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Dynamical perturbations of Earth-type planets in binary star systems

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Abstract

In this study, we investigate gravitational perturbations (i.e. mean motion resonances MMR and secular resonances SR) on an Earth-type planet moving in the habitable zone which are caused by a Jupiter-Saturn pair and a distant secondary star. While MMRs can be easily determined via a simple formula SRs need a more sophisticated technique for their determination. However, in a binary system the location of such a perturbation can be determined in a simpler way, namely with the aid of a semi-analytical method which has been developed recently [1], [2]. As an example we show the results for a "G-M" binary star system (i.e. a G-type host-star and an M-type secondary star) for which we consider a stellar distance of 50 au and study different locations of the Jupiter-Saturn pair.

1. Introduction

After two decades of exo-planetary research our Earth is still the only habitable planet we know, which leads to the question whether solar system-like configuration need to be discovered to find an exo-Earth. In addition, many stars in the solar neighborhood form binary or multiple star systems which motivated us to study the gravitational perturbations in the circumstellar habitable zone (HZ) of a "G-M" binary star system where the G-type star hosts three planets: a Jupiter-Saturn pair and a terrestrial planet in the habitable zone, and the M-type star is the perturbing secondary. Considering a stellar separation of 50 au, one can calculate the locations of gravitational perturbations in the area of the terrestrial planet. Depending on the location of the gas planets Jupiter and Saturn we have determined the positions for the arising SRs between ~0.3 and 1.9 au, where some SRs can be found inside the HZ. In case the positions of the SR and the terrestrial planet are equal, the SR might cause an increase in the orbital eccentricity of the terrestrial planet. As a consequence the conditions for habitability will change for this planet so that stronger variations in the insolation arise (as discussed in [3])

2. Semi-analytical method

With the aid of the well-known Laplace-Lagrange secular perturbation theory (see e.g. [4]) one can derive an analytical solution for the proper frequencies of test-planets moving in a certain area – in our case between 0.1 and 2 au. To apply this theory we have to consider nearly zero eccentricities and inclinations for these orbits.

For the giant planets we compute the orbital motion and use a frequency analysis [5] to determine their proper frequencies. In case a frequency of a giant planet equals that of a test-planet an SR occurs.

3. Results

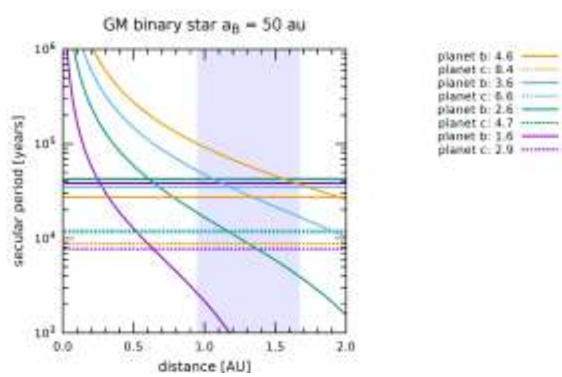

Figure 1: Location of the SR for different Jupiter (= planet b) - Saturn (= planet c) configurations. The blue vertical band marks the HZ.

The application of the semi-analytical method to various Jupiter-Saturn configurations in a binary star system with stellar separation of 50 au is shown in

Figure 1. In this figure, Jupiter is labeled as planet b (full lines) and Saturn as planet c (dashed lines). All Jupiter-Saturn configurations are in 5:2 MMR like in the solar system but closer to the G-type host-star as indicated in the legend to the right of the figure. We moved the two planets towards the host-star due to stability reasons caused by the perturbing secondary star.

The locations of the SRs are defined by crossings of a horizontal line (which define the proper period of the giant planets) with a curve (i.e. proper period of test-planets) of the same color. This result shows that only two planets cause SRs in the HZ. Which is the case if Jupiter’s semi-major axis is 3.6 au and if Saturn’s semi-major axis is 4.7 au. In all other cases the SRs are outside the HZ.

A more detailed study (of various masses and semi-major axes of the secondary star) is in progress and will be published soon.

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