Build-A-Planet: Kepler 20b

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Motivation

Understanding the composition of an exoplanet can help us understand the process of formation of solar systems and specifically rocky planets. However, given that we cannot directly observe the planet for its interior composition, we must turn to the star and its spectra to find what materials were available to make the planet. With this knowledge, we could then better understand how a planet might structure its core and mantle if we know the radius and mass already. We specifically chose to investigate the composition of Kepler 20b for several reasons. It has a two star, Tatooine-like star system and falls within the radius gap as discussed in Fulton et al. 2017 with a radius of 1.91 Earth radii. Furthermore, it is extremely close to its stars at 0.04537 AU with a very high mass of 8.7 M_E.

Methods

Initially, use Nasa Exoplanet Archive to get the molar ratio of [Fe/H] for the star and use Griffith Et al. (2021) to then get the molar ratio over iron [X/Fe]. To use ExoPlex, the arguments for the stellar composition require the molar ratio over Magnesium [X/Mg]. Therefore, it can scaled to the Magnesium abundance with the following equation,

$$[\mathrm{X/Mg}] = \frac{10^{[X/H]} * 10^{X-H}}{10^{[Mg/H]} * 10^{Mg-H}} \qquad \textbf{Equation 1}$$

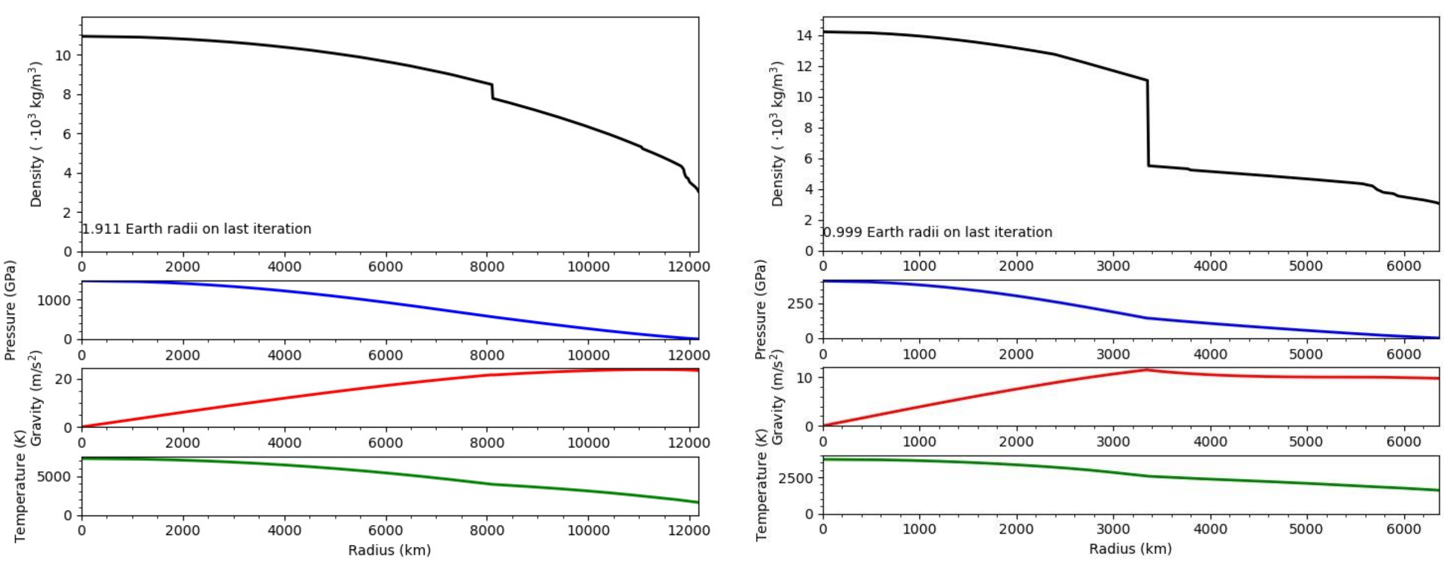
to get the molar ratios [Si/Mg] = 0.692, [Fe/Mg] = 0.759, [Al/Mg] = 0.0759, and [Ca/Mg] = 0.049. Then, we use the orbital separation and planet radius to determine its irradiance relative to the Earth to determine if it was truly a rocky planet. This led to the calculation of a surface irradiation 1275 times that of Earth while being 0.04537 AU away from its star which allowed us to assume that it has no significant atmosphere. Then, we plug in our molar ratios to get initial results of the expected radius and density along with radial profiles of the density, pressure, gravity, and time using the input of the literature mass, its upper bound error, and its lower bound error. This process was then repeated with adjusted core mass fractions of 30% Silicon and 10% Oxygen to find a closer expected radius to its literature value as seen in Fig. 1. Finally, we investigated the mantle mineralogy by plotting a profile of the fractional composition of different minerals to compare to the Earth's given by ExoPlex.

Results

	Officially Reported	Upper Bound	Lower Bound	Officially Reported	Upper Bound	Lower Bound
(Input value) Mass (M_E)	8.7	10.8	6.5	8.7	10.8	6.5
Radius (R_E)	1.796	1.89	1.67	1.91	2.01	1.77
Density (g/cm^3)	8.269	8.782	7.679	6.872	7.245	6.426
Core Radius Fraction (% of R)	48.02	47.91	48.23	66.55	66.37	66.82
Core Si Mass Fraction	0	0	0	30	30	30

Table 1

After inputting our molar ratios and planet mass with errors into Exoplex, we got the following results in Table 1 for the planet structure with the 30% Silicon adjusted core mass fraction on the right. The literature values were 1.91 R_E (+0.12 -0.21) and 6.5 (+0.2 -0.27). Thus, when comparing our calculated values with the literature values, we see that the calculated radius falls within the error in all cases but is even closer to the exact value when the core silicon mass fraction is adjusted. Also, we can see the initial density is significantly different than the literature value and outside the errors. But, when the adjusted core mass fractions are applied, we get the density much closer and fall within the error when using the officially reported mass and the lower bound. When running ExoPlex with the adjusted core mass



fractions, we were able to get the following radial profiles for Kepler 20bon the left and Earth for comparison, on the right.

Fig. 1: Radial profiles of Kepler 20b (left) and Earth (right) depicting density, pressure, gravity, and temperature.

In comparison to the radial profiles of the Earth, we can see the core mantle boundary as a much smaller difference in the density that occurs relatively closer to its surface.

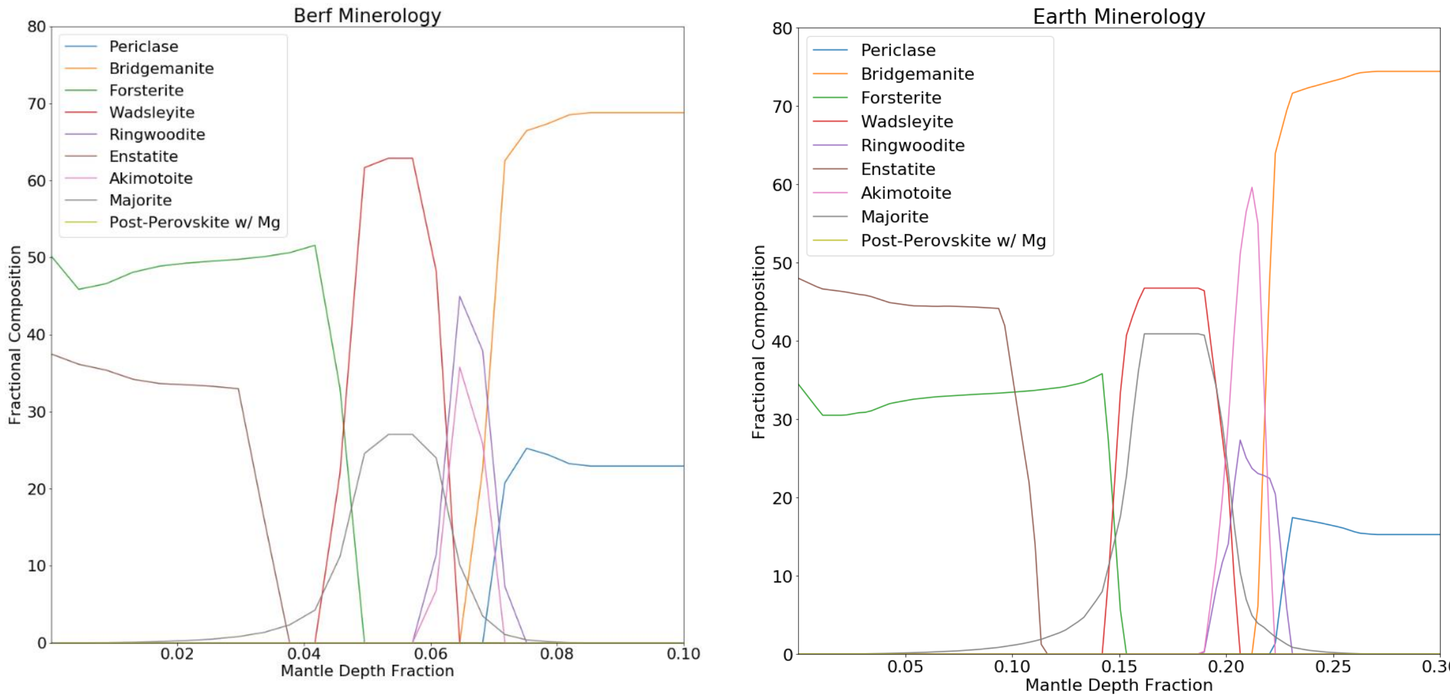


Fig. 2: Fractional composition of different minerals as a function of the mantle depth fraction for Kepler 20b (left) and Earth (right)**.**

Then, comparing the mineralogy composition of the mantle for Kepler 20b and the Earth we can see the distribution of varying minerals occurs significantly closer to the surface. In addition to this, we can also see the fractional composition of pairs of minerals flipped between the two planets such as Forsterite with Enstatite and Ringwoodite with Akimotoite.

Conclusions

Ultimately, we can see that given the stellar composition and mass of Kepler 20b, we can compose a structure of the planet match its radius and density using Exoplex and testing varying core compositions. From our results, we can see that the core is significantly bigger in relation to its radius compared to Earth along with a smaller density variation at the core-mass boundary. With further analysis, we would have liked to spend more time on the calculations of the presence of an atmosphere using the exobase temperature and further testing the core composition to better match the reported density. Also, further analysis of the calculated stellar abundances may also be necessary for better results due to the resulting need for the Si and O core mass fractions.

Contributions

Kevin Hoy – Mineralogy

Joshua Kingsbury – Stellar to Planet composition

Avidaan Srivastava - Presentation

Logan Steele – Report

References

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