Current Understanding of the Earth's Core

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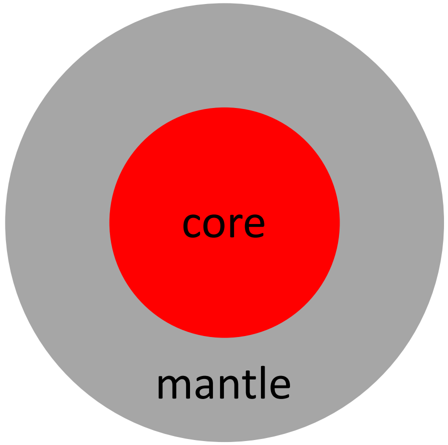
Outline

- Density Structure
- Core composition
  - Light elements
  - Radiogenic elements
  - Noble gases

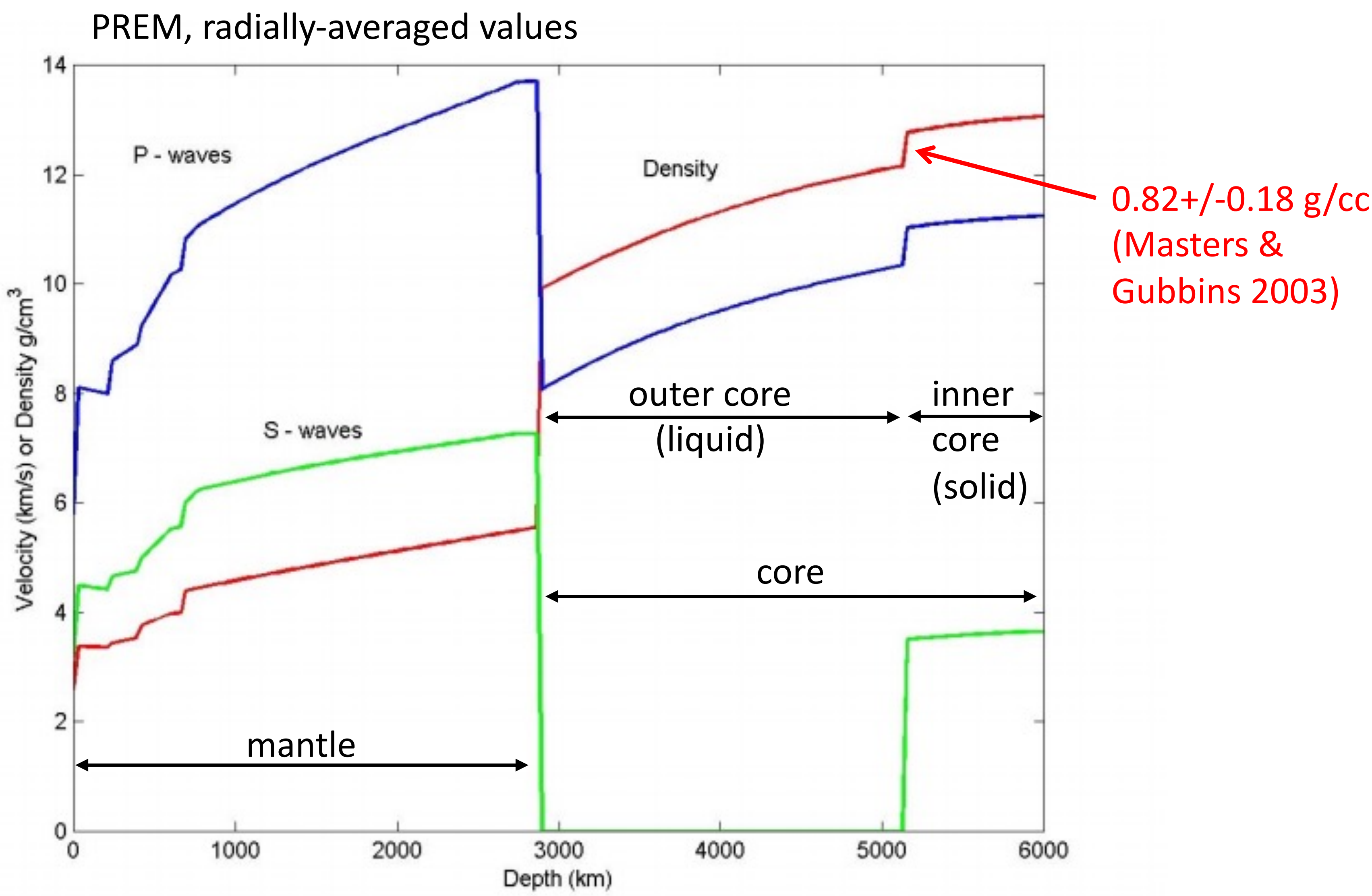


Density structure of the Earth

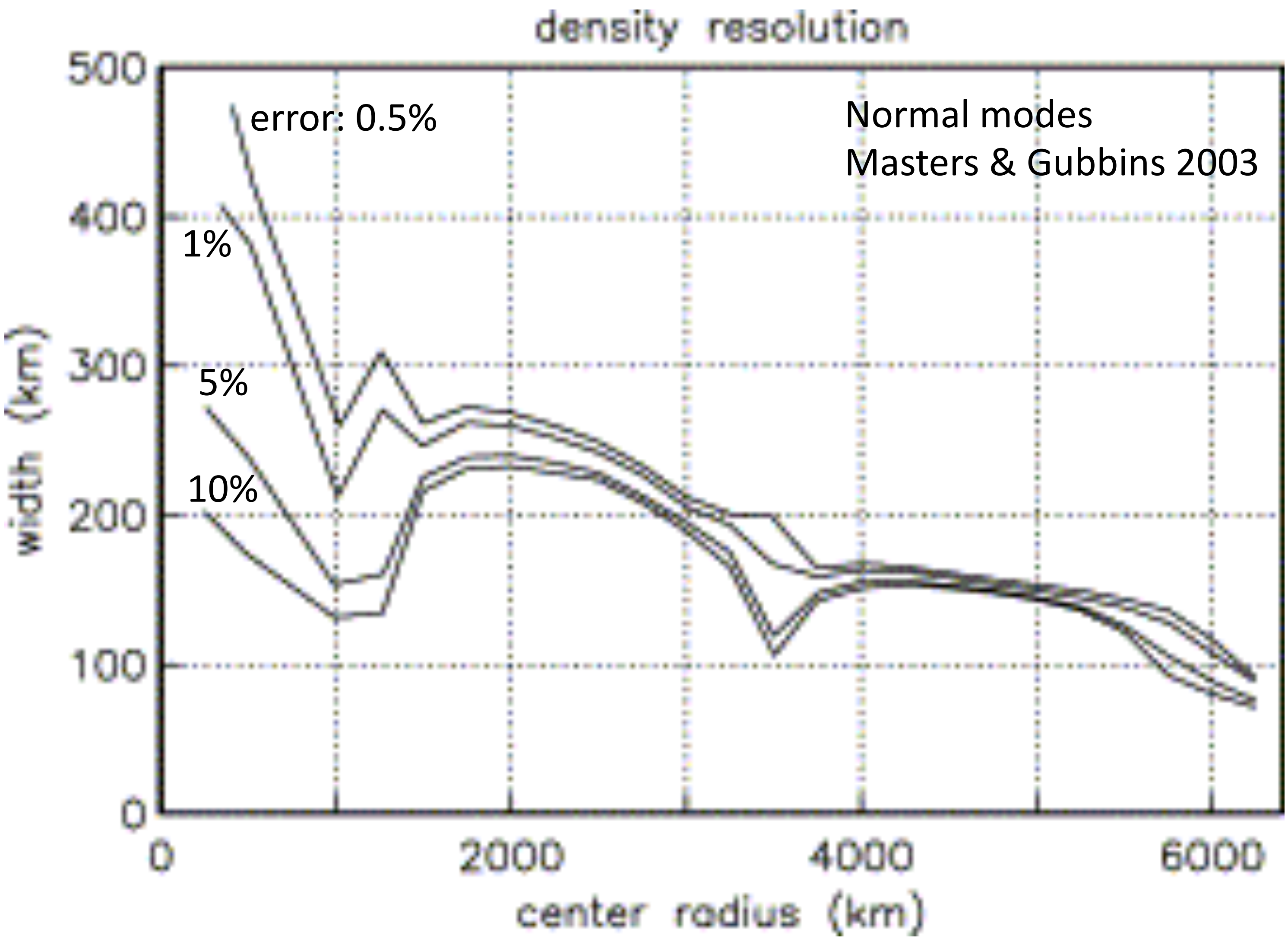
- Derived from measurements of seismic wave speeds (v_p, v_s) and/or normal mode oscillation frequencies
- Adams-Williamson equation

$$\frac{d\rho}{dr} = -\frac{\rho(r)g(r)}{v_p^2 - \frac{4}{3}v_s^2}$$

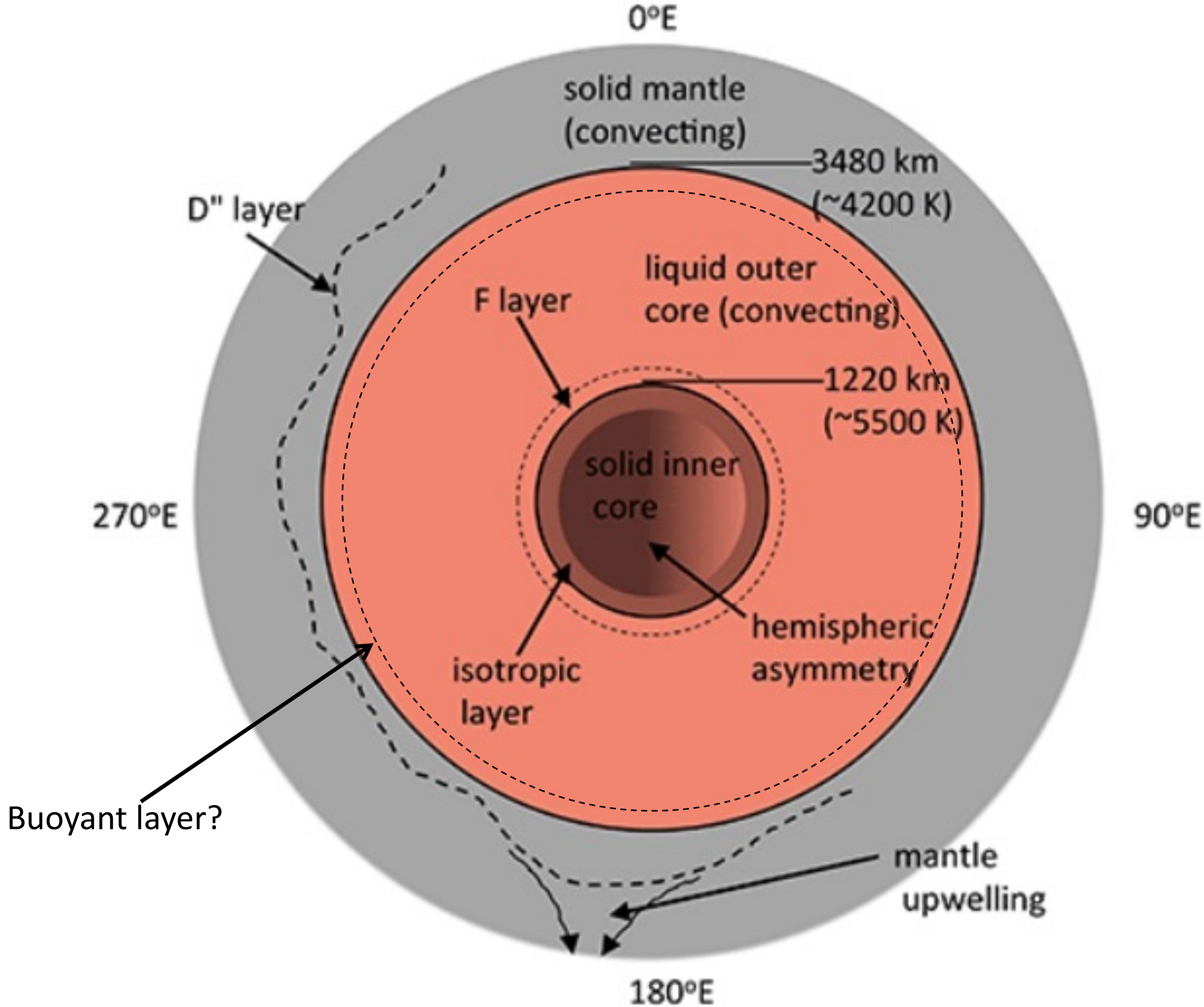
Density Structure



Density Resolution



Nimmo (2022), Oxford Research Encyclopedia, https://doi.org/10.1093/acrefore/9780190647926.013.204

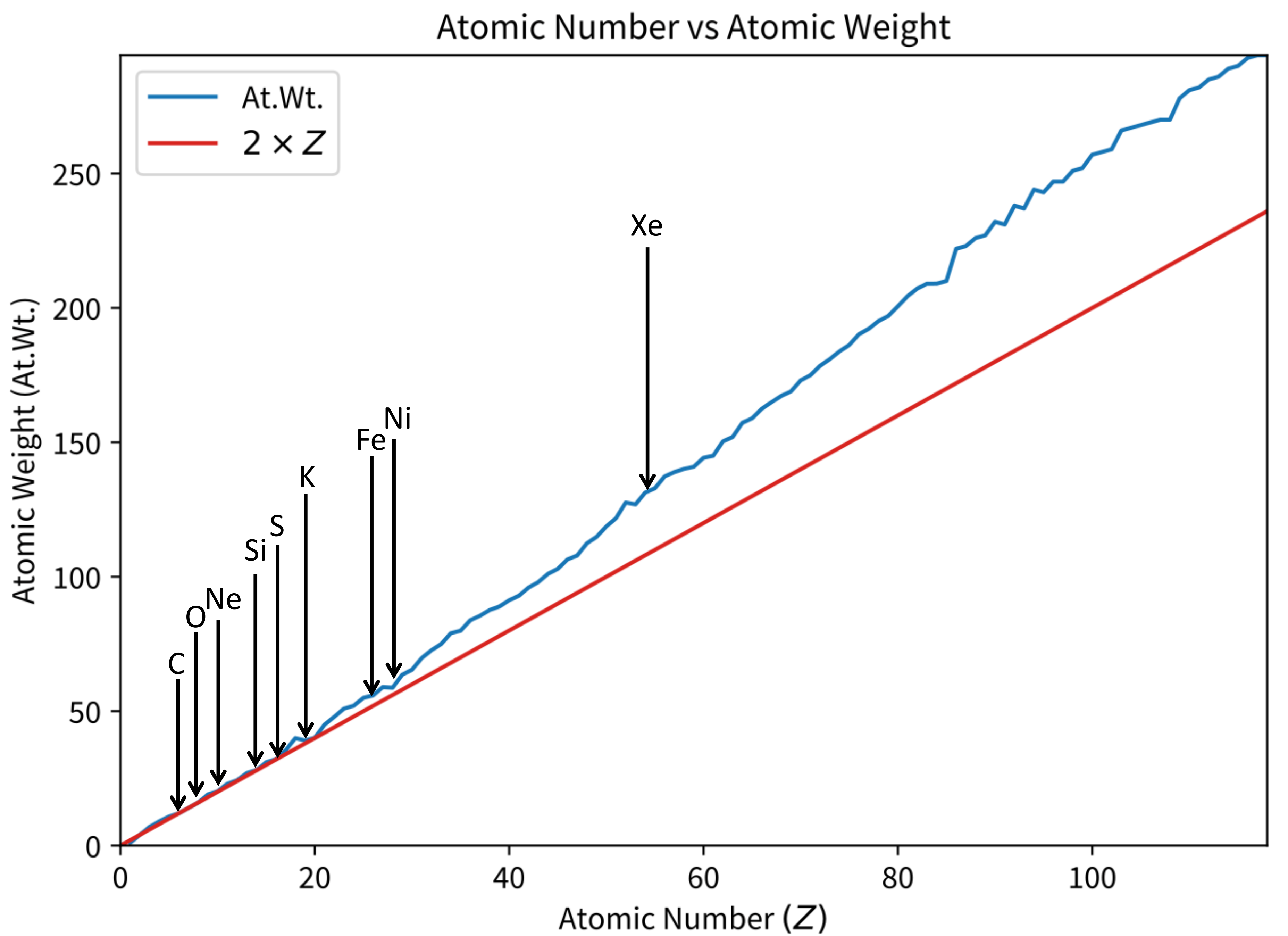


Layers in the core?

- "F-layer" at the bottom of the outer core
  - 150 km thick, stably stratified?
  - Density change ~0.5 g/cc across layer
  - Could be a gradient in O (Gubbins et al. 2008)
- Stable layer at the top of the outer core?
  - Existence is disputed (Buffett et al. 2016, Helffrich & Kaneshima 2010, Irving et al. 2018)
  - ~300 km thick, light by ~0.6 g/cc
  - Could be a result of accumulation of light elements (e.g. O,Si) or be a non-convecting part of the outer core

Core Light Elements

- Based on cosmochemical models (McDonough & Sun 1995) the core contains Fe with about 5.5wt% Ni
- But the measured density of the core is too light by 7-10% to be a pure Fe-Ni alloy
- So the Earth contains one or more light elements
- Usual candidates are H,C,O,Si,S


Atomic Number vs Atomic Weight
At.Wt.
2 × Z
Atomic Weight (At.Wt.)
Atomic Number (Z)
0
50
100
150
200
250
0
20
40
60
80
100
C
O
Ne
Si
S
K
Fe
Ni
Xe

Which light element is present?

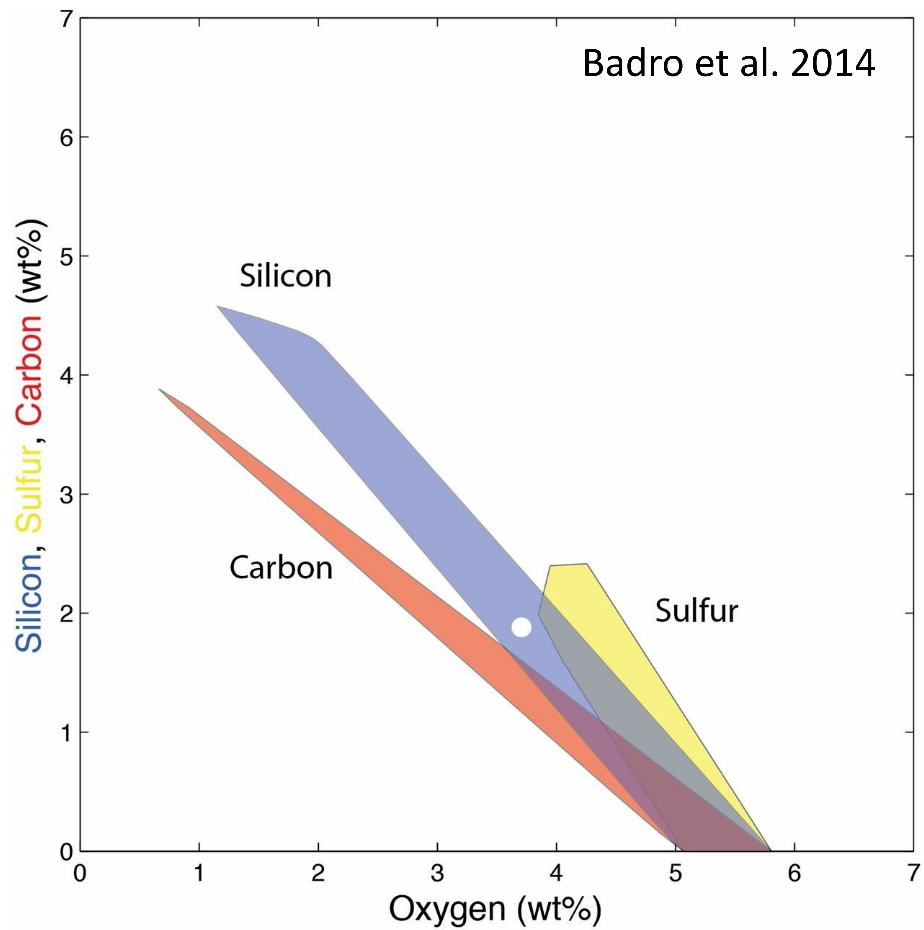
- Two ways of addressing this question:
  - Compare densities and seismic velocities [non-unique]
  - Use partitioning models [assumption-dependent]

Density jump at the ICB

- The inner core is denser than the outer core by 0.36-0.62 g/cc *after taking the phase change into account* (Masters & Gubbins 2003)
- So the inner core contains fewer light elements than the outer core
- Oxygen is excluded from the solid core, whereas S and Si are not (Alfe et al. 2002, Ozawa et al. 2010)
- So the outer core must contain O

Densities and seismic velocities

- In principle, different light elements may produce different densities & velocities
- Measurements at correct P,T conditions are hard
- Sometimes *ab initio* simulations are used instead
- No single element can satisfy the observations
- There is little agreement, although oxygen is commonly found



Partitioning models

- "Partitioning" means the extent to which an element goes into the core rather than the mantle on melting
- Experiments at Earth-relevant conditions are difficult (e.g. Fischer et al. 2020 vs. Blanchard et al. 2022)
- "Partition coefficient" depends on P,T,fO_2
- Assumptions of initial fO_2 and composition have a big effect on the conclusions
- There is little agreement on how fO_2 has evolved with time (e.g. Badro et al. 2015, Rubie et al. 2015)

- But most models favour Si and O as the dominant core light elements

What about S,C and H?

- C core content ~0.1 wt% (Fischer et al. 2020, Blanchard et al. 2022)
- S is a possibility from velocity/density measurements; S partitioning experiments suggest <2 wt% in core (Suer et al. 2017)
- Both C and S are strongly depleted in most precursor Earth materials
- H could be as high as 0.6 wt% (Tagawa et al. 2021)
- But would require cores to form and acquire gas before the nebular dispersed (<5 Myr) – unlikely but not impossible

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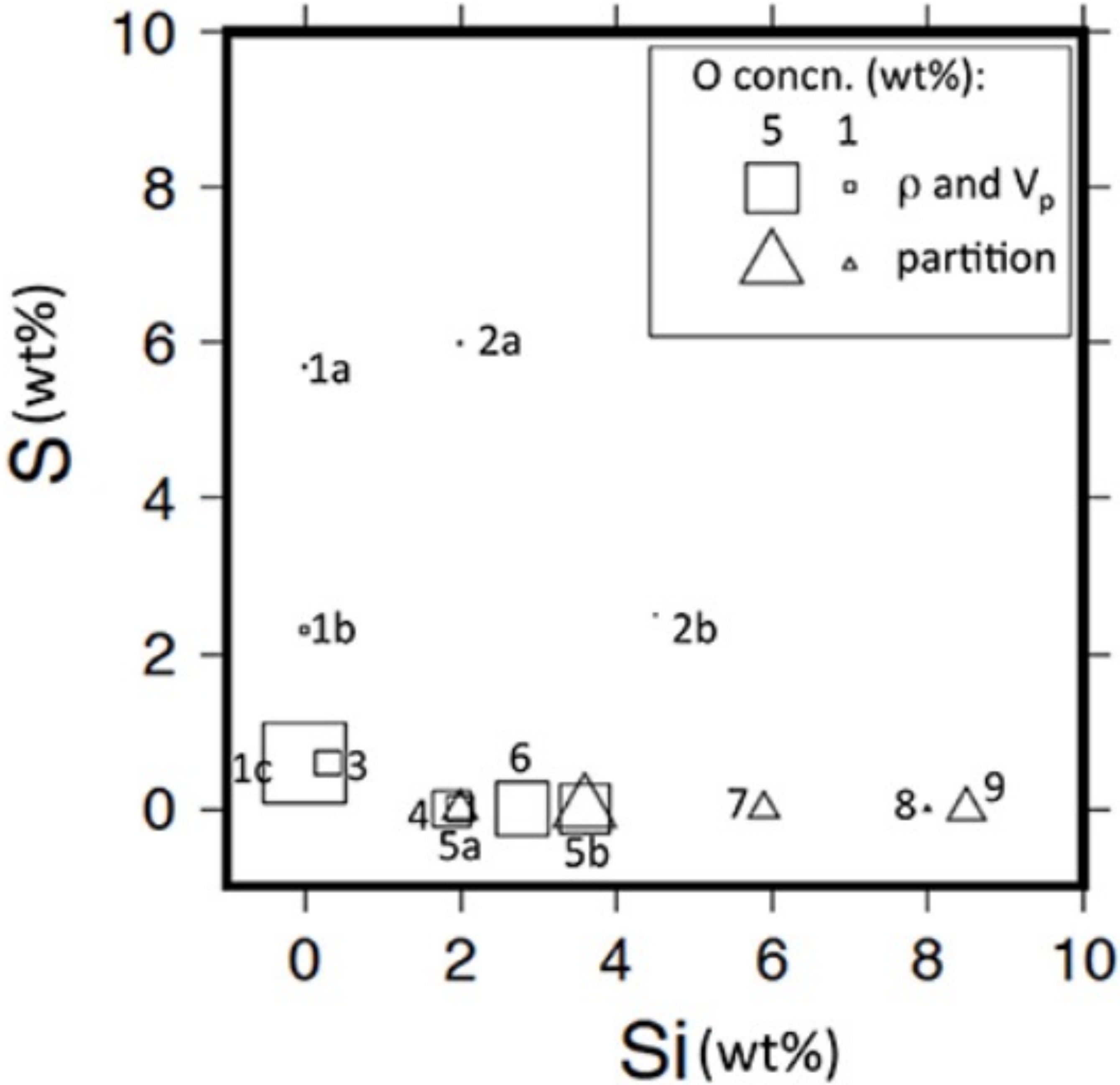

1. Huang et al. (2011)
2. Morard et al. (2013)
3. Umemoto & Hirose (2020)
4. Badro et al. (2014)
5. Badro et al. (2015)
6. Badro et al. (2007)
7. Fischer et al. (2015)
8. Rubie et al. (2011)
9. Rubie et al. (2015)

Radiogenic Elements

- The Earth's heat engine is powered by long-lived radiogenic elements: K,U,Th
- U and Th are thought to reside exclusively in the mantle ("lithophile")
- But some K might be found in the core
- Radioactive K can significantly alter the thermal and magnetic history of the core (e.g. Nimmo et al. 2004)
- Partitioning data (Blanchard et al. 2017, Xiong et al. 2018) suggest only ~30ppm K in the core, too small to be important

Noble gases

- ~$5x10^{-13}$ concentration for ^{3}He (Olson & Sharp 2022)
- ~$2x10^{-13}$ for ^{3}He and ~$7x10^{-12}$ for ^{22}Ne (Bouhifd et al. 2020)
- ~ 3x10-9 for ^{40}Ar (from radioactive decay) (Wang et al. 2022)
- These are very uncertain numbers
- But the concentrations are very low!

Summary

- Density Structure
  - *Well-known, except for possible layers at top and bottom of outer core*
- Core composition
  - Light elements: *O, probably Si, possibly S*
  - Radiogenic elements: *K at the tens of ppm level*
  - Noble gases: *Concentrations very low (~10^{-13}-10^{-9})*