N-body models of black holes with star accretion in galactic nuclei

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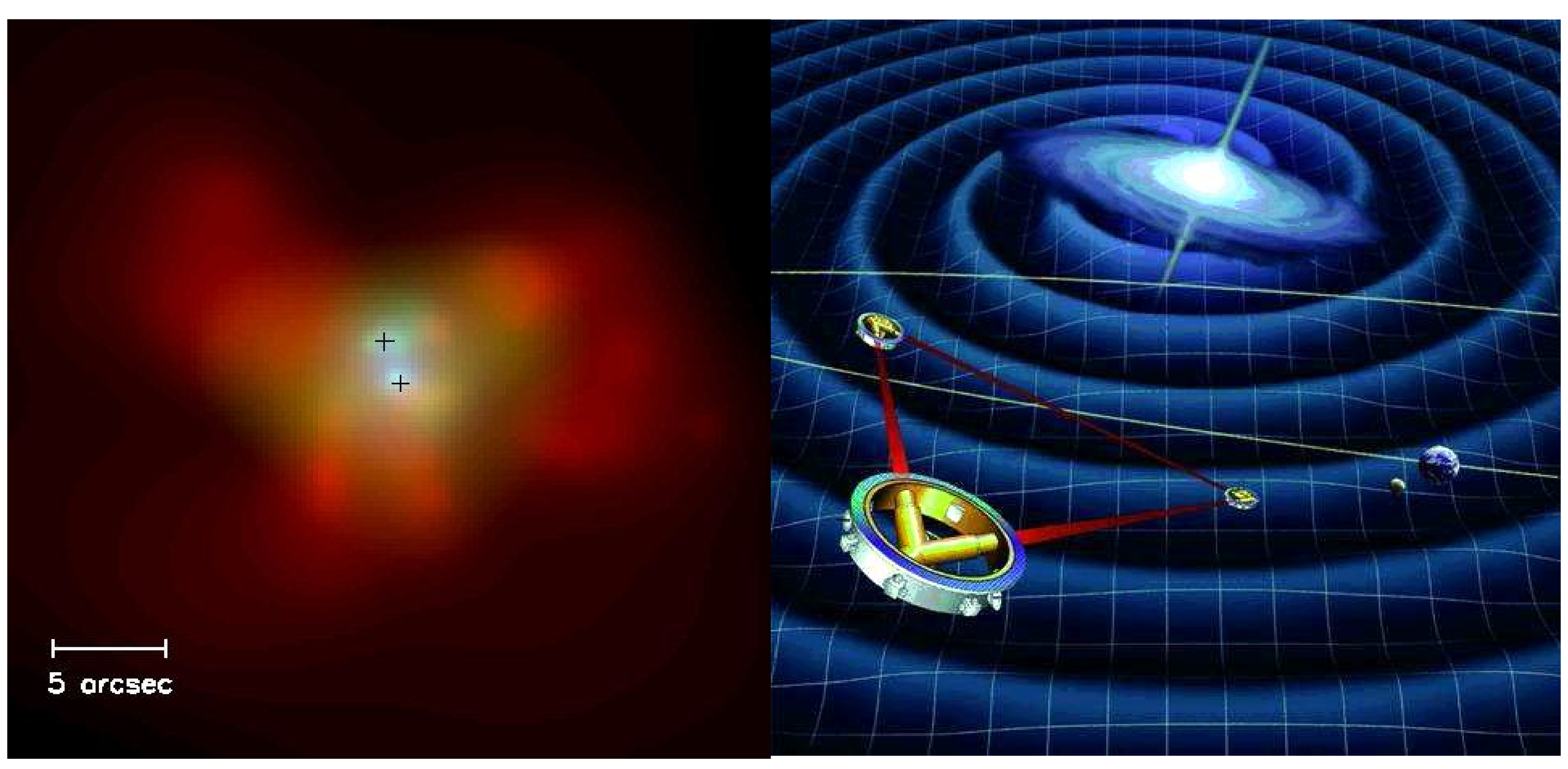
Supermassive Black Holes in Galactic Nuclei

Many, if not all galaxies harbour supermassive black holes. If galaxies merge, which is quite common in the process of hierarchical structure formation in the universe, their black holes sink to the centre of the merger remnant and form a tight binary. Depending on initial conditions and time supermassive black hole binaries are prominent gravitational wave sources, if they ultimately come close together and coalesce. We model such systems as gravitating N-body systems (stars) with one or more massive bodies (black holes), including if necessary relativistic corrections to the classical Newtonian gravitational forces (Kupi et al. 2006, Berentzen et al. 2009).

Kupi, G., Amaro-Seoane, P., Spurzem, R. , Dynamics of compact object clusters: a post- Newtonian study, 2006, Mon. Not. Royal Astron. Soc. 371, 45.
Berentzen, I., Preto, M., Berczik, P., Spurzem, R., Binary Black Hole Merger in Galactic Nuclei: Post-Newtonian Simulations, 2009, The Astrophysical Journal 695, 455



Figures on Top:

Left: X-Ray observation of two nuclei of a galaxy after merging, both bright spots are interpreted as hot gas around a supermassive black hole, which cannot be directly resolved. The distance between both black holes is 3000 light years (Picture from S. Komossa, Max-Planck-Institute for Extraterrestrial Physics in Garching near Munich, Germany).

Right: Artist's Impression of the space-based LISA laser interferometer satellites, designed to detect gravitational waves from massive black hole coalescences in the entire universe (Picture: ESA). Our team is linked to the German LISA consortium for the research on astrophysical gravity wave generation by binary black holes in galactic nuclei.

Model Description

In this work we have done a set of N-body simulations with a single massive black hole, adopting the widely used N-body model unit system: G=1, total mass of the cluster M=1 and total energy of the cluster E= -0.25 (Heggie & Mathieu 1986). Initially, all the models have a seed black hole at the origin with zero velocity. The black hole's mass is set to be 0.01 in model unit. The model cluster contains N=16k, 32k, 64k particles, following a Plummer distribution.
When the distance between a star and the black hole is less than the tidal radius(R_t), the star is disrupted by the black hole and all its mass is added to the black hole. We treat the tidal radius here as a free parameter, and vary it in the simulations in order to do a scaling to realistic physical conditions in galactic nuclei. In N-body units we set the tidal radius of the black hole to be 10 and 10 .

References:
Heggie D.C., and Mathieu R. D. 1986, in The use of Supercomputers in Stellar Dynamics. Eds. McMillan, S., Hut, P., Springer-Verlag, Berlin, p. 232

Simulation Results

We report results from our simulations. All simulations are running with the massively parallel direct N-body code phi-GRAPE (using many GPU's for acceleration in parallel) on the GPU cluster at NAOC, up to 1000 N-body time units, which is about 300 half-mass crossing times.

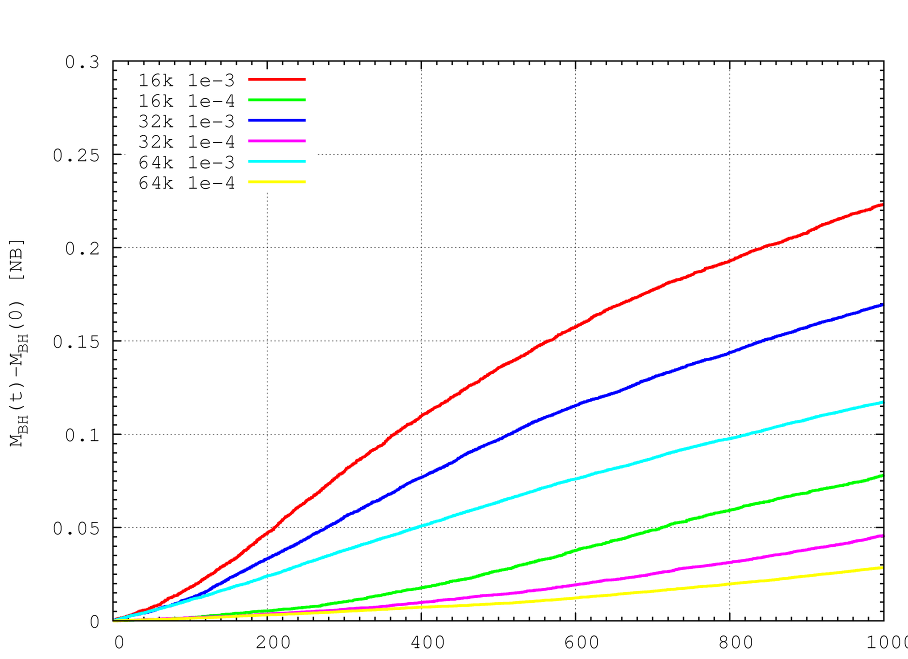


Figure 1 Black hole's mass evolution as a function of time in N-body unit. The y-axis is the black hole's mass at time t subtracts its initial mass(e.g. 0.01). Those runs with R_t=1e-3 have a final mass one order of magnitude larger than the initial mass.

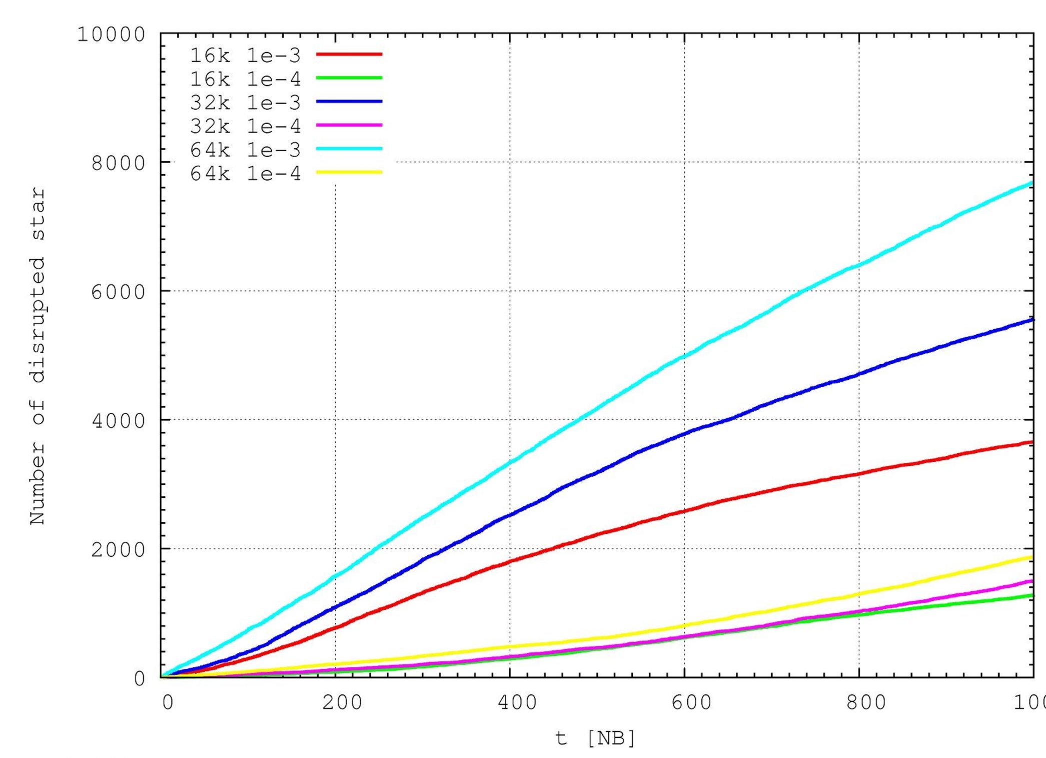


Figure 2 Number of disrupted stars as a function of time. In the R_t=10 case, we see large differences among the 3 models. While in the R_t=10 case, the differences are much smaller, indicate that they have approximately same disruption rate(see Figure 4).

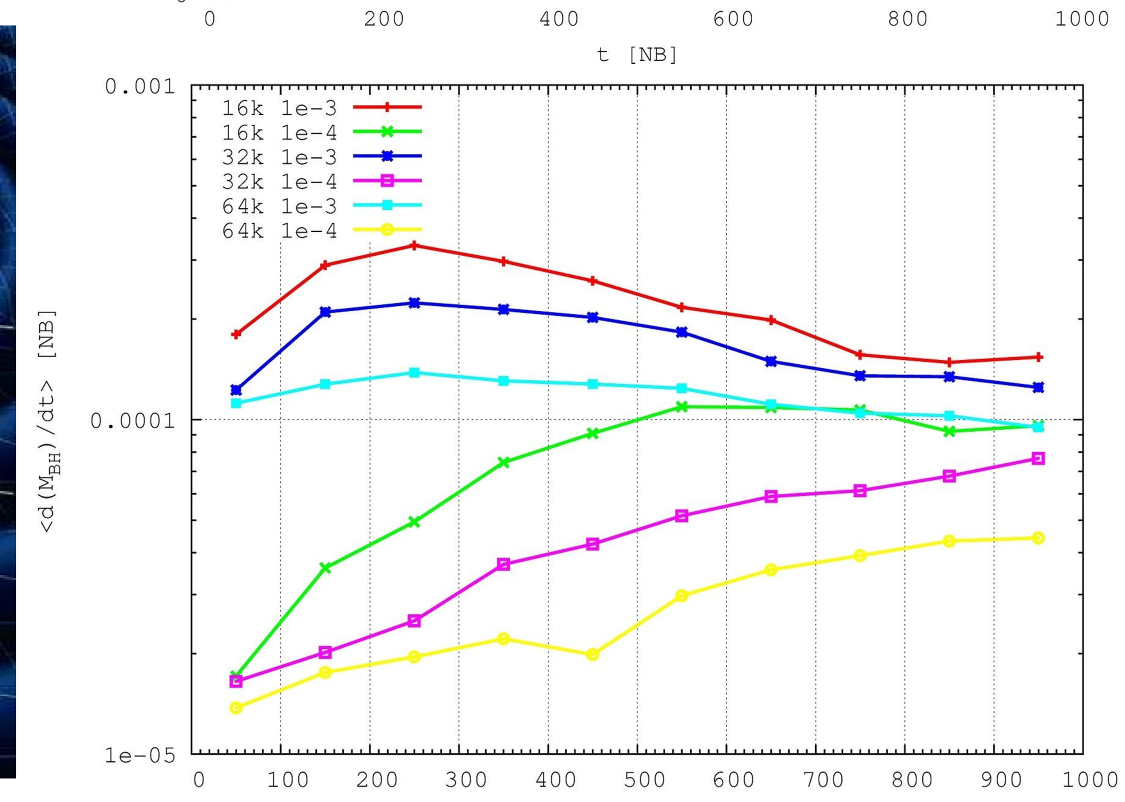


Figure 3 Mean mass accretion rate. The data points are averaged over 100 N-body time. Different behaviors can be seen between the two Rt cases. The accretion rate of Rt=1e-3 runs begins to decrease after about 200 N-body time unit, while the Rt=1e-4 runs keep on increasing, except for the 16k run which slightly decreased at the end.

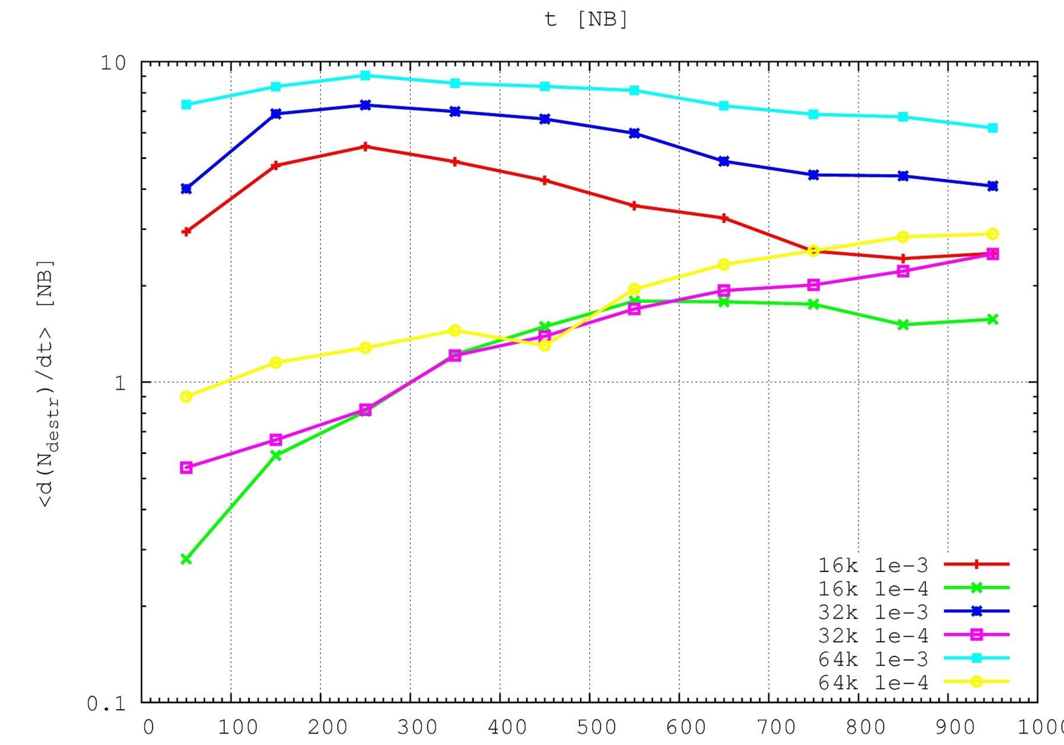
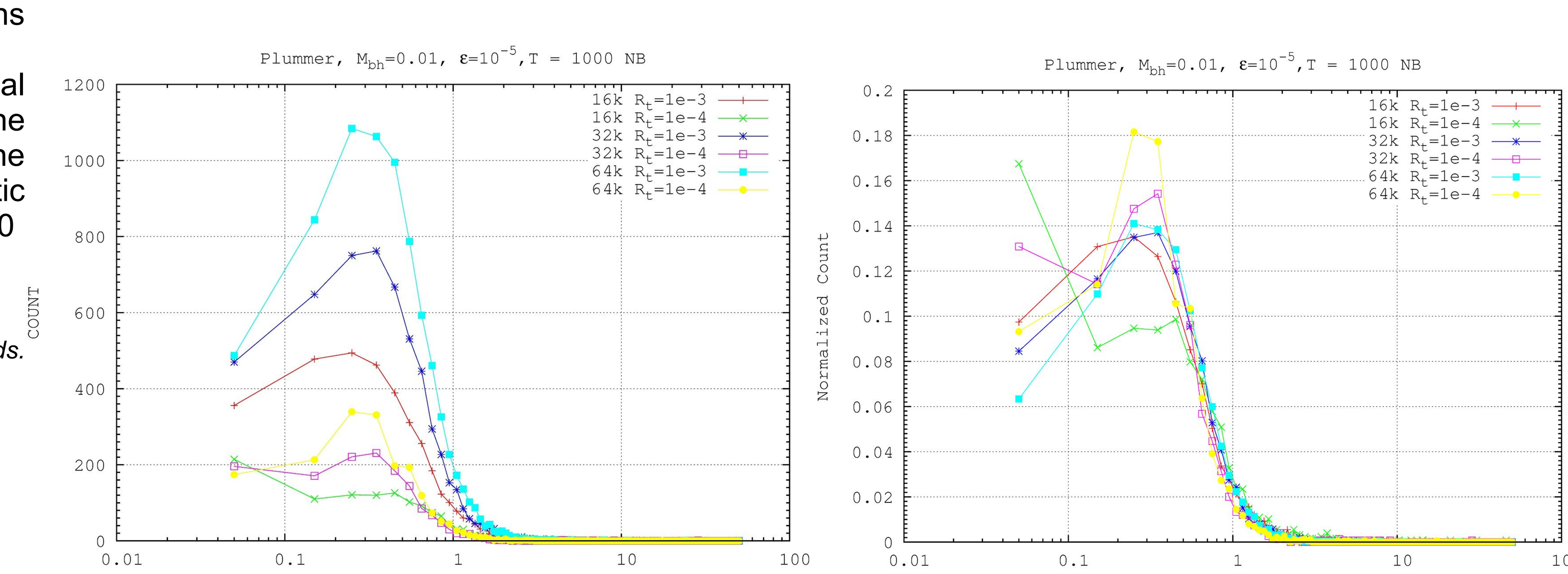


Figure 4 (*left)* Mean disruption rate given by number counts.

Figure 5 (*below left*) Rmax distribution of the disrupted stars. Rmax is the maximum radius a disrupted star can reach in the cluster. A crest can be found between 0.2 and 0.5 , except for the "N=16k R_t=1e-4" case. This region is around the critical radius, within which a loss-cone is presented(Frank & Rees 1976).
(*below right*) Normalized R_max distribution. All data points are divided by the total number of disrupted stars over the whole simulation.



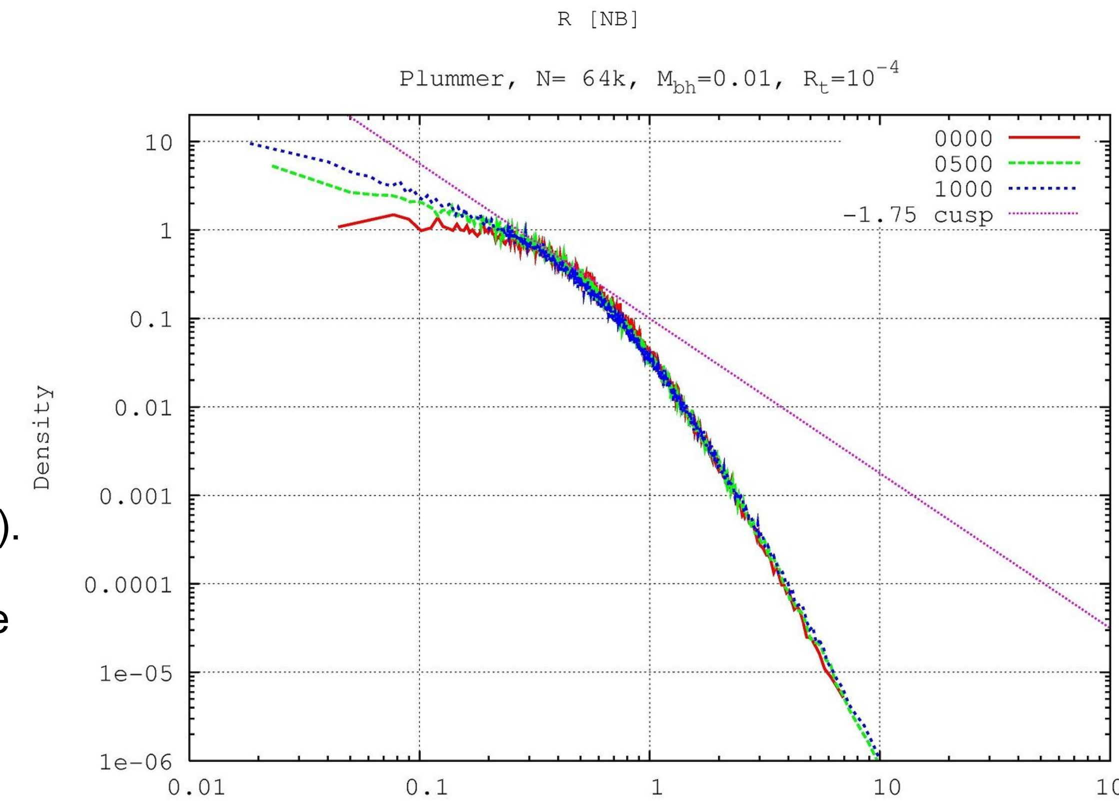


Figure 6 (*left*) Density profile. We measured the cluster's density profile at 3 different times. As the system evolves, a central cusp forms within the black hole's influence radius. But we didn't see a -1.75 cusp(Bahcall & Wolf 1976) in all the models. The black hole's Brown motion and large tidal radius may suppressed the central density.

References:
Bahcall, J. N. and Wolf, R. A. 1976, ApJ, 209, 214
Frank, J., and Rees, M. J. 1976, MNRAS, 176, 633