Dynamical Evolution of Dense Stellar Systems
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Is our Sun a Singleton?

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Abstract. Most stars are formed in a cluster or association, where the number density of stars can be high. This means that a large fraction of initially-single stars will undergo close encounters with other stars and/or exchange into binaries. We describe how such close encounters and exchange encounters can affect the properties of a planetary system around a single star. We define a singleton as a single star which has never suffered close encounters with other stars or spent time within a binary system. It may be that planetary systems similar to our own solar system can only survive around singletons. Close encounters or the presence of a stellar companion will perturb the planetary system, often leaving planets on tighter and more eccentric orbits. Thus planetary systems which initially resembled our own solar system may later more closely resemble some of the observed exoplanet systems.

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Stars are most often formed in some sort of cluster or association. In such environments the number density of stars can be significantly higher than in the solar neighborhood. Thus, close encounters between stars might be common. If a single star with a planetary system suffers a close encounter with another star, the orbits of the planets might be changed. Sometimes this change can be enough for one or more planets to be ejected entirely from the system. Most likely this will happen long after the encounter, due to the strong planet-planet interactions induced by the close encounter. If one or more planets are ejected, the remaining planets will most often be left on tighter and more eccentric orbits. It is also possible that the close encounter does not cause the ejection of any planets and instead just stirs up the eccentricities of the planets somewhat.

If a single star instead encounters a binary system, it can be exchanged into it. When this occurs, the orientation of the orbital plane of the planets with respect to that of the companion star is completely random. This means that in about 70 per cent of the cases, the inclination between the two will be larger than 40°. When that happens, the Kozai Mechanism will operate (Kozai 1962). Given that the binary is not too wide, the Kozai Mechanism will cause the eccentricities of the planets to oscillate. If the planetary system contains multiple planets, this eccentricity pumping can cause strong planet-planet interactions, causing the orbits of the planets to change significantly and sometimes also ejecting one or more planets (Malmberg *et al.* 2007)

In our own solar system, the orbits of the planets are nearly circular. Furthermore, all the massive planets are found far out from the sun. This is however not the case for the observed exoplanets. Many of these systems contain one or more eccentric planets and

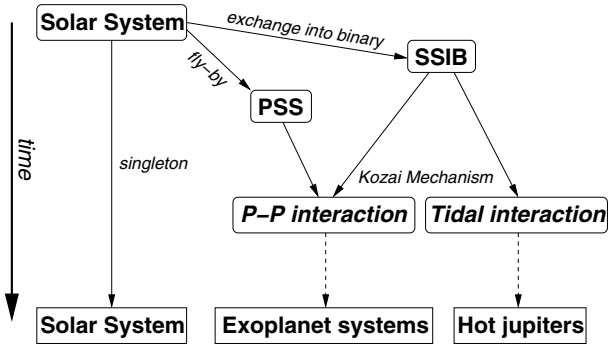

Figure 1. This flow-diagram outlines what can happen to a solar system orbiting an initially single star inside a stellar cluster. SSIB stands for Solar System In Binary, PSS stands for Perturbed Solar System and P-P interaction stands for Planet-Planet interaction.

also often massive planets on tight orbits. We propose that at least some of the observed exoplanet systems were once resembling the solar system, but were later altered into the planetary system we observe today, through interactions in stellar clusters. It might be that planetary systems like our own solar system can only exist around stars which formed single and has never experienced a close encounter with another star or been inside a stellar binary. We define such a star to be called a singleton. In Fig. 1 we give an outline of what can happen to a solar system like planetary system when inside a stellar cluster. Only around singletons will a planetary system remain solar-system-like until today, while if it orbits a star which suffer strong interactions with other stars it will today instead either be a Hot Jupiter system (see for example Fabrycky & Tremaine 2007; Wu *et al.* 2007) or contain planets on elliptical orbits (Takeda & Rasio 2005).

To explore how large the fraction of singletons is in the solar neighborhood (and thus to understand how common solar system like planetary system may be) we have numerically simulated a large range of stellar clusters, typical of those in which most of the stars in the solar neighborhood formed (Malmberg *et al.* 2007). From our simulations we estimate the singleton fraction for single stars with masses similar to that of the sun to be between 0.90 and 0.95. This means, that between 5 and 10 per cent of all planetary systems around solar mass stars can have been altered by dynamical interactions in stellar clusters, such as described above, into some of the observed exoplanet systems.

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References

Kozai, Y. 1962, *AJ*, 67, 591
Malmberg, D., Davies, M. B., & Chambers, J. E. 2007, *MNRAS*, 377, L1
Malmberg, D., de Angeli, F., Davies, M. B., Church, R. P., Mackey, D., & Wilkinson, M. I. 2007, *MNRAS*, 378, 1207
Fabrycky, D. & Tremaine, S. 2007, arXiv:0705.4285
Takeda G. & Rasio F. A., 2005, *ApJ*, 627, 1001
Wu, Y., Murray, N. W., & Ramsahai, J. M. 2007, arXiv:0706.0732