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# The Effect of Tidal Field on the Depletion of Dark Matter from Globular Clusters

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GRAPE-A

## 1 Introduction

Observations of a number of globular clusters ($\omega$ Cen, NGC 7078, NGC 6171, NGC 7099, and NGC 6341) by Scarpa et al. (2007) reported that while these globular clusters having different sizes, different masses, and different dynamical histories, they have a common property of having constant velocity dispersion at large radii. This flattening of velocity dispersion at the outer parts of clusters might indicate the presence of dark matter halo.

Formation of globular clusters may have link with formation of ultra-compact dwarf galaxies (UCDs) since there are some similarities in their structural and kinematic properties, except the high of mass-to-light (M/L) ratio of UCDs (Mieske et al. 2008).

N-body simulations by Baumgardt & Mieske (2008) showed that the high M/L ratio in UCDs can be caused by the existence of a significant dark matter fraction within the half-mass radius of present-day UCDs.

If some globular clusters formed in a similar way to UCDs, a substantial amount of dark matter might remain in their outer parts, which may cause a flattening of the velocity dispersion.

Therefore we follow the evolution of globular clusters composed out of a mix of stars and dark matter particles to examine the influence of external tidal field on the depletion of dark matter.

## 2 The Models

We conduct a number of $N$-body simulations, using the collisional $N$-body code NBODY4 (Aarseth 1999) and performed on the GRAPE6 computers (Makino et al. 2003). Globular clusters are composed out of a mix of stars and dark matter particles with number of particles N = 25.000, 50.000 and 100.000. Stars and dark matter particles initially follow the same density distribution, which is given by Plummer model. Dark matter is represented by low-mass particles with masses of 0.1 $M_{\odot}$ (Binney & Tremaine, 1987). Minimum and maximum masses of our stars are set equal to 1.0 $M_{\odot}$ and 100

$M_{\odot}$ respectively to follow a Kroupa (2001) mass function. Mass fraction of the dark matter and the stars is 1:1. Tidally perturbed clusters are assumed to orbit a Milky Way-like galaxy at R=8.5 kpc.

## 3 Results

Fig.1 depicts the evolution of lagrangian radii in the model of an isolated cluster. Lagrangian radii are radii contain a certain fraction of the total mass of the cluster, i.e. 1 %, 5 %, 10%, 50 %, 70 % of the cluster mass. The dynamical friction time for a Plummer model is given by (Baumgardt & Mieske 2008) :

$$t_{fric} = 0.035 \frac{\sqrt{M}_{tot} {R_{half}}^{3/2}}{\sqrt{G} m} \tag{1}$$

where $M_{tot}$ is the total cluster mass, $R_{half}$ is the cluster half-mass radius, $G$ is the gravitational constant and $m$ is the mass of an inspiraling star. The increase of the lagrangian radii of the dark matter particles indicates that they are moving to the outer part of the cluster. On the other hand, in the inner part, when the lagrangian radii contain 20 % or less of the total mass of star, the lagrangian radii of stars shrink slowly with time. This occurs due to dynamical friction and mass segregation of stars.

Fig.2 shows the fraction of dark matter mass to the stellar mass inside the isolated cluster and the tidally perturbed clusters with N=25.000, 50.000 and 100.000 particles. After about 1.5 friction times, only about 10 % of initial dark matter mass remains within the core radii. After about 2 friction times, about 40 % - 60 % of initial dark matter mass left inside the half-mass radius of clusters, while at least 80 % of initial dark matter amount still remains in the outer part of tidally perturbed clusters.

## 4 Conclusions

Our simulation shows that dark matter is depleted from the center of globular clusters due to dynamical friction and mass segregation of stars. After about 1.5 friction times, the globular clusters have expelled almost all amount of the dark matter from their centers. An external tidal field from a Milky Way-like galaxy effects to deplete the dark matter in the outer part of clusters. However, within about 2 friction times (some Giga years) more than 80 % of dark matter's initial amount still remain in the outer part of clusters. This might explain the existence of significant amount of dark matter in the outer part of some observed globular clusters.

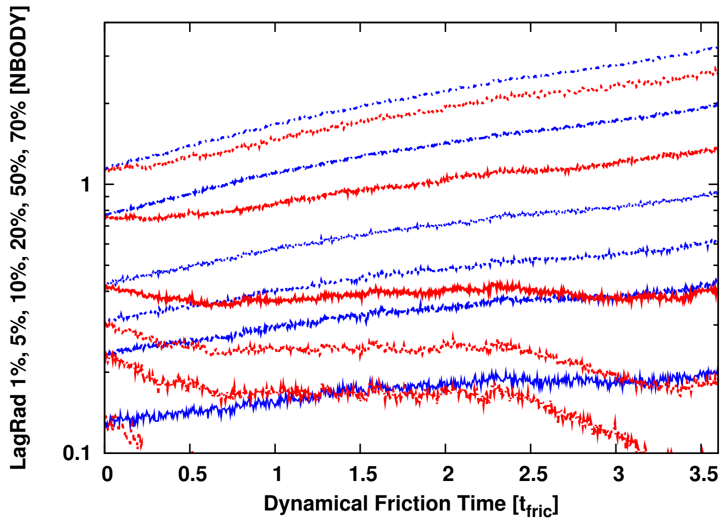


Figure 1: The increase of the lagrangian radii of the dark matter particles (blue lines) indicates that they are moving to the outer part of the cluster. On the other hand, the lagrangian radii of stars (red lines) in the inner part of the cluster shrink slowly due to dynamical friction and mass segregation of stars.

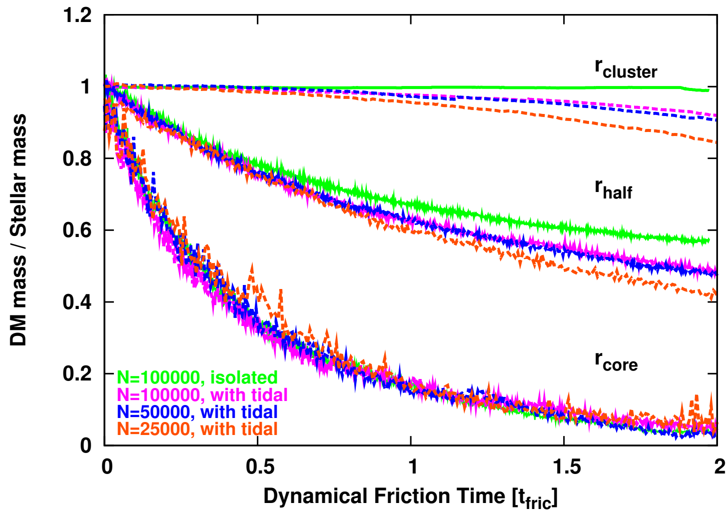


Figure 2: After about 1.5 friction times, the globular clusters have expelled almost all amount of dark matter from their cores. Due to higher mass loss, small-N clusters suffer stronger influence of the tidal field, so that the dark matter fraction in the outer part of that clusters decreases faster than the ones in the large-N clusters. Tidal field depletes the dark matter from clusters less than 20 % of their initial amount within about 2 friction times.

## 5 References

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