Evolution of the Binary Fraction in Globular Clusters

John Fregeau
UCSB-KITP
The properties of globular clusters encode details of the galaxy formation process (Ashman & Zepf 1992).

Unfortunately, many seemingly fundamental properties of globular clusters lack convincing explanations (c.f. multiple He abundance in some clusters).

Triple MS of NGC2808 (Piotto 2008)
Initial Conditions?

- Ideally, one would like to know the properties of globular clusters at formation, since these properties relate directly to galaxy formation (and, of course, star formation in clusters).

- The clusters that can be observed best (those in our Galaxy), are almost universally old.

- Young super star clusters in other galaxies (as well as Westerlund 1 in our own Galaxy) yield some clues, since they are thought to be analogs of proto-globulars.

- A promising path is to perform “population synthesis” of cluster populations, via direct simulation of their evolution.
Current cluster core binary fractions are difficult to determine, but can be measured via, e.g., main-sequence fitting, radial velocity surveys, and extrapolation from observations of a few key populations (e.g., BY Dra, W UMa binaries).

While the observed binary fraction in low stellar density environments like the field and open clusters is rather large (>~50%), the binary fraction observed in globular cluster cores ranges from a few % to ~30%.

Is this low current binary fraction consistent with a relatively large initial binary fraction?

MS method in NGC 6397 (Davis, et al. 2008)
Binary Fraction Evolution

Many strongly coupled processes affect the binary population in a cluster:

- Internal to cluster: binary scattering interactions, binary stellar evolution, stellar collisions, mass segregation.

- External to cluster: tidal stripping due to host galaxy, disk shocking.

- Possible, but likely irrelevant: tidal capture, three-body binary formation.

The binary fraction is thus a good test of the degree of our understanding of cluster evolution.
N-Body vs. Simplified Monte-Carlo

N-Body (Hurley, et al.)

- “Kitchen sink” model since it includes all relevant physics and makes no simplifying assumptions.
- Computationally very expensive and requires special-purpose hardware.
- Finds generally that cluster core binary fraction increases (greatly) with time.

Simplified MC (Ivanova, et al.)

- Simplified dynamical model (constant density cluster core with extended halo), coupled with detailed treatment of stellar evolution, collisions, scattering interactions.
- Computationally less expensive, allowing parameter space studies.
- Finds generally that cluster core binary fraction always decreases (greatly) with time.
Apples vs. Oranges

\[ \log_{10}(n_c/pc^{-3}) \]

\[ f_{b,c} \]

- Ivanova, et al.
A Modern MC Code

- Monte Carlo method: stochastic solution of the Fokker-Planck equation using discrete representation of distribution function.

- Computation cost scales as $N \log N$ ($N$-body scales as $N^2$).

- Yields physical realization of cluster at each time step, allowing for inclusion of additional physics (binary interactions, stellar evolution, collisions, etc.)

- Have recently incorporated single and binary stellar evolution via “BSE” code (Hurley, Pols, & Tout 2000; Hurley, Tout, & Pols 2002).
Comparison w/ N-body (Hurley 2007)

N-body, \( f_b = 0\% \)
N-body, \( f_b = 5\% \)
N-body, \( f_b = 10\% \)
MC
MC (no SE)
MC (no tide)
Typical Evolution (R=8pc, fb=0.3)
General Evolution (R=8pc)
Comparison to Apples and Oranges?
General Evolution (R=2pc)
Preliminary Conclusions

- As suggested by earlier N-body calculations, the quasi-equilibrium, binary burning phase is certainly not generic.

- Core binary fraction generically increases with time, suggesting that either: 1) globular clusters were “born” with very small numbers of binaries, or 2) we simply haven’t found the appropriate cluster initial conditions.

- Although we haven’t exhaustively sampled parameter space, it appears difficult to create clusters which survive a Hubble time.
Forthcoming Studies

- Central BH: loss cone physics added; comparison with new HST observations showing a range of weak central density cusps; hints for the existence of IMBHs?

- Dynamical influence of stellar collisions: the accelerated mass loss due to collisions may provide enough energy to produce core sizes compatible with observations.

- Detailed study of production of individual species (LMXBs, CVs, BSSs, MSPs): first to compare with semi-analytical study of Fregeau (2008), then to model individual clusters (e.g., M4, 47 Tuc, NGC 6397).

- Synthetic observables: H-R diagrams, surface brightness profiles, etc.