Determining the age of ϵ Chamaeleontis with MIST Isochrones

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1. INTRODUCTION

Young moving groups (YMGs) are young stellar associations that drift throughout the Milky Way. These groups may be moving as a result of stellar cluster disruption, being dynamically induced by non-axisymmetric elements of the Milky Way (such as spiral arms and bar), or being remnants of past accretion events (Antoja et al. 2010). Movement is most likely due to a mix of all three of those motivations.

In order to determine the age of these moving groups and see if they are YMGs, astronomers often look Lithium abundances (da Silva et al. 2009). YMGs typically have ages on the order of tens of Myrs.

In this project, we study the YMGs β Pictoris Moving Group (BPMG), TW Hydrae (TWA), and η Chameleontis/Mamajek 1 (ETAC), in an attempt to better characterize the age of ϵ Chamaeleontis/Cha-Near (EPSC).

Astronomers have roughly dated BPMG to be ~ 20 Myrs old (Zuckerman et al. 2001; Gagné et al. 2015), TWA to be ~ 10 Myrs old (Gizis 2002; Sokal et al. 2018), ETAC to be ~ 8 Myrs old (Mamajek et al. 2000), and ESPC to be ~ 5 Myrs old (Murphy et al. 2013). Of course, the ages of objects within these YMGs can vary by several Myrs, so the ages given here are a rough average.

We plan on dating EPSC by using color magnitude diagrams (CMDs) and overplotting isochrones for typical YMGs (like BPMG, TWA, ETAC). When doing this, however, we must be wary of confounding factors, such as color excesses (Venuti et al. 2015). Stars may appear bluer, and have a blue excess, if they have an actively accreting disk around them. On the other hand, stars may appear redder if they have a colder non-accreting disk around them. This can shift the location of the star on the CMD and falsely shift the age we get by looking at isochrones (Walker 1972).

The reason we want to better characterize and confirm the expected age of EPSC is because it is home to TOI 1227, a young planet of great interest to astronomers. This planet is interesting because its host star has a mass $< 0.2 M_\odot$ and the transit is 2%, which indicates the planet is Jovian. The planet itself is less massive than Jupiter and the transit is present at many wavelengths, indicating that the planet is actually a planet and not an eclipsing binary. Preliminary results indicate this planet is likely undergoing Kelvin-Helmholtz contractions.

2. METHODS

2.1. *Data Cleaning*

We began by looking at the Gagne catalogue of stars in different YMGs. We wanted to do several things with this catalogue.

First, we wanted to cut the catalogue of stars so that we only had stars in BPMG, TWA, EPSC, and ETAC.

Second, we wanted to cut binary stars from the catalogue. In order to do so we eliminated stars with RUWE (Renormalised Unit Weight Error) < 1.2. RUWE is found in the `gaiadr2.ruwe` database, so we queried this database using the dr2 source ids from the catalogue. We merged the dataframe containing the RUWE data with the catalogue on the source id and then cut based on RUWE.

Third, we wanted to get the edr3 source ids for the objects in our cut catalogue in order to prepare our catalogue for use when the dr3 data is released in 2022. We queried the `gaiaedr3.dr2_neighbourhood` and `gaiadr2.gaia_source` databases using the following SQL code to cross match dr2 and edr3 ids:[1]

```
"""SELECT dr2.source_id, edr3.*
FROM gaiadr2.gaia_source AS dr2
JOIN gaiaedr3.dr2_neighbourhood AS edr3
ON dr2.source_id=edr3.dr2_source_id
WHERE """ + stri +
"""ORDER BY edr3.dr3_source_id"""
```

Several dr2 ids mapped to multiple edr3 ids. We eliminated duplicates by choosing the edr3 ids that had the closest angular distance to the dr2 ids. This id cross-matching dataframe was then merged into our cut catalogue.

Fourth, we queried `gaiadr2.gaia_source` for relevant data metrics, including parallax, B_p-R_p, B_p-R_p excess, and relative G magnitude. We also converted relative G magnitude to absolute G magnitude using the parallax. We then merged this in with our previous catalogue to get a comprehensive dataframe.

Lastly, we made cuts to the dataframe in order to eliminate stars with accretion disks, which could effect our dating of the YMGs for reasons discussed in the in-

[1] Note that stri is a string containing all the dr2 source ids for objects of interest. We referenced Brown et al. (2020) in writing this SQL query.

troduction (§1). We also cut out particularly dim stars, because such sources generally have a worse signal-noise ratio. For the dim stars, the cut was made at $G = 12$ mag. For the accretion disk stars, the cuts were made according to red and blue excess. A blue excess indicates the star has an actively accreting, hot disk. While a red excess indicates the existence of a cooler, inactive disk. For the blue excess, the cut was made according to the standard for the GAIA filters.

$$\text{excess} = \frac{B_p + R_p}{M_G}$$

This can be calculated in a relatively easy manner because the GAIA G filter matches up well with B_p and R_p filters (Fig.1).

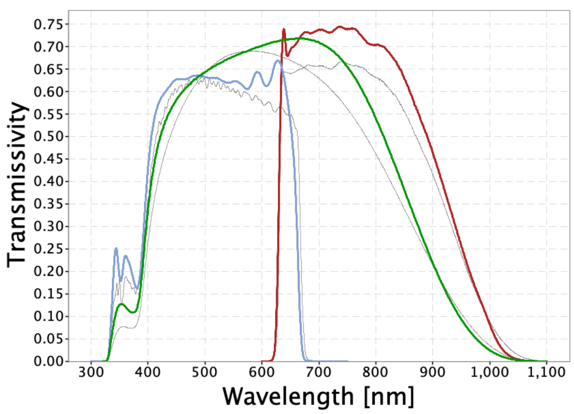

Figure 1. The GAIA EDR3 filter passbands. Note how the G-mag filter (green) lines up nearly as the sum of bp (blue) and rp (red) filters. Credits: ESA/Gaia/DPAC, P. Montegriffo, F. De Angeli, M. Bellazzini, E. Pancino, C. Cacciari, D. W. Evans, and CU5/PhotPipe team

Calculating the red excess proved a little more difficult. Typically, this is done with K-W3 (WISE/2MASS filters) color. While our dataframe does contain the values for the WISE/2MASS catalogues, there is no easy way to calculate the red excess like we did the blue. To make up for this, we define our set of isochrones (see §2.2) to completely contain (to $\sim 2 - 3\sigma$) the expected ages of the clusters. From here, we cut out any data points with a $B_p - R_p$ color more red than that of the reddest isochrone.

Our code and dataframe is set up to be dynamic, such that when data release 3 comes out, only a few intuitive changes will have to be made to change the data source.

2.2. *Isochrones*

The isochrone data obtained for this project comes from the MESA Isochrones & Stellar Tracks (MIST) project (Choi et al. 2016). Using the project's online Isochrone Web Interpolator, we create 4 Synthetic Photometry isochrones ranging in age from $\sim 1 - 31$ Myrs. These values where chosen to completely contain the expected ages of our clusters of interest within reasonable error. The youngest clusters are expected to ages ranging from $5 - 10$ Myrs (Sokal et al. 2018; Gizis 2002; Murphy et al. 2013; Mamajek et al. 2000), while the oldest, BPMG, is expected to have an age of 20 ± 6 Myrs. (Gagné et al. 2015). We chose to model solar metallicity and the default rotation rate ($\frac{v_{init}}{v_{crit}} = 0.4$) based on our findings in the literature.

3. RESULTS

Our final dataframe contained 177 stars across the four YMGs: 141 in BPMG, 13 in TWA, 17 in EPSC, and 6 in ETAC. Fig. 2 shows the distribution of stars in the final dataset in a histogram.

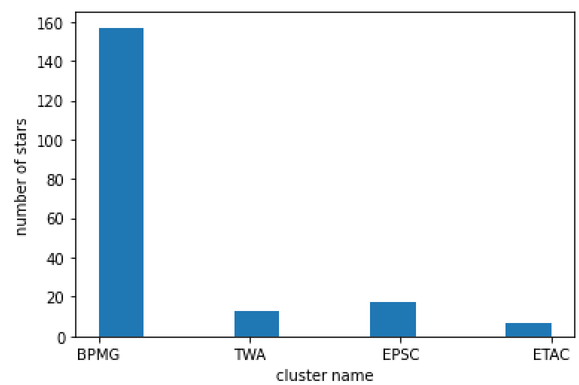

Figure 2. Histogram representing the distribution of stars across the four YMGs in the final dataset. BPMG clearly has the majority, followed by EPSC, TWA, and then ETAC.

Using this final dataset, we created our CMDs, shown in Fig. 3. We can tell that our CMDs are accurate since the data from each YMG roughly follows the isochrone corresponding to its age (the ages of the YMGS are listed in §1). We can also clearly see the effects of our data cleaning in the CMDs. There are no stars with strong red excesses and very few stars with blue excesses (and even these seem to be following the 31Myr isochrone). Using these CMDs, we can roughly constrain the age of EPSC and see if our findings support those currently in the literature.

4. CONCLUSION

Young moving groups are a research topic of interest to several subfields of astrophysics. In particular, the group ϵ Chamaeleontis is of recent interest to exoplanet astronomers using TESS data. By comparing EPSC to several well-known YMGs, we can get a greater sense of

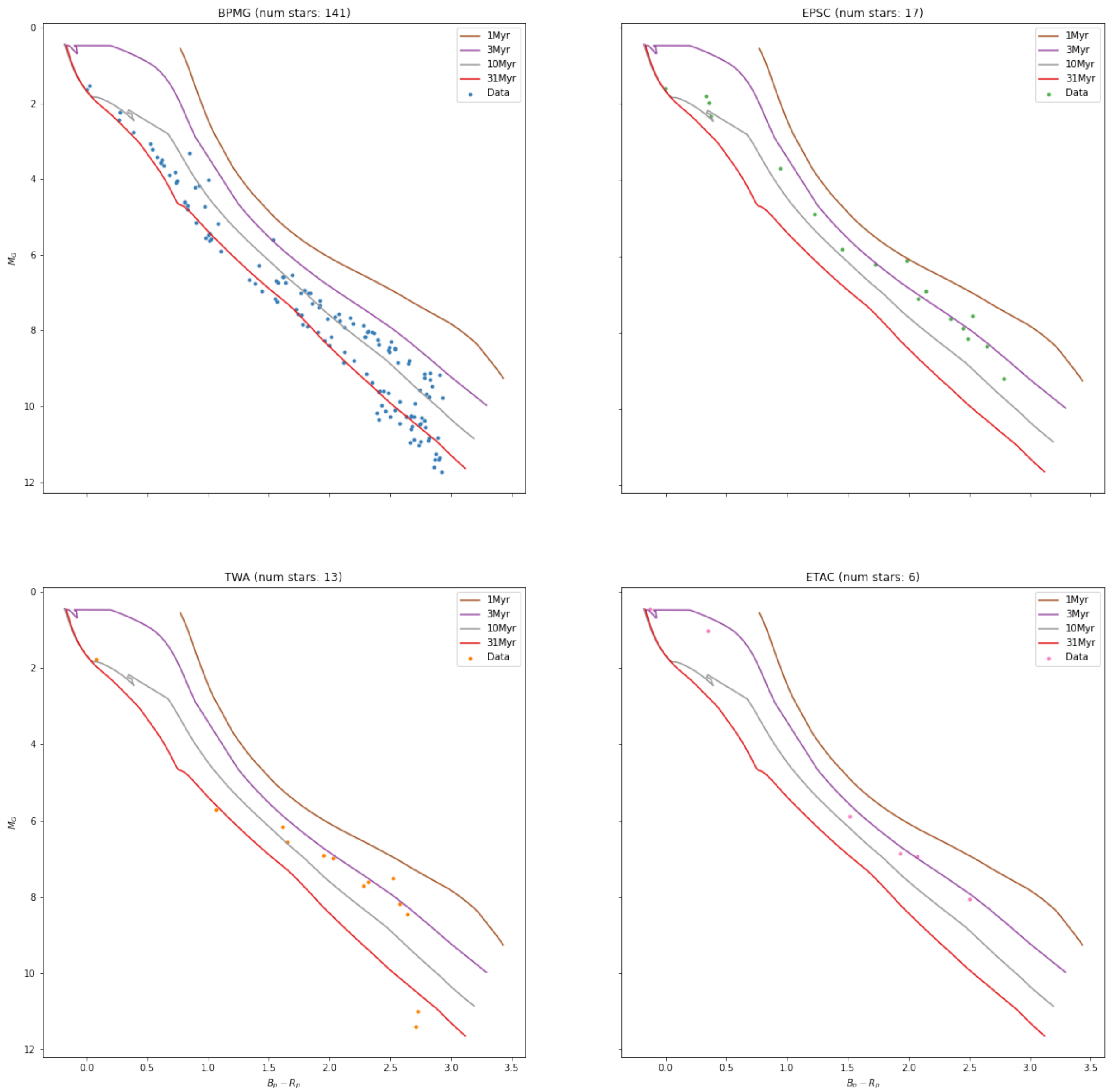

Figure 3. Stacked CMDs for each YMG of interest with representative isochrones overplotted. $B_p - R_p$ is used for color (an indication of blueness) and magnitude in the G band was used for magnitude. This data is from GAIA data release 2, as early data release 3 does not contain all the data relevant to our YMGs. Overplotted isochrones are from MISt and are discussed in more detail in §2.2.

its properties, including its age. Using MIST isochrones and comparing to three other well-known YMGs, we confirm the literature claiming that EPSC is of a similar ($\sim 1{-}30Myr$) age to the known YMGs, and believe that value may be closer to $\sim 3{-}10Myr$, on the younger side. Future research on YMG EPSC may utilize GAIA DR3 data, further reducing the error in this estimate.

REFERENCES

Antoja, T., Figueras, F., Torra, J., Valenzuela, O., & Pichardo, B. 2010, The Origin of Stellar Moving Groups, Vol. 4, 13–31

Brown, A. G., Vallenari, A., Prusti, T., et al. 2020, Astronomy and Astrophysics - A&A, doi: 10.1051/0004-6361/202039657

Choi, J., Dotter, A., Conroy, C., et al. 2016, ApJ, 823, 102, doi: 10.3847/0004-637X/823/2/102

da Silva, L., Torres, C. A. O., de La Reza, R., et al. 2009, A&A, 508, 833, doi: 10.1051/0004-6361/200911736

Gagné, J., Lafrenière, D., Doyon, R., Malo, L., & Artigau, É. 2015, ApJ, 798, 73, doi: 10.1088/0004-637X/798/2/73

Gizis, J. E. 2002, ApJ, 575, 484, doi: 10.1086/341259

Mamajek, E. E., Lawson, W. A., & Feigelson, E. D. 2000, ApJ, 544, 356–374, doi: 10.1086/317181

Murphy, S. J., Lawson, W. A., & Bessell, M. S. 2013, Monthly Notices of the Royal Astronomical Society, 435, 1325, doi: 10.1093/mnras/stt1375

Sokal, K. R., Deen, C. P., Mace, G. N., et al. 2018, The Astrophysical Journal, 853, 120, doi: 10.3847/1538-4357/aaa1e4

Venuti, L., Bouvier, J., Irwin, J., et al. 2015, Astronomy and Astrophysics - A&A, 581, A66, doi: 10.1051/0004-6361/201526164

Walker, M. F. 1972, ApJ, 175, 89, doi: 10.1086/151540

Zuckerman, B., Song, I., Bessell, M. S., & Webb, R. A. 2001, The Astrophysical Journal, 562, L87, doi: 10.1086/337968