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Project Proposal: Impacts of Stellar Binarity on Planetary Evolution

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1. INTRODUCTION

1.1. *Scientific Motivation*

As the number of known exoplanets increases, increasingly sophisticated analyses of exoplanet samples become possible. Nearly half of all solar-type stars detected to date have at least one companion (Raghavan et al. 2010). Although Earth-like planets are yet to be discovered in the habitable zone(HZ) of binary star systems, studies have shown that Earth-sized planets can form around a star of a binary system, and even have stable orbits in the star's HZ (Kaltenegger & Haghighipour 2013). In the past two decades, discoveries of exoplanets in close binary systems (i.e. binaries with stellar separations smaller than 50 AU) brought strong evidence to the fact that planetary formation around a star of a binary system is robust. Particularly, S-type binaries can host various planets including small, terrestrial-class objects (Kaltenegger & Haghighipour 2013).

Previous studies have agreed that the diversity of stars does not rule out their habitability (Winn & Fabrycky 2014). While binary systems certainly have a habitable zone where liquid water could exist on the planet's surface, life may struggle to find a foothold. Planets orbiting both stars are occasionally pushed out of the region. Due to the strong gravitational perturbation caused by the second star, the study of planetary orbits in binary star systems requires special attention. An important requirement for habitability in binary systems is of course the dynamical stability of HZ, which may increase the eccentricity of the planet. This may also affect the insolation of the Hertz planets, where perturbation depends on the distance and eccentricity of the substar.

Studies have also shown that for the wide binary hosts with separation greater than 100 AU, the planet occurrence rate was similar to that of the single stars. The statistically indistinguishable occurrence rate of planets hosts among single, binary, and multiple systems suggest that planets are as likely to form around single stars, as they are around components of binary or multiple systems with sufficiently wide separations. For closer binary systems, the planet occurrence rate differed from the wide binaries at a 94% confidence level and from the single stars at a confidence level of 99%. Figure 1 (Hirsch et al. 2020) shows the posterior distributions of the occurrence in the single, binary, close binary, and wide binary sub-samples.

In this project, we aim to analyze the stellar binarity on planetary evolution. The methods developed in this study have a great potential for doing statistical studies of planet detectability, and also for investigating the effect of stellar multiplicity on habitability of exoplanets.

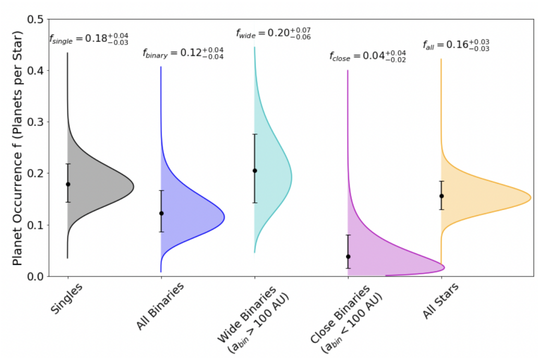

Figure 1. Normalized posterior distributions for the planet occurrence rates (number of planets per star) in different sub-samples. These PDFs are based on the likelihood function and include a Jeffreys prior on occurrence. (Figure 12 of (Hirsch et al. 2020))

1.2. *Project Data*

ML methods require data on which to learn, train and test. The full data set of known exoplanets to be used in this project is downloaded from the NASA Exoplanet Archive (Akeson et al. 2013) using the Application Programming Interface (API). NASA Exoplanet Archive is a database and toolset funded by NASA to support astronomers in the exoplanet community. The current content of the database includes interactive tables containing properties of all published exoplanets, Kepler planet candidates, threshold-crossing events, data validation reports and target stellar parameters, light curves from the Kepler and CoRoT missions and from several ground-based surveys, and spectra and radial velocity measurements from the literature (Akeson et al. 2013).

Additional photometry from the Gaia DR3 survey (van Leeuwen et al. 2022) may also be used in later analysis.

1.3. *Machine Learning*

Machine learning(ML) and deep learning techniques have proven to have a wide range of applications in various scientific research fields (Malik et al. 2022). Searching and identifying potential habitable exoplanet would rely on a least-squares approach applied to a set of stars in a dataset, which are prioritized by a ML classification method. Currently, due to the inherent variability of host stars, any method of detecting exoplanets is prone to confusion. Detection of exoplanets using accurate radial velocity (RV) observations is limited by pseudo-radial velocity signals introduced by stellar activity (Korhonen et al. 2015). In this work, we aim to delevope machine learning algorithms such as regression analysis to efficiently remove active noise and signals from RV observations.

2. TIMELINE

The project is scheduled to be completed within a year, and may extend into the summer if further analysis is required or a paper on the data is being written. The research will include reviewing the literature, exploring the data, developing the code and algorithms, and applying the code for analysis. The first few weeks of project time were spent reading general literature on exoplanet and binary systems, as well as exploring data and tools to be used in further analysis.

2.1. *October - early November*

During this time, literature will be reviewed in order to gain a better understanding of previous research conducted on habitability of planets in binary systems, as the developments of telescopes and tools for current data. Next, the data planned to be explored in this project would be analyzed through exploratory data analysis for machine learning. Relevant coding tools and packages would be studied to better understand the functions and strategies. In addition, some initial improvements will be attempted such as reproducing some plots in literature.

2.2. *November - December*

During this period, discussions with supervisor would continue to update progress on literature review and general concerns about future steps. By the end of November, the ML model code would initially be developed to identify exoplanets in the dataset. The code will be tested with existing observations and compared with current results to confirm that it is functioning properly.

2.3. *Late December - February*

As the ML algorithm code is developed, it will be used to identify exoplanets in binary star systems and determine their features such as radial velocity, eccentricity, metallicity, chemical composition and color classification. A comparative analysis will be made between single star system and double star system.

Similar analyses will be performed on stellar systems with more than two stars to investigate interesting features and implications for the habitability of planets in these systems.

2.4. *February - April*

If the analysis of all the target exoplanets and binary systems is not complete, then I will continue the analysis during this time. If it is completed, then after reviewing the findings, I will write a final report on the results and methods I used to obtain them during the semester.

This report is aimed to be turned into a paper, in which case it will take more time to finish. If necessary, the summer 2023 will be used to continue the creation of the paper and any revisions or final analysis that need to be made.

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