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# Milky Way globular clusters in the VVV Survey

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**Abstract.** The VVV Survey (Vista Variables in the Vía Láctea) is a large Near-Infrared Survey, covering the inner regions of the Milky Way. It includes 39 known globular clusters, and most likely several more, which so far were hidden behind massive dust and gas clouds. Here we present the integrated light photometry of the known globular clusters. In combination with its optical counterpart these data will be used to access the feasibility and accuracy of the photometric age determination for globular clusters, used in galaxies which are too distant for spectroscopic studies or resolved stellar photometry. The results provide convincing evidence that the integrated light of globular clusters is a feasible probe for age sub-population. Their detection is a first step in the study of galaxy formation and evolution in dependence on various galaxy parameters. We compare our results to previous studies based on 2MASS observations, and discuss the various difficulties and error sources.

**Key words.** Galaxy: globular clusters: general, individual – Galaxies: formation – Galaxies: evolution – Galaxies: star clusters: general

## 1. Introduction

Globular clusters have been used to probe the stellar populations in their host galaxies for several decades as valuable probes for the major star formation events. Due to the well known age -metallicity degeneracy (Worthey 1994) using the distribution of only optical broad band colors, e.g. $V$ and $I$ (Kundu & Whitmore 2001a,b) hampers the resolution of co-existing globular cluster populations. If we are to search for possible GC populations we have to combine color indices with a different age and metallicity sensitivity, e.g. $V$, $I$ and $K_s$

With the progress in modeling the integrated colors of Single Stellar Populations (SSPs) for different ages, metallicities and (more recently) $\alpha$ abundances (Vazdekis 1999; Bruzual & Charlot 2003; Maraston 2005) the underlying astrophysics of the integrated light photometry as a probe for GC populations is well understood- theoretically, but still lacks the confirmation based on its application to GCs with independently derived ages and/or metallicities. With the exception of our own Milky Way and its closest neighbors all possible target galaxies are too distant to be resolved into individual stars; it is clear that confirming the method of integrated GC photometry is paramount.

Using the integrated optical/near-infrared colors allows us to derive the cumulative age distribution within a GCS and compare it to the one derived for a simulated system with a known age structure. For example (and as de-

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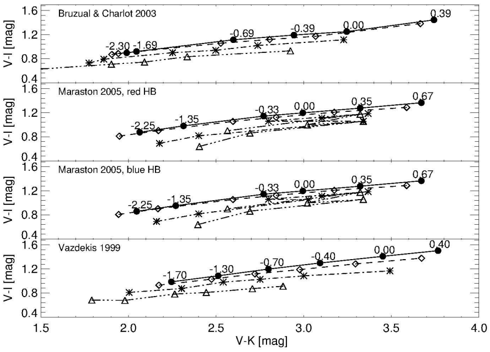


**Fig. 1.** Comparison between the optical/ near-infrared broadband colors $V-I$ *vs.* $V-K_s$ for different SSP models (see label). The models refer to a 13 Gyr (solid lines, solid circles), a 7 Gyr (dashed line, open diamonds), a 2 Gyr (dashed-dot line, cross) and a 1 Gyr (dashed-dot-dot line, open triangles) old population. The metallicity values are shown at the 13 Gyr isochrone.

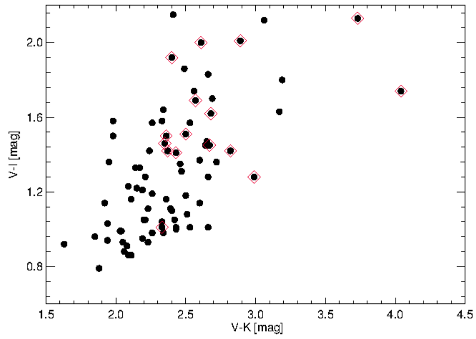


**Fig. 2.** $V-I$ *vs.* $V-K_s$ color-color diagram for Milky Way GCs. The optical colors are taken from (Harris 1996, edition 2010),whereas the $K_s$- band magnitude is from (Cohen 2007). Data point surrounded by a large open diamonds represent GCs which are also included in the VVV GC sample.

scribed in detail in Hempel & Kissler-Patig 2004), color distributions of GCSs consisting of 13 Gyr old GCs with a varying number of intermediate age clusters.

## 2. Data

Milky Way Globular Clusters (MWGCs) are ideal targets to demonstrate the feasibility of the integrated luminosity method, given that for most of them independent ages, and more importantly optical near-infrared observations are available. The latter are based on 2MASS observations and it seems straightforward to use the $(V-I)$ *vs.* $(V-K_s)$ color-color diagram to analyse the *known* age structure in the Milky Way Globular Cluster system. However, if we trust the combined optical (Harris 1996, , and references therein) and near-infrared colors (Cohen 2007), as shown in Figure 2, then the method is in fact questionable. Nevertheless, as discussed by Cohen (2007), there are several problems connected with the 2MASS data (e.g. spatial resolution, photometric depth), which we will be able to prevent using the VVV observations.

To avoid the above mentioned problems in our study of the integrated light of MWGCs we use data obtained within the Vista Variable Survey in the Vía Láctea (VVV, PI: Dante Minniti), carried out at the ESO/VISTA Telescope (Emerson et al. 2006; Dalton et al. 2006). This survey (Minniti et al. 2010) covers a 520 degree$^2$ field and includes 39 of the Milky Way Globular Clusters. During the first 2 years of the survey multi-color observations in 5 broad band filters (Y,Z,J,H, $K_s$) were obtained. The high pixel resolution of $0\farcs339$/pixel in combination with the large field of view of an individual tile (Minniti et al. 2010, and references therein), allows us to resolve the clusters far better than in the only oher systematic MWGC study in the infrared, carried out by Cohen (2007) using 2MASS, and also reach to a much fainter magnitude, e.g. $K_s \approx 18.0$ mag. Here we will focus on the J, H and $K_s$-band observations only, given their importance for the investigation of the extragalactic GCSs, and show the various challenges.

## 3. Method & problems

Using the photomtric data obtained within the VVV survey has several advantages, i.e. photometric depth, pixel resolution, and multi-color observations (Minniti et al. 2010). However, given that the GCs within the VVV survey

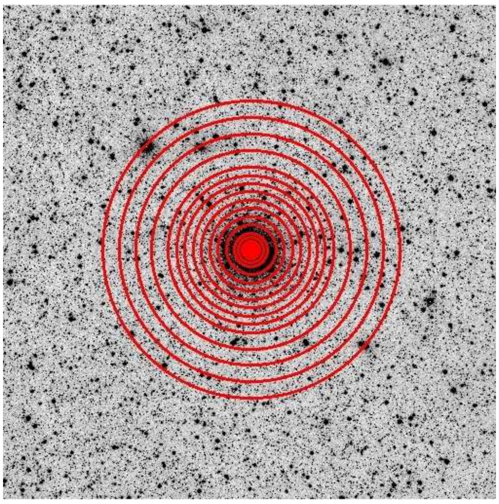

**Fig. 3.** 17.′0x17.′0 tile section in the $K_s$-band, centered on NGC 6380 (tile ID: b285), showing also the different apertures used to obtain the cluster flux.

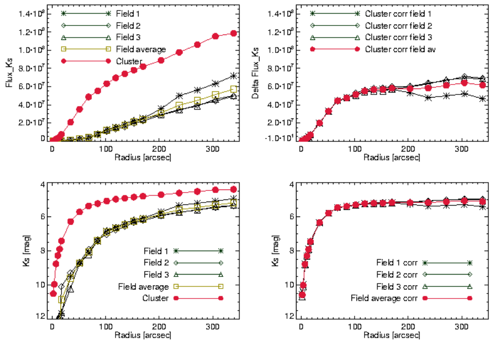


**Fig. 4.** $K_s$-band photometry for NGC 6380. The different panels show the integrated flux (top left) for the cluster and 3 different field regions, as well as their average. The top right panel shows the flux for the cluster after subtracting the corresponding field fluxes. Using the calibration data provided by CASU, the flux from the top left panel is converted into the total $K_s$-band magnitude.

are all found in the inner Bulge region (lon=[-$10^0$,+$10^0$] lat=[-$10^0$, +$5^0$]) we have to pay attention to various VVV related problems. First, and most importantly- the GCs are embedded in very crowded field regions (see Figure 3), i.e. the photometric data need to be corrected for the contamination by field stars. In addition, and also related to the VVV observing strategy, is the problem of saturated stars. Where 2MASS is missing the flux contribution of the low mass stars (field and cluster), due to the limiting magnitude of K=16.16 mag (e.g. for NGC 6380), stars observed in the VVV survey and brighter than 12 mag are saturated. Accounting for the flux of those stars, either with respect to the field populartion as well as the cluster stars is difficult. Last, but not least, the GC in this sample are partly found in an environment with varying, i.e. differential galactic reddening (Alonso-García et al. 2011). Although the last problem is more important for observations in the optical wavebands, its effect on the near-infrared photometry will be studied within the VVV survey as well.

For our study we use a 'curve of growth' approach, based on the GC centers from Harris (1996) and using the integrated flux obtained with Source Extractor (SE, Bertin & Arnouts 1996). Using the excellent astrometry of the VVV data we convert the known cluster WCS-coordinates into pixel coordinates and force SE to carry out aperture photometry for 26 different apertures, with a maximum radius of 1000 pixel, corresponding to 340 arcsec (see Figure 3). The same parameter setting (e.g. detection limit, aperture, background) is used to obtain the flux for 3 randomly selected field regions. We note that both cluster and field region are from the same tile, i.e. using the same calibration, airmass, seeing conditions. As shown in Figure 4 the flux of a given field varies, and depends also on the number of bright stars near/beyond the saturation limit. Which explains the large differences in flux for small apertures, where only few stars are detected. Each bright star in the field without a counter part in the cluster will result in severe biases. It is easy to understand that this is even more critical for the low mass GCs in our survey, e.g. Djorg 2 (Figure 5). Therefore we will use this method of cluster decontamination only for the more massive clusters, e.g. NGC 6380, as shown in this study. The selection will be done on grounds of the variation in flux in the field regions.

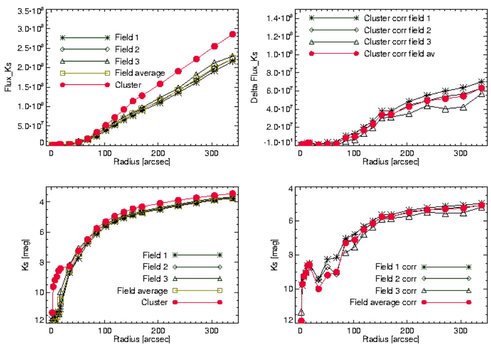


**Fig. 5.** $K_s$-band photometry for Djorg 2, a low mass cluster within the VVV survey. The panels correspond to the ones in Figure 4.

In contrast to the 2MASS results, suffering from the limit in photometric depth, the VV observations are hampered by a large number of saturated stars. The individual exposure time in the $J-$, $H-$, and $K_s$-band are very short, 6 sec, 4 sec, and 4 sec, respectively, but nonetheless a large number of saturated stars is found in any given image. Here we assume the saturated stars, as well as the level of saturation, to be distributed evenly in the field region and only very few of them to be genuine globular cluster stars. The latter assumption is another argument to apply this method only to massive clusters, the flux contribution of saturated GC stars to the integrated light of GC will be less significant in NGC 6380, compared to Djorg 2. As shown in Figure 5, the analysis of such low mass clusters depends strongly on the choice of field region.

## 4. Results & conclusions

Our aim is to develope a method to derive the integrated near-infrared light photometry for Milky Way Globular Clusters, and the brief study presented here is a first approach, suitable only for the more massive GC within our VVV survey. A direct comparison to the integrated photometry obtained by Cohen (2007) is at this point not possible, since those were derived for a maximum aperture of 50.″0 only, to avoid false correction of the field contamination in the outer cluster regions, resulting in a faulty fit to the cluster light profile. The fact that there are no possibilities to compare the results of different methods -yet, show also clearly the need for a cluster independent way to derive the integrated luminosities of those well resolved GCs.

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