Measuring Open Cluster Ages with Public Gaia Data

Version 3 for Punahou students: [1] Sep 2, 2024 [2] Sep 19, 2024 [3] Aug 27, 2025
This is copied from a larger document and over time more and more of the instructions will be included here. Dr. van Saders created the original document and will be available for questions when she visits.
This reference is designed as a quick guide for all of the steps we will discuss in class.
It contains stripped-down reminders of the datasets we'll be using, how to plot and manipulate data in TOPCAT, and a few FAQs about TOPCAT use that may be helpful as you work through the project.

Stellar Model Tracks

We'll be comparing our cluster data to stellar model tracks in a format called "isochrones". We learned about isochrones in the Gaia paper we just reviewed. Briefly, an isochrone is a set of many different stellar masses of stars, all viewed at exactly the same time. The model tracks we will use include a column that provides the age, the mass, the Gmag (apparent brightness from Gaia data) and the colors of the model tracks. You can compare the color-magnitude diagram of the clusters to the model tracks at different ages to estimate the ages of the clusters. The model tracks can be downloaded at:

Star cluster data folder

Table of Open Clusters
*Recommended clusters have a * next to their names: start with these!*

Name	Coordinates	Data file name	Comments	Extinction in G (mags)	Reddening in Bp-Rp (mags)
*M67	08 51 23.0 +11 48 50	M67.vot		0.16	0.08
*Pleiades	03 46 24.2 +24 06 50	Pleiades.vot		0.08	0.04
NGC6791	19 20 53.0 +37 46 41	NGC6791.vot	Tricky to find!	0.311	0.15
Hyades	04 29 47.3 +16 56 53	Hyades.vot		0.03	0.01
M37	05 52 17.8 +32 32 42	M37.vot	Tricky to find!	0.81	0.39
NGC2158	06 07 26.9	NGC2158.vot	Tricky to	0.96	0.46

	+24 05 56		find!		
NGC6633	18 27 22.8 +06 36 54	NGC6633.vot	Tricky to find!	0.49	0.23
NGC6819	19 41 18.5 +40 11 24	NGC6819.vot	Blackbelt level	0.63	0.31
M44/Praesepe	08 40 13.0 +19 37 16	M44.vot		0.07	0.03
*NGC 188	00 47 11.5 +85 14 38	NGC 188.vot		0.23	0.11
*NGC752	01 56 53.5 +37 47 38	NGC752.vot		0.11	0.05

Many of the quantities in the model grid are logged values. The units on each of the columns in the model tracks are as follows:

Log_age: log10 of the age in years. 6 corresponds to 1 million years, 9 to one billion years, etc.
Mass: mass of the star in solar masses (solar masses are the mass of our sun, about 2 x 10^{30} kg, or about 1 million Earth masses)
log_Teff: log10 of the surface temperature of the star in Kelvin (K). This is basically the same as the temperature, using logs makes plotting the vastly different temperatures between stars more manageable but you can ignore the log and just assume it's temperature.
log_L: log10 of the luminosity of the star in terms of solar luminosities. log_L = -1 is 10 times less luminous than the sun, log_l = 1 is ten times more luminous, and log_L = 0 is the same luminosity as the Sun.
Gmag: *apparent* Gaia magnitude (more general than BP or RP, as bright as the star appears from Earth)
BPmag: unreddened Bp magnitude (looking at the blue section of color, correcting for certain effects)
RPmag: unreddened Rp magnitude (looking at the red section of color, correcting for certain effects)
BPRP: unreddened Bp-Rp Gaia color

Once you feel comfortable with these datasets, you can download your own data here: VizieR
How do you get your own data? You won't need to for now but if you want to later, Dr. van Saders provided the following information on the tables she selected:

- Gaia Source ID, RA, Dec, Plx (parallax), e_Plx (error on the parallax), pmRA (proper motion in RA), pmDE (proper motion in declination), Gmag (apparent Gaia G magnitude), Bp (Bp magnitude), Rp (Rp magnitude), and Bp-Rp (color)
- Limited sources to Gmag < 20 to keep the file size from being enormous
- Searched in a 2-3 deg cone around the cluster center for sources
- Selected "unlimited" for the table entries on download, and VOTable format

Questions about the science, the process, your results, anything else? Drop questions at the end of this document, here: Questions.

Loading, plotting, and manipulating data in TOPCAT

If you have a question that isn't answered here, you can also reference the TOPCAT manual at: https://www.star.bris.ac.uk/~mbt/topcat/sun253/index.html

IMPORTANT: Saving a session in TOPCAT for later use:

TOPCAT allows you to save your session: all the tables you have loaded and the subsets you defined. Once you get to a place where you feel it would be nice to save your progress, you can:

1. Click on "File" in the main TOPCAT window, and click "Save Table(s)/Session"
2. Select the "Session" tab, and make sure all loaded tables you would like to save are checked.
3. You can select any output format, just remember which one it is. All of your cluster tables are in **votable format**, for example.
4. Choose a filename, and then navigate to the location you would like to save the session using either the filestore browser or the system browser
5. Click "ok"

To reload a session into TOPCAT: Use the "Load table" action under "File" to load the saved session you created; TOPCAT will recognize it as a saved session.

Note that save sessions *only preserve the data and subsets: they will not save the plots you have made.* If you want to save a plot, the best option is to go to the plot panel, and at the very top select the "export" menu and "save plot to file".

Section 1: Plotting Star Clusters

To load a table into TOPCAT, take the following steps:

1. Download the table to your hard drive
2. In TOPCAT, click File > Load Table
3. In the popup window, you can either click "Filestore Browser" or "System Browser". For the table formats we use here, System browser is likely the easiest to use; if you have a table in a different format and need to tell TOPCAT what the format is, Filestore Browser is the better option.

Plotting parallax and proper motion in TOPCAT:

1. With the table you'd like to plot selected in the main TOPCAT panel, click on the button that looks like a 3-dimensional cube  .
2. Under the position tab, set the columns you would like to plot: Plx (parallax), pmRA (proper motion in right ascension) and pmDE (proper motion in declination)

Questions about the science, the process, your results, anything else? Drop questions at the end of this document, here: Questions.

Discussion Question: Why does selecting a clump of stars in the 3D space defined by parallax and proper motion serve to identify cluster stars?

3. Under the "Form" tab, change "Mode" to "density" in the drop-down window. This will make structures much easier to see.
4. On the left-hand side of the panel, find the "Axes" menu, and click the "Range" tab. You can play with the limits shown on the plot by either manually providing numbers for the ranges, or changing the sliders. If you manually specify ranges, it's a good idea to reset the sliders by clicking on the  button.
5. Explore parallax/proper motion space, looking for a clump of stars that is the cluster.

Defining a cluster subset in your data:

1. In the 3D parallax/proper motion plot, isolate and zoom into the clump of points that you think is the cluster by changing the plot range displayed.
2. To create a subset, you can "lasso select" the stars you want using the  button at the top of the plot panel. For the lasso, you click it once, select the points you want on the plot, and then *click it again* to say you are done with your selection. Enter a subset name for your selected points, and then click "Add Subset"

Viewing a color-magnitude diagram of your data:

1. From the main TOPCAT panel, click the  button to make a 2D plot (with your desired table selected on the left-hand side).
2. On the "Position" tab, select the values you want to plot: Bp-Rp color for X, and Gmag (apparent Gaia magnitude) for Y
3. Go to the "Axes" menu on the left-hand side, click on the "Coords" tab in that menu, and tick the "Y flip" box. This inverts the G magnitude axis, so that brighter things (lower Gmag) are at the top, and fainter things (higher Gmag) are at the bottom.

Discussion Question: Why do we plot the Gmag axis in a color-magnitude diagram with small values at the top, and lage values at the bottom?

4. Click on the dataset menu on the left-hand side (looks something like: 

). Select the “Subsets” tab, and make sure that both “All” and your newly named subset are ticked: this will show your subset against all the other data. You can set the color of the subsets by changing the color on the menu after clicking on the subset. To view only your cluster subset, you can untick the “All” set.

Section 1 Discussion Question: In our color-magnitude diagram, only a small fraction of the stars are objects in our clusters. What are all the other stars, and why do they not at first glance appear to follow the same pattern as the cluster stars?

Section 2: Stellar Evolution with Data

Plot a subset of your clusters together:

1. Plot a subset of the clusters on the same plot, corrected for distance, reddening, and extinction: Pleiades, NGC752, NGC188, and M67
2. Start with one cluster color-magnitude diagram, any of the 4 above. In the subsets tab, untick the “All” subset and tick the cluster subset so that you are viewing just the cluster stars.
3. Click the  button to add a new dataset. You will see the new dataset show up in the list of datasets on the left hand side of the panel, with a name “<no table>”. In the “Position” tab, use the drop-down menus to select the Table you want to add and the values you want to plot (Bp-Rp and Gmag).

4. By default, the entire table will be plotted, but you only want the cluster subset. Click the “Subsets” tab, and make sure “All” is unticked and your cluster subset is checked.

For viewing the field (background) stars corrected for their distances:

1. Choose a cluster table you would like to use, and plot a color-magnitude diagram (Bp-Rp on the x-axis, and Gmag on the y).
2. Convert the y-axis from apparent to absolute magnitudes (i.e. magnitude corrected for distance). In the “Position” tab of the dataset menu, rewrite the Y dataseries to read: Gmag + 5*log10(Plx/100)
3. Next, we correct for dust extinction by subtracting the extinction in G from the equation for absolute magnitude (extinction has made the star appear *fainter* than it actually is) and subtracting the reddening value from Bp-Rp: reddening makes the star appear *redder* than it should be, subtracting the reddening will make it *bluer*. (You will need to change the expression for Bp-Rp to BPmag-RPmag, as TOPCAT has trouble with the “-” in the column name)
4. Look at the star cluster table below and subtract the reddening on the x-axis. Example for M67: BPmag-RPmag - 0.08
5. Final note: for extinction on the y-axis, you can subtract the Extinction in G in the table below from the value you use: Example for M67: Gmag+5*log10(Plx/100) - 0.16

Plotting the rest of the star clusters in the same window:

4. Follow all the steps as before to plot your group of 4 clusters, corrected for distance, extinction and reddening.

<u>Section 2 Discussion Questions:</u>

1. Describe what you notice about the clusters. How are they similar to each other? How are they different?

2. Without actually using isochrones to estimate ages, and simply relying on our discussion of stellar evolution, guess which of these clusters is the oldest? Which is youngest? Share with others in the class and justify your guess.

3. If you look at stars at the turnoffs of each of the clusters, what do you expect to see about their masses? Should turnoff stars in the older clusters be more or less massive than those in younger clusters? Explain your answer to someone else in the class and listen to their explanation.

To complete Section 2, add the rest of your star clusters to this graph of the 4 we chose initially.

Section 3: Stellar Evolution with Models

Download the file "MIST_isochrones.csv" from the Google Drive.

1. In TOPCAT, load this as a table. However, because this is not .vot format, we need to tell TOPCAT how to read it. Use the Filestore Browser, locate the file, and in the "Table Format" dropdown menu, select "CSV".
2. Now that the data is loaded, we'll define some subsets to make the tracks easier to use. Click on the  button to make a histogram with the data table selected. Select "log_age" as the column to plot.
3. For each age in the histogram, you can use the range sliders in the range tab of the Axes menu to zoom in so that only that histogram bar is shown. When you have the bar isolated, you can define a subset by clicking on the  button. The number in the table is the log10 age in yrs: i.e "6" corresponds to 1 million years, 8 to 100 million years, and 9 to 1 billion years, etc. The ages in the table (and useful name for your subsets) are: 1Myr, 100Myr, 500Myr, 1Gyr, 2Gyr, 3Gyr, 4Gyr, 5Gyr, 10Gyr. Make a subset for each.
4. Now, on a panel with cluster data, you can add the model table and plot Bp-Rp (or it might be listed as BPRP) versus Gmag. Under the subsets panel, you can select which ages you would like to show, and compare them to the data.

<u>Section 3 Discussion Questions:</u>

1. Experiment with overplotting stellar isochrones of different ages on your cluster sequences (making sure you have corrected the clusters for distance, extinction, and reddening). Estimate rough ages for each of the clusters and list them below:

2. Explore the model tracks by selecting various stars and looking at their properties (mass, temperature, luminosity). What patterns do you see in the turnoff stars as a function of age?

Questions?

Add questions that come up as you work through this here.