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Planetary Survival and Ejection in Transient Multiple Star Systems

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Abstract. Many planets have been detected in close binary stars with separation only ~ 20 AU. These discoveries challenge the current theory of planet formation because binary stars with such an close separation are thought to have strong perturbations and thus inhibit planet formation around them. To address this issue, another scenario had been suggested: the binary separation was wider enough for binary formation in early stages, but it shrank to the present one after a transient triple star phase (stellar scattering phase). Here, we investigate how could planet survive or be ejected under this scenario. We find that (1) the odds of planetary survival are significantly reduced if scatterings between planets and/or planetesimals are included (2) circumbinary planets/planetesimals could be readily formed during such a transient phase.

Keywords. Planet and satellites: formation; Methods: N-body simulations; Stars: binaries

1. Introduction

Among more than 800 detected exoplanets so far (http://exoplanet.eu/), ~ 60 of them reside in binary systems (Roell *et al.* 2012). Although most of these planet-bearing stars are wide binaries with separations >100 AU, there are five of them with binary separation only ~ 20 AU, including Gl86 Ab (Queloz *et al.* 2000), γ Cephei Ab (Hatzes *et al.* 2003), HD41004 Ab (Zucker *et al.* 2004), HD196885 Ab (Chauvin *et al.* 2011), and most recently α Centauri Bb (Dumusque *et al.* 2012). Planets in such binary systems challenge the current planetary formation theory, because stars in such close separation induce strong perturbations and thus inhibit planet formation around them (Thébault *et al.* 2006; Thébault *et al.* 2008; Paardekooper *et al.* 2008; Xie & Zhou 2008, 2009; Haghighipour 2010; Fragner *et al.* 2011; Giuppone *et al.* 2011).

The challenge becomes most critical in the case of HD196885 Ab, which is a giant planet with at least 3 Jupiter masses orbiting at 2.6 AU from the primary star. Given the orbit of the host binary (semimajor axis a_B=21 AU and eccentricity e_B=0.42), the planet is located very close to the boundary of stability (Holman & Wiegert 1999), where is highly perturbed and therefore strongly hostile to planet formation (Thébault 2011. One of the solutions, as suggested by Thébault 2011, is that the binary had a initially wider orbit, but later shrunk to the present one via close stellar encounter. Such a kind of scenario was first (Pfahl 2005; Portegies & McMillan 2005) applied to explain the origin of a planet candidate in HD188753 (Konacki, 2005)† and later to γ Cephei Ab by Marzari & Barbieri (2007a, 2007b) and Martí & Beaugé (2012).

In this communication, we numerically investigate how could planets survive or be ejected during such a stellar encounter process. We extend the model of Marzari &

† Its existence was later questioned and is still not confirmed (Eggenberger *et al.* 2007.)

Barbieri (2007a) by including other planetary objects, e.g., earth mass planets and/or planetesimals. Such a consideration allows us to study the effect of planet-planet scattering during stellar encounter phase. In the following, we describe our model and present some preliminary results.

2. Methods

Following Marzari & Barbieri (2007a), we consider a transient triple star system with masses and orbits elements summarized in table 1. Around the primary star, we assume a gas giant planet formed with 3 Jupiter mass at 2.6 AU (as HD196885 Ab) on a coplanar and circular orbit. In addition, between 0.5 and 2 AU round the primary, we put 1000 test particles (TPs, hereafter) aiming to model planetesimals or small planets. For each set of parameter shown in table 1, we perform 100 simulations for 10^7 yr using the MERCURY software package (Chambers 1999) by choosing the BULIRSCH-STOER integrator.

Table 1. Characteristics of HD 196885 and Model Initial setups

	Star				
	Primary	Secondary	Tertiary	Gas Giant	TPs
HD 196885 System[a]	$m = 1.3\,\mathrm{M}_\odot$	$m = 0.45\,\mathrm{M}_\odot$ $a = 21$ AU $e = 0.42$		$m > 3\,\mathrm{M_J}$ $a = 2.6$ AU e =0.48	
Model Initial Setups[b]	$m = 1.0\,\mathrm{M}_\odot$	$m = 0.4\,\mathrm{M}_\odot$ $a = 35$ AU $e = 0.2$ $i = 0°$	$m = 0.4\,\mathrm{M}_\odot$ $a = 70$ AU $e = 0.2$ $i = 20°$	$m = 3\,\mathrm{M_J}$ $a = 2.6$ AU e=0.0 $i = 0°$	$a \in [0.5\mathrm{AU}, 2\mathrm{AU}]$ e=0.0 $i = 0°$

[a] Chauvin *et al.* 2011
[b] For the secondary, planet and TPs, their orbital elements are with respect to the primary star, while for the tertiary star, its orbital elements are with respect to the barycenter of the inner binary stars. All other angular elements are set randomly from a uniform distribution.

3. Results

We summarize our preliminary results as the following:

• For the stars, such a initial orbital condition is generally long-term unstable. Stars would have close encounters and scattering with each other, eventually forming a closer binary with the third star being ejected out. In our 100 runs, there 2 , 45, 53 cases with the primary, secondary and territory star being the ejected star, respectively. All ejections occurred within less than 10^6 yr as shown in Fig.1. At this timescale, planet formation should be probably still ongoing.

• For the giant planet initial around the primary star, as can be seen from Fig.2, Although most of them were ejected, there are still about 20 in 100 cases where the planet survives at least 10^7 yr, suggesting it is quite possible to form a planet-bearing binary system like HD 196885 under the scenario of a transient triple star system.

• For the TPs, the results depend on if the giant planet is included in the simulation. For the case without the giant planet, the chance of TP survival, as shown in Fig.1 and 2, decreases with the increase of their initial semi-major axis and the duration of the transient triple star system phase. These results are expected since a TP would be more unstable if place it closer to the perturber with longer time span. For the case with giant planet, there is no such anti-correlation between the star ejection time and the remaining TP number, and the TP survival probability is significantly reduced as

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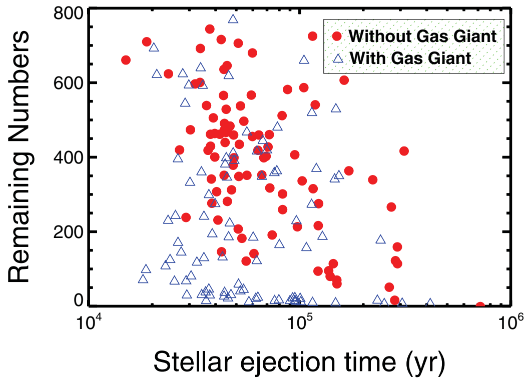

Figure 1. Number of remaining TPs as a function of time when the star is ejected, i.e., the duration of the transient triple star system phase. Triangles and circles are results of two sets of cases, respectively, with and without including the gas giant in the simulations. An anti-correlation between star ejection time and remaining TP number seems to appear in the latter.

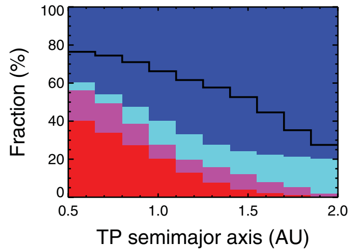

Figure 2. Possibilities of four types of outcomes (red = giant ejection + TP survival, pink = giant survival + TP survival, cyan = giant survival + TP ejection and blue = giant ejection + TP ejection). X axis denotes the initial semimajor axis of the TPs. Black histogram denote the results of without giant planet. TP survivals are much less if including the giant planet.

compared to the case without giant planet. Further more, in any case, for > 90 out of 100 runs, we observed that some TPs were scattered onto orbits that finally around the later formed closer binary star, i.e., circumbinary TPs, suggesting that circumbinary planets/planetesimals should be common if stellar scattering occurred.

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