N-body Simulations of Globular Clusters

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Dynamics of black holes in star clusters

- In clusters with short enough relaxation times, stellar collisions will occur frequently around and after core-collapse.
- The majority of the collisions occurs with the same star, leading to the run-away growth of a single object.
- This star can become a massive black hole containing up to 0.1% of the total cluster mass (Portegies Zwart & McMillan 2002).
- Such objects could provide the seeds for the massive black holes found in the centers of galaxies (Ebisuzaki et al. 2001).

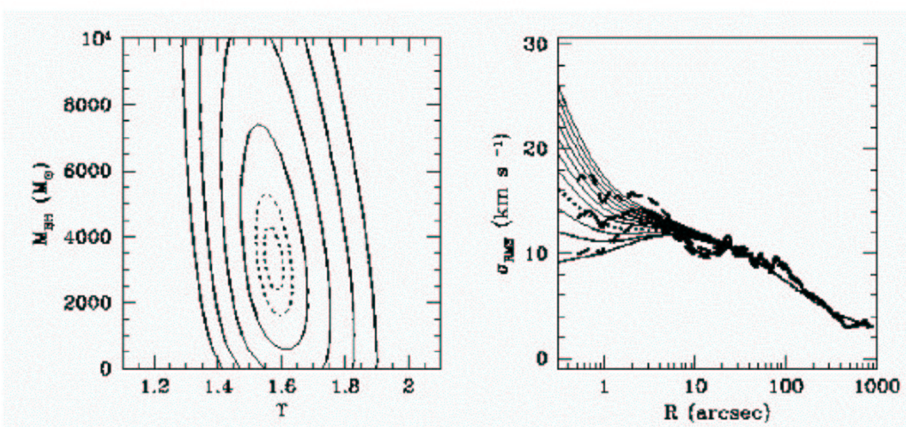
⇒ Central relaxation times for most globular clusters are too long for the above mechanism to work. Nevertheless, it would be an exciting discovery if such black holes could be found in them.

Observational evidence for massive black holes in star clusters

- Gerssen et al. (2002) and Gebhardt et al. (2002) report evidence for massive central black holes in the centers of globular clusters M15 and G1.
- Their reasoning was basically the same in both cases:

1) Take the projected light profile.
2) De–project it to obtain 3D density profile.
3) Integration gives L(<R).
4) Use Jean’s equation to get the velocity profile.
5) Assume constant M/L and fit the prediction to the observed velocity profile in the outer parts.

Observational results for M15



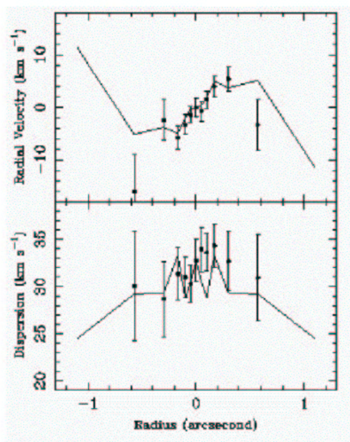
(from Gerssen et al. 2002)

The initial result for the BH mass was: $M_{BH} = (3.9 \pm 2.2) \cdot 10^3 M_\odot$

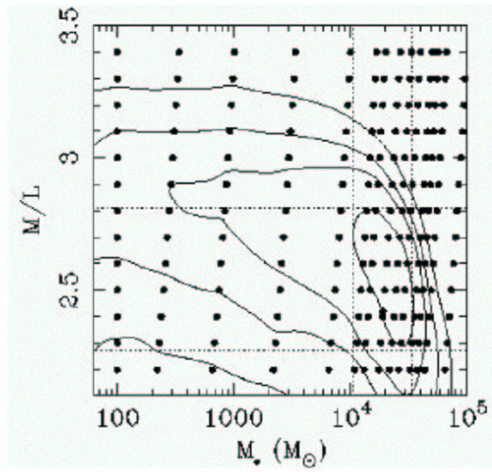
(later corrected to: $M_{BH} = (1.7 \pm 2.7) \cdot 10^3 M_\odot$)

Observational results for G1

Velocity dispersion measurements



Fit of BH mass and M/L

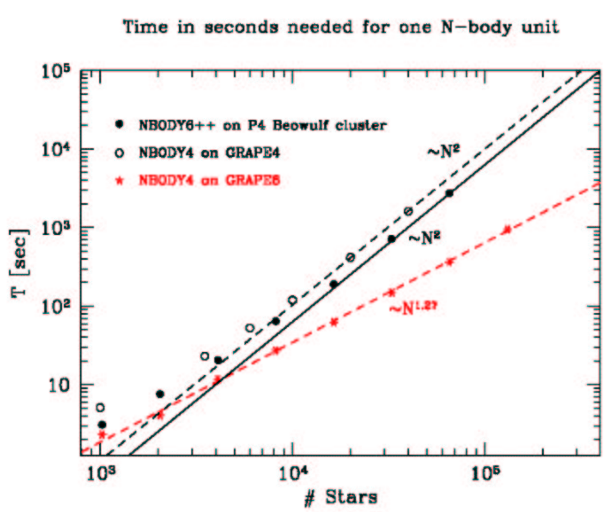


(from Gebhardt et al. 2002)

The best-fitting solution has $M_{BH} = 2 \cdot 10^4 M_\odot$ and $M/L_V = 2.6$.

N-body simulations on GRAPE6

- Compared with GRAPE4 or parallel computers, GRAPE6 is 10 to 30 times faster for high-N clusters.
- A cluster with 150.000 stars can be calculated to complete evaporation within 30 days on GRAPE6.



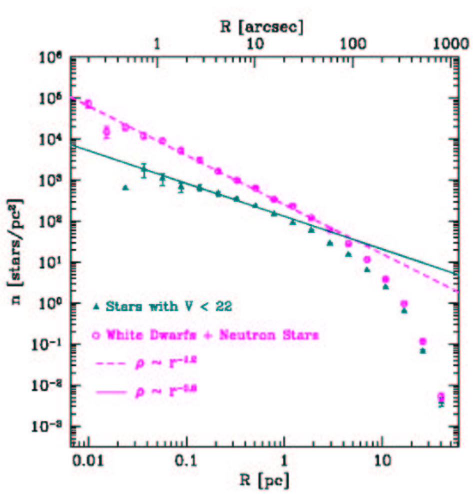
⇒ With GRAPE6 one has for the first time the chance to simulate small globular clusters with almost no restriction on input physics or starting condition.

N–body simulations of the globular cluster M15

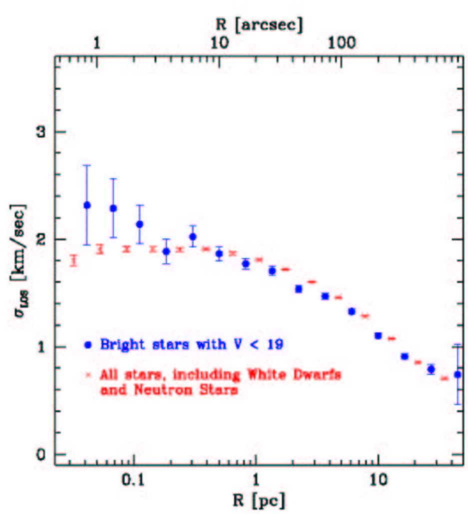
- Multi–mass star cluster with Kroupa (2001) mass–function and Hurley et al. (2000) type mass loss
- Number of cluster stars: N=131.072
- King Wo=7 model on circular orbit at R=8.5 kpc
- Two runs for N=128K with either 0% or 100% neutron star retention rate
- Core collapse happened at T=12.6/14.5 Gyr when about 25,000 Msun were still bound

Results of the *N*-body simulations

(1) Density profile

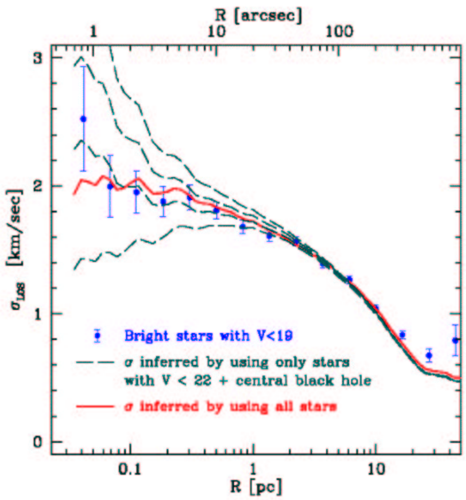


(2) Velocity dispersion

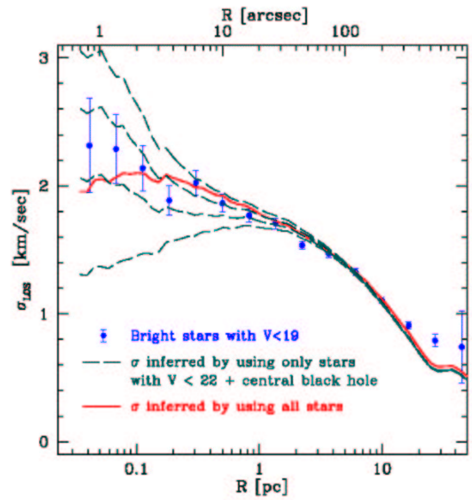


(3) Fit of the velocity dispersion

0% NS retention rate



100% NS retention rate



N-body simulations for G1

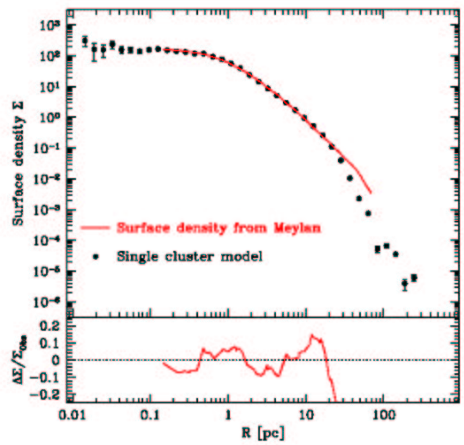
- Isolated star clusters, containing $N = 65.536$ stars with a Kroupa (2001) IMF and Hurley et al. (2000) type stellar evolution.
- Runs were starting either from King models with different W_0 or from the merger of two star clusters.
- In order to match the relaxation time of G1, we have to increase the radius of our clusters by:

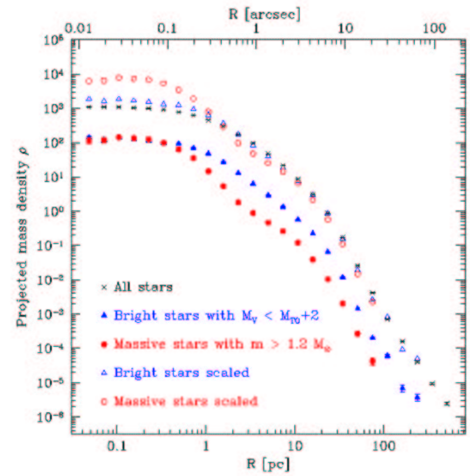
$$r_{hS} = r_{hG1} \cdot \left(\frac{N_{G1}}{N_S}\right)^{1/3} \cdot \left(\frac{\ln\gamma N_S}{\ln\gamma N_{G1}}\right)^{2/3}$$

- For each set of simulation, we varied r_h and mass of G1, and the initial density profile of our clusters.
- We performed runs until we achieved the best fit to the surface density and velocity profile of G1.

Results for King-model initial conditions

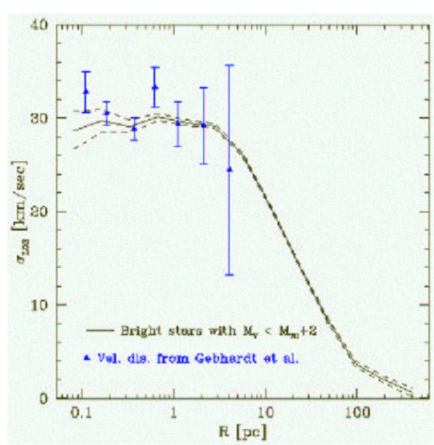
- Best fitting run starts with $W_0 = 7.5$ and fits the density distribution to within 10% for most radii.
- In the center of G1 mass-segregation of massive stars has set in and mass does not follow cluster light. ⇒ A constant M/L model will fail again.





Results (II): Velocity profile

- Similarly, the velocity profile can be fitted by the Nbody run.
- Best fitting M/L is 3.80, larger than the ratio of 2.8 obtained by Gebhardt et al. in case of no central BH.
- For this ratio, a chi–square test gives a 20% probability that the N–body data agrees with the observations of Gebhardt et al. and Djorgovski et al.



➢ The N–body data can therefore fit all observational data without the need for a central black hole.

Runs starting with the merger of two star clusters

A merger run can fit the surface density, velocity dispersion, radial velocity and ellipticity profile :