

Unraveling the Secrets of Star Clusters: A Methodical Approach to Transforming Gaia DR3 Data Archives into Classroom Experiments

Teodora Avramović, Milan Milošević
Faculty of Sciences and Mathematics, University of Niš, Serbia

Introduction

This classroom activity shows how students can estimate the age of an open star cluster from real astronomical observations. The exercise was inspired by the Winter School of Physics organized in January by the Faculty of Sciences and Mathematics in Niš. It was intended for upper-secondary students and introductory university courses.

Gaia DR3 provides parallaxes, proper motions and photometry for more than 1.5 billion stars [1]. For an open cluster, selected member stars can be placed on a color-magnitude diagram (CMD), using the intrinsic color $(B_p - R_p)_0$ and the absolute magnitude M_G [2].

In this exercise, we use the **Gaia color** $(B_p - R_p)_0$ on the x-axis and the absolute magnitude M_G on the y-axis. All stars of the same age lie along one isochrone (a curve on a CMD diagram that represents stars of different initial masses at the same point in their evolution). For this exercise we will use **PARSEC** [3] database, which was also used for calculation of theoretical isochrones.

The main-sequence turnoff (MSTO) point on a CMD is the specific location where stars depart from the main sequence because they have used up the hydrogen fuel in their cores [4].

Method

The full workflow includes two independent data downloads: Gaia DR3 data for selected cluster [1], and PARSEC isochrones for several ages that we will overlay over the CMD [3].

Provided Python script executes the retrieval and processing of Gaia DR3 data through the following steps:

1. sends an ADQL query to the Gaia archives for all stars in the circle around the cluster center with $G < 18.5 \text{ mag}$;
2. filters members by proper motion ($3\sigma_\mu$), parallax ($3\sigma_\pi$) and RUWE (measure of the quality of the astrometric solution);
3. calculates the intrinsic color $(B_p - R_p)_0$ and the absolute magnitude M_G , applying the distance modulus and extinction;
4. writes the result in a .csv file

For one cluster, we take several isochrones of different ages. The script retrieves the isochrone for the given log (age). The results of this program can also be loaded into Google Colab Notebook environment. [5] [6]

For Excel processing, we use columns BP_RP_0 (color) and M_G (magnitude) from GaiaCSV, and BP_RPIM_G columns from each isochrone - they directly represent coordinates to the CMD.

Key steps to perform data processing in Excel:

1. Loading CSV cluster
2. CMD diagram sketching
3. Loading and overlay isochrones
4. Identifying turnoff point
5. Mark turnoff point on diagram
6. Numerical fitting age using Excel Solver

Step 6 is particularly crucial, as the cluster age can be objectively determined by minimizing an objective function that evaluates the fit of the isochrone to the cluster's data points.

Numerical fitting in Excel Solver determines cluster age by minimizing the average distance between the stars with the help of PARSEC isochrones, where the **vertex of the fitted parabola** provides the best-fitting age within the adopted isochrone grid.

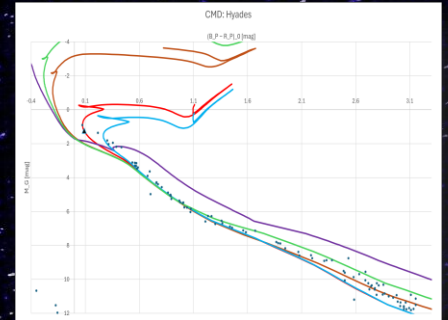
Lastly, after observing the magnitude of turnoff point, we can determine masses of stars and using relation for independent age assessment.

Results

In our example, the same workflow was applied to the Pleiades and Hyades. The same workflow can be applied to other clusters.

The given combination of Gaia DR3 data and PARSEC stellar-evolution models provides a practical method for estimating the ages of open star clusters: Thus, the obtained results are in satisfactory agreement with the expected values, considering the simplifying assumptions and the educational purpose of the exercise.

Primarily, this method was intended to illustrate how observational data can be compared with theoretical models in a classroom setting. Figure shows the CMD for the Hyades cluster. An analogous diagram can be obtained for the Pleiades.



Hyades CMD: Gaia DR3⁺ members with PARSEC isochrones; the MSTO is the age-sensitive feature.

	Pleiades	Hyades
Reference age	112 Myr	625 Myr
Classroom estimated	113 Myr	635 Myr

Theoretical and experimental results for Pleiades and Hyades

Conclusion

This exercise demonstrates how Gaia DR3 observations and PARSEC stellar-evolution models can be combined to estimate the ages of open star clusters, while providing students with practical experience in working with real astronomical data, interpreting color-magnitude diagrams, and connecting observations with theoretical models. Although the estimated ages depend on membership selection, extinction corrections and the adopted isochrone models, these limitations are appropriate for an educational exercise and provide a useful opportunity to discuss uncertainty and model dependence. The activity introduces a complete research-like workflow: data retrieval, selection, visualization, model comparison and physical interpretation.

References:

- [1] Gaia ESA archive, <https://gea.esac.esa.int/archive/>
- [2] Project for Observational Astronomy 2018/2019: Colour-magnitude diagram of an open cluster, Søren S. Larsen
- [3] PARSEC, <https://stev.oapd.inaf.it/PARSEC/>
- [4] Discovery of 28 open clusters with Gaia DR3
- [5] Gaia DR3 open-cluster members to CSV
- [6] PARSEC isochrone to CSV

