

AstroBITS: Open Cluster Project

I. Introduction

The observational data that astronomers have gathered over many years indicate that all stars form in clusters. In a cloud of hydrogen gas, laced with helium and a trace of other elements, something triggers a gravitational collapse. Stars form with a range of different masses and begin their lives. Over time, the gravitational pull of the parent galaxy will disrupt clusters but while they last, they present a snapshot of stars that have formed more or less at the same time and at the same place. So these clusters of stars are of great interest to astronomers.

We will be working with a type of cluster called an open cluster. Open clusters are distinct, both in appearance and properties, from the other common type of cluster, the globular clusters. The clusters we will examine are in our own Milky Way galaxy: those in other galaxies are too faint to observe with the 0.9m telescope at Kitt Peak, where most of the data were taken that we have available for you. You will examine data from a cluster observed with a modern CCD detector. Some of these clusters have not been examined in many years: their distance may have been determined from photographic plates, as long ago as 1930. As with any area in science, the chance to make an improved measurement is never to be missed! You will make measurements of the brightness (or magnitude) of numerous stars in the CCD images taken with the 0.9m telescope at Kitt Peak and construct what astronomers refer to as an H-R (or a color magnitude) diagram. You will grapple with the question of which stars in the image are cluster members and which are just foreground or background stars. And you can compare your results with a known calibration to determine the distance to the cluster.

This project requires a familiarity with the ImageJ image processing software, and Excel. Since the measurements need to be converted to astronomical magnitudes to compare with other astronomer's work, algebra and logs are involved. And while the basic astronomical concepts involved are outlined below, it is assumed that you will investigate these concepts further. *Be aware that this document is not a cookbook!* You should plan to read all the way through it first before you begin, and experiment.

2. Background

Why do clusters present a unique opportunity to determine distance? To answer this, we will take a quick foray into the properties of stars. Practically everything about a star is determined by the mass it has when it forms. Through a variety of methods, we have learned that the mass of stars range from about 100 to 0.01 times the mass of the sun. And the greater the mass, the greater the luminosity of the star. (Luminosity is just a measure of how much light a star produces if it were observed from a standard distance, which is taken to be about 30 light years away.) Over 100 years ago astronomers showed that there is a clear relationship between the luminosity (hence mass) of a star and its

temperature. A plot of an ensemble of stars showing their luminosity and temperature shows this relationship: this is called the H-R diagram from the initials of the two astronomers who first noted it. But not just any collection of random stars will show this: if the stars have differing distances from us, then their brightness will be a function both of their luminosity and their distance from us. So here is where clusters become so interesting. All the stars in a cluster ARE at the same distance from us, so plotting their apparent luminosity or brightness (what we can measure) versus their temperature produces an H-R diagram which can be compared with a H-R diagram for a cluster whose distance is known from other methods (parallax, which we discussed in module 6). And from the inverse square law for light (light intensity falls off inversely as the square of the distance) we can then get the distance to the cluster we are studying.

So in addition to measuring the brightness, we also need the temperatures of the stars in the cluster. The most accurate stellar temperatures are derived from their spectra, but these are not always easy to obtain. Instead, we will use the information we get from imaging the stars in a cluster through different filters. So, if we have images of a cluster in V and B for a cluster, we can measure the magnitudes of the stars in each filter. Then a plot of V versus the difference in magnitude, B-V produces what astronomers call a color magnitude diagram. (See an example in Figure 3)

To compare your results with those of astronomers, it will be important for you to understand the concept of astronomical magnitude. This is a measuring scale astronomers use: logarithms are involved here. See, for example: <http://csep10.phys.utk.edu/astr162/lect/stars/magnitudes.html> or http://outreach.atnf.csiro.au/education/senior/astrophysics/photometry_magnitude.html

3.0 The Open Cluster M26: An example

We will begin with images of M26, taken at the 0.9m WIYN telescope at Kitt Peak. Data in the B and V filter are available for download on the web site. (www.noao.edu/education/arbse/arpd/oc) We want to measure the brightness of as many stars in the cluster as possible. Each star must be measured in both filters, and these results compared for a measure of temperature. You will use ImageJ with the astronomy plugin to make these measurements.

Download ImageJ and install it if you don't already have it. Next download and install the astronomy plugin from the link on the cluster project page. When you download the astronomy plugins, you also will see a description of the toolbar and a link to a Webbook about using ImageJ for astronomical work: "An Introduction to Astronomical Image Processing with ImageJ" This website is a very good introduction to the entire subject of image processing, including "pretty pictures" which could be a project in itself. It explains the functions of the astronomy plugin commands.

The astronomy plugin is distributed as a zip file: installation is discussed in the webbook. After starting ImageJ, check to make sure the plugin is installed by looking under the Plugins menu where it should appear as a submenu called “astronomy”.

Download the M26, epoch 1 data, unzip and open both the B and the V image with ImageJ. Adjust the contrast: under Image, choose Adjust. Either the “auto” or a manual adjustment should produce a good display of the stars. Pay particular attention to improving the contrast to see the faintest stars possible. You should probably start with the B image as the stars are generally fainter in B: you don’t want to measure something in the V filter that you can’t see in B

We want to measure all the light that goes into forming a star. If it weren't for the earth's atmosphere, the star would cover only one pixel. However, the atmosphere jiggles the image so the result is close to a Gaussian profile. You can explore this a bit with the function "seeing profile" under astro plugin to decide how large a circle you should use to get all the light in the stellar image. This routine also calculates an average background (for example, was it a bright moonlit night? You don't want to add those counts to the star). The background is calculated by taking an annulus, or ring, around the star – the radius of this annulus is a variable that you can set.

See www.uni-sw.gwdg.de/~hessman/ImageJ/Book/Measuring_Brightness/index.html for a nice detailed explanation of this.

Set the “aperture parameters (“set aperture”) in the astronomy plugin with the values you obtained from “seeing profile”. Alternatively you can use values of 7 pixels for object radius, 10 for inner radius of background annulus, and 12 for outer radius. (See Fig. 1)

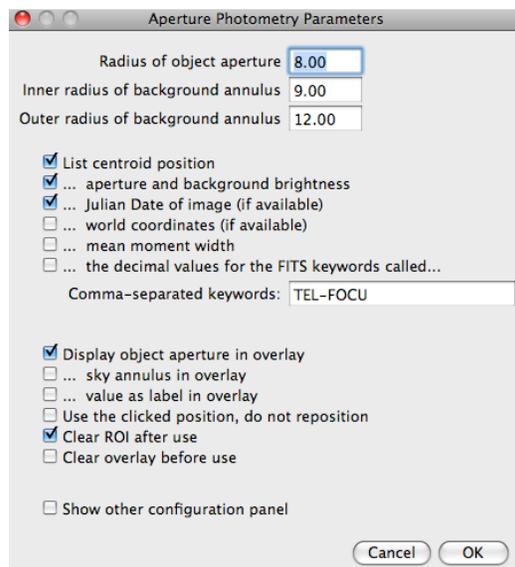


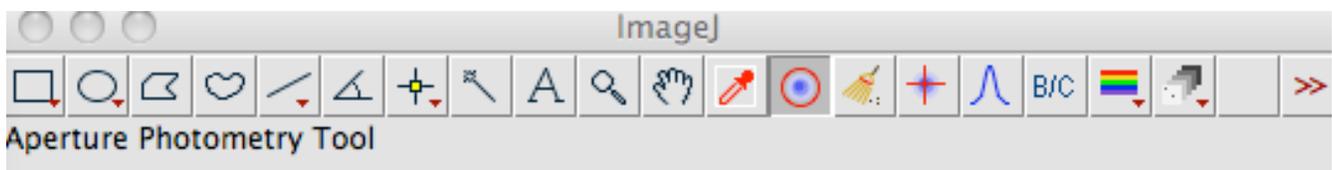
Figure 1: The aperture photometry display NOTE: there is a set Aperture option called "Clear ROI after use." Make sure you check that (explained in “Measuring brightness” guide) You may find it helpful to check “Display object aperture in overlay” so you can see which stars you have measured

Next, you need to open the V filter image and repeat, measuring the same stars. The x,y coordinates of the stars in this filter should be very similar (within a few pixels) to those in the B filter.

Once you have worked out a procedure that you are comfortable with, you are ready to measure a “lot” of stars. What’s a lot? Well in 1950 an astronomer would be happy to get this sort of data for 20 or 30 stars. Today an astronomer, using sophisticated software, would measure every star visible in the image. You will have to decide how much work you are willing to do. But make sure you measure stars with a large range in brightness. Save your measurements when you are finished!

3.1: Summary of Measuring Procedure:

- open imageJ
- click on the double arrows and choose Astronomy tools
- Use one of the image sets
- open the two images B (blue) and V (visual)
- adjust the Brightness/ contrast
- image> stacks > images to stacks
- when asked, type in the common title for each image (case sensitive)
- double click on the icon with a red circle around a blue area (aperture tool).



You must choose Radius of object aperture, inner radius of background annulus and outer radius of background annulus. The radius of object aperture must enclose all bright pixels of the object. The space between

the inner and outer radius of background radius is used to compute the background dark sky. By comparing these two values, imagej will calculate the brightness of the object.

Ensure that Sky annulus in overlay is checked and click ok.

Go to your stack of images, use the magnifier tool to zoom in on a group of stars. You will measure the brightness of 5 stars in three different filters.

Click on the aperture tool, now click on one star. A measurement window will open with the measure on one line(If the circle are not correct, change them.)

Go to another slice/ image and you will see the star circled. (You can if you prefer erase the red circle by clicking on the brush tool and clicking on the star.) Now, click on the aperture tool and measure the brightness of the star.

Repeat for the set of stars you have chosen

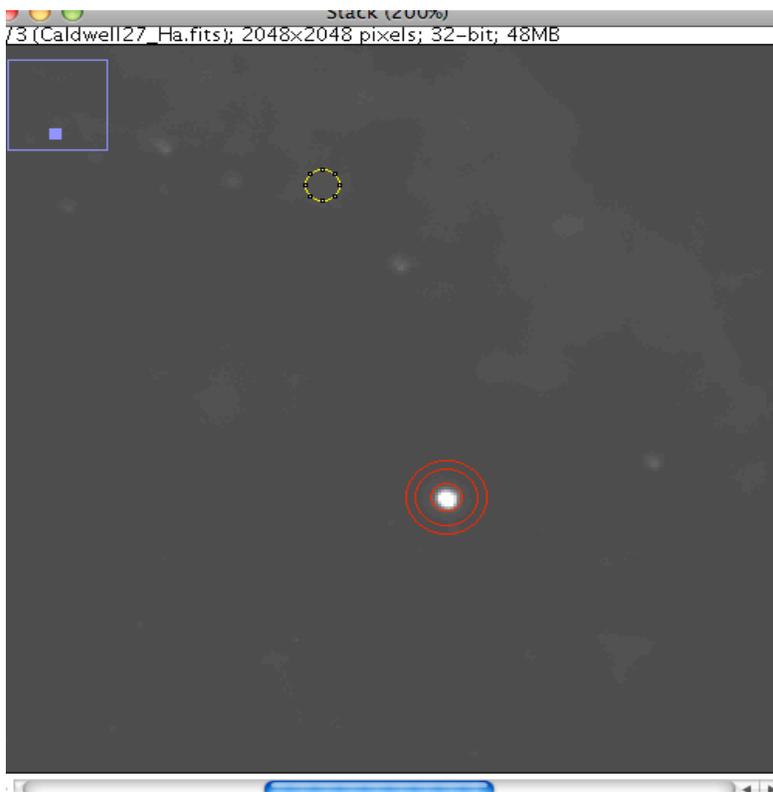


Fig. 2: aperture around star

3.2 Converting flux to magnitudes

Next, we must convert the measured flux, in the column labeled “source” to an apparent magnitude. Astronomical magnitudes are just a relative logarithmic quantity. The zero point is set by certain meta-standard stars. So, using these standards and measuring a few of the brighter members of M 26, we can derive the following relationships between measured intensity and magnitude:

$$\text{Mag (V)} = 21.6 - 2.5 \log_{10}(\text{source}_V / \text{V exposure time})$$

$$\text{Mag (B)} = 21.5 - 2.5 \log_{10}(\text{source}_B / \text{B exposure time})$$

Note that the constants in these two equations apply ONLY to this particular data set. They will be slightly different for other clusters, or other telescope.camera combinations.

So using your measurements (source_V and source_B) and the exposure times in seconds for each image (which you can find in the image header: pulldown Image, “show information”) calculate V magnitude, B magnitude, and the difference, B-V, for each star. The calculations can easily be done in Excel.

The final step is to plot apparent V magnitude vrs the difference, B- V magnitude. In order to compare with similar color magnitude diagrams, you will want to format your plot as it’s done in Fig. 3. If you have measured a good range in brightness your figure should look something like Figure 3. Note that while most of the stars fall along a curve that we call the main sequence, there are a good sprinkling of other stars as well. Some of the brighter ones may be evolved cluster members, or they may just be stars along the line of sight: from this plot we cannot tell.

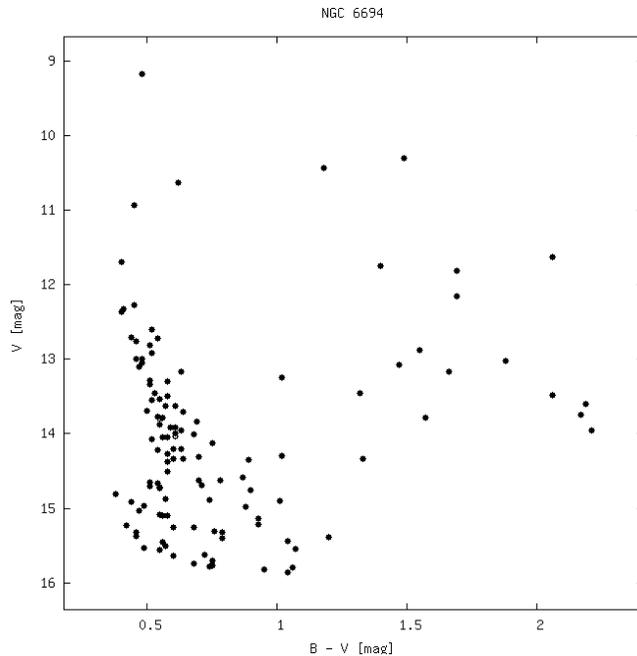


Figure 3: M26 (NGC 6694) (from www.univie.ac.at/webda/)

3.3 Analysis: finding the cluster distance

Your color-magnitude diagram (CMD) data plots the apparent magnitude, M_{apparent} versus the apparent color difference (B-V) of the stars. The apparent color difference is uncorrected for any reddening of the starlight by interstellar dust. (See sect 4.1 for more on what interstellar dust does to the starlight.) But by comparing the CMD of M26 with a cluster of stars reduced to a known distance of 10 parsecs you can estimate the reddening and derive the distance. Let's explore how.

Consider what we mean by a cluster at a distance of 10 parsecs: let's call this our standard cluster. In this case, we define the magnitudes of the stars as their absolute magnitudes. Figure 4 is an example of this. There are many clusters with very well determined distances that were used to form the mean cluster curve in figure 4.

The mean apparent magnitude of the M26 cluster stars minus the mean absolute magnitude in the standard cluster gives the distance, in parsecs, from this formula:

$$M_{\text{apparent}} - M_{\text{absolute}} = 5 \log (\text{distance in parsecs}) - 5 + 3.1 * \text{Excess}(B-V)$$

Distance in astronomy is generally measured in units of parsecs. A light year is 0.31 parsecs. We will use parsecs in this project because this formula relating distance and magnitude uses parsecs. For a derivation of this formula, often referred to the distance modulus formula, see:

http://outreach.atnf.csiro.au/education/senior/astrophysics/photometry_luminosity.html

The term Excess (B-V), expressed in magnitudes, refers to what astronomers call reddening, due to interstellar dust: see sect 4.0. You may be able to measure this from your plot as well.

You need to determine the offset, in magnitudes, between the mean curve in Fig. 4 and your curve for M 26. There are several ways you might do this: for example, start by plotting the values in the table below on the same scale as your M26 CMD and overlaying them. (Plotting on a transparency makes this easy.) Slide the curves until you think you have the best match. The difference in (B-V) between the two curves will give an estimate of the cluster reddening. The difference in the apparent magnitude of the cluster and the absolute magnitude of the mean curve gives you the difference, $M_{\text{apparent}} - M_{\text{absolute}}$. You now have the values needed to compute the distance from the distance modulus formula.

Table 1: values of absolute CMD, plotted in fig. 2

Spec. type	M_{absolute}	(B - V)
O5	-5.8	-0.35
B0	-4.1	-0.31
B2	-1.1	-0.16
A0	0.7	0
	2	0.13
F2	3.4	0.42
G5	5.1	0.7

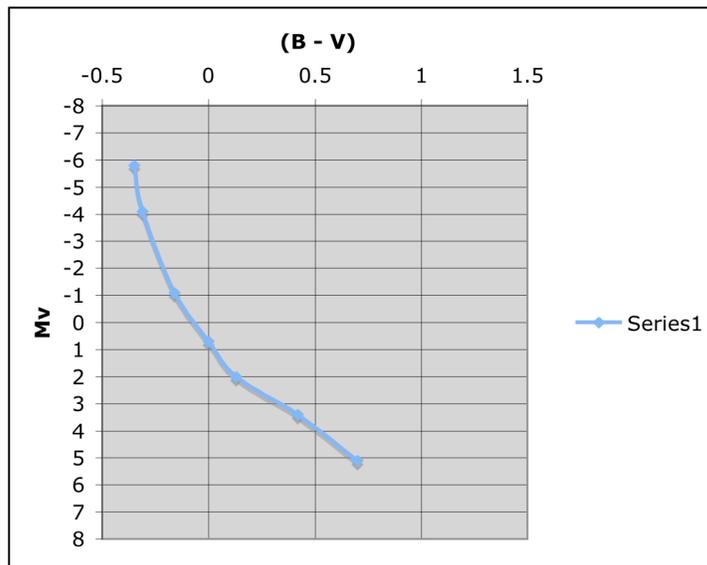


Figure 4: A standard plot of absolute magnitude M_V versus B-V

4.0 Further exploration: Interstellar dust, or reddening

Ah, interstellar dirt! Interstellar reddening is the term astronomers use to refer to the effect of dust between the stars. Tiny particles, bigger than atoms but smaller than anything the eye can see, contribute to both dimming the light and making objects appear redder. They do this by selectively absorbing more light at shorter wavelengths than at longer wavelengths. We see this in the reddened, dimmed sunset, or the air across a city on a smoggy day.

Early on, astronomers realized that something was dimming the clusters seen through the plane of the galaxy (which includes most open clusters) but was not as likely to affect globular clusters, often seen far out of the galactic plane. In general, we find that the total absorption in the red (or V) filter is about 3.1 times the reddening excess (B-V), which explains that term in the distance modulus formula. It is possible to accurately determine this color excess either from the use of a third color filter, or from spectra of some of the stars. The use of a third filter is beyond this project, but we might imagine that from spectra of selected stars, we can determine their color excess (B-V) by comparing the measured colors with the tabulated colors as a function of spectral type. For a good introduction, see: <http://burro.cwru.edu/Academics/Astr221/StarProp/dust.html>

5.0 And even further exploration: Cluster membership from spectra

It's clear there is a concentration of stars forming the cluster main sequence. Other stars in the upper right of the CMD clearly don't belong to this sequence. Are the brighter ones members? Or are they just so-called field stars, seen along the line of sight. You won't be able to determine this for sure, although spectra could be used to determine their temperature, and therefore probable membership in the cluster. We are gathering spectra for selected clusters, and will plan to put them on the web site.

You might also wonder about the faintest stars, below the main sequence. Are these members? The errors in their colors at these faint magnitudes makes it very difficult to tell if they are actually on the main sequence. A determination would take a larger telescope, and also independent data such as proper motions – but that's another project!