BINARY FORMATION MECHANISMS: CONSTRAINTS FROM THE COMPANION MASS RATIO DISTRIBUTION

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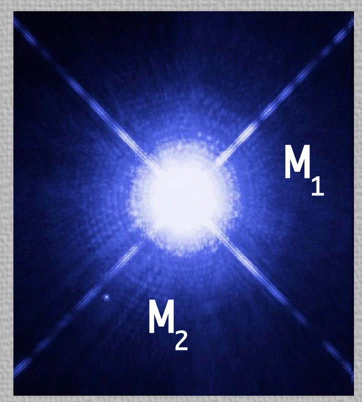
Abstract

"We present a statistical comparison of the mass ratio distribution of companions, as observed in different multiplicity surveys, to recent estimates of the single object mass function (Chabrier 2005, Bochansky et al. 2010). The main goal of our analysis is to test whether or not the observed companion mass ratio distribution (CMRD) as a function of primary mass and star formation environment is consistent with having been drawn from the field star IMF. We consider samples of companions for M dwarfs, G and OB stars, found in the field, open clusters, and star-forming regions and compare them with populations of binaries generated through Monte Carlo simulations by random pairing from the assumed IMF for a fixed primary mass. The analysis of connections between the CMRD and the IMF over a broad range of primary masses and variety of environments can help in discriminating different binary formation mechanisms and investigating the origin of the field."

Companion Mass Ratio Distribution



What is the companion mass ratio distribution (CMRD)?

For a sample of binary systems with

- primary star mass M_1
- secondary star mass M_2
- mass ratios $q=M_2/M_1$

the CMRD can be defined as the function, $\Phi(\log q)=dN/d\log q$, that gives the logarithmic distribution of the mass ratios for a chosen primary mass.

Why the CMRD?

- Many stars form in binary or higher order systems (e.g. Patience et al. 2002).
- It is a way to test predictions from binary formation theories.
- Might be independent of dynamical processing in clusters (Parker & Goodwin 2010).

Main questions

Is the CMRD the product of random pairing of stars from the single object IMF?

How does the answer depend on primary mass, environment and dynamical processing?

Is there a "universal" CMRD (as suggested by Metchev & Hillenbrand 2009)?

Methodology

Monte Carlo simulation of CMRDs

1. We select a multiplicity survey:
   - primary mass, M_1
   - # of companions, N

2. We assume:
   - Log-normal field IMF

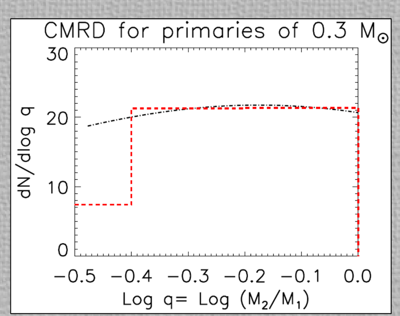
$$\frac{dn}{d\log m} \propto \exp\left\{-\frac{(\log m - \log m_c)^2}{2\sigma^2}\right\}$$

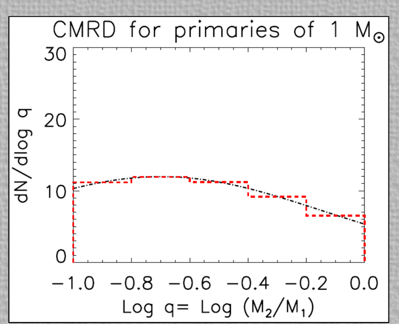
   (Chabrier 2005, Bochansky et al. 2010)
   - the primary mass, M1

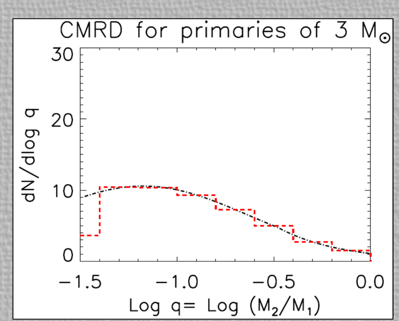
3. We want to reproduce:
   - the number of companions, N
   - M2 from random pairing

4. Monte Carlo simulations of the CMRD, to be compared with observations

5. Kolmogorov-Smirnov (KS) test to evaluate the differences







Simulations of CMRDs of N=50 companions for 0.3, 1 and 3 $M_\odot$ primary mass stars.

Samples

Among the multiplicity surveys in the field we have selected for our analysis three studies, each of which surveyed companions for a restricted range of primary masses (M dwarfs, solar-type stars and intermediate-mass stars).

We considered also three datasets of companions to solar-type stars from nearby star forming regions and open clusters (See Table 1).

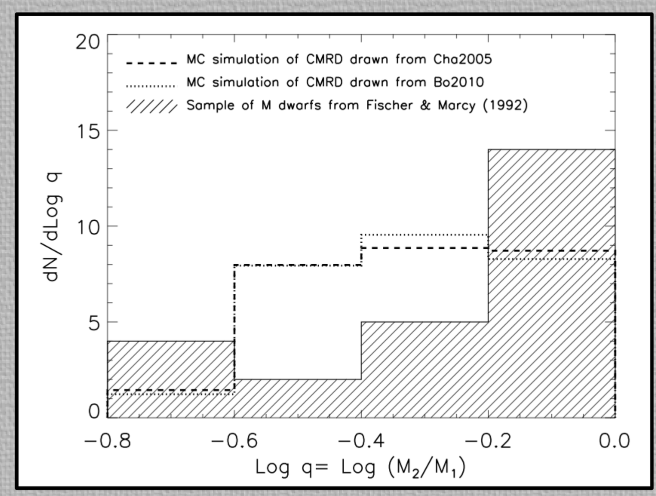
TABLE 1
SAMPLES PROPERTIES

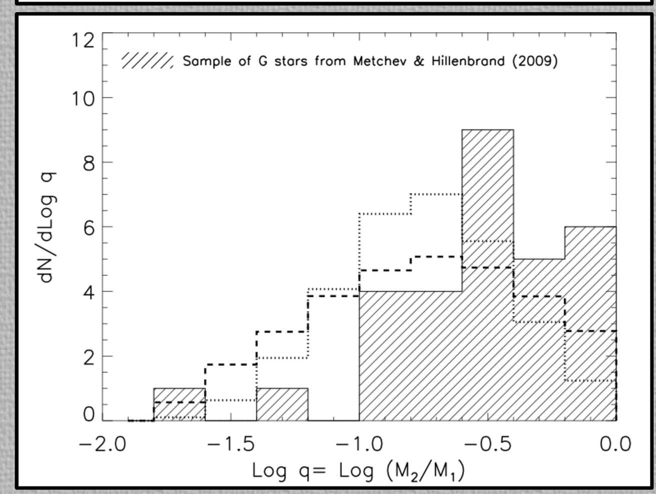
Sample	Reference	Type	No. systems	Separation (AU)
Field	Fischer & Marcy (1992)	M	27	1-2400
Field	Metchev & Hillenbrand (2009)	F/G	30	28-1590
ScoOB2	Kouwenhoven et al. (2005)	A/late-B	60	29-1612
Pleiades	Bouvier et al. (1997)	F/G	22	11-910
α Persei	Patience et al. (2002)	F/G	18	26-581
Chamaeleon I	Lafrenière et al. (2008)	F/G	13	20-800

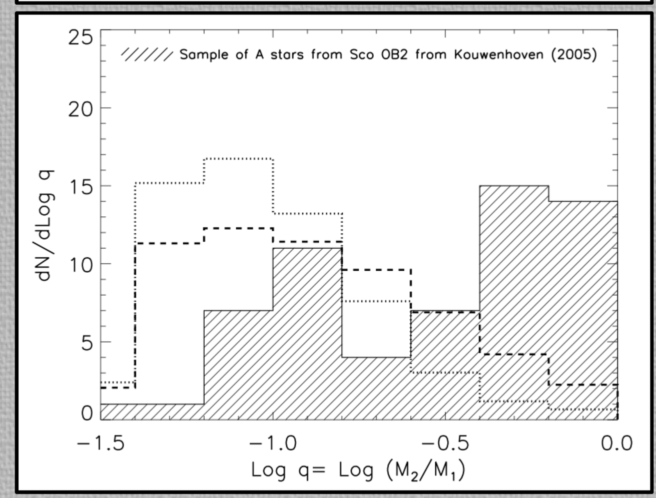
Results

...from the field

M dwarfs: ~1% KS test probability that the observations are consistent with the IMF. There is an overabundance of equal mass binaries in the observed sample compared to the predictions of random pairing.







G and intermediate mass stars: we can reject the hypothesis that the CMRD is consistent with the field IMF at more than 99.9% level. The observed mass ratios are more strongly peaked towards unity than it is shown in the simulations from the IMF.

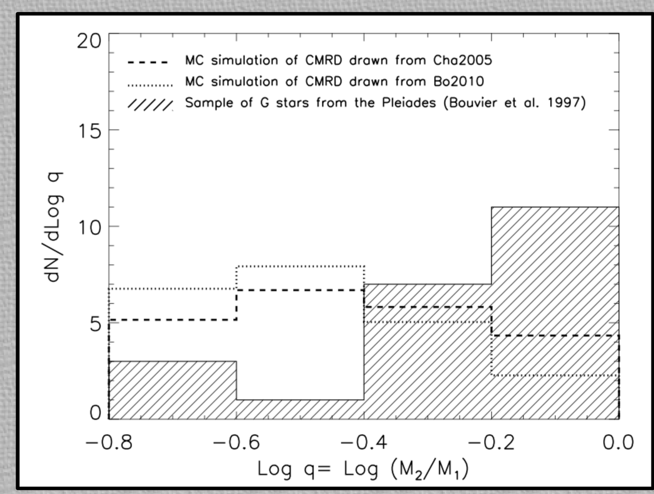
> This overall result would reject the hypothesis that the CMRD is consistent with having been drawn from the IMF and this statement seems to hold independent of the primary mass.

...from star forming regions

Pleiades: we reject the hypothesis of random pairing both in the case of Chabrier 2005 and Bochansky et al. 2010.

Chamaeleon I: we obtain agreement with the IMF (48% and 17% in the case of Chabrier 2005 and Bochansky et al. 2010 respectively). However the number of objects is quite small (13).

α Persei: a 4% KS test probability between Chabrier 2005 and the observations does not allow us to rule out the hypothesis in this case.



> At the moment, we cannot reject the possibility of random pairing in star forming regions. More complete or at least representative surveys of other clusters are needed.

TABLE 2
KS TEST PROBABILITIES

Sample	Cha2005 (%)	Bo2010 (%)	Flat CMF (%)	$dN/dM_2 \propto M_2^{-0.4}$ (%)
Fischer & Marcy (1992)	1	1	58	24
Metchev & Hillenbrand (2009)	0.08	10^{-3}	2	58
Kouwenhoven et al. (2005)	10^{-8}	10^{-13}	0.4	30
Bouvier et al. (1997)	0.07	10^{-4}	34	17
Patience et al. (2002)	4	0.1	27	89
Lafrenière et al. (2008)	47	17	30	76

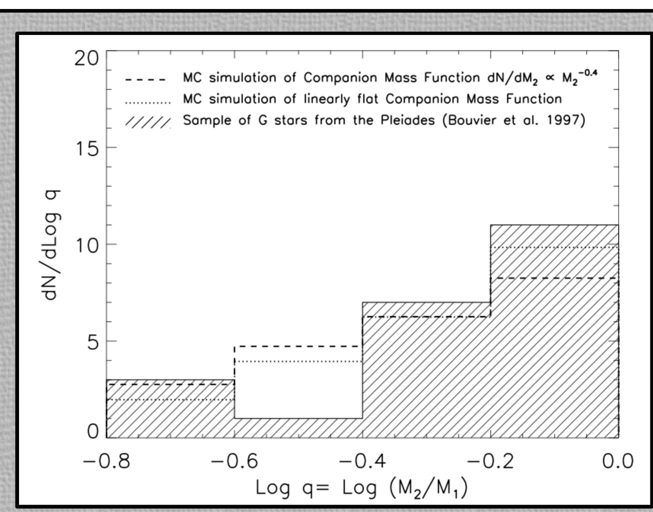
Other companion mass functions

We tested also:

- A flat companion mass function (CMF)
- The "universal" CMF of the form $dN/dM_2 \propto M_2^{-0.4}$

Generally, a flat distribution shows a better agreement with the observations than the IMF. In the field, only for the sample of A and late B-type primary binaries we can reject the hypothesis that the two distributions are consistent while the MC simulations for the young regions match well the observations.

Concerning the "universal" CMF we find a KS probability of agreement exceeding 15% for all samples.



Conclusions & Future prospects

In the field we can reject the hypothesis of CMRD drawn from the single object IMF.

Regarding field stars, the observed CMRDs show a **larger number of equal-mass systems than predicted by the IMF**. This is in agreement with fragmentation theories of binary formation.

In young associations at the moment we cannot reject the possibility of random pairing. Our results could be interpreted in the context of expected dynamical evolution. In any case, **larger and complete samples are needed** to test it.

In the field and in star forming regions, there is **evidence for a universal CMF of the form $dN/dM_2 \propto M_2^{-0.4}$**.

Further binary studies in young clusters are needed to study the dependence of the CMRD on dynamical processes and to test possible variations in the mass ratio distribution as tracers of different star formation mechanisms.
We plan to study the CMRD in Taurus (Reggiani et al. submitted proposal for MMT) **and ONC**.

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