Assessing the Habitability of Exoplanets*

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Abstract

In this paper, we examine detailed descriptions of planets and perform an assessment of their habitability. The analysis will be based on the methods taught and practiced in class, as well as independent research. Thus we demonstrate how to use the properties given; star/planet information, atmospheric composition, and other known values, to determine if that planet is capable of sustaining at least single celled life. We will look at planets 1 and 2 of the given three, corresponding to text files p1 and p2. The analysis was conducted using R (R Core Team (2020)). The data was obtained from http://astro.utoronto.ca/~ast251/AST251_2022_Project2/.

*Code and data are available at: https://github.com/haqbilal/Assessing-Hability-of-Exoplanets

1 Introduction

Firstly, a slightly looser definition of habitable from Kasting et al. (2014), is an Earth-like planet around different types of main-sequence stars having liquid water on its surface over an extended period of time. Moreover, the habitable zone is the range of orbital distances for which a planet described above may exist. For each case, we are given properties of the star, the planet, and other useful values to help determine the habitability of each planet.

1.1 Properties of the Star

From Raghavan et al. (2010), stars supporting habitable planets will have spectral class within the range of late F mid K. And according to Greicius (2015), stars must be at least a hundred million years old (and we assume the planets formed around the same time). Single-star systems will have more stable orbits, so they are more habitable. A luminosity that doesn't vary too much is ideal for habitability, keeping the energy output of the star similar at all times. Also, the luminosity is directly proportional to the star's habitable zone, while the radius is inversely proportional (Morris (2010)). Lastly, from Waltham (2017), stars smaller than 0.65 solar masses are statistically unlikely to host habitable planets. We can calculate the habitable zone using the formula:

$$\sigma_{SB} T^4 = \frac{L}{4\pi r^2} \tag{1}$$

where T is the temparature, σ_{SB} is the Stefan-Boltzmann constant, L is the luminosity, r is the radius of the star.

1.2 Properties of the Planet

The orbital period of a planet has no percieved effect on it's habitability (Shields et al. (2016)), but we may use the semi-major axis to determine if the planet is in the habitable zone (Morris (2010)). Further, using the habitable planets catalog ((n.d.)), we see that habitable planets often have a radius of between 0.5 and 1.5 Earth radii. From Bolmont et al. (2016), planets with eccentricity close to Earth's (0.01671) may be suitable for life, but the effect of high luminosity combined with high eccentricity is not known, so other methods may be used. Finally, planets containing one of CH4, H20, N2, O2, CO2 as the dominant compound in their atmospheres are likely candidates for habitability according to Konatham, Martin-Torres, and Zorzano (2020). Alongside, most candidate habitable exoplanets also contained H/He. Thus planets with this composition or an Earth-like composition are likely to be habitable.

1.3 Other Useful Properties

Primarily, locations with high star population density can be problematic to the formation of life on a planet, because of excess radiation from stellar evolution of all local stars (Skibba (n.d.)). Thus the optimal location for stars and their planets in terms of habitability is the disk of the Milky Way galaxy, where stars are more spaced apart, meaning their influence on other stars' planets is lessened. As atmospheric pressure increases, so does the habitability of a planet because it allows for water to exist in liquid form for a wider range of temperatures (Vladilo et al. (2013)). Thus planets with higher atmospheric pressures than Earth, and all other attributes similar, are more likely to be habitable as a result. By Del Genio et al. (2019), a bond albedo of ~0.3 (close to Earth) or 0 is often assumed when assessing the habitability of planets, but Earth's albedo of 0.3 is usually only the minimum required for a planet with an F-K type star. Thus planet's albedo can vary, and still result in a habitable world. From McKay (2014), water can exist in liquid form in the range -15 to 122 degrees Celsius, which is 258 to 395 degrees kelvin. Thus a planet with surface temperature in this range is required for life to grow and reproduce. In addition, the axial tilt of a planet causes different parts of a planet to be in direct radiation from it's star. This causes seasonal change on Earth, which has an axial tilt of 23.5 degrees. For example, if a planet's tilt is such that it's glaciers come into the star's radiance, then they would melt and allow for liquid water, even among other non-habitable conditions (Garner (2015)). In combination with a high albedo, a slowly rotating planet is a candidate for habitability because of long daytime illumination. A fast rotating planet (like Earth) with low albedo allows for more illumination during a smaller time period, to accomplish habitabiltiy as well (Yang et al. (2014)). Also, Lammer et al. (2009) indicates that a strong magnetic field is required for habitability, as it protects a planet from stellar wind eroding away the atmosphere necessary for life to exist.

2 Methodology

Now we apply the methods discussed above and assess the habitability of the planets provided in the dataset. Planet 1 corresponds to the dataset 'haqbila1_p1.txt' and Planet 2 corresponds to 'haqbila1_p2.txt'.

2.1 Planet 1

The properties of Star 1 (corresponding to Planet 1) are satisfactory to continue analysis. With a spectral type F, and an age of 2.55 Gyr, as well the system having no other stars, this star is capable of hosting habitable planets. The star's mass is 1.41 solar masses, greater than 0.65, meaning it isn't statistically unlikely to host habitable planets. We can calculate the habitable zone, given the luminosity of 3.91 and radius of 1.38, using equation (1):

$$
\begin{aligned}
T &= \left(\frac{L}{4\pi r^2 \sigma_{SB}}\right)^{\frac{1}{4}} \\
&= \left(\frac{3.91}{4\pi \cdot (1.38 \cdot 1.5 * 10^8)^2 \cdot 5.670367}\right)^{\frac{1}{4}} \\
&=
\end{aligned}
$$

2.2 Planet 2

3 Discussion and Next Steps

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