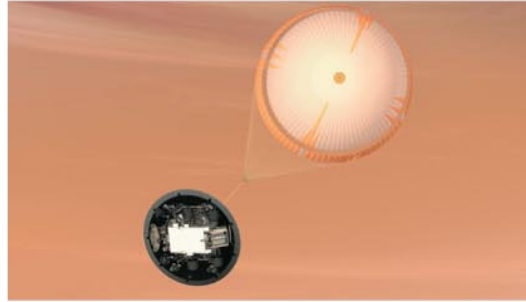
Orbiters

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

Probes or Landers



1 Friction slows spacecraft as it enters Mars atmosphere.



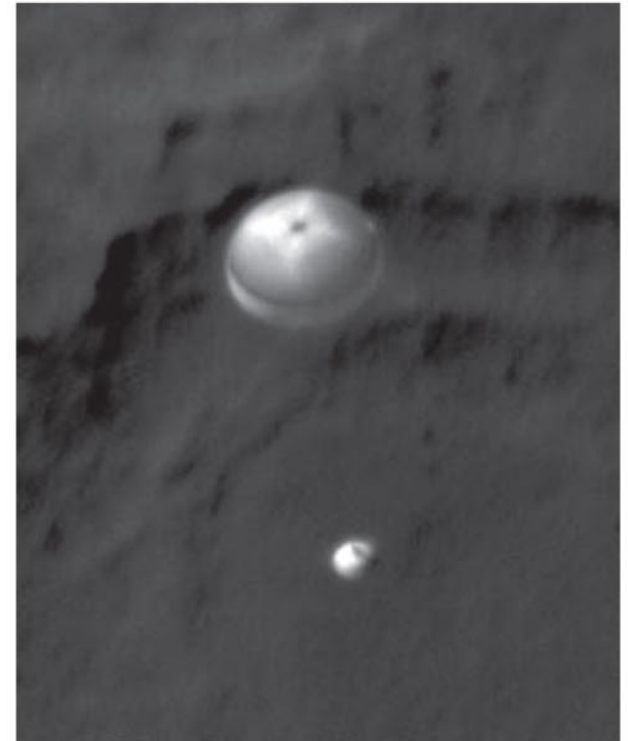
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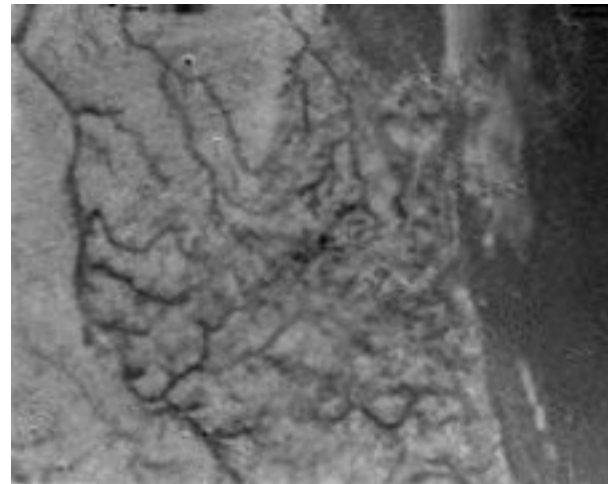
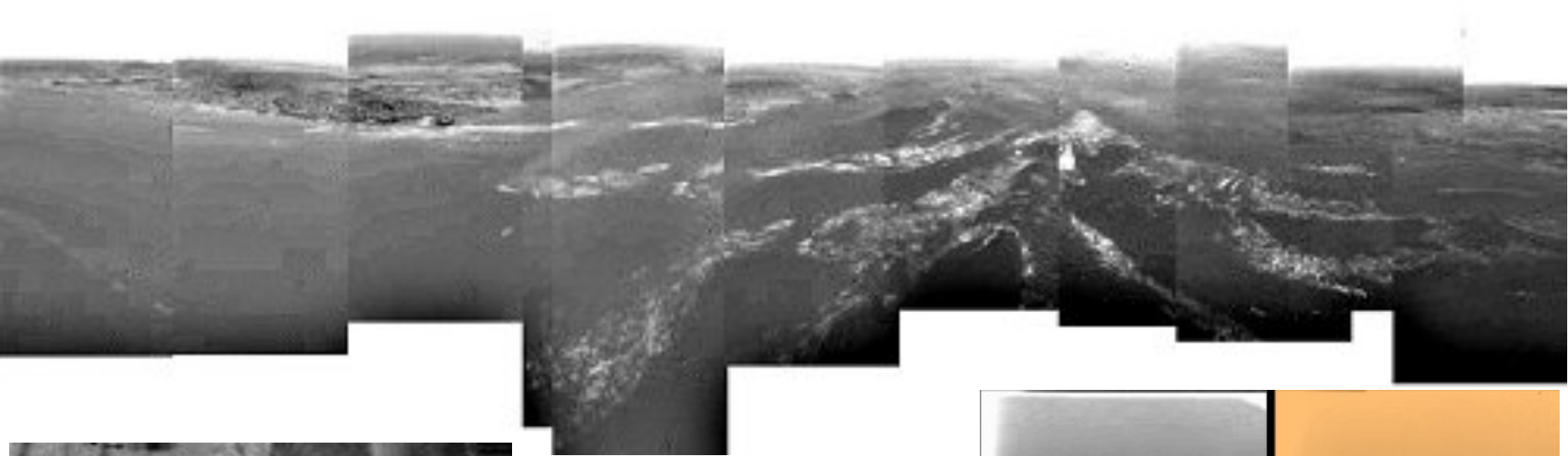
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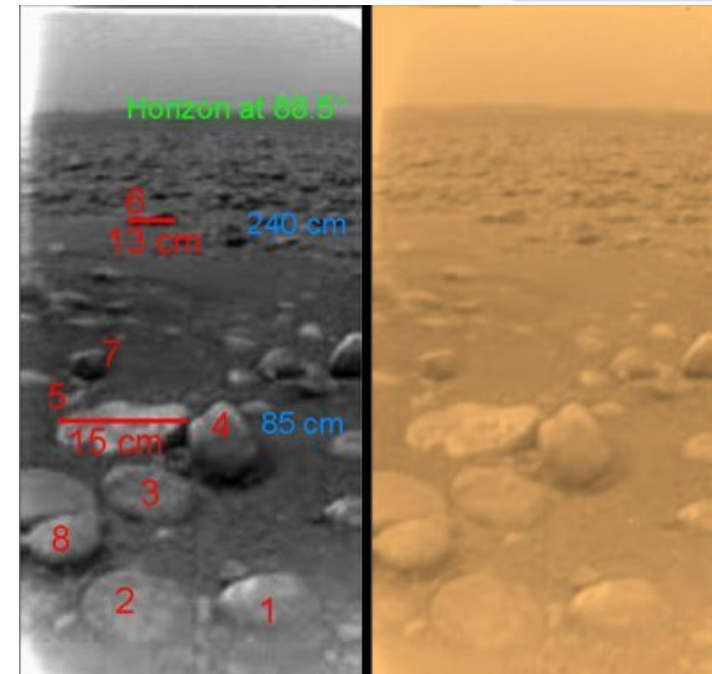
- Land on surface of another world
- Explore surface in detail

Descent of Cassini's Huygens Lander on Titan – January 14, 2005



Titan's winds during descent

Huygens' radar echo from Titan's ground

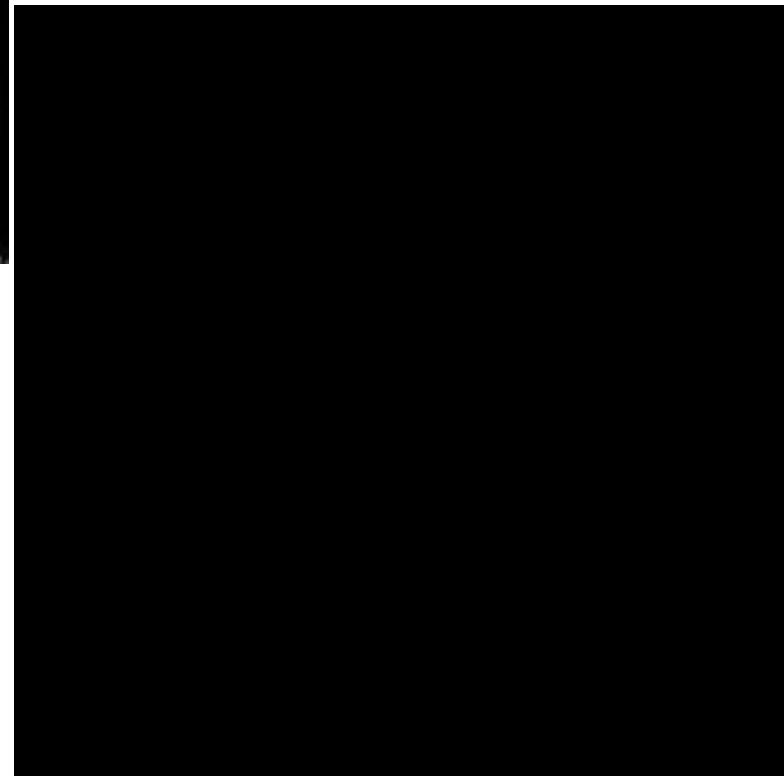


NEAR mission's descent on asteroid Eros



February 12, 2001

Final mission images upon descent



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.

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

A virtual fly-over our solar system

