Confirmation of two new Galactic bulge globular clusters: FSR 19 and FSR 25

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ABSTRACT

Context. Globular clusters (GCs) in the Milky Way (MW) bulge are very difficult to study for the following reasons: (i) they suffer from the severe crowding and Galactic extinction, which are characteristic of these inner Galactic regions; (ii) they are more prone to the effects of dynamical processes. Therefore, they are relatively faint and difficult to map. However, deep, near-infrared photometry like that provided by the VISTA variables in the Via Láctea Extended Survey (VVVX) allows us to map GCs in this crucial yet relatively uncharted region.

Aims. Our main goals are to study the true nature of the GC candidates FSR 19 and FSR 25 and measure their physical parameters.

Methods. We used the near-infrared VVVX database, in combination with the Two Micron All Sky Survey and Gaia EDR3 proper motions (PMs) and photometry to study ages, metallicities, distances, reddening, mean PMs, sizes, and integrated luminosities for FSR 19 and FSR 25. A robust combination of selection criteria allowed us to effectively clean interlopers among our samples.

Results. Our results confirm with a high level of confidence that both FSR 19 and FSR 25 are genuine MW bulge GCs. Each of the performed tests and resulting parameters provide clear evidence of the GC nature of these targets. We derive distances of 7.2 ± 0.7 kpc and D = 7.0 ± 0.6 (corresponding to distance moduli of 14.29 ± 0.08 and 14.23 ± 0.07) for FSR 19 and FSR 25, respectively. Their ages and metallicities are 11 Gyr and [Fe/H] = −0.5 dex for both clusters, which were determined from Dartmouth and PARSEC isochrone fitting. The integrated luminosities are M_KS (FSR 19) = −7.72 mag and M_Ks (FSR 25) = −7.31 mag, which places them in the faint tail of the GC luminosity function. By adopting a King profile for their number distribution, we determine their core and tidal radii (r_c, r_t). For FSR 19, r_c = 2.76 ± 0.36 pc and r_t = 5.31 ± 0.49 pc, while FSR 25 appears more extended with r_c = 1.92 ± 0.59 pc and r_t = 6.85 ± 1.78 pc. Finally, their mean GC PMs (from Gaia EDR3) are µ_l = −2.50 ± 0.76 mas yr⁻¹, µ_b = −5.02 ± 0.47 mas yr⁻¹ for FSR 19 and µ_l = −2.61 ± 1.27 mas yr⁻¹, µ_b = −5.23 ± 0.74 mas yr⁻¹ for FSR 25.

Conclusion. We demonstrate and confirm, based on the measured astrophysical parameters, that the two target clusters are indeed genuine and of low luminosity relatively metal-rich old GCs in the bulge of the MW.

Key words. stars: Population II – Galaxy: bulge – stars: variables: RR Lyrae – globular clusters: general – globular clusters: individual: FSR19 – globular clusters: individual: FSR25

1. Introduction

The confirmation of each new globular cluster (GC) of the Milky Way (MW) is a gift, as GCs are important tracers of the field stellar populations and provide valuable evidence relating to the formation of the Galaxy. Metal-poor GCs located in the Galactic bulge in particular may likely be the oldest objects in the Galaxy (e.g., Barbuy et al. 2016).

The new catalog of star clusters, associations, and candidates in the Milky Way by Bica et al. (2019) contains about 10 000 star clusters, including many new low-luminosity candidates discovered by the VVV survey (e.g., Minniti et al. 2017a; Camargo 2018; Garro et al. 2020, 2021), significantly increasing the bulge GC sample. While many of these have already been confirmed or discarded by follow up studies (e.g., Gran et al. 2019; Palma et al. 2019; Piatti et al. 2018), it is clear that the bulge GC census is incomplete (Ivanov et al. 2005; Minniti et al. 2017b).

In this work, we used the VISTA variables in the Via Láctea Extended Survey (VVVX), Two Micron All Sky Survey (2MASS), and Gaia EDR3 photometry survey data to study the properties of two MW bulge GC candidates. These are FSR 19 and FSR 25, first discovered by Froebrich et al. (2007) and located at (l, b) = 5.499, 6.071 deg and 7.534, 5.649 deg, respectively. Froebrich et al. (2007) searched for new star clusters in the MW using 2MASS, Skrutskie et al. (2006), presenting 1021 new candidates, with FSR 19 and FSR 25 among them. Buckner & Froebrich (2013) developed an automatic method to estimate distances and reddenings to 378 previously known open clusters and 397 new cluster candidates from Froebrich et al. (2007). This technique was based on JHK photometry alone and relied on models for the foreground contamination. The estimated distances to FSR 19 and FSR 25 were 3.80 kpc and 3.60 kpc, respectively, and therefore presumably away from the MW bulge. Kharchenko et al. (2013) combined kinematic and photometric membership to determine physical parameters for a large sample of star clusters in a homogeneous way. In particular, they obtained D = 5.98 kpc and M_KS = −7.96 mag for FSR 19, and D = 6.64 kpc and M_Ks = −8.80 mag.
Fig. 1. Zoomed-in image of the clusters in both optical (left) and near IR (right) for FSR 19 (upper frame) and FSR 25 (bottom frame). The middle frame shows the complex bulge region where the clusters are located. The position of the Galactic centre is shown with a white X. The red rectangle is the region covered by the VVV Survey, and the top part corresponds to the extension VVVX. The total field of view shown is 20X10 sqdeg. The Galactic major and minor axes are shown with dotted red lines.

Table 1. Derived parameters of FSR 19 and FSR 25 clusters.

| Parameter     | FSR 19     | FSR 25     |
|---------------|------------|------------|
| l (deg)       | 5.499      | 7.534      |
| b (deg)       | 6.071      | 5.649      |
| RA(J2000)     | 17:35:38.4 | 17:41:43.2 |
| Dec(J2000)    | -21:04:12  | -19:34:16  |
| μα* [mas yr⁻¹] | -2.50 ± 0.76 | -2.61 ± 1.27 |
| μδ [mas yr⁻¹] | -5.02 ± 0.47 | -5.23 ± 0.74 |
| AKs [mag]    | 0.19 ± 0.07 | 0.27 ± 0.01 |
| E(J − Ks) [mag]| 0.38 ± 0.06 | 0.54 ± 0.09 |
| (m − M)₀ [mag]| 14.29 ± 0.08 | 14.23 ± 0.06 |
| D [kpc]       | 7.2 ± 0.7   | 7.0 ± 0.9   |
| MKs [mag]    | -7.72       | -7.31       |
| MV [mag]     | -4.62       | -4.21       |
| [Fe/H] [dex] | -0.5        | -0.5        |
| Age [Gyr]    | 11          | 11          |
| R_c [pc]     | 2.76 ± 0.36 | 1.92 ± 0.59 |
| R_t [pc]     | 5.31 ± 0.49 | 6.85 ± 1.78 |

for FSR 25 and slightly less for FSR 19. However, we use VVVX and 2MASS near-infrared (NIR) photometry, which is less sensitive to extinction. A summary of the basic parameters derived for these clusters in this work are listed in Table 1.

In this paper we confirm FSR 19 and FSR 25 as genuine low-luminosity members of the Galactic bulge GC system, measuring their parameters and estimating their ages based on NIR data from the 2MASS and VVVX Survey, combined with Gaia EDR3 optical data. In Sect. 2, a description of the dataset is given. Section 3 describes the physical characterisation of the derived parameters such as reddening, extinction, colour-magnitude diagrams (CMDs), ages, metallicities, luminosities, and radii. In light of our findings, we discuss their physical nature in Sect. 4, and finally we summarise our conclusions in Sect. 5.

2. Gaia EDR3, 2MASS, and VVVX data.

Non-uniform and severe extinction towards the bulge of our Galaxy (e.g., Schlafly & Finkbeiner 2011; Alonso-García et al. 2017, 2018) is undoubtedly a major issue in photometric studies. Although far less so than in the optical wavebands, NIR observations do suffer from this effect. From the already completed VVV Survey, exquisite extinction maps have been derived (Alonso-García et al. 2017; Surot et al. 2020) which allow for a very detailed and homogeneous correction.
The VVVX Survey (Minniti 2018) maps the Galactic bulge and southern disc in the NIR with the VIRCAM (VISTA InfraRed CAMera) at the 4.1 m wide-field Visible and Infrared Survey Telescope for Astronomy (VISTA; Emerson & Sutherland 2010) at the European Southern Observatory (ESO) Paranal Observatory (Chile). In the Galactic bulge, the VVVX Survey covers about 600 sqdeg using the J(1.25 μm), H (1.64 μm), and Ks(2.14 μm) NIR passbands. The VVVX Survey data reduction and the archival merging were carried out at the Cambridge Astronomical Survey Unit (Irwin et al. 2004)(CASU) and VISTA Science Archive (VSA) at the Wide-Field Astronomy Unit (WFAU), using the VISTA Data Flow System (Cross et al. 2012). In order to deal with the high crowding in this region, we extracted the point spread function (PSF) photometry using the pipeline described in Alonso-García et al. (2018).

The 2MASS survey is an all sky survey in the NIR bands J(1.25 μm), H(1.65 μm), and Ks(2.16 μm) (Cutri et al. 2003; Skrutskie et al. 2006) observed with two dedicated telescopes located in both hemispheres working synchronously. The integration time of 7.8 s reaches 15.8, 15.1, and 14.3 mag at the J, H, and Ks bands, respectively. The data were processed by 2MASS production Pipe-line system 2MAPPS (Skrutskie et al. 2006).

Gaia EDR3 contains the apparent brightness in G magnitude for over $1.8 \times 10^9$ sources that are brighter than 21 mag, and for $1.5 \times 10^9$ sources, passbands $G_{BP}$ covering 330–680 nm, and $G_{RP}$ covering 630–1050 nm that are not available in DR1 and DR2. PMs are available for $1.4 \times 10^9$ sources with an accuracy of $0.02 \text{mas yr}^{-1}$ for sources brighter than $G = 15 \text{mag}$, $0.07 \text{mas yr}^{-1}$ for sources brighter than $G = 17 \text{mag}$, and $0.5 \text{mas yr}^{-1}$ for sources brighter than $G = 20 \text{mag}$ (Gaia Collaboration 2020). The data were processed by the Gaia Data Processing and Analysis Consortium (DPAC).

We used a combination of the NIR VVVX Survey together with 2MASS and optical Gaia EDR3 data. As we show in Sect. 3, this robust combination opens new windows for studies of highly reddened and crowded regions such as the MW bulge.

We distilled a sample of a relatively contaminant-free catalogue of most probable clusters members, drawn from the precise astrometry and PMs from Gaia EDR3, and also combining 2MASS+Gaia and VVVX+Gaia catalogues in a way to incorporate both the bright and the fainter sources. Stars with $Ks < 11 \text{mag}$ are saturated in VVVX photometry and we discarded all nearby stars with a parallax $>0.5 \text{mas}$. Consequently, we scrutinised the vector PM (VPM) diagrams in Fig. 2, which shows a sharp peak with respect to the stellar background distributions; we ascribed this to the clusters’ mean PMs. These mean PMs as measured by Gaia EDR3 are $\mu_\alpha = -2.50 \pm 0.76 \text{mas yr}^{-1}$, $\mu_\delta = -2.61 \pm 1.27 \text{mas yr}^{-1}$ and $\mu_\alpha = -5.02 \pm 0.47 \text{mas yr}^{-1}$, $\mu_\delta = -5.23 \pm 0.74 \text{mas yr}^{-1}$ for FSR
19 and FSR 25 with respect to the brighter clusters’ PMs. We showed the VPM diagrams for brighter sources with \( Ks < 12 \) mag matched in the 2MASS+Gaia catalogues and the fainter sources, with \( Ks > 12 \) matched in the VVVX+Gaia catalogues in Fig. 2 (upper frame) for FSR 19 and Fig. 2 (bottom frame) for FSR 25. For the rest of our analysis, we selected stars within 2.0 mas yr\(^{-1}\) of these mean VPM values (after extensive testing of the selection criteria: 1.0, 1.5, 2.0, 2.5 mas yr\(^{-1}\) ). Stars outside of the 2.0 mas yr\(^{-1}\) circle selected on the VPM diagrams but within the selected radius of 1.2` of the cluster’s centre, shown in yellow in Fig. 2, are likely stars from the surrounding field. We did not consider them in the following analysis.

3. Physical characterisation of the GC candidates FSR 19 and FSR 25

Both clusters are projected next to complex filamentary dark nebulae (FSR 19 in the vicinity of Barnard 268 and FSR 25 next to Barnard 276). Therefore, it is important to first consider the possibility that they could merely be background fluctuations. Figure 3 shows the optical Gaia source density maps of these regions. Clearly, an excess of stars above the background value is found at the location of FSR 19 and FSR 25. We select member stars within a circle of \( r = \sim 1.2` \) centred at the coordinates \((\alpha, \delta) = (263.915, -21.061)\) deg and \((265.437, -19.596)\) deg for FSR 19 and FSR 25, respectively. These correspond to \((l, b) = (5.499, 6.071)\) deg and \((7.534, 5.649)\) deg.

We compared the stellar densities of these central regions with those of randomly selected background fields of equal radii, which are labelled as a and b in Fig. 3. In support of the GC nature of the candidates, the luminosity functions (LFs) of the cluster regions are very different from those of the background fields. We tested other control fields as well, and in all cases there is a clear peak of red clump (RC) stars for the cluster regions, which is never seen in the background fields. Overdensities caused by the presence of RC stars are well studied features of bulge GCs and a strong indicator of their nature. RC stars are also tracers of prominent structures in the inner regions of the Galaxy (Gonzalez et al. 2015); in our case, our kinematic selection eliminates most field RC giants.

Figure 4 shows the luminosity functions in the G and Ks bands for a 1.2` radius field centred on the clusters for all objects with \( J - Ks > 0.7 \) mag for the PM-selected red giant members. These LFs clearly reveal the peaks due to the cluster’s RC giants at \( Ks = 12.85 \pm 0.05, 12.88 \pm 0.06, \) and \( G = 17.10 \pm 0.01, \) and \( G = 17.30 \pm 0.02 \) for FSR 19 and FSR 25.

A well-established indicator to estimate the probability of two samples being drawn from the same parent distribution is the Kolmogorov-Smirnov (KS) test. For our study, the null hypothesis (no difference in the origin of both samples) means that cluster and background field are statistically indistinguishable. The alternative hypothesis implies that the two LFs represent samples with different origins. The cumulative LF for each of the clusters with their respective comparison fields is shown in Fig. 5. The results of the KS test favoured the alternative hypothesis with a p-value of <0.0001 for both Ks and G mag LFs. Again, this points to a genuine GC nature of these targets.

In Figs. 6–9, we show the colour-magnitude diagram (CMD) of the cluster members that were selected from their PMs. The red giant branches (RGBs) are narrower, redder, and fainter than what is observed for the neighbouring fields. This supports the argument that the field stars are mainly coming from the foreground, less reddened populations in the Galactic plane (Garro et al. 2020), and we can hereto rule out any form of low-extinction window that could be disguised as stellar overdensities (e.g., Minniti et al. 2018; Saito et al. 2020). There remain some contaminating sources with colours \((J - Ks) > 0.2 \) mag and \((BP-RP) > -0.5 \) mag, which correspond to stars from the distant disc or the bar, or even the extended-cluster horizontal branches.

We corrected for extinction following the maps of Gonzalez et al. (2012) and Surot et al. (2020) in the NIR and Schlafly & Finkbeiner (2011) in optical wavebands. We used the RC calibration of Ruiz-Dern et al. (2018) where the absolute magnitude in the Ks-band is \( M_{Ks} = (1.601 \pm 0.009) \) and the mean colour is \( (J - Ks)_{0} = (0.66 \pm 0.02) \). The comparison with our previously derived values for the RC magnitudes and colours result in the following colour excesses and absorptions:

\[
E(J - Ks) = (0.38 \pm 0.06), \quad (0.54 \pm 0.09) \quad \text{and} \quad A_{Ks} = (0.19 \pm 0.07), \quad (0.27 \pm 0.01) \text{mag}, \quad \text{for FSR 19 and FSR 25, respectively.}
\]

Distance moduli can then be estimated by adopting \( A_{Ks}/E(J - Ks) = 0.5, \) which yields \( (m-M)_{0} = (14.29 \pm 0.08) \) mag and \( (14.23 \pm 0.07) \) mag for both FSR 19 and FSR 25. This translates into distances to the clusters \( D = (7.2 \pm 0.7) \) kpc and \( (7.0 \pm 0.6) \) kpc for FSR 19 and FSR 25.

In order to test the robustness of our result, we used the theoretical RC magnitude calibrations from Alves et al. (2002)
Gaia (Schlafly & Finkbeiner 2011) and the colour excess in the these translate into Gaia G extinction values (EDR3 optical photometry. Adopting the previously derived Gaia bands, BP and RP respectively. Assuming a 7.0 kpc for FSR 19 and for (−m − M)0 = (14.23) mag, (14.17) mag, D = 7.0 kpc, 6.8 kpc for FSR 25.

In addition, we also double checked our parameters using Gaia EDR3 optical photometry. Adopting the previously derived extinction values (A_V = 1.4 from Schlafly & Finkbeiner 2011) and the colour excess in the Gaia bands, BP and RP E(BP − RP) = 0.48 mag and 0.68 mag were derived.

We therefore used these values to estimate the distance modulus of (m − M)0 = 14.12 mag and 14.31 mag, corresponding to D = 7.0 kpc and 7.3 kpc for FSR 19 and FSR 25, respectively. These values are in very good agreement with those obtained from the NIR photometry.

We made use of theoretical isochrones to estimate the clusters’ metallicities and ages. Among the different models available, both PARSEC (Marigo et al. 2017) and Dartmouth (Dotter et al. 2008) isochrones seem to have gained acceptance for GC studies.

We present both sets of models for NIR (VVVX) and optical (Gaia) CMDs. The best fits are shown in Figs. 6–9, for which we used the derived distances and extinction values as explained above. Once these parameters were fixed, we over-plotted isochrones of different ages and then proceeded to vary the metallicity once an approximate age was derived. We note that this very small numbers are usually a rough estimate prone to relatively large errors arising from distance and extinction determination and especially small numbers affecting the areas of interest. This is also the case for us since the main-sequence turn-off is just below the limiting magnitude of the available photometry. In spite of this, Figs. 6–9 all support the GC nature of the targets, which is the main goal of this work.

Yet another parameter places FSR 19 and FSR 25 well in the regime of GC-candidates, namely their integrated luminosities. For this purpose, we added the luminosities of all stars from the PM decontaminated diagrams using a GC size of 6′. This very likely considers only RGB stars and neglects fainter, more numerous K and M dwarfs that could be cluster members. For FSR 19, we obtained a total luminosity M_Ks = −7.72 mag, which translates to an absolute visual magnitude M_V = −4.62 mag assuming a mean colour (V − K_s) = 3.1 mag given by Bruzual & Charlot (2003) assuming the Chabrier initial mass function with an age of 11 Gyr and metallicity of Z = 0.02 for the cluster. Similarly, FSR 25 shows a total luminosity of M_Ks = −7.31 mag, which corresponds to M_V = −4.21 mag. We emphasise that these values should be considered as rough lower limits for the luminosities. At a first glance, FSR 19 and FSR 25 could be close to the low-luminosity tail of the MW GCLF (M_V = (−7.4 ± 0.2) mag (Ashman & Zepf 1998; Harris 1991).

Additionally, we searched for more evidence of an old stellar population that could be related to the targets. RR Lyrae are well-known population II tracers and are usually found in GCs. However, FSR 25 does not host a known RR Lyrae population and there is only one potential candidate within the tidal radius of FSR 19. This is likely a fundamental mode pulsator or RRAb, has the ID 4118273101762688128, and is located at RA = 17:35:41.22; Dec = −21:02:16.9 (J2000). Its proper motion

Fig. 5. Cumulative probability of both targets’ clusters are shown with their respective comparison fields. For FSR 19, the fluctuations in the background comparison fields seem fairly uniform and vary in the field of FSR 25. The D statistic and calculated p value are shown in the legend of each panel.
Fig. 6. Optical and NIR PM decontaminated CMDs for FSR 19 cluster fitted with (Dartmouth isochrone, left panel; PARSEC isochrone, right panel). In all cases, the RGB stars are narrow, fainter, and redder than the fields. The position of RR Lyrae found in the cluster is indicated with the blue symbol.

$\mu_{\alpha} = 3.71 \pm 0.21 \text{ mas yr}^{-1}$; $\mu_{\delta} = -2.30 \pm 0.16 \text{ mas yr}^{-1}$) is consistent (within 3$\sigma$) with the mean proper motion estimated for FSR 19. Its mean $G$ magnitude is $17.517 \pm 0.025$ and colour BP–RP = 1.32. With a period $P = 0.4436972 \pm 0.0000003$ days it is also visible in our VVVX photometry, with $J = 15.42$, $H = 15.97$, and $K_s = 14.93$ mag. The expected number of RRab in these fields relatively far from the centre is estimated to be about 55 RRab per square degree, which gives an expected frequency of 0.00009 RRab inside the tidal radius of FSR19 (Navarro et al. 2021).

RR Lyrae stars are powerful distance indicators. We adopted the period-luminosity relation of Muraveva et al. (2018) to estimate a distance to FSR 19, which turns out to be $D = 7.2 \pm 0.22 \text{kpc}$. This value is in excellent agreement with the distance measured from the other methods (see above) and provides strong evidence to suggest that the RR Lyrae is a cluster member.

Finally, we also computed the radial profiles for both FSR 19 and FSR 25 with the purpose of ascertaining the true physical sizes of these targets. We adopted the centres as documented in Table 1 for FSR 19 and FSR 25.

We divided our sample into circular annuli with increasing radii of 0.067′, out to an outer radius of 2′. This provided an adequate balance between enough statistics of member stars and least contamination from interlopers (mostly foreground stars). Thereafter, the surface density was plotted as a function of the mean distance to the circular annulus. The King profile (King 1962) is a long-used function to fit this density, even if the true shape is likely more complex. However for the purpose of establishing the GC nature and to compare the resulting parameters with those of similar compact systems, we provide the results using this approach. Figure 10 shows that a King profile is indeed a good representation of the projected number density. Models under-predicting the central density have been interpreted as
an indication of GCs undergoing core-collapse processes (e.g., Zocchi et al. 2016). For our study, the innermost radial bins show a slight deficiency of member stars. Although this could hint to disruption processes, low number statistics and centre estimations are crucial and need to be improved before such a claim can be supported. For FSR 19, we obtained $r_c = 1.30'$, which at the adopted distance corresponds to $2.76 \pm 0.36$ pc. Similarly, $r_t = 2.50'$, which corresponds to $5.31 \pm 0.49$ pc. For FSR 25, the resulting sizes were $r_c = 0.87'$ (or $1.92 \pm 0.59$ pc) and $r_t$ of $3.10'$ ($6.85 \pm 1.78$ pc). These values are consistent with the typical MW GC radii listed in the 2010 Harris (1996) compilation.

4. Discussion

As explained in Sect. 3, both targets are located in the vicinity of filamentary dark nebulae, and the complex extinction pattern in this region of the MW means it is important to consider if FSR 19 and FSR 25 could simply be overdensities caused by an inhomogeneous differential extinction (see e.g., Dutra et al. 2002; Koposov et al. 2007; Bica & Bonatto 2011; Moni-Bidin et al. 2011), or even real clusters that are partially occulted by a dark cloud (such as the recently discovered giant GC FSR1758: Cantat-Gaudin et al. 2018; Barbá et al. 2019). Exploring the existing optical extinction maps (Schlegel et al. 1998; Schlafly & Finkbeiner 2011), we find no indication of reduced extinction in the fields of FSR 19 and FSR 25 that would suggest this possibility.

Fortunately, the multi-colour NIR photometry enables us to detect and map such windows of low extinction, which are interesting in their own because they allow us to pierce through the interstellar medium and probe the far sides of our Galaxy (e.g., Dutra et al. 2002; Saito et al. 2020; Minniti et al. 2018). However, we find no such NIR window of low extinction to match the positions of these clusters, reinforcing their genuine cluster nature.
It is interesting to note that Gran et al. (2019) discarded FSR 19 and FSR 25 as true GCs based on Gaia DR2 data. We note that the automatic procedure they adopted is sensitive to GCs that have distinct halo kinematics, but could in fact miss true GCs if their motions are similar to the MW bulge. We do not have radial velocities for our targets, and VVVX PMs are not available for these clusters because the time baseline of observations is still too short (~two years). However, we provide evidence for a number of physical tests that all point to the same conclusions: the presence of a real overdensity; the striking difference in the LF of their stellar populations compared to the field from a strong KS test; the appearance of the CMDs; the RR Lyra associated with FSR 19; the ages and metallicities, structural parameters, and the Gaia PMs signatures are clear, and they confirm the real GC nature.

Thus, in the light of all these independent findings, it seems that both FSR 19 and FSR 25 are genuine bulge GCs. They could very well belong to the few surviving GCs that formed from the initial protogalactic collapse of the Galaxy. Many of these GCs have undergone disruptive processes. Our results are consistent with the work of Kharchenko et al. (2013), who measured the tidal radius of these new clusters to be within 5–10 pc. Later, Kharchenko et al. (2016) measured some properties of the FSR sample using 2MASS and obtained a distance of 5.98 kpc and absolute luminosity $M_{K_s} = -7.96$ mag for FSR 19, which is in agreement with the measurements we obtained at a distance of $D = 7.2 \pm 0.7$ kpc and an absolute luminosity of $M_{K_s} = -7.72$ mag; similarly, for FSR 25 they obtained a distance of 6.67 kpc and an absolute luminosity of $M_{K_s} = -8.80$ mag, and while the distances agree within 3σ, the total luminosity is 1.5 mag brighter than ours, which could be an effect of the sample size used. The initial distance measurements done by Buckner & Froebrich (2013) using the $H$ band underestimated the actual distances to the two targets by 3.4 kpc. In addition,
we measured the ages, metallicities, core and tidal radii, distance moduli, and the absolute visual magnitude of the clusters, as shown in Table 1. Considering that we relied only on the isochrones to estimate the ages of these clusters, we caution that the true ages of these clusters are uncertain, but in accordance with bulge globular clusters placed approximately between 10 and 14 Gyr. FSR 19 and FSR 25 are both bulge GCs located about 8 deg from the Galactic centre, and their derived integrated luminosities show that these clusters are lying at the low end of the MW GC luminosity function. This partly explains why they were difficult to confirm in previous studies.

5. Conclusions

The combination of the clean photometric catalogue we obtained from the VVVX, *Gaia* EDR3, and 2MASS archives allowed us to demonstrate that FSR 19 and FSR 25 are both genuine low-luminosity GCs. For FSR 19, we find a reddening of $E(J - K_s) = 0.38 \pm 0.06$ mag and an extinction of $A_{K_s} = 0.19 \pm 0.07$ mag, and we measure a distance of $D = 7.2 \pm 0.7$ kpc based on the mean magnitudes of the RC: $K_s = 12.85 \pm 0.05$ mag. We computed a total luminosity of $M_{K_s} = -7.72$ mag and measured its structural parameters to be $r_c = 2.76 \pm 0.36$ pc and $r_t = 5.31 \pm 0.49$ pc. Based on the fit to theoretical isochrones, we also estimate a metallicity of $[\text{Fe/H}] = -0.5$ dex and an age $t$ of $\sim 11$ Gyr for this cluster.

For the GC FSR 25, we obtain a reddening of $E(J - K_s) = 0.54 \pm 0.09$ mag and an extinction of $A_{K_s} = 0.27 \pm 0.01$ mag, and we measure a distance $D = 7.0 \pm 0.6$ kpc based on the mean magnitudes of the RC: $K_s = 12.88 \pm 0.06$ mag. We computed a total luminosity of $M_{K_s} = -7.31$ mag and measured its structural parameters to be $r_c = 1.92 \pm 0.59$ pc and $r_t = 6.85 \pm 1.78$ pc. Based on the fit to theoretical isochrones, we also estimate a metallicity of $[\text{Fe/H}] = -0.5$ dex and an age $t$ of $\sim 11$ Gyr for this cluster.
Our newly confirmed clusters will indeed help increase the sample size of the MW GC system, especially in the innermost regions where they are most difficult to detect. Further work, including spectroscopic observations, is needed to compare the chemical signatures and orbital parameters for these new bulge globular clusters.

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Fig. 10. Radial profile distribution of the FSR 19 and FSR 25 stellar densities as a function of radii fitted with a profile (King 1962). The black line represents the fit.