

# Further probing the nature of FSR 1767

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Accepted 2009 May 5. Received 2009 April 27; in original form 2008 September 18

## ABSTRACT

With Two-Micron All-Sky Survey (2MASS) photometry and proper motions, Bonatto et al. suggested that FSR 1767 is a globular cluster (GC), while with *J* and *K* NTT/SOFI photometry Froebrich, Meusinger & Scholz concluded that it is not a star cluster. In this study, we combine previous and new evidence that are consistent with a GC. For instance, we show that the horizontal branch (HB) and red giant branch (RGB) stars, besides sharing a common proper motion, have radial density profiles that consistently follow the King's law independently. Reddening maps around FSR 1767 are built using the bulge RGB as reference and also Schlegel's extinction values to study local absorptions. Both approaches provide similar maps and show that FSR 1767 is not located in a dust window, which otherwise might have produced the stellar overdensity. Besides, neighbouring regions of similar reddening as FSR 1767 do not present the blue HB stars that are a conspicuous feature in the colour–magnitude diagram of FSR 1767. We report the presence of a compact group of stars located in the central parts of FSR 1767. It appears to be a detached post-collapse core, similar to those of other nearby low-luminosity GCs projected towards the bulge. We note that while the NTT/SOFI photometry of the star cluster FSR 1716 matches perfectly that from 2MASS, it shows a considerable offset for FSR 1767. We discuss the possible reasons why both photometries differ. We confirm our previous structural and photometric fundamental parameters for FSR 1767, which are consistent with a GC.

**Key words:** globular clusters: individual: FSR 1767.

## 1 INTRODUCTION

The predicted  $160 \pm 20$  total population of globular clusters (GC) in the Galaxy is not particularly large, especially when compared to those of other massive galaxies (e.g. Harris 1991). In this context, the identification of any new entry is crucial for studies of individual GCs and of properties of the Galactic system as a whole (e.g. Harris 1996, hereafter H03, for his 2003 updated GC data; Mackey & van den Bergh 2005; Bica et al. 2006). Studies dealing with the formation and evolution processes of the Milky Way's GC system will benefit from a statistically more complete GC parameter space. Of particular interest is the discovery of objects that occupy the intrinsically faint-GC distribution tail.

More recently, Froebrich, Scholz & Raftery (2007) (hereafter FSR07) provided a catalogue of stellar overdensities at low Galactic latitudes. It is important to study the overdensities in detail by means of field-star-decontaminated photometry (e.g. Bonatto & Bica 2007)

to establish their nature as GCs, open clusters (OCs) or Poisson fluctuations of dense stellar fields (Bonatto & Bica 2008a). Among the 1021 overdensities, FSR07 presented eight GC candidates selected based on density and richness, among them FSR 1767.

As discussed in Bonatto et al. (2007, hereafter Paper I), the Two-Micron All-Sky Survey (2MASS) field decontaminated *J* versus (*J* – *K*<sub>s</sub>) colour–magnitude diagram (CMD), the stellar radial density profile (RDP) and the proper motion (PM) of FSR 1767 are consistent with a nearby ( $d_{\odot} \approx 1.5$  kpc), low-luminosity ( $M_V \approx -4.7$ ) and extended ( $R_{\text{tidal}} \approx 7$  arcmin) GC projected against a rich bulge/disc ( $\ell = 352.6$  and  $b = -2.17$ ) field. The mean PMs of FSR 1767 derived in Paper I represent  $\approx 1.5\sigma$  detections, and thus should be taken as low statistical significance evidence. However, in a recent work based on NTT/SOFI *J*, *H* and *K* imaging, Froebrich et al. (2008) (hereafter FMS08) concluded that FSR 1767 is not a star cluster. This was based on a field-star-decontaminated *K* versus (*J* – *K*) CMD together with a colour–colour diagram, from which they concluded that no stellar sequence matched our isochrone solution (Paper I).

In this study, we provide supplementary evidence, drawn from different grounds, consistent with the identification of FSR 1767 as

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a GC. We also discuss the possible reasons why FMS08 reached a different interpretation. The methods employed in this study are basically the field-star decontamination of CMDs and RDPs (e.g. Paper I; Bonatto & Bica 2007) that are essential to disentangle FSR 1767 from the heavily contaminated field.

We recall the basic premises of the decontamination algorithm. It divides the full range of CMD magnitude and colours into a three-dimensional grid of cells with axes along the  $J$  magnitude and the  $(J - H)$  and  $(J - K_s)$  colours, estimates the number density of field stars in each cell based on the number of comparison field stars with magnitude and colours similar to those in the cell and subtracts the estimated number of field stars from each cell. With cell dimensions of  $\Delta J = 1.0$  and  $\Delta(J - H) = \Delta(J - K_s) = 0.2$ , the subtraction efficiency (the difference between the contamination and the number of subtracted stars in each cell), summed over all cells, is higher than 90 per cent. The radial location of the comparison field is discussed in the following sections.

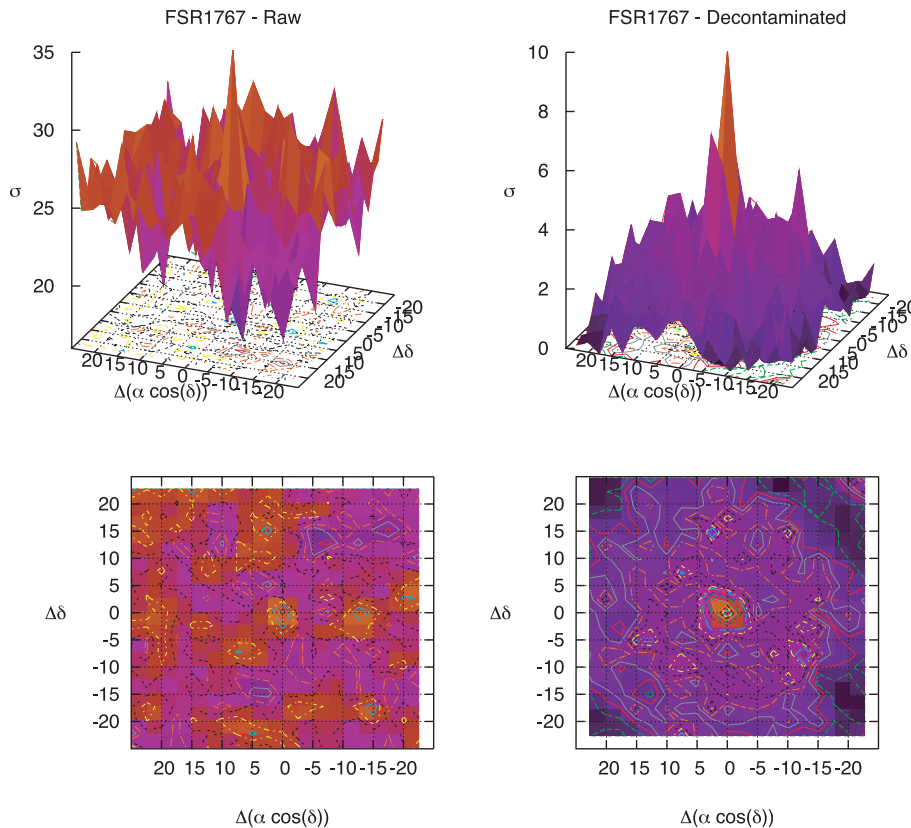
In Section 2, we complement Paper I discussions on the overdensity structure, which matches a King law both for horizontal branch (HB) and red giant branch (RGB) stars, and connect the results to the PM study of Paper I. In Section 3, we simulate, with 2MASS data, the NTT/SOFI background decontamination with a comparison field that was selected within the overdensity by FMS08. In Section 4, we describe a probable compact detached core that was not previously reported, and compare it to those of other low-luminosity GCs. In Section 5, we tentatively match the 2MASS and NTT/SOFI CMDs and discuss possible sources for the differences. Finally, concluding remarks are given in Section 6.

## 2 COMPLEMENTARY STRUCTURAL ANALYSIS TO PAPER I

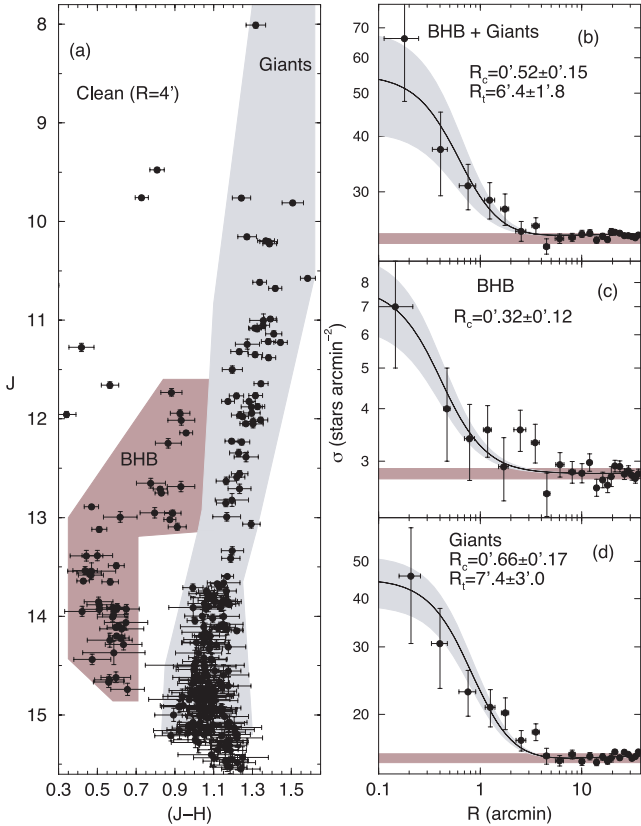
The centre of the FSR 1767 overdensity was determined by FSR07 (adopted in Paper I and by FMS08) as being located at (J2000)  $17^{\text{h}}35^{\text{m}}43^{\text{s}}$  and  $-36^{\circ}21'28''$ . In this paper, however, we found that the maximum number density of stars (Fig. 1, bottom-right panel) is located  $\approx 0.8$  arcmin to the south-east, at (J2000)  $17^{\text{h}}35^{\text{m}}44.8^{\text{s}}$  and  $-36^{\circ}21'42''$ . Hereafter, we refer to this location as the optimized centre. The small offset between both centre determinations has little effect on the analysis, since we work with CMDs extracted from wider regions (e.g. Fig. 2), which include both centres and by far the same stars.

In Paper I, we derived the core and tidal radii  $R_{\text{core}} \approx 0.54$  arcmin and  $R_{\text{tidal}} \approx 7$  arcmin, respectively, for FSR 1767. Besides, based on the stellar RDP, most of the probable member stars are contained within the radius  $R \approx 4$  arcmin (Fig. 2).

We show in Fig. 1 (top panels) a three-dimensional perspective of FSR 1767 by means of the stellar surface-density distribution ( $\sigma$ , in units of stars arcmin $^{-2}$ ), built with 2MASS photometry. Following, for example, Bonatto & Bica (2008a), we compute  $\sigma$  in a rectangular mesh with cells of dimensions  $2.5 \times 2.5$  arcmin $^2$ . The mesh reaches  $|\Delta(\alpha \cos(\delta))| = |\Delta\delta| \approx 25$  arcmin with respect to the optimized centre. Because of the important field-star contamination, the surface-density built with the observed photometry (left-hand panel) is somewhat irregular, but an excess stands out in the central cell. On the other hand, the field-star-decontaminated surface density presents an important enhancement around the core



**Figure 1.** Stellar surface density  $\sigma$  (stars arcmin $^{-2}$ ) of FSR 1767 (top panels) and the corresponding isopleth contours (bottom panels), built with the observed (left-hand panels) and field-star-decontaminated (right-hand panels) photometries.  $\Delta[\alpha \cos(\delta)]$  and  $\Delta\delta$  in arcmin.



**Figure 2.** Left-hand panel: field-star-decontaminated CMD of the region  $R < 4$  arcmin of FSR 1767. The shaded polygons represent the colour-magnitude filters used to separate BHB and giant stars from top to bottom: RDPs for the overall CMD, BHB and RGB. RDPs in panels (b) and (d) were fitted with the three-parameter King profile, while the two-parameter law was used in (c). Solid line: best-fitting King-like profile. Horizontal shaded polygon: offset field stellar background level. Shaded regions:  $1\sigma$  King fit uncertainty.

and halo region (right-hand panel). Similar conclusions follow from the respective isopleth contour maps (bottom panels), which confirm that the main body of FSR 1767 is contained within a region of  $\approx 4$  arcmin in radius, slightly elongated along the NE–SW direction. We conclude that the CMD sequences, enhanced by the decontamination algorithm and isolated with the colour–magnitude filters (Fig. 2, left-hand panel), are spatially closely related to the core/halo structure.

Evolutionary sequences present in the  $R < 4$  arcmin field-star-decontaminated CMD of FSR 1767 are separated into the probable blue HB (BHB) and RGB (Fig. 2, left-hand panel). Thus, we build RDPs for the BHB, RGB and BHB + RGB sequences separately (right-hand panels). They are described by analytical functions based on the two- or three-parameter profiles of King (1962) and King (1966), depending on the available statistics. The RDP and fit for both CMD sequences combined (panel b) are essentially the same as those in Paper I, which is consistent with the star cluster profile extending from the core to the halo (Fig. 1). Taken individually, both BHB and RGB RDPs behave as expected of a star cluster, i.e. they follow a King-like profile. Despite the lower number of stars, the BHB RDP (panel c) traces the cluster structure satisfactorily. Within uncertainties, the BHB and RGB profiles, as well as the combined sequences, share essentially the same spatial structure. The above is consistent with a physical system, in this case an old

star cluster, possibly a GC. Small differences in the structural radii with respect to those of Paper I can be accounted for by the more restricted magnitude ranges used here to define the RGB and BHB sequences better.

At this point, it is important to stress that both the CMD morphology and RDP of FSR 1767 are different from those of typical Poisson fluctuations of the dense bulge stellar field (e.g. Bica, Bonatto & Camargo 2008).

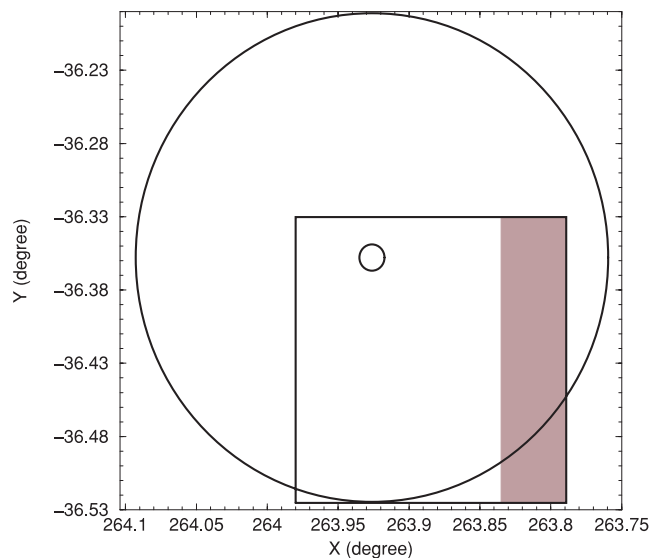
The structural analysis summarized in Fig. 2, coupled to the PM results discussed in Paper I (in which BHB and RGB stars share a common motion), are consistent with a GC nature for FSR 1767. Since the NTT/SOFI CMD photometry is saturated for  $K$  brighter than 10–11 in FMS08, the corresponding CMD and spatial distribution for brighter sequences could not be contemplated in that analysis.

### 3 SELECTION OF BACKGROUND AREAS

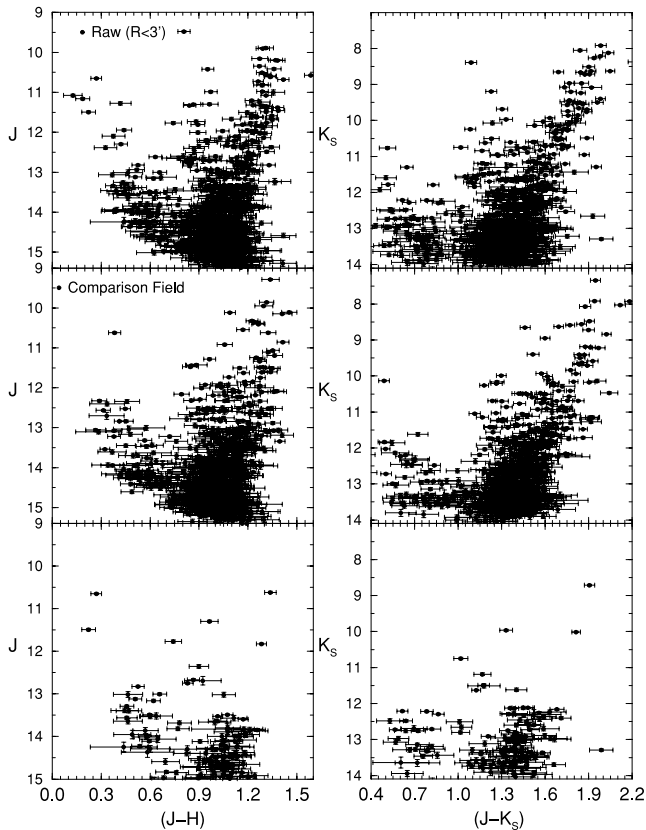
The background areas adopted in Paper I and FMS08 are different, hence it is important to discuss the consequences of such comparison fields on the resulting CMD morphologies. In Fig. 3, we show, schematically, the geometry of the NTT/SOFI observation with respect to the FSR 1767 overdensity, as described by the structural parameters given by FSR07. Because of the small NTT/SOFI field of view with respect to the dimensions of FSR 1767, their background selection occurred inside the overdensity, which is expected to cause oversubtraction of stars.

To test this hypothesis, we simulate the NTT/SOFI observational geometry with 2MASS data. The results are shown in Fig. 4, in which oversubtraction (from the decontamination algorithm) appears to be combined with saturation effects to produce the conspicuous depletion of the brighter stars.

For statistical representativeness of colours and magnitudes, in Paper I we used a wide outer ring ( $20 < R < 40$  arcmin) as comparison field. In this study, we still preserve the same properties, but with the comparison field taken from the more internal non-overlapping area  $11 < R < 20$  arcmin, just outside the tidal radius



**Figure 3.** Geometry of the FMS08 observations compared to the core (small circle) and tidal (large circle) radii derived by FSR07. The box schematically represents the SOFI camera CCD mosaic projection on the sky, and the shaded zone the background area adopted by FMS08.



**Figure 4.** 2MASS CMD simulations of the NTT/SOFI background subtraction made by FMS08 with a comparison field taken inside the overdensity. Left-hand panels:  $J \times (J - H)$  and right ones:  $K_s \times (J - K_s)$ . From top to bottom: whole field, equal-area comparison field according to the FMS08 geometry, and decontaminated CMDs.

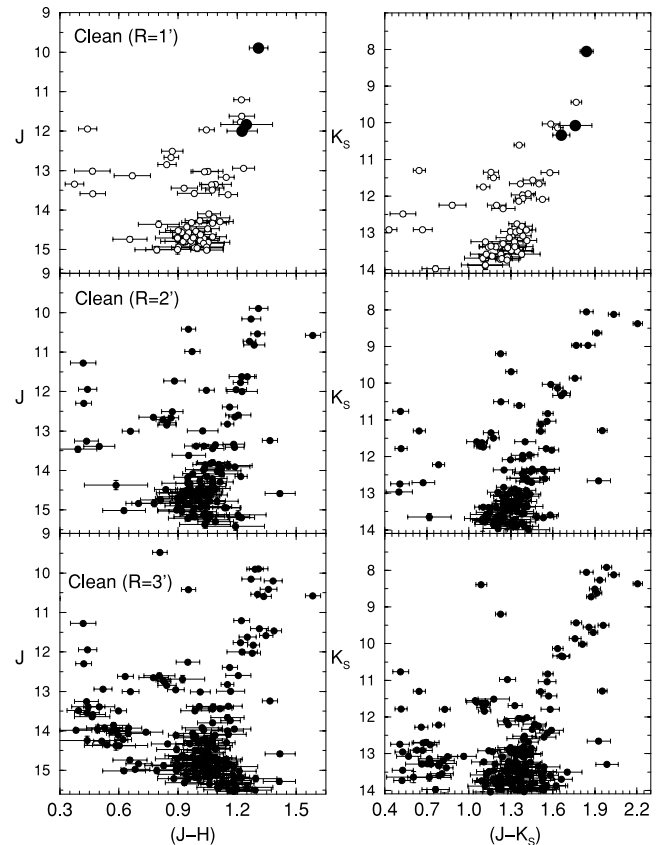
of  $R_{\text{tidal}} \approx 10$  arcmin (FSR07). The resulting  $J \times (J - H)$  and  $K_s \times (J - K_s)$  CMDs, for the extractions  $R < 1, 2$  and  $3$  arcmin, are shown in Fig. 5. We note that the external background selections of Paper I and the present one produce decontaminated CMDs with essentially the same morphologies.

As expected of a star cluster, the inner extractions of FSR 1767 present decontaminated CMD morphologies very similar to the overall extraction (Fig. 2), with the presence of the RGB and BHB sequences. Allowing for fit uncertainties, the inner extraction corresponds basically to the computed core of FSR 1767.

From the above, we conclude that, besides saturation effects which impaired FSR08 to reach the bright range of stars, an over-subtraction of stars of any magnitude probably occurred with the NTT/SOFI data.

### 3.1 The fundamental parameters derived in Paper I

The wide ring used as comparison field in Paper I and the more internal one of this work provide adequate statistics for a proper field star decontamination. No significant variations in the CMD morphology appear to occur as we interchange background areas closer or more distant from the tidal radius of FSR 1767. Indeed, CMDs of Paper I and those shown here are essentially the same. Thus, we show in Fig. 11 an isochrone fit that essentially confirms our previous cluster parameters, since the 2MASS sequences are well defined and populated, because they are not affected by saturation effects.

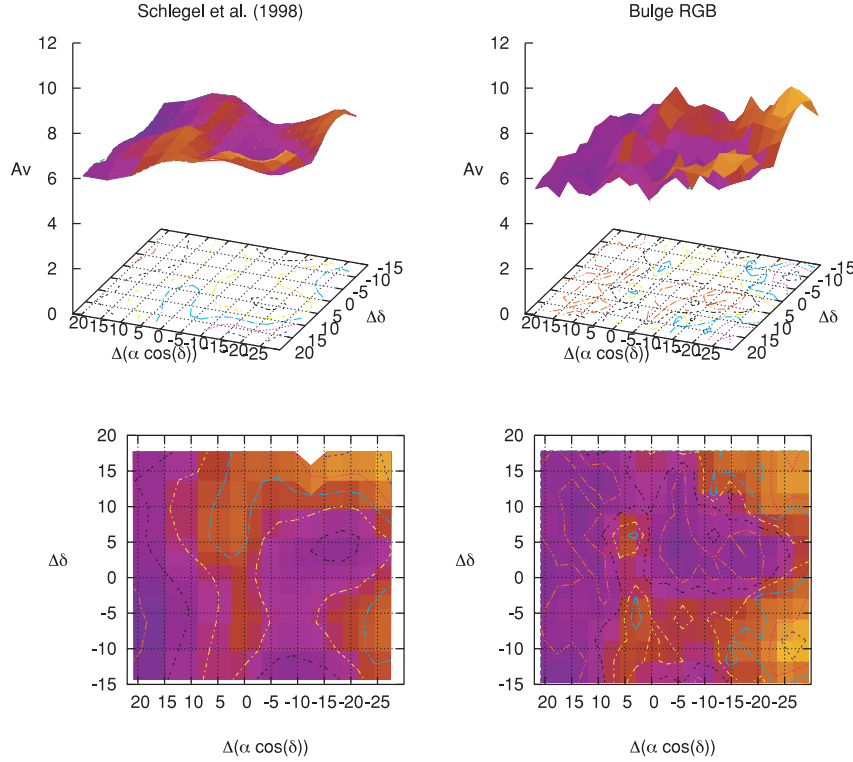


**Figure 5.** Field-star-decontaminated  $J \times (J - H)$  (left-hand panels) and  $K_s \times (J - K_s)$  (right-hand panels) CMDs for the extractions  $R < 1$  arcmin (top panels),  $R < 2$  arcmin (middle panel) and  $R < 3$  arcmin (bottom panel), adopting as comparison field the ring  $11 < R < 20$  arcmin. Results are essentially as in Paper I. Stars detected in the probable detached core (Section 4) are shown as filled circles in the top panels.

These values are a reddening  $E(J - H) = 0.63 \pm 0.03$  or  $E(B - V) = 2.0 \pm 0.1$ , an absorption  $A_{K_s} = 0.73 \pm 0.04$  or  $A_V = 6.2 \pm 0.3$ , a distance from the Sun  $d_{\odot} = 1.5 \pm 0.1$  kpc, galactocentric distance  $R_{GC} = 5.7 \pm 0.2$  kpc and a metallicity  $[\text{Fe}/\text{H}] \approx -1.0$ . Given the similar CMD morphologies (Paper I), the age of FSR 1767 may be comparable to that of the metal-poor ( $[\text{Fe}/\text{H}] = -1.2$ , H03) GC M 4 (NGC 6121), or  $\approx 12$  Gyr (e.g. Hansen et al. 2004).

### 3.2 Reddening maps

Local reddening variations may be a potential source of confusion. For instance, an apparent stellar overdensity would be expected if FSR 1767 (FMS08) lies within a dust window with respect to the surroundings, which could mimic a star cluster. To further investigate this issue, we have built reddening maps based on two independent approaches. First, we consider the reddening values provided by Schlegel, Finkbeiner & Davis (1998), derived from dust emission, for a spatial grid of dimension  $|\Delta(\alpha \cos(\delta))| \approx 25$  arcmin and  $|\Delta\delta| \approx 20$  arcmin, with FSR 1767 located at  $\Delta[\alpha \cos(\delta)] = \Delta\delta = 0$  arcmin. The resulting map (Fig. 6, left-hand panels) presents rather smooth reddening variations with values within the range  $5 \lesssim A_V \lesssim 8.5$ . The area occupied by FSR 1767 ( $R \approx 4$  arcmin) corresponds basically to the four central cells. Clearly, FSR 1767 is not located within an absorption minimum. We note, however, that its outskirts are relatively close to the borders of a dust window.

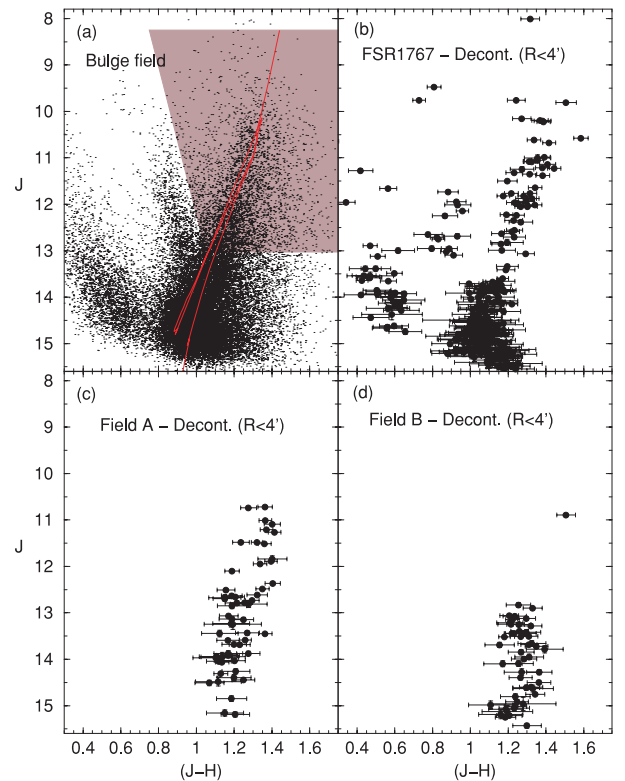


**Figure 6.** Reddening maps in the area of FSR 1767 built with the Schlegel et al. (1998) values (left-hand panels) and by considering star-by-star colour deviations from the bulge RGB (right-hand panels).  $A_V$  in magnitude;  $\Delta[\alpha \cos(\delta)]$  and  $\Delta\delta$  in arcmin.

Since positions with  $|b| < 5^\circ$  may have unreliable extinction estimates (Schlegel et al. 1998), we also compute the reddening in the area occupied by FSR 1767 by means of colour shifts exhibited by bulge RGB stars. We assume that the ring within 35–40 arcmin contains essentially bulge stars, whose CMD is described by the 10 Gyr solar-metallicity Padova isochrone (Fig. 7, panel a), set with  $A_V = 6.0$ . Taking the isochrone as the fiducial line for the bulge RGB, we compute  $A_V$  for all RGB stars within  $R \lesssim 20$  arcmin of the centre of FSR 1767. The resulting reddening map (Fig. 6, right-hand panels) is consistent – both in values and in topology – with that derived with Schlegel et al.’s estimates (left-hand panels).

We investigate whether regions with the same size ( $R = 4$  arcmin) and similar reddening as FSR 1767 also present a similar CMD morphology, in particular the BHB stars (Fig. 2). From the reddening maps (Fig. 6), we selected two such regions: Field ‘A’ located at  $\Delta[\alpha \cos(\delta)] = 0$  arcmin and  $\Delta\delta = 15$  arcmin and field ‘B’ at  $\Delta[\alpha \cos(\delta)] = -20$  arcmin and  $\Delta\delta = -7.5$  arcmin. For consistency, the CMDs of both fields were decontaminated with the same comparison field as that used for FSR 1767 in Paper I. Clearly, the decontaminated CMDs (Fig. 7) are very different from that of FSR 1767. A more objective perspective on these CMDs can be taken from statistical indices that deal with Poisson errors and CMD object/field contrast (Bica et al. 2008 and references therein).

The number of observed stars within  $R = 4$  arcmin of FSR 1767 is  $N_{\text{obs}} = 1311$ , while the number of decontaminated stars is  $N_{\text{dec}} = 276$ , which represents  $7.7\sigma$  with respect to the Poisson fluctuation of  $N_{\text{obs}}$ . On the other hand, Fields ‘A’ and ‘B’ have  $N_{\text{obs}} = 1274$  and 1333, and  $N_{\text{dec}} = 57$  and 51, respectively, which correspond to  $\approx 1.5\sigma$ . Statistically, the decontaminated CMD of FSR 1767 suggests a GC, while those of Fields ‘A’ and ‘B’ correspond basically to the Poisson fluctuation of typical bulge fields.



**Figure 7.** Panel (a): the bulge CMD set with the 10 Gyr solar-metallicity Padova isochrone; the RGB stars used to compute reddening are highlighted by the shaded polygon. The decontaminated  $R = 4$  arcmin CMD of FSR 1767 (b) is compared to those of Fields ‘A’ (c) and ‘B’ (d).

In addition, the most important point is that the BHB stars, which are a conspicuous feature in the CMD of FSR 1767, are not present in Fields ‘A’ and ‘B’.

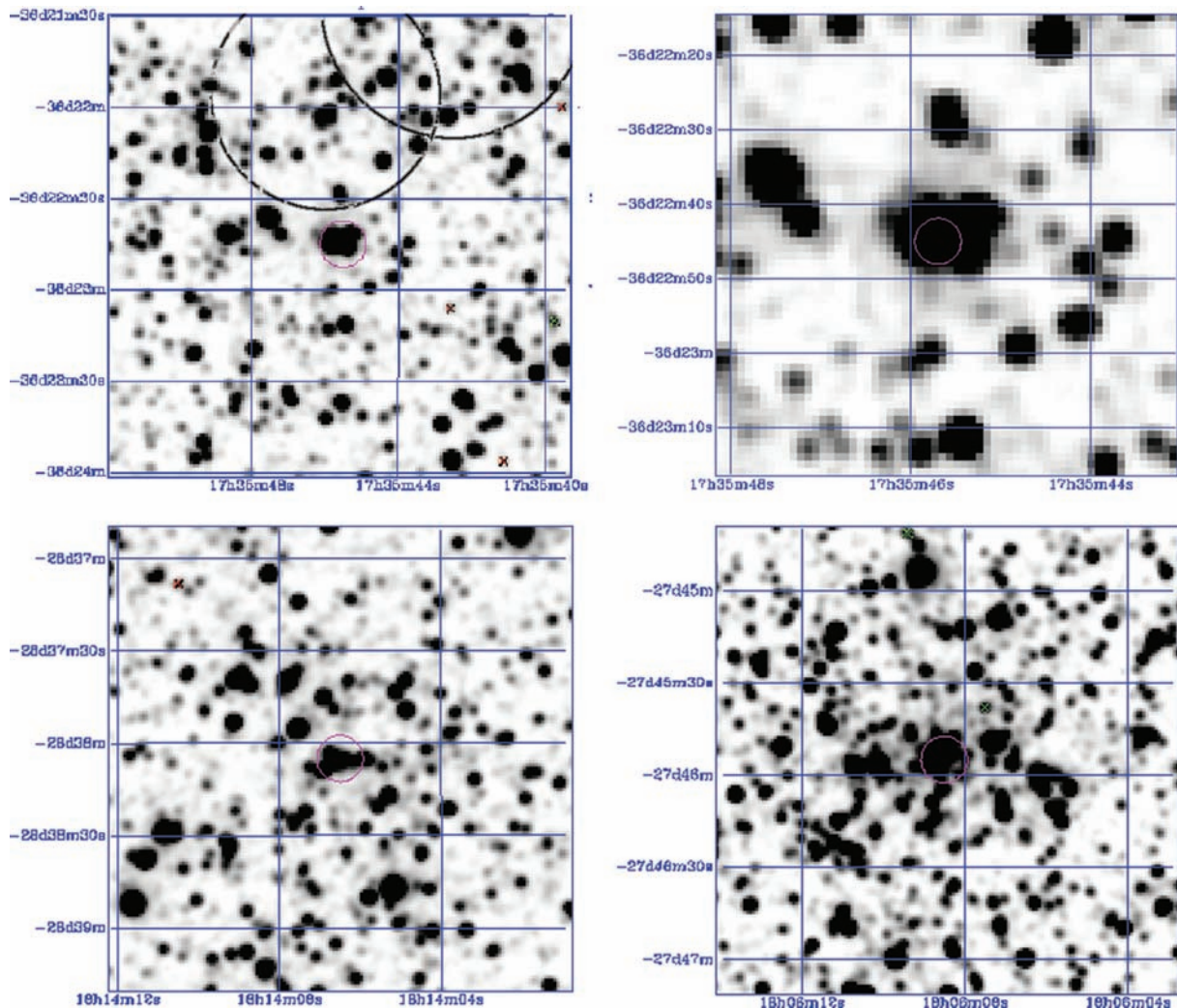
#### 4 A COMPACT STELLAR GROUP IN THE CENTRAL PARTS OF FSR 1767?

We report the detection of a compact stellar grouping at  $17^{\text{h}}35^{\text{m}}45.5^{\text{s}}$  and  $-36^{\circ}22'45''$ , with a diameter of  $\approx 12$  arcsec or  $\approx 0.09$  pc, at the inferred distance of FSR 1767 (Paper I). It is shifted  $\Delta[\alpha \cos(\delta)] = +0.18$  arcmin and  $\Delta\delta = -1.05$  arcmin with respect to the optimized centre of FSR 1767. If located in the general field, it might be interpreted as field fluctuation or a multiple star system. However, given the uncertainties in the core radius, this stellar group is projected near the border of the FSR 1767 core, as computed either by us or by FSR07 (Fig. 8, - top panels).

The possible core of FSR 1767 is less detached and populous than that of the considerably more massive GC NGC 6752 (Aurière & Ortolani 1989), which has a core radius of 0.17 arcmin (H03). In the 2MASS  $K_s$  image, the detached core encompasses the H03

core estimate. Ferraro et al. (2003) found that the core of NGC 6752 contains the cluster barycentre. The low-luminosity ( $M_V = -4.0$ ; Bonatto & Bica 2008b) GC AL 3 (bottom-left panel), at  $d_{\odot} = 6.0$  kpc, has a similarly detached central concentration, and is suspected to contain a post-collapse core (Ortolani, Bica & Barbuy 2006). An estimate of the core radius, based on 2MASS photometry, of  $0.4 \pm 0.3$  arcmin was provided by Bonatto & Bica (2008b). This value encompasses the probable detached core in that case. The slightly more luminous ( $M_V = -5.4$ ) GC NGC 6540 (bottom-right panel), at  $d_{\odot} = 3.4$  kpc (H03), has a detached post-collapse core (Trager, King & Djorgovski 1995), of estimated radius 0.03 arcmin (H03), which is well within the detached core shown in Fig. 8. With relatively high-resolution imaging, Lugger, Cohn & Grindlay (1995) found a mean diameter of 0.08 pc for resolved post-collapse cores, a value comparable to the size that we found in the centre of the nearby FSR 1767. Compact detached cores, and their probable relation to post-collapse cores, reflect advanced dynamical evolution in GCs (Trager et al. 1995).

Three of the stars in the compact core were detected by 2MASS. They fit in the general cluster CMD (Fig. 5, top panels) as two



**Figure 8.** Top-left panel: 2MASS  $J$  image covering a region of dimension  $2.5 \times 2.5$  arcmin<sup>2</sup> centred on the probable detached core (small circle). The core radii of FSR07 and this paper are shown by large circles, in the right- and left-hand panels, respectively. Top-right panel: close up ( $1 \times 1$  arcmin<sup>2</sup>) on the probable detached core of FSR 1767. Bottom panels: 2MASS  $2.5 \times 2.5$  arcmin<sup>2</sup>  $J$  images of the probable detached core of the slightly less massive GC AL 3 (left-hand panel) and the slightly more massive GC NGC 6540 (right-hand panel).

intermediate-brightness and one bright giants. This is consistent with the compact group of stars as being physically associated with FSR 1767. Finally, stars in the  $R = 1$  arcmin region of FSR 1767 (Fig. 5, top panels), which contain the King and detached cores, largely prefer the RGB and BHB CMD sequences as a whole, which again supports the stellar content of this inner region as compatible to that of a GC.

## 5 2MASS AND NTT/SOFI PHOTOMETRIES

Selection of a comparison field within the overdensity and/or saturation effects on the NTT/SOFI calibration of the bright CMD sequences of FSR 1767 may partly explain the different results of FMS08 and Paper I.

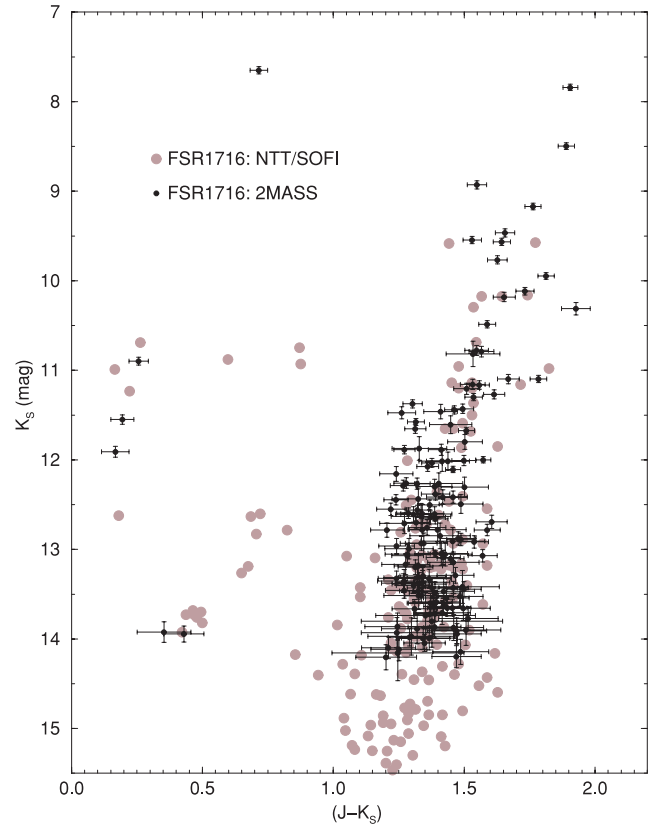
FMS08 report that variable cirrus occurred during the run, to the point that cloudy conditions were present for one object (FSR 0002). Besides, stars brighter than  $K \approx 10$ –11 are saturated. They use 2MASS stars for calibration of each object, but report difficulties with crowding, different resolution and saturation effects. At brighter magnitudes, they applied a separate fit of the 2MASS colours to their measured brightnesses for calibration.

As a first step to understand the source of discrepancy between FMS08 and Paper I over the nature of FSR 1767, we compare the NTT/SOFI data with 2MASS for FSR 1716 (FMS08) as a test cluster. The fact that FMS08 employ the  $K$  band while we use  $K_s$  does not introduce any significant difference, because  $K$  and  $K_s$  of red and blue standard stars (Persson et al. 1998), in general, do not differ by more than 0.03 mag.

FSR 1716 is a star cluster located at  $\ell = 329^\circ 8$  and  $b = -1^\circ 6$  with photometric and structural properties typical of an old (age  $\gtrsim 7$  Gyr) OC or a low-mass GC (Bonatto & Bica 2008c). For comparison purposes, we extracted 2MASS photometry within a region equivalent to that studied by FMS08 and applied the decontamination algorithm. As for the NTT/SOFI photometry, we took the available (decontaminated) points directly from fig. 11 of FMS08. Both sets of photometry are plotted in the  $K_s \times (J - K_s)$  CMD of Fig. 9, in which the NTT/SOFI and the 2MASS photometries show an excellent agreement over most of the sequences. As expected, the NTT/SOFI is about 1 mag deeper than 2MASS, and a saturation occurs for  $K \approx 10$ –11. A large number of cluster giants superimpose along the RGB. This comparison serves to show that systematic and significant differences between both photometries are not to be expected.

Returning now to FSR 1767, we apply the same strategy as above to compare the 2MASS data with the NTT/SOFI CMD shown in fig. 15 of FMS08. The results are shown in Fig. 10 (left-hand panel), in which it is clear that the NTT/SOFI sequences and the 2MASS data do not match. It is interesting that such discrepancy occurs within a single observation run, which might suggest some calibration problem. Besides, the close background 2MASS simulation discussed in Section 3 produced an oversubtraction, especially of bright blue stars. The behaviour of NTT data for close background subtractions should be explored in the future. However, it is remarkable how the NTT/SOFI sequences resemble a GC main-sequence turnoff (MSTO) and subgiant branch (SGB). In the right-hand panel, we apply a tentative correction to the NTT/SOFI data by  $\Delta K_s = -0.6$  and  $\Delta(J - K_s) = +0.3$ . By doing so, a 12 Gyr  $[\text{Fe}/\text{H}] = -1.2$  Padova isochrone set with Paper I parameters basically indicates that both sets are consistent, provided that observational/calibration effects occurred with the NTT/SOFI data.

FMS08 argued that the brighter and fainter stellar sets in their CMD diagram were differently reddened in the colour–colour di-

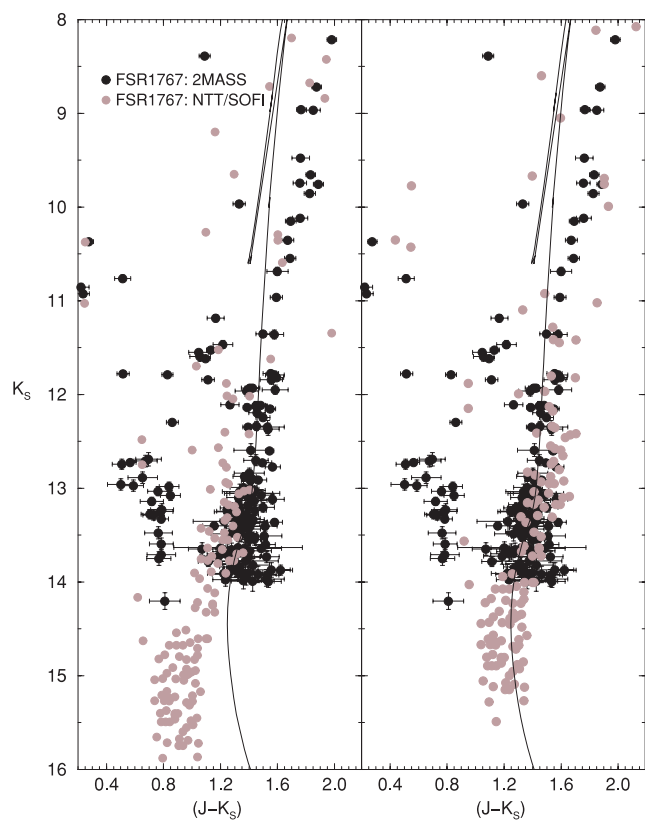


**Figure 9.** The NTT/SOFI photometry of FSR 1716 overlaps that from 2MASS. Decontaminated photometry is used in both cases.

agram (fig. 15 of FMS08). However, the colour–colour diagram appears to show MSTO and SGB stars that are equally reddened but with intrinsically different colours. In addition, in nature two sets of stars would not have such clear-cut reddening separation.

Finally, in Fig. 11 we show that the  $R = 4$  arcmin  $J \times (J - H)$  decontaminated CMD of FSR 1767 is well matched by both M4 and the 12 Gyr  $[\text{Fe}/\text{H}] = -1.2$  Padova isochrone set with Paper I parameters. However, in  $K_s \times (J - K_s)$  (right-hand panel) the RGBs split. The exceedingly blue RGB colour in Padova isochrones is a recurrent issue, probably associated to opacity and/or the alpha parameter in mixing length theory (Girardi, private communication). In addition, the fact that the RGB of FSR 1767 is slightly redder than that of M4 might suggest a somewhat higher metallicity. It might be like the bulge GCs with  $[\text{Fe}/\text{H}] = -0.9$  to  $-1.0$  that have BHBs. One example is NGC 6558 (Barbuy et al. 2007).

Morphological differences exhibited by the CMDs of FSR 1767 built with NTT (FMS08) and 2MASS (this paper) data are significant. Instead of a stellar cluster, FMS08 interpret the overdensity as resulting from locally decreased extinction. From our point of view, which is based on a series of consistent pieces of evidence, FSR 1767 cannot be excluded as a star cluster. A tentative explanation to reconcile both data sets would be that saturation effects, together with oversubtraction due to the limited NTT field of view, may have affected the NTT/SOFI calibrations. We emphasize that such problem or any other did not occur with FSR 1716 (in the same observing run), to the point that both photometries (NTT and 2MASS) agree. However, it is clear that this issue can only be settled with additional observations with a large telescope.



**Figure 10.** NTT/SOFI photometry of FSR 1767 compared to the 2MASS one, and the solution with the 12 Gyr  $[\text{Fe}/\text{H}] = -1.2$  Padova isochrone set with the parameters of Paper I. Left-hand panel: NTT/SOFI data as in FMS08. Right-hand panel: tentative match  $[\Delta K_s = -0.6, \text{ and } \Delta(J - K_s) = +0.3]$  of SOFI data with 2MASS.

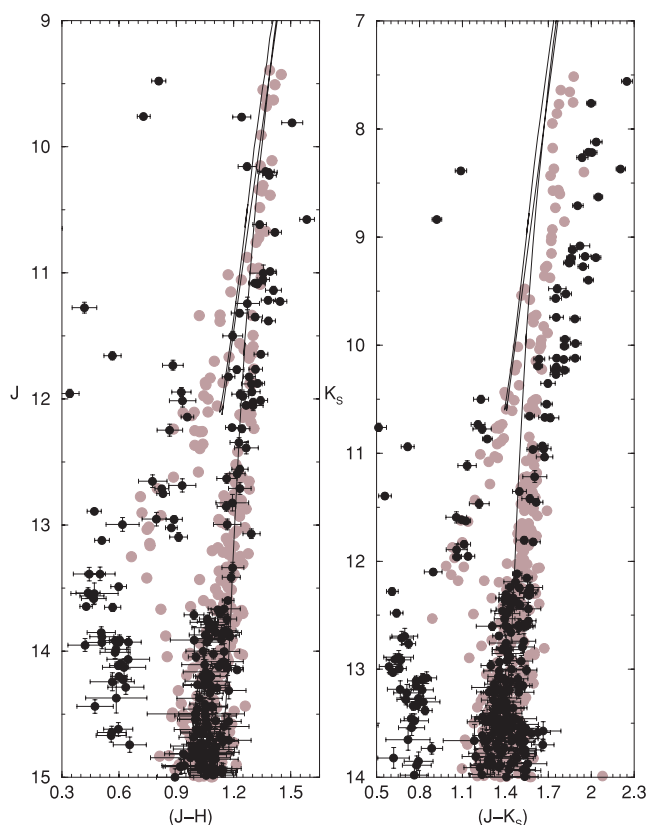
## 6 SUMMARY AND CONCLUSIONS

Field-star contamination is heavy in the direction of FSR 1767, to the point that statistical CMD and structural decontamination algorithms are required to unveil its properties and establish its nature. Taken isolately, each piece of evidence discussed above and in Paper I (e.g. CMD morphology, structural parameters of selected stellar sequences, reddening maps and PM, the latter with a relatively low statistical significance), suggests FSR 1767 as a star cluster. The consistency among several independent arguments, coupled to the absorption maps, represents additional support to FSR 1767 as an old star cluster. In this case, it would be a nearby low-luminosity, relatively metal-poor GC projected against the bulge.

We also found a peculiar compact stellar group in the central parts of FSR 1767 that is possibly a detached post-collapse core. It would be the nearest post-collapse core, closer than that in NGC 6397 (Trager et al. 1995).

Given the above, it would be very unlikely that (i) a rare peculiar compact field fluctuation would sit next to the mathematical core radius calculated from King fits that accurately matches the extended statistical overdensity; (ii) the overdensity, in turn, would harbour a stellar content that perfectly mimics GC CMD sequences and (iii) the stellar sequences of the overdensity would share a common motion on the sky. The presence of a compact core supports FSR 1767 as an unparalleled GC in terms of proximity, low luminosity and structure.

New possible GCs in the avoidance zone defined by Harris (1991) will necessarily be very contaminated and little contrasted, im-



**Figure 11.** Comparison of the 12 Gyr,  $[\text{Fe}/\text{H}] = -1.2$  Padova isochrone, with M4 (grey circles) and the  $R = 4$  arcmin decontaminated CMD of FSR 1767 (black circles).

mersed in dense disc and/or bulge fields. An isolated CMD or structural analysis alone might not be enough to unravel the nature of objects such as FSR 1767. Paper I and this study present consistent evidence that supports FSR 1767 as a GC. However, photometry obtained with a large telescope, including observations of adequate offset fields, would shed more light on the nature of FSR 1767.

## ACKNOWLEDGMENTS

We thank the anonymous referee for interesting suggestions. We acknowledge partial support from CNPq and FAPESP (Brazil) and MURST (Italy).

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