Variable stars in the inner Galactic globular clusters with the VVV

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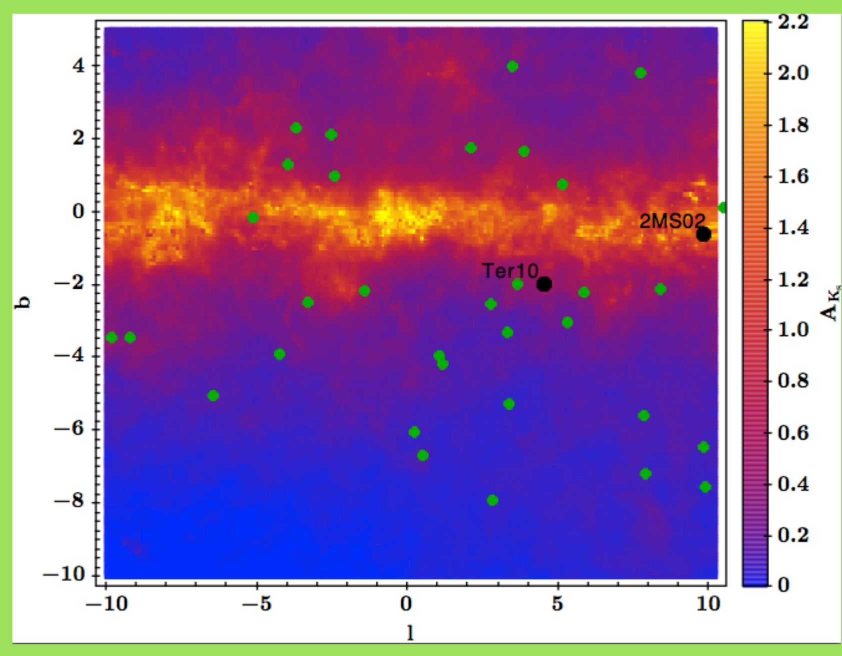
Abstract. **The Vista Variables in the Vía Láctea (VVV) survey has been observing the inner regions of the Milky Way during the last 6 years. There are 36 known globular clusters in the area surveyed. Most of them are poorly known, due to the elevated presence of gas and dust in their lines of sight. The VVV observations allow us not only to observe these globular clusters from their very centers out to their tidal radii and beyond at near-infrared wavelengths where the effect of extinction are highly diminished, but also to search for their variable stars thanks to the multi-epoch observations.**

In our contribution, we show the results of the analysis of the color magnitude diagrams of these clusters and the light-curves of their variable stars in two of these clusters, Terzan10 and 2MASS-GC02. We find the extinction towards both clusters to be elevated, non-standard, and highly differential. We also find both clusters to be closer to the Galactic center than previously thought. We finally discuss their Oosterhoff properties, and conclude that both clusters stand out from the dichotomy followed by most Galactic globular clusters.

We plan to extend a similar analysis to the rest of the Galactic globular clusters observed by the VVV survey

The VVV survey



Reddening map by Gonzalez et al. (2012) : http://mill.astro.puc.cl/BEAM/calculator.php

4m VISTA telescope in Cerro Paranal (Chile).

VIRCAM camera
16 detectors
Resolution: 0''.34 per pixel.
Total FOV: 1.48 x 1.11 deg^2
5 near-infrared filters: Z, Y, J, H, and K_s.

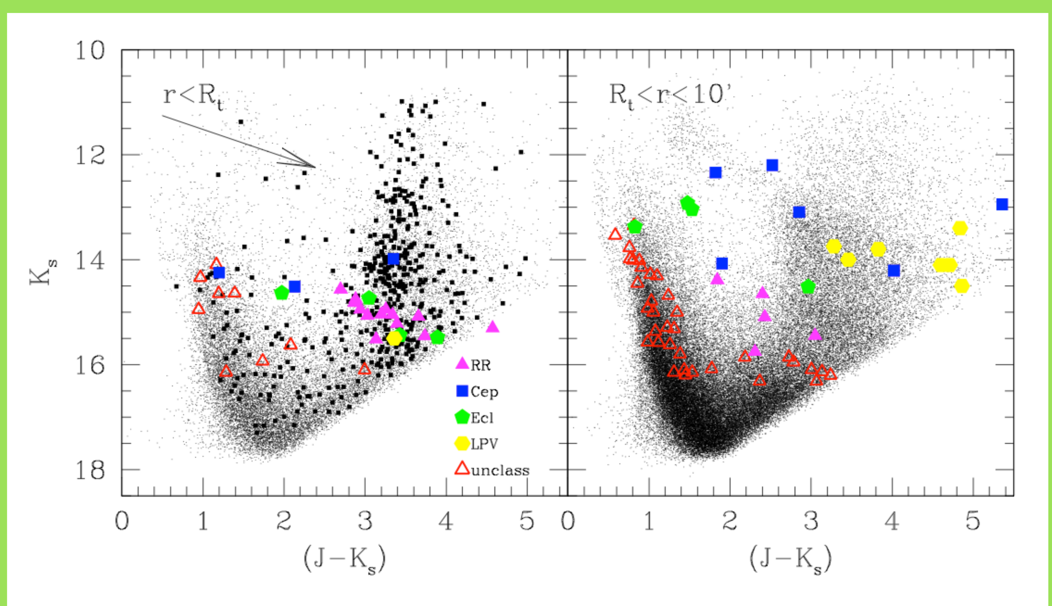
562 deg^2 surveyed in the inner Milky Way.
Galactic bulge:
-10.0° < l < +10.5°, -10.3° < b < +5.1°
Adjacent Galactic disc:
-65.3° < l < -10.0°, -2.25° < b < +2.25°

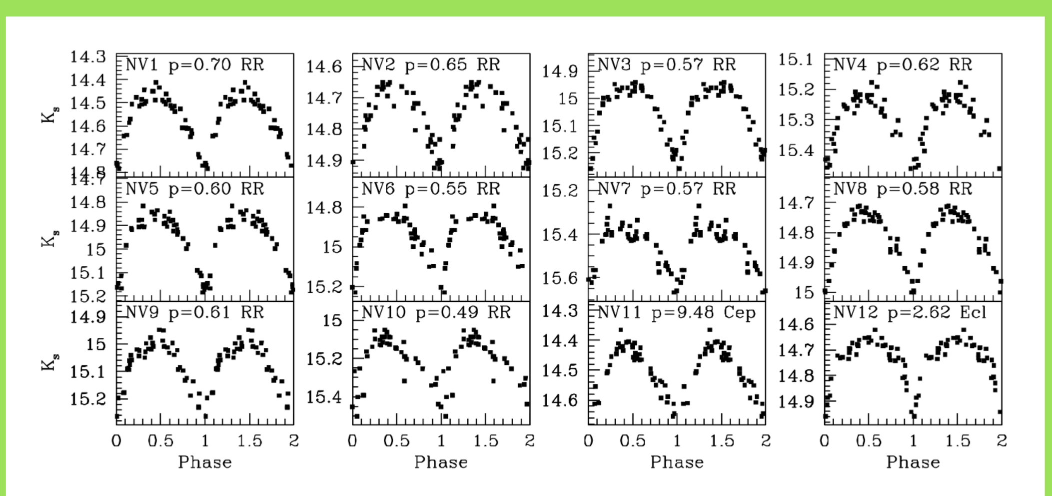
36 Galactic globular clusters in the area surveyed.

Variability campaign in K_s with ~100 epochs at the end of the survey.

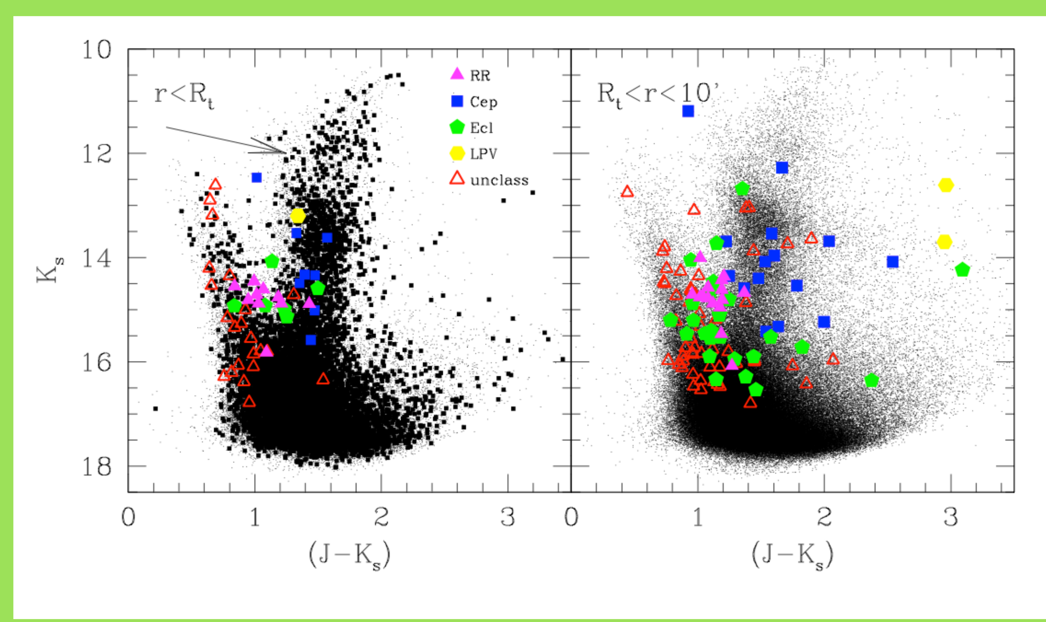
More information on the VVV:
https://vvvsurvey.org/

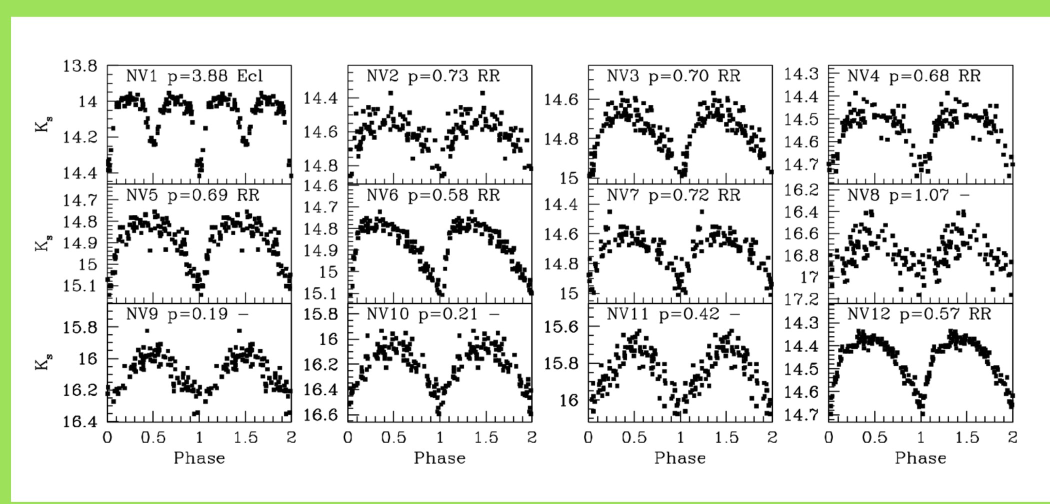
2MASS-GC02





Terzan10



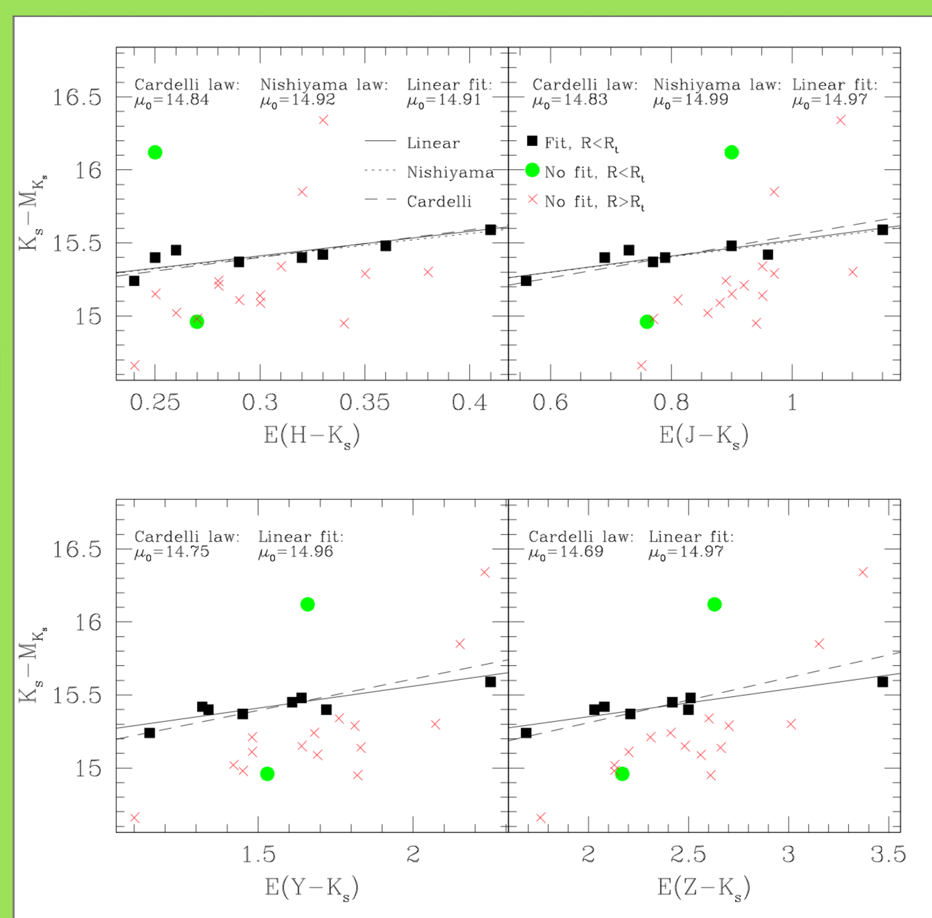


The top figures show the CMDs of both studied GCs out to their tidal radii, and of their surrounding region. The analysis of the CMDs is highly complicated by the poor population of both clusters, the presence of high differential and absolute extinction, and their lying in regions of elevated field stellar densities.

The presence of variable stars in these clusters, especially RR Lyrae stars, can help to greatly improve the accuracy of their physical parameters. We discovered **32 new variables inside the tidal radius of 2MASS-GC02** and 70 in a close surrounding region, while **for Terzan 10** we have found **48 new variables inside its tidal radius**, and 112 in its immediate surroundings. Their positions and types are presented in the top figures, and the phase-folded light curves of a sample of them, the closest to the GCs centers, are shown in the middle figures. Note that the current number of epochs in the Terzan 10 light curves is almost three times the number in 2MASS-GC02, but at the end of the survey the number will be the same.

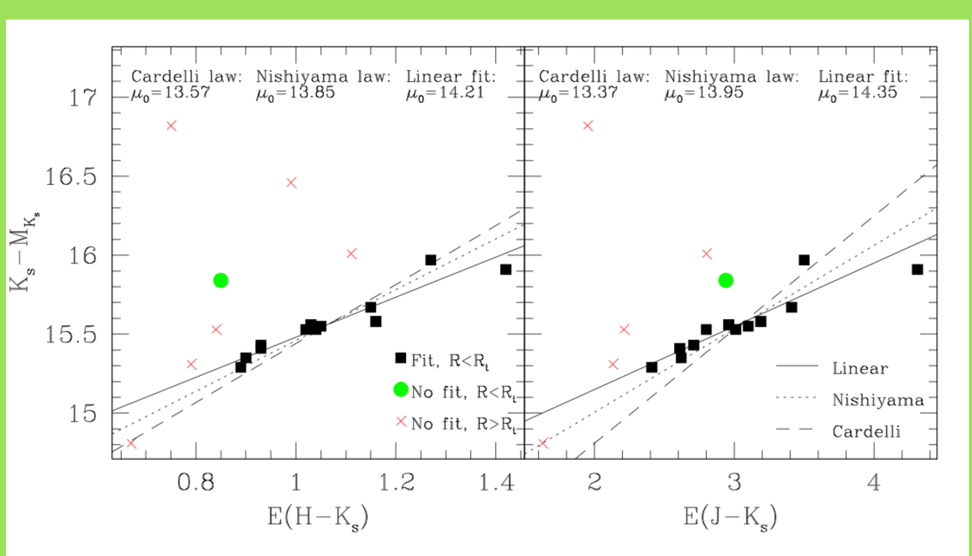
In both GCs, we found a significant number of **fundamental-mode RR Lyrae (12 in 2MASS-GC02, 8 in Terzan 10)** that we have used to accurately measure the extinctions and distances of these GCs, as we show in the bottom figures.

In the tables below, we show that **both clusters are closer to the Galactic center** than previously thought. We have also found **Terzan 10 to be beyond the Galactic center**, making it the only currently known GC to be on the far side of the Galactic bulge. **Extinction** towards both clusters is elevated (especially towards 2MASS-GC02) and highly differential, and it **follows a non-standard law,** with values for the selective-to-total extinction ratios similar to those quoted by Nishiyama et al. (2009).



	$R_{\odot,\mathrm{Harris96}}$ (kpc)	$R_{\mathrm{GC,Harris96}}$[a] (kpc)	$E(B-V)_{\mathrm{Harris96}}$	$R_{\odot,\mathrm{derived}}$ (kpc)	$R_{\mathrm{GC,derived}}$[a] (kpc)	$E(J-K_s)_{\mathrm{derived}}$
2MASS-GC 02	4.9	−3.6	5.16	7.1 ± 0.5 ± 0.9	−1.8± 0.3 ± 0.6	3.1
Terzan 10	5.8	−2.6	2.40	10.3 ± 0.2 ± 0.2	+2.1± 0.2 ± 0.2	0.86

	2MASS-GC 02	Terzan 10	Nishiyama09	Cardelli89
$A_{K_s}/E(H-K_s)$	1.27 ± 0.18 ± 0.23	1.29 ± 0.23 ± 0.3	1.61 ± 0.04	1.87
$A_{K_s}/E(J-K_s)$	0.40 ± 0.08 ± 0.13	$0.47 \pm 0.05^{+0.03}_{+0.03}$	0.528 ± 0.015	0.72
$A_{K_s}/E(Y-K_s)$	...	$0.23 \pm 0.02^{+0.02}_{+0.10}$	...	0.43
$A_{K_s}/E(Z-K_s)$	...	$0.15 \pm 0.02^{+0.01}_{+0.07}$	...	0.31



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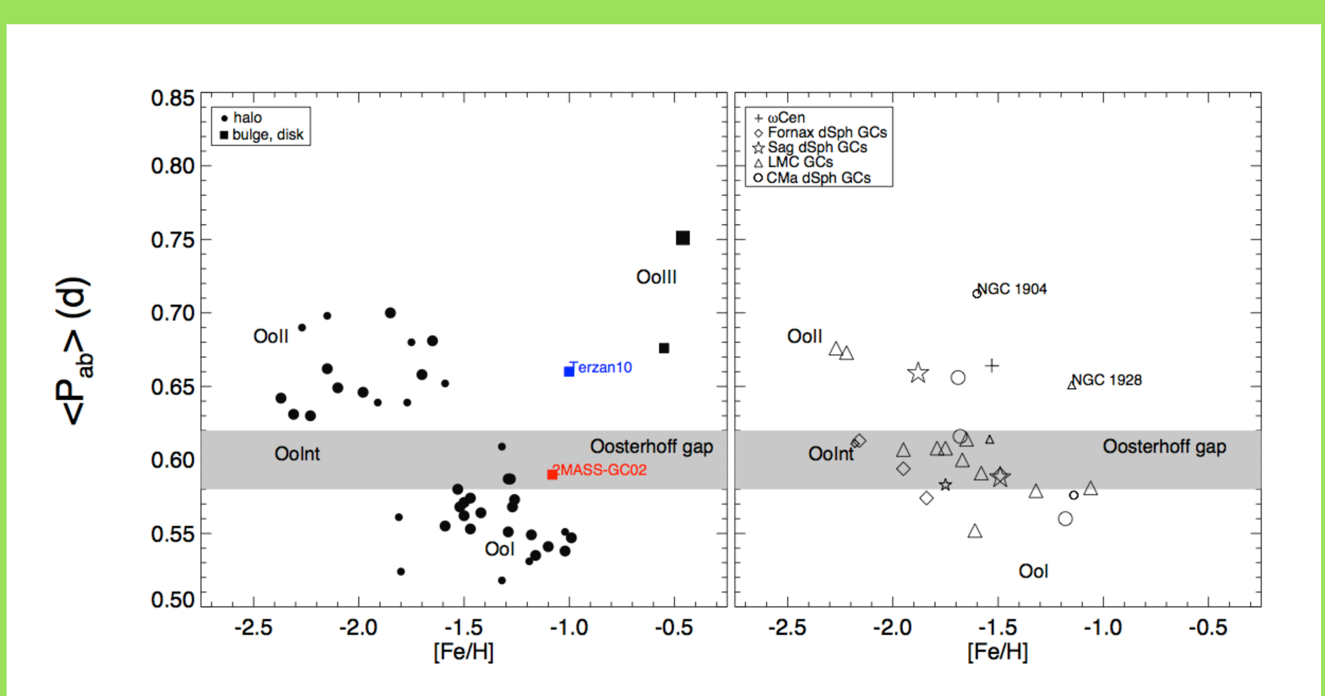
Oosterhoff properties



A particular characteristic of the Galactic GCs is the Oosterhoff dichotomy (Oosterhoff 1939; Catelan 2009). The GCs in the Milky Way are clumped into two main groups: Oosterhoff I GCs contain fundamental-mode RR Lyrae (RRab) with shorter periods (<P_{ab}> ~ 0.55 days), and Oosterhoff II have RRab's with longer periods (<P_{ab}> ~ 0.64 days), leaving an almost empty gap, the so-called Oosterhoff gap, at <P_{ab}> ~ 0.60 ± 0.02 days. This dichotomy seems not to be present in other nearby extragalactic systems, which tend to be preferentially Oosterhoff-intermediate.

We found **both studied clusters to have quite uncommon Oosterhoff properties**. Terzan 10 can be one of the most metal-rich Oosterhoff II GCs in the Galaxy, or belong to the scarcely-populated metal-rich Oosterhoff III group, depending on the true metallicity of this cluster. 2MASS-GC02, on the other hand, is located in the Oosterhoff gap where very few of the Galactic globular clusters lie.

Some of the other VVV clusters whose RRLyrae we are starting to explore now seem to lie outside the main Oosterhoff groups too.

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