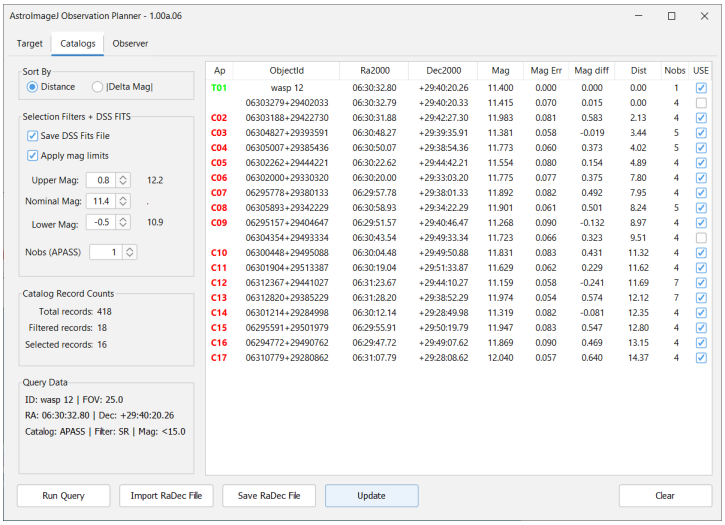
British Astronomical Association

Supporting amateur astronomers since 1890

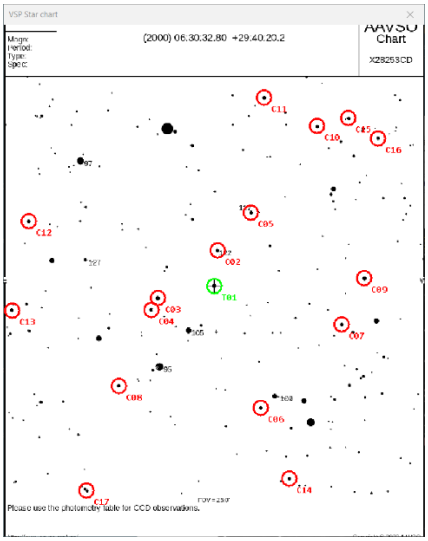
Workflow based Guide to using AstroImageJ for Exoplanet Transit Photometry

Part 1

(Full Guide)



Ap	ObjectId	Ra2000	Dec2000	Mag	Mag Err	Mag diff	Dist	Nobs	USE
T01	wasp 12	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	☐
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	☑
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	☑
C09	06295157+29404647	06:29:51.57	+29:40:46.47	11.268	0.090	-0.132	8.97	4	☑
	06304354+29493334	06:30:43.54	+29:49:33.34	11.723	0.066	0.323	9.51	4	☐
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	☑
C13	06312820+29385229	06:31:28.20	+29:38:52.29	11.974	0.054	0.574	12.12	7	☑
C14	06301214+29284998	06:30:12.14	+29:28:49.98	11.319	0.082	-0.081	12.35	4	☑
C15	06295591+29501979	06:29:55.91	+29:50:19.79	11.947	0.083	0.547	12.80	4	☑
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	☑



Selected WASP12 APASS records
Observation Planner | Catalogs Tab.

Richard Lee

24 January 2023

Contents

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	AIJ Home

Plate Solve Software

Title	Link
ANSVR Plate Solve Software	ANSVR
ASTAP Plate Solve Software	ASTAP

References:

Ref	Title	Link
[1]	A Guide to AstroImageJ Differential Photometry	BAA Guides
[2]	A Practical Guide to Exoplanet Observing	AIJ Home
[3]	AstroImageJ: Image Processing and Photometric Extraction for Ultra-Precise Astronomical Light Curves (Expanded Edition), Karen Collins, et al	
[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	VSP
AAVSO Photometric All Sky Survey	APASS Home
Digitized Sky Survey	DSS Wiki
NASA Exoplanet Archive	NASA Exo
EXOFAST - Quadratic Limb Darkening	EXOFAST
SIMBAD Astronomical Database – CDS (Strasbourg)	SIMBAD

2. Install Software

2.1. Download BAA Support Files

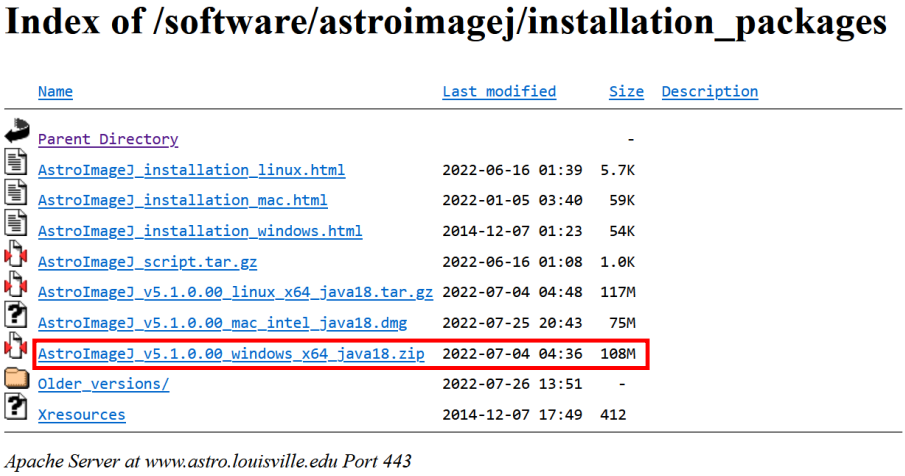
1. If necessary, create a new folder C:\Astro\Downloads.
2. From the BAA web site (select link BAA_AIJ in section 1), download and save 'BAA.Files for AIJ Guide Part 1.zip' in the C:\Astro\Downloads folder.
3. Extract files to the Downloads folder; the path to uncompressed folders is: C:\Astro\Downloads\BAA.Files 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	Size	Description
	Parent Directory		-	
	AstroImageJ_installation_linux.html	2022-06-16 01:39	5.7K	
	AstroImageJ_installation_mac.html	2022-01-05 03:40	59K	
	AstroImageJ_installation_windows.html	2014-12-07 01:23	54K	
	AstroImageJ_script.tar.gz	2022-06-16 01:08	1.0K	
	AstroImageJ_v5.1.0.00_linux_x64_java18.tar.gz	2022-07-04 04:48	117M	
	AstroImageJ_v5.1.0.00_mac_intel_java18.dmg	2022-07-25 20:43	75M	
	AstroImageJ_v5.1.0.00_windows_x64_java18.zip	2022-07-04 04:36	108M	
	Older_versions/	2022-07-26 13:51	-	
	Xresources	2014-12-07 17:49	412	

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

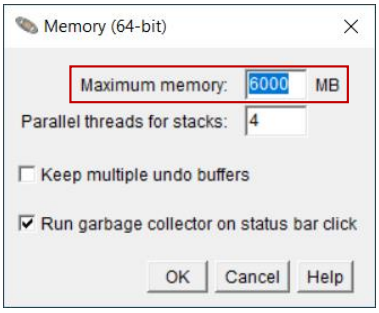
2. To follow instructions in this guide, copy and rename the uncompressed AstroImageJ folder to: C:\Astro\AstroImageJ.
3. Run AstroImageJ and, if the AstroImageJ Updater dialog opens, click [OK] to upgrade to 'daily build'.
4. To check the installed version, open AIJ and from the toolbar select Help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

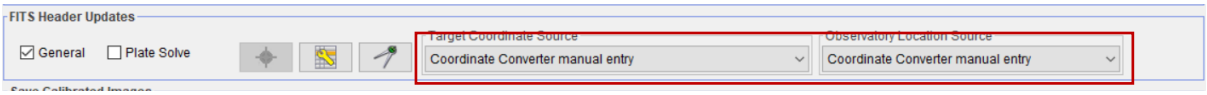


2. Enter 6000 in Maximum memory text box and click [OK] to close dialog, then close and re-open AIJ to register changes.

2.3.2. Configure DP Coordinate Convert Dialog

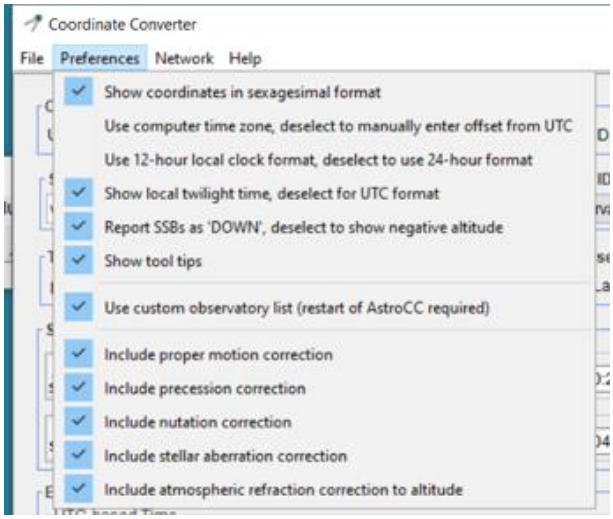
1. In the toolbar, click DP, CCD Data Processor Tool, to open the CCD Data Processor and DP Coordinates Converter windows.

2. In the CCD Data Processor | FITS Header Updates section, set the Target and Observation Source drop-downs to 'Coordinate Converter Manual Entry'.



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:



Notes:

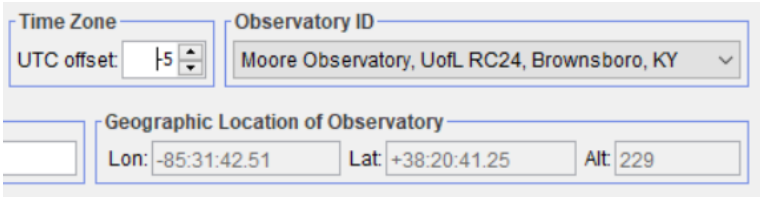
- Deselect the 2nd item to manually enter offset from UTC,
- Option to use either 12- or 24-hour clock formats
- Select the 'Use custom observatory list (…)' item.

4. To register selections, close and re-open the AIJ toolbar, and click DP 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 DP 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).

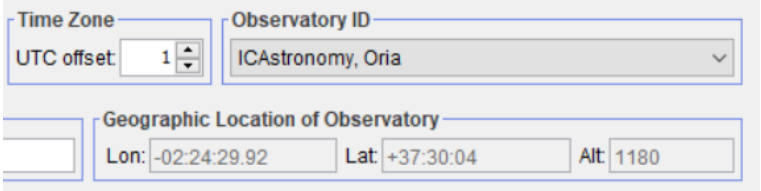
1. Navigate to and open observatories.txt file in a text editor; observatories.txt is in the AIJ home folder C:\Astro\AstroImageJ\observatories.txt.
2. Add a new entry in the #Custom Entries list with Observatory Name, Latitude, Longitude and Altitude, as specified in observatories.txt header comments
   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>37.50111 <tab> -2.40831 <tab> 1180	

```
Moore Observatory, UofL CDK20N, Brownsboro, KY  38.344836 -85.528889  229.0
Moore Observatory, UofL RC24, Brownsboro, KY  38.344791 -85.528476  229.0
ICAstronomy, Oria  37.50111  -2.40831  1180
Mt. Kent Observatory, USQ CDK20S, Queensland, Australia  -27.797861  151.855417  682.0
```

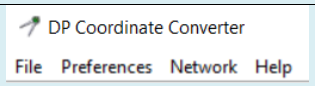
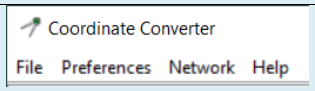
ICAstronomy entry in observatories.txt

3. Save and close observatories.txt file.
4. Close re-open AIJ, in the toolbar click DP 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:



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

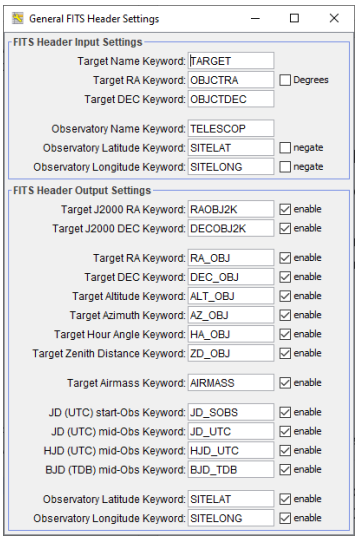
This guide *always* refers to the **DP Coordinate Converter** window,  , which links to the Target and Observatory Location Sources in the CCD Data Processor | FITS & Header Updates section.

Toolbar icon	AIJ Toolbar Description	Window Title	USE ?
	CCD Data Processor Tool	 **DP** Coordinate Converter	✓
	Coordinate Converter Tool	 Coordinate Converter	✘

2.3.5. Configure FITS Header Settings

1. Open AIJ, in the toolbar, click  , 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.

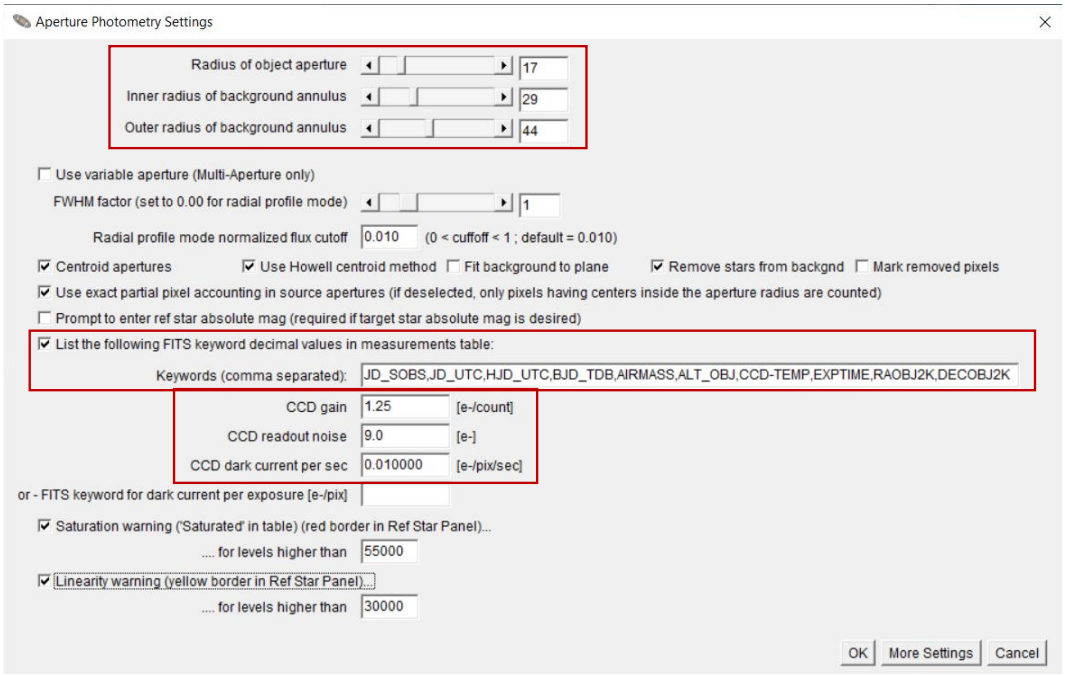
Note: The FITS Header Input Settings section is not used: Target and Observatory details are imported from the DP Coordinate Converter window.



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.



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.

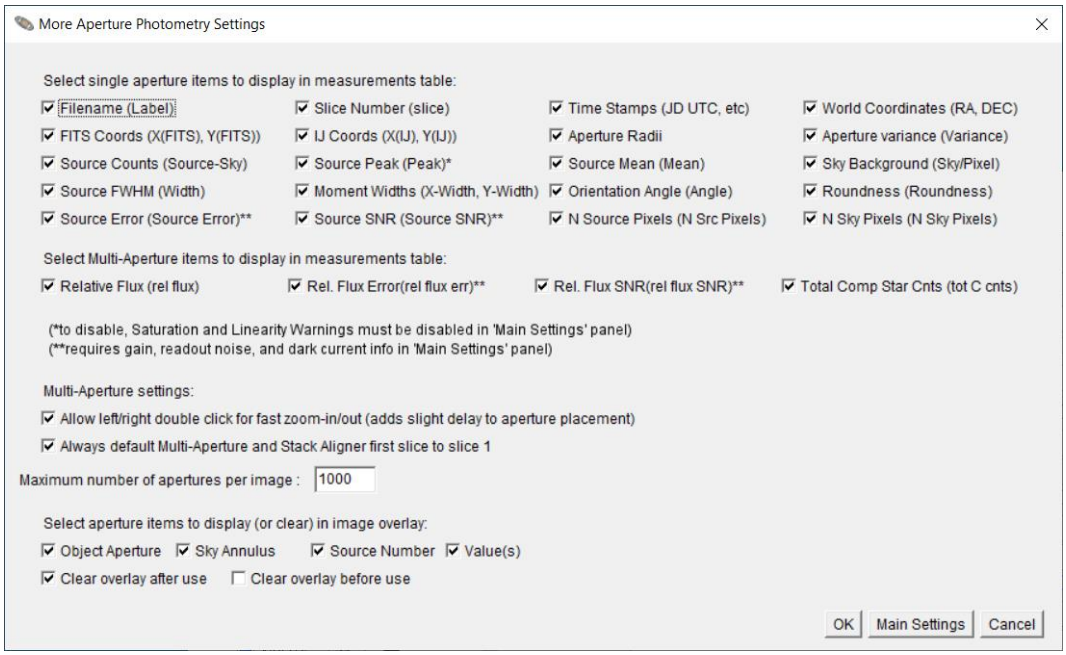
[2] Enter CCD values for Moore or ICA observatory as below:

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.



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

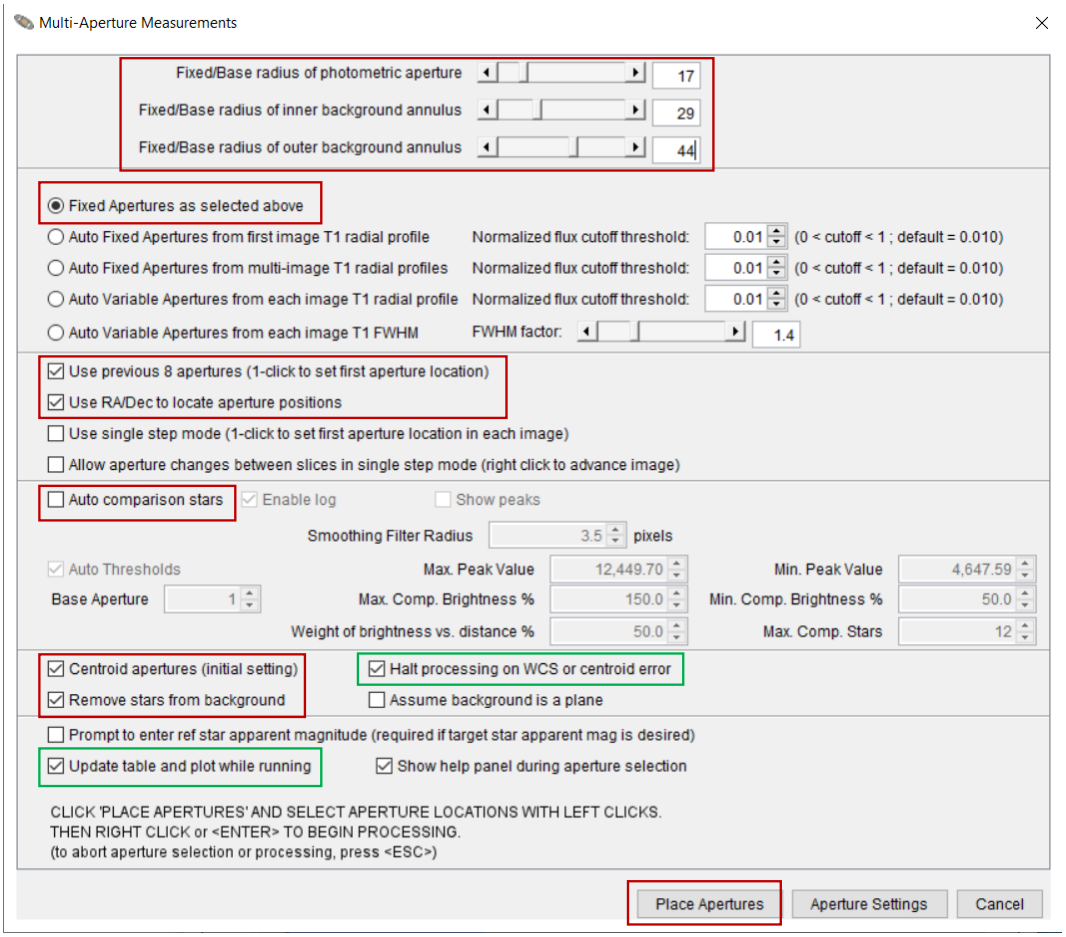
	Field	**Notes**
1	EXPTIME / EXPOSURE	Exposure time in seconds. [1]
2	JD_SOBS	Julian Date at start of exposure
3	JD_UTC	Julian Date at mid-exposure
4	Label	FITS filename
5	N_Sky_Pixels_T1	No. pixels in T1 sky aperture (outer annulus)
6	N_Src_Pixels_T1	No. Pixels in T1 source aperture (centre aperture)
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 1st 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  'perform multi-aperture photometry' to open the Multi-Aperture Measurements window and configure as indicated in the highlighted sections.



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.

1. 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:

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

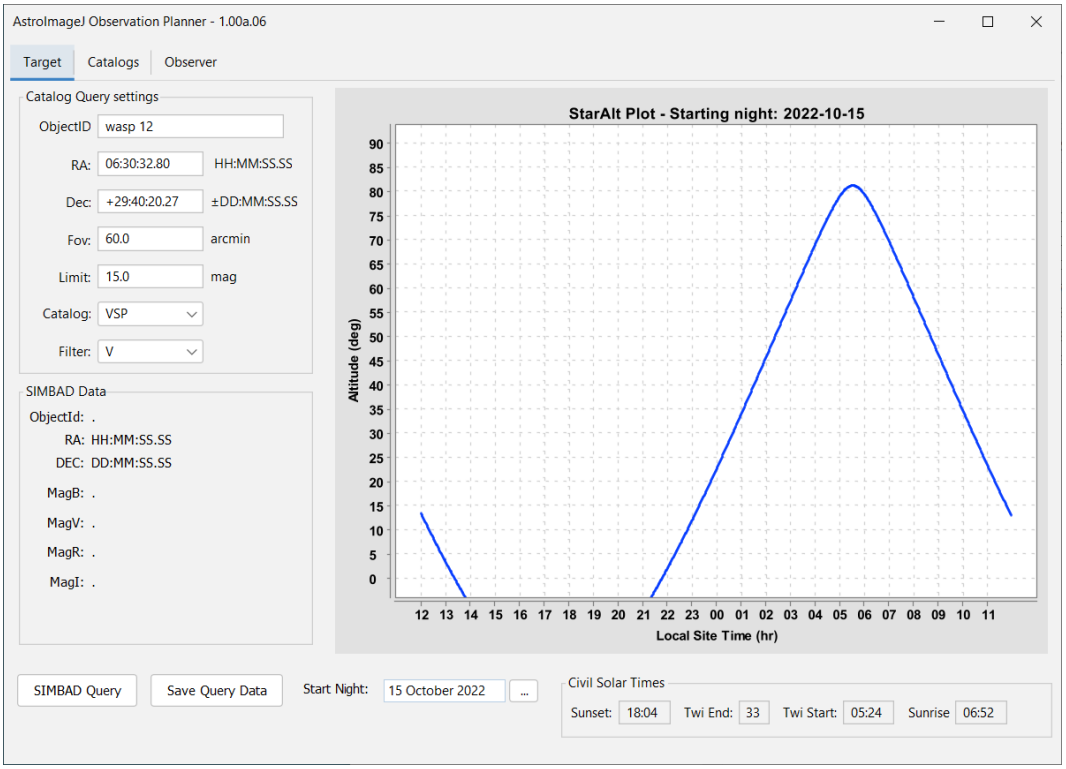
	Folder or File	Path	Notes
1	AstroImageJ home	C:\Astro\AstroImageJ	Path referenced in instructions
2	planner.jar	C:\Astro\AstroImageJ\plugins	AIJ plugins sub-folder
3	astro_plugins-1.0a.jar	C:\Astro\AstroImageJ\plugins\Astro Apps	User creates sub-folder
4	Java install	C:\Astro\AstroImageJ\jre\bin	For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

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

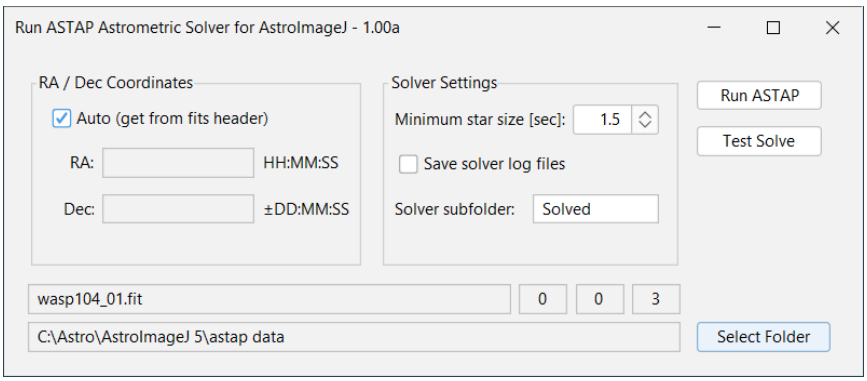
File path summary:

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.



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.

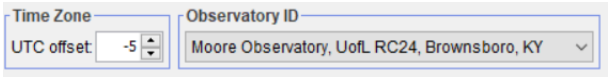
3.1. Introduction to Observation Planner

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

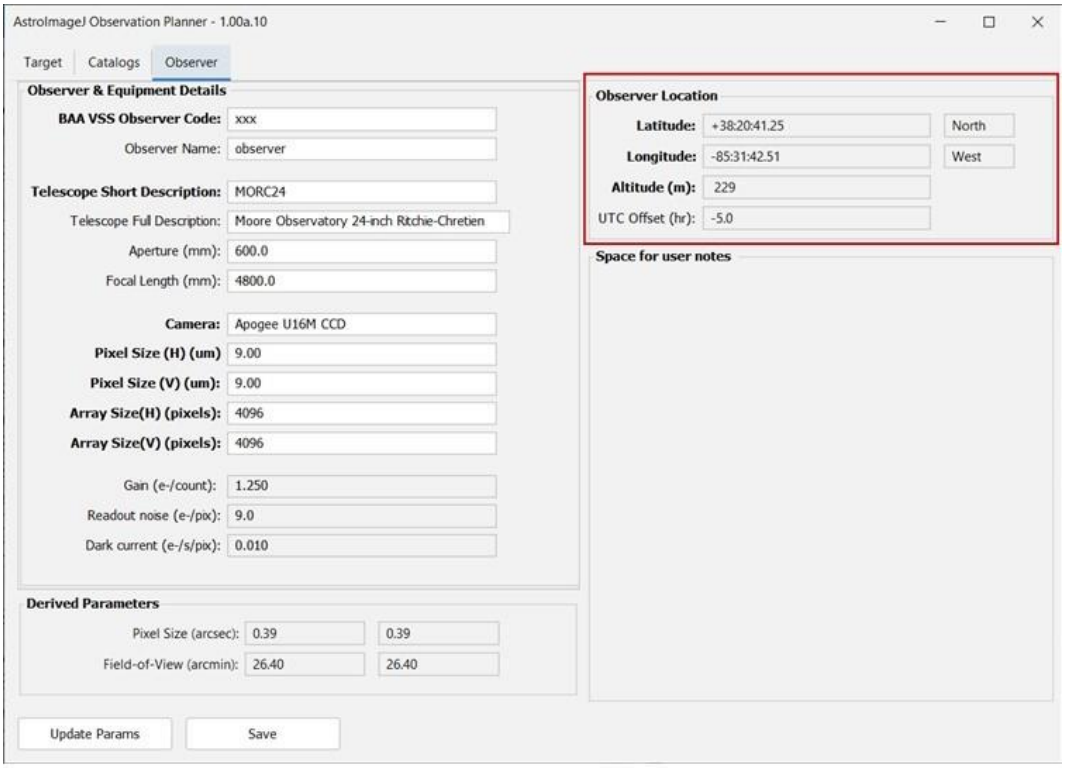
1. Open AIJ and click  , in the toolbar to open the DP Coordinate Converter window.
2. If not previously selected then select Moore Observatory, UofL, RC24, Brownsboro, KY from the Observatory ID dropdown and set UTC offset to -5.
3. Close AIJ then re-open AIJ | DP CC window and confirm Observatory and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



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.

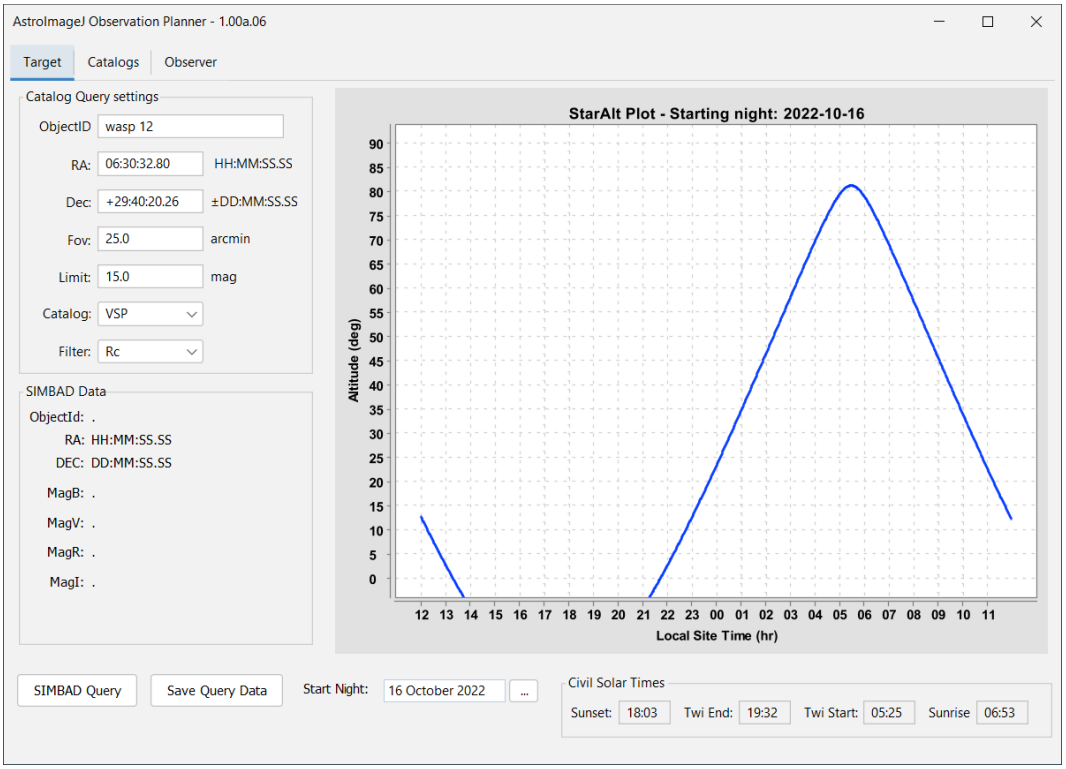
Dark current and Readout noise data is imported from AIJ Aperture Photometry Settings.

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).

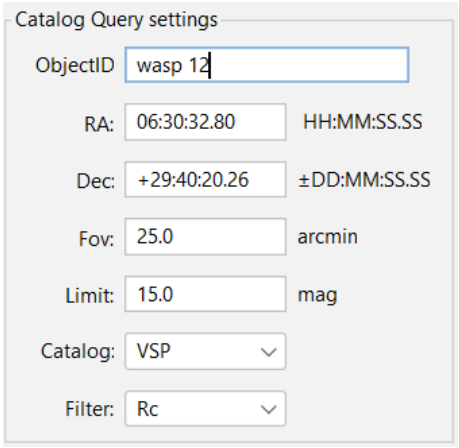
Controls

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.

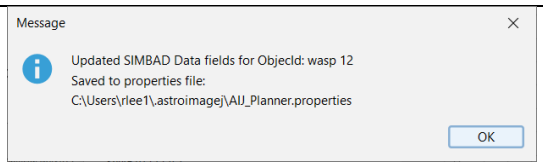
3.3.1. Setup WASP12 Parameters

1. Enter Catalog Query settings fields as below:



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.

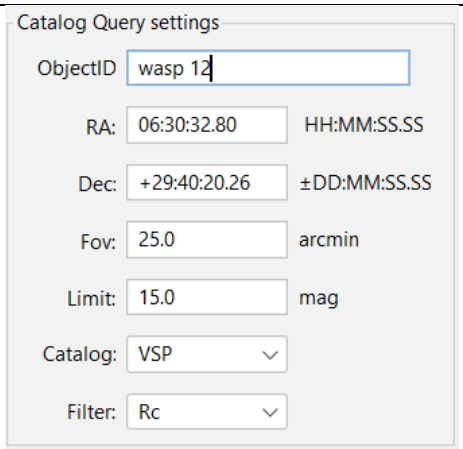
2. Click [SIMBAD Query] to run a name-based query on the SIMBAD database. After a short delay, a message dialog opens confirming updates to SIMBAD Data fields. The second dialog below is for a failed query based on ObjectID = wasp 12x (i.e., where wasp12x was not found).

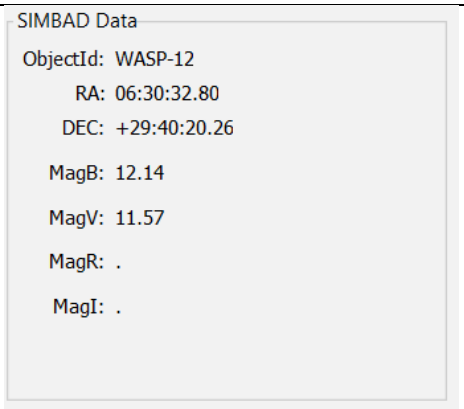


Message dialogs for successful and unsuccessful SIMBAD queries
ObjectID = wasp 12 and wasp 12x respectively

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

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

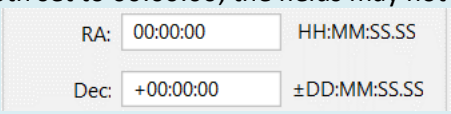




Catalog Query and SIMBAD Data after a succesful WASP12 SIMBAD database query

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

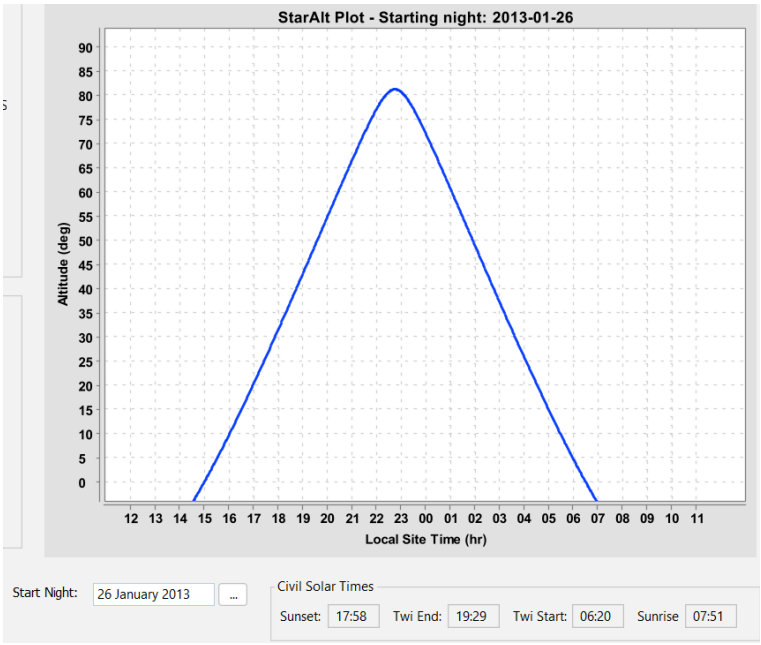
Intermittent bug alert:
When RA and Dec fields are both set to 00:00:00, the fields may not update after a SMBAD query.



This is an intermittent bug. Please try entering non-zero values in both fields (e.g., 01:00:00) and repeat the SIMBAD query

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.

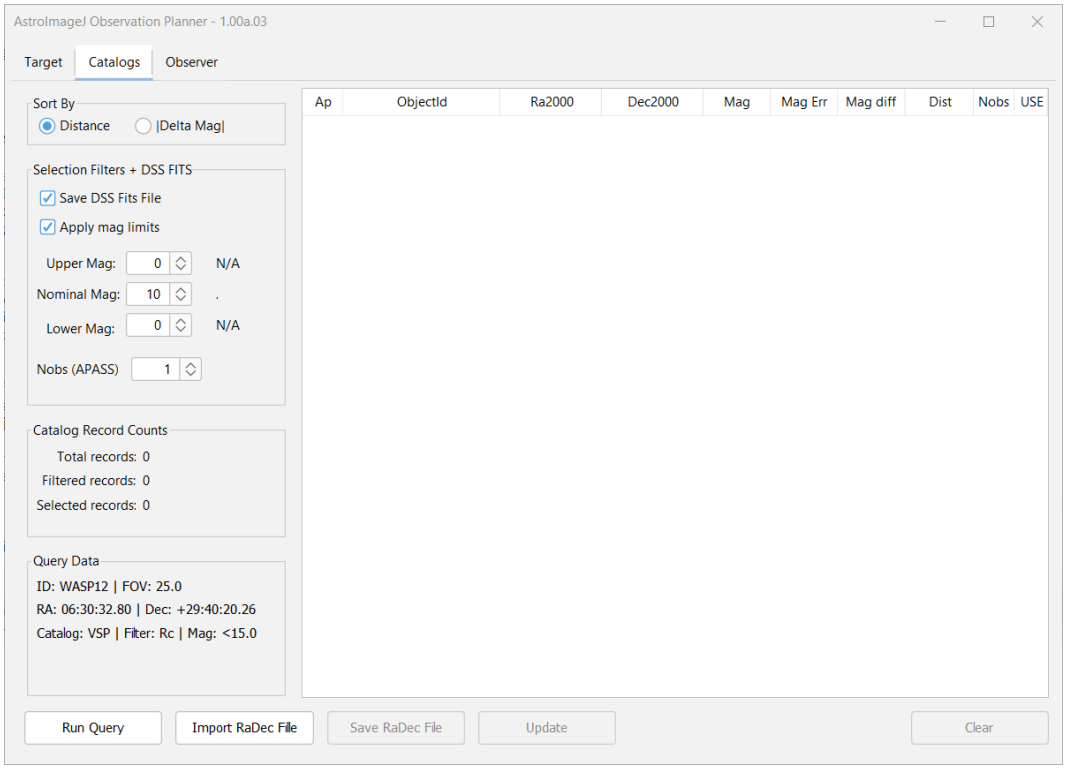


Wasp12 | Start Night: 2013-01-26

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:



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 (m_0) $\Delta = |m-m_0|$.

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

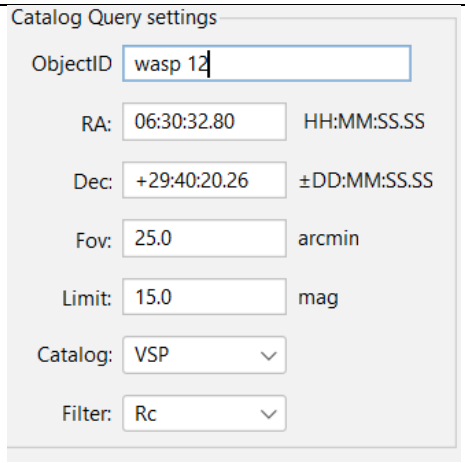
Summary of last saved Target | Catalog Query Settings data. This data is used to compile a query on selected catalog.

Data Table

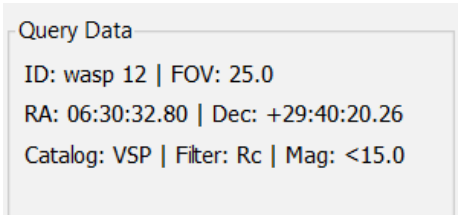
Tabulates target and filtered comparison star data, currently empty.

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.



VSP Query settings in Target Tab

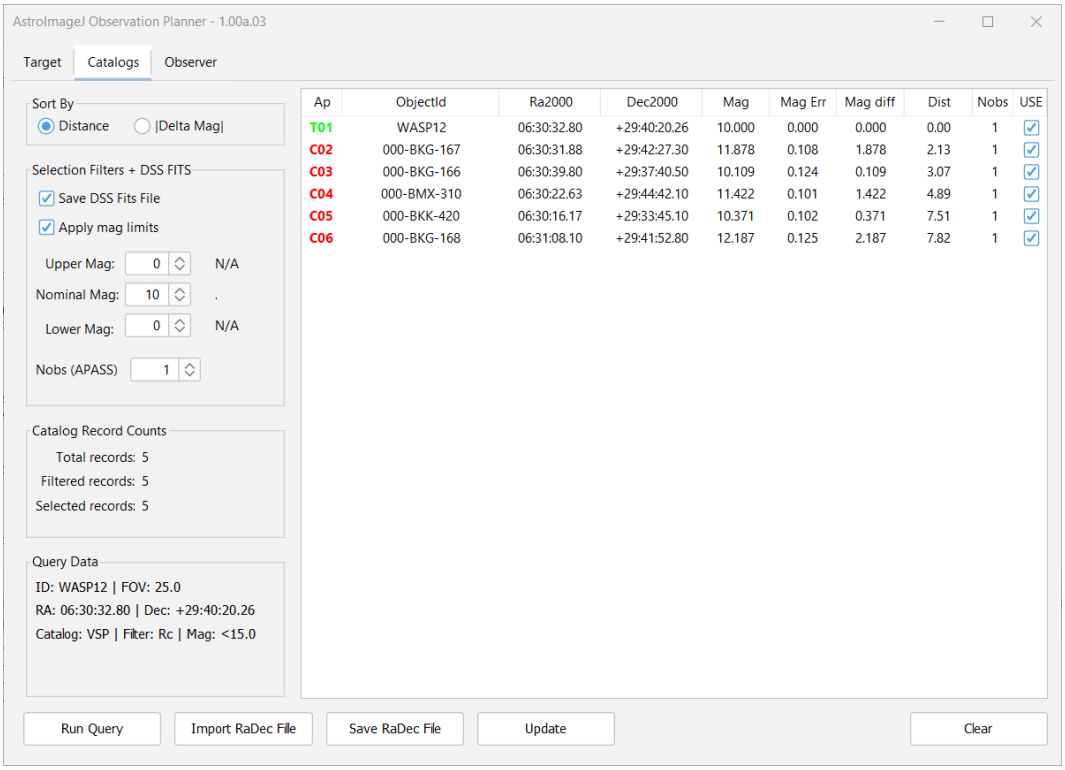


VSP Query settings in Catalogs Tab

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).

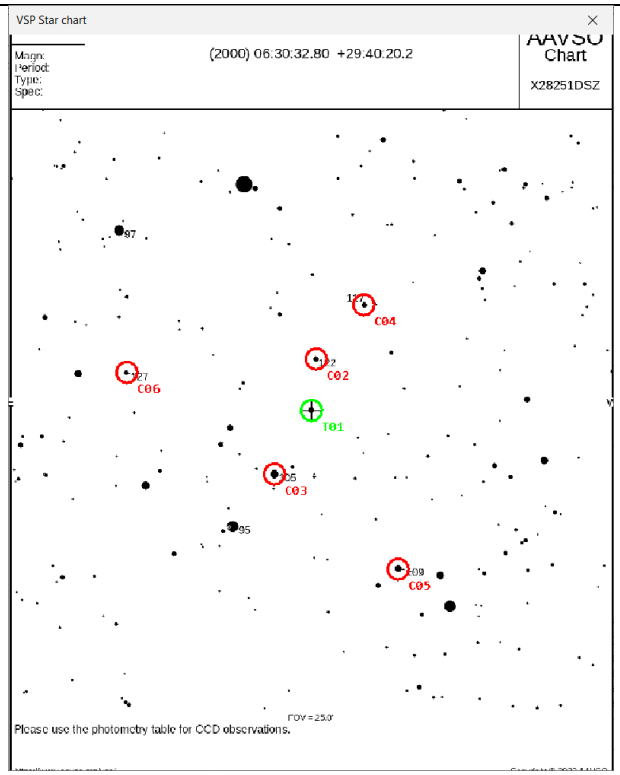
3. The data table is populated with 5 comparison star records and a chart opens displaying apertures centred on database stars.

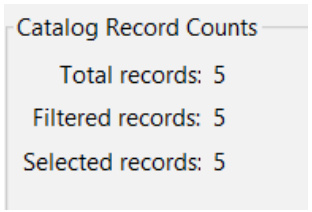


Header	T01	Cnn
Ap	Green T01 aperture identifies the target object	Red Cnn apertures identify the database comparison star objects
ObjectId	User name for target object	Database object names

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.





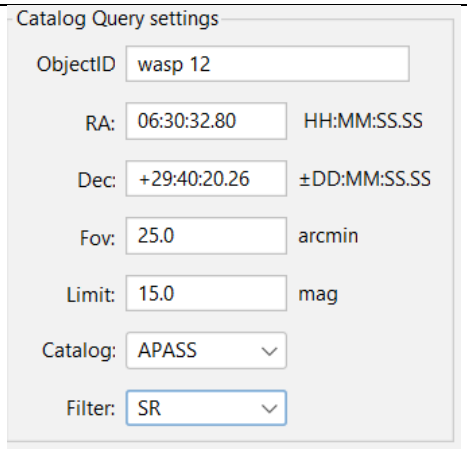
VSP catalog: Record counts = 5 | 5 |5

3.4.2. Run WASP12 | APASS Database Query

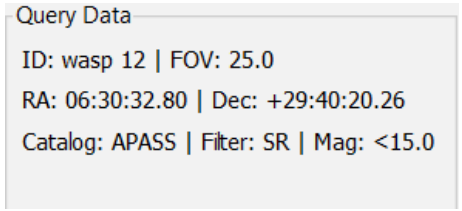
Run APASS query with no applied filters

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.

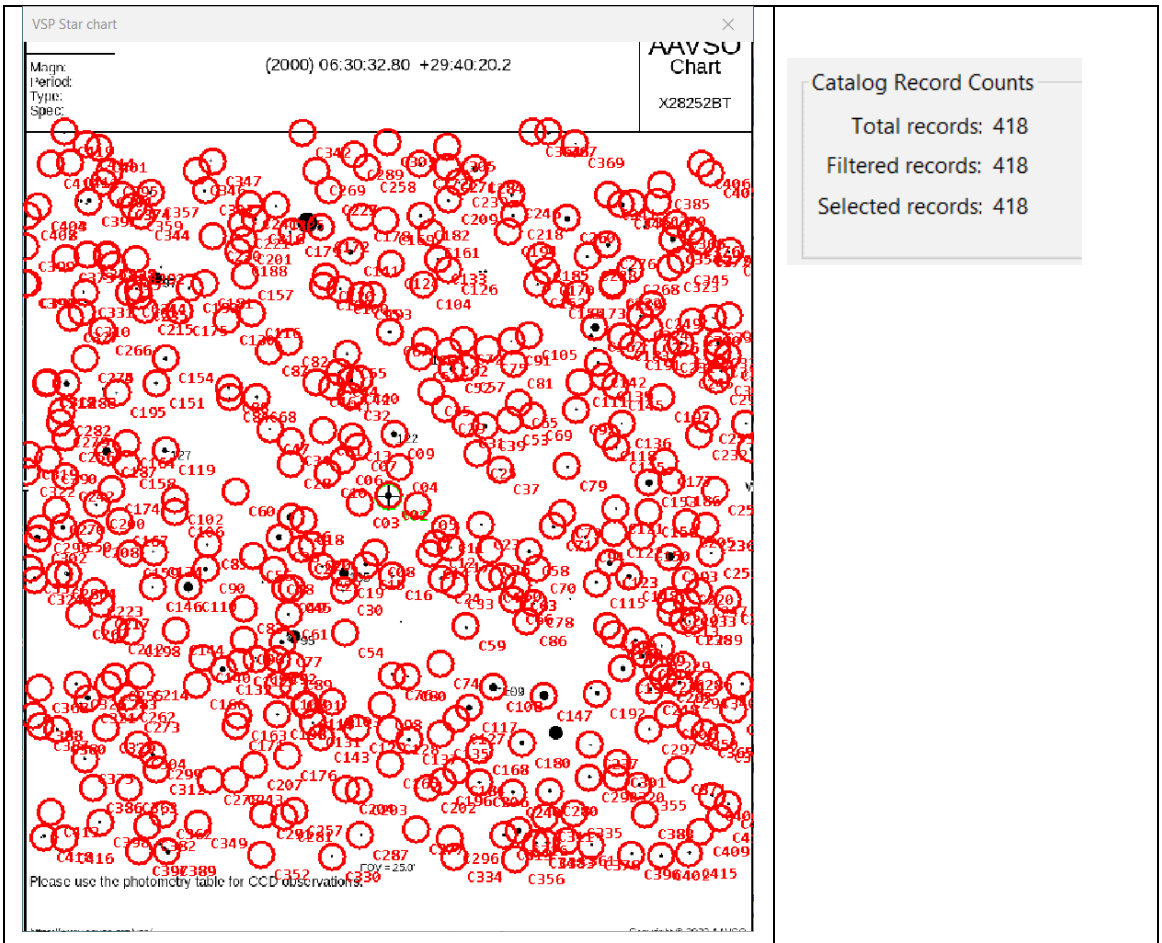


APASS Query settings in Target Tab



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.



Total records = 418, no filters applied

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 C02:

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

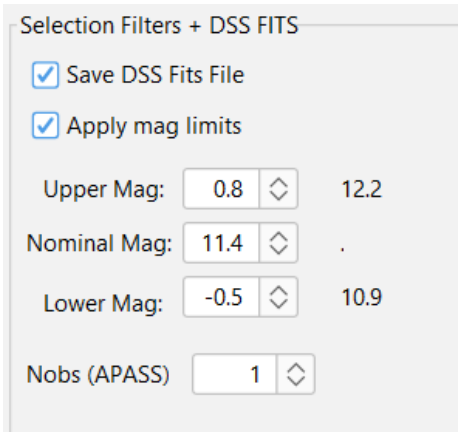
1. Select Sort By: Distance; the table automatically sorts in order of increasing distance from target coordinates.

Ap	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	☑

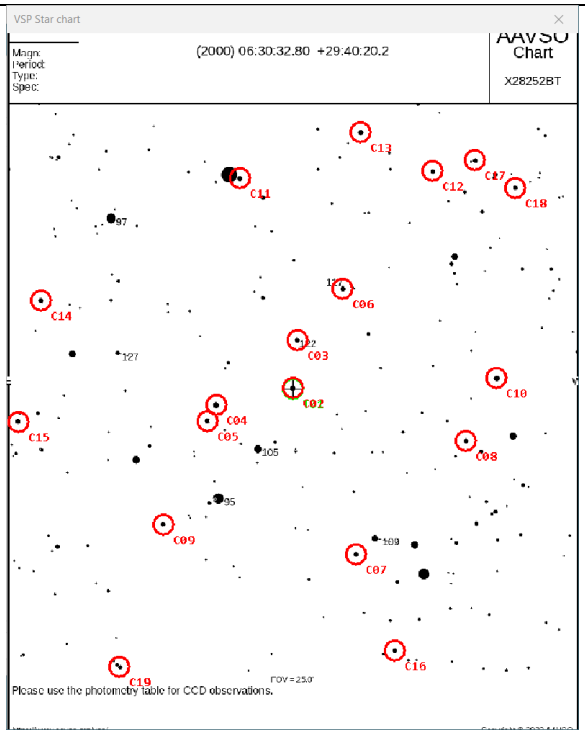
Duplicate Table Records

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).
3. 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].



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

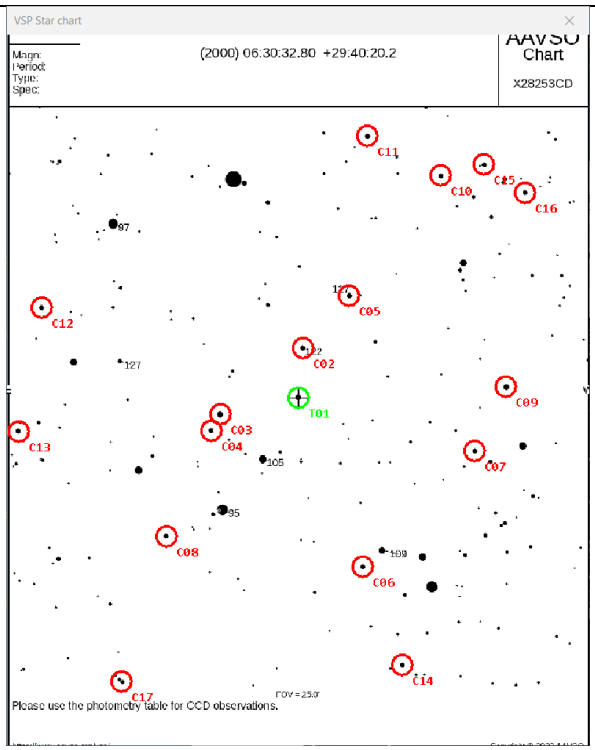


Catalog Record Counts
Total records: 418
Filtered records: 18
Selected records: 18

Mag filter applied: Record counts = 418 | 18 |18

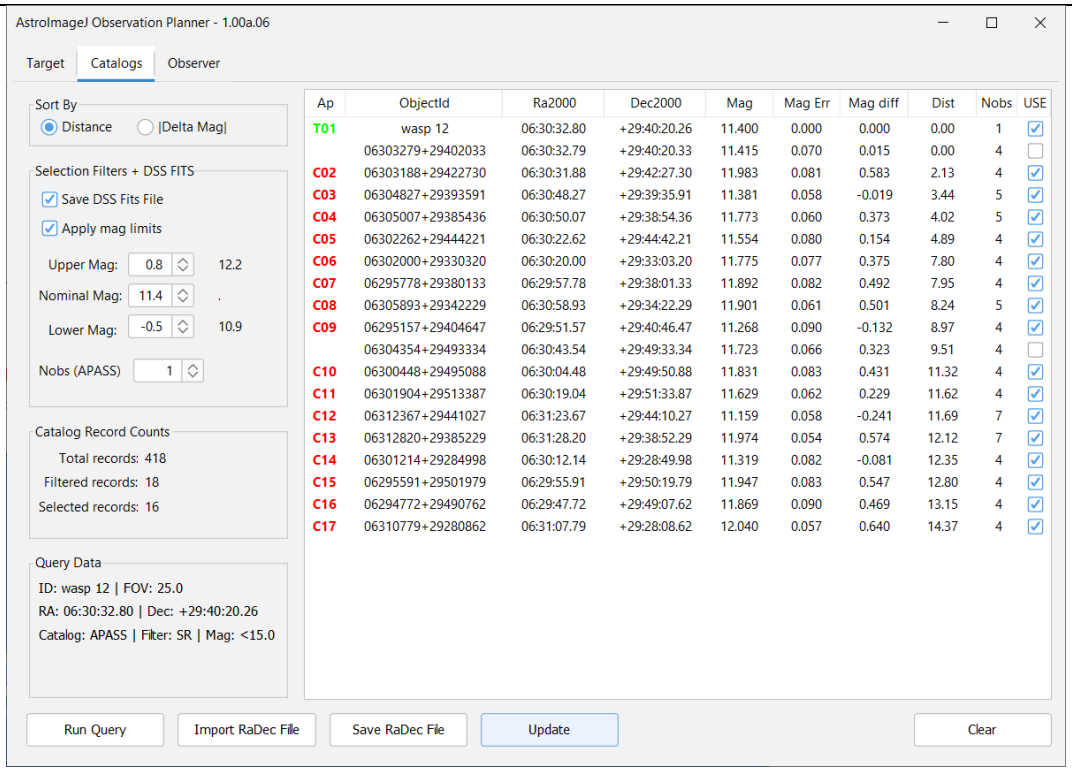
5. De-select rows C11 (proximity to bright neighbour) then de-select C02 (duplicate target star). Click [Update] to update counts and chart; the Selected records count drops from 18 to 16.

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



Catalog Record Counts
Total records: 418
Filtered records: 18
Selected records: 16

Mag filter plus 2 de-selected rows: Record counts = 418 | 18 |16



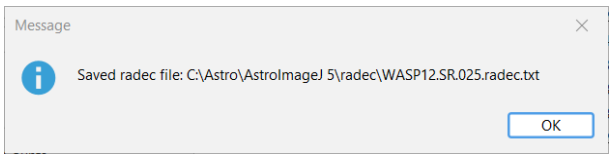
Ap	ObjectId	Ra2000	Dec2000	Mag	Mag Err	Mag diff	Dist	Nobs	USE
T01	wasp 12	06:30:32.80	+29:40:20.26	11.400	0.000	0.000	0.00	1	☑
	06303279+29402033	06:30:32.79	+29:40:20.33	11.415	0.070	0.015	0.00	4	☐
C02	06303188+29422730	06:30:31.88	+29:42:27.30	11.983	0.081	0.583	2.13	4	☑
C03	06304827+29393591	06:30:48.27	+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	☑
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	☑
C09	06295157+29404647	06:29:51.57	+29:40:46.47	11.268	0.090	-0.132	8.97	4	☑
	06304354+29493334	06:30:43.54	+29:49:33.34	11.723	0.066	0.323	9.51	4	☐
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	☑
C13	06312820+29385229	06:31:28.20	+29:38:52.29	11.974	0.054	0.574	12.12	7	☑
C14	06301214+29284998	06:30:12.14	+29:28:49.98	11.319	0.082	-0.081	12.35	4	☑
C15	06295591+29501979	06:29:55.91	+29:50:19.79	11.947	0.083	0.547	12.80	4	☑
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	☑

Filtered WASP12 APASS records in Catalogs tab: 418 | 18 |16

The Ap cell is blanked when the USE column is unchecked

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

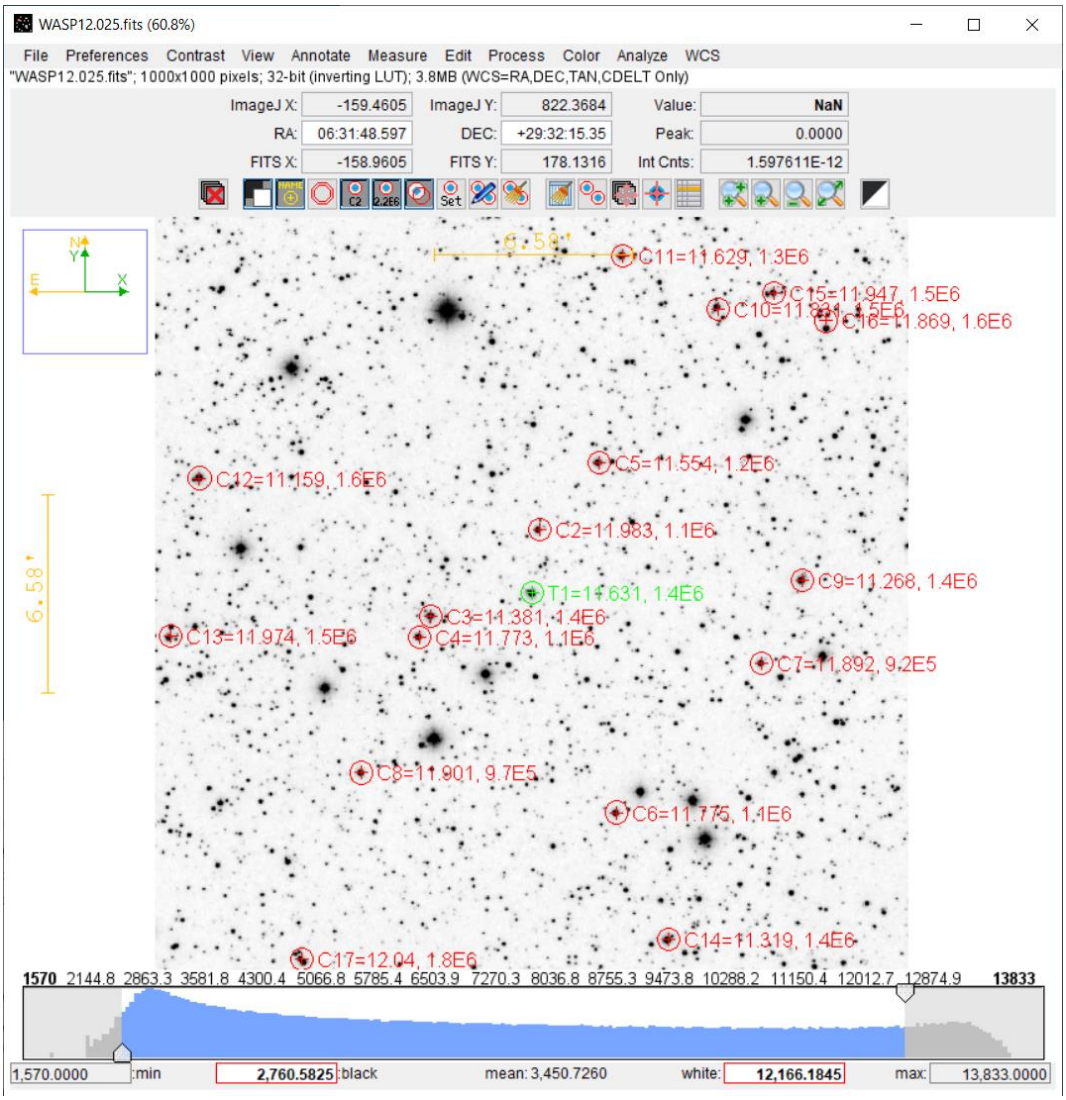
1. From the AIJ toolbar, select File | Open, then navigate to and open dss fits file WASP12.025.fits' (C:\Astro\AstroImageJ\dss\WASP12.025.fits). The dss image opens in a new AIJ Image Viewer window.

2. 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 'display as image negative' icon in the Viewer toolbar. Click 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

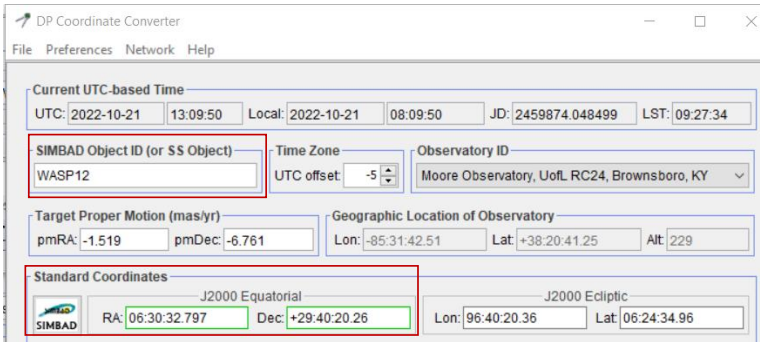
C:\Astro\ Datasets\WASP12.SR.2013_01_26\Calibration Files\Flats*flats_r*.fits

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 DP 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.



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

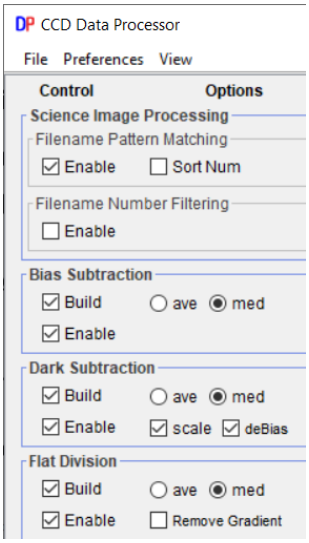
ASTAP is a popular alternative to ANSVR, with faster solve times and potentially smaller disk footprint for very small FOV images (<< 20 arcmin). Refer section 2 to install astap.jar plugin file and import the astap.jar user guide: User Guide Astap Solver for AstroImageJ.pdf.

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.



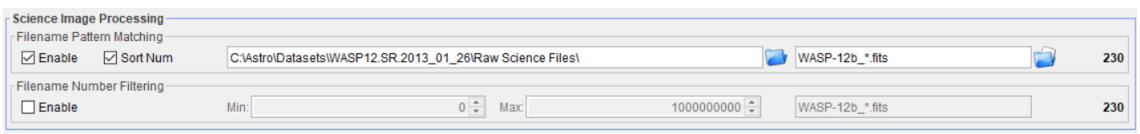
4.3.2. Set up Directories and File Wildcards

Science Image Processing section

Click the left folder icon 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.

1. Click the right folder icon 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.



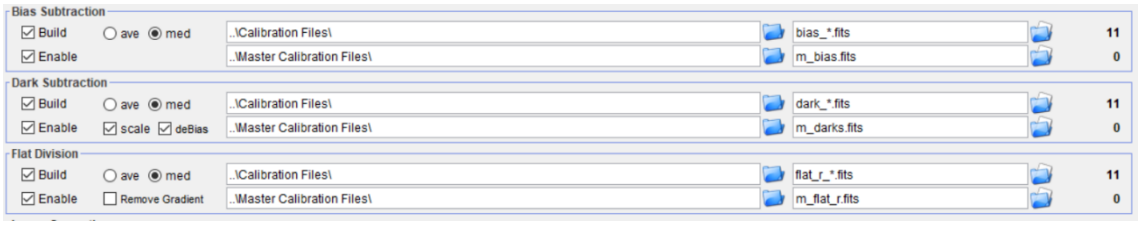
Calibration Processing sections

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

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

2. 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.



4.3.3. Save Calibrated (Reduced) Images

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

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

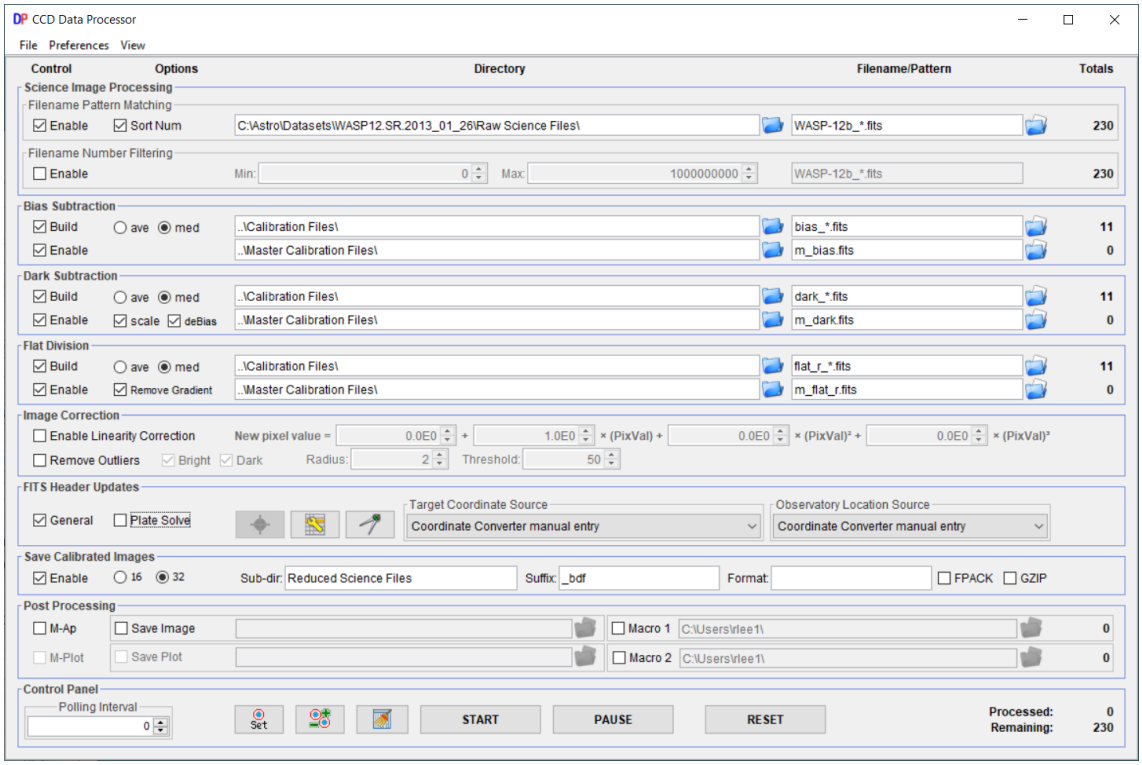
The next figure shows the CCD Processor window prior to running image reduction on 230 raw science files.

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.



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:

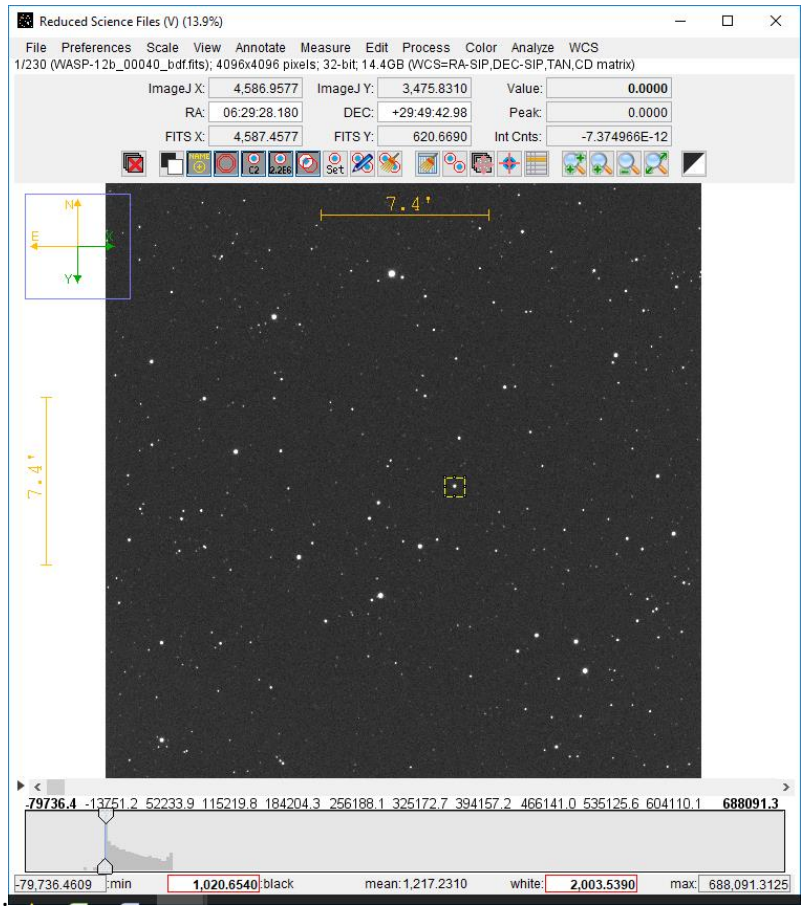
   From: C:\Astro\Datasets\WASP12.SR.2013_01_26\Raw Science Files\Reduced Science Files
   To: C:\Astro\Datasets\WASP12.SR.2013_01_26\Reduced Science Files

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 , left of the scroll bar, to start / pause image animation. Right click on this control to set animation speed and other options.

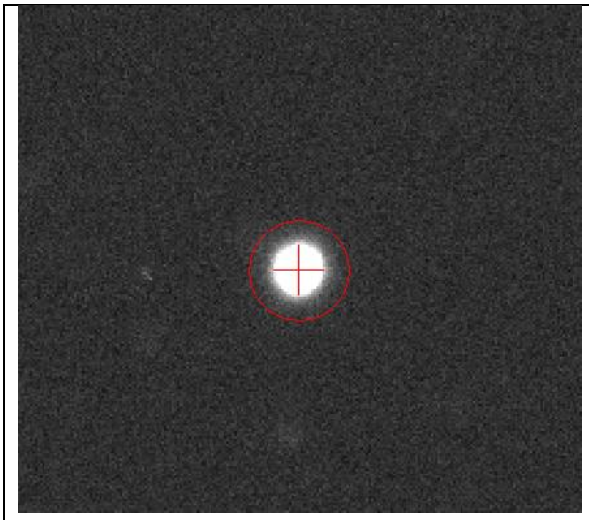
3. To remove an image from the stack, click , left-most icon.

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

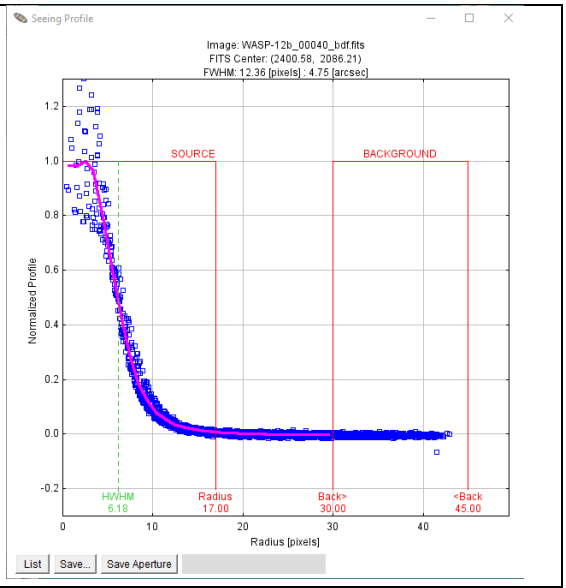
5.3. Photometry Measurement Apertures

5.3.1. Set aperture sizes

1. Click Set 'change aperture settings' to open the Aperture Photometry Settings window.
2. 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 as necessary 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



Object aperture (R = 20) enclosing a non-saturated star image



Seeing Profile window
FWHM = 12.36 [pixel] 4.75 [arcsec]
Apertures = 17 | 30 | 45

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

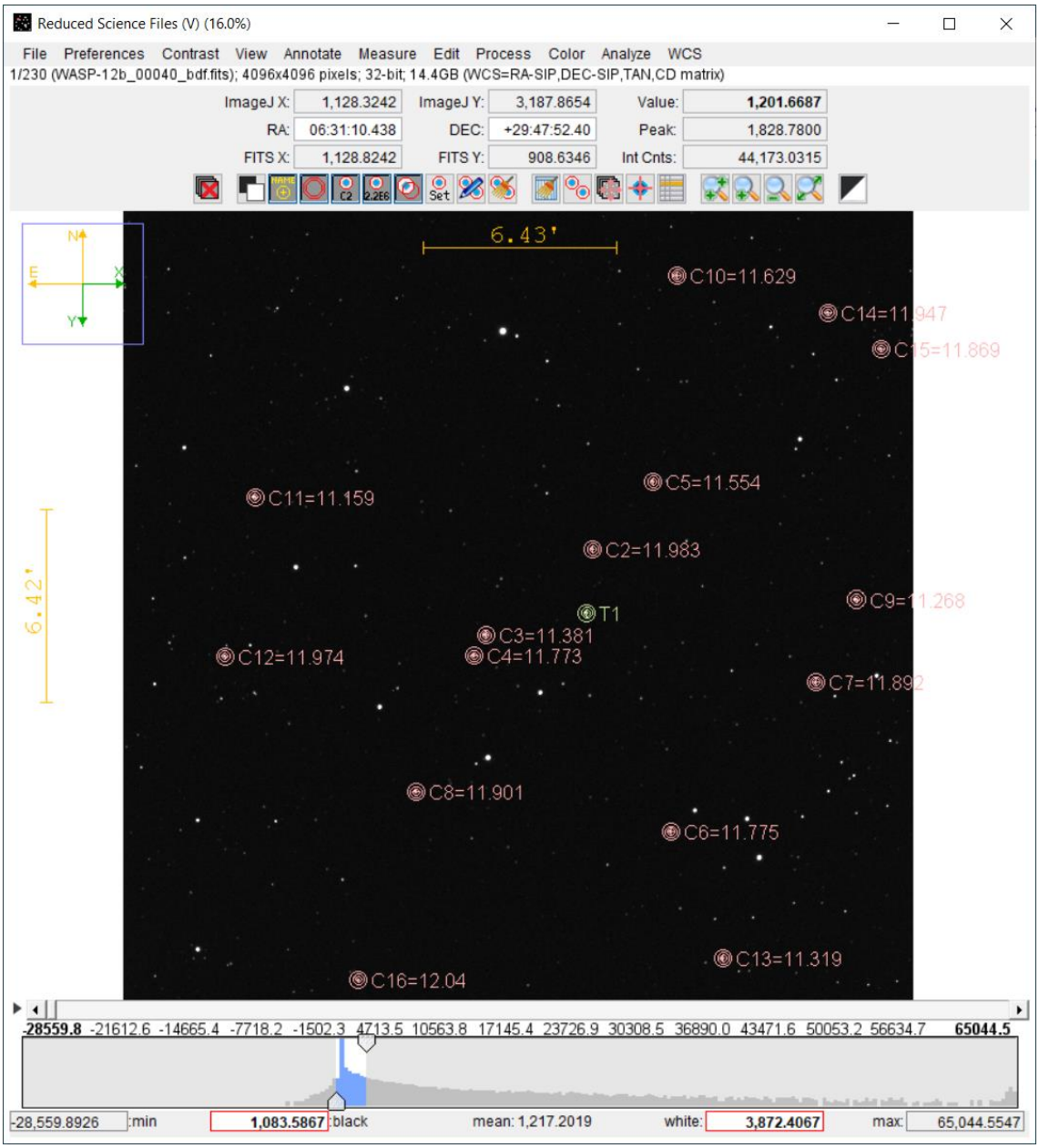
5. Click [Save Aperture] in the Seeing Profile window to import these aperture sizes.
6. Click Set in the Image Display window to open the Aperture Photometry Settings window and confirm that aperture sizes are now 17 | 30 | 45. Click [OK] to close the Aperture Photometry window
7. In the Image Viewer,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

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

5.3.2. Import radec apertures

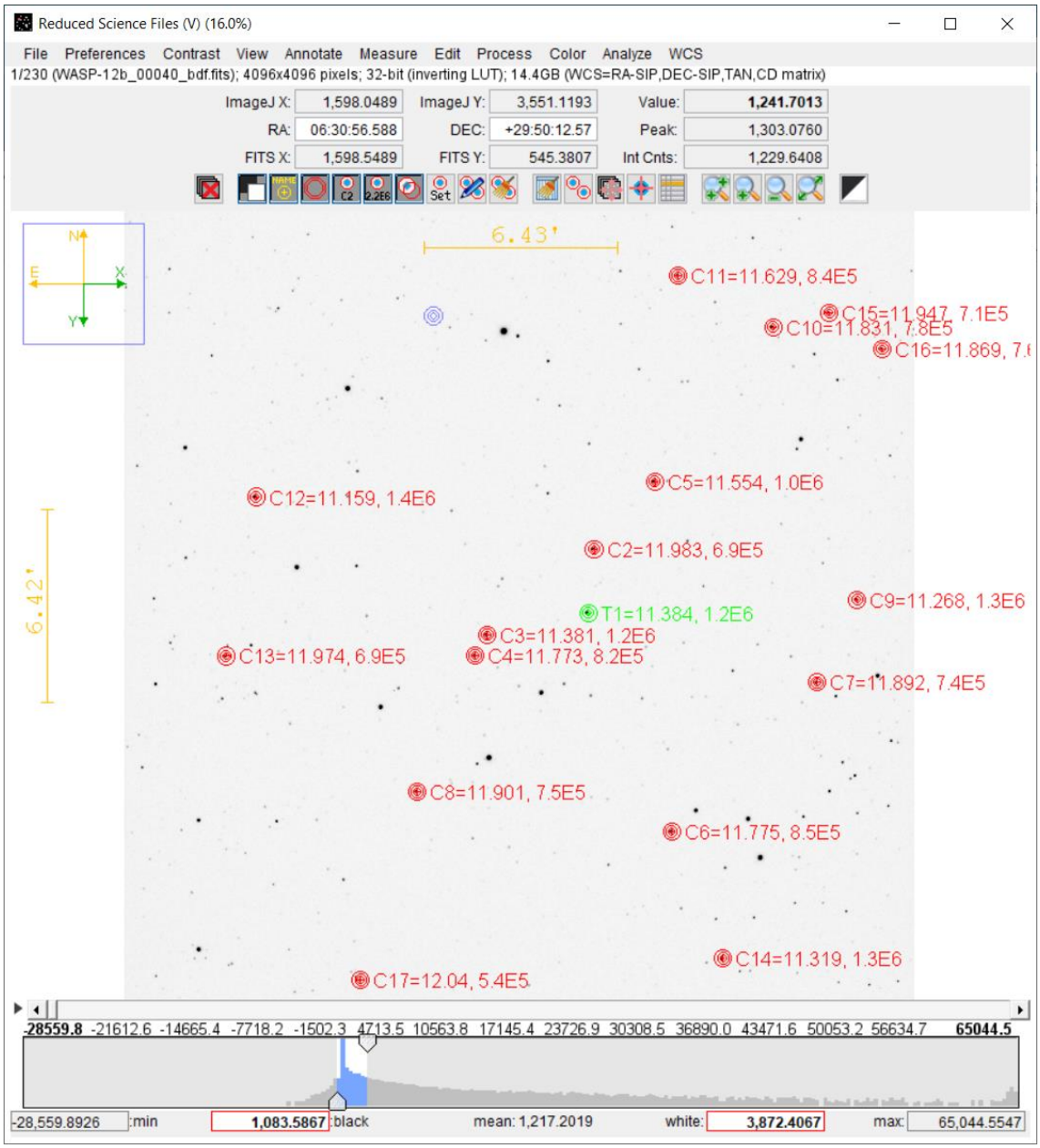
1. In the Image Display window, select File | Import apertures from RA / Dec list .. , navigate to and select .C:\Astro\AstroImageJ\radec\wasp12.SR.025.radec.txt to import and overlay the WASP12 image with the APASS set of apertures saved in section 3.

2. Click  'zoom to fit ...' to re-centre the image in the Viewer.



3. In the Image Viewer toolbar, click  'perform multi-aperture photometry' to open the Multi-Aperture Measurements window.

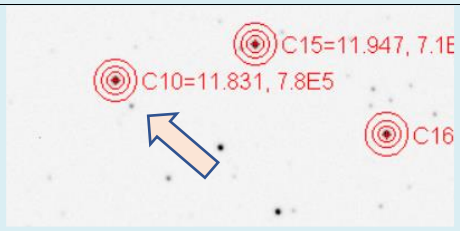
4. Click [Place Apertures] to close this window.In the Image Viewer, the aperture overlay is highlighted and measurement apertures are locked to object centroids.

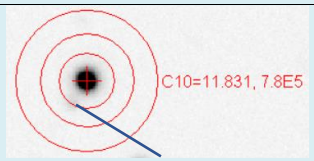


Aperture overlay after [Place Apertures] in Multi-Aperture Measurements
Negative image to enhance faint details

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.





Faint background object extending into 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 numbering after de-selecting C10 in upper figure

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  '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.

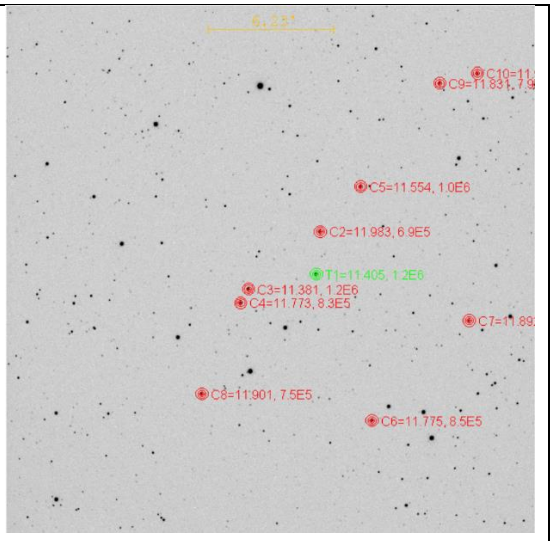
5.4. Run AIJ Photometry

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.

Ap	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	☐
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	☑
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	☐
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	☐
	06312820+29385229	06:31:28.20	+29:38:52.29	11.974	0.054	0.574	12.12	7	☐
	06301214+29284998	06:30:12.14	+29:28:49.98	11.319	0.082	-0.081	12.35	4	☐
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	☐

Apertures C2 – C10 in Planner | Catalogs Tab



Aperture overlay in AIJ | Image Viewer

1. 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  , zoom to fit image to window.

3. Click  , confirm aperture radii are 17 | 29 | 44 as above, then click [Place Apertures] to close window and return to Image Viewer. The apertures are highlighted and locked onto the object centroids. A Multi-Aperture Help window opens.

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):

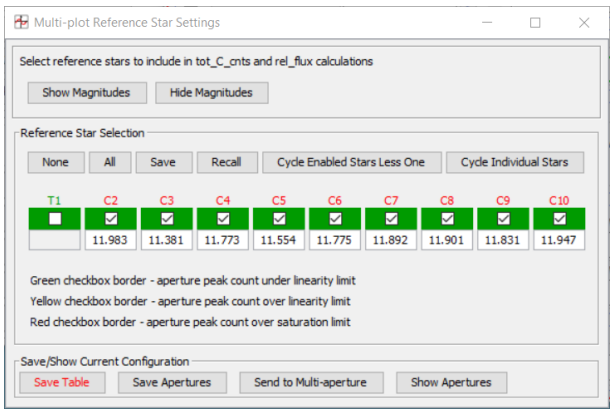
Window	Function
Multi-plot Main	Sets number of plots, plot titles and scales; user sets markers for transit-based normalisation and optional data exclusion
Multi-plot Y-data	Individual plot settings with de-trend and fit mode options
Data Set Fit Settings	Window accessing 7 term transit fit settings
Plot of Measurements	Time-based plot of transit and related data
MP Reference Star Settings	AIJ 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.

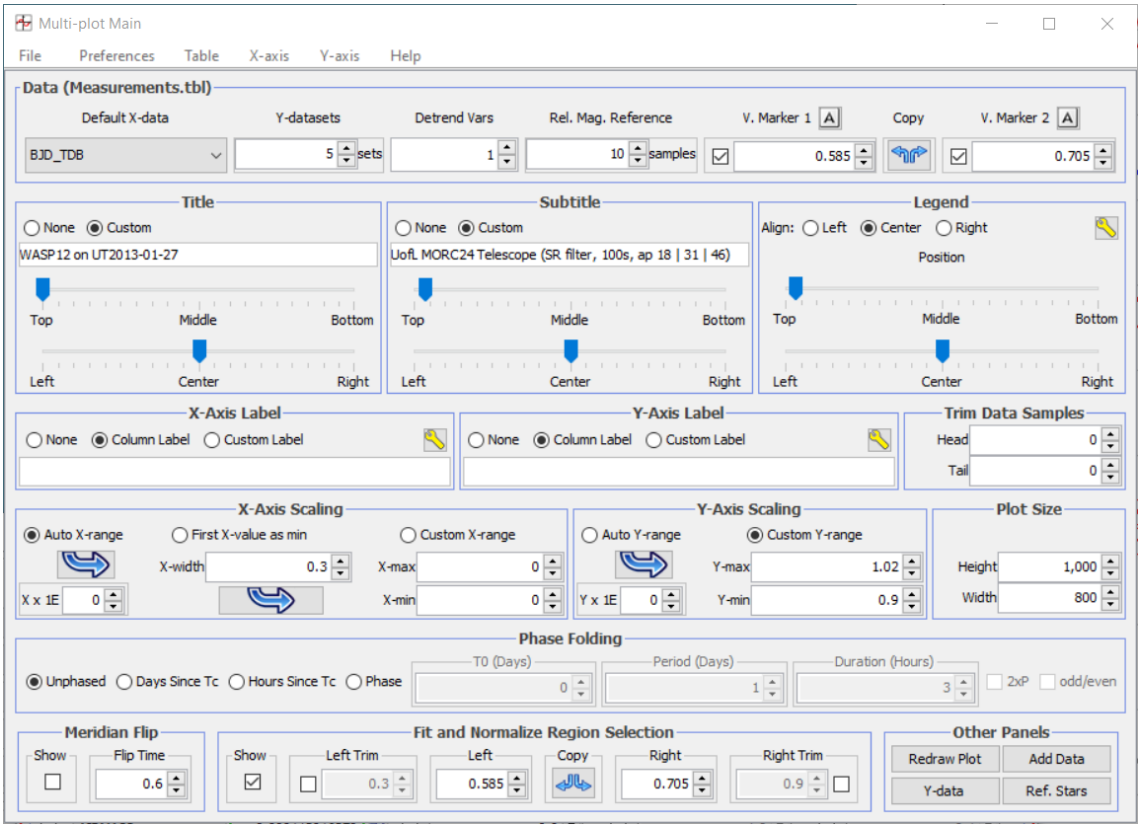
6.1. Open AIJ Plot Windows

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.

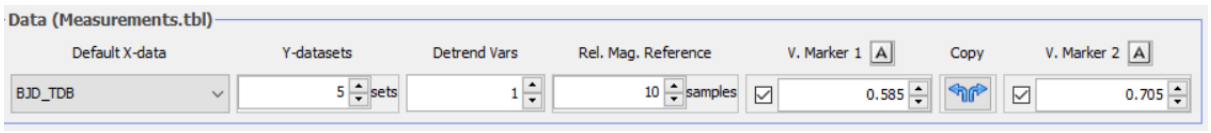


6.2. Multi-plot Main

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.



Data (Measurements.tbl)

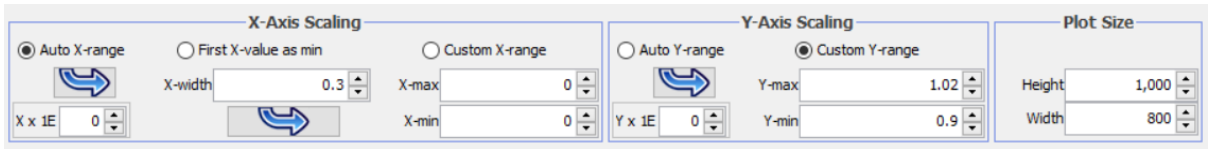


Default X-data	TDB-based barycentric Julian Date at exposure mid-point.
Y-datasets	5 plots, comprising 2 transit, airmass and sky plots, and a blank dataset
Detrend vars	Single detrend (by airmass), note no meridian flip in this dataset
V-Markers	User-sets these markers at transit ingress and egress.

Title, Subtitle and Legend

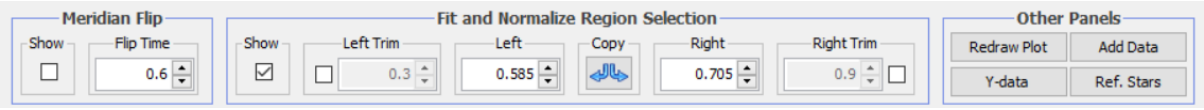
As shown in main figure.

Axis Scaling and Plot Size



X-Axis Scaling	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



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.

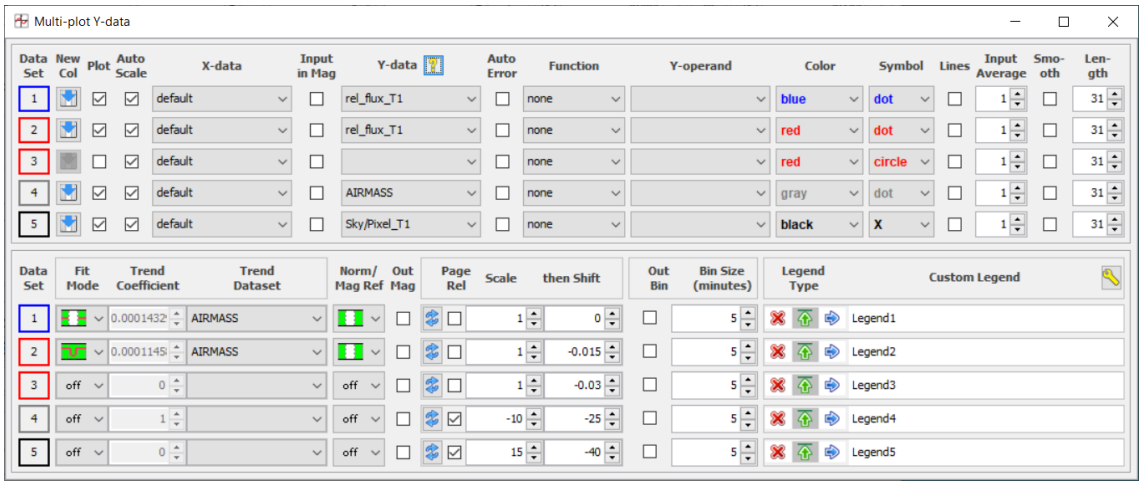
[**Add Data**] this function may corrupt measurements.tbl dataset - recommend to *NOT use* this function

Menu Options

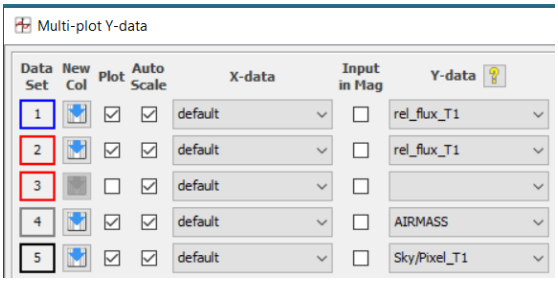
File	Large number of plot configuration and other options
Preferences	Uncheck 'Use –wide—Y-data columns to fold Y-axis rows as in the next section.
Help	Access a general multi-plot help window or a dialog displaying Data Naming Conventions.

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.



Multi-plot Y-data: Upper section



Data Set — Identifier common to upper and lower window sections

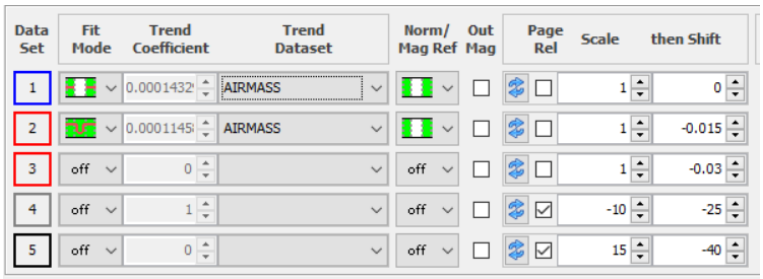
Plot — Check box controls plot visibility

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



Fit Mode — Data Set 1:  applies an AIRMASS detrend to the green shaded regions. This is the out-of-transit baseline region defined by the Left and Right markers in the Multi-plot Main window.
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  opens 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

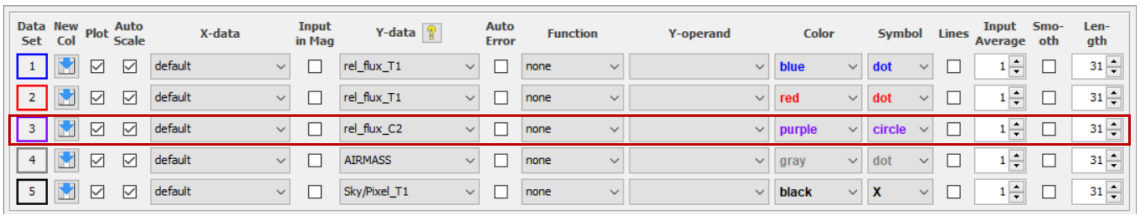
Example: add rel_flux_C2 as new dataset 3 in the Multi-plot Y-data window.

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:

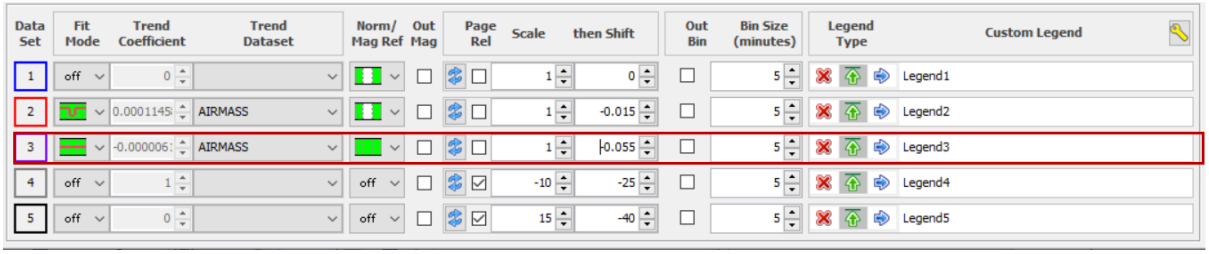


Data Set 3 - lower window settings

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:

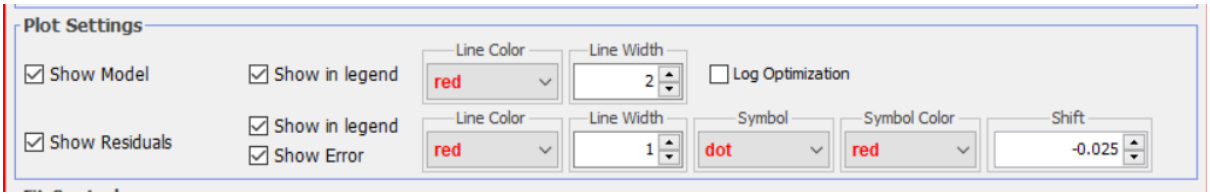


4. To save the current settings, MP Main | File | Save plot configuration …, navigate to the plots folder C:\Astro\AstroImageJ\plotcfg.

5. Save modified plot configuration as C:\Astro\AstroImageJ\plotcfg\ BAA.transit_amass_sky_update.

6.4. Fit Plot Settings

If the Data Fit Settings window is not already open, right-click on the data set Data Set 2 | Fit Mode icon  to open this window. The Data Fit window handles a 7-parameter fit to the transit dataset. This section covers the Plot Settings section, other sections are covered in a later section.



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

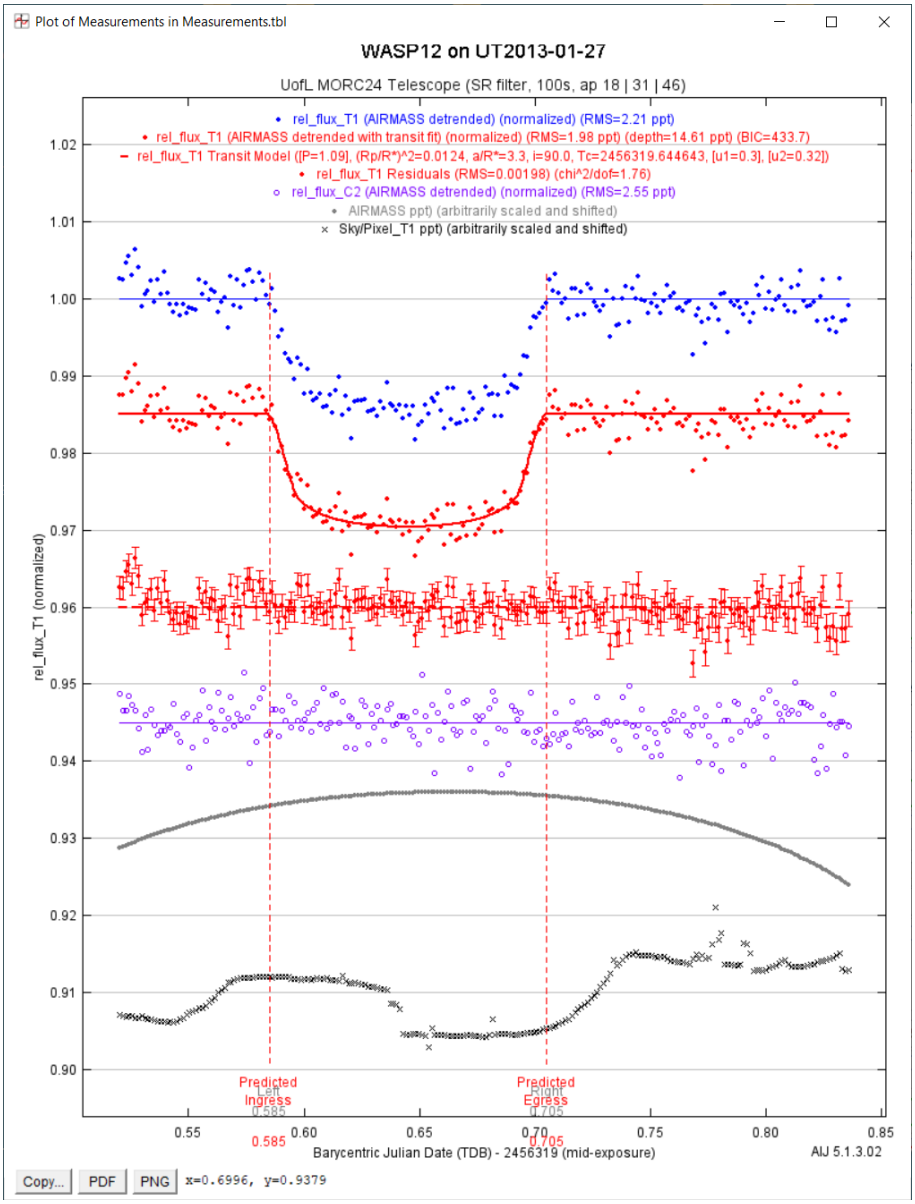
Datasets 1 and 2: Transit datasets

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

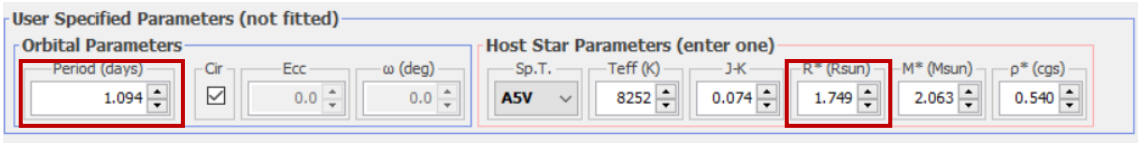
Header: Identifies dataset, applied detrend (AIRMASS), rms and fit statistics



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.

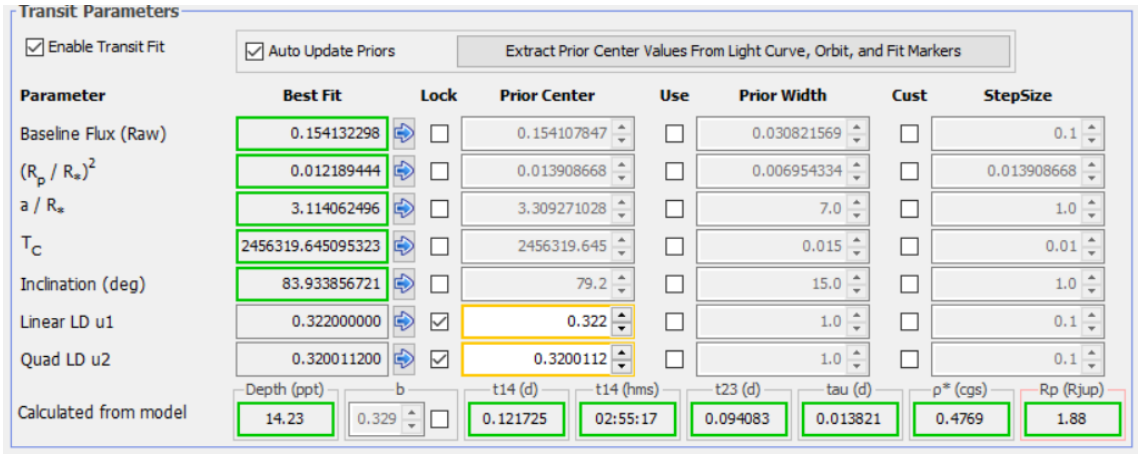
7.1. User Specified Parameters (not fitted)



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

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



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].
2. 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

0.32238801	0.32001120
EXOFAST u1, u2 values computed for WASP12 | Band = SDSS r'	

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

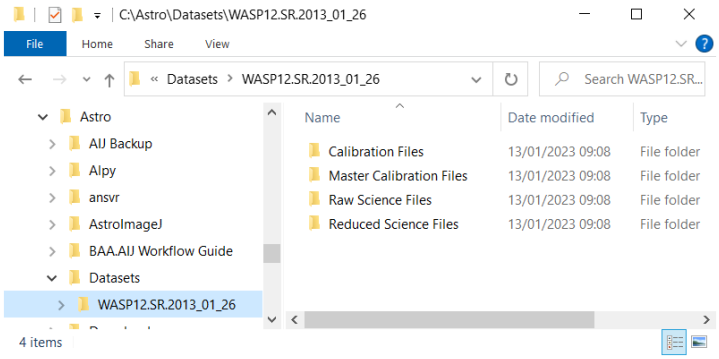
1. Create a set of WASP12 sub-folders in C:\Astro\datasets as follows:
   C:\Astro\Datasets\WASP12.SR.2013_01_26 [1]

   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]

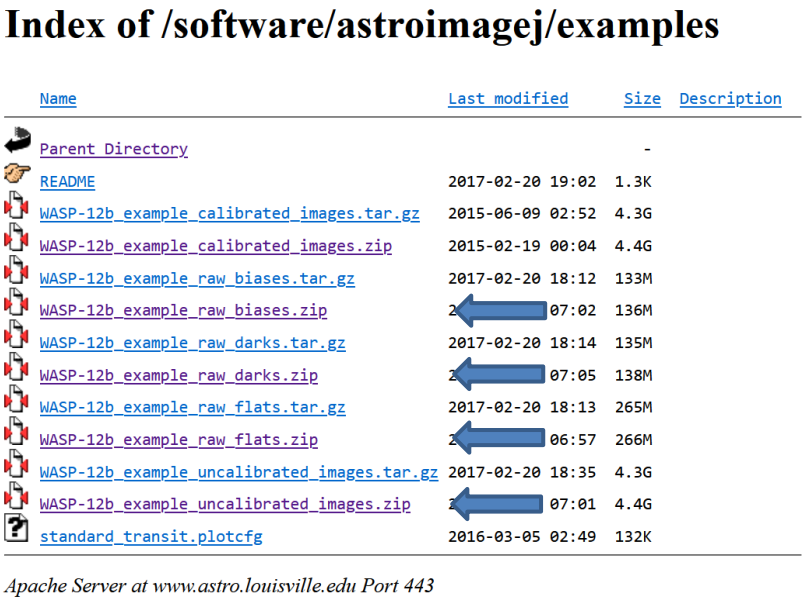
   C:\Astro\Datasets\WASP12.SR.2013_01_26\Reduced Science Files [3]



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



Appendix B: UofL Moore RC24 and ICAstronomy Data Sets

Observer Location	**Moore Observatory, KY**	**ICAstronomy, Oria**
Latitude	+38:20:41.25 38.344791	+37:30:03.96 37.5011
Longitude	-85:31:42.51 -85.528476	-02:24:29.88 -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 24-inch Ritchie-Chretien	ICAstronomy 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

[1] QSI683 gain is bin size dependent

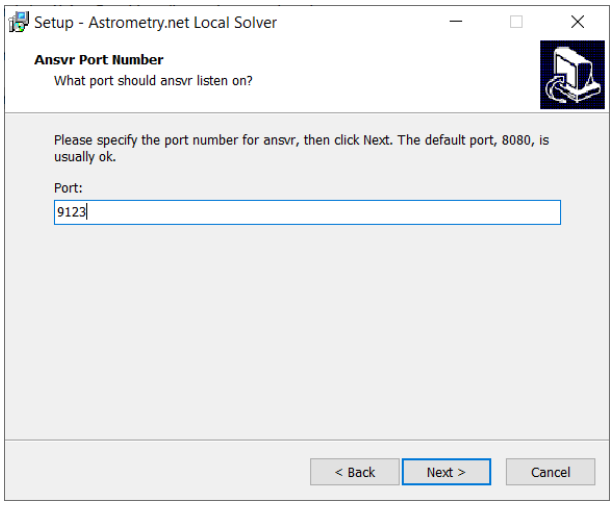
[2] QSI683 gain for 2x2 bin

Appendix C: Download and Configure ANSVR Plate Solve

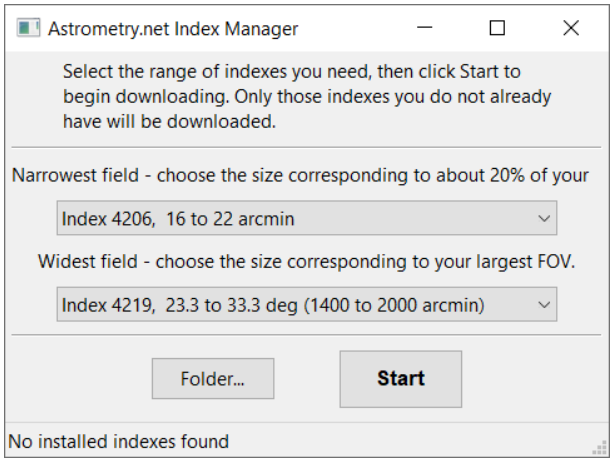
This Appendix covers downloading ansvr local plate solve software and setting up the AIJ DP Astrometry Settings window. Refer to section 1 for link to the ansvr web page. Note that Win10 file paths may differ from those given in the instructions.

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



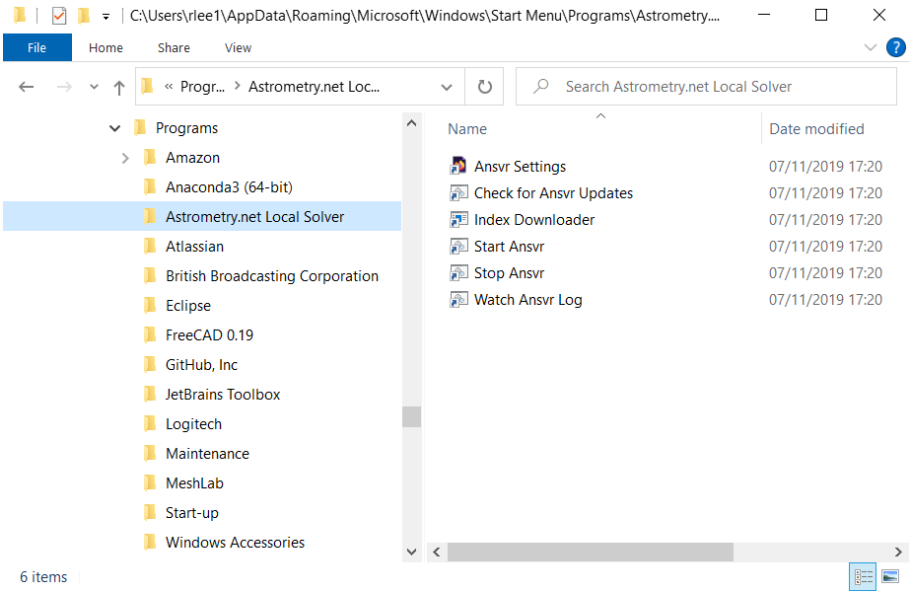
3. Continue with instructions 6 to 8.
4. Instruction 9 covers field size selection in the Astrometry.net Index Manager window. The following selection support ansvr plate solving WASP104 and WASP12 datasets. Download size of index files 4206 – 4219 is about 620 MB.



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.



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 DP in the toolbar to open the CCD Data Processor window and check the Plate Solve option in the FITS Header Updates section

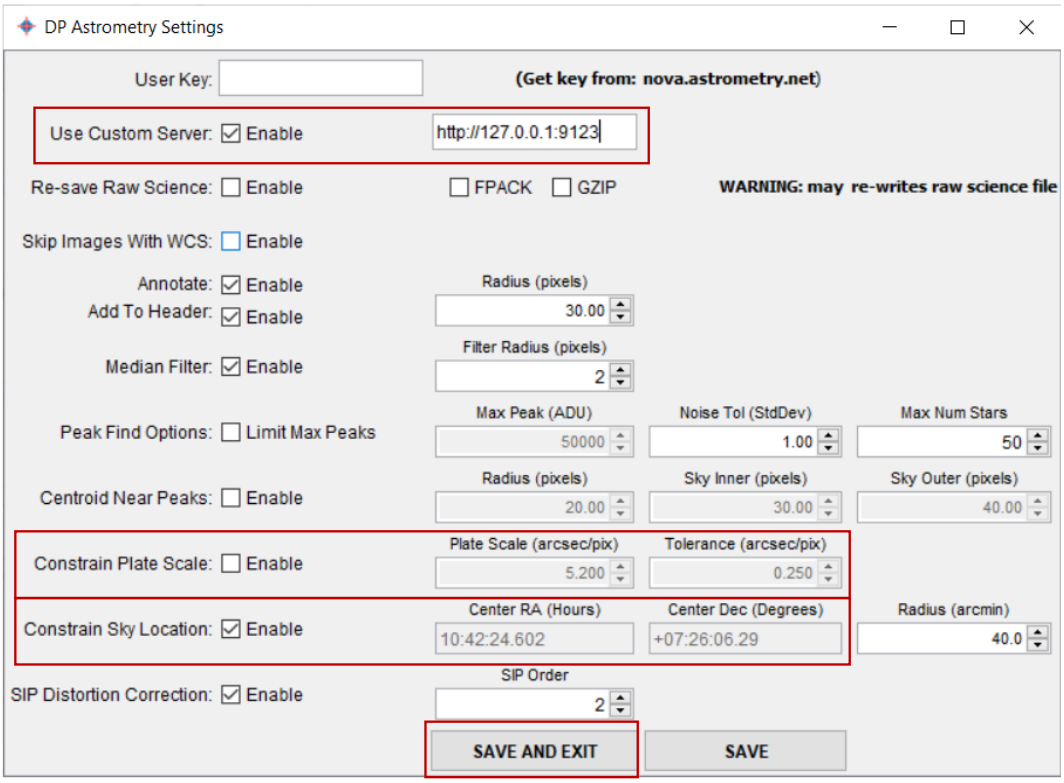
2. In the DP Coordinate Converter window, enter ObjectID wasp104 and press Enter to run a SIMBAD query and update the Standard Coordinates fields.
3. In CCD DP | FITS Header Updates, click , ‘Open plate solve settings panel’, to open the DP Astrometry Settings window.
4. Enable Use Custom Server option 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.

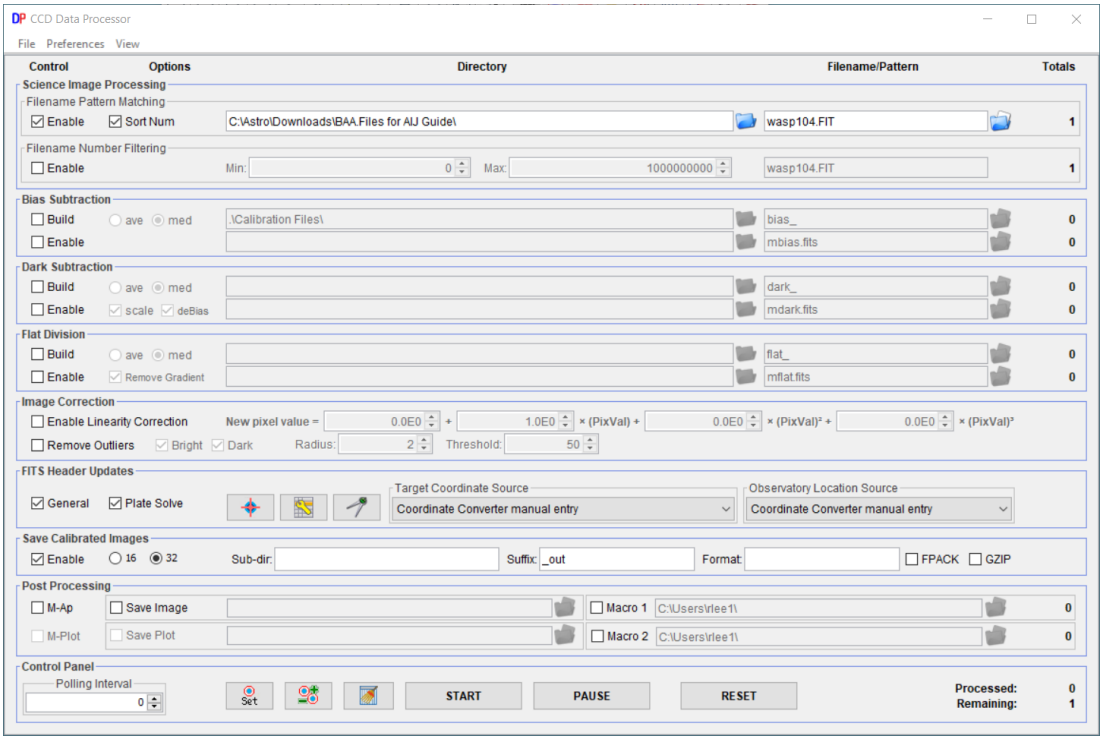
6. Enable Sky Location option, RA and Dec values should automatically be populated from DP CC coordinates, for ObjectId wasp104 in this case.

7. Finally, leave other settings as default and click [SAVE AND EXIT] to close window.



DP Astrometry Settings 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.



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.

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