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On the absolute age of the globular cluster M71

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Abstract. We investigated the Galactic globular cluster M71 (NGC6838, [Fe/H]=-0.78) by using optical (u', g', r', i', z') ground-based images, collected with the MegaCam camera at the Canadian-Franch-Hawaii-Telescope (CFHT). We provided a robust selection of the field and cluster candidate stars by using a new approach based on a 3D Color-Color-Magnitude-Diagram (CCMD). In order to investigate the cluster age, we compared the observed CMDs of the candidate cluster stars with appropriate isochrones. We found an age of 12±2.0 Gyr, in good agreement with literature values. Beside the classical isochrone comparison, we also estimated the age by using the 'knee method', which is independent by the uncertainties affecting the cluster distance and reddening. By applying the latter method to the $r', g' - r'$ and $r', u' - g'$ CMDs, we found a mean age of 12±1.0 Gyr. We found that the different methods suggest the same age, but the knee-method allows us to decrease the uncertainty by a factor of two. Our results confirm that M71 is an old metal-rich Galactic globular cluster.

Key words. Galaxy: globular clusters

1. Introduction

The globular cluster (GC) M71 (NGC 6838) is located in the Galactic bulge at l=56°.75 and b=-4°.56 (Harris 1996). Its distance from the Sun is $\approx 4\ Kpc$, while it visual distance modulus is DM=13.80 (Harris 1996). M71 is a fundamental benchmark to investigate metal-rich old stellar systems ([Fe/H]$\gtrsim$ -0.8). In particular, recent investigations provided in optical and near-infrared bands suggest an age of 11–12 Gyr (Grundahl, Stetson & Andersen 2002; Brasseur et al. 2010; VandenBerg et al. 2013), but several uncertainties still remain. The main problem in the determination of M71 age is due to the cluster position, which is strongly affected by field star contamination and by differential reddening (E(B-V)=0.25 ± 0.05 mag, Harris 1996; Schlegel, Finkbeiner & Davis 1998). In the new scenario suggested by Dotter, Sarajedini & Anderson (2011), M71 can also have a key role in the possible bifur-

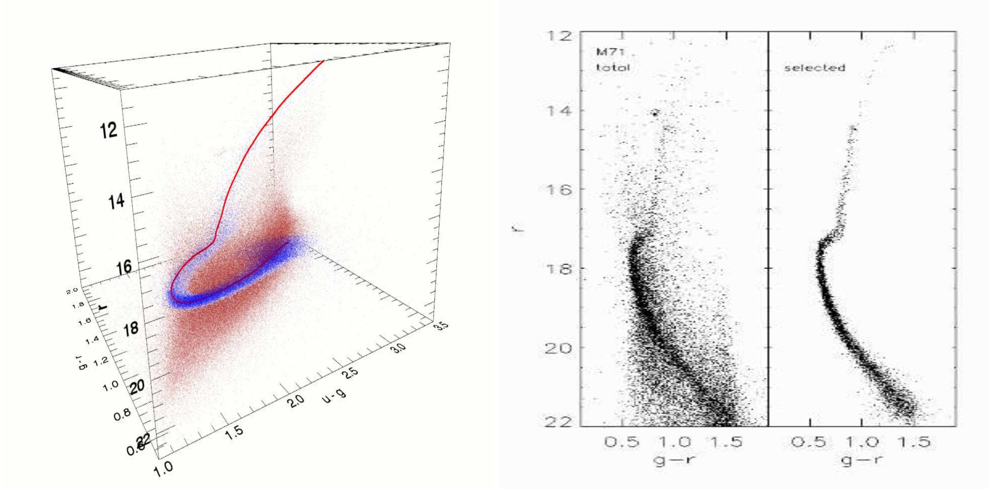

Fig. 1. Left panel: The $u' - g', g' - r', r'$ CCMD: the blue points are the candidate M71 stars selected along the ridgeline (in red). – Right panel: the $r', g' - r'$ CMD for the entire detected stars (left panel) and the selected candidate cluster stars (right panel).

cation of the age-metallicity relation of the inner and outer halo Galactic globulars. In next sections, we investigate the age of M71 by using the classical isochrone comparison at the Turn Off (TO) region and the knee-method previously applied by Bono et al. (2010) to infrared bands. The latter has the advantage to be independent of both reddening and distance modulus, which are the parameters that typically affect the age estimate with the classical isochrone method.

2. Data reduction and analysis

To investigate the age of M71 we used the ground-based data of the Canadian-Franch-Hawaii-Telescope (CFHT). The dataset consists on 50 images taken with the similar Sloan-Digital-Sky-Survey bands (u', g', r', i', z') of the MegaCam mosaic camera (36 CCDs, Field of View: FoV=1°x1°, scale=0.2 pixel/arcsec). We used the innermost 20 CCDs for a total FoV of 35 ′x60 ′, which is much larger than the sky area covered by M71, whose tidal radius is of the order of r_t=9 ′(Harris 1996). We provided individual frame photometry by using DAOPHOT (Stetson 1987) and we performed the photometric analysis by using ALLFRAME (Stetson 1994) simultaneously on the entire set of 1,000 frames. For the calibration to the standard system we used the local standard stars provided by Clem et al. (2007).

In order to distinguish the field and cluster stars in the crowded regions of M71, we used a new approach based on the Color-Color-Magnitude-Diagram (CCMD) shown in the left panel of Fig.1 (Di Cecco et al. in preparation). In particular, we reconstructed a 3D ridgeline in the $u' - g', g' - r', r'$ CCMD and we considered the candidate cluster stars those located within the ridgeline$\pm 2\sigma$, where σ is the quadratic sum of the photometric errors in the five bands. For the entire sample of stars and for the selected candidate cluster stars we show the $g' - r', r'$ CMD in the right panels of Fig.1.

In order to estimate the M71 age, we provided a set of isochrones (8-15 Gyr) by using the Pisa Stellar Evolution Data Base[1] described in Dell'Omodarme et al. (2012) and computed with the FRANEC evolutionary code (see also Degl'Innocenti et al. 2008). The models are computed with an alpha-enhancement [α/Fe] =+0.3 with respect to the recent solar heavy-

[1] `http://astro.df.unipi.it/stellar-models/`

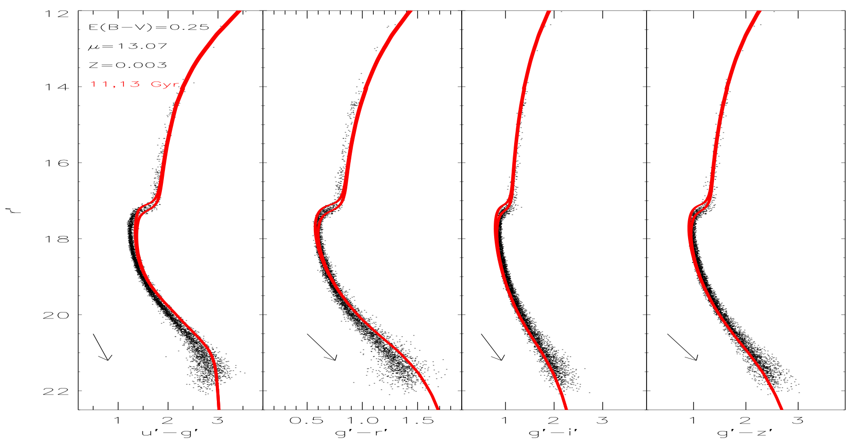

Fig. 2. CMDs of the candidate stars for M71 and 11-13 Gyr models. The arrows mark the reddening vectors.

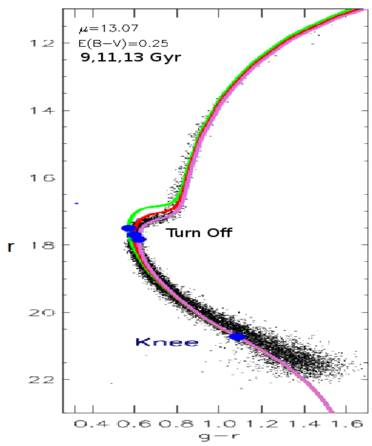

Fig. 3. Theoretical Turn Off and Knee magnitudes marked for the 9,11,13 Gyr isochrones in the r', $g' - r'$ CMD

element mixture by Asplund et al. (2009). By scaling the M71 metallicity ([Fe/H]=-0.82, Carretta et al. 2009) to the Asplund's mixture we obtained a global metallicity of Z=0.0036. For the theory we assumed a global metallicity of Z=0.003 (see Di Cecco et al in preparation). To reddened the isochrones we used the empirical relations of Cardelli, Clayton & Mathis (1989) with $R_V = 3.1$. By using a reddening of $E(B-V) = 0.25$ mag and an absolute distance modulus of $\mu = 13.07$ mag, we plotted the 11-13 Gyr models on the data in Fig.2. Taking into account the theoretical uncertainties, we found for M71 an age of 12±2.0 Gyr. We also noted that in the r', $u'-g'$ CMD a shift in color (~ 0.1 mag) between data and theory is present, as already observed by An et al. (2008).

Considering the occurrence of a 'knee' in the $u'-g'$, r' and $g'-r'$, r' CMDs at $r' \sim 20.5$-21 mag, we also estimated the M71 age with the method provided by Bono et al. (2010) in the near-infrared bands. The 'knee-method' permits to estimate the age by using the difference between the knee and the TO magnitude (Δ^{TO}_{Knee}) and it is independent by the distance modulus and reddening, whose uncertainties strongly affect the classical isochrone comparison. In order to estimate the observed TO and knee magnitudes, we used a spline interpolation along the CMDs ridgelines and we estimated the knee magnitude as the point of maximum curvature, by following the prescriptions of Bono et al. (2010). We obtained a Δ^{TO}_{Knee} = 2.47 mag and Δ^{TO}_{Knee} = 2.87 mag respectively for the $r', u' - g'$ and $r', r' - g'$ CMDs. By applying the same procedure to the 8-15 Gyr isochrones, we calculated the theoretical values. For the $r', g' - r'$ CMD and for the 9,11 and 13 Gyr isochrones we show the TO and the knee magnitudes in Fig.3. By comparing observed and theoretical values, we estimated for M71 a mean age of 12±1.0 Gyr. This latter result is in good agreement with previous estimates, but the uncertainty is a factor of two smaller.

3. Conclusions

We used CFHT u', g', r', i', z' photometric data to investigate the age of the globular Galactic M71. In order to distinguish candidate field and cluster stars, we provided a selection in the 3D color-color-magnitude diagram (CCMD). The comparison between the CMDs of candidate cluster stars and a set of isochrones suggests an age of 12±2.0 Gyr. Thanks to the occurrence of a knee along the $r', u' - g'$ and $r', g' - r'$ CMDs, we also estimated the M71 age by applying the 'knee-method' (Bono et al. 2010). In latter case we obtained a value of 12±1.0 Gyr, confirming the previous estimate. Moreover, we found that respect to the classical isochrone comparison, the knee-method reduces the uncertainties of a factor of two. Finally, we confirm the lack of a clear empirical evidence for an age-metallicity relation among metal-rich globular clusters.

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