Galaxy Threshing and Ultra-Compact Dwarfs in the Fornax Cluster

Michael D. Gregg, Michael J. Drinkwater, Michael J. Hilker, Steven Phillipps, J. Bryn Jones, & Henry C. Ferguson

Univ. of California, Davis, and Inst. for Geophysics and Planetary Physics, Lawrence Livermore National Laboratory; Univ. of Queensland; Univ. of Bristol; Univ. of Nottingham; & STScI

Abstract. We have discovered a new type of galaxy in the Fornax Cluster: “ultra-compact” dwarfs (UCDs). The UCDs are unresolved in ground-based imaging and have spectra typical of old stellar systems. Although the UCDs resemble overgrown globular clusters, based on VLT UVES echelle spectroscopy, they appear to be dynamically distinct systems with higher internal velocity dispersions and M/L ratios for a given luminosity than Milky Way or M31 globulars. Our preferred explanation for their origin is that they are the remnant nuclei of dwarf elliptical galaxies which have been tidally stripped, or “threshed” by repeated encounters with the central cluster galaxy, NGC1399. If correct, then tidal stripping of nucleated dwarfs to form UCDs may, over a Hubble time, be an important source of the plentiful globular cluster population in the halo of NGC1399, and, by implication, other cD galaxies. In this picture, the dwarf elliptical halo contents, up to 99% of the original dwarf luminosity, contribute a significant fraction of the populations of intergalactic stars, globulars, and gas in galaxy clusters.

Keywords: galaxies, interactions, clusters

1. Introduction

Dwarf galaxies account for only a small fraction of the total mass and light of galaxy clusters; nevertheless, they are a key element in the evolution of galaxy clusters. Evidence is gathering that evolution of rich clusters can be gauged by its present population of dwarf galaxies. Tidal interactions which whittle away at (Moore et al. 1996, Bekki, Couch, & Drinkwater 2001a) and even disrupt entire systems (Gregg & West 1998) can liberate debris from bright galaxies, giving rise to large populations of dwarf galaxies (Lopez-Cruz et al. 1996). In the opposite direction, dwarfs may lose their individual identities by accreting onto the central elliptical, creating cD galaxies. This ebb and flow of the dwarf galaxy population may be episodic and a measure of the dynamical state of a cluster (Lopez-Cruz et al. 1996), and a complete understanding of galaxy clusters must incorporate not only the present state of dwarf galaxies but also their life histories.

The Fornax Cluster Spectroscopic Survey (FCSS; Drinkwater et al. 2000a) is using the 2-Degree Field 400-fiber spectrograph on the Anglo-Australian Telescope to obtain spectra for every object down to $B_J <$
19.7 in a $4^\circ \times 3^\circ$ area centered on the Fornax cluster, about 14000 targets in all. The FCSS is unique in targeting all objects, stellar and nonstellar on Schmidt plates. This complete sample of galaxies over a large range of magnitude and surface brightness will permit study of the luminosity function and dynamics of Fornax in greater detail than has been done previously (e.g., Ferguson 1989). Now $\sim 70\%$ finished, the most exciting find from the FCSS is the identification of seven objects from the unresolved “stellar” targets which are “ultra-compact dwarf” (UCD) cluster members with $-13 < M_B < -11$, and sizes $\lesssim 100$ pc.

2. UCD Properties

Distributed widely across the cluster, the UCDs are not, as a class, associated with bright galaxies (Drinkwater et al. 2000b; Phillipps et al. 2001). The UCDs are $\sim 2$ magnitudes brighter than the largest globular clusters in NGC 1399 (Figure 1) and have absorption-line spectra indicative of older, moderately metal-poor stellar populations. All are classified as stellar in Schmidt plate material, which provides the target lists for the FCSS, and all but the brightest UCD are still essentially unresolved in ground-based CCD images in $\sim 1.2''$ seeing (Figure 1). Such objects are passed over by galaxy redshift surveys,
rejected because of their stellar appearance. Because the 7 UCDs are near our spectroscopic survey magnitude limit, we predict that many fainter UCDs exist in the cluster.

3. Relation of Ultra Compact Dwarfs to Other Galaxies
Though tiny and hard to find, the UCDs provide interesting insights into the longer term evolution of galaxies in a dense environment. Our favored interpretation of UCDs is that they are the durable central nuggets of nucleated dwarf ellipticals which have had their fragile, puffy halos tidally stripped or “threshed” by repeated close and intense encounters with the largest galaxies in the cluster (Bekki, et al. 2001a). Both the stripped halos, accounting for $\sim 98\%$ of a dE’s total light (Binggeli & Cameron 1991; Freeman 1993), and the surviving nuclei are dispersed into intracluster space or added to the envelopes of the brighter galaxies, especially cDs like NGC 1399. Such phenomena are not unique to rich clusters; tidally liberated streams of stars have been recognized around M31 and the Milky Way (e.g., Ibata et al. 2001a,b), and can perhaps account for the origin of M32 (Bekki et al. 2001b).

We have obtained HST STIS images of 5 UCDs plus a comparison dE in Fornax. These images do just resolve the UCD cores and show that they are structurally a good match to the nucleus of the comparison dE, after model subtraction of the dE halo (Figure 2). To further investigate the possible links among UCDs, dEs, and globular clusters, we have
Comparison of various early type objects, showing that UCDs may be more closely related to dE,N galaxies than to bona fide globular clusters. Sources for velocity dispersions are: UCDs are from our VLT echelle spectra; bright galaxies from Faber et al. 1987; dE,N data are from Geha et al. (2001) (Virgo dEs) or our own spectra for several Fornax dEs, including FCC303 (Figure 2) which was observed with the VLT echelle; M31 globulars from Djorgovski et al. (1997). A two component fit to the dE nucleus+halo has been used to estimate their separate luminosities to place the dE nucleus separately in the plot; it falls amongst the UCDs and is indicated by the tiny black filled square.

Figure 3. Comparison of various early type objects, showing that UCDs may be more closely related to dE,N galaxies than to bona fide globular clusters. Sources for velocity dispersions are: UCDs are from our VLT echelle spectra; bright galaxies from Faber et al. 1987; dE,N data are from Geha et al. (2001) (Virgo dEs) or our own spectra for several Fornax dEs, including FCC303 (Figure 2) which was observed with the VLT echelle; M31 globulars from Djorgovski et al. (1997). A two component fit to the dE nucleus+halo has been used to estimate their separate luminosities to place the dE nucleus separately in the plot; it falls amongst the UCDs and is indicated by the tiny black filled square.

obtained echelle spectra of 5 of the UCDs at the VLT using UVES and Keck with ESI. When placed in the $M_V-\sigma$ plane along with ellipticals, dEs, and Galactic+M31 globular clusters (Figure 3), the UCDs appear to be more closely related to brighter ellipticals than to globulars. The bright early types follow the well known $L \propto \sigma^4$ Faber-Jackson (1976) relation, while the globulars lie along a different locus with $L \propto \sigma^{1.7}$ (Djorgovski et al. 1997). The UCDs, though lying closer to globulars in this plane, fall along the extrapolated Faber-Jackson relation and are an order of magnitude too bright for their velocity dispersions to join the globular cluster relation.

4. Role of UCDs in Galaxy Cluster Evolution

If the threshing model of Bekki et al. (2001a) is correct and the UCDs have lost their envelopes – 98% of their light – while the nuclei are little
affected, then the UCDs would have begun life \( \sim 4.25 \) magnitudes brighter, in the regime of the nucleated dwarf ellipticals (Figure 3). The UCDs may hold the answer to the old puzzle of why cD and some other cluster ellipticals have such high “specific frequencies” of globular clusters, factors of several or more greater than globular populations around spirals like the Milky Way. During the gravitational interactions which remove their halos, many UCDs may be captured by the central elliptical where they can masquerade as globulars, accounting for the brightest cD halo star clusters. Threshing may also be able to explain the rest of the specific frequency excess in cDs. Figure 2 shows FCC303, a typical dE; in its halo are \( \sim 10 \) globulars (seen as point sources at the distance of Fornax). The specific frequency of dEs is high (Miller et al. 1998), comparable to that of a typical cD. Recycled dE halo material accumulated by a cD over a Hubble time provides a natural explanation for the large globular cluster populations of giant ellipticals in clusters. Through such tidal interactions in rich environments the evolution of bright galaxies and the cluster as a whole are intimately linked to the population of dwarf galaxies.

Acknowledgements

The authors acknowledge generous support from the National Science Foundation (AST 9970884), and NASA through STScI. Part of the work reported here was done at IGPP, under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

References

Bekki, K., Couch, W.J., & Drinkwater, M.J. 2001a, ApJL, 552, 105
Bekki, K., Couch, W.J., Drinkwater, M.J., & Gregg, M.D. 2001b, ApJL, 557, 39
Binggeli B., Cameron L.M., 1991, A&A, 252, 27
Djorgovski, S. G., et al. 1997, ApJL, 474, L19
Drinkwater, M.J., Phillipps, S., Jones, J.B., Gregg, M.D., Deady, J.H., Davies, J.I., Parker, Q.A., Sadler, E.M., & Smith, R.M., 2000a, A&A, 355, 900
Drinkwater, M.J., Jones, Gregg, M.D., & Phillipps, S., 2000b Pub. of the Astron. Soc. of Australia, 17, 227
Faber, S.M. & Jackson, R.E. 1976, ApJ, 204, 668
Faber, S.M. et al. 1987, ApJS, 69, 763
Ferguson, H.C. 1989, AJ, 98, 367
Freeman, K.C. 1993, in ASP Conf. Ser. 48, The Globular Cluster–Galaxy Connection, ed. G.H. Smith & J.P. Brodie (San Francisco: ASP), 608
Geha, M., Guhathakurta, P., & van der Marel, R. 2001. [astro-ph/0107010]
Gregg, M.D. & West, M.J. 1998, Nature, 396, 549
Ibata, R., Lewis, G. F., Irwin, M., Totten, E., & Quinn, 2001a, ApJ, 551, 294
Lopez-Cruz, O., et al. 1997 ApJL 475, L97
Moore, B., Katz, N., Lake, G., Dressler, A., & Oemler, A., Jr. 1996, Nature, 379, 613
Miller, B. W., Lotz, J. M. Ferguson, H. C., Stiavelli, M. & Whitmore, B. C. 1998, ApJ, 508, 133
Phillipps S., Drinkwater M.J., Gregg M.D., Jones, J.B., 2001, ApJ, 560, 201
