Introduction

In this observatory practical we will look at *stellar photometry.* More specifically, we will measure the relative brightness of pairs of stars using B, V and R filters. The basic concepts are described in Chapter 5 of your Lecture Notes.

Procedure

For this exercise we will use the SBIG ST-7E CCD camera, which is controlled by the program CCDOPS. The manual for the camera and software is available on the web (link on course web site) and you should look at these before starting the exercise.

WARNING: You will be attaching a rather large CCD camera and then pointing the telescope to high declination. There is the danger that the CCD camera might crash into the telescope's fork, causing serious damage. If it appears that the telescope is headed for a collision, be prepared to turn it off using the switch to the left of the red power light.

Your observatory supervisor will help you set up the CCD camera together with the filter holder. Please note that the ST-7E is a rather expensive device and it can be a bit difficult to get it set up right, so try to be careful. Turn on the thermoelectric cooler and set the temperature to around -20°. Check this temperature after 20 minutes or so and adjust the temperature so that the cooler is working at around 80% of its maximum rate. It is important that the CCD come to thermal equilibrium before any meaningful photometric data can be taken. This could take up to an hour or so.

Start up the telescope and computer. Point the telescope to a bright star such as Vega. You can do this directly with the goto command, but see the warning above concerning possible collisions between camera and fork. Get a reasonably good focus manually (remember to unlock first the primary mirror), centre the star in CCD's image frame and synchronize the coordinates.

As a warm-up exercise, point the CCD at a globular cluster such as M92 or M13. Optimize the focus, first manually and then with the electric focusser (remember to relock the mirror, after which you should not touch the manual focus). Take images with different exposure times, making sure that the maximum number of counts in a pixel is not more than around 40 000. It is probably easiest for now to not use a filter or to use only the V ('visual', i.e., greenish) filter. Save all images in FITS format in a folder named by the date, e.g., `9nov05`, using meaningful file names such as `m13_1.fit`, `m13_2.fit`, etc.

Do this again for an open cluster such as M29 or M52. Obtain images with no filter and with B, V and R filters.

The next target is the variable star δ-Cephei. Find this either using the goto feature or by setting directly the right ascension and declination. (Hold the mode key for about 2 seconds and release to show right ascension and declination.) If you have trouble finding δ-Cephei, resynchronize the telescope's coordinates on something close to it, such as the star Alderamin.

δ-Cephei is the prototype Cepheid variable star. Its magnitude varies between around 3.5 and 4.3 with a 5.4 day period. The importance of Cepheid variables stems from the fact that there is a relation between their period and absolute brightness or equivalently the absolute magnitude M. By measuring the period we can thus determine M, and by comparing this with the apparent magnitude m we can determine its distance d, by using the distance modulus,

$$m - M = 5 \log_{10} \frac{d}{10\,\mathrm{pc}} \,.$$

Around $41''$ away from δ-Cephei is a magnitude 6.3 star whose brightness is essentially constant. Our goal is to measure the magnitude difference between δ-Cephei and its companion, or equivalently we can use the well measured magnitude of the companion to give the apparent magnitude of δ-Cephei.

Obtain images of δ-Cephei and its companion with B, V, and R filters and with no filter. Again for each image ensure that the exposure time is such that the maximum number of counts in any pixel is not more than around 40 000. Take at least several images with each B, V, R and no filter.

Analysis

For any images of globular clusters try to adjust the brightness and contrast so that you can see as many stars as possible and include this in your lab report. Include some brief background information on globular clusters (if you did not already do this in an earlier practical).

For the open clusters and for δ-Cephei, the goal is to determine magnitude differences between pairs of stars.

For this part of the exercise you should analyze either the δ-Cephei or the open cluster data – you will probably not have time to do both. You can turn in the other analysis for a separate practical. It is probably best to start with the δ-Cephei data.

For at least one star pair, you should do the analysis 'by hand' (see below). The rest of the star pairs can be done either by hand (very tedious) or using the `AperturePhotometry` ImageJ plugin that you can find on the course website.

Determining magnitude difference 'by hand'

The basic procedure is outlined in Chapter 5 of your Lecture Notes. Use ImageJ to define a circular 'region of interest' (ROI), and use the 'measure' command to determine the number of counts in the region and its area. The radius of the region should be small enough that ROIs from different stars do not overlap, but it should be large compared to the full width at half maximum (FWHM) of a star. You should estimate the FWHM using a slim rectangular ROI through the middle of a star with the 'Plot Profile' command.

Remember that the 'measure' command actually gives the area in pixels and the average number of counts per pixel; you need to multiply these to obtain the total number of counts. By defining appropriate signal and background regions, find the magnitude difference Δm of a pair of stars (e.g., δ-Cephei and its companion) and its statistical uncertainty, $\sigma_{\Delta m}$.

Determining magnitude difference using `AperturePhotometry`

If you are using ImageJ on the teaching lab PCs, the **AperturePhotometry** plugin will be installed. Alternatively you can install ImageJ on your own PC, and then download `AperturePhotometry_.java` and put this in the plugins folder. The first time you start ImageJ you should then go to 'plugins', then select 'compile and run', and from there select `AperturePhotometry_.java`. You should only need to do this once; after the plugin has been compiled, AperturePhotometry should appear in the plugins menu.

1. Open the star image, and estimate roughly the background value (place the cursor on the background area away from any star).
2. Select the **AperturePhotometery** plugin from the plugins menu.
3. The program will prompt you for the threshold level for a star. This should be some amount comfortably above the background level and well below that of any star that you want to find. Experiment with different values.
4. The program will prompt you for the CCD's gain; for the SBIG ST-7E this is 2.3.
5. The program will find stars and indicate them on a red and white image. It will also indicate local peaks in the stars in blue. It will prompt the user for the radius of an aperture to draw around the star, taking as default half the minimum separation of any pair of stars. Either accept this default or enter a value which is at least larger than a couple times the FWHM of a star.
6. The program labels the stars starting from zero in order of increasing brightness. It prints a table of star pairs, their magnitude difference, and the statistical error based on the number of photoelectrons collected.

There is another plugin called MultiImagePhotometry which automates somewhat the procedure when you have a large number of images to process. Look for this along with some documentation on the course website.

For the δ-Cephei images, find the magnitude difference Δm and its statistical error, $\sigma_{\Delta m}$. Determine as well the Julian Date of each image.

Include brief background information on the variability of δ-Cephei.

If measurements from other students are available, include their data and yours in a plot of m_V versus time (JD).

As an extension objective, try to work out how you would determine the period of δ-Cephei given a number of observations at different times, not necessarily within a single period. As a start take a look at the website by Michael Richmond [1] and the references therein.

As another extension objective, determine the colour index $B - V$ for δ-Cephei. Discuss how and why this varies as a function of time.

For the cluster images, the goal is to produce a plot of m_V vs. $m_B - m_V$ for as many stars as possible in the cluster. For this exercise it is probably best to use the **AperturePhotometry** plugin. Include brief background information on this sort of plot and discuss what one can learn from it.

References

[1] Michael Richmond, `spiff.rit.edu/classes/phys445/lectures/period/period.html`.

G. Cowan
November 2005