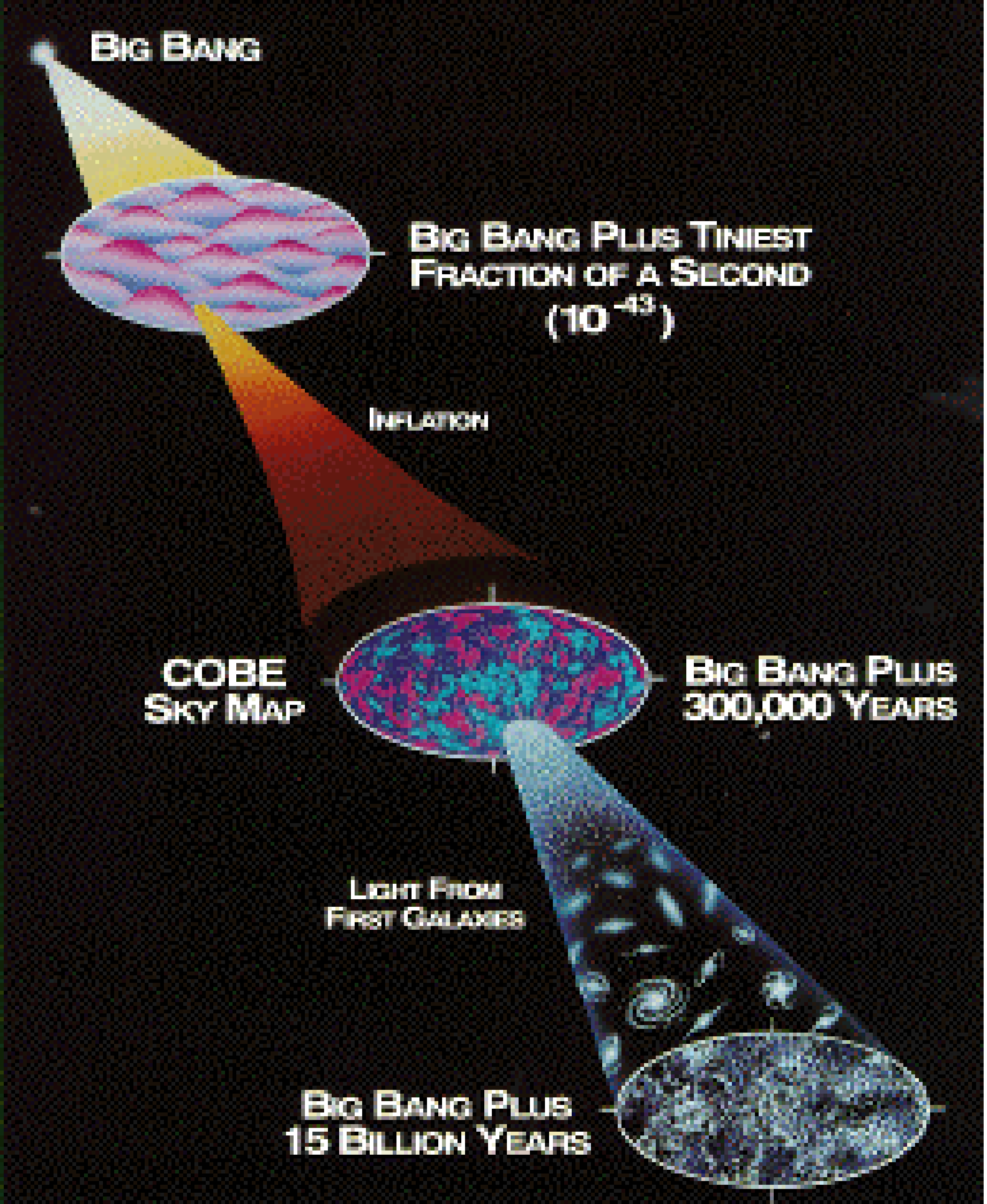


At the beginning…

Matter + antimatter

↓

Matter has the advantage

↓

baryons → quarks, leptons, electrons, photons (no protons or neutrons)

↓

Hadrons → protons, neutrons

↓

Hydrogen, helium (1:10 H:He)

Origin of the Universe

- Hubble observed the universe seemed to be expanding from a central point – origin of the Big Bang Theory
- Formation of subatomic particles → H and He nuclei, then cooling to form mostly H and He – still the most abundant elements in the universe

Nuclear reactions – the beginning

- Hydrogen fusion:

$${}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + \beta^{+} + \nu + 0.422MeV$$

$$\beta^{+} + \beta^{-} \rightarrow 1.02MeV$$

$${}^{2}_{1}H + {}^{1}_{1}H \rightarrow {}^{3}_{2}He + \gamma + 5.493MeV$$

$${}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + {}^{1}_{1}H + {}^{1}_{1}H + 12.859MeV$$

Proton-proton chain

$${}^{12}_{6}C + {}^{1}_{1}H \rightarrow {}^{13}_{7}N + \gamma$$

$${}^{13}_{7}N \rightarrow {}^{13}_{6}C + \beta^{+} + \nu$$

$${}^{13}_{6}C + {}^{1}_{1}H \rightarrow {}^{14}_{7}N + \gamma$$

$${}^{14}_{7}N + {}^{1}_{1}H \rightarrow {}^{15}_{8}O + \gamma$$

$${}^{15}_{8}O \rightarrow {}^{15}_{7}N + \beta^{+} + \nu$$

$${}^{15}_{7}N + {}^{1}_{1}H \rightarrow {}^{12}_{6}C + {}^{4}_{2}He$$

CNO cycle

$${}^{4}_{2}He + {}^{4}_{2}He \rightarrow {}^{8}_{4}Be$$

$${}^{8}_{4}Be + {}^{4}_{2}He \rightarrow {}^{12}_{6}C + \gamma$$

Triple-alpha fusion

<u>Particles</u>:

α - ${}^{4}_{2}He$

β – proton, aka positron (+)

γ - high energy photon

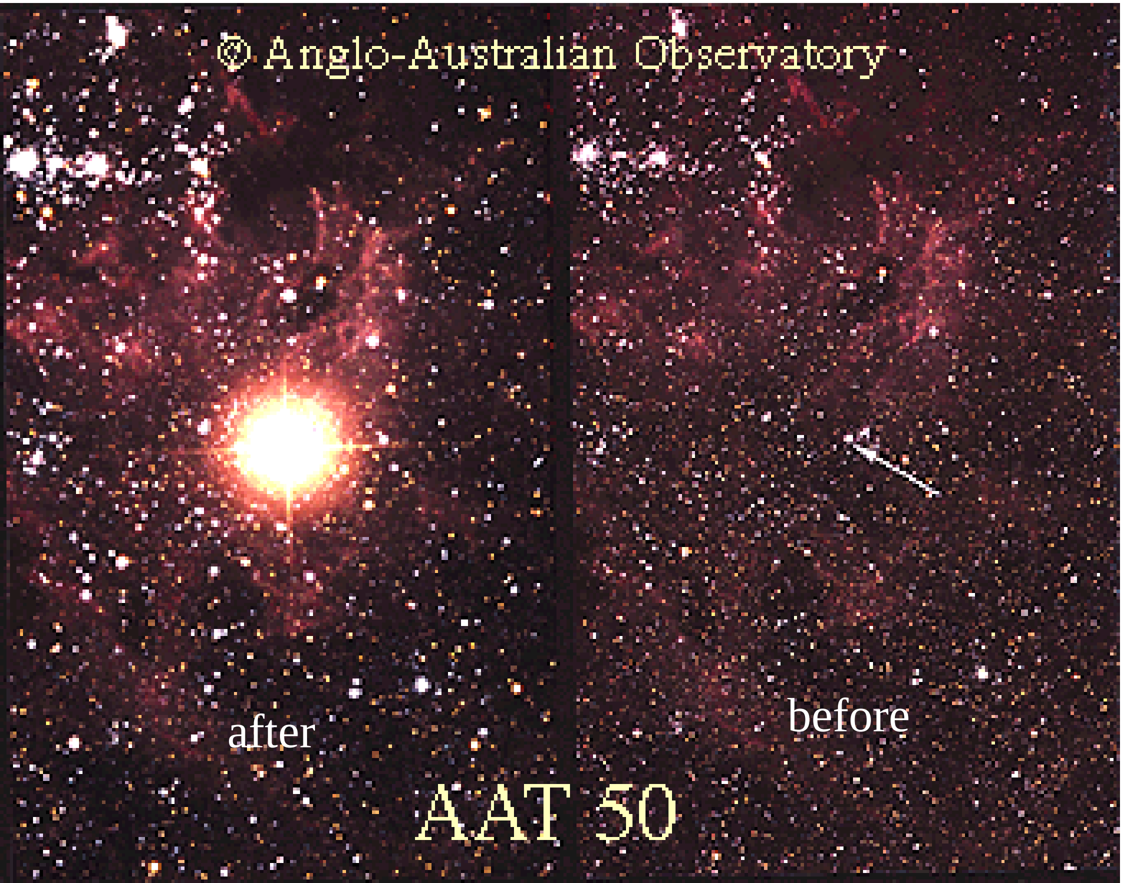
υ – neutrino

Nuclear reactions

- Helium Burning
  - Only goes to $^{56}_{26}Fe$…

$$^{12}_{6}C + ^{4}_{2}He \rightarrow ^{16}_{8}O$$

$$^{16}_{8}O + ^{4}_{2}He \rightarrow ^{20}_{10}Ne$$



What about the rest of the elements??

Neutron-capture Reactions

- At the end of a red star's life:

Neutrino capture

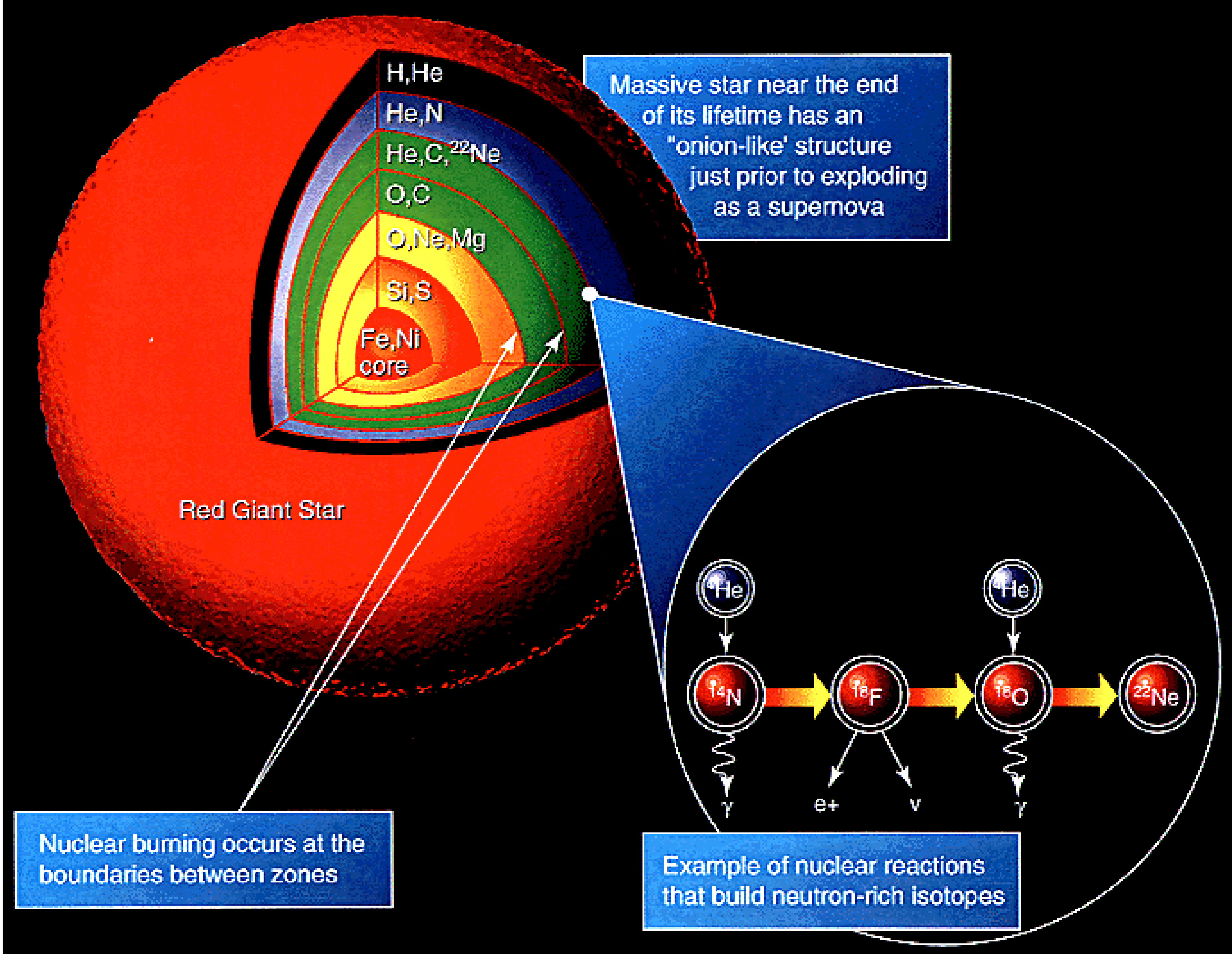
$$^{62}_{28}Ni + ^{1}_{0}n \rightarrow ^{63}_{28}Ni + \gamma$$

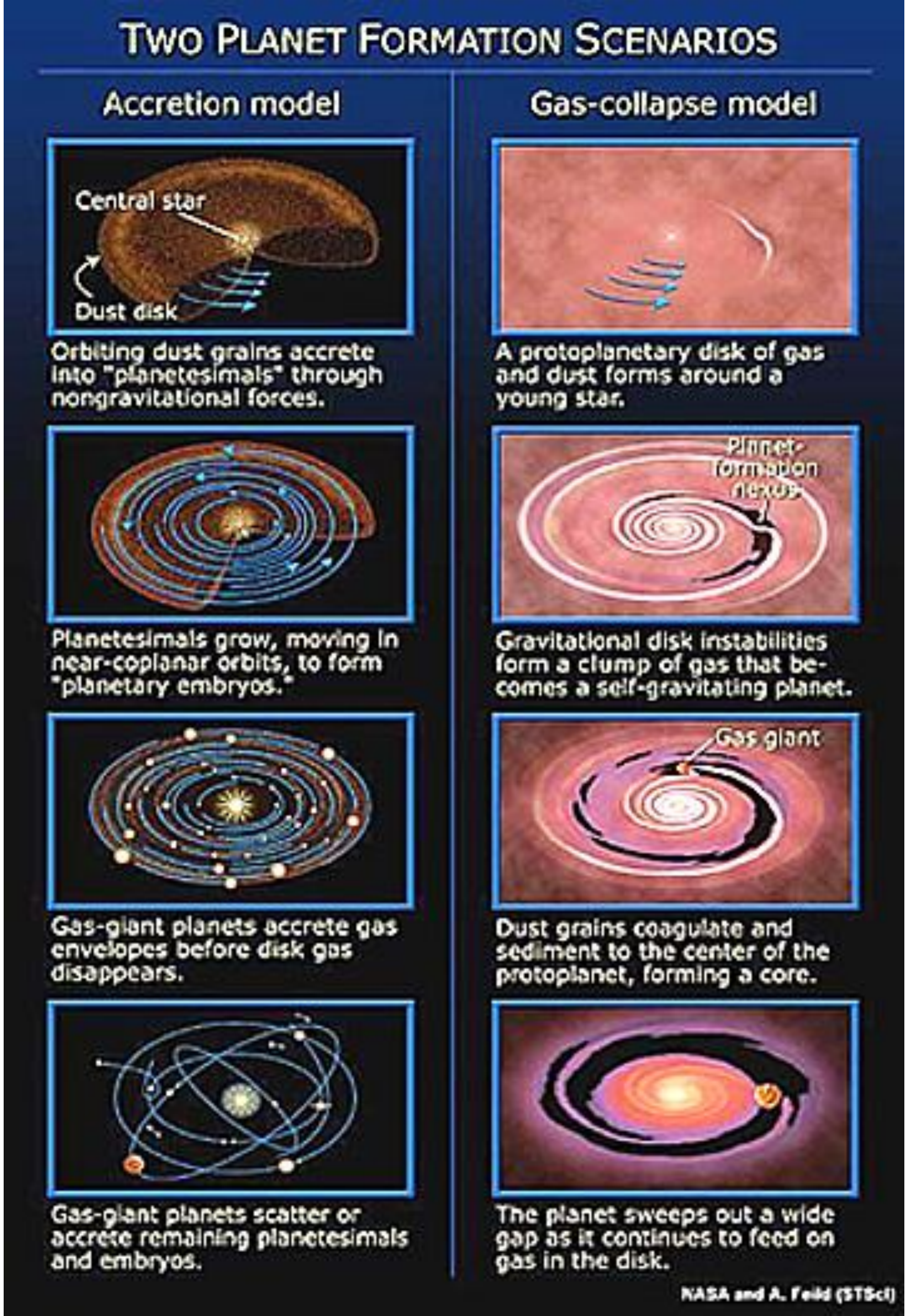
$$\Downarrow$$

Radioactive decay

$$^{63}_{28}Ni \rightarrow ^{63}_{29}Cu + \beta^{+} + \overline{\gamma}$$

Other elements have to have this occur very fast, the rate of neutron capture before radioactive decay requires a supernova


H,He
He,N
He,C,22Ne
O,C
O,Ne,Mg
Si,S
Fe,Ni core
Massive star near the end of its lifetime has an "onion-like' structure just prior to exploding as a supernova
Red Giant Star
4He
14N
18F
18O
22Ne
γ
e+
ν
γ
Nuclear burning occurs at the boundaries between zones
Example of nuclear reactions that build neutron-rich isotopes

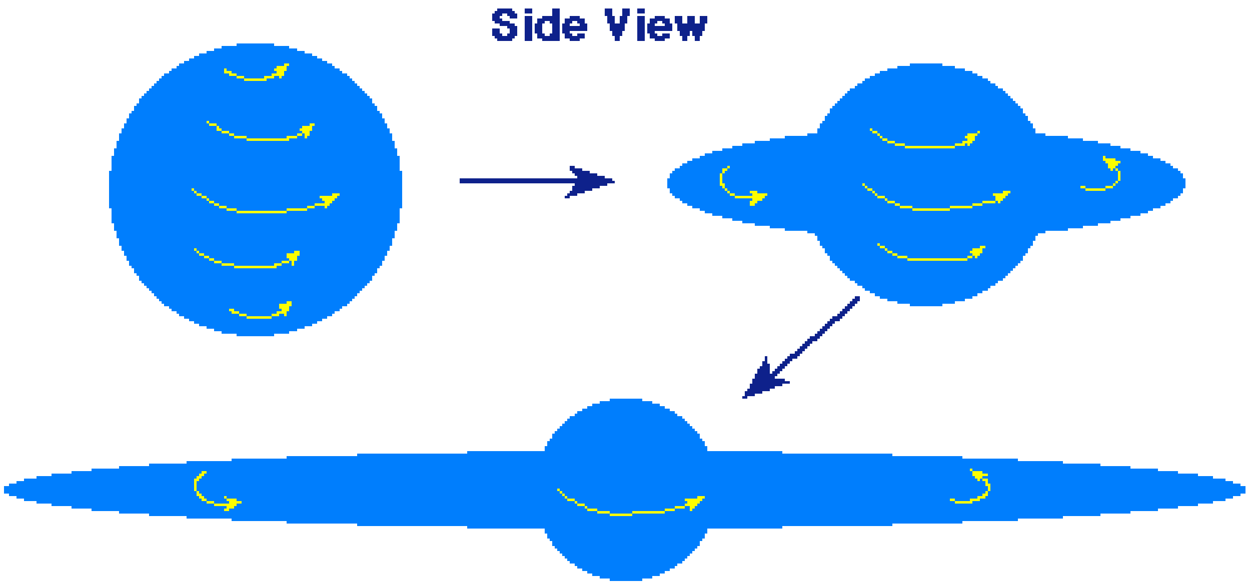

TWO PLANET FORMATION SCENARIOS
Accretion model
Gas-collapse model
Central star
Dust disk
Orbiting dust grains accrete into "planetesimals" through nongravitational forces.
A protoplanetary disk of gas and dust forms around a young star.
Planet-formation nexus
Planetesimals grow, moving in near-coplanar orbits, to form "planetary embryos."
Gravitational disk instabilities form a clump of gas that be-comes a self-gravitating planet.
Gas giant
Gas-giant planets accrete gas envelopes before disk gas disappears.
Dust grains coagulate and sediment to the center of the protoplanet, forming a core.
Gas-giant planets scatter or accrete remaining planetesimals and embryos.
The planet sweeps out a wide gap as it continues to feed on gas in the disk.
NASA and A. Feild (STScI)

Planetesmal theory

- Number of large ‘planetesmals’ which may have had significantly different compositions
- Collisions of these formed larger bodies which became planets – some think the chemical differences between core and mantle could be derived from this
- Moon formed from collision of Mars-sized body, likely altered the atmosphere significantly

Nebular Hypothesis

- Idea presents the solar system as a disk of material which on turning and gravitational attraction resulted in large bodies, which then reduced in size to form inner planets

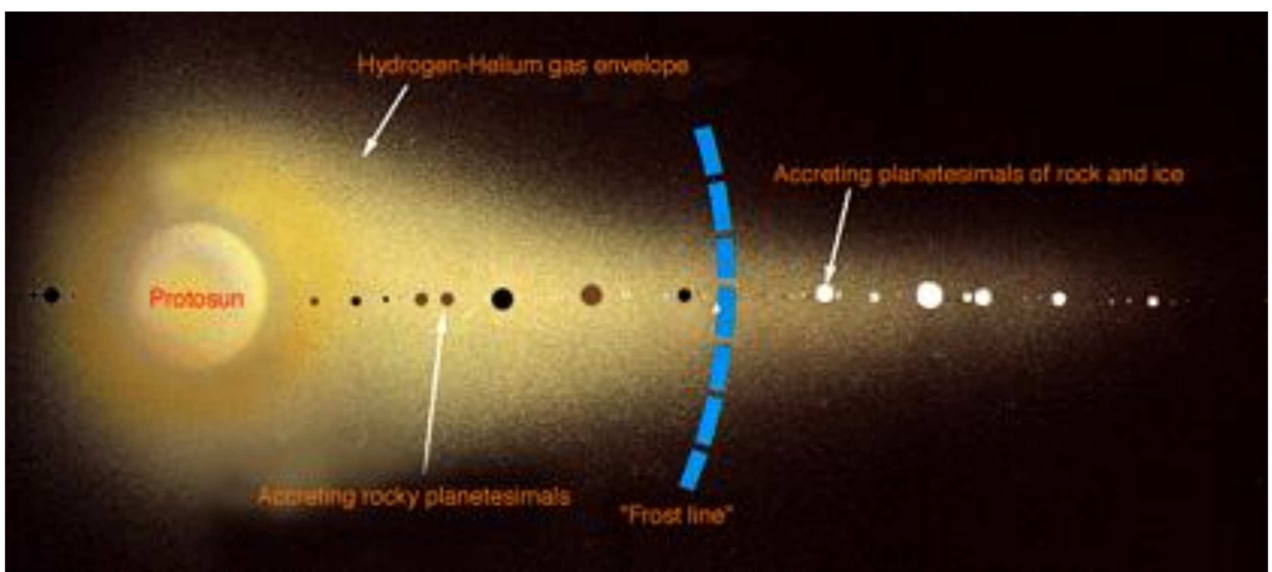


Temperature-Pressure gradients

- As the nebular material began rotating (gravitational, magnetic, electrostatic forces cause this), the material starts to develop some order
- The temperature and pressure gradients began chemical differentiation → because of condensation reactions, forming particles of solid material
  - NASA probes have 'seen' this in bodies thought to be actively forming planetoids

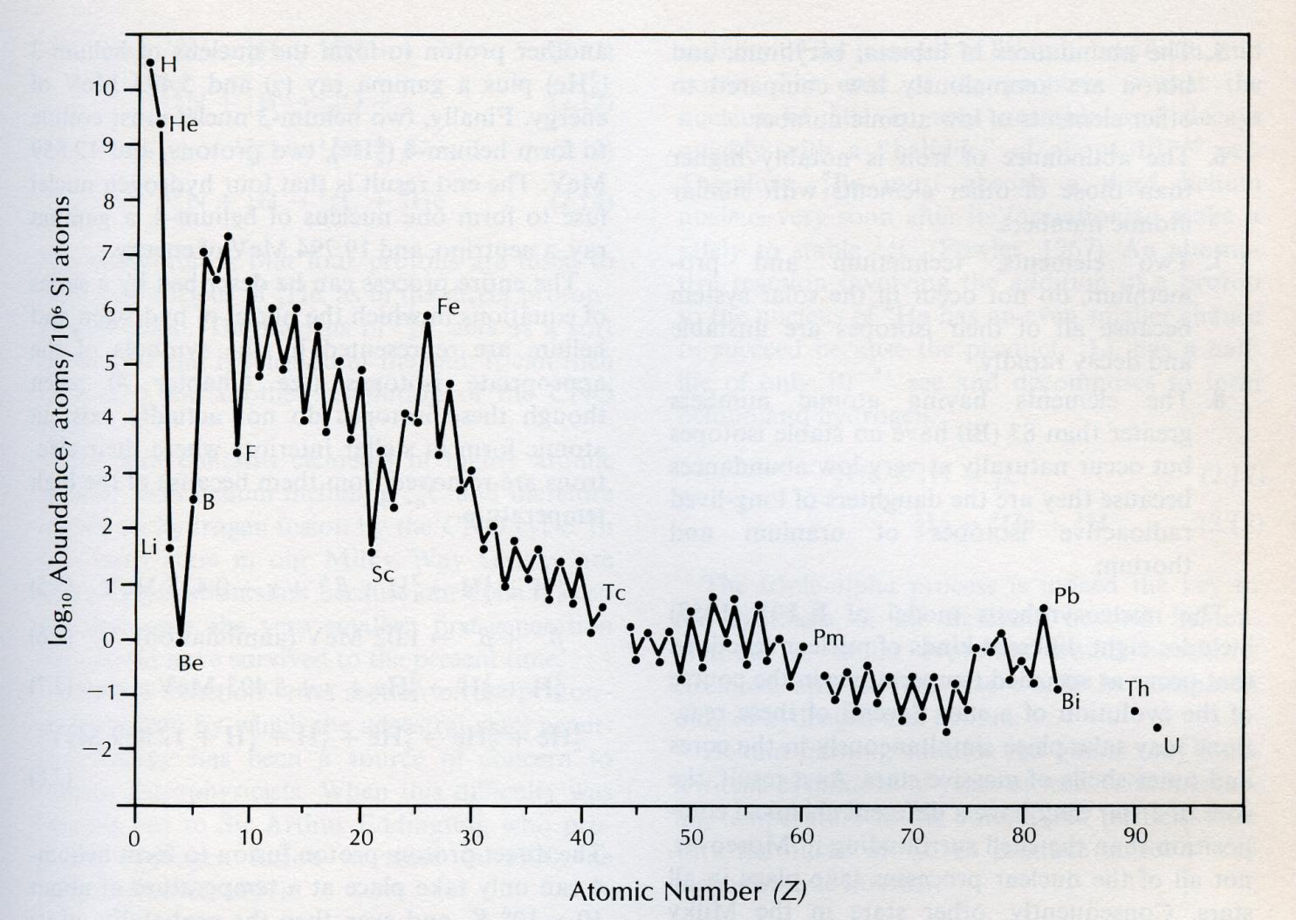
Condensation reactions

- Temperature thought to vary from 2000-40 K
  - Closer to the sun $\rightarrow$ refractory oxides (CaO, Al_2O_3, TiO_2, REE oxides), Fe and Ni metals
  - Further out, silicates form
  - Finally, ices (H_2O, NH_4, CH_4, etc) form

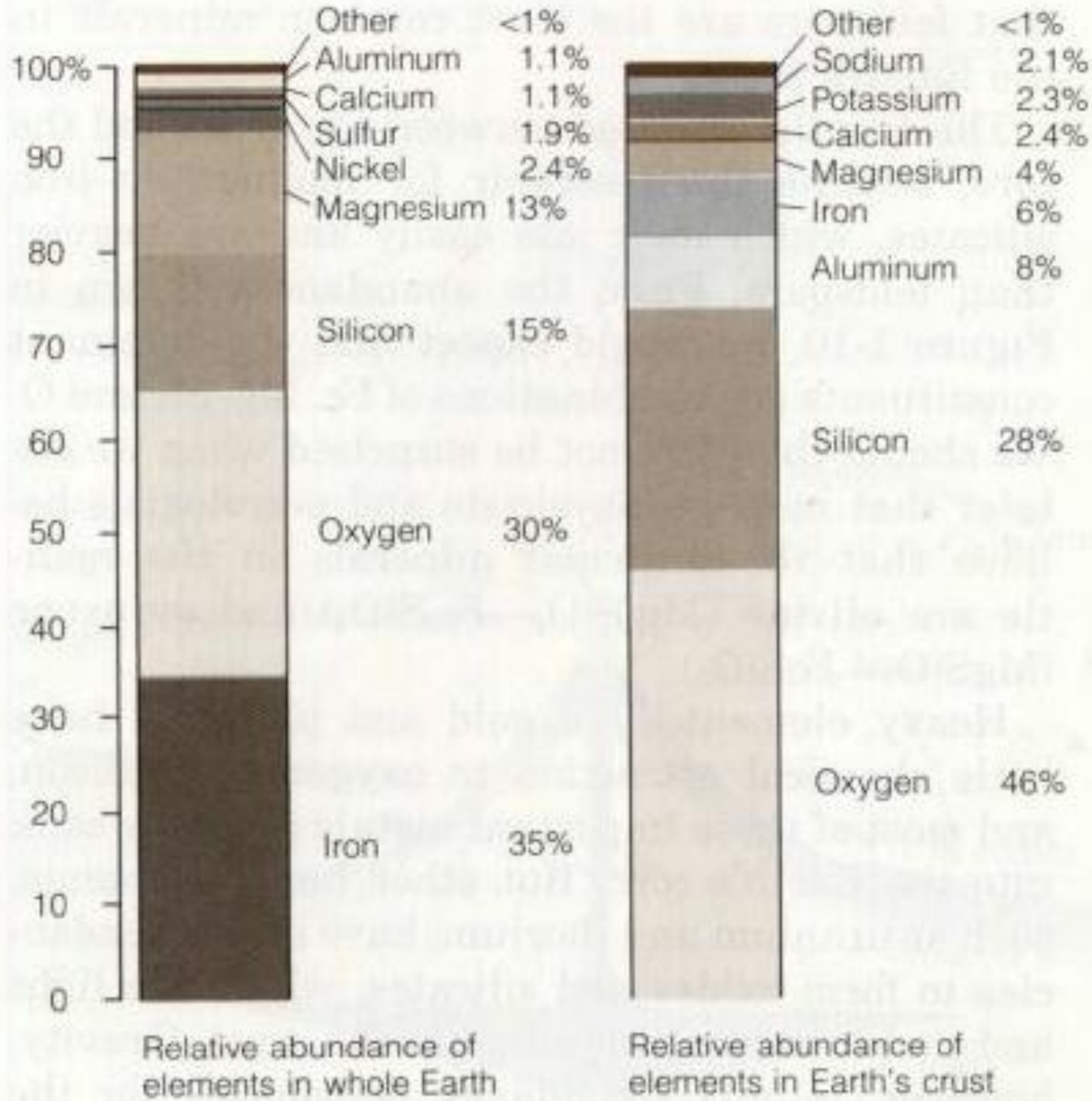


Elemental abundances

- O – 62.5% (atomic %)
- Si – 21.2%
- Al – 6.5%
- Fe – 1.9%
- Ca – 1.9%
- Na – 2.6%
- K – 1.42%
- Mg – 1.84%

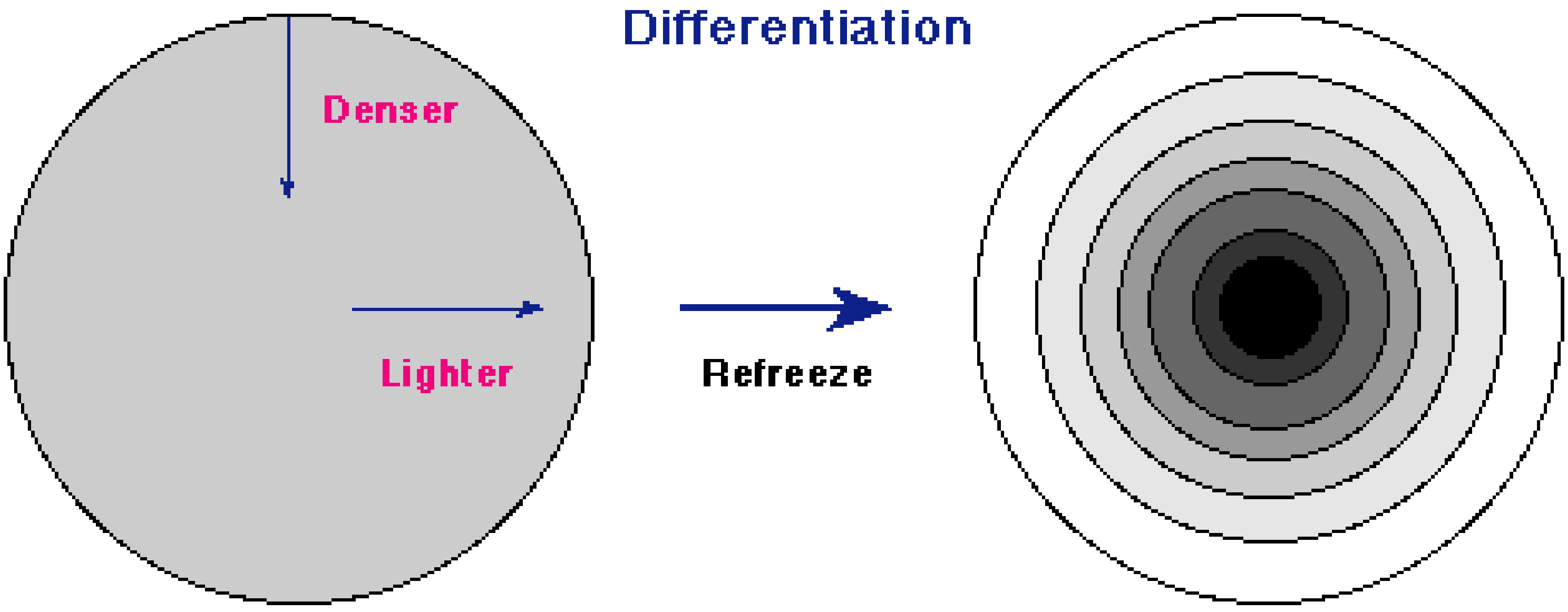


- Nuclear reactions determine element abundance…
- Is the earth homogeneous though?
- Is the solar system??
- Is the universe???

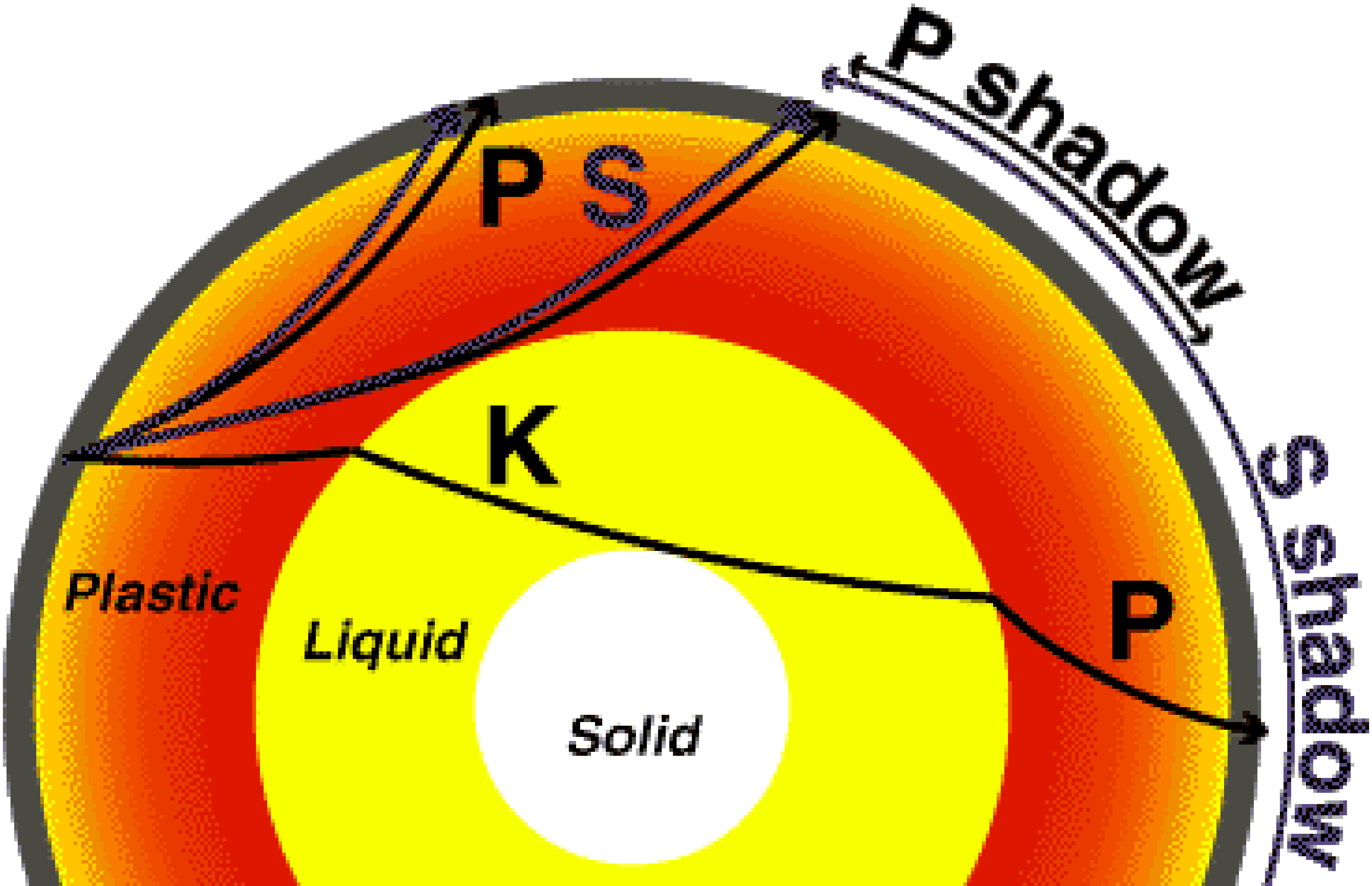


Earth’s Chemical Differentiation

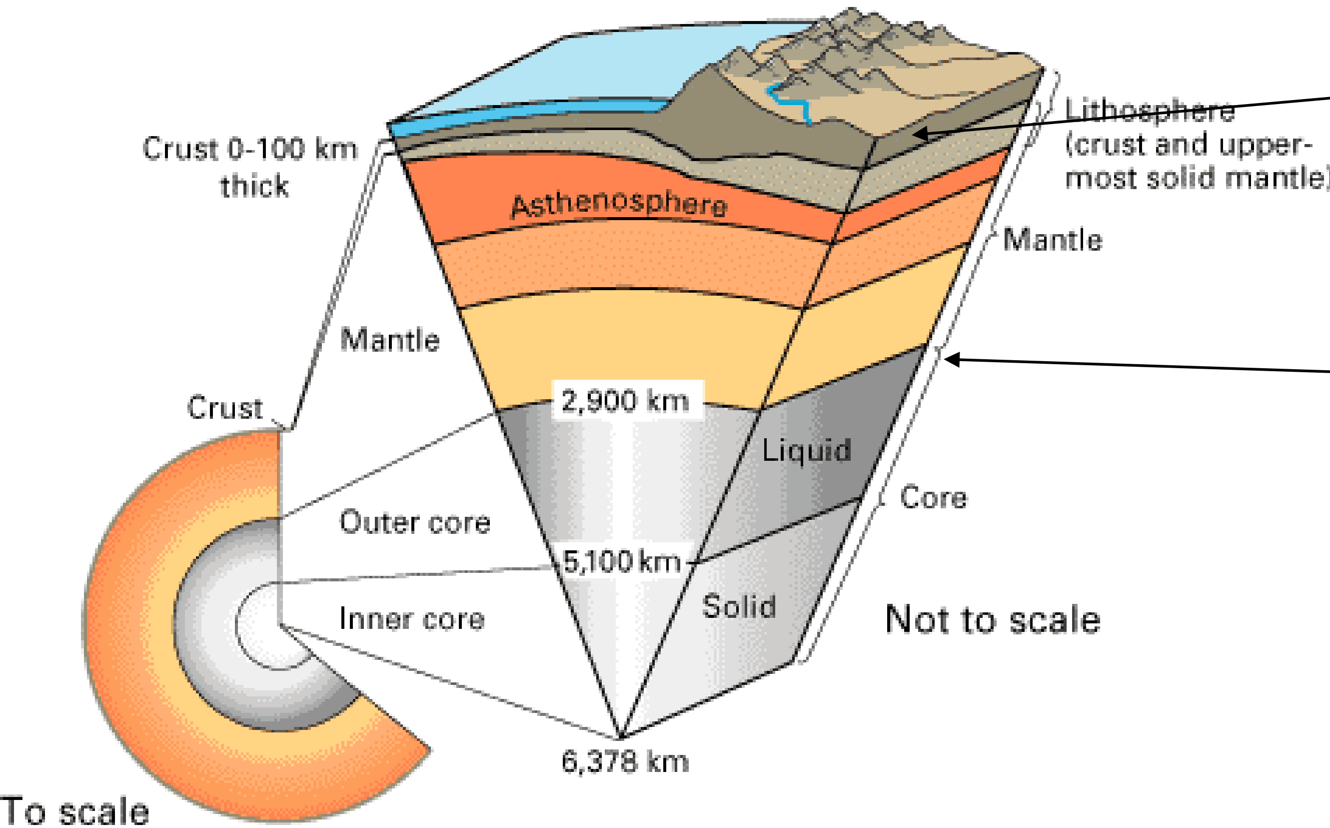
- In earth’s early history, it was molten, and the chemicals continued to differentiate throughout it based on physical principles



Seismic waves – Earth's structure



3 Major Zones, 2 Transitions



crust

MOHO - ~40km

mantle

Wiechert-Gutenberg discontinuity

core

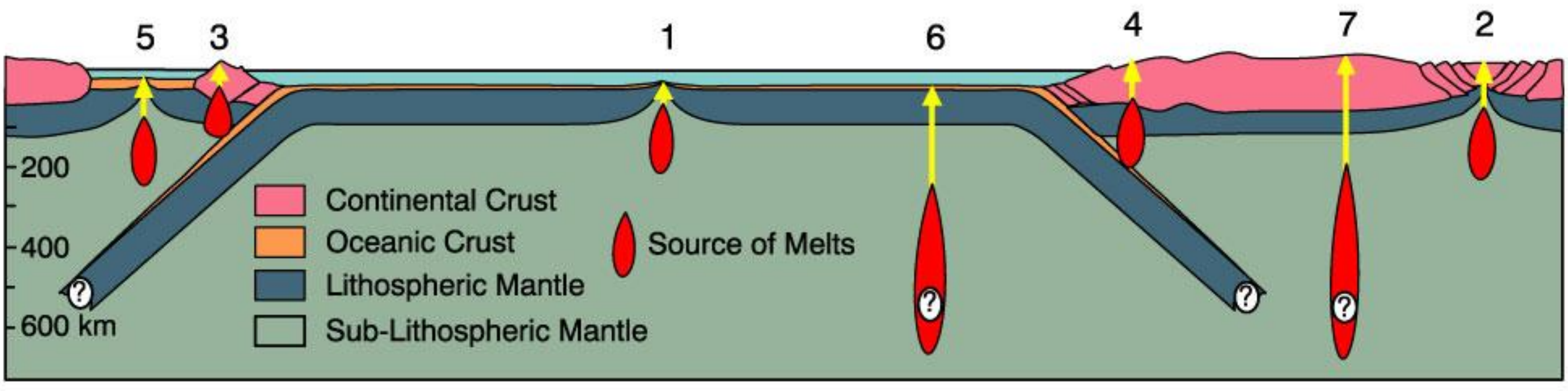
Crustal Differentiation

- The earth's crust has widely varying chemistry → why is that?

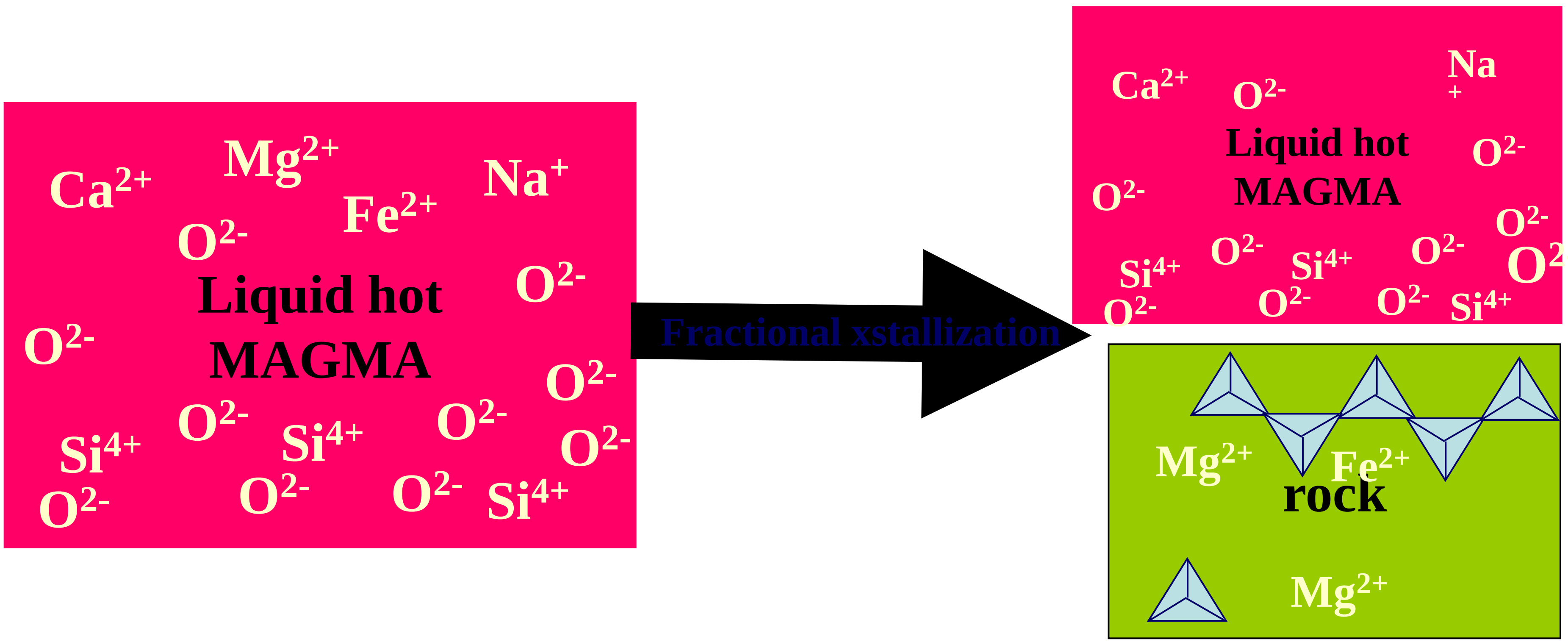
- Differentiation processes affect all major rock types
- Wide variety of specific reactions happen as igneous, metamorphic, and sedimentary rocks form, change, transport ions, and 'decompose' which result in geochemical differentiation

Plate Tectonics - Igneous Genesis

1. Mid-ocean Ridges
2. Intracontinental Rifts
3. Island Arcs
4. Active Continental Margins
5. Back-arc Basins
6. Ocean Island Basalts
7. Miscellaneous Intra-Continental Activity
   - kimberlites, carbonatites, anorthosites...



- **How does Magma composition change?**
  - **Hot material in different parts of the mantle?**
  - **Melts some rocks into it – interacts with surrounding material (Partial Melting)**
  - **Fractional crystallization → crystals form and get separated form source**

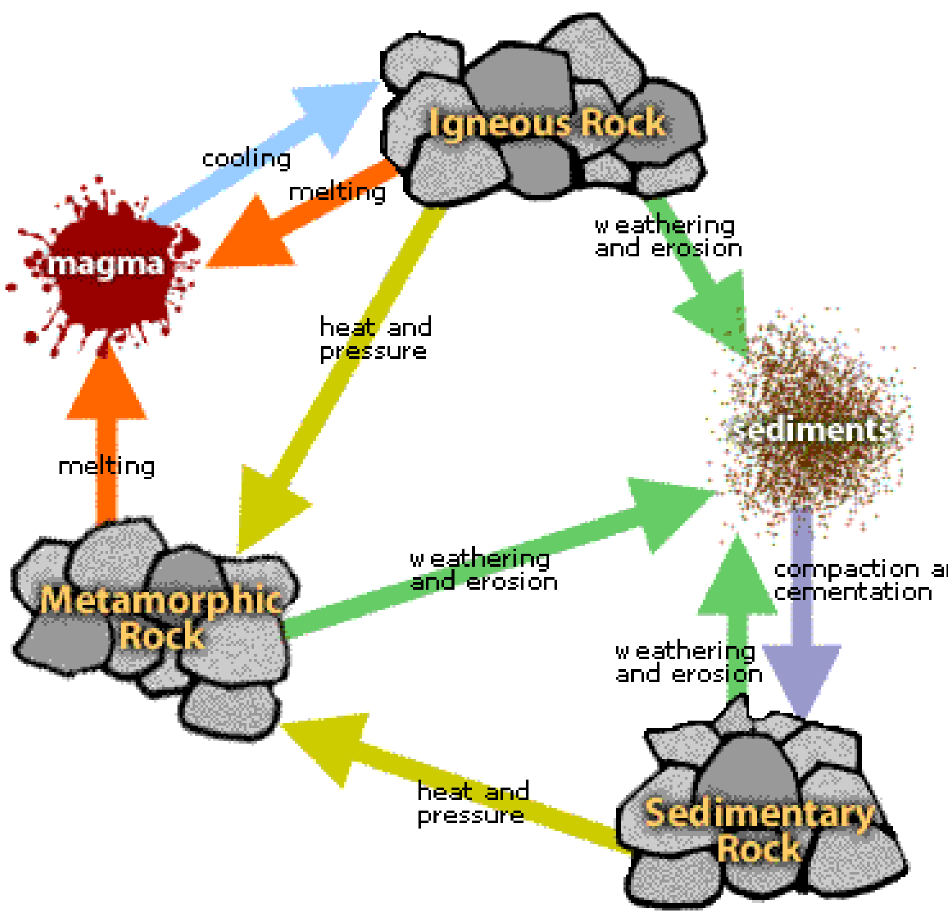


Metamorphic Rocks

- Agents of Change → T, P, fluids, stress, strain
- **Metamorphic Reactions!!!!**
  - Solid-solid phase transformation
  - Solid-solid net-transfer
  - Dehydration
  - Hydration
  - Decarbonation
  - Carbonation

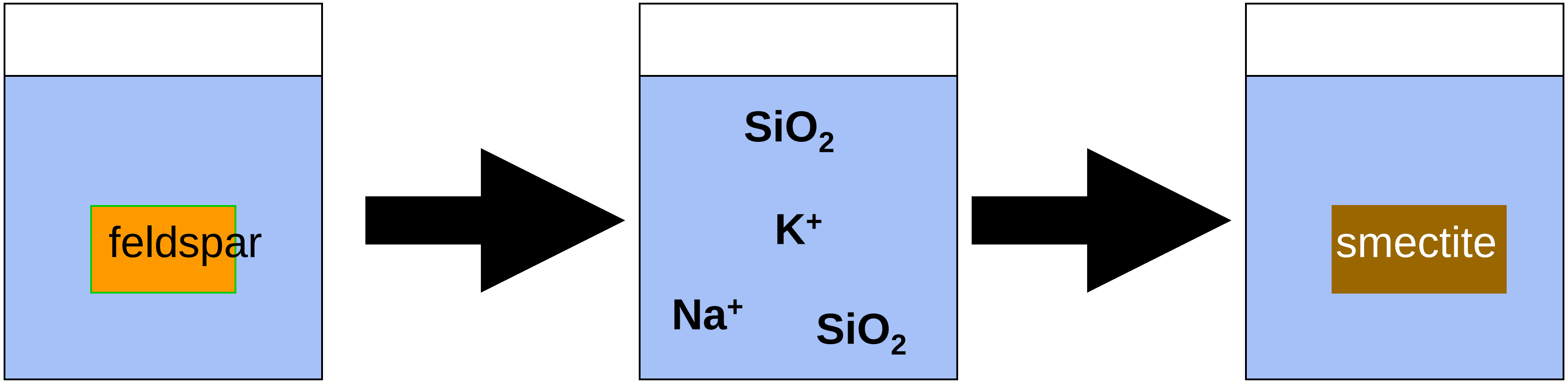
Sedimentary Materials

- Sedimentary rocks cover 80% of the earth's surface but only comprise ~1% of the volume of the crust



Aqueous Species

- Dissolved ions can then be transported and eventually precipitate
- Minerals which precipitate from solution are rarely the same minerals the ions dissolved out of
- Why would they need to be transported before precipitating?



Earth = anion balls with cations in the spaces…

- View of the earth as a system of anions packed together → By size and abundance, Si and O are the most important
- If we consider anions as balls, then their arrangement is one of efficient packing, with smaller cations in the interstices
- Closest packed structures are ones in which this idea describes atomic arrangement – OK for metals, sulfides, halides, some oxides

Packing

- Spheres and how they are put together
- HCP and CCP models are geometrical constructs of how tightly we can assemble spheres in a space

- Insertion of smaller cations into closest packed arrays yield different C.N.'s based on how big a void is created depending on arrangement