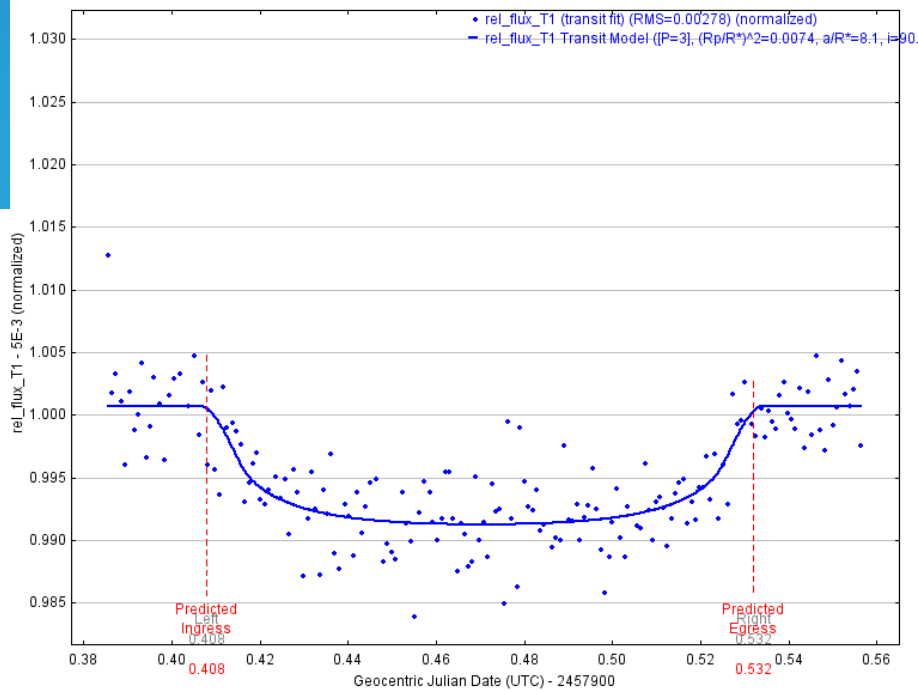
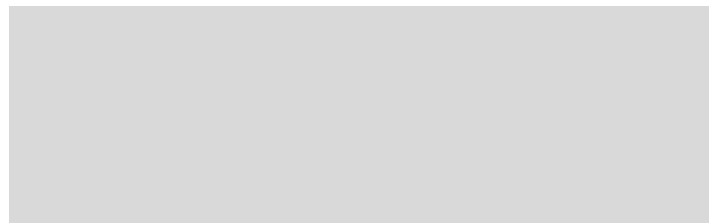


Wasp-48b



# STEP BY STEP TUTORIAL ON ASTROIMAGE J

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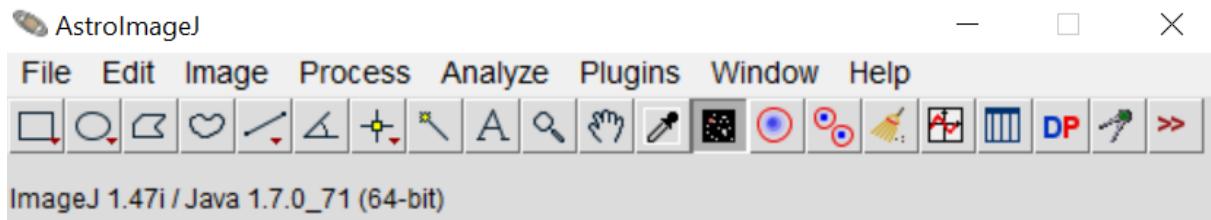
## I/ Introduction

This guide is a step by step tutorial aimed at obtaining a light curve on AstroImageJ. Following the steps is essential in order to obtain the desired result.

First of all, the accuracy of the curve depends not only on good photometric treatment. Indeed, the type of camera, telescope, and the weather influence the quality of the images taken. Thus, we must consider the dataset uncertainties and understand that he is not sure of getting what you want despite all goodwill.

This tutorial presents all the image processing steps (including calibration) that can be performed on the software. It is possible to speed up the processing process by doing steps on software on PRISM but in our case we show that everything is possible on AstroImageJ.

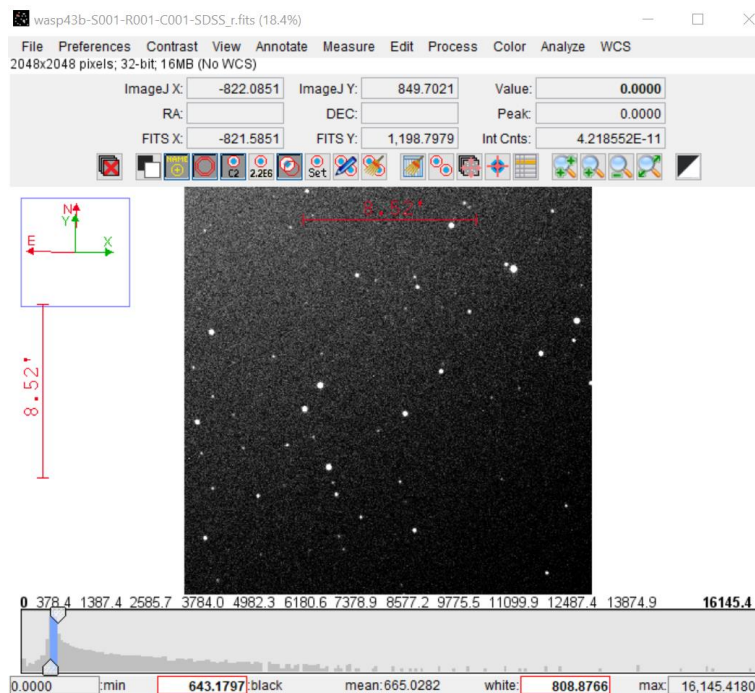
AstroImageJ looks like this at startup:



Most of the tools in this software will not be useful for our study, we are only using part of the software.

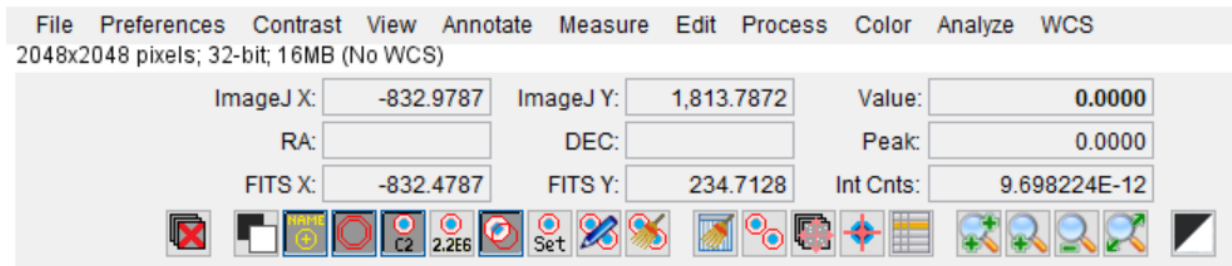
- Opening an image

In the File tab, you can first open an image by clicking Open. This window will then appear :



## II/ Image calibration

Let's take a closer look at the controls that will serve us

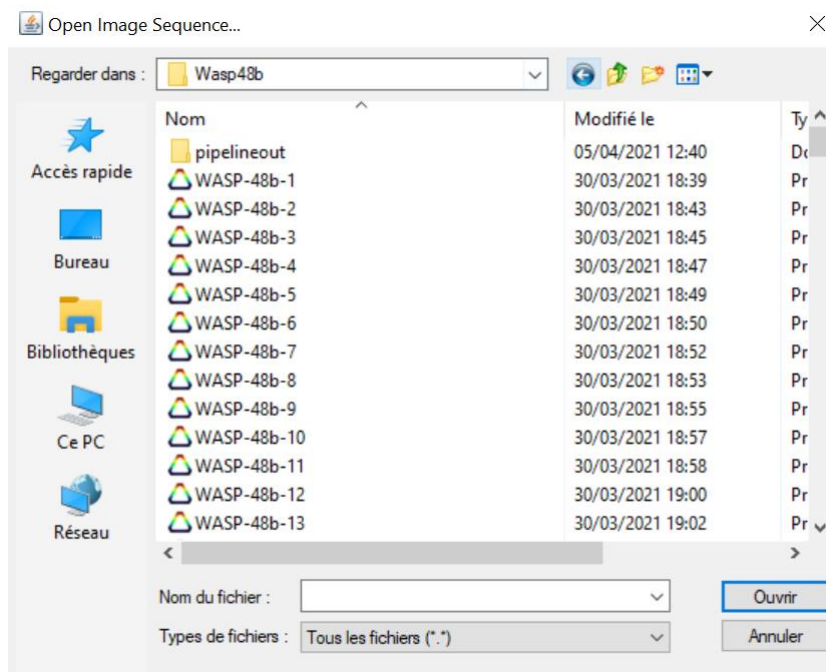


As we can see the RA and DEC boxes are empty. These correspond to the equatorial data system. This celestial coordinate system is a reference system (therefore independent of the position of the observer). If these data are not visible and you observe the mention "NO WCS" then you will have to calibrate the images.

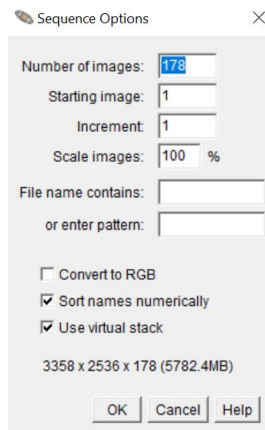
You have two options: preprocess the images on another software like PRISM or do it with AstroImageJ. We will present here the processing with this software for the reasons mentioned in the introduction.

- Opening of the sequence of images

Close the window containing the image and return to the AstroImageJ start bar. In the File tab, go to Import then Image Sequence. This window will then open :



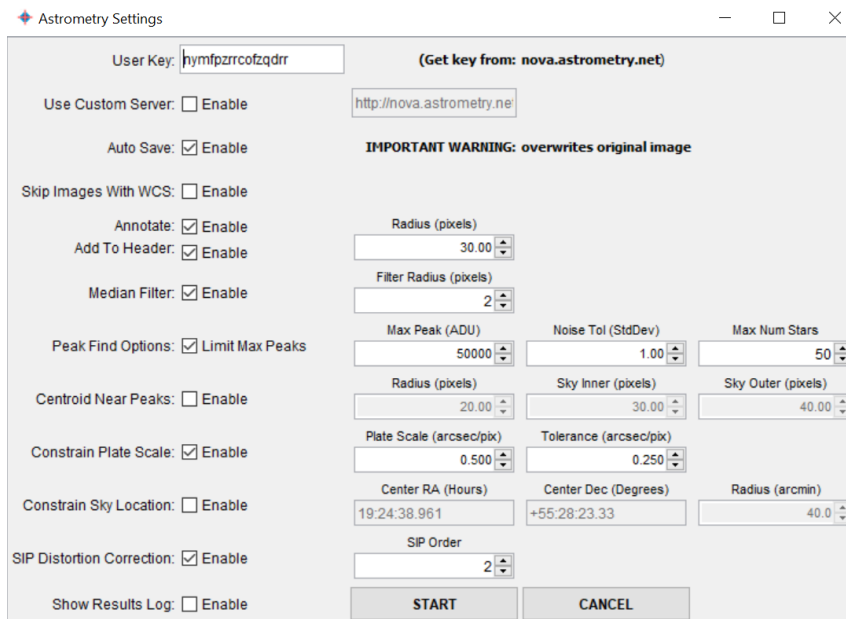
Select any photo, press Open and a new window will appear :



You must then enter the exact number of images in your dataset, check the same boxes and press OK. A window with the selected image opens as it did the first time. Now we will be able to start the calibration.

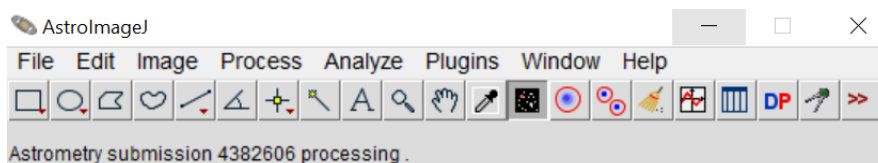
- Alignment of images to a reference system

In the WCS tab, go to "Plate solving Astronomy.net with options" and you will then have to enter the following parameters :

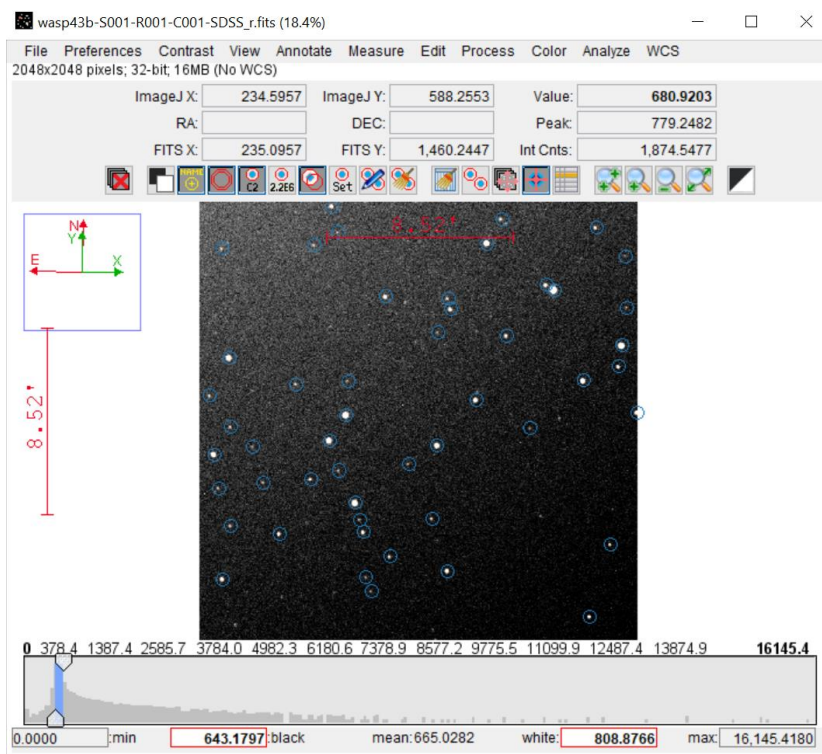


Warning : it is very important to enter this User Key and to check Auto Save.

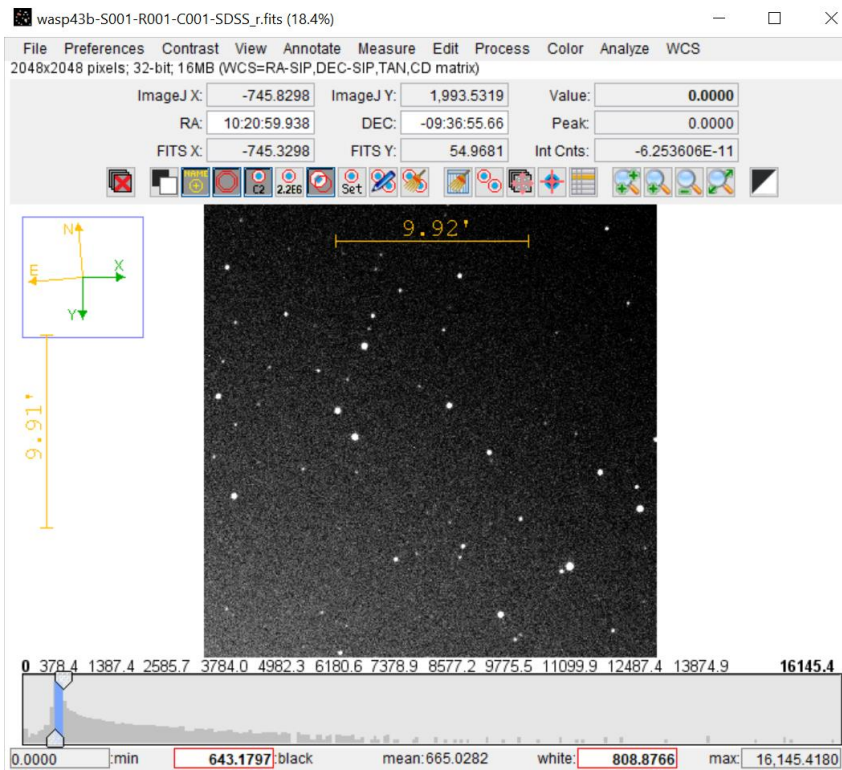
Once the parameters have been entered, click on Start and the calibration will be able to begin. You will be able to know if your manipulations are correct if you observe on the command bar this sentence:



You will also be able to observe blue circles around the stars: calibration is in progress.



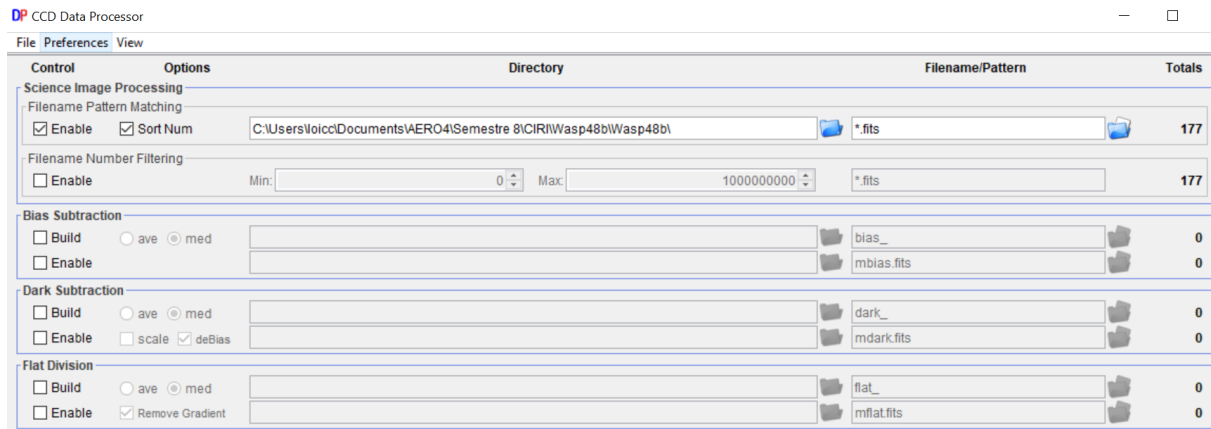
Once the calibration is complete for a photo, you will get this result with yellow lines. You can also observe that there are coordinates for RA and DEC now.



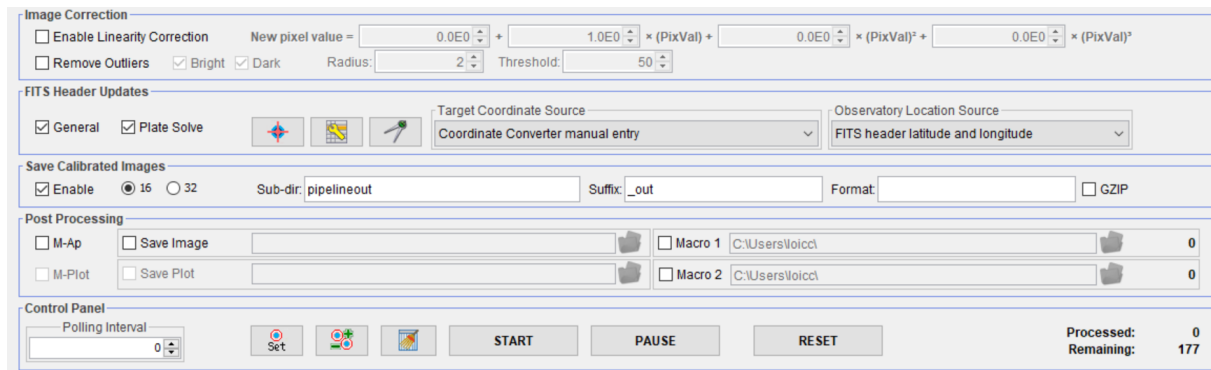
Once all the images are calibrated and all have RA and DEC, you can proceed to the next step. Check this data carefully, an image without this information will not be taken into account during the processing steps that will follow.

### III/ Image preprocessing phase

Close the window and return to the software start bar. Click on the blue and red DP (CCD Data Processor). Two windows open, one of which is of particular interest to us.



In Science Image Processing, click on Directory to select the folder where all your calibrated images are located. You can optionally add bias, dark and flat (obtained with PRISM) if your dataset contains them (handling is the same).

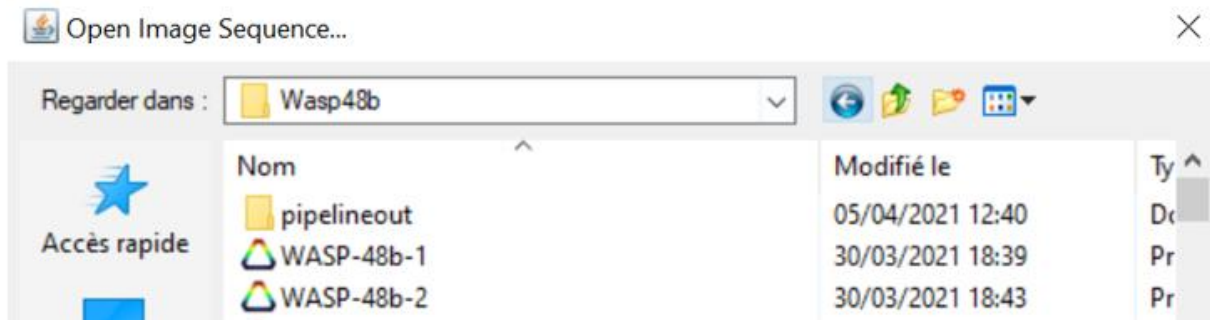


Going down to the bottom of the page you can check the appropriate boxes for FITS Header Updates and choose the right parameter for the “Target Coordinate Source” command.

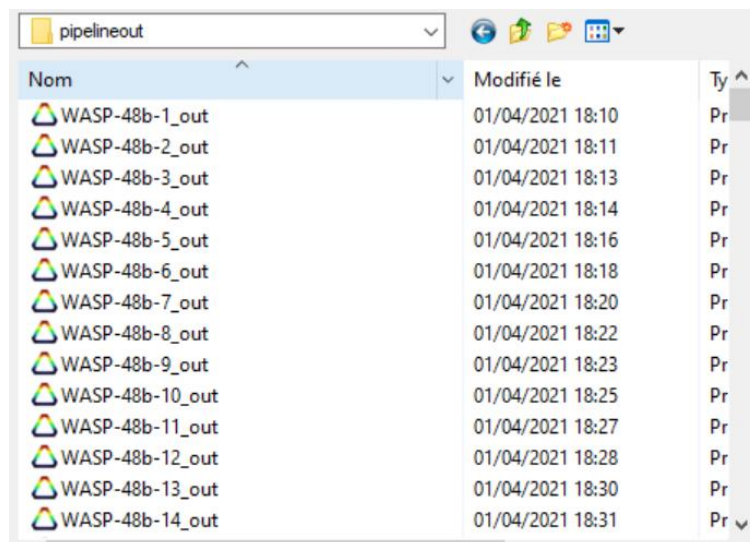
Once everything has been prepared, you can now click on START and the treatment will start. During this phase make sure that the software does not stop until you see "Remaining: 0". If during the execution of the treatment, AstroImageJ returns you an error message, check that you have carried out each step correctly and chosen the correct parameters.

- Opening of the pre-processed image sequence

When processing is complete, close the CCD Data Processor window and return to the start bar. You will repeat the previous command. Go to the File tab, Import then Image Sequence.



Unlike last time, you have a "pipelineout" folder created. Click on it and you will have access to all the processed photos. All processed images contain the suffix "\_out".



Select any image, indicate the total number of images processed and click OK. Your image opens and we will now move on to studying your exoplanet.

- Identification of our target star

Before taking the photometric measurement, you need to know the location of your exoplanet. To find out, enter the name of your exoplanet on a browser and find its RA and DEC.

Then go to the site <https://aladin.u-strasbg.fr/AladinLite/> and enter the coordinates. It will give you a picture of the location of your exoplanet. Compare with your photo on AstroImageJ to find it. Once you know where it is, we can start the next step.



## IV/ Multi-aperture photometry

Go back to your window with your image and select the "perform multi-aperture photometry" box (both red and blue circles)



This window is displayed. You must uncheck and check the boxes as indicated otherwise you will not get results.

Multi-Aperture Measurements ×

Radius of object aperture <  >

Inner radius of background annulus <  >

Outer radius of background annulus <  >

Use previous 4 apertures (1-click to set first aperture location)

Use RA/Dec to locate aperture positions

Use single step mode (1-click to set first aperture location in each image)

Allow aperture changes between slices in single step mode (right click to advance image)

Centroid apertures (initial setting)       Halt processing on WCS or centroid error

Remove stars from background       Assume background is a plane

Vary aperture radius based on FWHM

FWHM factor (set to 0.00 for radial profile mode): <  >

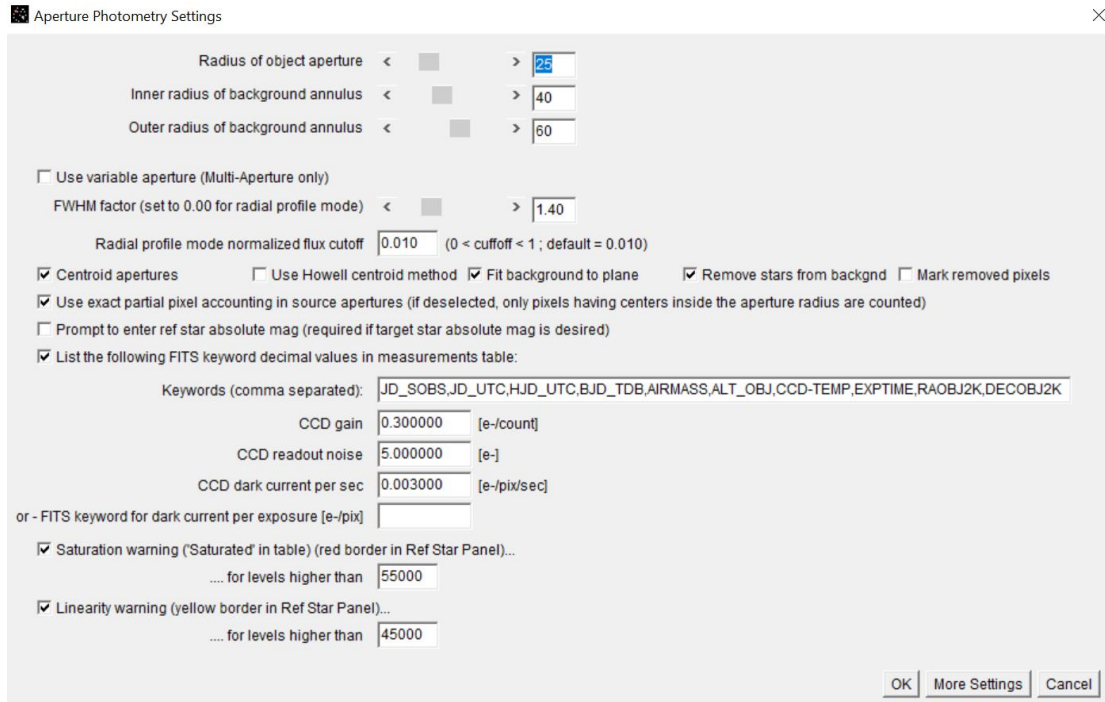
Radial profile mode normalized flux cutoff:  (0 < cutoff < 1; default = 0.010)

Prompt to enter ref star apparent magnitude (required if target star apparent mag is desired)

Update table and plot while running       Show help panel during aperture selection

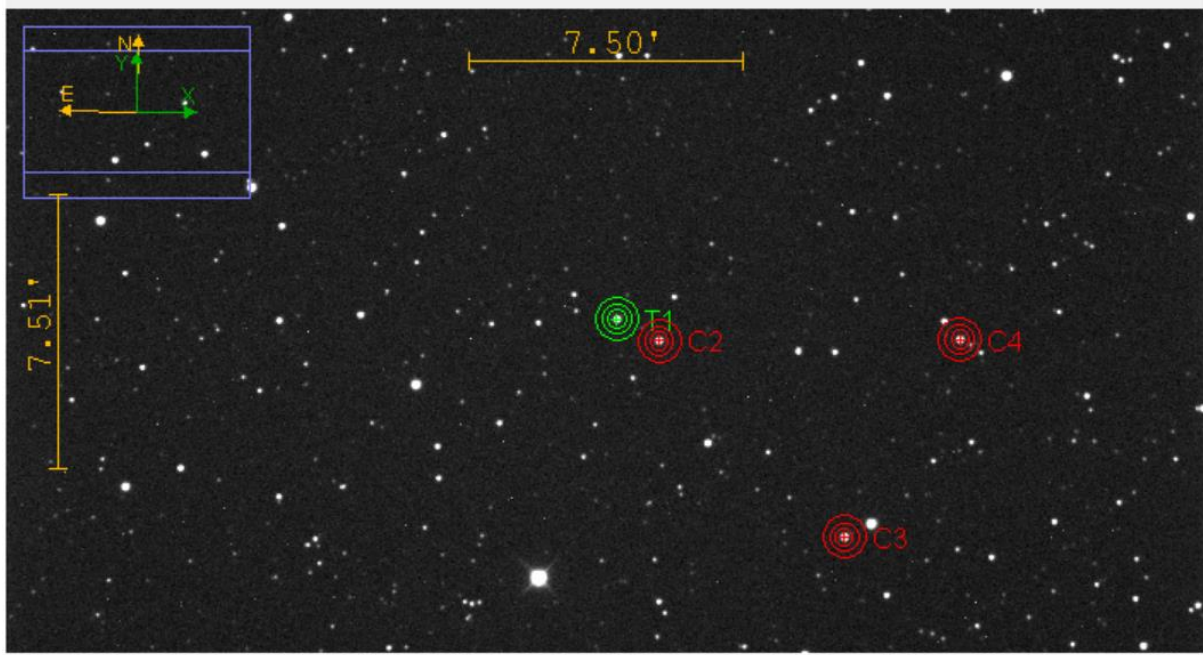
CLICK 'PLACE APERTURES' AND SELECT APERTURE LOCATIONS WITH LEFT CLICKS.  
THEN RIGHT CLICK or <ENTER> TO BEGIN PROCESSING.  
(to abort aperture selection or processing, press <ESC>)

Once everything has been followed, click on "Aperture Settings". This window will appear and you should have the same settings. For the CCD part, it depends on the camera so by default, if you don't know them, enter those ones.



Click on OK then "Place Apertures". You will first take as T1 (for Target) the star around your exoplanet. Then, you have to take several targets to refine the calculations. It is important to take close targets.

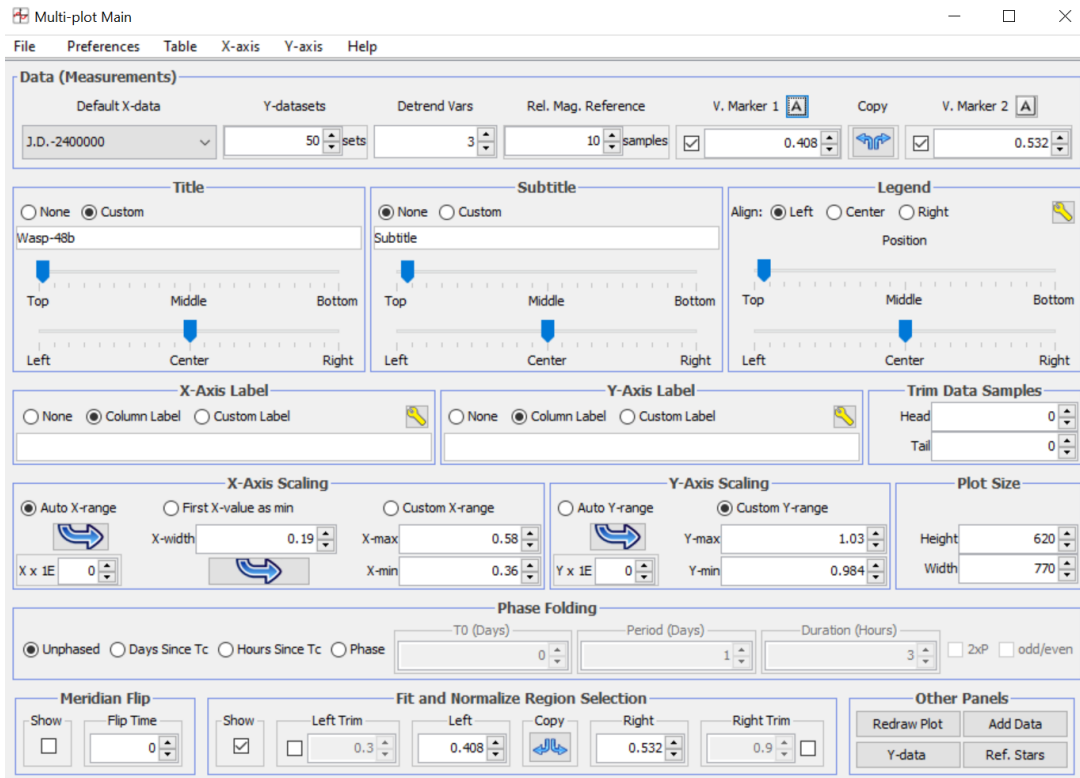
For this, it is necessary to choose stars which have a similar magnitude and characteristics. Look closely at the "Peak" and "Int Cnts" that appear when you hover your mouse over a star. They should be fairly close to the values of your T1.



For example, you will get this. Once the choice of targets is complete (no need to take more than five), click on "Enter" on your computer and the analysis will begin.

## V/ Obtaining the light curve

The scan ends and many windows open. The window below interests us because it allows us to configure the graph. We can determine the X-range and Y-range, give a title and especially fit and normalize region selection. This information will show the precise times when the transit starts and ends.

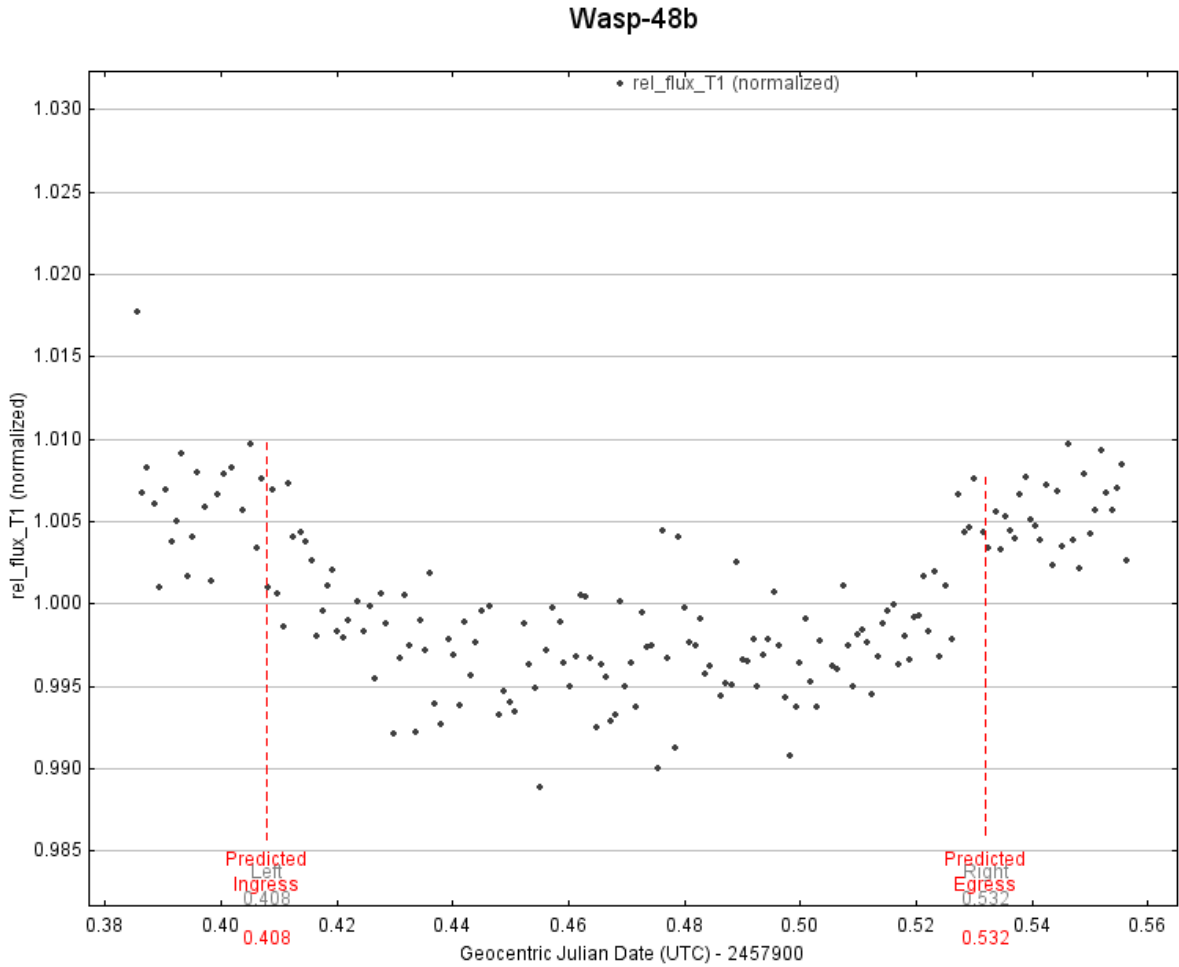


For the "Multi plot Y-data" window, this is used to plot the graphs. What interests us is Target 1 because it is our study star. In the Y-data column, select rel\_flux\_T1. Then check the Plot box and you will get your first graph.

Multi-plot Y-data

Data Set	New Col	Plot	Auto Scale	X-data	Input in Mag	Y-data	Auto Error	Function	Y-operand	Color	Symbol	Lines	Bin Size	Smoothing	Length
1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	default	<input type="checkbox"/>	rel_flux_T1	<input type="checkbox"/>	none		dark gray	dot	<input type="checkbox"/>	1	<input type="checkbox"/>	31
2	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	default	<input type="checkbox"/>	rel_flux_T1	<input type="checkbox"/>	none		blue	dot	<input type="checkbox"/>	1	<input type="checkbox"/>	31
3	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	default	<input type="checkbox"/>	rel_flux_C3	<input type="checkbox"/>	none		pink	dot	<input type="checkbox"/>	1	<input type="checkbox"/>	31
4	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	default	<input type="checkbox"/>	rel_flux_C4	<input type="checkbox"/>	none		red	dot	<input type="checkbox"/>	1	<input type="checkbox"/>	31
5	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	default	<input type="checkbox"/>		<input type="checkbox"/>	none		orange	dot	<input type="checkbox"/>	1	<input type="checkbox"/>	31
6	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	default	<input type="checkbox"/>		<input type="checkbox"/>	none		yellow	dot	<input type="checkbox"/>	1	<input type="checkbox"/>	31

Here's what you can get. The study does not end here though. Indeed, here you have obtained a normalized scatter plot of the values of the target star. This is not the end result.



- Exoplanet transit light curve

We must therefore return to the Multi plot Y-data window and slide to the right of the window to obtain the parameters that interest us. Head to the Fit Mode column. You can observe that for the first line, corresponding to our normalized light curve, it is selected on "off".

For the second line we will select another fit mode, corresponding to the transit and more suited to the light curve. So choose the one you see in the screenshot.

Color	Symbol	Lines	Bin Size	Smooth	Length	Fit Mode	Trend Select	Trend Coefficient	Trend Dataset	Norm/ Mag Ref
dark gray	dot	<input type="checkbox"/>	1	<input type="checkbox"/>	31	off	<input checked="" type="radio"/> <input type="radio"/> <input type="radio"/>	0		<input checked="" type="checkbox"/>
blue	dot	<input type="checkbox"/>	1	<input type="checkbox"/>	31	<input checked="" type="checkbox"/>	<input checked="" type="radio"/> <input type="radio"/> <input type="radio"/>	0		<input checked="" type="checkbox"/>
pink	dot	<input type="checkbox"/>	1	<input type="checkbox"/>	31	off	<input checked="" type="radio"/> <input type="radio"/> <input type="radio"/>	0		<input checked="" type="checkbox"/>

A new window will appear. Take time to observe that the parameters are present (circled in green). If you have aligned your images with the World Coordinate System, all boxes are filled in automatically.

You just have to go down to the Plot Settings section. Uncheck the Residuals and check the boxes as on the screen (Show Model and Show in legend). This will allow you to achieve the smoothed transit light curve you want.

$(R_p / R_*)^2$	0.007418441	<input type="checkbox"/>	0.009255799	<input type="checkbox"/>	0.004627899	<input type="checkbox"/>	0.009255799	
$a / R_*$	8.117892244	<input type="checkbox"/>	8.465711558	<input type="checkbox"/>	7.0	<input type="checkbox"/>	1.0	
$T_C$	2457900.470532075	<input type="checkbox"/>	2457900.47	<input type="checkbox"/>	0.015	<input type="checkbox"/>	0.01	
Inclination (deg)	89.999999877	<input type="checkbox"/>	86.0	<input type="checkbox"/>	15.0	<input type="checkbox"/>	1.0	
Linear LD u1	0.300000000	<input checked="" type="checkbox"/>	0.3	<input type="checkbox"/>	1.0	<input type="checkbox"/>	0.1	
Quad LD u2	0.679740541	<input type="checkbox"/>	0.3	<input type="checkbox"/>	1.0	<input type="checkbox"/>	0.1	
Calculated from model	b 0.000	t14 (d) 0.128149	t14 (hms) 03:04:32	t23 (d) 0.107729	tau (d) 0.010210	$\rho^*$ (cgs) 1.1234	(e)SpT G5V	$R_p$ ( $R_{Jup}$ ) 0.84

Use	Parameter	Best Fit	Lock	Prior Center	Use	Prior Width	Cust	StepSize
<input type="checkbox"/>			<input type="checkbox"/>	0.0	<input type="checkbox"/>	1.0	<input type="checkbox"/>	0.1
<input type="checkbox"/>			<input type="checkbox"/>	0.0	<input type="checkbox"/>	1.0	<input type="checkbox"/>	0.1
<input type="checkbox"/>			<input type="checkbox"/>	0.0	<input type="checkbox"/>	1.0	<input type="checkbox"/>	0.1

Fit Statistics	RMS (norm)	chi <sup>2</sup> /dof	BIC	dof	chi <sup>2</sup>
Fit Statistics	0.002779	0.830776	190.5011	171	142.0627

Plot Settings		Line Color	Line Width	Symbol	Symbol Color	Shift
<input checked="" type="checkbox"/> Show Model	<input checked="" type="checkbox"/> Show in legend	blue	2			
<input type="checkbox"/> Show Residuals	<input checked="" type="checkbox"/> Show in legend <input type="checkbox"/> Show Error	magenta	1	dot	magenta	0.0

Fit Control		Fit Update Options	Fit Tolerance	Max Allowed Steps	Steps Taken
Fit Control	<input checked="" type="checkbox"/> Auto Update Fit	Update Fit Now	1.0E-10	20,000	2205

Go back to the first columns and return to Y-data. For the second line, select rel\_flux\_T1 for the first line, then check the Plot box.

If all the steps have been followed, you will then have the same thing as on the second line.

Data Set	New Col	Plot	Auto Scale	X-data	Input in Mag	Y-data	Auto Error	Function	Y-operand	Color	Symbol	Lines	Bin Size	Smoothing	Length	Fit Mode
1	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	default	<input type="checkbox"/>	rel_flux_T1	<input type="checkbox"/>	none		dark gray	dot	<input type="checkbox"/>	1	<input type="checkbox"/>	31	off
2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	default	<input type="checkbox"/>	rel_flux_T1	<input type="checkbox"/>	none		blue	dot	<input type="checkbox"/>	1	<input type="checkbox"/>	31	on

You can now admire your light curve corresponding to the transit of your exoplanet around the target star. Congratulations, you have succeeded!

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