Exoplanets in PCEB

Planets around post-common envelope binaries

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In Short

- Motivation: Growing number of observations have suggested the presence of planets around highly evolved binary systems. The existence of planetary companions in such violent environments raises the question of their origin and survivability.
- Goals: We will study the effect of common envelope evolution of the binary star on the dynamics of pre-existing first generation planets.
- Methods: We will perform high resolution three-dimensional global hydrodynamic simulations of the common envelope gas with different energy budget to model different stellar mass ejection events. We study its effect on the planets around the binary by determining the change in their orbital properties.

Recent observations have revealed a variety of exoplanetary systems such as hot Jupiters, super Earths and planets around binary stars called circumbinary planets. It is well-known that more than 50% of all the stars are found in binary or multiple stellar systems. A significant fraction of these are White Dwarf and a low mass Main Sequence binary star type Post-Common Envelope Binaries (PCEB). A handful of such systems have provided evidence for the presence of planets [1]. Certainly this number will increase with the advent of missions such as TESS and JWST, as many PCEB systems might host planetary companions. PCEBs are formed after the transient phase of common envelope (CE). The more massive (primary) star evolves faster than the secondary star, to become a red giant. If the two stars of the binary are close enough, mass from primary star envelope is transfered over the secondary companion. This results in the engulfment of the secondary star in the red giant envelope leading to a shared envelope stage, containing the core of the giant and the companion star. As the core and the companion revolve around each other inside the CE, due to drag forces there is a transfer of energy and angular momentum from the orbit of secondary star to the CE, leading to the expulsion of the envelope. Most of the envelope material is ejected leaving behind a white dwarf and the secondary star in a tighter binary (on a narrow orbit of around the solar radius) with orbital periods of just hours or days [2].

When seen from earth, the components of the PCEB are found to eclipse each other several times a day. For such tight binaries, the close to perfect orbital signals are found to vary and the observations of these eclipsing time variations (TTV) provide the evidence for potential planets, despite the dramatic evolutionary paths of a binary star. There are alternative explanations for the deviations from the observed (O) versus calculated (C) binary orbital period (O-C diagram) such as the Applegate mechanism due to magnetic activity of the secondary star but some of the TTV binaries are mostly explained by the circumbinary planets [1].

A well-constrained and therefore the most certain case is NN Serpentis, whose eclipse timing variations can be explained by the presence of a planetary system. NN Ser is an eclipsing short period binary which consists of a white dwarf star and a main-sequence dwarf star of masses 0.535$M_\odot$ and 0.111$M_\odot$ respectively. It has been observed to host two giant planets of masses $7M_{Jup}$ and $1.7M_{Jup}$. They have moderately elliptical orbits of eccentricities 0.144 and 0.222 and semi-major axes of 5AU and 3AU respectively [3]. This system serves as a prime example to study the possible scenarios of origin of circumbinary planets, their dynamical stability as the binary system evolves and the stellar activity. These planets could have formed jointly with the binary and survived the CE phase of binary evolution, namely First Generation (FG) planets. The other possible scenario is that they might have formed after the CE event, from the back-falling material of the bound ejecta [4], namely second generation (SG) planets [5]. The question of how such circumbinary planets form or how they are dynamically affected by the stellar evolution is far from being understood. It is important to determine if and under which conditions FG planets survive different stages of stellar evolution and if the post-CE system has sufficient bound material to form protoplanetary disks heavy enough for jupiter-mass planet formation.

In this project, we aim to study how different stellar mass loss events during the CE phase of the binary evolution affect the orbital/kinematic properties of the potential FG planets using NN Ser as the exemplary system. We will perform global three-dimensional (3D) high-resolution hydrodynamical simulations using the 3D MPI-parallel, adaptive mesh refinement (AMR) code FLASH [7]. In figure 1, we present a snapshot from one of our test simulations to show how the CE gas interacts heavily with the pre-existing planets and alter the properties of their orbits.

Motivated by this, we plan to scan the possible parameter space of CE properties and address the questions such as how the orbital properties of the FG planets like semi-major axis, eccentricity and inclination change. Previously, in our semi-analytic work [6], we investigated the impact of stellar mass ejections on the probability of survival of FG planets during the CE phase of PCEB systems. We derived a set of simple equations for the orbital properties of the circumbinary planets both before and after the CE event, taking NN Ser as the example system. We plan to compare our results from numerical simulations with those obtained from the semi-analytical study. We will study the amount of angular momentum transfer between CE gas and planets. We will determine the amount of mass of the envelope gas which is ejected and bound to the system and eventually if the bound mass is sufficient to form the second generation disks around the binary.

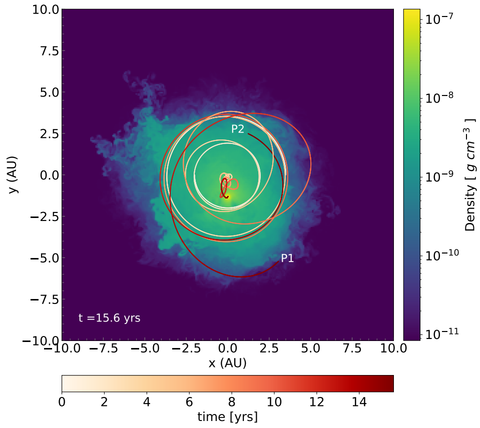

Figure 1: *From our preliminary numerical work, we present a snapshot of gas density distribution in x-y plane with the orbital trajectories of the two FG planets, P1 and P2 at 15.6 yrs. This corresponds to the case when the ratio of kinetic to gravitational potential energy of the gas is 1/10. It is evident how the common envelope gas can influence the orbits of the planets such as their eccentricity and the semi-major axis, when the planets initiated on circular orbits.*

WWW

https://www.physik.uni-hamburg.de/en/hs/group-banerjee/members/banerjee-robi.html

More Information

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DFG Subject Area

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