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FSR 1767 - a new globular cluster in the Galaxy

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ABSTRACT

The globular cluster (GC) nature of the recently catalogued candidate FSR 1767 is established in the present work. It results as the closest GC so far detected in the Galaxy. The nature of this object is investigated by means of 2MASS colour-magnitude diagrams (CMDs), the stellar radial density profile (RDP) and proper-motions (PM). The properties are consistent with an intermediate metallicity ($[Fe/H] \approx -1.2$) GC with a well-defined turnoff (TO), red-giant branch (RGB) and blue horizontal-branch (HB). The distance of FSR 1767 from the Sun is $d_\odot \approx 1.5$ kpc, and it is located at the Galactocentric distance $R_{GC} \approx 5.7$ kpc. With the space velocity components $(V, W) = (184 \pm 14, -43 \pm 14)\,\mathrm{km\,s^{-1}}$, FSR 1767 appears to be a Palomar-like GC with $M_V \approx -4.7$, that currently lies ≈ 57 pc below the Galactic plane. The RDP is well represented by a King profile with the core and tidal radii $R_{core} = 0.24 \pm 0.08$ pc and $R_{tidal} = 3.1 \pm 1.0$ pc, respectively, with a small half-light radius $R_h = 0.60 \pm 0.15$ pc. The optical absorption is moderate for an infrared GC, $A_V = 6.2 \pm 0.3$, which together with its central direction and enhanced contamination explains why it has so far been overlooked.

Key words: (Galaxy:) globular clusters: individual (FSR 1767)

1 INTRODUCTION

With some exceptions, Globular Clusters were formed in the initial phases of the Galaxy and preserve information in their structure and spatial distribution that is essential to probe the early Milky Way physical conditions. Thus, derivation of the present-day spatial and luminosity distribution of GCs, as well as their physical and chemical properties, is important to better understand the formation and evolution processes and trace the geometry of the Galaxy (e.g. Mackey & van den Bergh 2005; Bica et al. 2006).

The number of known Galactic GCs has been slowly increasing as deeper surveys are carried out. The compilation of Harris (1996, and the update in 2003[1] - hereafter H03) contains 150 members. Later additions to the GC population include the far-IR GC GLIMPSE-C01 (Kobulnicky et al. 2005), the young halo GC Whiting 1 (Carraro 2005), two stellar systems detected with the Sloan Digital Sky Survey (SDSS) in the outer halo, SDSS J1049+5103 (Willman 1) and SDSS J1257+3419 that might be GCs or dwarf galaxies (Willman et al. 2005; Sakamoto & Hasegawa 2006), and AL 3, a bulge GC with a blue HB (Ortolani et al. 2006). Recently, Froebrich et al. (2007b) found evidence that FSR 1735 is a GC in the inner Galaxy, and Belokurov et al. (2007) found the faint halo GC SEGUE 1 using SDSS. Finally, Koposov et al. (2007) reported the discovery of two very-low luminosity halo GCs (Koposov 1 and 2) detected with SDSS.

In a recent observational effort to uncover potential star clusters, Froebrich et al. (2007a) carried out an automated search for stellar overdensities using the 2MASS[2] database for $b < 20^\circ$, which resulted in a list of 1021 candidates. Based on diagnostic diagrams involving number of stars, core radius and central density, they classified 9 of these as GC candidates. In the present work we investigate the nature of the GC candidate FSR 1767 by means of 2MASS CMDs, proper motions and a detailed structural analysis.

In Sect. 2 we analyze near-IR CMDs, proper motions and cluster structure. In Sect. 3 we discuss cluster properties. Concluding remarks are given in Sect. 4.

[1] *http://physun.physics.mcmaster.ca/Globular.html*

[2] *http://www.ipac.caltech.edu/2mass/releases/allsky/*

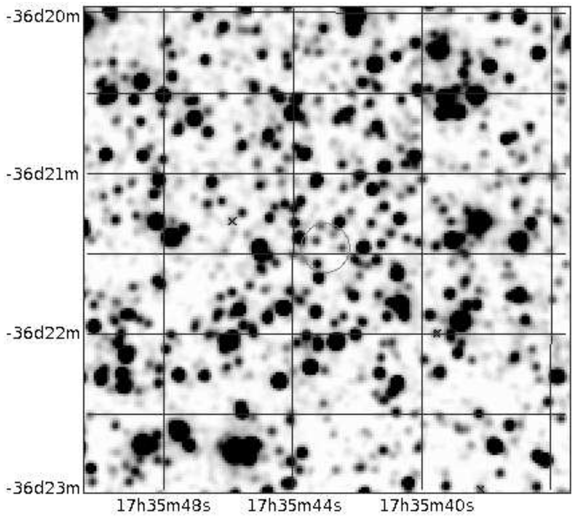

Figure 1. $3' \times 3'$ 2MASS H image of FSR 1767. The small circle marks the central region of FSR 1767 (Sect. 2). North is up and East is left.

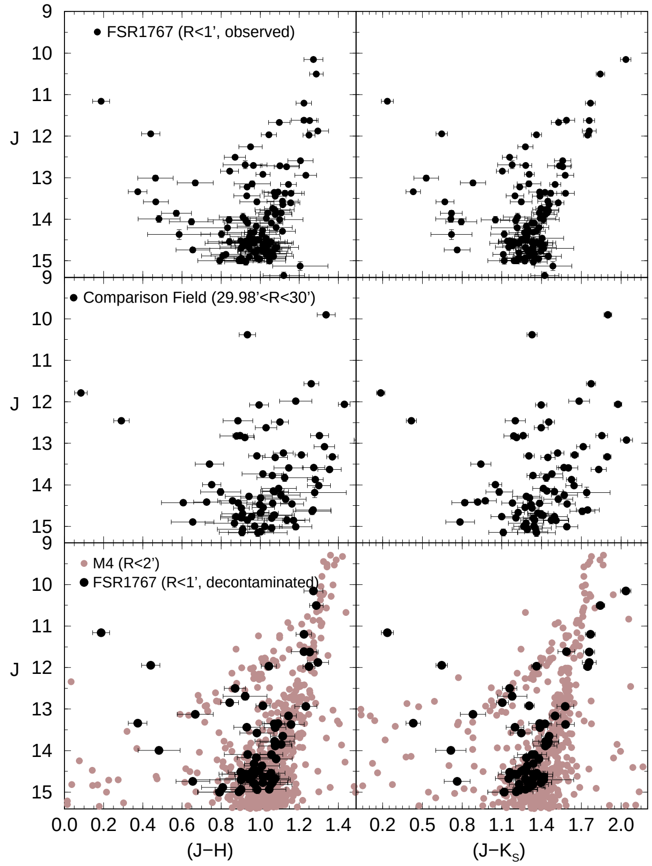

Figure 2. The CMD of the central $R < 1'$ extraction of FSR 1767 (top) is compared to an equal area offset field extraction (middle). Bottom: the field-star decontaminated $R < 1'$ CMD (filled circles) presents similarities with the $R < 2'$ CMD of M 4 (gray).

2 PHOTOMETRIC PARAMETERS

The coordinates of FSR 1767 (Froebrich et al. 2007a) are $\alpha(J2000) = 17^h\,35^m\,43^s$ and $\delta(J2000) = -36^\circ\,21'\,28''$, which correspond to the Galactic coordinates $\ell = 352.6^\circ$ and $b = -2.17^\circ$. We are dealing with a $4^{\rm th}$ quadrant cluster projected against the bulge in Scorpius. The following analysis is based on J, H and K_s 2MASS photometry taken from VizieR[3] and tools as described in e.g. Bonatto & Bica (2007). As photometric quality constraint, 2MASS extractions were restricted to stars with uncertainties in J, H and K_s smaller than 0.25 mag. A typical distribution of errors as a function of magnitude can be found in Bonatto & Bica (2007). About 75% of the stars have errors smaller than 0.06 mag. The 2MASS H image of FSR 1767 (Fig. 1) shows that field star contamination is important.

Fundamental parameters of FSR 1767 are derived by comparison with the nearby, intermediate-metallicity ($d_\odot \approx$ 2.2 kpc, [Fe/H] = −1.2) GC M 4 (H03, and references therein). To minimize field contamination effects, we first examine the $J \times (J-H)$ and $J \times (J-K_s)$ CMDs of a central ($R < 1'$) extraction around the cluster center (top panels of Fig. 2). The stellar density profile in this region presents a high contrast with respect to the background (Sect. 2.2). Features displayed by these CMDs are significantly different from the more scattered ones of the comparison field (middle panels). They resemble the TO, RGB and HB sequences displayed by the $R < 2'$ region of M 4 (bottom panels). The latter CMDs of FSR 1767 contain statistically significant sequences that result from applying the field-star decontamination algorithm (Bonatto & Bica 2007). Basically, the algorithm takes into account the relative densities of probable field and cluster stars in small CMD cubic cells with sides along J, $(J-H)$ and $(J-K_s)$. It is sensitive to local variations of field contamination with colour and magnitude. As comparison field we use the region $10' < R < 40'$ to improve background star-count statistics.

The match between the CMD morphologies of FSR 1767 and M 4 results from applying $\Delta(m-M)_J = 0.7 \pm 0.1$ and $\Delta E(J-H) = 0.58 \pm 0.05$ to M 4. The match provides for FSR 1767 a reddening $E(J-H) = 0.63 \pm 0.03$, which converts to $E(B-V) = 2.0 \pm 0.1$, corresponding to $A_V = 6.2 \pm 0.3$[4]. This absorption coincides with that derived from Schlegel et al. (1998) in the direction of FSR 1767, which implies that essentially all the reddening arises in the foreground disk. The resulting distance from the Sun is $d_\odot = 1.5 \pm 0.1$ kpc, which places it as the closest GC, since among the optical GCs M 4 and NGC 6397 are located at $d_\odot = 2.2$ and $d_\odot = 2.3$ kpc, respectively (H03). The nearest IR GC is GLIMPSE-C01 at $d_\odot \approx 4$ kpc (Kobulnicky et al. 2005). Adopting $R_\odot = 7.2$ kpc as the Sun's distance to the Galactic center (Bica et al. 2006), the Galactocentric distance of FSR 1767 is $R_{GC} = 5.7 \pm 0.2$ kpc, and it is displaced about 57 pc below the plane. This solution is shown in the bottom panels of Fig. 2 for both 2MASS colours.

We further analyze the CMD morphology of FSR 1767

[3] *http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=II/246*

[4] Reddening transformations are $A_J/A_V = 0.276$, $A_H/A_V = 0.176$, $A_{K_S}/A_V = 0.118$, and $A_J = 2.76 \times E(J-H)$ (Dutra, Santiago & Bica 2002), with $R_V = 3.1$.

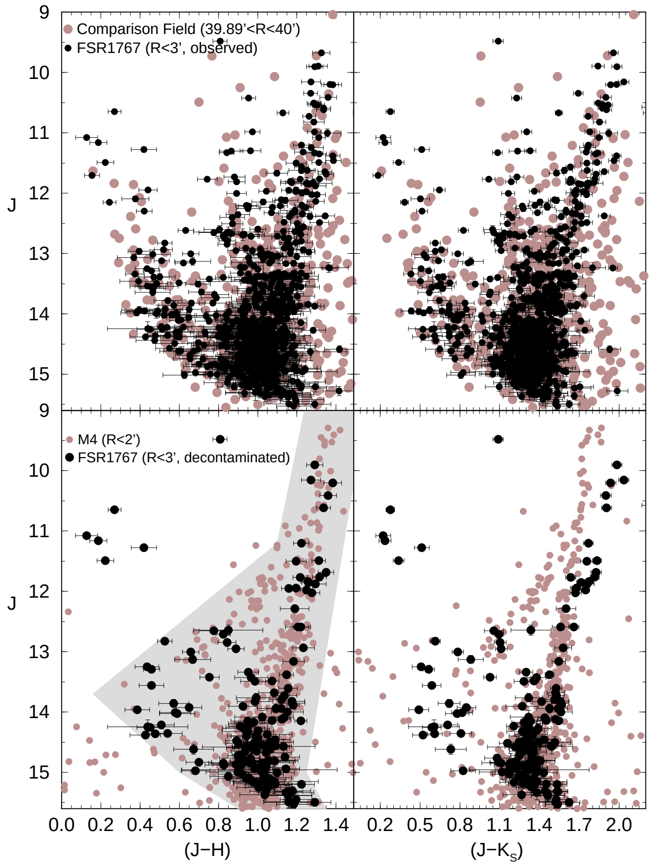

Figure 3. Top: $R < 3'$ CMD of FSR 1767 (black circles) compared to the equal area CMD of the offset field (gray). Bottom: comparison with the $R < 2'$ CMD of M 4 (gray). Shaded area: colour-magnitude filter used to select stars for the radial density profile (Sect. 2.2).

by examining the region $R < 3'$, that basically contains the bulk of the cluster stars (Sect. 2.2). Likewise in the $R < 1'$ extraction, the field decontamination reveals stellar density excesses that correspond to the TO, RGB and HB sequences similar to those of M 4 (Fig. 3). The results are consistent with an intermediate-metallicity GC that contains some blue HB stars. In terms of stellar content, FSR 1767 appears to be similar to the low-mass GCs AL 3 (Ortolani et al. 2006), Palomar 13 (Siegel et al. 2001) and AM 4 (Inman & Carney 1987), which contain about 10–20 giants. The combined number of RGB and HB stars in M 4 ($M_V = -7.2$, H03) is ~ 10 larger than that in FSR 1767. Assuming a similar scaling for the total luminosity and the number of giants, we estimate $M_V \approx -4.7$ for FSR 1767, consistent with its low-luminosity nature.

2.1 Proper motions

Another clue to the GC nature of FSR 1767 is provided by NOMAD[5] proper motion data (Fig. 4) taken for stars in the same region as the 2MASS data. NOMAD is based on the International Celestial Reference System (ICRS) whose origin is located at the barycenter of the solar system. However, we note that the correspondence between NOMAD and 2MASS is not complete. For instance, among the 750 stars detected with 2MASS for $R < 3'$, 173 ($\approx 23\%$) are included in NOMAD. Most of the $R < 3'$ NOMAD stars form a compact clump, defined by $|\mu_\delta| = |\mu_\alpha \cos(\delta)| \lesssim 50\,\mathrm{mas\,yr^{-1}}$, in the PM components plane (panel a). About 75% of these stars have PM errors smaller than $10\,\mathrm{mas\,yr^{-1}}$. Systematic differences in the PM component distributions for $R < 3'$ with respect to the comparison field are apparent in the respective, nearly Gaussian histograms (panels b and c). Besides different values of the distribution maximum in both PM components, there are significant excesses of stars in $R < 3'$ with respect to the comparison field at several bins (panels c and d). From Gaussian fits to the distributions we measure the average values $\langle\mu_\alpha \cos(\delta)\rangle = 2.81 \pm 2.85\,\mathrm{mas\,yr^{-1}}$ and $\langle\mu_\delta\rangle = -8.78 \pm 2.82\,\mathrm{mas\,yr^{-1}}$ for stars in the region $R < 3'$, and $\langle\mu_\alpha \cos(\delta)\rangle = -2.53 \pm 2.01\,\mathrm{mas\,yr^{-1}}$ and $\langle\mu_\delta\rangle = -3.66 \pm 2.04\,\mathrm{mas\,yr^{-1}}$ for the comparison field. A more physical interpretation on the motion of FSR 1767 is provided by the UVW space velocity components, where U is positive towards the Galactic center, V in the direction of the Galactic rotation and W towards the North Galactic Pole. We take $U = 0$ since radial velocity is not available. After correcting for a peculiar Solar motion of $(U_\odot, V_\odot, W_\odot) = (+10.00 \pm 0.36, +5.25 \pm 0.62, +7.17 \pm 0.38)\,\mathrm{km\,s^{-1}}$ (Dehnen & Binney 1998), and taking into account the circular velocity of the Sun, $220\,\mathrm{km\,s^{-1}}$, we derive the cluster's space motion components $(V, W) = (184 \pm 14, -43 \pm 14)\,\mathrm{km\,s^{-1}}$ with respect to a stationary Galactic reference frame. These velocities were computed using the cluster distance, $d_\odot = 1.5\,\mathrm{kpc}$. We conclude that most of the space motion of FSR 1767 is prograde and similar to the expected circular velocity at its Galactocentric distance, suggesting that this could be a GC sharing a disk kinematics. Currently, FSR 1767 lies below the plane moving away from it at an angle $\theta = 13^\circ \pm 4^\circ$. When transposed to the $R < 3'$ CMD (panel f), the PM clump stars consistently should belong mostly in the MS/TO, RGB and HB sequences defined by the decontaminated photometry. As expected for a star cluster, the MS/TO, RGB and HB stars share a similar kinematics.

2.2 The structure of FSR 1767

Structural parameters are derived by fitting the King (1966) law to the stellar radial density profile, built with colour-magnitude filtered photometry for $R < 40'$ (e.g. Bonatto & Bica 2007). The filter (Fig. 3) removes contamination of stars with colours deviant from cluster sequences in the CMD. The resulting profile (Fig. 5), shown in absolute units corresponding to $d_\odot = 1.5\,\mathrm{kpc}$, presents a prominent density excess over the background, especially for $R < 2\,\mathrm{pc}$ ($\approx 4.5'$). Within uncertainties, most of the RDP is well represented by a King law characterized by a core radius $R_{core} = 0.24 \pm 0.08\,\mathrm{pc}$ ($\approx 0.54'$), and a tidal radius $R_{tidal} = 3.1 \pm 1.0\,\mathrm{pc}$ ($\approx 7'$), with a concentration parameter $c = \log(R_{tidal}/R_{core}) = 1.1 \pm 0.2$. The present value of R_{core} results the same as that in Froebrich et al. (2007a), but their tidal radius is $\approx 50\%$ larger than the present one. FSR 1767 presents a small half-light radius, $R_h = 0.60 \pm 0.15\,\mathrm{pc}$ ($\approx 1.4'$), measured in the J band. These

[5] *http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=I/297*

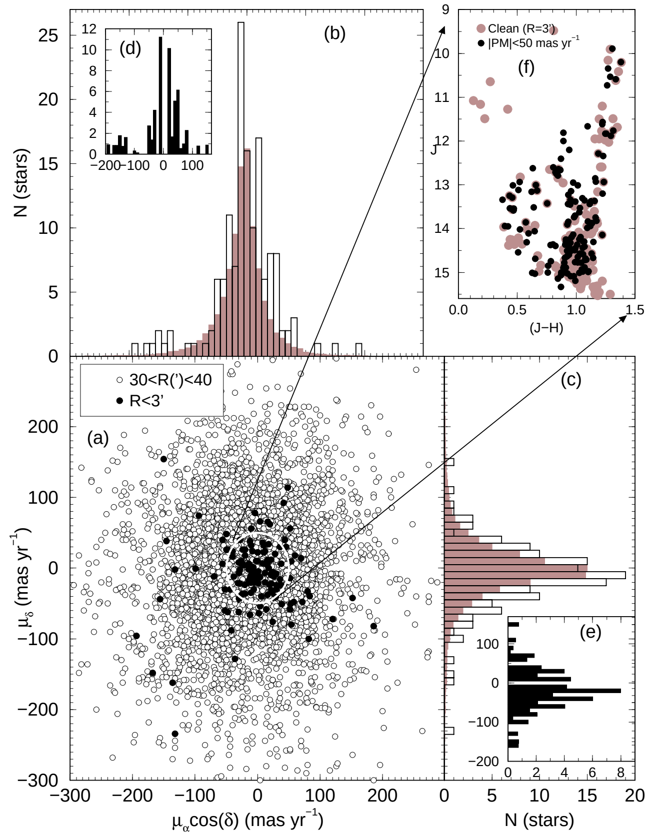

Figure 4. (a): Proper motion component distribution of the stars within $R < 3'$ (filled circles) and those within $30' < R < 40'$ (empty circles). The white circle isolates low-PM stars with $|\mu_\delta| = |\mu_\alpha \cos(\delta)| \lesssim 50\,\mathrm{mas\,yr^{-1}}$. (b and c): Comparative histograms of the $R < 3'$ stars (white) and comparison field (shaded), which was scaled to match the projected areas. (d and e): Excess of stars in $R < 3'$ with respect to the comparison field. (f): Low-PM stars (filled circles) occur mostly in the MS/TO, RGB and HB sequences of the decontaminated photometry (gray circles).

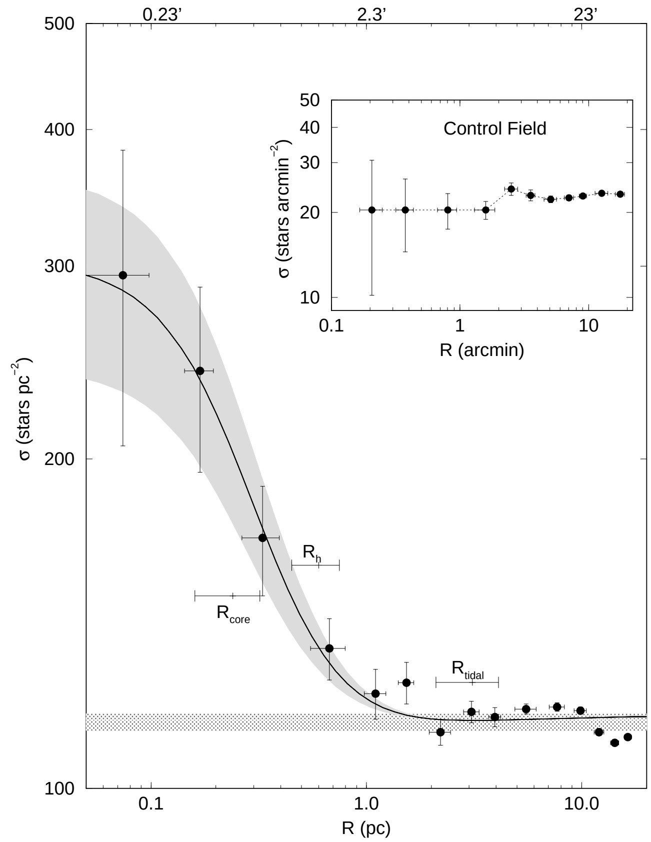

Figure 5. Stellar RDP (filled circles) of FSR 1767 in absolute scale. Solid line: best-fit King profile. Horizontal shaded region: offset field stellar background level. Core, half-light and tidal radii are indicated. Gray regions: 1σ King fit uncertainty. The angular scale is in the upper abscissa. Inset: RDP of a nearby control field.

values put FSR 1767 in the small-radii tail of the Galactic GCs distribution (e.g. Mackey & van den Bergh 2005).

2.3 Testing a control field

FSR 1767 is projected against a dense bulge stellar field that is expected to produce CMDs of an old population. This can be clearly seen in the CMDs of a randomly selected control field located at $\ell = 353.6^\circ$ and $b = -2.17^\circ$, about 1° to the east of FSR 1767 (Fig. 6). These CMDs contain basically the bulge TO, giant branch and some disk stars. When applied to the central $R < 2'$ extraction, the decontamination algorithm removes most of the stars in the CMDs, leaving only a few that reflect the expected statistical fluctuation of the dense field.

To test the hypothesis that the high stellar densities associated with central directions might produce RDPs that mimic those of star clusters we apply the same algorithm (Sect. 2.2) to the control field (Fig. 6). The resulting RDP is characterized by fluctuations typical of a dense stellar field distribution (inset of Fig. 5).

3 DISCUSSION

The previous analyses strongly indicate that FSR 1767 is a Palomar-like GC, a class of GCs that can be basically characterized by low mass and $M_V > -6$. H03 contains 30 GCs that satisfy these criteria, $\approx 2/3$ of which are original Palomar GCs. Structural properties of the Palomar and massive (i.e. non-Palomar) GCs are investigated in Fig. 7 with data from H03. The main difference between both classes of GCs is the more concentrated distribution of tidal radii towards smaller values occurring for the Palomar GCs (panel a). The distributions of half-light and core radii, on the other hand, are similar (panels b and c). Reflecting this, the concentration parameters of the Palomar-like GCs tend to be smaller than those of the massive ones (panel d). The Palomar-like GCs follow the well-known (e.g. Mackey & van den Bergh 2005; Djorgovski & Meylan 1994) relation of increasing cluster radii with Galactocentric distance (panels e to g). However, as expected from panel (a), the Palomar-like GCs tend to have smaller tidal radii than the massive ones for a given Galactocentric distance, especially for small R_{GC} (panel g). The bottom panels show how M_V relates with the cluster radii and Galactocentric distance. In all cases, the structural parameters of FSR 1767 are consistent with those of a low-mass Palomar-like GC dwelling inside the Solar circle, at $R_{GC} \approx 5.7$ kpc.

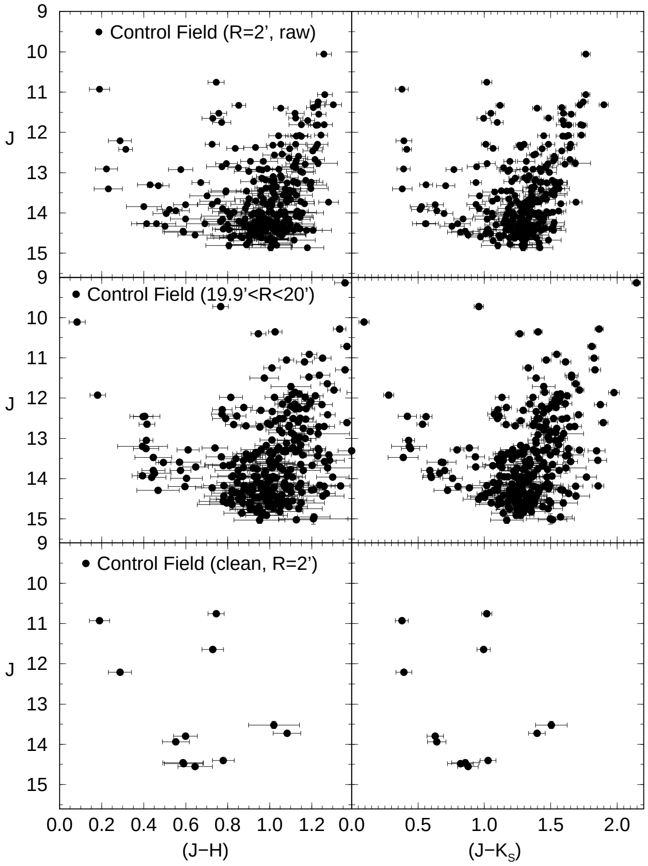

Figure 6. Top: central extraction of a control field taken from a bulge direction. Middle: equal area extraction taken from the border. Stars that remain in the decontaminated CMDs (bottom) correspond to the expected density fluctuation of the dense field.

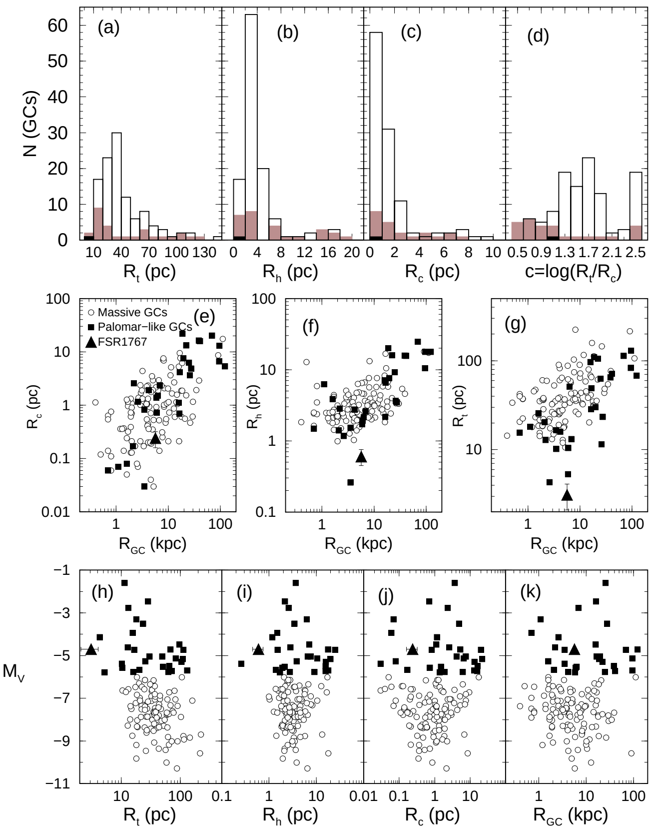

Figure 7. Top: structural parameters of the Palomar-like ($M_V > -6$) GCs (gray-shaded histogram) compared to the massive ($M_V < -6$) ones (white). FSR 1767 is indicated by a black square. Middle: cluster radii as a function of Galactocentric distance. Bottom: M_V as a function of the cluster radii and Galactocentric distance. FSR 1767 presents structural properties of a Palomar-like GC. Except for FSR 1767, the data are from H03.

The small size of FSR 1767, especially the tidal radius, may be a consequence of its low-mass nature associated with the inner-Galaxy location, a region with enhanced tidal stress. In the long term, dynamical heating of a GC is expected as a consequence of tidal interactions by shocks due to disk and bulge crossings as well as encounters with massive molecular clouds. This enhances the rate of low-mass star evaporation and accelerates the process of core collapse, especially for low-mass clusters (e.g. Djorgovski & Meylan 1994). One consequence of the evolution of GCs inside the Solar circle may be a depopulation of the low-mass tail of the GC distribution.

4 SUMMARY AND CONCLUSIONS

FSR 1767 was first identified as a stellar overdensity projected against the bulge by Froebrich et al. (2007a) in an automated star cluster survey using 2MASS. They classified it as a GC candidate. Combining near-IR photometry and proper motions we conclude that FSR 1767 is a new GC in the Galaxy. The census (Bica et al. 2006) and recent discoveries (Sect. 1) indicate that FSR 1767 is the 158^{th} GC detected in the Galaxy. FSR 1767 is remarkably close to the Sun at $d_\odot = 1.5 \pm 0.2$ kpc (≈ 1.5 kpc inside the Solar circle), resulting as the nearest GC so far detected. It lies close to the Galactic plane at $Z \approx -57$ pc. According to the proper motion properties (Sect. 2.1), the space velocity components are $(V, W) = (184 \pm 14, -43 \pm 14)\,\mathrm{km\,s^{-1}}$. Currently, FSR 1767 is moving away from the plane at an angle $\theta = 13^\circ \pm 4^\circ$. The photometric and structural properties are consistent with a Palomar-like GC in the inner Galaxy with $M_V \approx -4.7$, i.e. a low-mass GC containing few giants. Its structure is characterized by core, half-light and tidal radii of 0.24 ± 0.08 pc, 0.60 ± 0.15 pc and 3.1 ± 1.0 pc, respectively. The TO, RGB and HB of FSR 1767 are readily detected in the present near-IR CMDs (consistent with the proximity), as well as the upper MS and blue HB stars. Based on the similarity with the CMD morphology of M 4, a metallicity [Fe/H] ≈ -1.2 and an absorption $A_V = 6.3 \pm 0.3$ are estimated. The Palomar-like nature, projection against the bulge, and the fact that the bulk of its stars require IR photometry owing to a relatively high absorption, can explain why FSR 1767 has been so far overlooked. The fact that in less than three years five new Palomar-like GCs have been identified, AL 3 in the bulge, FSR 1767 at $R_{GC} \approx 5.7$ kpc, and the three SDSS low-luminosity ones in the halo (Sect. 1), suggests that the number of low-mass GCs may be considerably larger than previously thought.

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