

Halo and bulge/disk globular clusters in the S0 galaxy NGC 1380*

Markus Kissler-Patig^{1,2}, Tom Richtler¹, Jesper Storm³, and Massimo Della Valle⁴

¹ Sternwarte der Universität Bonn, Auf dem Hügel 71, D-53121 Bonn, Germany

² UCO/Lick Observatory, University of California, Santa Cruz, CA 95060, USA

³ European Southern Observatory, Casilla 19001, Santiago 19, Chile

⁴ Dipartimento di Astronomia, Università di Padova, Vicolo Osservatorio 5, I-35122 Padova, Italy

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Abstract. We investigated the globular cluster system of the S0 galaxy NGC 1380 in the Fornax cluster with deep *BVR* photometry. We identified two, presumably old, populations of globular clusters. The blue globular clusters seem to be counterparts to the halo globular clusters in our Milky Way. They have comparable colors and magnitudes, are spherically distributed around the elliptical galaxy but have a very flat surface density profile. The red population follows the stellar light in ellipticity and position angle, has a similar magnitude distribution to the blue clusters, and a surface density profile comparable to that of globular clusters in other Fornax ellipticals. From their colors the red clusters appear slightly more metal rich than the metal rich globular clusters in the Milky Way. We associate this red population with the bulge and disk of NGC 1380. While these two populations are compatible with a merger formation, we unfortunately see no hint in favor nor against a past merger event in the galaxy.

This would be the first identification of halo and bulge globular clusters in an early-type galaxy by their colors and spatial distribution, and could hint to the presence of halo *and* bulge globular clusters in all galaxies.

The globular cluster luminosity functions in the three colors will be discussed in detail in a separate paper together with the implications of the absolute magnitude of SN 1992A.

Key words: galaxies: NGC 1380; elliptical and lenticular; star clusters

1. Introduction

The astrophysical interest in investigating extragalactic globular cluster systems is mainly fed from two sources: first the relation between properties of the globular cluster systems and

properties of the host galaxies can be interpreted in the context of galaxy evolution and may provide information about merger history, bulge/halo populations, formation of globular cluster systems, Dark Matter content etc. For recent review articles and data compilations, see Harris & Harris (1996), Richtler (1995), and Ashman & Zepf (1997).

Second, the globular cluster luminosity function can be calibrated as an extragalactic distance indicator (e.g. Jacoby et al. 1992, Whitmore 1996) and enables distance determinations with HST out to a hundred Mpc.

NGC 1380 is an S0 galaxy in the Fornax cluster (see Tab. 1 for general information). It was selected for observation as part of a study of the applicability of the turn-over magnitude of the globular cluster luminosity function as a distance measure, in particular for studying the dependence of turn-over magnitude on Hubble type. Furthermore, the Fornax cluster provides an important stepping stone for the extragalactic distance scale, by hosting three well observed supernovae of Type Ia: SN80D and SN81N in NGC 1316, and SN92A in NGC 1380. SN92A ranks among the best spectroscopically and photometrically observed (Kirshner et al. 1993, Suntzeff 1996). The distance scale aspects of this work will be detailed in a separate paper (Della Valle et al. 1997).

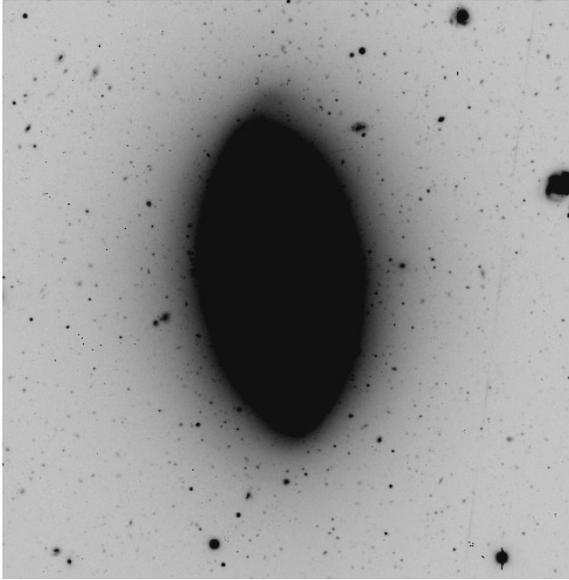
In the present paper we concentrate on the globular cluster system as a subpopulation of its host galaxy. Due to the quality of the presented data, this objective is very interesting particularly with regard to the S0 nature of the galaxy and to the comparison with other E and S0 galaxies in Fornax, which have been recently studied by Kissler-Patig et al. (1997). One of the most interesting aspects of the data is the color distribution of globular clusters since only a few globular cluster systems have been studied deeply in 3 colors, as is the case with the present data (Sect. 3). The total number of globular clusters and the specific frequency are derived in Sect. 4. A blue and a red population of globular clusters are identified, and their properties are discussed in Sect. 5. Since S0 galaxies can be understood as being a transition form between elliptical and spiral galaxies (e.g. Nieto & Bender 1989), their globular cluster systems might

Send offprint requests to: mkissler@ucolick.org

* Based on data collected at the European Southern Observatory, Chile

Table 1. General data of our target galaxy, taken from de Vaucouleurs et al. (1991) and Poulain (1988)

name	RA(2000)	DEC(2000)	l	b	type	m_V	$B - V$	$V - R$	V_0 [km s $^{-1}$]
NGC 1380	03 36 27	-34 58 33	235.93	-54.06	S0	11.81	0.98	0.57	1841

**Fig. 1.** NGC 1380, B image, 15000 seconds

provide additional clues concerning their position in the Hubble sequence. Our conclusions in this respect are drawn in Sect. 6.

2. Observation and reduction

The B , V , and R images were obtained at the 3.5m New Technology Telescope (NTT) at La Silla with the ESO Multi-Mode Instrument (EMMI). The exposure times were chosen to reach approximately the same magnitude beyond the expected turnover in all three bands (see Tab. 2). Thus the stacked frames have equivalent exposure times of 15000 seconds in B , 7800 seconds in V and 2400 seconds in R with effective seeing values of $1.05''$, $1.00''$ and $0.95''$ respectively. A summary of the exposures is presented in Tab. 2. The sizes of the fields are 4.98 by 4.98 arcmin with a pixel size of $0.29''$ in B using the blue arm of EMMI, and 6.29 by 6.29 arcmin with a pixel size of $0.37''$ in V and R where the red arm of EMMI was employed.

Isophotal models of the galaxy were built with the ISOPHOTE package under IRAF, and subtracted from the original images in order to get flat, homogeneous backgrounds for the point source search. The photometry was done with DAOPHOT under IRAF. The DAOFIND limit was set to three standard deviations of the sky noise value. Between 2100 and 2600 objects were found in each color. Completeness calculations were done with artificial star experiments, adding 200 artificial stars per run over 100 runs in each color. Our 60% completeness limits in individual colors are $B = 25.8$ mag, $V = 24.7$ mag, $R = 24.1$ mag.

Table 2. Summary of the NGC1380 observations at the ESO NTT.

Date	Filter	Exposure time (sec)	Number of exposures
04/09/92	V	600	1
19/09/92	V	600	2
15/11/92	V	600	1
15/11/92	R	600	1
16/11/92	V	600	3
16/11/92	R	600	3
22/11/92	B	1200	2
22/11/92	B	1800	7
22/11/92	V	600	6

The calibration was done using eight local standards around NGC 1380 which were reasonably isolated and well exposed. Our calibration relation allowed us to recover the magnitudes of the local standards with an accuracy of 0.021 mag in B , 0.016 mag in V and 0.006 mag in R . Our calibrated magnitudes were finally compared to the local standards used in the SN campaign (Cappellaro et al. 1997) and found to have a systematic offset of 0.07 ± 0.01 mag in B , 0.08 ± 0.01 mag in V , and 0.095 ± 0.015 mag in R . We decided to match our calibration with the one used for the SN, and applied the shifts to our measured magnitudes. Note that this shift is negligible for the colors, number of globular clusters and morphological properties, i.e. the main issues of this paper.

We combined our B , V and R object samples and obtained a list of 908 objects detected in the three colors. Clearly extended objects in this sample were rejected using the chi and sharp values returned by DAOPHOT, to leave us with 710 “point sources”. We selected these in colors ($0.7 < B - R < 1.9$, 468 bona fide globular cluster candidates, see also Sect. 3) to derive morphological properties and the globular cluster luminosity function. And we selected the point sources with errors smaller than 0.1 mag in $B - R$ and $B - V$ (328 objects) to investigate the color distributions.

3. Globular cluster colors

In this section we discuss the colors of the point sources on our frame. We assume $E(B - V) = 0.0$ towards Fornax (Burstein & Heiles 1982). Further, Kirshner et al. (1993) derived a reddening towards supernova 1992A in NGC 1380 of $E(B - V) \simeq 0.0$, on the basis of the missing interstellar UV -lines in their spectra. We are therefore confident that our colors are affected by internal reddening in NGC 1380 only, if at all (see below).

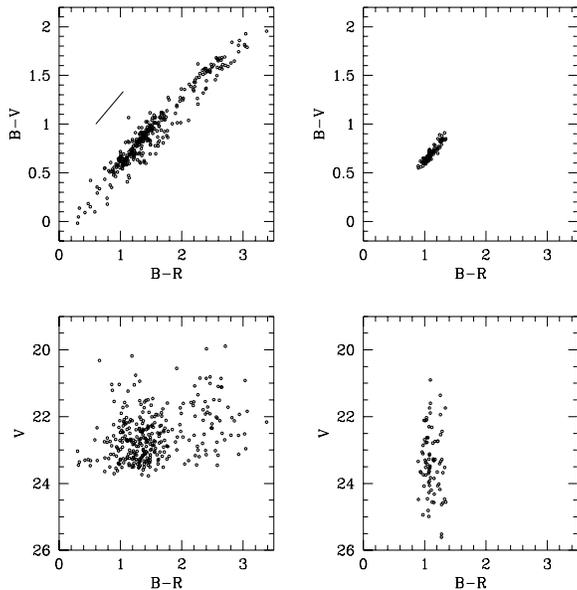


Fig. 2. Color and magnitude comparison between NGC 1380 and Milky Way globular clusters. On the left hand side we show a color-color and a color-magnitude diagram for NGC 1380, on the right hand side the corresponding diagrams for the Milky Way. The left upper panel includes a reddening vector according to Cardelli et al. (1989). All point sources around NGC 1380 with $B - R$ and $B - V$ errors less than 0.1 mag were plotted.

We plotted the colors of all point sources with errors in $B - V$ and $B - R$ smaller than 0.1 mag in Fig. 2. On the left hand side we plotted $B - V$ versus $B - R$, and V versus $B - R$ for NGC 1380, on the right hand side the equivalent plots for the Milky Way globular clusters (de-reddened according to the values given in Harris 1996, and for an arbitrary distance modulus of 31.0). Figures 3 and 4 show the histograms over $B - V$ and $B - R$ for the same sample. We rejected a dozen from over 300 objects that have colors bluer than the bluest Milky Way globular clusters ($B - R < 0.8$) as potential contamination by foreground stars or background galaxies. Further, a clear gap is visible at $1.9 < (B - R) < 2.2$ mag. Objects redder than $B - R = 2.0$ are most likely background galaxies, with about a third of them associated with a background cluster (see Sect. 3.2). Finally, what might appear to the eye as a potential parallel sequence in the color-color diagram of NGC 1380 is span by less than 20 of the 300 objects, and might be a combination of photometric errors and low-redshift background galaxies. No systematics in positions, colors or magnitudes were found for this sample, that might hint to 5-10% residual contamination of our globular cluster sample. We focus in the following section onto point sources with colors between $0.7 < (B - R) < 1.9$ mag, that we estimated to be good globular clusters candidates.

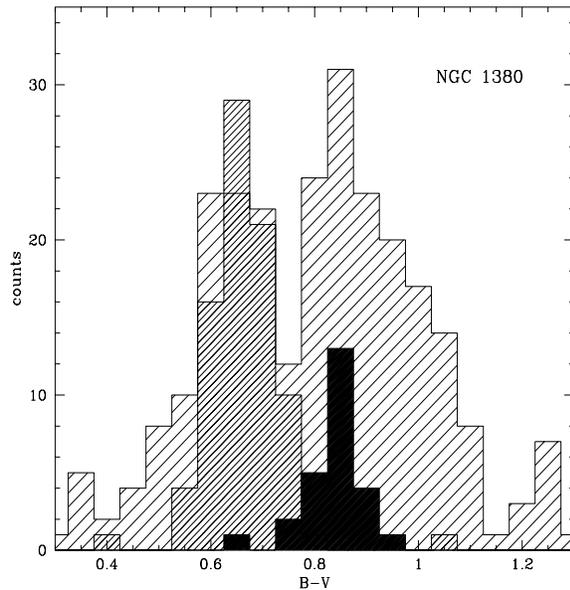


Fig. 3. $B - V$ color histogram of point sources around NGC 1380. Globular clusters have colors between $0.4 < B - V < 1.2$, objects with $B - V > 1.3$ are most likely background galaxies. Overplotted are the colors of metal-poor (grey shaded) and metal rich (dark shaded) Milky Way globular clusters.

3.1. Halo and bulge globular clusters?

Both color distributions ($B - V$ and $B - R$) are broader than expected from our errors in the photometry alone (< 0.1 mag). A KMM test (Ashman et al. 1994) rejects a unimodal distribution in favor of two Gaussians with more than 96% confidence for both colors. The two peaks are identified at $(B - V) = 0.65$ and 0.94 mag and $(B - R) = 1.08$ and 1.52 mag. As a comparison, we divided the Milky Way globular clusters into metal-poor ($[Fe/H] < -0.9$ dex) and metal-rich ($[Fe/H] > -0.9$ dex) objects, and over-plotted their color distributions (double hashed and black histogram respectively) in Figs. 3 and 4.

The blue globular clusters in NGC 1380 match exactly the metal-poor globular clusters of the Milky Way in both colors. Further, these blue clusters are not brighter than expected (see below) and there is no evidence that NGC 1380, an S0 galaxy, has undergone an interaction or a merger in the last several Gyr (see Sect. 6.1). We therefore reject the possibility that the blue color of the clusters is due to a younger age, and are confident that they are the counterpart in NGC 1380 of the halo globular clusters in our Milky Way (see Sect. 6.2).

The red globular clusters, on the other hand, are partly matched in colors by the metal-rich clusters of the Milky Way, but extend to slightly redder colors. This could be due to different effects. First, we did not include in our plot Milky Way clusters that could not be accurately dereddened. These mostly include metal-rich clusters close to the plane of the galaxy (e.g. Zinn 1985), i.e. our comparison sample suffers some incompleteness at the red end. But this can certainly not explain the whole red tail. Second, we could consider some internal reddening

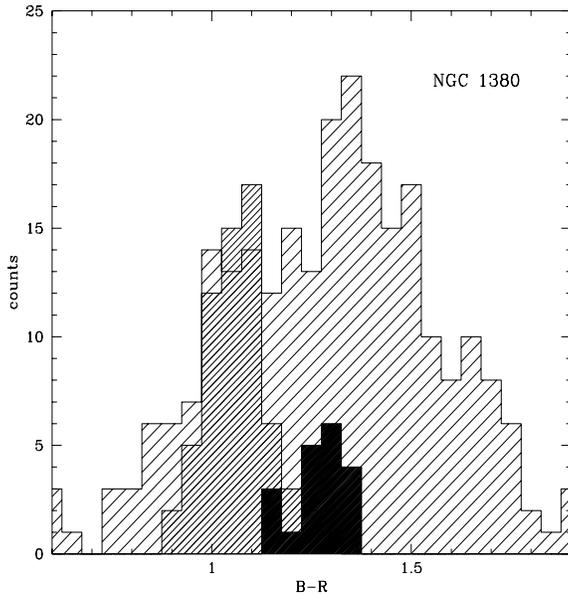


Fig. 4. $B - R$ color histogram of point sources around NGC 1380. Globular clusters have colors between $0.7 < B - R < 1.9$, objects with $B - R > 2.0$ are most likely background galaxies. Over-plotted are the colors of metal-poor (grey shaded) and metal rich (dark shaded) Milky Way globular clusters.

ing in NGC 1380. However, the mean and median magnitudes differ by less than 0.2 mag in V when we divide the red clusters into two samples at $(B - R) \simeq 1.45$ (see also Sect. 3.1, Fig. 6), that is, the reddest globular clusters are not dimmed by extinction, making significant internal reddening unlikely as already mentioned above. Finally, assuming these clusters to be roughly of the same age as the Milky Way clusters, the red color would be a metallicity effect. If we extrapolate a color-metallicity relation for the Milky Way ($[Fe/H] = -5.4(\pm 0.3) + 3.7(\pm 0.3)(B - R)$, using the compilation of Harris 1996), the mean color of the red globular clusters $B - R \simeq 1.50$ would lead to a metallicity of about solar, as observed in elliptical galaxies (e.g. the compilation of Ashman & Zepf 1997).

The magnitude distributions of the red and blue clusters are similar. We show in Fig. 6 the B globular cluster luminosity functions for the blue, the red, and all globular clusters located at distances from $35''$ to $150''$ from the center of NGC 1380. The best Gaussian fits to the data return turn-over luminosities of $m_B^{TO} = 24.5 \pm 0.15$ mag and $m_B^{TO} = 24.3 \pm 0.15$ mag for the blue and red samples respectively, and $m_B^{TO} = 24.38 \pm 0.1$ mag for the combined sample (see also Della Valle et al. 1997). In V and R the turn-overs still agree with the changing mean colors of the sample (i.e. $m_B^{TO} - m_V^{TO} = 0.7 \pm 0.2$, $m_B^{TO} - m_R^{TO} = 1.1 \pm 0.2$ for the blue clusters; $m_B^{TO} - m_V^{TO} = 0.9 \pm 0.2$, $m_B^{TO} - m_R^{TO} = 1.3 \pm 0.2$ for the red clusters). These results agree well with the values found for other small early-type galaxies in Fornax (Kohle et al. 1996), indicating from their magnitudes that our two populations are likely to be old. Note however, that metal-poor (blue) globular clusters should

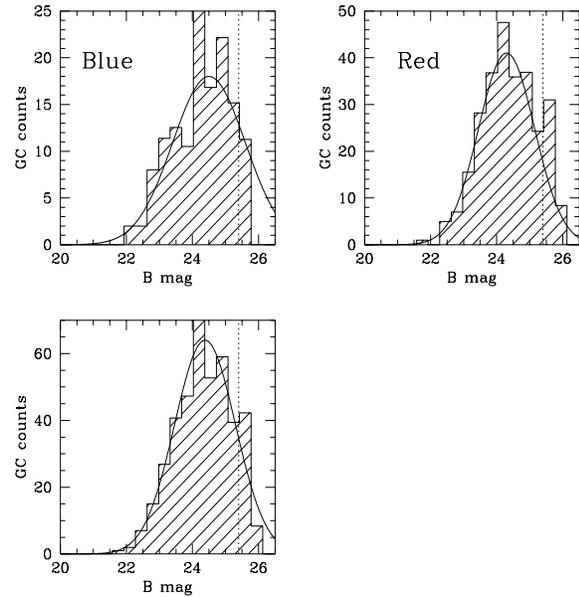


Fig. 5. Globular cluster luminosity functions in B for blue and red globular clusters around NGC 1380 (upper panels), and for the combined sample (lower panel). The best Gaussian fits are over-plotted, and the dotted line marks the 50% completeness limit.

be brighter than metal-rich (red) globular cluster at the same age (e.g. Ashman et al. 1995), and the effect should increase toward bluer colors. In contrast, our data hint to a systematically brighter *red* sample, even if the effect is hard to disentangle from our errors. Assuming mean metallicities similar to the halo and the bulge of the Milky Way, magnitude differences between blue and red clusters should be of the order of $\Delta B \simeq 0.35$, $\Delta V \simeq 0.25$, and $\Delta R \simeq 0.20$, according to Ashman et al. (1995). This is just outside the range compatible with our errors, and we conclude that some age effect is compensating for the metallicity effect and be brightening our red clusters, i.e. the red globular clusters may be slightly younger than the blue ones. According to the population synthesis models of Fritze-v. Alvensleben & Burkert (1993), the red cluster would have to be about 3 Gyr younger on average than the blue ones. Worthey's (1994) models return a similar age difference of less than 4 Gyr (assuming in both cases a similar globular cluster mass distribution for the red and blue clusters).

In summary, NGC 1380 appears on the basis of colors to have two distinct populations of old globular clusters, which will be confirmed by their spatial distribution in Sect. 5. The blue globular clusters are very similar to the metal-poor counterparts in the Milky Way halo. The red globular clusters are, in the mean, slightly redder, i.e. most likely more metal-rich than the metal-rich population in the Milky Way. Further, there is weak evidence that the red population could be 3-4 Gyr younger than the blue one.

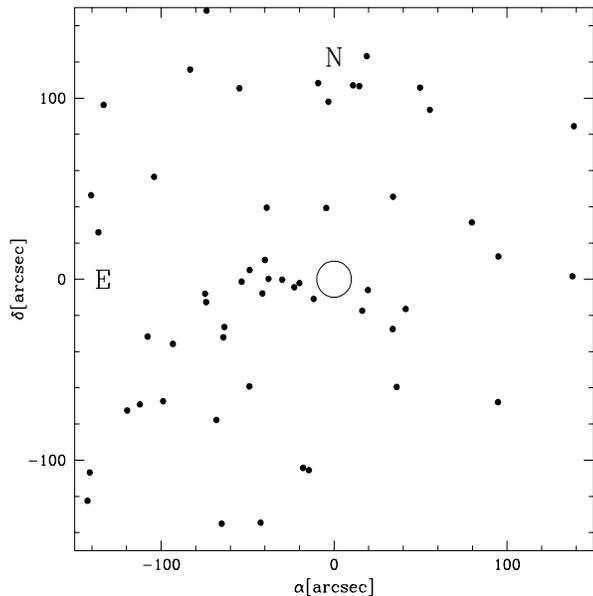


Fig. 6. Distribution of the objects with $2.1 < (B - R) < 2.7$ around NGC 1380

3.2. A background galaxy cluster

Figure 6 shows the location of objects with colors between $2.1 < (B - R) < 2.7$ mag. More than a third of them are concentrated in a group $30''$ east of the center of NGC 1380. These objects have V magnitudes between 21.0 and 22.9 mag, and so cannot be reddened globular clusters, which would appear more than 1 magnitude fainter than the brightest blue objects ($V > 22.0$) if suffering from extinction. This supports the conclusion already mentioned above that there is little internal extinction in NGC 1380. Further, these objects fit the K -corrected colors and magnitudes of early-type galaxies at $z = 0.5 \pm 0.1$ (e.g. Coleman et al. 1980). Finally we measured the Gaussian FWHM of these objects with $22 < B < 23$ mag to be $1.14'' \pm 0.02''$, compared to globular cluster candidates in the same magnitude range that have $1.03'' \pm 0.02''$. We suggest that these objects are likely to belong to a galaxy cluster at intermediate redshift.

As a last consistency check we consider all point sources with $B - R < 2.0$ to be mostly globular clusters, but all point sources with $B - R > 2.0$, and *all* extended sources to be background galaxies, we end up with roughly 33500 background galaxies per square degree down to $V = 23.5$ (i.e. 231 objects on 24.8 square arcmin), which compares well with e.g. Smail et al.'s (1995) deep counts, that predict about 33000 objects per square degree. If, however, most point sources with $B - R > 2.0$ were reddened globular cluster, we would end up with less than 2/3 of the expected background galaxies.

4. The number of globular clusters and specific frequency

4.1. The number of globular clusters

The globular cluster system is fully covered by our frame, as shown by our density profiles in Sect. 5.2. We therefore do not have to apply any corrections for geometrical incompleteness and can concentrate on the number of globular clusters found on our images.

One way to compute the number of globular clusters around NGC 1380 is to integrate analytically our globular cluster luminosity functions (see Della Valle et al. 1997). We then get 555 ± 33 globular clusters, averaged over the B , V , and R globular cluster luminosity functions.

Another method is to count the number of globular clusters (i.e. point sources with $0.7 < (B - R) < 1.9$ and $0.4 < (B - V) < 1.2$), down to our turn-over magnitudes and multiply them by two, assuming the luminosity function to be symmetric around the turn-over magnitude. We get 564 ± 20 objects as a mean from counts down to $m_B^{TO} = 24.38$ mag, $m_V^{TO} = 23.67$ mag, and $m_R^{TO} = 23.16$ mag, multiplied by two.

If we divide our sample by color as proposed in the last section, we get 191 ± 10 red globular clusters and 91 ± 10 blue globular clusters from counts down to the same turn-over magnitudes. This is a total of 382 ± 20 red and 182 ± 20 blue globular clusters around NGC 1380, and a ratio of roughly 2 to 1 red to blue globular clusters.

4.2. The specific frequency

In order to derive the specific frequency, we need to adopt a distance modulus for NGC 1380. Here we use the distance modulus derived from the globular cluster luminosity function (see Della Valle et al. 1997) of $(m - M) = 31.35 \pm 0.16$, in excellent agreement with the distance modulus derived from Cepheids by the HST Key project for NGC 1365 (another Fornax member) of $(m - M) = 31.32 \pm 0.19$. The visual V magnitude of NGC 1380 is $m_V = 9.91 \pm 0.10$ mag (see Sect. 1). The specific frequency, using $M_V = -21.44 \pm 0.21$ and $N_{GC} = 560 \pm 30$, is then $S_N = 1.5 \pm 0.5$. As a comparison, the mean for elliptical galaxies in Fornax (excluding NGC 1399) is $S_N = 4.0 \pm 1.0$ (Kissler-Patig et al. 1997), the neighbour S0 galaxy NGC 1387 has an $S_N = 3.2 \pm 1.1$ (Kissler-Patig et al. 1997), and S_N is known to decrease with later types (Harris 1991). NGC 1380, an S0 type galaxy, has a somewhat low but still normal specific frequency for a S0 galaxy in a clusters.

5. Morphological properties

In the following section we investigated the ellipticity and position angle, as well as the surface density profile of the globular cluster system. These properties are then compared with those of the host galaxy light. We used the sample defined in Sect. 2, i.e. all point sources found on all three frames, selected in color. Further, to avoid any errors introduced by completeness corrections, we considered only objects brighter than the 80% completeness limit in all three colors.

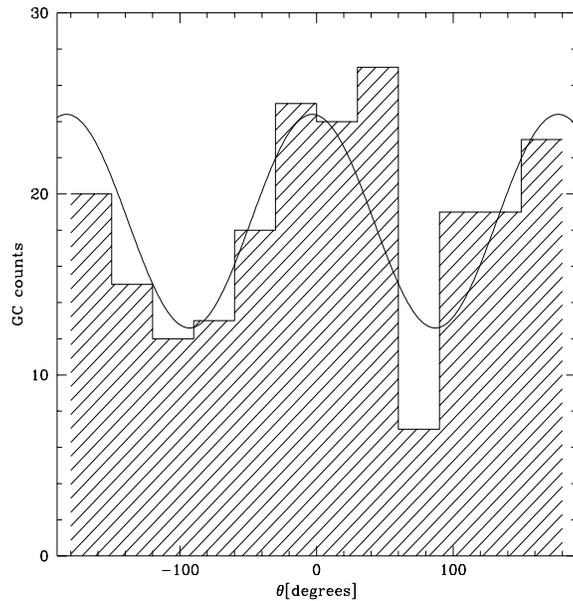


Fig. 7. The angular distribution of the globular clusters around NGC 1380 in 30° sectors. The over-plotted solid line is the best fit to the data, and coincides in position angle and ellipticity with the galaxy light.

5.1. Ellipticity and position angle

To determine the ellipticity and position angle of the globular cluster system, we further considered only globular clusters far enough from the center ($\simeq 50''$) not to suffer from increased detection incompleteness, and close enough ($< 150''$) to lie within a ring totally enclosed on the frame in order to avoid geometrical completeness corrections. We were left with a sample of 220 bona fide globular clusters.

These objects were then divided into sectors 30° wide around the center of NGC 1380. The result is plotted in Fig. 7. In case of a spherical distribution, we would expect a constant number of globular clusters at all position angles. Instead we see two peaks at the position angle of the galaxy, representing an elongated globular cluster system. The best fit of a double cosine returns a position angle of $3^\circ \pm 10^\circ$ and an ellipticity of $\epsilon_{\text{GCS}} = 0.5 \pm 0.2$ (following our method applied in Kissler-Patig et al. 1996), compared to a position angle of $5^\circ \pm 5^\circ$ and an ellipticity of $\epsilon = 0.45 \pm 0.10$ for the galaxy, taken from our isophotal models in B , V , and R . Note that we get very similar results for the properties of the globular cluster system when changing the sector width, or using the objects from individual colors only. The globular cluster system of NGC 1380 seems to follow the ellipticity and position angle of the galaxy light.

However, if we divide our objects into blue and red clusters as discussed in Sect. 3, and plot their angular distribution (see Fig. 8, we applied a point symmetry around the center of NGC 1380 to increase the counts in each bin), we note that the red sample follows the galaxy in ellipticity and position angle, but that the blue globular clusters are rather spherically distributed around the galaxy (constant number of clusters at all angles).

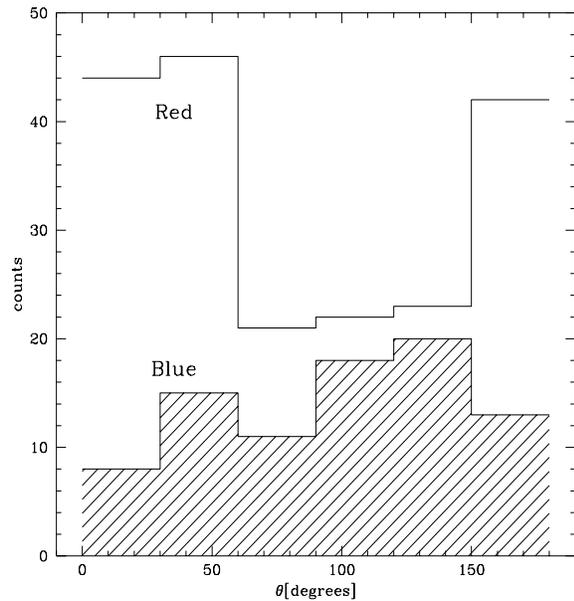


Fig. 8. The angular distribution of halo and bulge globular clusters around NGC 1380 in 30° sectors, after a point symmetry around the center of the galaxy.

While the red clusters seem to be associated with the galaxy light, the blue clusters appear to be morphologically decoupled, which indicates a distinction in halo and bulge/disk globular clusters.

5.2. The surface density profile

The surface density profile of the globular cluster system was investigated on the B , V , and R images individually in order to be compared with the galaxy light profile in the respective color. We used all objects (point sources and extended objects) found on the frame down to the 80% completeness limit in the individual colors ($B < 25.5$, $V < 24.4$, $R < 23.9$). We computed the number of globular clusters in 16 elliptical ($\epsilon_{\text{GCS}} = 0.5$ see last section) rings, $14.5''$ wide on the B image, $18.5''$ wide on the V , and R image. The last five rings suffer from more than 20% geometrical incompleteness, the last ring is only covered to 30% by our frame, and thus should be regarded with caution. The mean major axis and corresponding surface density with its error are shown in Tab. 3. The profiles are plotted in Fig. 9. The right panels show the raw counts with our estimated background as dotted line. The left panels show the corrected surface density of the globular clusters, together with the light profile of the galaxy in the respective filter, taken from our isophotal models.

We fitted the globular cluster surface density profiles with a power law of the form $\rho \sim r^x$, where ρ stands for the surface density of the globular clusters or the surface intensity of the galaxy light, and r for the semi-major axis of both the globular cluster density profile and the light of the galaxy (taken from our isophotal models, see Sect. 2). The profiles were fitted over

Table 3. Surface density profiles in B , V , and R . The individual columns for each color list the mean major axis in arcsec and the corresponding surface density with its error in counts per square arcmin

B data		V data		R data	
a	density	a	density	a	density
7	456.9 ± 67.3	9	334.8 ± 45.1	9	140.0 ± 29.1
22	313.5 ± 32.1	28	229.2 ± 21.5	28	190.7 ± 19.6
36	212.0 ± 20.5	46	122.9 ± 12.2	46	131.4 ± 12.6
51	125.9 ± 13.3	65	91.3 ± 8.9	65	108.7 ± 9.7
65	116.7 ± 11.3	83	62.2 ± 6.4	83	71.7 ± 6.9
80	85.5 ± 8.7	102	49.2 ± 5.2	102	48.1 ± 5.1
94	73.1 ± 7.4	120	40.7 ± 4.3	120	37.4 ± 4.1
109	76.6 ± 7.1	139	28.8 ± 3.4	139	30.0 ± 3.4
123	51.2 ± 5.4	157	29.7 ± 3.2	157	27.5 ± 3.1
138	54.9 ± 5.4	176	27.5 ± 3.0	176	25.8 ± 2.9
152	54.2 ± 5.6	194	26.4 ± 3.2	194	23.4 ± 2.8
167	49.0 ± 5.6	213	28.5 ± 3.4	213	26.2 ± 3.2
181	43.5 ± 5.4	231	20.8 ± 3.0	231	24.2 ± 3.1
196	64.8 ± 6.6	250	21.2 ± 3.1	250	22.4 ± 3.0
210	58.9 ± 6.8	268	30.8 ± 3.7	268	28.9 ± 3.5
225	61.5 ± 7.8	287	20.0 ± 3.0	287	20.2 ± 2.9

different radii (starting between $0''$ and $30''$ and extending out between $80''$ and $160''$), while varying the background estimate by up to 50% around the mean of the last 8 bins of Tab. 3. We get slopes of $x = -1.55 \pm 0.5$, -1.63 ± 0.08 , and -1.60 ± 0.20 in B , V , R respectively for the globular clusters where the errors reflect the range of values obtained by varying the background level and the fitting range. For the galaxy light we obtained $x = -1.33 \pm 0.06$, and -1.34 ± 0.06 in B and V . Because of a lower signal-to-noise in R we forced an isophotal model with fixed angle on the image, distorting the profile and making a fit unreliable in this filter. The total globular cluster system appears to be compatible with the density profile of the galaxy light.

The galaxy profile appears clearly flatter than an $R^{1/4}$ profile, probably due to a significant disk to bulge ratio (see also Bothun & Gregg 1990). We could not disentangle both components in our profile fits. Note further that Horellou et al. (1995) suggest from the absence of HI and weak CO emission, that NGC 1380 might have suffered tidal stripping. If this happened recently enough, the galaxy might still be kinematically hot.

We also investigated the surface density profiles of the red and blue population individually. Their globular cluster surface density profiles are plotted against radius and semi-major axis in Fig. 10. We fitted the surface density profiles as described above (varying fitting radii and background level) and obtained a slope of $x = -2.5 \pm 0.3$ for the red objects, and $x = -1.0 \pm 0.4$ for the blue objects. The blue objects follow a significantly flatter surface density profile than the red objects and even appear slightly flatter than the galaxy light. The red objects follow a steeper profile than the galaxy light, but with a slope similar to that of the profiles of globular cluster systems in small early-type galaxies (e.g. Kissler-Patig 1997). The profile of the red objects agrees roughly with a $R^{1/4}$ profile, and could be associated with the main stellar component of NGC 1380. The superposition

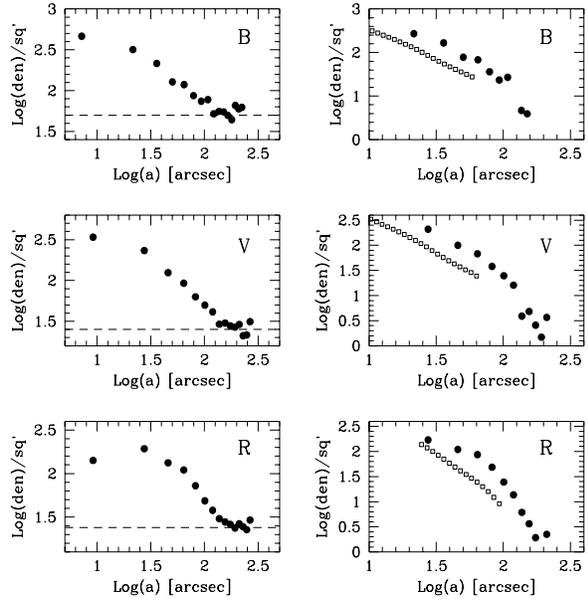


Fig. 9. Surface density profiles of all objects (left) and globular clusters (right) around NGC 1380.

of both red and blue profiles make the overall globular cluster system look almost as flat as the galaxy light, as shown above.

6. The origin of the two populations

We identified two populations of globular clusters in the S0 galaxy NGC 1380. These two populations differ clearly in their spatial distribution and in color but apparently not in their magnitude distribution. As explained in Sect. 3.1, they must differ in metallicity and possibly somewhat in age. Thus these two populations must have formed in different processes, probably at slightly different epochs.

Two main alternatives for the presence of red and blue globular clusters exist.

- Multi-modal color distribution in early-type galaxies could be associated with a merger event that induced the formation of new, more metal-rich globular clusters (red population), superimposed on the old, metal-poor (blue) populations of the progenitors (e.g. Ashman & Zepf 1992, Zepf & Ashman 1993).
- The bi-modal color distribution in the Milky Way corresponds to the metal-poor globular clusters associated with the halo and accretion of small companions (e.g. Zinn 1996), and to the metal-rich population associated with the bulge and disk.

6.1. Did NGC 1380 form by merging?

S0 galaxies are thought to be the continuation of the Hubble sequence from disky ellipticals towards higher disk-to-bulge ratios (e.g. Kormendy & Bender 1996). If low luminosity ellipticals formed by mergers, S0's might be expected to have formed via merging too. As a rather luminous early-type galaxy in a cluster, NGC 1380 is expected to have formed at early times

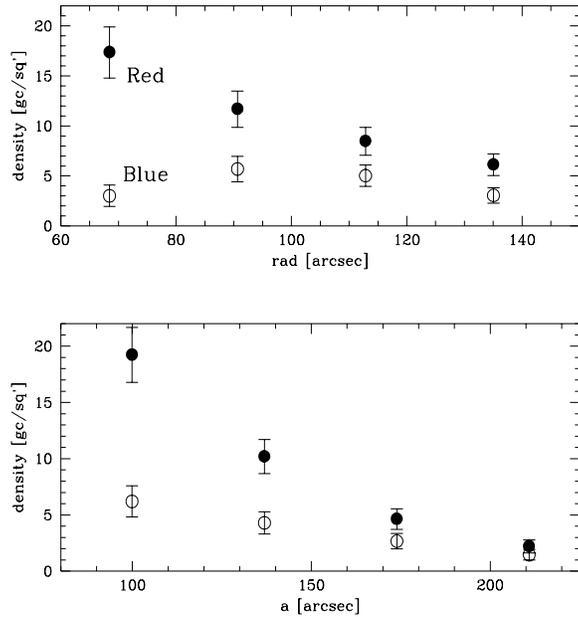


Fig. 10. Surface density profiles of red and blue globular clusters around NGC 1380, plotted once against the radius in arcseconds (upper panel) and once against the semi-major axis (lower panel).

(e.g. Bender, Burstein & Faber 1993). NGC 1380 appears as an isotropic oblate rotator (D’Onofrio et al. 1995) and shows no substructure, but this does not exclude a merger. NGC 1380 is not reported to show any signs for a recent merger event in its history, and we find no anomalies (ripples or shells) except maybe for a slightly warped disk, by subtracting our isopotential models. The absence of detectable HI and CO (Horellou et al. 1995) is interpreted as a hint to stripping but does not contradict an early merger event either. We note however that NGC 1380 is the second brightest early-type galaxy (after the central giant elliptical NGC 1399) in the Fornax cluster, and would most likely to be the product of a merger in hierarchical formation scenarios. However we are left with neither any clear observational signs in favor nor against a past merger event for the galaxy.

The globular cluster system, from the properties of blue and red globular clusters, seem to be in agreement with the model of Ashman & Zepf (1992), with respect to the morphological properties (newly formed, i.e. red cluster, would be more centrally concentrated, the old clusters more extended). The only open issue would be the low specific frequency despite the high number of red (new) relative to blue (old) clusters. The low specific frequency indicates that no excess of globular clusters (when compared to stars) was formed in the merger event, leaving the specific frequency at a normal value after the merger. However, on the other hand, the red population in NGC 1380 is more than twice as numerous as the blue one, implying that the merger event formed twice as many globular clusters as were brought in by the progenitor galaxies. Both points combined imply that the merger was highly effective in forming new stars. Unfortunately no quantification is possible at this stage, but as a comparison, the Antennae (NGC 4038/4039) currently

forms 700 new globular clusters candidates from which many are expected to survive (Whitmore & Schweizer 1995). The end product of these two Sb/Sc spirals is expected to have a specific frequency around 2, and might be close to what NGC 1380 looks like today.

Therefore, we cannot rule out nor conclude that NGC 1380 is a merger product, but if it formed in a merger, we note two interesting facts: first, since the age of the red globular clusters seem to be less than 4 Gyr younger than the blue ones (see Sect. 3.3.1), the merger must have happened at very early times. Second, if all red globular clusters formed in the merger, the globular clusters to star formation rate implies that mergers might not necessarily change the specific frequency of galaxies, despite producing a high number of new clusters.

6.2. An analogy to the Milky Way?

Alternatively, if NGC 1380 never experienced a major merger event, the two populations of globular clusters might be thought of the analogy of the halo and bulge/disk globular cluster population in the Milky Way.

Following characteristics are compatible with such a picture. The magnitudes of blue and red globular clusters are similar within few tenth of a magnitude, reducing the age difference to a few Gyr (see Sect. 3.3.1), i.e. the spread also observed in the Milky Way (Chaboyer et al. 1996). From their luminosities and colors the two populations of globular clusters in NGC 1380 appear old (> 12 Gyr, according to the model of Worthey 1994). The blue globular clusters have luminosities and colors comparable to the halo clusters in the Milky Way, and are spherically distributed. NGC 1380 has a higher number of blue clusters (180 ± 20) than the Milky Way ($\simeq 100$), but is also more luminous. Further the red clusters follow closely the shape (ellipticity and position angle) of the stellar component (mainly bulge), and also share the same mean color with the stellar population ($B - V = 0.94$ for the red globular clusters (see Sect. 3.3.1), compared to $B - V \simeq 0.98$ for the galaxy (see Tab. 1)).

However, such an analogy has its limits. The blue clusters have a far more flatter profile than the halo clusters in the Milky Way. In the Galaxy, the halo population falls off spatially with a power of -3.5 , i.e. in projection with a power of -2.5 , distinctly steeper than in NGC 1380. One could speculate that if indeed the galaxy suffered stripping lately (see above), this might account for the flatter profile of the outer globular clusters. However, we further do not expect the red globular clusters to be younger in this analogy. There is now main sequence photometry for the most metal-rich galactic bulge clusters (Ortolani et al. 1995, Fullton et al. 1995), which indicates for these clusters an age comparable with that of halo clusters. The youngest galactic globular clusters are not found among the bulge but among the halo clusters: Several objects are known to be older by a few Gyr than the bulk of halo clusters and it is attractive to conjecture that they are the debris of accreted dwarf galaxies (e.g. Zinn 1996). This scenario in its simple form is not very probable for NGC 1380, because dwarf galaxies should be metal poor

and accordingly also their debris, and therefore enrich the blue population with younger globular clusters.

Whatever the formation processes are, keeping this line of argumentation implies for NGC 1380 a bulge formation *after* halo formation, which fits to some theories of bulge formation (Wise et al. 1997).

We note in passing, that it seems difficult to associate all red globular clusters in NGC 1380 with its disks as proposed in the Milky Way by Zinn (1996), given their large number and their spatial distribution. Alternatively at least part of the red globular cluster population might be associated with the bulge as proposed for the Milky Way by Minniti (1995) and Burkert & Smith (1997).

Finally we note that the two alternatives given above are not mutually exclusive. On the one hand, an unanswered question about the Milky Way is whether bulge and thick disk formed as a result of an interaction or merger, making both hypothesis valid at the same time. On the other hand, one could think of two red populations, namely one brought in by the bulges/thick disks of the progenitors, and the other formed during the merger event.

7. Summary and conclusions

We detected two clearly distinct populations of globular clusters in NGC 1380, pointing to two different globular cluster formation events in this galaxy. To our knowledge, the identification of a population of halo clusters would be the first identification of an halo component in a S0 galaxy. Of great help is of course the unusually deep limiting magnitude in our study. Therefore the comparison with GCSs of other elongated early type galaxies might remain vague. Recently, Elson (1997) reported two distinct stellar populations in the S0 NGC 3115, however could not study their properties due to too small spatial coverage. Since S0 galaxies can be seen as the extension of early-types in the Hubble sequence (Nieto & Bender 1989), and given the similarity of the properties of bulges of spirals and ellipticals (Bender et al. 1992, Wise et al. 1997), blue “halo” globulars could be present in all early-type galaxies. If elliptical galaxies are mostly bulge dominated, the color distributions of the globular clusters in elliptical galaxies will look unimodal and “red” as long as the halo population represents only a small fraction of the total system. This could be the case in NGC 720 (Kissler-Patig et al. 1996), where no spherical component in the globular clusters system could be detected. The current detection limit of two populations largely depends on the number ratio of the two populations, the accuracy of the photometry, and the photometric system used. While multiple populations are detected in several bright elliptical galaxies (e.g. summary by Ashman & Zepf 1997), the current broad band photometry investigations can barely exclude “unimodal” color distributions in normal, small elliptical galaxies, with two coeval populations differing only in metallicity (e.g. Kissler-Patig et al. 1997), leaving the issue open.

The different formation processes of the two globular cluster populations in NGC 1380 are not well enough constrained

by our data to differentiate between a merger formation or a Milky Way analogy. However we note that in case of a merger formation, the merger event must have happened at very early times, and despite producing a large number of new globular clusters, it did not increase the specific frequency of the galaxy. Finally, the blue globular clusters, despite many similarities to the Milky Way halo clusters, have a much flatter radial profile.

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