MAD Science Demonstration Proposal
A new spin to constrain the absolute age of 47 Tucanae

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Abstract:
We plan to collect accurate and deep J, K-band photometry of the Galactic Globular Cluster (GGC) 47Tuc (NGC 104). The new NIR data will provide a unique opportunity to constrain its 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 function 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 RR Lyrae stars.

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. 1). 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 ≈ 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 very dense cluster 47Tuc. 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 seven GCs covering a wide range in metallicity and dynamical properties: NGC 3201 and NGC 288 have already been observed; two metal-poor (NGC 7099, NGC 6752) and two metal-rich (NGC 6352, NGC 6496) GCs have been approved for the SD2. The present proposal is for 47Tuc, the template metal-rich cluster (see Fig. 1). 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 104	00 24 04.893	-72 05 03.52	J,K_s	$10-21$	4×6240	4×1

Guide stars list and positions

Note that among the two dozens of guide stars brighter than V=11.8. We are only listing those with $V\leq11.5$. The final list will be selected according to the seeing conditions.

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	-46.80	+04.28	11.902	GS4	-14.09	-54.42	11.960	GS7	-15.47	-17.42	11.664
GS2	-36.84	+28.88	11.727	GS5	+45.44	-19.22	11.201	GS8	+47.24	+29.48	11.682
GS3	-31.11	+26.78	10.468	GS6	+15.26	-31.62	11.630	GS9	-04.26	+06.38	11.870

Time Justification:

We plan to collect NIR data in four different fields located across the cluster centre and partially overlapped. For each pointing we plan to collect J,Ks-band data four magnitudes below the TO point with S/N≈10. Based on our experience with the NGC 3201 data, we estimate the following exposure times per field for 47Tuc ($\mu\sim13.4\pm0.2$):

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**

The total time per pointing is 1.73 h, thus the total time we request is $\mathbf{t_{tot}}$ = **7h**.

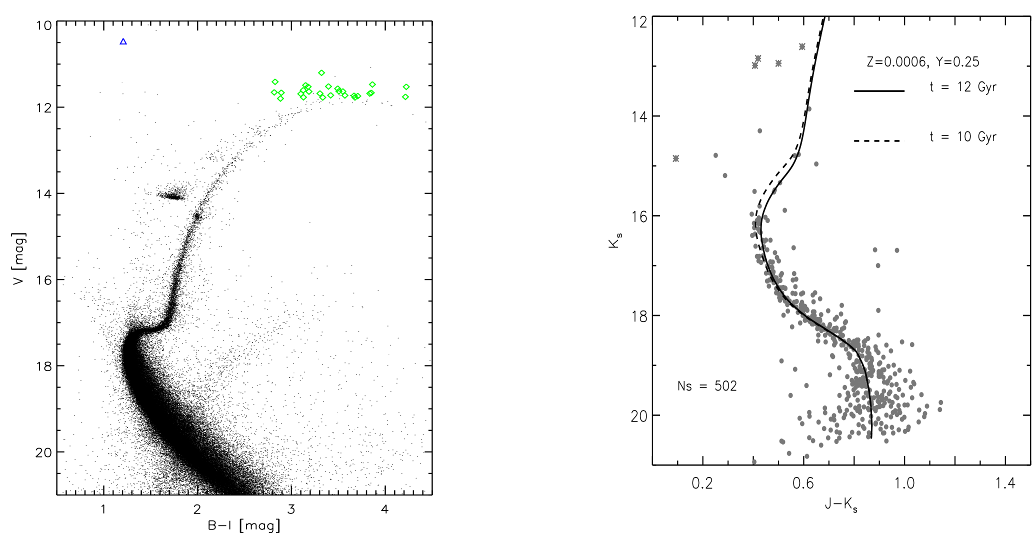

Figure 1: **Left:** $V,B-I$ Color-Magnitude Diagram of 47Tuc (left) based on our ground-based data. The blue triangle marks a guide star brighter than V=11, while the losanges mark the guide stars brighter than V=11.8 located within two arcmin from the cluster center. **Right:** $K_s, J-K_s$ Color-Magnitude 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 discussed in the text is located at $K_s\sim19$ and $J-K_s\sim0.85$ mag.