Understanding The Composition & Structure of a Planet

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Motivation:

In order to discover the approximate density and structure of a planet, we must understand not only the planet itself but also it's parent star. Discovering the stellar composition of the parent star allows us to find out the radius and density of the planet in question, using it's measured mass. This work can be done by using the academic software 'ExoPlex', which is a software capable of modeling a planet based on the composition of its host star, comparing them to Earth and our sun to discover the properties of the exoplanet in question. For our project, Trappist-1b was chosen, which is a rocky planet discovered by transit in 2016. Being the planet closest to the red dwarf star Trappist-1, the solar system is about 40.7 light years away from Earth. This planet was chosen to be analyzed due to having a mass, radius and gravity similar to Earth. However, mainly due to being in close proximity with parent star Trappist-1, temperatures are significantly higher than on Earth. The extremely high temperature of Trappist-1b has an influence on the composition of the planet, but the magnitude to which it plays is relatively unknown. In this project, our mission is to determine the properties of Trappist-1b.

Methods:

To investigate the composition of Trappist-1b, we first must study its host star's properties and composition. We will be using the Iron to Hydrogen ratio Fe/H = 0.05350 from

Griffith et al. 2020. Given this value, we will use the figures from this paper as well as logarithmic relationships:

$$[N/M] = \log \frac{N/M}{N_\odot/M_\odot}$$

$$N/M = N_\odot/M_\odot \cdot 10^{[N/M]}$$

to find Fe/Mg and Si/Mg of the star. Once we have found these values, we will need to determine the surface irradiation. To calculate this, we need to consider the formula of Luminosity for a blackbody irradiator:

$$L_t = 4 \cdot r^2\pi \cdot \sigma_{SB} \cdot T^4$$

The luminosity from the reflection of the star:

$$L_s = 4 \cdot r_s^2\pi \cdot \sigma_{SB} \cdot T_s^4$$

$$L_p = \frac{L_s}{4\pi a^2} \cdot \pi r^2$$

And combing them to find a total surface flux:

$$F = \frac{L_s + L_p}{4\pi r^2}$$

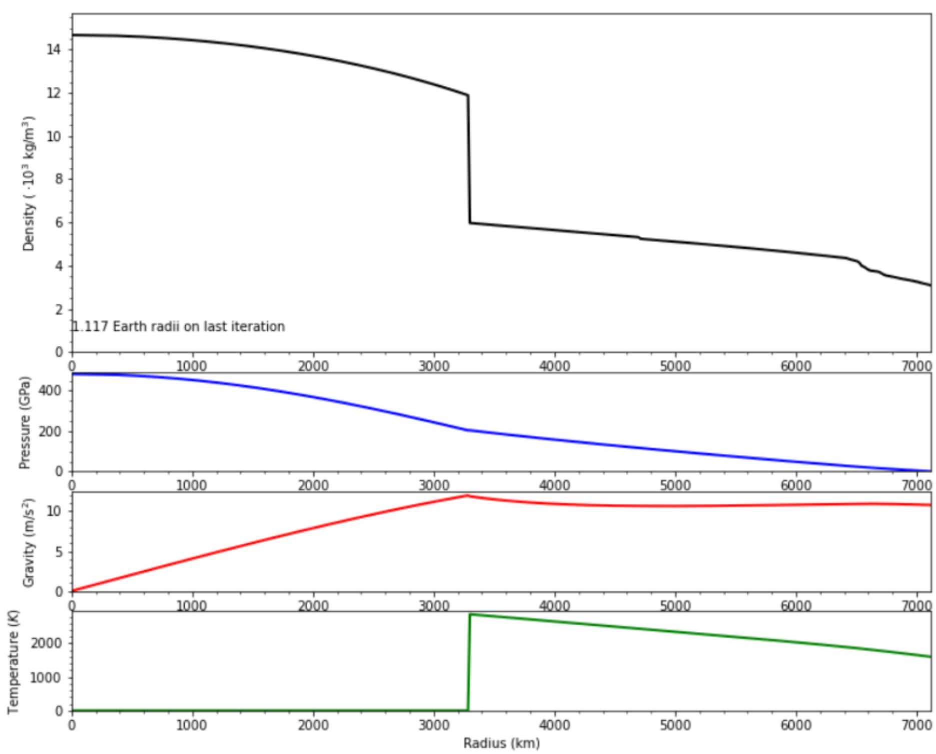
We will then use these values to find the expected radius and density of our target planet and subsequently compare its data with that of the Earth.

Results:

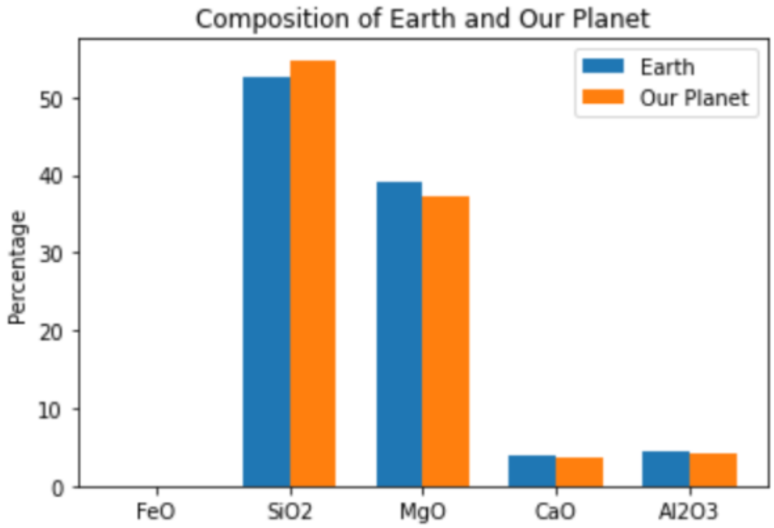
With the logarithmic relations we were able to find values for Trappist-1's composition to be that of [Fe/Mg] = 0.599 and [Si/Mg] = 0.985. Using this data in ExoPlex, we can find values for the mass of Trappist1-b to be 1.374 Earth mass and 1.117 Earth radii. Plugging in the values for surface irradiation yields a flux of approximately 2835.2 Watts per square meter.

Now that we know this, we can use the python package to find reasonable uncertainties for the values of our mass, radius and density for our target planet. We find a maximum mass of 1.44 Earth mass and radius of 1.133 Earth radius, while having a minimum mass of 1.305 Earth mass and 1.101 Earth radius. This corresponds to a density of 4.417 grams per cubic centimeters, with a maximum of 5.45 g /cm^3 and a minimum of 5.37 g / cm^3. These uncertainties are approximately within 1%, which may be due in part to the precise values of mass and radius we have of the planet.

Next, we will adjust the values of [Fe/Mg] with our uncertainties in mind to estimate the probable range of core mass fraction and core composition.



Here we use a core mass fraction of 23.80 and we can find Ca/Mg ~ 0.07 and Al/Mg ~0.09. This allows us to compare our target case to that of Earth.



Element Fraction:	Earth:	Trappist 1b:
FeO	0.0%	0.0%
SiO2	52.55%	54.80%
MgO	39.17%	37.33%
CaO	3.81%	3.63%
Al2O3	4.46%	4.25%

Conclusion:

To conclude our study of Trappist-1b, we discovered how it's composition parallels to Earth's. Both have 52-55% SiO2, 37-40% MgO, 4.2-4.5% Al2O3, 3.6-3.9% CaO, and no FeO. Despite the significant difference in temperature among the two planets and their parent stars being different, their compositions are very similar, with each value within 10% of one another. This indicates how accurate of a resource ExoPlex is when calculating elemental composition. With help from NEA, we were able to calculate fairly accurate values for the mass, radius, and density of Trappist 1-b, being 1.374 ± .069 Earth masses (5.0% uncertainty), 1.117 ± .016 Earth radii (1.4% uncertainty) and 5.417 ± .035 g/cm^3 (0.65% uncertainty) respectively. Given the slim margins of error, it is fair to say the calculations made by NEA and ExoPlex are very accurate and precise. A future study which could be done as a result of this study is to analyze why, exactly, the elemental composition of Trappist-1b is similar to Earth, despite the planets having having differences in temperature, the types of their parent stars, and the distance from which they orbit their stars. Analyzing the true accuracy of ExoPlex, as well as discovering the true importance of a planet's mass, radius, and density when it comes to elemental abundance could be worked on. The findings from Griffith et. Al (2020) were important, and a new, more recent study could help our certainty. In conclusion, our objective of analyzing the stellar equivalent of an exoplanet, Trappist-1b, based on the composition of its parent star, Trappist-1, proved to be successful, and despite not being habitable for life due to high temperatures, the planet's composition can be compared to that of Earth's.

References:

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