Quantifying the Effects of Temperature on Rocky Exoplanets

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51st ESLAB Symposium: Extreme Habitable Worlds

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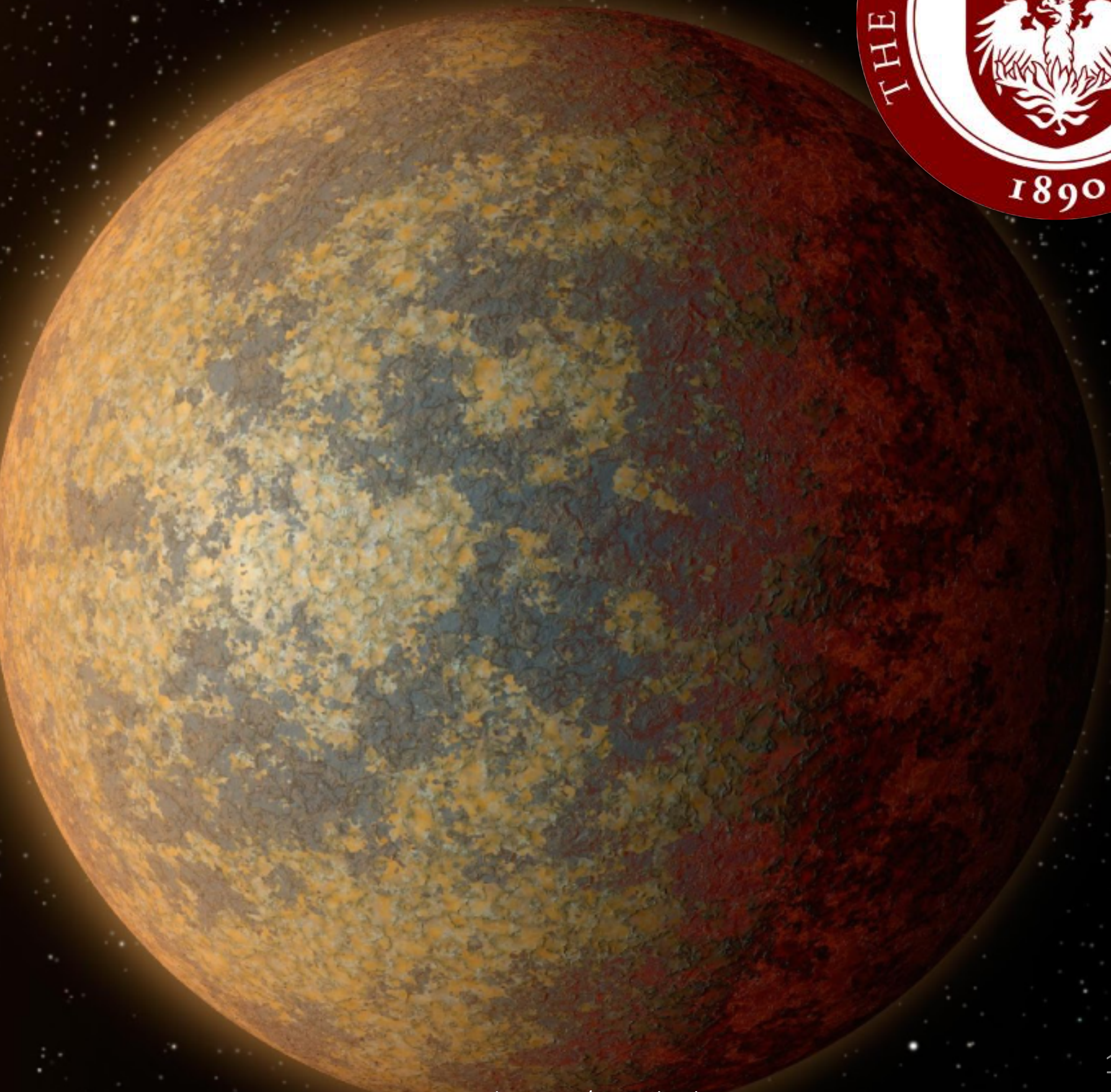
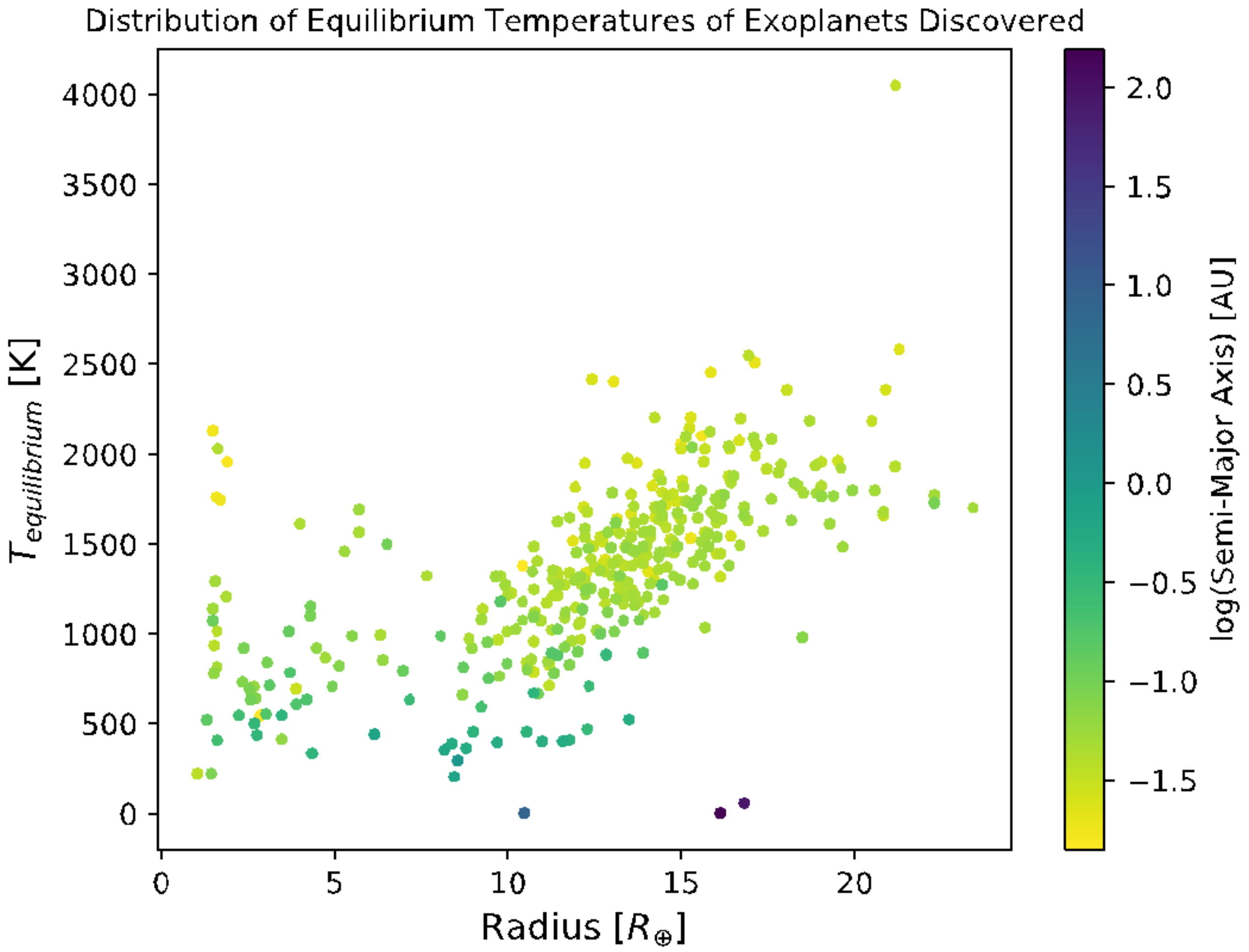


Credit: NASA/JPL-Caltech

Why another model for rocky exoplanets?

- Rocky exoplanets could have very different temperature profiles than the Earth:
  - The **proximity** to their host stars
  - Super-Earths may **begin even hotter** than the Earth did



Modeling Rocky Planets with PyPlanet

PyPlanet can model spherical planets of any composition, number of layers and temperature profile. We use a simplified two layer model.

Input Parameters

- Number of layers
- Central pressure and transition pressures
- Composition of layers or equations of state
- Temperature profiles

→

PyPlanet

- Equation of state solver if only composition specified
- 4^{th} order Runge Kutta numerical methods to solve:

$$\frac{dP}{dr} = \frac{-GM\rho}{r^2}$$

$$\frac{dM}{dr} = 4\pi r^2 \rho$$

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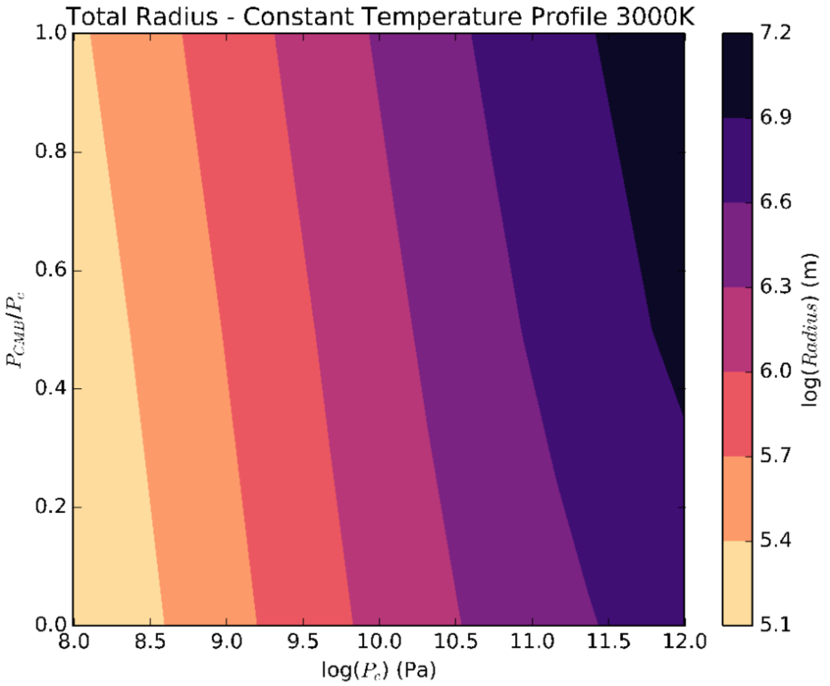
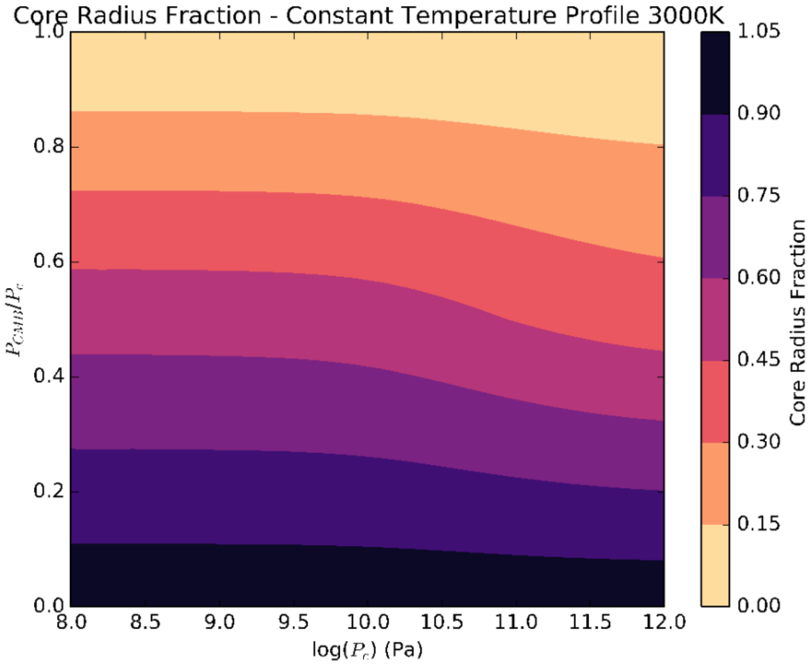
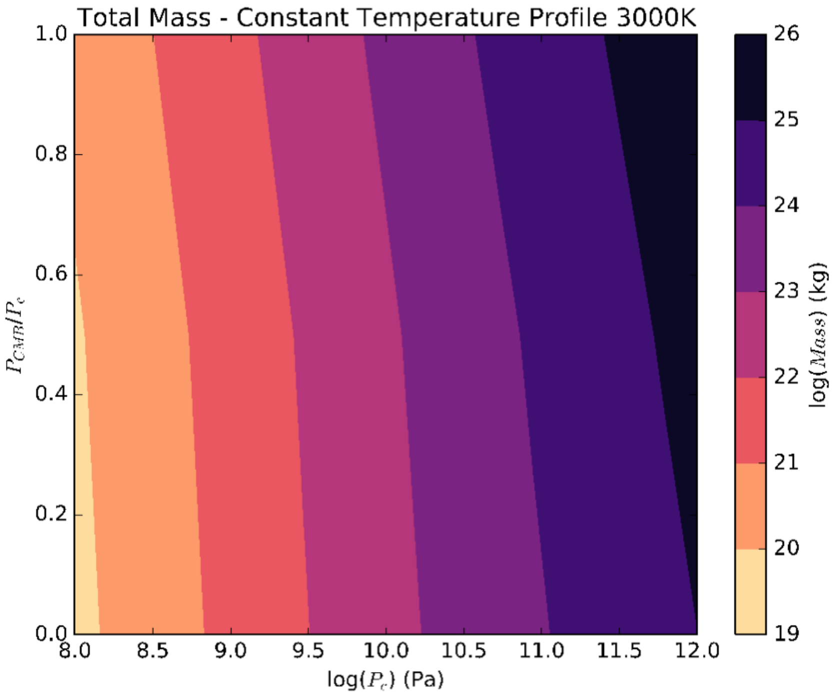
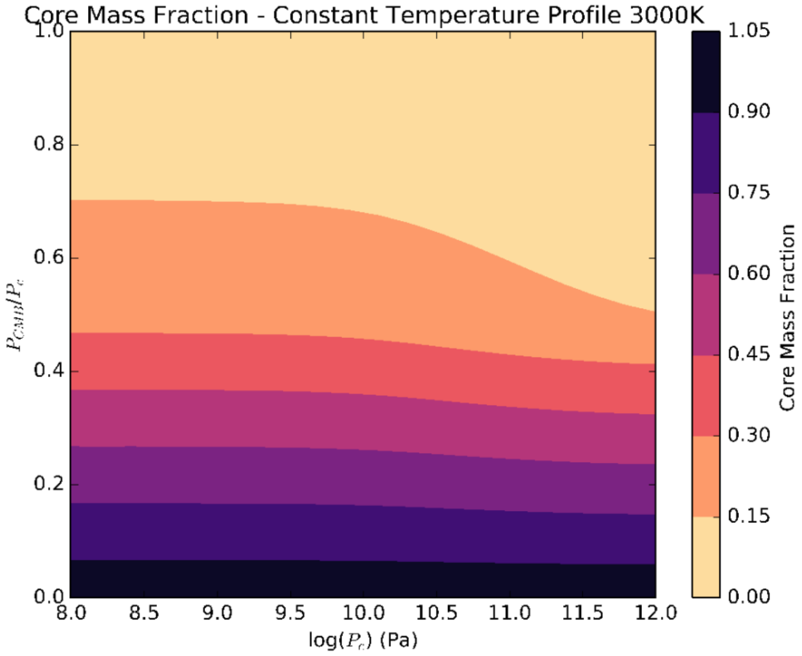
Output Parameters

- Overall properties of planet
- Properties of each layer of the planet









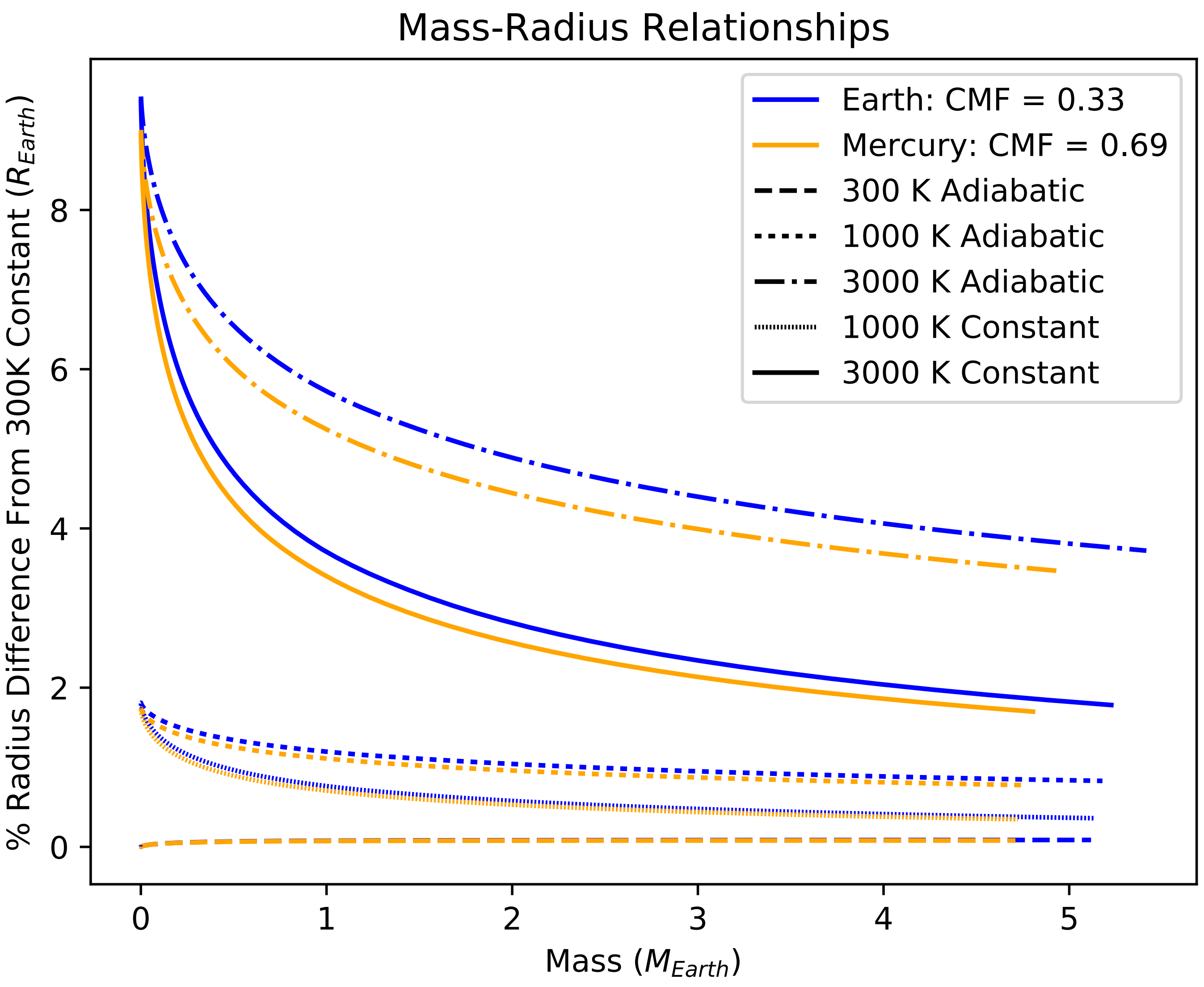
Results – Planetary Grids

- We have successfully modeled a grid of planets with central pressures similar to Earth's.
- These equations of state correspond to temperatures of 3000K

P_c = central pressure
P_{CMB} = transition pressure at core-mantle boundary

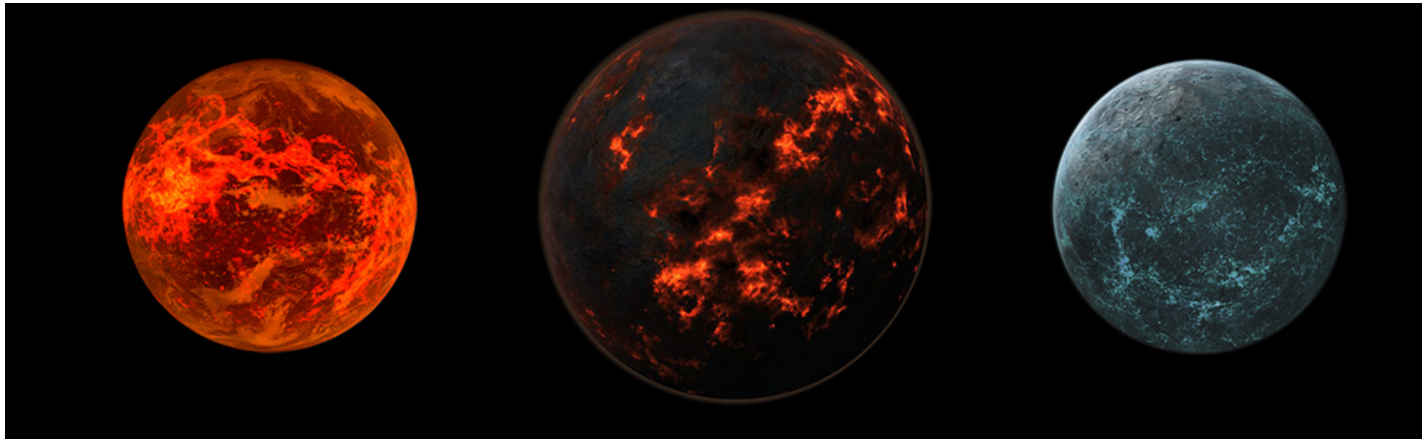
Results – Mass-Radius Relationships

We modeled completely adiabatic and isothermal planets having either Earth or Mercury compositions.



Summary of Work

- Developed PyPlanet to model rocky exoplanets with realistic temperature profiles and equations of state
- Thermal expansion can have a significant effect on rocky planet radii: this effect is larger than current observational radius uncertainties in discovered exoplanets
- Inferences about rocky exoplanet bulk compositions from mass and radius measurements should take into account the thermals effects explored here



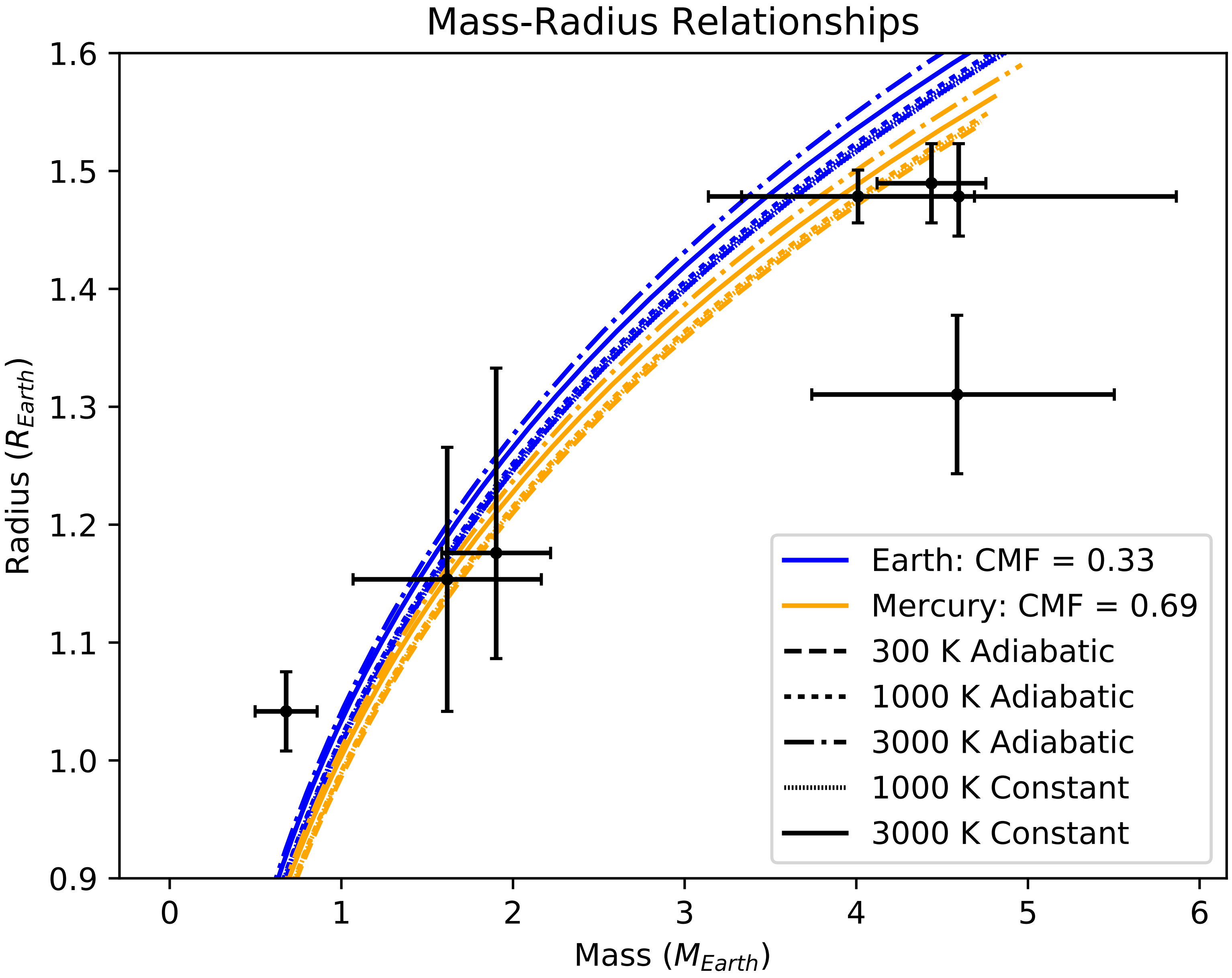
PyPlanet is available at ***github.com/sabrinastronomy/PyPlanet***

Acknowledgements

Professor Leslie Rogers

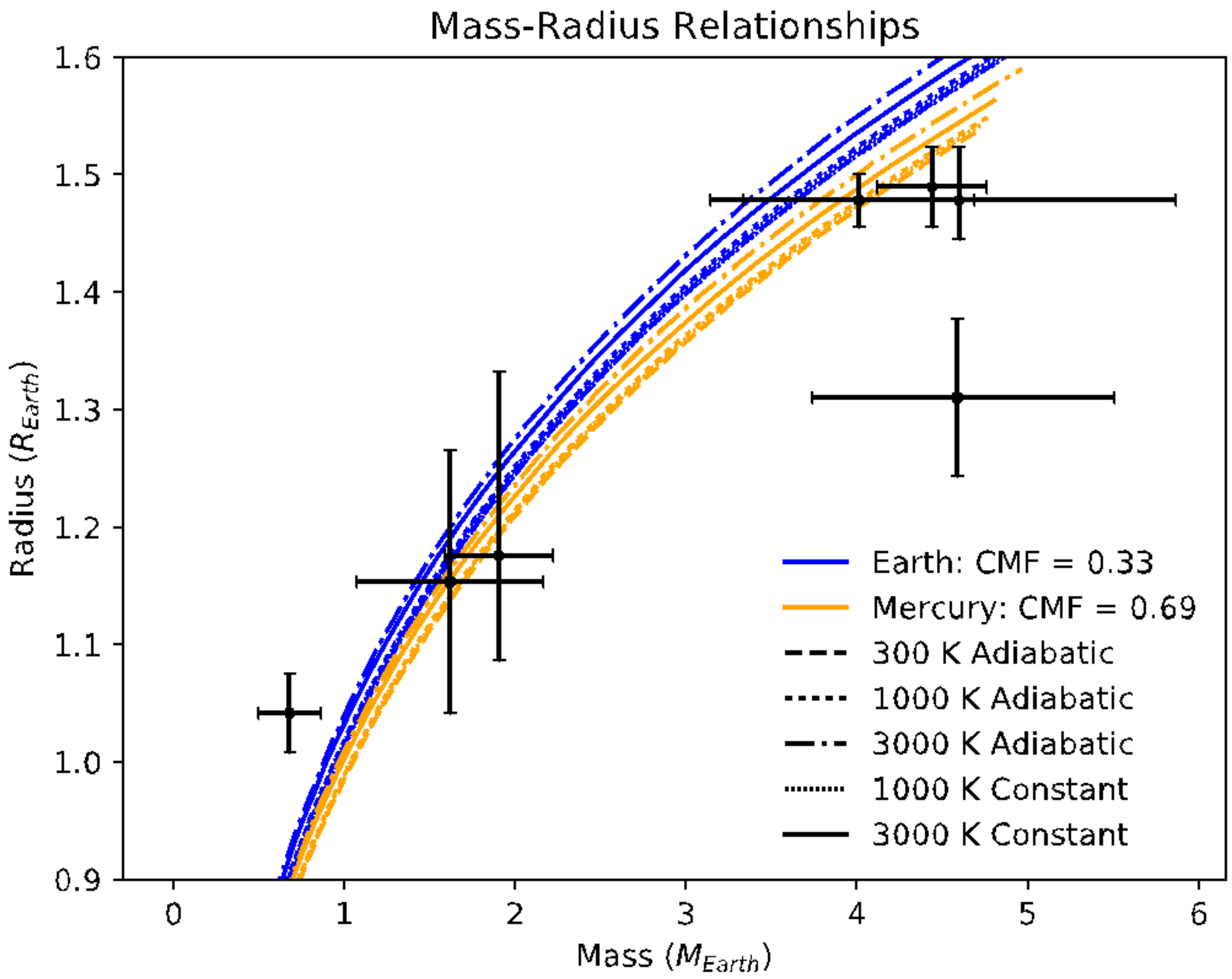
Dr. Nadia Marounina

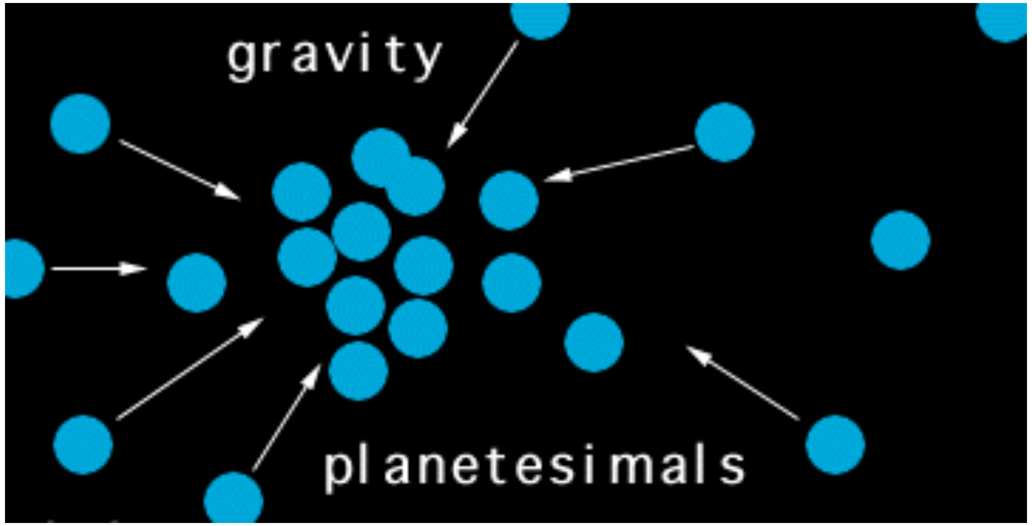
Future Work – Applying M-R Relationships



Next Steps

- **Consider** phase transitions in our model. How large of an effect will this have?
- **Comparing** our simulations to transit and radial velocity observations of exoplanets





Credit: University of Oregon

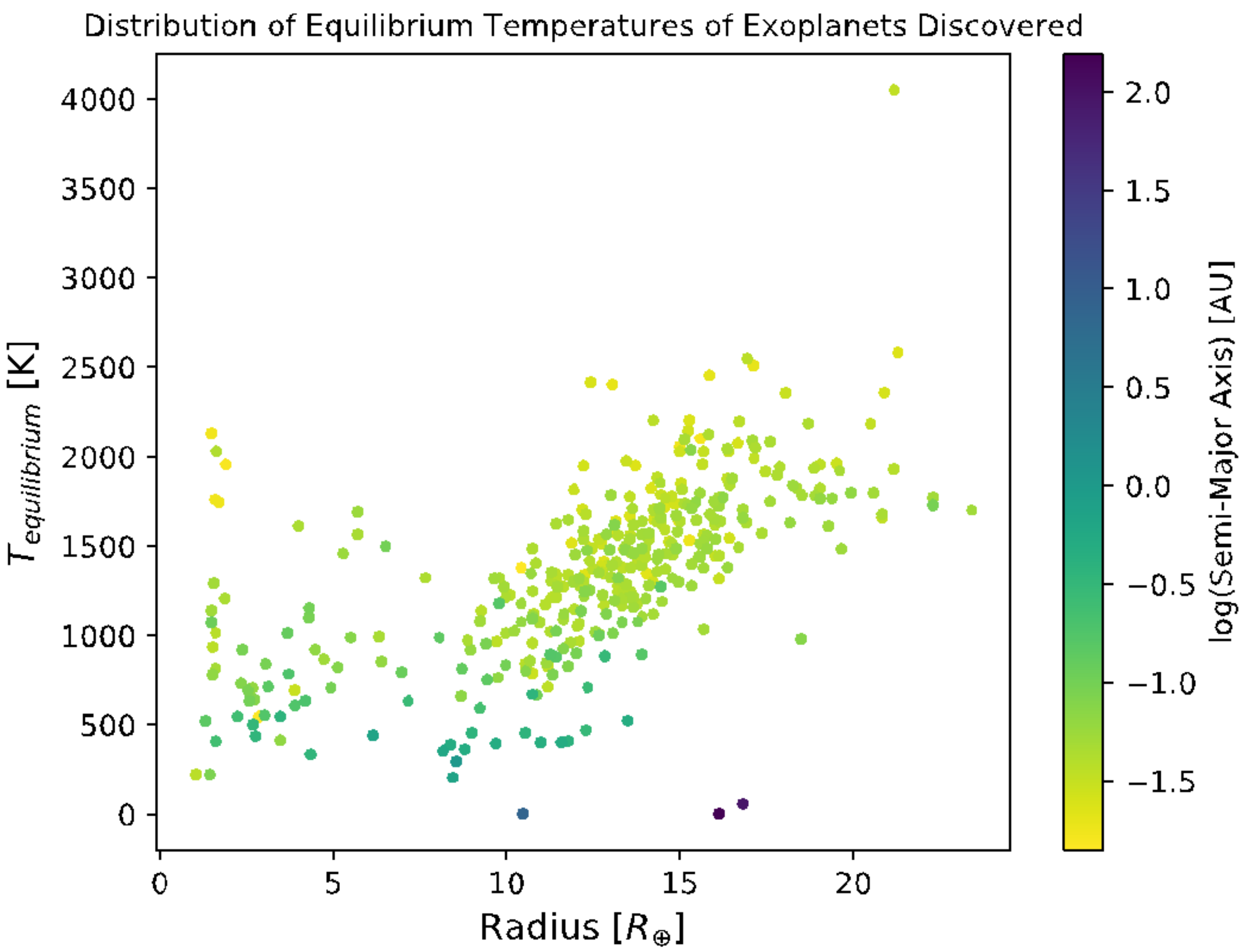
$$E_{thermal} + h(E_{grav}) = 0$$

$$T \sim h\frac{E_{grav}}{MC} \sim h\frac{GM^{2/3}\rho^{1/3}}{C}$$

Super-Earths may begin even hotter than the Earth did

T – initial temperature of planet
h – parameter describing how much gravitational energy goes into heating planet
M – mass of planet
C – specific heat capacity
G – gravitational constant
R – planet radius
ρ - density

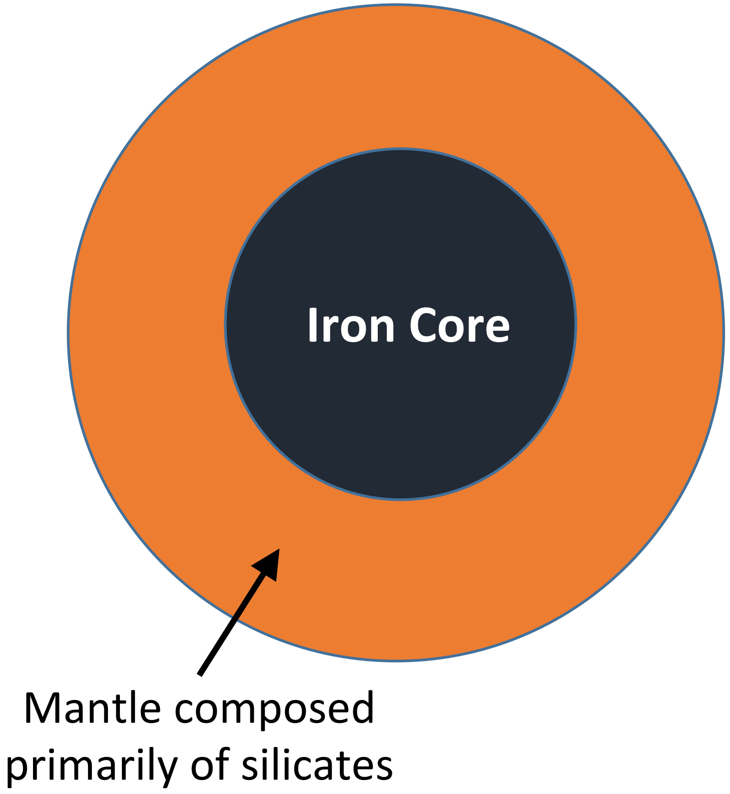
Many exoplanets discovered close to their host stars



Data taken from NASA Exoplanet Archive

Our Model: 2-Layer Rocky Planets

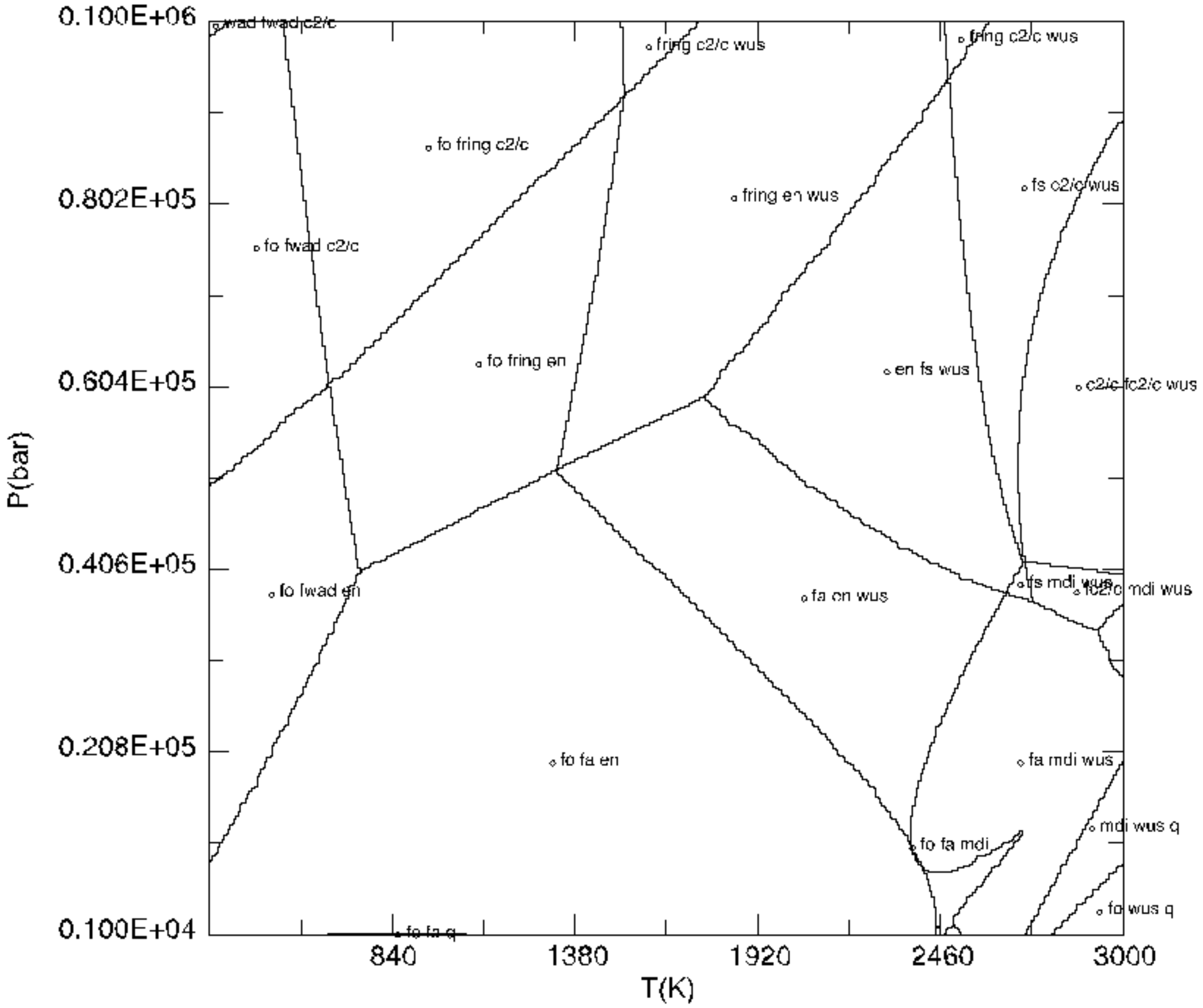
To leading order, we can model differentiated rocky planets with an iron core and silicate mantle.



Relevancy to Habitability

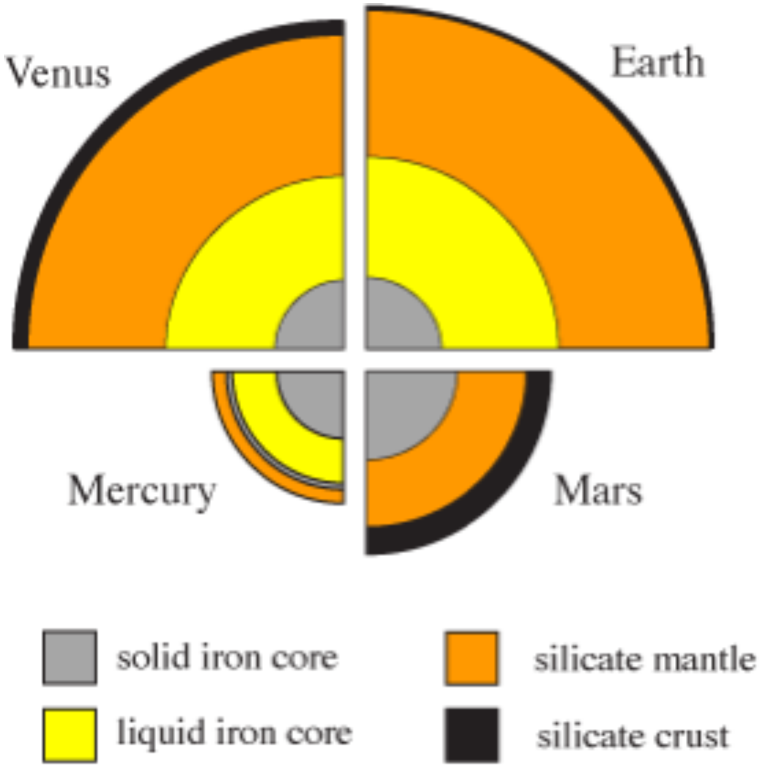
- how the effect of thermal expansion and the wider diversity of potential rocky exoplanet thermal profiles than previously considered could affect our interpretation of exoplanet M-R measurements.
- Exoplanet M-R measurements are a way to learn (in a rough way) about compositions of rocky planets around other stars.
- Rocky planet bulk compositions are relevant to habitability

Considering Phase Transitions – Perple_X



PerpleX Credit: Connolly (2009)

Introduction to Rocky Planets



Terrestrial planet interiors to same scale

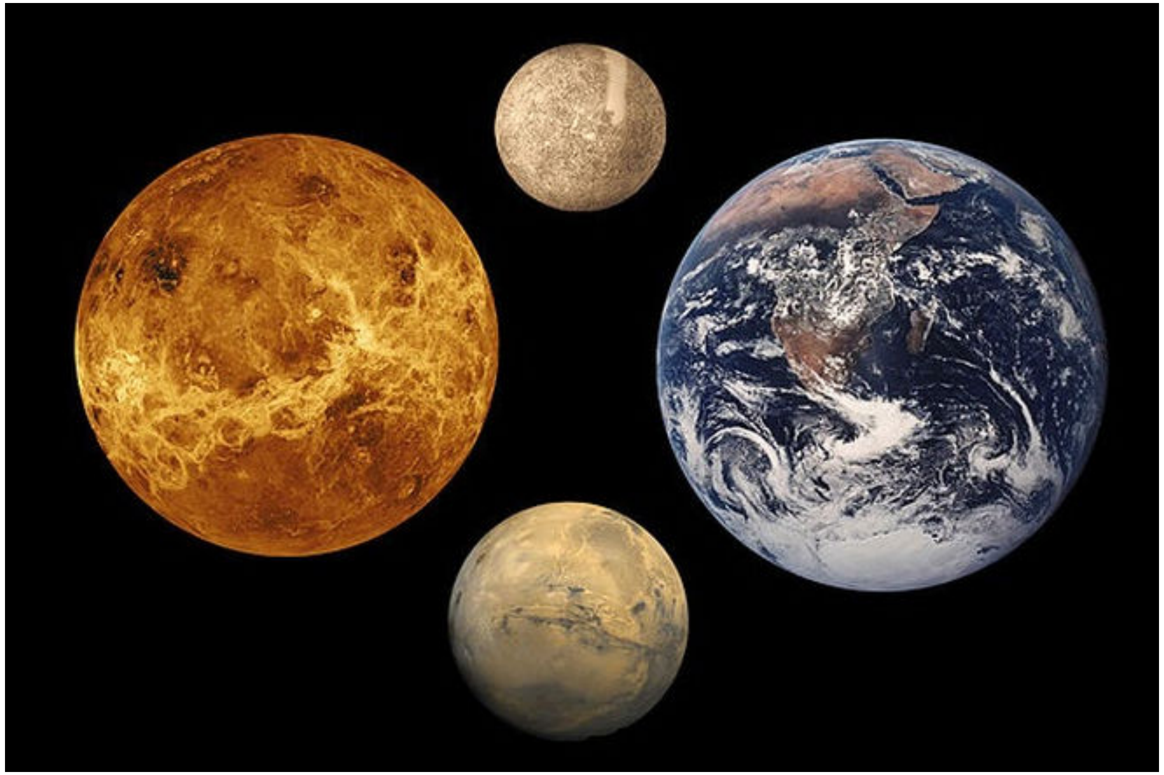


Image courtesy of Nick Strobel
at www.astronomynotes.com