Roger Freedman • Robert Geller • William Kaufmann III

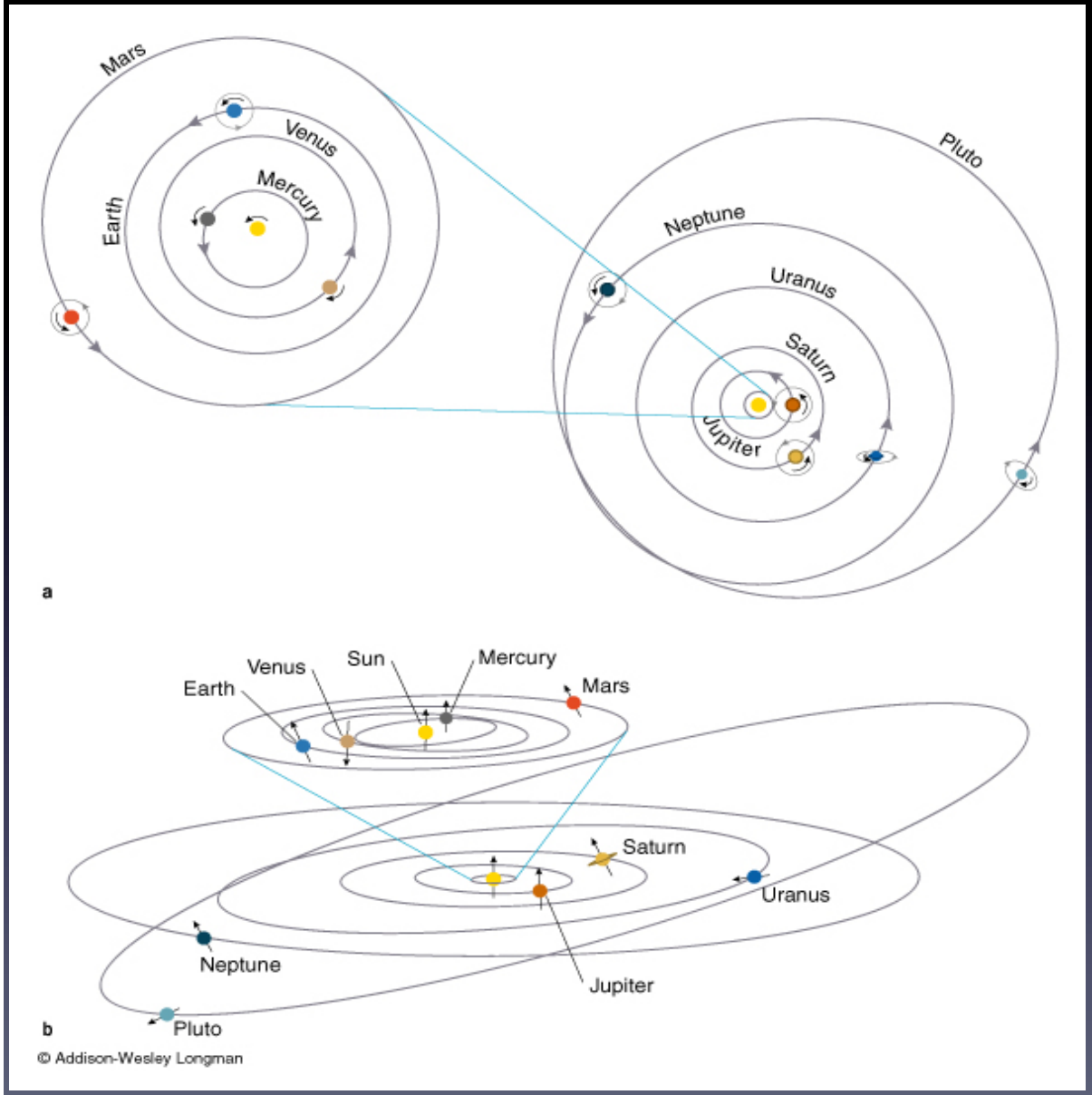
Universe

Tenth Edition

Chapter 7

Comparative Planetology I: Our Solar System

Orbits



- Planet orbits are nearly circular and lie in same plane
- Planets all orbit in same direction (CCW)

Recall:
Planets are tiny compared to distances between them.

7-1: The solar system has two broad categories of planets: Earthlike and Jupiterlike

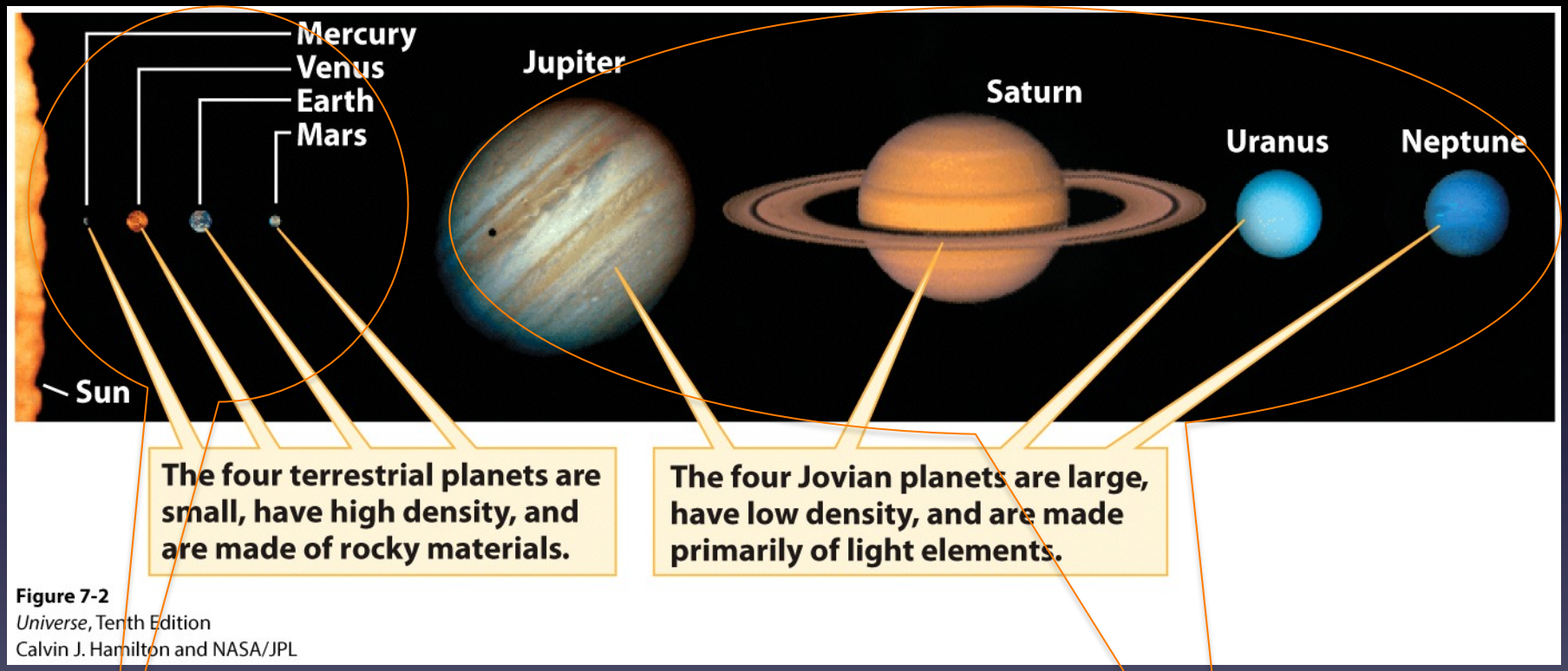


Figure 7-2
Universe, Tenth Edition
Calvin J. Hamilton and NASA/JPL

The Planets to Scale. Orbit distances are NOT to scale!!

Terrestrial Planets

Jovian Planets

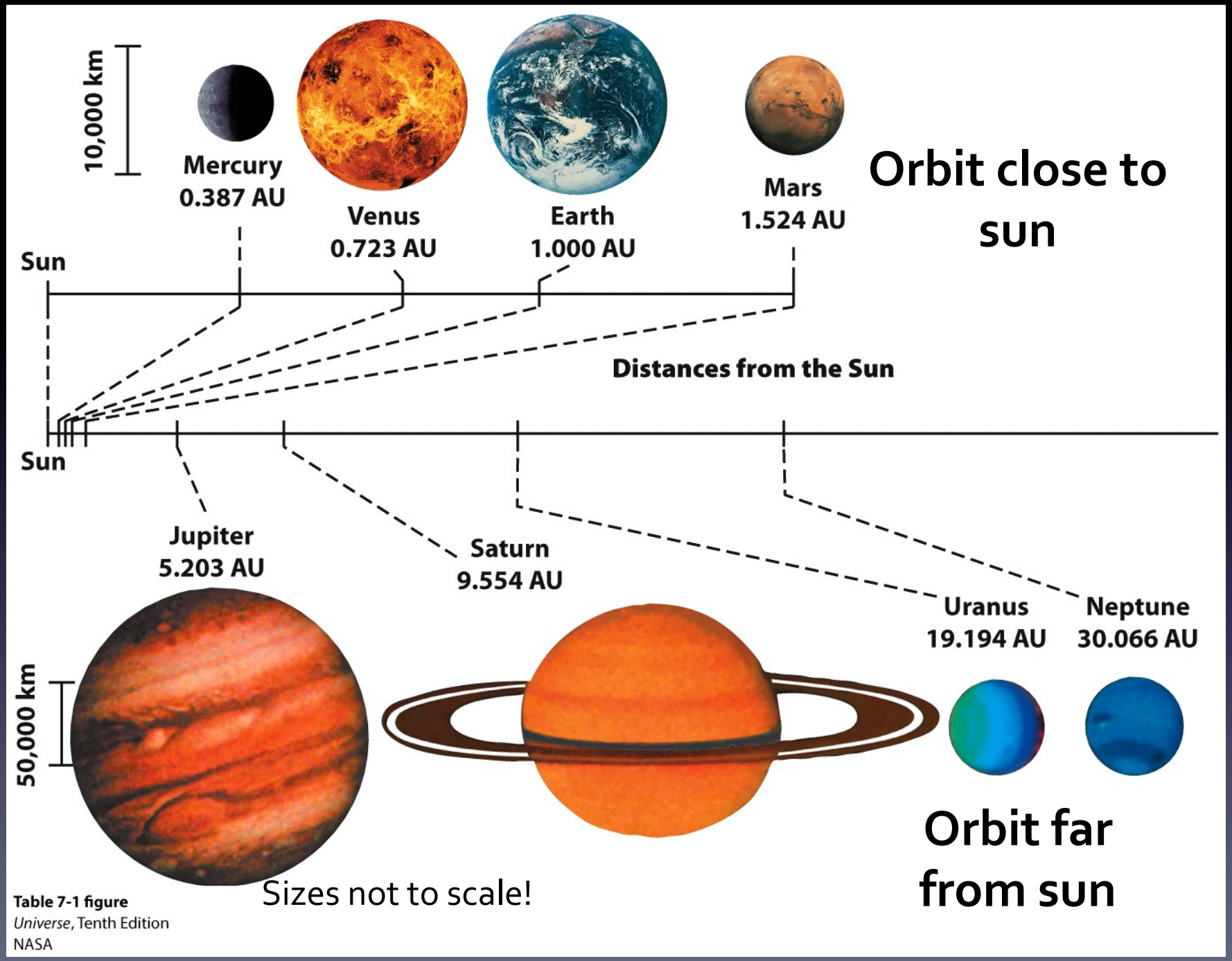

10,000 km
Mercury
0.387 AU
Venus
0.723 AU
Earth
1.000 AU
Mars
1.524 AU
Orbit close to sun
Sun
Distances from the Sun
Sun
Jupiter
5.203 AU
Saturn
9.554 AU
Uranus
19.194 AU
Neptune
30.066 AU
50,000 km
Orbit far from sun
Sizes not to scale!
Table 7-1 figure
Universe, Tenth Edition
NASA

TABLE 7-1 Characteristics of the Planets

	The Inner (Terrestrial) Planets			
	Mercury	**Venus**	**Earth**	**Mars**
Average distance from the Sun (10^6 km)	57.9	108.2	149.6	227.9
Average distance from the 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)	3.302×10^{23}	4.868×10^{24}	5.974×10^{24}	6.418×10^{23}
Mass (Earth = 1)	0.0553	0.8150	1.0000	0.1074
Average density (kg/m3)	5430	5243	5515	3934

Table 7-1 part 1
Universe, Tenth Edition

TABLE 7-1 Characteristics of the Planets

	The Outer (Jovian) Planets			
	Jupiter	**Saturn**	**Uranus**	**Neptune**
Average distance from the Sun (10^6 km)	778.3	1429	2871	4498
Average distance from the 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)	1.899×10^{27}	5.685×10^{26}	8.682×10^{25}	1.024×10^{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
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Table 7.2 Comparison of Terrestrial and Jovian Planets

Terrestrial Planets	*Jovian Planets*
Smaller size and mass	Larger size and mass
Higher density	Lower density
Made mostly of rock and metal	Made mostly of hydrogen, helium, and hydrogen compounds
Solid surface	No solid surface
Few (if any) moons and no rings	Rings and many moons
Closer to the Sun (and closer together), with warmer surfaces	Farther from the Sun (and farther apart), with cool temperatures at cloud tops

7-2: Seven large satellites are almost as big as the terrestrial planets

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

R I V U X G (NASA/JPL/Space Science Institute)

Table 7-2
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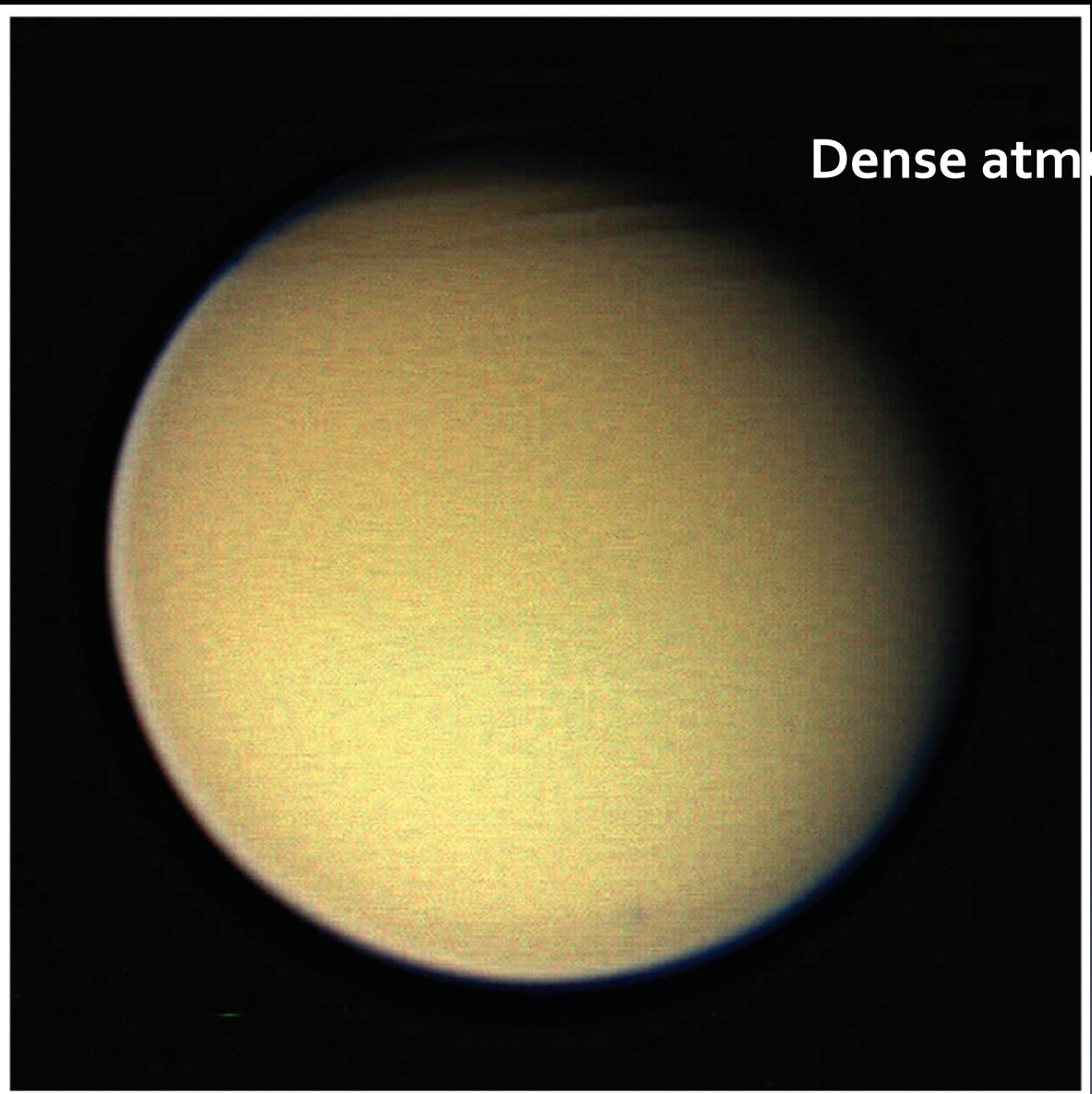
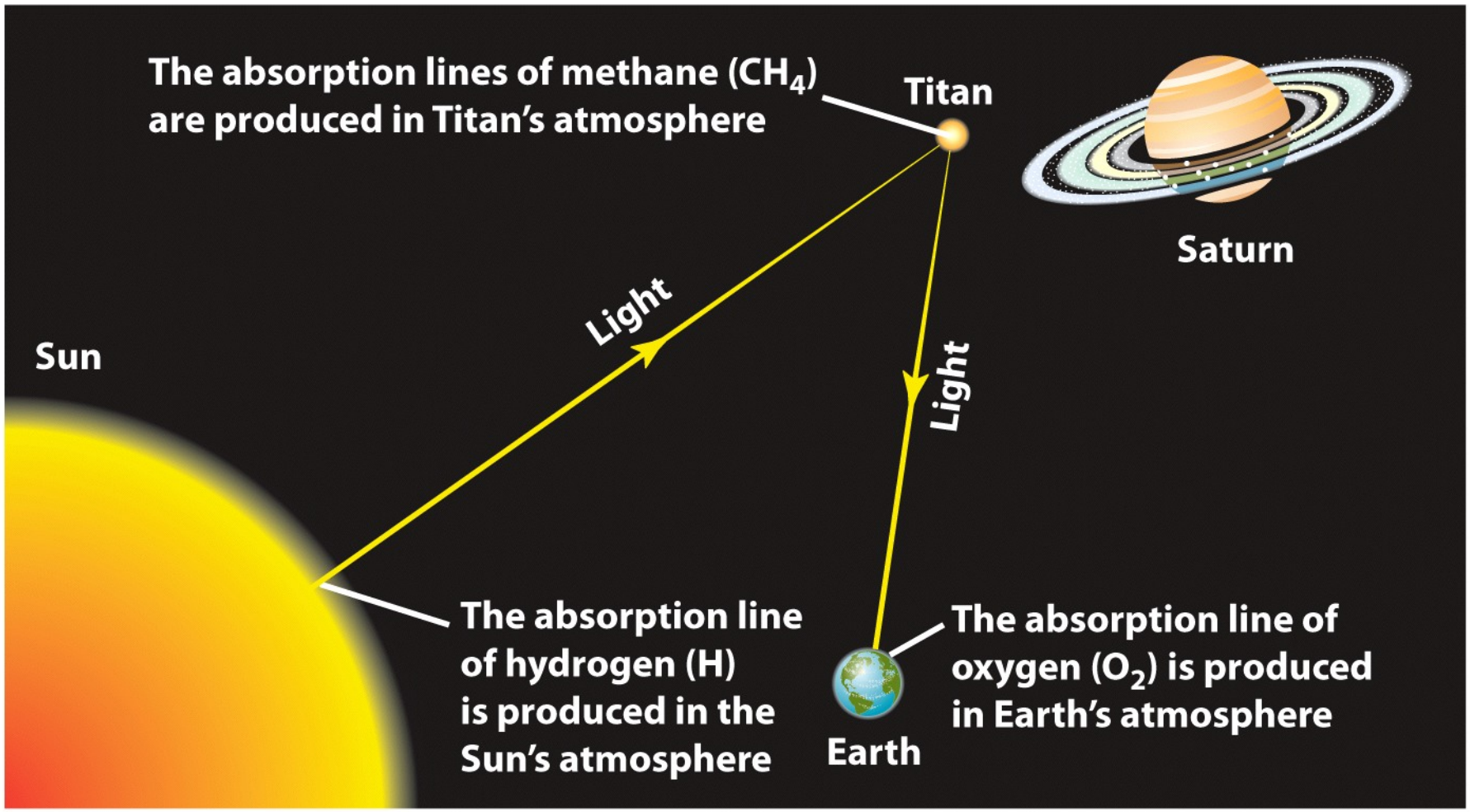


Dense atmosphere!

Saturn's satellite Titan

Figure 7-3a
Universe, Tenth Edition
NASA/JPL/Space Science Institute



Interpreting Titan's spectrum

Figure 7-3c
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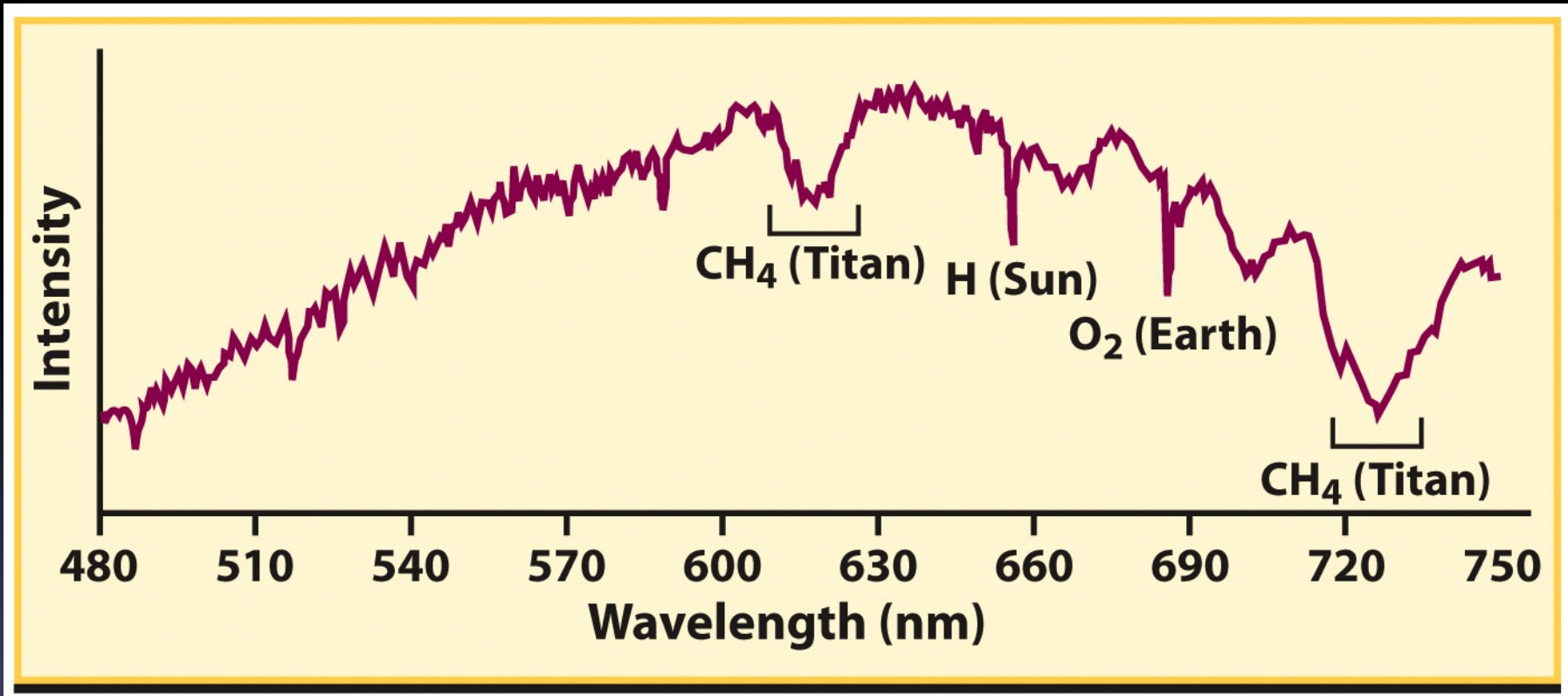
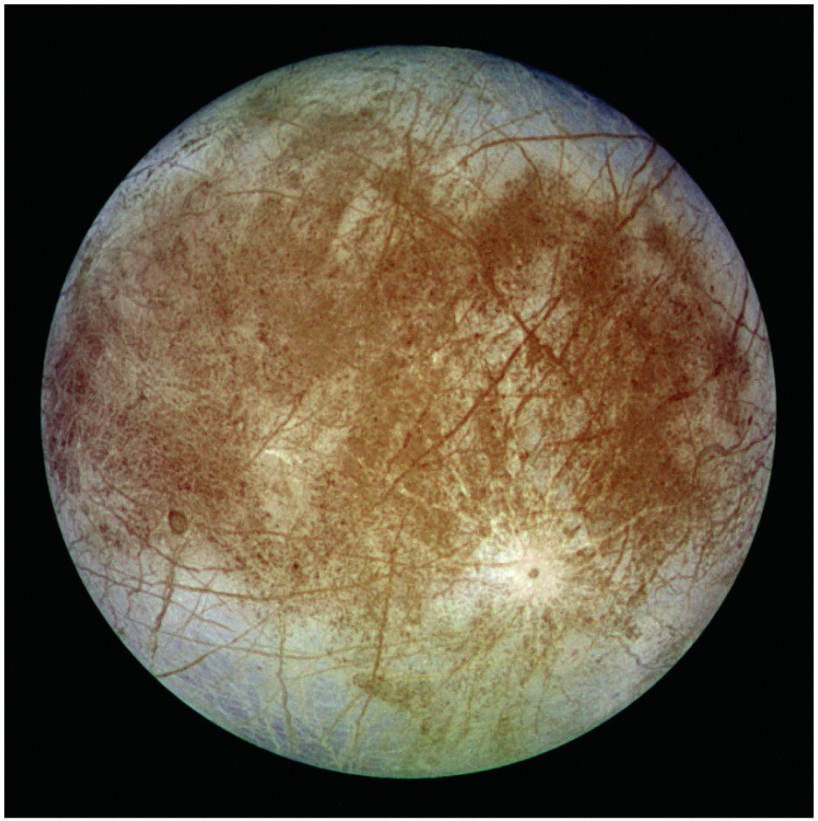
Analyzing a Satellite's Atmosphere through its Spectrum



The spectrum of sunlight reflected from Titan

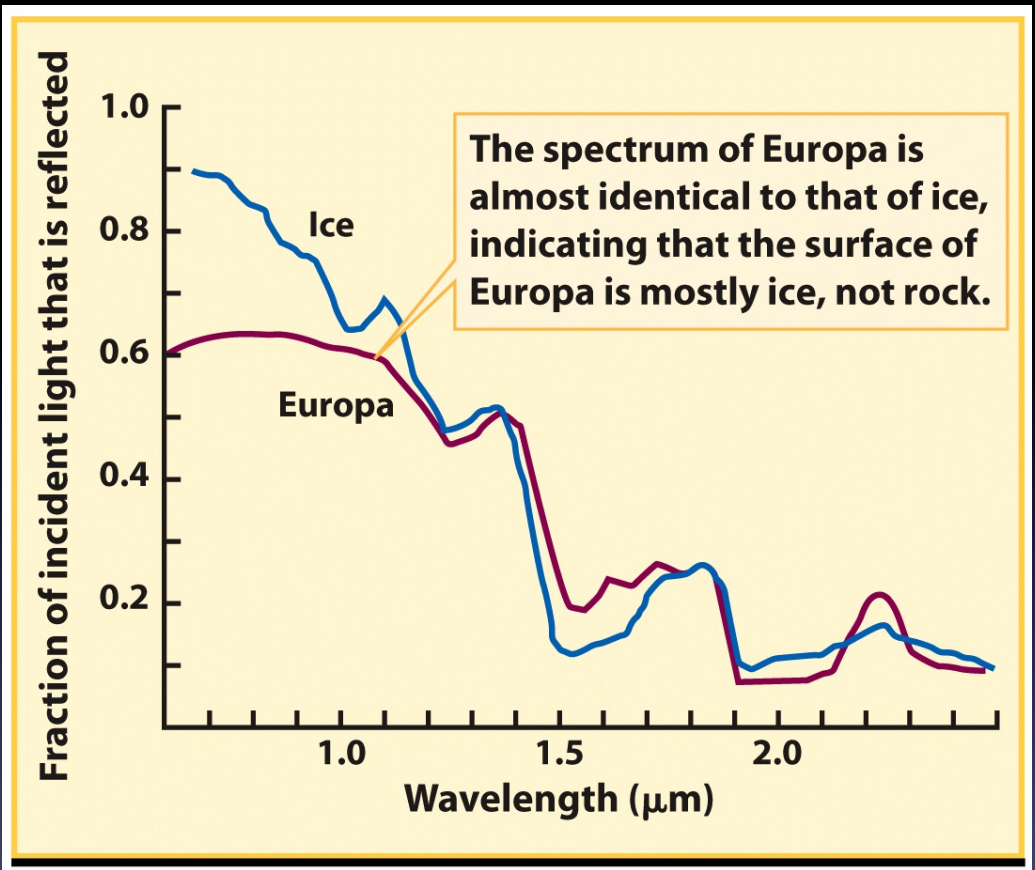
Figure 7-3b
Universe, Tenth Edition

Analyzing a Satellite's Atmosphere through its Spectrum



Jupiter's moon Europa

Figure 7-4a
Universe, Tenth Edition
NASA



The spectum of light reflected from Europa

Figure 7-4b
Universe, Tenth Edition

Analyzing a Satellite's Surface from its Spectrum

7-4: The Jovian planets are made of lighter elements than the terrestrial planets

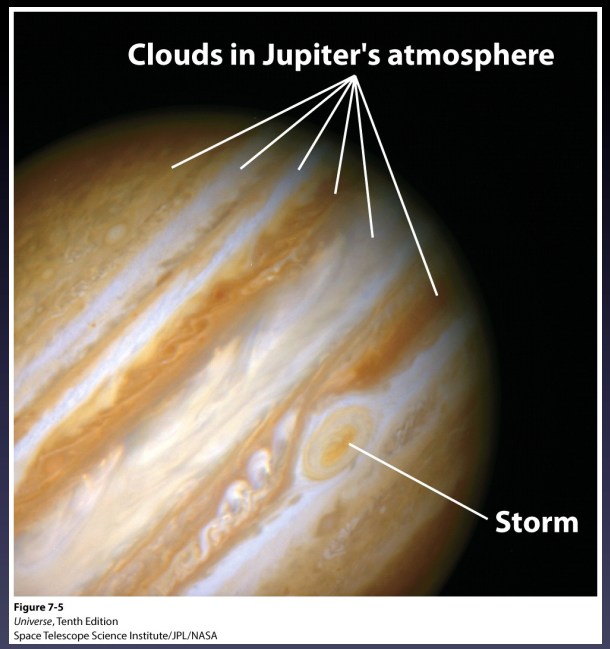


Figure 7-5
Universe, Tenth Edition
Space Telescope Science Institute/JPL/NASA

A Jovian Planet

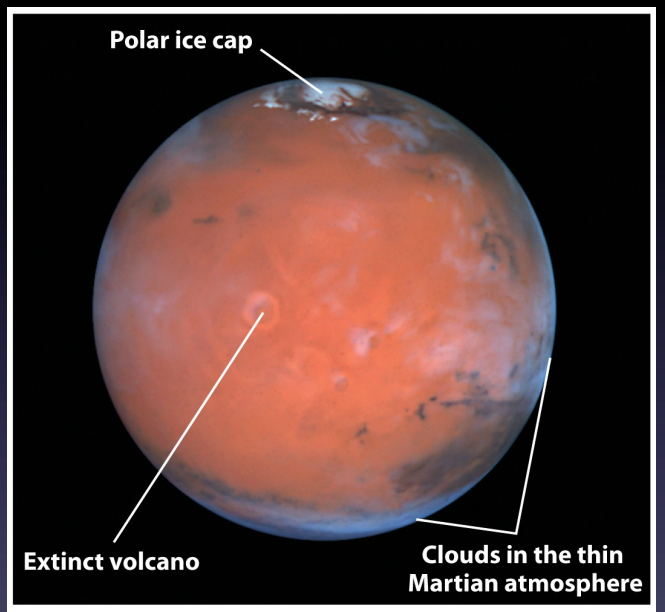


Figure 7-6
Universe, Tenth Edition
Space Telescope Science Institute/JPL/NASA

A Terrestrial Planet

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
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Compositions due to temperature

- H, He always gases
- Far from sun, metals, rocks, and H compounds are solid particles (ices): Jovian planets bodies were made of these: became large
- Large and cold: able to capture H, He into enormous atmospheres

Compositions due to temperature

- Close to sun, only rocky/metals are solid: terrestrial planet bodies are made of these: small.
- Low gravity, hot: can't capture fast-moving light elements (H, He) so don't create large atmospheres

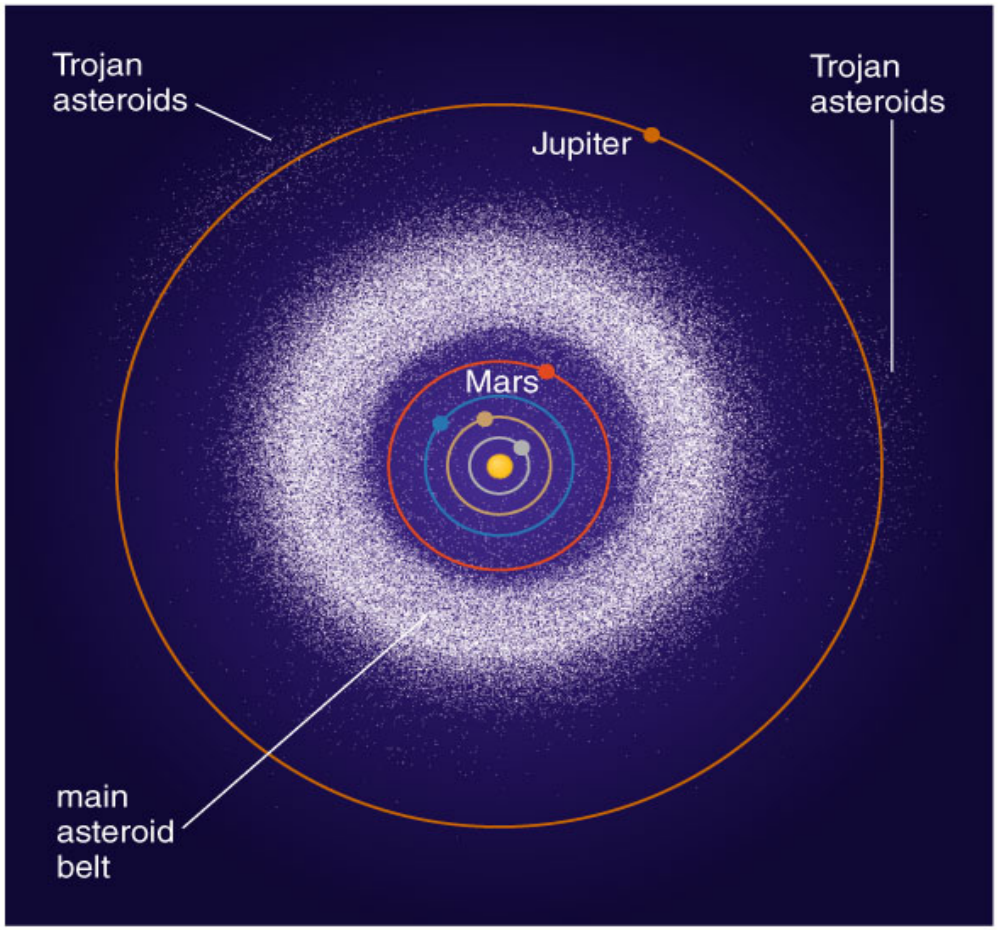
7-5: Small chunks of rock and ice also orbit the Sun

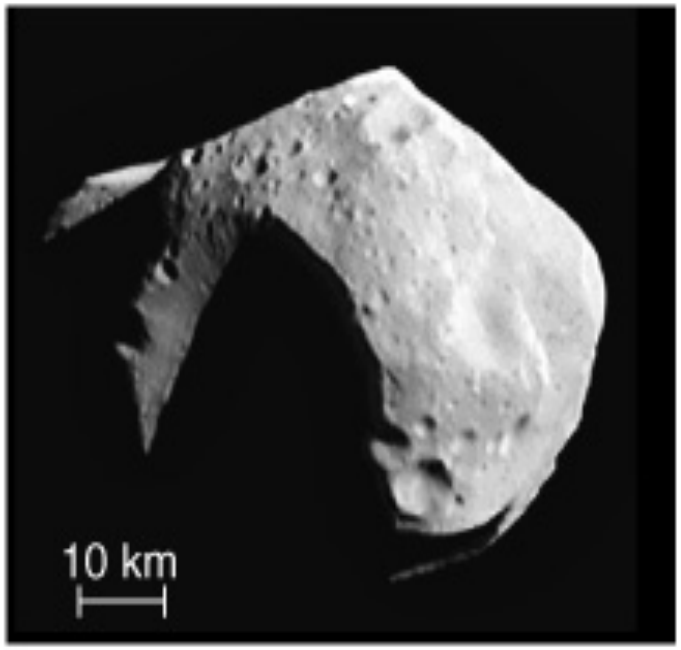
Figure 7-7
Universe, Tenth Edition
NEAR Project, NLR, JHUAPL, Goddard SVS, NASA

An Asteroid

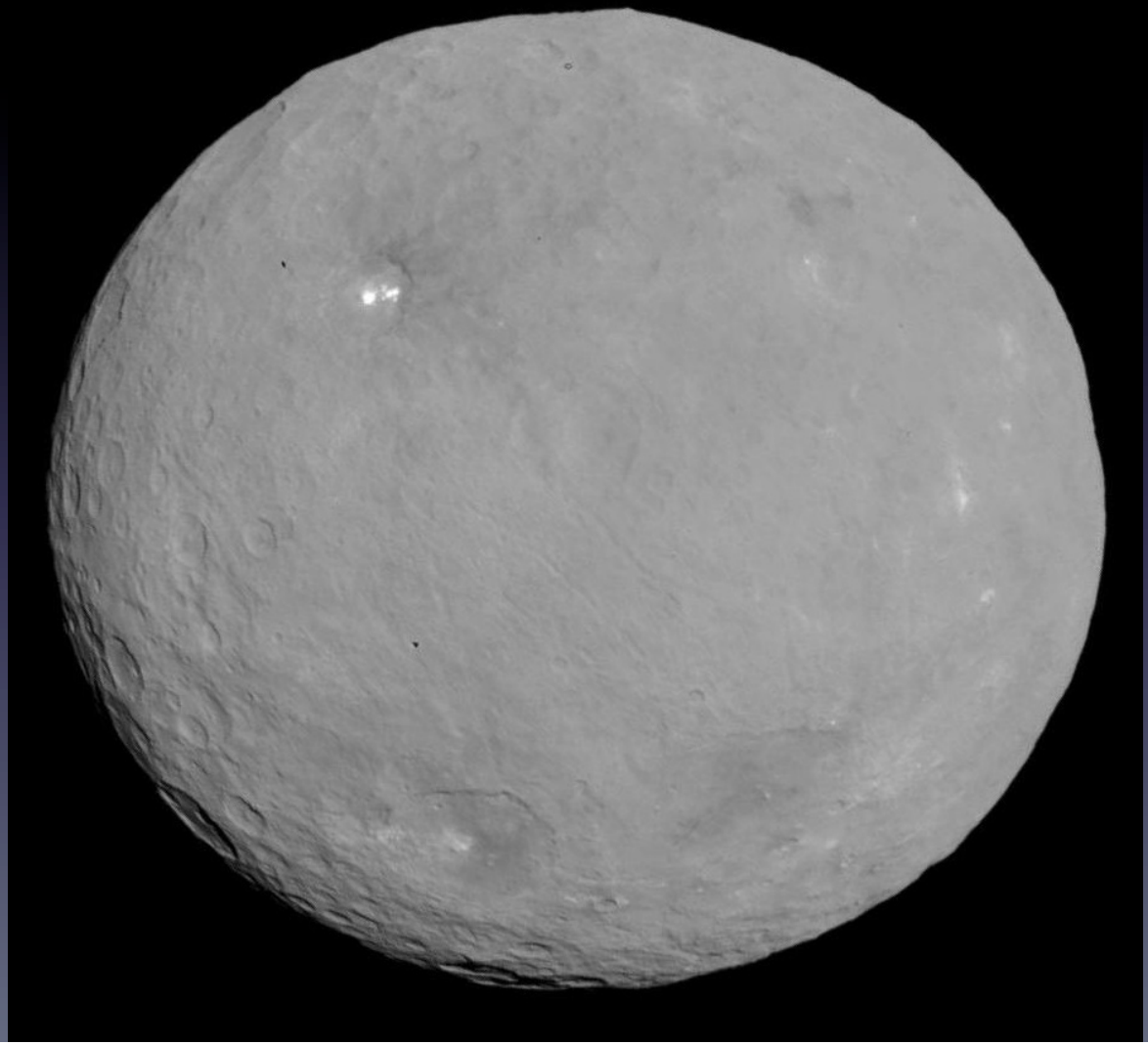
Asteroid Belt

Most asteroids orbit between Mars and Jupiter





Asteroid Ceres



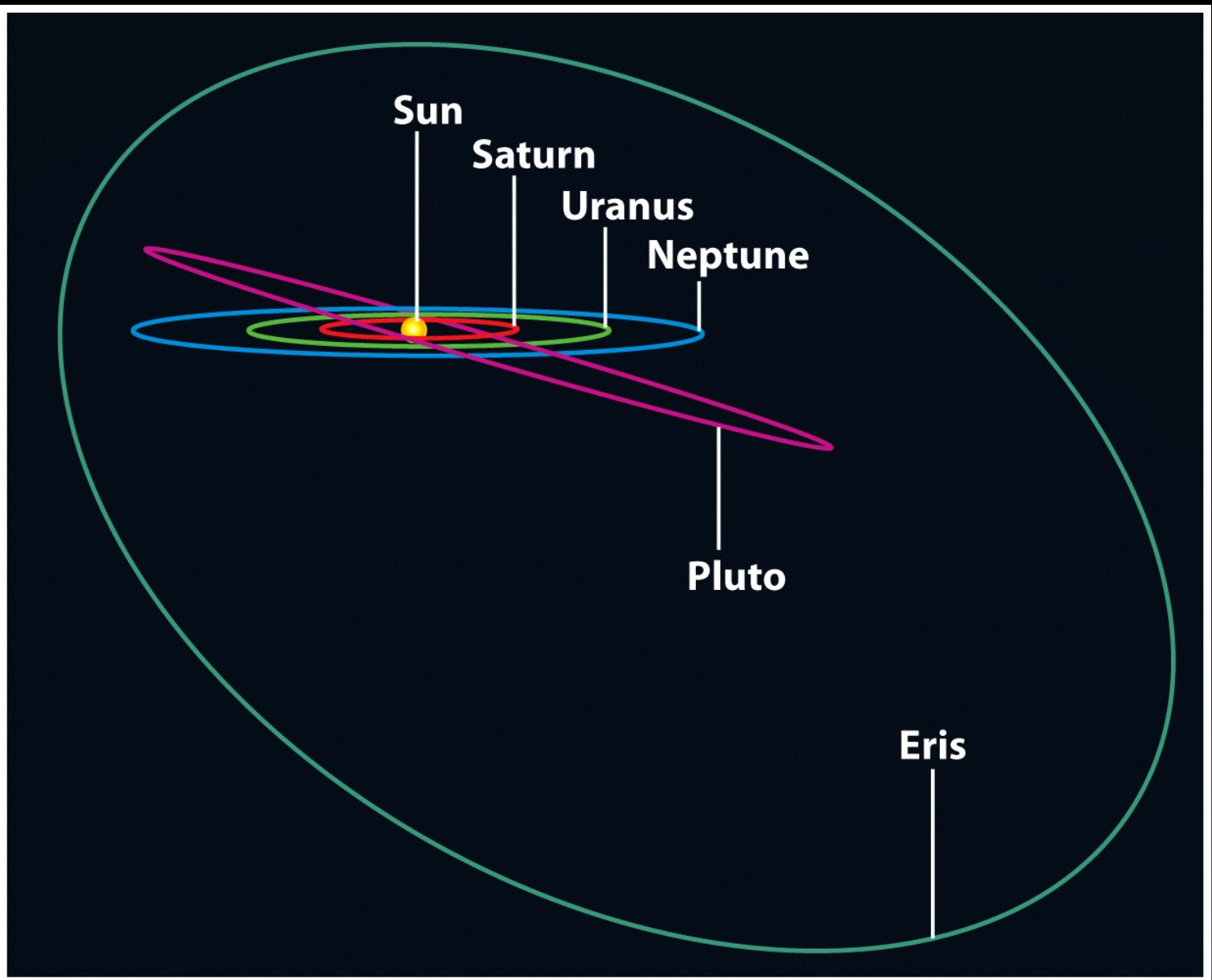
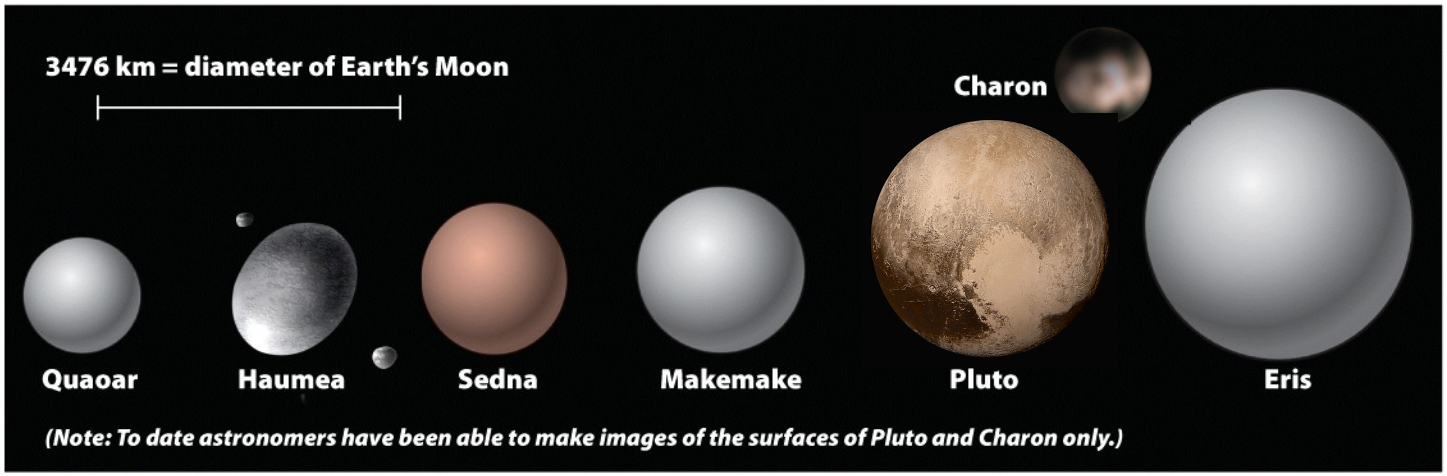


Figure 7-8
Universe, Tenth Edition

Trans-Neptunian Objects

TABLE 7-4 Seven Large Trans-Neptunian Objects

	Quaoar	Haumea	Sedna	Makemake	Pluto	Charon (satellite of Pluto)	Eris
Average distance from the 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
					2370		2326



R I V U X G

(Haumea: A. Field [STScI]/NASA; Charon: Lanthanum-138; all others: Alan Stern [Southwest Research Institute]/Marc Buie [Lowell Observatory]/ NASA/ESA)

Table 7-4
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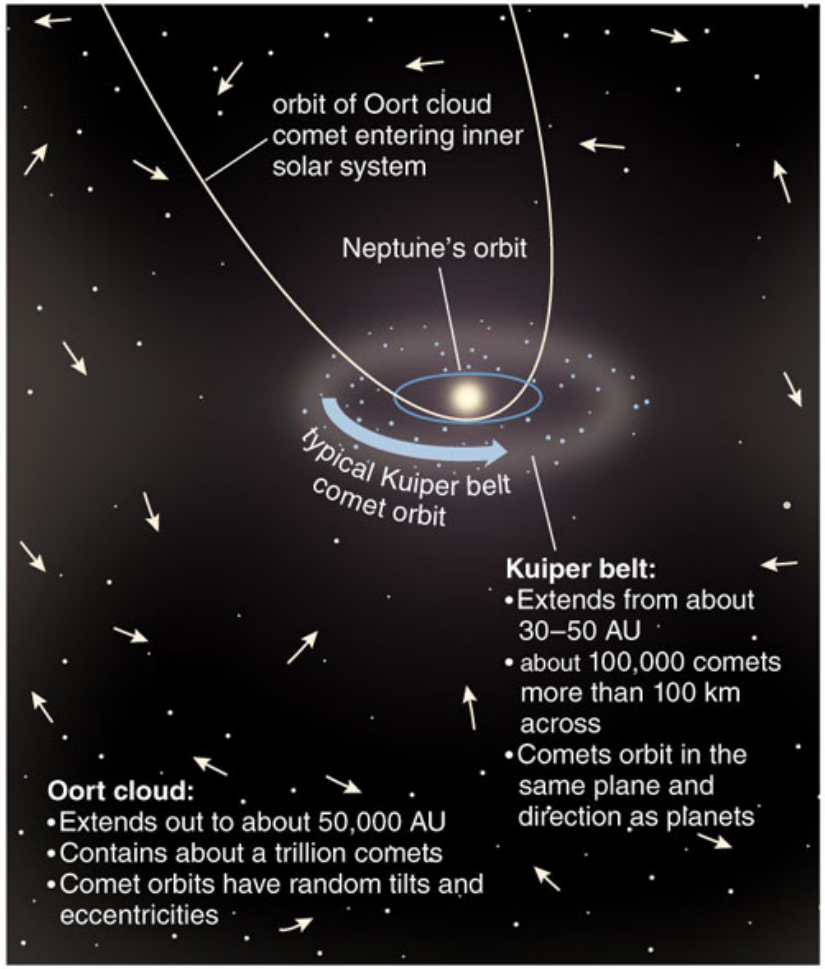
Most TNOs orbit in Kuiper Belt



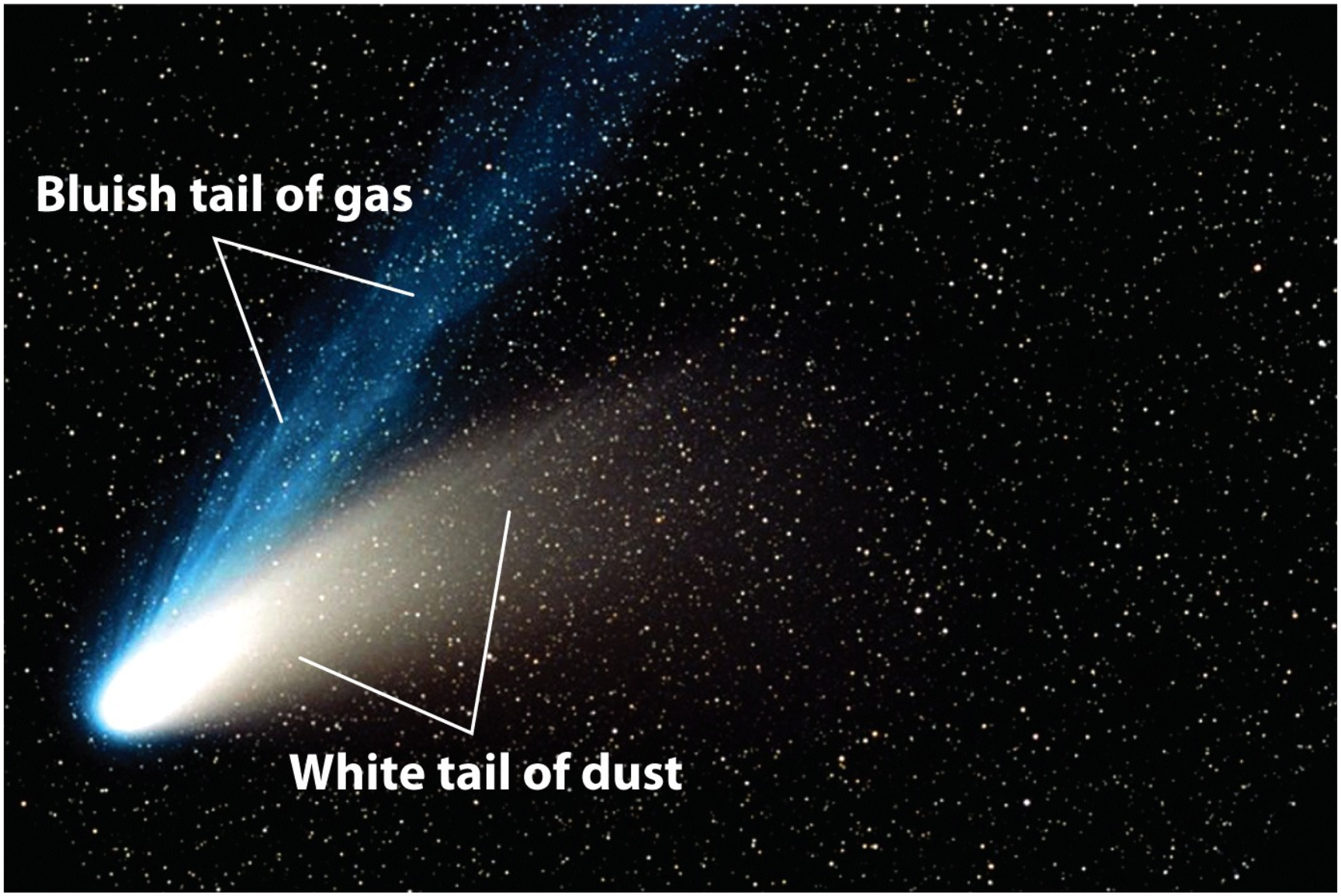
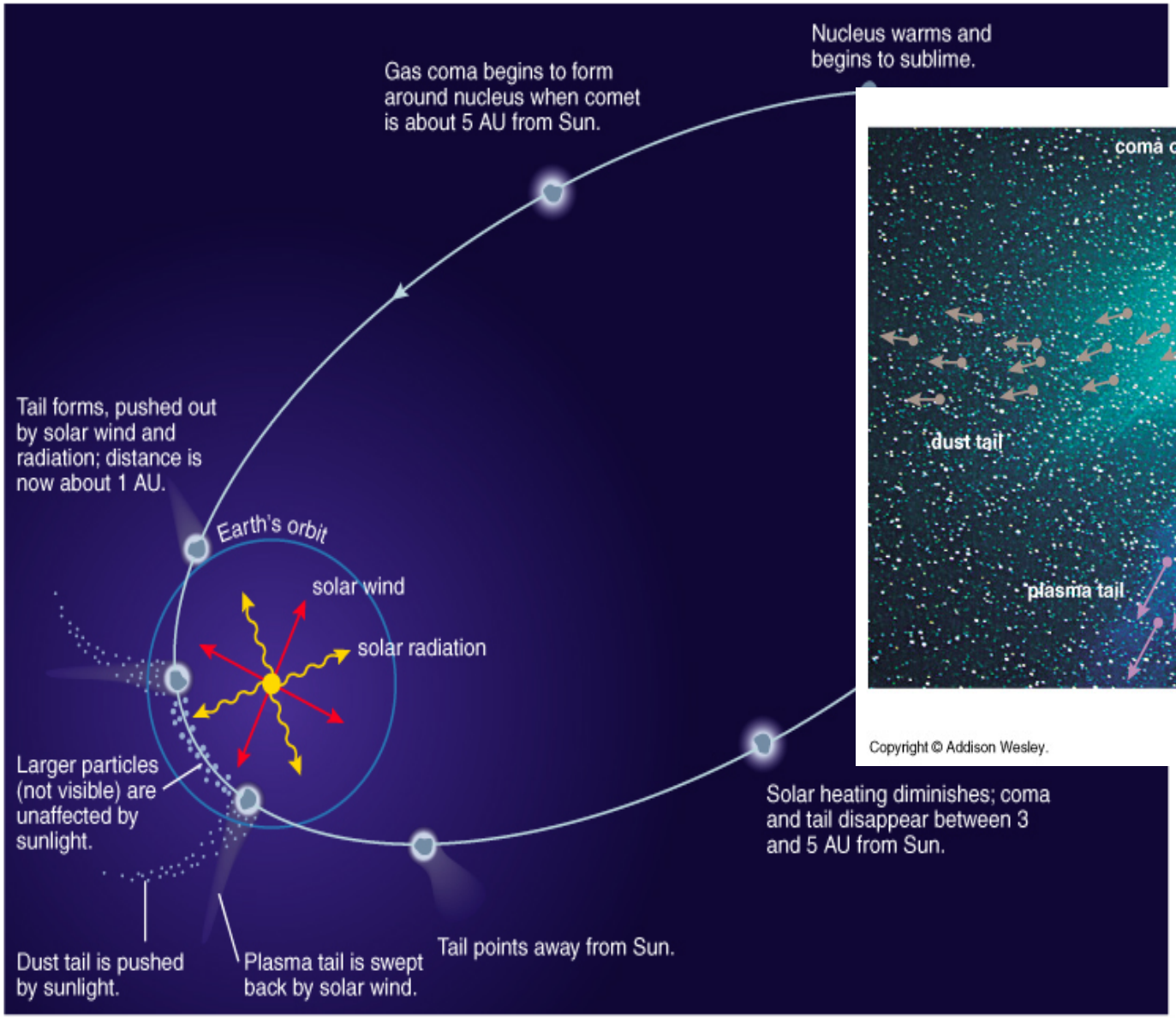
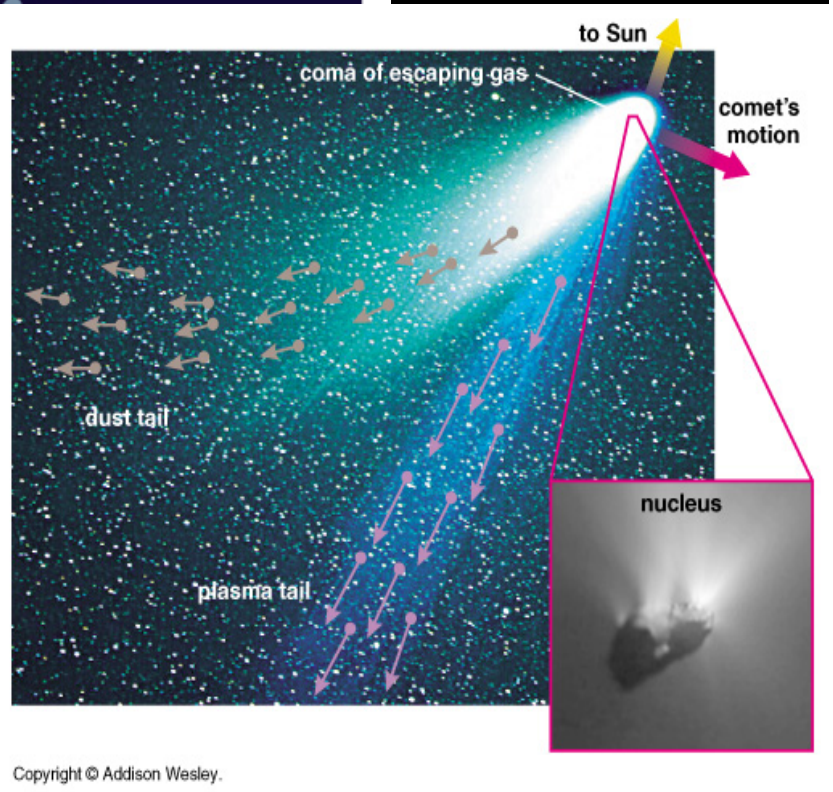


Figure 7-9
Universe, Tenth Edition
Agencia el Universal/AP Images

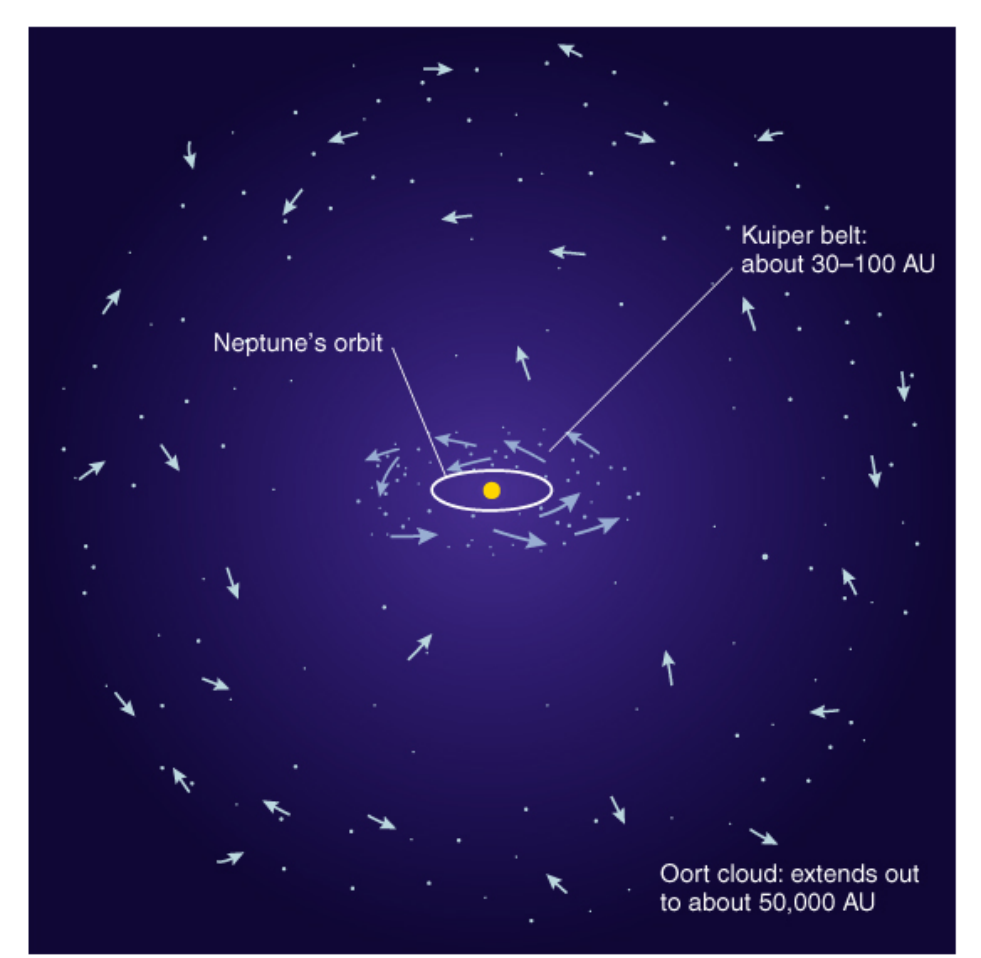
A Comet

Comets

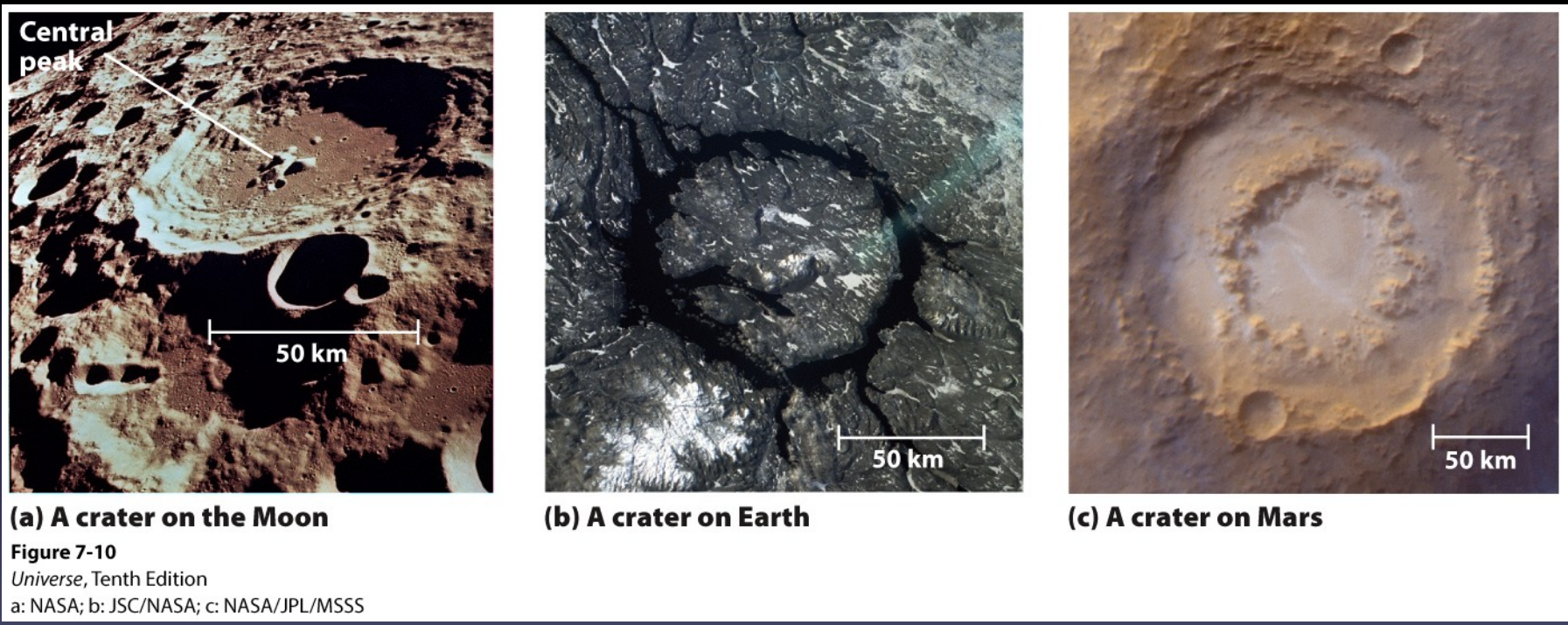

Nucleus warms and begins to sublime.
Gas coma begins to form around nucleus when comet is about 5 AU from Sun.
Tail forms, pushed out by solar wind and radiation; distance is now about 1 AU.
Earth's orbit
solar wind
solar radiation
Larger particles (not visible) are unaffected by sunlight.
Dust tail is pushed by sunlight.
Plasma tail is swept back by solar wind.
Tail points away from Sun.
Solar heating diminishes; coma and tail disappear between 3 and 5 AU from Sun.
© Addison-Wesley Longman


to Sun
coma of escaping gas
comet's motion
dust tail
plasma tail
nucleus
Copyright © Addison Wesley.

Most comets orbit in the Oort Cloud



7-6: Craters on planets and satellites are the result of impacts from interplanetary debris



(a) A crater on the Moon (b) A crater on Earth (c) A crater on Mars

Figure 7-10
Universe, Tenth Edition
a: NASA; b: JSC/NASA; c: NASA/JPL/MSSS

Impact Craters

Craters tell us about the interiors and histories of planets (and moons)

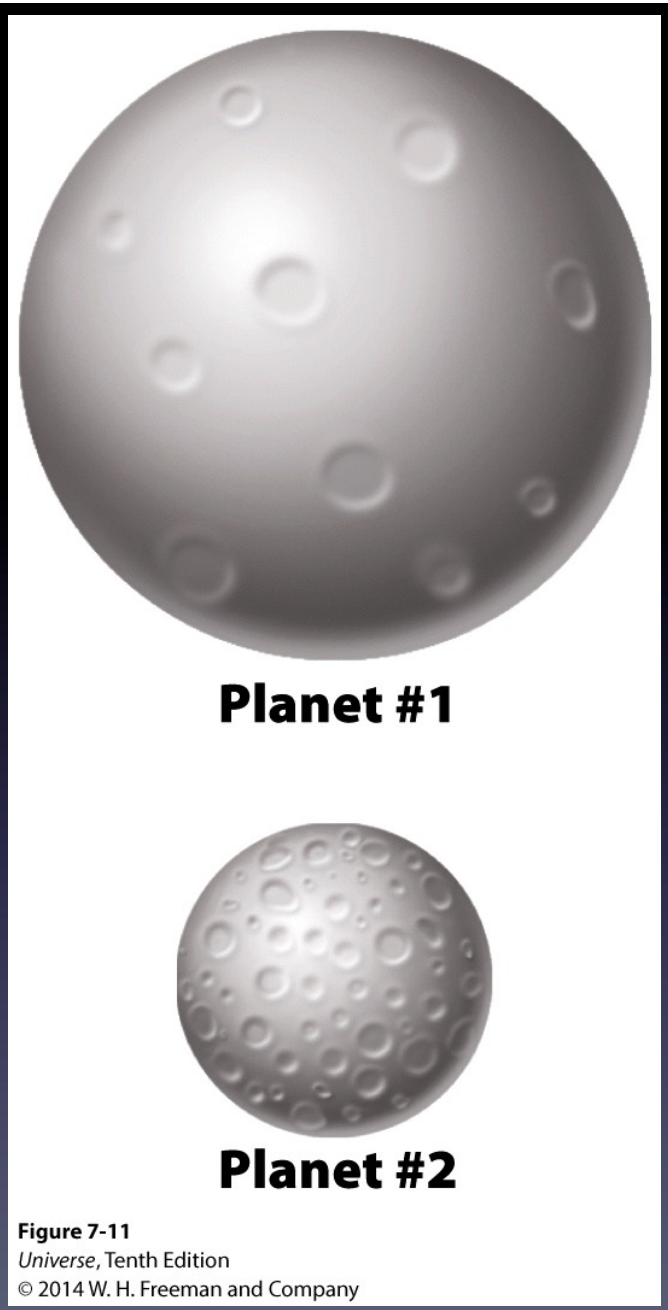


Figure 7-11
Universe, Tenth Edition

Planet Size and Cratering

- All solid surfaces were heavily cratered long ago
- Geologic processes (volcanic/tectonic) resurface planet/moon erasing craters
- More craters = less activity = older surface

Planet #1

Planet #2

Compared to planet #1, planet #2:
— has 1/2 the radius
— has 1/4 the surface area (so it can lose heat only 1/4 as fast)
— but has only 1/8 the volume (so it has only 1/8 as much heat to lose)

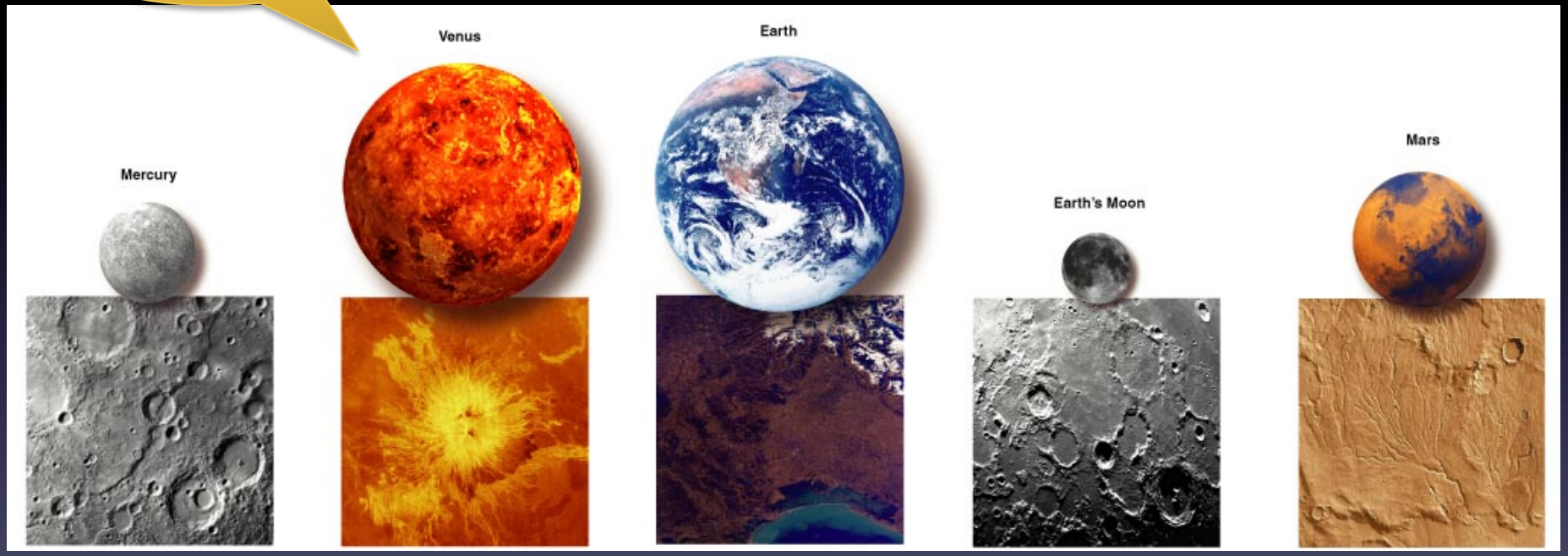
Hence compared to planet #1, planet #2:
— will cool off more rapidly
— will sustain less geologic activity
— will have more craters

Figure 7-11
Universe, Tenth Edition

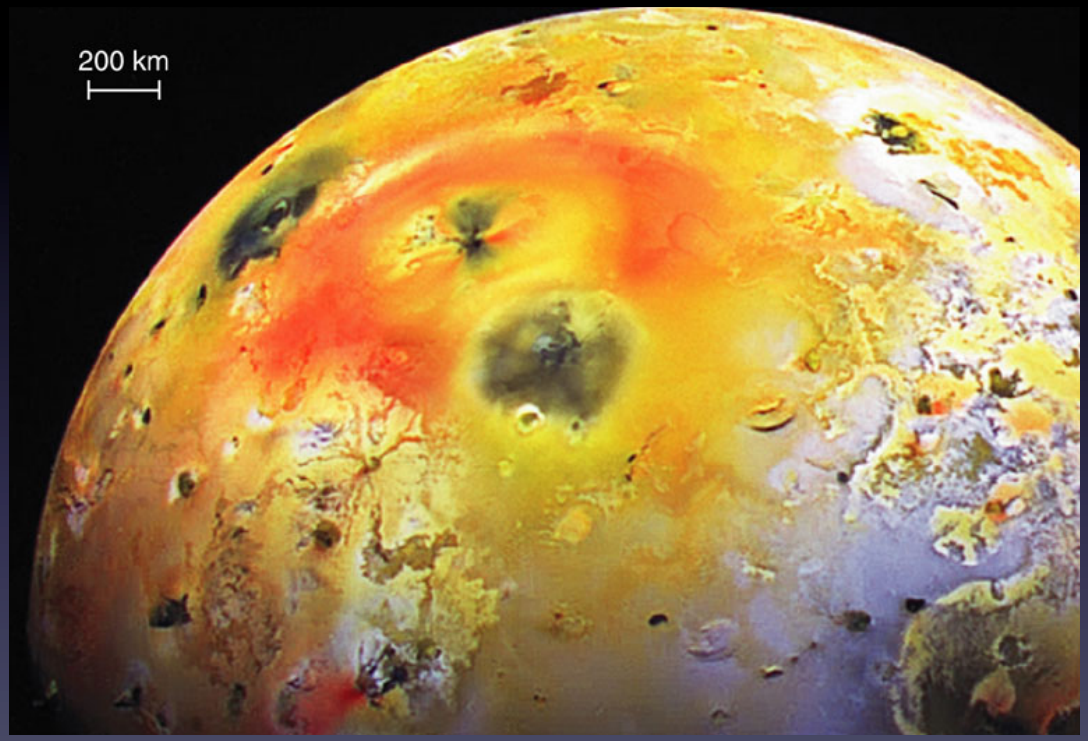
Planet Size and Cratering

Larger worlds are more active, fewer craters left

False color!



Exception: Io



- Small moon of Jupiter
- NO craters, all volcanoes…
- Source of interior heat: tidal stresses from Jupiter

7-7: A planet with a magnetic field indicates a fluid interior in motion

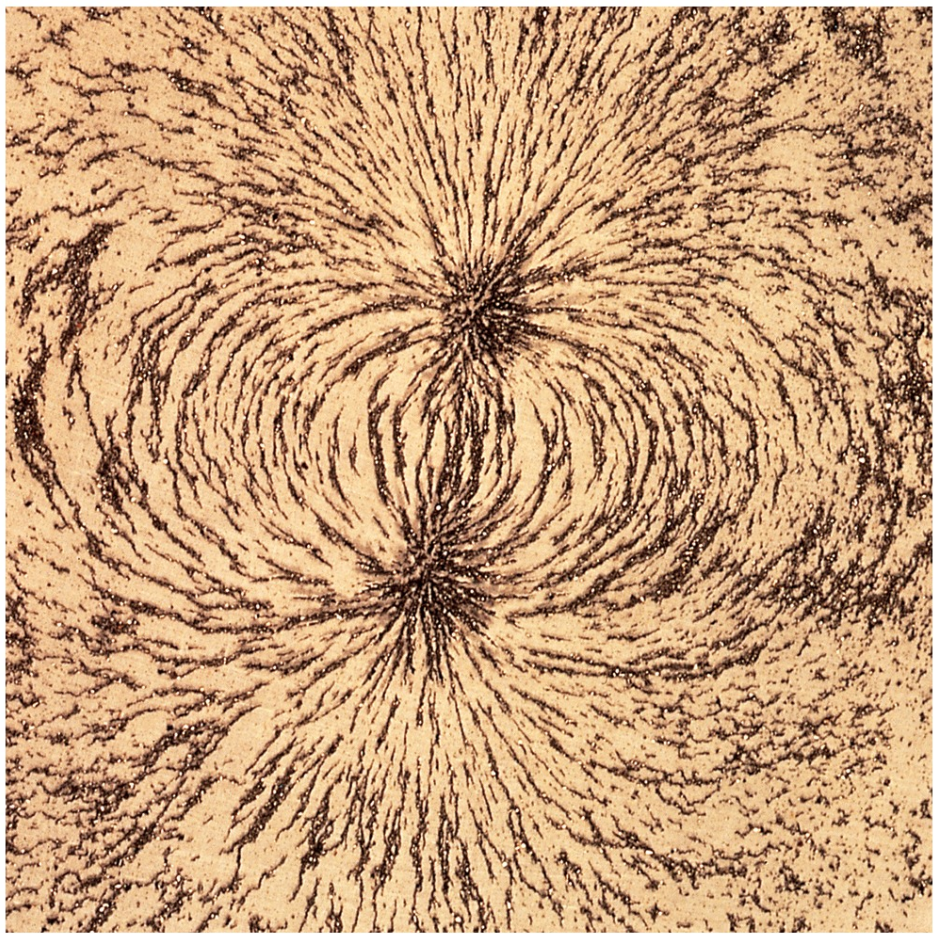


Figure 7-13a
Universe, Tenth Edition
Jules Bucher/Photo Researchers

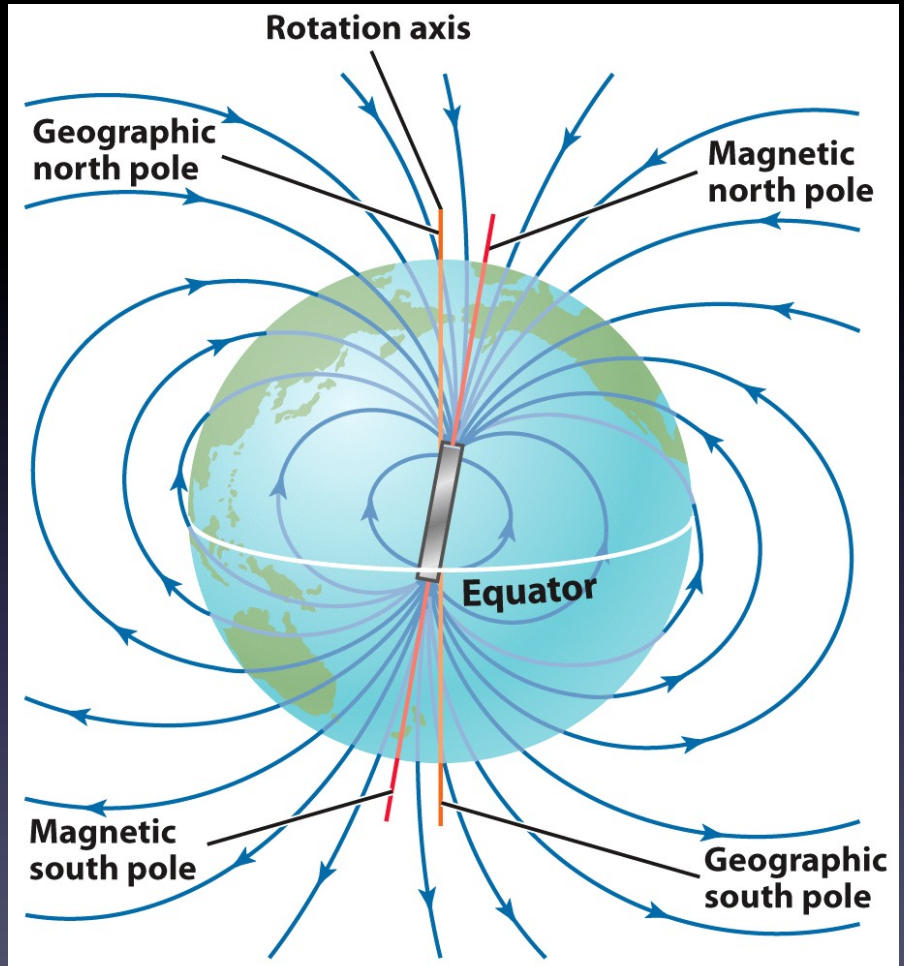


Figure 7-13b
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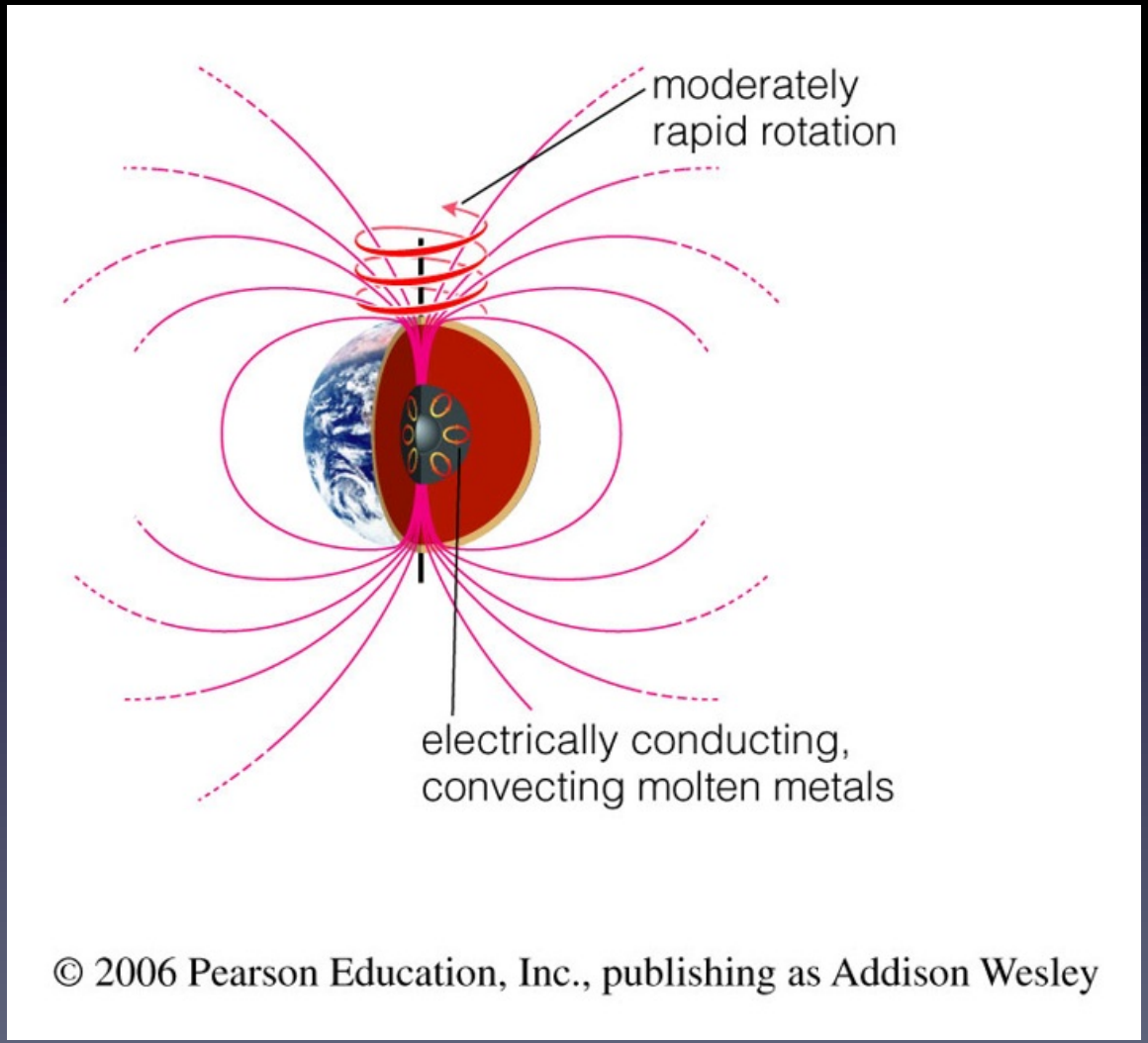
The Magnetic Fields of a Bar Magnet and of Earth

Sources of Magnetic Fields

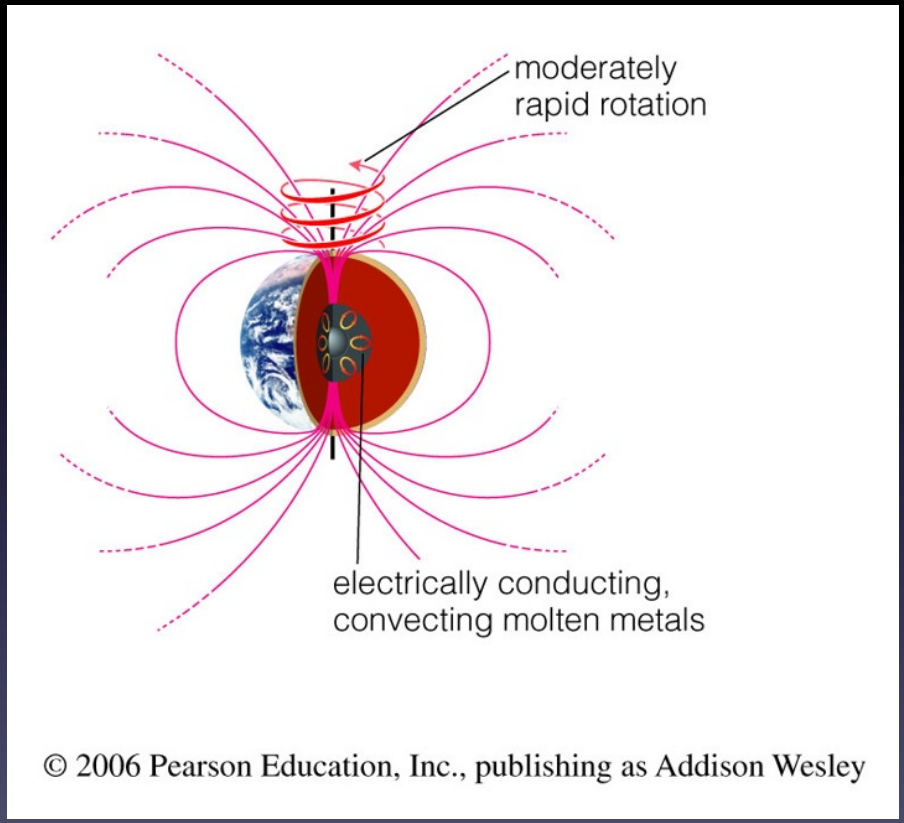


A world can have a magnetic field if charged particles are moving inside

3 requirements:

- Molten (electrically conducting) interior
- Convection
- Moderately rapid rotation

Probing Planet Interiors



- Magnetic fields originate in interiors: tell us conditions deep inside a planet

Planetary Magnetic Fields

- Moon, Mars: none now, but relic fields in rocks show that they had them in the past
- Mercury: Weak one (surprising)
- Venus: No (rotates too slowly?)
- Earth: Yes
- Jupiter and Saturn: Yes – very strong. From rapid rotation and presence of liquid metallic H
- Uranus and Neptune: Yes – strong and weird. Source not clear: compressed water (and ammonia) layer? Mix of H and rocky material?

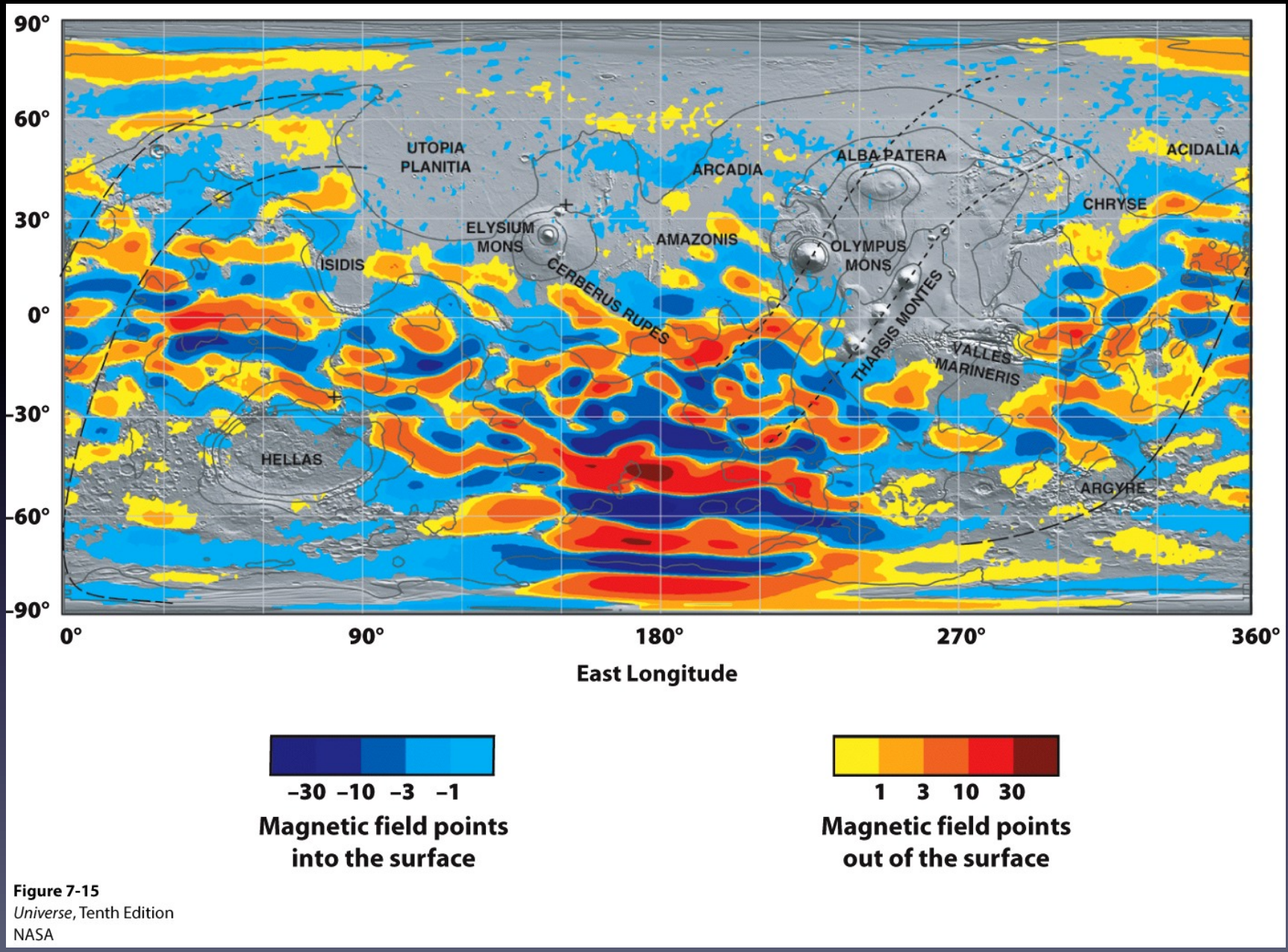


Figure 7-15
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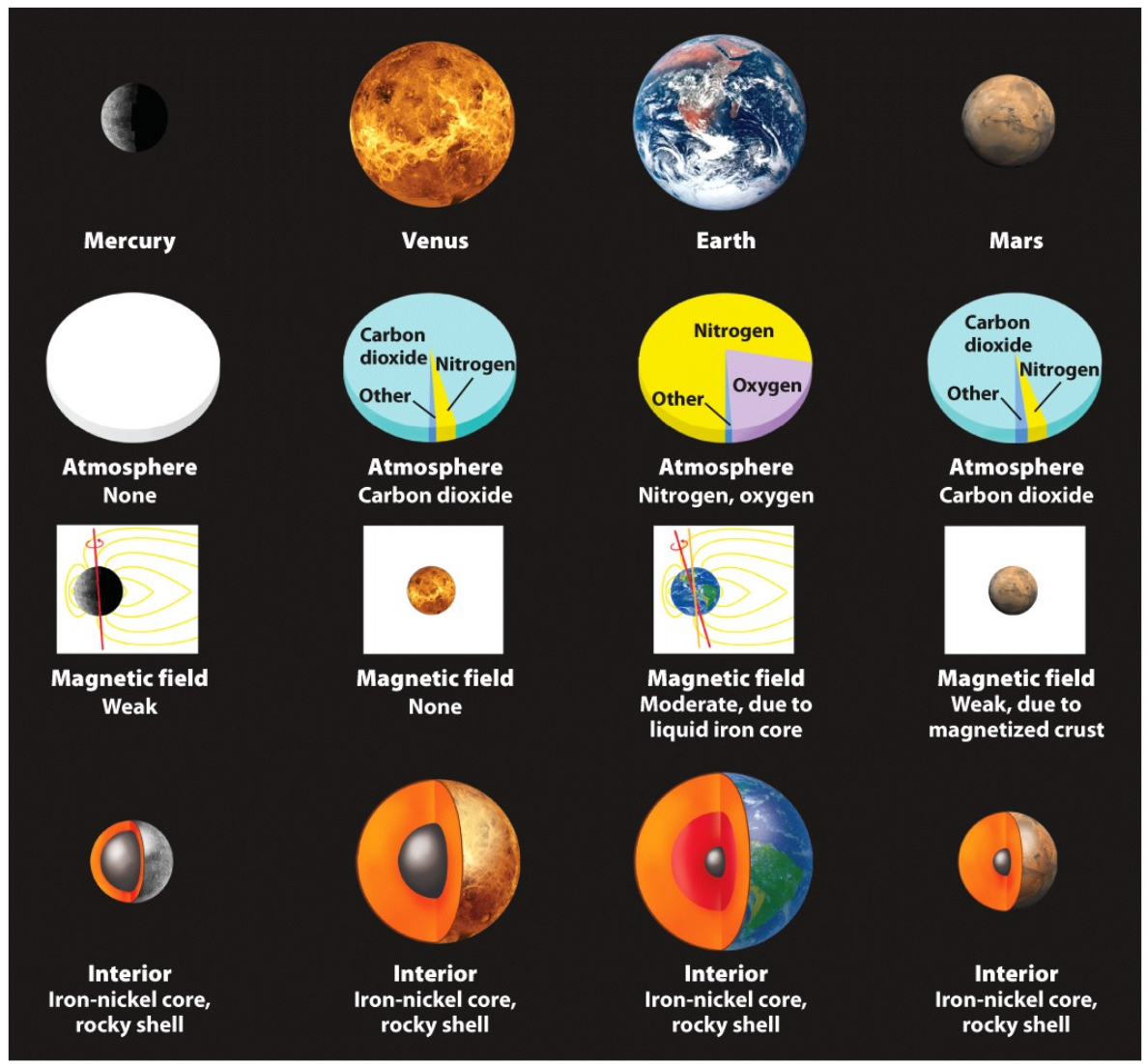
NASA

Relic Magnetism on Mars

7-8: The diversity of the solar system is a result of its origin and evolution



Cosmic Connections 7 Figure 1
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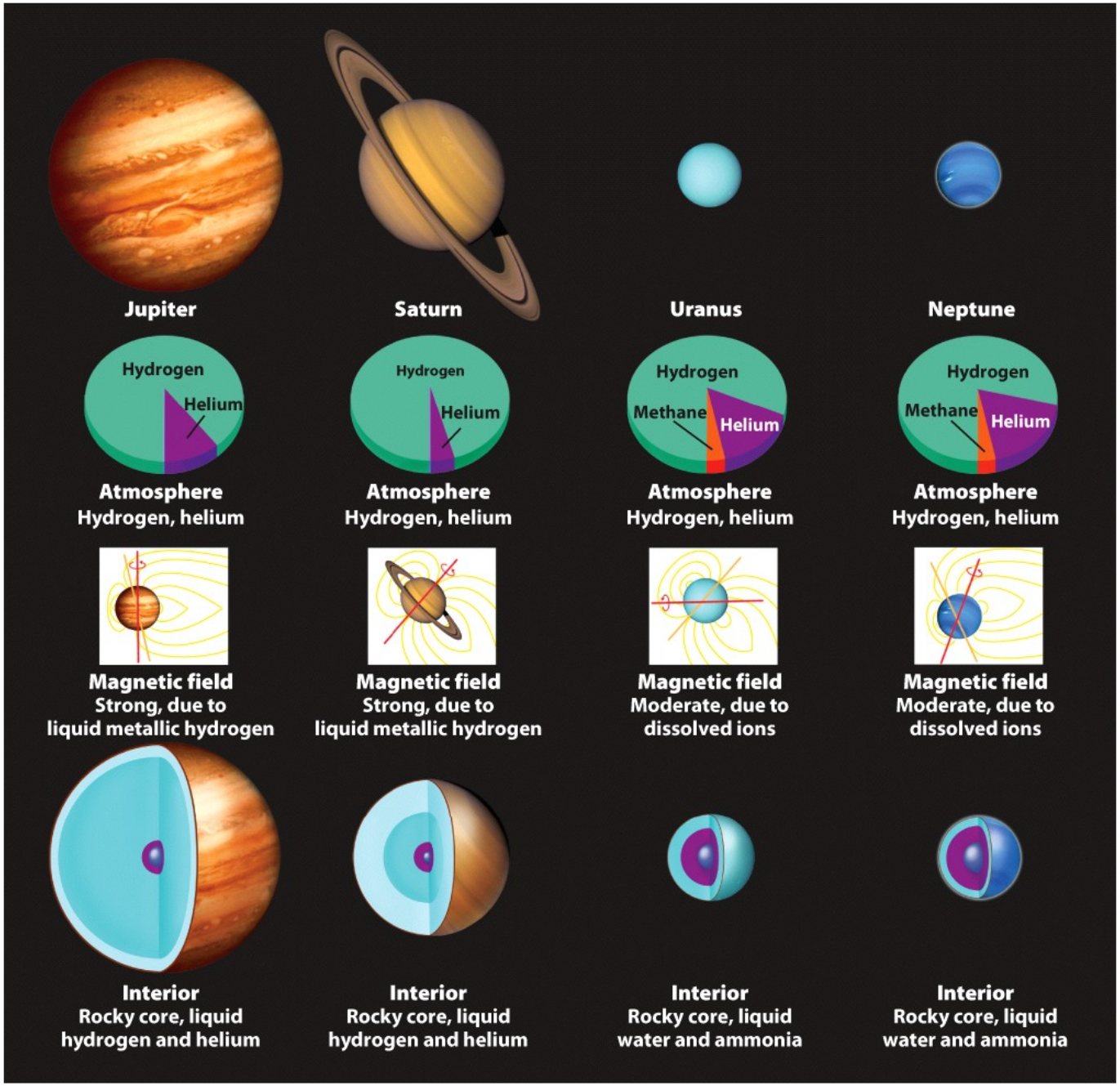
Characteristics of the Planets



Cosmic Connections 7 Figure 2
Universe, Tenth Edition

Characteristics of the Planets

Key Ideas

- **Properties of the Planets:** All of the planets orbit the Sun in the same direction and in almost the same plane. Most of the planets have nearly circular orbits.
- The four inner planets are called terrestrial planets. They are relatively small (with diameters of 5000 to 13,000 km), have high average densities (4000 to 5500 kg/m3), and are composed primarily of rocky materials.
- The four giant outer planets are called Jovian planets. They have large diameters (50,000 to 143,000 km) and low average densities (700 to 1700 kg/m3) and are composed primarily of light elements such as hydrogen and helium.

Key Ideas

- **Satellites and Small Bodies in the Solar System:** Besides the planets, the solar system includes satellites of the planets, asteroids, comets, and trans-Neptunian objects.
- Seven large planetary satellites (one of which is our Moon) are comparable in size to the planet Mercury. The remaining satellites of the solar system are much smaller.

Key Ideas

- Asteroids are small, rocky objects, while comets and trans-Neptunian objects are made of ice and rock. All are remnants left over from the formation of the planets.
- Most asteroids are found in the asteroid belt between the orbits of Mars and Jupiter, and most trans-Neptunian objects lie in the Kuiper belt outside the orbit of Neptune. Pluto is one of the largest members of the Kuiper belt.

Key Ideas

- **Spectroscopy and the Composition of the Planets:** Spectroscopy, the study of spectra, provides information about the chemical composition of objects in the solar system.
- The spectrum of a planet or satellite with an atmosphere reveals the atmosphere's composition. If there is no atmosphere, the spectrum indicates the composition of the surface.
- The substances that make up the planets can be classified as gases, ices, or rock, depending on the temperatures at which they solidify.

Key Ideas

- **Impact Craters:** When an asteroid, comet, or meteoroid collides with the surface of a terrestrial planet or satellite, the result is an impact crater.
- Geologic activity renews the surface and erases craters, so a terrestrial world with extensive cratering has an old surface and little or no geologic activity.
- Because geologic activity is powered by internal heat, and smaller worlds lose heat more rapidly, as a general rule smaller terrestrial worlds are more extensively cratered.

Key Ideas

- **Magnetic Fields and Planetary Interiors:** Planetary magnetic fields are produced by the motion of electrically conducting liquids inside the planet. This mechanism is called a dynamo. If a planet has no magnetic field, that is evidence that there is little such liquid material in the planet's interior or that the liquid is not in a state of motion.
- The magnetic fields of terrestrial planets are produced by metals such as iron in the liquid state. The stronger fields of the Jovian planets are generated by liquid metallic hydrogen or by water with ionized molecules dissolved in it.