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A4_3 Exoplanets, Life and Beyond

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Abstract

In 1964, Kardashev proposed a system classifying planets on their technological advancement through the use of energy on Earth. In this paper, by using the same methodology and exoplanet data, we attempt to create a more accurate and less anthropocentric system by suggesting a new threshold for a type-I civilisation. We employed data from 571 exoplanets and 661 stars to ascertain a new value of 1.12×10^{23} W for a type-1 civilisation. In doing this, we have formed an overgeneralised system that is overtaken in bias' towards common inhabitable planets such as "Hot Jupiters" and thereby anomalising Earth.

Introduction

The Kardashev scale is used by physicists and philosophers to quantify the development of alien civilisations and explore the evolution of Earth-based technology. This scale allows physicists to interpret astronomical anomalies such as the unusual light fluctuations of Tabby's Star [1]. Kardashev's scale involves three levels based on the energy available to the Earth from the Sun. This makes the model anthropocentric and as such is not an accurate representation of other systems due to the variability in physical properties. In this study, we utilize Kardashev's method to propose a new value for a type-I civilisation that expands the model to include exoplanets. Kardashev proposed that a civilisation must be able to harness all of the energy that falls on a planet in order to achieve type-I status. Using the Earth as his basis, this was calculated to be 1.74×10^{17} W [2]. Yet, because of its Earth-centricity, it is not fit to use this model as each system is different. This work attempts to generalise the classifications so that the model is less anthropocentric and more available to future studies.

Method

Information on 3791 exoplanets and 661 host stars was taken from the open exoplanet catalogue [3]. The catalogue lists confirmed and unconfirmed exoplanets, stars and systems detected by exoplanet surveys across the world such as TRAPPIST and WASP. In this paper, we used only the data on the confirmed stars and exoplanets. Many had to be ignored as the parameters needed for calculations were not known. This meant that 571 out of 3791 exoplanets in total were used. In his proposition, Kardashev used the power falling on the Earth from the Sun to define type-I status. We will use this method, however we will calculate the power falling on all known exoplanets by their host star and average across this array. This will give a generalised overview of what energy is needed for a type-I status. To do this, we assumed that host stars are isotropic radiators and used equation (1) to calculate the total power output of each star.

$$P_s = A_s T^4 \sigma \epsilon \quad (1)$$

P_s = power output of a star (W), A_s = surface area of star (m^2), T = temperature of star (K), σ = Stefan-Boltzmann constant (W m K^{-4}) and ϵ = emissivity of a blackbody

Then with P_s, we used equation (2) to calculate the amount of power that falls on the planet from the host star and average across the array of exoplanets. This equation was used as a planet absorbs roughly the same amount of light from its star as a flat circle of area πr^2.

$$P_p = \frac{P_s}{4}\left(\frac{R_p}{a}\right)^2 \quad (2)$$

P_p = power incident on the planet (W), R_p = radius of planet (m) and a = distance between star and exoplanet (m) [4].

Error Analysis

Due to the large data set, we used the mean absolute error (MAE) to calculate the uncertainty in the final value. Approximately half of the data points did not have errors and those that did, had a very small error. In the final value these errors would not have a significant impact, therefore we only used the MAE.

$$MAE = \frac{1}{n}\sum |x - x_i| \quad (3)$$

x = average value, x_i = individual value and n = number of data points

Results

We discovered that the average amount of energy falling on all known exoplanets is $1.12 \times 10^{23} \pm 1.667 \times 10^{20}$ W, as calculated using equation (1) and (2). This means that a planet must receive and harness at least this much from its host star to achieve type-I status. A civilisation could do this through large-scale solar technology such as a heliostat power plant; in which a tower collects sunrays reflected from mirrors to power turbines by condensing liquid [5].

Discussion

The amount of power falling on Earth from the Sun is 1.74×10^{17} W. This is much smaller than the average amount of power falling on a exoplanet from its host star. In straying away from an anthropocentric model, we have anomalised Earth and formed a system that has bias towards more common exoplanets such as "Hot Jupiters". This means that the Earth and planets like the Earth would never be able to achieve type-I status. However any civilization capable of extracting all power available to it from its star would have similar technological prowess. The value we have calculated is much larger due to the prevalence of "Hot Jupiters" in the exoplanet catalogue. This creates a bias away from Earth-like planets which could be argued as counterproductive as the only known habitable planet is Earth. The error analysis does not take this fact into account and only shows the variability in the values when averaging. The error analysis does show there is little variability which could presume a large amount of "Hot Jupiters".

Conclusion

To conclude, we have attempted to define a new classification system that quantifies the technological developments of all known planets rather than just the Earth as Kardashev did in 1964. We calculated that to achieve type-I status a planet must harness $1.12 \times 10^{23} \pm 1.667 \times 10^{20}$ W from its host star. However, as argued in the discussion this model has a bias away from more habitable planets that the error analysis does not take into account. We propose that a better method would be to only study exoplanets in the Goldilocks's zone of stars and consider other sources of energy such as geothermal.

References

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