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# Galactic nuclei formation via globular cluster merging

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**Abstract.** Preliminary results are presented about a fully self-consistent $N$-body simulation of a sample of four massive globular clusters in close interaction within the central region of a galaxy. The $N$-body representation (with $N = 1.5 \times 10^6$ particles in total) of both the clusters and the galaxy allows to include in a natural and self-consistent way dynamical friction and tidal interactions. The results confirm the decay and merging of globulars as a viable scenario for the formation/accretion of compact nuclear clusters. Specifically: i) the frictional orbital decay is $\sim 2$ times faster than that predicted by the generalized Chandrasekhar formula; ii) the progenitor clusters merge in less than 20 galactic core-crossing times ($t_b$); iii) the NC configuration keeps quasi-stable at least within $\sim 70 t_b$.

**Key words.** Stellar Dynamics – Methods: numerical – Galaxies: kinematics and dynamics – Galaxies: star clusters

## 1. Introduction

Nuclear clusters are common across the Hubble sequence (Matthews et al. 1999; Schödel et al. 2007). In particular, the ACS Virgo Cluster Survey (Côté et al. 2006) shows many compact nuclei at the photocenters of many of early-type galaxies ($> 66\%$ for $M_V < -15$). Their half-mass radii ($r_h$) are in the $2 \div 62$ pc range, with average value $\langle r_h \rangle = 4.2$ pc, and scale with the nucleus luminosity as $r_h \propto L_n^{0.5 \pm 0.003}$. Brighter ($M_V < -20.5$) core-Sersic galaxies lack resolved stellar nuclei. The mean of the frequency function for the nucleus-to-galaxy luminosity ratio in nucleated galaxies, Log $\eta = -2.49 \pm 0.09$ is *indistinguishable* from that of the Super massive black hole–to-bulge mass ratio, Log $(M_\bullet/M_{gal}) = -2.61 \pm 0.07$, calculated in 23 early-type galaxies with detected supermassive black holes (SBHs).It is thus argued that resolved stellar nuclei are the low-mass counterparts of nuclei hosting SBHs detected in the bright galaxies. If this view is correct, then one should think in terms of central massive objects, either SBHs or compact stellar clusters (CSCs), that accompany the formation and/or early evolution of almost all early-type galaxies. Comparing the nuclei to the nuclear clustersof late-type spiral galaxies reveals a close match in terms of size, luminosity, and overall frequency. A formation mechanism that is rather insensitive to the detailed properties of the host galaxy properties is required to explain this ubiquity and homogeneity.

Another observational relevant point is the growing evidence of presence of very massive

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($> 10^7$ $M_\odot$) YOUNG star clusters in Antennae, Magellanic Clouds, M33, M82, Fornax dSph (Fritze-v. Alvensleben 1999; de Grijs et al. 2005; Fusi Pecci et al. 2005), as well as OLD (Harris & Pudritz 1994) in M87 and Virgo ellipticals.

Harris et al. (2006) indicate how up to a 40% of the total mass in GCS of brightest cluster galaxies is contributed by massive (p.d.mass $> 1.5 \times 10^6$ $M_\odot$, in good agreement with recent theoretical results by Kratsov & Gnedin (2005). Putting together these observational data (presence of resolved stellar nuclei in galaxies and likely initial presence of massive star clusters, raise two questions and possible answers. The questions are: i) how are these 'stellar'nuclei formed?, and ii) why very massive stellar clusters are no more observed in many galaxies? The (possible) answers could be resumed in: resolved stellar nuclei are formed via massive stellar clusters merging, after a substantial orbital decay toward the galactic central region. In the following we describe some of our work done recently to give substance to this explanation.

## 2. Nuclei as remains of merged Globular Clusters?

Many papers dealt with dynamical friction on massive objects orbiting galaxies. It seems well ascertained that sufficiently massive and compact clusters may decay towards their parent galaxy central region in a time short respect to the Hubble time. The less symmetries in the galactci potential, the quicker the orbital decay, tha depends (obviously) also on the initial orbital energy and angular momentum. An enhancement of the classical frictional deceleration caused by background stars is due to tidal braking torque caused by the galactic potential. As a consequence, it has been proved in quite general cases that after less than 1 Gyr many GCs are limited to move in the inner galactic region. Do they merge and form a Compact Star Cluster? The first positive answer to this question was given by Tremaine et al. (1975) who were the first to examine the modes of cluster merging in the inner region of M 31. Here, we summarize the results presented in Capuzzo-Dolcetta & Miocchi (2008b) of a fully self-consistent $N$-body simulation of the close interaction of a sample of four massive globular clusters (GCs) in the central region of a galaxy. Both the clusters and the galaxy are represented by mutually interacting particles, thus including in a natural and self-consistent way dynamical friction and tidal interactions. This study represents a substantial improvement in the analysis of the frictional decaying and merging of GCs in galactic nuclear regions, a scenario first tackled by semi-analitical approaches (Tremaine et al. 1975; Capuzzo-Dolcetta 1993) and then pursued by $N$-body experiments (Oh & Lin 2000; Capuzzo-Dolcetta & Miocchi 2008a). Clarifying the role of the above-mentioned dynamical effects is important also to understand the formation and origin of Nuclear Clusters (NCs) (e.g. Oh & Lin 2000; Bekki et al. 2004).

## 3. Models and Results

Each GC is represented by 256,000 particles initially distributed according to a King profile whose structural parameters are taken from the set of the most compact clusters simulated in Capuzzo-Dolcetta & Miocchi (2008a). The GCs are initially located at rest within the galactic core (see Fig. 1). The galactic model is given by a spherical and isotropic Plummer phase-space distribution sampled with 512,000 particles. The simulation is performed with our own parallel tree-code using individual and variable time-steps (Miocchi & Capuzzo-Dolcetta 2002).

The simulation results can be re-scaled with any given set of galactic structural parameters. One possible choice for these parameters is the following: core radius $r_b = 200$ pc; core-crossing time $t_b = 0.54$ Myr; central density $\rho_{b0} = 370$ $M_\odot$ $pc^{-3}$.

The main results of the simulation can be summarized as follows: i) the frictional orbital decay is $\sim 2$ times faster than that given by the use of the generalized Chandrasekhar formula; ii) the progenitor clusters (initially located within the galactic core) merge in less than 20 galactic core-crossing time ($\sim$ 11 Myr),

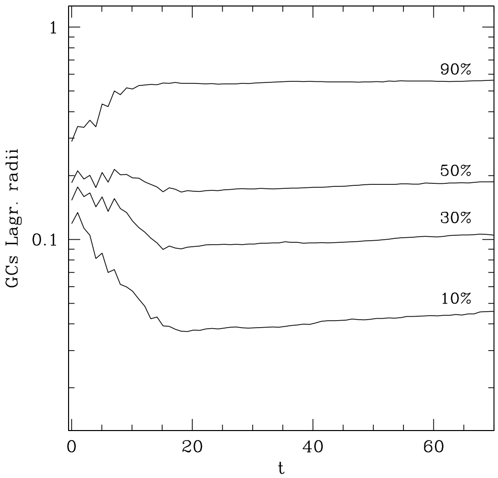


**Fig. 1.** Evolution of the Lagrangian radii of the four GCs as a whole.

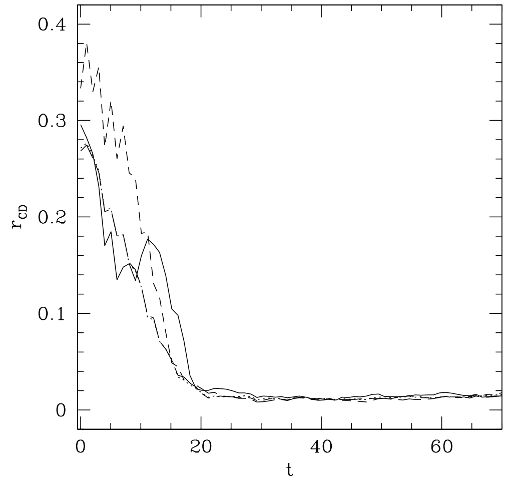


**Fig. 2.** Upper panel: time evolution of the distance of the cluster CD from the galactic centre (rCD).

see Fig. 1 and Capuzzo-Dolcetta & Miocchi (2008b); iii) the NC configuration is quasi-stable at least within the simulated time ($\sim$ 70$t_b$ $\sim$ 40 Myr); iv) the total surface density profile has the typical appearance of a nucleated galaxy central profile, see Fig. 3; v) the global velocity dispersion profile *decreases* towards the centre as found in the Geha et al. (2002) observations. These results are described in more detail in Capuzzo-Dolcetta & Miocchi (2008b).

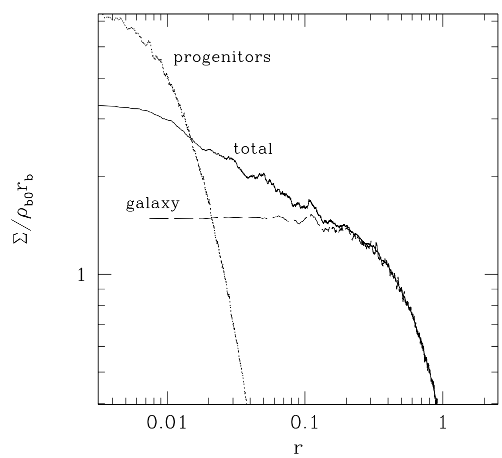


**Fig. 3.** Projected surface density profiles of the final configuration of the whole system (galaxy plus NC) (solid line) and, for the sake of comparison, of the galaxy stellar component only (long dashed line). The dotted line is the profile of the 'summed' four GC progenitors.

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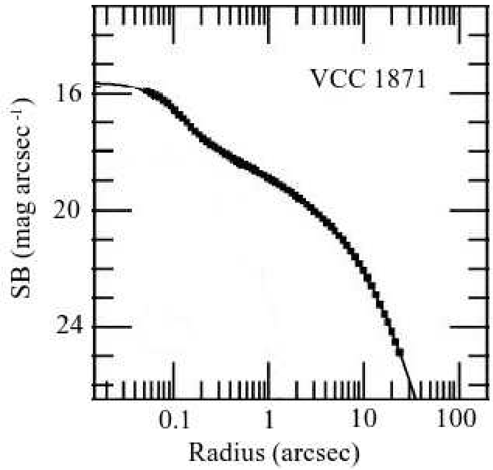


**Fig. 4.** Surface brightness (g-band) profile of the dwarf elliptical galaxy VCC 1871 in the Virgo cluster (from (Côté et al. 2006)).

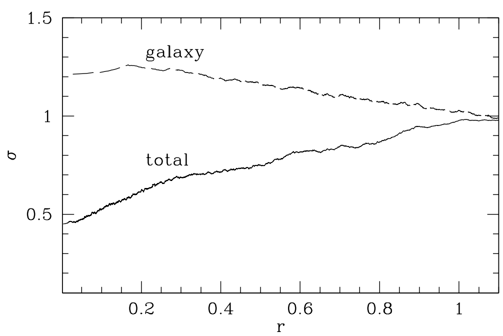


**Fig. 5.** Projected radial behaviour of the velocity dispersion in the last system configuration. Line symbols are as in Fig. 4.

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