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Asteroid flux and water transport towards circumprimary habitable zones in binary star systems

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Abstract

Dynamical simulations show that the outcome of planetary formation process can lead to various planetary architectures (i.e. location, size, mass and water content) when the star system is single or double. In the late phase of planetary formation, when embryo-sized objects dominate the inner region of the system, asteroids are also present and can provide additional material for objects inside the habitable zone (HZ). In this study, we make a comparison of several binary star systems' characteristics and their efficiency to move icy asteroids from beyond the snow-line into orbits crossing the HZ. In our results, we highlight the key role of secular and mean motion resonances, causing an efficient flux of asteroids to the HZ on a short timescale. This in turn leads to asteroids bearing a non negligeable amount of water towards the HZ and available for any planets or embryos moving in this area. We also discuss how mass loss mechanisms can alter the water content on asteroids' surface.

Introduction

Up to now, almost two thousands exoplanets are listed, not to mention the almost three thousands candidates from Kepler observations. Most of them orbit single stars, but some planets or planetary systems were found in multiple star ystems. In our solar neighbourhood, almost 70% of the known systems are composed of multiple stars. The question of habitability in binaries, by taking into account the combined radiation and dynamical effects for the determination of the HZ borders, has already been studied in [1] for known systems and they conclude that both stars could harbor potential habitable planets in their respective HZ.
Previous studies [2] of planetary formation from embryo-sized objects in such systems show the stochastic behaviour of the simulations on the architecture of the planetary system formed. Planets can form in the HZ but they can be dry or almost dry. However, smaller objects are also present in the feeding area, providing additional material. The main question we tackle in this study is the efficiency of a secondary star to move icy asteroids from beyond the snow-line into orbits crossing the HZ. Considering various binary star characteristics, how much water can be transported into the habitable zone and on which timescale? If mass loss processes on asteroids'surface are accounted for, how much water can really end on any planets or embryos moving in the HZ?

Numerical simulations

Our study is focused on a primary G-type star with mass $M_\star = 1\ M_\odot$ and we investigate the dynamical effect of a secondary of either F, G, K and M-type, on an asteroid belt. The studied binary star systems encompass relatively tight configurations, i.e. semi-major axes in a range of $a_b \in [25{:}100]$ au. This parameter has been changed in steps of 25 au in our simulations. The secondary is on an elliptical coplanar orbit with eccentricities $e_b \in [0.1{:}0.5]$ increased in steps of 0.2. We modeled a belt of 10000 asteroids (remnants from the late phase of planetary formation process) beyond the snow line. The planetesimals are placed randomly around the primary star and move under the gravitational influence of the two stars and a gas giant placed at 5.2 au with a mass equal to Jupiter's mass.
Contrary to a single star system, the presence of a secondary star causes secular perturbations which position, for a given giant planet location, is strongly related to the binary system's characteristics. Figure 1 shows the maximum eccentricity of test particles initially on a circular coplanar orbit and placed below the orbit of the gas giant planet (•). Several scenarios are studied but only results for a_b = 50 and 100 au

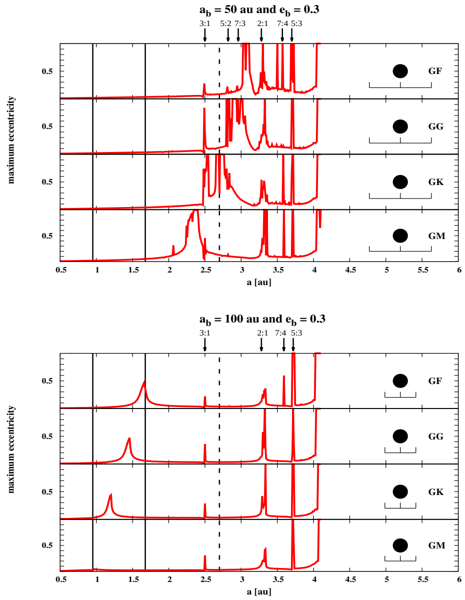

Figure 1: Maximum eccentricity of test particles initially placed on a circular-plan orbit, below the giant planet (•) at 5.2 au. In both cases, the secondary is on an elliptical coplanar orbit. *Bottom panel*: the secondary is at a_b = 100 au. When varying the secondary's mass, MMRs can become stronger and the secular perturbation inside the HZ (straight vertical lines) moves outward. *Top panel*: the secondary is at a_b = 50 au. The secular perturbation exhibits the same behaviour, however it reaches the icy asteroid belt region, located after the snow-line at 2.7 au (dashed line).

are shown for a fixed value e_b = 0.3. We can clearly identify, for the case of a_b = 100 au, the perturbed area moving outward for increasing secondary's mass. For this particular case, the secular perturbation lies inside the HZ (straight lines). When decreasing a_b, this secular perturbation moves outward and can reach the asteroid belt region, located after the snow-line at 2.7 au (dashed vertical line). For this case, the secular perturbation overlaps with the mean motion resonances (MMRs) whereas objects inside the HZ move on quasi-circular orbit.

In our results, we highlight the key role of secular perturbation and MMRs and we analyse the consequences of such dynamics on:

- the stability of asteroids in such binary systems i.e. their lifetime and dynamical outcome
- the transport of water to the HZ
- the probability for an asteroid to deliver its water content to any planets or embryos moving in the HZ

We show that binary star systems can produce a more efficient flux of asteroids to the HZ on a short timescale. This in turn leads to asteroids bearing a non negligeable amount of water to the HZ compare to single star systems. However, mass loss mechanisms such as ice sublimation, collision and strong XUVs from a younger primary star, can alter the water content on asteroids' surface. We discuss the consequences for water delivery to planets or embryos inside the HZ.

Conclusion

We show in our study how different is the dynamics in single and binary star systems when including a giant planet: the asteroid flux and water transport is boosted by the strengh of secular and mean motion resonances in binary star systems. Indeed, asteroids increase their eccentricity much faster and can rapidly reach the HZ region. This implies additional water sources in the HZ. However, mass loss processes can drastically decrease the amount of water beared to the HZ.

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