MAD Science Demonstration Proposal
A new spin to constrain the absolute age of Metal Rich Globular Clusters

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Abstract:
We plan to collect accurate and deep J, K-band photometry of the Galactic Globular Clusters (GGCs) NGC 6352 and NGC 6496. The new NIR data will provide a unique opportunity to constrain their absolute age with an accuracy of the order of 1 Gyr. Together with deep optical data (HST, ground-based), these observations will provide a robust discrimination between cluster and field stars (color-color plane), and thus accurate luminosity functions from the turn-off region down to the regime of very-low-mass stars.

Scientific Case:
The absolute age of GGCs is the crossroad of several astrophysical problems. It provides (a) a lower limit to the age of the universe, (b) robust constraints on stellar evolutionary models, and (c) an accurate chronology for the assembly of the halo, bulge, and disk of the Milky Way (Buonanno et al. 1998, A&A, 333, 505; Stetson et al. 1999, AJ, 117, 247; Rosenberg et al. 1999, AJ, 118, 2306; Salaris et al. 1998, A&A, 335, 943; Gratton et al. 1997, ApJ, 491, 749; de Angeli et al. 2005, AJ, 130, 116). Current models suggest that metal-rich (MR) GGCs such as 47 Tuc ([Fe/H]=-0.76), M71 ([Fe/H]=-0.73), NGC 6352 ([Fe/H]=-0.70), and NGC 6496 ([Fe/H]=-0.64) are on average 2 Gyr younger than the bulk of metal-poor (MP) GCs. However, no firm conclusion has been reached yet. The estimate of the absolute age of GCs is hampered by uncertainties in their distance moduli and reddening values. These problems are even more severe for MR GCs in the Galactic bulge, since they usually suffer differential reddening. Moreover, they have red HBs and therefore their distances cannot be estimated using either RR Lyrae stars or Zero-Age Horizontal-Branch models.

Based on NIR photometry collected with MAD@VLT for the NGC 3201—a GC affected by differential reddening—our group showed that the hook of the lower main sequence, caused by the H_2 opacity, can be used to estimate the absolute age of GCs (see Fig. 2). The difference in color between this feature and the turn-off (TO) is strongly correlated with the cluster age. This method presents several advantages: *i)* it is minimally affected by distance and reddening uncertainties, since the color excess E(J-K) is $\approx$ 2.5 smaller than E(V-I); *ii)* the hook location does not depend on the cluster age and it is a robust theoretical prediction. In this mass range ($\leq 0.3 M_{\odot}$) the treatment of the convection is adiabatic (no mixing length).

Finally, we note that the image quality and spatial resolution of MAD are mandatory to perform accurate photometry in the crowded Bulge regions. Our group has already been involved in the reduction of J, K-band data collected with MAD and has provided the deepest $K, J-K$ CMDs for ω Cen and NGC 3201.

Immediate objectives

• We plan to collect MAD@VLT data for six GCs covering a wide range in metallicity and dynamical properties: NGC 3201 and NGC 288 have already been observed; NGC 7099 and NGC 6752 are the subject of a companion proposal (PI: A. Di Cecco). The present proposal is for two metal-rich and reddened GCs (see Fig. 1), namely NGC 6352 (E(B-V)=0.25) and NGC 6496 (E(B-V)=0.25, Pulone et al. 2003, A&A, 399, 121). The homogeneity of the NIR-optical data and cluster isochrones will allow us to constrain age differences to the order of 1 Gyr.

• Accurate and deep NIR photometry for these GCs will allow us to constrain the **absolute** age with an accuracy of the order of one Gyr. Moreover, we will produce optical and NIR catalogs, and derive independent **absolute** age estimates using the TO region in the $K, V-K$ CMD.

• The use of the color-color plane ($V-J, I-K$) will allow us to separate candidate field and cluster stars, and in turn to provide an accurate Luminosity Function of the lower Main Sequence (see Pulone et al. 2003).

• The stronger temperature sensitivity of the $V-K$ color will allow us to constrain the binary fraction and the accuracy of current color-temperature relations.

Targets and integration time

Target	**RA**	**DEC**	**Filter**	**Magnitudes**	**Total integration time** (sec)	**Field** (arcmin)
NGC 6352	17 25 29.2	-48 25 22	J,K_s	$10-21$	2×6240	2×1
NGC 6496	17 59 02.0	-44 15 54	J,K_s	$10-21$	2×7200	2×1

Guide stars list and positions

Note that for NGC 6496 we give two different asterisms. The appropriate triplet will be selected according to the seeing conditions.

Target NGC 6352				NGC 6496							
ID	$\mathbf{RA}''_{rel}$	$\mathbf{DEC}''_{rel}$	**V**	ID	$\mathbf{RA}''_{rel}$	$\mathbf{DEC}''_{rel}$	**V**	ID	$\mathbf{RA}''_{rel}$	$\mathbf{DEC}''_{rel}$	**V**
GS1	-25.57	+39.90	12.213	GS1	+02.05	+46.83	12.853	GS1	+02.05	+46.83	12.853
GS2	+05.95	-47.00	11.722	GS2	+40.82	-13.41	12.881	GS2	+40.82	-13.41	12.881
GS3	+41.77	+23.80	12.099	GS3	-28.65	-32.81	11.400	GS4	+44.91	-43.31	11.969
GS4	-23.00	-24.20	12.794	...	...	...	...	...	...	...	...

Time Justification:

We plan to collect NIR data in two different fields located across the cluster centres. For each pointing we plan to collect J,Ks-band data four magnitudes below the TO point with S/N$\approx$ 10. Based on our experience with the NGC 3201 data, we estimate the following exposure times per field for NGC 6352 ($\mu \sim 13.6$):

t(K_s)**=** 5 **(images)** $\times$ [10×24 **(target) +** 10×24 **(sky)**] **+ 1200 (acquisition)=3600 sec**

t(J) **=** 3 **(images)** $\times$ [10×24 **(target) +** 10×24 **(sky)**] **+ 1200 (acquisition)=2640 sec**

and for NGC 6496($\mu \sim 14.8$):

t(K_s)**=** 6 **(images)** $\times$ [10×24 **(target) +** 10×24 **(sky)**] **+ 1200 (acquisition)=4080 sec**

t(J) **=** 4 **(images)** $\times$ [10×24 **(target) +** 10×24 **(sky)**] **+ 1200 (acquisition)=3120 sec**

The total time per pointing are 1.73 h (NGC 6352) and 2 h (NGC 6496), thus the total time we request for the two clusters is $\mathbf{t_{tot}} = \mathbf{7.5h}$.

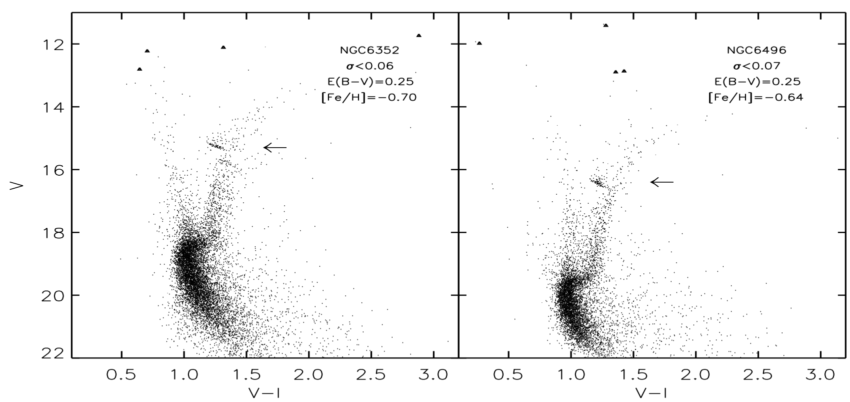

Figure 1: $V, V-I$ Color-Magnitude Diagrams of NGC 6352 (left) and NGC 6496 (right) based on our ground-based data. The triangles mark the guide stars, and the arrow the magnitude of red HB stars.

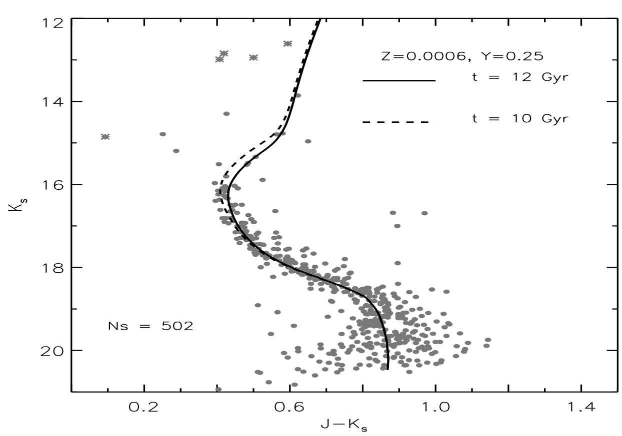

Figure 2: $K_s, J-K_s$ Color-Magnitude Diagram of NGC 3201 based on a single MAD pointing. Both data reduction and calibration are preliminary. The dashed and solid lines show two cluster isochrones (10, 12 Gyr) at fixed chemical composition (Castellani et al. 2007). The asterisks display HB stars. The hook in the lower MS is located at $K_s \sim 19$ and $J-K_s \sim 0.85$ mag.