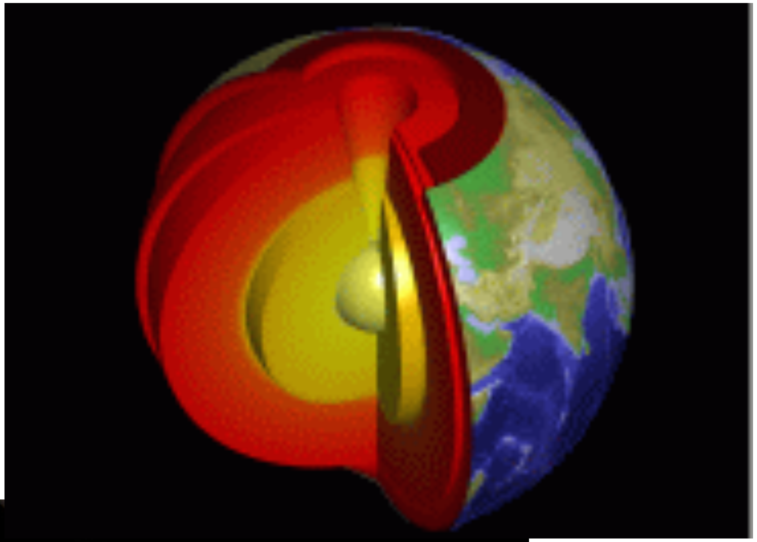
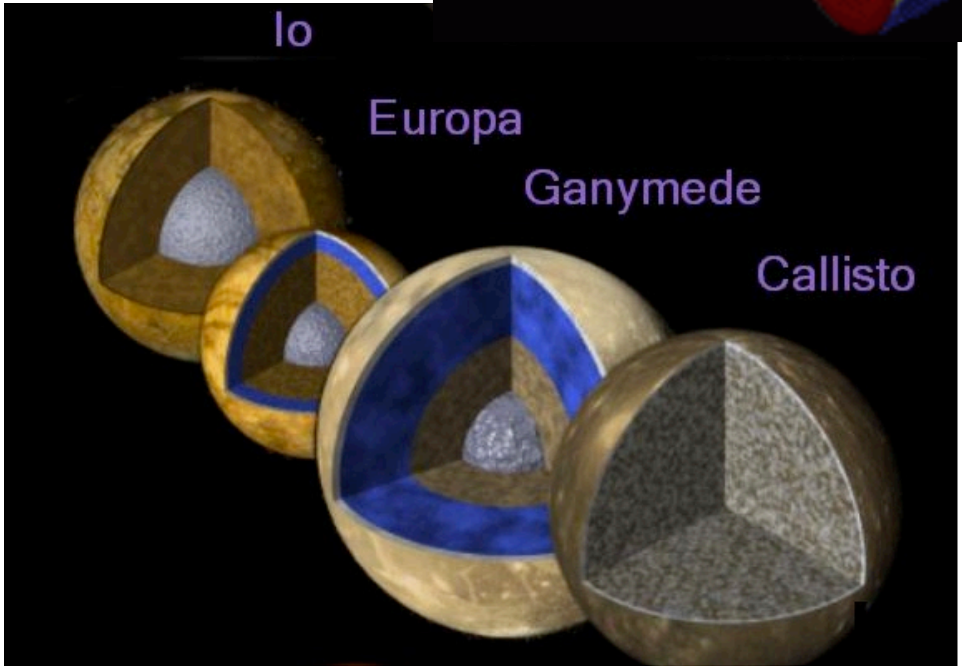
Planetary Interiors

Read chapter 6!!





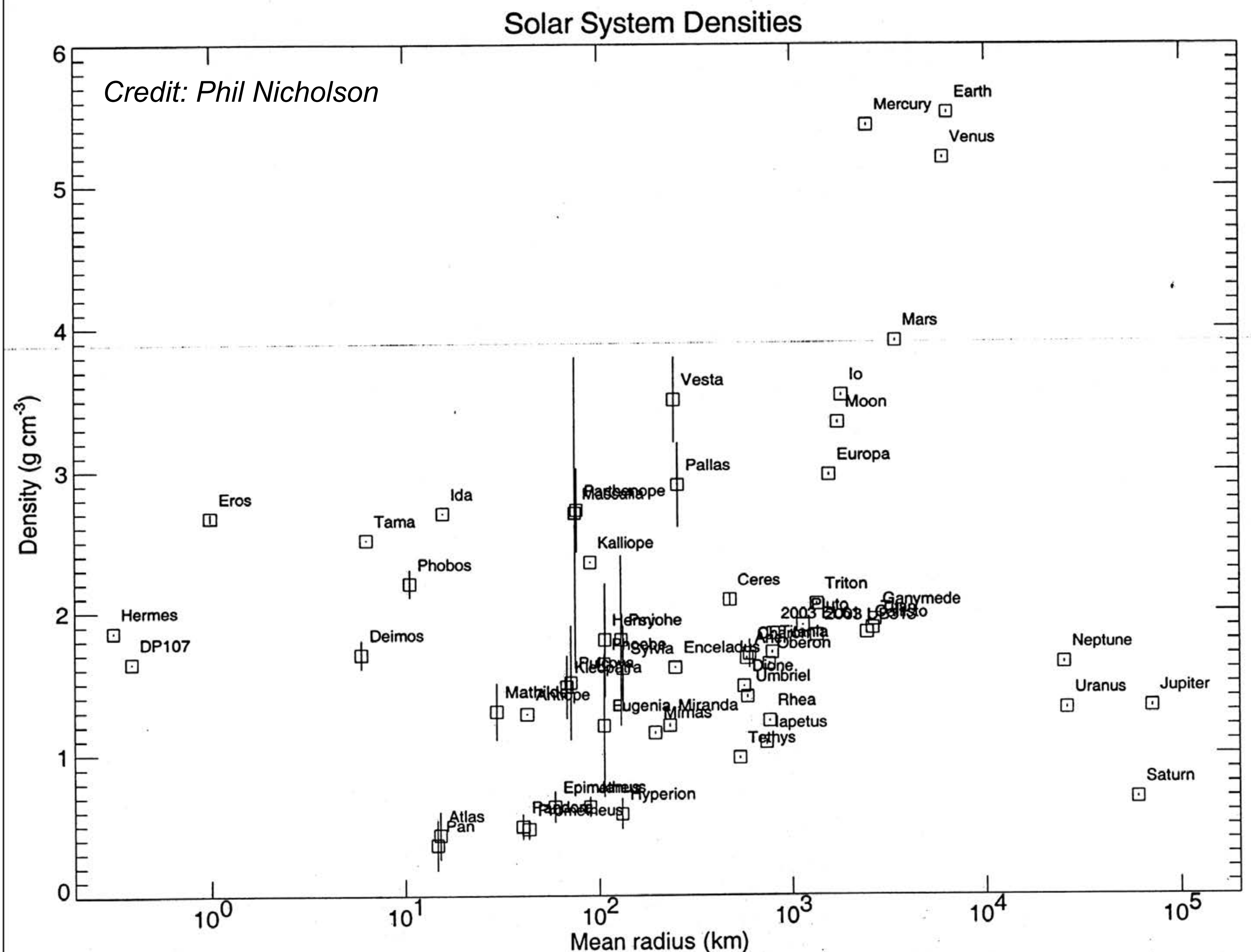
Planetary Interiors

We'd like to know:

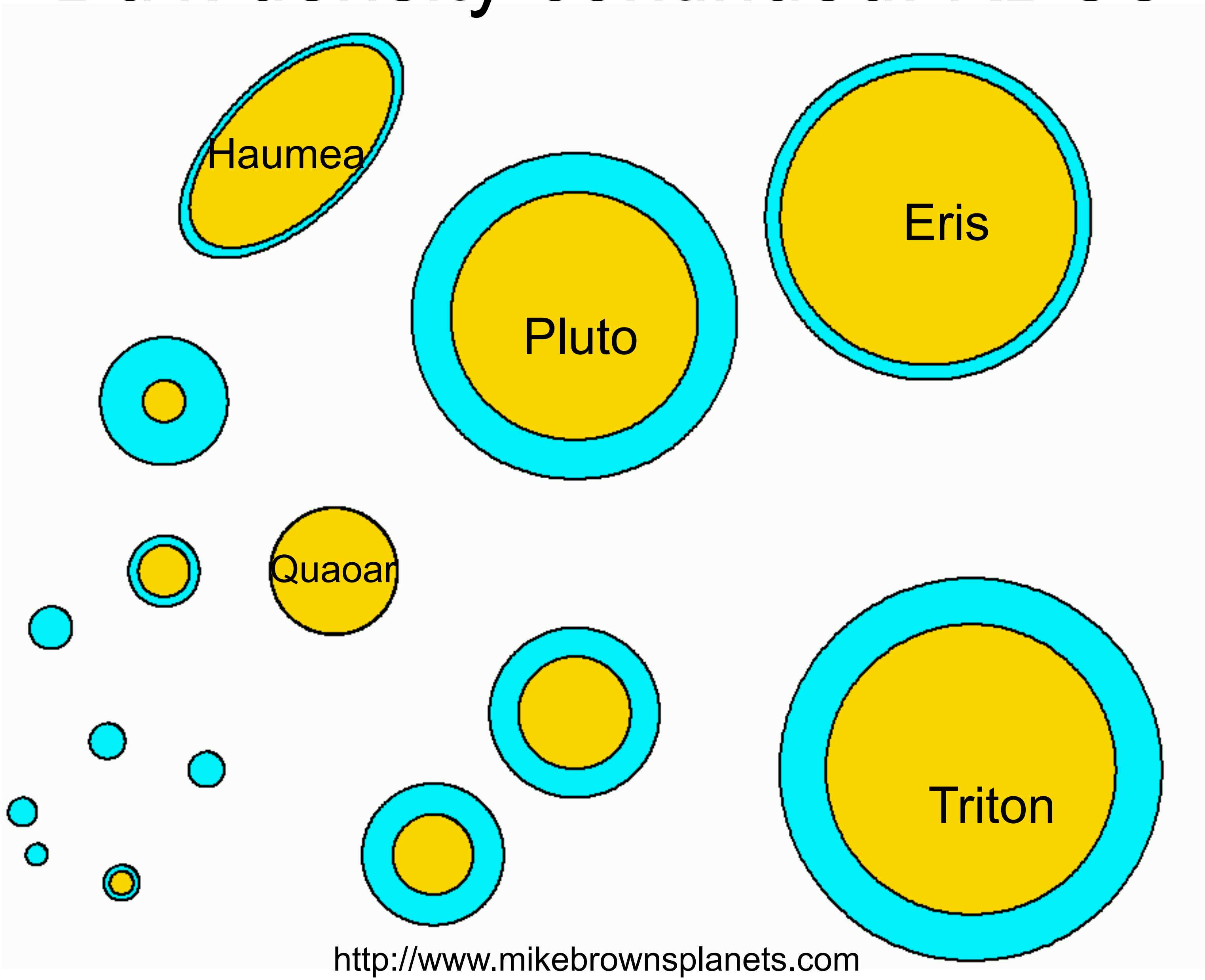
- Composition (bulk, and how it varies w/ depth)
- State of matter (function of temperature, pressure)
- Sources of internal energy

What we can measure:

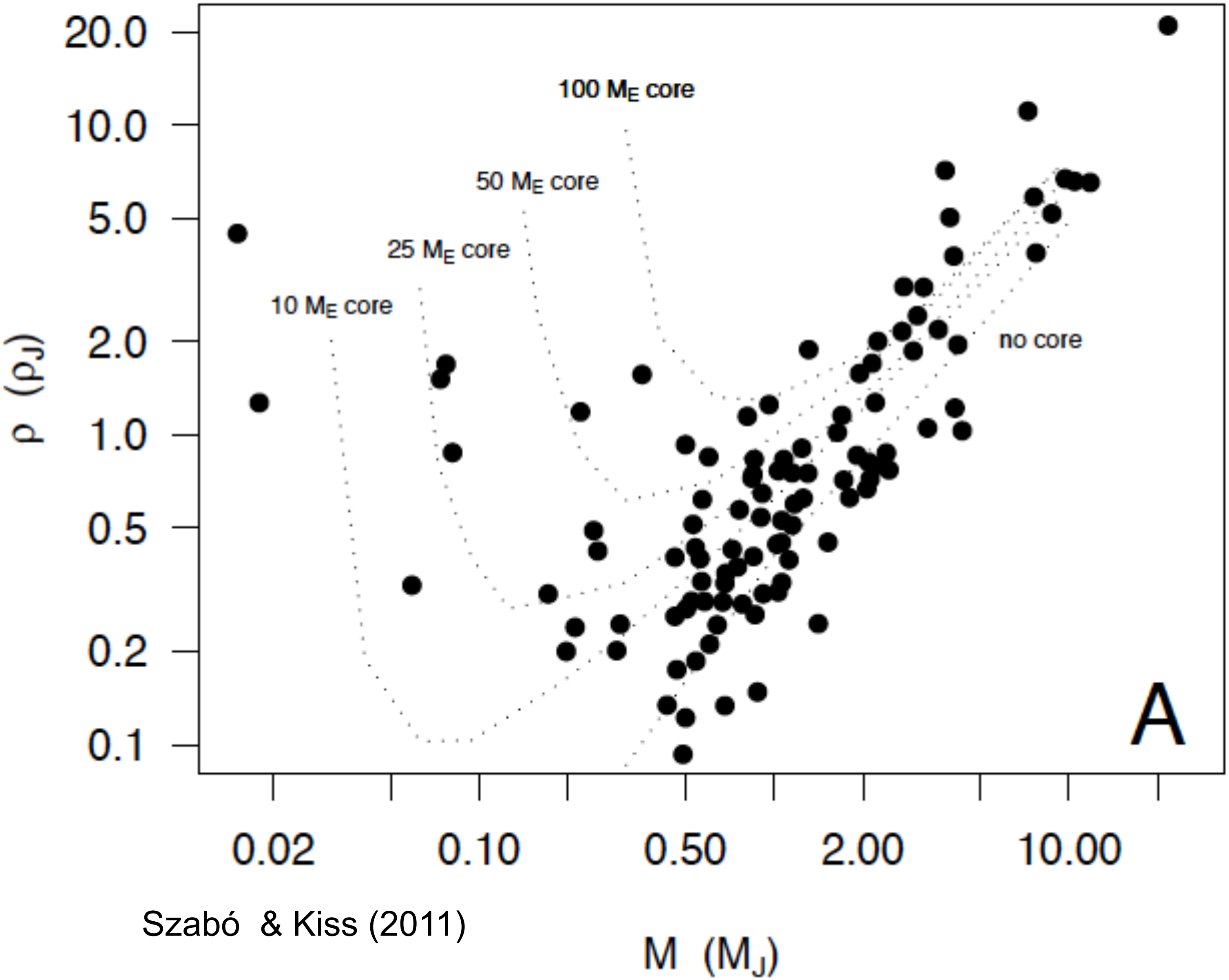
- Surface/atmospheric composition
- Mass, radius (→density)
- Gravity field
- Rotation and oblateness
- Magnetic field
- Temperature → heat flux
- Seismic wave propagation
- Topography, surface morphology


Solar System Densities
Credit: Phil Nicholson
Density (g cm^{-3})
Mean radius (km)
0
1
2
3
4
5
6
10^0
10^1
10^2
10^3
10^4
10^5
Earth
Mercury
Venus
Mars
Io
Moon
Europa
Vesta
Pallas
Eros
Ida
Tama
Kalliope
Phobos
Ceres
Triton
Ganymede
Hermes
DP107
Deimos
Enceladus
Oberon
Umbriel
Rhea
Iapetus
Tethys
Miranda
Eugenia
Neptune
Uranus
Jupiter
Saturn
Hyperion
Atlas
Pan

Bulk density continued: KBOs



Bulk density continued: exoplanets



Szabó & Kiss (2011)

Planetary Interiors

Earth's Interior Structure

Hydrostatic Equilibrium

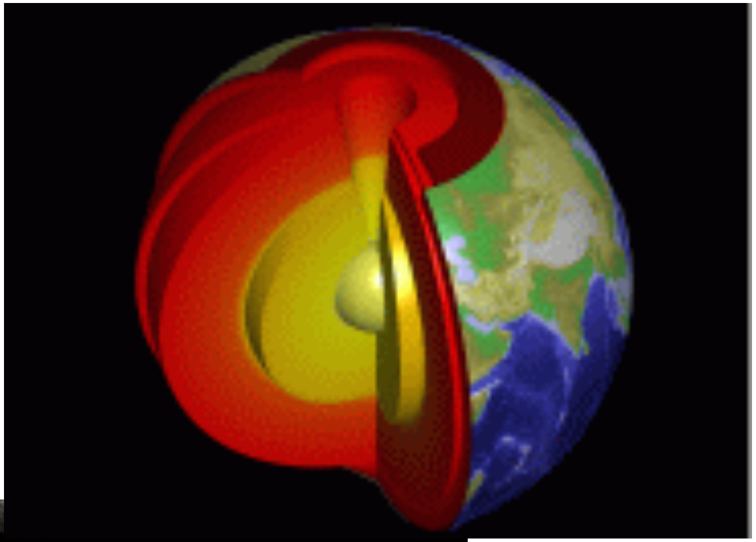
Heating

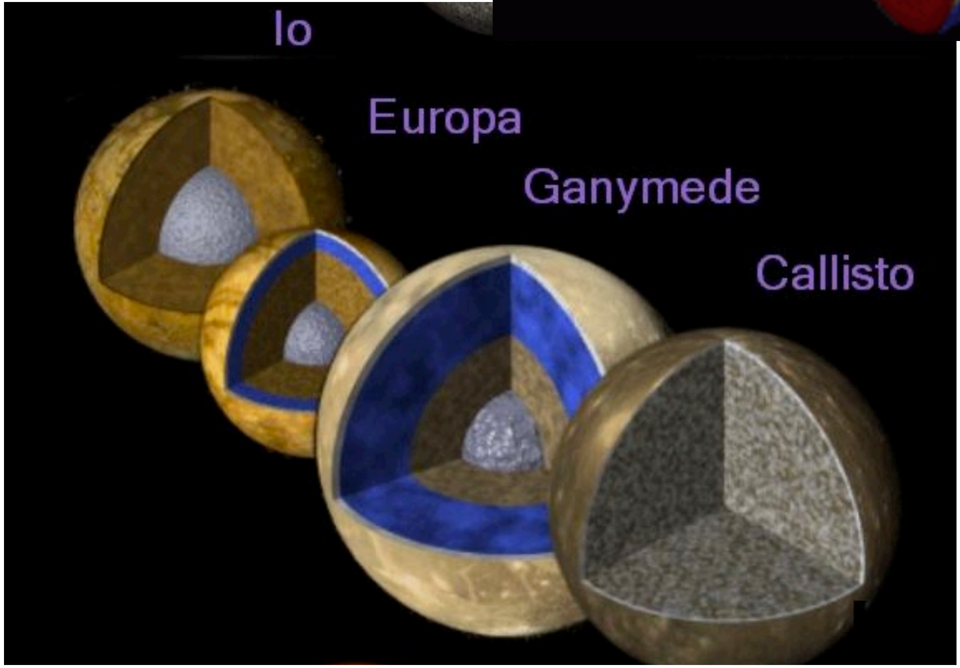
Constituent Relations

Gravitational Fields

Isostasy

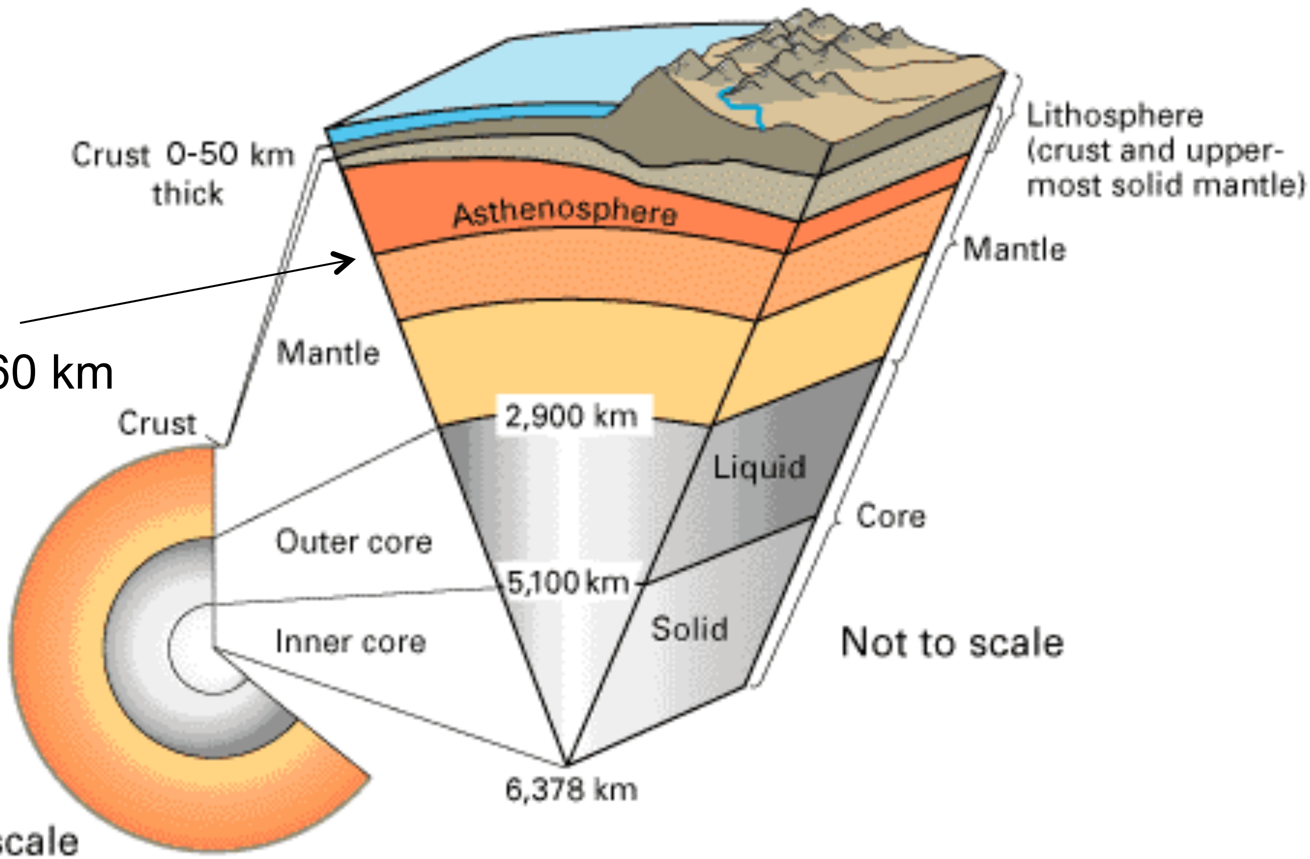
Magnetism





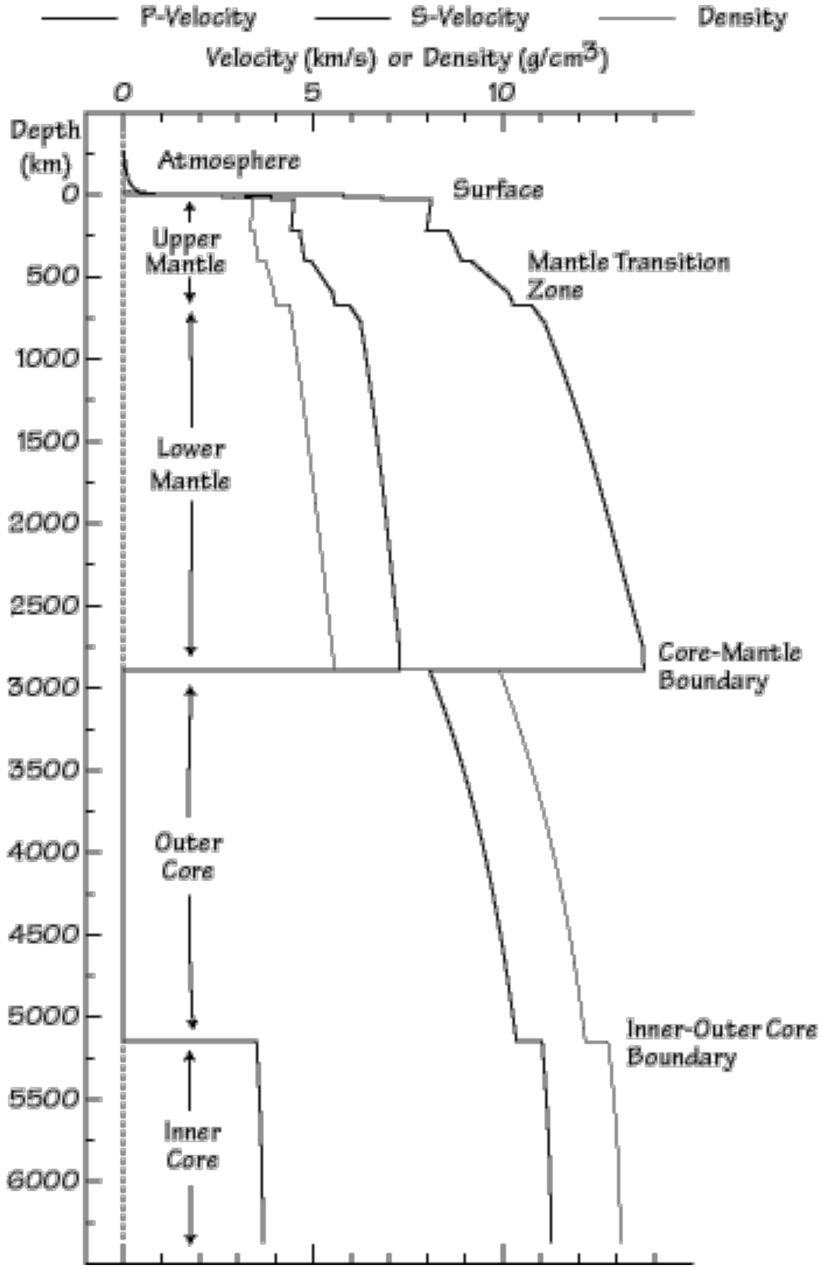
Earth's Interior - Our Terrestrial Template

Mineral phase transition @ 660 km

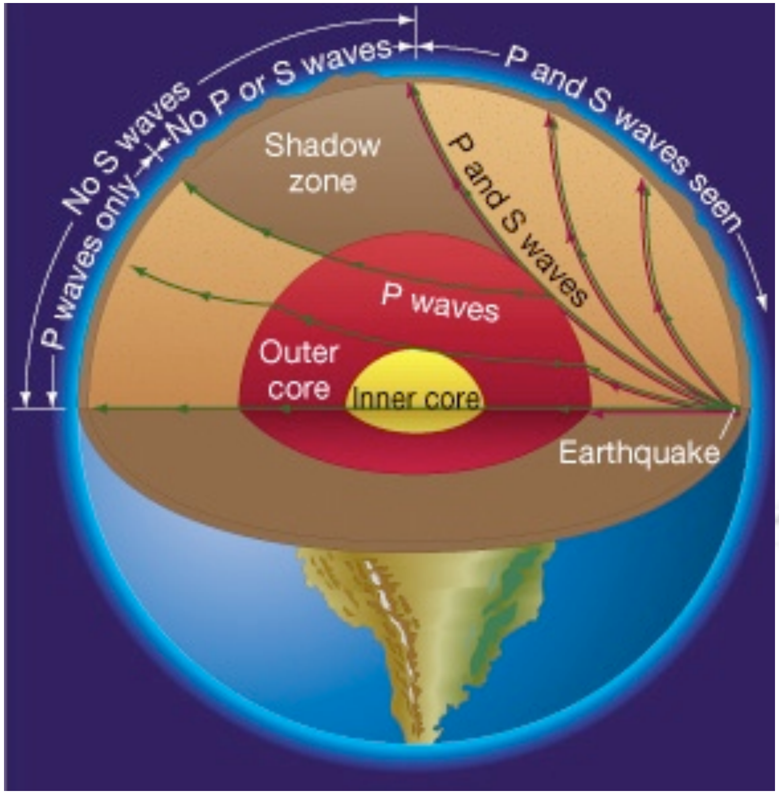


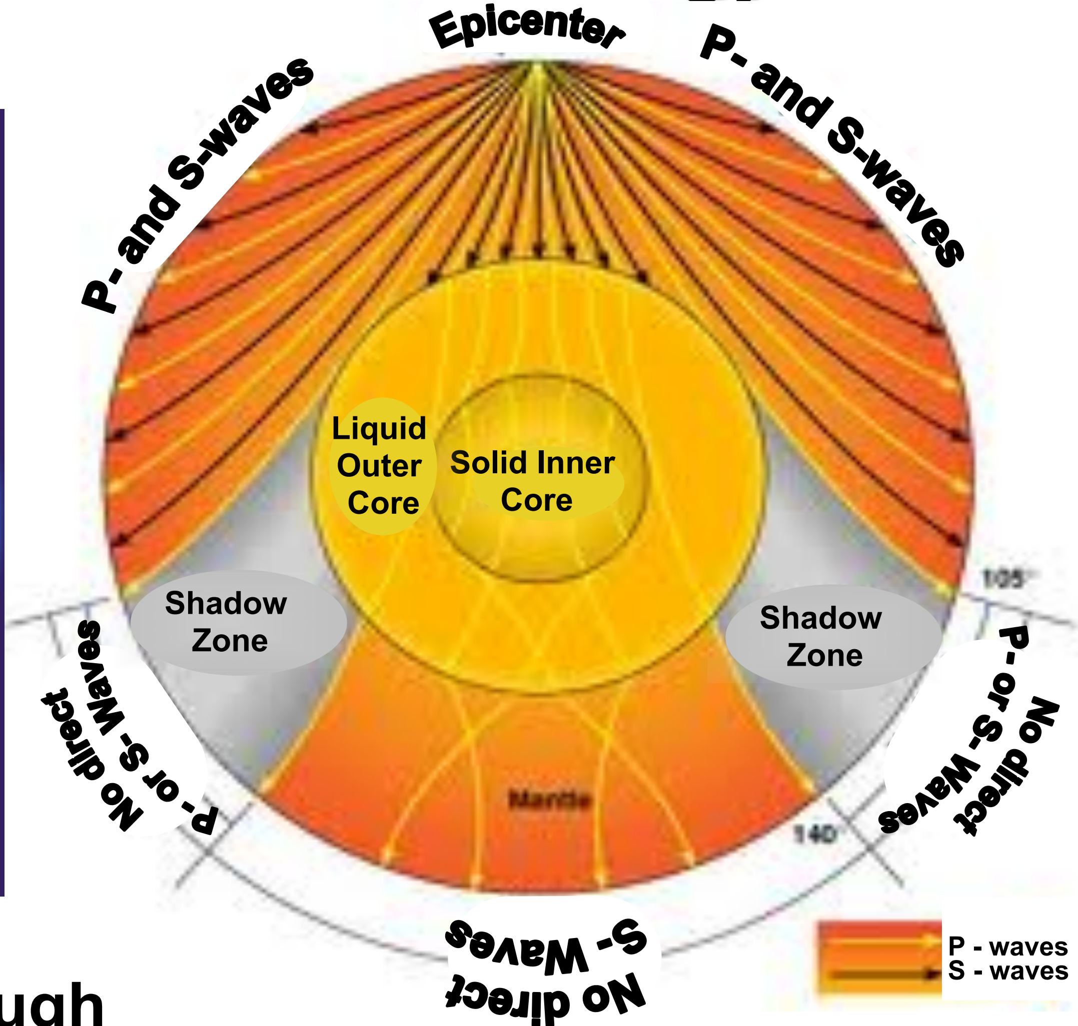
Determined through a combination of observation and modeling, validated/refined via seismology.

Earth's Interior - Our Terrestrial Template



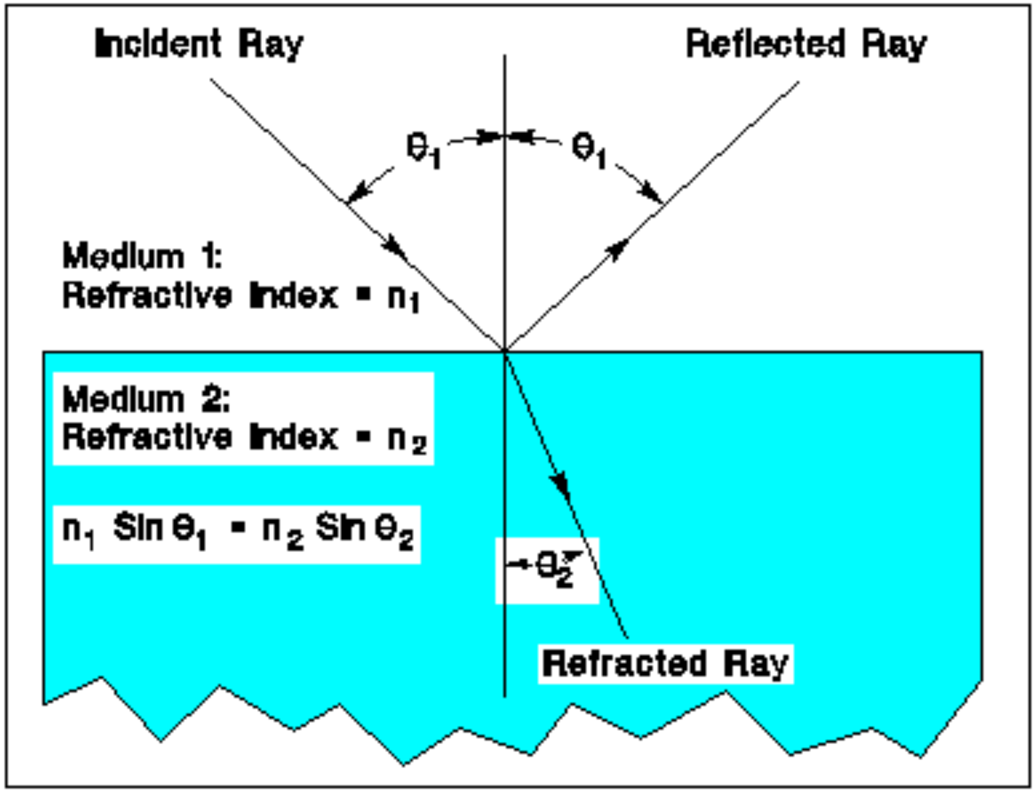
Earth’s Interior - Seismology





P - waves can travel through the liquid outer core, while S - waves cannot. Waves are also deflected away from areas of higher density, creating shadow zones where no S - or P - waves are observed.

Wave Phenomena: Snell's law



Snell's law

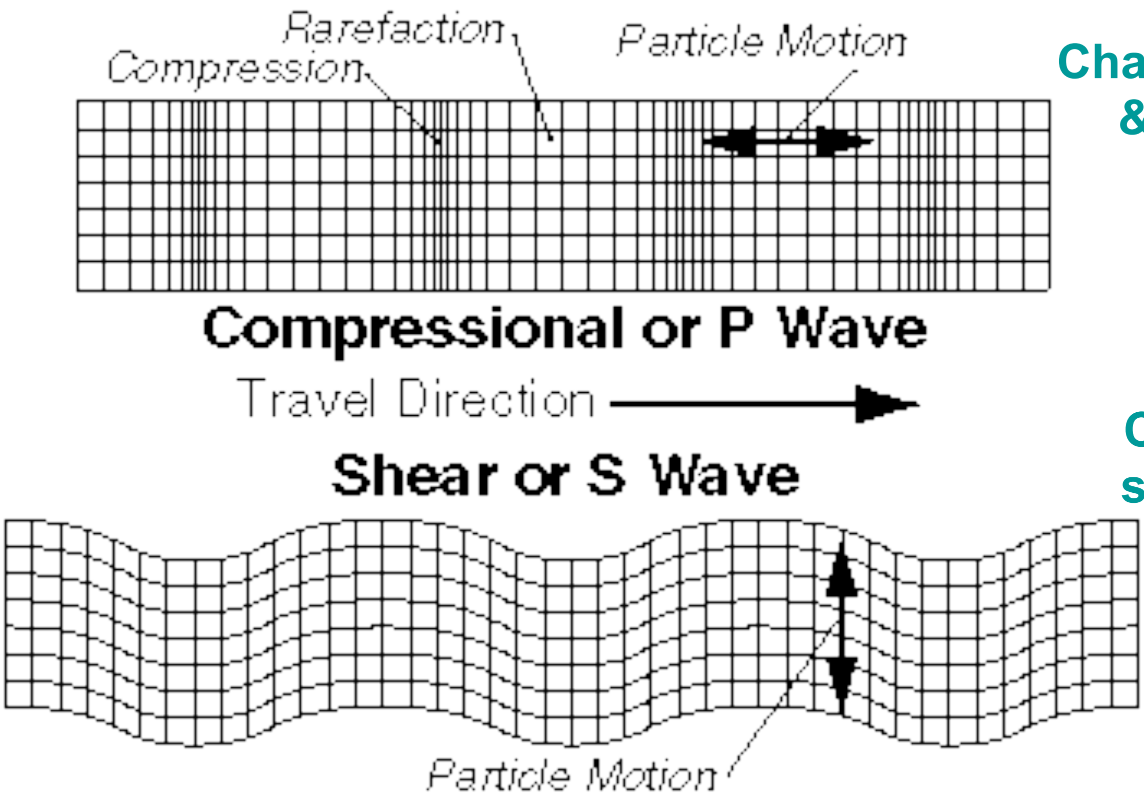
$n = c/v$ (by definition)

therefore

$\sin\theta_1/\sin\theta_2 = v_1/v_2$

Propagation through smoothly varying densities
→ smoothly curved trajectory

Earth's Interior - Seismology



Change in shape & in volume

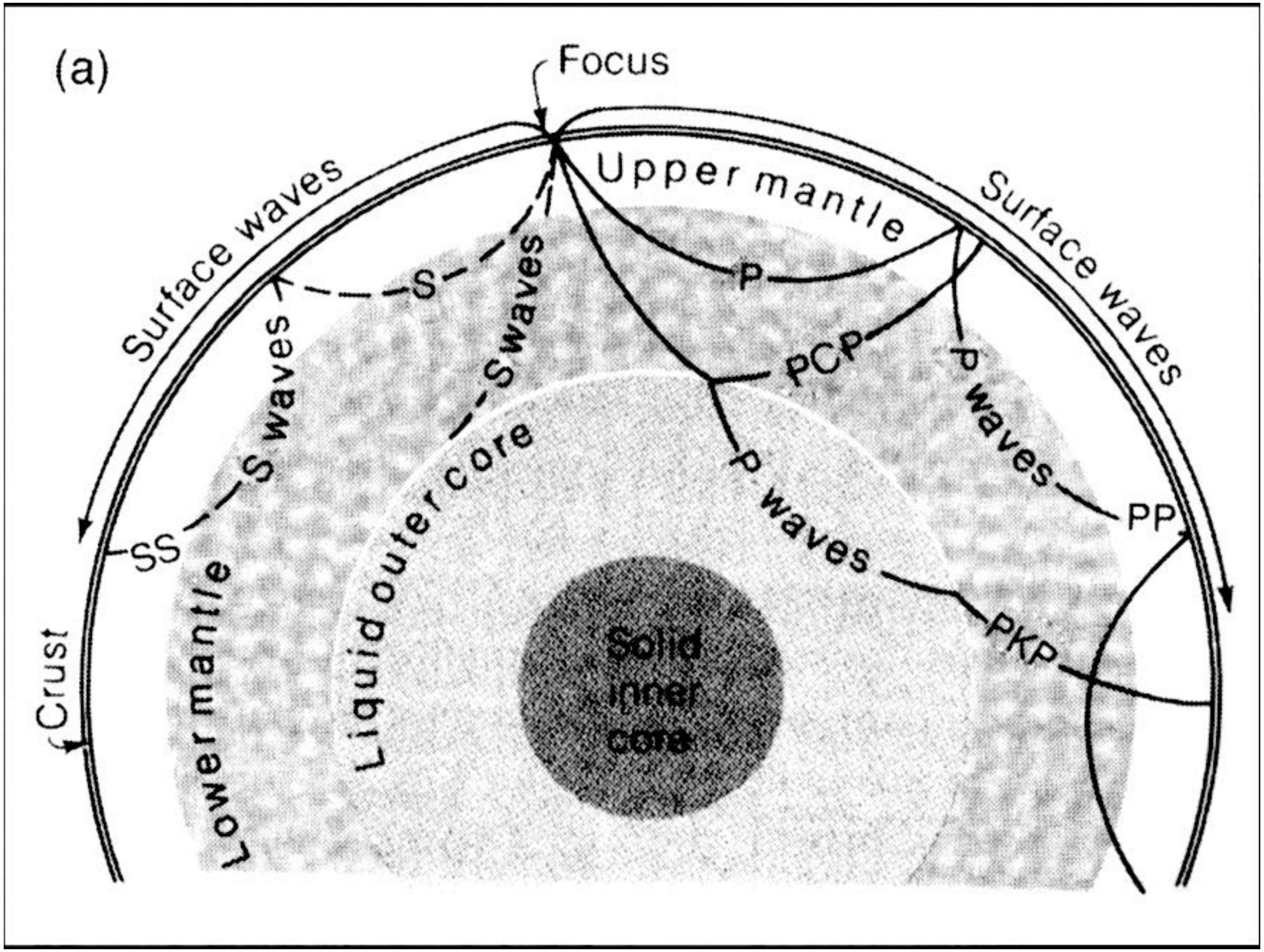
$$v_P = \sqrt{\frac{K_m + \frac{4}{3}\mu_{rg}}{\rho}}$$

Change in shape only

$$v_S = \sqrt{\frac{\mu_{rg}}{\rho}}$$

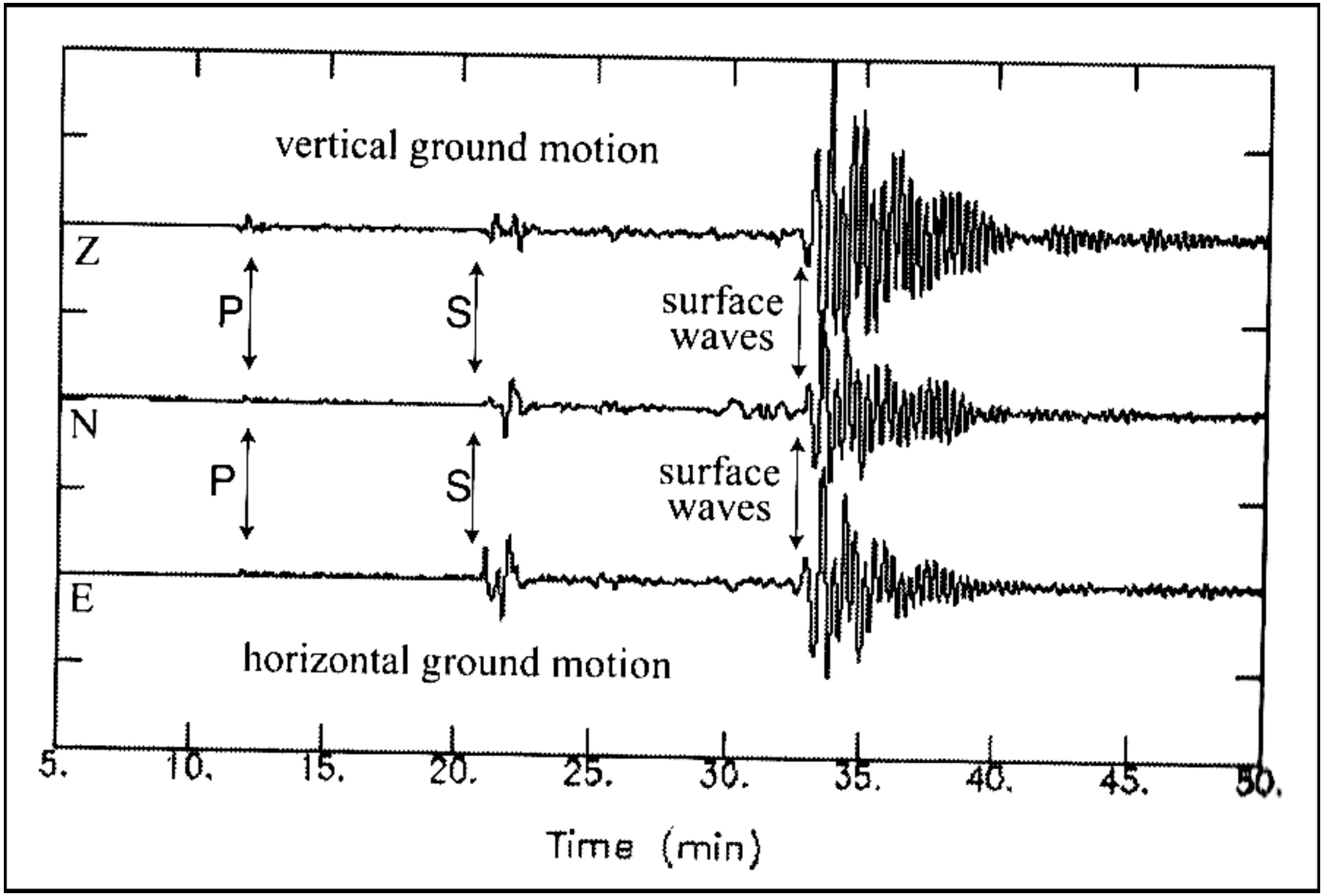
The velocities of these body waves are described above, where K_m is the bulk modulus, or the messure of stress needed to compress a material. μ_{rg} is the shear modulus, or the messure of stress needed to change the shape of a material without changing the volume.

Earth’s Interior - Seismology



de Pater & Lissauer (2010)

Earth's Interior - Seismology



de Pater & Lissauer (2010)

Many seismic stations allow us to watch these propagate…

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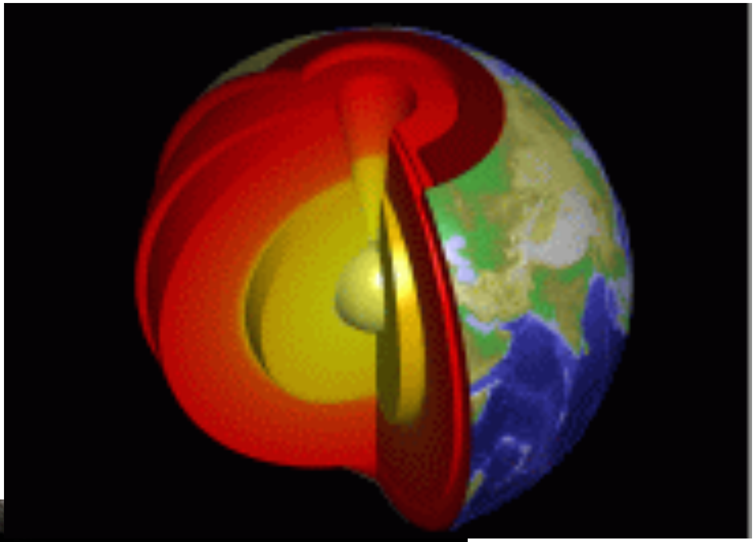

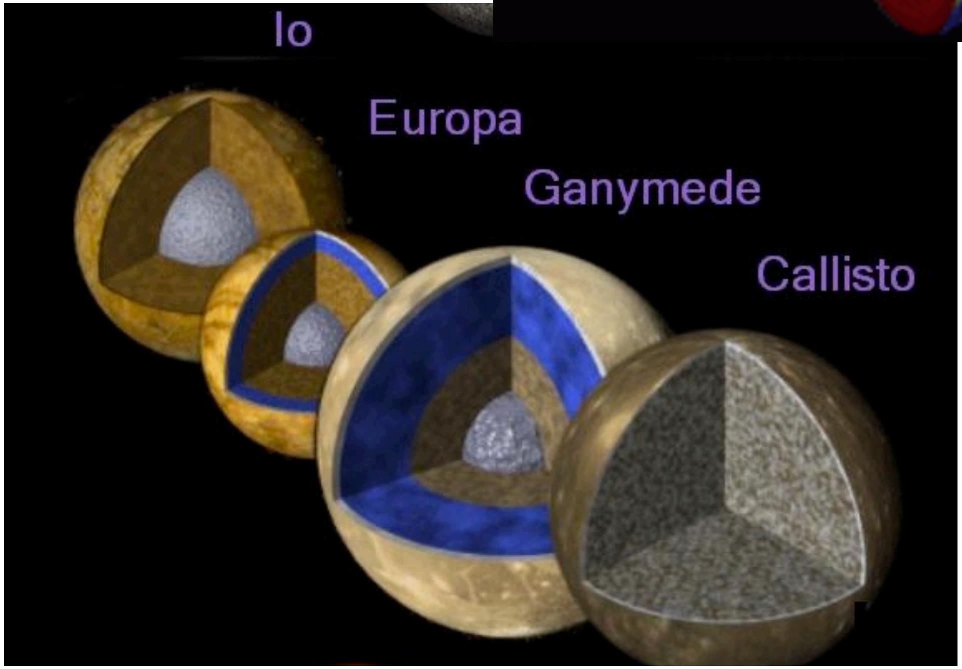

Hydrostatic Equilibrium

First order for a spherical body: Internal structure is determined by the balance between gravity and pressure:

$$P(r) = \int_r^R g_P(r')\rho(r')\,dr'$$

Which is solvable if the density profile is known. If we assume that the density is constant throughout the planet, we obtain a simplified relationship for the central pressure:

$$P_C = \frac{3GM^2}{8\pi R^4}$$

*** Which is really just a lower limit since we know generally density is higher at smaller radii.**

Hydrostatic Equilibrium

Alternatively you can approximate the planet as a single slab with constant density *and* gravity, which gives a central pressure 2x the the previous approach.

Generally speaking, the first approximation works within reason for smaller objects (like the Moon) even though their densities are not entirely uniform.

The second approximation overestimates the gravity, which somewhat compensates for the constant density approximation and is close to the solution for the Earth. It is not enough to compensate for the extreme density profile of planets like Jupiter.

~Mbar pressures for terrestrial planets!