Remotely operated robotic telescopes – the MicroObservatory Robotic Telescope Network

Updated 2024 February 17

Please note that w**hile 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 Exoplanet Transit Database (ETD)
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

Contents

1.0 Introduction

This project is identified as; **EXPLOIT 103 – MicroObservatory Robotic Telescope** on the EXoPLanet Orbit REsearch (EXPLORE) webpage 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

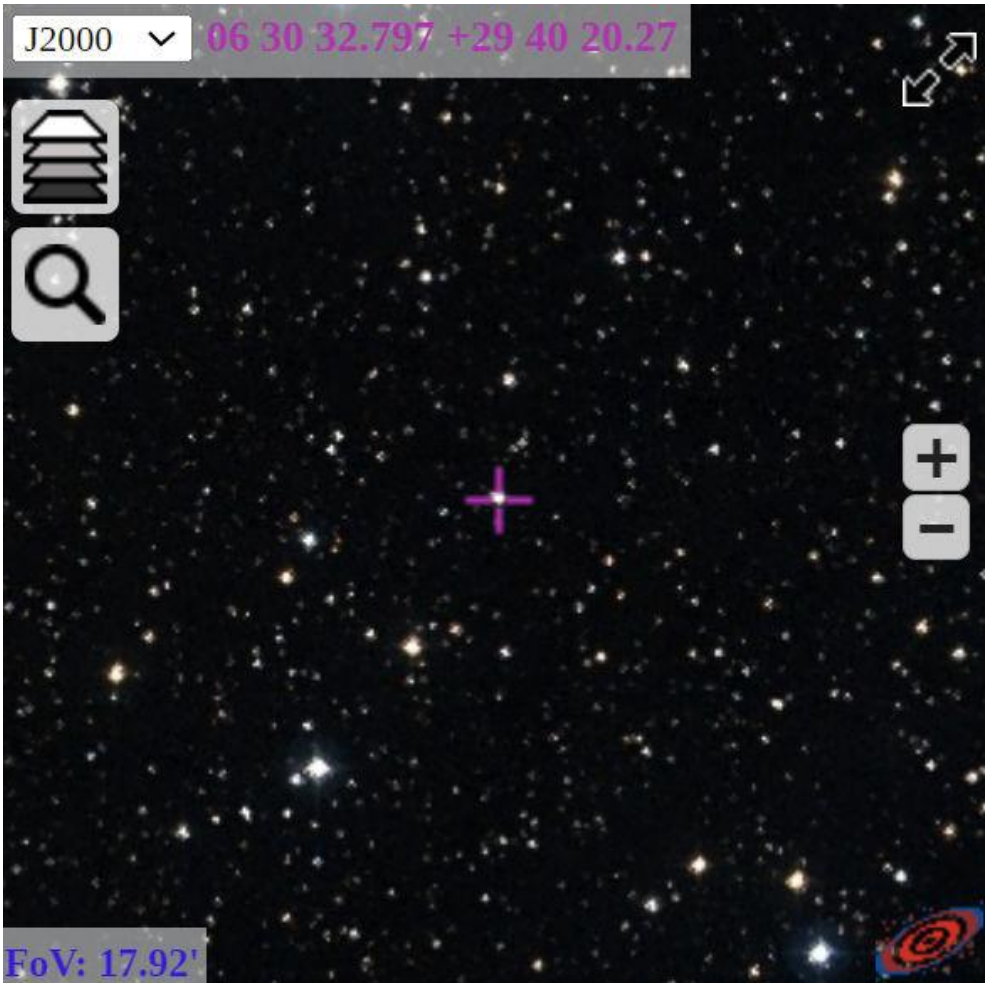


Figure 1.1 WASP-12b finder chart Credit ExoClock

WASP-12b data can be found on the exoplanets.org website here. 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 Harvard and Smithsonian Center for Astrophysics and can be found here. 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

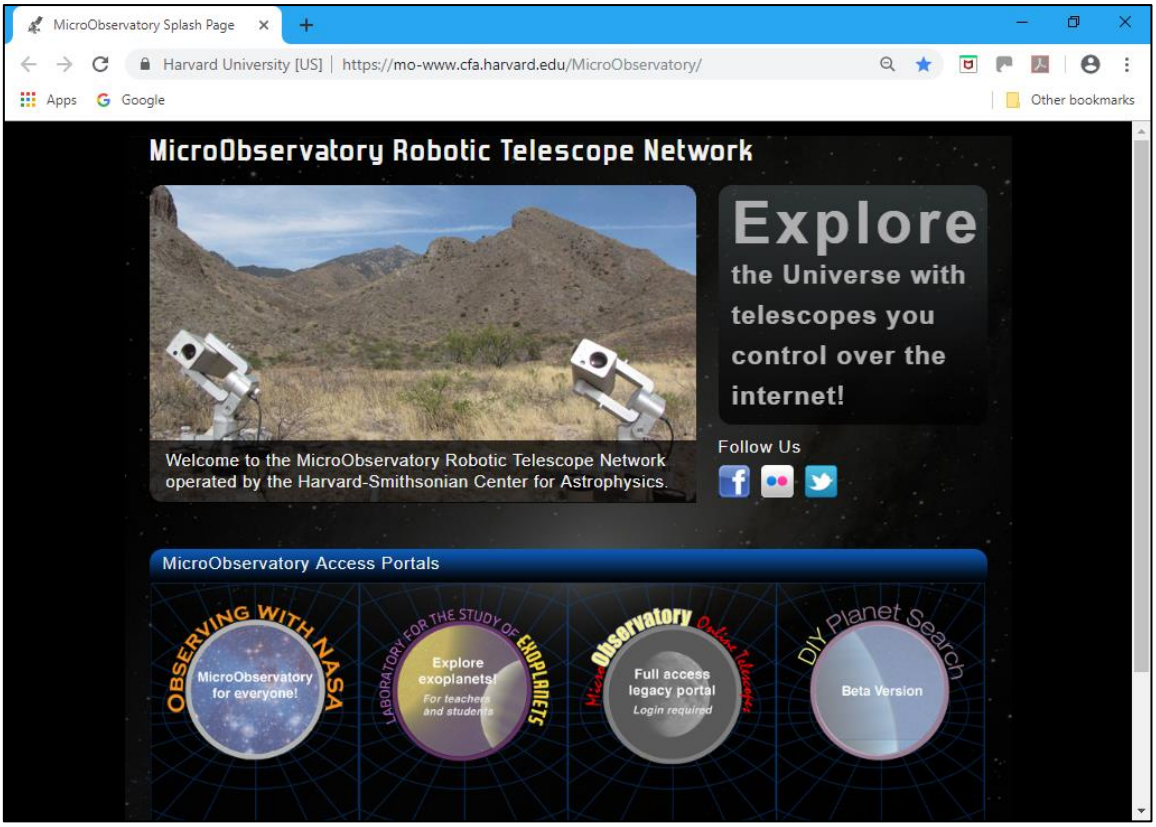


Figure 2.1 Robotic telescope home page.

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

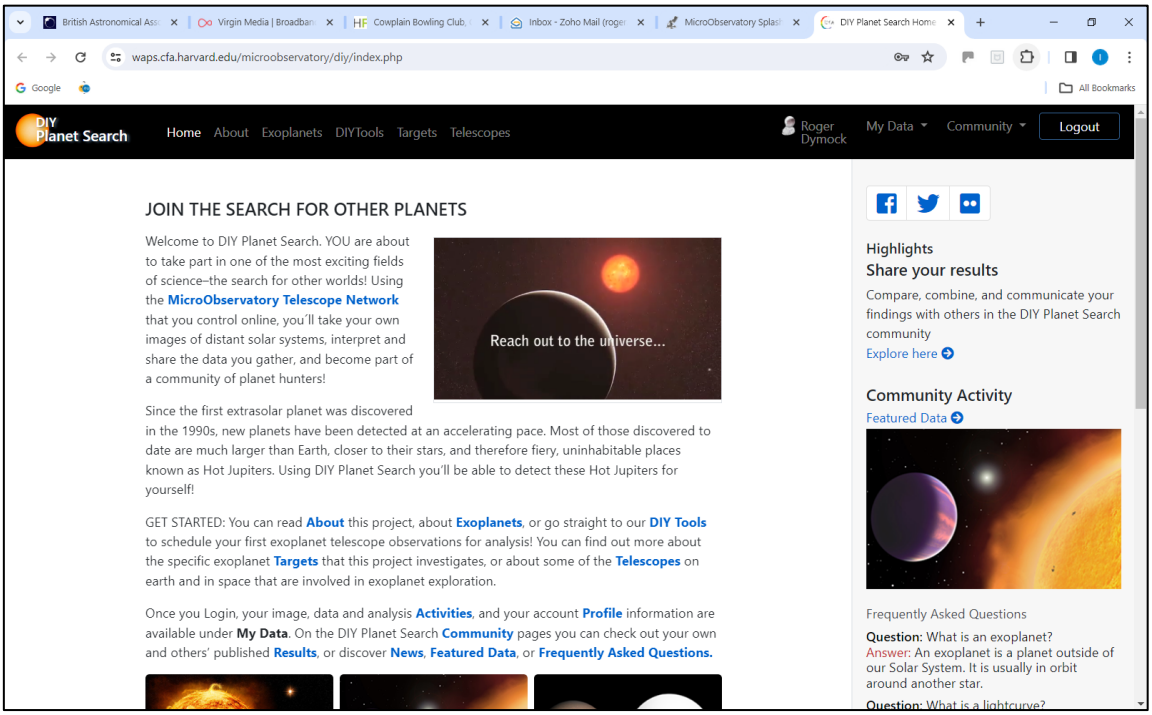


Figure 2.2. Log in/Register screen

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.

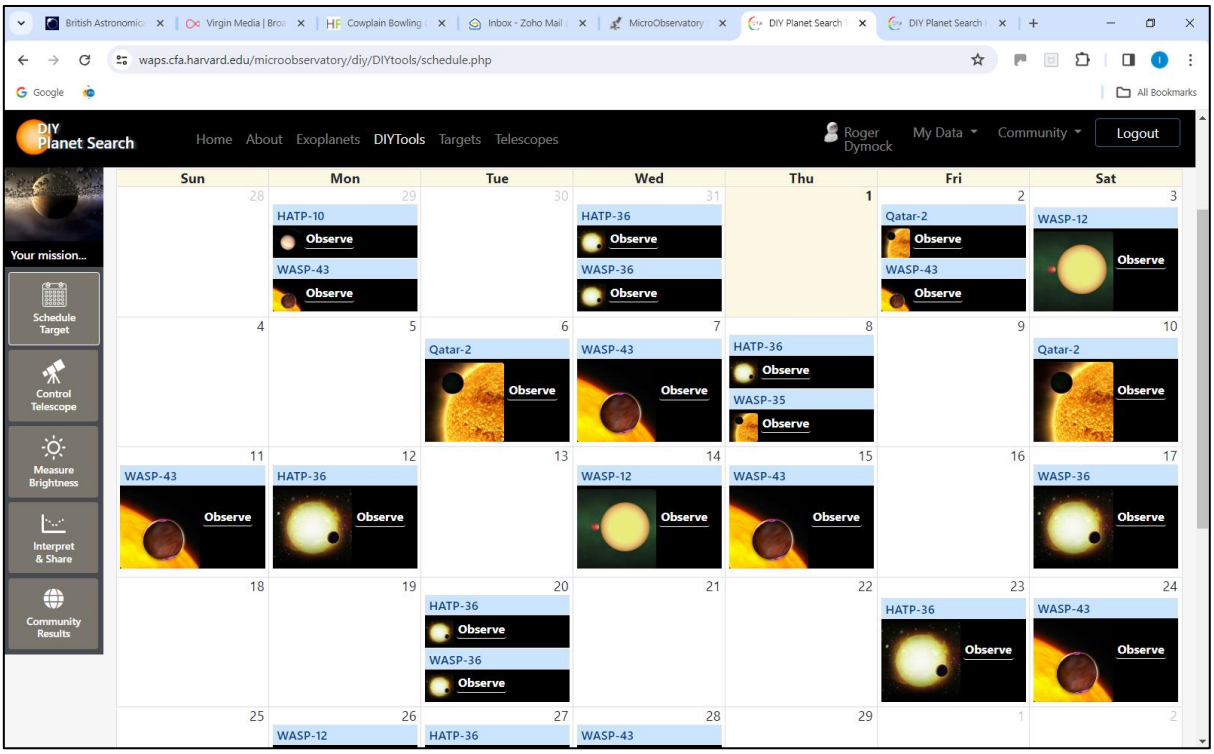


Figure 3.1. Targets for current month

WASP-12 was selected on February 3rd and 14th. 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.

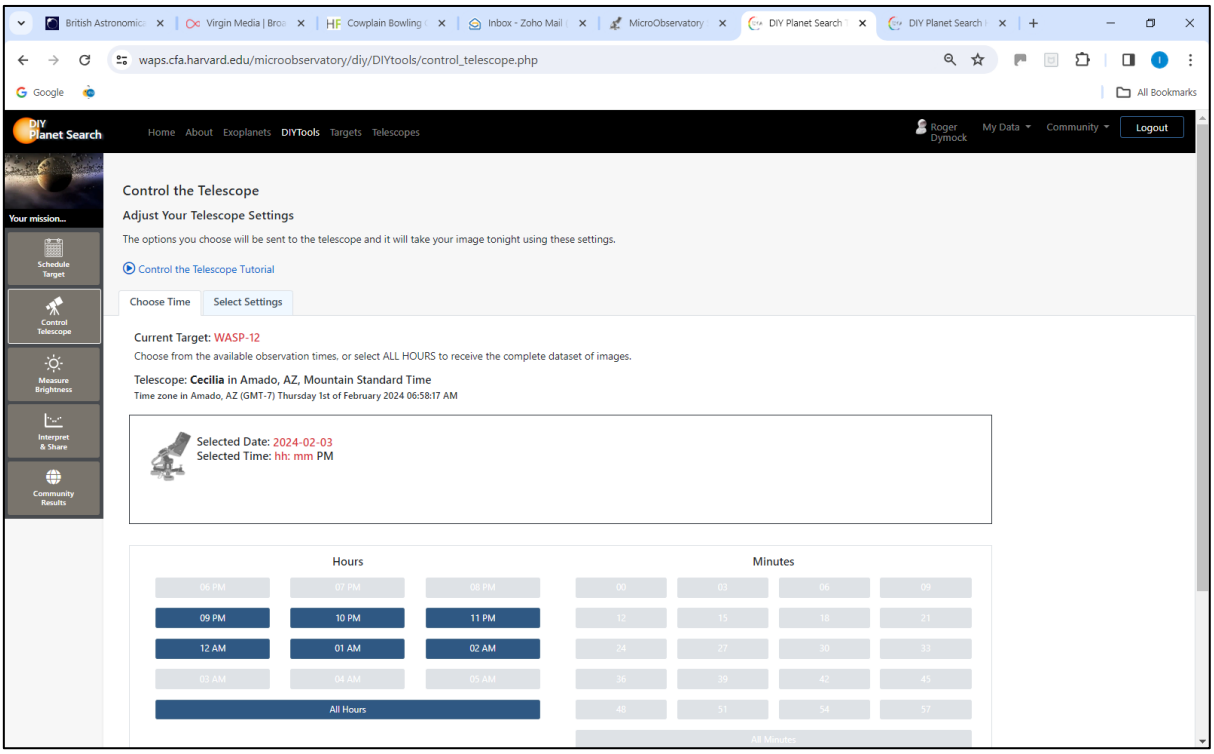


Figure 3.2. Control the Telescope

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).

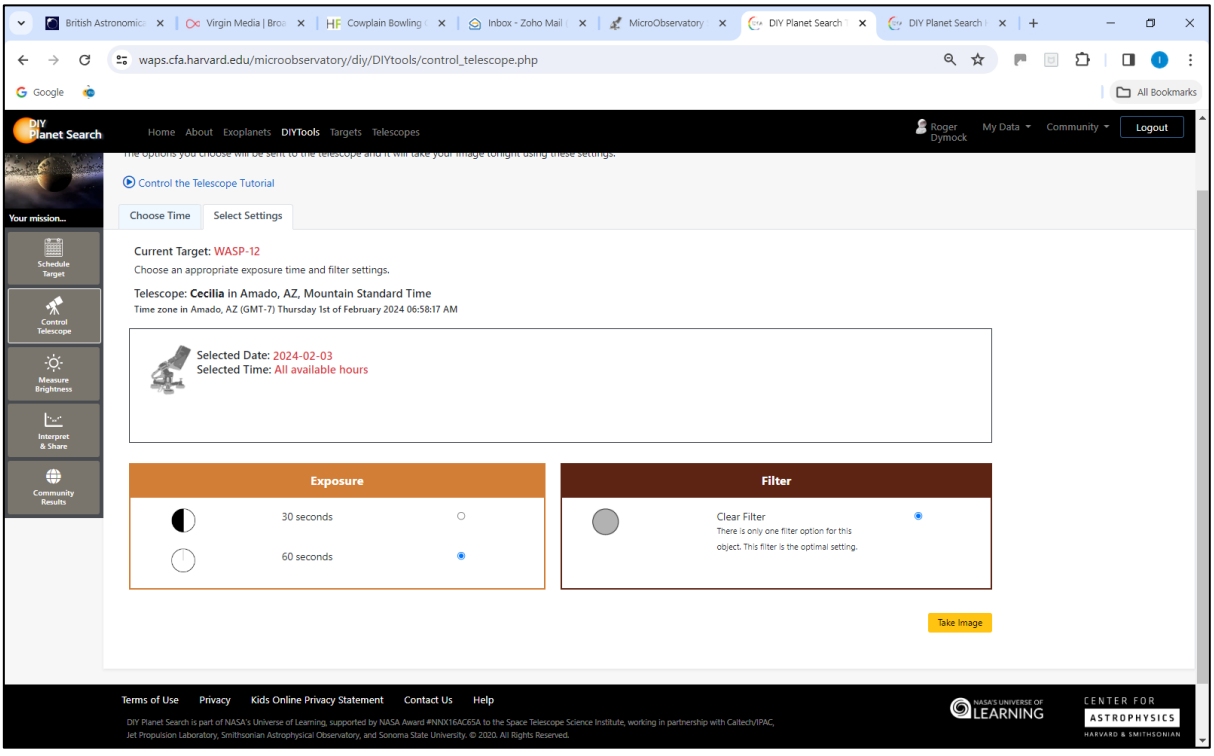


Figure 3.3. DIY Tools page ‘Select Settings’ tab.

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.

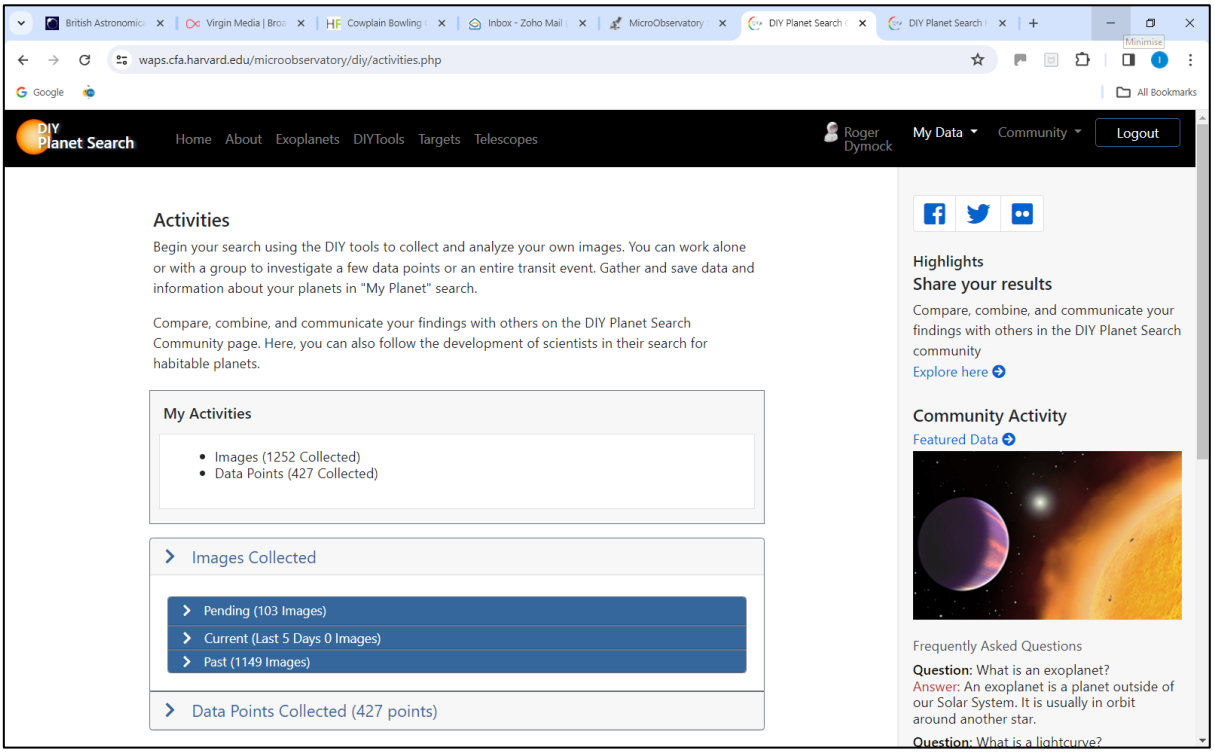


Figure 3.4. Activity status page.

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 (http://mo-www.cfa.harvard.edu/MicroObservatoryLegacy/ControlCenter/index.html) – Figure 4.1

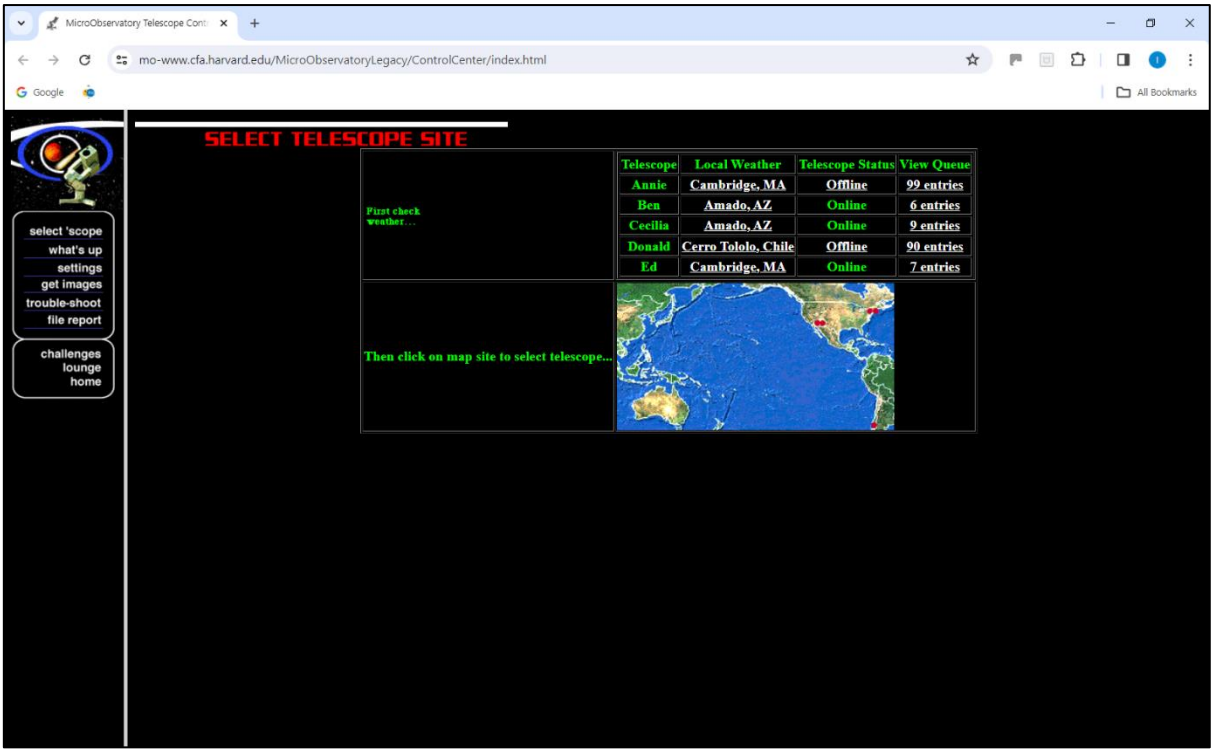


Figure 4.1. Control center

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.

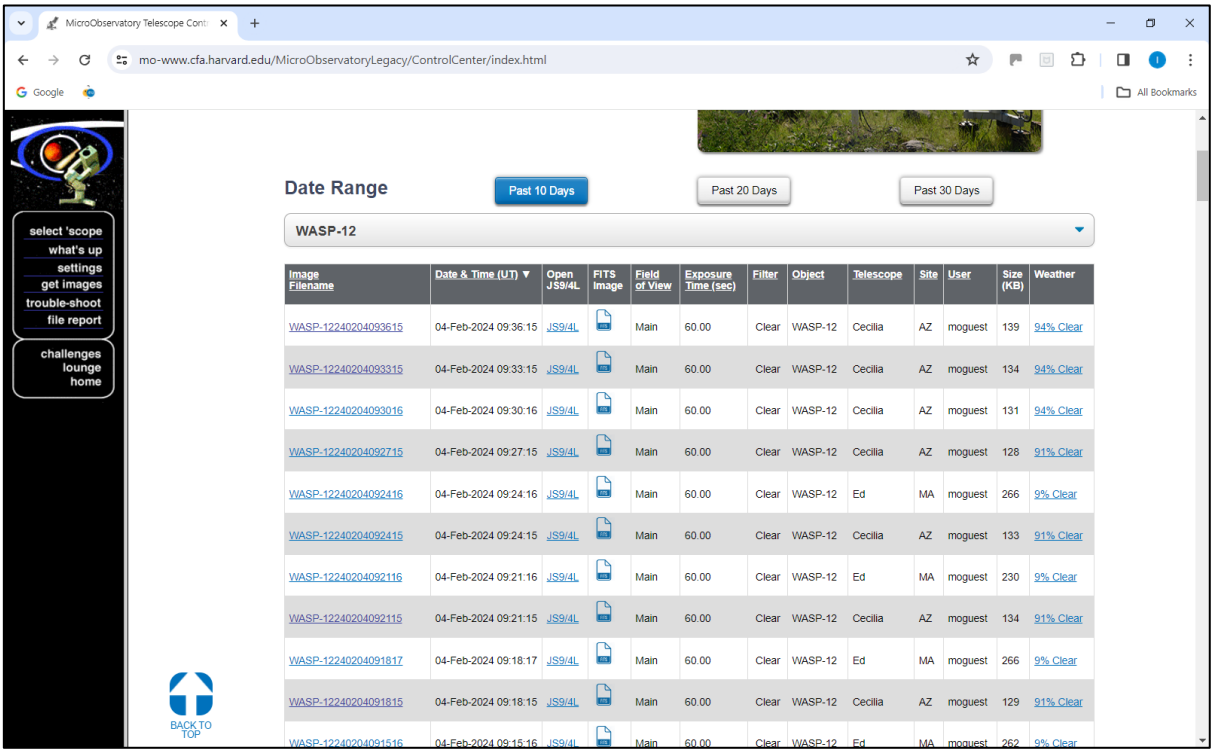


Figure 4.2. Image list

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.

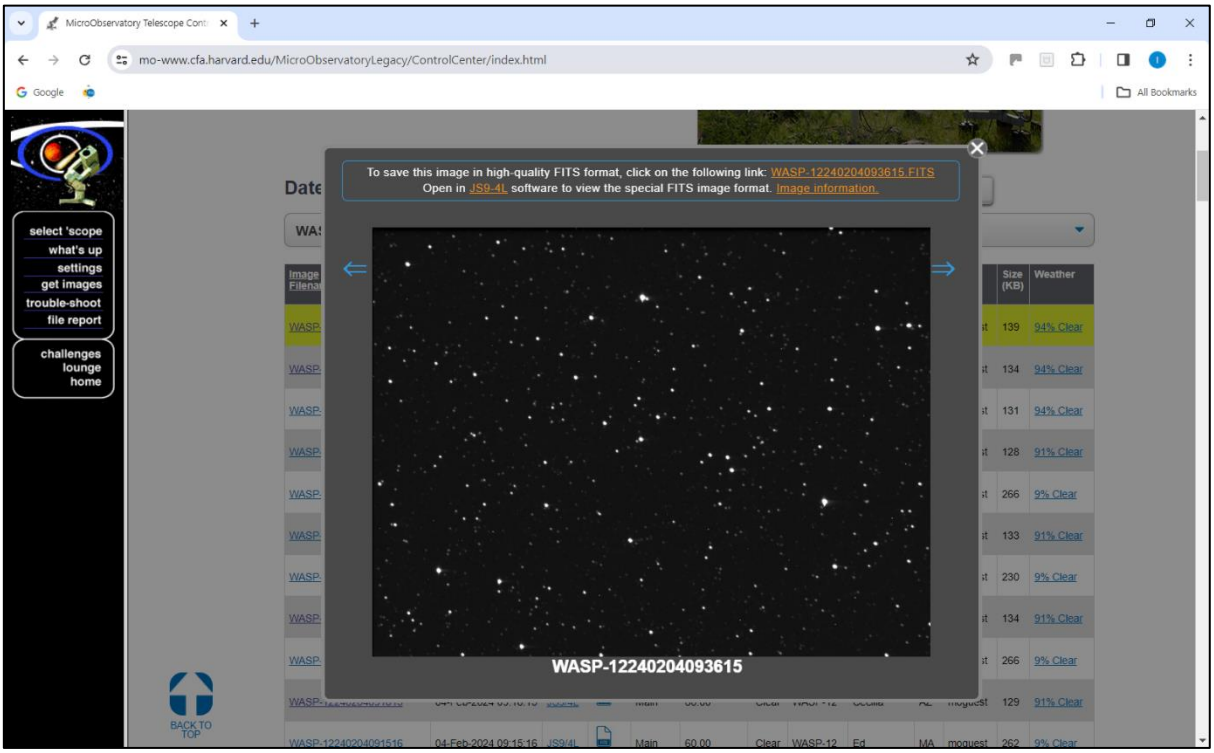


Figure 4.3. FITS image

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 'Workflow based Guide to using AstroImageJ for Exoplanet Transit Photometry' 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

MicroObservatory 31.68 -110.88 1268

In the DP Coordinates Converter window select MicroObservatory in the Observatory ID drop down and set the Time Zone UTC Offset to -7
Set;

Gain (e/ADU)	53.6
Readout noise	15 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

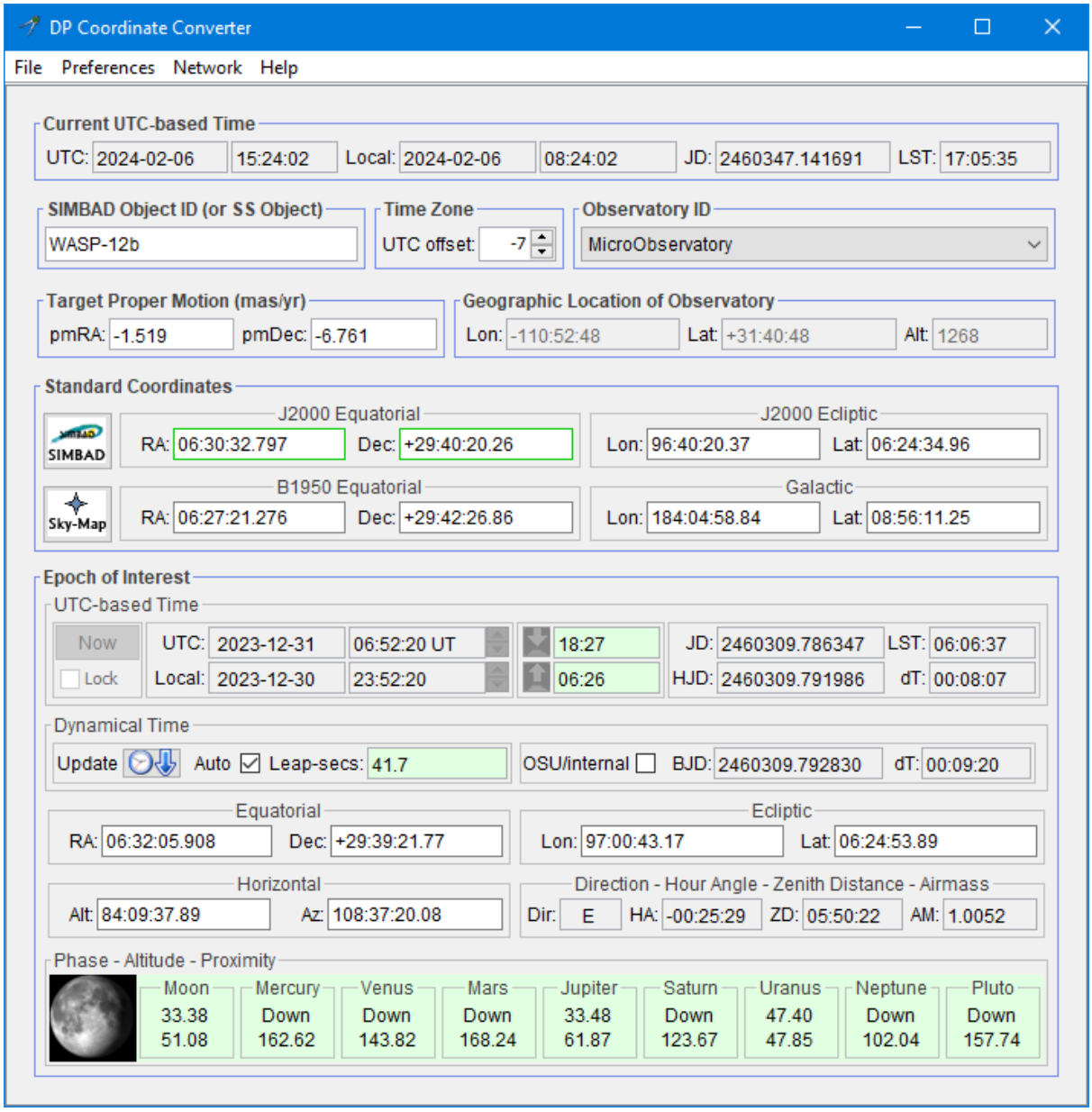


Figure 5.1 Selection of MicroObservatory and Time zone

3.2.2 Input Observer and Equipment Details in the Observation Planner

Select Plugins/AstroApps/Run 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 boxes
Pixel Size (arcsec) 5.1, 5.1
Field-of-View (arcmin) 55.25,42.5

Click on Save

Target Tab
Catalogue Query 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

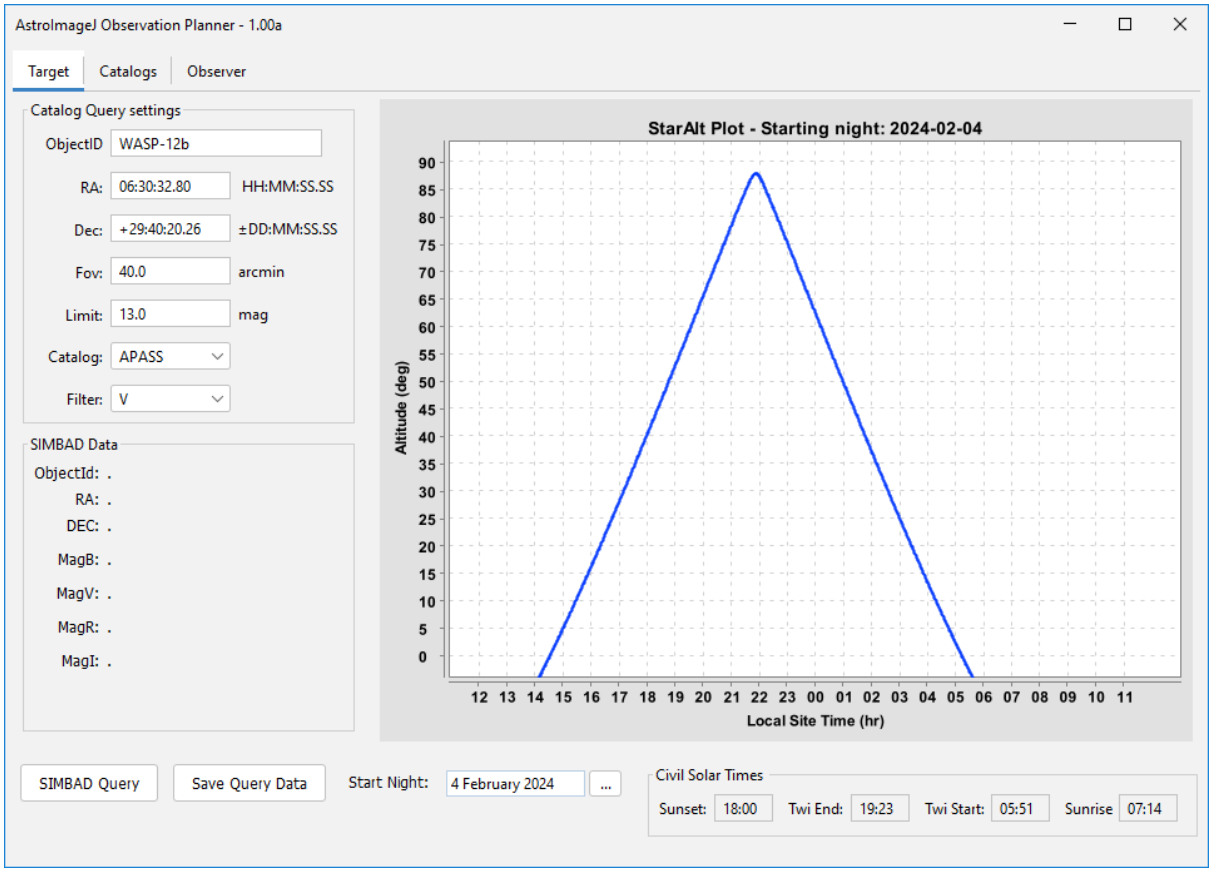


Figure 5.2. Target data for WASP-12b

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 https://app.aavso.org/vsp/ - 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

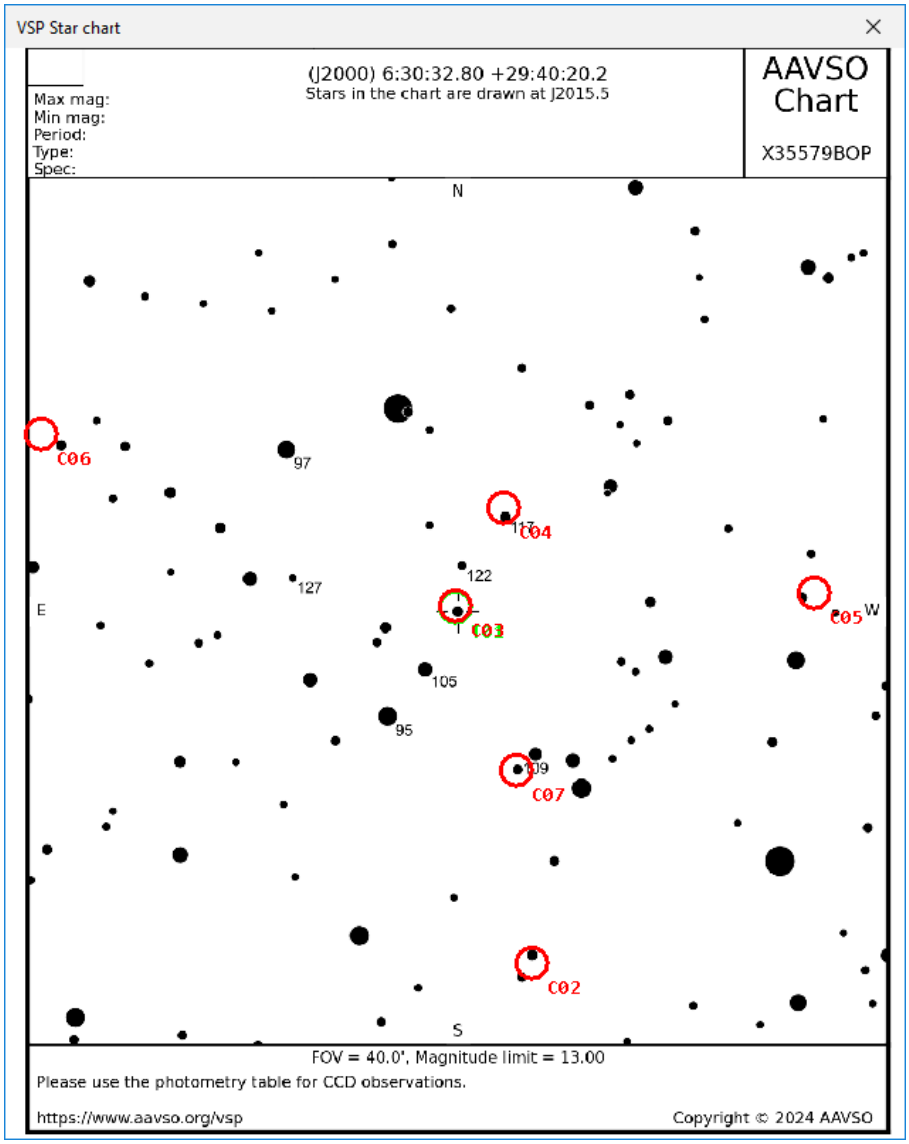
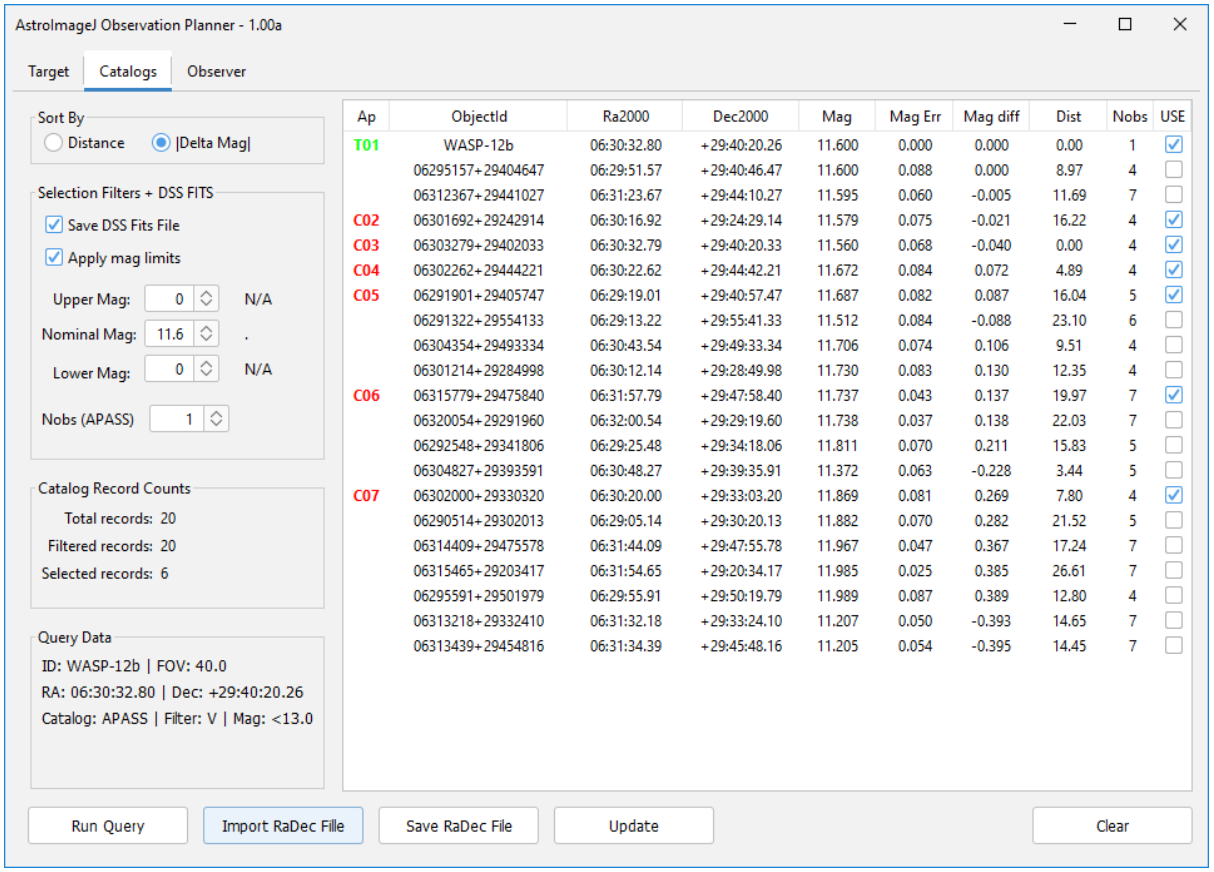


Figure 5.3 AAVSO chart



Ap	ObjectId	Ra2000	Dec2000	Mag	Mag Err	Mag diff	Dist	Nobs	USE
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	☐

Figure 5.4. Data table

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

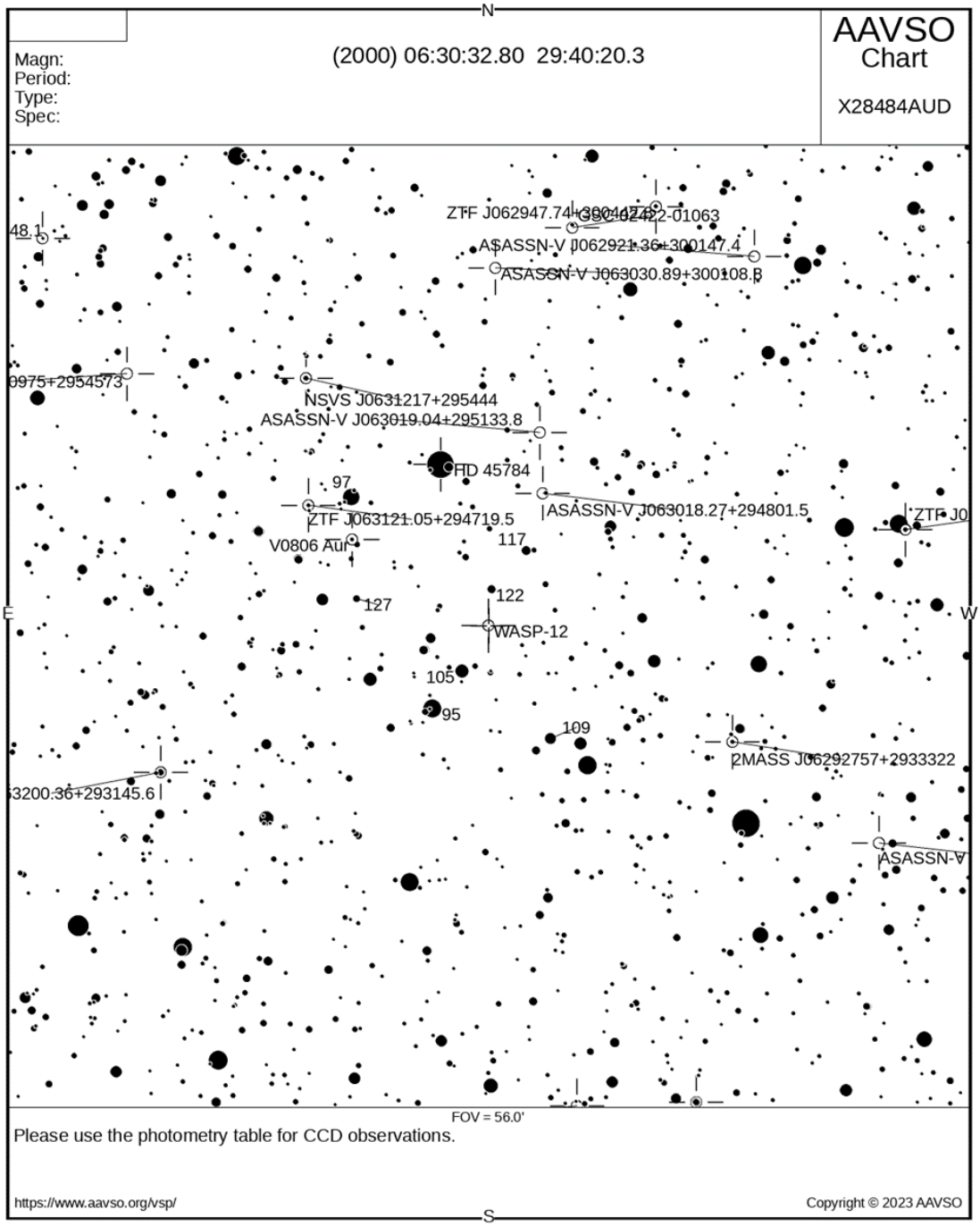
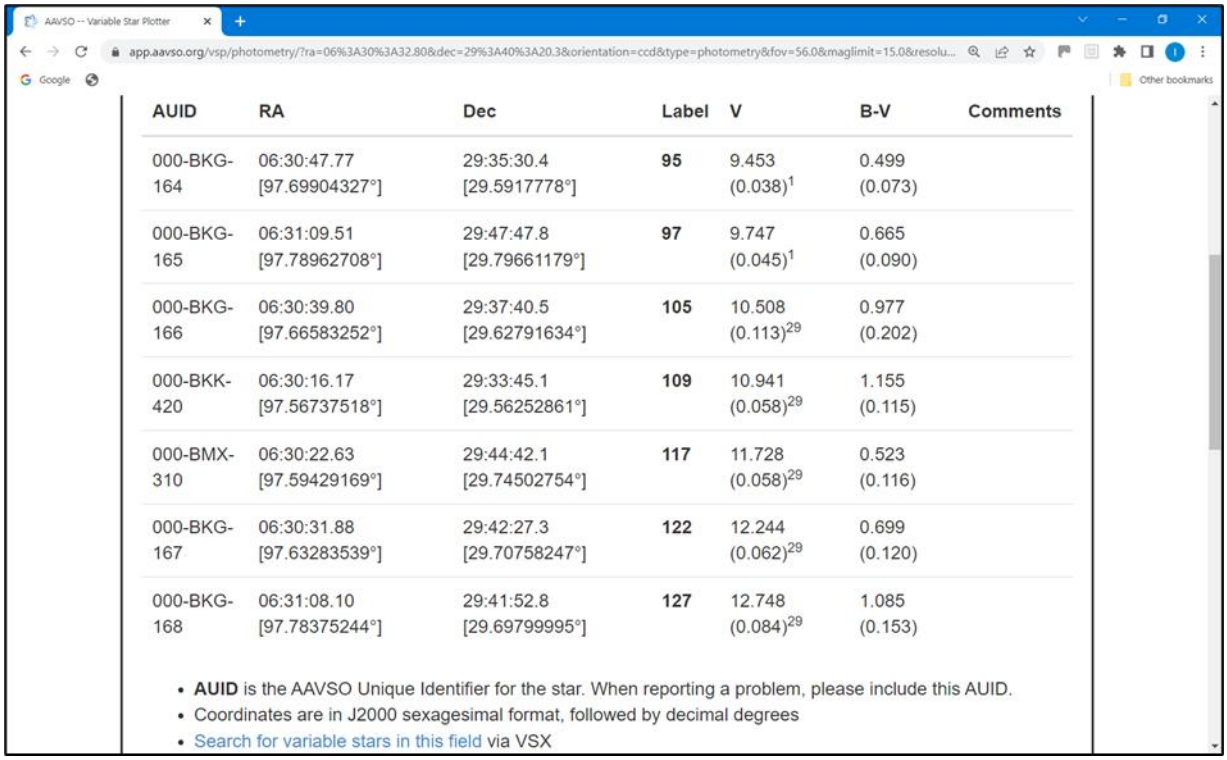


Figure 5.5. AAVSO chart indicating variable stars



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

- **AUID** is the AAVSO Unique Identifier for the star. When reporting a problem, please include this AUID.
- Coordinates are in J2000 sexagesimal format, followed by decimal degrees
- Search for variable stars in this field via VSX

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 https://vizier.cds.unistra.fr/viz-bin/VizieR
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

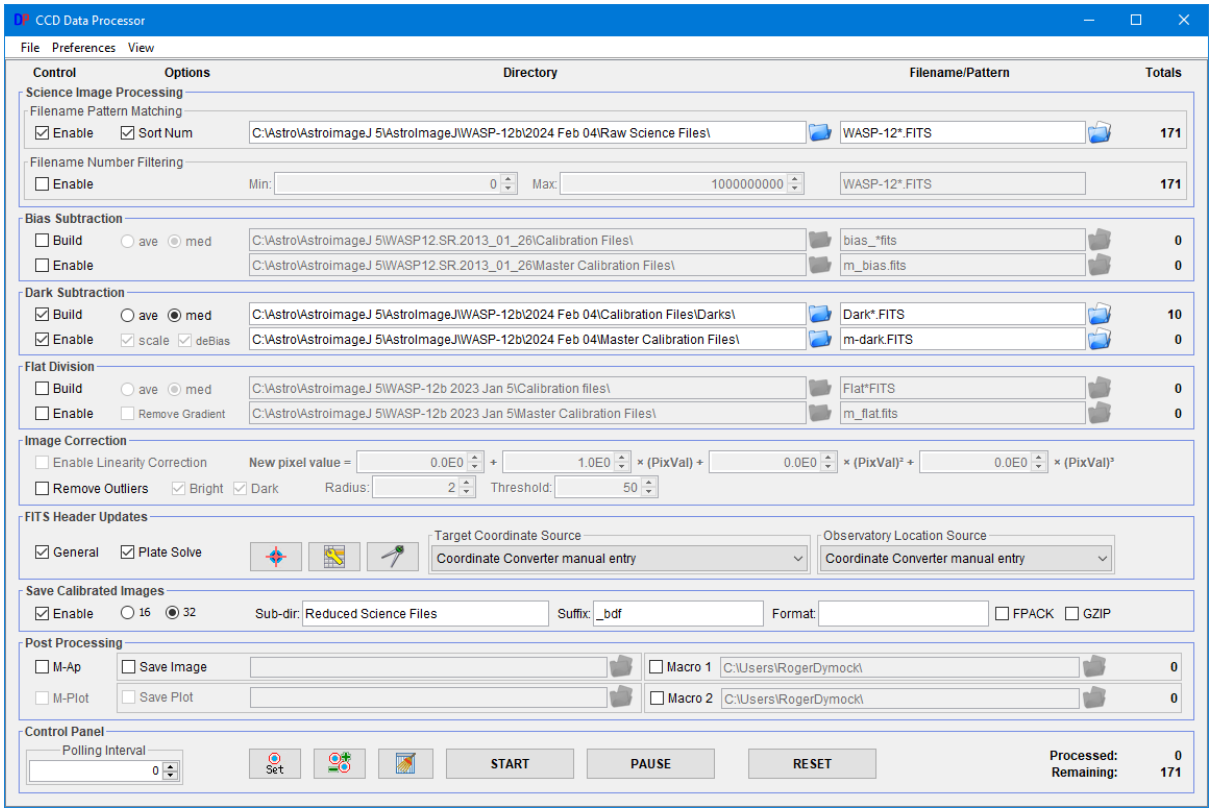


Figure 5.7 CCD Data Processor window prior to running image reduction

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

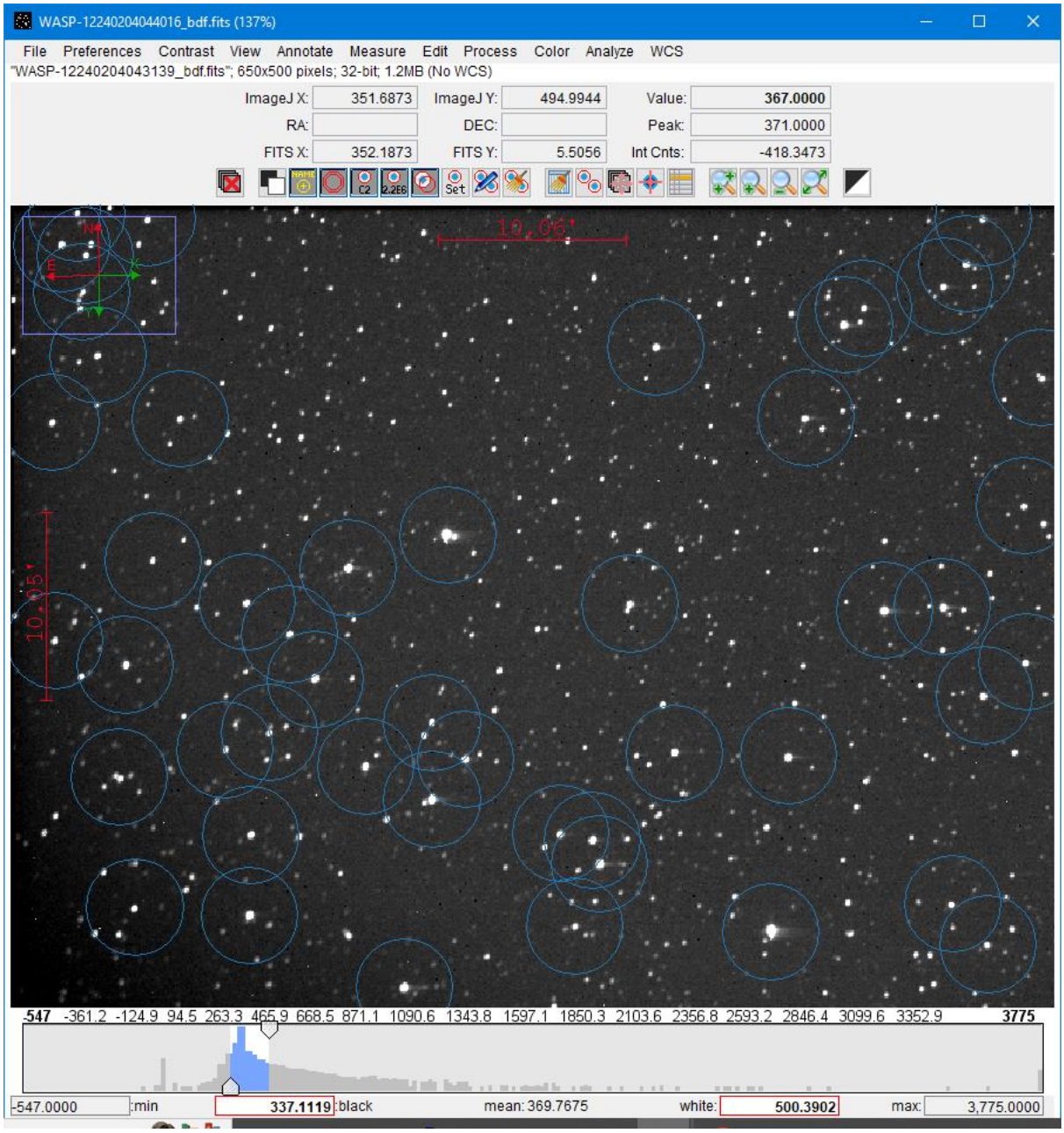


Figure 5.8. Plate Solving window

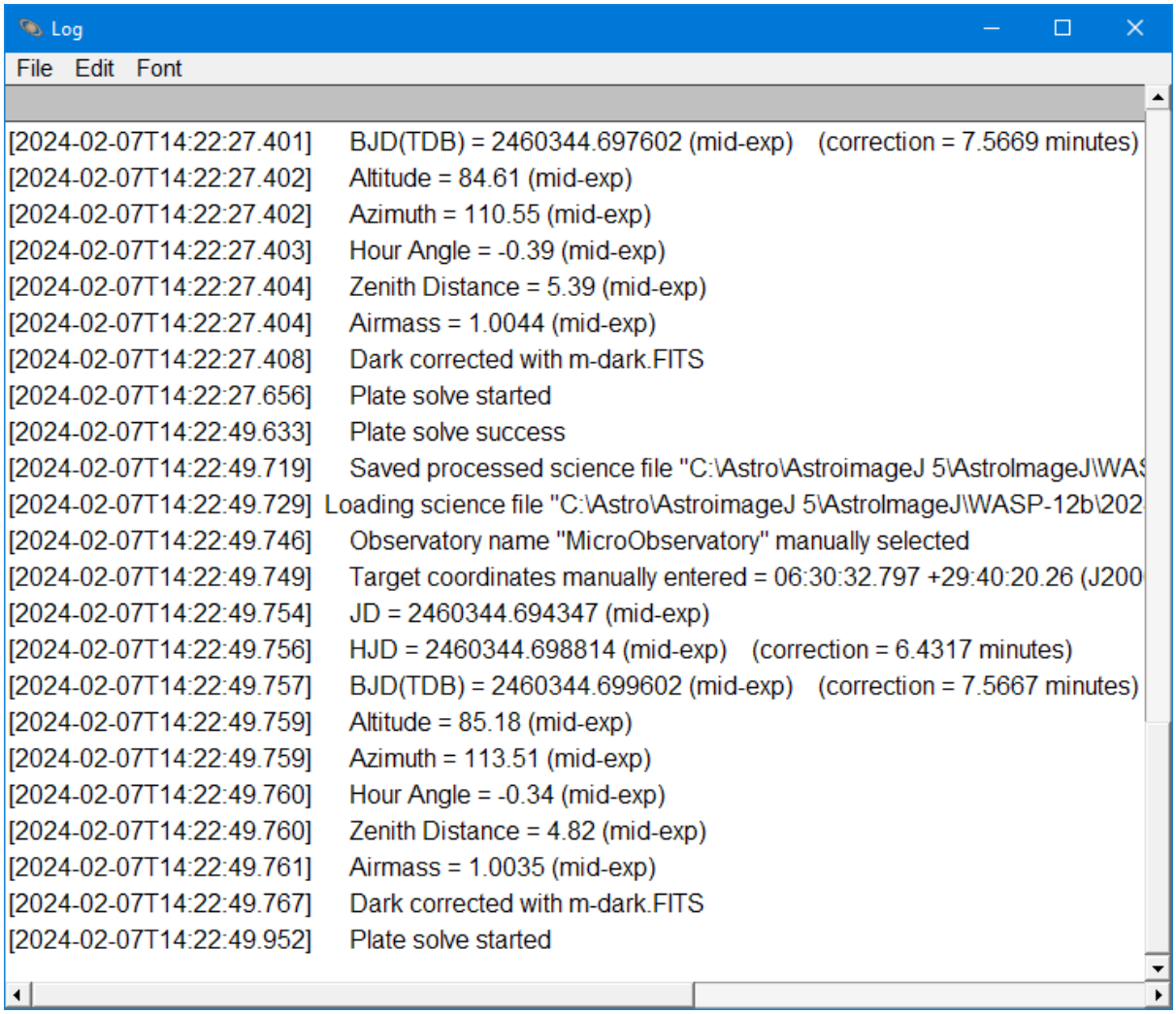


Figure 5.9. Plate Solving Log

5.0. AstroImageJ Photometry
Key steps are (referring to 'Workflow based Guide to using AstroImageJ for Exoplanet Transit Photometry' 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

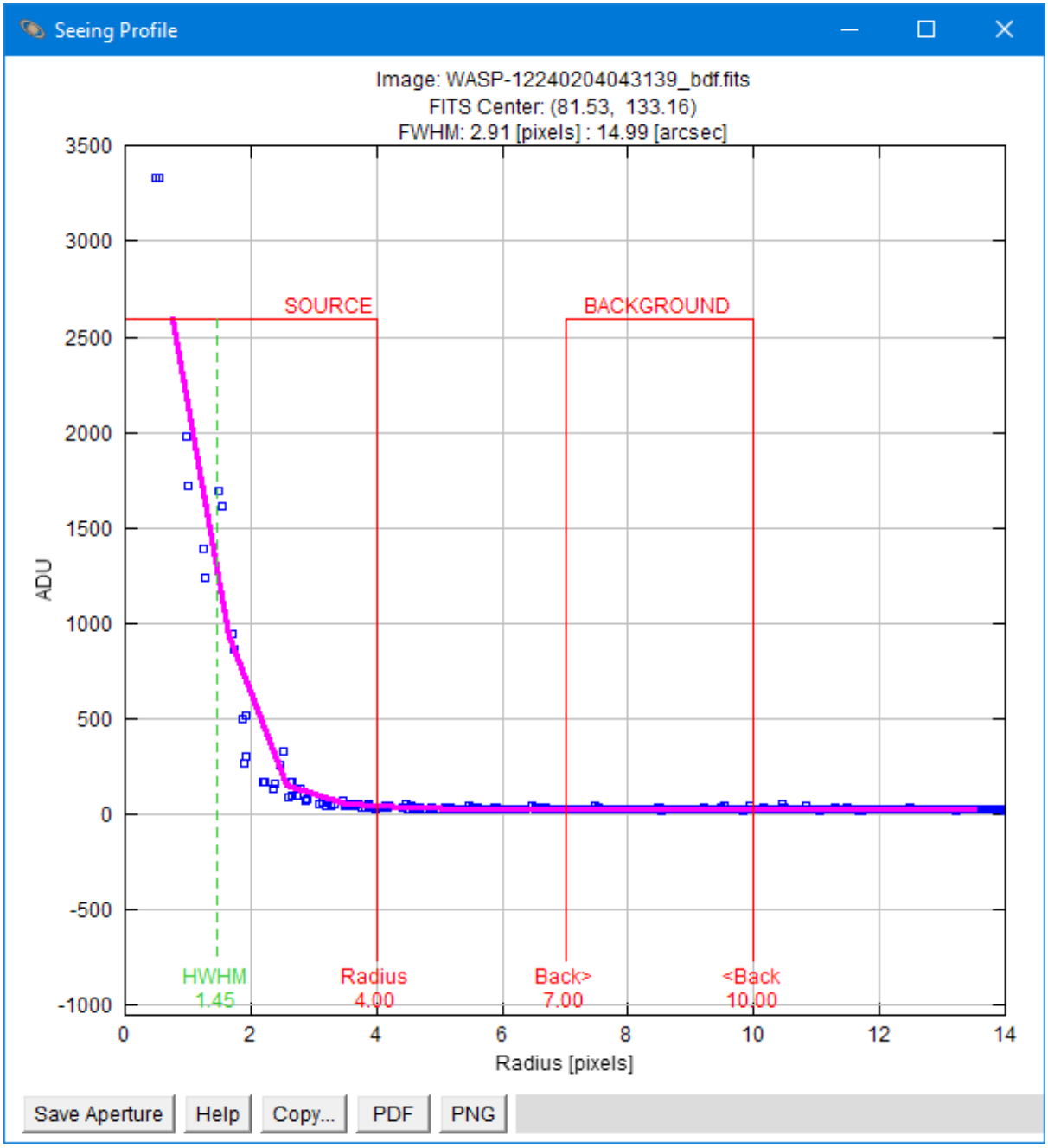


Figure 5.10. Seeing Profile window.

5.3.2. Import radec apertures

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

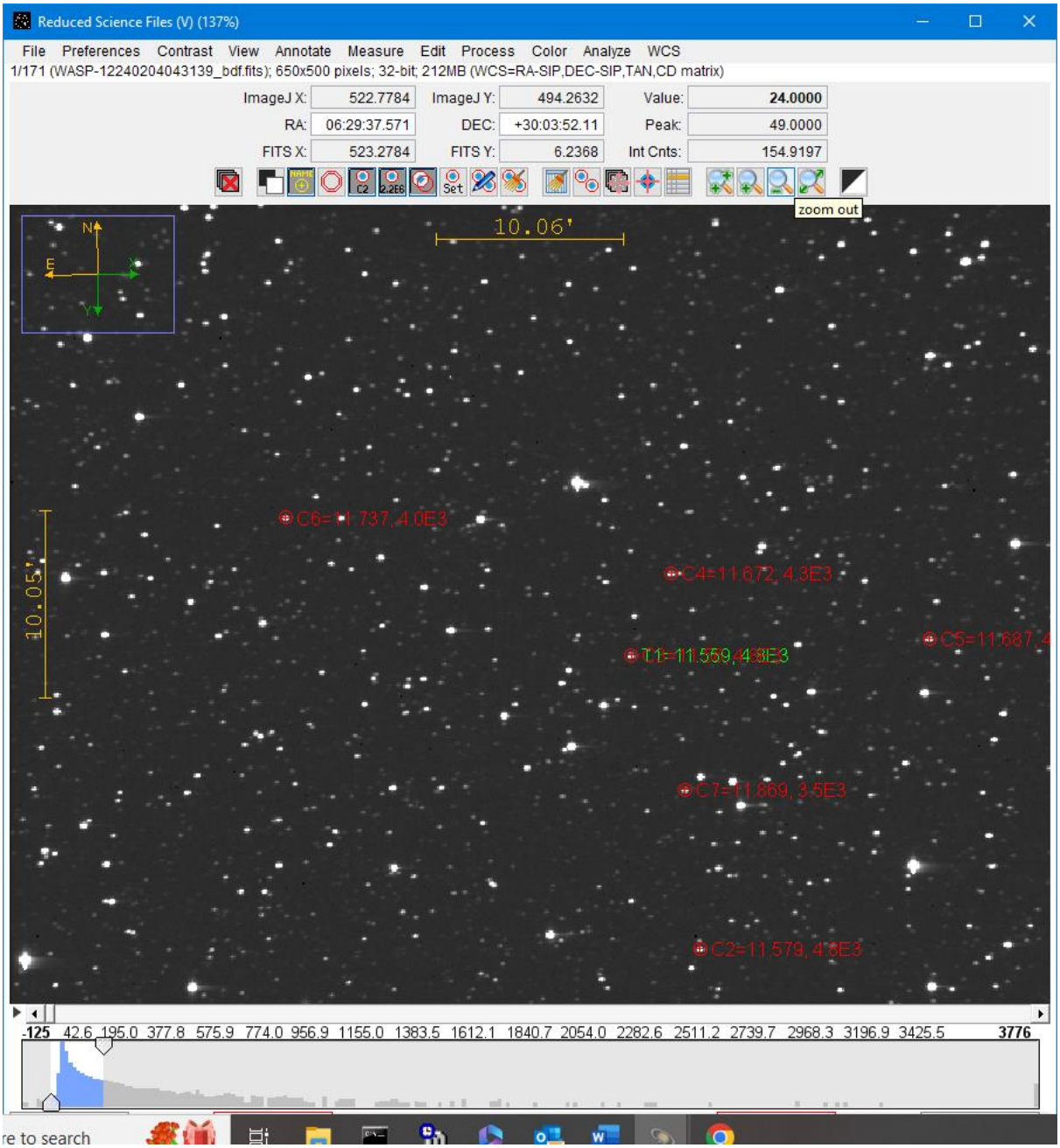


Figure 5.11 Target and comparison stars overlays

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 https://www.exoworldsspies.com/en/scheduler/ - Figure 5.12, second line.

Planet	Star RA/DEC J2000	R_{mag} mag	Transit Depth mmag	Duration hours	Observing times [UTC−7.0] and target position 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 https://www.aavso.org/jd-calculator
UT – BJD conversion https://astroutils.astronomy.osu.edu/time/utc2bjd.html
UT – HJD conversion https://britastro.org/computing/applets_dt.html

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 ExoClock Database 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 https://astrodennis.com/Guide.pdf 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 https://astroutils.astronomy.osu.edu/exofast/limbdark.shtml 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-43-b_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.

Figure 5.13 Data Set 2 Fit Settings

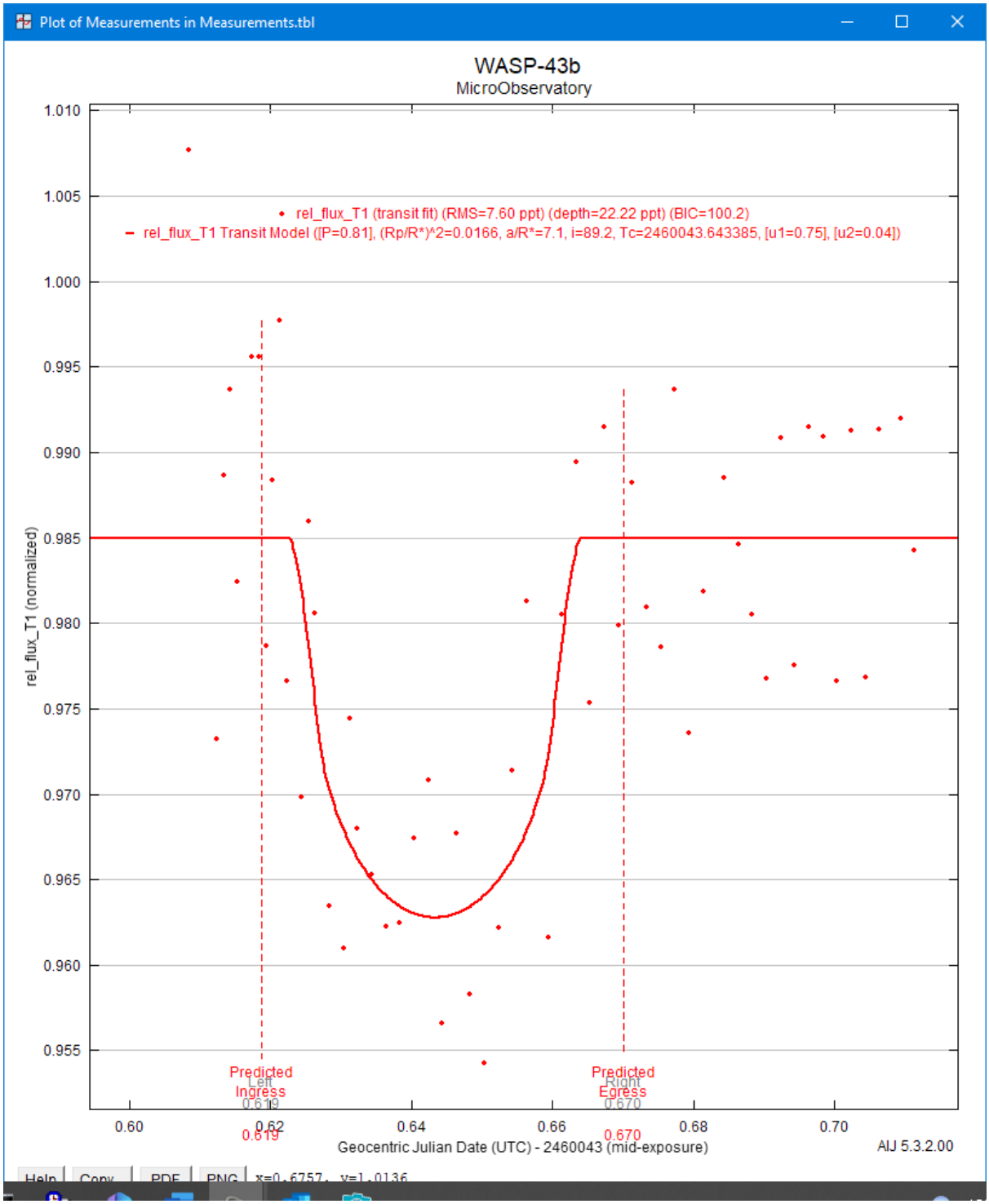


Figure 5.14. WASP-43b transit light curve

6.0 Uploading results to the Exoplanet Transit Database (ETD)

6.1 Accessing the database

The home page is at http://var2.astro.cz/ETD/archive.php 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

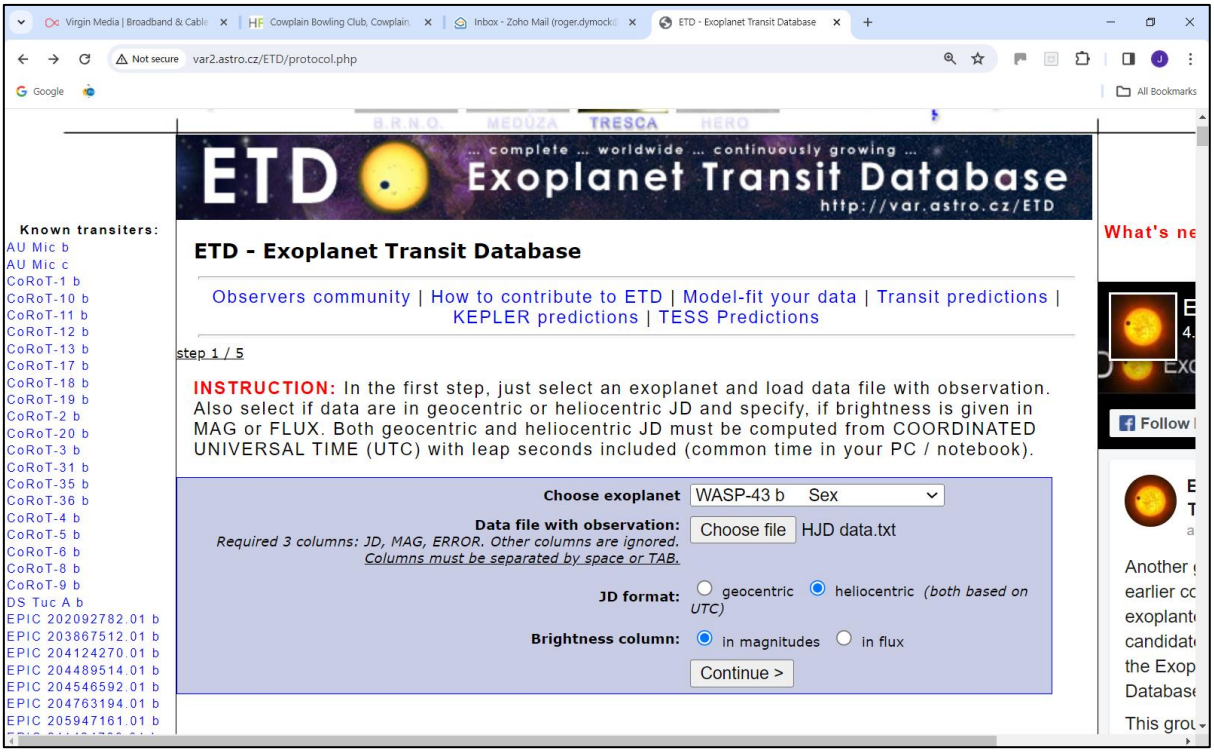


Figure 6.1. TRESCA input for WASP-43b

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.

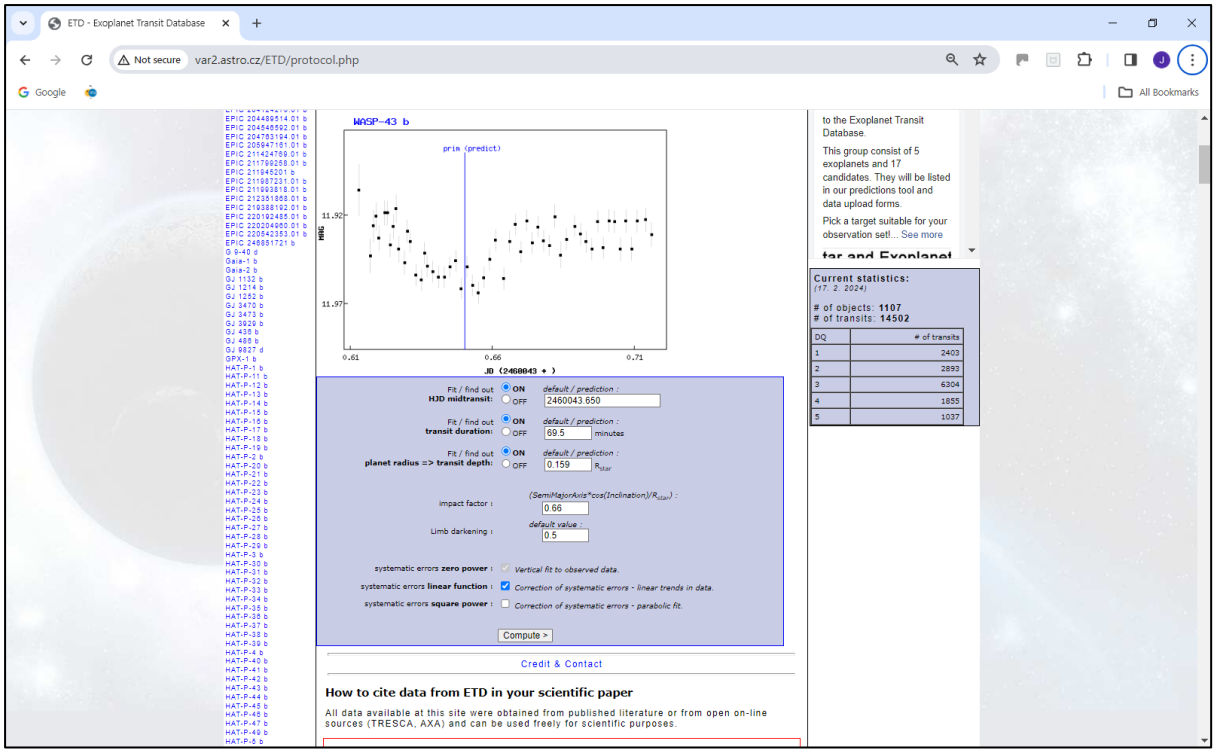


Figure 6.2. TRESCA input page

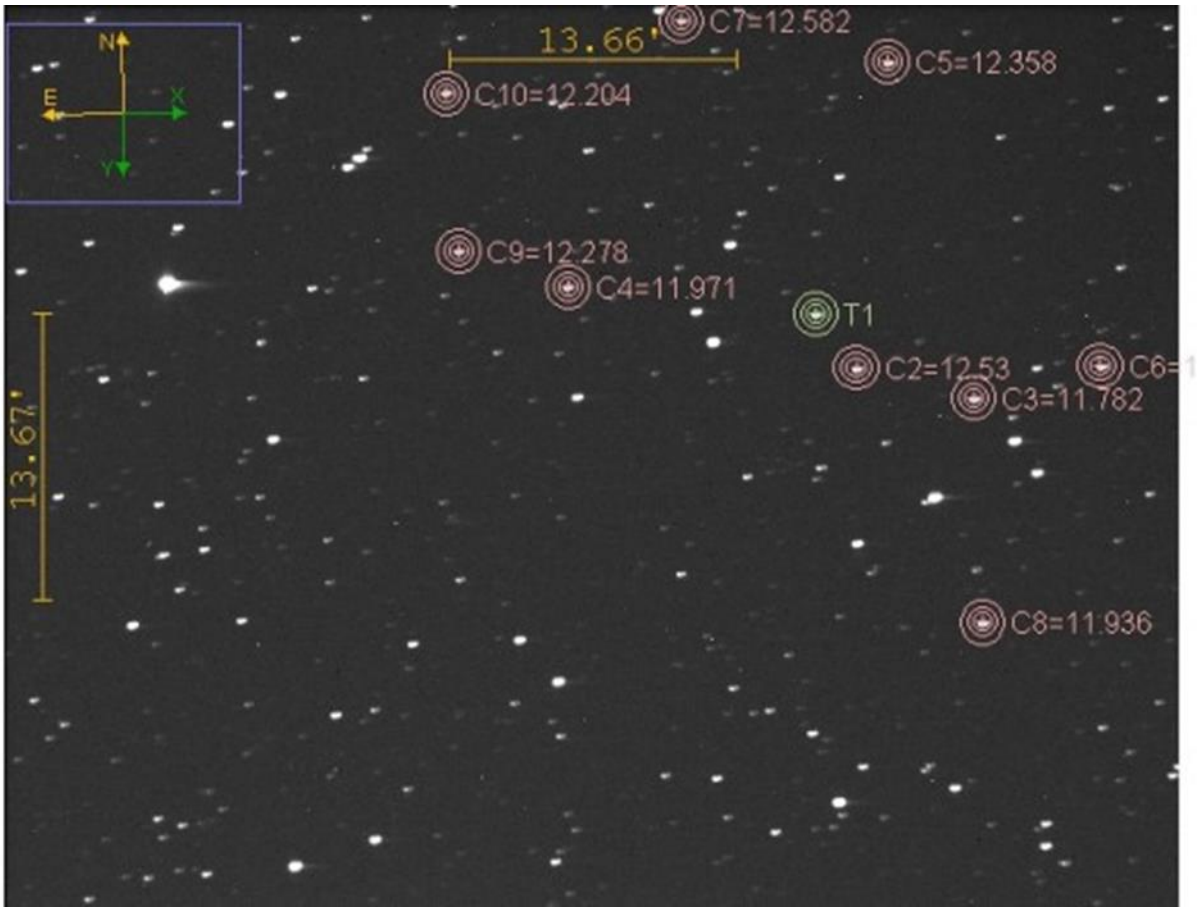


Figure 6.3 WASP-43b Field of View

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

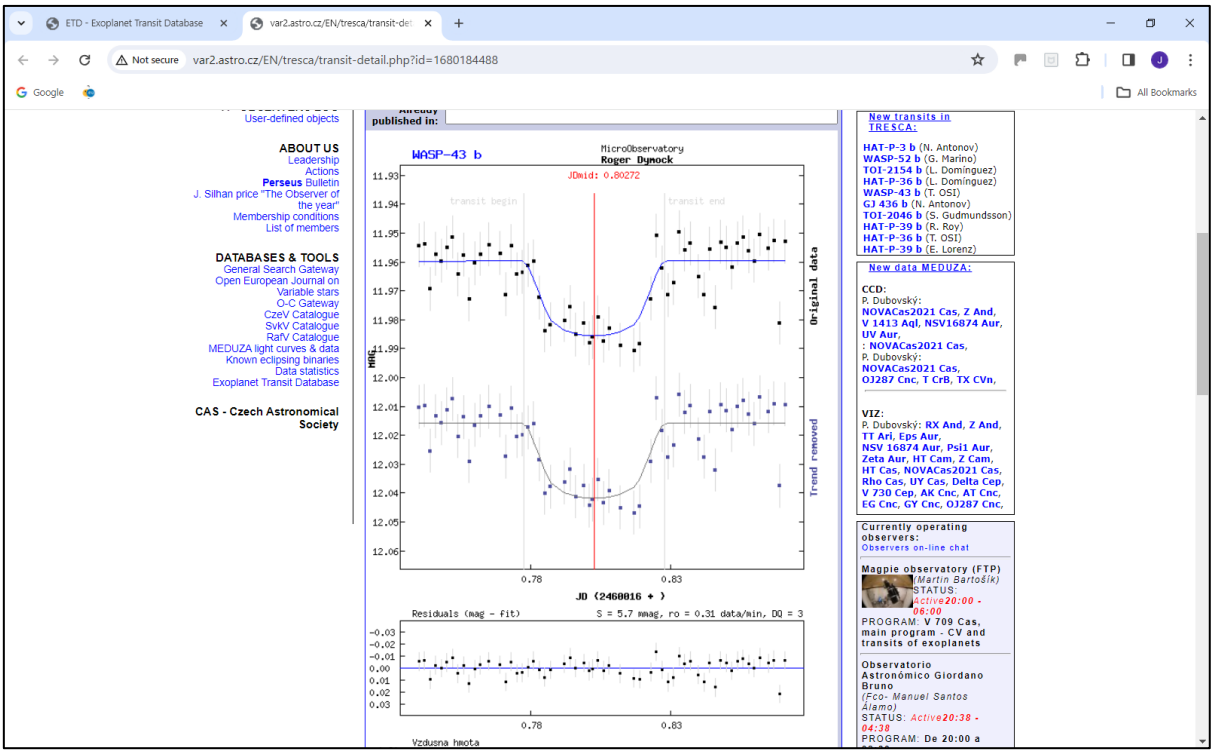


Figure 6.4. TRESCA database entry for WASP-43b

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

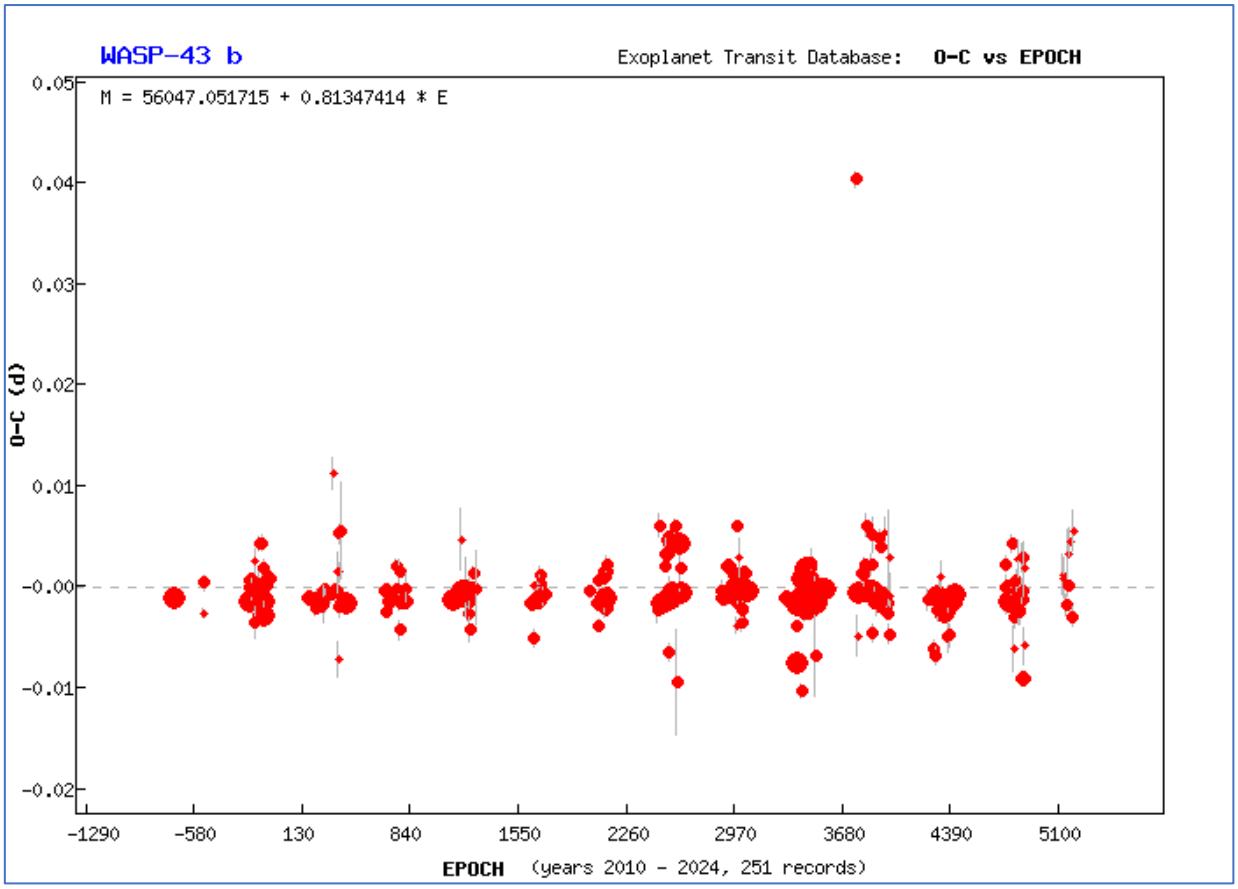


Figure 6.5. WASP-43b Credit ETD

7.0 MicroObservatory data

Telescope

Name;	Cecilia
Type;	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