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GLOBULAR CLUSTER SYSTEMS OF EARLY-TYPE GALAXIES

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ABSTRACT

Properties of 53 globular cluster systems are investigated. Strong correlations are found between parent galaxy luminosity and both the slope of the radial density profile for clusters and the width of the cluster color (metallicity) distribution. These correlations are in the sense that the most luminous early-type galaxies are embedded in cluster systems that have the shallowest radial gradients and exhibit the broadest color distributions. The data suggest a scenario in which luminous early-type galaxies have a more complex evolutionary history than fainter ones. A problem with the interpretation of the present data is that it is difficult, or impossible, to disentangle the strongly correlated effects of high parent galaxy luminosity, presence of a core or boxy isophotes, and shallow radial cluster density gradients.

Subject headings: galaxies: clusters: general — galaxies: evolution — galaxies: stellar content

1. INTRODUCTION

The present morphology of a galaxy depends on the physical nature of its ancestral object or objects. It is now generally believed (see, e.g., Kissler-Patig 1997a) that early-type galaxies of the "core" subtype were likely assembled by mergers between mainly stellar ancestral objects. On the other hand, early-type "power law" galaxies are thought to have evolved by the collapse of a single protogalaxy or from mergers between gas-rich ancestors (see van den Bergh 1998 for a review). It is therefore clearly of interest to search for possible correlations between the profile types of E, S0, and Sa parent galaxies and characteristics of their entourage of globular clusters. However, the interpretation of such correlations is rendered somewhat uncertain by the fact that power-law galaxies are, in the mean, much less luminous than galaxies with cores (Bender et al. 1989). It is therefore difficult to distinguish between correlations that are mostly due to luminosity effects and those that are mainly driven by some aspect of evolutionary history that affects profile type. An additional complication is that cluster systems evolve more rapidly (mostly by destruction of low-mass clusters) in dense, low-luminosity galaxies than they do in lower density, giant systems (Murali & Weinberg 1997).

2. PROPERTIES OF GLOBULAR CLUSTER SYSTEMS

The properties of globular cluster systems surrounding galaxies have been reviewed by Harris (1991). A recent compilation of data on cluster systems is given by Harris (1996).[1] An up-to-date listing of some of the characteristics of globular cluster systems surrounding early-type galaxies is given in Table 1. This table is mainly based on a recent compilation by Kissler-Patig (1997b), supplemented by information on the radial luminosity distributions of parent galaxies by Faber et al. (1997), by D. A. Forbes (1997, private communication), and by Jaffe et al. (1994). In Table 1, galaxies with central cores in their radial profiles are denoted by "C," and those exhibiting power-law profiles by "P" (these are types I and II of Jaffe et al., respectively). Also given in Table 1 are estimates of the specific globular cluster frequency S (Harris & van den Bergh 1981), the slope of the radial density distribution of clusters, α [defined by $\sigma(\text{cl}) \propto r^{\alpha}$], and a characterization of the color (metallicity) distributions of the globular cluster systems. In the table, "S" denotes a system with a relatively narrow color distribution, and "B" a cluster system that has a broad (or bimodal) color distribution. Also given are the normalized Fourier coefficients $a(4)/a$, which describe the isophotal shapes for parent galaxies. Positive and negative values of $a(4)/a$ denote "disky" and "bulgy" objects, respectively. Hubble classification types have *not* been included in Table 1, because E and S0 classification types by expert morphologists are only loosely correlated with their photometric characteristics (van den Bergh 1989). However, since Table 1 contains only 53 entries, most conclusions about the interrelationships between various parameters describing cluster systems surrounding early-type galaxies will remain highly tentative until more cluster observations become available.

3. CORRELATIONS AMONG CLUSTER AND GALAXY PROPERTIES

The data in Table 1 can be used to establish three kinds of correlation: (1) those between different characteristics of globular cluster systems, (2) those between the properties of their parent galaxies, and (3) correlations between the characteristics of cluster systems and those of their parent galaxies. For such statistical discussions it is convenient to divide cluster systems into cluster-rich systems, with $S > 5.0$, and cluster-poor ones, with $S < 5.0$. Furthermore, cluster systems can be divided into those exhibiting flat radial density distributions ($\alpha > -1.75$) and those with steep radial density gradients ($\alpha < -1.75$). The parent galaxies can also be divided into luminous objects, with $M_V < -21.5$ ($H_0 = 75$ km s^{-1} Mpc^{-1} assumed), and fainter ones with $M_V > -21.5$. Finally, the parent galaxies can be assigned to boxy [$a(4) < 0$] or disky [$a(4) > 0$] subtypes.

3.1. *Characteristics of Globular Cluster Systems*

Table 1 can be used to investigate the correlations between the specific globular cluster frequency S and the radial cluster density gradient α, between S and the color (metallicity) distribution of clusters, and between α and the color distributions of clusters.

Figure 1 and Table 2 show that the systems with steep radial gradients tend to be cluster-poor, with $S < 5$,

[1] Details can be found at the World Wide Web site of the McMaster University department of physics.

TABLE 1

PROPERTIES OF GLOBULAR CLUSTER SYSTEMS WITH EARLY-TYPE PARENT GALAXIES[a]

Designation	M_V	Profile Type[b]	$100a(4)/a$	S	α	Color
NGC 221	−16.3	P	...	0.8	0.0	...
NGC 524	−21.9	C	...	4.8	−1.7	...
NGC 720	−21.2	C	0.7	2.2	−2.2	...
NGC 1052	−20.4	...	Irr	3.0	−2.26	...
NGC 1275	−23.3	...	...	4.3	...	B
NGC 1374	−19.8	...	0.0	4.9	−1.8	S
NGC 1379	−19.9	...	0.2	3.4	−2.1	S
NGC 1387	−20.2	...	...	3.2	−2.2	S
NGC 1399	−21.7	C	0.1	12.4	−1.6	B
NGC 1404	−21.0	...	0.5	3.5	−2.0	S
NGC 1427	−20.0	...	0.7	5.1	−2.0	S
NGC 1549	−20.8	C	−0.4	0.8	−1.8	...
NGC 1553	−21.0	...	...	2.3	−2.3	...
NGC 3311	−22.3	...	...	15.0	−1.3	B
NGC 3115	−21.1	P	...	2.3	−1.84	...
NGC 3115 DW1	−17.7	...	...	4.9	−1.8	S
NGC 3226	−19.6	...	...	7.0	−2.5	...
NGC 3377	−20.1	P	1.2	2.1	−1.9	...
NGC 3379	−21.0	C	0.2	1.2	−1.8	...
NGC 3384	−20.3	P	0.0	1.1	...	...
NGC 3557	−22.6	...	0.0	0.4	...	...
NGC 3607	−20.7	...	Irr	4.2	−2.6	...
NGC 3842	−23.1	C	−0.3	7.7	−1.2	...
NGC 3923	−22.1	C	−0.4	6.4	...	B
NGC 4073	−23.1	...	...	4.8	−0.95	...
NGC 4278	−19.8	C	−1.0	8.7	−1.85	S?
NGC 4340	−20.0	...	...	8.0	...	...
NGC 4374	−21.7	C	−0.4	6.6		S?
NGC 4365	−21.8	C	−1.1	5.0	−1.15	B
NGC 4406	−21.8	C	−0.7	6.3	...	S?
NGC 4472	−22.6	C	−0.3	5.6	−1.68	B
NGC 4486	−22.4	C	0.0	13.9	−1.61	B
NGC 4494	−21.0	...	0.3	5.4	−1.06	B?
NGC 4526	−21.4	...	...	7.7	...	...
NGC 4552	−21.2	C	−2.0	8.0	...	B?
NGC 4564	−20.1	P	2.2	10.0	...	...
NGC 4621	−21.2	P	1.5	6.3	...	...
NGC 4636	−21.7	C	−0.2	7.5	−1.0	...
NGC 4649	−22.2	C	−0.5	6.9	...	...
NGC 4697	−21.6	P	1.4	2.5	−1.9	...
NGC 4874	−23.0	C	...	14.3	...	...
NGC 4881	−21.6	...	...	1.0	0.0	...
NGC 4889	−23.5	C	Irr	6.9	...	...
NGC 5018	−22.6	...	...	1.1	−1.3	B
NGC 5128	−22.0	...	...	2.6	−1.5	B
NGC 5481	−20.2	...	...	2.5	−1.7	S?
NGC 5629	−21.7	...	...	5.0	...	...
NGC 5813	−21.0	C	Irr	7.2	−2.18	S
NGC 5846	−22.1	...	0.0	4.5	...	...
NGC 6166	−22.7	C	...	9.0	−0.95	S?
NGC 7768	−22.9	C	...	2.8	−1.3	...
UGC 9958[c]	−23.4	...	...	12.0	−1.2	...
UGC 9799[d]	−23.4	C	...	21.0	−1.4	...

[a] Mostly taken from Kissler-Patig 1997b.
[b] (P) power-law profile; (C) profile with central core.
[c] In A2107.
[d] In A2052.

TABLE 2

SPECIFIC CLUSTER FREQUENCY AND RADIAL DENSITY GRADIENT OF CLUSTERS

Gradient	$S < 5$	$S > 5$
$\alpha < -1.75$	14	4
$\alpha > -1.75$	8	10

whereas those with shallow radial gradients mostly have $S > 5$. A χ^2 test of this 2×2 contingency table (see Conover 1980, p. 144) shows that there is only a 4% probability ($\chi^2 = 4.2$ with 1 degree of freedom) that specific cluster frequency and radial profile type are uncorrelated.

Table 3 shows the relation between the B (broad/binary) versus S (single/sharp) color distribution of clusters and the radial density gradients α of cluster systems. This 2×2

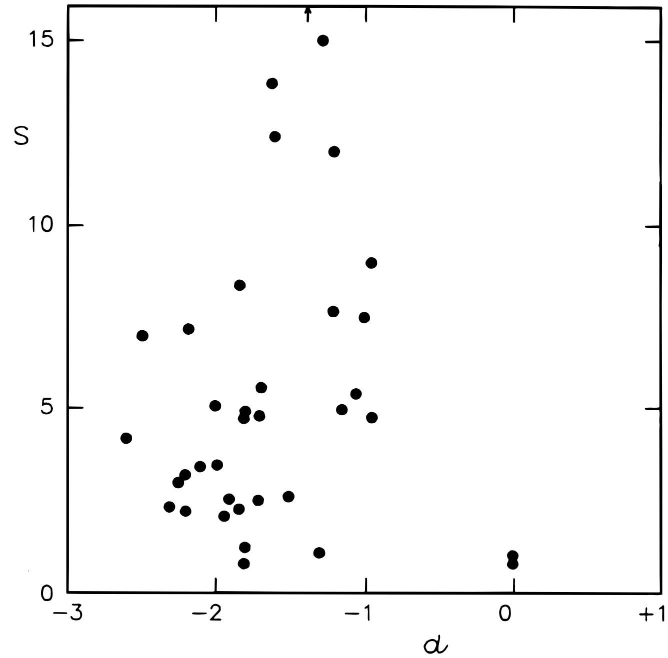

FIG. 1.—Specific globular cluster frequency S as a function of the slope α of their radial density distribution. High-S galaxies tend to have shallow slopes, whereas low-S galaxies generally exhibit steep slopes.

contingency table shows that there is less than a 0.1% probability ($\chi^2 = 14$ with 1 dof) that the radial density gradients and the color distributions of clusters are uncorrelated. Perhaps unexpectedly, the color distributions of globular cluster systems do *not* correlate significantly ($\chi^2 = 1.7$ with 1 dof) with the specific cluster frequency S.

3.2. *Relation between Galaxy and Cluster Characteristics*

Table 4 shows the values of χ^2 for 2 × 2 contingency tables relating the radial profile type, absolute magnitude, and isophotal shape of parent galaxies with the specific frequency, radial gradient, and color distribution of their globular cluster systems. The table shows that the most significant correlation observed is that between parent galaxy luminosity and the radial density gradient of cluster systems. This correlation is in the sense that the most luminous parent galaxies are surrounded by cluster systems that have the shallowest gradients. The existence of such a relation was first established by Harris (1986, 1993). The only other significant correlation is that between parent galaxy luminosity and cluster color distribution. Luminous parent galaxies tend to have B (broad/binary) color distributions, hinting at a complex evolutionary history, whereas cluster systems of the S type, which have a single sharp peak in their color (metallicity) distributions, tend to have lower luminosity parent galaxies.

TABLE 3

COLOR DISTRIBUTION AND RADIAL DENSITY GRADIENT OF GLOBULAR CLUSTER SYSTEMS

Gradient	Broad ("B")	Sharp ("S")
$\alpha < -1.75$......	0	7
$\alpha > -1.75$......	7	0

TABLE 4

χ^2 DISTRIBUTIONS FOR 2 × 2 CONTINGENCY TABLES BETWEEN PARAMETERS DESCRIBING CLUSTERS AND PARENT GALAXIES

Cluster Parameter	C/P	M_V	$a(4)$
S	5.2	4.1	4.7
α...........................	2.2	23	3.0
B/S........................	...	16	3.9

3.3. *Correlations between Parent Galaxy Characteristics*

Table 5 shows a 2 × 2 contingency table between $a(4)$ and the radial density profile type of the parent galaxy. This correlation, which has a probability of less than 0.5% ($\chi^2 = 8.1$ with 1 dof) of being due to chance, is in the sense that boxy galaxies mostly have cores, whereas the majority of disky galaxies exhibit power-law profiles. For lower luminosity galaxies, deviations from this relation may be produced by tidal distortions of the outer isophotes of early-type galaxies (Nieto & Bender 1989). Table 6 demonstrates that galaxies with cores are more luminous than those with power-law profiles ($\chi^2 = 7.5$ with 1 dof). Finally, Figure 2 and Table 7 show ($\chi^2 = 6.6$ with 1 dof) the relation between the isophotal shape parameter $a(4)$ and the parent

TABLE 5

RADIAL PROFILE TYPE AND DEVIATIONS FROM ELLIPTICAL ISOPHOTES

$a(4)$	Power Law ("P")	Core ("C")
Positive.......	4	3
Negative......	0	11

TABLE 6

PARENT GALAXY LUMINOSITY AND RADIAL PROFILE TYPE

Luminosity	Power Law ("P")	Core ("C")
$M_V < -21.5$......	1	16
$M_V > -21.5$......	6	6

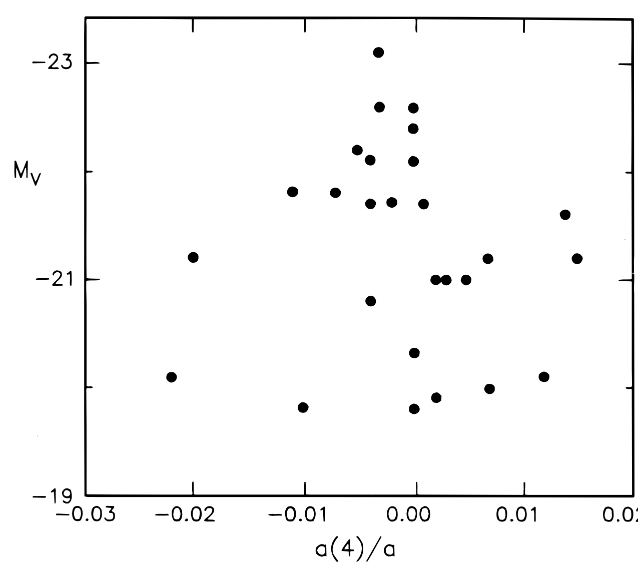

FIG. 2.—Plot of the isophotal shape parameter $a(4)/a$ vs. parent galaxy luminosity M_V. The majority of "disky" early-type galaxies are fainter than $M_V = -21.5$ ($H_0 = 75$ km s^{-1} assumed), whereas "boxy" early-type galaxies are mostly brighter than $M_V = -21.5$.

TABLE 7

ISOPHOTE SHAPE AND PARENT GALAXY LUMINOSITY

Luminosity	$a(4) > 0$	$a(4) < 0$
$M_V < -21.5$......	2	8
$M_V > -21.5$......	9	3

galaxy luminosity. This table shows that, as has been known for many years (Bender et al. 1989), early-type galaxies with boxy isophotes tend to be more luminous than disky ones.

4. SUMMARY AND CONCLUSIONS

The specific frequency of globular clusters in late-type galaxies is low. It is not yet possible to draw any statistically significant conclusions about the global characteristics of the globular cluster systems associated with galaxies of types Sb, Sc, and Ir. However, the situation is more favorable for the generally richer cluster systems associated with early-type galaxies. Table 1 summarizes the data that are presently available on 53 globular cluster systems associated with galaxies of types E, S0, and Sa. From this compilation it can be seen that luminous parent galaxies, which usually have cores and boxy isophotes, are generally surrounded by globular cluster systems exhibiting shallow radial density gradients. Furthermore, the globular clusters associated with luminous parent galaxies tend to have a broader color (metallicity) distribution than those that are associated with less luminous parent galaxies.

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REFERENCES

Bender, R., Surma, P., Döbereiner, S., Möllenhoff, C., & Madejsky, R. 1989, A&A, 217, 35
Conover, W. J. 1980, Practical Nonparametric Statistics (New York: Wiley)
Faber, S. M., et al. 1997, AJ, in press
Harris, W. E. 1986, AJ, 91, 822
———. 1991, ARA&A, 29, 543
———. 1993, in ASP Conf. Ser. 48, The Globular Cluster–Galaxy Connection, ed. G. H. Smith & J. P. Brodie (San Francisco: ASP), 472
———. 1996, AJ, 112, 1487
Harris, W. E., & van den Bergh, S. 1981, AJ, 86, 1627
Jaffe, W., Ford, H. C., O'Connell, R. W., van den Bosch, F. C., & Ferrarese, L. 1994, AJ, 108, 1567
Kissler-Patig, M. 1997a, in ASP Conf. Ser. 116, The Nature of Elliptical Galaxies, ed. M. Arnaboldi, G. S. Da Costa, & P. Saha (San Francisco: ASP), 498
———. 1997b, A&A, 319, 83
Murali, C., & Weinberg, M. D. 1997, MNRAS, 288, 749
Nieto, J.-L., & Bender, R. 1989, A&A, 215, 266
van den Bergh, S. 1989, PASP, 101, 1072
———. 1998, Galaxy Morphology and Classification (Cambridge: Cambridge Univ. Press)