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GLOBULAR CLUSTERS IN GALAXIES BEYOND THE LOCAL GROUP. IV. THE ELLIPTICAL GALAXIES NGC 524 AND 1052

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ABSTRACT

We describe the global properties (total populations and spatial structures, derived by starcounts) of the globular cluster systems in two large E/S0 galaxies: NGC 524, the central giant in the compact cluster CfA 13 ($V_0 \approx 2300$ km s^{-1}); and NGC 1052, the only major elliptical in the loose southern group HG 44 = Cetus I ($V_0 \approx 1150$ km s^{-1}). In NGC 1052, the halo cluster system is small (specific frequency $S \approx 3$, on the low end of the range for ellipticals) and more compact than normal (surface density $\sigma \approx r^{-2.3}$). The globular cluster system in NGC 524 is somewhat more populous ($S \approx 6$, similar to the Virgo ellipticals) and structurally more extended ($\sigma \approx r^{-1.7}$). We conclude from NGC 524 that a privileged location of central dominance within a cluster does not seem to be enough by itself to guarantee the existence of an anomalously populous cluster system ($S \approx 20$) such as is seen in the central supergiant ellipticals in Virgo, Fornax, and Hydra.

Subject headings: clusters: globular — galaxies: individual — galaxies: structure

I. INTRODUCTION

The globular cluster populations found in the many giant Virgo elliptical galaxies still represent the best known halo cluster systems outside the Local Group (Hanes 1977*a*, *b*; Harris and Racine 1979; Strom *et al.* 1981; Forte, Strom, and Strom 1981). However, information about the total cluster populations and structural characteristics of globular cluster systems has now begun to accumulate for galaxies in a wider variety of environments. In the other papers of this series (Harris and van den Bergh 1981 [Paper I]; van den Bergh and Harris 1982 [Paper II]; Harris, Harris, and Harris 1984 [Paper III]; Harris 1985 [Paper V]), the initial stages of a more systematic attack on these goals have been presented for several galaxies in and around the main Virgo cluster.

A much less well studied part of the sky is the region around the Virgo *anticenter*, at southern galactic latitudes. In these directions one is looking directly away from the Local Supercluster (see de Vaucouleurs 1975; Tully 1982) toward other groups and clusters which presumably have little infall motion relative to the locally dominant Virgo Cluster core (e.g., Aaronson *et al.* 1980, 1982; Tully and Shaya 1984). The most prominent nearby anticenter system is in Fornax (a large cluster itself, centered on NGC 1399), but many other smaller groups are to be found in the ~10–30 Mpc distance range (de Vaucouleurs 1975; Geller and Huchra 1983; Huchra and Geller 1982, and references cited therein).

In this paper, we report the discovery and initial analysis of globular cluster systems around two E/S0 type galaxies, NGC 524 and 1052, both members of small anticenter groups. Table 1 summarizes some basic parameters for these two galaxies (mostly from de Vaucouleurs, de Vaucouleurs, and Corwin 1976, hereafter RC2). Our results are based on photographic plate material obtained at the Canada-France-Hawaii Telescope (CFHT) during a three-night observing run in 1982 November. Data for several other galaxies (mostly selected Fornax ellipticals) will be discussed in subsequent papers.

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II. STARCOUNT DATA

All the photographic material consisted of CFHT prime-focus plates on sensitized (2% forming gas baked 4 hr at 65°C) IIIa-J + GG 385. In a target galaxy, a globular cluster system is visible (if successfully detected) as a concentration of faint, starlike images around the galaxy center over a region of several arc minutes' diameter. If (as is the case here) no calibration sequence is available in the program field to permit complete photographic photometry of the faint images, some first-order quantitative information about the globular cluster system (its spatial structure and total population) can still be derived via radial star counts. The cluster system is measurable as a systematic inward increase in image number density above the surrounding "background" density.

Our procedures for completing and analyzing the star counts follow those described previously in Papers I–III. Each

TABLE 1
BASIC GALAXY PARAMETERS

Parameter	NGC 524	NGC 1052
Type	−1 (RC2); E1	−5 (RC2); E4
l	136°.5	182°.0
b	−52°.5	−57°.9
V_T	10.55	10.54
Group	CfA 13	HG44 = Cetus I
V_0[a]	2602 km s^{-1}	1400 km s^{-1}
ΔV[b]	−270 km s^{-1}	−250 km s^{-1}
$M_V{}^T$	$-21.29 + 5 \log h$	$-19.76 + 5 \log h$

[a] Mean radial velocity of group (relative to Local Group center).
[b] Estimated correction to V_0 for Virgocentric infall motion of Local Group (Geller and Huchra 1983).

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TABLE 2

STARCOUNTS IN NGC 524[a]

Ring	r (arcmin)	Ring Area (arcmin^2)	n	σ (arcmin^{-2})	σ_{cl} (arcmin^{-2})
1[b].....	(0.42)	(1.50)	(88)	(58.67 ± 6.25)	(49.07 ± 6.28)
2......	1.022	4.915	181	38.83 ± 2.74	29.23 ± 2.81
3......	1.768	8.192	189	23.07 ± 1.68	13.47 ± 1.78
4......	2.501	11.468	188	16.39 ± 1.20	6.79 ± 1.34
5......	3.228	14.730	205	13.92 ± 0.97	4.32 ± 1.14
6......	3.953	18.004	219	12.16 ± 0.82	2.56 ± 1.02
7......	4.677	21.266	270	12.70 ± 0.77	3.10 ± 0.98
8......	5.399	24.526	265	10.80 ± 0.66	1.20 ± 0.89
9......	6.122	27.768	322	11.60 ± 0.65	2.00 ± 0.89
10......	6.843	31.003	324	10.45 ± 0.58	0.85 ± 0.84
11......	7.564	34.335	355	10.34 ± 0.55	0.74 ± 0.81
12......	8.284	37.493	352	9.39 ± 0.50	...

[a] Counts from CFHT plate PF-3012, 2 hr exposure on IIIa-J + GG 385.

[b] Ring 1 is the innermost circle; effectively the inner third of that circle is blocked by the central spheroid light.

of us carried out our starcounting separately (one plate each for the two program galaxies) and averaged our results afterward. The resulting data are presented in Tables 2 and 3. In these tables, successive columns give (1) ring number (each ring being 3.16 mm wide), (2) effective ring radius, defined as $r = (r_1 r_2)^{1/2}$ where r_1, r_2 are the inner and outer radii of the annulus; (3) ring area A in arcmin^2; (4) number n of counted images within the ring, the average of our two count series; (5) calculated image number density $\sigma = n/A$; (6) calculated residual number density of globular clusters, $\sigma_{cl} = \sigma(r) - \sigma(\mathrm{background})$. Both the effective ring radius r and area A have been corrected for the geometric radial plate scale variation of the CFHT prime focus, according to a preliminary calibration of the wide-field corrector (Salmon 1983). In the notation of Chiu (1976), the true radial field angle r on the sky is related to the measured linear distance R on the plate by

$$r \approx \psi_0 R(1 + b_3 R^2 + b_5 R^4) . \quad (1)$$

Here $\psi_0 \approx 13''.7\ \mathrm{mm}^{-1}$ is the nominal scale at plate center; for R in mm the CFHT interpolation constants are $b_3 \approx -9.04 \times 10^{-7}\ \mathrm{mm}^{-2}$, $b_5 \approx -2.06 \times 10^{-12}\ \mathrm{mm}^{-4}$. The following sections present our analysis of the separate data sets.

TABLE 3

STARCOUNTS IN NGC 1052[a]

Ring	r (arcmin)	Ring Area (arcmin^2)	n	σ (arcmin^{-2})	σ_{cl} (arcmin^{-2})
1[b].....	(0.37)	(1.579)	(60)	(38.00 ± 4.9)	(32.80 ± 4.9)
2......	1.022	4.915	92	18.72 ± 1.95	13.52 ± 1.96
3......	1.768	8.192	74	8.97 ± 1.05	3.77 ± 1.06
4......	2.501	11.468	85	7.41 ± 0.80	2.21 ± 0.82
5......	3.228	14.730	107	7.26 ± 0.70	2.06 ± 0.72
6......	3.953	18.004	107	5.94 ± 0.58	0.74 ± 0.60
7......	4.677	21.266	108	5.08 ± 0.49	...
8......	5.399	24.526	129	5.26 ± 0.46	...
9......	6.122	27.768	142	5.11 ± 0.43	...
10......	6.843	31.003	160	5.16 ± 0.41	...
11......	7.564	34.355	189	5.51 ± 0.40	...
12......	8.284	37.493	189	5.04 ± 0.37	...

[a] Counts from CFHT plate PF-3018, 90 min exposure on IIIa-J + GG 385.

[b] Ring 1 is the innermost circle; effectively the central quarter is blocked by the galaxy spheroid.

III. NGC 524

NGC 524 is the central galaxy in the compact group number CfA 13 of Geller and Huchra (1983). The other radial-velocity members of the group include NGC 489, 502, 516, 518, 522, 525, and 532. The mean heliocentric radial velocity of the eight known members is $V_r = 2476\ \mathrm{km\ s^{-1}}$, with a line-of-sight dispersion $\sigma_V \approx 205\ \mathrm{km\ s^{-1}}$. The velocity of NGC 524 itself is just 49 $\mathrm{km\ s^{-1}}$ smaller, i.e., within $\sim\frac{1}{4}\,\sigma$ of the group mean. In addition, NGC 524 is at or close to the projected geometric center of the group, and is almost as luminous as all the other group members *combined*. In summary, NGC 524 presents one of the most clear-cut cases known of a giant galaxy at the center of, and completely dominating, its surrounding cluster. The group CfA 13 as a whole is so compact, and its central member so dominant, that a more appropriate view might be to consider it as a single fairly isolated giant accompanied by several orbiting satellites.

Another group, CfA 12, is at nearly the same mean velocity ($V_r = 2276\ \mathrm{km\ s^{-1}}$) and $\sim 5°$ further south (corresponding to a projected separation of $\sim 2h^{-1}$ Mpc for $h = H_0/100\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$). Other than this, the surrounding region appears to be relatively clear of significant galaxy groupings.

The structural appearance of NGC 524 itself (Fig. 1 [Pl. 2]) is also unusually interesting. Outside a radius of $r \approx 20''$ the isophotes of the system (Hodge and Steidl 1976; Barbon, Capaccioli, and Rampazzo 1982) stay virtually circular and highly regular. Its classification as an S0 (Barbon, Capaccioli, and Rampazzo) depends partly on a set of tightly wound, faint dust lanes around $r \sim 40''$ (see Fig. 1), but also seems to depend partly on the presence of a face-on "disk" at $r \approx 1'$–$2'$ which is actually a set of ringlike features or arcs around the central spheroid. These show up plainly on our CFHT plate (a 2 hr exposure in sub-arcsecond seeing). Given the improbability of viewing a ring system almost face-on, another possibility should be considered that they may be shells of stellar material collected around a pre-existing giant elliptical galaxy.

We find no traces of any current interaction between NGC 524 and other group members: a deep high-contrast print of our plate (kindly produced for us by David Malin at the AAT, and shown in Fig. 2 [Pl. 3]) reveals only the continuing smooth outward extension of the symmetric central galaxy, with no evidence for tidal tails, bridges, or arcs. If the ringlike features noted closer in are indeed segments of shells seen in projection, formed by the accretion and "wrapping" of a cold disk of a neighboring galaxy (Quinn 1983, 1984; Schweizer 1983), then such an accretion and merger must have occurred long enough ago for most of the debris to have settled in and homogenized. One piece of circumstantial evidence which may be relevant is that the other, smaller members of CfA 13 are almost all lenticular or disk systems.

Our IIIa-J plate of NGC 524 reveals a plainly visible swarm of globular clusters around the central galaxy. We estimate that the vast majority of these excess starlike images are within 2 mag of the plate limit (or fainter than $B_J \approx 23$, if our count limit is at $B_J \approx 24.5$, where B_J is the blue magnitude on the IIIa-J system; see § V below). After NGC 3311, the cD galaxy in Hydra I (Harris, Smith, and Myra 1983), NGC 524 is now the second most distant galaxy in which a globular cluster system has been detected.

The star count data of Table 2 have been plotted (σ vs. r) in Figure 3. The central increase in σ due to the cluster population is evident, though even beyond $r \approx 6'$ a slight gradient

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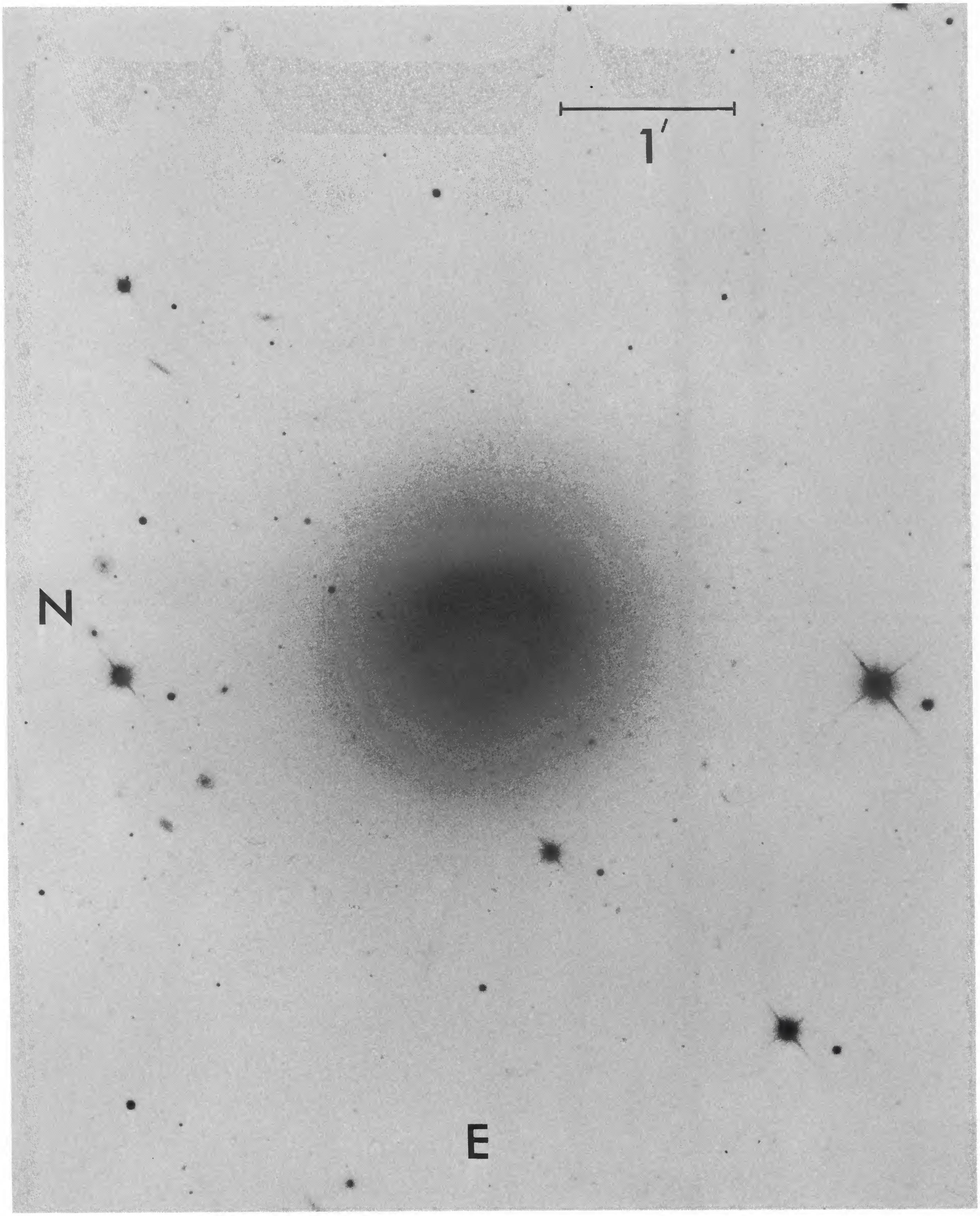

FIG. 1.—Photographic reproduction of NGC 524, from CFHT plate PF-3012 (2 hr exposure, IIIa-J + GG 385, in ~0″.8 seeing). Note delicate ringlike structure around the central spheroid, which at lower resolution appears as an amorphous "disk."

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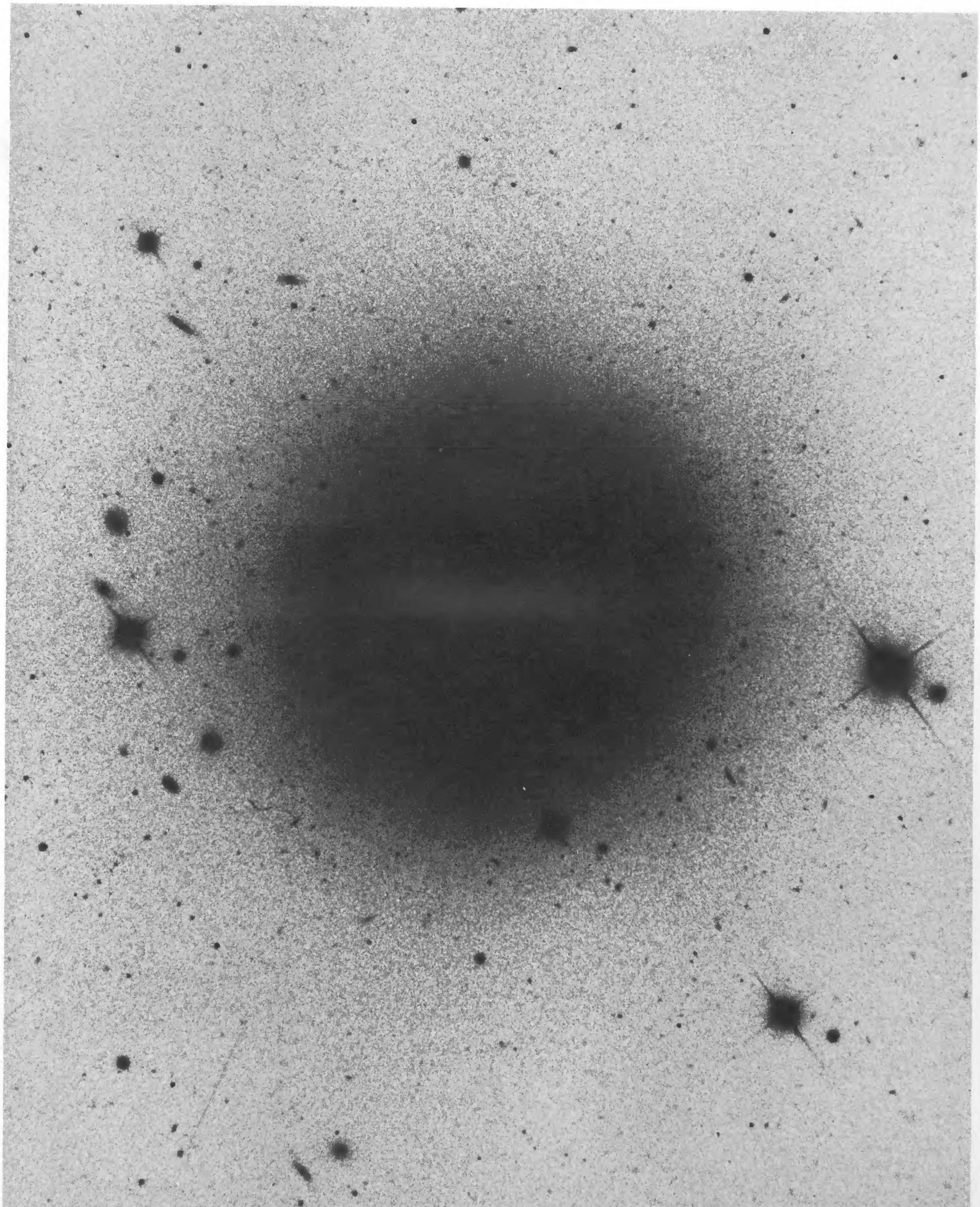

FIG. 2.—High-contrast reproduction of NGC 524, printed to the same scale as Fig. 1. Note regular and nearly circular extension of the outer isophotes.

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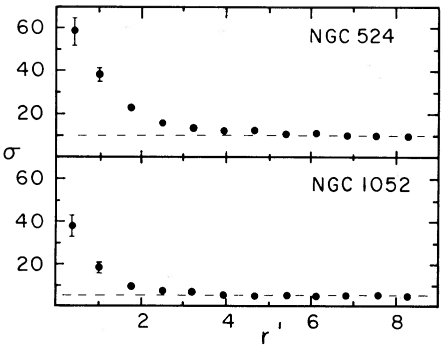

FIG. 3.—Starcount data for NGC 524 and 1052, from Tables 2 and 3. Image number density σ (objects arcmin^{-2}) is plotted versus radius r in arcminutes. Adopted background levels indicated by dashed lines.

with r still continues. Thus to estimate the "background" level σ_b to which the counts level off at large radii, we have used the approach described in Paper V: an $r^{1/4}$ type model is fitted by least squares to the data, with an added background term [$\sigma(r) = a_0 + a_1 \exp(a_2 r^{1/4})$; the constants a_0, a_1, a_2 are produced by the best-fit solution]. The finally adopted σ_b is then essentially the average of the predicted background a_0 from the model fit (which slightly underestimates the true background in a predictable way; see Paper V) and the value of the model curve at the largest fitted radius, $\sigma(r_n)$. From this approach for NGC 524 we find $\sigma_b = 9.6 \pm 0.6$ arcmin^{-2}, which is only slightly lower than, e.g., the straight average of the outer three rings [$\sigma(r_{10} - r_{12}) = 10.0 \pm 0.4$]. Over rings 1–12, the excess number of counted images above this background level is then $N_{\rm cl} = 700 \pm 150$, which is by hypothesis the measured cluster population down to the limiting magnitude of the counts. In § V we use these parameters to derive the cluster total population and system profile.

IV. NGC 1052

The elliptical NGC 1052 (classified E4; RC2) is part of a fairly loose association of galaxies near $l = 180°$, $b = -60°$. DeVaucouleurs (1975) places NGC 1052 in the Cetus I group (G15), and Huchra and Geller (1982) in their equivalent group 44. According to de Vaucouleurs, Cetus I also contains the NGC 1068 subgroup, which in turn has almost the same membership as Geller and Huchra's (1983) group CfA 32. Each of these systems is claimed to contain 6 to 12 major member galaxies, and their mean redshifts are all similar within their internal errors. Though not a giant galaxy (see Table 1), NGC 1052 is the only elliptical of any substantial size in the association; the majority of its group neighbors are spirals (the spectacular face-on Sc spiral NGC 1042 is only 15′ away). Adopting Huchra-Geller group 44 as the nominal parent group, we find it to have a mean heliocentric radial velocity of 1419 km s^{-1} (data from Sandage and Tammann 1981) with a line-of-sight dispersion of 107 km s^{-1}. NGC 1052 is at 1471 km s^{-1} or 0.5 σ from the mean; but the *geometric* center of the group is harder to define in such a loose configuration as this.

Lastly, NGC 1052 is known to contain a compact ($r < 10''$) nuclear radio and infrared source (P0238−084) which is mildly variable (e.g. Rogstad and Ekers 1969; Heeschen 1970; Rieke and Low 1972; Dent and Kapitzky 1976). It also appears in a catalog of milli-arcsecond radio sources (Morabito *et al.* 1982). Optically, around $r \approx 0'.5$ some faint dust lanes and knots are visible in the spheroid light (as is not uncommon for ellipticals in loose, spiral-rich groups). However, its outer isophotes as seen on high-contrast prints reveal quite regular structure with no evidence for tidal interactions.

The globular cluster system detected around NGC 1052 (see Fig, 4 [Pl. 4]) is about equally visible to eye inspection on our plates as the one in NGC 524. In actuality, it is a much smaller and less populous system since NGC 1052 is by far the less luminous and distant of the two galaxies. Our star count data are summarized in Table 3 and plotted in Figure 3. In the outermost six rings (7–12), $\sigma(r)$ is constant within the errors, and we adopt the average there as the background level: $\sigma_b = 5.20 \pm 0.17$ arcmin^{-2}. The residual total in rings 1–6 of excess images (globular clusters) is $N_{\rm cl} = 220 \pm 25$.

V. ANALYSIS

The radial distributions of the globular cluster systems around their parent galaxies are illustrated in Figure 5, where we have plotted $\sigma_{\rm cl} = \sigma - \sigma_b$ against r in the usual logarithmic plane. The structure of the NGC 524 system is of course the more well defined of the two (more populous, over a larger radial range), but in both cases $\sigma_{\rm cl}(r)$ is reasonably close to the $\sigma_{\rm cl} \propto r^{-2}$ distribution which characterizes many normal ellipticals and their halos. (The innermost data point in each case should be given low weight, since the counts there are likely to be strongly affected by the bright spheroid; Fig. 5 indicates the effect of a factor of 2 incompleteness.)

Least squares solutions according to either a simple power law or an $r^{1/4}$ law for the cluster distributions give the following results:

For NGC 524:

$$\begin{aligned} \log \sigma_{\rm cl} &= (3.93 \pm 0.20) - (2.45 \pm 0.17) r^{1/4} \qquad (r^{1/4}\ \text{law}) \\ &= (1.50 \pm 0.04) - (1.71 \pm 0.12) \log r \qquad (\text{power law})\,. \end{aligned} \tag{2}$$

For NGC 1052:

$$\begin{aligned} \log \sigma_{\rm cl} &= (4.46 \pm 0.30) - (3.31 \pm 0.40) r^{1/4} \qquad (r^{1/4}\ \text{law}) \\ &= (1.16 \pm 0.06) - (2.26 \pm 0.27) \log r \qquad (\text{power law})\,. \end{aligned} \tag{3}$$

Just as in previous systems (cf. Papers I, V) there is little to choose between these two formulations within the errors of the data. Unfortunately, we are unable to make direct comparisons between the structure of the cluster systems and the underlying halo light, since available surface photometry (Barbon, Capaccioli, and Rampazzo 1982; Longo and de Vaucouleurs 1983) does not extend to large enough radii for a meaningful comparison. Nevertheless, it is clear from the numerical results of equations (2) and (3) that these two cluster systems are not as "flat" spatially as the supergiant systems of M87, M49, and NGC 3311 (Paper V), in which $\Delta \log \sigma_{\rm cl}/\Delta \log r$ is more typically ~ -1.5. The result for NGC 1052 especially indicates that it is a considerably smaller and more compactly structured system than in the larger ellipticals, or even in the giant Sa spiral NGC 4594 (Paper III). The present results confirm the rough trend, first noticed by Harris and Racine (1979), for globular cluster systems to become less centrally concentrated with increasing galaxy luminosity; this is, however, not a relation which is strictly followed, as is discussed in more detail in Paper V. Its interpretation in terms of the relative ages of the cluster system and the galaxy halo itself (the cluster system might form relatively earlier in a giant protogalaxy, thus ending up with a flatter structure than the halo, which could dissipate energy and collapse further before forming stars) has

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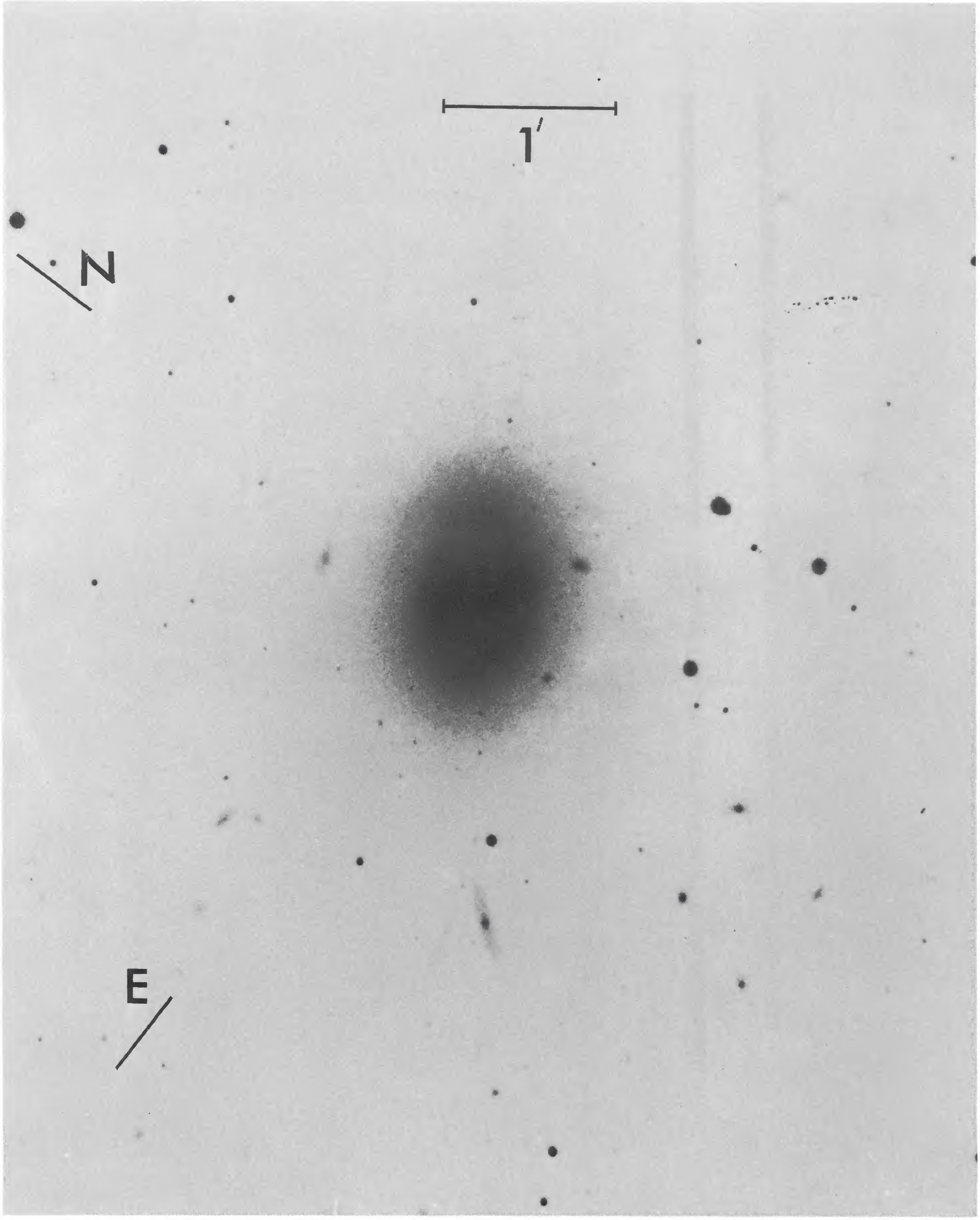

FIG. 4.—Photographic reproduction of NGC 1052, from CFHT plate PF-3018 (90 min exposure, IIIa-J + GG 385, in ~1″ seeing)

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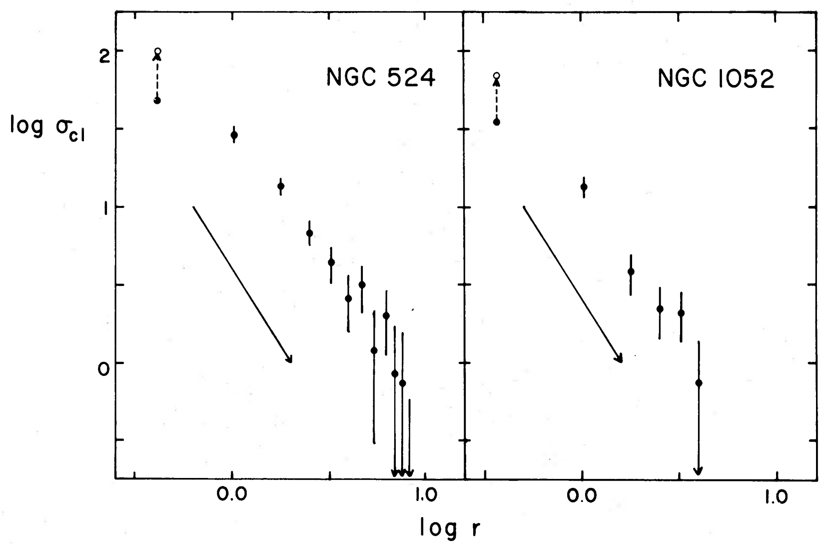

FIG. 5.—Radial structure profiles for the globular cluster systems in the two program galaxies. Projected number density of globular cluster images, $\sigma_{cl} = \sigma - \sigma_b$, is plotted versus radius r in arcminutes, on logarithmic scales. In each case the innermost point ($r < 1'$) is suspected of being significantly affected by light from the spheroid masking faint images; dashed arrows indicate effect of a factor of 2 incompleteness. Long arrow at lower left in each panel indicates slope for $\sigma \propto r^{-2}$ (see eqs. [2] and [3]).

also been frequently mentioned and may be the most reasonable current hypothesis (Harris and Smith 1976; Harris and Racine 1979; Strom *et al.* 1981; Harris, Smith, and Myra 1983; Paper V).

Lastly, we may use the current data on NGC 524 and 1052 to comment briefly on their total cluster populations and specific frequencies. From the method described in Paper I, we use the "background" density (σ_b) of counted images (mostly faint background galaxy images, plus some foreground stars) to estimate the effective limiting magnitude of our counts. (As in previous papers, we emphasize that this limiting magnitude should not be thought of as a strict *photometric* limit, since images can be seen and counted fainter than they can be measured photometrically). As before, we use the Bahcall and Soneira (1981) model fields to predict σ_b(stars), added to the Jarvis and Tyson (1981) data for σ_b(field galaxies) to predict σ_b(total) as a function of J magnitude [where $J \approx B - 0.28$ $(B - V)$]. Then for NGC 524, substitution of $\sigma_b = 9.6$ arcmin^{-2} yields $J_{lim} = 24.7 \pm 0.2$; and for NGC 1052, $\sigma_b = 5.2$ arcmin^{-2} yields $J_{lim} = 24.2 \pm 0.2$.

With these limits, the observed cluster populations N_{cl}(N524) $= 700 \pm 150$, N_{cl}(N1052) $= 220 \pm 25$ can be translated into estimated total populations N_t over all magnitudes by the use of a conventional assumed luminosity function (cf. Paper I). Finally, normalizing N_t to the parent galaxy luminosity $M_V{}^T$ gives the specific frequency $S = N_t 10^{0.4(M_V + 15)}$, as defined in Paper I. The numerical results are summarized in Table 4: successive columns give (1) an assumed value for the Hubble constant H_0, (2) the resultant galaxy distance (the recession velocity corrected for Virgocentric infall, divided by H_0), (3) integrated absolute magnitude of the galaxy, (4) estimated total cluster population N_t ($= N_{cl}$ corrected for all magnitudes), and (5) the specific frequency. The quoted errors in N_t and S include both the internal errors in N_{cl} and J_{lim}.

The S values for both galaxies ($S \approx 6$ for NGC 524, $S \approx 3$ for NGC 1052) are in the normally established range for ellipticals generally. With respect to other E/S0's in small groups, for which the overall average is $S \approx 4.5$ (Harris 1981), NGC 1052 is on the low end of the range; while the value for NGC 524 is instead similar to the average for the Virgo cluster ellipticals (Hanes 1977*a*, *b*; Harris 1981). In both cases, our counts sampled the luminosity function of the cluster system deeply enough that the deduced S values are not extremely sensitive to the assumed distances. We suggest that these two galaxies reinforce the previously stated views that real differences do seem to exist among cluster systems, in both their specific frequencies and their global structural characteristics.

The low specific frequency for NGC 1052 cannot be considered surprising, given its size and location in a rather amorphous group. Similar results were found (e.g., Paper I) for such ellipticals in other small clusters. However, the result for NGC 524 is potentially a more important one because of its large size (comparable in luminosity with the biggest Virgo members) and utterly dominant group position. The other giant ellipticals which are centrally dominant in their groups, and which have known globular cluster systems, are M87 in Virgo (Harris and Smith 1976), NGC 3311 in Hydra I (Harris, Smith, and Myra 1983), and NGC 1399 in Fornax (Dawe and Dickens 1976). All of these stand out with anomalously populous cluster systems. (For M87 and NGC 3311, the specific frequencies are $S \approx 20$; exact numbers are not yet available for NGC 1399, but will appear in a later paper, Hanes and Harris

TABLE 4

ESTIMATES OF SPECIFIC FREQUENCY

Assumed H_0 (km s^{-1} Mpc^{-1})	d (Mpc)	$M_V{}^T$	N_t	S
NGC 524:				
50..........	47	−22.8	11000 ± 4700	8.5 ± 3.6
75..........	31	−21.9	3300 ± 1000	5.7 ± 1.8
100..........	23	−21.3	1800 ± 500	5.5 ± 1.5
NGC 1052:				
50..........	23	−21.3	900 ± 220	2.7 ± 0.7
75..........	15	−20.4	430 ± 80	2.9 ± 0.5
100..........	12	−19.8	300 ± 50	3.8 ± 0.6

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1985). Thus it would not have been unexpected to find NGC 524 in a similar situation. The plain lesson to be learned from the observational results presented here would seem to be that central dominance is not enough *by itself* to produce an anomalously populous halo cluster system, or one that is structurally unusual. The richness and structure of the surrounding environment (i.e., whether the central galaxy is part of a major system like Virgo or Fornax) is clearly an additional factor of importance. Although current evidence tends to favor the view that the bulk properties of the globular cluster systems that we *now* see were the ones built in at time of formation, additional observations for systems in a wide variety of environments will help to develop this still rudimentary picture.

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