Determining M52's cluster age from its Color-Magnitude Diagram

Codrin P. Oneci*
MIT Department of Physics
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This article presents observations and analysis through which the age of the open cluster M52 was determined. Literature presents a variety of cluster ages for the Messier object M52. Observations in r', i' and calibration CCD frames were done at Wallace Astronomical observatory. By fitting Padova isochrones through the color magnitude diagram of M52 I was able to determine the cluster age of M52 as $80Myr + 60Myr/-20Myr$.This project shows that the various ages from the interval 60-140 Myr are plausible and that stars of M52 formed recently and at slightly different times.

I. INTRODUCTION

Stellar clusters are groups of stars located in the same physical region of the Galaxy. Globular clusters are gravitationally bound, while open clusters are not. Color-magnitude diagrams (CMD) for stellar clusters are used for determining the age of clusters. CMDs are created by plotting the color index of stars from the cluster against the absolute magnitude of stars from a cluster. In such a CMD one can observe stars that are on the path of becoming red giants (stars that depleted their hydrogen fuel and cannot start a more energetic thermonuclear cycle) in a region called "turnoff point". Since for a cluster most stars are formed from the same matter, it is useful to associate ages to clusters with the purpose of studying stellar evolution models. Stellar isochrones are curves in CMD and Hertzsprung-Russell diagrams representing the population of stars that have different masses but the same composition and age. In the past isochrones were fitted by hand by astronomers in order to determine a cluster age using models of stars from the main sequence and doing fitting at the turnoff point. Modern computational tools allow us to automate this process, and in the last years significant steps forward have been made [1].

M52 is a young open cluster from the Messier catalog that is visible with naked eye. M52 was chosen as an object of study because it is not very sensible to atmospheric noise (it has a low magnitude) and is very well suited for observations from MIT Wallace Astronomical Observatory (WAO) (its equatorial coordinates are included in the window of objects that can be observed during the fall nights at WAO). Since M52 contains a large variety of stars, its plausible isochrones have a high spread in age. That may imply that different fitting and extraction algorithms would be biased toward specific age values [2].

II. BACKGROUND

The cluster age of M52 is 60±10 million years (Myr) when Padova isochrones are fitted through its color magnitude diagram in the (J, J-H) coordinates [3]. This result is in accordance to previous knowledge of the age of M52 situated between 35 and 135 Myr. Older results [4] suggest an age of 95 Myr from ubvy photometry of chosen stars from the cluster, with a distance modulus of 11.3±0.1 (corresponding to approximately 1.7 kiloparsecs). In the past M52 attracted attention of astronomers due to the F7Ib supergiant that is part of it [5]. Isochrone fitting is most frequently based on simple stellar populations, for which metallicity and mass distributions are tried until the data from the CMD is fitted by an evolutionary program [6].

III. OBSERVATIONS

I have gathered data using a remote-controlled 14-in Celestron with equatorial mount and STL1001E CCD sensor and SLOAN filter wheel. The observations were made at the Wallace Astronomical Observatory in the evenings of 7 and 14 October 2020. For the frames with nonzero exposure time, the exposure time of choice was 40s.The r' and i' filters were chosen in order to obtain high signal to noise ratios in the measurements. By using large wavelength filters I avoided having additional noise in the star CCD observations. Moreover the seeing due to atmospheric refraction is lower and thus the source extraction algorithm gives a lower flux estimation uncertainty. This improved the estimation of the magnitudes and resulted in a more precise CMD.

TABLE I. Data Table

CCD Frame Type	Repeats	Observation
r'	20	
i'	20	
Dark	20	14-in Celestron + STL1001E
Bias	20	
Flat Field r'	10	
Flat Field i'	10	

* codrin@mit.edu

IV. DATA REDUCTION AND ANALYSIS

Using the repeated frames, I computed the arithmetic average of the arrays falling in specific categories (Darks, Biases, r', i' etc.). Afterwards I had to compute the calibrated frames according to the formula:

$$CCD_{calibrated} = \frac{CCD_{raw} - D - B}{FF}$$

where D is the averaged Dark signal, B is the average Bias and FF is the flat field normalization array for the corresponding filter.

Further in the 30'x30' FOV frames I defined a virtual circular aperture that is centered on M52 and occupies 0.6 of the linear FOV. The size of this aperture was chosen empirically: large enough to have a continuity of stars in the main sequence of M52 in the CMD, such that the distribution of stars and the turnoff point is evident, but small enough to minimize star-noise caused by stars that are in the aperture but are not included in M52, so they appear as being scattered in the CMD.

Since I worked with r' and i' data I then extracted the sources in the calibrated frame using the Python SEP library (which finds isoluminant contours and fits ellipsoid sources with gaussian distributions of signal). Thus I obtained flux levels in both r' and i' filters. I transformed this fluxes into magnitudes using the photometric formula

$$m_0 - m_1 = -2.5 log \frac{F_1}{F_0}$$

where m_0 and F_0 are the magnitude and flux of the reference star (Vega for instance) while m_1 and F_1 are the magnitude and flux of the star that is under analysis.

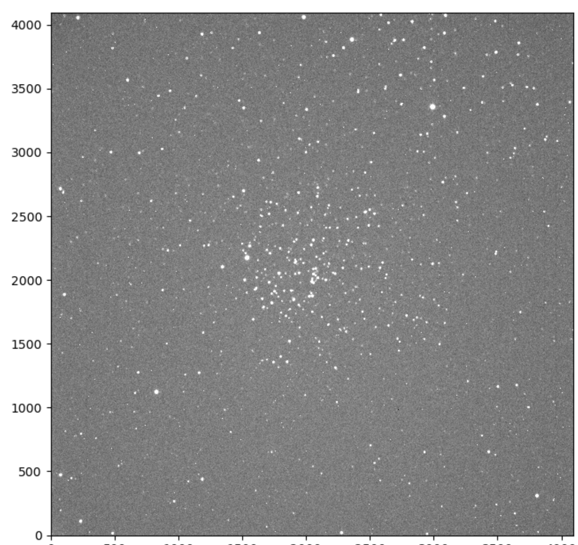

FIG. 1. M52 raw image in the r' filter.

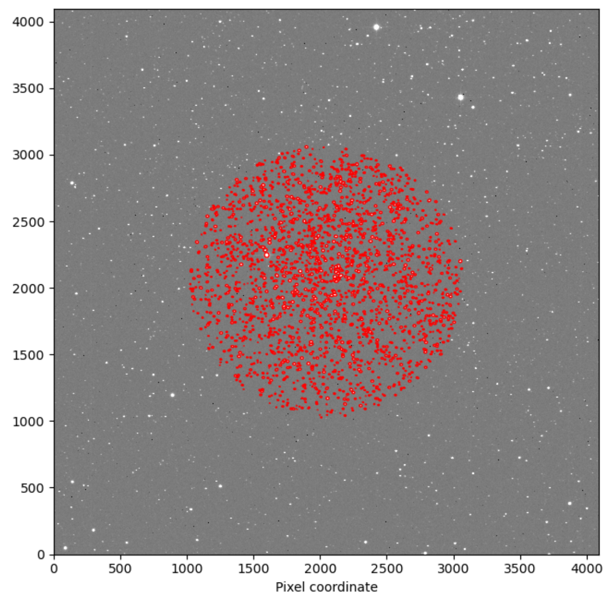

FIG. 2. M52 calibrated image in the i' filter, with extracted sources shown as red ellipsoids. The circular aperture is centered on M52 and has diameter 0.60xFOV.

V. RESULTS AND ANALYSIS

The obtained i' and r' pair magnitudes had to be then translated to a color index r'-i' and an absolute magnitude i'. I identified GAIA NGC 7654 766 (maximum apparent luminosity in the chose aperture) for and then used a correction factor of 22.38 mag for finding absolute i'. For this calibration I observed that NGC 7654 766 has apparent magnitude in the i' filter of 8.38 mag, while initially that would correspond to -14 mag in my raw result. In principle I could have obtained the same result using the known distance modulus for M52 11.1 mag .

I obtained the CMD for M52 by plotting absolute i' against the r'-i' color index. Subsequently I had to retrieve already computed Padova isochrones from the research group server. I further wrote software for transforming their relevant columns from a .dat file into the Numpy arrays needed for this project. Data retrieved was in the SDSS ugriz photometric system. By plotting together the CMD of M52 and the Padova isochrones of ages 20-140 Myr, I observed that translating the CMD using an extinction coefficient of E(r'-i')=0.2 was necessary to match the main sequence of Padova isochrones for stars that are having still much hydrogen to burn (stars that are not close to the turn-off point). The sum of the extinction coefficient aforementioned and the raw color index gave the intrinsic color indexes of M52 stars. I used [Fe/H]=-0.11 in the retrieved Padova isochrones, because I knew from literature that the M52 cluster is young. As I did not find iron-line metallicity analysis results for M52, I have made the assumption that these stars should have slightly sub-solar metallicity.

This analysis resulted in the cluster age $t_{M52,new}$ =

$80Myr + 60Myr/-20Myr$.

In the language of hypothesis testing, we would be curious to see whether the null hypothesis

$$H_0 : t_{M52,new} = t_{M52,literature}$$

passes the t-test with 95 percent confidence interval or if we should consider the alternate hypothesis to be more lilely.

The t-value is

$$t = \frac{t_{M52,new} - t_{M52,literature}}{(\sigma(t_{M52,new})^2 + \sigma(t_{M52,literature})^2)^{1/2}}$$

Observe that $|t| = 0.25 < 1.96$ so we conclude that the null hypothesis is the most likely hypothesis. The results of this project reconfirm previous literature findings.

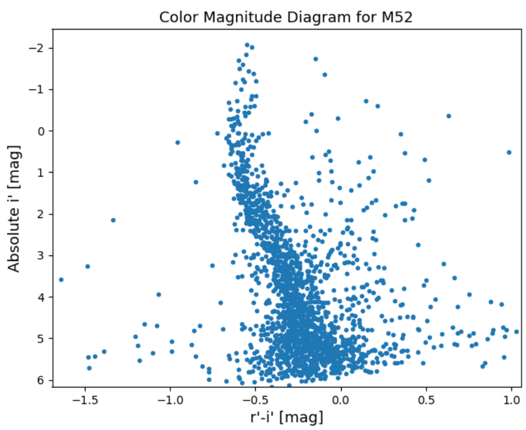

FIG. 3. Color-magnitude plot of M52. The vertical axis shows absolute i' magnitudes, while the horizontal axis has r'-i' color indexes for individual stars. The values are not corrected for extinction and absorption of light from the open cluster.

VI. CONCLUSION

Based on the Padova isochrone fitting in the CMD of M52 I determined the cluster age to be $t_{M52,new} = 80Myr + 60Myr/-20Myr$. This is in accordance to previous literature results of $t_{M52,literature} = 60Myr \pm 10Myr$ [3].

This project shows that the various ages from the interval 60-140 Myr mentioned in astrophysics literature are all plausible. A potential explanation of this fact is that stars of M52 formed at slightly different times. As the cluster is definitely young, different star formation times may account for the high dispersion in its age estimated through isochrone fitting. In order to investigate this hypothesis in the future one would need to create a spatial model of M52 stars and analyse separately stars from different regions of the clusters, after correcting for the star dynamics from the formation of the cluster: one would expect stars that were in proximity during the star formation time to originate from the same gas matter and to have the same age.

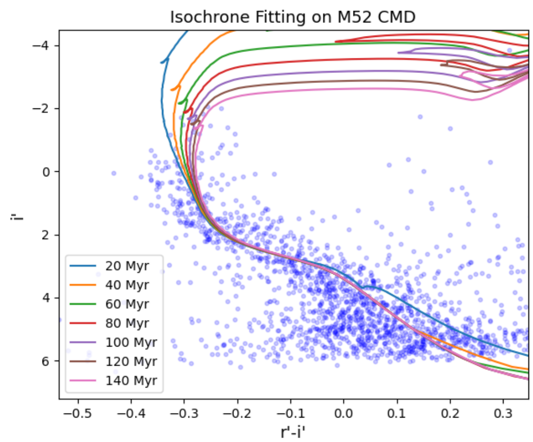

FIG. 4. Relevant age Padova Isochrones fitted on the CMD of M52. You can see that all the isochrones fit well most of the CMD, the differences becoming evident only at the turnoff point.

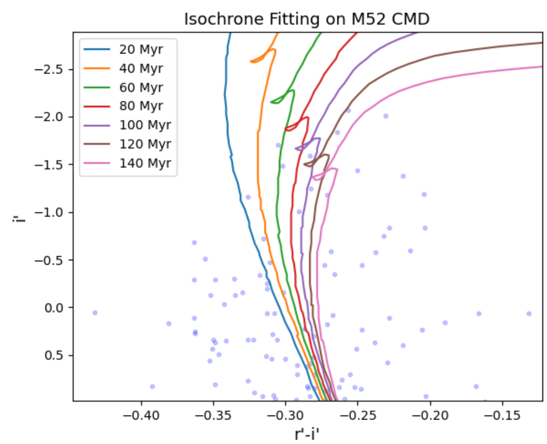

FIG. 5. Detail of the turnoff point of M52.

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