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The stellar content of the Sagittarius Dwarf Galaxy*

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Abstract. We present V,I deep CCD photometry for three fields of the dwarf galaxy in Sagittarius (Sgr), located at l=5.6^o, b=-14.1^o. One of the fields is centered on the globular cluster NGC 6715 (M54), which lies in one of the dense clumps of the Sgr galaxy. Comparing the CMD of Sgr with those of globular clusters which are believed to be kinematically associated with the dwarf galaxy (Da Costa & Armandroff 1995), we conclude that the stellar population of Sgr presents a spread in metallicity of -0.71≤[Fe/H]≤-1.58, and that the dominant population (≃10 Gyr old) is extremely similar to the star content of the associated globular cluster Terzan 7. The estimated distance to Sgr is d≃24.55 Kpc.

Key words: techniques: photometry – stars: HR-diagrams – stars: luminosity function – galaxies: irregular – galaxies: stellar content

1. Introduction

Ibata et al. (1994, 1995; hereafter both indicated with IGI) identified a new dwarf galaxy of the Local Group, located in the constellation of Sagittarius. The dwarf was detected as a moving group of stars with mean radial velocity significatively different from that of the stars in the bulge. It is located at a distance of about 25 Kpc from the Sun, subtending an angle of 22 × 8 degrees on the sky (Ibata et al. 1997). The new galaxy is comparable in size and luminosity to the dwarf spheroidal Fornax, which is the largest galaxy known in the Local Group. The recent discovery of two planetary nebulae (Zijlstra & Walsh 1996) confirms that Sgr is similar in mass to the Fornax dwarf, which contains a planetary nebula as well. The other, less massive, dwarfs of the Local Group seem not to contain any star in such a short evolutionary phase.

Although the CM diagram of IGI is heavily contaminated by the rich population of foreground disk and bulge stars, nonetheless it clearly shows the presence of an intermediate-old dominant population.

Mateo et al. 1995a (hereafter MUSKKK), presented the CCD photometry of a field in Sagittarius, which reaches I≃22.3. After having statistically removed the field stars from the CM diagram, they concluded that Sgr is dominated by a intermediate-old population which is younger than that of the bulk of galactic globular clusters. They also found evidence of a feature in the CMD which could be interpreted as a weak component of intermediate age or, alternatively, as a population of blue stragglers. Finally, from the color of the red giant branch they estimated that the metallicity of the dominant population is about [Fe/H]≃-1.1. Mateo et al. (1995b) extensively discussed the properties of a handful of RR Lyrae variables in the field of Sgr.

Sarajedini & Layden (1995, hereafter SL) presented the V,I CCD color magnitude diagram for two fields. The first field is centered near the globular cluster M54 and covers both the cluster and the central region of Sgr, while the second field is centered 12 arcmin north of the cluster. From the analysis of the CMD they found that the bulk of Sgr is formed by a relatively metal-rich population of [Fe/H]≃-0.52, and that a component of lower metallicity ([Fe/H]≃-1.3) could also be present.

Sgr is the nearest galaxy to the Milky Way which has been discovered until now, and numerical simulations confirm that Sgr is presently in phase of being disrupted by the Galaxy (Kathryn et al. 1995).

This idea is supported by Mateo et al. (1996) and by Alcock et al. (1997), who found that Sgr is considerably more extended than previously believed, suggesting that this dwarf has probably suffered at least one - and perhaps many - strong tidal encounters with the Milky Way during past perigalacticon passages.

Another piece of evidence of the strong interaction between Sgr and the Milky Way is that two of the clusters (Ter 7 and Arp2) which have radial velocities similar to that of Sgr, and then suspected to be kinematically associated with Sgr (Da Costa &

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* Based on observations collected at the European Southern Observatory, La Silla, Chile.

Armandroff 1995), are anomalously young compared to the bulk of galactic globulars (Buonanno et al. 1994, 1995a,b).

Recently Fahlman et al. (1996; hereinafter FMRTS) detected the upper end of the main sequence in the background field around the globular cluster M55, which is projected in the sky about 40 arcmin east of Sgr. Having interpreted this feature as the turn-off of Sgr, they used the Vandenberg & Bell (1985) isochrones to give an estimate of the age of the galaxy, and concluded that Sgr is between 10 and 13 Gyr old, although this conclusion is admittedly based on a handful of stars.

Finally, the complex history of Sgr has been confirmed by Ng & Schulthesis (1996) who detected a carbon-star which, if its membership to Sgr will be confirmed, hints at the existence of a stellar population about 4 Gyr younger than the dominant population.

In this paper we present deep V,I CCD photometry of Sgr, in two separate fields, far from those of SL and MUSKKK. Our aim is twofold: first, to explore whether the results above summarized depend on the specific region of Sgr examined (considering the extension of Sgr this aspect is particularly important) and, second, to investigate the nature of the Sgr population.

Deep V,I photometry of the field near M54, already studied by SL, is also presented.

In Sect. 2, we describe the observations and the reduction procedures, while the resulting C-M diagrams are presented and discussed in Sect. 3. The stellar content of Sgr is studied and compared to that of associated globular clusters in Sect. 4. The conclusions are drawn in Sect. 5.

2. Observations and reductions

2.1. Observations

Observations of a field which includes a portion of Sgr and of M54 (α_{2000}=18^{h}55'03", δ_{2000}=$-$30^{o}28'42") were first obtained using EFOSC2 at the ESO/MPI 2.2 m at La Silla during September 1994.

In August 1995 additional observations of Sgr were obtained with the 3.5 m ESO-NTT. The telescope was equipped with EMMI which mounted the coated Loral CCD 2048 X 2048. A series of frames was taken in two different field of the galaxy, one centered at α_{2000}=18^{h}53'44", δ_{2000} =$-$30^{o}28'23" (*field 1*) and the other centered at α_{2000}=18^{h}59'44", δ_{2000}=$-$30^{o}59'45" (*field 2*).

The three observed fields are sketched in Fig. 1 (a,b,c). Several Landolt (1992) stars (from 7 to 15), were observed for calibration throughout each night.

The details of the observations, with the exposure time and seeing conditions, are listed in Table 1.

Table 1. Journal of observations

Date	*Filter*	*Exp.time*	*Seeing*	*Field*	*Tel.*
6 aug. 95	V	240 s	0.70″	Sgr 1	NTT
6 aug. 95	I	300 s	0.74″	Sgr 1	NTT
7 aug. 95	V	20 s	1.12″	Sgr 1	NTT
7 aug. 95	I	30 s	0.95″	Sgr 1	NTT
6 aug. 95	V	240 s	0.89″	Sgr 2	NTT
6 aug. 95	I	300 s	0.67″	Sgr 2	NTT
7 aug. 95	I	300 s	0.65″	Sgr 2	NTT
7 aug. 95	V	20 s	0.80″	Sgr 2	NTT
7 aug. 95	I	30 s	0.86″	Sgr 2	NTT
7 sep. 94	B	60 s	0.85″	M54	2.2
7 sep. 94	B	1200 s	0.93″	M54	2.2
7 sep. 94	B	600 s	0.98″	M54	2.2
7 sep. 94	B	300 s	0.95″	M54	2.2
7 sep. 94	V	300 s	0.89″	M54	2.2
7 sep. 94	V	300 s	0.92″	M54	2.2
7 sep. 94	V	240 s	0.95″	M54	2.2
7 sep. 94	V	240 s	0.95″	M54	2.2
7 sep. 94	V	120 s	0.92″	M54	2.2
7 sep. 94	I	300 s	0.88″	M54	2.2
8 sep. 94	I	180 s	0.82″	M54	2.2
8 sep. 94	B	300 s	0.90″	M54	2.2
8 sep. 94	B	300 s	0.99″	M54	2.2
8 sep. 94	B	480 s	0.95″	M54	2.2
8 sep. 94	I	300 s	0.89″	M54	2.2
8 sep. 94	I	180 s	0.91″	M54	2.2
8 sep. 94	I	180 s	0.93″	M54	2.2
8 sep. 94	I	180 s	0.82″	M54	2.2
8 sep. 94	I	180 s	0.85″	M54	2.2
8 sep. 94	I	180 s	0.85″	M54	2.2
8 sep. 94	I	60 s	0.86″	M54	2.2
8 sep. 94	I	60 s	0.88″	M54	2.2
8 sep. 94	I	60 s	0.93″	M54	2.2

2.2. Reduction procedures

After having applied the basic procedures of pre-reduction (bias and dark current subtraction, trimming, flatfield correction, etc.) we reduced the NTT frames using DAOPHOT II, while the frames taken at the 2.2 m, which are extremely crowded, were reduced using ROMAFOT (Buonanno et al. 1983, Buonanno & Iannicola 1989), because this package allows an easy and continuos interaction of the operator during the reductions.

We detected 9154 stars in *field 1* and 6975 stars in *field 2* down to V$\simeq$23 for the NTT observations and 7928 stars in the field around M54, observed with the 2.2 m.

The tables giving the x,y coordinates, relative to an arbitrary origin, V magnitudes and V-I colors, can be obtained via *Internet* from host *"coma.mporzio.astro.it"* using the "anonymous ftp" service (directory */pub/SAGIT*; files *sagit1.cal*, *sagit2.cal*, *M54.cal* and *README*). The same data will be also stored in the CDS database. The conversion from instrumental magnitudes into the Johnson standard system was obtained using a set of primary calibrators (Landolt 1992) which spanned a wide range in color ($-$0.360 $\leq$V-I$\leq$ 2.030), and has been computed separately for each telescope and for each photometric night.

For NTT we obtained color equations in the form:

$$V = v - 0.001(\pm 0.020)\cdot (v-i) + const.$$

$$I = i - 0.076(\pm 0.020)\cdot (v-i) + const.$$

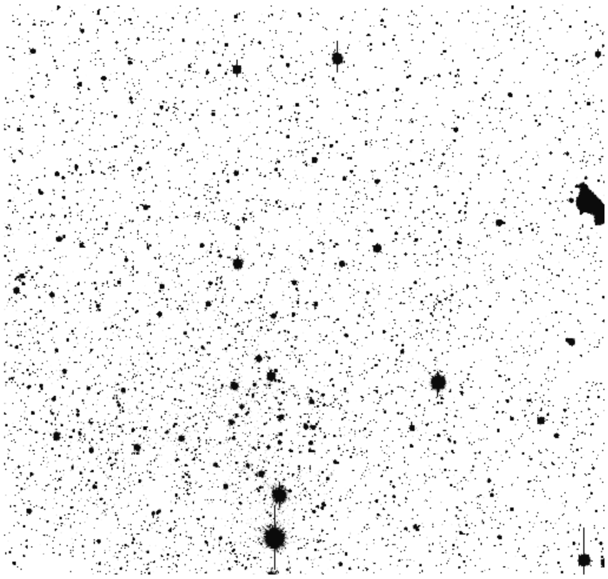

Fig. 1. a The Sagittarius Dwarf (field 1). The size of the field is 9 × 8.5 arcmin

Fig. 1. b The Sagittarius Dwarf (field 2). The size of the field is 9 × 8.5 arcmin

While for the 2.2m we obtained:

B = b + 0.348($\pm$ 0.010)· (b-v) + *const.*

V = v + 0.096($\pm$ 0.005)· (v-i) + *const.*

I = i + *const.*

where B, V and I are the magnitudes in the standard system, and b, v and i are the instrumental magnitudes. The formal errors in the zero point of the calibration were: 0.04 mag in V and 0.03 mag in I for the NTT data; 0.05 mag in B, 0.03 mag in V and 0.02 mag in I for the 2.2m data. The r.m.s. of the residuals for the standards, respectively for the NTT and

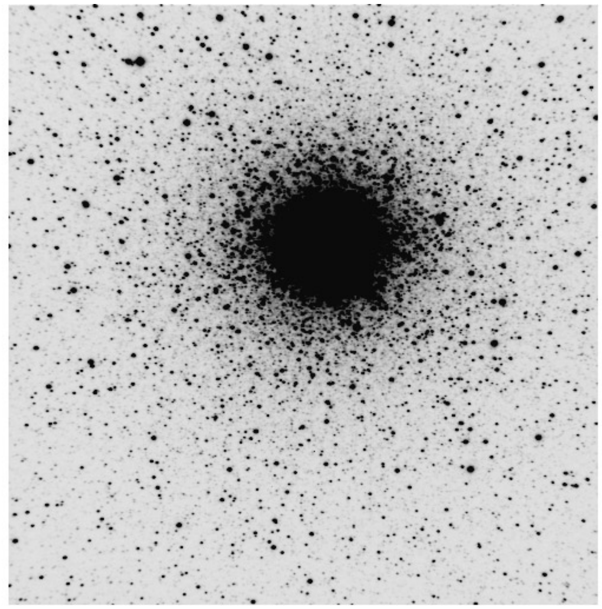

Fig. 1. c The Sagittarius Dwarf (field M54). The size of the field is 5.6 × 5.7 arcmin.

the 2.2 m, resulted $\sigma_{V_{NTT}}$=0.018, $\sigma_{I_{NTT}}$=0.012, $\sigma_{B_{2.2}}$=0.022, $\sigma_{V_{2.2}}$=0.013, $\sigma_{I_{2.2}}$=0.009.

3. Color magnitude diagrams for Sgr and M54

Figs. 2 and 3 show the V, V-I diagrams for the stars of Sgr, respectively in *field 1* and *field 2*, while the CMD of the field centered on M54 observed at the 2.2m is presented in Fig. 4a for the whole frame excluding the most central region, (r≤60 arcsec), and in Fig. 4b for the annulus with 134≤r≤157 arcsec. The latter region, selected as it presents both a manageable degree of crowding and a high probability of cluster membership, allows a reliable estimate of the turn-off of M54.

Given the galactic latitude of the observed fields, they are strongly contaminated by foreground stars. However, as already noted by SL and MUSKKK the main bright features belonging to Sgr turns out to be relatively well separated from the foreground stars, and are therefore easily distinguishible.

Two major features to note in Fig. 4a are, first, a well populated, steep RGB with $V_{tip} \simeq$15.2 and $(V-I)_{tip} \simeq$1.75 and, second, a well-defined Blue Horizontal Branch (BHB), located at V≃18.2 and extending towards (V-I)≃0. Since both these features are clearly absent in Fig. 2 and Fig. 3, we confirm the suggestion of SL that they must belong to M54.

Fig. 4a also shows another fairly-populated sequence which emerges near V≃19.5 and, extending towards the bright red side of the CMD, reaches V≃16.2 and (V-I)≃1.9. This sequence, detectable also in Figs. 2 and 3, has been identified by SL as the RGB of the dominant population of Sgr.

Passing to the CMDs of *field 1* and *field 2* we note, first of all, that they are extremely similar, witnesses of a homogeneous evolution of this dwarf galaxy.

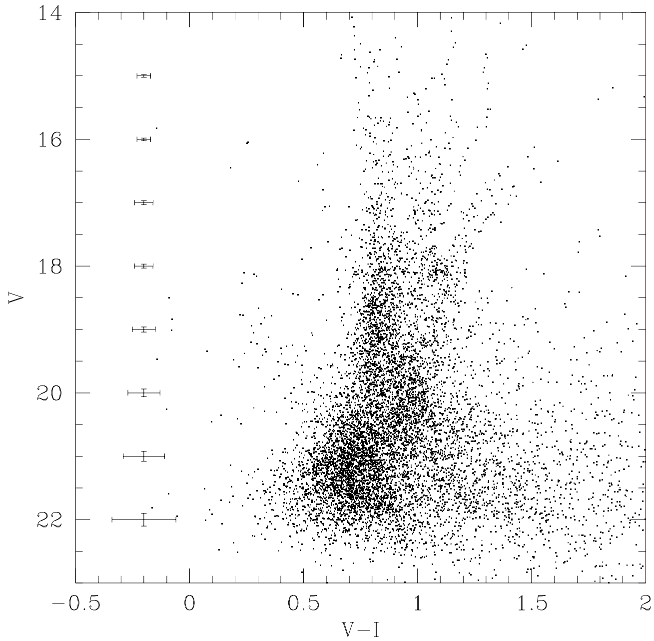

Fig. 2. CMD of stars in Sagittarius field 1. The error bars (derived with DAOPHOT) for bins of magnitude and colour are shown on the left of the diagram.

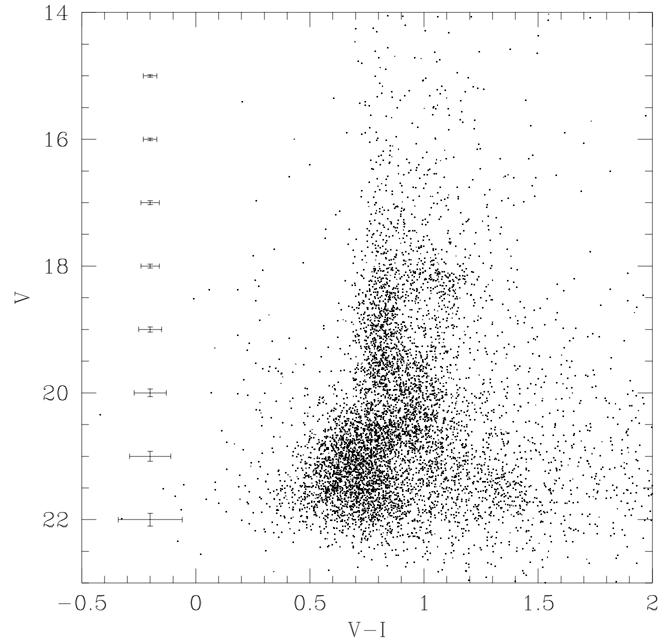

Fig. 3. CMD of stars in Sagittarius field 2

The most prominent features detectable of Fig. 2 and Fig. 3 are discussed below.

3.1. The HB locus of Sgr

A clump of stars (V ≃18.1 and V-I ≃1.1) is visible at the blue side of the red giant branch; this clump has been already identified by MUSKKK and SL as the HB locus of the dominant population of Sgr (this feature is much more evident in Fig. 2). The same clump is also visible in Fig. 4 (a and b) (V ≃18.25), where it appears embedded in the rich RGB of M54, but slightly shifted to the red.

3.2. The Sgr Red Giant Branch

A fairly steep RGB which reaches V≃15.5 and V-I≃1.9 whose observed dispersion, larger than the photometric errors, hints at a dispersion in metallicity within Sgr. Although, this suggestion is based on a limited number of stars, and then prevents us to draw firm conclusions. We observe that the same RGB is well visible also in the field "M54" (Fig. 4a). It is important to notice, however, that the metal-rich RGB in the field "M54", measured at its base, is redder by Δ (V-I) = 0.12±0.06 than the RGB in *field 1 and field 2*.

There are three possibilities to explain this observational result: first, an inconsistency of the two (independent) calibrations; second, a differential reddening within Sgr; third, a metallicity gradient within Sgr. To disentangle the problem, we first compared the RGB loci of the CMD in *field 1* and *field 2* with the data of MUSKKK (their Fig. 1). The comparison is shown in Fig. 5; it discloses that no displacement exists in the average color of each bin of magnitude between the two data sets. We therefore conclude that, within the uncertainties related to the small number of stars in such evolutionary phase, a reasonable agreement exists between the data of MUSKKK and those presented in this paper, supporting the reliability of our calibration of *fields 1* and *2*.

Then we compared the data of Fig. 4 with those of SL for the field centered on M54. Fig. 6 show the differences in color and magnitude for the 1295 stars in common. Both the diagrams of Fig. 6 show a fairly symmetrical distributions around the zero, with a slight residual color equation, of the order of 0.04 mag, for (V-I)≃1.5. Since this color equation goes in the sense that the RGB of SL is even redder than that obtained in the present paper for M54, we conclude that the difference detected in the RGB colors cannot be attributed to uncertainties in the calibration of the three fields of Sgr. We are inclined, therefore, to infer that the stars of Sgr present an intrinsic color gradient within the main body of the dwarf.

We pass now to examine whether the galactic reddening is responsible of the observed color shift of Δ(V-I) = 0.12±0.06. If this would be the case, we should expect to observe that the red HB clump, would result in the *field M54* fainter than in the *fields 1* and *2* by ΔV = 0.30±0.15. Actually we observed that the red HB clump in the *field M54* is fainter than the clumps in *fields 1* and *2* by only ΔV = 0.15± 0.03 magnitudes, which is marginally consistent with the value of ΔV=0.30±0.15 expected under the hypotesis that a absorption gradient exists whithin Sgr.

We therefore remain with the last possibility, i.e. that the observed color-shift is due to a spread in metallicity. To check the viability of such hypothesis, we estimated the possible spread in metallicity using the empirical relation of Castellani et al. (1996)

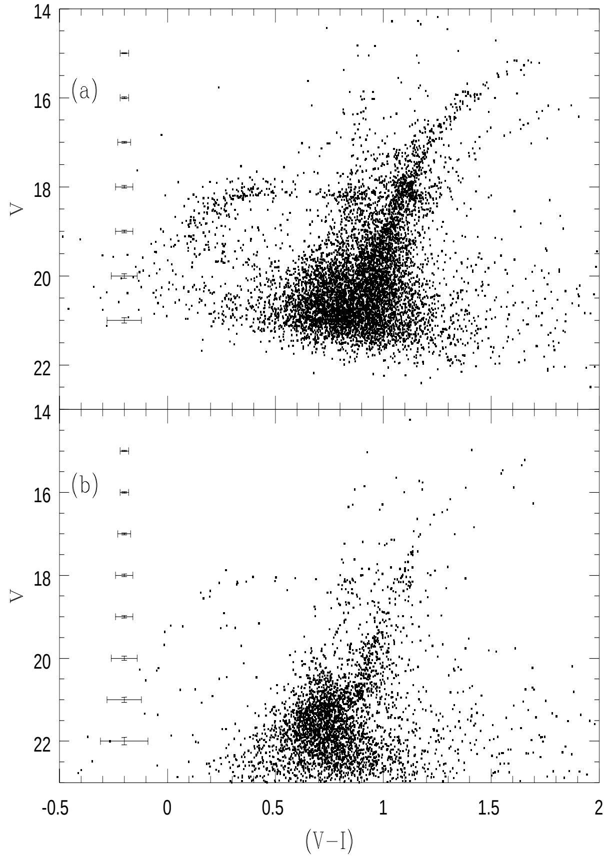

Fig. 4a and b. CMD of the field centered on M54, for the region r ≥ 60” (**a**) and, for the annulus with 134”≤ r ≤ 157” (**b**). The error bars for each bin of magnitude and color (from the relation given by Ferraro et al. 1990) are also shown on the right of the diagram.

Δ[Fe/H] = Δ(V-I) / 0.24. From Δ(V-I) = 0.12± 0.06 one obtains Δ[Fe/H] =0.50±0.25. To see how such difference in metallicity would reflect in the luminosity of the HB clump, we used the relation of Lee et al. (1990) M_V(HB) = 0.15·[Fe/H]+0.82, and obtained ΔV = 0.09±0.04, which is in good agreement with the observed value ΔV = 0.15± 0.03. It seems therefore, that a difference in metallicity of Δ[Fe/H]≃0.50 accounts for all the photometric observables of *field 1*, *field 2* and *field M54* of Sgr.

There is, actually, an alternative explanation based on the ambiguity in the back-to-front ratio in Sgr. Interpreting the location of the RGBs in different fields of Sgr as a difference in magnitude instead of a difference in color, one can slide the CMD of *field M54* by about 0.15 mag brighter and superimpose it to the CMD of *fields 1* and *2*. In other words the observed features are compatible with a bizarre shape of Sgr which would present the two edges (*fields 1* and *2*) 2.3 Kpc nearer to the Sun than the central region (*field M54*).

3.3. The field stars and the Sgr TO

The CMDs of Fig. 2 and Fig. 3 show a swath of stars scattered diagonally from the lower right to about the center of the diagram and the almost vertical distribution at V-I≃0.85, V≤19. These stars are probably to be ascribed to the bulge + disk population along the line of sight (see also MUSKKK). It is important to notice that, although the faint extension of the vertical sequence makes the Sgr turn-off region somewhat confused, newertheless the main structures are visible, allowing a rough estimate of the location of the turn-off point.

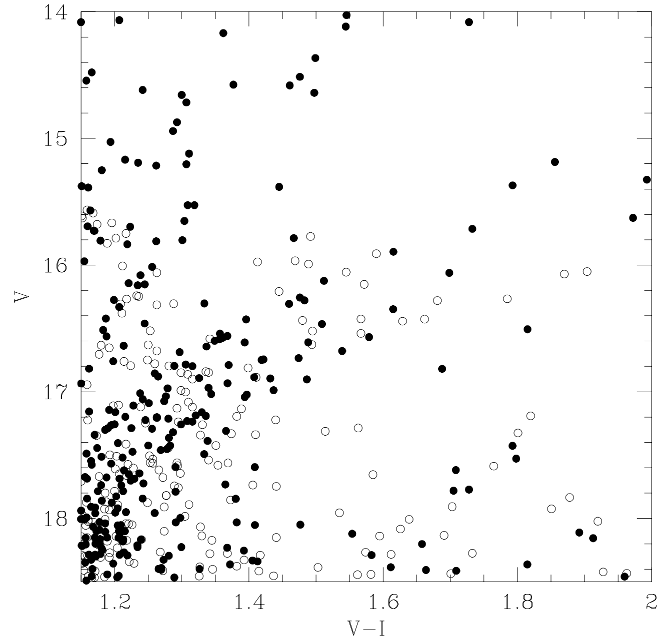

Fig. 5. The RGB of Sgr. The data of Fig. 2 and Fig. 3 are indicated with full dots. The data of MUSKKK are reported as open dots. The good coincidence of the two set of data is clearly visible.

To this purpose we first splitted the cumulative CMDs of *fields 1* and *2* in intervals of 0.2 magnitudes, then for each bin we computed the histograms in color of the stars fainter than V = 20.5. Finally, in order to determine the mode of the color histogram, we performed a gaussian fit to each distribution whose modal values are reported in Table 2. Inspection of Table 2 reveals that the bluest color of the ridge line is V-I ≃ 0.70, corresponding to the magnitude interval centered at V = 21.2. Therefore, we will assume, as a first guess, V_{TO} = 21.2 ± 0.1 for Sgr.

3.4. Another horizontal sequence?

A nearly horizontal sequence, which starts from the position of the Sgr HB clump, and reaches V-I≃0.7 (crossing the vertical sequence of field stars) is detectable at a close inspection of the Sgr CMDs.

The magnitude level of this sequence, which appears ubiquitous in Sgr, can be derived from the luminosity function of the stars detected in *field 1* in the interval 17.5≤V≤18.5 and V-I ≤ 1.0, here shown in Fig. 7. Fitting a gaussian to the peak of the LF in the interval 17.9≤V≤18.2, we derived V_{peak} = 18.09 ± 0.08, where the error represents the halfwidth of the gaussian.

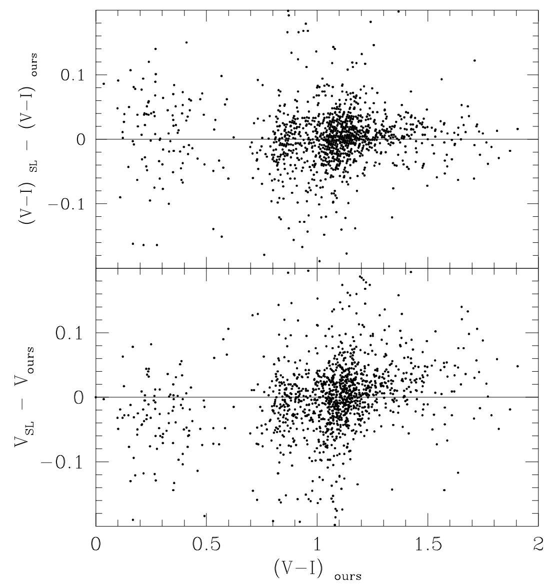

Fig. 6. Star-by-star comparison of the present photometry (*field M54*), with that of SL.

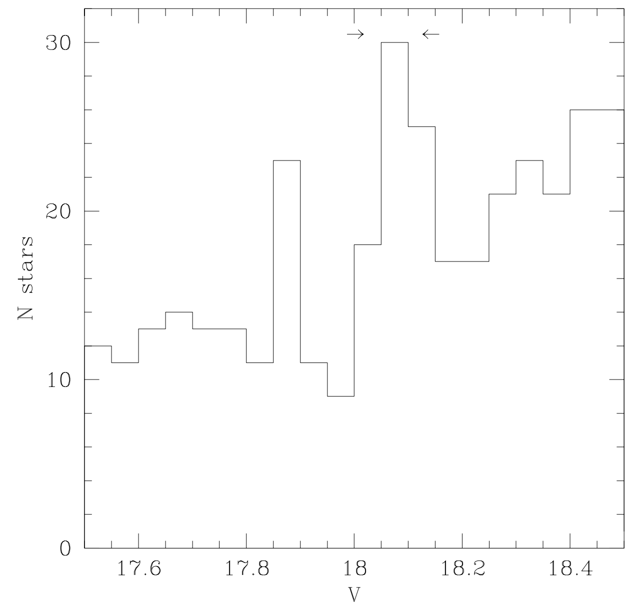

Fig. 7. Histogram of the stars bluer than V-I = 1.0; the location of the horizontal sequence is easily seen at $V \simeq 18.09$ (see text)

Table 2. The ridge line of Sgr for the turn-off region

V	$(V-I)_{mode}$
20.6	0.81
20.8	0.77
21.0	0.73
21.2	0.70
21.4	0.71
21.6	0.72
21.8	0.75
22.0	0.76

3.5. Metallicity estimate

In order to estimate the mean metallicity of the dominant population, we show in Fig. 8 the giant branch loci of the globular clusters M2 ([Fe/H]=-1.58) and 47 Tuc ([Fe/H]=-0.71) (data taken from Da Costa & Armandroff 1990), superimposed to the CMD of Sgr *field 1* having adopted $(m-M)_V$ = 17.50, A_V = 0.55 and E_{V-I} = 0.22 (see Sect. 4). Inspection of Fig. 8 reveals that the RGB of Sgr is delimited by the fiducial lines of M2 and 47 Tuc, indicating that the dominant population of Sgr falls in the range of metallicity -1.58≤[Fe/H]≤-0.71 The average value of metallicity, therefore turns out to be [Fe/H]=-1.1±0.3, in agreement with the value found by MUSKKK and at variance with that of SL.

4. Stellar populations in the Sagittarius dwarf

In order to understand the observed stellar content of a complex system, the common practice is to select CMDs of the simplest well-studied stellar groups, in general globular clusters, and then to identify in the complex systems those features which characterize the template. This procedure is particularly strightforward for Sgr because Da Costa & Armandroff (1995), studying the relative distances and motions, suggested that the globular clusters Terzan 7, Terzan 8, Arp 2 and M54 could have been originated from the Sgr galaxy itself. It is particularly significative in this context that two of these clusters, Ter 7 and Arp 2, have been found peculiarly young and, therefore, suspected to be captured by the Milky Way (Whitelock et al. 1996).

4.1. Terzan 7

The V, B-V CMD of Ter 7 was obtained by Buonanno et al. (1995b). The main results of that study are that Ter 7 is a metal-rich globular cluster (-1≤[Fe/H]≤-0.5, depending on the adopted metallicity indicator), located at about 25 Kpc from the galactic center whose age is about 4 Gyr lower than the bulk of other globular clusters.

To perform the comparison with the present photometry of Sgr, we first derived an empirical relationship to transform the B-V to V-I colors. The relation we obtained from the photometry of several globular clusters, is

$$(V-I) = -0.105\cdot(B-V)^2 + 1.221\cdot(B-V) - 0.078$$

(valid in the colour range $0.0 \leq$ B-V ≤ 1.5).

This empirical relation turned out to be in excellent agreement with that of Smecker-Hane et al. (1994, hereafter SH), considered that the largest difference does not exceede 0.1 mag in color in the interval of validity (see Table 3).

After having transformed the V, B-V diagram of Ter 7 into the corresponding V, V-I diagram, we adopted E_{B-V}=0.06 (Buonanno et al. 1995b), and then, E_{V-I}=1.24·E_{B-V}=0.07

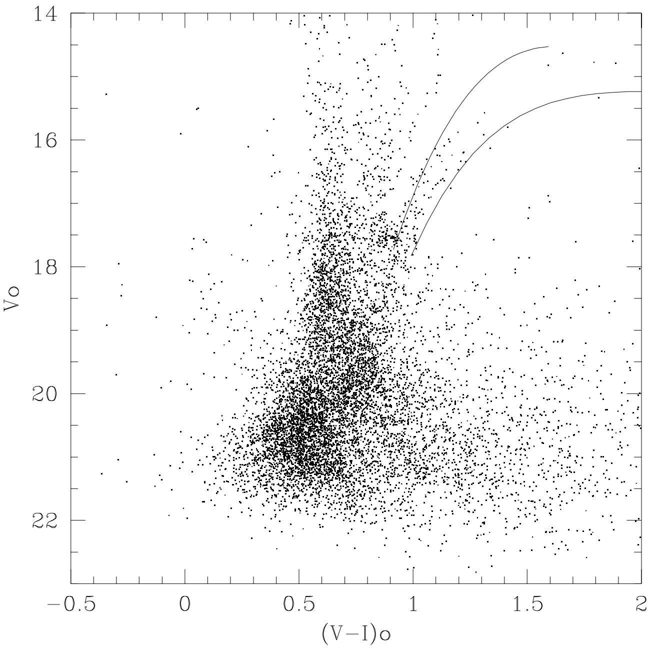

Fig. 8. CMD (corrected for reddening and extinction) of field 1 of Sgr with superimposed the RGBs of the two galactic globular clusters 47 Tuc ([Fe/H]≃-0.71), and M2 ([Fe/H]≃-1.58)

Table 3. The empirical relationship between (B-V) and (V-I)

$(B-V)_{ours}$	$(V-I)_{SH}$	$(V-I)_{ours}$
0.0	0.00	-0.08
0.5	0.54	0.51
1.0	1.08	1.04
1.5	1.62	1.52

(Cardelli et al. 1988), A_V=3.3·E_{B-V}=0.198 for Ter 7, and E_{V-I}=0.22 and A_V=0.55 for Sgr (following MUSKKK),

Fig. 9a shows the superimposition of the CMDs of Ter 7 and Sgr, having considered the relative reddening and extinction.

It is of extreme interest to notice that the overall morphology of Ter 7 well reproduce that of Sgr in each evolutionary phase. In particular the giant branches are exactly overlapping each other and the HB of Ter 7 lies in the same position of the HB clump of Sgr. In other terms, from a simple inspection of the relative location of the main branches, one concludes that Sgr lies at the same distance of Ter 7 from the sun, and that a population *Ter 7-like* is an important contributor to Sgr.

The strong similarity of the two systems is reinforced noting that the TO of Ter 7 is positioned exactly in the TO region of Sgr. This conclusion can be put on more quantitative grounds: having estimated, in fact, $V_{TO} \simeq 21.2$ (see Sect. 3), we obtained for Sagittarius $V_{TO_0} = V_{TO} - 0.55 = 20.65 \pm 0.1$, which is in agreement with V_{TO_0} = V_{TO}-0.198=20.76±0.08 obtained for Ter 7 (Buonanno et al. 1995b). These evidence support the conclusion that Ter 7 has a common origin with Sgr, and that

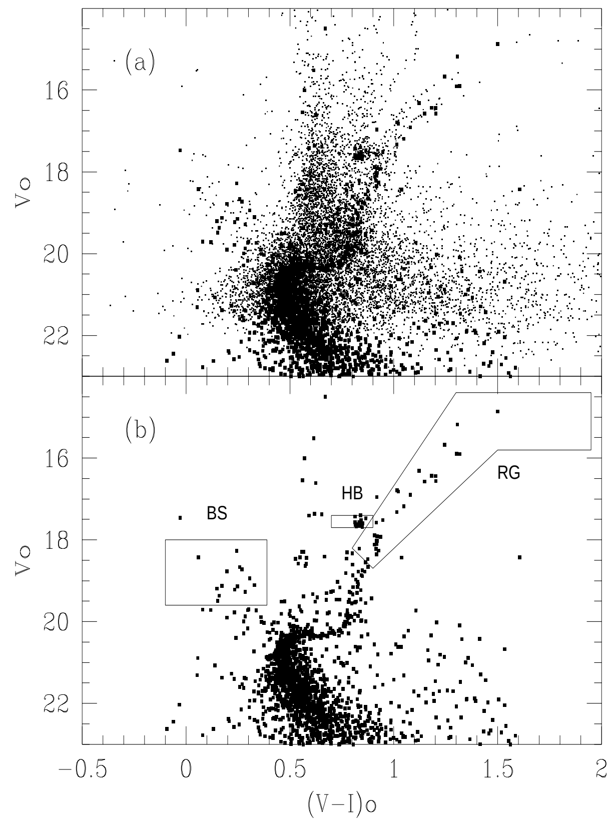

Fig. 9a and b. (**a**) superimposition of CMDs V vs V-I of Ter 7 and Sgr (see text for details); (**b**) CMD of Ter 7 with regions marked, showing points used to count the stars along different evolutionary phases.

the age of the dominant population in Sgr is the same of that estimated by Buonanno et al. (1995b) for Ter 7, i.e. 4 Gyr lower than 47 Tuc.

Given the importance of this issue, we ask now whether the similarity between the dominant population of Sgr and that of Ter 7 is confirmed by the lifetimes along the different evolutive phases. This can be accomplished by stellar counts along the different branches. Given the crowding along the branches of the CMDs for Sgr, we first selected three boxes in which the counts could be confidently performed. These boxes are sketched in Fig. 9b, where the separation between the different phases is well-defined. The counts for the horizontal branch (labeled "HB"), the Red Giant Branch ("RG") and the Blue Stragglers region ("BS") are reported in Table 4, where columns 2 and 3 refer respectively to Sgr and Ter 7, and column 4 shows the ratio of the counts for the two systems. The errors are computed on the basis of the Poisson statistics.

Inspection of Table 4 reveals that, altough one could expect to observe in Sgr a mixture of populations (including possible field stars), the relative populations of Sgr and Ter 7 turn out to be extremely consistent, leading to the conclusion that at least the portion of the galaxy sampled in this paper is largely constituted by the same stellar population of Ter 7. It is worth to notice that the same conclusion holds for the population of blue

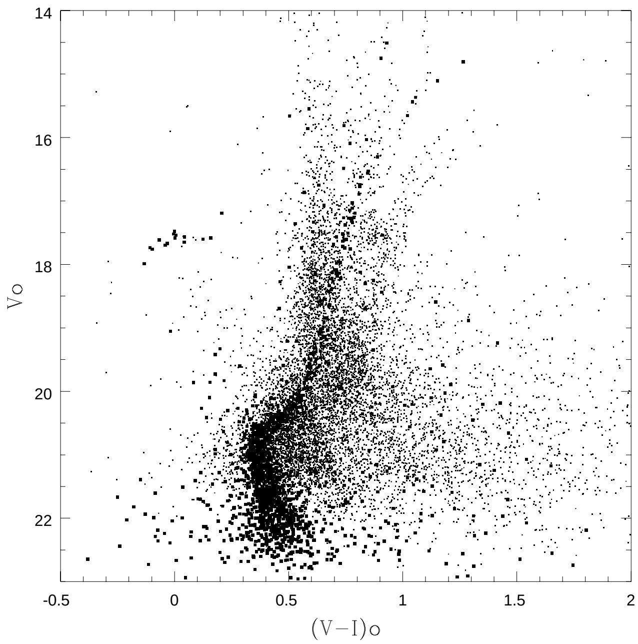

Fig. 10. Superimposition of CMDs V_0 vs $(V - I)_0$ of Arp 2 and Sgr (see text for details)

Table 4. Stars in the various evolutive phases

Phase	*Sgr*	*Ter7*	*Ratio*
HB	97	24	4.04 ± 1.24
RG	126	29	4.34 ± 1.19
BS	61	14	4.36 ± 1.72

stragglers, indicating that whatever are the parameters which favor the existence of BSs (primordial conditions, environment etc.), these parameters appear at work both in Ter 7 and in Sgr.

4.2. Comparison with Arp 2

The second comparison we performed is between Sgr and Arp 2 ([Fe/H]≃-1.8, Buonanno et al. 1995a). Fig. 10 shows the CMD of Arp 2 superimposed to that of Sgr. For Arp 2 we adopted, following Buonanno et al. (1995a), E_{V-I}=0.136 and A_V=0.34, while for Sgr we used the same color and magnitude corrections of the previous section. An additional shift ΔV=0.37 mag was finally applied, having adopted $(m-M)_0$=17.32 and $(m-M)_0$=16.95 respectively for Arp 2 and Sgr.

Inspection of Fig. 10 reveals that the giant branch of Arp 2 is located exactly in the region of the CMD of Sgr where several giants bluer than those of the dominant population of Sgr are observed. It would be therefore tempting to identify this region of the CMD as formed by a population *Arp 2-like*. There is however a significant obstacle to such identification, because Arp 2 presents a relatively rich population of 14 blu HB stars, which appears virtually absent in Sgr.

Considering that Fig. 10 suggests that the Sgr RGB we have tentatively identified as *Arp 2-like* is grossly populated by the same number of stars of the RGB of Arp 2, and considering that there are 14 HB stars in the CMD of Arp 2, one would expect to find of the order of 14 ± 4 HB stars in Sgr.

A possibility, admittedly speculative, would be that the *Arp 2-like* population of Sgr is slightly younger than Arp 2 itself by, say, about 2 Gyr. This would shift the blue HB observed in Arp 2 to the red by 0.5 mag, where it should be noted as a slight bump in the luminosity function of the field stars. A more generic conclusion is that the presence of a population of stars similar to those of Arp 2 cannot be excluded in Sgr, but that, in this case, the in-famous HB second parameter must be invoked. At this stage we have no indications on the nature of this conjectured second parameter.

4.3. Photometry of M54 (NGC6715)

The study of M54 is important by itself because it lies in the densest region of Sgr and, according to Da Costa & Armandroff (1995), it is likely to be associated to the Sgr galaxy. The estimated metallicity of M54 is [Fe/H]=-1.79±0.08 (SL), very similar to that of Arp 2, but with quite different structural parameters (central concentrations are c=0.90 and c=1.84, respectively for Arp 2 and M54).

From a simple inspection of the CMD in Fig. 4a we see that this field presents a pronounced HB, extending bluewards to V-I=0, which, as already noted, is completely absent in *field 1* and *field 2* and it is, therefore, to be attributed to M54.

The luminosity of the HB was estimated to be V_{HB}=18.2±0.1, having computed the mean and the rms of all the stars of Fig. 4a in the box 17.5≤V≤18.5, 0.4≤V-I≤0.8, which is likely to include only HB stars.

Most of the features detectable in Fig. 4a are naturally present also in the CMD of SL. In particular, the well-populated RGB is visible, extending up to V_{tip}≃15.2. Some attention deserves the red HB located at V≃18.23 and (V-I)≃0.85, which is fainter than the blue HB. In order to identify the nature of this feature we start trying to estimate the numbers involved, plotting in Fig. 11 the luminosity functions of the data of Sgr *fields 1 and 2* and of the *field M54*, for stars in the color interval 0.75≤ V-I ≤ 1.0. The counts have been normalized in the interval 14.0 ≤ V ≤ 17.0, and V-I≤ 1.0 because, given the extremely different nature of populations of *field 1* and *field 2* on one side, and *field M54* on the other, we preferred to refer to the number of foreground stars, which are largely present in that color and magnitude interval.

From Fig. 11 one immediately notes that a bump at V≃18.09 is clearly visible for *field 1* and *field 2* while the *field M54* presents a more prominent bump at V≃18.23. Therefore, while we confirm the early suggestion of SL that such "anonymous RHB" belongs to Sgr dwarf galaxy, we remain with the problem of explaining the different relevance of the feature in the three fields.

One (marginally viable) possibility is that we are observing a simple fluctuation of the data, which show a casual increase in

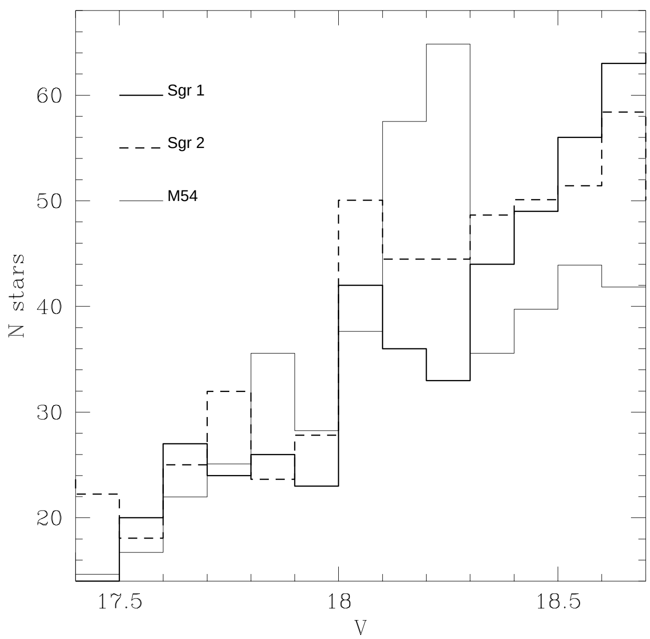

Fig. 11. Luminosity function of Sgr *field 1*, *field 2* and of the field centered on M54, in the color range $0.75 \leq V \leq 1.0$

that particular color and magnitude interval and in that particular field.

Another possibility is that such "anonymous RHB" in the *field M54* is, at least in part, formed by the photometric blending of stars belonging to the red HB of the dominant metal-rich population of Sgr and of blue HB stars of M54. Such a possibility was already suggested in quite a different context by Ferraro et al. (1991) and its viability is easy to test. In fact, one can ask whether any "anonymous RHB star" could randomly split into two stars, one falling in the region of the Sgr metal-rich red HB and the other belonging to the blue HB of M54. Experiments show that this could actually be the case, and consequently that the red clump, which apparently forms an extension of the blue HB of M54 could be, at least in part, a photometric artifact due to the extremely high crowding of the images.

An objective of obvious interest of the present study is to determine the TO luminosity of M54. Given the confusion of the TO region, due both to the crowding and to the faintness of the images, we followed two independent approaches to the problem.

First, we divided the turn-off region of Fig. 4a in intervals of 0.1 magnitudes. Then, we derived for each interval the histogram in color and fitted these color distribution with a gaussian. The maximum of these gaussian were finally reported in Table 5 in the magnitude interval $20.9 \leq V \leq 21.9$. Inspection of Table 5 immediately leads to identify the turn-off luminosity of M54, in correspondence of the bluest point of the ridge line V_{TO}=21.6±0.1.

Having already determined V_{HB} = 18.2±0.1 one obtains ΔV_{HB}^{TO}=3.40±0.14, which, within the errors, is formally identical to the mean value ΔV_{HB}^{TO}=3.55±0.09 obtained for the bulk of galactic globular clusters by Buonanno et al. (1989).

Table 5. The ridge line of M54 in the turn-off region

V	$(V-I)_{mode}$
20.9	0.81
21.0	0.77
21.1	0.76
21.2	0.76
21.3	0.76
21.4	0.76
21.5	0.75
21.6	0.73
21.7	0.76
21.8	0.78
21.9	0.79

Given the importance of these issue, we approached the problem of determining the age of M54 with an alternative method based on the morphology of the HB. The origin of the observed very blue HB morphologies has been long debated (see Lee et al. 1994 and Fusi Pecci et al. 1996 for two different points of view); however, introducing a new quantitative observable, (B2-R)/(B+V+R), where B2 is the number of HB stars with $(B-V)_0 \leq -0.02$, Buonanno & Iannicola (1995) proposed the following relation to compute the relative age of globular clusters of similar metallicity, taking into account the central density of the cluster and the HB morphology:

Δt_9=3.45(B2-R)/(B+V+R)-0.58logρ_0+0.34 (1)

Having adopted for M54 E_{B-V}=0.15 and logρ_0=4.72 (Djorgovski 1994) we performed the following counts, B2=19, B=100, V=18, R=8, obtaining (B2-R)/(B+V+R)=0.09±0.05, where the errors are computed on the basis of Poisson statistics (Fig. 12 shows an enlargement of the HB region of the V_0, $(B-V)_0$ CMD).

The second step was to compare the counts in the M54 to those made in clusters of similar metallicity and HB morphology.

We found, in particular, for NGC4147 ([Fe/H]=-1.80, logρ_0=3.58) (B2-R)/(B+V+R)=0.12±0.13 (Friel et al. 1987), and for NGC6101 ([Fe/H]=-1.80±0.1, logρ_0=1.57) (B2-R)/(B+V+R)=0.04±0.02 (Sarajedini & Da Costa 1991).

We then applied Eq. (1) differentially, in order to derive the age of M54 relatively to that of the other two clusters and obtained:

Δt_9(M54-NGC4147) = -0.76 ±0.44

Δt_9(M54-NGC6101) = -1.63 ±0.17

These relative ages were then used to pass to *relative* ΔV_{HB}^{TO} and, finally, to estimate V_{TO} for M54. To pass from relative age to relative TO-HB difference in magnitude, we used Eq. (6b) of Buonanno et al. (1989):

log t_9=0.37ΔV_{HB}^{TO}-0.06[Fe/H]-0.81,

and obtained:

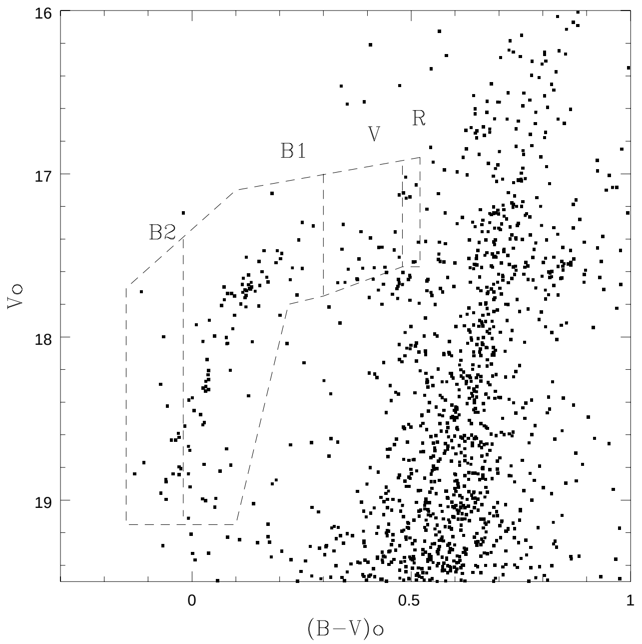

Fig. 12. Enlargement of the HB of M54. The four dashed boxes are those used for star counts along the HB.

$\delta\Delta V_{HB}^{TO}$(M54-NGC4147)=-0.06±0.05

$\delta\Delta V_{HB}^{TO}$(M54-NGC6101)=-0.14±0.04

Adopting for NGC4147 ΔV_{HB}^{TO}(4147)=3.60±0.20 (Friel et al. 1987) we finally obtained for M54 ΔV_{HB}^{TO}=3.54±0.21, while adopting for NGC6101 ΔV_{HB}^{TO}(6101)=3.40±0.20 (Sarajedini & Da Costa 1991) we obtained for M54 ΔV_{HB}^{TO}=3.26±0.20.

The average value of the difference in magnitude between the horizontal branch and the main sequence turn-off for M54 turned out to be:

ΔV_{HB}^{TO}=3.40±0.28

which is in excellent agreement with the value derived from Table 5.

In conclusion we find that M54, although kinematically associated with Sgr, presents the same characteristics (age, HB morphology, second-parameter) of a typical galactic globular cluster, and that a M54-like population do not significatively contributes to the Sgr field stars population.

5. Discussion and summary

We have performed deep CCD photometry of the Sagittarius dwarf galaxy, spanning from the main sequence TO to the tip of the red giant branch.

Two of the fields are located in the outskirts of the dwarf galaxy, while the third field is centered on M54, in such a way that a direct comparison allowed to single out features which are characteristic of the globular cluster or of the dwarf galaxy.

Notwithstanding the uncertainty tied to the poor statistic, the spread in color observed along the RGB of *field 1* and *field 2* result beyond any possible photometric errors. The most likely explanation is that we are observing a spread in metallicity, whose boundaries are those suggested by the RGB of M2 ([Fe/H]=-1.58) on one side, and the RGB of 47 Tuc ([Fe/H]=-0.71) on the other. In addition, the RGB of the field centered on M54 is even redder than this latter limit, giving hints of the existence of a more metal-rich population. The presence of an asymptotic giant branch and, then, of a younger population, cannot be excluded from our data.

The distance modulus has been estimated from the luminosity of the horizontal branch, obtaining a value of $(m\text{-}M)_0$=16.95, corresponding to a distance of d=24.55±1.0 Kpc, in good agreement with MUSKKK.

Probably the most important result of the present study is that comparing the CMD of Sgr with those of the kinematically associated globulars, we found that the dominant stellar population of Sgr is very similar to the population of the "young" globular Ter 7, while the presence of a population Arp2-like is dubious. The population of M54 appears clearly different from that of Sgr. All these findings put strong constraints to the Sgr star formation history.

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