SXR208

Project 1: Colour–Magnitude Diagrams of Star Clusters

Contents

Bold terms in the text below refer to the Glossary in *Observing the Universe*, the course book for SXR208.

1.1 Aims and objectives

The aim of this project is to construct colour–magnitude diagrams (CMDs) for two open clusters and one globular cluster in order to appreciate the different properties of the stellar populations they contain.

The objectives are:

- To plan a sequence of observations of targets and calibration frames sufficient to meet the aim of the project. In this project, the targets are star clusters.
- To obtain **CCD** images of appropriate stellar clusters through two **broad-band** filters along with appropriate calibration frames.
- To reduce the image frames using **bias frames**, dark frames and **flat fields**.
- To perform **aperture photometry** on the stars in each cluster and obtain their **magnitudes** relative to a star of known magnitude in the same field.
- To import these magnitudes into a **spreadsheet** from which the colour–magnitude diagram is constructed.
- To analyse and interpret the colour–magnitude diagrams in order to draw conclusions about the stellar populations, ages and distances of each cluster.

1.2 Introduction

This project is concerned with stellar photometry – that is measuring the **apparent magnitudes** of stars through one or more astronomical filters. The targets of observation are star clusters, which means that many individual stars of interest (typically tens or hundreds of stars) will be contained within each target image that you obtain.

As well as obtaining images of the clusters themselves, you will need to obtain appropriate calibration frames to correct for the bias signal and **dark current**, and to carry out a flat-field-correction. However, in this project you will *not* be asked to measure standard stars in order to determine the **extinction coefficient** ε and **zero-point offset** ζ to calibrate your magnitudes. Instead you will use a reference star of known magnitude in each target image, and determine the magnitudes of other stars relative to this reference point.

The quickest part of this project is likely to be actually taking the images of the star clusters. Planning the observations, including which targets to observe when, which calibration frames to take, etc. and analysing the data, are each likely to take far longer. It is therefore vital to plan how your group will carry out this project, including who will do what and when.

1.3 Background

To begin with, we review some ideas about star clusters, and about astronomical magnitudes and colours.

☐ What are the two types of star cluster that are present in the Galaxy and how do they differ from each other?

■ Open clusters are loose collections of typically a few hundred stars in the galactic disc. These clusters are generally young, with ages of a few million to a billion years old. Their stars belong to Population I. Globular clusters are tightly bound collections of typically a few hundred thousand to a million stars in the Galactic halo. These clusters are generally old with ages of a few billion years. Their stars belong to Population II.

As noted above, in this project you will obtain colour–magnitude diagrams (CMDs) of two open clusters of different ages and one globular cluster. Your aim will be to investigate the differences between the CMDs of these three clusters and explain these differences in terms of the cluster ages. You will also estimate the distances to the open clusters using the technique of main-sequence fitting.

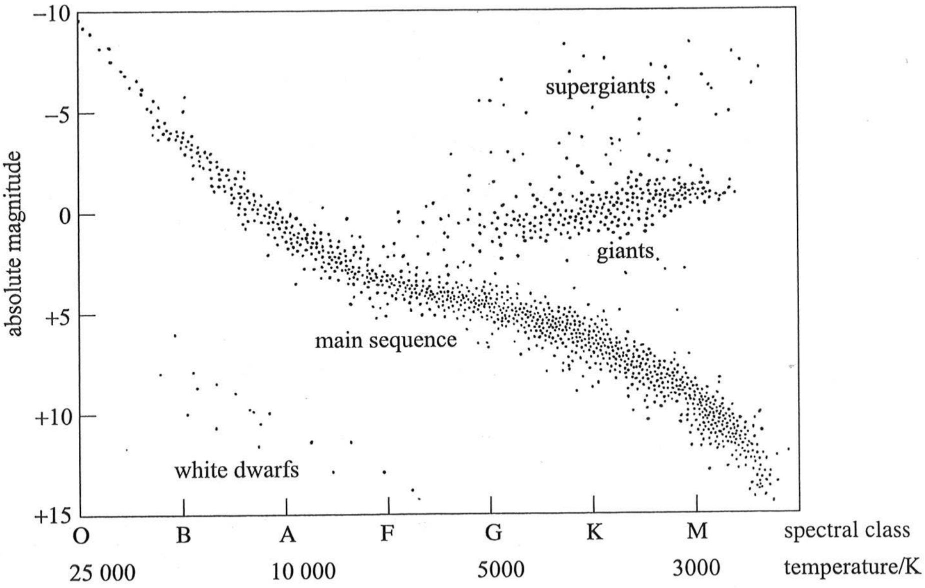

Figure 1.1 A Hertzsprung–Russell diagram (HRD), showing the areas corresponding to stars of particular types.

A CMD plots the apparent magnitude of stars against their **colour index**, where an astronomical colour index is simply the difference between two magnitudes obtained through different filters. A CMD of a star cluster is the *observational* analogue of a Hertzsprung–Russell diagram (HRD). On a HRD, absolute magnitude or **luminosity** is plotted increasing up the vertical axis (i.e. most luminous stars near the top) and spectral type or **temperature** increasing to the left is plotted on the horizontal axis (i.e. hottest stars on the left), as shown in Figure 1.1.

☐ Why is it possible to replace luminosity with apparent magnitude when studying a star cluster?

■ All the stars in the cluster are at roughly the same distance and suffer from the same amount of **interstellar extinction**. Therefore the apparent magnitude, m, of all the stars is related to their absolute magnitude, M, by a simple offset, according to:

$$M = m + (5 - 5 \log_{10}(d/\mathrm{pc}) - A) \tag{1.1}$$

where d is the distance to the cluster and A is the interstellar extinction of the cluster in question. The absolute magnitude of each star in the cluster is proportional to the logarithm of its luminosity.

☐ Why is it possible to replace temperature with a colour index such as $(B - V)$ when studying a star cluster?

■ Magnitudes obtained through different filters, such as B and V, sample different parts of the star's blackbody-like continuum spectrum. A *difference* between two apparent magnitudes is proportional to the *ratio* of two fluxes. Since all the stars are at the same distance, this is also proportional to the ratio of two luminosities in different parts of the spectrum. Since stars with different temperatures will have different spectra, they will also have different colours.

Hertzsprung–Russell diagrams and colour–magnitude diagrams are vital tools for understanding the evolution of stars and their composition. HRDs produced from theoretical calculations can be tested against observational HRDs to judge the accuracy of a particular theory. As you will see later, CMDs of star clusters can be used for distance determination purposes and also to indicate the ages of different stellar populations.

We now consider which particular star clusters you will observe.

1.4 Preparing for the observations

The targets you will observe are shown in Table 1.1. The names of the clusters are given in the first column. 'M' indicates the designation of the cluster in the Messier Catalogue, and 'NGC' its designation in the New General Catalogue of nebulae. The approximate right ascension (*RA*) and declination (*dec*) of the clusters are given in columns 2 and 3. The fourth column lists the observing season in which it is appropriate to observe the clusters. Which three clusters you observe will depend on the time of year you are at the observatory. The fifth and sixth columns list the constellations in which the clusters lie and their approximate diameter in arcminutes. The final column indicates the previously measured interstellar extinction to the cluster, to which we shall return later.

Table 1.1 The targets for observation.

Cluster	*RA*	*dec*	Season	Constell.	Size/arcmin	$E(B-V)$
M29 NGC6913	20h 24min	+38° 30′	Autumn	Cyg	10	0.74
M39 NGC7092	21h 32min	+48° 26′	Autumn	Cyg	29	0.01
M15 NGC7078	21h 30min	+12° 10′	Autumn	Peg	12	0.10
M36 NGC1960	05h 36min	+34° 08′	Spring	Aur	10	0.22
M67 NGC2682	08h 51min	+11° 48′	Spring	Cnc	25	0.06
M3 NGC5272	13h 42min	+28° 23′	Spring	CVn	16	0.01

TASK 1.1 Use a planisphere or software to work out roughly when each of the three clusters appropriate for your observing season rises and sets at your location on the night of observation. Use this information to decide in which order you will make the observations and at roughly what times. ♦

TASK 1.2 Use the on-line Digitized Sky Survey (DSS) to obtain a **finding chart** for each of the clusters that you will observe. Print out hardcopies of these and note the **image scale** and orientation on them. The DSS may be found at

http://ledas-www.star.le.ac.uk/DSSimage/

You will probably need finding charts around 30 arcmin across. ♦

☐ How does the **field-of-view** of a **telescope** depend on its **focal length** and the linear size of the detector?

■ The field-of-view, in radians, is equal to the linear size of the detector divided by the focal length of the telescope.

Check the parameters of the telescope and detector that you will be using and calculate the field-of-view that will fall on the CCD. Your finding charts should cover at least the angular size of the CCD images that you will obtain.

TASK 1.3 From the finding charts, identify a star of about magnitude 9 or 10 that is clearly visible within or near each cluster. These will be your reference stars for the photometry. It is important that the three reference stars are not too bright, or else they will saturate the CCD when you expose for long enough to see the cluster stars. Equally they should not be too faint, or else they will give insufficient signal-to-noise. Then use on-line resources, such as the *Aladin* and *Vizier* tools at the Centre de Données astronomiques de Strasbourg (CDS), to determine the Johnson *B* and *V* magnitudes of these stars. The CDS may be found at

http://cdsweb.u-strasbg.fr/CDS.html

Some guidelines on using the *Aladin* and *Vizier* tools may be found in the Appendix to these project notes. ♦

TASK 1.4 Decide what calibration frames (bias frames, dark frames, flat fields) you will need to reduce your observations, and decide when you will obtain these frames during your observations. ♦

At this point you should discuss your plans, and the outcomes from TASKS 1.1–1.4, with a tutor before proceeding.

1.5 Data taking

If the sky is clear enough, proceed to take the data as outlined below. If it is not, you should use the data that have been previously obtained, and go to Section 1.6.

Begin by starting up the MaximDL software. You will use this software to control the CCD on the telescope and take exposures. Details about how to operate the CCD, focus the telescope and take exposures are all given in the *Observatory Manual*.

TASK 1.5 If it's not already been done, switch on the telescope drive and CCD camera and cool the CCD down to its operating temperature. To begin, you will need to verify that your telescope's pointing is set up correctly and that the optics are correctly focused. Set the telescope to point at an appropriate bright star. Verify that the pointing is sufficiently accurate and that the telescope is focused correctly onto the CCD. If either is not set properly, then make appropriate adjustments, as detailed in the *Observatory Manual* until they are OK. ♦

For each cluster you will need to obtain two images, or sets of images: one through the B-filter and one through the V-filter. The integration times you use will need to be long enough that faint stars are detected, but not so long that your reference stars **saturate** the detector, or the field drifts significantly during the exposure. You may wish to experiment with exposures of 5 s, 10 s and 30 s for instance. You can also average multiple images of the same field to obtain a longer effective exposure. Don't worry if 3 or 4 of the brightest stars in the image are saturated – you can look up the magnitudes of these bright stars at the CDS – it is far more important that the majority of the stars are adequately exposed and that your 9th or 10th magnitude reference stars are not saturated. To make the data reduction easier, it is simplest if all your images through the same filter have the same exposure time.

It is good practice to obtain bias frames and dark frames before and after your target observations, or interspersed between them. Also, it is most convenient if your dark frames have the same exposure times as your target frames, as this saves having to scale them later.

Remember that you will need to take flat fields through each of the same filters as your target observations. Acquiring all these images constitutes TASK 1.6.

TASK 1.6 Obtain B- and V-band images of your three clusters along with appropriate bias frames, dark frames and flat fields. Details on how to take exposures may be found in the *Observatory Manual*. ♦

As you obtain each target image or calibration frame, verify that it is adequate for its purpose by quickly examining it on screen. If the image drifts during exposure, if the stars you are interested in saturate, if they are underexposed, or the image is otherwise unsuitable, then repeat the observation until you obtain one that is satisfactory. When you have a suitable image, make sure you save the file and note down the details in your observing log.

1.6 Analysis

The initial part of the data analysis will also be carried out using the MaximDL software, and the subsequent part will be done using an Excel spreadsheet. Comprehensive details regarding how to use the software are contained in the *Observatory Manual.*

1.6.1 Data reduction

The first part of the analysis is to reduce each of the target frames.

TASK 1.7 Subtract the bias and dark current from each target frame and carry out the flat-field-correction. Details for this procedure are given in the bulleted list below. ♦

- Start up the MaximDL software and begin by opening up all the V-band images of the targets that you wish to use. (You should already have identified which target frames are suitable.) If these target images all have the same exposure times, you can use the same set of dark frames for them all. If they don't, you will have to reduce the images in two or more batches, each of which have the same exposure time.
- From the *Process* menu, select *Set calibration* and use the input boxes to identify which bias frames, which dark frames and which flat fields you will use to reduce these V-band target images. (You should already have identified which bias, dark and flat-field frames are suitable.) Select *median* as the mode for combining the flats, biases and darks.
- From the *Process* menu, then select *Calibrate all* to carry out the bias and dark subtraction and the flat-field-correction on each of your target images. After this has been done, it is a good idea to save each of the reduced target images under a new name, indicating that they have been flat-fielded and corrected for bias and dark current.
- If necessary, combine multiple exposures of the same target through the same filter into a single image, using the *Combine* option from the *Process* menu to create an average image. Save the resulting average images of each cluster under appropriate names.
- You should then close down all the V-band images before repeating the calibration process on all the B-band images of your targets using the appropriate bias frames, dark frames and flat fields, and then averaging together the B-band images of each target, as you did with the V-band images. Remember to save the reduced images and the combined images under appropriate names.

1.6.2 Aperture photometry

The next stage is to perform aperture photometry on each of the stars of interest in each image of each cluster. Unfortunately, the MaximDL software is not explicitly designed for carrying out two-colour photometry on a large number of stars in single images (rather it is designed for measuring the magnitudes of the same few stars in a large number of images to construct a **light curve**, or brightness variation with time). However, it is possible to persuade the software to do what we wish, albeit with a little more effort, as the following discussion illustrates.

For the purposes of this project, we shall assume that all the stars that are visible in the image of an open cluster are members of that cluster. In practice this will not be absolutely true as there will be foreground and background interlopers, but it is a good approximation. In more detailed long-term studies, one may measure the proper motion of all the stars to verify cluster membership. We shall return to this issue when we consider the colour–magnitude diagrams that you produce.

As you may have realized, it will be impossible to carry out aperture photometry on the stars in the central regions of a globular cluster – they are simply too close together to be spatially resolved. For the globular cluster that you have observed, you will only be able to measure the magnitudes of those stars on the outskirts of the cluster that are clearly resolved. However, this will still leave you plenty to choose from!

TASK 1.8 Measure the apparent magnitudes of all the appropriate stars on the reduced B-band and V-band images of each target cluster. Details for this procedure are given in the bulleted list below. ♦

- Open up the reduced, average V-band image and the reduced, average B-band image of one of your clusters. You can adjust the brightness and contrast of an image by holding down the *Shift* button whilst clicking the left mouse button and dragging the pointer across the image in question. Adjust the display in this way so that you can see the *maximum* number of stars in your images.
- Before you go any further, it is useful to print a copy of an image of the cluster that you are analysing. To do this, select the *Print* option from the *File* menu. You may need to write on this hardcopy to identify your reference star and target stars during the rest of this procedure.
- Now select the *Photometry* option from the *Analyze* menu. Then, from the *Analyze Photometry* box, under *Mouse click tags as* select *New reference star*. Use the mouse to position the photometry aperture on the chosen reference star in your B-band image (i.e. the star for which you have already looked up its magnitudes) and click to position it. If you check the box labelled *Snap to centroid* the photometry aperture will centre itself accurately on the object you've selected. Leave the *Ref Mag* box empty, or type in zero.
- Note that you if you accidentally tag the wrong star, you can delete the tag by clicking on the object reference number in the *Tagged objects* box and then clicking on *Untag*. You can also move an aperture from one star to another by clicking on the aperture in the image, and then dragging it to a new location.
- You may also resize the photometry aperture and background sky annulus by clicking the right mouse button whilst the pointer is over the image, and choosing new values for the various radii. However, the default values are usually adequate. If you do resize the apertures, for example when taking measurements of the globular cluster where stars are very close together, make sure you use the same target aperture and background aperture sizes for *all* stars on the same image.
- Now from the *Analyze Photometry* box, under *Mouse click tags as* select *New object*. Then use the mouse to position the photometry aperture in turn on each star in the B-band image whose magnitude you wish to measure. (There will generally be less stars visible in B than in V, so selecting the stars on the B-band image means that they will most probably be on the V-band image too. The converse would not necessarily be the case.) Note that the aperture photometry tool can only store measurements of up to 29 stars (30 including the reference object), but for each star you select on the B-band image, it will automatically select the same star on the V-band image too by aligning the star pattern.
- So, when you have selected no more than 29 target stars, click on the *View Plot* button from the *Analyze Photometry* box. This displays a graph of the magnitude variation with time of all the stars you have measured. You should see two data points for each star: one is the relative V-band magnitude, the other is the relative B-band magnitude. Now click on the *Save Data* button from the graph box. This allows you to save your photometry data in 'csv' (comma separated values) format, which can be read by Excel. The resulting file contains the relative B-band and V-band magnitudes of each star, along with its index number (1 to 29 plus the reference object for which the relative magnitudes are both zero).
- If you wish to record the measurements of more than 29 target stars from a single image, you will need to start the photometry again (with the same reference star and aperture size!) and save further sets of (up to) 29 values in further 'csv' files.

1.6.3 Constructing the CMD

The result of the process above will be a series of files each containing relative *B* and *V* magnitudes of up to 29 target stars in a particular cluster. The first step is to combine these files, if necessary, so that you have a single file containing all the relative *B* and *V* magnitudes for the stars in each cluster (i.e. 3 files in total, one for each cluster). Then you can calculate the true *B* and *V* magnitudes of each star and use these data to plot CMDs for each cluster.

TASK 1.9 Combine the relative B- and V-band data for each cluster into single spreadsheet files, calculate the *B* and *V* magnitudes of each star, and then plot a CMD for each cluster. Details for this procedure are given in the bulleted list below. ♦

- Open up a blank Excel spreadsheet and paste into this all the *B* and *V* magnitudes from the 'csv' files for the stars in a particular cluster. Include each set of 29 stars, if you obtained more than one set. By default, each star's magnitude will lie in a *different* column, but all the *V* magnitudes will lie in the *same* row and all the *B* magnitudes will lie in the *same* row.
- Enter the true *B* and *V* magnitudes of the reference star in a column near the left-hand edge of the sheet, in two rows somewhere below the rows containing the relative magnitudes of all the cluster stars. In the rest of these two rows, calculate the *B* and *V* magnitudes of each cluster star by *adding* the magnitude of the reference star to the relative magnitude of the cluster star in each case.
- In a row immediately *above* the *B* and *V* magnitudes that you have just calculated, use the spreadsheet's calculation facilities to determine the $(B - V)$ colour index for each of the target stars.
- Using Excel's chart-plotting options, plot a scatter graph of the *V* magnitude (vertical axis) versus $(B - V)$ colour (horizontal axis) for all the target stars in the cluster. You will need to adjust the axes to ensure that the magnitudes increase *downwards* on the vertical axis (i.e. apparent brightness increasing upwards). You may also need to alter the limits of each axis, the spacing of tick marks or grid lines, and the position of the axes themselves. Make sure your graph has appropriate labels on the axes and an informative title. Some guidance in using spreadsheets may be found in the *Observatory Manual.*
- Repeat the above steps for each for the clusters you have observed.

You should now have colour–magnitude diagrams for each of the three clusters.

1.7 Discussion

As noted above, a CMD is usually plotted with apparent magnitude increasing downwards and colour index $(B - V)$ increasing to the right.

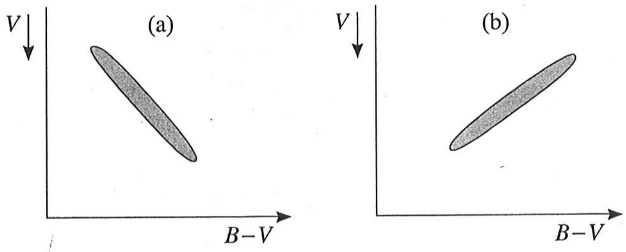

Figure 1.2 (a) and (b) illustrate schematic tracks in CMDs of star clusters.

☐ If a CMD contains stars falling on the track shown in Figure 1.2a, what can you say about how the temperatures of the stars vary with their apparent brightness?

■ Apparent magnitude, *V*, increases downwards, so the stars' apparent brightness increases upwards. The value of the colour index $(B - V)$ increases towards the right, so stars on the left have a numerically smaller value of $(B - V)$ than stars on the right. In other words, stars on the left have a smaller difference between their *B* and *V* magnitudes than stars on the right. This could be due to a numerically smaller *B* value or a numerically larger *V* value. So, stars on the left must be relatively *brighter* in B or *fainter* in V, when compared with stars on the right. Since the *B* magnitude (blue) is measured at shorter wavelengths than the *V* magnitude (green–yellow), stars that are relatively brighter in B or fainter in V are hotter.

So a *smaller* numerical value of $(B - V)$ indicates a *hotter* star.

Considering the track shown in Figure 1.2a, the brightest stars are hotter than the faintest stars.

☐ If a CMD contains stars falling on the track shown in Figure 1.2b, what can you say about how the temperature of the stars varies with their apparent brightness?

■ Following a similar argument to that outlined above, the track shown in Figure 1.2b indicates that the brightest stars are cooler than the faintest stars.

In fact the track shown in Figure 1.2a follows the trend that is seen in the *main sequence*, whereas the track shown in Figure 1.2b follows the trend that is seen in the *giant branch* (post main-sequence evolution).

When a star cluster is born, its initial CMD will show all its stars to lie on the main sequence. The most massive stars are hotter (i.e. bluer) and brighter and lie at the top of the main sequence; the least massive stars are cooler (i.e. redder) and fainter and lie at the bottom of the main sequence. As stars age, they move off the main sequence onto the giant branch.

☐ Which stars will move off the main sequence first?

■ The most massive stars evolve more quickly. So the first stars to move off the main sequence will be the hotter (i.e. bluer), brighter ones.

For a given star cluster, depending upon its age, parts of both the main sequence and the giant branch may be visible in its CMD (as shown in Figure 1.3). The upper point of the main sequence that is populated by stars is called the main-sequence turnoff. Above this point, almost all the stars have evolved off the main sequence onto the giant branch. The position of the main-sequence turnoff therefore indicates the age of the cluster.

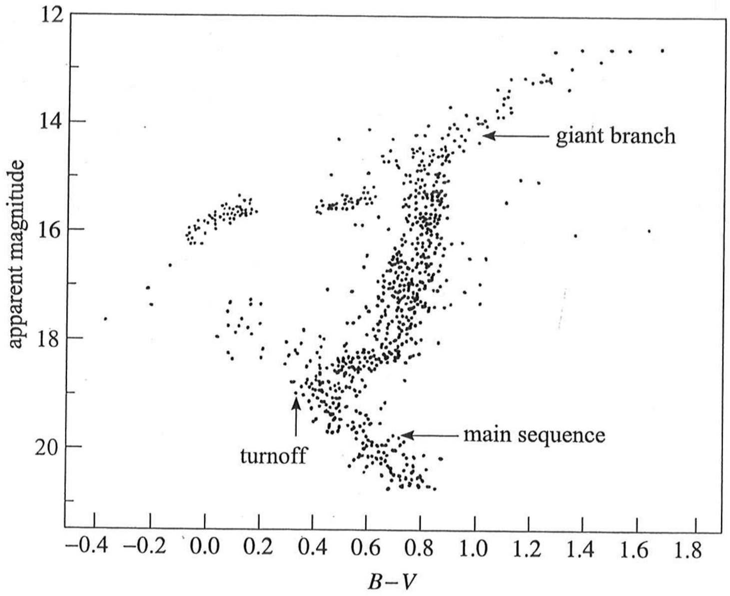

Figure 1.3 A CMD of a particular star cluster.

☐ In general terms, how do the CMDs that you have obtained differ from that shown in Figure 1.3?

■ Your data have a limiting magnitude that is much brighter than that shown in Figure 1.3, i.e. there will be a limiting magnitude (possibly around magnitude 14 or 15) below which you detect no stars. This means that some part of the CMD will not be visible to you. You may *only* see the giant branch, or the upper part of the main sequence for instance.

1.7.1 Identifying the main sequence and giant branch

Using the information above regarding how the colours of stars should vary with their magnitude on the main sequence and on the giant branch, consider the following:

TASK 1.10 For each of the CMDs that you have constructed, can you identify the main sequence? Can you identify the giant branch? Where they are visible, sketch in the positions of the main sequence and giant branch on each of your CMDs. Can you identify any likely interloper stars on your CMDs that may not belong to the clusters? ◆

Discuss your answers with a tutor before moving on.

1.7.2 Distances to star clusters

We can use the main sequence that you have identified on your CMDs to determine the distance to each open cluster, using the technique of main-sequence fitting. We start by considering how colours of stars are affected by interstellar extinction.

The *colour excess* $E(B-V)$ of a star is defined as the difference between its observed colour $(B-V)$ and its intrinsic colour $(B-V)_0$:

$$E(B-V) = (B-V) - (B-V)_0 \qquad (1.2)$$

Note that colour excess E is a function of the colour index $(B-V)$. The expression '$E(B-V)$' does *not* mean 'E times $(B-V)$'. This colour excess is in turn related to the interstellar extinction by the relationship

$$A_V \cong 3E(B-V) \qquad (1.3)$$

The colour excess E of each the stars in a given cluster will be virtually identical. This value has been measured for each of the open clusters you have observed, and the colour excesses are included in Table 1.1. Therefore the interstellar extinction can be calculated in each case.

Now, by definition a main sequence star of spectral type A0 has an intrinsic colour of $(B-V)_0 = 0.0$. So the observed colour of an A0 main sequence star in the clusters you have looked at is simply equal to the colour excess of the cluster, i.e.

$$(B-V)_{A0} = E(B-V).$$

TASK 1.11 Using the $E(B-V)$ values listed in Table 1.1, and the position of the main sequence found from each of your open cluster CMDs, estimate the apparent V-band magnitude of an A0 main sequence star in each of your open clusters. If the main-sequence turnoff is below where the A0 stars should be, you will have to extrapolate the main sequence to where the A0 stars would have been. Be sure to include an estimate of the uncertainty in the value of $m_V(\text{A0})$ for each cluster. ◆

The absolute V magnitude of an A0 main sequence star is $M_V = +0.70$, so you can use a rearranged version of Equation 1.1 to determine the distance to each of the open clusters you have observed:

$$d/\text{pc} = 10^{\left(\frac{m_V - M_V + 5 - A_V}{5}\right)} \qquad (1.4)$$

TASK 1.12 Use Equation 1.4 to determine the distance to each of the open clusters that you have observed. Be sure to include an estimate of the uncertainty in the distance to each open cluster. ◆

1.7.3 Ages of star clusters

As noted earlier, on the main sequence, brighter and bluer stars (top of the main sequence) are more massive than fainter and redder stars (bottom of the main sequence). Furthermore, the more massive a star, the shorter is its main-sequence lifetime. Since all stars in a cluster were born at roughly the same time, they are all the same age. Therefore, the point at which the main sequence turns off to become the giant branch is an indication of the age of the cluster. The older the cluster, the lower down the main sequence will be this turnoff point.

TASK 1.13 Given the position of A0 stars on the open cluster main sequences that you have identified above, and the positions of the giant branches where seen, put the three clusters you have observed in order of increasing age. Which cluster is the oldest and which is the youngest? ◆

> Discuss your answers to the last three tasks with a tutor before you conclude this project.

Appendix: Using *Aladin* and *Vizier* at the CDS

The *Aladin* and *Vizier* tools at the Centre de Données astronomiques de Strasbourg (CDS) may be found at

http://cdsweb.u-strasbg.fr/CDS.html

They allow you to load up images of any part of the sky that have been obtained with various all-sky surveys (such as those carried out by the Palomar Schmidt Telescope or the 2 Micron All Sky Survey) and overlay onto those images catalogues of objects from a multitude of surveys in different parts of the electromagnetic spectrum. Information on each object in those catalogues can then be displayed at the click of a mouse button. For our purposes, we shall use merely a subset of *Aladin* and *Vizier*'s capabilities – displaying optical images of a patch of sky and overlaying some star catalogues to determine the magnitudes of a few objects of interest.

- After connecting to the web site, click on the link to *Aladin* at the top of the page or further down where it says *Aladin sky atlas.*
- On the following page click on *Launch Aladin applet*, and the Aladin viewer will eventually open in your web browser when the applet has downloaded.
- Click on the *Load* button near the top of the window, and a new window will open named *Server selector*, currently with a title of *Aladin image database.*
- In this second window, type the *RA* and *dec* coordinates of the object you are interested in into the *Target* box and an image radius in arcminutes in the *Radius* box, and then click on *Submit.*
- Eventually, a list of image surveys that cover these coordinates will appear in the *Server selector* window. Click on one of these, such as the 'POSSII optical R' (Palomar Optical Sky Survey, release II, optical R-band), and yet another window, headed *Info frame* opens.
- Click the *Load* button on this third window. Eventually an image from your selected survey, at your selected coordinates, will appear in the original Aladin viewer window.
- Now go back to the *Server selector* window and click on *Vizier catalogs*. From the choices that present themselves, select 'optical' in the *Wavelength* box, and select 'stars' in the *Astronomy* box. Then click on *Submit.*
- Eventually a fourth window will open listing all the catalogues that match your search criteria (i.e. optical catalogues of stars). Select two or three likely looking catalogues such as the 'Tycho and Hipparcos catalogues', the 'Bonner Durchmusterung' and the 'All-sky compiled catalogue', then click on *Submit.*
- Eventually, the data from these catalogues will be loaded into the Aladin window and overlaid on the image.
- If you click the cursor on any object in the image that appears in one of the catalogues (indicated by coloured symbols), the catalogue information on the object will appear at the bottom of the screen. This information may include positions, magnitudes, parallax, proper motion, spectral type, and other data too. If you hover the cursor over any one of these numbers, the line above will give a description of what the number represents. In this way you can determine the Johnson B-band and V-band magnitudes of any target of interest that appears in a suitable catalogue.
- If the star catalogues you have chosen don't include *B* and *V* magnitudes of the stars you are interested in, you can simply select some further catalogues to overlay on your image.