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Probability of Earth Similarity for the Current TESS Planet Candidates

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Abstract

The Transiting Exoplanet Survey Satellite (TESS) has so far discovered a multitude of potentially habitable planet candidates. The next step in confirming the habitability of these exoplanets will be spectroscopic observations by the next generation of telescopes. In an effort to prioritize candidates for these observations, we have calculated probability density functions for the Earth Similarity Indexes (ESIs; Schulze-Makuch, D. et al., 2011) of planet candidates using a Monte Carlo method. Furthermore, we have integrated the density functions to provide probabilities that a planet candidate has an Earth-like (>0.8 ESI) composition or a Mars-like (>0.7 ESI) composition. As radial velocity measurements have not yet been obtained for many TESS planet candidates, the density of the planets used in the calculations is obtained using the mass-radius relationship created by Ning, B. et al (2018) which in turn is based on data taken from the Kepler mission. Future work will include integrating radial velocity measurements of mass into the calculations and simulating the most Earth-like planets using a 3-D general circulation model.

1. Introduction

The specific definitions of what constitutes a generally habitable planet as we know it are inextricably linked to life as we know it, i.e. life on Earth. Thus, the search for habitable exoplanets is a search for relatively Earth-like worlds. In order to characterize exoplanets in this way, we use the Earth Similarity Index (ESI) as described in Schulze-Makuch et al. (2011). Though this method is relatively simple, it works especially well for the limited amounts of data available on observed exoplanets.

The Transiting Exoplanet Survey Satellite (TESS) has so far discovered a multitude of potentially habitable planet candidates. As more planet candidates are detected and confirmed, it becomes increasingly important to strategically search for signs of habitability with which to differentiate and prioritize the candidates. A survey such as this one is significant because it is the first application of the ESI to the TESS dataset. This will facilitate a prioritization of planet candidates for future observations to detect their mass and analyze their composition.

2. Methods

Data used in this survey was collected from the Data Validation (DV) Files provided for the public on the Mikulski Archive for Space Telescopes. These files are the result of the DV software used by the TESS Science Processing Operations Center which is performed on preconditioned light curves. The fitting procedure used by DV is informed by the Transiting Planet Search algorithm and it creates multiple limb-darkened fits based on different sets of detected transits. For this survey, we used the parameters from fit created for the full set of all transits for a given planet. This ensures that the most data was used in the calculation of the output parameters, and therefore a more robust conclusion can be reached.

Planetary radius and surface temperature, parameters required to calculate the ESI, as well as their uncertainties were taken from the DV files. As the observations used to create these files use the transit method, mass is not currently available.

2.1 Sampling

A planet candidate was surveyed if it met the following three conditions. First, the planet candidate was within or near the habitable zone of its star as defined and calculated by Kopparapu et al. (2013) based on its fitted semi-major axis and the effective flux of the star. Second, the planet candidate was within or near the Terran range of radii (0.5-1.8 Earth Radii) based on its fitted radius. Third, the uncertainty in the planet candidate's radius was no larger than ½ of its fitted value, i.e. that the radius would be positive within 2σ. In all of these conditions, 'near' is taken to be within 1σ of the range indicated.

2.2 Calculations

As the mass of the planet candidates is not known, it must be calculated before the density can be obtained. To this end, we used a Python package called MRExo (Kanodia et al., 2019) to obtain a probability distribution function (PDF) for mass based on the fitted radius and its uncertainty. Utilizing this PDF and assuming that the radius is normally distributed, we used a Monte-Carlo Method (MCM) to construct a PDF for the density to be used in further calculations.

As the ESI for surface conditions relies on the escape velocity which in turn relies upon the mass and radius of the planet candidate, a similar MCM was used to construct a PDF for the escape velocity.In addition, the fitted equilibrium temperature was assumed to be normally distributed and 30 K was added on top to approximate additional warming due to an Earth-like atmosphere.

With these PDFs constructed, we then used a final MCM to construct PDFs for the internal, surface, and total ESIs for each planet candidate. All three ESIs were plotted along with their average and mode values for easy comparison. Finally, we integrated the total ESI from 0.8 to 1 to determine greater than Earth-like probability and from 0.7 to 1 to determine the probability of greater than Mars-Earth-likeness.

3. Conclusions and Discussions

Though no planet has an Earth-like average ESI, there are many planet candidates that show promising displays of habitability, such as TIC 201878287 b as shown in figure 1. In total, there are six planet candidates with >0.6 average total ESIs, TICs 38698751 b, 114794572 c, 152821098 b, 201878287 b, 281542064 b, and 337217173 b. These are promising, especially in the most probable ESI values, which tend to be near 0.7 or above, but can not confidently be ruled Earth-like. This seems to be primarily due to the model used for the construction of the density PDF. As the sample used to create the model is based on data from the Kepler mission, the model tends away from Earth-

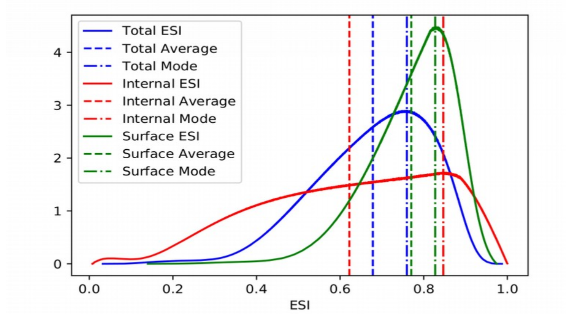

Figure 1: The graph of TIC 201878287 b is obviously skewed by its the large spread of its internal ESI's PDF though the most probable ESI values are quite high.

like densities, whether higher or lower. This is evident in the graphs as the internal ESI is skewed, sometimes drastically, away from 1. We believe this is mostly due to the large uncertainties present in the data and model. Even with the constraints on uncertainty in creating the sample, the uncertainties tended to be quite significant. This would occasionally result in the probability that the candidate's radius was actually near to the Earth's being quite low and thus skewing the interior ESI down. Furthermore, the lack of available mass data for exoplanets hampers the model and drives uncertainty up.

Nevertheless, this survey has identified several planet candidates with relatively high ESIs. We are confident that these candidates should be prioritized in the next set of observations, particularly those that would constrain their masses.

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