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Water transport to the habitable zone and impact probabilities in the early phases of planetary systems in binary star systems

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Abstract

By now, observations of exoplanets have found more than 50 binary star systems hosting 71 planets. We expect these numbers to increase as more than 70% of the main sequence stars in the solar neighbourhood are members of binary or multiple systems. The planetary motion in binary star systems depends strongly on both the parameters of the stellar system (stellar separation and eccentricity) and the architecture of the planetary system (number of planets and their orbital behaviour). In case a terrestrial planet moves in the so-called habitable zone (HZ) of its host star, the habitability of such a planet depend on many parameters. A crucial factor is certainly the amount of water.
We present here a statistical study to assess the water transport of icy bodies to the habitable zone for various binary system characteristics (binary separation, eccentricity and stellar star type of the secondary). We aim to highlight the most efficient systems for the migration of asteroids located beyond the snow-line to the habitable zone and therefore, the water delivery into planets.

1. Introduction

Since the discovery of the first planet orbiting a sun-like star in 1995, the number of exoplanets found as exponentially increased. Up to now, more than one thousand planets are listed, not to mention the almost three thousands candidates from Kepler observations. Most of them orbits around single star, but some planets or planetary systems orbit also around multiple systems. Because the techniques used (like radial velocity, transit, direct imaging, etc ...) are not powerful enought to detect huge number of Earth-like (or with lower mass) planets, most of the exoplanets known are giant and orbit generally closed to their host star. But, it is a certainty that more habitable Earth-like planets will be found in the next decades with the improvement of current observational techniques which will allow to observe further – most of the planets found lie is the Solar neighborhood – and with better resolutions. There, almost 70% of the known systems are composed of multiple stars. So the question of habitability in such systems, mainly in binaries, has already been studied in Eggl et al. [2013] for known systems and they conclude that both stars can harbor habitable planets in their respective HZ.
Water is the main ingredient defining an habitable planet. First simulations of planetary formation in such systems show the stochastic behaviour of the architecture of the planetary system formed [Haghighipour and Raymond, 2007]. Therefore, among this diversity of planets formed, the main question we would like to answer in our study is if a dry or almost dry planet can be fed with water by a bombardement of wet small bodies in such binary systems. What would be the influence of the secondary star on the efficiency of the flux of small bodies and the transport of water in habitable zone, and on the bombardement duration?

2. Numerical simulations and results

Our study is focused on a primary G-type star with mass M = 1 $M_\odot$ and we investigate the dynamical effect of a secondary G, K and M-type. The mass for the K-type is set to 0.7 $M_\odot$ and the M-type to 0.4 $M_\odot$. We did not consider larger masses as we only study S-type motion around the primary star. The binary separation goes from tight to large as we explore the semi-major axis companion from 25 AU to 100 AU. The secondary will be on an ellipical-plan orbit with eccentricity e_b= 0.1 - 0.3 - 0.5. We consider a Jupiter-like planet at a_J = 5.2 AU in a circular orbit and with mass equal to $1M_J$. As we assume that Jupiter and the planets are formed, we do not take into account the effect of gas drag. A

debris disk is modelised as a ring of 100 asteroids with maximum mass m equal to Ceres mass[1] and the total mass of the ring is $M_R = 5\times10^{-3}$ $M_\oplus$. As we focus on the transport of icy bodies, the minimum semi-major is set to the position of the snow-line. Finally, an Earth-like planet on a circular plan orbit is randomly place in the HZ in order to simulate the gravitational influence of the Earth onto incoming asteroid in the HZ.
We numerically integrated the system for 10 Myr, considering only gravitational perturbation. To make this study statistical, the debris disk is cloned 100 times. Thus, the statistics will be made with 10000 asteroids. As no impacts with the planet in the HZ can be detected (at least with a very low probability), we assumed that an asteroid entering the HZ for the first time, will hit a planet. Therefore, the total water mass fraction of this asteroid will be delivered to the planet. This water mass fraction takes into account the water mass loss due to ice sublimation throughout the integration. As a result, up to 60 oceans can be transported to the HZ in some systems. The small number of oceans for some systems does not mean that only few of oceans would be transported. It highlights the fact that the delivery process would require longer time to drastically increase the number of oceans, as many asteroids are still present in the system after 10Myr of integration. Besides, the binary companion will have a strong effect on the time duration of this bombardement.

3. Summary and Conclusions

We present here a statiscal study to highlight the most efficient binary systems for the water transport and delivery to habitable zone. This study is supposed to follow the planetary formation process and to simulate a late havy bombardment in binary star systems. This work will also present some outputs for the impact probabilities assessment in the HZ, but also a comparison with single star systems.

[1]Ceres mass is equal to $4.73\times10^{-10} M_\odot$

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