

From Pixels to Planets – Transitioning from AstroImaging to Exoplanet Science

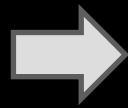
- Dr. Dennis M. Conti
Lead, AAVSO Exoplanet Special Interest Group

Use your Astrolmaging skills to contribute to the discovery of new exoplanets...

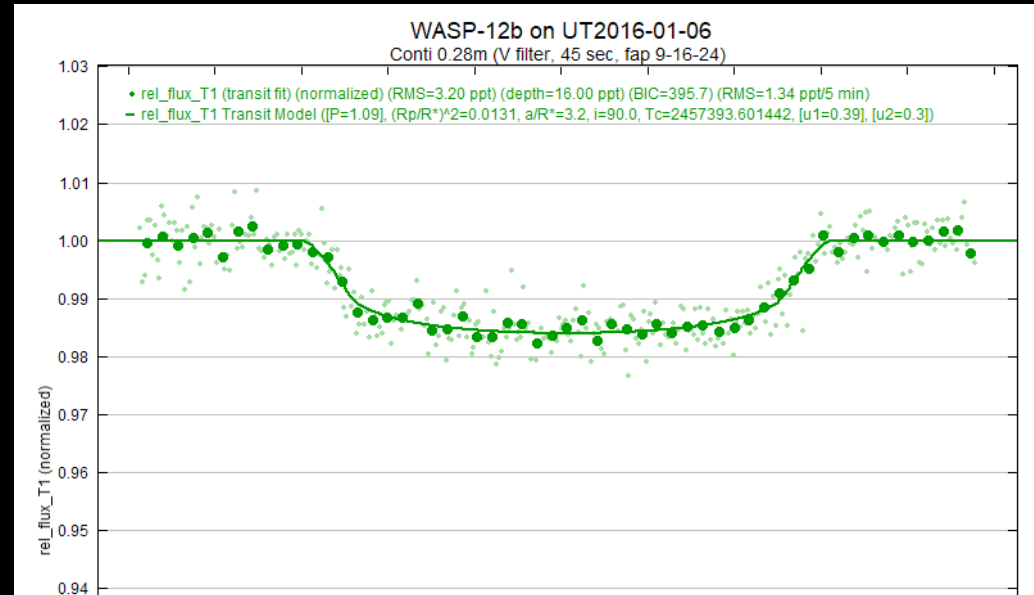
and go from this:



Pleasing to the eye
and of aesthetic value



to this:



Pleasing to the imagination
and of scientific value

So, why get involved in exoplanet observing?

- Satisfy our desire to “discover”
- Jump start your astronomy enthusiasm
- Use your imaging skills and equipment in a whole different way
- Work side-by-side with professional astronomers
- Learn about photometry – may lead to other interests: variable stars, eclipsing binaries, transient events, etc.
- Contribute to NASA’s quest for the next Earth 2.0

Earth 2.0 Key Ingredients

Has a rocky (vs. gaseous) surface



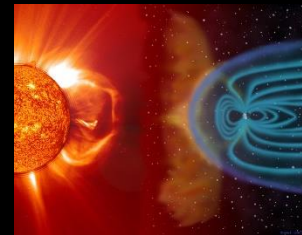
Able to support liquid water on its surface



An atmosphere with key biosignatures



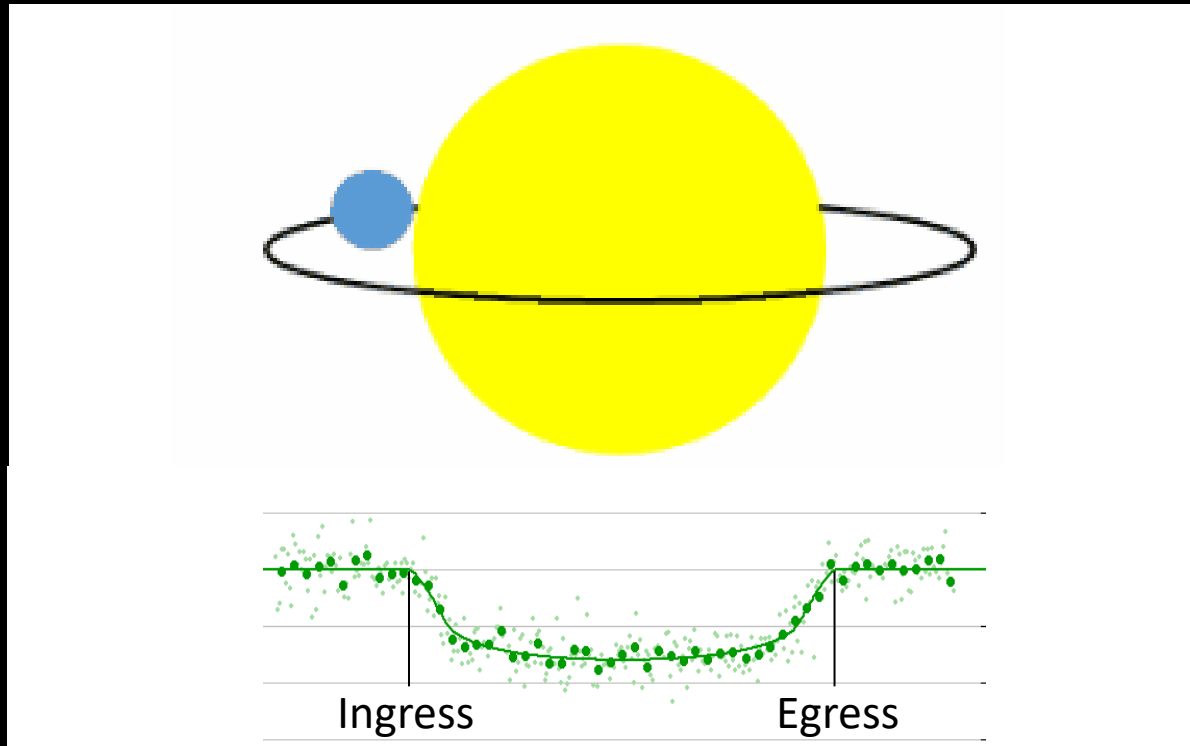
Has a magnetic field to protect it from its host star's radiation



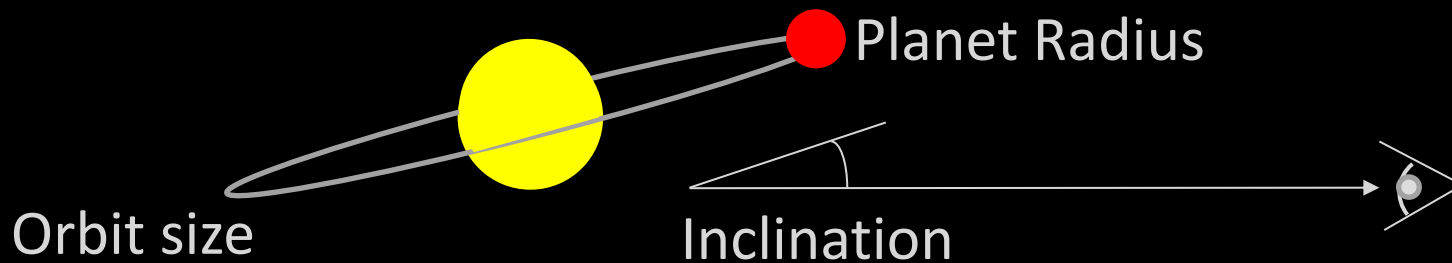
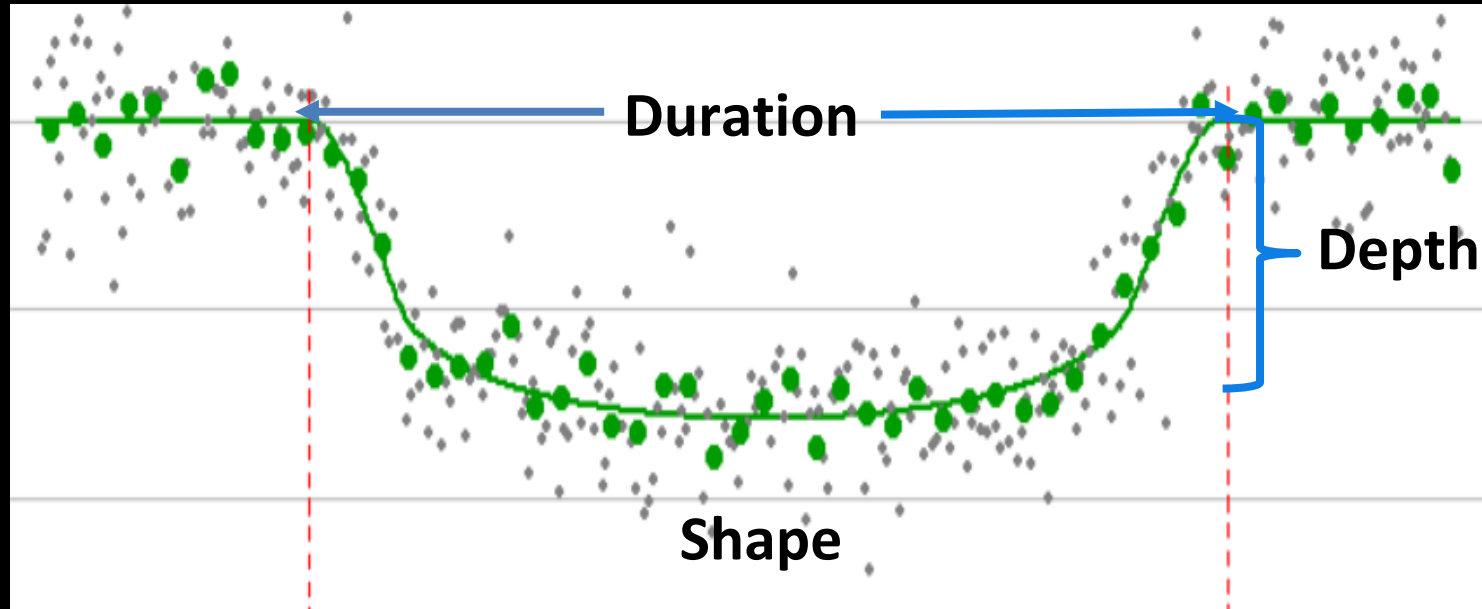
What contributions to science can I make?

- Help confirm some of these key ingredients
- Refine the ephemerides (e.g., the period) of new exoplanets
- Help professionals rule out “false positive” detections
- Using “transit timing variations,” help discover companion planets and orbital decays
- Participate in TESS, NASA’s current exoplanet discovery mission

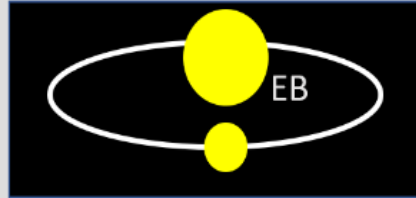
How Exoplanets are Detected



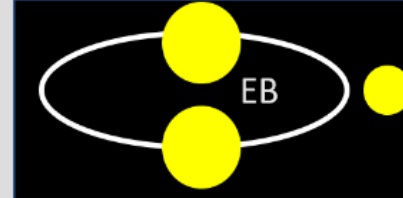
We can learn a lot from the light curve!



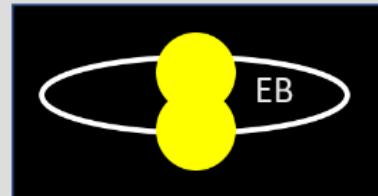
Amateur astronomer observations help rule out false positives:



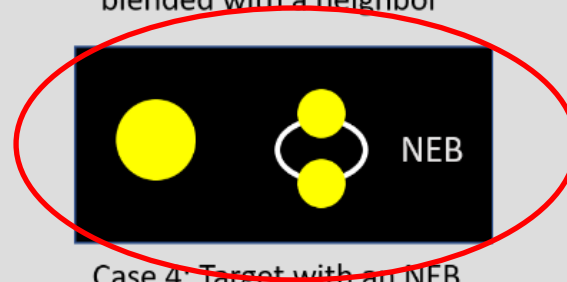
Case 1: Target is an EB



Case 2: Target is an EB, but blended with a neighbor



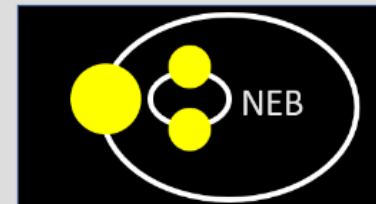
Case 3: Target is an EB with secondary grazing primary



Case 4: Target with an NEB resolvable by ground-based telescopes



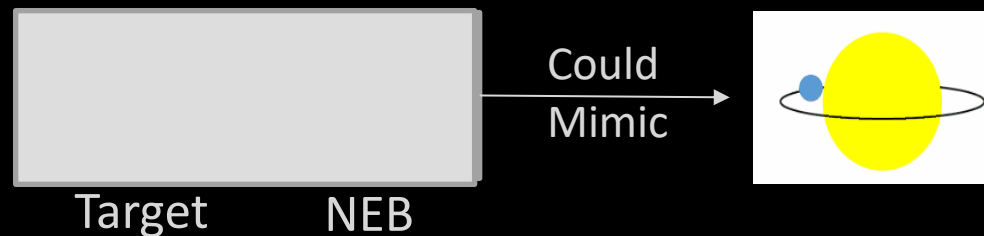
Case 5: Target with an NEB not resolvable by ground-based telescopes



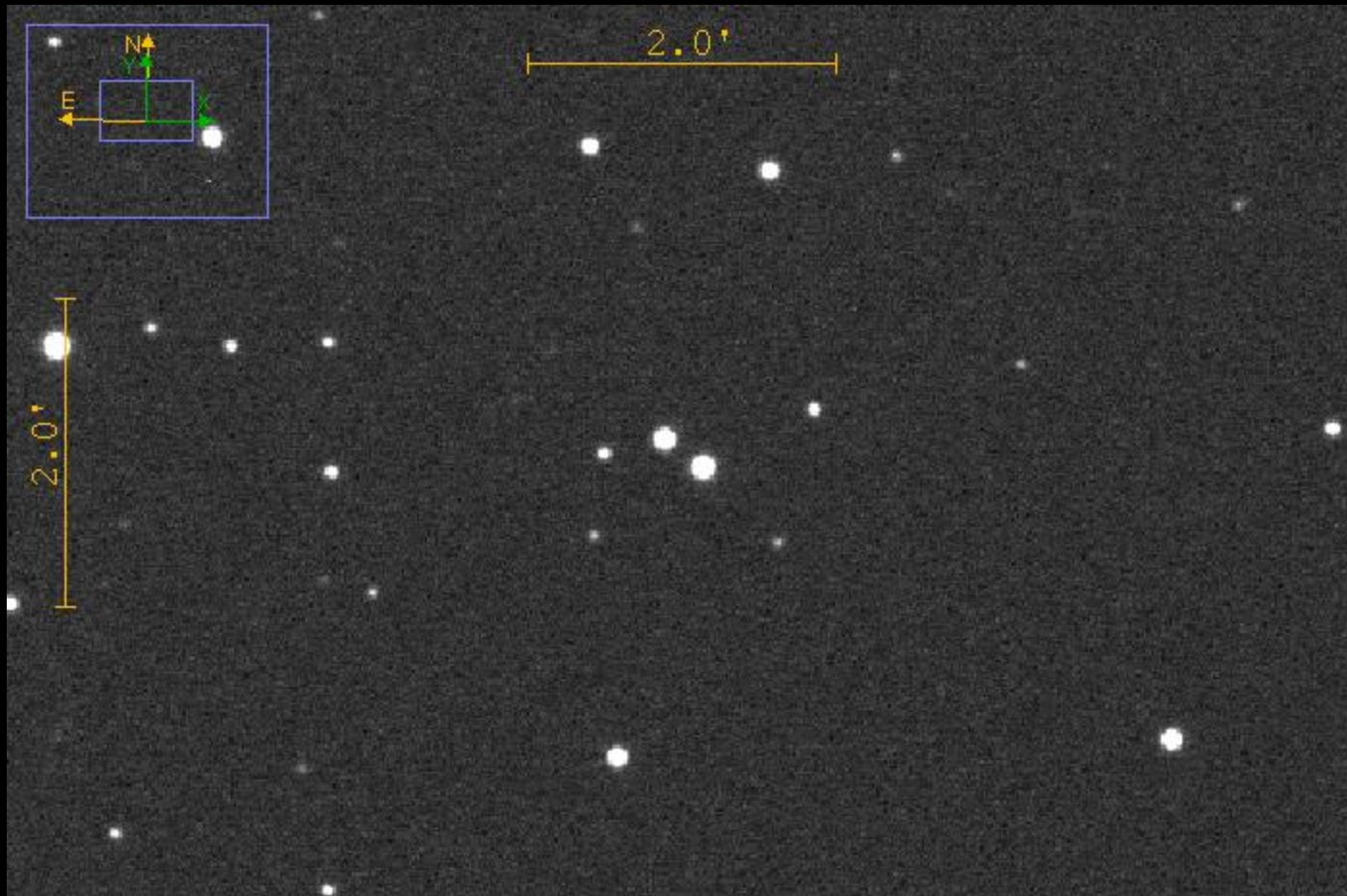
Case 6: Target and an NEB are orbiting each other

A Common TESS False Positive: A Near-by Eclipsing Binary

- The light from multiple stars may be **blended together**
- Thus, dips in light could be caused by either a true exoplanet transit or by a near-by eclipsing binary (NEB)
- Ground-based, follow-up observations are needed to sort out true exoplanet transits from a NEB



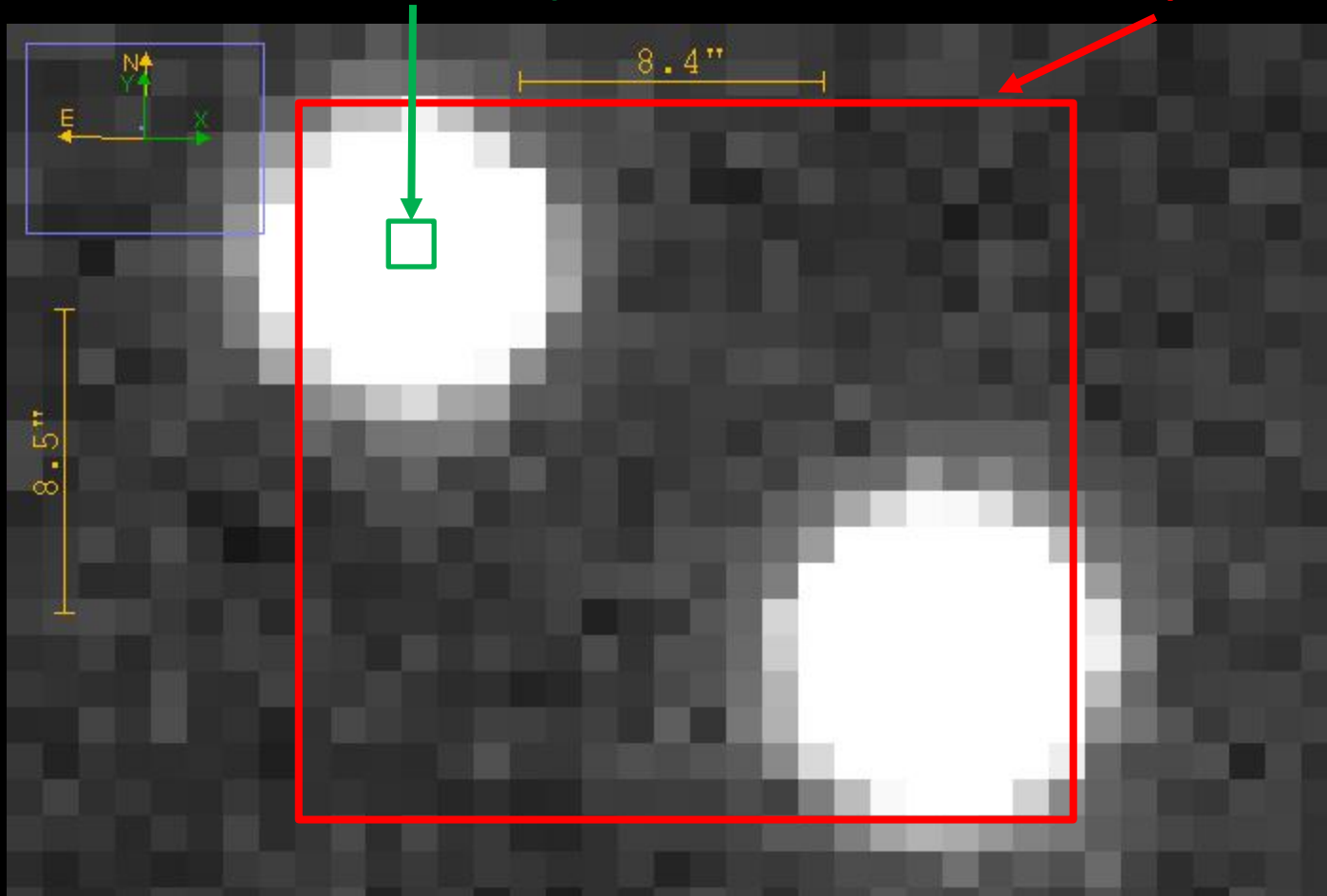
Example: A Typical Ground-Based Image



Pixel Sizes

Ground-based pixel

TESS pixel

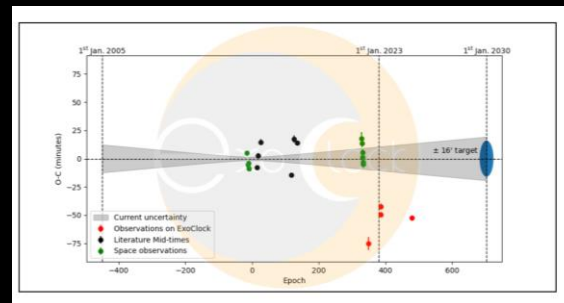


Pixel Sizes



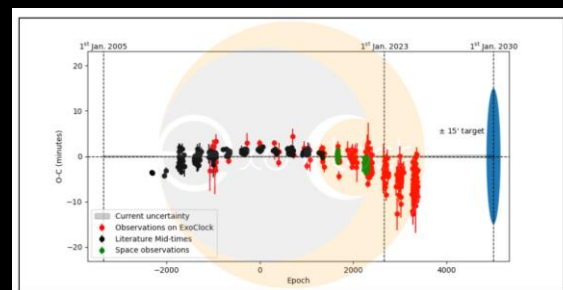
Transit Timing Variations (TTVs)

- TTVs: Differences between observed and predicted transit times
- Helps identify possible **companion planets**:



K2-19b
Credit: ExoClock

- Helps identify **orbital decay**:



WASP-12b
Credit: ExoClock

Exoplanet Observing vs. Astrolmaging: What's Generally the Same

- **Same seeing conditions:** <5 arc-seconds
- **Same gear:** mount, optical tube, camera, guide scope, filter wheel
 - Ideally, aperture > 4"
- **Same software** for navigation, guiding, and auto-scheduling
- **Same calibration** techniques using bias, darks, flats

Exoplanet Observing vs. Astrolmaging: What's Different




- Target selection:
 - usually only **one target** per night
 - either **self-selected** or part of an **organized effort**
- Optional use of a standard **photometric filter** (e.g., Johnsons Cousins, SDSS)
- Ideally, more stringent guiding requirements
- The observing session:
 - **length**: 4-6 hours
 - **exposure time**: set to maximize SNR of target star
- Post-processing:
 - use (free) **exoplanet analysis software** (e.g., AstrolmageJ)
- Time base:
 - **BJD_TDB** – Barycentric Julian Date, Barycentric Dynamical Time

The Process

1. Determine potential targets whose transits are observable at a given location for a given night


<https://astro.swarthmore.edu/transits/transits.cgi>

Search: Show if visible transit % + baseline % > 0 V_{max}: Depth_{min}: ppt Overlap: m. Other Site

Local evening date	Name	V or Gaia mag	Start—Mid—End	Duration	BJDTDB start—mid—end	Elev. at start, mid, end ±1 hrs	% of transit (baseline) observable, Suggested obs. start, end	Az. at start, mid, end ±1 hrs	HA at start, mid, end ±1 hrs	RA & Dec (J2000)	Period (days)	Depth (ppt)	Comments
(ESTSEDT)	HAT-P-36 b Finding charts: Annotated , Aladin , SkyMap , Airmass plot , ACP plan Info: Exoplanet Archive , Simbad , Gaia , TIC	12.1 Moon 87% @42°	20:35 21:35—22:42 —23:49 00:49 ±0:00	2:14	10420.5699 10420.6164 10420.6629	57° 68° 79° 86° 76°	 100% (91%) 20:45—00:49	68° 70° 65° 328° 291°	-3.0 -2.0 -0.9 +0.2 +1.2	12:33:03.89 +44:54:55.32	1.33	18.9	
Fri. 2024-04-19 Nautical twilight 20:45 – 05:05 (ESTSEDT)	Qatar-6 b Finding charts: Annotated , Aladin , SkyMap , Airmass plot , ACP plan Info: Exoplanet Archive , Simbad , Gaia , TIC	11.5 Moon 87% @53°	22:25 23:36—00:24 —01:12 02:24 ±0:11	1:36	10420.6558 10420.6892 10420.7225	43° 56° 64° 69° 70°	 100% (100%) 22:25—02:24	97° 113° 129° 154° 202°	-3.4 -2.3 -1.5 -0.6 +0.5	14:48:50.42 +22:09:09.41	3.51	18.4	
Fri. 2024-04-19 Nautical twilight 20:45 – 05:05 (ESTSEDT)	WASP-104 b Finding charts: Annotated , Aladin , SkyMap , Airmass plot , ACP plan Info: Exoplanet Archive , Simbad , Gaia , TIC	11.8 Moon 87% @10°	23:24 00:24—01:17 —02:10 03:10 ±0:00	1:46	10420.6880 10420.7247 10420.7613	50° 41° 32° 23° 11°	 62% (50%) 23:24—01:30	220° 237° 249° 260° 270°	+1.6 +2.7 +3.5 +4.4 +5.4	10:42:24.57 +07:26:06.28	1.76	14.7	

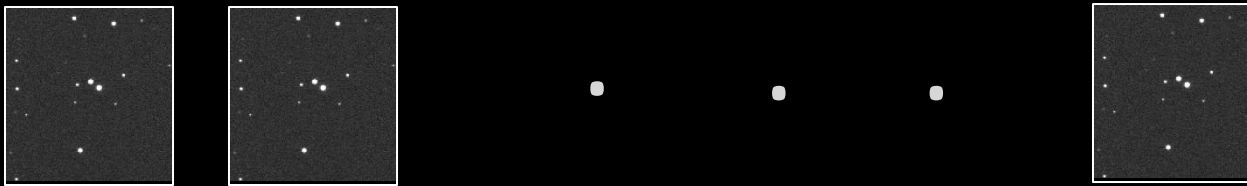
The Process (cont'd)

2. Select a specific target whose predicted transit depth is observable given observer's seeing and instrumentation

Fri. 2024-04-19	<input type="checkbox"/> Qatar-6 b	11.5	22:25 23:36— 00:24 —01:12 02:24 ±0:11	1:36	10420.6558 10420.6892 10420.7225	43° 56° 64° 69° 70°		97° 113° 129° 154° 202°	-3.4 -2.3 -1.5 -0.6 +0.5	14:48:50.42 +22:09:09.41	3.51	18.4
Nautical twilight 20:45 – 05:05 (ESTSEDT)	Finding charts: Annotated , Aladin , SkyMap ; Airmass plot , ACP plan Info: Exoplanet Archive , Simbad , Gaia , TIC	Moon 87% @53°					100% (100%) 22:25—02:24					

3. Select an appropriate exposure time and filter

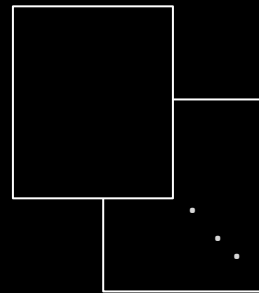
4. Take images of target star from at least 45 min prior to ingress to 45 min after egress



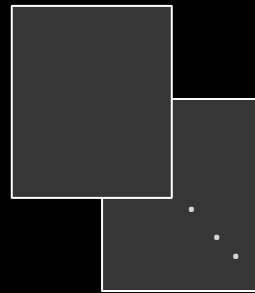
≈ 4-6 hours

The Process (cont'd)

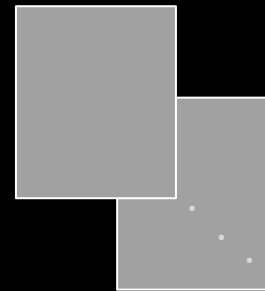
5. Calibrate Images



Bias



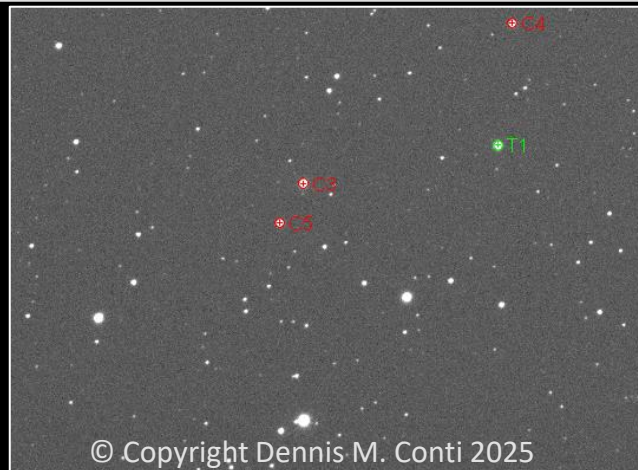
Darks



Flats

Using
AstroImageJ
or
other software

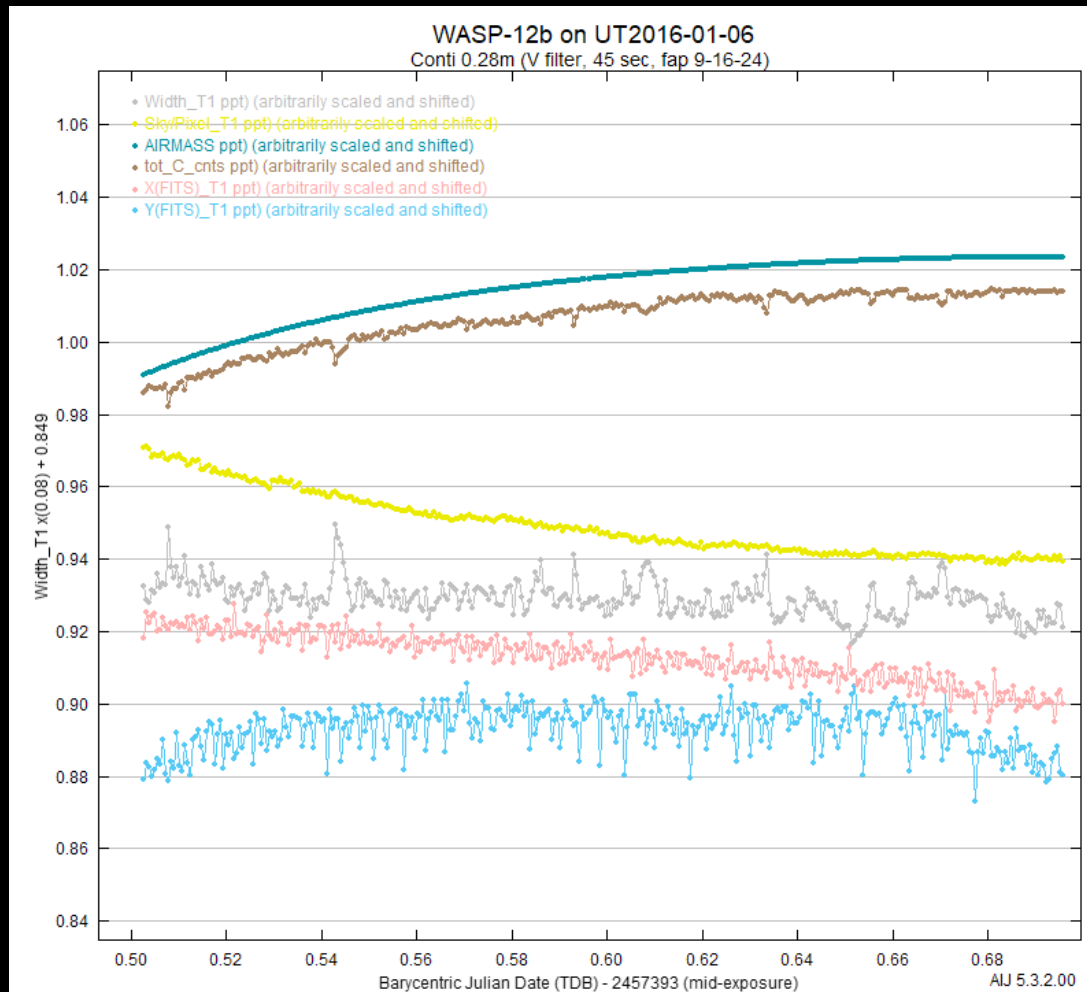
6. Perform differential photometry on calibrated images



Using
AstroImageJ

The Process (cont'd)

7. Review systematics— e.g., using AstrolImageJ



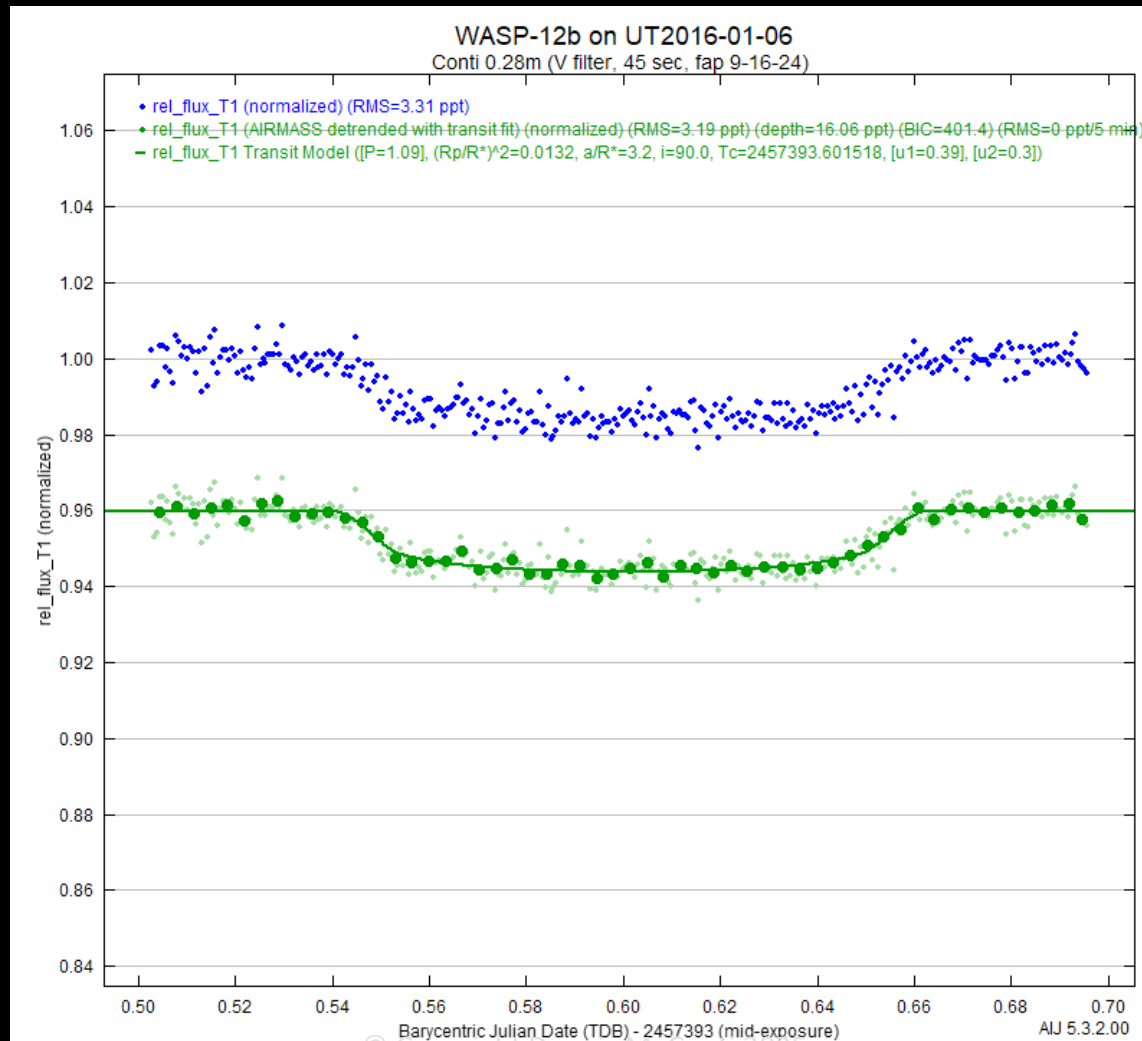
Airmass
Comparison star flux

Sky background
Star PSF width

Image shift: X axis
Image shift: Y axis

The Process (cont'd)

8. Conduct an exoplanet model fit – e.g., using AstrolmageJ



Results

Raw data

Model fit

Available Sample Files

Exoplanet Observing

astrodenis.com

A Practical Guide to Exoplanet Observing

I have prepared "A Practical Guide to Exoplanet Observing" both for those who have never done exoplanet observing, as well as for the more advanced exoplanet observer. Not only does it describe "best practices" for exoplanet observing, but it also is a step-by-step guide for using AstroImageJ, a freeware program, for conducting all aspects of exoplanet observing - from image calibration to model fitting. The latest version of the Guide can be found [here](#). A French version of Revision 3.1 can be found [here](#). Many thanks to Jean-Bruno Desrosiers, Serge Bergeron, and Manon Bouchard for the French translation. Also, a Spanish version of Revision 4.2 can be found [here](#). Many thanks to Pere Guerra, et al., for the Spanish translation.

The latest Exoplanet Worksheet Template referenced in the Guide (and for which Appendix A of the Guide is an example) can be found [here](#). Shaded fields are computed fields from previous entries on the worksheet.

The following are the .zip files of the calibration, science images and AstroImageJ plotconfig files that were used in the AstroImageJ example in the Guide, as well as in the AAVSO Exoplanet Observing Course:

1. [Bias.zip](#)
2. [Darks.zip](#)
3. [Flats.zip](#)
4. [ScienceImages.zip](#)
5. [WASP-12_Plotconfig.zip](#)

Finally, a zip file containing another general-purpose plot configuration file that can be used as a starter for AstroImageJ can be found [here](#).

I welcome all comments on the Guide, which can be sent to me directly at the email address below.

AstroImageJ Macro for Creating an AAVSO Exoplanet Report

In support of the AAVSO Exoplanet Database, an AstroImageJ (AIJ) macro has been developed. Documentation on how to obtain and use this macro can be obtained by clicking [here](#).

28459

Presentations and Publications

The following are my presentations and other publications:

Next Steps

- Visit astrodennis.com:
 - review: “A Practical Guide to Exoplanet Observing”
 - download [sample images](#) (matches the example in the Guide)
- Visit aavso.org/exoplanet-section
 - try observing some of the sample test targets
 - join AAVSO Exoplanet Special Interest Group and attend quarterly zoom sessions
- Participate in the [AAVSO Exoplanet Forum](#)
- Attend AAVSO courses, webinars, meetings
- Join the [TESS science team](#)
 - be named as co-author on discovery papers
- Contact me for further information:
dennis@astrodennis.com