<u>Remotely operated robotic telescopes – the MicroObservatory Robotic Telescope</u> <u>Network</u>

Updated 2024 February 17

Please note that while you may use HOPS and ExoClock on-line analysis to process MicroObservatory observations do not submit your observations to the ExoClock database. The reason for this is that multiple observers may submit results of their analysis of the same set of observations which is causing some confusion.

However, you can upload your results to the <u>Exoplanet Transit Database (ETD)</u> To do so;

- Select 'How to contribute to ETD on the above-mentioned page
- Select 'Use on-line protocol'
- Follow the instructions to load data to both TRESCA and the ETC

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1.0 Introduction

This project is identified as; **EXPLOIT 103 – MicroObservatory Robotic Telescope** on the <u>EXoPLanet Orbit REsearch (EXPLORE) webpage</u> together with links to AstroImageJ tutorials.

This tutorial refers to WASP-12b and then switches to WASP-43b due to problems with obtaining good images for the former. A finder chart is shown in Figure 1.1



Figure 1.1 WASP-12b finder chart

Credit ExoClock

WASP-12b data can be found on the exoplanets.org website <u>here</u>. It is located at RA 06:30:12.794, Dec +29:40:20.2

2.0 Accessing the network

I must thank Martin Fowler for his considerable help with this project.

The network is operated by the <u>Harvard and Smithsonian Center for Astrophysics</u> and can be found <u>here</u>. The exoplanet section is accessed by clicking on the 'DIY Planet Search' button in the bottom right-hand corner of the home page – Figure 2.1



Figure 2.1 Robotic telescope home page.

This brings up the Log in/Register screen – Figure 2.2



Figure 2.2. Log in/Register screen

3.0 Target selection

After logging and selecting DIYTools the screen shown in Figure 3.1 is presented which shows targets for the current month.



Figure 3.1. Targets for current month

WASP-12 was selected on February 3^{rd} and 14^{th} . The next step is to set up the observing run by clicking on 'Observe' for that object. This opens the Control the Telescope page – Figure 3.2.

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		Hours			Minutes			
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	12 AM	01 AM	02 AM					
	03 AM	04 AM	05 AM					
		All Hours						
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Figure 3.2. Control the Telescope

Under the 'Choose Time' tab select 'All Hours' which switches to the 'Select Settings' tab – Figure 3.3. Input the Exposure time and Filter as suggested (they may already be set to the appropriate values).

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Your mixedon.	Choose Time Select Settings Current Target: WASP-12 Choose an appropriate exposure time and filter settings. Telescope: Cecilia in Amado, AZ, Mountain Standard Time Time zone in Amado, AZ (GMT-7) Thursday 1st of February 2024 06:58:17 AM Selected Date: 2024-02-03 Selected Time: All available hours		
() Community	Exposure Filter		
Results	30 seconds O 60 seconds •	۲	
	Terms of Use Privacy Kids Online Privacy Statement Contact Us Help DIY Raw Start of NASK: Universe of Learning supported by NASK Award MARCEACEAS to be Space Telecope Science Institute, working in partnership with Callech/IVAC,	Take Image	CENTER FOR ASTROPHYSICS

Figure 3.3. DIY Tools page 'Select Settings' tab.

Repeat the above for each target selected.

Clicking on 'Take Image' in the bottom right-hand corner of the screen displays the target and number of images to the left of that button. Images should be available within three days. Selecting 'My Data/Activities' at the top of the page opens the page shown in Figure 3.4.

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Planet Search Home About Exoplanets DIVTools Targets Telescopes	My Data 👻 Community 👻 Logout
Activities	
Begin your search using the DIY tools to collect and analyze your own images. You can work alone or with a group to investigate a few data points or an entire transit event. Gather and save data and information about your planets in "My Planet" search.	Highlights Share your results
Compare, combine, and communicate your findings with others on the DIY Planet Search Community page. Here, you can also follow the development of scientists in their search for habitable planets.	Compare, combine, and communicate your findings with others in the DIY Planet Search community Explore here •
My Activities	Community Activity
Images (1252 Collected) Data Points (427 Collected)	Featured Data 🔊
> Images Collected	
> Pending (103 Images)	
Current (Last 5 Days 0 Images)	Frequently Asked Questions
> Past (1149 Images)	Question: What is an exoplanet?
> Data Points Collected (427 points)	our Solar System. It is usually in orbit around another star.
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Figure 3.4. Activity status page.

4.0 Downloading images and dark frames (for off-line analysis)

Images can be analysed on-line but this tutorial covers downloading the images and analysing them using AstroImageJ

4.1 Downloading images – the less time-consuming method

There are time consuming and somewhat less time-consuming methods but only the latter will be covered here My thanks to Martin Fowler for his advice as on the latter.

A list of images and dark frames can be found at (<u>http://mo-</u> www.cfa.harvard.edu/MicroObservatoryLegacy/ControlCenter/index.html) – Figure 4.1

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		Telescope	Local Weather	Telescope Status	View Queue		
		Annie	Cambridge, MA	Offline	99 entries		
	First check	Ben	Amado, AZ	Online	<u>6 entries</u>		
select 'scope	weather	Cecilia	Amado, AZ	Online	9 entries		
what's up		Donald	Cerro Tololo, Chile	Offline	90 entries		
settings		Ed	Cambridge, MA	Online	7 entries		
trouble shoot file report challenges lounge home	Then click on map site to select telescope	R.S.		No. of the second se			

Figure 4.1. Control center

To obtain your images select 'get images' from the list on the left of the page. Under Data Range select the period and required object - in this example Past 10 Days and WASP-12b – Figure 4.2.

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what's up settings get images trouble-shoot	lmage Filename	<u>Date & Time (UT)</u> ▼	Open JS9/4L	FITS Image	Field of View	Exposure Time (sec)	Filter	<u>Object</u>	Telescope	Site	<u>User</u>	Size (KB)	Weather			
file report	WASP-12240204093615	04-Feb-2024 09:36:15	<u>JS9/4L</u>		Main	60.00	Clear	WASP-12	Cecilia	AZ	moguest	139	94% Clear			
challenges lounge home	WASP-12240204093315	04-Feb-2024 09:33:15	<u>JS9/4L</u>		Main	60.00	Clear	WASP-12	Cecilia	AZ	moguest	134	94% Clear			
	WASP-12240204093016	04-Feb-2024 09:30:16	<u>JS9/4L</u>		Main	60.00	Clear	WASP-12	Cecilia	AZ	moguest	131	94% Clear			
	WASP-12240204092715	04-Feb-2024 09:27:15	<u>JS9/4L</u>		Main	60.00	Clear	WASP-12	Cecilia	AZ	moguest	128	91% Clear			
	WASP-12240204092416	04-Feb-2024 09:24:16	<u>JS9/4L</u>		Main	60.00	Clear	WASP-12	Ed	ма	moguest	266	9% Clear			
	WASP-12240204092415	04-Feb-2024 09:24:15	<u>JS9/4L</u>		Main	60.00	Clear	WASP-12	Cecilia	AZ	moguest	133	91% Clear			
	WASP-12240204092116	04-Feb-2024 09:21:16	<u>JS9/4L</u>		Main	60.00	Clear	WASP-12	Ed	ма	moguest	230	9% Clear			
	WASP-12240204092115	04-Feb-2024 09:21:15	<u>JS9/4L</u>		Main	60.00	Clear	WASP-12	Cecilia	AZ	moguest	134	91% Clear			
	WASP-12240204091817	04-Feb-2024 09:18:17	<u>JS9/4L</u>		Main	60.00	Clear	WASP-12	Ed	МА	moguest	266	9% Clear			
	WASP-12240204091815	04-Feb-2024 09:18:15	<u>JS9/4L</u>		Main	60.00	Clear	WASP-12	Cecilia	AZ	moguest	129	91% Clear			
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Figure 4.2. Image list

Unfortunately, the images still have to be downloaded one at a time but the number of mouse clicks required is much reduced. However, it does allow each image to be examined and accepted or discarded as necessary.

Example folder set-up for AstroImageJ;

- Widows(C:)/Astro/AstroImageJ 5/AstroImageJ
 - WASP-12b/2024 Feb 04
 - Calibration Files/Darks
 - Master Calibration Files
 - Raw Science Files

To review and download images;

- click on the object name in the Image Filename column to bring up the image shown in Figure 4.3
- right click on the image name in the top right-hand corner
- select Save link as from the drop down window
- save to the required folder
- click on the next image and etc.

The MicroObservatory takes an image every 2 minutes so for WASP-12b with a transit duration of 3 hours and adding 1 hour before and 1 after would give around 150 images.



Figure 4.3. FITS image

To download dark frames;

- select Past 10 days and Dark-C-
- select 10 dark frames around the date of observation, ensuring they have the same exposure times as your images and are listed as 'Opaque'
- click on Dark-C-etc in the Image Filename column

- save to Calibration Files/Darks

- click on the next image and etc. until a total of 10 have been saved

5.0 Using AstroImageJ to produce a transit light-curve of WASP-12b

This section refers to the <u>'Workflow based Guide to using AstroImageJ for Exoplanet Transit</u> <u>Photometry</u>' by Richard Lee. Rather than repeat all the details here please refer to that for a full description of the process.

Notes below are specific to the MicroObservatory and WASP-12b referring to sections in the above-mentioned guide

2.3.4. Set up a New Observatory Location

In the observatories.txt file add details for the MicroObservatory

MicroObservatory31.68-110.881268In the DP Coordinates Converter window select MicroObservatory in the Observatory ID
drop down and set the Time Zone UTC Offset to -7-7Set;Gain (e/ADU)53.6Readout noise15 electrons

Dark current (e-/s/pix) 15 electrons/pixel/sec

3.2.1 If not previously selected then select MicroObservatory in the Observatory ID dropdown and set UTC offset to -7 - Figure 5.1

📌 DP Coordin	ate Con	verter						– 🗆 X
ile Preference	es Netv	vork Help						
Current UTC UTC: 2024-	C-based -02-06 iject ID (Time 15:24:02 or SS Object)	Local: 2024-02-0	16	08:24:02 Observat	JD: 246034	47.141691	LST: 17:05:35
WASP-12b			UTC offset:	-7	MicroOb	servatory		~
Target Prop	per Moti	on (mas/yr)	Ge	ograpi	nic Location of	Observatory		
pmRA: -1.5	519	pmDec: -6.7	'61 Lo	n: -11	0:52:48	Lat: +31:40):48	Alt: 1268
Standard Co	oordinat	tes J2000 E	quatorial			J2	2000 Ecliptic	
SIMBAD	RA: 06:3	30:32.797	Dec: +29:40:20	.26	Lon: 9	6:40:20.37	Lat: 0	06:24:34.96
		B1950 E	quatorial				Galactic	
Sky-Map	RA: 06:2	27:21.276	Dec: +29:42:26	.86	Lon: 1	84:04:58.84	Lat	08:56:11.25
Epoch of Int	terest — d Time -							
Now	UTC:	2023-12-31	06:52:20 UT		18:27	JD: 246030	09.786347	LST: 06:06:37
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RA: 06:3	2:05.90	B Dec: +	29:39:21.77		Lon: 97:00:43	.17	Lat: 06:24	4:53.89
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Phase - Alt	titude - F Moon 33.38 51.08	Proximity Mercury Down 162.62	Venus Ma Down Do 143.82 168	ars wn 8.24	Jupiter 33.48 61.87	Saturn Ur Down 4 123.67 4	ranus Ne 7.40 D 7.85 10	eptune Pluto bown 02.04 157.74

Figure 5.1 Selection of MicroObservatory and Time zone

3.2.2 Input Observer and Equipment Details in the Observation Planner

Select Plugins/AstroApps/Ru	n Planner App
Observer Tab	
Telescope Short Description;	Cecilia
Telescope Full Description;	Maksutov reflector
Aperture (mm);	152
Focal length (MM);	550
Camera;	KAF 1402ME,
Pixel size (H) (um)	6.8 microns binned 2x2 to 13.6x13.6 microns
Pixel size (V) (um)	6.8 microns binned 2x2 to 13.6x13.6 microns
Array Size (H) (pixels)	650 (1317 binned 2x)
Array Size (V) (pixels)	500 (1035 binned 2x)

Click on Update Params to update Derived Parameters boxesPixel Size (arcsec)5.1, 5.1Field-of-View (arcmin)55.25,42.5

Click on Save

Target Tab	
Catalogue Qu	ery Settings;
Object ID;	WASP-12b
RA;	06:30:12.8
Dec:	+29:40:20.2
FOV	50
Limit	13 (WASP-12b is 11.57 V mag)
Catalogue	VSP
Filter	V (MicroObs images are unfiltered)

3.3.2. In the Target tab, click the ellipsis control (...) to open the calendar and set Start Night to 4 February 2024. Observed from the MicroObservatory WASP-12b reaches maximum altitude at about 22:00 Local Site Time - Figure 5.2



Figure 5.2. Target data for WASP-12b

3.4.1. Check Query Data is correct for WASP-12b

To use comparison stars of similar magnitude the magnitude limits were set to +/-1.5 to give 5 comparison stars.

Selecting comparison stars of similar colour and identification of any variables was done using the AAVSO Variable Start Plotter <u>https://app.aavso.org/vsp/</u> - Figures 5.3 and 5.4.

3.4.2 Run APASS query Paragraph 2, select V filter

Apply magnitude filter to WASP-12 records Magnitude limits were set to +/-0.3



Figure 5.3 AAVSO chart

Ap	ObjectId	Ra2000	Dec2000	Mag	Mag Err	Mag diff	Dist	Nobs
T01	WASP-12b	06:30:32.80	+29:40:20.26	11.600	0.000	0.000	0.00	1
	06295157+29404647	06:29:51.57	+29:40:46.47	11.600	0.088	0.000	8.97	4
	06312367+29441027	06:31:23.67	+29:44:10.27	11.595	0.060	-0.005	11.69	7
C02	06301692+29242914	06:30:16.92	+29:24:29.14	11.579	0.075	-0.021	16.22	4
C03	06303279+29402033	06:30:32.79	+29:40:20.33	11.560	0.068	-0.040	0.00	4
C04	06302262+29444221	06:30:22.62	+29:44:42.21	11.672	0.084	0.072	4.89	4
C05	06291901+29405747	06:29:19.01	+29:40:57.47	11.687	0.082	0.087	16.04	5
	06291322+29554133	06:29:13.22	+29:55:41.33	11.512	0.084	-0.088	23.10	6
	06304354+29493334	06:30:43.54	+29:49:33.34	11.706	0.074	0.106	9.51	4
	06301214+29284998	06:30:12.14	+29:28:49.98	11.730	0.083	0.130	12.35	4
C06	06315779+29475840	06:31:57.79	+29:47:58.40	11.737	0.043	0.137	19.97	7
	06320054+29291960	06:32:00.54	+29:29:19.60	11.738	0.037	0.138	22.03	7
	06292548+29341806	06:29:25.48	+29:34:18.06	11.811	0.070	0.211	15.83	5
	06304827+29393591	06:30:48.27	+29:39:35.91	11.372	0.063	-0.228	3.44	5
C07	06302000+29330320	06:30:20.00	+29:33:03.20	11.869	0.081	0.269	7.80	4
	06290514+29302013	06:29:05.14	+29:30:20.13	11.882	0.070	0.282	21.52	5
	06314409+29475578	06:31:44.09	+29:47:55.78	11.967	0.047	0.367	17.24	7
	06315465+29203417	06:31:54.65	+29:20:34.17	11.985	0.025	0.385	26.61	7
	06295591+29501979	06:29:55.91	+29:50:19.79	11.989	0.087	0.389	12.80	4
	06313218+29332410	06:31:32.18	+29:33:24.10	11.207	0.050	-0.393	14.65	7
	06313439+29454816	06:31:34.39	+29:45:48.16	11.205	0.054	-0.395	14.45	7
)								
	C02 C03 C04 C05 C06 C07	T01 WASP-12b 06295157+29404647 06312367+29441027 C02 06301692+29242914 C03 06303279+29402033 C04 06302262+29444221 C05 06291901+29405747 06291322+29554133 06304354+29493334 06301214+29284998 C06 06320054+29291960 06292548+29341806 06304827+29393591 C07 C07 06302000+29330320 06304827+2939591 C06315465+2920313 06314409+29475578 06315465+29203417 06325591+29501979 06313218+29332410 06313439+29454816 06313439+29454816	T01 WASP-12b 06:30:32.80 06295157+29404647 06:29:51.57 06312367+29441027 06:31:23.67 C02 06301692+29242914 06:30:32.79 C03 06303279+29402033 06:30:32.79 C04 06302262+29444221 06:30:22.62 C05 06291901+29405747 06:30:43.54 06304354+2949334 06:30:43.54 06304354+294998 06:30:12.14 C06 06315779+29475840 06:31:57.79 06320054+29291960 06:32:00.54 06302054+29393591 06:30:48.27 C07 0632000+29330320 06:30:20.00 06290514+29302013 06:29:514 06314409+2947578 06:31:44.09 06315465+29203417 06:31:44.09 06315465+29203417 06:31:44.55 06295591+29501979 06:29:55.91 06313218+29332410 06:31:32.18 0631433+29454816 06:31:34.39	T01 WASP-12b 06:30:32.80 + 29:40:20.26 06295157+29404647 06:29:51.57 + 29:40:46.47 06312367+29441027 06:31:23.67 + 29:44:10.27 C02 06301692+29242914 06:30:32.79 + 29:40:20.33 C04 06302262+2944221 06:30:22.62 + 29:44:2.1 C05 06291901+29405747 06:29:19.01 + 29:40:57.47 06201322+29554133 06:29:13.22 + 29:49:33.34 06304354+29493334 06:30:43.54 + 29:49:33.34 06301214+29284998 06:30:57.79 + 29:47:58.40 0632054+29291960 06:32:00.54 + 29:29:19.60 06320054+29291960 06:30:20.00 + 29:39:35.91 C06 06315779+29475840 06:30:20.00 + 29:39:35.91 C07 06302000+2933020 06:30:20.00 + 29:39:35.91 C07 06302000+2933020 06:30:20.00 + 29:30:20.13 06314409+29475778 06:31:44.09 + 29:20:34.17 06295591+2920179 06:31:32.18 + 29:33:24.10 06313218+29332410 06:31:32.18 + 29	T01 WASP-12b 06:30:32.80 + 29:40:20.26 11.600 06295157+29404647 06:29:51.57 + 29:40:46.47 11.600 06312367+29401027 06:31:23.67 + 29:40:46.47 11.600 06312367+29402033 06:30:32.79 + 29:40:20.33 11.579 C03 06302262+2944221 06:30:22.62 + 29:44:2.21 11.672 C04 0602262+29444221 06:30:22.62 + 29:44:2.21 11.672 C05 06291901+29405747 06:29:13.22 + 29:45:41.33 11.512 06304354+29493334 06:30:43.54 + 29:49:33.34 11.706 06301214+29284998 06:30:12.14 + 29:28:49.98 11.737 06320054+29291960 06:32:00.54 + 29:29:19.60 11.738 06292548+29341806 06:29:25.48 + 29:30:3.20 11.802 06310200+293302.0 06:30:20.00 + 29:30:3.20 11.802 06290514+2930213 06:31:44.09 + 29:40:20.13 11.802 06214409+29475578 06:31:44.09 + 29:40:20.13 11.802 06215465+29203417	T01 WASP-12b 06:30:32.80 +29:40:20.26 11.600 0.000 06295157+29404647 06:29:51.57 +29:40:46.47 11.600 0.088 06312367+29441027 06:31:23.67 +29:40:46.47 11.500 0.088 06303279+29402033 06:30:32.79 +29:24:29.14 11.579 0.075 C03 06303279+29402033 06:30:22.62 +29:44:42.11 11.672 0.084 C04 06302262+29444221 06:30:22.62 +29:44:42.11 11.672 0.084 C05 06291901+29405747 06:29:13.21 +29:40:57.47 11.687 0.082 06304354+29493334 06:30:43.54 +29:49:33.34 11.706 0.074 06301214+29284998 06:31:57.79 +29:47:58.40 11.737 0.043 06320054+29291960 06:32:00.54 +29:29:19.60 11.738 0.037 0632054+29291960 06:32:00.54 +29:29:19.60 11.738 0.037 0632054+29291960 06:32:00.54 +29:29:19.60 11.737 0.043 063004827+2933320	T01 WASP-12b 06:30:32.80 +29:40:20.26 11.600 0.000 0.000 06295157+29404647 06:29:51.57 +29:40:46.47 11.600 0.088 0.000 06312367+29441027 06:31:23.67 +29:44:10.27 11.595 0.060 -0.005 C02 06303279+29402033 06:30:32.79 +29:44:21.11 11.579 0.075 -0.021 C03 06302262+29444221 06:30:22.62 +29:44:42.11 11.672 0.084 0.072 C05 06291901+29405747 06:29:13.22 +29:54:133 11.512 0.084 -0.088 06304354+29493334 06:30:43.54 +29:49:33.34 11.706 0.074 0.106 06301214+29284998 06:31:57.79 +29:47:58.40 11.737 0.043 0.137 06320054+29291960 06:32:00.54 +29:29:19.60 11.738 0.037 0.138 06292548+293310 06:32:00.54 +29:29:19.60 11.738 0.037 0.138 06290514+29302013 06:32:00.54 +29:29:19.60 11.738 0	T01 WASP-12b 06:30:32.80 +29:40:20.26 11.600 0.000 0.000 8.97 06312367+29404647 06:29:51.57 +29:40:46.47 11.600 0.088 0.000 8.97 06312367+29441027 06:31:23.67 +29:44:10.27 11.595 0.060 -0.005 11.69 C02 06301692+29242914 06:30:16.92 +29:24:29.14 11.579 0.075 -0.021 16.22 C03 0630226+29444221 06:30:22.62 +29:44:2.1 11.672 0.084 0.072 4.89 C05 06291901+29405747 06:29:19.01 +29:40:57.47 11.687 0.082 0.087 16.04 06291322+29554133 06:29:13.22 +29:55:41.33 11.512 0.084 -0.088 23.10 06301214+29284998 06:30:12.14 +29:29:49:33.44 11.730 0.033 0.130 12.35 C06 06315779+29475840 06:31:57.79 +29:47:55.840 11.737 0.043 0.137 19.97 06320054+29291960 06:32:00.54 +29:29:1

Figure 5.4. Data table

The AAVSO Variable Start Plotter <u>https://app.aavso.org/vsp/</u> was used to select comparison stars of similar colour and identify any variables – Figures 5.5 and 5.6



Figure 5.5. AAVSO chart indicating variable stars

AUID	RA	Dec	Label	V	B-V	Comments
000-BKG-	06:30:47.77	29:35:30.4	95	9.453	0.499	
164	[97.69904327°]	[29.5917778°]		(0.038) ¹	(0.073)	
000-BKG-	06:31:09.51	29:47:47.8	97	9.747	0.665	
165	[97.78962708°]	[29.79661179°]		(0.045) ¹	(0.090)	
000-BKG-	06:30:39.80	29:37:40.5	105	10.508	0.977	
166	[97.66583252°]	[29.62791634°]		(0.113) ²⁹	(0.202)	
000-BKK-	06:30:16.17	29:33:45.1	109	10.941	1.155	
420	[97.56737518°]	[29.56252861°]		(0.058) ²⁹	(0.115)	
000-BMX-	06:30:22.63	29:44:42.1	117	11.728	0.523	
310	[97.59429169°]	[29.74502754°]		(0.058) ²⁹	(0.116)	
000-BKG-	06:30:31.88	29:42:27.3	122	12.244	0.699	
167	[97.63283539°]	[29.70758247°]		(0.062) ²⁹	(0.120)	
000-BKG-	06:31:08.10	29:41:52.8	127	12.748	1.085	
168	[97.78375244°]	[29.69799995°]		(0.084) ²⁹	(0.153)	

Figure 5.6. AAVSO list showing magnitude and colour

(B-V) colour and mag matches 0.4 < (B-V) < 0.7

Mag range in AIJ 10.9<11.4<11.9 (+/_0.5)

Check, using AIP4WIN, that target and comparison stars are not saturated

Manually compared AIJ selected comparison stars against Vizier/APASS and deselected those outside the B-V range above <u>https://vizier.cds.unistra.fr/viz-bin/VizieR</u> Checked that no comparison stars were variables using AAVSO data above.

Selected comparison stars are shown in Table 5.1 and will be stored as radec.txt in AstroImageJ

ID	RA	Dec	B-V	V
WASP-12b	06:30:32.80	+29:40:20.27	0.578	11.560
C2	06:30:22.62	+29:44:42.21	0.516	11.672
C3	06:30:20.00	+29:33:03.20	0.451	11.869
C4	06:31:32.18	+29:33:24.10	0.441	11.207
C5	06:29:19.01	+29:40:57.47	0.658	11.687
C6	06:30:16.92	+29:24:29.14	0.503	11.579
C7	06:31:57.79	+29:47:58.40	0.690	11.737

Table 5.1. Comparison stars

4.4. Run Science Image Reduction

CCD Data Processor window after set-up and prior to running image reduction is shown in Figure 5.7.

In this example only Dark frames are used as the MicroObservatory does not provide Flat fields.

Plate Solve (ANSVR) is not disabled as the MicroObservatory images are not plate solved.

To begin click 'Start' at the bottom of the CCD Data Processor window. This process takes some time – approx. 20 secs per image on my desktop PC

DP CCD Data Proc	cessor			o x
File Preferences	View			
Control Science Image	Options Processing	Directory Filename/Pattern		Totals
Enable	Sort Num	C:\AstrolAstroimageJ 5\AstroImageJ\WASP-12bl2024 Feb 04\Raw Science Files\ 🔰 WASP-12*.FITS		171
Filename Num	ber Filtering		7	171
Bias Subtractio	n	Cilástelásteirossa LEWACR42 CR 2042 04 26/0elikration Eilen		0
Enable	⊖ ave ⊚ med	C:\AstroWstroimageJ 5WASP12.SR.2013_01_20lCambradoil Pries\ m bias_fits	5	0
Dark Subtractio	on			
Build	🔾 ave 🔘 med	C:\Astro\AstroimageJ 5\AstroImageJ\WASP-12b\2024 Feb 04\Calibration Files\Darks\		10
🗹 Enable	🗹 scale 🗹 deBias	C:\Astro\AstroimageJ 5\AstroImageJ\WASP-12b\2024 Feb 04\Waster Calibration Files\		0
Flat Division				
Build	🔾 ave 🔘 med	C:\Astro\AstroimageJ 5\WASP-12b 2023 Jan 5\Calibration files\		0
Enable	Remove Gradient	C:\Astro\AstroimageJ 5\WASP-12b 2023 Jan 5\Master Calibration Files\		0
Image Correction	on earity Correction utliers 🗹 Bright 🗹	New pixel value = 0.0E0 ÷ + 1.0E0 ÷ × (PixVal) + 0.0E0 ÷ × (PixVal) ² + 0.0E0 ÷ × (PixVa	ixVal) ³	
FITS Header Up	dates			
🗹 General	Plate Solve	Target Coordinate Source Observatory Location Source Coordinate Converter manual entry	\sim	
Save Calibrated	i Images			
🗹 Enable	○ 16	Sub-dir. Reduced Science Files Suffix: _bdf Format Format	GZIP	
Post Processin	Ig			
🗌 М-Ар	Save Image	Macro 1 C:\Users\RogerDymock\		0
M-Plot	Save Plot	Macro 2 C:\Users\RogerDymock\		0
Control Panel				
Polling In	0	Set Start PAUSE RESET Proc.	essed: aining:	0 171

Figure 5.7 CCD Data Processor window prior to running image reduction

Plate Solving window and Log are shown in Figures 5.8 and 5.9



Figure 5.8. Plate Solving window

S Log — 🗆	×
File Edit Font	
	_
[2024-02-07T14:22:27.401] BJD(TDB) = 2460344.697602 (mid-exp) (correction = 7.5669 minute	es)
[2024-02-07T14:22:27.402] Altitude = 84.61 (mid-exp)	
[2024-02-07T14:22:27.402] Azimuth = 110.55 (mid-exp)	
[2024-02-07T14:22:27.403] Hour Angle = -0.39 (mid-exp)	
[2024-02-07T14:22:27.404] Zenith Distance = 5.39 (mid-exp)	
[2024-02-07T14:22:27.404] Airmass = 1.0044 (mid-exp)	
[2024-02-07T14:22:27.408] Dark corrected with m-dark.FITS	
[2024-02-07T14:22:27.656] Plate solve started	
[2024-02-07T14:22:49.633] Plate solve success	
[2024-02-07T14:22:49.719] Saved processed science file "C:\Astro\AstroimageJ 5\AstroImageJ\W	VAS
[2024-02-07T14:22:49.729] Loading science file "C:\Astro\AstroimageJ 5\AstroImageJ\WASP-12b\2	202
[2024-02-07T14:22:49.746] Observatory name "MicroObservatory" manually selected	
[2024-02-07T14:22:49.749] Target coordinates manually entered = 06:30:32.797 +29:40:20.26 (J2	200
[2024-02-07T14:22:49.754] JD = 2460344.694347 (mid-exp)	
[2024-02-07T14:22:49.756] HJD = 2460344.698814 (mid-exp) (correction = 6.4317 minutes)	
[2024-02-07T14:22:49.757] BJD(TDB) = 2460344.699602 (mid-exp) (correction = 7.5667 minute	es)
[2024-02-07T14:22:49.759] Altitude = 85.18 (mid-exp)	
[2024-02-07T14:22:49.759] Azimuth = 113.51 (mid-exp)	
[2024-02-07T14:22:49.760] Hour Angle = -0.34 (mid-exp)	
[2024-02-07T14:22:49.760] Zenith Distance = 4.82 (mid-exp)	
[2024-02-07T14:22:49.761] Airmass = 1.0035 (mid-exp)	
[2024-02-07T14:22:49.767] Dark corrected with m-dark.FITS	
[2024-02-07T14:22:49.952] Plate solve started	

Figure 5.9. Plate Solving Log

5.0. AstroImageJ Photometry

Key steps are (referring to <u>Workflow based Guide to using AstroImageJ for Exoplanet</u> <u>Transit Photometry</u>' by Richard Lee).

5.1. Import Image Stack

5.3. Photometry Measurement Apertures

The Seeing Profile window, Figure 5.10, displays the Source and Background apertures -4, 7 and 10 pixels respectively



Figure 5.10. Seeing Profile window.

5.3.2. Import radec apertures

Figure 5.11 shows an image overlaid with apertures indicating the target and comparison stars.



Figure 5.11 Target and comparison stars overlays

5.4. Run AIJ Photometry

When complete multiple windows are displayed. Select the Measurements Window and save the Measurements table (this can also be opened at a later date to process the data).

Unfortunately, the data for this observation was poor so, to save time and effort, the rest of this guide relates to WASP-43b imaged on 2023 April 8/9, mid-transit was at 2023 April 08, 20:28 Local/2023 April 09, 03:38 UT. Fortunately I had saved all the images and data relating to this observation. Some you lose and some you win!!! Moral of the story – always back up your images and data.

7.0 Transit Analysis in AstroImageJ

To obtain the observed transit times examine the first and last images (which are usually -/+

1hr of the transit ingress and egress). I use Astrometrica to do this and the times of the images were, 19:35 Local 2023 April 08/02:35 UT, April 09 and 22:03 2023 April 08 Local/05:03 April 09 UT.

Predicted transit times can be obtained using the Exo Worlds Spies Transit Scheduler <u>https://www.exoworldsspies.com/en/scheduler/</u> - Figure 5.12, second line.

Planet	Star		Transit		Observing times [UTC-7.0] and target position					
	RA/DEC J2000	R _{mag} mag	Depth I mmag	Duration hours	1h Before Ingress	Transit Start	Mid Transit	Transit End	1h After Egress	
WASP-43b ExoClock Priority: LOW Min. aperture: 5.85"	10:19:38.0089 -09:48:22.603	12.08	29.73	1.23	2023/04/08 18:51 33° SE	2023/04/08 19:51 41° SE	2023/04/08 20:28 45° SE	2023/04/08 21:05 48° S	2023/04/08 22:05 48° S	
WASP-43b ExoClock Priority: LOW Min. aperture: 5.85"	10:19:38.0089 -09:48:22.603	12.08	29.73	1.23	2023/04/12 20:28 46° S	2023/04/12 21:28 48° S	2023/04/12 22:05 47° S	2023/04/12 22:42 44° SW	2023/04/12 23:42 36° SW	

Figure 5.12 Predicted transit times

Useful date conversion websites;

AAVSO JD calculator <u>https://www.aavso.org/jd-calculator</u>

UT - BJD conversion https://astroutils.astronomy.osu.edu/time/utc2bjd.html

UT – HJD conversion <u>https://britastro.org/computing/applets_dt.html</u>

Note – the predicted local transit times for the MicroObservatory are UT-7 so; Transit start is 2023 April 08. 19:51 Local/2023 April 09, 02:51 UT, JD 2460043.61875 Transit end is 2023 April 09, 21:05 Local/2023 April 09, 04:05 UT, JD 2460043.67014 The JD dates and times were calculated using the AAVSO JD calculator;

The Transit Duration is given as 1.23 hrs on the <u>ExoClock Database</u> and shown in Figure 5.12.

In Multi-plot Main window enter;

- Transit Start and End dates (decimal portion) in Fit and Normalise Region Selection

- At top right click Copy arrows to import dates

- In Default X-data select JD_UTC

- In X Axis Scaling

- check Custom X-range

- set X-min to transit ingress -1 hr, 01:51 UT, 2460043.57708

Note this was altered to 2460043.6 due to imaging starting later

- set X-max to transit egress +1 hr, 05:05 UT, 2460043.71181

- after making any changes click Redraw Plot under Other Panels

To invert the Y-axis to show the transit light curve in its usual format, Figure 5.14, select Y-axis from the bar at the top of the window and uncheck 'invert Y-axis'

In Multi-plot Y data window;

- select JD_UTC in row 2 in the X-data column

See A Practical Guide to Exoplanet Observing by Denis M. Conti at <u>https://astrodennis.com/Guide.pdf</u> section 7.6 and on for Model Fit guide

In Data Set 2 Fit Settings window – Figure 5.13 (on completion) - enter value in R*(Rsun) box – 0.6629471 obtained from https://exoplanetarchive.ipac.caltech.edu/overview/WASP-43b

 - enter Linear and Quad values of 0.74987325 and 0.040338549 obtained from <u>https://astroutils.astronomy.osu.edu/exofast/limbdark.shtml</u> in Priors Center column and check Lock

- enter orbital period of 0.81347 obtained from

https://exoplanetarchive.ipac.caltech.edu/overview/WASP-43b#planet_WASP-43b_collapsible

Detrend Parameters

- select start under Detrend Parameter Selection for automatic selection

The Data Set 2 Fit Settings window, Figure 5.13, shows the calculated Parameters and figure 5.14 the resulting transit light-curve.

💶 Data Set 2 Fit Settings						– 🗆 X
File Auto Priors						
Here Constitut Demonstra	- (rel_flux_T1				
User Specified Parameters (not fitted) Orbital Parameters Period (days) Cir Ecc ω (deg) Sp.T. Teff (k) J-K R* (Rsun) M* (Msun) p^* (cgs) 0.81347 ω 0.0 ω 0.0 ω 4083 0.777 0.663 0.594 2.809 ω						
Transit Parameters						
Enable Transit Fit	Auto Update Priors	Extract Prior Center	Values From Li	ight Curve, Orbit, and	Fit Markers	s
Parameter	Best Fit Lo	ock Prior Center	Use	Prior Width	Cust	StepSize
Baseline Flux (Raw)	0.271808903 🕏	0.272132917 🛓		0.054426583 💂		0.1 🚔
$(R_{p} / R_{*})^{2}$	0.016625459	0.020946345		0.010473172		0.020946345 💂
a / R _*	7.055235231 🖨	5.805910953		2.0 🔺		1.0 🔺
Т _с	2460043.643384621 🕏 🛛	2460043.644445 🔺		0.04 🔺		0.04
Inclination (deg)	89.243639974 🕏	83.6		1.0 🔺		1.0 🔺
Linear LD u1	0.749873250 🕏	0.74987325 🜩		0.3 💂		0.27 🛓
Quad LD u2	0.040338549 🔷 🗟	0.040338549 🛓		0.3 💂		0.040338549 🛓
Calculated from model	Depth (ppt) b	t14 (d) t14 (hm	s) t23	(d)tau (d)	ρ*	(cgs) — — Rp (Rjup) —
	22.22	00:59:4	0.03	0.004802	10.0	0.83
Detrend Parameters	Best Fit Lo	ck Prior Center	lise	Prior Width	Cust	StenSize
AIRMASS V		0.0		0.0001		0.1
 עדנ		0.0		1.0		0.1
		0.0		1.0 +		0.1 🔷
Fit Statistics						
Fit Statistics	-RMS (ppt) 7.600306	- chi²/dof BI 1.570632 100.2	C 2290	-dof 51	8	chi²
Fit Optimization Outlier Removal Φ Clean N × σ: 4 0	Comparison Star S Quick Optimize Iter. Remaining:	Selection Start Max Det N/A Min. B	rrend Pars.: IC Thres.:	Detrend Parameter	Selection stive Optin er. Remain	nize V Start ing: 0
Plot Settings						
Show Model	Show in legend	Line Width	🗌 Log Op	timization		
Show Residuals	Show Error red	ine Color Line Width 2	Circle	ol — Symbol Co v red		-0.025
s 🖬 🥫 📼	<u>b</u> 🗘 🚾	N 🔁 🔯				

Figure 5.13 Data Set 2 Fit Settings



Figure 5.14. WASP-43b transit light curve

6.0 Uploading results to the Exoplanet Transit Database (ETD)

6.1 Accessing the database

The home page is at <u>http://var2.astro.cz/ETD/archive.php</u> and you will need to log in or register – button top left of page

From there click on 'How to contribute to ETD'

Select Method 2, Submit your observation to TRESCA Database and click on 'on-line protocol'.

Complete input data as shown in Figure 6.1. The data file needs to be a text file of three columns, Heliocentric Julian Date HJD), Magnitude and Error in text format extracted from the AstoImageJ Measurements table for WASP-43b.

His can be done by importing the Measurements table in to Excel, deleting all but the required columns and saving those as a Text (Tab delimited) file



Figure 6.1. TRESCA input for WASP-43b

On the next page, Figure 6.2, click 'Compute' and then 'Send protocol to Tresca database'

You will also need to provide an image of the field of view, Figure 6.3.



Figure 6.2. TRESCA input page



Figure 6.3 WASP-43b Field of View

On the TRESCA Project – Exoplanets page select Send Transit Observation to database etc. and your data will be uploaded – Figure 6.4



Figure 6.4. TRESCA database entry for WASP-43b

Figure 6.5 shows the transit times (O-C) for WASP-43b. Very stable as you can see.



7.0 MicroObservatory data

Telescope	
Name;	Cecilia
Туре;	5.25", f/3.6, 152mm Maksutov reflector
Focal length	550 mm
Camera;	KAF 1402ME, 1317x1035 binned 2x2 to 650 x 500 pixels
ADUs	12 bit CCD therefore max ADU is 4096 (Note 2)
Pixel size	6.8x6.8 microns binned 2x2 to 13.6x13.6 microns
Plate scale	5.17"/pixel
Image size	56' wide x 43' high
Filter;	Clear
Note	Image FITS header states 16 bit as 12 bit is not a valid parameter
Location	
Whipple Observatory;	Lat 31.68N (+31 40 48N), Long -110.88 (110.88, 110 52 48W)
Time Zone;	-7