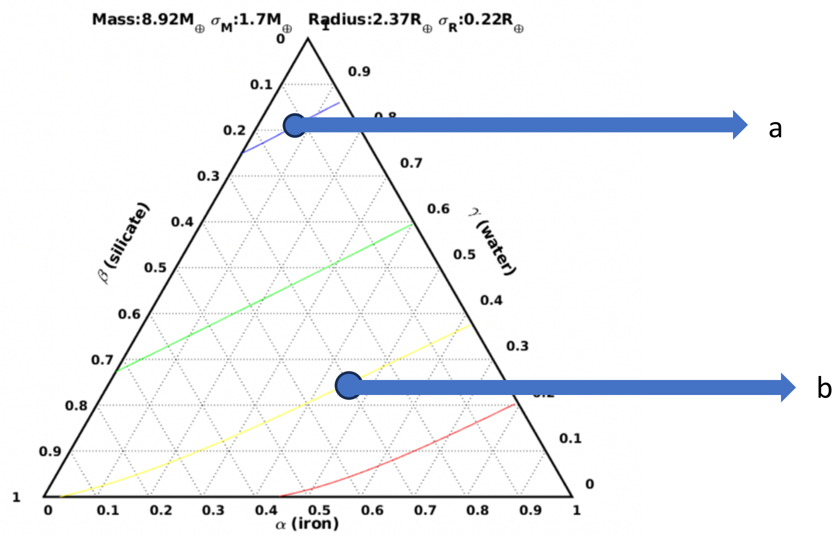
Homework 3 – Planet Interiors

1. Please refer to the ternary diagram of K2-18b below:



If you need a refresher on how to read a ternary diagram, please refer to Figure 3 of Zeng and Seager (2008), titled “A Computational Tool to Interpret the Bulk Composition of Solid Exoplanets based on Mass and Radius Measurements”.

a) What is the composition of K2-18b in terms of percent iron, silicates, and water at position a?

b) What is the composition of K2-18b in terms of percent iron, silicates, and water at position b?

c) K2-18b’s host star has a Temperature of 3450 K, a mass of 0.495 solar masses, and a radius of 0.469 R_sun. The planet has an orbital semi-major axis of 0.159. What is the planet’s equilibrium temperature? What is the RV signal amplitude of K2-18b (assuming the orbit is circular)? And what is the transit depth of the planet?

d) If you wanted to improve the density constraints on K2-18b, knowing that the best RV instruments give a per-pointing precision of ~1 m/s, would you want to obtain better transit data for a better radius constraint or more radial velocities for a better mass constraint (feel free to refer to the current error bars on mass and radius from the ternary diagram).

e) So far we have assumed that the eccentricity of K2-18b is 0. What if it's not? What is the semi-amplitude of the RV signal if you increase it's eccentricity to 0.1 (assume the same planet mass)? What about 0.3? Is this potentially measurable with current RV instruments?

2. Programming problem – Planet compositions

In this problem, we will compare the observed masses and radii of exoplanets to theoretical models to investigate the compositional diversity of planets. First, download the compositional grid developed by Zeng, Sasselov, & Jacobsen (2016). The grid is posted on Li Zeng's website at

https://www.cfa. harvard.edu/˜lzeng/tables/mrtable3.txt

The file has 44 columns. The first column is the mass of a model planet (in $M_\oplus$) and the remaining columns are corresponding radius (in $R_\oplus$) assuming that the planet has the composition described in the column title. (You can read more about the grid on the main page of Li's website at https://www.cfa.harvard.edu/˜lzeng/planetmodels.html)

a. Using the model tracks you downloaded, generate a diagram showing the mass-radius curves for planets with the following compositions: 100% Fe, 50% Fe, 30%Fe, Rock, 25%H2O, 100%H2O, and cold H2/He.

b. Why aren't these curves simply lines of constant density?

c. Add the Solar System planets and your favorite solar system moon to your diagram. How well do the Zeng et al. models describe the actual compositions of these planets? (i.e., are the planets closest to the model tracks that best match their compositions?)

d. Consulting the Confirmed Planets table on the NASA Exoplanet Archive (https://exoplanetarchive.ipac.caltech.edu/cgi-bin/TblView/nph-tblView?app=ExoTbls&config=PS), make a second version of your planet composition plot showing all of the exoplanets with both mass and radius estimates. Include the mass and radius errors reported in the table as error bars and make some cut (your choice!) on quality (ie – error bars have to be better than 50% or bulk density has to be better than 30% after propagating mass and radius error bars together).

e. Write a few sentences describing how the measured masses and radii of the exoplanets compare to the expectations from theoretical models. Which planetary compositions best describe planets of different masses? Are any planets in "forbidden" regions? Why might that be?