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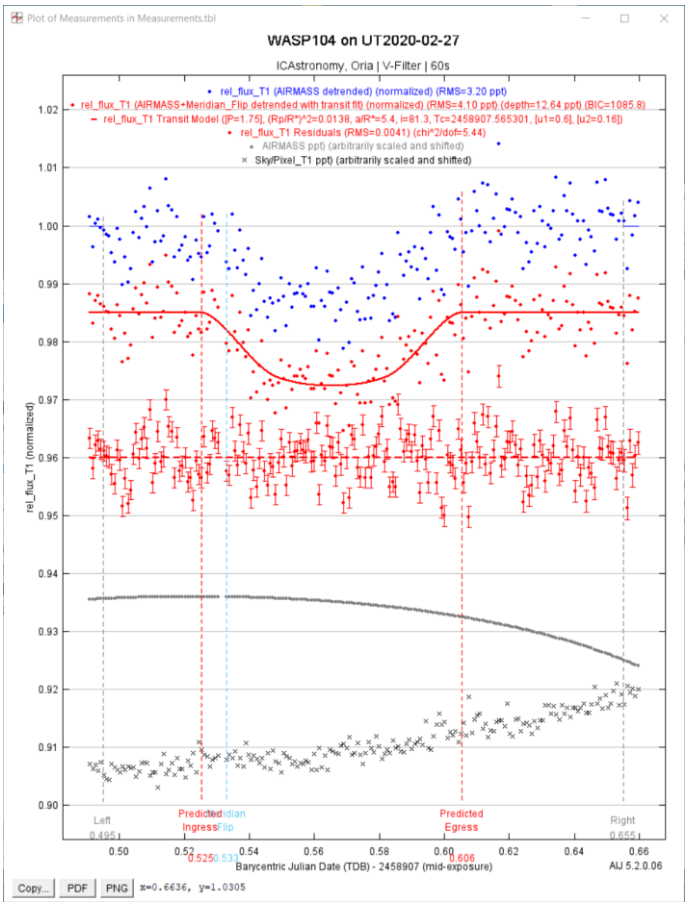
Workflow based Guide to using AstroImageJ for Exoplanet Transit Photometry

Part 2

(Short-form Guide)



Model transit plots WASP104 on UT2020-02-27

Richard Lee

24 January 2023

Contents

1. Introduction

Part 2 provides short form instructions for using AIJ v5 with a WASP104 transit dataset hosted on Dropbox. The instructions are intended for users familiar with AIJ and assumes all required software, including Planner plugin and ansvr plate solving software, have been installed. If necessary, refer to Part 1 for instructions to install and configure software.

The WASP104 dataset was acquired on UT2020-02-27 from ICA Astronomy site in Oria, Spain. Compared to the Part 1 WASP12 dataset, additional processing tasks are:

- WASP104 images are not plate solved - instructions refer to default ansvr plate solver.
- Meridian flip - images were acquired with a GEM mount tracking across the meridian
- Saturated reference star – demonstrates re-running photometry with a modified radec file

AIJ Configuration File

AIJ settings are saved to the AIJ_Prefs.txt file located in Users Settings folder C:\Users\<user>\.astroimagej. The BAA WASP104 Dataset Files package (see Appendix), includes a custom settings file BAA.AIJ_Prefs.txt. Section 2 details replacing an existing AIJ_Prefs.txt with the BAA version then setting observatory and camera parameters to process the WASP104 dataset. Parameters to process WASP104 dataset are tabulated in an Appendix in Part 1.

BAA Dataset Files

Treating the WASP104 as a potential 'BAA campaign' object, the supplied file BAA.DATASET.WASP104.TXT contains target J2000, V-mag and data required for user input to the Fit Settings window. Refer Appendix for details.

Transit Results

Table transit times and depth are computed in the Fit Settings window from a five-parameter model fit, including manual entry of the u1 and u2 limb darkening terms.

2. Configuration and Dataset Files

Refer to Part 1 | section 1 for a link to download BAA support files.

Download and import configuration and WASP104 dataset files

1. From the BAA web site (link BAA_AIJ in Part 1 | section 1), download and save 'BAA.AIJ Guide Part 2.zip' in folder C:\Astro\Downloads.
2. Extract zip file to C:\Astro\Downloads folder; path to the uncompressed folder is: C:\Astro\Downloads\BAA.Files for AIJ Guide Part 2.
3. In C:\Astro\Downloads\ BAA.Files for AIJ Guide Part 2 folder, open BAA.README.AIJ_GUIDE_2.TXT in a text editor and follow instructions to copy configuration and other files to respective folders.
4. Download WASP104 dataset from Dropbox links detailed in BAA.README.AIJ_GUIDE_2.TXT; unzip and save in:
   C:\Astro\Datasets\WASP104.V.2020_02_27\Raw Science Files (200 files)
   C:\Astro\Datasets\WASP104.V.2020_02_27\Calibration Files (30 files)

Overwrite BAA AIJ_Prefs configuration file

1. Navigate to AIJ User Settings folder (C:\Users\<user>\.astroimagej).
2. In User Settings folder, rename AIJ_Prefs.txt to AIJ_Prefs.bak and rename BAA.AIJ_Prefs.txt to AIJ_Prefs.txt.

3. Short-form Procedure

3.1. Set up Software

Set up DP Coordinate Converter

1. Open AIJ | DP Coordinate window, select Observatory ID = ICAstronomy, Oria and set UTC offset to 1.
   Note: Refer Part 1 | section 2 for instructions to setup a custom observatory.
2. Run a SIMBAD query on ObjectID: WASP104.
3. Close and re-open AIJ and confirm new DPCC settings have registered.

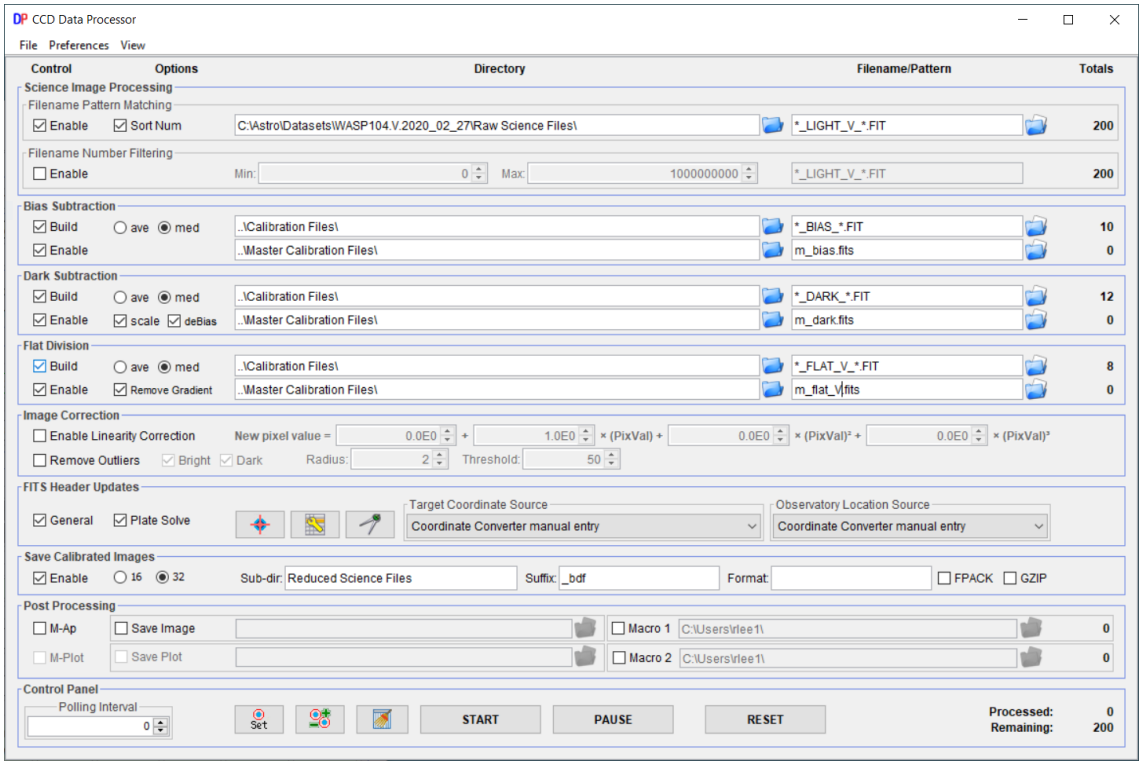
Set up Aperture Photometry Settings

1. Open AIJ | CCD Data Processor window, in Control Panel click 

to open the Aperture Photometry Settings window.
2. Confirm Keywords list includes 'EXPTIME' and not 'EXPOSURE'; edit list as necessary.
3. Edit three CCD fields for ICAstronomy values listed in Part 1 | Appendix.
4. Close and re-open AIJ and confirm settings have registered.

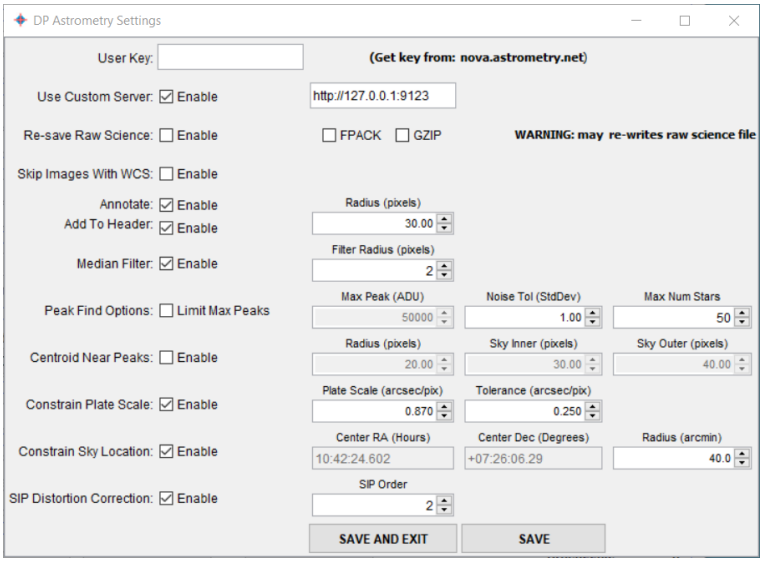
Set up CCD Data Processor for WASP104 dataset

1. Open AIJ | CCD Data Processor window.
2. Science Image Processing | Directory: navigate to and Select folder C:\Astro\Datasets\WASP104.V.2020_02_27\Raw Science Files
3. Science Image Processing | Filename/Pattern: enter *_LIGHT_V_*.FIT and confirm Totals = 200.
4. Bias Subtraction | Filename/Pattern: enter *_BIAS_*.FIT, confirm Totals = 10
5. Dark Subtraction | Filename/Pattern: enter *_DARK_*.FIT, confirm Totals = 12.
6. Flat Division | Filename/Pattern: enter *_FLAT_V_*.FIT, confirm Totals = 8.
7. Change master flat filename from m_flat_FILTER.fits to m_flat_V.fits.
8. Confirm CCD DP window settings against the following figure:



Set up DP Astrometry Settings for WASP104 dataset

1. Open CCD Data Processor | DP Astrometry Settings window  .
2. Enable Use Custom Server option and enter server address. In example below this is configured for port 9123.
   Note 1: Plate Scale is set to 0.87 arcsec / pixel, image scale for 2x2 binned WASP104 image set.
   Note 2: Custom Sky Location text boxes are automatically populated from DP CC J2000 Equatorial fields.



3. Optional: enable option to Skip Images with WCS to bypass plate solve if repeating WASP104 image reduction.
4. Click [SAVE AND EXIT] to close window.

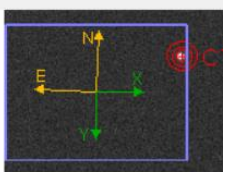
3.2. Run AIJ Photometry

Run CCD Processor for WASP104 dataset

1. In CCD Data Processor window, click [START] to run image reduction process on WASP104 Raw Science images.
2. When image reduction process is finished, move the Reduced Science Files folder up one level as follows:
   From: C:\Astro\Datasets\WASP104.V.2020_02_27\Raw Science Files\Reduced Science Files
   To: C:\Astro\Datasets\WASP104.V.2020_02_27\Reduced Science Files

Run visual inspection for WASP104 dataset

1. AIJ toolbar | File |Import Image Sequence: ensure Use virtual stack is checked, then navigate to and open folder C:\Astro\Datasets\WASP104.V.2020_02_27\Reduced Science Files.
   First reduced image opens in Image Viewer window.
2. Viewer | View: select 'Invert' option from View menu to orientate image N-E => up-left as below.



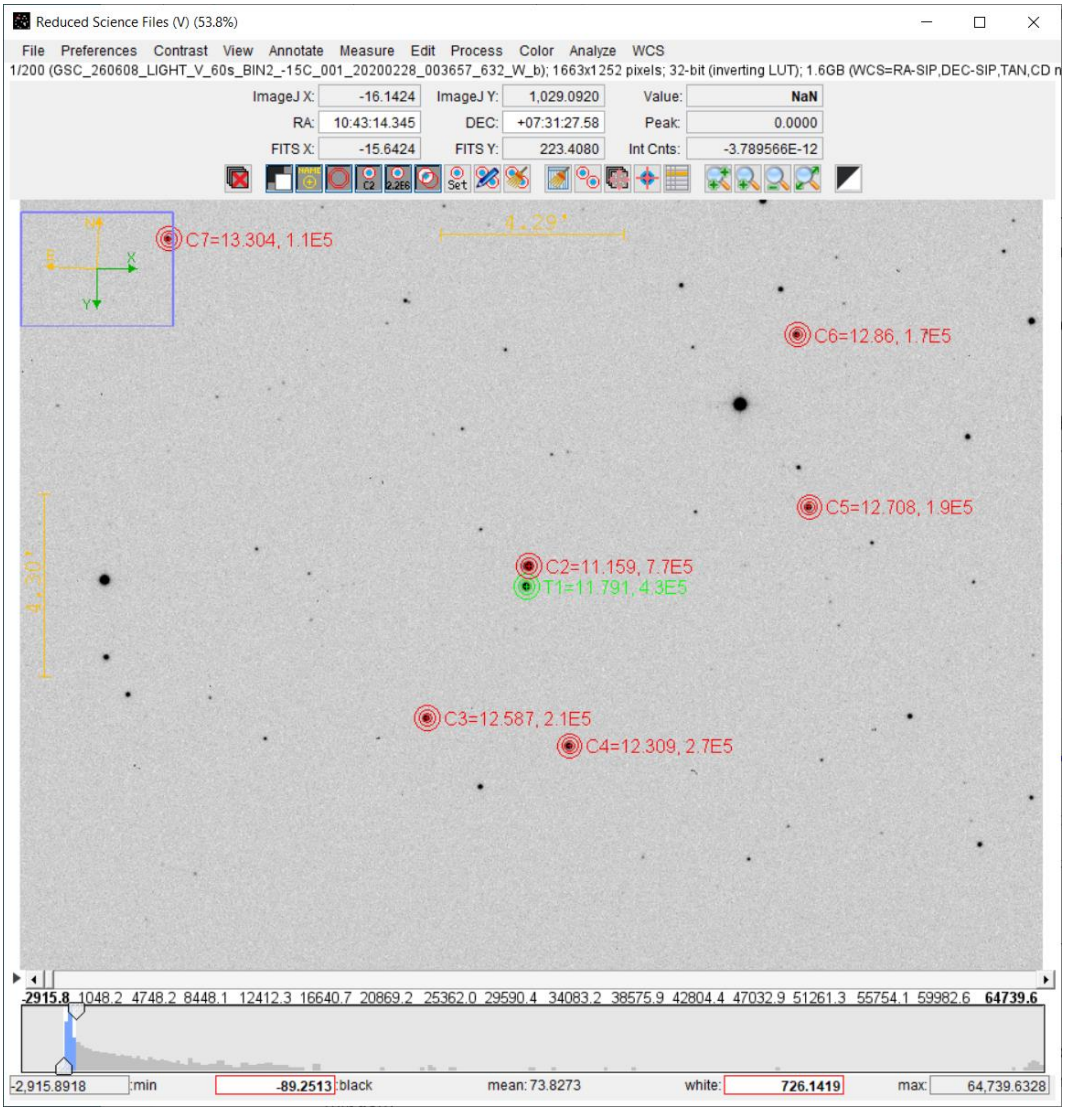
3. Click 'Play' icon (left side of horizontal scroll bar) and review image quality; click 'Pause' icon to pause at current displayed image.
4. To delete any poor-quality images from the image stack, pause at the defective image and click in the Viewer toolbar.
   Option: since the fits file is *not* deleted, note the fits filename of any reject image and manually remove the file from the Reduced Science Files folder.

Set up aperture radii for WASP104 dataset

1. Alt-Left click on a bright non-saturated star image to open the Seeing Profile window and click [Save Aperture].
2. In Viewer window, open the Multi-Aperture Measurements window and confirm that the aperture radii match.
3. Close the Multi-Aperture Measurements and Seeing Profile windows and clear aperture overlay on current image.

Import radec apertures for WASP104 dataset

1. Viewer | File | Import apertures from RA/Dec list: navigate to and select C:\Astro\AstroImageJ\radec\WASP104.V.018.radec.txt to import and overlay aperture set on current image. Zoom image to fit screen to as necessary.
2. Ensure group of toolbar aperture buttons (5) are selected as shown in figure below
3. Open Multi-Aperture Measurements window, then click [Place Apertures] to close window, lock apertures to object centroids and open Multi-Aperture Help window.

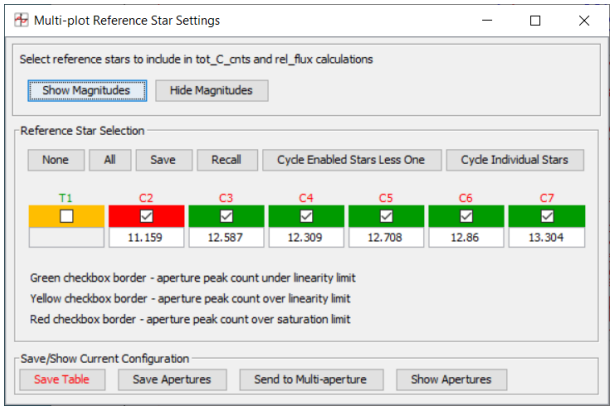


Run photometry for WASP104 dataset

1. Click Viewer title bar to ensure window is active then press <Enter> to start processing.
2. When processing is finished, activate the Measurements window, File | Save As:
   C:\Astro\Datasets\WASP104.V.2020_02_27\Measurements.tbl
   Option: to assist importing data into a spreadsheet, save measurements data to second file:
   Measurements.txt

Review reference star selection for WASP104 dataset

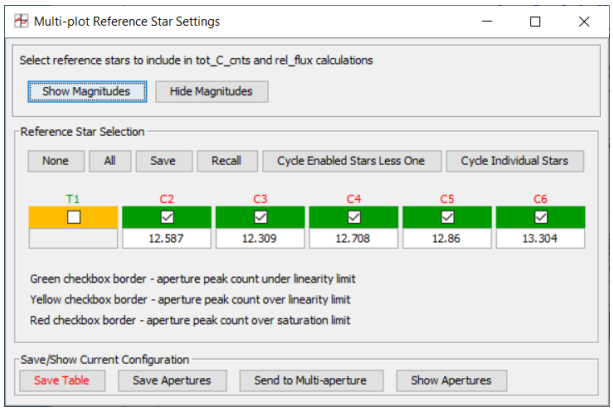
1. Activate the Multi-Plot Reference Star Settings window.
   The red checkbox is coloured red, indicating that the peak count has exceeded the saturation limit.
   Note: linearity and saturation limits are set in the Aperture Photometry Settings window.



Option: Run photometry with updated radec apertures

Optional section to demonstrate updating photometry results with C2 removed from radec aperture set.

1. Close and re-open AIJ, then from the toolbar, Plugins | Astro Apps | Run Planner App.
2. In Planner | Catalogs tab: click [Import Radec File], and open WASP104.V.018.radec.txt (i.e., the radec file for the current MP Reference Stars).
3. Uncheck 'USE' for C2 (ObjectId : 10422444+07263510), then click the following button sequence: [Update], [Save Radec File], [Clear], [Import Radec File].
4. Re-open WASP104.V.018.radec.txt and confirm ObjectId: 10422444+07263510 is deselected in the aperture table.
5. Close the Planner app and VSP Star chart.
6. Run photometry for WASP104 Reduced Science Files as above, again using (the now updated) aperture set: WASP104.V.018.radec.txt
7. When photometry run is finished, activate the Multi-Plot Reference Star Settings window and confirm all reference star checkboxes are green.



8. In Multi-Plot Main | File | Save data to file, save photometry results to: C:\Astro\Datasets\WASP104.V.2020_02_27\Measurements.tbl, confirm replacing existing file.

Meridian flip time (BJD_TDB) for WASP104 dataset

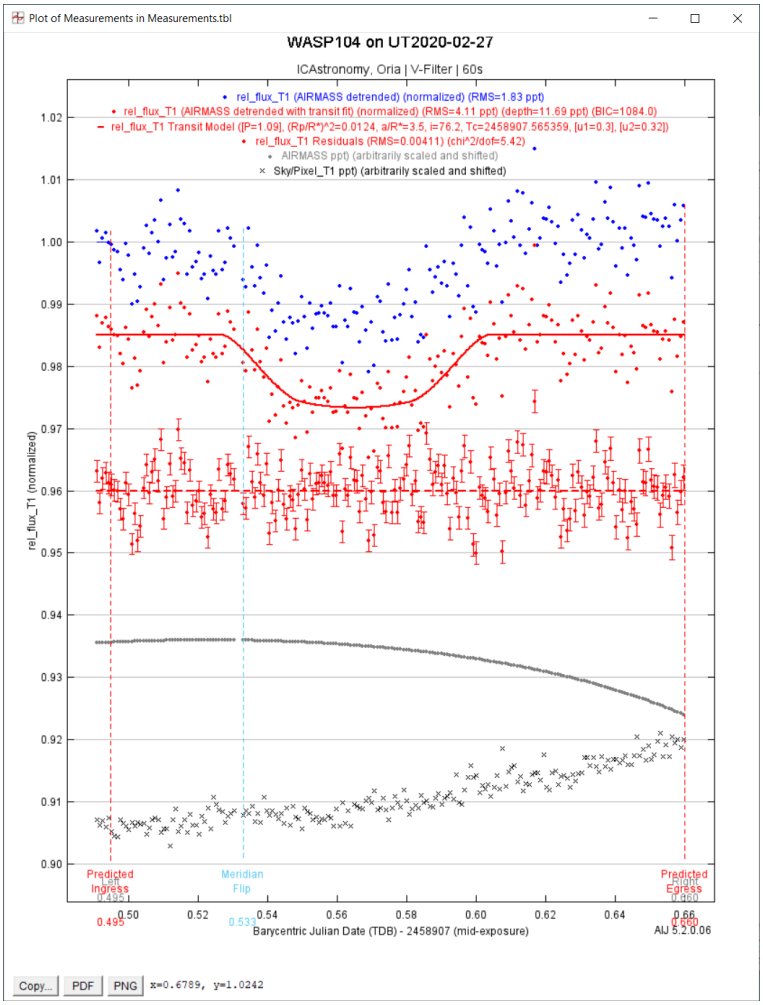
1. Compute the fractional BJD_TDB time of meridian flip as detailed in Appendix.
   Result: Flip Time = **0.532**.

3.3. AIJ Multi-Plot and Transit Analysis

Configure Multi-Plot for WASP104 dataset

1. Close and re-open AIJ, in the click toolbar icon  , MultiPlot Tool, to open Multi-plot Main and other Multi-plot windows.
2. Activate the Multi-plot Main window, select MP Main | File | Open table from file… then navigate to and select: C:\Astro\Datasets\WASP104.V.2020_02_27\Measurements.tbl.
3. MP Main | File | Open plot configuration from file…: navigate to and select C:\Astro\AstroImageJ\plotcfg\BAA.transit_amass_flip.plotcfg.
4. Enter MP Main Title: WASP104 on UT2020-02-27
5. Enter MP Main Subtitle: ICAstronomy, Oria | V-Filter | 60s
6. V. Marker 1: click on scroll-up control to move chart data left until it reaches the 'Predicted Ingress' marker line.
7. V. Marker 2: click on scroll-down control to move chart data right until it reaches the 'Predicted Egress' marker line.
8. In the Fit and Normalize Region section, click 

to copy V. Marker values into the Left and Right textboxes.
9. In the Meridian Flip section, enable Show and enter Flip Time = **0.532** (see previous section). The WASP104 plot below feature:
   - Left and Right marker lines coincide with the Predicted Ingress / Egress lines.
   - The solid red line is an initial transit fit to the WASP104 dataset.
   - The dashed cyan line marks the time of the meridian flip.



10. MP Main | File | Save plot configuration: save as: C:\Astro\AstroImageJ\plotcfg\WASP104.transit_amass_sky.plotcfg.

Set up Fit Settings for WASP104 dataset

1. Open file C:\Astro\Datasets\WASP104.V.2020_02_27\BAA.DATASET.WASP104.TXT in a text editor.
2. Activate the Fit Settings window and enter the following data into Fit Settings | User Specified Parameters text boxes:
   Orbital Parameters | Period (days): **1.755** <= README | NASA EXOPLANET | P
   Host Star Parameters | R*(Rsun): **0.965** <= README | NASA EXOPLANET | R*/Rsun
3. Enter the following data into Fit Settings | Transit Parameters | Prior Center text boxes:
   Linear LD u1: **0.601** <= README | EXOFAST | U1
   Linear LD u2: **0.164** <= README | EXOFAST | U2
4. If necessary, enable the Linear LD and Quad LD check boxes.

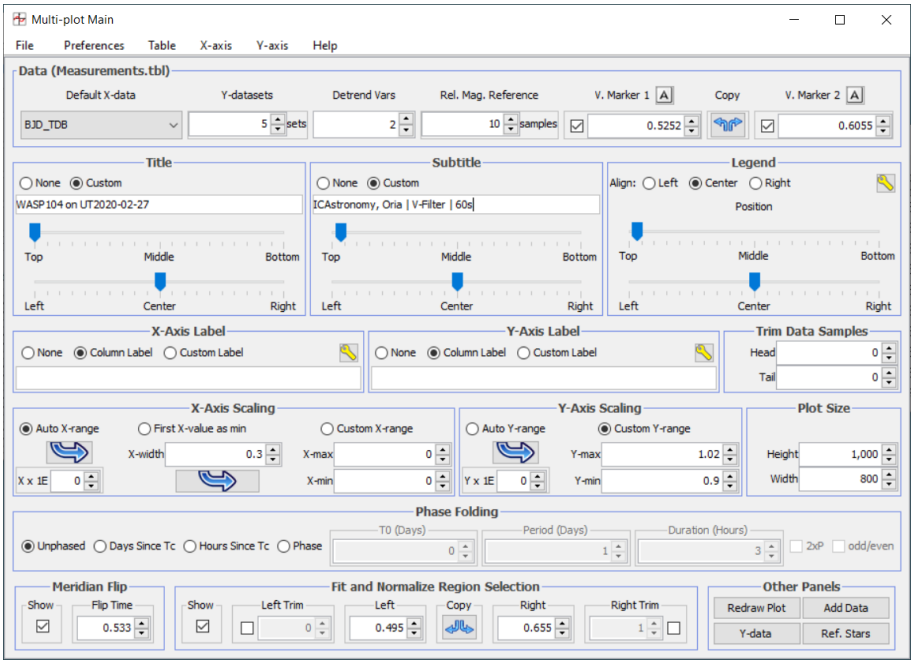
Tabulate model results for WASP104 dataset

1. Activate and position the Plot of Measurements window and MP Main windows to view windows side-by-side.
2. In MP Main, using scroll control, move V. Marker 1 to mark the Predicted Ingress in the Plot of Measurements

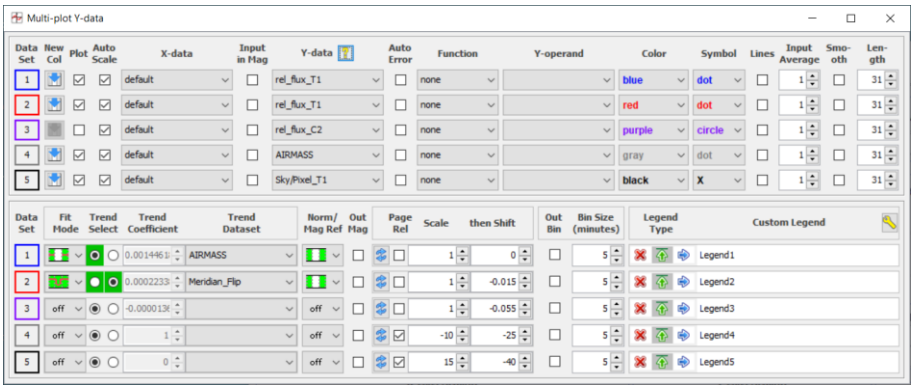
3. Repeat with V Marker 2 to mark transit egress.
   Note: For fine control of line marker positions, right-click in one of the V. Marker text boxes to open a small dialog, then set the Stepsize to 0.001.
4. Activate Fit Settings window: Fit Settings | File | Save fit results as text file, navigate to C:\Astro\Datasets\WASP104.V.2020_02_27 and save as WASP104.transit_results.txt.
5. MP Main | File | Save plot configuration: save as: C:\Astro\AstroImageJ\plotcfg\WASP104.transit_amass_sky.plotcfg, confirm replacing existing file.
6. Fit Settings | Transit Parameters, complete results table for WASP104 transit (typical results, your values may slightly differ):

WASP104 Transit Parameters		
Parameter	**Units**	**Value**
Tc		2458907.56530
Depth	ppt	12.64
T14	hms	01:55:04

Final Multi-plots for WASP104 dataset

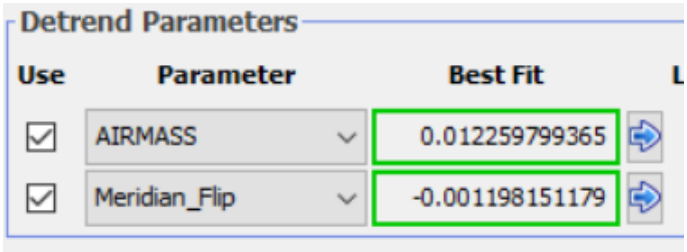


Multi-Plot Main

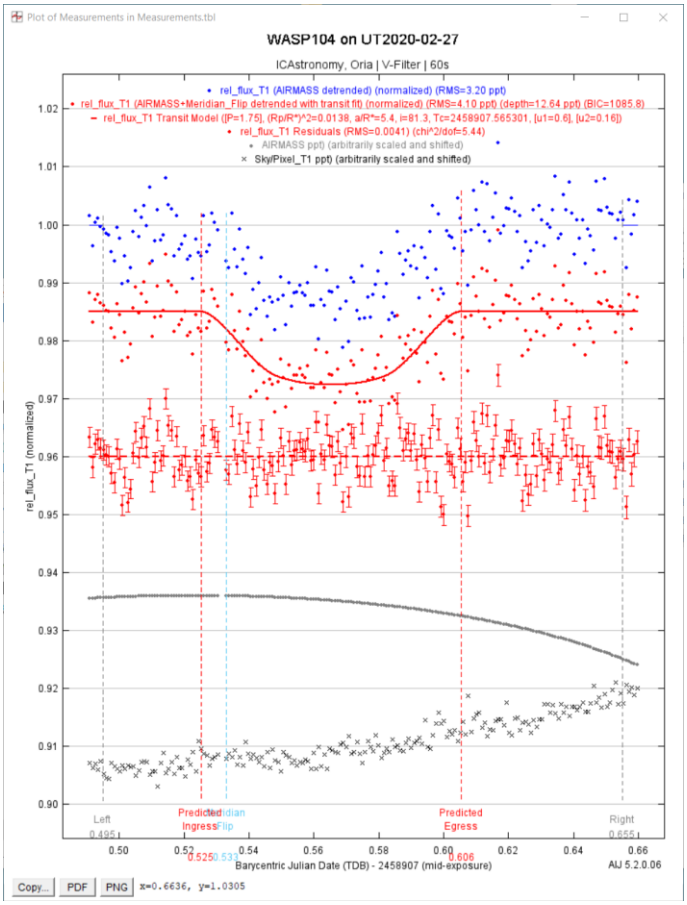


Multi-plot Y-data

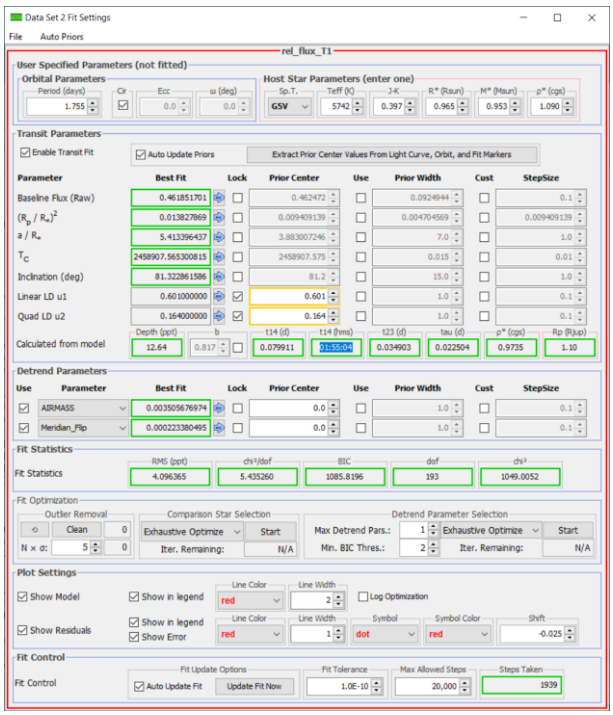
MP Y-data: AIRMASS & Meridian_Flip Detrend



Fit Settings: AIRMASS & Meridian_Flip Detrend



Plot of Measurements

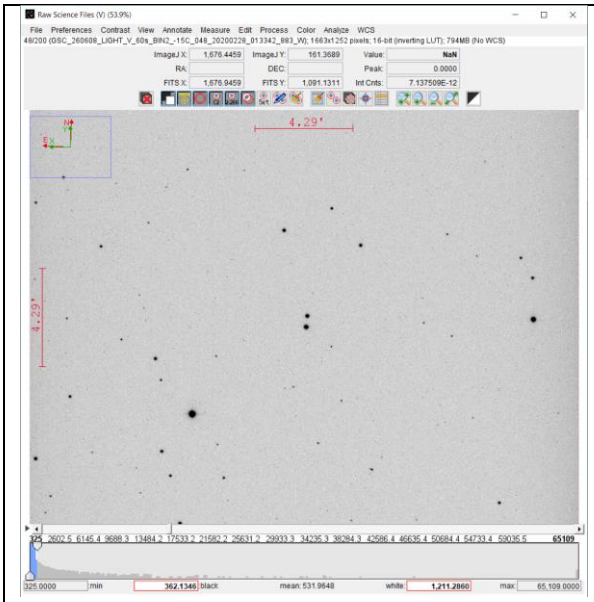
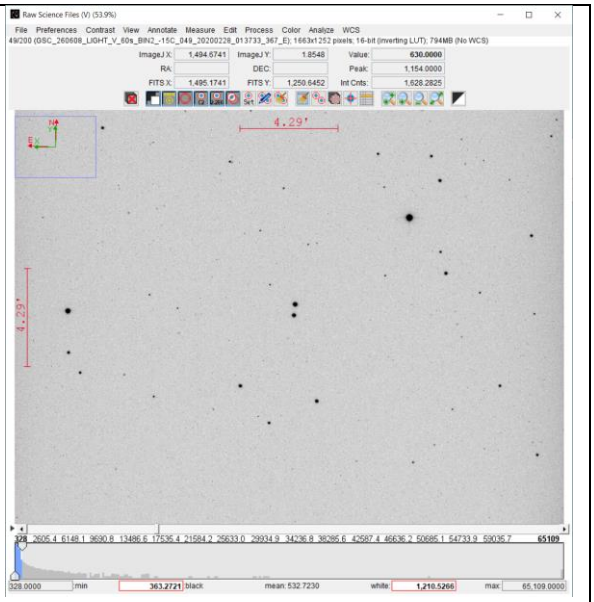


Fit Settings

APPENDIX A: Compute BJD_TDB Time of Meridian Flip

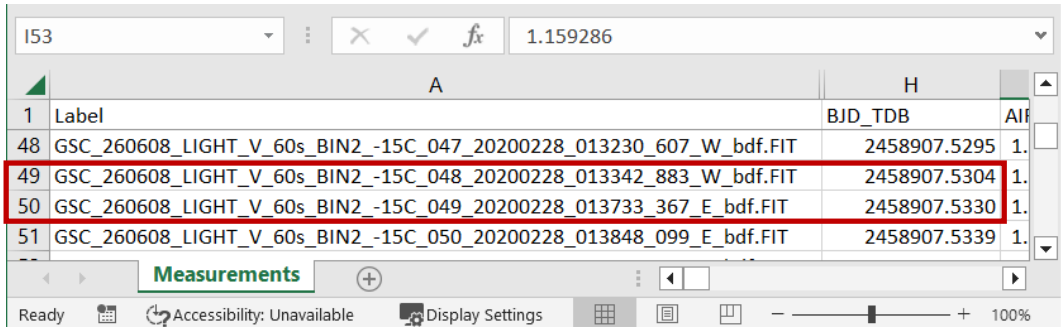
Identify pre- and post-meridian flip images

1. AIJ toolbar | File |Import Image Sequence: ensure Use virtual stack is checked, then navigate to and open folder containing *unprocessed* image files: C:\Astro\Datasets\WASP104.V.2020_02_27*Raw Science Files*.
   The first unprocessed (raw) science image opens in an Image Viewer window.
2. Scroll through the image stack and identify the image pair where the star fields rotate 180°. In the example below, the immediate pre- and post-flip filenames end with '…_W.FIT' and '…_E.FIT' respectively.

	
GSC_260608_..._048_20200228_013342_883_W.FIT	GSC_260608_…_049_20200228_013733_367_E.FIT
Last pre-flip image	First post-flip image

Compute meridian flip JD time

1. Open photometry measurements file C:\Astro\Datasets\WASP104.V.2020_02_27\Measurements.txt (or Measurements.tbl) in Excel or other spreadsheet; import data with <tab> delimiter.
2. Referring to the figure below, search the Label column to find the last pre-flip image filename (.._883.FIT) and note this row and the next row fractional BJD_TDB values, 0.5304 and 0.5330 respectively in this example.



	A	H
1	Label	BJD_TDB
48	GSC_260608_LIGHT_V_60s_BIN2_-15C_047_20200228_013230_607_W_bdf.FIT	2458907.5295
49	GSC_260608_LIGHT_V_60s_BIN2_-15C_048_20200228_013342_883_W_bdf.FIT	2458907.5304
50	GSC_260608_LIGHT_V_60s_BIN2_-15C_049_20200228_013733_367_E_bdf.FIT	2458907.5330
51	GSC_260608_LIGHT_V_60s_BIN2_-15C_050_20200228_013848_099_E_bdf.FIT	2458907.5339

3. Taking the average of these BJD_TDB values, rounded to 3 places, the fractional meridian flip time is **0.532** (= (0.5304 * 0.5330) / 2).
   Note: when prompted in the Guide, enter this value in Multi-plot Main | Meridian Flip | Flip Time field.

APPENDIX B: BAA WASP104 Dataset Files

Example files for WASP104

File	Notes
BAA.DATASET.WASP104.TXT	Data for BAA 'Campaign Target' object. J2000 coordinates, mag data, NASA EXOPLANET & EXOFAST transit fit data
BAA.AIJ_Prefs.txt	Standard BAA photometry settings; user updates observatory and camera data
WASP104.V.018.radec.txt	AIJ radec format aperture file, V-mag, 18 arcmin FOV
BAA.transit_amass_flip.plotcfg	Multi-plot configuration file with airmass & meridian flip detrend

Fit Settings Window – user inputs for V-mag filter

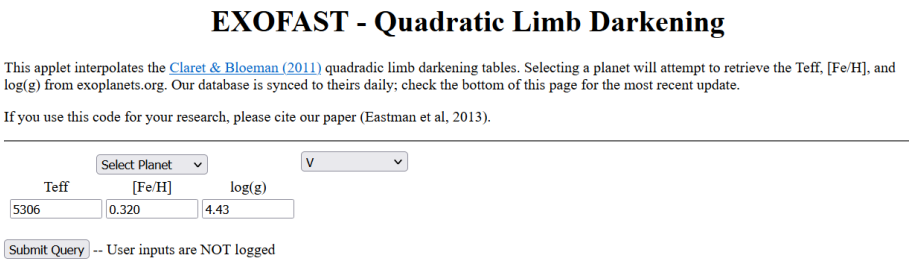
NASA EXOPLANET: https://exoplanetarchive.ipac.caltech.edu/

1. Search on WASP104 in the NASA EXOPLANET Home Page
2. Read the following Planetary and Stellar Parameters
   - WASP-104 b P(days) 1.755
   - WASP104 $R_*(R_\odot)$ 0.965
   - WASP104 T_{eff}(K) 5306
   - WASP104 Metallicity (dex) 0.320
   - WASP104 log g (log10(cm/s2)) 4.43

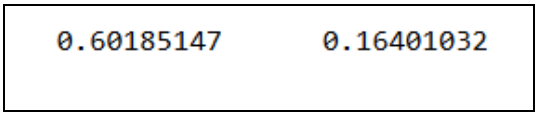
Source	TICv8	Gaia DR2	Bonomo et al. 2017
T_{eff} (K)	5306.0000 $^{+164.1340}_{-97.2841}$	5123.500 $^{+216.367}_{-123.067}$	5450±130
Metallicity (dex)	---	---	0.320±0.090
γ (km/s)	---	---	---
$v \sin i$ (km/s)	---	---	0.40±0.70
Age (Gyr)	---	---	3.0±2.0
ρ_* (g/cm^3)	1.4266737 $^{+0.4007445}_{-0.2671875}$	---	---
M_* ($M_\odot$)	0.9100000 $^{+0.1080450}_{-0.1116850}$	---	1.076±0.049
R_* ($R_\odot$)	0.96522200 $^{+0.06423370}_{-0.04865080}$	1.0202371 $^{+0.0508368}_{-0.0810033}$	0.963±0.027
log g (log$_{10}$(cm/s^2))	4.4278500 $^{+0.0656373}_{-0.1013030}$	---	---
Sp. T	---	---	---
L_* (log$_{10}$($L_\odot$))	-0.1769817 $^{+0.0109338}_{-0.0178067}$	-0.1896361 $^{+0.0049116}_{-0.0049678}$	---

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

1. Open EXOFAST page.
   Note that WASP104 is not listed in Select Planet drop down
2. Select or enter:
   - BAND V
   - Teff 5306
   - [Fe/H] 0.320
   - Log g 4.43



3. Click [Submit Query] to compute Quadratic Limb Darkening coefficients:



u1 = 0.601

u2 = 0.164