Extragalactic Star Clusters
IAU Symposium Series, Vol. 207, 2002
Doug Geisler, Eva K. Grebel, and Dante Minniti, eds.

Dynamical Friction in dE Globular Cluster Systems

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Abstract. The dynamical friction timescale for globular clusters to sink to the center of a dwarf elliptical galaxy (dE) is significantly less than a Hubble time if the halos have isothermal profiles and the globular clusters formed with the same radial density profile as the underlying stellar population. We examine the summed radial distribution of the entire globular cluster systems and the bright globular cluster candidates in 65 Virgo and Fornax Cluster dEs for evidence of dynamical friction processes. We find that the bright dE nuclei could have been formed from the merger of orbitally decayed massive clusters, but the faint nuclei are several magnitudes fainter than expected. These faint nuclei are found primarily in $M_V > -14$ dEs which have high globular cluster specific frequencies and extended globular cluster systems. In these galaxies, the formation of new star clusters, high central dark matter densities, extended dark matter halos, or tidal interactions may act to prevent dynamical friction from collapsing the entire globular cluster population into a bright nucleus.

1. Introduction

Dwarf elliptical galaxies are ideal environments in which to study globular cluster systems (GCSs). dEs have little gas, dust or star-formation and globular cluster candidates are easily identified in these typically low surface brightness, low luminosity galaxies. Disk and bulge shocking, which destroy many clusters in giant galaxies (Fall & Rees 1977) are uneffective in dEs. The blue GCSs of giant galaxies may be built up from the accretion of dEs and dSphs (Côté et al. 1998). Because dE GCSs are simple compared to giant galaxies and easier to detect

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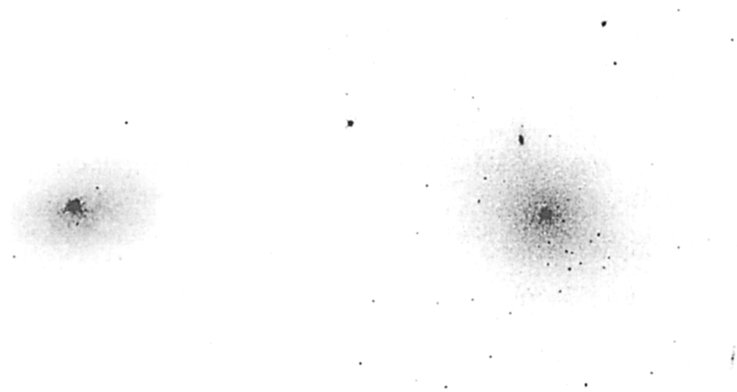

Figure 1. FCC 46 (left) has an off-center blue nucleus ($V-I = 0.60$). VCC 940 (right) has a bright central nucleus ($V - I = 1.07$).

than in star-forming dwarf galaxies, the study of dE GCSs can add new insight into the formation and evolution of GCSs.

Globular cluster systems, in turn, are important tracers of their host galaxy's star formation histories, dynamics and dark matter distribution, and morphological evolution. dEs are dominated by old stellar populations, but many dEs and dSphs have intermediate age stellar populations and extended periods of star-formation (Grebel 1997). They are thought to be dark matter dominated with increasing mass to light ratios with fainter dEs (Peterson & Caldwell 1993), but their lack of HI and low surface brightnesses makes their dark matter contents difficult to constrain. Finally, the evolution of dEs from gas-rich galaxies to gas-poor objects and the formation of the compact nuclei observed in many dEs are poorly understood.

2. Data

We have obtained HST WFPC2 F555W (2×230 seconds) and F814W (300 seconds) observations of 65 dEs with $-11 > M_B > -17$ in the Virgo and Fornax clusters (Figure 1). Globular cluster candidates were selected by their $V - I$ colors ($0.5 < V - I < 1.5$) and size (FWHM < 2.5 pixels) and corrected for background contamination (Miller et al. 1998).

Many dEs possess compact stellar nuclei. These nuclei are barely resolved even at HST resolution, and appear to be massive star clusters in the center of the galaxies. Nuclei occur more often in bright dEs than in faint dEs (Sandage et al. 1985) and in the center of clusters than in the outskirts (Ferguson & Sandage 1989). It is unclear whether most nuclei formed via a nuclear starburst, as appears to be the case for NGC 205 and FCC 46, or via dynamical friction of one or several massive globular clusters (Tremaine, Ostriker, & Spitzer 1975).

3. Dynamical friction in dEs

A cluster orbiting a galaxy will experience a drag force due to its gravitational interaction with the surrounding gas and stars, causing it to lose energy and spiral into the center of the galaxy. For a globular cluster on a circular orbit in an isothermal halo,

$$t_{DF} = \frac{2.64 \times 10^2}{\ln\Lambda} \left(\frac{r_i}{2\ \mathrm{kpc}}\right)^2 \left(\frac{v_c}{250\ \mathrm{km\ s^{-1}}}\right) \left(\frac{10^6 \mathrm{M}_\odot}{\mathrm{M}_{\mathrm{GC}}}\right) \mathrm{Gyr} \qquad (1)$$

where ln Λ is the Coulomb logarithm, r_i is the initial radius, v_c is the circular velocity, and M_{GC} is the mass of the globular cluster (Binney & Tremaine 1987). dEs have typical scalelengths $\sim$ 1 kpc, and velocity dispersions $\sim$ 10-70 km s^{-1} (Peterson & Caldwell 1993), thus the timescale for a massive globular cluster to spiral into the center is much less than a Hubble time (Hernandez & Gilmore 1998). Dynamical friction should have a strong impact on dE GCSs.

We have performed a set of Monte Carlo simulations of the evolution of dE globular cluster radial distributions to determine the impact of dynamical friction over time on dE GCSs (Lotz et al. 2001). We used the analytic expression for r(t) and made some simple assumptions: 1) the globular clusters have isotropic orbits; 2) the globular clusters have the same exponential distribution as the underlying stellar light; 3) the dark matter is in an isothermal halo and traces the stellar halo; and 4) that the initial cluster mass function is approximately the same as the present day mass function. The globular clusters' radii were allowed to decay with time and all clusters that ended up at the center of the dE were assumed to have merged with the nucleus. After 10 Gyr, we find little change in the radial distribution of all globular clusters except for the faintest dEs. However, we do expect to find a depletion of massive globular clusters ($> 2.5 \times 10^5$ M$_\odot$) in the inner regions of dEs.

Because each dE in our sample typically has only a handful of globular cluster candidates, it is difficult to examine to radial distribution of globular clusters in individual dEs. In Figure 2, we have summed the radial distribution of globular cluster candidates for all 65 dEs in our sample, correcting for background contamination, scalelength and ellipticity. We find that the radial distribution of all globular clusters agrees well with the exponential light profile of dEs. However, there is a slight deficit of clusters brighter than $\mathrm{M}_V = -8.0$ within the inner two scalelengths. It is possible that these massive clusters have orbitally decayed and formed the dE nuclei.

4. Formation of dE nuclei

Could the observed dE nuclei have formed through dynamical friction acting on one or more massive globular clusters? Most dE nuclei have colors similar to their globular cluster candidates ($V-I \sim 0.95$), although we observed two blue nuclei ($V-I \sim 0.6$) and the nuclei brighter than -11 tend to be redder than the average color of the globular clusters (Lotz et al. 2001). Faint dEs are less likely to have nuclei and have fainter nuclei than bright dEs (Figure 3, left).

Using the same assumptions as before, we repeated our Monte Carlo simulations to predict the mass and magnitude of nuclei formed via dynamical friction

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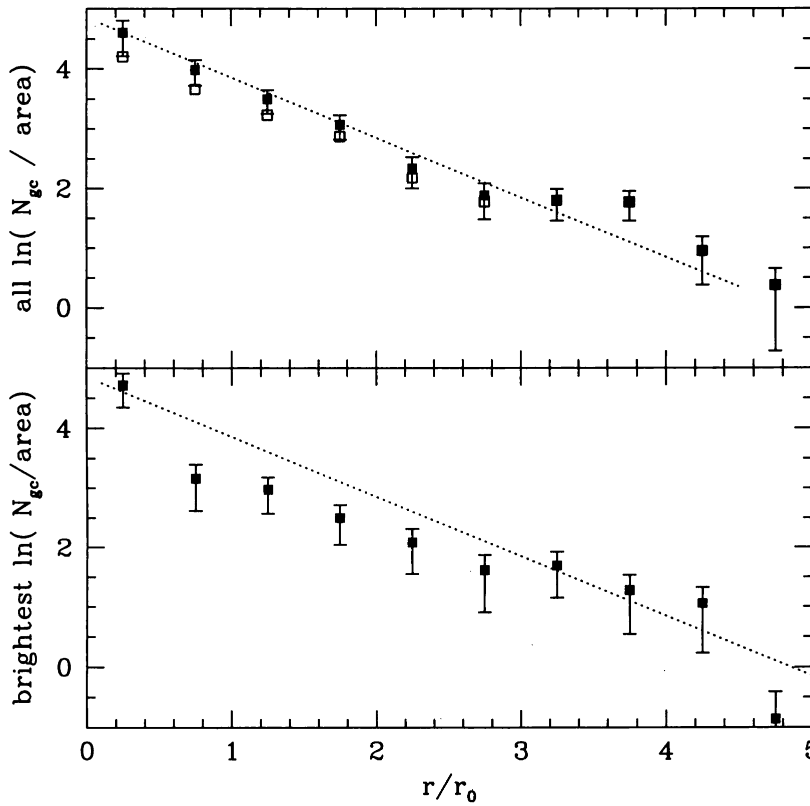

Figure 2. The summed dE GCS radial distribution scaled by the exponential scalelength of the galaxy for all cluster candidates excluding the nuclei (top) and bright ($M_V > -8$) cluster candidates (bottom) compared to an exponential distribution (dashed line).

for each dE in our sample. The initial number of clusters was estimated using the present number of globular clusters and the predicted dynamical friction destruction efficiency for each dE. The faintest dE are expected to have over half of their initial globular cluster population merge into a nucleus in less than a Hubble time. However, we find that the predicted magnitudes of the nuclei in faint dEs are much brighter than observed (Figure 3, right).

5. Conclusions

For simple assumptions, the dynamical friction timescale is less than a Hubble time in dEs. We see some evidence for the depletion of bright globular clusters within the inner few scalelengths, so dynamical friction may form some dE nuclei. However, if this is true, we expect dynamical friction to be very efficient at destroying globular clusters and faint dE to have bright nuclei and no surviving

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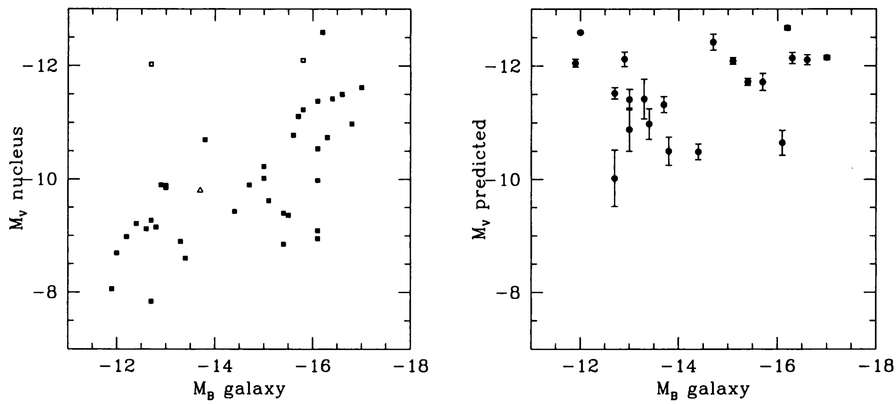

Figure 3. dE M_B vs nucleus M_V observed (left) and predicted (right). The photometric errors for the observed nuclei are smaller than the points and the blue nuclei are shown as open squares. The error bars in the right are the dispersion in the predicted nuclear magnitudes for each galaxy due to random sampling of the cluster mass function.

globular clusters. Instead we find that faint dE have faint or no nuclei and high specific frequencies. Thus dynamical friction must be inefficient in the faintest dEs. The clusters in these galaxies could be younger than their dynamical friction timescales. The faint dE could have extended or dense dark matter halos, which would lengthen the decay timescales. Or they could be more likely to be tidally disturbed (Oh, Lin, & Richer 2000).

References

Binney, J. & Tremaine, S. 1987, Galactic Dynamics, (Princeton: Princeton University Press)

Côté, P., Marke, R. O., & West, M. J. 1998, ApJ, 501, 554

Grebel, E. 1997, Rev. Mod. Astron., 10, 29

Fall, S. M. & Rees, M. J. 1977, MNRAS, 181, 37P

Ferguson, H. C., & Sandage, A. 1989, ApJ, 346, L53

Hernandez, X. & Gilmore, G. 1998, MNRAS, 297, 517

Lotz, J. M., Telford, R., Ferguson, H. C., Miller, B. W., Stiavelli, M., & Mack, J. 2001, ApJ, 552, 572

Miller, B. W., Lotz, J. M., Ferguson, H. C., Stiavelli, M., & Whitmore, B. C. 1998, ApJ, 508, L133

Oh, K. S., Lin, D. N. C., & Richer, H. B. 2000, ApJ, 531, 727

Peterson, R. C., & Caldwell, N. 1993, AJ, 105, 1411

Sandage, A., Binggeli, B., & Tammann G.A. 1985, AJ, 90, 1759

Tremaine, S. D., Ostriker, J. P., & Spitzer, L. 1975, ApJ, 196, 407

Discussion

J. Gallagher: Is it the dynamical friction process that is efficient or is it possible that our representation of dynamical friction could be at fault? In particular, is it possible that the small physical sizes of dEs could be a factor that produces difficulties when one uses a standard Chandrasehkar dynamical friction formulation?

J. Lotz: Oh, Lin Richer (2000), Oh & Lin (2000) have done a full N-body simulation of the effect of dynamical friction on the globular system of the Fornax dSph and a brighter dE - they find that dynamical friction should be quite efficient at forming nuclei and some heating mechanism is needed to explain the extended GCS of Fornax. However, they assume dE/dSph are isotropic King halos and there are suggestions that dSph are highly anisotropic, so the Chandrasekar formula and the assumption of isotropy may not hold for dE.

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