

Colour-magnitude diagrams of the inner halo globular clusters NGC 5986 and NGC 6712*

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Abstract. We present V and I photometry for NGC 5986 and B and V for NGC 6712. NGC 5986 has a blue extended horizontal branch, while NGC 6712 has a composite red and blue horizontal branch, where the latter extends to unusual bluer colours. Both clusters have RR Lyrae.

We derive a reddening $E(B-V) \approx 0.29$ and a distance from the Sun $d_{\odot} \approx 11.2$ kpc for NGC 5986, and $E(B-V) \approx 0.33$ and $d_{\odot} \approx 7.9$ kpc for NGC 6712.

Their galactocentric distances of $R_{GC} = 5.2$ and 3.6 kpc respectively, locate them in the inner halo; NGC 6712 could be considered to be located in the bulge.

NGC 6712 has $|z| \approx 500$ pc, indicating that the cluster is crossing the disk.

We estimate metallicities of $[Fe/H] = -1.6$ and -1.0 respectively for NGC 5986 and NGC 6712.

Key words: stars: Hertzsprung–Russell (HR) and C-M diagrams – Galaxy: globular clusters: individual: NGC 5986, NGC 6712

1. Introduction

CCD Colour-Magnitude Diagrams (CMD) are becoming available for many globular clusters. Such data allow a better understanding of their metallicity, reddening and spatial distribution, which in turn improves the knowledge of the galactic subsystems.

The study of known globular clusters in the area within 5° of the Galactic center, by means of CCD CMDs, is now complete (Barbuy et al. 1998, Ortolani et al. 1999). The status of CCD photometry for the surrounding zone of $20^{\circ} \times 20^{\circ}$ has been discussed in Barbuy et al. (1999). Beyond the $20^{\circ} \times 20^{\circ}$ region, corresponding to halo globular clusters, very few clusters still require CCD data. NGC 6712 was recently studied with very deep V and R VLT images by De Marchi et al. (1999), how-

ever they concentrated their study on main sequence stars in a small field, with the purpose of deriving the low main sequence luminosity function. They conclude that tidal forces have significantly stripped its lower mass stars as a result of incursions into the central parts of the Galaxy. They presented a R vs. $V - R$ CMD for the main sequence, while the present study aims at analysing the brighter cluster sequences. NGC 5986 had only recently a V vs. $V - I$ CCD CMD presented, together with a series of other clusters, by Rosenberg et al. (2000), corresponding to an offcenter region of $3.8' \times 3.8'$. In the present study we discuss CMD spatial extractions, and infer from the derived parameters its precise location in the Galaxy.

NGC 5986, also named ESO329-SC18 and GCL 37, is located in Lupus at $\alpha_{2000} = 15^{\text{h}} 46^{\text{m}} 03.5^{\text{s}}$, $\delta_{2000} = -37^{\circ} 47' 10''$ ($l = 337.02^{\circ}$, $b = 13.27^{\circ}$). NGC 5986 is a compact cluster with concentration parameter $c = 1.80$, core radius $r_c = 0.21'$, tidal radius $r_t = 13.2'$ and half light radius $r_h = 1.4'$ (Trager et al. 1995). Zinn (1980) obtained, from integrated photometry, $[Fe/H] = -1.80$ and $E(B-V) = 0.29$. From integrated DDO photometry, Bica & Pastoriza (1983, hereafter BP83) obtained $[Fe/H] = -1.55$ and $E(B-V) = 0.22$. Hesser & Shawl (1985) give an integrated spectral type F9 for this cluster, suggesting an intermediate metallicity. Smith (1984) estimated a relatively high metallicity of $[Fe/H] = -0.57$ from the ΔS method using 5 RR Lyrae. Rutledge et al. (1997) from CaII spectroscopy of individual giants give $[Fe/H] = -1.65$, adopting Zinn & West (1984, hereafter ZW84) metallicity scale and -1.35 adopting Carretta & Gratton (1997, hereafter CG97). The compilations by Webbink (1985) and Harris (1996, hereafter H96, as updated in <http://physics.mcmaster.ca/Globular.html>), report $[M/H] = -1.72$, $E(B-V) = 0.25$, $d_{\odot} = 10.5$ kpc, and $[Fe/H] = -1.58$, $E(B-V) = 0.27$, $d_{\odot} = 10.5$ kpc, respectively.

A photographic V vs. $B - V$ Colour-Magnitude Diagram was presented by Harris et al. (1976), which showed a blue Horizontal Branch (HB). The cluster contains several variable stars (Rosino 1962) and Liller & Lichten (1978) confirmed that 8 RR Lyrae variables belong to the cluster.

NGC 6712, also named GCL 103, is located in Scutum at $\alpha_{2000} = 18^{\text{h}} 53^{\text{m}} 04.3^{\text{s}}$, $\delta_{2000} = -08^{\circ} 42' 22''$ ($l = 25.35^{\circ}$, $b = -4.32^{\circ}$). Zinn (1980) provides $[Fe/H] = -1.17$, $E(B-V) = 0.39$,

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and ZW84 give $[\text{Fe}/\text{H}] = -1.01$. BP83 found it metal-rich and estimated $E(B-V) = 0.30$.

Hesser & Shawl (1985) give an integrated spectral type F5, suggesting a low metallicity. Rutledge et al. (1997) report $[\text{Fe}/\text{H}] = -1.07$ (ZW84 scale) and -0.94 (CG97 scale).

Webbink (1985) and H96 list $[\text{M}/\text{H}] = -1.26$, $E(B-V) = 0.48$, $d_{\odot} = 6.2$ kpc, and $[\text{Fe}/\text{H}] = -1.01$, $E(B-V) = 0.45$, $d_{\odot} = 6.9$ kpc, respectively.

Martins & Harvel (1981) presented a V vs. $B - V$ photographic CMD reaching the HB, showing a populated red HB with some stars at the blue side of the HB. These authors derived a reddening $E(B-V) = 0.33$. Cudworth (1988) produced a V vs. $B - V$ photographic CMD by selecting members through proper motion analysis. The CMD reaches $V \approx 17.5$ at the level of the subgiant branch, and shows a composite HB morphology with a red HB more populated than the blue one.

Rosino (1966, 1978) list 15 red irregular variables, 7 Miras, 10 red semi-regular and several RR Lyrae. Sawyer Hogg (1973) lists 21 variables in the cluster area, among which 10 are probable RR Lyrae members.

This cluster is also well-known for hosting an X-ray source (Grindlay et al. 1984).

NGC 6712 has a loose structure with $c = 0.90$ (Trager et al. 1995); the tidal radius is $r_t = 7.4'$, the core radius $r_c = 0.93'$ and the half light radius $r_h = 1.3'$.

In Sect. 2 we present the observations and calibrations. In Sects. 3 and 4 we discuss NGC 5986 and NGC 6712 respectively. The concluding remarks are given in Sect. 5.

2. Observations

NGC 5986 was observed in the night of 1998 July 3, with the 1.5m Danish telescope at ESO (La Silla). We employed an EFOSC camera equipped with a Loral/Lesser CCD detector C1W7 with 2052x2052 pixels. The pixel size is $15 \mu\text{m}$, corresponding to $0.39''$ on the sky, which provides a full field of $13' \times 13'$.

NGC 6712 was observed in the night of 1986 May 30 with the Danish telescope. The direct CCD camera equipped with the RCA ESO CCD # 1 of 320x512 pixels of size $30 \mu\text{m}$ was used. The pixel size projected on the sky is $0.74''$ and the total field of view covers $2.5' \times 4.0'$. On 2000 March 5 new data were collected with the same telescope and with the same equipment as described above for NGC 5986.

The log of observations is provided in Table 1.

In Fig. 1 is shown a 10 sec V exposure of NGC 5986 for a field extraction of $6.5' \times 6.5'$ (1000x1000 pixels). This is clearly a populous cluster. In Fig. 2 is shown the full field V exposure (60 sec) of NGC 6712, corresponding to the March 2000 run. The cluster is rather loose, and not as populous as NGC 5986.

Daophot II was used to extract the instrumental magnitudes. For calibrations we used Landolt (1983, 1992) standard stars.

The derived calibration equations for the 1998 run are:

$$V = 24.443 + 0.007(B - V) + v$$

$$I = 23.122 - 0.040(V - I) + i$$

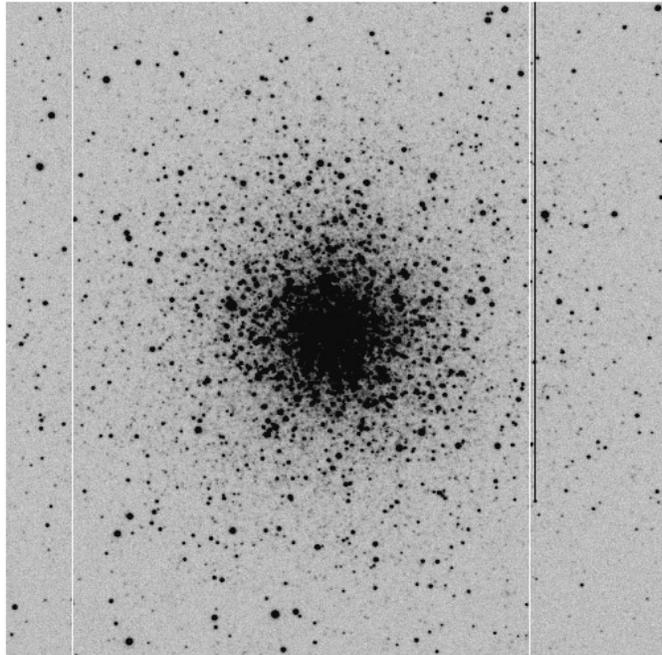


Fig. 1. V image extraction (10 sec) of NGC 5986. Dimensions are $6.5' \times 6.5'$ (1000x1000 pixels). North is at the top and east to the left.

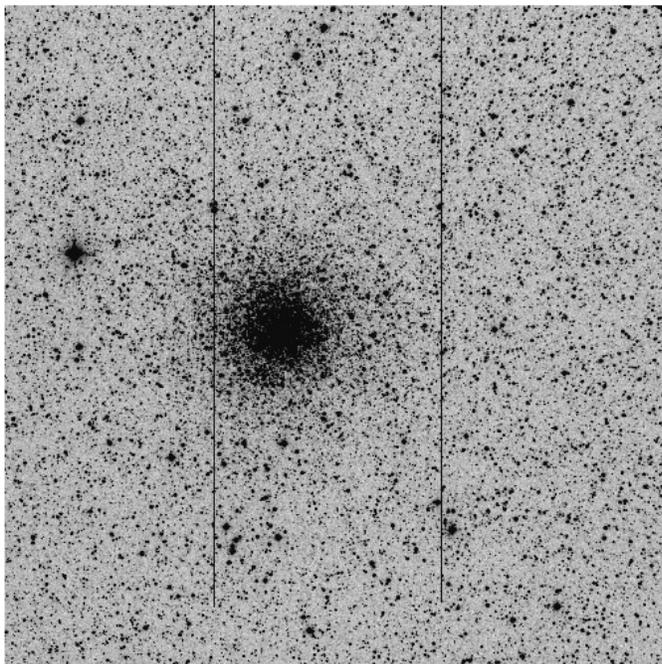


Fig. 2. V image full field (60 sec) of NGC 6712 with dimensions $13' \times 13'$. North is at the top and east to the left.

reduced to 1 sec. exposure and 1.0 airmass. The zero point calibration errors arising from crowding effects are estimated to be about ± 0.03 mag. The CCD shutter time uncertainties (0.3 sec) related to short exposures done for standard stars, lead to additional 3% error, which is propagated to the calibrations of the long exposure cluster frames. The final magnitude zero point uncertainty is estimated to be ± 0.05 . The atmospheric extinc-

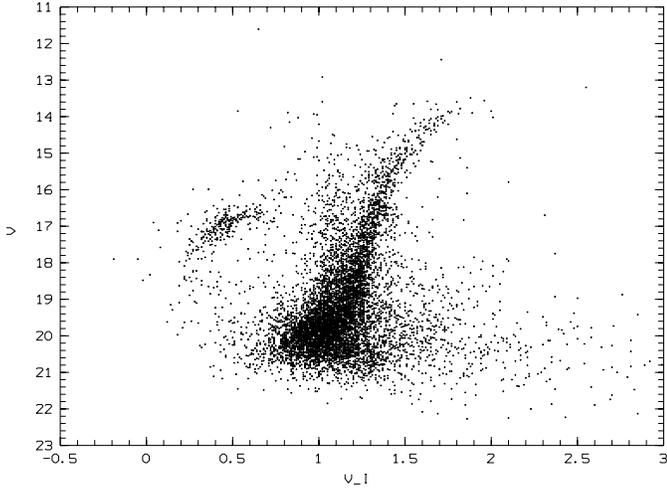


Fig. 3. NGC 5986: V vs. $V - I$ CMD extraction of a large field with dimensions $12.9' \times 12.6'$ (1982x1932 pixels) containing NGC 5986 and field.

Table 1. Log of observations

Target	Filter	Date	Exp. (sec.)	Seeing (")
NGC 5986	V	03.07.98	10	1.4
	I	"	8	"
	I	"	15	"
	V	"	50	"
	I	"	40	"
NGC 6712	B	30.05.86	120	1.8
	V	"	60	1.6
	V	05.03.2000	60	1.2
	B	"	120	1.3
	B	"	240	1.3

tion was corrected with the La Silla coefficients ($C_V = 0.13$, $C_I = 0.1$ mag/airmass).

The calibration equations for the 2000 observations of NGC 6712 are:

$$V = 26.46 + 0.01(B - V) + v$$

$$B = 26.35 + 0.1(B - V) + b$$

for 10 sec. and 15 sec. respectively, at 1.25 airmasses.

3. NGC 5986

3.1. Colour-magnitude diagrams

In Fig. 3 we show a wide field with size $12.9' \times 12.6'$ V vs. $V - I$ diagram of NGC 5986. The cluster has a relatively high galactic latitude, but a disk main sequence (MS) is clearly seen, which is probably related to the Upper Centaurus Lupus OB association (de Zeeuw et al. 1999). The cluster sequences are well populated with a blue extended HB. The present CMD reaches $V \approx 20.5$, thus 3 magnitudes deeper than the photographic CMDs but not as deep as the diagram by Rosenberg et al. (2000). Relative to

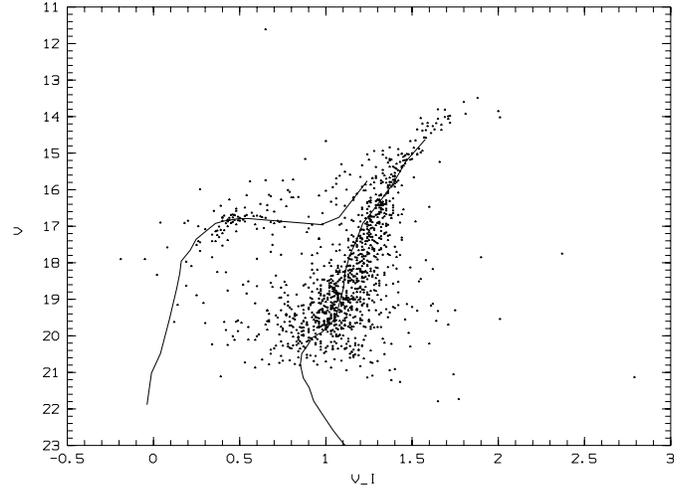


Fig. 4. NGC 5986: V vs. $V - I$ CMD extraction of $r < 70''$ ($r < 180$ pixels). The mean locus of NGC 6752 is superimposed.

Rosenberg et al. our diagram covers a wider area, which allows a spatial analysis.

In a central extraction of $r < 70''$ ($r < 180$ pixels) given in Fig. 4, the disk MS is essentially absent and the cluster HB becomes well defined. A mean locus of NGC 6752 (Rosino et al. 1997) is overplotted on this figure, where the fit made by eye was intended to obtain a best match to the BHB. The comparison between the cluster sequences and the mean locus indicates that the metallicity of NGC 5986 is similar to that of NGC 6752 ($[Fe/H] = -1.55$, H96).

3.2. Cluster reddening and distance

The upper part of the blue HB (BHB) is located at $V_{BHB} = 16.75 \pm 0.15$ and the colour of the RGB at the level of the BHB is $V - I = 1.28 \pm 0.03$. The $V - I$ colour of the RGB at the HB level for NGC 6752 is $V - I = 0.95 \pm 0.04$, giving a difference of $\Delta(V - I) = 0.33$. Adopting $E(B - V) = 0.04$ for NGC 6752 (H96), and $E(V - I)/E(B - V) = 1.31$, we get $E(V - I) = 0.38$ which converts to $E(B - V) = 0.29$ and $A_V = 0.90$ ($R = A_V/E(B - V) = 3.1$) for NGC 5986.

The HB absolute magnitude for $[Fe/H] \approx -1.6$ is $M_V = 0.6$ (Buonanno et al. 1989), and there results an absolute distance modulus of $(m - M)_o = 15.25 \pm 0.25$, and a distance from the Sun of $d_\odot = 11.2 \pm 1.0$ kpc.

The Galactocentric coordinates of the cluster, assuming a distance of the Sun to the Galactic center of $R_\odot = 8.0$ kpc (Reid 1993), are $X = -1.3$ ($X < 0$ is our side of the Galaxy), $Y = -4.3$ and $Z = 2.6$ kpc. The Galactocentric distance is $R_{GC} = 5.2$ kpc.

3.3. Variable stars

Rosino (1962) showed that the cluster contains RR Lyrae stars, and Liller & Lichten (1978) increased the number of identified variables to 12, among which 8 are RR Lyrae cluster members.

In Fig. 5 the 10 variables within our CCD frame are indicated by circles on a CMD corresponding to an extraction of $r < 78''$ (r

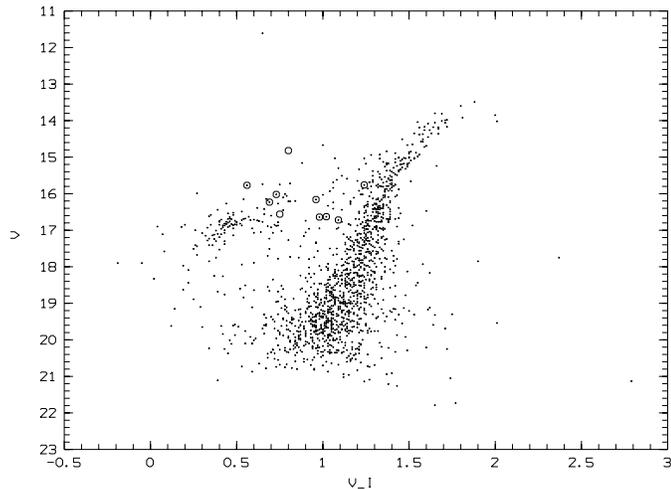


Fig. 5. NGC 5986: V vs. $V - I$ CMD with an extraction of $r < 78''$ ($r < 200$ pixels) where the variables identified by Rosino (1962) and Liller & Lichten (1978) are indicated by circles.

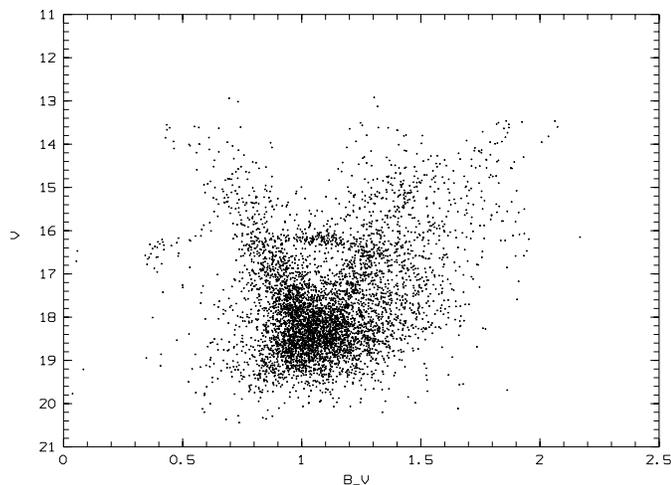


Fig. 6. NGC 6712: whole frame V vs. $B - V$ diagram.

< 200 pixels). Two of them are not contained in this extraction of $r < 70''$, but they are in the larger area CMD of Fig. 3. The diagram shows that, as pointed out by Liller & Lichten (1978), 8 of them are in locations compatible with being member RR Lyrae.

Castellani & Quarta (1987) have classified NGC 5986 as an Oosterhoff type II globular cluster. Since the presently derived cluster metallicity is $[\text{Fe}/\text{H}] \approx -1.6$, NGC 5986 appears to be among the most metal-rich clusters of OoII class.

4. NGC 6712

4.1. Colour-magnitude diagrams

In Fig. 6 we show the whole frame V vs. $B - V$ diagram of NGC 6712. The diagram is well populated showing a number of features. The cluster bright sequences are clear, including a RGB and a HB covering a considerable range of colours. The present CMD reaches $V \approx 19$, at the cluster subgiant level. The

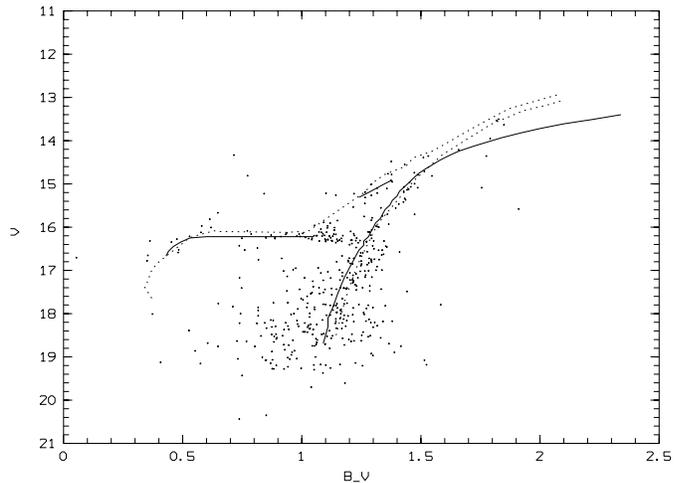


Fig. 7. NGC 6712: V vs. $B - V$ CMD for an extraction of $r < 47''$ ($r < 120$ pixels), where the mean loci of NGC 5904 (dashed line) and NGC 6171 (solid line) are overlotted.

contamination by the field is important as seen from the blue MS, which is expected since the cluster is projected close to the Galactic plane ($b = -4.3^\circ$).

In Fig. 7 a central extraction of $r < 47''$ ($r < 120$ pixels) shows that the cluster sequences become clearer. The morphology of the HB shows a striking colour range, with a red and a blue components, similar to that of NGC 6171 (M107) (see e.g. Ferraro et al. 1991), of $[\text{Fe}/\text{H}] = -1.04$ (H96). The red HB is more populated, with a different morphology relative to more metal-rich clusters such as 47 Tuc, where the HB is clumpy and close to the RGB (Desidera & Ortolani 1997). The brighter magnitudes at the red edge of the blue HB appear to be due to probable RR Lyrae members near their maximum light (Sect. 4.3).

4.2. Cluster parameters

4.2.1. Metallicity

In Fig. 7 the mean loci of the globular clusters NGC 5904 (Sandquist et al. 1996) of $[\text{Fe}/\text{H}] = -1.29$ (H96) and of the slightly more metal-rich cluster NGC 6171 (Ferraro et al. 1991) are overlotted on the cluster CMD.

The RGB as well as the HB are suitably fitted by the mean locus of NGC 6171, suggesting a comparable metallicity. With the mean locus of NGC 5904 there is no simultaneous fit of the RGB, red HB and blue HB. As shown in Fig. 7 where the RGBs are superimposed, the red HB of M5 is bluer, which suggests a higher metallicity for NGC 6712.

Therefore NGC 6712 appears to have a metallicity around $[\text{Fe}/\text{H}] \approx -1.0$. This estimate agrees well with the near-infrared photometry reported by Kyeong & Byun (1998).

NGC 6712 has a wide HB colour range, similar to those of the blue tail clusters NGC 6388 and NGC 6441 (Rich et al. 1997), with the difference that the latter clusters are more metal-rich and present more strongly sloped HBs. In addition, as shown by Pritzl et al. (2000), the RR Lyrae variables in NGC 6388 and

NGC 6441 have exceedingly long periods for their metallicity, unlike the case in NGC 6712 (e.g. Clement 1997). A closer analogue to NGC 6712 is thus provided by NGC 6171, except that its blue HB extends more to the blue, at the same magnitude level of the red HB. We note that a comparison with theoretical synthetic HB simulations for the cluster metallicity, surprisingly indicates that the observed blue HB of NGC 6171 is bluer and/or brighter than predicted by the models. The discrepancy is even more pronounced for NGC 6712. Observations using bluer passbands should prove very useful to further explore this result.

For the case of gently sloping HBs among the more metal-rich of the intermediate metallicity globular clusters, the reader is referred to Brocato et al. (1999) and Sweigart (1999).

Finally, we find for the HB morphology parameter $(B-R)/(B+V+R) = -0.59$ (where B, V and R are respectively the numbers of blue HB, RR Lyrae and red HB stars), confirming the previous estimation by Lee (1990).

4.2.2. Cluster reddening and distance

The HB is located at $V_{HB} = 16.2 \pm 0.1$ and the colour of the RGB at the HB level is $B - V = 1.27 \pm 0.05$. The difference with respect to a best fit with NGC 6171 is $\Delta(B-V)_{(NGC6712-NGC6171)} = 0.0$, implying that the reddening of NGC 6712 is the same as that of NGC 6171 (H96), estimated to be $E(B-V) = 0.33$. This value is somewhat lower than most estimates in the literature (Sect. 1). Adopting $R = 3.1$ we get $A_V = 1.02$, and using $M_V^{HB} = 0.7$ (Buonanno et al. 1989), there results $(m-M)_\odot = 14.48$, and the distance to the Sun $d_\odot = 7.9 \pm 1.0$ kpc for NGC 6712.

Assuming the distance of the Sun to the Galaxy center to be $R_\odot = 8.0$ kpc, the Galactocentric coordinates are $X = -0.9$ kpc, $Y = 3.4$ kpc and $Z = -0.6$ kpc. The distance from the Galactic center is $R_{GC} = 3.6$ kpc.

4.3. Variable stars

Sawyer Hogg (1973) lists 21 variables, out of which 14 are found in the present CCD frames ($13' \times 13'$). An additional RR Lyrae variable, KC 460, has been reported by Cudworth (1988) and is listed in the latest upgrade to Sawyer Hogg's catalogue (Clement 1997).

We used the charts by Sandage et al. (1966) to identify the variables, which are overplotted with circles on the CMD extraction ($r < 58.5''$) of Fig. 8.

The location of 8 variables near the HB indicates that they are probable RR Lyrae members: 4 are on the blue side and the other 4 on the red side of the RR Lyrae gap. Among these, 4 are in the central extraction (open circles with dots). The two brighter blue stars indicated as variables are V17 and V6. Cudworth (1988) reports V17 as a non-variable field star, and the RR Lyrae V6 as a probable member.

NGC 6712 has been catalogued as an Oosterhoff type I (OoI) globular cluster by Castellani & Quarta (1987). A recent period shift analysis carried out for this cluster by Cateian et al. (1998a) suggests a “normal” behaviour in the period-

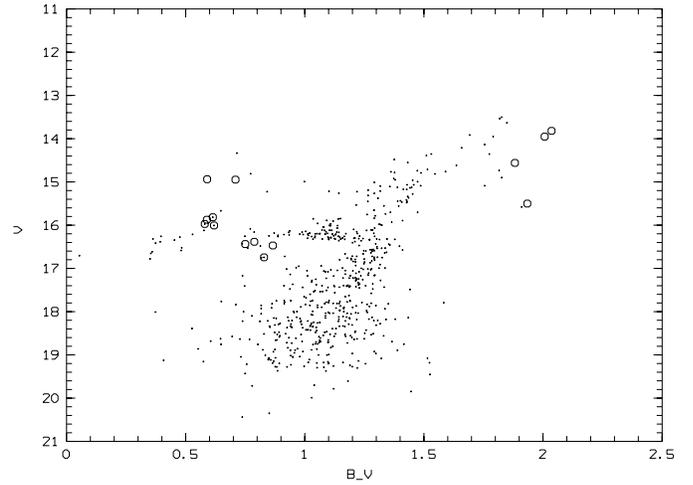


Fig. 8. NGC 6712: V vs. $B - V$ CMD extraction for $r < 58.5''$ ($r < 150$ pixels) with variable stars superimposed.

temperature plane for its metallicity, in contrast with the case of NGC 6171 which appears to have its RR Lyrae variables shifted towards shorter periods at a fixed equilibrium temperature. More data are needed to settle this issue, especially in view of the evidence that NGC 6712 may have a bimodal HB (Cateian et al. 1998b and references therein).

The red variables near the tip of the RGB are classified by Rosino (1966) as semi-regular, irregular and Long Period variables.

From brighter to fainter in Fig. 8 they are V10 (Irr), V2 (SR), V8 (SR), V7 (LP). They may be related to the cluster or to the disk, since they are located in the outer parts of the frame. According to proper motion measurements of Cudworth (1988), V8 and V7, as well as another bright red variable (V21) in NGC 6712 are likely cluster members. NGC 6712 is thus one of the few globular clusters presenting Long Period Variables, which is an indication that it is rather metal rich (Rosino 1978).

5. Conclusions

From the CMD morphology, we find that the metallicity of NGC 5986 is $[Fe/H] \approx -1.6$, similar to that of NGC 6752, while NGC 6712 appears to have $[Fe/H] \approx -1.0$, similar to NGC 6171.

NGC 5986 has a blue extended horizontal branch, and NGC 6712 has a populated red HB together with a blue HB. Both clusters contain RR Lyrae. NGC 5986 is located at a distance from the Sun $d_\odot \approx 11.2$ kpc. Despite its large distance from the Sun, its direction is such that it is in the inner halo ($R_{GC} = 5.2$ kpc).

NGC 6712 is located at $d_\odot = 7.9$ kpc and at a galactocentric distance of $R_{GC} = 3.6$ kpc. Although for the cluster the angular separation from the center is rather large, it is compatible with being within the bulge volume. It remains to be confirmed whether it belongs to the inner halo population or a bulge intermediate metallicity component.

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