AST221_A2_ClusterCMD

October 24, 2025

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1 Assignment 2: Measuring the Ages of Stellar Clusters

1.1 Before you begin

Assuming you have loaded this file into your Jupyter Notebooks workspace, make sure to press the "play" button at the top of the page in each box. This will render the Markdown into nicely-formatted text.

Select **View -> Show Line Numbers** from the menu at the top to the screen. This will make line numbers appear in each of the blocks of code below. For this assignment we have added specific instuctuions such as "Edit the parameter on Line 5" to make it clear what is required. Unfortunately, you will need to check this again everytime you open this workbook, or refresh the JupyterHub.

1.2 Introduction

This Jupyter Notebook will serve as the template the third question on Assignment 2. You will be working through the content it contains and then filling in your own work in the spaces provided. In order to complete this assignment you will require the following (all of which will be provided to you):

- The files OpenCluster1_Gaia_AST221.csv and OpenCluster2_Gaia_AST221.csv, which contain information on the position, parallax, proper motion, and brightness measurements for several hundred stars in two Milky Way open clusters from the Gaia satellite.
- A set of eight files with names of the format: isochrone_solar_[AGE].csv, where each file has a different age between 1 Myr and 5 Gyr. These are files that contain information on the expected absolute magnitudes that stars of different inital masses will have depending on their age. You will use these to determine the age of these two stellar clusters (more information on these files is provided below).

In the sections below, every individual sub-questions have been written in Red Text . Some questions require you to make edits to bits of code that we have provided, in which case we specify the specific lines you are required to edit. Other questions are short answer (paragraph) format, asking you to summarize what you learned from various portions of the activity. In cases where paragraph-stype answers are required, we have indicated where you should enter your responses in Blue Text.

Please reach out of you have any questions.

2 Phase 1: Plotting the Observed Color-Magnitude Diagrams:

We will first explore what the observed data looks like for the two open clusters. In particular, we are going to be plotting examples of the 'Color-Magnitude Diagrams'(CMDs) that were discussed first discussed in Lecture 9. These are the 'observer equivlanet' to a Hertzsprung Russell Diagram. In our case we are going to be plotting CMDs using observations in three photometric bands that are used by the Gaia satellite. We will be making plots with the Gaia_G band on the vertical axis and the Gaia_BP minus Gaia_RP color on the horizontal axis. Gaia_G is a very broad filter that collects much of the optical light from stars, while Gaia_BP is a blue filter and Gaia_RP is a red filter.

The columns provided in the OpenCluster1_Gaia_AST221.csv and OpenCluster2_Gaia_AST221.csv files (and their units) are listed on quercus.

QUESTION 3A: Read in the Data Files for the Observed Cluster Data and Calculate Relevant Quantities In question 3B you will be asked to plot a color-magnitude diagram for both stellar clusters that has the OpenCluster1_Gaia_AST221.csv and OpenCluster2_Gaia_AST221.csv. Here we are going to prepare the data that we will need to do this. * First, edit lines 5 and 6 below so that they read in the two csv files with the cluster data. * Then uncomment lines 14 and 15 and add/complete any lines of code that will allow you to end up with one array (called cluster1_absoluteG) that contains the **absolute** Gaia_G band magnitudes for the cluster stars and a second array (called cluster1_BP_minus_RP) that contains the Gaia_BP minus Gaia_RP color for the cluster stars. In some cases you may simply be able to select relevant magnitude columns from the data files provided. In others you may need to use other columns in the file to perform some intermediate calculations.
* Repeat the previous step for the cluster 2 data in the bottom part of this code block.

Note: if you aren't sure how to start here, we recommend looking at both the python tutorial documents and your response to questions 3A and 3B from assignment 1.

[ ]:
```python
from astropy.io import ascii
import numpy as np

# Read in the files (complete both lines of code here to read in the data files):
cluster1_data =
cluster2_data =

#####################################################################################
# Select and/or calculate anything you need in order to end up with two arrays
# for each cluster with the Absolute G-band magnitudes and BP-RP color, respectively:
#######################
#Cluster 1:

#cluster1_absoluteG =
#cluster1_BP_minus_RP =
```

```
####################
#Cluster 2:

#cluster2_absoluteG =
#cluster2_BP_minus_RP =
```

QUESTION 3B: Plot the Gaia CMD for both clusters and label any relevant features. If you run the code below, it will make a plot of the Gaia CMD for your cluster 1 data, using your results from question 3A. Run it. Then modify the code as follows: * First, uncomment lines 8 and 9. You should add two numbers between the () in each line to set the lower and upper bounds of each axis. In particular, we always plot CMDs so that the brighter stars are on the top (and fainter star on the bottom) and so that bluer/hotter stars are on the left (and redder/colder stars are on the right). Add appropriate ranges so that this convention is followed. * Second, add three lines of code in lines 13 to 15 so that there are appropriate labels for the x and y axes (with units) and an overall title for the plot with the name of the cluster (e.g. 'Cluster 1'). * Third, add text to the plot to label any features that you can identify in the CMD. Line 18 provides example code for how to do this. Uncomment it and see what it does. Then feel free to move/copy/edit this line to add labels to your figure. If you aren't sure how to identify any features in the plot, I recommend reviewing section 13.3 of the textbook. * Fourth, repeat the above process to make an equivalent plot for the second star cluster.

[ ]:
```
import matplotlib.pyplot as plt
import matplotlib

fig=plt.figure(figsize=(5,6))
plt.scatter(cluster1_BP_minus_RP,cluster1_absoluteG,s=10,color='black')

# Uncomment and edit these lines so that bright stars are shown on the top and bluer stars on the left.
#plt.ylim()
#plt.xlim()

#Add three lines of code to display x and y axes labels (with units)
# and an overall plot title with the cluster name (i.e. "Cluster 1").




#Edit/move/copy this line to add labels for different features in the CMD.
#plt.text(0.5,10,"Example Label")

plt.show()
```

QUESTION 3C: Discuss your Results from 3B. Describe in words what you see in the plots for both cluster CMDs above. Refer to the labels you added when discussing specific features and why you identified them as you did. Are there cases where you could identify certain features in one cluster and not the other? Which of the two clusters do you think is older. Clearly explain the rational for your answer.

INSERT YOUR RESPONSE TO QUESTION 3C HERE.

3 Phase 2: Measuring Ages with Isochrones

We will now go through the process of measuring the ages for these clusters in a slightly more quantitative way. To do this we are going to use a type of data set know as an **isochrone**. An isochrone is a set of data that describes what the properties of a set of stars with different initial masses are expected to be *at a certain snapshot in time after they were formed*. This is different from an **evolutionary track** which tells us what the properties of a star with a a specific mass are expected to be *as a function of time*.

To construct an isochrone, you would first compute a set of evolutionary tracks for a wide range of stellar masses (e.g. 0.1 to 200 $M_{\odot}$) with a stellar evolution code like MESA. Then, you would choose what age of stellar population you are interested in (i.e. a young stellar population that only formed 10 Myr ago vs. and old stellar population that formed 10 Gyr ago). You would then grab the appropriate timestep from each of the (many) stellar evolution tracks to see what the properties of each star are at that snapshot in time. By 'properties' here we mean things like temperature and luminosity. Or, equivalently, the absolute magnitudes in a set of observed filters.

For this phase of the question, we have provide you with a set of 8 isochrones. These come from the MIST project (https://waps.cfa.harvard.edu/MIST/) which constructed isochrones based on stellar evolution models run with MESA. The isochrones we have provided you with are all for stars with solar metallicity–which is appropriate for the two star clusters you are considering here.

The names of the isochrone files are all of the form isochrone_solar_[AGE].csv, where there are 8 different ages that span 1 Myr to 5 Gyrs. The columns provided in each of these files (and their units) are listed on quercus.

QUESTION 3D: Overplot the isochrones on you Gaia CMDs to determine their ages. If you run the code below, it will read in the file for one of the isochrones and plot it. Run this code to see what it does. Note that by adding both the 'label' flag within the plot command and the line 'plt.legend()' that a legend now appears within the plot. You should modify this code in order to use the set of isochrones provides to determine the approximate ages for your clusters. Specifically:

- Copy over code from question 3B, above, so that the data from cluster 1 appears on the plot along with the isochrone. You should also copy over code for the axes labels and plot title, and ensure that the CMD has bright stars on top and blue stars on the left (although you may want to increase the axes ranges from what you used above).
- Read in some of the other isochrone data files and compare them to the observed data to determine what the approximate age for the cluster is. For the final plot in your submission you should include the three isochrones (of the 8 provided) that come closest to fitting the data for the cluster (i.e. the 'best' option in your opinion along with the isochrone that is next younger and next older amonst those provided). The three isochrones should all be plotted in different colors and labeled in the legend according to their ages.
- Repeat this process for cluster 2 (i.e. have a second plot that includes your data for cluster 2 and the three isochrones that come closest to reproducing the data).

[ ]:
```
iso1 = ascii.read('isochrone_solar_1Gyr.csv')

fig=plt.figure(figsize=(5,6))
plt.
  ↪plot(iso1['Gaia_BP']-iso1['Gaia_RP'],iso1['Gaia_G'],color='green',label='1Gyr')
plt.legend()

plt.show()
```

QUESTION 3E: Discuss your Results from 3D. Describe in words your results from question 3D. What age to you estimate for both clusters? Describe what feature(s) you used to make this assessment. Comment on the uncertainty in your analysis. Roughly what mass range of stars are still on the main sequence for each of the clusters?

INSERT YOUR RESPONSE TO QUESTION 3E HERE.

QUESTION 3F: Blue Stragglers Are there any stars that appear to be "above" the main sequence turn off in either cluster? What are these and what are possible explanations for their existence? Reading section 13.3 might be helpful but you should then cite at least one addition source for ideas on their origins.

INSERT YOUR RESPONSE TO QUESTION 3F HERE.