IN SEARCH FOR POTENTIAL SURFACE OCEAN PROXIES AMONG EXOPLANETARY PARAMETERS.

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Introduction: Surface habitability on exoplanets is a major question in extrasolar research. Oceans in general, and the interaction between landmasses and water were crucial driving forces during the biological evolution on Earth. Before the recent successful exploration of the first exoplanets with high water content around Kepler-138 [1], ocean planets have been searched in various ways, such as studying the early conditions of star systems [2], and the planet surface-sea interaction and ocean dynamics on those planets [3]. Here, some of the potential influencing factors of the ocean forming on exoplanets are summarized. Such an overview is based on the putative connection between planetary characteristics, revealed by mathematical statistical analysis.

Data and Methods: The research was executed in the following steps:

Step 1. In order to examine all the available exoplanets, NASA's Exoplanet Archive was accessed [4]. The database consists of 5187 confirmed exoplanets, some of them in the same star system. During the first approach, unfiltered data was used. Secondly, the database was filtered to the planets found in the habitable zone (see below) (230 planets).

Step 2. Calculation of the habitable zone (HZ) [5]:

Step 3. Searching for trends in the unfiltered and filtered data with heatmaps created a in Python environment (**Figs. 1a** and **b**).

Step 4. The review of the connection between planetary characteristics to assess their influence on the possibility of a liquid water ocean on an exoplanet's surface.

There are multiple "strong" correlations can be found (Results/Discussion), with a value of r>0.6.

Results/Discussion:

The filtered database analysis (containing only the planets found in the habitable zone) indicated the following (**Fig. 1b**). The connection (Pearson correlation coefficient, *r* is calculated for all the cases) between the planetary characteristics (planetary radius, planetary mass) and the semi-major axis (0.67 and 0.33) in the habitable zone is quite peculiar since it is not similar to the Solar System.

Planetary radius. There is a strong correlation (0.67) between the planetary radius and planetary semi-major axis in the habitable zones (**Fig. 1b**), but there is no significant correlation (0.07) in the case of unfiltered data (**Fig. 1a**). The negligible correlation can be explained by the high variety of systems and in the exoplanet population. In any case, our current understanding of planetary formation generally tends to support this correlation.

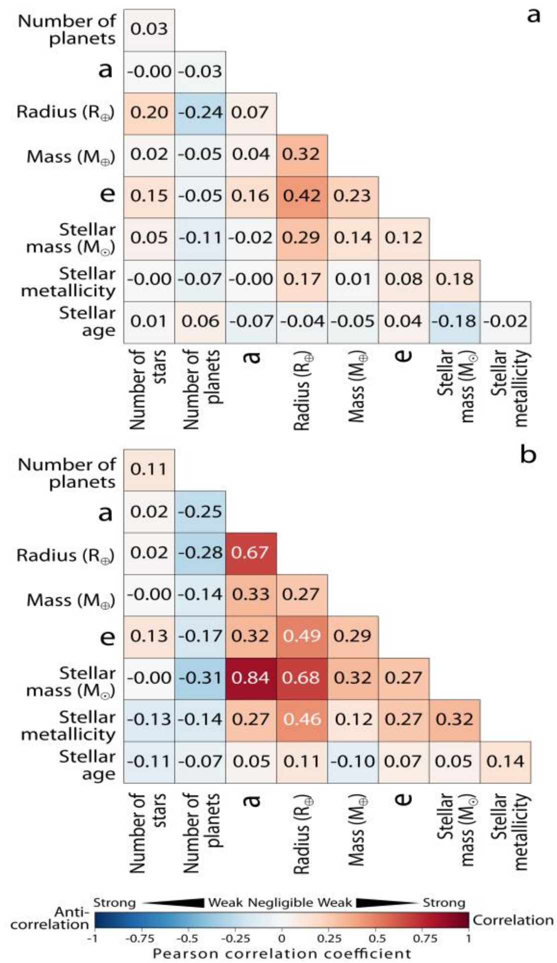

Figure 1. *The correlation heatmap of ocean-forming factors, with confirmed exoplanets (5186) (**a**); and with the planets in the habitable zone by the calculation (230). (**b**) Abbreviations: a – semi-major axis (AU); e – orbital eccentricity*

The correlation (0.46) between stellar metallicity and planetary radius can be explained as follows: during planet formation, in older star systems with lower metallicities, it is much harder for a protoplanet to accumulate enough material to reach sufficient mass for a Jupiter-like gas giant or even the mass of a super-Earth [6], [7]. Earlier studies also showed that there is a correlation between higher stellar metallicities and planet appearance frequency [8], but in our case, no significant correlation was found.

The strongest anticorrelation can be found between the planetary radius and the number of planets in the system (-0.28; and -0.24, at the unfiltered data). It is known that exoplanets with larger radii are generally easier to find with the transit detection method, this anticorrelation is unexpected. Whether this anticorrelation is due to orbital, formation, or observational bias effects, is yet to be answered.

Most likely the correlation between the stellar mass and planetary radius (0.68) is the byproduct of the transit detection method [9], since around more luminous stars, it is easier to detect planets with larger radii because a transit of small planets causes only a minor fluctuation in its star brightness.

Semi-major axis. There is a moderate association (0.33) between the planetary mass and planetary semi-major axis in the habitable zones (**Fig. 1b**), but no association was recognized using the unfiltered data (see above; **Fig. 1a**).

Many extrasolar planets with relatively short orbital periods tend to have low eccentricities [10], and a moderate correlation (0.32 in the case of planets in the HZ, Fig. 1b) in the database also assures this. This is because of their proximity to their parent star, which causes tidal circularization on large timescales [11].

The strongest correlation on the matrices can be found between the stellar mass - planetary semi-major axis pair (0.84). This is an expected correlation originating from the definition of the habitable zone: since main-sequence stars with greater mass have a much larger luminosity ($L \propto M^3$), therefore the zone where a planet can orbit without being too hot, extends further away from the star, with a greater semi-major axis and vice versa.

The number of planets in the system. The inverse correlation between the stellar mass and the number of planets in the star system (-0.31) seems to support earlier studies [12]. Firstly, the more massive O, B, and A-type stars have short lifetimes, and their HZ's edges advance outwards much more quickly than the HZ of the lower-main sequence stars, therefore it is hard to determine a stable environment around them. Also, their extreme solar wind is thought to be counter-effective for planet formation [13], since their protoplanetary disc evaporates more quickly.

Conclusion: In this study, we focused on the statistical data of the confirmed exoplanets and their star systems. The two heatmaps help to visualize the connection and moderate/strong correlation between various planetary and star system characteristics. The found correlations (e.g., 0.67 between the planetary radius and planetary semi-major axis in the habitable zones) could be used in later studies as a baseline, to assess the occurrence of global oceans. The associations suggest that the mentioned parameters can be possibly also used as proxies, to fine-tune the detection methods for star systems that are more likely to host terrestrial planets with a global ocean.

References:

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