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The cradle of the Sun

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Abstract

Most stars form not in isolation but as part of a group of stars referred to as cluster or association[2]. There are many indications that the Sun also formed as part of such a group of stars. Here we investigate what the most likely birth environment for the Sun was. We first show that there are basically two kinds of stellar groupings - clusters and associations. These two groups significantly differ in their temporal development and most importantly in the way the stellar density changes over time. We perform simulations of these different type of clusters and determine the frequency of potentially solar system shaping events. With these simulations we can narrow down the extensive mass radius regime of existing clusters to just two cases that of potential environments of the early solar system - these are (i) massive associations with $>$ 10 000 stars but relative large initial half-mass radii of over 1 pc or (ii) less massive ($\sim$ 1000 stars) compact clusters with initial half-mass radii in the range 0.1-0.3 pc.

1. Introduction

Most stars are born in groups, which formed from dense cores in giant molecular clouds (GMCs). Here we want to investigate in how far interactions with the other groups members potentially shape the resulting planetary systems and in particular our own solar system. Such stellar groups can be divided in two categories - clusters and associations. Where clusters are considerably are more compact and therefore have a much higher stellar density than associations of the same age. However, both are highly dynamical entities and are there density develops considerably over the first 10-20 Myr [3]. Fig. 1 shows the density development in these two groups as a function of cluster age.

There are many indications that the solar system also formed in a cluster[1]. For example the steep drop in mass density at 30 AU in the solar system is often interpreted that an external process lead to disc truncation at such a size. Basically two external processes could lead to such disc truncation either a stellar fly-by external photo evaporation. The former would be just induced by the gravitational effect of a passing neighbouring star, the latter by the radiation of a nearby massive star. Both processes are most likely in stellar groups that contain at least a few hundred members. Here we mainly concentrate on the case where a stellar fly-by caused such a disc truncation. We ask the question what kind of star cluster would have been the most likely birth environment of the Sun.

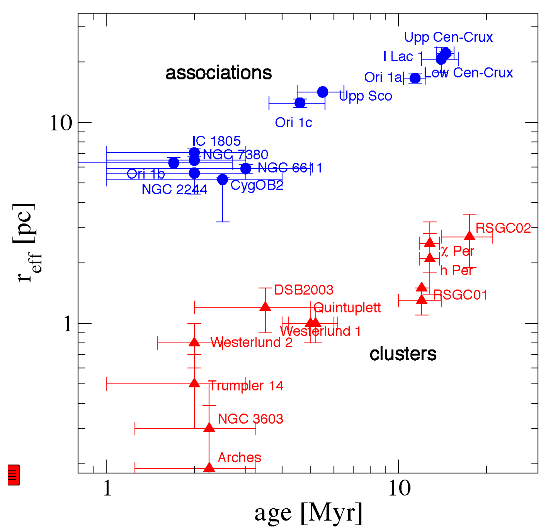

Figure 1: Half-mass radius vs. age of young stellar groups showing the distinct differences in development between associations and clusters.

2. Method

We performed two type of simulations to determine the effect of stellar fly-bys on early solar systems. First, we simulate the dynamics of stellar clusters and associations reproducing the two typical temporal sequence shown in Fig. 1. In each of these simulations we recorded the parameters of each close stellar fly-by.

Second, we performed an extensive parameter study of the effect parameter study that gives the various effects of such a fly-by on a protoplanetary disc or an already formed planetary system. In a last step we analyse just the solar type stars and determine the likelihood for a cut-off at 30 AU.

3. Results

As to be expected, close fly-bys are much more common in massive dense clusters than in associations, which have lower stellar densities. The perturbers in dense clusters are usually of equal or lower mass than the Sun. Differences can also be found concerning the eccentricity of the solar system forming fly-bys. In associations mots fly.bys occur on nearly parabolic orbits whereas in dense clusters this is not the case. Three- or many-body interactions happen relatively often in such dense environments.

The Sun is not part of an association today, which could be a result of the birth association's disruption due to the galactic field[4] or gas expulsion [3], after which only between 10-20% of all stars remain behind as a bound remnant. Even these remnant cluster might dissolve completely on time scales of 100 Myr or longer. The number of solar-system analogues which are ejected from an association after 20 Myr is even for the most massive association 104 -117 systems.

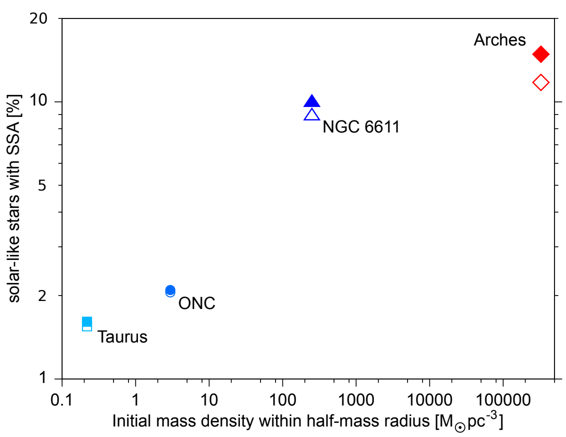

Figure 2: Frequency of solar sytem forming fly-bys of average cluster density: Example clusters are indicated.

The Arches-like cluster produces nearly twice the number of solar system analogues (SSA) as the NGC 6611 model, 250 after 3 Myr. However, in contrast to NGC 6611, this number decreases slowly with time, so there will roughly 210 systems left after 10 Myr. Clusters similar to our model (SFE = 70%) lose up to 15% of their stellar mass within the first 10 Myr after star formation, mostly due to stellar interactions. This means that about 32 SSAs would be ejected after 10 Myr. This number seems quite small, however, the clusters continue to lose stars with time due to stellar interactions, so the total number of ejected systems increases with time, e.g. 42 (20%) ejected SSAs at 20 Myr.

The position at which most solar system forming fly-bys occur varies strongly among the different association and cluster models. The Taurus model reacts slowest on the gas expulsion, therefore, most fly-bys occur around 0.1-0.3 pc.

4. Summary and Conclusions

Is it more likely that the solar system was born in an association or a stellar cluster? This question cannot fully be answered yet, as here only the initial 10 Myr have been modelled, over the following 4.5 Gyr still stellar fly-bys happen which could further alter the systems. However, solar-system analogues in "small" associations are - in terms of absolute numbers - quite rare because naturally the absolute number of solar-like stars increases with the number of association/cluster members and discs in such systems usually remain larger than 50 AU. Quantitatively, the absolute number of SSAs in Taurus-like environments is on average less than 1, in an ONC-like associations 4, and it increases significantly in very massive association like NGC 6611 to roughly 130, see also Figure 2.

Summarising, the solar system was most probably born in a massive association like NGC 6611 or a cluster like Arches. It is important to note, however, that we only consider the formation and destruction of SSAs by stellar fly-bys. Other effects, like for example external photo-evaporation, have to be taken into account to finally answer the question where our solar system was born.

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