Dynamical Evolution of Dense Stellar Systems
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Capture-Induced Binarity of Massive Stars in Young Dense Clusters

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Abstract. Observations show that for massive stars the binary frequency seems to be higher than for lower mass stars in young dense clusters. This suggests that in clusters like the ONC different mechanisms are at work in the formation of high-mass binary or multiple systems than for low-mass stars. We investigate the stellar dynamics in young dense clusters to determine the role of capture in binary formation in high-mass stars. It turns out that in contrast to lower mass stars capture is a frequent process for massive stars. However, this does not necessarily lead to long lasting binary systems but is often of transient nature. Nevertheless, capture processes could account for 15-25% of the observed 'binaries' of the OB-stars (75%) in Orion.

Keywords. open clusters and associations, binaries: general, stellar dynamics, methods: n-body simulations

1. Introduction

Observations indicate that in young stellar clusters the binary fraction for massive stars is higher than for solar mass stars. For the Orion Nebula Cluster (ONC) there is a binary frequency of $\sim$ 50% for solar-mass stars compared to 70-100% for the massive O- and B-stars. In principle there are only two explanations for the higher binary frequency of massive stars in comparison to intermediate mass stars: either massive stars are more likely to be binaries primordially, or their binarity increases within the first Myr of their existence in a significant way. Here we restrict ourselves to the second possibility, i.e. we start with the assumption that the primordial number of binaries is the same for solar-mass and massive stars and ask whether dynamical processes can lead to a sufficient amount of additional binaries to explain the difference in observed binary frequency between solar-mass and massive stars. As a model cluster we chose the Orion Nebula Cluster, because it is one of the densest clusters in the Galaxy, so if capture processes play any role one should find indications for it here.

2. Method

For simplicity we start with a system initially consisting only of single stars - the influence of both primordial binaries and discs around the stars are excluded from this first study. In the cluster simulations we followed the dynamical development of $\sim$ 4000 stars in an virial equilibrium situation, i.e. $Q_{vir} = 0.5$, with a spherical density distribution $\rho(r) \sim r^{-2}$ using NBODY6++. Gas components and the potential of the background molecular cloud OMC 1 were neglected in these simulations. The most massive star was assigned a mass $M^* = 50$ M$_\odot$ and all other stars' masses according to the mass distribution given by Kroupa (2001). The quality of the dynamical models was judged by comparing them to observational data at 1–2 Myr, marking the range of the mean ONC age.

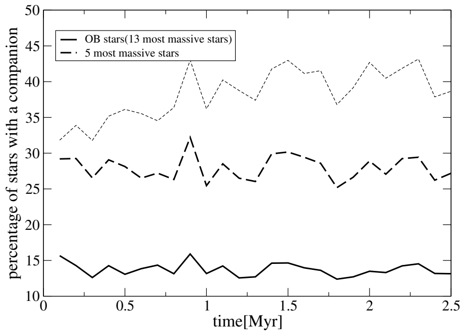

Figure 1. Average binary rate as a function of time for the 5 most massive stars (solid line), all 13 OB stars counting two massive stars in a binary only once (dashed line) and counting them both (dotted line).

3. Result

All capturing encounter events with an eccentricity $\epsilon < 1$ are recorded. These so formed bound systems are transient binary systems (TBS). As to be expected these capturing encounters mostly happen early on in the cluster development, close to the cluster centre and mainly involve one of the most massive stars. Fig. 1 shows the percentage of the 5 and 13 (number of OB stars in the ONC) most massive stars of the cluster to have at least one companion as a function of time. If a TBS is taken into account only once if both stars were massive, 10–15% of the OB stars and 25–30% of the five most massive stars would form at 2 Myrs and would appear as binaries. The thin dashed line shows the case where these massive TBSs are considered twice. This is equivalent to the likelihood of a specific star to be in a TBS and it is ~ 40 % at 2 Myr. So for the most massive stars of the cluster there is a high likelihood of being a TBS and appear as a binary. It is actually sufficient to explain the difference in binary rates between massive and solar-mass stars.

But what are the properties of these capture-formed TBSs? At 1–2 Myrs, the most likely age of the ONC, the average periastron of the most massive TBS is between 50-200 AU. The mass ratio in these TBSs develops from an initial preference of low-mass companions to companions with high mass. At an cluster age of 2–5Myr the maximum of q lies in the range of 0.6-0.8. The most massive star usually captures just one of the 10 most massive stars as companion and not necessarily the second most massive star. The average eccentricity in these TBSs is $\epsilon \sim 0.5$–0.6. The bound state lasts on average several times 10^6yrs in contrast to bound state durations of on average $< 10^5$ yrs for lower mass stars. So in very young clusters these massive stars would *appear* as binaries but are actually just running through a succession of TBS.

4. Conclusion

In cluster environments similar to the ONC, massive stars have a much higher probability of involvement in a capturing encounter than solar-mass stars. Assuming a cluster age of 1–2 Myr, at least 10–15% of the OB stars in the ONC are in a bound state caused by capturing processes.

Reference

Kroupa, P. 2001, MNRAS 322, 231