Binary Properties in Dynamically Decaying Few-Body Clusters

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Abstract

We investigate the dynamic decay of nonhierarchical young stellar clusters by direct numerical integrations. We statistically compare the properties of remnant decay products resulting from two different initial mass functions (IMF). One IMF extends its lower mass cutoff into the brown dwarf regime. We show that the final binary properties are rather robust with respect to variations of the initial conditions. Characteristic trends in the binary frequencies, mass ratio distributions, and binary separation distributions can be found in the end-states of decaying few-body clusters that are consistent with observations. This supports the idea that few-body clusters form frequently in fragmenting cloud cores, and that dynamical processes are important in that phase.

1 Introduction

Few-body clusters play probably an important role during the star formation process: hydrodynamic calculations show that fragmentation during molecular cloud core collapse is expected for a wide range of initial conditions, and that these fragments might be forming stars during their subsequent evolution (see e.g. Bonnell et al. 1992, Boss 1996, Bate & Burkert 1997). And there is mounting evidence that fragmentation of clouds into protoclusters (see e.g. Motte et al. 1998; Ohashi or André, this volume) or protobinaries (Looney et al. 1997) is observable and frequent in molecular cloud cores. These observations are especially important in view of studies of the binary frequency in star forming regions, which tend to discover many pre-main sequence binary or multiple stars, often more than expected in samples which are restricted to older, main-sequence stars.

The focus of our work is therefore directed in bridging the gap of cloud collapse calculations to stable endstates by mapping the initial state of young few-body clusters into long-lived stellar remnants, consisting of single, binary and hierarchical multiple systems. Our main goal is to statistically characterize the complete decay of a few-body cluster by an in-depth analysis of its remnants using state-of-the-art numerical integration techniques. We aim to understand the influence of initial conditions such as varying mass spectrum, geometrical arrangement, cluster size, or virial status to the end-state distribution. In this contribution we specifically focus on the comparison of two different mass functions, one of them extending the masses of the few-body cluster well into the brown dwarf regime down to a cut-off of 0.01 $M_\odot$. For a detailled description of our conceptual approach we refer to Sterzik & Durisen (1998).

2 Initial Conditions

In our previous work we model an initial mass spectrum for the few-body clusters and involve a two-step process for the generation of stellar masses: in a first step, we choose a total system mass ("clump mass") according to a power law ($M_{tot} \propto M^{-1.5}$), which approximates the observed clump mass spectra in molecular clouds (see e.g. Elmegreen & Falgarone 1996). Constrained by this clump mass, we apply another power law for selecting individual stellar masses. This approach yields a final stellar mass spectrum which comes rather close to the actual observed mass spectrum (see Kroupa et al. 1991). This approach not only results in a reasonable shape of the IMF, but also shows considerable promise for reproduction of observed trends in binary fractions and mass ratio distributions along the main sequence, especially for an initial cluster made up of 4 bodies (see also Durisen et al. 1999). In the following, we call this model CM4$_{SD}$, and refer for further details to Sterzik & Durisen (1998). We now explore a mass spectrum which is generated on a similar ground, but extending its lower mass cutoff down to $0.01 M_\odot$. We call this mass spectrum CM4$_{BD}$, and compare both functions in Figure 1 with the Kroupa et al. mass function. We do not intend to model an accurate mass function (the shape of the IMF in the substellar regime is still not very well constrained, but see e.g. Reid, this volume). Rather we want to demonstrate the effect of a high abundance of substellar objects and brown dwarfs on the final system configuration in dynamical decaying few-body clusters.

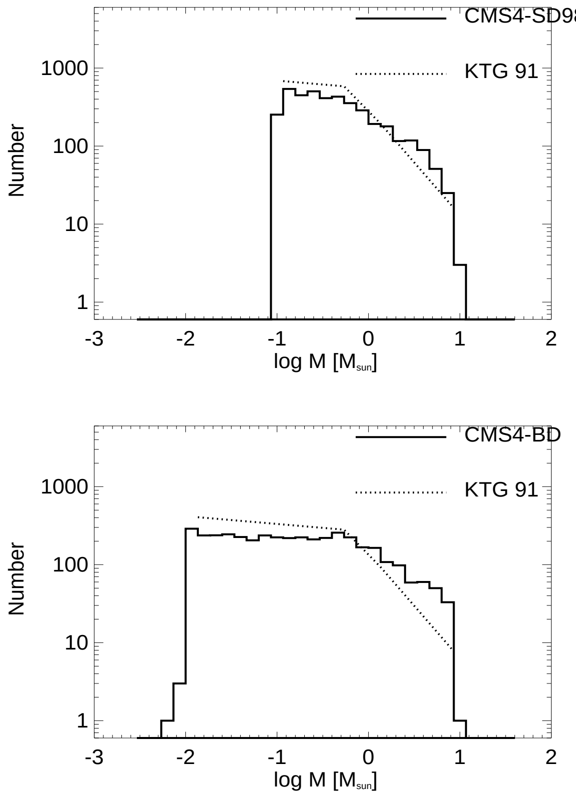

Figure 1: Mass spectra for model CM4$_{SD}$ (upper panel) and CM4$_{BD}$ (lower panel), compared to the Kroupa et al. 1991 distribution.

3 Results

3.1 Multiplicity Fractions

In the following we refer to the following labels indicating the approximate spectral type that stars in these mass intervals would have on the main sequence:

- L: substellar, $M \leq 0.075 M_\odot$
- M: Late M-type stars, $0.075 M_\odot \leq M \leq 0.2 M_\odot$
- MK: M & K-type stars, $0.2 M_\odot < M \leq 0.5 M_\odot$
- KG: Solar-type stars, $0.5 M_\odot < M \leq 1.2 M_\odot$
- F+: F-type stars & earlier, $1.2 M_\odot < M \leq 10 M_\odot$

We summarize the multiplicity fractions within each group in Table 1. The "total" refers to the total number of remnant *systems* whose most massive star (primary) is in that mass bin. The multiplicity fracions (single fraction SF, binary fraction BF$_p$, triple fraction TF$_p$, quadruple fraction QF$_p$) refer only to systems having a *primary* in that mass bin.

Not surprisingly, for both mass functions the lowest mass objects are almost entirely singles, as these objects get most easily ejected by dynamical processes. Also, an increasing binary fraction with primary mass is established. We note, that even including a large number of substellar objects does not render the multiplicity fractions too unrealstic, when compared to observations. A clear prediction of this model involving dynamical evolution in few-body clusters having substellar components is that those get ejected easily as singles in the

model	mass	total	SF	BF_p	TF_p	QF_p
	L	0	-	-	-	-
	M	832	1.00	.00	.00	.00
$CM4_{SD}$	MK	794	.81	.15	.04	.00
	KG	545	.32	.52	.13	.03
	F+	505	.07	.73	.16	.04
	L	1064	1.00	.00	.00	.00
	M	321	.97	.03	.00	.00
$CM4_{BD}$	MK	365	.38	.53	.07	.01
	KG	356	.10	.71	.16	.03
	F+	321	.02	.86	.09	.02

Table 1: Multiplicity fractions for remnant systems with primaries in five mass bins.

fields with relative high dispersion velocities. This could be the reason why binary searches for very low-mass companions around field stars tend to be difficult, and brown dwarf searches in the field seem to be more successful (see Reid, this volume).

3.2 Mass Ratio Distributions

Next we consider the distribution of secondary masses within a remnant binary having a specific primary mass. Observationally it is known that the mass ratio q (secondary divided by primary mass) mildly increases for M and K type primaries (Fischer & Marcy 1992), but rises as q decreases towards a peak between $q = 0.2 \ldots 0.4$ for solar type stars (Duquennoy & Mayor 1991). From dynamical modelling one knows that pairing of binaries within clusters preferentially occurs between the two most massive components of the cluster, a fact known as dynamical biasing (see, e.g. McDonald & Clarke 1993). We emphasize that the analysis of the mass ratio distribution potentially gives an important clue to constrain binary formation models, such as the one presented here. In Table 2 we summarize the outcome of the pairing statistics according to the numerical integration.

model	mass	total	L	M	MK	KG	F+
	L_p	0	-	-	-	-	-
	M_p	3	-	1.00	-	-	-
$CM4_{SD}$	MK_p	119	-	.20	.80	-	-
	KG_p	285	-	.14	.53	.33	-
	$F+_p$	368	-	.08	.20	.40	.31
	L_p	3	1.00	-	-	-	-
	M_p	10	.40	.60	-	-	-
$CM4_{BD}$	MK_p	194	.14	.50	.36	-	-
	KG_p	253	.19	.30	.39	.12	-
	$F+_p$	276	.13	.19	.19	.29	.20

Table 2: Relative fractions of secondaries within remnant binary systems having primaries in five mass bins.

We note that very low-mass companions are dynamically allowed even for higher mass primaries. But they are rare, as expected from dynamical biasing.

3.3 Binary Separation Distributions

Finally we investigate the properties of the binary semi-major axis distributions for both underlying mass spectra, and present the results in Figure 2. For a scaling to physical units we assume a constant specific energy for each few-body cluster, as explained in Sterzik & Durisen 1998. In this case the resulting separation distributions depends on the primary mass of the binary, but the general shape of the distributions is in good agreement with the (log-normal) shape of the separation distribution infered for solar type stars in the field by Duquennoy & Mayor (1991). The simulated separation distributions are in general somewhat narrower than the observed ones. We speculate that the field star distribution might be blended and composed of a mix of binaries originating from different star forming sites having different physical conditions (and therefore different physical scaling properties).

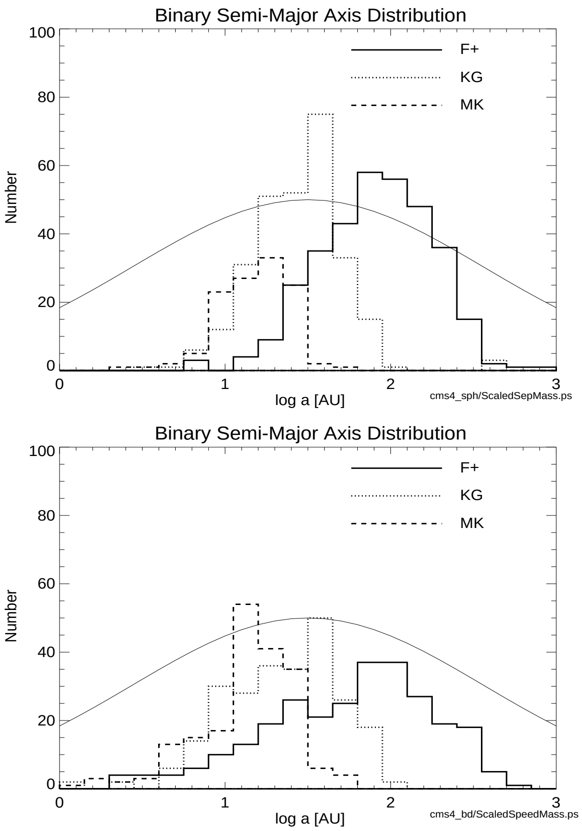

Figure 2: Binary semi-major axis distribution for model $CM4_{SD}$ (upper panel) and $CM4_{BD}$ (lower panel).

4 Conclusions

We have performed a statistical study of complete few-body decays for $N = 4$ clusters using direct orbit integrations. Two different initial mass spectra have been compared, one of them extending its lower mass cut-off well into the brown dwarf regime. We note that the general trends with respect to multiplicity fractions, mass ratio distributions, and binary separation distributions are only weakly sensitive on the precise lower cut-off of the underlying mass function. If the IMF is a product of a two-step process involving a clump mass spectral distribution, and if the resulting object mass spectrum extends down to substellar masses, the lowest mass objects are preferentially dynamically ejected singles. Only a minority – up to 10% of *all* substellar objects present in the IMF – can be members in binaries with higher mass primaries. If this scenario is correct, brown dwarf companions are rare around stars, and are more abundant as free floating objects.

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