Earth and Planetary Sciences (ES1101)

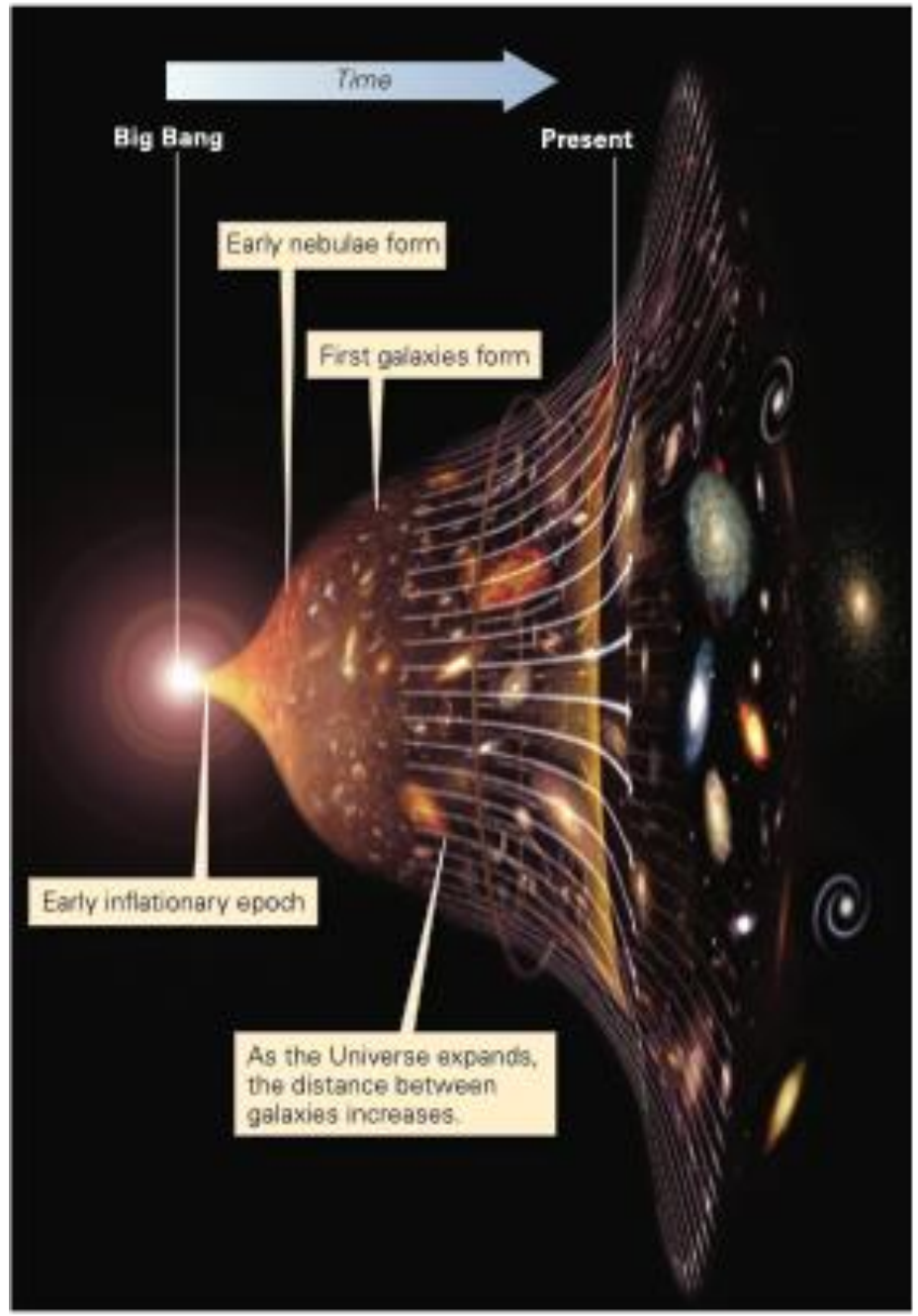
Autumn 2024

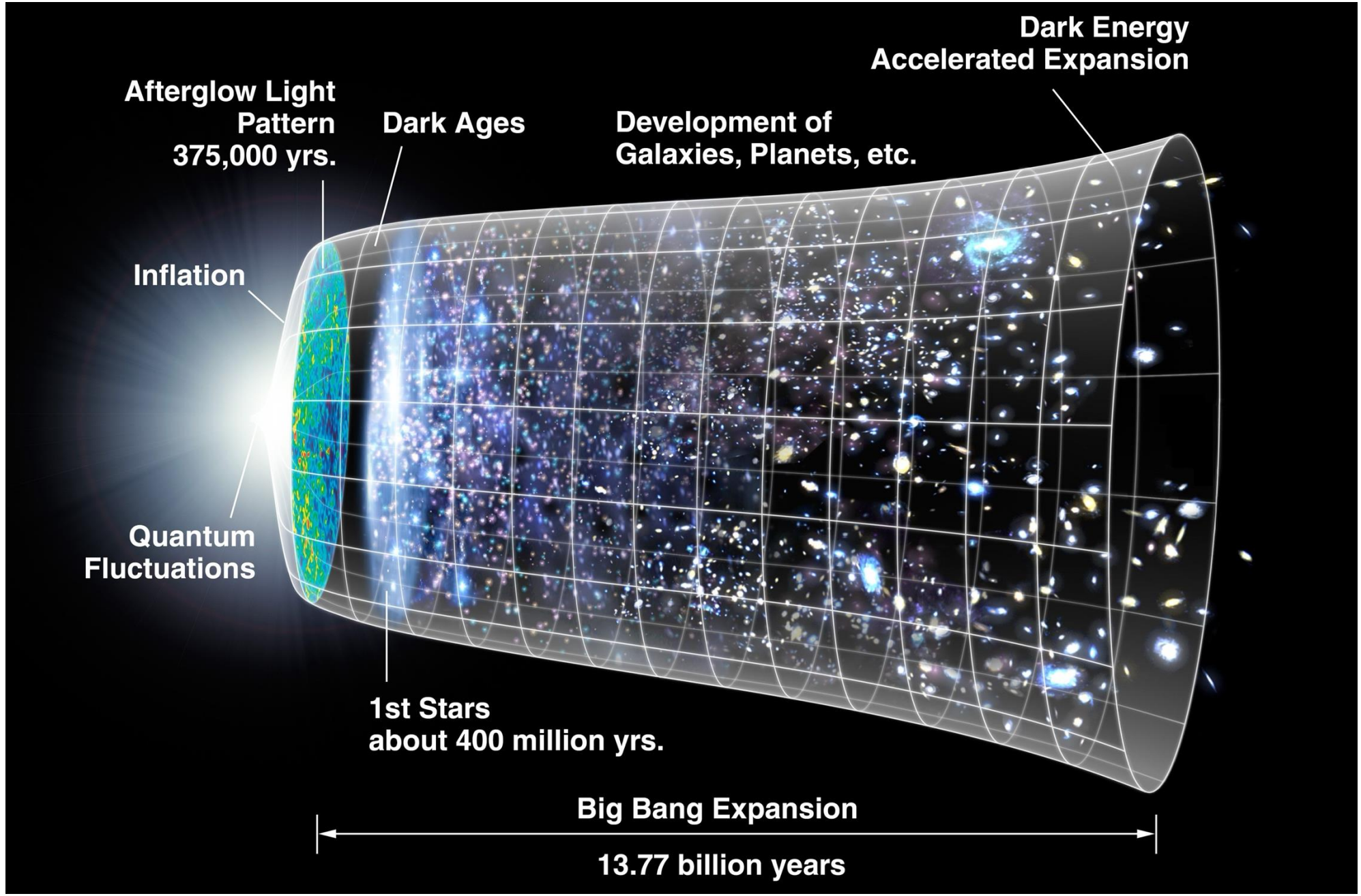
Origin of the Universe

Most accepted : Big Bang

- **~14 billion years ago (bya). All mass in universe compressed to single point 10^{9} kg m^{-3} density, $T=10^{12}$ K started to expand.**

- **Aggregates of ejected material collapsed gravitationally to form earliest stars.**


Time
Big Bang
Present
Early nebulae form
First galaxies form
Early inflationary epoch
As the Universe expands, the distance between galaxies increases.


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
375,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.77 billion years

Temperatures in cores increased due to compressional heating

When temperatures reached 10 million K, nuclear fusion of H into He and other elements began, releasing energy to power the stars.

As early stars aged, they ultimately exploded, ejecting elements to the universe around

Origin of the Sun

- **4.6 billion years interstellar material aggregated to form cloudy mass, the solar nebula**

- **Sun formed from gravitational collapse of solar nebula**

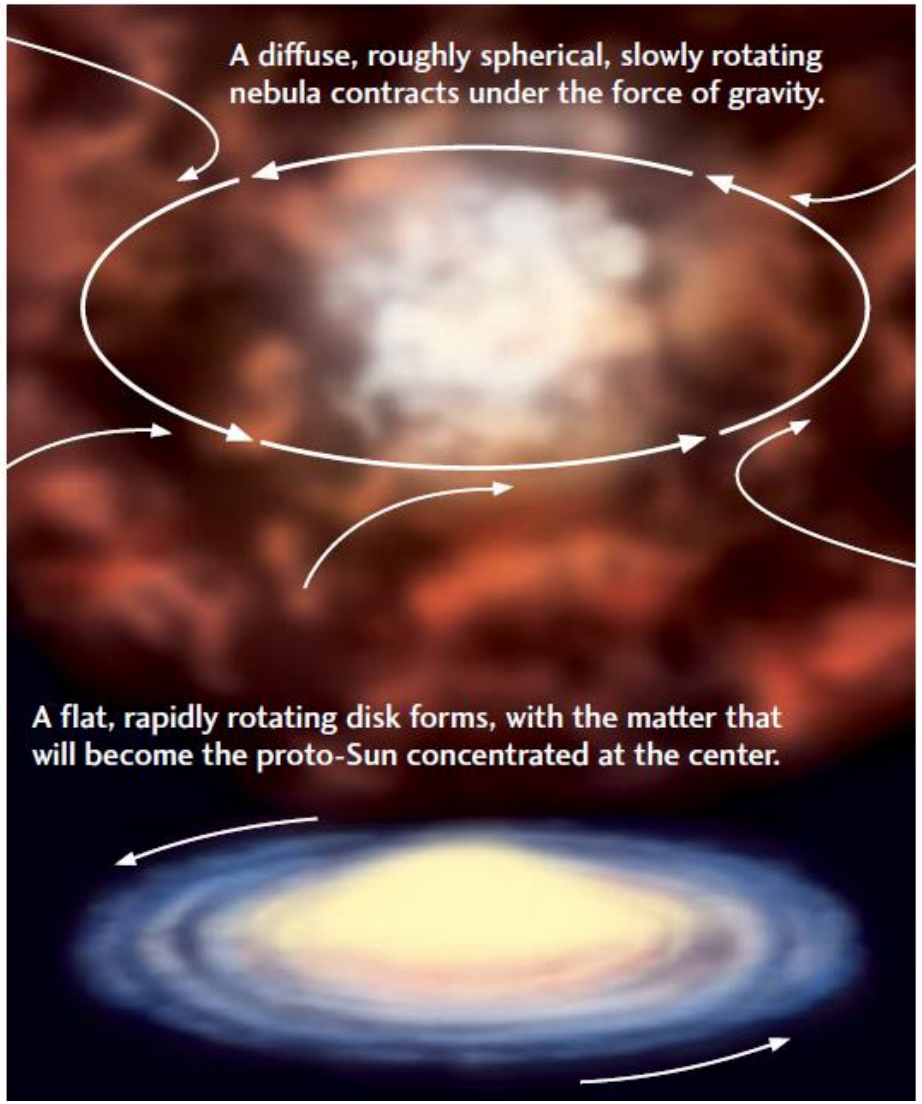
Origin of the Earth

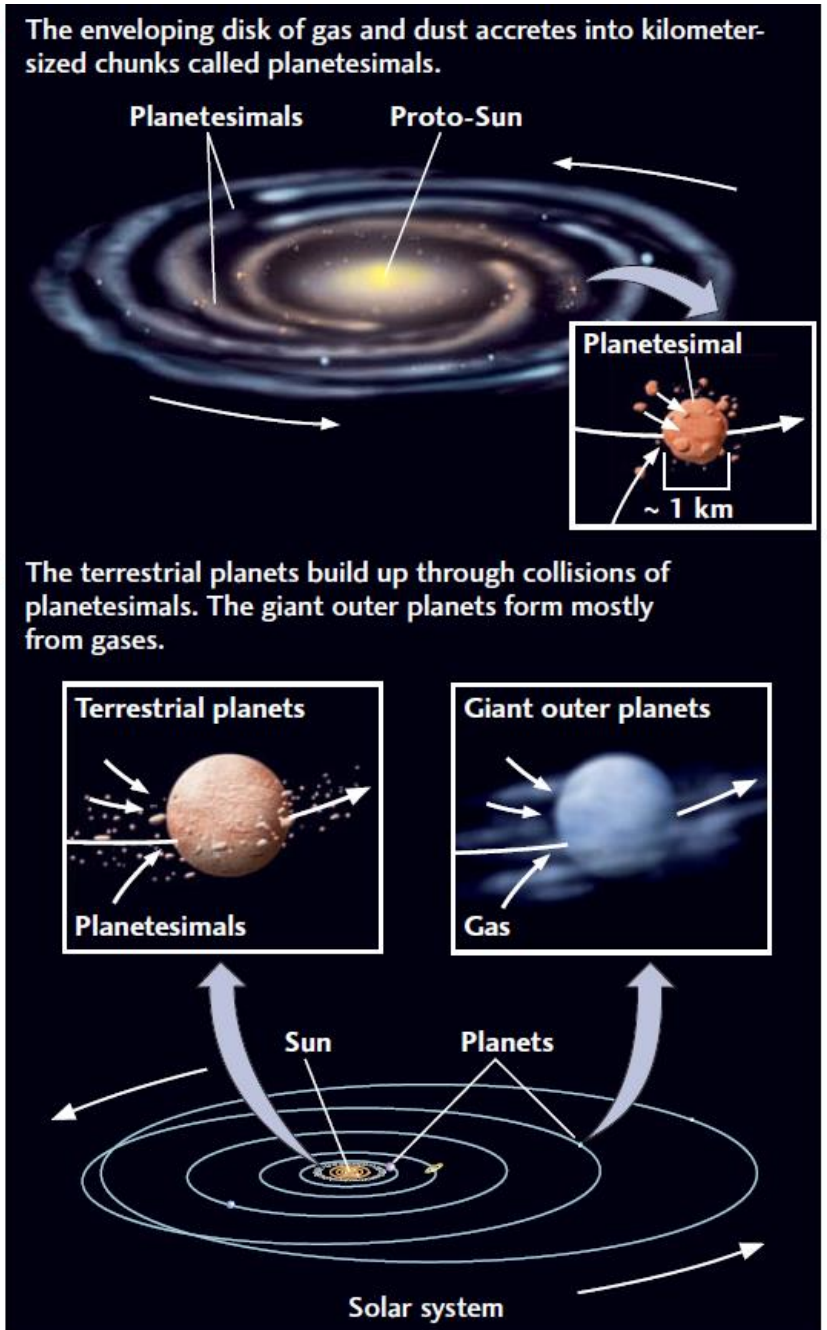
- **~4.6 billion years ago, rock-forming elements, which were gases at high temperature in solar nebula, condensed into small solid grains as nebula cooled.**

- **Grains accreted to planetesimals, such as asteroids and comets.**

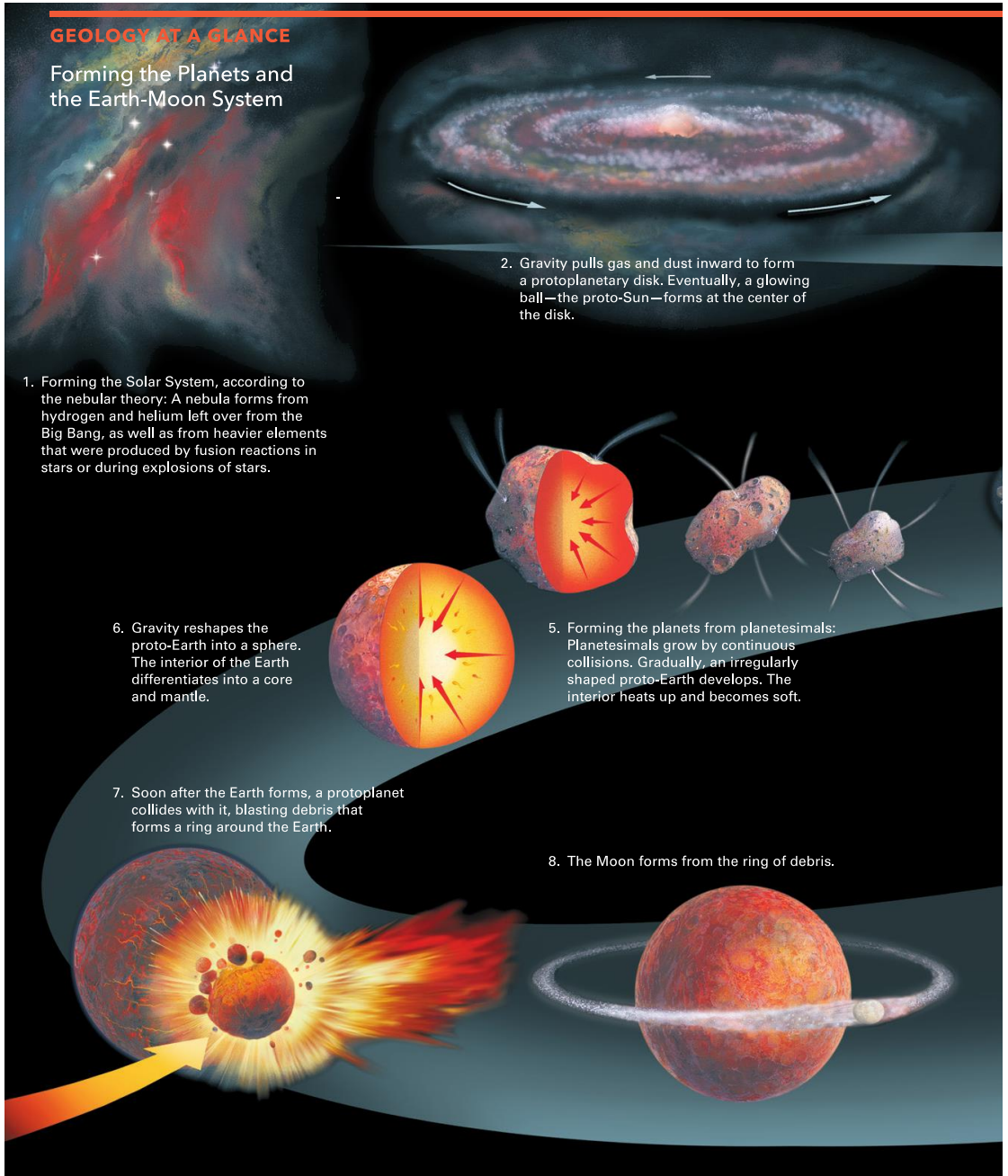
- **Planetesimals accreted to form the Earth and other planets**

Origin of Our Solar System

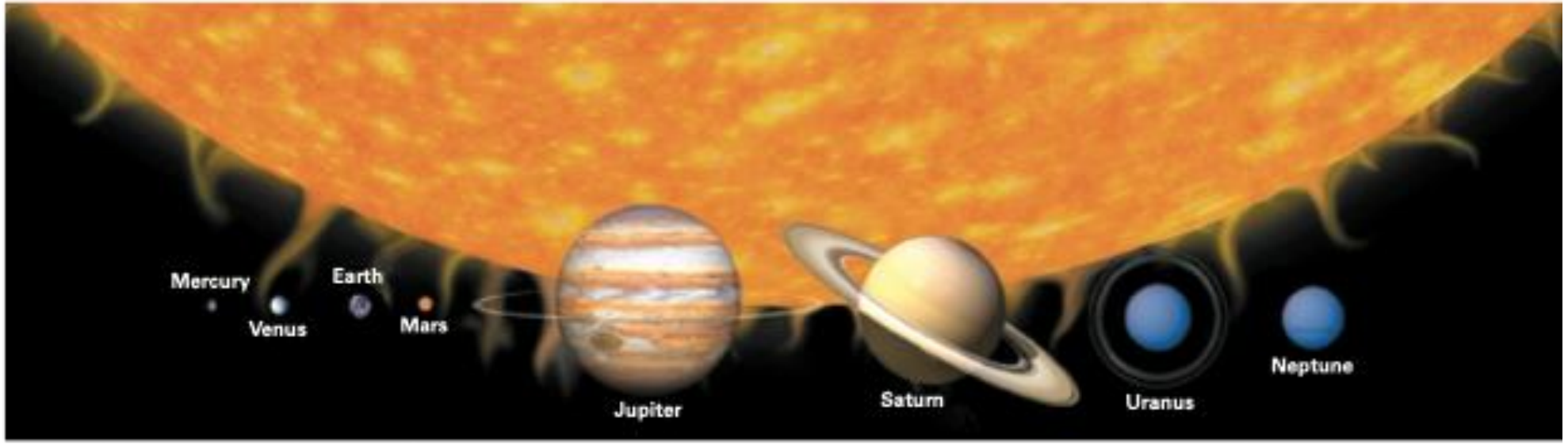




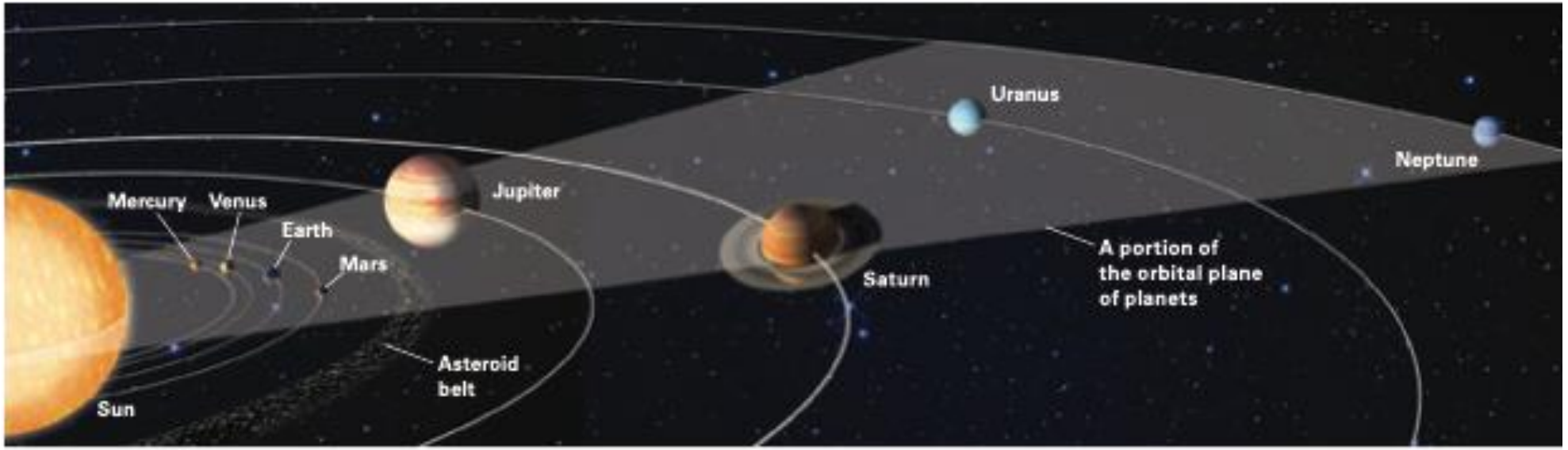
Origin of Our Solar System



Our Solar System



(a) Relative sizes of the planets. All are much smaller than the Sun, but the gas-giant planets are much larger than the terrestrial planets. Jupiter has a diameter about 11.2 times greater than that of the Earth.



(b) Relative positions of the planets. This figure is not to scale. If the Sun in this figure was the size of a large orange, the Earth would be the size of a sesame seed 15 meters away. Note that all planetary orbits lie roughly in the same plane.

The Planets

- **Inner Planets: Mercury, Venus, Earth, Mars**
  Characteristics: Lost much of the volatiles
  Smaller in size
  Rocky and metallic (Fe-Ni)

- **Outer Planets: Jupiter, Saturn, Uranus, Neptune**
  Characteristics: Larger
  Icy
  Gaseous

- **Asteroidal Belt between the Mars and Jupiter;**
  Meteorites ; intermediate in characteristics

- **Kuiper Belt in the outer solar system- beyond Neptune- Comets are thought to come from here**

- **What happened right after the Earth formed ?**

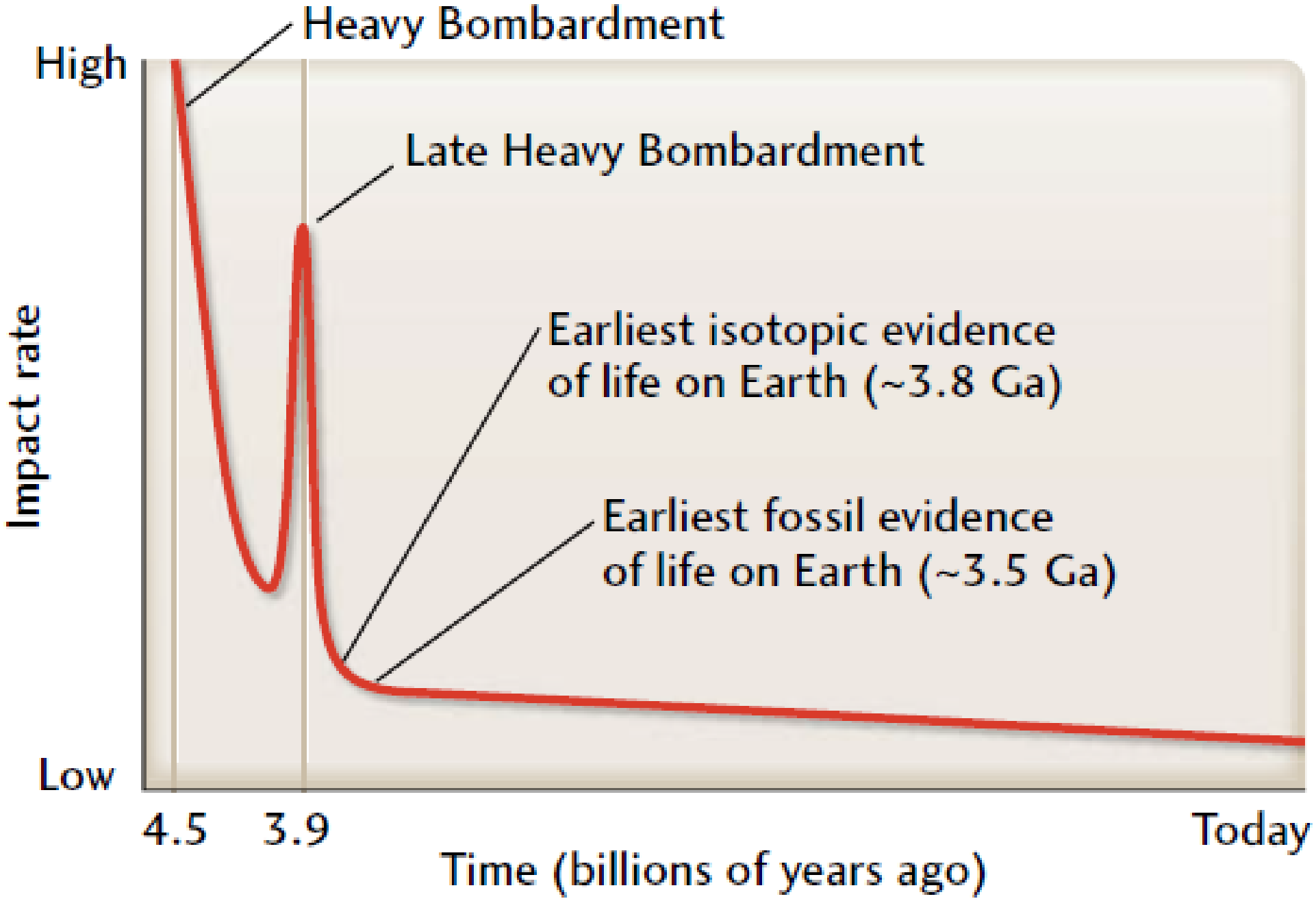
Giant Impact

After the formation of the Earth, a period of intense bombardment by asteroids happened

The Moon probably formed by Giant Impact

Age of the Earth

Bracketed by the age of the oldest known meteorite 4.56 b.y and the oldest Apollo Moon Rock 4.46 b.y as ~4.53 by


Heavy Bombardment
High
Late Heavy Bombardment
Earliest isotopic evidence
of life on Earth (~3.8 Ga)
Earliest fossil evidence
of life on Earth (~3.5 Ga)
Impact rate
Low
4.5
3.9
Today
Time (billions of years ago)

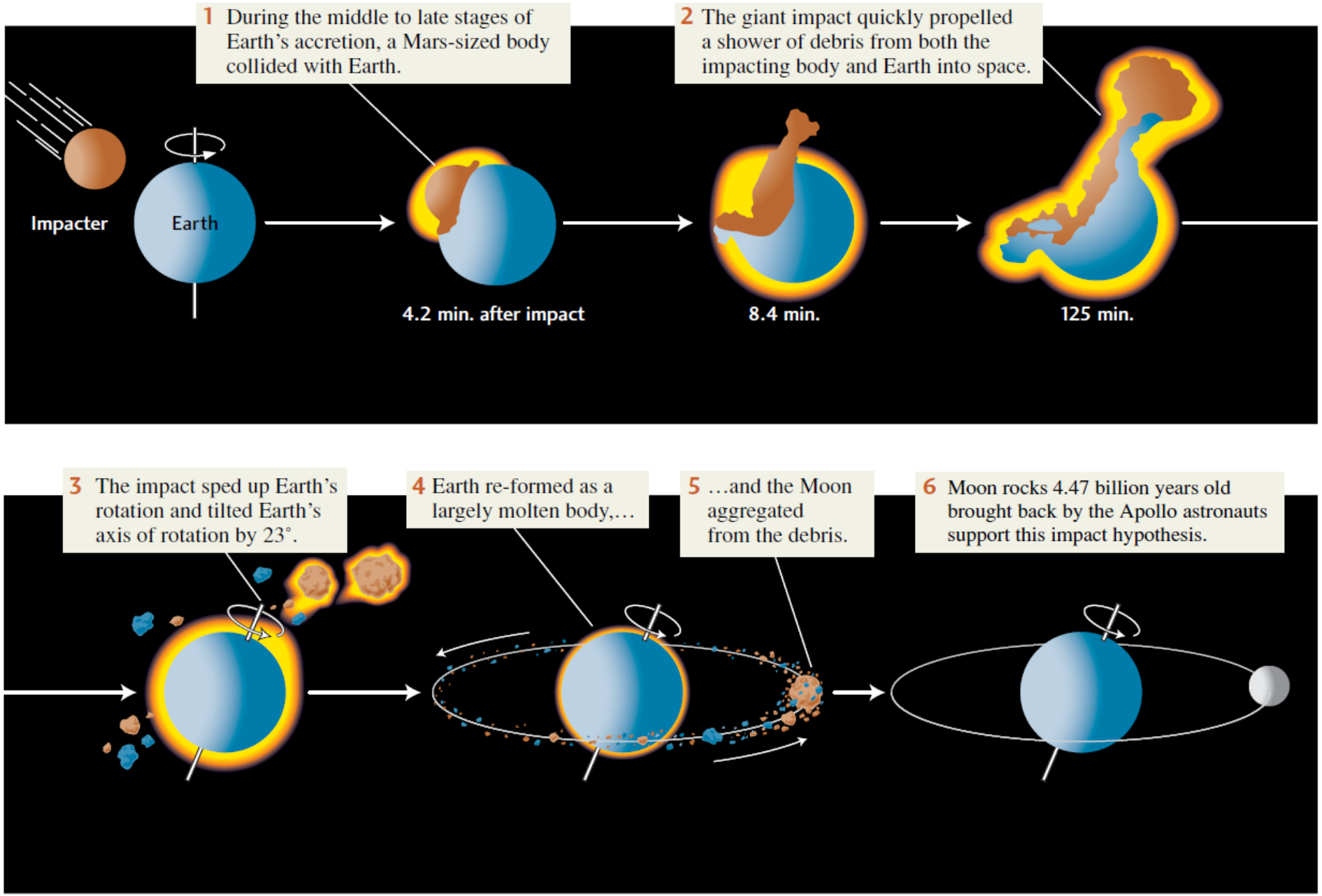


FIGURE 9.4 ■ Computer simulation of the impact of a Mars-sized body on Earth. [*Solid-Earth Sciences and Society.* Washington, D.C.: National Research Council, 1993.]

Differentiation of the Earth

Due to Giant Impact and internal heating (radioactivity) it is estimated that about 70% of the Earth got molten after its formation

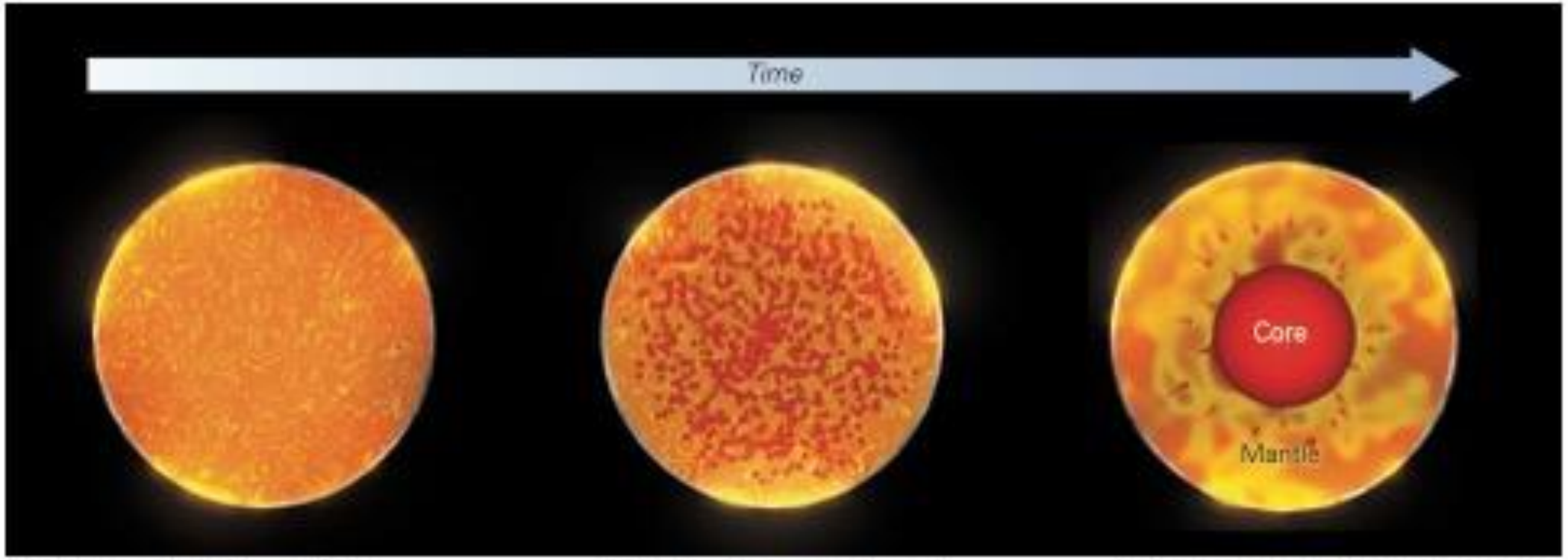
Differentiation produced core and mantle

Further melting and differentiation of the Mantle produced the Crust

The Crust also formed very early as we have rocks in the crust as old as ~4.4 by

Differentiation of the Earth

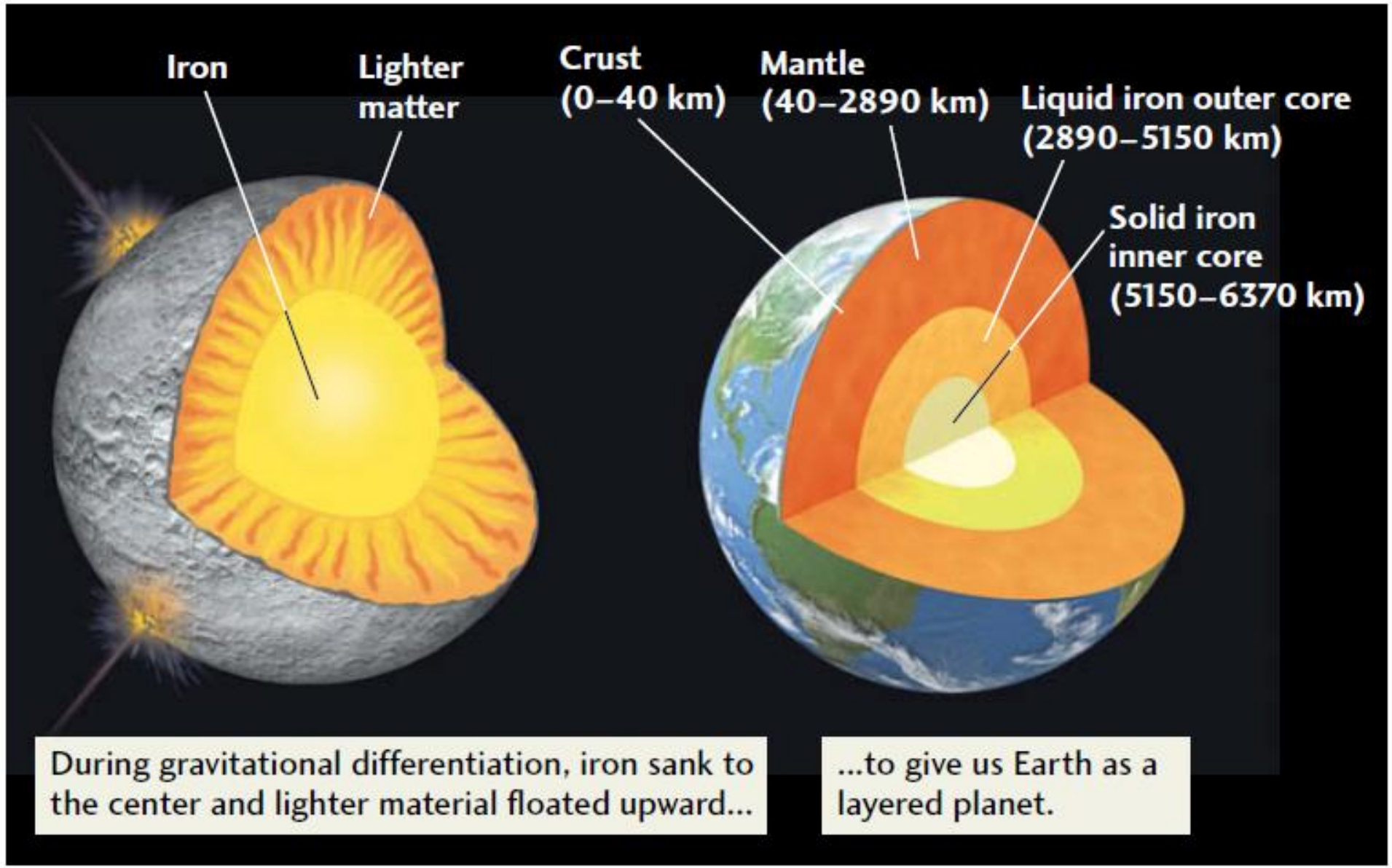
FIGURE 1.16 Differentiation of the Earth's interior.



(a) Early on, the Earth was fairly homogeneous inside.

(b) When the temperature got hot enough, iron began to melt.

(c) The iron accumulated at the center of the planet to form a metallic core.


Iron
Lighter matter
Crust (0–40 km)
Mantle (40–2890 km)
Liquid iron outer core (2890–5150 km)
Solid iron inner core (5150–6370 km)
During gravitational differentiation, iron sank to the center and lighter material floated upward...
...to give us Earth as a layered planet.

Abundance of elements in different parts of the Earth

Chemical Composition of Earth's Major Layers

By the mid-twentieth century, geologists had discovered al
of Earth's major layers—crust, mantle, outer core, and inne
core—plus a number of more subtle features in its interio
They found, for example, that the mantle itself is layere
into an *upper mantle* and a *lower mantle*, separated by a *tran
sition zone* where the rock density increases in a series o
steps. These density steps are not caused by changes in th
rock's chemical composition, but rather by changes in th
compactness of its constituent minerals due to the increas
ing pressure with depth. The two largest density jumps i
the transition zone are located at depths of about 410 km
and 660 km, but they are smaller than the density increase
across the Moho and core-mantle boundaries, which *ar*
due to changes in chemical composition (Figure 1.12).

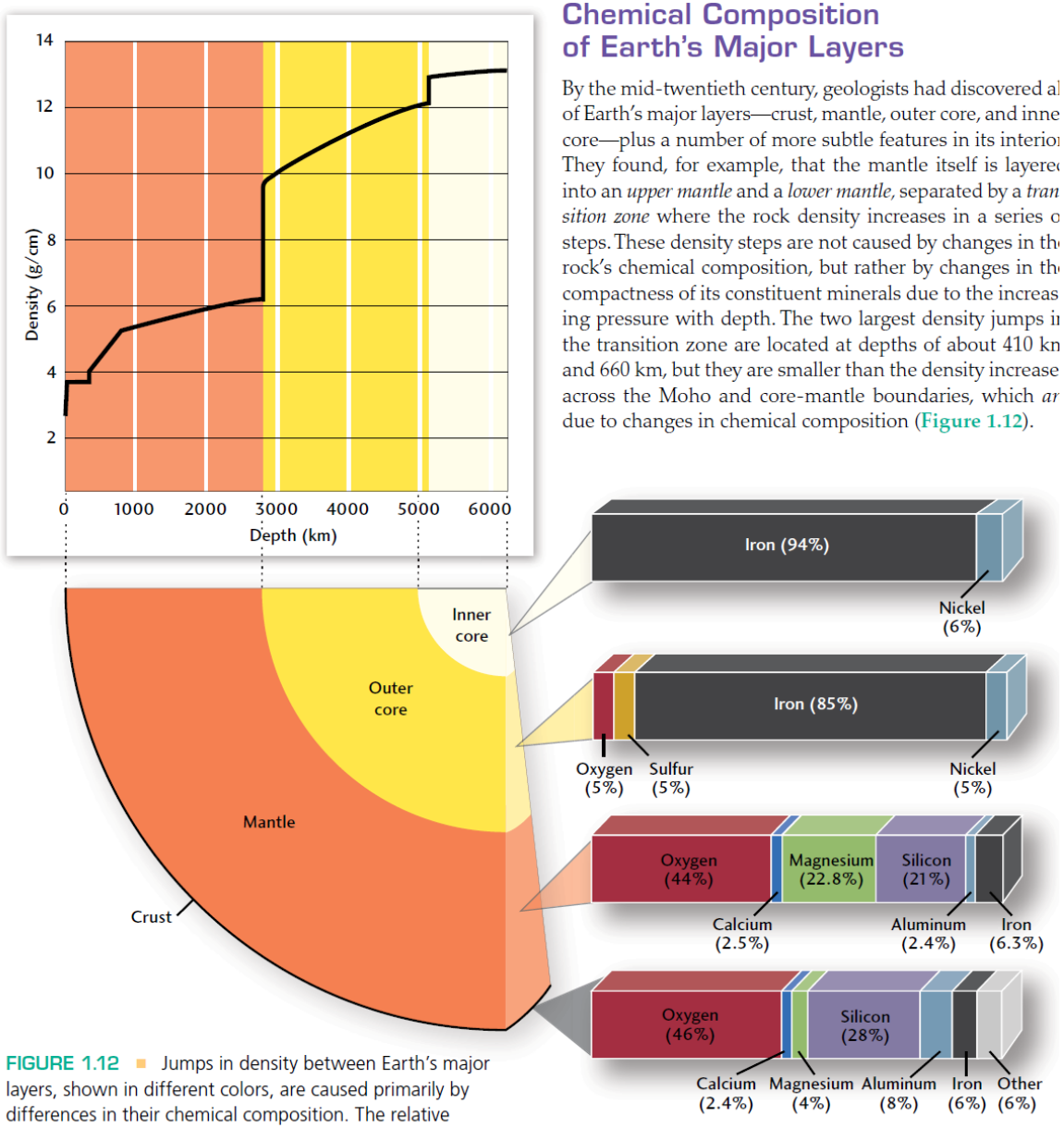
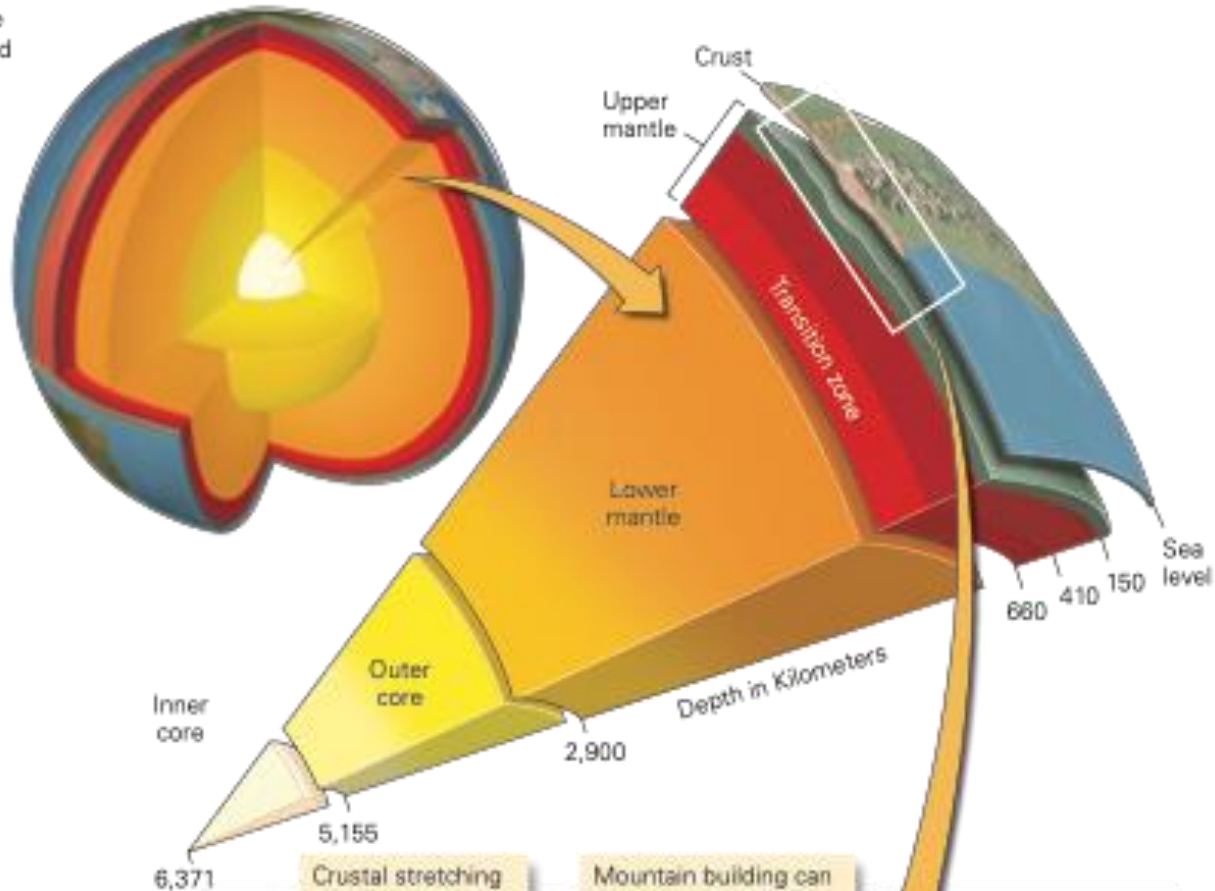


FIGURE 1.12 ■ Jumps in density between Earth's major layers, shown in different colors, are caused primarily by differences in their chemical composition. The relative amounts of the main elements are depicted in the bars on the right.

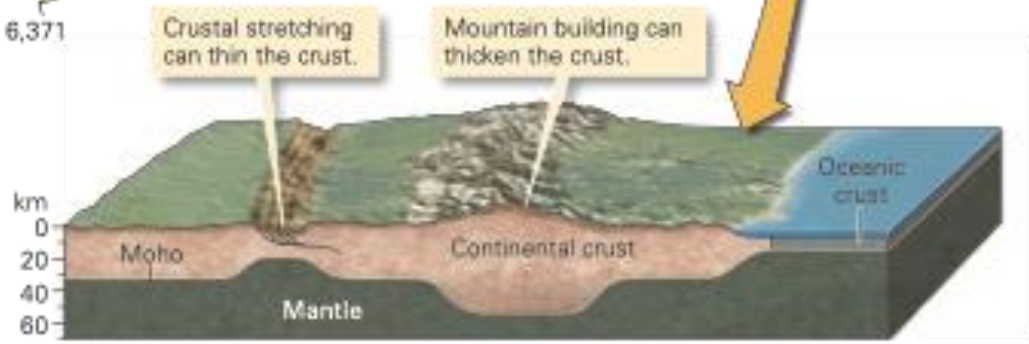
Earth's Interior

FIGURE 2.14 A modern view of the Earth's interior layers.

(a) By studying earthquake waves, geologists produced a refined image of the Earth's interior, in which the mantle and core are subdivided.



(b) There are two basic types of crust. Oceanic crust is thinner and consists of basalt and gabbro. Continental crust varies in thickness and rock type.



The Earth as an interacting system

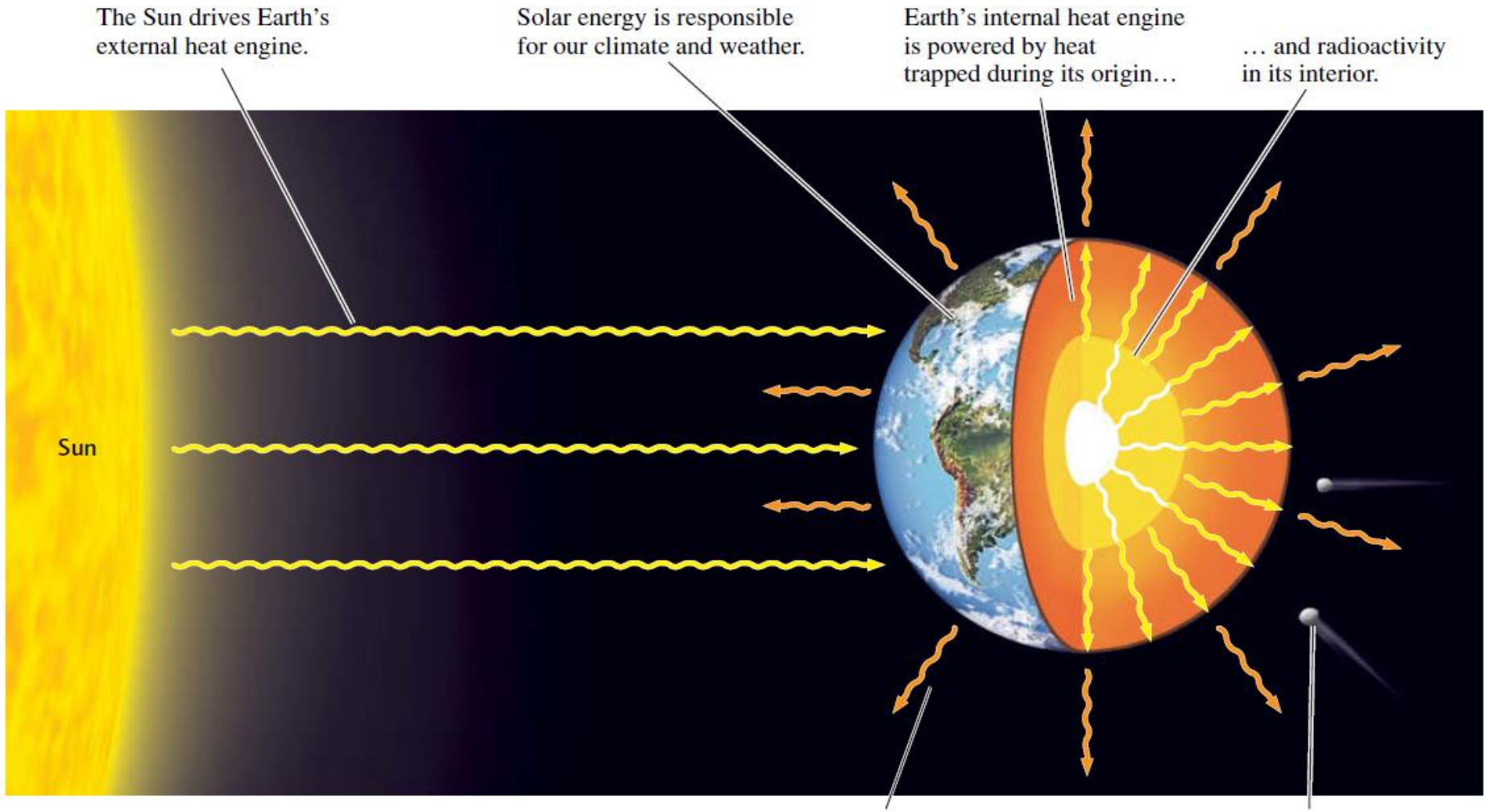


FIGURE 1.13 ■ The Earth system is an open system that exchanges energy and mass with its surroundings.

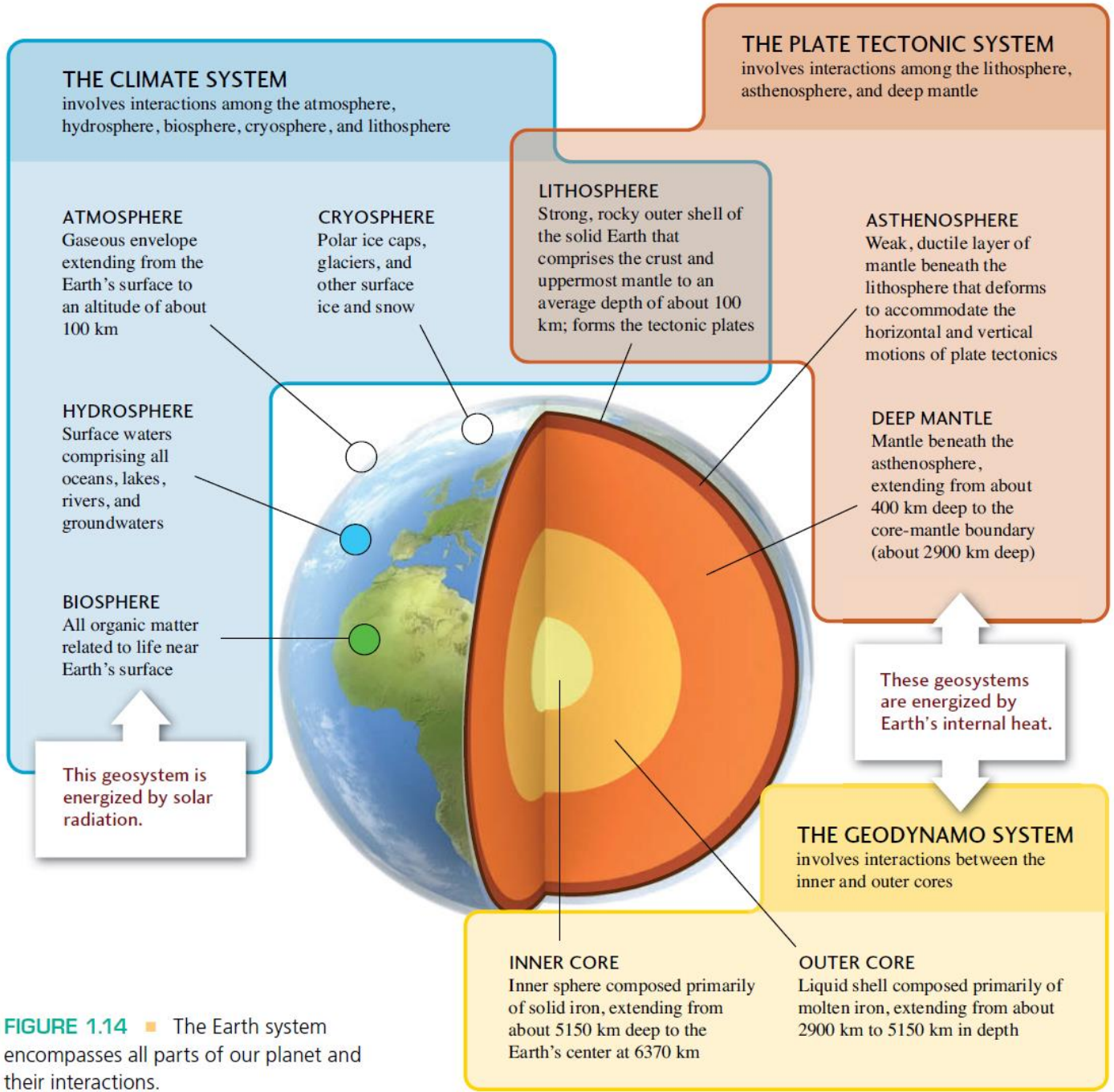


FIGURE 1.14 ■ The Earth system encompasses all parts of our planet and their interactions.