

Observatory Safety

Working at night in proximity to moving equipment is potentially hazardous, and safety is our primary concern when observing. Each observing session is overseen by a member of academic staff or a postgraduate demonstrator, who is designated as the Night Officer. The Observatory is covered by the School of Physics safety rules, but in addition there are the following:

- * Students may never observe on their own.
- * All those intending to observe must have been shown around the dome during daylight hours.
- * Anyone wanting to go out to the dome should request permission from the Night Officer. You should inform the Night Officer when you return from the roof.
- * All those going out on the roof at night must carry a torch.
- * Access to the dome is via the non-slip pathway highlighted by yellow lines **only**. Do not run on the roof, and do not leave the path.
- * No-one will be allowed to observe if they are under the influence of alcohol etc.
- * Do not lean against the dome. The dome is remotely operated and can rotate at any time, and dome rotation is preceded by a warning tone.
- * In the event of a fire in the dome, those in the dome should leave the roof immediately, activating the fire alarm point in the mezzanine stairwell, and make their way to the normal assembly point. Other observers should follow the normal fire procedure.
- * In the event of a fire in the main building, all observers on the roof should immediately leave the roof via the mezzanine floor stairwell.

All users should also be aware of the following important aspects of Observatory safety:

- * The risers on the roof are potential trip hazards, and are clearly marked with warning tape
- * The access door to the dome is low (4 feet) - mind your head.
- * There are two emergency stop switches for the dome, one is a switch on the front of the blue DDW box (marked ALL STOP), the other is a push button near the dome door. Make sure you are familiar with the location of these switches and their operation.
- * Be aware that the telescope can slew without warning.

Observers who behave recklessly will be asked to leave the building, and will be reported to the Head of School

Introduction

The object of this experiment is to estimate the ages of stellar clusters using photometric data from the University of Exeter Observatory (<http://www.astro.ex.ac.uk/obs/>).

Ages, masses, and radii of stars can be inferred from their location on a Hertzsprung-Russell (H-R) diagram, a plot of stellar luminosity against effective temperature (Hertzsprung 1911, Russell 1913). An observational version of the H-R diagram is the colour-magnitude diagram, which can be constructed from magnitude measurements at just two wavelengths (eg. Fig.1). Colour-magnitude and H-R diagrams are discussed in many astronomy textbooks (eg. Smith 1995 sects. 9.1 and 9.3) and in PHY3142.

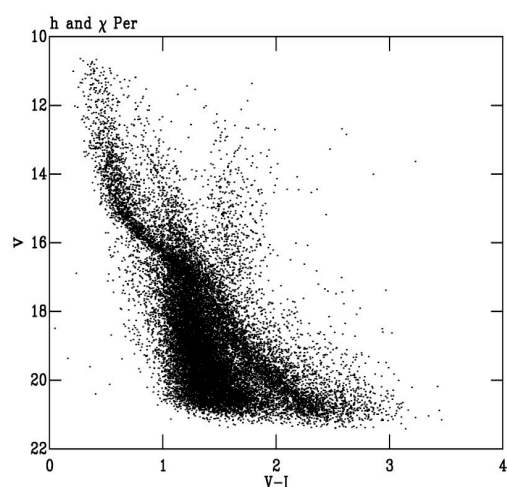


Figure 1. Colour-magnitude diagram for the double cluster h and χ Per, from images in the V and I band filters (see Equipment) (N. Mayne, adapted from Mayne et al. 2007)

Data from previous observing runs will be provided for analysis. There will also be the opportunity for some students to make their own observations during night-time sessions at the Observatory.

Theory

Magnitudes and colour index

The magnitude system is used in astronomy to quantify the flux of an object relative to a standard star; it is a logarithmic scale since the response of the eye is logarithmic. The apparent magnitude m of a star is given by

$$m - m_0 = 2.5 \log(F_0/F)$$

where m_0 is the magnitude of the standard star, F is the flux of the star and F_0 is the flux of the standard star. The logarithms here are to the base 10. The star Vega is defined to have a magnitude of $m_0=0$ and has a well-measured flux F_0 at many wavelengths. Brighter stars have lower magnitudes.

The apparent magnitude does not account for the distance to the target. To convert an apparent magnitude m into an absolute magnitude M , the distance D (in units of parsecs) must be known:

$$M = m - 5 \log(D/10\text{pc})$$

The absolute magnitude is the magnitude an object would have if it were located at a distance of 10 parsecs. With absolute magnitudes, it is possible to compare the intrinsic luminosity of astronomical objects.

Magnitudes can be measured from emission over a broad range of wavelengths (eg. the eye detecting visible light) or over the narrower range passed by a transmission filter. An object's difference in magnitudes between wavelength filters is known as its colour index. For example the colour index from the V and R filters shown under Equipment is $M_V - M_R$ and is usually written V-R. The colour index depends on the relative amount of the blackbody radiation transmitted through each of those filters, which again depends on the peak of the blackbody spectrum for a given T_{eff} .

Stellar luminosity and effective temperature

The relationship between stellar luminosity and temperature follows from the fact that stars basically emit a black-body spectrum. The stellar luminosity L is related to the effective temperature T_{eff} and stellar radius R by the Stefan-Boltzmann law,

$$L = 4\pi R^2 \sigma T_{\text{eff}}^4$$

where $\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$ is Stefan's constant. On a Hertzsprung-Russell diagram plotting $\log(L)$ against $\log(T_{\text{eff}})$, lines of constant radius appear as straight lines.

The relationship between a star's effective temperature and its colour is given by the shape of the black-body spectrum. The visible colour depends on whether the peak emission falls more towards the red or the blue end of the visible range, according to Wien's displacement law,

$$\lambda_{\text{max}} T_{\text{eff}} = b$$

where λ_{max} is the wavelength of the peak, T_{eff} the effective temperature and $b = 2.898 \times 10^{-3} \text{ m K}$ is Wien's displacement constant.

Equipment

Observatory

WARNING: THE TELESCOPE LENS AND OTHER OPTICAL SURFACES ARE EASILY DAMAGED AND SHOULD NEVER BE TOUCHED.

The observatory telescope is a 10" diameter Meade LX-200 Schmidt-Cassegrain. Fig.2 below shows an image of such a telescope and diagrams of the optical path (though the diagram is for the smaller version of the same telescope).

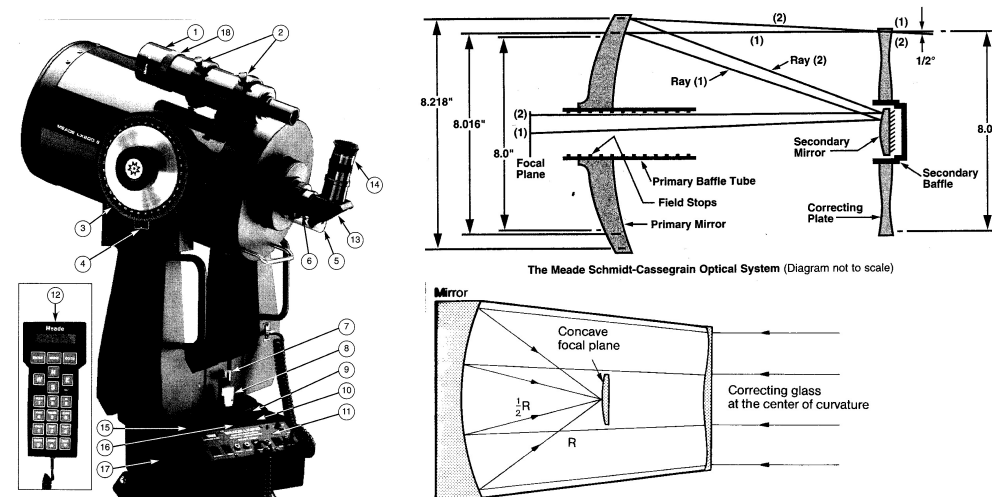


Figure 2. (left) The Meade LX200 telescope used in the astronomy lab. is shown along with the control panel for pointing adjustments; (right) the optical layout showing the path of light rays from the astronomical target (Meade instruction manual).

The telescope is equipped with a robotic focus, a set of wavelength filters, and a computer-controlled CCD (Charge-Coupled Device).

The SBIG ST-10XME CCD imaging array consists of 2184×1472 $6.8\mu\text{m}$ light-sensitive pixels (SBIG CCD manual, 2004). This array is similar to those in digital cameras.

CCDs are not perfect devices and several calibration steps are needed to make final astronomical images. Even the action of reading out the CCD will produce some counts, and a zero second exposure is called a *bias frame* since it measures this low level noise. An exposure with a closed shutter also results in signal even though light is not incident on the array.

An image with a time equal to the exposure but with the shutter closed is called a *dark frame*, and the counts in the dark frame are caused by thermal noise giving some electrons enough energy to be collected along with the source generated charge. The telescope CCD camera needs to be used in the setting that automatically takes a dark frame. This dark current is reduced by lowering the temperature, so the camera is cooled. The dark frame also includes the bias term.

The sky can also be bright enough to produce a signal on the detector, in addition to the dark current background, so an image of the night-time sky is also recorded to subtract off this background.

The pixels are not exactly the same in their response, and the variations need to be measured by observing a blank sky or a uniformly illuminated panel in the dome. If it is clear, you will take sky observations just after sunset to perform this calibration. This image is called a *sky flat* and the astronomical images need to be divided by the sky flat. Further information on CCDs can be found in the SBIG CCD manual (2004), Smith (1995) Sect. 3.3.3 or Howell (2006).

The unfiltered CCD is sensitive to a wide range of wavelengths of visible light. To restrict the wavelength range, filters are placed in the optical path between the telescope and the CCD. The telescope is equipped with standard B,V and R filters (Bessell 1990). The wavelengths which are transmitted by the filters are shown in Fig. 3.

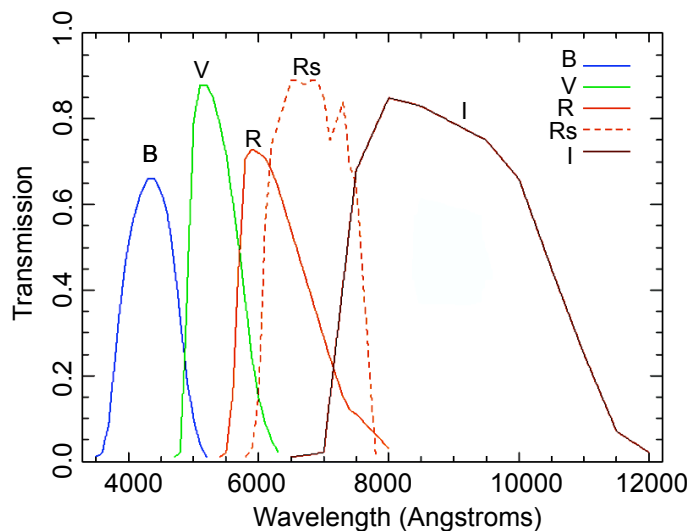


Figure 3. The transmission as a function of wavelength plotted for standard astronomical filters (Lick Observatory – http://mthamilton.ucolick.org/techdocs/filters/BVRI_plot.html)

Reduction and analysis equipment

Mac computers running the astronomical software packages IRAF (see IRAF home page) and SAOImage DS9 (see DS9 reference manual) are provided for data analysis.

Method

Observations

Plan the observing session beforehand. First, make a list of required observations using the information above on CCDs and filters. Check that the list includes observations (a) to image the stellar clusters in the V and R bands, (b) to remove sources of noise, and (c) to calibrate the magnitude scale of the images. Second, using the list and software provided, select the best clusters for observing at this time of year from this Observatory. Bring this planning with you to the night-time observing session.

At the telescope, take images of an open cluster and a globular cluster, plus the necessary calibration images, through the V and R filters.

Data reduction

In this part of the practical, stellar fluxes (magnitudes) are extracted from CCD images from the University of Exeter Observatory and used to produce a colour-magnitude diagram. The

process is called data reduction, because combining images reduces the amount of disk space needed to store the information. Detailed notes on how to achieve this using the available software will be provided.

Several steps are required to produce a calibrated cluster image. First, multiple observations of a target or calibration field are combined to form a single image. Then the dark current and sky background contributions to the image are subtracted. Next, the image is divided by the sky flat to compensate for the varying gain of individual pixels of the CCD. This process can be repeated for each set of cluster data.

Automated source extraction software is used to obtain photometry (magnitudes) for the stars in the field. For this analysis, instead of using Vega as a standard, one of the stars in the field will be a standard with known magnitudes in the V and R filters. Calculate the magnitude offset for the cluster image by comparing the measured magnitude for this star with the known values. Use this offset to convert the fluxes of all the stars into apparent magnitudes.

Look up the distance to the two clusters and convert the relative magnitudes to absolute magnitudes. Calculate the V-R colour index for each star from the fluxes at the two wavelengths. Plot the absolute V magnitudes against colour to produce a M_V vs. V-R colour-magnitude diagram for each cluster.

Analysis

Based on your reading on Hertzsprung-Russell diagrams, explain what physical property of the stars corresponds to each axis and why the axes are plotted in the direction of increasing values shown in Fig. 1. Explain what type of star is in each cluster and describe the differences in stellar structure. State which cluster is younger and give an explanation to support your statement.

References

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