

Workflow based Guide to using AstroImageJ for Exoplanet Transit Photometry

Part 1

(Full Guide)

										 Type: Spec:		×2
ort By	Ap	ObjectId	Ra2000	Dec2000	Mag	Mag Err	Mag diff	Dist	Nobs	 · · · ·		
Distance Delta Mag	T01	wasp 12	06:30:32.80 06:30:32.79	+29:40:20.26 +29:40:20.33	11.400	0.000	0.000	0.00	1		· O	
election Filters + DSS FITS	C02	06303279+29402033 06303188+29422730	06:30:32.79	+29:40:20.33 +29:42:27.30	11.415 11.983	0.070	0.015	2.13	4		$\smile_{\rm cu}$	0
	C02	06304827+29393591	06:30:48.27	+29:42:27:50	11.381	0.081	-0.019	3.44	5		•.	0 0
Save DSS Fits File	C04	06305007+29385436	06:30:50.07	+29:38:54.36	11.773	0.060	0.373	4.02	5		•	- C10 (
Apply mag limits	C05	06302262+29444221	06:30:22.62	+29:44:42.21	11.554	0.080	0.154	4.89	4		•	•
Upper Mag: 0.8 0 12.2	C06	06302000+29330320	06:30:20.00	+29:33:03.20	11.775	0.077	0.375	7.80	4		· •	
	C07	06295778+29380133	06:29:57.78	+29:38:01.33	11.892	0.082	0.492	7.95	4			
Iominal Mag: 11.4 🗘 .	C08	06305893+29342229	06:30:58.93	+29:34:22.29	11.901	0.061	0.501	8.24	5	· ·	0	
Lower Mag: -0.5 0 10.9	C09	06295157+29404647	06:29:51.57	+29:40:46.47	11.268	0.090	-0.132	8.97	4	0	\bigcup_{as}	
		06304354+29493334	06:30:43.54	+29:49:33.34	11.723	0.066	0.323	9.51	4	C12	_	
lobs (APASS) 1 🗘	C10	06300448+29495088	06:30:04.48	+29:49:50.88	11.831	0.083	0.431	11.32	4			
	C11	06301904+29513387	06:30:19.04	+29:51:33.87	11.629	0.062	0.229	11.62	4	127	002	
	C12	06312367+29441027	06:31:23.67	+29:44:10.27	11.159	0.058	-0.241	11.69	7	i .	- +	•
atalog Record Counts	C13	06312820+29385229	06:31:28.20	+29:38:52.29	11.974	0.054	0.574	12.12	7		8	
Total records: 418	C14	06301214+29284998	06:30:12.14	+29:28:49.98	11.319	0.082	-0.081	12.35	4	O	U as	
Filtered records: 18	C15	06295591+29501979	06:29:55.91	+29:50:19.79	11.947	0.083	0.547	12.80	4		9105	O _m
elected records: 16	C16	06294772+29490762	06:29:47.72	+29:49:07.62	11.869	0.090	0.469	13.15	4	•		
	C17	06310779+29280862	06:31:07.79	+29:28:08.62	12.040	0.057	0.640	14.37	4			
uery Data												
D: wasp 12 FOV: 25.0										· · · · · ·	C08 _ *103	
A: 06:30:32.80 Dec: +29:40:20.26											• • • • • • • • • • • • • • • • • • • •	•
atalog: APASS Filter: SR Mag: <15.0											005	• 11
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Selected WASP12 APASS records Observation Planner | Catalogs Tab.

Richard Lee

24 January 2023

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1. Introduction

Part 1 of the AstroImageJ User Guide (this document) covers installation of AIJ and supporting software, providing detailed instructions to configure software for processing exoplanet photometry. Part 1 examples are based on WASP12 dataset which can be downloaded from the AIJ website (see Appendix).

Part 2 is a short form guide for more experienced users, based on processing WASP104 dataset.

1.1. Overview

Section 2 covers installing and setup of AstroImageJ v5and Observation Planner plugin software. Note that downloading and configuring ansvr plate solve software is covered in an Appendix.

Section 3 covers observation planning. The section walks through running the Observation Planner plugin to generate a radec file to import aperture coordinates into AIJ.

Section 4 covers image reduction in AIJ. The user configures the CCD Data Processor window to import WASP12 raw science and calibration fits files, then runs the image reduction process. Fits image files can be plate solved using ANSVR or ASTAP software.

Section 5 covers photometry analysis in AIJ. The user imports the image set and, based on visual inspection, may remove poor quality images from the processing stack. This section is largely based on Section 4 in ref [1].

Section 6 covers AstroImageJ Multi-plot (MP) windows configured to plot transit and other data sets. The three plot configuration windows are complex and Dennis Conti's Guide (ref [2]) was invaluable in preparing this section.

Section 7 briefly covers modelling transit data in AIJ to compute transit timing and depth parameters. This section also leans rather heavily on ref [2].

Tutorial file paths and user instructions are for Win10 or Win7. Both options for plate solving software are currently Windows-only. With this exception, most procedures should apply on Linux, although this is untested.

Best Practice: Closing AstroImageJ toolbar after parameter changes

On closing, AIJ saves current configuration data to AIJ_Prefs.txt file. On my PC the path to this file is C:\Users\rlee1\.astroimagej\AIJ_Prefs.txt.

To ensure any changed settings are saved:

- Close any open windows, DP Coordinate Converter, CCD DP Data Processor, etc
- Close the AIJ toolbar through either Toolbar | File | Quit or Toolbar | Close icon
- Re-open AIJ and confirm the new settings have been retained.

1.2. AstroImageJ v5

Version 5 was released in January 2022. Refer below for a link to AIJ forum for an overview of new features introduced in this version.

Functions to set variable apertures have been enhanced in AIJ v5. In non-crowded star fields, variable apertures would be useful in cases where significant defocus occurs over an observation session. AIJ v5 also introduces Auto comparison star option as an alternative to importing radec coordinate based apertures covered in this Guide. These enhanced or new features can be accessed on the Multi-Aperture Measurements window.

1.3. Resources

BAA On-line Resources

Links to BAA files and folders; refer section 2 for instructions to download, unzip and copy to C:\Astro sub-folders

Title	Link
BAA.Files for AIJ Guide Part 1	BAA AIJ
BAA.Files for AIJ Guide Part 2	

WASP12b dataset

Title	Link
Example data for User Guide Part 1	<u>AlJ Home</u>

Plate Solve Software

Title	Link
ANSVR Plate Solve Software	ANSVR
ASTAP Plate Solve Software	<u>ASTAP</u>

References:

Ref	Title	Link
[1]	A Guide to AstroImageJ Differential Photometry	<u>BAA Guides</u>
[2]	A Practical Guide to Exoplanet Observing	
[3]	AstroImageJ: Image Processing and Photometric Extraction for Ultra-Precise Astronomical Light Curves (Expanded Edition), Karen Collins, et al	<u>AIJ Home</u>
[4]	AstroImageJ 2.4.1 User Guide	
[5]	BAA Photometry Spreadsheet (version 2.10)	BAA Spreadsheet
[6]	Guide to using ASTAP Solver for AstroImageJ	Ref link BAA_AIJ

Other On-line Resources

Title	Link
AAVSO Variable Star Plotter	<u>VSP</u>
<u>A</u> AVSO <u>P</u> hotometric <u>A</u> ll Sky <u>S</u> urvey	APASS Home
Digitized Sky Survey	<u>DSS Wiki</u>
NASA Exoplanet Archive	NASA Exo
EXOFAST - Quadratic Limb Darkening	<u>EXOFAST</u>
SIMBAD Astronomical Database – CDS (Strasbourg)	<u>SIMBAD</u>

2. Install Software

2.1. Download BAA Support Files

- 1. If necessary, create a new folder C:\Astro\Downloads.
- 2. From the BAA web site (select link BAA_AIJ in section 1), download and save 'BAA.Files for AIJ Guide Part 1.zip' in the C:\Astro\Downloads folder.
- Extract files to the Downloads folder; the path to uncompressed folders is: C:\Astro\Downloads\BAA.Files for AIJ Guide Part 1 (folder contains plugins, plotcfg and other files)

2.2. Download AstroImageJ v5 (or later)

Link to AstroImageJ installation packages:

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

1. Download AstroImageJ 5.x windows x64 java18

Index of /software/astroimagej/installation_packages

	Name	Last modified	<u>Size</u>	Description
2	Parent Directory		-	
	<u>AstroImagel_installation_linux.html</u>	2022-06-16 01:39	5.7K	
	<u>AstroImageJ_installation_mac.html</u>	2022-01-05 03:40	59K	
Ē	<u>AstroImagel_installation_windows.html</u>	2014-12-07 01:23	54K	
- 🚺	<u>AstroImagel_script.tar.gz</u>	2022-06-16 01:08	1.0K	
<u></u>	AstroImageJ_v5.1.0.00_linux_x64_java18.tar.gz	2022-07-04 04:48	117M	
2	<u>AstroImageJ_v5.1.0.00_mac_intel_java18.dmg</u>	2022-07-25 20:43	75M	
L.	AstroImageJ_v5.1.0.00_windows_x64_java18.zip	2022-07-04 04:36	108M	
	<u>Older_versions/</u>	2022-07-26 13:51	-	
?	Xresources	2014-12-07 17:49	412	

Apache Server at www.astro.louisville.edu Port 443

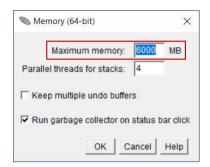
- 2. To follow instructions in this guide, copy and rename the uncompressed AstroImageJ folder to: C:\Astro\AstroImageJ.
- 3. Run AstroImageJ and, if the AstroImageJ Updater dialog opens, click [OK] to upgrade to 'daily build'.
- 4. To check the installed version, open AIJ and from the toolbar select Help | About AstroImageJ ... The About AstroImageJ dialog opens with installed version (5.2.0.06 at time of writing

2.3. Configure AstroImageJ v5

2.3.1. Configure AIJ Memory Allocation

Example to setup AIJ memory allocation to access up to 75% of installed RAM, in this case 6 GB of 8 GB installed RAM.

1. From the AIJ Toolbar, select Edit | Options | Memory & Threads .. to open the Memory (64-bit) dialog.



2. Enter 6000 in Maximum memory text box and click [OK] to close dialog, then close and re-open AIJ to register changes.

2.3.2. Configure DP Coordinate Convert Dialog

- 1. In the toolbar, click e, CCD Data Processor Tool, to open the CCD Data Processor and DP Coordinates Converter windows.
- 2. In the CCD Data Processor | FITS Header Updates section, set the Target and Observation Source drop-downs to 'Coordinate Converter Manual Entry'.

FITS Header Updates			
General 🗌 Plate Solve	* 📉 🤊	Coordinate Source Coordinate Converter manual entry	Coordinate Converter manual entry
Save Calibrated Images			

The caliper icon 🗾 toggles display of the DP Coordinate Converter window.

3. In the DP Coordinate Converter window, click on 'Preferences' menu header then check / uncheck the Preference settings as below:

10	Coord	inate Converter						
File	Preferences Network Help							
	3	Show coordinates in sexagesimal format Use computer time zone, deselect to manually enter offset from UTC Use 12-hour local clock format, deselect to use 24-hour format	D					
ſ	~	Show local twilight time, deselect for UTC format	10					
	~	Report SSBs as 'DOWN', deselect to show negative altitude	rv:					
T1	~	Show tool tips	54					
	~	Use custom observatory list (restart of AstroCC required)	_a					
	4	Include proper motion correction						
	4	Include precession correction	23					
r	~	Include nutation correction						
	~	Include stellar aberration correction)4					
E	~	Include atmospheric refraction correction to altitude	F					

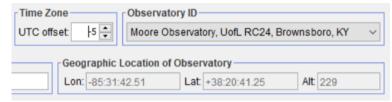
Notes:

- Deselect the 2nd item to manually enter offset from UTC,
- Option to use either 12- or 24-hour clock formats
- Select the 'Use custom observatory list (...)' item.
- 4. To register selections, close and re-open the AIJ toolbar, and click P to open the DP Coordinate window. Confirm Preferences menu settings are as shown above.

2.3.3. Select Observatory Location

Instructions to select an existing observatory location (Moore Observatory, RC24) in the DP Coordinates Converter window (refer Appendix).

- 1. Open AIJ and in the toolbar click P to open the DP Coordinates Converter window.
- 2. Select Moore Observatory, UofL RC24, Brownsboro, KY from the Observatory ID drop down and set the Time Zone UTC Offset to -5.
- 3. Confirm Geographic Location of Observatory as below:



2.3.4. Setup a New Observatory Location

Instructions to add a new custom observatory entry (ICAstronomy) to observatories.txt (refer Appendix).

- 1. Navigate to and open observatories.txt file in a text editor; observatories.txt is in the AIJ home folder C:\Astro\AstroImageJ\observatories.txt.
- 2. Add a new entry in the #Custom Entries list with Observatory Name, Latitude, Longitude and Altitude, as specified in observatories.txt header comments

Example: add ICAstronomy, Oria, Spain to custom observatories list:

Name:	ICAstronomy, Oria		
Latitude:	+37:30:03.96 (N)	37.50111	
Longitude:	-02:24:29.88 (W)	-2.40831	
Altitude (m):	1180		
Entry:	ICAstronomy, Oria <tab< td=""><td>>37.50111 <tab> -2.40831 <tab> 11</tab></tab></td><td>.80</td></tab<>	>37.50111 <tab> -2.40831 <tab> 11</tab></tab>	.80
ſ	Noore Observatory, UofL CDK20	N, Brownsboro, KY 38.344836 -85.528889	229.0
P	Noore Observatory, UofL RC24,	Brownsboro, KY 38.344791 -85.528476 22	29.0
1	CAstronomy, Oria 37.50111	-2.40831 1180	
L L L L L L L L L L L L L L L L L L L	At. Kent Observatory, USQ CDK	20S, Queensland, Australia -27.797861 151	.855417 682.0

ICAstronomy entry in observatories.txt

- 3. Save and close observatories.txt file.
- 4. Close re-open AIJ, in the toolbar click 😐 to open the DP Coordinates Converter window.
- 5. Select ICAstronomy, Oria from the Observatory ID drop down and set the Time Zone UTC Offset to 1.
- 6. Confirm Geographic Location of Observatory as below:

Time Zone	Observa ICAstror	itory ID nomy, Oria		~
Geographic Lon: -02:24:2		of Observatory Lat: +37:30:04	Alt	1180

Note: AstroImageJ has two near-identical Coordinate Converter dialogs accessible from the toolbar.

This guide *always* refers to the **DP Coordinate Converter** window, P, which links to the Target and Observatory Location Sources in the CCD Data Processor | FITS & Header Updates section.

Toolbar icon	AIJ Toolbar Description	Window Title	
DP	CCD Data Processor Tool	DP Coordinate Converter File Preferences Network Help DP Coordinate Converter	~
1	Coordinate Converter Tool	Coordinate Converter File Preferences Network Help Coordinate Converter	×

2.3.5. Configure FITS Header Settings

- 1. Open AIJ, in the toolbar, click P, CCD Data Processor Tool, to open the CCD Data Processor window.
- 2. In the CCD DP | FITS Header Updates section, click to open the General FITS Header Settings dialog.
- 3. Enable all the FITS Header Output keywords as below. The important keywords are Airmass and JD-based times, other keywords are informative.

Note: The FITS Header Input Settings section is not used: Target and Observatory details are imported from the DP Coordinate Converter window.

📉 General FITS Header Settings	-	
FIT'S Header Input Settings		
Target Name Keyword:	TARGET	
Target RA Keyword:	OBJCTRA	Degrees
Target DEC Keyword:	OBJCTDEC	
Observatory Name Keyword:	TELESCOP	
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:	RA_OBJ	enable
Target DEC Keyword:	DEC_OBJ	🗹 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

4. Close the FITS Header Settings dialog.

2.3.6. Configure Aperture Photometry Settings - 1

1. In the CCD DP | Control Panel section click to open the Aperture Photometry Settings window.

S Aperture Photometry Settings		×
Radius of object aperture Inner radius of background annulus Outer radius of background annulus	Image: 10 min state Image: 10 min	
Use variable aperture (Multi-Aperture only) FWHM factor (set to 0.00 for radial profile mode) Radial profile mode normalized flux cutoff	▲ 1 0.010 (0 < cuffoff < 1; default = 0.010)	
Centroid apertures Guse Howell cer Use exact partial pixel accounting in source aper Prompt to enter ref star absolute mag (required if List the following FITS keyword decimal values in Keywords (comma separated):	target star absolute mag is desired) measurements table:	Remove stars from backgnd Mark removed pixels rs inside the aperture radius are counted) IRMASS.ALT_OBJ.CCD-TEMP.EXPTIME.RAOBJ2K,DECOBJ2K
CCD gain CCD readout noise CCD dark current per sec or - FITS keyword for dark current per exposure [e-/pix] Saturation warning ('Saturated' in table) (red bord for levels higher than	1.25 [e-/count] 9.0 [e-] 0.010000 [e-/pix/sec]	
C [Linearity warning (yellow border in Ref Star Pane for levels higher than)	OK More Settings Cancel

Aperture radius settings	17 29 44 typical values
JD-Keywords	JD_SOBS, JD_UTC, HJD_UTC, BJD_TDB
Exposure Keywords	EXPTIME or EXPOSURE [1]
J2K Keywords	RAOBJ2K, DECOBJ2K Target J2000 coordinates
Other Keywords	AIRMASS, CCD-TEMP
CCD data	CCD gain, readout noise and dark current, estimated values for Apogee U16M CCD used to acquire WASP12 images [2]

[1] If the camera software saves exposure time with keyword EXPOSURE, then *overwrite* EXPTIME with EXPOSURE in the list of keywords, as below.

Keywords (comma separated): JD_SOBS,JD_UTC,HJD_UTC,BJD_TDB,AIRMASS,ALT_OBJ,CCD-TEMP EXPOSURE,RAOBJ2K,DECOBJ2

[2] Enter CCD values for Moore or ICA observatory as below:

CCD Parameter	Observatory	
	Moore	ICA
CCD gain (e-/count)	1.25	1.1
CCD readout noise (e-)	9.0	8.0
CCD dark current (e-/pix/sec)	0.01	0.01

Close AIJ toolbar to register these settings. Re-open AIJ | CCD DP | Aperture Photometry Settings window and confirm values have been retained.

2.3.7. Configure Aperture Photometry Settings - 2

1. In the Aperture Photometry Settings window, click [More Settings] to open the More Aperture Photometry Settings dialog. Confirm that the *only unchecked* item is 'Clear overlay before use', all other items are selected.

Select single aperture items to disp	play in measurements table:		
Filename (Label)	Slice Number (slice)	Time Stamps (JD UTC, etc)	World Coordinates (RA, DEC)
FITS Coords (X(FITS), Y(FITS))	IJ Coords (X(IJ), Y(IJ))	Aperture Radii	Aperture variance (Variance)
Source Counts (Source-Sky)	Source Peak (Peak)*	🔽 Source Mean (Mean)	🔽 Sky Background (Sky/Pixel)
Source FWHM (Width)	Moment Widths (X-Width, Y-Width)	✓ Orientation Angle (Angle)	Roundness (Roundness)
Source Error (Source Error)**	Source SNR (Source SNR)**	▼ N Source Pixels (N Src Pixels)	▼ N Sky Pixels (N Sky Pixels)
Select Multi-Aperture items to displa	ay in measurements table:		
Relative Flux (rel flux)	Rel. Flux Error(rel flux err)**	Rel. Flux SNR(rel flux SNR)**	Total Comp Star Cnts (tot C cnts)
	ity Warnings must be disabled in 'Main S Id dark current info in 'Main Settings' pane		
(**requires gain, readout noise, an Multi-Aperture settings:		1)	
(**requires gain, readout noise, an Multi-Aperture settings:	d dark current info in 'Main Settings' pane st zoom-in/out (adds slight delay to apertu	1)	
(**requires gain, readout noise, an Multi-Aperture settings: I♥ Allow left/right double click for fas I♥ Always default Multi-Aperture and	d dark current info in 'Main Settings' pane st zoom-in/out (adds slight delay to apertu 1 Stack Aligner first slice to slice 1	1)	
(**requires gain, readout noise, an Multi-Aperture settings: I♥ Allow left/right double click for fas I♥ Always default Multi-Aperture and	d dark current info in 'Main Settings' pane st zoom-in/out (adds slight delay to apertu d Stack Aligner first slice to slice 1 uge : 1000	1)	
(**requires gain, readout noise, an Multi-Aperture settings: I Allow left/right double click for fas I Always default Multi-Aperture and aximum number of apertures per ima	d dark current info in 'Main Settings' pane st zoom-in/out (adds slight delay to apertu I Stack Aligner first slice to slice 1 uge : 1000 clear) in image overlay:	1)	
(**requires gain, readout noise, an Multi-Aperture settings:	d dark current info in 'Main Settings' pane st zoom-in/out (adds slight delay to apertu d Stack Aligner first slice to slice 1 uge : 1000 clear) in image overlay: G Source Number IV Value(s)	1)	

AstroImageJ saves the results of photometry analysis in the form of a data table saved in measurements.tbl text file. Table data headers include:

	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

2.3.8. Configure Multi-Aperture Measurements

The Multi-Aperture Measurements window is accessed from an AIJ Image Viewer window displaying a fits image file.

The path to wasp_12.025.fits file imported into the Image Viewer is C:\Astro\Downloads\BAA.Files for AIJ Guide\wasp_12.025.fits. The path to the radec file is C:\Astro\Downloads\BAA.Files for AIJ Guide\wasp12.V.025.radec.txt.

- 1. Open AIJ, in the toolbar select File | Open... then navigate to and select wasp_12.025.fits (see above) to open a DSS image in an Image Viewer window.
- 2. In the Image Viewer, select File | Import apertures from RA/Dec list... then navigate to and select radec file wasp12.V.025.radec.txt (see above) to import aperture set.
- 3. In the Image Viewer toolbar, click fperform multi-aperture photometry' to open the Multi-Aperture Measurements window and configure as indicated in the highlighted sections.

	Fixed/Base radius	of photometric aperture	17		
	Fixed/Base radius of inr	ner background annulus	▶ 29		
	Fixed/Base radius of ou	ter background annulus	44		
Fixed #	Apertures as selected above	a			
O Auto Fi	ixed Apertures from first ima	ige T1 radial profile Normal	ized flux cutoff threshold:	0.01 📥 (0 < cutoff < 1 ; de	fault = 0.010)
O Auto Fi	ixed Apertures from multi-im	nage T1 radial profiles Normal	ized flux cutoff threshold:	0.01 - (0 < cutoff < 1 ; de	fault = 0.010)
O Auto V	ariable Apertures from each	image T1 radial profile Normal	ized flux cutoff threshold:	0.01 🚔 (0 < cutoff < 1 ; de	fault = 0.010)
O Auto V	ariable Apertures from each	image T1 FWHM FWHM	factor:	1.4	
	revious 8 apertures (1-click)	to set first aperture location)			
	A/Dec to locate aperture pos				
		et first aperture location in each i	(maga)		
_		slices in single step mode (right)	2 .		
	· · ·				
	omparison stars 🗹 Enab				
		Smoothing Filter Radius	3.5 🌩 pixels		
🖂 Auto Ti	hresholds	Max. Peak Valu		Min. Peak Value	4,647.59
Base Ape	erture 1 ≑	Max. Comp. Brightness	% 150.0 🗘	Min. Comp. Brightness %	50.0
	V	/eight of brightness vs. distance	% 50.0 ♀	Max. Comp. Stars	12
Centro	id apertures (initial setting)	Halt processing on	WCS or centroid error		
Remo	ve stars from background	Assume backgroun	d is a plane		
Promp	t to enter ref star apparent n	nagnitude (required if target star	apparent mag is desired))	
	e table and plot while runnin	g Show help panel d	luring aperture selection		
🗹 Update					

Highlighted settings

- Aperture radii set in Aperture Photometry Settings window above.
- Fixed Apertures located at radec coordinates (on plate solved images)
- Disable option for Auto comparison stars
- Centroid apertures and remove stars from background (see tooltips)
- Green highlighted settings are optional

4. Click [Place Apertures] to save changes and close this window and return to the Image Viewer then close the AIJ toolbar.

2.4. Import BAA Support Files

Refer section 2.1 to download, unzip and copy support files to C:\Astro\Downloads folder. In this section, we create a set of AstroImageJ sub-folders and copy download files into these folders.

- Open text file: C:\Astro\Downloads\BAA.Files for AIJ Guide Part 1\BAA.README.AIJ GUIDE 1.TXT.
- 2. Follow README instructions to create new folders and copy downloaded files into C:\Astro\AstroImageJ sub-folders.
- 3. Create a new folder C:\Astro\Datasets, root folder for imaging fits files datasets.

2.5. Configure Observation Planner for AstroImageJ

2.5.1. File paths:

	Folder or File	Path	Notes
1	AstroImageJ home	C:\Astro\AstroImageJ	Path referenced in instructions
2	planner.jar	C:\Astro\AstroImageJ\plugins	AIJ plugins sub-folder
3	astro_plugins-1.0a.jar	C:\Astro\AstroImageJ\plugins\Astro Apps	User creates sub-folder
4	Java install	C:\Astro\AstroImageJ\jre\bin	For ref: Java 18 or later

Paths to downloaded jar files and folder created in previous section.

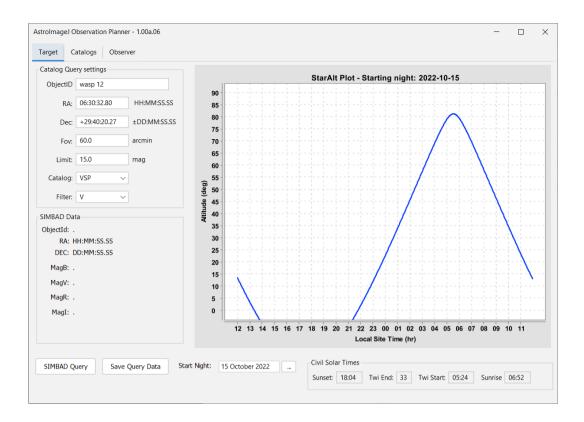
2.5.2. Confirm Software Install

1. Run AstroImageJ and from toolbar select Plugins | Astro Apps | Run Planner App. The following message dialog should open:



Note: If the dialog fails to open, please check paths to software items 1 - 4 in the software table above.

2. Click [OK] to close the dialog to open the Planner window configured for wasp12 target star.



3. Click the Observer tab and verify the location matches the observatory location and UTC offset configured in section 2.1 (Moore or ICA observatory).

2.6. Download and Configure Plate Solving Software

Importing radec apertures for photometry processing requires astrometric or plate solved fits images. On-line plate solving is relatively slow, and impractical for large images sets.

2.6.1. Option 1: Download and install ANSVR Plate Solve Software

Runs a local instance of astrometry.net plate solving; ANSVR is fully integrated into AstroImageJ.

- Integrated into CCD Data Processor
- Up to 20 GB download to solve small field of view images
- Typical solve times ~ 5 8 s/image

Refer Appendix for detailed instructions to download and install ansvr software.

Option 2: Download and install ASTAP Plate Solve Software

Runs as an AstroImageJ plugin, currently Windows only, possible future extension to Linux. ASTAP is a good option for processing large numbers of images on an slower PC.

- Partial integration through AstroImageJ plugin
- Database < 1 GB
- Typical solve times < 1.5 s / image

File path summary:

Paths to downloaded jar file (see above) and ASTAP.EXE software.

	Folder or File	Path	Notes
1	AstroImageJ home	C:\Astro\AstroImageJ	Path referred to in instructions
2	astap.jar	C:\Astro\AstroImageJ\plugins	AIJ plugins sub-folder
3	ASTAP.exe	C:\Program Files\astap	Default install path
4	H18 database	C:\Program Files\astap	Same folder as exe file

Confirm software install

- 1. To confirm **ASTAP.EXE** installation, click on shortcut to open the Astrometric Stacking Program and fits viewer (ASTAP), then close this window.
- 2. To confirm **astap.jar** plugin installation, open AIJ and from the toolbar select Plugins | Astro Apps | Run ASTAP App. The Run ASTAP Astrometric Solver for AstroImageJ window should open.

RA / Dec Coordinate		Solver Settings Minimum star size [sec]: 1.5 🗇	Run ASTAP
RA:	HH:MM:SS	Save solver log files	Test Solve
Dec:	±DD:MM:SS	Solver subfolder: Solved	
vasp104_01.fit		0 0 3	

Refer Guide to using ASTAP Solver for AstroImageJ for detailed instructions to run this plugin.

3. Observation Planning

This section covers inputting observer details in AIJ, running on-line database queries, and creating radec file with aperture coordinates to import into AIJ. To demonstrate, the final sub-section describes how to overlay apertures onto a DSS image.

Refer to section 2 to download and configure of software and to Appendix to download WASP12 example fits files.

3.1. Introduction to Observation Planner

Observation Planner is a Java plugin for AstroImageJ (AIJ) which runs from the AIJ toolbar. The main function is to download and select comparison star data from an on-line star catalog. Planner converts selected data into radec file format to import aperture coordinates into AIJ. Candidate comparison stars can be filtered based on magnitude and the software plots apertures on a VSP chart for visual inspection. The user interface comprises three tabs for observer, target and catalogs functions, described in the context of a AstroImageJ-based photometry workflow sequence.

3.2. Setup Observer Location

3.2.1. Select Moore Observatory in AIJ

- 1. Open AIJ and click 🖳 , in the toolbar to open the DP Coordinate Converter window.
- 2. If not previously selected then select Moore Observatory, UofL, RC24, Brownsboro, KY from the Observatory ID dropdown and set UTC offset to -5.
- 3. Close AIJ then re-open AIJ | DP CC window and confirm Observatory and Time Zone settings as below.



3.2.2. Configure observatory location in Observation Planner

The Observer Location data is imported from the DPCC window. Observer and Equipment Details section contains manual entry data fields. The Observer tab is usually a one-time setup.

1. From AIJ toolbar, select Plugins | Astro Apps | Run Planner App to open the AstroImageJ Observation Planner dialog then click on the 'Observer' tab.

bserver & Equipment Details			Observer Locati	on	
BAA VSS Observer Code:	xxx		Latitude:	+38:20:41.25	North
Observer Name:	observer		Longitude:	-85:31:42.51	West
elescope Short Description:	MORC24		Altitude (m):	229	
Telescope Full Description:	Moore Observat	ory 24-inch Ritchie-Chretien	UTC Offset (hr):	-5.0	
Aperture (mm):	600.0		Space for user n	otes	
Focal Length (mm):	4800.0				
Camera:	Apogee U16M C	CD			
Pixel Size (H) (um)					
Pixel Size (V) (um):	9.00				
Array Size(H) (pixels):	4096				
Array Size(V) (pixels):	4096				
Gain (e-/count):	1.250				
Readout noise (e-/pix):	9.0				
Dark current (e-/s/pix):	0.010				
erived Parameters					
Pixel Size (arcset	c): 0.39	0.39			
Field-of-View (arcmin): 26.40 26.40					

Observer Location

Observer Location details are imported from AIJ; confirm by cross-checking with DPCC window then close the DPCC window.

Observer and Equipment Details

This section Is largely based on the BAA spreadsheet (Ref [5]). Bold highlighted labels are required fields for submitting results to the BAA database. The default values are chosen to process the WASP12 example images.

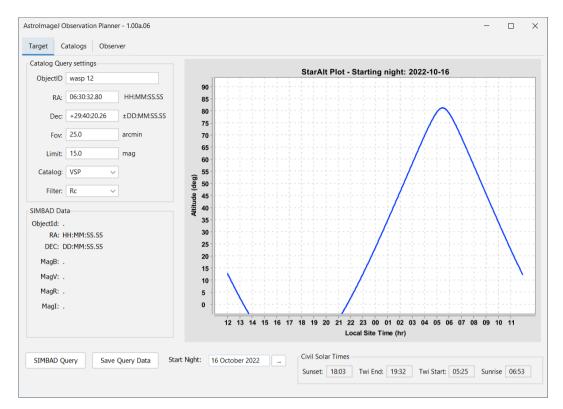
Dark current and Readout noise data is imported from AIJ Aperture Photometry Settings.

Derived Parameters

Pixel size ("/pixel) and field-of-view (arcmin) computed from telescope and camera parameters.

3.3. Specify Target in Observation Planner

In the Planner dialog, click the Target tab configured on first use for WASP12 example images.



Catalog Query settings

Target object parameters to run a query on an on-line database, VSP (Variable Star Plotter) in this figure. Tooltips provide a short description and acceptable data range for each field.

SIMBAD Data

Results of ObjectId-based query on the SIMBAD database.

StarAlt Plot

Object altitude plot over 24 hr at observer's location, runs from Start Night noon to next day noon.

Civil Solar Times

Local times for Sunset and Sunrise, plus Twilight for current Start Night. The default Start Night is the date today (16 October 2022 in this figure).

Controls

Button controls run and save results of SIMBAD queries; click _____ to change the Start Night.

The StarAlt plot shows the maximum altitude of WASP12 target is about 6 am local time on 16 October 2022, with UTC offset = -5 hr. Maximum altitude advances by 2 hr / month (= 24 hr / 12 month), so in January, WASP12 should reach maximum altitude around midnight at Moore Observatory.

3.3.1. Setup WASP12 Parameters

1. Enter Catalog Query settings fields as below:

Catalog Query settings						
ObjectID	wasp 12					
RA:	06:30:32.80	HH:MM:SS.SS				
Dec:	+29:40:20.26	±DD:MM:SS.SS				
Fov:	25.0	arcmin				
Limit:	15.0	mag				
Catalog:	VSP ~					
Filter:	Rc v					

RA and Dec coordinates values automatically update after a SIMBAD query (*but see Alert below*). The FOV is slightly smaller than the derived value in Observer tab. The VSP catalog is the AAVSO Variable Star Plotter database and the WASP12 images were exposed with a red filter.

 Click [SIMBAD Query] to run a name-based query on the SIMBAD database. After a short delay, a message dialog opens confirming updates to SIMBAD Data fields. The second dialog below is for a failed query based on ObjectID = wasp 12x (i.e., where wasp12x was not found).

Message X Messa	ye ×
Updated SIMBAD Data fields for Objectd: wasp 12 Saved to properties file: C:\Users\rfee1_astroimage]\AU_Planner.properties	ObjectId field: wasp 12x not found in SIMBAD database OK
Message dialogs for successful and un ObjectID = wasp 12 and wasp	•

3. Close the message dialog, the Catalog Query settings and SIMBAD Data section should be updated with SIMBAD results.

Catalog Query settings	SIMBAD Data
ObjectID wasp 12	ObjectId: WASP-12
RA: 06:30:32.80 HH:MM:SS.SS	RA: 06:30:32.80
RA: 06:30:32.80 HH:MM:SS.SS	DEC: +29:40:20.26
Dec: +29:40:20.26 ±DD:MM:SS.SS	MagB: 12.14
Foy: 25.0 arcmin	MagV: 11.57
Fov: 25.0 arcmin	MagR: .
Limit: 15.0 mag	MagI: .
Catalog: VSP V	
Filter: Rc 🗸	L
Catalog Query and SIMBAD Data after a	succesful WASP12 SIMBAD database query

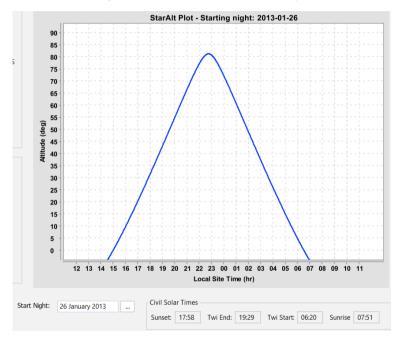
Note: MagV = 11.57, implies an estimated value for MagR \approx 11.5.

4. Click [Save Query Data] to save settings to properties file and close the message dialog.

Intermittent bug alert:				
When RA and Dec fields are both se	t to C	0:00:00, the	fields may not	update after a SMBAD query.
	RA:	00:00:00	HH:MM:SS.SS	
	Dec:	+00:00:00	±DD:MM:SS.SS	
This is an intermittent bug. Please tr repeat the SIMBAD query	ry en	tering non-ze	ro values in bc	oth fields (e.g., 01:00:00) and

3.3.2. Start Night

1. In the Planner | Target tab, click the ellipsis control ____ to open the calendar and set Start Night to 26 January 2013. Note: clicking 'Clear' resets to the date today.



Wasp12 | Start Night: 2013-01-26

Observed from the Moore Observatory, WASP12 reaches maximum altitude at about 23:00, local time.

3.4. Run On-Line Database Query

Click the Catalogs tab to open the catalogs interface with an empty data table:

AstroImageJ Observation Planner - 1.00a.03								_		\times
Target Catalogs Observer										
Sort By	Ap	ObjectId	Ra2000	Dec2000	Mag	Mag Err	Mag diff	Dist	Nobs	USE
Distance Delta Mag										
Selection Filters + DSS FITS										
Save DSS Fits File										
Apply mag limits										
Upper Mag: 0 🛇 N/A										
Nominal Mag: 10 🗘 .										
Lower Mag: 0 O N/A										
Nobs (APASS)										
Catalog Record Counts Total records: 0										
Filtered records: 0										
Selected records: 0										
Query Data										
ID: WASP12 FOV: 25.0										
RA: 06:30:32.80 Dec: +29:40:20.26										
Catalog: VSP Filter: Rc Mag: <15.0										
Run Query Import RaDec File	s Sa	we RaDec File	Update						Clear	

Sort By

Options to sort table data in order of increasing:

- radial distance (in arcmin) from target object position. or
- increasing absolute difference (Δ) between comparison magnitude (m) and nominal target magnitude (m₀) $\Delta = |m-m_0|$.

Selection Filters + DSS Fits

Option to download a DSS fits file for specified coordinates and field-of-view (default = checked) Option to apply mag limits to filter table data (default = checked).

Spin controls to set upper and lower mag bands to filter table data. 'N/A' implies limit is disabled. Nobs (APASS) filters table data by minimum number of observations, applicable to APASS catalog only.

Catalog Record Counts

Displays total number downloaded records plus counts for filtered and user-selected records.

Query Data

Summary of last saved Target | Catalog Query Settings data. This data is used to compile a query on selected catalog.

Data Table

Tabulates target and filtered comparison star data, currently empty.

3.4.1. Run WASP12 | VSP Database Query

1. Confirm Query Data values are as below, with Catalog: VSP and Filter: Rc. Also check that 'Save DSS Fits File' option is checked.

Catalog Que	ery settings		
ObjectID	wasp 12		Query Data
RA:	06:30:32.80	HH:MM:SS.SS	ID: wasp 12 FOV: 25.0
Dec:	+29:40:20.26	±DD:MM:SS.SS	RA: 06:30:32.80 Dec: +29:40:20.26 Catalog: VSP Filter: Rc Mag: <15.0
Fov:	25.0	arcmin	
Limit:	15.0	mag	
Catalog:	VSP ~		
Filter:	Rc ~		
VSP Qu	uery settings in	n Target Tab	VSP Query settings in Catalogs Tab

If necessary, switch back to the Target tab and edit Catalog Query settings to these values. Click [Save Query Data] and return to Catalogs page.

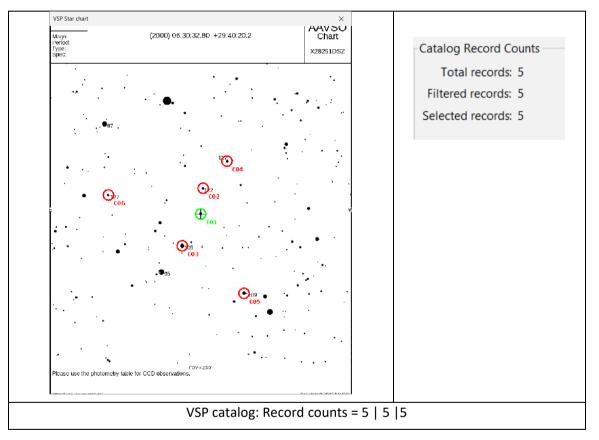
- 2. Click [Run Query] to run a query on the VSP and DSS databases note that the queries can take a few seconds. Close the confirmation dialog(s).
- 3. The data table is populated with 5 comparison star records and a chart opens displaying apertures centred on database stars.

Sort By	Ap	ObjectId	Ra2000	Dec2000	Mag	Mag Err	Mag diff	Dist	Nobs	þ
Distance Delta Mag	T01	WASP12	06:30:32.80	+29:40:20.26	10.000	0.000	0.000	0.00	1	
0 0.	C02	000-BKG-167	06:30:31.88	+29:42:27.30	11.878	0.108	1.878	2.13	1	
Selection Filters + DSS FITS	C03	000-BKG-166	06:30:39.80	+29:37:40.50	10.109	0.124	0.109	3.07	1	
Save DSS Fits File	C04	000-BMX-310	06:30:22.63	+29:44:42.10	11.422	0.101	1.422	4.89	1	
	C05	000-BKK-420	06:30:16.17	+29:33:45.10	10.371	0.102	0.371	7.51	1	
Apply mag limits	C06	000-BKG-168	06:31:08.10	+29:41:52.80	12.187	0.125	2.187	7.82	1	
Upper Mag: 0 🛇 N/A										
Nominal Mag: 10 🗘 .										
Lower Mag: 0 🛇 N/A										
Nobs (APASS) 1										
Total records: 5										
Filtered records: 5										
Selected records: 5										
Selected records. 5										
Query Data										
Query Data ID: WASP12 FOV: 25.0										
ID: WASP12 FOV: 25.0										
ID: WASP12 FOV: 25.0 RA: 06:30:32.80 Dec: +29:40:20.26										
ID: WASP12 FOV: 25.0										

Header	T01	Cnn
Ар	Green T01 aperture identifies the target object	Red Cnn apertures identify the database comparison star objects
ObjectId	User name for target object	Database object names

Ra2000, Dec2000	Target J2000 coordinates, image centre	Database J2000 coordinates
Mag	Target Nominal Mag	Database mag for selected filter or magnitude band
Mag Err	N/A	Database mag error for selected mag band
Dist	N/A	Radial distance to target coordinates in arcmin
Nobs	N/A	Number of observations (APASS catalog)
USE	Checked	Default state is checked; user unchecks to de-select table row

The next Figure shows the AAVSO chart centred on target, extent defined by the Catalog Query FOV. The over-lay set of apertures correspond to table coordinates.



3.4.2. Run WASP12 | APASS Database Query

Run APASS query with no applied filters

- 1. Click [Clear] to clear the data table and close the chart.
- 2. Click the Target tab, from the Catalog Query settings drop-downs, first select the APASS catalog then select SR filter. Click [Save Query Data] to save selections and close confirmation message dialog.

The Catalogs tab query data should match the Catalog Query settings user inputs as below.

- Catalog Que	ery settings		
ObjectID	wasp 12		Query Data
RA:	06:30:32.80	HH:MM:SS.SS	ID: wasp 12 FOV: 25.0 RA: 06:30:32.80 Dec: +29:40:20.26
Dec:	+29:40:20.26	±DD:MM:SS.SS	Catalog: APASS Filter: SR Mag: <15.0
Fov:	25.0	arcmin	
Limit:	15.0	mag	
Catalog:	APASS ~		
Filter:	SR ~		
APASS C	Query settings	in Target Tab	APASS Query settings in Catalogs Tab

3. In the Catalogs tab, click [Run Query] to run a query on the APASS database. The query returns more than 400 records matching the Catalog Query settings.



Note: APASS records do not include an object identifier. The Planner app generates a unique identifier based on Ra and Dec coordinates, with name format HHMMSSSS±DDMMSSSS.

Formatting example for Ap CO2:

Ap	ObjectId	Ra2000	Dec2000
T01	WASP12	06:30:32.80	+29:40:20.26
C02	06303279+29402033	06:30:32.79	+29:40:20.33

Apply magnitude filter to WASP12 records

1. Select Sort By: Distance; the table automatically sorts in order of increasing distance from target coordinates.

Ар	ObjectId	Ra2000	Dec2000	Mag	Mag Err	Mag diff	Dist	Nobs	USE
T01	WASP12	06:30:32.80	+29:40:20.26	10.000	0.000	0.000	0.00	1	
C02	06303279+29402033	06:30:32.79	+29:40:20.33	11.415	0.070	1.415	0.00	4	
603	00000700-00400550	06.00.07.00	- 20-40-0F FC	45 475	0.000	F 47F	0.00	A	

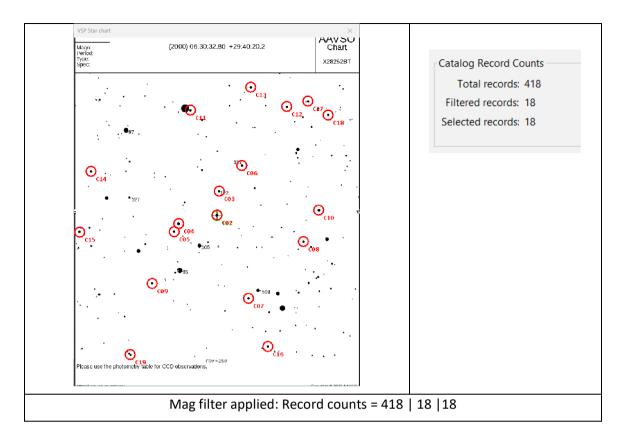
Duplicate Table Records

Note that aperture C02 (id = 06303279+29402033), the Dist field is 0.00, indicating T01 and C02 are duplicate records. Taking the catalog mag value (11.415) for this row should be a good estimate for the Nominal Mag field.

- 2. Enter Nominal Mag = 11.4 (roughly equal to C02 catalog mag in the previous figure).
- Type or use spin controls to set mag limits: Upper Mag = 0.8 and Lower Mag = -0.5. The 'N/A' labels change to display upper and lower magnitude limits. Note: these settings are loosely based on recommendations in section 6.4.2 in A Practical Guide to Exoplanet Observing, Ref [2].

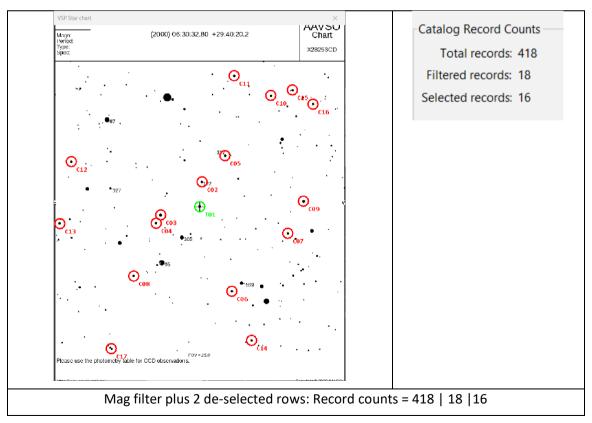
-Selection Filters		rs .										
Selection miters	+ 05511	5										
🗹 Save DSS Fi	ts File											
Apply mag limits												
Upper Mag:	Upper Mag: 0.8 🗘											
Naminal Mary	11 4 2											
Nominal Mag:	11.4	2 ·										
	-0.5 <	10.9										
Lower Mag:	-0.5	10.9										
Nobs (APASS)	1	\diamond										
. ,		-										

4. Click [Update], the Filtered records count drops from 418 to 18.



5. De-select rows C11 (proximity to bright neighbour) then de-select C02 (duplicate target star). Click [Update] to update counts and chart; the Selected records count drops from 18 to 16.

Note that the Ap column updates automatically when a USE cell is selected or de-selected



06303279+29402033 063032.79 +294020.33 11.415 0.070 0.015 0.00 4 Selection Filters + DSS FITS 06303188+29422730 06303188 +294227.30 11.983 0.081 0.583 2.13 4 Save DSS Fits File C03 0630427+29393591 06304.82 +294227.30 11.983 0.081 0.583 2.13 4 6 Apply mag limits C04 063005007+29385436 06302.62 +293442.21 11.554 0.060 0.373 4.02 5 C05 0630262-29444221 06302.26.02 +2944.42.21 11.554 0.080 0.154 4.89 4 6 C06 06302000+29330320 06302.26.02 +2944.42.21 11.554 0.082 0.492 7.95 4 6 C07 06295778+29380133 06295.57.78 +2938.01.33 11.892 0.082 0.492 7.95 4 6 C08 0630393+29342229 06304354 +29495.01.33 11.921 0.061 0.501 8.24 5 6 C09 06295157+29404647 06304.48	Sort By	Ap	ObjectId	Ra2000	Dec2000	Mag	Mag Err	Mag diff	Dist	Nobs	U
Selection Filters + DSS FITS CO2 06303188+29422730 06303.18.8 +294227.30 11.983 0.081 0.583 2.13 4 CO2 Save DSS Fits File CO2 06303188+29422730 063048.27 +293935.91 11.881 0.058 -0.019 3.44 5 CO2 063004827+29393591 06304.8.27 +293935.91 11.811 0.058 -0.019 3.44 5 CO2 063002067+29385436 063005.007 +293364.36 11.773 0.060 0.373 4.02 5 CO2 06302262+29444221 06302.200 +293303.20 11.775 0.077 0.375 7.80 4 CO2 CO7 0632262+29444221 06302.200 +29330.20 11.775 0.077 0.375 7.80 4 CO2 CO7 0632262+2944421 0.6302.200 +29330.133 11.892 0.082 0.492 7.95 4 CO2 CO7 06302.482 49330.20 11.775 0.077 0.375 7.80 4 CO2 CO3 0630043.542494933.44 0630.43.54 +29493.33.41 11.22 0.061 0.501 8.24 5 CO2	Distance Delta Mag	T01	wasp 12	06:30:32.80	+29:40:20.26	11.400	0.000	0.000	0.00	1	
✓ Save DSS Fits File C03 06304827 +29393591 1050 1331 0.053 -0.001 9 3.44 5 5 ✓ Apply mag limits C04 06304827 +29383591 11.1311 0.005 0.0151 4.89 4 5 Upper Mag: 0.8 12.2 063042627 +29383530 11.773 0.060 0.373 4.02 5 Lower Mag: 0.5 10.9 0.6302200 +29330320 063022.02 +2944.42.21 11.554 0.080 0.154 4.89 4 6 Lower Mag: -0.5 10.9 0.6295178 +29380133 06302.000 +29330320 11.775 0.077 0.375 7.80 4 6 Lower Mag: -0.5 10.9 0.6295178 +29404647 062951517 +29404647 11.268 0.090 -0.132 8.97 4 6 Cotal records: 1 0.6312867+294404647 06304.48 +294950.88 11.831 0.083 0.431 11.32 4 6 Cotal records: 1 0.63128627 06304.824 +294949.50.8			06303279+29402033	06:30:32.79	+29:40:20.33	11.415	0.070	0.015	0.00	4	C
Cod 063005007+29385436 0630:50.07 +2938:54.36 11.773 0.060 0.373 4.02 5 Upper Mag: 0.8 12.2 06302262+29444221 063022.62 +29:44.42.21 11.554 0.080 0.154 4.89 4 6 Nominal Mag: 11.4 	Selection Filters + DSS FITS	C02	06303188+29422730	06:30:31.88	+29:42:27.30	11.983	0.081	0.583	2.13	4	
Cos 06302262+29444221 06302262 +294442.21 11.554 0.080 0.154 4.89 4 Upper Mag: 0.8 12.2 Cos 06302200+29330320 06302200 +29330320 11.775 0.077 0.375 7.80 4 0.000 Nominal Mag: 11.4 . . . Cos 06302200 +29330320 11.775 0.077 0.375 7.80 4 0.000 0.154 4.89 4 0.000 0.0154 4.89 4 0.000 0.0154 4.89 4 0.000 0.0154 4.89 4 0.000 0.0154 4.89 4 0.000 0.0154 4.89 4 0.000 0.0154 4.89 4 0.000 0.0154 4.89 4 0.000 0.0154 4.89 4 0.000 0.0153 8.97 4 0.000 0.0152 8.97 4 0.000 0.0132 8.97 4 0.000 0.0132 8.97 4 0.000 0.0132 8.97 4 0.000 0.0132 8.97 4 0.000 <	Save DSS Fits File	C03	06304827+29393591	06:30:48.27	+29:39:35.91	11.381	0.058	-0.019	3.44	5	
Upper Mag: 0.8 12.2 Nominal Mag: 11.4 0 Lower Mag: 0.5 10.9 Nobs (APASS) 1 0 1 0 06300200+29330320 0630220.00 +293303.20 11.775 0.0375 7.80 4 Lower Mag: 0.5 10.9 06295778+29380133 062957.78 +29340133 11.892 0.082 0.492 7.95 4 6 Nobs (APASS) 1 0 0 0630048+29493344 06300448 +294940647 11.268 0.090 -0.132 8.97 4 6 C10 0630048+29495088 06300448 +294943.34 11.723 0.066 0.323 9.51 4 6 C11 06310942+2943334 06300448 +29495.088 11.811 0.083 0.431 11.32 4 6 C12 063102267+29441027 0631:23.67 +2944:10.27 11.159 0.058 -0.241 11.69 7 6 C12 06312367+29441027 0631:23.67 +2944:10.27 11.99 0.58 -0.241 <td>Anniu man limita</td> <td>C04</td> <td>06305007+29385436</td> <td>06:30:50.07</td> <td>+29:38:54.36</td> <td>11.773</td> <td>0.060</td> <td>0.373</td> <td>4.02</td> <td>5</td> <td></td>	Anniu man limita	C04	06305007+29385436	06:30:50.07	+29:38:54.36	11.773	0.060	0.373	4.02	5	
Corp 06295778+29380133 0629:57.78 +293801.33 11.892 0.082 0.492 7.95 4 Nominal Mag: 11.4 <td>Apply mag limits</td> <td>C05</td> <td>06302262+29444221</td> <td>06:30:22.62</td> <td>+29:44:42.21</td> <td>11.554</td> <td>0.080</td> <td>0.154</td> <td>4.89</td> <td>4</td> <td></td>	Apply mag limits	C05	06302262+29444221	06:30:22.62	+29:44:42.21	11.554	0.080	0.154	4.89	4	
Nominal Mag: 11.4 Commonial Mag: 11.2 Commonial Mag: 11.2 Commonial Mag: 11.2 Commonial Mag: 11.2 Commonial Mag: 0.6304354 +29.492.2.2 11.901 0.061 0.501 8.24 5 Commonial Mag: Commonial Mag: Commonial Mag: 0.6304354 +29.442.2.2 11.901 0.061 0.501 8.24 5 Commonial Mag: C	Upper Mag: 0.8 🗇 12.2	C06	06302000+29330320	06:30:20.00	+29:33:03.20	11.775	0.077	0.375	7.80	4	
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06304354+29493334 0630435.4 +294933.34 11.723 0.066 0.323 9.51 4 Nobs (APASS) 1 1 0 063004354+29493334 0630044.8 +294950.88 11.831 0.083 0.431 11.32 4 6 Catalog Record Counts 1 06310267+29441027 063128.20 +2949.50.88 11.811 0.083 0.431 11.32 4 6 Catalog Record Counts 1 06312867+29441027 063128.20 +294410.27 11.59 0.058 -0.241 11.69 7 6 C12 06312802+29385229 0633128.20 +293452.29 11.974 0.054 0.574 12.12 7 6 C14 06301214-29284998 0633012.14 +292849.88 11.319 0.082 -0.081 12.35 4 6 Selected records: 16 06294772+29490762 062947.72 +2949.07.62 11.869 0.090 0.469 13.15 4 6 Query Data ID: wasp 12 FOV: 25.0 RX: 06:30:32.80 Dec: +29:40:20.26 0631:07.79 +2928:08.62 12.040 0.057		C08	06305893+29342229	06:30:58.93	+29:34:22.29	11.901	0.061	0.501	8.24	5	
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Catalog Record Counts C13 06312820+29385229 06312820 +29:38:52.29 11.974 0.054 0.574 12.12 7 5 Total records: 418 C14 06301214+29284998 063:012.14 +29:28:49.98 11.319 0.082 -0.081 12.35 4 6 Selected records: 16 C15 06295591+29501979 062:95:591 +29:28:49.98 11.819 0.082 -0.081 12.35 4 6 C16 06294772+29490762 062:95:591 +29:28:08.62 12.040 0.057 0.640 13.15 4 6 Cuery Data ID: wasp 12 FOV: 25.0 RA: 06:30:32.80 Dec: +29:40:20.26 12.102 0.057 0.640 14.37 4 6		C11	06301904+29513387	06:30:19.04	+29:51:33.87	11.629	0.062	0.229	11.62	4	
Total records: 418 C14 063/1224998 063/1244 +293/3022.9 11.3/14 0.004 0.014 12.12 7 Filtered records: 18 C15 063/1244 +293/3022.9 11.3/19 0.083 0.0547 12.35 4 6 Selected records: 16 C15 0629591+29501979 0629:55.91 +293/90.762 11.869 0.090 0.469 13.15 4 6 Query Data C17 06310779+29280862 0631:07.79 +2928:08.62 12.040 0.057 0.640 14.37 4 6 Query Data ID: wasp 12 FOV: 25.0 RA: 06:30:32.80 Dec: +29:40:20.26 ID		C12	06312367+29441027	06:31:23.67	+29:44:10.27	11.159	0.058	-0.241	11.69	7	_
Filtered records: 18 C15 06295591+29501979 0629:55.91 +29:5019.79 11.947 0.003 0.547 12.80 4 Selected records: 16 C16 06294772+29490762 06:29:47.72 +29:5019.79 11.869 0.090 0.469 13.15 4 C Query Data C17 06310779+29280862 06:31:07.79 +29:28:08.62 12.040 0.057 0.640 14.37 4 C Query Data Dis wasp 12 FOV: 25.0 RA: 06:30:32.80 Dec: +29:40:20.26 E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E E <t< td=""><td>-</td><td>C13</td><td>06312820+29385229</td><td>06:31:28.20</td><td>+29:38:52.29</td><td>11.974</td><td>0.054</td><td>0.574</td><td>12.12</td><td>7</td><td></td></t<>	-	C13	06312820+29385229	06:31:28.20	+29:38:52.29	11.974	0.054	0.574	12.12	7	
Selected records: 16 C16 06294772+29490762 062947.72 +294907.62 11.869 0.090 0.469 13.15 4 Query Data C17 06310779+29280862 06:31:07.79 +2928:08.62 12.040 0.057 0.640 14.37 4 0 ID: wasp 12 FOV: 25.0 RA: 06:30:32.80 Dec: +29:40:20.26 C17 06:31:07.9 +29:28:08.62 12.040 0.057 0.640 14.37 4 0	Total records: 418	C14	06301214+29284998	06:30:12.14	+29:28:49.98	11.319	0.082	-0.081	12.35	4	
Query Data ID: wasp 12 FOV: 25.0 RA: 06:30:32.80 Dec: +29:40:20.26	Filtered records: 18	C15	06295591+29501979	06:29:55.91	+29:50:19.79	11.947	0.083	0.547	12.80	4	
Query Data ID: wasp 12 FOV: 25.0 RA: 06:30:32.80 Dec: +29:40:20.26	Selected records: 16										
	ID: wasp 12 FOV: 25.0 RA: 06:30:32.80 Dec: +29:40:20.26										

Save Radec File

Click [Save RaDecFile] to save current data table to AIJ compatible radec text file. A dialog opens confirming WASP12.SR.025.radec.txt is saved in radec sub folder. Note that saving a radec file over-writes an existing file without warning.



Import Radec File

- 1. Close message dialog and click [Clear] to clear the data table.
- 2. Click [Import Radec File] and select WASP12.SR.025.radec.txt from the 'Select radec file' dialog.
- 3. Click [Open] to populate the data table with the filtered and selected data set. The data table should be the same as previous table figure except record counts are now 18 | 18 |16.

File Paths

Paths to radec and dss files, based on AIJ installed in folder AstroImageJ 5. The software automatically creates radec and dss folders as needed.

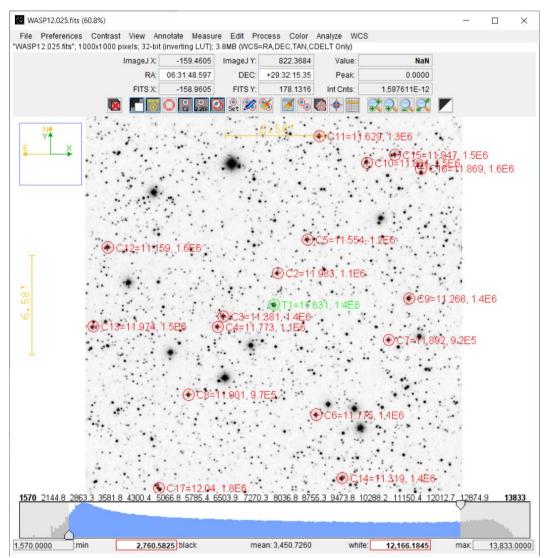
Path to radec txt file	C:\Astro\AstroImageJ\radec\WASP12.SR.025.radec.txt
Path to dss fits file	C:\Astro\AstroImageJ\dss\WASP12.025.fits

3.5. Overlay DSS Image with radec Apertures

- From the AIJ toolbar, select File | Open, then navigate to and open dss fits file WASP12.025.fits' (C:\Astro\AstroImageJ\dss\WASP12.025.fits). The dss image opens in a new AIJ Image Viewer window.
- In the Image Viewer, select menu item File | 'Import apertures from RA/Dec list...' to open the Import apertures dialog. Navigate to and open 'WASP12.SR.025.radec.txt' (C:\Astro\AstroImageJ\radec\WASP12.SR.025.radec.txt) to import the aperture set (16 apertures)
- 3. If necessary, click 🌌 'zoom to fit image to window' icon in the viewer toolbar to centre image.

Note 1: To display negative image as below, click To display as image negative' icon in the Viewer toolbar. Click To again to revert to normal image display.

Note 2: The WASP12 DSS image is crowded with faint, high mag stars. The WASP12 example images are much 'cleaner', so we defer further aperture selection / de-selection until section 5.



4. AstroImageJ Image Reduction

Refer to Appendix for instructions to download the WASP12 example files and copy Raw Science and Calibration fits files to their respective folders repeated below for convenience:

Raw science files => C:\Astro\Datasets\WASP12.SR.2013_01_26\Raw Science Files (230 files)

Calibration files => C:\Astro\Datasets\WASP12.SR.2013_01_26\Calibration Files (33 files).

Note that the raw science files are plate solved.

The root folder for the WASP12 unzipped image set is WASP12.SR.2013_01_26, based on imaging with a red filter and observation starting on 26th January 2013.

The bias, darks and flats calibration files are copied into a single folder (Calibration Files). An alternative is to copy bias, darks and flat fits files into individual sub-folders:

C:\Astro\Datasets\WASP12.SR.2013_01_26\Calibration Files\Bias*bias*.fits

C:\Astro\ Datasets\WASP12.SR.2013_01_26\Calibration Files\Darks*darks*.fits

C:\Astro\ Datasets\WASP12.SR.2013_01_26\Calibration Files\Flats*flats_r*.fits

Change the relative paths in the CCD DP window to Bias, Dark and Flat sections in CCD Data Processor window accordingly.

4.1. DP Coordinate Converter Target Data

Note that the Target and Observation Sources should be set to 'Coordinate Converter manual entry'.

- 1. Open AIJ and from the toolbar, click red to open the CC Data Processor and DP Coordinate Converter (DPCC) windows.
- 2. If necessary, select Moore Observatory, UofL, RC24, Brownsboro, KY from the Observatory ID dropdown and set UTC offset to -5. Close and re-open DP CC window and confirm any changes have been registered.
- 3. Enter WASP12 in the DPCC | SIMBAD Object ID text field and press [Enter] to run a SIMBAD query. The dialog should update with WASP12 J2000 coordinates.

Current UTC-based	Time							
UTC: 2022-10-21	13:09:50	Local: 2022-10-	-21 08:0	9:50	JD: 2	459874.048499	LST:	09:27:34
WASP12	or SS Object)-	UTC offset	present	Observa Moore (ory, UofL RC24, Bi	rownsbo	oro, KY
		UTC offset	proving	Moore (Observato		rownsbo	oro, KY

4.2. Plate Solve Options

Optional section: The WASP12 example fits files are already plate solved and this section can be skipped in a first reading.

4.2.1. ANSVR

ANSVR is fully integrated into AIJ; refer Appendix for instructions to download and setup ansvr to run with AIJ.

4.2.2. ASTAP

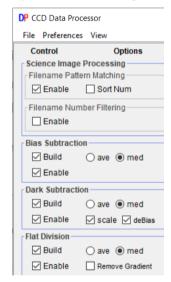
ASTAP is a popular alternative to ANSVR, with faster solve times and potentially smaller disk footprint for very small FOV images (<< 20 arcmin). Refer section 2 to install astap.jar plugin file and import the astap.jar user guide: User Guide Astap Solver for AstroImageJ.pdf.

4.3. Set up CCD Data Processor Window

Image reduction in AIJ consists of building master calibration files then running the science image reduction process. Compiling master files and image reduction can be done in a single sequence. Note that the following screenshots are based on saving bias, darks and flats fits files to a single calibration folder.

4.3.1. Master Calibration Build Settings

Select Enable and Build med (median) options as shown in the next figure. Select scale and deBias in the Dark Subtraction section to enable exposure time scaling.



4.3.2. Set up Directories and File Wildcards

Science Image Processing section

Click the left folder icon is to open a dialog titled 'Select primary directory containing science files'. Navigate to and select the Raw Science Files folder:

C:\Astro\Datasets\WASP12.SR.2013_01_26\Raw Science Files.

 Click the right folder icon is to open 'Select a file' dialog. Select and open the first file in the list (e.g., wasp-12b_00040.fits). The Filename/Pattern field 'WASP-12b_*.fits' is a wild-card pattern matching 230 files the Raw Science Files folder.

Science Image Processing					
🗹 Enable 🛛 Sort Num	C:\Astro\Datasets\WASP12.SR.2013_01_26\Raw Science File	es\ 🔂 🚺	WASP-12b_*.fits		230
Filename Number Filtering					
Enable	Min: 0 🔹 Max:	100000000 🗘 V	WASP-12b_*.fits		230

Calibration Processing sections

Set up Bias, Dark and Flat sections as below. The Directory entries are identical and should be a onetime setting, assuming no changes in the Calibration folder structure.

Unprocessed calibration fits files: ...\Calibration Files\ Processed master fits files: ...\Master Calibration Files\

- Filename/Pattern wildcards are generated by clicking on the right-hand folder icon and selecting a file appropriate to that section; example files are bias_00106.fits, dark_00150.fits or flat_r_00002.fits. Note that AIJ has detected 11 of each fits file type in the common Calibration Files folder.
- 3. Enter master filenames m_bias.fits, m_darks.fits and m_flat_r.fits in the respective fields.

on					
🔾 ave 🔘 med	\Calibration Files\		bias_*.fits		11
	Waster Calibration Files\		m_bias.fits		0
ion					_
🔾 ave 🔘 med	\Calibration Files\		dark_*.fits	2	11
🗹 scale 🗹 deBias	Waster Calibration Files\		m_darks.fits	2	0
🔾 ave 🔘 med	\Calibration Files\		flat_r_*.fits	2	11
Remove Gradient	Waster Calibration Files\		m_flat_r.fits		0
	on ○ ave ● med ☑ scale ☑ deBias ○ ave ● med	O ave (e) med /Calibration Files\ /Waster Calibration Files\ O ave (e) med /Calibration Files\ /Salibration Files\ /Waster Calibration Files\ /Waster Calibration Files\ /Waster Calibration Files\ /Calibration Files\	O ave (e) med \Calibration Files\ \Master Calibration Files\ O ave (e) med \Calibration Files\ O ave (e) med \Calibration Files\ O ave (e) med \Calibration Files\	O ave (e) med .\Calibration Files\ >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>	O ave @ med ./Calibration Files\ > bias_fifts > ./Master Calibration Files\ > m_bias_fifts > > on > > > > O ave @ med ./Calibration Files\ > > > Scale If deBlas ./Master Calibration Files\ > > > O ave @ med ./Calibration Files\ > > > O ave @ med ./Calibration Files\ > > >

4.3.3. Save Calibrated (Reduced) Images

In the Save Calibrated Images section, enter Sub-dir: 'Reduced Science Files' and Suffix: '_bdf'.

1	Save Calibrated	l Images	i						
	Enable	0 16	32	Sub-dir:	Reduced Science Files	Suffix:	_bdf	Format	GZIP FPACK

Processed FITS filenames are appended '_bdf' and saved to a sub-folder in Raw Science Files: C:\Astro\Datasets\WASP12.SR.2013_01_26\Raw Science Files\Reduced Science Files.

4.4. Run Science Image Reduction

The next figure shows the CCD Processor window prior to running image reduction on 230 raw science files.

Directory entries are based on a single Calibration folder containing bias, darks and flat files. The median-combined calibration files are saved in a Master Calibration Files folder.

Plate Solve (ANSVR) has been disabled, and Target and Observatory are as specified in the DPCC window.

The Processed / Remaining counts in the bottom right corner provide a running tally of processed science files.

1. Click [START] in the Control Panel at the bottom of the CCD Data Processor. A Log window opens, with a running record of each image process. Refer to the log for details.

P CCD Data Proce File Preferences								-	
Control	Options		Directo	ry			Filename/Pat	tern	Totals
Science Image P Filename Patter									
	Sort Num	C:\Astro\Datasets\WASP12.SR.2	013_01_26\Raw So	ience Files\			WASP-12b_*.fits		230
Filename Numb	er Filtering								
Enable	-	Min:	0 🗘 Ma	x	1	00000000 🗘	WASP-12b_*.fits		230
Bias Subtraction									
🖂 Build 🛛	🔾 ave 🔘 med	\Calibration Files\				<u></u>	bias_*.fits		11
🗹 Enable		Waster Calibration Files\					m_bias.fits		0
Dark Subtraction	1								
Build (🔾 ave 🔘 med	\Calibration Files\					dark_*.fits		11
Enable [🗹 scale 🗹 deBias	Waster Calibration Files					m_dark.fits		0
Flat Division						-			
	🔾 ave 🔘 med	\Calibration Files\					flat_r_*.fits		11
	Remove Gradient	Waster Calibration Files\					m_flat_r.fits		0
Image Correction		New pixel value =	0.0E0 +	4.050	(PixVal) +	0.050	★ (PixVal) ² +	0.0E0 * × (PixVal)3	
Enable Line	anty Correction tliers 🗹 Bright 🔽		2 + Threshold			0.0E0	× (PIXVal) ² +	0.0E0 V (PixVal)	
		Dark Radius.		. 50	Y				
FITS Header Upd	ates		Target Coordinate S	ource			Observatory Location Source		
General [Plate Solve	* 📉	Coordinate Convert	er manual entry		~	Coordinate Converter manua	al entry 🗸 🗸	
Save Calibrated I	Images								
Enable (○ 16	Sub-dir: Reduced Science Files	\$	Suffix: _bdf		Format:		FPACK GZIP	
Post Processing									
M-Ap	Save Image				Macro 1	C:\Users\rlee1\			0
M-Plot	Save Plot			1	Macro 2	C:\Users\rlee1\		1	0
Control Panel									
Polling Inte		Set 😫 🚿	START		AUSE	RES	T	Processed:	
	0 🜩	Set 革 📶	START	P	AUSE	RESI		Remaining:	23

2. When processing is finished, the master calibration file totals should equal 1, confirming that master bias, darks and flats files were compiled. Uncheck the 'Build' check boxes (3) to prevent AIJ re-building these files in any subsequent runs.

Note: somewhat confusingly, once processing is finished the Processed and Remaining totals revert to 0 and 230 respectively.

3. Move the Reduced Science Files folder (containing 230 processed fits files) up one level:

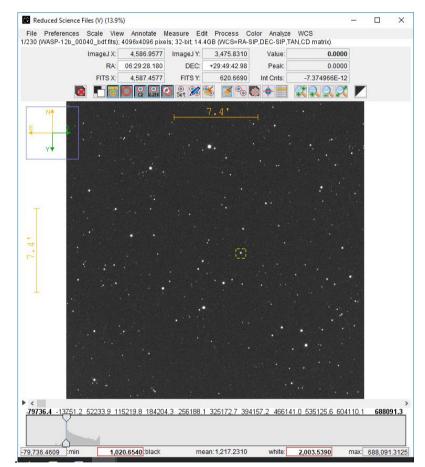
From:C:\Astro\Datasets\WASP12.SR.2013_01_26\Raw Science Files\Reduced Science FilesTo:C:\Astro\Datasets\WASP12.SR.2013_01_26\Reduced Science Files

5. AstroImageJ Photometry

5.1. Import Image Stack

- 1. Open AIJ and from the toolbar, select File | Import | Image Sequence ... to open the Import Image Sequence dialog. Ensure the 'Use virtual stack' check box is selected.
- 2. Click [Browse] navigate to and select the folder containing the reduced WASP12 images: C:\Astro\Datasets\WASP12.SR.2013_01_26\Reduced Science Files (Matched files = 230).
- 3. Click [OK] to close the dialog. An Image Viewer window opens displaying the first WASP12 image (WASP-12b_00040_bdf.fits). Note the yellow N-E pointers indicate this is a plate-solved image.

Refer to chapter 5 in 'AstroImageJ 2.4.1 User Guide, ref [4], for a detailed description of available functions in this window



4. Select menu item View then the appropriate Invert ... option to orientate image N-E up and left as above.

5.2. Visual Inspection of Image Quality

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

1. Use the scroll bar controls highlighted below to inspect individual images.

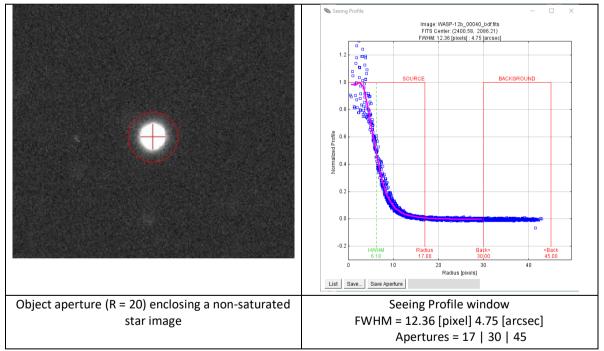
- 2. Click the Play icon L, left of the scroll bar, to start / pause image animation. Right click on this control to set animation speed and other options.
- 3. To remove an image from the stack, click **a**, left-most icon.

Note: this function only removes the image from current photometry stack. The FITS file is *not* deleted from the Reduced Science Files directory.

5.3. Photometry Measurement Apertures

5.3.1. Set aperture sizes

- 1. Click d'change aperture settings' to open the Aperture Photometry Settings window.
- Enter 20, 24 and 30 in the top three aperture and annulus fields. The exact values are not critical but the object aperture must be large enough to fully enclose the image of a single star. Click [OK] to close this window.
- 3. Click toggle aperture display is a snecessary so that the "Live Photometer" is a single circle overlay as shown below.
- 4. Alt-Left click on a bright non-saturated star image the star highlighted in the Image Viewer above is a good candidate. The Seeing Profile for the selected star opens in a new window



Note that aperture sizes can vary by a few pixels from these values.

- 5. Click [Save Aperture] in the Seeing Profile window to import these aperture sizes.
- 6. Click Set in the Image Display window to open the Aperture Photometry Settings window and confirm that aperture sizes are now 17 | 30 | 45. Click [OK] to close the Aperture Photometry window
- 7. In the Image Viewer, click ^{SS} 'clear apertures ..' to clear any overlays.

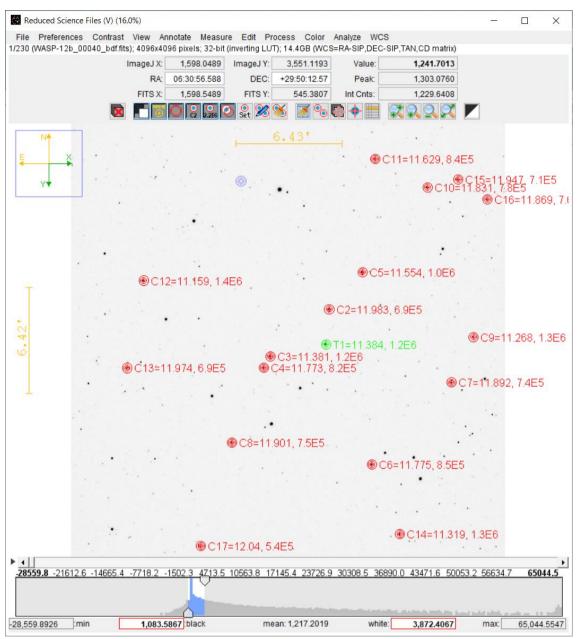
8. Enable the group of five toolbar aperture buttons as shown here:



5.3.2. Import radec apertures

- In the Image Display window, select File | Import apertures from RA / Dec list ..., navigate to and select .C:\Astro\AstroImageJ\radec\wasp12.SR.025.radec.txt to import and overlay the WASP12 image with the APASS set of apertures saved in section 3.
 - Reduced Science Files (V) (16.0%) П × File Preferences Contrast View Annotate Measure Edit Process Color Analyze WCS 1/230 (WASP-12b_00040_bdf.fits); 4096x4096 pixels; 32-bit; 14.4GB (WCS=RA-SIP,DEC-SIP,TAN,CD matrix) ImageJ X: 1,128.3242 ImageJ Y: 3,187.8654 1,201.6687 Value 06:31:10.438 +29:47:52.40 Peak: 1,828.7800 RA: DEC: 1,128.8242 44,173.0315 FITS X: FITS Y: 908.6346 Int Cnts: < ° C2 2.2E6 0 Set 22 C) 🔶 O. €C10=11.629 €C14=11 0 C 15=11.869 @C5=11.554 C11=11.159 @C2=11.983 © C9=11.268 12=11.974 C8=11.901 C6=11.775 @C13=11.319 ©C16=12.04 **>** 4 28559.8 -21612.6 -14665.4 -7718.2 -1502.3 4Z13.5 10563.8 17145.4 23726.9 30308.5 36890.0 43471.6 50053.2 56634.7 65044.5 :min mean: 1.217.2019 -28,559.8926 1,083.5867 black white: 3,872.4067 max: 65,044.5547
- 2. Click 🖾 'zoom to fit ...' to re-centre the image in the Viewer.

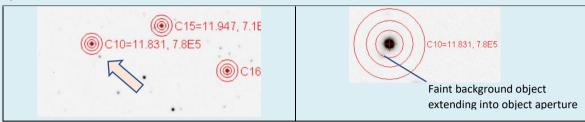
3. In the Image Viewer toolbar, click ^{log} 'perform multi-aperture photometry' to open the Multi-Aperture Measurements window. 4. Click [Place Apertures] to close this window. In the Image Viewer, the aperture overlay is highlighted and measurement apertures are locked to object centroids.



Aperture overlay after [Place Apertures] in Multi-Aperture Measurements Negative image to enhance faint details

5.3.3. Remove an aperture from radec set

This is an optional section to demonstrate deleting one aperture from the radec set. In Comparison aperture C10, there is a faint background object that extends into the object aperture.



- 1. Open Observation Planner | Catalogs tab (AIJ toolbar | Plugins | Astro Apps | Run Planner | Catalogs tab), click [Import Radec File] and open wasp12.SR.025.radec.txt. The data table should be populated with coordinates for T01 to C17 apertures with two rows de-selected.
- 2. Uncheck 'USE' for Ap C10, aperture numbers for rows that follow update automatically as below.

C10	06300448+29495088	06:30:04.48	+29:49:50.88	11.831	0.083	0.431	11.32	4	 ✓
C11	06301904+29513387	06:30:19.04	+29:51:33.87	11.629	0.062	0.229	11.62	4	
C12	06312367+29441027	06:31:23.67	+29:44:10.27	11.159	0.058	-0.241	11.69	7	
	06300448+29495088	06:30:04.48	+29:49:50.88	11.831	0.083	0.431	11.32	4	
C10	06301904+29513387	06:30:19.04	+29:51:33.87	11.629	0.062	0.229	11.62	4	
C11	06312367+29441027	06:31:23.67	+29:44:10.27	11.159	0.058	-0.241	11.69	7	
	Change in	table row nu	mbering after	de-select	ing C10 i	n upper fi	gure		

- 3. Click [Save Radec File] to over-write wasp12.SR.025.radec.txt. To check, click [Clear] then [Import RaDec File] and confirm changes.
- 4. In the Image Viewer, click ¹ 'clear apertures and annotations from overlay'.

Import radec apertures wasp12.SR.025.radec.txt and confirm aperture marked C10 in the above figure has been removed from the aperture set.

5.4. Run AIJ Photometry

Preparation for this section:

- A visual check was made of the image stack,
- Aperture radii set to (or close to) 17 | 29 | 44,
- Aperture set has been down-selected to C2 C10, see table and aperture overlay below.

									6,231
Ар	ObjectId	Ra2000	Dec2000	Mag	Mag Err	Mag diff	Dist	Nobs USE	
T01	wasp12	06:30:32.80	+29:40:20.26	11.400	0.000	0.000	0.00	1 🗸	
	06303279+29402033	06:30:32.79	+29:40:20.33	11.415	0.070	0.015	0.00	4	₩C
C02	06303188+29422730	06:30:31.88	+29:42:27.30	11.983	0.081	0.583	2.13	4 🗹	
C03	06304827+29393591	06:30:48.27	+29:39:35.91	11.381	0.058	-0.019	3.44	5 🗹	
C04	06305007+29385436	06:30:50.07	+29:38:54.36	11.773	0.060	0.373	4.02	5 🗹	
C05	06302262+29444221	06:30:22.62	+29:44:42.21	11.554	0.080	0.154	4.89	4 🗹	
C06	06302000+29330320	06:30:20.00	+29:33:03.20	11.775	0.077	0.375	7.80	4 🗹	@C5=11.554.1.0F
C07	06295778+29380133	06:29:57.78	+29:38:01.33	11.892	0.082	0.492	7.95	4 🗹	
C08	06305893+29342229	06:30:58.93	+29:34:22.29	11.901	0.061	0.501	8.24	5 🗹	
	06304354+29493334	06:30:43.54	+29:49:33.34	11.723	0.066	0.323	9.51	4	€C2=11.983, 6.9E5
C09	06300448+29495088	06:30:04.48	+29:49:50.88	11.831	0.083	0.431	11.32	4 🗹	
	06301904+29513387	06:30:19.04	+29:51:33.87	11.629	0.062	0.229	11.62	4	@T1=11405,12E6
	06312820+29385229	06:31:28.20	+29:38:52.29	11.974	0.054	0.574	12.12	7	@C3=11.381, 1.2E6
	06301214+29284998	06:30:12.14	+29:28:49.98	11.319	0.082	-0.081	12.35	4	€C4=11.173,8.3E5
C10	06295591+29501979	06:29:55.91	+29:50:19.79	11.947	0.083	0.547	12.80	4 🗹	
	06294772+29490762	06:29:47.72	+29:49:07.62	11.869	0.090	0.469	13.15	4	
	06310779+29280862	06:31:07.79	+29:28:08.62	12.040	0.057	0.640	14.37	4	
									€ C8=11:901, 7.5E5
									€C6=11.775,83
	Apertures	$C_2 - C_2$	10 in Pl	anne	er I C	atalo	gs T	ab	Aperture overlay in AIJ Image Viev

- Open AIJ and from the toolbar select File | Import | Image Sequence ..., navigate to and open the C:\Astro\Datasets\WASP12.SR.2013_01_26\Reduced Science Files folder. Confirm there are 230 matched files and click [OK] to close window. The Image Viewer opens with the first reduced science image.
- 2. Import radec file C:\Astro\AstroImageJ\radec\wasp12.SR.025.radec.txt and click *s, zoom to fit image to window.*
- 3. Click Solution of the second secon
- 4. To ensure Image Viewer is active, click on the title bar, then press [Enter] to start AIJ time resolved photometry processing.

If the Multi-Aperture Measurements | Update and plot while running check box is selected, then several windows open:

- Plot of Measurements: plots relative flux and other parameters during processing.
- 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.

5. When processing is complete, select Measurements window | File | Save As ..., navigate to folder C:\Astro\Datasets\WASP12.SR.2013_01_26 and save as 'Measurements.tbl'.

Note: Measurements.tbl can be opened as a tab-delimited text file in Excel or other spreadsheet software. The file comprises a header row then a data row for each image in the image stack (230 data rows for WASP12 data set).

6. AstroImageJ Multi-Plot

The following four setup windows plus graphic window make up AIJ Multi-plot (MP):

Window	Function
Multi-plot Main	Sets number of plots, plot titles and scales; user sets markers for transit-based normalisation and optional data exclusion
Multi-plot Y-data	Individual plot settings with de-trend and fit mode options
Data Set Fit Settings	Window accessing 7 term transit fit settings
Plot of Measurements	Time-based plot of transit and related data
MP Reference Star Settings	AlJ recomputes photometry results when user changes aperture selection [1]

[1] The Multi-plot Reference Star Settings window is not covered in this Guide

NOTE:

The next sections walk through transit fit and other data plot setups. These instructions refer to two plot configuration files: 'BAA.transit_amass_sky.plotcfg' and

'BAA.transit_comp_amass_sky.plotcfg'.

Refer to section 2 for instructions to download and copy to plotcfg files to folder C:\Astro\AstroImageJ\plotcfg.

6.1. Open AIJ Plot Windows

- 1. If AIJ is open, close then re-open and click 🖭 'MultiPlot Tool' several Multi-plot windows open.
- 2. Locate the Multi-plot Main window, select MP Main | File | Open table from file ... to open a dialog titled Select measurement table.
- 3. Navigate to and open C:\Astro\Datasets\WASP12.SR.2013_01_26\measurements.tbl.
- 4. In MP Main, select File | Open plot configuration from file.. to open a dialog titled Open plot configuration.
- 5. Navigate to and select C:\Astro\AstroImageJ\plotcfg\ BAA.transit_amass_sky.plotcfg.
- 6. In MP Main | Other Panels, click [Ref. Stars] to activate the Multi-plot Reference Star Settings window (shown below) and close this window.

forence C	tar Selectio								
None	All	Save	Recall	Cyde	Enabled Sta	ars Less Or	e Cy	yde Individi	ual Stars
Т1	C2	C3	C4	C5	C6	C7	C8	C9	C10
		\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark		
	11.983	11.381	11.773	11.554	11.775	11.892	11.901	11.831	11.94
ellow che	ckbox bord	er - apertur er - apertur - aperture	e peak cour	nt over line	arity limit				

6.2. Multi-plot Main

The following figure shows the Multi-plot Main window configured for 5 Y-datasets and 1 Detrend variable. Note there may be differences to plotcfg file in minor settings such as Subtitle etc.

🖶 Mult	i-plot Main					- 🗆 X
File	Preferences Table	X-axis Y-axis	Help			
Data ((Measurements.tbl)					
	Default X-data	Y-datasets	Detrend Vars R	el. Mag. Reference	V. Marker 1 A Cop	y V. Marker 2 A
BJD_T	DB ~	5 🔹 sets	1 +	10 - samples	0.585	0.705
	Title		Su	btitle	I	Legend
◯ Non	e 💿 Custom		○ None O Custom		Align: 🔵 Left 💿 Cente	er 🔿 Right 🛛 🔨
WASP12	2 on UT2013-01-27		UofL MORC24 Telescope (SF	R filter, 100s, ap 18 31 46)		Position
Тор	Middle	Bottom		fiddle Bott		Middle Bottom
Left	Center	Right		Center Rig		Center Right
	X-Axi	s Label		Y-Axis Label		Trim Data Samples
○ Nor	ne	Custom Label	None 🔘	Column Label 🔵 Custom La	bel 🔨	Head 0 🖨
						Tail 0 📮
		X-Axis Scaling		<u>Ү-А</u> у	is Scaling	Plot Size
Auto	X-range OFirst X	-value as min	O Custom X-range	O Auto Y-range	Custom Y-range	
0	X-width	0.3 🗘 X	(-max 0 🗘	- У-	nax 1.02 🗘	Height 1,000
X x 1E	0 🖨		X-min 0 🖨	Y x 1E 0 🜩 Y	min 0.9 🛓	Width 800 🜩
			Phas	e Folding		
🖲 Unp	ohased 🔿 Days Since Tc (⊖ Hours Since Tc) Pha	ase	0 -) Duration (Hou	3 ♣ 2xP odd/even
Show	Meridian Flip Flip Time 0.6	Show Left Trim	Fit and Normalize R	Copy Right 0.705	Right Trim	Other Panels Redraw Plot Add Data Y-data Ref. Stars

Data (Measurements.tbl)

Data (Measurements.tbl)-						
Default X-data	Y-datasets	Detrend Vars	Rel. Mag. Reference	V. Marker 1 A	Сору	V. Marker 2 A
BJD_TDB ~	5 🔹 sets	1 🛓	10 samples	0.585 🛉	16	0.705 🛉

Default X-data TDB-based barycentric Julian Date at exposure mid-point.

Y-datasets 5 plots, comprising 2 transit, airmass and sky plots, and a blank dataset

Detrend vars Single detrend (by airmass), note no meridian flip in this dataset

V-Markers User-sets these markers at transit ingress and egress.

Title, Subtitle and Legend

As shown in main figure.

Axis Scaling and Plot Size

	X-Axis Scaling		1	Y-Axis Scaling	Plot Size	1
Auto X-range	◯ First X-value as min	Custom X-range	O Auto Y-range	Custom Y-range		
\leq	X-width 0.3	X-max 0	\leq	Y-max 1.02	Height 1,000	
X x 1E 0 🛓		X-min 0	Y x 1E 0	Y-min 0.9 👻	Width 800 🖨	

X-Axis Scaling Auto X-range, sizes axis to span the entire time-based dataset.

Y-Axis Scaling Custom Y-range, scaled to fit plot legend, transit and other plots.

Plot Size Size of Plot of Measurements window (in pixel).

Meridian Flip, Fit and Normalize, Other Panels

Me	ridian Flip		Fit	and Normalize	Region S	election]	Other	Panels
Show -	Flip Time	Show	Left Trim	Left	Сору	Right	Right Trim	Redraw Plot	Add Data
	0.6 🛨		0.3 🛓	0.585 🛖	جاله	0.705 🛫	0.9 🛨 🗖	Y-data	Ref. Stars

Meridian Flip Not applicable for WASP12 dataset

Fit / Normalize Options to trim leading and trailing data, Left and Right Trim fields respectively, are

disabled in this figure. Click to insert V-Marker values into the Left and Right fields

Other Panels Refresh plot and open other plot windows.

Note: It is easy to get lost in the myriad AIJ plot windows. [**Redraw Plot**] refreshes the Plot of Measurements chart, and [**Y-data**] activates the Multi-plot Y-data window.

[Add Data] this function may corrupt measurements.tbl dataset - recommend to NOT use this function

Menu Options

File	Large number of plot configuration and other options
Preferences	Uncheck 'Use –wide—Y-data columns to fold Y-axis rows as in the next section.
Help	Access a general multi-plot help window or a dialog displaying Data Naming
	Conventions.

6.3. Multi-plot Y-Data

The following figure is a Multi-plot Y-data window in 'folded' state (see MP Main Menu Options) with five data sets. Data sets 1 and 2 are transit plots, data sets 4 and 5 plot airmass and a sky-related parameter. Data set 3 is currently unused and its plot check box is deselected.

ata Set	New Col	Plot	Auto Scale		X-data	Input in Mag		Y-dat	a 📍	Aut		Function	1	Y-operand		Colo	r	Symb	ol	Lines	Input Average	Smo- oth	Len- gth
1		\checkmark	\checkmark	default	~		rel_f	lux_T1		~] no	ne v		~	bl	ue	~	dot	~		1 -		31
2		\checkmark	\checkmark	default	~		rel_f	lux_T1		-] no	ne v		~	re	d	~	dot	\sim		1 -		31
3				default	~					-] no	ne v		~	re	d	~	circle	~		1 -		31
4		\square		default	~		AIRM	IASS		-] no	ne v		~	gr	ay	~	dot	\sim		1 -		31
5		\checkmark		default	~		Sky/	Pixel_T1		-	no	ne v		~	bl	ack	~	x	~		1 -		31
											_												
	Fi Mo		Tre Coeffi		Trend Dataset			n/ Ou Ref Ma		Scal	le	then Shift	Out Bin	Bin Size (minutes)		egend Type			c	uston	Legend		6
et		de	Coeffi		Dataset	_	Mag R			Sca	le 1 ÷			(minutes)		Гуре	Le	gend1	C	iuston	1 Legend		6
ata iet 1	Мо	de V	Coeffi	cient	Dataset	~	Mag R	čef Ma ∼ □	g Rel	Scal		0	Bin	(minutes)	ا 🗶	Type		gend1 gend2	C	uston	ı Legend		4
et 1 2	Mo	de ~ (~ (Coeffi	cient 132 🔹 A	Dataset	~	Mag R	čef Ma ∼ □	g Rel 🕸 🗆 🕸 🗆	Scal	1 🗘	0.015	Bin	(minutes)	ا 🗶	Type) Le		C	uston	Legend		
et 1		de ~ (~ (Coeffi	cient 132 ÷ A 145 ÷ A	Dataset	~	Mag R	<pre>kef Ma </pre>	g Rel 🐉 🗆 🏶 🗆	Sca	1 ‡ 1 ‡	0 •	Bin	(minutes)	ו א א	Type	 Le Le 	gend2	C	uston	Legend		

Multi-plot Y-data: Upper section

🖶 Mu	lti-plo	ot Y-d	ata				
Data Set		Plot	Auto Scale		X-data	Input in Mag	Y-data 💡
1		\checkmark	\checkmark	default	~		rel_flux_T1
2		\checkmark	\checkmark	default	~		rel_flux_T1
3			\checkmark	default	~		
4			\checkmark	default	~		AIRMASS
5			\checkmark	default	~		Sky/Pixel_T1

Data Set Identifier common to upper and lower window sections

Plot Check box controls plot visibility

- X-data 'default' is the Multi-plot Main | Default X-data (BJD_TDB in this example)
- Y-data drop-down dataset selections of transit (rel_flux_T1), airmass and sky brightness (Sky/Pixel_T1)

The right-side controls set plot colours and symbols. Input Average combines adjacent data to reduce scatter, set to 1 in this example.

Multi-plot Y-data: Lower section

Data Set	Fit Mode	Trend Coefficient	Trend Dataset	Norm/ Mag Ref	Out Mag	Page Rel	Scale the	en Shift
1		0.0001432	AIRMASS ~	· ·		\$	1 🔹	0
2	 ~	0.0001145	AIRMASS \sim	· ·		\$	1 🛓	-0.015
3	off \checkmark	0	~	off \checkmark		≉ □	1 🔹	-0.03 🔹
4	off \checkmark	1 🔺	~	off \checkmark		参 ☑	-10 🔹	-25 🔹
5	off \checkmark	0	~	off \checkmark		参 ☑	15 🔹	-40 🔹

Fit Mode Data Set 1: Data Set

Data Set 2: AIRMASS detrend and transit fit. Other Data Sets are 'off'.

Refer to the detailed tooltip for more details. A right-click on even the Data Set Fit Settings window.

- Trend Dataset Transit datasets (datasets 1 & 2) are 'detrended' by AIRMASS (i.e., each dataset is divided by airmass)
- Norm/Mag Ref Transit datasets are normalised to 1.0 over the baseline regions; see Fit Mode | Data Set 1.

Page Rel, Scale, then Shift

Parameters to control plot placement and scaling. Transit data sets have Scale = 1 and offset for visibility. Data sets 4 and 5 are checked 'Page Rel' to auto-scale and offset towards the bottom of the chart. Refer extensive tooltips for details.

6.3.1. Add Comparison Star to Multi-plot Y-data

Example: add rel_flux_C2 as new dataset 3 in the Multi-plot Y-data window.

Data Set 3 - upper window settings

- 1. Click the Y-data control for Data Set 3 and select 'rel_flux_C2' from the drop-down list. If necessary, select the Plot checkbox for Data Set 3.
- 2. Change dataset 3 to a distinctive colour and symbol, in this example, purple and circle as below.

Dataset 3 settings in the upper part of the folded Multi-plot Y-data:

Data Set	New Col	Plot	Auto Scale	X-data		Input in Mag	Y-data 💡		Auto Error	Function		Y-operand	Color		Symbo	ol	Lines	Input Average	Smo- oth	Len- gth
1		\checkmark	\checkmark	default	\sim		rel_flux_T1	\sim		none	\sim	~	blue	~	dot	\sim		1 🔹		31 🔹
2		\checkmark	\checkmark	default	\sim		rel_flux_T1	\sim		none	\sim	~	red	~	dot	~		1 🛓		31 🔹
3		\checkmark	\checkmark	default	\sim		rel_flux_C2	\sim		none	\sim	~	purple	~	circle	~		1 🛓		31 🔹
4		\square	\checkmark	default	\sim		AIRMASS	\sim		none	\sim	~	gray	~	dot	~		1 🗘		31 🔹
5		\square	\checkmark	default	~		Sky/Pixel_T1	\sim		none	\sim	~	black	~	x	\sim		1 🛉		31 🔹

Data Set 3 - lower window settings

3. Data Set 3:

Select Fit Mode , Trend Dataset: AIRMASS and Norm / Mag Ref: . This combination applies an airmass detrend then a linear fit each over the full data set.

Leave Scale = 1 Set 'then Shift' field to offset the plot, offset = -0.055 applied below. Dataset 3 settings in the lower part of the folded Multi-plot Y-data:

Data Set	Fit Trend Trend Mode Coefficient Dataset		Norm/ Mag Ref	Out Mag	Page Rel	Scale th	en Shift	Out Bin	Bin Size (minutes)	Legend Type	Custom Legend
1	off ~ 0 *	~			≉ □	1 🛓	0		5 🖕	🗶 🕢 🆃	Legend1
2	0.0001145 + AIRMASS	~	· ·		\$	1 🔹	-0.015		5 🛓	🗶 🕢 🛸	Legend2
3	-0.000006: 🔹 AIRMASS	~	×		\$	1 🛓	0.055 🔹		5 💂	🗶 🕢 🏓	Legend3
4	off ~ 1 +	\sim	off \checkmark		参 ☑	-10 🔹	-25 🔹		5 💺	🗶 🕢 🛸	Legend4
5	off V 0 🔺	~	off \checkmark		参 ☑	15 🔹	-40 🔹		5 🖕	🗶 🕢 🆃	Legend5

- 4. To save the current settings, MP Main | File | Save plot configuration ..., navigate to the plots folder C:\Astro\AstroImageJ\plotcfg.
- 5. Save modified plot configuration as C:\Astro\AstroImageJ\plotcfg\ BAA.transit_amass_sky_update.

6.4. Fit Plot Settings

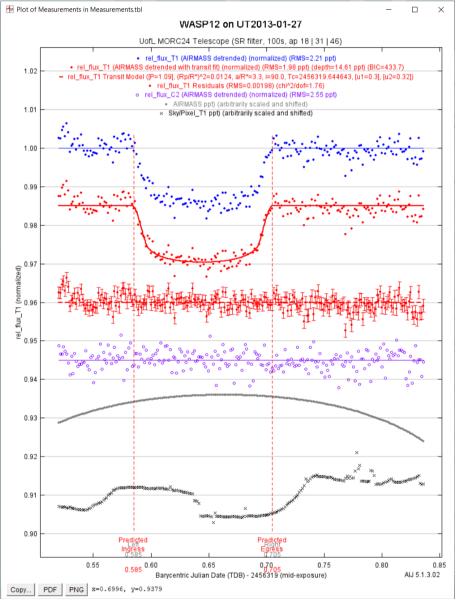
Show Model	Show in legend	Line Color Line Width
Show Residuals	✓ Show in legend ✓ Show Error	Line Color Line Width Symbol Symbol Color Shift red V I O O O O O O O O O O O O O O O O O O

Data Set Fit Settings | Plot Settings section

This section is configured to plot a transit model curve and residuals with error bars. Both plots are red and the residuals are offset by -0.025.

6.5. Plot of Measurements

Datasets 1 and 2:	Transit datasets
Dataset 3:	Fit residuals dataset
Dataset 4:	Comparison star dataset (added in a previous section)
Datasets 5 and 6:	Airmass and SkyPixel_T1 show detrend and sky conditions respectively
Header:	Identifies dataset, applied detrend (AIRMASS), rms and fit statistics



7. Transit Analysis in AstroImageJ

The figure below shows the full Data Set Fit Settings window. The user inputs data into two fields in the Orbital and Host Star Parameter sections. The Transit Parameters section handles a 7-parameter fit to the airmass detrended transit photometry data. In this figure, the user has entered values for the limb-darkening coefficients u1 and u2. Locking these parameters reduces the number of independent fit variables to 5. Transit depth and timing parameters are listed in the 'Calculated from model' row.

Data Set 2 Fit Settings							- 🗆 🗙
File Auto Priors							
rel_flux_T1-							
User Specified Parameters (not fitted) Orbital Parameters Period (days) Cir Ecc Cir Ecc Sp.T. Teff (K) Sp.T. Teff (K)							
1.094 -		ω (deg) 0.0		52 🗘	J-K - R* (Rsun) 0.074 ↓ 1.749 ↓	2.063	
Transit Parameters							
Enable Transit Fit	Auto Update Priors	s	Extract Prior Center	Values Fi	rom Light Curve, Orbit, and	l Fit Marker	s
Parameter	Best Fit	Lock	Prior Center	Use	Prior Width	Cust	StepSize
Baseline Flux (Raw)	0.154132298	۵	0.154107847 🛓		0.030821569 🜲		0.1 🜲
$(R_{p} / R_{*})^{2}$	0.012189444	۵	0.013908668 🛓		0.006954334		0.013908668 💂
a / R _*	3.114062496	۵	3.309271028 🔹		7.0 🔹		1.0 🔺
т _с	2456319.645095323	۵	2456319.645 🔹		0.015 🔹		0.01
Inclination (deg)	83.933856721	۵	79.2 🔺		15.0 💂		1.0
Linear LD u1	0.322000000	⊳ ∨	0.322		1.0 🔺		0.1 🔺
Quad LD u2	0.320011200	⊳ ∠	0.3200112 🔹		1.0 🛓		0.1 🔺
Calculated from model	Depth (ppt)	b	t14 (d)t14 (h		-t23 (d)		(cgs) — Rp (Rjup)
Calculated from model	14.23 0.329	÷	0.121725 02:55	17	0.094083 0.013821	0.4	4769 1.88
Detrend Parameters							
Use Parameter	Best Fit	Lock	Prior Center	Use	Prior Width	Cust	StepSize
AIRMASS ~	0.000191715080	۵	0.0 🛓		1.0 💂		0.1
Fit Statistics	RMS (ppt)	-	hi²/dof E		dof		-chi ²
Fit Statistics	2.251226			.9499	224	5	31.1880
Fit Optimization		C L C L				e de la com	
Outlier Removal	Comparison Exhaustive Optim			etrend Pa	Detrend Parameter ars.: 1 - Exhaus		
	Exhibitistive optim		beare	BIC Thre		er. Remain	
N × σ: 5 • 0							
N × σ: 5 ÷ 0							
	Show in legend	Line red	Color Line Width]	og Optimization		
Plot Settings		red			og Optimization Symbol Symbol Co red	olor V	Shift -0.025 👻
Plot Settings	Show in legend	red Line	Color Line Width		Symbol Symbol Co	olor ~	

7.1. User Specified Parameters (not fitted)



Orbital and Host Star Parameters can be imported from the NASA Exoplanet Archive: <u>https://exoplanetarchive.ipac.caltech.edu/.</u>

- 1. Click this link to open the NASA Archive in default browser. Enter WASP12 in the 'Explore the Archive search field and click [Search] to open the WASP-12 Overview page.
- 2. Click on the WASP-12b Planetary Parameters link, locate orbital period P(days) = 1.0914, and enter this value in the Fit Settings | Orbital Parameters | Period (days) field.
- 3. In the same web page, click on the WASP-12 Stellar Parameters link, locate the stellar radius $R*(R_{\odot}) = 1.749$, and enter this value in the Fit Settings | Host Star Parameters | $R^*(Rsun)$ field.

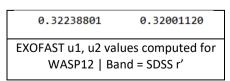
7.2. Transit Parameters

Transit Parameters		_						
Enable Transit Fit	Fit 🗸 Auto Update Priors		Extract Prior Center Values From Light Curve, Orbit, and Fit Markers					
Parameter	Best Fit	Lock	Prior Center	Use	Prior Width	Cust	StepSize	
Baseline Flux (Raw)	0.154132298 🕏		0.154107847 粪		0.030821569 🐥		0.1 🔺	
(R _p / R _*) ²	0.012189444		0.013908668 粪		0.006954334		0.013908668 🔹	
a / R _*	3.114062496		3.309271028 🛓		7.0 🔺		1.0 🔹	
т _с	2456319.645095323		2456319.645 🔹		0.015 🔶		0.01 🔹	
Inclination (deg)	83.933856721 🖨		79.2 🔺		15.0 🔺		1.0 🔺	
Linear LD u1	0.322000000 🖨		0.322 🛓		1.0 🔺		0.1	
Quad LD u2	0.320011200		0.3200112 🛓		1.0		0.1	
Calculated from model	Depth (ppt) b 14.23 0.329	•	t14 (d) t14 (hm 0.121725 02:55:	<u> </u>	-t23 (d)		0.4769 Rp (Rjup)	

LD terms u1 and u2 can be imported from the EXOFAST - Quadratic Limb Darkening page:

https://astroutils.astronomy.osu.edu/exofast/limbdark.shtml

- 1. Click this link to open the EXOFAST applet in default browser. Select WASP12 and SDSS r' from the 'Select Planet' and 'Band' drop downs respectively and click [Submit Query].
- Copy the computed LD values u1 = 0.322 and u2 = 0.320 into the respective (yellow highlighted) Prior Center fields. If necessary, select both the Lock check boxes



The bottom row lists parameters computed from the transit model, including transit depth = 14.7 ppt (part-per-thousand) and ingress-egress parameters t14 and t23. Refer tooltips for individual parameter descriptions.

Appendix A: Download WASP12b Example Fits Files

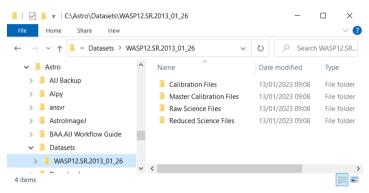
 Create a set of WASP12 sub-folders in C:\Astro\datasets as follows: C:\Astro\Datasets\WASP12.SR.2013_01_26 [1]

C:\Astro\Datasets\WASP12.SR.2013_01_26\Raw Science Files

C:\Astro\Datasets\WASP12.SR.2013_01_26\Calibration Files

C:\Astro\Datasets\WASP12.SR.2013_01_26\Master Calibration Files [2]

C:\Astro\Datasets\WASP12.SR.2013_01_26\Reduced Science Files [3]



- [1] root folder indicating start night (26-Jan-2013) and imaging filter (SR)
- [2] folder for master bias, darks and flats fits files
- [3] folder for processed science fits files
- 2. Download the uncalibrated example images indicated below from the WASP12b dataset link in section 1 and extract files to the Raw Science Files and Calibration Files folders as follows:

WASP-12b example uncalibrated images => WASP-12b example raw bias, darks and flats files => Raw Science Files Calibration Files

Index of /software/astroimagej/examples

	Name	Last modified	<u>Size</u>	Description
۶	Parent Directory		-	
T	README	2017-02-20 19:02	1.3K	
- M	<u>WASP-12b_example_calibrated_images.tar.gz</u>	2015-06-09 02:52	4.3G	
- 🔁	WASP-12b_example_calibrated_images.zip	2015-02-19 00:04	4.4G	
- 🖞	<u>WASP-12b_example_raw_biases.tar.gz</u>	2017-02-20 18:12	133M	
<u></u>	<u>WASP-12b_example_raw_biases.zip</u>	2 07:02	136M	
L)	WASP-12b_example_raw_darks.tar.gz	2017-02-20 18:14	135M	
L)	WASP-12b_example_raw_darks.zip	2 07:05	138M	
L)	WASP-12b_example_raw_flats.tar.gz	2017-02-20 18:13	265M	
- 🔁	WASP-12b_example_raw_flats.zip	06:57	266M	
L.	WASP-12b_example_uncalibrated_images.tar.gz	2017-02-20 18:35	4.3G	
L.	WASP-12b_example_uncalibrated_images.zip	07:01	4.4G	
?	<u>standard_transit.plotcfg</u>	2016-03-05 02:49	132K	

Apache Server at www.astro.louisville.edu Port 443

Observer Location	Moore Observatory, KY	ICAstronomy, Oria		
Latitude	+38:20:41.25	+37:30:03.96		
	38.344791	37.5011		
Longitude	-85:31:42.51	-02:24:29.88		
	-85.528476	-2.4083		
Altitude (m)	229	1180		
UTC Offset (Hr)	-5 (EST)	+1 (CET)		
Observer & Equip Details				
Telescope Short Descript	MORC24	ICA_CDK14		
Telescope Full Descript.	Moore Observatory	ICAstronomy		
	24-inch Ritchie-Chretien	14-inch CDK		
Aperture (mm)	600	355		
Focal Length (mm)	4800	2470		
Camera	Apogee U16M CCD	QSI683		
Pixel Size (H) (um)	9.0	5.4		
Pixel Size (V) (um)	9.0	5.4		
Array Size (H)	4096	3320		
Array Size (V)	4096	2500		
AIJ Aperture Photometry Settings				
Pixel bin [1]	1 x 1	2 x 2		
CCD gain (e-/count)	1.25	1.1 [2]		
CCD readout noise (e-)	9.0	8.0		
CCD dark current	0.01	0.01		
Data set	WASP12B	WASP104		
Catalog	APASS	APASS		
Filter	SR (SDSS)	V (Johnson)		
Start Night	2013-01-27	2020-02-27		

Appendix B: UofL Moore RC24 and ICAstronomy Data Sets

[1] QSI683 gain is bin size dependent

[2] QSI683 gain for 2x2 bin

Appendix C: Download and Configure ANSVR Plate Solve

This Appendix covers downloading ansvr local plate solve software and setting up the AIJ DP Astrometry Settings window. Refer to section 1 for link to the ansvr web page. Note that Win10 file paths may differ from those given in the instructions.

Install ansvr plate solve software

- 1. Open link to ansvr install web page and accept default file locations in instructions 1 to 4.
- 2. Instruction 5: either accept default port 8080 or change to a custom port number (e.g. 9123 as below) to avoid potential clash with another application on this port

🛃 Setup - Astrometry.net Local Solver	_		×
Ansvr Port Number What port should ansvr listen on?			Ð
Please specify the port number for ansvr, then click Next. Th usually ok.	e default por	rt, 8080, is	3
Port:			
9123			7
< Back	Next >	Ca	incel

- 3. Continue with instructions 6 to 8.
- Instruction 9 covers field size selection in the Astrometry.net Index Manager window. The following selection support ansvr plate solving WASP104 and WASP12 datasets. Download size of index files 4206 – 4219 is about 620 MB.

Astrometry.net Index Manager	_		\times				
Select the range of indexes you need, then click Start to begin downloading. Only those indexes you do not already have will be downloaded.							
Narrowest field - choose the size corresponding to about 20% of your							
Index 4206, 16 to 22 arcmin $\qquad \sim$							
Widest field - choose the size corresp	onding to you	ır largest	FOV.				
Index 4219, 23.3 to 33.3 deg (1400) to 2000 arcm	in)	~				
Folder	Start						
No installed indexes found							

Index files 4206 - 4219

- 5. Option: Click [Folder...], create and select new folder C:\Astro\ansvr\data, otherwise skip this step and accept default file path.
- 6. Click [Start] to start file download. As noted in instruction 10, the download can be cancelled and resumed as necessary.

- 7. Instruction 11: when download is completed, open a File Explorer window, enter 'shell:startup' in the address bar, then select the Astrometry.net Local Solver folder to access Ansvr Settings item.
- 8. Open the Ansvr Settings item to confirm ansvr is running as instruction 12.

	aming\Microsoft\Windows\Start Menu\Programs\	
File Home Share View ← → ▼ ↑ 📜 « Progr > Astrometr	ry.net Loc → 🕐 🔎 Search Ast	trometry.net Local Solver
✓ Programs	^ Name	Date modified
> 📜 Amazon	🗾 Ansvr Settings	07/11/2019 17:20
📜 Anaconda3 (64-bit)	Check for Ansvr Updates	
📜 Astrometry.net Local S		07/11/2019 17:20
📜 Atlassian	🔊 Start Ansvr	07/11/2019 17:20
📙 British Broadcasting Co	orporation 🛛 🔊 Stop Ansvr	07/11/2019 17:20
Eclipse	🔊 Watch Ansvr Log	07/11/2019 17:20
FreeCAD 0.19		
📙 GitHub, Inc		
📜 JetBrains Toolbox		
Logitech		
Maintenance		
📙 MeshLab		
📜 Start-up		
Windows Accessories		
items		8== 8

9. Option – to easily access this folder, save a shortcut to the Astrometry.net Local Solver folder in C:\Astro\ansvr folder,

Configure AIJ Astrometry Settings

1. Open AIJ, click P in the toolbar to open the CCD Data Processor window and check the Plate Solve option in the FITS Header Updates section



- 2. In the DP Coordinate Converter window, enter ObjectID wasp104 and press Enter to run a SIMBAD query and update the Standard Coordinates fields.
- 3. In CCD DP | FITS Header Updates, click , 'Open plate solve settings panel', to open the DP Astrometry Settings window.
- 4. Enable Use Custom Server option and enter server address and default or custom port, as set during ansvr install:

Default port (8080):	http://127.0.0.1:8080
Custom port (e.g. 9123):	http://127.0.0.1:9123

Note: the text box tooltip refers to default port 8080.

5. If the image plate scale is known, enable Constrain Plate Scale and enter Plate Scale and Tolerance; where the plate scale is not known, disable Constrain Plate Scale.

- 6. Enable Sky Location option, RA and Dec values should automatically be populated from DP CC coordinates, for ObjectId wasp104 in this case.
- 7. Finally, leave other settings as default and click [SAVE AND EXIT] to close window.

DP Astrometry Settings			-		×
User Key:	(Get key from: nova.astrometry.net)				
Use Custom Server: 🗹 Enable	http://127.0.0.1:9123]			
Re-save Raw Science: 🗌 Enable	FPACK GZIP	WARNING: may	re-writes ra	aw scienc	æ file
Skip Images With WCS: 🗌 Enable					
Annotate: 🔽 Enable	Radius (pixels)				
Add To Header: 🗹 Enable	30.00 🖨				
	Filter Radius (pixels)				
Median Filter: 🗹 Enable	2 荣				
_	Max Peak (ADU)	Noise Tol (StdDev)	Max N	lum Stars	
Peak Find Options: 🗌 Limit Max Peaks	50000 🗘	1.00 🚔		5	0 🗘
	Radius (pixels)	Sky Inner (pixels)	Sky Ou	ter (pixels))
Centroid Near Peaks: 🗌 Enable	20.00 💂	30.00 💂		40.0	0 🗘
	Plate Scale (arcsec/pix)	Tolerance (arcsec/pix)	1		
Constrain Plate Scale: Enable	5.200 🔹	0.250 💂			
	Center RA (Hours)	Center Dec (Degrees)	Radius	s (arcmin)	
Constrain Sky Location: 🗹 Enable	10:42:24.602	+07:26:06.29		40.	0 🌲
	SIP Order		-		
SIP Distortion Correction: 🗹 Enable	2 🗘				
	SAVE AND EXIT	SAVE			

DP Astrometry Settings configured for Custom Server

8. Test run installed ansvr: configure CCD DP window to process the downloaded wasp104.fit file as below (C:\Astro\Downloads\BAA.Files for AIJ Guide\wasp104.FIT) with Plate Solve and Save Calibrated Images both enabled and all image reduction options disabled.

DP CCD Data Pro	cessor						— (⊐ ×
File Preference								
Control	Options		Directory			Filename/Patte	m	Totals
Filename Patt								
Enable	Sort Num	C:\Astro\Downloads\BAA.Files f	or AlJ Guide\		2	wasp104.FIT		1
Filename Number Filtering								
Enable		Min:	0 🜲 Max:	100000000	(wasp104.FIT		1
Bias Subtraction	on							
Build	🔵 ave 💿 med	.\Calibration Files\				bias_		0
Enable						mbias.fits		0
Dark Subtracti	on							
Build	🔾 ave 💿 med					dark_		0
Enable	🗹 scale 🗹 deBias					mdark.fits		0
Flat Division								
Build	🔾 ave 🔘 med					flat_		0
Enable	Remove Gradient					mflat.fits		0
Image Correct		New States		< (PixVal) +	0.050 4	× (PixVal) ² +		
	nearity Correction		0.0E0 + 1.0E0 + 2 + Threshold: 50		0.0E0 -	× (PixVal)* +	0.0E0 🔹 × (PixVal) ³	
_	Dutliers 🗹 Bright 🖸	Dark Radius.	Z V Intestiold. 50	Y				
FITS Header Updates								
General	Plate Solve	🔶 📉 🥠	Coordinate Converter manual entry			coordinate Converter manual	entry ~	
Save Calibrate	d Images							
Enable	○ 16	Sub-dir:	Suffix: _out	F	ormat		FPACK GZIP	
Post Processi	ng							
🗌 М-Ар	Save Image	Macro 1 C:\Users\rlee1\			0			
M-Plot	Save Plot			Macro 2 C:\Users\r	rlee1\			0
Control Panel								
Polling I	o হ	Set 👫	START P	AUSE	RESET		Processed: Remaining:	0 1

- 9. Click [START] to run ansvr plate solve; on completion, the Log window should read 'Plate solve success' and save in C:\Astro\Downloads\BAA.Files for AIJ Guide\wasp104_out.FIT.
- 10. Open wasp104_out.FIT in AIJ Image Viewer (AIJ Toolbar | File | Open... then navigate to and

select C:\Astro\Downloads\BAA.Files for AIJ Guide\wasp104.FIT). Click *(display fits header'* in the Image Viewer toolbar to open the FITS Header Editor window.

11. Keyword CD1_1 (row 90) is the image scale in deg / pixel (ignore any minus sign).

89	CRPIX2	627
90	CD1_1	-0.000240535163607
91	CD1_2	-9.9302002216E-06

- 12. Convert pixel scale: CD1_1 = 0.000240 deg / pixel = 3600 x 0.000241 = 0.87 arcsec / pixel
- 13. Re-open the DP Astrometry Settings window, enable Constrain Plate Scale option and enter 0.87 in the Plate Scale text box, then click [SAVE AND EXIT] to close this window.

_	Plate Scale (arcsec/pix)	Tolerance (arcsec/pix)	
Constrain Plate Scale: 🗹 Enable	0.870 🚖	0.250 🚖	

14. In CCD DP window, click [START] to re-run plate solve on wasp104.fit; the ansvr plate solve process should run faster with fixed plate scale.

Appendix X: Software Licence

Planner.jar and astro_plugins-x.jar are open-source software licensed under GPL-3.0. Source code can be downloaded from GitHub repositories:

https://github.com/richardflee/observation_planner_for_astroimagej https://github.com/richardflee/astap_solver_for_astroimagej