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Have many globulars disappeared to the galactic centres? The case of the Galaxy, M 31 and M 87

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Abstract. The radial distribution of globular clusters in our Galaxy, M 31 and M 87 is studied and compared with that of halo stars. The globular cluster distributions seem significantly flatter than those of the parent-galaxy stellar bulge. Assuming this is a consequence of an evolution of the globular cluster distribution in these galaxies, a comparison with the (unevolved) stellar distribution allows us to obtain estimates of the number and total mass of clusters lost.

It results that the cluster systems in our Galaxy and in M 31 have been initially about one third richer than now, and twice as abundant in M 87. The estimated mass in form of globular clusters lost is compatible with the nucleus masses of these galaxies.

Key words: galaxies: star clusters – galaxies: evolution – galaxies: nuclei – Galaxy: globular clusters – galaxies: M 31; M 87

1. Introduction

The globular cluster systems (GCSs) in the two Virgo giant galaxies M 87 and M 49 are clearly less concentrated than the halo star distribution (Harris, 1986). Probably this feature is not common to all galaxies, even though in many cases the available data are probably not good enough to compare reliably the cluster and halo distributions. Anyway, a safe statement is that no case has been found where the GCS is more centrally concentrated than the halo (Harris, 1991) This is confirmed by the recent HST WFPC2 observation of 14 elliptical galaxies (Forbes et al. 1996).

A possible explanation of this difference in the distributions has been suggested by Harris & Racine (1979) and by Racine (1991) as a difference in the formation ages of halo stars and globular clusters. Following these authors, globular clusters are formed earlier, when the density distribution was less peaked. This possibility cannot be ruled out, however it is not supported by any evidence of a significant older age for globular clusters with respect to the halo: this age difference should be large enough to have allowed the mother galaxy to contract enough to form halo stars in a distribution as more concentrated than globulars as observed. Note that in disk galaxies the epoch of cluster formation could be early enough to force chemical enrichment but not to take on a distinct spatial structure (Harris 1986). Moreover, this picture does not explain why the tails of the two density distributions are about the same. Probably, a simpler explanation, working in the majority of cases, is the coeval birth of globular clusters and halo stars, with a further evolution of the GCS radial distribution while the collisionless halo stands almost unchanged. The causes of evolution are dynamical friction and tidal interaction with a compact nucleus; these phenomena can act to deplete the GCS in the denser inner galactic regions and therefore to modify the initial radial distribution just in the central region leaving unchanged the outer profile, which remains similar to that of the halo component (Aguilar, Hut & Ostriker 1988, Capuzzo-Dolcetta & Tesseri 1997). If this is true, the halo radial profile clearly represents the shape of the initial cluster distribution.

In Sect. 2 we discuss briefly the causes of the evolution of GCS distribution in galaxies and some problems related to their observational detection. In Sect. 3 we show our method to deduce the initial GC radial distribution, while in Sect. 4 and 5 we present and discuss the results.

2. Globular cluster system evolution

There are various indications that the GCS in a galaxy does not behave like a dissipationless system, as the halo component is. Actually, even if the galaxy is not a spiral where disk shocking is an important cause of evolution, the tidal shock due to the passage near to the galaxy centre or to interaction with a concentrated spheroid, and dynamical friction (which acts to carry massive clusters closer and closer to the centre) are relevant causes of GCS evolution. This leads to a more or less important change of the GCS spatial distribution and mass function. The relevance of the mentioned phenomena depends on the galaxy characteristics: triaxiality enhances the efficiency of both of them (Ostriker, Binney & Saha 1989, Long, Ostriker & Aguilar 1992, Pesce, Capuzzo-Dolcetta & Vietri 1992, Capuzzo-Dolcetta 1993 (here-

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Send offprint requests to: R. Capuzzo-Dolcetta after CD), Capuzzo-Dolcetta 1997). In particular, Pesce et al. (1992) showed that clusters on box orbits in a triaxial potential lose their orbital energy at a rate one order of magnitude larger than on loop orbits of comparable size and energy (even if they are quite elongated). It is very likely that a large fraction, if not all, of globular clusters are actually moving on box orbits and certainly not on quasi-circular loops, due to their early formation during the almost radial proto-galaxy collapse (see Binney 1988). So, previous evaluations of dynamical friction efficiency based on clusters moving on circular orbits were undoubtely *over-simplified* and leading to significantly overestimated values of the dynamical braking time-scales. This means that massive globulars in triaxial galaxies have probably suffered a lot of dynamical braking and have reached the centre of the mother galaxy where they can merge to form a super-massive object (not necessarily a black hole) or can feed a pre-existent one.

The first to consider, in a simplified scheme, the possibility of galactic nucleus development in Local Group galaxies were Tremaine et al. (1975) and Tremaine (1976). They found $1.4\times10^7 M_\odot \lesssim M_{n,Galaxy} \lesssim 5\times10^7 M_\odot$ and $M_{n,M\ 31}$ = $2.4\times10^7 M_\odot$, which are about a factor 10 larger than the recent evaluation of our galaxy nucleus mass by Eckart & Genzel (1996) ($M_n \approx 2\times10^6 M_\odot$), and a factor 3 smaller than the most recent M 31 nucleus mass estimate by Bacon et al. (1994) but quite in agreement with those of Dressler & Richstone (1988) and Kormendy (1988).

Of course this nucleus, if massive enough, can shatter the incoming globulars before they are totally orbitally decayed. CD examined in details the two contemporary effects and found that -assuming as typical globular cluster masses 10^5, 10^6, and 10^7 $M_\odot$- nuclei as massive as 5×10^6 $M_\odot$, 2×10^8 $M_\odot$ and 5×10^9 $M_\odot$ are, respectively, needed to effectively halt the infall of globular clusters to the potential minimum.

Two equally interesting scenarios (quantitatively supported in CD) are open:

i) a triaxial galaxy without a primordial massive nucleus can drive the merging of a significant mass in the form of orbitally decayed massive globulars in a time scale of the order of few 10^8 yrs, eventually leading, with modes which are not trivial to be studied, to a central object massive enough to stop further mass infall;

ii) a moderately massive primordial nucleus is fed by decayed globulars such to produce a gravitational luminosity in the range of normal AGNs and to grow in mass until a steady state is reached. If the mass of the primordial nucleus is large enough, dynamical friction on globular clusters is overwhelmed by the tidal shattering (see also Charlton and Laguna 1995), and, moreover, the massive central object also changes the orbital structure around it (see Gerhard and Binney 1985).

2.1. Is dynamical friction an effective cause of GCS evolution ?

The usual meaning of dynamical friction is that of an approximation for the collective influence of the stellar background on the motion of a satellite. It has been extensively studied in the last twenty years, and we just remind, among the major contributions to the study of its relevance on globular cluster sinking alone or coupled with other relevant phenomena, papers by Tremaine et al. (1975), Tremaine (1976), Fall & Rees (1977), Aguilar et al. (1988), Long, Ostriker & Aguilar (1992), Pesce et al. (1992), Capuzzo-Dolcetta (1993). The dynamical friction scheme has the overwhelming advantage to avoid the complete N-body integration but also the, obvious limitation of giving answers which depend on the hypotheses done in its application (form of the galactic potential, qualitative shape of satellite orbits, feedback of other concurrent phenomena, etc.). A careful evaluation of the assumptions made in the many papers devoted to the study of the role of dynamical friction allows, in the majority of cases, to understand why some authors seem to obtain contrasting results.

As an example, the often cited result by Fall & Rees (1977) that only globular clusters more massive than $\approx 3\times10^7 M_\odot$ have had time to spiralize to the galactic centre *critically* depends on the assumption of circular orbits for the clusters.

It is out of the scopes of this paper to discuss these controversies, however it seems theoretically ascertained that in triaxial galaxies, and probably whenever globulars move on almost radial orbits, the dynamical friction decay times are rather short for clusters with mass in a reasonable range (Pesce et al. 1992, CD). Let us, instead, discuss some observational arguments invoked by some authors to question the actual role of dynamical friction (which actually apply just to CGSs in M 31 and M 87, two of the best studied cases).

Now, while it is now quite accepted that the inner part of M 31 is triaxial (Lindblad 1956; Stark 1977; Bertola et al. 1991) and so it is a galaxy where dynamical friction and tidal distruption effects should be significantly enhanced, a triaxiality for M 87 is not evident. Good CCD photometric data by Zeilinger et al. (1993) for the inner M 87 region show almost round isophotes in the inner M 87 region ($r < 3''$) and a twisting occurs at $3''$ from the centre, the major axis being shifted to a position perpendicular to the jet and the ellipticity grows up to 0.2 at $r \simeq 80''$. This means that M 87 is not necessarily one of the best candidate to investigate about the evolution of CGS distribution.

With regard to M 31 two serious observational points are:
i) the M 31 galactic nucleus seems to be significantly redder than globular clusters (Surdin and Charikov, 1977), ii) M 31 globular clusters seem to show a trend of increasing metallicity toward the galactic centre (Huchra et al. 1991); anyway this trend, see Fig. 2 in van den Bergh (1991) is quantitatively questionable.

Let us explain why in our opinion points i) and ii) are much less serious indication against the importance of dynamical friction and GCS evolution mechanism than it is superficially thought.

First of all, the above mentioned data do not constitute a significant sample to extract general conclusions, referring just to one galaxy, anyway a trend of redder integrated colours towards the centres is a common feature of many galaxies (Gallagher et al. 1980), and needs in any case an explanation.

According to various authors, due to the apparent high metallicity of central region of M 31, the decayed high mass clusters should have been more metal abundant (redder) than the ones presently observed, and this needs a correlation between mass and metallicity for globular clusters.

This metal abundance-mass correlation for globular clusters is claimed to be *ad hoc* because of the poor correlation presently observed between metal content and total *luminosity* of galactic globulars. There is an important *caveat* before concluding that also a Z mass-correlation is not holding. It comes by the fact that the Z-L correlation cannot be considered exactly representative of a Z mass-correlation because the mass-luminosity ratio actually depends on the metal content, and it increases with Z.

This means that a flat Z-L correlation transforms into a (more or less steep) *increasing* $M(Z)$. Moreover, what is observed now is the *present* luminosity-Z correlation, which, in the case of efficiency of the dynamical friction braking is biased (with respect to the initial) towards lower luminosities (masses) and metallicities, likely hiding an initial stronger correlation.

A mass-metallicity relation for globular clusters is, anyway, not merely an *ad hoc* hypothesis, being verified for instance, in galaxies: the brighter galaxies contain redder, in the average, globulars (see van den Bergh 1991 for M 31 and our Galaxy's clusters) and has a physical interpretation on the basis of a steeper, with increasing mass, potential well to be overcome by the enriched material expelled by SNs.

Another point that seems hardly compatible with the claimed efficiency of dynamical friction (acting more on massive globulars) is that in M 87 no dependence of the globular cluster luminosity function on galactocentric distance is found.

2.2. *The radial dependence of the GCS luminosity function*

There are various reasons why the lack of evidence of a radial dependence of GCS luminosity function is not a significative point against dynamical friction to be occurring on clusters: i) even if a spatial trend of the luminosity function is present (massive globulars moved to inner regions), it is expected to occur in quite central regions (within the bulge star core radius, see Capuzzo-Dolcetta and Tesseri 1997) not easily covered by adequate observations; ii) projection effects weaken any radial trend of the luminosity function; iii) dynamical friction reduces the average galactocentric distance of massive GCs more than that of light globulars, but this contemporarily means they are shifted to inner galactic zones where they likely lose their individuality because they become hardly observable and more easily destroyed by the intense tidal field.

Let us give some quantitative support to point ii). Suppose we have a sample of globular clusters whose mean mass $< m >$ varies with the galactocentric distance in a way to have smaller masses in external regions ($< m >$ varies from 10^6 $M_\odot$ to 10^5 $M\odot$ going from the centre to 5 times the core radius) and with a mass spectrum corresponding to a gaussian V-magnitude function characterized by a dispersion around the mean magnitude which is larger ($\sigma_V^2 = 3$) in peripheral galactic regions than around the centre ($\sigma_V^2 = 1.5$) (this is what qualitatively expected when dynamical friction and tidal disruption have been effective). Assuming $(M/L)_{V\odot} = 1.6$ and that the GCS is distributed spherically according to the modified Hubble profile

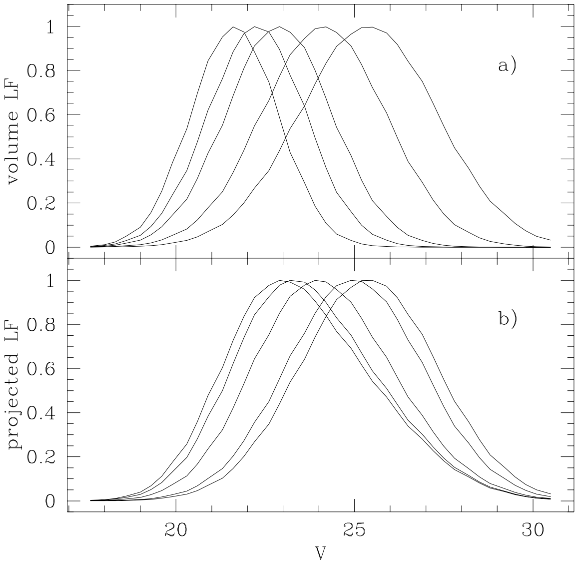

Fig. 1. a normalized V-magnitude volume luminosity functions of the GCS at various galactocentric distances ($r/r_c = 0, 0.25, 0.5, 1, 5$); **b** projected luminosity functions at the same (projected) galactocentric distances as in panel **a**.

$$n(r) = n_0 \left[1 + \left(\frac{r}{r_c}\right)^2\right]^{-\frac{3}{2}} \tag{1}$$

we can compare the volume LF with the projected LF, sampled at various distances from the centre in a galaxy with a distance modulus $(m - M)_V = 31.3$ (similar to Virgo cluster) (see Fig. 1 a,b).

Projection should reduce the difference among the peak magnitudes and the widths of the LF sampled at various galactocentric distances. Actually, Fig. 1 shows how a V-peak difference of 4 mag reduces to just 2.5 mag, while the width of the projected LF results almost constant (independent of the galactocentric distance).

We conclude that a radial dependence of the width of such LFs would be undetectable, while the detection of a variation in the V-peak would require globular cluster sampling *well within* the galaxy core, because (as it is seen in Fig. 1 b) the V-peaks of the LF sampled at $r = r_c$ and $r = 5r_c$ differ for a quantity similar to the standard deviation of the mean ($\sigma_\mu \simeq 0.1\ mag$ for a typical total sample of $\approx$ 500 clusters). This explains why, even if evolutionary effects have been active on GCSs, LF radial trends have not been detected in the past. Higher resolution observations are needed to have larger sample abundances in inner galactic regions.

3. Present and initial radial distributions

A way to estimate the number of globular clusters lost during the evolution of a globular cluster system was suggested by

McLaughlin (1995) who applied it to the M 87 galaxy. This estimate is based on the assumption that the stellar bulge and the globular cluster distributions were initially the same (due to a coeval formation) and on that the shape of the stellar distribution has remained unchanged. The first hypothesis is supported by the observed similarity of the stellar bulge and globular cluster projected profiles in the outer regions (outside a certain distance $\bar{r}$ from the centre) of various galaxies. The second hypothesis stands firmly on that the bulge is a collisionless system.

The initial globular cluster distribution $n_0(r)$ (assumed to be equal in shape to the present stellar distribution) is, practically, obtained by a scaling of the present stellar distribution to the GCS one ($n(r)$). Of course also the projected initial density profiles, $\sigma_0(r)$, are assumed to be the same. Once $n_0(r)$ or $\sigma_0(r)$ have been determined, the number of missing clusters is given by the integral over the whole galaxy of the difference between n_0 and n (or σ_0 and σ).

3.1. The data sets and interpolations

We consider the well established data sets of GCSs in our Galaxy, M 31 and M 87, this latter mainly for the sake of a comparison with McLaughlin's (1995) results.

To fit the stellar distribution of M 31 and M 87 we used the model of de Vaucouleurs (1958) and for our Galaxy the Young's model (1976); good (least-square) fits to the globular cluster distributions are obtained by means of a modification of the empirical King's models (King 1962).

To obtain the initial globular cluster distribution we vertically shift the stellar distribution to match, in the external region ($r \geq \bar{r}$), the GCS distribution, so to have a scaling factor, d, depending on $\bar{r}$. Thus, we can represent the initial globular cluster distribution by:

$$\mathrm{Log} n_0 = \mathrm{Log} n_s + d(\bar{r}) \tag{2}$$

$$\mathrm{Log} \sigma_0 = \mathrm{Log} \sigma_s + d(\bar{r}) \tag{3}$$

where $n_s(r)$ and $\sigma_s(r)$ are the (observed) stellar distribution volume and surface densities. Hereafter distances r will be given in Kpc ; volume and surface number densities will be given in Kpc^{-3} and Kpc^{-2} respectively.

4. Number of clusters missing in our Galaxy and M 31

4.1. Our Galaxy

The most complete set of data of galactic globular clusters is still given by Webbink (1985). It refers to 154 globular clusters. For our purposes we need only the distance of each cluster from the galactic centre. Our best fit to the present distribution is:

$$n(r) = \left\{ \left[\frac{1}{1+\left(\frac{r}{2}\right)^2} \right]^{0.5} - \left[\frac{1}{1+\left(\frac{b}{2}\right)^2} \right]^{0.5} \right\}^3 \tag{4}$$

where $b = 49$.

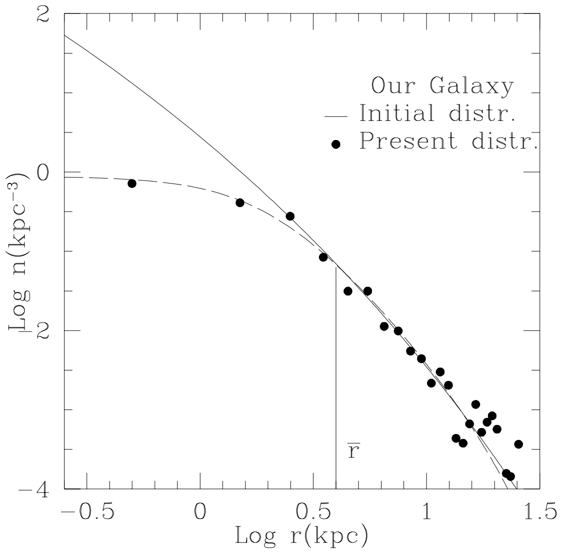

Fig. 2. The globular cluster initial distribution (solid curve) and the present one (dashed curve) for our Galaxy. The vertical line refers to the point $\bar{r}$ where the bulge and GCS profiles start to overlap

As distribution of bulge stars in our Galaxy we use the Young's model (1976) (see Fig. 2). Thus we obtain the initial globular cluster distribution:

$$n_0(r) = 426.exp \left[-7.669 \cdot \left(\frac{r}{2.7} \right)^{0.25} \right] \left(\frac{r}{2.7} \right)^{-0.875} \tag{5}$$

The estimated number of globular clusters lost for our Galaxy is N_l = 56, i.e. about 36% of the present sample's abundance.

4.2. Andromeda (M 31)

Various compilations of data for globular clusters in M 31 are available. We refer to the "Adopted Best Sample" of Battistini et al. (1993) compilation, for it is the most complete and best discussed source of data for the radial distribution of globular clusters in this galaxy.

The flattening of the M 31 globular cluster distribution compared to that of the star spheroidal component was first noted by de Vaucouleurs & Buta (1978), later questioned by Wirth, Smarr & Bruno (1985) who claimed a large part of this flattening as being due to incompleteness. The completeness of the Battistini et al. data in the inner bulge region is well addressed, and a residual flattening of their adopted samples with respect to the spheroidal star component is evident.

Matching the globular clusters data with a King's model leads to the following analytical fit to the present globular cluster distribution (angular distances are transformed into Kiloparsecs adopting for M 31 the distance modulus $(m - M)_V$ = 24.07 (Battistini et al. 1980):

$$\sigma(r) = 16.7 \left\{ \left[\frac{1}{1+\left(\frac{r}{0.7}\right)^2} \right]^{0.5} - \left[\frac{1}{1+\left(\frac{a}{0.7}\right)^2} \right]^{0.5} \right\}^{1.52} \tag{6}$$

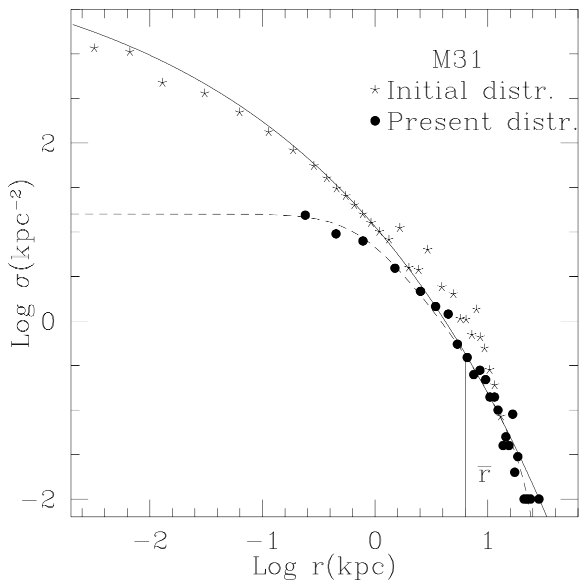

Fig. 3. Initial and present globular cluster distributions in M 31, fitted by expressions (7) (dashed curve) and (6) (solid).

where $a = 30$. The data for the stellar distribution are taken from de Vaucouleurs (1958), assuming that the stellar density distribution follows the luminosity distribution (see Fig. 3). We obtain the initial globular clusters distribution:

$$\sigma_0(r) = 822.2 \cdot exp\left[-7.427 \cdot r^{0.2} + 3.1\right] \ . \tag{7}$$

The surface integral of $\sigma_0(r) - \sigma(r)$ gives $N_l \simeq 85$ as number of globular clusters lost; this is 30% of the present number.

4.3. Evaluation of globular cluster mass fallen to the galactic centres

An approximate value of the mass fallen to the centre of M 31 and our Galaxy can be given by mean of the knowledge of N_l and of the average mass of destroyed globular cluster $< m_l >$. The determination of $< m_l >$ requires a detailed evaluation of the tidal distruption and dynamical friction effects on an assumed initial mass function. Since the two phenomena erode the GCS on opposite sides of the mass function, the mean value of the globular cluster mass $< m >$ is not expected to change very much in time whenever the initial mass function is not too asymmetric, and thus it can be chosen as a good reference value for $< m_l >$. This is confirmed by results obtained with a theoretical model (Capuzzo-Dolcetta & Tesseri 1997) under the hypothesis of a flat initial mass function.

The knowledge of the mean mass of globular clusters, $< m >= 3.2 \cdot 10^5 M_\odot$ for our Galaxy and $< m >= 2.7 \cdot 10^5 M_\odot$ for M 31, gives as mass lost $M_l = 1.8 \cdot 10^7 M_\odot$ and $M_l = 2.3 \cdot 10^7 M_\odot$, respectively. These values should be compared with the nucleus masses in our galaxy ($2.5 \div 3 \cdot 10^6 M_\odot$, see Krabbe et al. 1995, Eckart and Genzel 1996) and in M 31 ($10^7 M_\odot$, Dressler & Richstone 1988, Kormendy 1988, Melia 1992; the recent paper by Bacon et al. 1994 gives $7 \times 10^7 M_\odot$).

4.4. An important source of error

A significant source of error of the method described in Sect. 3 to evaluate N_l is the estimate of $\bar{r}$, i.e. the indetermination of the region within which the globular cluster distribution profile has evolved. A relative error in $\bar{r}$ induces an error in $N_l(\bar{r})$:

$$\frac{\Delta N_l}{N_l} = \frac{\partial N_l}{\partial \bar{r}} \frac{\bar{r}}{N_l} \frac{\Delta \bar{r}}{\bar{r}}, \tag{8}$$

being:

$$\frac{\partial N_l}{\partial \bar{r}} = \ln\ 10 \cdot 2\pi \cdot 10^{d(\bar{r})} \cdot d'(\bar{r}) \int_0^{\bar{r}} \sigma_s(r) r\ dr \tag{9}$$

or, when the spatial density is available:

$$\frac{\partial N_l}{\partial \bar{r}} = \ln\ 10 \cdot 4\pi \cdot 10^{d(\bar{r})} \cdot d'(\bar{r}) \int_0^{\bar{r}} n_s(r) r^2\ dr \ . \tag{10}$$

where $d'(\bar{r})$ is the derivative of $d(\bar{r})$ with respect to $\bar{r}$.

The error (8) may be significant when $\bar{r}$ is large because it implies large areas (or volumes) where clusters are counted.

Evaluations of Eq. (9) and (10) with our best $\bar{r}$ values for M 31 and our Galaxy give $0.75\Delta\bar{r}/\bar{r}$ and $0.63\Delta\bar{r}/\bar{r}$, respectively, while for M 87 (see next Section) it results to be $1.5\Delta\bar{r}/\bar{r}$.

5. M 87

For the sake of comparison with previous work (McLaughlin 1995) we applied our method to M 87. The data are taken from McLaughlin (1995) and from de Vaucouleurs and Nieto (1978, 1979) for globular clusters and spheroid stars, respectively.

To transform angular distances to linear ones we assumed for M 87 the distance 15.7 Mpc.

The fits we obtained from those distributions are:

$$\sigma(r) = 21 \left\{ \left[\frac{1}{1 + \left(\frac{r}{1.2}\right)^2} \right]^{0.5} - \left[\frac{1}{1 + \left(\frac{c}{1.2}\right)^2} \right]^{0.5} \right\} \tag{11}$$

$$\sigma_0(r) = 67.62 \cdot exp\left[-3.848 \left(\frac{r}{1.543}\right)^{0.2957} + 3.85\right] \ . \tag{12}$$

where $c = 60$.

We have fixed $\bar{r}$ as the point where the two distributions clearly show the same shape, as it is shown in Fig. 4 ($\bar{r} = 15.8 Kpc$).

The number of globular clusters lost is found to be $N_l = 3565$, which is slightly less than the number of globular clusters presently observed. Note that McLaughlin (1995) found a much smaller value 1150 for N_l.

The reason of this difference between our and McLaughlin's values of N_l is that he chose a significant smaller value ($8 Kpc$) for $\bar{r}$. This corresponds to move his adopted King's model representing the initial shape of cluster distribution vertically down more than us, so its initial cluster sample is significantly less abundant (see also Fig. 4). We have numerically evaluated the error induced on N_l by an error in $\bar{r}$, finding that an error $\Delta\bar{r}/\bar{r}$

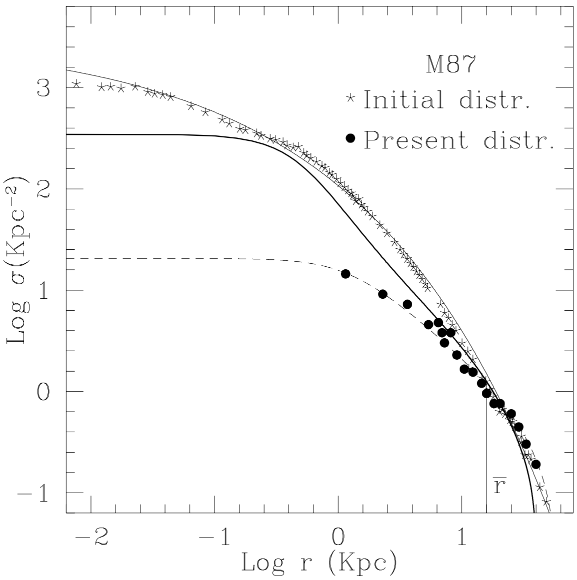

Fig. 4. The initial and the present globular cluster distributions in M 87. The thin solid and the dashed curves are our best analytical fits (eqs. (12) and (11), and our best determination of $\bar{r}$ is shown. For comparison, the McLaughlin's (1995) initial cluster distribution is shown as thick solid line.

reflects in a relative error for $\Delta N_l/N_l \simeq 1.5\Delta\bar{r}/\bar{r}$; i.e. much greater than for our Galaxy and M 31.

This large sensitivity of N_l on the choice of $\bar{r}$ is most of the explanation of the great difference between our value of N_l and that given by McLaughlin ($N_l \simeq 1150$).

Actually, our larger value of $\bar{r}$ is needed to avoid that in external regions the resulting initial cluster distribution passes *below* the present one. Fig. 5 shows that the distribution obtained shifting vertically the bulge star profile to intersect the present GCS distribution at $\bar{r} = 8Kpc$ would represent an acceptable initial distribution for the GCS just if we accept as realistic that in regions external to $r \geq 8Kpc$ there are at present *more* clusters than initially. This implies the existence of a mechanism which populated the external regions, while dynamical friction and tidal distruption depopulated the inner regions.

The analytical fits to the initial cluster population are obtained with different functions: McLaughlin used, for both globular clusters and star bulge, isotropic, single mass King's (1966) models (with same value, 2.35, for the parameter c, and a core radius $r_c = 1'.02 = 4.6\ Kpc$ for the GC system and $r_c = 7'' = 0.5$ Kpc for the bulge), while we used an empirical King's (1962) model to fit the present globular cluster distribution and the de Vaucouleur's (1958) model to fit the bulge distribution. Anyway, the difference in the form of analytical fits is of minor importance, as we now explain. While our and McLaughlin's fits to the *present* GCS distribution are very similar except in that our fit has a slightly higher core density ($Log\ \sigma(Kpc^{-2}) = 1.3$ instead than 1.1), our de Vaucouleur's fit to the stellar bulge distribution gives a central density significantly larger than McLaughlin's (it is well known that King's models are less peaked than de Vaucouleur's laws). McLaughlin in his 1995 paper justifies the choice of a King's 'core' model for the initial cluster distribution (which clearly departs from the true bulge profile within $\sim 0.2\ Kpc$ of the centre, as shown by Fig. 4) to avoid the, presumed, too high central density that would be obtained for the cluster system when following the bulge profile. We see that the initial projected profile (12) corresponds to a central inter-cluster distance of the order of 50 pc which is low but not too low to allow mutual tidal interaction excluding that clusters can form in such environment. In any case we prefer not to introduce another free parameter and keep the assumption of similarity between the cluster initial profile and the stellar bulge one also in the inner galactic regions. This is quite reliable because we found that the innermost region (where de Vaucouleurs' model differs from King's) contributes negligibly to the N_l determination: our σ_0 gives only 95 clusters within $r \simeq 0.2\ Kpc$ from the centre, i.e. 2% of N_l, against 45 given by the McLaughlin's profile (0.2 Kpc is the extension of the region where the observed bulge profile is actually more peaked than the core model).

That the difference in the analytical fits can account for just a minor part of the in N_l is confirmed by that we obtain $N_l \simeq 728$ instead of $N_l \simeq 1150$ if we adopt the same value ($\bar{r} = 8\ Kpc$) used by McLaughlin to obtain the initial GCS distribution. Note that the N_l so determined is even less than the McLaughlin's one.

Now, if we take as mean mass of the globular clusters in M 87 $< m >= 6.6 \cdot 10^5 M_\odot$ (McLaughlin 1995) our estimate of the mass lost is $2.35 \cdot 10^9 M_\odot$. If we compare this value with the nucleus mass of M 87 (which is estimated to be $\simeq 2.4 \cdot 10^9 M_\odot$ within 18 pc of the nucleus, see Ford et al. 1994) we see, also in this case, that the distruption of globular clusters could have strongly influenced the formation and feeding of the central nucleus of this galaxy.

6. Conclusions

It is both a reasonable and simple hypothesis that the globular cluster and spheroidal components of galaxies formed contemporarily during the first stages of protogalaxy collapse so to have, initially, the same spatial distribution. Observed (and kinematic) spatial differences should be explained on the basis of evolution of the globular cluster system (GCS).

We have given reference to quantitative studies which point out the role of dynamical causes of this evolution in galaxies where clusters move on sufficiently radial orbits. We have also explained why most of the observational data available is, at present, insufficient to rule out that such an evolution occurred. To state something meaningful, observations of clusters in the innermost regions (i.e. within the bulge core) to compare with clusters in outer regions of their parent galaxy, as well as kinematic data to determine the cluster velocity ellipsoid are needed.

Through the comparison between the globular cluster and spheroidal radial distributions we determined the number, N_l, of clusters lost in our Galaxy, M 31 and M 87. We found that the GCSs of our Galaxy, M 31 and M 87 should have been initially 1.4, 1.3, and 1.8 times more populous than now.

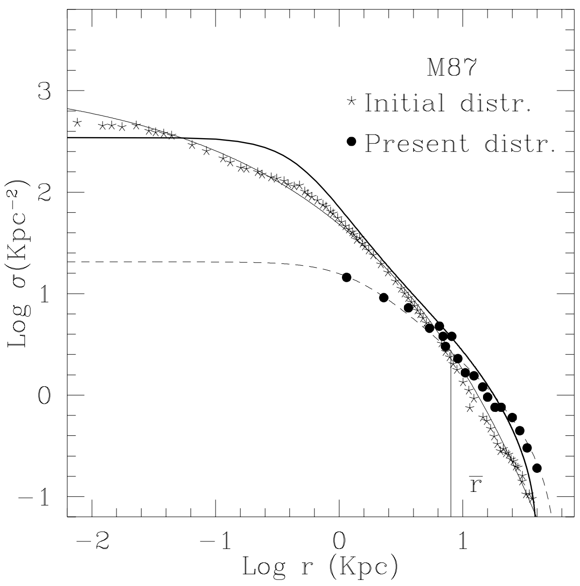

Fig. 5. Our initial cluster distribution obtained letting $\bar{r} = 8\ Kpc$. The thick solid line is the McLaughlin's (1995) initial cluster distribution fit.

The mass of missing clusters has likely gone to the centre of the parent galaxy, where it can contribute to enrich the nucleus by an amount of the order of $N_l < m >$, where $< m >$ is the (present) mean value of cluster mass. This corresponds to $1.8 \cdot 10^7 M_\odot$, $2.3 \cdot 10^7 M_\odot$ and $2.35 \cdot 10^9 M_\odot$ for the Galaxy, M 31 and M 87, respectively.

It is relevant noting that these values are all very similar to available estimates of the nucleus masses in these galaxies. This is not sufficient to say that the nuclei are entirely formed via mass of decayed globular clusters, but surely indicates that deeper investigation, both theoretical and observational, in this direction is worth to be done.

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