ASTR 121 – Spring 2016

Lab 4 – Cluster H-R Diagrams

Important dates:

- Prelab due: Monday, 3/27
- Rough draft due: Monday, 4/3
- Final draft due: Friday, 4/7

Science Goals:

At the end of this lab, you should be able to…

- Locate main sequence stars on the Hertzsprung-Russel (H-R) Diagram
- Construct H-R diagrams from real data
- Determine the age of and distance to star clusters

MATLAB Goals:

In this lab, you will apply MATLAB knowledge to…

- Read in and use data from tab-delimited files
- Create plots to clearly display several data sets at once
- Read in and manipulate data from “struct” files

Background

The Hertzsprung-Russell diagram is a figure that is used extensively in astronomy. Also referred to as the H-R diagram, it helps one understand stellar evolution by showing the relationship between a set of stars' luminosities and surface temperatures. Though the most basic H-R diagram shows luminosity as a function of surface temperature, (with the temperature on a reversed axis,) there are many equivalent quantities that are plotted on either axis, such as spectral type or color index in place of temperature, and absolute magnitudes in place of luminosity, or apparent magnitudes in place of brightness. Note that luminosity and temperature are physical properties of the star, while spectral type, color index, and apparent magnitude are observables.

A particular variation of the H-R diagram, called a color-magnitude diagram (CMD) is used often in observational astronomy. A CMD plots apparent magnitude as a function of a particular color index, typically B-V. Because this plot uses apparent magnitude rather than luminosity or absolute magnitude, it requires that all objects represented in it are at approximately the same distance. If all objects are the same age in addition to being at the same distance, the diagram as a whole can be used to determine the age of the objects.

For this reason, star clusters are a good candidate for use in color-magnitude diagrams. In this lab, we will use in particular open clusters, which are groups of several thousand stars that formed from a single giant molecular cloud. Because they share the same origin, we can assume with little uncertainty that they are the same age and the same distance away from us. Therefore, a CMD can be used to determine the age and distance of an open cluster.

The age of an open cluster is characterized by its turn-off point, which is essentially where the main sequence ends on the diagram. Stars with masses greater than the main sequence mass at the turn-off point have already evolved past the main sequence stage. Since the rate at which a star evolves is determined almost exclusively by mass, there is a clear relationship between the mass at the turn-off and the age of a cluster. We can compare the location of the turn-off point of real data to those of theoretical models in order to determine the age of the cluster: stellar evolution models can show how a whole population of stars with a wide range of masses, all born at the same time, would appear over time. The models we will be using in this lab give absolute magnitude (related to luminosity) and color-index (related to temperature) at different points in time. Each of these snapshots in time is called an isochrone, and show the CMD of a cluster at a given moment.

In addition to determining the age of the clusters, you will determine the distance using a measurement called the “distance modulus”. Imagine an object with absolute magnitude *M*. By definition, the absolute magnitude is equal to the apparent magnitude *m* at a distance of 10 pc. If you change the distance of the observer to the object, the apparent magnitude *m* will also change. The difference between absolute magnitude *M* and apparent magnitudes *m* is therefore directly related to the distance. The distance modulus is the value (*m-M*) and is directly related to the distance D :

$$m-M=5\log_{10}(D)-5$$

Solving the equation for the distance (measured in parsecs), the equation becomes:

$$D=10^{0.2(m-M+5)}$$

About the Data

This lab has two parts: in the first, you will examine the open cluster M45, for which you will need the file ‘m45.txt’ from ELMS. In the second part, you will need two additional files, one of them, “m67.txt”, is similar to that of ‘m45.txt’, but for the open cluster M67. These data are from the SIMBAD astronomical database and the Sloan Digital Sky Survey. Each file is a tab-delimited file with four columns: Number, Reference, apparent B magnitude and apparent V magnitude. You will only need the latter two columns.

The third file you will retrieve from ELMS, “isochrones.mat”, which contains B and V absolute magnitudes for theoretical star clusters of varying ages. To load the data, type ‘load isochrones.mat’. The new variable that appears is a 1x1 struct. If you type ‘isoc’ (the name of the variable) you will see it is composed of two more structs, ‘e8’ and ‘e9’. To look into ‘e8’, type ‘isoc.e8’. You will see ‘isoc.e8’ is further composed of 9 more structs. To look at one of them, type ‘isoc.e8.one’. Within this struct, you will see 3 arrays, ‘B’, ‘V’, and ‘logage’, which are B absolute magnitudes, V absolute magnitudes, and the base ten log of the age, in years.

Try navigating through the isochrones file, looking in ‘e9’ as well. Each third level file (e.g., ‘isoc.e8.six’) represents one star cluster. The age of a cluster is given by its name in the files: ‘isoc.e8.six.V’ is the V magnitudes for a star cluster that is 6×10^8 years old.

Part 1: Examining Star Cluster Data and Exploring Photometric Filters

In this part of the lab, you will examine the data for an open cluster.

1. In a MATLAB script, read in the data for the open cluster M45. Create a CMD by plotting V apparent magnitude as a function of (B-V), remembering to flip axes as needed. As this is a set of individual points representing distinct stars, have the figure plot points rather than connecting them in a line. Add appropriate axes and title, and include this figure in your report. *Which direction does temperature increase on the x-axis? What features can you identify on this CMD?*

2. On your CMD, look for a main sequence star with (B-V) of 0.5. *What surface temperature would this star have?* Using your Planck function from the previous lab, plot the blackbody curve of an object with this temperature. Include this figure in your report.

3. The data includes apparent magnitudes in the B and V filters. Show on your blackbody plot which wavelength range each filter allows through, as well as the central wavelength of each filter. Include this figure in your lab report.

4. Explore several other values of (B-V) and observe how the blackbody curve changes in relation to where the filters are. Show at least one other curve on the same figure (you can normalize each curve for easier comparison). *Qualitatively, how does the combination of the blackbody function and filter width yield the (B-V) color index for a star? How does it change for stars of different temperatures?*

Part 2: Determining the Ages of Star Clusters

Now we will look at real data: given the B and V apparent magnitudes for two star clusters, and a set of isochrones, you will determine the age of and distance of the clusters.

1. First, try looking at the data for one of the isochrones. For the isochrone representing a cluster that is $5\text{x}10^9$ years old, create a CMD as you did in Part 1. Once you've clearly plotted the first isochrone, overlay isochrones with ages of $9.5\text{x}10^9$, $2\text{x}10^8$, and $7\text{x}10^8$ years. .

2. The isochrones show the absolute magnitudes of the model stars, M. Since we don't yet know the distances to the clusters M45 and M67, the CMD data you will explore for them will give the measured (apparent) magnitudes of their stars, m. *How far away would M45 be if the apparent magnitudes of its stars and the corresponding absolute magnitudes of the stars on the best-match isochrone were the same? What would the distance modulus be in this case?*

3. It is unlikely that M45 will be exactly that distance away. Since you will want to compare the stars in these theoretical models to the stars in M45 directly, try re-plotting your isochrone data, with apparent magnitude on the y-axis, as if the model stars were now 40pc away. (Hint: find the distance modulus). *How does distance (and the distance modulus) relate to the position of the isochrones?*

4. Once you've understood how to open, plot, and manipulate the isochrones, create a new script. Read in the data for the M45 cluster and create a color magnitude diagram as you did in step 1. *Does this cluster look young or old?*

5. On the same figure, plot an isochrone (it doesn't matter which for now; make a rough guess and once you finish writing the script to generate the plot, you can determine which is best). Add a legend defining the two items being plotted, as well as axes and a title.

6. When your script is functional, you can start looking for the best matching isochrones. If it's helpful, try plotting multiple isochrones at once with the M45 data. Keeping in mind the fact that different distances will change the apparent magnitude of the isochrones, *what features will you look for to match an isochrone to the star cluster?*

7. The age of the best matching isochrone will be the age of the star cluster. *How can you attribute an uncertainty to the age?*

8. When you've decided on the isochrone and the amount of vertical shift it needs to best match the data, copy your script and repeat the process for M67. *How does this cluster's CMD compare to that of M45?* Make sure the legends include the name of the cluster, the determined age, and the shift used. *What is the uncertainty on your value for the shift?*

9. Using the distance modulus of each fit, calculate the distance to each of the two clusters, as well as their uncertainties, using the distance modulus equation given in the introduction.

Report

Your report should contain the following:

1. *Cover page*: Follow the model and guidelines in the rubric.
2. *Abstract:* In a paragraph or two, summarize the scientific purpose of the lab, what was done, the results, and your conclusions.
3. *Introduction:* In several paragraphs, discuss the background information regarding the purpose of the lab and its goals.

4. *Methodology:* Describe the data you used in this lab. Then, explain how you determined the age of each star cluster (making sure to explain the criteria you used for matching isochrones) and its distance modulus.
5. *Analysis:* Explain how you calculated the distance to each star cluster after matching it to an isochrone, and the uncertainty in this distance (using error propagation). Additionally, assign an uncertainty to your measurement of the age, and justify this decision.
6. *Discussion:* Compare your expectation to your results. Discuss whether or not your ages make sense. Consider what color the brightest stars on the main sequence are, and what implications this has regarding the age. Do your ages according to the isochrones fit what you would expect? Why are we doing this analysis with star clusters, and not a random collection of stars? Make sure to also answer any questions in this handout (in italics).
7. *Appendix:* Include all scripts, functions, and data that isn't already represented in your report.

Remember to upload any functions and scripts as .m files on ELMS, as well as a PDF of your lab report.