Searching for variable stars in the VVV globular clusters

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Abstract. The VVV is currently surveying the central regions of the Milky Way at near-infrared wavelengths, including 36 known Galactic globular clusters. We already have data in several filters to generate their color-magnitude diagrams. We also have enough epochs to begin producing the light-curves of the cluster stars and look for any possible member variable stars. We are especially interested in RR Lyrae stars, since they are abundant in Galactic globular clusters, and the period-luminosity relation they show at near-infrared wavelengths, can help enormously in providing accurate distances and reddenings for the most extincted and poorly studied inner Galactic globular clusters. We center our attention here in the preliminary analysis of three of these clusters: NGC 6441, Terzan 10 and 2MASS-GC02.

1. Introduction

The globular cluster (GC) system in the Milky Way is formed by around 150 known objects. The Galactic GCs are old systems, representing a fossil record of the Galaxy, and can provide us with interesting hints about its formation and its early evolution. As such, a proper understanding of the Galactic GCs physical parameters is of considerable importance. Photometrically, the tools more used to study the Galactic GCs and get reliable values for their distances, metallicities, ages, extinguions and other characteristics, have been the analysis of their color-magnitude diagrams (CMDs) and the analysis of the light-curves of their member variable stars. The most common and characteristic variable type of star in GC is the RR Lyrae type. These variables lie in the instability strip region that crosses the horizontal branch (HB) in the CMD of the cluster. RR Lyrae in Galactic GCs are classified in two main types according to the radial mode in which they pulsate: RRab (or RR0) pulsate in the fundamental radial mode, and RRc (or RR1) pulsate in the first overtone radial mode. An interesting characteristic of Galactic GCs in which RR Lyrae variables are present, is the so-called Oosterhoff dichotomy (Catelan 2009; Smith et al. 2011): the Galactic GCs tend toward clumping in two main groups, Oosterhoff I with shorter fundamental periods ($< P_{ab} >$ ~ 0.55 days) and Oosterhoff II with longer fundamental periods ($< P_{ab} >$ ~ 0.64 days), leaving
an almost empty gap at \( <P_{ab}> \sim 0.60 \) days. This dichotomy seems not to be present in the GC system of our neighbor galaxies.

Most of the Galactic GCs lie inside the Solar Circle, and a significant number of them are located towards the Galactic center. Observations towards low Galactic latitudes where most of the inner Galactic GC lie, are highly complicated by the considerable amount of extinction produced by the gas and dust present. Therefore the study of these GCs have been historically neglected, and their physical parameters have not been as accurately determined as the ones from the GCs located in other regions with low or negligible extinction (Alonso-García et al. 2012). This situation is rapidly changing with the advent of new state-of-the art telescopes and instruments to observe at near-infrared wavelengths where extinction is highly diminished \( (A_{K_s} \sim 0.1 A_V) \). One project that will greatly increase our knowledge of the inner Galactic GCs is the VVV survey.

2. VVV survey

The Vista Variables in the Via Lactea (VVV) survey is a currently ongoing ESO public survey (Minniti et al. 2010; Saito et al. 2010; Catelan et al. 2011). It is being conducted with the 4m Vista telescope located in the Cerro Paranal Observatory, in Chile. The Vista Telescope, and VIRCAM, its wide-field camera, are especially suited for near-infrared observations. The VIRCAM camera provides observations with a field of view of \( 1.48 \times 1.11 \) deg\(^2\) and a spatial resolution of 0.′′34 per pixel. The VVV is surveying 562 deg\(^2\) in the Galactic bulge (\(-10.0^\circ < l < +10.5^\circ \) and \(-10.3^\circ < b < +5.1^\circ \) ) and in an adjacent region of the Galactic disc (\(-65.3^\circ < l < -10.0^\circ \) and \(-2.25^\circ < b < +2.25^\circ \) ). A total of 36 known globular clusters lie in the region surveyed (Harris 1996; Minniti et al. 2010), plus new GC candidates are being discovered (Minniti et al. 2011; Moni Bidin et al. 2011). The survey is going to provide an atlas of the Galactic inner regions in five near-infrared filters (\(Z, Y, J, H,\) and \(K_s\)), and the light-curves in \(K_s\) for the objects found. Observations in the different filters have already been taken, along with observations in \(K_s\) in some different epochs, enough to produce preliminary CMDs and light-curves for the stars in the surveyed inner Galactic GCs. In the next sections we will focus in three of them: NGC 6441, Terzan 10 and 2MASS-GC02.

3. NGC 6441

NGC 6441 is not a common metal-rich globular cluster. In addition of having a short red HB, typical of metal-rich globular clusters, it has a blue HB component, as first found by Rich et al. (1997). It also presents a significant amount of variables, and among them a high number of RR Lyrae (Layden et al. 1999; Pritzl et al. 2001; Corwin et al. 2006), another rare characteristic in metal-rich clusters. Moreover these variables have unusually long periods, which has conducted to classify this GC, along with its twin, NGC 6388, in a completely new Oosterhoff type: the Oosterhoff III class. Differential reddening across its field makes its optical CMD difficult to interpret (Layden et al. 1999; Pritzl et al. 2001). But the different evolutionary sequences get narrower in the near-infrared CMD (see figure [1]), allowing the comparison with theoretical models. In figure [1] we have overplotted an old-age isochrone from the PGPUC library (Valcarce et al. 2012), the only one so far that provides isochrones in the Vista filter
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system. Using the values from iron content, distance, and color excess from the Harris catalog (Harris 1996), we can see that the agreement with the observational CMD is good. Unfortunately, our data does not allow us to accurately define the main-sequence turn-off point, and that way better constrain the age of the cluster.

Figure 1. Near-infrared CMD of the inner 2′ of NGC 6441. We have overplotted a 13 Gyr isochrone from the PGPUC library (Valcarce et al. 2012), with the iron content and moved using the distance and color-excess provided in the current version of the Harris catalog (Harris 1996).

Figure 2. Light-curves at different wavelengths for one of the already-known NGC 6441 variables, V42, a RRab type star. The $K_S$ light-curve comes from our VVV data, while the $I$ light-curve comes from the OGLE survey (Soszyński et al. 2011), and the $B$ and $V$ data from the study by Pritzl et al. (2001).
There are more than 150 variables already discovered in this GC, many of which are RR Lyrae. Although at near-infrared wavelengths their amplitude is reduced and the shape of the RRab light-curves is more sinusoidal (see figure 2), the quality of our data and the present sample of the light-curve (45 epochs for NGC 6441) allow us to look for more variables, and to characterize amplitudes, periods and mean magnitudes and colors. Using these parameters and the RR Lyrae period-luminosity relation in the near-infrared (Bono et al. 2001; Cassisi et al. 2004; Catelan et al. 2004), we will better define the extinction and distance to this GC.

4. Terzan 10 and 2MASS-GC02

Terzan 10 and 2MASS-GC02 are recently discovered, highly-extincted, low-mass, Galactic globular clusters (see Harris catalog). Terzan 10 was discovered by Terzan (1971), and 2MASS-GC02, even more recently, by Hurt et al. (2000), using data from 2MASS. The high extinction in their line of sight ($A_V \sim 7.5$ for Terzan 10, and $A_V \sim 16$ for 2MASS-GC02) makes them extremely faint and difficult to observe in the optical bands, but not at near-infrared bands.

The VVV data allow us to produce CMDs for these objects from the tip of the RGB down to the SGB region (see figure 3). But the analysis of the CMD here is complicated by other fact: their low number of member stars, and the high number of field stars in the regions they are located. In addition, differential reddening across the field of both GCs is clearly present in their near-infrared CMDs, despite reddening being highly diminished at these wavelengths, making their CMDs even more difficult to interpret.

In both cases the presence of RR Lyrae would help to better constrain these GC parameters. Borissova et al. (2007) found five RR Lyrae candidates for 2MASS-GC02, but no candidates have been reported so far for Terzan 10. We have not been able to confirm any of the candidates found in Borissova et al. (2007), but we have found 5 more RR Lyrae candidates in 2MASS-GC02, and for the first time, we have found 5 RR Lyrae candidates in Terzan 10 (see figure 4). Our selection of RR Lyrae candidates was done according to shape of the light-curve, period, and position in the CMD (see figures 3 and 4). At present, we have 33 epochs in 2MASS-GC02, which more than doubles the number of epochs in Borissova et al. (2007) study, and 90 epochs in Terzan 10. A surprising fact in these two GCs is their Oosterhoff classification. 2MASS-GC02 has a mean period for their RR Lyrae candidates of $<P> \sim 0.61$, which puts it in the Oosterhoff gap, while Terzan 10 has a mean period for their RR Lyrae candidates of $<P> \sim 0.65$, making it an Oosterhoff II candidate, which is strange for the reported metallicity of this object, $[Fe/H] = -1.00$ according to the Harris catalog (Harris 1996). These results, however, should be considered with care due to the small number of RR Lyrae candidates found so far in these two objects. We should also note that the reported metallicities from literature do not come from high-resolution spectroscopy. We are currently refining our analysis to try to find more RR Lyrae variables in these GCs and provide a more complete and statistically significant sample of variables for these two GCs.
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5. Conclusions

The VVV survey will provide a highly improved view of the GCs located in the inner regions of the Milky Way. The use of near-infrared wavelengths will allow us to penetrate through the gas and dust that hide these GCs and produced clean CMDs and high-quality light-curves for their variable members. Analysis of those CMDs and light-curves will let us infer more accurately these objects physical parameters and finally include the precise characteristics of this elusive sample in the studies of GC in our Galaxy. In these proceedings, and as examples of the coming analysis, we have shown the CMDs and the RR Lyrae light-curves for three GCs that lie inside the region surveyed: NGC 6441, Terzan 10 and 2MASS-GC02. A preliminary analysis from its

Figure 3. Near-infrared CMDs of the inner 2’ of Terzan 10, on the left, and of 2MASS-GC02, on the right. Our RR Lyrae candidates are marked as red triangles.

Figure 4. Light-curves of one of the new RR Lyrae candidates found in Terzan 10, on the left, and in 2MASS-GC02, on the right. Note that the current number of epochs in the Terzan10 candidate is almost three times the number in 2MASS-GC02, but at the end of the survey the number will be the same.
CMD show that NGC 6441 values for its distance and extinction agree quite well with current values from literature, while the CMDs from Terzan 10 and 2MASS-GC02 are more difficult to analyze. For these last two clusters, we have found new RR Lyrae variable candidates. Their Oosterhoff classification suffers from small statistics, but looks rather uncommon. Terzan 10 seems to be an Oosterhoff II type but with too high an iron content to belong to the group, while 2MASS-GC02 seems to be in the Oosterhoff gap, where very few Galactic GC lie.

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