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Brown Dwarf Companion Frequencies and Dynamical Interactions

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Abstract. Numerical simulations are used to explore how gravitational interactions within young multiple star systems may determine the binary properties of brown dwarfs. We compare different scenarios for cluster formation and decay and find that brown dwarf binaries, although possible, generally have a low frequency. We also discuss the frequencies of brown dwarf companions to normal stars expected from these models.

1. Introduction

If stars form together in small clusters, their dynamical evolution is governed by chaotic gravitational interactions between the members early in their lifetime. In this picture, the lowest mass members (brown dwarfs, BD's) are most strongly affected by the dynamics and may be ejected during their accretion phase (Reipurth & Clarke 2001). Hydrodynamics calculations can follow the collapse and accretion processes within young forming stellar clusters (e.g., Bate, Bonnell, & Bromm 2002) but provide limited statistics on outcomes. In a complementary approach, we study the evolution of many realizations of initially non-hierarchical few-body point mass systems by direct orbit integrations, as described in Sterzik & Durisen (1995, 1998). Although neglect of remnant molecular gas and disk accretion may limit the applicability of our model to real star formation, the concentration on stellar dynamical effects allows us unprecedented numerical and statistical accuracy in determining the properties of end-products, and forms the basis for meaningful statistical comparisons with observations. We can use these comparisons to assess whether dynamical processes have imprinted themselves on real systems in a verifiable way.

In fact, Durisen, Sterzik & Pickett (2001) showed that the slow increase of multiplicity fraction with stellar primary mass can be understood from dynamical cluster decay alone, if cluster formation includes a combination of two processes: selection of the total mass for each stellar cluster from a clump mass spectrum (CMS), followed by selection of the individual member masses from a stellar mass spectrum (SMS) subject to the constraint of the cluster total mass. In this way, stellar masses are distributed more uniformly within each cluster, even though the stars overall match a proper stellar initial mass function (IMF).

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This two-step process circumvents the overly strong dependence of the binary fraction with primary mass found in earlier dynamical decay studies of clusters (e.g., McDonald & Clarke 1993).

The shape of the IMF in the sub-stellar regime critically determines the details of the pairing statistics for the lowest masses. Having modern observational constraints on the underlying mass function, we can try to derive reasonable BD binary properties from dynamical decay models. In this contribution, we calculate BD multiplicity frequencies assuming an up-to-date sub-stellar mass function and compare different formation scenarios. The results presented here form part of a larger study, to be reported elsewhere (Sterzik & Durisen 2003), which will explore general BD properties resulting from dynamical cluster decay.

2. Monte Carlo Simulations

Let us consider three different scenarios for stellar cluster decay. It is well known that cluster dynamics tend to favor pairing of objects with large masses, a process sometimes termed 'dynamical biasing'. If we assume complete 'dynamical biasing', this means that within a given cluster with sorted cluster masses $m_1, m_2, m_3, ...$ with $m_1 \geq m_2 \geq m_3$ *only* the most massive pair will form a stable binary. If the masses for these stars are chosen randomly from an IMF (McDonald & Clarke 1993) without regard to a cluster mass constraint, we refer to these models as '1 step: bias'. But true weighting factors for the pairing probabilities in a cluster deviate from 100% dynamical biasing, and have to be determined by direct integrations. In addition, a '2-step' mass selection process via a CMS and SMS is observationally appealing. We call this second conceivable model '2 step: dynamics', in order to reflect the two-step mass selection and the true cluster dynamics. Finally, as a third (extreme) formation model, we consider random pairing of stars, potentially caused by strong tidal or dissipative effects during stellar encounters, within clusters formed by a two-step process. We refer to this model as '2 step: random'.

Details of the Monte-Carlo (MC) procedure and how to generate binary and multiplicity fractions can be found in Durisen, Sterzik & Pickett (2001). In short, cluster masses are constrained by a choice from the CMS (for two-step selection), and a variable number of cluster members $N = 1$ to 10 have masses drawn from a SMS. Typically 100,000 cluster realizations have been calculated for each of the three scenarios. The CMS and SMS are chosen to yield an acceptable IMF, including the mass distribution of BD's.

2.1. Multiplicity Fractions

Although the MC method actually generates only binaries and singles, it can be checked against results of direct integrations of cluster decay. We find a good reproduction of the N-body calculation statistics when we interpret the MC "binary" fraction to include higher order systems. Figure 1 displays resulting multiplicity fractions (MuF) versus primary mass. The different curves refer to the three different scenarios discussed above. Note that the MuF must tend toward zero at low masses, because no lower mass secondaries exist. The data points show results from observations of multiplicity fractions for different primary mass ranges, which include - to our knowledge - a statistically mean-

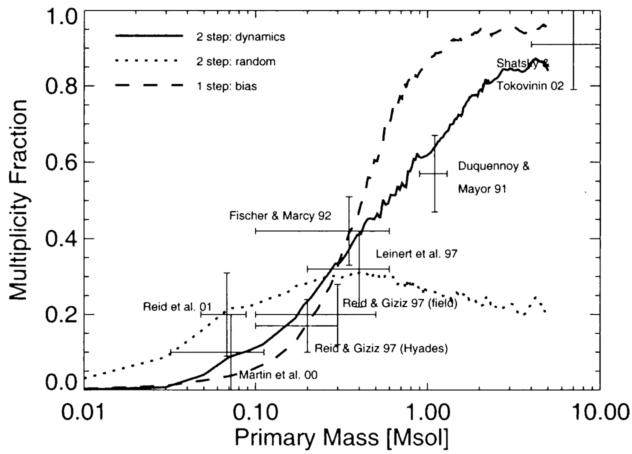

Figure 1. Multiplicity fractions versus primary mass for different models, compared with observational data.

ingful sample. We try to estimate fair primary mass ranges and errors from the original references, if they are not directly given. BD binary fractions reported at this conference are about 20% (see the contributions of Brandner and Close).

The full line refers to the dynamical binary formation model with our latest weights and mass functions (labelled '2 step: dynamics'). The dashed line is based on the same IMF, but does not take into account the two-step cluster total mass constraint set by the CMS. It also assumes 100% dynamical biasing during the MC pairing ('1 step: bias'). Not surprisingly, and already noted by McDonald & Clarke (1993), the '1 step: bias' MuF is too steep a function of primary mass, and does not - except for an intermediate mass range - fit the more gradual increase actually observed. Our third choice includes the cluster mass constraint but uses equal weights for all forming binaries, mimicking random pairing (dotted line, '2 step: random'). In this case, the MuF is relatively smooth. It increases significantly for very low masses to a broad peak near the peak in the IMF, then falls away gently at high masses.

2.2. BD companion fractions

The MC calculations also reveal the fraction of BD secondaries per primary mass bin. In Table 1 we summarize the results for the three models explained above. For simplicity, in this case, only binaries not multiples are considered. We define the BD companion frequency as $BF_{BD} = N(B_{BD}|P)/[N(S|P) + N(B|P)]$ with $N(B_{BD}|P)$ indicating the number of binary systems that have a companion in the BD mass regime and a primary in mass bin P, and $N(S|P), N(B|P)$ being the total number of single and binary systems having a (primary) mass P. This definition guarantees that the total BF is the sum of the companion frequencies for all secondary mass bins. Primary masses are interpreted as spectral types.

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Primary	2-step: dyn.	1step: bias	2step: ran.
M-	0.09	0.05	0.17
M+	0.07	0.05	0.13
K	0.06	0.05	0.10
G	0.03	0.05	0.08
F+	0.02	0.04	0.06

Table 1. BD companion frequencies as function of primary masses ranges (calibrated as spectral types on the main sequence).

In all cases, BD's are rather rare companions to stars. The '2-step: dynamics' model predicts a gradual decrease of the BD companion frequency from late M-type primaries to early type stars. In this model, 9% of all late stars with masses corresponding to a late M spectral type should have BD companions, whereas BD companions are expected for only 2% of stars more massive then $1.2 M_{\odot}$. If random pairing processes dominate the formation of BD companions, as a high BD MuF might suggest, these fractions tend to roughly double. A complete dynamical biasing model with masses drawn from a 1-step IMF leads to an almost invariant BD companion fraction of $\approx$ 5% for all primary masses.

3. Conclusions

We have compared three different models of binary star formation in young few-body clusters with respect to their predictions with regard to BD companion frequencies and to the dependence of the multiplicity fraction on primary mass. We note that a model employing a two-step mass selection process with subsequent dynamical interactions between cluster members tends to agree best with the observed trend of increasing multiplicity with primary mass in the stellar regime. Both the other models, especially random pairing, fail in this regard. On the other hand, a BD binary fraction above 20% appears - for the IMF assumed - to be more consistent with 'random pairing' mechanisms. If a 20 % binary fraction holds up for BD's, it may be telling us that different mechanisms dominate the pairing process in different mass ranges. Additional insight would be gained from statistically significant observations of the true BD binary companion fractions to stars. The predicted BD companion frequencies are low for all pairing scenarios studied here, but their absolute values and their dependence on the mass (or spectral type) of the primary are fairly different.

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