Infinite Worlds

ARIEL Space Mission Special Issue
The e-magazine of the Exoplanets Division
Of the Asteroids and Remote Planets Section

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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

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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/](https://arielmission.space/)
ARIEL will use transit spectroscopy to characterise the atmospheres of ~1000 exoplanet.

Relevant documentation;

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
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
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.

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

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](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/](http://catserver.ing.iac.es/staralt/) using the Starobs option.

### 5.2 Comparison stars

Comparison stars 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](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/](https://www.aavso.org/apps/vsp/) was accessed to check for variable and comparison stars near the target.
Appendix A1

<table>
<thead>
<tr>
<th>Target</th>
<th>RA</th>
<th>Dec</th>
<th>V mag</th>
<th>B-V</th>
<th>Depth (mmag)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAT-P-20b</td>
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<td>24 20 11.9</td>
<td>11.34</td>
<td>1.2</td>
<td>20</td>
</tr>
</tbody>
</table>

Table A1.1. Target data

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

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

Table A1.2. Comparison star data

Figure A1.4. Object visibility
Appendix A2

<table>
<thead>
<tr>
<th>Target</th>
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<th>Dec</th>
<th>V mag</th>
<th>B-V</th>
<th>Depth (Mmag)</th>
</tr>
</thead>
<tbody>
<tr>
<td>XO-6b</td>
<td>06 19 10.39</td>
<td>73 49 39.7</td>
<td>10.25</td>
<td>0.360</td>
<td>14</td>
</tr>
</tbody>
</table>

Return to target list

Table A2.1. Target data

![XO-6b](ariel-gbhu.azurewebsites.net/database/planets/XO-6b/)

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

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

Table A2.2. Comparison star data
Figure A2.3. Object visibility
Appendix A3

<table>
<thead>
<tr>
<th>Target</th>
<th>RA</th>
<th>Dec</th>
<th>V mag</th>
<th>B-V</th>
<th>Depth (mmag)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAT-P-6b</td>
<td>23:39:05.81</td>
<td>42:27:57.5</td>
<td>10.44</td>
<td>0.469</td>
<td>14</td>
</tr>
</tbody>
</table>

Table A3.1. Target data

Return to target list

Figure A3.1 Star and transit data
Figure A3.2. Finder chart
Nominal criteria for comparison star selection.

$0.269 < (B-V) < 0.669$

$8.94 < V = 10.44 < 11.94$

**Table A3.2. Comparison star data**

<table>
<thead>
<tr>
<th>Comp star</th>
<th>RA</th>
<th>Dec</th>
<th>V mag</th>
<th>B-V</th>
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</thead>
<tbody>
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<td>1</td>
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<td>+42 24 38.09</td>
<td>11.710</td>
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<tr>
<td>2</td>
<td>23 39 15.75</td>
<td>+42 20 47.60</td>
<td>12.752</td>
<td>0.724</td>
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<tr>
<td>3</td>
<td>23 39 36.79</td>
<td>+42 34 51.92</td>
<td>11.826</td>
<td>0.377</td>
</tr>
<tr>
<td>4</td>
<td>23 39 37.67</td>
<td>+42 26 49.11</td>
<td>11.450</td>
<td>0.339</td>
</tr>
<tr>
<td>5</td>
<td>23 38 47.40</td>
<td>+42 31 44.1</td>
<td>12.451</td>
<td>1.028</td>
</tr>
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</table>

Note. Data for Comparison star 4 are from Guide and Comparison star 5 from the AAVSO.
Figure A3.4. Object visibility
Appendix A4

<table>
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<th>B-V</th>
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</thead>
<tbody>
<tr>
<td>WASP-13b</td>
<td>09 20 24.71</td>
<td>33 52 56.8</td>
<td>10.42</td>
<td>0.459</td>
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</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Comp star</th>
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<th>B-V</th>
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<tr>
<td>1</td>
<td>09 20 23.48</td>
<td>+33 59 16.04</td>
<td>13.872</td>
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<tr>
<td>2</td>
<td>09 20 02.97</td>
<td>+33 55 45.60</td>
<td>13.240</td>
<td>0.933</td>
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<tr>
<td>3</td>
<td>09 19 51.49</td>
<td>+33 52 23.82</td>
<td>13.867</td>
<td>0.385</td>
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<tr>
<td>4</td>
<td>09 20 33.07</td>
<td>+33 46 36.50</td>
<td>11.653</td>
<td>0.467</td>
</tr>
<tr>
<td>5</td>
<td>09 21 08.51</td>
<td>+33 48 20.72</td>
<td>11.092</td>
<td>0.939</td>
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</table>

Table A4.2. Comparison star data
Figure A4.4. Object visibility
Appendix A5

<table>
<thead>
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<th>B-V</th>
<th>Depth (mmag)</th>
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<tr>
<td>XO-4b</td>
<td>07 21 33.17</td>
<td>58 16 05.20</td>
<td>10.67</td>
<td>0.492</td>
<td>10</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Comp star</th>
<th>RA</th>
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<th>V mag</th>
<th>B-V</th>
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<tbody>
<tr>
<td>1</td>
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<td>+58 18 38.25</td>
<td>12.319</td>
<td>0.665</td>
</tr>
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<td>07 21 09.31</td>
<td>+58 16 05.17</td>
<td>10.510</td>
<td>0.719</td>
</tr>
<tr>
<td>3</td>
<td>07 21 57.40</td>
<td>+58 15 10.08</td>
<td>11.622</td>
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<tr>
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<td>+58 11 20.18</td>
<td>10.518</td>
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<td>07 20 45.90</td>
<td>+58 17 18.44</td>
<td>11.512</td>
<td>1.106</td>
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Table A5.2. Comparison star data
Figure A5.4. Object visibility
Appendix A6

<table>
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<td>35 26 49.60</td>
<td>10.30</td>
<td>0.506</td>
<td>11</td>
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</table>

Table A6.1. Target data

Return to target list
Figure A6.2. Finder chart
Nominal criteria for comparison star selection.

0.306 < (B-V) < 0.706

8.80 < (V) < 11.80

<table>
<thead>
<tr>
<th>Comp star</th>
<th>RA</th>
<th>Dec</th>
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<th>V mag</th>
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<tbody>
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<td>0.557</td>
<td>12.612</td>
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<tr>
<td>3</td>
<td>22 52 38.29</td>
<td>+35 27 13.96</td>
<td>0.745</td>
<td>12.704</td>
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<tr>
<td>4</td>
<td>22 51 43.33</td>
<td>+35 33 00.20</td>
<td>0.541</td>
<td>12.394</td>
</tr>
<tr>
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<td>+35 31 58.99</td>
<td>0.452</td>
<td>10.904</td>
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Table A6.2. Comparison star data

Note. Data for Comparison star 5 is from Guide
Figure A6.4. Object visibility
## Appendix A.7

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<th>Depth (mmag)</th>
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</thead>
<tbody>
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<td>HAT-P-17b</td>
<td>21 38 08.74</td>
<td>30 29 19.4</td>
<td>10.54</td>
<td>0.802</td>
<td>20</td>
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</table>

Table A7.1. Target data

[Return to target list](#)

![HAT-P-17b](attachment://HAT-P-17b.png)

Figure A7.1
Nominal criteria for comparison star selection.

\[ 0.602 < (B-V) < 0.1002 \]

\[ 9.04 < (V) < 12.04 \]

<table>
<thead>
<tr>
<th>Comp star</th>
<th>RA</th>
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<th>V mag</th>
<th>B-V</th>
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</thead>
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<td>+30 33.2211</td>
<td>11.921</td>
<td>0.270</td>
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<tr>
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<td>21 38.2825</td>
<td>+30 26.1103</td>
<td>11.322</td>
<td>0.400</td>
</tr>
<tr>
<td>3</td>
<td>21 37.5721</td>
<td>+30 34.3334</td>
<td>12.494</td>
<td>0.598</td>
</tr>
<tr>
<td>4</td>
<td>21 38.2239</td>
<td>+30 36.0302</td>
<td>9.050</td>
<td>0.503</td>
</tr>
<tr>
<td>5</td>
<td>21 38.1233</td>
<td>+30 24.0988</td>
<td>9.397</td>
<td>0.301</td>
</tr>
</tbody>
</table>
Figure A7.4

Optimum observing time, Observing site coordinates: -1.0000E 54.0000, year 2019

Altitudes at Middle-Dark-Time

Sundown hours above altitude 30°

List of objects

1 object: 21.5 hours = 230°F

Circle above frame represent Full Moon and the "C" symbol on a curve means the Moon is closer than 15°.

The thick dotted line above the curves represents the total sundown hours for each day of the year.

Comments
Appendix A.8

<table>
<thead>
<tr>
<th>Target</th>
<th>RA</th>
<th>Dec</th>
<th>V mag</th>
<th>B-V</th>
<th>Depth (mmag)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAT-P-3b</td>
<td>13 44 22.59</td>
<td>48 01 43.2</td>
<td>11.58</td>
<td>0.817</td>
<td>16</td>
</tr>
</tbody>
</table>

Table A8.1

Return to target list

Figure A8.1
Nominal criteria for comparison star selection.
\[0.617 < (B-V = 0.817) < 1.017\]
\[10.08 < (V = 11.58) < 12.08\]

<table>
<thead>
<tr>
<th>Comp star</th>
<th>RA</th>
<th>Dec</th>
<th>V mag</th>
<th>B-V</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13 44 36.38</td>
<td>+48 03 52.56</td>
<td>12.770</td>
<td>0.807</td>
</tr>
<tr>
<td>2</td>
<td>13 44 11.84</td>
<td>+47 55 08.00</td>
<td>10.694</td>
<td>0.684</td>
</tr>
<tr>
<td>3</td>
<td>13 44 35.66</td>
<td>+48 08 33.94</td>
<td>13.193</td>
<td>0.606</td>
</tr>
<tr>
<td>4</td>
<td>13 43 40.61</td>
<td>+48 08 30.29</td>
<td>11.178</td>
<td>0.560</td>
</tr>
<tr>
<td>5</td>
<td>13 45 21.80</td>
<td>+47 58 24.41</td>
<td>12.575</td>
<td>1.154</td>
</tr>
</tbody>
</table>
Figure A8.4
Appendix A9

<table>
<thead>
<tr>
<th>Target</th>
<th>RA</th>
<th>Dec</th>
<th>V</th>
<th>B-V</th>
<th>Depth (mmag)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WASP-11b</td>
<td>03 09 28.55</td>
<td>30 40 24.9</td>
<td>11.60</td>
<td>0.964</td>
<td>23</td>
</tr>
</tbody>
</table>

Table A9.1

Note. No ETD entry for this target

Refer to target list

Figure A9.1
Figure A9.3

Nominal criteria for comparison star selection.

\[0.764 < (B-V) = 0.964 < 1.164\]

\[10.90 < (V) = 11.60 < 12.90\]

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

Table A9.2
Figure A9.4

Optimum observing time, observing site coordinates: -1.0000 E 54.0000, year 2019

Altitudes vs. Wible-Dark-Time

Sunrise hours above altitude 30°

List of objects
- 3° above

The thick dotted line above the curves represents the total sunrise hours for each day of the year.

Comments

1 object, 3° altitude + 30° above.
# Appendix A10

<table>
<thead>
<tr>
<th>Target</th>
<th>RA</th>
<th>Dec</th>
<th>V mag</th>
<th>Depth (mmag)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAT-P-12b</td>
<td>13 57 33.48</td>
<td>43 29 36.7</td>
<td>12.84</td>
<td>28</td>
</tr>
</tbody>
</table>

Table A10.1

[Return to target list](#)

![Figure A10.1](image-url)

Figure A10.1
Figure A10.3

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

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

Table A10.2
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

![Anaconda 2019.10 for Windows Installer](image)

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

Suggest you use whatever destination folder is shown and then select ‘Next’
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.
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.
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.
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
That’s about it for installation.
Appendix C

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

1.0 Data download
Go to https://exoworldspies.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.
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

<table>
<thead>
<tr>
<th>RA</th>
<th>Dec</th>
<th>B-V</th>
<th>V mag</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 30 54.14</td>
<td>+06 25 45.90</td>
<td>0.894</td>
<td>11.798</td>
</tr>
</tbody>
</table>

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

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

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.
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, 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.
Select Run Reduction and Alignment. On completion the window in Figure C3.4 is displayed in which some images were deselected.
Select RUN ALIGNMENT. On completion the Photometry window is displayed – 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.
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.
WASP – 2Ab

Dymock
Holomon Station / 2800 FL scope / CCD

relative flux

predicted ingress start

\[ \frac{R_p}{R_*} = 0.164 \pm 0.002 \]

predicted egress end

\[ T_{\text{Eclipse}} = 2457581.4193 \pm 0.0005 \]

residuals

\[ \text{rms}_{\text{res}} = 4.9 \times 10^{-3} \]

phase

Figure C3.11
6. Final graph

After a couple of minutes the final graph will pop up, showing the planet name (a), the observation information (b), the detrended light curve with the best-fit model (c) the fitted parameters (d), the residuals (e), and their RMS (f).

Figure C.12

Roger Dymock
Assistant Director ARPS Exoplanets Division
2019 December 3