Multi Aperture Photometry (MAP) with AstroImageJ

Up until this point you have taken a series of separate images of a star cluster through 2 different photometric filters (B and V). The work flow was then: calibrate these through the various steps of: bias subtraction, dark current subtraction and flat fielding. This results in science images.

1. Import the sciences image sequence into AIJ for a given filter and align them to remove any relative shifts in star positions.

2. Combine all the images in the aligned stack to a single image, to improve the signal to noise ratio and thus get more accurate photometric measurements.

3. Plate solve each of the two images by either using your locally installed version of astrometry.net or uploading your images to nova.astrometry.net and waiting for it to plate solve and then download the new image which now RA/DEC coordinates inserted into the fits headers. Plate solving allows us to identify a star or stars in the image which we will use as comparison or reference stars whose magnitude through either B or V filters is known by looking up information on them using e.g. SIMBAD or ALADIN data bases. Before we can start differential photometry on each image there is one more stage which will make the process much easier. So far in creating these 2 science images (one through each filter) we aligned and combined 100 images in each of the two filter sets. But there may still be small relative shifts of stars between the final 2 science images through B and V. We want to remove this. So just run the alignment process again but only on these two images. Just go to import image sequence and choose only the 2 science images through B and V and run the align routine. We will see below why this step is needed.

Start Differential Photometry

Now it is time to perform differential photometry on the 2 images. This first involves choosing a comparison star in the field.

1. Open the first image (either the one through V or B) and choose a relatively bright star. Place the mouse pointer over it and right click. This will launch SIMBAD and it will try to find the star. If it fails it will at least display the RA/DEC coordinates of the star. You can copy and paste these into SIMBAD. Go to SIMBAD and there is a box for entering search data. Paste

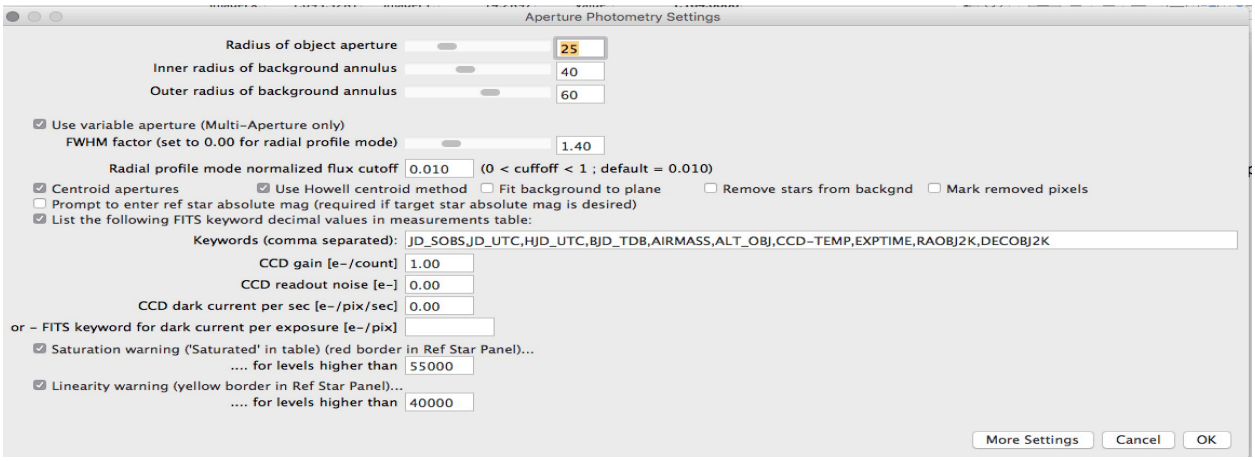
the coordinates and hit enter. It will then show an image of the star and its surrounding stars and a list of brighter stars beginning with the one you have chosen. These are shown on the image with red highlighted markers on them.

2. Click on the star you have chosen which will be at the top of the list. It will open another page and a lot of data on the star is shown including its apparent magnitude through various filters. Make a note of the magnitude of your comparison star through the filter whose science image you are working with.

3. Now it is time to place apertures around all the target stars whose apparent magnitudes you wish to determine and an aperture around the comparison star you have chosen and whose magnitude we know.

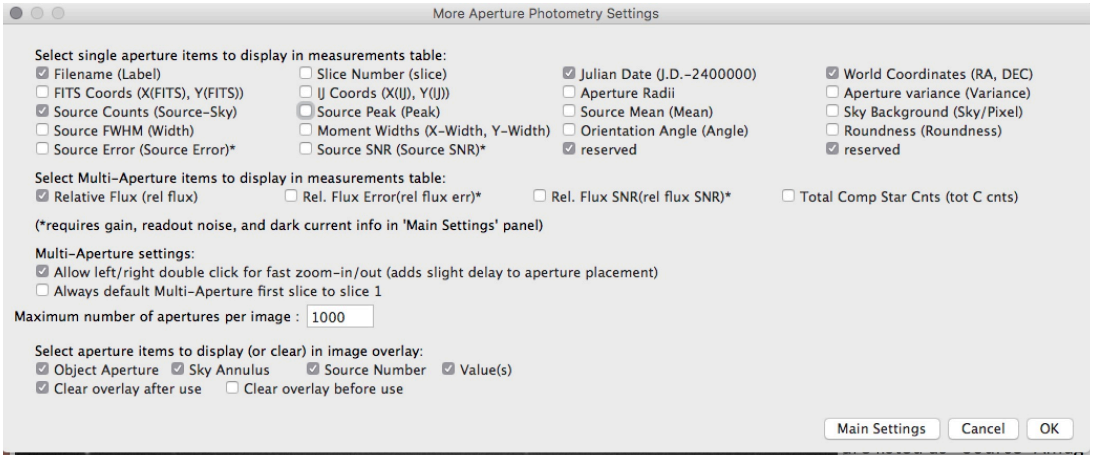
4. Make sure the icons shown below are switched on:

5. Click on the 'Set' Apertures button in the above menu and choose the various options shown below in the new window that open:



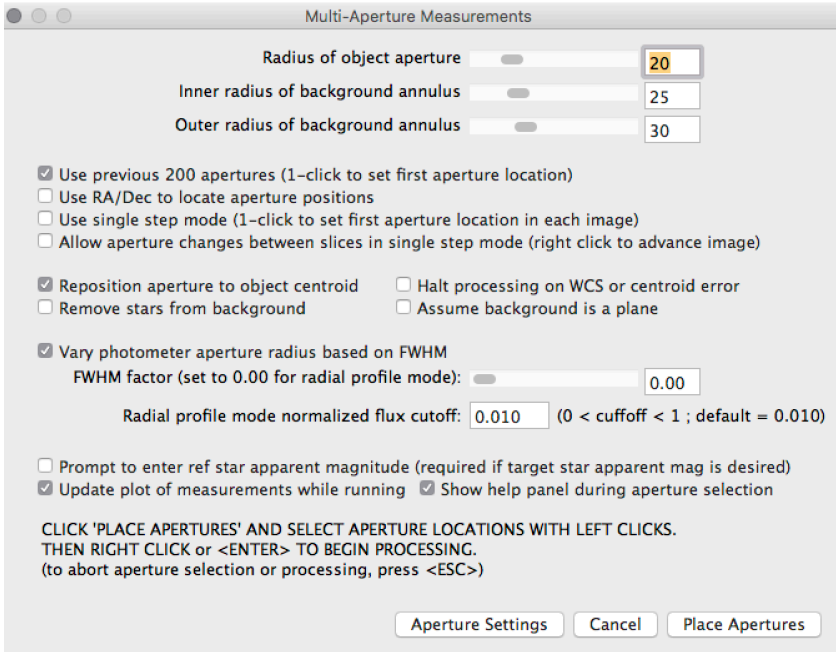
keep the standard values for aperture radii for now. You can play with different settings later. The CCD settings for our camera are: gain= 1, read out noise= 11e and dark current = 0.5e/pix/sec.

6. Click the more settings tab at bottom right and choose following settings. This just minimises the amount of data generated when MAP is run, most of which we don't need. You can always change these values later on your data and re-run.



7. Click ok and return to the main AIJ toolbar. Click on the perform MAP icon 

8. In the settings window choose the following options:



Make sure the 'Halt processing on WCS or centroid error' is unchecked. Otherwise if MA photometry cannot locate the centroid of star (sometimes happens for a few very faint stars) it will halt processing and no output will be produced. It is better to continue processing but just

remove these stars by hand from the measurements table later. They will be easily identifiable as 'NaN' appears in the magnitudes list.

9. Click on Place Apertures to begin placing apertures over target stars and the comparison star you choose earlier. Target star apertures will appear green and the comparison star aperture red. First go to your comparison star you choose earlier. Place a red aperture on it. AIJ will then open a box and ask you to input the magnitude of that star. Then continue placing ONLY target star apertures in say 10 stars of varying brightness. This is just for practice at this stage. To generate a good colour-magnitude diagram will need selecting a hundred stars, the more the better.

10. In placing apertures make sure that if they are overlapping (which is allowed), that there are no stars in the outer ring of the aperture because that will give a false reading of the sky background count. This outer ring of the aperture is meant only to have sky counts.

11. IMPORTANT FOR LATER: make a note of the location (RA/DEC) of the first target star aperture you placed. A good idea is to take a screen grab of the image with all the apertures placed on it.

12. To run the MAP hit enter. Several windows will open. This is a bit annoying but it is possible to choose options that will limit what windows are launched after MAP is completed. Close all of those except the 'measurements' window and the 'multi-plot main' window. The 'measurements' window is a single line with all the data in it of all the stars you selected and other info. It is actually a table. To make it more user friendly it is better to 'transpose' it so we see information on separate lines. To do this in the 'multi-plot main' window go to -> table-> transpose currently selected table.

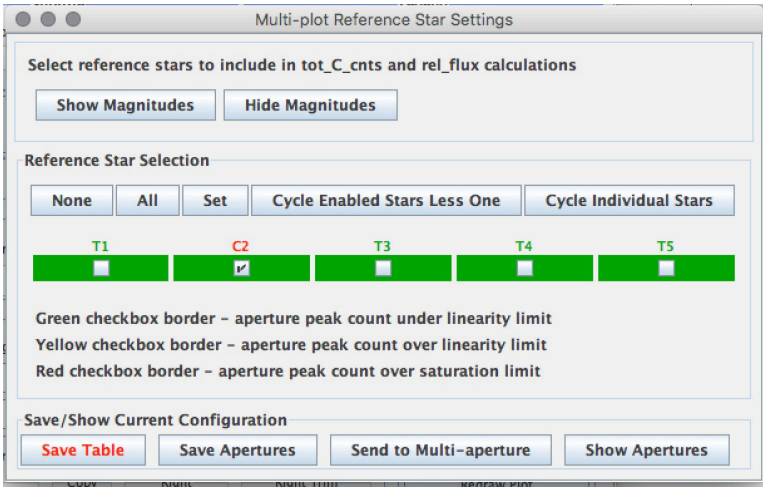
13. Now it will open another window showing your data table in a much nicer format.

14. The table will now show a list of relative fluxes of all the target stars you selected. But it also it will show a list of apparent magnitudes of those target stars because earlier you entered the magnitude of the comparison star! These apparent magnitudes are listed as 'Source_Amag_Txxx ' at the very end of the table, and are what we will need in creating the colour-magnitude diagram later. They can be copy and pasted into an excel spreadsheet.

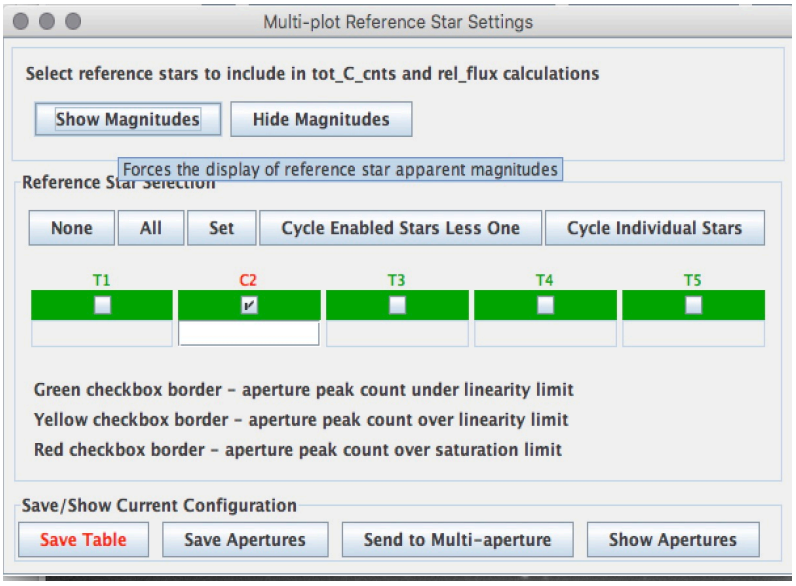
15. Now that we have all the apparent magnitudes through one filter we want to repeat the procedure for the image taken through the second filter. To do this close the current image and open the second science image.

16. Now remember earlier we aligned the two images? This is why. Instead of going through and manually clicking on all the same stars to put apertures on them as before, AIJ remembers the locations of all the apertures you created in the previous image! You can automatically place them there is an option when you hit  click on the option 'use previous xxx apertures'. You then MUST click on the exact same first target star you chose on the previous image (which is why we needed to record the location of this star earlier). Then AIJ will overlay automatically all the same apertures! This can only work if the stars in the 2 images are aligned. So now you know why we did this earlier.

17. Run MAP by hitting enter. Now we need to make an important change. AIJ still thinks the comparison star has the magnitude we entered before, but of course it is now different as we have chosen a different filter. So we need to tell AIJ this. You will see one of the windows open is called 'multi plot reference star settings'



18. C2 is our comparison star. We need to change the magnitude of it. To do so click on 'Show Magnitudes' This will open a drop-down box below the star where you can change the magnitude you previously entered



19. Enter the new magnitude of the comparison star through the filter used in the image (refer to the SIMBAD info) and press enter. This will generate more new windows and a new table with updated magnitude info on all the target stars. Transpose this latest table again and save this. You can now copy and paste these magnitudes into your spreadsheet.

20. At this point you will have two data columns in your spreadsheet one of target star apparent magnitudes m_B and m_V taken through V and through B filters. You now almost have all you need to make your first colour-magnitude diagram by plotting $m_B - m_V$ vs m_V. You won't see too much structure in the plot at this stage given that you have only chosen a few target stars.

21. Once you are happy with all stages, go back and repeat MAP but this time choose as many target stars as you can. At least 100 maybe 200. Remember you need only do this once on one of the 2 images as AIJ saves the positions of your apertures. But don't forget to record the position of your fist target star T1!

Converting Apparent to Absolute magnitudes

In order to later estimate the age of our star cluster by fitting so-called Isochrones to the colour-magnitude diagram (using TOPCAT software), it is better to convert the apparent magnitudes we have so far generated, to absolute magnitudes, because these are used in Isochrones available from various online databases.

The standard fomula for a given filter relating absolute M and apparent magnitude m is:-

$$M = m - 5 \log_{10}(d) + 5$$

where d is the distance to an object measured in parsecs.

For you given cluster, look up its distance in parsecs and then create 2 new data columns in your spreadsheet labelled M_B and M_V. Note that this is just a constant offset on each of the apparent magnitudes, once d is known.

As a first basic Colour-Magnitude plot using Excel, plot M_V on the y-axis and $M_B - M_V$ along the x-axis of a scatter plot. Note that in excel the first column of data is plotted along the x-axis the second column of date along the y-axis in a scatter plot.

Later we will use the much more sophisticated plotting software TOPCAT to make the same plots, using the data in your spreadsheet. TOPCAT allows the overlay of multiple Isochrones onto the colour-magnitude diagram, thus allowing us to estimate its age.