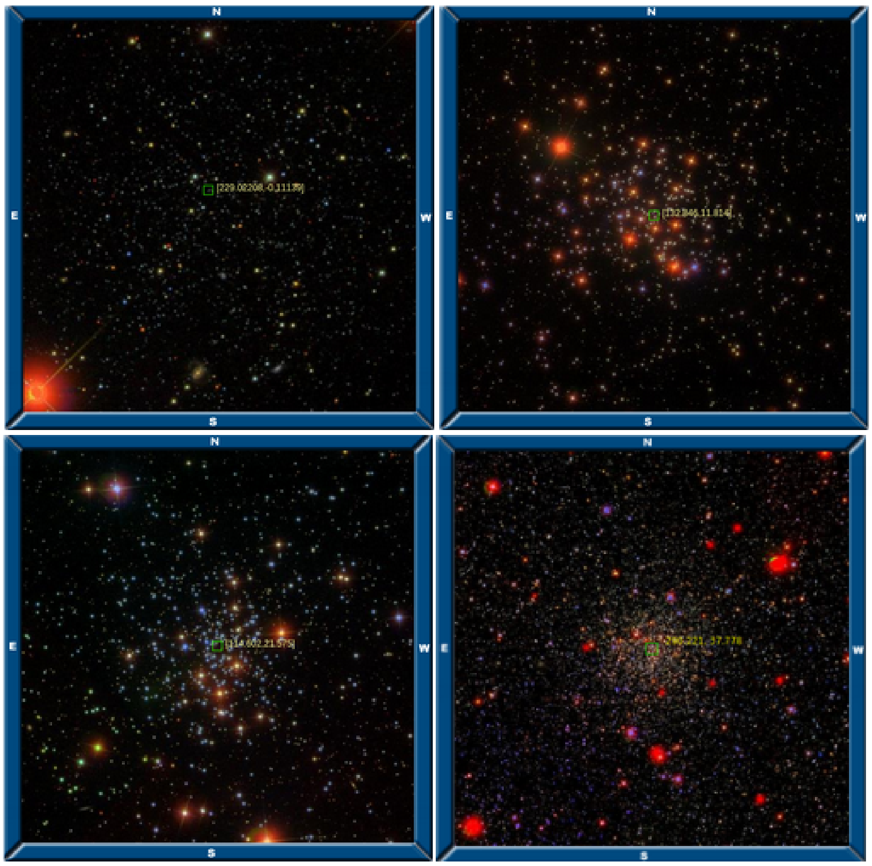
AST220 Stellar physics course:

Challenge: Colour-magnitude diagrams of nearby star clusters: Photometry and Modelling

Project Description: In this challenge, you will produce colour-magnitude diagrams of several nearby clusters. You will use data from the SDSS survey including catalogue data. You will also learn to make your own photometric measurements using the SAO Gaia software package. You will then combine the data to make colour-magnitude plots for all the clusters, and derive the ages and metallicities of the clusters using the *Parsec model code*.

The star clusters we will study:
Pal 5, M67, NGC2420, NGC6791
(top left, top right, bottom left, bottom right)



Cluster name	Distance modulus	Metallicity (Z/H)	Extinction Av	Type
Pal 5	16.83	-1.41	0.186	GC
M67	9.61	+0.00	0.093	open
NGC2420	12.00	-0.37	0.124	open
NGC6791	13.02	+0.40	0.416	GC

Automatic photometry from the SDSS

Using the navigate tool from the SDSS DR17, search for a cluster, and look at the image. You can change the zoom using the 'Scale ("/pix)' option.
What do the units of this number mean?

By clicking on different objects in the image, you can see the automatic photometric measurements that the SDSS survey made.
Record the g-band and r-band luminosity of 5-10 stars in the image. Calculate their g-r colour. Comment on how the value of the g-r colour depends on the colour you see in the image.

You will now collect all of the automatic measurements of the g-band and r-band magnitudes using the rectangle search tool: rectangle search. You must choose optical data. You must set the range of Right Ascension (RA) and Declination (Dec), and the SDSS database will provide all of the measurements. Use the navigate tool to decide a good range. Note: the cluster extends further than it appears, so use a generous wide range of RA and Dec to not leave out any cluster stars.

Save all the data to a CSV file (Comma Separated Values, this is an ascii text file, where each column is separated by commas). Using python or topcat, make colour magnitude diagrams and compare your result (side by side) with the matching cluster shown in figures 12-16 from ***this paper****.*

In the navigate tool, you can select the tick-box ‘Photometric objects’ to see which stars have automatically measured photometry.

Test this for one or two clusters. What do you see? Why do you think this might be happening when SDSS tries to make automatic measurements of the star magnitudes?

Manual photometry on the SDSS images using the SAO Gaia software.

Each person will choose a single cluster. You will now conduct manual photometry on the inner regions of the cluster where the automatic photometry has failed. A g-band and r-band SDSS image for each cluster is provided on your computer.

First, load up the SAO Gaia software:
> export STARLINK_DIR=star-2021A
>source $STARLINK_DIR/etc/profile
>gaia &

Now, open the r-band fits file. A fits file shows each pixel of the image, and you can see the counts in a pixel at the position of the cursor.

Experiment with the ‘autocut option’. What effect does it have on the counts from stars, and why?

Try changing the colour map. Now open the Aperture Photometry window. With this tool, you can draw circles (‘Apertures’) on the image with your mouse, and measure the pixel values inside of the aperture.

First, zoom in on one of the stars you choose earlier in the SDSS image. Click ‘Define Object Aperture’, and draw a circle around the star. Make sure all of the light from the star is included inside the aperture by varying the ‘Auto-cut’ value. When you are ready, click ‘Calculate’. The total counts inside the Object Aperture are given by the ‘Sum in Aperture’ result.

This ‘Sum in Aperture’ value includes counts from the star but also counts from objects in front or behind the star (called the ‘sky’). This must be subtracted so that we only measure counts from the stars. This is done using a ‘Sky Aperture’. When you drew the Object Aperture around the star, there was also an annulus surrounding your Object Aperture which is called the ‘Sky Aperture’. The counts inside this annulus were used to calculate the amount of sky counts inside your Object Aperture (shown by the ‘Sky Value’ result). Ideally you do not want other stars to fall inside the Sky Aperture as they will affect the sky counts.

What effect would having a star in the ‘Sky Aperture’ have on the measurement of the counts in the Object Aperture?

Adjust the position of the Sky Annulus using ‘Annulus inner/outer scale’ sliders. If the stars are very close together and it is impossible to use an annulus, you can also make a separate circular Sky Aperture (try this out by going to ‘options’ at the top of the Aperture Photometry Window).

When you click ‘Calculate Results’, you will also get a ‘Magnitude result’. As the images are not yet calibrated, we cannot trust this value yet. We will now calibrate the images by comparing with the SDSS automatic photometry. The ‘Magnitude Result’ is calculated using:

$$mag = -2.5 \log10(counts) + K_{calib}$$

where K_calib is the ‘Frame Zero Point (mags)’ value in the Aperture Photometry Window. We must choose this value carefully to calibrate the images.

Using 5-10 stars in each image, calculate what value the ‘Frame Zero Point (mags)’ must have for the ‘Magnitude result’ to match the measurement from the SDSS automatic photometry. The value of the ‘Frame Zero Point’ will vary a little between the stars. Use an average value (removing any large outliers) to decide the final value you will use for the image. After you have put this value in for the ‘Frame Zero Point (mags)’, your image is calibrated.

Now, you can measure the magnitudes of other stars that do not have automatic SDSS photometry. Try to aim to measure the magnitudes of at least 50 stars. Note, you can define multiple Object Apertures at the same time. When you click ‘Calculate results’, measurements for all the apertures will be made at the same time, and the results are saved in the ‘Results’ file (default name is ‘GaiaPhotoLog.dat’). You should also regularly save the position of your apertures to a separate file (File>Save Apertures). Then, when you are finished you can recover the positions of all these Object Apertures on the g-band filter image. Switching on the ‘Auto-centre’ option allows the apertures to automatically move to be more centred on each star.

After calibrating the g and r-band image, measure the magnitudes of >50 stars and save them to a file. Combining the results for the g-band and r-band, make a colour-magnitude plot of your new results, and add them to the results from the automatic SDSS photometry to make a ‘Master’ colour magnitude diagram.

6) Modelling of the ‘Master’ colour diagrams.

We will now attempt to measure the ages of all the star clusters using the colour-magnitude modelling code *Parsec*. Parsec uses a web-based form, and runs the simulation remotely on their servers. After the simulation is finished, they provide the results as an ascii file that we can download locally.

Open the *Parsec* webpage: [Parsec]
There are many options. We will generally use the Default values that are provided unless otherwise stated (e.g., Parsec Version 1.2). As we are comparing with SDSS

photometry, you must choose the correct ‘Photometric system’. Use the values given in the Table of star cluster properties to set-up the model for each star cluster separately.

In our first exercise, we will choose a single value for the metallicity from the Table for each cluster. Choose a range of possible ages from 1 Gyr to 15 Gyr (>age of the Universe) in steps of 0.5 Gyr. Output isochrone tables for each cluster, and plot the isochrones on the colour-magnitude diagram.

What do you think is the best matching age for each star cluster? With a figure, show your best choice and a value above and below your best choice to demonstrate why this is the best age.

Now, using a single value for the age (the best value you found previously), vary the metallicity. Show with a figure how the shape of the colour-magnitude diagram changes as the metallicity. By fine-tuning the metallicity and age, see if you can improve the fit to the observations for a cluster, and give your best fit values.

Bonus question: If you have time, test if you see a change in the colour-magnitude diagram for stars near the cluster centre compared to stars further away from the centre, and describe your results.