Planet Densities and Planet Processes

Week 5

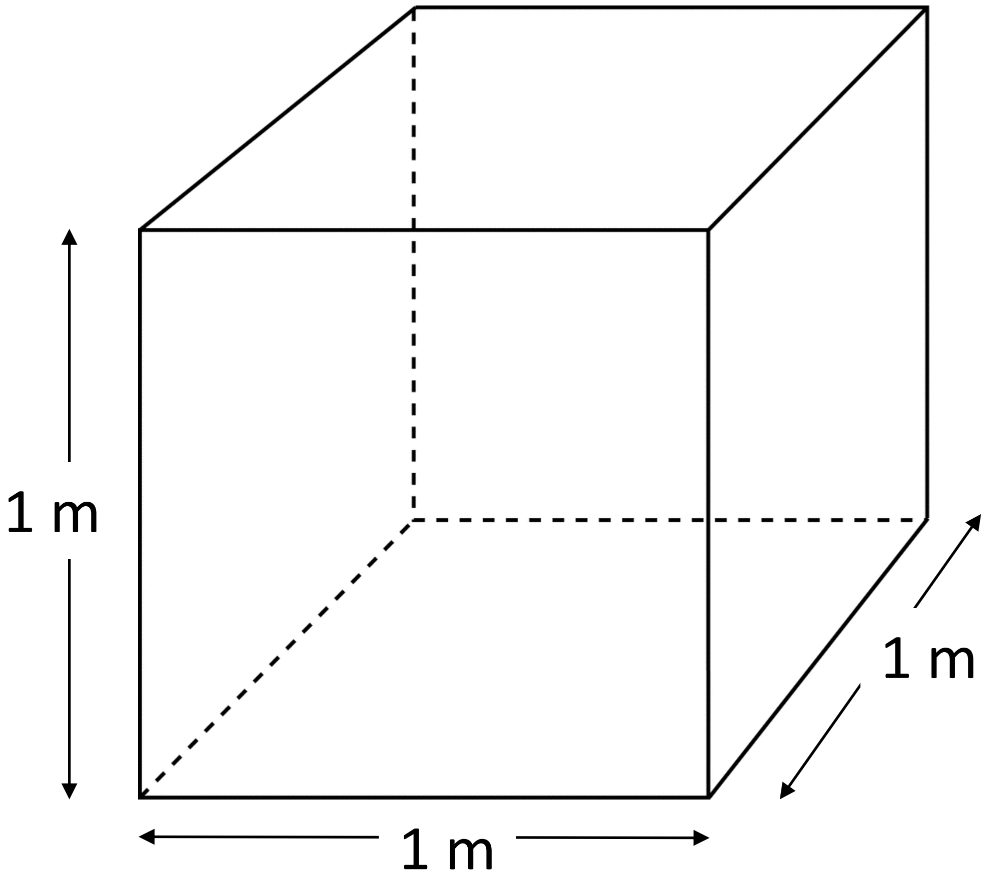
Planets are made of matter

- What are planets made of?
- How is matter distributed in the Solar System?
- How is matter distributed within planets?

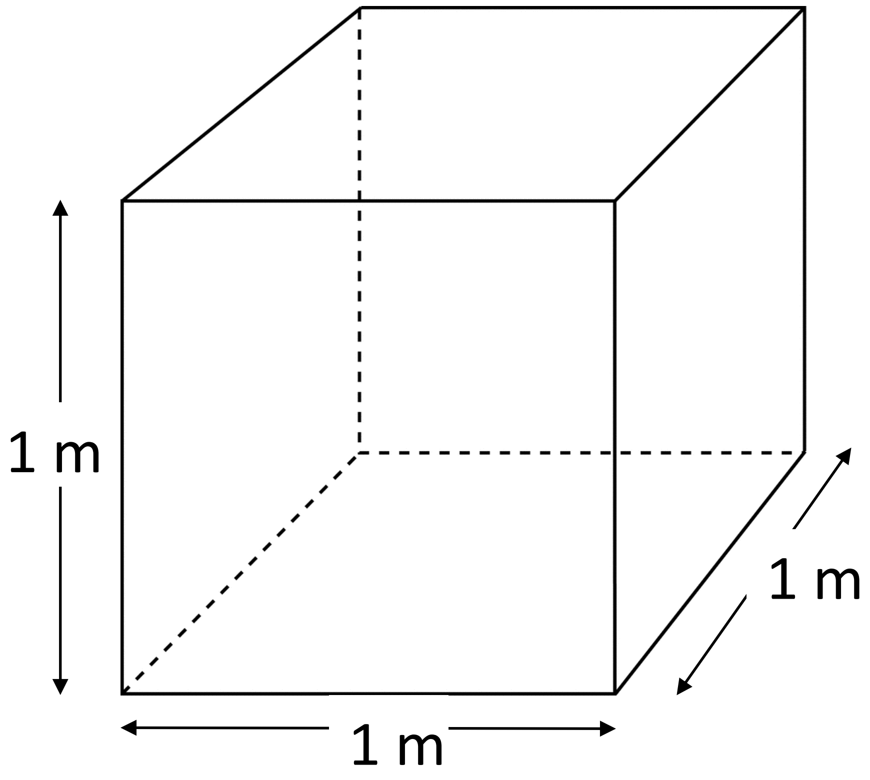
Planet density

- Density is the amount of mass (kg) in a given volume (m^3)

$$\rho = \frac{m}{v}$$



What affects density?



If we hold volume constant:

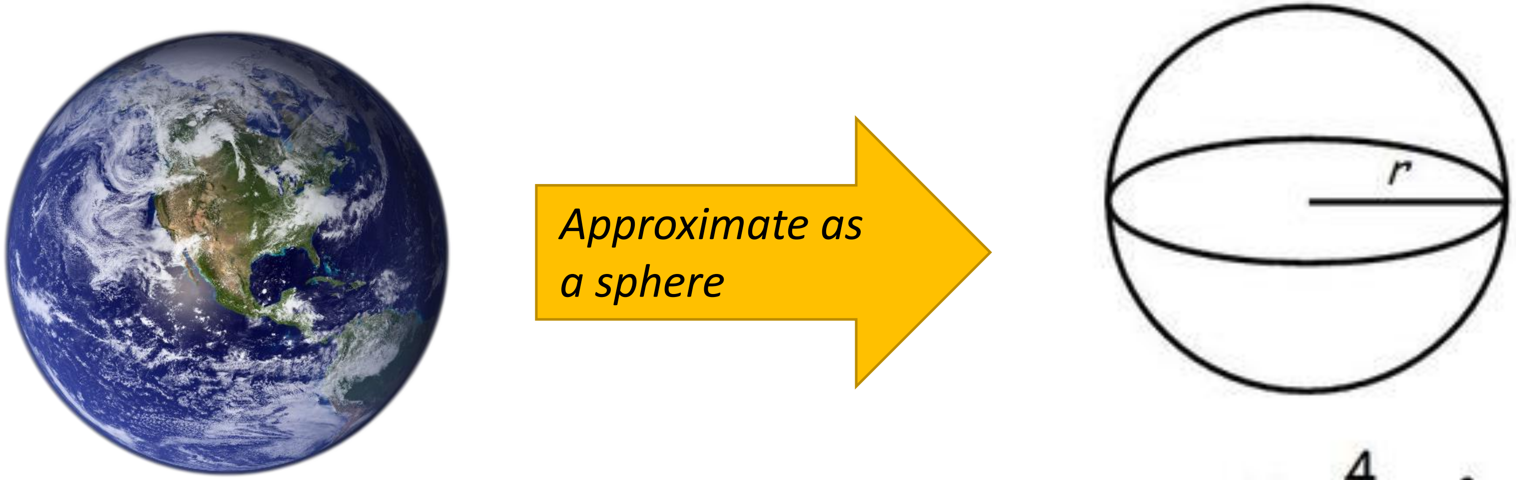
- How much material we pack into a space
  - Solid vs. liquid vs. vapor
- What the matter is made of
  - Gas vs. Ice vs. Rock vs. Metal

Measuring density of planets

We need to know the mass and the volume

Mass → from orbital relationships and gravitational attraction

Volume → from planet size and geometry



$$V = \frac{4}{3}\pi r^3$$

Let's calculate Earth's density

$$v = \frac{4}{3}\pi r^3$$

$$\rho = \frac{m}{v}$$

Earth

mass = 5.98 x 10^{24} kg

diameter = 12,742 km

$$v = \frac{4}{3}\pi(\frac{12{,}742{,}000\ \text{km}}{2})^3$$

$$v = \frac{4}{3}\pi(6371000\ \text{m})^3$$

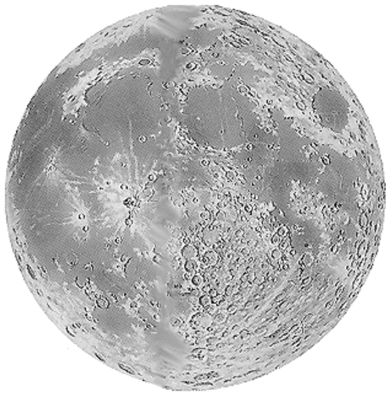
$$v = 1.083 * 10^{21}\ \text{m}^3$$

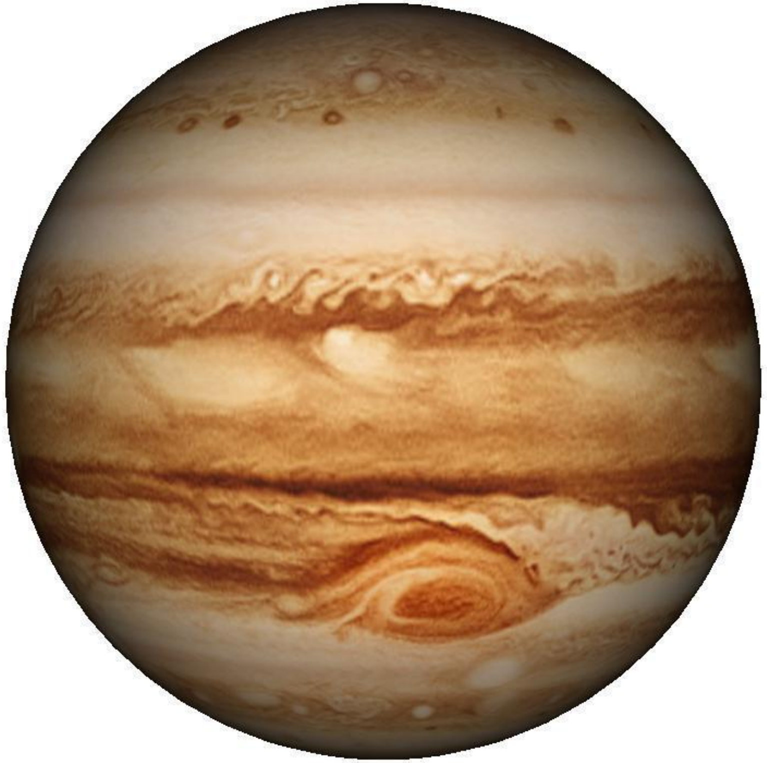
$$\rho = \frac{5.98 * 10^{24} kg}{1.083 * 10^{21}\ \text{m}^3}$$

$$\boldsymbol{\rho = 5515\ \text{kg/m}^3}$$

Let's compare densities

$$\rho = \frac{m}{v} \qquad v = \frac{4}{3}\pi r^3$$





Earth

mass = 5.98×10^{24} kg

diameter = 12,742 km

$\rho = 5515 \text{ kg/m}^3$

Moon

mass = 7.36×10^{22} kg

diameter = 3,475 km

$\rho = 3346 \text{ kg/m}^3$

Jupiter

mass = 1.9×10^{27} kg

diameter = 143,884 km

$\rho = 1326 \text{ kg/m}^3$

Densities of the planets

Planetary Data*

Planet	Mass (10^{24} kg)	Diameter (km)	Density (kg/m^3)	Length of Day[1] (hours)	Distance from Sun (10^6 km)	Orbital Period[2] (days)	Orbital Velocity[3] (km/s)
Mercury	0.330	4879	5427	4222.6	57.9	88.0	47.9
Venus	4.87	12,104	5243	2802.0	108.2	224.7	35.0
Earth	5.97	12,756	5515	24.0	149.6	365.2	29.8
Mars	0.642	6794	3933	24.7	227.9	687.0	24.1
Jupiter	1899	142,984	1326	9.9	778.6	4331	13.1
Saturn	568	120,536	687	10.7	1433.5	10,747	9.7
Uranus	86.8	51,118	1270	17.2	2872.5	30,589	6.8
Neptune	102	49,528	1638	16.1	4495.1	59,800	5.4
Pluto (dwarf)	0.0125	2390	1750	153.3	5870.0	90,588	4.7

* Numerical data based on NASA information.

[1]Length of Day (hours) – This is the average time in hours that it takes for the Sun to move from the noon position in the sky at a point on the equator back to the same position.
[2]Orbital Period (days) – This is the time in Earth days that it takes for the planet to orbit the Sun.
[3]Orbital Velocity (km/s) – This is the average velocity, or speed, of the planet in kilometers per second as it orbits the Sun.

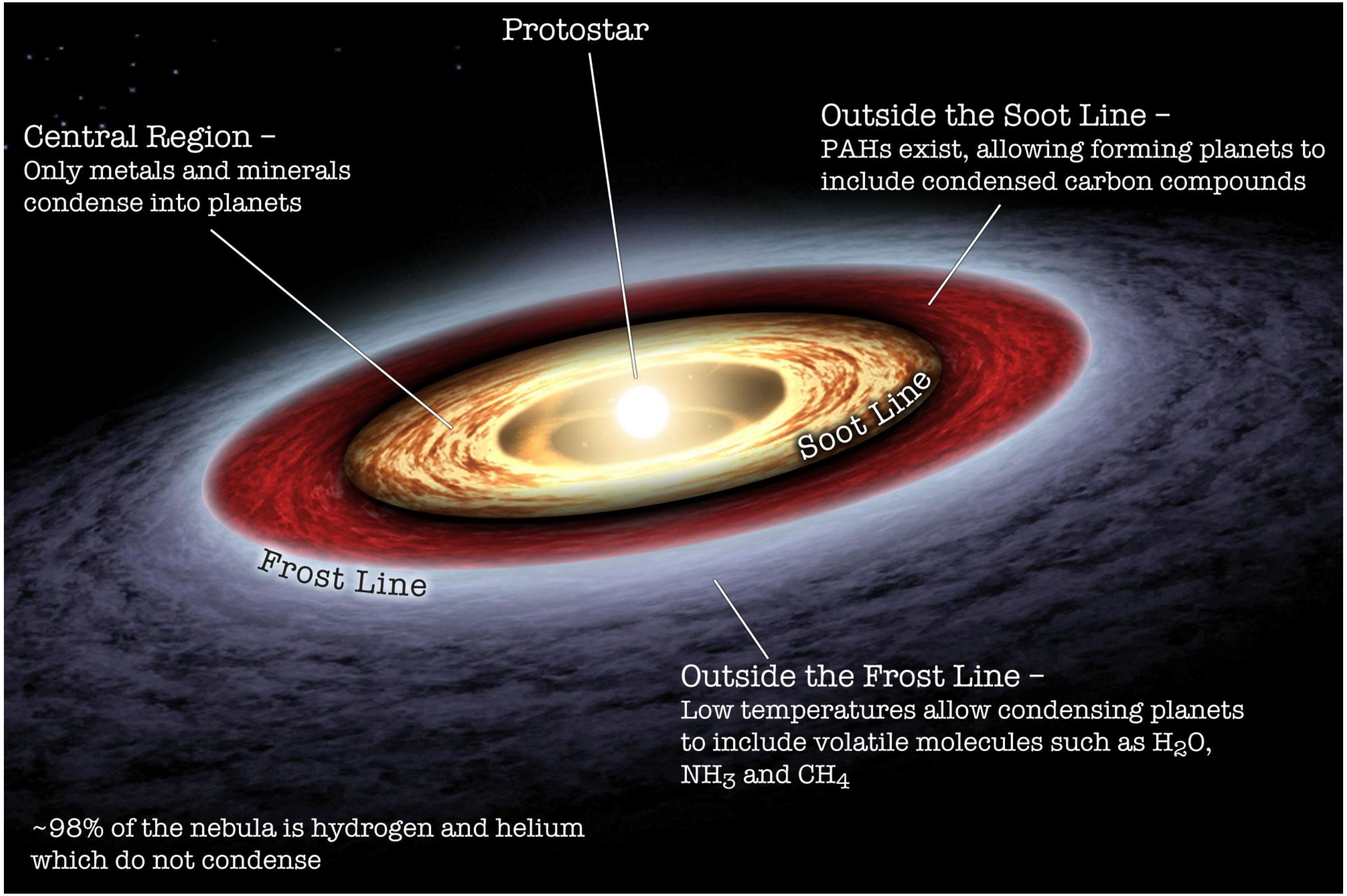
What does the density of planets tell us?

Inner planets
Density ≥ 4000 kg/m^3

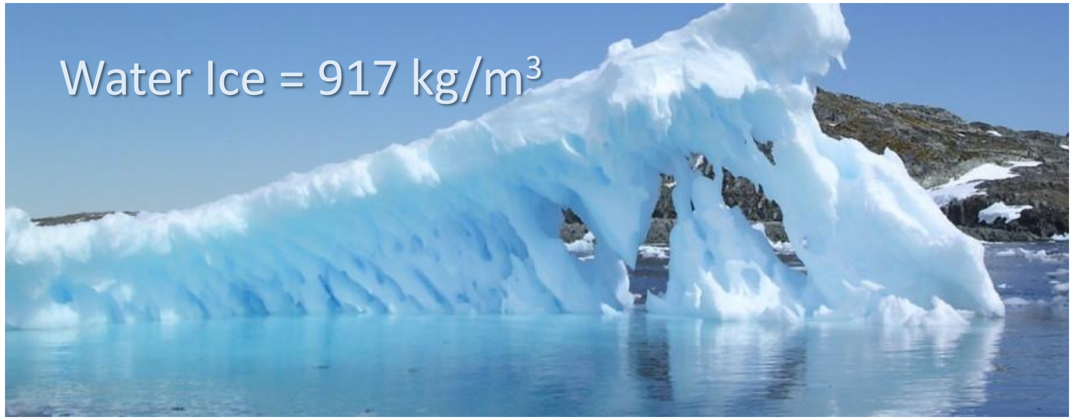
Outer planets
Density ≤ 1600 kg/m^3

- ***Inner and outer planets are fundamentally different***

The "<u>frost line</u>": Outer planets form where lower temps allowed volatile materials to condense (water, methane, etc.)



Density of materials



Iron metal = 7874 kg/m^3

What is Earth made of?

<u>Earth</u>

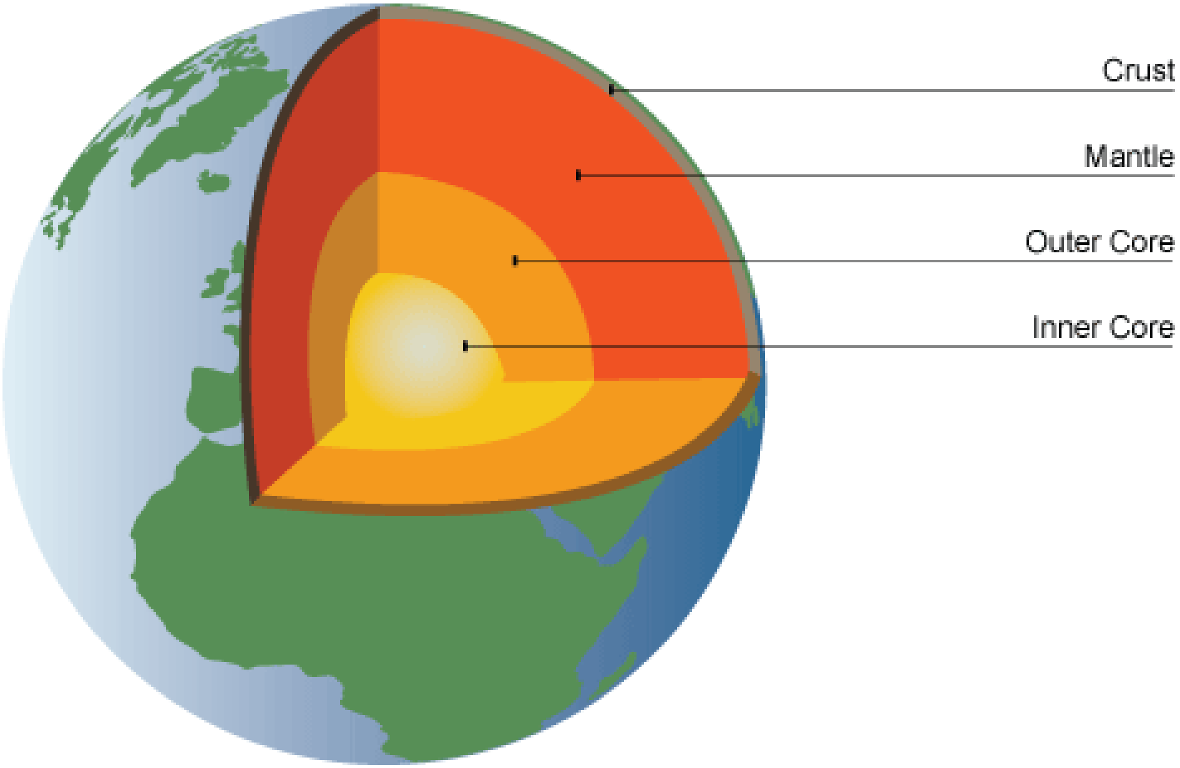
mass = 5.98×10^{24} kg

diameter = 12,742 km

$\rho = 5515 \text{ kg/m}^3$

- We know the outer portions of Earth are made of
  - Water (1000 kg/m^3)
  - Ice (917 kg/m^3)
  - Rock (~3200 kg/m^3)
- Earth must have some heavier stuff somewhere
- We know that much of Earth is made of metal, specifically Iron (Fe)

Structure of Earth

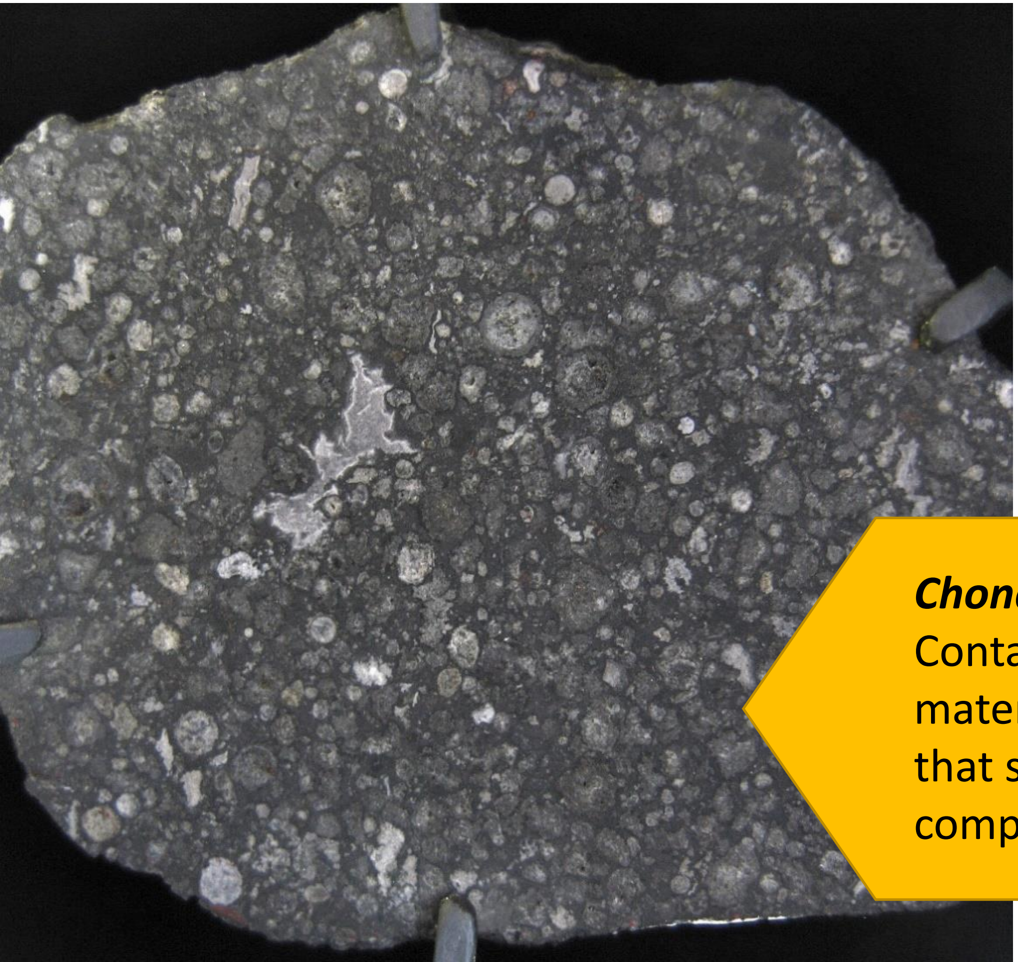


- Crust and Mantle are made of rock
- Core is made of metal (mostly iron + some nickel)
  - Outer core is molten iron
  - Inner core is solid iron

How do we know?

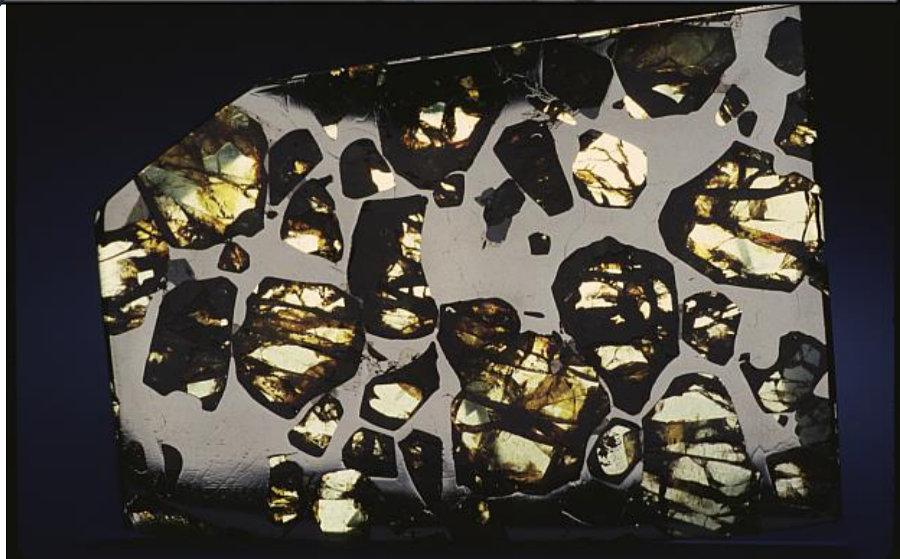
Evidence for metallic core

Meteorites provide evidence



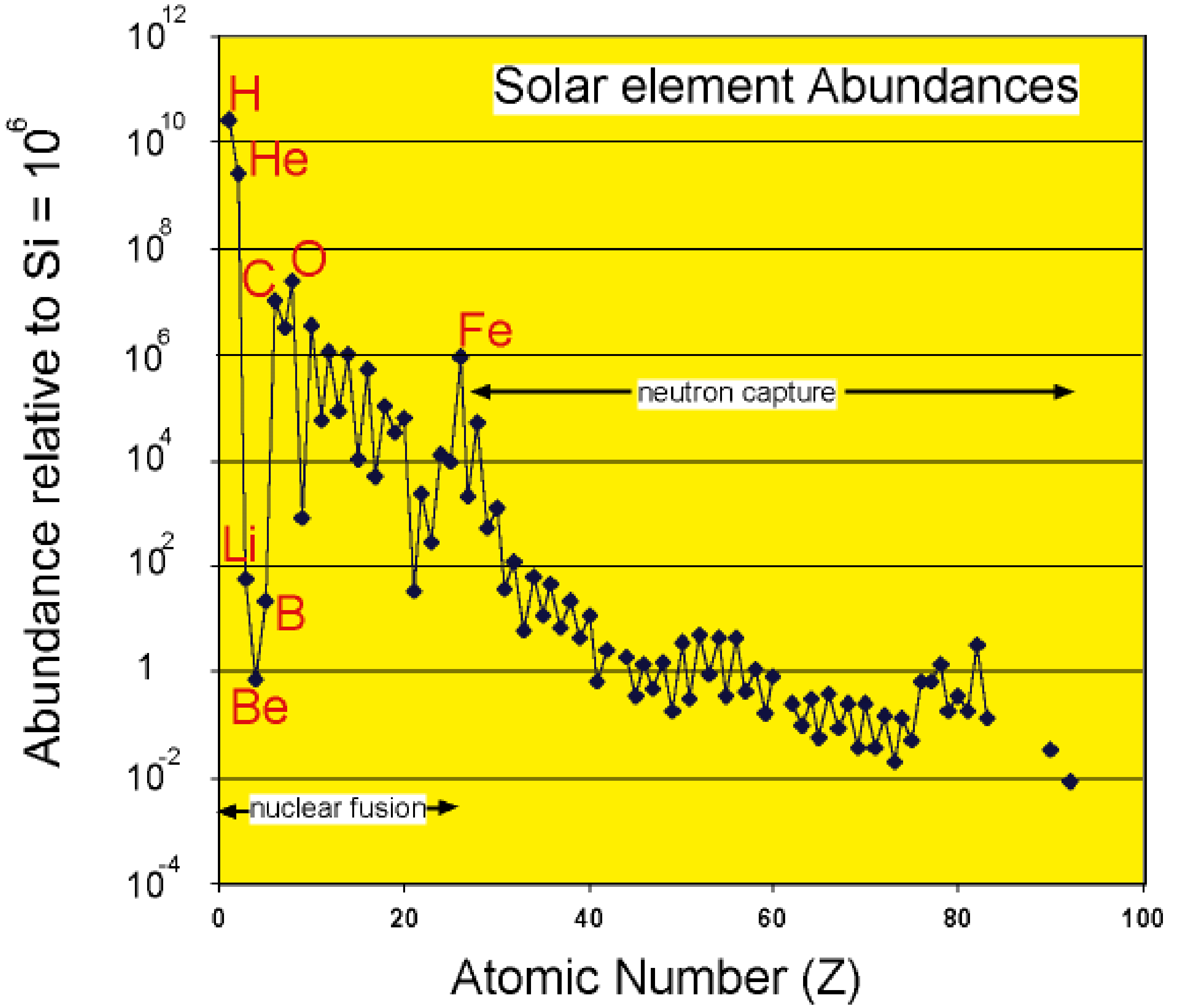
Iron meteorites
Cores of planetesimals

(Below a stony-iron meteorite called a "pallasite"… iron mixed with a mineral called "olivine"…from a core-mantle boundary of a planetesimal



Chondrites
Contain earliest accreted materials called "chondrules" that show solar system composition

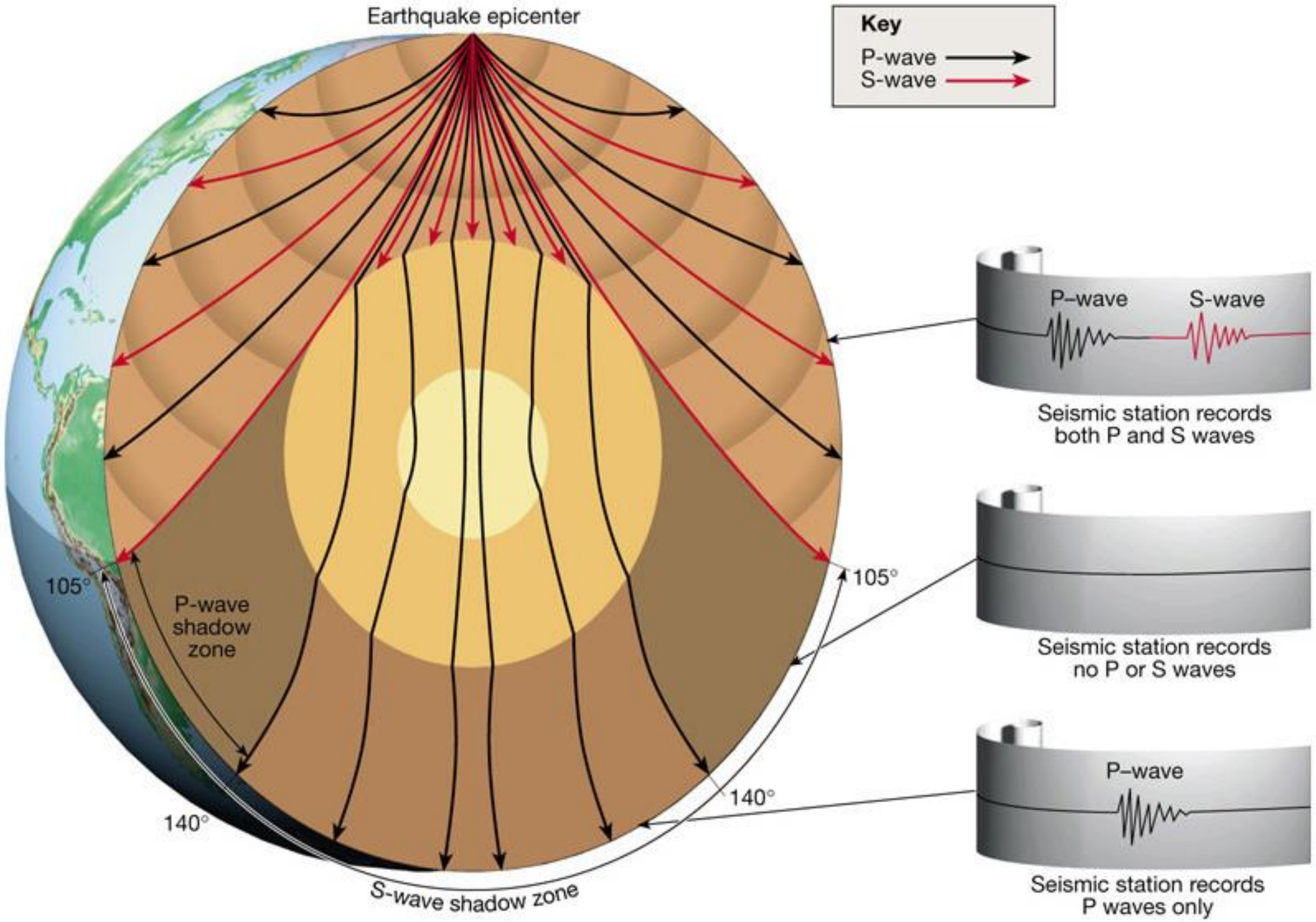
Evidence for metallic core



Sun's Composition

- The abundance of solar elements shows large amounts of Iron (Fe)
- Solar composition tells us the starting composition of the solar system

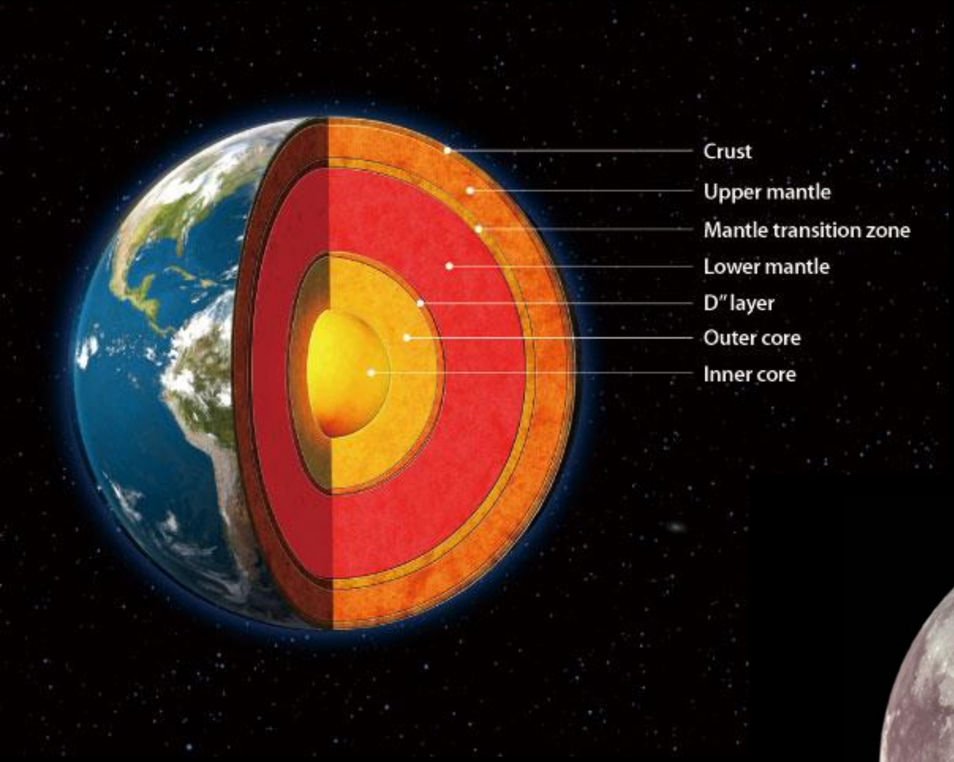
Evidence for metallic core

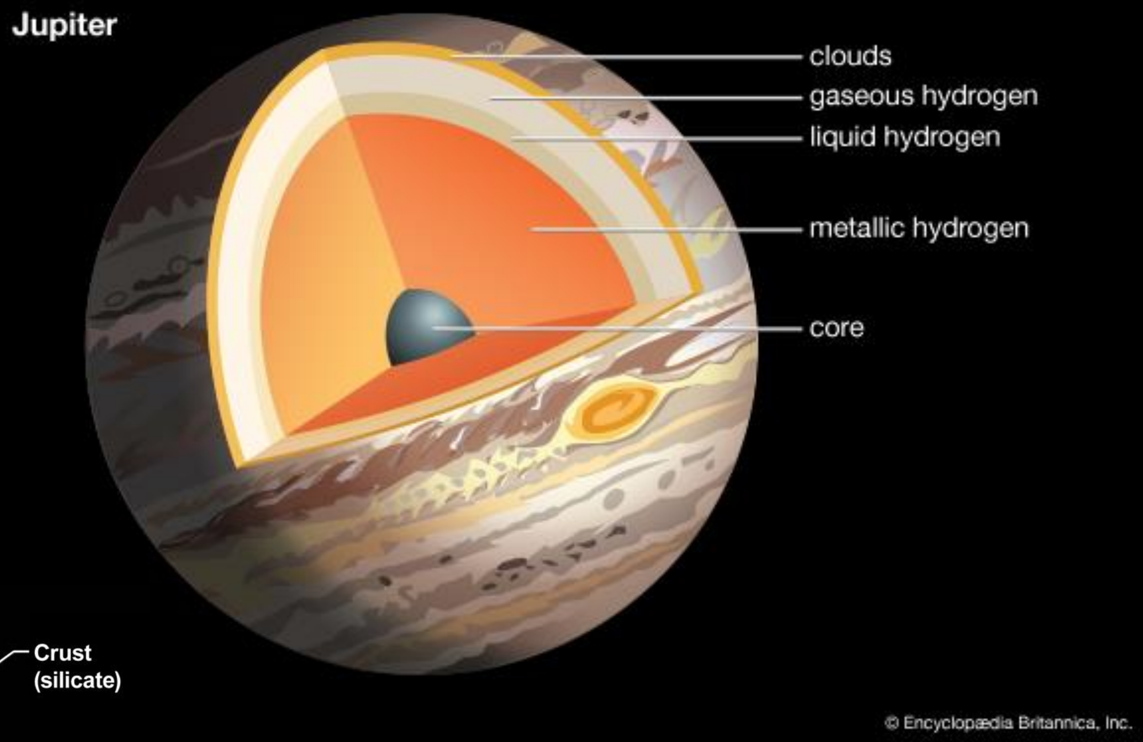


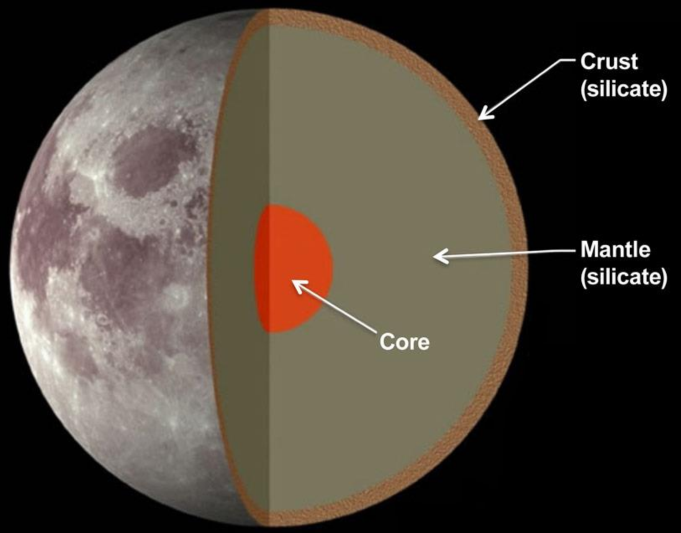
Seismic Waves

- We record sound waves moving through the Earth
- The way the move tells us about the internal structure

Structure of Earth informs us about the structure of other planets

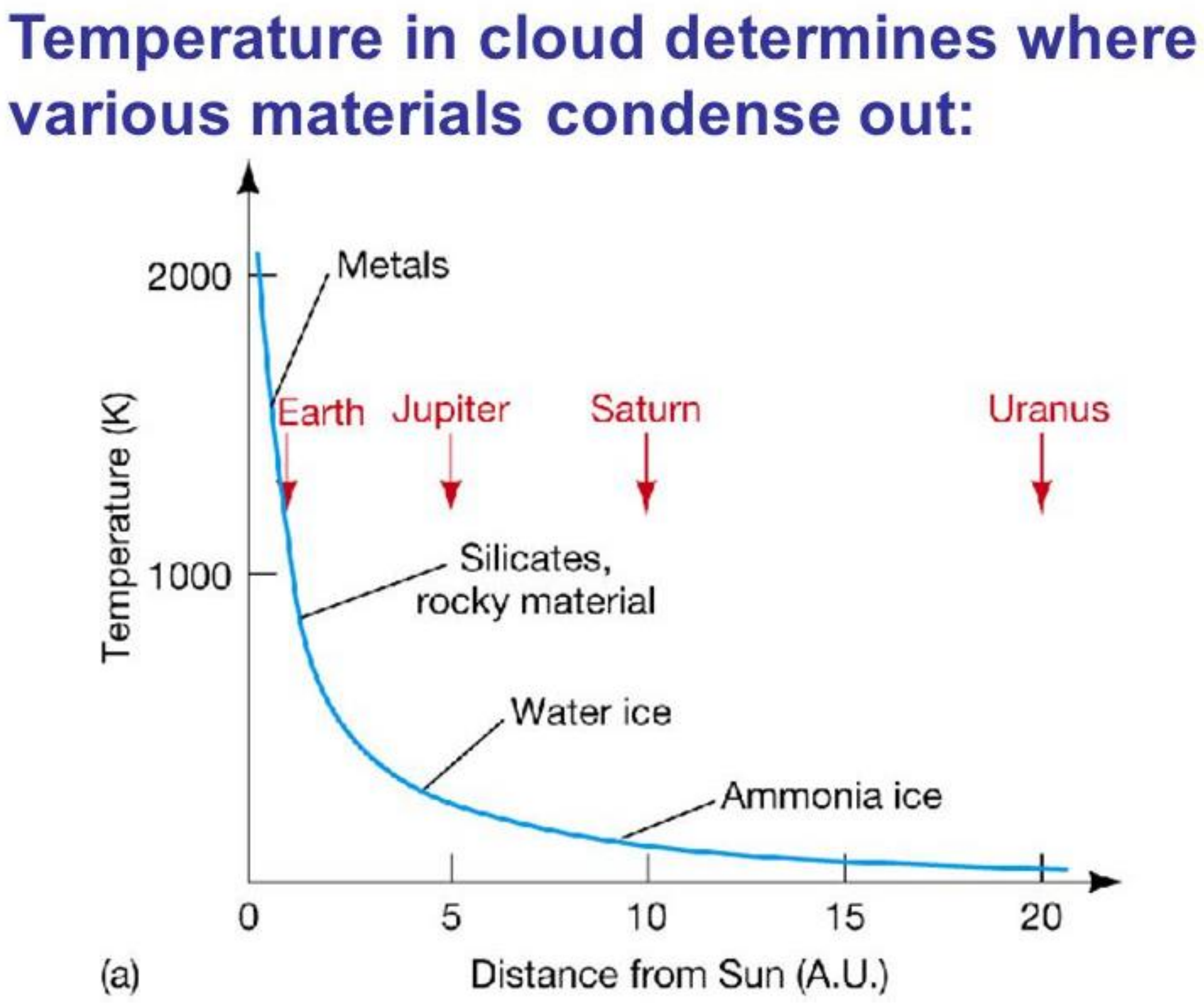


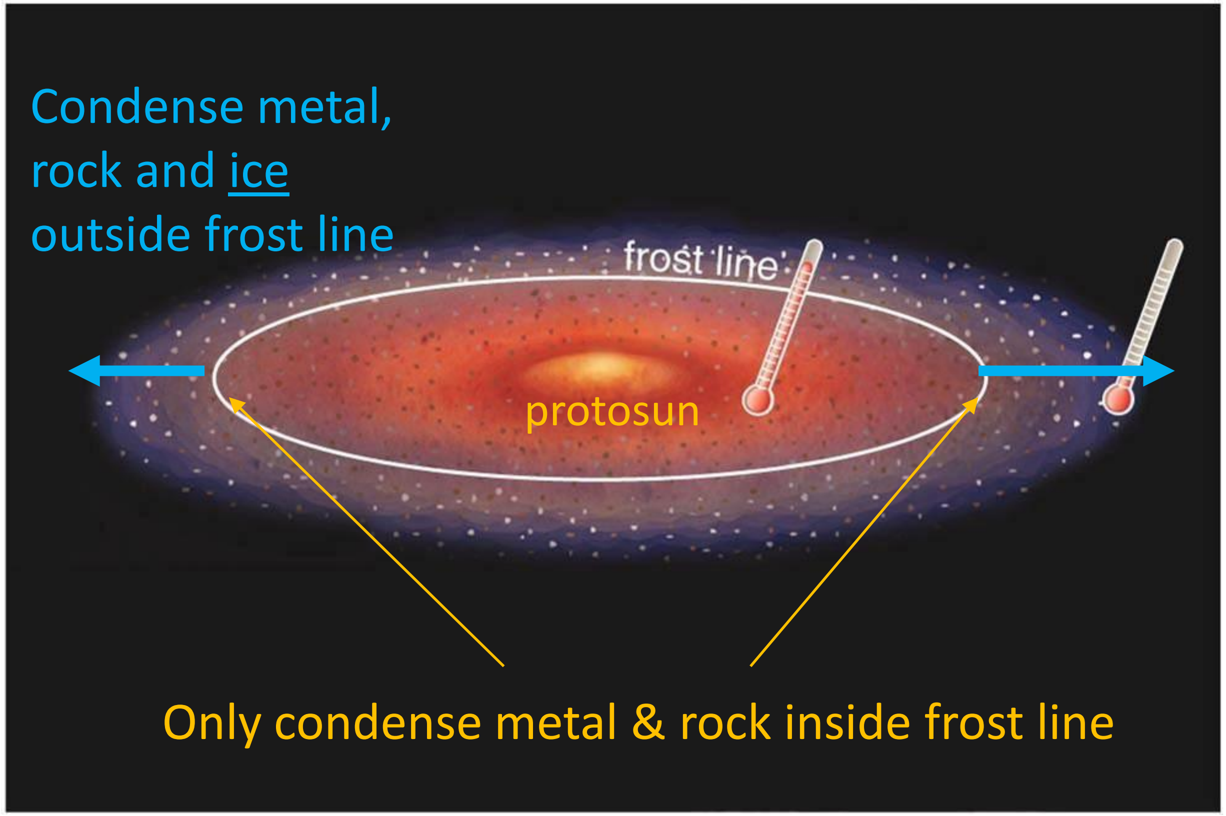




Planets generally get denser with depth and have a core of dense rocky material or metal

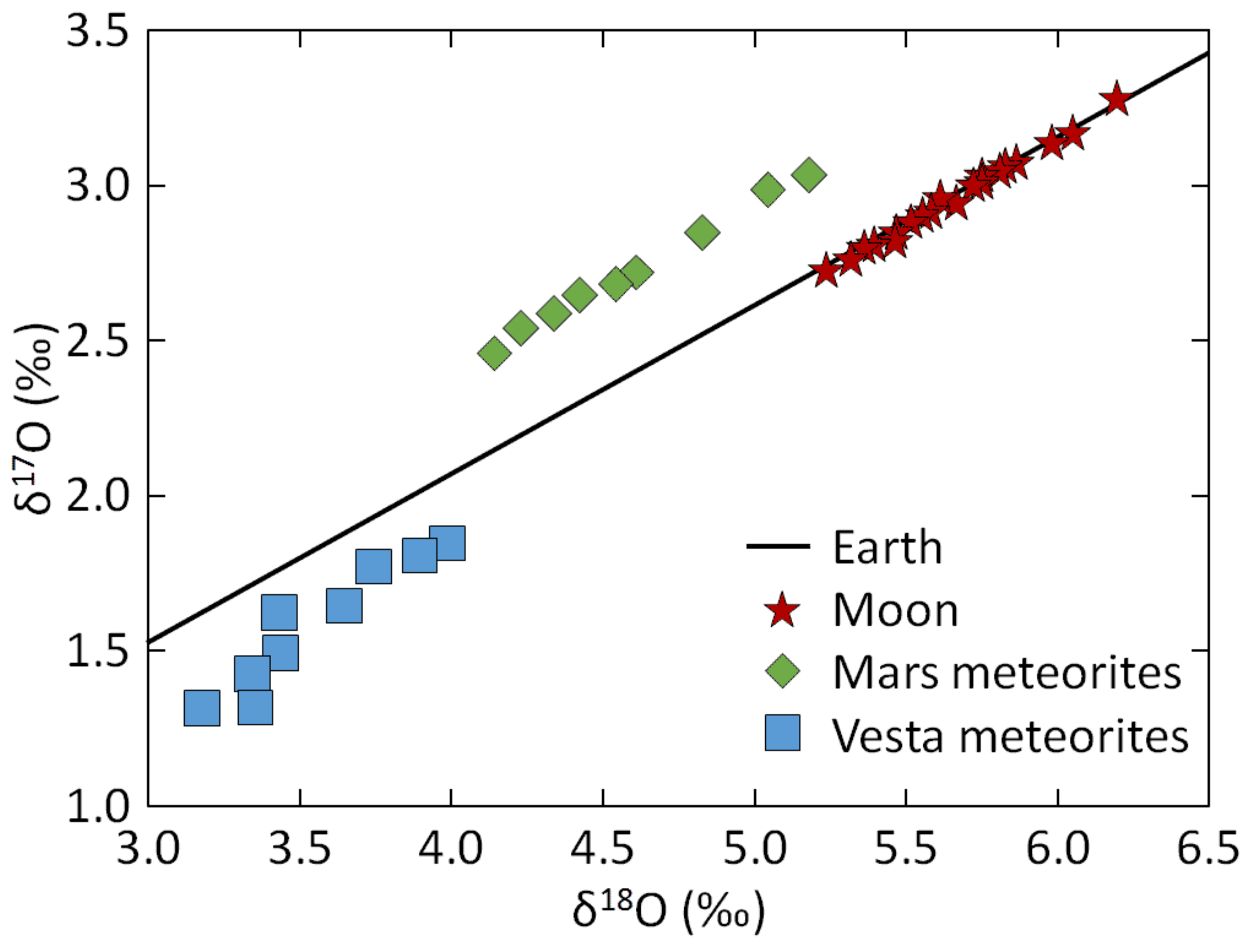
Compositional zones in the solar nebula

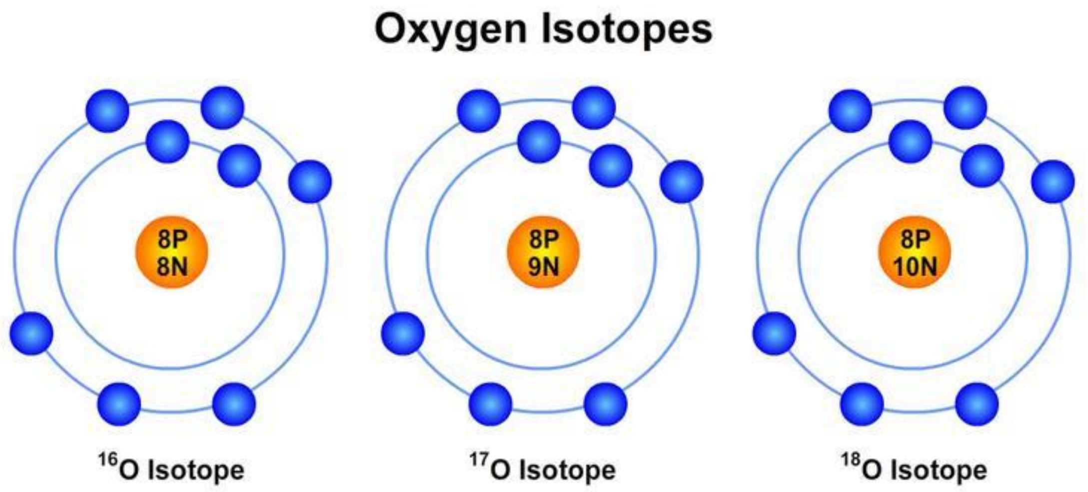




- Chemical zones away from the early Sun
- Even get subzones (e.g. Mercury different from Earth in the rocky planet zone)

Compositional zones in the solar nebula

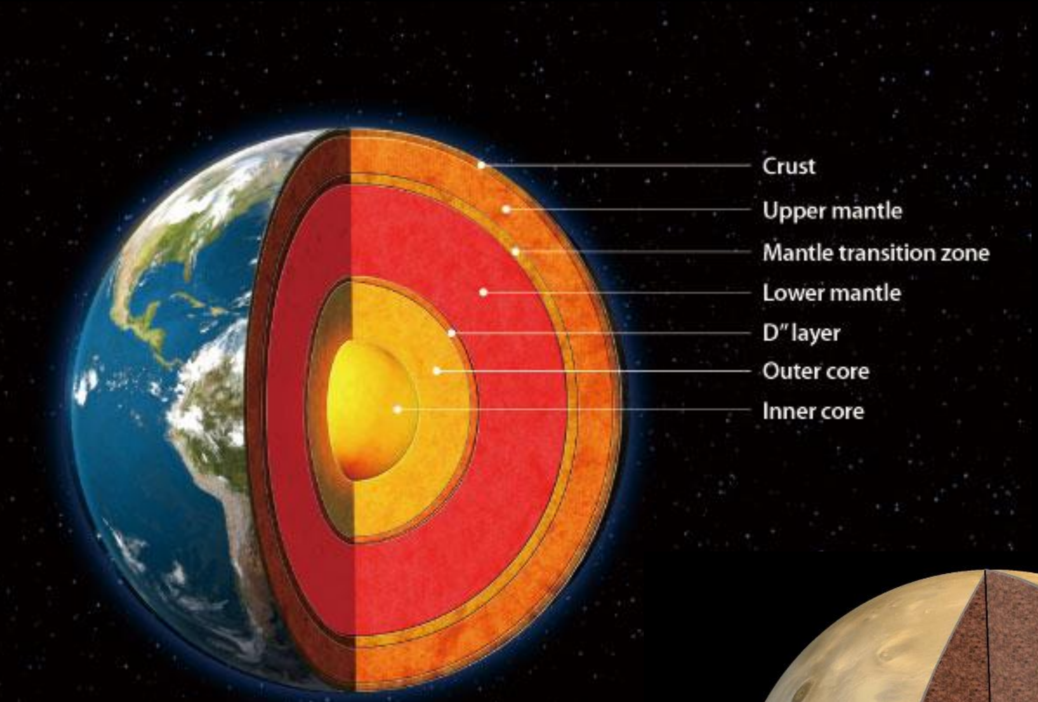




Chemical zones in solar system also seen in more sophisticated measurements like oxygen isotopes

- *Different zones with different ratios of heavy and light oxygen*

Structure of planets affect how they spin (rotate on their axis)

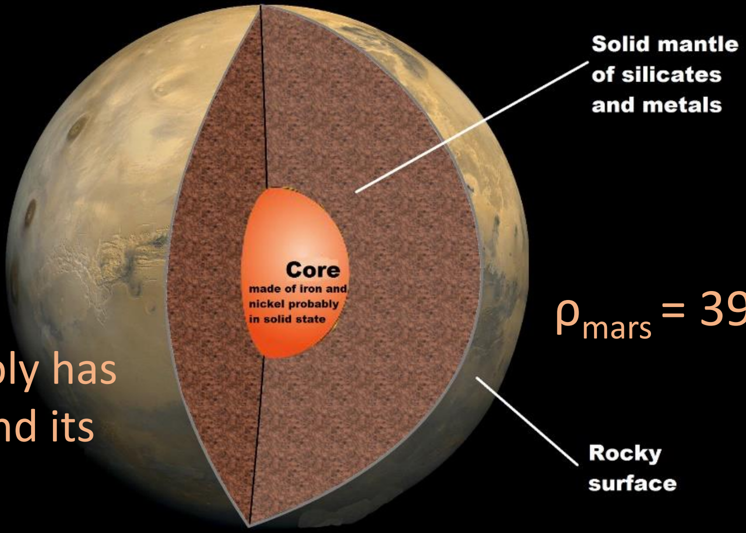


ρ_{earth} = 5500 kg/m^3

Planets conserve angular momentum

The more concentrated the mass is to the center, the faster the planet can spin

We can use spin rates of planets to help understand the distribution of material inside



ρ_{mars} = 3900 kg/m^3

Mars: Core of Fe and Ni, but probably has more Sulfur due to how it rotates and its overall density

Evolution of planets and moons

What are major features of planets and moons?

Size	Density & Composition	Location
• Large gas giants	• Low-ρ, gaseous	• Outer planets
• Small planets	• High-ρ, rocky	• Inner planets & Moon
• Smaller moons	• Medium-ρ, icy	• Rocky and icy moons in orbit around gas giants

Effects of size, composition and location

Outer Planets

- Condense more solids → bigger cores
- Large planets can gravitationally attract gases (hydrogen) and moons
- Cannot observe solid parts of planet
- Have large masses and large gravitational effects on other solar system objects

Effects of size, composition and location

Solid planets and moons

- Support geologic activity
  - volcanics and tectonics)
  - from **heat escaping** from the planet or moon
- Internal planetary heat from:
  - Formation (differentiation/core formation and effect of gravity)
  - Radioactive decay
- Size dictates how they evolve over time
  - Small planets lose heat faster than larger planets
  - Geologic activity stops when heat is gone

Effects of size, composition and location

Size

- Outer planets condense more solids → bigger cores
- Large planets can gravitationally attract gases (hydrogen) and moons

Density & Composition

- Rocky planets behave differently because they become solids and support geologic activity
- Size dictates how they evolve over time

Location

- Rocky and icy moons in orbit around gas giants