

Open Clusters:

N-body models ...

Jarrod Hurley



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NBODY4/6 software

(Aarseth 1999, PASP, 111, 1333
Hurley et al. 2001, MN, 323, 630)

- includes stellar evolution
 - ▶ fitted formulae as opposed to “live” or tables
 - ▶ rapid updating of M , R etc. for all stellar types and metallicities
 - ▶ done in step with dynamics
- and a binary evolution algorithm
 - ▶ tidal evolution, magnetic braking, gravitational radiation, wind accretion, mass-transfer, common-envelope, mergers
- and as much realism as possible
 - ▶ perturbed orbits (hardening & break-up), chaotic orbits, exchanges, triple & higher-order subsystems, collisions, etc.
 - ... regularization techniques
 - + Hermite integration with GRAPE
 - + block time-step algorithm
 - + external tidal field ...

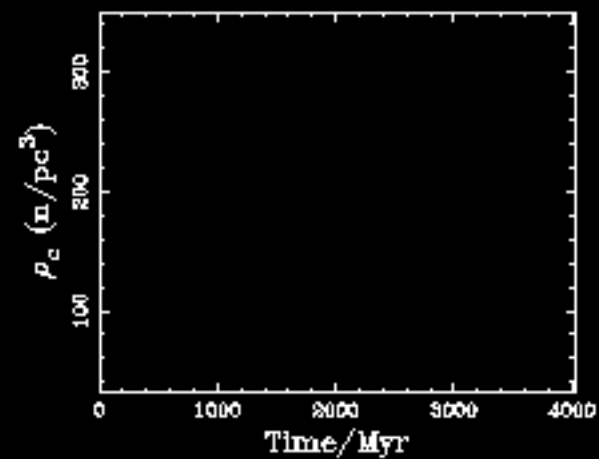
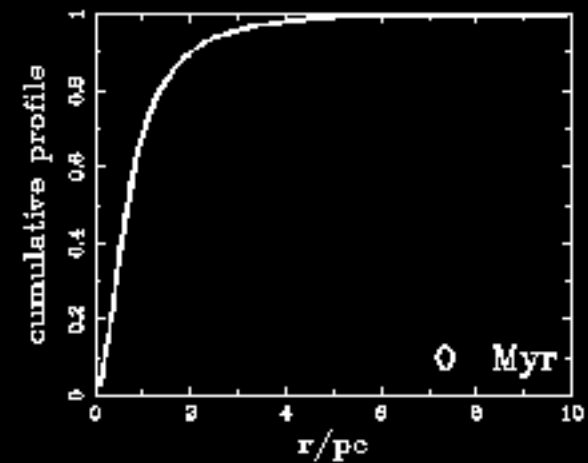
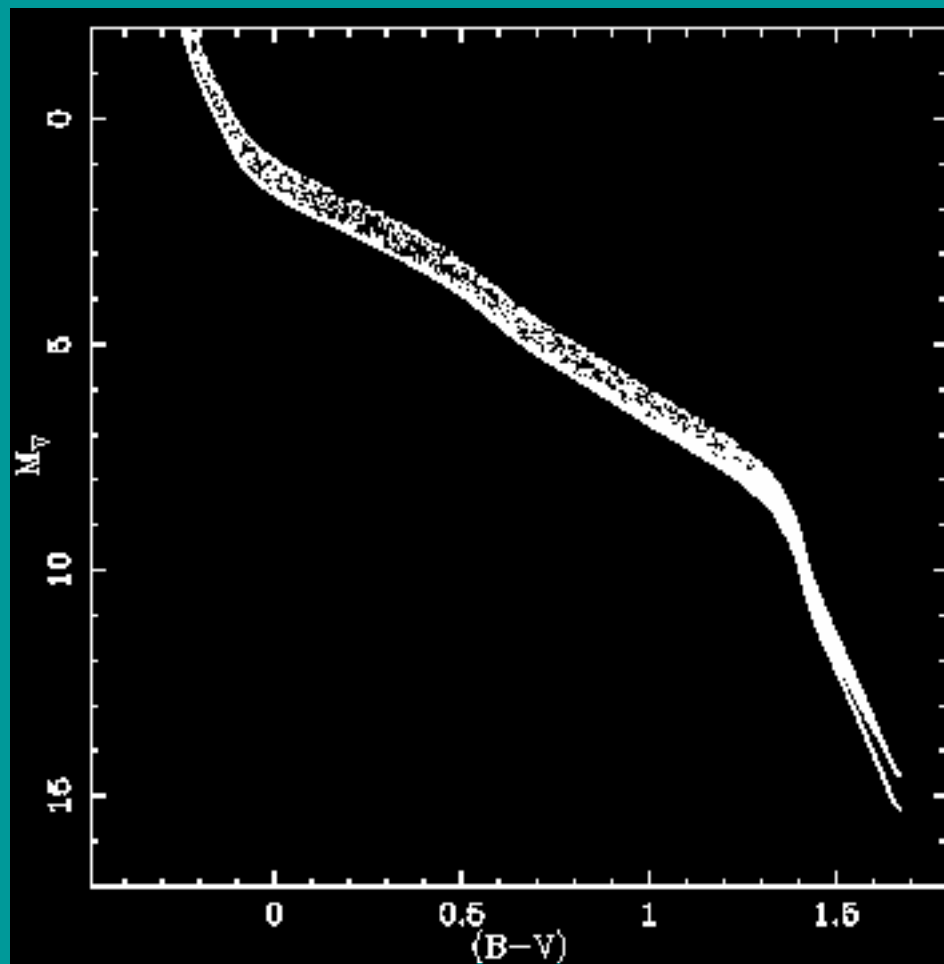
Simulation of a Rich Open Cluster

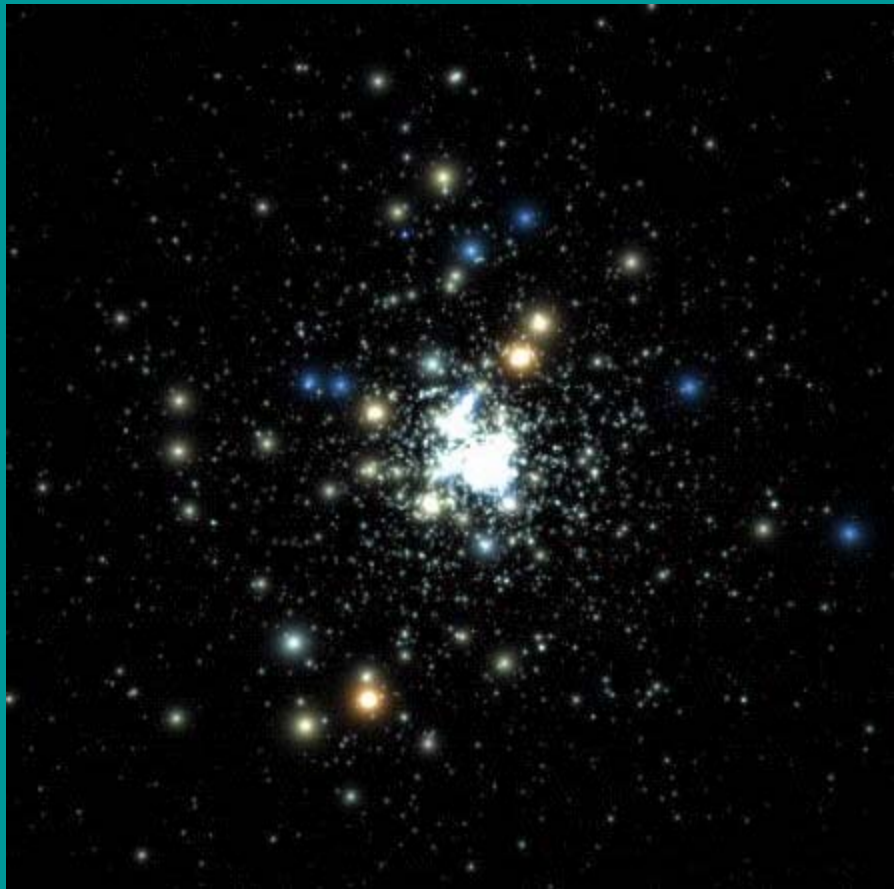
➔ Initial Conditions

- 12,000 single stars ($0.1 - 50 M_{\odot}$)
- 12,000 binaries (a : flat-log, e : thermal, q : uniform)
- solar metallicity ($Z = 0.02$)

- Plummer sphere in virial equilibrium
- circular orbit at $R_{gc} = 8$ kpc
 - ▶ $M \sim 18700 M_{\odot}$
 - ▶ tidal radius 32 pc
 - ▶ $T_{rh} \sim 400$ Myr
 - ▶ $\sigma \sim 3$ km/s
 - ▶ $n_c \sim 200$ stars/pc³

 - ▶ 6-7 Gyr lifetime
 - ▶ 4-5 weeks of GRAPE-6 cpu

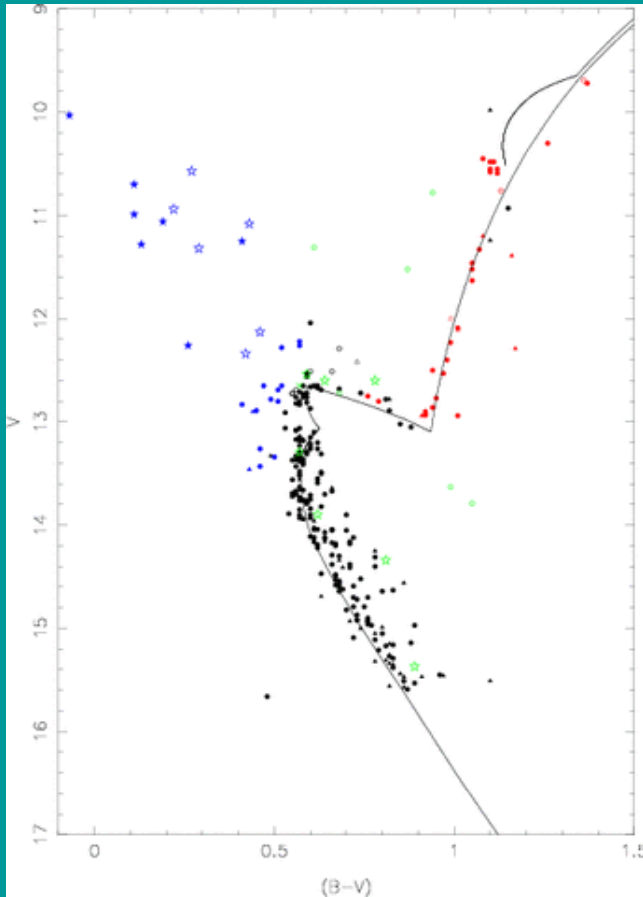




M67 at 4 Gyr?

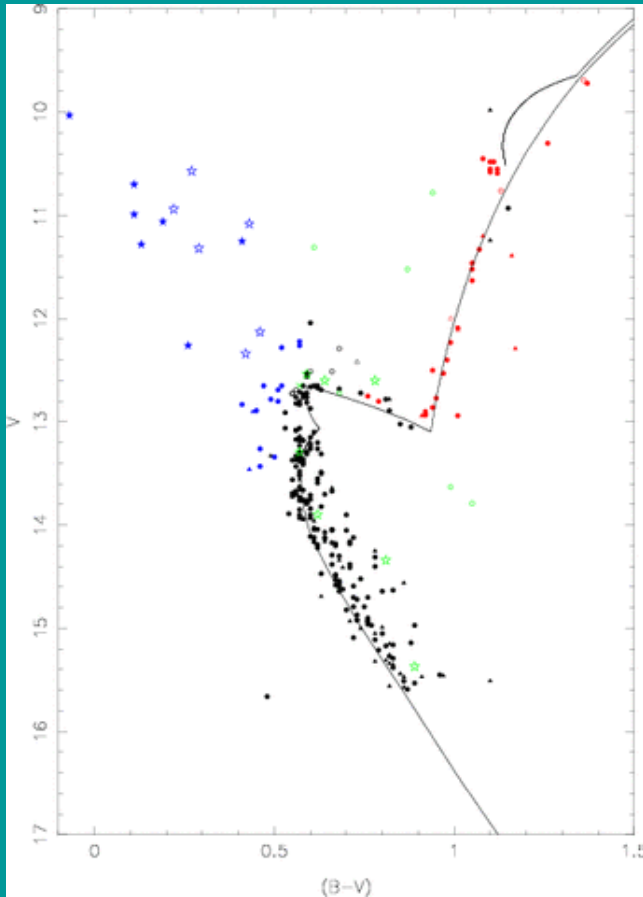
- solar metallicity ✓
- 50% binaries ✓
- $N \sim 2000$ and $1300 M_{\odot}$ luminous mass ✓
- tidal radius 15pc ✓
- half-mass radius 2.5pc ✓
- core radius 0.6pc ✓

M67 Observed CMD



- 29 blue stragglers
- $N_{bs}/N_{ms,2TO} \sim 0.15$
- centralized population
- half in binaries

M67 Observed CMD

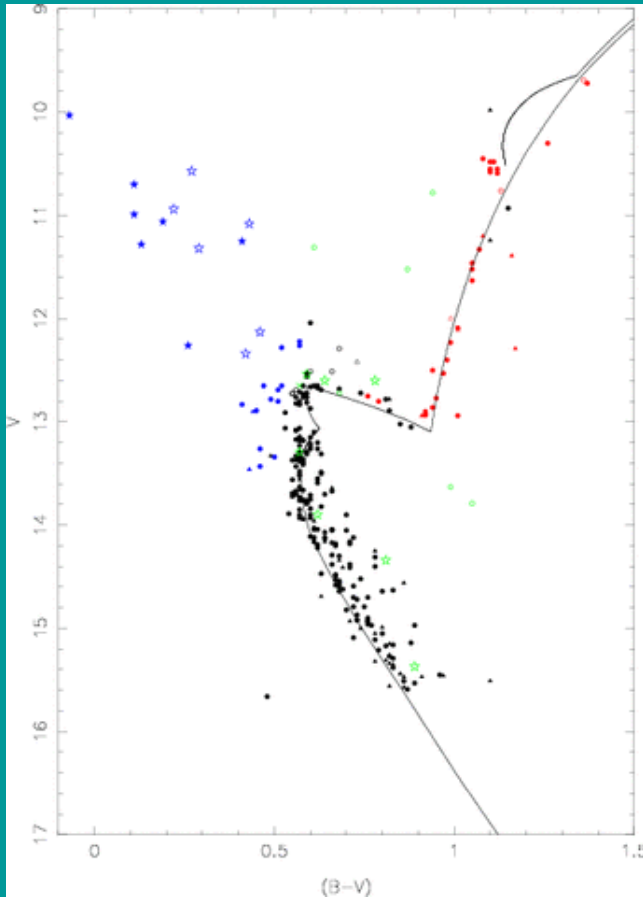


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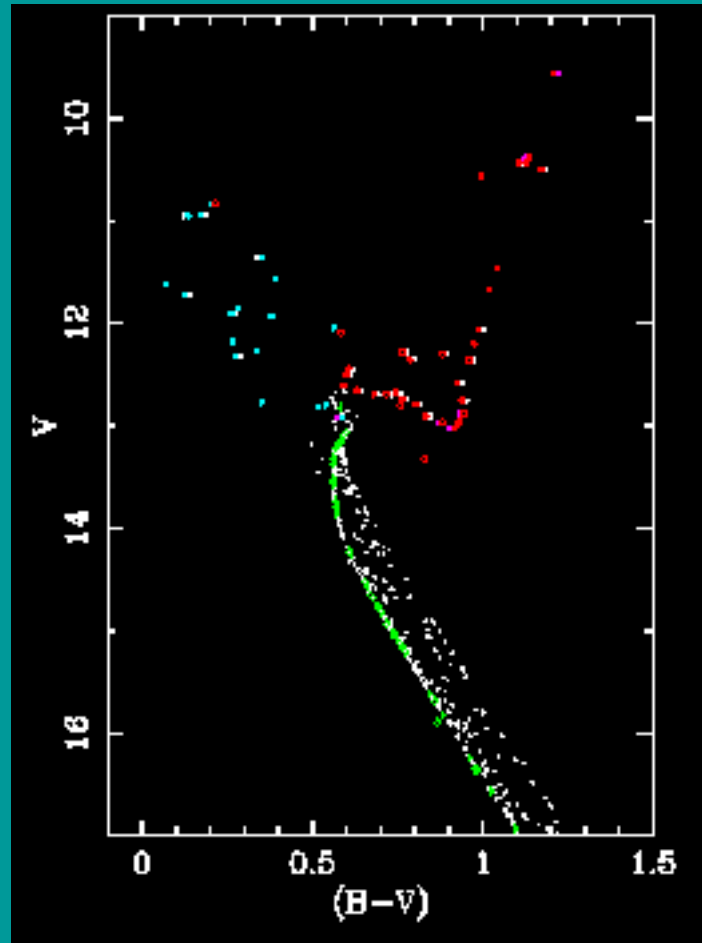
4d, $e=0.2$
846d, $e=0.5$
1003d, $e=0.3$
1221d, $e=0.1$

M67 Observed CMD



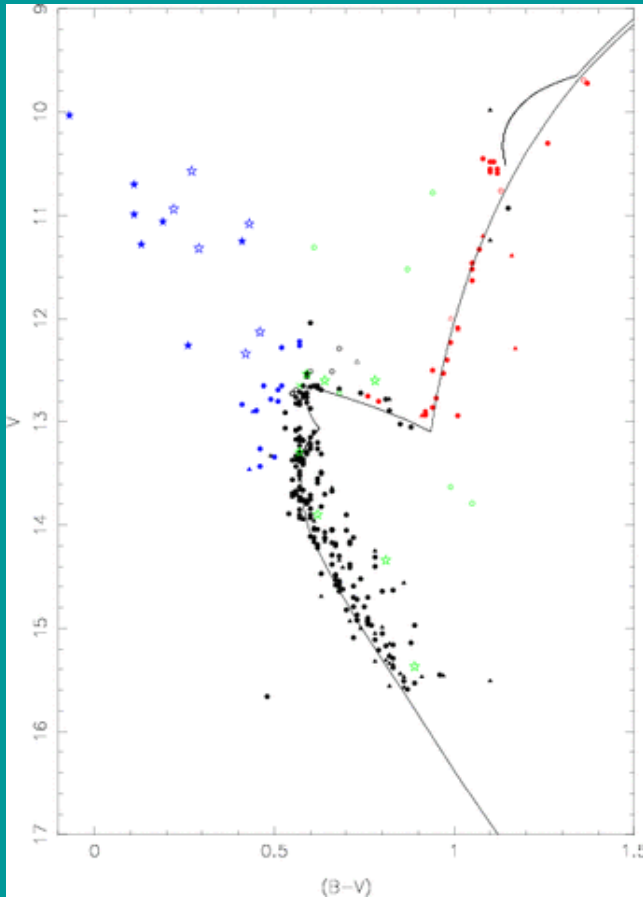
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N-body Model CMD



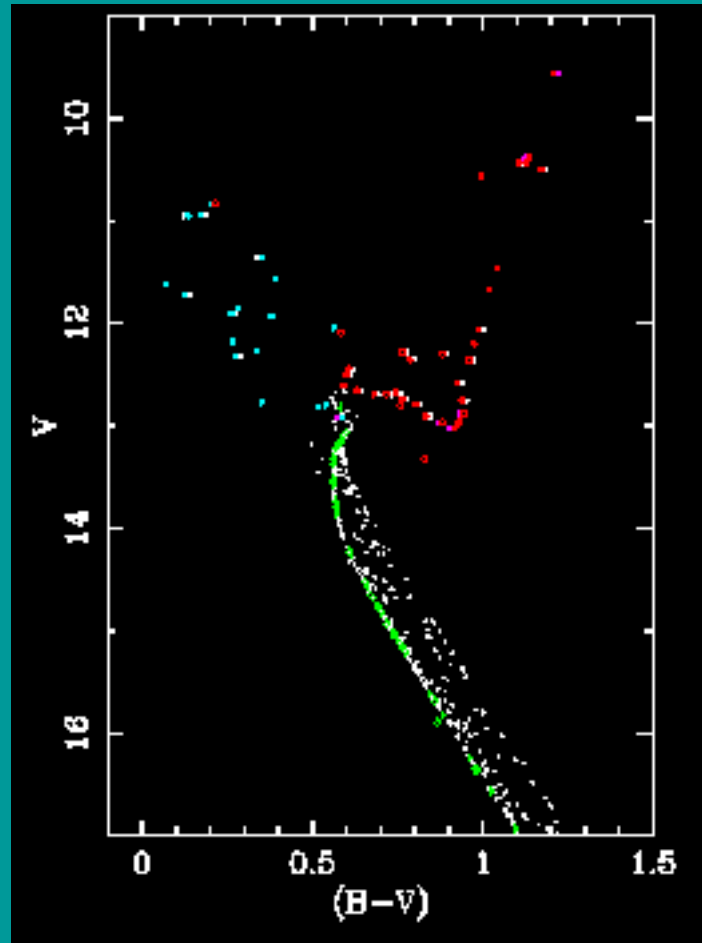
- 25 blue stragglers
- $N_{bs}/N_{ms,2TO} = 0.18$
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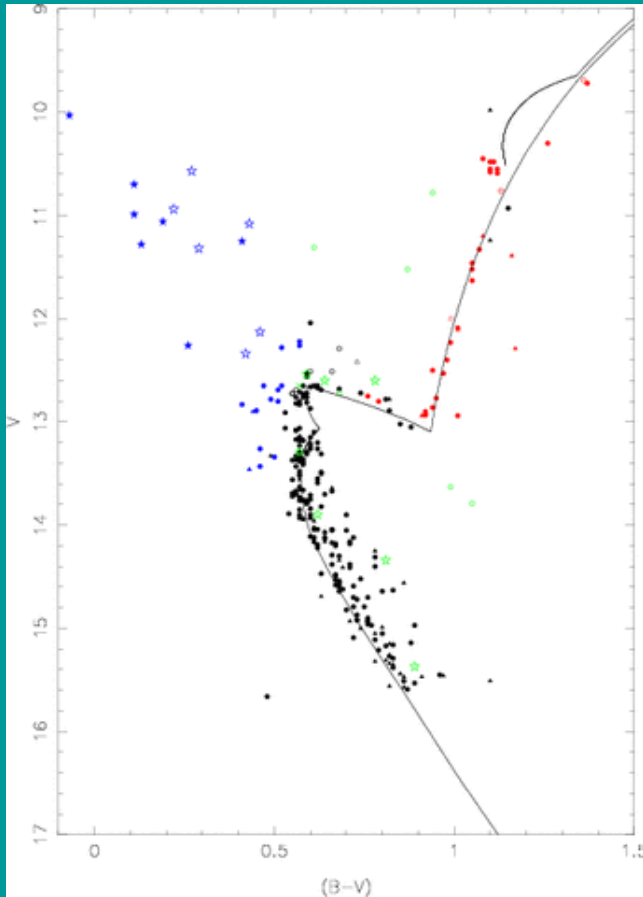
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N-body Model CMD



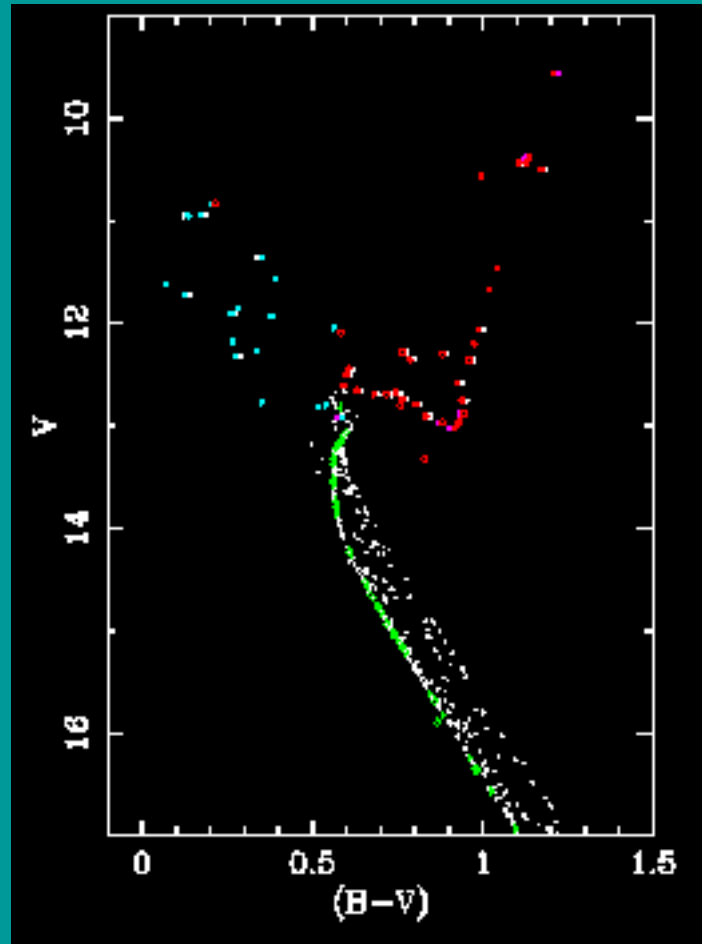
- 25 blue stragglers \longrightarrow 15 via dynamics
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N-body Model CMD

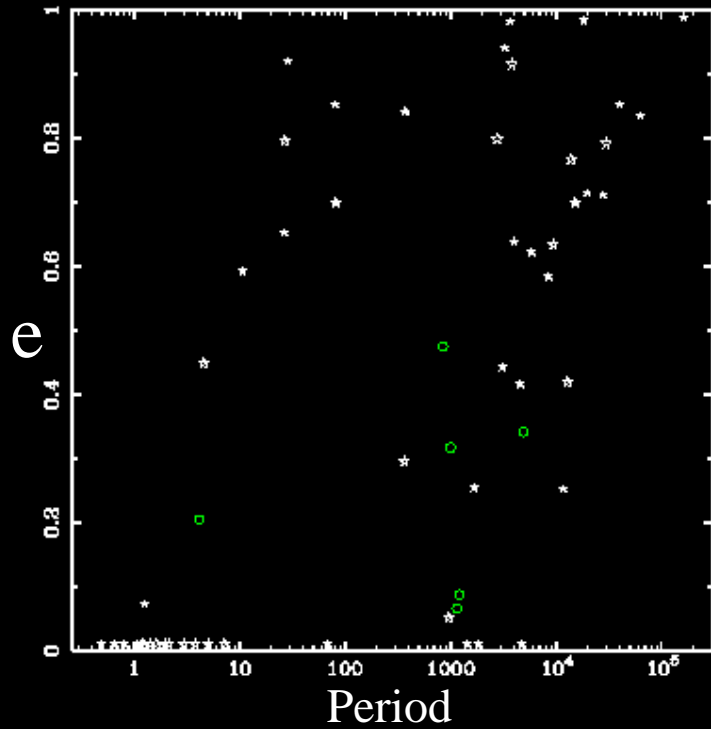


- triples
- exchanges
- collisions
- hardening



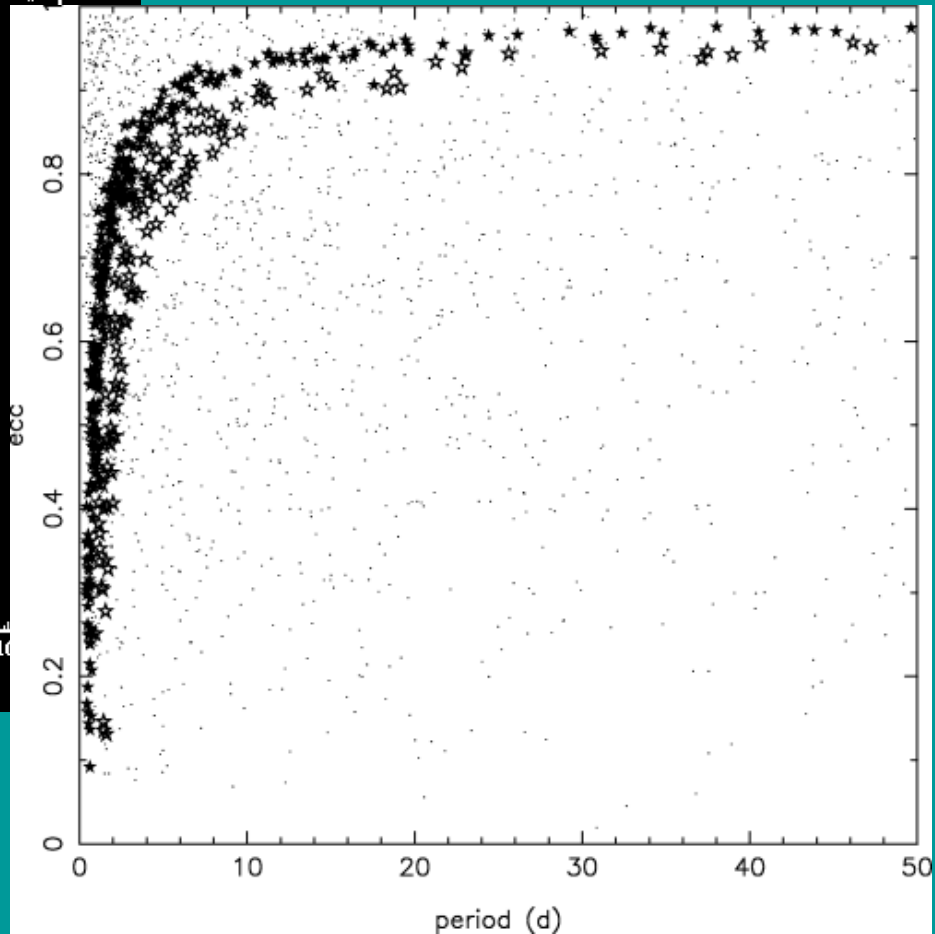
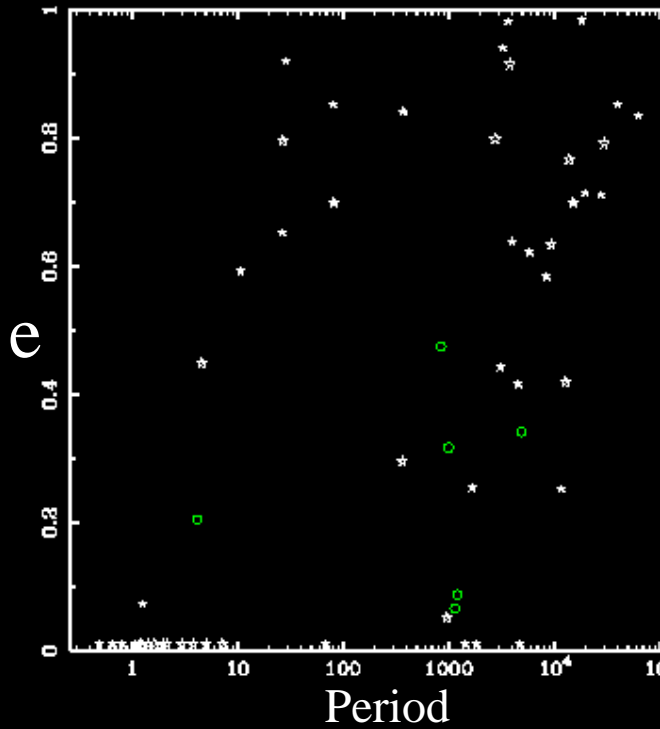
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BS-binaries (3-4 Gyr)



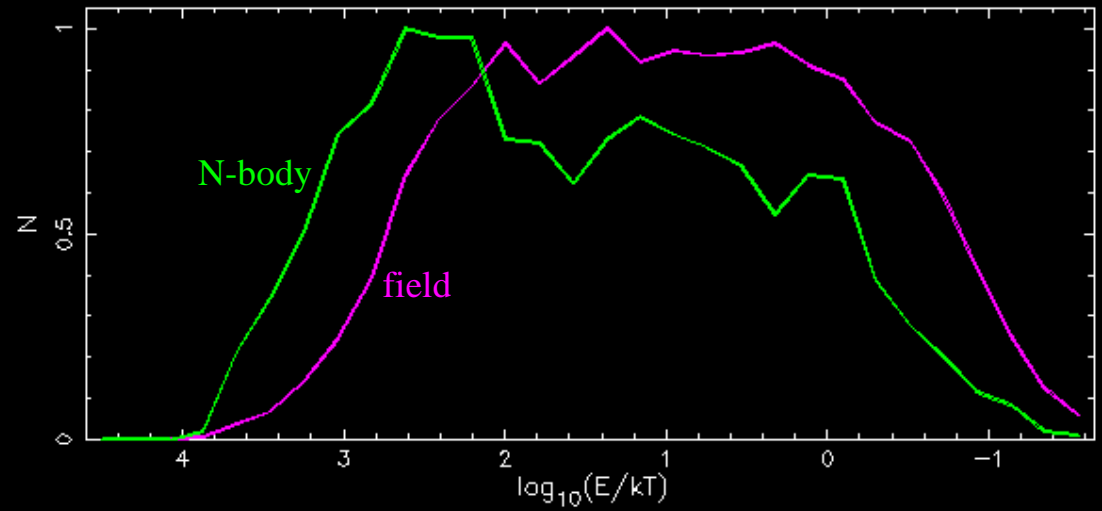
← all observed orbital configurations

BS-binaries (3-4 Gyr)

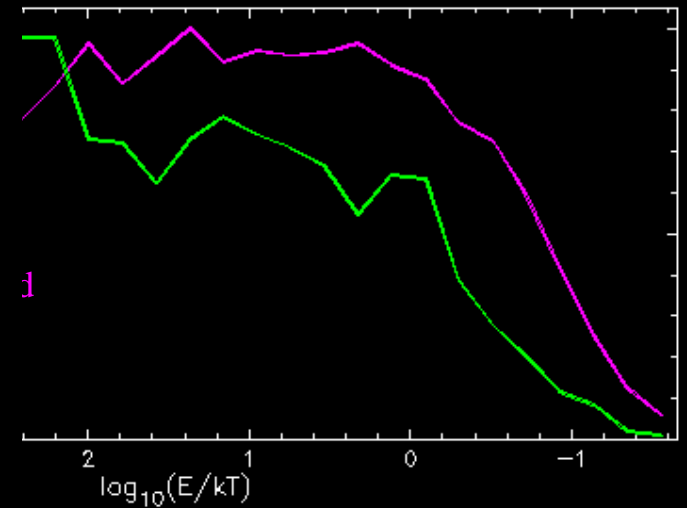
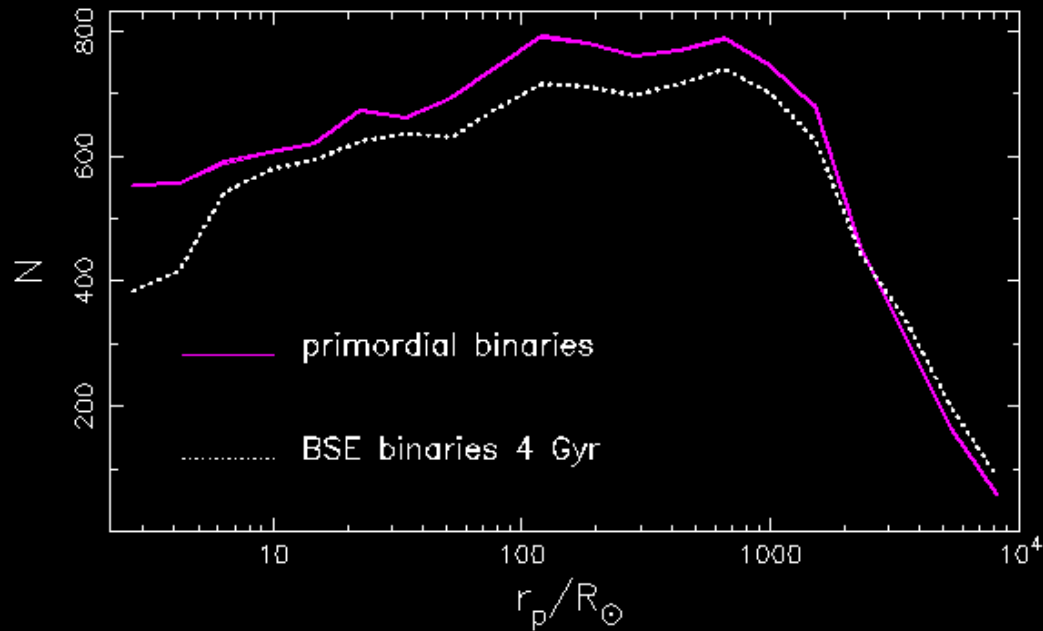


$P_{\text{circ}} \sim 7\text{-}8\text{d}$ (binary evolution) cf. $\sim 12\text{d}$ observed
-> same or slightly less for M67 simulation
-> increase for 100k simulations?

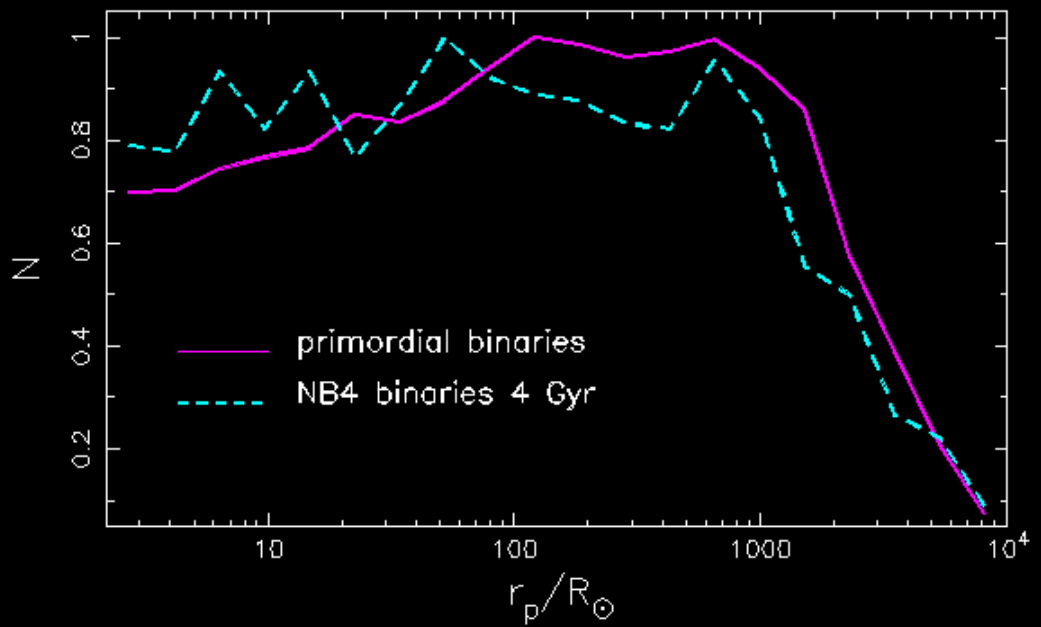
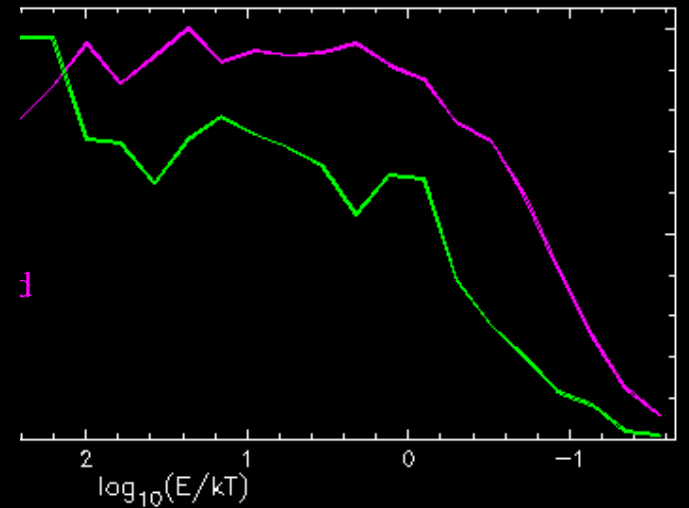
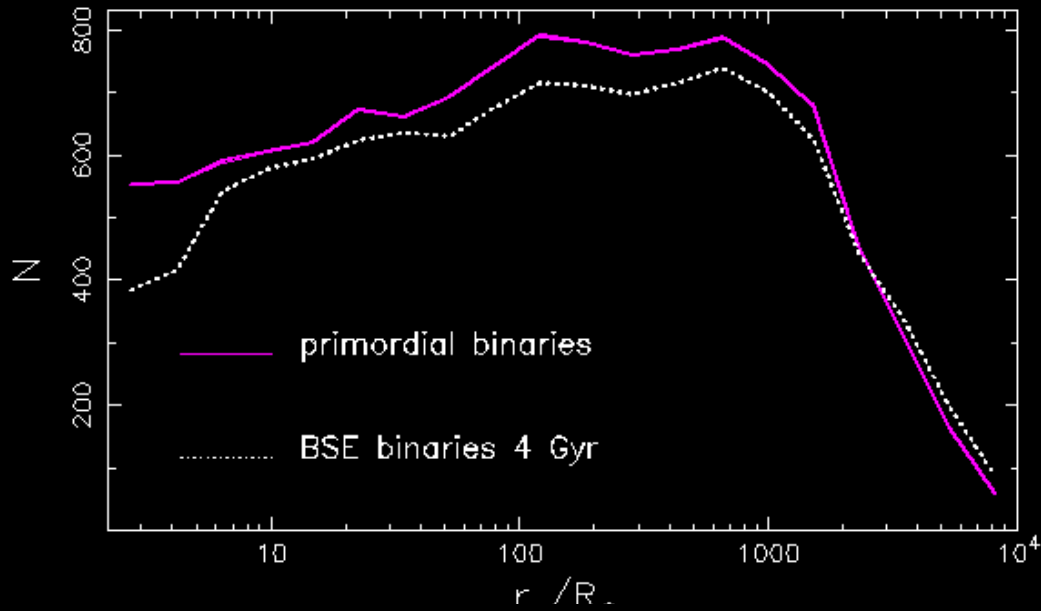
Binding Energy Distribution of Binaries



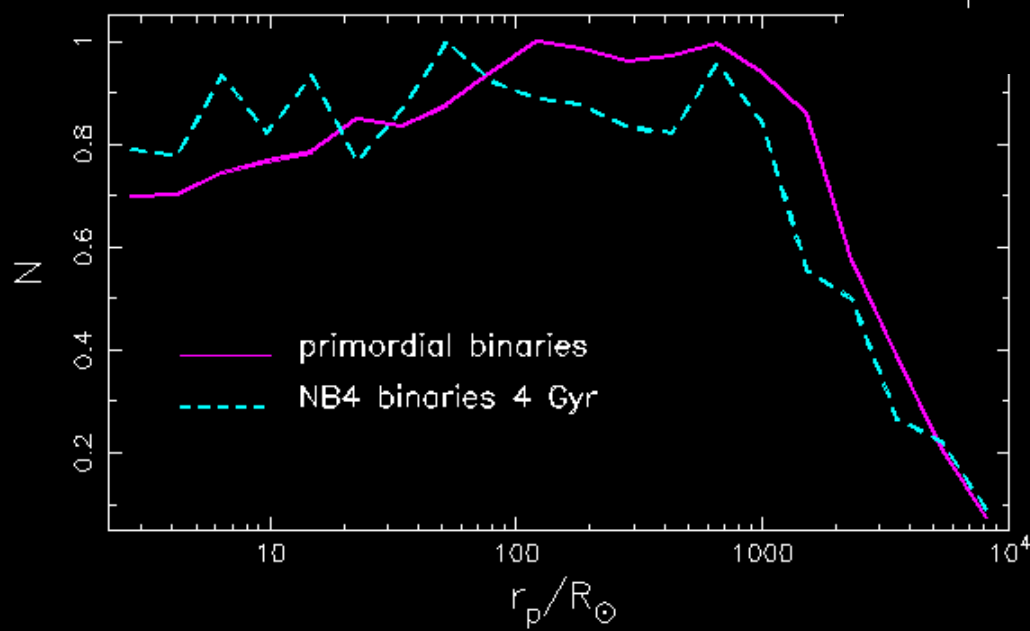
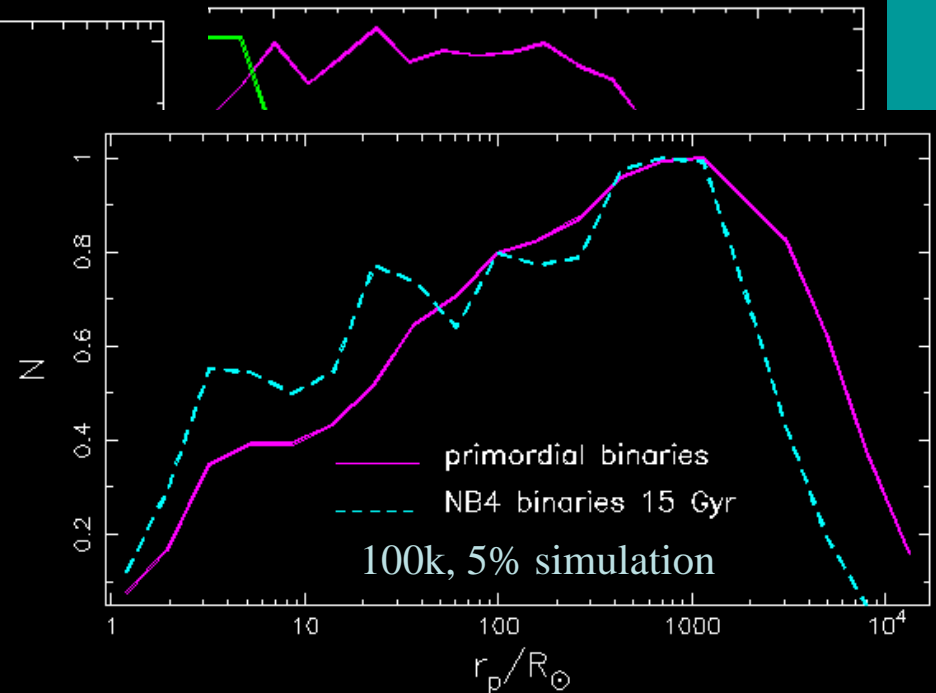
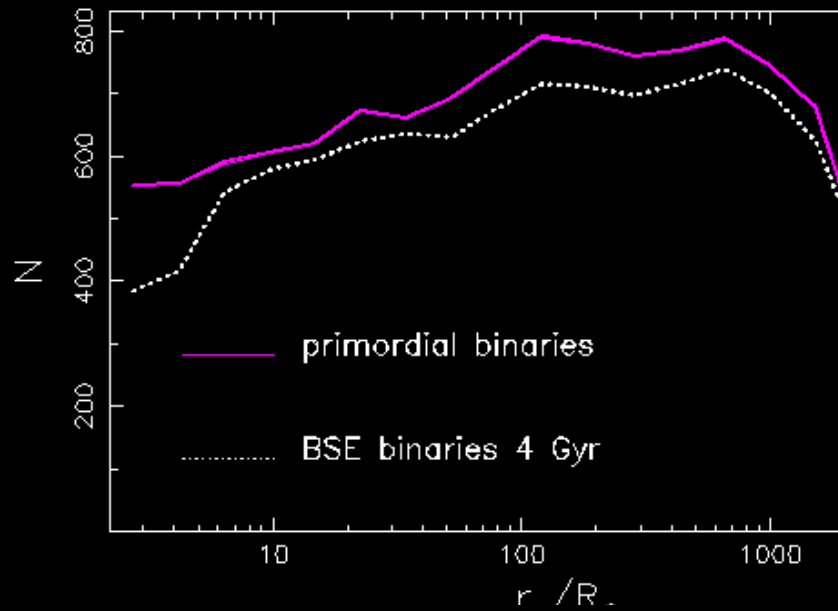
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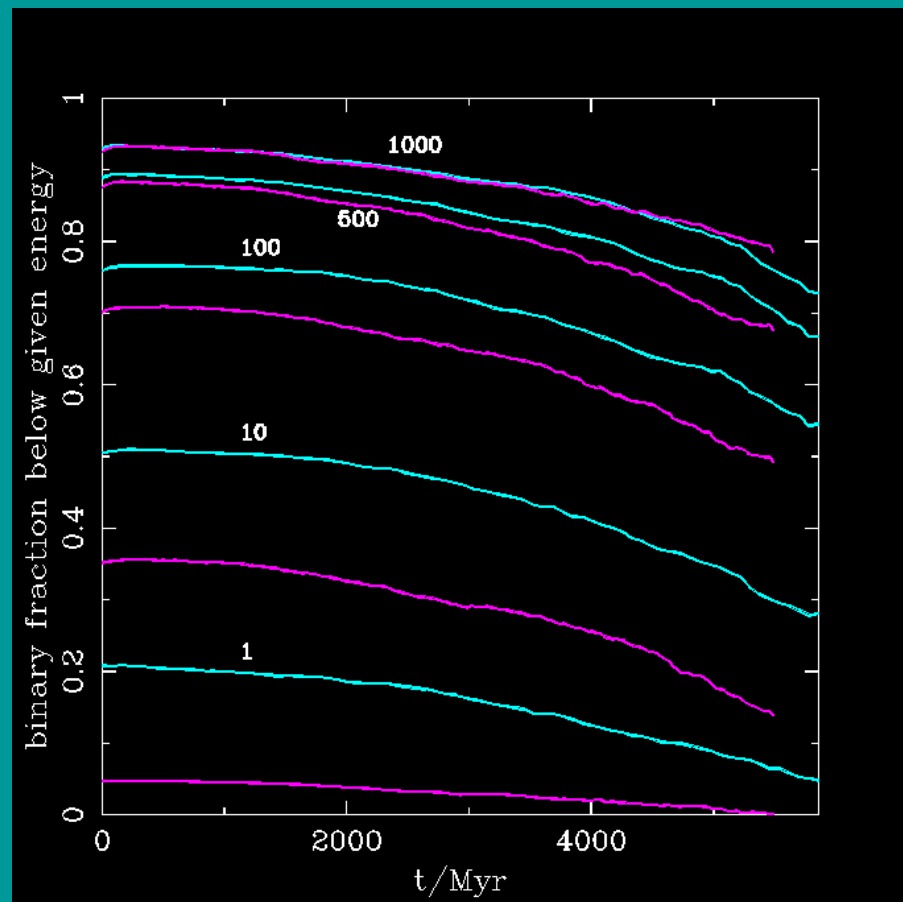
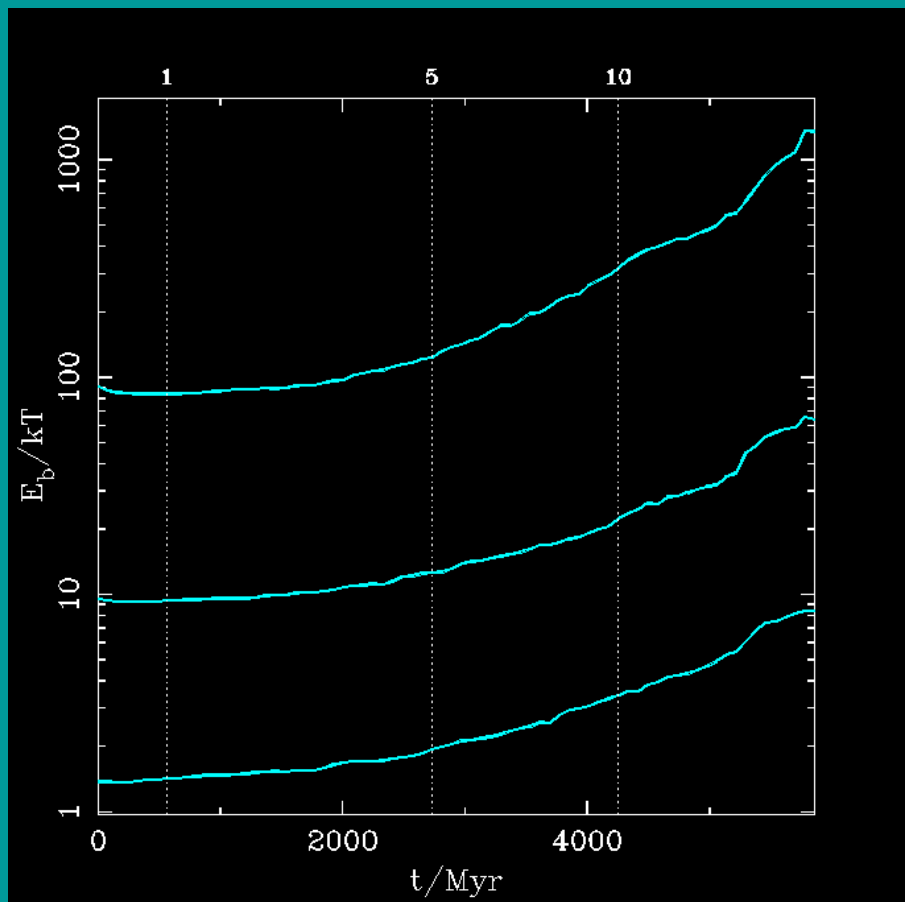


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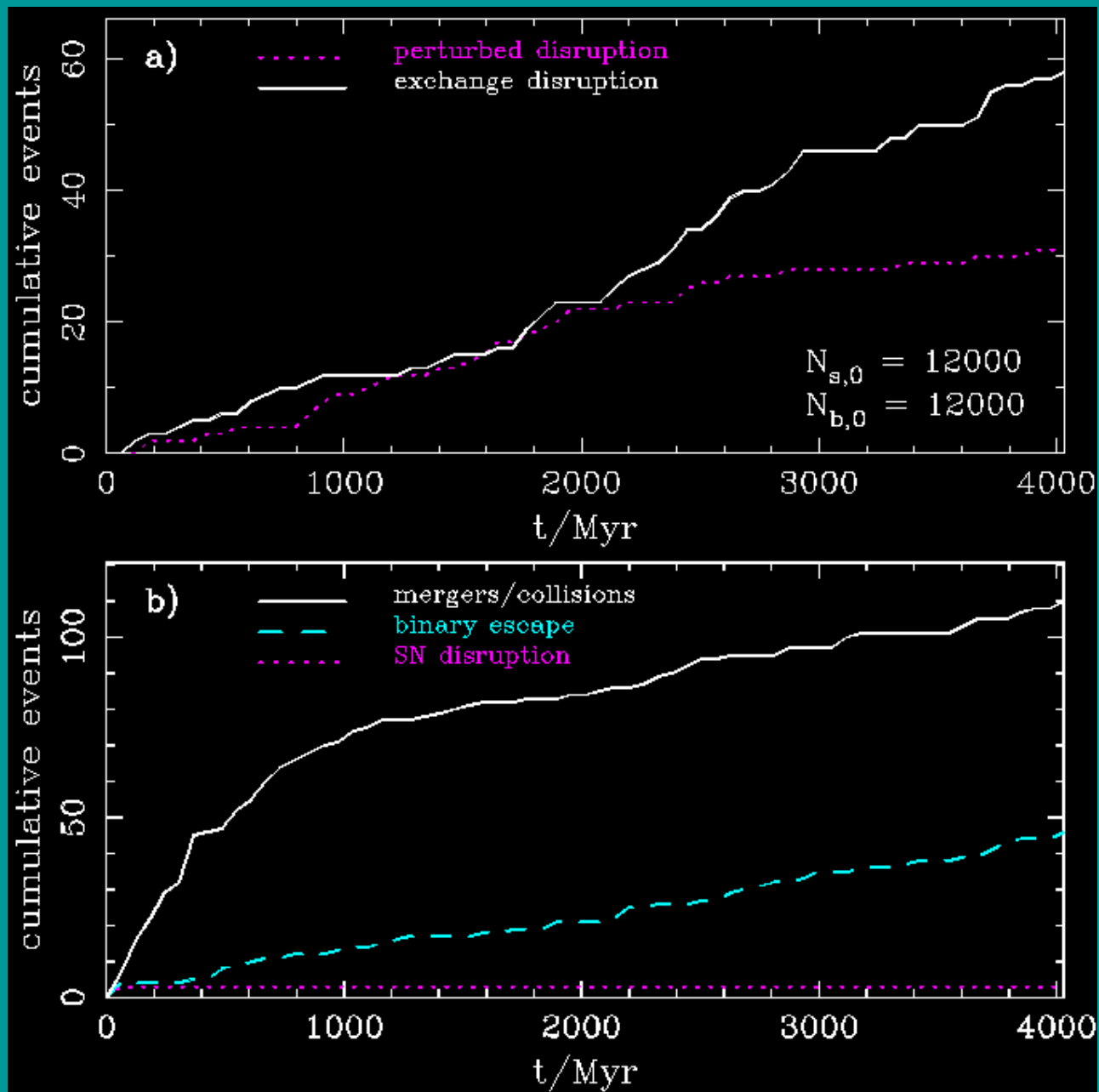


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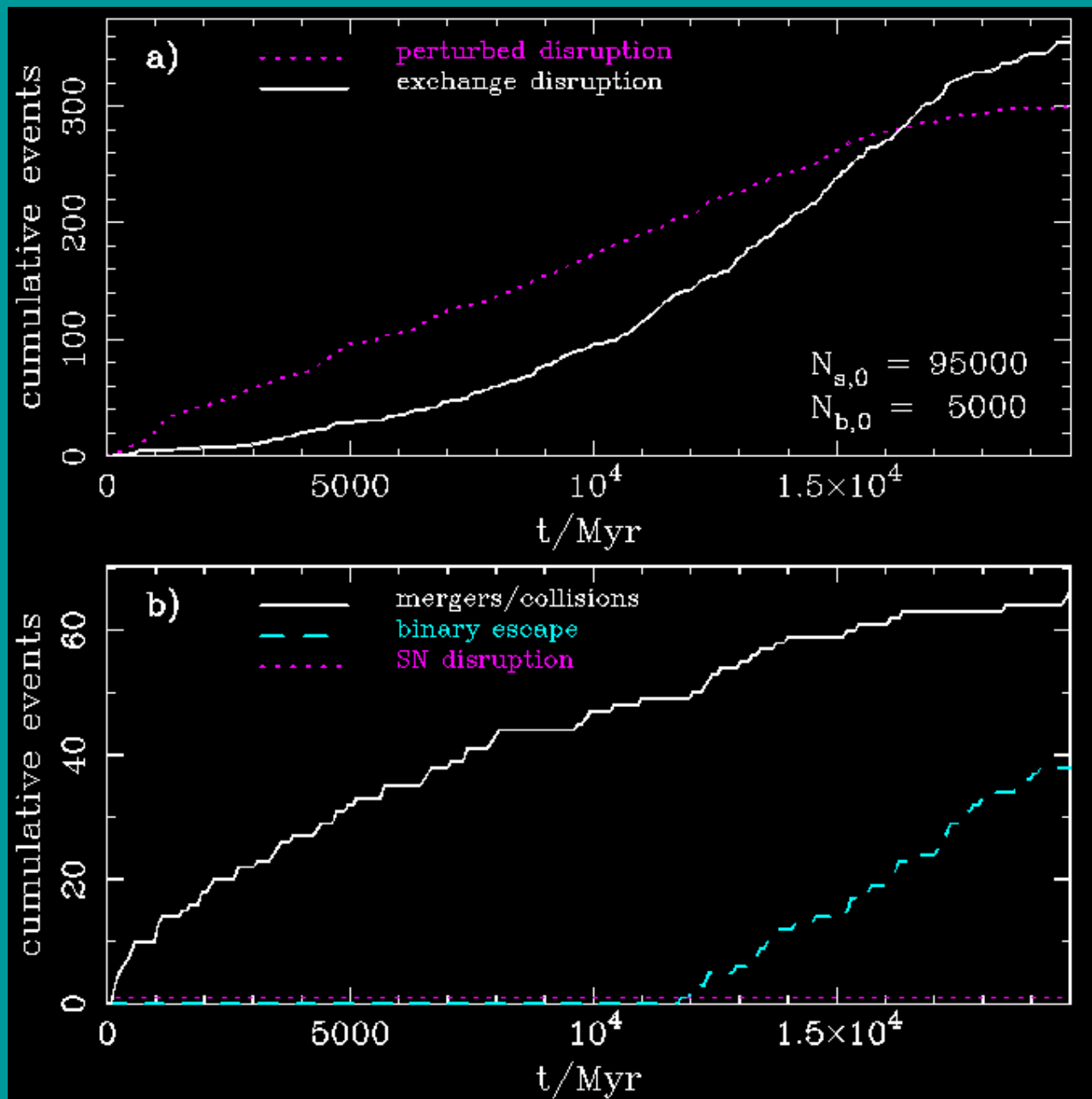




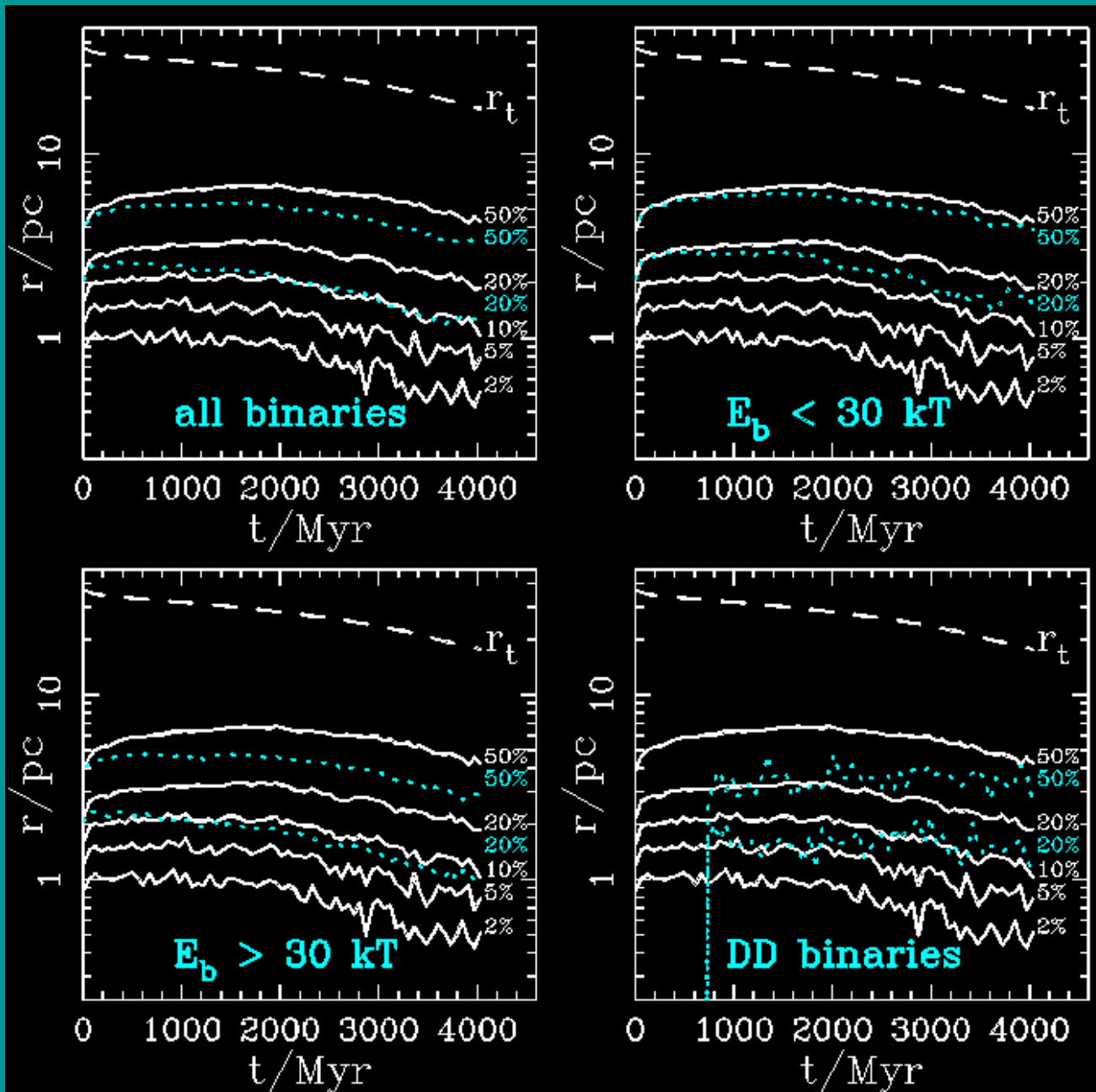
Core

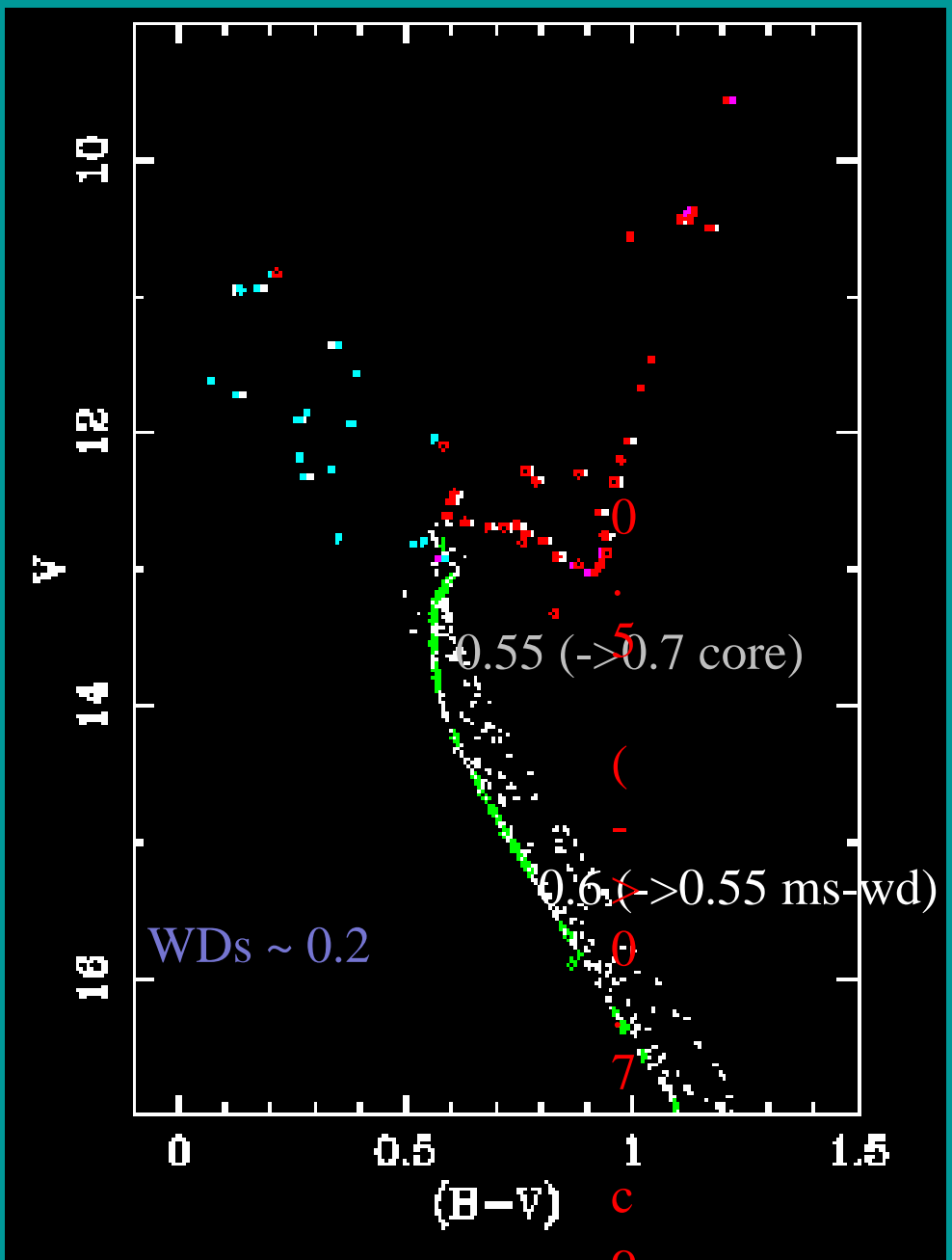


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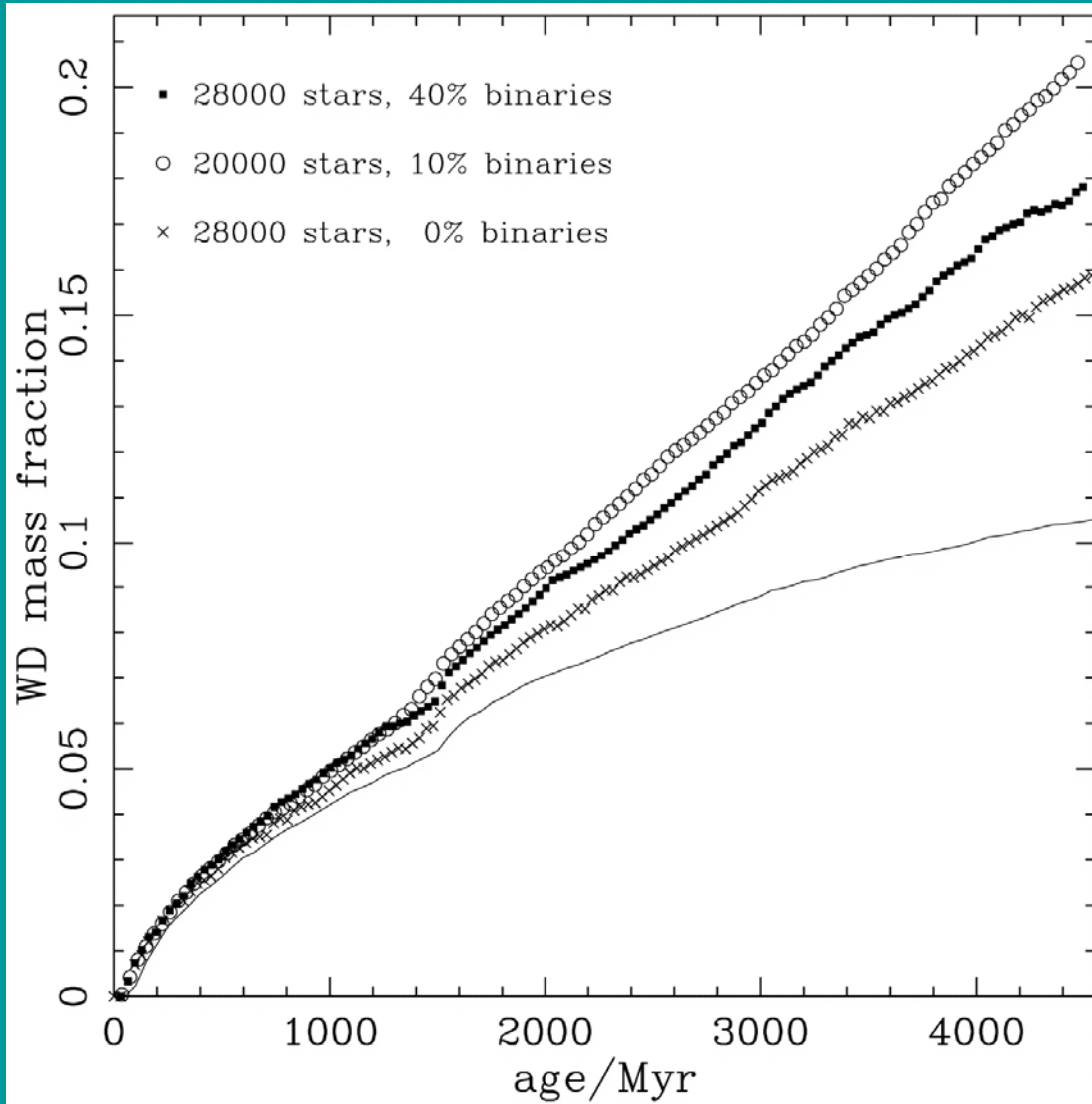


Where are the binaries?





White dwarf fractions -> kicks?



M67 observed ~ 0.1

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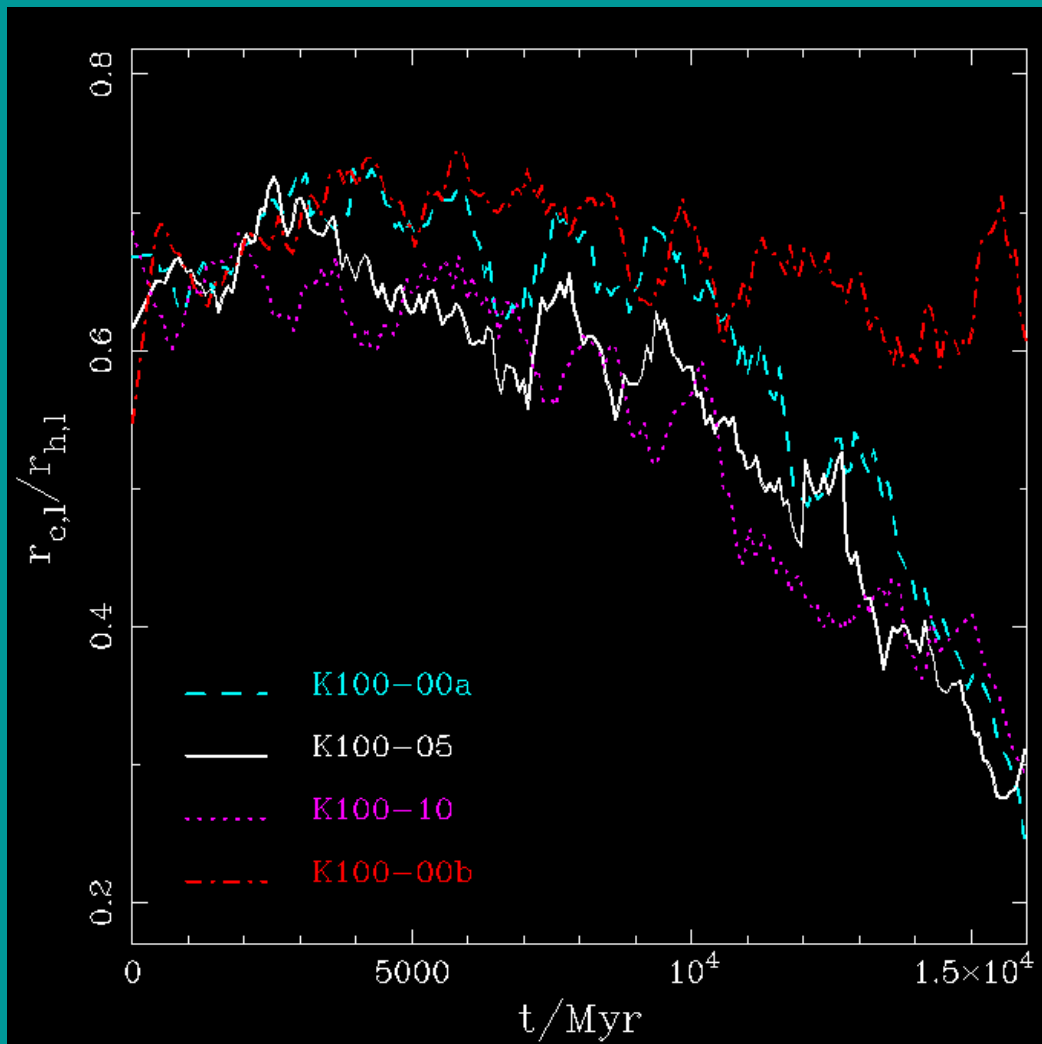
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Binary Effects on Evolution



Binary Effects on Evolution

