Age of Stellar Clusters

ASTR 591, Fall 2023

In this semester long project, you will measure the age of stellar clusters, compare with measurements from classmates, and write a short journal article about your results. All the files you need are provided for you. **This project is to be done independently of the other groups. You may not discuss methodology with the other groups.** This is very important. A key component of this project is comparing your results with your classmates to determine how uncertain your results are. If you discuss methodology, everyone's answers will be exactly the same, and you can't compare! **You are not being graded on getting the right age, but you are being graded on your comparison and interpretation of results with classmates.**

1 Project Overview

Gaia is a space observatory launched by the European Space Agency in 2013. It is creating a 3D map of our Milky Way. Through Gaia observations, precise magnitudes and parallaxes are available for millions of stars.

Clusters are groups of hundreds or thousands of stars that formed at the same time. Because massive stars die more rapidly, the main sequence turn-off point of a cluster can be used to determine its age. In practice, this is done by making a color-magnitude diagram of a cluster and fitting a theoretical model called an isochrone.

You will create color-magnitude diagrams using Gaia observations for 14 clusters. You will then fit isochrones to each of these color-magnitude diagrams to determine the cluster age. Finally, you will use the RA and Dec of each cluster to calculate its galactic latitude. You will correlate galactic latitude with age to draw conclusions about the Milky Way's evolution.

2 Getting Started

The three files you need can be found on the Google Drive. `Age of Clusters-Final-2021.ipynb` is the python notebook that you will use to plot your clusters. It has very descriptive instructions. **Read carefully before asking questions!** You can run this notebook using your favorite software. This program also reads the files `cluster_cat.csv` and `isochrones.txt`, so you need to place them in the same directory as your notebook. It is a good practice to open files and look at them before reading them into a code. You can open the `.csv` file with any spreadsheet software, and you can open the `.txt` file with any plain text editor.

3 Plotting your cluster

The file `cluster_cat.csv` contains Right Ascension, Declination, and photometry from Gaia Data Release 2. Gaia contains the mean magnitude from three photometric filters: g (green),

[0] https://www.cosmos.esa.int/web/gaia/dr2

bp (blue), and rp (red). You will make color-magnitude diagrams of the open clusters in Table 1, and the globular clusters in Table 2. The diagrams should plot the red magnitude on the y-axis and the blue magnitude minus the red magnitude on the x-axis. The x axis value represents a color difference, a.k.a. color, while the y-axis is just the brightness of one filter.

Name	RA (J2000)	Dec (J2000)	Distance (pc)
NGC 3293	10:35:49	-58:13:48	2750
M 11	18:51:05	-06:16:12	1900
M 26	18:45:18	-09:23:00	1533
M 35	06:08:54	+24:20:00	858
M 44	08:40:24	+19:40:00	177
M 45	03:47:00	+24:07:00	135
M 46	07:41:46	-14:48:36	1656

Table 1: This table tells us the coordinates of the centers of **open clusters**, along with their name and distance from Earth. NGC 3293 is used as the default example in the code.

First, you will need to select the stars from the file corresponding to a given cluster. To do so, determine the distance of all stars in the file from the center of your chosen cluster using a formula for the distance between two points on a sphere. You will consider that only stars within a certain angular distance threshold from the center coordinates you used are in your chosen cluster. I suggest starting with a threshold of $15'$, plotting a color magnitude diagram of the resulting stars, and then seeing how your diagram changes as your threshold decreases. Once you have chosen a final threshold, make sure your final plot has labeled axes. (These instructions are repeated in more detail in the python notebook.)

Name	RA (J2000)	Dec (J2000)	Distance (pc)
47 Tuc	00:24:05.4	-72:04:53.2	4001
M 2	21:33:27.0	-00:49:23.7	16,863
M 3	13:42:11.6	+28:22:38.2	10,400
M 5	15:18:33.2	+02:04:51.7	7499
M 13	16:41:41.6	+36:27:40.8	6800
M 14	17:37:36.2	-03:14:45.3	9290
M 30	21:40:22.1	-23:10:47.5	8300

Table 2: This table tells us the coordinates of the centers of **globular clusters**, along with their name and distance from Earth. 47 Tuc is used as the default example in the code.

4 Measuring Age

Cluster age is measured by fitting isochrones to the cluster magnitude diagram. Age is determined from the turn-off point–where cluster members leave the main sequence and become red giants. Isochrones are theoretical models relating turn-off point to age based on state of the art understanding of stellar evolution. Isochrones spanning $\log \mathrm{Age} = 7.5 - 10.0\,[\mathrm{Gyr}]$ are in the file `isochrones.txt`. Each isochrone lists age, stellar mass (in $M_\odot$), luminosity, temperature, and G, G_BP, G_RP magnitudes. Isochrones are based on the PARSEC models from Bressan et al. (2012) and were calculated using the web interface http://stev.oapd.inaf.it/cgi-bin/cmd.

Start with the globular clusters as the open clusters will have fewer stars and will be more difficult to fit. First, use the distance modulus to calculate the absolute magnitude in the G_RP band. Then, determine which stars in your plot are in the cluster and should be included when fitting the isochrone. Plot all isochrones on your color-magnitude diagram. Does it look like the cluster has as any reddening? How can you tell? If you think your cluster is reddened, estimate $E(G\_BP - G\_RP)$ and de-redden the cluster.

Overplot all the isochrones on your clusters and identify the best fit line. You will turn in a plot of the absolute magnitude of G_RP on the y-axis and G_BP-G_RP (de-reddened) on the x-axis. Your final plot should only include the best fit isochrone and an additional label for which age isochrone the line corresponds to.

You must turn in all cluster plots and ages by October 31. They cannot be turned in late.

5 Data Analysis Write Up

After you turn in your isochrone age plots, you will complete a write-up in the style of a journal article. In addition to your color-magnitude plots, you need to compile all the measured ages from your classmates and make a plot of age vs. latitude from the galactic plane. In your plot, use two different symbols for globular and open clusters. You will write using the standard professional typsetting system: LaTeX. Overleaf.com provides free AASTeX templates for you to use. Create an account on Overleaf and search "Templates" for AAS Journals. You should find a template called "AASTeX for submission to AAS Journals." Click on this and begin filling in the `.tex` file. Your formatting does not need to be perfect! If you are having trouble figuring out how to format something in LaTeX, and you can't find the answer from a simple Google search, please ask.

You paper should contain the following sections:

1. Abstract. Write this last. It should be a 200 word summary of your paper.

2. Introduction. Discuss the relevant literature. Draw from the papers that were presented in class.

3. Data. Include a short description of Gaia and the isochrone library. Again, draw from the papers presented in class.

4. Analysis. Describe how you measured the absolute magnitude of you cluster and how you de-reddened it. If you did not perform any de-reddening, describe why. Discuss how you decided which stars should be included when fitting the isochrones. Discuss which isochrones best matched your chosen cluster. Which ages produced an acceptable

fit? Which age produced the best fit? Include your isochrone plot with a descriptive caption. Include your isochrone plots here. **Add on:** how do your measurements compare with those in the literature? The literature, in this case, is your classmates results. I will put all color magnitude diagrams in a folder so you can look through the ages your classmates calculated.

5. Discussion. This is where you will discuss your plot of age vs. galactic latitude for all clusters. What trend do you notice? Is there a difference between globular and open clusters? What can you infer about how the Milky Way formed? Which measurements, globular or open clusters, are more uncertain? Why? Do the trends change if you take a classmate's age as the "true" value instead of your own?

6. Conclusions. Restate the cluster ages and the relationship between latitude and age.

Your first draft is due Wednesday, November 22.

When you write a scientific article, you submit to a journal and another astronomer referees your paper. This is the peer review process. I will serve as the "referee". I will provide a referee report on your paper, and you **must** fix the issues that I raise in order to successfully complete the project. **Your final paper is due December 15.**