Galactic Star Clusters

Introduction

A color-magnitude diagram is a plot of apparent magnitude versus the (B-V) color index of a group of stars. An H-R diagram is usually a plot of absolute magnitude versus spectral type or color index. Note that these are equivalent: a plot of brightness versus stellar temperature.

Clusters (close spatial groups of stars) form from a single clump of gas at a particular time. Thus, we can safely assume that the stars in a cluster have roughly the same distance (and thus distance modulus), age, and initial chemical composition. As a result, the location of a cluster star in the color-magnitude diagram relative to its companions is due primarily to its mass. Astronomers can then use this information to check theories of how stars evolve, i.e. change over time.

For example, we know that low mass stars live longer than high mass stars. If this is correct, then a very old cluster should contain only low mass main sequence stars. Furthermore, low mass stars also form much more slowly than high mass stars. Thus, a very young cluster should contain more high mass main sequence stars, because the low mass stars haven't made it onto the main sequence yet.

Equipment

Open Internet Explorer and point the browser to the following URL:

`http://www.astro.lsa.umich.edu/~grad/clusters`

The program will begin loading a set of color-magnitude diagrams for eight clusters in our galaxy. Notice that the diagram plots apparent magnitude, V, vs. color index, (B-V). However, along the top x-axis is a quantity labeled $(B\text{-}V)_0$, which is the color index corrected for interstellar reddening (we'll get to that later). Color index is a measure of the color of a star. The smaller the value of (B-V), the bluer the color of the star.

Choose a cluster and click somewhere on the plot. You should see blue cross-hairs. Values corresponding to the cross-hairs are printed in the lower right.

Finally, turn the ZAMS on with the menu in the upper right. This will produce a red gridded overlay; identify the ZAMS line and compare the red axes with those of the color-magnitude diagram underneath. Moving the slider bars will allow you to slide the ZAMS around; clicking the arrows will allow finer adjustments. Use the menu to turn the ZAMS on and off.

Turn-off Point and Age

We can determine the age of a cluster fairly accurately using the turn-off point, the spot where stars begin to deviate from the main sequence. Below the turn-off, stars are still burning hydrogen in their cores, happily living on the main sequence. Above the turn-off point, stars have exhausted their core hydrogen. For a younger cluster, the turn-off point is closer to the blue (high mass, bright) end of the main sequence, and for older clusters, it is closer to the red end of the main sequence.

Construct a table as follows:

Cluster	$(B\text{-}V)_0$	Cluster Age	$(V\text{-}M_V)$	Distance (pc)	$E(B\text{-}V)$
M67					
...					

To accurately locate the turn-off point, use the ZAMS overlay. First, match up the *upper* x-axis of the *overlay* and the upper x-axis of the *diagram* at $(B\text{-}V)_0 = 0.0$ by using the horizontal slider. Then slide the overlay up/down with the vertical slider until you get what you consider to be the best match between the star data points and the ZAMS line. When fitting clusters with a lot of scatter, try to match the narrower parts of scatter to the curve, and generally try to keep the ZAMS to the lower left of the scatter since objects not on the main sequence are probably above and right of the ZAMS. When you've got a match, you will be able to see where the star data "peels off" from the ZAMS – this is the turn-off point. Use the cross-hairs to measure $(B\text{-}V)_0$, and record this in your table.

Use the graph of cluster age vs. turn-off point color included in this lab by matching your $(B\text{-}V)_0$ to the value on the x-axis and reading the corresponding age off the y-axis. Record the age in your table, estimating your uncertainty.

Distance Modulus

The distance modulus is the quantity $(m\text{-}M)$: the difference between the apparent and absolute magnitudes. We measure this vertical offset between the cluster stars (m) and a set of standard stars (M), by sliding the standard stars (the ZAMS) up or down until they line up with the cluster stars. To find the distance modulus, keep your ZAMS overlay lined up as before so the ZAMS matches the star data points. Clicking the crosshairs at any point will measure V from the cluster color-magnitude diagram and M_V from the ZAMS overlay. Subtract to get $(V\text{-}M_V)$. (This is even easier if you click where $M_V = 0$.) Record the distance modulus in your table, recording your uncertainty.

To convert this into the distance of the cluster, we must invert the distance modulus equations.

$$\begin{aligned} (V\text{-}M_V) &= -5\ \log(d/10\ \text{pc}) && (26) \\ d &= (10\ \text{pc}) \times 10^{(V-M_V)/5} && (27) \end{aligned}$$

Record the distance in your table. Use error propagation to determine your uncertainty.

Effects of Interstellar Dust

You may have noticed that the sun or bright full moon can appear orange or even red at sunset or sunrise. This is because you are looking through a lot of dust in the air at those angles. Dust tends to absorb and selectively scatter blue light more effectively than red. The red light can pass by the dust grains more easily than the blue, so we end up receiving a higher fraction of the red light that is emitted than of the blue. This applies to dust in our atmosphere (resulting in a redder, dimmer sun at sunset) and also applies to dust between the stars (resulting in much the same thing).

So two things occur due to interstellar dust: reddening (redder light) and extinction (less light).

Reddening

Our observed color index $(B\text{-}V)$ may be larger (redder) than the true color index of the stars due to the reddening effect of the dust. We estimate how much reddening has occurred by using the spectral type to calculate an intrinsic, un-reddened color index. This is labeled $(B\text{-}V)_0$. The difference between the observed color index $(B\text{-}V)$ and the intrinsic color index $(B\text{-}V)_0$ is called the color excess, or $E(B\text{-}V)$, of the star. This is defined as:

$$E(B\text{-}V) = (B\text{-}V) - (B\text{-}V)_0 \qquad (28)$$

If you look at the upper and lower x-axes on the cluster color-magnitude diagrams, you will notice that in each case the $(B\text{-}V)$ and $(B\text{-}V)_0$ scales are offset such that the $(B\text{-}V)_0$ scale is shifted to the right with respect to the lower scale (to the right corresponds to a lower value of the color index, and thus is bluer). This should make sense in light of the reddening effects of dust. Measure the color excess for each diagram by using the cross-hairs to measure $(B\text{-}V)_0$ and $(B\text{-}V)$ at some point in the plot. Once again, a little math should give you $E(B\text{-}V)$. (And once again, clicking where $(B\text{-}V)_0 = 0$ will make this trivial.) Record the color excess in your table.

Extinction

Stars also appear dimmer due to interstellar dust. This is called extinction. Extinction affects our measurement of a star's brightness and therefore our determination of the star's distance if we use the distance modulous equation. Let's find out how extinction has affected our data.

Construct a table as follows:

Cluster	True Distance, d (pc)	Measured Distance, d' (pc)	d'/d
M67	800		
...			

Obtain the true distances to the star clusters from your GSI. Rewrite your distances in the column marked d' (your measured distance) and calculate the ratio d'/d for the third column. Notice the errors.

1. Draw a sketch, with a dust cloud and several rays of light (blue light and red light). Include the effects the dust has on the light. Explain what else, besides reddening, could happen to the appearance of a cluster because of dust.
2. Plot the ratio d'/d versus $E(B\text{-}V)$. Describe the trend you see in your data. Carefully and logically explain the physical reasons for this trend.
3. Suppose you have two clusters that are both 1000 pc away, but are in different constellations. One of the clusters has $E(B\text{-}V)= 0.6$, while the other has a color excess of 0. What does this tell you about the distribution of dust in the Galaxy?
4. Draw a sketch of a color-magnitude diagram, and indicate which regions in the chart represent red/blue, bright/dim, and cool/hot stars. What kind of stars live in each region?
5. Cluster Mel 20 contains objects in the lower right of the CMD that are not on the main sequence. These are not evolved red giant stars – how can you tell? What stage of stellar evolution do they represent?
6. While there was quite a bit of variation in the clusters we looked at, none of them was as old as a globular cluster (these were galactic clusters). If you were to look at a color-magnitude diagram of a very, very old cluster, what would you expect to see? Draw a sketch as well as explain any new features.
7. Could you use the technique we have used here to find the age of a single star (not in a cluster)? Why/why not? In general, can you tell anything about the age of a single star from an H-R diagram?