RR Lyrae Stars in the Inner Galactic Globular Clusters

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The innermost Galactic globular clusters are poorly known. Strong reddening in the line of sight and high stellar densities in the surrounding fields are among the main drawbacks to study these type of objects when we look at low latitudes. The Vista Variables in the Vía Láctea (VVV) survey is contributing to solve the situation. Covering most of the Galactic Bulge and providing high-resolution images in the near infrared, the VVV survey successfully helps to overcome the difficulties we face when observing these clusters of stars. Not only that, but VVV multi-epoch observations enable us to look for variable stars in the sampled globular clusters. Paramount among these variable stars are the RR Lyrae, because they are frequent in globular clusters and their tight period-luminosity relation has promoted their use as standard candles. We are searching for the presence of RR Lyrae variable stars in the inner Galactic globular clusters that lie inside the area surveyed by the VVV. The newly detected RR Lyrae stars, along with the ones reported in other previous studies and surveys, are then used to learn about these inner Galactic globular clusters and to more properly constrain the physical parameters of these poorly known sample of stellar aggregates.

1 Introduction

The Milky Way Galaxy contains more than 150 known globular clusters (GCs) (Harris, 1996), plus a few more new candidates (Minniti et al., 2011; Moni Bidin et al., 2011; Minniti et al., 2017a), most of which lie inside the Solar circle. However, the study of many of the GCs located in the innermost region of the Galaxy has been historically neglected due to two main reasons: 1) the significant interstellar reddening that the GCs at low-latitude lines of sight suffer, and 2) the high stellar densities present in the field when we look towards the Galactic Bulge. The first of these problems makes some of these GCs invisible in optical wavelengths. For the ones we can detect, their color-magnitude diagrams (CMDs) are usually not very deep, showing only the brightest sequences, which are usually broadened due to differential extinction along the GC field of view. This limits significantly the ability of these CMDs as instruments to learn about the physical characteristics of these objects. The second drawback makes it difficult to separate clusters from field stars, especially for the cases of poorly-populated GCs, which are quite common among the ones in the innermost Galaxy. The VVV survey is helping to overcome these difficulties.

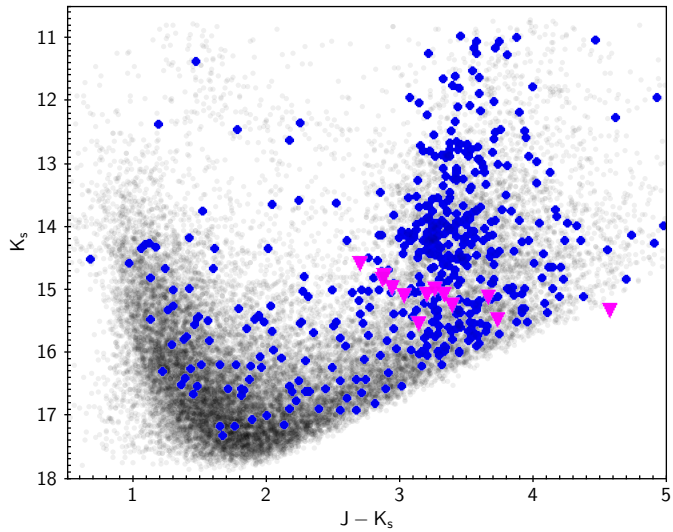

Fig. 1: K_s vs. $J - K_s$ CMD of 2MASS-GC02, one of the most reddened and poorly-populated of the VVV globular clusters. The smaller-sized, translucent dots (in black in the online color version of the plot) show all the sources inside the tidal radius of the GC. Sources from the field clearly dominate, with red giant stars from the Galactic Bulge superimpose with the red giant branch of the GC, and blue stars from the main sequence of the foreground Galactic Disk are also numerous. The RGB of 2MASS-GC02 is more clearly seen when plotting only sources inside the half-light radius of the GC (larger dots, in blue in the online color version of the plot), although the number of sources is not high now, and some contamination from the surrounding field is still present. Using their tight period-luminosity relation, the numerous RR Lyrae stars discovered inside this GC (solid inverted triangles, in magenta in the online color version of the plot) allow us to better constrain the distance and reddening to 2MASS-GC02. Figure adapted from Alonso-García et al. (2015).

2 The VVV Survey

The VVV is one of the six ESO public surveys that started in 2010 with the 4.1m VISTA telescope, located in Cerro Paranal, Chile (Minniti et al., 2010; Saito et al., 2012). The VVV survey observed for 6 years an area of 562 square degrees in the Galactic Bulge and an adjacent region in the inner Galactic Disk. Nowadays, its extension, VVV-X, is observing a region in the inner Galaxy which is 3 times bigger. The near-infrared camera installed in the telescope provides a wide field of view, 1.5×1.1 square degrees in the sky per pointing, with a resolution of $0.34''$ per pixel. The VVV surveys the inner Galactic area in five wide-band near-infrared filters, Z, Y, J, H, and K_S, although for the multi-epoch observations only the K_S filter is used. Observations in the near-infrared have the advantage of diminishing to a great extent the effects of extinction ($A_{K_s} \sim 0.1 A_V$). This way, thanks to its wide-field, high-resolution, near-infrared observations, the VVV survey is successfully contributing to the analysis of the stellar populations in the inner Galactic regions, including the GCs located there.

There are 36 known Galactic GCs located in the area surveyed by the VVV, and many new candidates have been recently discovered thanks to the VVV (Minniti et al., 2011; Moni Bidin et al., 2011; Minniti et al., 2017a,c). However, even though the deep near-infrared VVV observations allow the systematic observation of these heavily reddened GCs, and even though we have developed pipelines to efficiently extract the PSF photometry to take full advantage of the high-resolution and high-quality VVV images in heavily crowded regions like the environments in the inner Galaxy (Alonso-García et al., 2015, 2017), the high stellar densities of the Galactic Bulge and inner Galactic Disk complicates the precise interpretation of the CMDs that we can build for the VVV GCs. It is difficult to separate between members of the GCs located in these regions, especially the most poorly-populated ones (see Figure 1). Fortunately, the multi-epoch observations of the VVV survey allow for the use of other means that are being used to learn about these star clusters. Proper-motion techniques are helping to efficiently decontaminate the CMDs of the GCs from stars in the surroundings (Contreras Ramos et al., 2017), although for objects with similar kinematics as the stars in the Bulge, a broader time baseline is still needed for more precision. The other use of the multi-epoch observations is to search for variable stars, especially those that can be used as standard candles, like the RR Lyrae stars.

3 RR Lyrae Stars in the Inner Galactic Globular Clusters

RR Lyrae variable stars are radial pulsators located in the region where the instability strip crosses the horizontal branch (Catelan, 2009). Their high number among old metal-poor stellar populations, relatively high brightness, and well-calibrated period-luminosity relation have promoted their use as standard candles. Interestingly for our science, RR Lyrae stars are quite numerous in many of the Galactic metal-poor clusters (Clement et al., 2001), and their period-luminosity relation is particularly tight in the near-infrared (Longmore et al., 1986, 1990; Catelan et al., 2004). Therefore, we can use the multi-epoch VVV photometry to search for these variable stars in the inner Galactic GCs, and their period-luminosity relation to derive more precisely such important physical parameters as the distance or extinction to these GCs. In fact, if a given VVV GC suffers from strong differential reddening, and the presence of these variable stars is highly significant in this GC, we can even use them to measure the extinction law in the line of sight towards this object (Alonso-García et al., 2015). We have started this characterization for some of the VVV GCs (Alonso-García et al., 2013, 2015), and intend to continue for the rest of the VVV and VVV-X GCs, including any new ones we can find in our analysis of the survey images (Minniti et al., 2017c,b).

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