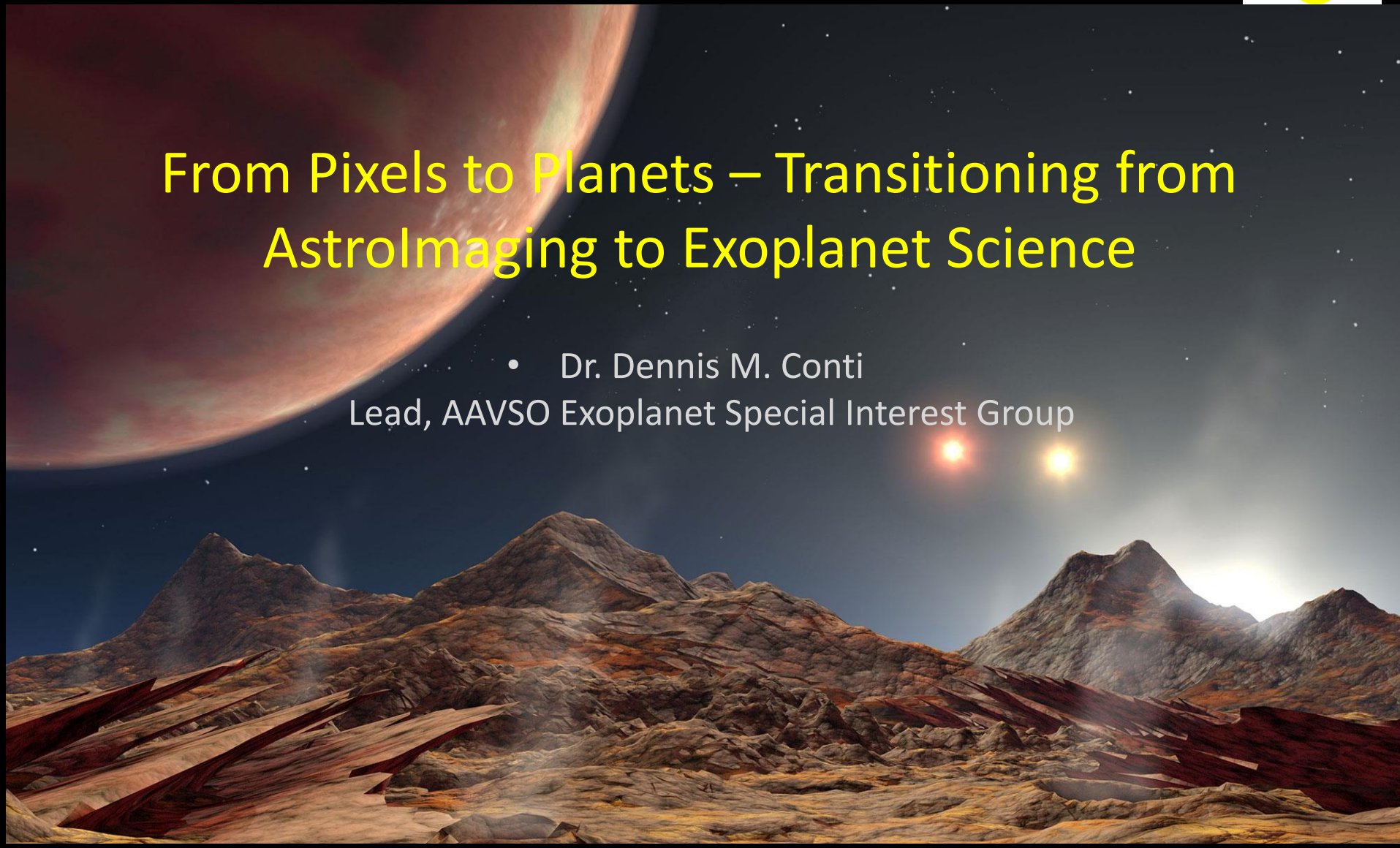
From Pixels to Planets – Transitioning from AstroImaging to Exoplanet Science

- Dr. Dennis M. Conti

Lead, AAVSO Exoplanet Special Interest Group

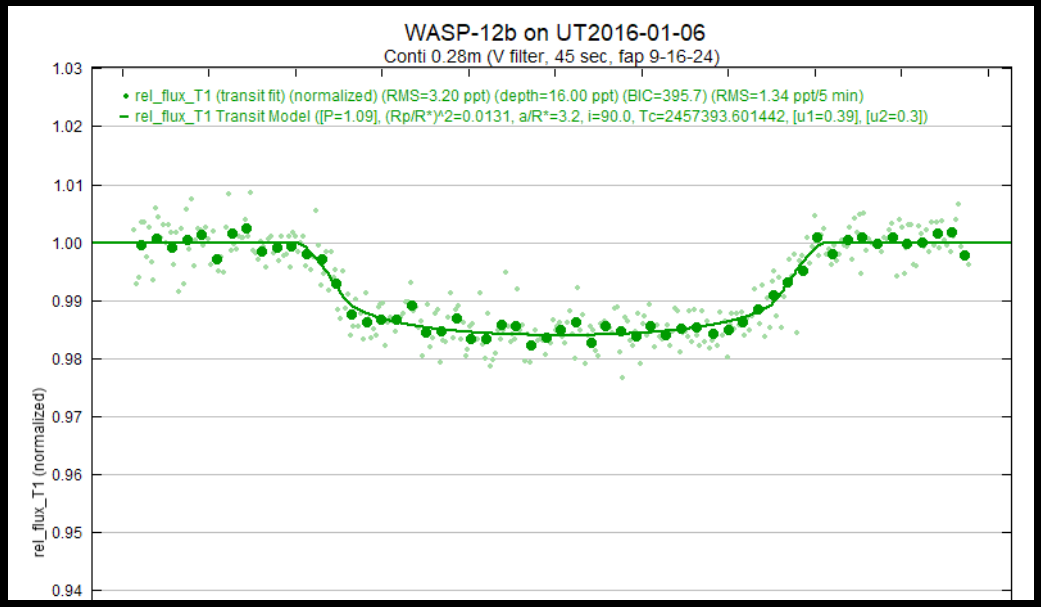


Artist rendering of: Exoplanet LTT 1445Ab, Credit: NASA

Use your AstroImaging skills to contribute to the discovery of new exoplanets…

and go from this:

to this:



Pleasing to the eye
and of aesthetic value

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

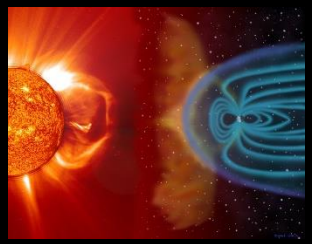
Earth 2.0 Key Ingredients

Has a rocky (vs. gaseous) surface

Able to support liquid water on its surface

An atmosphere with key biosignatures

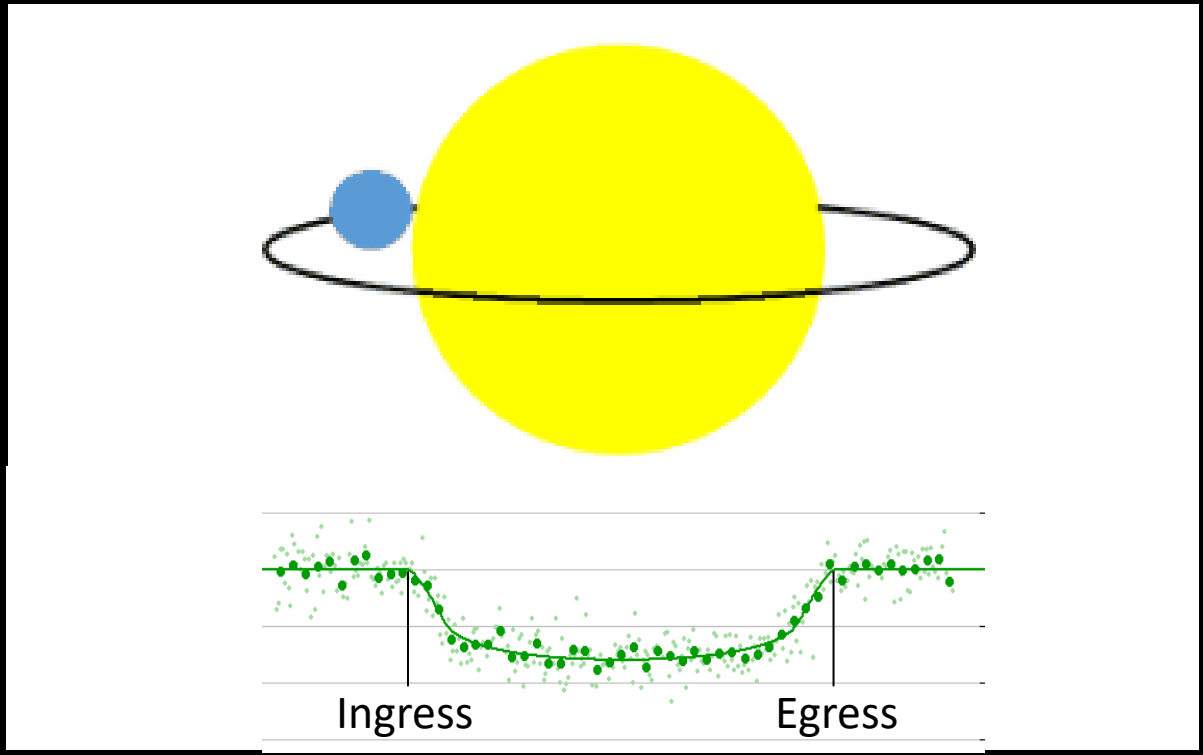
Has a magnetic field to protect it from its host star's radiation



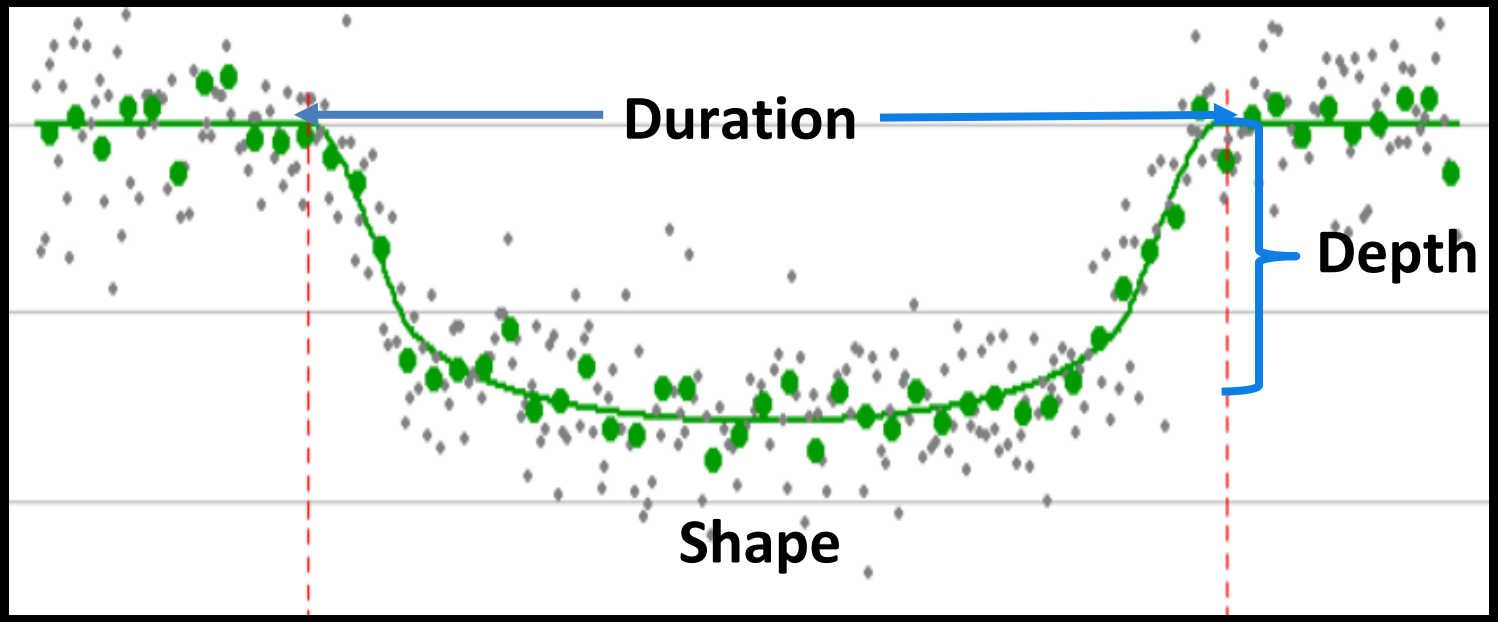
What contributions to science can I make?

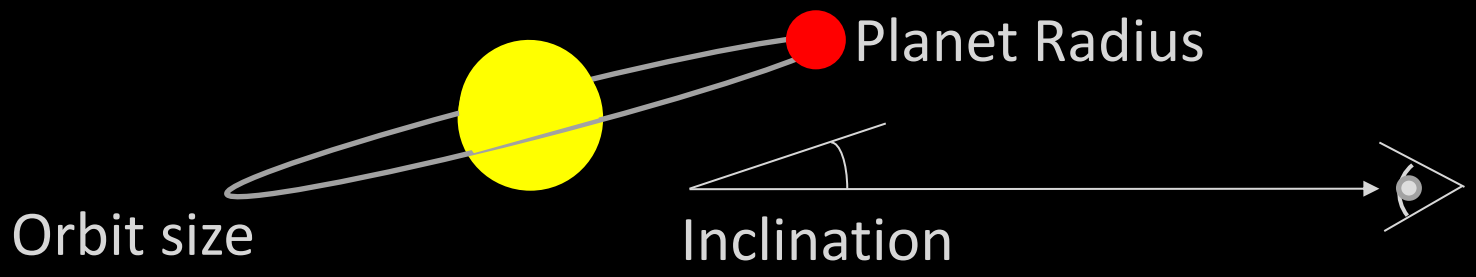
- Help confirm some of these key ingredients
- Refine the ephemerides (e.g., the period) of new exoplanets
- Help professionals rule out "false positive" detections
- Using "transit timing variations," help discover companion planets and orbital decays
- Participate in TESS, NASA's current exoplanet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

How Exoplanets are Detected

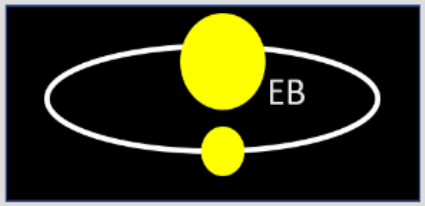


We can learn a lot from the light curve!

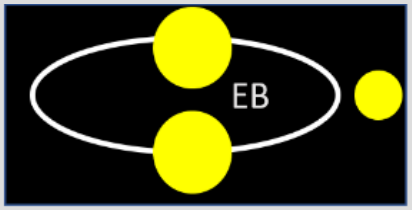




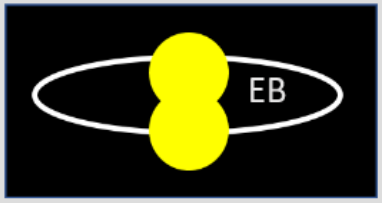
Amateur astronomer observations help rule out false positives:



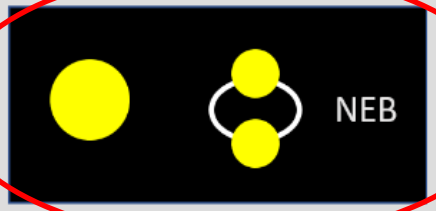
Case 1: Target is an EB



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

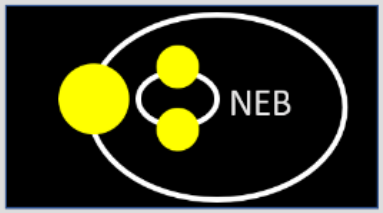


Case 3: Target is an EB with secondary grazing primary



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

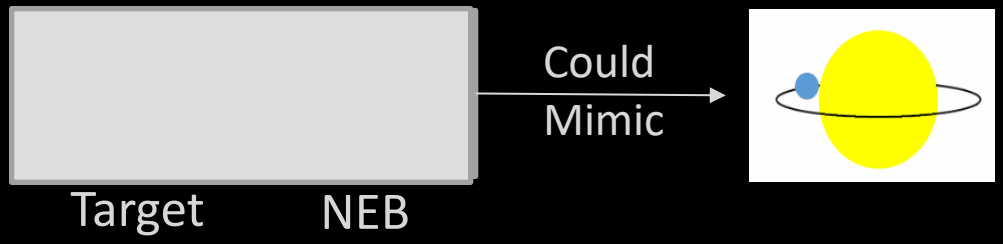
Case 5: Target with an NEB not resolvable by ground-based telescopes



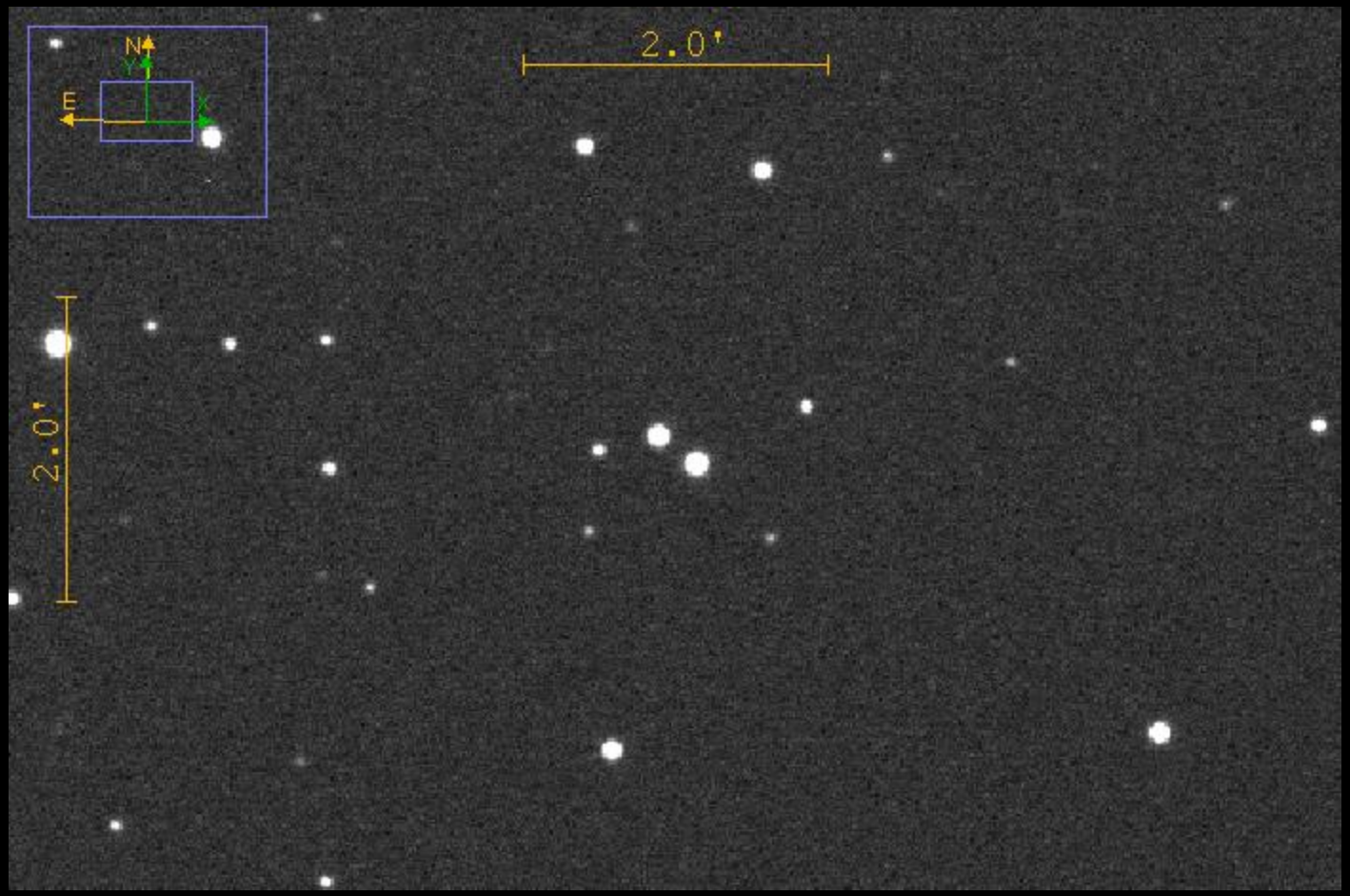
Case 6: Target and an NEB are orbiting each other

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

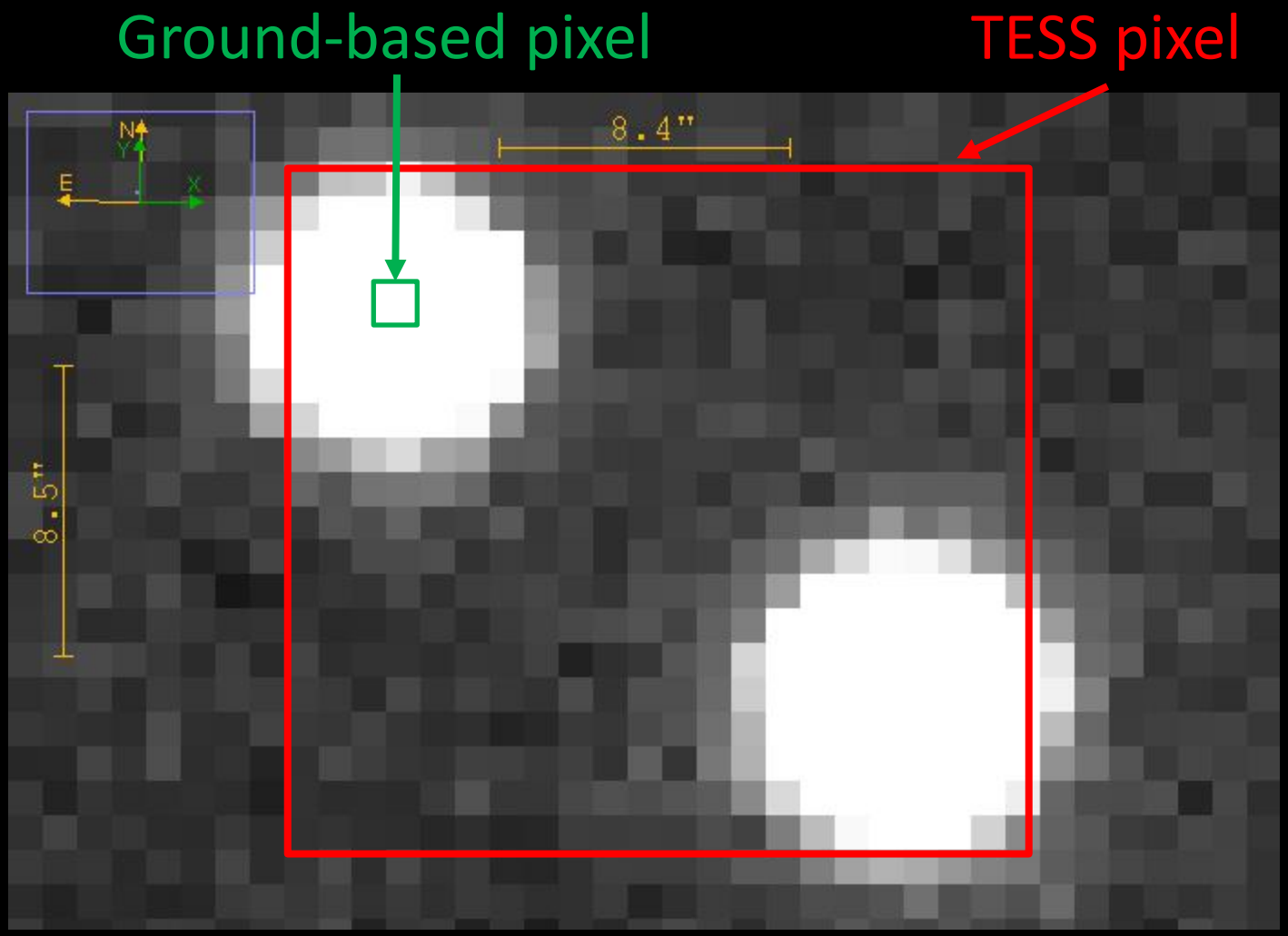
- The light from multiple stars may be blended together
- Thus, dips in light could be caused by either a true exoplanet transit or by a near-by eclipsing binary (NEB)
- Ground-based, follow-up observations are needed to sort out true exoplanet transits from a NEB



Example: A Typical Ground-Based Image



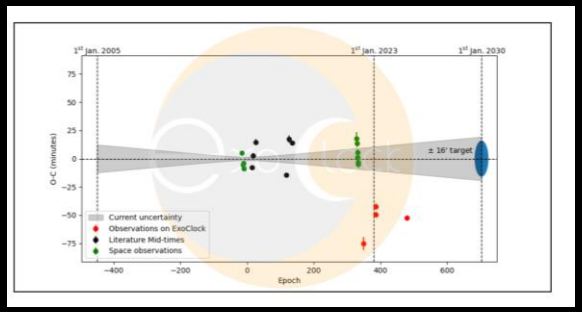
Pixel Sizes



Pixel Sizes

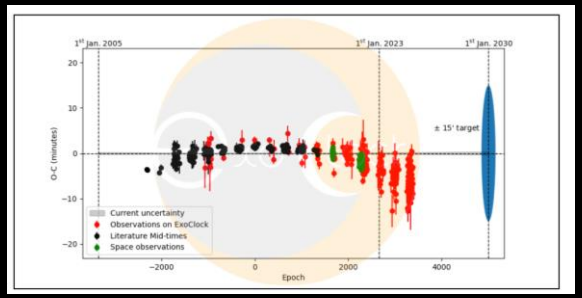
Transit Timing Variations (TTVs)

- 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. AstroImaging: What's Generally the Same

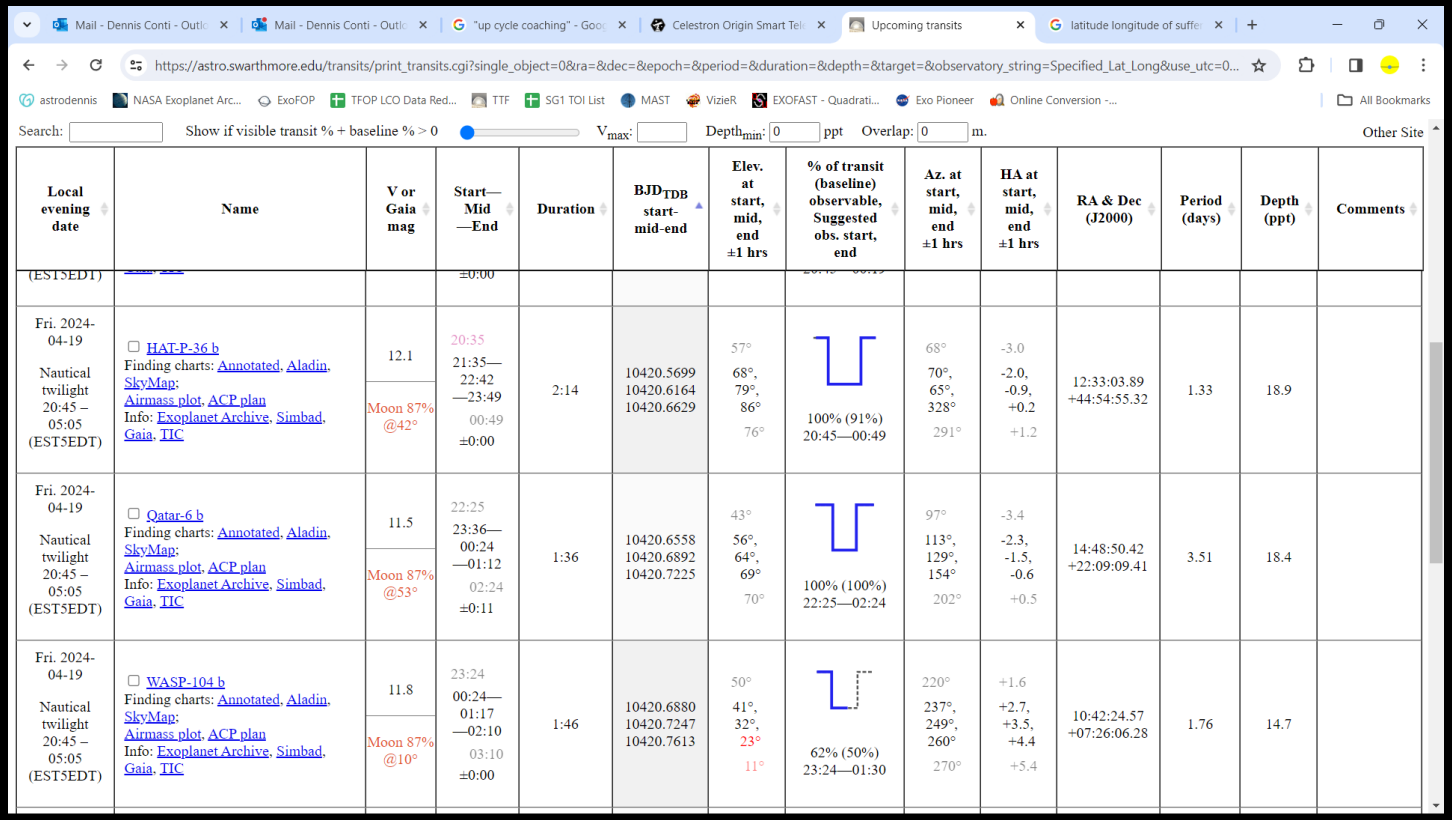
- Same seeing conditions: <5 arc-seconds
- Same gear: mount, optical tube, camera, guide scope, filter wheel
  - Ideally, aperture > 4"
- Same software for navigation, guiding, and auto-scheduling
- Same calibration techniques using bias, darks, flats

Exoplanet Observing vs. AstroImaging: 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., AstroImageJ)
- 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}: $Depth_{min}$: 0 ppt Overlap: 0 m. Other Site

Local evening date	Name	V or Gaia mag	Start—Mid—End	Duration	BJD_{TDB} 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
(EST5EDT)			±0:00										
Fri. 2024-04-19 Nautical twilight 20:45 – 05:05 (EST5EDT)	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 (EST5EDT)	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 (EST5EDT)	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	

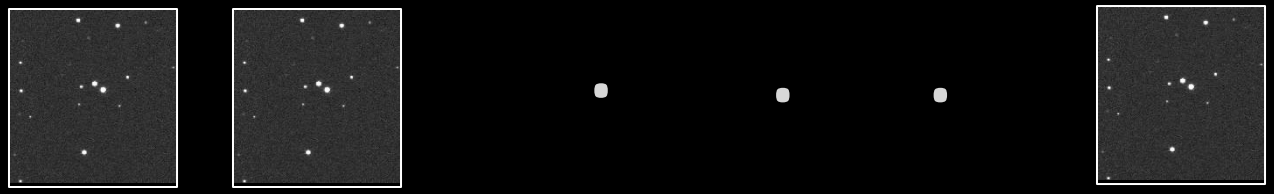
The Process (cont'd)

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

Fri. 2024-04-19 Nautical twilight 20:45 – 05:05 (EST5EDT)	☐ 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

3. Select an appropriate exposure time and filter

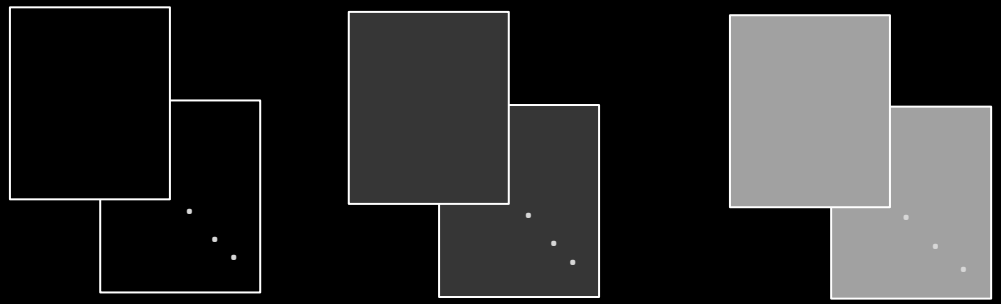
4. Take images of target star from at least 45 min prior to ingress to 45 min after egress



≈4-6 hours

The Process (cont'd)

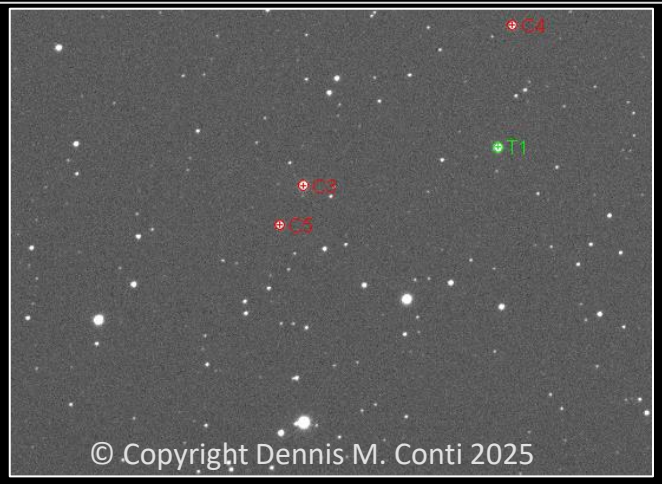
5. Calibrate Images



Bias Darks Flats

Using AstroImageJ or other software

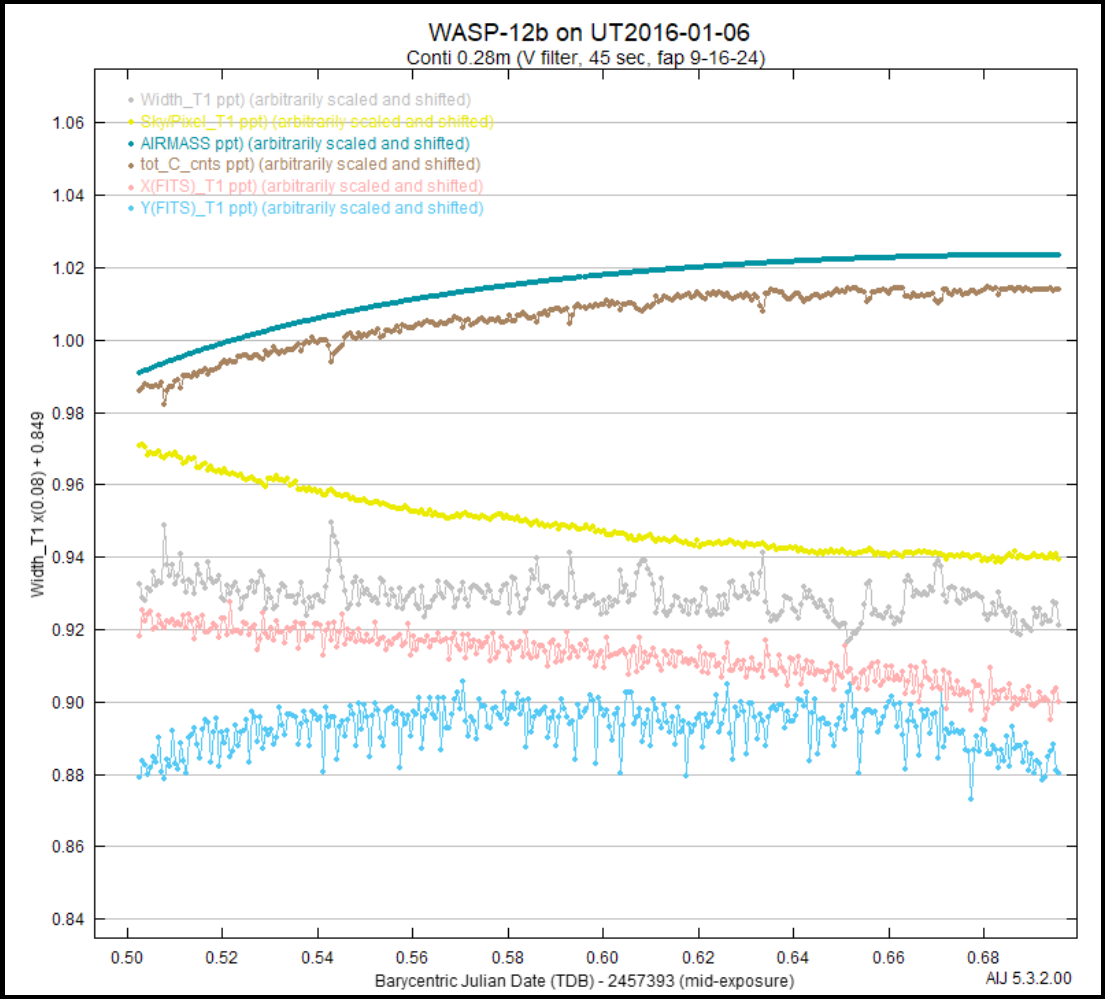
6. Perform differential photometry on calibrated images



Using AstroImageJ

The Process (cont'd)

7. Review systematics– e.g., using AstroImageJ



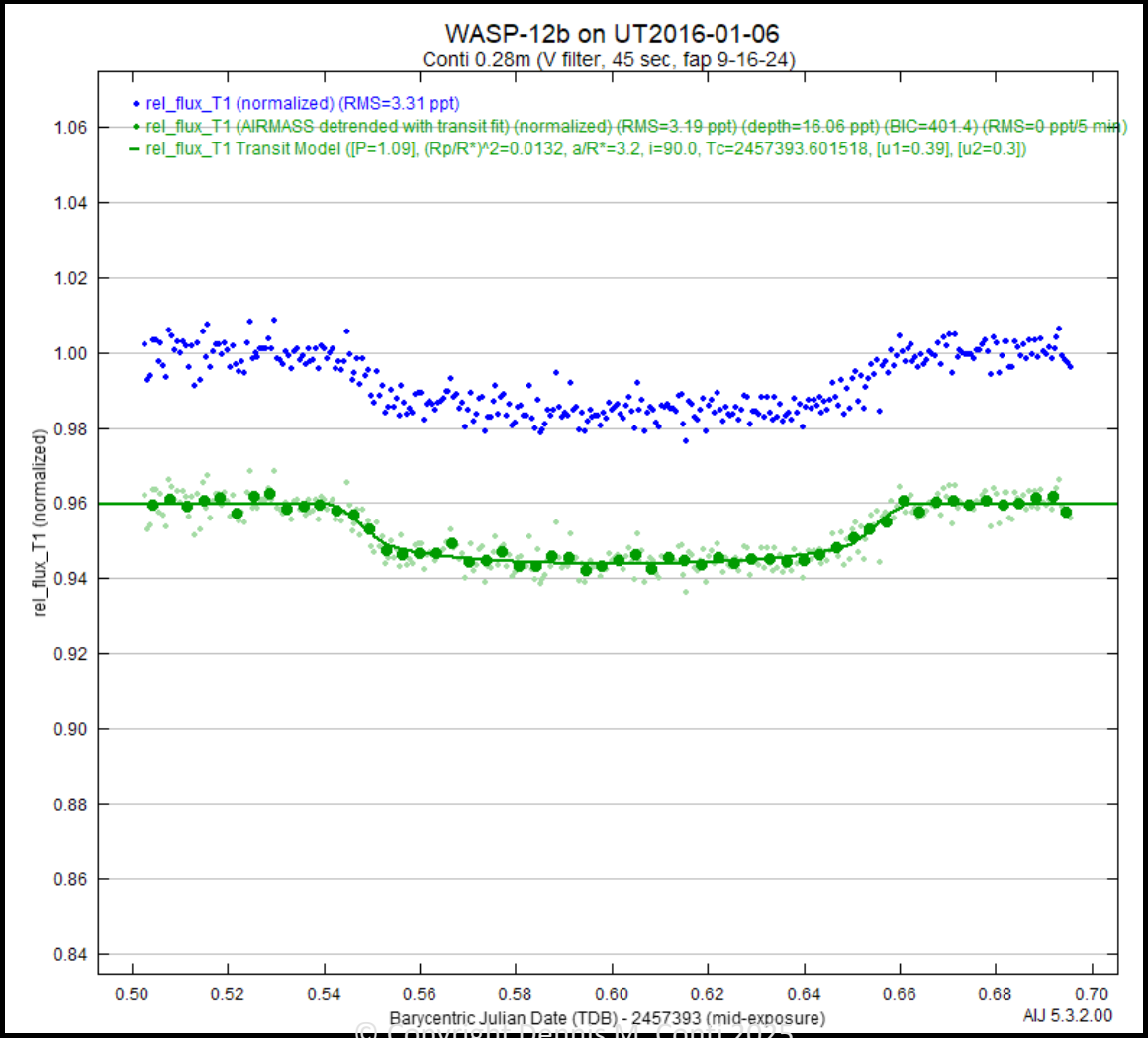
Airmass
Comparison star flux

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 AstroImageJ

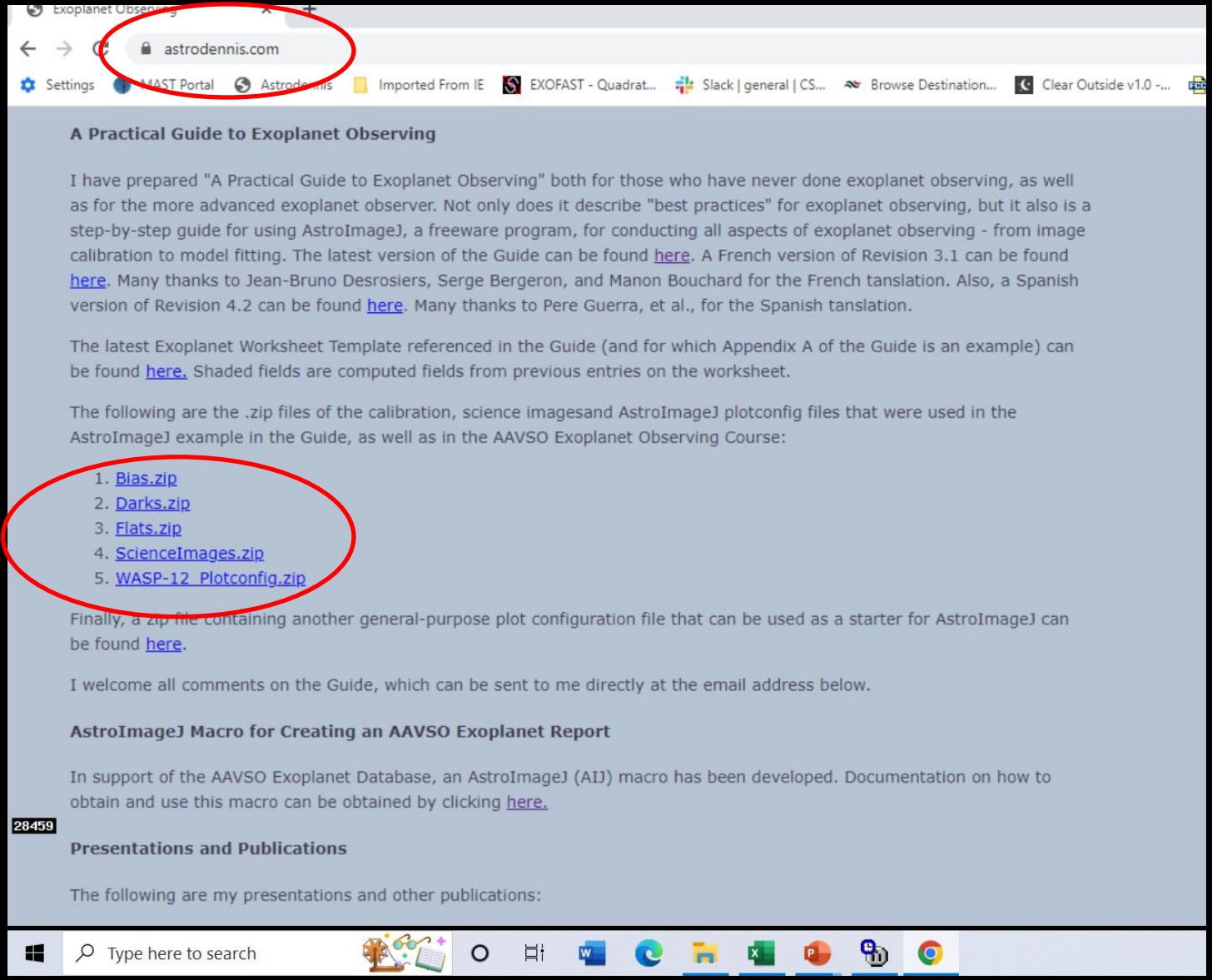


Results

Raw data

Model fit

Available Sample Files



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