

NAME: _____

OPEN CLUSTERS LAB

What will you learn in this Lab?

An open cluster is a group of stars that were born at the same time and can be studied to determine both the distance and age of the member stars purely based on the stellar brightness at different temperatures. You will use provided data for a number of clusters to determine their distances and ages, and assess the accuracy of the method.

What do I need to bring to the Class with me to do this Lab?

For this lab you will need:

- A copy of this lab script
- A pencil
- A scientific calculator

I. Introduction:

Stars form in general not as individual objects but rather in clusters. This is a natural consequence of the collapse of an interstellar molecular cloud, which at one point in its evolution must fragment for collapse to continue. As such an ensemble of stars is formed, not all with equal masses, the distribution of sizes (masses) follows a remarkable universal “quality control” curve called the Initial Mass Function (IMF). Within a cluster fewer high mass stars form than low mass.

From an observational standpoint, there are two main types of stellar clusters: open and globular. The two have very different life histories, with the former being a relatively young object, and the latter generally being very old and dating back to the formation of the galaxy in which they reside. While globulars have been around for billions of years, open clusters usually disperse over millions of years. Globular clusters, which are spherical collection of hundreds of thousands of stars that are found in the halo of a galaxy, contain considerably more stars than the less dense open clusters, which are found in the disk. We will focus on open clusters in this lab, but many of the assumptions and techniques applied here also hold for globulars. The best example of an open cluster in the northern sky is the Pleiades, an easily observed object in the constellation Taurus.

II. HR Diagram

The ability to analyze open clusters hinges on our knowledge of the Hertzsprung-Russell Diagram (Color Magnitude Diagram), an incredibly useful tool for observational astronomy. In case you haven't yet been exposed to this tool, the following will serve as a useful introduction to the topic at hand. The observable properties of stars are quite simple: their

brightness (absolute magnitude) and their color. These quantities can be converted into more useful properties by using some additional laws of astronomy.

From Wien’s law we know that the color of a star is related to the surface temperature of that star -- a bluer star is hotter, a redder star is cooler. Color can be mathematically expressed as the difference between a star’s magnitude (energy output) in two different colors, such as blue and yellow. This color quantity is called B-V (where B and V stand for “blue” and “visual,” the latter is basically yellow-green).

The second piece in this puzzle is the application of Stefan’s law. A star’s luminosity is the total energy radiated per second from the entire surface of the star. So, it is possible to express a star’s luminosity as:

$$L = 4\pi R^2 \sigma T^4$$

where σ is Stefan’s constant. That is, if you know the *surface temperature* and *radius* of a star then you can predict how much *energy* is being emitted by the star’s surface.

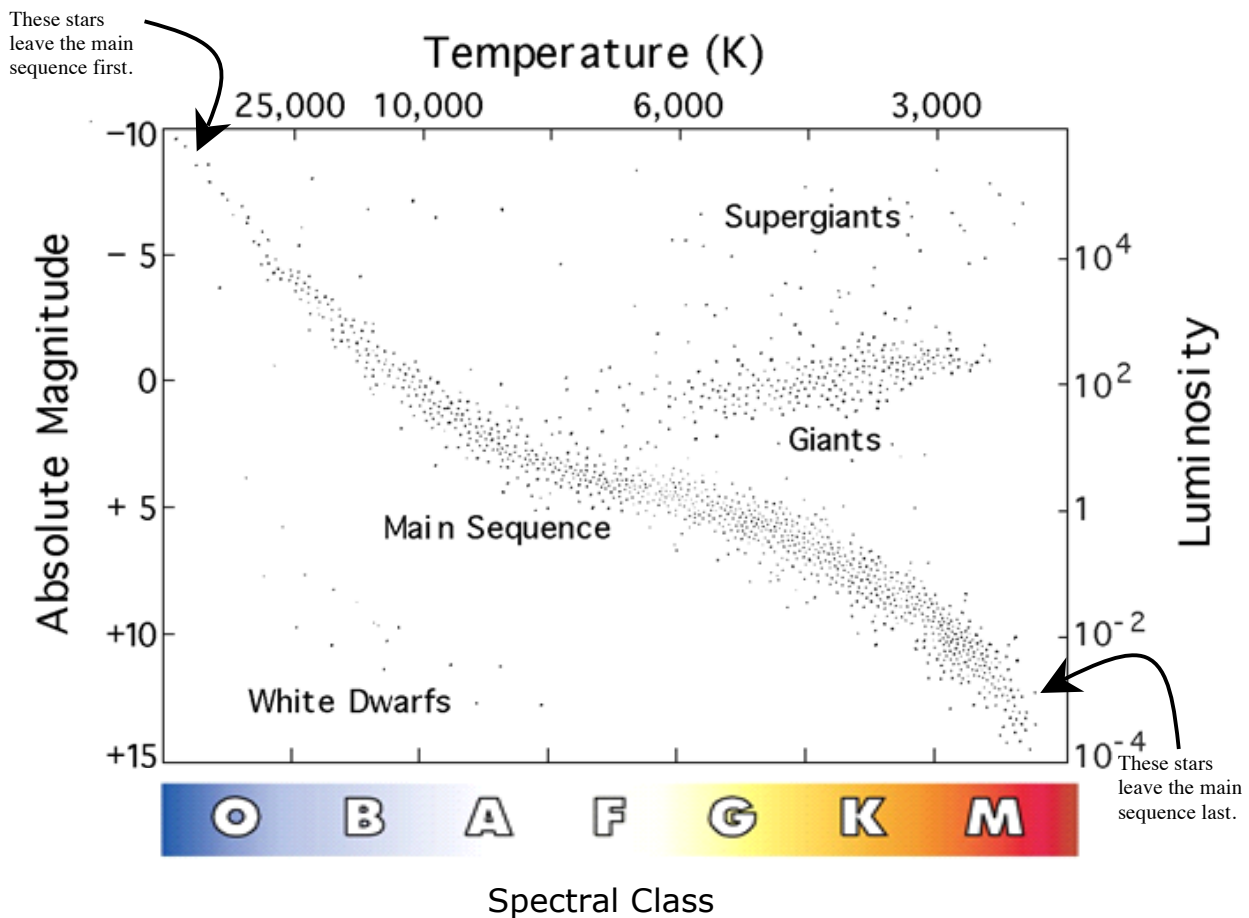


Figure 1: Example H-R Diagram. Stars get hotter as you go further left on the diagram and get brighter as you go further toward the top. For main sequence stars the most massive and largest stars are found in the top left corner

The final piece we use to calibrate the whole H-R diagram is the application of the inverse-square law for nearby stars. If a star is close enough to us we see it move relative to distant stars as we orbit the Sun through parallax. If we know the distance to the star, and we can

measure how bright the star appears to be, then we can infer how the bright the star is if you're standing next to it, using the inverse-square law. So, for the closest star you can independently determine the star's distance, brightness, temperature and size. Once this has been done for a group of the nearest stars, we can calibrate the various types of stars that there are. These categories are called spectral types and allow us to group together stars with the same types of observed spectra, colors and brightness. This is what ends up on an H-R diagram. An example of an H-R diagram is shown in Figure 1.

III. Turn off and Age of Cluster

The rate at which hydrogen gas is fused into helium at the core of any given star is a strong function of the gas pressure and temperature in that core. In turn, these properties are driven by the weight of material pressing down on the core, i.e. the mass of the star. Thus the more massive the star, the faster the star burns its core hydrogen into helium. In fact so sensitive is the reaction rate that it more than makes up for the difference in masses seen in a cluster of stars. The end result of this is that the large, massive stars in a cluster “live fast, die young” as they burn up all their core fuel in a matter of only several million years, compared to 10^{10} years for a star more like the Sun in mass.

Each area where stars tend to congregate in Figure 1 has a special meaning in the evolution of stars. The period of a star's life where it simply burns hydrogen in its core is called the *Main Sequence*, and corresponds to a very specific track on the H-R Diagram. When the hydrogen in the core is exhausted, the star moves away from the Main Sequence – it “turns off” the sequence. Because the Main Sequence also maps mass (the upper left end being more massive than the lower right), the stars on the upper left are going to burn up their hydrogen faster and turn off sooner than the stars on the lower right. Thus, if you plot all the stars in a cluster on a H-R Diagram you will see some on the Main Sequence, some that have already turned off, and some being caught in the act of doing so. It is the stars *just now turning off* that are important to us. If we can determine how old these “turn off” stars are we can by extension know how old all the stars in the cluster are, since it is assumed they all formed together at the same time.

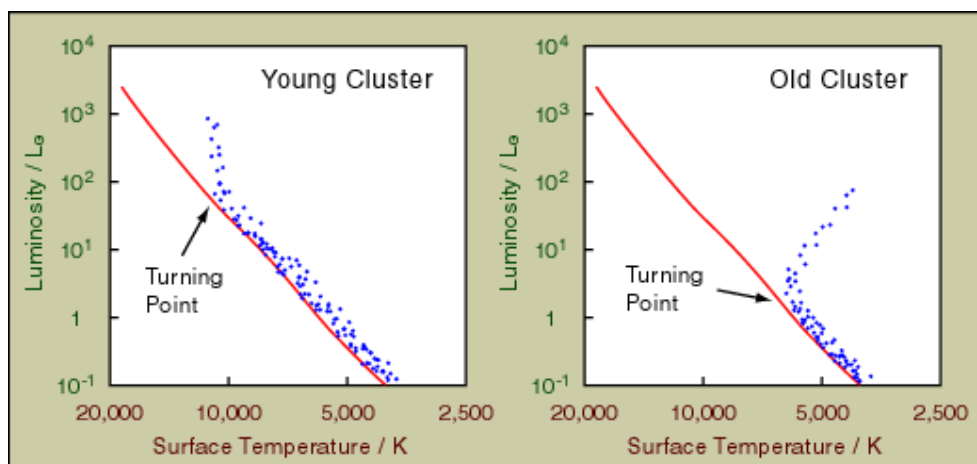


Figure 2: HR Diagrams of a young and old cluster showing the turnoff point.

Figure 3 illustrates how the turnoff point moves down the main sequence as you consider redder (colder and less massive) stars. It shows turnoff points for different real clusters. The age labels along the right y-axis denote how old a main sequence star with that color will be when it begins to turnoff.

In this H-R diagram (Figure 3), the two axes represent two observables: the brightness of the star versus the color of the star (expressed as the difference of two color magnitudes). Again, absolute magnitude has been used as a measure of overall brightness – this is the apparent magnitude of a star when it is viewed at a distance of 10 pc (by definition), and is used as a standard definition to allow direct comparison of stars with wildly different brightness. Recall that absolute and apparent magnitudes are related by the *distance modulus* equation:

$$m - M = 5 \log_{10} \left(\frac{d}{10 \text{ pc}} \right) \quad \text{solved for } d: d = 10^x \text{ where, } x = \frac{(m - M + 5)}{5}$$

where m is the apparent magnitude, M is the absolute magnitude, and d is the distance to the star expressed in parsecs ($1 \text{ pc} = 3.09 \times 10^{16} \text{ m}$). Since it is *absolute magnitude* that is plotted on the y-axis here (and not the more easily determined *apparent magnitude*), simply observing how bright the stars in a cluster are isn't enough. **We must know the distance to the cluster in order to convert apparent magnitude to absolute magnitude and correctly analyze it.**

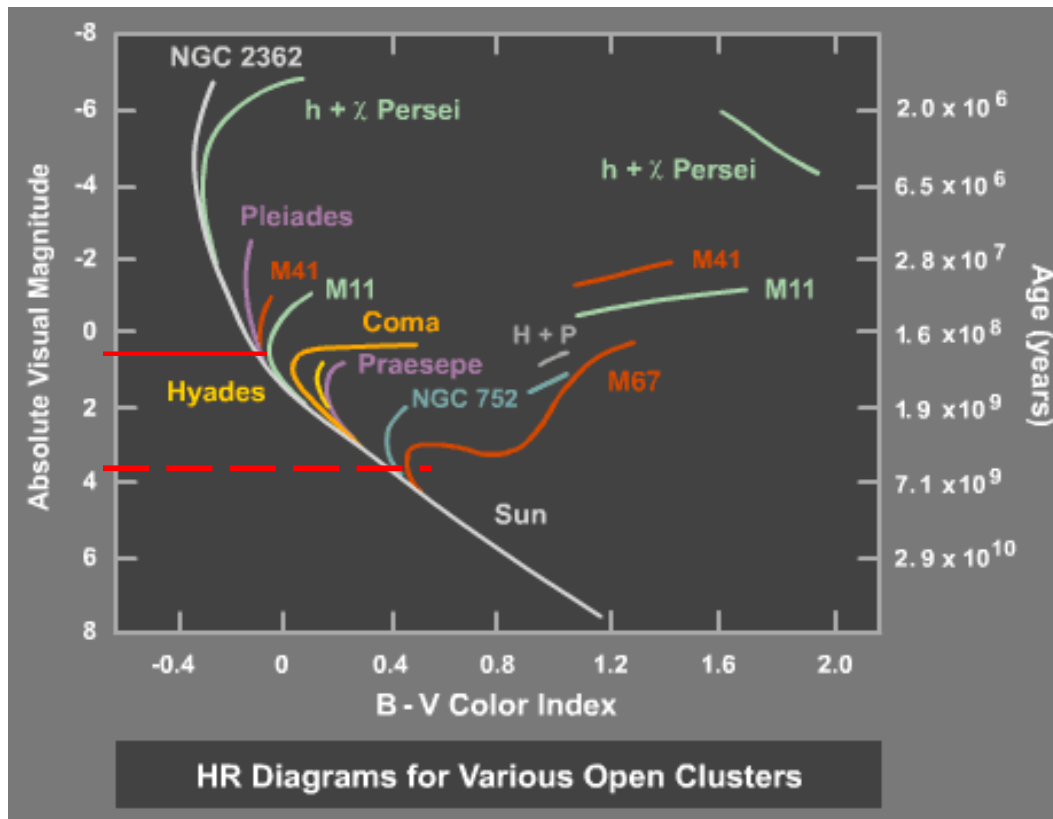


Figure 3: Another H-R diagram illustrating only the main sequence and the different turnoff points for different real clusters. (Higher mass stars on the main sequence are bluer than low mass stars.) The solid line shows the turnoff point for cluster M41, absolute magnitude (M) \sim 0.5, which corresponds to an age of $\sim 2.2 \times 10^8$ years. The dash line is the turnoff for M67, $M \sim$ 4, age $\sim 4.5 \times 10^9$ years.

IV. The Experiment

Part I: Background Questions

Q1. Will a blue star have a positive or negative B-V color? _____

Q2. What is the spectral type/class (OBAFGKM) for the hottest/most massive stars along the **main sequence**? (Look at Figure 1.) What color are these stars?

Spectral type: _____ Color: _____

Q3. Why does a star leave the **main sequence**?

Q4. a) What is the spectral type of stars that leave the **main sequence** first? _____

b) Describe the properties of these stars, including, color, temperature, luminosity (brightness), mass, size, and lifetime compared to other stars.

Q5. a) What is the spectral type of stars that leave the main sequence second? _____
Third? _____, Fourth? _____

b) Describe the trends of stars that leave the main sequence over time? That is how do properties like color, mass, size, etc. change. Redder or bluer, smaller or bigger, etc. . .

Q6. a) Looking at Figure 3, what is the absolute magnitude of cluster M11's main sequence turnoff point?

b) What age does that absolute magnitude correspond to?

Part II: Procedure

You are going to use data from a sample of open clusters to determine both their ages and their distances. This data was taken from the online cluster database WebDA (<http://www.univie.ac.at/webda/>). However, before you can use this for age determination, you will need to first determine the distance to the cluster. The simplest way to do this is to compare the clusters' H-R diagrams with a "standard" one derived from "standard stars".

Q7. Use the following data to plot a standard H-R diagram.

- Make sure you use the provided graph paper (pg. 10), as this will facilitate an accurate comparison to the cluster data (note the y-axis inversion: to illustrate increasing brightness, you plot decreasing magnitude).
- Draw a best-fit line (not necessarily a straight line) through the data points. You do not need to label each spectral type.
- Copy your Standard Stars graph on to the transparency provided by your TA. It will make it easier to line up the standard star graph to the different cluster CM Diagrams. Make sure to copy the entire graph on the transparency including the numbers for each axis.

Spectral Type	Temp. (K)	M_V	$B-V$	Spectral Type	Temp. (K)	M_V	$B-V$
O5	35000	-5.8	-0.35	G0	6000	+4.4	+0.58
B0	21000	-4.1	-0.31	G5	5400	+5.1	+0.70
B5	13500	-1.1	-0.16	K0	4700	+5.9	+0.89
A0	9700	+0.7	0.00	K5	4000	+7.3	+1.18
A5	8100	+2.0	+0.13	M0	3300	+9.0	+1.45
F0	7200	+2.6	+0.27	M5	2600	+11.8	+1.63
F5	6500	+3.4	+0.42	M8	2300	+16.0	+1.80

Table 1: Absolute magnitude and color data for standard main sequence stars

Q8. One cluster at a time, compare the observed data with your standard star data.

- By placing one on top of the other to determine the vertical offset between the two (average the difference between **three** y-values from your best fit lines) and then find **the distance** to the cluster.
- Hint: recall that the y-axis for one of your graphs is "m" and for the other graph is "M" – similar to what you did in the pre-lab. Do not use points from the table, instead look at the graphs and compare your best-fit lines.
- Record your distance calculation for the clusters in the provided data table.

Q9. For each cluster, locate the apparent turn-off point of its main sequence.

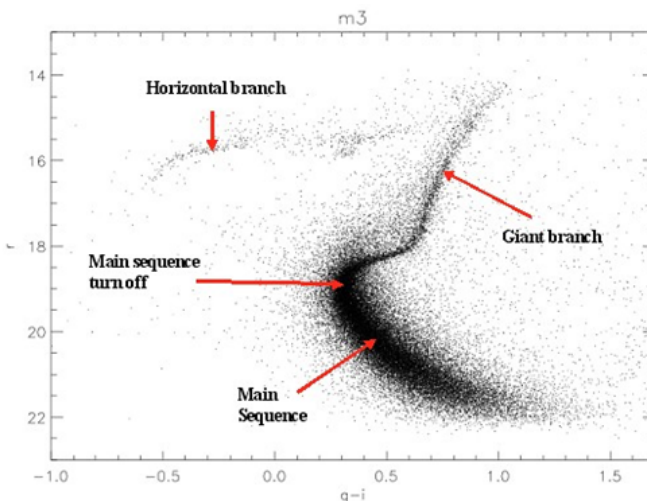
- Measure off the V apparent magnitude of where the turn off occurs.
- Use the average $m_V - M_V$ you found for Q8 to solve for the absolute magnitude of the cluster's turnoff. $m_{V\text{turnoff}} - (m - M)_{\text{average}} = M_V$
- Record these magnitude values in your data table.

Q10. Now, compare your absolute magnitude to Figure 3 and **determine the age** of the cluster. Record these age in the data table. **Example is on the following page.**

The following is an example of how to locate and use the turnoff point to measure the age of the cluster using the provided CM Diagram (Fig. 4).

- Step 1 - The Main sequence turnoff for the cluster M3 in figure 4 is about $m = 19$.
- Step 2 - Assume $m - M = 13.5$.
- Step 3 - Solve for M . $19 - M = 13.5$, $M = 5.5$.
- Step 4 - Now take that absolute magnitude and measure off the age of the cluster using Figure 3.
- Step 5 - Age $\sim 1.1 \times 10^{10}$ years.

Figure 4: Example HR Diagram of M3, a globular cluster. The left figure shows how to measure the turn off point. The apparent magnitude for the turnoff is $\sim m=19$.



Q11. Your TA will supply you with the actual distances of the clusters studied tonight. Record those in your data table. Then, calculate your percent error in measured distance and record that as well.

Percent Error Equation
$$\%error = \left| \frac{(calculated - actual)}{actual} \right| \times 100\%$$

Cluster Name	V-M _v				Distance (pc)	MS Turnoff M _v	Age (yr)	Actual distance (pc)	% Error in distance
	1	2	3	Average					
M67									
NGC 0188									
NGC 1817									
NGC 2158									
NGC 7510									

Table 2: Your data from tonight’s lab

PART III: Additional Questions

Q12. Explain why the turn-off point on the H-R Diagram of a cluster tells you the age of that cluster. Include information about the life cycle of stars and properties of clusters.

Q13. Consider what the interstellar medium (ISM), or dust, does to light traveling through it.

- a. Does it make the light we receive look redder or bluer?
- b. Would it be brighter or fainter?
- c. How would the position of all the stars and the turn off point be shifted on the CM Diagram? To the Left or Right for B-V? Up or Down for apparent magnitude?

Q14. Based on your answers to questions 8 above, how would dust between us and the cluster affect the age determination for a cluster? (older, younger, or stay the same) Remember, what you measure to determine age and how that measured value would be changed by dust.

Q15. How would dust between us and the cluster affect the distance measurement to that cluster? (further, closer, or stay the same). Hint: It might be useful to work out how the distance would change by plugging in numbers into the equation.

Q16. The clusters you looked at tonight have established ages ranging from 30 million to 4 billion years. Were older clusters easier or harder to find the main sequence turn-off for? Why might this be the case?

Q17. Given that the most massive stars (O stars) typically only have lives as long as 5 million years, do you expect there to be massive O stars still in existence in any of the clusters you studied tonight? Explain your reasoning.

Q18. Were you more accurate in determining the distances to some clusters than others? If so, what was it about the clusters that you were less successful in distance fitting that made measurement difficult?

Summarize what you have learned in this lab:

