Exoplanets – Is There an Alternative Home?

Raghad Ebrahim Rashed

1 Introduction

In 1977, NASA launched Voyager 1 and 2, carrying a "message from Earth", which was like a 'time capsule' with a record greeting message of 55 languages intended to introduce humanity to any intelligent extraterrestrial life that might reach out. Our curiosity persists: Are we alone or is there another habitable world beyond our solar system?
This data analysis project aims to study confirmed exoplanet habitability based on their stellar/planetary characteristics, orbital zones. The study uses habitability models [2],[3] to apply constraints to thousands of candidates and isolate those most similar to Earth.

2 Problem Statement

Despite the discovery of +5,800 exoplanets, only a few may support life according to current calculations. One challenge is to build a systematic method for identifying planets that meet scientific criteria for habitability. To achieve that:

- **Stellar Spectral type**: Identify exoplanets that orbits main-sequence stars (Luminosity Class-V), stars with spectral classes (K, G and M stars).
- **Measurable**: Calculate the optimized habitable zone (HZ), the inner and outer HZ (Recent venues, Early Mars) a planet with semi-major axis falling within these boundaries classified as habitable.
- Exoplanets are compared to the solar system planets radius and classified accordingly, **(Terrestrial, Super-Earth)** are planets with most poor-metallically stars, which has more habitability chance (as they are less likely to receive UV light)
- **Earth-Similarity Index (ESI)** is a multi-parameter measurement that scales how similar a planet is to Earth, ranging from zero (no similarity) to one (an exact match to Earth)[3]. A planet with an ESI ≥ 0.8 that also meets the above criteria is considered an excellent candidate for habitability.

3 Objectives

- To develop a systematic method to filter out +5800 exoplanets using astronomical and physical criteria to find habitable candidates.

- To provide a ranked list of top candidates exoplanets for further astrobiological studies.

4 Target Audience

- Astrobiologists and researchers in related fields of space science.
- Data analyst with an interest in space science.

5 Datasets

- **Source**: NASA Exoplanet Archive.
- **Confirmed Planets**: 5869 as of the study.

Each row represents a unique planet, described by more than 100 spectroscopic and astrophysical characteristic columns.

6 Data Handling

The data was processed using the following steps:

- **Filtering by Star Type**: G, K, and M main-sequence stars.
- **Habitable Zone Selection**: Applied Kopparapu HZ bounds to select valid orbital zones.
- **Planet Classification**: Retained rocky planets based on radius and mass.
- **ESI Calculation**: Used radius, mass, surface temperature, and escape velocity to calculate similarity scores.
- **Handling Missing Values**: Columns with less nulls were chosen as a metric, the nulls were excluded. Missing radius values were estimated using Mass-Radius approximation relation.

7 Analysis and Findings

From the initial 5869 exoplanets:

- **5278** met stellar criteria.
- **2445** were rocky planets (Terrestrial,Super-earth).
- **62** remained within the habitable zone.
- **21** rocky planets falls in th HZ and had an Earth Similarity Index (ESI) above 0.8.

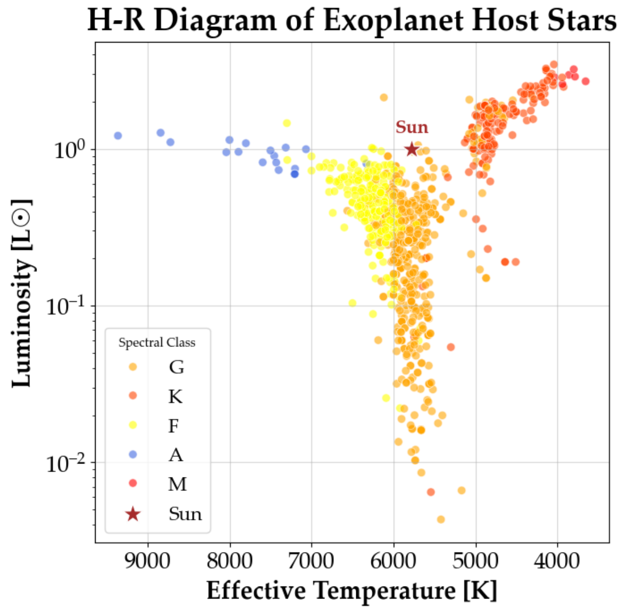

Figure 1: The diagnoal from upper left to lower right represents the "The main sequence stars". The star's spectral type and age determine the long-term habitability zone. For a planet to be habitible, we need a starhost to be in late F or G, to mid-K,

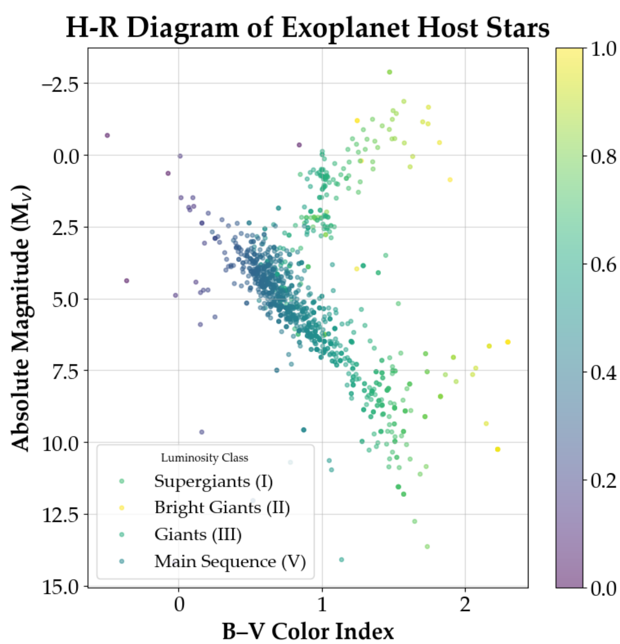

Figure 2: As observed, main sequence stars (luminosity Class V) are especially significant in the search for habitable planets

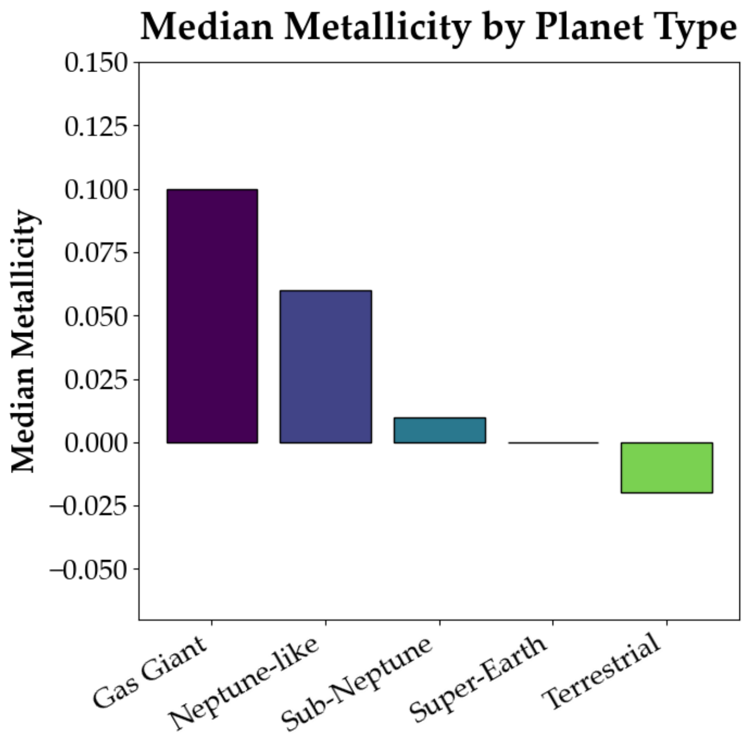

Figure 3: Planet with poor-metal stars (Low Metallicity) are the ones with more habitability potential. Rocky planets (Terrestrial, Super-Earth)

8 Future Works

- More advanced science/statistical based approximation to handle the missing values.
- Consider machine learning models for predicting habitability.

9 Limitations

- Other crucial criteria such as the planet chemical composition were ignored due to lack of atmospheric or magnetic field data.
- Planets with insufficient/missing data were excluded, possibly omitting candidates.
- The method were not compared with literature, we need to include error analysis and model evaluation.

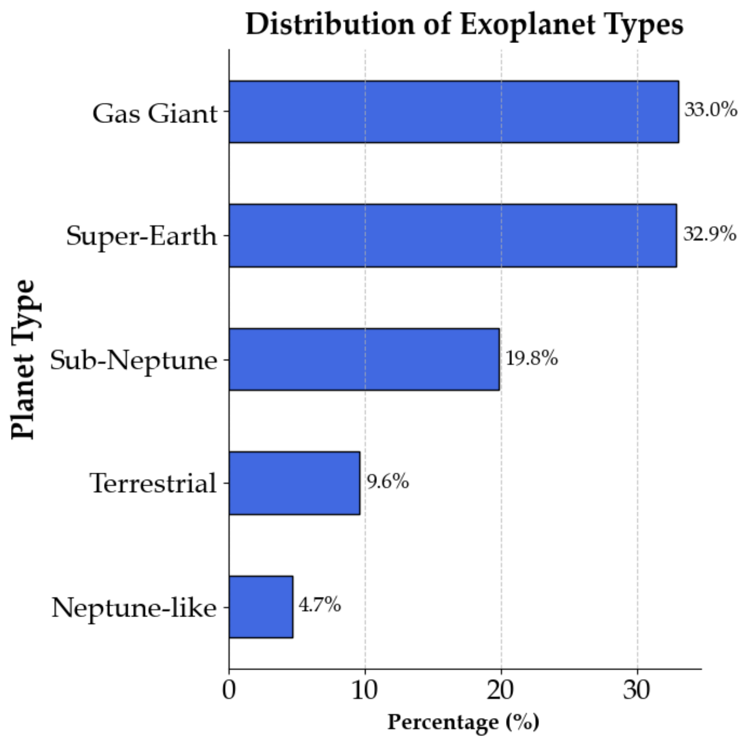

Figure 4: Most of the exoplanets are massive-planet, since their effect on their star systems are observable using the transient method.

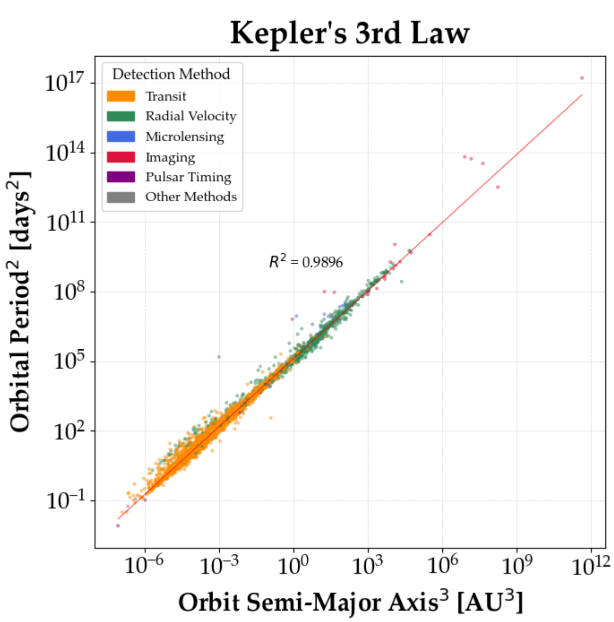

Figure 5: The current techniques are usually sensitive only to systems with massive-planets with short-period ranges shorter than earth. In contrast, studies of planet occurrence have shown that long-period, small-radius planets are the most common outcome of planet formation in the Milky Way [4].

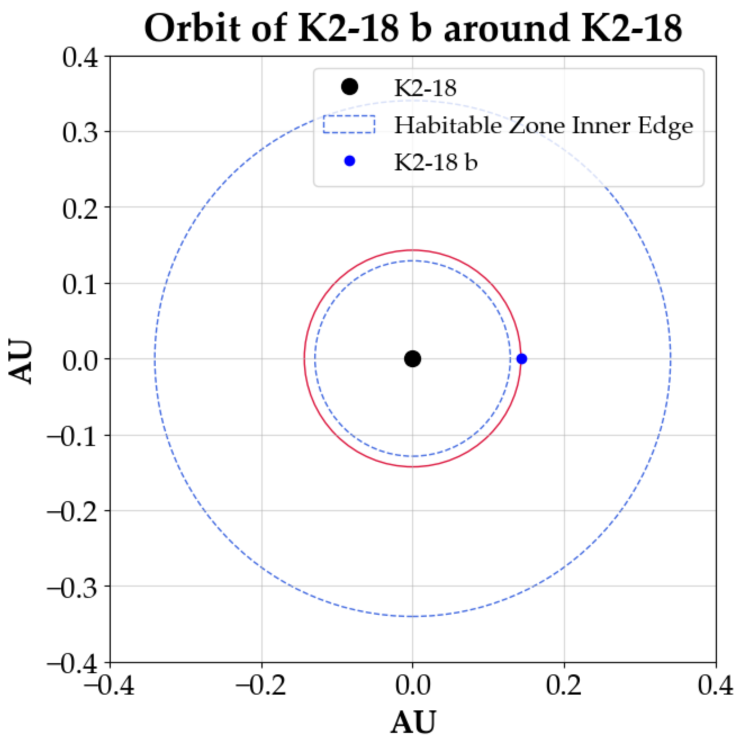

Figure 6: K2-18b orbits its host star, K2-18, within the optimized habitable zone (HZ). This super-Earth planet, with an Earth Similarity Index (ESI) of approximately 0.8, has shown evidence of potential biological signatures based on chemical composition analysis, as announced this month, April-2025!

10 References

1. NASA Exoplanet Archive
2. Kopparapu, R. K., et al. (2014). *Habitable Zones Around Main-sequence Stars.*
3. Cardenas, R., & Hearnsaw, J. (2013). *Planetary Habitability Modeling.*
4. Planetary Characterization 2024 Conference Paper.
5. Metal-rich Stars and Planet Habitability – Max Planck Institute.
6. Foundations of Astrophysics – Cambridge University Press.