# **AstroImageJ *Flash* Guide**

v1.4 (latest revision 2017 Nov; original version 2016 Oct)

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## Introduction

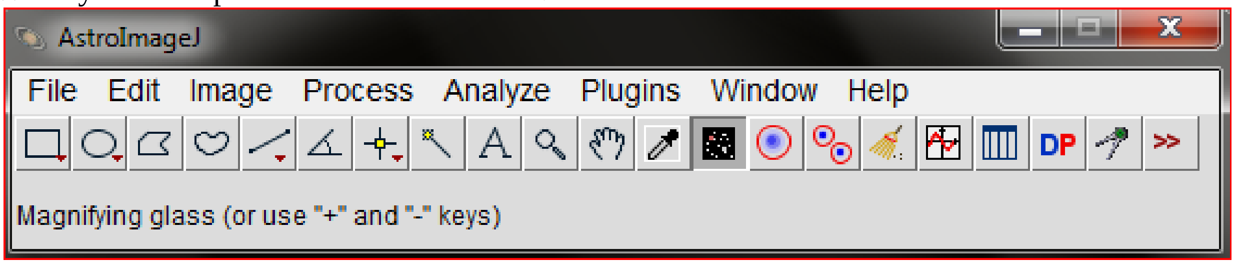
AstroImageJ (AIJ) is a set of astronomical tools for carrying out astronomical differential photometry on CCD data. In addition to calibrating the data and producing light curves, it can perform exoplanet transit modeling as well. The purpose of this document is not to show all the things that AIJ can do; instead it to help the user very quickly carry out the *bare minimum* steps needed to produce a light curve. After a light curve is made, the user can then go back and try out more options and advanced techniques. Note: You should read the entire document before attempting to calibrate your data.

The AIJ code is maintained by Karen Collins (Vanderbilt and Fisk Universities) and is based on the NIH program "ImageJ", plus astronomy-specific additions created (mostly) by Fredrick Hessman (Georg-August-Universitat, Goettingen). AIJ is written in Java, it works on a wide variety of operating system platforms. Get the program from this website and install it: http://www.astro.louisville.edu/software/astroimagej. Once installed, the very first step is to update the program by starting AIJ and going to the Help menu. This is important because the version above is not updated and features and bug patches are frequently added to AIJ.

Before doing anything with AIJ, it is important that you have your data organized. I strongly recommend you create a new folder (directory) and put all your image files (*.fit or *.fits) for the night into that folder. You will need at least twice as much free disk space as the raw data you download, since after the calibrations, you will have two data sets. (Once you have calibrated the data, you can delete the raw data.)

Also you will need the following information: The MLO CCD camera has a readout noise of 3.88 electrons and a gain of 2.13. Because we used liquid nitrogen to cool the CCD, the dark noise is negligible (<2 e- per pix per hour). The CCD is linear up to 45,000 ADU (counts) and saturation problems occur at about 55,000. (You don't need the following info but for completeness: The camera has an E2V 42-40 CCD with 2048x2048 pixels. The pixels are 13.5 microns across, which is 0.36 arcseconds on the 40-inch telescope. If you bin the CCD 2x2, then the image scale is 0.72 arcseconds/pixel.)

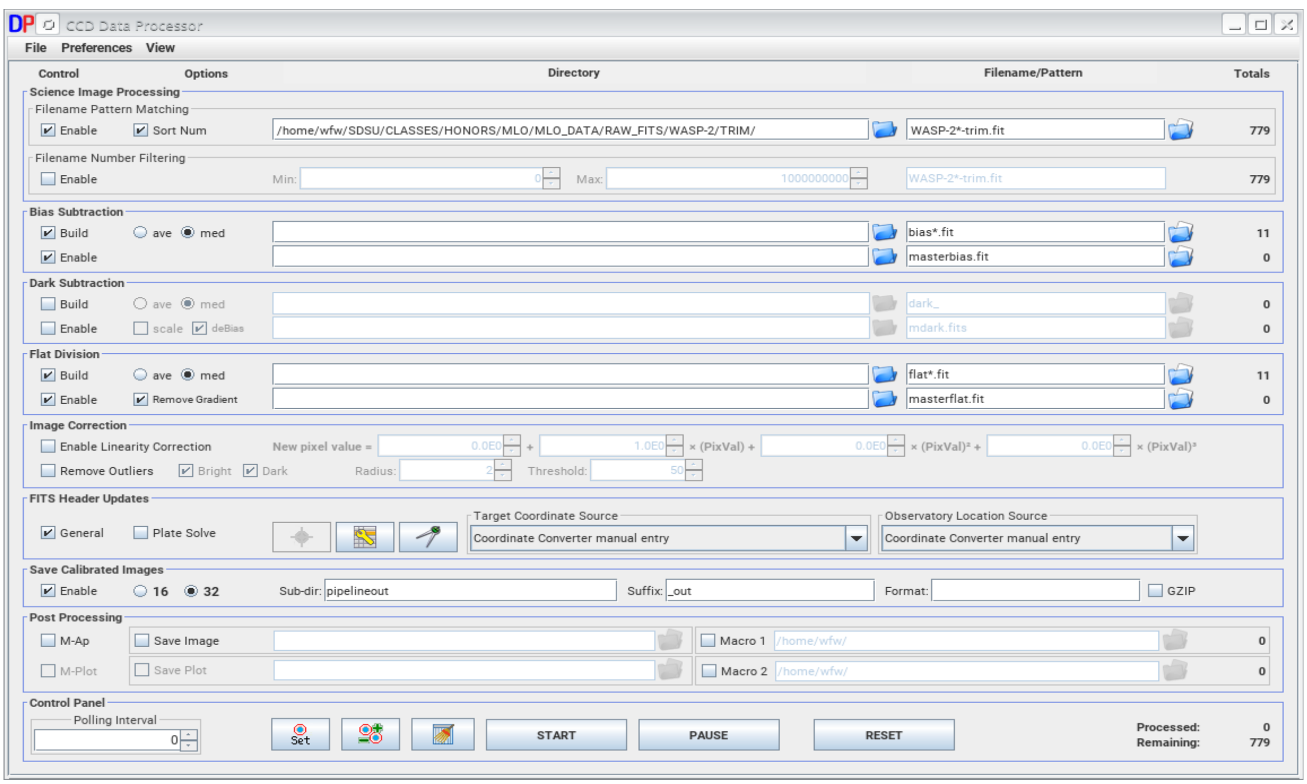
When you start up AIJ it will look like this:

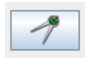


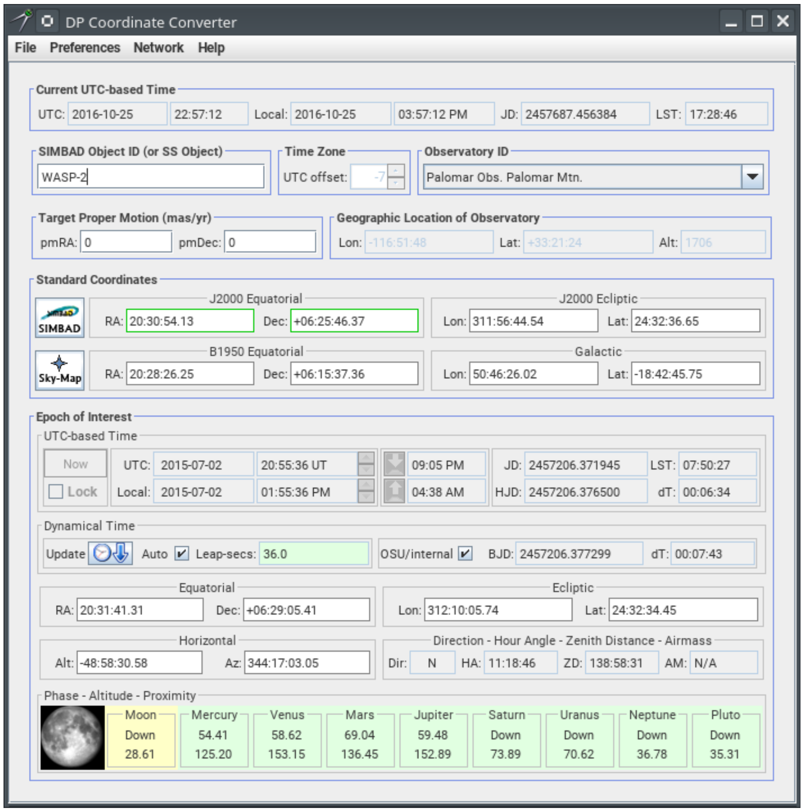

If you haven't already updated AIJ, be sure to do so now. Click help. Also, see Notes and Tips at the end of this document.

## Data Calibration:

Click the "DP" button to start the CCD "Data Processor". This will open a new window that will look like this:

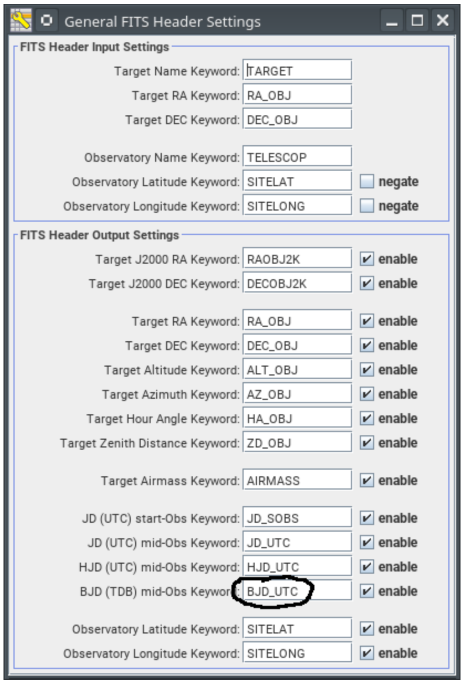


It may also automatically open another window, the “DP Coordinate Converter”. If it doesn’t, click on the “compass” icon  in the FITS Header Update section. The DP Coordinate Converter looks like this:




There is a lot of information here, but we only need to do two things. First, enter the name of your target in the SIMBAD Object box (e.g. WASP-2). Then choose the appropriate observatory as the Observatory ID (e.g. choose Mt. Laguna Observatory or Palomar Observatory). The Standard Coordinates panel should now have the correct RA and Dec for your star (if you have a working internet connection). To speed things up, uncheck the OSU/internal box. This makes AIJ compute the BJD time instead of using the BJD tool at the Ohio State University. You can leave this checked if you have a fast internet connection. Exit the Coordinate Converter when done by clicking on “File” in the upper left, then exit in the pull-down menu.

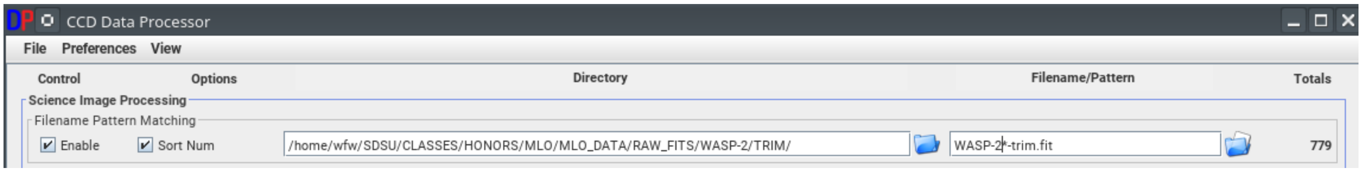
Now we are back to the Data Processor window. It has lots of options and looks complicated, but it is pretty simple. But there's one "bug" we *may* need to correct for, then we can take care of the rest. Find the icon that looks like a wrench in the "FITS Header Updates" section. Click on the icon, and it will bring up the General FITS Header Settings window.



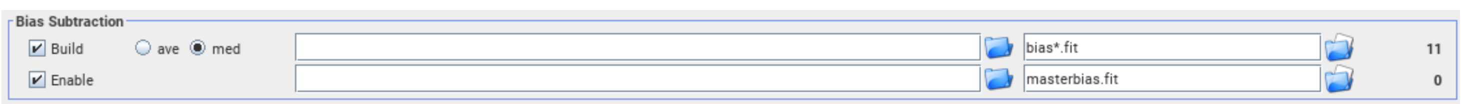

Toward the bottom, you *may* need to change the BJD entry from "BJD_UTC" to "BJD_TDB". Close/exit the window and this fixes the bug. Now we are back to the Data Processor.

Keep in mind that while it looks quite complex, the Data Processor will really be doing just three things: creating a master bias image, creating a master flat field image, then calibrating the science data by subtracting off the master bias and then dividing by the master flat. This may involve hundreds of millions of arithmetic operations, but fortunately for you, someone already wrote the program to do all that! All we have to do it tell AIJ where the data are, what the names of the files are, and click the correct buttons.

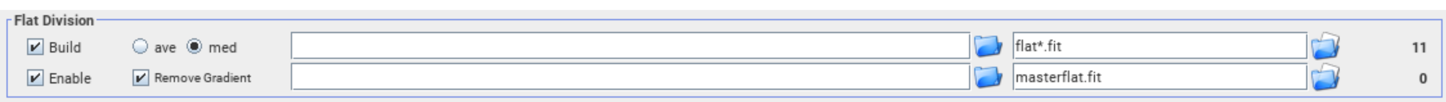
First let's tell AIJ where to find the data files. At the top of the window, enter the path (folder or directory name) of where the target data reside into the box at the top called Science Image Processing. (If the box is grayed out and you can't enter anything, click the enable box to the left.) Then enter the filename pattern that matches your target star observations. In other words, you want AIJ to know what you target star filenames are, and not confuse them with the calibration files. So for example, if all your science observations start with the letters “HD209”, enter “HD209*” in the Filename/Pattern box. Be careful: uppercase/lowercase matters here.




Now let’s tell AIJ how to make a “master” bias image. Go to the Bias Subtraction area and check the “Build” box and select the median option (the “med” button). In the Filename/Pattern box enter something like “bias*.fit” to tell AIJ the names of all your bias images [note that the character “*” acts like a wildcard so that any file that starts with the letters b-i-a-s will be treated as a bias image]. Now enter a filename for the master bias file: “masterbias.fit” is a good name.

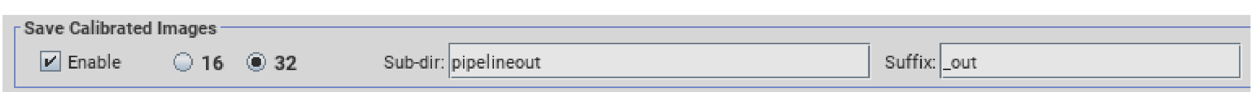



Now we do the same for the flat fields. Tell AIJ to median combine the flats, the name of the flat field files, and the name of the flat field image to save (“masterflat.fit” or something like that). The remove gradient is a fine detail - it may or may not help. Leave it unchecked for now, but later you may want to re-calibrate your data and can enable this option.




Notice that at the far right you’ll see numbers that tell you how many bias and flatfield images AIJ has found in the directory you specified. There are 11 of each in the above example.

In the “Saved Calibrated Images” section near the bottom of the window, click on the 32 button. This tells AIJ to do 32-bit floating point math, not 16-bit integer arithmetic. Then enter a name for the folder that will contain your calibrated science images. The default is “pipelineout” and it is fine to keep that. Also enter the suffix that will be appended onto you science image filenames. The default is “_out” and that is fine.



Okay, we are just about ready to do the bias and flat field calibrations. If they are not already checked, check the "Enable" box for the Bias Subtraction panel, the 'Enable" box in the Flat Division panel, and the "Enable" box in the Science Image Processing (SIP) section at the top. Also, make sure the "General" box is checked in the FITS Header Updates section, and also the Save Calibrated Images box is enabled. I recommend you keep the sub-dir name "pipelineout" and the suffix "_out" to denote that these are calibrated files.

When you are ready, click "Start". AIJ will pop open (i) a log file window and (ii) an image display window that shows the CCD images as they are being calibrated. The calibration may take ~10 minutes depending on how many data images (CCD files) we have. If you have thousands of large CCD image, it can take tens of minutes. If you have just a few hundred, this may only take a few minutes, depending on the speed of your computer.

During this calibration step AIJ will create many new files. Two of these are the masterbias.fit and masterflat.fit files. And in the "pipelineout" subfolder there will be all the calibrated CCD images. Congrats, you now have science-quality data to work with!

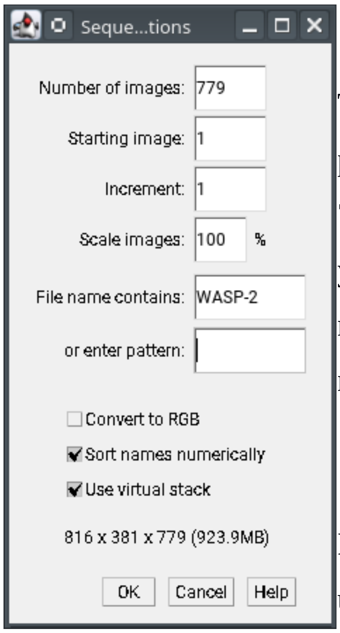
Exit/close the CCD Data Processor window, the image display window, and any log file windows, leaving only the main AIJ window open.

## **Image Alignment**

If the telescope is good at keeping the star on the same pixels all night long (known as "tracking" or "guiding") then after the previous calibration step we can start doing the aperture photometry. But if the star jumps around or drifts a lot, then the software may have trouble finding the star after a big jump. The program will then stop with an error message, or worse, it may think a different star is the one you are interested in and give you bad results! So to fix this, we will first need to align all the images. While this is pretty straightforward, if there are big jumps, even this step can fail when done in an automated mode. When that happens, you simply have to tell AIJ where the target star is located on every image. That's a lot of mouse clicking if you have 1000 images, but at least it works. We will assume that the jumps are not so bad that we need to go into manual mode, but it's good to know such an option exists.

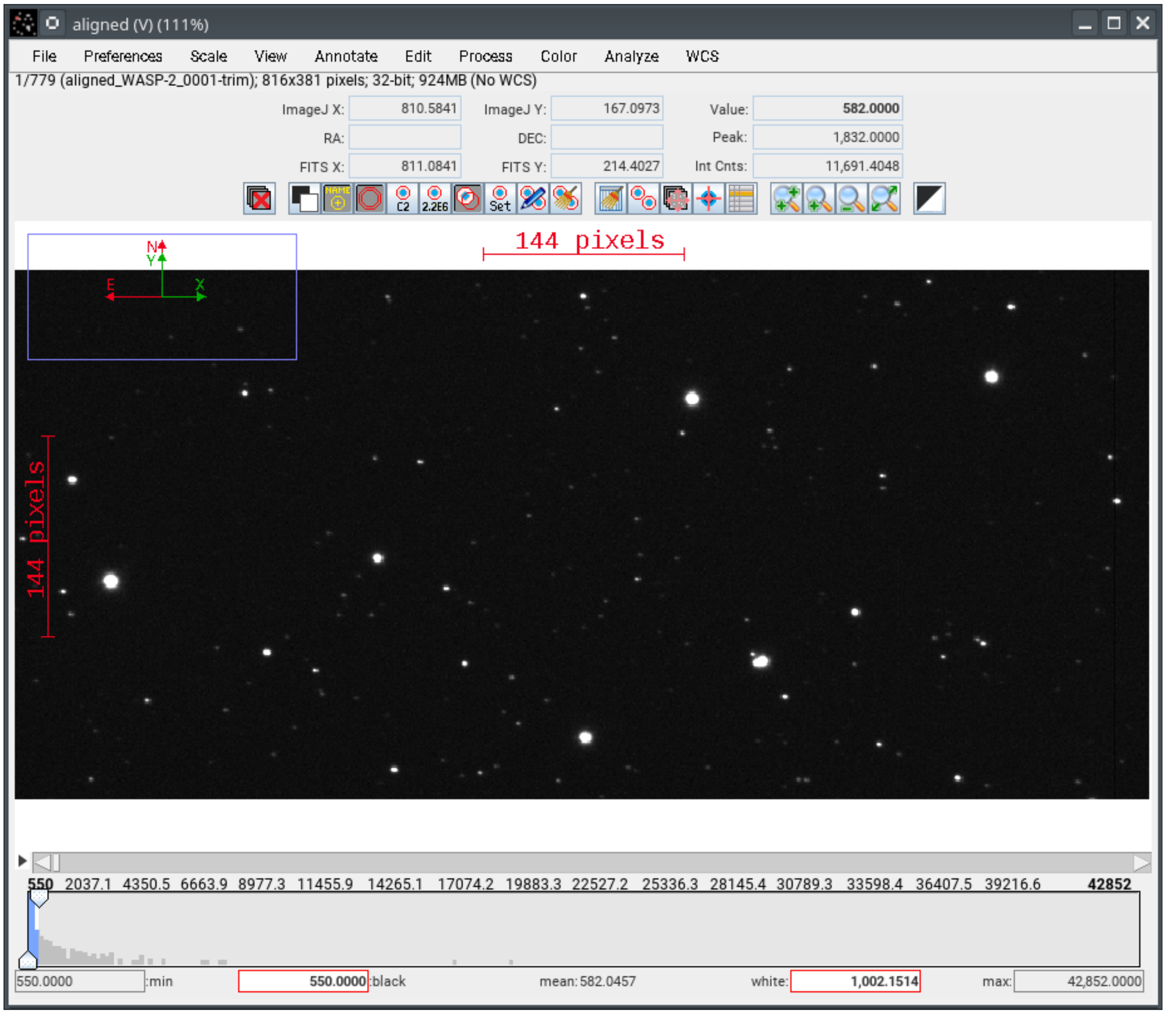
So do we need to align the images? The answer is yes if there are any jumps that are substantially larger then your photometry aperture. That usually means 10 pixels or so. The good news is that there's no harm in aligning things, so it is always safe to do. So let's get started.

In the main AstroImageJ window,  load in the *calibrated* data (not the original raw data!).  To do so, click on "file", the select "import" > "image sequence" tab. Open the folder that contains your calibrated images (the default name is "pipelineout" and they should suffix "_out.fit") and choose *just one* of your calibrated images (the first one is best) and click Open. Then following Sequence Options window pops up:



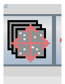

This tells you how many target images AIJ has found and will process. Verify that this is correct. In the above example, there are 779 science target image files (.fit files). If you want to make sure you are not unintentionally including any calibration images (like masterflat.fit), you can enter part of the target filename into the "file name contains" box. (Do not include an asterisk * as a wildcard.)

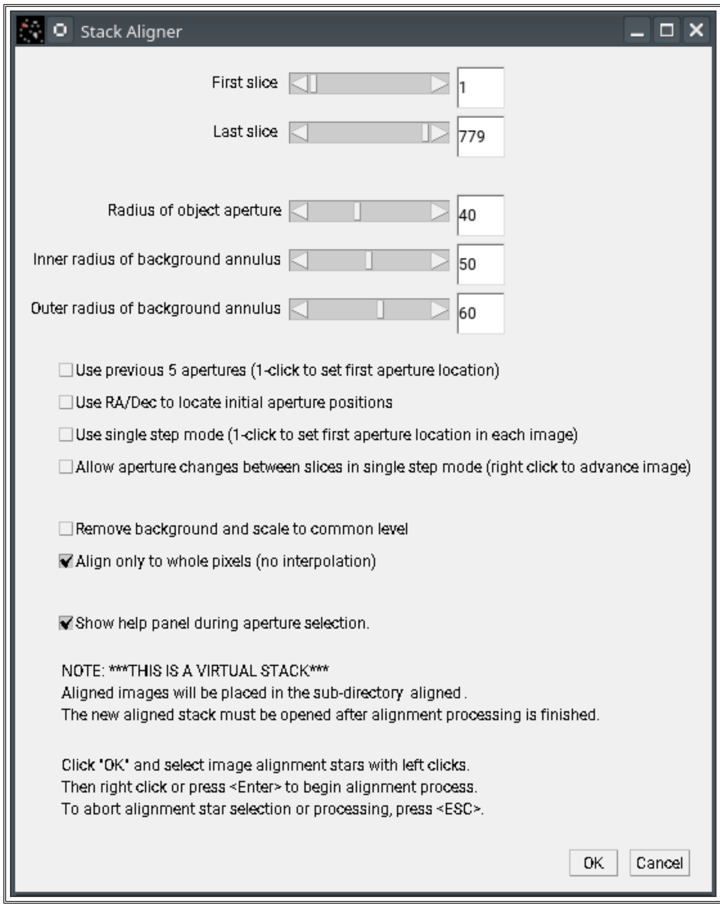
If you choose "Use virtual stack" AIJ will run faster, but it may take up a lot of the memory on your computer. Ironically, if it takes up too much memory, everything will come to a slow crawl. If you don't check the box, then AIJ will read the CCD images one by one off of your disk. This is slower, but uses much less memory. (I've found that either option works fine on most computers, but if you have an old laptop that is already running slowly, it is probably safer to not use the virtual stack.) Click OK, and a new window will appear that displays the first image in the sequence. It will look something like this:



Verify that the correct number of images have been found by looking at the numbers just under the “File” tab in the upper left. In the above example, it says “1/779” (filename), meaning that this is the first of 779 images to be aligned.

If the image looks too dark or light, you can adjust things with the two sliders at the bottom. The blue part of the histogram range (shown in gray) is the range that is displayed. You can adjust this to your taste. Note that the brightness may be inverted (black stars on a white sky). This is often much better when viewing things on a screen and especially printing things out. The look-up table (LUT) can be inverted by clicking on the icon with the black+white boxes.

Now that we've selected the images, let's click on the "align stack" button icon that looks like this:  . A window will pop up that has the options for how to do the alignment.

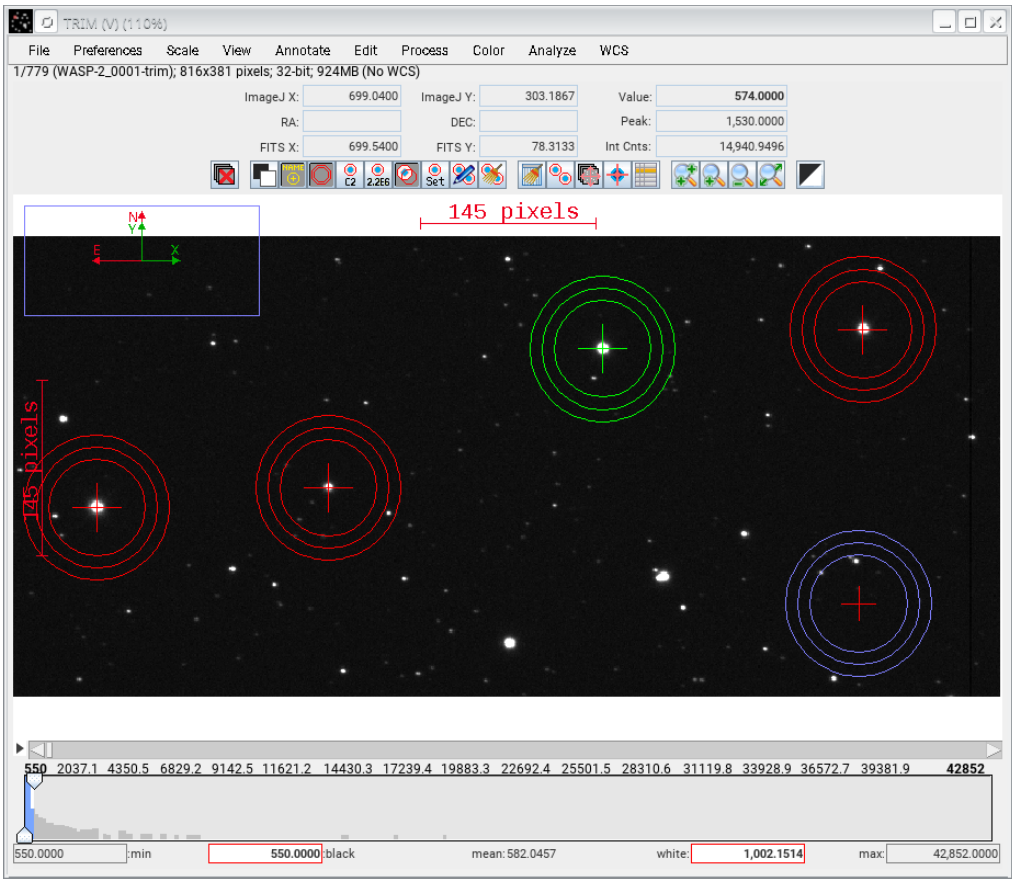



The first and last "slice" should correspond to the images in the sequence, and typically the first slice is 1 and the last slice is the number of science images to align. (This may be one less that the total number of images, since the first image won't be aligned - it is the reference image.)

The "Radius of object aperture" is the most important number in the alignment step. It needs to be big enough to encompass the largest jump size between any two images. But it should not be too big, or AIJ might find the wrong star. In this example, it is set at 40 pixels, and this is about the size of the biggest jump during this particular night. But 20 pixels might be better if there are no large jumps. The inner and outer radius of the background is not important for image alignment, but they need to be a little bit larger than the object radius.

The option to align to whole pixels may be useful in some cases, but it does not matter much for aperture photometry. (It matters if you want to combine all the images into one single sharp image that is equivalent to a very long exposure.) Click OK and a big window with the first image will be displayed like shown below. As the night goes on, the stars may drift a lot if the telescope autoguider is not being used. To see how much drift, use the slider bar located above the histogram part (the gray bar near the bottom with the left and right arrows at the ends). Slide the bar from the left to the right to see the different CCD images. By comparing the first and last images, you can get an idea of what stars to use to align the images - any stars that drift off the CCD cannot be used for anything.

In the image, move your cursor around to choose a few bright, clean, isolated stars. To select a star, click with the left mouse button. Always pick your target star first. Choose at least 3 stars, don't pick a star too close to any edge, and always avoid a star that is too bright and saturated (above 65,536 counts, which is $2^{16}$).



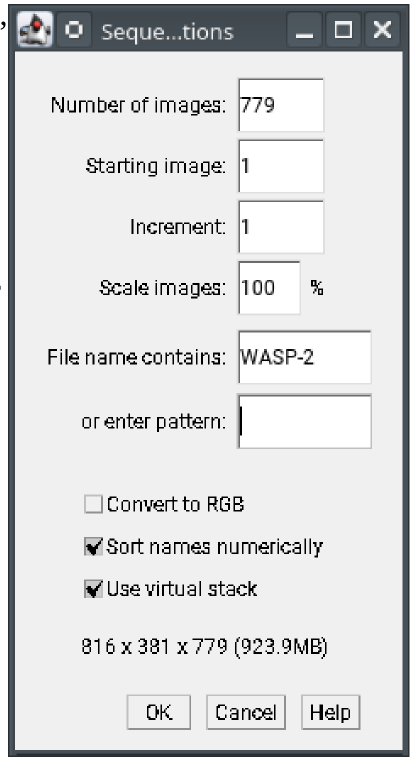

Your image will look something like the above, though of course the star pattern will be different. The green circles denote the target star, and the red circles show the comparison stars. (The blue ones just follows your mouse/cursor). The radii of the circles were set in the prior dialog box to be 40 pixels from the center, and the sky annulus goes from 50 to 60 pixels. It might be better to choose smaller circles, but it is hard to know in advance. In this example, only 4 stars were used. If you can find more bright isolated stars (~10), then use more. The good news is that you can try this several times, and there's no harm is trying several sizes.

Once you have selected your stars, hit the return key and AIJ will then display all the images and track their positions. It will look like the image is jittering around a bit, and you may see the occasional cosmic ray. As the night goes on, you may see the focus change a bit, or the sky conditions grow worse and the background level get brighter.

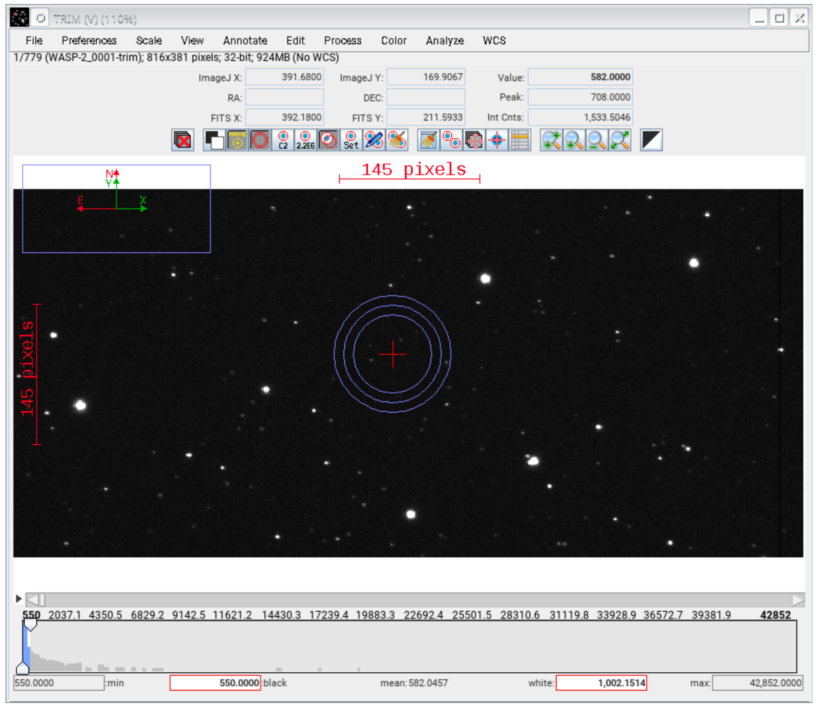
When the alignment step is done, AIJ will tell you it has completed the task. It writes to disk all the images, with the prefix “aligned_” in front of the filenames. The aligned images are saved into a subfolder called “aligned”. *These are the images to use for differential photometry.* Be sure to use these images, not the un-aligned ones in the “pipeline_out” directory. While it is not necessary, it keeps your screen tidy to close the window that displays the images and apertures, getting you back to just the small AstroImageJ panel.

## Differential Aperture Photometry

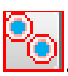
Now that we have calibrated (and aligned) CCD images ready to go, we can start the process of making a differential photometry light curve. In the main AstroImageJ window, we will load in the *calibrated* data (not the original raw data!). If you aligned the images, be sure to load in the aligned images. As before, click on the “file” tab > “import” > “image sequence” tab. Choose the folder that contains your calibrated images (the default name is “pipelineout”, *but you may need to go to the “aligned” directory*) and choose *just one* of your calibrated images (the first one is best). The following window pops up, and if it looks okay (meaning the correct number of images is listed) then click OK.



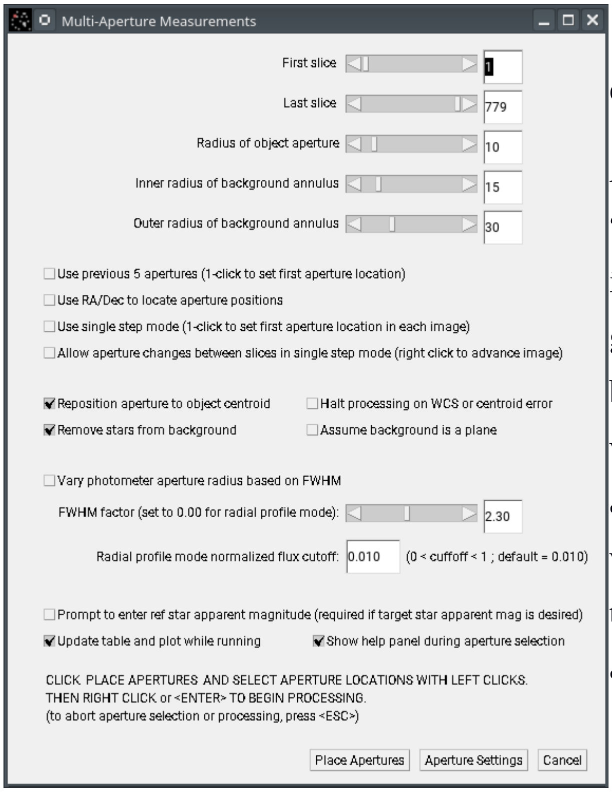
A large window will open and the first image will be displayed. So far, this looks very much the same as the image alignment procedure.




To carry out the differential photometry, we will need to select a few stars and measure their brightness (total flux) in every image.

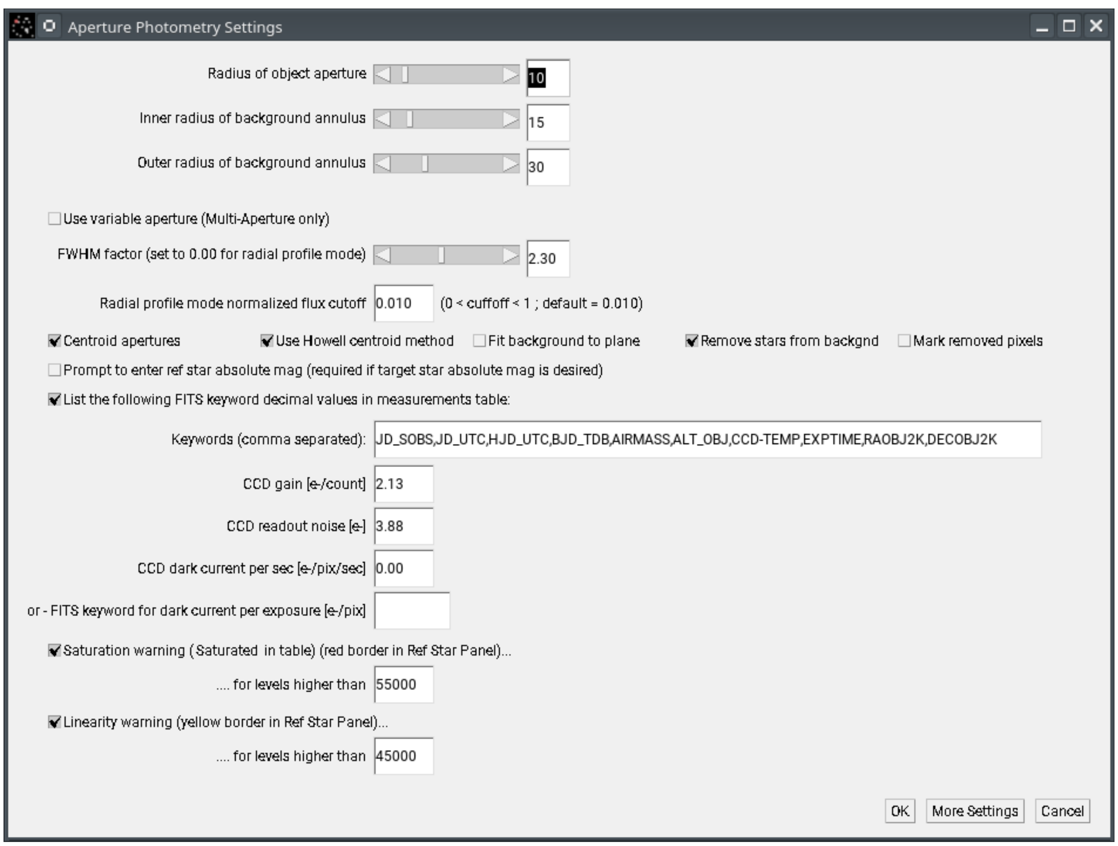
We use the multi-aperture photometry tool for that. Click on the symbol with the two apertures .

A window will appear where you can specify the first and last image to measure (the "slice" number) and the size of the apertures, i.e., the radius of the object aperture and the background sky annulus. You need to pick the target aperture with some care. You want it large enough to capture most of the light from the star, but small enough that it minimizes faint pixels that contain mostly noise. In general, it is a tradeoff between accuracy and precision. A good starting guess is something like 1 or 2 times the full-width-half-max (fwhm) of the star. So typically, this is roughly 5-10 pixels. Let's start with 10 pixels as an initial guess. You may want to repeat this with a different size later. The background sky annulus needs to be larger than the object aperture. Choose an inner radius is bigger than the object aperture and beyond the edge of the "bright part" of the star. The outer radius should be at least 10  pixels larger than the inner. It can be very big (like 50 pix), but don't make it too big in case there are residual flat field tilts that have not calibrated out, or if there is true nebulosity nearby.



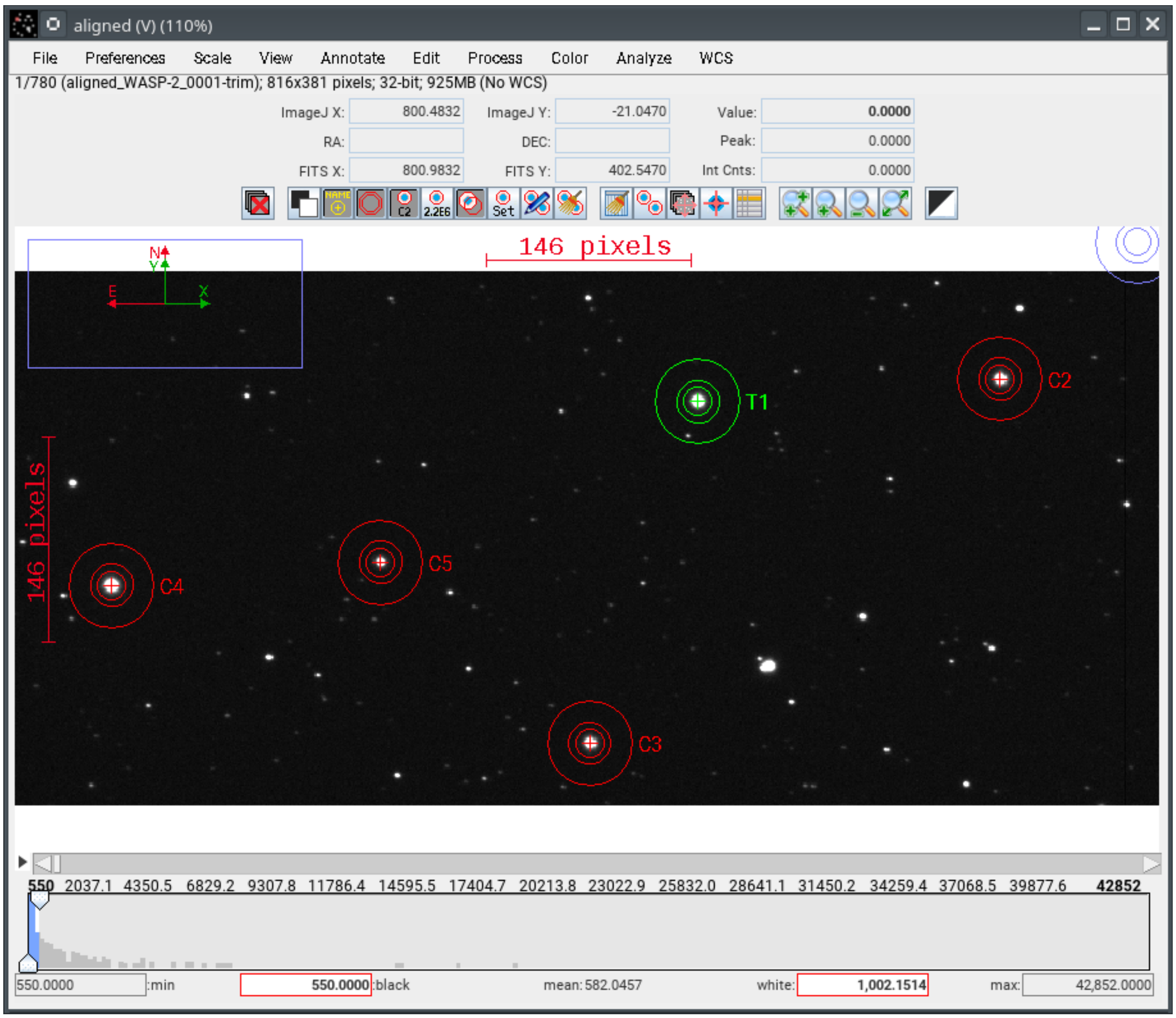

Most of the other values you can leave as the default setting, as shown here.

At the bottom of this window is a button called "Aperture Settings".This is where you tell AIJ information about the CCD you are using, like the gain and the readout noise of the CCD. Click on this button to bring up the Aperture Photometry Settings window. Enter in the CCD gain, CCD readout noise, and CCD dark current (if any). Also enter the levels where the CCD starts to become non-linear because the star is too bright and saturates. Typically these are around 35-45,000 and 65,536.



For MLO, the CCD has been tested to be linear up to 45,000 ADU. If you want to be cautious about the saturation you can choose number which are somewhat lower. These have no impact on the results, but a warning message will be recorded in the output file that the object may not be trustworthy if its peak exceeds these thresholds.

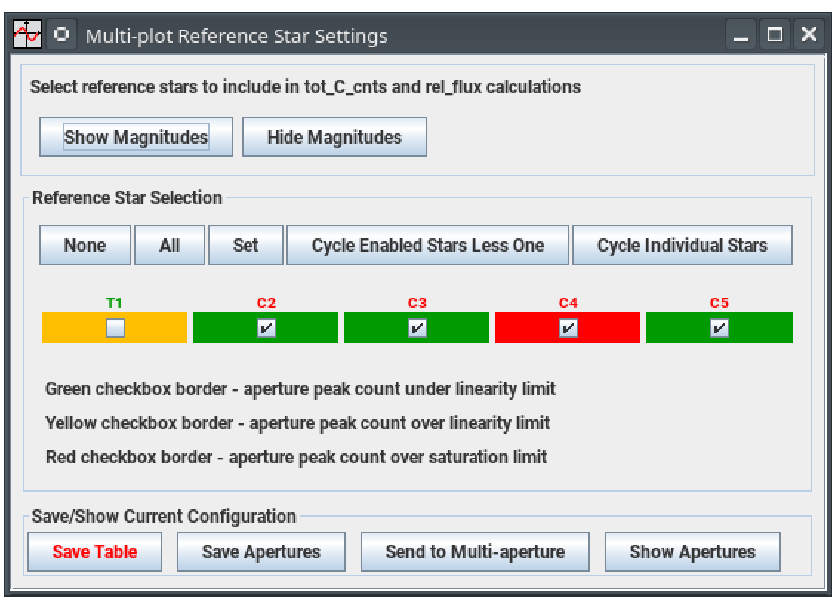
Click OK when done, and this brings you back the previous window. At the bottom, click "Place Apertures" to tell AIJ which stars to use. This will close the current window and display the first image. The cursor will show the aperture size (inner circle) and the sky annulus region (the middle outer circles).



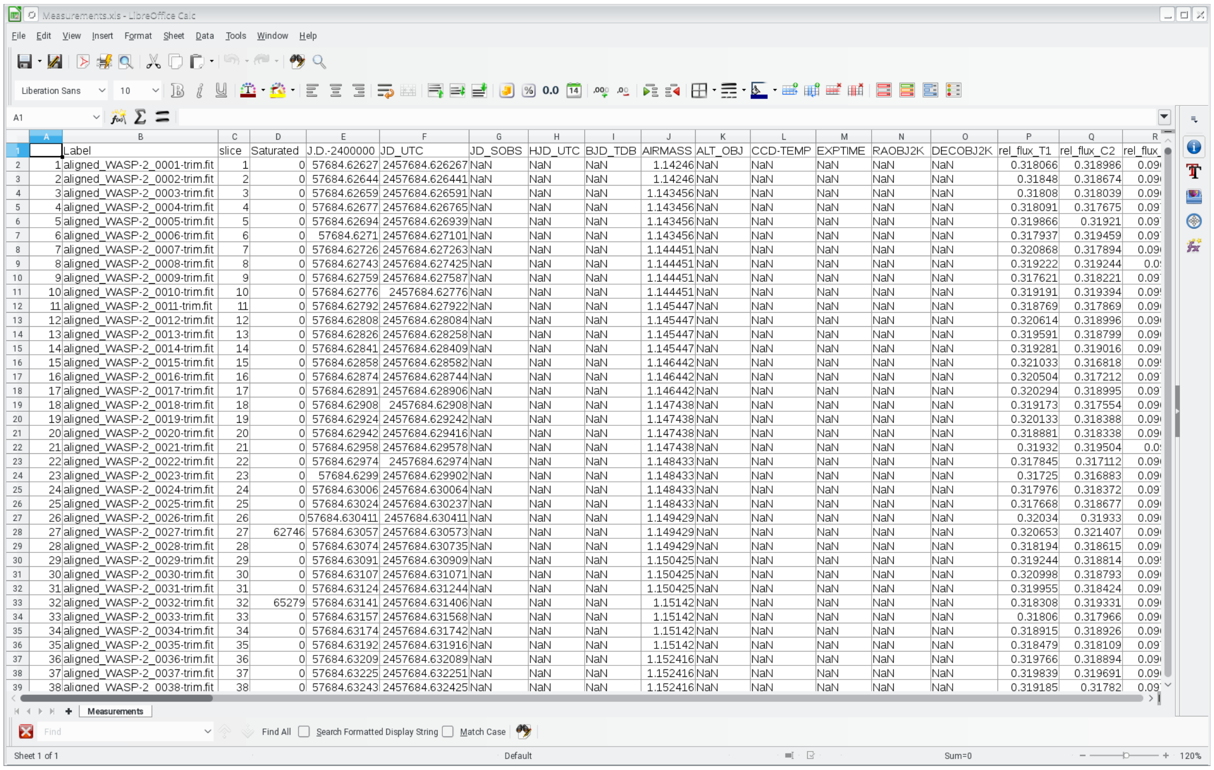
As before, to choose your stars put your cursor over the star and left-click with the mouse. *The first star you choose must be your target star.* It will be indicated by a set of green rings and the symbol "T1". The next left-mouse clicks will then select your comparison stars (shown with red apertures). The target star will always have number "T1" and the comparison stars will always have numbers C2, C3, C4,...  You want *at least* 2 comparison stars, but more is better. Ideally they should be about the same brightness as your target star. Don't choose faint stars or stars that look blended with other stars, or overly bright (saturated) stars, or stars too close to any edges. Do not to choose stars that might drift off the CCD if the guiding was poor.

When you are finished choosing the target and comparison stars, press "enter" to begin the aperture photometry processing. A bunch of windows may pop up (depending on the option settings), showing you AIJ making the measurements on each of the images. Note that for about 1000 CCD images, the differential aperture photometry could take roughly 5-15 minutes, depending on how fast your computer is. On the image display, you can see the apertures measuring the light from the stars. Another window will show the points being drawn one-by-one as they are measured. Several other windows related to the options for plotting will pop up. It may make your computers creen very crowded!

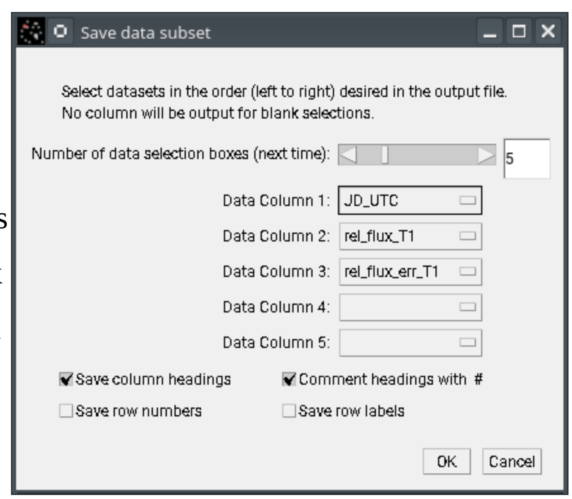
Fortunately with all these things going on there's really only one thing we need to do, and that is to save the results to a file that we can then use later. While the plotting tools in AIJ have some powerful capability, they are also very cumbersome to use and are unforgiving. So let's plot things using some other simpler program (like qtgrace). To save the results from AIJ, find the "Multi-plot Reference Star Setting" window, and at the bottom left is the "save table" button.



Click this and all the AIJ results will be stored to a large spreadsheet file called "Measurements.xls". You can then open this with a spreadsheet program and see all the information it contains.




The three most important columns are the time, the differential flux in the target (which is the brightness of the star relative to the comparison stars), and the uncertainty in the differential flux. There are several times one could use. The "JD_UTC" column is one choice. The target star light curve is in the column called "rel_flux_T1" (standing for relative flux from target T1), and its error bars are in the column "rel_flux_T1". You might want to copy these column to a separate spreadsheet page, then save these as a simpler spreadsheet or as a plain text file. This humongous spreadsheet has all the differential aperture photometry in it. This is good, but very unwieldy.




A much cleaner way to save the light curve is as so: Find the "Multi-plot Main" window and click on "File", then in the long pull-down menu, click on the "Save data subset to file". Select the three columns you want to save to do the science you want: these are going to be time, flux, and uncertainty. For time, you can use either JD_UTC or BJD_TDB. For flux, you want "rel_flux_T1" for your target. For the uncertainty, you want "rel_flux_err_T1". Once you select the three columns you want, click OK. Save the file with a name like "exoplanet_aperture10.dat" or something similar (though you can keep the default name "Measurements_subset.dat"). The "aperture10" is to remind you of the size of the aperture you used to do the photometry. Now you can make a light curve figure from this simple 3-column file with xmgrace/qtgrace or whatever program you prefer.

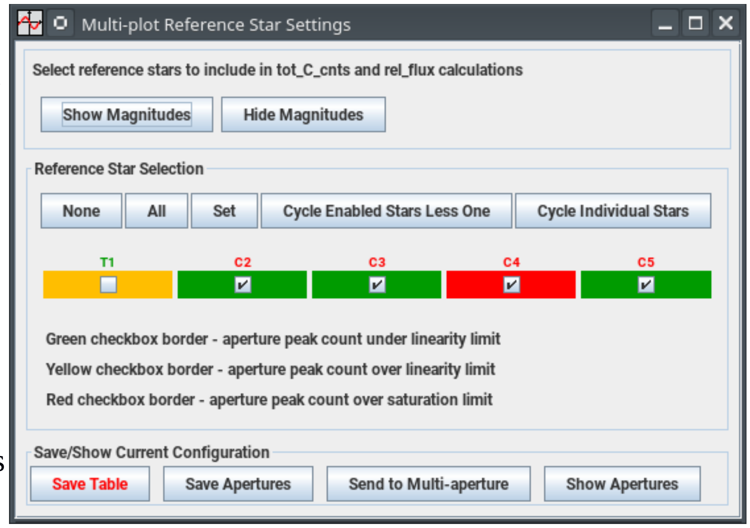
## **DOING IT BETTER:**

After you complete your first differential aperture photometry data reduction, you might be wondering, did I choose all those parameters correctly? What if I choose a different size aperture? Or what if I used different comparison stars? The former question requires you to run AIJ again, but now that you know how to do it, it'll go much faster and easier. Just be sure to copy your prior results (the spreadsheet and the Measurements_subset.dat file) to someplace where AIJ won't overwrite them. The size of the aperture can make a huge difference on the quality of the resulting light curve. Alas, there is no easy way to know what size to use - you just do a few and see which one comes out better. By "better", I mean that the light curve is less noisy. One could carefully measure the light curve noise (the rms or standard deviation in regions outside of a transit for example), but often just eyeballing it gets you most of the way there.

If there are not lots of stars close to overlapping, the size of the sky background annulus makes little difference, once it is big enough to contain lots of pixels. So you don't need to play with this option.

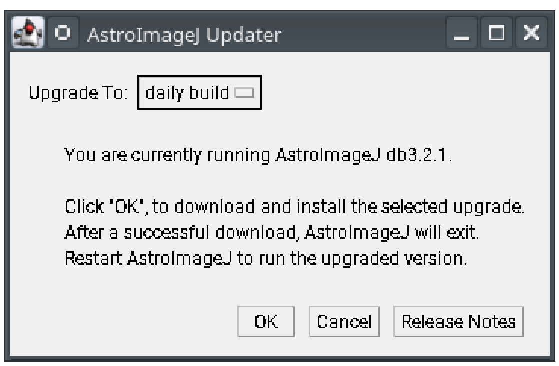
To determine what comparison stars to use, AIJ has a very nice feature to let you test different cases very easily. It might be that one of your stars is actually a variable star, or has some other peculiarity (or is just faint and noisy). With this feature you can quickly see if any of your stars are not so good. Find the Multi-plot Reference Star Settings window.

The (usually green) boxes with the C2, C3, C4, etc. labels stand for the individual comparison stars. By clicking on the box, you toggle whether or not that particular comparison star is used. So for example, if you click on the C2 box, you will “turn off” comparison star #2, and the relative photometry won’t use that star. This is very useful in case a comparison star turns out to actually be a variable star, or is so faint that it just adds noise, or for whatever reason it just misbehaves (maybe it is on a bad pixel?). Toggle on and off the various comparison stars and look at how the plot changes to determine which stars you want to keep. Once you decide on which stars, and what size aperture, save the results.

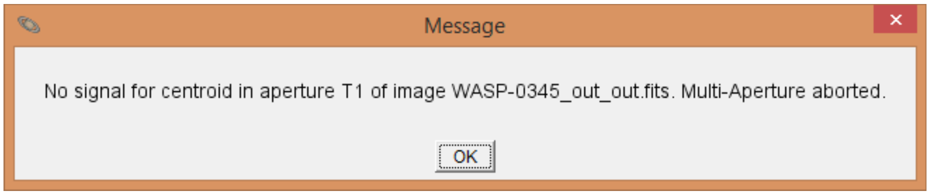



## NOTES AND TIPS

NOTE 1: As of 2016 Oct 26, you will need the “daily build” of AIJ to have the latest version that includes a patch to enable reading of MLO fits header exposure time. This is necessary if you want AIJ to determine precise times, like BJD. So when updating AIJ (under the Help button on the main AIJ panel and update AstroImageJ), choose the daily build in the pulldown menu. Note that you actually have to scroll *up* to get this option - it is a bit hidden.



NOTE 2: It is possible during the differential photometry measurement process that you may receive an error similar to this:




By clicking the  icon you can remove the offending image from the sequence list that AIJ is working on.  You can then restart the multi-aperture photometry processing from the next image. But go back and check to see why AIJ had trouble. Find out what is wrong, and determine if it is justifiable to delete that image - was it somehow bad? Clobbered by a cosmic ray?

NOTE 3: This document was based in part on a draft AIJ guide written by Matthew Garrett (SDSU Astronomy undergrad student) in 2015. Thanks Matthew!