Displacement of supermassive black holes

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Introduction

We present high-accuracy direct N-body simulations of black holes escaping from Galactic cores due to radiation kicks following the merger of binary black holes (Fig. 1). Kicks to merger remnants span a range from a few hundreds km/s up to a few thousands km/s for some specific spin alignments [R1]. The observational signature of these events is the displacement of the hole from the galaxy center, after which the black hole can either fall back to the center or escape the galaxy. We study the amplitude of the displacement as a function of the kick velocity, the infall time and the effect of the recoil on the galaxy structure.

Method

In order to follow the evolution of the galactic nucleus after the merger event, we use the direct summation parallel integrator phiGRAPE [R2] on the Gravity Simulator GRAPE cluster (Fig. 2). We adopt as initial conditions the end products of previous simulations of hardening black hole binaries in galactic nuclei [R3], which evolved Dehnen models (N=1.2x10^5) with different concentration parameter (x=0.5,1,0.15) and binaries with different mass ratio. These simulations stop when the hardening stalls due to depletion of stars in the loss cone. At this point, we replace the binary with a single black hole and impart it a variable kick. We consider a black hole of mass M_{BH}=0.015 M_{sun} and velocity kicks V_{kick} in the range 0.1-1 V_{esc}, where V_{esc} represents the local escape speed from the galaxy. All the simulations use zero softening.

Results: displacement of SMBHs

![Graph showing displacement of the black hole and corresponding velocity as a function of time for different values of the black hole kick.](image)

Fig 3 shows the displacement of the black hole and the corresponding velocity as a function of time for two different values of the black hole kick. For small kicks (V_{kick} ~ 0.1 - 0.3 V_{esc}), the black hole wanders in the core and its motion is dominated by Brownian effects and close encounters with nearby stars. For intermediate to large kicks (V_{kick} = 0.4 - 0.9 V_{esc}), the black hole shows a damped oscillatory motion, with occasional perturbations from close encounters, until its velocity reaches the Brownian velocity [R4]. The black hole orbit decays on a dynamical friction timescale, which can be approximately 43 (c/0.6) (0.015/M_{BH}) (0.1/p), where c represents the stellar velocity dispersion and p the local density. As the central density drops in response to the black hole, this timescale increases. For large kicks (V_{kick} > V_{esc}), the black hole escapes the galaxy.

Results: mass deficits

![Graph showing density profile for different values of the kick.](image)

The escaping black hole affects the local stellar distribution in the form of a mass deficit. Fig 5 shows the density profile for different values of the kick. The dotted line represents the analytical profile of a Dehnen model with concentration parameter y = 0.5. The dashed line indicates the density profile of the initial model, after the black hole binary has stalled. We see that a mass deficit is already present due to the ejection of stars on low angular momentum orbits. The colored solid lines show the profile for different kicks at the times when the black hole falls back to the center. We note that the amount of mass deficit depends on the magnitude of the kick to the black hole.

Conclusions

- We simulated the evolution of galactic nuclei containing merged black holes which receive a velocity kick during the final stages of the mergers.
- We found that the black hole is displaced from the center and shows a damped oscillatory motion until its velocity reaches the Brownian velocity.
- We found that the escaping black hole affects the structure of the nucleus in the form of a mass deficit. For a given galaxy model, the deficit is proportional to the kick velocity.

References