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Exploring the Habitable Zone for Kepler planetary candidates

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Abstract

This paper outlines a simple approach to evaluate habitability of terrestrial planets by assuming different types of planetary atmospheres and using corresponding model calculations. Our approach can be applied for current and future candidates provided by the Kepler mission and other searches. The resulting uncertainties and changes in the number of planetary candidates in the HZ for the Kepler February 2011 data release are discussed. To first order the HZ depends on the effective stellar flux distribution in wavelength and time, the planet albedo, and greenhouse gas effects. We provide a simple set of parameters which can be used for evaluating current and future planet candidates from transit searches.

1. Introduction

The NASA Kepler mission recently announced 1235 planetary candidates [1]. We use atmospheric models to explore the potential for habitability of Kepler planetary candidates. We focus on the circumstellar HZ, that was defined by Kasting et al. [3] as an annulus around a star where a planet with an atmosphere and a sufficiently large water content like Earth can host liquid water permanently on a solid surface. This definition of the HZ implies surface habitability because it is defined to allow remote detectability of life as we know it. Kepler planetary candidates with radii below 2 Earth's radii are consistent with models of potentially rocky planets.

The three main points of this paper [2] are: (1) to provide a simple approximation eq.(1) for habitability of Earth-like planets from the data provided by transit surveys like Kepler (using maximum albedo values from atmospheric models Fig.1) to assess their potential as a habitat, (2) to demonstrate that one needs to consider the individual stellar parameters to determine the limits of the HZ, and (3) to explore the change in the sample located in the HZ due to individual factors in eq.(1) and associated errors [2].

2. Summary and Conclusions

To simply estimate if a planet is potentially habitable ($175K < T_{eq} < 270K$), one can use eq.(1) to approximate T_{eq} for Earth-like planets around different stars using albedo from Fig.1. *r* is radius, *T* temperature, *A* the Bond albedo and *e* eccentricity [4] of the planet, *D* the planet's semi major axis, and *β* represents the fraction of the planetary surface that reradiates the absorbed flux. Note that for a rapid rotating planet β should be set to one (see [2]).

$$T_{eq\_pl} = T_{star}\left((1-A)\, r_{star}^{2} / (4\, \beta\, D^{2}(1-e^{2})^{1/2}) \right)^{1/4} \quad (1)$$

Assuming circular orbits and 50% cloud coverage in accordance to the "Venus water loss limit" leads to 27 Kepler planetary candidates with $175K < T_{eq} < 270K$. Among those are 3 planetary candidates that have radii smaller than 2 Earth radii.

Fig. 2 show the temperature as well as the extent of the HZ for the Kepler planetary candidates that could potentially be habitable. Many of the 54 planetary candidates announced in the Kepler sample in the HZ, based on simple calculations, are - with a more detailed study, outside the HZ of their host stars, because Teq is above 270K (see Table 1 [2]).

Applying our analysis to the whole Kepler planetary sample of 1235 transiting planetary candidates, assuming the maximum Earth-like Bond albedo for rocky planet atmospheres (see Fig.1), results in 12, 27, 67 planetary candidates with T_{eq} smaller than the water loss limit (T_{surf} = 373K) for 0%, 50% and 100% clouds respectively. Among those are 2, 3, 6 planets respectively, that have radii below 2 Earth radii consistent with rocky planets (KOI1026.01, 854.01, 701.03, 268.01, 326.01, 70.03) [2].

The potentially rocky planet candidates in multiple systems in the Kepler February 2011 data release, KOI701.3 and KOI70.3 are extremely interesting objects because their mass could be determined using transit time variations to calculate a mean density and potentially confirm high density and rocky characteristics (Table 1 [2]). Assuming errors will reduce T_{eq} (see Discussion) KOI314.02, 899.03, 446.02, 518.02, and 70.03 are also part of that sample.

Fig.1 shows the maximum albedo at the inner edge of the HZ (left) and the inner edge of the HZ for water loss (solid lines) and onset greenhouse (dashed lines) for 0%, 50% and 100% cloud coverage for main sequence stars from 3700K to 7200K. Using the maximum and minimum albedo values at the inner and outer edge of the HZ respectively and eq.(1), one can calculate a minimum T_{eq} for a planetary candidate to assess habitability [2].

Fig. 2 shows the limits of the HZ for 0%, 50% and 100% cloud coverage for all Kepler candidates that could be rocky and potentially be habitable. Note that the HZ is only defined for rocky planets, the focus of our search for habitable conditions. Fig. 2 also shows that the individual stellar parameters need to be taken into account to determine the limits of the Habitable Zone. For several Kepler planetary candidates the nominal (line) and individual (crosses) stellar limits of the HZ differ (solid lines for 0%, 50% and dashed line for 100% cloud coverage) [2].

The location of the Kepler planets is consistent with our expectations to find hot small planets first and cooler ones when further Kepler data and thus planets in larger orbits, are available.

2.1 Discussion

The biggest change in T_{eq_pl} results from the change of albedo of the planets depending on the cloud coverage (see Fig.1) what maintains 12 and 2 potentially rocky planets for a clear atmospheres and 67 and 4 potentially rocky planetary candidates for 100% cloud coverage respectively. Note that even if these small planetary candidates can be confirmed to have a mean density consistent with a rocky composition, many aspects can prevent a planet in the HZ from being habitable, e.g. limited amount of water or other ingredients essential for life. Therefore the atmosphere of planets has to be characterized to explore if the planet is a potential habitat or shows signs of life.

Due to the large average distance of 500-1000pc to its target stars, Kepler's results can only provide statistics of the amount of planets per star. That, as well as the increasing number of small potentially rocky planets shown by the new Kepler results, strengthens the scientific case for a mission to find and characterize such small planets orbiting stars close to our Sun.

3. Figures

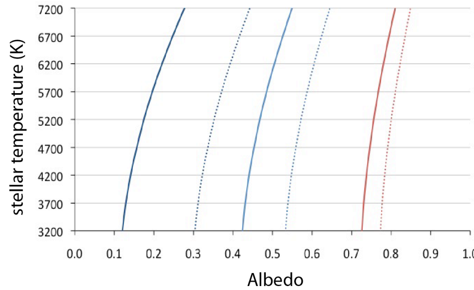

Fig. 1: Maximum albedo at inner edge of the HZ [2].

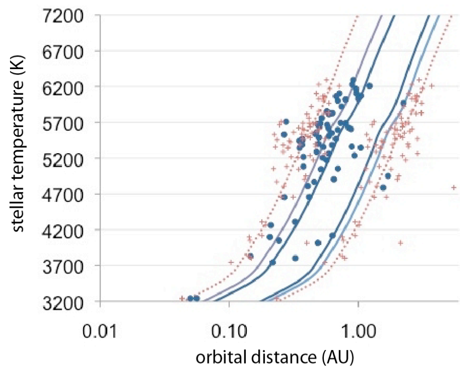

Fig. 2: Extent of the HZ for (left) water loss limit for 0% and 50% cloud coverage (inner limits) and 100% cloud coverage (outer limit dashed line). Individual HZ limits are indicated with crosses [2].

References

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