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Dynamical limitations on the habitability of planets in binary star systems

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Abstract

Wide binary star systems with circumstellar exoplanets are generally believed to be conducive to habitable planets. We demonstrate that in the presence of a giant planet secular perturbations can affect the habitable zone (HZ) for a wide range of system parameters. Such perturbations lead to enhanced eccentricities of terrestrial planets and are detrimental to sustain habitable conditions on the planet. We develop a diagnostic tool based on analytical models that allows an easy identification of observed binary systems lacking habitable conditions from a dynamical point of view.

1. Introduction

Extrasolar planets have been detected in a great diversity of configurations. Especially, exoplanets are also present in binary and multiple star systems. The "Catalogue of Exoplanets in Binary Star Systems[1]" currently lists 125 planets in 88 different binary systems.

The habitability of a terrestrial planet is sensitive to its orbital eccentricity [7]. An increased eccentricity leads to strong variations in the insolation onto the planet, and thus to temperature fluctuations with large amplitudes. Secular perturbations from massive perturbers act to increase the planet's eccentricity. It has been shown that even wide binaries with stellar separations > 1000 au can cause an increase in planetary eccentricities which can lead to ejections [3].

Here, we focus on binary systems with circumstellar planets. We assume that there is a terrestrial planet in the HZ of the host star and a giant planet exterior to it, with a distant companion star (secondary) as a perturber. For such a configuration there always exist specific combinations of the secondary's orbital parameters that lead to enhanced perturbations in the HZ. The aim of our study is to identify these parameter combinations (depending on e.g. stellar masses, separation, eccentricity) for a wide variety of systems.

[1] http://www.univie.ac.at/adg/schwarz/multiple.html

2. Methods

The orbital precession frequencies of the planets are the key point in the dynamical description of the system. There already exists a semi-analytical method to determine these frequencies, see [6] and [2]. We extend this method and are now able to describe the dynamics by two coupled analytical models: the Andrade-Ines & Eggl [1] model and the Laplace-Lagrange model [5].

Since there is a multi-dimensional parameter space to cover, we focus on cases that are most relevant for habitable terrestrial planets. We vary the masses of both the host and secondary star; the choice of the host star's mass sets the location of the HZ [4]. We also take the secondary star's orbital distance and eccentricity as free parameters, which are generally poorly constrained from observations for wide binaries. Then, for a range of giant planet masses and distances, we can determine whether a secular perturbation would affect the HZ.

3. Results

The figure shows an example of a binary star system that consists of a G-type host star and an M-type secondary. The grey-shaded areas indicate combinations of the secondary star's orbital eccentricity and distance (as a function of the giant planet's fixed distance) for which the secular perturbation affects some part of the HZ. In such a case, a terrestrial planet in that part of the HZ would have an orbital precession frequency that corresponds to the one of the giant planet. The resonance between these two frequencies creates large scale variations of the terrestrial planet's orbital eccentricity, and hence limits its residence time inside the HZ.

As the figure demonstrates, even relatively far away secondary stars might push a terrestrial planet in the HZ to become eccentric. Depending on the actual orbital distance of the giant planet there always exist combinations of secondary star parameters that lead

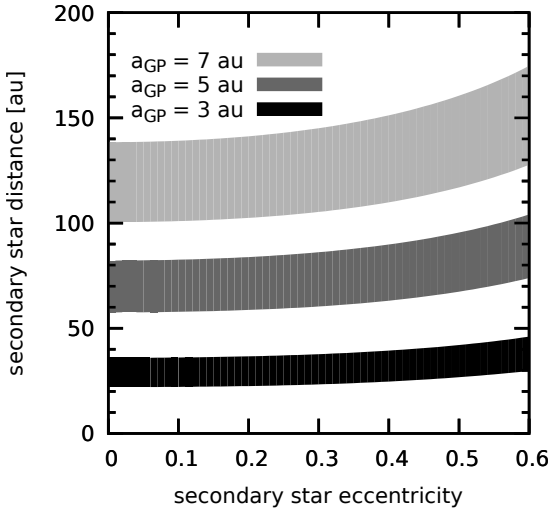

Figure 1: In a binary star system with a giant planet at different distances (see legend) a secular pertubation affects the habitable zone when the orbital parameters of the secondary star fall into the grey shaded areas.

to this kind of perturbations. For more distance giant planets the "zone of perturbations" becomes more extended than for close-in giants.

Apart from this one example, there are countless other configurations that could be realized. We are working to establish a catalogue that includes template systems, that can be used for a quick assessment of observed binary stars in the light of the findings above.

4. Conclusions

- In wide binary star systems with a giant planet, secular perturbations can affect the habitable zone for a wide range of orbital parameters of the secondary star.

- Due to the secular perturbation a terrestrial planet in the HZ would become more eccentric, which in turn increases the insolation onto the planet.

- Habitability over extended periods of times requires a limited variation in insolation, hence strong fluctuations in the eccentricity can severely limit the effective habitability of a planet.

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