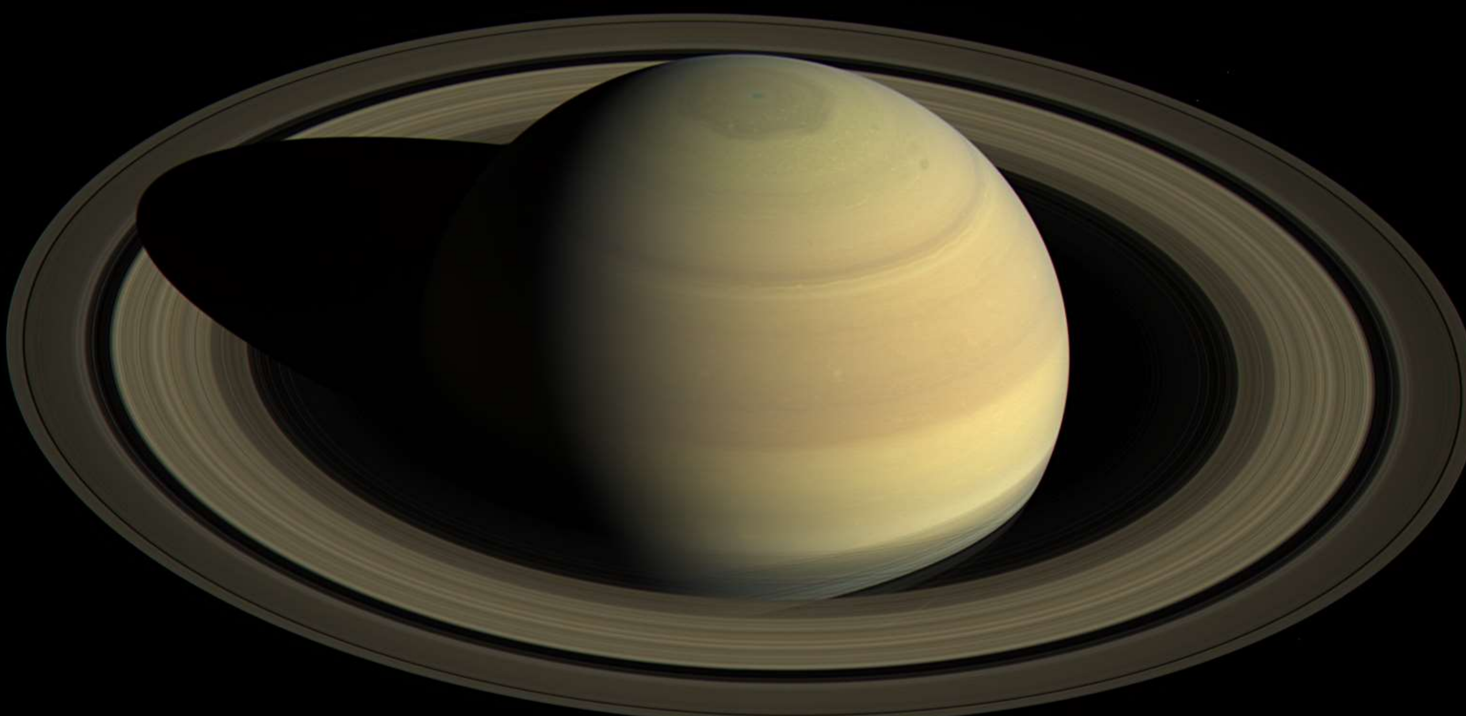
AST 2002
Introduction to Astronomy



A Few Quick Things…

E-mailing me: Must have AST2002 in the subject

Mary Hinkle, Graduate Teaching Assistant:
Office Hours: Mon 1:30-3:00pm. PSB 316

My office hours: Mon 3:00-4:00pm. PSB 308
Tue 3-4 pm. PSB 308

First Mid-term was last week… Friday 9th February.

Next Knights Under the Stars Event – Thur 22nd Feb 7-8:30pm

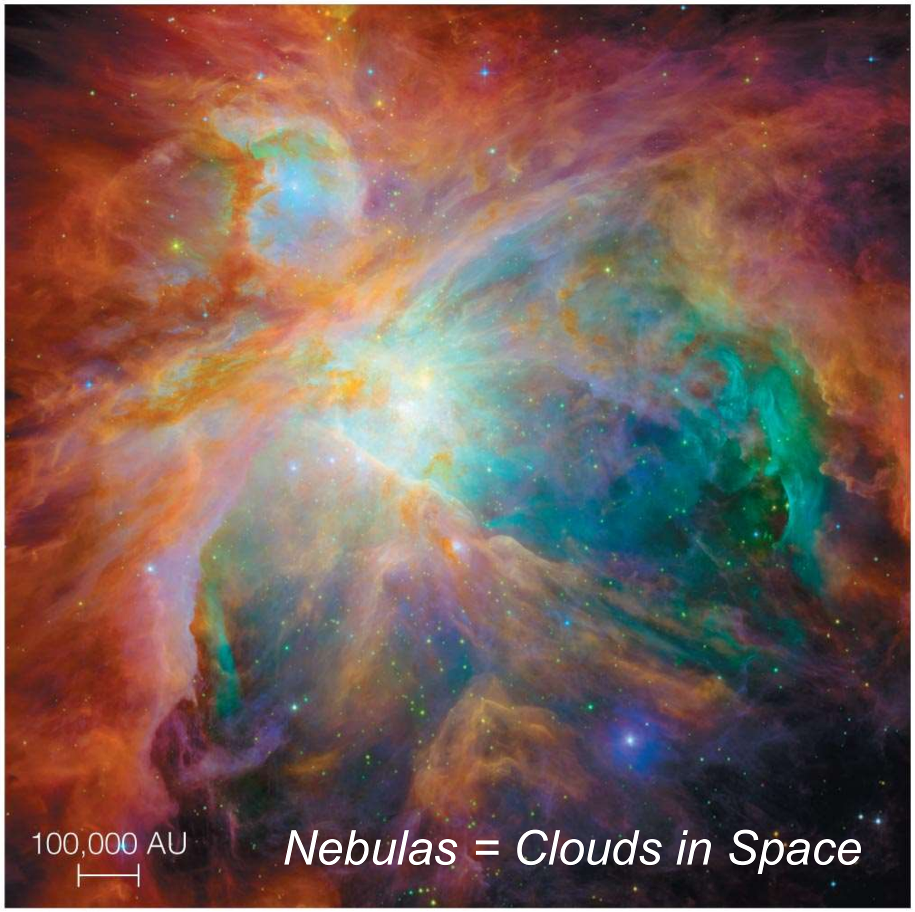
Summary of Last Time

Part III – Learning from other Worlds

- **Chapter 6:** Formation of the Solar System
- A Brief Tour of the Solar System
- The Nebular Theory of Solar System Formation
- Explaining the Major Features of the Solar System
- The Age of the Solar System

- **Chapter 7:** Earth and the Terrestrial Worlds
- Today: Earth as a Planet
  - Why is Earth geologically active?
  - What processes shape Earth's surface
  - How does Earth's atmosphere affect the planet?

Nebula Theory



Nebulas = Clouds in Space

Proposed by Kant and Laplace (independently) over 200 years ago.

Solar System formed from a huge cloud of interstellar dust and gas.

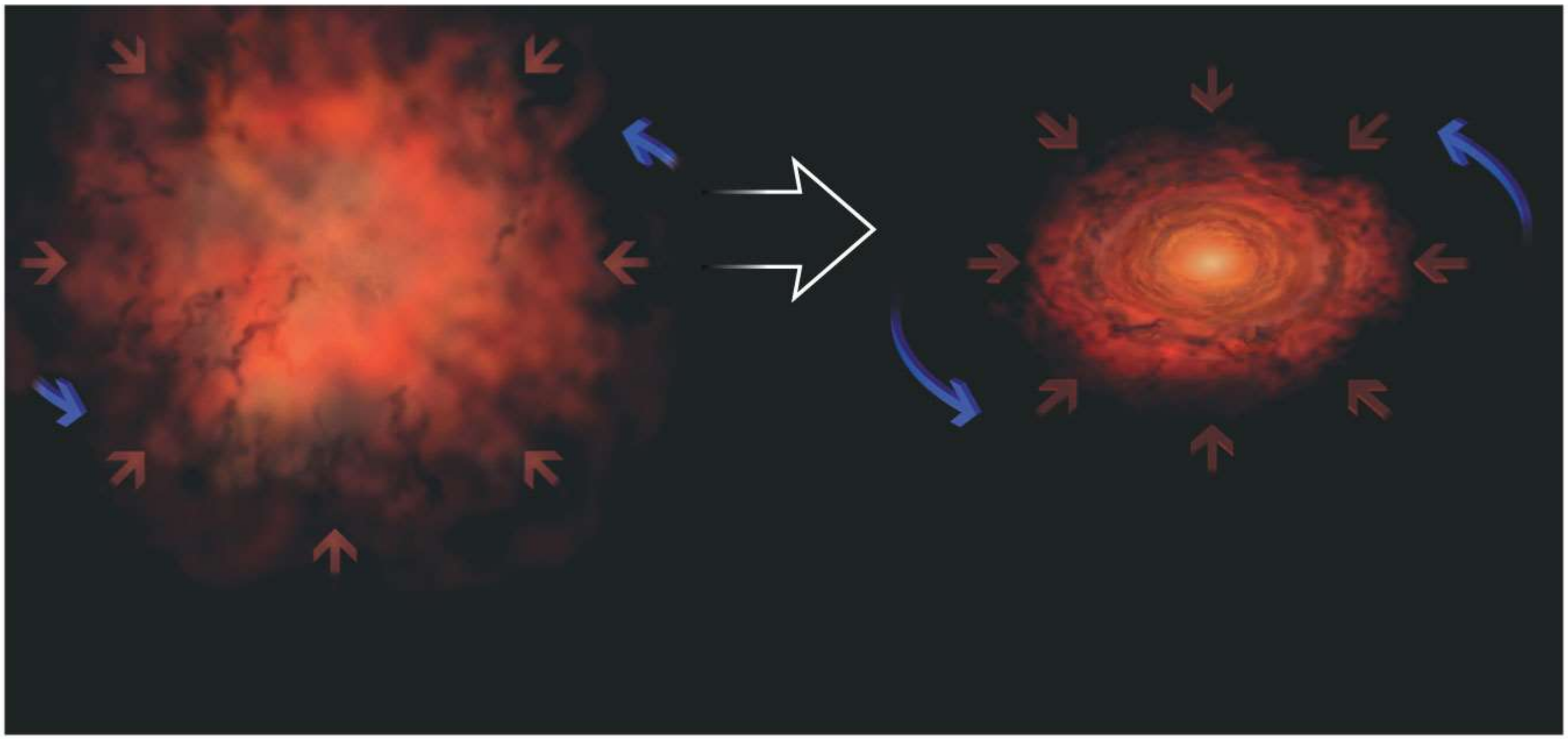
Two Guiding Physical Laws:

i) Gravity: (also that potential energy -> kinetic energy/heat)

ii) Conservation of Angular Momentum

Also need to consider some physical properties of elements and molecules…

Cloud Collapse – Conservation of Angular Momentum (=m×v×r)



An initial cloud, a few light years across at low temperature (~10 K), roughly spherical, with imperceptible levels of angular rotation visible… *process may be nudged into starting to contract.*

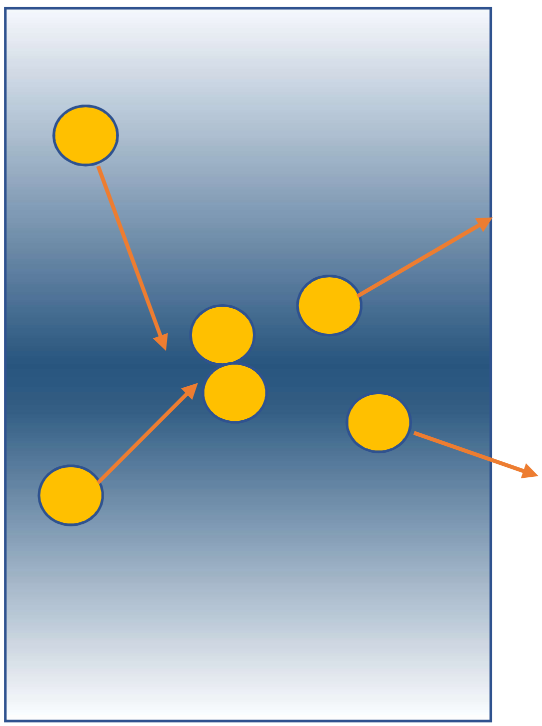
As it collapses under gravity, it becomes smaller (a few hundred AU) and hotter (P.E. → K.E.). Gravity and temperature will be greatest at the center…

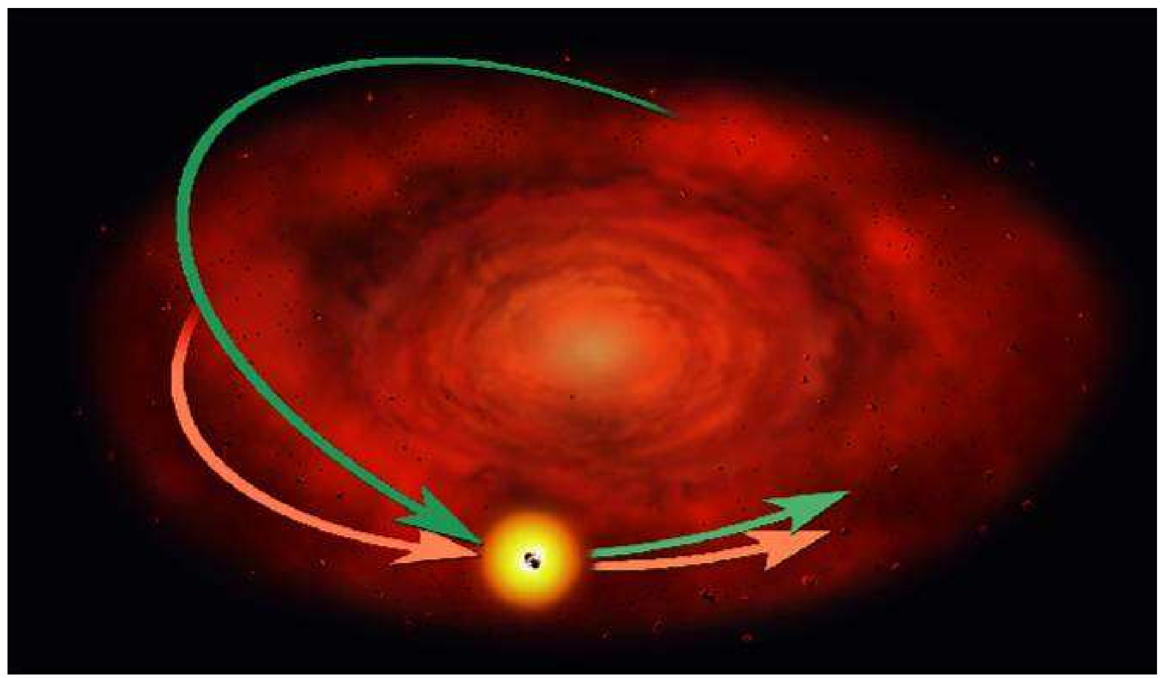
The smaller it gets, the faster it spins

Flattening of the Solar Nebula

As the nebula collapses, clumps of gas collide & merge.

- Their random velocities average out into the nebula's direction of rotation.
- Gravity also plays a role in flattening; heavier objects will be confined to plane.
- The spinning nebula assumes the shape of a disk.





Orderly Motions in the Solar System

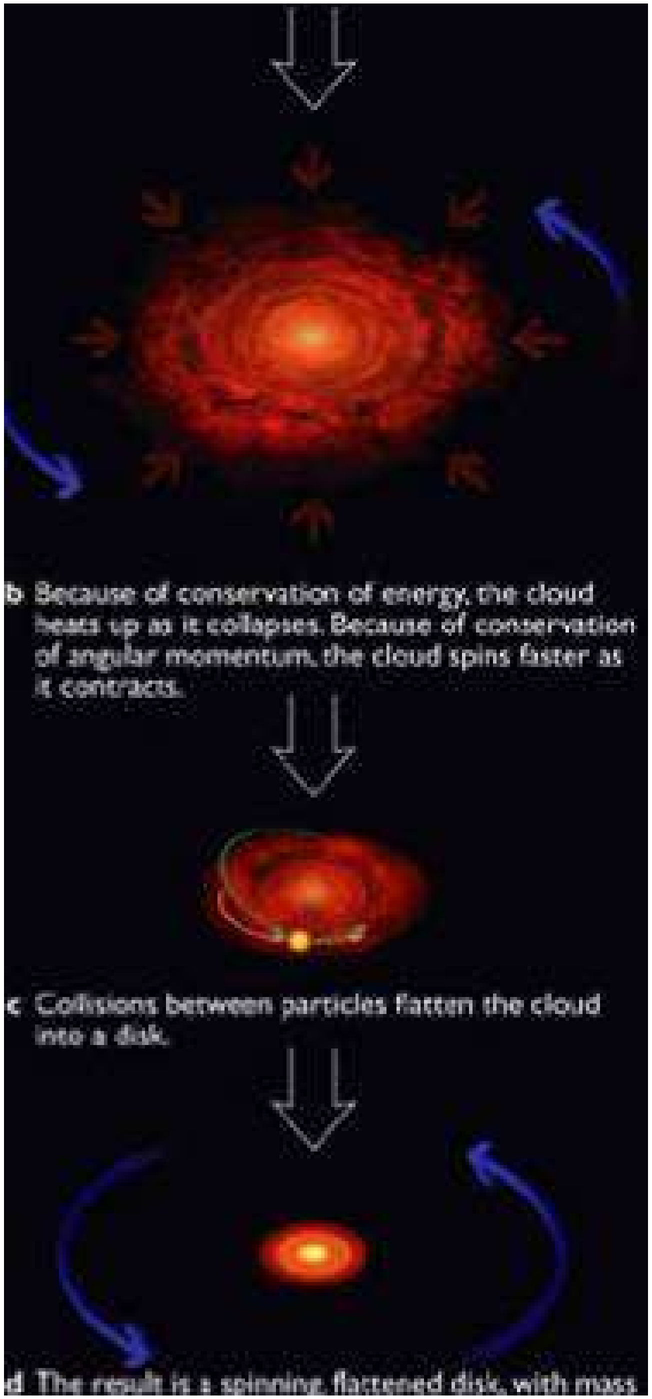
The Sun formed in the very center of the nebula.

- temperature & density were high enough for nuclear fusion reactions to begin

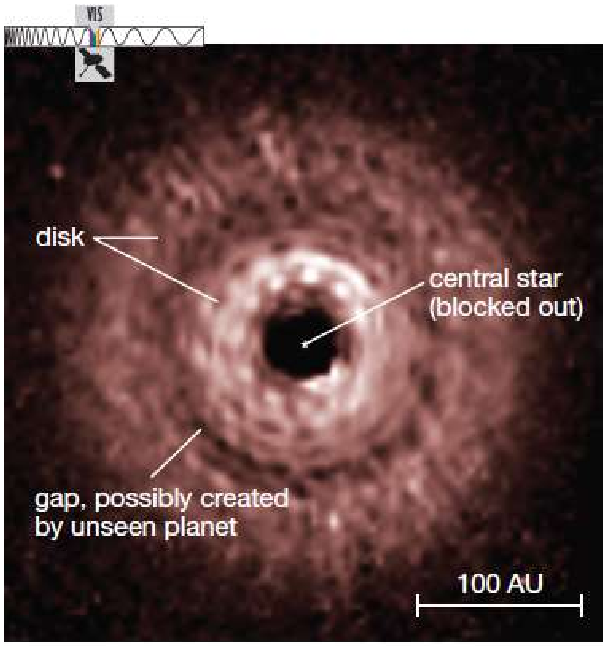
The planets formed in the rest of the disk.

This would explain the following:

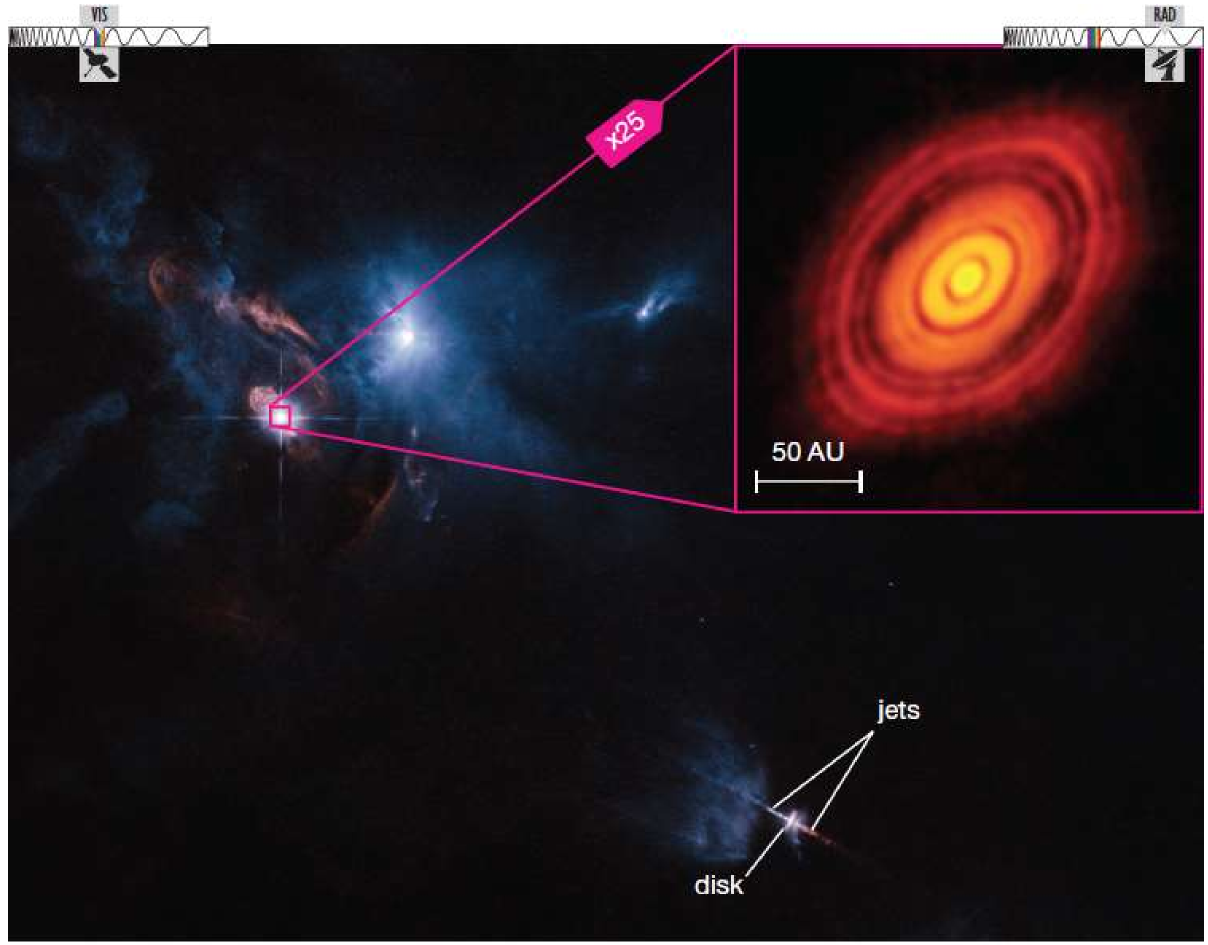
- all planets lie along one plane (in the disk)
- all planets orbit in one direction (the spin direction of the disk)
- the Sun rotates in the same direction
- the planets would tend to rotate in this same direction
- most moons orbit in this direction
- most planetary orbits are near circular (collisions in the disk)



Protoplanetary Disks Around other Stars!



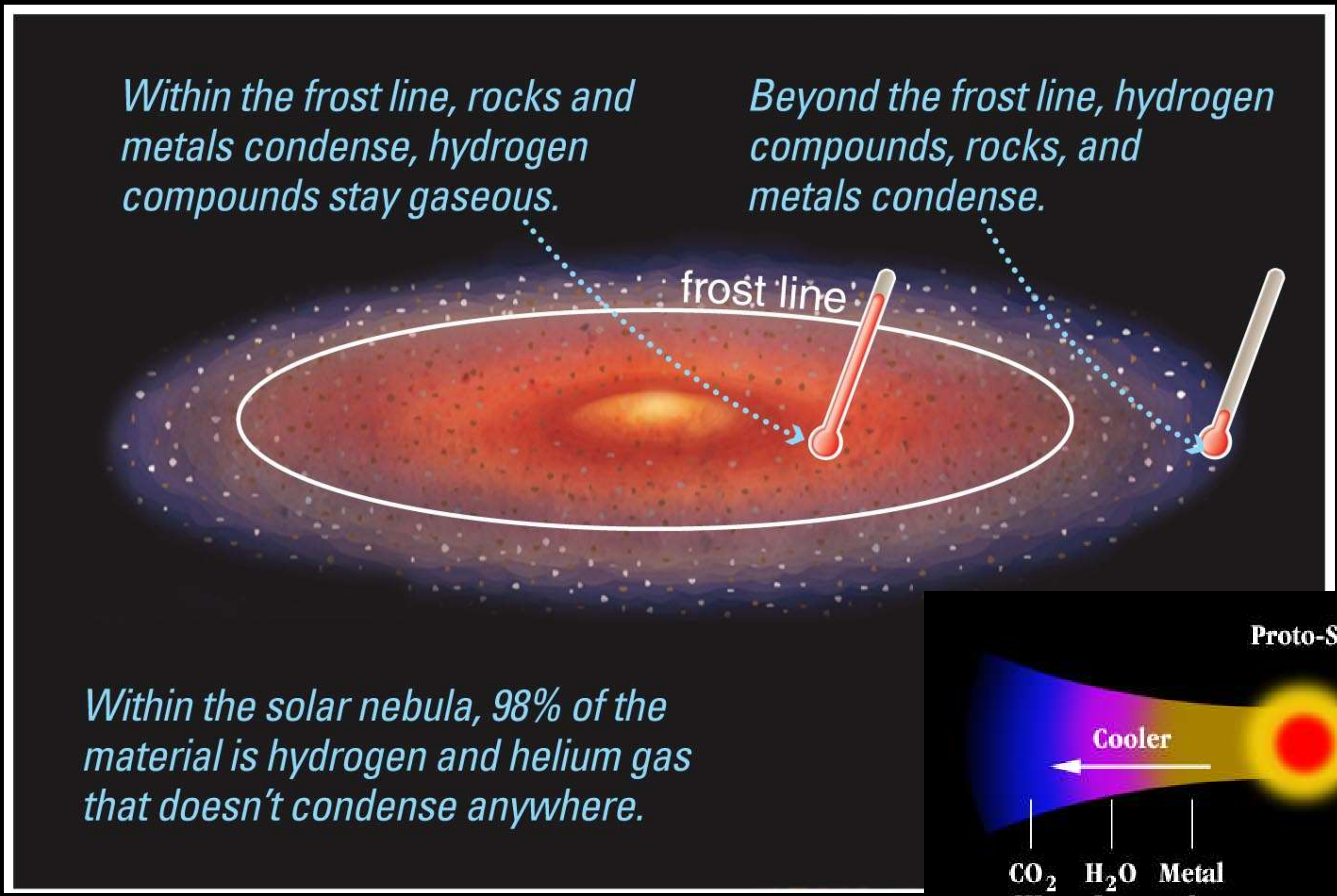
a This Hubble Space Telescope image shows a flattened, spinning disk around the star TW Hydrae. This particular disk also shows at least one circular "gap" in which material seems to have been cleared away, probably by a planet forming in the disk, which would have a gravitational attraction that would tend to sweep up material along its path.

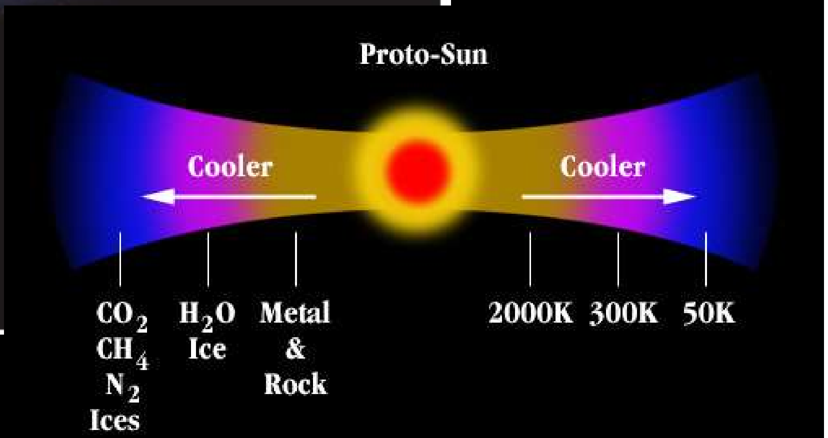


b The inset, from the Atacama Large Millimeter/submillimeter Array (ALMA), shows a disk around a star named HL Tauri; the concentric gaps in the disk are almost certainly regions being cleared as planets form. The disk diameter is about three times that of Neptune's orbit around the Sun. The background image, from the Hubble Space Telescope, shows the star-forming region in which this disk is located. Another disk, seen edge-on with jets extending outward, appears at lower right.

Why are there Two Types of Planets?

Condensation: As you move away from the Sun, it - more material can form solids

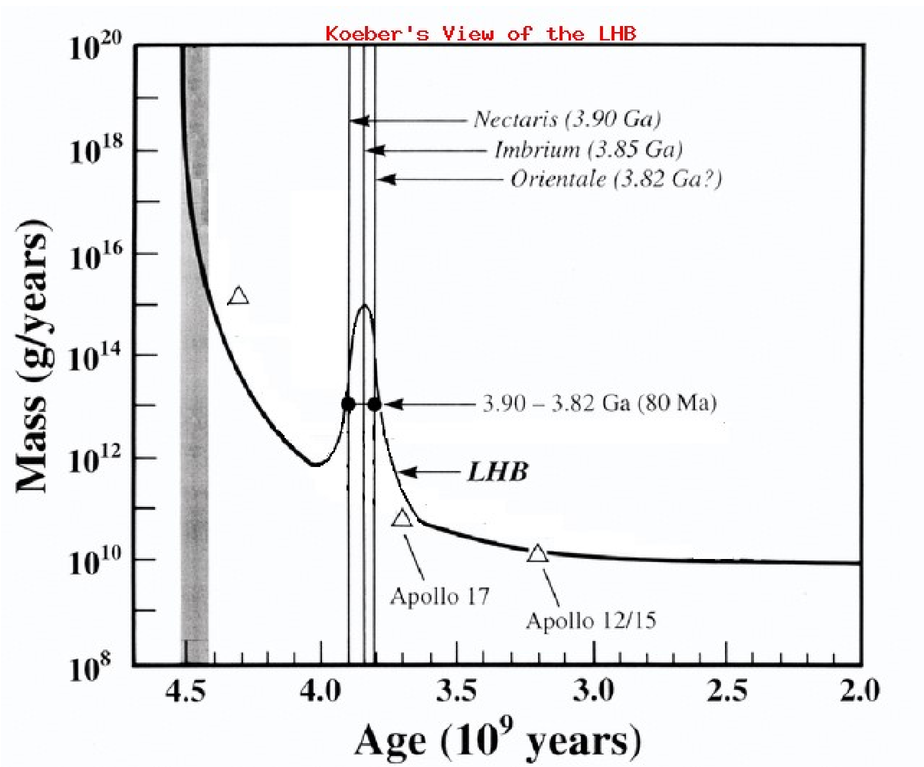


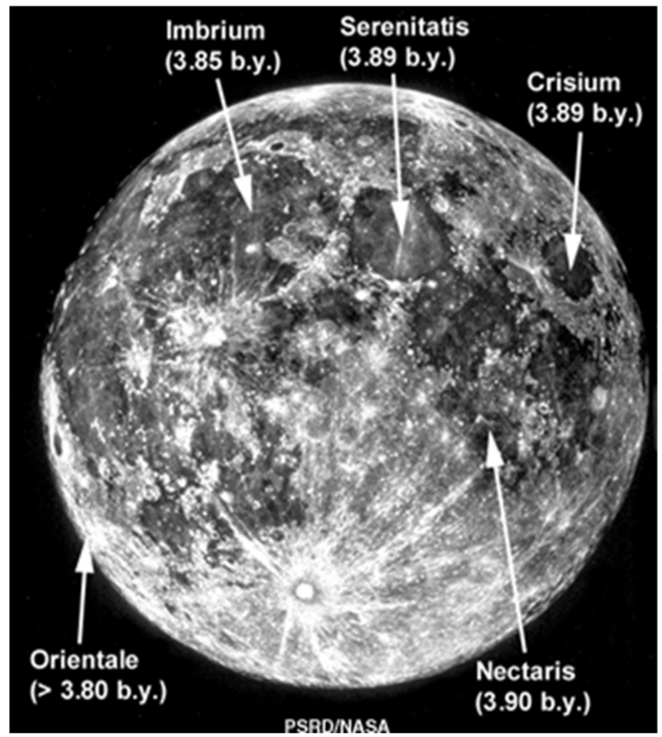


Do We have Any Evidence of the Late Heavy Bombardment?

YES!

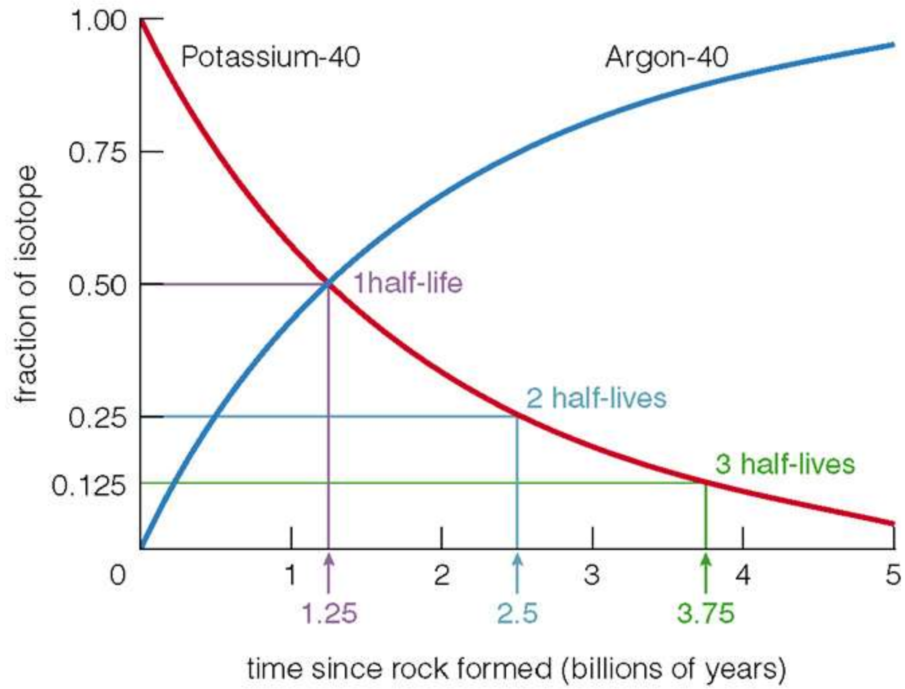
Well, we have about 3 data points which were determined by radiometric dating of rocks, from crater impacts on the Moon…





What is Radiometric Dating?

- Elements have isotopes which are unstable i.e. **radioactive**.
- Take Potassium…0.011% of all Potassium is K-40, which is radioactive. It spontaneously changes in to Argon-40 in a process called **radioactive decay**. *Careful with those Bananas!*
- **Probability:** The time it takes half the amount of a radioactive isotope to decay is called its **half life**. For K-40, this is about 1.25 billion years



- By knowing rock chemistry, we chose a stable isotope which does not form with the rock…its presence is due solely to decay.
  - → **K-40 (potassium) is incorporated into rocks, but Ar-40 is not!**
- Measuring the relative amounts of **BOTH** isotopes and knowing the half life of the radioactive isotope tells us the age of the rock.

iClicker Question

Question: You are dating a rock based on the proportion of the parent isotope potassium-40 (half-life 1.25 billion years) and its daughter isotope argon-40.

What is the age of the rock if you find there is three times as much argon-40 as potassium-40?

A. 1.00 billion years
B. 1.25 billion years
C. 2.50 billion years
D. 3.75 billion years

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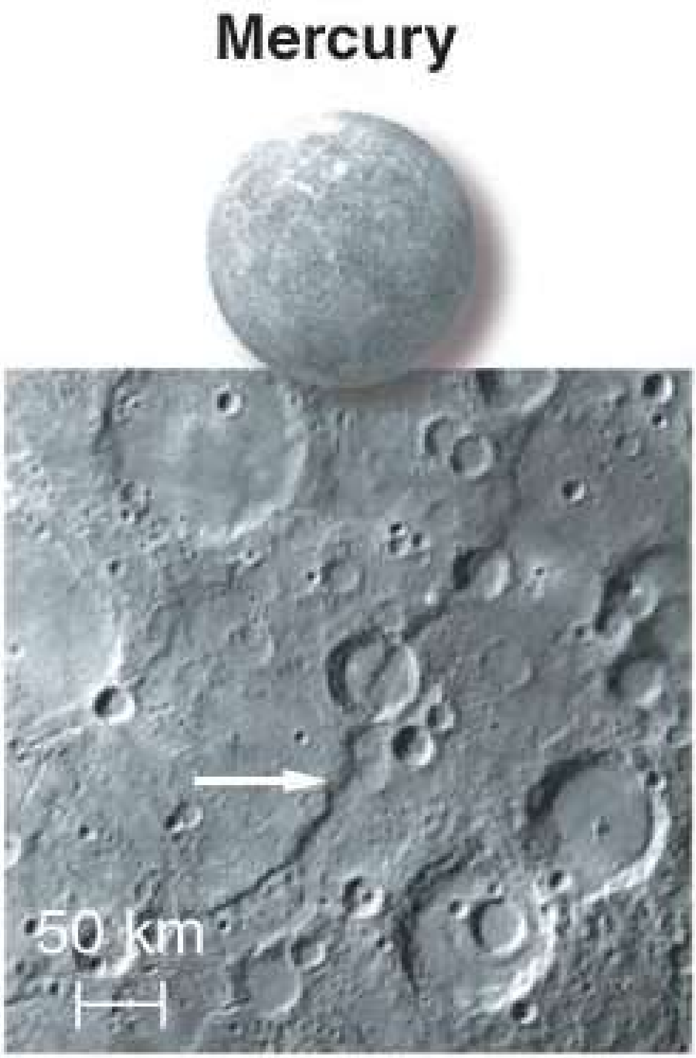
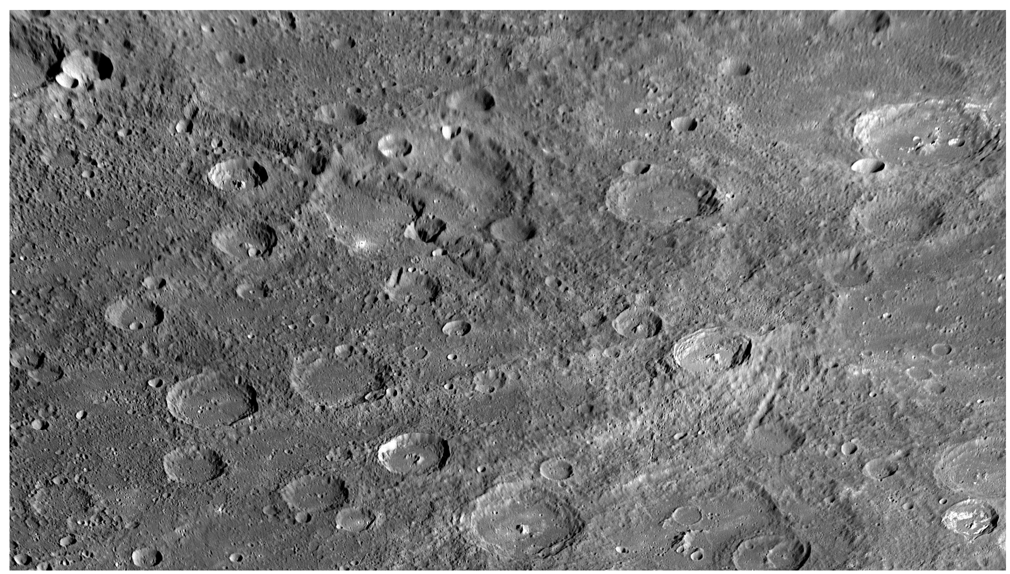
Mercury

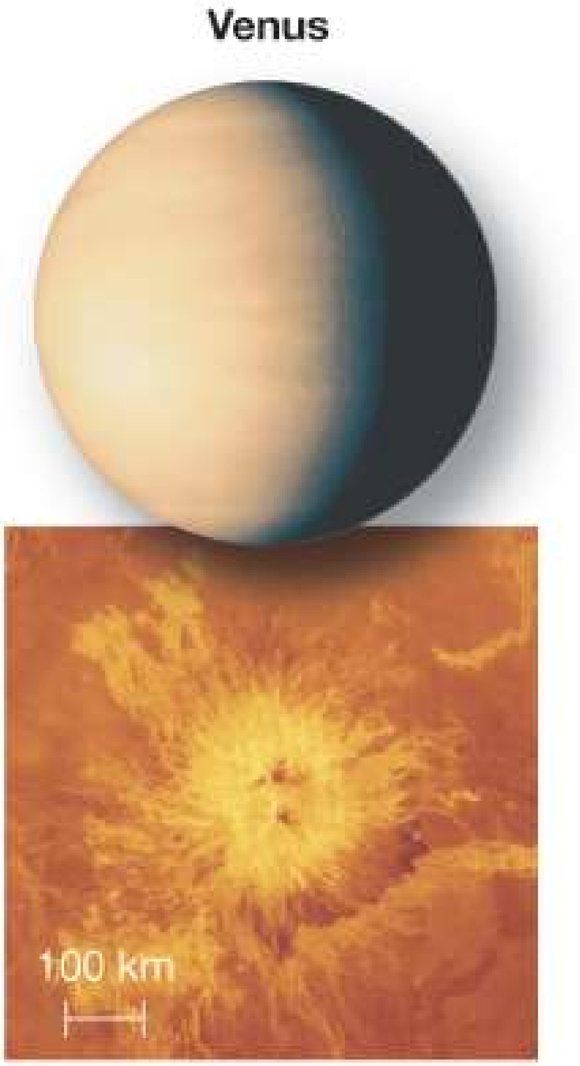


- Craters
- Smooth plains
- Cliffs/Scarps



Venus

- Volcanoes
- Few craters



Cloud-penetrating radar revealed this twin-peaked volcano on Venus.

Earth

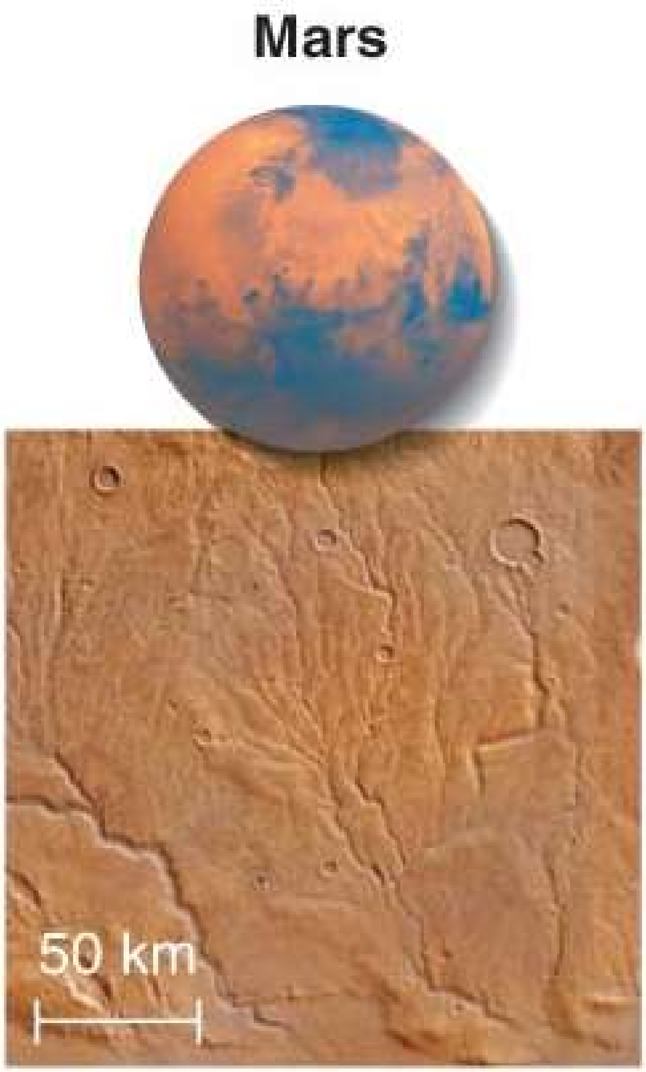
- Volcanoes
- Craters (not many)
- Mountains
- Riverbeds

The Moon

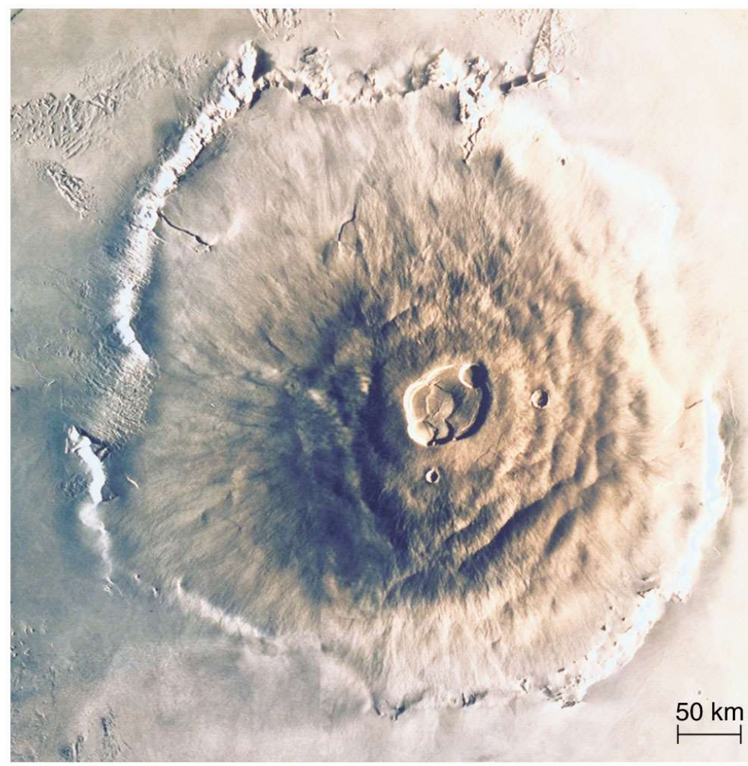
Earth's Moon

- Craters
- Smooth plains

Mars

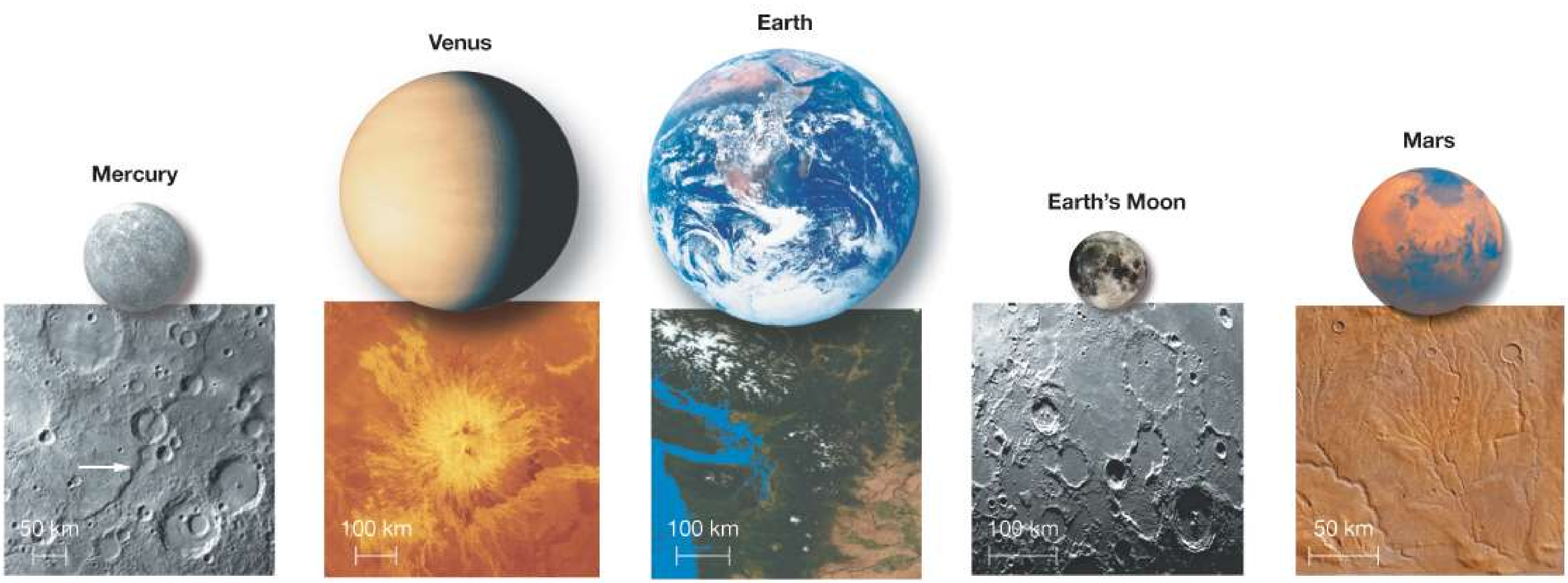


- Some craters
- Volcanoes
- Riverbeds?



Comparative Planetology

Why have the surfaces of planets turned out so differently, even though they formed at the same time from the same materials? *What processes are shaping these surfaces?*



Heavily cratered Mercury has long steep cliffs (arrow).

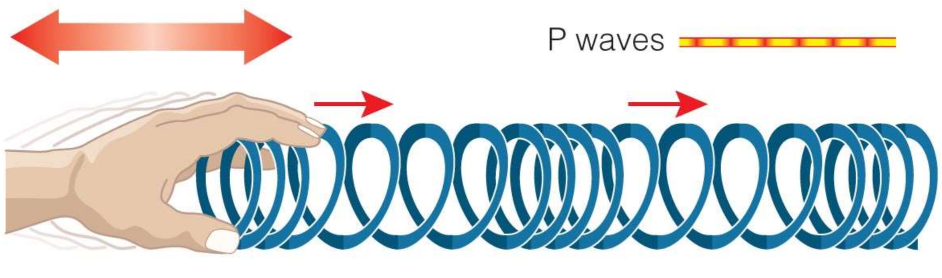
Cloud-penetrating radar revealed this twin-peaked volcano on Venus.

A portion of Earth's surface as it appears without clouds.

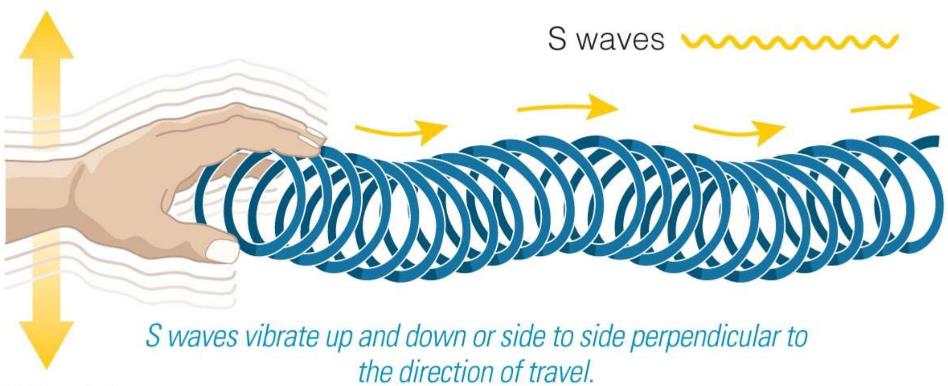
The Moon's surface is heavily cratered in most places.

Mars has features that look like dry riverbeds; note the impact craters.

How do we know what's inside a planet?



P waves result from compression and stretching in the direction of travel.



S waves vibrate up and down or side to side perpendicular to the direction of travel.

Seismometers

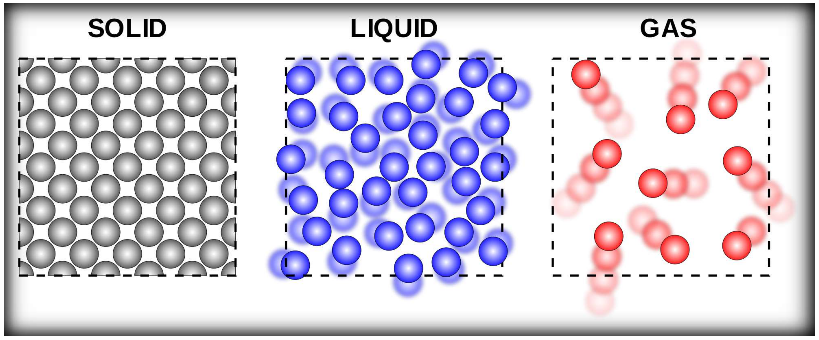
- Look at Earthquakes!

P waves push matter back and forth.

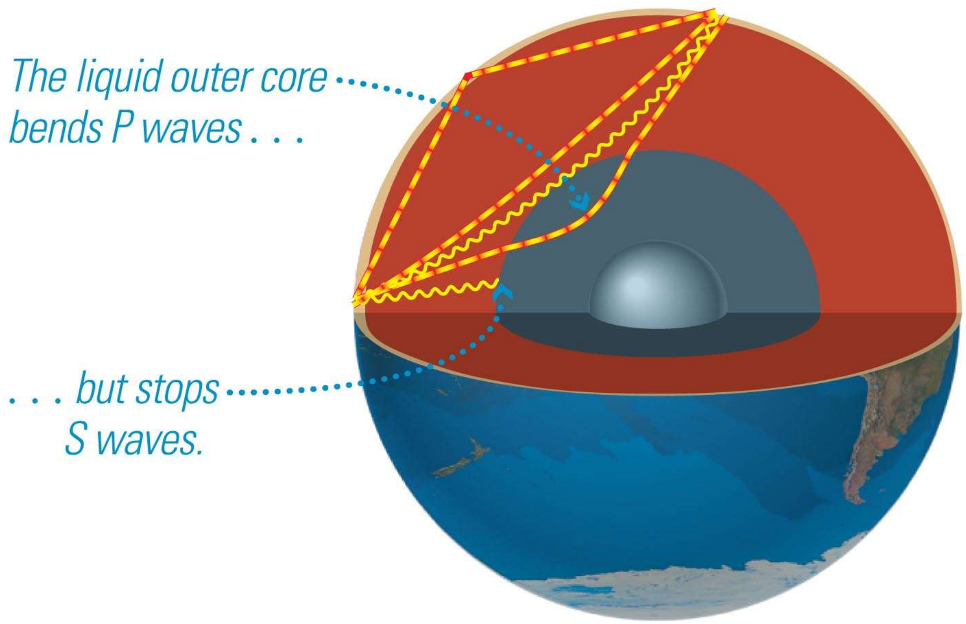
- Can travel through solids, liquids and gases

S waves shake matter side to side.

- Can not travel through liquids or gases



How do we know what's inside a planet?

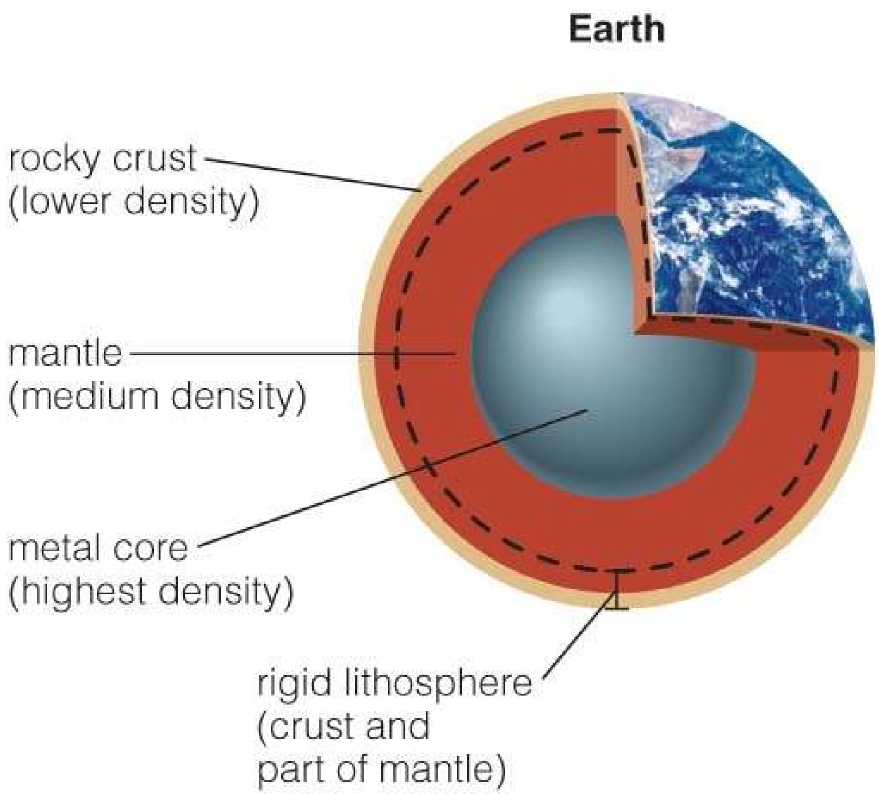


P waves go through Earth's core, but S waves do not.

We conclude that Earth's core must have a liquid outer layer.

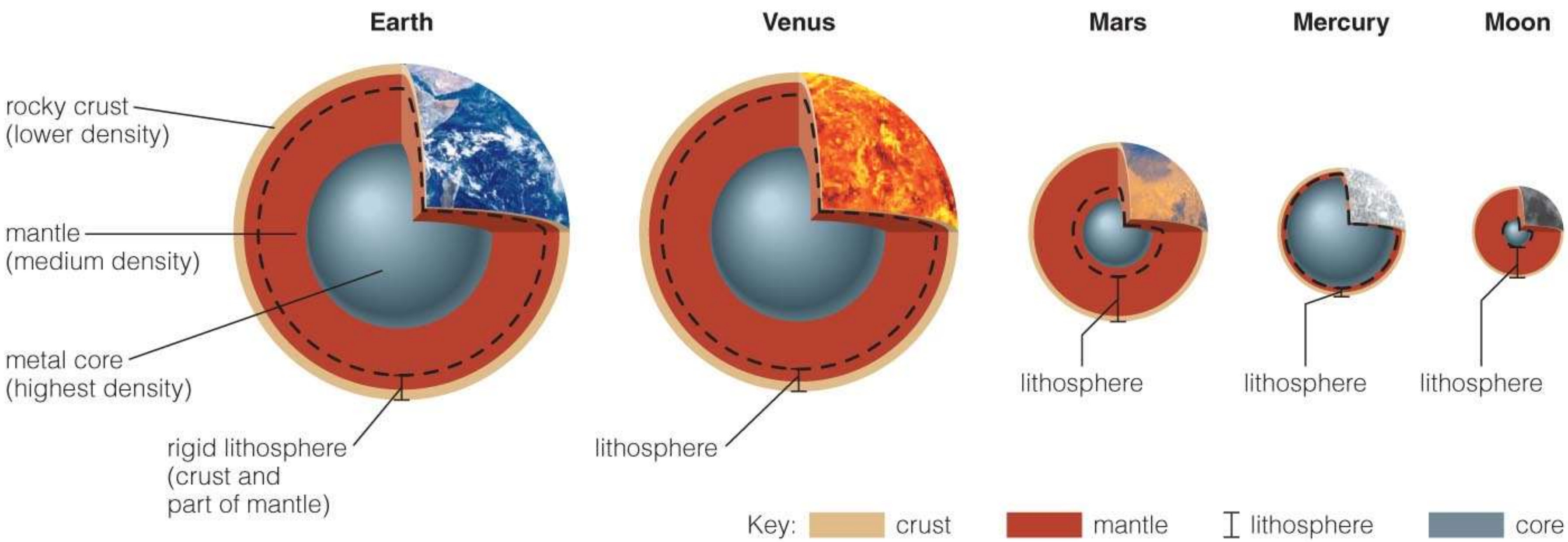
Also, bear in mind that this also means that most of the REST of the Earth is <u>SOLID</u> (*not molten magma!)*

Earth's Interior



- **Core:** Highest density; nickel and iron
- **Mantle:** Moderate density; minerals with silicon, oxygen, etc.
- **Crust:** Lowest density; granite, basalt, etc.

Terrestrial Planet Interiors



Applying what we have learned about Earth's interior to other planets tells us what their interiors are probably like.

Thought Question

Why do water and oil separate?

A. Water molecules repel oil molecules electrically.

B. Water is denser than oil, so oil floats on water.

C. Oil is more slippery than water, so it slides to the surface of the water.

D. Oil molecules are bigger than the spaces between water molecules.

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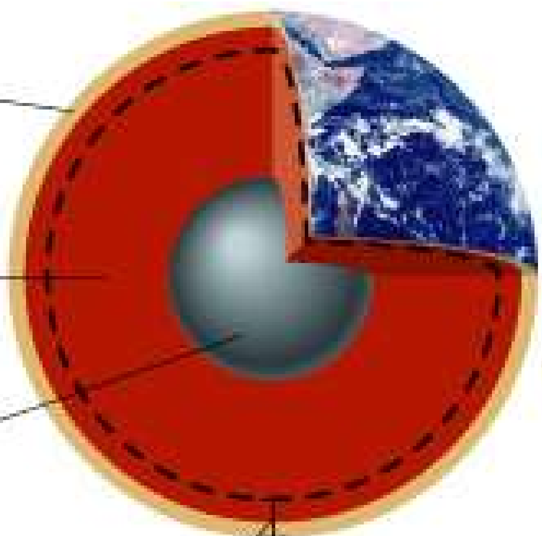
Differentiation

- Gravity pulls high-density material to center
- Lower-density material rises to surface
- Material ends up separated by density
- Iron-Nickel sinks to the core…
- *This process generates more heat…*

Gravitational potential energy → Kinetic energy



Thought Question

What is necessary for *differentiation* to occur in a planet?

A. It must have metal and rock in it.

B. It must be a mix of materials of different density.

C. Material inside must be able to flow.

D. All of the above

E. B and C

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Thought Question

Do rocks s-t-r-e-t-c-h?

A. No. Rock is rigid and cannot deform without breaking.

B. Yes, but only if it is molten rock.

C. Yes. Rock under strain may slowly deform.

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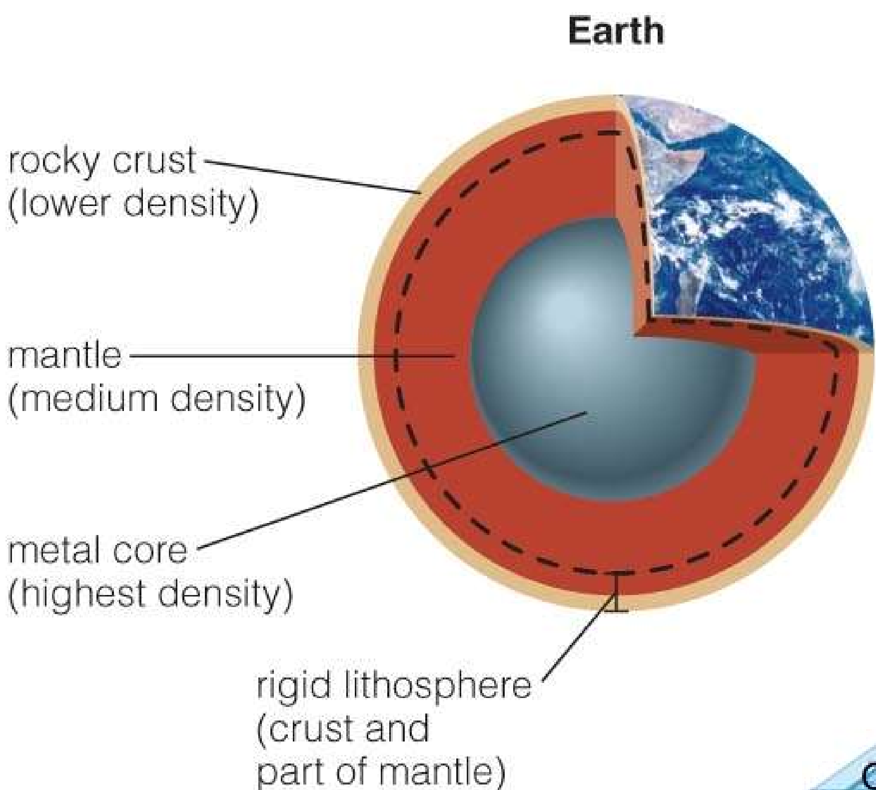
Deformation of Rocks

- Silly Putty Stretches if you pull it slowly apart…
- If you pull it Fast, it snaps and breaks…

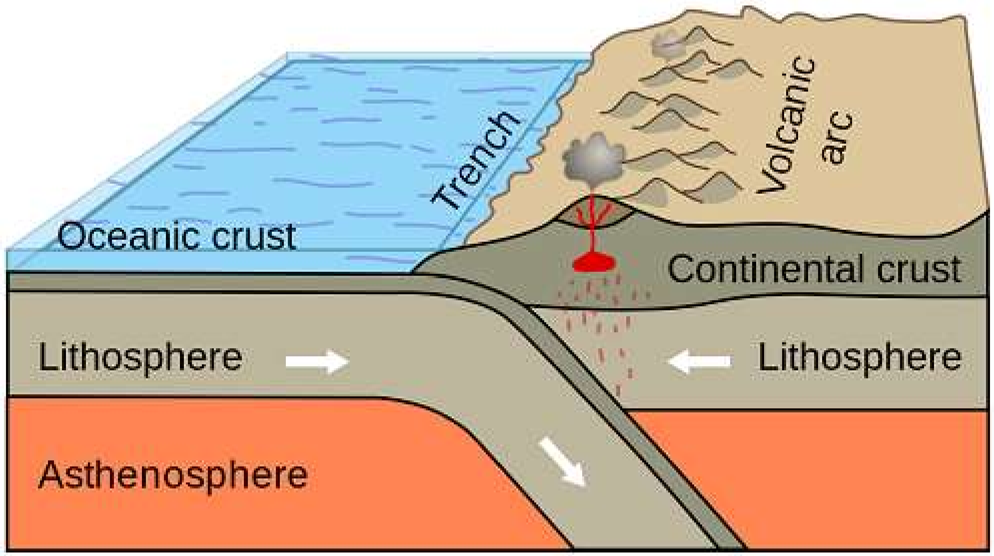
Similarly…

- Rock stretches when pulled slowly but breaks when pulled rapidly.
- The gravity of a large world pulls slowly on its rocky content, shaping the world into a sphere.

Lithosphere



- A planet's outer layer of **cool, rigid rock** is called the lithosphere.
- It "floats" on the warmer, softer rock that lies beneath.

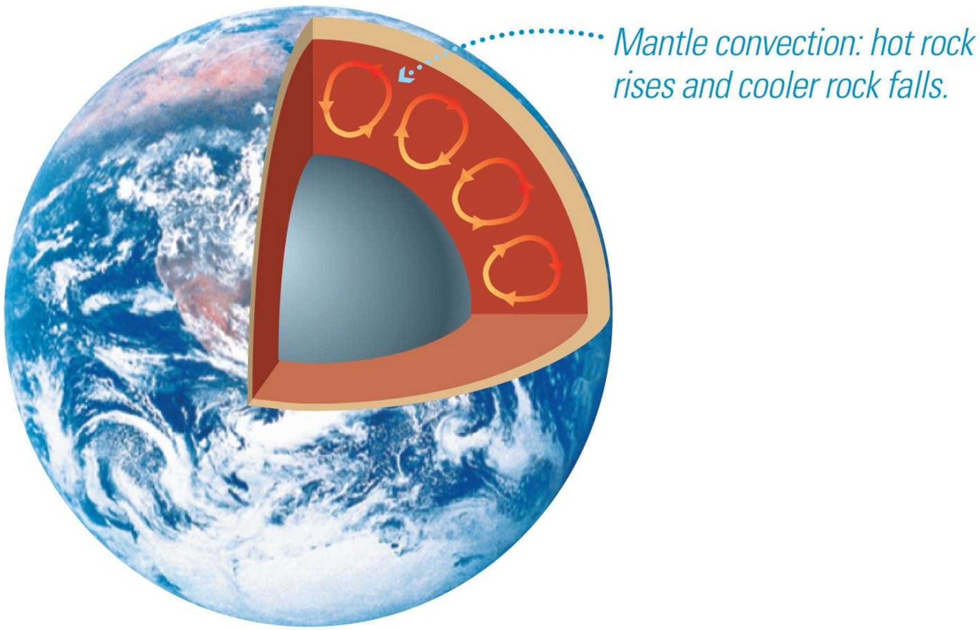


Heat Drives Geological Activity

Convection: Hot rock rises, cool rock falls.

One convection cycle takes 100 million years on Earth.

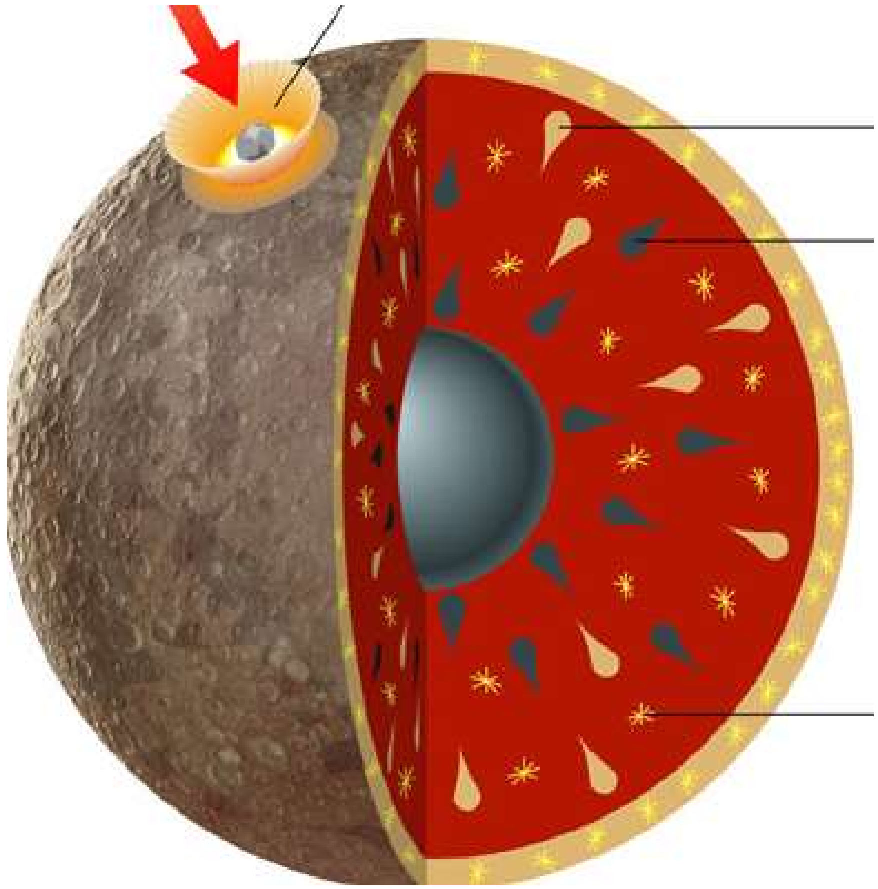
Remember, we are still talking about solid rocks…



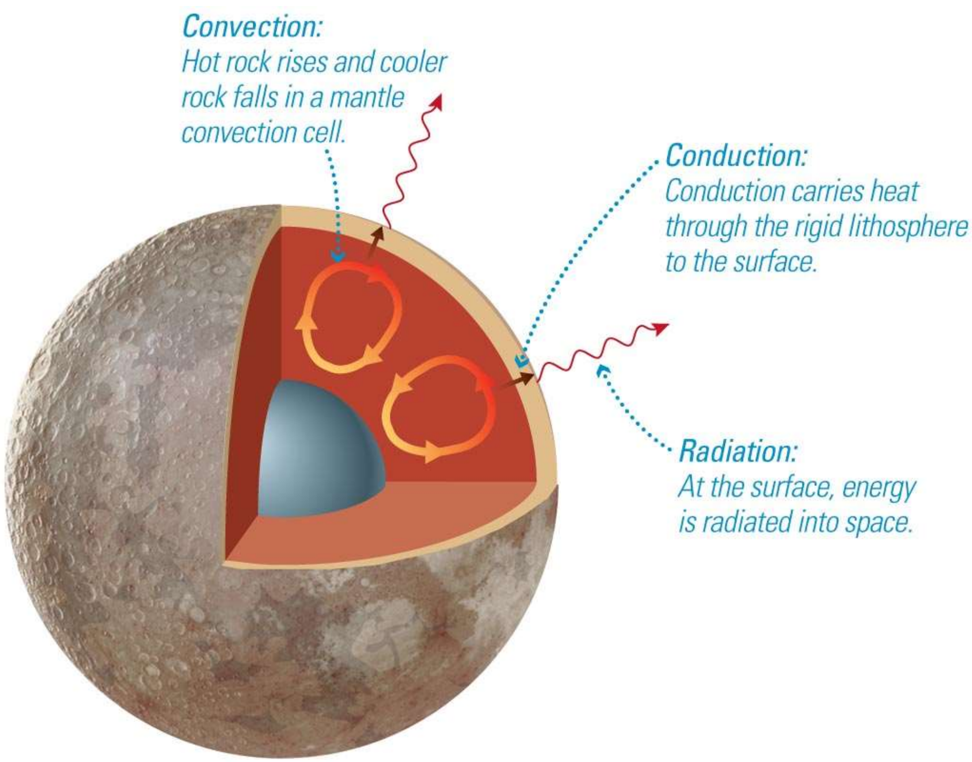
Sources of Internal Heat

1) Gravitational potential energy (early)
2) Differentiation (early)
3) Radioactivity
4) Impacts on a Surface (Heavy Bombardment mostly early)

Of these, radioactive decay is the main energy source today.



Cooling of Interior



- **Convection** transports heat as hot material rises and cool material falls. (movement)
- **Conduction** transfers heat from hot material to cool material. (touch)
- **Radiation** sends energy into space.

Thought Question

What cools off faster?

A. A Large cup of Coffee
B. A teaspoon of coffee in the same cup

Thought Question

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Thought Question

What cools off faster?

A. A big terrestrial planet
B. A small terrestrial planet

Thought Question

What cools off faster?

A. **A big terrestrial planet**

B. A small terrestrial planet

Thought Question

What cools off faster?

A. ~~A big terrestrial planet~~

B. A small terrestrial planet

Surface Area-to-Volume Ratio

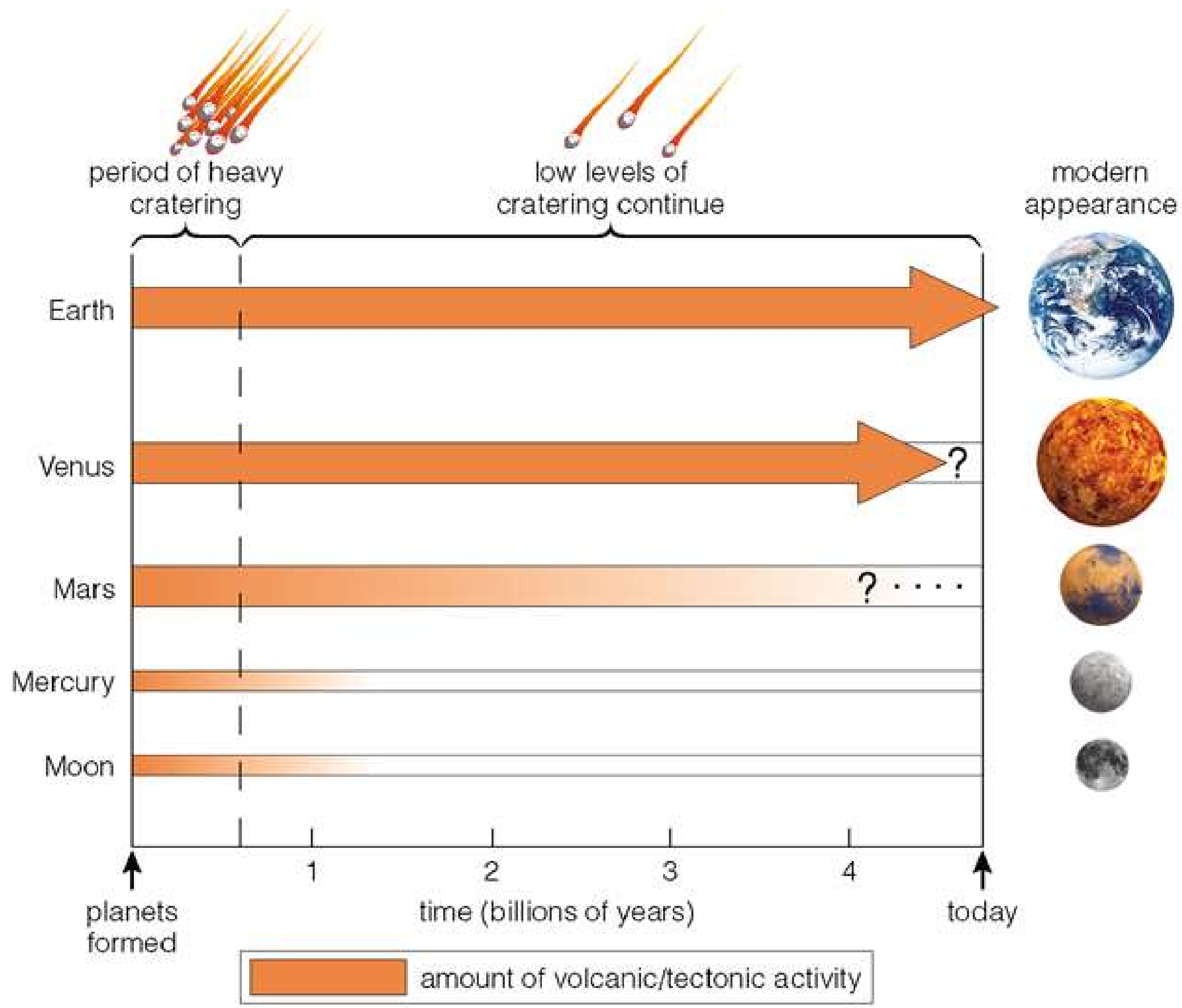
- Heat content depends on volume. $\frac{4}{3}\pi r^3$
- Loss of heat through radiation depends on surface area. $4\pi r^2$
- Time to cool depends on surface area divided by volume:

$$\textbf{Surface area-to-volume ratio} = \frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{3}{r}$$

- Larger objects have a smaller ratio and cool more slowly.

What Causes Geological Activity?

- HEAT drives activity
- Smaller worlds cool off faster and harden earlier
- The Moon and Mercury are now geologically "dead"



iClicker Question

Do you think differentiation is likely to happen in a *very* small solar system body?

A. Yes
B. No
C. Maybe

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A. Yes

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Comparative Planetology

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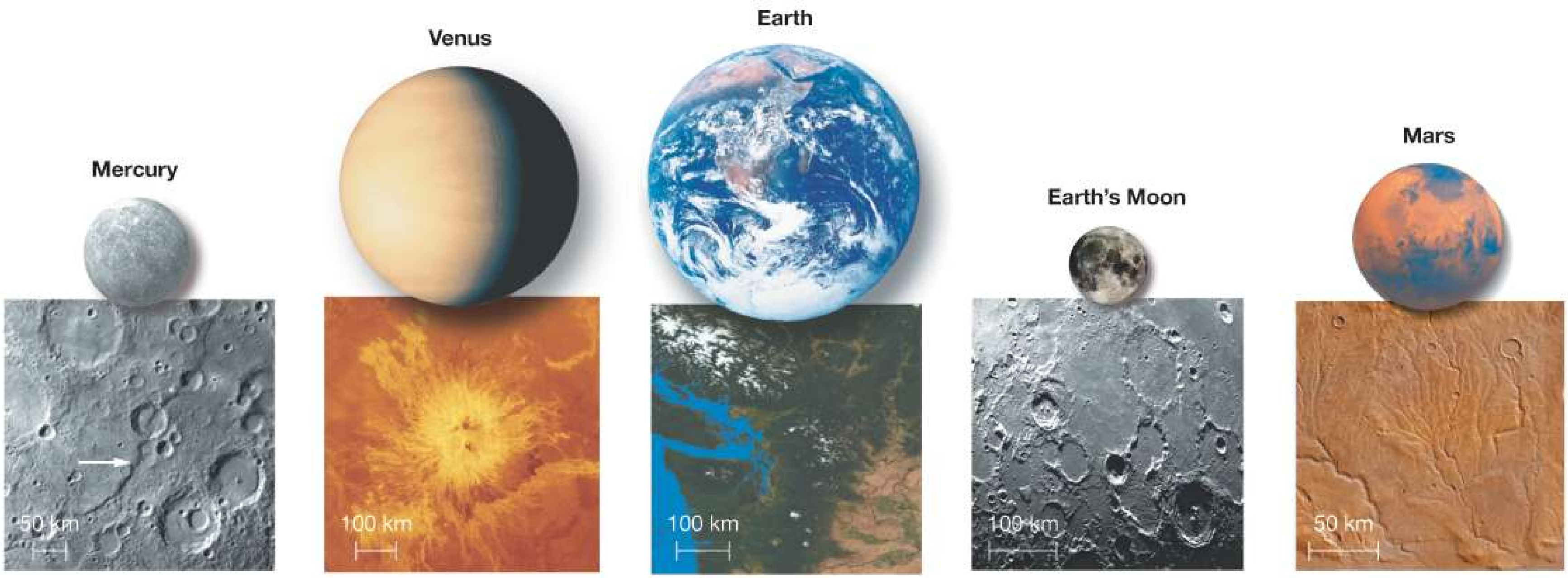


Heavily cratered Mercury has long steep cliffs (arrow).

Cloud-penetrating radar revealed this twin-peaked volcano on Venus.

A portion of Earth's surface as it appears without clouds.

The Moon's surface is heavily cratered in most places.

Mars has features that look like dry riverbeds; note the impact craters.

Geological Processes

Impact cratering

- Impacts by asteroids or comets

Volcanism

- Eruption of molten rock onto surface

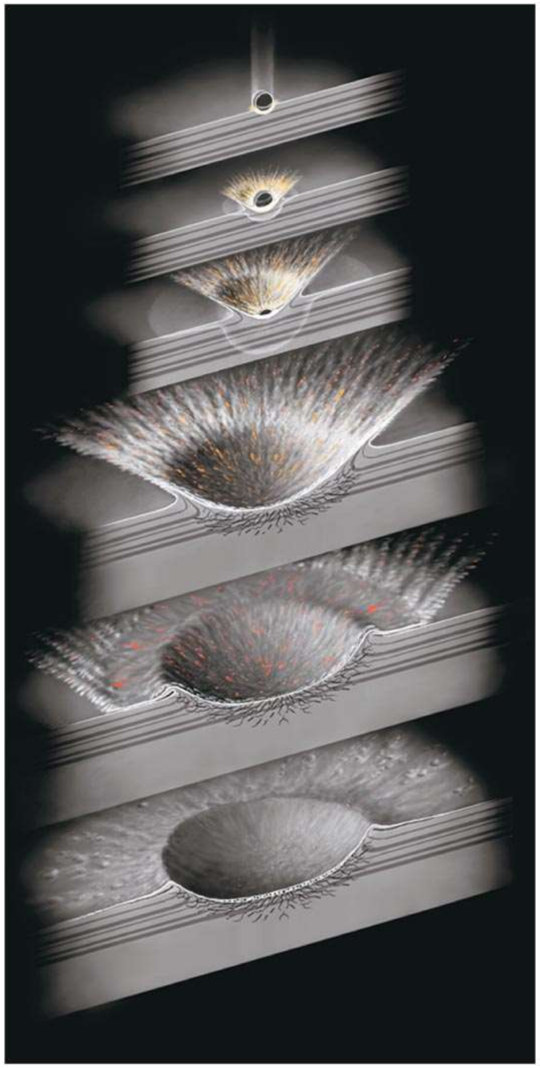
Tectonics

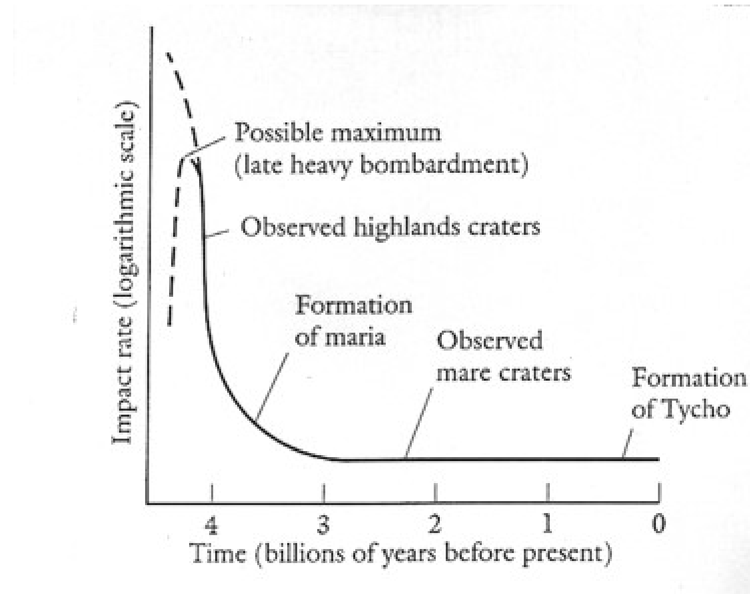
- Disruption of a planet's surface by internal stresses

Erosion

- Surface changes made by wind, water, or ice

Impact Cratering





- Most cratering happened soon after the solar system formed.
  - Late heavy bombardment??
- Craters are about 10 times wider than the objects that made them, and 1-2 times deeper.
- Small craters greatly outnumber large ones.
- Can inform you of the age of an objects surface
  - No cratering? must be a fresh surface!

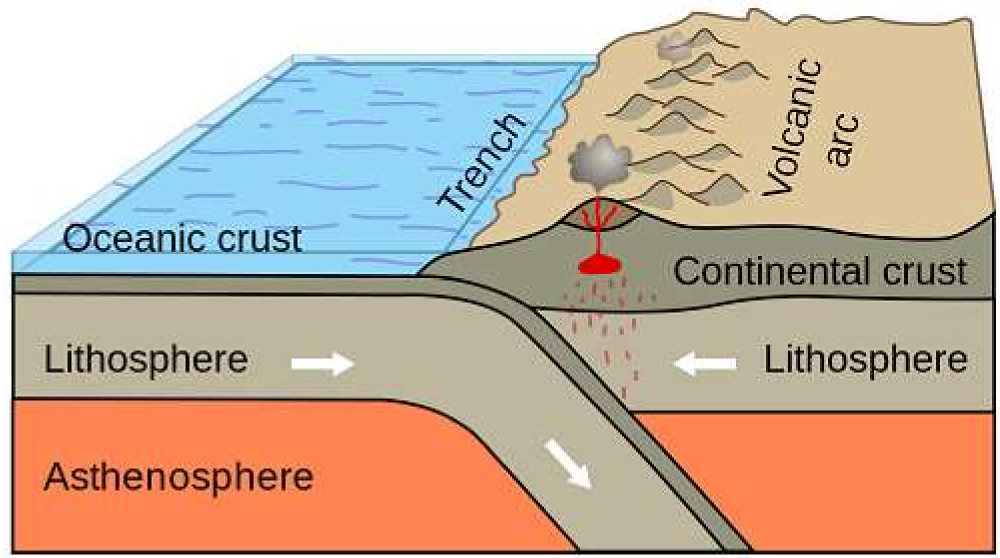
What can you tell me about the surface of Saturn’s moon Enceladus?

Volcanism

Volcanism happens when molten rock (usually from submerged lithosphere) finds a path to the surface

Molten rock is called lava after it reaches the surface

The melting point of a rock is affected by pressure, so rocks can melt more easily at the surface

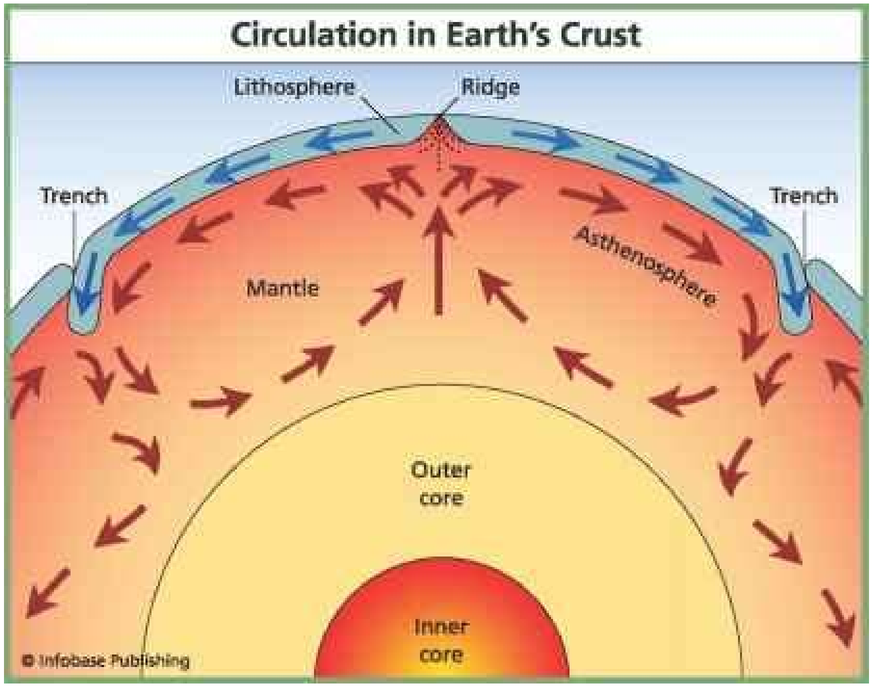


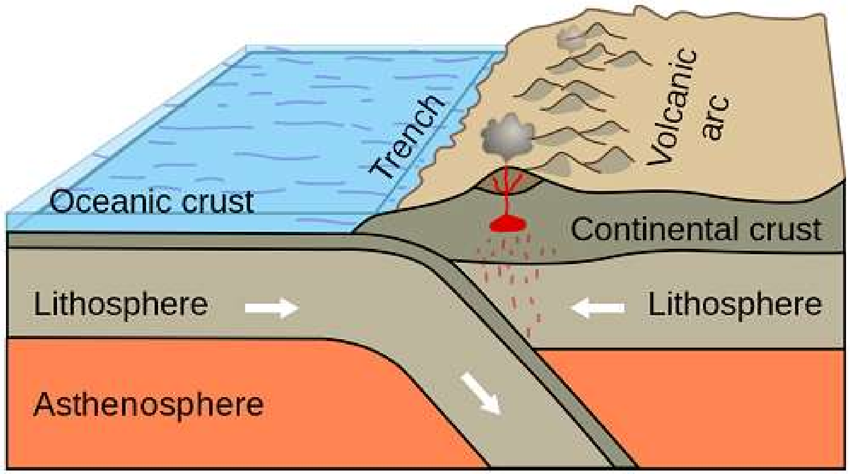
Outgassing

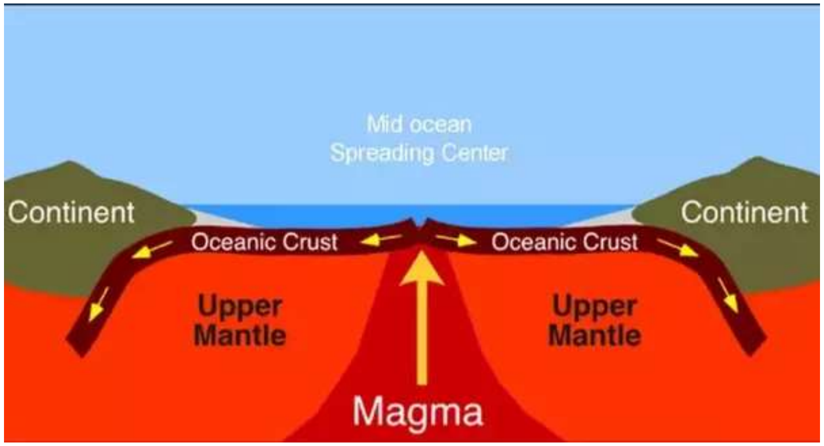
- Volcanism also releases gases from Earth's interior into the atmosphere.
- N_2, along with CO_2 and H_2O are released, originally bought to the earth from planetesimals.
- N_2 is 77% of our atmosphere today.

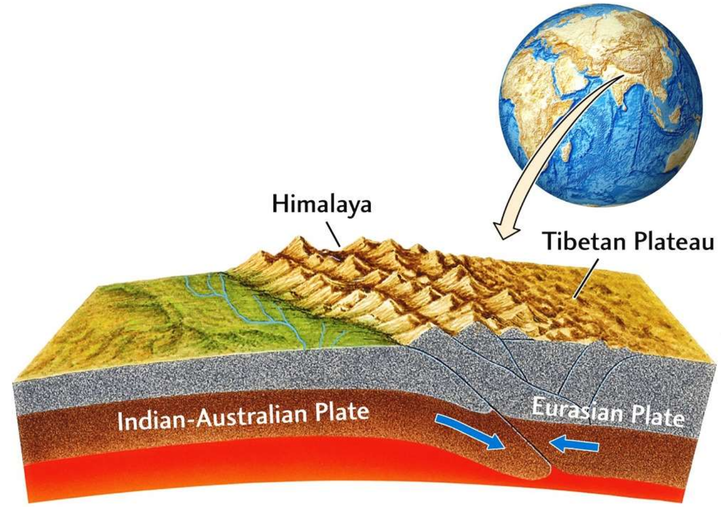
Tectonics

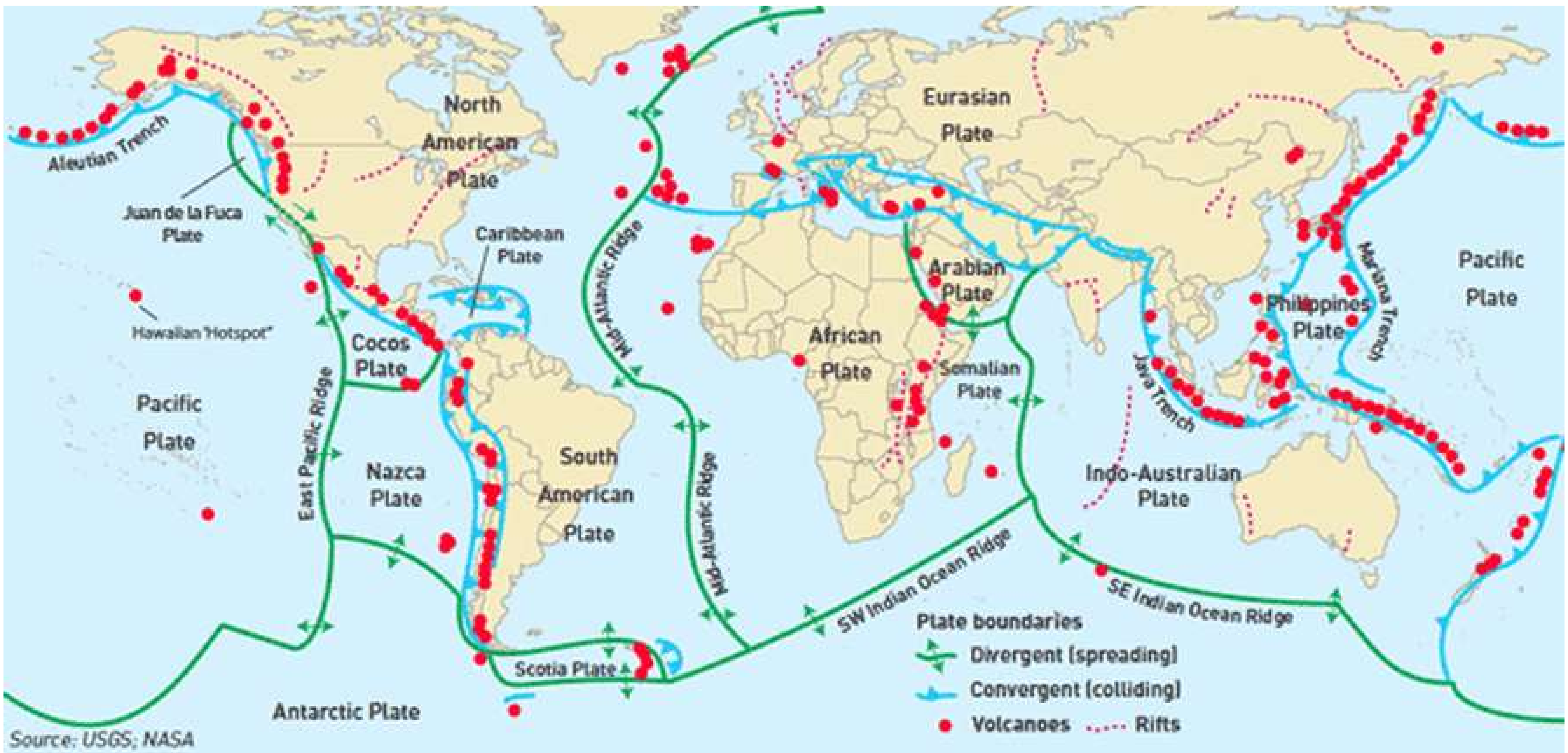
- Convection of the mantle creates stresses in the crust called tectonic forces.
- Compression forces make mountain ranges and trenches.
- A valley/ridge can form where the crust is pulled apart.
- Plates are continually recycled over ~ 100 Myrs





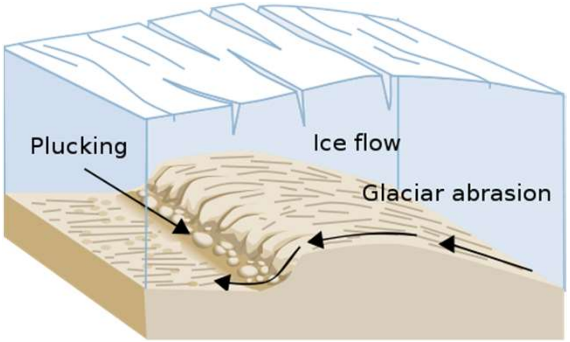

Mid ocean
Spreading Center
Continent
Continent
Oceanic Crust
Oceanic Crust
Upper
Mantle
Upper
Mantle
Magma


Himalaya
Tibetan Plateau
Indian-Australian Plate
Eurasian Plate

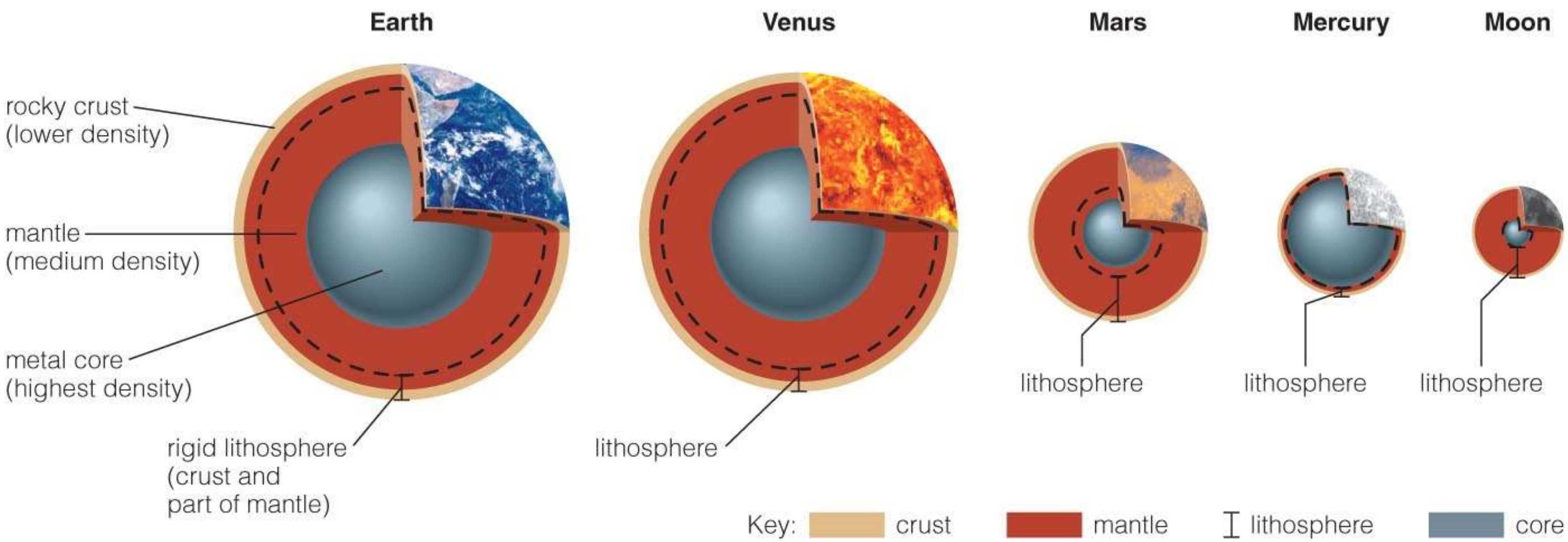

Aleutian Trench
Juan de la Fuca Plate
North American Plate
Caribbean Plate
Hawaiian 'Hotspot'
Cocos Plate
Pacific Plate
East Pacific Ridge
Nazca Plate
South American Plate
Mid-Atlantic Ridge
Mid-Atlantic Ridge
African Plate
Eurasian Plate
Arabian Plate
Somalian Plate
Philippines Plate
Mariana Trench
Pacific Plate
Java Trench
Indo-Australian Plate
SW Indian Ocean Ridge
SE Indian Ocean Ridge
Scotia Plate
Antarctic Plate
Plate boundaries
Divergent (spreading)
Convergent (colliding)
Volcanoes
Rifts
Source: USGS; NASA

Erosion

- Erosion is a blanket term for weather-driven processes that break down or transport rock.
- Rivers, glaciers, wind, deposition (e.g., deltas)



Next Time



- We will discuss atmospheres and magnetospheres.
- We will take a look at Mercury, the Moon, and Mars…

End of Todays Lecture