Whole “shebang” *N*-body Simulations

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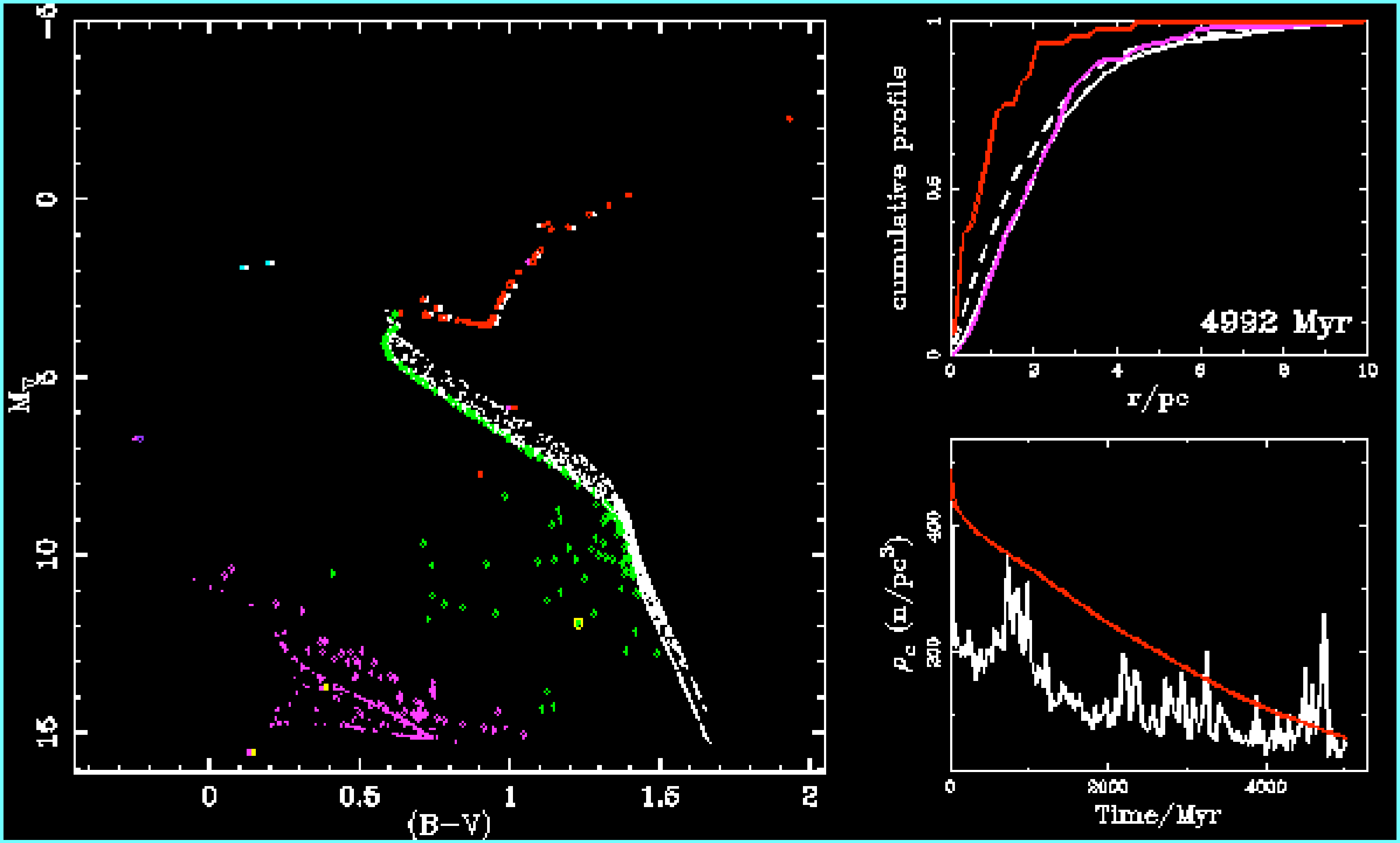


An Illustrative Example:

Simulation of an open cluster performed with NBODY4 on a GRAPE-6

- includes stellar evolution (formulae derived from detailed models)
- includes binary evolution (recipe based approach)
- for a description of NBODY4 see Aarseth, 1999, PASP, 111, 1333 and Hurley et al., 2001, MNRAS, 323, 630

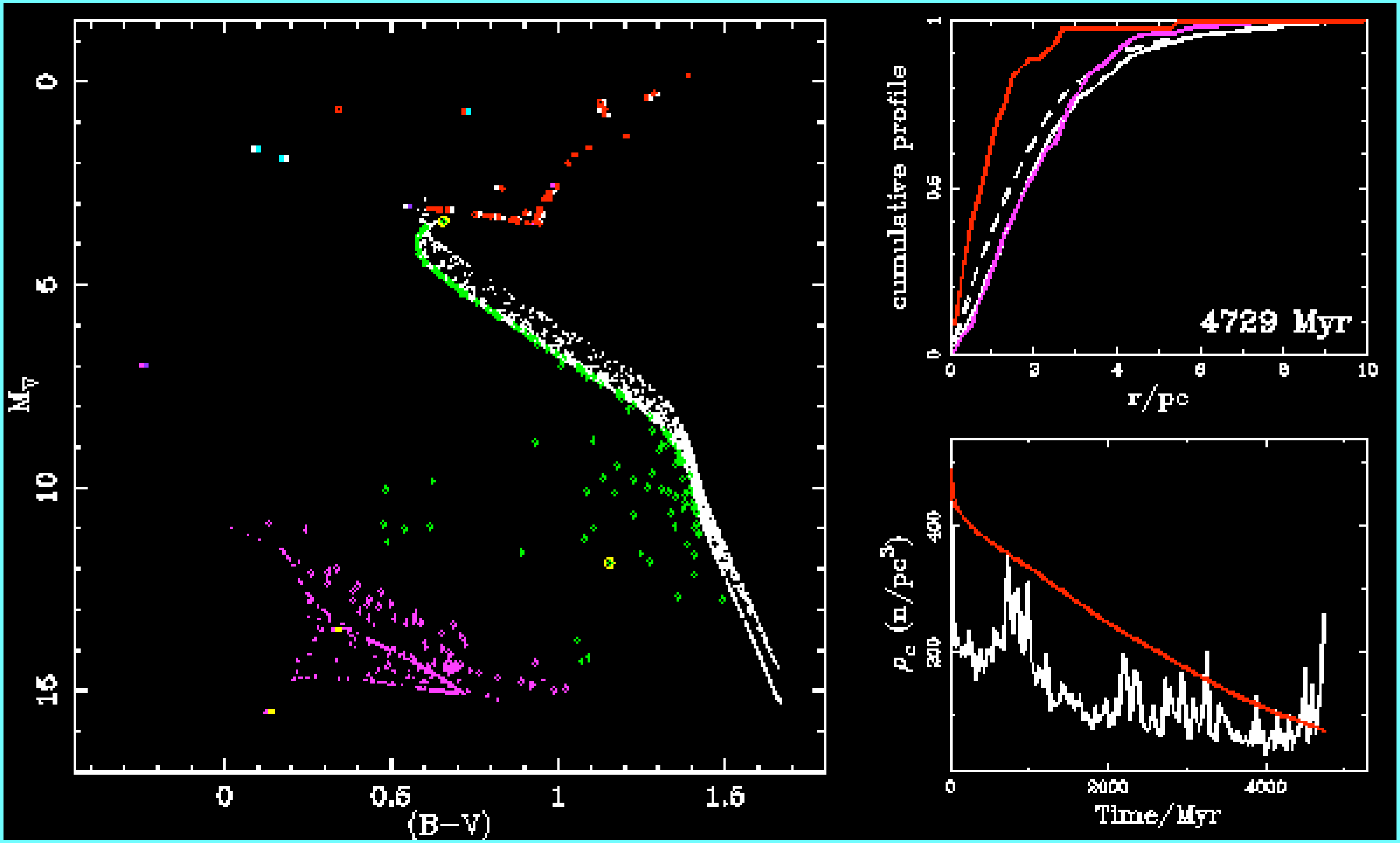
Initial conditions

- 28,000 stars drawn from IMF between 0.1 and 50 M_{sun}
- 40% primordial binaries, i.e. 12,000 single stars and 8,000 binaries
- total cluster mass of 14,300 M_{sun}
- Plummer density profile and stars in virial equilibrium
- evolved in a standard Galactic tidal field (220 km/s at 8.5 kpc)

Evolved for ~6 Gyr (3-4 weeks of GRAPE-6 cpu)

- average number density of stars in core was 200 stars/pc^3
- velocity dispersion was ~2-3 km/s
- half-mass radius was ~4 pc
- average half-mass relaxation timescale was ~300 Myr

→ see next slide for a movie of this simulation ...



Click on the CMD to play the movie...

(starts at 4729 Myr for purpose of illustration
- then plays from 0 to 6000 Myr using snapshots taken at ~32 Myr intervals
- you may want to view the legend/description on the next page and then return)

Colour-Magnitude Diagram Legend:

- single main-sequence (MS) star, MS-MS binary
- single white dwarf (WD)
- WD-WD binary
- MS-WD binary [active CV]
- MS star in binary (non-MS or WD companion)
- Blue Straggler (BS)
- sub-giant, giant, or supergiant star
- naked Helium star
- WD in binary (non-MS or WD companion)
- Neutron star or Black Hole (only shown if in binary)

e.g. BS-WD binary

Upper-Right Panel:

Cumulative radial profiles of selected sub-populations (at current time):

- single MS stars
- MS-MS binaries
- single giants
- single WDs

Lower-Right Panel:

Evolution of selected cluster properties to the current time:

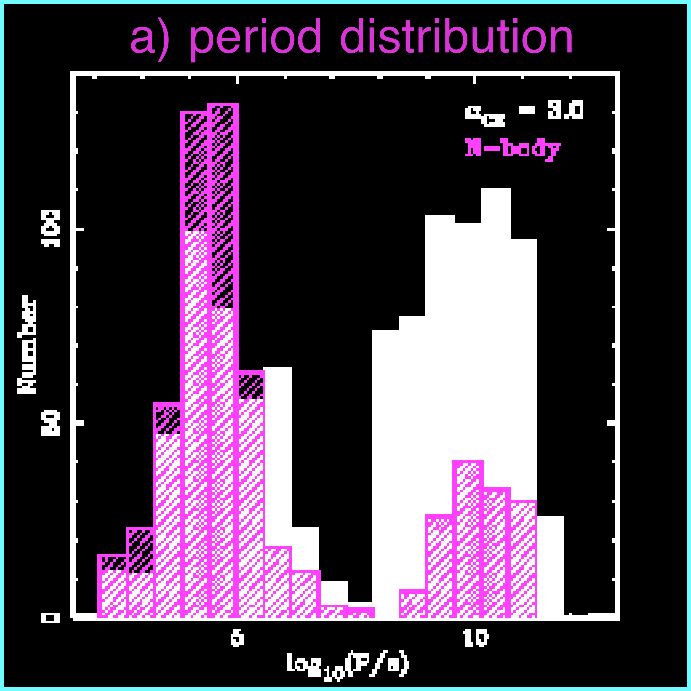
- number density of stars in the core
- cluster mass as fraction of initial cluster mass (scales from 1 to 0)

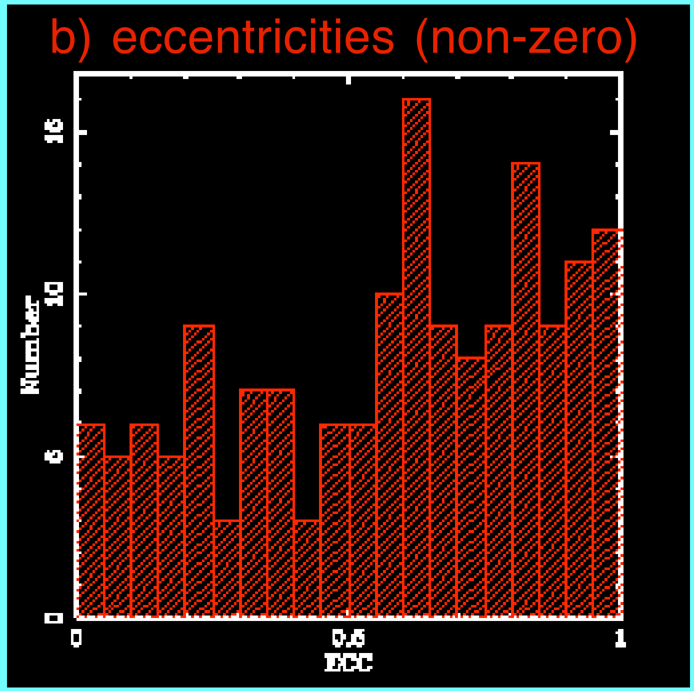
Double-WD Parameters (after 4 Gyr):

Figure a) shows the period distribution of all DWD binaries when the primordial binary population of the N-body simulation is evolved outside of the cluster environment (solid white histogram) and compares that with the distribution returned by the N-body simulation (hatched pink). The same binary evolution algorithm is used in both cases.

- Note the destruction of wide binaries and the enhancement of close binaries in the cluster.

Figure b) shows the eccentricity distribution of all non-circular DWDs in the N-body case.





- 21% of DWDs are formed via exchange interactions
- 27% are non-circular (but only 5% of those with merger timescales < 10 Gyr)

Supra-Chandrasekhar DWD Merger Rate:

- 2 WDs, $M_b > 1.44\ M_{sun}$, $T_{grav} < 12$ Gyr
  - 10x expected (non-dynamical) merger events
- Blame for enhancement shared equally between:
  - exchange interactions
  - pre-DWD perturbations
  - post-DWD perturbations
- Type Ia supernova?
- AIC collapse to NS?
  - interesting either way

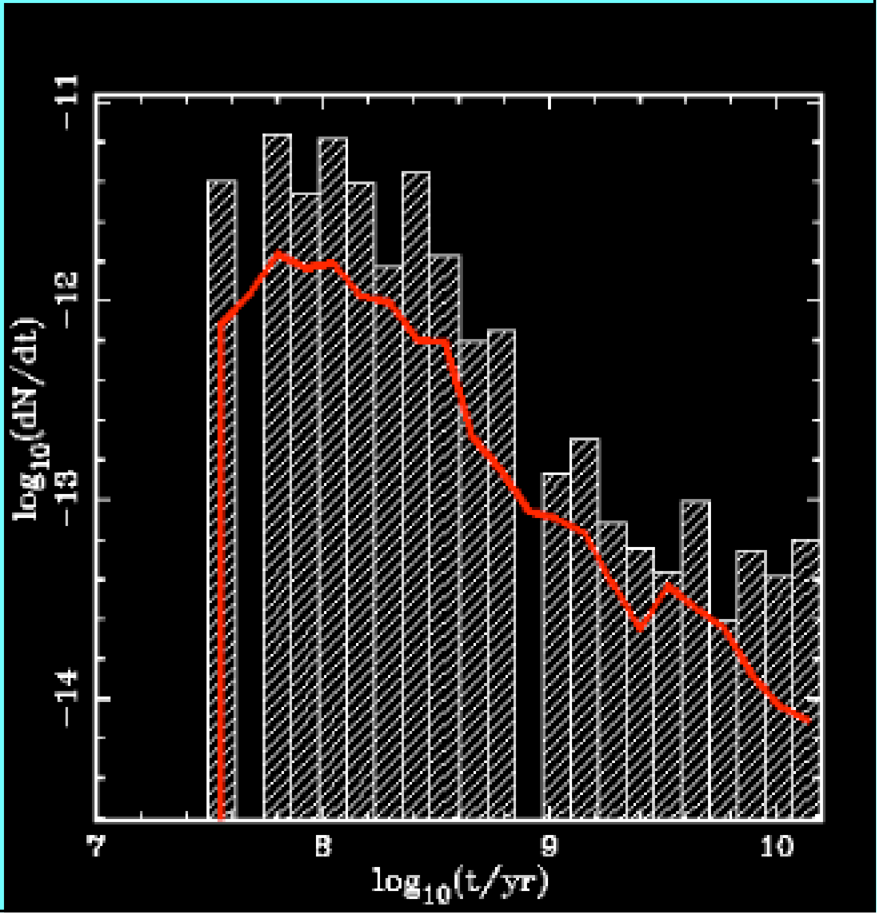


Figure: Supra-Chandrasekhar DWD merger rate for an instantaneous burst population. Shown for a composite of NBODY4 simulations performed to date (histogram) and for the identical primordial binary populations evolved without cluster dynamics (red line).

Main Collaborators:

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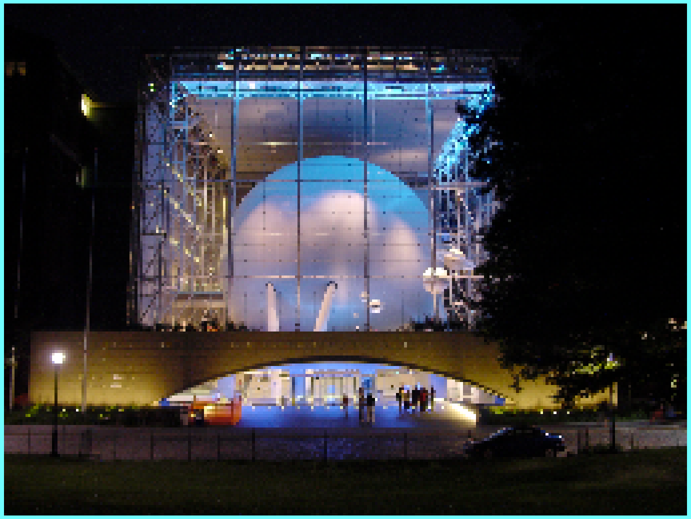

Further Reading:

The Promiscuous Nature of Stars in Clusters

Hurley & Shara, 2002, ApJ, 570, 184

Star Clusters as Type Ia Supernova Factories

Shara & Hurley, 2002, ApJ, 571, 830

White Dwarf Sequences in Dense Star Clusters

Hurley & Shara, 2003, astro-ph/0302119