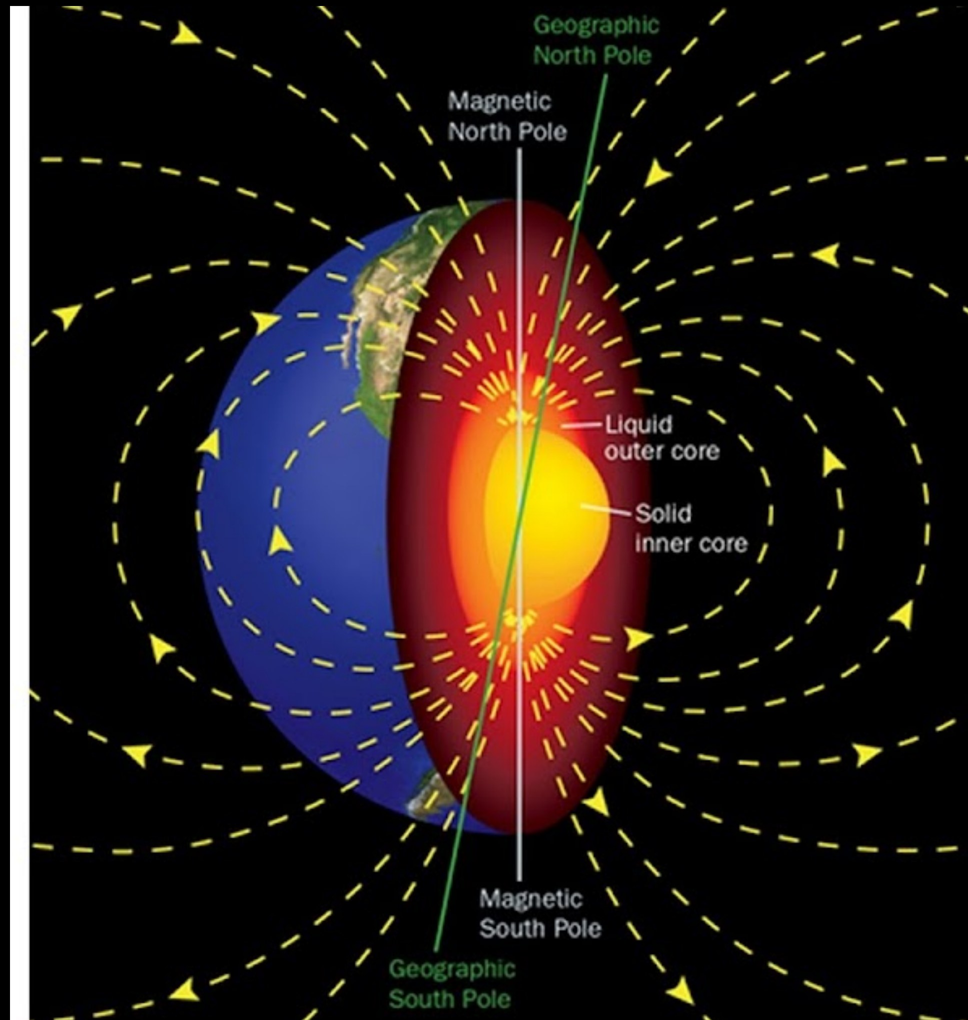
Planetary Interiors:

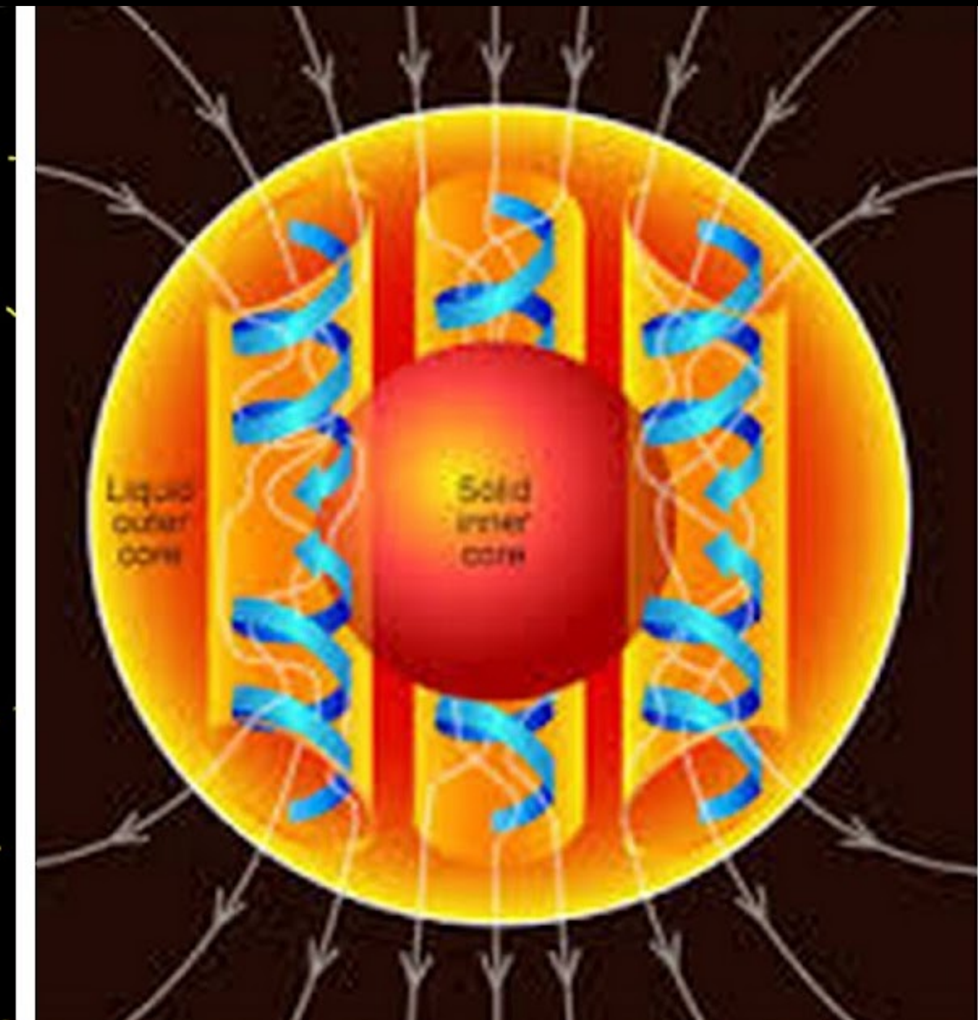
We can not examine the interiors of planets directly (even our own). Thus, we build computer models. A computer model basically takes the known laws of physics (in mathematical form) and calculates what are the conditions at any particular point inside the planet. To perform these calculations, a computer model needs a series of input parameters, such as:

density as a function of radius
rotation rate
magnetic field
temperature as function of radius
chemical composition

We can check the computer model by observing boundary conditions, things that we can measure at the surface of the planet, such as:

total mass
mean density
surface temperature
strength of magnetic field at surface
thickness of crust
seismic activity

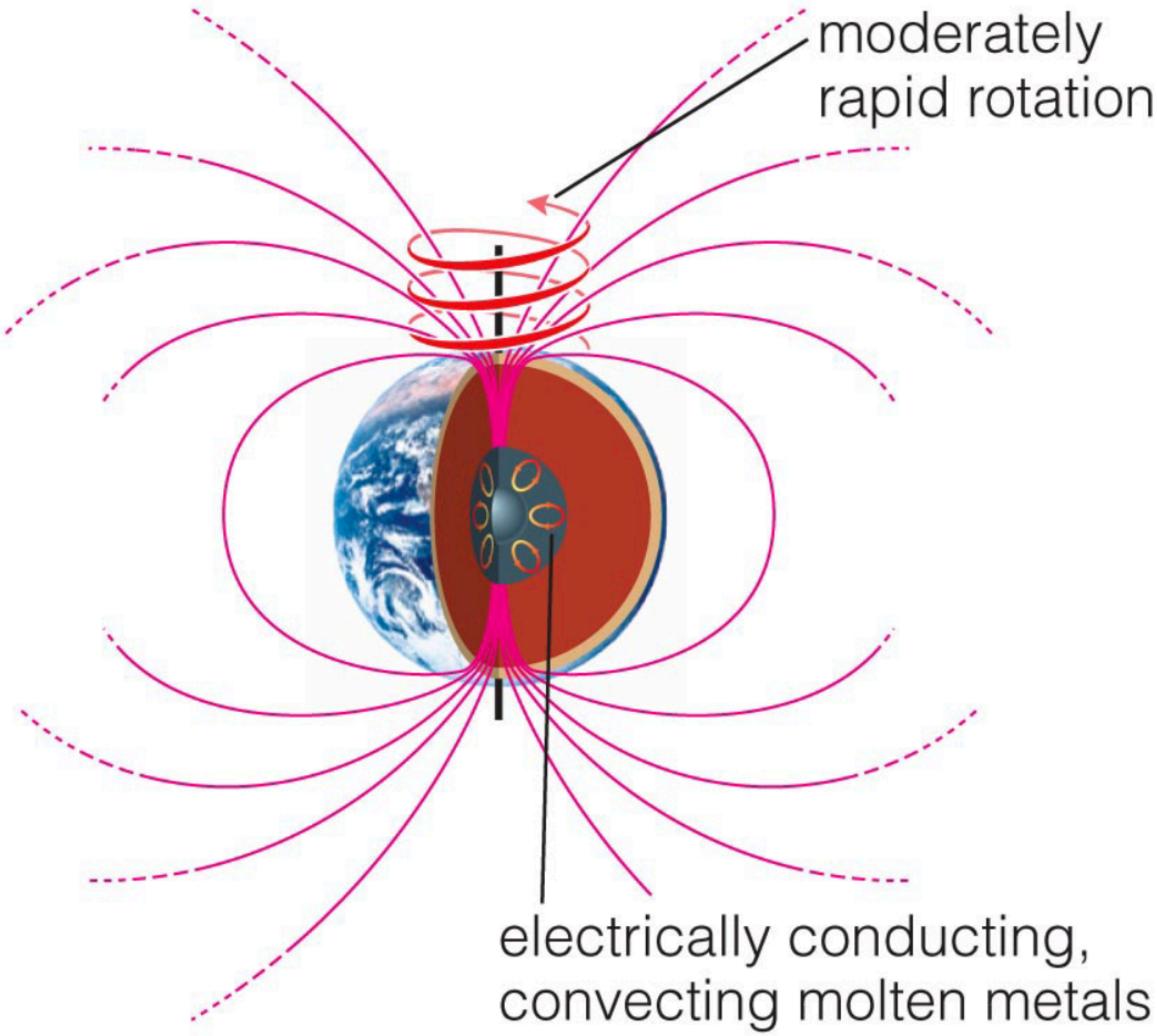




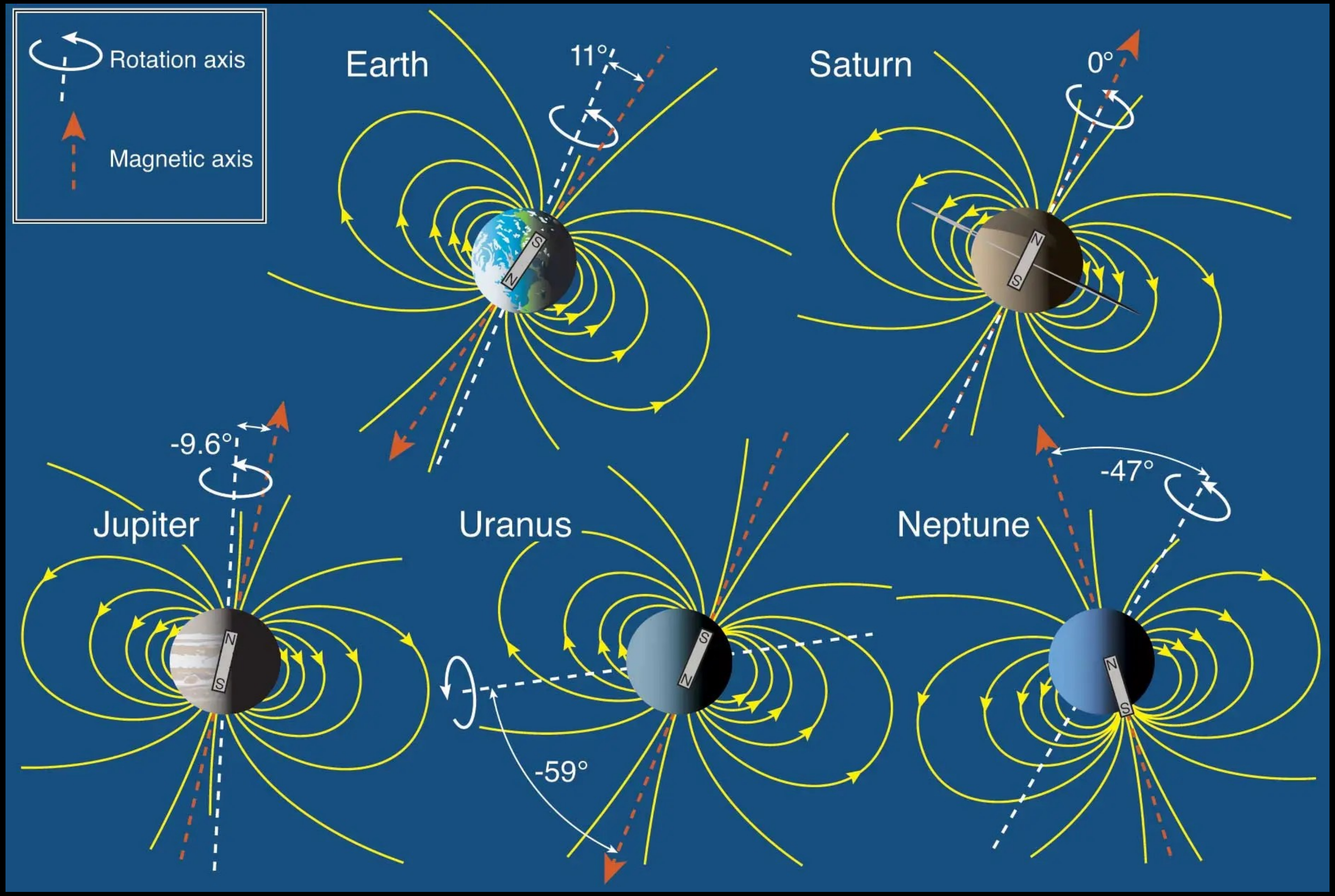
A planet's magnetic field also provides a peek into its interior. For planetary magnetic fields are generated deep in the core of the world. Our understanding of the origin to magnetic fields in planets is very poor.

We know that the Earth's magnetic field must be a generated field and we know that a conducting fluid in motion generates a dipole magnetic field. The nature of this field and its evolution is governed by the area known as magnetohydrodynamics. The liquid outer core of the Earth is the conducting fluid, free electrons being released from metals, such as Fe (iron) and Ni (nickel), by friction and heat.

Sources of Magnetic Fields



- A world can have a magnetic field if charged particles are moving inside.
- Three requirements:
  – Molten, electrically conducting interior
  – Convection
  – Moderately rapid rotation

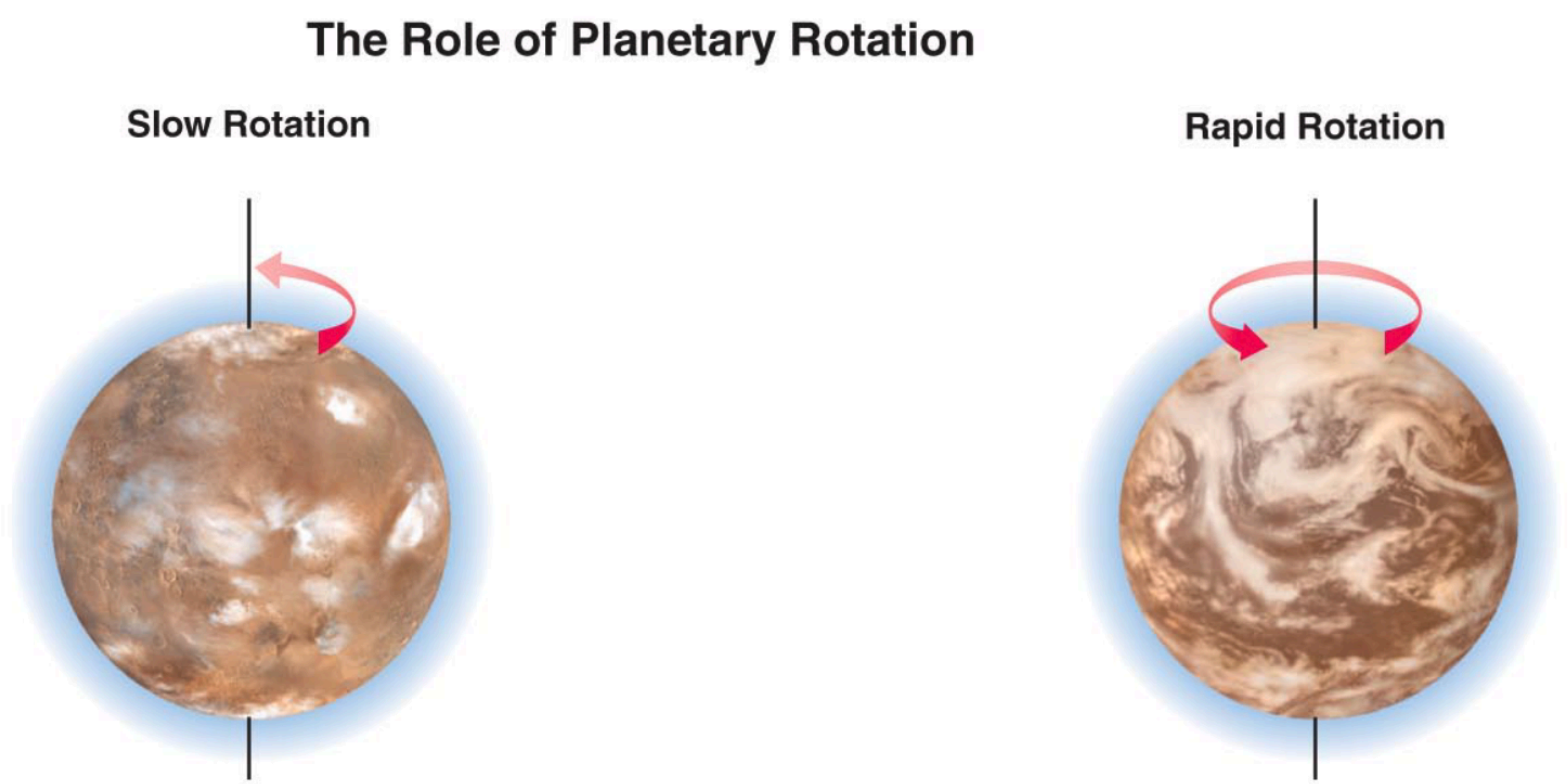


For the planets it is key to know that a magnetic field indicates that:

1) the planet has a large, liquid core
2) the planet has a core rich in metals (source of free electrons)
3) the planet has a high rotation rate

The strength of the magnetic field is telling you something about the combination of the above factors. For example, Mercury has a weak magnetic field. But, since it has a very low rotation rate we conclude that it has a large liquid core. Mars has a high rotation rate (similar to Earth's), but a magnetic field that is 1/800th the strength of the Earth's. Therefore, we conclude that Mars has a very small core.

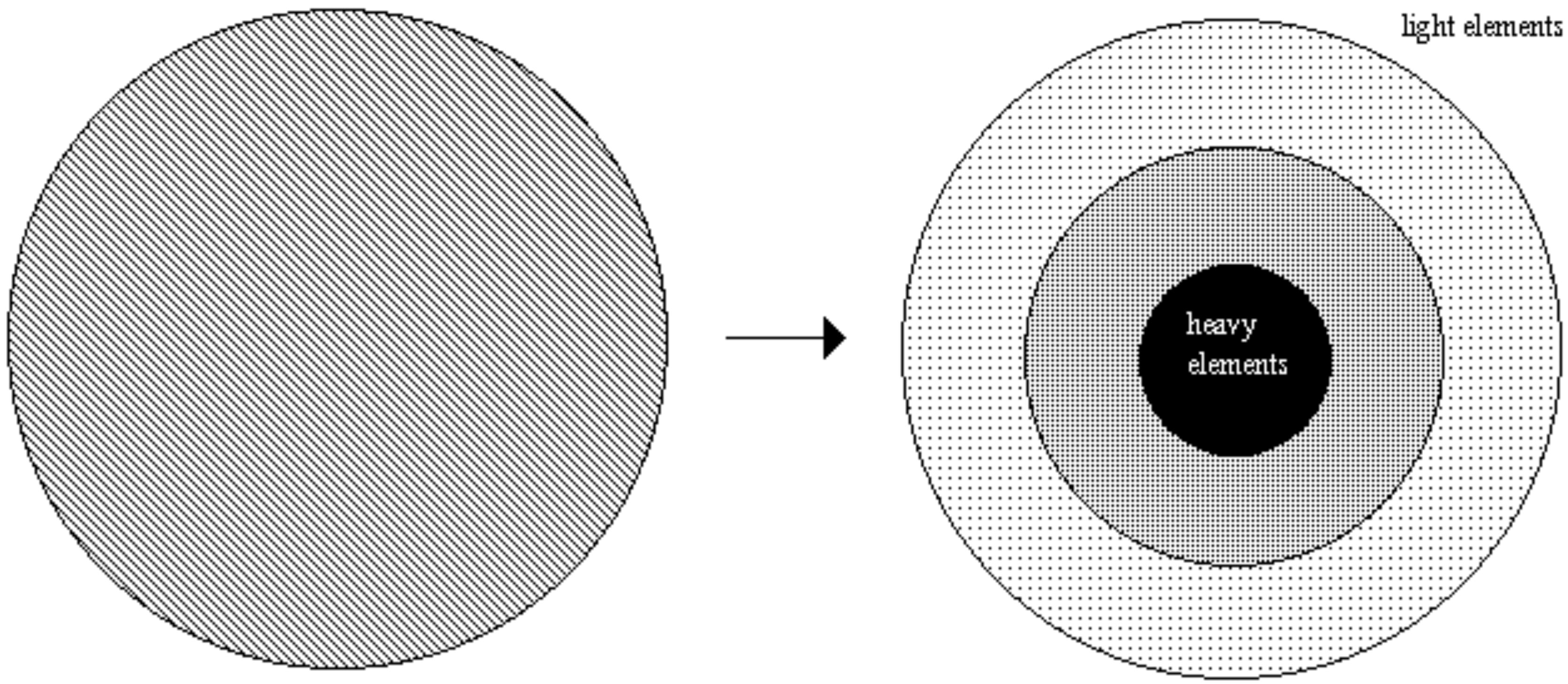
Role of Rotation

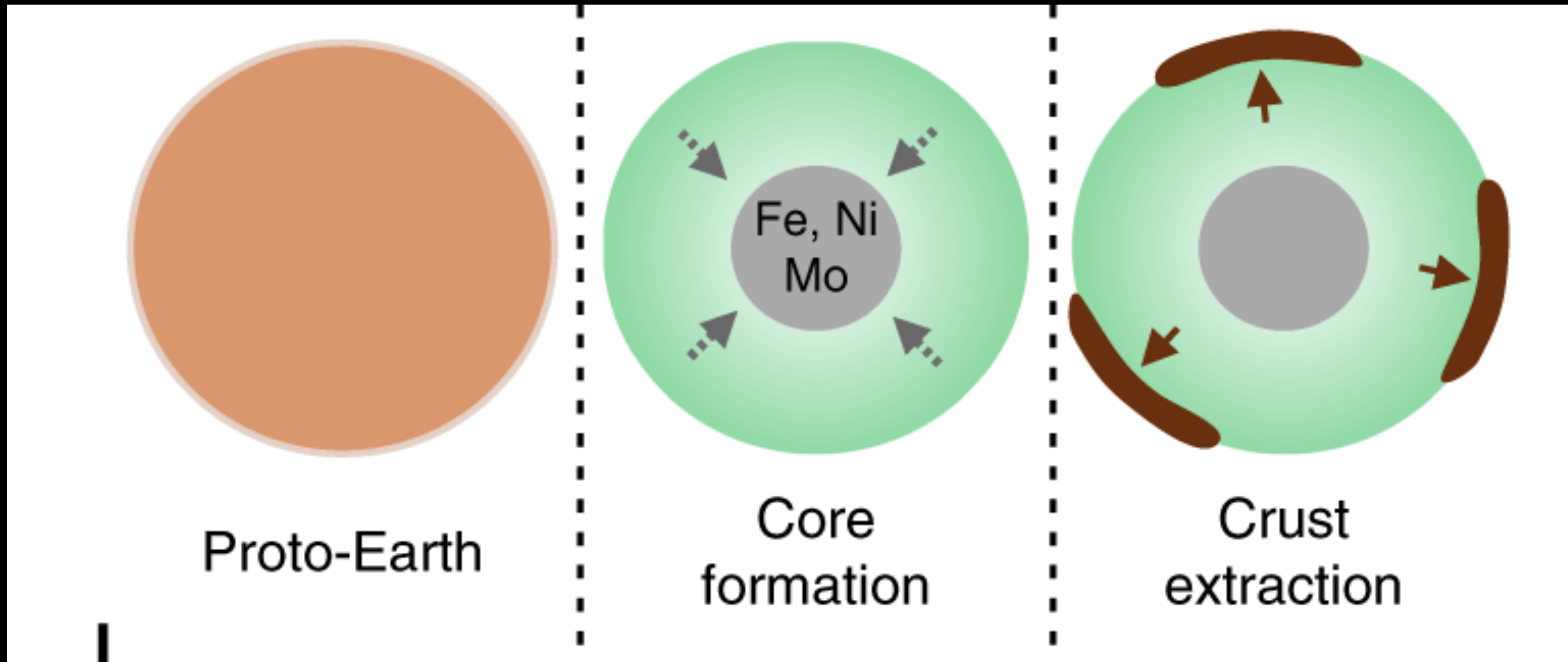


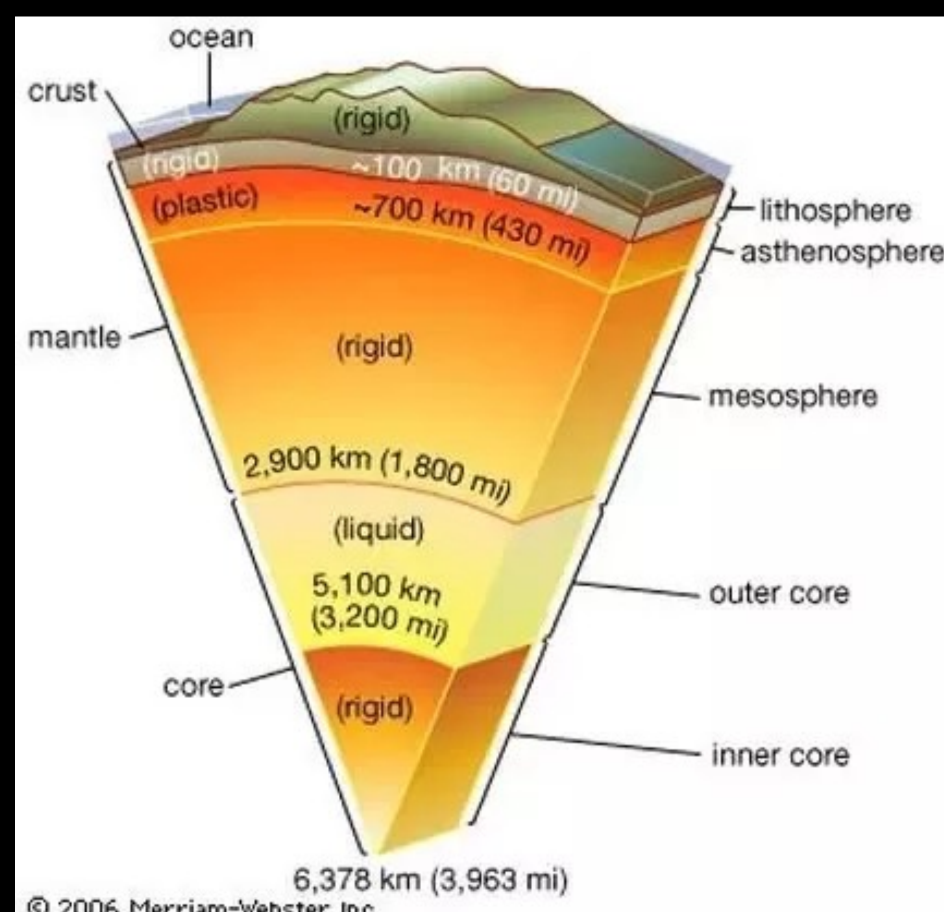
- Planets with slower rotation have less weather, less erosion, and a weak magnetic field.
- Planets with faster rotation have more weather, more erosion, and a stronger magnetic field.

Chemical Fractionation

when a planet initially forms, is interior is evenly mixed in composition. As time passes (a few million years) the heavy metals sink to the center, lighter elements rise to the top.




Fe, Ni
Mo
Proto-Earth
Core
formation
Crust
extraction


ocean
crust
(rigid)
(rigid)
~100 km (60 mi)
(plastic)
~700 km (430 mi)
lithosphere
asthenosphere
mantle
(rigid)
mesosphere
2,900 km (1,800 mi)
(liquid)
5,100 km
(3,200 mi)
outer core
core
(rigid)
inner core
6,378 km (3,963 mi)
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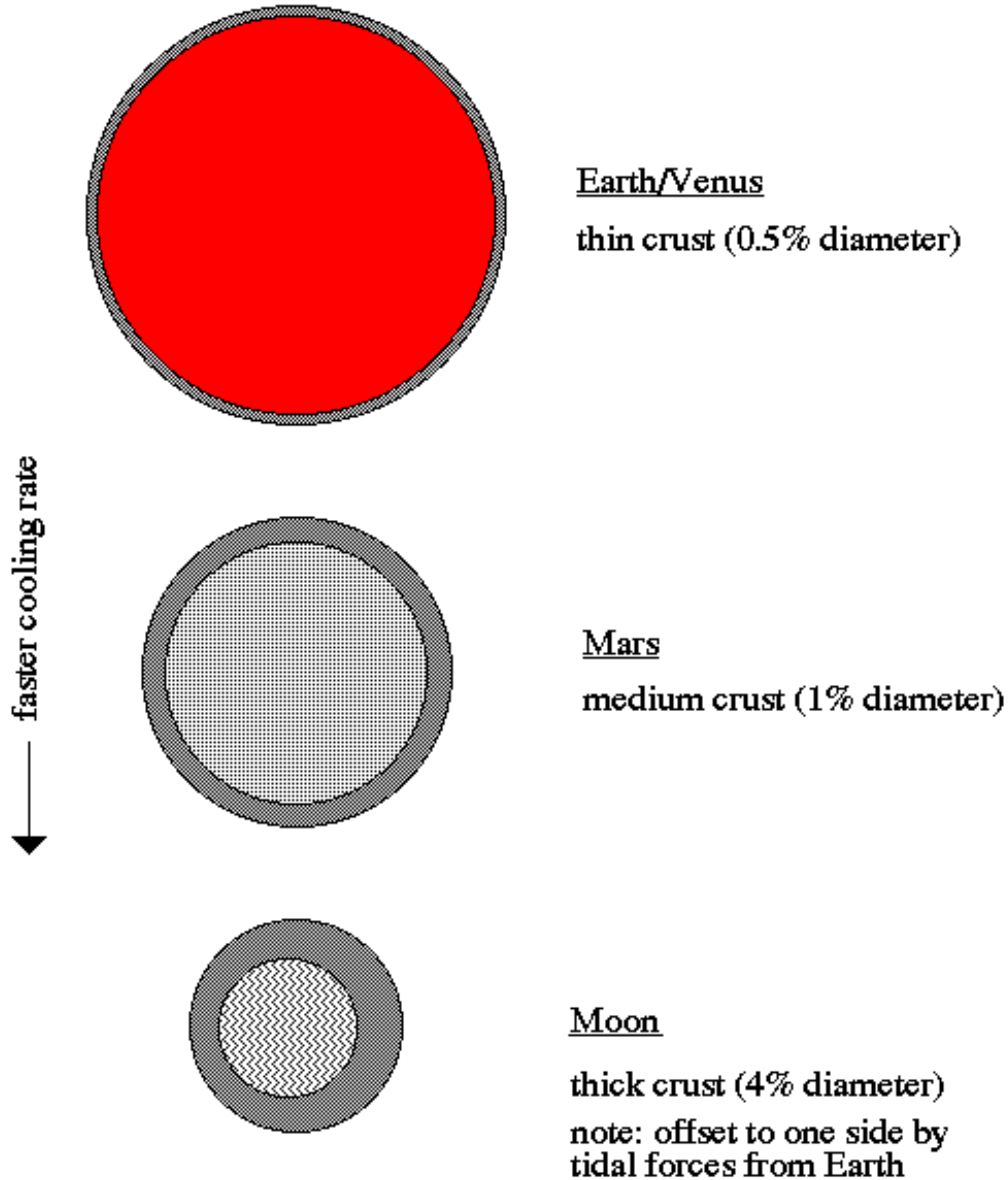
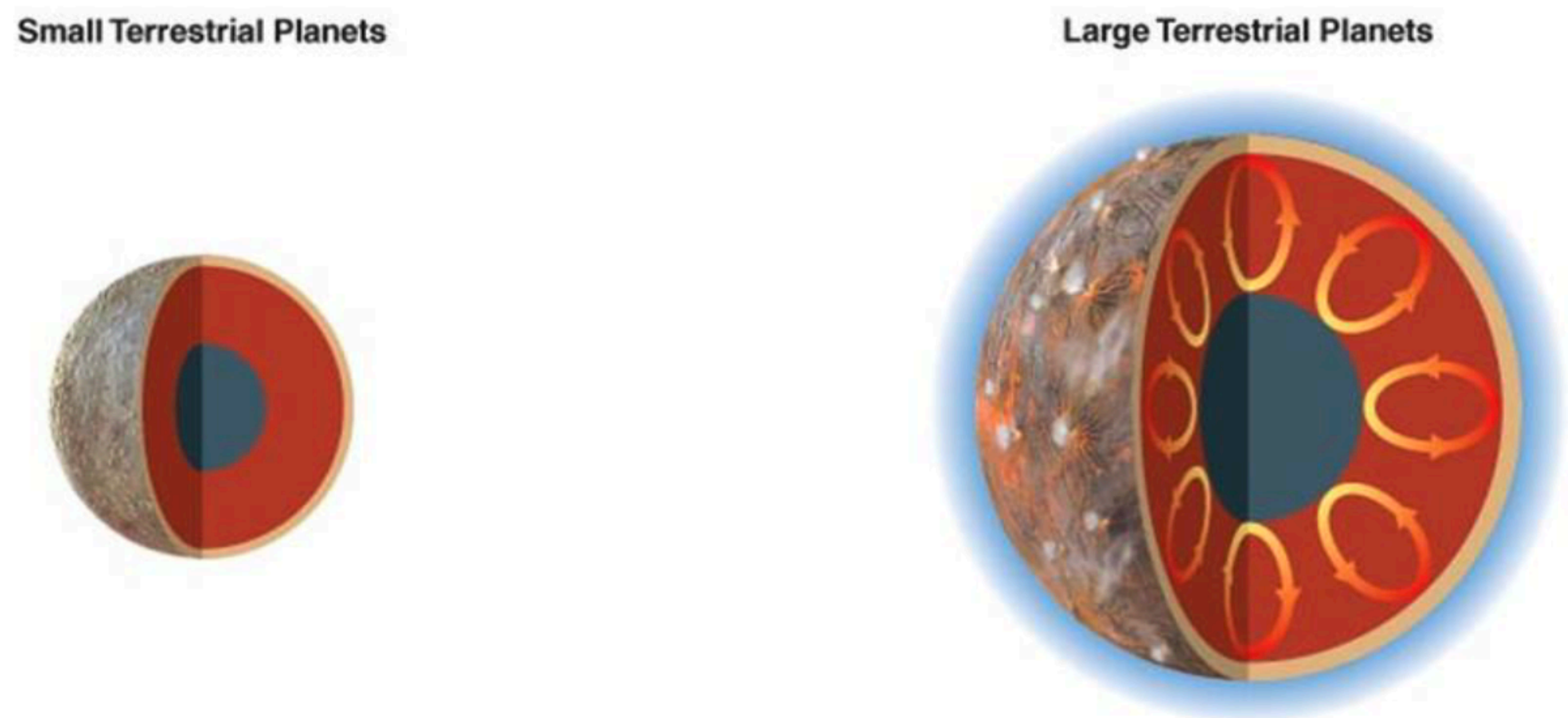
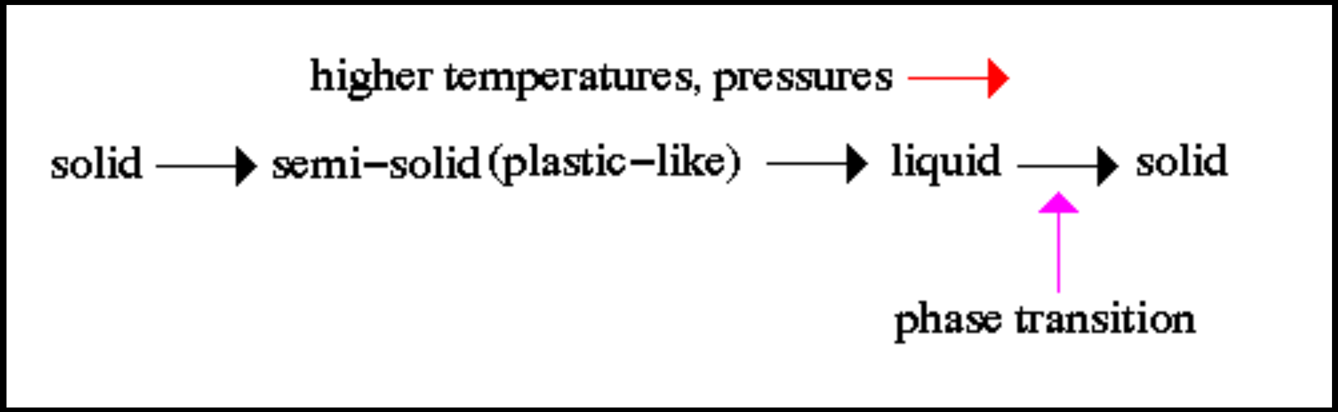


(crust thickness not drawn to scale)

Role of Planetary Size

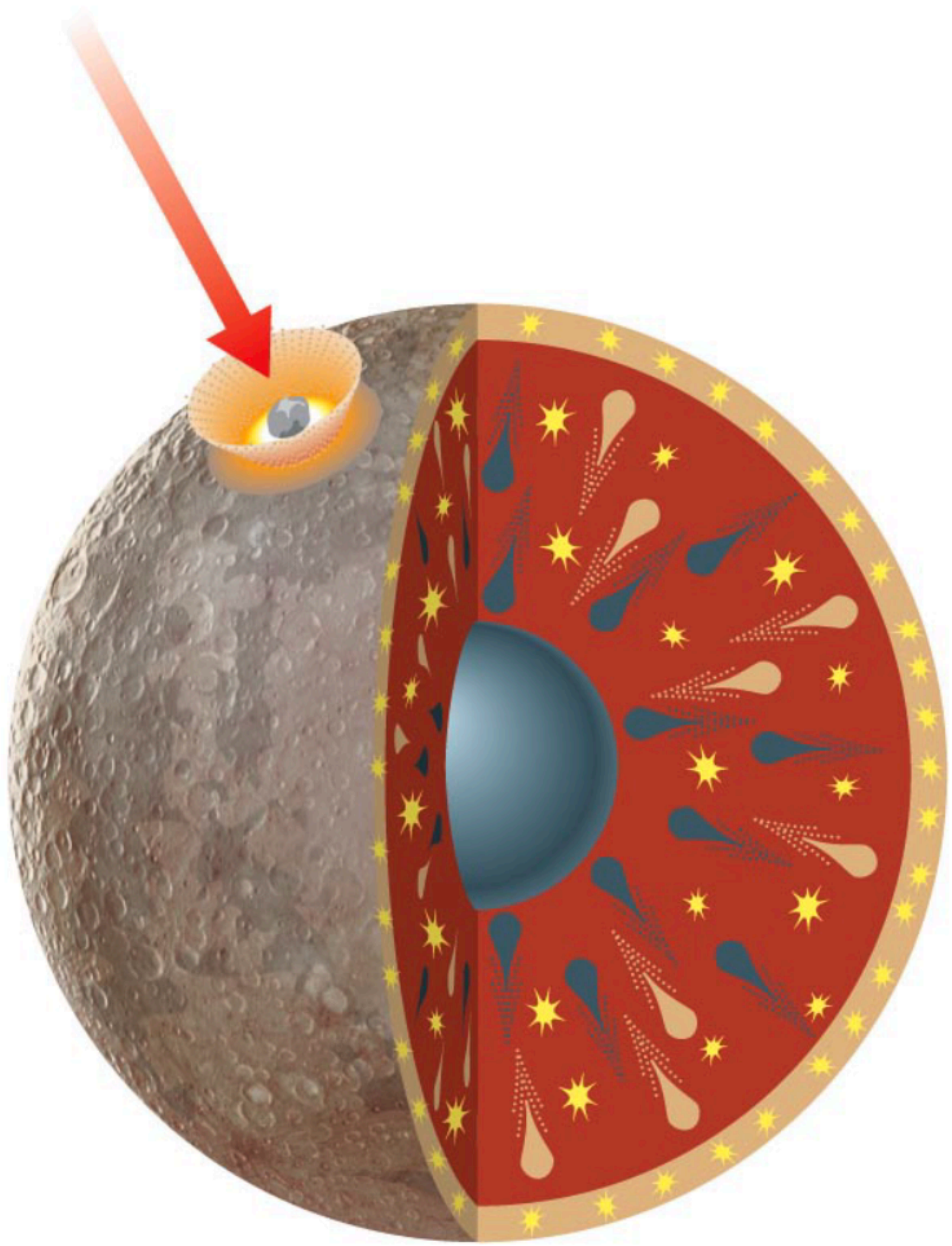


- Smaller worlds cool off faster and harden earlier.
- Larger worlds remain warm inside, promoting volcanism and tectonics.
- Larger worlds also have more erosion because their gravity retains an atmosphere.



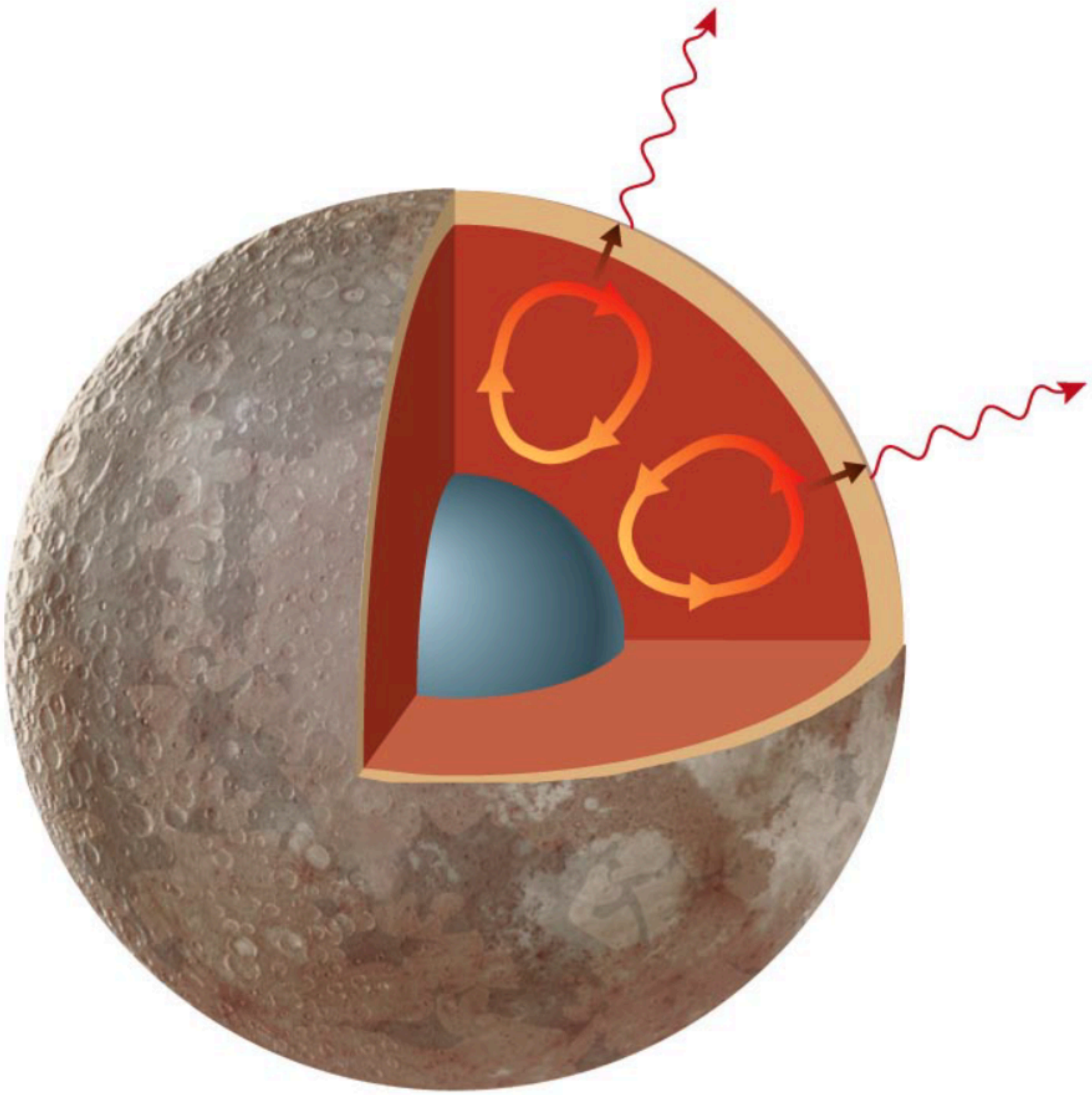
The make-up of planet interiors is dominated by the physics of materials under high temperatures and pressures. Starting with cold, low pressure regions, rocky materials are straight solids. As one goes deeper into a planet the temperature and pressures go up. Solids become semi-solid, plastic-like materials. With higher temperatures and pressures, semi-solids become liquids. With even higher temperatures and pressures liquid or molten rocky materials undergo a phase change and become solids again. That is why the very inner cores of the Earth and Venus are solid, surrounded by liquid outer cores.

Heating of Planetary Interiors



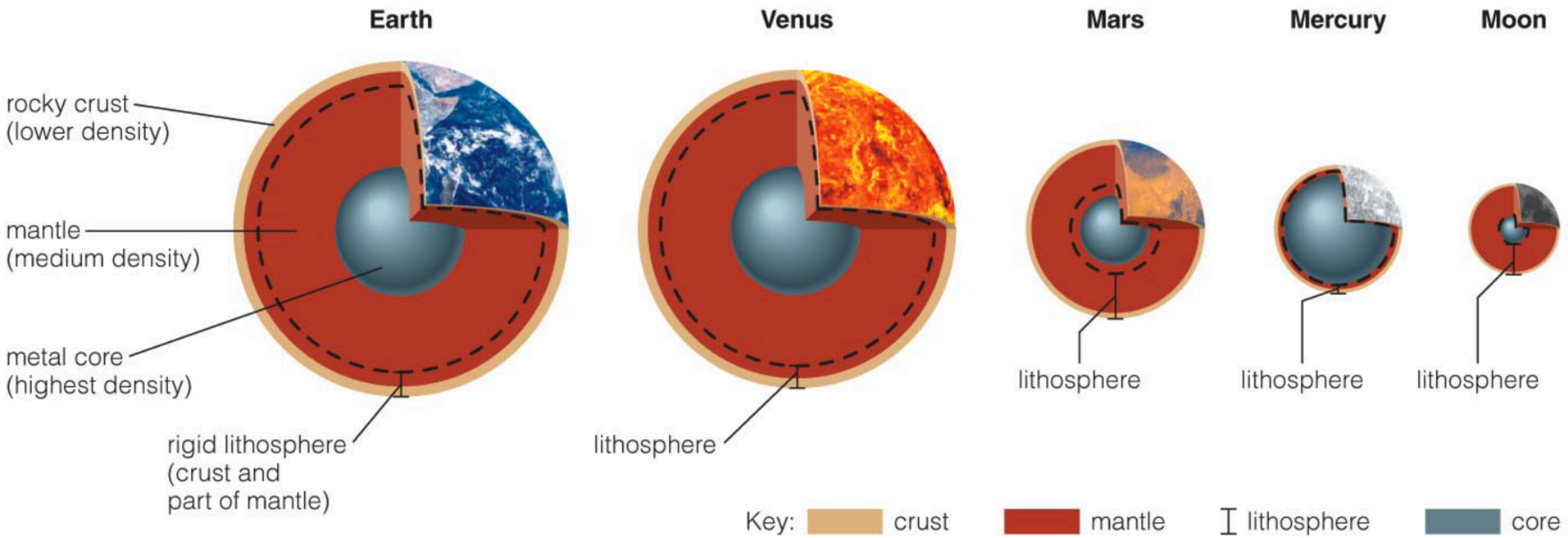
- **Accretion** and **differentiation** when planets were young
- **Radioactive decay** is most important heat source today.

Cooling of Planetary Interiors



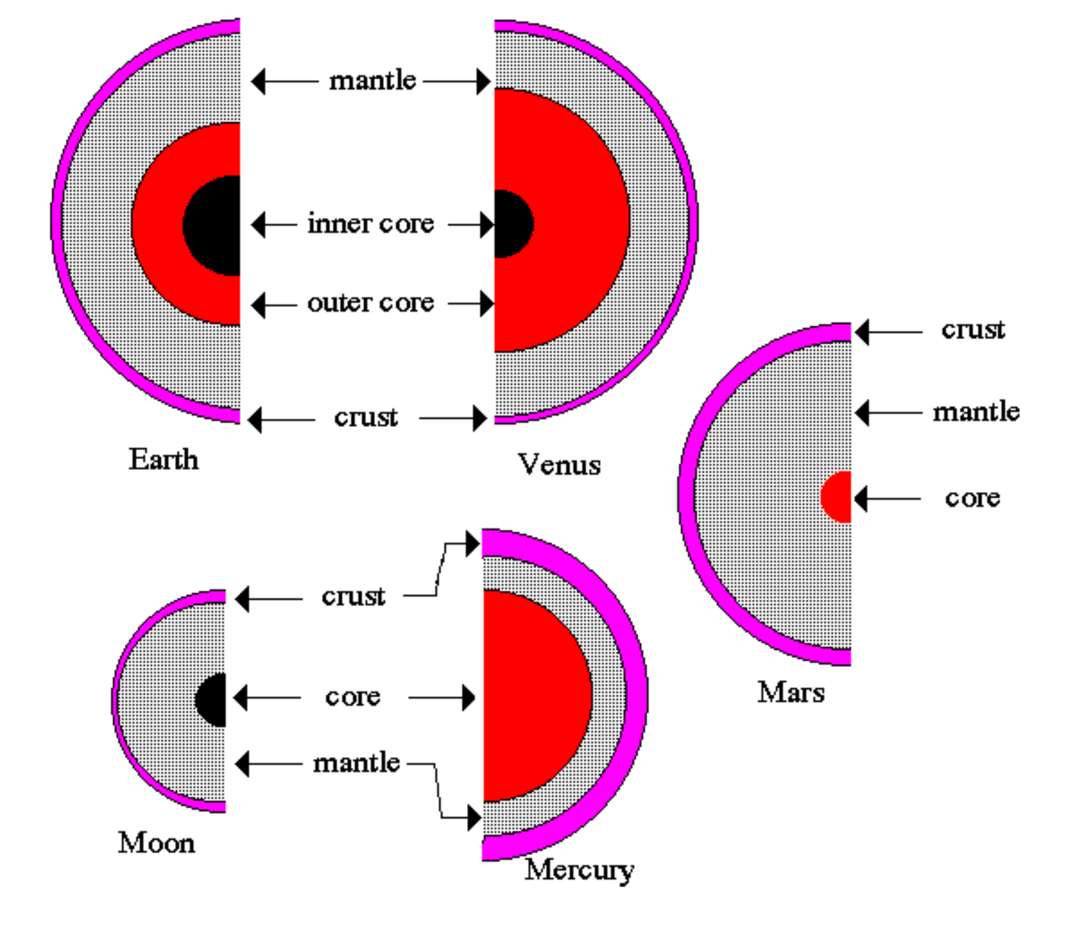
- **Convection** transports heat as hot material rises and cool material falls.
- **Conduction** transfers heat from hot material to cool material.
- **Radiation** sends energy into space.

Role of Size



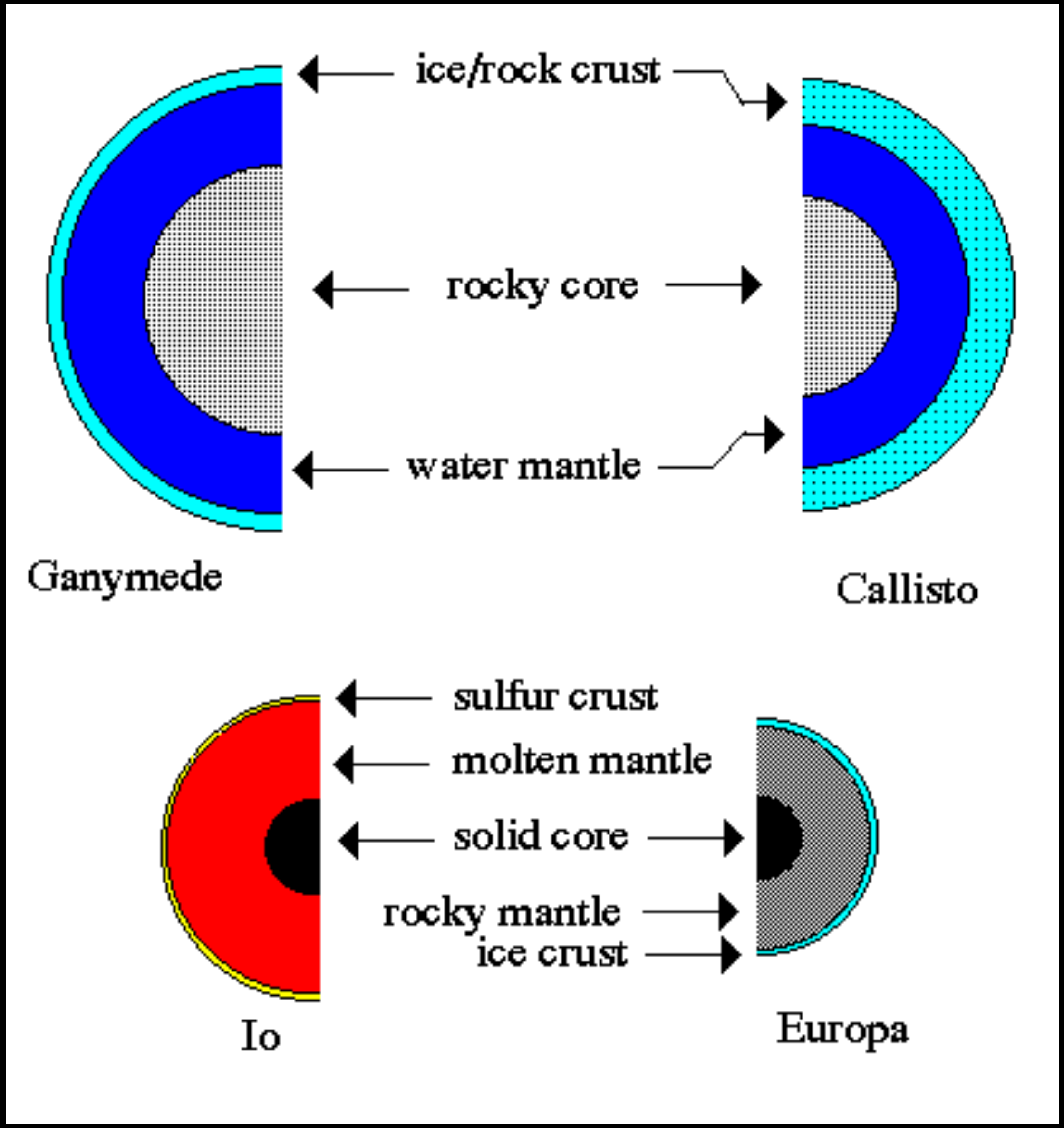
- Smaller worlds cool off faster and harden earlier.
- The Moon and Mercury are now geologically "dead."

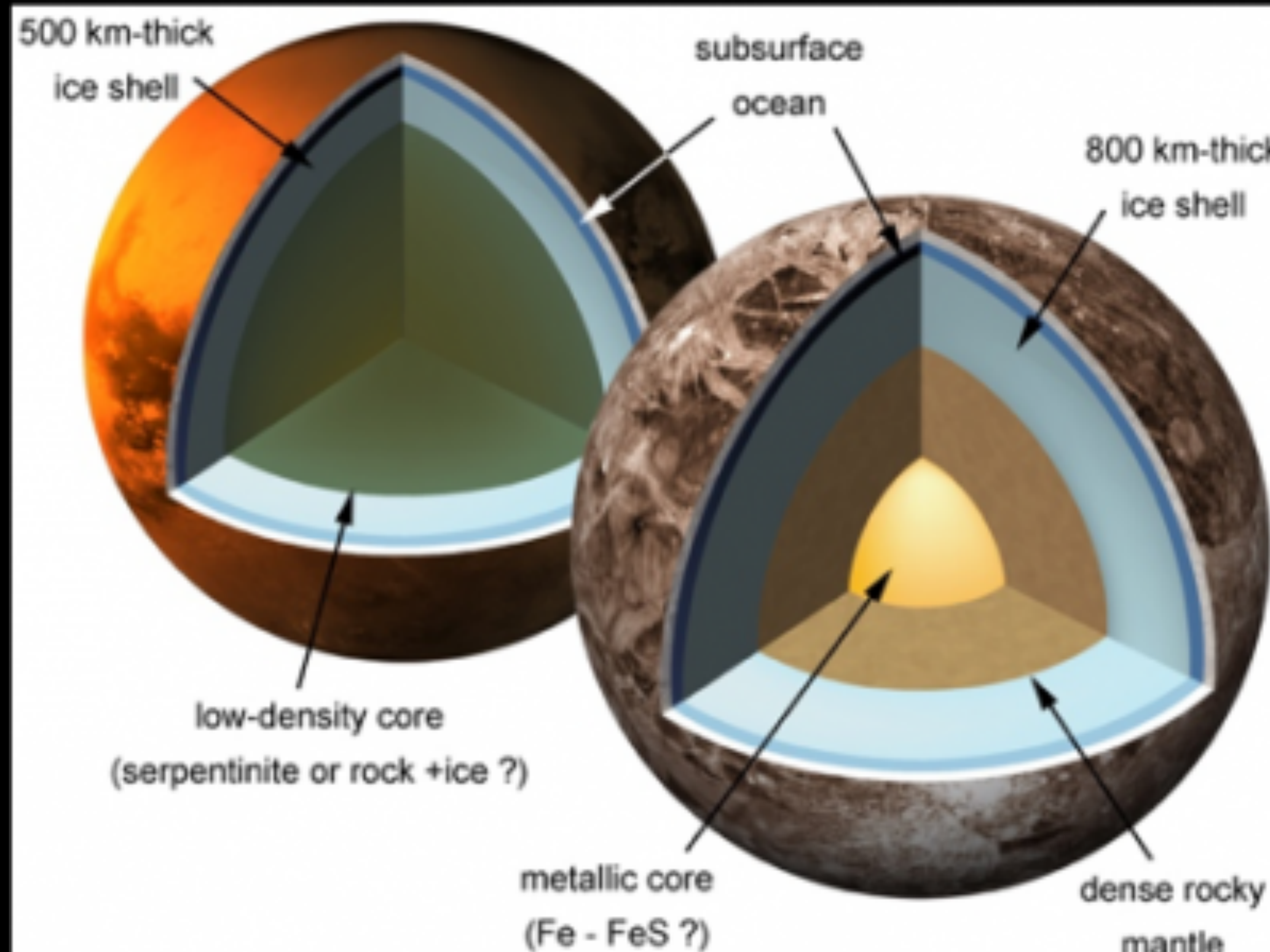
Why doesn't Venus have a magnetic field? Being much hotter than the Earth, it is likely that Venus has a metallic liquid outer core, but is unlikely to be convecting. Is there no inner core to drive convection? Or is the core in a steady hot state, i.e., no cooling? Or is a reversal currently occurring (magnetic steady-state)?



What is the state of Mars' core? Although Mars does not have a magnetic field, significant magnetisation of the crustal rocks suggest that a dynamo existed in the past and has since ceased operation. Was this due to the cooling and solidification of the convecting liquid or perhaps some other process involving a change in the dominant heat transfer mechanism?

The icy bodies of the outer solar system differ widely in internal structure and surface morphology, their current state reflecting the heat generation and transport in their interiors. From the smallest to the largest of these bodies, there is evidence for liquid water beneath an outer shell of ice.





Jupiter's moon Callisto seems scarcely to have differentiated and to have experienced little endogenic activity, whereas Ganymede (see figure) is differentiated, with a probable liquid iron core generating an intrinsic magnetic field, and a surface mouldedby a billion years of extensional activity and cryovolcanic flooding. Saturn's moon Titan (see figure) has a low-density core, consisting of either a rock-ice mixture or hydrous silicates (there is no Fe inner core, and no magnetic field), and yet it has outgassed to create a dense atmosphere. In all three cases, there is evidence for global oceans under 10s to 100s of km of ice.