# BINARY-SINGLE ENCOUNTERS OF 10 $M_\odot$ BLACK HOLES INCLUDING THE EFFECTS OF GRAVITATIONAL RADIATION

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**Abstract.** We compute the outcomes of close encounters between a binary and a single black holes including the effects of gravitational radiation reaction. All masses of individual black holes are assumed to be 1 $M_\odot$. We found that merger of two black holes takes place during the encounters in some cases. Thus the gravitational radiation can act as a mechanism for the dissipation of energy of a cluster mainly composed of 10 $M_\odot$ black holes which are produced by the evolution of high mass stars. The merger probability depends on many parameters in a complex way. Our preliminary calculations show that about 10 % of the strong encounters (i.e., $r_p \sim a$) between a binary of hardness 100 and a single lead to mergers of two black holes in the stellar system of one-dimensional velocity $\sigma = 100$ km/s.

## 1. Introduction

Evolution of high mass stars leads to the formation of black holes of around 10 $M_\odot$ (Brown & Bethe 1994). If such black holes are present in a dense cluster of low mass stars ($m \sim 0.7$ $M_\odot$), many interesting dynamical phenomena occur (Lee 1995). Black holes form a a subcluster within the central parts of the stellar system as a result of dynamical friction. The subsystem then undergoes core collapse and the density of black hole cluster grows rapidly. Binaries between black holes can be formed efficiently via three-body processes. These binaries release energy to the cluster through the interactions with single black holes.

During the course of interactions between a hard binary and a single, any two objects can become very close. A merger occurs if the amount of gravitational radiation is large. Here we report some preliminary results



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of numerical simulations of three-body encounters including the effects of gravitational radiation.

## 2. Basic Scheme and Numerical Method

The numerical method we adopt here is is based on the three-body regularization scheme developed by Aarseth & Zare (1974). The general relativistic effects are included as perturbations in this regularization scheme. The dynamical effect of gravitational radiation back reaction was computed by adopting the 2.5 post-Newtonian correction formula given by Damour (1987). We also incorporate the first post-Newtonian term, but the general results are not sensitive to this term. Our numerical program was tested against the analytical result by Peters (1964) for the orbital decay of an isolated binary.

## 3. Results

For our preliminary calculations, we have fixed the eccentricity at $e = 0.67$. We also fixed one-dimensional velocity dispersion of the background cluster at 100 km/sec. We have sampled 112 random directions for initial relative velocity between the single and the center of mass of the binary for a given set of $v_{rel}$, $e$, $x$, $r_p$ (minimum distance between binary and single), and $\sigma$. The orbital phase of the binary at the beginning of the calculation was fixed in all 112 samplings. About 5 to 20 % of strong encounters ($r_p \sim a$ where $a$ is the semi-major axis of the binary orbit) between a hard binary of $x = 100$ and a single are found to experience mergers when $v_{rel} \sim \sigma$. The merger fraction becomes about 1% or less if $x \sim 10$, and $r_p \sim a$. More extensive calculations with larger number of samplings and wider parameter range are being carried out and the results will be published elsewhere.

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