AstroImageJ and BAA Photometry Database Tutorial

Updated 2019 May 9th

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Appendix A

Using images that have not been plate solved.

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1.0 Introduction

A step by step example using WASP-12b images downloaded from

<u>https://www.astro.louisville.edu/software/astroimagej/examples/</u> AstroImageJ software and a user guide can be downloaded from <u>https://www.astro.louisville.edu/software/astroimagej/</u>

This tutorial is based on;

- Ref. 1 <u>A Guide to AstroImageJ Differential Photometry</u> Version 2.06, 21 October 2018 by Richard Lee
- Ref. 2 Plate solving/Track and Stack in AIJ by Richard Lee
- Ref. 3 AstroImageJ 2.4.1 User Guide plus Getting started with Differential Photometry
- Ref. 4 The AstroImageJ Cookbook by Grady Bryce, Edited by Dennis M. Conti
- Ref. 5 A Practical Guide to Exoplanet Observing by Dennis M. Conti
- Ref. 6 BAA Photometry Database Help and User Guides

Ref. 7 – BAA Photometry Spreadsheet Notes – The VSS CCD photometry spreadsheet

An example using images that are not plate solved is included in Appendix A

2.0 Installation and Set-up

2.1 Installation

Download and install AstroImageJ plus the Java runtime engine as highlighted in Ref. 1 Appendix E. Running Windows 10 I have found that installing the software and images in an AstroImageJ folder on the C Drive rather than in the Program Files (x86) folder prevents access problems. Update AstroImageJ to the latest level by opening the application and accessing Help/Update AstroImageJ/Upgrade to; down arrow/Scroll up to 'daily build/OK

Download and unzip; Uncalibrated images, Biases, Darks and Flats and unzip to the file directories as shown below (Appendix A in Ref. 1);

AstroImageJ WASP-12b Calibration Files Bias Darks Flats Master Calibration Files Raw Science Files Reduced_Science_Files (note underscores) radec.txt (See 2.2 (b) below) standard_transit.plotcfg.txt (See Appendix B below)

After unzipping all the files you should have;

- 11 each of Bias, Darks and Flats

- 230 Raw Science Files (also known as Uncalibrated images)

Configure AIJ and VSS_Photometry as per Appendix B in Ref.1.

2.2 Set-up a) SIMBAD Coordinates

Open AIJ, Figure 2.1, and click on the Delicon, enter WASP-12b in the SIMBAD Object ID text box and press enter to populate the Standard Coordinates fields with WASP RA and Dec data - Figure 2.2. Make sure you have selected the DP icon and not the adjacent Divider like icon.

If the SIMBAD Object ID and Observatory ID drop-downs are greyed out check that the Target Coordinate and Observatory Location Source drop-downs in the CCD Data Processor window, Figure 3.1, are both set to Coordinate Converter manual entry.

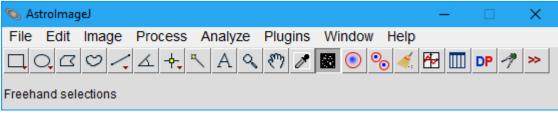


Figure 2.1 AstroImageJ window

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			Equatorial				184:04:5	Gala	ctic)8:56:1			
Epoch of In]
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Alt: -47:2	21:02.6	Horizontal	316:55:17.32		Dir: N		Hour Ai	ngle - Zenith 18 ZD: 13					
Phase - Al	titude - P Moon Down 33.48	Mercury	Venus 37.54 163.05	Mars 7.42 131.24	Jup Dov 31.	wn	Saturn 61.06 123.71	Uranus Down 91.29	1	ptune 1.60 24.81	Plu 50.0 169.	61	

Figure 2.2 DP Coordinate Converter window

Clicking on the icon accesses the SIMBAD web page for WASP-12b – Figure 2.3.

Similarly, the similarly, the superior of the target area depending on which survey is selected – Figure 2.4. Stellarium is the only planetarium software I have found which will display exoplanets and will be the subject of a later tutorial. Figure 2.5 shows a similar field of view to Figure 2.4 with the WASP-12 data displayed and the star itself circled.

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Figure 2.3. SIMBAD data for WASP-12b

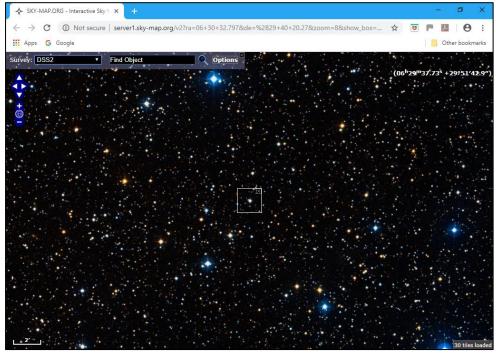


Figure 2.4. Image of target area.

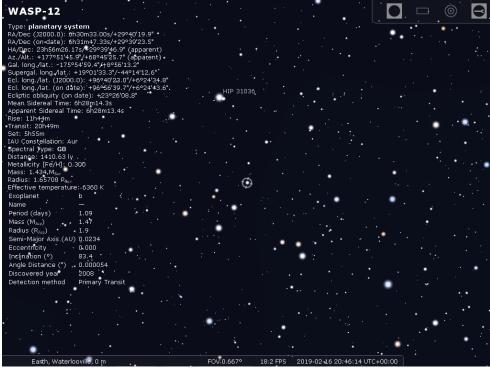


Figure 2.5 Stellarium field of view showing WASP-12

b) Aperture File

Create radec.txt aperture file by copying the data shown in Ref 1, Appendix C into a text editor, Notepad in this example - Figure 2.6, and then saving in the WASP-12b folder. The first line in each block is the data for the target star and the following are the data for the comparison stars.

Untitled - Notepad	×
<u>File Edit Format View Help</u> #WASP-12b, 06:30:32, +29:40:20, 0, 1, 99.999 #000-BKG-164, 06:30:47, +29:35:30, 1, 1, 9.453 #000-BKG-165, 06:31:09, +29:47:47, 1, 1, 9.747	^
#000-BKK-166, 06:30:39, +29:37:40, 1, 1, 10.568 #000-BKK-420, 06:30:30, +29:33:45, 1, 1, 10.568 #000-BKK-421, 06:29:51, +29:40:46, 1, 1, 11.697	
<pre>#000-BKG-167, 06:30:31, +29:42:27, 1, 1, 12.285 #000-BKG-168, 06:31:08, +29:41:53, 1, 1, 12.782 # #RA, Dec, Ref Star, Centroid, Magnitude</pre>	
#KA, bec, her Star, centroid, magnitude 06:30:32, +29:40:20, 0, 1, 99.999 06:30:47, +29:35:30, 1, 1, 9.453 06:31:09, +29:47:47, 1, 1, 9.747	
06:30:39, +29:37:40, 1, 1, 10.568 06:30:16, +29:33:45, 1, 1, 10.984 06:29:51, +29:40:46, 1, 1, 11.697	
06:30:31, +29:42:27, 1, 1, 12.285 06:31:08, +29:41:53, 1, 1, 12.782	
<	> .::

Figure 2.6. Aperture file copied into Notepad

3.0 Image Calibration

3.1 Building Master Calibration Files

Select the AIJ/CCD Data Processor window by clicking on the icon (this also opens the DP Coordinate Convert window which can be closed).

Configure this window as follows;

- deselect Science Image Processing/Enable
- Select Build and Enable for Bias Subtraction, Dark Subtraction and Flat Division and median combine for all three
- Select the folders from which the Bias, Dark and Flat frames are to be imported by clicking, in turn, on the bias_, dark_ and flat_folder icons on the respective lines, navigating to and selecting, in turn, the AstroImageJ/WASP-12b/Calibration Files/Bias, Darks and Flats folders
- Identify the file type by clicking on the folder icon to the right of each of the bias_, dark_ and flat_ boxes and selecting the first file in each, Bias, Dark and Flat folders
- Select the folder which will store the master calibration files by clicking on, in turn, the mbias.fits, mdark.fits and mflat.fits folder icons and navigating to and selecting AstroImageJ/WASP-12b/Master Calibration Files folder in each case

The configured window is shown in Figure 3.1.

P CCD Data Pro	ocessor				- 0 >
File Preference	es View				
Control Science Image			Directory		Filename/Pattern
Enable	Sort Num	C:\Users\RogerDymock\			filenamepattern.fits
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Enable		C:\AstroImageJ\WASP-12b\Ma	aster Calibration Files\		Dias.fits
Oark Subtracti				1.	
Build	🔾 ave 💿 med	C:\AstroImageJ\WASP-12b\Ca	alibration Files\Darks\		its *fits
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lat Division — D Build	◯ ave . ● med	C:\AstroImageJ\WASP-12b\Ca	alibration Files/Flats/		*fits
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ost Processi	ng				
M-Ap	Save Image			Macro 1 C:\Users\Roger	Dymock\
M-Plot	Save Plot			Macro 2 C:\Users\Roger	Dymock\
Control Panel - Polling I	nterval ——				

Figure 3.1. Configured CCD Data Processor window

Click on the START button to process the calibration files. If you are scratching your head, as I was, as to the whereabouts of this button then scroll down!!! Progress is shown in the Log window, Figure 3.2. The totals on the right-hand side of the page will now read 11 and 1 for each set of configuration files indicating the number of each processed and that a master file has been saved.

If you get a message indicating lack of memory go to the AstoImageJ toolbar and select Edit/Options/Memory and Threads and set Maximum memory to 2000MB.

🗞 Log	– 🗆 X	
File Edit Font		
		^
[2019-02-18T13:52:40.496]	Dark corrected with mdark	
[2019-02-18T13:52:40.496]	Gradient removed from ca	
[2019-02-18T13:52:40.496]	Normalized calibrated flats	
[2019-02-18T13:52:40.965]	Saved master flat file "C:V4	
[2019-02-18T13:52:40.981]		
[2019-02-18T13:52:40.983]	*************FINISHED***********	
[2019-02-18T13:52:40.984]		~
<		>

Figure 3.2. Log window

3.2 Science File calibration

In the CCD Data Processor window;

- Deselect Bias, Dark and Flat Build boxes
- Select the Enable Science image processing checkbox
- Select the Raw Science File directory and file type as for the calibration files (boxes at top of screen)
- Enable Save Calibrated images and 32 bit option
- Specify directory for saving calibrated images; Reduced_Science_Files and Suffix; _bdf
- The Plate Solve option is not required as WASP-12b files are already plate solved

Click on the START button to process the science images. The AIJ Image Display, Figure 3.3, window opens and shows each image as it is processed. Similarly, the Log window, Figure 34, shows progress and indicates 'Finish' when the calibration sequence is complete. It is advisable not to do anything else on the computer when this, and any other, sequences are running as some applications can 'throw a wobbly' if you do so. Whether this is the case with AIJ I cannot say but best to be careful.

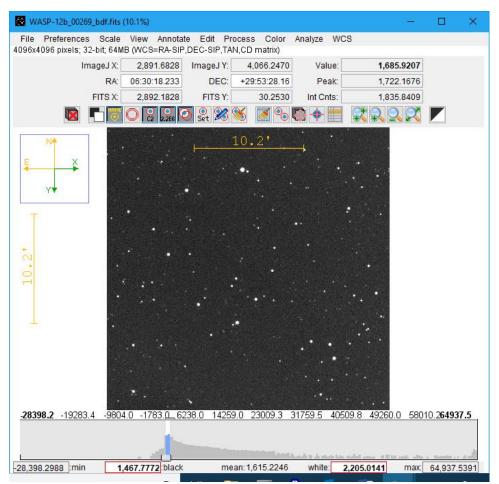


Figure 3.3. AIJ Image Display window

SLog File Edit Font	- 0
019-02-21T09:42:20.623]	JD = 2456319.828945 (mid-exp)
2019-02-21T09:42:20.623]	HJD = 2456319.833805 (mid-exp) (correction = 6.9976 minutes)
2019-02-21T09:42:20.625]	BJD(TDB) = 2456319.834569 (mid-exp) (correction = 8.0980 minutes)
2019-02-21T09:42:20.625]	Altitude = -47.01 (mid-exp)
019-02-21T09:42:20.625]	Azimuth = 316.53 (mid-exp)
019-02-21T09:42:20.625]	Hour Angle = 9.82 (mid-exp)
019-02-21T09:42:20.625]	Zenith Distance = 137.01 (mid-exp)
019-02-21T09:42:20.625]	Airmass = -1.0000 (mid-exp)
019-02-21T09:42:20.968]	Bias corrected with mbias.fits
019-02-21T09:42:20.968]	Dark corrected with mdark fits and exposure time scaling factor 100.0/100.0=1.0
019-02-21T09:42:20.968]	Flat corrected with mflat.fits
019-02-21T09:42:21.903]	Saved processed science file "C:VAstrolmageJ/WASP-12b/Raw Science Files/Reduced_Science_Files/WASP-12b_00268_bdf.
019-02-21T09:42:21.909]	Loading science file "C:\AstroImageJ\WASP-12b\Raw Science Files\WASP-12b_00269.fits" (230 of 230)
019-02-21T09:42:24.508]	Observatory name "Custom Lon, Lat, and Alt entry" manually selected
019-02-21T09:42:24.510]	Target coordinates manually entered = 06:30:32.797 +29:40:20.27 (J2000)
019-02-21T09:42:24.510]	JD = 2456319.830324 (mld-exp)
019-02-21T09:42:24.512]	HJD = 2456319.835184 (mid-exp) (correction = 6.9975 minutes)
019-02-21T09:42:24.512]	BJD(TDB) = 2456319.835948 (mid-exp) (correction = 8.0979 minutes)
019-02-21T09:42:24.512]	Altitude = -47.35 (mid-exp)
019-02-21T09:42:24.512]	Azimuth = 316.92 (mid-exp)
019-02-21T09:42:24.514]	Hour Angle = 9.85 (mid-exp)
019-02-21T09:42:24.514]	Zenith Distance = 137.35 (mid-exp)
019-02-21T09:42:24.514]	Airmass = -1.0000 (mid-exp)
019-02-21T09:42:24.862]	Blas corrected with mbias.fits
019-02-21T09:42:24.862]	Dark corrected with mdark fits and exposure time scaling factor 100.0/100.0=1.0
019-02-21T09:42:24.862]	Flat corrected with mflat.fits
019-02-21T09:42:26.457]	Saved processed science file "C:\AstroImageJ\WASP-12b\Raw Science Files\Reduced_Science_Files\WASP-12b_00269_bdf.
019-02-21T09:42:26.469]	
019-02-21T09:42:26.469]	**********FINISHED**********
019-02-21T09:42:26.469]	

Figure 3.4. Log window indicating calibration sequence is complete.

The calibrated science files are created in a sub-folder in the Raw Science Files folder. When processing is finished close AIJ and move this folder to C:\AstroImagJ/Wasp-12b/Reduced_Science_Files.

4.0 Photometry – generating a transit light curve

4.1 Set up

Select the calibrated images - AIJ Tool bar/File/Import/Image Sequence, navigate to the Reduced_Science_Files folder and open the first image listed. The Sequence Options window opens – Figure 4.1. Select Sort names numerically and Use virtual stack then OK.

🧠 Sequence Options	×
Number of images: Starting image: Increment: Scale images:	230 1 1 100 %
File name contains:	
or enter pattern:	
Convert to RGB Sort names num Use virtual stac	merically
4096 x 4096 x 230	(14720.0MB)
ок	Cancel Help

Figure 4.1. Sequence Options window

The selected image, WASP-12b_00040_bdf.fits, opens – Figure 4.2. Ensure north is up and east to the left – adjust using View/Invert X and/or Y as required.

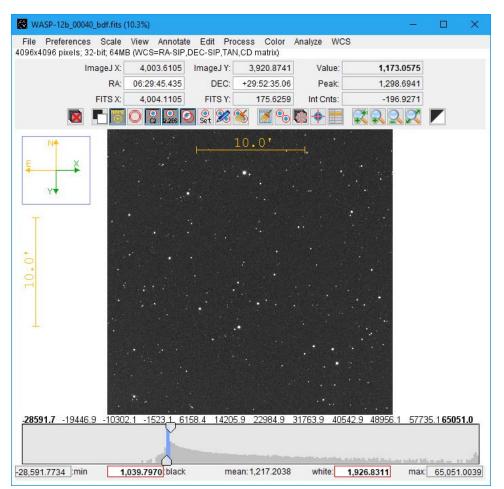


Figure 4.2. Image Display window showing first reduced science image.

Select the Set icon to open the Aperture Photometry Settings widow – Figure 4.5. Set;

- Radius of object aperture
- Inner radius of background annulus = 24
- Outer radius of background annulus = 30
- Then OK to close window.

Toggle the aperture display icon to de-select the background apertures. You will need to zoom in to see the apertures clearly – Figure 4.4.

= 20

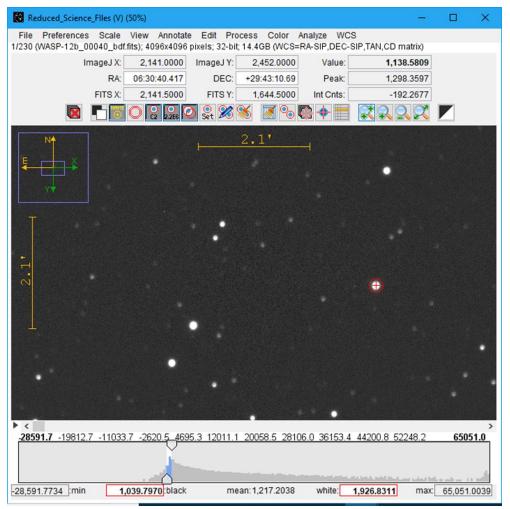


Figure 4.4. Background apertures deselected

Alt/Left click on a bright, non-saturated star to display the Seeing Profile – Figure 4.4.

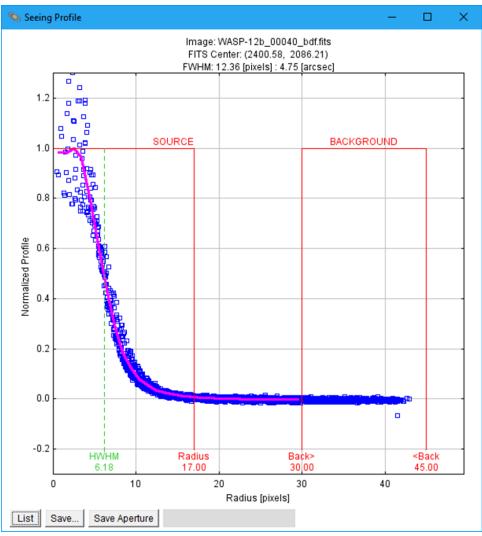


Figure 4.4. Seeing Profile

Click on Save Aperture in the Seeing Profile window to select the suggested aperture sizes, on $\textcircled{\colored{Set}}$ in the Image Display window to confirm these settings – Figure 4.5 – and then OK to close the Aperture Photometry Settings window. Select $\textcircled{\colored{Set}}$ to clear apertures and click $\textcircled{\colored{Set}}$ to toggle display of sky apertures.

Aperture Photometry Settings		×
Radius of object aperture	< > 18	
Inner radius of background annulus	< > 32	
Outer radius of background annulus	< > 48	
Use variable aperture (Multi-Aperture only)		
FWHM factor (set to 0.00 for radial profile mode)	< > 1.40	
Radial profile mode normalized flux cutoff	0.010 (0 < cuffoff < 1 ; default = 0.010)	
I ⊂ Centroid apertures I Use Howell cent	troid method 🔲 Fit background to plane 🛛 🔽 Remove stars from backgnd 🔲 Mark removed pixels	
Prompt to enter ref star absolute mag (required if	target star absolute mag is desired)	
List the following FITS keyword decimal values in	measurements table:	
Keywords (comma separated):	JD_SOBS,JD_UTC,HJD_UTC,BJD_TDB,AIRMASS,ALT_OBJ,CCD-TEMP,EXPTIME,RAOBJ2K,DECOBJ2K	
CCD gain [e-/count]	1.00	
CCD readout noise [e-]	0.00	
CCD dark current per sec [e-/pix/sec]	0.00	
or - FITS keyword for dark current per exposure [e-/pix]		
Saturation warning ('Saturated' in table) (red borde	er in Ref Star Panel)	
for levels higher than	55000	
Linearity warning (yellow border in Ref Star Panel))	
for levels higher than	40000	
	OK More Settings Can	cel

Figure 4.5. Revised aperture settings

A visual check of image quality can be carried out using the scroll bar controls below the image in the Reduced_Science_Files window.

The images can be inspected manually by stepping through the stack, or automatically, using

the scroll bar below the image Figure 4.6. To remove an image, click on the ¹⁴² icon. This removes the image from the sequence but does not delete it.

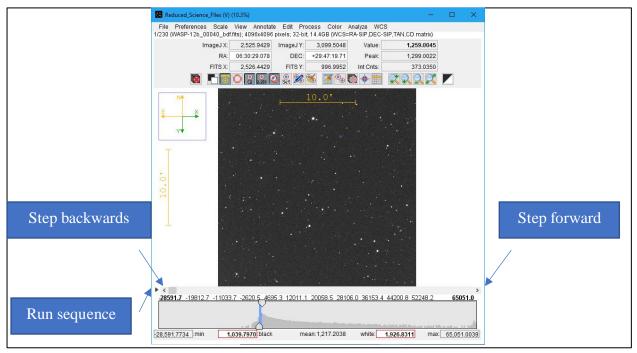


Figure 4.6. Image review sequencing

Right clicking on the Run Sequence arrow brings up the Animation Options window which allows various settings to be altered – Figure 4.7.

Animation Options	×
Speed (0.1-1000 fps): First Frame:	7 1
Last Frame:	230
☐ Loop Back and F ▼ Start Animation	orth
ОК	Cancel

Figure 4.7. Animations Options window

4.2 Photometry

In the Image Display window select File/Import apertures from RA/Dec list and navigate to and select the radec.txt file – Figure 2.6. This overlays the target and comparison star selection on the image (make sure you have the first image in the stack selected if you have been inspecting the images. As you can see in Figure 4.8 the overlays may be offset from the selected stars.

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Figure 4.8. Initial positioning of the target and comparison star overlays.

To correct for this, open the Multi-Aperture Measurements window - Figure 4.9 - by clicking

on the **Solution** icon.

Multi-Aperture Measurements		×
First slice	<	> 1
Last slice	<	> 230
Radius of object aperture	<	> 17
Inner radius of background annulus	<	> 30
Outer radius of background annulus	<	
		> 45
☑ Use previous 8 apertures (1-click to set first apertu	ure location)	
Use RA/Dec to locate aperture positions		
Use single step mode (1-click to set first aperture	location in each ima	ge)
Allow aperture changes between slices in single s	step mode (right click	(to advance image)
🔽 Reposition aperture to object centroid 🛛 🔽 Half	processing on WCS	or centroid error
Remove stars from background	ume background is a	a plane
Vary photometer aperture radius based on FWHM		
FWHM factor (set to 0.00 for radial profile mode):	<	> 1.40
Radial profile mode normalized flux cutoff:	0.010 (0 < cuffo	off < 1 ; default = 0.010)
Prompt to enter ref star apparent magnitude (requ	ired if target star app	arent mag is desired)
▼ Update plot of measurements while running ▼ S		
CLICK 'PLACE APERTURES' AND SELECT APERTU THEN RIGHT CLICK or <enter> TO BEGIN PROC (to abort aperture selection or processing, press <e< td=""><td>ESSING.</td><td>TH LEFT CLICKS.</td></e<></enter>	ESSING.	TH LEFT CLICKS.
Plac	e Apertures Apertu	ure Settings Cancel

Figure 4.9. Multi Aperture Measurements window

Select Place Aperture which centres the apertures over their respective stars – Figure 4.10.

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Figure 4.10. Apertures correctly centred (enlarged image).

To start the photometry processing press Enter. A number of windows open;

- Plot of measurements, Figure 4.11
- Multi-plot Y-data., Figure 4.12
- Multi-plot Reference Star Settings, Figure 4.13
- Multi-plot Main, Figure 4.14
- Measurements, Figure 4.15

These are used during the model fit process which is described in Appendix B.

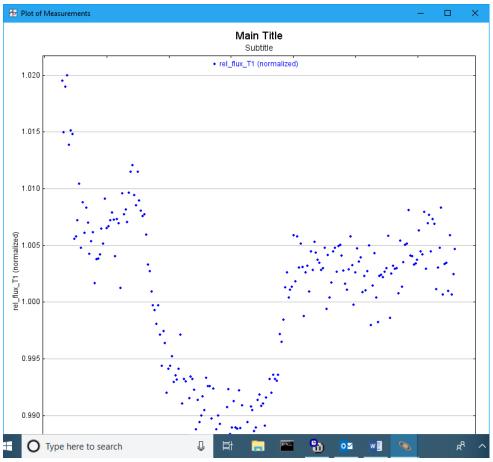


Figure 4.11. Plot of measurements window

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3			\checkmark	default		~		rel_flux_C3	~		none	\sim	~	pink	~	dot	~		1 -
4			\checkmark	default		~		rel_flux_C4	~		none	\sim	~	red	~	dot	~		1 -
5			\checkmark	default		~		rel_flux_C5	~		none	\sim	~	orange	~	dot	~		1
6			\checkmark	default		~		rel_flux_C6	~		none	\sim	~	yellow	~	dot	~		1 -
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8			\checkmark	default		~		rel_flux_C8	~		none	\sim	~	purple	~	dot	~		1

Figure 4.12. Multi-plot Y-data window

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Save/Show Current Configuration													
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Figure 4.13. Multi-plot Reference Star Settings window

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Figure 4.14, Multi-plot Main window

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Figure 4.15. Measurements window.

On completion of processing save the data as Measurements.txt (not xls as will be indicated in the File name box) by selecting, in the Measurements window, File/Save as and navigating to the WASP-12b folder.

5.0 BAA Photometry Database

5.1 BAA Photometry Spreadsheet

This spreadsheet must be used to create files in the correct format for inputting to the BAA Photometry Database. It can be downloaded from <u>Notes on submitting Observations</u>. You may also find this referred to as the VSS_Photometry_Spreadsheet (its name before updating to the BAA Photometry Spreadsheet).

The steps to do this are;

- a) Using the BAA Photometry Database Spreadsheet
 - set up directories
 - import the photometry file generated using AstoImageJ
 - create BAA Photometry Database Report File
- b) Accessing the BAA Photometry Database
 - open and log in
 - select and upload file created using the above-mentioned spreadsheet

Open the spreadsheet, review the instructions under the READ ME FIRST tab and then select the Buttons tab – Figure 5.16

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elect Equipment/Object Settings le or Old Version of Spreadsheet	Directory: C:\Astrolma	geJ\WASP-12b				
le of Old Version of Spreadsheet	File name: VSS_Photo	metry_Spreadsheet_o	ld.xlsm	Optional		
Import Photometry File	Create BAA VSS Report Fil	e Create AAV	'SO Report File	Load Equipment/Object Settings	Save Equipment/Object Settings	:t
Instructions This spreadsheet can import file Use the Select buttons to pick t the file names and paths must b If using AIP4Win/2 "Ensemble P	he files and directories. The S be typed/copied into the above	Select buttons do not a boxes. The path mus	vork in some older vers it include the drive lette	ions of Excel, in which cas r. Eg C:\My Documents	se the	
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Figure 4.16. BAA Photometry Spreadsheet

Click on Select Photometry Import File, navigate to and open Measurements.txt in the WASP-12b folder. The File name changes to Measurements.txt and the Type field shows AstroImageJ. You may need to enable editing and content.

Click on Select Export Directory, navigate to and select the WASP-12b folder.

In the BAA VSS report file name enter 'BAAVSSWASP-12b.txt and delete the entry in the AAVSO report file name box – Figure 4.17.

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Figure 4.17. Updated spreadsheet.

Select the Results sheet, clear any previous entries and enter the data in the User Input columns C to G - Figure 4.18.

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Figure 4.18 Results sheet.

Enter user data under the ObsvEqmt tab – Figure 4.19.

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Figure 4.19. User Equipment input

Select the Buttons sheet, click on the Import Photometry File button which populates the rest of the worksheets. Note that some stars have not been used to avoid various warnings since

the tutorial uses V mag reference magnitudes but the WASP images were taken with a red filter.

Create a BAA Photometry Database formatted file by clicking on 'Create BAA VSS Report File'. The file is saved as BAAVSS WASP-12b.txt. Close the spreadsheet.

5.2 Login to BAA Photometry database

The <u>database</u> can be accessed from the BAA homepage under Observations in the list on the right-hand side of the page – Figure 5.1.

The Help button opens a list of User Guides. This section is based upon <u>'Loading and Editing</u> <u>Observations'</u>.

Note that for the purpose of this exercise observations will only be uploaded to the holding area and not committed to the live database. Note that only the person submitting the observation scan view them in this area

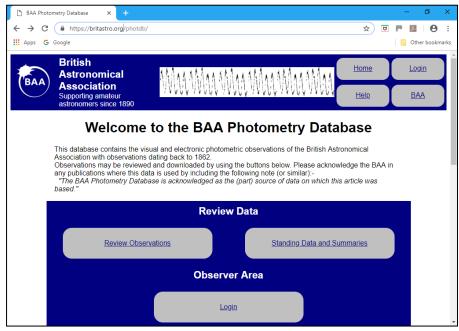


Figure 5.1. BAA Photometry Database home page

Login via the button in the observer area – Figure 5.2

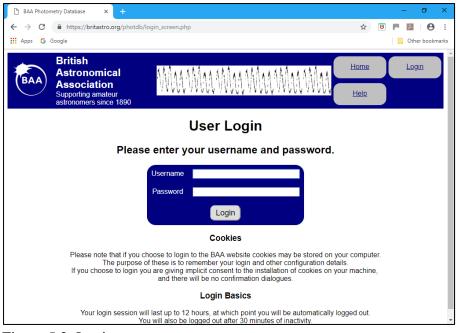


Figure 5.2. Login screen

This takes you to a screen from which observation scan be uploaded – Figure 5.3.

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Welco	me to the BAA	Photometry Data	ase				
This database contains the visual and back to 1862. Observations may be reviewed and do data is used by including the following "The BAA Photometry Database is an	wnloaded by using the buttons note (or similar):-		n any publicat		-		
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Figure 5.3. Input screen

5.3 Uploading data

This section copies instructions from the <u>BAA Photometry Database User Guide to Loading</u> and <u>Editing Observations</u>

Selecting Upload Observations opens the Screen of the same name – Figure 5.3. Click on Choose Files and navigate to and Open the BAAVSS WASP-12b.txt file saved at the conclusion of section 4.2 above. Click on Upload.



Figure 5.3 Upload Observations screen

A summary screen results, Figure 5.4, including any warnings

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Figure 5.3. Upload summary screen

Selecting 'Click to toggle Warning Summary Detail' Shows the warnings (Which are to be expected at this time) – Figure 5.4.

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Figure 5.4. Warning details

Clicking on 'Review and Commit Observations' leads to the Uncommitted Observation Summary – Figure 5.5. In the Object Type box select Exoplanet and click on Create New Object since WASP-12b is not in the database as indicated in Figure 5.4 above.

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Figure 5.5. Uncommitted Observation Summary.

At this point the observations could be committed by selecting the 'Commit All Uncommitted Observations' button, Figure 5.6, but, as this is a test exercise they will not be.

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Figure 5.6. Uncommitted Observations Summary

5.4 Reviewing observations

This example refers to observations uploaded by Paul Leyland – the first person to use this facility.

After logging in select Review Observations - Figure 5.7

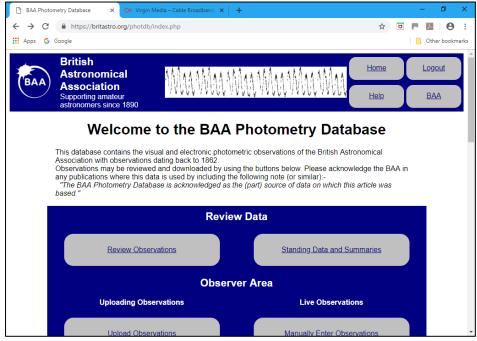


Figure 5.7. BAA Photometry Database Welcome page

In the subsequent Review Observations screen – Figure 5.7; - select Exoplanet in the Filter by object type box - click on Apply Filter

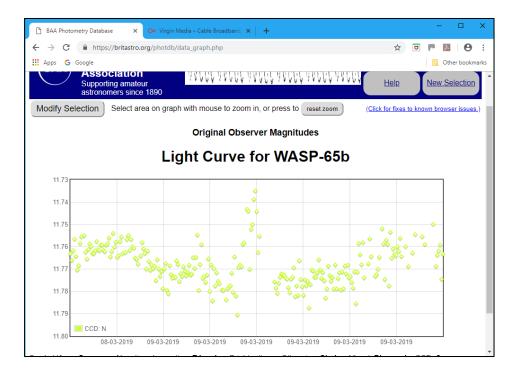
- select WASP-65b – Exoplanet in the Select Object box

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		Data Table	Download Data		
		Optional Pa	rameters		
			UT (Works out JD from UT and vice versa)		•

Figure 5.7. Review Observations page

You then have the option of displaying a light curve, Figure 5.8, or data, Figure 5.9, or downloading data by clicking on the relevant button.

Note; When returning to the Review Observations screen check that the filter and selected object are as required as these may change depending on whether the browser back button/arrow or the Modify Selection button is used.



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2458551.624340	9 Mar 2019 02:59:03	Equal	11.7745	0.0029	P C Leyland	CCD	0.4m Relay Cassegrain SBIG-8XE	No Filter	Custom
2458551.623715	9 Mar 2019 02:58:09	Equal	11.7592	0.0026	P C Leyland	CCD	0.4m Relay Cassegrain SBIG-8XE	No Filter	Custom
	~ • •								

Figure 5.8. WASP-65b light curve

Figure 5.9. WASP-65b data table (Part)

The data is downloaded as a csv file which can, for example be imported into an Excel spreadsheet – Figure 5.10. The 'bump' in the centre of the dip was due to the observer's dome not moving in sync with the telescope.

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Figure 5.10. WASP-65b data downloaded and imported into Excel

Appendix A Using images that have not been plate solved

Contents

- 1.0 Introduction
- 2.0 Set-up
- 3.0 Photometry

1.0 Introduction

A step by step example using images of HAT-P-25b obtained by Portsmouth University students working with members of the Hampshire Astronomical Group at their Clanfield observatory.

2.0 Set-up

Open AIJ, Figure 2.1, and click on the icon. In the 'Observatory ID' box select 'Custom on(gitude), Lat(itude) and Alt(itude)', 50deg 56' 18.81"N, 1deg 01' 07.01"W, 154m and enter the required data (for the Clanfield observatory). Enter HAT-P-25b in the SIMBAD Object ID text box and press enter to populate the Standard Coordinates fields with HAT-P-25b data - Figure 2.2.

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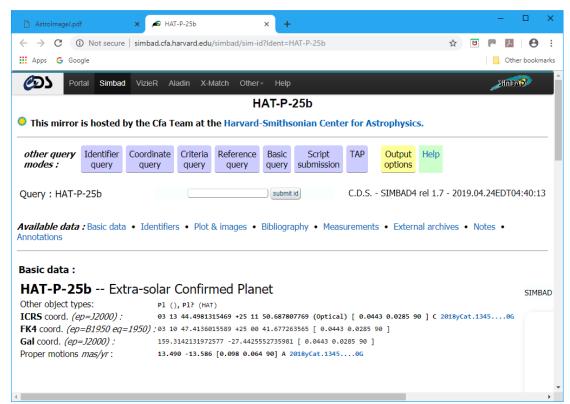
Figure 2.1 AstroImageJ window

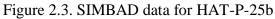
DP Coordinate Converter × ile Preferences Network Help Current UTC-based Time UTC: [2019-04-24] 0839:50 Local: [2019-04-24] 09:39:50 AM JD: [2456597.861000] LST: [22:44:08] SIMBAD Object ID (or SS Object) Time Zone Observatory ID HAT:P-25b UTC offset 1: Custom Lon, Lat, and Alt entry Target Proper Motion (maskyr) Geographic Location of Observatory ID Target Proper Motion (maskyr) Geographic Location of Observatory pmRA_0 pmDec_0 Lon: 01:01:07:01 Lat +50:56:18.81 Att 154 Standard Coordinates J2000 Equatorial Galactic simMaD RA_03:10:47.463 Dec +25:00:41 Lon: (159:18:51:15 Lat -27:26:33.2 Epoch of Interest UTC: 2013-01:27 07:55:40 UT 06:02 PM JD: 2456319.830324 LST: 16:18:39 Ucok Local: 2013-01:27 07:55:40 UT 06:02 PM JD: 2456319.830324 LST: 16:18:39 <											
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Figure 2.2 DP Coordinate Converter window

Clicking on the icon accesses the SIMBAD web page for HAT-P-25b – Figure 2.3.

Similarly, the survey is selected – Figure 2.4. Stellarium is the only planetarium software I have found which will display exoplanets and will be the subject of a later tutorial. Figure 2.5 shows a similar field of view to Figure 2.4, but with a different orientation, with the HAT-P-25b data displayed and the star itself circled.





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Figure 2.4. Image of target area.



Figure 2.5 Stellarium field of view showing HAT-P-25b

3.0 Photometry

Select the calibrated images - AIJ Tool bar/File/Import/Image Sequence, navigate to the folder containing the images and open the first image listed. The Sequence Options window opens – Figure 3.1. Select Sort names numerically and Use virtual stack then OK.

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Figure 3.1. Sequence Options window

The selected image, hat25b001fits, opens – Figure 3.2. Ensure north is up and east to the left – adjust using View/Invert X and/or Y as required. Note that the images have been deliberately defocused so that the light is spread over more pixels allowing for a more accurate measurement of light intensity and to avoid saturation.

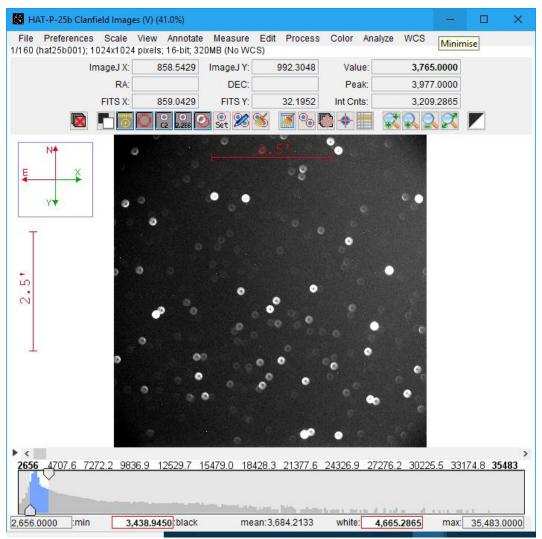


Figure 3.2. Image Display window showing first reduced science image.

Select the Align stack using apertures icon to open the Stack Aligner window Figure 3.3. Clear all but the last two boxes and set the three radii to 20, 45 and 50 respectively. The Radius of object aperture was set to 20 rather than the 40 recommended in Richard Lee's tutorial to enable the T aperture to be set over the target star. Note that the first and last images are shown in the First and Last slice boxes.

Stack Aligner		×
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Inner radius of background annulus	<	> 45
Outer radius of background annulus	<	> 50
🗌 Use previous 3 apertures (1-cli	ck to set first apertur	e location)
🗌 Use RA/Dec to locate initial ape	erture positions	
🗌 Use single step mode (1-click t	o set first aperture lo	cation in each image)
Allow aperture changes betwee	en slices in single st	ep mode (right click to advance image)
Remove background and scale	to common level	
Align only to whole pixels (no in	terpolation)	
Show help panel during aperture	re selection.	
NOTE: ***THIS IS A VIRTUAL STA Aligned images will be placed in		aned'
The new aligned stack must be o		-
Click "OK" and select image aligr Then right click or press <enter> To abort alignment star selection</enter>	to begin alignment p	rocess.
		OK Cancel

Figure 3.4. Stack Aligner window

Select T1 and two comparison stars, C1 and C2 and press Enter to start the alignment process. The image can be enlarged if necessary to facilitate selecting the target and comparison stars. The images will be stepped through and a message, Figure 3.5 indicates completion. Click OK to close window. The aligned images are stored in a sub-folder, Aligned, in the folder containing the original images.

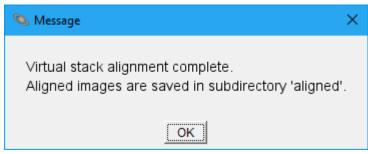


Figure 3.5. Alignment complete message window

The aperture sizes were reset to 15/18/21 to avoid interference from the star adjacent to the target star – click on the Set icon to do this. Save these settings by selecting File/Save apertures and naming the folder Aligned apertures for example.

Close the window and select the first of the aligned images – File/Import/Image/Image Sequence/aligned and choosing the first aligned image. Click on the Multi-aperture icon

to open the Multi-Aperture Measurements window – Figure 3.6. Check Use previous 3 apertures etc. leave other settings as is and click on Place Apertures.

Multi-Aperture Measurements	×
First slice	< > 1
	1
Last slice	< 160
Radius of object aperture	< > 15
Inner radius of background annulus	< > 18
Outer radius of background annulus	< > 21
Use previous 3 apertures (1-click to set first apertur —	re location)
Use RA/Dec to locate aperture positions	
Use single step mode (1-click to set first aperture lo	ocation in each image)
Allow aperture changes between slices in single st	tep mode (right click to advance image)
Centroid apertures (initial setting)	processing on WCS or centroid error
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Radial profile mode normalized flux cutoff:	0.010 (0 < cuffoff < 1 ; default = 0.010)
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THEN RIGHT CLICK or <enter> TO BEGIN PROCE (to abort aperture selection or processing, press <es< td=""><td></td></es<></enter>	
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Place	Apertures Aperture Settings Cancel

Figure 3.6. Multi-Aperture Measurements window

Click on the target star and the target and check star apertures will then be aligned over their respective stars – Figure 3.7.

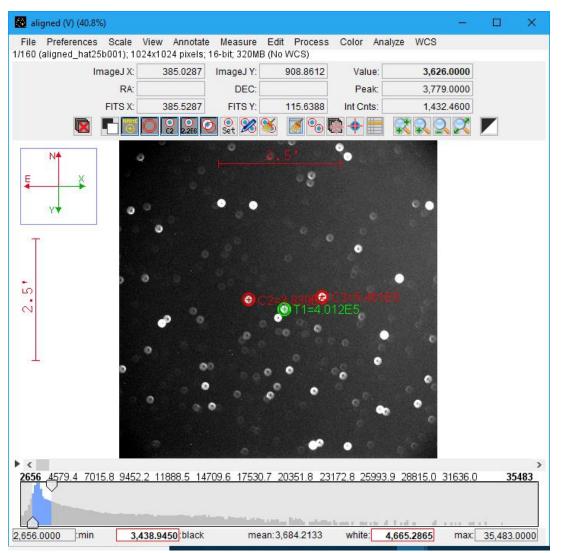


Figure 3.7. Placement of apertures over target and comparison stars.

Press Enter to start the analysis. A number of windows open; - Plot of measurements, Multiplot Y-data, Multi-plot Reference Star Settings, Multi-plot Main and Measurements. These are used during the model fit process which is described in a separate tutorial. Completion is indicated by the Measurements window which lists all the processed images – Figure 3.8.

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151	aligned_hat25b151.FIT	151.000000	0.000000	55571.421134	2455571.421134	
152	aligned_hat25b152.FIT	152.000000	0.000000	55571.421944	2455571.421944	
153	aligned_hat25b153.FIT	153.000000	0.000000	55571.422755	2455571.422755	
154	aligned_hat25b154.FIT	154.000000	0.000000	55571.423576	2455571.423576	
155	aligned_hat25b155.FIT	155.000000	0.000000	55571.424398	2455571.424398	
156	aligned_hat25b156.FIT	156.000000	0.000000	55571.425208	2455571.425208	
157	aligned_hat25b157.FIT	157.000000	0.000000	55571.426019	2455571.426019	
158	aligned_hat25b158.FIT	158.000000	0.000000	55571.426840	2455571.426840	
159	aligned_hat25b159.FIT	159.000000	0.000000	55571.427650	2455571.427650	
160	aligned_hat25b160.FIT	160.000000	0.000000	55571.428472	2455571.428472	~
<						>

Figure 3.8. Measurements window

On completion of processing save the data as Measurements.txt (not xls as will be indicated in the File name box) by selecting, in the Measurements window, File/Save as and navigating to the HAT-P-25b folder.

Appendix B Model fit

Contents

- 1.0 Introduction
- 2.0 Set-up
- 3.0 Model fit

1.0 Introduction

The objective of this exercise is to fit a light curve to the data and thus allow various exoplanet parameters to be measured.

2.0 Set-up

Process the WASP-12b images as in section 2 to 4 above.

3.0 Model fit

A fully detailed description of this process is described section 7.6 onwards in <u>A Practical Guide to Exoplanet Observing</u> by Dennis M. Conti.

To begin the model fit process select the MultiPlot icon on the AstroImageJ toolbar. This will open several screens; Multi-plot Main, Multi-plot Y-data, Measurements.txt (saved at the end of section 4.2, Photometry above), Multi-plot Reference Star Settings and Plot of Measurements.txt – Figure 3.1. If the Measurements.txt file does not open (and no plot is displayed) then do so be selecting, in the Multi-plot Main window, File/Open table from file and selecting Measurements.txt. Load the supplied plot configuration file by, in the Multi-plot Main window, selecting File/Open plot configuration file and selecting standard_transit.plotcfg.

In the Default X-data drop-down select J.D.-2400000 and the plot of the target and comparison light curves will then be displayed.

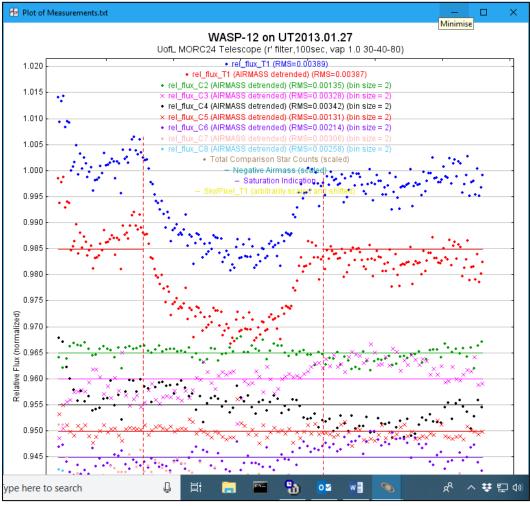


Figure 3.1 Plot of measurements showing transit light curve of WASP-12b and reference stars

In the Multi-plot Main window the V.Marker 1 and V.Marker 2 indicate the ingress and egress times respectively. These can be adjusted by using the up/down arrows in the boxes as has been done for the egress marker – Figure 3.2.

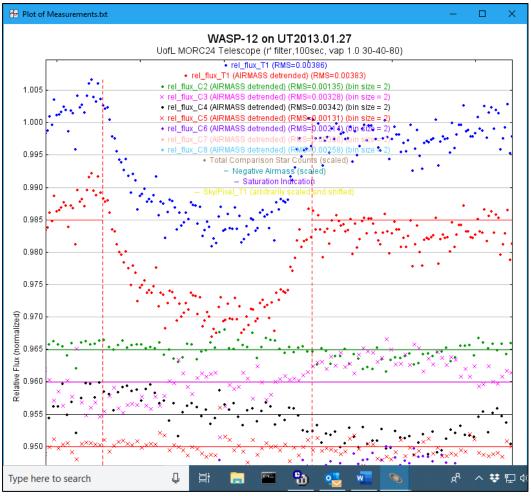


Figure 3.2 Adjusted egress marker

In the Fit and Normalize Region Selection at the bottom of the Multi-plot Main window copy

ماله

the V.Marker 1 and 2 settings by clicking on the Copy icon

The Multi-plot Y-data screen is shown in two parts, Figures 3.3(a) and (b). The Data Sets listed are;

1) Target star raw data

2) Target star with detrend data (in this case, Airmass) applied

3-7) Comparison stars

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2		\checkmark	\square	default		\sim		rel_flux_T1	\sim		none	-	~	red	\sim	dot	~ [] [1 🔹	
3		\checkmark	\checkmark	default		\sim		rel_flux_C2	\sim		none	-	~	dark gre	\sim	dot	~ [] [2 🔹	
4		\checkmark	\checkmark	default		\sim		rel_flux_C3	\sim		none	-	~	magenta	\sim	X	~ [2 🔺	
5		\checkmark	\checkmark	default		\sim		rel_flux_C4	\sim		none	~	~	black	\sim	dot	~ [] [2 🔺	
6		\checkmark	\checkmark	default		\sim		rel_flux_C5	\sim		none	~	~	red	\sim	x	~ [] [2 🔺	
7			\checkmark	default		\sim		rel_flux_C6	\sim		none	~	~	purple	\sim	dot	~ [] [2 🔺	
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9		\checkmark	\checkmark	default		\sim		rel_flux_C8	\sim		none	-	~	light blue	\sim	dot	~ [2 🔺	
10		\checkmark	\checkmark	default		\sim		tot_C_cnts	\sim		none	~	~	brown	~	dot	~ [1 🔺	
11			\checkmark	default		\sim		AIRMASS	\sim		none	~	~	teal	\sim	line	~ [] [1 🔺	
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Figure 3.3(a). Multi-plot Y-data (left) window

🔁 Multi-plot Y-data — 🗆 🗙																
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Figure 3.3 Multi-plot Y-data (right) window

Under Fit Mode for Data Set 2 select Transit Fit by clicking on the Down arrow in the Fit Mode Column and selecting the option as indicated in Figure 3.4. This will fit a light curve to Data Set 2 (the detrended data), Figure 3.5 and open the Data Set 2 Fit Settings – Figure 3.6 (Note that this figure shows the updated values as described below and that Fit Control/Auto Update Fit is checked so any changes will be automatically applied)

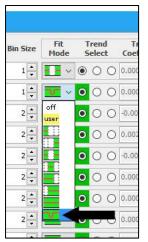


Figure 3.4. Transit Fit selection

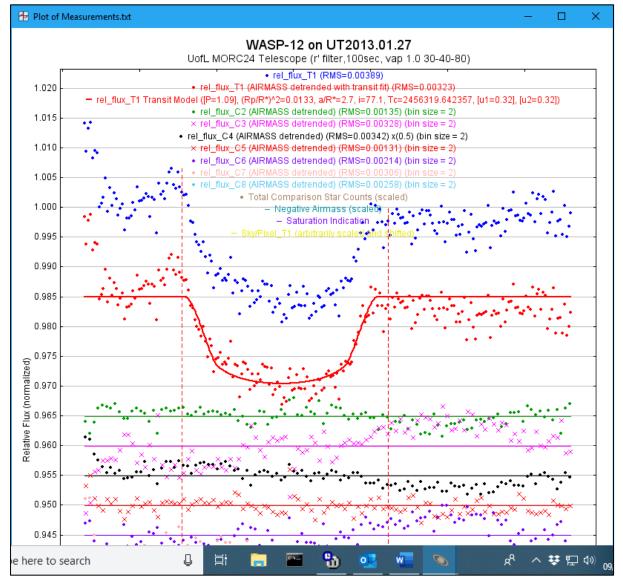


Figure 3.5. Light curve fitted to Data Set 2, Detrended data

🚾 Data Set 2 Fit Settings							– 🗆 X			
File Auto Priors										
rel_flux_T1										
User Specified Parameters (not fitted)										
$ \begin{array}{c} \text{Orbital Parameters} \\ \text{Host Star Parameters (enter one)} \\ \text{Period (days)} \\ \text{Cir} \\ \text{Cir} \\ \text{Ecc} \\ \text{Ecc} \\ \text{Cir} \\ Ci$										
1.0914203										
Transit Parameters										
🗹 Enable Transit Fit	Auto Update Prior	s	Extract Prior Cent	er Values	From Light Curve, Orbit, a	and Fit Mark	ers			
Parameter	Best Fit	Lock	Prior Center	Use	Prior Width	Cust	StepSize			
Baseline Flux (Raw)	0.048846447		0.048859609 💂		0.009771922 🛓		0.048859609 💂			
$(R_{p} / R_{*})^{2}$	0.012421992		0.014895242 🛓		0.007447621 🛓		0.014895242			
a / R _*	2.973022734		2.987322451 🔹		2.0 🛓		1.0			
Tc	2456319.639882964		2456319.644491291 🔹		0.04 🛓		0.01			
Inclination (deg)	81.107606022		82.5 💂		1.0 🔺		1.0 🔺			
Quad LD u1	0.390560810		0.39056081 💂		0.3 🛓		0.1			
Quad LD u2	0.302699200		0.3026992 💂		0.3 🛓		0.1			
b t14 (d) t14 (hms) t23 (d) tau (d) p* (cgs) (e)SpT Rp (Rjup) Calculated from model 0.460 0.122198 02:55:58 0.090981 0.015608 0.4169 A0V 1.19										
Detrend Parameters			,		,					
Use Parameter	Best Fit	Lock	Prior Center	Use	Prior Width	Cust	StepSize			
AIRMASS	0.000474112358		0.0 💂		0.0001 🛓		0.1			
J.D2400000	-0.001213916704		0.0 💂		1.0 🔺		0.1			
Width_T1	~		0.0		1.0 🔺		0.1 🔺			
Fit Statistics				BIC	dof					
Fit Statistics	RMS (norm) 0.002464		516930 82							
Plot Settings										
Line Color — Line Width —										

Figure 3.6. Data Set 2 Fit Settings window

In the Data Set 2 Fit Settings window enter the following parameters (obtained from Exoplanets.eu);

Orbital Parameters/Period = 1.09142245

Host Star Parameters;

- Spectral Type = G0. Entering the Spectral Type will update the boxes to its right

 $- R^* (Rsun) = 1.657$

The values for the quadratic limb darkening coefficients, Quad LD U1 and Quad LD U2, associated with the host star and the particular filter being used can be found by using the limb darkening coefficient calculator at

http://astroutils.astronomy.ohio-state.edu/exofast/limbdark.shtml - Figure 3.7

EXOFAST - Quadratic Limb Darke X +			-			×				
← → C ① Not secure astroutils.astronomy.ohio-state.edu/exofast/limbdark.shtml	☆	۵		ン	0	:				
Apps G Google				Other	book	marks				
EXOFAST - Quadratic Limb Darkening This applet interpolates the <u>Claret & Bloeman (2011)</u> quadradic limb darkening tables. Selecting a planet will attempt to retrieve the Teff, [Fe/H], and log(g) from exoplanets.org. Our database is synced to theirs daily; check the bottom of this page for the most recent update. If you use this code for your research, please cite our paper (Eastman et al, 2013).										
WASP-12 b V Teff [Fe/H] log(g) Teff [Fe/H] log(g) Submit User inputs are NOT logged										
Copyright © Jason Eastman (Email) All Rights Reserved. Questions, comments, or bug reports encouraged. exoplanets.csv last updated Wed Jul 20 14:41:55 2016										

Figure 3.7. Limb darkening calculator

Entering the planet's name and filter (band) used returns the values 0.39056081 0.30269920 which are placed in the Prior Center Column and locked. The AIRMASS Prior Center value should be left 0.0.

Reference stars can be selected/deselected using The Multi-plot Reference Star Settings screen – Figure 3.8.

🔁 Multi-plot	Reference	Star Settin	gs			—		×	
Select reference stars to include in tot_C_cnts and rel_flux calculations Show Magnitudes Hide Magnitudes									
Reference Sta	Reference Star Selection None All Set Cycle Enabled Stars Less One Cycle Individual Stars								
Yellow check	box border	- aperture p	oeak count o	C5 10.984 nder linearity ver linearity er saturation	limit	C7 ✓ 12.285	C8 ✓ 12.782	2	
Save/Show Current Configuration Save Table Save Apertures Send to Multi-aperture Show Apertures									

Figure 3.8. Multi-plot Reference Star Settings window

Data is saved via the Multi-plot Main screen selecting File/Save all (with options)... which brings up the Save all settings window – Figure 3.9

🔁 Save all settings		×							
0.1.17									
Select items to save when	2								
🔽 Image 🔽 Plot	🗹 Plot Config 🔽 Data Table 🔽 Apertures 🔽 Fit Panels 🔽 Fit Text 🛛 🔽 Log								
🔽 Data Subset	✓ Show Data Subset Panel								
Science Image display suffix:	_field								
Plot image display suffix:	Lightcurve								
Plot config file suffix**:	_measurements								
Full data table file suffix**:	_measurements								
Data table subset file suffix:	_datasubset								
Aperture file suffix:	_measurements								
Fit panel image suffix:	_fitpanel								
Fit data text file suffix:	_fitpanel								
Log file suffix:	_calibration								
Save images in PNG for	Save images in PNG format (uncheck for JPEG format)								
	d data table suffix the same so that the plot config data table file is opened by drag and drop.								
	Save Files Now Save Settings Only Canc	el							

Figure 3.9. Save all settings window

Deriving the exoplanet's radius is described in Exoplanet Observing for Amateurs (Second Edition (Plus), Appendix D, by Bruce Gary.

End of tutorial.