Foundations of Earth Science

Eighth Edition

The Nature of the Solar System

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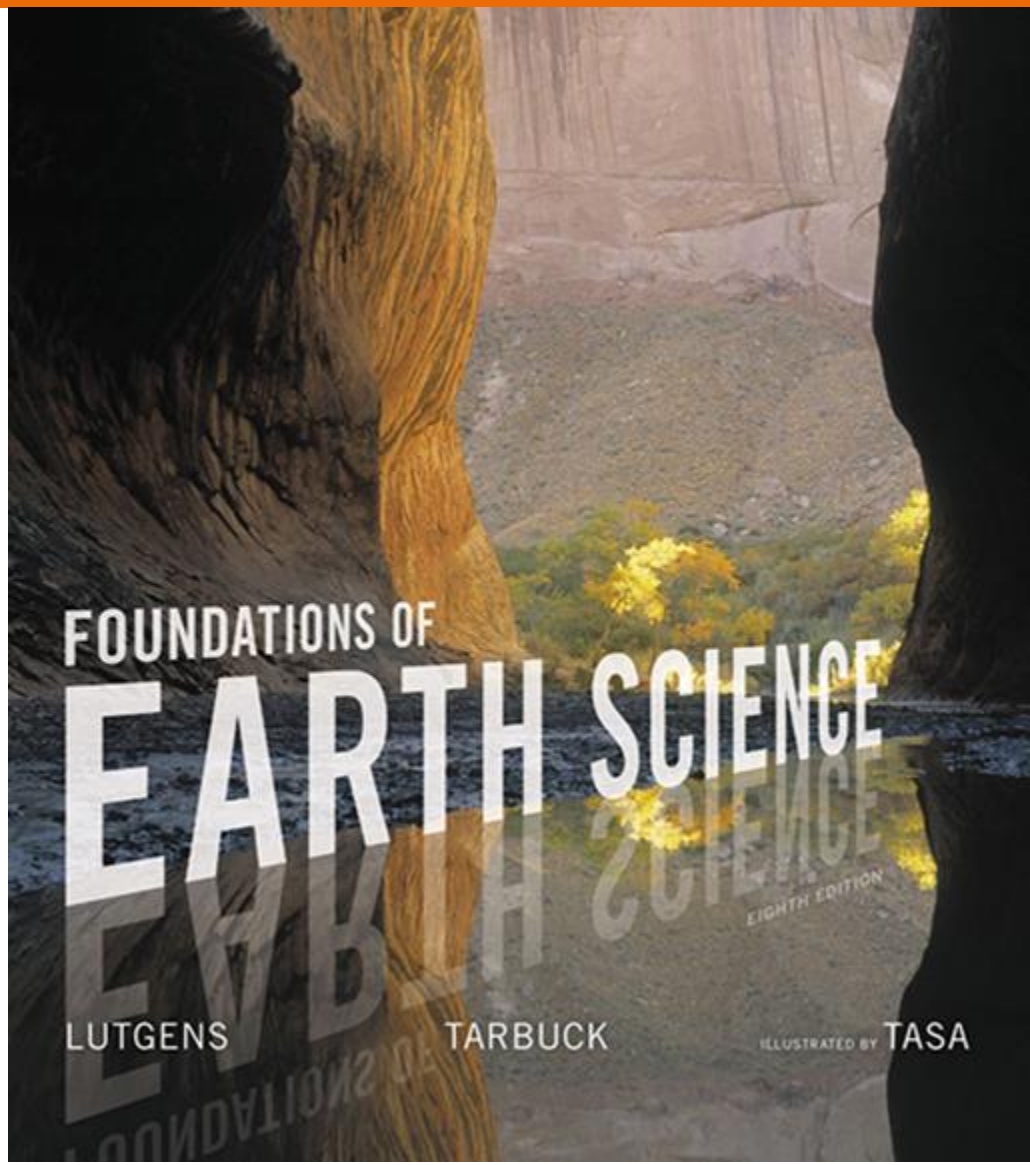


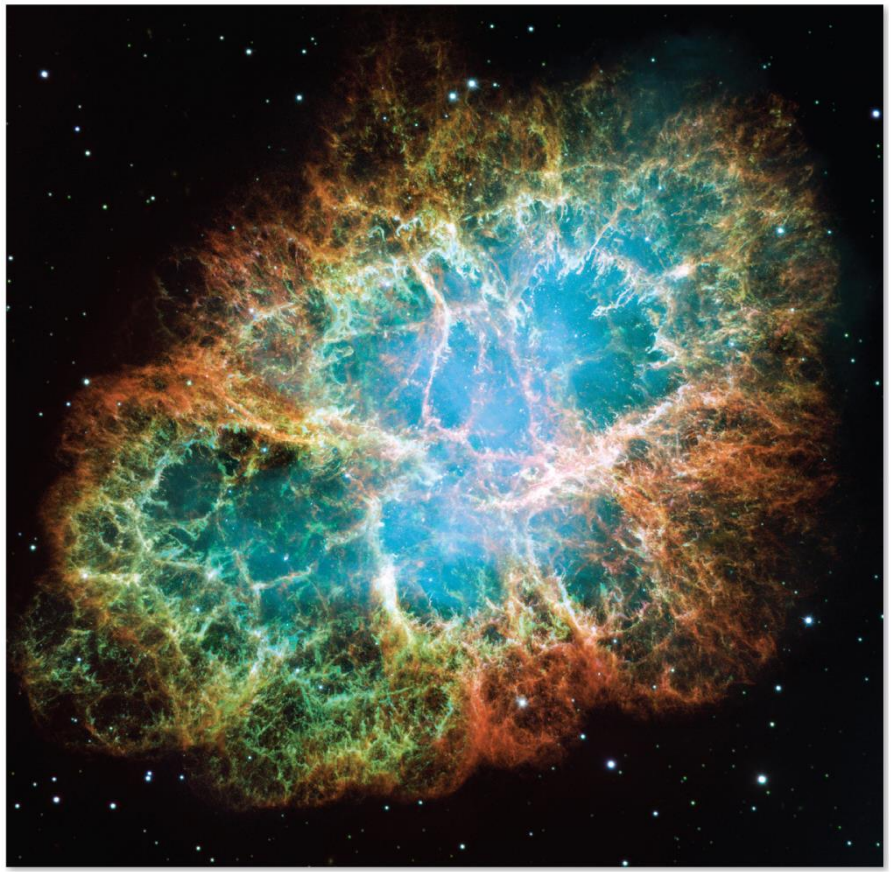
Focus Questions 15.1

- Explain the geocentric view of the solar system.
- Describe how it differs from the heliocentric view.

Ancient Astronomy

- Ancient Greeks
  - Used philosophical arguments to explain natural phenomena
  - Also used observational data
  - Most held a **geocentric** view of the universe
    - "Earth-centered" view
    - Earth as a motionless sphere at the center of the universe
    - Stars on the **celestial sphere**
      - Transparent, hollow sphere
      - Celestial sphere turns daily around Earth
  - Aristarchus first to propose **heliocentric** (sun-centered) universe

Ancient Astronomy



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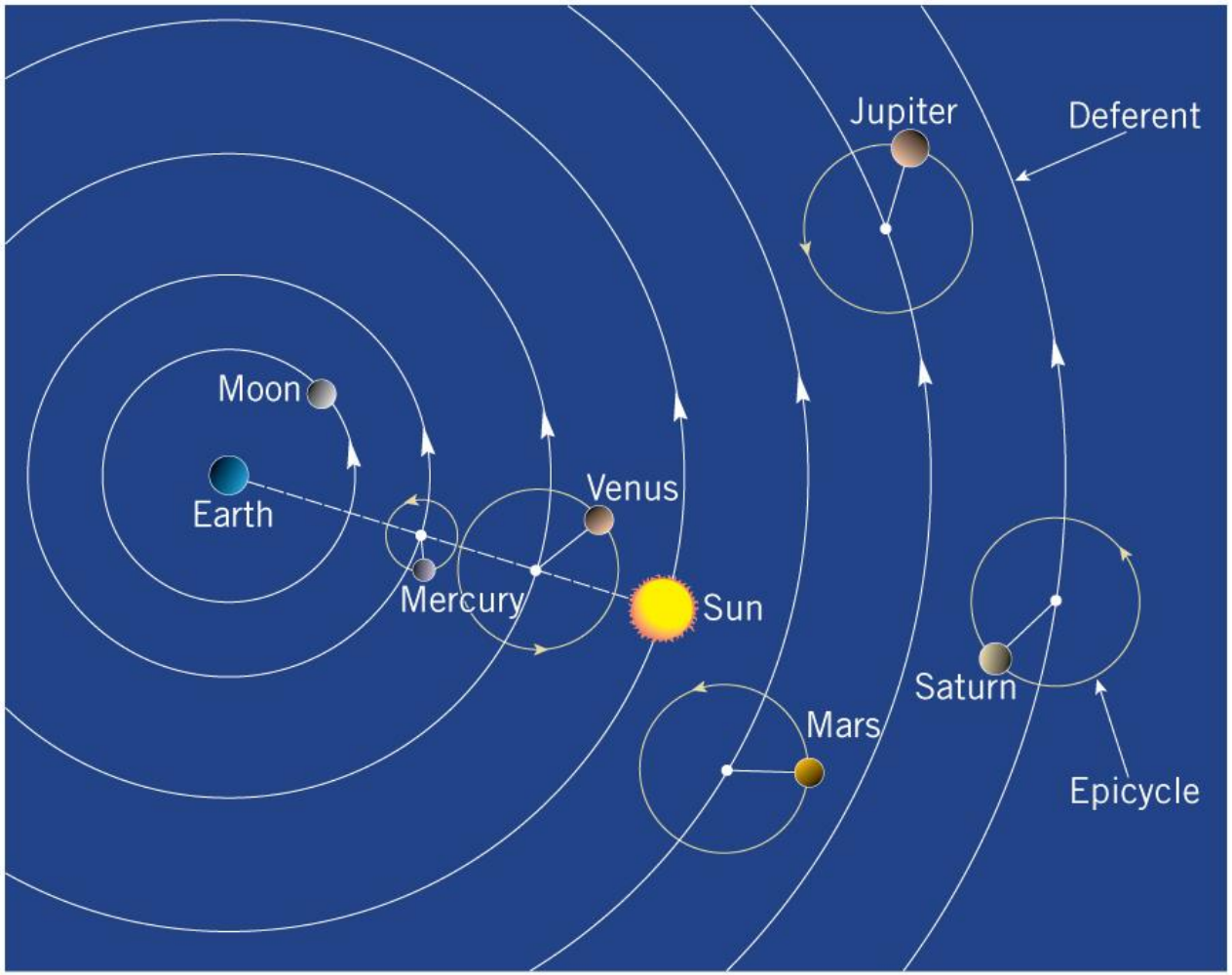
Ancient Astronomy

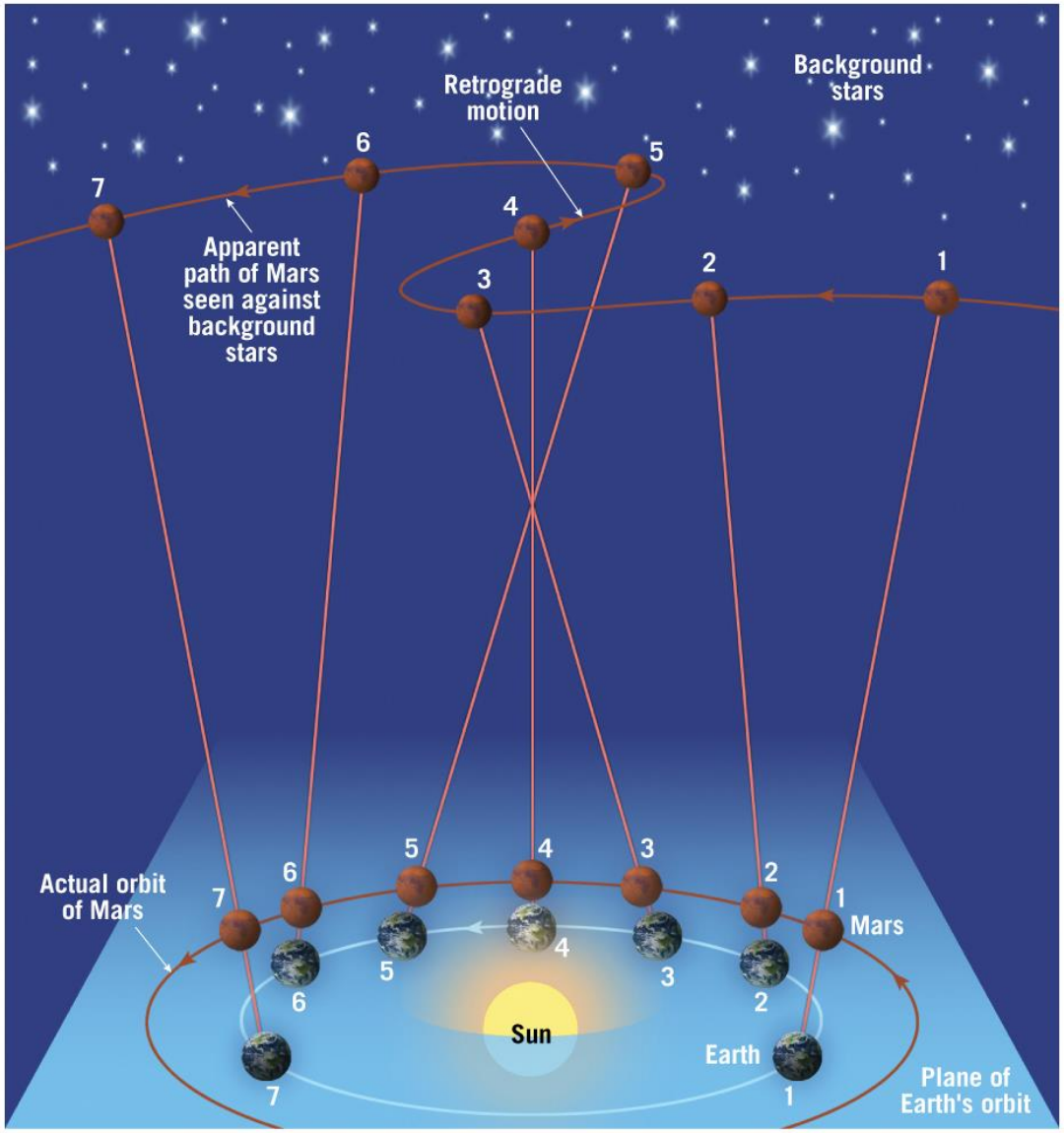


A.

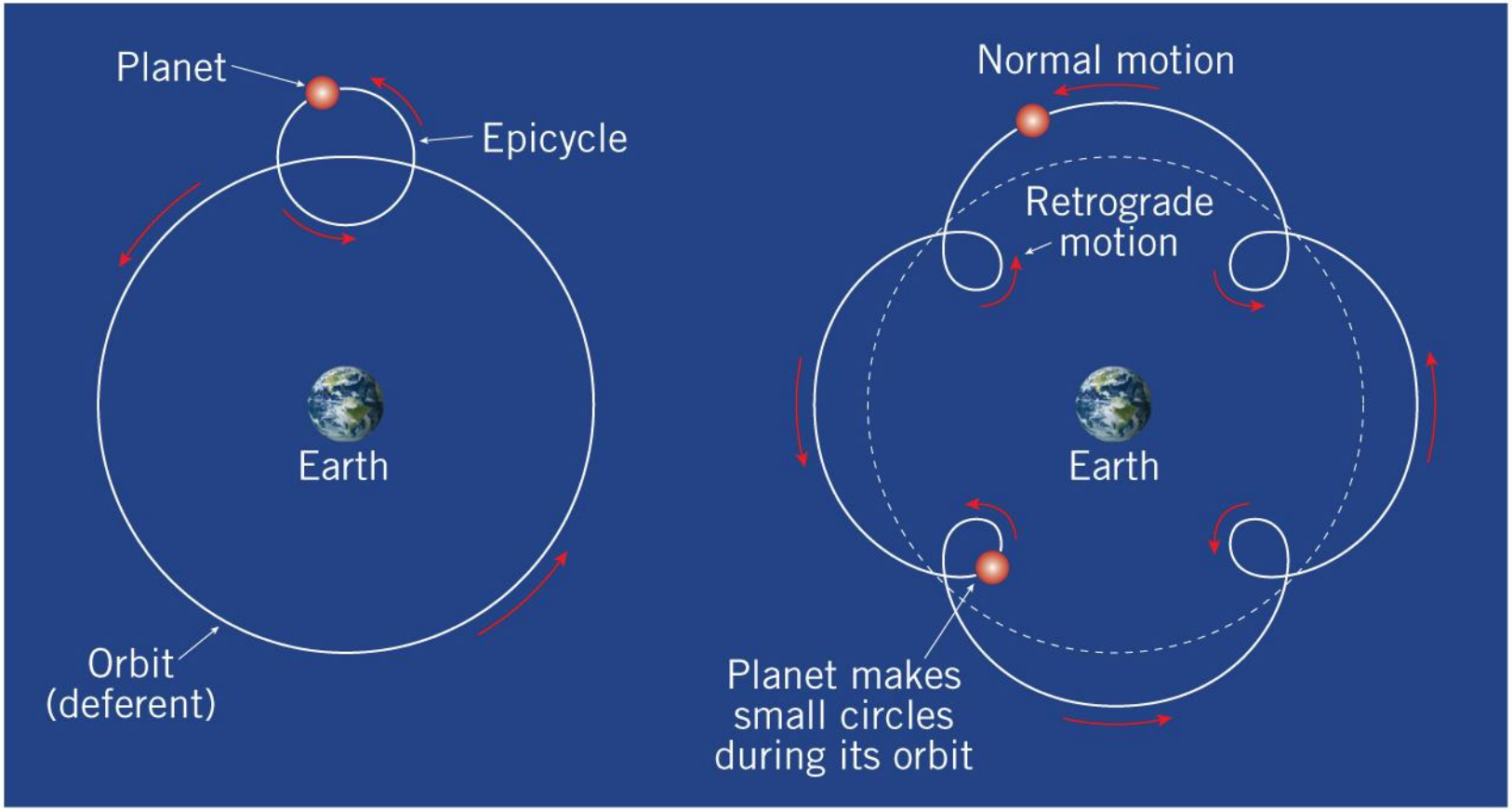
Ancient Astronomy

- **Ptolemaic system**
  - A.D. 141
  - Geocentric model
  - To explain **retrograde motion**, Ptolemy used two motions for the planets
    - Large orbital circles, called deferents, and
    - Small circles, called *epicycles*

Ancient Astronomy



Ancient Astronomy

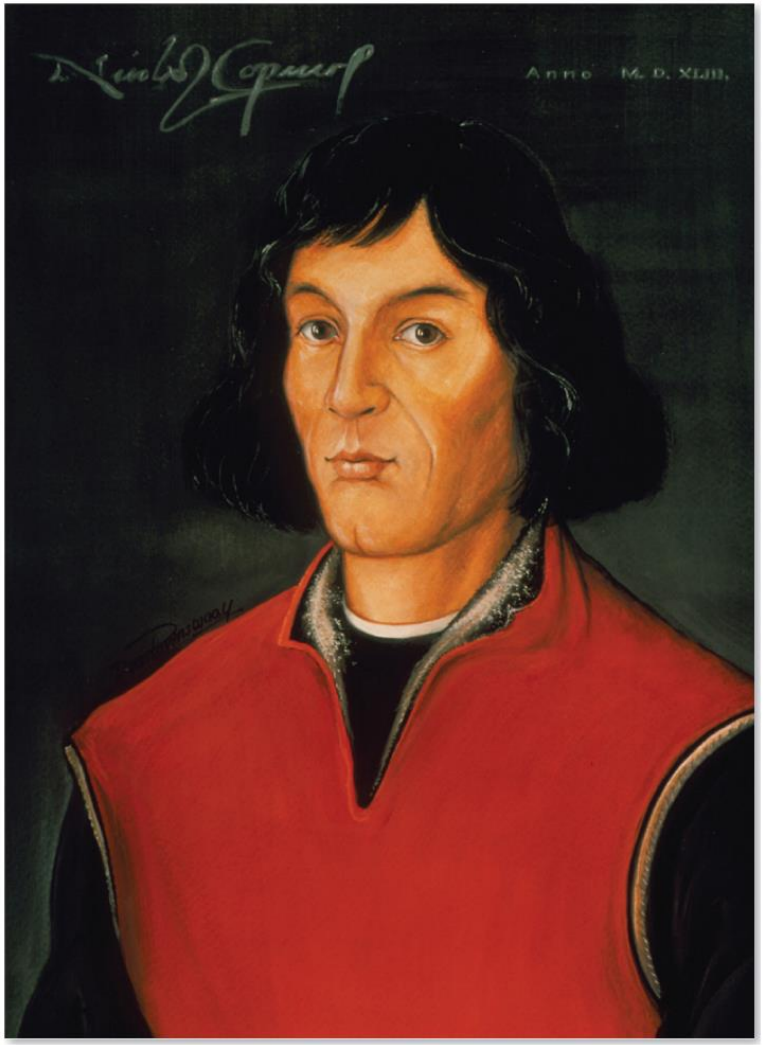


Focus Question 15.2

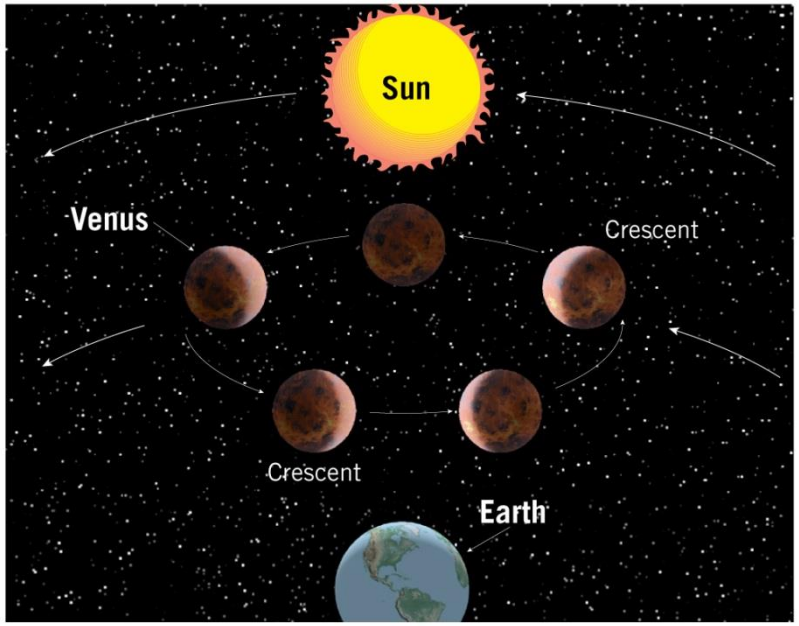
- List and describe the contributions to modern astronomy of Nicolaus Copernicus, Tycho Brahe, Johannes Kepler, Galileo Galilei, and Isaac Newton.

The Birth of Modern Astronomy

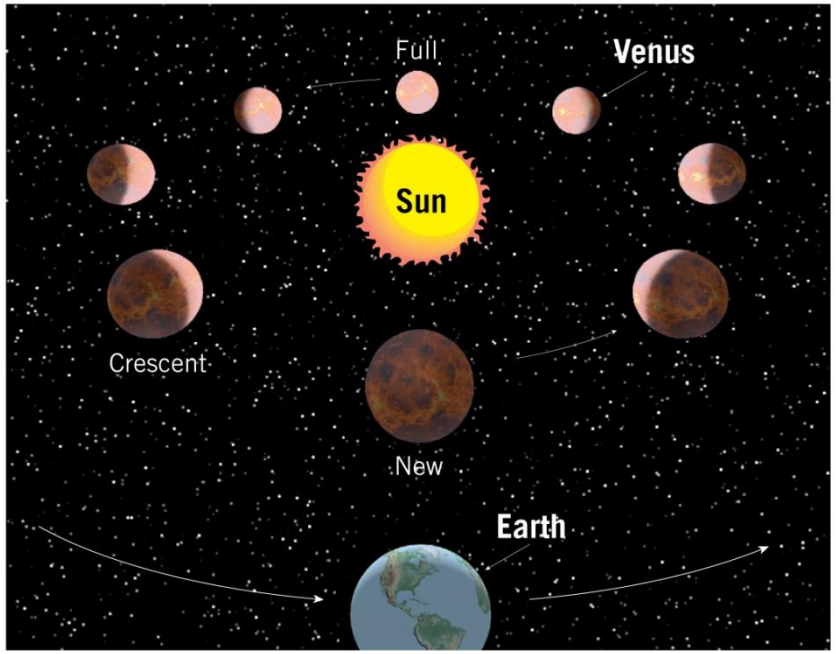
- Nicolaus Copernicus (1473–1543)
  - Concluded Earth was a planet
  - Constructed a model of the solar system that put the Sun at the center, but he used circular orbits for the planets
  - Ushered out old astronomy



The Birth of Modern Astronomy



A. In the Ptolemaic (Earth-centered) system, the orbit of Venus lies between the Sun and Earth, as shown here. Thus, in an Earth-centered solar system, only the crescent phase of Venus would be visible from Earth.



B. In the Copernican (Sun-centered) system, Venus orbits the Sun and hence all of the phases of Venus should be visible from Earth.

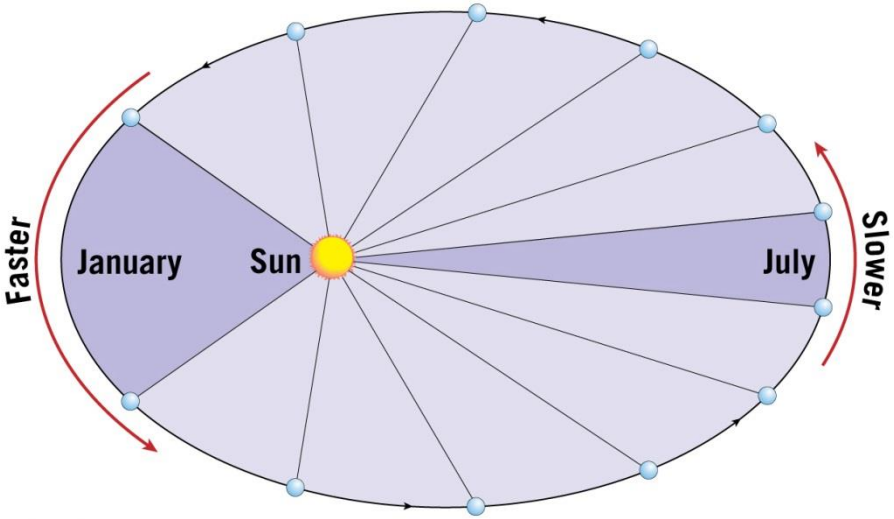
The Birth of Modern Astronomy

- Tycho Brahe (1546–1601)
  - Precise observer
  - Tried to find *stellar parallax*
    - The apparent shift in a star's position due to the revolution of Earth
  - Did not believe in the Copernican system because he was unable to observe stellar parallax

The Birth of Modern Astronomy

- Johannes Kepler (1571–1630)
  - Ushered in new astronomy
  - Planets revolve around the Sun
  - Three laws of planetary motion
    - Orbits of the planets are elliptical
    - Planets revolve around the Sun at varying speeds
    - There is a proportional relation between a planet's orbital period and its distance to the Sun (measured in **astronomical units** *(AU's)*— One AU averages about 150 million kilometers, or 93 million miles)

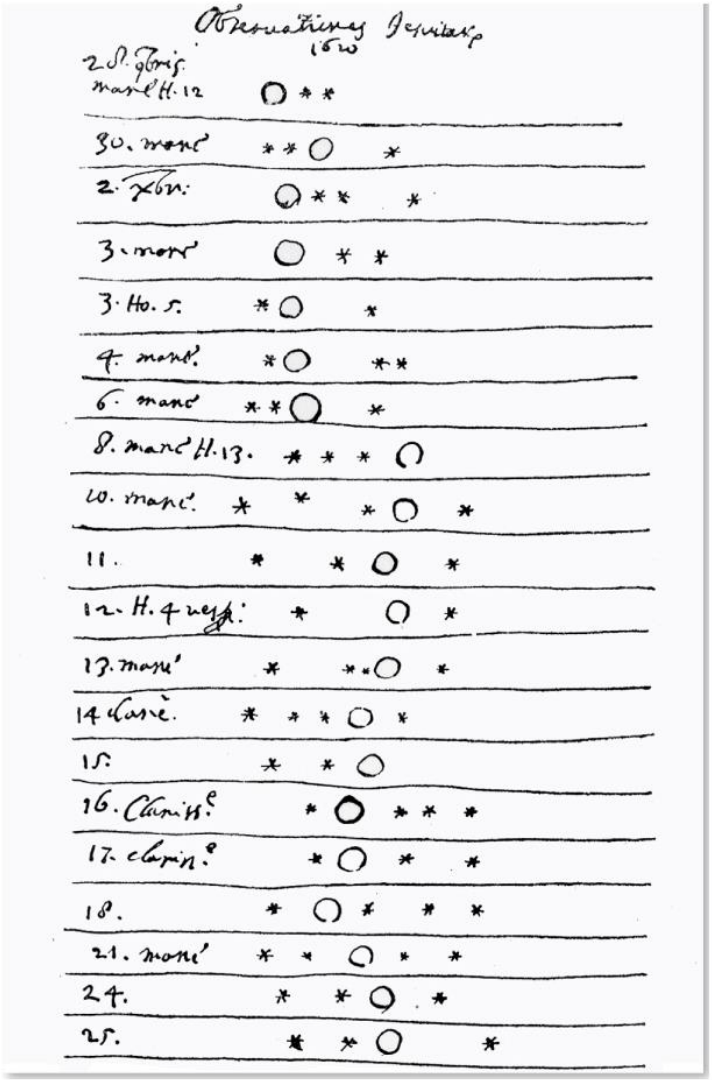
The Birth of Modern Astronomy



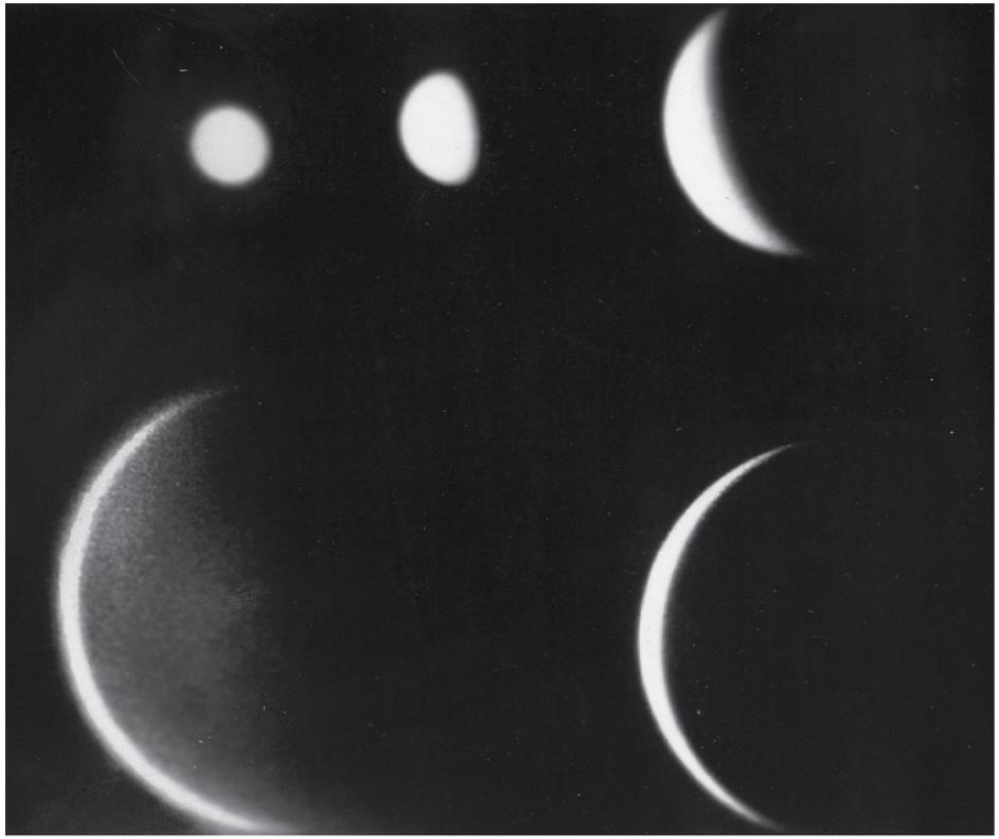
The Birth of Modern Astronomy

- Galileo Galilei (1564–1642)
  - Supported Copernican theory
  - Used experimental data
  - Constructed an astronomical telescope in 1609
    - Four large moons of Jupiter
    - Planets appeared as disks
    - Phases of Venus
    - Features on the Moon
    - Sunspots

The Birth of Modern Astronomy



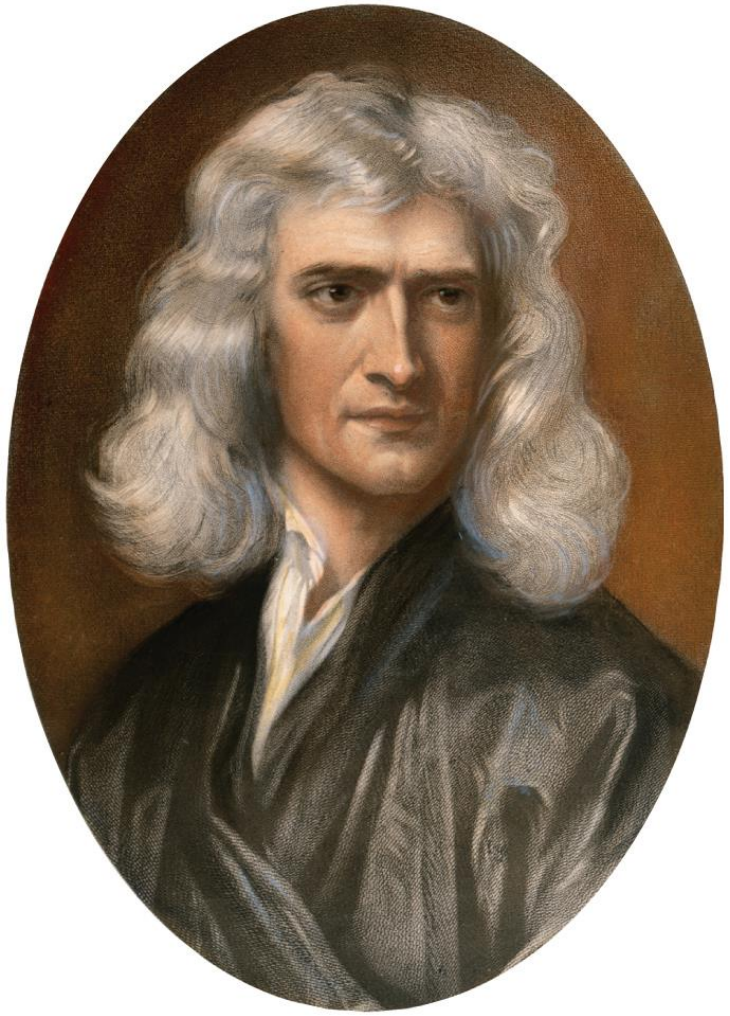
The Birth of Modern Astronomy



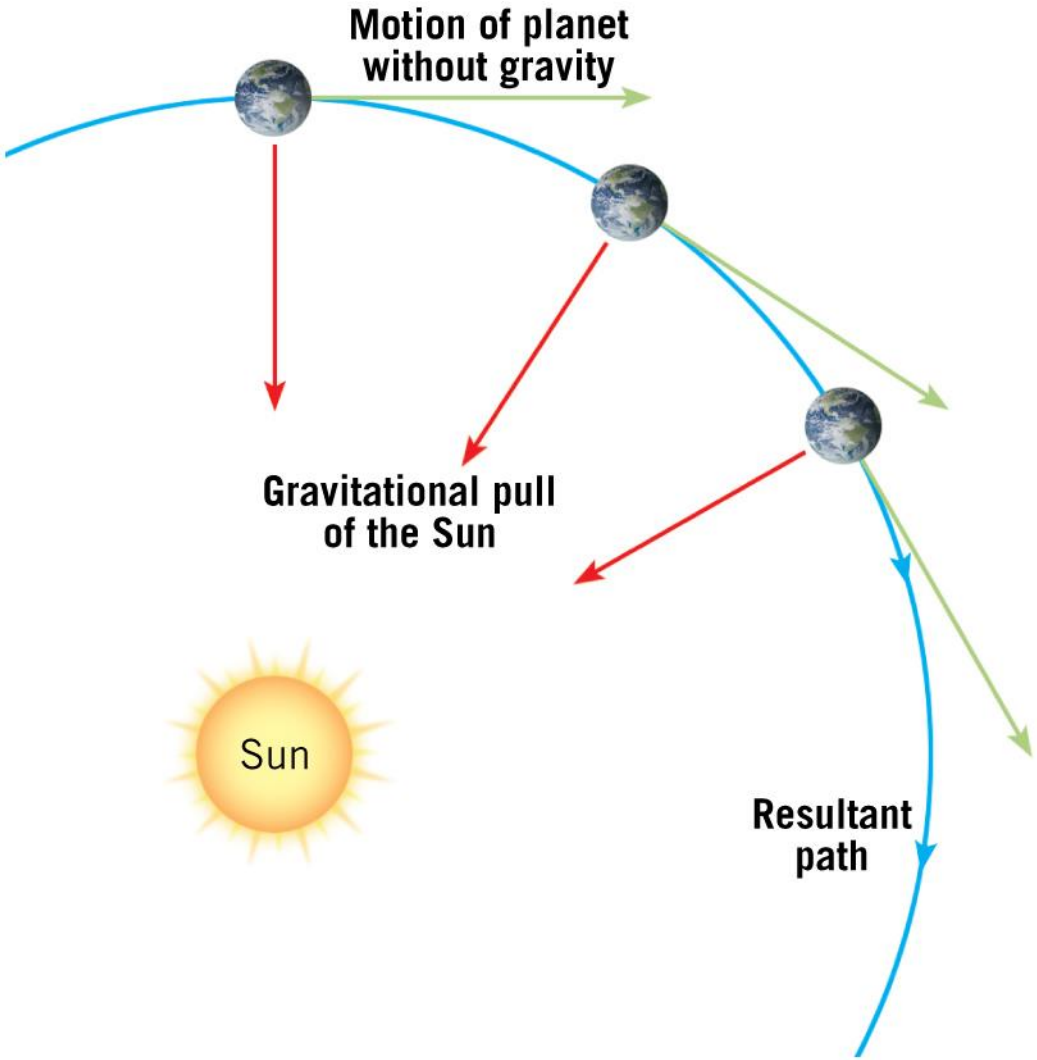
C. As Galileo observed, Venus goes through a series of Moonlike phases. Venus appears smallest during the full phase when it is farthest from Earth and largest in the crescent phase when it is closest to Earth. This led Galileo to conclude that the Sun was the center of the solar system.

The Birth of Modern Astronomy

- Sir Isaac Newton (1643–1727)
  - **Law of universal gravitation**
  - Proved that the force of gravity, combined with the tendency of a planet to remain in straight-line motion, results in the elliptical orbits discovered by Kepler



The Birth of Modern Astronomy



Focus Questions 15.3

- Describe the formation of the solar system according to the nebular theory.
- Compare and contrast the terrestrial and Jovian planets.

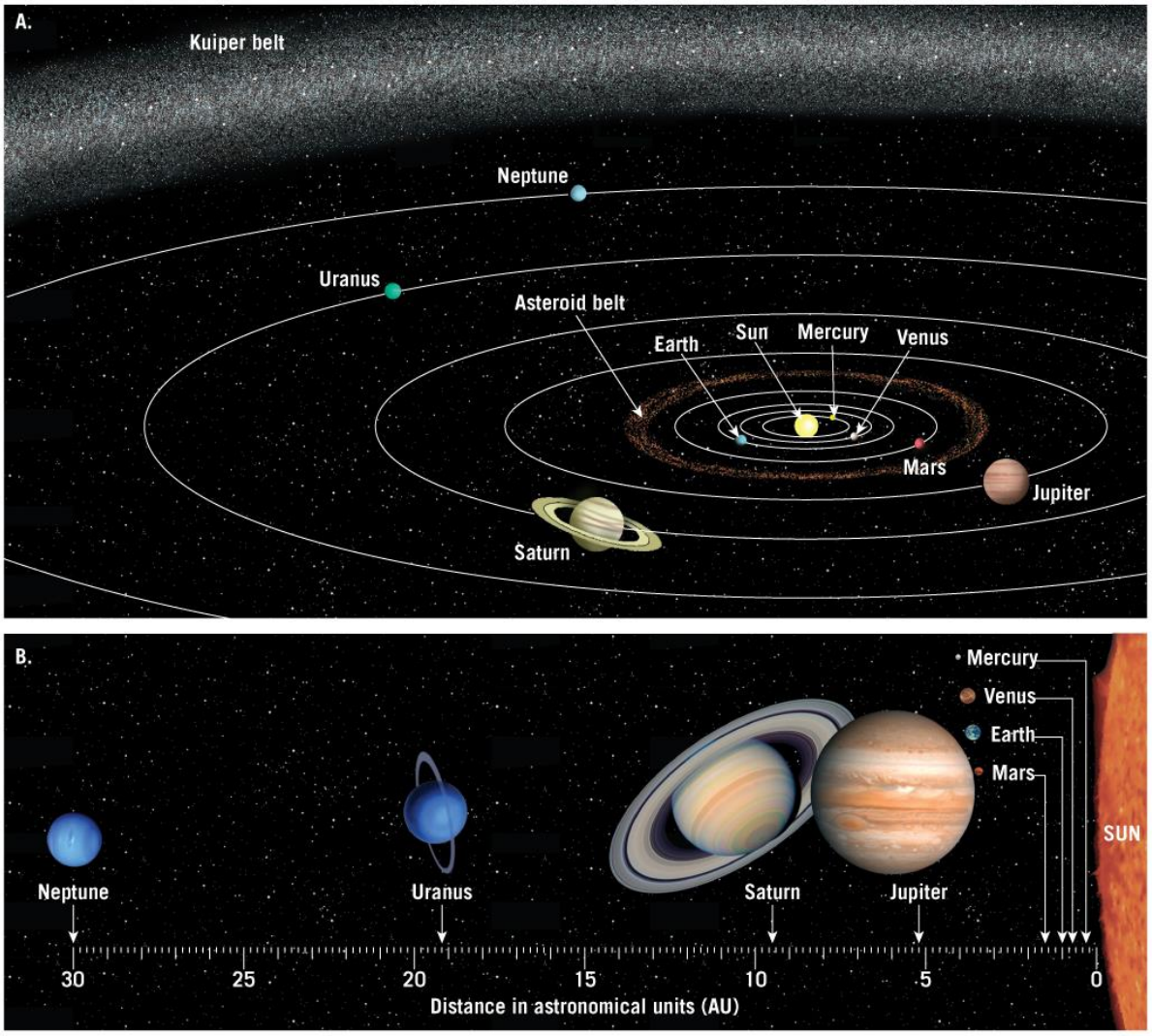
Our Solar System: An Overview

- **Nebular theory**
  - Planets formed ~ 5 billion years ago
  - Solar system condensed from a **solar nebula**
- Most material collected at center as the hot *protosun*
- Other material formed a flattened rotating disc
  - Matter in the disc cooled and collided forming **planetesimals**

Our Solar System: An Overview

- As the ***protoplanets*** formed, the materials that compose them separated
  - Dense metallic elements (iron and nickel) sank toward their centers
  - Lighter elements (silicate minerals, oxygen, hydrogen) migrated toward their surfaces
  - Process called *chemical differentiation*
- Due to their surface gravities, Venus and Earth retained atmospheric gases
- Due to frigid temperatures, the Jovian planets contain a high percentage of ices

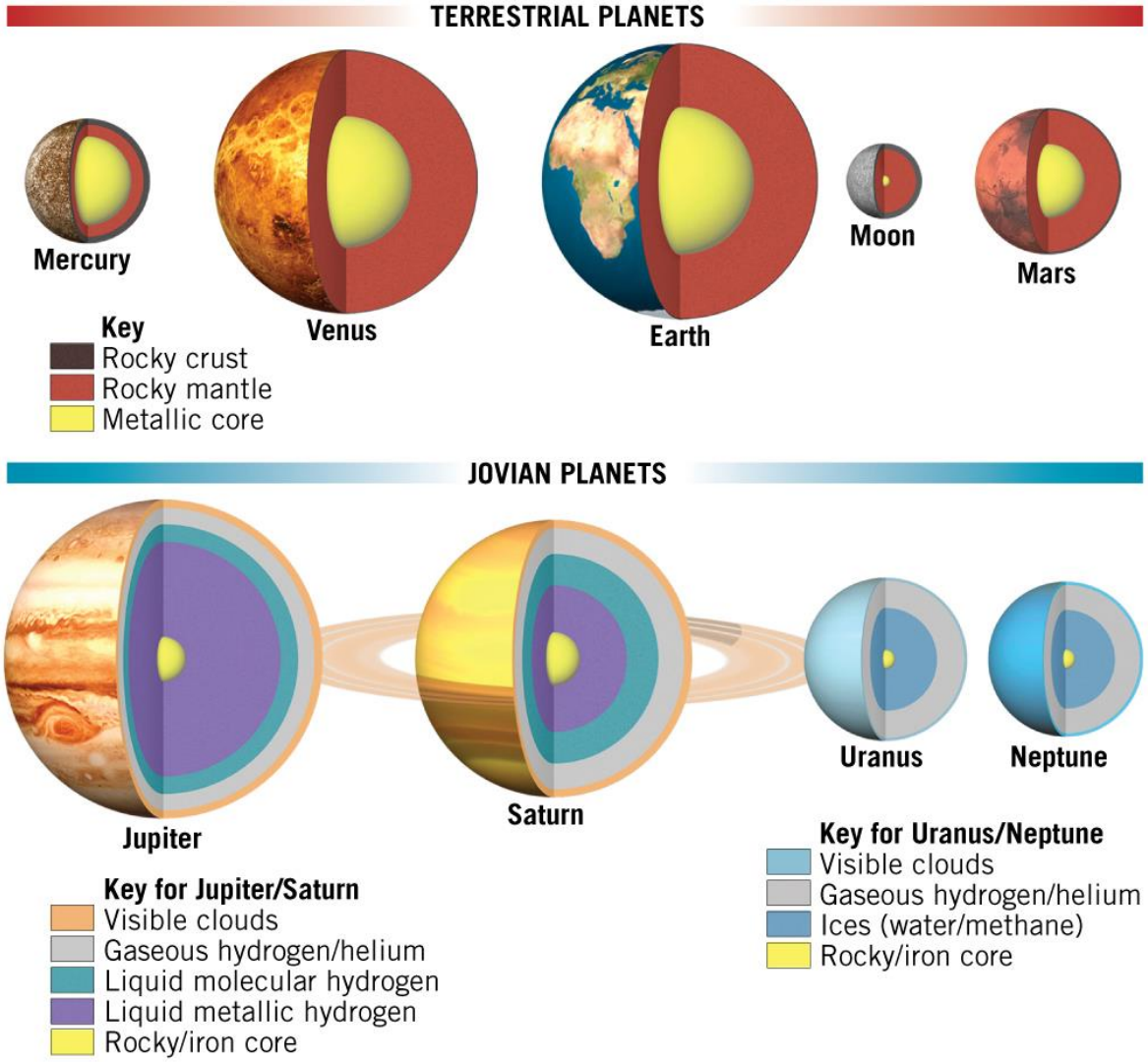
Our Solar System: An Overview



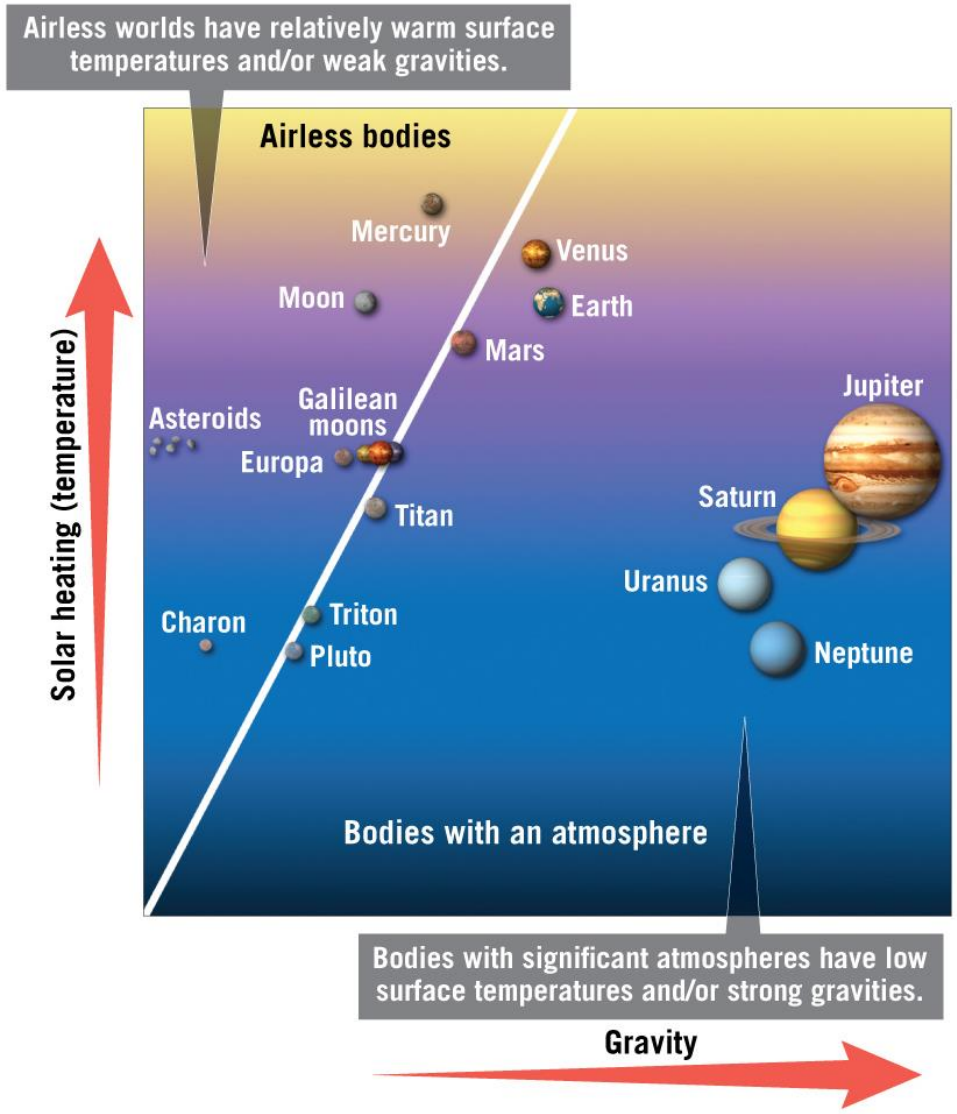
Our Solar System: An Overview

- Two groups of planets occur in the solar system
  - ***Terrestrial*** (Earth-like) inner planets
    - Mercury, Venus, Earth, Mars
    - Small, dense, rocky
    - Low escape velocities
  - ***Jovian*** (Jupiter-like) outer planets
    - Jupiter, Saturn, Uranus, Neptune
    - Large, low density, gaseous—*gas giants*
    - Massive
    - Thick atmospheres composed of hydrogen, helium, methane, and ammonia
    - High escape velocities

Our Solar System: An Overview



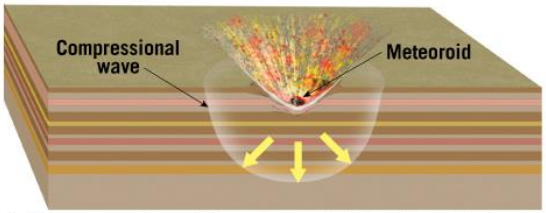
Our Solar System: An Overview



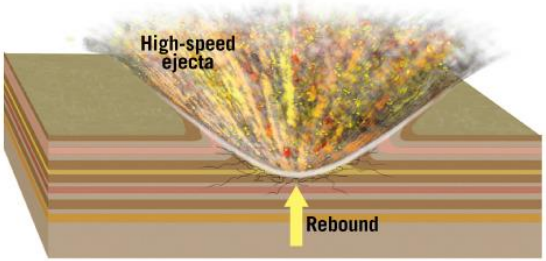
Our Solar System: An Overview

- Planetary Impacts
  - Occurred throughout history of solar system
  - Bodies that have little or no atmosphere
    - No air resistance to prevent impact
    - Smallest pieces of debris reach the surface
    - At high velocities, debris produces microscopic cavities on individual mineral grains!
  - Large **impact craters** result from collisions with massive bodies, such as asteroids and comets

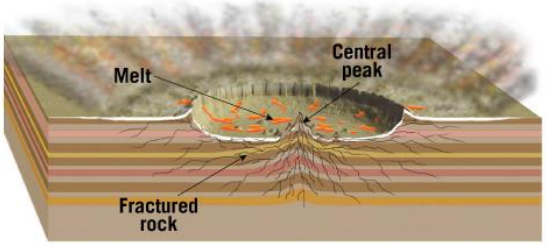
Our Solar System: An Overview



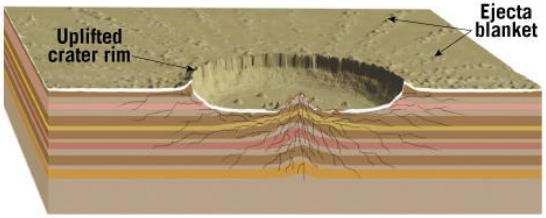
A. The energy of a rapidly moving body is transformed into heat and shock waves.



B. The rebound of over-compressed rock causes debris to be explosively ejected from the crater. Some of this material may melt and be deposited as glass beads.

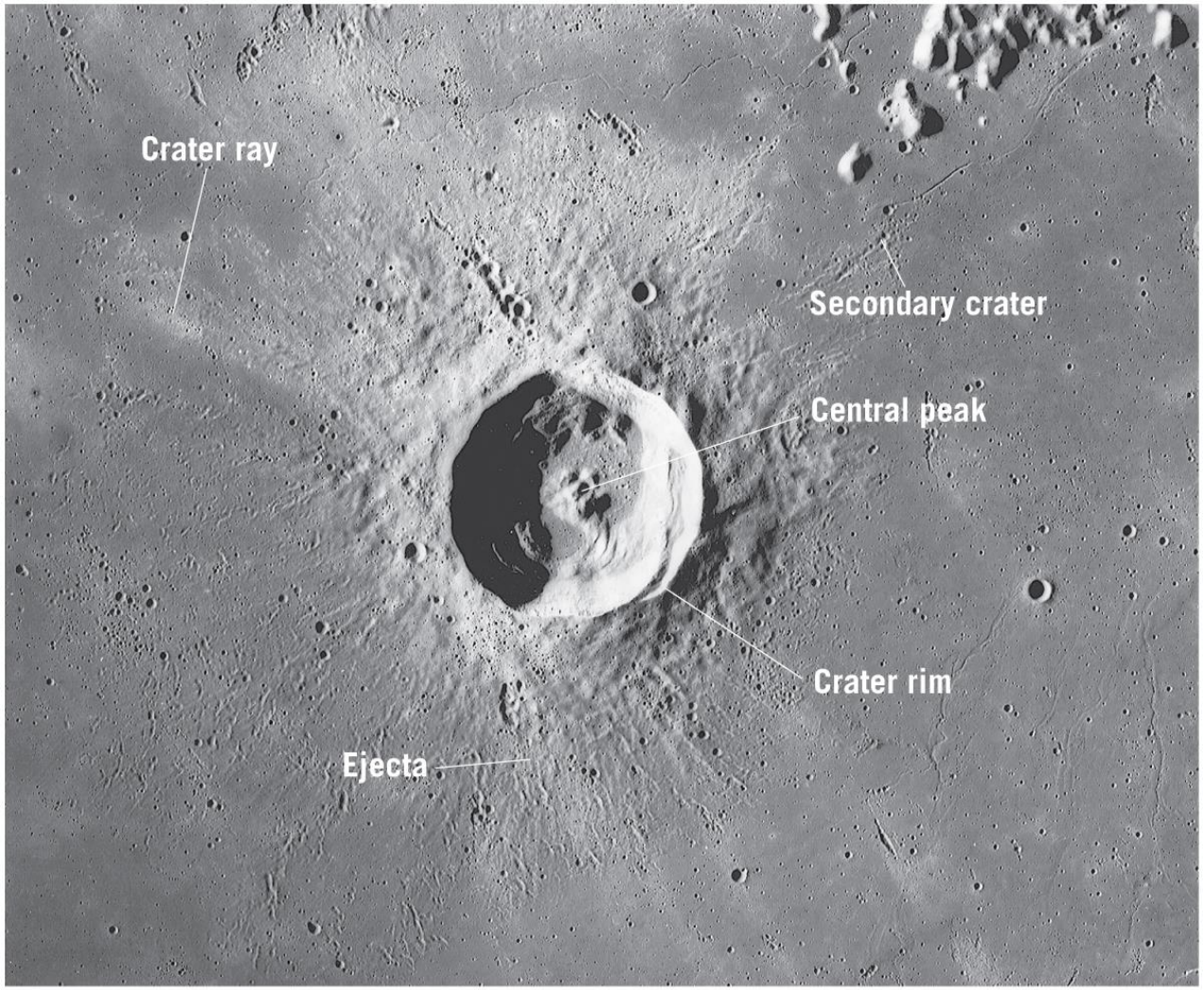


C. Large craters may contain areas of ock that was melted by the impact and a rebounded central peak.



D. Ejected material forms a “blanket” around the crater.

Our Solar System: An Overview



Focus Questions 15.4

- List and describe the major features of Earth's Moon.
- Explain how maria basins were formed.

Earth's Moon: A Chip Off the Old Block

- General characteristics
  - Diameter of 3475 km (2150 mi)
    - Unusually large compared to its parent planet
  - Density
    - 3.3 times that of water
    - Comparable to Earth's crustal rocks
    - Perhaps Moon has a small iron core
  - Gravitational attraction is one-sixth of Earth
    - No atmosphere
    - Tectonics no longer active
    - Surface bombarded by micrometeorites
      - Gradually make the landscape smooth

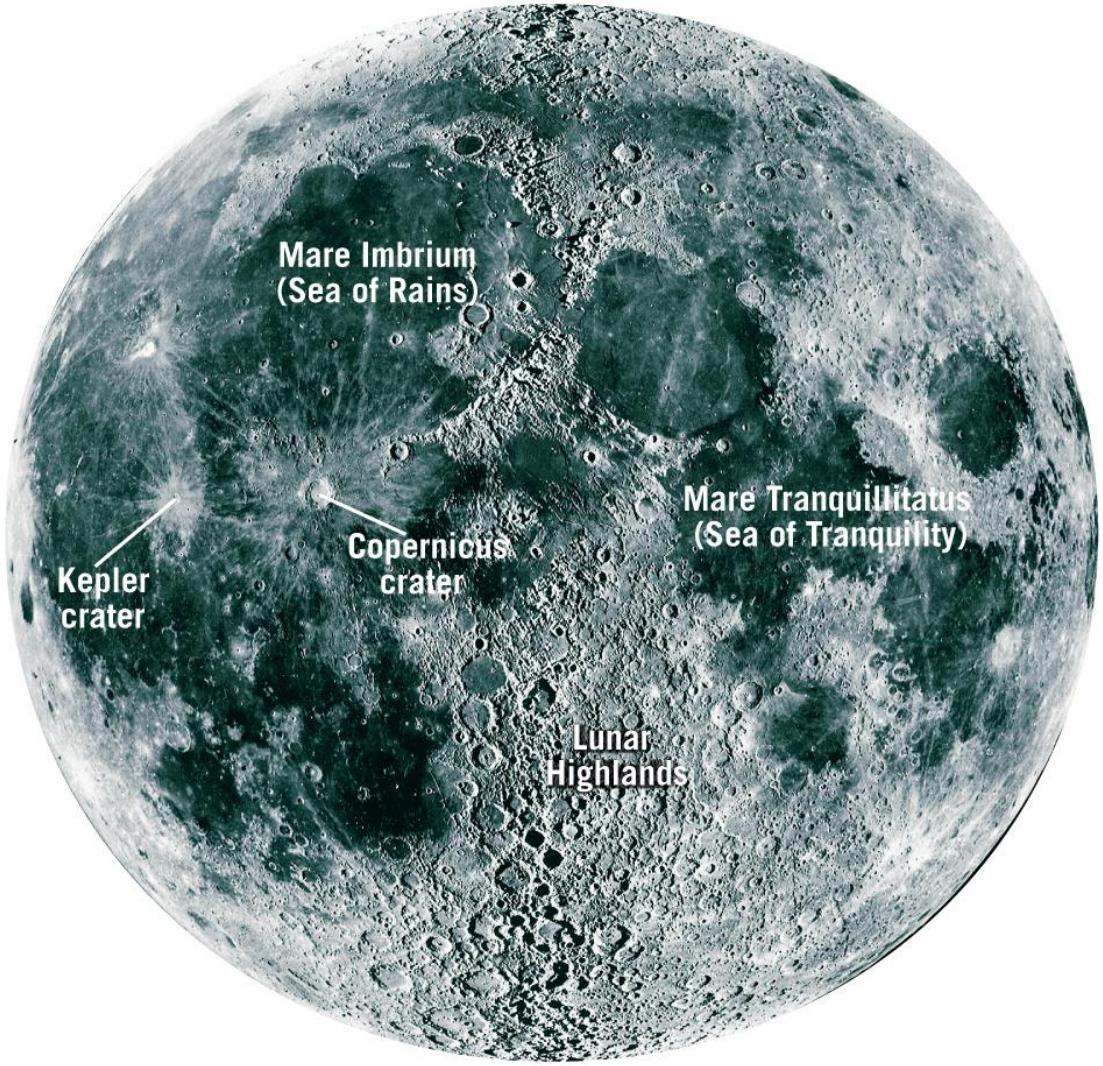
Earth's Moon: A Chip Off the Old Block

- Consensus is that the Moon formed as a result of a collision
  - Mars-sized body collided with semimolten Earth
  - ~4.5 billion years ago
  - Some ejected debris thrown into orbit coalesced to form the Moon
- Impact model
  - Consistent with Moon having
    - Proportionately smaller core than Earth's
    - Lower density than Earth

Earth's Moon: A Chip Off the Old Block

- Lunar surface
  - Two types of terrain:
    - **Maria** (singular, *mare*), Latin for "sea"
      - Dark regions
      - Fairly smooth lowlands
      - Originated from asteroid impacts and lava flooding
    - **Highlands**
      - Bright, densely cratered regions
      - Make up most of the Moon
      - Make up all of the "back" side of the Moon
      - Older than *maria*

Earth's Moon: A Chip Off the Old Block

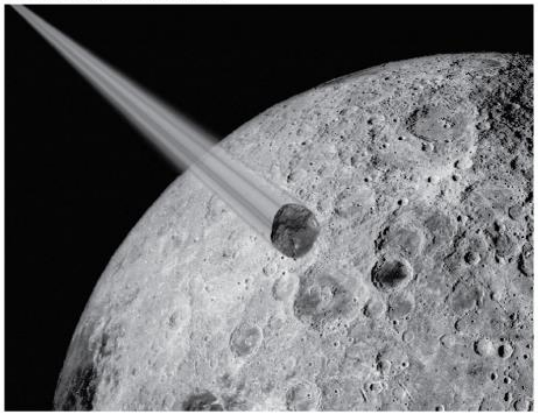


Earth's Moon: A Chip Off the Old Block

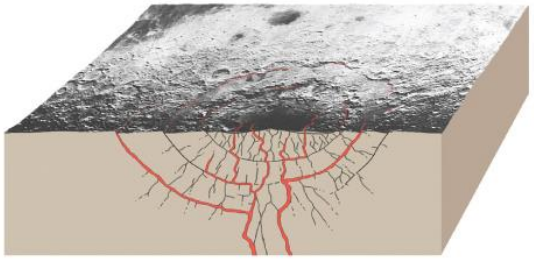
- Lunar surface
  - Craters
    - Most obvious features of the lunar surface
    - *Ejecta*
    - *Occasional rays*
      - Associated with younger craters

Earth's Moon: A Chip Off the Old Block

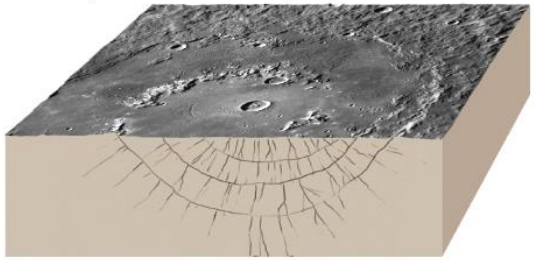
Impact of an asteroid-size body produced a huge crater hundreds of kilometers in diameter and disturbed the lunar crust far beyond the crater.



Filling of the impact crater with fluid basalts, perhaps derived from partial melting deep within the lunar mantle.



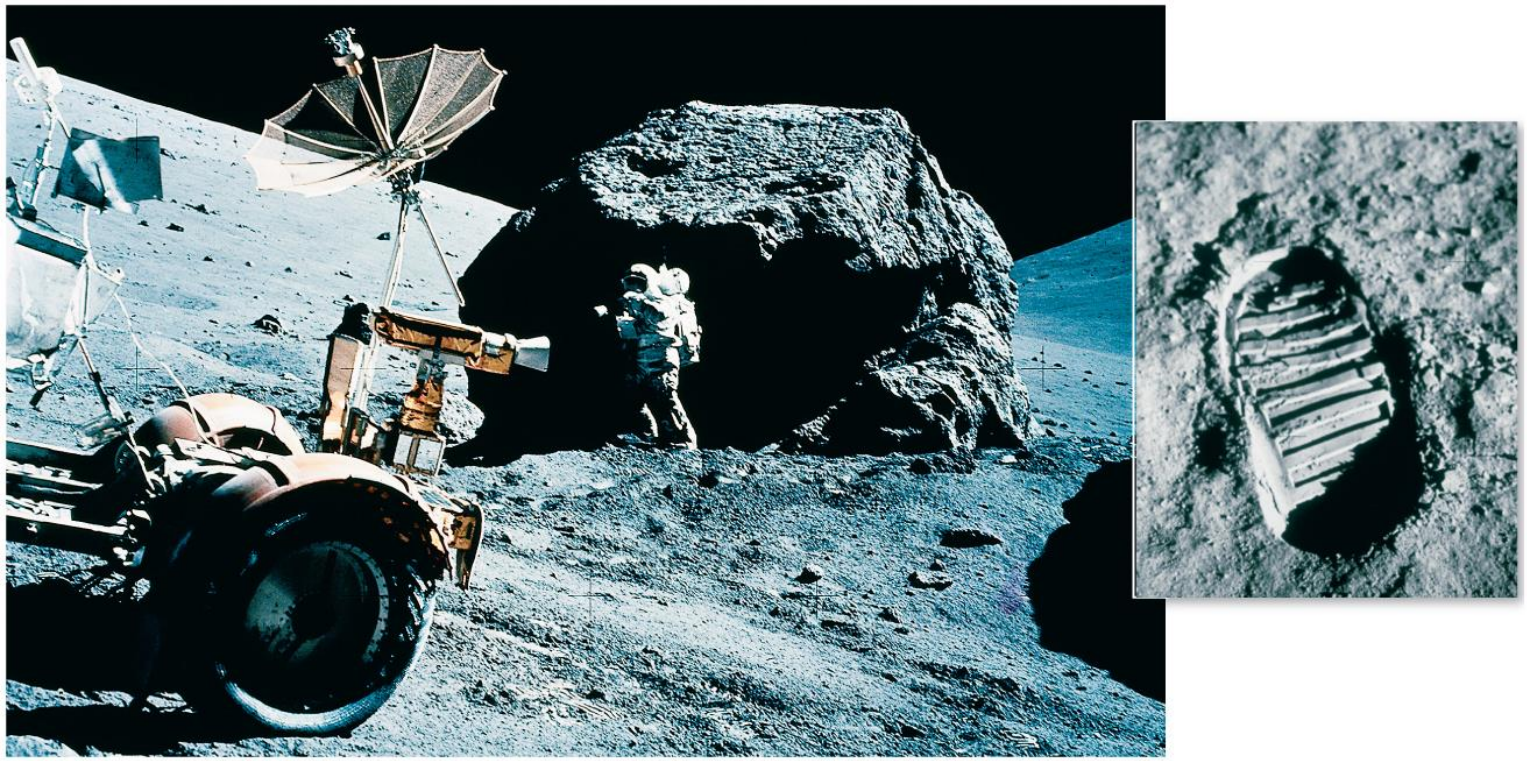
Today these lava-filled basins make up the lunar maria and similar large structures on Mercury.



Earth's Moon: A Chip Off the Old Block

- Lunar surface
  - Lunar regolith
    - Covers all lunar terrains
    - Gray, unconsolidated debris
    - Composed of:
      - Igneous rocks
      - Breccia
      - Glass beads
      - Fine lunar dust

Earth's Moon: A Chip Off the Old Block



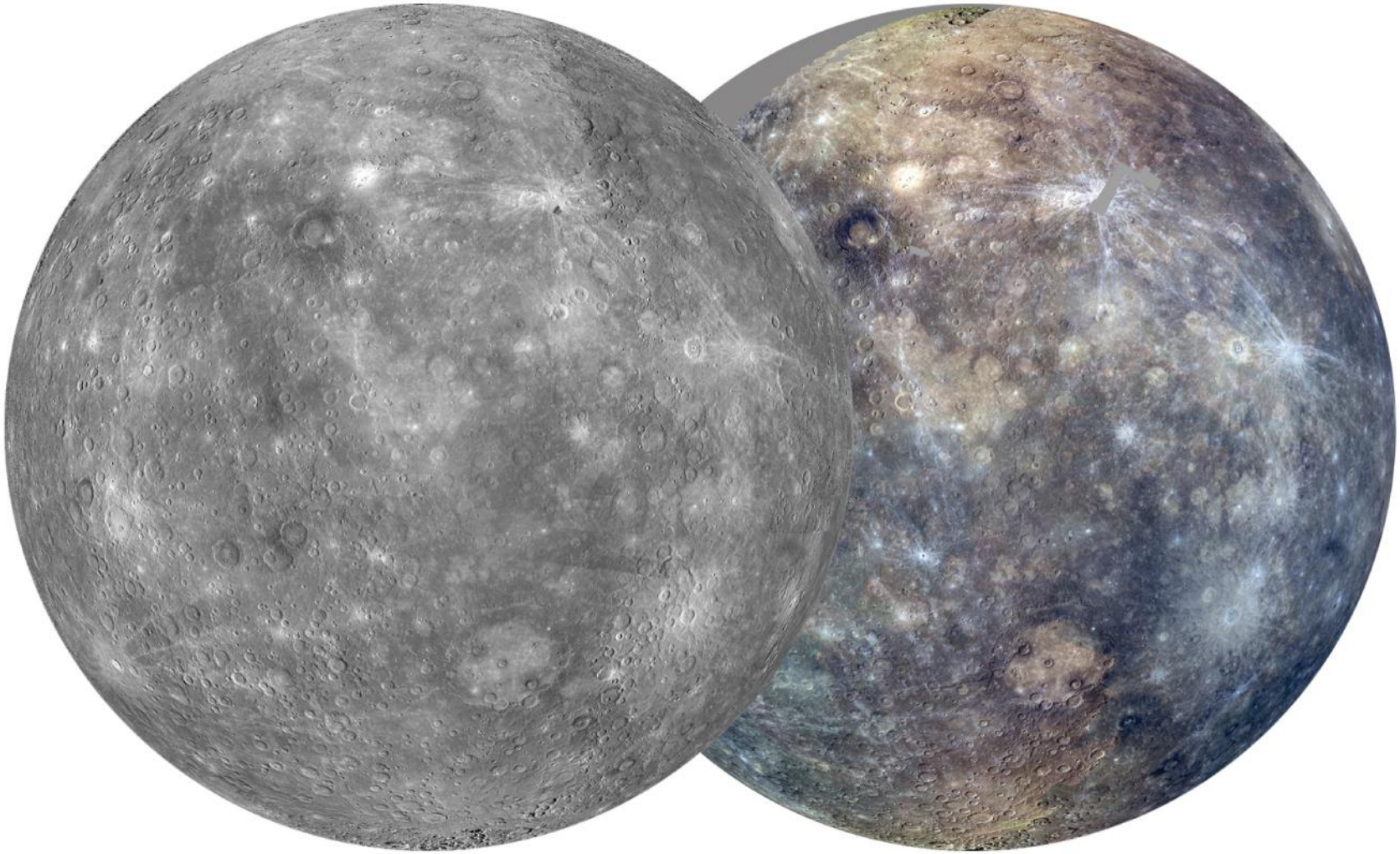
Focus Questions 15.5

- Outline the principal characteristics of Mercury, Venus, and Mars.
- Describe their similarities to and differences from Earth.

Terrestrial Planets

- **Mercury: The Innermost Planet**
  - Smallest planet
  - Revolves around the Sun quickly (88 days)
  - Rotates slowly on its axis
  - Mercury's day–night cycle lasts 176 Earth-days
  - Greatest temperature extremes: –173°C to 427°C
    - Resembles Earth's Moon in that it has very low reflectivity, no sustained atmosphere, numerous volcanic features, and a heavily cratered terrain

Terrestrial Planets



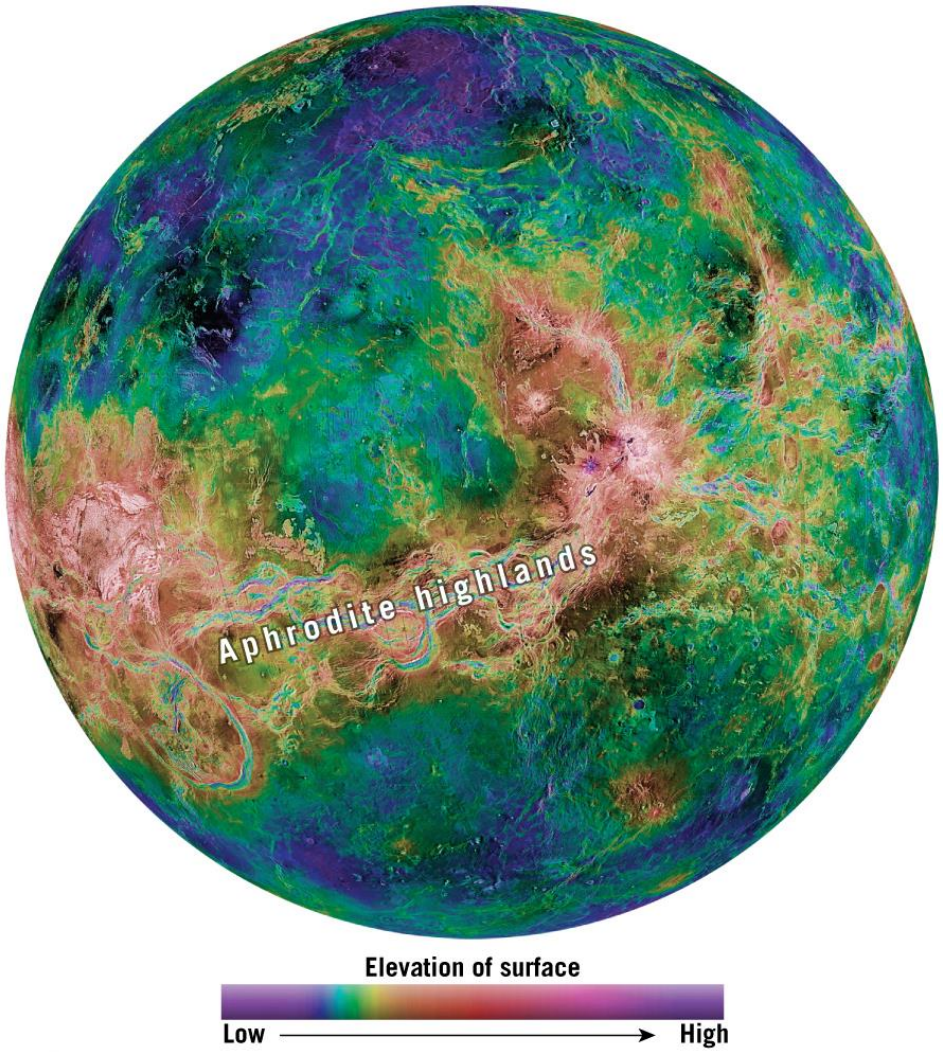
Terrestrial Planets

- **Venus: The Veiled Planet**
  - Orbits in a near perfect circle every 225 Earth-days
  - Rotates in the opposite direction of other planets
  - Rotates slowly: 1 Venus day is 243 Earth-days
  - Has the densest atmosphere of the terrestrial planets
    - 97% carbon dioxide
    - Extreme greenhouse effect
    - Surface temperature averages about 450°C day and night
    - Surface is completely hidden by a thick cloud layer of tiny sulfuric acid droplets

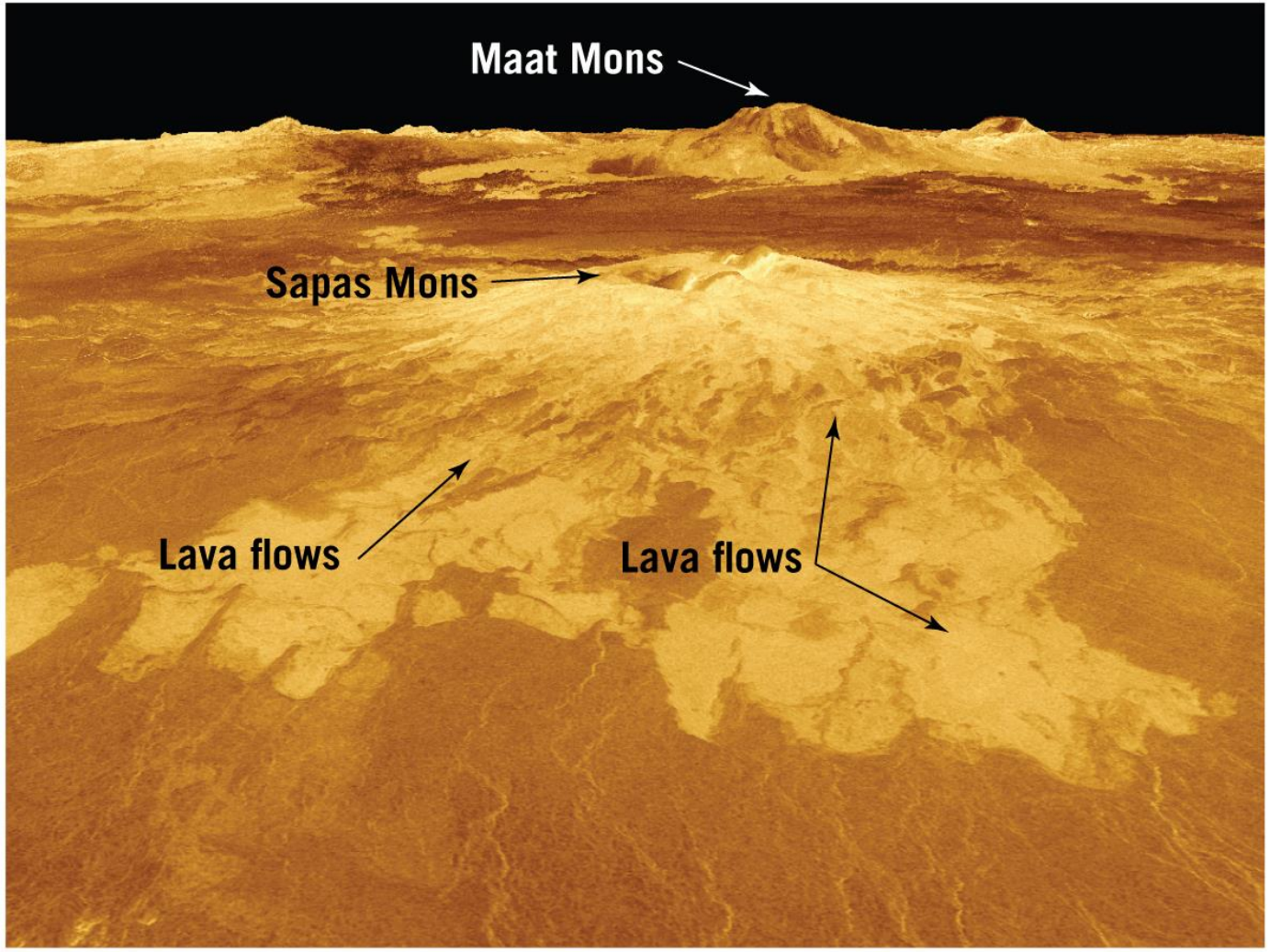
Terrestrial Planets

- Composition probably similar to Earth's
- Weak magnetic field means internal dynamics must be very different from Earth's
- More than 1000 volcanoes >20 km wide identified

Terrestrial Planets



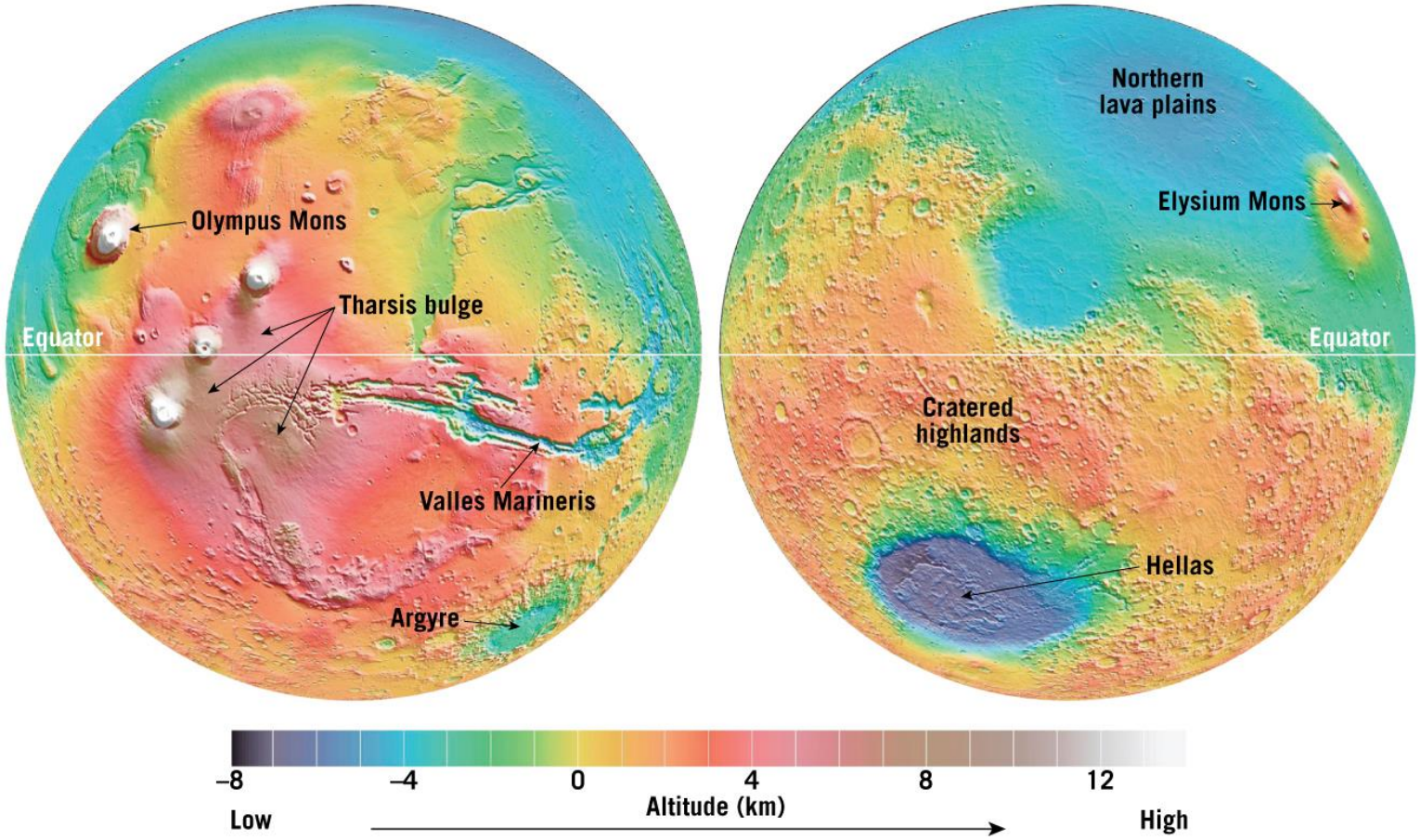
Terrestrial Planets



Terrestrial Planets

- **Mars: The Red Planet**
  - Fourth planet from the Sun
  - Half the diameter of Earth
  - Revolves around the Sun in 687 Earth-days
  - Surface temps range from lows of –140°C at the poles in winter to highs of 68°C at the equator in summer
  - Very thin atmosphere: 1% as dense as Earth's
    - Consists of 95% carbon dioxide
    - Small amounts of nitrogen, oxygen, and water vapor

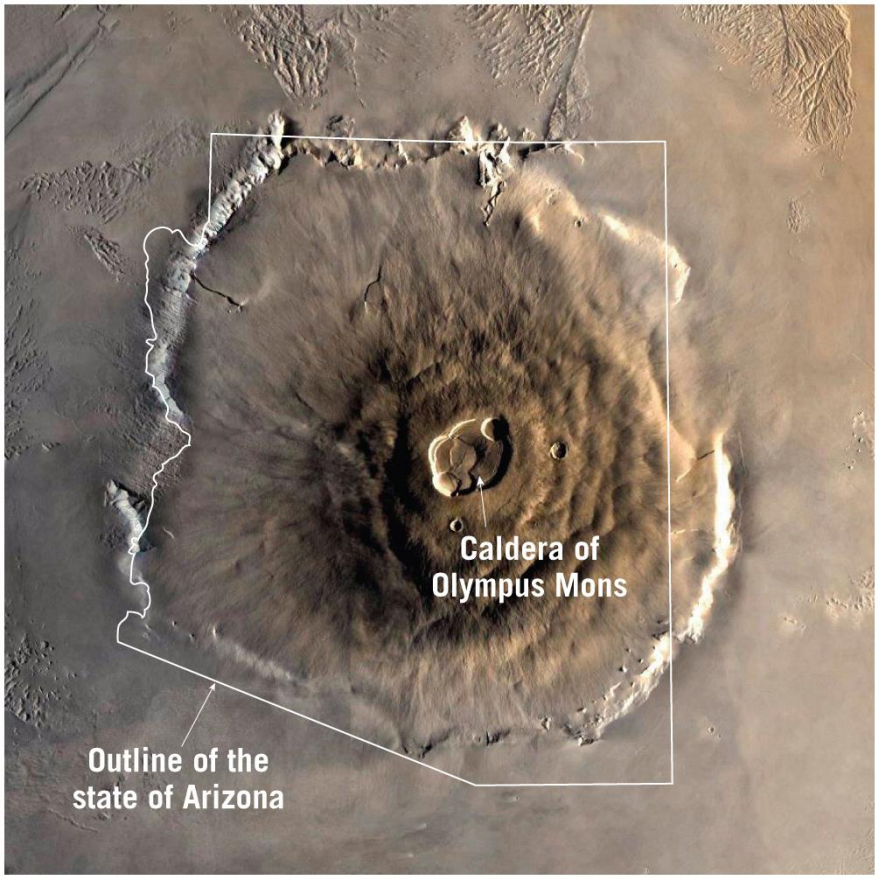
Terrestrial Planets

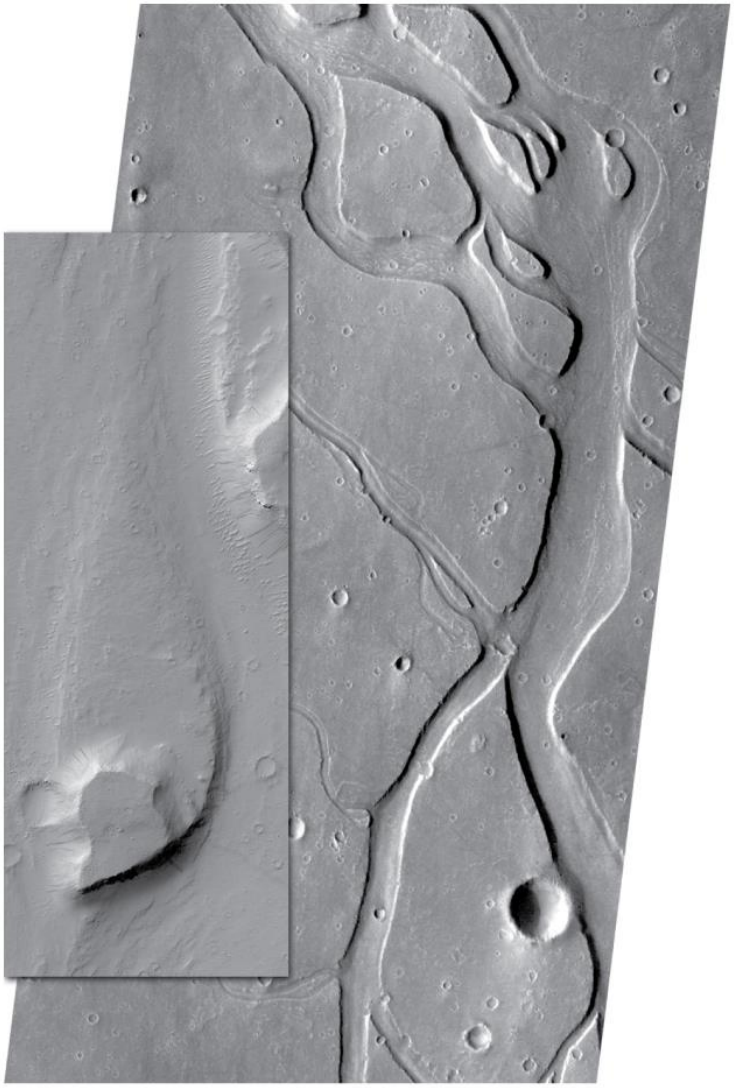


Terrestrial Planets

- Two-third of Mars' surface is cratered highlands
- If Mars had abundant water, it would flow north, forming an ocean
- Mars has some of the largest volcanoes in the solar system, including Olympus Mons
- The dominant force of erosion is wind
- Poleward of 30°, water ice is found within 1 m of surface

Terrestrial Planets





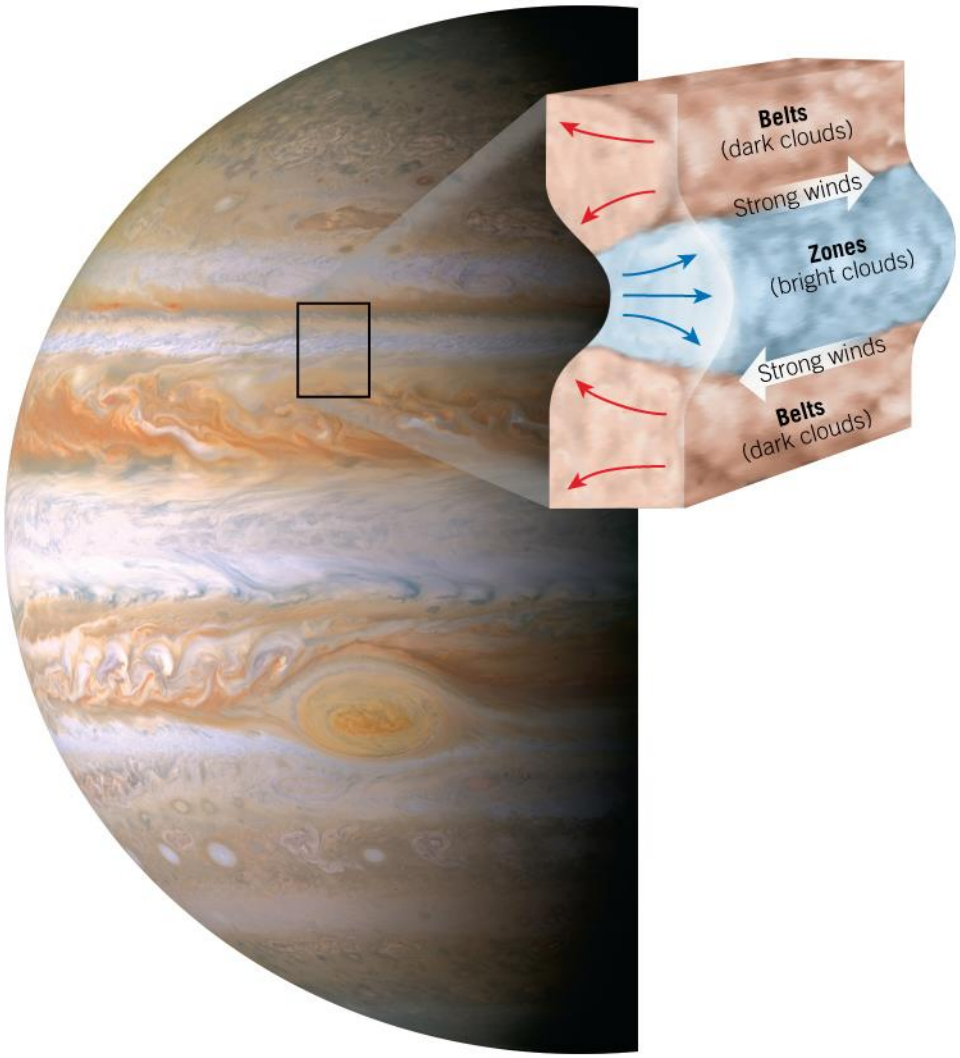
Focus Question 15.6

- Summarize and compare the features of Jupiter, Saturn, Uranus, and Neptune, including their ring systems.

Jovian Planets

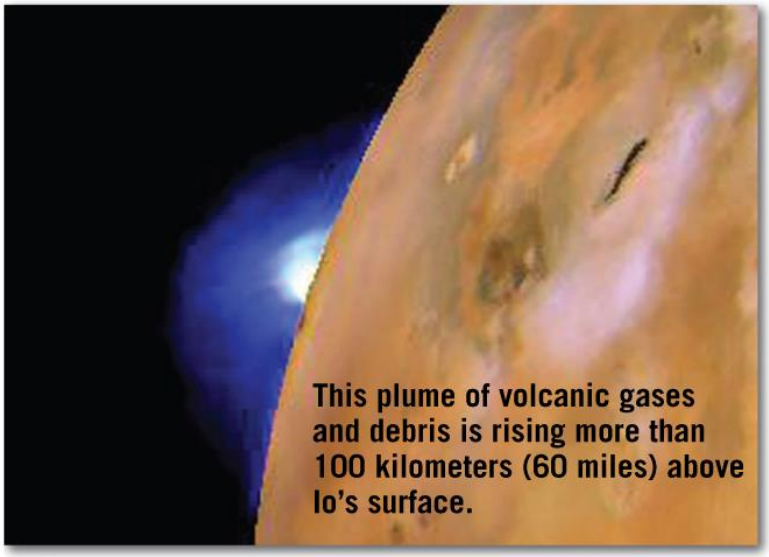
- **Jupiter: Lord of the Heavens**
  - Largest planet—very massive
    - 2.5 more massive than combined mass of planets, satellites, and asteroids
  - Orbits the sun once ever 12 Earth years
  - Rapid rotation—slightly less than 10 hours
  - Banded appearance
    - Multicolored
    - Bands are aligned parallel to Jupiter's equator
    - Generated by wind system's rapid rotation
  - *Great Red Spot*
    - In planet's Southern Hemisphere
    - Counterclockwise rotating cyclonic storm

Jovian Planets



Jovian Planets

A.



B.

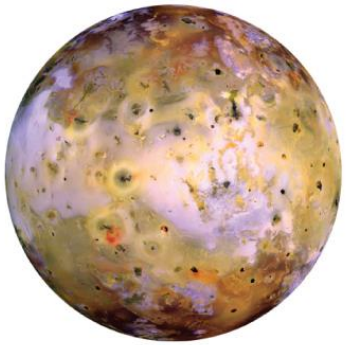
Jovian Planets

- Three main cloud layers:
  - Warmest, lowest layer
    - Mainly water ice
    - Appears blue-gray
  - Cooler middle layer
    - Ammonium hydrosulfide droplets
    - Brown to orange-brown
  - Upper layer
    - Ammonia ice
    - White, wispy

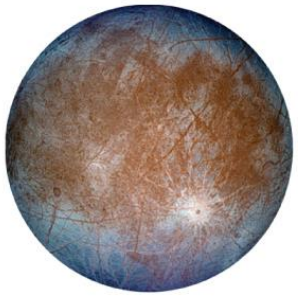
Jovian Planets

- At least 67 moons
  - Four largest moons discovered by Galileo
    - *Callisto*—Outermost Galilean moon
    - *Europa*—Smallest Galilean moon
    - *Ganymede*—Largest Jovian satellite
    - *Io*—Innermost Galilean moon and volcanically active

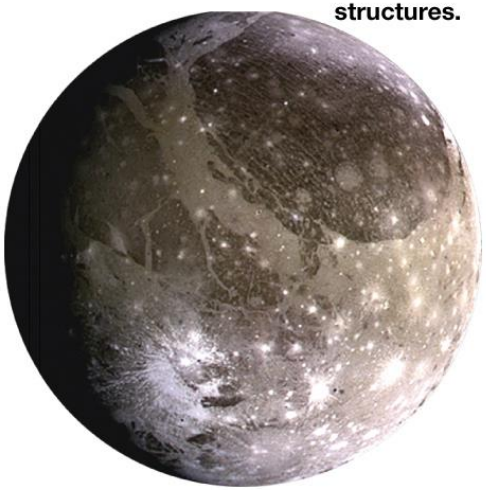
Jovian Planets



A. Io, perhaps the most volcanically active body in our solar system, has more than 80 active, sulfurous volcanic structures.



B. Europa's icy surface is quite flat and thought to cover a vast ocean composed of briny water.



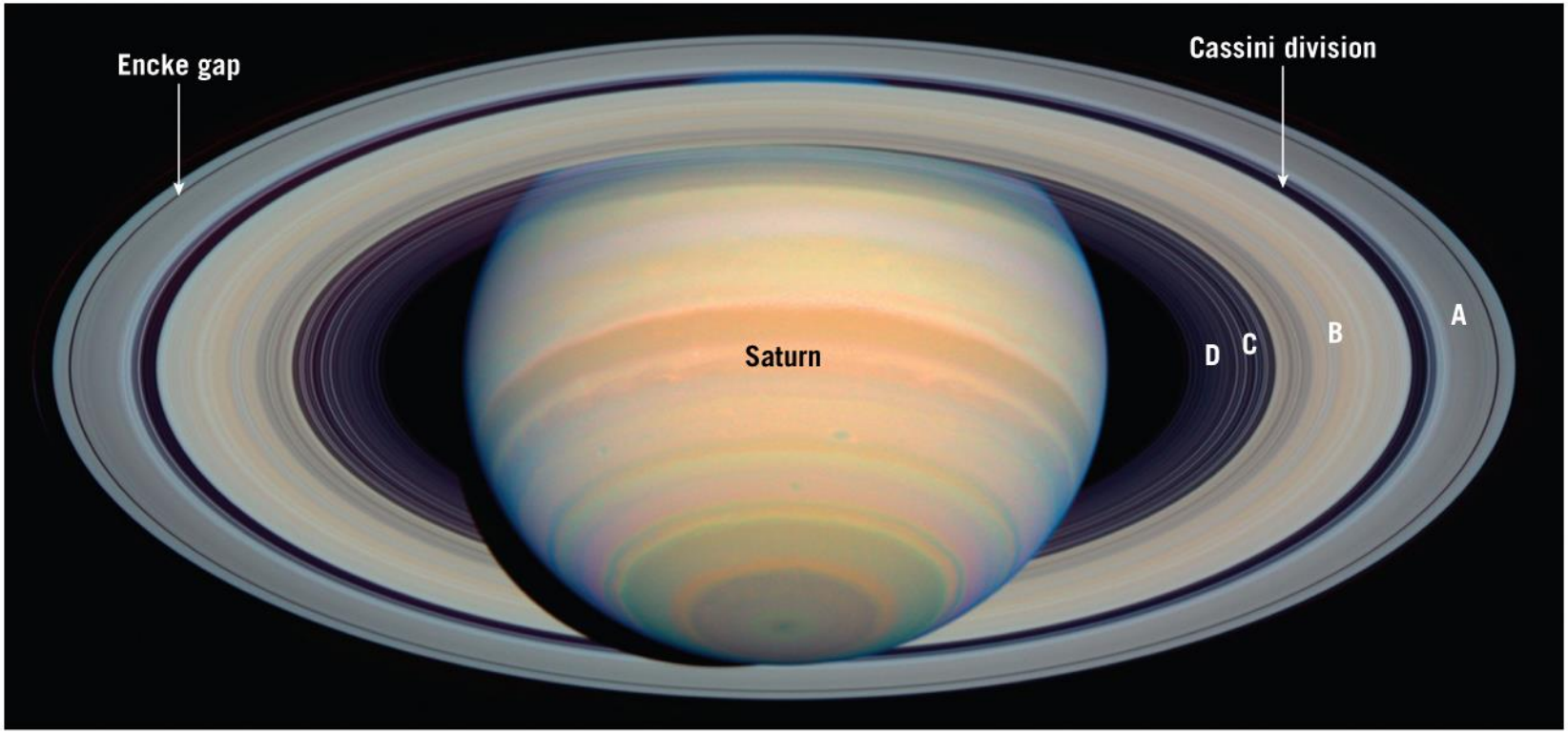
C. Ganymede, the largest of the Jovian satellites, contains both smooth as well as cratered regions, which suggest this body is still active.

D. Callisto, the outermost of the Galilean satellites, is densely cratered, much like Earth's Moon.

Jovian Planets

- **Saturn: The Elegant Planet**
  - 29 Earth years for one revolution around the Sun
  - Similar to Jupiter in
    - Atmosphere
    - Composition
    - Internal structure
  - Most striking feature is ring system
    - Discovered by Galileo in 1610
    - Ring nature determined by Christiaan Huygens 50 years later

Jovian Planets



Jovian Planets

- Other features of Saturn
  - Dynamic atmosphere
    - 93% hydrogen and 3% helium by volume
    - Clouds composed mainly of ammonia, ammonium hydrosulfide, and water
      - Segregated by temperature
  - Large cyclonic storms similar to Jupiter's Great Red Spot
  - Emits roughly twice as much energy as it receives
    - Must have an internal heat source

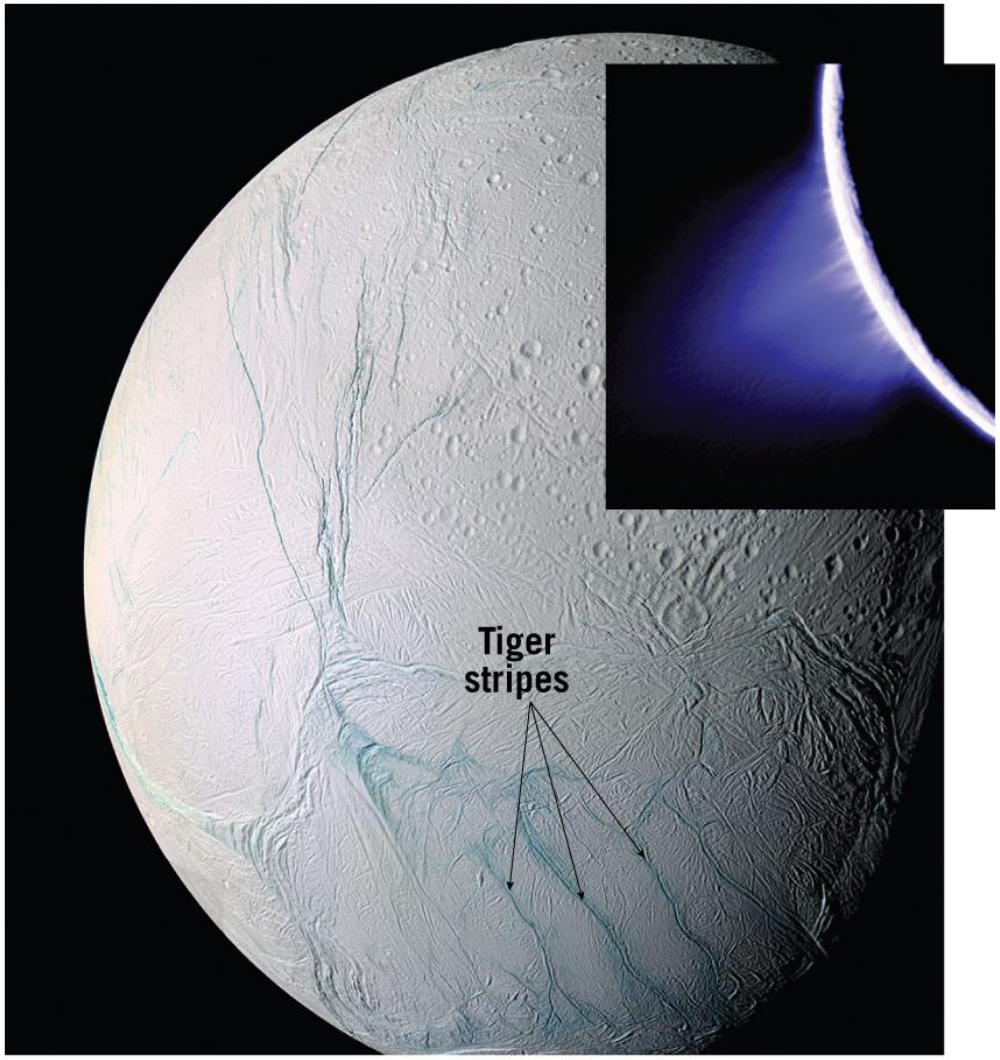
Jovian Planets

- Saturn's Moons
  - 62 known moons; 53 named moons
  - Vary significantly in size, shape, surface age, and origin
    - 23 "original" satellites formed in tandem with parent planet
  - Titan
    - Largest Saturnian moon
    - Second largest moon in the solar system
    - Has a substantial atmosphere
  - Enceladus
    - **Cryovolcanism** – eruption of magmas derived from partial melting of ice

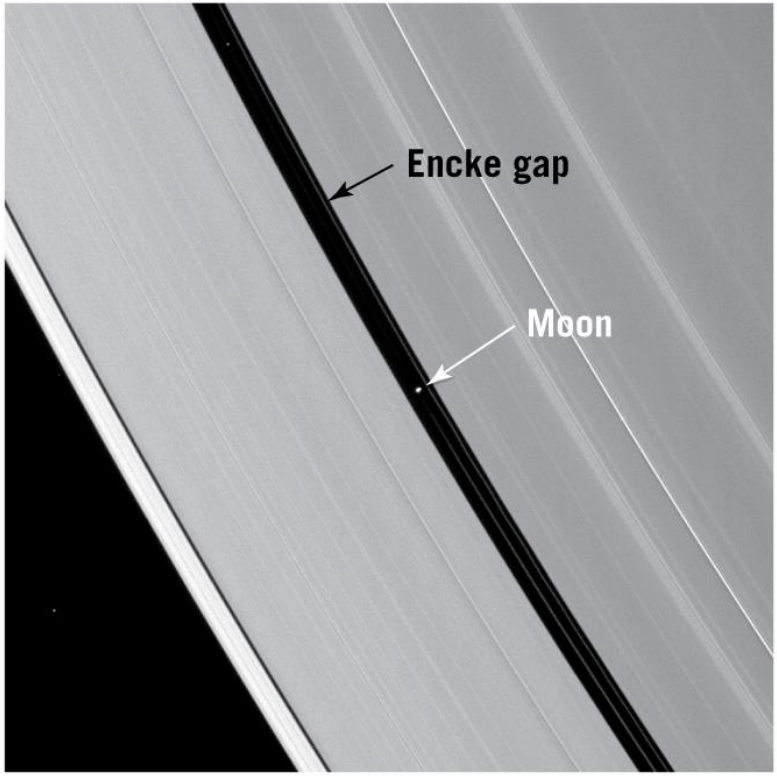
Jovian Planets

- Saturn's Rings
  - Composed of small particles (mainly water ice, lesser amounts of rocky debris) that orbit the planet
  - Most fall into one of two categories of particle density
  - Thought to be debris ejected from moons
  - Origin is still being debated

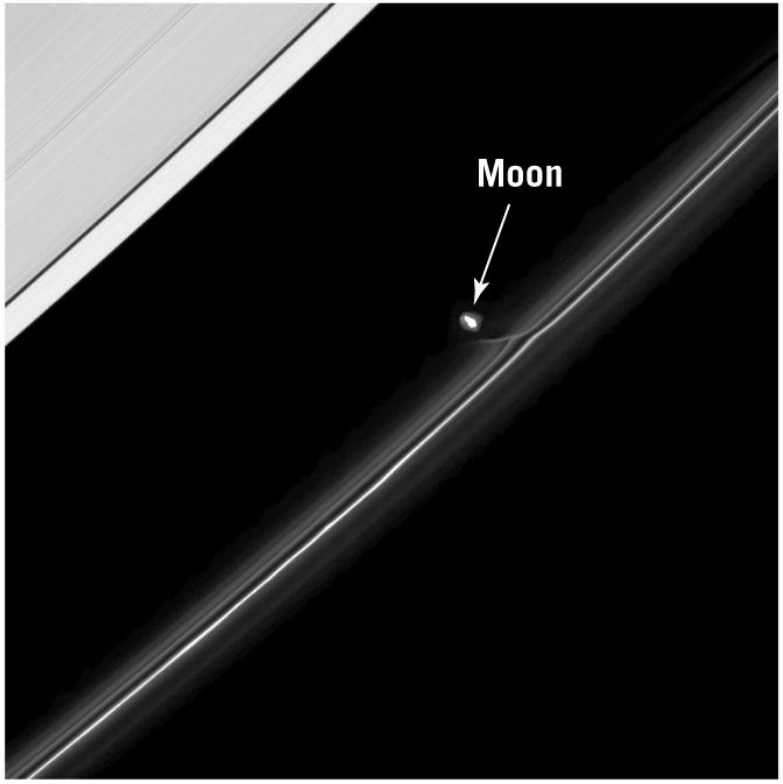
Jovian Planets



Jovian Planets



A. Pan is a small moon about 30 kilometers in diameter that orbits in the Encke gap, located in the A ring. It is responsible for keeping the Encke gap open by sweeping up any stray material that may enter.



B. Prometheus, a potato-shaped moon, acts as a ring shepherd. Its gravity helps confine the particles that make up Saturn's thin Fring.

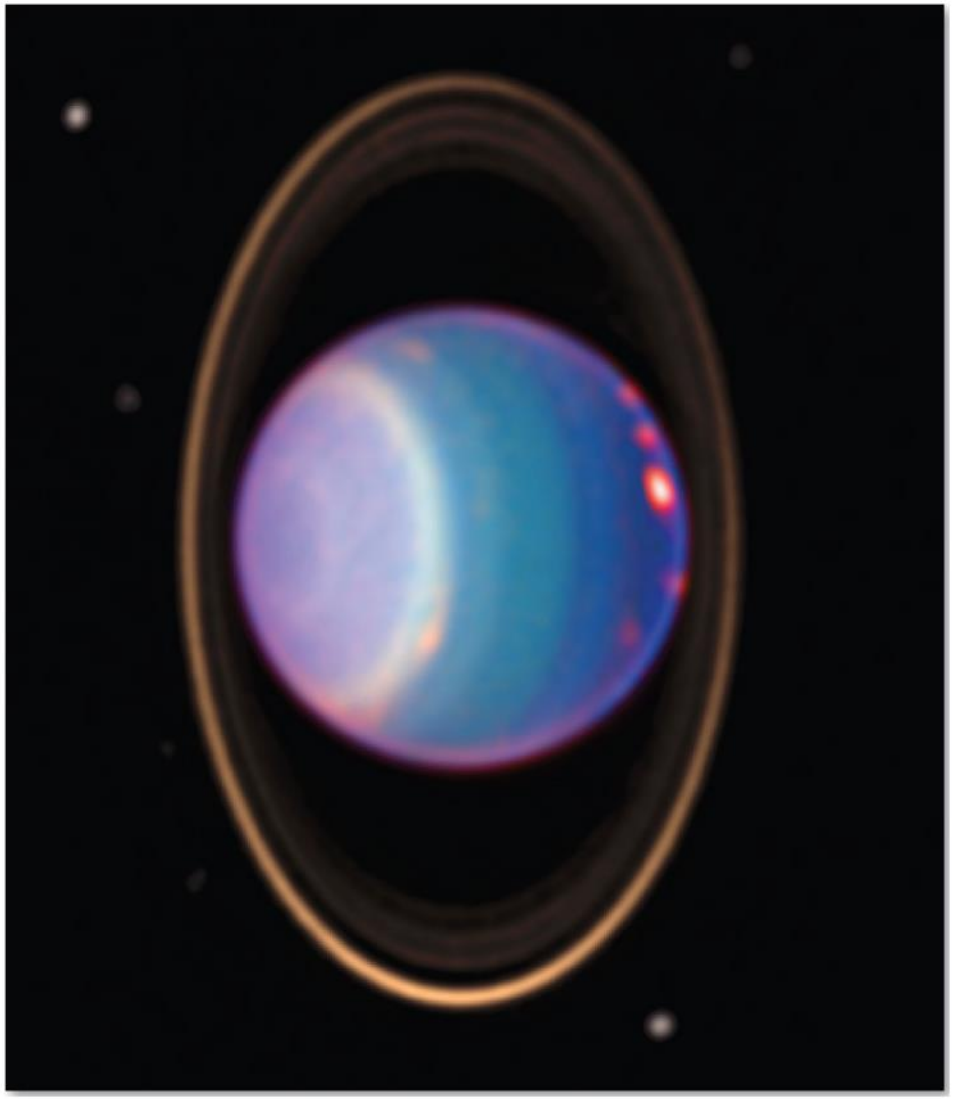
Jovian Planets

- **Uranus and Neptune: Twins**
  - Uranus: The Sideways Planet
    - 84 Earth years for one revolution
    - Rotates “on its side”
    - Rings
    - Large moons have varied terrains
  - Neptune: The Windy Planet
    - 165 Earth years for one revolution
    - Dynamic atmosphere
    - One of the windiest places in the solar system
    - *Great Dark Spot*
    - White cirrus-like clouds above the main cloud deck

Jovian Planets

- Uranus's Moons
  - Uranus's five largest moons have varied terrains
  - Innermost was recently geologically active
- Uranus's Rings
  - Discovered in 1977 that Uranus had five rings
  - More recent observations indicate that Uranus has atleast 10 rings

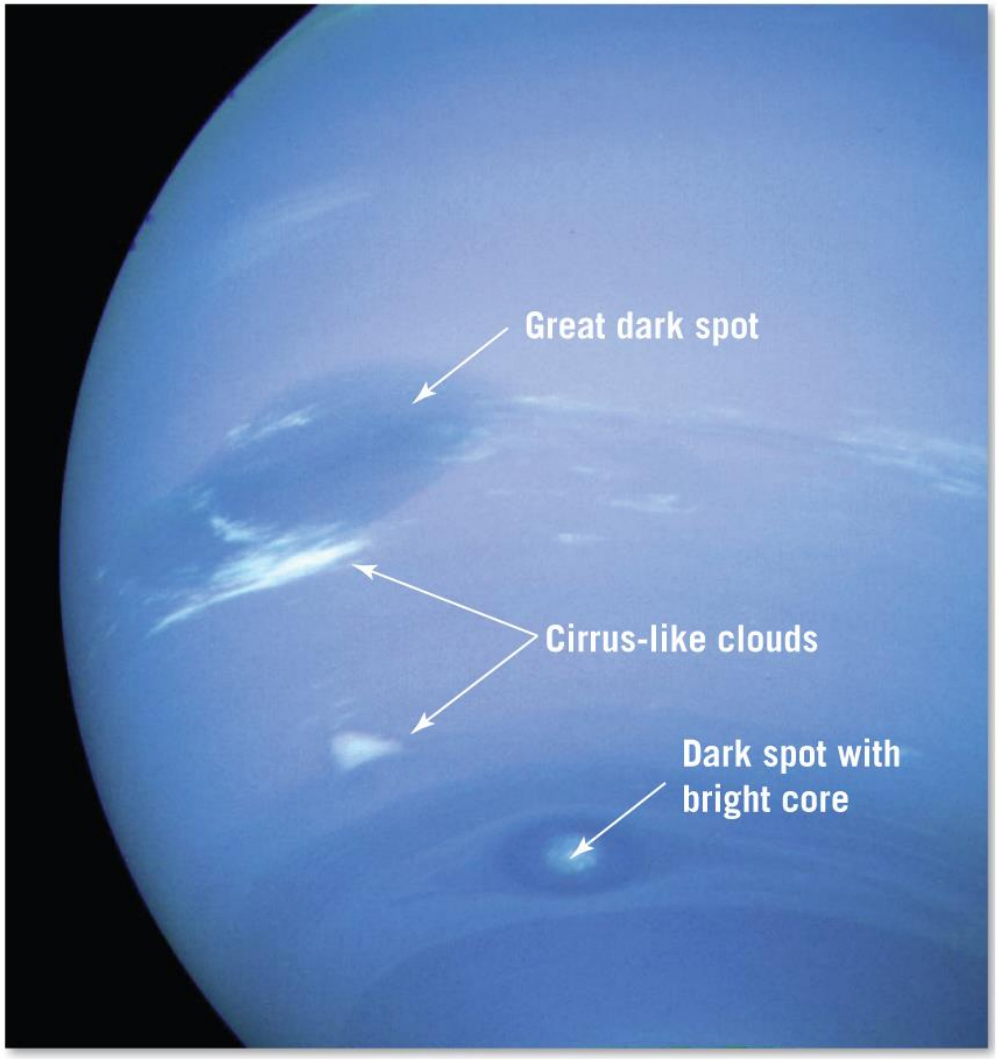
Jovian Planets



Jovian Planets

- Neptune's Moons
  - 14 known satellites
  - *Triton*
    - Largest Neptune moon
    - Cryovolcanism
      - Icy magma is a mixture of water ice, methane, and probably ammonia
      - Generate outpourings of ice lavas great distances across the surface
      - Occasionally produce explosive eruptions
        - » Ice equivalent of volcanic ash
- Neptune's Rings
  - Neptune has five named rings
  - Two broad and three narrow

Jovian Planets



Focus Question 15.7

- List and describe the principal characteristics of the small bodies that inhabit the solar system.

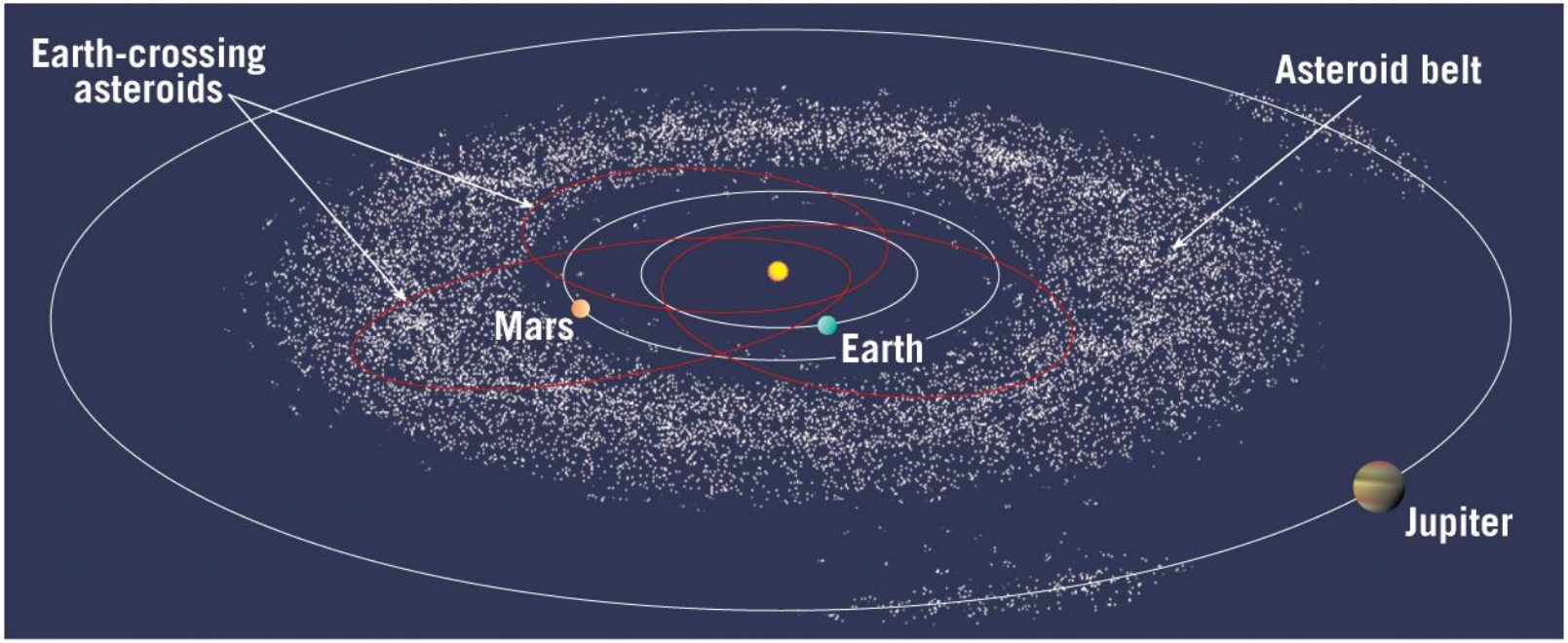
Small Solar System Bodies

- Other solar system objects classified into two broad categories:
  - **Small solar system bodies**—including asteroids, comets, and meteoroids
  - **Dwarf planets**

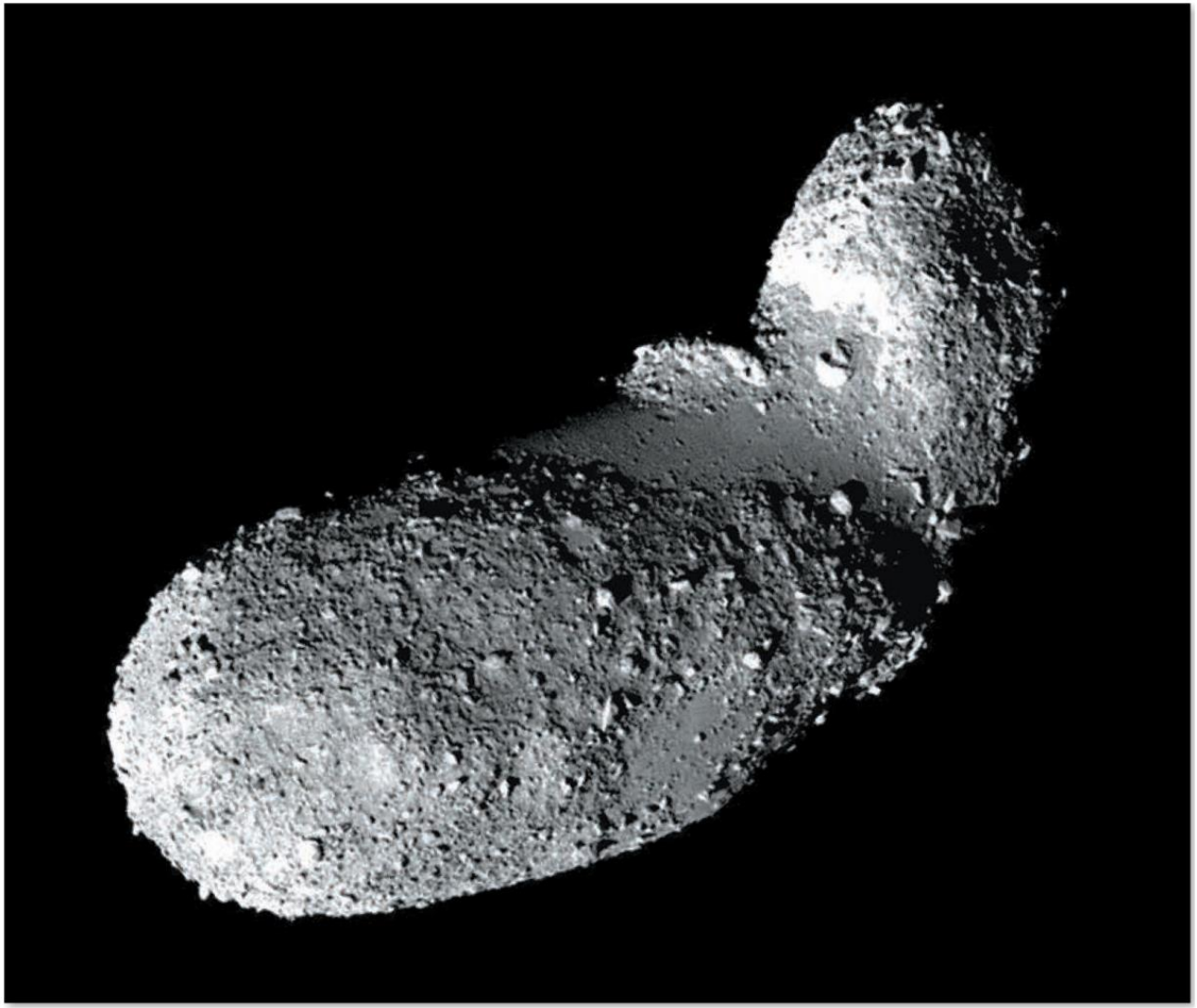
Small Solar System Bodies

- **Asteroids**: Leftover Planetesimals
  - Small bodies that remain from the formation of the solar system
  - Most in **asteroid belt** between Mars and Jupiter
  - Some have very eccentric orbits
  - Many recent impacts on the Moon and Earth were collisions with asteroids
  - Irregular shapes

Small Solar System Bodies



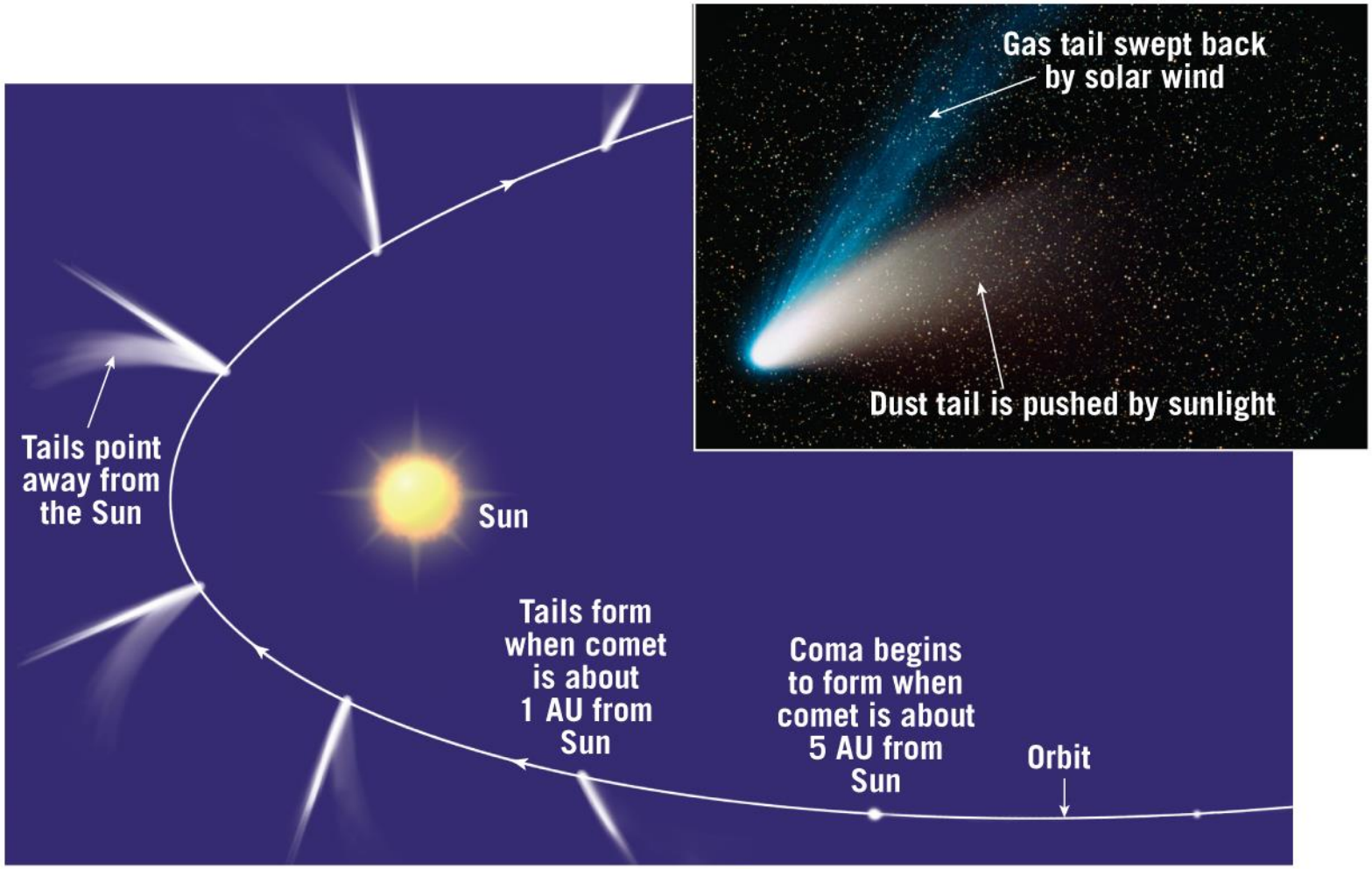
Small Solar System Bodies



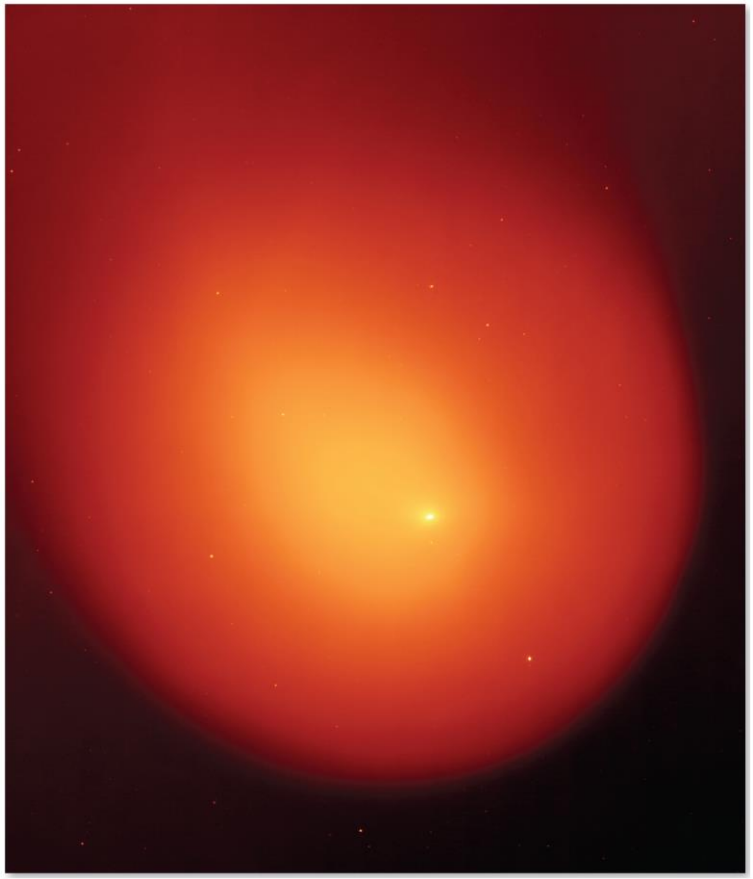
Small Solar System Bodies

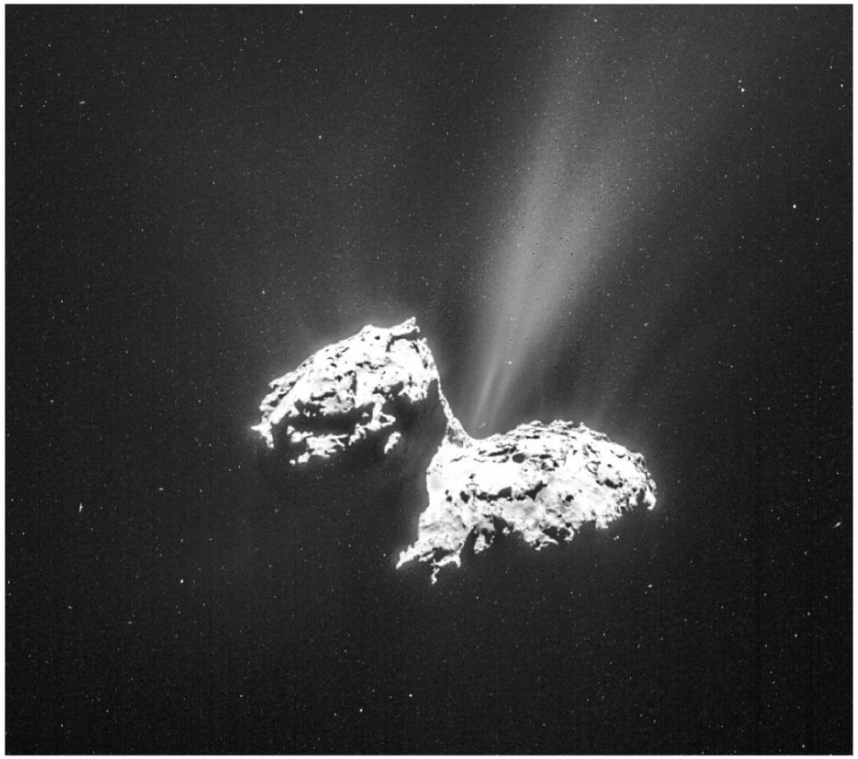
- **Comets**: Dirty Snowballs
  - Loose collections of rocky material, dust, water ice, and frozen gases (ammonia, methane, and carbon dioxide)
  - **Nucleus**—small central body
    - 1 to 10 km diameter
  - Frozen gases vaporize when near the Sun
    - Produces a glowing head called the **coma**
    - Some may develop a tail that points away from Sun
  - Originate in **Kuiper belt** or **Oort cloud**

Small Solar System Bodies



Small Solar System Bodies



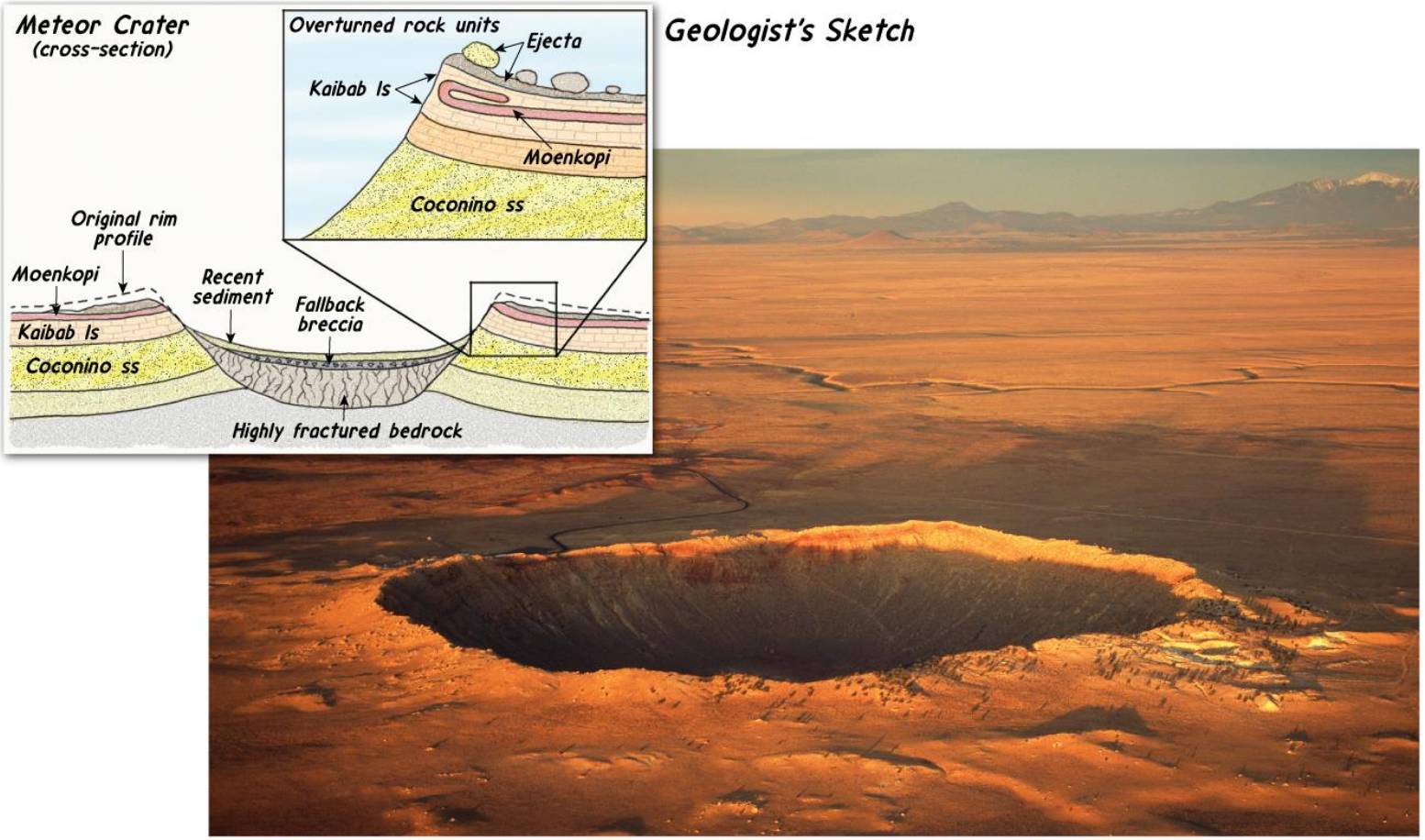


Small Solar System Bodies

- Meteors, Meteoroids, and Meteorites
  - Called ***meteors*** when they enter Earth's atmosphere
  - A ***meteor shower*** occurs when Earth encounters a swarm of meteoroids associated with a comet's path
  - Called ***meteorites*** when they are found on Earth
    - Types classified by composition
      - Irons
        - » Mostly iron, 5–20% nickel
      - Stony
        - » Silicate minerals with inclusions of other minerals
      - *Stony irons*
        - » Mixtures

Small Solar System Bodies

Small Solar System Bodies



Small Solar System Bodies

- Dwarf Planets
  - Orbit the sun
  - Essentially spherical due to their own gravity
  - Not large enough to sweep their orbits clear of other debris
  - Pluto's diameter: 2370 km (1470 mi)
    - ~1/5 Earth's diameter
    - <1/2 Mercury's diameter
  - Eris (Kuiper belt object)
  - Ceres (largest-known asteroid)

Small Solar System Bodies