Age of Stellar Clusters

ASTR 591, Fall 2019

In this semester long project, you will measure the age of two 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. **You may not discuss methodology with your classmates. You may only discuss trouble with code or LaTeX syntax.** 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 Plotting your cluster

The file `cluster_data.csv` contains Right Ascension, Declination, and photometry from Gaia Data Release 2 (https://www.cosmos.esa.int/web/gaia/dr2). Gaia contains three photometric filters: G (green), G_BP (blue), and G_RP (red). You will make color-magnitude diagrams of one open cluster (Table 1) and one globular cluster (Table 2). The diagram should plot G_RP on the y-axis and G_BP − G_RP on the x-axis.

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: Open Clusters

You will need to select the stars from the file that are in each cluster. You should convert the cluster center RA and Dec (listed in the tables) to decimal degree format. Next, determine the distance of all stars in the file from the cluster center using a formula for the distance between two points on a sphere. You will determine that all stars within a certain distance threshold are in the cluster. I suggest starting with a threshold of $15'$ and seeing how your diagram changes as your threshold decreases. Make sure your final plot has labeled axes.

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: Globular Clusters

When you turn in your plot, answer the following questions:

1. What physical property of stars does each axis represent?
2. What stellar attributes determine a star's location in the diagram?
3. The y-axis should run backwards (larger numbers at the bottom) for your plot to be consistent with the HR diagram. Why is this?

2 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 your globular cluster as your open cluster 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 you 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.

Fit all the isochrones to your clusters and measure the reduced χ^2. The isochrone with the reduced χ^2 closest to 1 is the best fit. 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. Plot the cluster members used to fit the isochrone in a different symbol and color than the rest of the stars on your plot. Overplot the best fit isochrone. List your reduced χ^2 and isochrone age on the plot.

3 Data Analysis Write Up

After you turn in your isochrone age plot, you will complete a write-up in latex using the template I provide on Overleaf. This will form the Analysis section of your paper. 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 had the lowest reduced χ^2. Which ages produced an acceptable fit? Which age produced the best fit? Include your isochrone plot with a descriptive caption.

4 Analysis of Class Results

I will post the ages for everyone's clusters, and I will post the data write-ups. You need to compile all ages and make a plot of age vs. distance from the galactic center. Note, the distance from the galactic center is not the same as the distance to the cluster. You will need to calculate the distance from the galactic center, and I will want to see the equations you used in the final paper. In your plot, use two different symbols for globular and open clusters. Also, include all the measurements (each cluster should have two or three measurements).

5 Final paper

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. This is the section you already wrote and turned in. 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. Why are your values different? Which is more reliable? To answer these questions, you will need to read your classmates' data analysis sections. **You may not discuss methodology with classmates. You need to base all conclusions on only what is presented in their papers.**

5. Discussion. This is where you will discuss your plot of age vs. distance 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 distance and age.