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A PRELIMINARY SURVEY OF COLLAPSED CORES IN THE MAGELLANIC CLOUDS' GLOBULAR CLUSTERS[1]

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ABSTRACT

We present a preliminary report on a surface photometry survey for collapsed cores in the Magellanic Clouds' globular clusters. We give core morphology classifications for the 33 globular clusters examined so far. One cluster, NGC 2019, shows definite signs of a collapsed core, and two others, NGC 1774 and NGC 1951, appear as strong candidates. This detection of postcollapse cores outside the Milky Way opens some interesting prospects for future dynamical studies. However, the fraction of collapsed-core clusters appears to be smaller in the Magellanic Clouds than in the Galaxy. This may be due in part to their younger ages, or to the limitations imposed by the seeing effects. It is also possible that the relative scarcity reflects the physical difference in the tidal field environments between the Galaxy and the Clouds, in agreement with a trend found earlier, viz., that the tidal shocks from disk passages accelerate dynamical evolution and enhance the propensity for core collapse.

Subject headings: clusters: globular — galaxies: Magellanic Clouds — photometry — stars: stellar dynamics

I. INTRODUCTION

In recent years, extensive and vigorous observational and theoretical activity related to the problems of core collapse and postcollapse evolution have changed and greatly improved our understanding of the dynamical evolution of globular clusters (GCs), and self-gravitating systems in general. Some excellent reviews can be found in the proceedings edited by Goodman and Hut (1985) and Grindlay and Philip (1987). Theoreticians have predicted for a long time that core collapse should occur in self-gravitating systems (Hénon 1961; Antonov 1962; Lynden-Bell and Wood 1968; see also the review by Spitzer 1985). Observationally, the situation was, until recently, much less clear. For many years it appeared that most or all GCs are well described by the King (1966) models, and the central brightness peak in M15 seemed to be a unique exception (King 1975; Newell and O'Neil 1978). The turning point was the realization that core collapse can be stopped and reversed by the formation of a central binary, which serves as a source of energy. A post–core-collapse cluster then assumes the characteristic projected density profile of a singular isothermal sphere, viz., a power law with the slope close to -1. Such morphology was indeed found in about 20% of all Galactic globular clusters (Djorgovski and King 1984, 1986; Djorgovski *et al.* 1986). The existence of postcollapse cores is probably the first empirically confirmed case of a global (radial) instability in self-gravitating systems. Many interesting questions still remain: the existence of core oscillations, the exact relations between the relaxation, collapse, and recovery time scales, and the influence of tidal shocks and mass loss, etc.

GCs in Magellanic Clouds provide a potentially very useful "laboratory" for investigations of some of these questions, in many ways complementary to the Galactic globular cluster system. They have a much wider range of ages, and generally shorter dynamical time scales, mostly because of their smaller masses and radii (Kontizas 1984; Elson, Fall, and Freeman 1987). They may be an interesting dynamical puzzle here: the clusters look dynamically relaxed, but in many cases they are not old enough for the two-body relaxation to have accomplished this (Freeman 1974; but see Meylan 1987*c*, 1988). Finally, they live in a much quieter tidal field environment.

Observationally, the problem is more difficult, because of the greater distance to the Clouds, but still tractable: scaling from the known cases in our Galaxy, we expect to see the characteristic power-law cores extending up to several arcsec in radius. This *Letter* is a preliminary report on the first stage of a systematic survey of globular cluster cores in the Magellanic Clouds.

II. THE OBSERVATIONS

From the lists given by van den Bergh (1981), we selected a complete, magnitude-limited sample of star clusters in both the LMC and SMC. So far, the data have been obtained and reduced from some 55 clusters. Twenty-two of them appear to be bright young associations or open clusters, whose surface brightness profiles are strongly affected by the stochastic fluctuations from low numbers of relatively bright stars. We are left with 33 apparently genuine GCs of all ages.

[1] Based on observations made at the European Southern Observatory, La Silla, Chile.

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The data consist of CCD images obtained with the 2.2 m telescope at the European Southern Observatory, at Cerro La Silla, Chile, during the nights of UT 1986 December 29, 30, and 31. The CCD used was the RCA 320 × 512 (ESO number 5), mounted at the Cassegrain focus (f/8.01). The effective pixel size was 0".363. The weather conditions were marginally nonphotometric to photometric, with seeing FWHM values ranging from 0".6 to 1".5. For each cluster, one or more exposures were obtained in the *B* and *V* bands, with typical integration times of about 180 s, individually adjusted in order to avoid any saturated pixels in the central parts of each cluster. All frames were processed using standard techniques.

A full and detailed analysis of the observational material on these 55 clusters will take considerable time and effort to complete and interpret. What we have done as a first step, is to derive good radial profiles for the 33 selected globulars. The methods and the software are the same ones that were used by Djorgovski and King (1984, 1986) for their Galactic survey. The essential algorithms were described by Djorgovski (1987), and references therein.

III. RESULTS AND DISCUSSION

In Table 1 we give the core morphology classification for the surveyed clusters. The columns are as follows: column (1), the NGC number or other designation: N for NGC, L for Lindsay (1958), SL for Shapley and Lindsay (1963); column (2) the cluster core classification, following the notation used by Djorgovski and King (1986), viz., c = collapsed, c? = probable/possible c, n?c? = weak indications of c, n = normal, or King-model–like, n? = probable n, and ? = unclassifiable; and column (3) the age class: VY = very young, Y = young, I = intermediate, and O = old, from the color-based age determinations by van den Bergh (1981), which are in a fair agreement with those by Searle, Wilkinson, and Bagnuolo (1973), Hodge (1983), or Elson and Fall (1985). Of the 33 entries in the table, one is classified "c", two are "c?", five are "n?c?", 10 are "n?", 13 are "n", and two are "?". The distinguishing characteristic which serves as the basis for our classifications is the shape of the surface brightness profile near the center (but outside the seeing disk, of course): King-model (n) clusters have flat, resolved cores and steep envelopes, whereas the postcollapse (c) clusters have a power-law shape with the slope ~ -1.

The first result is that we do detect some clusters with a definite or a probable postcollapse morphology, namely NGC 2019, 1774, and 1951, and possibly some others. The existence of a postcollapse core in NGC 2019 (and possibly also in NGC 2005) has been confirmed independently by Mateo (1987*a*, *b*, *c*). These are the first detections of postcollapse cores outside our Galaxy proper, and they demonstrate feasibility of the studies hinted at in the Introduction (§ I). These clusters appear to be quite similar morphologically to their Galactic counterparts. It is interesting that our best case, NGC 2019 is classified as old, but that the two other suspects are both classified as young; we do not have yet the necessary information to compute their *dynamical* ages, e.g., the half-mass relaxation times ($t_{\rm rh}$).

The observed surface brightness profiles of the remaining clusters were fitted to multimass King-Michie models, all of

TABLE 1

CLASSIFICATION OF CLUSTER CORES

Name (1)	Type[a] (2)	Age Class[b] (3)	Name (1)	Type[a] (2)	Age Class[b] (3)
L8	n	O	N1951 ...	c?	Y
L47	n	I	N1978 ...	n	O
L56	n	VY	N1994 ...	n?	VY
N222	n	Y	N2002 ...	?	VY
N256	n	Y	N2019 ...	c	O
N265	n	Y	N2025 ...	n?	Y
N330	n?	Y	N2031 ...	n?	Y
N411	n	O	N2070 ...	n?c?	VY
N1774 ...	c?	Y	N2098 ...	?	VY
N1783 ...	n?c?	O	N2100 ...	n?	VY
N1786 ...	n	O	N2136 ...	n?c?	Y
N1805 ...	n?	VY	N2157 ...	n?	Y
N1806 ...	n	O	N2164 ...	n	Y
N1847 ...	n?	Y	N2210 ...	n?	O
N1855 ...	n	Y	N2214 ...	n?c?	Y
N1866 ...	n	Y	SL106 ...	n?c?	Y
N1917 ...	n?	O			

[a] Notation from Djorgovski and King 1986; c = collapsed, c? = probable/possible c; n?c? = weak indications of c; n? = probable n; n = normal or King-model–like; and ? = unclassifiable.

[b] Age classification from van den Bergh 1981: VY = very young; Y = young; I = intermediate; and O = old.

them calculated with an isotropic velocity dispersion, and the IMF exponent $x = 1.5$ (see Gunn and Griffin 1979, and Meylan 1987*a*, *b* for applications of such models to ω Centauri and 47 Tucanae).

To illustrate the present results, and the quality of the data, we show several surface brightness profiles in Figure 1. The surface brightness profile of an n cluster, NGC 1978, which is well fitted by a King-Michie model with a concentration index $c = 1.7$, is displayed in Figure 1*a*. In Figures 1*b*, 1*c*, and 1*d*, are shown the clusters classified as c and c?, namely, NGC 2019, 1951, and 1774.

We cannot do much statistical analysis with the 33 cluster sample studied in this *Letter*, but the results are suggestive of a lower fraction of collapsed-core clusters in the Clouds, when compared to what was found for the Galactic system by Djorgovski and King (1986): about 20% of the galactic GCs showed signs of a collapsed core, compared to less than 10% for the Clouds' GCs. It is possible that this difference is caused in part by a selection effect: some postcollapse cores with small radial extent may be hidden in the seeing disks. However, it is also tempting to attach a dynamical significance to this effect: the weaker tidal field generated by both the LMC and SMC may be less effective in accelerating the core collapse in these clusters. In our Galaxy, clusters at smaller galactocentric radii, which are subjected to stronger tidal shocks, show a much larger fraction of collapsed cores (Chernoff, Kochanek, and Shapiro 1986; Djorgovski and King 1986; Chernoff and Djorgovski 1988). The Clouds' GCs are on the average younger than the Galactic GCs, but they also may have somewhat shorter dynamical time scales. We need better estimates of both cluster ages (from the stellar population studies) and their relaxation times (from a more detailed analysis of surface photometry and kinematics), before

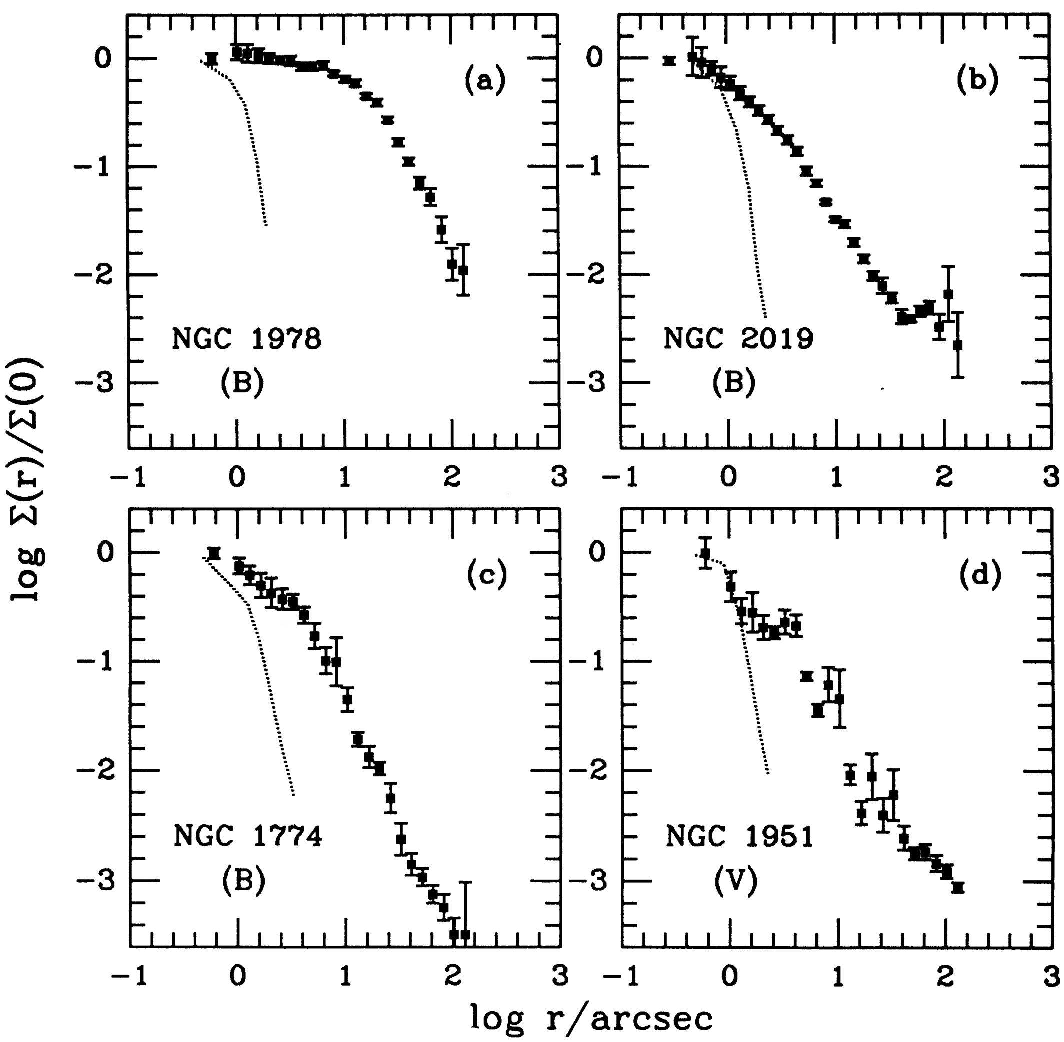

FIG. 1.—Relative surface brightness profiles for four clusters. (*a*) NGC 1978, which is well fitted by a King-Michie model with the concentration index $c = 1.7$; (*b*) NGC 2019, which appears to have a collapsed core; (*c*) NGC 1774, and (*d*) NGC 1951, both of which may have collapsed cores. Profiles (*a*)–(*c*) were derived from *B* frames, and profile (*d*) was derived from a *V* frame. The dotted lines represent the point-spread functions.

much more can be said about this intriguing effect and its possible dynamical implications.

The relatively large distance is a considerable difficulty in a search for collapsed clusters in Magellanic Clouds. For example, in the case of the Galactic c cluster NGC 7099, at an adopted distance of 7.2 kpc, 1″ corresponds to 0.035 pc, whereas for the LMC clusters, at a reasonable distance of 50 kpc, 1″ corresponds to 0.24 pc. The present survey is thus only the first step in a more complete search: we can classify many or most cores from our standard ground-based observations, but for many intermediate or uncertain cases, and for more detailed studies of confirmed post–core-collapse clusters, we will need seeing-compensated, or space-based observations. Rich dynamical payoffs can make such efforts quite worthwhile.

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