

Globular vs Open Clusters: A Dynamical Perspective

OR

The Formation and Evolution of Mini-Clusters

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What is a “Mini-Cluster”?

- “**Mini-clusters**”: Bound configurations of stars ($N \geq 3$) within star clusters
 - Gravitationally bound (i.e. $E < 0$)
 - Subject to a tidal field from its host cluster
- Strong environmental dependence for mini-cluster formation and evolution
- Intimately connected to star cluster evolution, multiplicity and the formation of stellar exotica

What is a “mini- cluster”?

First, consider a
typical 1+2
encounter in a
dense cluster.

Movie credit:
Aaron Geller
(Northwestern
University)

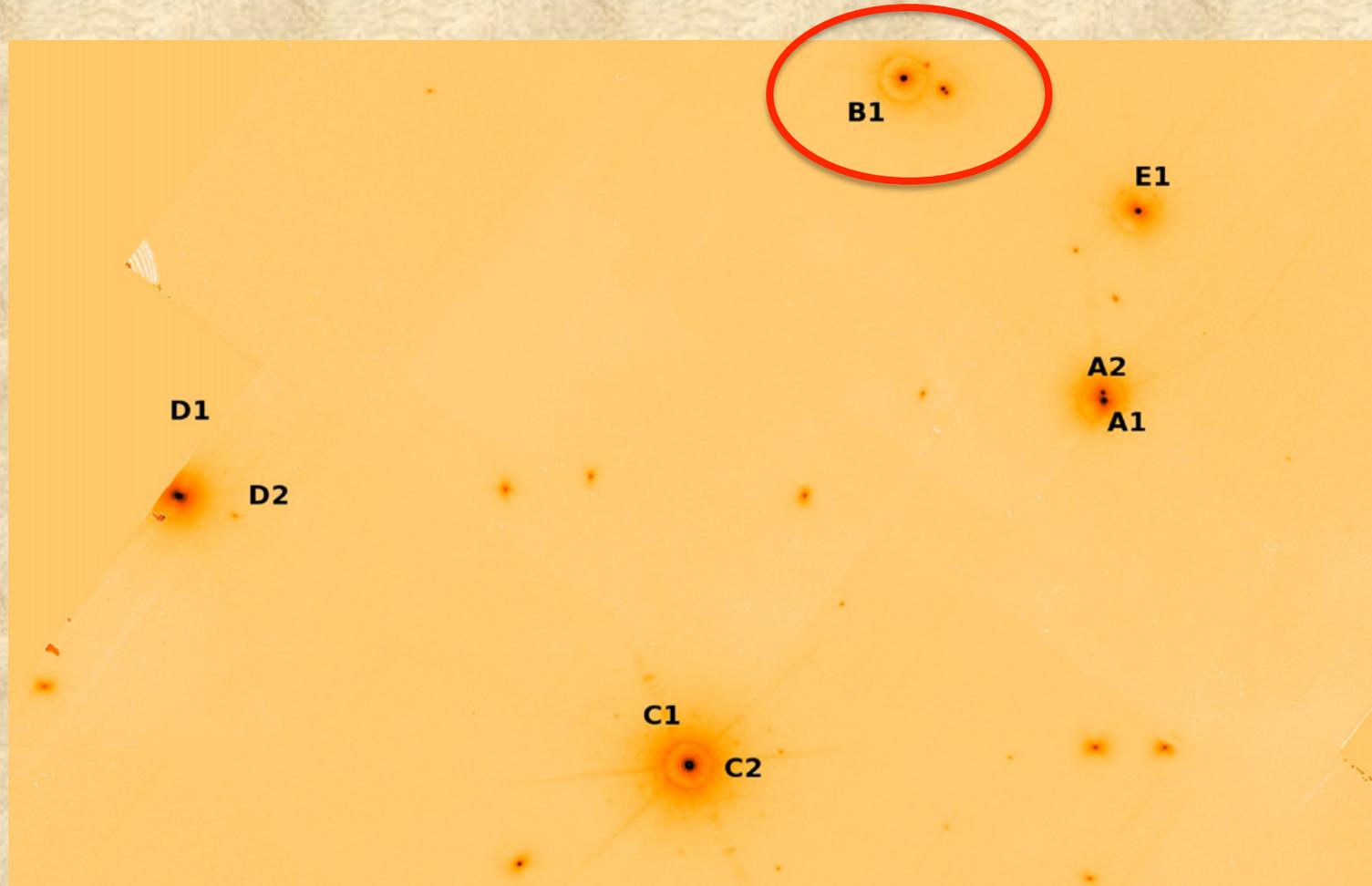


What is a “mini- cluster”?

Next, consider what would happen if another binary star interrupts the ongoing interaction.

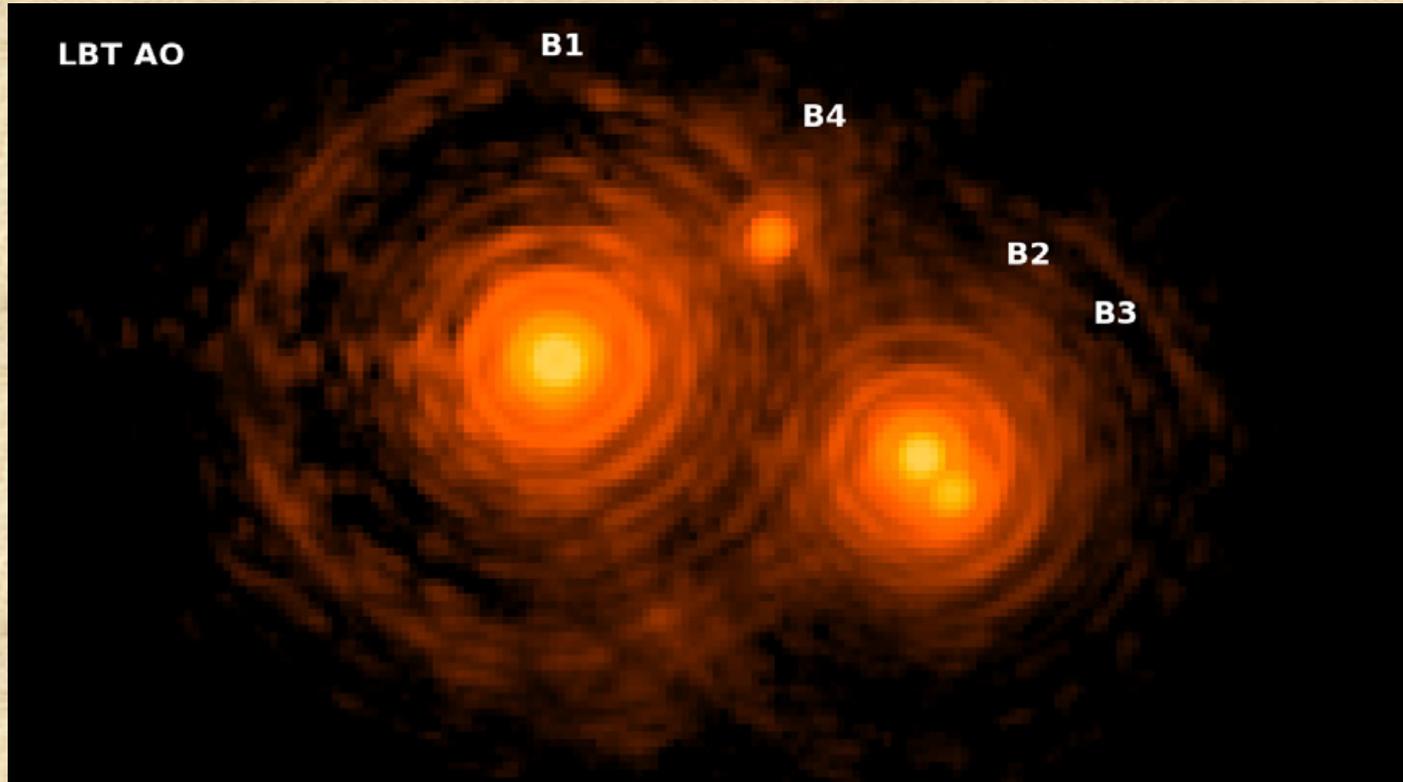
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Motivation



The θ^1 Ori B group in the Orion Trapezium cluster, a “mini-cluster” composed of 5 stars (B5, not seen here, is in a close binary with B1), observed with the 8.4m LBT adaptive secondary AO system (Close et al. 2012, ApJ, 749, 180).

Motivation



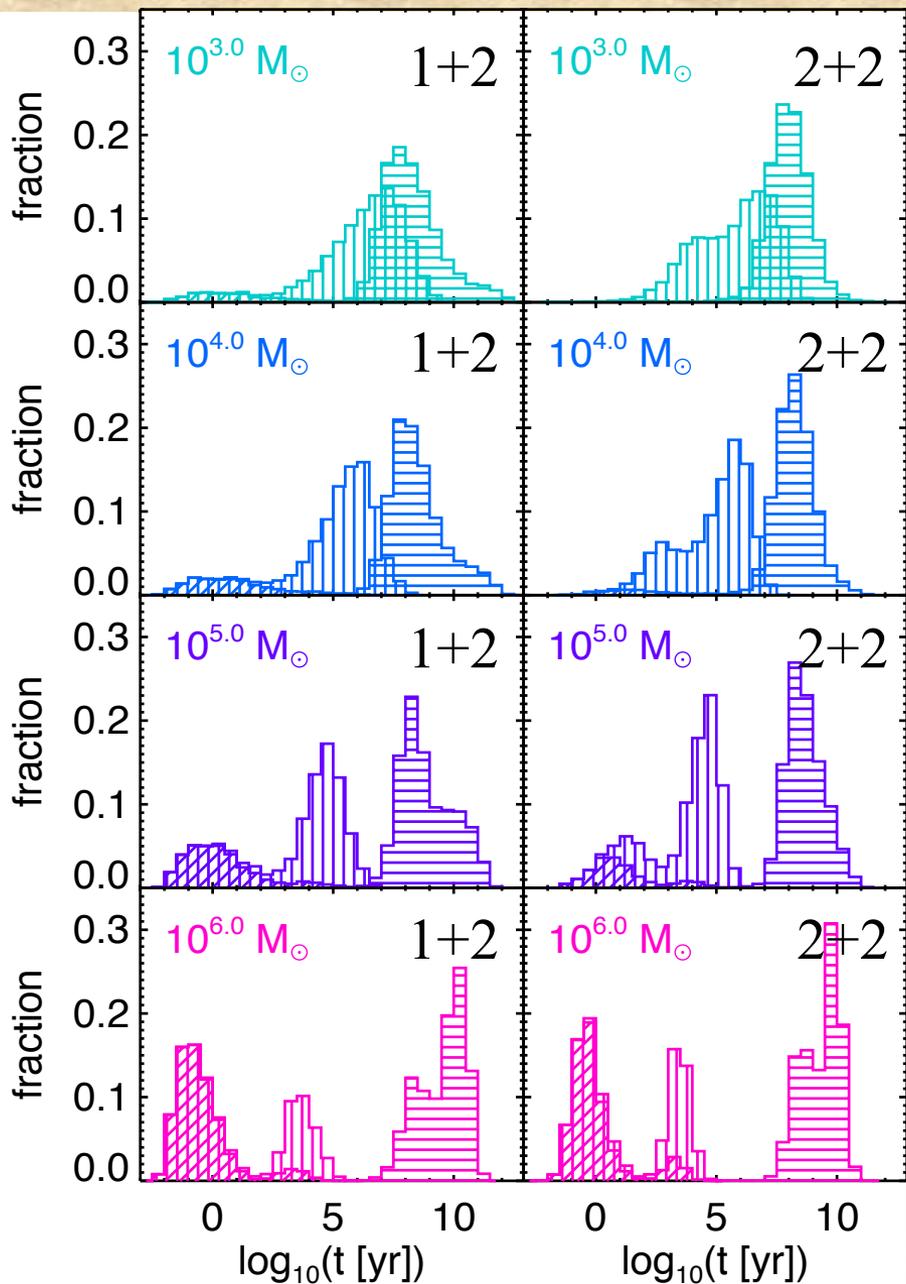
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Motivation

- Several unusual systems have been discovered in old open clusters (OCs):
 - S1082 (M67; van den Berg 2001): a triple with 2 BSs
 - WOCS 013016 (NGC6819; Talamantes et al. 2010): a BS in a coalescing contact binary?
 - WOCS 007006/V3 (NGC6819; Talamantes et al. 2010): a triple containing a BS as the outer companion?
 - Star 7782 (NGC 188; Mathieu & Geller 2009): a short period binary ($P \sim 1$ day) containing two BSs
 - X1 (NGC6819; Gosnell et al. 2012): candidate qLMXB
- What does this imply about OC (and GC) dynamics?

Open vs Globular

Characteristic	Open	Globular
Mass	$M_c \sim 10^2 - 10^3 M_\odot$	$M_c \sim 10^4 - 10^6 M_\odot$
Density	$\rho_0 \sim 10 - 10^3 M_\odot \text{ pc}^{-3}$	$\rho_0 \sim 10^4 - 10^6 M_\odot \text{ pc}^{-3}$
Age	$\tau \sim 1 \text{ Myr} - 1 \text{ Gyr}$	$\tau \sim 10 - 12 \text{ Gyr}$
Velocity Dispersion	$\sigma_0 \sim 0.1-1 \text{ km/s}$	$\sigma_0 \sim 1-10 \text{ km/s}$
Multiplicity	$f_b \sim 10-50\%$ $f_t \sim 2-10\%?$	$f_b \sim 1-10\%$ $f_t \sim ???$
Encounters	$3 \leq N \leq 6? 7? 8?$	$3 \leq N \leq 4$
Exotica	BSs, CVs, qLMXBs?	BSs, CVs, LMXBs, MSPs

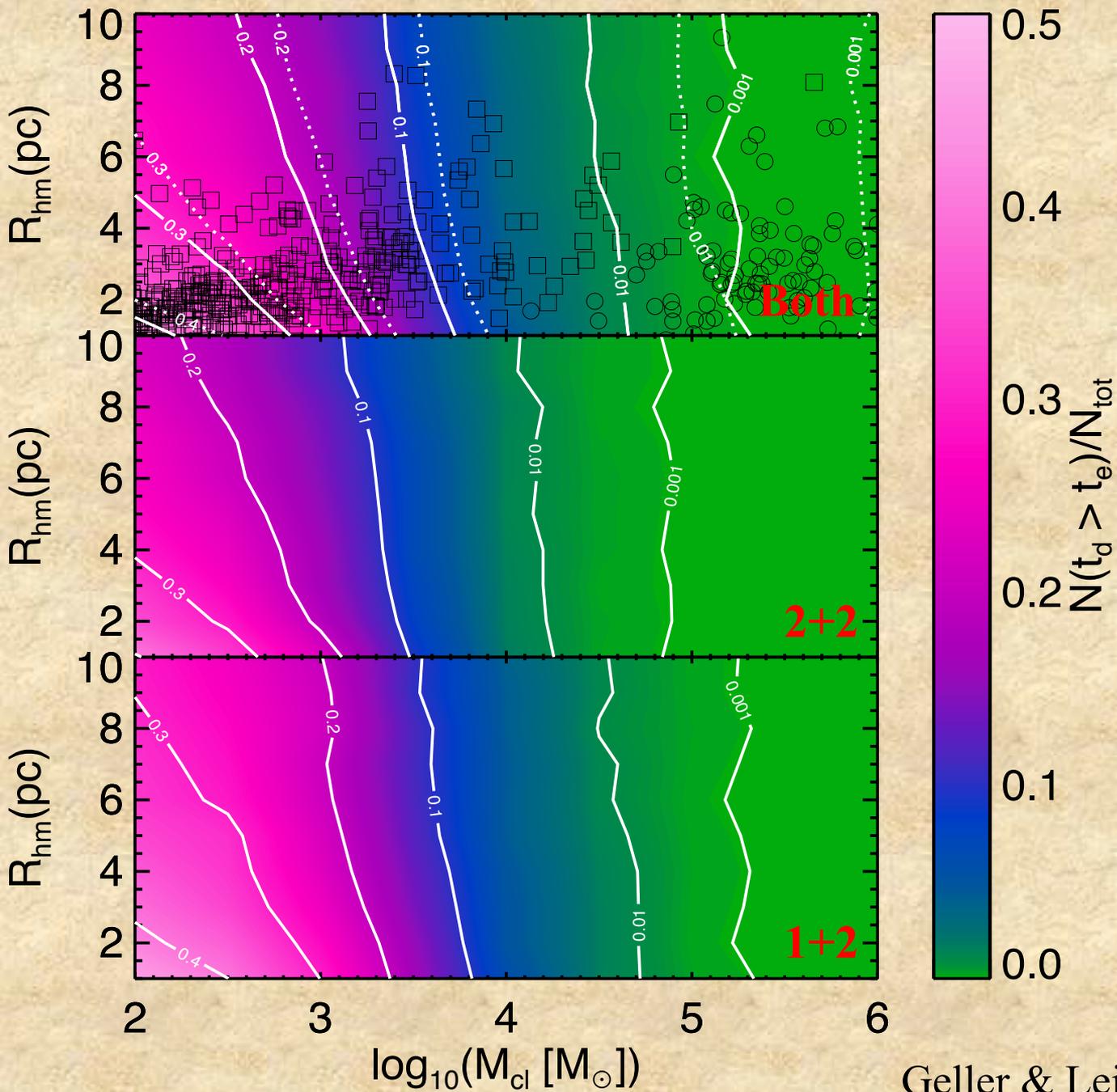


The frequency of interrupted encounters shown via 1+2 (left) and 2+2 (right) scattering experiments performed with FEWBODY, and suitable to clusters with $r_h = 3$ pc and the indicated total cluster masses. The histograms are normalized by the total number of simulations (10^4 for each inset).

Horizontally-hatched: Time until the next encounter.

Vertically-hatched: Total encounter duration.

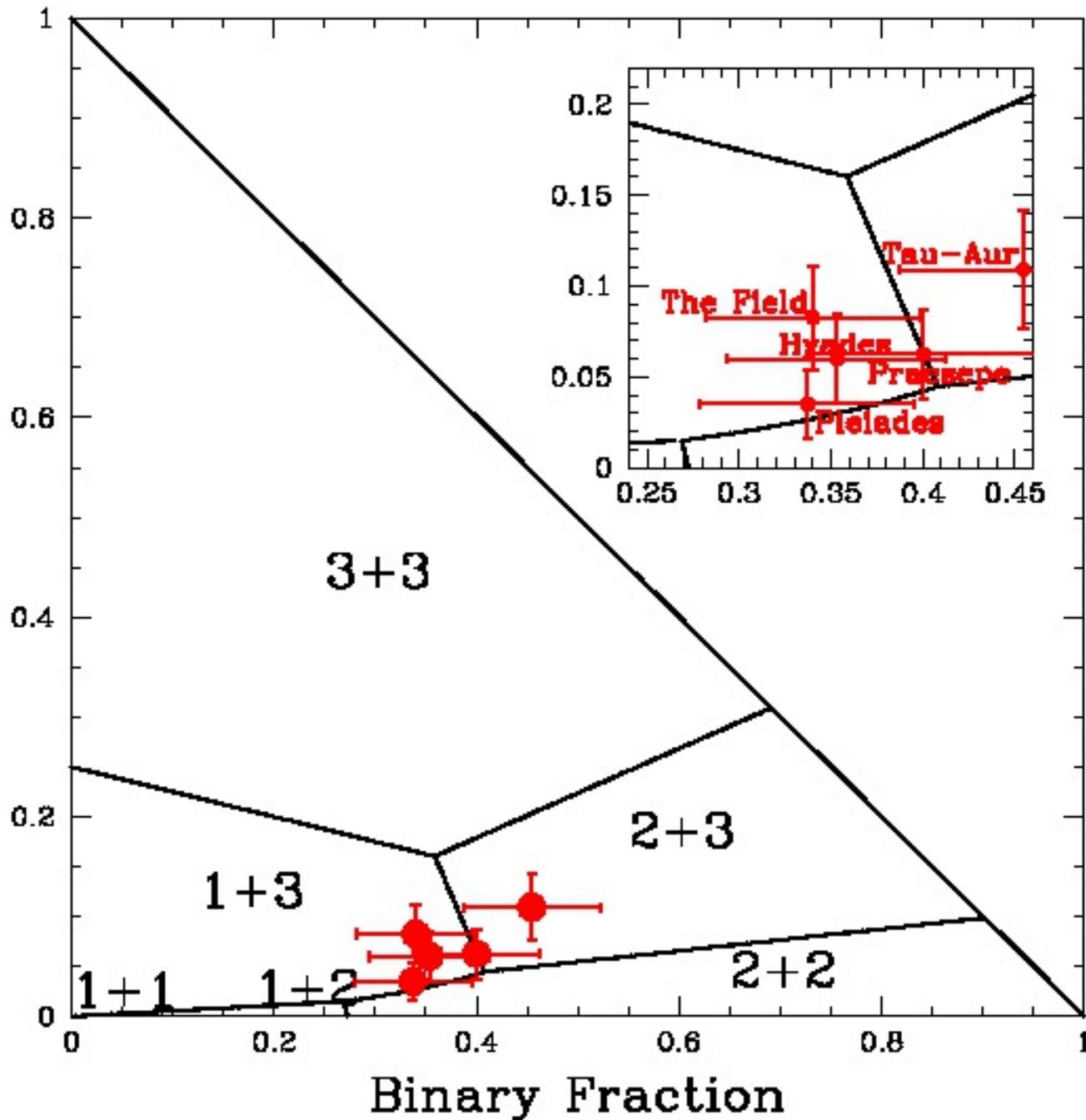
Diagonally-hatched: Encounters that resulted in at least 1 (left) and 2 (right) direct collision(s).



Contour plots showing the fraction of interrupted 1+2 (bottom) and 2+2 (middle) encounters, as well as their combined fraction (top).

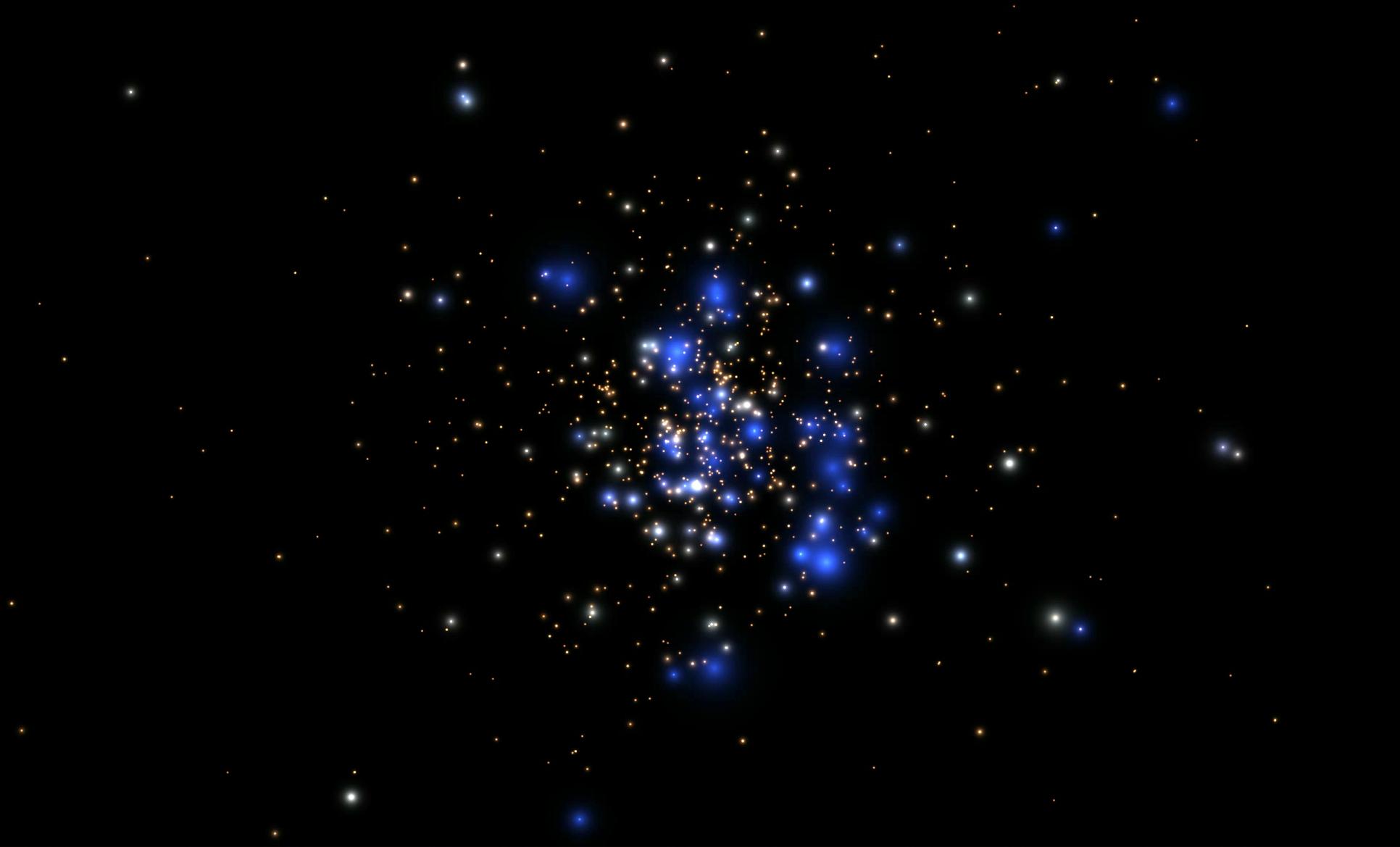
The open circles and squares show the observed data for a suite of globular and open clusters, respectively. These data are taken from Harris (1996), Piskunov et al. (2008) and Kharchenko et al. (2013).

Triple Fraction



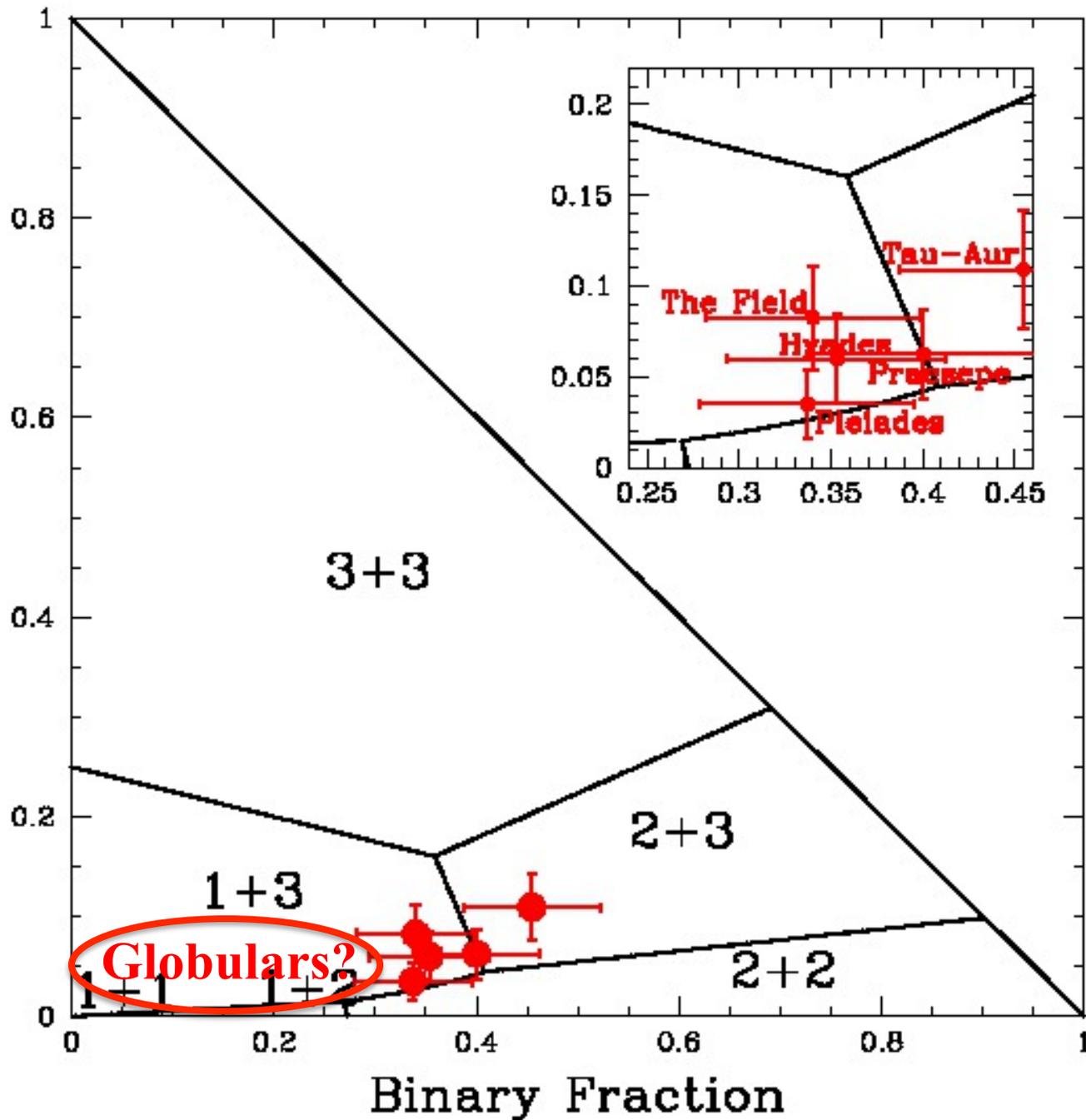
For surprisingly small numbers of triples, they can be undergoing dynamical encounters as frequently as either single or binary stars.

Leigh & Geller
2013, MNRAS,
432,2474



N-body simulation of a Pleiades-like cluster. Movie credit: Aaron Geller (Northwestern University; <http://faculty.wcas.northwestern.edu/aaron-geller/visuals.php>).

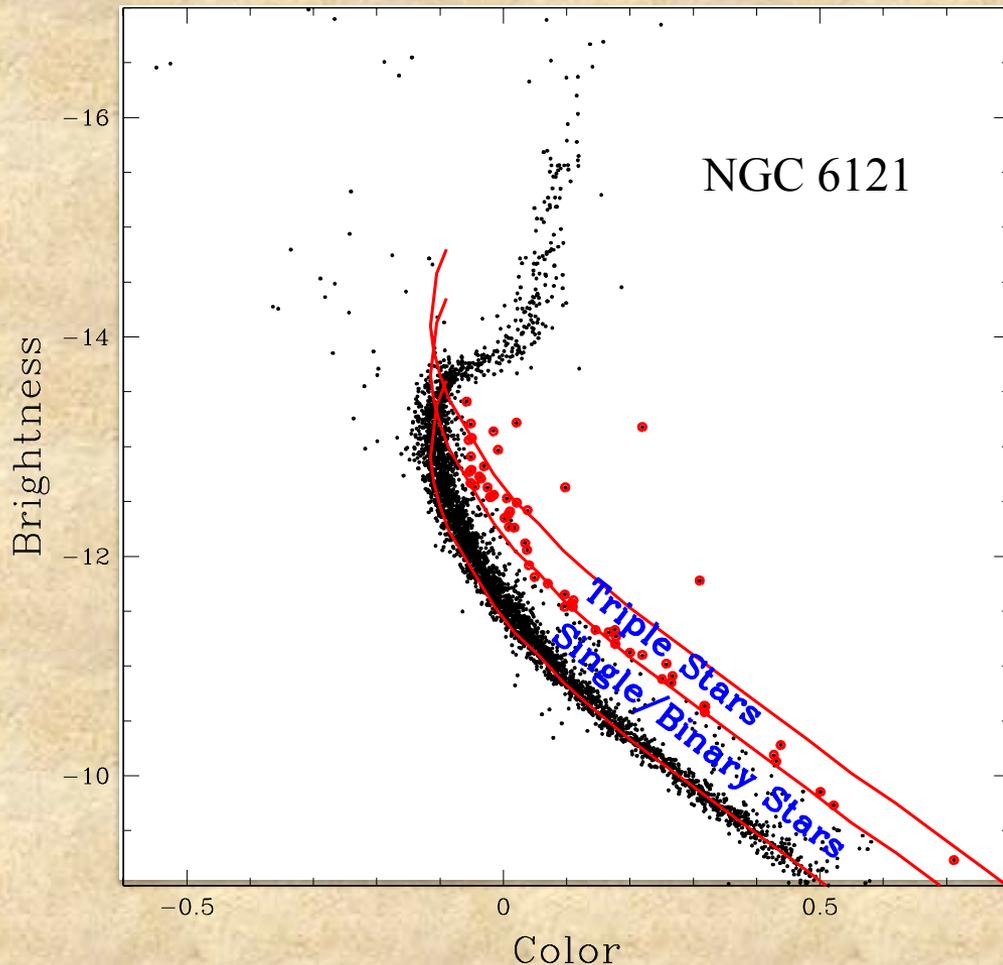
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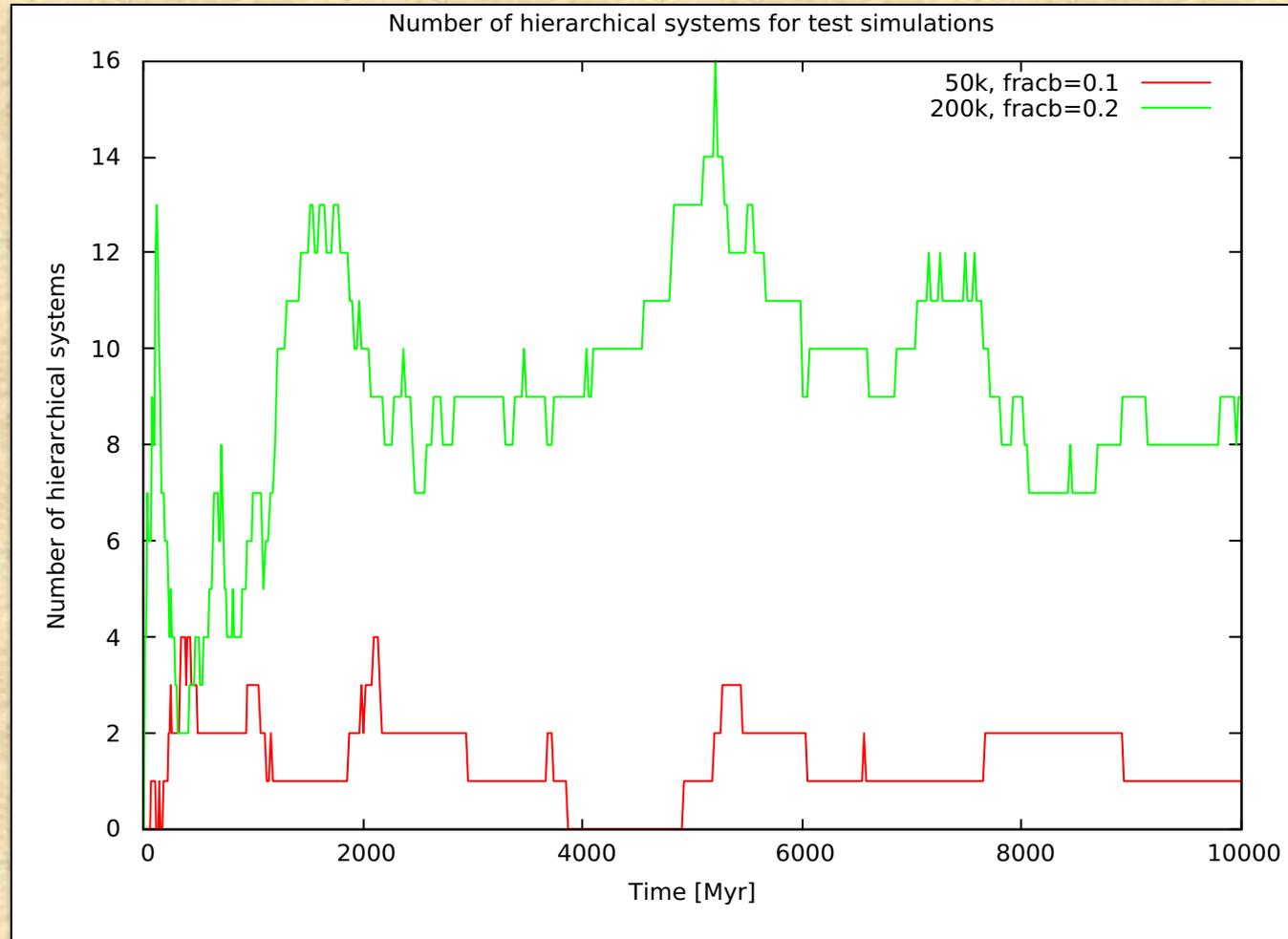
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What about globular clusters?



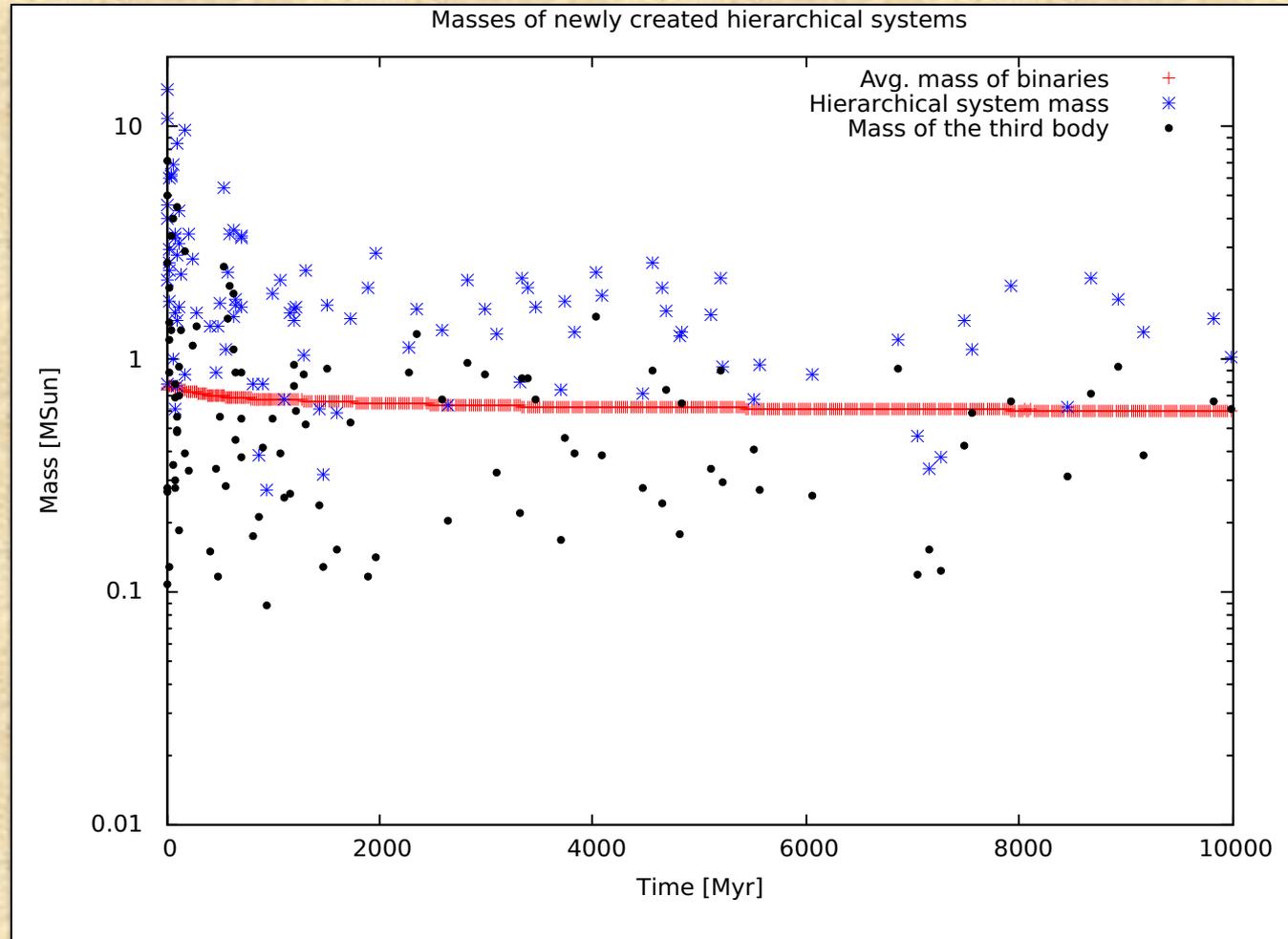
There are 60 triple candidates shown here, and this is a *lower limit*. This implies $f_t \geq 1\%$. The probability of a chance alignment of stars occupying this region of the CMD is $< 1\%$. Thus, some of these triple candidates are *real*.

Globular Cluster Simulations



MOCCA Monte Carlo simulations for globular cluster evolution, with $N=50k$ (red) and $N=200k$ (green), showing the time evolution of the number of higher-order multiples (Hypki & Giersz, in preparation).

Globular Cluster Simulations



MOCCA Monte Carlo simulations for globular cluster evolution ($N=200k$) showing the time evolution of the mean binary mass along with the masses of any dynamically-formed triples (Hypki & Giersz, in preparation).

Summary

- “Mini-clusters” form in star clusters of all types
- Up to $\sim 20\text{-}40\%$ of all small-N encounters can be interrupted in compact low-mass open clusters
- This is $\leq 1\%$ in most globular clusters
 - Good news for Monte Carlo models of cluster evolution
 - Encounters with $N > 4$ require triples
 - Triples should be present in GCs, albeit with short encounter times