	<p>INVESTIGATION OF M16, AN OPEN CLUSTER IN SERPENS</p>
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The following series of image processing activities utilizes the program UCSB Image, by Russell Woods. This software is available by request from the Remote Access Astronomy Project at UCSB, and was funded by a grant from the UCSB Office of Instructional Development. If you do not have this software, you can achieve the same results by using the on-line Sky Image Processor available from Virginia Polytechnic University at <http://www.phys.vt.edu/~jhs/SIP/>.

NOTE: Before starting this lab, be sure you have the M16 images in R, V, and B. The data can be downloaded from http://www.deepspace.ucsb.edu/images/tricolor/M16_BVR.ZIP

Background:

M16 is an interesting example of an open cluster, because it is also surrounded by a region of faint nebulosity. While it is called the Eagle Nebula by most observers, Robert Burnham (author of Burnham's Celestial Handbook) prefers the name Star Queen Nebula. For a really good overview of stars, here's a great website I found: http://www.le.ac.uk/physics/faulkes/web/stars/o_st_overview.html.

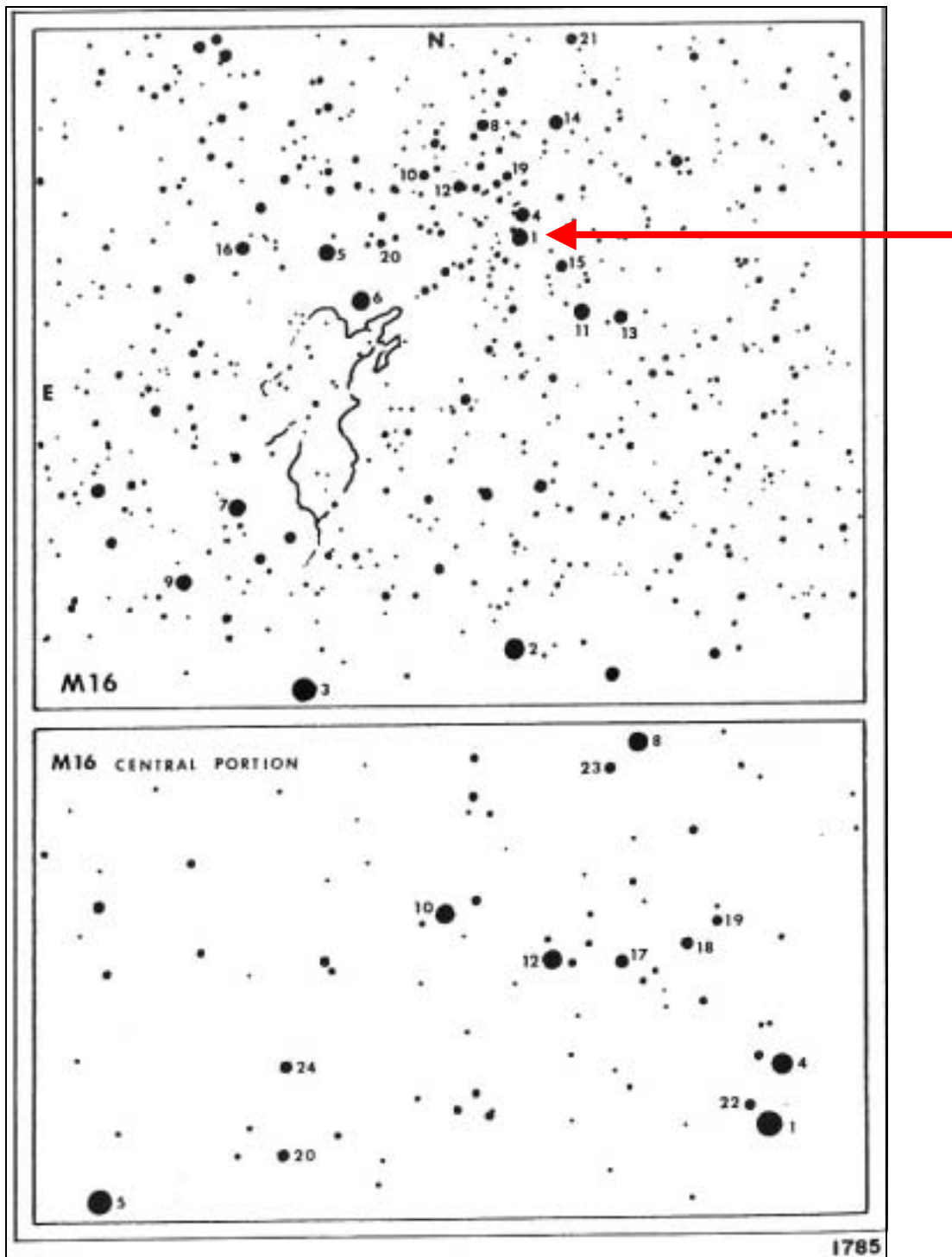
In this lab you will use digital images taken at UCSB with the 14" reflector and sensitive CCD camera to:

- * find the magnitudes of stars in M16 in Blue and Visual wavelengths and plot the magnitudes of the stars in the Visual as a function of the "B-V" index of stars;
- * estimate the absolute magnitude range for the cluster by comparing your plot with the H-R diagram and calculate the approximate distance to the cluster;
- * estimate the age of the cluster from the "turn-off point";
- * make a tri-color composite image of the cluster and discover the "true" color of the nebulosity surrounding it (the "Eagle Nebula").

Part 1. B-V photometry of M16

Procedure:

1. Open the file M16-V.FTS. This image was taken with a "V-band" filter, which has its peak response in the center of the visible spectrum (yellowish-greenish, around 550 nm).



In order to match the finder chart from Burnham's, you will need to perform a 90° rotation, followed by a vertical flip. These options are found under the Create option from the menu bar. Adjust the Histogram of the image so that you can see the nebosity and stars in better contrast.

2. Photometry. Click on View from the upper menu bar, then Photometry. This brings up a new window.

Setting your photometry options:


1. Radius of star: You can vary this for each star you want to capture.
2. Sky Annulus: Set the inner radius to be a pixel larger than your star radius, and set the outer radius to be a few pixels larger than the inner radius. You can play with the values – it will depend, in any given image, on the density of stars in the image. (This software, at this time, cannot distinguish overlapping diffraction disks of stars that are close to each other in the starfield, so we "guestimate".)
3. Set your reference star: Find a nice round star on the image, and match it with a labeled star in Burnham's finder chart. Look up its magnitude in the chart below, and enter that as the reference magnitude. The program will calculate the other magnitudes in reference to this one.

CLUSTER M16 - MAGNITUDES AND SPECTRA								
1.	8.24	O5e	9.	9.69	B0+B5	17.	10.81	B2
2.	8.27	K0	10.	9.86	O9	18.	11.06	O8?
3.	8.30	B0+O8	11.	9.88	B1:	19.	11.22	B1
4.	8.77	O7	12.	9.94	B0	20.	11.24	B1
5.	8.95	O8	13.	10.05	B1	21.	11.30	O8+O5
6.	9.43	O9	14.	10.05	O6	22.	11.41	O9
7.	9.48	B1	15.	10.36	O9	23.	11.60	B0:
8.	9.60	O8	16.	10.74	B1	24.	11.62	K2:

4. Make sure you have checked the "Create List" option. When you are finished selecting stars, click "Save List". Name the file something appropriate, and save it somewhere. It will be saved as a comma-delimited text file.
5. Check your list in Excel. Import the text file as a comma-delimited file, and you'll see the chart. Check to see if there are any values of "99"; those are mistaken "clicks" where you accidentally got the sky – delete those entirely. Sort the sheet according to x-coordinate so that you can refer them to the corresponding stars in the B image (which you'll look at next).

Repeat this process for the image M16-B.FTS

For your reference magnitude in the B-image, we use the following calibration trick:

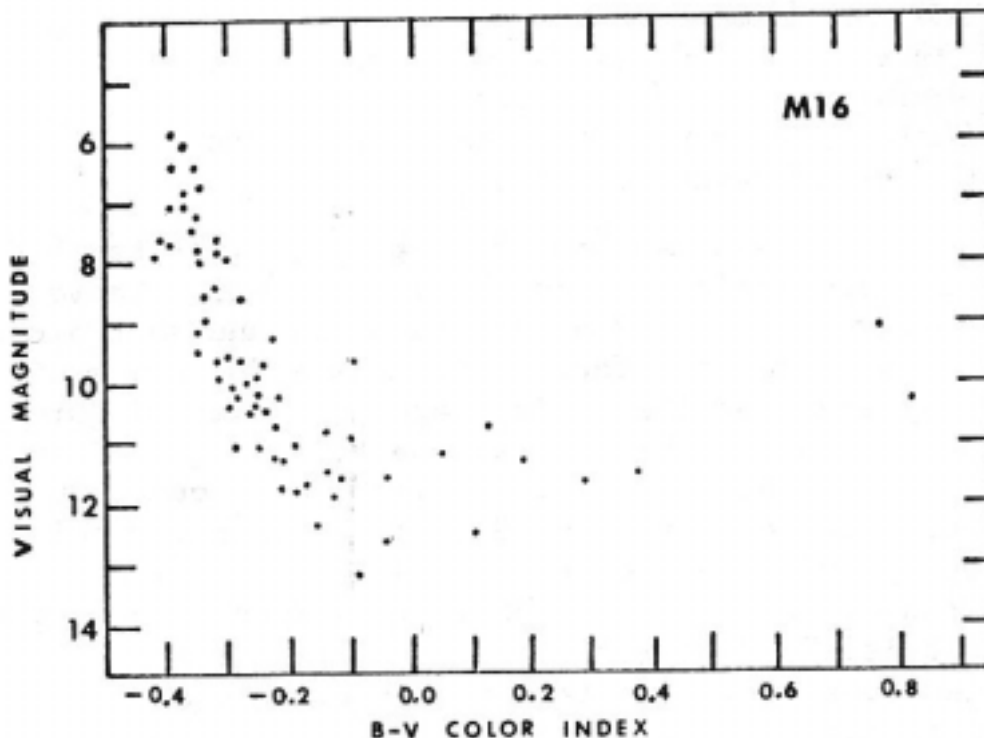
 **Star #1 is an O5 star**, and according to Norton's 2000.0 Catalogue, O5 stars generally have a B-V index of -.35. So, since $M_V = 8.24$, and $B-V = -.35$, therefore, the B value that you should input for your reference magnitude is $8.24 - .35 = 7.89$.

Once you have your stars selected in both images, bring both the V and B images on screen. You will now have to visually correlate them in each image, so you can order them properly in Excel. Once you have them correlated, you can subtract them in Excel.

The goal is to collect, on one worksheet, all the stars that are common to both images, for which you have B and V magnitudes, and calculate B-V indices.

Making the graph: You can easily do this in Excel. The x-axis should be the B-V values, and the y-axis should be the V magnitudes. (These are apparent magnitudes, remember.) Use the "scatter plot" option, and don't connect the dots.

Compare with the chart of V vs. B-V from Burnham's:

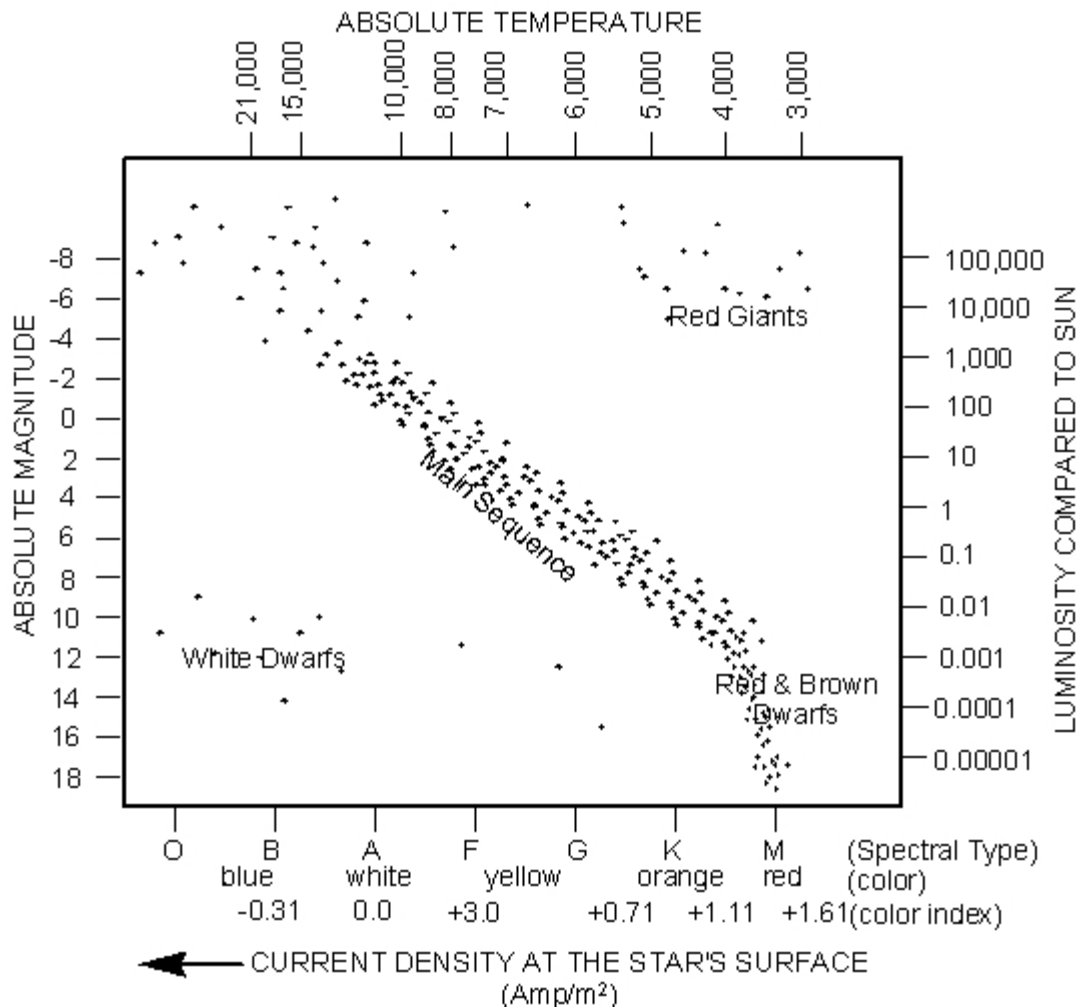


- A) What part of the HR diagram does your graph fit best?
- B) What type of stars are the brightest stars in M16?
- C) Is this cluster young, middle-aged, or old? How can you tell from the types of stars it contains?
- D) There are some points that lie to the right of the main sequence, yet are not bright. What could these represent?

Part 2. Estimating the distance to M16:

1) Find the visual magnitudes of the brightest and dimmest of the stars in M16 from your graph. Since there is a tremendous amount of dust in the region, the starlight appears both dimmer and redder than it really is. The average correction for reddening is .782, so you should subtract .782 from each V magnitude that you found.

Now we do what is called "curve fitting". We go to an actual H-R diagram, and visually try to find where our stars would plot vertically, given that the B-V indices are the references for the horizontal axis.



Since most of the B-V values for M-16 lie between -.4 and -.1 or 0, you can see that they would have to be among the hottest blue-giant stars. Estimate where on the H-R diagram they would like, and estimate their absolute magnitude range. (Note: the two diagrams are NOT drawn at the same scale, so the curve that appears steep in Burnham's plot will not be steep on the total HR diagram plot.)

Now find the brightest and dimmest stars, and use them in the distance formula to estimate the distance to M16 using the distance formula for each of these two stars.

$$d = 10^{(m - M + 5)/5}$$

where d = distance in parsecs, m = visual magnitude, M = absolute magnitude from H-R diagram.

Brightest _____ Dimmest _____

$m =$ _____ $m =$ _____ (apparent mag. from your graph)

$M =$ _____ $M =$ _____ (absolute mag. from H-R diagram)

$d =$ _____ $d =$ _____ (distance in parsecs)

average distance = _____

Estimates of the distance to M16 range between about 2000 and 3300 parsecs, with 2500 being the most widely accepted value, according to Burnham's Celestial Handbook.

- * Why do you think it is so difficult to measure the distance to M16?
- * M16 is believed to lie in the Sagittarius spiral arm of our galaxy; what could this location have to do with distance measurements to the cluster?

Part 3. Making a tricolor image of the Eagle Nebula and M16.

Now bring up three images: M16V.FTS, M16B.FTS, M16R.FTS. The way we make true-color images is to add up the images that were taken with red, blue, and visual (green) filters, and then assign relative color indices to them in the software. Each pixel in the summed image has an R, a G, and a B value which is the weighted sum of the R, G, and B values of the corresponding pixels in each of the three images.

1. First histogram-limit each of the three images. You will notice that the image taken with the red filter has the best detail; why do you think that is?
2. Then you have to align them. Under "Create", select "Aligned image". The program will prompt you to select three stars in the "active image" (the one whose title bar is blue instead of gray), and then prompt you to select another image to align with it. Be sure to select the same stars, in the same order. Then click on "align". You can see the differences by clicking on "view differences". If you don't like your alignment, click on Undo and try again.

When you have two images aligned, line up the third one in the same way. I suggest you save and re-name these images. For example, if you start with the R image, and line up the V image to it, then save the adjusted V image as something like, "V lined up with R", or some other way you will remember it. (The software has its own default nomenclature, which I personally find confusing!)

3. Select "Create", "Tricolor". On the upper menu bar there will now appear a new set of options that pertain to this operation only. Under "Set Source" set the R-image as the red, the V-image as the green, and the B-image as the blue. You should then have a tri-color image. If you don't like the color, you can try adjusting the histograms and doing the addition again. (The hardest part was getting the aligned images.)

- * What color is the nebulosity???
- * What does that tell you about its composition???
- * How does the composition of the nebula help place additional constraints on the age of the cluster?

Part 4. Finding the age of the cluster from its turnoff point on the H-R diagram.

*A note about this: Finding ages of star clusters from turn-off points is really only useful for old clusters, like the globulars. The stars of M-16 don't really have a turnoff point yet, as they are all really young, and still burning hydrogen. To really get a good feeling for how this works, see the wonderful activity in Chapter 3 of the booklet **Teaching About Cosmology** by Lawrence Krauss and Glen Starkman, which you can order from the website of the American Association of Physics Teachers: www.aapt.org.*

One of the reasons why so much useful information can be extracted from studying star clusters is that the stars in a cluster all began forming from the same initial cloud of gas and dust. We can infer, therefore, that all the stars in a given cluster are at approximately the same distance from us, have approximately the same chemical compositions, and are all the same age, although at different stages in their evolution. The STAGE of a star's life in any cluster depends on the MASS of the star; the larger a star is, the faster it uses its nuclear fuel and the hotter and brighter it is. A low mass star will take much longer to reach the Main Sequence and begin fusing hydrogen in its core than a high mass star, and will spend more time on the main sequence before it exhausts its hydrogen supply.

A color-magnitude diagram of a star cluster is like a snap shot of all the stars at one time, with each star being at a different stage in its development. The point at which a star leaves the main sequence is called its TURNOFF point. At this stage in a star's development, the star has exhausted the hydrogen in its core and is on its way toward becoming a red giant, fusing helium in its core. If you can measure the point in the color-magnitude diagram of a star cluster where the most massive stars are leaving the main sequence and heading for the red giant region, you can estimate the age of the entire cluster - that is, the time since the first stars in the cluster began their lives on the Main Sequence.

Let T = the life expectancy of a star on the main sequence, compared to the life expectancy of the Sun, T_{\odot} .

$T = \text{fuel} / \text{rate of fuel consumption}$
... but the fuel is just the mass, and the rate of fuel consumption is the luminosity, so...

$$T = \text{Mass} / \text{Luminosity}$$

...but Luminosity = $\text{Mass}^{3.5}$, so...

$T = M / M^{3.5} = 1 / M^{2.5}$...and if we express the mass in terms of solar masses, the age will be in terms of solar lifetimes.

To estimate the age from the luminosity alone, we work backwards:

$L = M^{3.5}$... so $M = L^{1/3.5}$... so we can substitute this value for the mass back into the equation for the life expectancy, and get

$$T = 1 / M^{2.5} = 1 / (L^{1/3.5})^{2.5} = 1 / L^{(2.5/3.5)} = 1 / L^{.7143} \text{ where } L \text{ is actually } L/L_{\odot} \text{ and } T \text{ is } T/T_{\odot}.^1$$

So, to find the age of the open cluster M16 in terms of solar lifetimes, we must find the luminosity of the stars at the turnoff point for this cluster, in terms of solar luminosities.

To do this, you need to determine absolute magnitudes for each star, using the accepted value of 2500 parsecs for the distance to the cluster, and then determine the luminosities. You also need to convert the B-V indices to effective Temperatures, then plot the log of the Luminosity as a function of effective Temperature, with the highest effective temperatures to the LEFT.

1. Calculating absolute visual magnitude using distance formula:

Assuming a distance of 2500 parsecs for M16, calculate the absolute magnitudes from the apparent magnitudes you derived in IMAGE32, using the "distance formula":

$$d = 10^{(m - M + 5) / 5} \quad \text{yields} \quad M = m - 5 \log d + 5$$

2. Correction for interstellar extinction:

Now, recall that this cluster lies in a spiral arm, and there is a great deal of interstellar dust in the way. This dust actually makes the stars appear dimmer than they really are, a phenomenon which is called INTERSTELLAR EXTINCTION. The correction for interstellar extinction in our neighborhood is 1 magnitude for each kiloparsec; that is, for each kiloparsec (1,000 parsecs) a star is actually 1 magnitude BRIGHTER than it would otherwise appear. So, you have to apply this correction to your estimates of M above.

distance to M16 = 2500 pc = _____ kpc

correction for interstellar extinction = _____ magnitudes

all this yields : $M = (m - 5 \log d + 5) - 2.5$

(Note: we have not applied a correction to the B-V indices for interstellar REDDENING. If we did, would this correction make the B-V indices more NEGATIVE or more POSITIVE???)

3. Applying a Bolometric correction:

The luminosity of a star is the TOTAL light output of the star at ALL wavelengths, but you only looked at visual and blue wavelengths, so we need to use an empirical correction factor...

We must relate the absolute magnitude of the stars to the absolute BOLOMETRIC magnitude of the Sun, that is, the absolute magnitude of the Sun as measured at ALL wavelengths. The formula for this is given as

$$M = 4.72 - 2.5 \{ \log (L/L_{\odot}) \}^2$$

which yields: $L/L_{\odot} = 10^{(4.72 - M) / 2.5}$ (you can fill in the steps yourself!)

Suggestion: Use your favorite spreadsheet program to calculate the corrected absolute magnitudes, and then plug those values into the calculation for luminosity.

4. Converting B-V index to effective Temperature

In order to compare your luminosity data with a standard “ZAMS” (Zero Age Main Sequence) model, from which you can attempt to find the turnoff point for this open cluster, you need to convert the B-V indices to effective temperatures. You can use the following table from Shu’s INTRODUCTION TO ASTRONOMY to interpolate effective temperatures for your B-V indices:

B-V index	T-eff.
-0.45	35,000
-0.31	21000
-0.17	13500
0	9700
0.16	8100
0.3	7200
0.45	6500
0.57	6000
0.7	5400

(page 162, 1982 edition)

You can use Graphical Analysis, by Vernier Software to plot T-effective vs. B-V index, then use

the interpolation function between the data points to find the approximate temperatures for the B-V indices you calculated for M16.

5. Graphing L/L_{\odot} :

Finally you are ready to make your H-R diagram for M16! Plot the log of L/L_{\odot} on the y axis, and the effective Temperature on the x axis, BEING SURE TO PUT THE HIGHEST TEMPERATURES CLOSEST TO THE ORIGIN! Don't have the program connect the dots; you do that by hand, using your best eyeball fit...

6. Attempting to find the age of the cluster from the turnoff point:

Compare your graph with a standard ZAMS model in any astronomy reference book. Find the point on your graph where the stars with the highest luminosities appear to "head for the red giant region". From the value of $\log(L/L_{\odot})$ at that point, calculate L/L_{\odot} . From the formula for $T/T_{\odot} = 1/(L/L_{\odot})^{.7143}$, calculate T/T_{\odot} . This is the age of the star cluster in terms of solar lifetimes. Since $T_{\odot} = 10^{10}$ years, to find the absolute age of the cluster in years, multiply the value you derived for T/T_{\odot} by 10^{10} .
