

A Guide to AstroImageJ Differential Photometry



Image Display Interface with WASP-12b Target and Comparison Aperture overlay

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1. Introduction

The BAA VSS Guide to AstroImageJ Photometry covers:

- Image reduction and photometry processing in AstroImageJ (AIJ)
- Steps in creating BAA VSS Report files from an AIJ measurements data file
- Demonstrate importing AIJ RA/Dec coordinate-based apertures into plate solved images

Chapter 10 in the AstroImageJ User Guide is a step-by-step guide to differential photometry in AstroImageJ (AIJ) based on the WASP-12b example files and is the first step in learning to use the software. The WASP-12b FITS files can be downloaded from the AIJ web site. The chapter is self-contained and can be followed without reading the entire User Guide.

This guide follows on from my article Introduction to AstroImageJ (AIJ) in the <u>June 2018 VSS Circular</u>. The aim is to assist BAA VSS members with some familiarity with AIJ in creating VSS report files using the example WASP-12b FITS files. The guide covers image reduction, importing photometry results and creating a BAA VSS report file using the VSS_Photometry spreadsheet.

Software	Version	Notes
AstrolmageJ	db3.2.1	AlJ User Guide is the main software reference; there are also a number of on-line tutorials
VSS_Photometry	V2.05 (or later)	Excel spreadsheet converts AIP4WIN and AstroImageJ photometry results to BAA VSS Report files.
WASP-12b FITS files	N/A	4GB+ download of raw image and calibration FITS files. From FITS header, these images were exposed with a red filter.

1.1. Software Summary

AlJ performs image reduction, photometry processing and calculation of target ensemble magnitude. Results are saved to a text file, *measurements.txt*. Measurements.txt is imported into VSS_Photometry for conversion to VSS Report format.

Software, example files and documentation can be downloaded from the AstroImageJ web page http://www.astro.louisville.edu/software/astroimagej/

1.2. Comments on AIJ Tutorial Guide

- The VSS_Photometry spreadsheet was designed for AIP4WIN photometry files and recently extended to import AIJ data. For the user, one obvious difference is how the two programs label the comparison star apertures, starting with C1 in AIP4WIN and with C2 in AIJ. For example, AIP4WIN would label four comparison apertures in sequence C1, C2, C3 and C4 while in AIJ the target aperture is labelled T1 then C2, C3, C4 and C5. VSS_Photometry follows the AIP4WIN format and in the Results sheet Comparisons are labelled C1, C2 ...
- 2. The aperture file used in this guide, *radec.txt*, lists J2000 coordinates and Comparison star Johnson V band magnitudes. These values were downloaded from the AAVSO VSP for WASP-12. The WASP-12b images were exposed with a red filter and, because of filter mismatch, the Results sheet in VSS_Photometry shows large (Calc-Quote) differences in the Data Checks section. In section 5, a second set of results for Landolt field SA113, exposed with a Johnson-V filter, report 'OK' Magnitude Checks for each Comparison.

2. Overview

Fig 2.1 illustrates the exchange of time-resolved photometry data between AIJ and VSS_Photometry.



Fig 2.1:Overview of AstroImageJ + VSS_Photometry Analysis Sequence

Observer settings are covered in Appendix B. The main text walks the user through each stage from initialising target data through to creating a BAA-VSS format report file.

Plate solve option: Chapter 7 of the <u>AstroImageJ Users Guide</u> covers set-up and running Astrometry.net to plate solve FITS images through AIJ. The aperture file *radec.txt* comprises a list of target and comparison star RA/Dec coordinates. Importing these coordinates into AIJ enables the software to place apertures on a plate-solved image.

The WASP-12b example files are already plate solved so this step is not required to follow this guide. *Manual aperture option*: Refer to the AstroImageJ User Guide and other tutorials for placing apertures on star images based on finder charts.

AlJ photometry results are saved in text file *measurements.txt*. VSS_photometry imports measurements.txt, computes target magnitude and exports a BAA VSS format results file.

While not required for BAA VSS photometry, AIJ also computes heliocentric (HJD) and barycentric (BJD) times taking DP Coordinate Converter observer and target parameters (see section 3.2 and Appendix B for setting up DP Coordinate Converter data).

3. Science Image Reduction

3.1. Software Setup

Setup directories and configure AIJ to follow this guide as detailed in the following appendices:

Appendix A: recommended directory set-up for example files.

Appendix B: configure AIJ and VSS_Photometry for Moore Observatory (University of Louisville) and equipment parameters

3.2. SIMBAD Coordinates

This section illustrates importing SIMBAD coordinates into the DP Coordinate Convert dialog.

- 1. Open AIJ and from the Toolbar and click P to open the CCD Data Processor and DP Coordinate Converter windows.
- 2. In DP Coordinate Converter window Fig 3.1, enter "WASP-12b" in the SIMBAD Object ID text box and press <Enter> to populate Standard Coordinates fields.

Optional: click the SIMBAD icon to open the SIMBAD web page for WASP-12b (Extra-solar Confirmed Planet)

SIMBAD Obje				18-05-11	12:2	1:37	JD: 2	458250.18	1678	LST: 01:57:07
SIMBAD Object ID (or SS Object) Time Zone WASP-12b UTC offset			Observatory ID Moore Observatory, UofL RC24, Brownsboro, KY					ownsboro, KY		
Target Prope pmRA: 0	er Motion	(mas/yr) pmDec: 0		Geog Lon:	raphic Lo -85:31:42	cation of	Observ Lat	atory +38:20:41.2	5	Alt: 229
Standard Coo Simbad R	ordinates	J2000 32.794	Equatorial Dec: +2	9:40:20.29)	Lon: 96	6:40:20.	J2000 I 33	Ecliptic Lat: (06:24:34.99
Sky-Map	RA: 06:27	B1950 21.267	Equatorial Dec: +2	9:42:26.55	;	Lon: 18	34:04:59	Gala	Lat:	08:56:11.01
UTC-based	erest I Time —									
UTC-based	UTC: 2 Local: 2	013-01-27 013-01-27	07:55:40 03:55:40	UT	19:5 19:5	58	JD: 2 HJD: 2	2456319.83 2456319.83	0324 5184	LST: 10:40:36 dT: 00:07:00
UTC-based	UTC: 2 Local: 2 Time	013-01-27 013-01-27) 🗹 Leap-se	07:55:40 03:55:40 cs: 35.0	UT	19: 07: 0SU/in	58 51 ternal 🗌	JD: 2 HJD: 2	2456319.83 2456319.83 456319.835	0324 5184	LST: 10:40:36 dT: 00:07:00 dT: 00:08:06
UTC-based	UTC: 2 Local: 2 Time Auto 1:25.369	013-01-27 013-01-27 I Leap-se Equatorial Dec:	07:55:40 03:55:40 cs: 35.0 +29:39:38.	UT	0SU/in Lon:	58 51 ternal	JD: 2 HJD: 2 BJD: 2	2456319.83 2456319.83 456319.835 — Ecliptic - La	0324 5184 i948 t. 06:2	LST: 10:40:36 dT: 00:07:00 dT: 00:08:06 4:36.44

Fig 3.1: WASP-12b Coordinates in DP Coordinate Converter

3.3. Aperture File

Create *radec.txt* aperture file and save in WASP-12b folder as detailed in Appendix C.

3.4. Reduce Science FITS Files

Image reduction steps in AIJ are:

- (i) build master calibration files and
- (ii) run science image reduction process
- 1. Select the AIJ / CCD Data Processor window and configure for building master calibration files as fig 3.2

Bias / Dark / Flat: Build and Enable selected, med (median) combine Dark: scale and deBias selected to enable exposure time scaling Note: the Science Image Processing Enable checkbox is *not* selected

DP CCD Data Pro	cessor		_	
File Preferences	View			
Control	Options	Directory	Filename/Pattern	Totals
Filename Patt	e Processing ern Matching			
Enable	Sort Num	C:\AstroImageJ\WASP-12b\Raw Science Files\	WASP-12b_*.fits	0
Filename Nur	nber Filtering	Min: 0 + Max 100000000 +	WASP-12b_*.fits	0
Bias Subtracti	on			
🗹 Build	🔾 ave 💿 med	C:\AstroImageJ\WASP-12b\Calibration Files\Bias\	🕽 *.fits	11
🗹 Enable		C:\AstroImageJ\WASP-12b\Master Calibration Files\	m_bias.fits	0
Dark Subtracti	ion			
🗹 Build	🔾 ave 💿 med	C:\AstroImageJ\WASP-12b\Calibration Files\Darks\	🕽 *.fits	11
🗹 Enable	🗹 scale 🗹 deBias	C:\AstroImageJ\WASP-12b\Waster Calibration Files\	m_dark.fits	0
Flat Division				
🗹 Build	🔾 ave 💿 med	C:\AstroImageJ\WASP-12b\Calibration Files\Flats\	🕽 *.fits 🧊	11
🗹 Enable	Remove Gradient	C:\AstroImageJ\WASP-12b\Master Calibration Files\	m_flat_R.fits	0



- To import raw calibration files, click the folder icon and navigate to the respective calibration file directory, e.g. C:\AstroImageJ\WASP-12b\Calibration Files\Bias\, etc.
 A simple file pattern (*.fits) is sufficient if each directory contains only single file type.
 Fig 3.2 shows 11 bias, dark and flat FITS files.
- To specify master calibration files, select the master calibration directory e.g. C:\AstroImageJ\WASP-12b\Master Calibration Files\. In Fig 3.2 the master calibration filenames are m_bias.fits, m_dark.fits and m_flat_R.fits. Totals = 0 indicates that no master calibration files have been saved yet. Refer section 6.5 AIJ Users Guide for details of AIJ Data Reduction Algorithms
 Click [STAPT] to initiate processing of calibration files a log window energy detailing effect.
- 4. Click [START] to initiate processing of calibration files; a Log window opens detailing offset and scaling corrections.

When the process is finished, totals = 1 indicates that the master calibration files have been saved.

5. Deselect Bias, Dark and Flat Build check boxes and select the Enable checkbox in Science Image Processing section. Specify the raw image file directory and matching pattern, Fig 3.3.

DP CCD Data Pro	cessor		-	
File Preferences	View			
Control	Options	Directory	Filename/Pattern	Totals
Filename Patt	ern Matching			
Enable	Sort Num	C:\AstroImageJ\WASP-12b\Raw Science Files\	WASP-12b_*.fits	230
Filename Nur	nber Filtering	Min: 0 🗘 Max 100000000 🗘	WASP-12b_*.fits	230

Fig 3.3: Enable Science Image Processing

6. Enable Save Calibrated Images and select 32 bit option.

Enter "Reduced_Science_Images" and "_bdf" in the Sub-dir and Suffix textboxes respectively, Fig 3.4.

NOTE: Option to select Plate Solve (on-line Astrometry.net plate solve, refer chapter 7 in AIJ Users Guide). Not required for WASP-12b files which are already plate solved.

ction —					
inearity Correction	New pixel value = 0.0E0	+ 1.0E0 + ×(PixVal) +	0.0E0 🔹 × (PixVal) ² +	0.0E0 🔹 × (PixVal)3	
Outliers 🛛 🗹 Bright	Dark Radius: 2	Threshold: 50 🜩			
Jpdates					
Plate Solve	Targe Coor	et Coordinate Source dinate Converter manual entry	Observatory Location Coordinate Converter	Source manual entry ~	
ed Images					
16	Sub-dir: Reduced_Science_Files	Suffix: _bdf	Format:	GZIP	
sing		~)			
Save Image		Macro 1	C:\Users\Owner\		0
Save Plot		Macro 2	C:\Users\Owner\	1	0
I					
	tion inearity Correction Outliers Bright Ipdates Plate Solve ed Images 0 16 @ 32 ing Save Image Save Plot	ton inearity Correction New pixel value = 0.0E0 Outliers Bright Dark Radius: 2 Ipdates Plate Solve Plate Solve Save Image Save Image Save Plot	tion inearity Correction New pixel value = 0.0E0 + 1.0E0 × (PixVal) + Outliers Plate Solve Plate Solve Plate Solve O16 32 Sub-dir: Reduced_Science_Files Suffixc_bdf Ing Save Image Macro 1 Macro 2 Macro 4	tion inearity Correction New pixel value = 0.0E0 ‡ + 1.0E0 ‡ × (PixVal) + 0.0E0 ‡ × (PixVal) ² + 0.0	tion inearity Correction New pixel value = 0.0E0 \$ + 1.0E0 \$ × (PixVal) + 0.0E0 \$ × (PixVal) ² + 0.0E0 \$ × (PixVal) ² Outliers Bright Dark Radius: 2 \$ Threshold: 50 \$ Ipdates Plate Solve Target Coordinate Source Coordinate Converter manual entry Coordinate Converter manual entry ed Images 0 16 @ 32 Sub-dir: Reduced_Science_Files Suffix bdf Format: GZIP Ing Save Image Macro 1 C:\Users\Owner\

Fig 3.4: Calibrated image options

- Click [START] to commence processing of science images. The AIJ Image Display interface opens with the first science image then cycles through each image. The Processed and Remaining counts in the CCD DP dialog monitor progress and a Log window documents the image reduction process (several minutes for WASP-12b files).
- 8. When processing science images is finished, close AIJ and move the reduced image files:
 - From: C:\AstroImageJ\WASP-12b\Raw Sciences Files\Reduced_Science_Files
 - To: C:\AstroImageJ\WASP-12b\Reduced_Science_Files

3.5. Referencing Target File Path

As an alternative to specifying full file paths, the Bias, Dark and Flat directories can be referenced to the Science Image Directory detailed in the tooltip in fig 3.5.

Filename Pat	ttern Matching	[[
Enable	Sort Num	C:\AstroImageJ\WASP-12	b\Raw Science Files\				WASP-12b_*.fits		230
Filename Nu	mber Filtering								
Enable		Min:	0 🗘	Max:	1000	000000	WASP-12b_*.fits		230
Bias Subtract	ion								
🗹 Build	🔾 ave 💿 med	\Calibration Files\Bias\					bias_*.fits		11
🗹 Enable		Waster Calibration Files	1			2	m_bias.fits		0
Dark Subtract	tion					Enter the directory	name for the master bias	image	
🗹 Build	🔾 ave 💿 med	\Calibration Files\Darks\				or browse to the d	irectory using the button t	o the right.	11
Enable	🗹 scale 🗹 deBias	Waster Calibration Files	١			-leave blank to use	tory path or: • the science image directo	ory.	0
- Flat Division -						use .\ to define a	sub-directory relative to th	e science directory.	
Build	🔾 ave 💿 med	\Calibration Files\Flats\				use\ to define a	parent directory relative to flat_r_*.fits	o the science directory.	11



7

4. AIJ Photometry

4.1. Configure Measurement Apertures

- Open AIJ and from the AIJ Toolbar, import image sequence *Toolbar | File | Import | Image Sequence* .. navigate to the Reduced_Science_Folder and select the first file (WASP-12b_00040_bdf.fits).
- The Sequence Options dialog opens, select Sort names numerically and Use virtual stack options. Click [OK] to open the first reduced science image in the AIJ Image Display Interface, Fig 4.1. The yellow N-E pointers indicate this is a plate-solved image.

Refer to chapter 5 in the AIJ Users Guide for a detailed description of available functions.



Fig 4.1: Image Display Interface: WASP-12b_00040_bdf.fits

- Option: select View and the appropriate *Invert.*. option so that N-E is orientated up and left as Fig 4.1.
- 4. Initial set-up of apertures sizes to measure Seeing Profile:

Click change aperture settings it o open the Aperture Photometry Settings window. Enter object / inner / outer radius = 20 / 24 / 30 in and [OK] to close the window. Although the exact values are not critical, the object aperture must be large enough to fully enclose the image of a single star.

5. Click toggle aperture display is a snecessary to *de-select* the sky background apertures so that the "Live Photometer" is a single circle overlay as shown in Fig 4.2a

6. Alt-Left click on a bright non-saturated star image – the star highlighted in Fig 4.1 is a good candidate. The Seeing Profile for the selected star opens in a new window, Fig 4.2b



7. Click [Save Aperture] in the Seeing Profile window to select the suggested aperture sizes then

click set in the Image Display window to confirm as shown in Fig 4.3. Optionally, edit Seeing Profile generated aperture radius values to preferred values relative to FWHM ≈ 12.5 pixel.





8. Click [OK] to close Aperture Photometry Settings window, click clear apertures .. ¹¹ to clear any aperture overlays and click ¹² to toggle display of sky apertures.

4.2. Visual Check of Image Quality

The image stack can be inspected either manually stepping through the stack or by running an animation.

- 1. Use the scroll bar controls highlighted in Fig 4.4 to inspect individual images.
- 2. Click on Click on this control left of the scroll bar to start / pause image animation. Right click on this control to set animation speed and other options.

< -79736.4 -13751.2	52233.9 115219	.8 184204.3 2561	88.1 <u>325172.7 3</u> 9	94157.2 466141.0	<u>) 535125.6 604110.1</u>	> 1 <u>688091.3</u>
-79,736.4609 :min	1,020.654	10:black	mean:1,217.2310) white:	2,003.5390 max:	688,091.3125

Fig 4.4: Image inspection controls

3. To remove an image from the stack, click M, left-most icon. Note: this function only removes the image from current photometry analysis sequence, the FITS file is *not* deleted from the Reduced_Science_Files directory.

4.3. Run AlJ Photometry

1. In the Image Display window, select *File | Import apertures from RA / Dec list* ..., navigate to and select radec.txt file to import the aperture set. Click zoom to fit .. 🔀 to re-centre the image. As shown in Fig 4.5a, initial placement will probably be offset from star centroids.



- 2. Open the Multi-Aperture Measurements window (Page Display), click [Place Apertures] to centre the apertures on star centroids (Fig 4.5b); the Multi-Aperture Help dialog opens.
- 3. Press <Enter> to start AIJ time resolved photometry processing. Several windows open, including:

Plot of Measurements: can be configured to plot relative flux and other parameters during processing. Refer section 10.2.1.10 in the AIJ Users Guide for more details about Multi-plot. Measurements window: displays a table of photometry results.

NOTE: Apertures track frame-to-frame shifts in star centroids including image rotation after a meridian flip.

- 4. When processing is complete, select *Measurements | File | Save As* .. navigate to WASP-12b director and save as "Measurements.txt", replacing existing file.
- 5. Close AlJ

5. Processing Results in VSS_Photometry

5.1. Setup VSS_Photometry Spreadsheet

- 1. Open VSS_Photometry.XLSM and select the Buttons tab.
- Click [Select Photometry Import File] button, navigate to and select measurements.txt in the WASP-12b directory.

The software automatically detects the photometry file format and the Type field displays: 'AstroImageJ'.

- 3. Click [Select Export Directory] button, navigate to and select the WASP-12b directory.
- In BAA VSS report file name textbox, enter "BAAVSS WASP-12b.txt".
 Fig 5.1 shows the Buttons sheet with WASP-12b directory and file names, including AAVSO report file.

Select Photometry		Directory:	C:VAstroImageJ/WASP-12b
Import File		File name:	measurements.txt Type: AstroImageJ
Select Export	E	eport directory:	C:\AstroImageJ\WASP-12b
Directory	BAA VSS r		BAAVSS WASP-12b.txt
	AAVSO r	eport file name:	AAVSO WASP-12b.txt
Select Equipment/Ob	ject Settings	Directory:	C:\Users\User\Documents\Astronomy\VSS\Photometry Spreadsheets 3C66A Template B2.03.xls Optional
File or Old Version of	Spreadsheet	File name:	
Import Photometry	/ File	Create BAA V	SS Report File Create AAVSO Report File Load Save Equipment/Object Settings Settings

Fig 5.1: Buttons sheet configured for WASP-12b

5. Select the Results sheet, clear previous entries and enter *red-text* data as shown in Fig 5.2. Star Designation and Reference Magnitude values taken from *radec.txt*, see Appendix C.

-							
	Observation	n Summary	columns W and X	R	ed - Requ	ired, Blue -	Optional,
			icer explanation				
	Chart	AAVSO WASP-12b	Star-Apertu	re			Airr
	Filtor	V	Sky Annulu	S			Observa
	r iiter	v	Inner Radius	s			Block
	Photometry Time	Start Exposure	Sky Annulu	S			Julian D
	Stamp	Statt Exposure	Outer Radiu	IS			Julian Di
	Timing Error	1.00	Automati	cally		Check	or
			populated	1		AAV50	only
	Star Data & Su	ummary Calculation	s (Individual V	/ariab	le Measu	rements to	Right)
			<u>User Inp</u>	<u>ut</u> /		1	
		Star	AIP4WIN	l (Ir	clude in	Refere	nce 🧯
	Туре	Designation	Star	_ _ /	Analysis	Magnitude	Error
	AAVSO Results	WASP-12b	Var				
	BAAVSS Results	WASP-12b	Var				-
_	Comparison	000-BKG-164	C1		Yes	9.453	
	Comparison	000-BKG-165	C2		Yes	9.747	
	Comparison	000-BKG-166	C3		Yes	10.568	
_	Comparison	000-BKG-420	C4		Yes	10.984	
	Comparison	000-BKG-421	C5		Yes	11.697	
_	Comparison	000-BKG-167	C6		Yes	12.285	
	Comparison	000-BKG-168	C7		Yes	12.782	
	Comparison						

5.2. Import Results in VSS_Photometry

- 1. Select the Buttons sheet, click [Import Photometry File] button and close dialogs when data import is finished.
- 2. Select Results sheet Fig 5.3

Note: The large Calc-Quoted Differences (red coloured cells) resulting from a mismatch between V-band Reference magnitudes and WASP-12b imaged with red filter (see comments in section 1.2). Refer to Appendix F for an example of reference star photometry results

Star Data & Su	ummary Calculations	(Individual Variable Measurements to Right)				delete	not space				
		User Input	1	1		/	Res	ults		Data Checks	s
	Star	AIP4WIN	Include in	Refere	nce	Average	Average	Std Dev	Average	Calc - Quoted	
Туре	Designation	Star	Analysis	Magnitude	Error	Magnitude	Error	Magnitude	Weight	Difference	1
AAVSO Results	WASP-12b	Var				11.683	0.041	0.009			
BAAVSS Results	WASP-12b	Var				11.683	0.041	0.009			
Comparison	000-BKG-164	C1	Yes	9.453		9.556	0.041	0.002	0.395	0.103	Γ
Comparison	000-BKG-165	C2	Yes	9.747		9.739	0.041	0.004	0.323	-0.008	
Comparison	000-BKG-166	C3	Yes	10.568		10.464	0.041	0.003	0.139	-0.104	
Comparison	000-BKG-420	C4	Yes	10.984		10.791	0.041	0.003	0.092	-0.193	
Comparison	000-BKG-421	C5	Yes	11.697		11.539	0.041	0.004	0.033	-0.158	
Comparison	000-BKG-167	C6	Yes	12.285		12.257	0.041	0.004	0.011	-0.028	
Comparison	000-BKG-168	C7	Yes	12.782		12.697	0.041	0.005	0.006	-0.085	
-	1					1				1	

Fig 5.3: Results sheet for WASP-12b photometry V-band reference / R-filter exposures

- 3. To remove a comparison star from photometry analysis, click on the 'Yes' entry in the 'Include in Analysis' column and select 'No' from the drop down options
- 4. To select a Check star for submitting AAVSO report, click on 'Yes' entry then select 'Check'. In Fig 5.4, 000-BKG-420 is de-selected from analysis and 000-BKG-421 selected as the AAVSO check star.

Star Data & St	ummary Calculations	(Individual Variable Measurements to Right)					
		<u>User Input</u>	/	1			
	Star	AIP4WIN	Include in	Referen	се		
Туре	Designation	Star 🍼	Analysis	Magnitude	Error		
AAVSO Results	WASP-12b	Var					
BAAVSS Results	WASP-12b	Var					
Comparison	000-BKG-164	C1	Yes	9.452			
Comparison	000-BKG-165	C2	Yes	9.747			
Comparison	000-BKG-166	C3	Yes	10.568			
Comparison	000-BKG-420	C4	No	10.984			
Comparison	000-BKG-421	C5	Check	11.697			
Comparison	000-BKG-167	C6	Yes	12.285			
Comparison	000-BKG-168	C7	Yes	12.782			

Fig 5.4: Results sheet Yes / No / Check selections

5.3. Export BAA VSS or AAVSO Report Files

To create a BAA VSS formatted report file, select the Buttons sheet and click [Create BAA VSS Report File] button to save e.g. ..\WASP-12b\BAAVSS WASP-12b.txt.

To create an AAVSO formatted report file, select the Buttons sheet and click [Create AAVSO Report File] button to save e.g. ..\WASP-12b\AAVSO WASP-12b.txt.

6. Summary

Analysing time series photometry images in AstroImageJ is relatively straightforward: the more complex software features, including multi-plot, de-trending data and multivariate transit fit analysis, are not required for creating VSS Report files.

In addition to variable star photometry, other cases where BAA members might consider using AstroImageJ include:

- For observers who are new to stellar photometry, AstroImageJ is free to down-load with several sets of example data on the AIJ home page and other sites.
- AAVSO recommends AstroImageJ for exoplanet photometry. Chapter 7 in <u>A Practical Guide to</u> <u>Exoplanet Observing</u> (Dennis Conti) describes using AIJ for this application. This chapter also works with a WASP-12b data set and covers Multi-plot functions in detail.
- Asteroid light curve photometry: in the Multi-plot Main window, select File | Create Minor Planet Centre (MPC) format .. to create MPC formatted data.
- More experienced observers might consider AstroImageJ as an alternative to AIP4WIN, for example. The user forum is well supported by Karena Collins at the University of Louisville. AstroImageJ release notes are listed <u>here</u>.

Users familiar with other photometry software should find the transition to AIJ fairly straightforward. All users are encouraged to check out the AIJ website referenced in the Introduction section for a functions list, tutorials and link to the AIJ forum.

Appendix A: Example File Directories

After downloading WASP-12b raw image and calibration example files (over 4GB) set up directories as Fig A1.1.

Create and save a blank text file *measurements.txt* in the WASP-12b folder.

radec.txt is the WASP-12b aperture file used in this guide, see Appendix C.

📙 🛃 🚽 C:\AstroImageJ\WASP-12b					-		×
File Home Share View							^ 🕐
Image: Pin to Quick access Copy Paste Pin to Quick access Paste shortcut	Move Copy to T	■ Rename	New item •	Properties	Select all		
Clipboard	Organise		New	Open	Select		
← → × ↑ 📙 > This PC > System (C	:) > AstroImageJ > WAS	P-12b		~ Ö	Search WASP-12b		Q
🏪 System (C:)	^	Nam	ne ^	Date modified	Туре	Size	
Astro			Calibration Files	12/05/2018 11:26	File folder		
🔥 AstroImageJ			Master Calibration Files	12/08/2018 09:54	File folder		
WASP-12b			Raw Science Files	12/08/2018 10:13	File folder		
Calibration Files			Reduced_Science_Files	12/08/2018 10:12	File folder		
Bias			measurements.txt	14/08/2018 15:25	TXT File		0 KB
Darks			radec.txt	11/08/2018 12:44	TXT File		1 KB
	_						
Master Calibration Files							
Raw Science Files							
Reduced_Science_Files	~	<					>
6 items 1 item selected 0 bytes							:::: >

Fig A1.1: WASP-12b directories used in text

Appendix B: Configure Software

Set up observer location and equipment parameters in AIJ and VSS_Photometry, and configure multi-aperture settings in AIJ.

NOTE: Boxed sections detail important instructions for configuring AstroImageJ software.

- 1. Open VSS_Photometry and select ObsvEqmt sheet
- 2. To follow the tutorial using WASP-12b example files, input University of Louisville into Observer & Equipment fields shown in Fig B1.1 and save changes:

Observer & Equipment Details Red - Re						uired, Blue ·	- Optional
Observer Details							
BAAVSS Observer Code	UOL						
AAVSO Observer Code							
Observer Name	Universi	ty of L	ouisville, K	Y			
Location Details							
Location Code	No long	er use	d				
	Deg		Min	Sec	Hem		
Latitude		38	20	41	N		
Longitude		85	31	42	W		
Height (m)		230					
Telescope Details							
Telescope Short Description	RC 0.6r	n f/8					
Description	RC Opti	cal Sy	stems Uof	_ MORC24			
Aperture (mm)		610					
Focal Length (mm)		4900					
C D / "							
Camera Details							
Observation Method	CCD						
Camera	U16M						
Pixel Size (arcsec)		0.38	0.38				
Gain (e-/ADU)		1.25					
Dark Current (e-/pixel)		0.20					
Readout Noise (e-/pixel)		9					

Fig B1.1: Details for WASP-12b example files

- 3. Open AIJ and from the Toolbar click DP to open the DP Coordinate Converter window.
- 4. In the DP CC window, click Preferences and select Use custom observatories list (...). Close AIJ then re-open AIJ and the AIJ / DP CC window
- 5. Click on Observatory ID and select *Moore Observatory, UofL, RC24, Brownsboro, KY*, Fig B1.1a.
- 6. Informative only: Edit Time Zone / UTC offset for Eastern Standard Time.

🔊 DP Coordinate Converter	
e Preferences Network Help	
Current UTC-based Time UTC: 2018-09-15 08:49:54 Lo	cal: 2018-09-15 10:49:54 JD: 2458376.867991 LST: 02:44:52
SIMBAD Object ID (or \$\$ Object) WASP-12b	Time Zone UTC offset: 4 Moore Observatory, UofL RC24, Brownsboro, KY
Target Proper Motion (mas/yr) pmRA: 0 pmDec: 0	Geographic Location of Observatory Lon: -85:31:42.51 Lat +38:20:41.25 Alt 229

Fig B1.1a: Observatory ID and Time Zone

- 7. To set up a custom observatory, navigate to the AIJ home directory and edit *observatories.txt* to add a new entry formatted as specified in the file header. Close observatories.txt and save changes. The new observatory should now be available from the Observatory ID drop-down.
- 8. Select the CCD Data Processor window. In the FITS Header Updates section, select options:
 - Target Coordinate Source: Coordinate Converter manual entry

Observatory Location Source:

Coordinate Converter manual entry

FITS Header Updates	* 🛐 🤊	Target Coordinate Source Coordinate Converter manual entry	Observatory Location Source Coordinate Converter manual entry ~
Save Calibrated Images			[

Fig B1.2: Target and Observatory data imported from DP CC settings

9. Click 📧 to open the General FITS Header Settings panel Fig B1.3

😸 General FITS Header Settings	-	
FITS Header Input Settings		
Target Name Keyword:	OBJECT	
Target RA Keyword:	RA	Degrees
Target DEC Keyword:	DEC	
Observatory Name Keyword:	OBSERVAT	
Observatory Latitude Keyword:	SITELAT	negate
Observatory Longitude Keyword:	SITELONG	🗹 negate
FITS Header Output Settings		
Target J2000 RA Keyword:	RAOBJ2K	🗹 enable
Target J2000 DEC Keyword:	DECOBJ2K	🗹 enable
Target RA Keyword:	OBJCTRA	🗸 enable
Target DEC Keyword:	OBJCTDEC	🗸 enable
Target Altitude Keyword:	ALT_OBJ	🗸 enable
Target Azimuth Keyword:	AZ_OBJ	🗸 enable
Target Hour Angle Keyword:	HA_OBJ	🗸 enable
Target Zenith Distance Keyword:	ZD_OBJ	🗹 enable
Target Airmass Keyword:	AIRMASS	🗹 enable
JD (UTC) start-Obs Keyword:	JD_SOBS	🗸 enable
JD (UTC) mid-Obs Keyword:	JD_UTC	enable
HJD (UTC) mid-Obs Keyword:	HJD_UTC	🗹 enable
BJD (TDB) mid-Obs Keyword:	BJD_TDB	enable
Observatory Latitude Keyword:	SITELAT	🗹 enable
Observatory Longitude Keyword:	SITELONG	🗸 enable

Fig B1.3: Setup FITS Header Keywords

- Enable all the FITS Header Output keywords as shown. The important keywords are Airmass and JD-based times, the others are informative.
 The FITS Header Input Settings section is not used; Target and Observatory details are imported from the DP Coordinate Converter window
- 11. Close the FITS Header Settings dialog.

12. Click in the Control Panel row (bottom row) of the CCD DP window to open the first of two rather busy dialog windows, Fig B1.4.

Aperture Photometry Settings		×
Radius of object aperture Inner radius of background annulus Outer radius of background annulus	< > 16 < > 28 < > 42	
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)	
Centroid apertures Use Howell cer	troid method 🔲 Fit background to plane 🛛 🔽 Remove stars from backgnd 🔲 Mark removed pixels	
Use exact partial pixel accounting in source aper	ures (if deselected, only pixels having centers inside the aperture radius are counted)	
Prompt to enter ref star absolute mag (required it	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,CCD-TEMP,EXPTIME,RAOBJ2K,DECOBJ2K	
CCD gain	1.25 [e-/count]	
CCD readout noise	9.000000 [e-]	
CCD dark current per sec	0.010000 [e-/pix/sec]	
or - FITS keyword for dark current per exposure [e-/pix]		
🔽 Saturation warning ('Saturated' in table) (red bord	er in Ref Star Panel)	
for levels higher than	55000	
Linearity warning (yellow border in Ref Star Pane)	
for levels higher than	30000	
	OK More Settings Can	cel

Fig B1.4: Page 1 of 2 Aperture Photometry Settings



- 13. Enter values for CCD gain, CCD readout noise and pixel dark current (e-/pix/sec) listed below, estimate values for the U16M camera used for WASP-12b test images.
- 14. Check FITS keywords in measurements table include:

JD_SOBS, JD_UTC,HJD_UTC,BJD_TDB,AIRMASS,CCD-TEMP,EXPTIME (*or* EXPOSURE), RAOBJ2K,DECOBJ2K

15. Confirm check boxes are selected as indicated

Other settings:

Aperture radii settings in the upper section, these are set in main text.

Below that are a number of options with default selections.

Keywords to include in FITS header correspond to the General FITS Header settings dialog.

- 16. Click [More Settings] to open the second window. All except the last item are selected (Clear overlay before use).
- 17. Close the Aperture Photometry Settings dialog.



Fig B1.5: More Aperture Photometry Settings dialog

Note: Single and Multi-Aperture selections (24)

Appendix C: Target and Comparison Aperture File

Copy / Paste box text into a text editor and save as *radec.txt* in WASP-12b folder.

```
#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-BKG-166, 06:30:39, +29:37:40, 1, 1, 10.568
#000-BKK-420, 06:30:16, +29:33:45, 1, 1, 10.984
#000-BKK-421, 06:29:51, +29:40:46, 1, 1, 11.697
#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
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
#
```

File format:

1 st character :	'#' => comment line ignored by AIJ
RA, Dec:	J2000 coordinates in HH:MM:SS and +/-dd:mm:ss formats
Ref Star:	0 => Target, 1 => Comparison
Centroid:	1 => centre aperture on star centroid
Magnitude:	99.999 => no magnitude (target star)
	otherwise catalog magnitude (comparison star)

Appendix D: Required FITS Header Terms

The AIJ results file Measurements.txt must contain the following fields. If any are missing then attempts to import measurements data will be aborted with appropriate error message :

	Field	Notes
1	EXPTIME / EXPOSURE	Exposure time in seconds. [1]
2	JD_SOBS	Julian Date at start of exposure
3	JD_UTC	Julian Date at mid-exposure
4	Label	FITS filename
5	N_Sky_Pixels_T1	No. pixels in T1 sky aperture (outer annulus)
6	N_Src_Pixels_T1	No. Pixels in T1 source aperture (centre aperture)
7	Sky/Pixel_T1	Sky background flux / pixel
8	Sky_Rad(Max)	Sky annulus outer radius (pixel)
9	Sky_Rad(Min)	Sky annulus inner radius (pixel)
10	slice	Image stack index
11	Source_Radius	Source aperture radius (pixel)
12	Source_SNR_C2	Computed SNR for first comp star
13	Source_SNR_T1	Computed SNR for target star
14	Source-Sky_C2	Sky-corrected flux for 1 st comp star
15	Source-Sky_T1	Sky-corrected target flux

[1] EXPTIME or EXPOSURE are valid FITS header fields for AstroImageJ data processing; VSS_Photometry v2.06 or later can import data containing either keyword.

Appendix E: AstroImageJ Windows Installation Packages

Link to AIJ installation packages (if this link fails, then an internet search for "AstroImageJ" should locate the home page and download links):

(https://www.astro.louisville.edu/software/astroimagej/installation_packages/

NOTE: Boxed sections detail important instructions for installing AstroImageJ software.

Index of /software/astroimagej/installation_packages

	Name	Last modified	Size	Description
2	Parent Directory		-	
ľ	AstroImageJ installation linux.html	2014-12-07 01:05	39K	
Ē	AstroImageJ installation mac.html	2017-01-20 12:15	5.3K	
Ē	AstroImageJ installation windows.html	2014-12-07 01:23	54K	
L)	AstroImageJ script.tar.gz	2014-12-07 18:05	1.2K	
Ē	AstroImageJ user guide 2.0 partial.pdf	2014-12-07 17:50	1.9M	
L)	AstroImageJ v3.2.0 20160201 linux.tar.gz	2016-02-01 04:16	7.7M	
Þ	AstroImageJ v3.2.0 20160201 mac.zip	2016-02-01 02:30	10M	
Þ	AstroImageJ v3.2.0 20160201 windows.zip	2016-02-01 03:52	7.9M	
D.	AstroImageJ v3.2.0 20170222 windows java7 x32.zip	2017-02-22 05:41	51M	
Ð	AstroImageJ v3.2.0 20170222 windows java7 x64.zip	2017-02-22 05:39	54M	
?	Xresources	2014-12-07 17:49	412	

Fig E1: AstroImageJ Installation Packages

The highlighted links will download either Windows 32 or 64 bit versions plus a copy of the Java runtime engine. The next figure shows a typical installation:

ciipuoaru	Organise	NEW OF	Jein Select		
\leftrightarrow \rightarrow \checkmark \uparrow \square \rightarrow This PC \rightarrow System (C:) :	> AstrolmageJ		~ Ō	Search Astrolmage.	م ر
🗸 🛄 Desktop	^	Name	Date modified	Туре	Size
> OneDrive		📙 jre	18/08/2018 14:30	File folder	
> 🤱 ffl		luts	18/08/2018 14:31	File folder	
✓		macros	18/08/2018 14:31	File folder	
3D Objects		META-INF	18/08/2018 14:31	File folder	
			18/08/2018 14:31	File folder	
> Desktop		release_notes_files	18/08/2018 14:31	File folder	
> 🟥 Documents		🖬 about.jpg	18/08/2018 14:30	JPG File	2 KB
> 👆 Downloads		AstrolmageJ.cfg	18/08/2018 14:31	CFG File	1 KB
> 🎝 Music		👒 AstrolmageJ.exe	18/08/2018 14:30	Application	196 KB
> 📰 Pictures		🗞 astronomy_icon.ico	18/08/2018 14:30	lcon	32 KB
> 🏝 rfl (astro-pc)		astronomy_icon.png	18/08/2018 14:30	PNG File	10 KB
(B) Current P-2		file_extension_association_help.txt	18/08/2018 14:30	TXT File	2 KB
S U- SymAS		🕌 ij.jar	18/08/2018 14:30	Executable Jar File	7,102 KB
> 📔 Videos		JavaScriptEvaluator.class	18/08/2018 14:30	CLASS File	2 KB
✓ L System (C:)		📓 LICENSE.txt	18/08/2018 14:30	TXT File	35 KB
> 📙 Astro		MacAdapter.class	18/08/2018 14:30	CLASS File	2 KB
> 🔄 AstrolmageJ		📔 README-64bit.txt	18/08/2018 14:30	TXT File	2 KB
> Intel		release_notes.html	18/08/2018 14:30	Firefox HTML Doc	222 KB
18 items	~				

Fig E2: AIJ Installation

Folder jre contains the java runtime engine. File AstroImageJ.cfg is a short text file which is created when AIJ is run for the first time. A Windows Defender Firewall dialog may open, select [Allow access], close and re-open the AstroImageJ toolbar.



Link to the WASP-12b example files; Windows users can download the large *WASP-12b example uncalibrated images.zip* file (4.4GB)

https://www.astro.louisville.edu/software/astroimagej/examples/

Note: AIJ can run from a USB memory stick configured with the installation files and directories in Fig E2

Appendix F: V-Band Photometry of Landolt Reference Stars

Fig F1 shows the results of an imaging series taken with a V-Johnson filter. The Calc-Quoted Differences are less than 0.015 mag and all Magnitude Checks are flagged 'OK'.

The SA113 objects are Landolt reference stars with mmag uncertainties in catalog V-band magnitudes.

Star Data & Su	ummary Calculations	(Individual Vari	able Measu	rements to f	Right)	/ delete	not space)	DAAVSS	sneet and AAV	SU sneet		
		User Input	1	/		/	Res	<u>ults</u>		Data Checks	(Cells Turn R	led when Limit	Exceeded)
	Star	AIP4WIN	Include in	Referer	псе	(Average	Average	Std Dev	Average	Calc - Quoted	Min	Max	Magnitude
Туре	Designation	Star	Analysis	Magnitude	Error	Magnitude	Error	Magnitude	Weight	Difference	Magnitude	Magnitude	Check
AAVSO Results	SA113-339	Var				12.241	0.004	0.005			12.248	12.231	
BAAVSS Results	SA113-339	Var				12.241	0.004	0.005			12.248	12.231	
Comparison	SA113-259	C1	Yes	11.742		11.745	0.004	0.002	0.445	0.003	11.748	11.743	OK
Comparison	SA113-233	C2	Yes	12.398		12.407	0.004	0.004	0.198	0.009	12.412	12.398	OK
Comparison	SA113-260	C3	Yes	12.406		12.393	0.004	0.003	0.202	-0.013	12.399	12.388	OK
Comparison	SA113-239	C4	Yes	13.038		13.041	0.005	0.005	0.084	0.003	13.048	13.029	OK
Comparison	SA113-250	C5	Yes	13.160		13.154	0.005	0.007	0.071	-0.006	13.167	13.140	OK
Comparison													

Fig F1: Results sheet for SA113 photometry V-band reference / V-filter exposures

Appendix Z: Document Change Record

Revision Date	Notes
15 Sept 2018	Initial release
20 Oct 2018	Changes to Appendices to assist installing AstroImageJ, updating to db 3.2.1 and Aperture settings required to import data into the VSS_Photometry spreadsheet. Key instructions are highlighted in blue-shaded text boxes, including EXPTIME / EXPOSURE conversion implemented in VSS_Photometry v2.06
	Extended list of FITS header terms in Appendix D
21-Oct-2018	Changes following user comments:
	Section 2: clarify plate solve is optional and highlight manual aperture placement (latter option is covered in AIJ Users Guide)
	Section 4.1, optional setting N-E orientation
	Section 5.2: Add Fig 5.4 and text to illustrate Yes / No / Check selections in 'Include in Analysis' column. Add option to save AAVSO report file and move Landolt reference star photometry to Appendix F