Using Exoplex to Determine the Composition of Trappist-1f

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Introduction

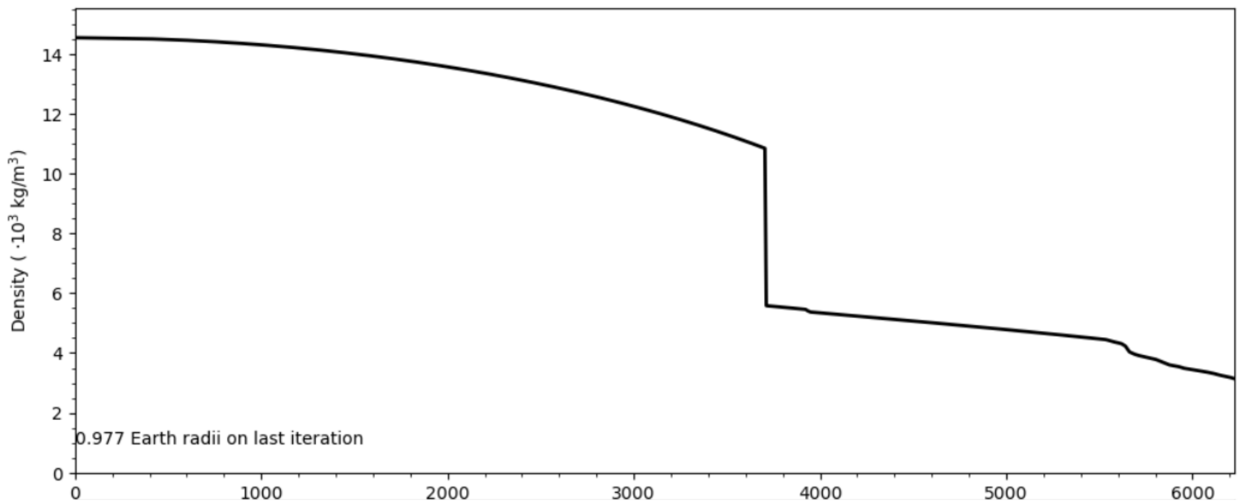
When studying exoplanets, we can directly observe two common parameters: planet mass and radius. This means that we can only calculate the planet's density. However, we are able to use a series of differential equations to calculate several other planetary parameters. To achieve this, we will use a computer program called ExoPlex. This will utilize the differential equations with known stellar and planetary parameter inputs to “build” a new exoplanet. The result will be a combination of derivations and estimations that are new planetary parameters. This will allow researchers to understand more about exoplanets and planetary systems. The planet we have chosen to observe is Trappist-1f. Trappist-1 has a system of 7 exoplanets all within an orbital radius smaller than the orbital radius of Mercury around our sun. These are all rocky planets with suggested evidence of water. This implies that this system may be a great location to continue the search for extraterrestrial life and habitable worlds.

Methods

The ExoPlex method uses the inputs: planet mass, stellar [Fe/Mg], and stellar [Si/Mg]. It will then output the planet's radius, density, pressure, gravity, temperature, core-mass fraction, core-radius fraction, and core-mantle boundary. We will now apply this method to Trappist-1f. *Griffith et al., 2020* gives us the following stellar abundances of Trappist-1: [Si / Mg] = *1.124* and [Fe / Mg] = 1.72. Trappist-1f also has a mass of *1.039 Earth mass.* We can input these values into ExoPlex and analyze the results.

Results

For our first run of Exoplex, we used only planet mass and stellar composition. From this input, this resulting figure shows the model planet's density as a function of radius.



<u>Figure 1</u>: Above is a plot of the density of Trappist-1f as a function of radius. We can see dramatic drops where the layer of the planet transitions.

The program calculated that the planet has a radius of .977 earth radii or 6224 kilometers. The step in density near 3700 kilometers is where the core transitions into the planet's mantle, and there is a slightly smaller step around 5600 kilometers where the mantle transitions to the crust. The exoplanet archive lists the uncertainty of Trappist 1f, plus/minus .031 earth masses, which results in an uncertainty in ExoPlex's generated radius of .008 earth radii, or approximately 50 kilometers. The actual radius of Trappist 1f is 1.05 earth radii, which is not included in the uncertainty range. Therefore, there is a discrepancy between our ExoPlex model and the measured values for Trappist-1f that is not accounted for by mass uncertainty.

Since there is a clear discrepancy between our values from the literature's values, we must adjust our planet's composition. This requires a new input of the mass fractions of light elements found in the core of the planet into ExoPlex. We will add an oxygen core-mass fraction of *0.255*.

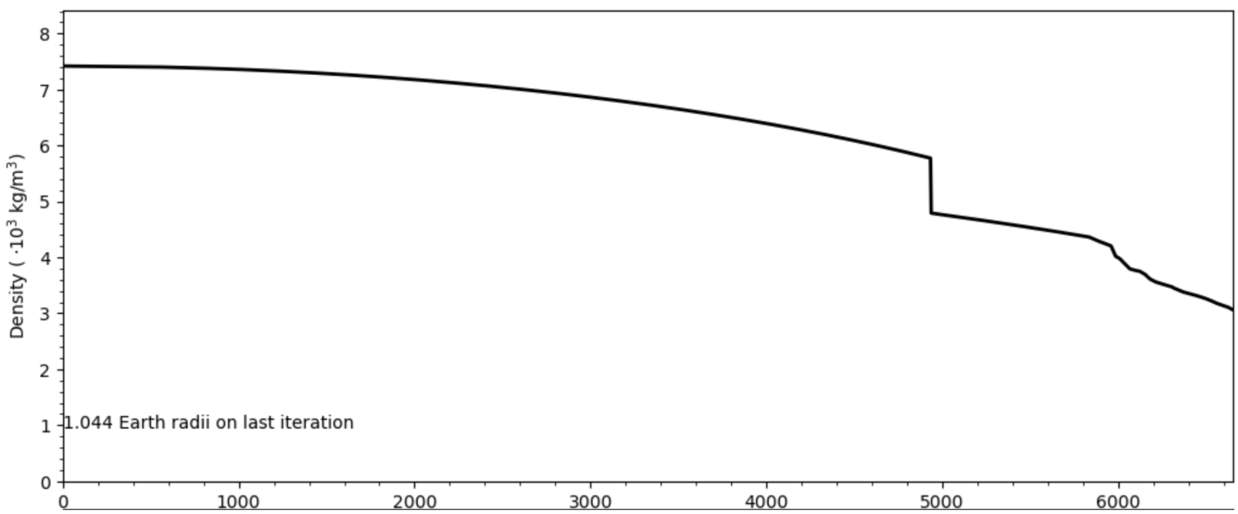


Figure 2: We can see the density of Trappist-1f as a function of its radius with an updated value of the oxygen core-mass fraction.

The program calculated that the planet has a radius of 1.044 Earth radii. Adding oxygen to the core increases our planet's radius and core mass and radius fractions. Our density is almost cut in half from our previous run. The step in density near 5000 kilometers is where the core transitions into the planet's mantle, and there is a slightly smaller step around 6000 kilometers where the mantle transitions to the crust. Even though these parameters more closely match the given values, this model may not be the most realistic due to the high amount of oxygen in the core.

Using the following equation for temperature,

$$T_{\text{eq}} = \left(\frac{L\,(1 - A_B)}{16\sigma\pi a^2} \right)^{1/4}$$

where *T* is the equilibrium temperature, *A* is the Albedo, *a* is the orbital distance, *L* is luminosity, and ***σ*** is the Stefan-Boltzmann constant, we can now calculate the flux and temperature of

Trappist-1f from stellar irradiation. This will result in a flux of *463 W/m*^{2} and an equilibrium temperature of *212 K*. Considering that the literature suggests the presence of oceans and an atmosphere on Trappist-1f, it might be wise to compare this planet to Earth itself, especially after seeing that their masses and radii are so similar. We might consider a third compositional model of our planet, where we revert back to solely the stellar parameters with no adjustments to the light elements found in the core. In this scenario, we found the radius came up a little short compared to the expected radius. Considering the extremely similar irradiation between Earth and 1-f, it is possible that a potential solution to this very minor discrepancy between the observed and our predicted radii is an atmosphere or ocean layer, similar to Earth's, that is not accounted for by ExoPlex.

Conclusion

We've found that Trappist-1f is likely to have a very similar composition to Earth. In our initial run of ExoPlex, using all default parameters except for the Fe/Mg and Si/Mg, we can examine the stellar irradiation this planet receives. Along with the planet's mineralogy, we can see how these compare with Earth to determine whether considering these planets to be analogous is valid. While Earth has some minerals that weren't observed in Trappist-1f, and the reverse is true as well, the minerals appear to have a similar composition otherwise. The densities of the planets are also much closer when we don't adjust the oxygen in the core; this suggests that the model with near-Earth parameters is the closest to reality, and the discrepancy in the radius might be explained by Exoplex not accounting for an atmosphere or oceans. We would need to conduct more research to confirm or deny this theory.

References

"NASA Exoplanet Archive." *NASA Exoplanet Archive*, https://exoplanetarchive.ipac.caltech.edu/.

https://iopscience.iop.org/article/10.3847/1538-4357/aad95d/pdf