Estimating Properties of Stellar Populations Using the Isochrone Method

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Introduction

Star-forming regions are molecular clouds that become gravitationally unstable and collapse into stars. These stars not only have a shared origin in time but also share other parameters important in the context of stellar evolution.

These areas of our night sky are known as stellar clusters, which include open clusters, located in disks of spiral galaxies such as our Milky Way (see Figure 1). Open clusters are up to several billions of years old, making them some of the oldest astronomical objects visible in our sky.

Figure 1: *The observations of stars in the Hyades open cluster can be used as the input data to analyze with the isochrone method. This image was generated as part of the Digitized Sky Survey 2. Credit: NOIRLab/NSF/AURA/Digitized Sky Survey 2 (2020)[1]*

The makeup of a stellar cluster can be represented with help of a Hertzsprung-Russel Diagram (HRD), which shows positions of stars on the diagram (see Figure 2). The locus formed from plotting the stars of different masses, but at the same age is called the stellar isochrone.

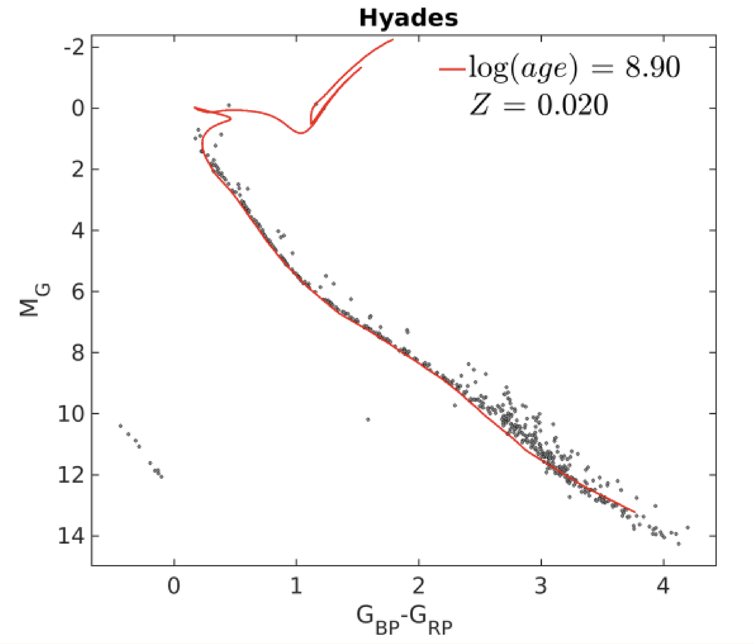

Figure 2: *The stellar isochrone of the Hyades cluster as shown in Figure 1 plotted along the cluster's HRD. It was obtained for an age of 794 million years. The stars that are the most massive will be the most advanced along their evolution track compared to the low-mass stars. Credit: Gaia Collaboration, et al. (2018)[1]*

To compare stellar evolution model results to observed data, a model isochrone, constituting a collection of synthetic stars of the same age, is constructed with the help of stellar evolution code.

The aim of this work is to estimate the average model properties of observed stellar populations in application to observations of stellar clusters. To verify the correct operation of the method, we use synthetically generated stellar populations. The method to construct the cluster isochrone is detailed in the next section.

Methods

The stellar model library is obtained using the Modules for Experiments in Stellar Astrophysics code.[3] Our database contains a series of stellar evolution models covering initial masses between 0.05 $M_\odot$ to 40 $M_\odot$, for select values of metallicity, Z, and stellar rotation rates, Ω/Ω_{crit}, where Ω_{crit} is the stellar break-up velocity.

The synthetic stellar population (cluster) data were obtained as follows. First, a synthetic population of stars was created with randomly chosen masses, metallicities, and rotation rates. The masses were generated according to the adopted stellar Initial Mass Function (IMF). In this work, the *Kroupa broken power law*[4] was used (see Figure 3). The metallicity and the rotation rates of individual stellar models were drawn from Gaussian distributions with average values of the synthetic stellar population.

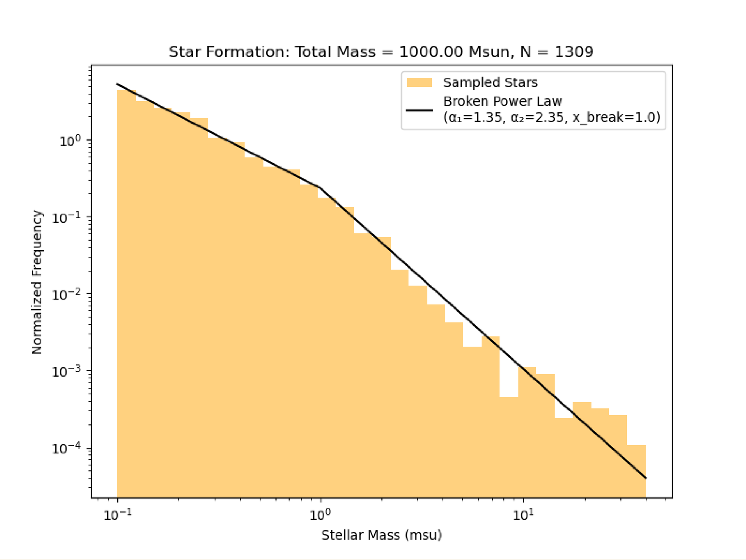

Figure 3: *This graph represents a distribution of mass in a synthetic star cluster, sampled according to the Kroupa IMF. The sample mass corresponds to 1309 stars and 1,000 solar masses.*

As soon as the synthetic cluster is created, a tri-linear interpolation method is used to find effective temperatures and luminosities of synthetic stars for a trial value of the cluster's age. Next, the so-constructed isochrone is compared in terms of goodness of fit to the observed stellar cluster data. Finally, optimal parameters of the stellar population can be estimated using one of the available optimization methods. This concludes the process of finding the parameters of observed stellar populations in the isochrone method.

Results

In this work, the process of fitting the parameters of the stellar population was not done. The following demonstrates how the isochrones change with time (see Figure 4). The stellar isochrones were calculated with respect to time, starting at intervals from one million years until the cluster was one billion years old. The stars coevolved together, but the most massive stars disappear from the isochrone when their core collapses at the end of their evolutionary track in the stellar database. This explains the lack of white dwarfs and other remnants from the graph.

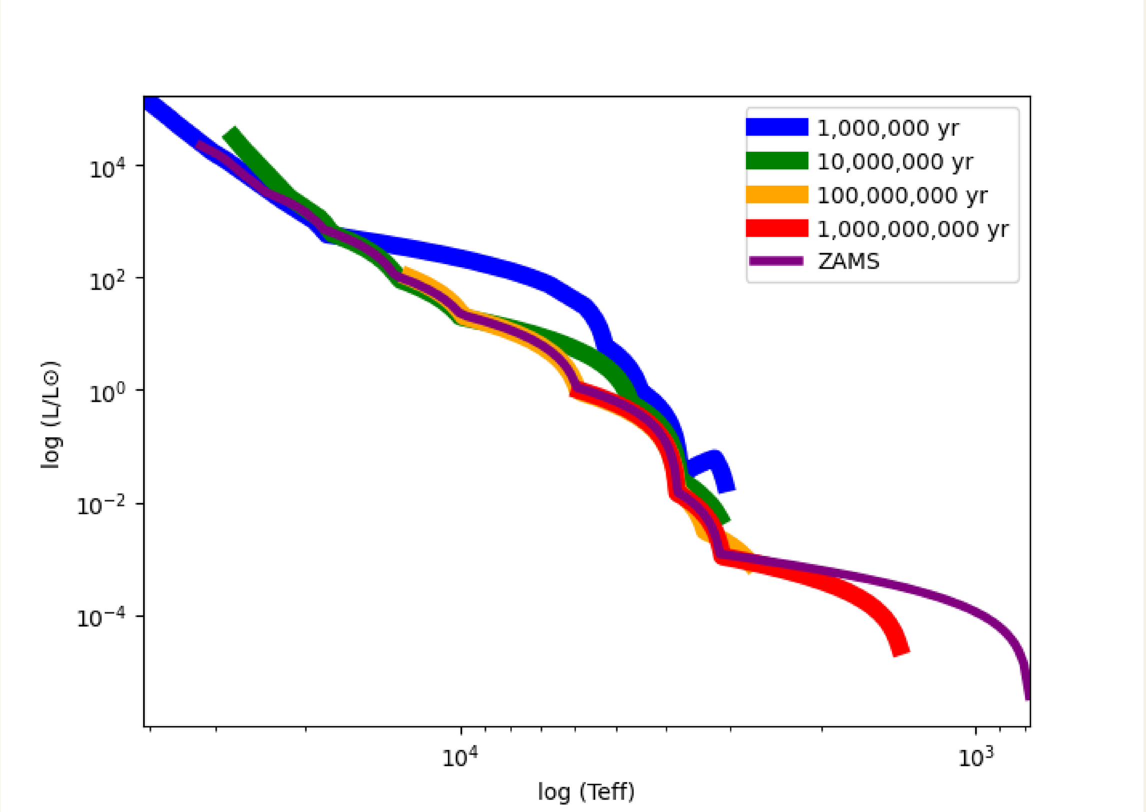

Figure 4: *This HRD includes the isochrones of a synthetic cluster as it is evolved through time. The graph starts with the star cluster at one million years old and evolves the cluster by orders of magnitude until it is a billion years old, which is an age that matches that some of the oldest star clusters in our universe.*

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Conclusions and Future Work

The isochrone's evolution in age reflects the evolution of the stellar population of a given locus with average properties. Figure 4 represents the first step in verifying a correct operation of the implemented isochrone method. To achieve this point, it was necessary to learn the astrophysics behind star formation and the stars' coevolution in a stellar cluster. Additionally, the coding expertise gained included running and troubleshooting MESA simulations, as well as applying the IMF and calculating the isochrones. Both the astrophysics and computing aspects provided the means of implementing and verifying the isochrone method; however, the coding aspect ended up the limiting factor which presented challenges in implementing the perturbations in the synthetic observational data.

Possible next steps include extending the database to larger ranges of parameters. In addition to the Kroupa IMF, the Chabrier IMF[5] could be used to evaluate the underlying assumptions about star formation process such as the length of the star formation burst. Ultimately, the isochrone method could be applied to observations of actual stellar populations like that seen in Figure 1, and a similar process of fitting the isochrone as detailed in the methods.

References

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