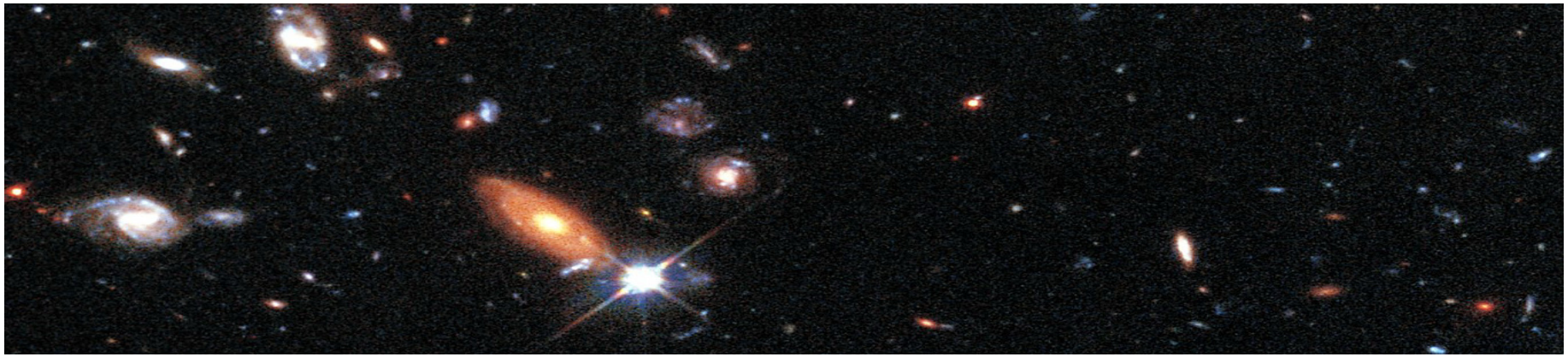
Cosmology

- Conscious thought distinguishes humans.
  - Developed across 1,000s of generations.
  - Lends us curiosity, insight, and the ability to learn.
- As a result, we seek to explain our surroundings.
  - Where do we come from?
  - Where do we fit in the Universe?
  - Why are we here?

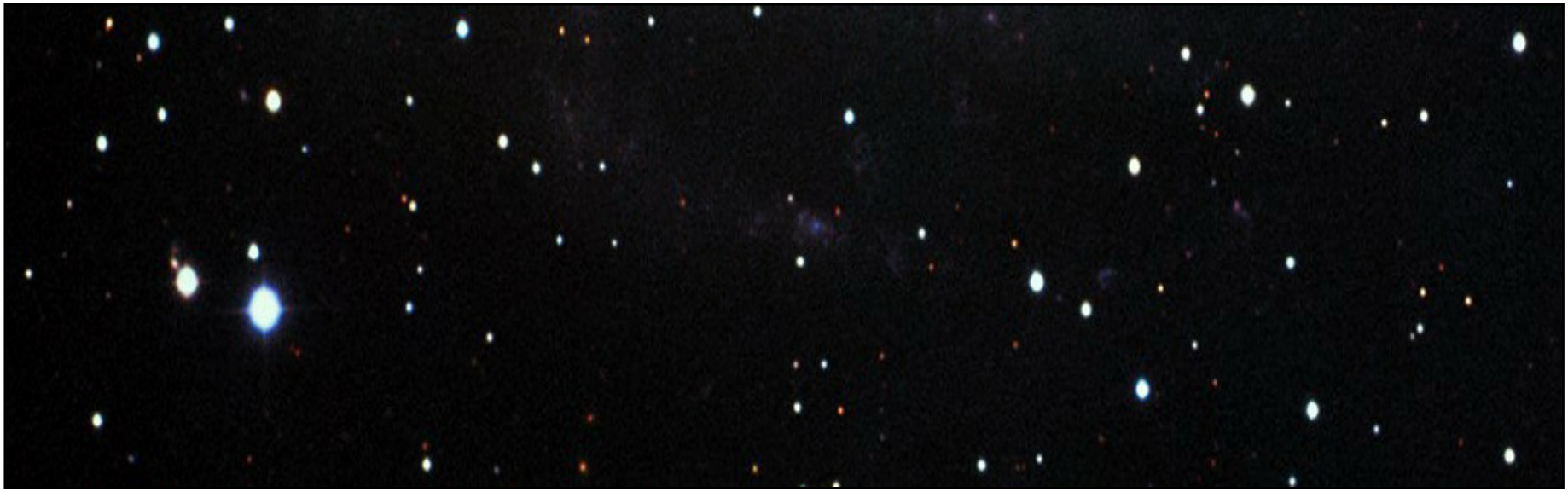
Cosmology

- Study of the structure and history of the Universe.
- Cosmology is a complicated science.
  - Requires thinking in unfamiliar scales of space and time.
    - Spatial scales.
      - Attometers (10^{-21} meters), to
      - 10s of billions of light years (9.46^{22} meters +).
    - Temporal scales.
      - Attoseconds (10^{-21} seconds), to
      - 10s of billions of years (3.15^{17} seconds +).



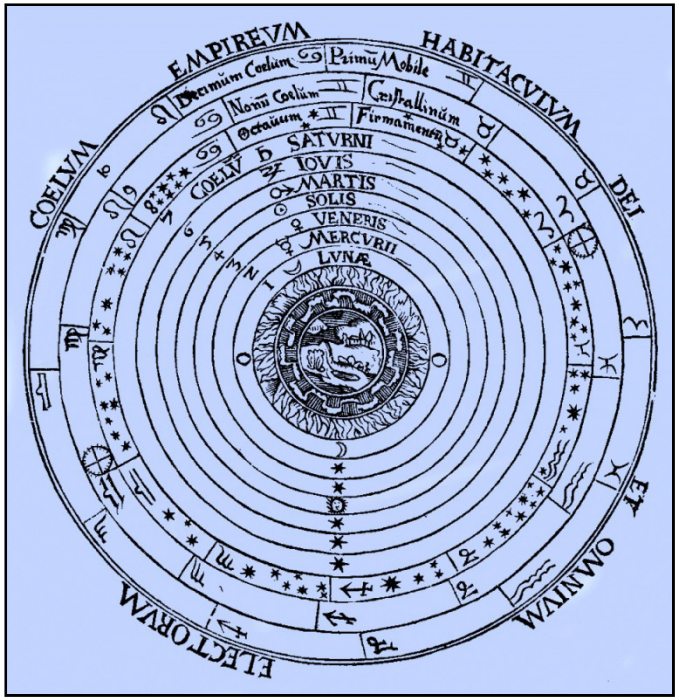
Earth's Changing Place

- 3,000 years ago, humans knew the heavens well.
  - They knew that stars were fixed relative to other stars.
  - They knew that stars moved predictably across the sky.
  - They saw retrograde motion separating planets from stars.
  - They did not think of Earth as a planet, however.
- Movement in the heavens was attributed to deities.



An Evolving Image of Earth

- The ancients thought the Universe was geocentric.
  - Heavenly bodies circle around a motionless central Earth.
  - "Proven" by Ptolemy (100–170 B.C.), the idea was wrong.
  - The idea held as religious dogma for 1,400 years.
- A heliocentric (sun-centered) universe was proposed by the Greeks ~ 250 B.C.



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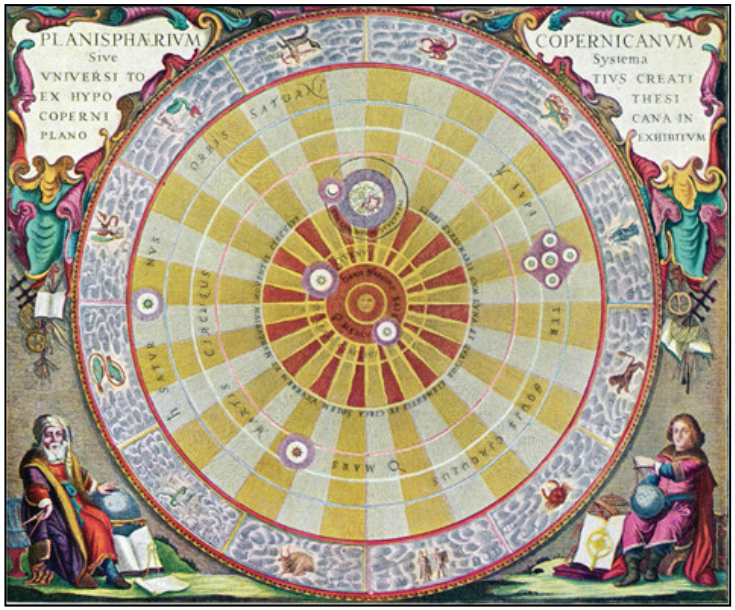
The Renaissance

- Rebirth of rational thought in 15th century Europe.
- Spawned a new age of scientific discovery.
  - Copernicus – Published evidence for heliocentricity.
  - Kepler – His elliptical planetary orbits refuted Ptolemy.
  - Galileo – Observed moons orbiting Jupiter.
  - Newton – Planet motion explained by his Theory of Gravity.
- Natural laws governed natural events.
- Geocentricity faded away.



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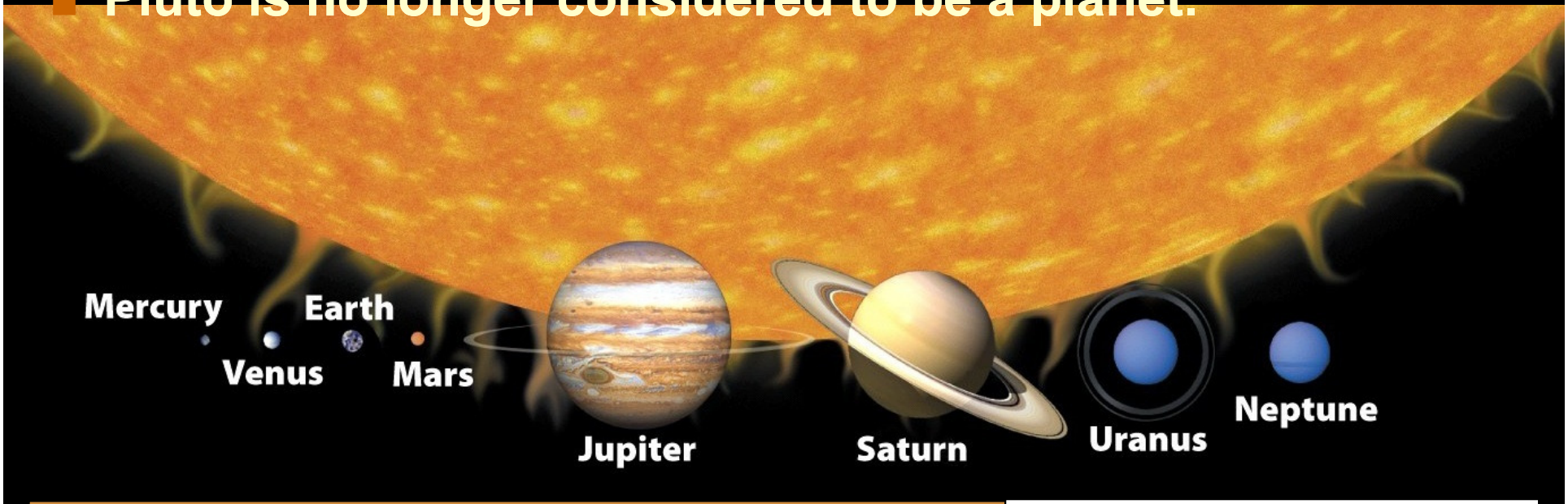
The Solar System

- Solar system: A sun, planets, moons and other objects.
- Earth shares the solar system with 7 planets. A planet…
  - Is a large solid body orbiting a star (the Sun).
  - Has a nearly spherical shape.
  - Has cleared it's neighborhood of other objects.
- Moon – A solid body locked in orbit around a planet.
- The solar system also includes asteroids and comets.

The Planets

- Two groups of planets occur in the solar system.
  - Terrestrial (Earthlike) Small, dense, rocky planets.
    - Mercury, Venus, Earth, and Mars.
  - Jovian (Jupiter-like) Large, low density, gas-giant planets.
    - Jupiter, Saturn, Uranus, and Neptune.
- Pluto is no longer considered to be a planet.



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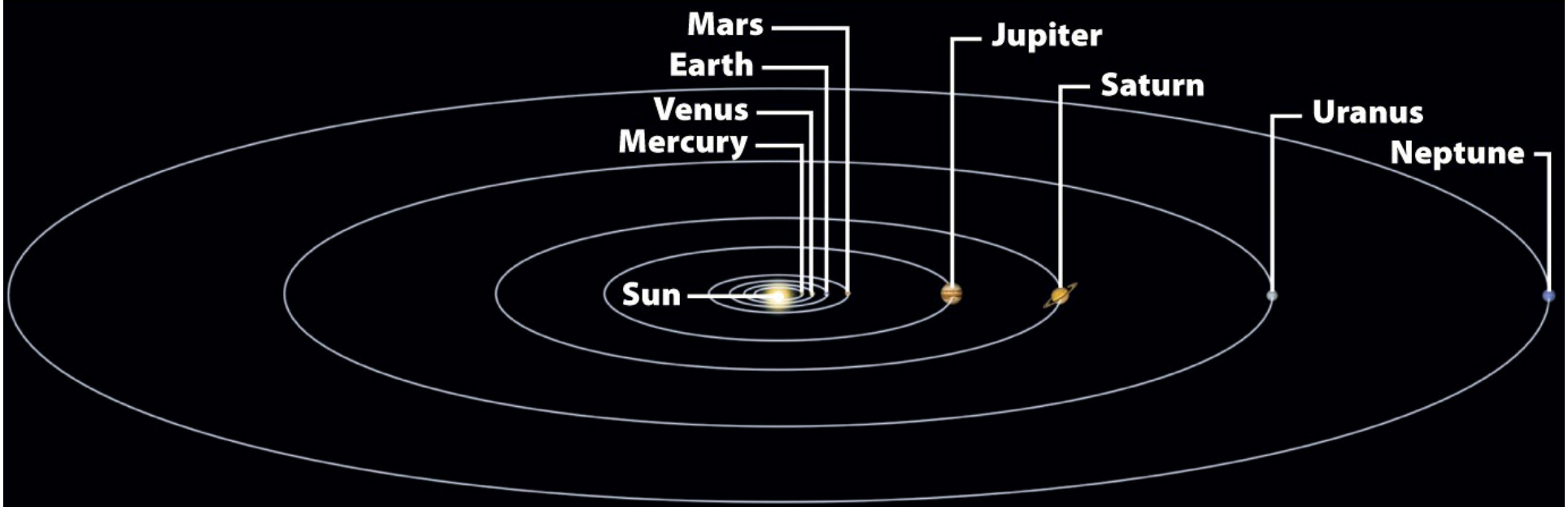
The Solar System

- The Terrestrial planets are the 4 most interior.
- The Jovian planets occupy the 4 outermost orbits.
- The asteroid belt lies between Mars and Jupiter.
- Planet orbital planes lie within 3º of the Sun's equator.



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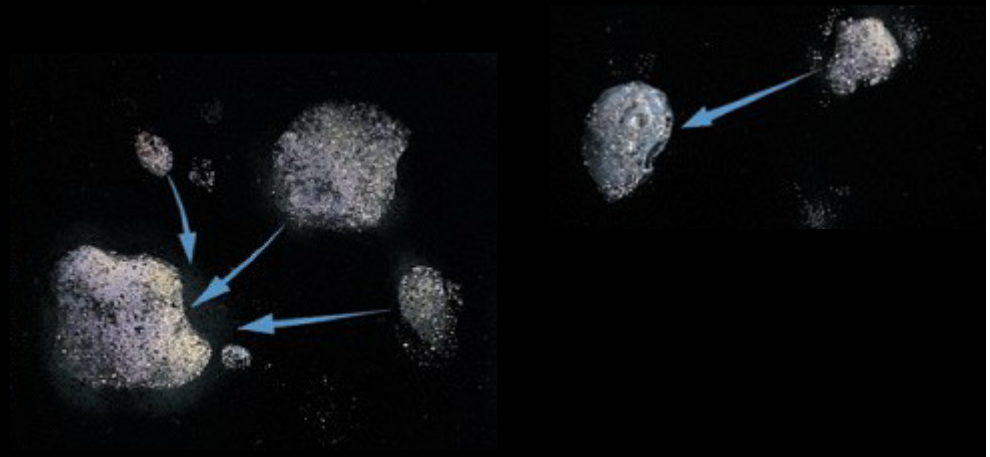
Solar System Formation

- The Nebular Theory.
- A 3rd, 4th or nth generation nebula forms ~4.56 Ga.
  - Hydrogen and Helium left over from the big bang.
  - Heavier elements produced by stellar nucleosynthesis.
- This material coalesces into an accretion disc.

Solar System Formation

- The ball at the center grows dense and hot.
- Fusion reactions begin; the Sun is born.
- Dust in the rings condenses into particles.

- Particles coalesce to form planetesimals.



Solar System Formation

- Planetesimals accumulate into a larger mass.
- An irregularly-shaped proto-Earth develops.
  - The interior heats up and becomes soft.

  - Gravity shapes the Earth into a sphere.

  - The interior differentiates into a-Fe core and stony mantle.

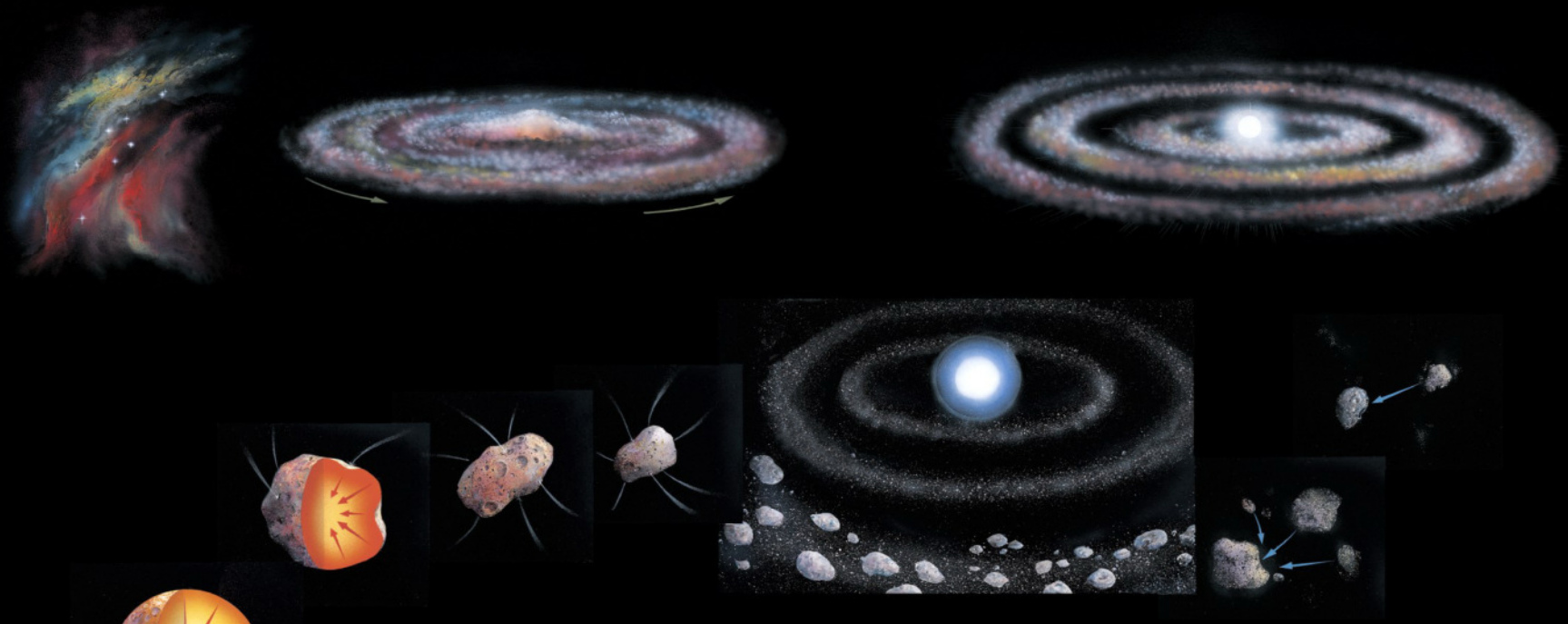
Solar System Formation

- Soon, a small planetoid collides with Earth.
- Debris forms a ring around the Earth.
- The debris coalesces and forms the Moon.

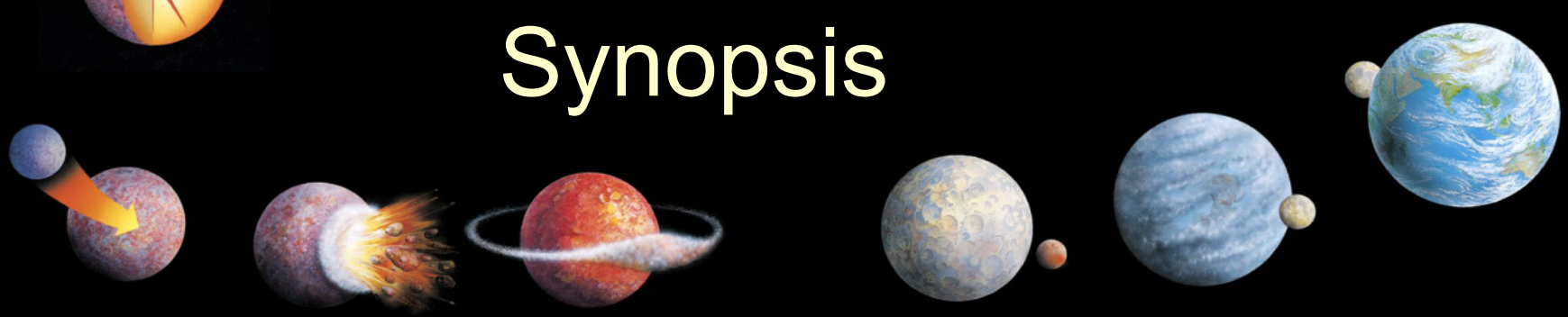
Solar System Formation

- The atmosphere develops from volcanic gases.
- When the Earth becomes cool enough.
  - Moisture condenses and accumulates.
  - Comet bombardment adds more water.
  - The oceans are born.

Solar System Formation



Synopsis



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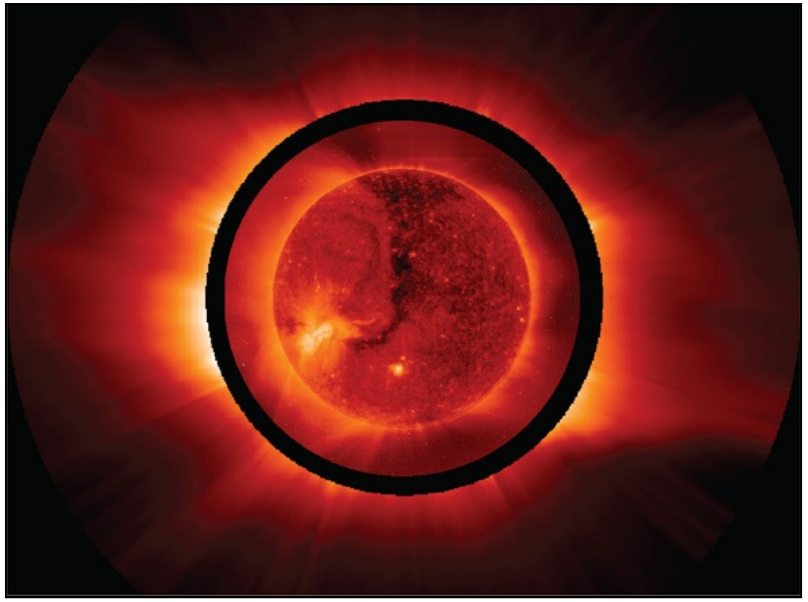
Earth

- What would solar system visitors notice about Earth?
  - A magnetic field.
  - An atmosphere.
  - Surface features.
    - Continents.
    - Oceans.
    - Polar ice caps.
    - Evidence of humanity?

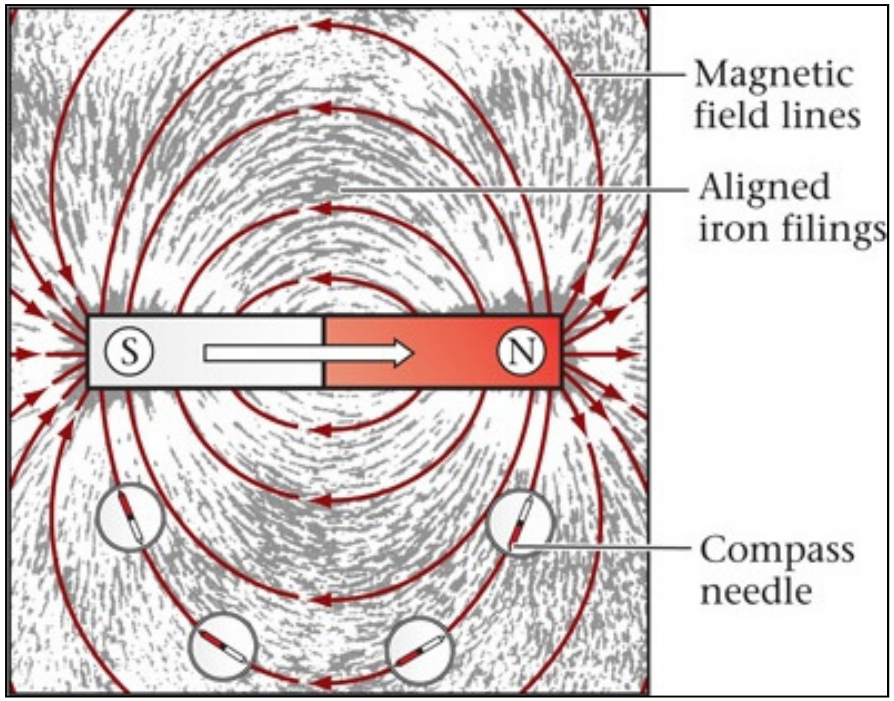
The Celestial Neighborhood

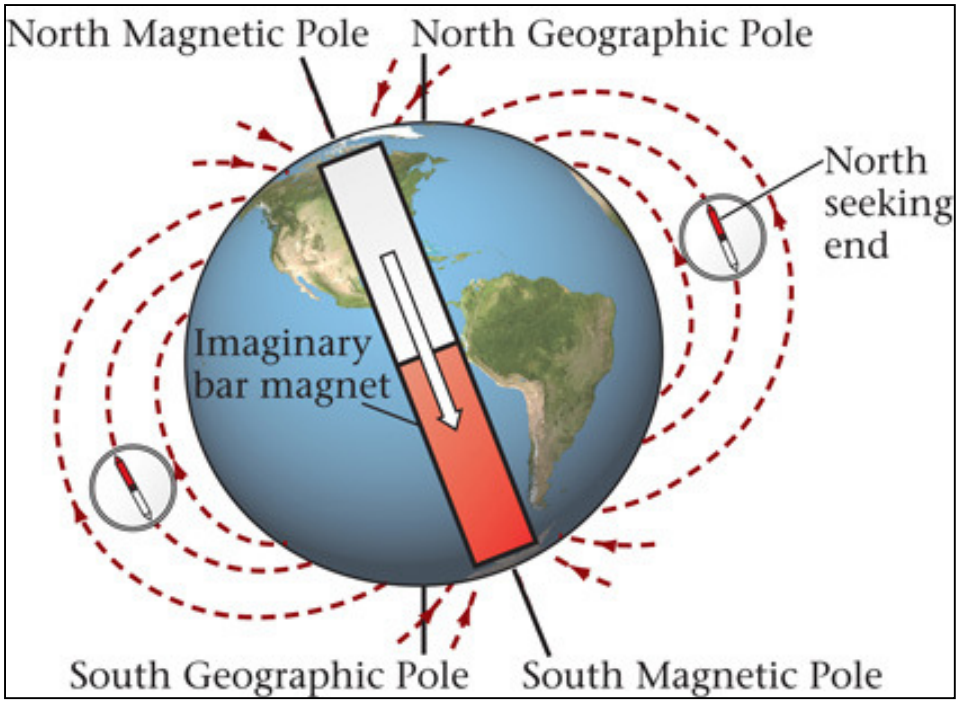
- Interstellar space is a vacuum with scarce matter.
- Matter greatly increases approaching the Sun.
- The Sun ejects matter into space as the Solar Wind.
- Solar Wind…
  - Magnetically charged particles.
  - Stream outward in all directions.
  - Consists of…
    - Protons (+ charge).
    - Electrons (– charge).
- A small percentage of the Solar Wind hits Earth.



Magnetic Field

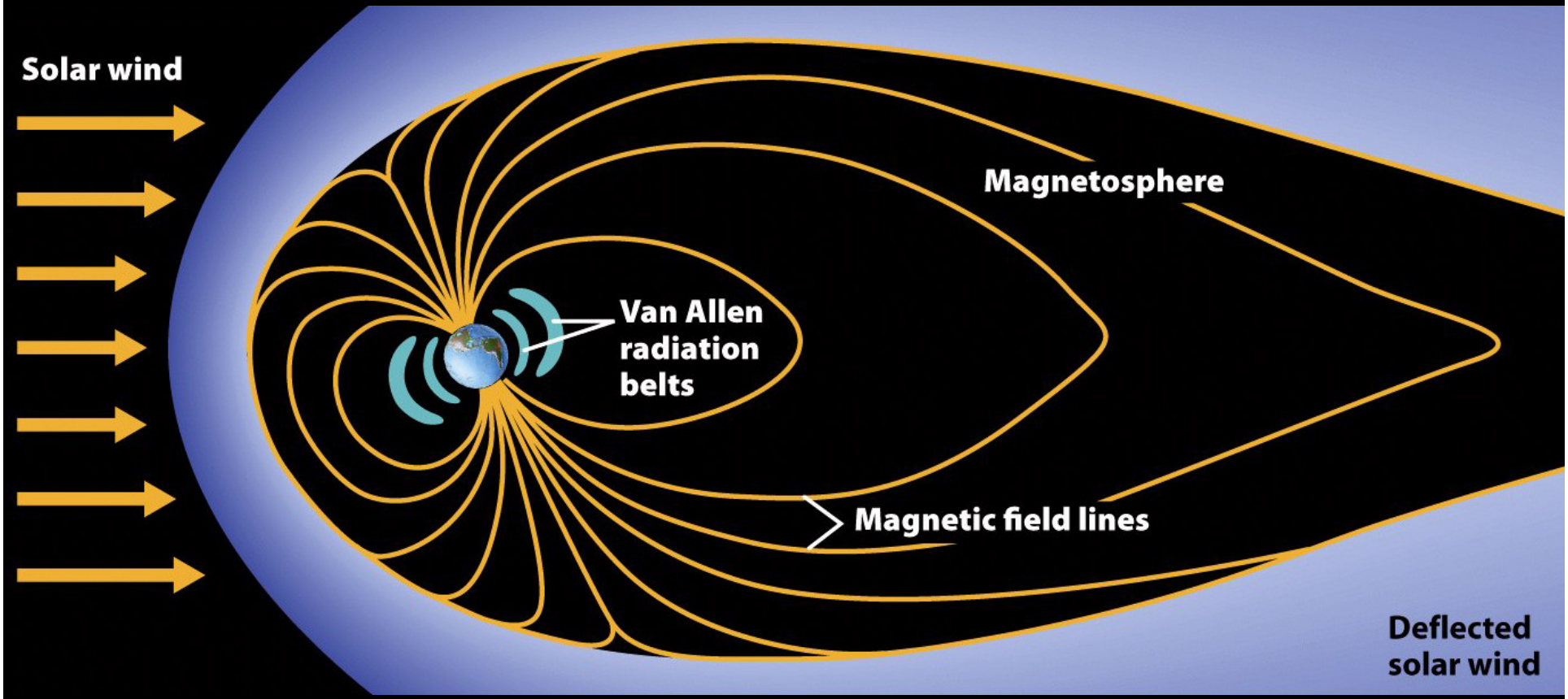
- Like a bar magnet, Earth has a dipolar magnetic field.
- Magnetic field lines flow from N to S and…
  - Extend into space and weaken with distance from Earth.
  - Create a shield around Earth (the magnetosphere).





The Van Allen Belts

- The solar wind is deflected by the magnetosphere.
- Near Earth, the stronger magnetic field forms the Van Allen belts, which arrest deadly cosmic radiation.



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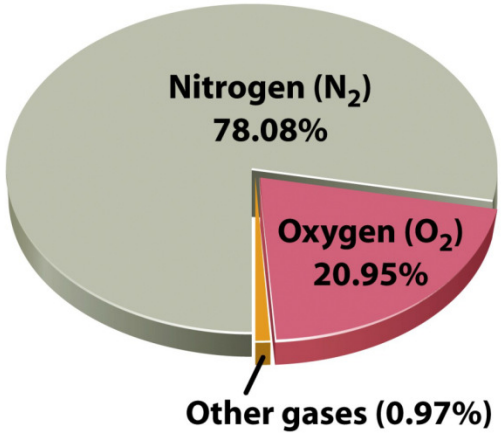
Aurorae

- Some ions escape Van Allen belts.
  - Pulled to the magnetic poles, the ions generate light.
- Spectacular aurora follow solar flares.
  - Aurora borealis – Northern lights.
  - Aurora australis – Southern lights.

The Atmosphere

- Earth, with an atmosphere, is unique among the planets
- Densest at sea-level, the atmosphere thins upward.
- The atmosphere is mostly nitrogen (N_2).
- Oxygen was absent from the atmosphere before 2.5 Ga.



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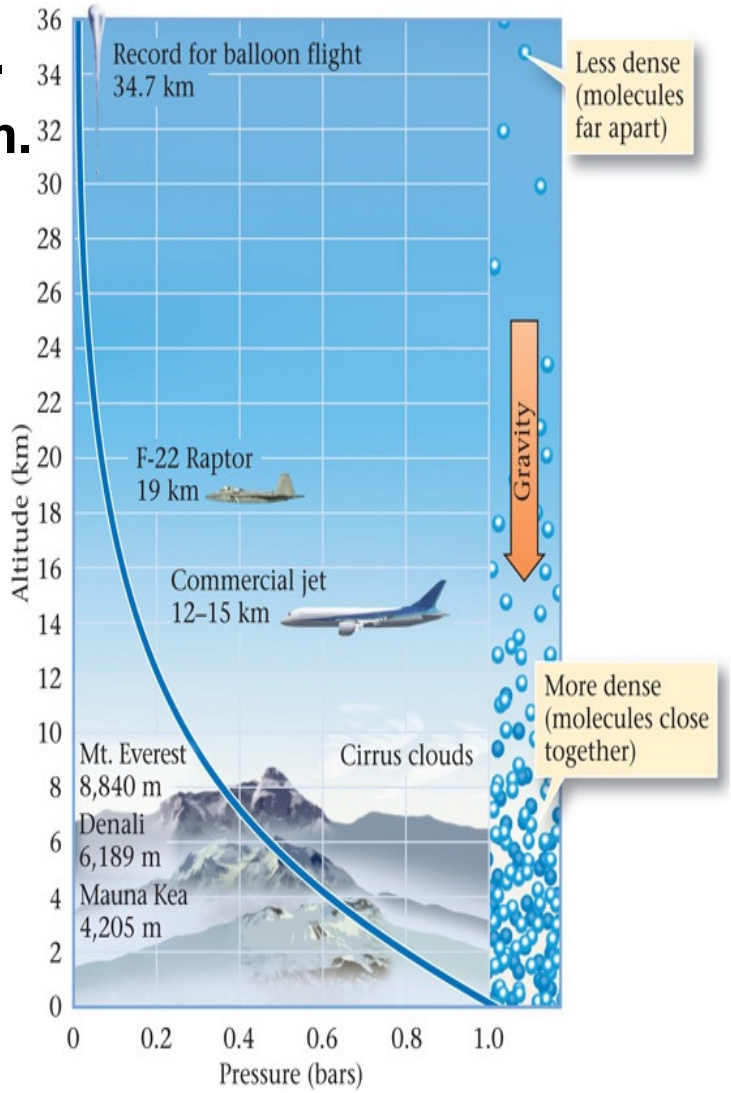
The Atmosphere

- **99% of atmosphere is below 50 km.**
  - **The rest (1%) is between 50 and 500 km.**
- **Sea-level atmospheric P = 14.7 psi.**



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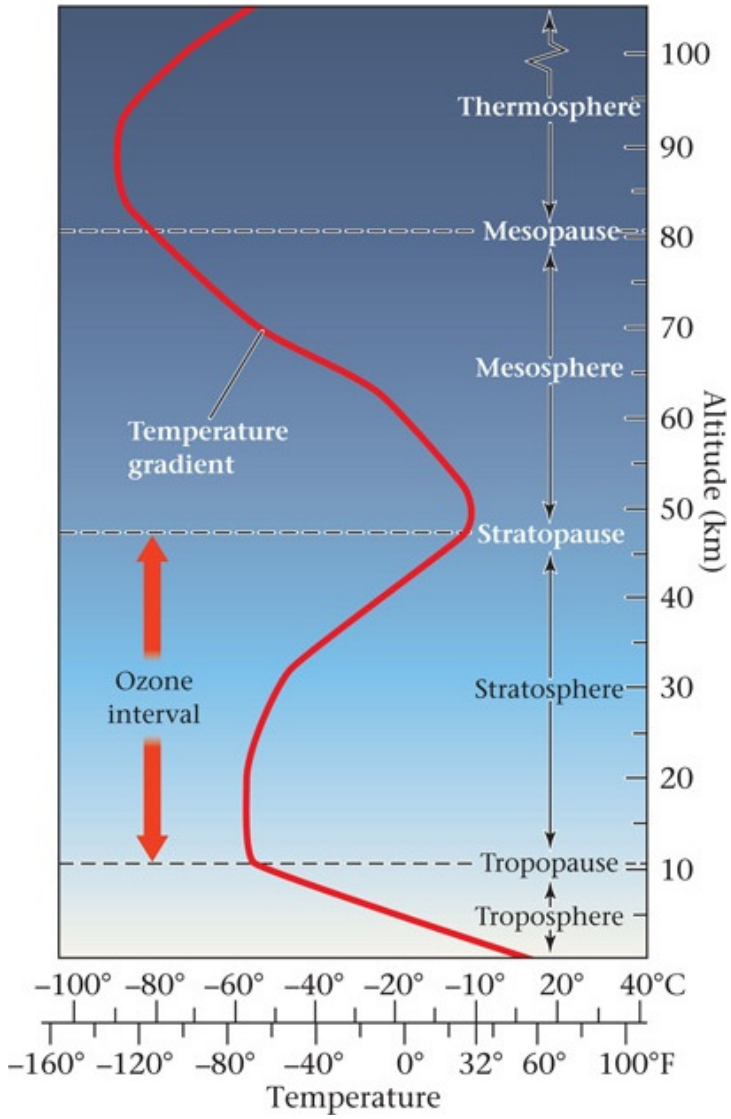
The Atmosphere

- **The atmosphere is layered.**
  - **Troposphere (0–11 km).**
    - **Mixing layer.**
    - **Weather is limited to this layer.**
  - **Tropopause (11–12 km).**
  - **Stratosphere (12–47 km).**
  - **Mesosphere (47– 81 km).**
  - **Thermosphere (> 81 km).**
  - **Boundaries between layers are termed “pauses.”**



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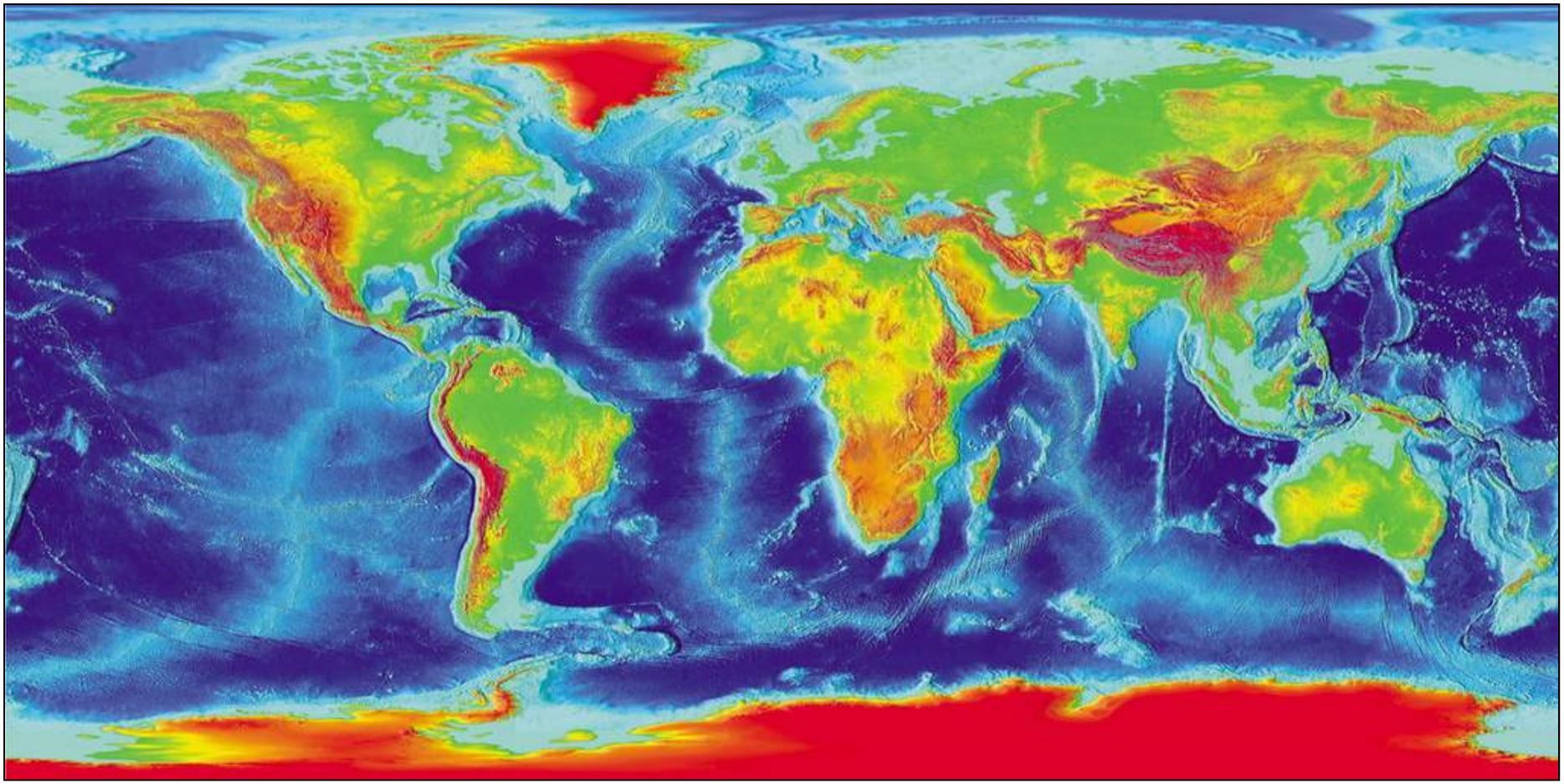
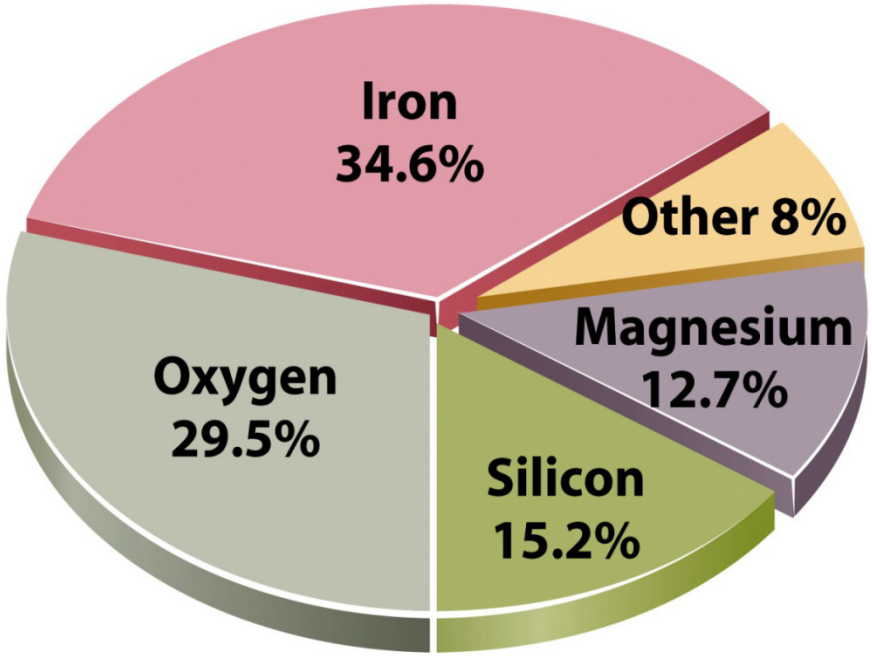
Surface Features

- Earth's surface: continents are high; oceans are low.
- Due to the differing buoyancy of each type of crust.



Elemental Composition

- 90% percent of Earth is comprised of 4 elements.
  - Iron (Fe) – 35%
  - Oxygen (O) – 30%
  - Silicon (Si) – 15%
  - Magnesium (Mg) – 10%
- The remaining elements?
  - Form 10% of Earth.



Earth Materials

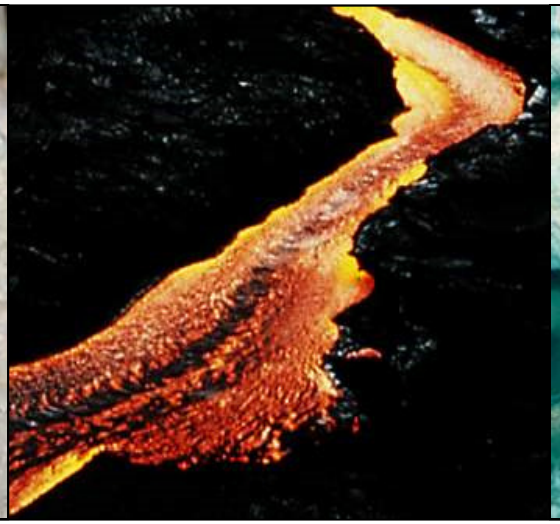
- Organic chemicals – Carbon containing compounds.
  - Biological remains (wood, peat, lignite, coal, and oil).
  - Geologically rare (decompose in contact with oxygen).
- Minerals – Inorganic crystalline solids.
  - Comprise rocks and, hence, most of the earth.
  - Most minerals on Earth are silicates (based on Si and O).

Earth Materials

- Glasses – Noncrystalline mineral-like matter.
- Rocks – Aggregates of minerals. There are many types.
  - Igneous – Cooled from a liquid (melt)
  - Sedimentary – Debris cemented from preexisting rock.
  - Metamorphic – Rock altered by pressure and temperature.
- Sediments – Accumulations of loose mineral grains.

Earth Materials

- Metals – Solids made of metallic elements.
- Melts – Rocks that have been heated to a liquid.
  - Magma – Molten rock beneath the surface.
  - Lava – Molten rock at the surface.
- Volatiles – Materials that turn into gas at the surface.
  - H_2O, CO_2, CH_4, and SO_2,
  - Volatiles are released from volcanic eruption.

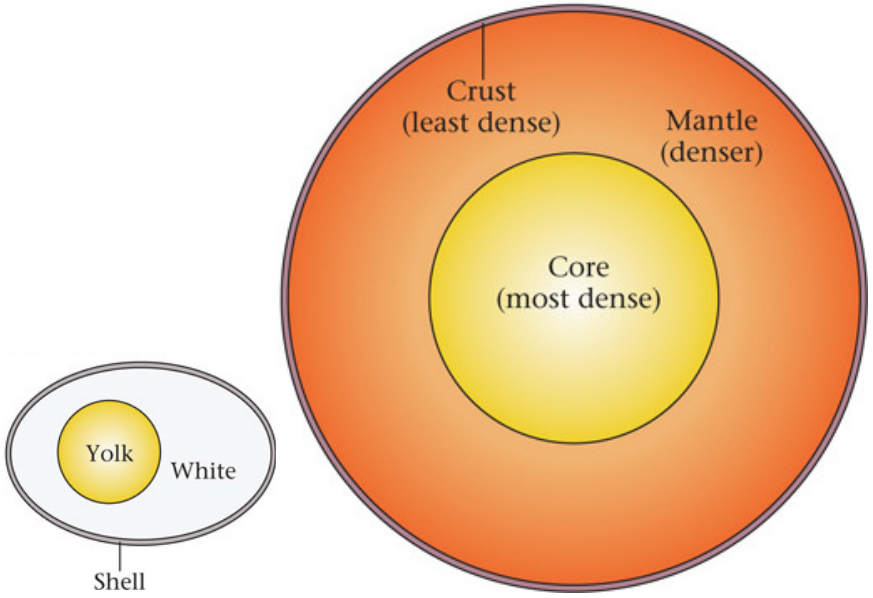


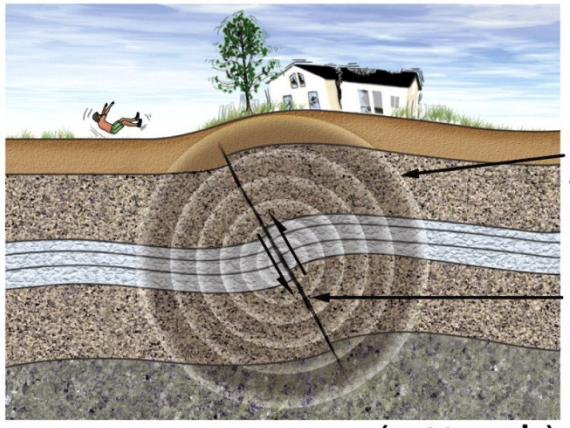
A Layered Earth

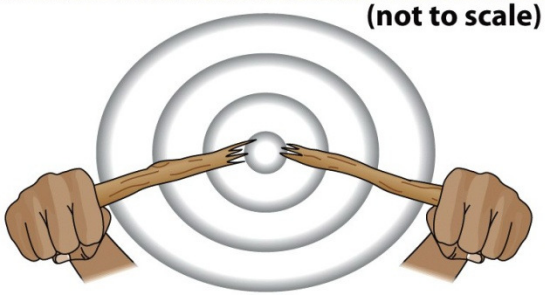
- We live on the thin outer skin of Earth.
- Early perceptions about Earth's interior were wrong.
  - Open caverns filled with magma, water, and air.
  - Furnaces and flames.
- We now know that Earth is comprised of layers.
  - The Crust.
  - The Mantle.
  - The Core.
    - Outer Core.
    - Inner Core.

A Layered Earth

- **Hard-boiled egg – Like an egg, Earth has 3 main layers.**
- **Earthquakes – Seismic waves pass through Earth.**
  - **Seismic waves permit analysis of the interior.**
    - **Wave velocity changes with density.**
    - **Velocity changes give depth of layer changes.**

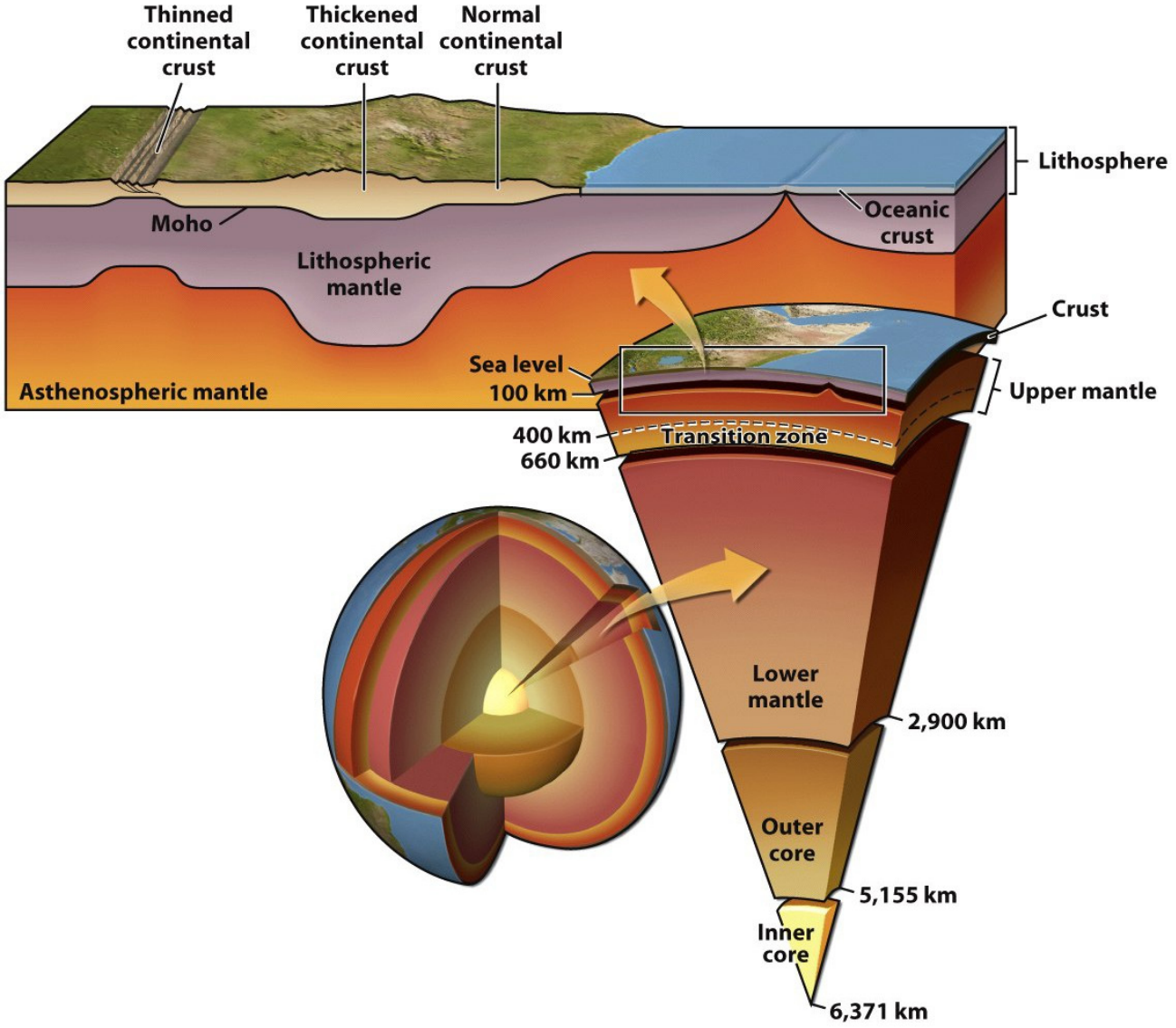






Earth's Interior Layers

- Crust
  - Continental
  - Oceanic
- Mantle
  - Upper
  - Lower
- Core
  - Outer - Liquid
  - Inner – Solid



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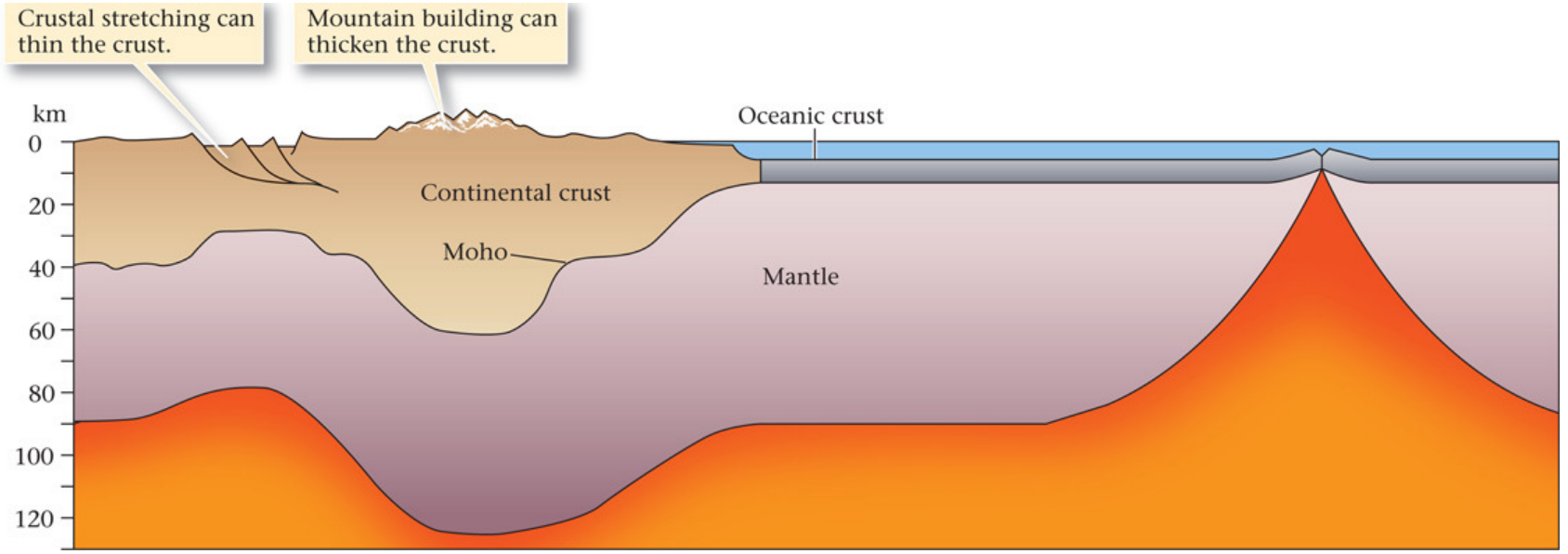
The Crust

- The outermost "skin" of Earth with variable thickness.
  - Thickest under mountain ranges (70 km - 40 miles).
  - Thinnest under mid-ocean ridges (3 km – 2 miles).
- The Mohorovicic discontinuity is the base of the crust.
  - The "Moho" separates the crust from the upper mantle.
  - Andrija Mohorovičić found this change in P-wave velocity.



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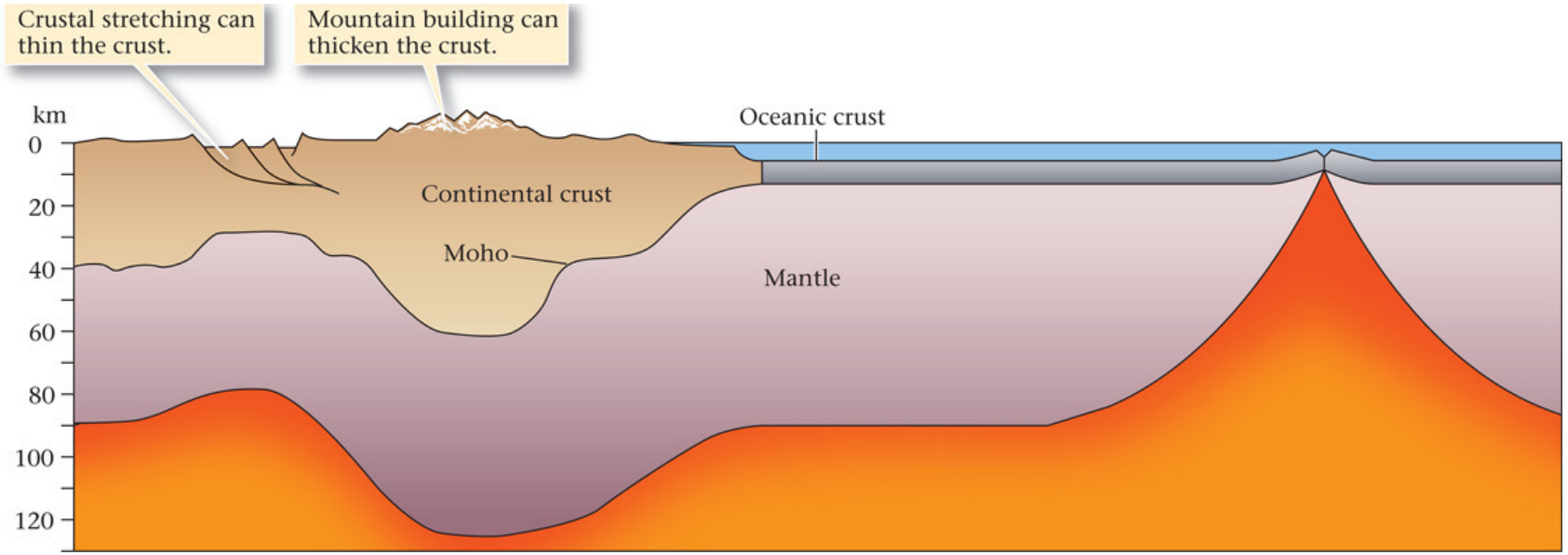
Two Types of Crust

- **Continental crust – Granitic, underlies the continents.**
  - **Average rock density about 2.7 g/cm^3.**
  - **Average thickness 35–40 km.**
- **Oceanic crust – Basaltic, underlies the ocean basins.**
  - **Density about 3.0 g/cm^3.**
  - **Avgerage thickness 7–10 km.**



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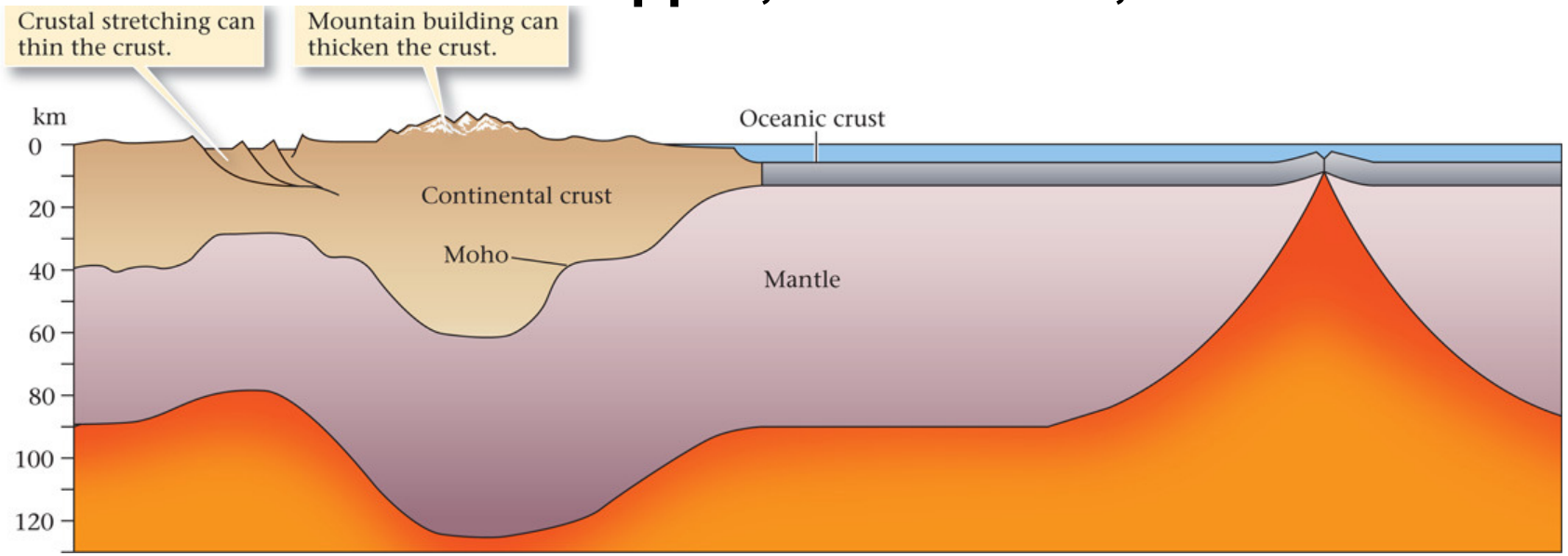
Earth's Mantle

- Solid rock layer between the crust and the core.
- 2,885 km thick, the mantle is 82% of Earth's volume.
- Mantle composition is the ultramafic rock peridotite.
- Below ~100–150 km, the rock is hot enough to flow.
- It convects: Hot mantle rises, cold mantle sinks.
- Three subdivisions: Upper, transitional, and lower.



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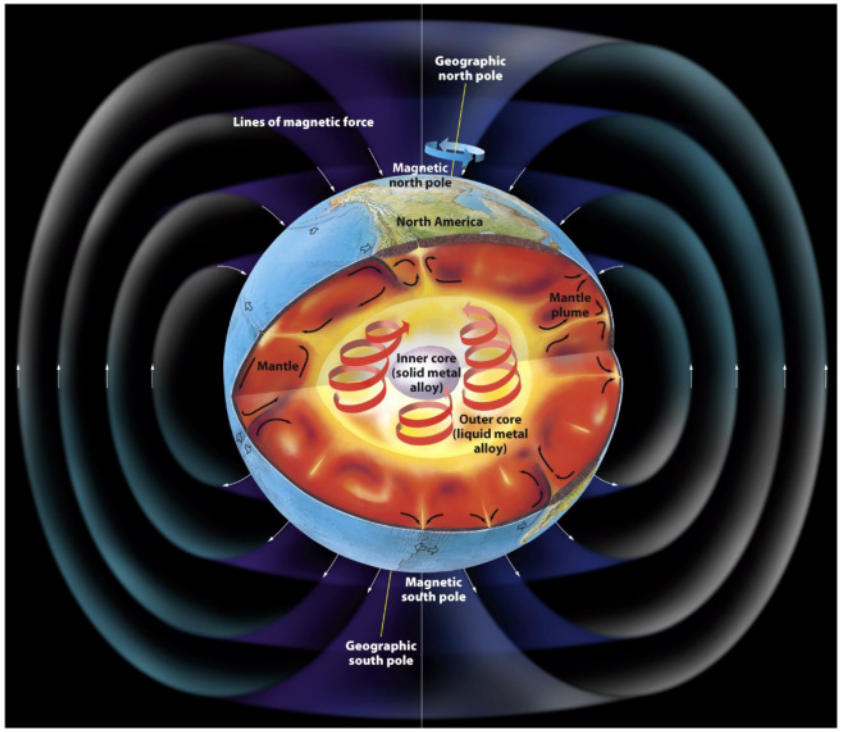
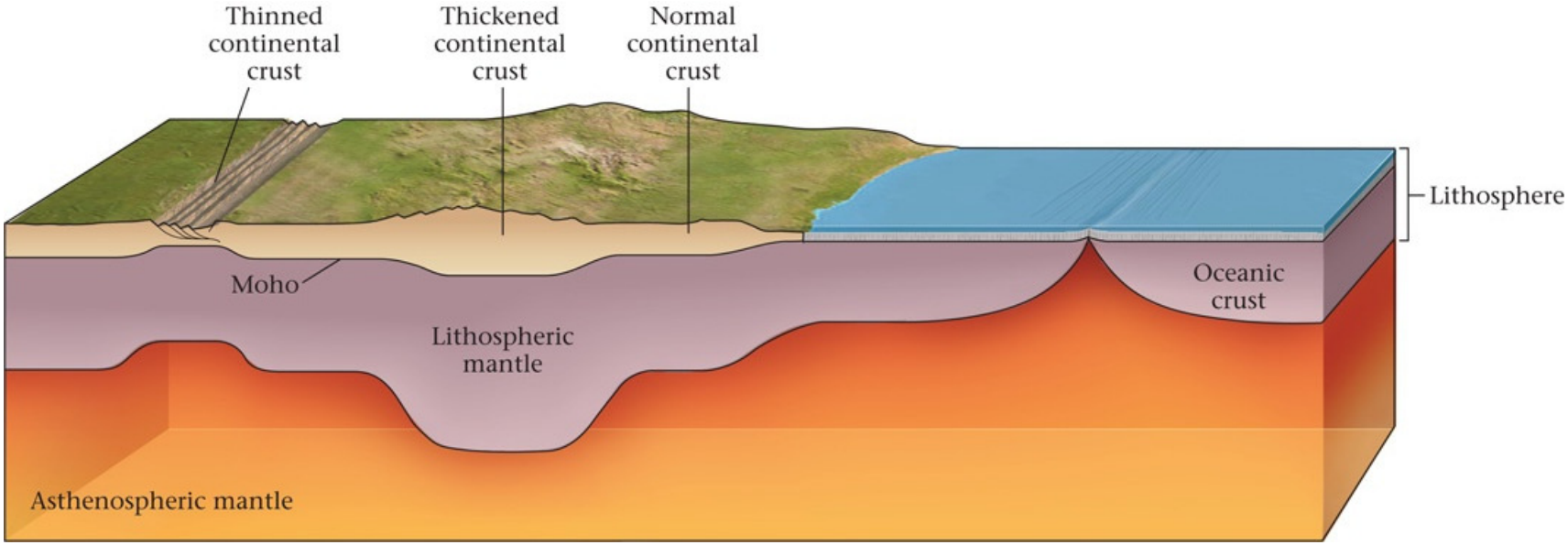
The Core

- An iron-rich sphere with a radius of 3,471 km.
- 2 components with differing seismic wave behavior.
  - Outer core
    - Liquid iron-nickel-sulfur
    - 2255 km thick.
    - Density – 10-12 g/cm^3
  - Inner core
    - Solid iron-nickel alloy.
    - Radius of 1220 km.
    - Density – 13 g/cm^3.
- Flow in the outer core generates the magnetic field.



Lithosphere–Asthenosphere

- **Lithosphere – The outermost 100–150 km of Earth.**
  - **Nonflowing, rigid material that moves as tectonic plates.**
  - **Made of 2 components: Crust and upper mantle.**
- **Asthenosphere – Upper mantle <u>below</u> lithosphere.**
  - **Shallow under oceans; deep under continents.**
  - **Flows as a soft solid.**



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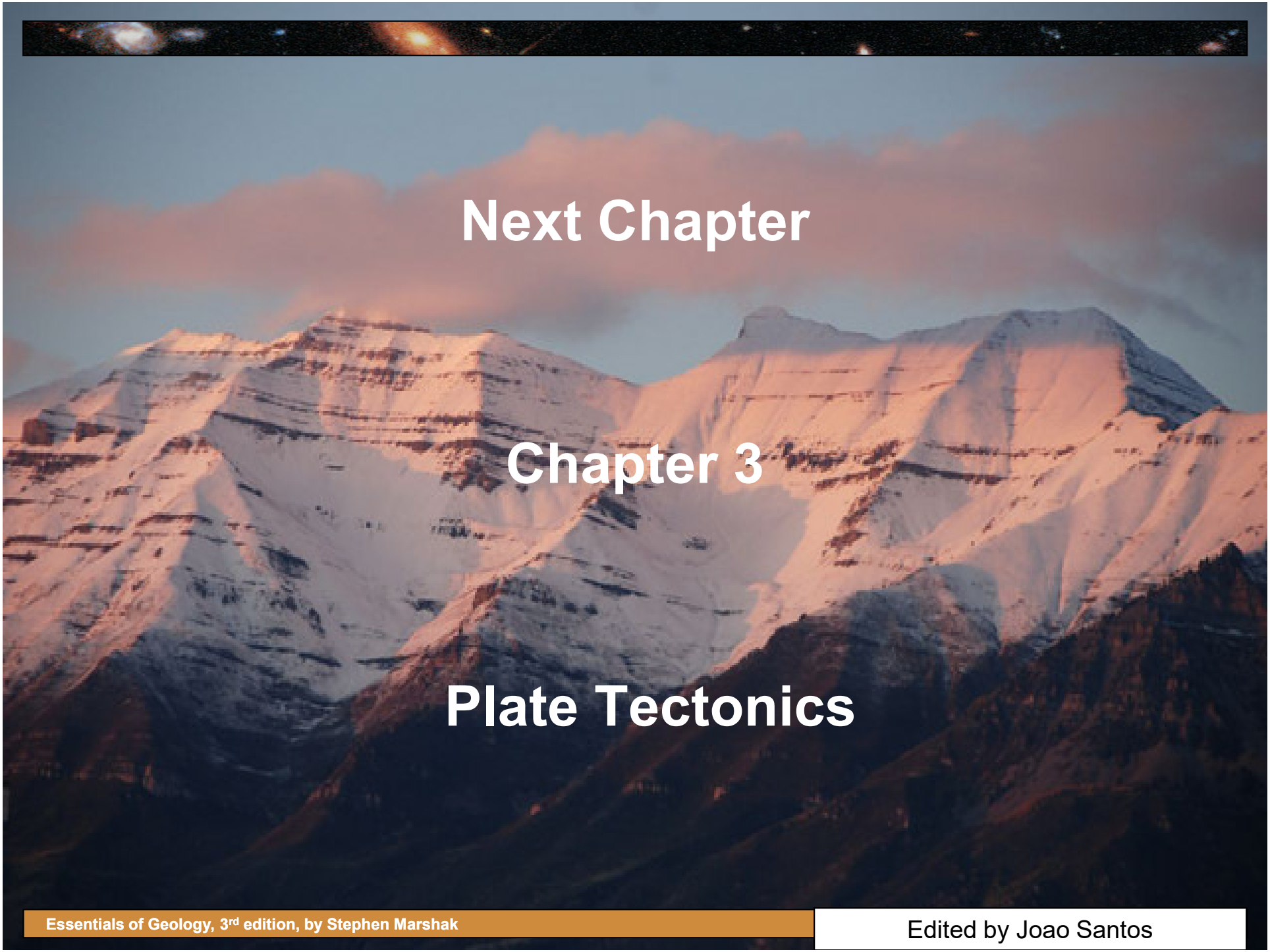

Next Chapter

Chapter 3

Plate Tectonics

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