2009 Achievement Report of NAOJ Simulation Project

The Depletion of Dark Matter from the Center of Globular Clusters

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GRAPE-A

1 Introduction

Some massive globular clusters are reported to have some properties in common with Ultra-compact dwarf galaxies (UCDs). UCDs are star cluster size systems with mass in the range of $10^6 M_\odot - 10^8 M_\odot$ and half mass radii of 10-100 pc. A recent paper by Mieske et al. (2008) showed that in the parameter space which gives empirical description of the structural and kinematic properties of stellar spheroids, UCDs are located at the extension of the dwarf galaxies and globular cluster planes. This might indicate a relation between formation of UCDs and globular clusters.

However, observation of UCDs showed that mass-to-light (M/L) ratio of UCDs are on average about twice as large than those of globular clusters at comparable metallicity, and larger than those predicted from stellar populations for their age. The higher M/L ratio can be interpreted in a number of ways, one being a significant amount of dark matter in the cluster centers (Baumgardt & Mieske 2008).

One possible explanation for elevated high mass-to-light ratio in UCDs is by the existence of a substantial amount of dark matter funneling through adiabatic gas infall and later stripping of dwarf galaxies (Bekki, Couch & Drinkwater 2001, Goerdt 2008).

Following the UCD formation scenario proposed by Goerdt (2008), a recent paper by Baumgardt & Mieske (2008) followed by means of N-body simulations the evolution of star clusters composed out of a mix of stars and dark matter particles. They found that the dark matter gets removed from the central regions due to dynamical friction and mass segregation of stars.

UCDs have inspiral times significantly longer than a Hubble time and therefore a significant dark matter fraction remains within the half-mass radius of the present-day UCDs. Dark matter therefore seems a viable explanation for the elevated M/L ratio for UCDs.

Globular clusters on the other hand have shorter inspiral times so that only 20 % or less of the original dark matter would remain within their half-mass radius, explaining why their mass-to-light ratios are in agreement with predictions from stellar evolution models. If not tidally stripped, the dark matter should still reside in the outer parts of globular clusters.

Observations of a number of globular clusters by Scarpa et al.(2007) reported a flattening of the velocity dispersion in the outer cluster parts. This could be due to a number of reasons like contamination of the stellar sample by background stars or the tidal interaction of a globular cluster with the gravitational field of the Milky Way, but it might also indicate the presence of a dark matter halo.

Detailed simulations are necessary to confirm that the observed flattening of the velocity dispersion in the outer parts of globular clusters is due to a dark matter halo. For this purpose, we want to explore the influence of an external tidal field on the outer velocity field of globular clusters and the depletion of the dark matter.

2 The Model

We conduct a number of N-body simulations, using the collisional N-body code NBODY4 (Aarseth, 1999), to follow the evolution of the dark matter content star clusters in Plummer model. We assume that stars initially follow a Kroupa (2001) mass function with minimum and maximum masses of our stars are set equal to 1.0 $M_{\odot}$ and 100 $M_{\odot}$ respectively. Dark matter is represented by low-mass particles with masses of 0.1 $M_{\odot}$. In this present model, we evolved clusters of 25000 particles, consist of 9350 stars and 15650 dark matter particles with relative mass fraction in the dark matter and in star is 1:2. The cluster is assumed to orbit in a circular orbit around a Milky Way like galaxy at R=8.5 kpc.

3 Results

Fig.1 shows the fraction of dark matter mass to the stellar mass inside the cluster core (assumed to be the region inside the 5 % lagrangian radius of the cluster) and inside the half-mass radius of the cluster. After about 400 Nbody unit of time, or about 1 friction time, the dark matter fraction within the half-mass radius decreases into about 40 % of the initial dark matter amount while inside the core the amount of dark matter remains same. Fig.2 depicts the increase of the lagrangian radii of the dark matter which indicates that dark matter particles are moving to the outer part of the cluster. On the other hand, the lagrangian radii of stars shrink slowly with time due to dynamical friction and mass segregation.

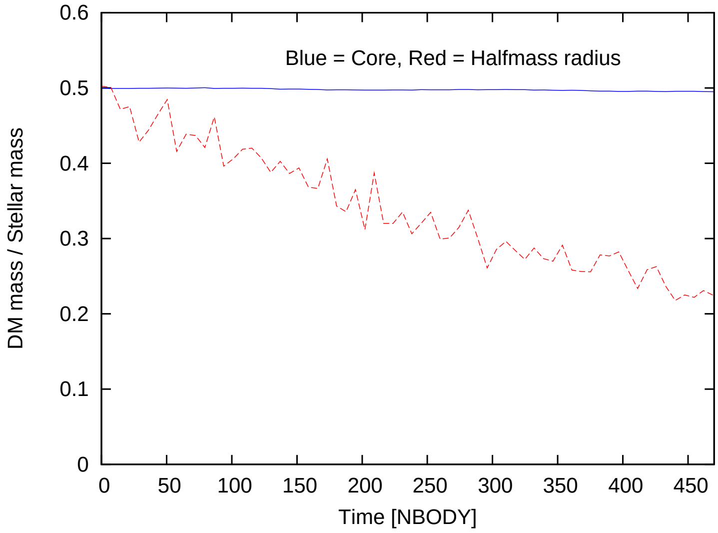

Figure 1: Dark matter fraction. The core radius is assumed to be equal to the 5 % lagrangian radius of the cluster.

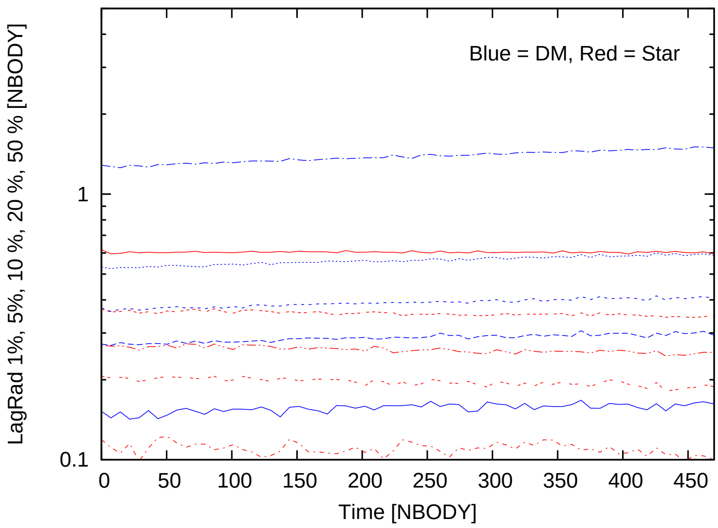

Figure 2: Evolution of lagrangian radii, i.e. radii which contain a certain fraction of the total mass of stars (red lines) and dark matter particles (blue lines).