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Evolution of Merger Remnants with Supermassive Black Holes

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Abstract. We present results of numerical simulations of mergers of spiral galaxies using GADGET (Springel, Yoshida, & White 2001). In three of these simulations one of the progenitor galaxies contained a central supermassive black hole (BH), as well as one simulation which did not contain a BH. The merger remnants were evolved to an age of ~ 13 Gyr to examine the evolution of the shape of each merger remnant. The results of these simulations were compared to observations of elliptical galaxies, which show that older galaxies appear rounder than younger ones (Ryden, Forbes, & Terlevich 2001).

We found that the simulations in which the BH mass was fixed throughout the evolution influence the shape of their host galaxies on timescales less than 3 Gyr. These simulations show little trend of shape with age beyond this time. In the simulations in which the BH mass increased linearly over the duration of the simulation, there is a significant evolution of the shape of the remnant throughout its lifetime, comparable to the observational trend.

1. Simulations and Results

In two of the simulations with BHs, the mass of the BH was 1% and 0.1% of the luminous mass of the merger remnant, excluding the dark matter halos. In the third BH simulation, the mass of the BH increased linearly over the course of the simulation from 0.025% to 0.4% of the luminous matter. One simulation was performed with no BH. The progenitor galaxies were identical disk-bulge-halo galaxies of mass ratios 1:1:5.8. Scaled to physical values, the total mass of the merger remnant was 8×10^{11} $M_\odot$, the unit of length was 3.5 kpc, making the total integration time ~ 13 Gyr. The total number of particles in each simulation was 98,304. The gravitational softening between BHs and particles was reduced as far as computationally viable, with $\epsilon = 10^{-3}$. For reference, the half-mass radius of the merger remnants was generally ~ 1.6.

The top row in Figure 1 shows the observed trend in the apparent axis ratio q of elliptical galaxies. The cumulative distributions of q are shown at different fractions of the effective radius of each galaxy, R_e. The older galaxies are rounder than the younger ones. As the radius gets smaller, this effect becomes more pronounced. In order to properly compare the simulation results to these observations, two dimensional projections of the simulation snapshots were cre-

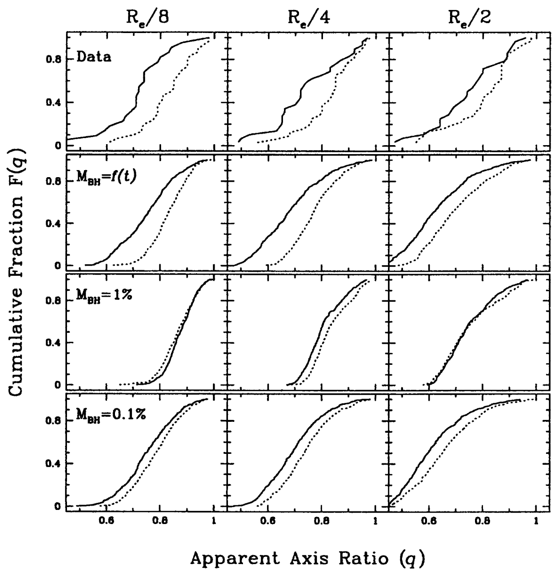

Figure 1. *Top Row*– The cumulative distributions of q for elliptical galaxies younger that 7.5 Gyr (*solid line*) and older (*dotted line*). The three lower rows are the same data for two-dimensional projections of different N-body simulations. The columns are three different effective radii: $R_e/8$, $R_e/4$, and $R_e/2$.

ated at every output time by the cloud-in-cell method, in which the length of each cell was 0.03 in N-body. Each projection was smoothed by a Gaussian filter with a half-width of 4 cells. The values of q at different radii were calculated by the observational software package XVista. For each snapshot, this process was repeated at ten random lines of sight.

Due to the discreteness of the simulation, there was some shape evolution in the simulation with no BH. Using the increase in the mean q for this simulation, the three BH simulations were corrected for shape evolution that is not due to the BHs themselves. The lower three panels in Figure 1 show the cumulative distributions of q for the same age split as for the observational data in the top row. The BHs with constant mass do not show different distributions for young and old galaxies. The mean q for the simulation with M_{BH}=1% BH is closer to unity than that of the smaller BH, but the different between young and old galaxies is relatively the same. For the simulation with the growing BH, the young and old galaxies show significantly different shape distributions comparable to that seen in the observations.

References

Ryden, B., Forbes, D., & Terlevich, R. 2001, MNRAS, 326, 1141

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