

GLOBULAR CLUSTERS IN GALAXIES BEYOND THE LOCAL GROUP. IX. MORE ON THE FORNAX ELLIPTICALS

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ABSTRACT

For four of the brightest elliptical galaxies in the Fornax cluster (NGC 1374, 1379, 1387, and 1399), we compare the spatial distribution of their globular cluster systems with the underlying halo light distributions. In NGC 1374, 1379, and 1387, we find no persuasive evidence that the cluster systems differ strongly in radial extent from the galaxy light itself. For the central giant NGC 1399, in which the best cluster data exist, we find that the globular cluster distribution follows the halo surface-brightness profile remarkably well. In this respect, NGC 1399 is *unlike* the dominant Virgo ellipticals M49 and M87, where the cluster systems are more extended than the halo light; instead, it is more nearly similar to NGC 3311, the central giant elliptical in the Hydra cluster. The case of NGC 1399 further reinforces the special status of the central giant ellipticals in large clusters of galaxies.

I. INTRODUCTION

It has become increasingly evident that the "halo" of a major galaxy, far from being a homogeneous subsystem of its parent galaxy, may contain quite distinct subcomponents of its own. In particular, evidence exists for several galaxies that the *globular cluster system* can follow different radial structure and metallicity distributions than does the *halo light*; see Harris and Racine 1979; Strom *et al.* 1981; Grillmair *et al.* 1986; Lauer and Kormendy 1986; Cohen 1987; and the previous papers in this series, notably Harris and van den Bergh 1981 (Paper I) or Harris 1986 (Paper V). Such differences are usually in the sense that the cluster system is more spatially extended and more nearly spherically symmetric than the rest of the halo, leading to the suggestion that the globular cluster system may have formed systematically earlier than the bulk of the halo (see the references cited).

In the preceding manuscript of this series [Hanes and Harris 1986b (Paper VIII)], we presented star counts around five of the large E/S0 galaxies in the Fornax cluster (NGC 1374, 1379, 1387, 1399, 1404) and used these to derive the global structures and total populations of their globular cluster systems. The principal results from this study were:

(a) The dominant central elliptical, NGC 1399, has a large and extended globular cluster system with about three times the normal population (i.e., specific frequency S) for E galaxies. In this respect it is similar to the central supergiant E's in Virgo (M87), Hydra I (NGC 3311), and Coma (NGC 4874), and supports the interpretation that such environments are preferred locations for uniquely vigorous cluster formation (Harris, Smith, and Myra 1983; Paper V; Harris 1987a,b).

(b) Three of the other Fornax members (NGC 1374, 1379, 1387) have specific frequencies in the range $S \approx 6$, similar to the range established for the Virgo ellipticals (Hanes 1977; and Paper I) but about a factor of 2 larger than the galaxies found in smaller and sparser groups (Harris 1981).

(c) One galaxy (NGC 1404) appears to have an unusually small ($S \sim 1$) and rather sharply truncated cluster system.

Since it lies within the outskirts of NGC 1399, it may have been affected by its much larger neighbor.

In Paper VIII, we were unable to make any comparisons between the radial structures of the cluster systems in these five Fornax galaxies and their halos, since no surface photometry for them covering sufficiently large radii ($r \geq 10$ arcmin) was available then. Now, however, Schombert (1986) has published an extensive catalog of new surface photometry for large E/S0 galaxies, including four of our Fornax objects, and such a comparison can be made. The results (described below) reveal some interesting contrasts with the E galaxies in Virgo and elsewhere.

II. RADIAL STRUCTURES

Schombert's (1986, and private communication) published photometry of NGC 1399 in particular extends to radii going well beyond our star counts, and so a full comparison of the surface density of globular clusters with the surface intensity of the halo is possible. Schombert's work reveals that NGC 1399 has an extended envelope of low central concentration, typical of many "brightest cluster member" (BCM) galaxies (see the discussion of Schombert). Along with its central geometric location and radial velocity near the mean for the Fornax system (Paper VIII; Harris 1987a), this evidence strongly suggests that NGC 1399 is sitting at or near the dynamic center of its environment.

In Fig. 1, we show the projected number density of globular clusters σ_{cl} plotted against radius from the center of NGC 1399 in arcminutes (all numbers taken from Table 3 of Paper VIII). Superimposed on this is the run of halo surface brightness μ_V , taken directly from Schombert and arbitrarily shifted vertically to provide the best overall match between the two sets of data (Schombert's profiles have been renormalized from kpc to arcmin with his adopted distance scale of $H_0 = 50$ km/s/Mpc). With the possible exception of the outermost half-dozen globular cluster data points, the radial profiles of the two halo subsystems agree substantially. (In fact, little weight should be placed on the star-count points for $r \geq 10'$: a decrease of just one standard deviation in

the adopted background count level, from 5.4 field images/arcmin², would bring the cluster distribution into complete agreement with the halo light profile. If NGC 1399 does have an envelope of the size suggested by the Schombert data, then it would have reached somewhat past the extreme radial limit ($r \sim 20'$) to which star counts could be carried on our prime-focus plates (see Paper VIII). If the cluster system is similarly extensive, then the background count in turn could have been overestimated by a few percent.) We conclude that the halo of NGC 1399 and its globular cluster system have very similar radial structures, within the combined observational uncertainties.

This conclusion is already interesting. Note that the *globular cluster system* in NGC 1399 is, in its radial profile, nearly a twin of those in the supergiant Virgo ellipticals M87 and M49 (Paper VIII). However, in those two Virgo galaxies the underlying halo appears to be *more* centrally concentrated than the cluster system (by $\Delta \log \sigma / \Delta \log r \sim 0.7$; see Figs. 4 and 7 of Paper V and compare them with Fig. 1 here). The key is that *NGC 1399 itself* is more spatially extended than either M87 or M49, by just enough to bring it into coincidence with its cluster distribution. This same result was discovered for the Hydra I central giant, NGC 3311 (Harris, Smith, and Myra 1983), which has the least centrally concentrated halo of clusters yet studied and has just as high a specific frequency as in M87 or NGC 1399.

Although these results further support the special nature of the central giant ellipticals found at the centers of large systems of galaxies, they also show that these galaxies dis-

play an intriguing variety within their own class. The presence of an anomalously populous cluster system in such galaxies seems to be much more directly connected with their unique location within their environment rather than other factors such as, for example, the cD phenomenon or sheer size (Harris 1987a). Although the four galaxies known to be in this category (M87, NGC 1399, NGC 3311, NGC 4874) are all virtually at the dynamical centers of their surroundings, only two have the gently sloped outer envelopes that might lead them to be described as cD's, and two of them are *not* the most luminous galaxies (BCM's) in their clusters.

We now turn to three other Fornax members from Paper VIII for which wide-field surface photometry is now available: NGC 1374, 1379, and 1387. In Fig. 2, we display the comparison between globular cluster surface density σ_{cl} and halo surface brightness μ_V for these three galaxies, in the same way as for Fig. 1. Although the cluster systems in these three are all much smaller than in NGC 1399, and therefore the internal uncertainties in σ_{cl} are considerably larger, there appears to be a systematic effect in all three such that the cluster radial profiles are flatter (less centrally concentrated) than the halo light. In view of similar results for other galaxies (cf. Papers I and V), such a conclusion is not unexpected.

Nevertheless, we believe that *no* claim should be made that there is a significant difference between the radial profiles for $r \geq 2'$ in these three galaxies. There are two reasons for saying this. First is that much of the impression of such a difference comes from the 'discrepant' innermost point in each panel, which falls well below the μ_V curve. In fact, this behavior of the cluster distribution near the center may indicate a genuine paucity of clusters in the nuclear region. In the past, possible incompleteness of the star counts close to the bright nucleus was often blamed (e.g., Paper I; Harris and Smith 1976), but recent CCD and electronographic imaging has confirmed the reality of this feature in the central parts of the M87 cluster system (Lauer and Kormendy 1986; Grillmair, Pritchet, and van den Bergh 1986; Held, Nieto, and Wlerick 1987). Furthermore, strong indications of the same central 'vacancy' of clusters show up in a wide variety of other galaxies, from a dwarf companion of NGC 3115 (Hanes and Harris 1986a) to the giant Sa Sombrero (Harris *et al.* 1984) as well as several large ellipticals (Paper V and references cited).

The magnitude of the discrepancy between clusters and galaxy light for systems like the Fornax or Virgo ellipticals may be emphasized by noting that their effective radii are typically $r_e \leq 1'$, i.e., half the projected light is contained within that radius. If half the *globular clusters* were also contained within the same central circle, we would have expected to find many dozens of easily visible cluster images within $r \sim 2'$ for the three smaller galaxies being discussed here. These simply do not appear. (For NGC 1399, the effective radius derived by Schombert is considerably larger at $r_e \geq 7'$, so that almost its entire cluster system was included in our counts. It should be noted that our estimates of the specific frequencies in Paper VIII did include corrections for the number of clusters expected to lie within the innermost arcminute of the galaxies. This correction was done by a modest inward extrapolation of the observed σ_{cl} curves, not the galaxy light profiles.) In any case, the extreme central behavior, which may be due to a rather special set of formation processes or dynamical evolution in the dense centers of galaxies, may not be typical at all of the more global agreement

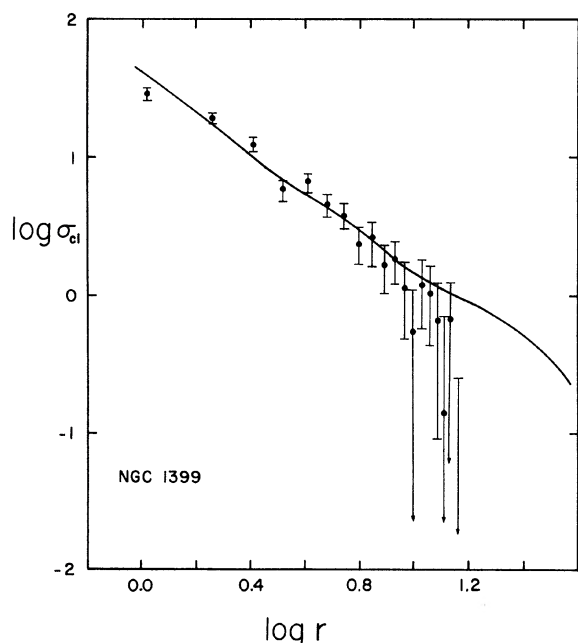


FIG. 1. Projected number density of globular clusters (log number per square arcminute) plotted against log radius (in arcminutes) around the central Fornax elliptical NGC 1399. The cluster counts are from Paper VIII, and the error bars represent the combined effects of sampling statistics and internal uncertainty in the density of field objects. The curve (solid line) is the radial surface-brightness profile in V , as determined by Schombert (1986); it has been shifted vertically to match the cluster counts such that $\mu_V = 25$ corresponds to $\log \sigma_{cl} = 0.14$.

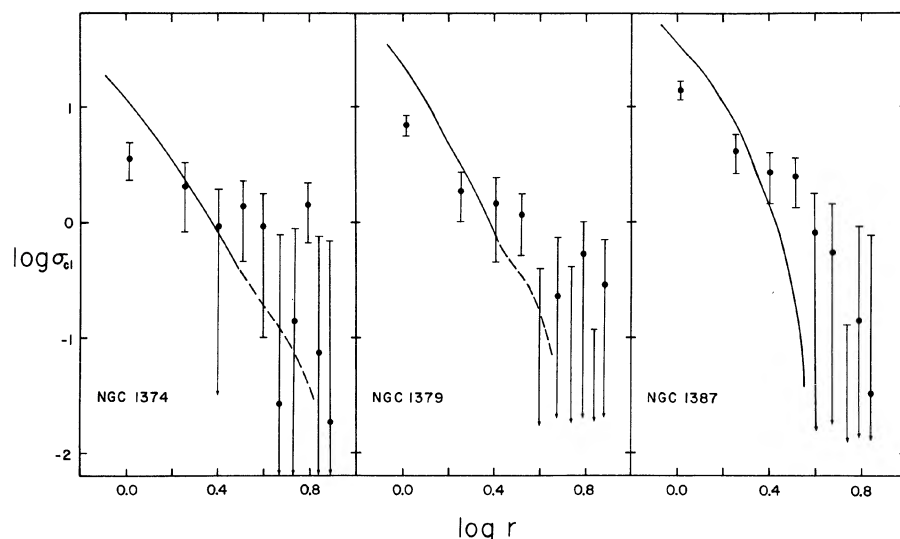


FIG. 2. Surface density of globular clusters plotted against radius, for three other Fornax ellipticals as described in the text. The scales are the same as in Fig. 1, and in each case the solid line shows the Schombert μ_V halo profile matched arbitrarily to the cluster distribution. Broken lines represent regions of more uncertain photometry (see Schombert 1986). The cluster counts with their background corrections are exactly as given in Paper VIII: the adopted background levels are $\sigma_b = 3.50 \text{ arcmin}^{-2}$ (NGC 1374), 4.16 arcmin^{-2} (NGC 1379), and 5.30 arcmin^{-2} (NGC 1387). A surface brightness of $\mu_V = 25$ corresponds to $\log \sigma_{cl} = 0.30$ (NGC 1374), 0.55 (NGC 1379), and 0.60 (NGC 1387), respectively.

between the large-scale cluster distribution and the underlying galaxy light.

The second and equally important reason for being wary of the initial impression from Fig. 2 is that the plotted cluster counts were derived from *adopted background counts* σ_b , deduced from the iterative profile-fitting technique described in Paper V. The raw star counts $\sigma(r) = \sigma_b + \sigma_{cl}(r)$ are assumed to follow some analytic model, such as the standard $r^{1/4}$ law with a constant added background. Then, by iterative fitting of the observed counts to the model, both the background level and the profile shape (the model parameters) are deduced. By contrast, a strictly empirical approach would be simply to assume that the outermost few star-count points have already leveled off to the true background σ_b , and to subtract this value from the rest of the data. A fuller discussion of the relative merits of these methods is found in Paper V; but the point of importance here is that there may be little to choose between the two approaches if the cluster system is rather small and the data therefore become internally noisy, as is the case in Fig. 2. For

the same data, the model-fitting procedure will necessarily yield a deduced background level *slightly* lower than the simple average of the outermost points, by an amount depending on the detailed characteristics of the data (see Paper V).

To illustrate this latter point, we have replotted the three cluster system profiles in Fig. 3, but now with the background counts taken equal to the *average level of the outermost four counted rings* (equivalent to $r > 5'$). Compared with the model-fitted backgrounds used in Fig. 2, these new backgrounds are different by only $0.4 \text{ objects/arcmin}^2$ at most (and always less than one standard deviation in σ_b), but the qualitative effect is noticeable. As in Fig. 2, we have matched up the halo surface-brightness curves again by arbitrary vertical shifts. For the systems in NGC 1374 and 1379, it is now more evident that no significant difference between the cluster system profile and the halo can be claimed: the power-law slopes are $\alpha \equiv \Delta \log \sigma_{cl} / \Delta \log r \simeq -2.5 \pm 0.9$ for the cluster systems excluding the innermost point, and $\alpha \sim -3.0$ to -3.5 for the halo light in Schombert's data. Thus the unavoidably large internal uncertainties in the

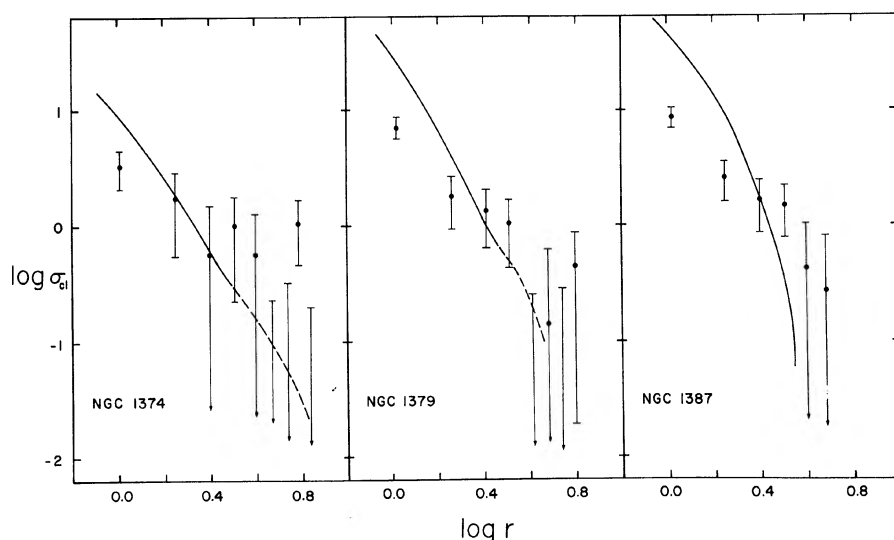


FIG. 3. The same data as in Fig. 2, except that the cluster counts were recalculated with the new values for the surrounding background density as described in the text. The adopted levels are $\sigma_b = 3.90 \text{ arcmin}^{-2}$ (NGC 1374), 4.26 arcmin^{-2} (NGC 1379), and 5.40 arcmin^{-2} (NGC 1387), in each case the direct average of the measured density in the outermost four counted rings. The surface-brightness curves (solid lines) have been matched to the data such that $\mu_V = 25$ now corresponds to $\log \sigma_{cl} = 0.20$ (NGC 1374), 0.70 (NGC 1379), and 0.70 (NGC 1387).

slopes mask any small remaining differences (of the order of $\Delta\alpha \sim 0.5$ or so) between them.

For the third galaxy, NGC 1387, the match between the cluster system and the halo is clearly the poorest, but even here a genuine difference is only on the borderline of being statistically significant ($\Delta\alpha > 1$). This galaxy has the most steeply truncated surface-intensity curve of the lot, more characteristic of its classification as SB0 rather than the others discussed here (which are all E0–E2). Given the available data for other S0 or disk-type galaxies with more well-studied globular cluster systems such as NGC 3115 (Hanes and Harris 1986a) or NGC 4594 (Harris *et al.* 1984), a slight difference in mean ellipticity between cluster system and halo and hence in the effective radial scale of Fig. 3 could well exist, but the present material is not good enough to evaluate this possibility for NGC 1387.

III. SUMMARY

The extensive cluster system in NGC 1399 matches rather closely in spatial structure the outer halo of its parent galaxy, which has the unusually extended envelope that many centrally placed supergiant ellipticals do. In this respect it differs from the Virgo giants M87 and M49 (which are somewhat more centrally concentrated objects than their

cluster systems), and is instead more nearly like NGC 3311 in Hydra. If the development of an extended cD-like envelope is due to capture and merger events early in the central galaxy's history, then the resulting structural similarity between the halo and the cluster system can be understood qualitatively as the result of extensive mixing in phase space which would cause all types of halo objects, clusters and field stars alike, to converge to the same more diffuse radial structure (Paper V; and Harris, Smith, and Myra 1983).

The smaller cluster systems in the other Fornax ellipticals NGC 1374, 1379, and 1387 are not significantly different in structure from their parent galaxy halos, within the rather broad limits allowed by their sketchier data. As a by-product of this investigation, we find that the iterative model-fitting technique described in Paper V for determining the background level of the star counts around these galaxies appears to give results accurate to within one standard deviation, i.e., to well within its own statistical uncertainty.

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