ASU Arizona State University

School of Earth and Space Exploration

NExSS

ExoPlex Mass-Radius Code

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Sagan Summer Workshop
7-16-2019

Jargon for astronomers:

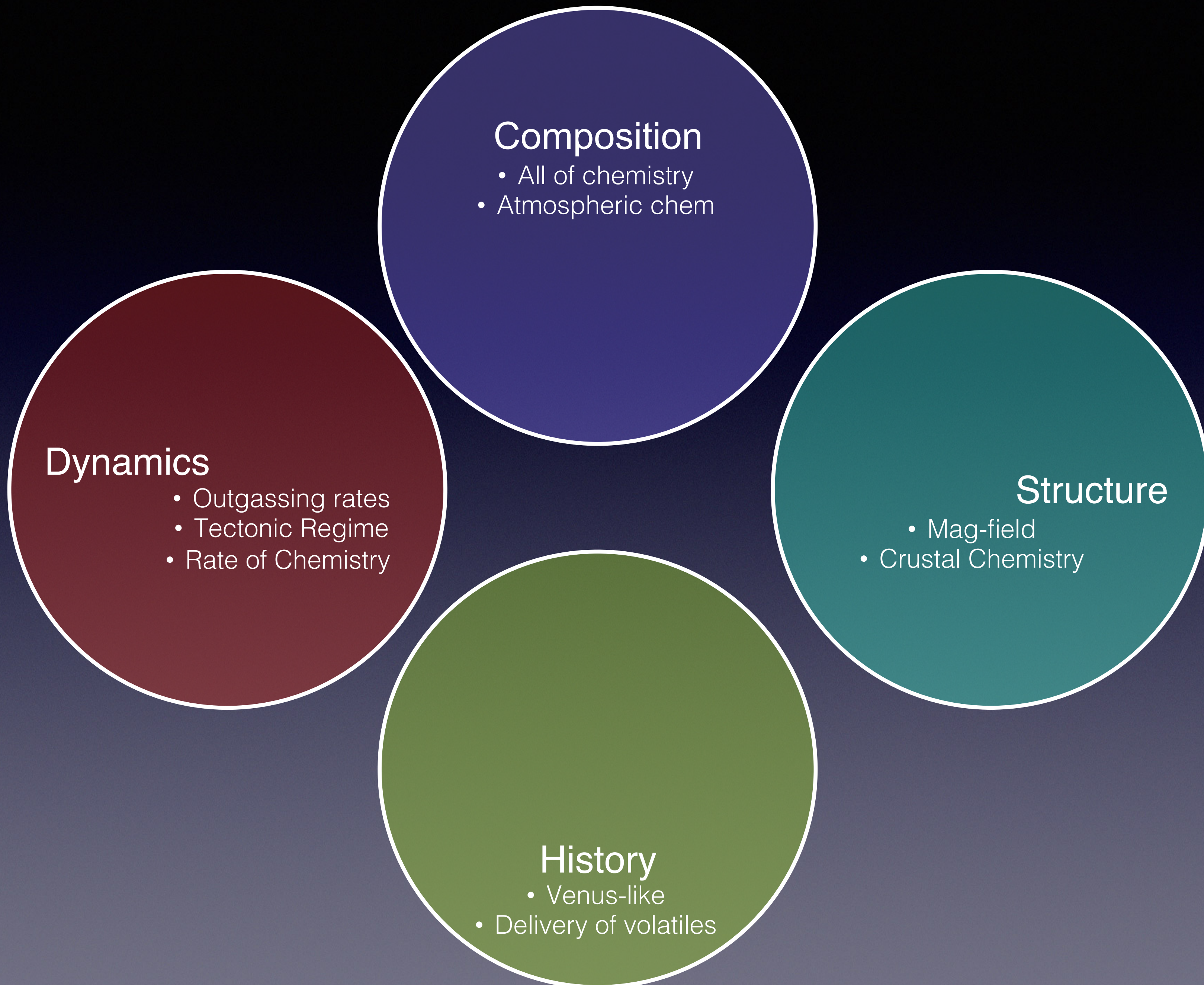
Core: Fe/Ni/X sphere in middle of rocky planets

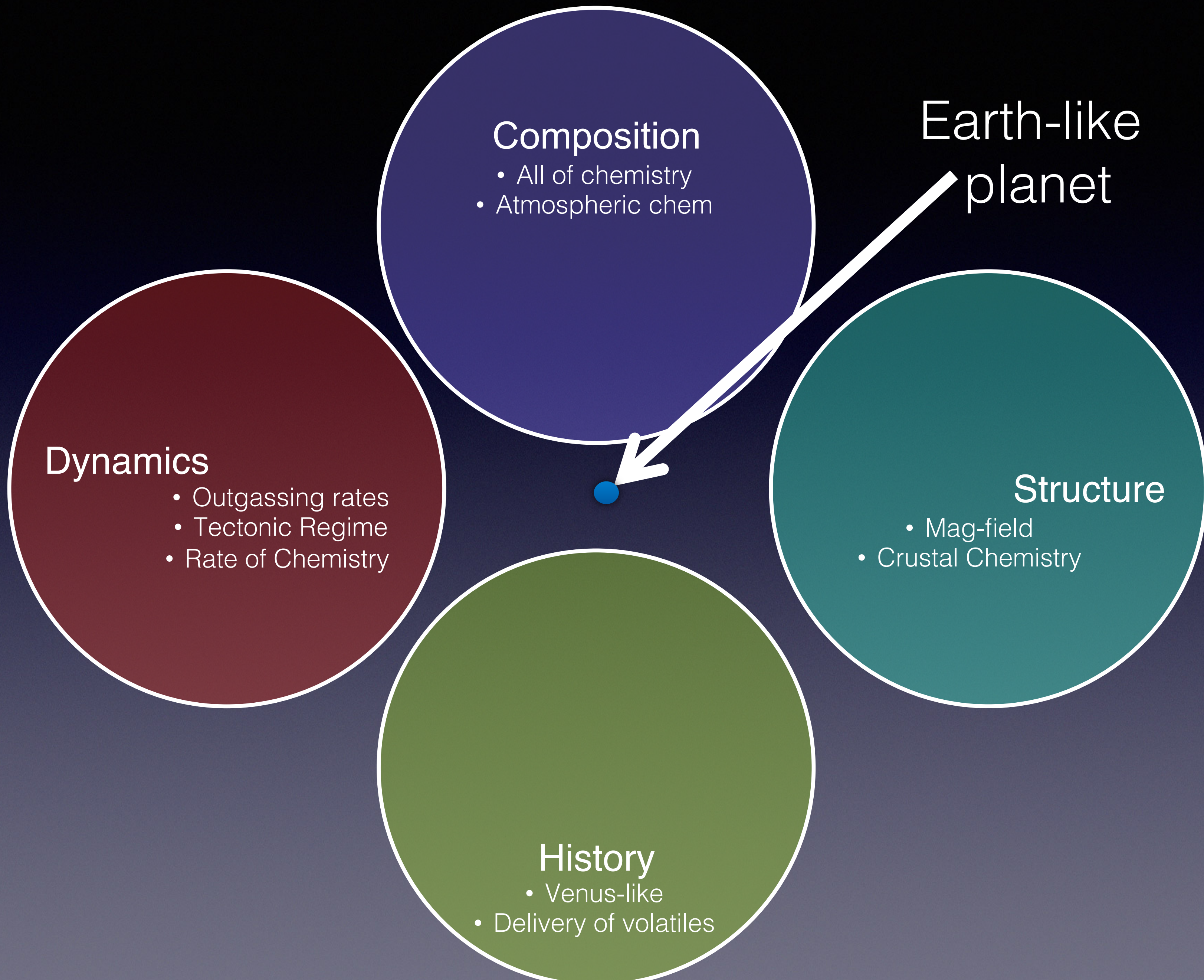
Mantle: The rocky part

Metal: Not everything $Z > Z_{He}$

CMB: Core mantle boundary

What makes a habitable planet?
(An Exogeoscientist’s View)


Composition
• All of chemistry
• Atmospheric chem
Dynamics
• Outgassing rates
• Tectonic Regime
• Rate of Chemistry
Structure
• Mag-field
• Crustal Chemistry
History
• Venus-like
• Delivery of volatiles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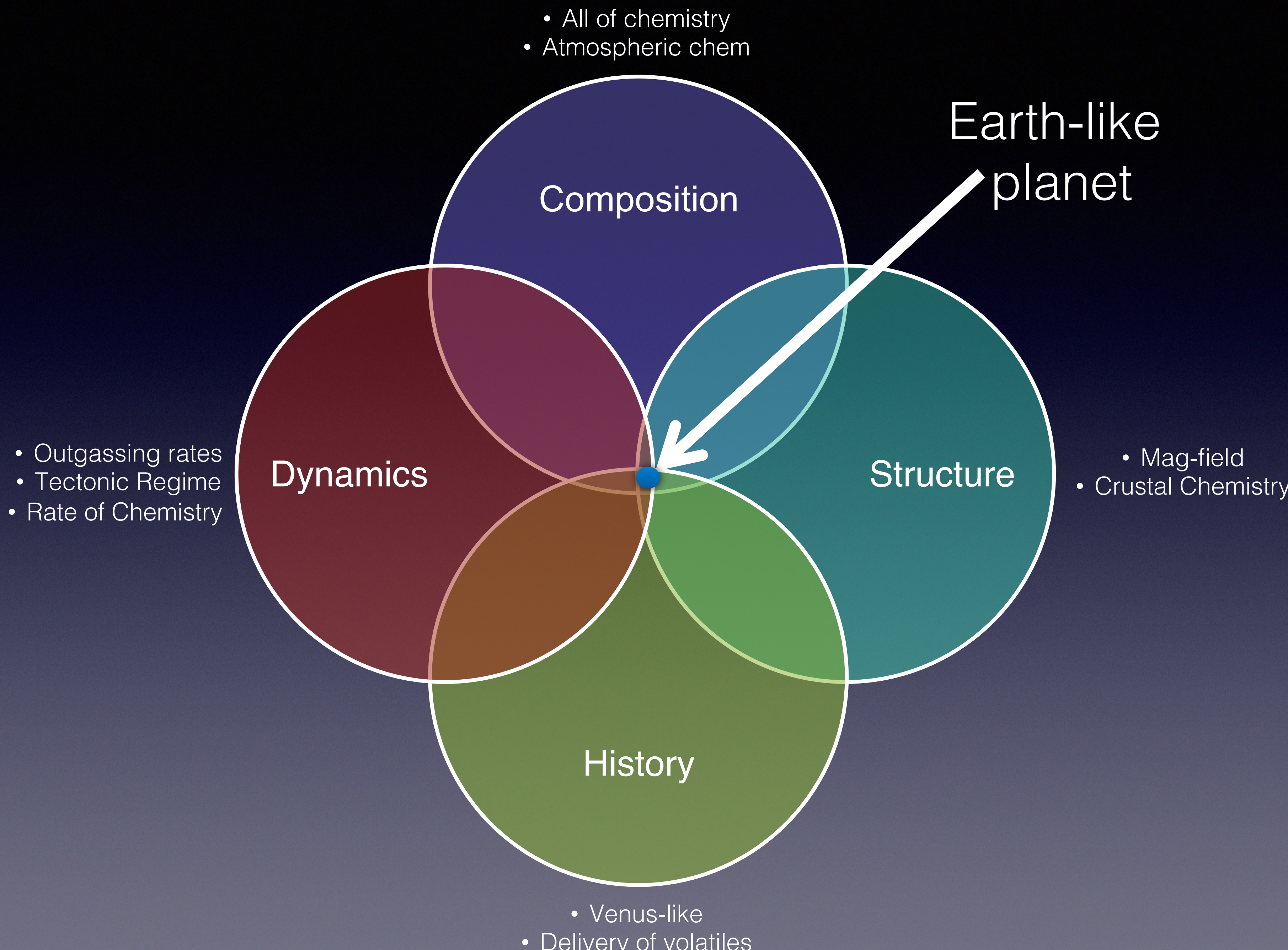

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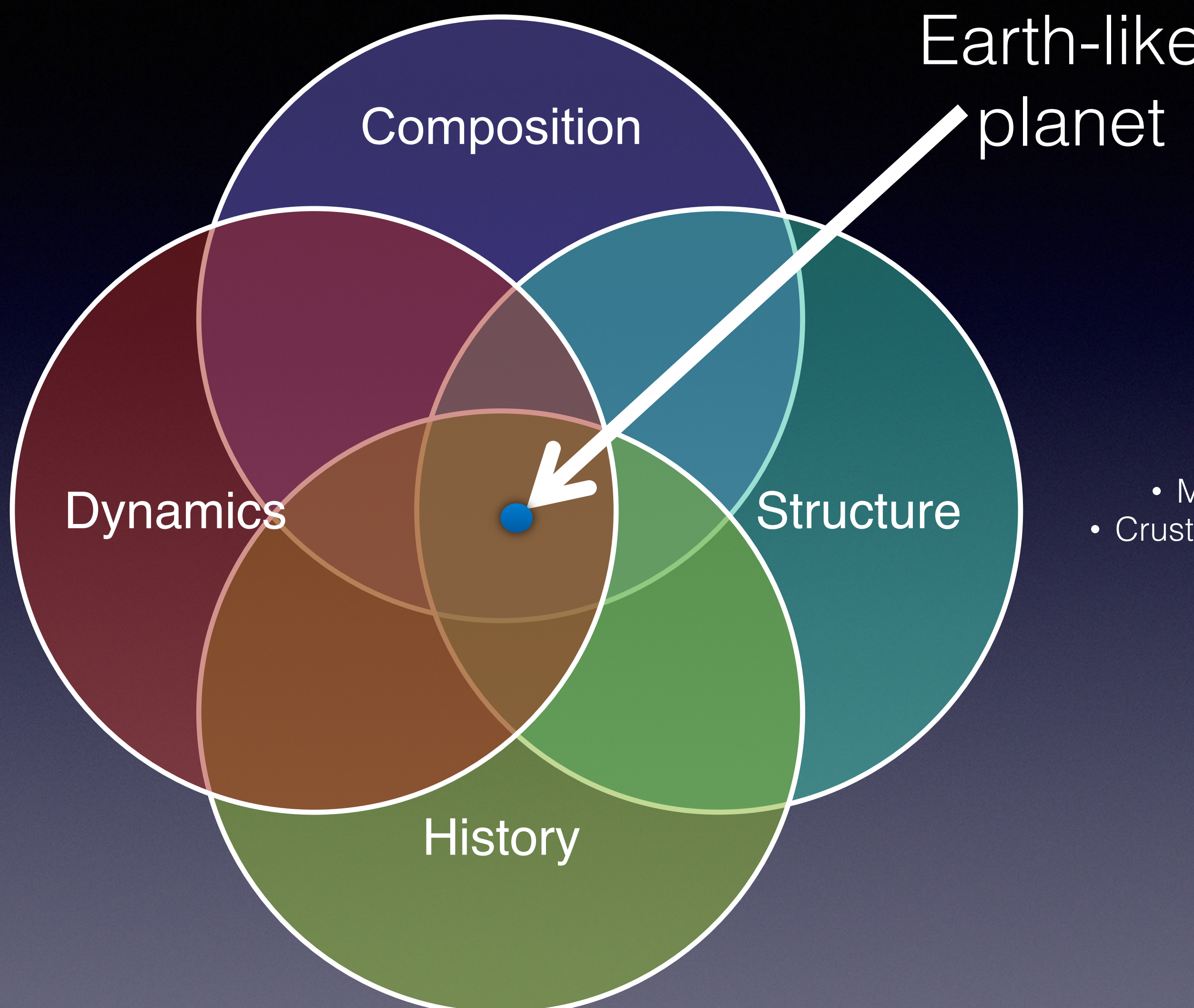
- All of chemistry
- Atmospheric chem



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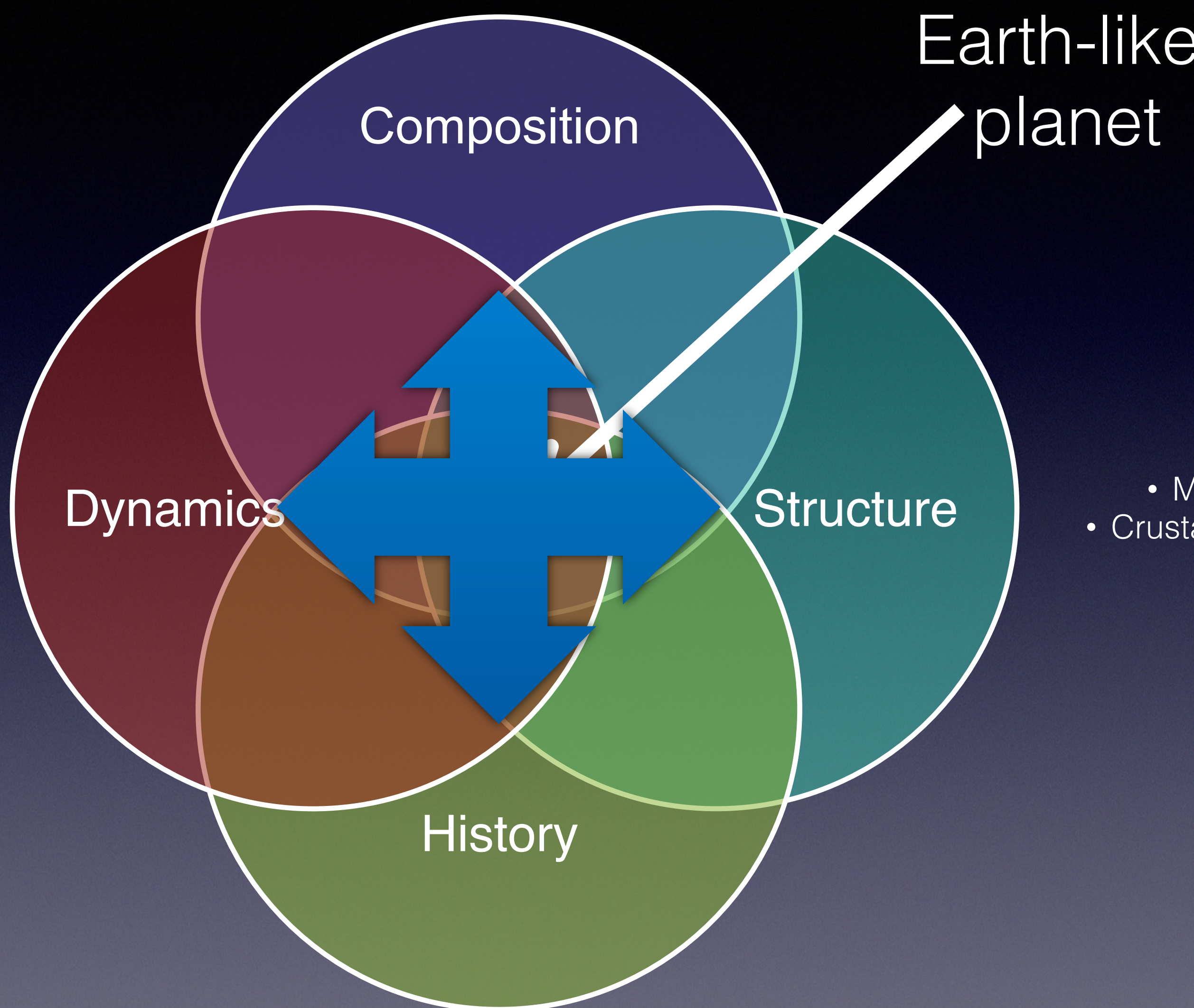

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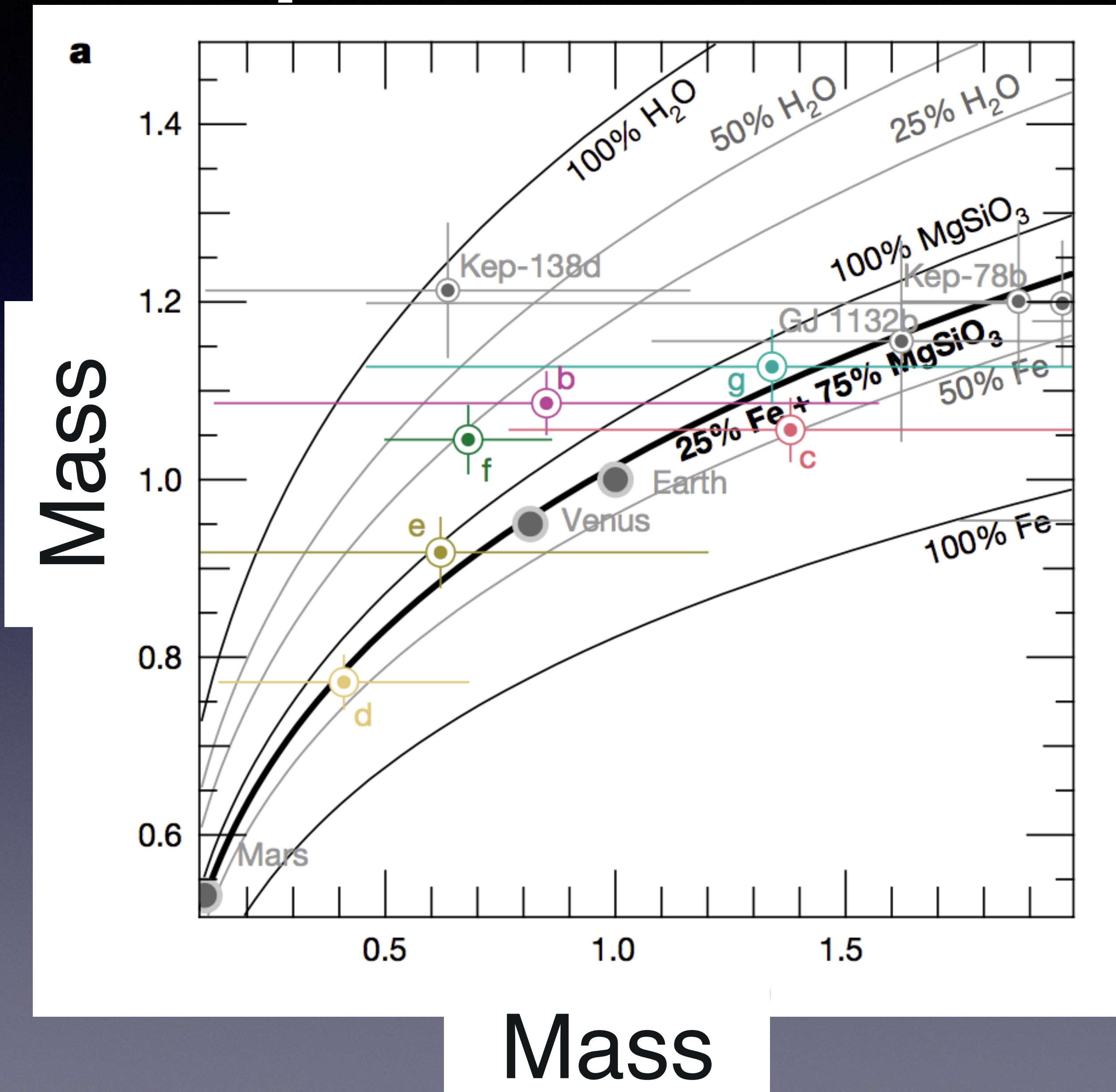
Earth-like planet

But what can we actually feasibly observe, even indirectly?

- Venus-like
- Delivery of volatiles

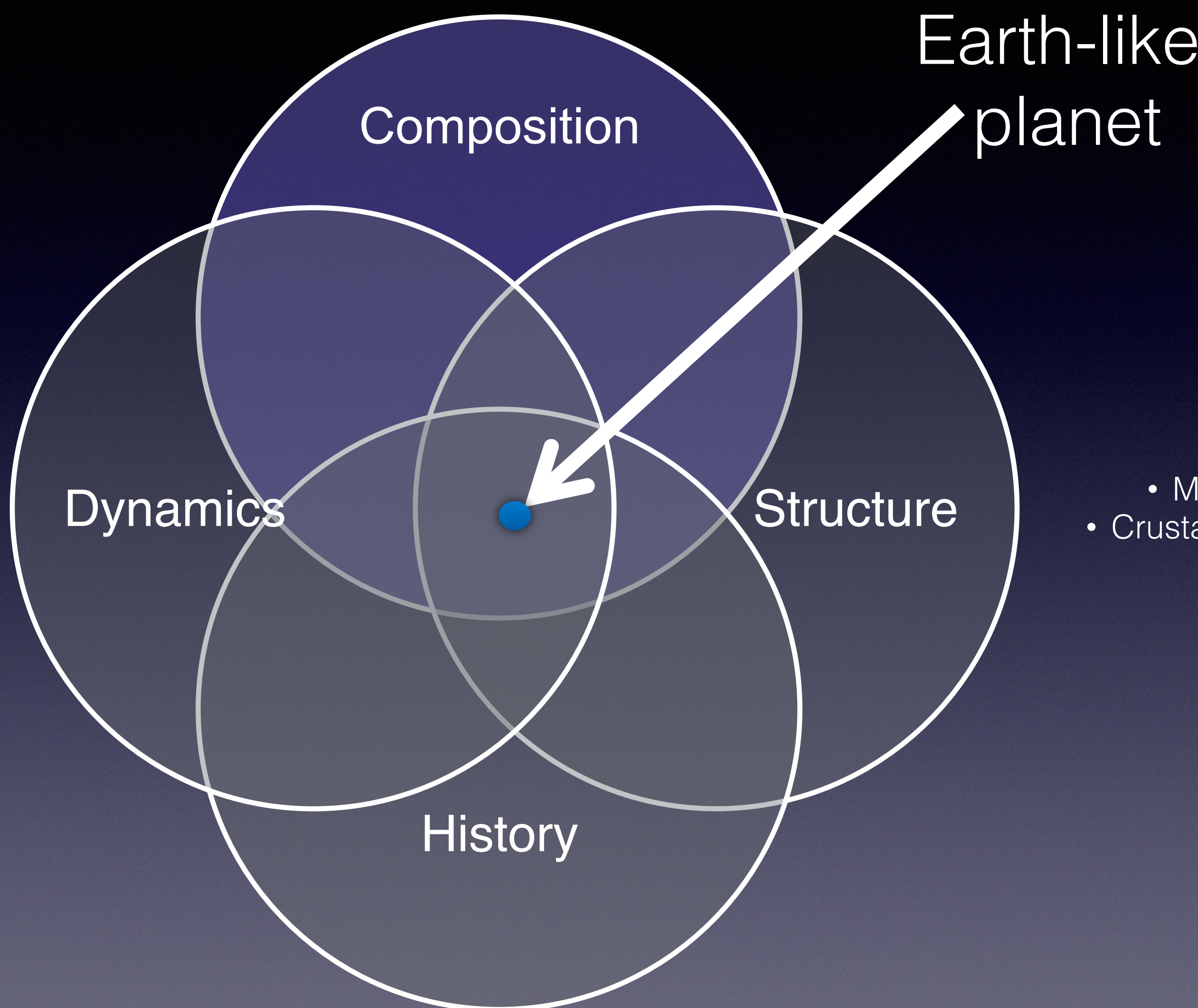
Exoplanet Observables



Atmosphere
orbits

Gillon et al., 2017

- All of chemistry
- Atmospheric chem



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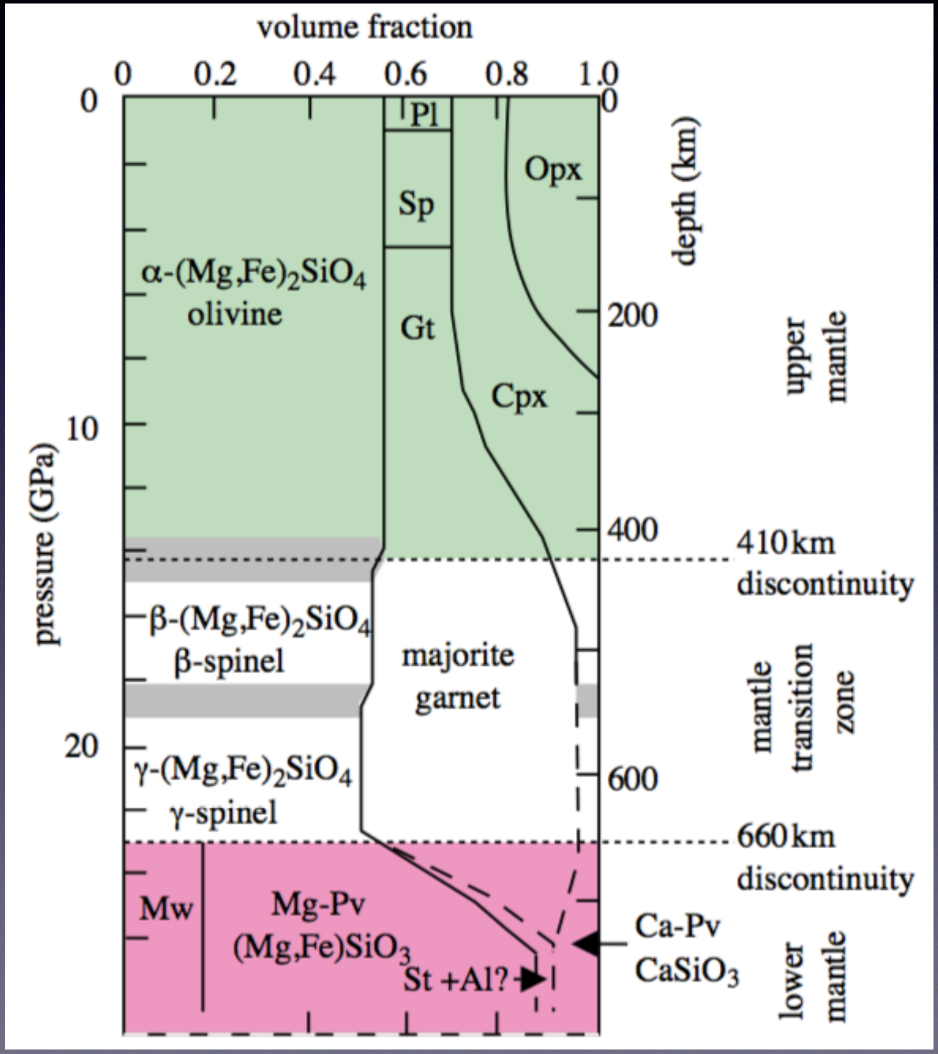
The Habitable [as we know it] Planet



Bovolo, 2005

Composition

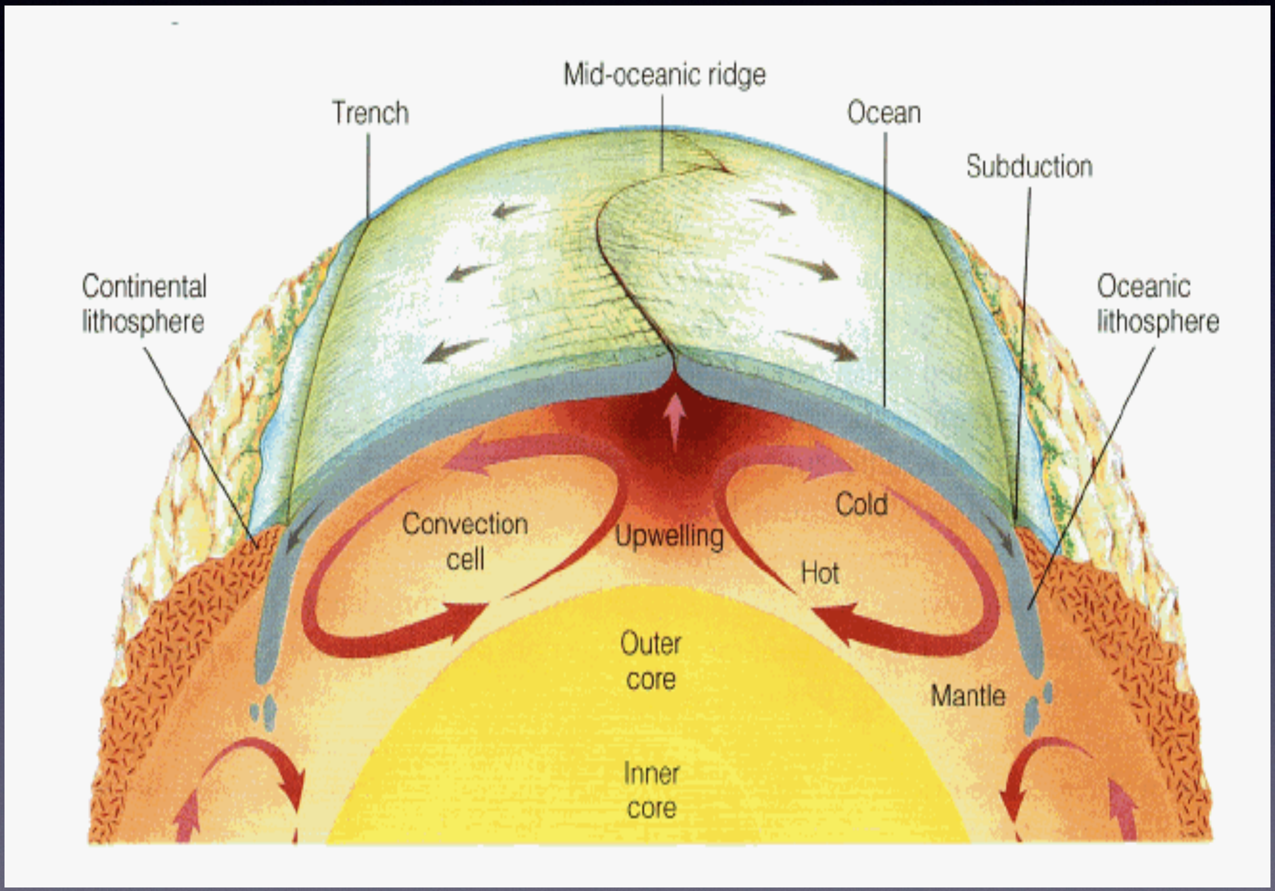
~~Structure~~

~~Dynamics~~

~~History~~

The Habitable Planet

as we know it



SERC

Composition

~~Structure~~

~~Dynamics~~

~~History~~

The Habitable Planet

as we know it

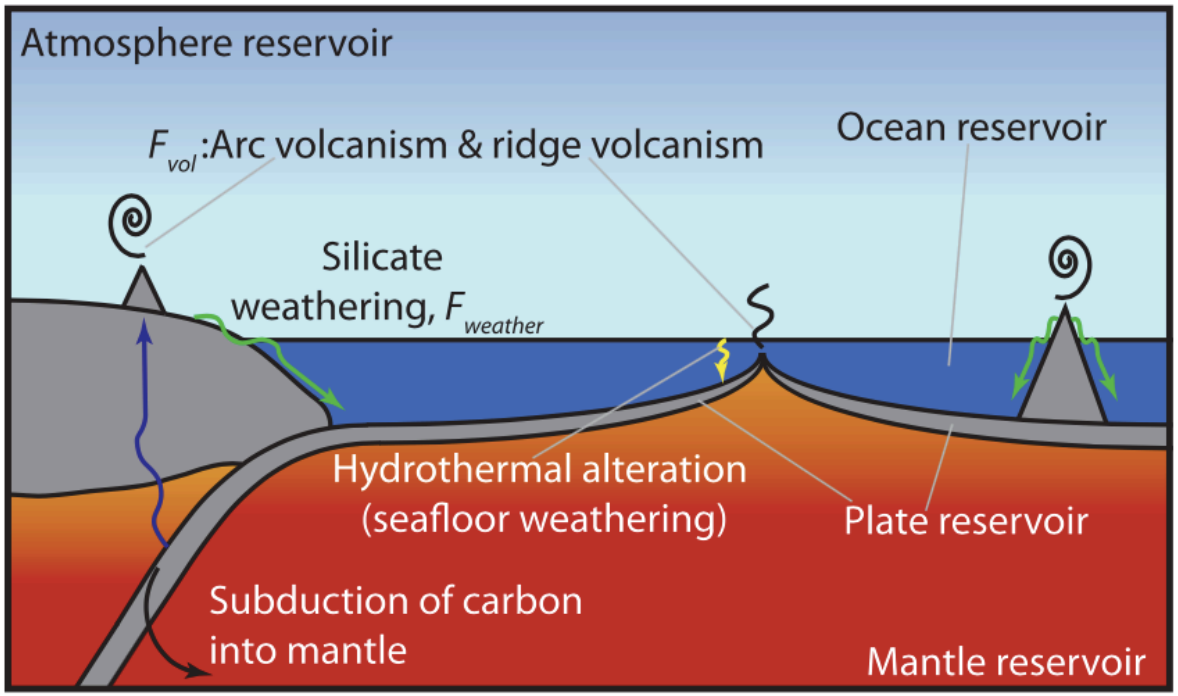


Figure 4. Schematic diagram of the global carbon cycle after *Foley* [2015].

Foley & Driscoll 2016

Composition

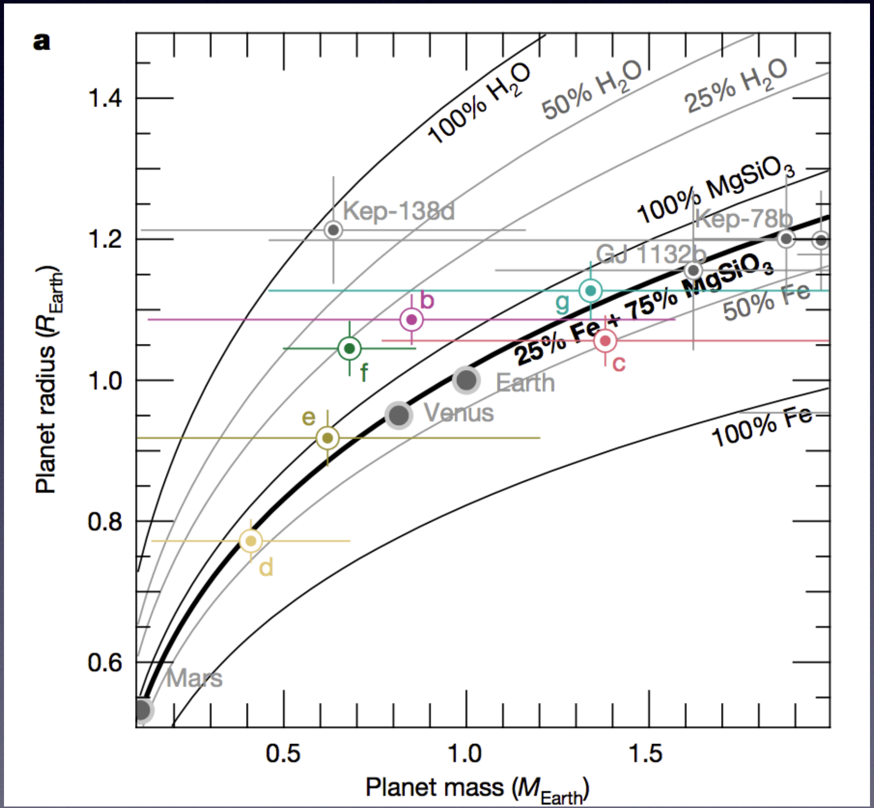
~~Structure~~

~~Dynamics~~

~~History~~

The Habitable Planet

as we know it



Gillon et al., 2017

Basic EARTH Stats:

1 Earth Radius

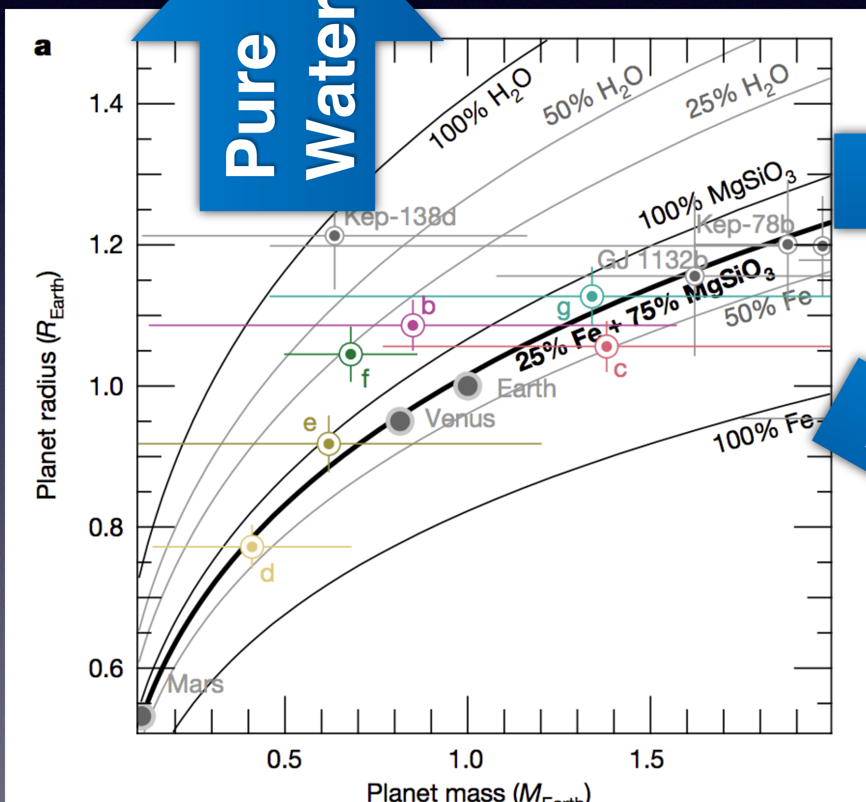
1 Earth Mass

1 Earth Average Density

(5.515 g/cc)

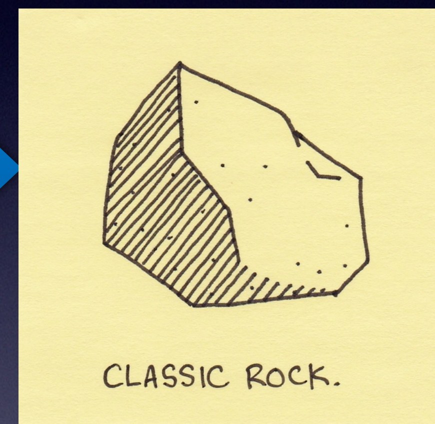
Mass Radius Diagram

Pure Water



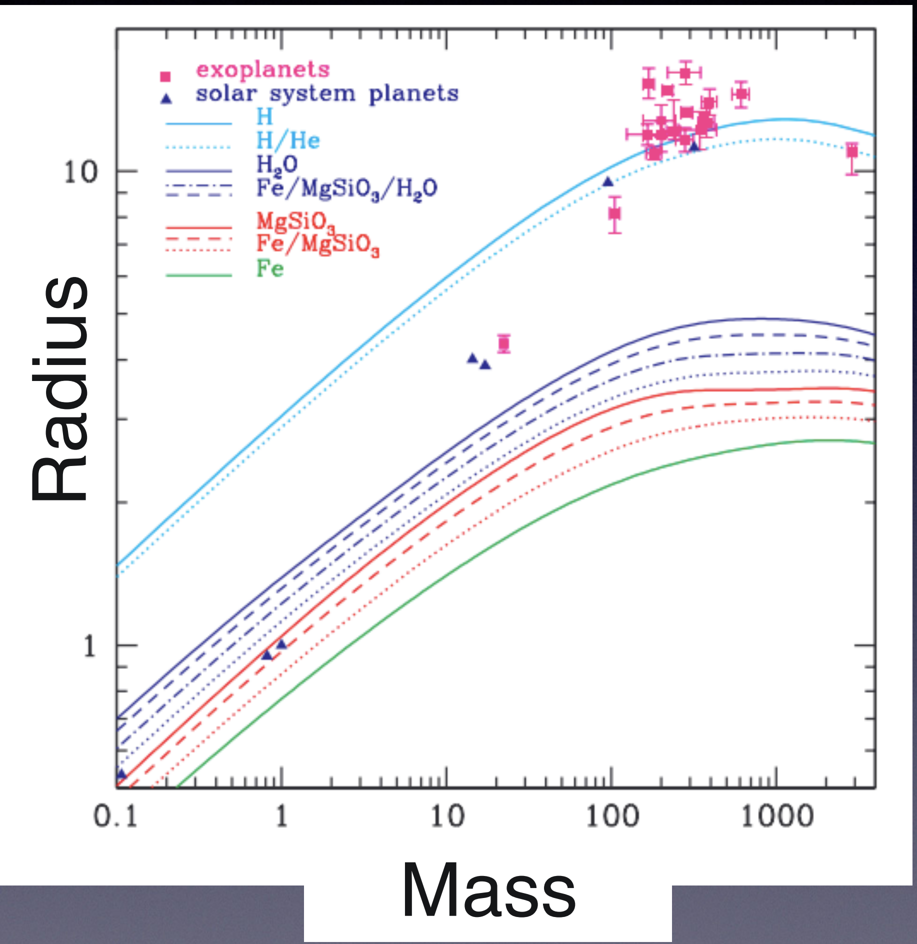
Gillon et al., 2017

Pure Rock

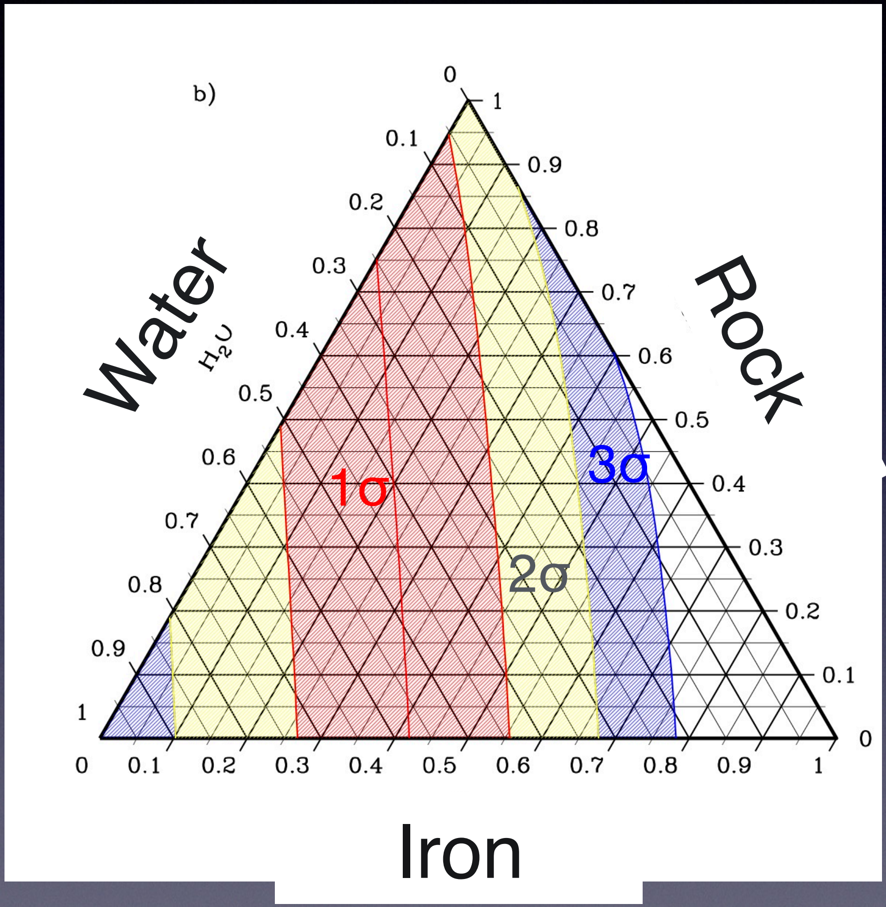


Pure METAL

How do we “measure” *composition?*

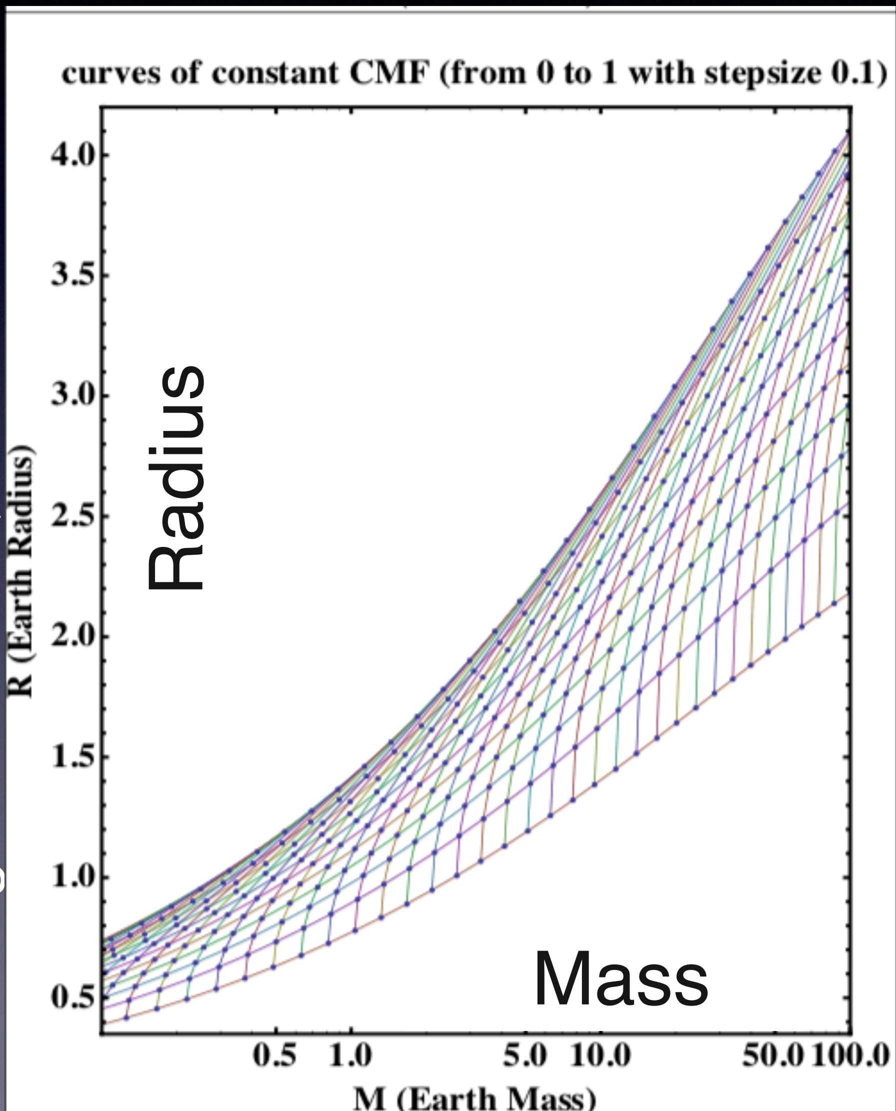


Seager et al., 2007
See also work of D. Valencia



GJ 581d:
Rogers & Seager, 2009

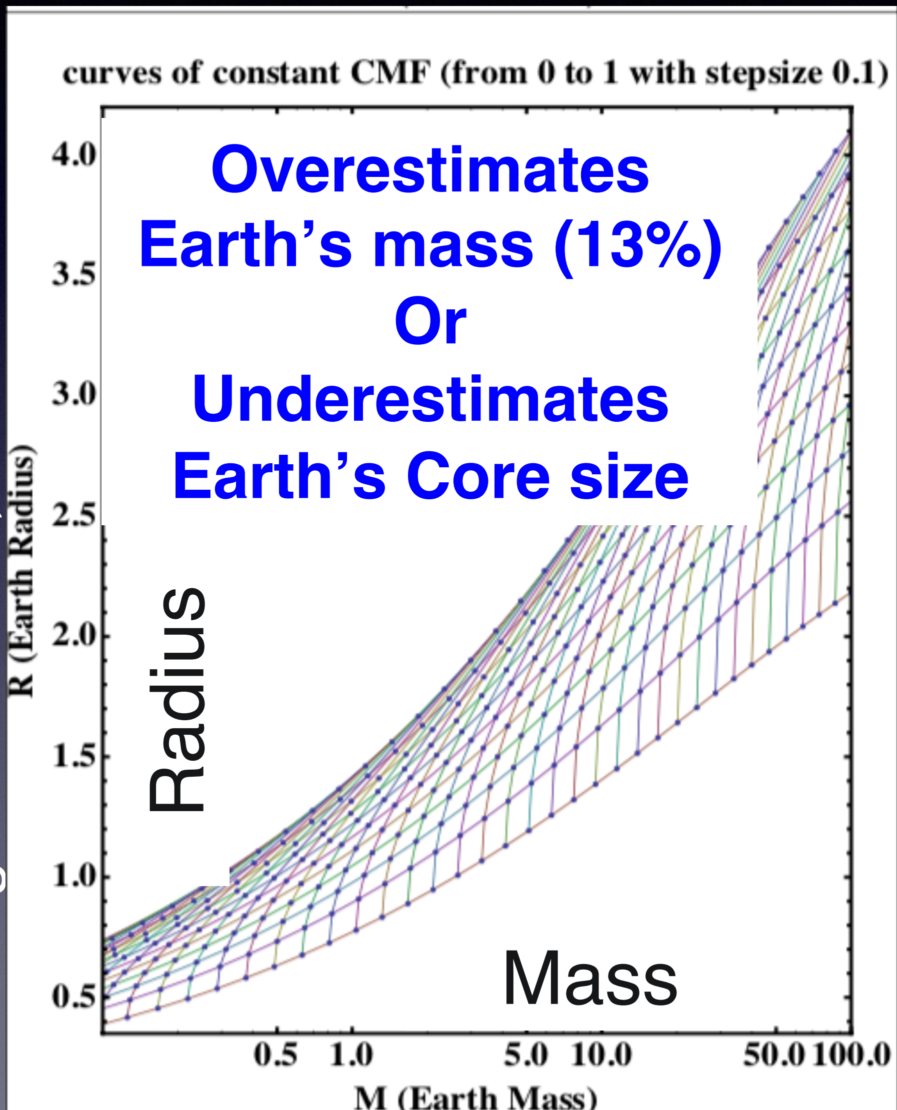
Mass-radius grids

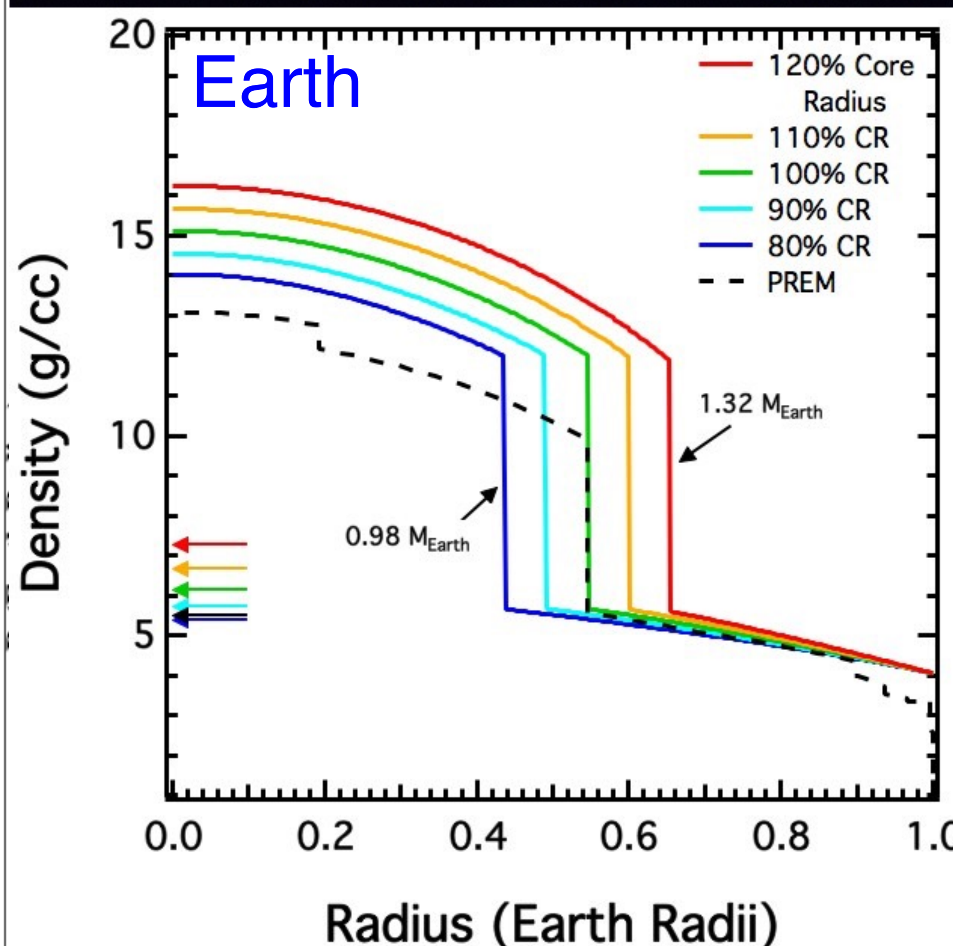


Zeng & Sasselov, 2013

Grids for
Rock ($MgSiO_3$)
Water
Iron
0.1 -100 Earth masses

Mass-radius grids

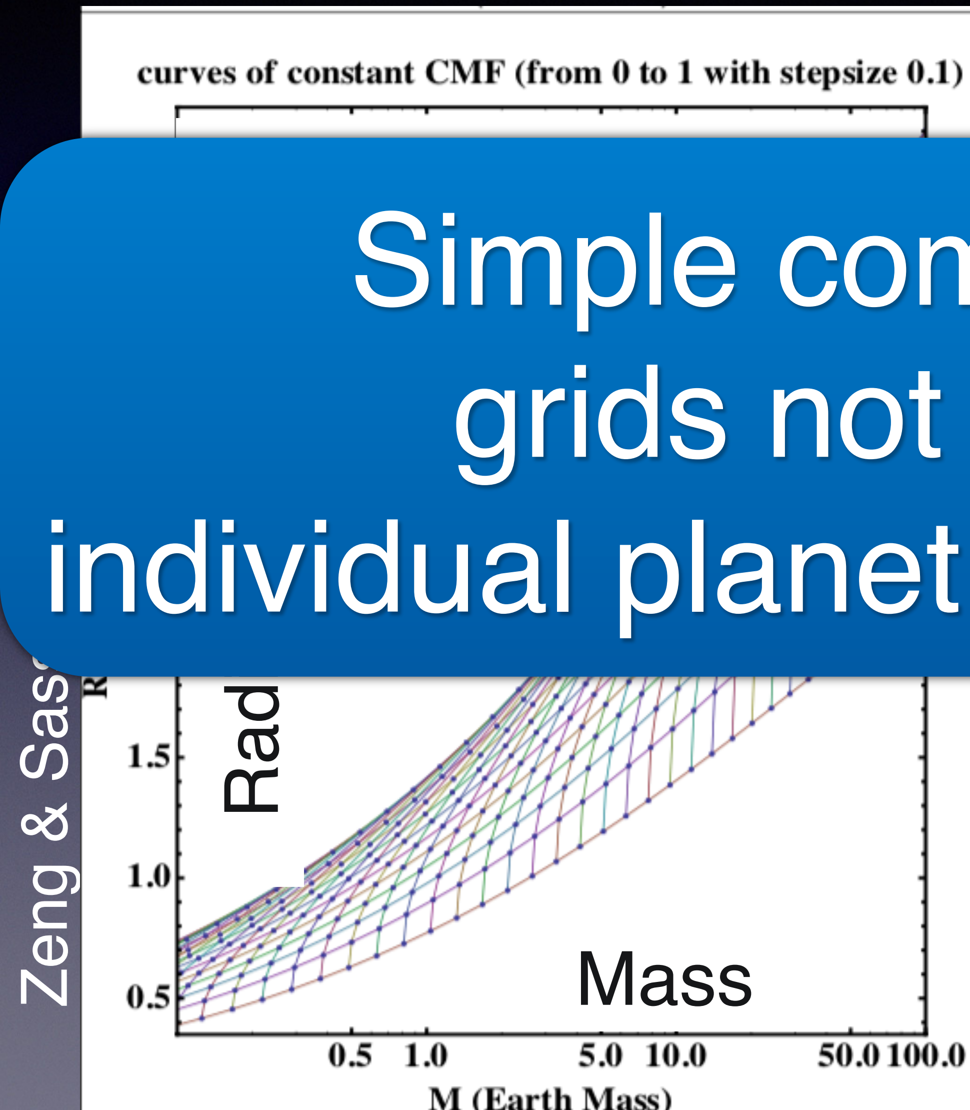


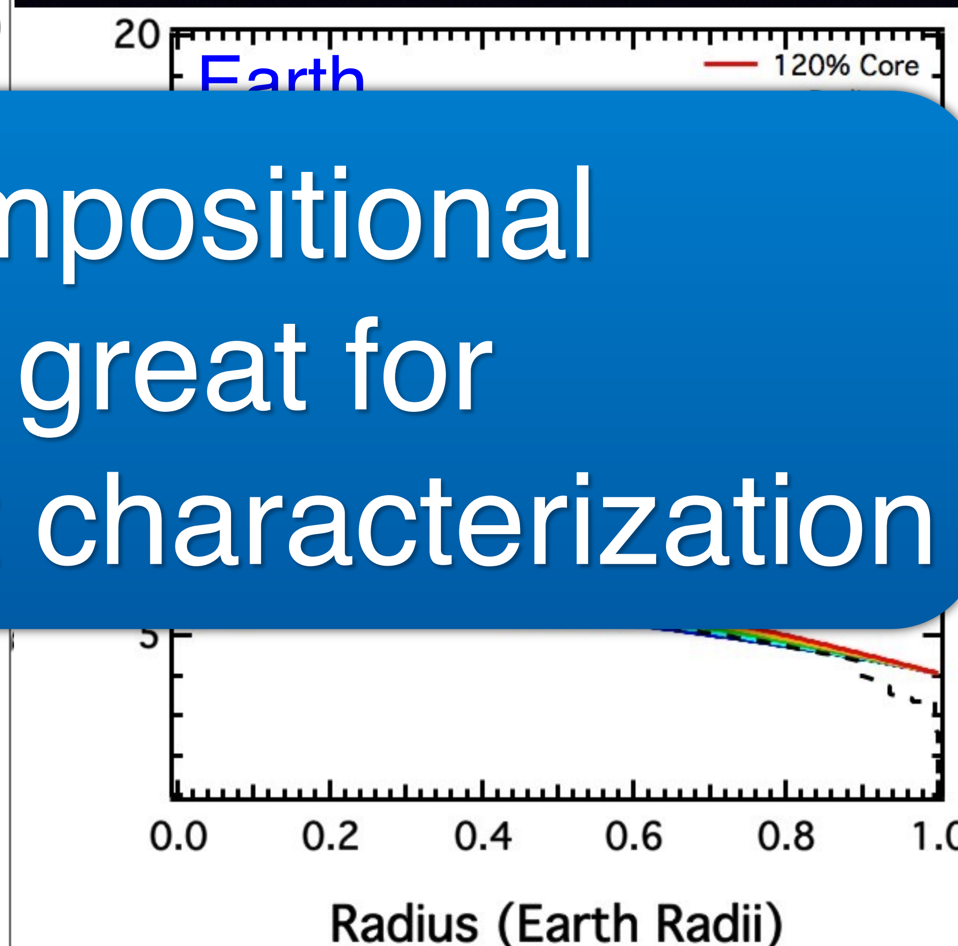


Zeng & Sasselov, 2013

Unterborn et al., 2016

Mass-radius grids

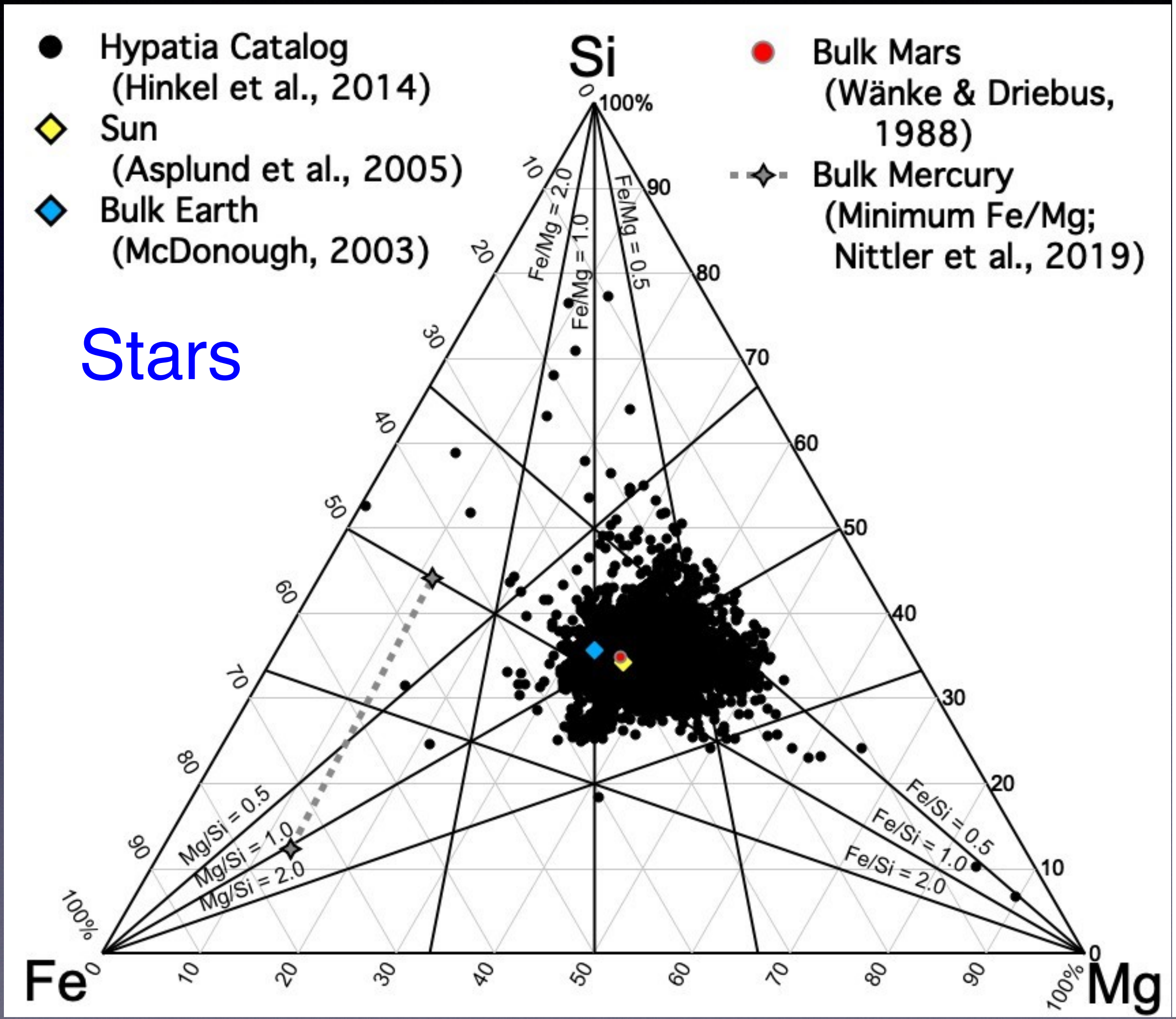




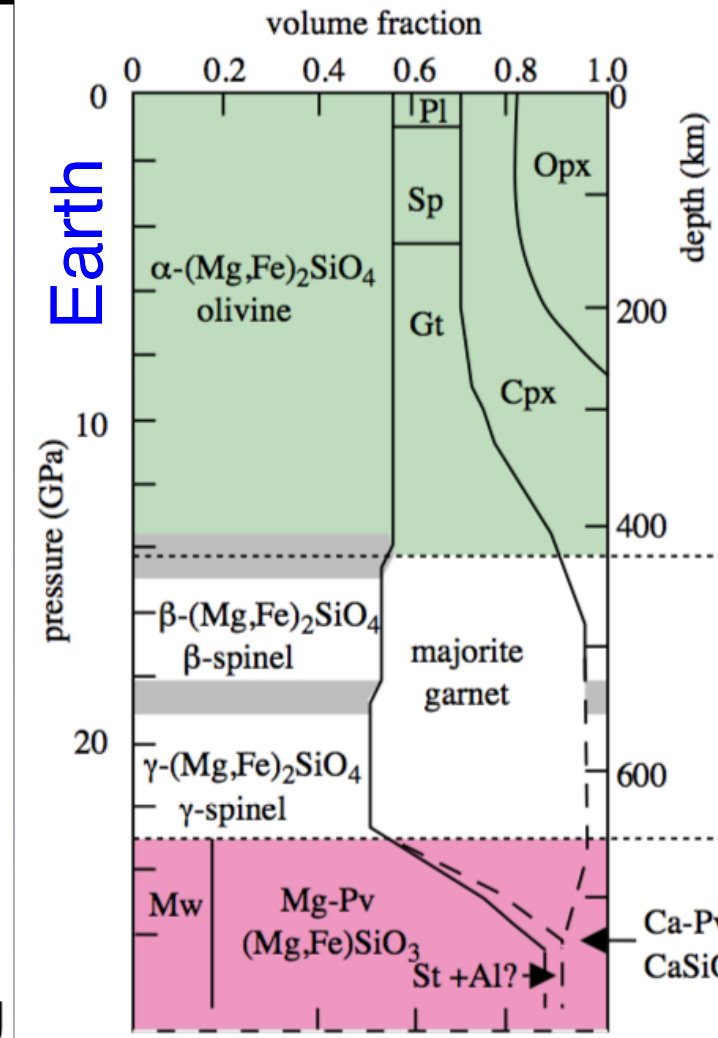
Unterborn et al., 2016

Simple compositional grids not great for individual planet characterization

Compositional Diversity

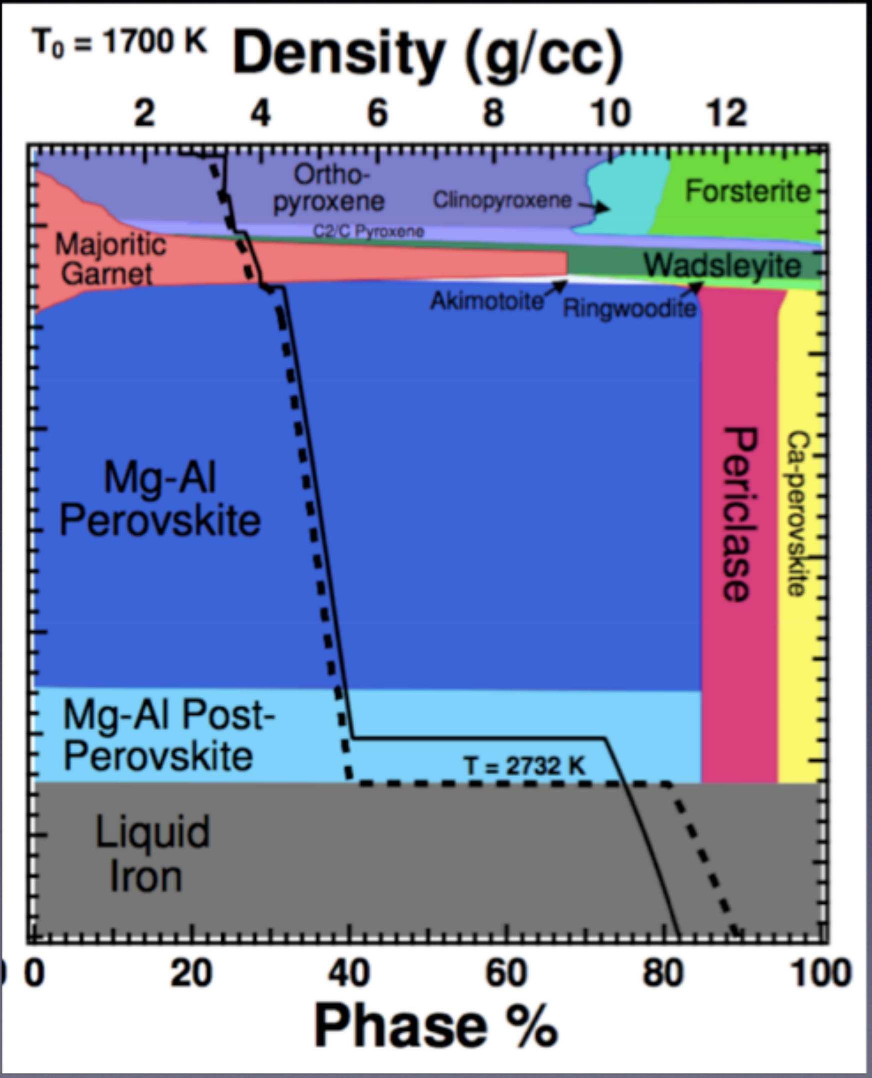


Unterborn & Panero, 2019



Bovolo, 2005

Mass-Radius-Composition

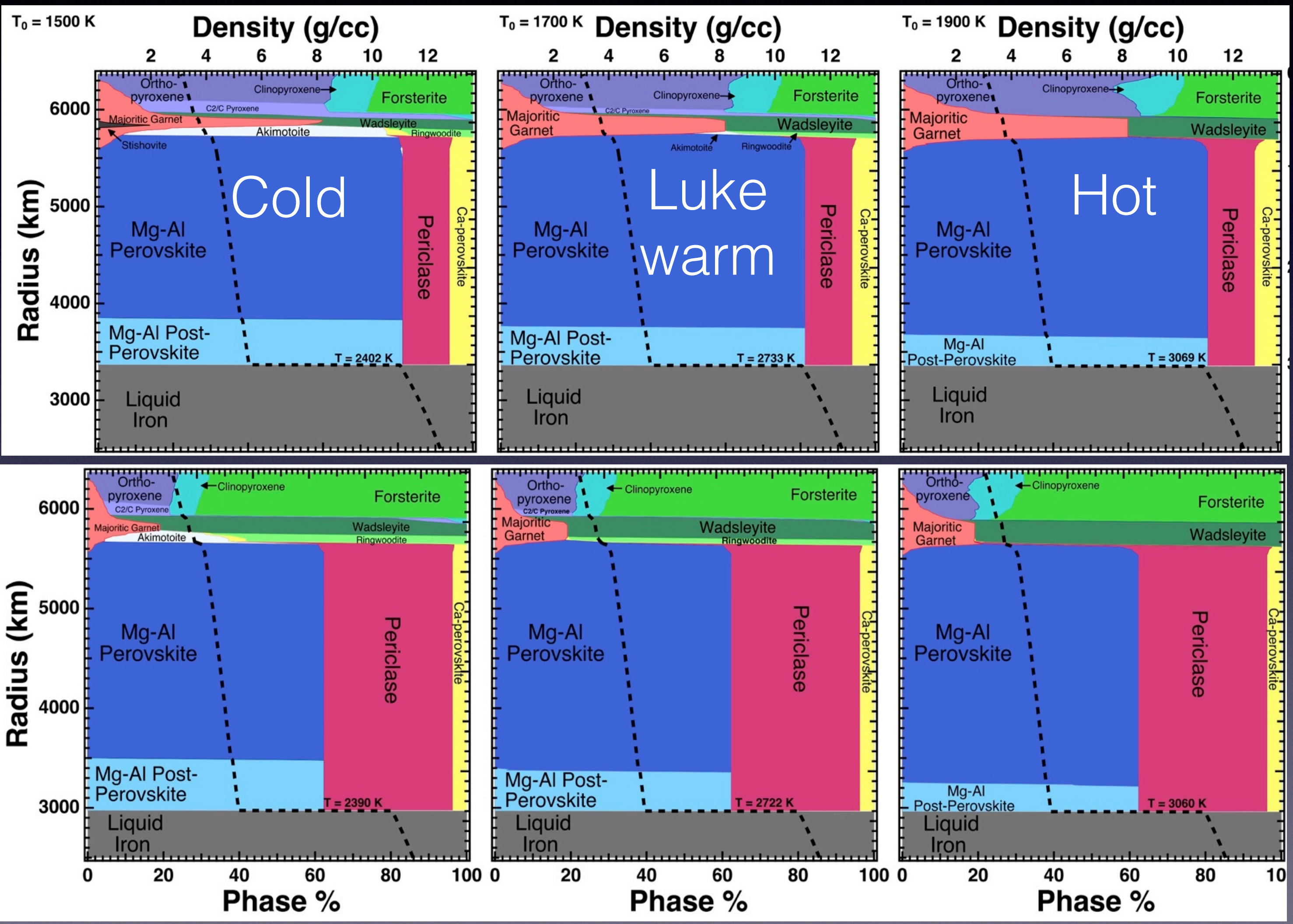


Solar Composition, 1 Earth Mass

- Planet Interiors are not simple!
- One input composition but not
- all one mineral
- Why not let thermodynamics decide the mineralogical hosts of elements?

1. Dorn et al. 2015 (Bayesian)
2. Unterborn et al., 2018 (Forward)
3. Hinkel & Unterborn, 2018 (stellar compositions)
4. Unterborn & Panero, 2019 (comparisons to grids, outline phase space)

ExoPlex



<u>Earth</u>

Mg/Si = 1.1

Fe/Mg = 0.9

Al/Mg = 0.1

Ca/Mg = 0.07

<u>Random Star</u>

Mg/Si = 1.5

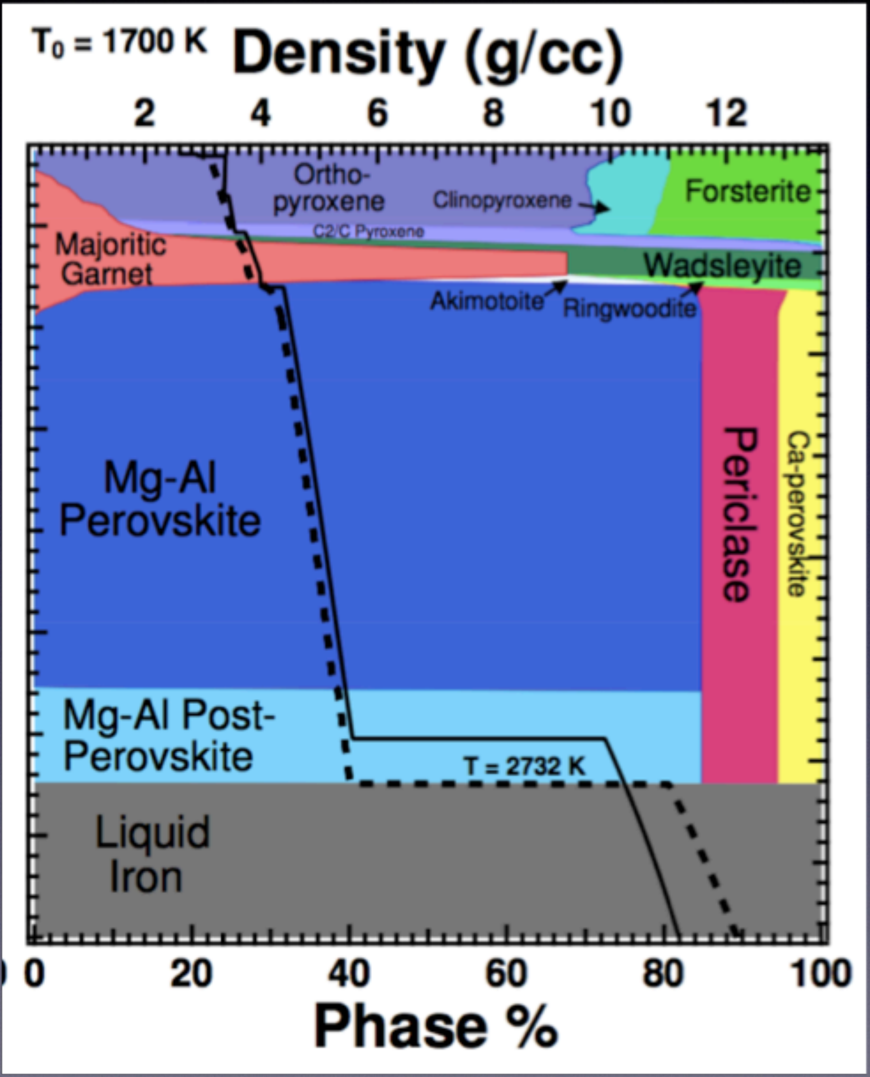
Fe/Mg = 0.5

Al/Mg = 0.04

Ca/Mg = 0.04

Hinkel & Unterborn, 2018 *ApJ*

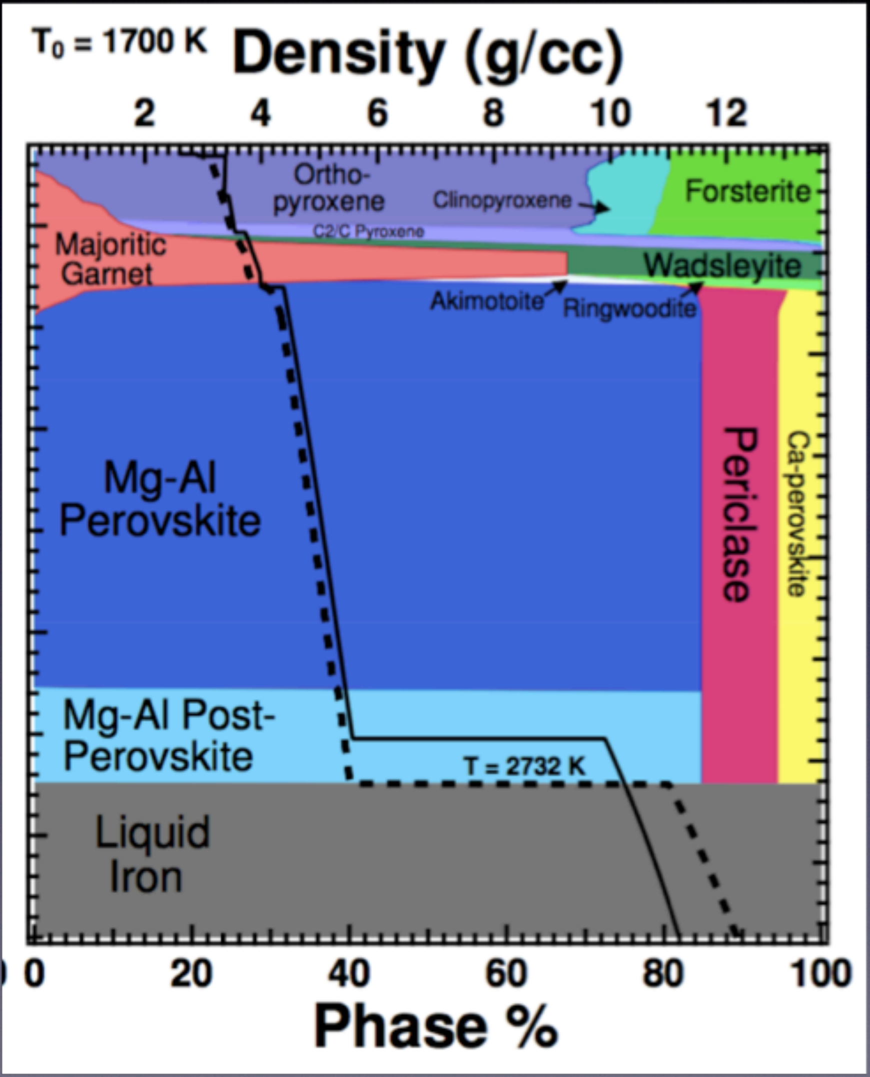
ExoPlex



Solar Composition, 1 Earth Mass

- Why not let thermodynamics decide the mineralogical hosts of elements?
- Use PerPlex to solve for stable mineralogy and thermodynamic properties
- Derives P, T, ρ, mineralogy, & core size for planet of given mass or radius as fxn of depth

ExoPlex Grids!



Solar Composition, 1 Earth Mass

- >100 Gb of P, T, ρ, C_P, α
- Valid over 2σ of stellar abundances

$0.5 \leq Si/Mg \leq 2$

$0.02 \leq Ca/Mg \leq 0.1$

$0.04 \leq Al/Mg \leq$

$FeO \leq 0.20$

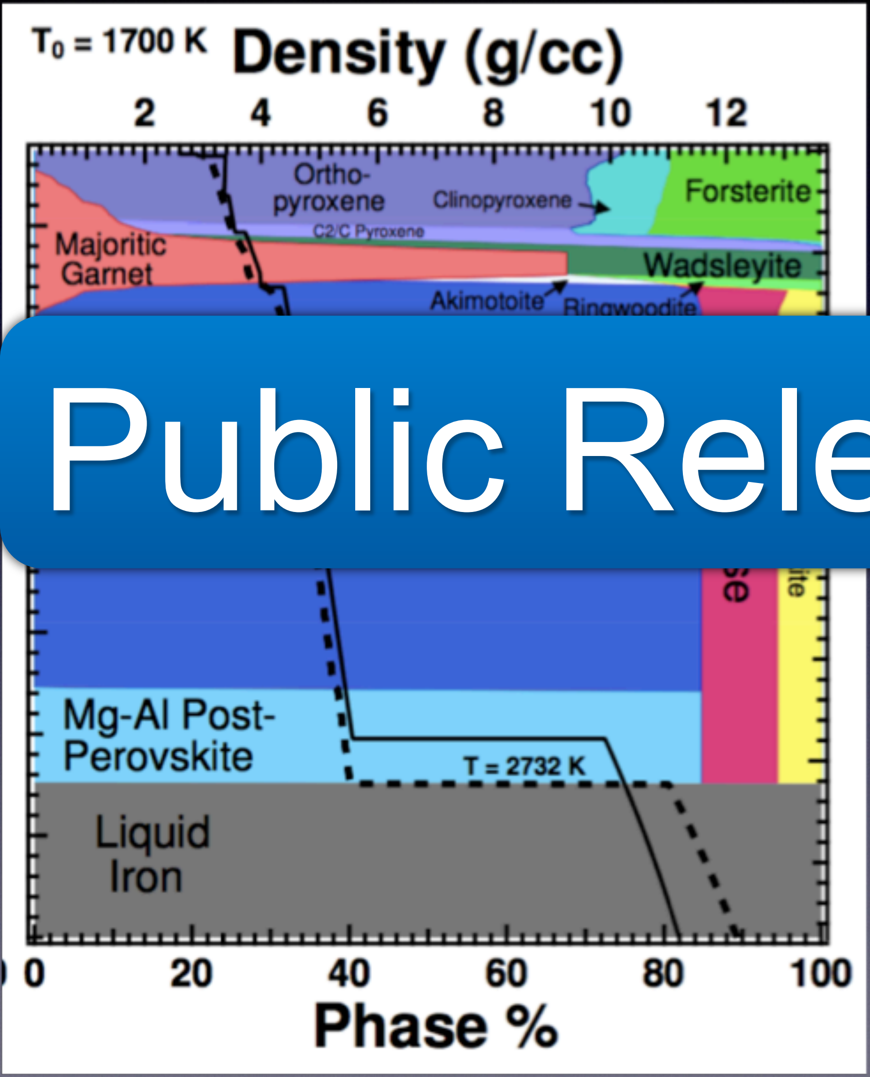
$1400 \leq$ Mantle $T_P \leq 2000$ K

Mass ≤ 8 Earth masses

H_2O phase diagram (water + ices)

Core light elements (S, O, Si)

ExoPlex Grids!



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Public Release Q4 2019

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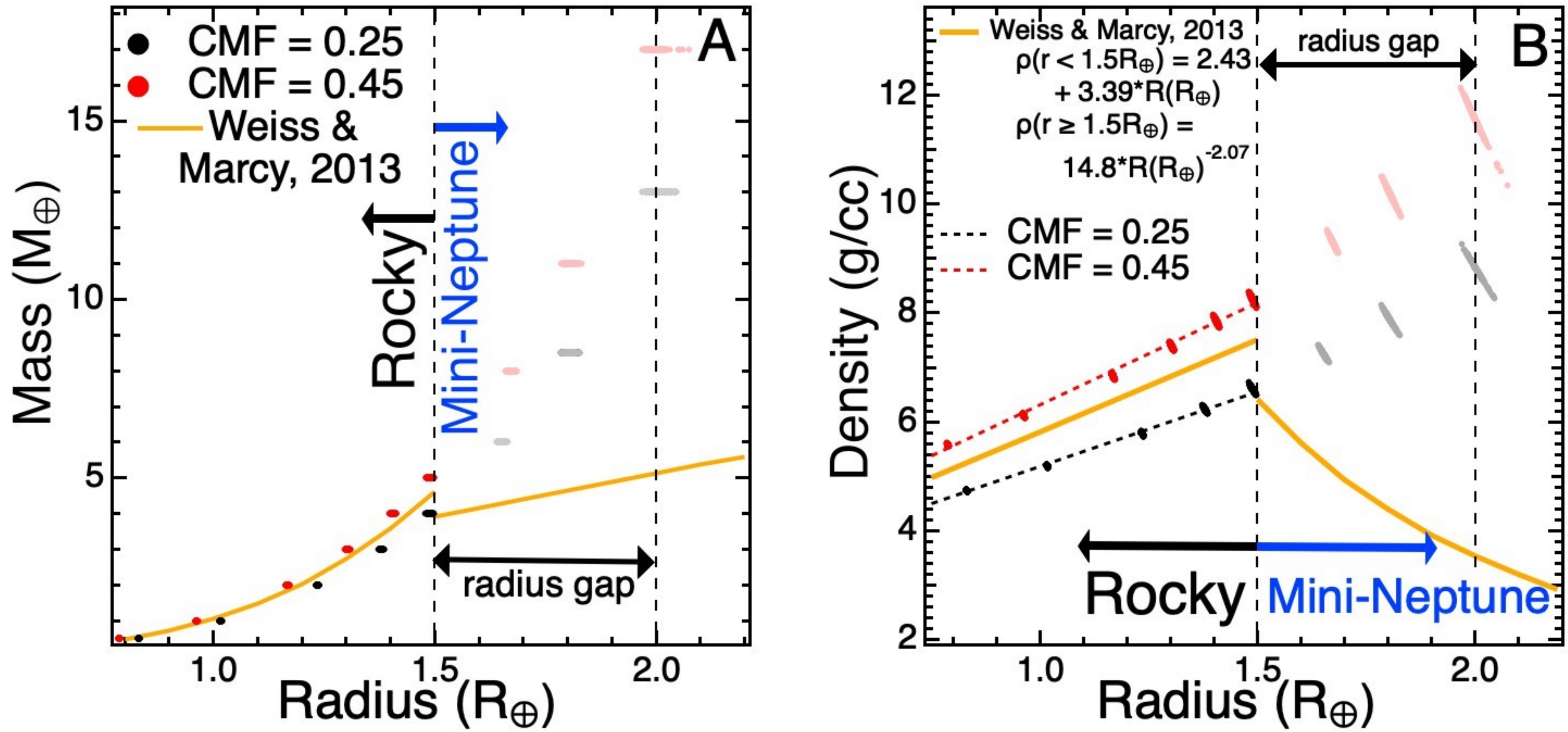
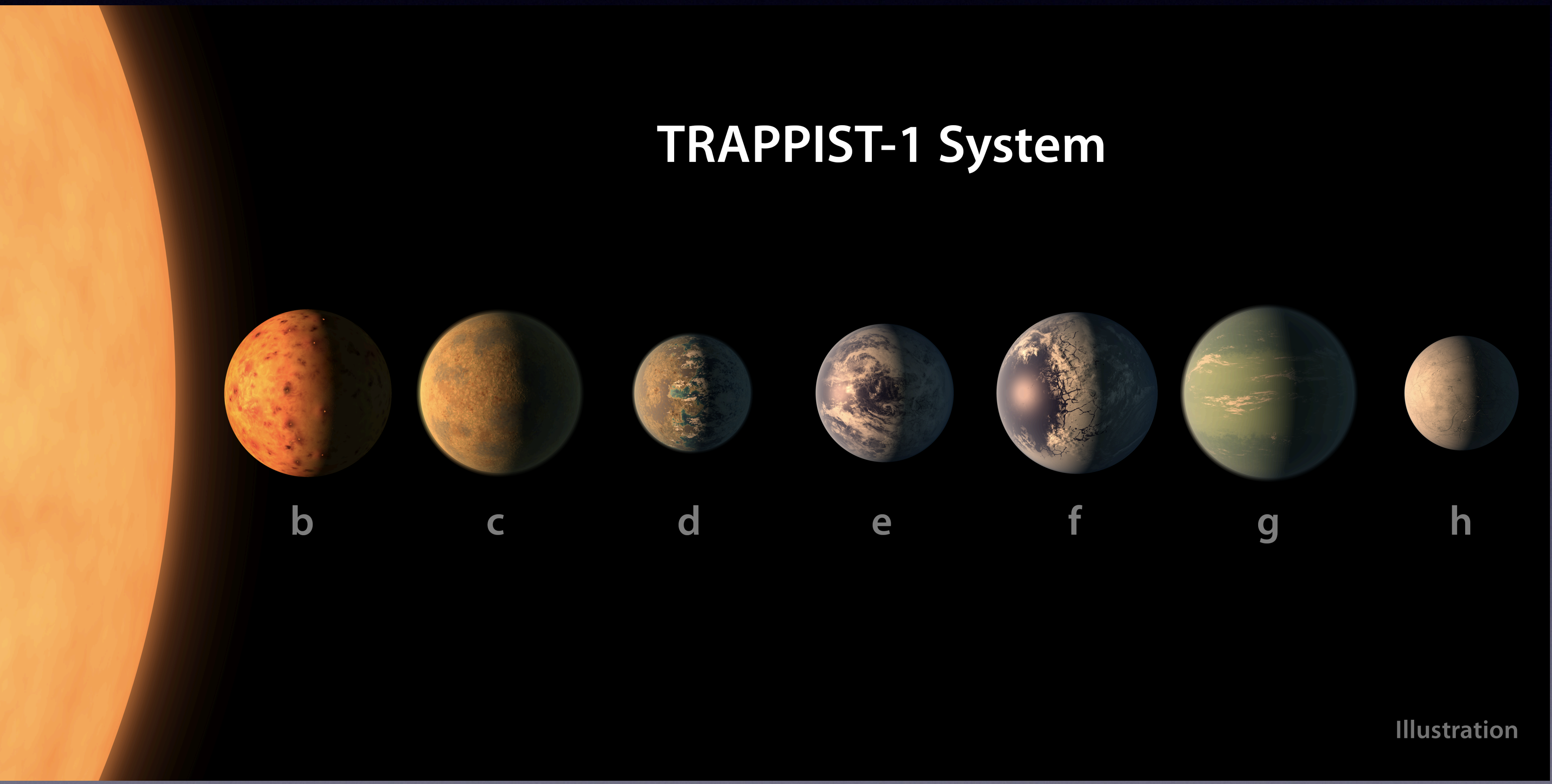


Mantle pressure, mantle temperature, core pressure

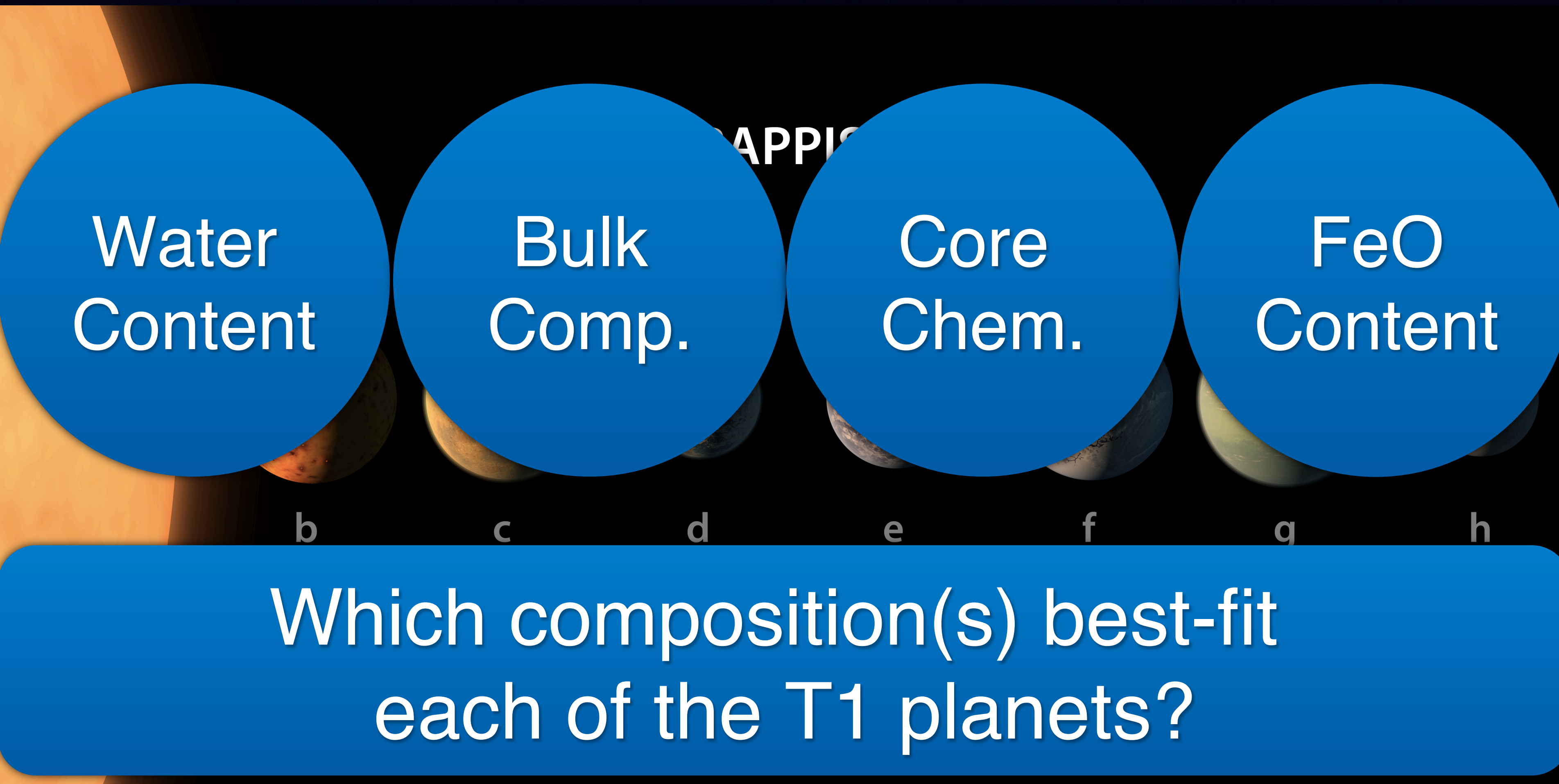
Unterborn & Panero, 2019

Hands-on Session: Characterizing TRAPPIST-1



NASA

Hands-on Session: Characterizing TRAPPIST-1



Water Content

Bulk Comp.

Core Chem.

FeO Content

Which composition(s) best-fit each of the T1 planets?

NASA

Conclusions

- Mass and Radius provide clue to planetary interior composition
- M-R may provide key insights into interpretation of atmospheric composition, geodynamic state, mineralogy, others?
- Most M-R grids only great for broad studies, individual planet systems require more precise models (e.g. ExoPlex)
- TRAPPIST-1 among best measured rocky plan ets but what compositions are their measured M-R consistent with?