ARIEL Space Mission

The ExoClock Project – Version 3

Originated 2020 April 17

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

2.1   The ExoClock project

Ground-based exoplanet observations in support of the ARIEL space mission - https://www.exoclock.space/project

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 at https://www.exoclock.space/users/signup/
- Log in at https://www.exoclock.space/users/login/
- register you telescopes and check your schedule at https://www.exoclock.space/project
- 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://www.exoclock.space/database/observations
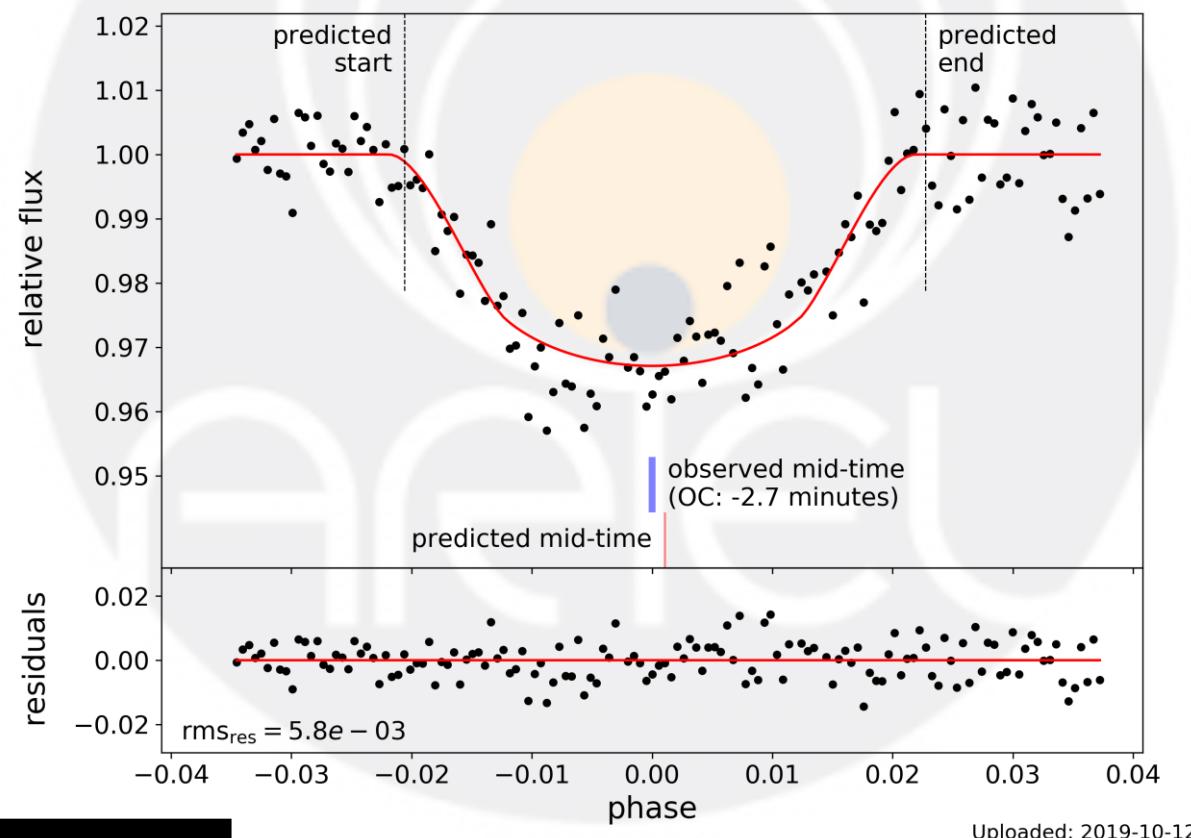
WASP – 52b

2018-10-19

Stephen Futcher[*] (Hampshire Astronomical Group), Kirsten Ogilvie-Goddard (University of Portsmouth), Louise Cleaver (University of Portsmouth), and Helena Faustino Vieira (University of Portsmouth)

Hampshire Astronomical Group, Clanfield Observatory / Telescope: Ritchey-Chrétien (24.0")
Camera: Moravian G4-9000 / Filter: Lum / Exp.: 60.0 s

predicted start

predicted end

observed mid-time
(OC: -2.7 minutes)

predicted mid-time

$rms_{res} = 5.8e - 03$

Uploaded: 2019-10-12

Figure 2.1.1. WASP-52b transit light-curve

You don't have to own your own telescope to participate. Martin Fowler and myself use 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://www.exoclock.space/database/observations
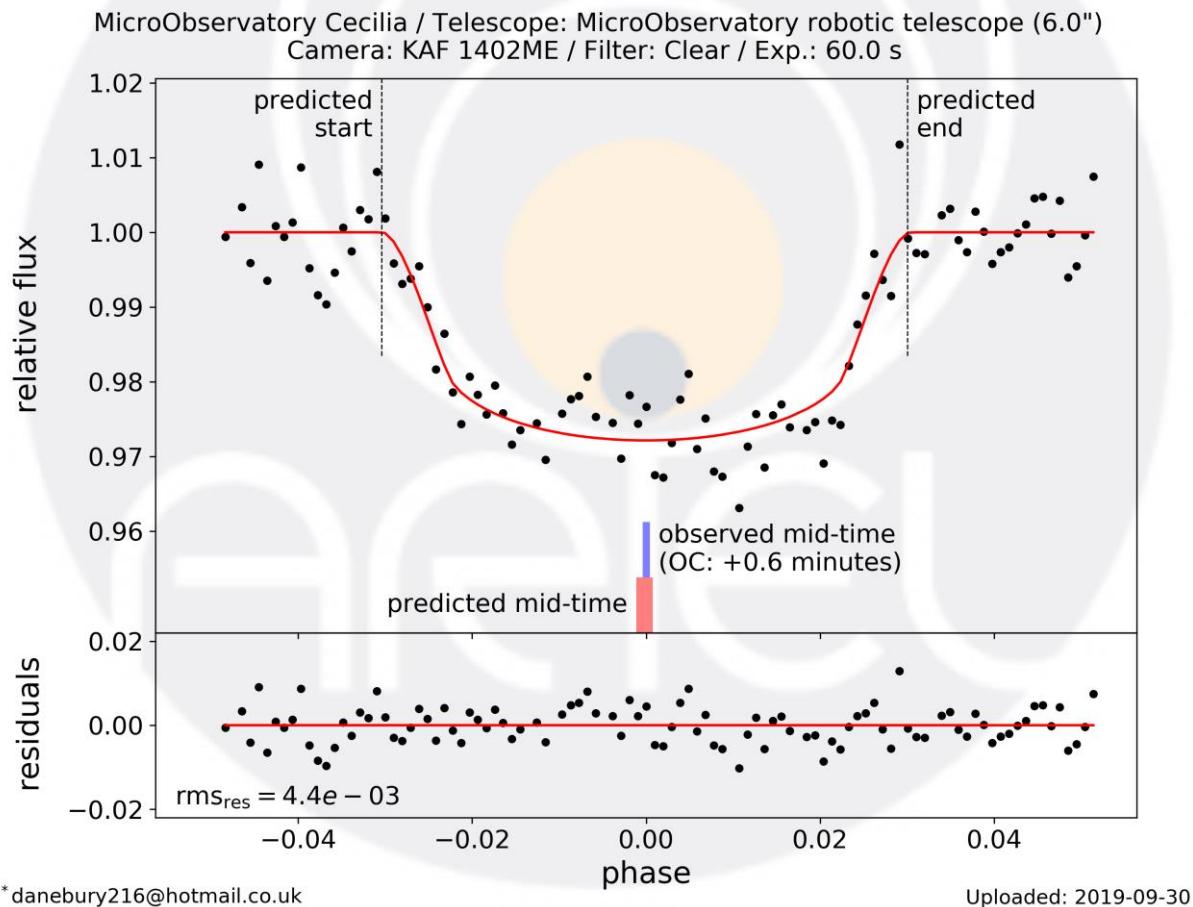
Figure 2.1.2. HAT-P-32b transit light-curve

Accessing the ExoClock Ephemerides page for a specific exoplanet, in this example HAT-P-32b, shows an O-C plot – Figure 2.1.3. The shaded area shows the uncertainty of the ephemeris as a function of time, the red dots indicate observations submitted to the ExoClock database and the blue circle shows the requirement for ARIEL.
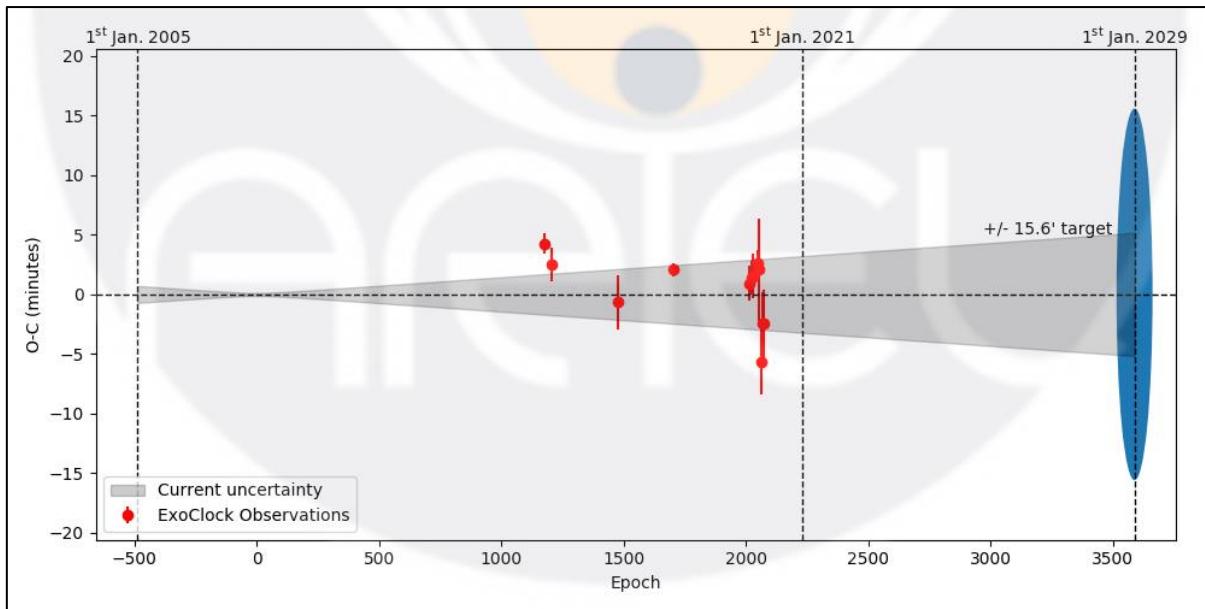
Figure 2.1.3 Observed vs Calculated plot for HAT-P-32b

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. Note that a clear or no filter can be used – many of the observations on the ExoClock Observations database were so obtained. 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://www.exoclock.space/database/planets 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://www.exoclock.space/database/planets
- 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

A number of targets suitable for UK observers have been selected, Table 5.5.1, and finder charts and comparison star data included in the appendices. The objectives of providing comparison stars are;
- identify stars of similar magnitude and colour (B-V) where possible
- provide a spread across the image
- ensure consistency of observations

While these objectives are an ideal case not all of them could be met for any specific target. Observers in other locations should access the websites mentioned below and input their specific location.

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)
- medium priority (prediction uncertainty lower than 10 minutes for 2020 but higher than 10
  minutes for 2028, or reference older than 2016)
- V mag brighter than 13
- transit depth >=10
- altitude >20 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		Appendix no.	Target
A1	HAT-P-20b		A17	K2-29b
A2	XO-6b		A18	HAT-P-32b
A3	HAT-P-6b		A19	TrES-3b
A4	WASP-13b		A20	XO-1b
A5	XO-4b		A21	WASP-43b
A6	HAT-P-8b		A22	HAT-P-36b
A7	HAT-P-17b		A23	WASP-36b
A8	HAT-P-3b		A24	CoRoT-10b
A9	WASP-11b		A25	KPS1-b
A10	HAT-P-12b		A26	HAT-P-15b
A11	WASP-10b		A27	HAT-P-18b
A12	HD189733b		A28	HAT-P-19b
A13	HAT-P-22b		A29	HAT-P-23b
A14	Kepler-447b		A30	HAT-P-37b
A15	TrES-1b		A31	HAT-P-3b
A16	WASP-85Ab		A32	HAT-P-41b

Table 5.5.1. Selected targets

Clicking on the exoplanet name in the ExoWorlds Spies Transit Scheduler displays a finder chart and star and transit data. Accessing the ExoClock Ephemerides database displays the same data but without the left-hand side bar and this is displayed in the appendices.

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

| Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-20b	07 27 39.95	24 20 11.5	11.35	1.2	20

Table A1.1. Target data
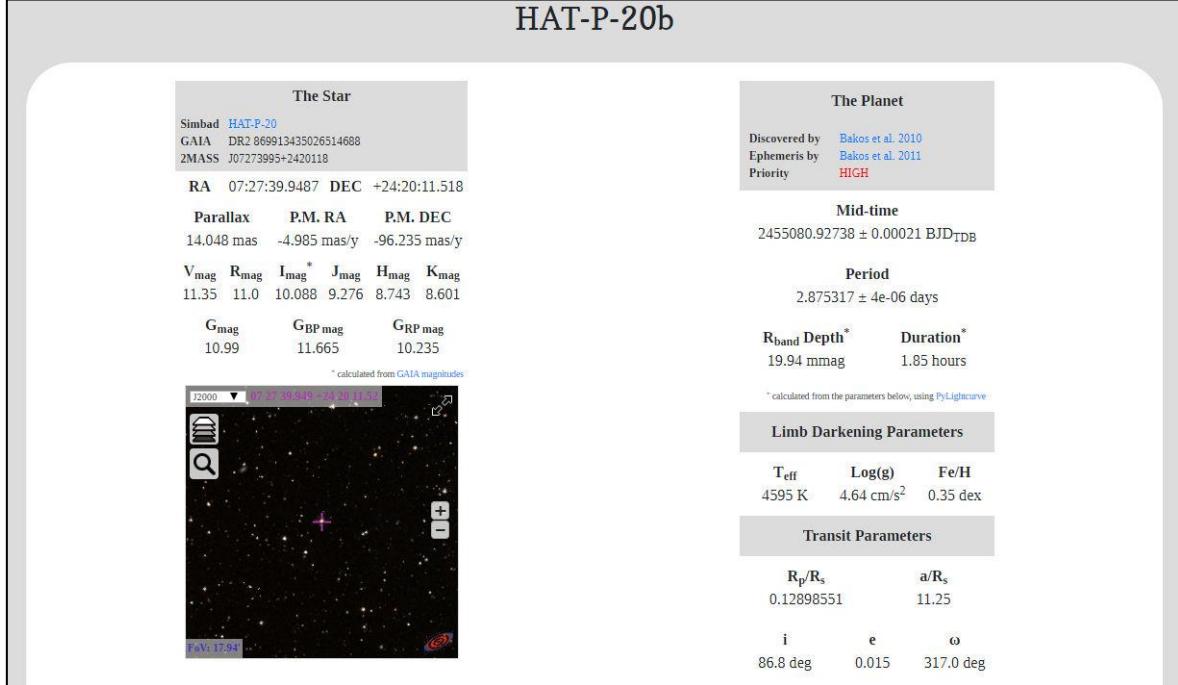
Figure A1.1. Star and transit data
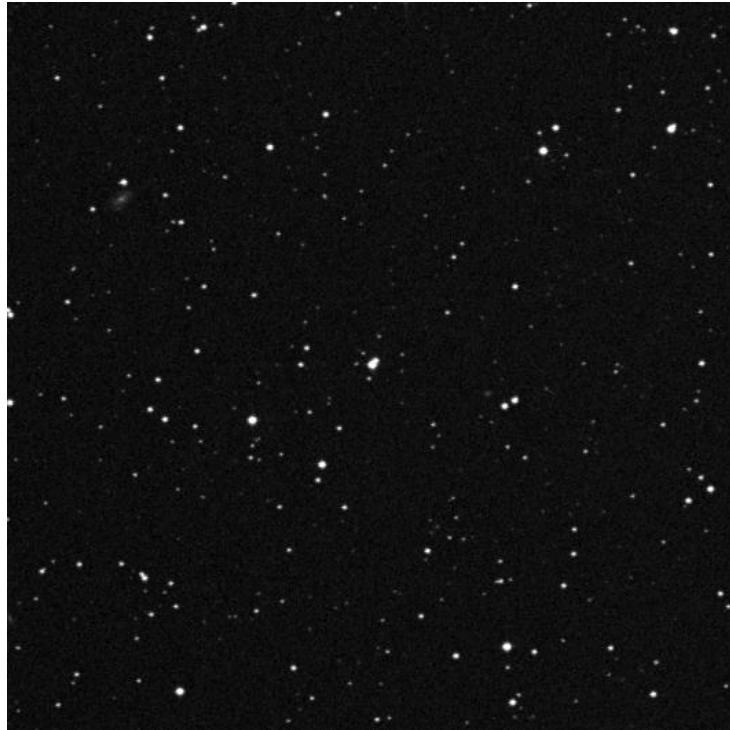

Figure A1.2. STScI DSS chart
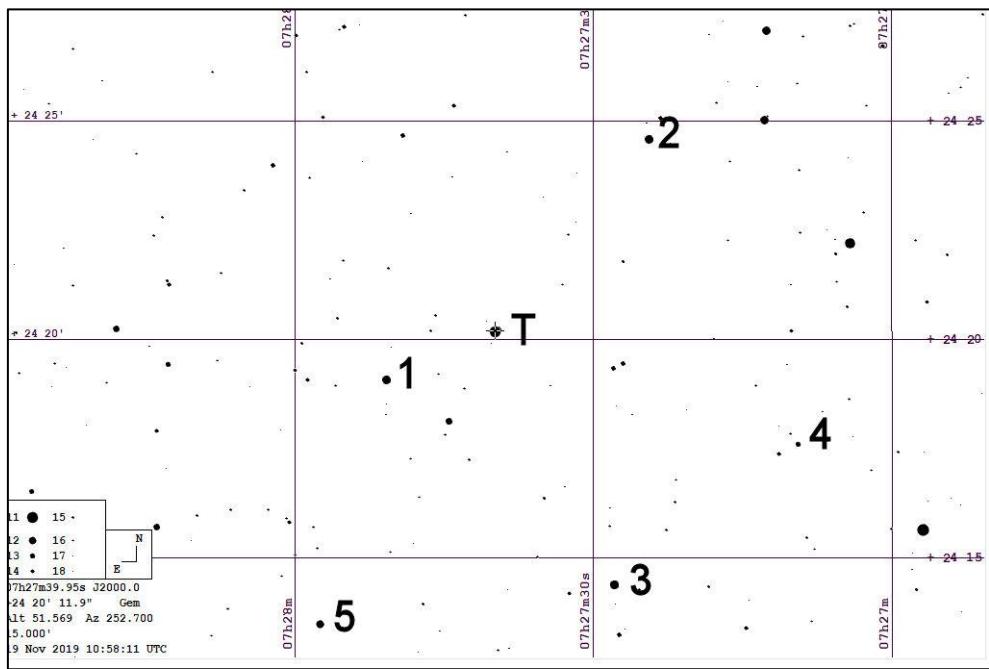
Figure A1.3. Guide finder chart, 15' x 15'

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

| Target	RA	Dec	V mag	B-V	Depth (Mmag)
XO-6b	06 19 10.37	73 49 39.6	10.25	0.360	14

Table A2.1. Target data
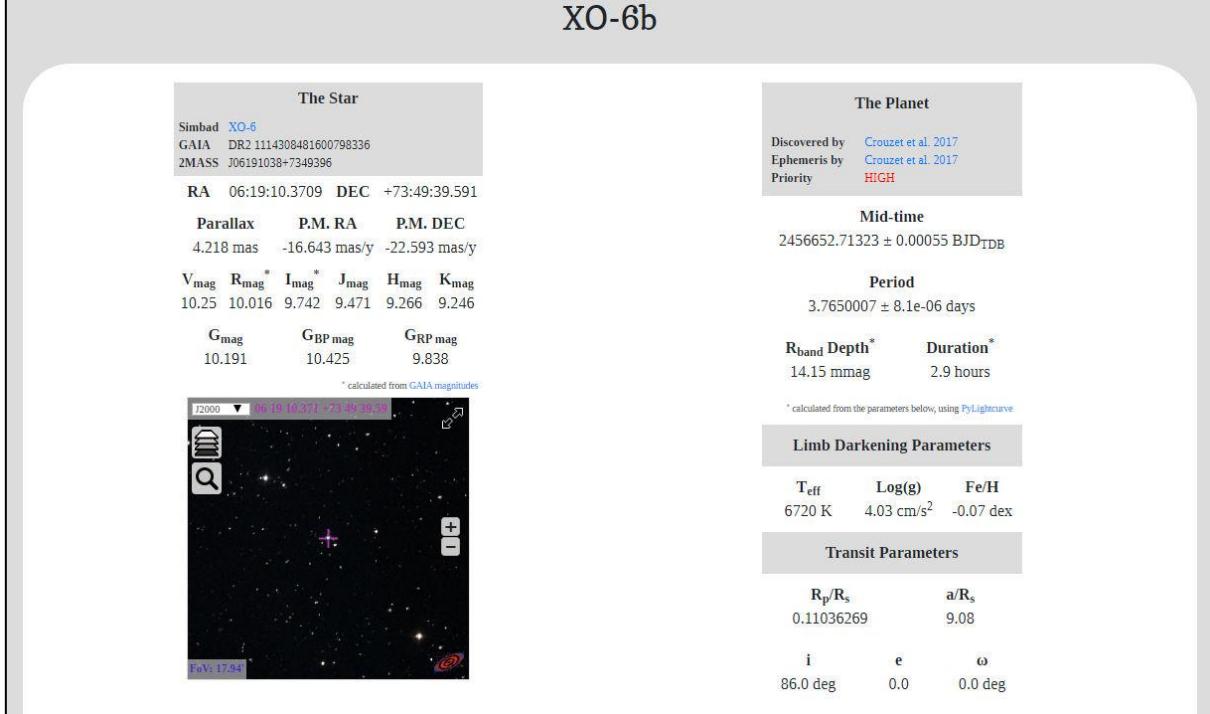
Figure A2.1 Star and transit data
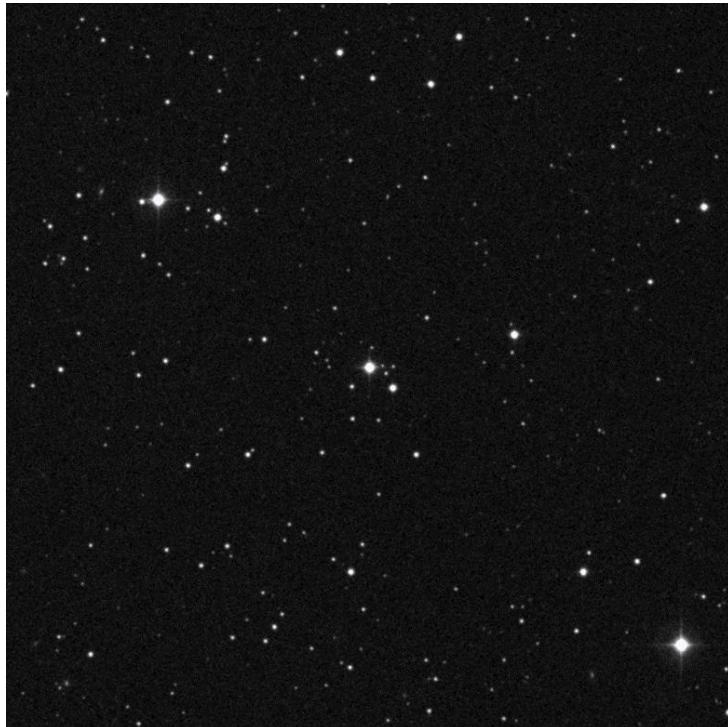
Figure A2.2. STScI DSS chart
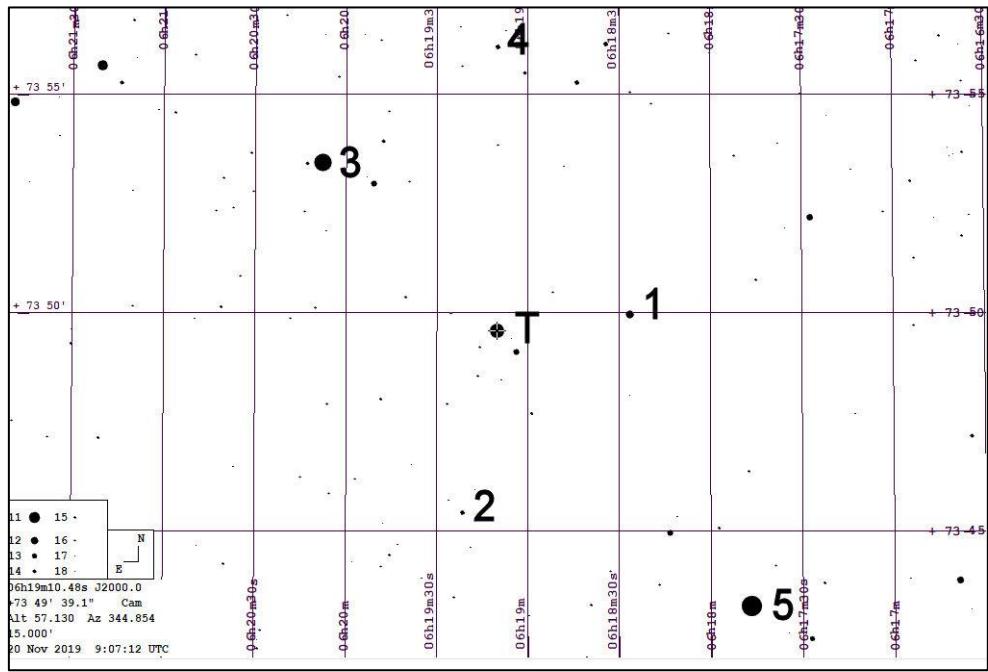
Figure A2.3. Guide finder chart, 15' x 15'

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

Appendix A3

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-6b	23 39 05.81	42 27 57.5	10.47	0.469	10

Table A3.1. Target data
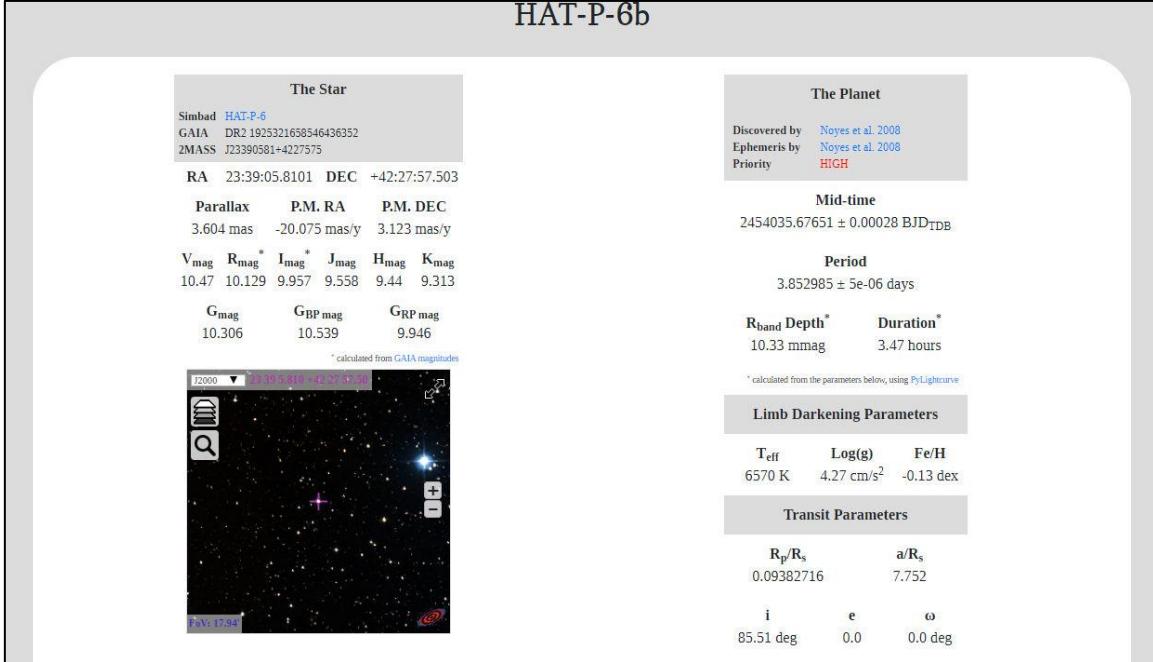

Figure A3.1 Star and transit data
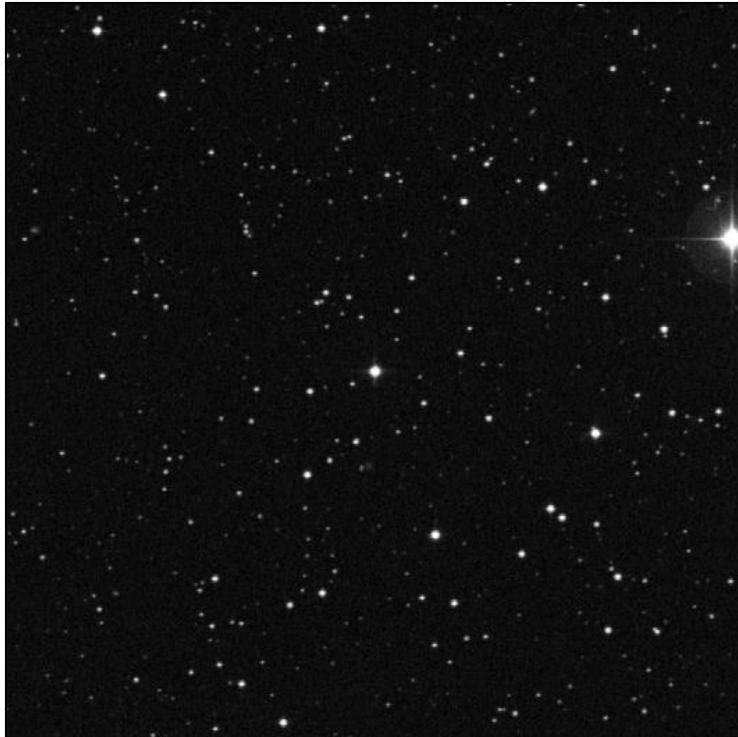
Figure A3.2. STScI DSS chart
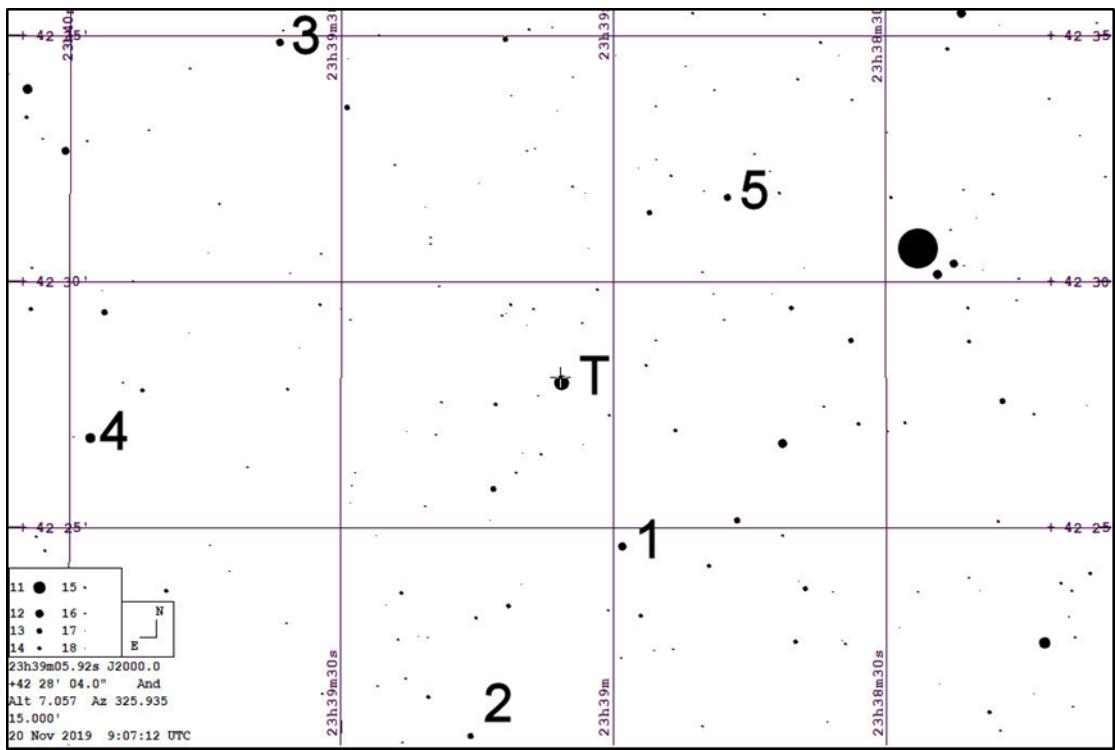
Figure A3.3. Guide finder chart, 15' x 15'

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

Appendix A4

Target	RA	Dec	V mag	B-V	Depth (mmag)
WASP-13b	09 20 24.71	33 52 56.7	10.42	0.459	10

Table A4.1. Target data
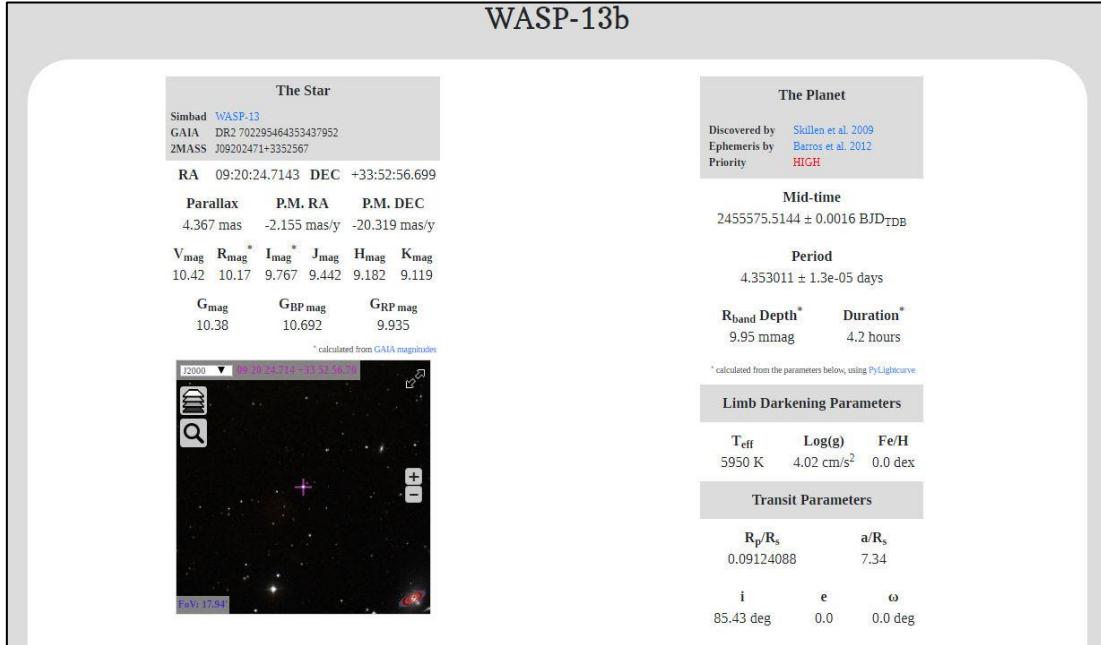


Figure 4.1. Star and transit data
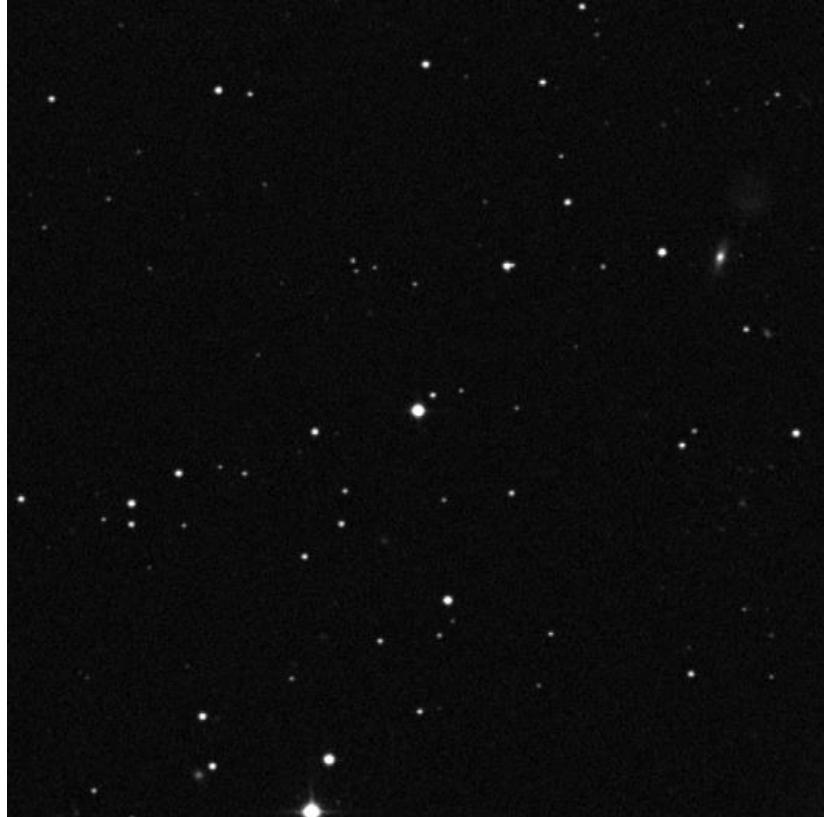
Figure A4.2. STScI DSS chart
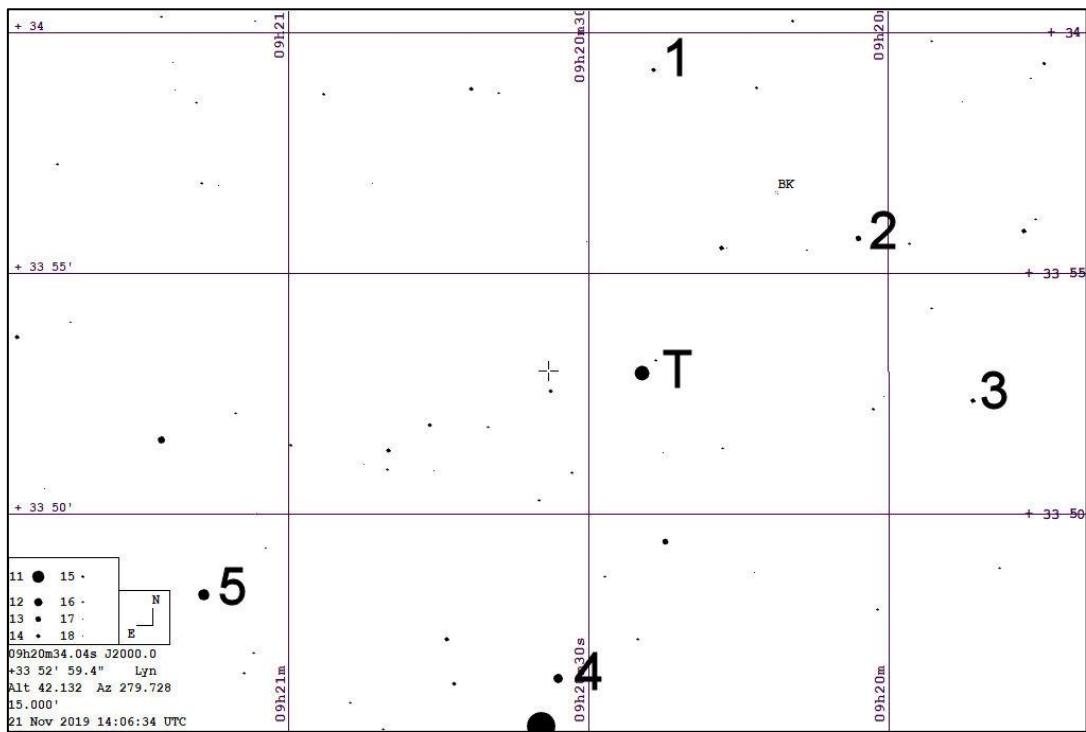
Figure A4.3. Guide finder chart, 15' x 15'

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

Appendix A5

Target	RA	Dec	V mag	B-V	Depth (mmag)
XO-4b	07 21 33.16	58 16 05.1	10.81	0.492	10

Table A5.1. Target data
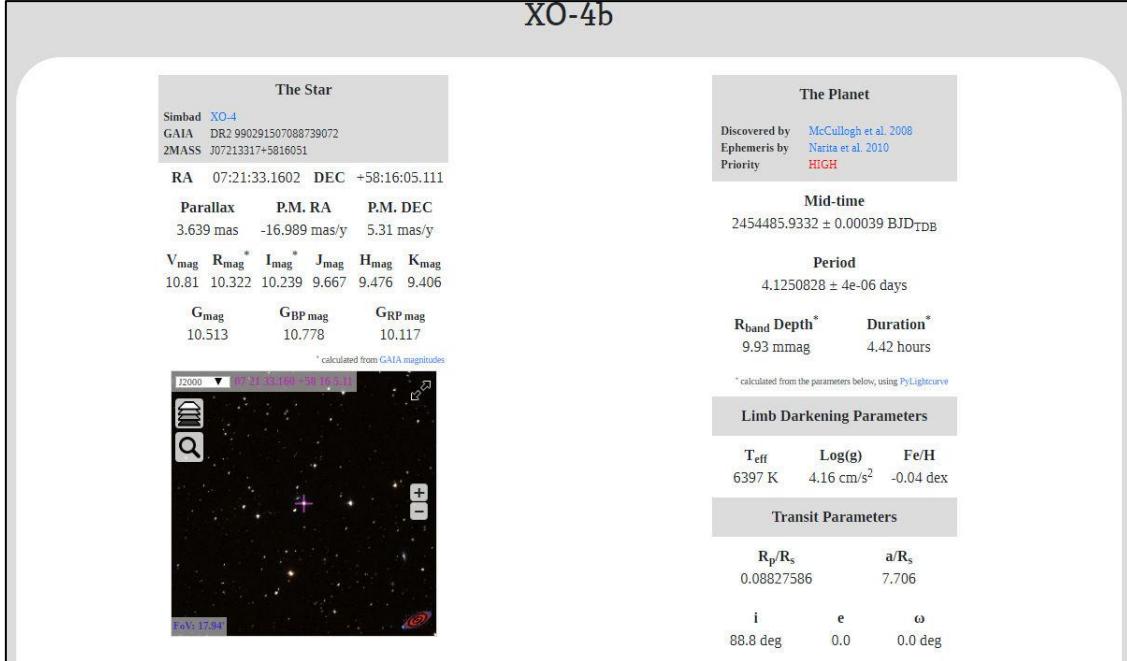
Figure A5.1. Star and transit data
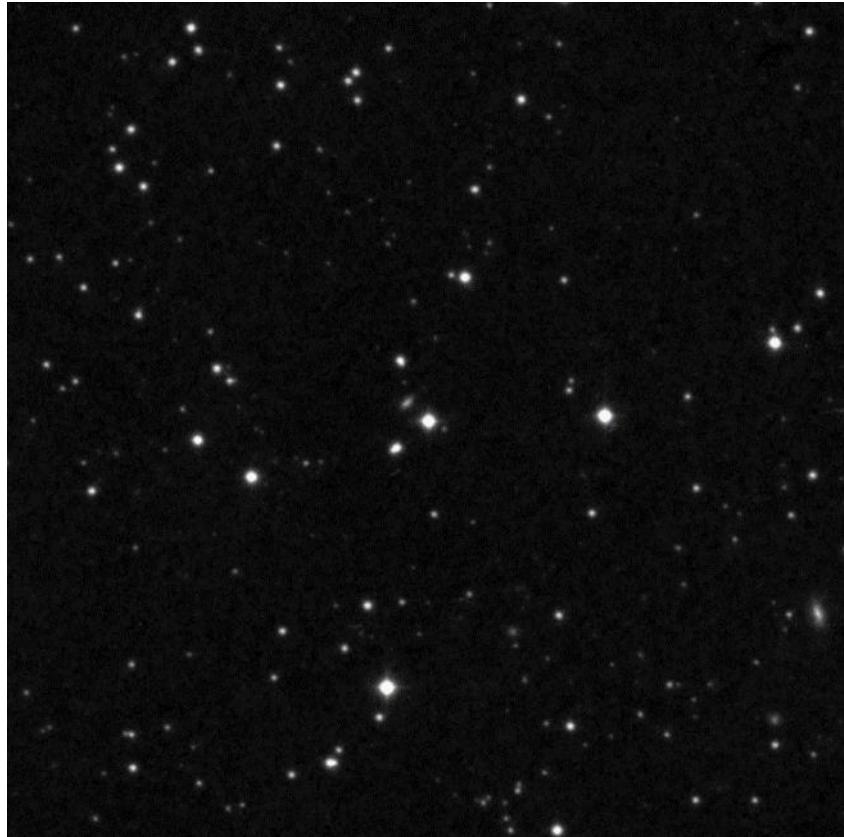
Figure A5.2. STScI DSS chart
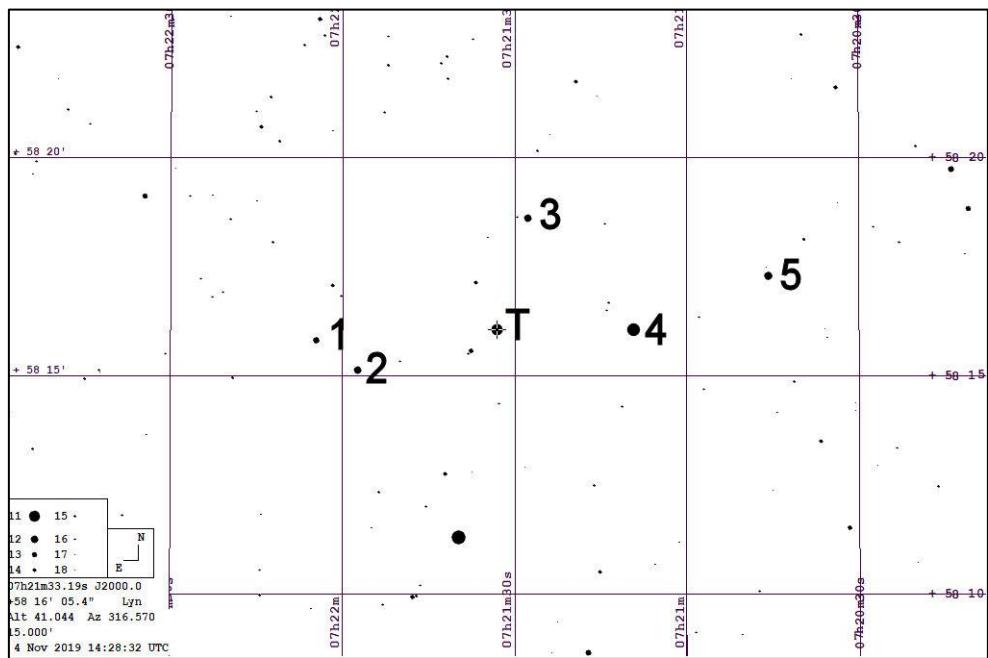
Figure A5.3. Guide finder chart, 15' x 15'

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

Appendix A6

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-8b	22 52 09.86	35 26 49.61	10.36	0.506	11

Table A6.1. Target data
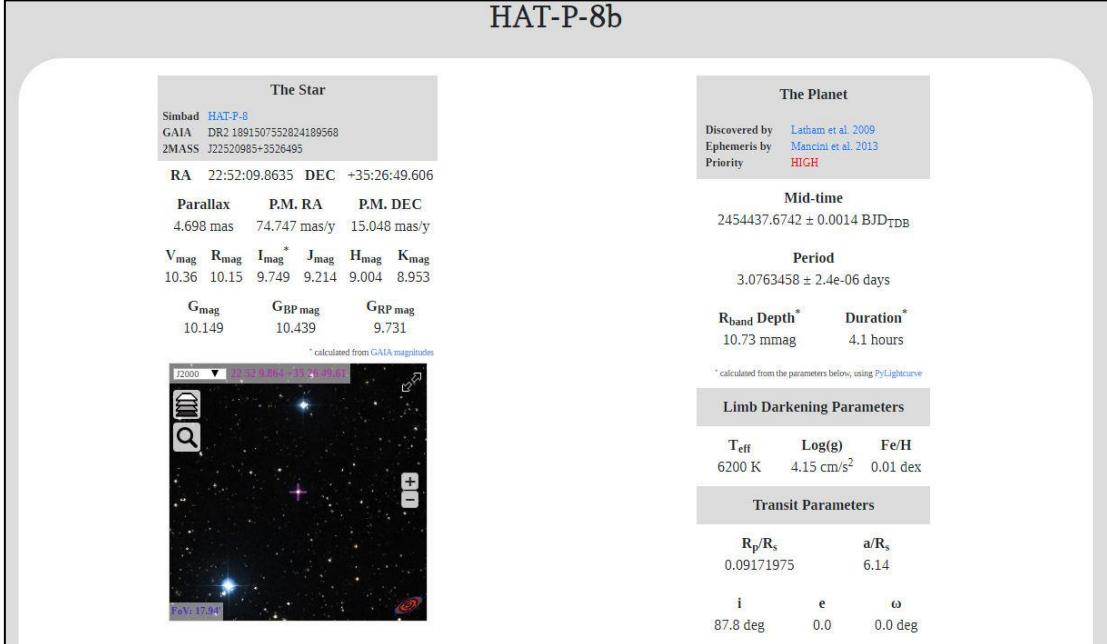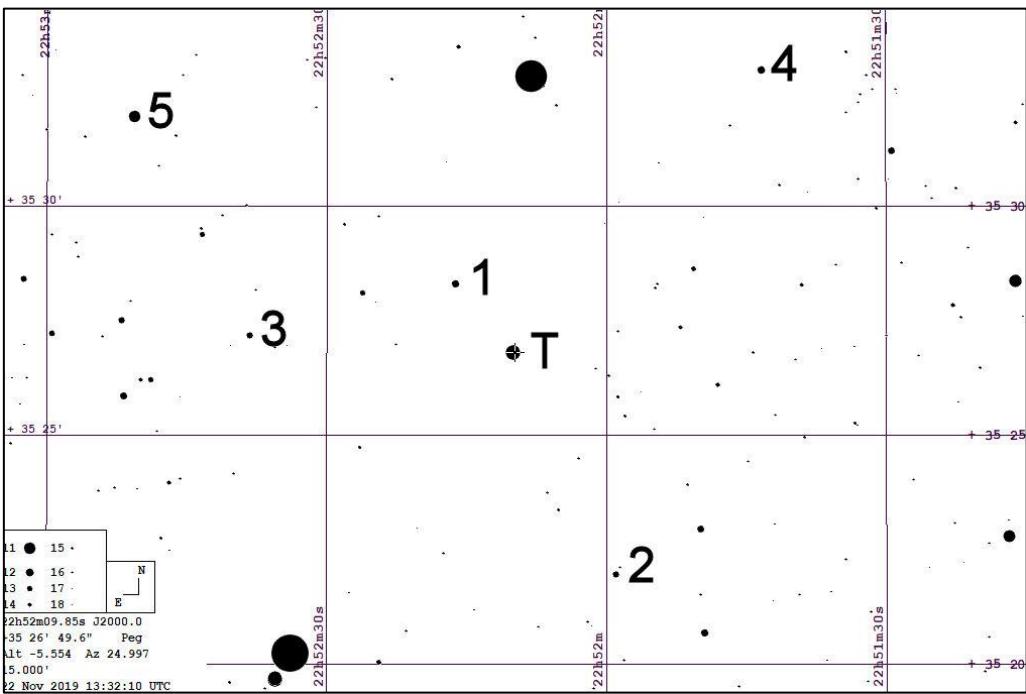
Figure A6.1. Star and transit data

Figure A6.2. STScI DSS chart

A6.3. Guide finder chart, 15' x 15'

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

Appendix A.7

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-17b	21 38 08.73	30 29 19.4	10.38	0.802	21

Table A7.1. Target data
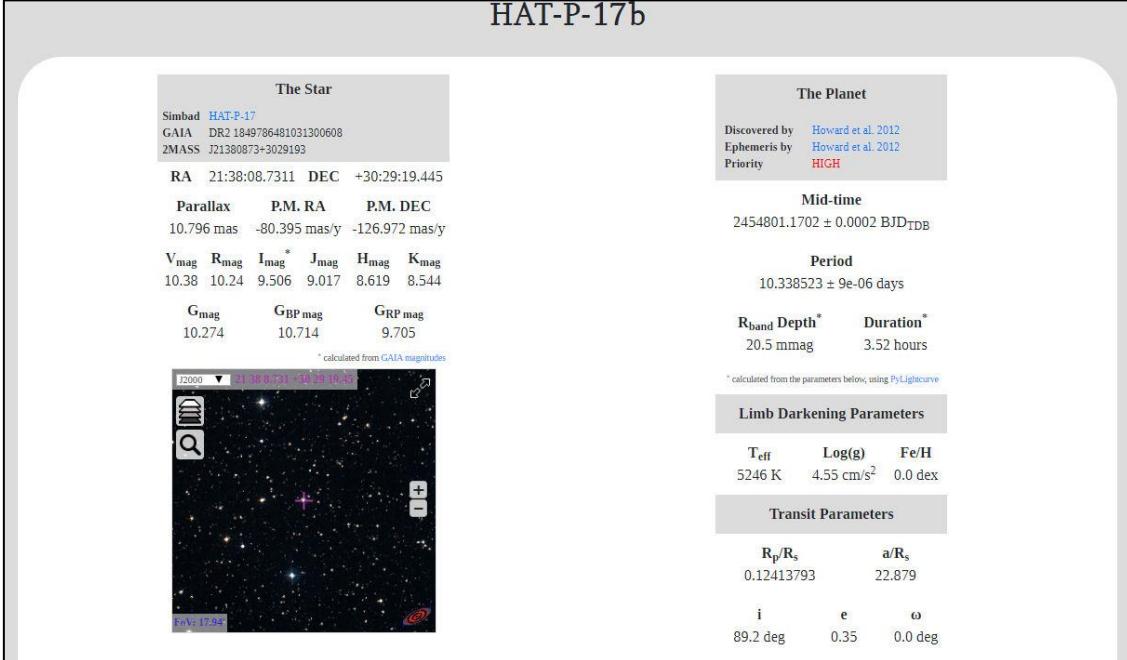
Figure A7.1. Star and transit data
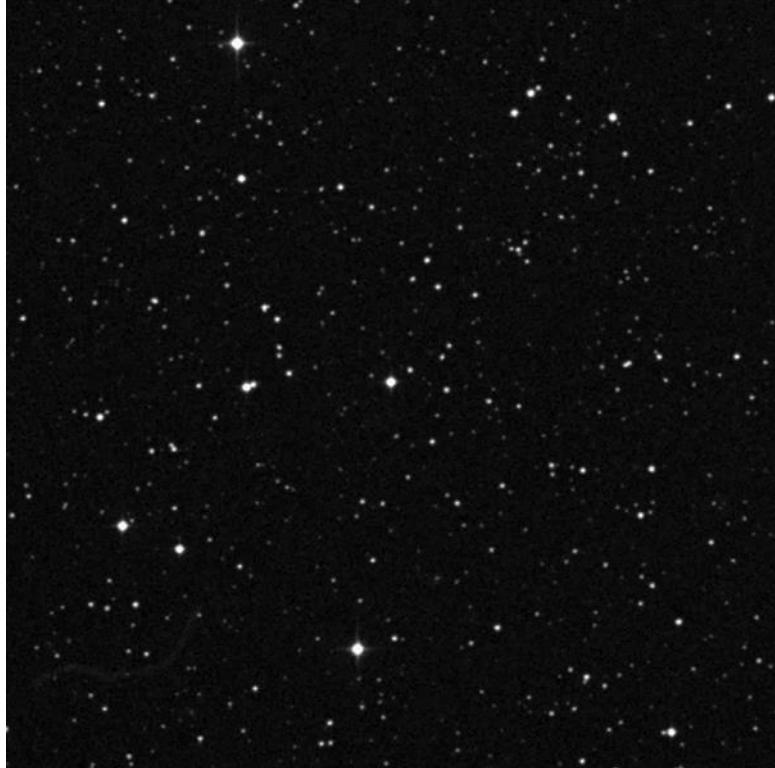
Figure A7.2. STScI DSS chart
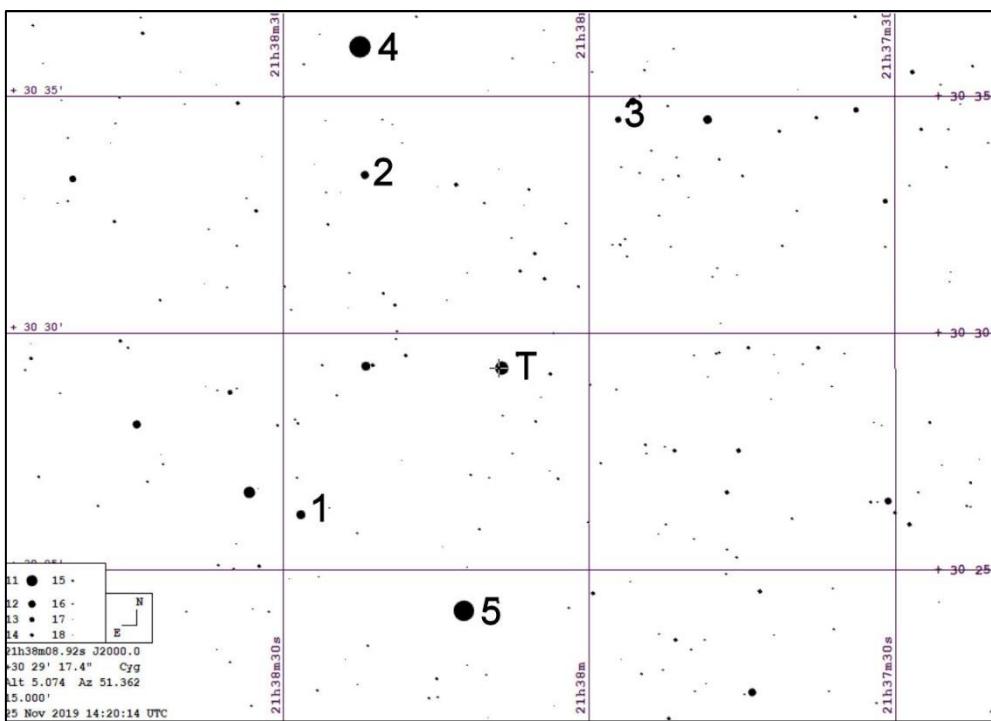
Figure A7.3. Guide finder chart, 15' x 15'

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. Comparison star data

Appendix A.8 [Return to target list](#)

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-3b	13 44 22.59	48 01 43.2	11.86	0.817	16

Table A8.1. Target data
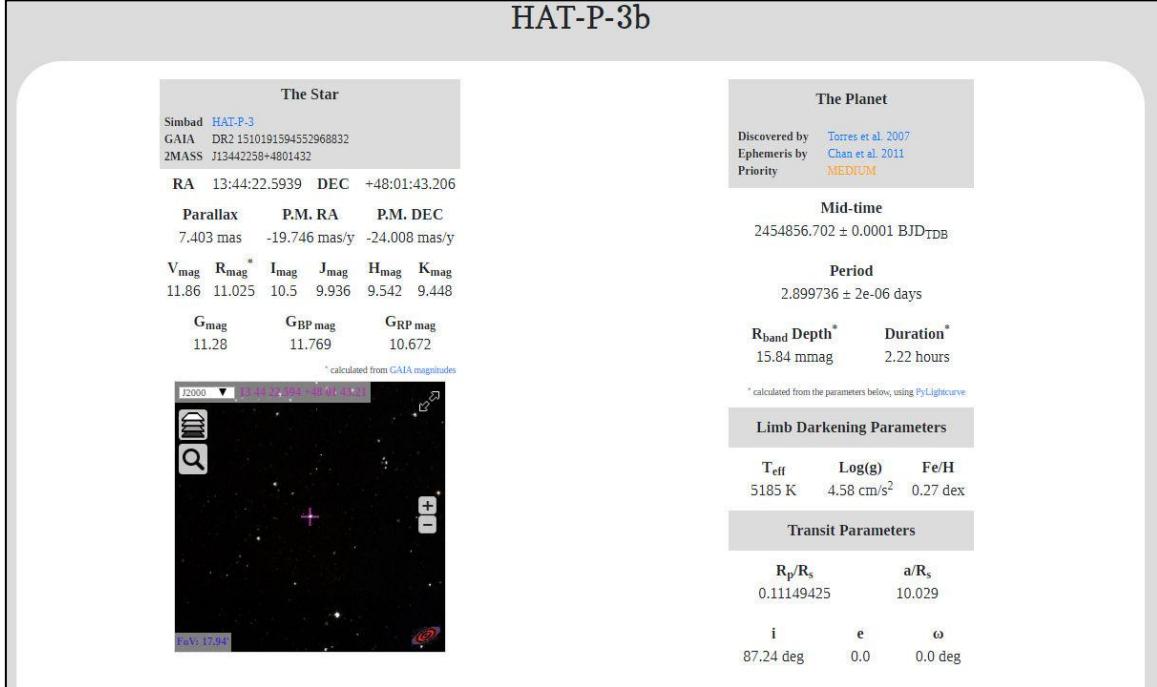
Figure A8.1. Star and target data

Figure A8.2. STScI DSS chart
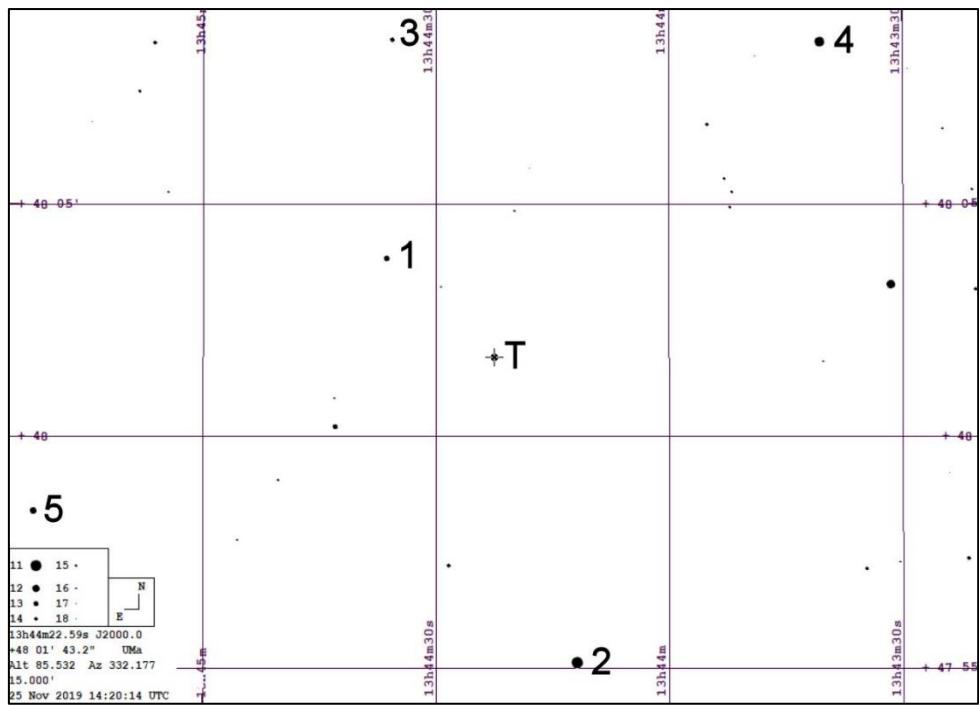
Figure A8.3. Guide finder chart, 15' x 15'

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. comparison star data

Target	RA	Dec	V	B-V	Depth (mmag)
WASP-11b	03 09 28.54	30 40 24.9	11.57	0.964	23

Table A9.1. Target data
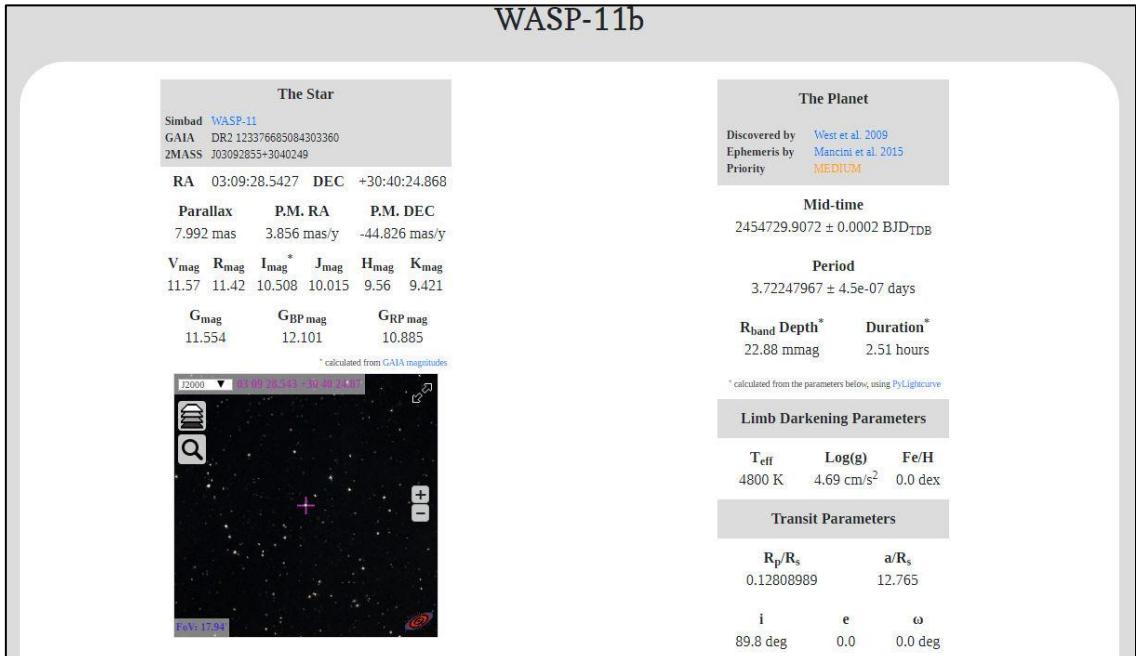
Figure A9.1. star and transit data
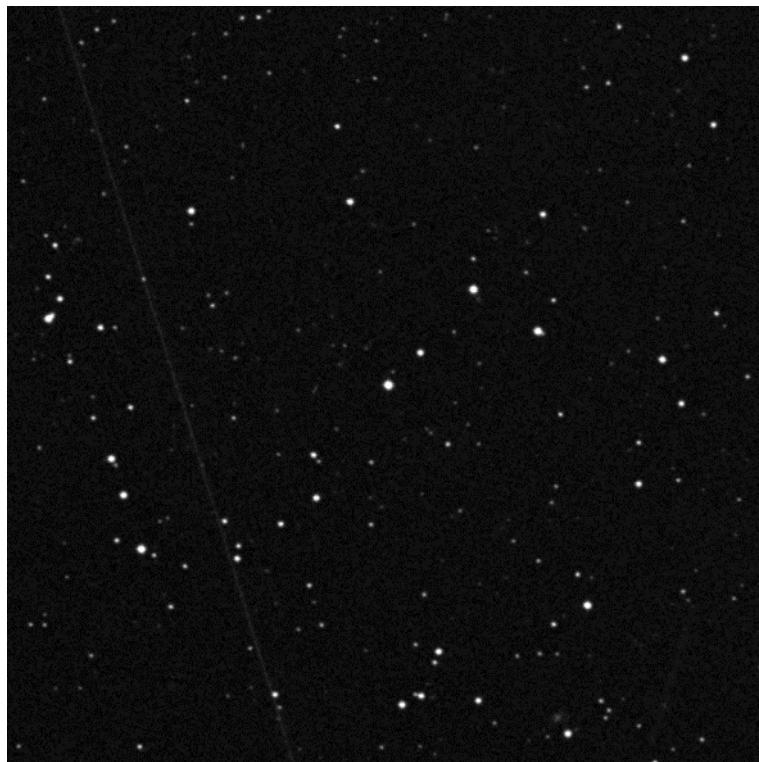
Figure A9.2. STScI DSS chart
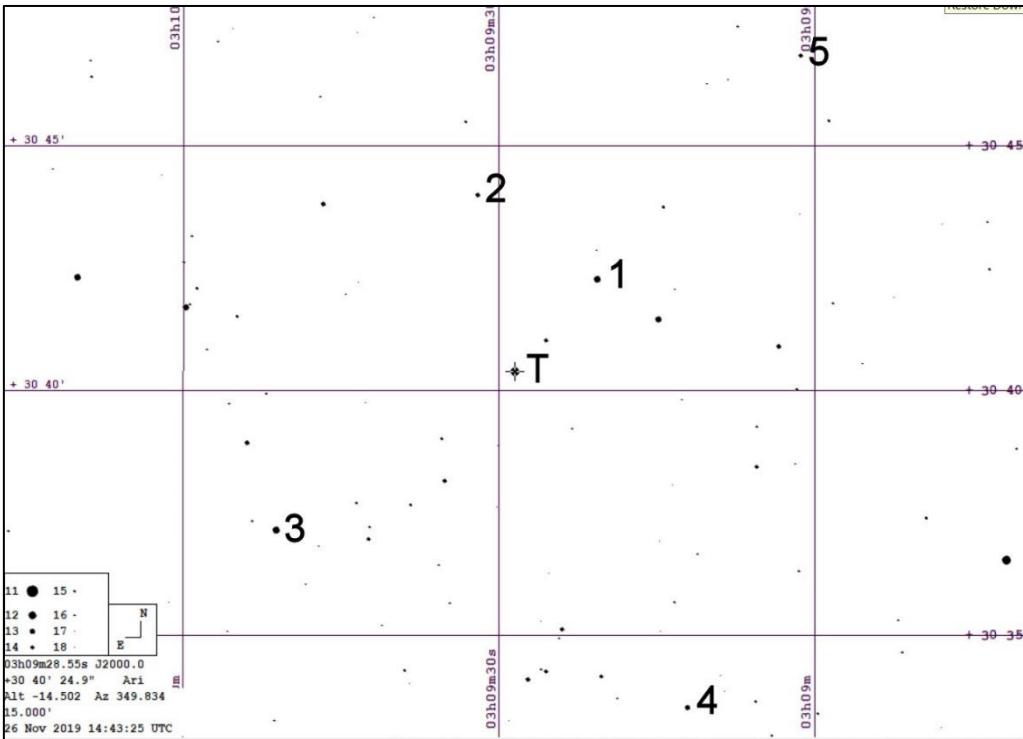
Figure A9.3. Guide finder chart, 15' x 15'

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. Comparison star data

Appendix A10

| Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-12b	13 57 33.47	43 29 36.6	12.84	1.086	28

Table A10.1. Target data
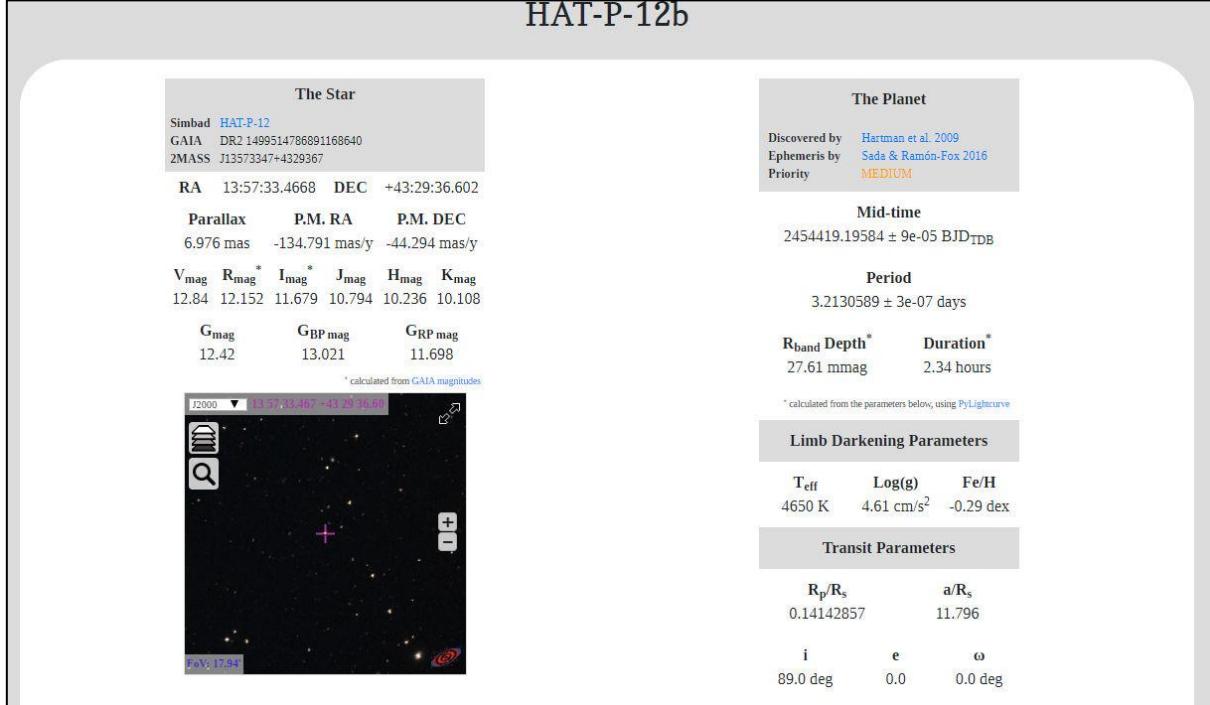
Figure A10.1. Star and transit data

Figure A10.3. STScI DSS chart
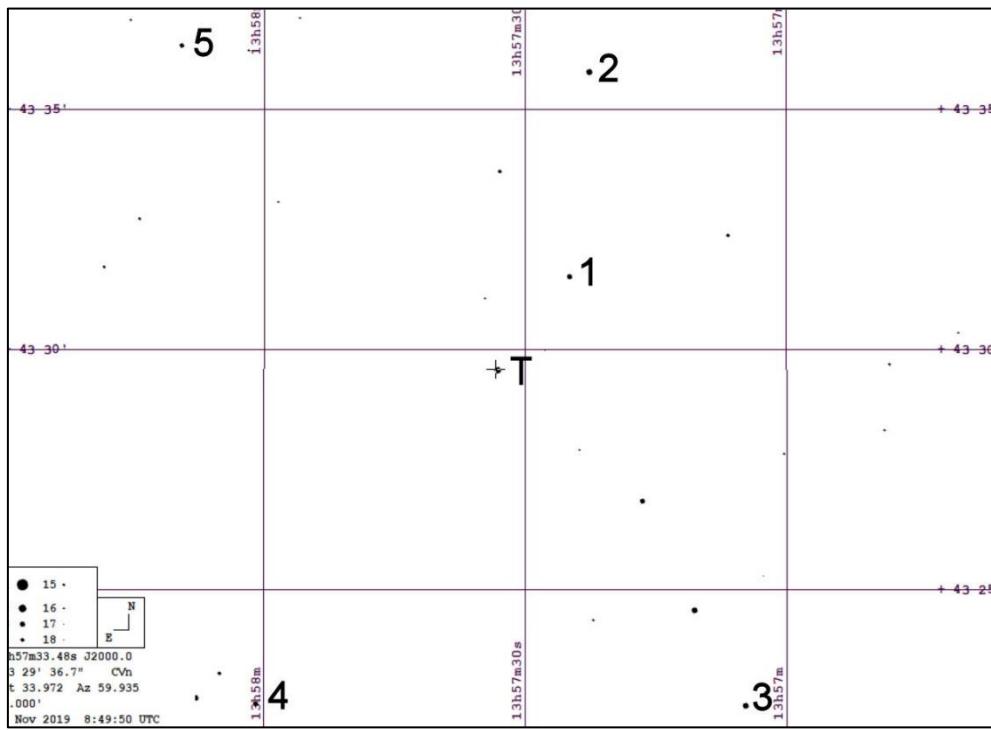
Figure A10.2. Guide finder chart, 15' x 15'

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. comparison star data

Appendix A11 [Return to target list](#)

| Target	RA	Dec	V mag	B-V	Depth (mmag)
[WASP-10b](#)	23:15:58.30	+31:27:46.3	12.7	1.110	34

Table A11.1. Target data
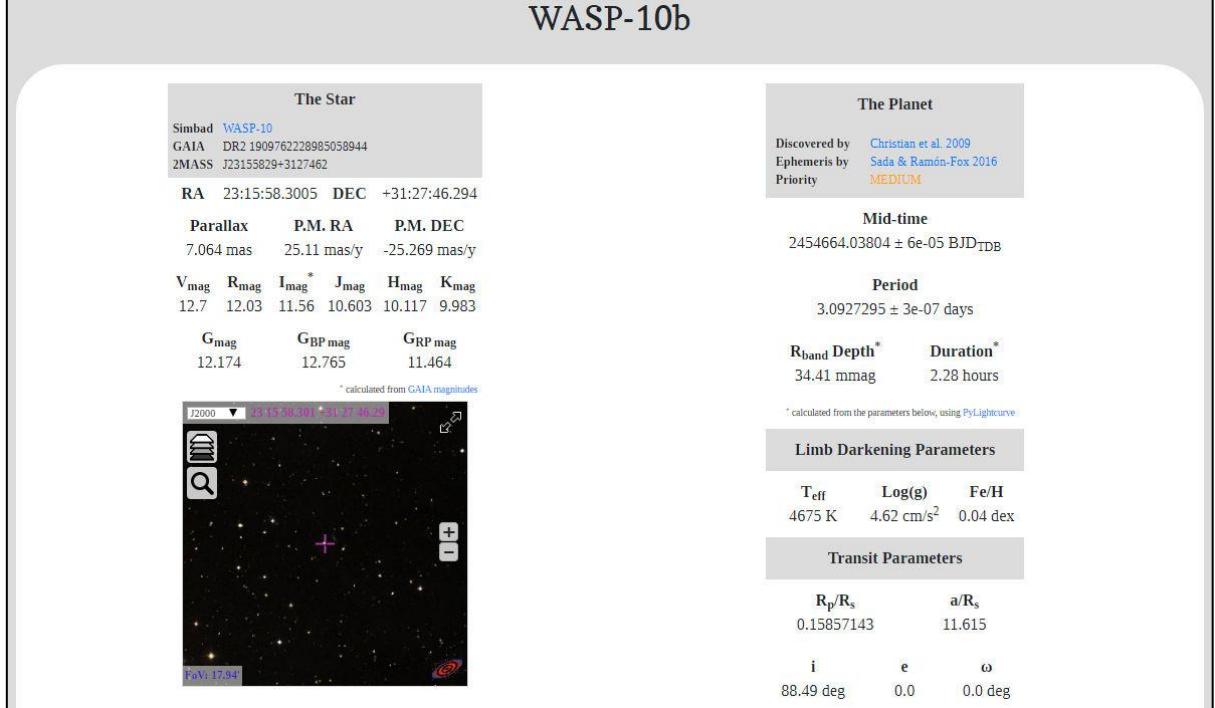
Figure A11.1. Star and transit data

Figure A11.3. STScI DSS chart
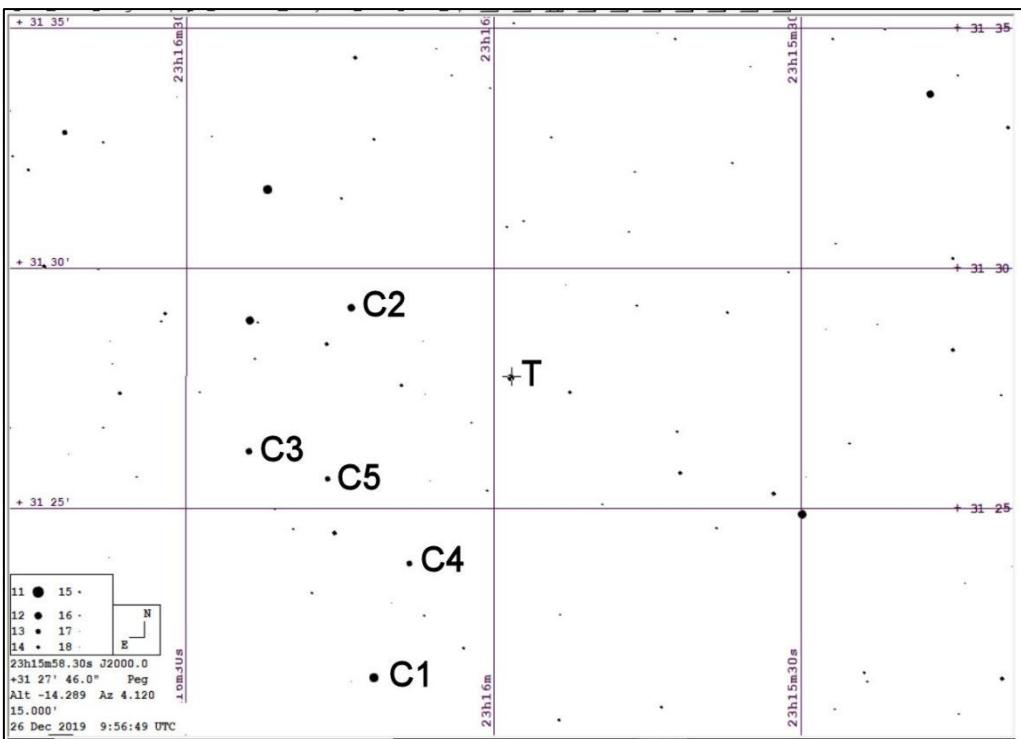
Figure A11.2. Guide finder chart, 15' x 15'

Comp star	RA	Dec	V mag	B-V
1	23 16 11.70	31 21 30.0	11.306	0.712
2	23 16 13.91	31 29 13.2	11.972	0.542
3	23 16 23.93	31 26 13.7	12.351	0.645
4	23 16 08.19	31 23 52.7	12.604	0.564
5	23 16 18.23	31 25 39.3	12.840	0.646

Table A11.2. Comparison star data

Appendix A12

| Target	RA	Dec	V mag	B-V	Depth (mmag)
HD189733b	20:00:43.71	+22:42:39.1	7.65	0.932	28

Table A12.1. Target data
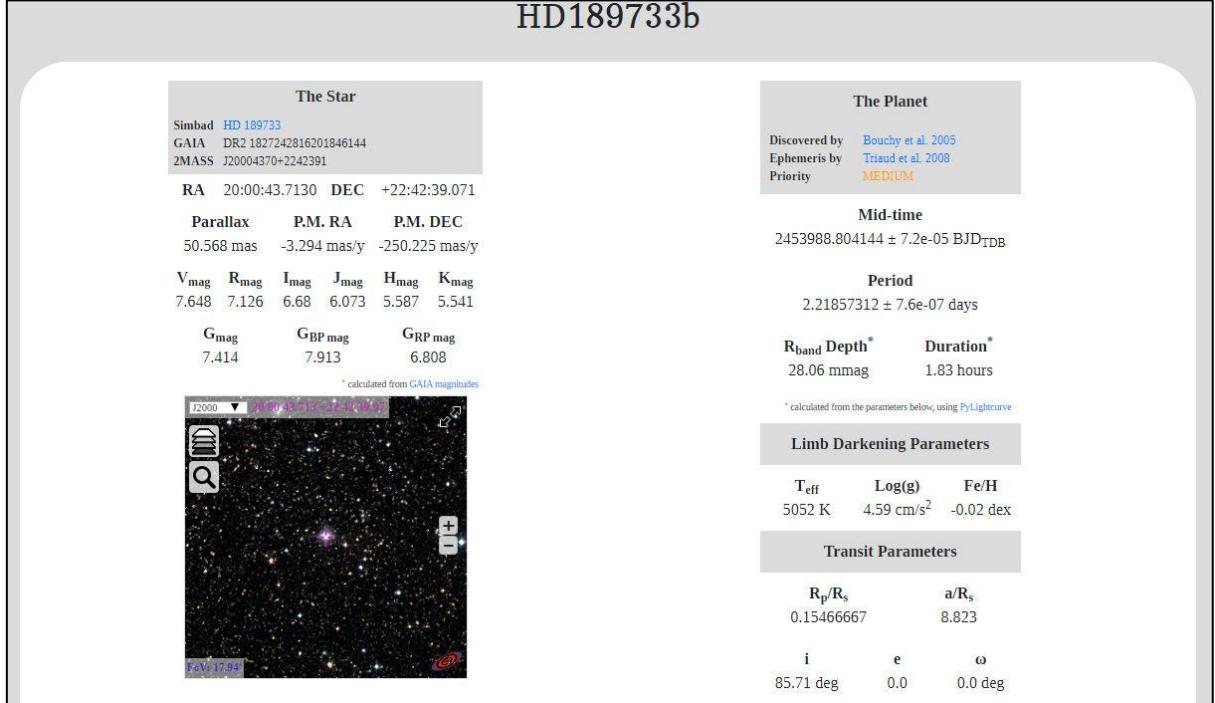
Figure A12.1. Star and transit data

Figure A12.2. STScI DSS chart
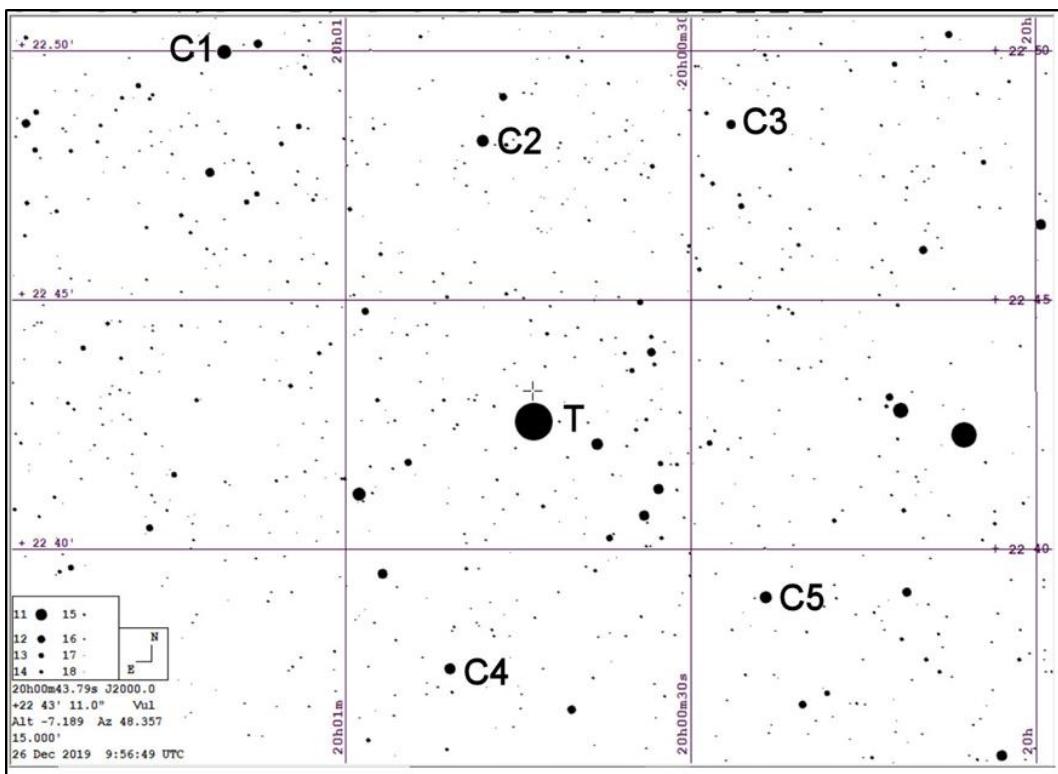
Figure A12.3. Guide finder chart, 15' x 15'

Comparison star	RA	Dec	V mag	B-V
1	20 01 10.65	+22 49 58.10	10.419	0.442
2	20 00 48.16	+22 48 12.20	10.751	0.567
3	20 00 26.53	+22 48 31.40	11.572	0.596
4	20 00 50.91	+22 37 36.10	11.157	0.441
5	20 00 23.51	+22 39 02.60	10.800	0.567

Table A12.2. Comparison star data

Appendix A13

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-22b	10:22:43.59	+50:07:42.0	9.76	0.843	14

Table A13.1. Target data
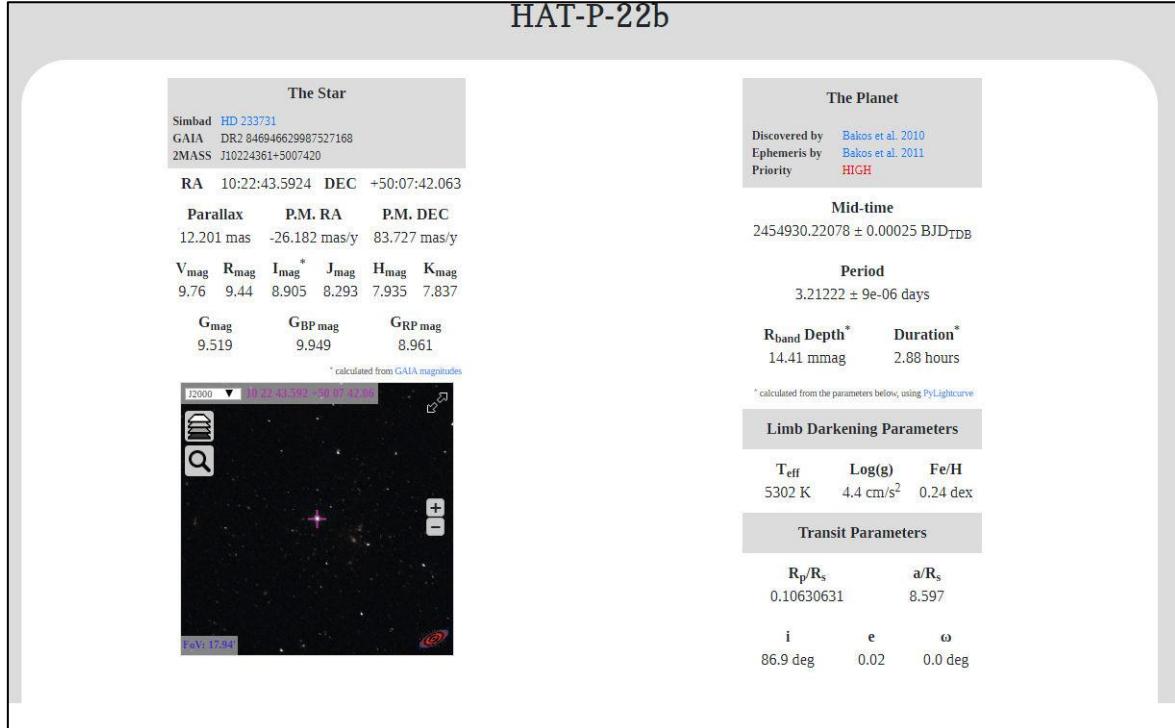
Figure A13.1. Star and transit data
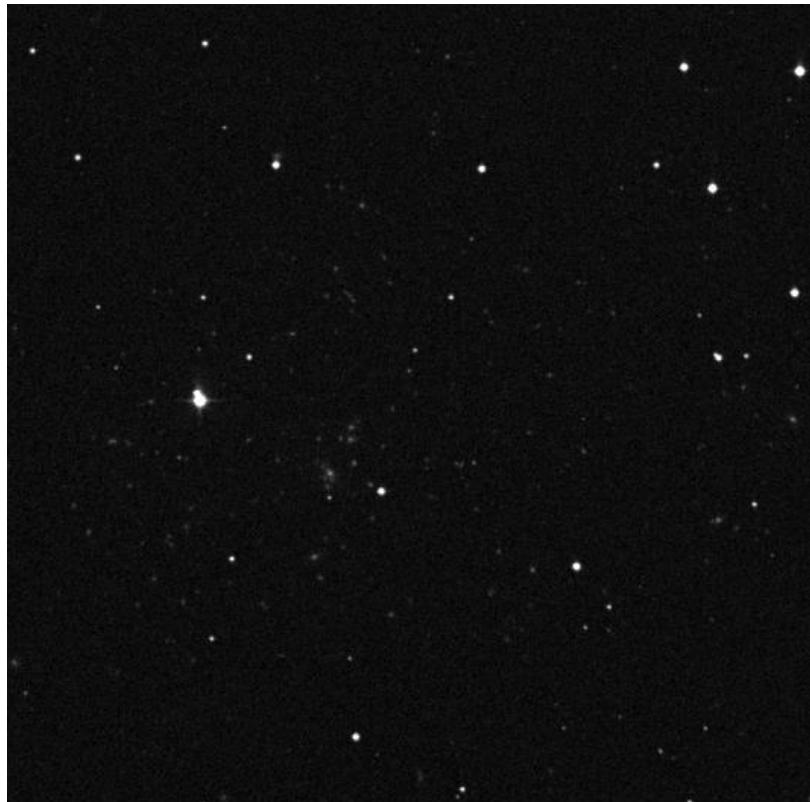
Figure A13.2. STScI DSS chart
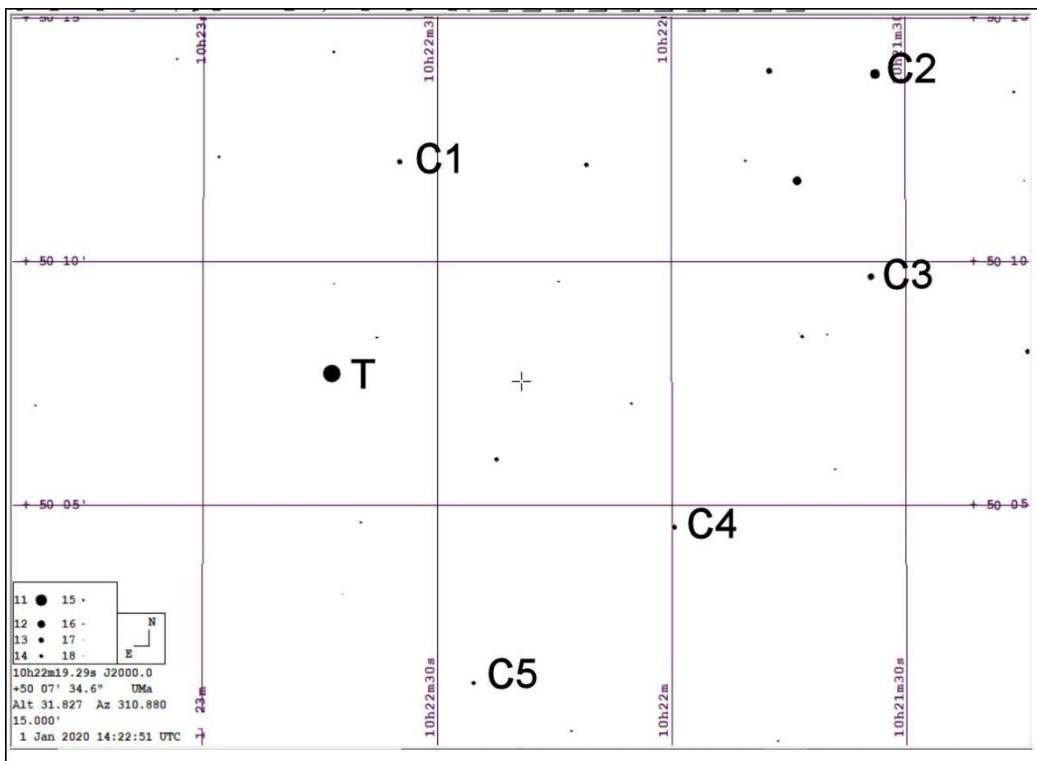
Figure A13.3. Guide finder chart, 15' x 15'

Comparison star	RA	Dec	V	B-V
1	10 22 34.89	+50 12 05.19	13.180	
2	10 21 33.90	+50 13 52.79	11.288	1.009
3	10 21 34.40	+50 09 43.51	12.530	
4	10 21 59.70	+50 04 36.22	13,100	
5	10 22 25.30	+50 01 24.07	13.760	

Table A13.2. Comparison star data

Appendix A14 No ETD entry for this target

Target	RA	Dec	V mag	B-V	Depth (mmag)
Kepler-447b	19:01:04.46	+48:33:35.9	12.55		26

Table A13.1. Target data
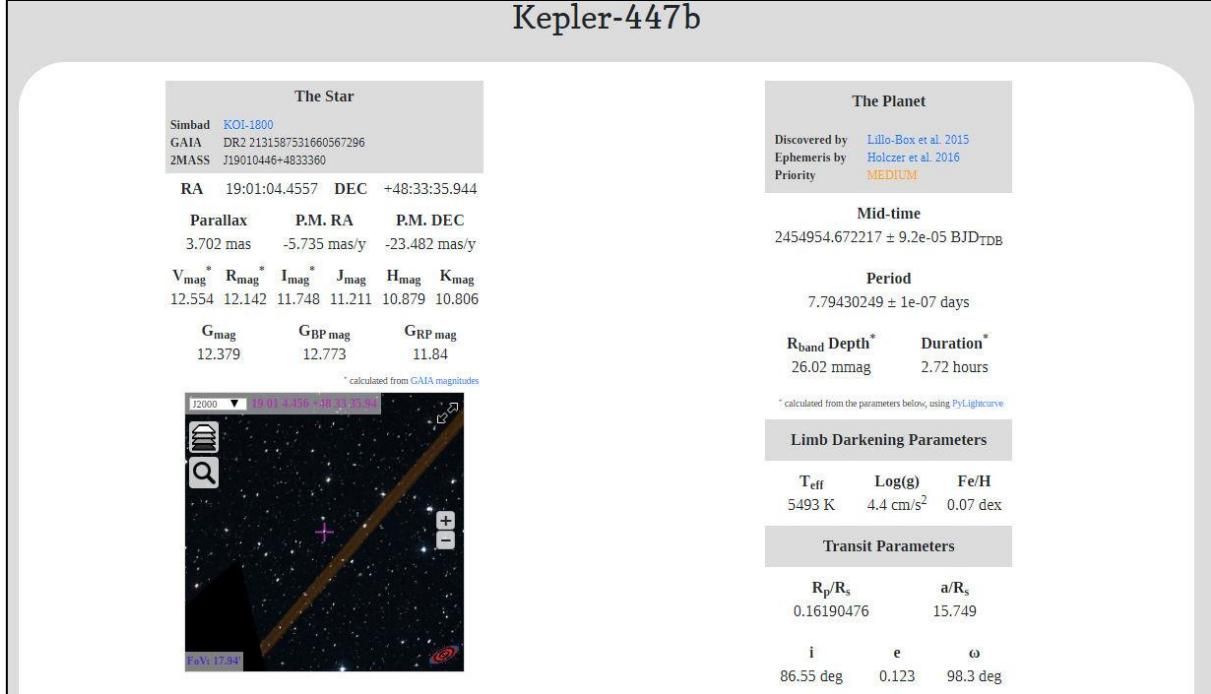

Figure A14.1. Star and transit data

Figure A14.2. STScI DSS chart
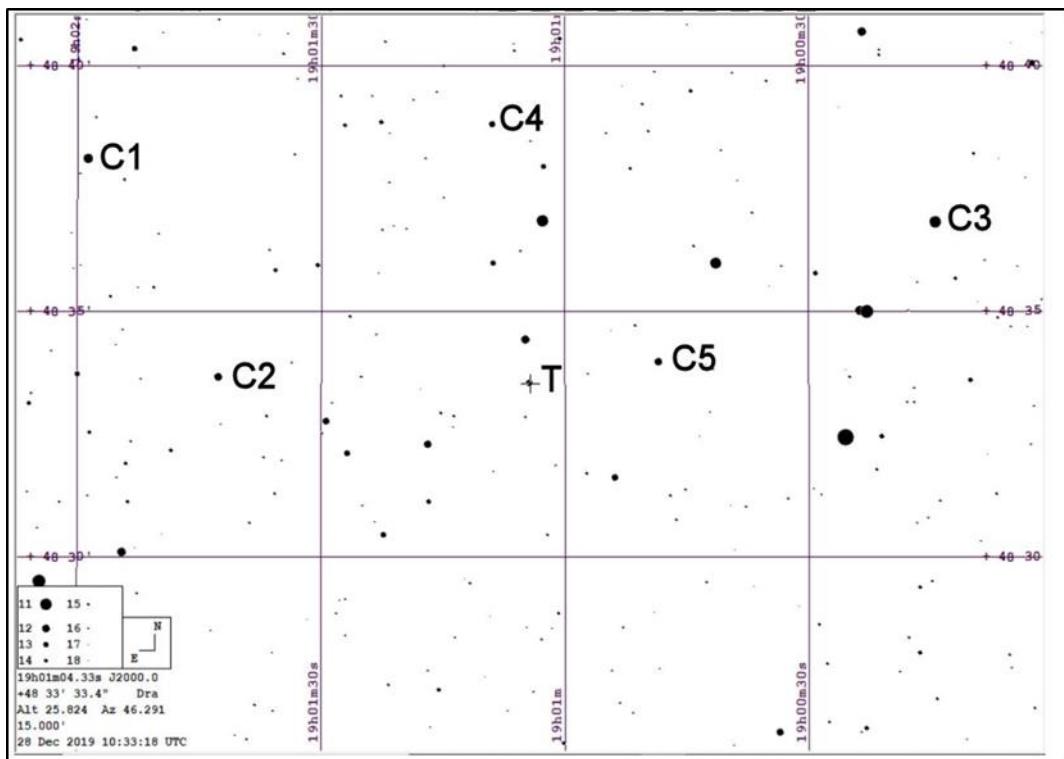
Figure A14.3. Guide finder chart, 15' x 15'

Comparison star	RA	Dec	V	B-V
1	19 01 58.77	+48 38 07.70	11.45	1.48
2	19 01 42.64	+48 33 41.40	12.00	1.37
3	19 00 14.42	+48 36 49.91	11.01	0.66
4	19 01 09.01	+48 38 51.01	12.61	
5	19 00 48.58	+48 34 11.53	12.10	

Table A14.2. Comparison star data

Appendix A15

| Target	RA	Dec	V mag	B-V	Depth (mmag)
TrES-1b	19:04:09.85	+36:37:57.4	11.42	0.600	25

Table A15.1. Target data
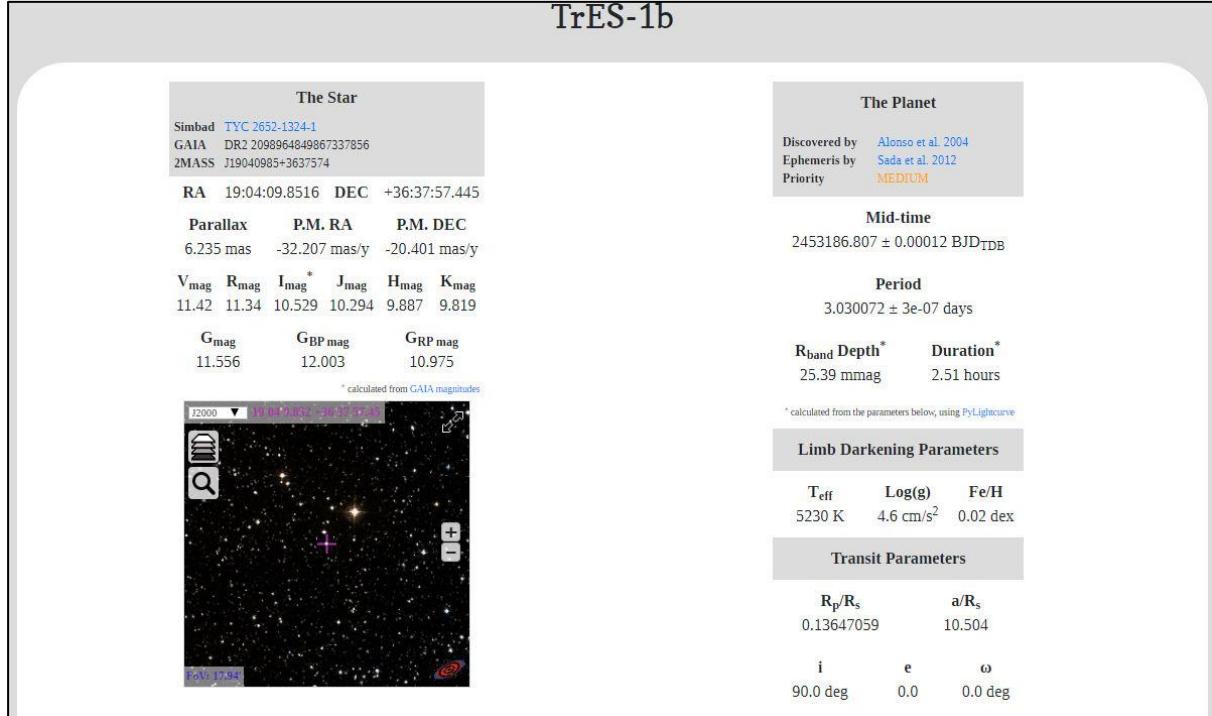
Figure A15.1. Star and transit data

Figure A15.2. STScI DSS chart
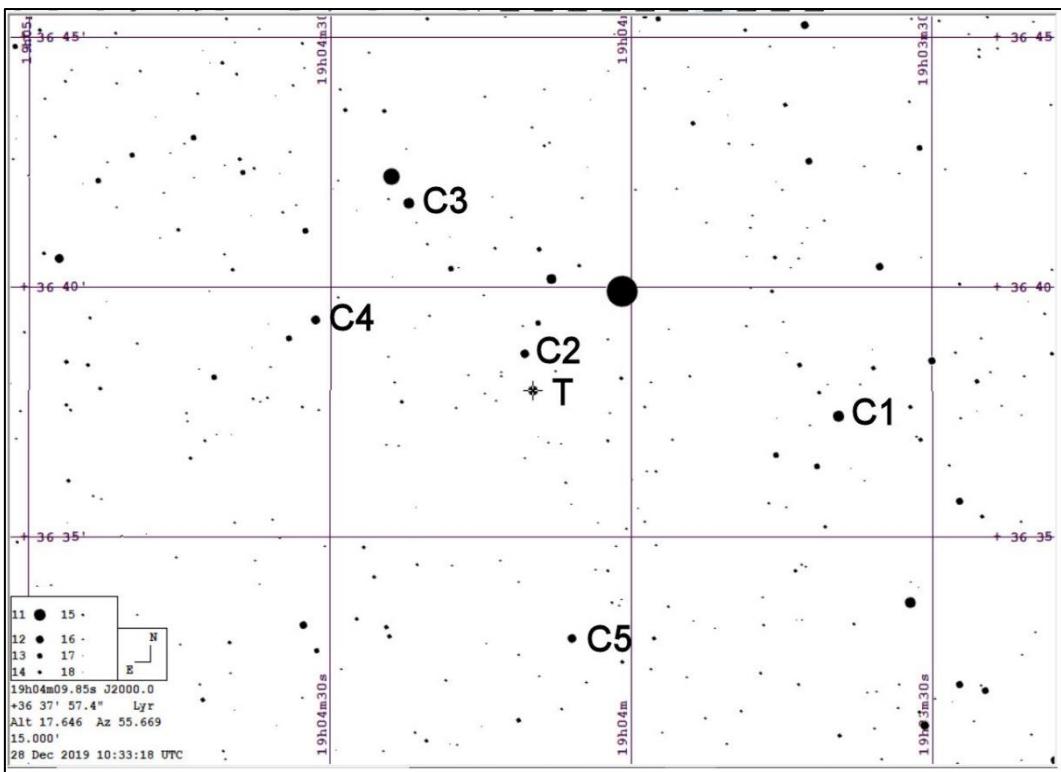
Figure A15.3. Guide finder chart, 15' x 15'

Comparison star	RA	Dec	V mag	B-V
1	19 03 39.34	+36 37 25.70	10.954	0.687
2	19 04 10.58	+36 38 40.80	11.506	0.961
3	19 04 22.17	+36 41 41.70	11.265	1.120
4	19 04 31.45	+36 39 20.80	11.414	1.267
5	19 04 05.99	+36 33 00.40	12.021	1.081

Table A15.2. Comparison star data

Appendix A16 Return to target list

Target	RA	Dec	V mag	B-V	Depth (mmag)
WASP-85Ab	11:43:38.01	+06:33:49.4	10.72	0.731	24

Table A16.1. Target data

WASP-85Ab

The Star

Simbad BD+07 2474
GAIA DR2 3909745223886018432
2MASS J11433800+0633494

RA 11:43:38.006 DEC +06:33:49.43

Parallax	P.M. RA	P.M. DEC
7.02 mas	-77.24 mas/y	11.016 mas/y

V_{mag}	R_{mag}	I_{mag}^*	J_{mag}	H_{mag}	K_{mag}
10.72	10.34	9.935	9.275	8.925	8.733

G_{mag}	$G_{BP\,mag}$	$G_{RP\,mag}$
10.624	10.902	9.993

* calculated from GAIA magnitudes

The Planet

Discovered by Močnik et al. 2016
Ephemeris by Močnik et al. 2016
Priority MEDIUM

Mid-time
2456847.473634 ± 1.4e-05 BJD$_{TDB}$

Period
2.6556777 ± 4.4e-07 days

R_{band} Depth*	Duration*
23.75 mmag	2.59 hours

* calculated from the parameters below, using PyLightcurve

Limb Darkening Parameters

T_{eff}	Log(g)	Fe/H
6112 K	4.53 cm/s^2	0.0 dex

Transit Parameters

R_p/R_s	a/R_s
0.13510638	8.922

| i	e	ω
89.69 deg	0.0	0.0 deg

Figure A16.1. Star and transit data
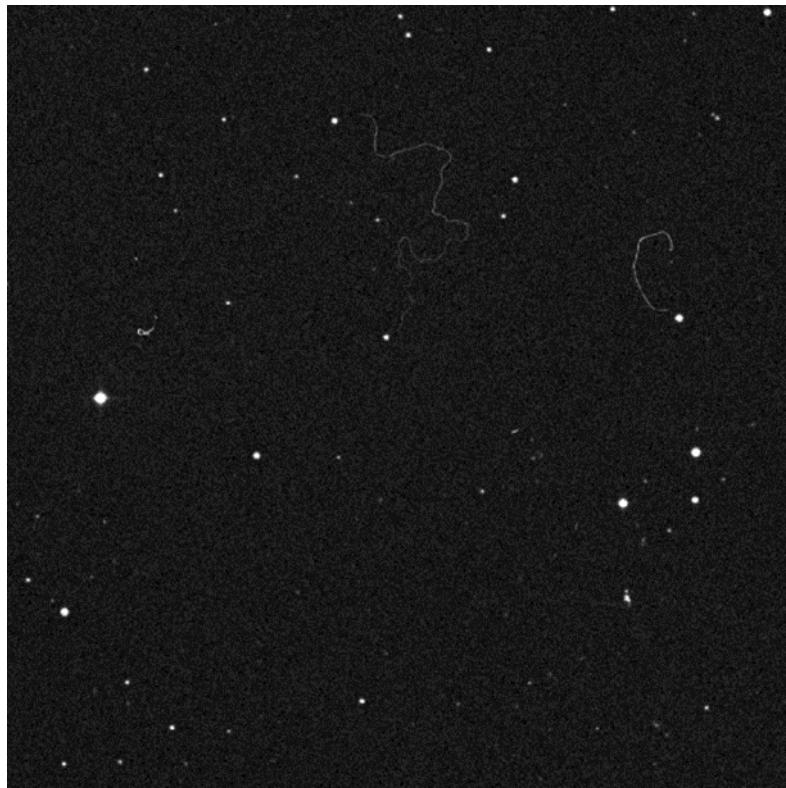
Figure A16.2. STScI DSS chart
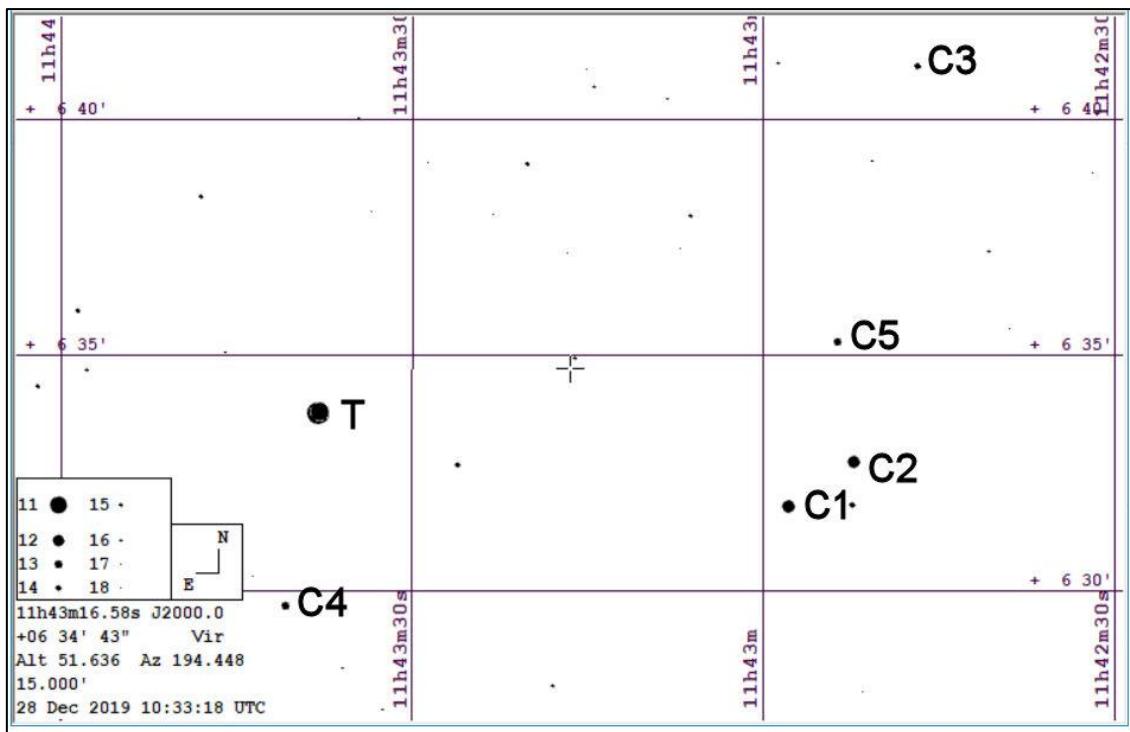
Figure A16.3. Guide finder chart, 15' x 15'

Comparison star	RA	Dec	V mag	B-V
1	11 42 57.99	+06 31 49.00	11.928	0.611
2	11 42 52.34	+06 32 46.98	11.910	
3	11 42 46.89	+06 07 00.11	13.660	
4	11 43 40.84	+06 29 43.98	12.892	0.585
5	11 42 53.71	+00 06 53.99	13.240	

Table A16.2. Comparison star data

Appendix A17 No ETD entry for this target

Target	RA	Dec	V mag	B-V	Depth (mmag)
K2-29b	04:10:40.88	+24:24:06.3	12.56	1.099	25

Table A17.1. Target data
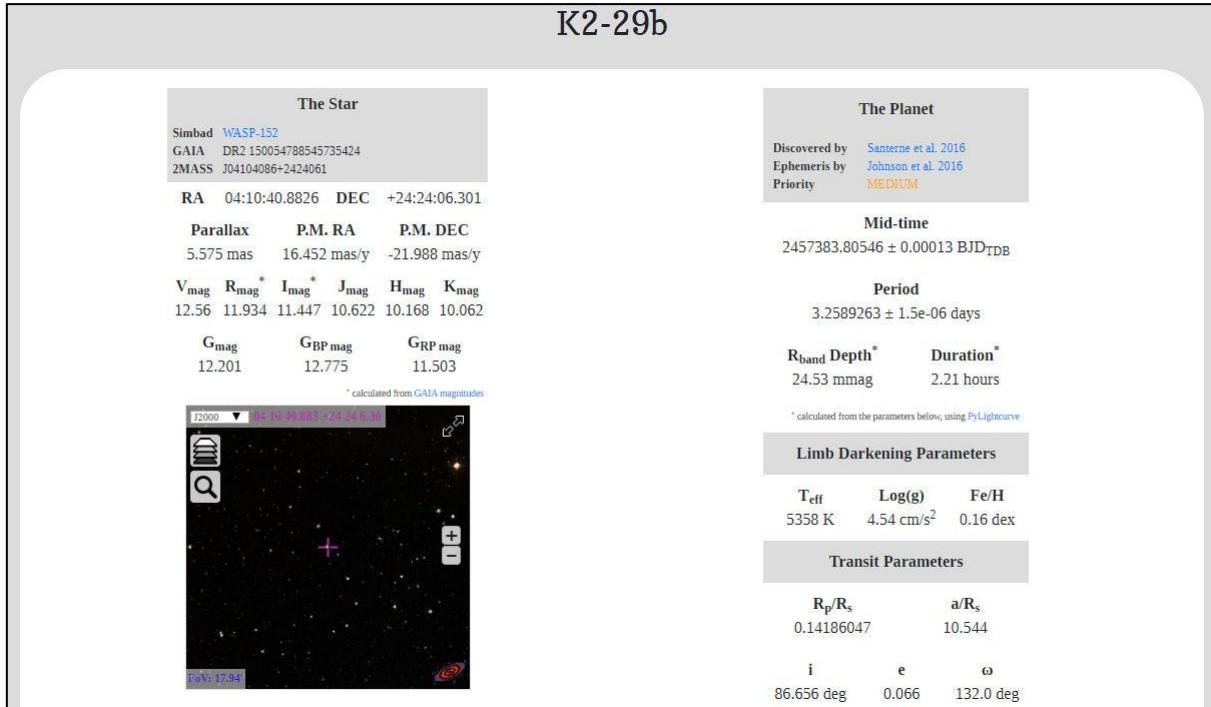
Figure A17.1. Star and transit data

Figure A17.2. STScI DSS chart
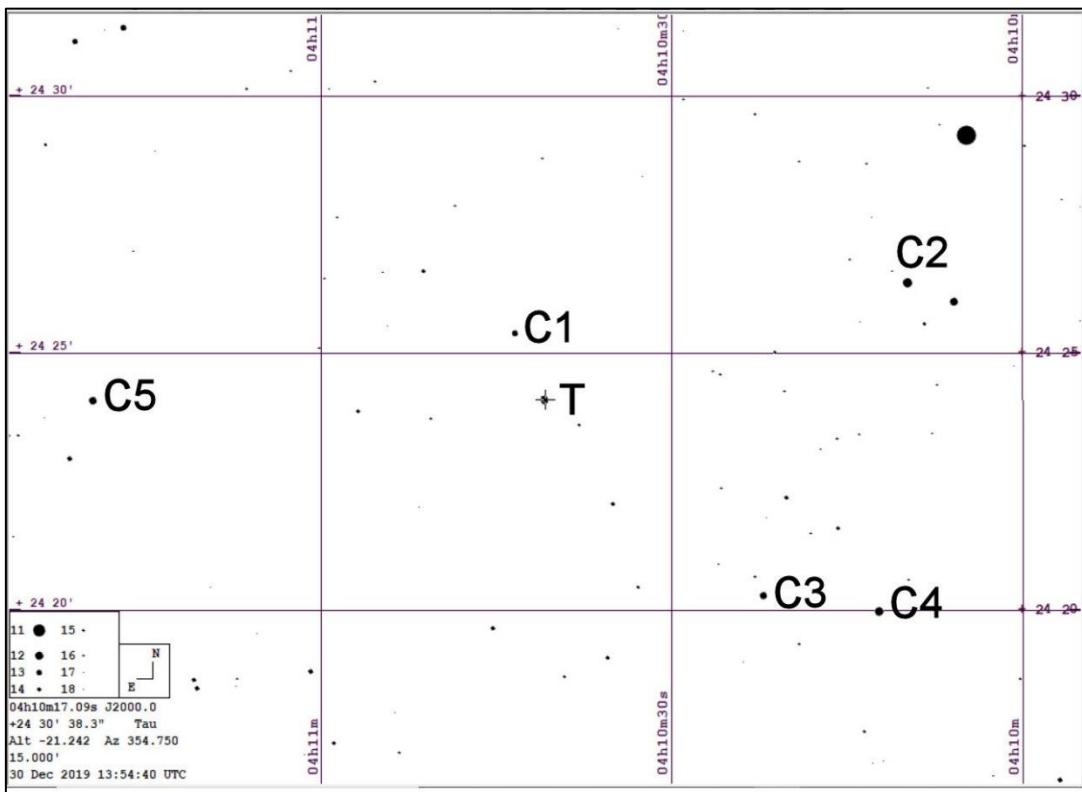
Figure A17.3. Guide finder chart, 15' x 15'

Comparison star	RA	Dec	V mag	B-V
1	04 10 43.45	+24 25 24.35	12.729	0.835
2	04 10 09.83	+24 26 21.76	11.815	1.254
3	04 10 22.22	+24 20 17.99	12.389	0.742
4	04 10 12.30	+24 19 59.97	12.057	1.134
5	04 11 19.50	+24 24 05.80	12.373	1.182

Table A17.2. Comparison star data

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-32b	02:04:10.28	+46:41:16.2	11.44	0.546	30

Table A18.1. Target data
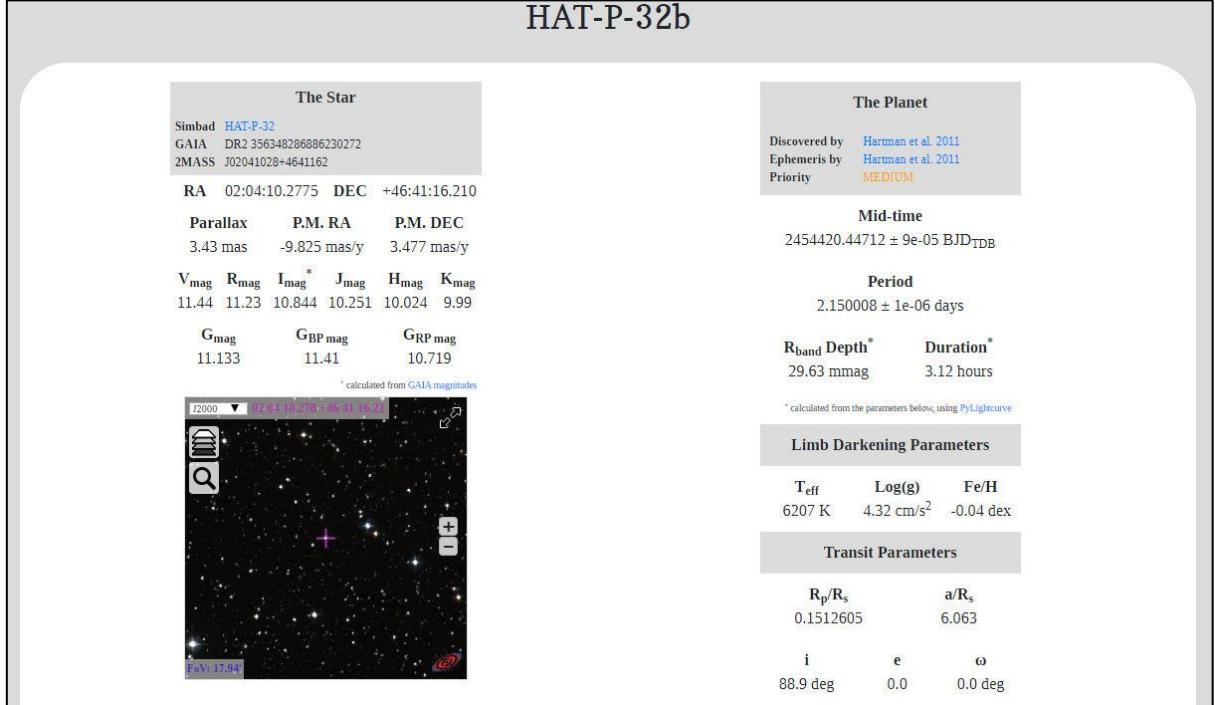
Figure A18.1. Star and transit data

Figure A18.2. STScI DSS chart
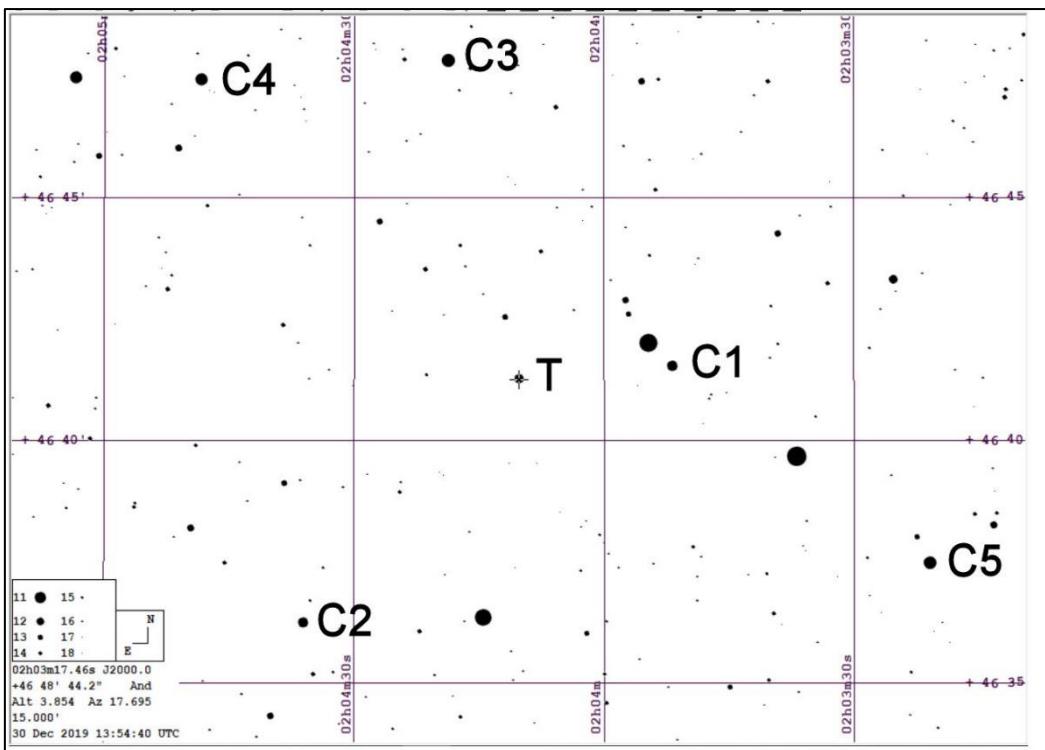
Figure A18.3. Guide finder chart, 15' x 15'

Comparison star	RA	Dec	V mag	B-V
1	02 03 51.78072	+46 41 32.0280	11.242	1.375
2	02 04 36.07176	+46 36 14.9652	11.482	1.138
3	02 04 18.68232	+46 47 50.7804	10.443	0.914
4	02 04 48.39432	+46 47 27.2724	10.598	0.558
5	02 03 20.91408	+46 37 29.0424	10.695	1.154

Table A18.2. Comparison star data

Target	RA	Dec	V mag	B-V	Depth (mmag)
TrES-3b	17:52:07.02	+37:32:46.2	12.40	0.623	27

Table A19.1. Target data
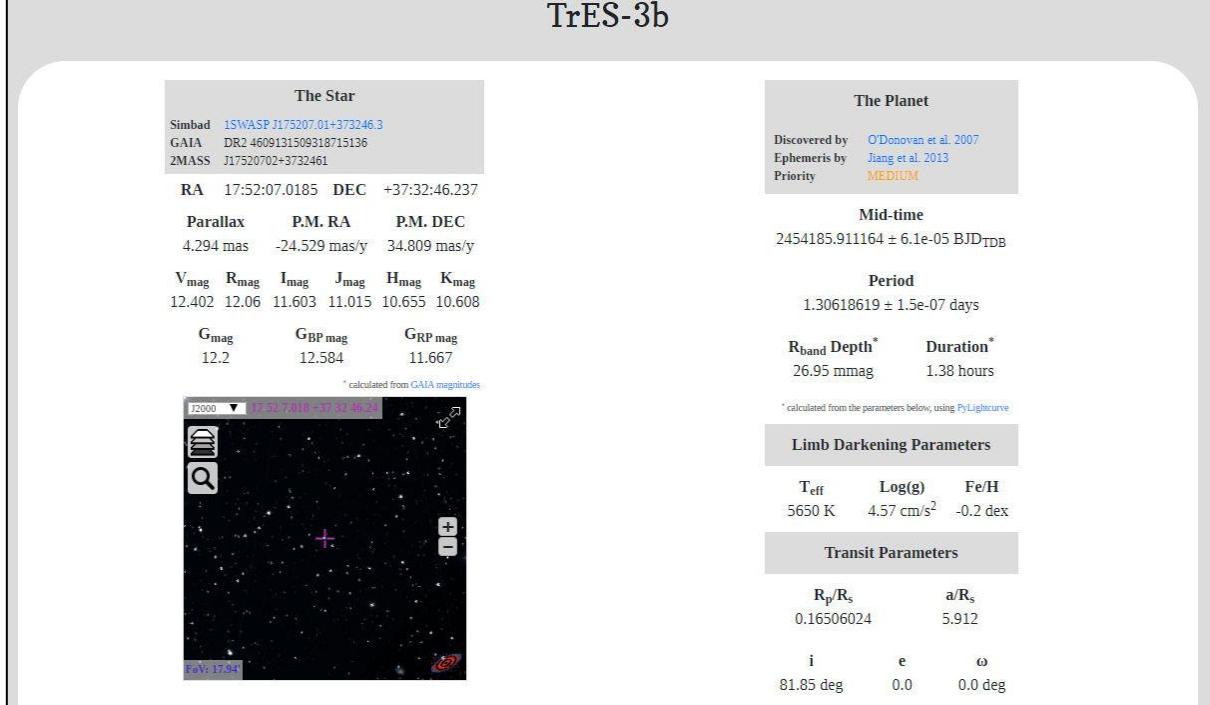
Figure A19.1. Star and transit data
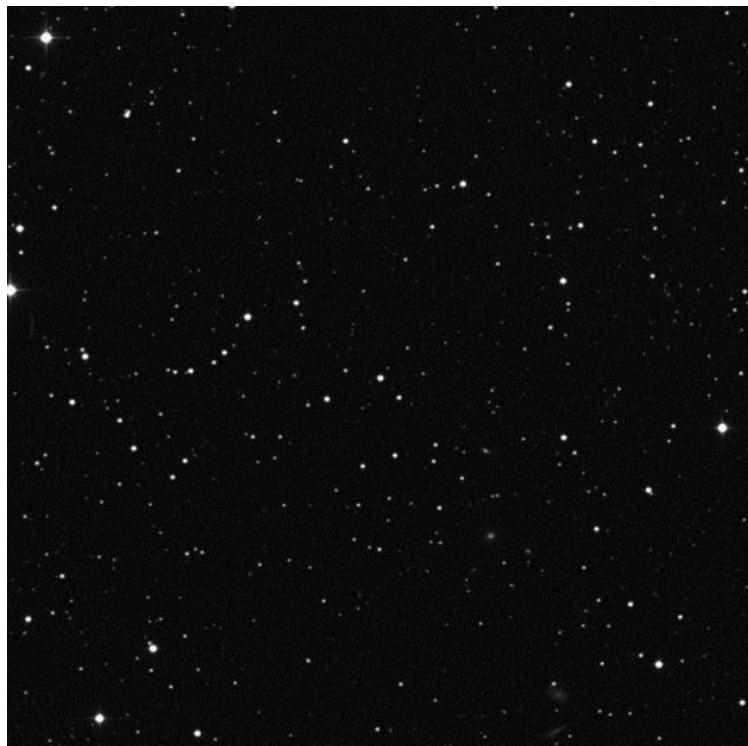
Figure A19.2. STScI DSS chart
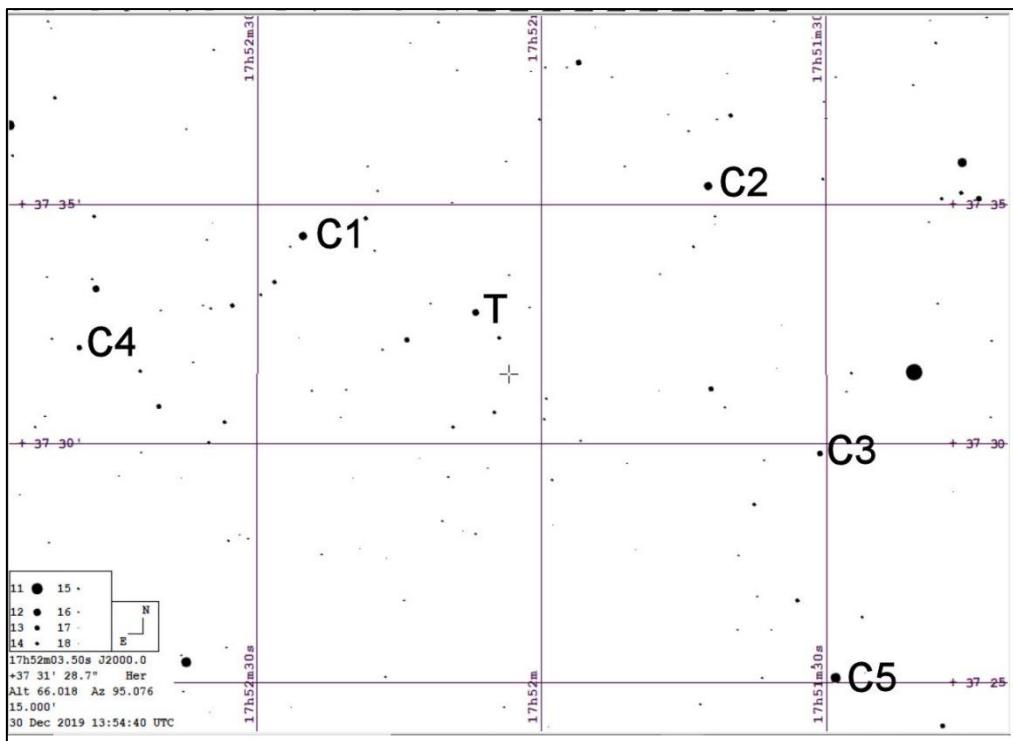
Figure A19.3. Guide finder chart, 15' x 15'

Comparison star	RA	Dec	V mag	B-V
1	17 52 25.18752	+37 34 21.9756	11.779	0.758
2	17 51 42.48024	+37 35 24.4500	12.257	0.639
3	17 51 30.67680	+37 29 48.3828	12.586	0.437
4	17 52 48.71568	+37 32 02.4288	12.895	0.406
5	17 51 29.12448	+37 25 07.3236	11.427	0.377

Table A19.2. Comparison star data

Appendix A20

Target	RA	Dec	V mag	B-V	Depth (mmag)
XO-1b	16:02:11.85	+28:10:10.4	11.25	0.601	23

Table A19.1. Target data
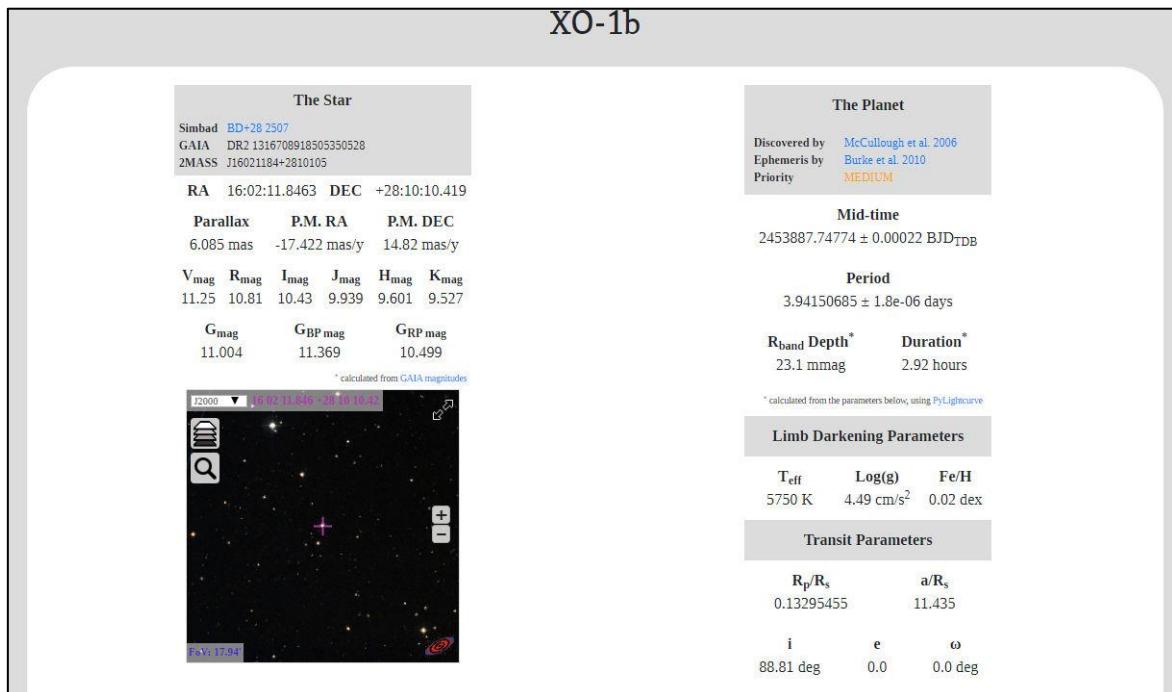
Figure A20.1. Star and transit data

Figure A20.2. STScI DSS chart
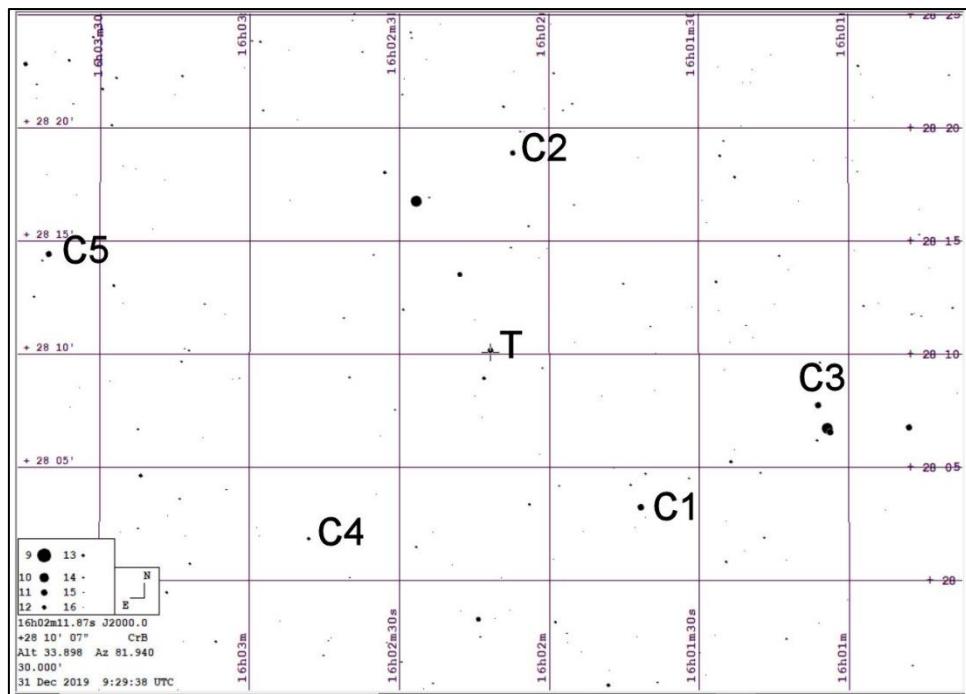
Figure A20.3. Finder chart, 30' x 30'

Comparison star	RA	Dec	V mag	B-V
1	16 01 41.67	+28 03 14.97	10.851	0.938
2	16 02 07.31	+28 18 53.14	11.279	1.097
3	16 01 06.16	+28 07 45.30	10.950	0.965
4	16 02 48.12	+28 01 51.04	12.475	0.672
5	16 03 40.31	+28 14 26.02	11.107	0.517

Table A20.2. Comparison star data

Target	RA	Dec	V mag	B-V	Depth (mmag)
WASP-43b	10 19 38.01	-09 48 22.60	12.4	1.3	30

Table A21.1 Target data
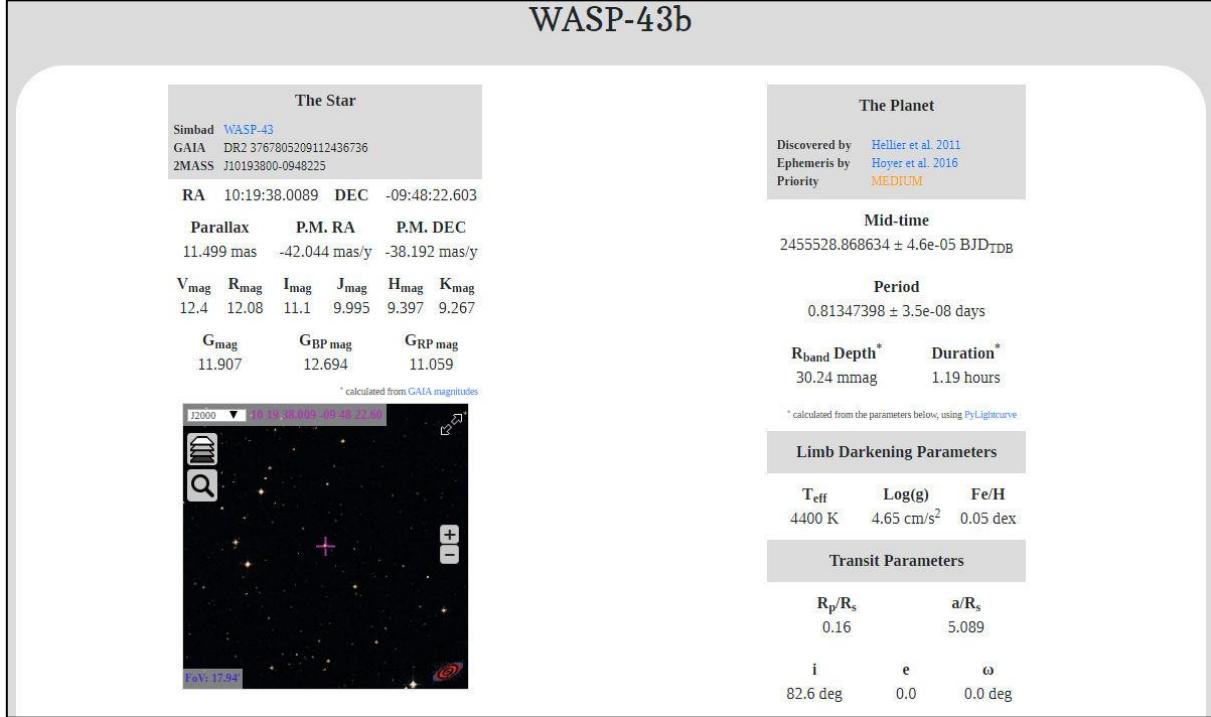
Figure A21.1 Star and transit data

Figure A21.2 STScI DSS chart
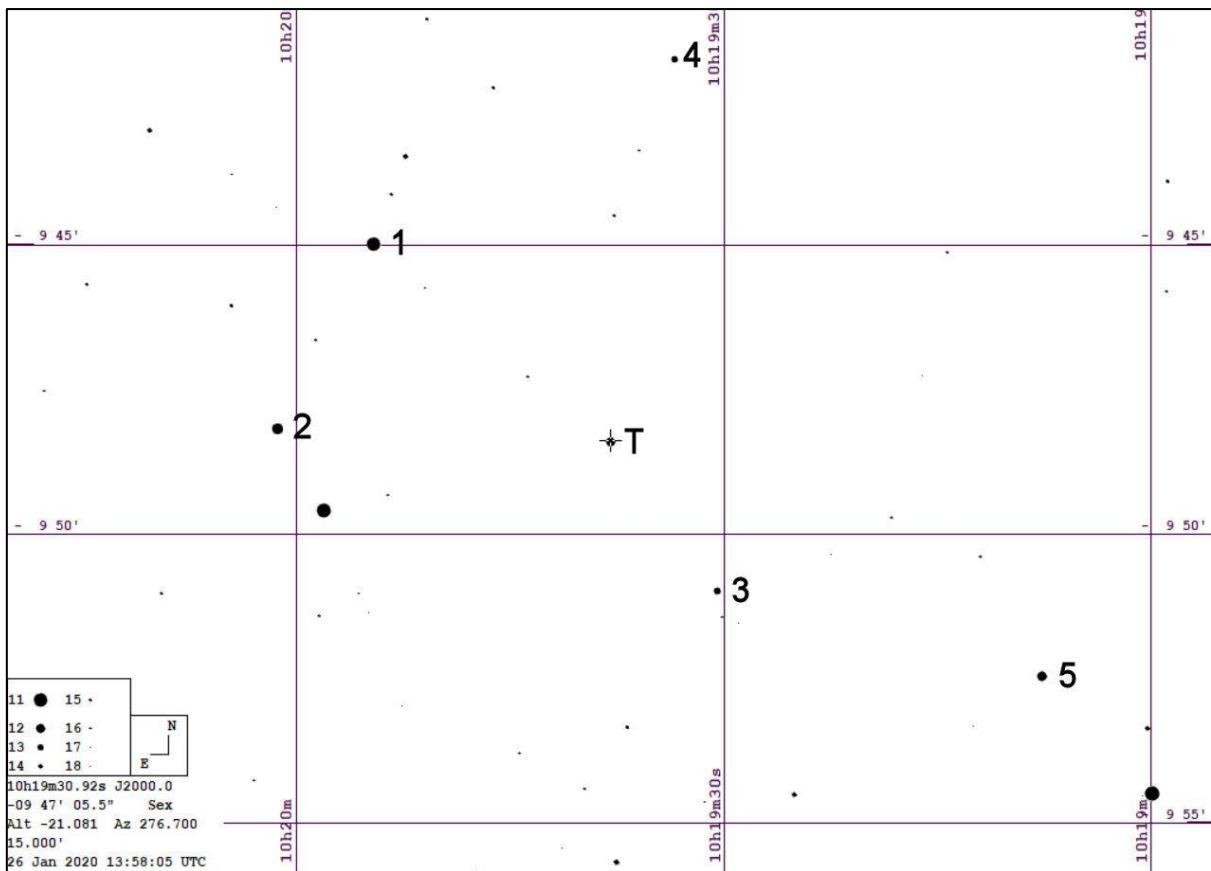
Figure A21.3 Guide finder chart, 15' x 15'

Comparison star	RA	Dec	V	B-V
1	10 19 54.60	-09 44 58.72	11.129	0.629
2	10 20 01.29	-09 48 10.17	11.655	0.870
3	10 19 30.44	-09 50 58.17	12.687	0.584
4	10 19 33.50	-09 41 46.33	13.232	1.307
5	10 19 07.67	-09 52 27.43	11.992	0.688

Table A21.2 Comparison star data

Appendix A22

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-36b	12 33 03.91	+44 54 55.20	12.15	0.931	18

Table A22.1 Target data
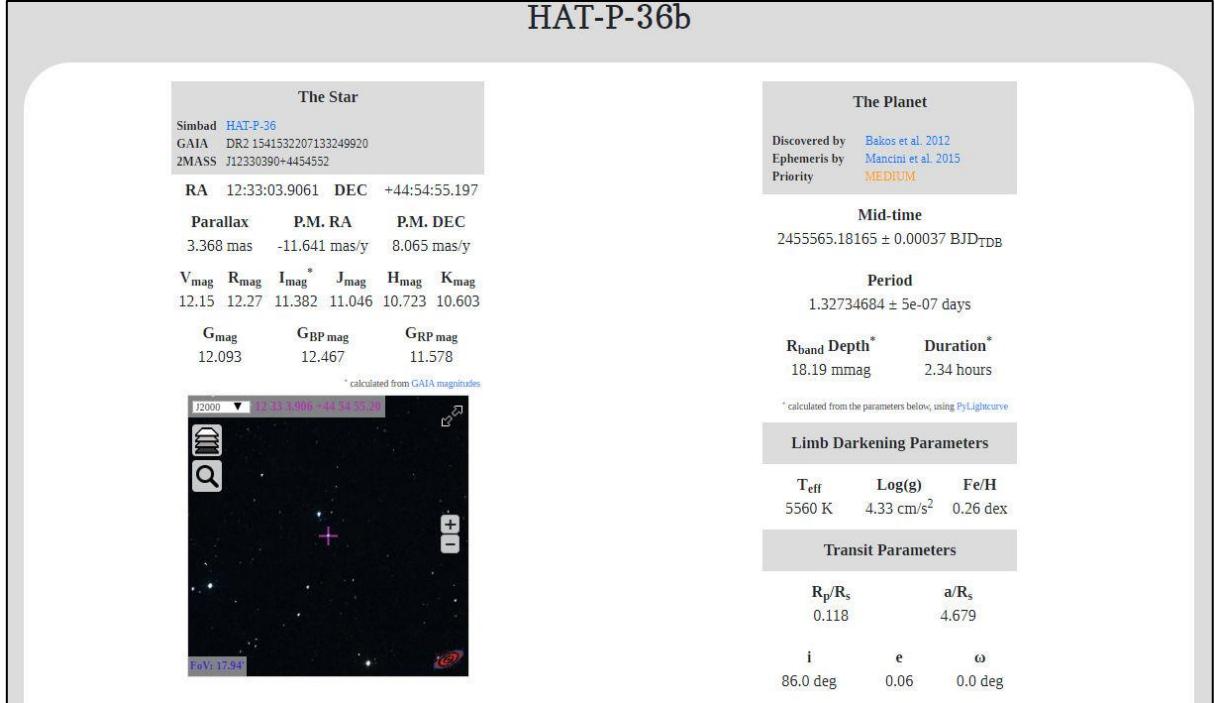
Figure A22.1 Star and transit data

Figure A22.2 STScI DSS chart
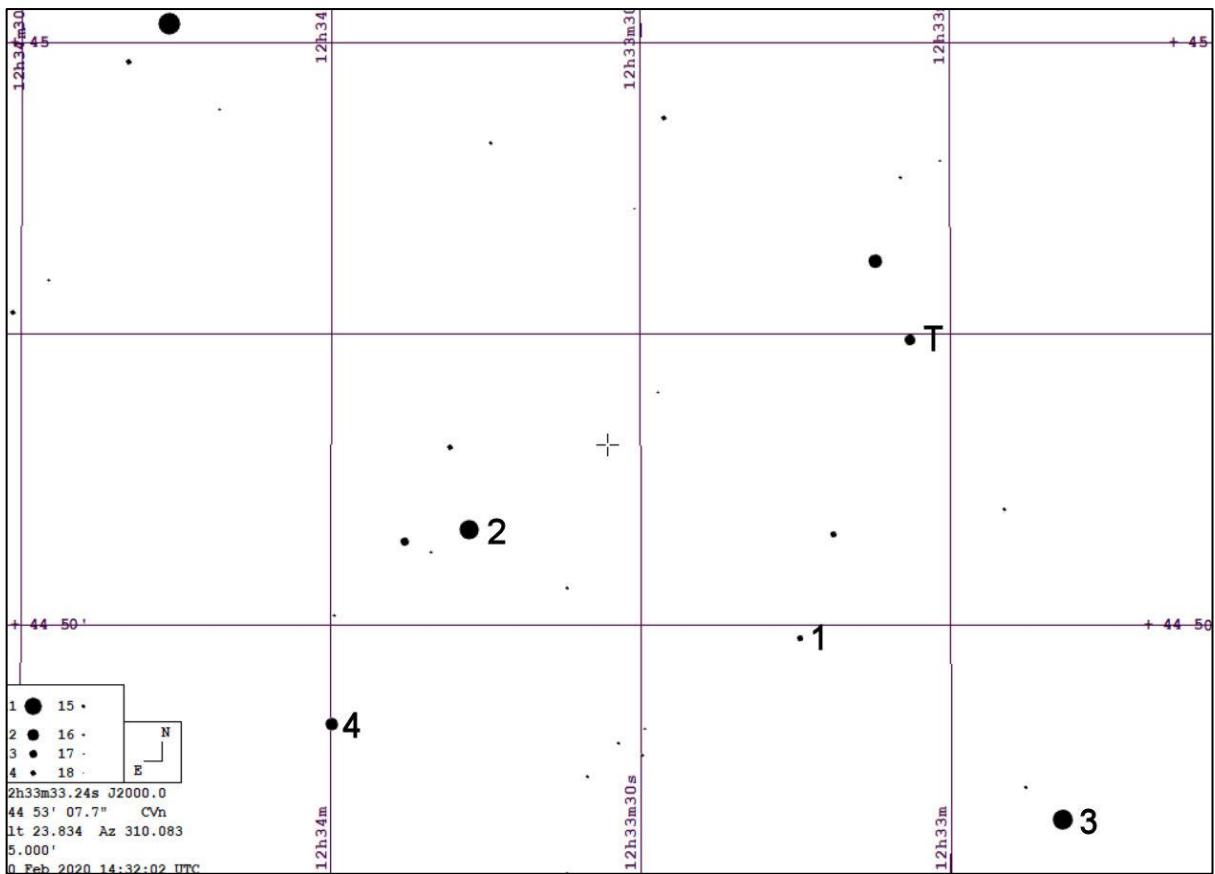
Figure A22.3 Guide finder chart, 15' x 15'

Comparison star	RA	Dec	V mag	B-V
1	12 33 14.52	+44 49 49.37	13.693	0.749
2	12 33 46.64	+44 51 39.38	10.717	0.902
3	12 32 49.25	+44 46 41.18	10.499	1.674
4	12 33 59.84	+44 48 18.71	11.427	0.826

Table A22.2 Comparison star data

Appendix A23

Target	RA	Dec	V mag	B-V	Depth (mmag)
WASP-36b	08 46 19.30	-08 01 37.01	12.7	0.613	22

Table A23.1 Target data
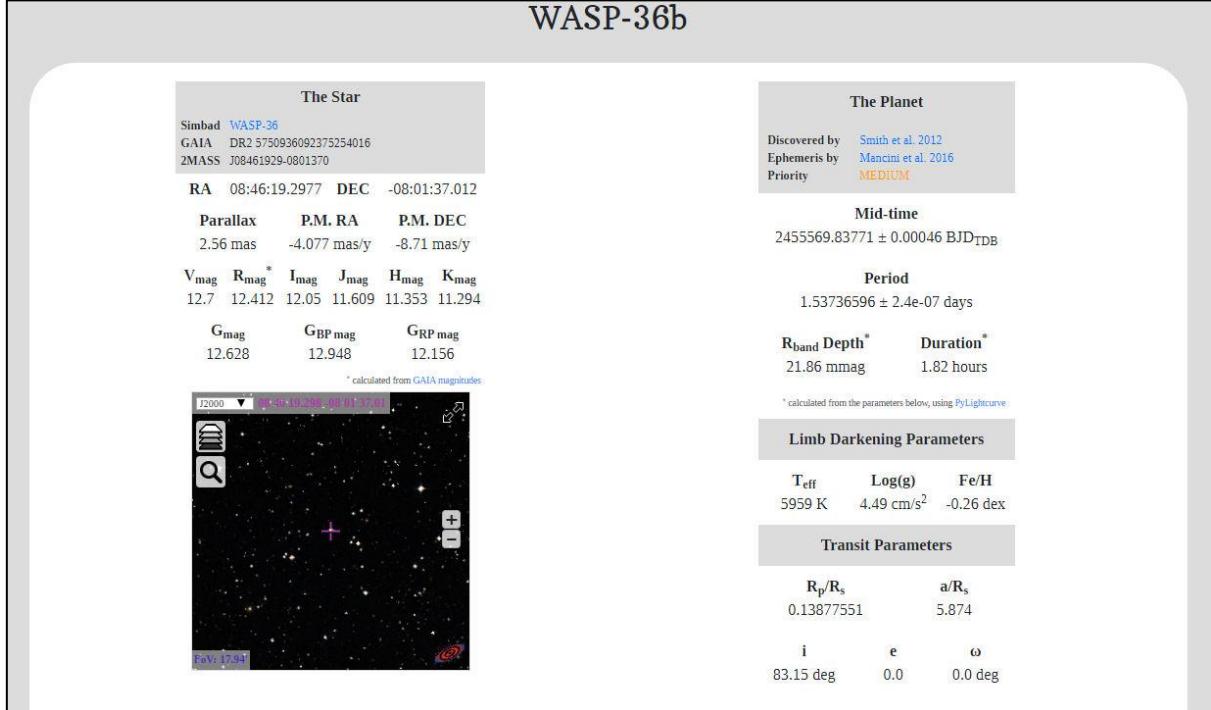
Figure A23.1. Star and transit data

Figure A23.2. STScI DSS chart
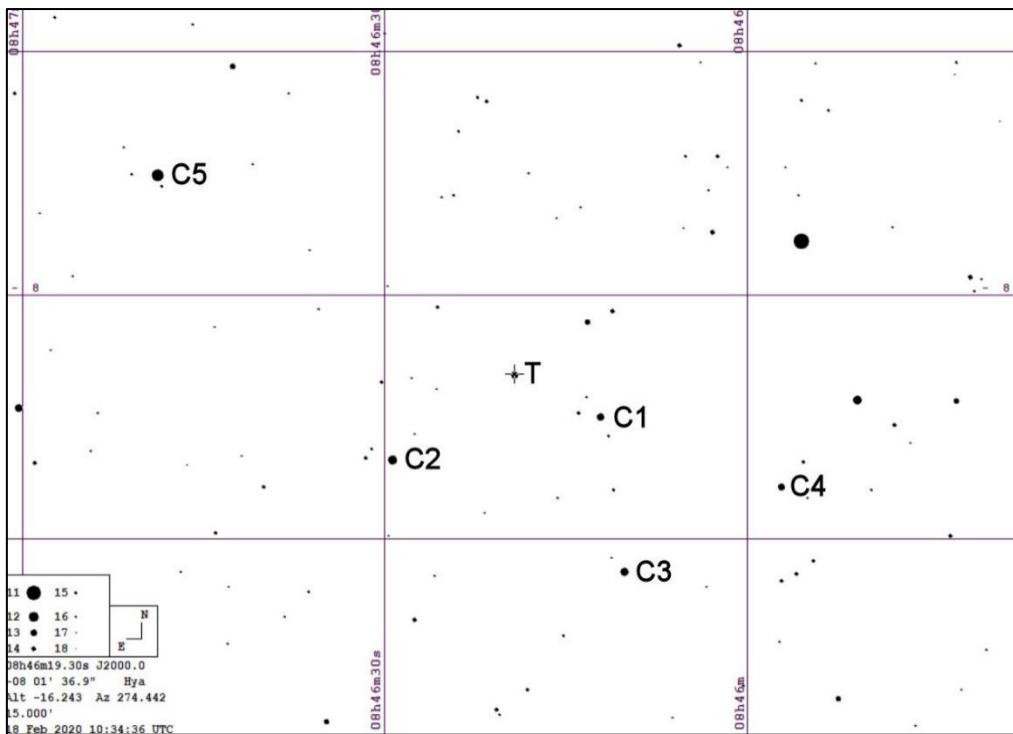
Figure A23.3 Guide chart

Comparison star	RA	Dec	V	B-V
1	08 46 12.16	-08 02 28.87	12.820	0.975
2	08 46 29.33	-08 03 22.55	12.283	1.008
3	08 46 10.13	-08 05 41.00	12.573	0.471
4	08 45 57.13	-08 03 55.70	13.183	0.652
5	08 46 48.80	-07 57 32.94	11.439	0.823

Table A23.2. Comparison star data

Appendix A24

Target	RA	Dec	V mag	B-V	Depth (mmag)
CoRoT-10b	19 24 15.29	+00 44 46.00	15.2	1.5	17

Table A24.1 Target data
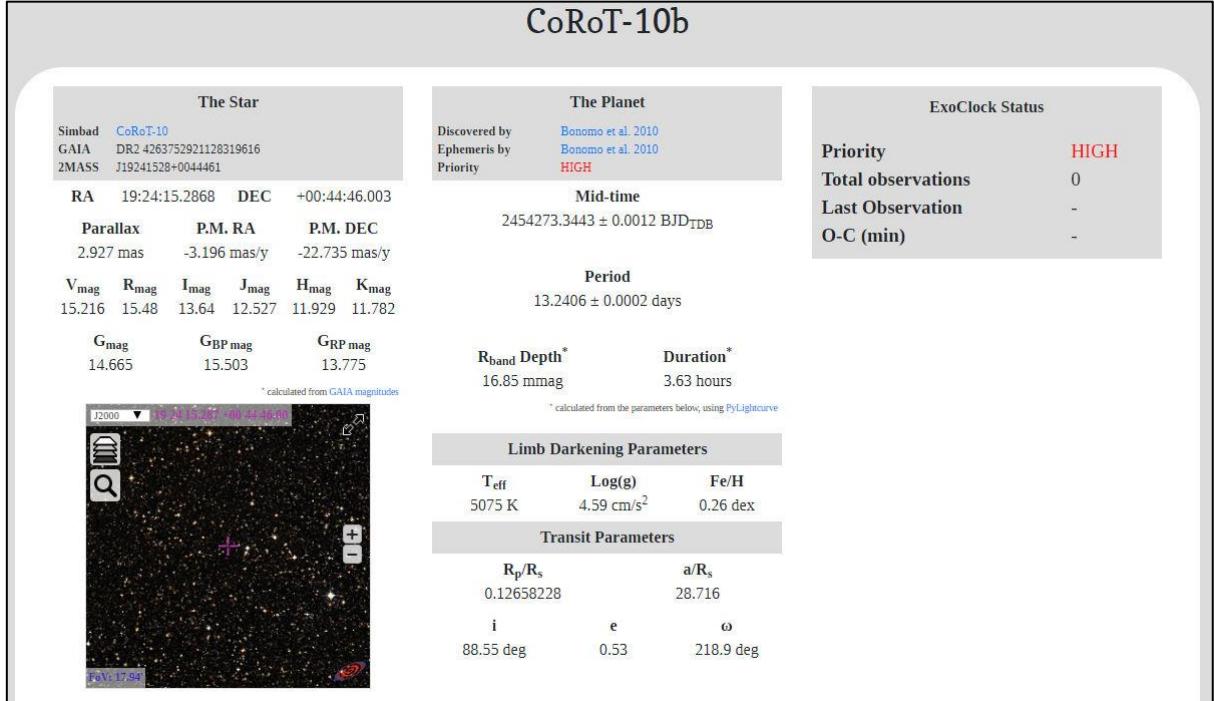
Figure A24.1 Star and transit data
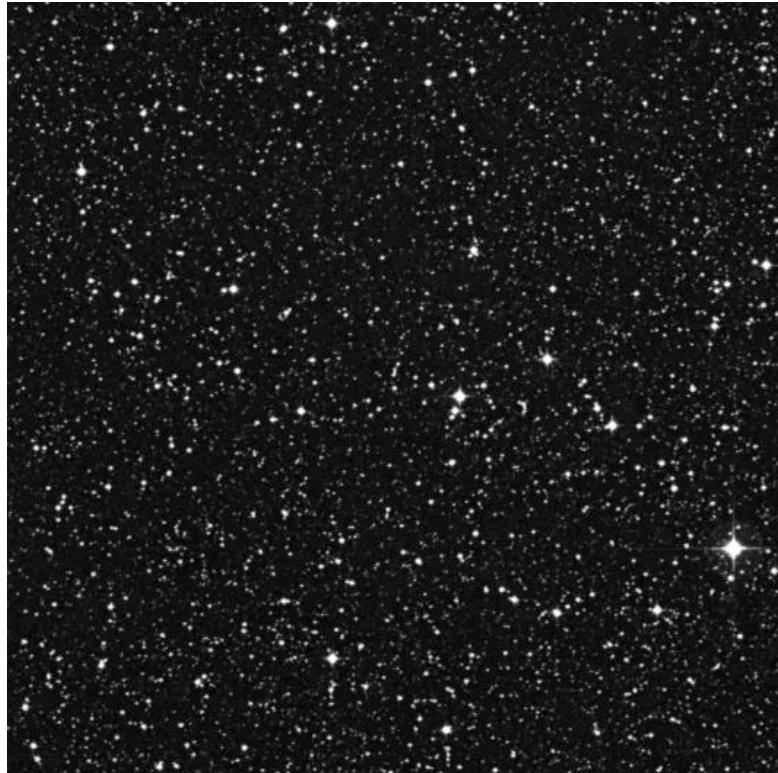
Figure A24.2. STScI DSS chart
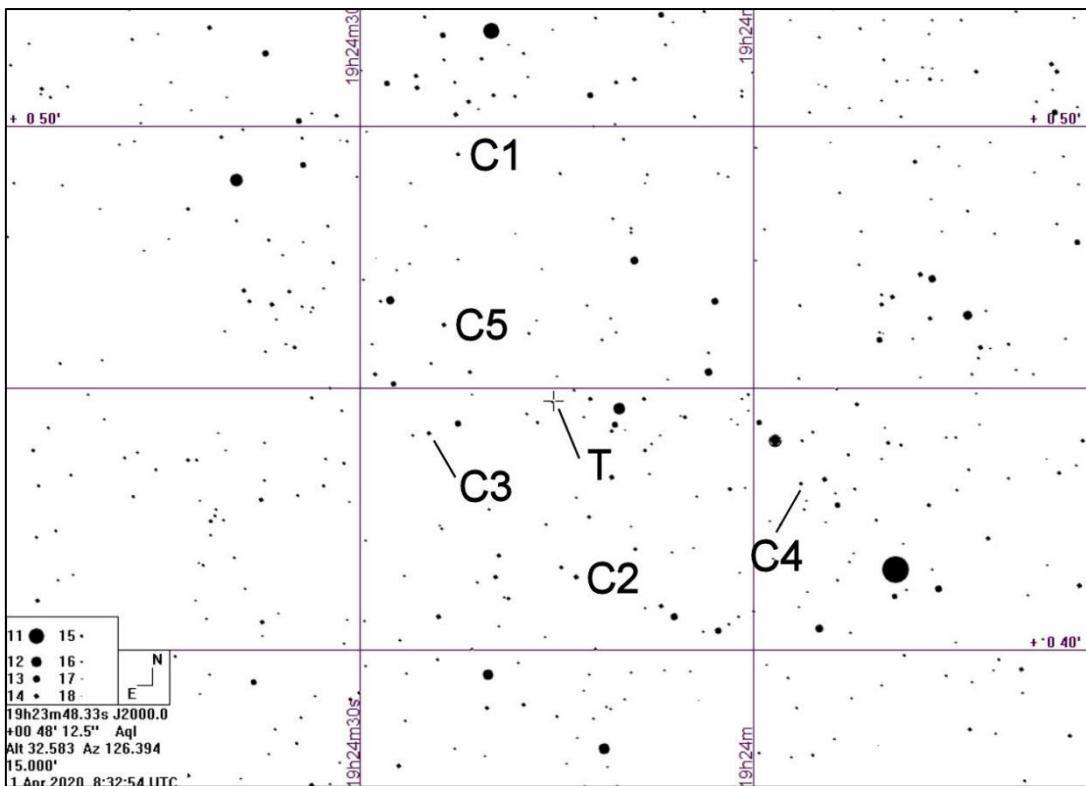
Figure A24.3 Guide chart

Star	ID	RA	Dec	V	B-V
Target	T	19 24 15.29	+00 44 46.00	15.2	1.5
Comparison	C1	19 24 22.64	+00 49 29.59	14.8	1.9
Comparison	C2	19 24 13.58	+00 41 25.34	14.1	1.5
Comparison	C3	19 24 24.72	+00 44 10.18	14.4	1.6
Comparison	C4	19 23 56.43	+00 43 12.72	15.0	1.6
Comparison	C5	19 24 23.63	+00 46 14.27	14.4	1.7

Table A24.2. Comparison and target star data

Appendix A25

Target	RA	Dec	V mag	B-V	Depth (mmag)
KPS1-b	11 00 40.18	+64 57 50.35	13.0	0.9	15

Table A25.1 Target data
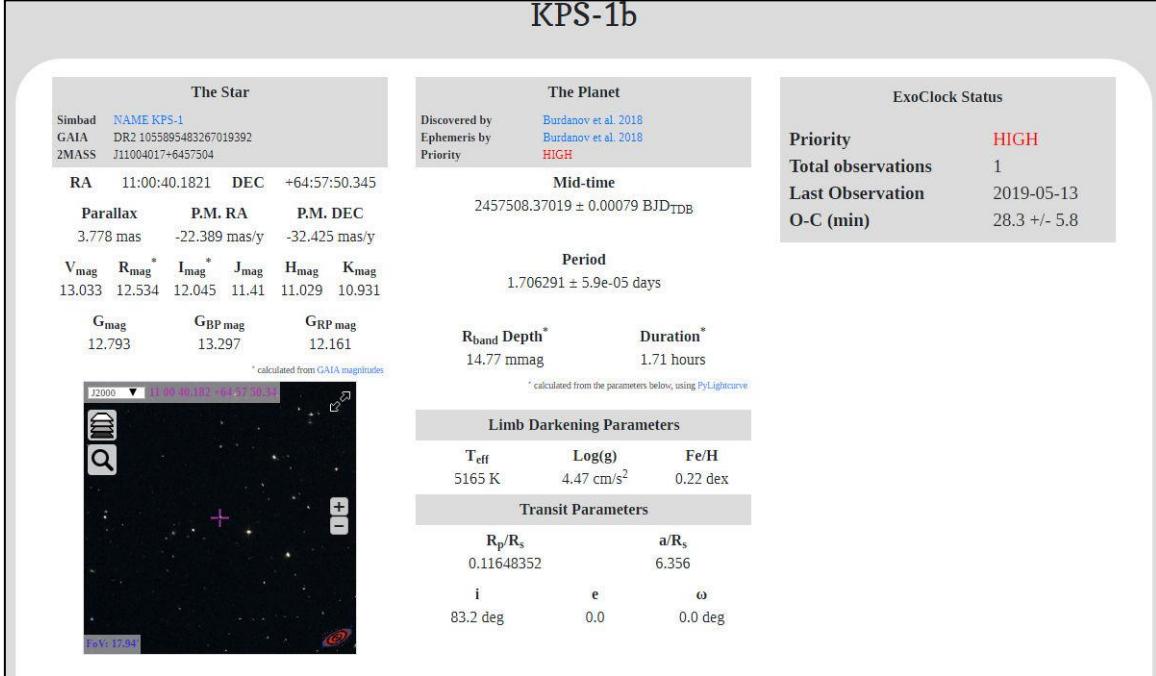
Figure A25.1 Star and transit data

Figure A25.2. STScI DSS chart
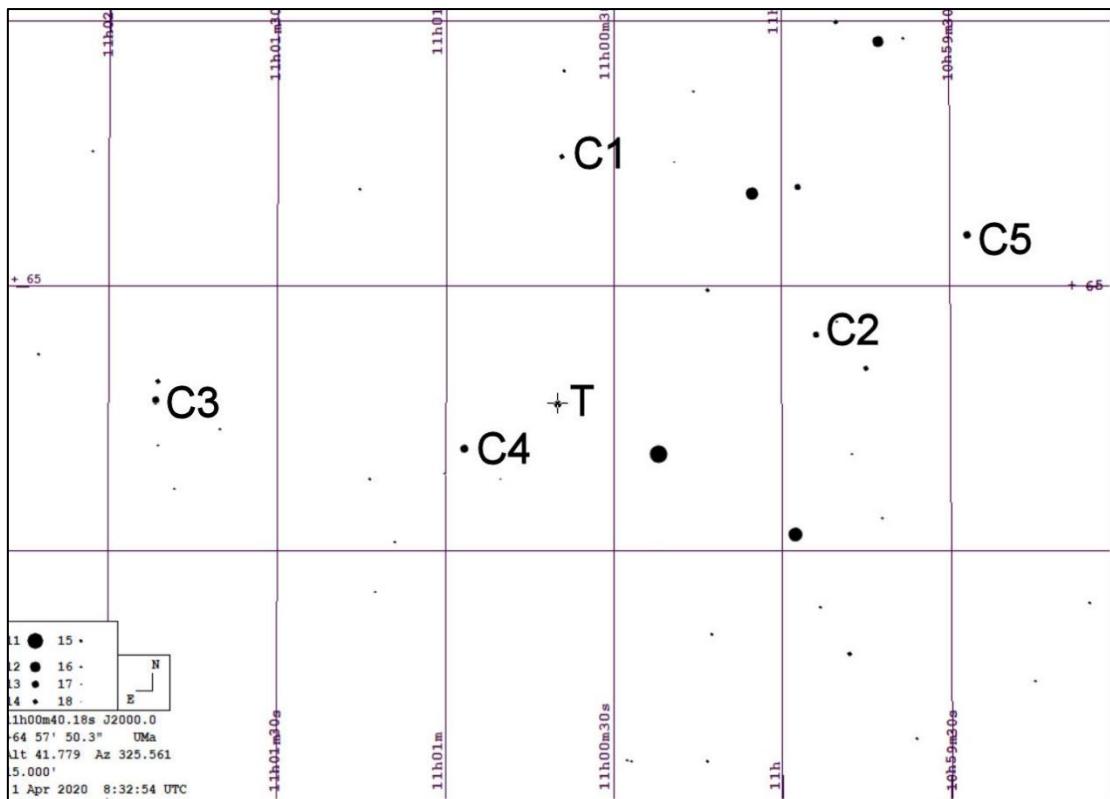
Figure A25.3 Guide chart

Star	ID	RA	Dec	V	B-V
Target	T	11 00 40.18	+64 57 50.35	13.0	0.9
Comparison	C1	11 00 39.32	+65 02 29.98	13.9	0.6
Comparison	C2	10 59 53.99	+64 59 08.15	13.4	0.6
Comparison	C3	11 01 51.77	+64 57 52.25	13.0	0.5
Comparison	C4	11 00 56.90	+64 56 59.19	12.6	0.4
Comparison	C5	10 59 26.97	+65 01 00.71	13.0	0.9

Table A25.2. Comparison and target star data

Appendix A26

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-15b	04 24 59.53	+39 27 38.31	12.4	0.6	14

Table A26.1 Target data
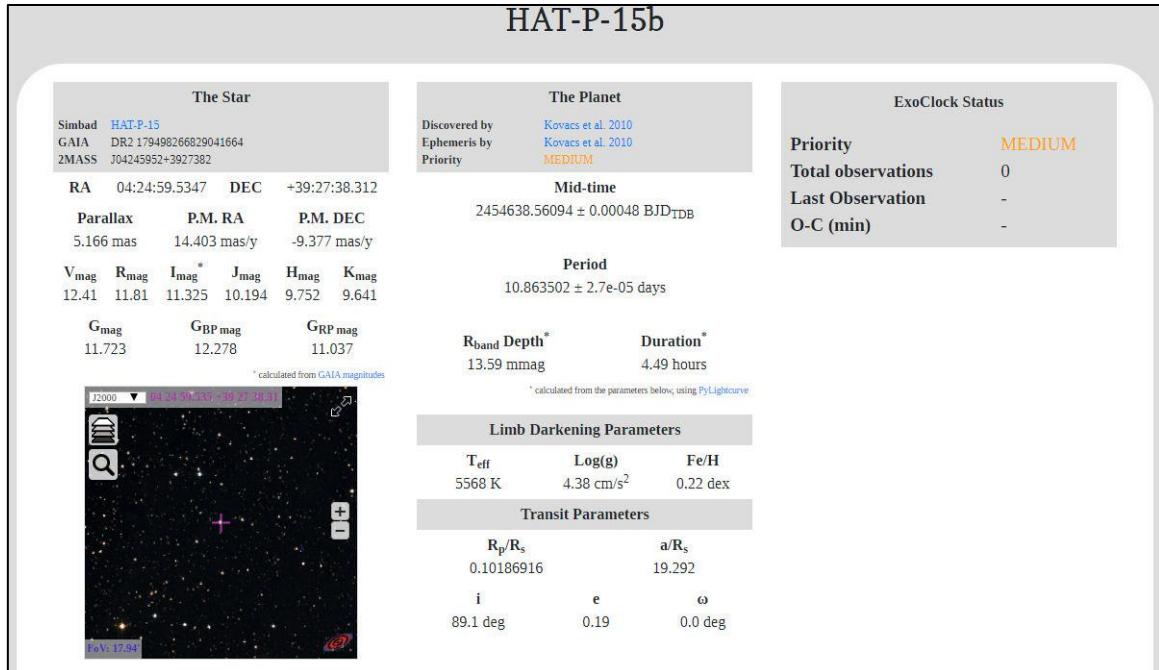
Figure A26.1 Star and transit data

Figure A26.2. STScI DSS chart
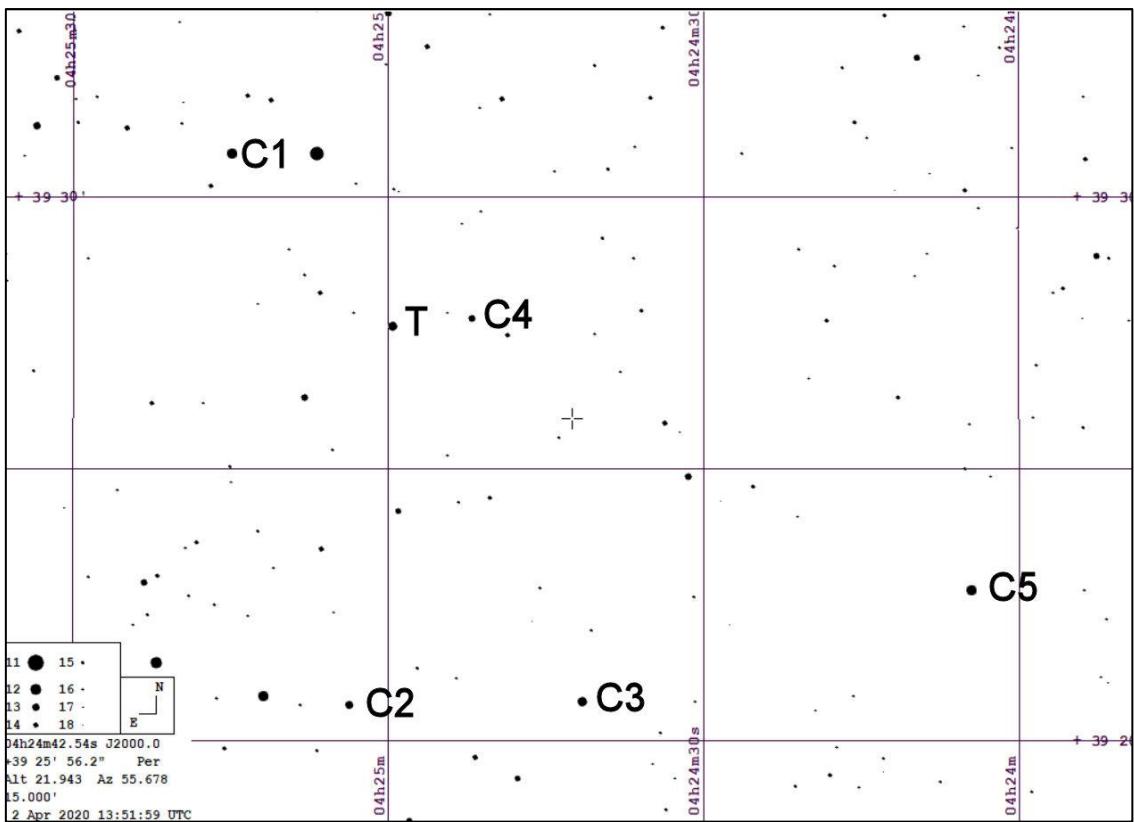
Figure A26.3 Guide chart

Star	ID	RA	Dec	V	B-V
Target	T	04 24 59.53	+39 27 38.31	12.4	0.6
Comparison	C1	04 25 14.90	+39 30 47.69	12.3	0.7
Comparison	C2	04 25 03.79	+39 20 40.67	12.9	0.8
Comparison	C3	04 24 41.56	+39 20 43.99	12.5	0.8
Comparison	C4	04 24 52.06	+39 27 47.93	13.5	0.9
Comparison	C5	04 24 04.51	+39 22 47.48	12.1	0.6

Table A26.2. Comparison and target star data

Appendix A27

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-18b	17 05 23.15	+33 00 44.94	12.8	1.0	25

Table A27.1 Target data
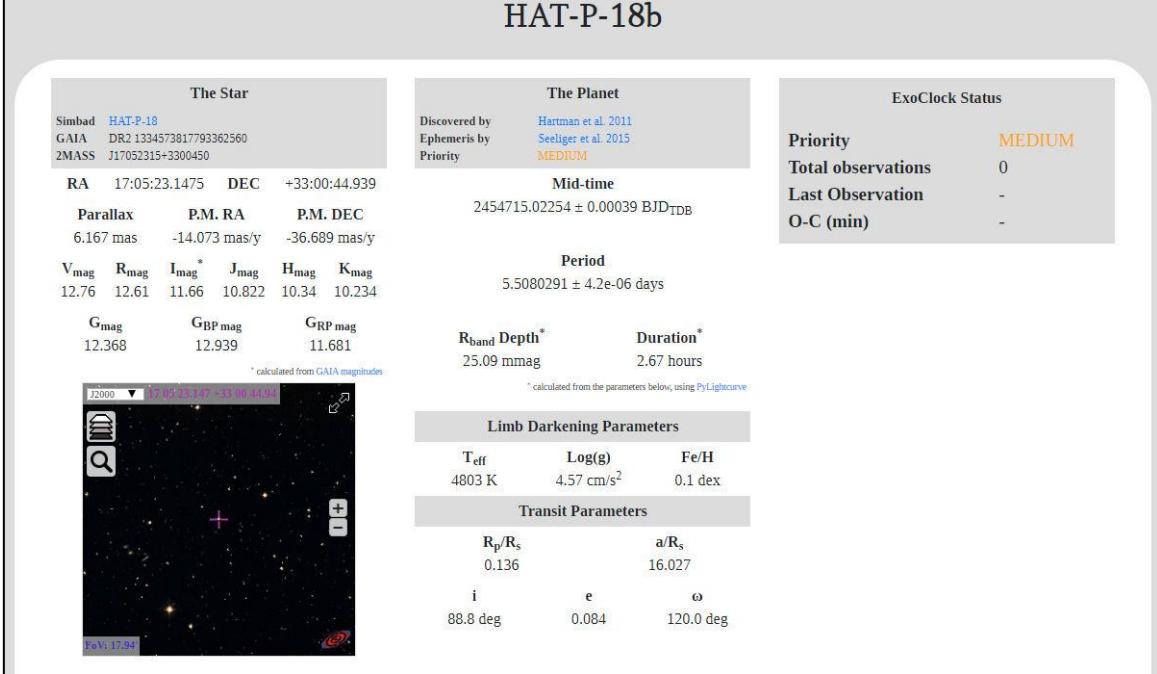
Figure A27.1 Star and transit data

Figure A27.2. STScI DSS chart
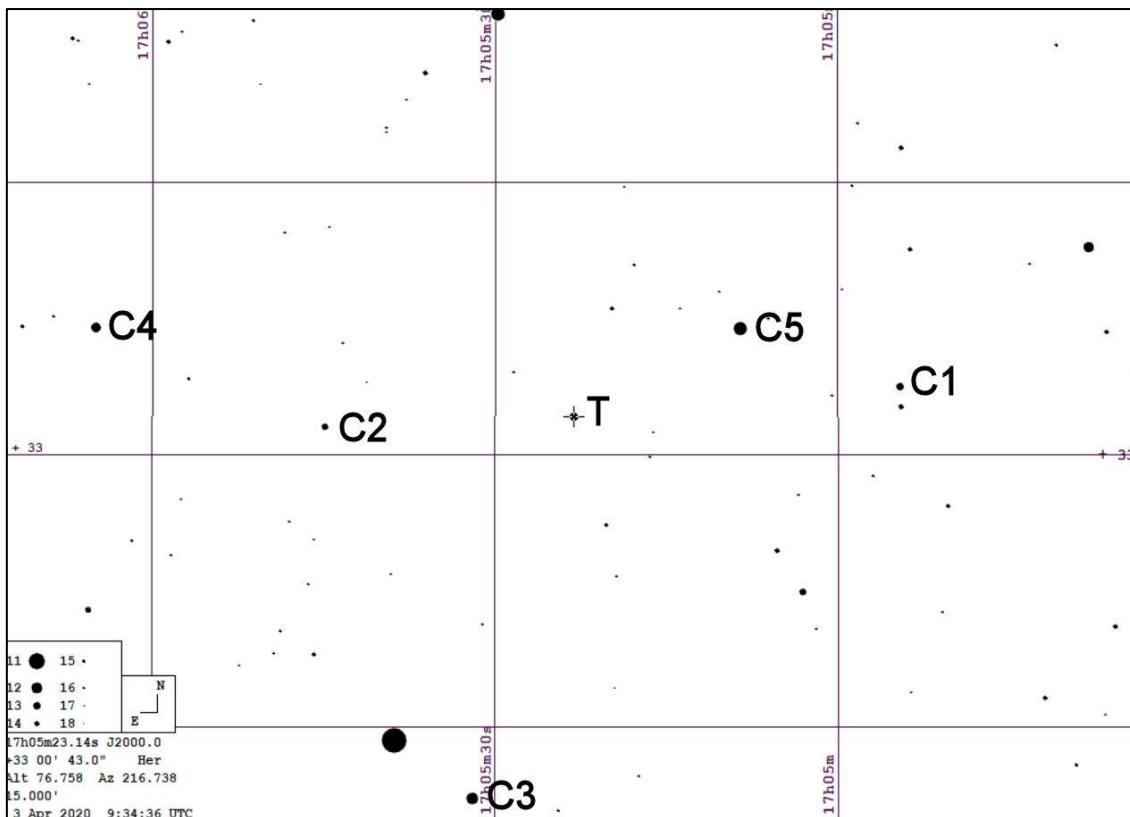
Figure A27.3 Guide chart

Star	ID	RA	Dec	V	B-V
Target	T	17 05 23.13	+33 00 44.51	12.7	1.0
Comparison	C1	17 04 54.53	+33 01 17.69	13.1	0.8
Comparison	C2	17 05 44.94	+33 00 32.37	13.1	0.6
Comparison	C3	17 05 31.94	+32 53 41.53	11.7	0.9
Comparison	C4	17 06 04.95	+33 02 21.41	12.5	1.1
Comparison	C5	17 05 08.52	+33 02 19.48	11.2	1.3

Table A27.2. Comparison and target star data

Appendix A28

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-19b	00 38 04.01	+34 42 41.55	12.0	1.0	26

Table A28.1 Target data
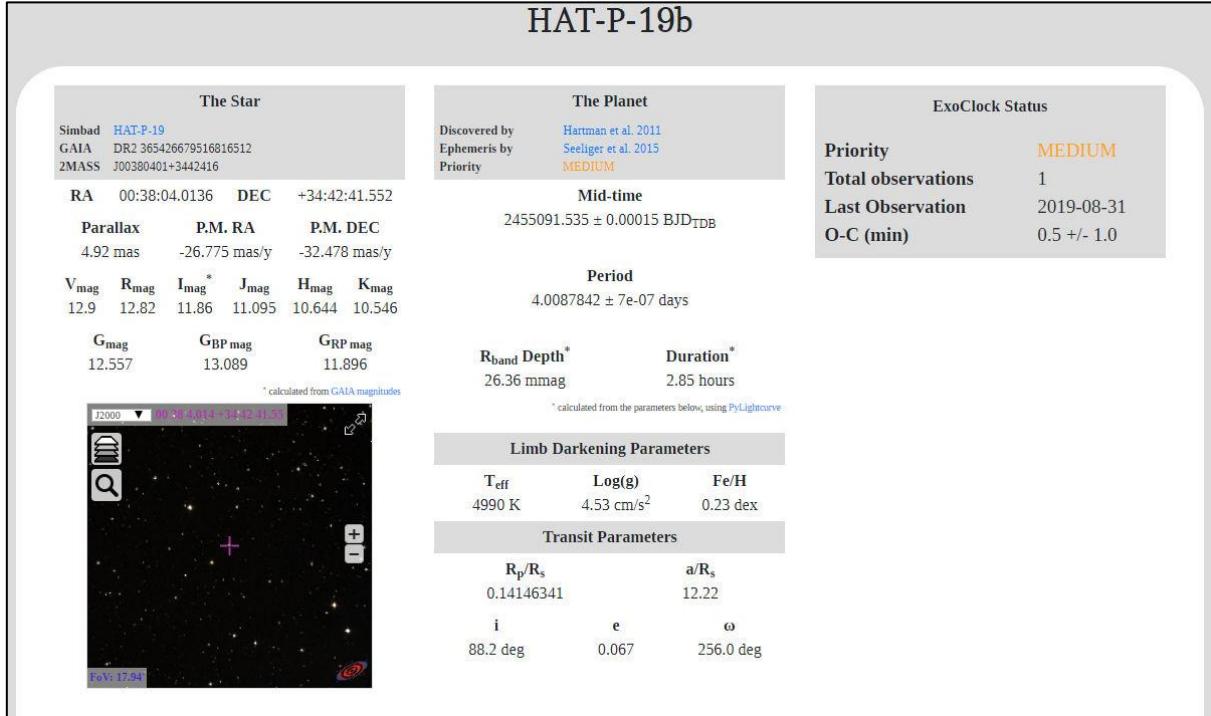
Figure A28.1 Star and transit data

Figure A28.2. STScI DSS chart
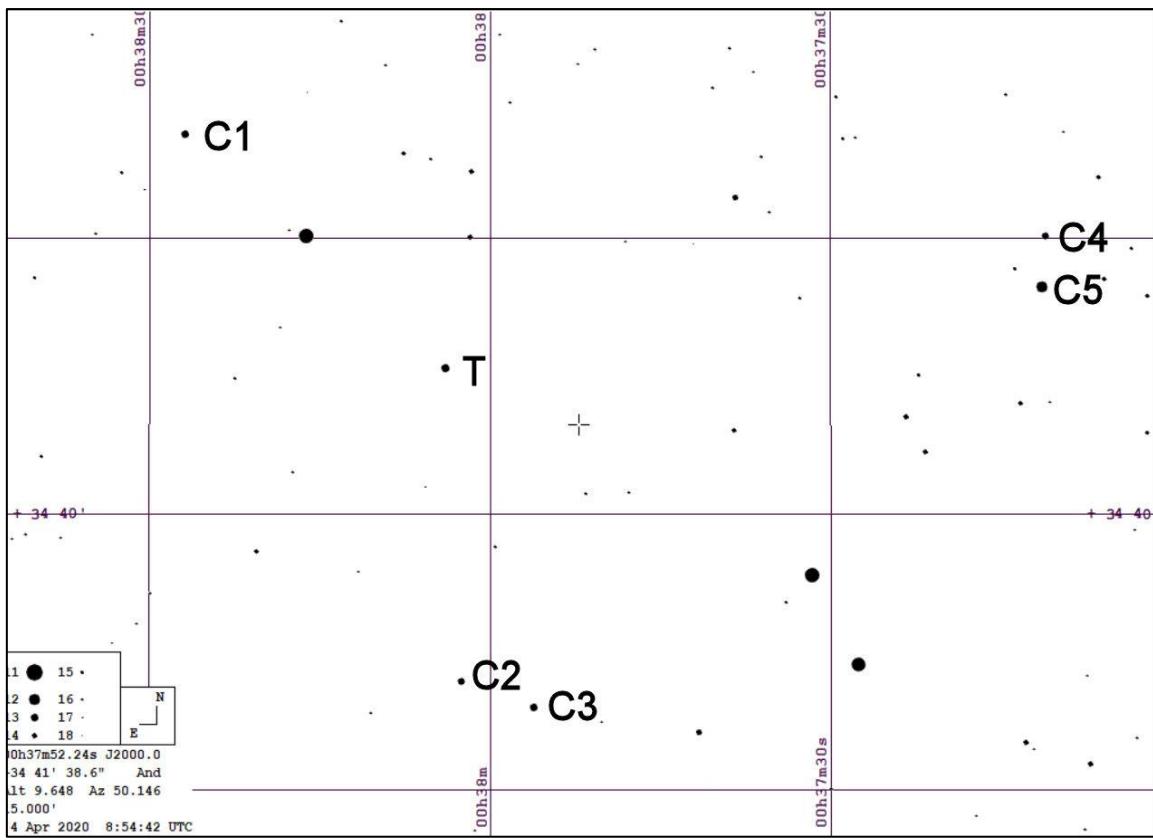
Figure A28.3 Guide chart

Star	ID	RA	Dec	V	B-V
Target	T	00 38 03.98	+34 42 41.14	12.9	1.0
Comparison	C1	00 38 26.86	+34 46 55.33	12.8	0.6
Comparison	C2	00 38 02.54	+34 37 00.62	13.0	0.6
Comparison	C3	00 37 56.16	+34 36 31.72	13.0	1.1
Comparison	C4	00 37 11.12	+34 45 04.76	13.3	1.0
Comparison	C5	00 37 11.40	+34 44 07.34	12.0	0.5

Table A28.2. Comparison and target star data

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-23b	20 24 29.72	+16 45 43.81	12.3	0.7	17

Table A29.1 Target data
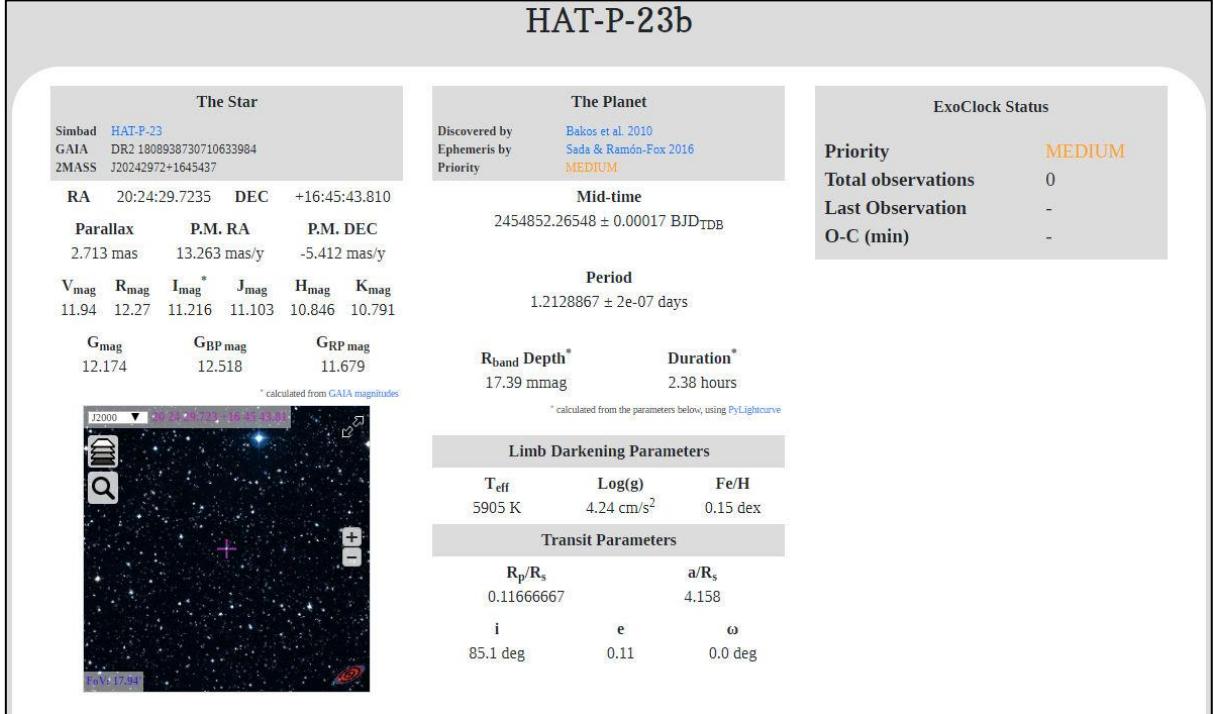
Figure A29.1 Star and transit data
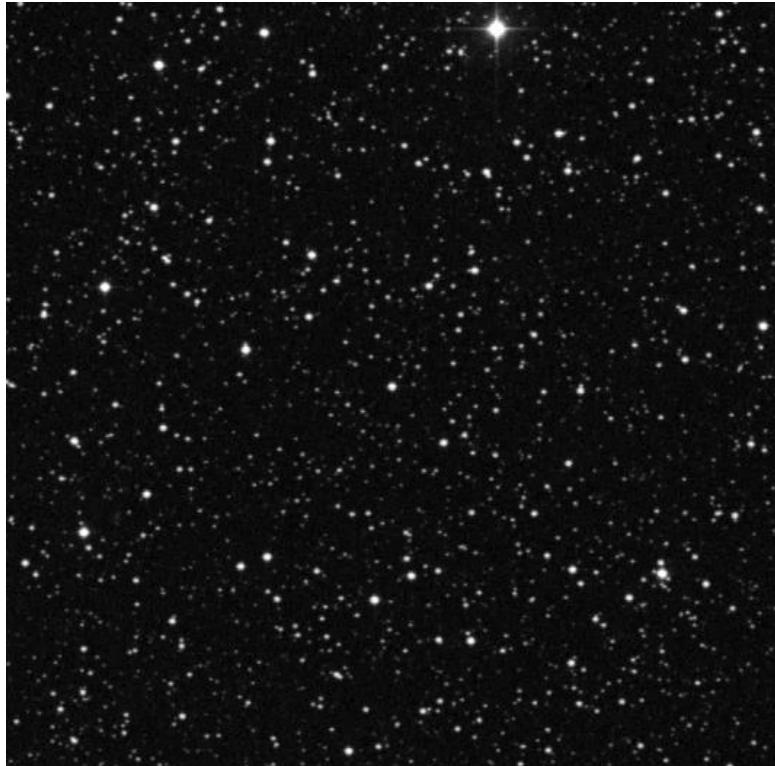
Figure A29.2. STScI DSS chart
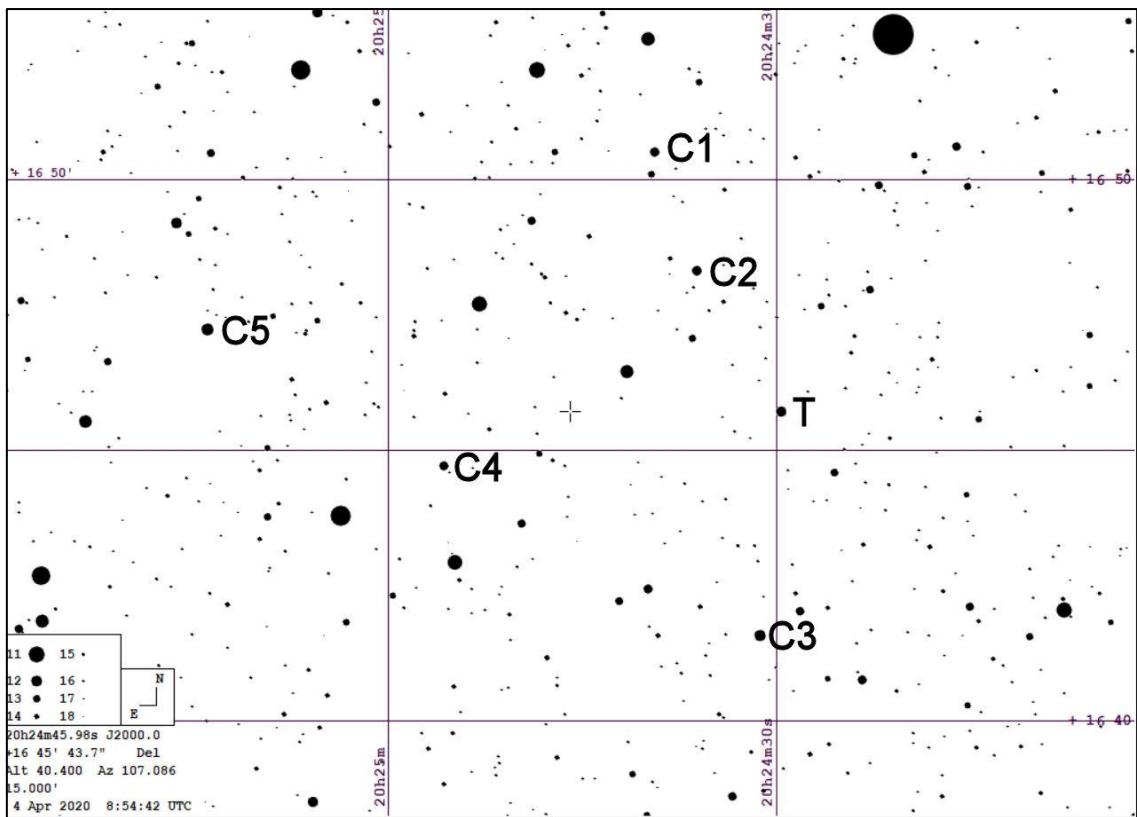
Figure A29.3 Guide chart

Star	ID	RA	Dec	V	B-V
Target	T	20 24 29.73	+16 45 43.77	12.3	0.7
Comparison	C1	20 24 39.46	+16 50 32.00	12.4	0.6
Comparison	C2	20 24 36.18	+16 48 18.39	12.3	0.6
Comparison	C3	20 24 31.26	+16 41 34.67	12.0	1.2
Comparison	C4	20 24 55.62	+16 44 42.89	12.6	0.8
Comparison	C5	20 25 13.95	+16 47 14.43	11.5	1.1

Table A29.2. Comparison and target star data

Appendix A30

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-37b	18 57 11.06	+51 16 08.85	13.6	0.8	24

Table A30.1 Target data
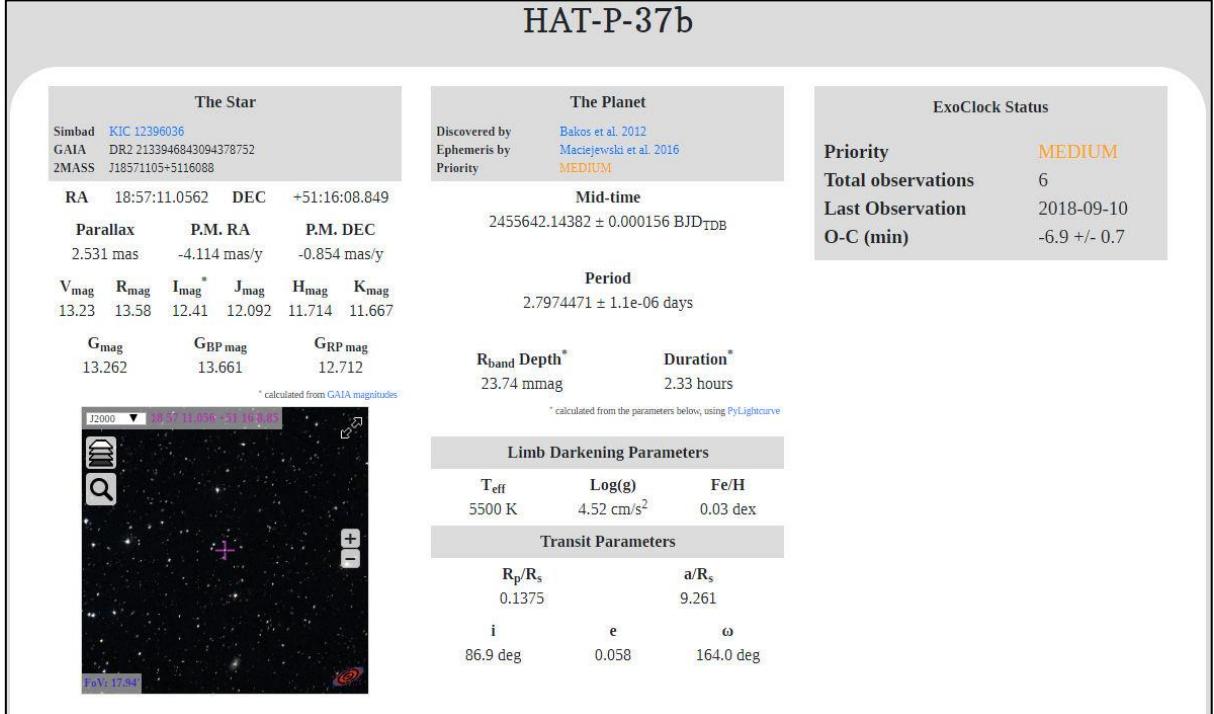
Figure A30.1 Star and transit data

Figure A30.2. STScI DSS chart
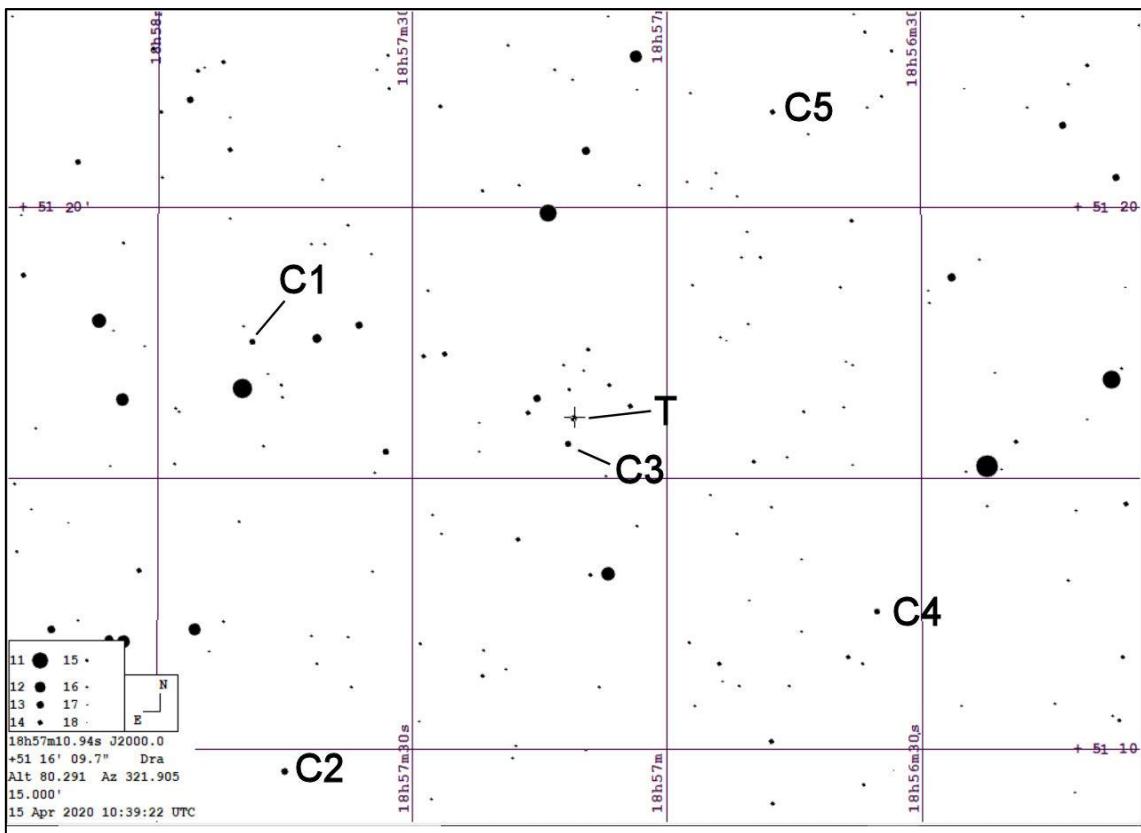
Figure A30.3 Guide chart

Star	ID	RA	Dec	V	B-V
Target	T	18 57 11.05	+51 16 08.79	13.6	0.8
Comparison	C1	18 57 48.84	+51 17 34.29	13.7	0.7
Comparison	C2	18 57 44.97	+51 09 37.90	13.4	1.0
Comparison	C3	18 57 11.62	+51 15 41.09	13.5	0.6
Comparison	C4	18 56 35.26	+51 12 35.26	13.6	0.6
Comparison	C5	18 56 47.51	+51 21 47.85	14.0	0.8

Table A30.2. Comparison and target star data

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-3b	13 44 22.59	+48 01 43.21	11.9	0.8	16

Table A31.1 Target data
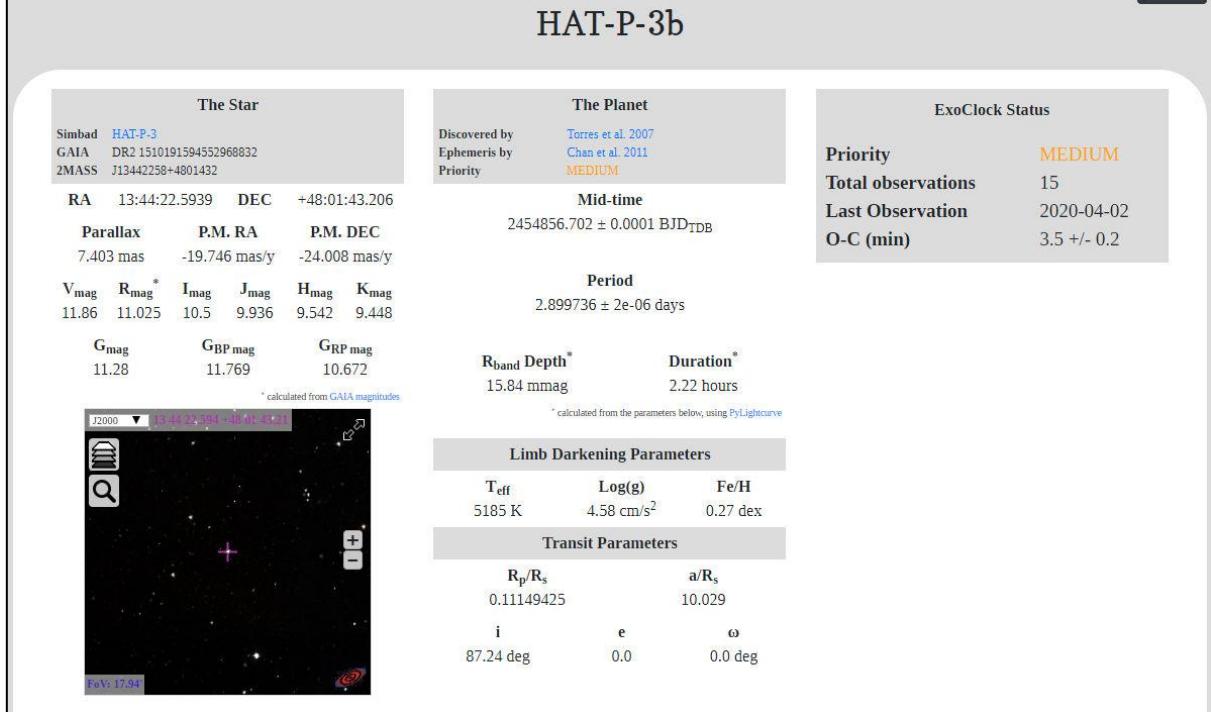
Figure A31.1 Star and transit data

Figure A31.2. STScI DSS chart
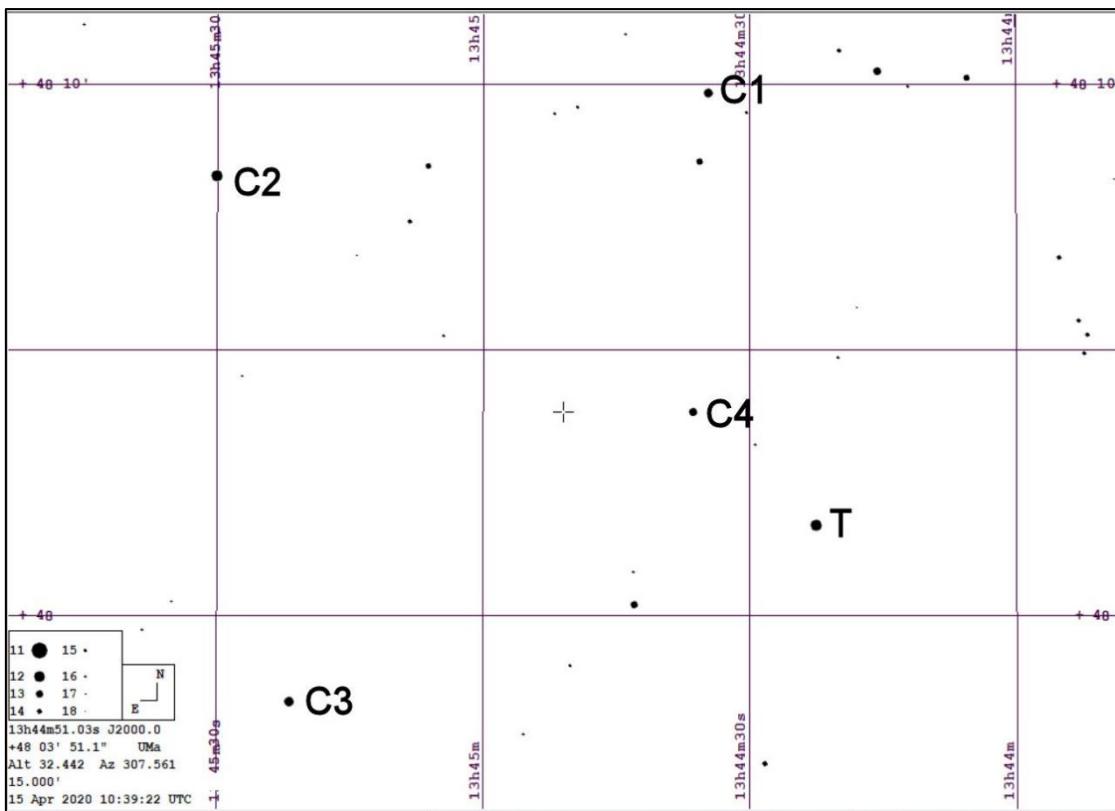
Figure A31.3 Guide chart

Star	ID	RA	Dec	V	B-V
Target	T	13 44 22.56	+48 01 43.01	11.5	0.8
Comparison	C1	13 44 34.64	+48 09 51.58	12.4	0.6
Comparison	C2	13 45 29.98	+48 08 16.58	11.8	1.2
Comparison	C3	13 45 21.80	+47 58 24.41	12.6	1.2
Comparison	C4	13 44 36.38	+48 03 52.56	12.8	0.8

Table A31.2. Comparison and target star data

Appendix A32

Target	RA	Dec	V mag	B-V	Depth (mmag)
HAT-P-41b	19 49 17.44	+04 40 20.78	11.4	0.6	14

Table A32.1 Target data
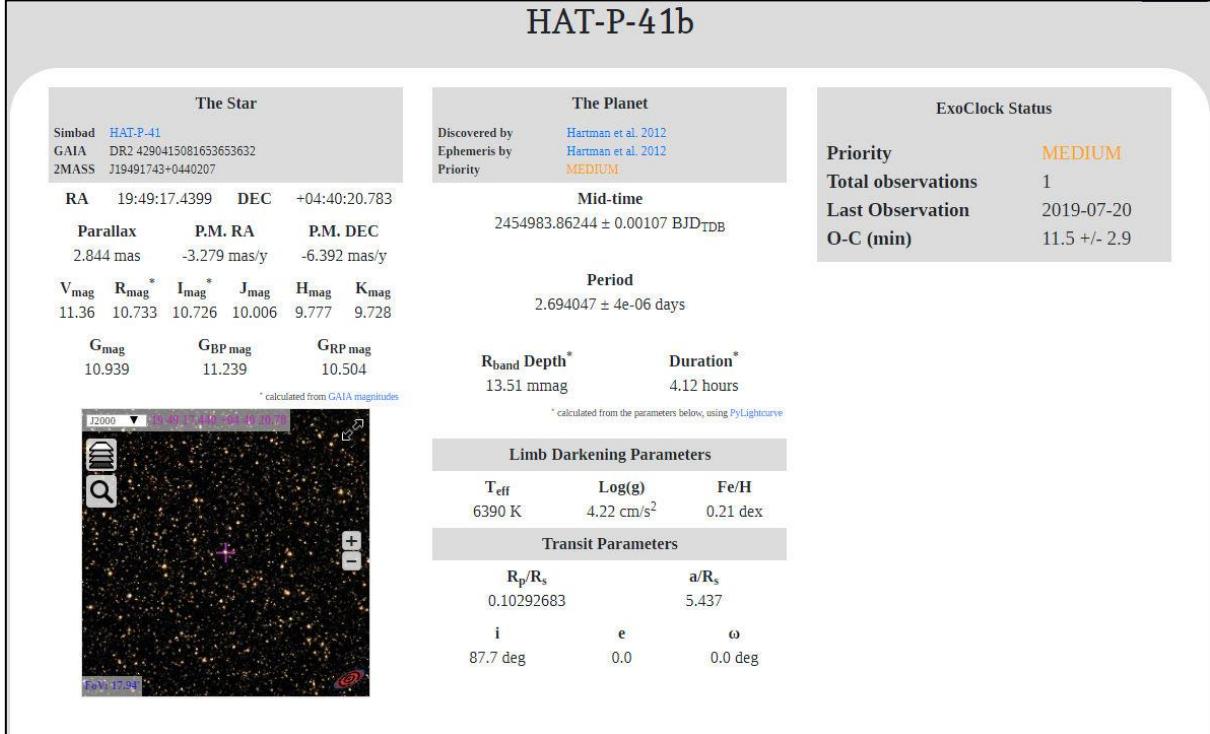
Figure A32.1 Star and transit data
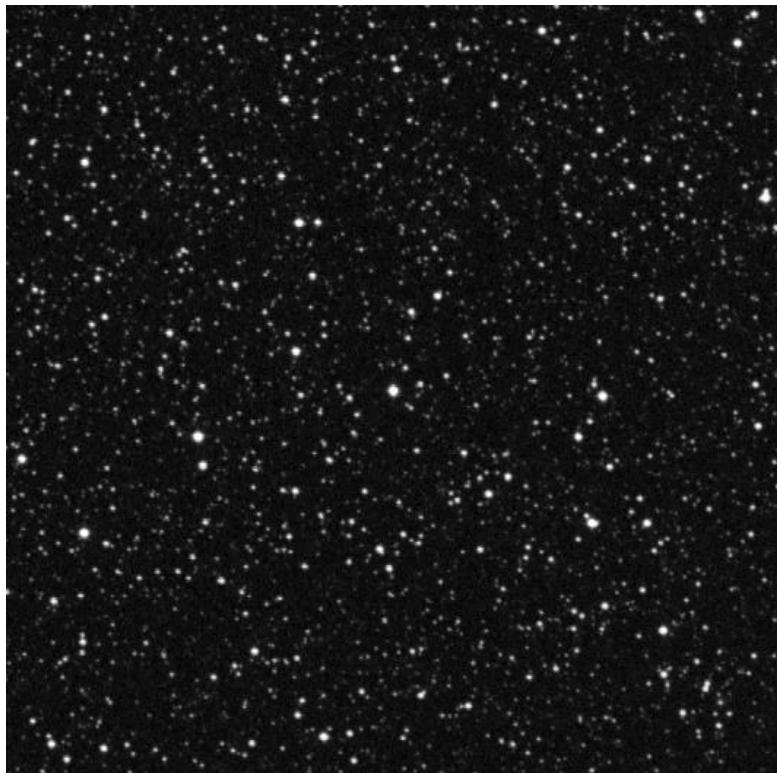
Figure A32.2. STScI DSS chart
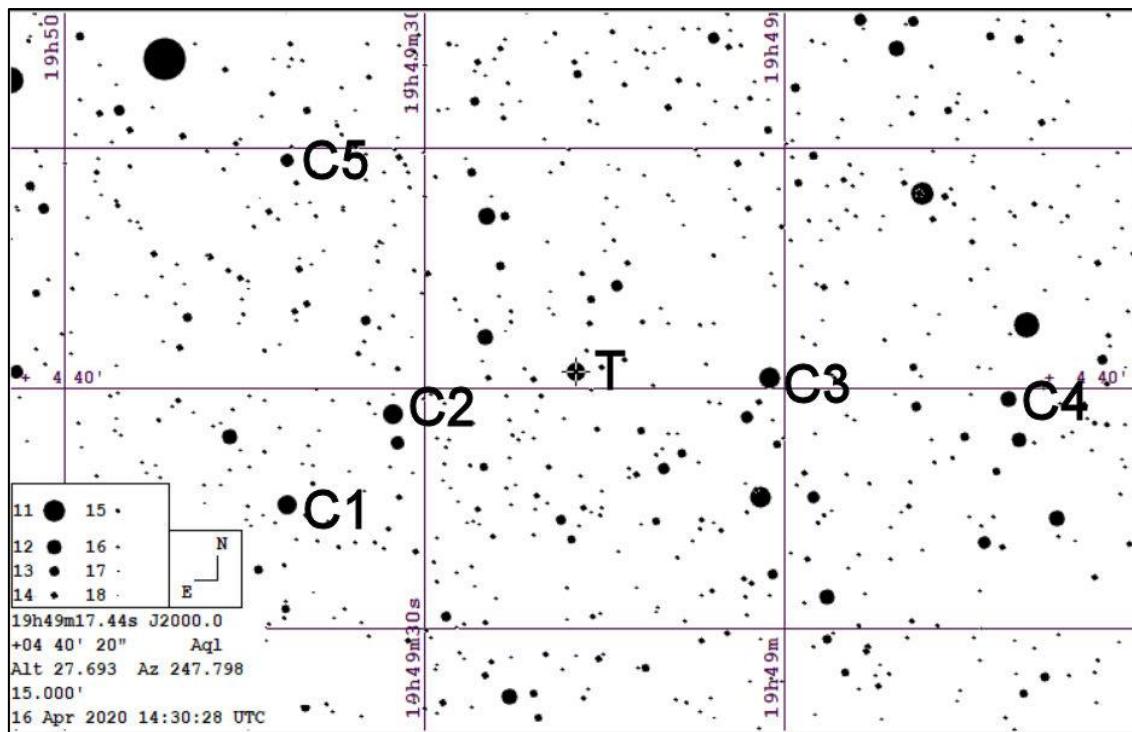
Figure A32.3 Guide chart

Star	ID	RA	Dec	V	B-V
Target	T	19 49 17.43	+04 40 20.72	11.0	0.6
Comparison	C1	19 49 41.53	+04 37 35.21	11.2	0.6
Comparison	C2	19 49 32.65	+04 39 27.16	11.0	1.4
Comparison	C3	19 49 01.17	+04 40 15.19	11.6	1.6
Comparison	C4	19 48 41.33	+04 39 47.85	12.0	1.2
Comparison	C5	19 49 41.44	+04 44 46.85	12.3	0.7

Table A32.2. Comparison and target star data

Appendix B

Python/HOPS installation notes

1.0   Python Installation
See https://exoworldsspies.com/en/software/

A User Manual is available at https://www.exoworldsspies.com/static/HOPS2.6_manual.pdf

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
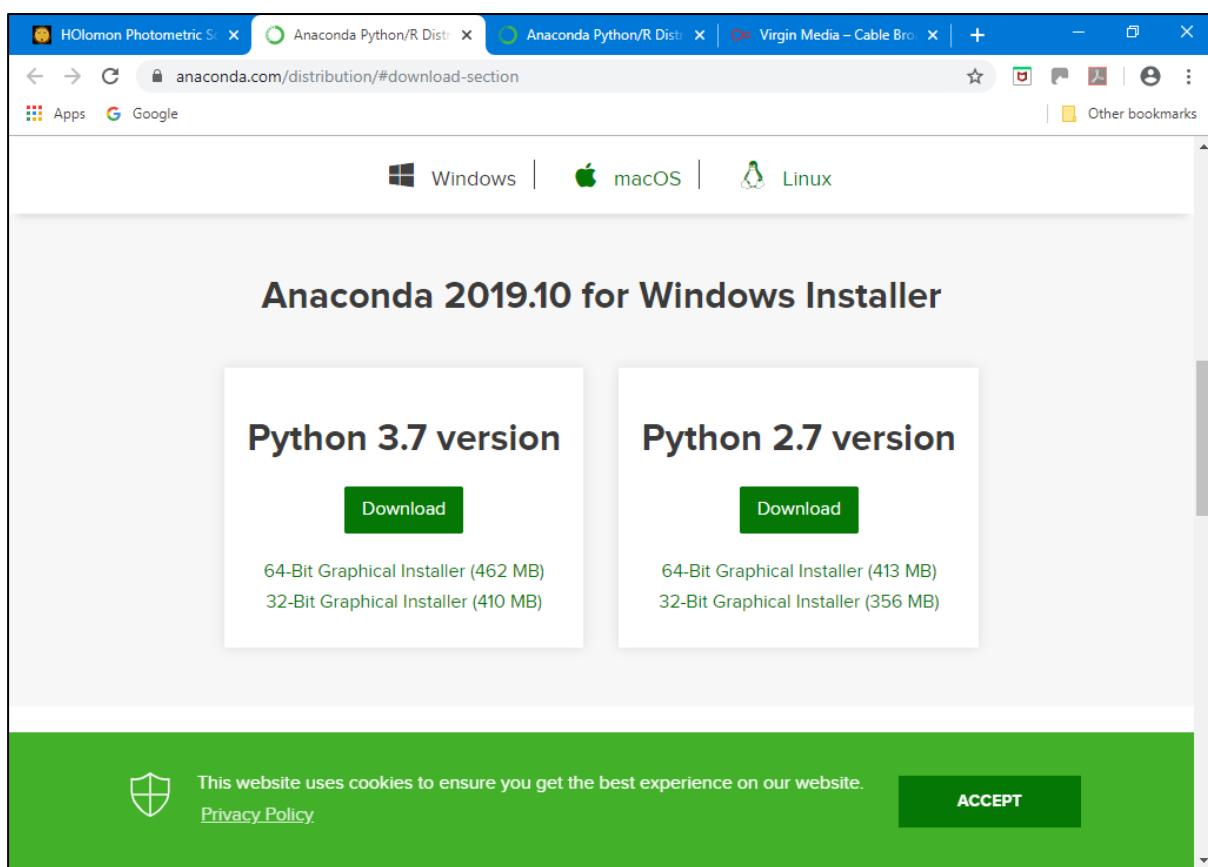
Figure B1.1

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
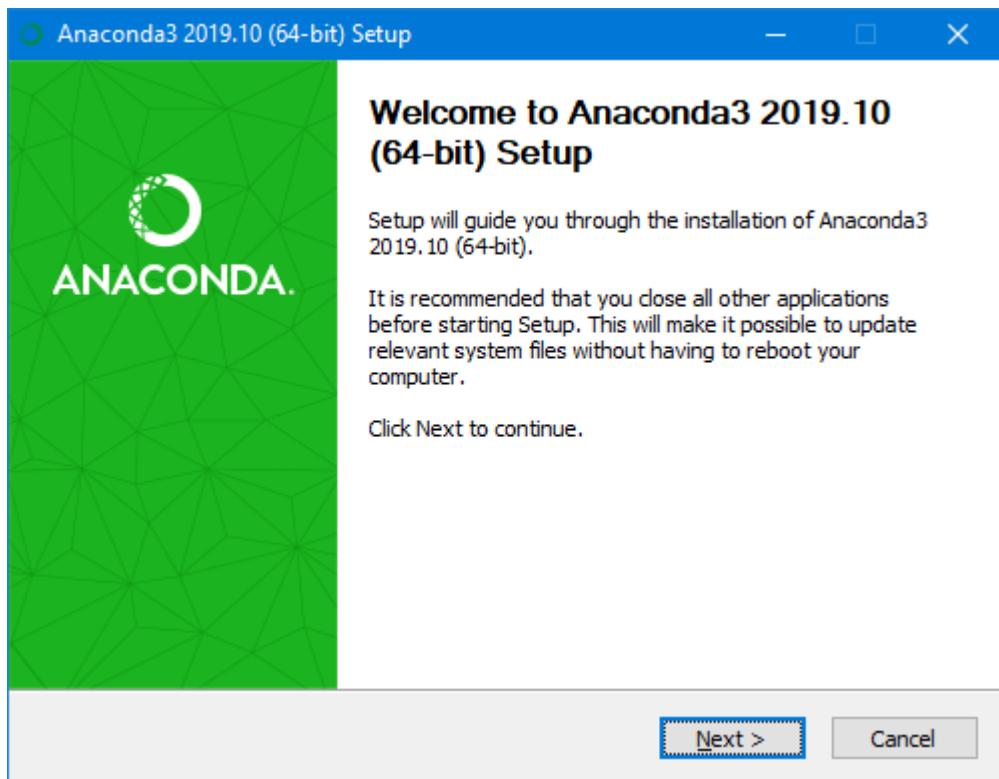
Figure B1.2

Select 'Next'
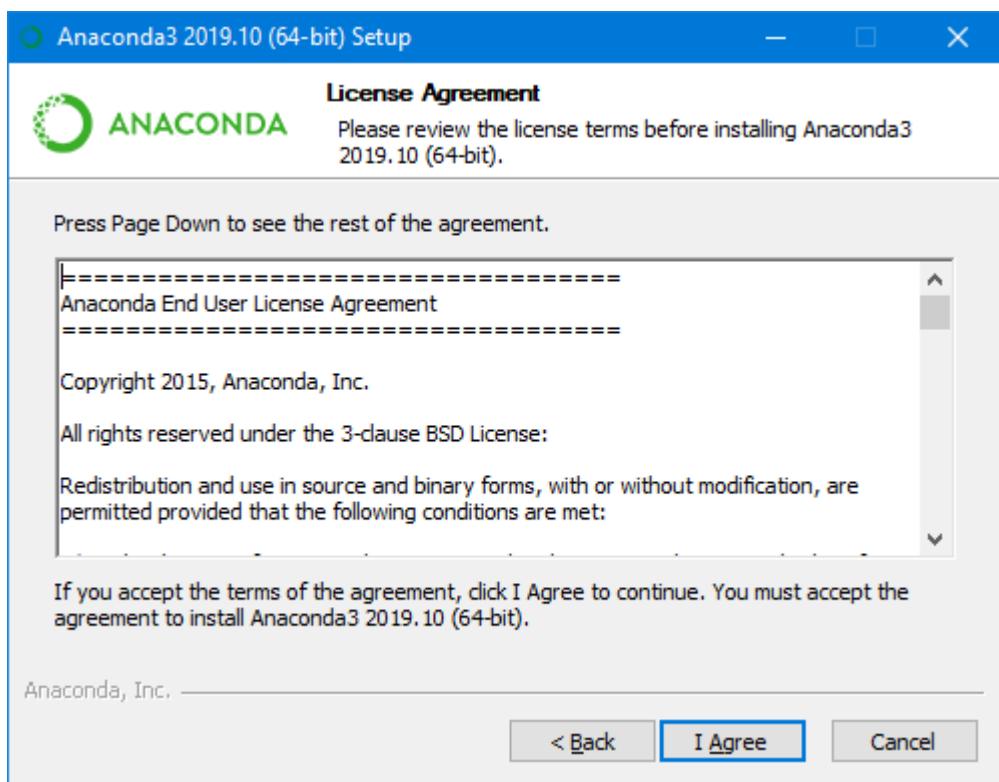
Figure B1.3

Select 'I Agree'
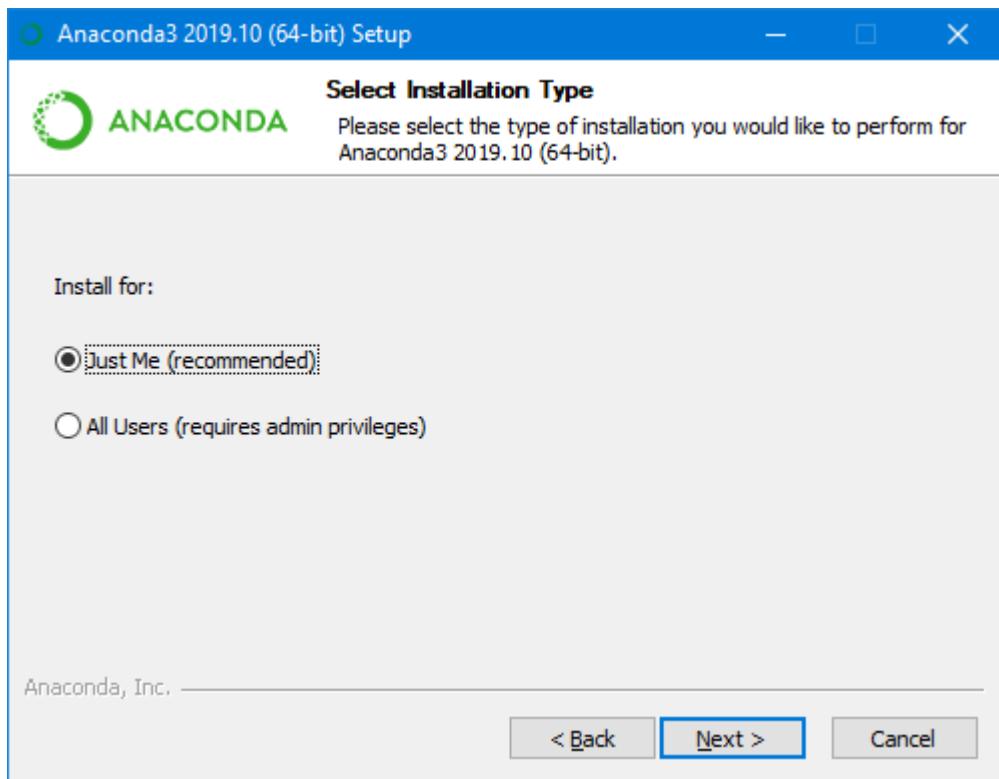
Figure B1.4

Select 'Just Me (recommended) and then 'Next'
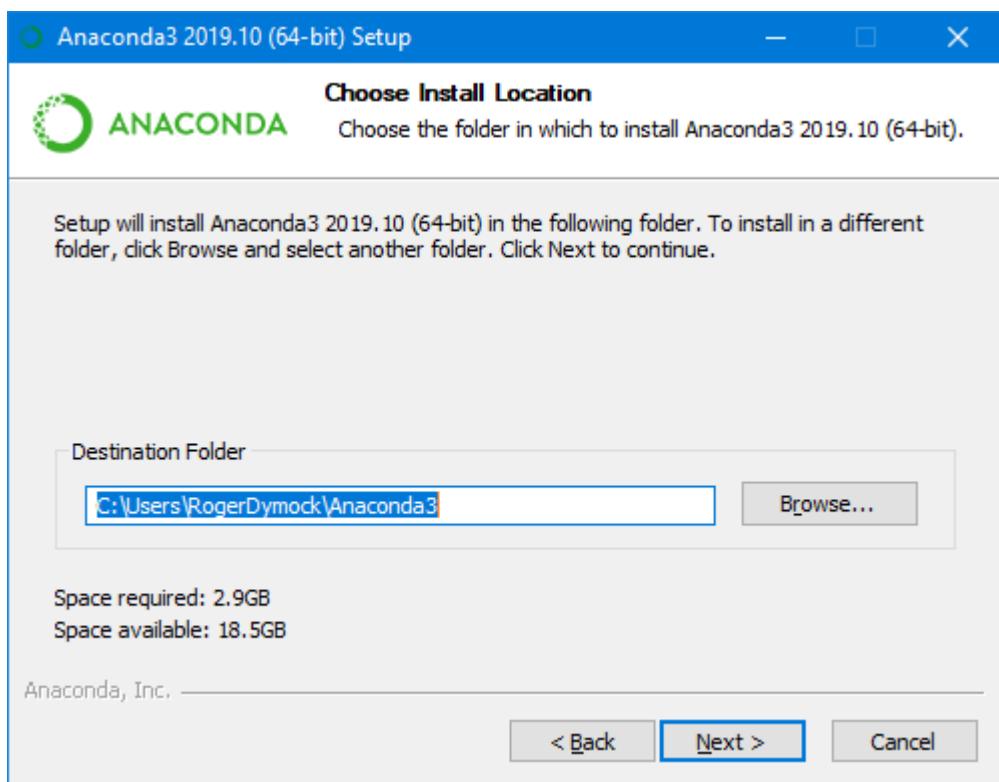
Figure B1.5

Suggest you use whatever destination folder is shown and then select 'Next'
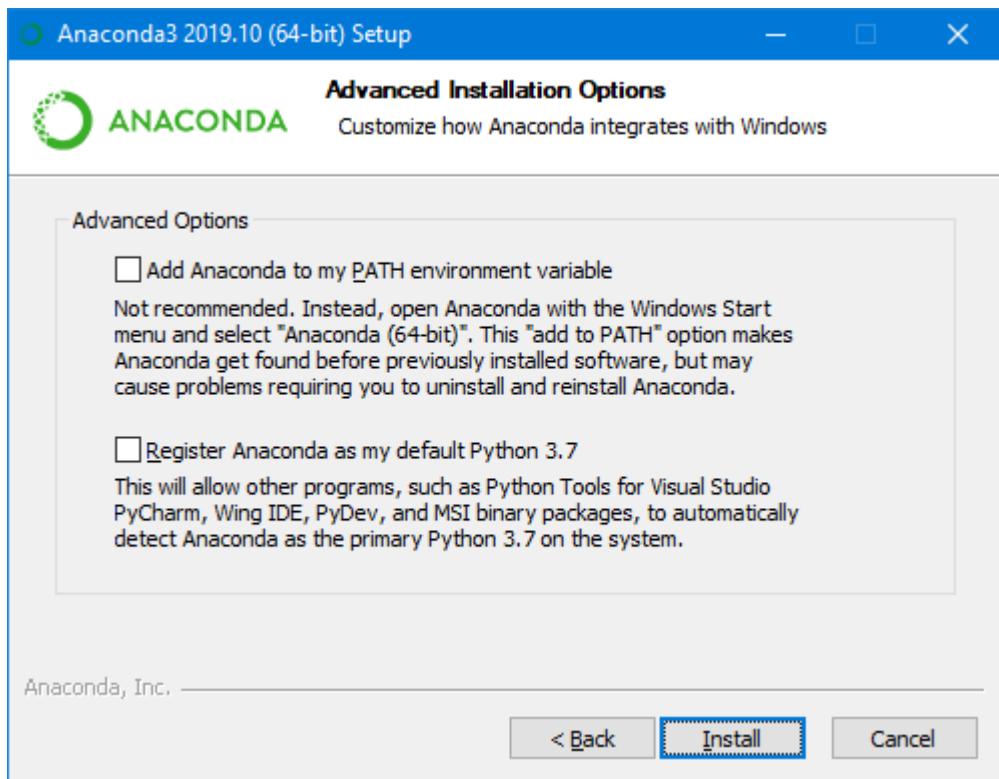
Figure B1.6

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.
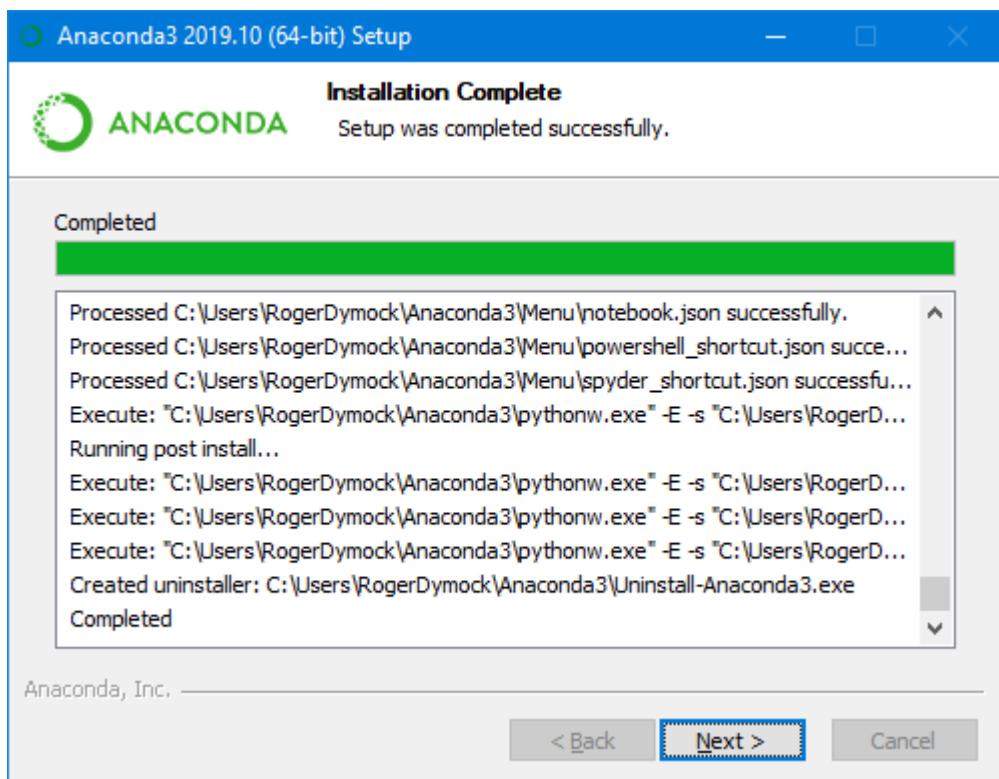
Figure B1.7

Select 'Next'
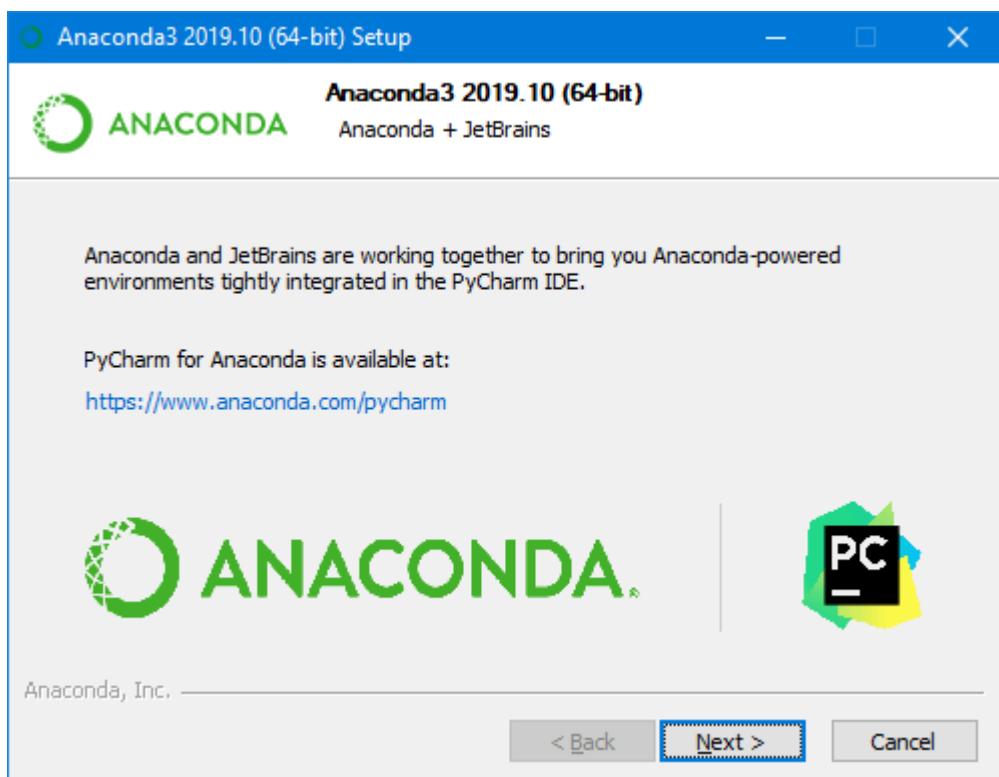
Figure B1.8

Select 'Next'
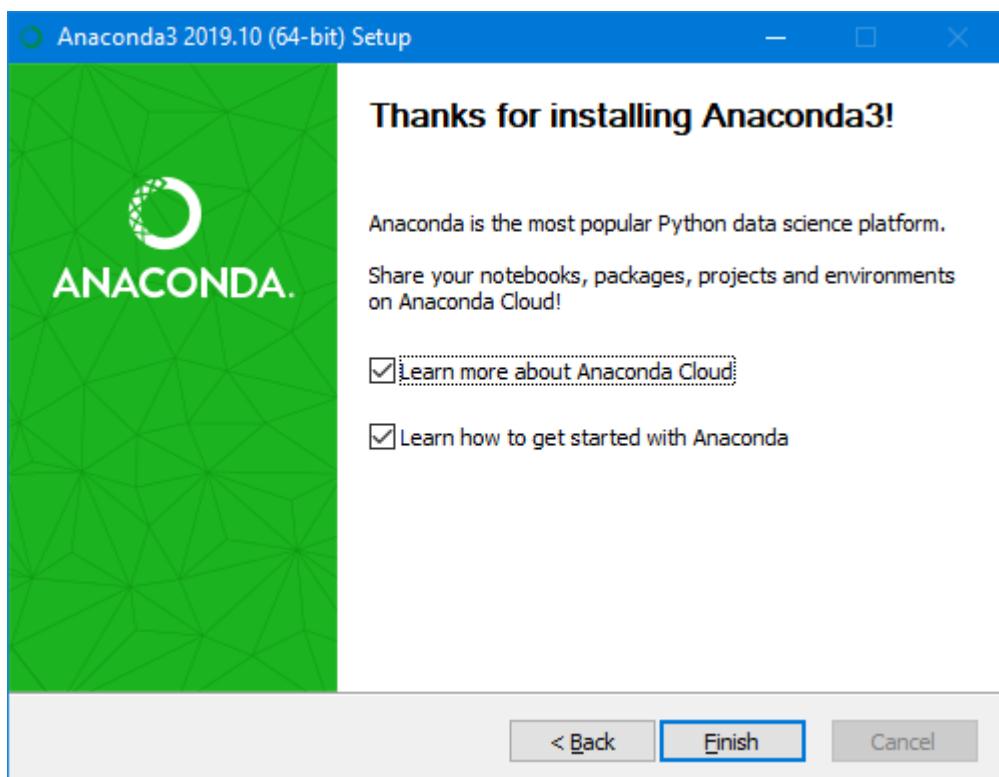
Figure B1.9

Tick or untick two boxes as required and then select 'Finish'

2.0   HOPS Installation

Download the code from GITHUB
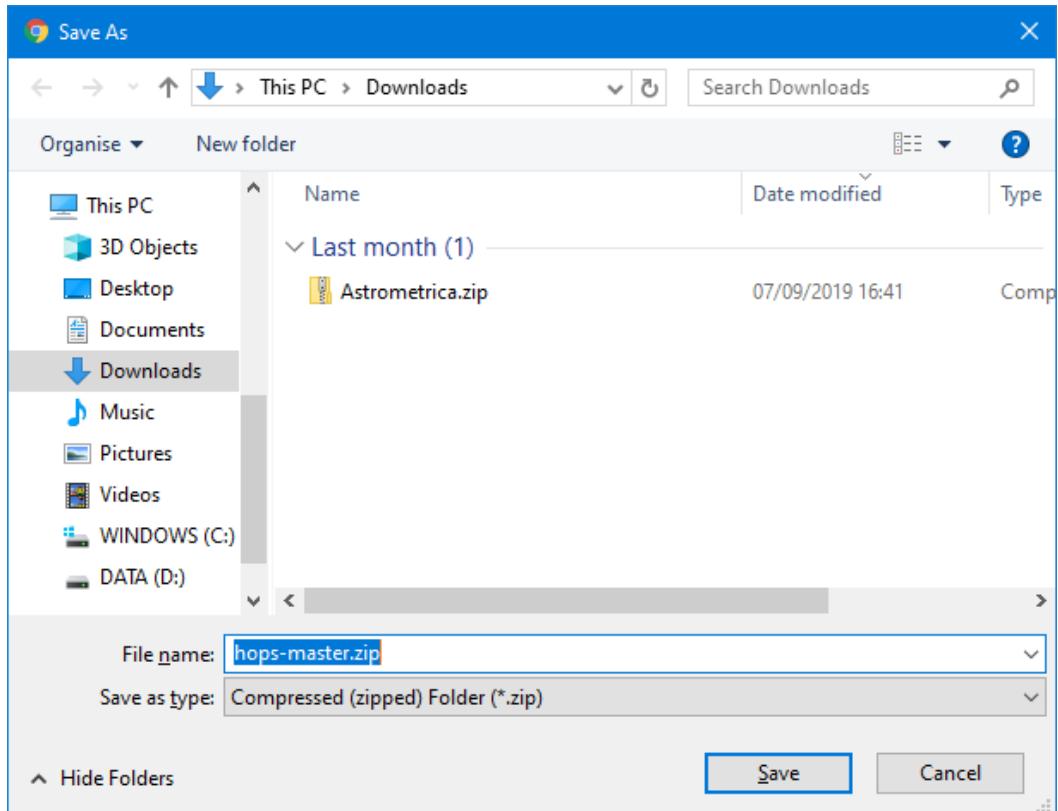
Figure B2.1

Select 'Save'

Unzip by right-clicking on the 'hops-master.zip file and selecting Extract all.
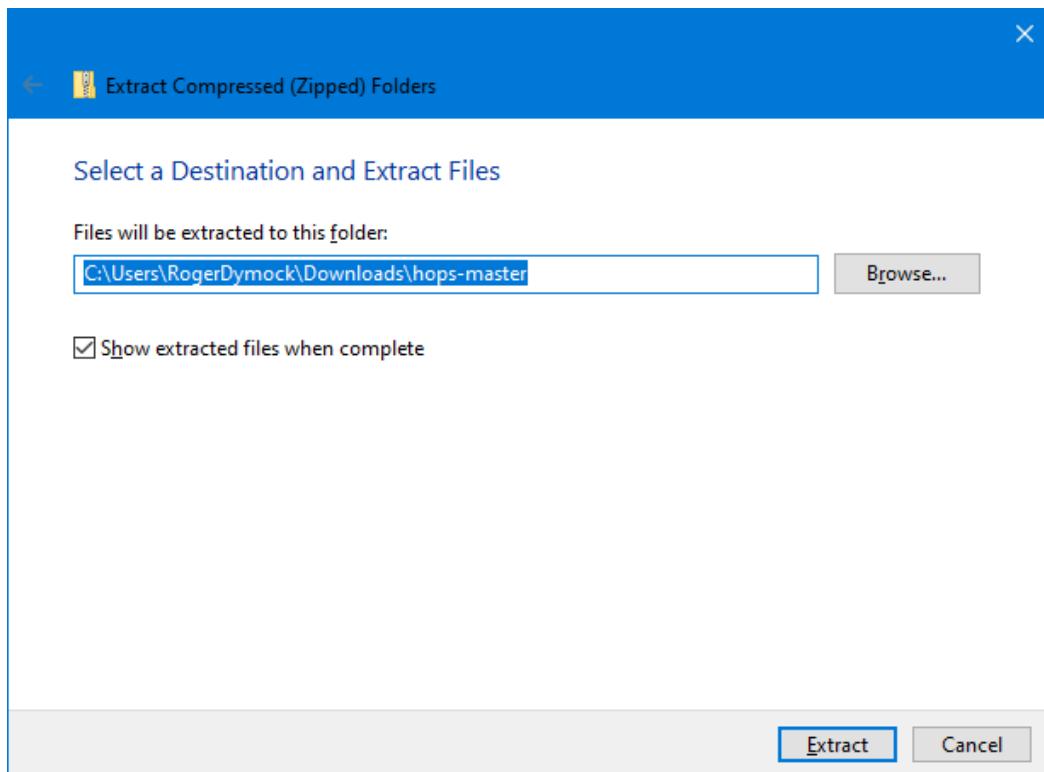
Figure B2.2

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.
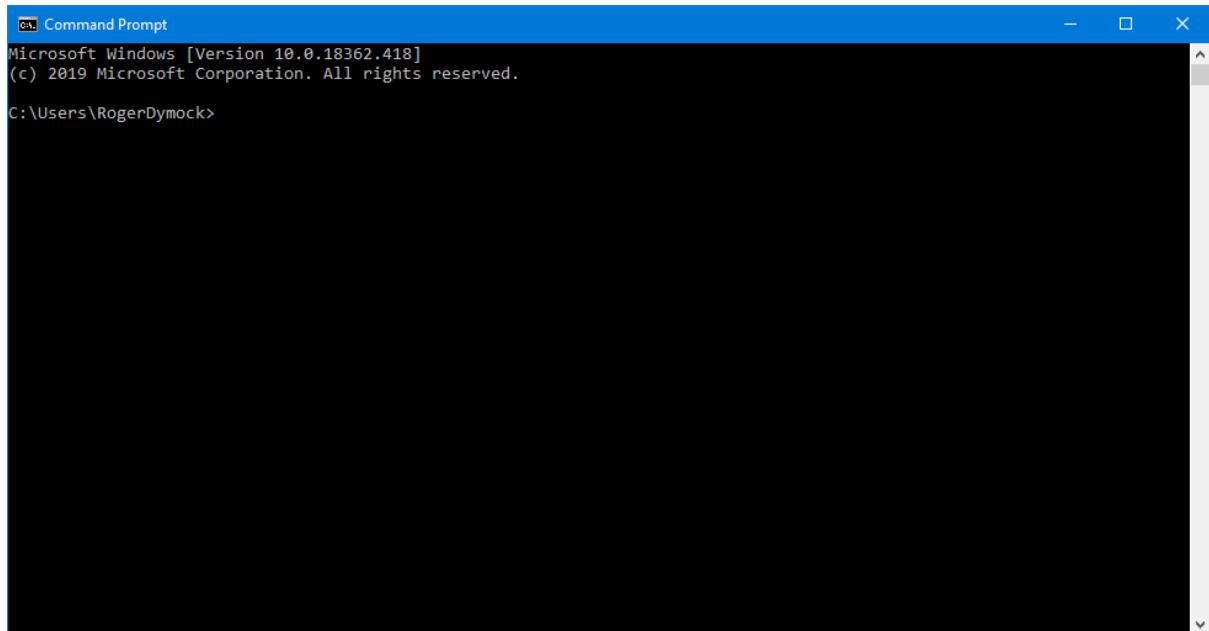
Figure B2.3

hops.cmd

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

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


```
C:\WINDOWS\system32\cmd.exe

C:\Users\RogerDymock\Desktop>python "C:\Users\RogerDymock\Anaconda3\lib\site-packages\hops-2.4.1-py3.7.egg\hops"
no display found. Using non-interactive Agg backend
gzip was not found on your system! You should solve this issue for astroquery.eso to be at its best!
On POSIX system: make sure gzip is installed and in your path!On Windows: same for 7-zip (http://www.7-zip.org)!
Loading... Please wait for the main window to appear.
```

Figure B2.5

Figure B2.6

That's about it for installation.

Appendix C

Running HOPS

1.0   Introduction
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. HOPS may have been updated since this was written so please refer to the latest User Manual at https://www.exoworldsspies.com/static/HOPS2.6_manual.pdf

Tis example uses images of TrES-3b obtained on 2020 April 15 using the MicroObservatory robotic telescope

It is convenient to organise your data as per the instructions in the HOPS manual; i.e.
- Keep all scientific and reduction frames in one folder without subfolders
- Use a specific identifier for the scientific frames e.g.tres
- Use a specific identifier for the bias frames, not containing the same identifier as the
   scientific frames e.g. bias (none available in this example)
- Use a specific identifier for the dark frames, not containing the same identifier as the
   scientific frames e.g. dark
- Use a specific identifier for the flat frames, not containing the same identifier as the
   scientific frames e.g. flat (none available in this example)

2.0 Analysis
Double click on the hops.cmd icon and wait until the window in Figure C2.1 is displayed.
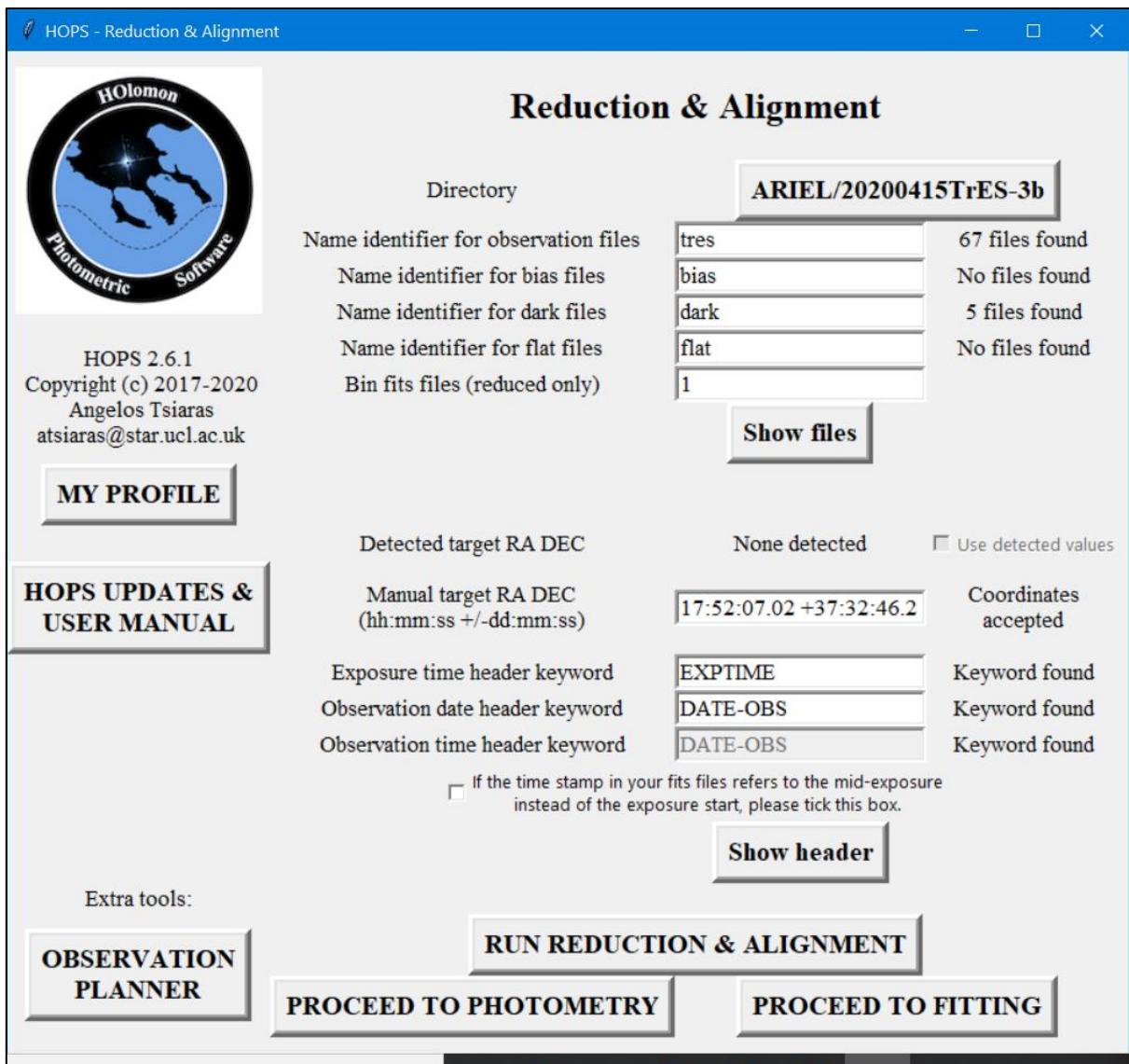
Figure C2.1. HOPS Reduction window (populated as below)

Select the 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, tres and dark files and the quantities of images and calibration frames will now be listed. You may also need to enter RA and Dec if this is not picked up from the FITS header. The Reduction window, C2.1, is now populated.

Select My Profile, fill in the observatory data and click on Update – Figure C2.2 shows data for the MicroObservatory robotic telescope. Do not leave 'None' in any of the boxes as this will cause an error later.

Figure C2.2. Profile for MicroObservatory robotic telescope

Select Run Reduction and Alignment. On completion the window in Figure C2.3 is displayed.

Alignment omits saturated sources. It will not use stars with peak higher than the 2/3s of the saturation limit (65000 for a 16 bit camera). You can change this by modifying the second line of the log.yaml file.

Important note from HOPS manual
The alignment process relies heavily on your first image. This is a good moment to check your first image again and verify that it is not overexposed and that the tracking is representative of your observation in total. If your first image is not of good quality, select it as faulty here (step d on the next slide), it will save you a lot of time!
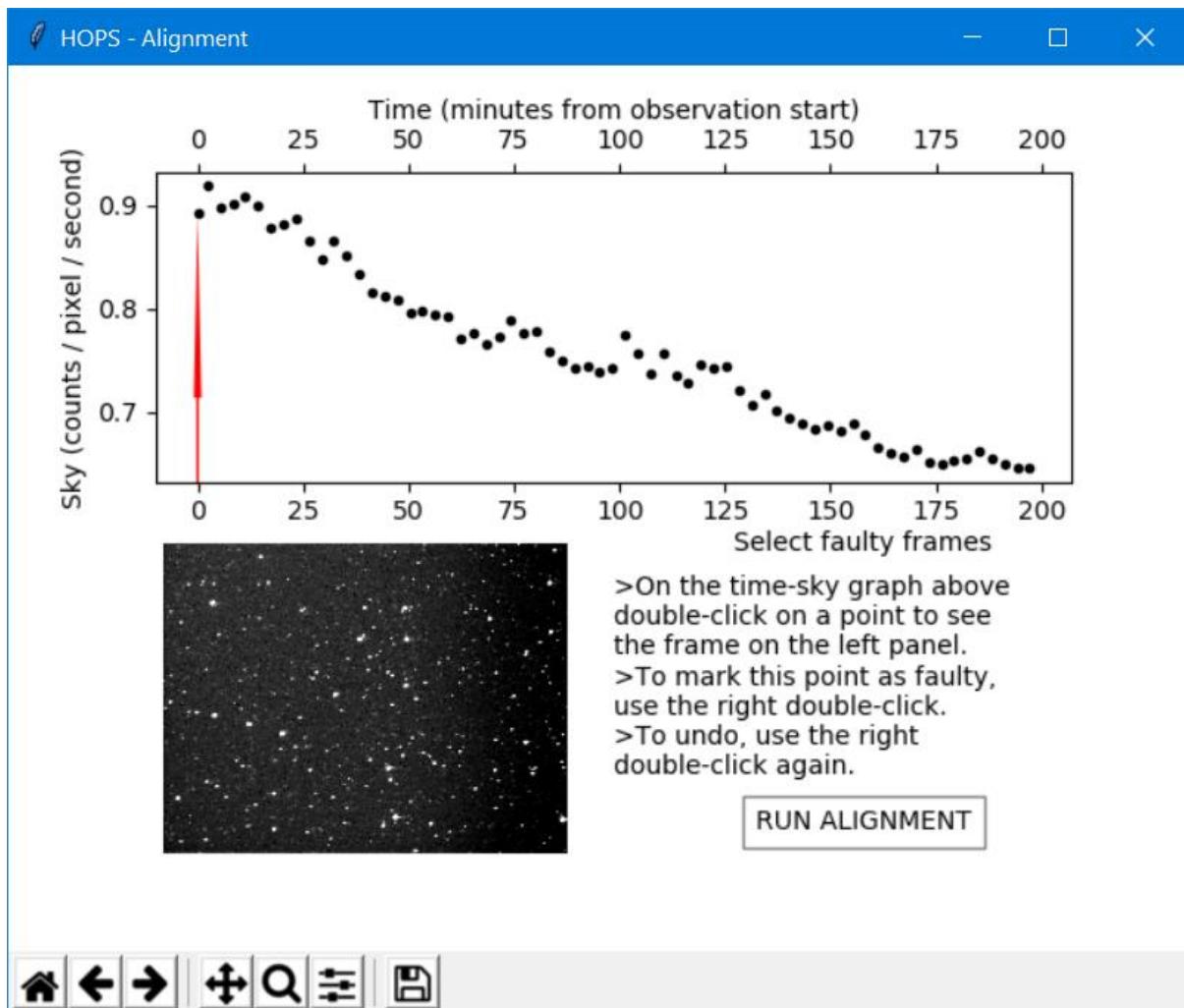
Figure C2.3

Select RUN ALIGNMENT. On completion two windows are displayed; Photometry, Figure C2.4 and Plot, Figure C2.5. Orientate the image to match the finder chart - Figure C2.6 which was obtained from this document, Appendix A19
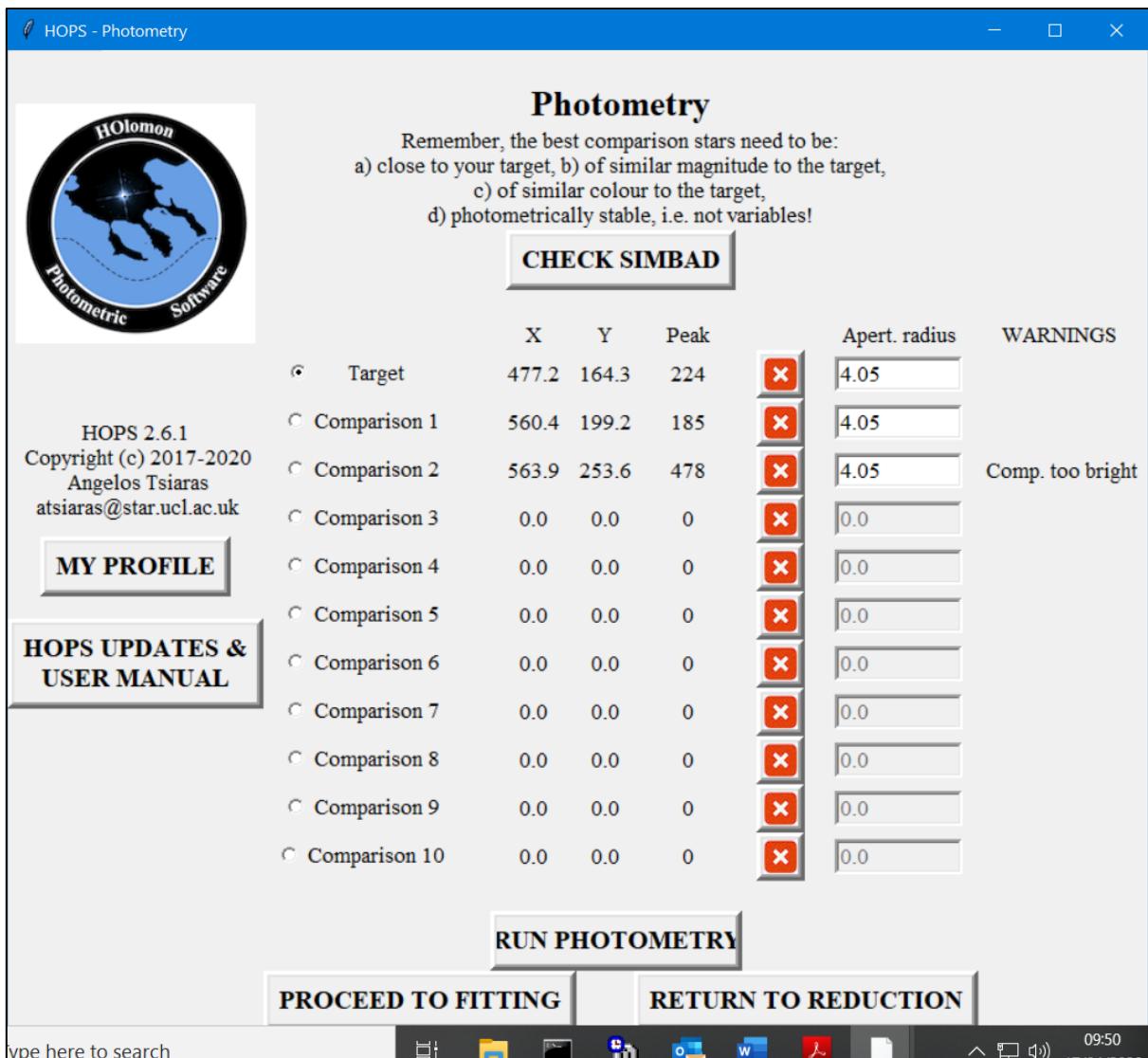
Figure C2.4 Photometry window
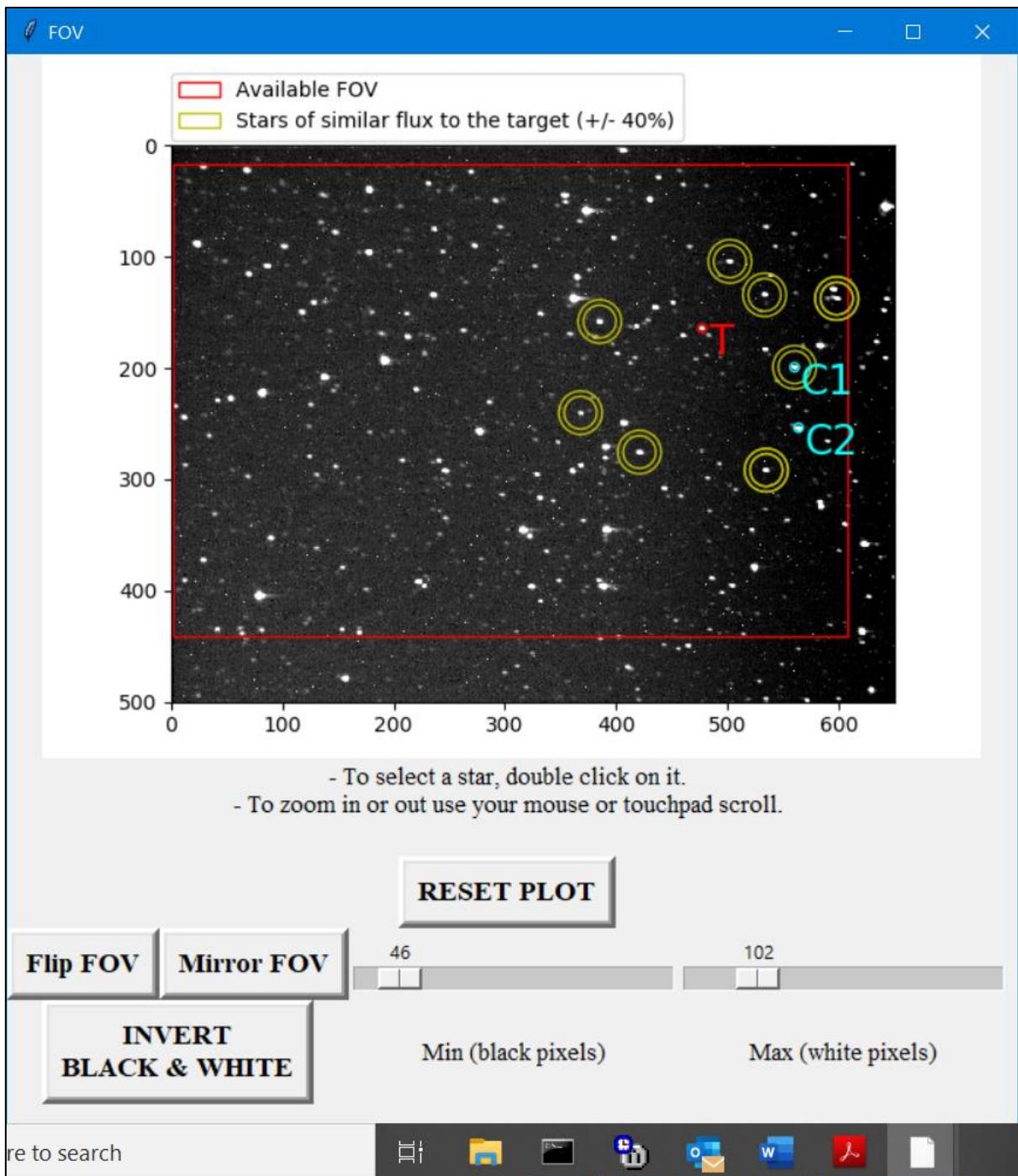
Figure C2.5. Plot window

Stars of similar magnitude are identified but not used in this example.
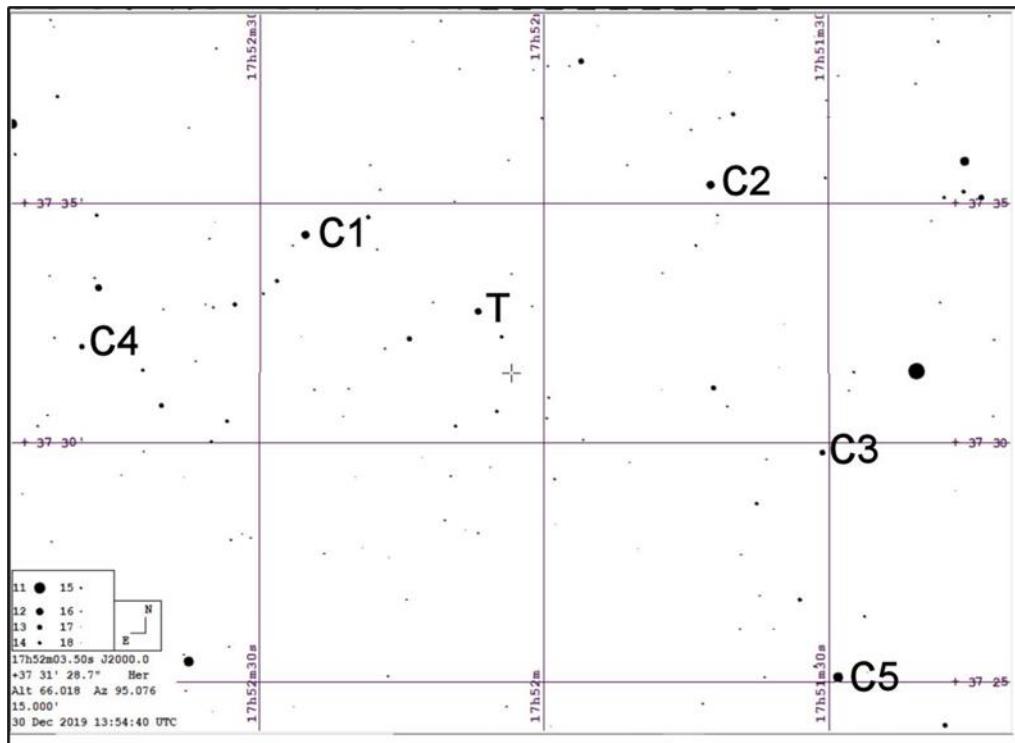
Figure C2.6. Finder chart

An initial run showed that C1, C2 and C4 as shown in Figure C2.6 were not suitable so C3 and C5 were selected – identified as C1 and C2 in Figure C2.4.

The next step is to Select Run Photometry to calculate the light curve – Figure C2.7 shows the light-curves for the target and the two comparison stars.
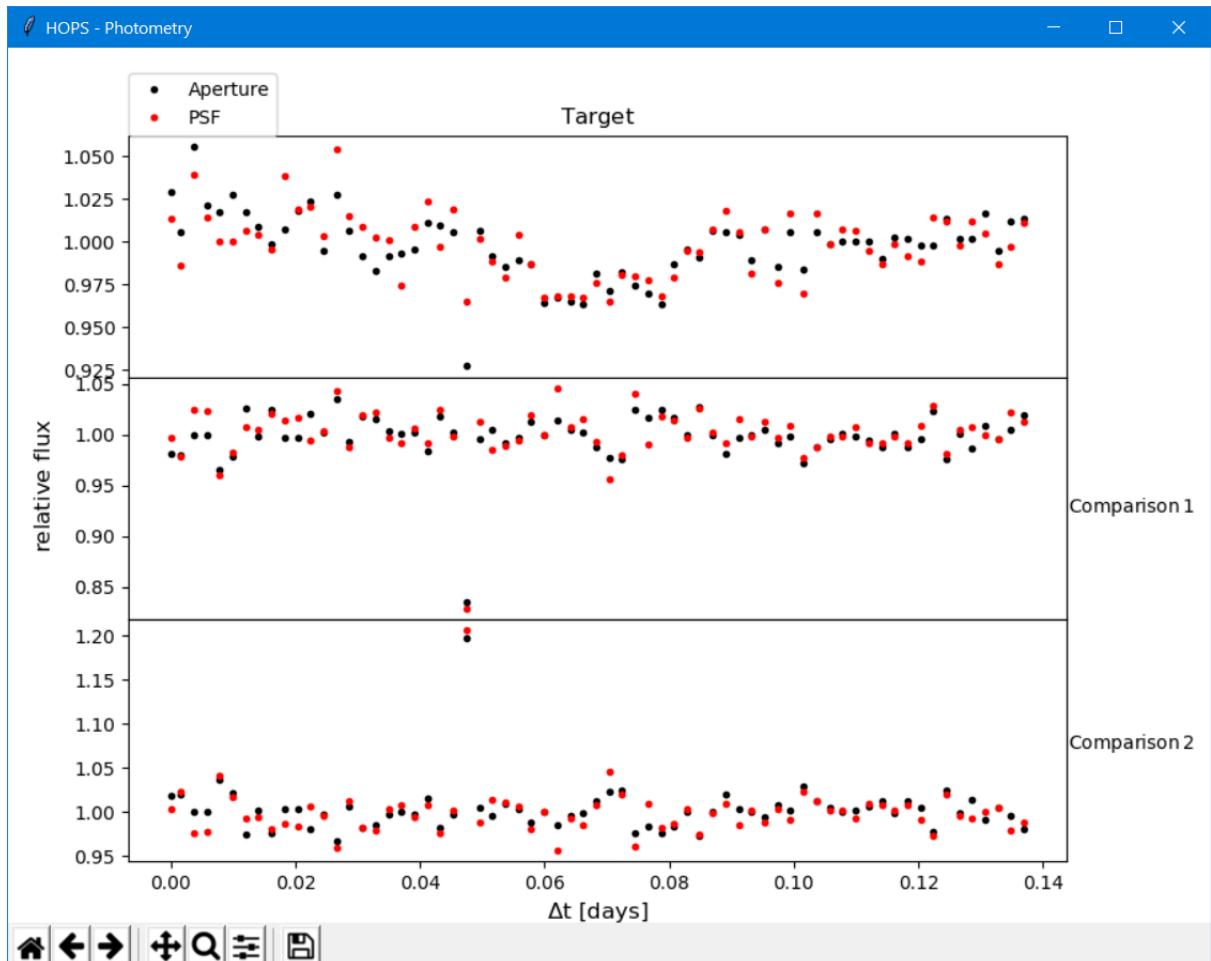
Figure C2.7. Light curves of target and comparison stars.

Close the window shown in Figure C2.7 and select Proceed to Fitting – Figures C2.8 and C2.9 are displayed which shows observatory, host star and exoplanet data and a preview of the transit light curve. The data in Figure C2.8 can be verified by referring to, for example, the Extrasolar Planets Encyclopaedia
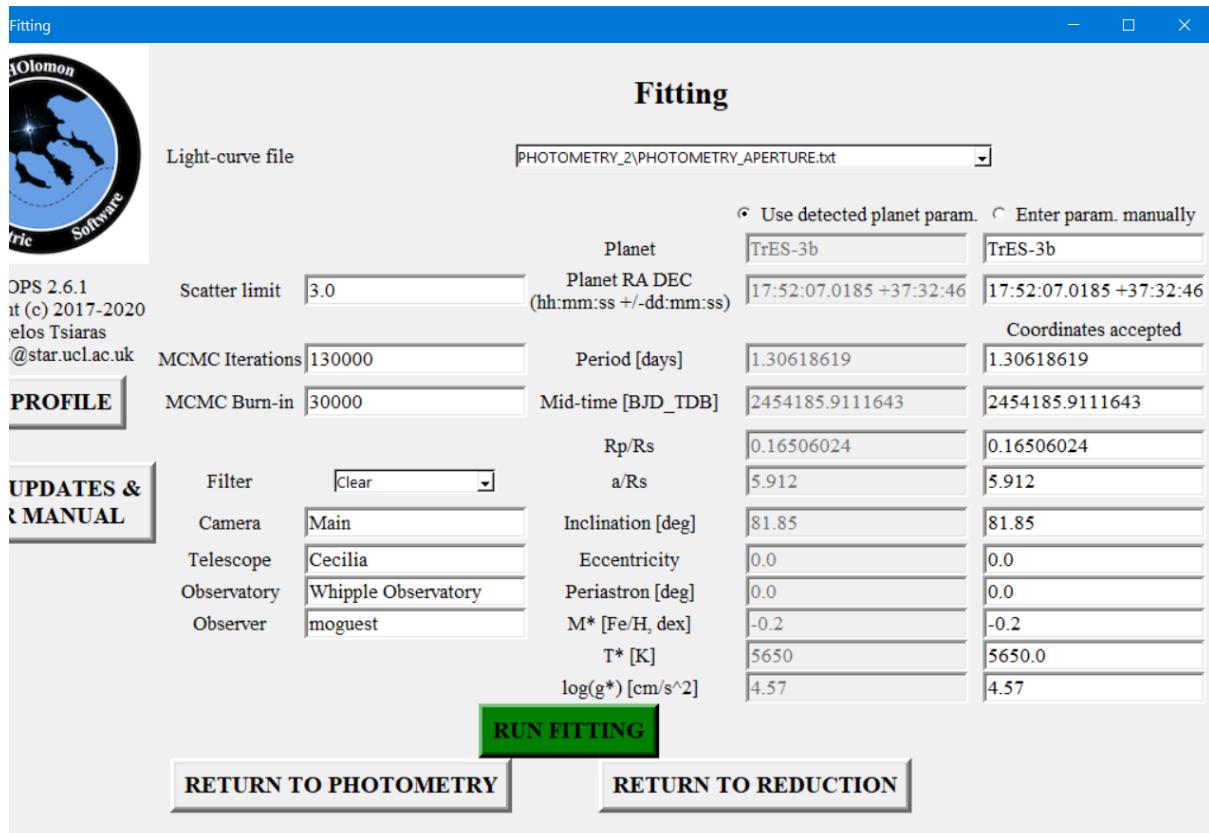
Figure C2.8. Fitting data
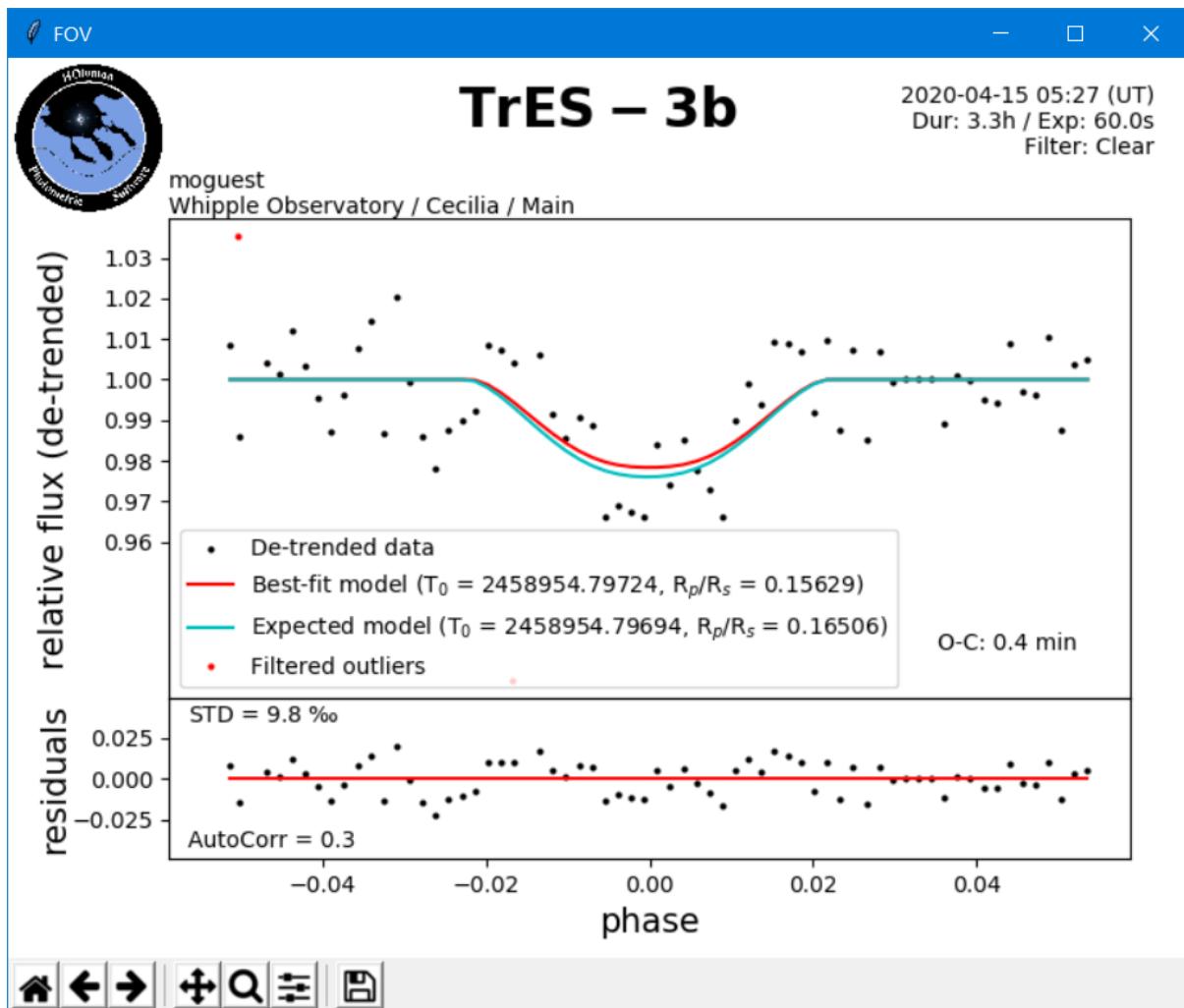
Figure C2.9. Preliminary transit light curve

On the Fitting screen you can choose to use aperture or Gauss (PSF) fitting. A filter must be chosen before proceeding but this may already be filled in from your profile. If you are satisfied with the preview then select Run Fitting. The result is shown Figure C2.10 using the Aperture Light-curve file and Figure C2.11 using the Gauss Light-curve file.
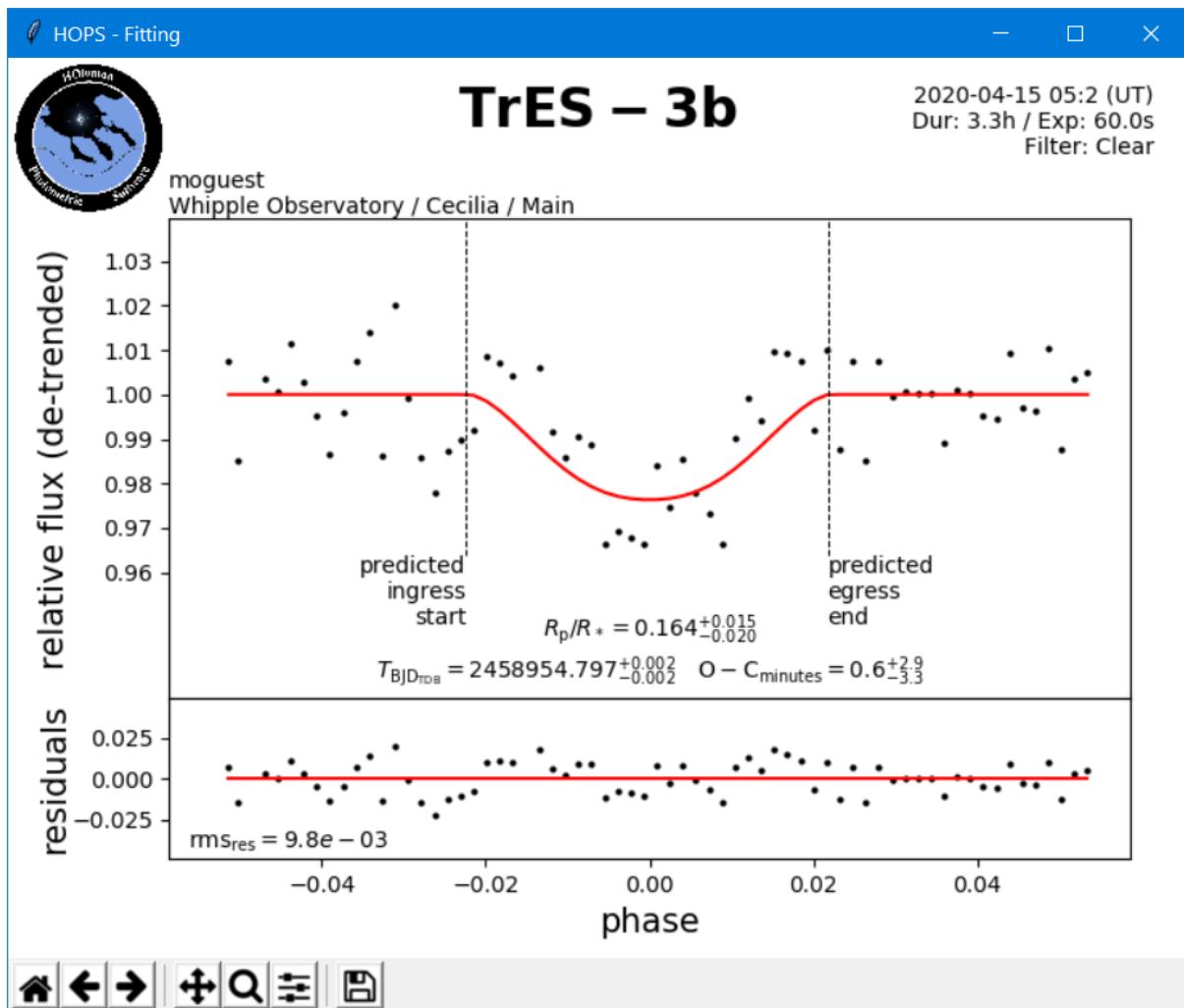
Figure C2.10. Final light curve (Aperture file)
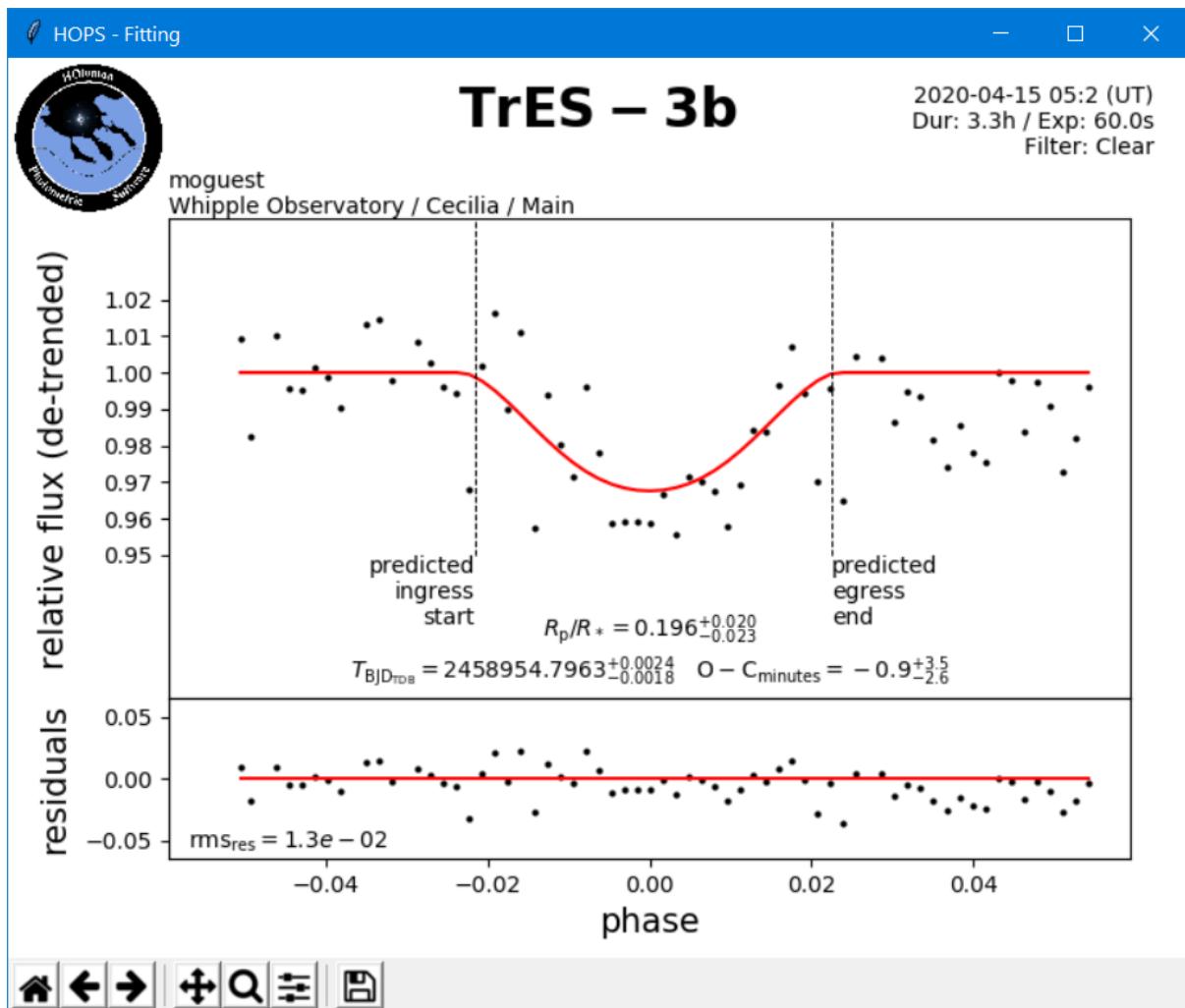
Figure C2.11. Final Light curve (Gauss file)

3.0   Submitting results to the ExoClock project

The file ' ExoClock_info.txt',below, is located in the Photometry folder and indicates which file should be uploaded – PHOTOMETRY_GAUSS.txt in this case.

```
------------------------------------------------------------------------------------------------

The ExoClock Project is an effort to keep the ephemerides of
exoplanets as precise as
possible for planning future observations. If you have observed an
exoplanet you can
contribute your observation at:

https://www.exoclock.space

File to upload: PHOTOMETRY_GAUSS.txt
(this is a suggestion based on the scatter
of your light curves, you can also try
uploading PHOTOMETRY_APERTURE.txt)

Planet: TrES-3b
(this is the closest known exoplanet found
in the catalogue, if this is not the target
you observed, please ignore)
```

```
Time format: JD_UTC
(UTC-based Julian date)

Time stamp: Exposure start
(the time produced refers to the beginning of each exposure)

Flux format: Flux
(flux of target over summed flux of comparisons)

Filter: Clear

Exposure time in seconds: 60.0
-------------------------------------------------------------------------------------------------------
```

To upload your results;
- go to the ExoClock homepage at https://www.exoclock.space/project
- Log-in (assuming you are registered)
- select My lab/Upload Observation and complete the observation data, Figure C3.1, and click on 'Upload Observation'

Figure C3.1. Observation data for TrES=3b
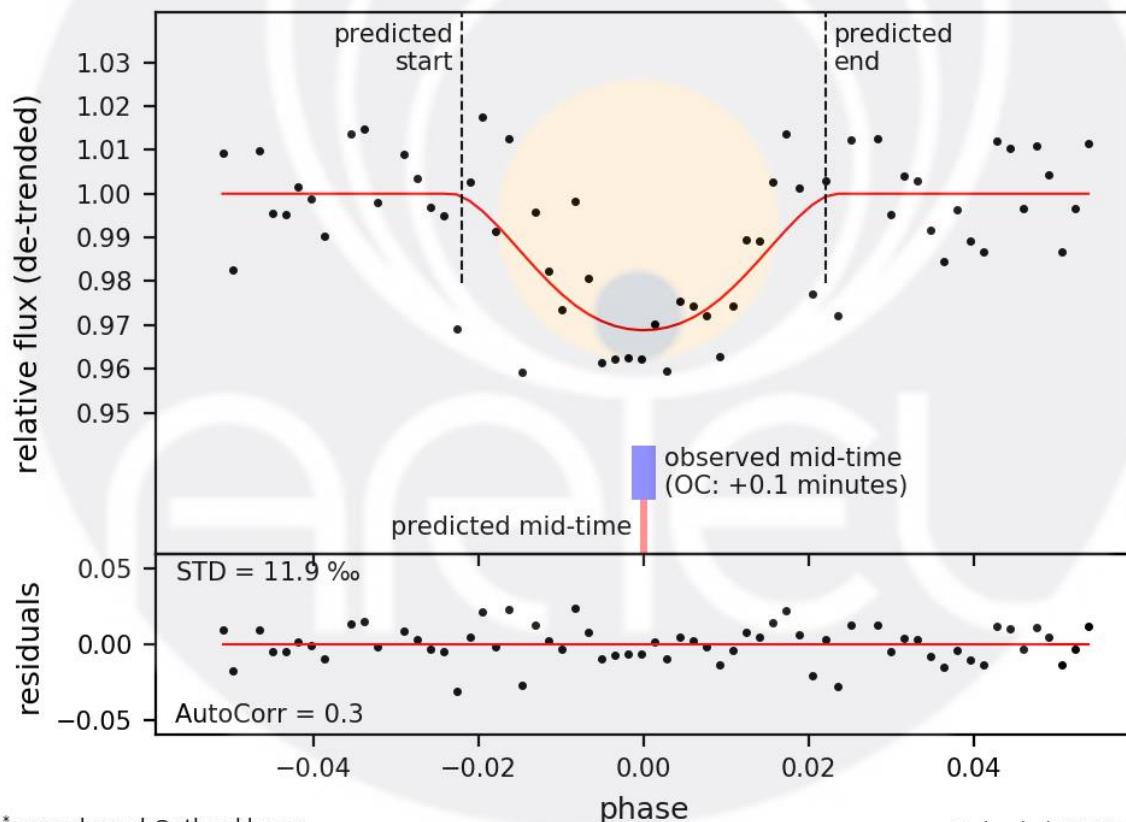
Complete the upload by selecting 'Submit' and clicking on 'Update Observation'. Figure C3.2 resulting.

Figure C3.2. Uploaded transit light-curve.

Selecting My Profile/My Observations shows the status of your submissions – Figure C3.3.

Figure C3.3. Submission status.

An email will be sent to you when your observation has been verified and is on the ExoClock Observations database.

Roger Dymock
Assistant Director ARPS Exoplanets Division
2020 January 9