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Age of Stellar Clusters: Computational Project ASTR 591

Joseph Havens,[1] Reuben Honeychurch-Turner,[1] and Paul Kury[1]

[1] *Department of Physics and Astronomy, University of Kansas, Lawrence, KS 66045, USA*

ABSTRACT

This project presents a comprehensive analysis of the ages of twelve stellar clusters, encompassing both open and globular types, utilizing isochrone fitting techniques. Employing open-source data from the GAIA mission, we estimate the ages of six open star clusters (M11, M26, M35, M44, M45, M46) and six globular star clusters (M2, M3, M5, M13, M14, M30), using isochrone fitting based on their color-magnitude diagrams. Additionally, we explore the correlation between the ages of these clusters and their galactic latitudes, offering valuable insights into the spatial distribution and evolutionary timeline of these celestial bodies, showing a slight correlation between age and distance from 0 galactic latitudes. The findings illustrate the age differences between open and globular clusters, enhancing our understanding of stellar evolution and the history of the Milky Way, through analyzing the open and globular clusters with their ages.

1. INTRODUCTION

Understanding the ages of celestial objects (like stars) plays a pivotal role in understanding the formation and evolution of the Milky Way and other galaxies, as well as the underlying processes governing stellar evolution. Star clusters, both open and globular, provide a unique opportunity for astronomers to investigate the development of many different stars which were presumably born at the same time.

Cluster ages can be determined through isochrone fitting. This method assumes that all the stars in a cluster form at roughly the same time. This means all stars in a cluster have roughly the same age. If they were all formed simultaneously (and since not all stars are equally massive), they would produce the theoretical "zero-age main sequence" where all of the stars at the time of their birth lie exactly on the main sequence in the HR-diagram, a scatter-plot showing the relationship between absolute magnitudes (intrinsic brightness) and spectral types (temperatures). As the clusters (i.e. the stars) age, the higher mass stars will burn through their hydrogen more quickly, leaving the main sequence at an earlier time than low mass stars, which remain on the main sequence longer. This characteristic arrangement in the HR-diagram can be modeled for different ages, forming isochrones. Stars lying on this theoretical line in the HR-diagram should therefore have approximately the same age. This allows to estimate a clusters age by selecting the best fitting isochrone out of a catalog of isochrones for multiple ages (Voyages 2023).

Open star clusters are characterized by a relatively small number of stars loosely bound by their mutual gravitational attraction. Their members are typically young, and the clusters themselves are situated within the Galactic disk. In contrast, globular star clusters are ancient, densely packed assemblies of stars who progressively concentrate towards the center of the cluster. Due to their wide range of location distribution, open clusters may be harder to isolate, making examining them harder. These two types of clusters with their vastly different age ranges represent two distinct epochs (i.e. a relatively recent epoch (a few million years ago) for open clusters and an ancient epoch (billions of years in the past) for globular clusters) in the life of the universe, which makes them valuable probes of its evolution. They help us understand the composition and environment in the universe these stars were born in (Chen et al. 2004).

Measuring ages of stellar objects can provide valuable insights into stellar evolution and galactic archaeology, i.e. the formation of galaxies. Age measurements are generally very imprecise and should be treated as rough estimates. This is especially true for young open clusters, where member stars are few and scattered in the turn-off region and there are no sub-giants to guide the isochrone fitting (Brogaard et al. 2023).

Furthermore, it is of interest to investigate a possible correlation between the clusters location and its age. This can be done by plotting the estimated ages against their galactic latitude, which is a measure of their distance from the plain of the Milky Way. By doing this, we can compare the ages of clusters in the plain of the galaxy to those outside.

In this study, we aim to measure the ages of six open star clusters and six globular star clusters by employing a technique known as isochrone fitting to the measured data. This will help us understand the relationship between the ages of these clusters, as well as investigate correlations between age and location based on their galactic latitude, as mentioned above.

2. DATA

The GAIA (Global Astrometric Interferometer for Astrophysics) Mission of the European Space Agency (ESA) launched a space observatory in 2013 whose primary goal is to provide a very accurate dynamical 3D map of our galaxy and beyond. The aim is to produce a catalog for star magnitudes up to 20, which corresponds to more than one billion stars or about 1% of the stars of our the Milky Way (ESA 2013).

For this examination, primarily the position data (declination and right ascension) of the measured stars, along with different magnitudes (i.e. filters for the "G", "BP," and "RP" bands) where used to group these stellar objects into clusters and examine their ages. Additionally, measured parallax was used to further refine the selection process.

Determining estimates for the ages of the different clusters was done by obtaining a library of several isochrones and fitting them to the data-points of the selected stars in a HR-diagram. Each isochrone corresponds to a certain age. In this examination, isochrones with ages ranging from $10^{7.5}$ to 10^{10} years were used (on the graphs it will say Gyrs instead). They were generated by an online tool maintained by Léo Girardi at the *Osservatorio Astronomico di Padova*. More details can be found on its website (Girardi 2023).

3. ANALYSIS

Firstly, we calculated the absolute magnitude of the clusters using the apparent magnitude that were measured by GAIA using the equation:

$$M = m - 5 * log_{10}(distance/10) \tag{1}$$

We then de-redddened the stars by subtracting the blue light from the extinction factor to cancel the effect of the reddening. When choosing the stars to be included within the plots, we considered all plot points then tried to see which fit any of the isochrones. To do this, we changed multiple parameters including the extinction and the cutoff radius. As shown in figures 1 and 2, the isochrones range in value from $10^{8.2}$ years to $10^{9.8}$ years. All of the isochrones that were chosen were used because they had the best fitting lines that we could find. The best of these were the 8.7 isochrone for M35 and the 9.8 isochrone for M30, which both followed the star plots extremely well. Our isochrones have resulted in very similar times to the literature, and as such, are good approximations for the ages of the clusters.

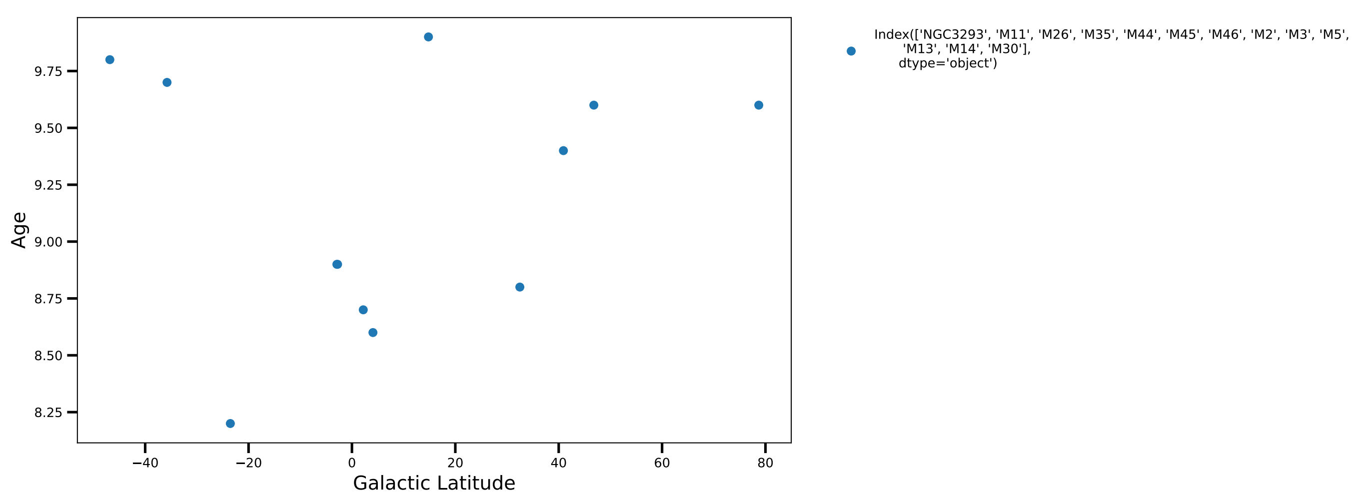
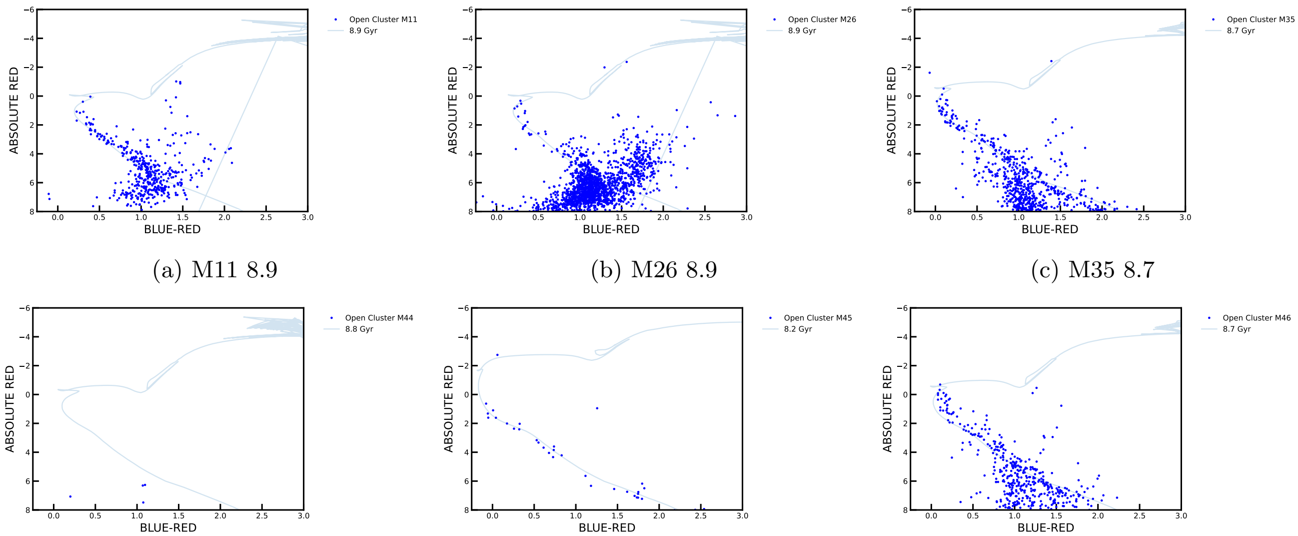


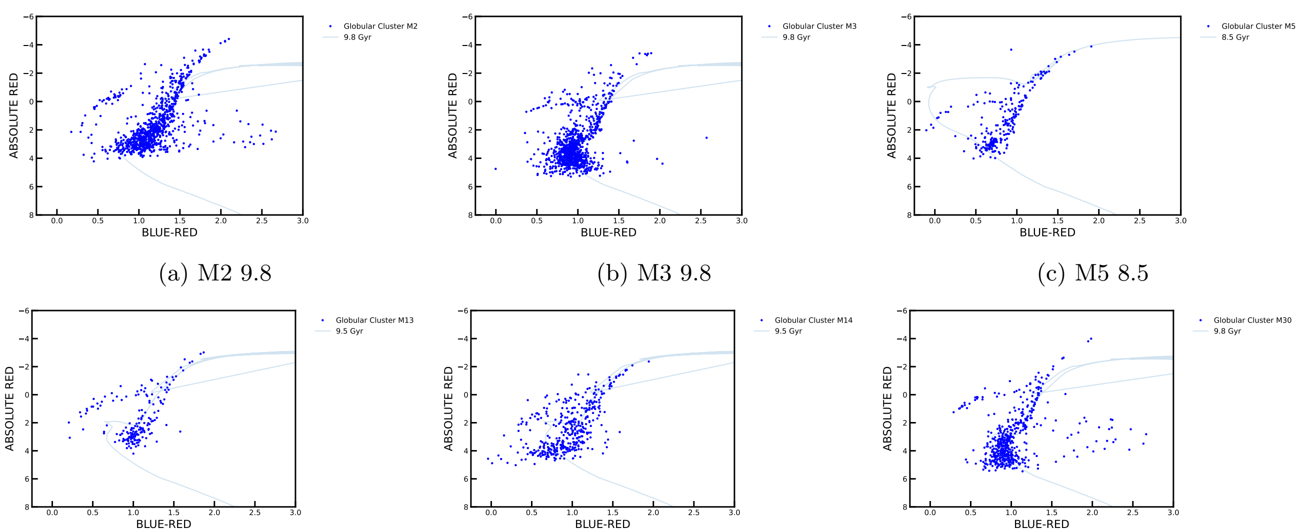
Figure 1: Plot of the ages of the different clusters against the glactic latitude



(a) M11 8.9 (b) M26 8.9 (c) M35 8.7

(d) M44 8.8 (e) M45 8.2 (f) M46 8.7

Figure 2: Open clusters with their isochrones



(a) M2 9.8 (b) M3 9.8 (c) M5 8.5

(d) M13 9.5 (e) M14 9.5 (f) M30 9.8

Figure 3: Globular clusters with their isochrones

Open clusters		Globular clusters	
Name	Age / Gyr	Name	Age / Gyr
M11	8.9	M2	9.8
M26	8.9	M3	9.8
M35	8.7	M5	8.5
M44	8.8	M13	9.5
M45	8.2	M14	9.5
M46	8.7	M30	9.8

Table 1: Estimated ages for all inspected clusters

4. DISCUSSION

While there is a wide range in the ages of the clusters, on the whole, the globular clusters are about a power of 10 years older than the open clusters. This is not surprising, since most globular clusters are older than open ones, with some being nearly as old as the universe itself. The same cannot be said of open clusters, which if any were formed as long ago as the globular clusters, would have dispersed by this point. While there is a clear difference between the ages of the two cluster types, there appears to be very slight correlation between the ages and how far from 0 galactic latitude the clusters lie. From this, we can infer that, since the closer to galactic center clusters are younger, clusters that are older are more likely to be either in the outer halo of the Milky Way, or even outside of our galaxy. That said, the measurements of the globular clusters are by far the more uncertain, since the ages were the best approximations of the isochrones, which were unreliable for both the open and globular cluster, but moreso for the globular clusters.

5. CONCLUSION

In this study, we have systematically determined the ages of a selection of open and globular star clusters, utilizing the technique of isochrone fitting. When an entire class of undergraduate scientists repeat this task, we can find the mean of the guesses to arrive at a statistically sound approximation of the ages. The clusters' ages have been estimated based on their positions in the color-magnitude diagram, matching them with theoretical isochrones. Our analysis revealed that the open clusters (M11, M26, M35, M44, M45, M46) exhibit ages ranging from 8.2 to 8.9 Gyr, whereas the globular clusters (M2, M3, M5, M13, M14, M30) are significantly older, with ages ranging from 8.5 to 9.8 Gyr.

Furthermore, our study extended to examining the relationship between the ages of these clusters and their galactic latitudes. The analysis included plotting the estimated ages against their galactic latitudes to explore any potential correlation. This approach aimed to discern patterns in the spatial distribution of these clusters in relation to their ages. The resulting plots show no notable differentiation between the ages of clusters located near the plane of the Milky Way and those situated away from it. Such insights contribute to our understanding of the spatial-temporal distribution of star clusters in our galaxy.

This research enriches our comprehension of stellar evolution and the chronology of the Milky Way. It not only corroborates the general understanding that globular clusters are among the universe's oldest known objects but also provides refined age estimations that can be instrumental in future astrophysical investigations. Our findings are in line with current astrophysical theories and add to the growing body of knowledge in stellar and galactic astronomy.

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