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Panchromatic fits to the globular cluster NGC 6366

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Abstract. We present panchromatic isochrone fits to the color magnitude data of the globular cluster NGC 6366, based on HST ACS/WFC and SOAR photometric data. Before performing the isochrone fits, we corrected the photometric data for differential reddening and calculated the mean ridge line of the color magnitude diagrams. We compared the isochrones of Dartmouth Stellar Evolution Database and PAdova and TRieste Stellar Evolution Code (with microscopic diffusion starting on the main sequence). Based on previous determinations of the metallicity of this cluster we test it from [Fe/H]=-1.00 to [Fe/H]= -0.50, and the age from 9 to 13 Gyrs. The uncertainties do not decrease when we fit simultaneous colors. We also find that the Dartmouth Stellar Evolution Database isochrones have a better fit in the sub giant branch and low main sequence than the PAdova and TRieste Stellar Evolution Code. Considering the most recent spectroscopic determination of the metallicity ([Fe/H]= -0.67), we find E(B-V)=0.67±0.02, (m-M)$_V$=14.94±0.05 and 11±2 Gyr for NGC 6366.

Key words. Globular clusters: general – Globular clusters: individual – Stars: color magnitude diagram – Galaxy: fundamental parameters

1. Introduction

Galactic globular clusters are considered the ideal laboratories for the study of stellar evolution, mainly because their color magnitude diagram (CMDs) have very specific characteristics. The stars, in most globular clusters, follow a single isochrone, suggesting that they formed rougly at the same time and with the same metallicity.
To obtain the astrophysical parameters of the globular cluster is necessary to fit models to the stars in the CMD. But this fitting is not simple, because there are two physical parameters that can vary to generate the models to be compared with the data, age and metallicity, and two other fitting parameters, extinction and distance. One method commonly used is the fit ”by eye”, but it is necessary to be aware of the uncertainties in the construction of isochrones, since they increase the uncertainties in the fit.
Among the problems of the evolutionary models are the lack of a precise description of convection. Red giant stars have deep convective envelope causing a large uncertainty in the structure. Another problem is that stars lose mass (higher for the most massive stars) in the form of a stellar wind and this loss increases several orders of magnitude for stars that al-

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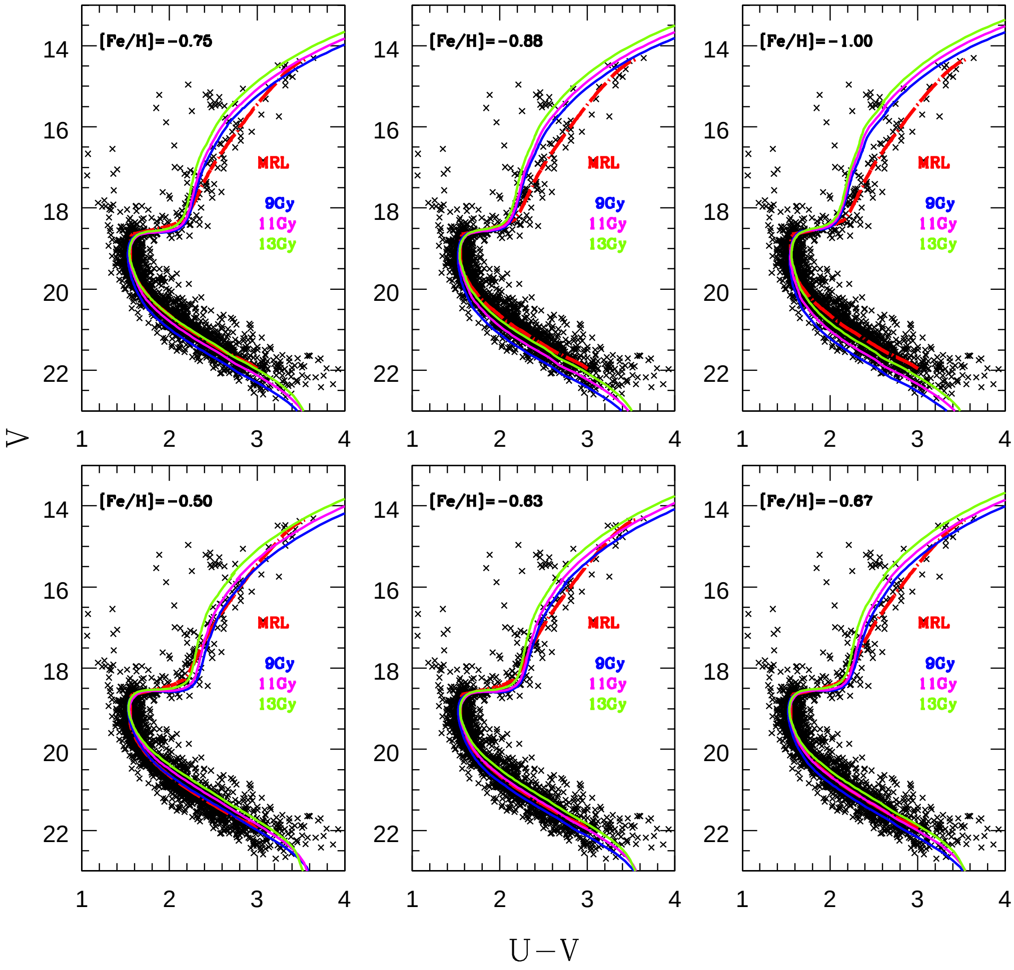

Fig. 1. Fitting of the DSED to the mean ridge line (red dash-dotted line) of NGC 6366, at U-V color, considering all the range of metallicity determinations for this cluster and ages of 9 Gyr (blue line), 11 Gyr (magenta line) and 13 Gyr (green line). The best fit is found at metallicity [Fe/H]=-0.67, value consistent with the most recent spectroscopic determination by Da Costa & Armandroff (1995).

ready left the main sequence. Predicting the rate of mass loss theoretically is very difficult, and what the evolutionary models use are the values of mass loss consistent with observations of stars that are at a similar stage. This value depends heavily on metallicity, and this dependence is difficult of measurement, causing uncertainties. It is still necessary to account the uncertainties associated with opacity tables, especially when dealing with molecular opacities. This effect is important not only in the cooler giant stars, but also in the lower main sequence.

According to Bolte & Hogan (1995), if the brightness of the main sequence turn off is used to determine the age of globular clusters, the only source of uncertainty significantly large is the determination of distance and an uncertainty of 25% in distance generates an uncertainty of 22% in age.

Attempting to decrease the uncertainties of isochrone fittings to globular clusters, we performed panchromatic isochrone fits of the globular cluster NGC 6366, based on archival HST ACS/WFC and our own 4.1m SOAR photometric data. We compared the isochrones of Dartmouth Stellar Evolution Database [DSED - Dotter et al. (2008)] and PAdova and TRieste Stellar Evolution Code [PARSEC - Bressan et al. (2012)], models with microscopic diffusion starting on the main sequence (Jofré & Weiss 2011).

2. Observations

The optical data of NGC 6366 discussed in this work was observed with the SOAR telescope. The images were centered on the cluster core and the exposure times for each filter were divided as follows: 6x(1800s) to U; 5x(30s), 2x(300s) and in 1x(1800s) and 5x(30s), 2x(300s) and 2x(1800s) V . The photometry was obtained with psf fitting using DAOPHOT (Stetson 1987). To obtain the magnitudes in the standard photometric system, stars belonging to the cluster itself were used. the standard magnitudes for these stars were obtained through the catalog of standard stars of Peter Stetson (`http://www3.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/community/STETSON/standards/`). The photometric data of HST ACS/WFC was obtained from `http://www.astro.ufl.edu/~ata/public_hstgc/`. This data was obtained as part of the HST treasury program "An ACS Survey of the Galactic Globular Clusters"[GO10775 P.I. Ata Sarajedini, (Sarajedini et al. 2007)]. The images were centered at the cluster core and consists of 10x(140s) and 1x(10s) exposures in the F606W and F814W filters.

3. Data Analysis

To perform the analysis, the first step involves correcting the photometric data for differential reddening by dividing the field of view across the cluster in a regular cell grid, then extract the Hess diagram from each cell, shifting it, along the reddening vector, until it matches the mean diagram [Bonatto, Campos & Kepler (2013), MNRAS, submitted].

To take into account the effects of binarity and also the scattering photometry, before performing any fitting to the CMDs, we calculated the mean ridge line of each CMD. The fitting of the DSED and PARSEC models to the mean ridge line of the three colors (VxB-V, VxU-V and F606WxF606W-F814W) was performed considering all the range of metallicity previously determined for this cluster (-1.0<[Fe/H]<-0.5, Ferro et al. (2008) and references therein) and ages ranging from 9 Gyr to 13 Gyr. In Fig. 1 we show the fitting of DSED models to the mean ridge line at U-V color. It is not difficult to notice, by looking at the low main sequence and the sub giant branch that, as the metallicity decreases, the models have a better fit to the data, until [Fe/H]=-0.67, when the best fit is found, this value is consistent with the spectroscopic determination by Da Costa & Armandroff (1995). As metallicity continues to decrease, the models no longer fit the data.

The fitting for the three colors with [Fe/H]=-0.67±0.07 (Da Costa & Armandroff 1995) (Fig. 2) shows that while the best fit to U-V color occurs at age 9 Gyr, for B-V color the best fit is at 11 Gyr and for F606W-F814W color the best fit is found with 13 Gyr. In other words, a single model does not fit the three colors simultaneously, and the uncertainties do not decrease when simultaneous colors are fitted. Indicating that the evoluionary models still have unsolved problems, such as photometric zero points and opacity tables.

Another interesting point to notice in Fig. 2 is the fact that DSED models have a better fit at the lower main sequence and at the sub giant branch than the PARSEC models; therefore we use the DSED fittings to determine the parameters of the cluster. Before we find the relations between the colors, to obtain the parameters, we determined the total to selective extinction for stars belonging to this cluster directly, following Ducati, Ribeiro & Rembold (2003), and we find R_V=3.06±0.14. We also used Cardelli, Clayton & Mathis (1989) relations to estimate E(B-V)=1.02E(F606W-F814W) and E(B-V)=0.57E(U-V). We find the following parameters for NGC 6366:

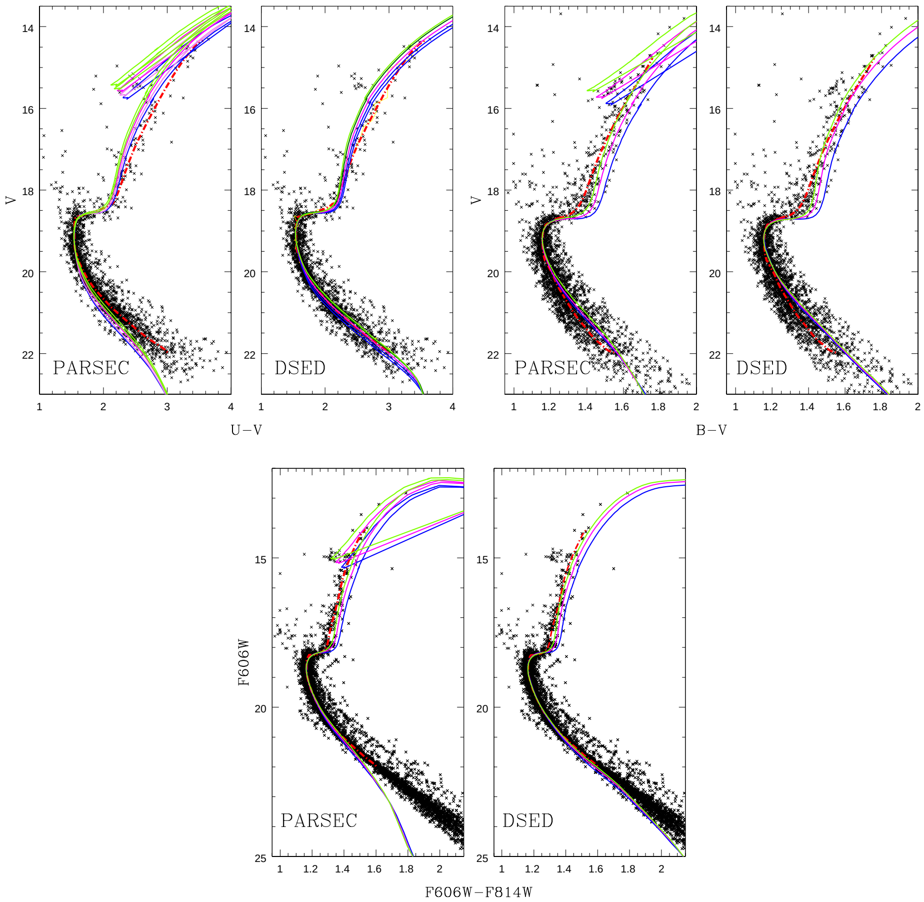

Fig. 2. Fitting of PARSEC and DSED models to the mean ridge line (red dash-dotted line) of the SOAR and ACS/WFC data, with [Fe/H]=0.67±0.07 (Da Costa & Armandroff 1995) and ages of 9 Gyr (blue line), 11 Gyr (magenta line) and 13 Gyr (green line). The uncertainties do not decrease when we fit simultaneous colors, because a single model does not fit the three colors simultaneously. The DSED models have a better fit in the Hertzprung gap and the lower main sequence than the PARSEC models.

E(B-V)= 0.69±0.02(int)±0.04(ext)
$(m\text{-}M)_V$= 15.02±0.07(int)±0.13(ext)
Age= 11±2 Gyr.

4. Conclusions

The uncertainties of isochrone fittings to NGC 6366 do not decrease when we fit multiple colors, due to the fact that a single model does not fit three colors simultaneously. It indicates that the isochrone models may still have problems that remain unsolved, possibly photometric zero points and opacity tables. Other important point is that the DSED models have a better fit to the data than PARSEC models, mainly in the sub giant branch and the low main sequence, the last one is possibly realted to the equation of state adopted by Dotter et al. (2008) for stars with low mass.

With the total to selective relation R_V=3.06±0.14, determined for stars belonging to this cluster, we estimated E(B-V)=1.02E(F606W-F814W) and E(B-

V)=0.57E(U-V). With that we determined the parameters of NGC 6366 as being: E(B-V)= 0.69±0.02(int)±0.04(ext); $(m-M)_V$= 15.02±0.07(int)±0.13(ext) and Age= 11±2 Gyr.

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