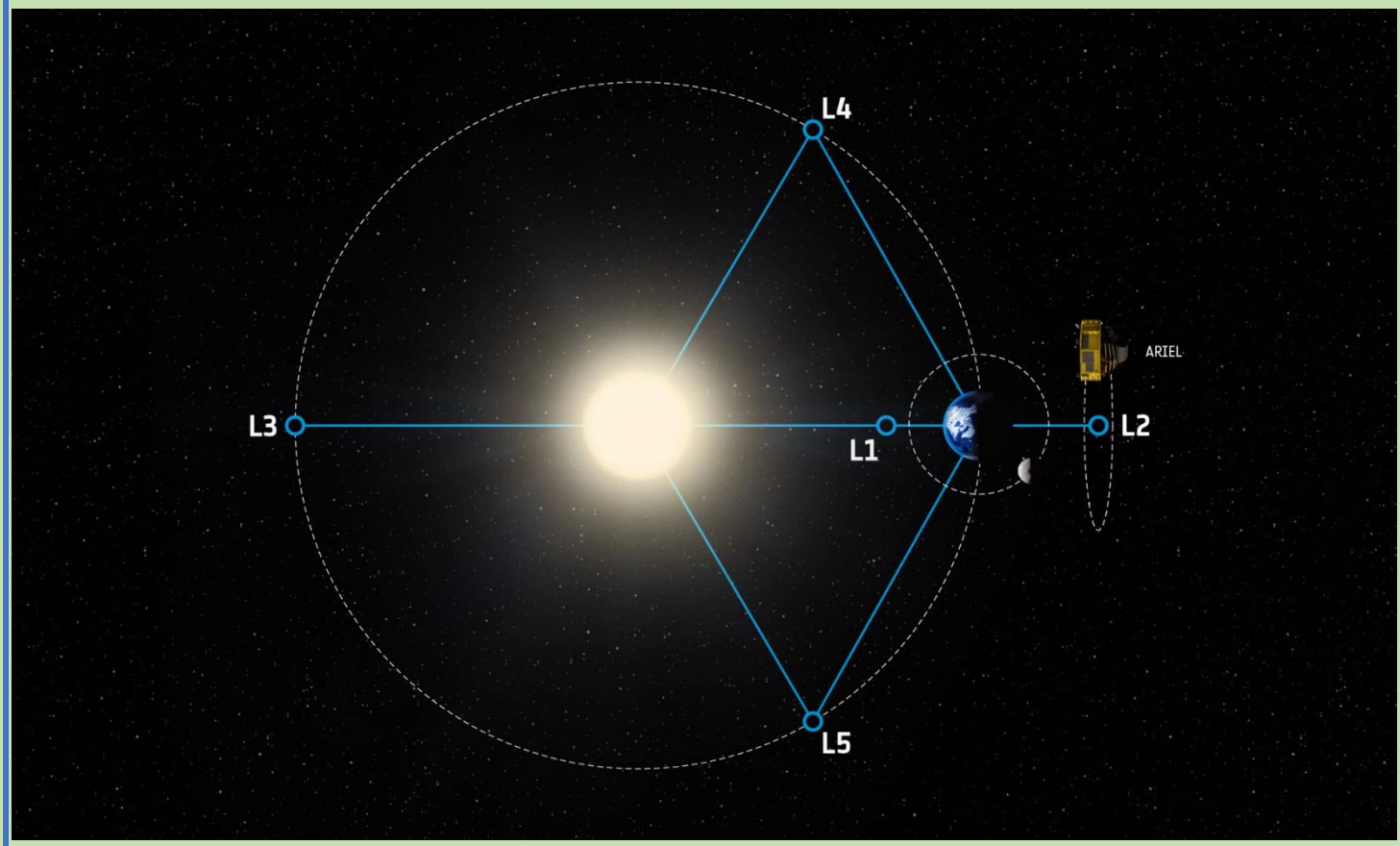
British Astronomical Association
Supporting amateur astronomers since 1890

Infinite Worlds



Credit:ESA/STFCRAL Space/UCL/Europlanet-Science Office

ARIEL Space Mission Special Issue

The e-magazine of the
Exoplanets Division
Of the
Asteroids and Remote Planets Section

Issue 5 2019 December

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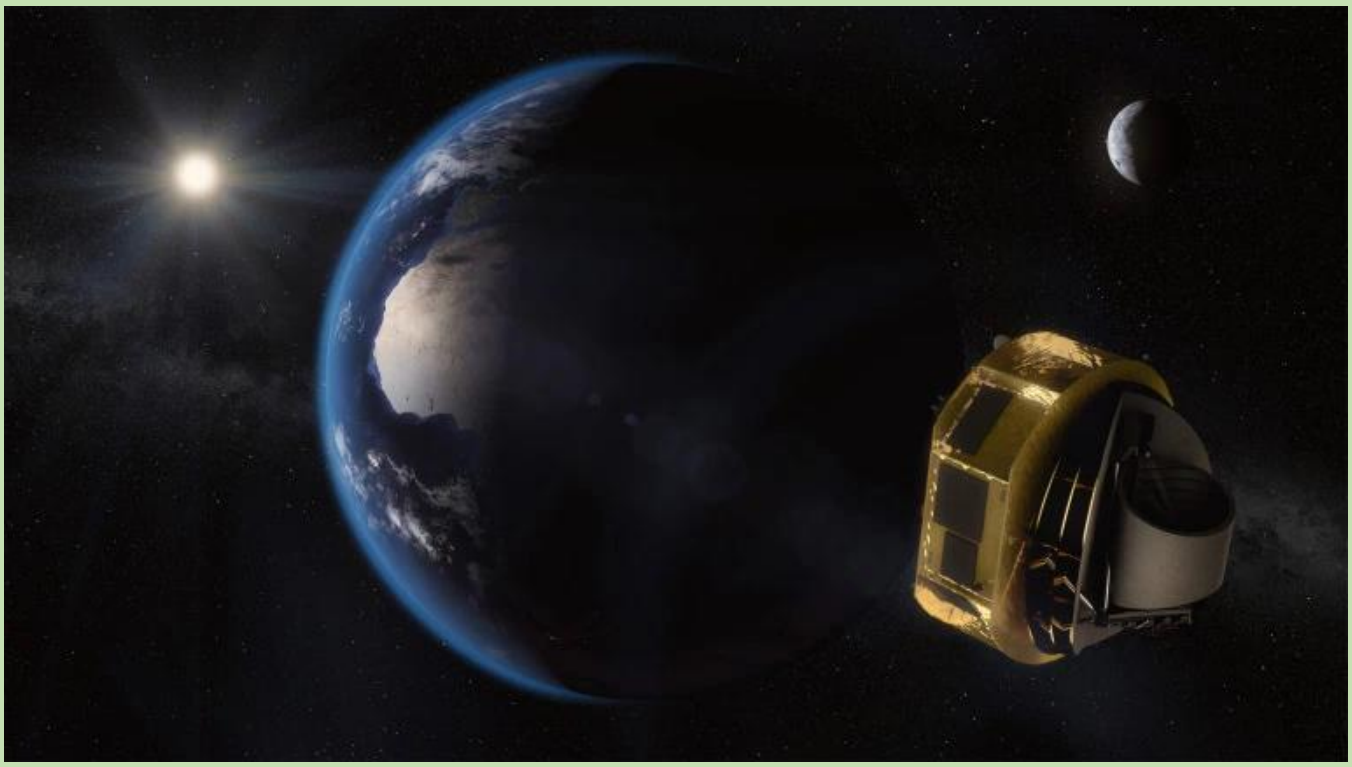


Introduction to this special issue

This issue is devoted to the ARIEL Space Mission's ExoClock Project. Observers are invited to participate in ground-based observations of exoplanet transits in support of the project.

Please do let me have your comments and whether or not you have found the information included here of use.

This document plus related presentations from the ARPS meeting held recently will be uploaded to the Exoplanets website.

ARIEL Space Mission

The ExoClock Project

Originated 2019 December 5

Contents

1.0 Introduction

The Exoplanet Division is participating in a pro-am project supporting the ARIEL space mission with ground-based exoplanet observations. This is a great opportunity to get started in exoplanet transit observations and make a significant contribution to the mission.

The objective of this document is to encourage participation in this project and provide help in installing the Python/HOPS software, imaging and generating transit light-curves.

Data for an initial selection of target stars is shown in the appendices. More can be found on the ExoWorlds Spies Transit Scheduler.

Mark Salisbury is our contact point with Ariel for this project.

2.0 The ARIEL space mission

The mission website is at ARIEL Space Mission - https://arielmission.space/
ARIEL will use transit spectroscopy to characterise the atmospheres of ~1000 exoplanet.

Relevant documentation;
ESA Assessment Study Report - https://sci.esa.int/documents/34375/36249/1567260310680-ESA_SCI-2017-2_ARIEL.pdf
A chemical study of exoplanets with ARIEL - https://link.springer.com/article/10.1007/s10686-018-9598-x

Those interested in astrobiology may find much of interest in the above-mentioned documents. The presentation, ‘An Introduction to Astrobiology’ given by Peta Bosley at the ARPS meeting held on 2019 September 29 can be found here (link to be added when this document is finalised and uploaded to Exoplanets website).

2.1 The ExoClock project

Ground-based exoplanet observations in support of the ARIEL space mission - https://ariel-gbfu.azurewebsites.net/

There is a need to confirm the ephemerides, transit times, of the approximately 1000 ARIEL targets. Some of these targets will not have been observed for a several years, therefore their predicted transit times could be in error and thus missed by ARIEL when imaging that particular event.

The project offers observers;
- ephemerides
- target prioritisation with alert system
- personalised observation schedule
- direct publications for participants
- continuous feedback to observers

To participate;
- register you telescope and sign up/login at https://ariel-gbfu.azurewebsites.net/users/login/
- check your schedule at https://ariel-gbfu.azurewebsites.net/schedule/today
- observe a transit; beginners guide at https://exoworldsspies.com/en/observers/
  analyse your observation; software at https://exoworldsspies.com/en/software/
- upload your light curve; login required

A transit light-curve of WASP-52b obtained by Steve Futcher, Hampshire Astronomical Group, and Portsmouth University students is shown in Figure 2.1.1. It can also be viewed on the ExoClock Observations webpage at
https://ariel-gbfu.azurewebsites.net/database/observations

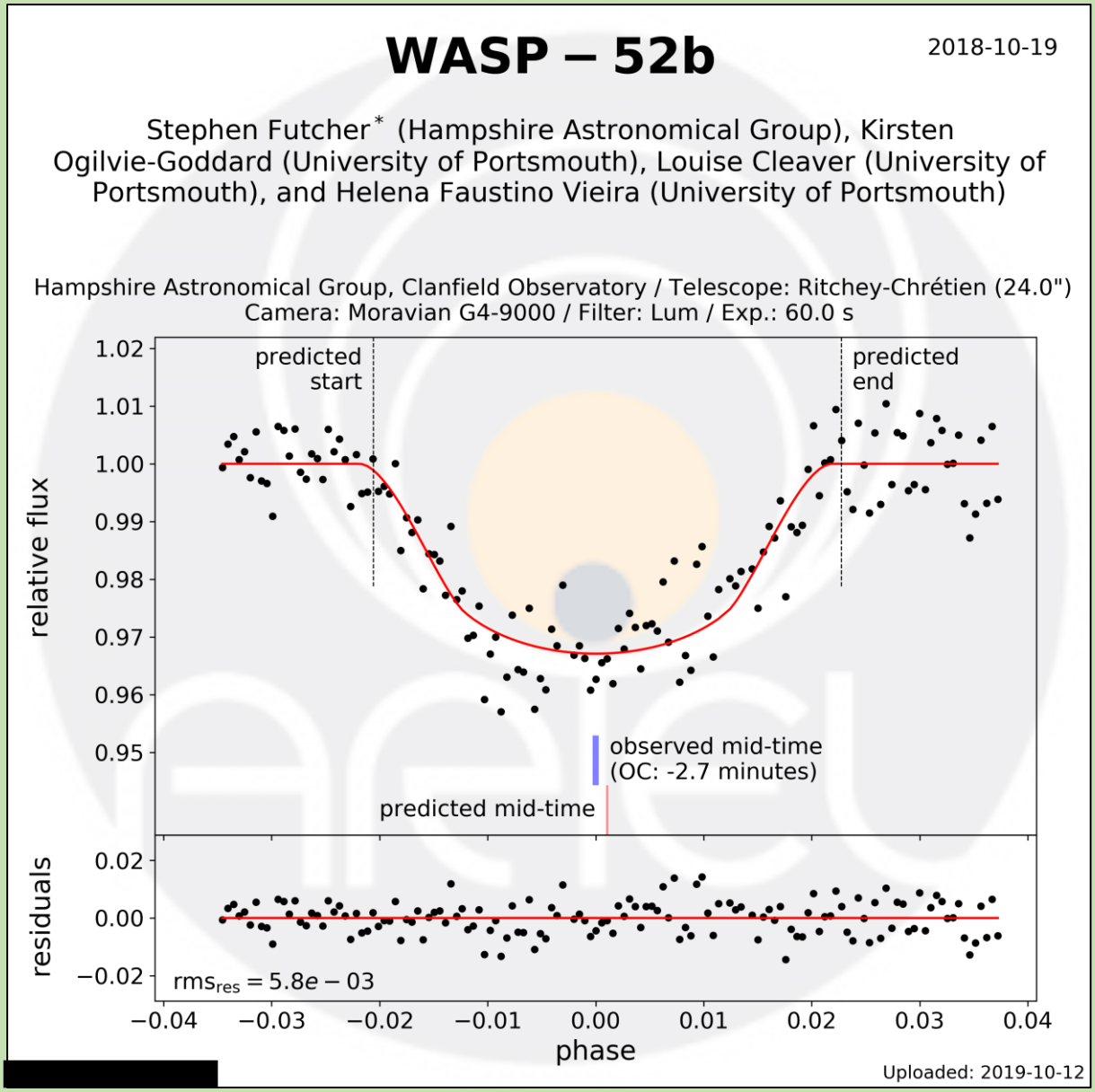


Figure 2.1.1. WASP-52b transit light-curve

You don't have to own your own telescope to participate. Martin Fowler uses the MicroObservatory robotic telescope to obtain a light-curve of HAT-P-32b – Figure 2.1.2. It can also be viewed on the ExoClock Observations webpage at https://ariel-gbfu.azurewebsites.net/database/observations

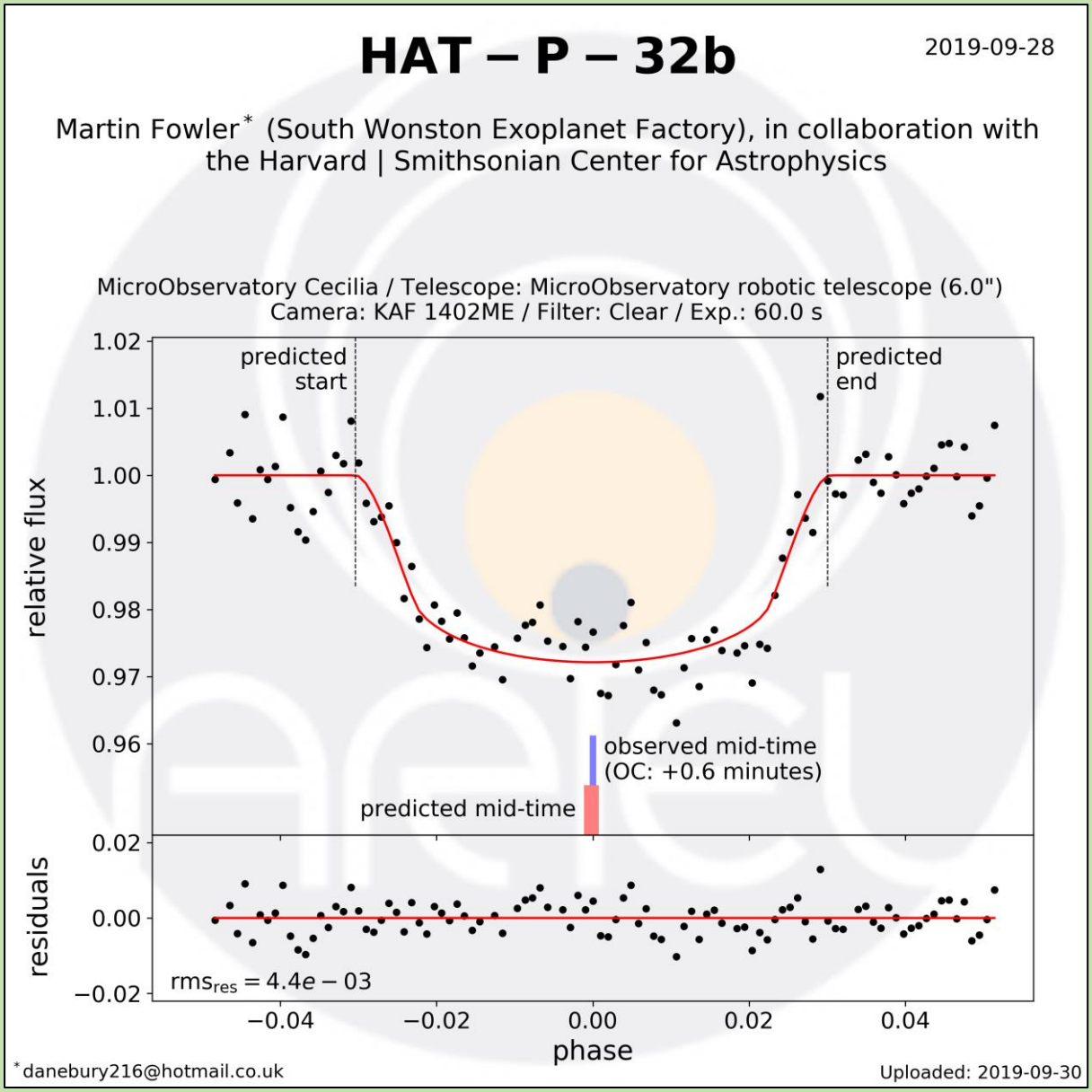


Figure 2.1.2. HAT-P-32b transit light-curve

2.2 ExoWorlds Spies

Website at www.exoworldsspies.com. Here observers can find information on;
- installation and use of HOPS software (Software and For observers) – see Appendix B
- practice targets (NAV/For observers) – see Appendix C

3.0 Imaging and analysis process

The ExoWorlds Spies website Observing an exoplanet transit webpage describes the ExoClock projects preferred imaging process. There is a link to the HOPS user manual – HOPS is the software to be used for image analysis.

The forthcoming workshop – section 4.0. may bring about some modifications to these processes – as they say, watch this space.

It may help observers to obtain consistent results if comparison stars are defined for the ARIEL targets - https://ariel-gbfu.azurewebsites.net/database/ See appendix A for finder charts

(Guide) and comparison stars plus a link to the relevant entry in the Exoplanet Transit Database. Transit times can be obtained from the ExoWorlds Spies Transit Scheduler, the Exoplanet Transit Database or Find Exoplanet Transits

4.0 Workshop

A workshop, hosted by ARIEL personnel, is planned for 2020 January, Topics under consideration include;

- ARIEL mission update
- understanding of how amateurs can assist the ARIEL mission
- coordination of observing programs of suggested targets
- targets. A list is available at https://ariel-gbfu.azurewebsites.net/database/
- comparison stars
- timing e.g. Barycentric Julian Date (BJD) or Heliocentric Julian Day (HJD)
- equipment requirements; e.g. 8in reflector, 6in refractor
- use of robotic telescopes e.g. the MicroObservatory robotic telescope
- imaging techniques
- use of filters e.g. R (Cousin Rc or Sloan r' for example) or Clear
- the photometry process
- familiarisation with HOLomon Photometric Software (HOPS)

5.0 ARIEL targets

5.1 Target selection

Plan is to select a number of targets suitable for UK observers and provide finder charts and comparison star data. See appendices for data for stars listed in Table 5.5.1. If this proves successful, then more charts and data will be generated.

The ExoWorlds Spies Transit Scheduler can be used to provide targets depending on location and telescope size. The targets listed in Table 5.5.1 were selected using;

- latitude; 54 degrees (Approx UK centre)
- longitude; -1.0 degrees (Approx UK centre)
- telescope aperture; 8 ins
- preferred time zone; 0 hrs
- Next 12 Months

From the list Targets were selected using the following criteria;

- high priority (prediction uncertainty higher than 10 minutes for 2020) – A1 to A8
- medium priority (prediction uncertainty lower than 10 minutes for 2020 but higher than 10 minutes for 2028, or reference older than 2016) – A8 to A10
- V mag brighter than 13
- transit depth >=10
- altitude >30 degrees during transit

For transit times for a specific planet access;

- Exoworlds Spies Transit Scheduler

or

- Exoplanet Transit Database

or

- Find Exoplanet Transits

The link under Target in Table 5.5.1 takes you to the relevant appendix. The link in the table at the beginning of each appendix is to the Exoplanet Transit Database.

Appendix no.	Target	RA	Dec	V mag	Depth (mmag)
A1	HAT-P-20b	07 27 39.95	24 20 11.9	11.34	20
A2	XO-6b	06 19 10.39	73 49 39.7	10.25	14
A3	HAT-P-6b	23 39 05.81	42 27 57.5	10.44	10
A4	WASP-13b	09 20 24.71	33 52 56.8	10.42	10
A5	XO-4b	07 21 33.17	58 16 05.2	10.67	10
A6	HAT-P-8b	22 52 09.86	35 26 49.6	10.30	11
A7	HAT-P-17b	21 38 08.74	30 29 19.4	10.54	20
A8	HAT-P-3b	13 44 22.59	48 01 43.2	11.58	16
A9	WASP-11b	03 09 28.55	30 40 24.9	11.60	23
A10	HAT-P-12b	13 57 33.48	43 29 36.7	12.84	28

Table 5.5.1. Selected targets

Clicking on 'More' displays a finder chart and star and transit data – included in appendices.

STScI DSS charts are obtained from http://archive.stsci.edu/cgi-bin/dss_form using the HST Phase 2 (GSC1) option.

The best time of the year to observe the selected targets can be ascertained using the Object Visibility facility at http://catserver.ing.iac.es/staralt/ using the Starobs option.

5.2 Comparison stars

Comparison star were selected to be close to the target star in both magnitude and colour i.e.; V mag +/- 1.5 and (B-V) +/- 0.2. Stars may be selected outside these ranges to give a spread of comparison stars across the image and if there are few that meet these criteria. Data extracted from Vizier/APASS catalogue at http://vizier.u-strasbg.fr/viz-bin/VizieR-3?-source=II/336/apass9&-out.max=50&-out.form=HTML%20Table&-out.add=_r&-out.add=_RAJ,_DEJ&-sort=_r&-oc.form=sexa The AAVSO Variable Star Plotter at https://www.aavso.org/apps/vsp/ was accessed to check for variable and comparison stars near the target.

Appendix A1

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-20b	07 27 39.95	24 20 11.9	11.34	1.2	20

Table A1.1. Target data

Return to target list

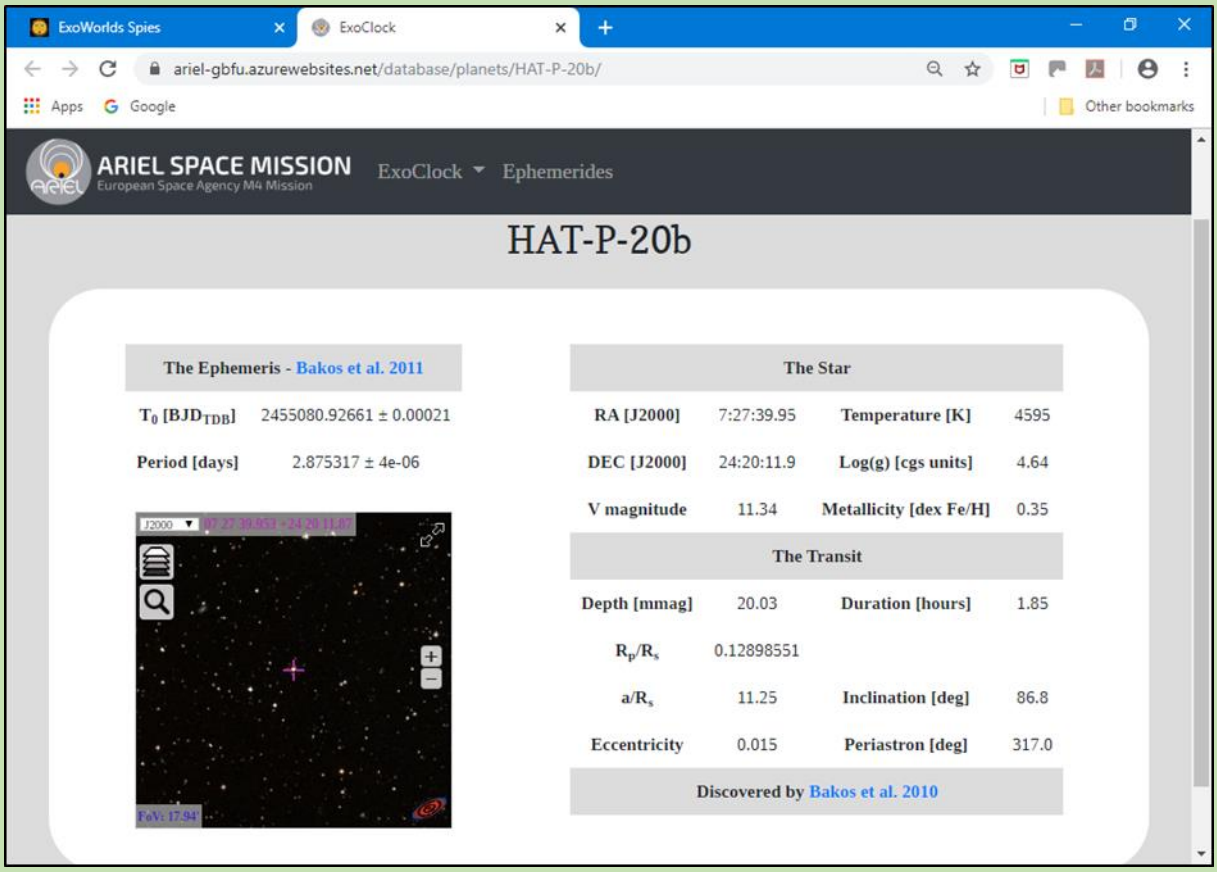


Figure A1.1. Star and transit data

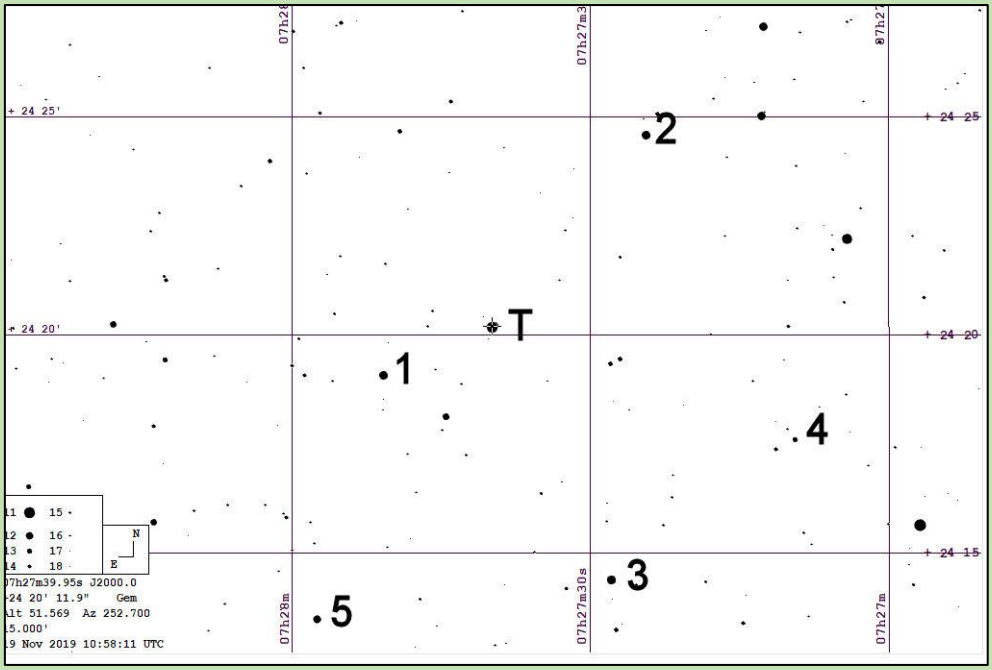


Figure A1.2. Finder chart

Figure A1.3. STScI DSS chart

Nominal criteria for comparison star selection (can exceeded to obtain spread and number of comparison stars).
1.0<(B-V=1.2)<1.4
9.84<(V=11.34)<12.84

Comparison star	RA	Dec	V	B-V
1	07 27 50.80	+24 19 04.82	11.481	0.526
2	07 27 24.40	+24 24 36.64	11.891	1.291
3	07 27 27.88	+24 14 23.82	11.770	1.264
4	07 27 09.47	+24 17 38.48	13.128	0.769
5	07 27 57.44	+24 13 29.72	12.089	0.771

Table A1.2. Comparison star data

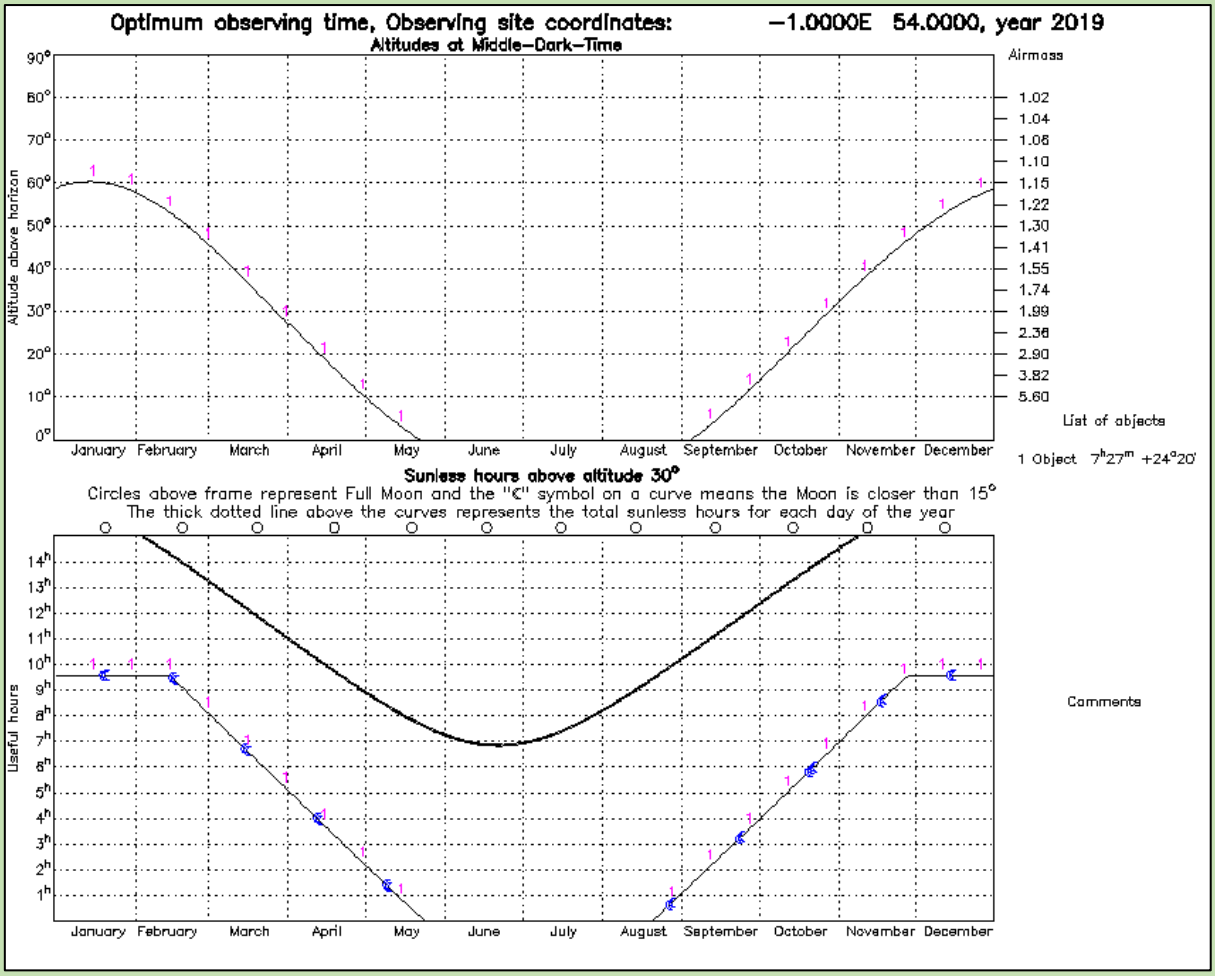


Figure A1.4. Object visibility

Appendix A2

Target	RA	Dec	V mag	B-V	Depth (Mmag)
XO-6b	06 19 10.39	73 49 39.7	10.25	0.360	14

Return to target list

Table A2.1. Target data

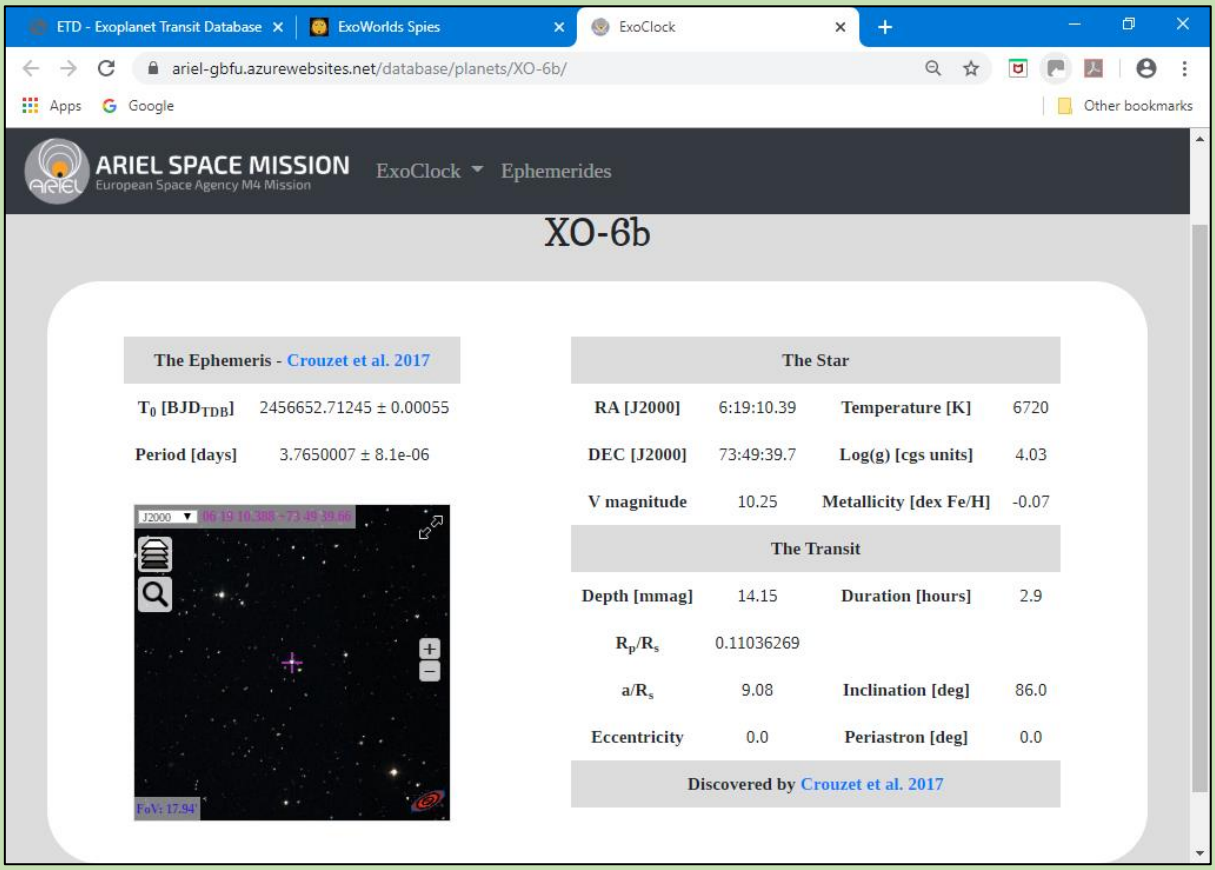


Figure A2.1 Star and transit data

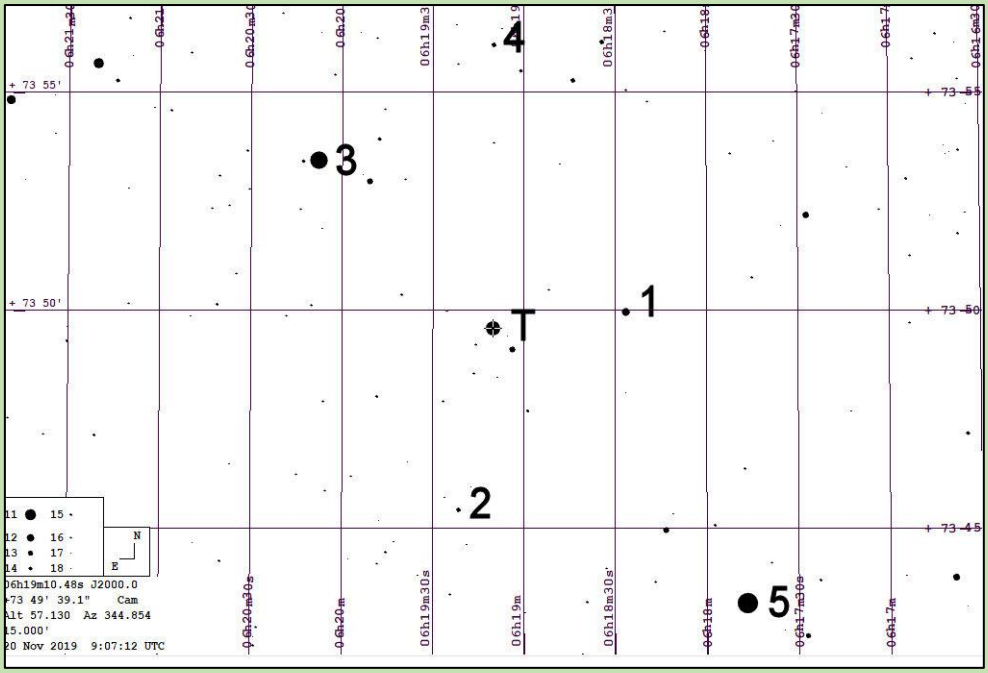


Figure A2.1. Finder chart

Figure A2.2. STScI DSS chart

Nominal criteria for comparison star selection.
0.160<(B-V=0.360)<0.560
8.75<(V=10.25)<11.75

Comp star	RA	Dec	V mag	B-V
1	06 18 26.80	+73 50 02.07	12.012	0.996
2	06 19 50.99	+73 53 02.01	12.510	0.657
3	06 20 07.82	+73 53 29.85	9.843	0.471
4	06 19 10.14	+73 56 09.75	13.302	0.960
5	06 17 47.11	+73 43 20.58	9.450	0.995

Table A2.2. Comparison star data

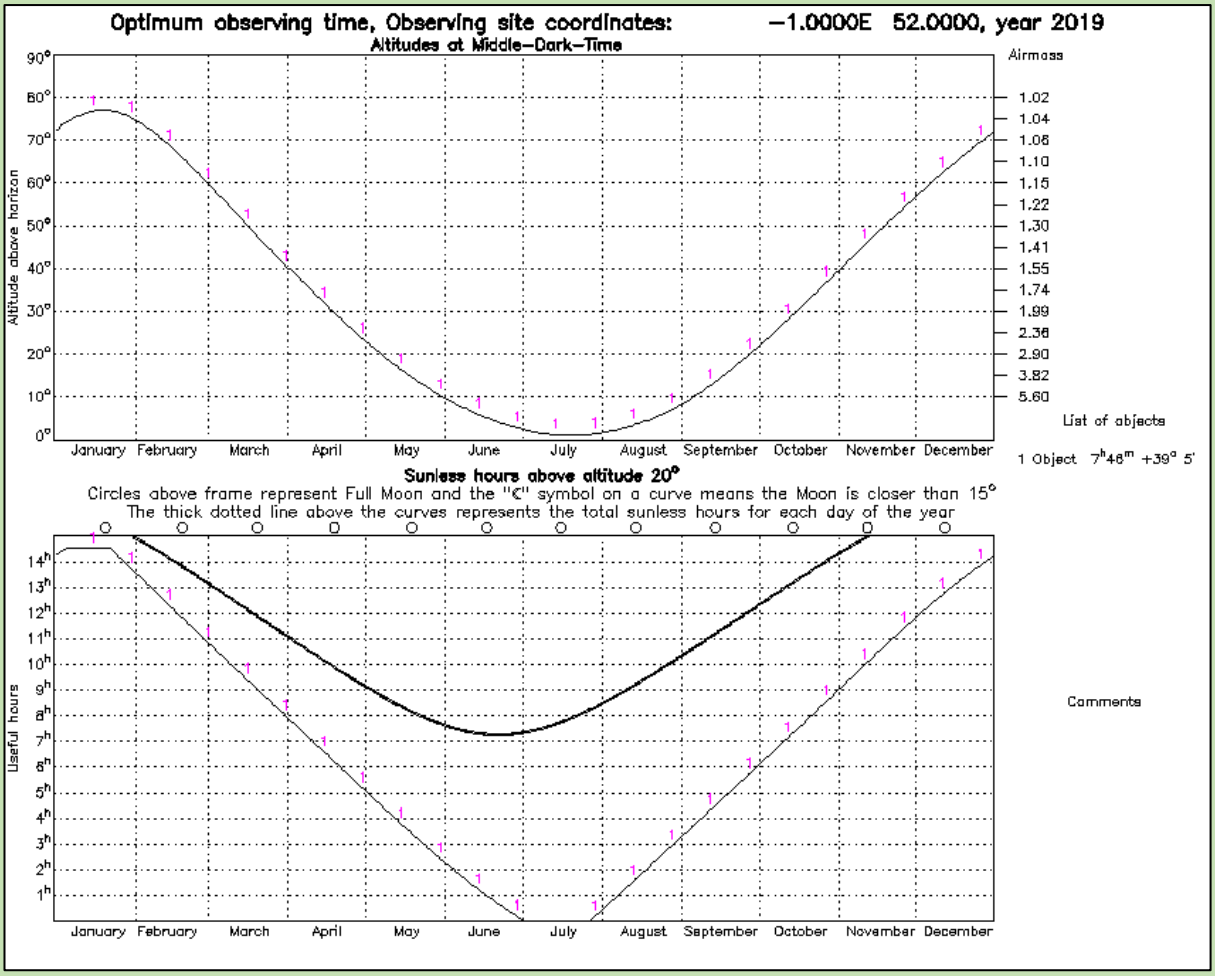


Figure A2.3. Object visibility

Appendix A3

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-6b	23 39 05.81	42 27 57.5	10.44	0.469	14

Table A3.1. Target data

Return to target list

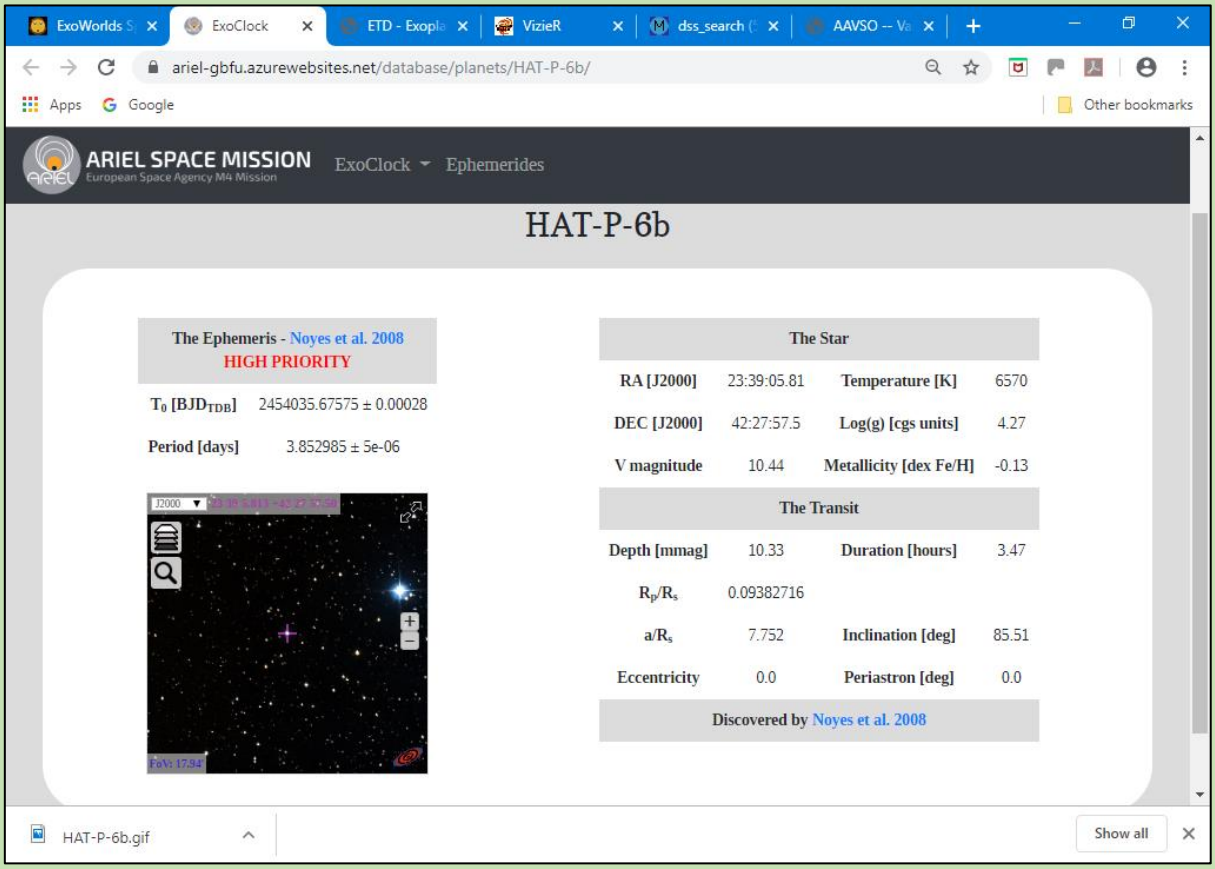


Figure A3.1 Star and transit data

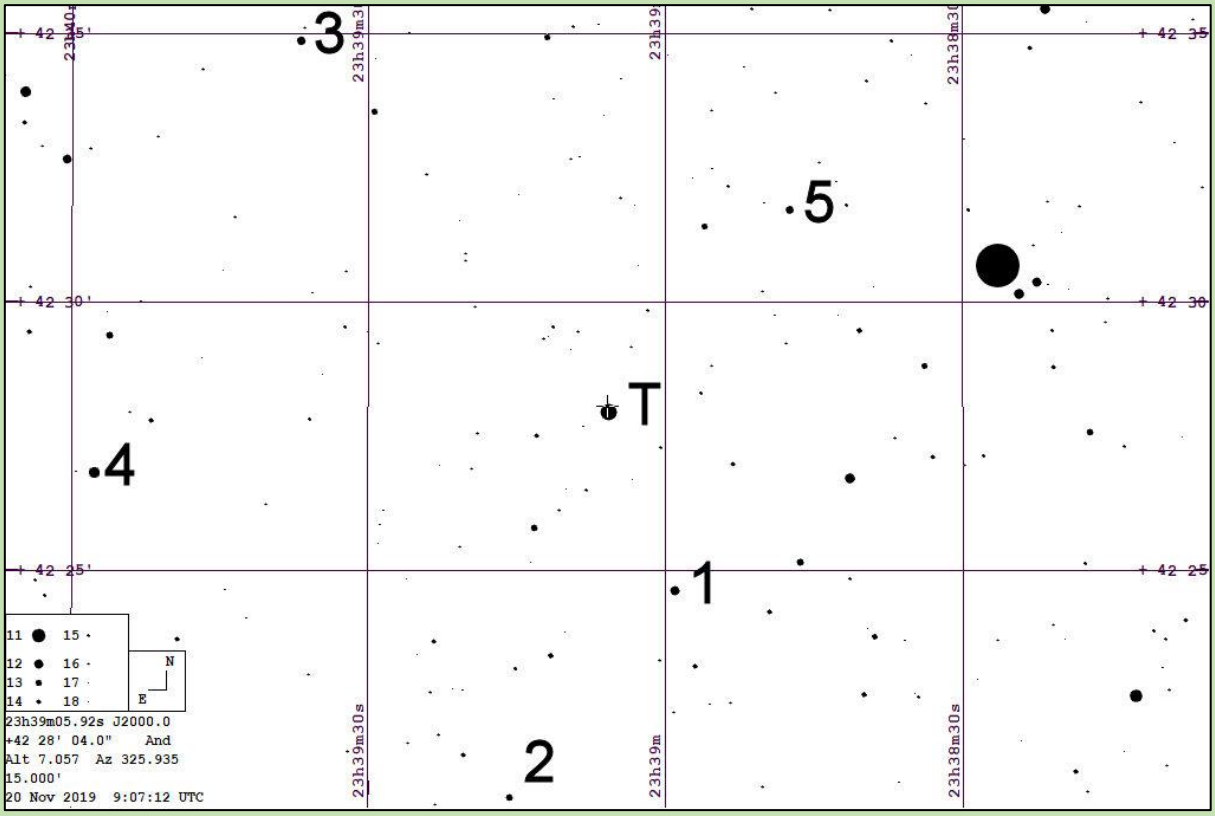


Figure A3.2. Finder chart

Figure A3.3. STScI DSS chart

Nominal criteria for comparison star selection.
0.269<(B-V=0.469)<0.669
8.94<(V=10.44)<11.94

Comp star	RA	Dec	V mag	B-V
1	23 38 59.06	+42 24 38.09	11.710	0.736
2	23 39 15.75	+42 20 47.60	12.752	0.724
3	23 39 36.79	+42 34 51.92	11.826	0.377
4	23 39 37.67	+42 26 49.11	11.450	0.339
5	23 38 47.40	+42 31 44.1	12.451	1.028

Table A3.2. Comparison star data

Note. Data for Comparison star 4 are from Guide and Comparison star 5 from the AAVSO

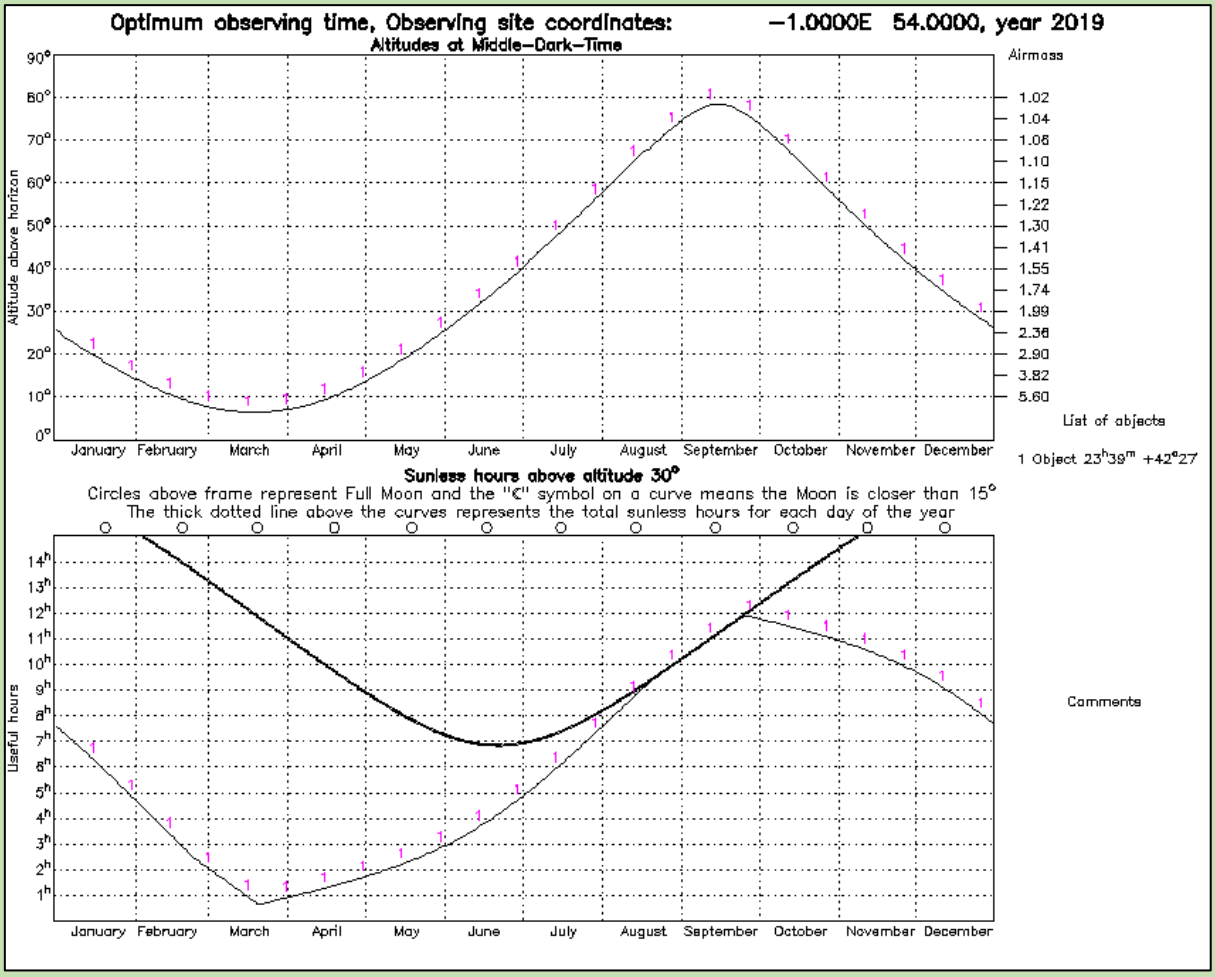


Figure A3.4. Object visibility

Appendix A4

Target	RA	Dec	V mag	B-V	Depth (mmag)
WASP-13b	09 20 24.71	33 52 56.8	10.42	0.459	10

Table A4.1. Target data

Return to target list

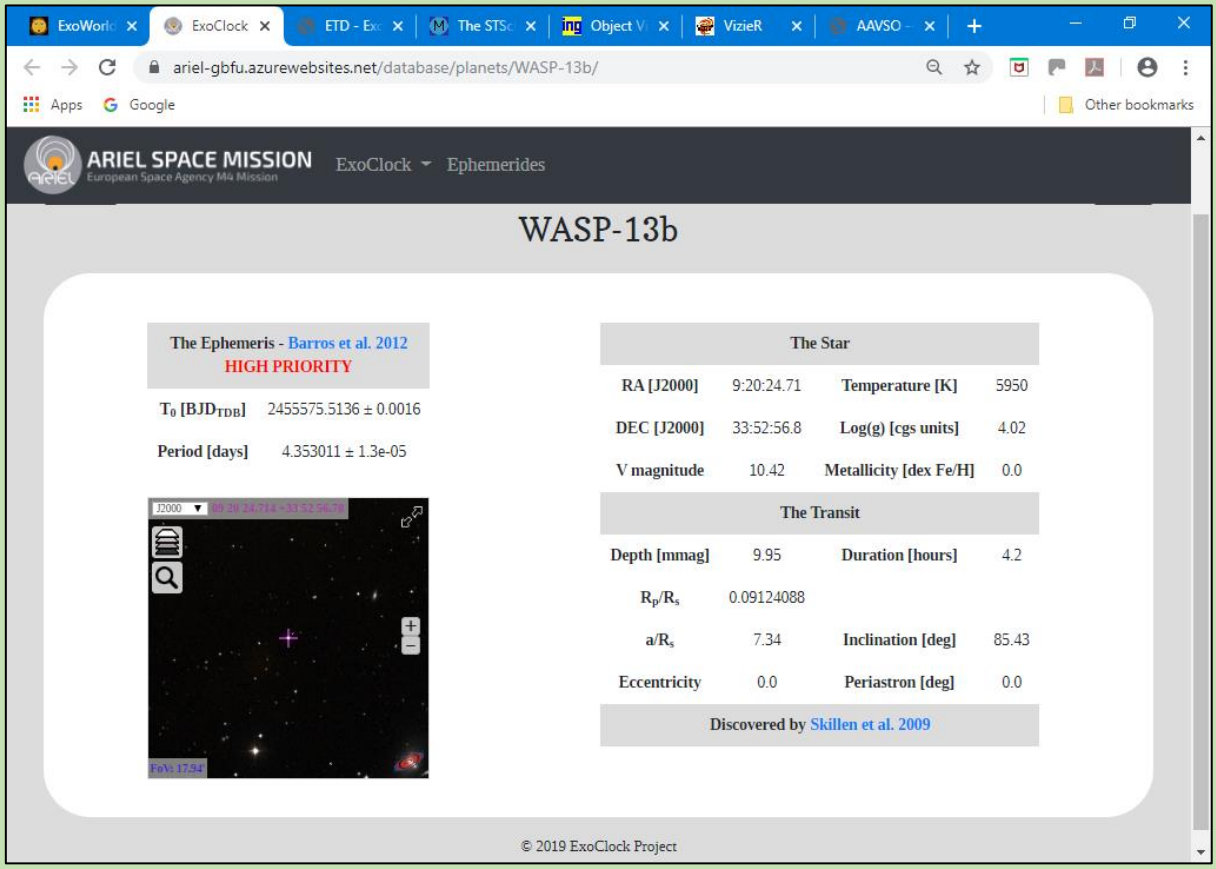


Figure 4.1

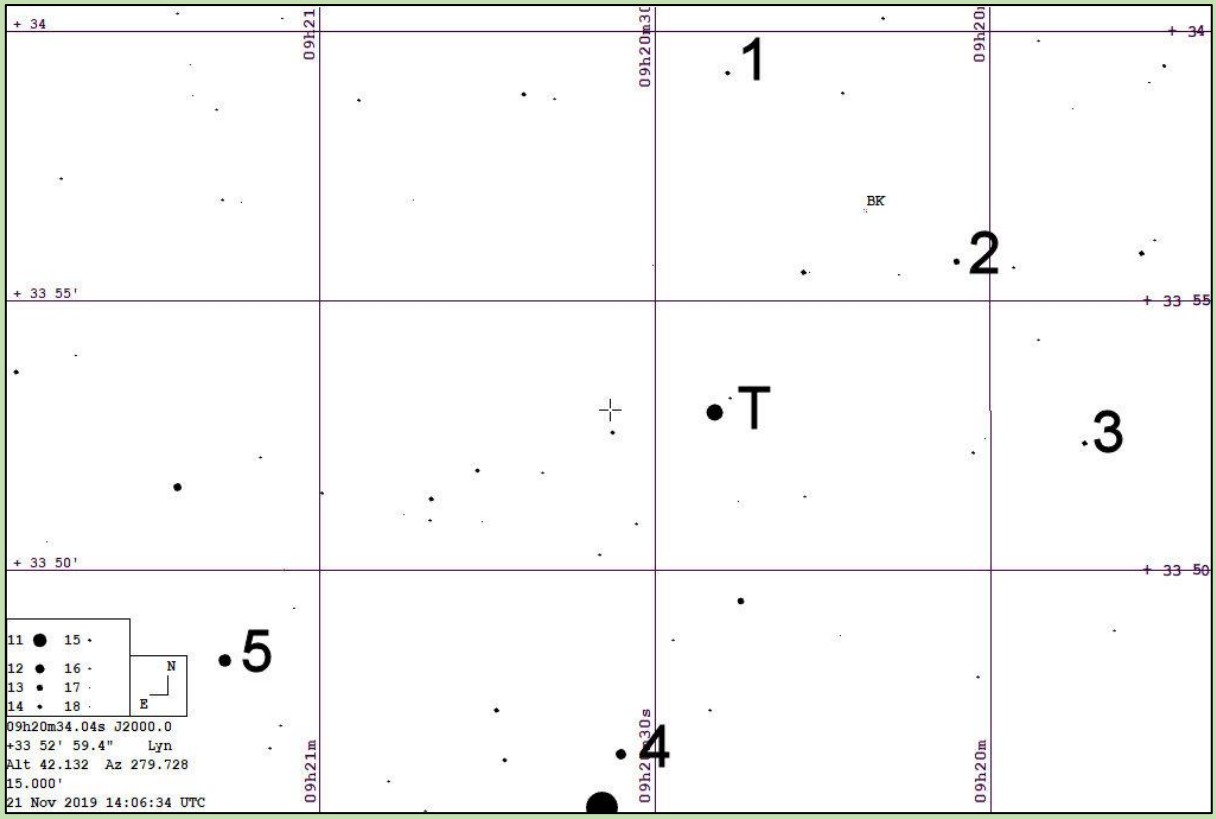


Figure A4.2. Finder chart

Figure A4.3. STScI DSS chart

Nominal criteria for comparison star selection.
0.259<(B-V=0.492)<0.659
8.92<(V=10.42)<11.92

Comp star	RA	Dec	V mag	B-V
1	09 20 23.48	+33 59 16.04	13.872	0.565
2	09 20 02.97	+33 55 45.60	13.240	0.933
3	09 19 51.49	+33 52 23.82	13.867	0.385
4	09 20 33.07	+33 46 36.50	11.653	0.467
5	09 21 08.51	+33 48 20.72	11.092	0.939

Table A4.2. Comparison star data

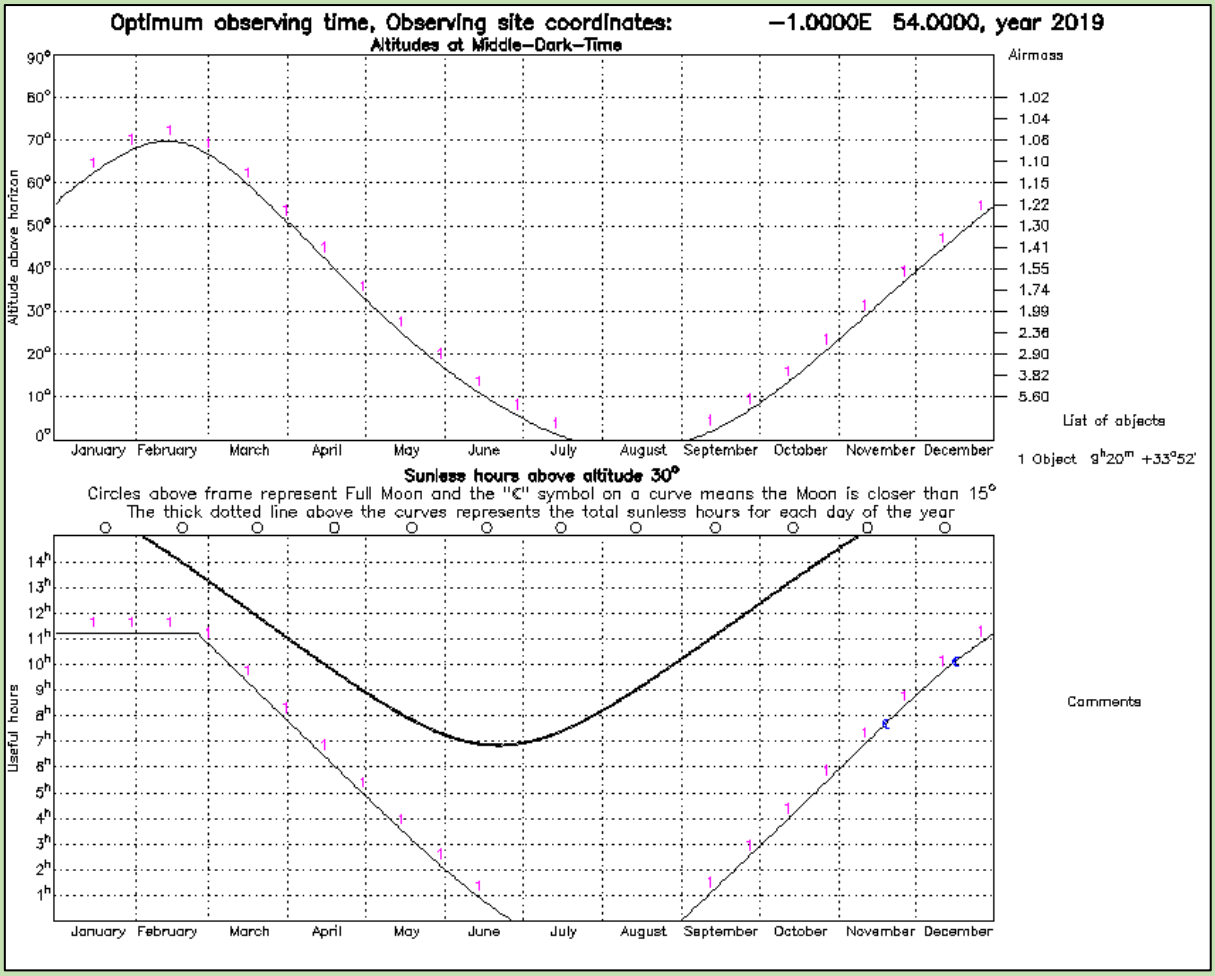


Figure A4.4. Object visibility

Appendix A5

Target	RA	Dec	V mag	B-V	Depth (mmag)
XO-4b	07 21 33.17	58 16 05.20	10.67	0.492	10

Table A5.1. Target data

Return to target list

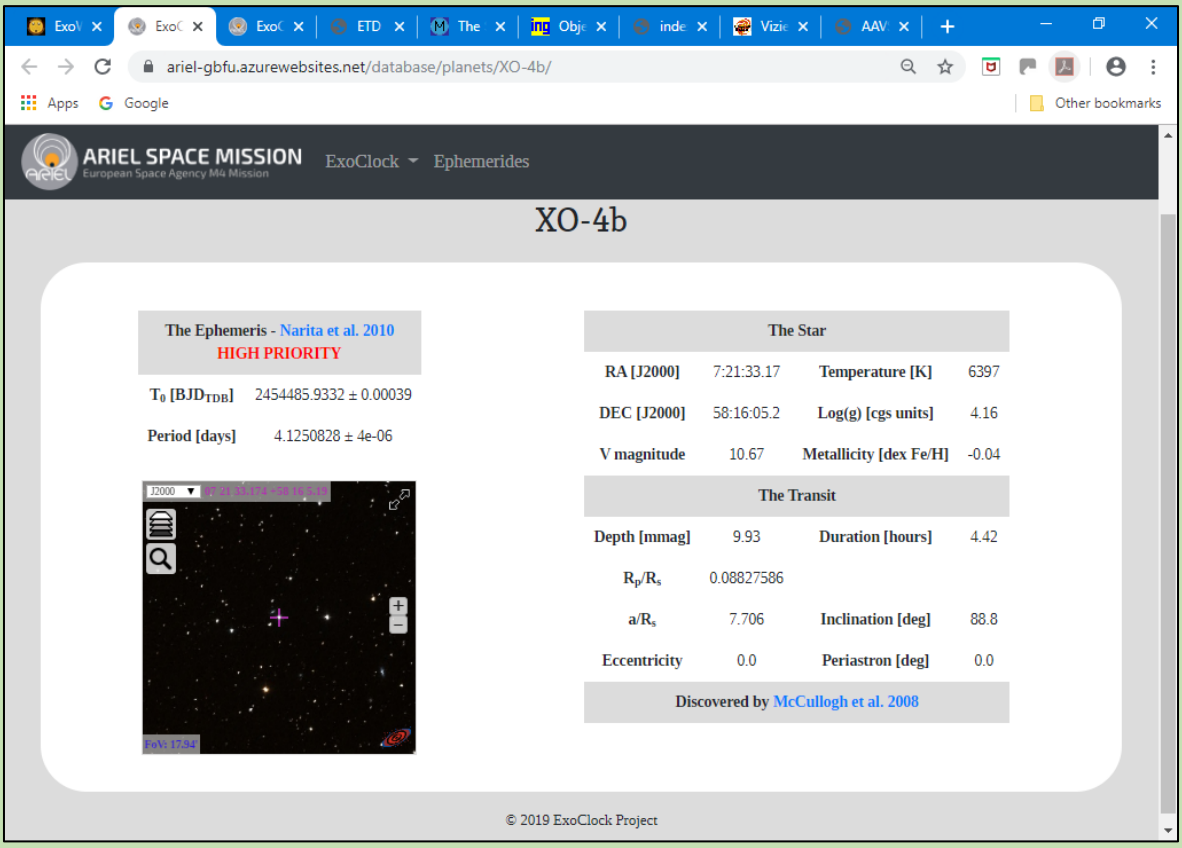


Figure A5.1

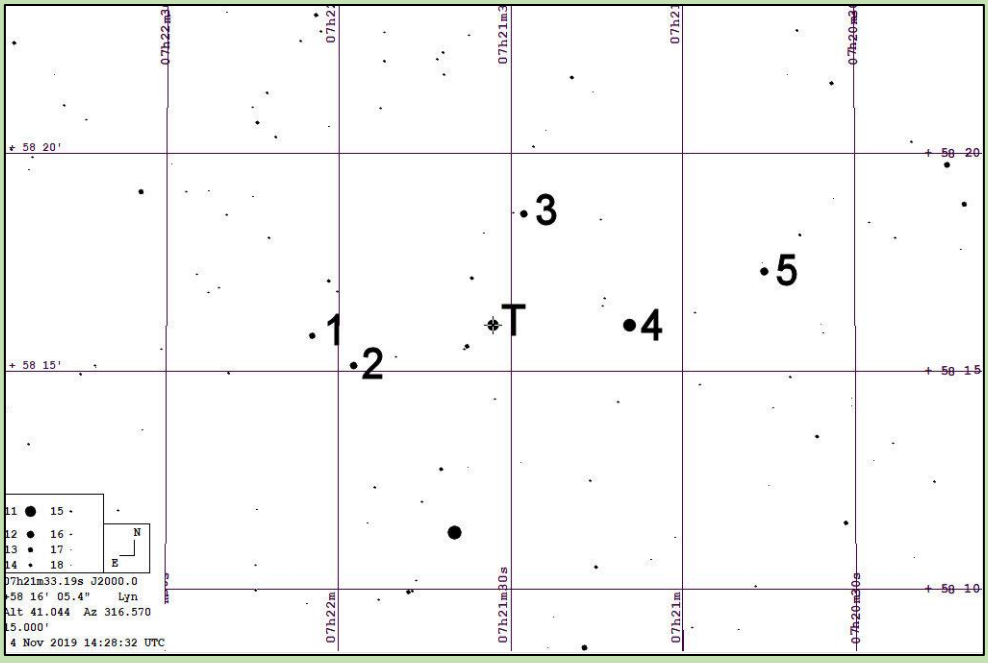


Figure A5.2. Finder chart

Figure A5.3. STScI DSS chart

Nominal criteria for comparison star selection.
0.292<(B-V=0.492)<0.692
9.162<(V=10.662)<12.162

Comp star	RA	Dec	V mag	B-V
1	07 21 27.73	+58 18 38.25	12.319	0.665
2	07 21 09.31	+58 16 05.17	10.510	0.719
3	07 21 57.40	+58 15 10.08	11.622	0.412
4	07 21 39.81	+58 11 20.18	10.318	1.553
5	07 20 45.90	+58 17 18.44	11.512	1.106

Table A5.2. Comparison star data

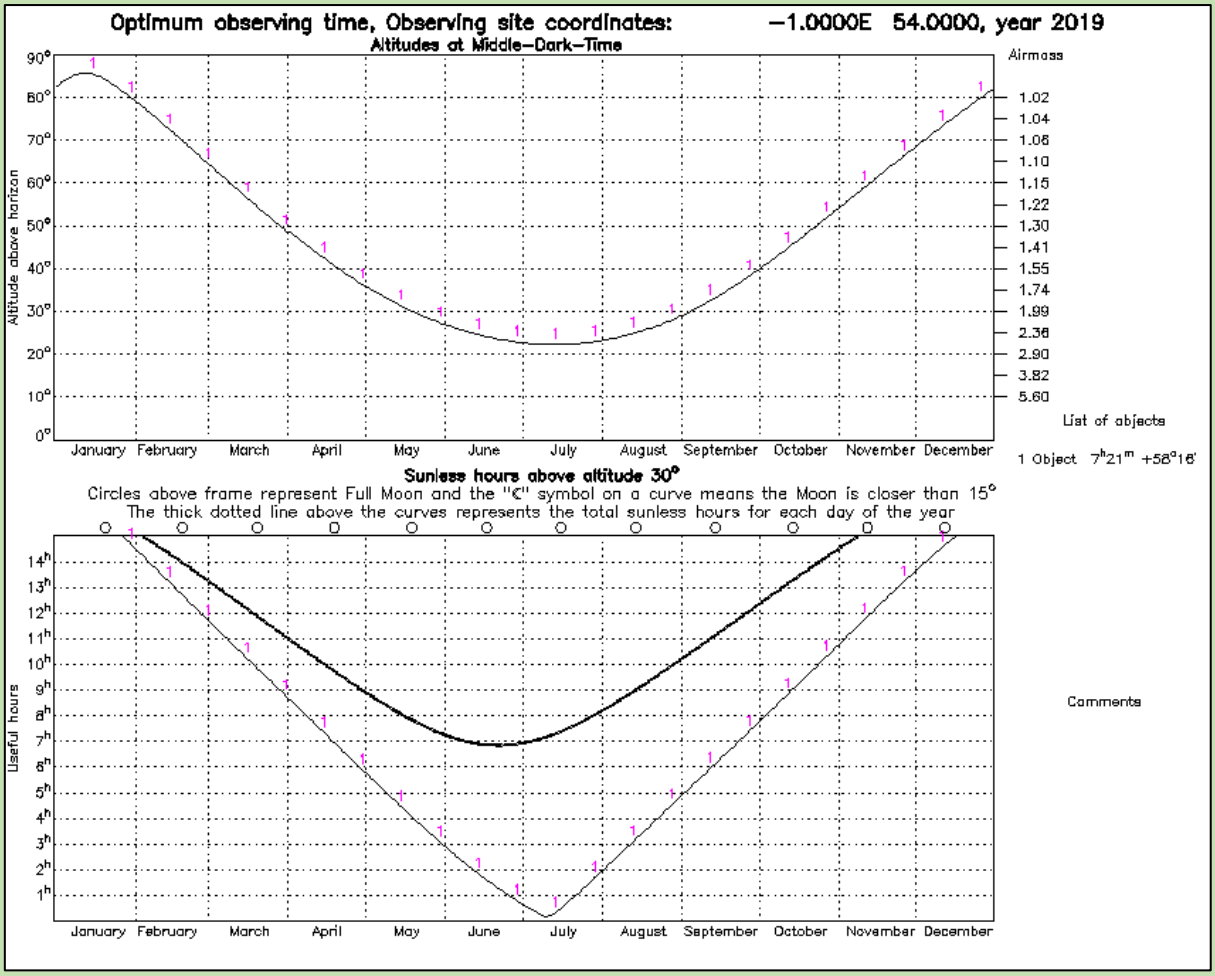


Figure A5.4. Object visibility

Appendix A6

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-8b	22 52 09.86	35 26 49.60	10.30	0.506	11

Table A6.1. Target data

Return to target list

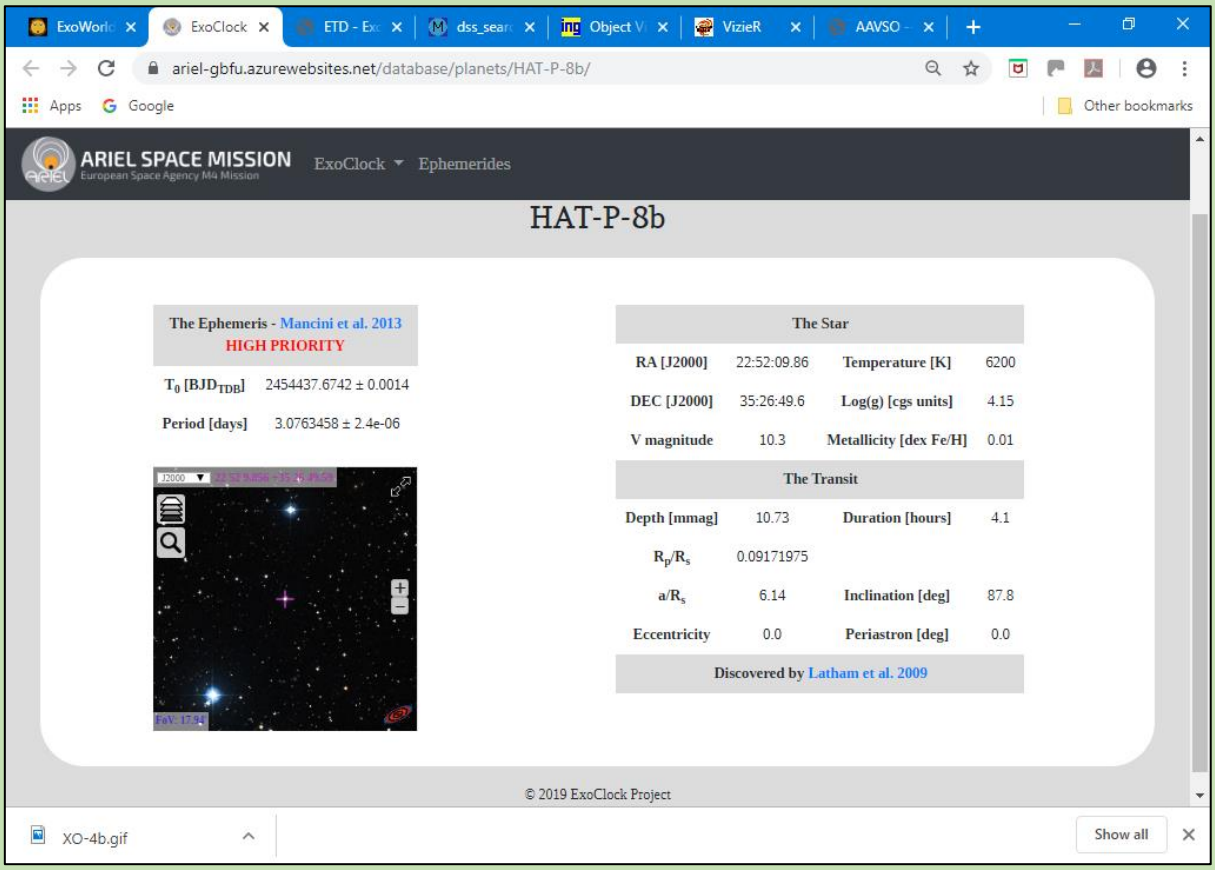


Figure A6.1

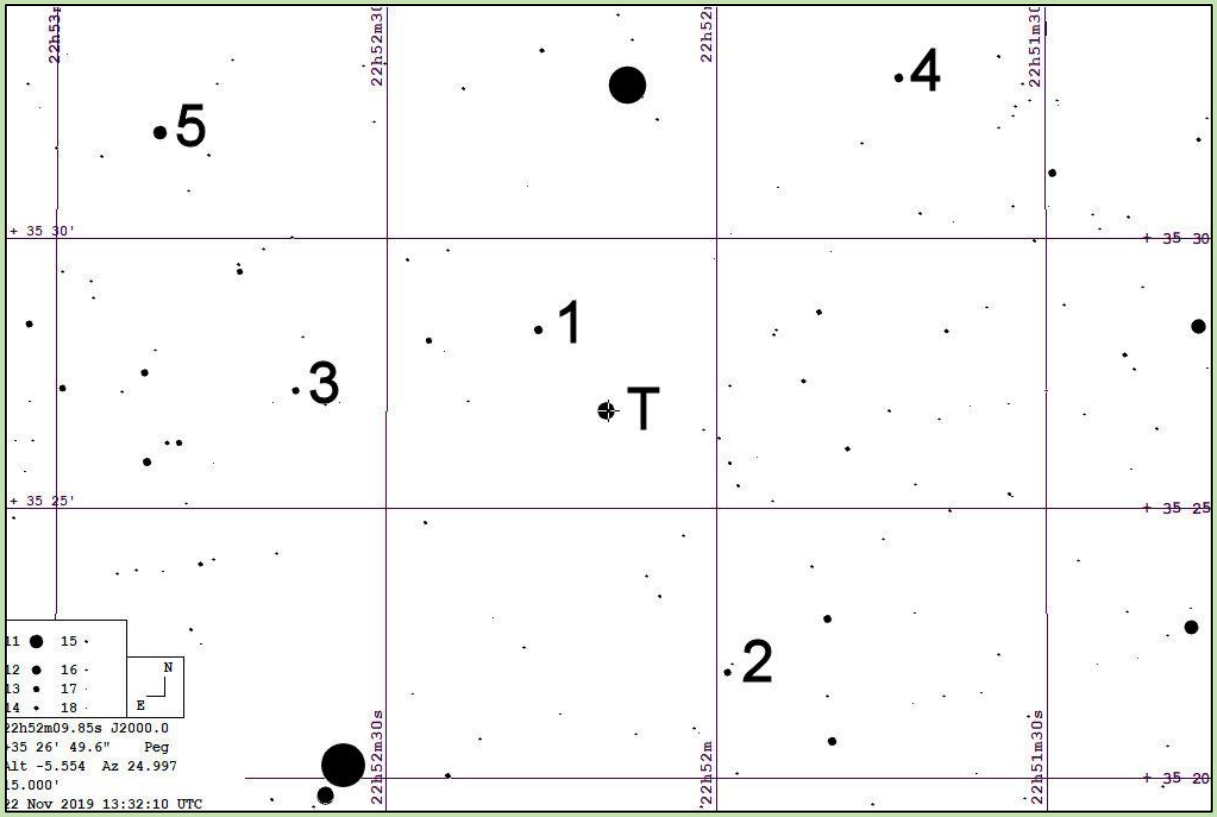


Figure A6.2. Finder chart

Figure A6.3. STScI DSS chart

Nominal criteria for comparison star selection.
0.306<(B-V=0.506)<0.706
8.80<(V=10.30)<11.80

Comp star	RA	Dec	B-V	V mag
1	22 52 16.18	+35 28 19.57	0.464	12.430
2	22 51 58.98	+35 22 00.86	0.557	12.612
3	22 52 38.29	+35 27 13.96	0.745	12.704
4	22 51 43.33	+35 33 00.20	0.541	12.394
5	22 52 50.66	+35 31 58.99	0.452	10.904

Table A6.2. Comparison star data

Note. Data for Comparison star 5 is from Guide

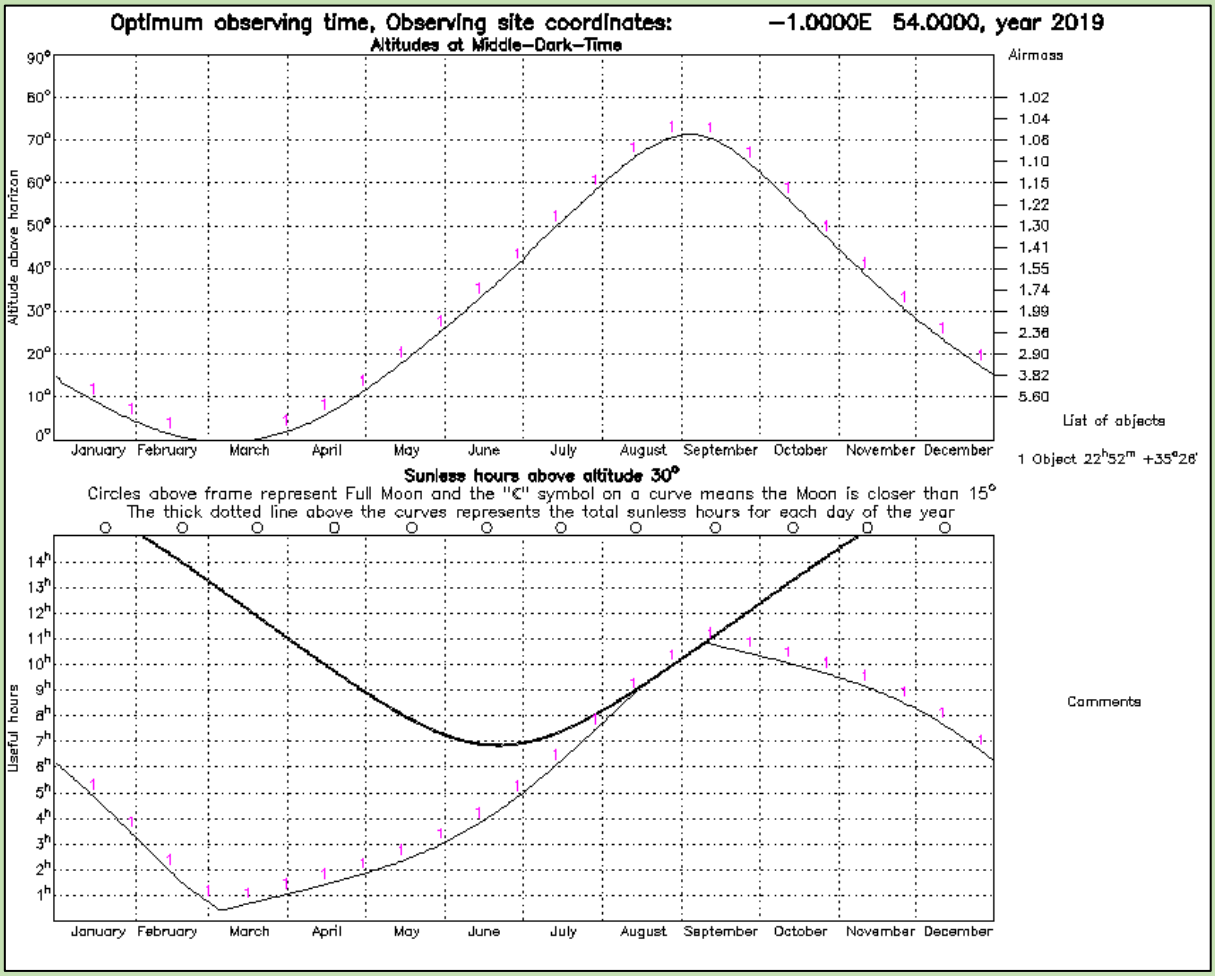


Figure A6.4. Object visibility

Appendix A.7

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-17b	21 38 08.74	30 29 19.4	10.54	0.802	20

Table A7.1. Target data

Return to target list

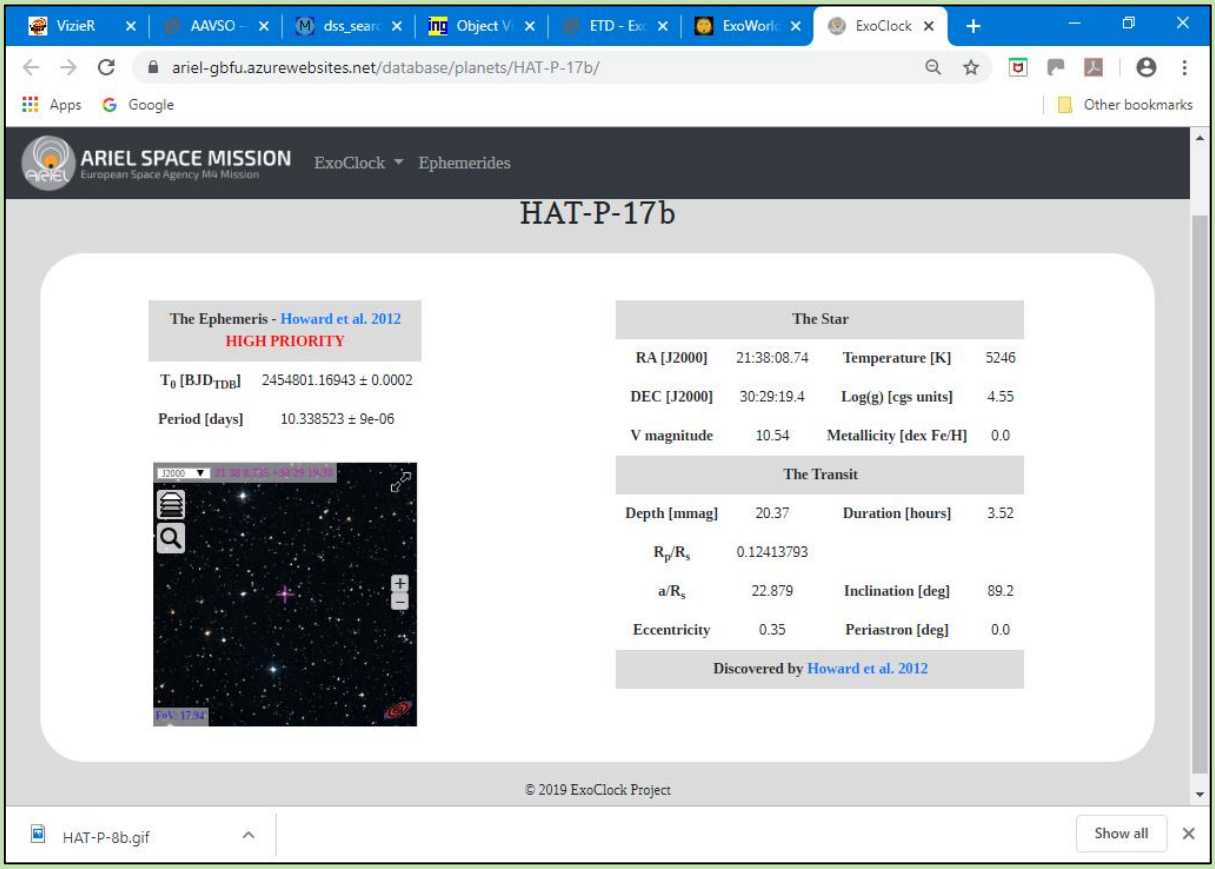
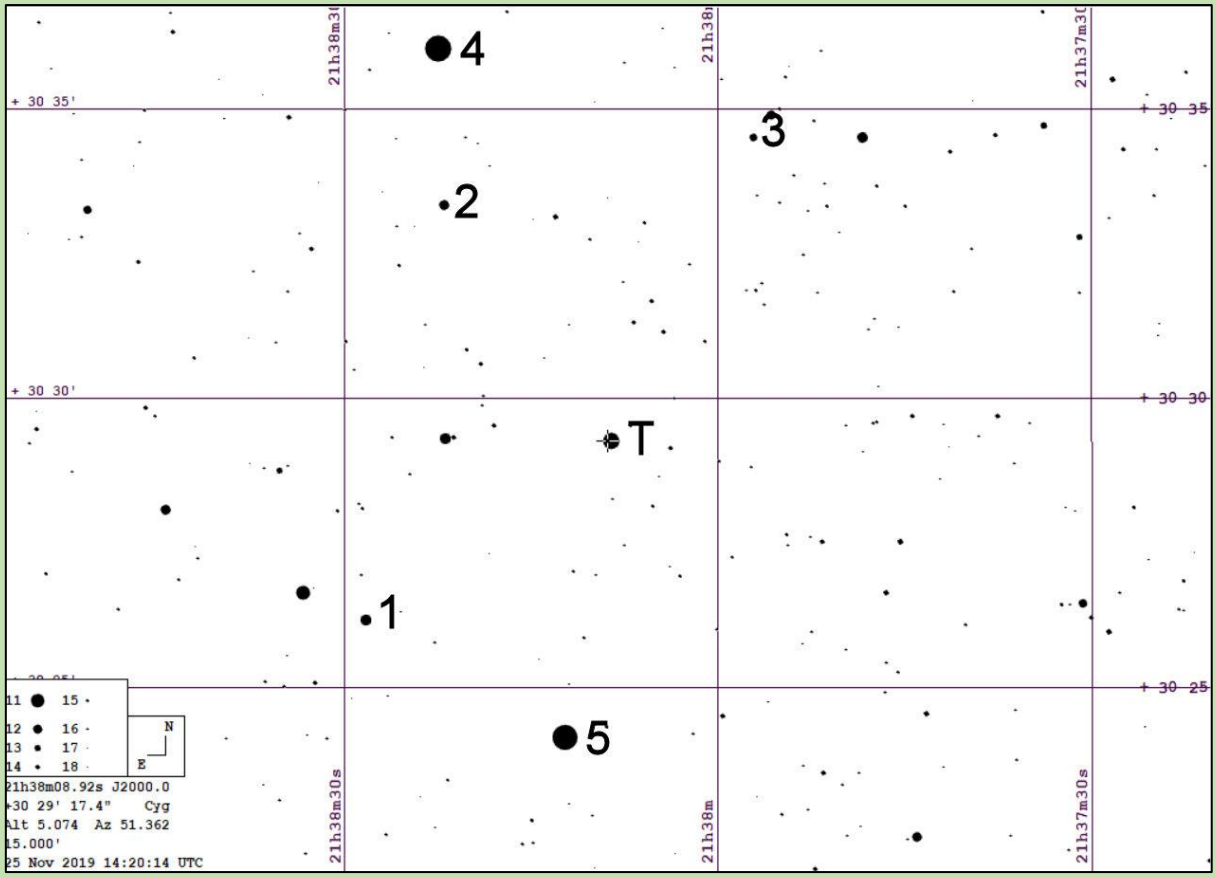


Figure A7.1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2
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+ 30 35'
+ 30 30'
+ 30 25'
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21h38m
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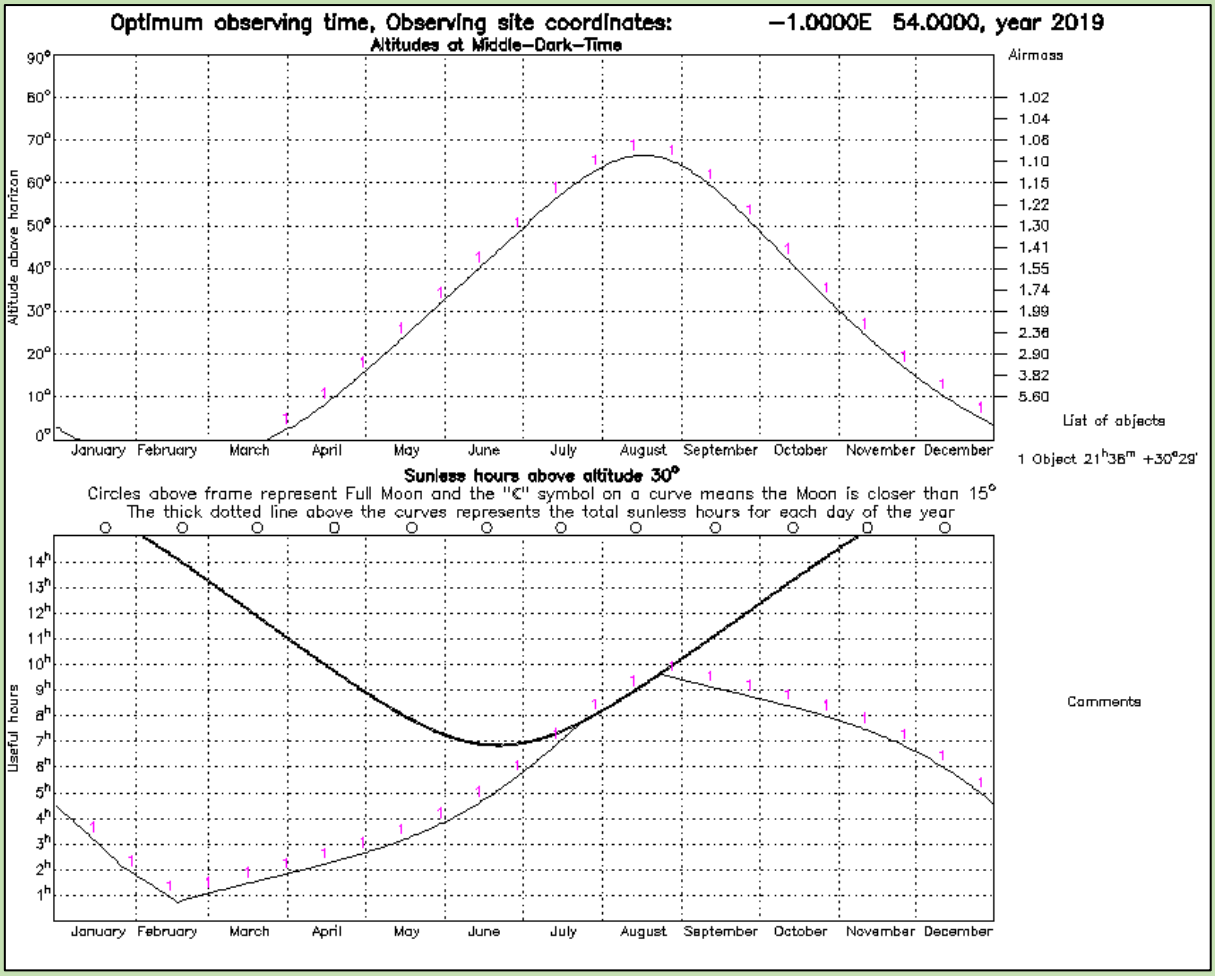
11 15
12 16
13 17
14 18
N
E
21h38m08.92s J2000.0
+30 29' 17.4" Cyg
Alt 5.074 Az 51.362
15.000'
25 Nov 2019 14:20:14 UTC
Figure A7.2

Figure A7,3

Nominal criteria for comparison star selection.
0.602<(B-V=0.802)<0.1.002
9.04<(V=10.54)<12.04

Comp star	RA	Dec	V mag	B-V
1	21 38 21.99	+30 33 22.11	11.921	0.270
2	21 38 28.25	+30 26 11.03	11.322	0.400
3	21 37 57.21	+30 34 33.34	12.494	0.598
4	21 38 22.39	+30 36 03.02	9.050	0.503
5	21 38 12.33	+30 24 09.88	9.397	0.301

Table A7.2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Altitudes at Middle-Dark-Time
Altitude above horizon
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80°
70°
60°
50°
40°
30°
20°
10°
0°
January February March April May June July August September October November December
Airmass
1.02
1.04
1.06
1.10
1.15
1.22
1.30
1.41
1.55
1.74
1.99
2.36
2.90
3.82
5.60
List of objects
1 Object 21h36m +30°29'
Sunless hours above altitude 30°
Circles above frame represent Full Moon and the "€" symbol on a curve means the Moon is closer than 15°
The thick dotted line above the curves represents the total sunless hours for each day of the year
Useful hours
14h
13h
12h
11h
10h
9h
8h
7h
6h
5h
4h
3h
2h
1h
January February March April May June July August September October November December
Comments

Figure A7.4

Appendix A.8

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-3b	13 44 22.59	48 01 43.2	11.58	0.817	16

Table A8.1

Return to target list

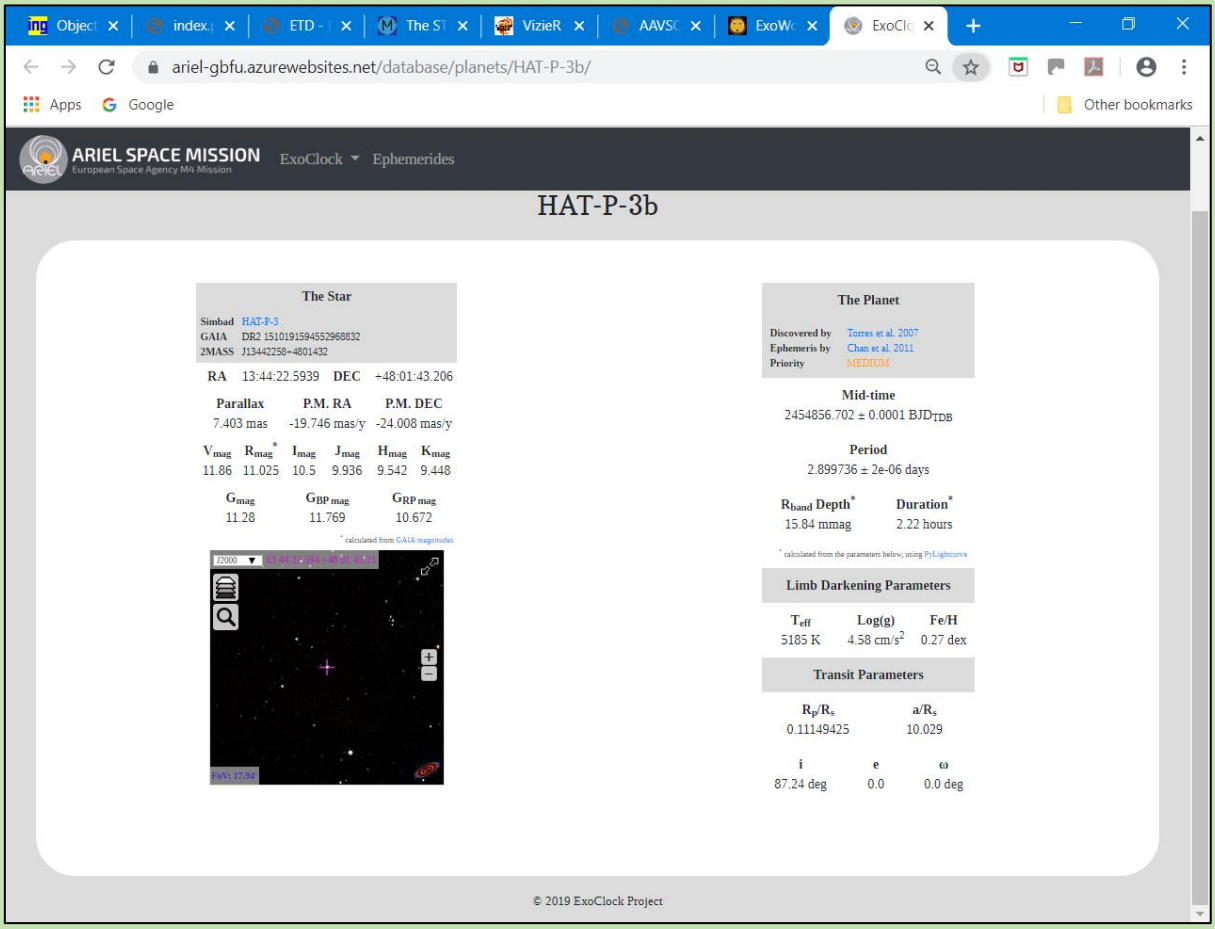


Figure A8.1

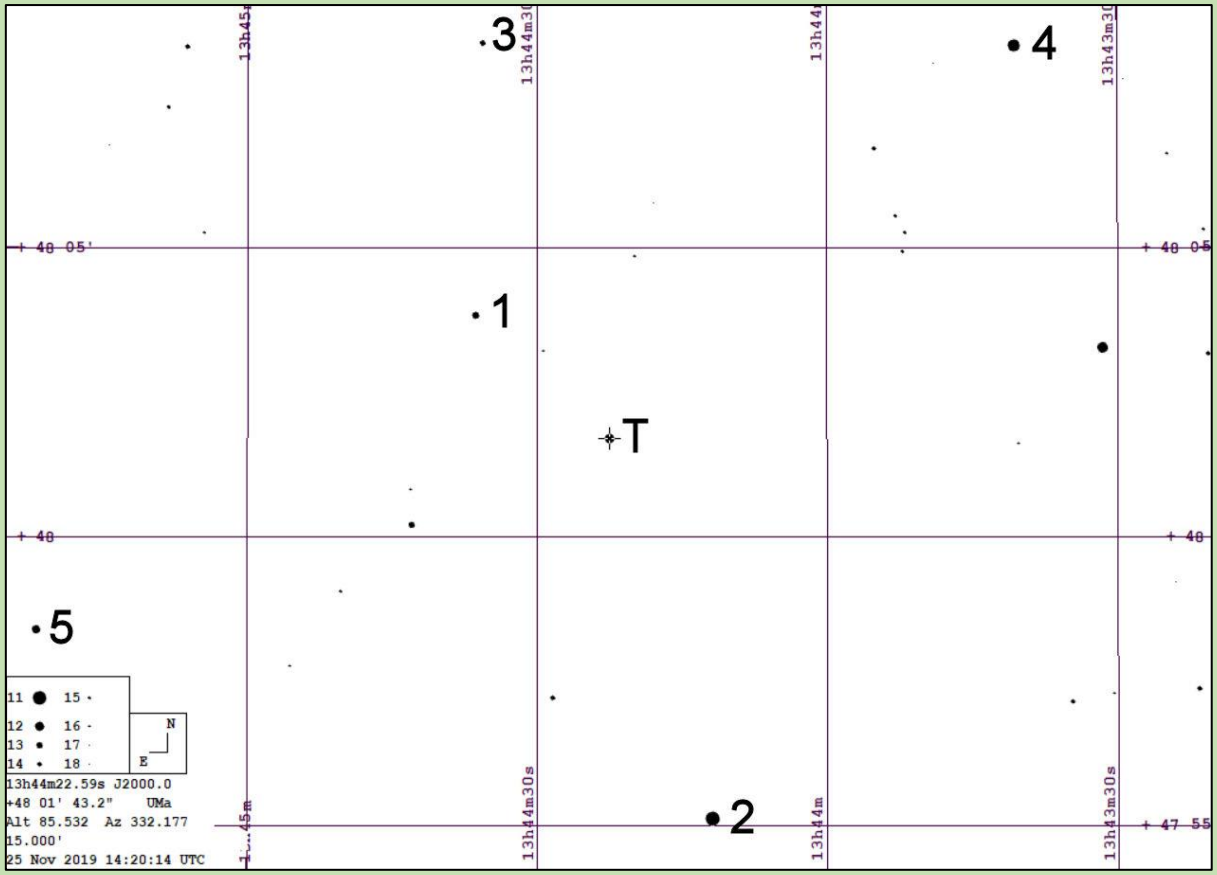

3
4
1
T
5
2
+48 05'
+48
+47 55
13h44m30s
13h43m30s
11 15
12 16
13 17
14 18
N
E
13h44m22.59s J2000.0
+48 01' 43.2" UMa
Alt 85.532 Az 332.177
15.000'
25 Nov 2019 14:20:14 UTC
Figure A8.2

Figure A8.3

Nominal criteria for comparison star selection.
0.617<(B-V=0.817)<1.017
10.08<(V=11.58)<12.08

Comp star	RA	Dec	V mag	B-V
1	13 44 36.38	+48 03 52.56	12.770	0.807
2	13 44 11.84	+47 55 08.00	10.694	0.684
3	13 44 35.66	+48 08 33.94	13.193	0.606
4	13 43 40.61	+48 08 30.29	11.178	0.560
5	13 45 21.80	+47 58 24.41	12.575	1.154

Table A8.2

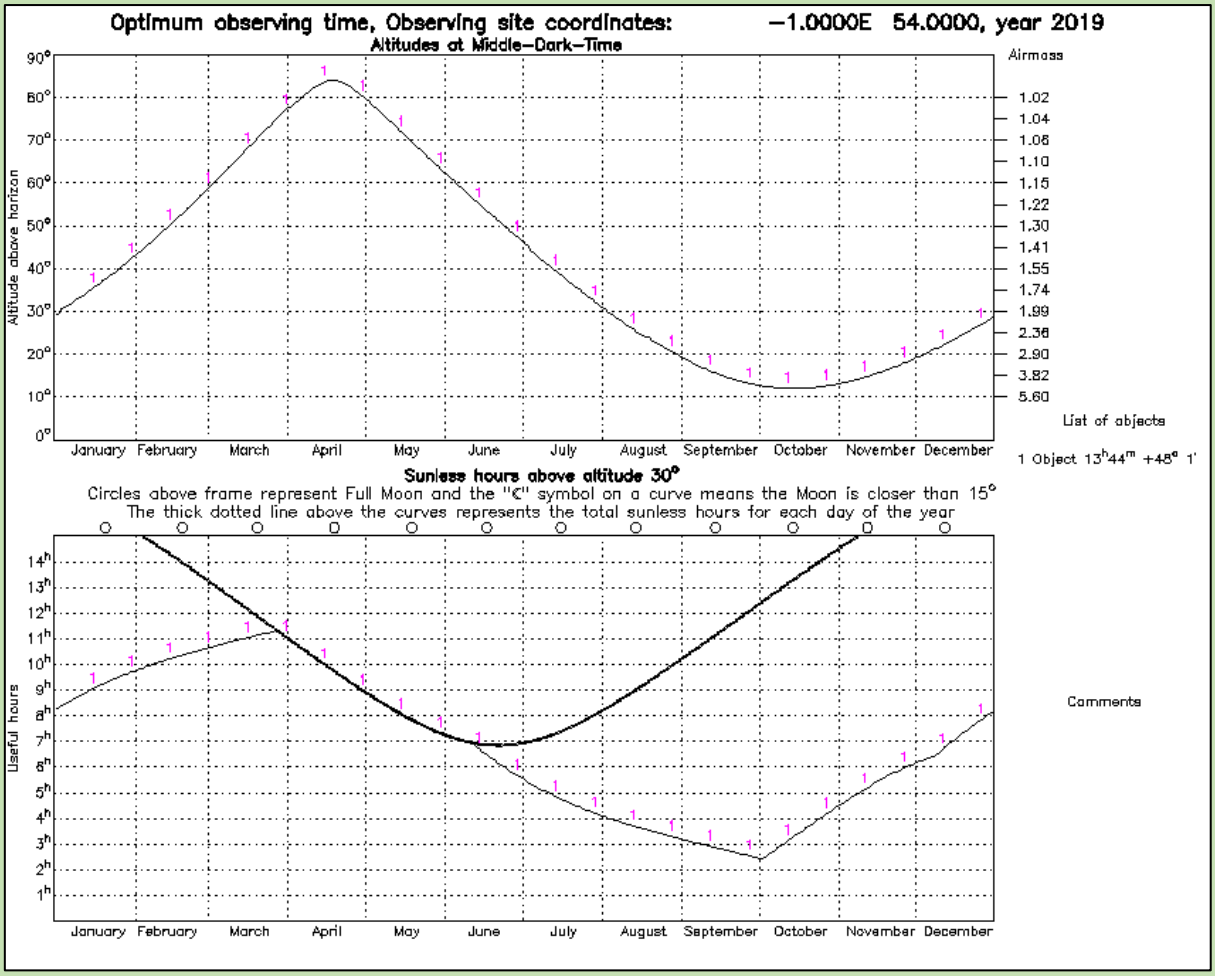

Optimum observing time, Observing site coordinates: −1.0000E 54.0000, year 2019
Altitudes at Middle−Dark−Time
Altitude above horizon
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
January February March April May June July August September October November December
Airmass
1.02
1.04
1.06
1.10
1.15
1.22
1.30
1.41
1.55
1.74
1.99
2.36
2.90
3.82
5.60
List of objects
1 Object 13h44m +48° 1'
Sunless hours above altitude 30°
Circles above frame represent Full Moon and the "€" symbol on a curve means the Moon is closer than 15°
The thick dotted line above the curves represents the total sunless hours for each day of the year
Useful hours
14h
13h
12h
11h
10h
9h
8h
7h
6h
5h
4h
3h
2h
1h
January February March April May June July August September October November December
Comments

Figure A8.4

Appendix A9

Target	RA	Dec	V	B-V	Depth (mmag)
WASP-11b	03 09 28.55	30 40 24.9	11.60	0.964	23

Table A9.1

Note. No ETD entry for this target

Return to target list

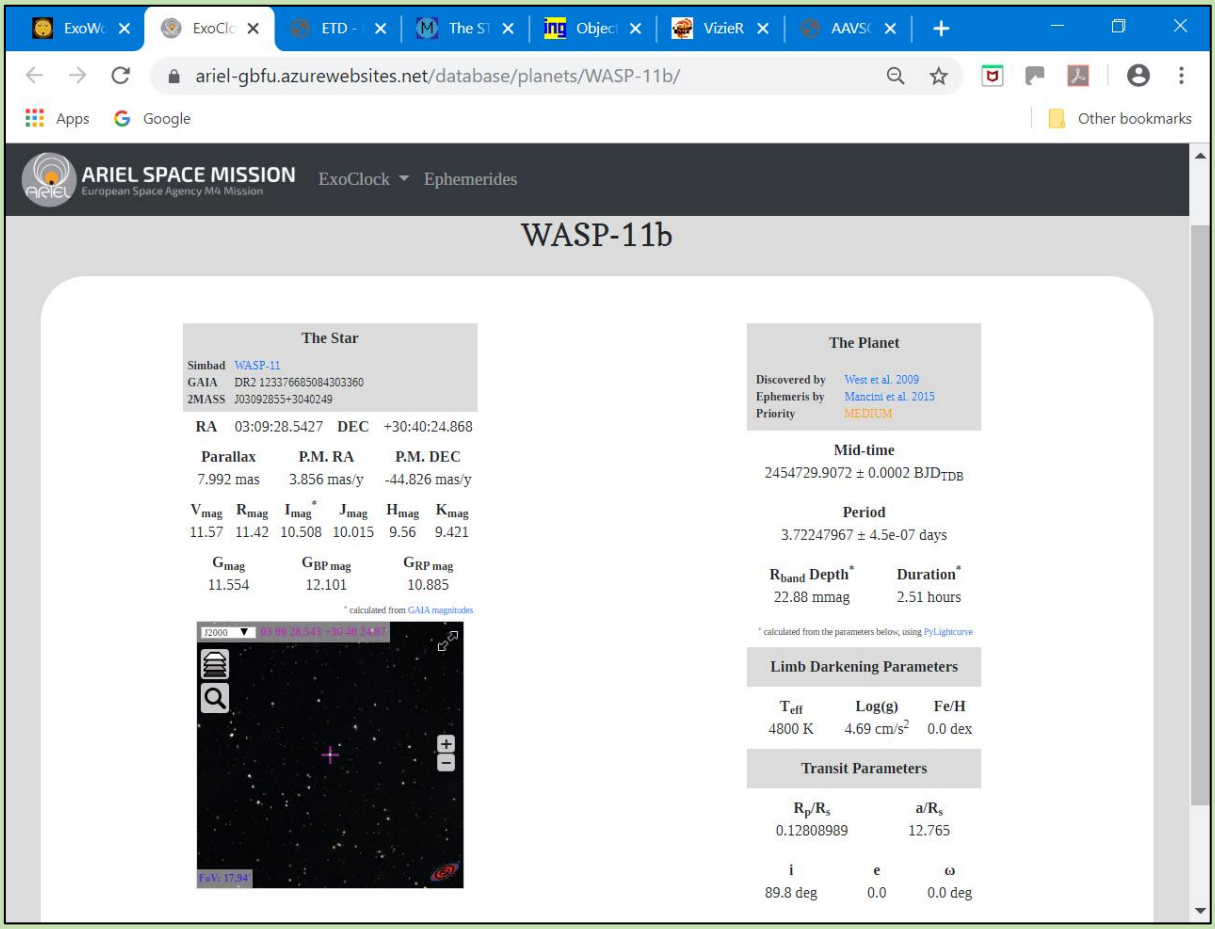
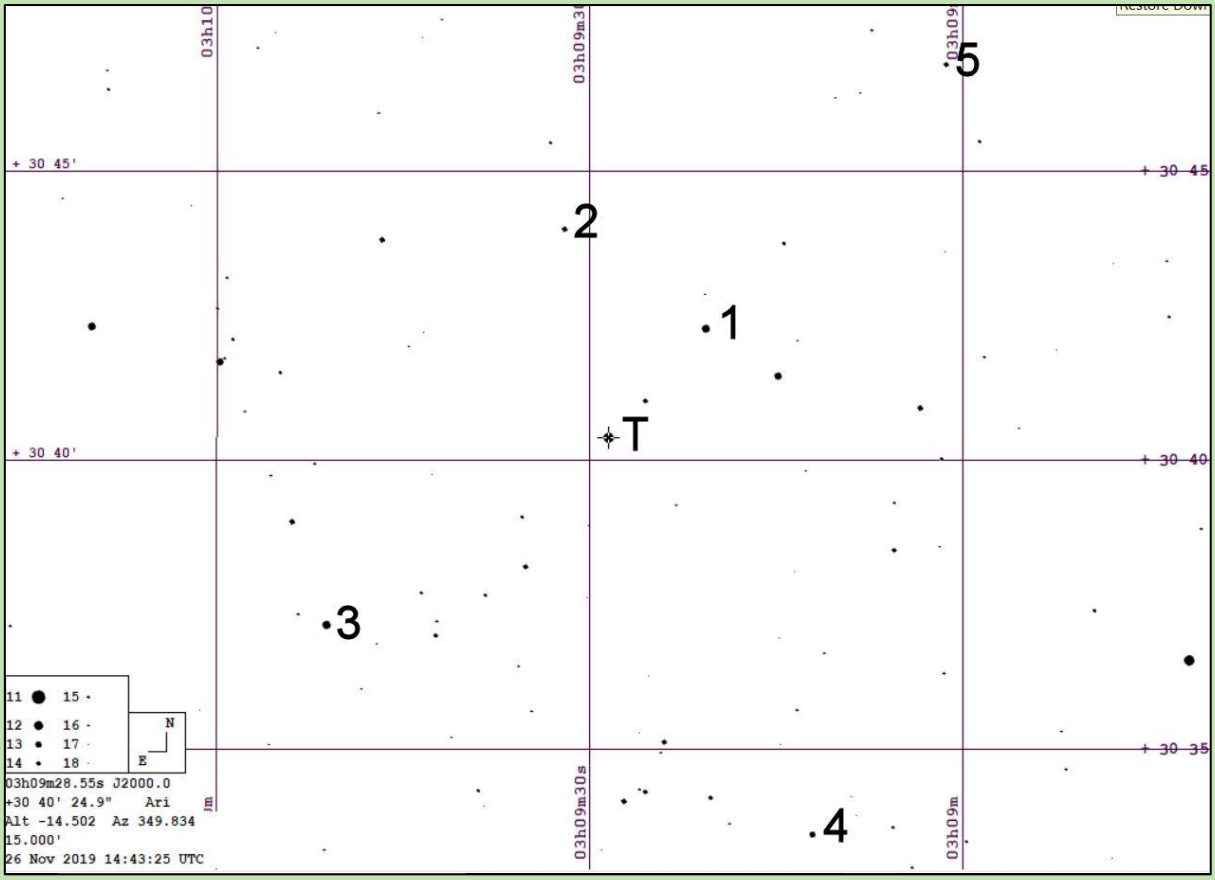


Figure A9.1


03h10
03h09m30s
03h09
+ 30 45'
+ 30 40'
+ 30 35'
5
2
1
T
3
4
11 15
12 16
13 17
14 18
N
E
03h09m28.55s J2000.0
+30 40' 24.9" Ari
Alt -14.502 Az 349.834
15.000'
26 Nov 2019 14:43:25 UTC
Figure A9.2

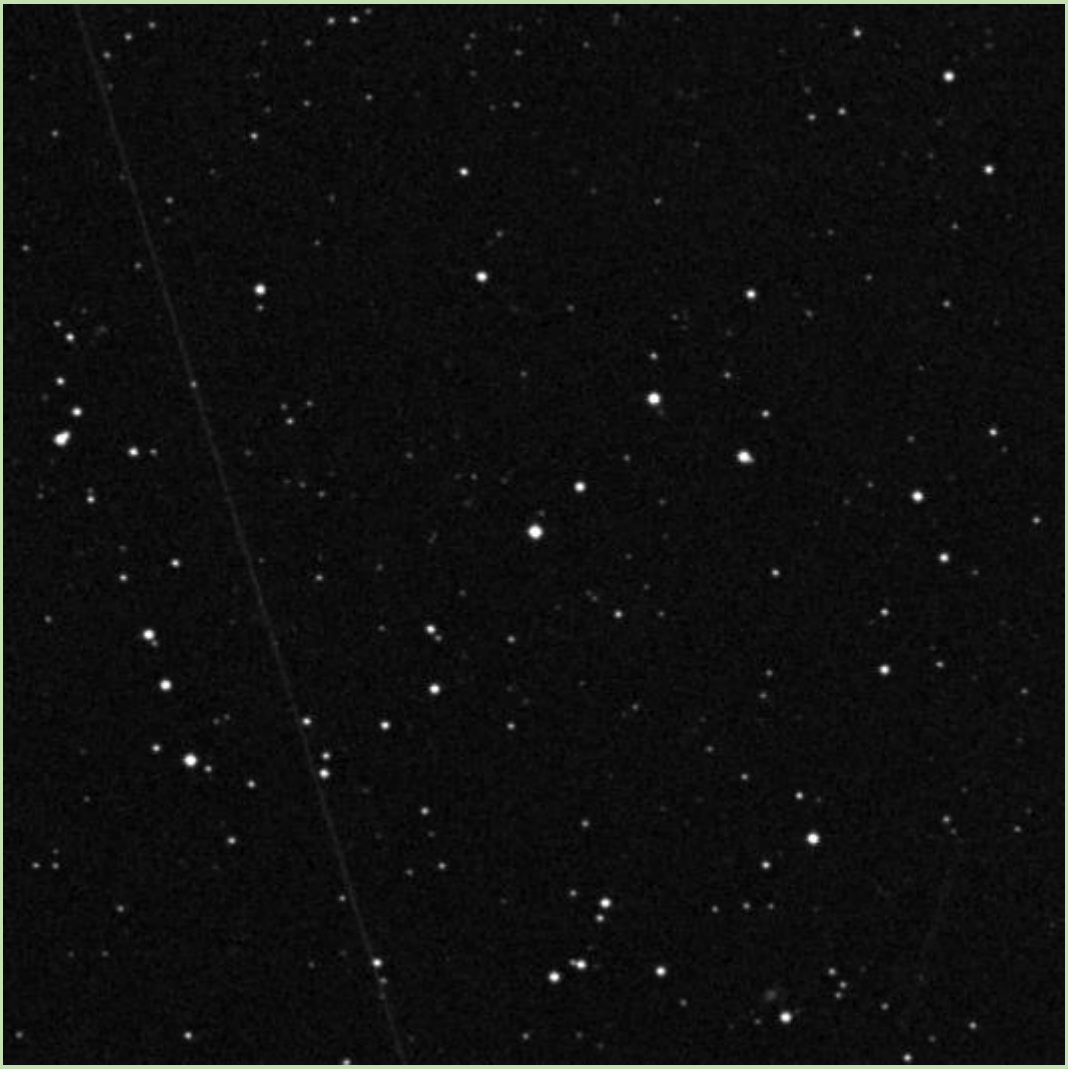


Figure A9.3

Nominal criteria for comparison star selection.
0.764<(B-V=0.964)<1.164
10.90<(V=11.60)<12.90

Target	RA	Dec	V mag	B-V
1	03 09 14.81952	+30 41 29.0436	12.625	0.716
2	03 09 32.07264	+30 44 02.4324	13.567	0.746
3	03 09 51.18816	+30 37 11.2548	12.480	1.120
4	03 09 12.08064	+30 33 33.1380	13.456	1.311
5	03 09 01.28328	+30 46 52.3704	13.853	1.257

Table A9.2

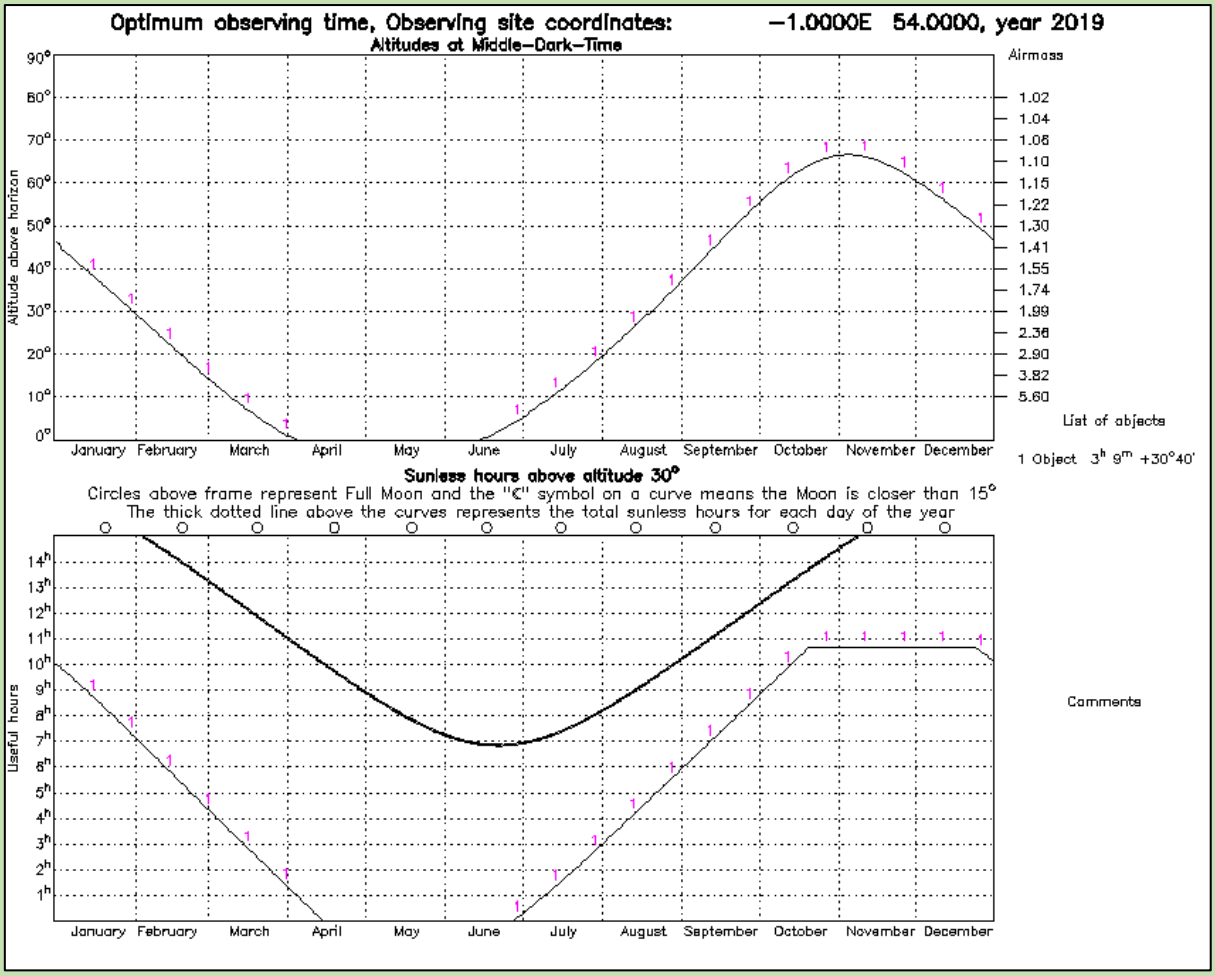

Optimum observing time, Observing site coordinates: −1.0000E 54.0000, year 2019
Altitudes at Middle−Dark−Time
Altitude above horizon
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
January February March April May June July August September October November December
Airmass
1.02
1.04
1.06
1.10
1.15
1.22
1.30
1.41
1.55
1.74
1.99
2.36
2.90
3.82
5.60
List of objects
1 Object 3h 9m +30°40'
Sunless hours above altitude 30°
Circles above frame represent Full Moon and the "€" symbol on a curve means the Moon is closer than 15°
The thick dotted line above the curves represents the total sunless hours for each day of the year
Useful hours
14h
13h
12h
11h
10h
9h
8h
7h
6h
5h
4h
3h
2h
1h
January February March April May June July August September October November December
Comments

Figure A9.4

Appendix A10

Target	RA	Dec	V mag	Depth (mmag)
HAT-P-12b	13 57 33.48	43 29 36.7	12.84	28

Table A10.1

Return to target list

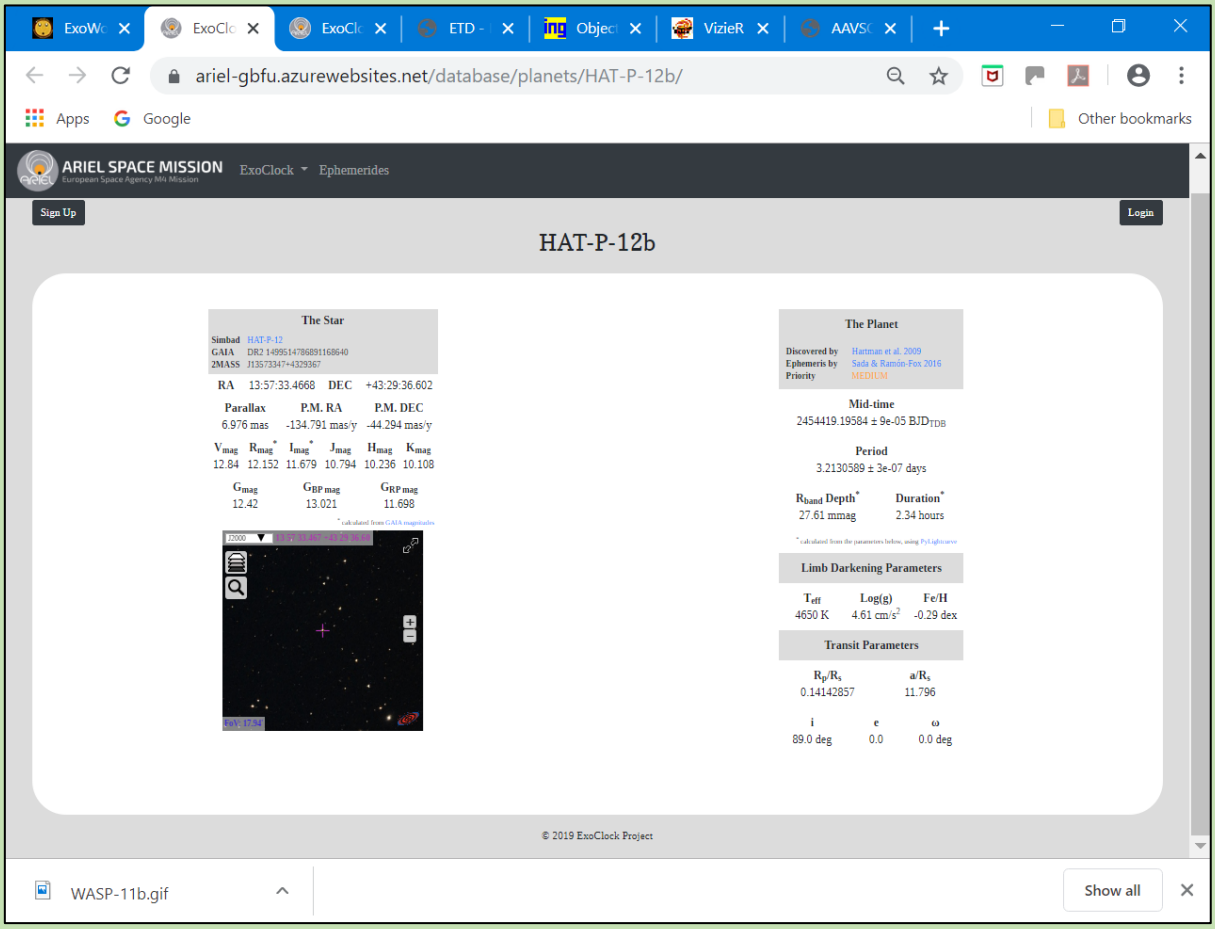


Figure A10.1

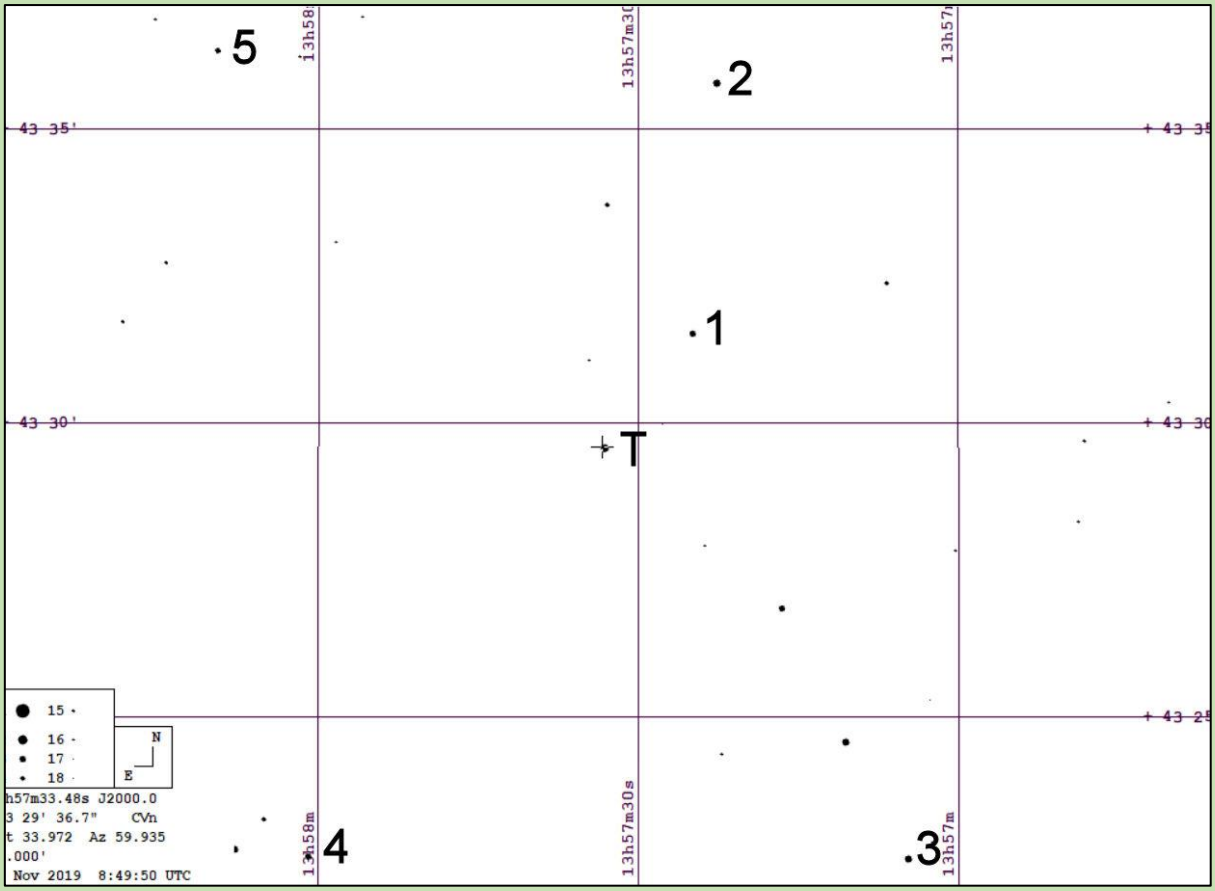


Figure A10.2

Figure A10.3

Nominal criteria for comparison star selection.
0.886<(B-V=1.086)<1.286
11.266<(V=12.766)<13.266

Comp star	RA	Dec	V mag	B-V
1	13 57 24.99	+43 31 33.60	13.130	0.921
2	13 57 22.64	+43 35 48.35	12.626	0.771
3	13 58 00.95	+43 22 39.54	13.197	1.005
4	13 57 04.84	+43 22 36.07	12.811	0.893
5	13 58 09.52	+43 36 21.46	13.305	0.678

Table A10.2

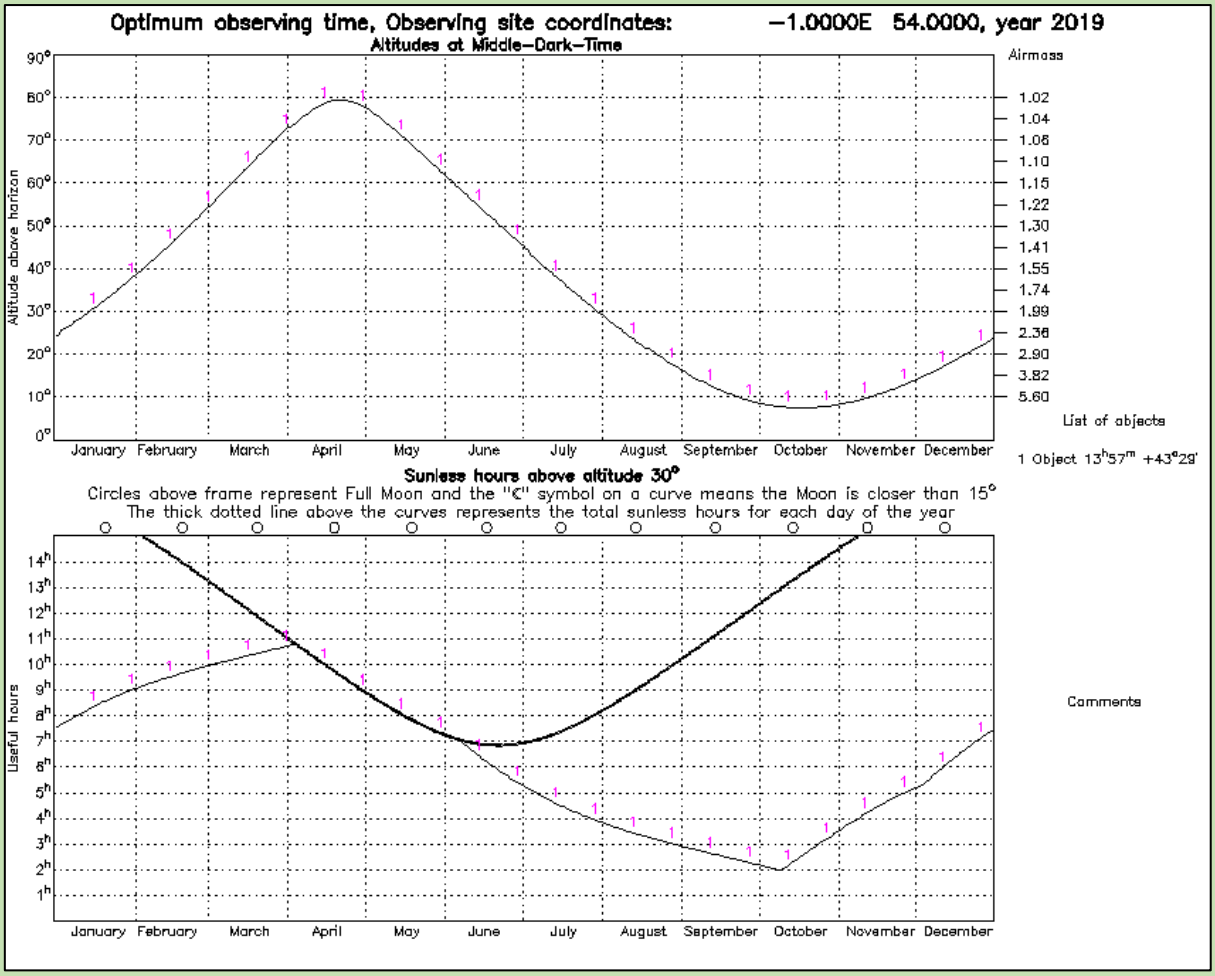

Optimum observing time, Observing site coordinates: −1.0000E 54.0000, year 2019
Altitudes at Middle−Dark−Time
Altitude above horizon
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
January February March April May June July August September October November December
Airmass
1.02
1.04
1.06
1.10
1.15
1.22
1.30
1.41
1.55
1.74
1.99
2.36
2.90
3.82
5.60
List of objects
1 Object 13h57m +43°29'
Sunless hours above altitude 30°
Circles above frame represent Full Moon and the "€" symbol on a curve means the Moon is closer than 15°
The thick dotted line above the curves represents the total sunless hours for each day of the year
Useful hours
14h
13h
12h
11h
10h
9h
8h
7h
6h
5h
4h
3h
2h
1h
January February March April May June July August September October November December
Comments

Figure A10.4

Appendix B

Python/HOPS installation notes

1.0 Python Installation

See https://exoworldsspies.com/en/software/

Installation has been problematic for some, including myself, so these notes and screenshots will help you through the process. Please follow the installation instructions exactly as described on the above website.

Visit the Anaconda website

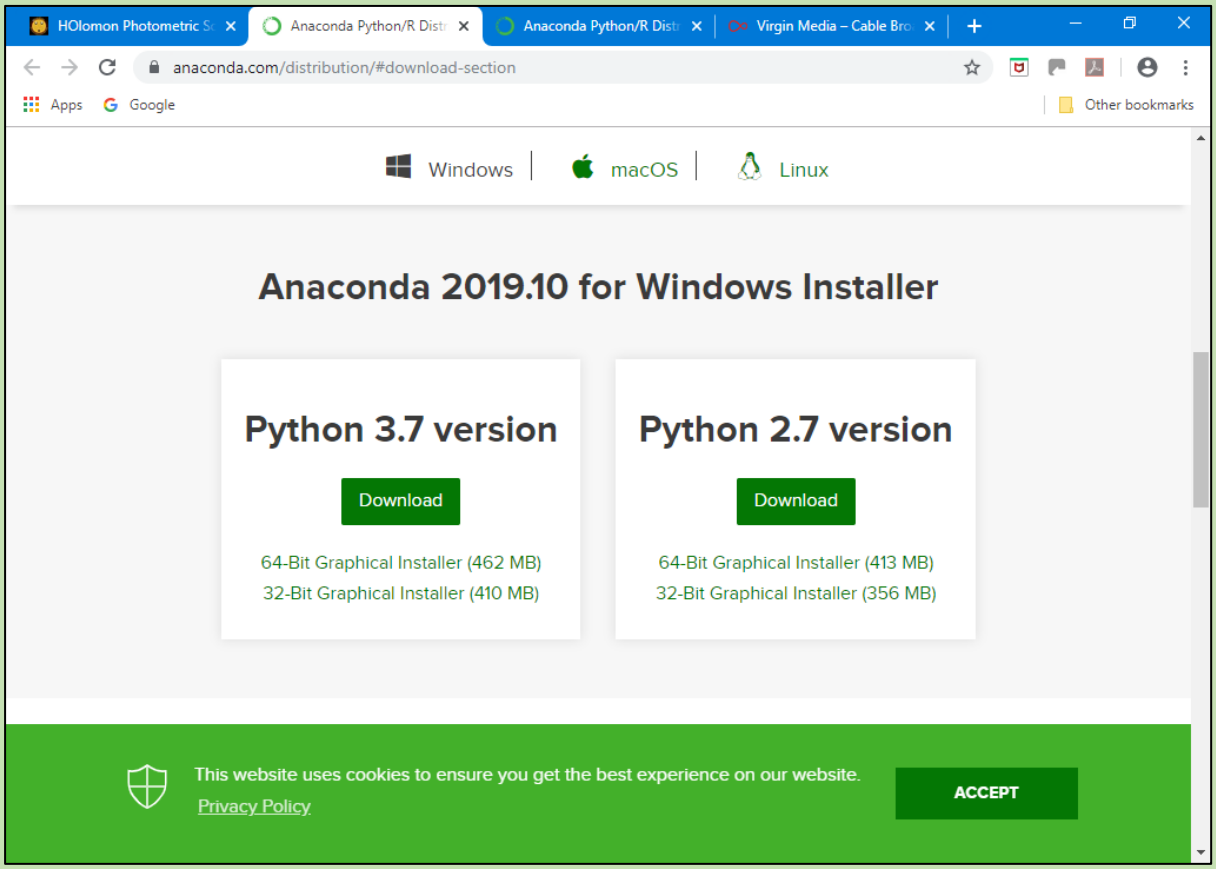


Figure B1.1

Click on “Download” under Python 3.7 version and choose 64 or 32 bits to suit your system and save (in Downloads for example).

Open file

Figure B1.2

Select ‘Next’

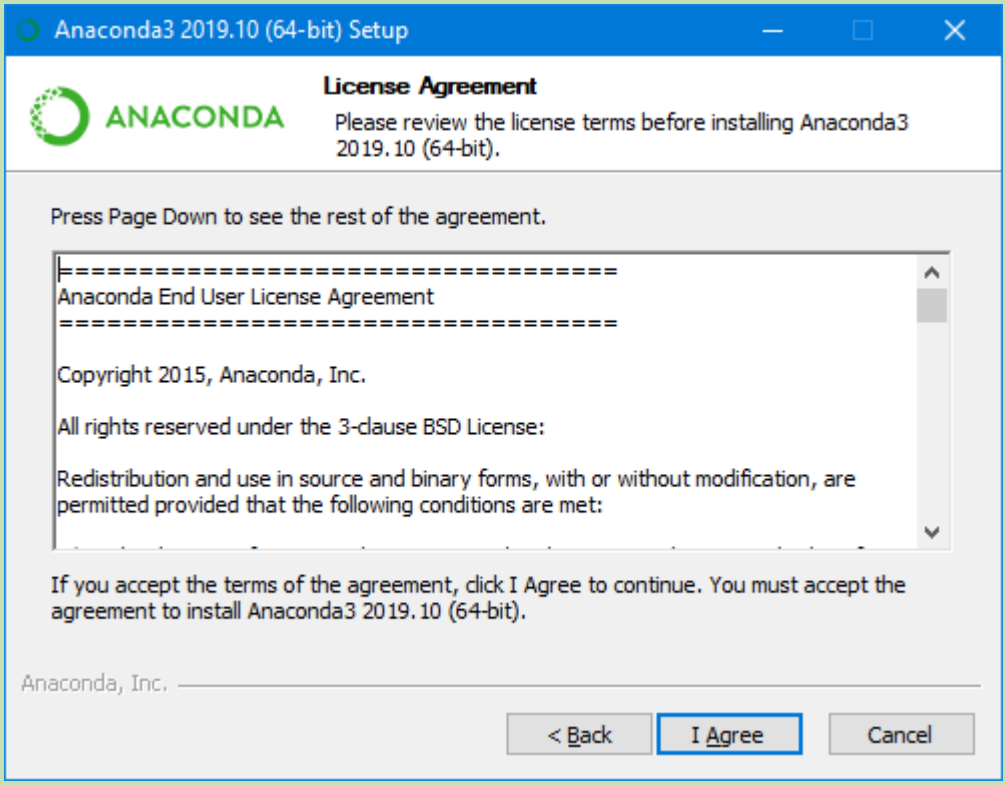


Figure B1.3

Select ‘I Agree’

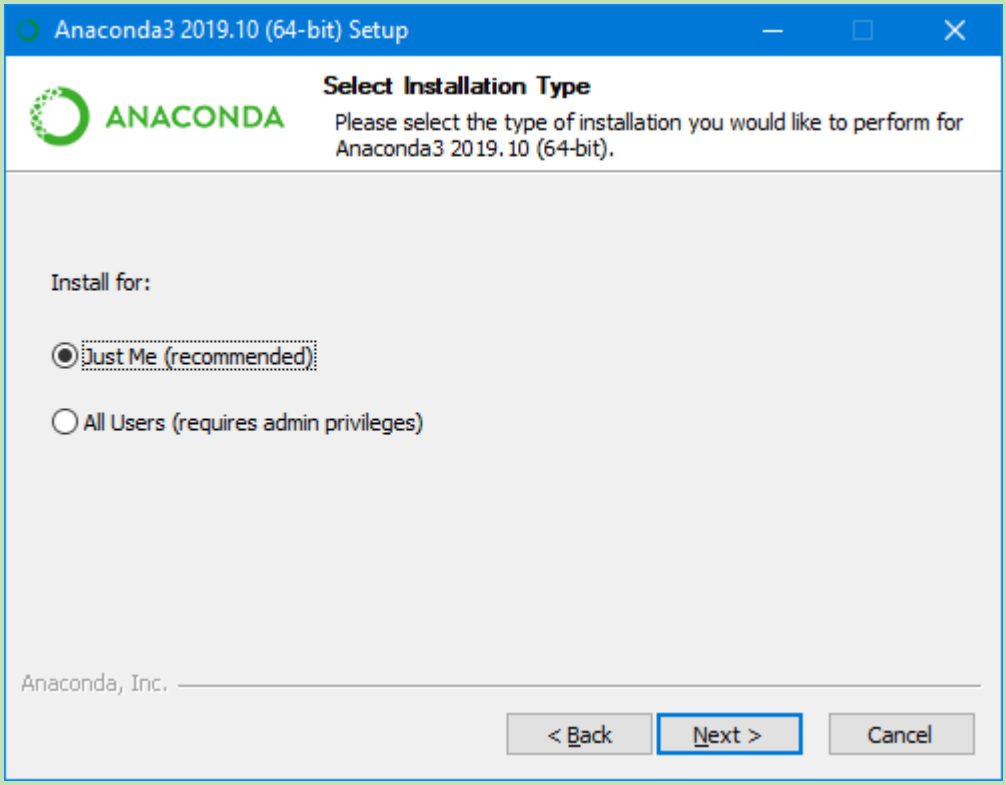


Figure B1.4

Select ‘Just Me (recommended) and then ‘Next’

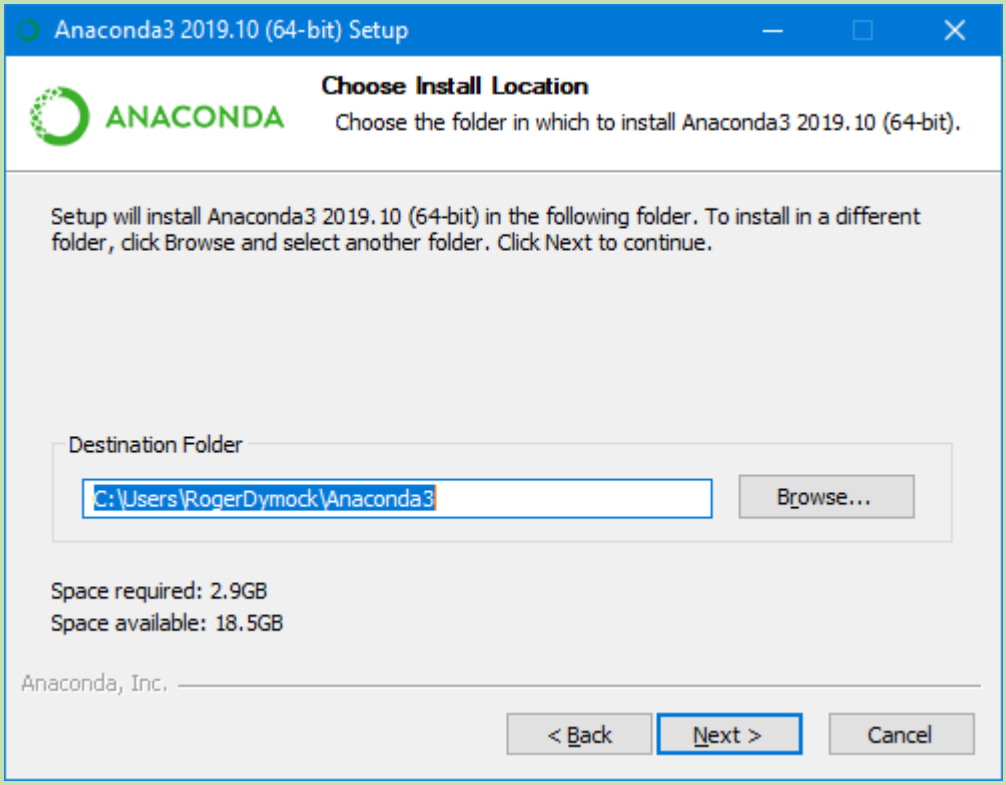


Figure B1.5

Suggest you use whatever destination folder is shown and then select ‘Next’

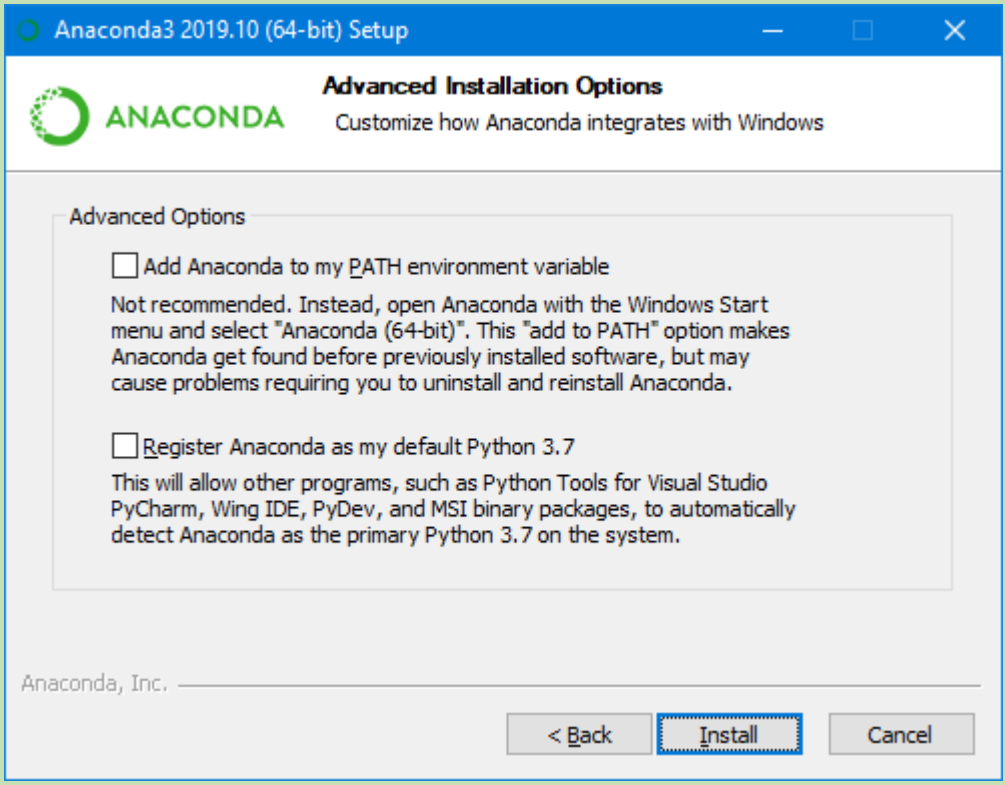


Figure B1.6

Very important - check both boxes (Don't leave blank as in this screen shot) and then select 'Install'

This next bit takes several minutes to complete.

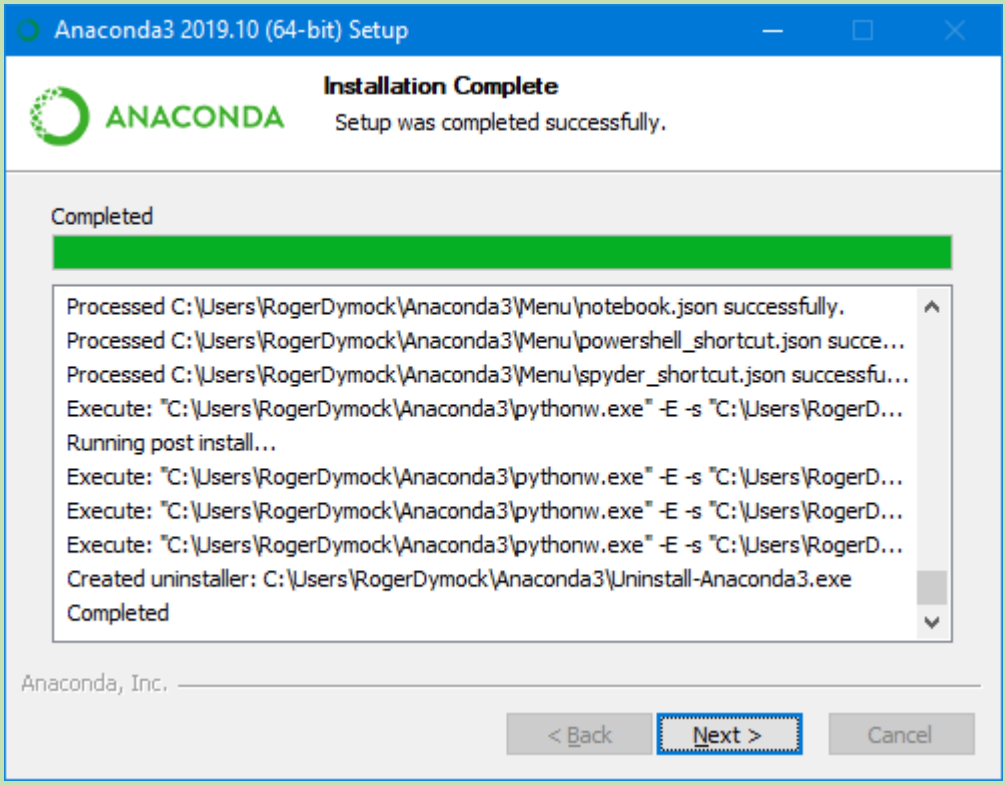


Figure B1.7

Select ‘Next’

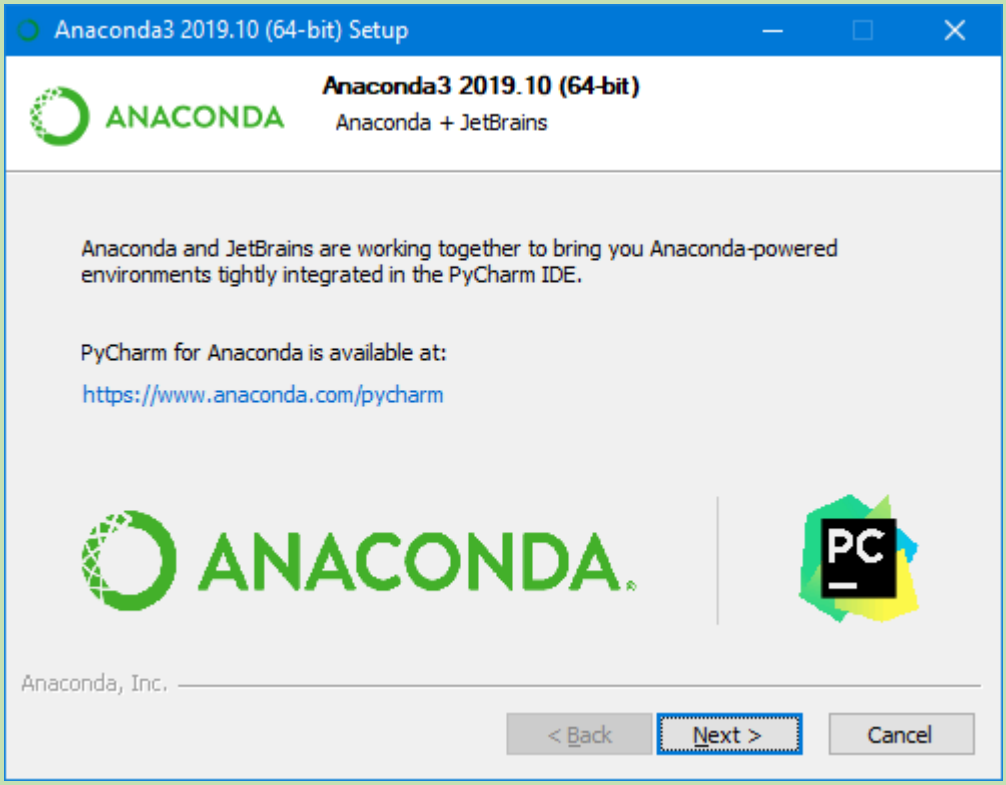


Figure B1.8

Select ‘Next’

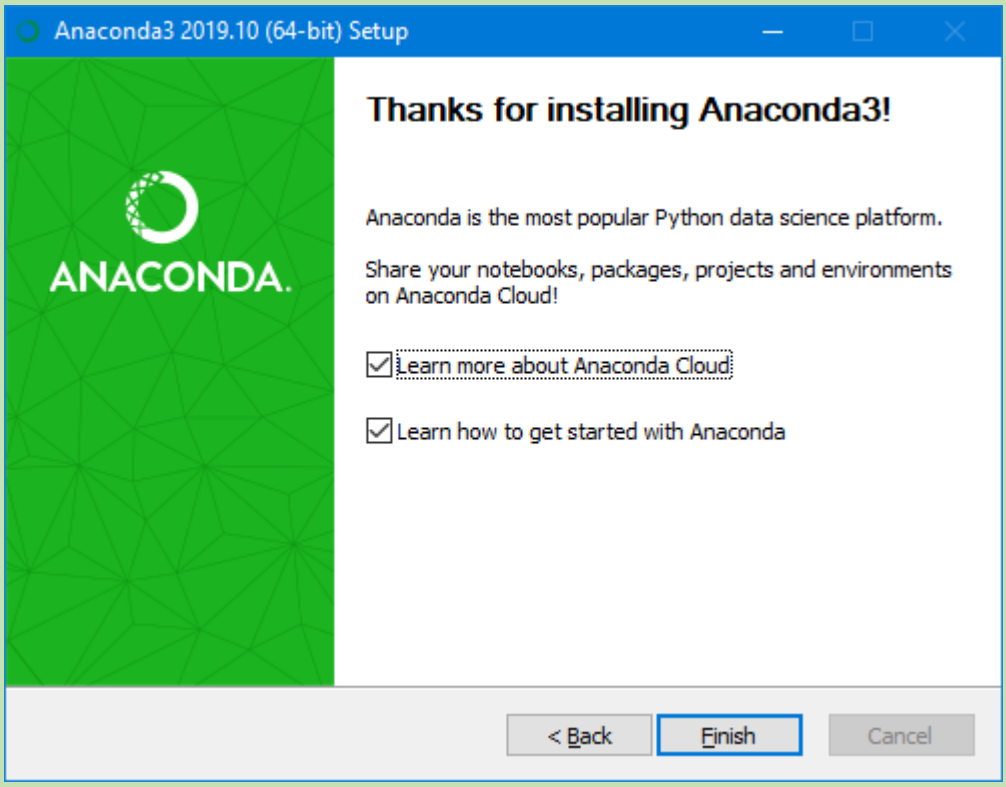


Figure B1.9

Tick or untick two boxes as required and then select ‘Finish’

2.0 HOPS Installation

Download the code from GITHUB

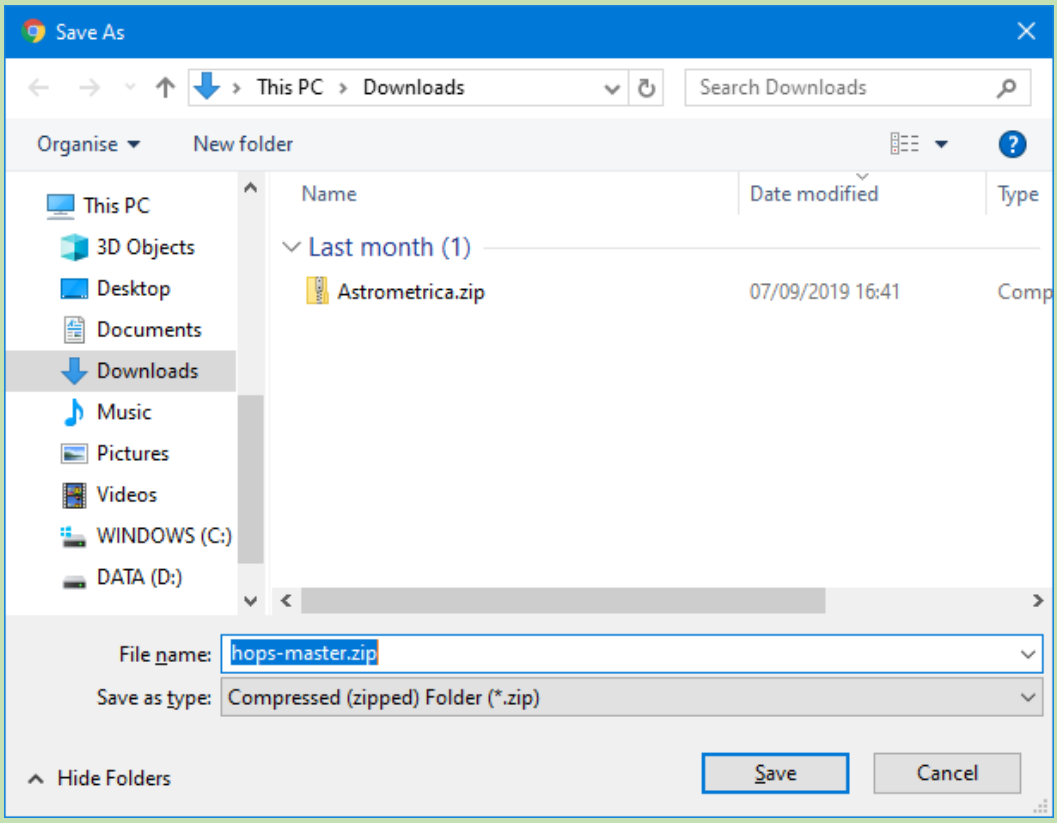


Figure B2.1

Select ‘Save’

Unzip by right-clicking on the ‘hops-master.zip file and selecting Extract all.

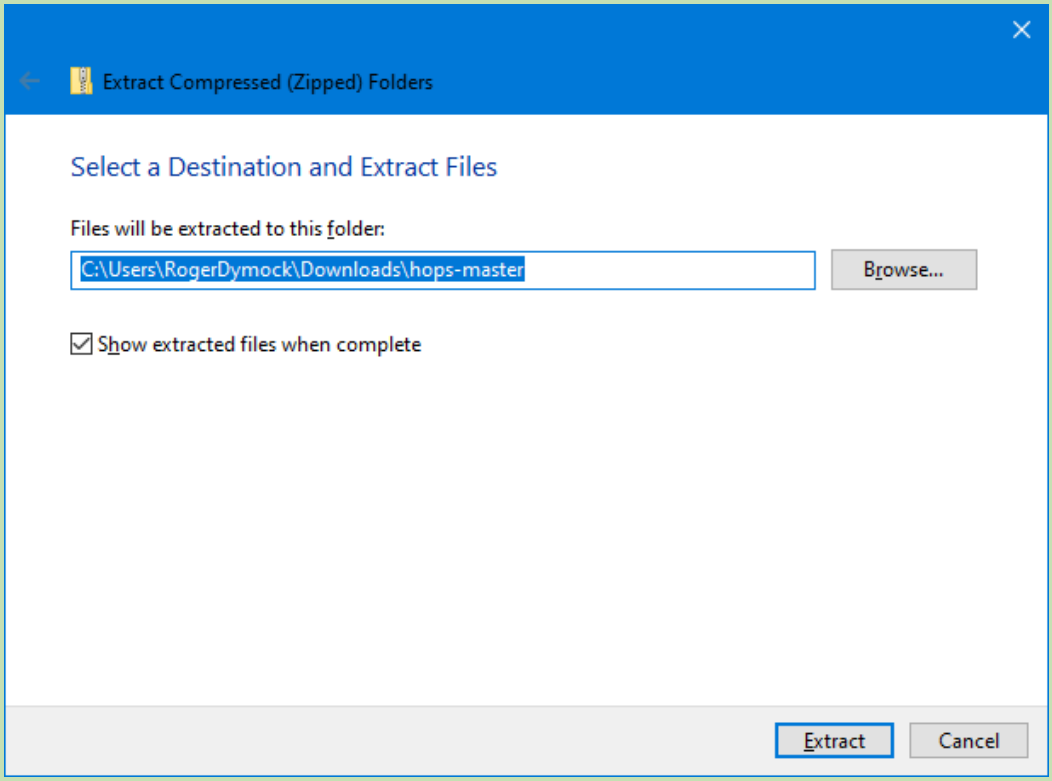


Figure B2.2

Select ‘Extract’

In the folder ‘hops-master double’ click ‘windows_installer.cmd’. This brings up a window similar to that below. Not the actual one but that disappears on completion of installation so couldn’t capture it.

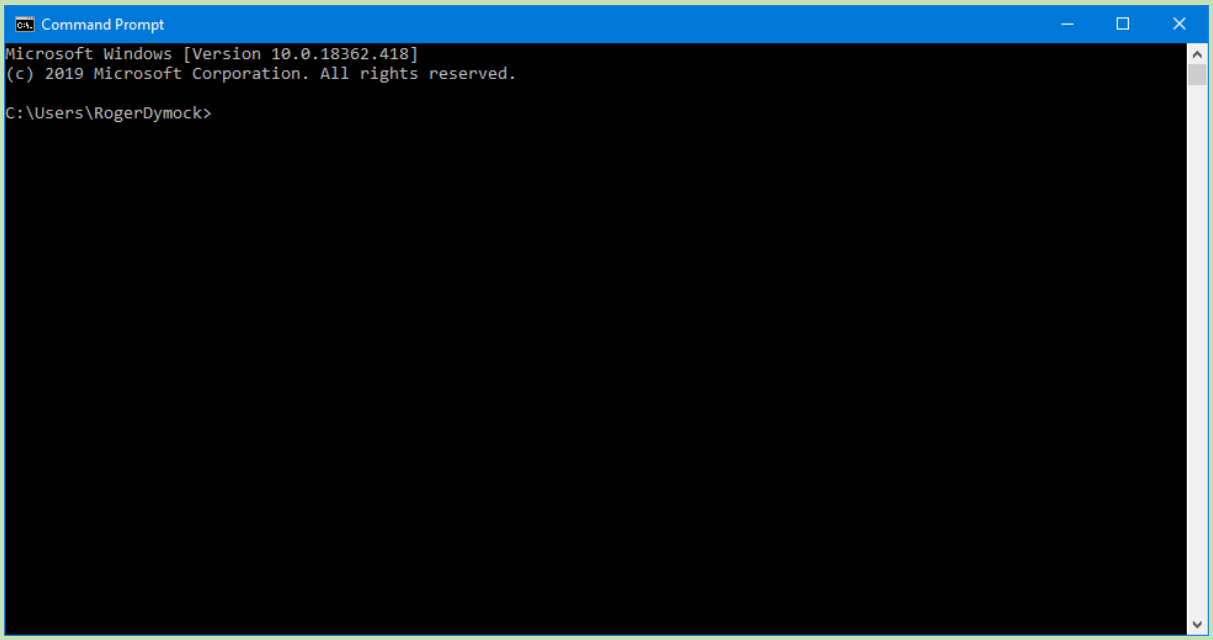


Figure B2.3

hops.cmd

The hops.cmd icon, , is placed on your desktop.

Double clicking on that opens two windows, Figures B2.5 and B2.6.

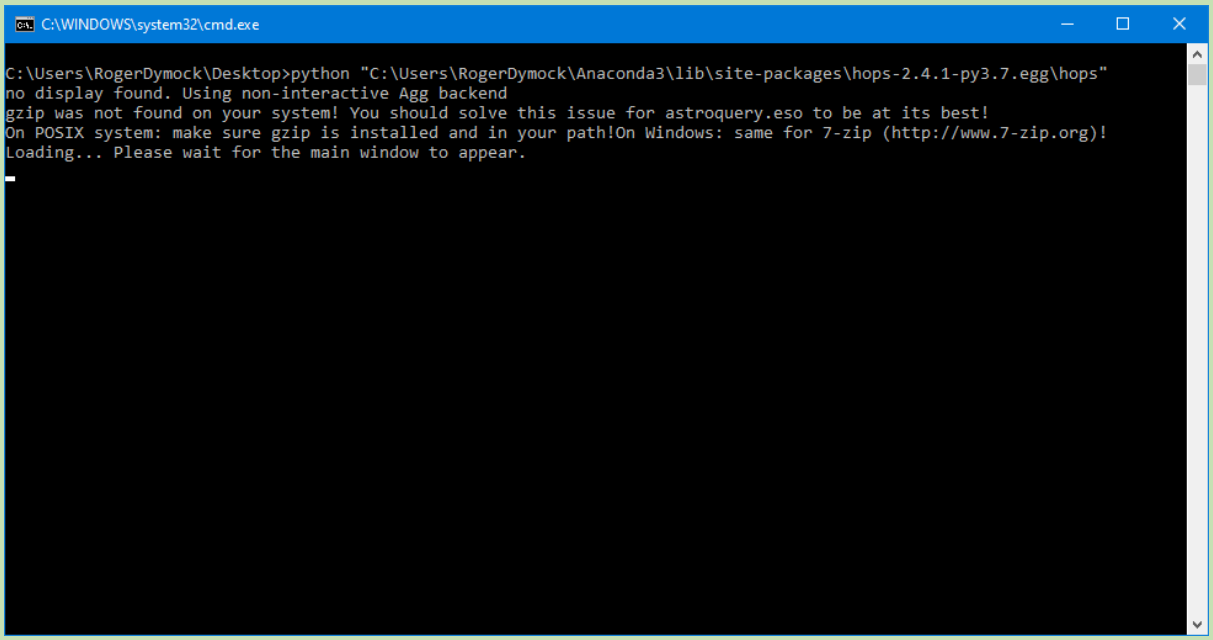


Figure B2.5

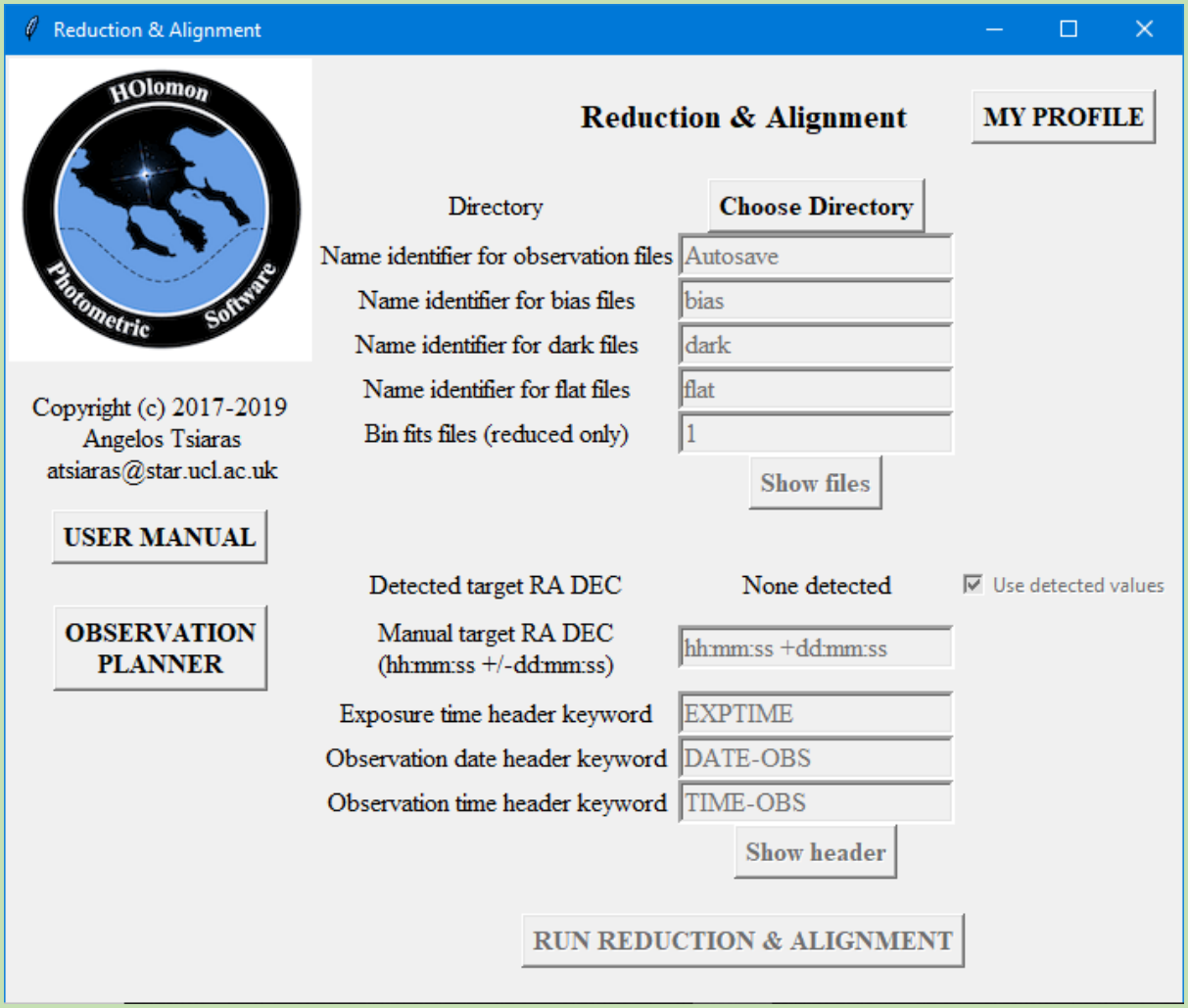


Figure B2.6

That's about it for installation.

Appendix C

The HOPS User Manual and Data Analysis video at https://exoworldsspies.com/en/software/ provide detailed instructions on running HOPS but this example may be of help.

1.0 Data download

Go to https://exoworldsspies.com/en/observers/ and choose a dataset – in this example HAT-P32b. The screen shot in Figure C1 will be displayed.

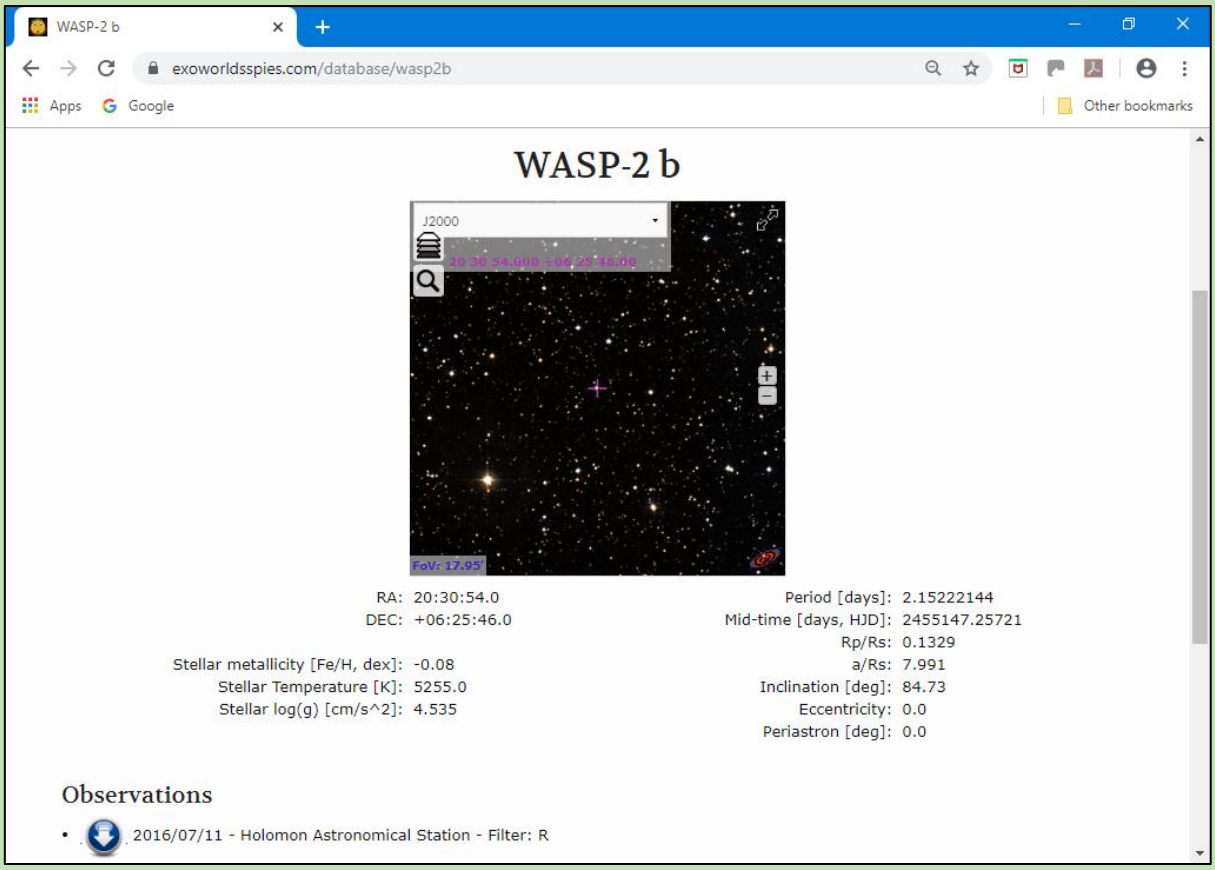


Figure C1.1. Selected target

Click on the arrow below 'Observations' – resulting in Figure C2.

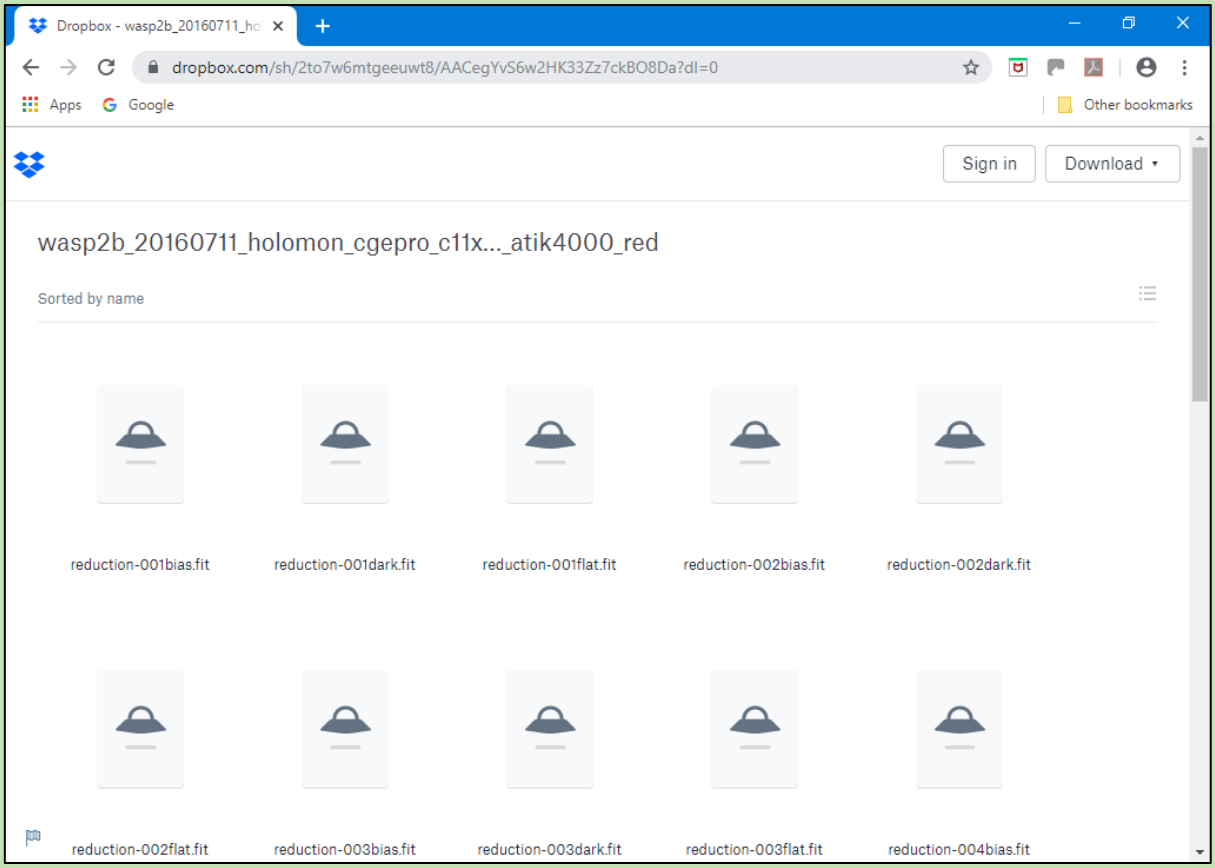


Figure C1.2. Selected data

Select Download/Direct download and save to a convenient folder.

Examine the images and delete those of poor quality or with satellite trails. If there is a meridian flip, as in this case, then reorient the later images to coincide with the earlier ones.

It is convenient to organise your data as per the instructions at https://exoworldsspies.com/en/observers/ i.e.

- Keep all scientific and reduction frames in one folder without subfolders
- Use a specific identifier for the scientific frames e.g.WASP-10b-001.fits etc
- Use a specific identifier for the bias frames, not containing the same identifier as the scientific frames e.g. bias-001.fits etc
- Use a specific identifier for the dark frames, not containing the same identifier as the scientific frames e.g. dark-001.fits etc
- Use a specific identifier for the flat frames, not containing the same identifier as the scientific frames e.g. flat-001.fits etc

2.0 Target data and selection of comparison stars

RA	Dec	B-V	V mag
20 30 54.14	+06 25 45.90	0.894	11.798

Table C2.1

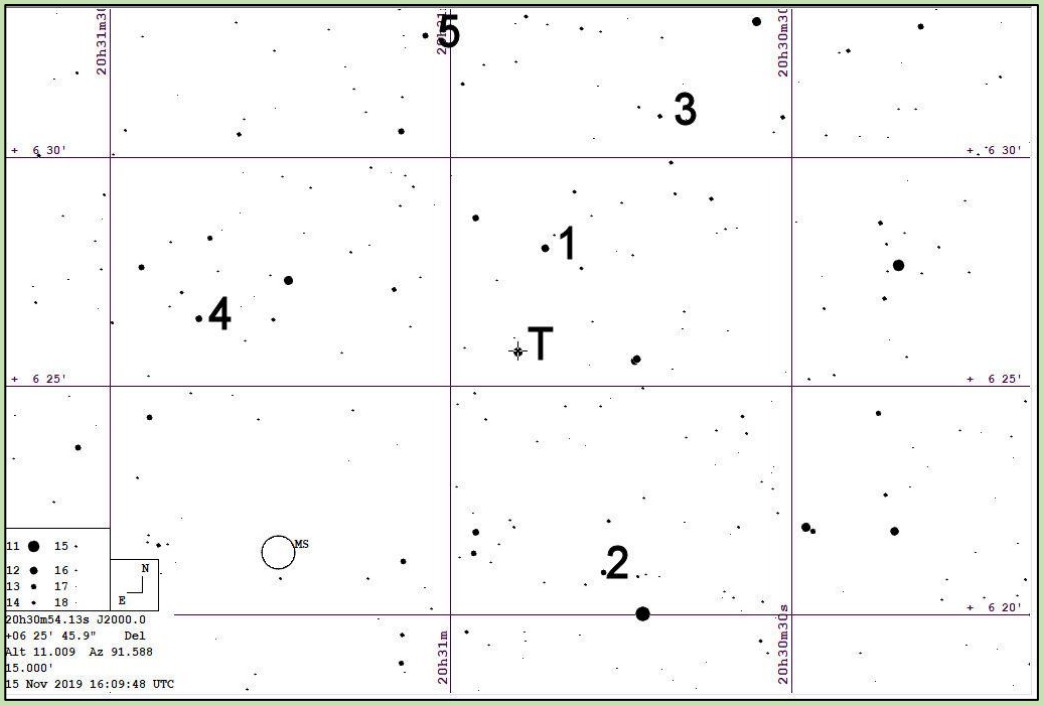


Figure C2.2

Nominal criteria for comparison star selection (data from Vizier/APASS)
0.694<(B-V=0.894)<1.094, 10.298<(V=11.798)<13.298

Comp star	RA	Dec	B-V	V
1	20 30 51.73	+06 28 01.14	0.631	12.028
2	20 30 46.52	+06 20 56.90	0.821	13.046
3	20 30 41.49	+06 30 54.58	0.652	12.985
4	20 31 22.21	+06 26 28.26	0.928	11.924
5	20 31 02.21	+06 32 40.58	0.718	12.663

Table C2.2

3.0 Analysis

There is a video at https://exoworldsspies.com/en/software/ a User Manual below the video window.

Double click on the hops.cmd icon and wait until the window in Figure C3 is displayed.

Figure C3.1. Reduction and Alignment window

Select he directory in which the images (observation files in HOPS terminology) are stored by clicking on the Directory box and navigating to the relevant folder. Enter the Name identifier for observation files, wasp-2, bias, dark and flat files and the quantities of images and calibration frames will now be listed. The Reduction and Alignment window is now populated – Figure C3.2.

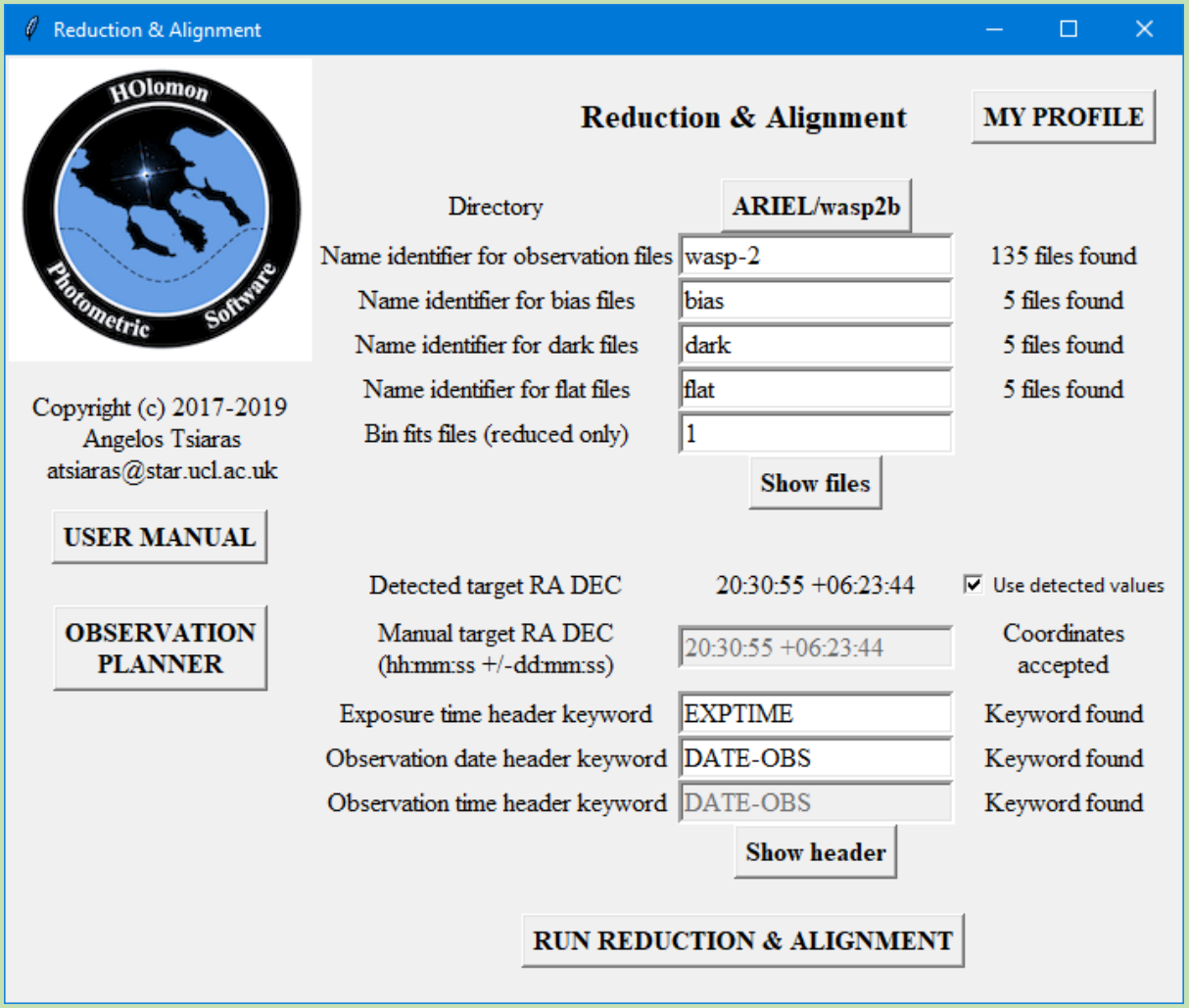


Figure C3.2

Select My Profile, fill in the observatory data and click on Update – Figure C3.3 shows as much as could be gleaned from the FITS header and a web search. For the purposes of this exercise do not leave ‘None’ in any of the boxes as this will cause an error later.

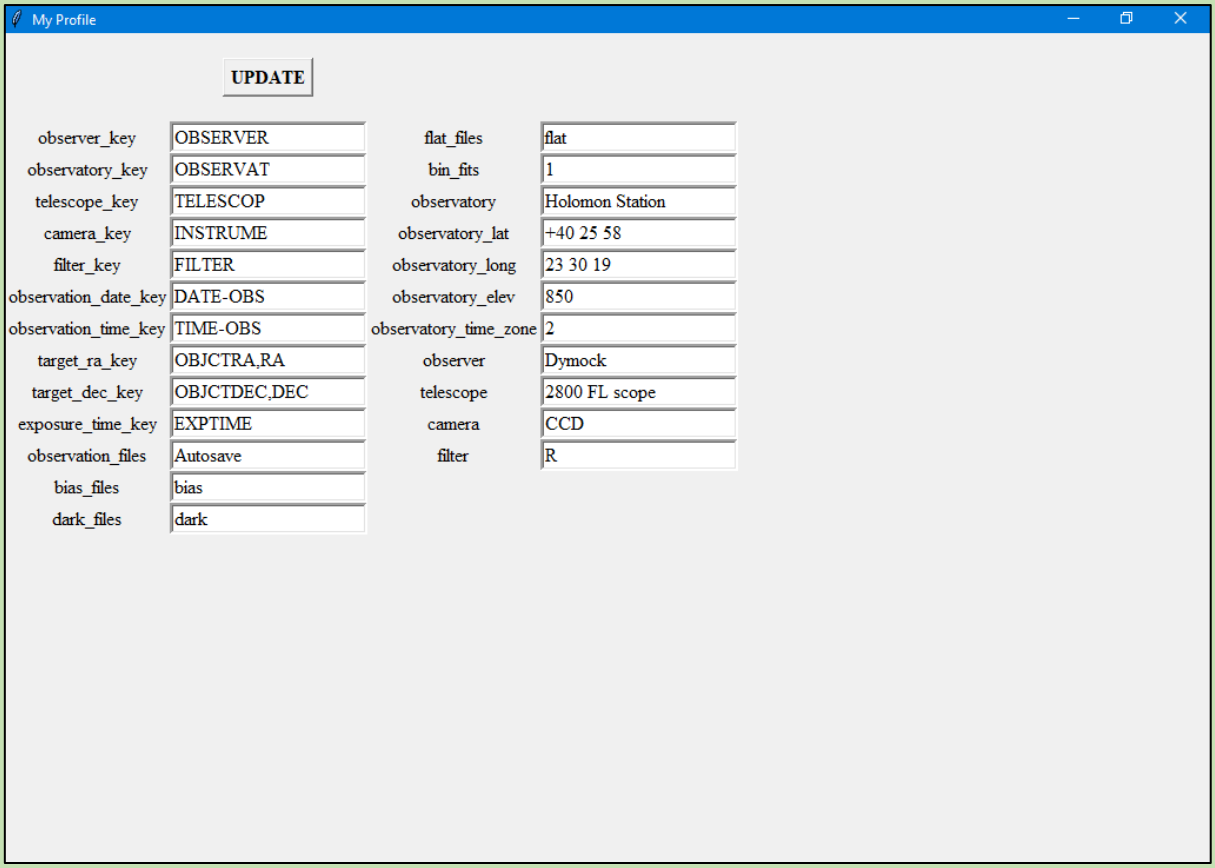


Figure C3.3

Select Run Reduction and Alignment. On completion the window in Figure C3.4 is displayed in which some images were deselected.

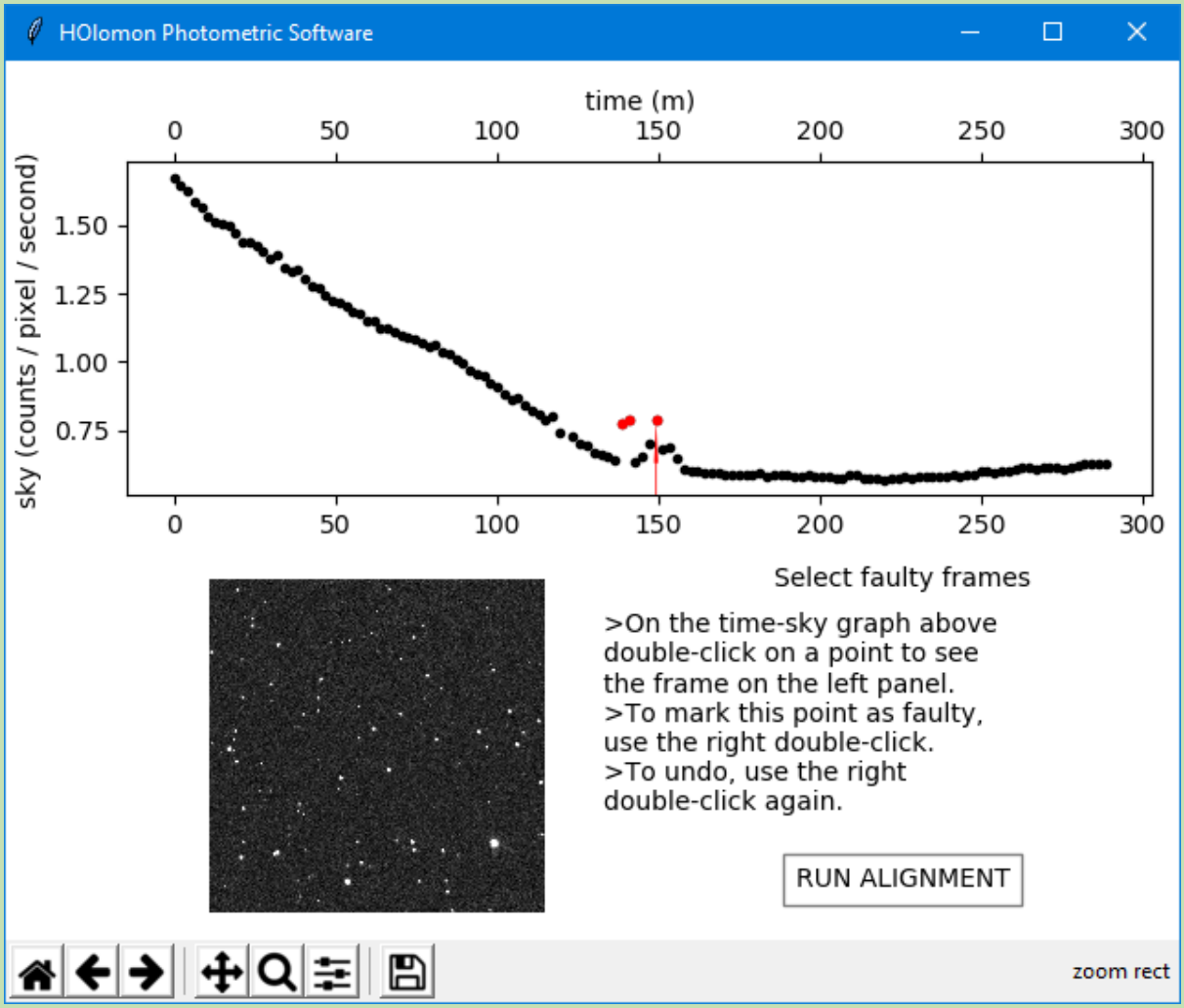


Figure C3.4

Select RUN ALIGNMENT. On completion the Photometry window is displayed – Figure C3.5.

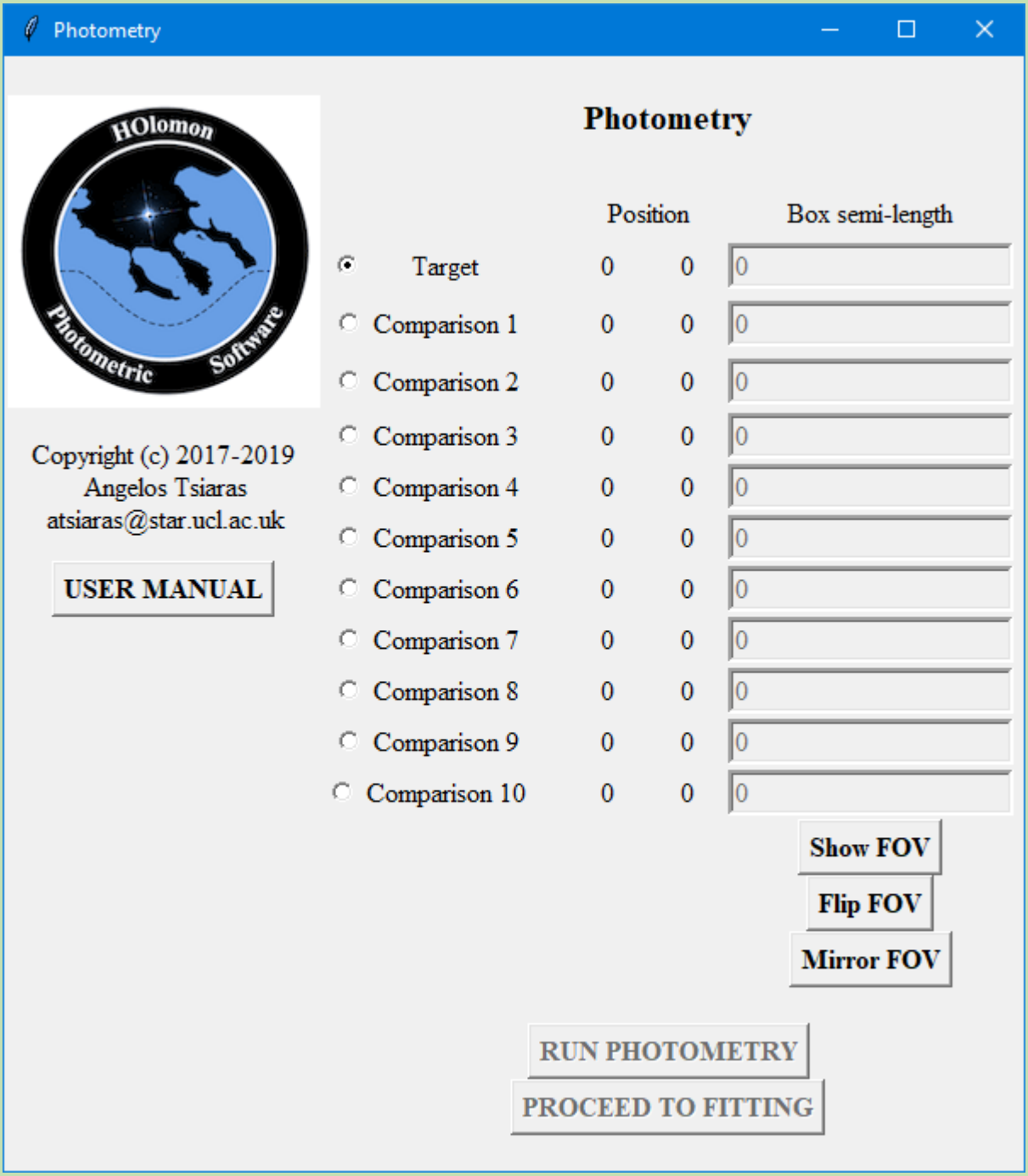


Figure C3.5

Click Show FOV and orientate the image to match the chart in Figure C3.2 – Figure C3.6

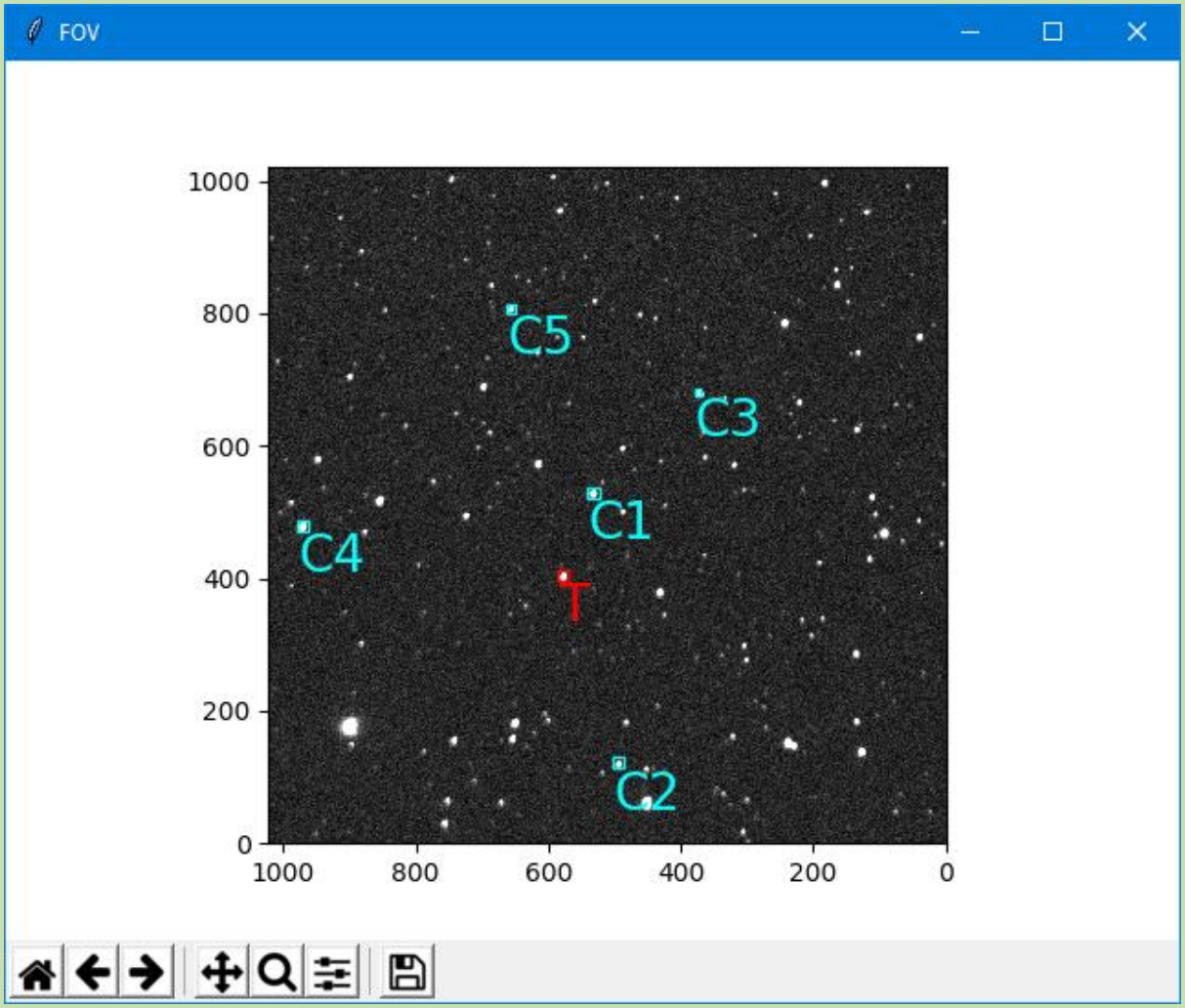


Figure C3.6

Select Target and Comparison stars as listed in Table C2.2 – Figures C3.7 and C3.8

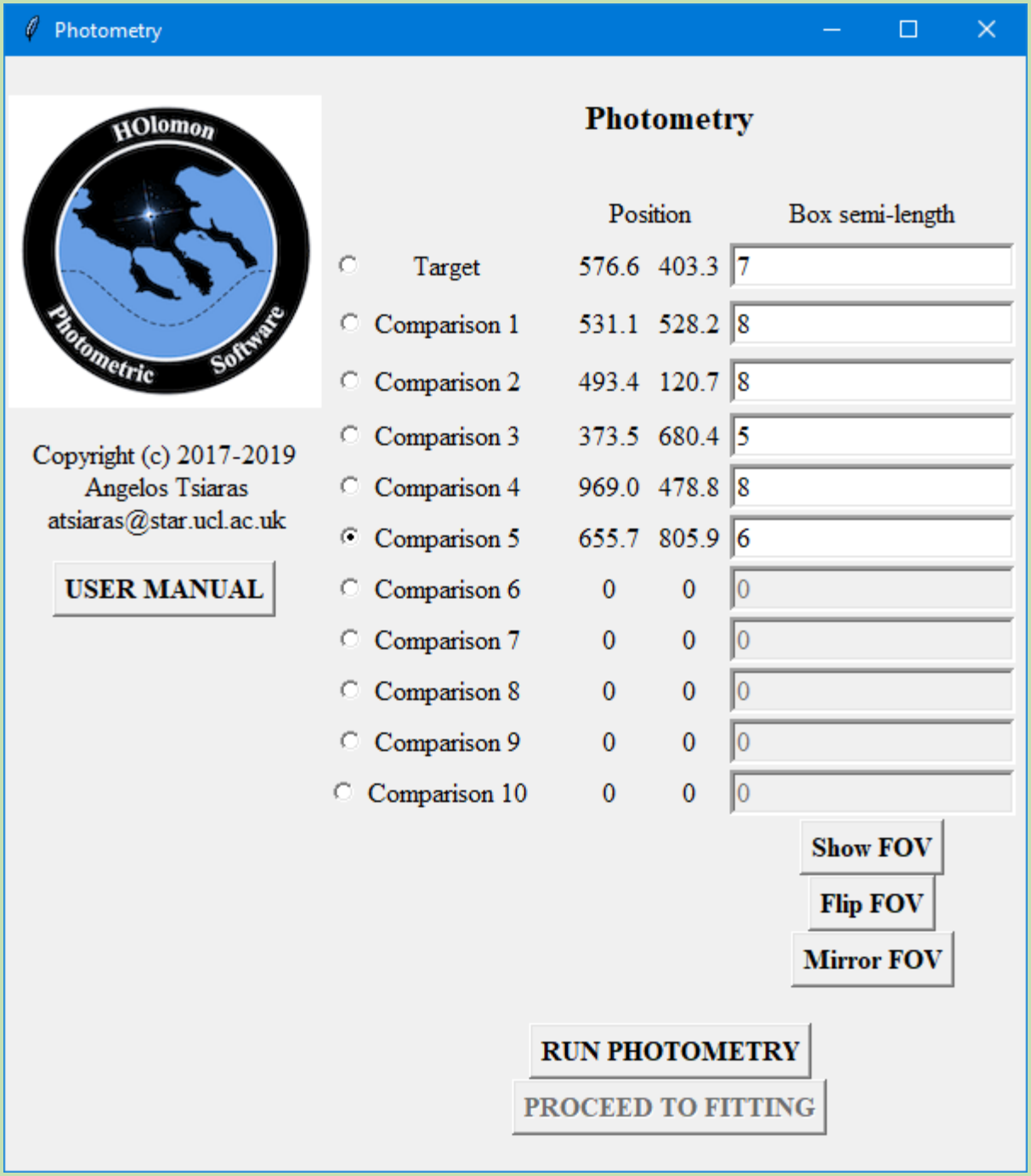


Figure C3.7

Select Run Photometry to calculate the light curve – Figure C3.8 is displayed.

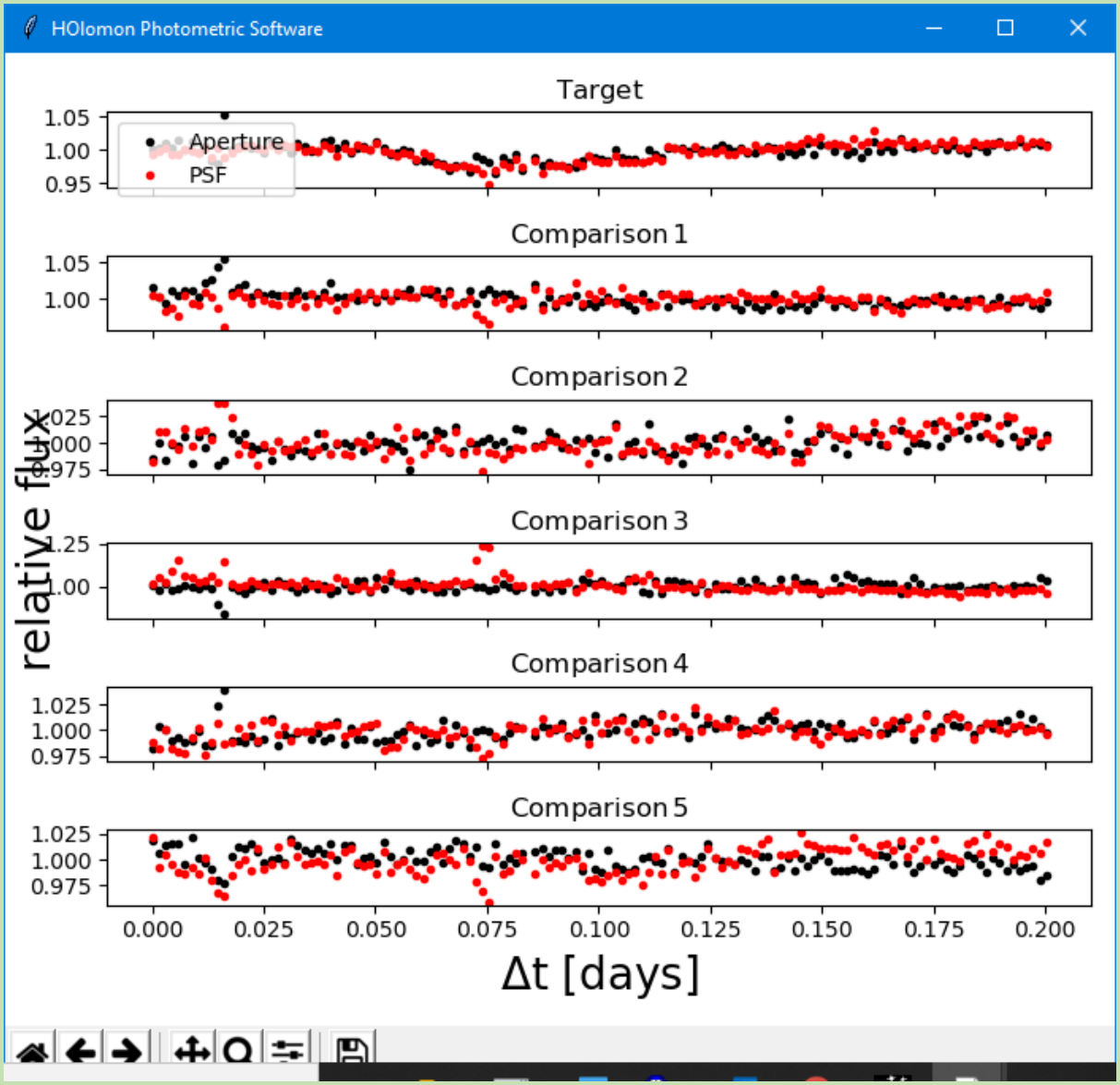


Figure C3.8

Close the window shown in Figure C3.8 and select Proceed to Fitting – Figure C3.9 is displayed which shows observatory, host star and exoplanet data. This data can be verified by referring to, for example, the Extrasolar Planets Encyclopaedia

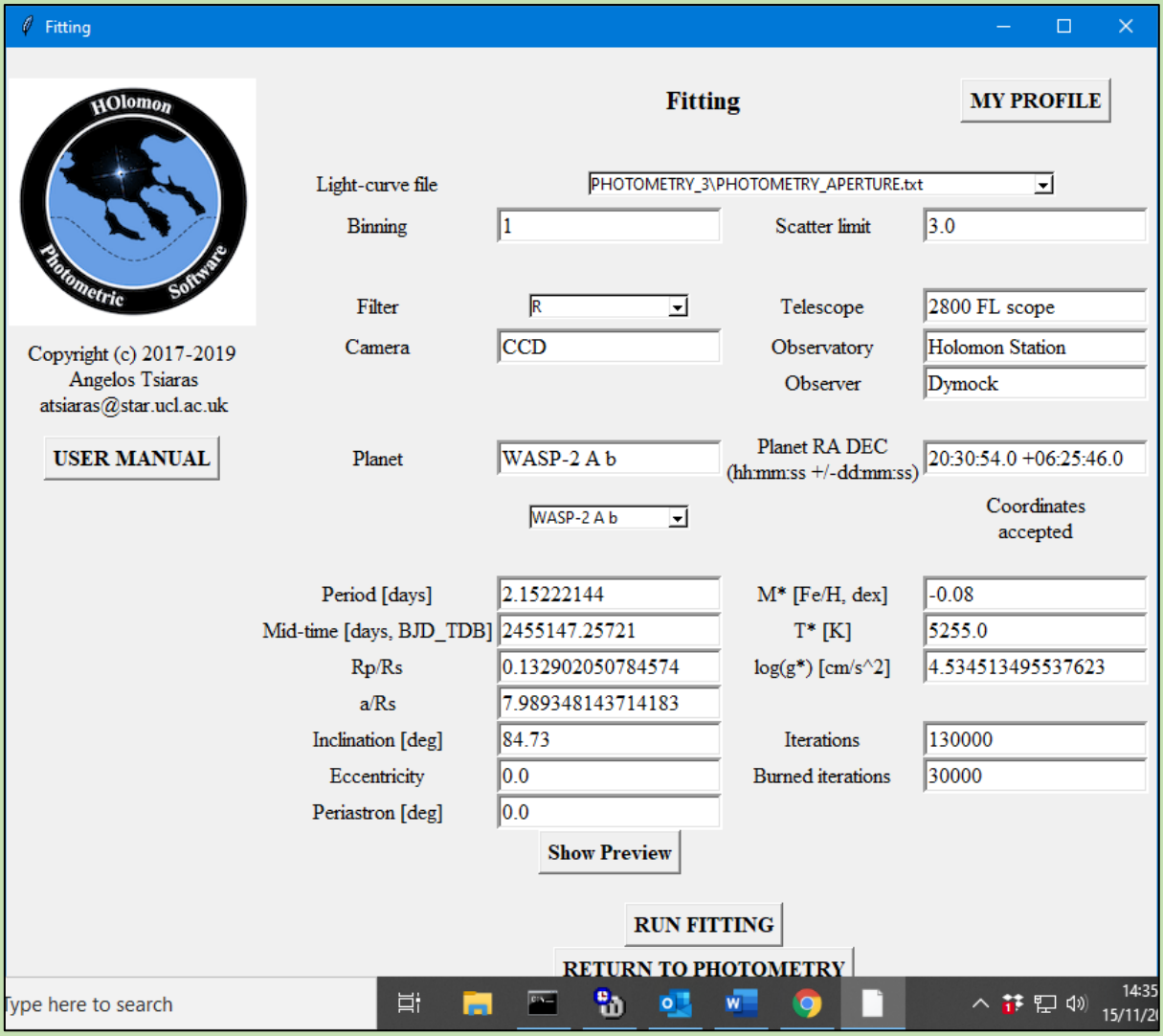


Figure C3.9

Select the Light-curve file from your various attempts and aperture or Gauss (psf) fitting you wish to use. Click on Show Preview to see a preview of the fitted light-curve – Figure C3.10.

The raw light-curve and model fit (red line) are shown at the top while the detrended light curve and model fit (red line) and the expected model, cyan line, are shown at the bottom.

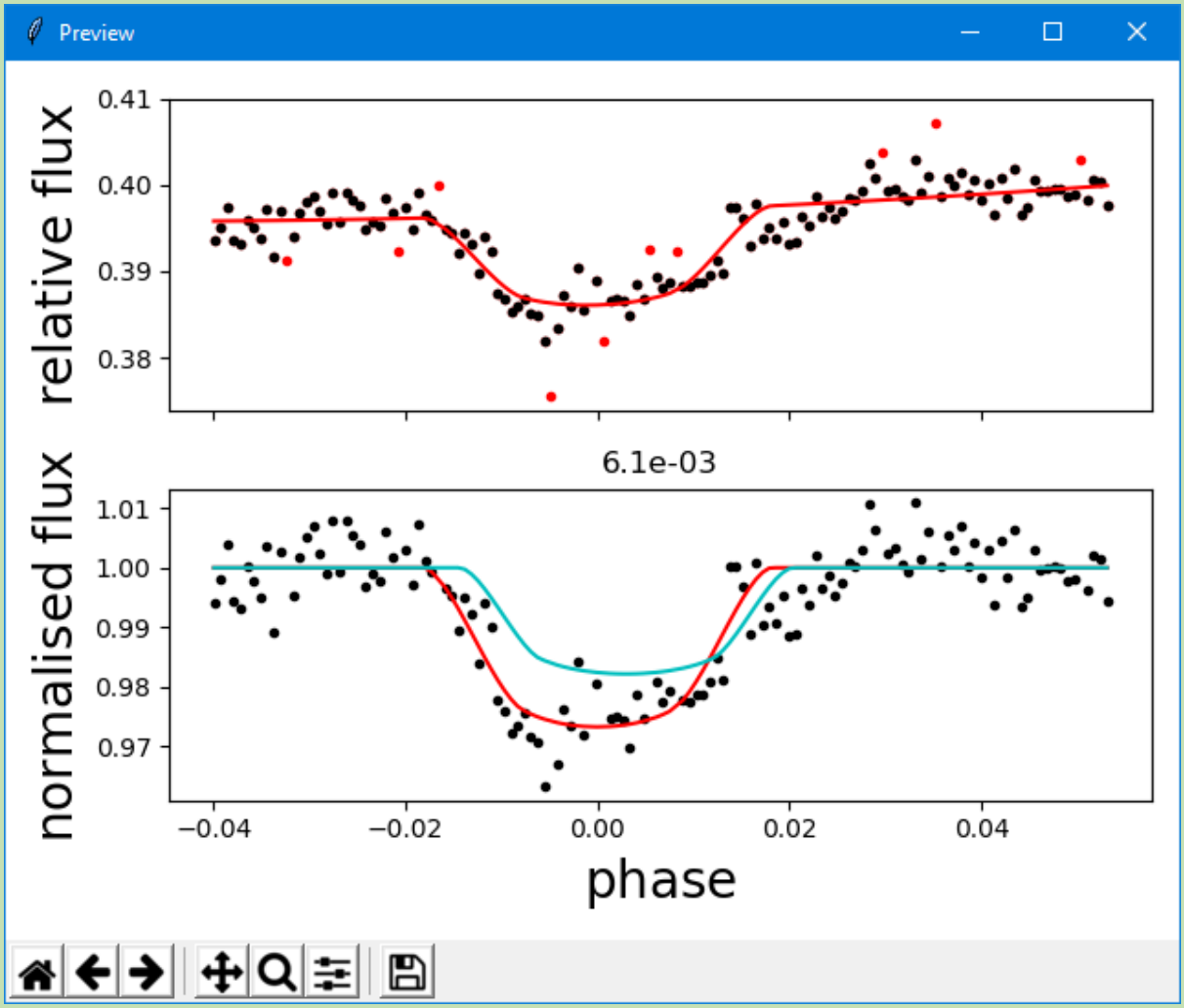
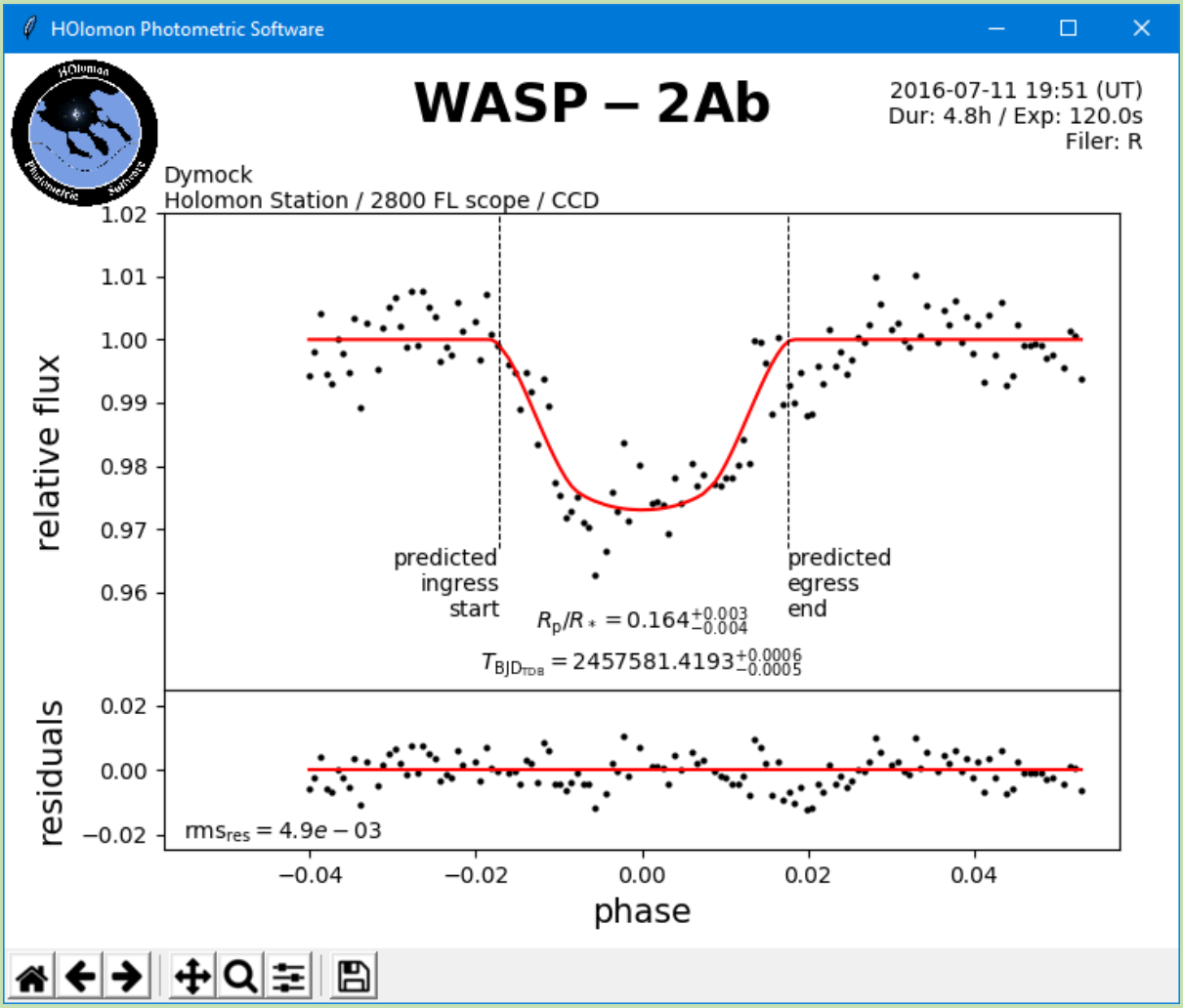


Figure C3.10

If the result is satisfactory click on RUN FITTING to obtain the final result, Figure C3.11. Data included is shown in Figure C.12. obtained from the User Manual.

Other data and images available are itemised in the User Manual PP30-32.


HOlomon Photometric Software
WASP – 2Ab
2016-07-11 19:51 (UT)
Dur: 4.8h / Exp: 120.0s
Filer: R
Dymock
Holomon Station / 2800 FL scope / CCD
relative flux
1.02
1.01
1.00
0.99
0.98
0.97
0.96
predicted ingress start
predicted egress end
$R_p/R_* = 0.164^{+0.003}_{-0.004}$
$T_{BJD_{TDB}} = 2457581.4193^{+0.0006}_{-0.0005}$
residuals
0.02
0.00
−0.02
$rms_{res} = 4.9e-03$
−0.04
−0.02
0.00
0.02
0.04
phase
Figure C3.11

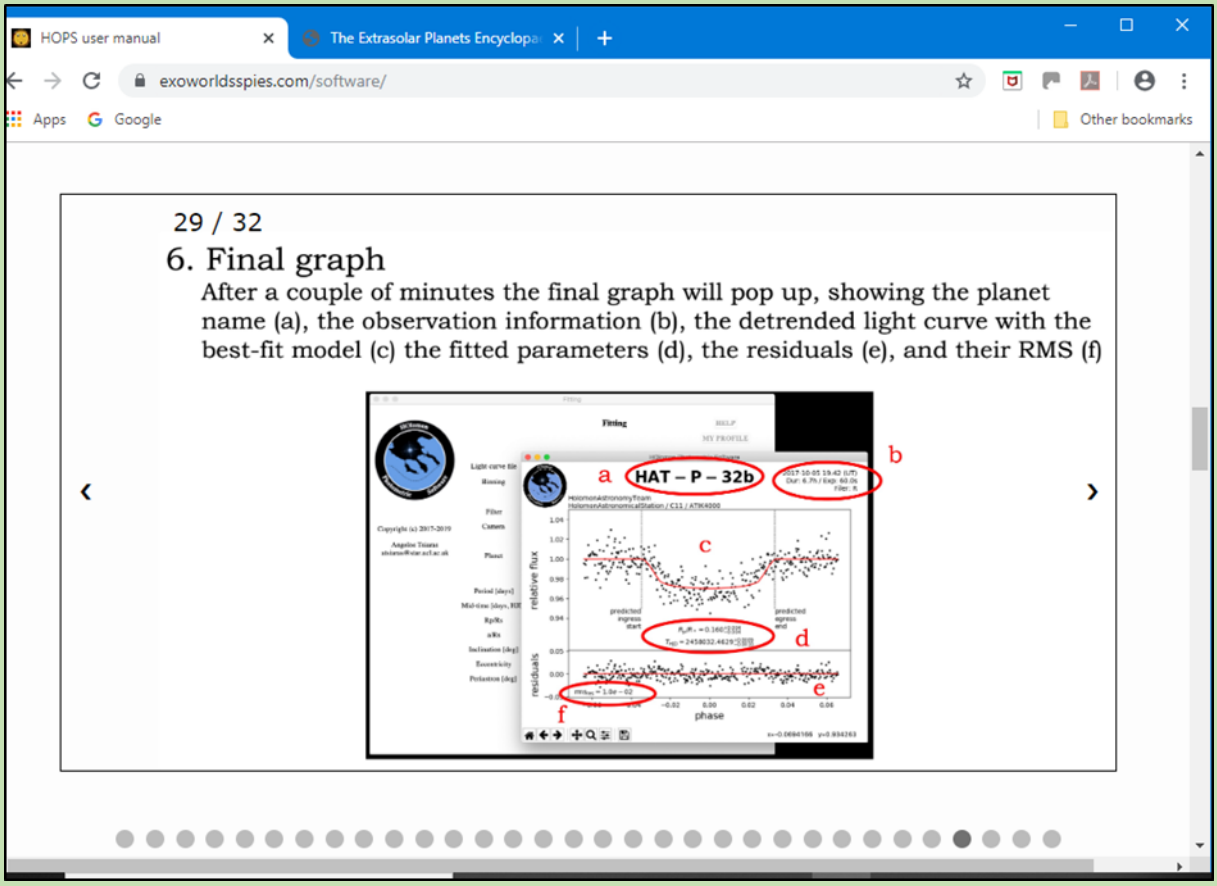


Figure C.12

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