

**Exercise 10: How to tell how far away stars and star clusters are**  
**Photometry** is the determination and use of the color spectrum of astronomical objects to determine the objects' properties. Two properties you will investigate in this exercise are distance and age. The objects you will use are stars in various clusters in the Milky Way galaxy and beyond. This is known as the *Color Index method* of distance determination.

### Part I — Figuring out a color index

As seen in Wien's Law, the color of a star is related to its temperature. So to figure out how far away or how old a star is, one needs to agree to a **color index** which anyone can use and will not be affected by the distance to the star (remember, the star should get *dimmer* when it's further away, not change color!).

With the advent of colored **filters** in color photography, this idea became easier to implement. One could take color time-exposure photos of the stars using various filters and then compare the results.

1. Given a red star and a blue star of equal magnitude (apparent brightness) and given a yellow filter, which would appear brighter?
2. Given a red star and a blue star of equal magnitude (apparent brightness) and given a blue filter, which would appear brighter?

Hipparchus, in the second century BC, decided that a star of **magnitude** one (first magnitude — as bright as some of the brightest stars in the sky) should be 100 times as bright as a star of magnitude six (sixth magnitude — the limit of human vision). This works out to be a 2.512 times increase in brightness for every *lower* magnitude (Hipparchus didn't work this out — this work was done in the eighteenth century AD). So the magnitude scale is a logarithmic scale, just like the Richter scale for earthquake magnitudes.

In the early twentieth century, it was shown that if one measured the magnitude of star's brightness using an image of the star taken with a yellow filter (problem 1a — call this the **V or visual index**) and if one did the same with a blue filter (problem 1b — the **B or blue index**), then the quantity **B-V** (B minus V) could be related to the star's temperature. This is the B-V color index.

3. a. What color stars tended to have the hottest surface temperature? the coolest?  
b. What temperature stars tend to have **negative** B-V index numbers? What temperature stars tend to have **positive** B-V index numbers?

## Part II— A very basic correlation using the color index

By the 1920's, various astronomers had evidence that the temperature of a star was also related to the star's **luminosity** (the intrinsic "brightness" of a star). So, to quantify the luminosity without using non-standard brightness units, astronomers developed the **absolute magnitude** scale, which is the magnitude of a star if it could be viewed from a standard 10 parsecs away). This takes away the distance-dimming effect. When the absolute magnitude (M) was plotted against the B-V index for lots of stars, the correlation became apparent.

Access <http://www.pa.msu.edu/~hufnagel/activities/cmd.act.html>, which is Beth Hufnagel's site at Michigan State University. She teaches an introductory astronomy course and her site has a clever B-V index exercise, from which I've lifted the following data for two clusters:

### CLUSTER 1

Star Number	Brightness in Visual Magnitudes	Color B-V
133	14.4	1.28
165	7.6	0.12
522	11.9	0.90
980	4.2	-0.10
1234	6.8	-0.02
1266	8.3	0.32
1305	13.5	1.14
1355	14.0	1.19
1432	2.9	-0.13
1766	9.1	0.43
1797	10.1	0.52
1040	15.8	1.44
2406	11.1	0.72
2601	15.0	1.51

4. Plot the B-V color index (x-axis) versus the absolute brightness in visual magnitudes (y-axis) on standard graph paper. One weird thing: put 0 high up on the y-axis, and number sequentially *downwards*. Make sure you have room for the *negative* B-V values. Remember to label axes and title the graph. What famous astronomy diagram does this resemble?

5. Using your assignment 5, label the various areas of your diagram which correspond to the text's figure.

### Part III — Using the index to figure out distance and age

Astronomers, including Hubble, began to use the graph above as a powerful tool to determine stellar properties. Initially, the *method of standard candles* for individual stars was applied to whole **clusters** within the Milky Way. You will recreate this distance determination.

You should have three sheets of paper with the B-V versus magnitude plots of NGC 3292, 47 Tucanae and NGC 362/Small Magellanic Cloud. You should also have a transparency of the B-V versus magnitude plot for nearby stars.

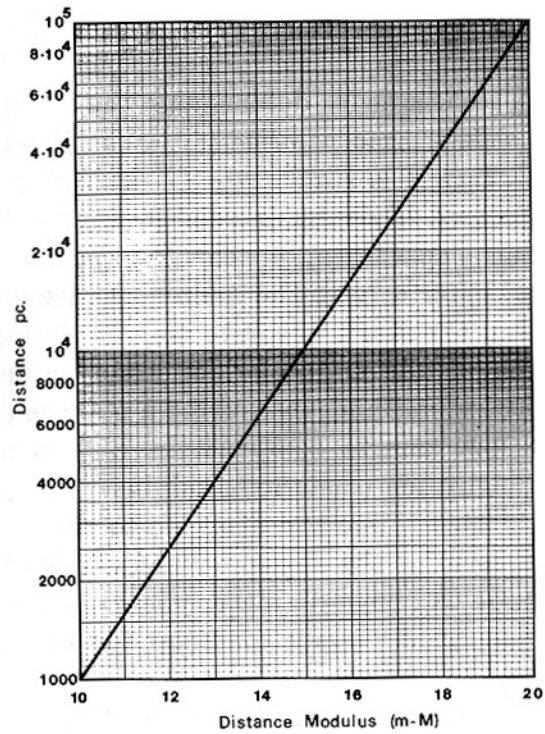
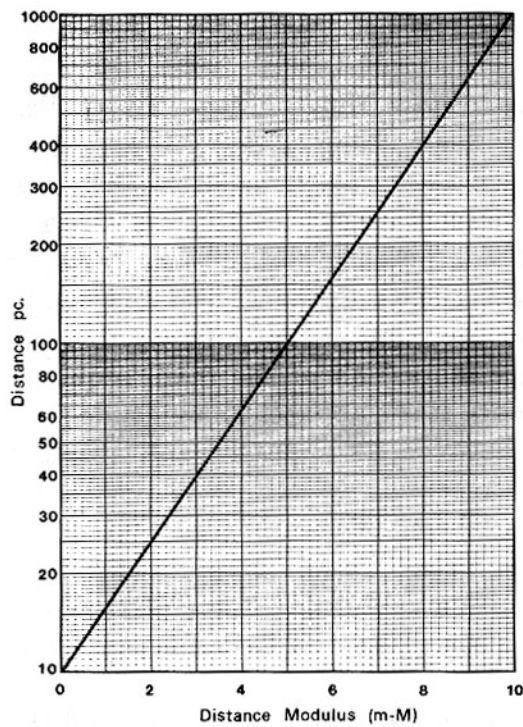
6. To determine the age of a cluster:

- Pick a cluster's graph. Align the transparency such that the axes of the two graphs coincide.
- This is somewhat tricky: while keeping the axes pointed in the right direction (in other words, *without* rotating the sheet), slide the transparency over the other graph until the pattern of points on the transparency nearly or exactly *matches* the pattern of points on the underlying graph (in other words, such that the slope of a best fit line in both graphs are coincident).
- Notice that the y-axis is now offset. For example, the "10" on the transparency is no longer on the same level as the "10" on the underlying sheet. Calculate the offset (this is easy). Notice that this offset is the difference on the two graphs between  $m$ , the magnitude of the cluster's stars, and  $M_v$ , the magnitude of nearby stars. Write this offset, called the **distance modulus**, into the table below.

Cluster	Distance modulus	Distance (pc)
NGC 3292		
47 Tucanae		
NGC 362		
Small Magellanic Cloud		

Repeat the process for all four clusters.

7. Now use the graph on the next page to translate the distance modulus to an actual distance in parsecs, and fill in the last column on the table.



8. This process of distance determination is called **main-sequence fitting**. Why does this work? Hint: think of the method of standard candles and the distribution of stars according to temperature and color.

9. The **relative age** of the stars within a cluster can be determined by the spectral type. For instance, consider the NGC 3293 cluster. What spectral type (using the Cannon OBAFGKML stars) seem to abound in this cluster? So is this a relatively old or relatively young cluster?

10. Order the four clusters in terms of *increasing* apparent age.