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Build-A-Planet: Trappist-1e

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1. INTRODUCTION

The search for habitable worlds and life has been a goal of human civilization since they gazed away from Earth. Today's astronomers are beginning to have the tools available to probe these fundamental questions. Using these new observational tools, potentially habitable worlds are becoming in reach to be studied. One of these systems is that of Trappist-1. Even though there are seven planets in the Trappist-1 system (Gillon et al. 2017), Trappist-1e has been one of the most famous examples of an exoplanet in the habitable zone of its host star. So when applying these observation techniques to Trappist-1e, we could be looking at a planet that not only has water, but the components to be a habitat for humans and lifeforms of it's own.

2. TRAPPIST-1E

In order to characterize Trappist-1e, we make use of data from various studies in the literature (Agol et al. 2021; Grimm et al. 2018; Gillon et al. 2017). Each study presents mass and radius measurements of Trappist-1e that agree to one sigma. Table 2 shows the orbital period, mass, and radius as reported by various studies of Trappist-1e. Of these studies, Agol et al. (2021) used data provided from Spitzer, Hubble, Kepler K2, and various ground based data which resulted in robust measurements of planetary parameters.

3. TRAPPIST-1 STELLAR COMPOSITION

In order to model our planet, we need to begin with some basic information about the system. One is able to obtain a good estimate of the planetary metallicity by using the assumption that it is

Mass ($M_\oplus$)	Radius ($R_\oplus$)	Orbit (au)	Literature
0.692 ± 0.022	0.920 ± 0.013	0.029	Agol et al. (2021)
0.772 ± 0.077	0.910 ± 0.027	0.029	Grimm et al. (2018)
0.62 ± 0.58	0.918 ± 0.039	0.028	Gillon et al. (2017)

Table 1. Mass and radius measurements from the literature.

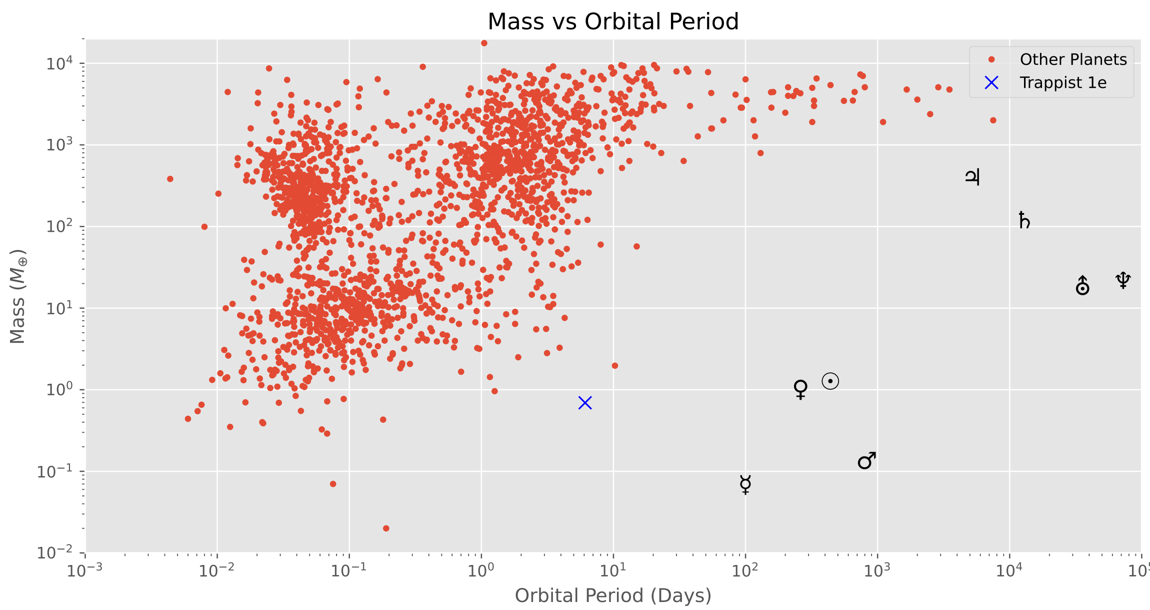

Figure 1. Trappist-1e, denoted by the blue x, is a low mass planet with an orbital period on the longer end for radial velocity and transit studies. Its period is short compared to that of Earth, however.

equivalent to its host star. Trappist-1 has a stellar metallicity of $[Fe/H] = 0.05350 \pm 0.08800$ (Ducrot et al. 2020), which we use in our work as a starting point for our calculations. Since planets contain significant magnesium and silicon quantities, it would be of use to determine $[Mg/Fe]$ and $[Si/Fe]$ for the host star.

Unfortunately we do not have direct measurements of the abundance of Si and Mg in Trappist-1. We however can estimate the abundance using the work of Griffith et al. (2021), which relates different stellar abundances to one-another. For Trappist-1, we thus adopt $[Mg/Fe] = 0.1$ and $[Si/Fe] = 0.05$ moving forward (Griffith et al. 2021). The abundance for Fe and Si in relation to Mg can then be

Name	$\%(O)_C$	CMF	CRF	$\%(FeO)_M$	$\%(SiO_2)_M$	$\%(MgO)_M$	$\%(CaO)_M$	$\%(Al_2O_3)_M$
Trappist-1e	0.06	26.69	51.58	0.0	58.2	34.5	3.4	3.9
Earth	0.037	32.5	54.6	8.18	44.71	38.73	3.17	3.98

Table 2. Core and mantle mass composition of Trappist-1e and Earth. Earth's mantle composition values are given by Workman & Hart (2005).

described by:

$$
\begin{aligned}
[Mg/H] &= [Fe/H] + [Mg/Fe] = 0.1535 \\
[Si/H] &= [Fe/H] + [Si/Fe] = 0.1035 \\
[Si/Mg] &= [Si/Fe] - [Mg/Fe] = -0.05 \\
[Fe/Mg] &= -[Mg/Fe] = -0.1
\end{aligned}
\tag{1}
$$

These need to be put into a usable form by the package we utilize, `ExoPlex`. We obtain the molar ratio of Si and Fe to Mg by using solving the definition of $[X/Mg]$ for the stellar molar abundance. As stated before, these abundances are then used for initial inputs for Trappist-1e. Abundance values for the sun are given by $(N_{Si}/N_{Mg})_\odot = 1.18$ and $(N_{Fe}/N_{Mg})_\odot = 0.79$ (Chaisson & McMillan 1999). The abundances for Trappist-1e are then just simply:

$$
\begin{aligned}
(N_{Si}/N_{Mg})_{1e} &= (N_{Si}/N_{Mg})_\odot \exp^{[Si/Mg]} = 1.13 \\
(N_{Fe}/N_{Mg})_{1e} &= (N_{Fe}/N_{Mg})_\odot \exp^{[Fe/Mg]} = 0.71
\end{aligned}
\tag{2}
$$

These values are those used in our fits for the planetary radii and composition.

4. EXOPLEX FITS

The aim of our study was to reproduce the radius measurements shown in Table 2. By doing so, we observe the various types of planetary composition that results. Modeling of Trappist-1e is done with the `ExoPlex` package. Through `ExoPlex` we can vary different parameters about Trappist-1e's core composition to match the radius value. We only match to the work of Agol et al. (2021), since it appears to be the most recent and robust measurement of Trappist-1e's mass and radius.

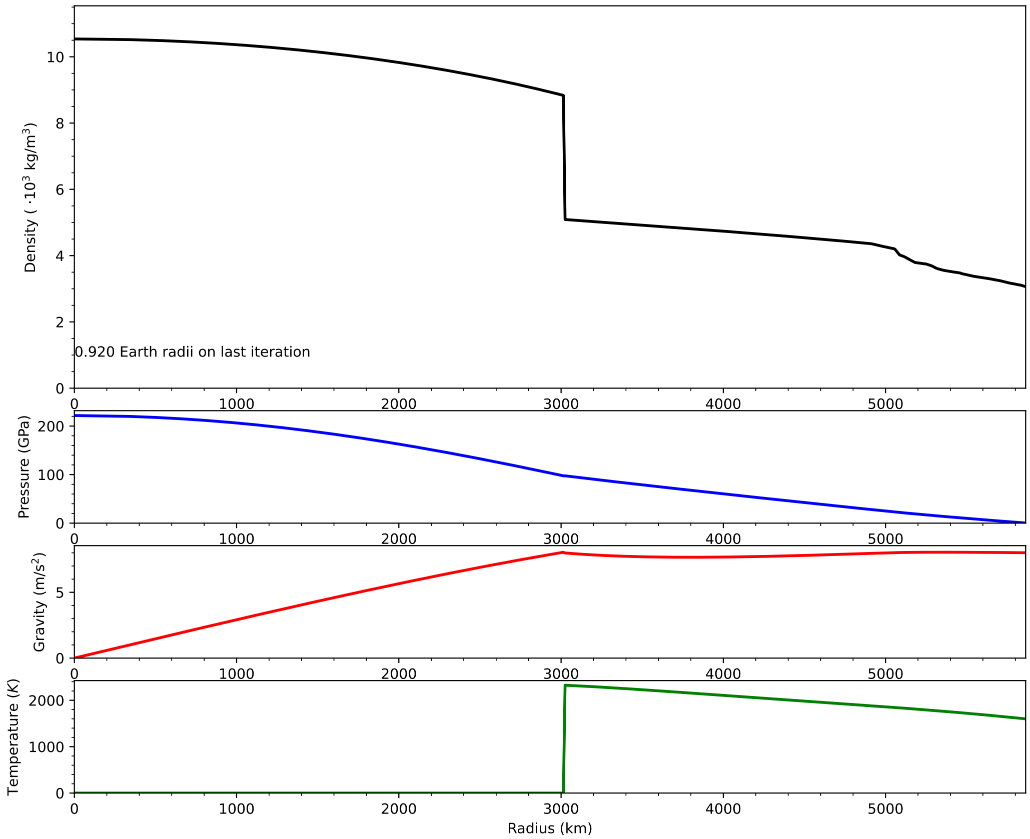

Figure 2. Example output figures from `ExoPlex` for the mass and radius from Agol et al. (2021). The core is iron dominated and extends to around $3000km$, from which a differentiated mantle begins.

When first running `ExoPlex` without adjusting any core composition and just assuming a homogeneous Fe core, the radius from the fit already was in agreement with some of the studies Table 2. A solid iron core gave a radius of $R_1e = 9.14R_\oplus$, but we wanted to more accurately represent the reported values from the transit timing measurements in Agol et al. (2021). We increased the amount of oxygen within the core in our fits, and this actually resulted in the radius increasing. Adjusting the silicon and sulfur in the core did not increase the radius of the planet, which was our desired affect. These values could have been adjusted to vary the mantle/core composition and seen the affects it has, but that work could be done in future studies.

We assumed an oxygen abundance within the core of 6% by weight, which inflated the radius of Trappist-1e to the observed radius of $9.20R_{\oplus}$. Planetary composition results are given in Table 4, which shows the core mass fraction (CMF), core radius fraction (CRF), as well as the composition of molecules in the mantle. Fig. 2 gives various parameters returned by the fit plotted over the radius of the planet. It can be noted that the core of Trappist-1e extends to $3000km$, after which the mantle begins. This core is iron dominated, which we determined in the initial fit of the planet. After which the highly differentiated mantle of the planet begins, resulting in a large drop in the density since the iron contents are concentrated within the core.

5. DISCUSSION

Constraining abundances of rocky terrestrial planets is important as it can detail how similar these planets are to our own Earth. This is especially important as we continue the search for life outside of our Solar System. With our resulting parameters from `ExoPlex` as given in Table 4, we are able to compare the composition of Trappist-1e to that of the Earth. Using values from Workman & Hart (2005), we find that the mantle of the Earth is fairly abundant in SiO_2 as well as MgO, followed by smaller abundances of a few more molecular constituents, notably FeO, CaO, and Al_2O_3. Looking at Trappist-1e, we find that the abundance percentages are very similar to that of the Earth, implying that their overall composition is comparable to rocky, terrestrial planet. Additionally, we find that both planets have a fairly similar core mass fraction.

Though the overall composition of both planets are very similar, Trappist-1e falls within the habitable zone, and it's atmosphere isn't hydrogen rich like the puffy gas giants (de Wit et al. 2018), there is no current strong evidence that points to potential life on this planet. However, with more in depth probes with the *James Webb Space Telescope* of the Trappist-1 system, future results will be able to give us better constraints on heavier biogenic molecules that can help us determine this planet's habitability.

6. CONTRIBUTIONS

- *Aiden Zelakiewicz* - AZ lead the coding, wrote Sections 3 and 4 in the paper, and assisted in literature searching.
- *Sydney Petz* - SP created the presentation and lead searching the literature. SP wrote the Discussion section of the paper and compared the results to previous literature and Earth.
- *Justin Anderson* - JA presented and created the NEA comparison plot. JA wrote sections 1 and 2 of the paper.

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