From Astro-Imaging to Exoplanet Science: Same Gear, New Excitement!

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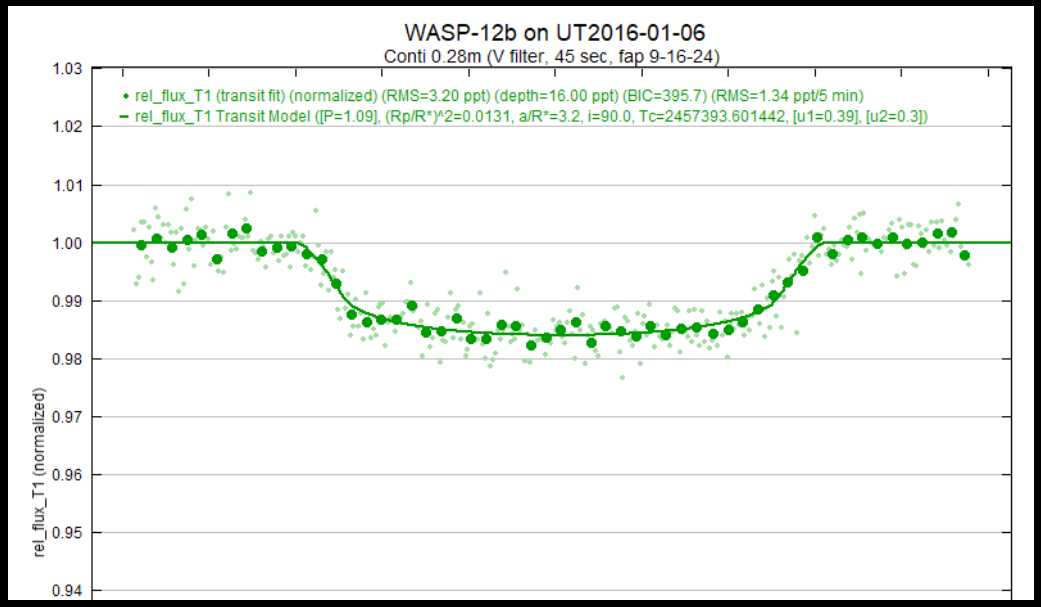
Artist rendering of: Exoplanet LTT 1445Ab, Credit: NASA

Use your Astro-Imaging 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 our astronomy enthusiasm
- Use our 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

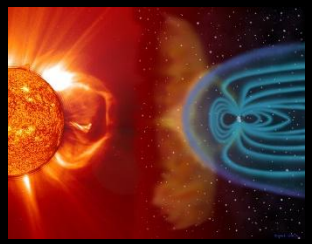
Earth 2.0 – Some Key Ingredients

Density suggesting a rocky vs. gaseous surface

Able to support liquid water on its surface

An atmosphere with key biosignatures

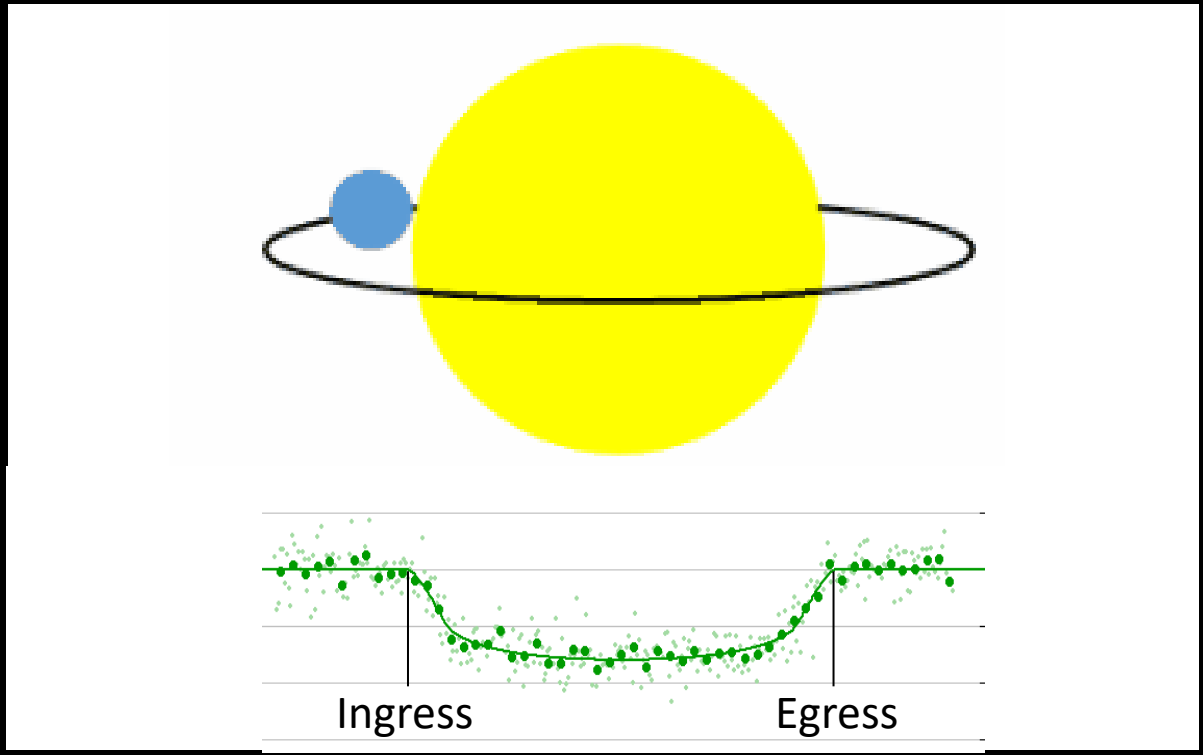
Has a magnetic field to protect it from its host star's radiation



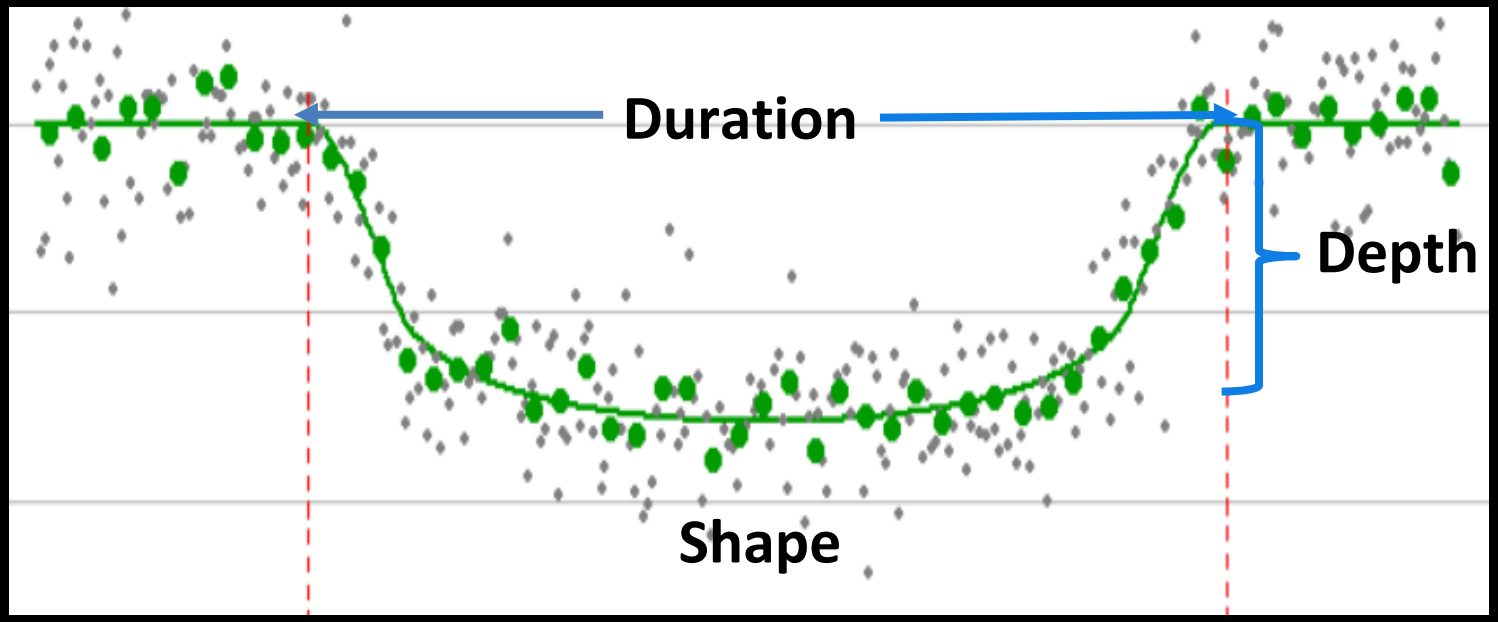
What contributions to science can I make?

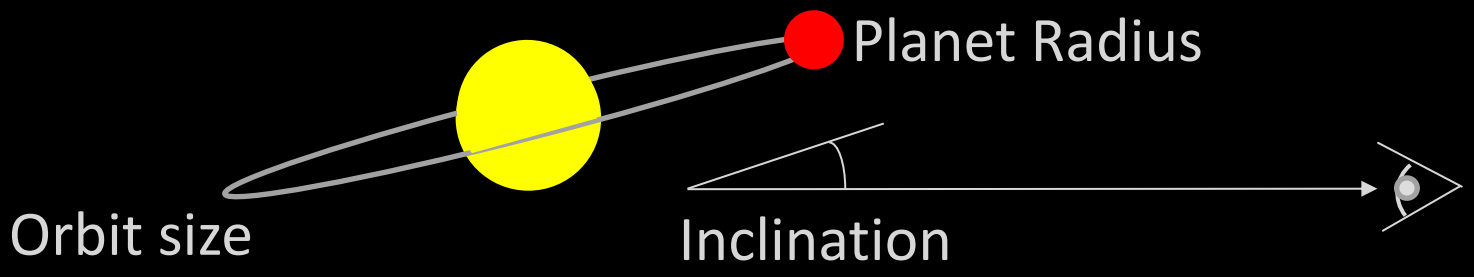
- Help refine the exoplanet's radius - a key part of density
- Refine the ephemerides (e.g., the period) of new exoplanets
- Help professionals rule out false positives
- Participate in TESS (Transiting Exoplanet Survey Satellite)
  - NASA's ongoing exoplanet discovery mission since 2018
  - 919 confirmed exoplanets to-date
  - 8,013 candidate exoplanets waiting confirmation

How Exoplanets are Detected

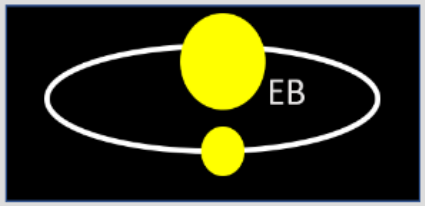


We can learn a lot from the light curve!

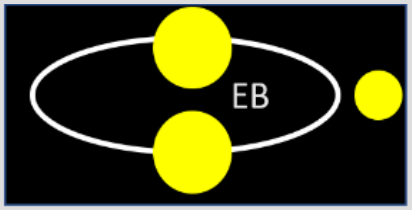




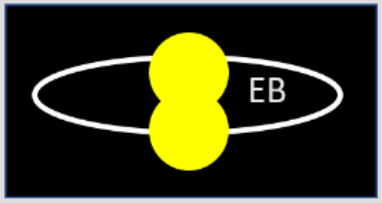
Amateur astronomer observations help rule out false positives:



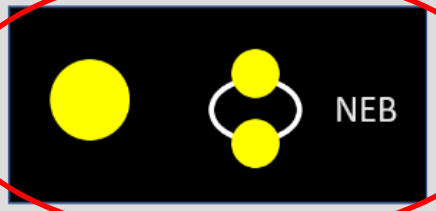
Case 1: Target is an EB



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

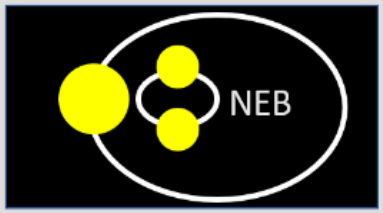


Case 3: Target is an EB with secondary grazing primary



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

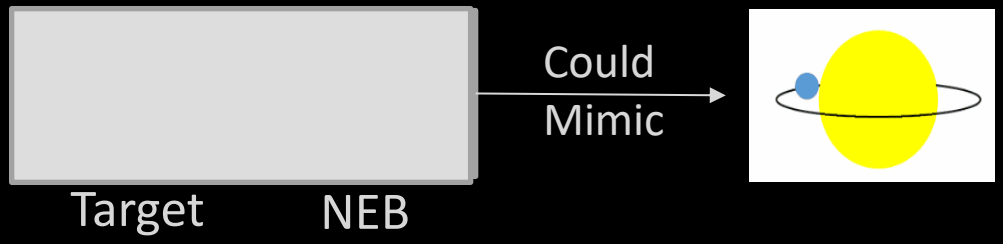
Case 5: Target with an NEB not resolvable by ground-based telescopes



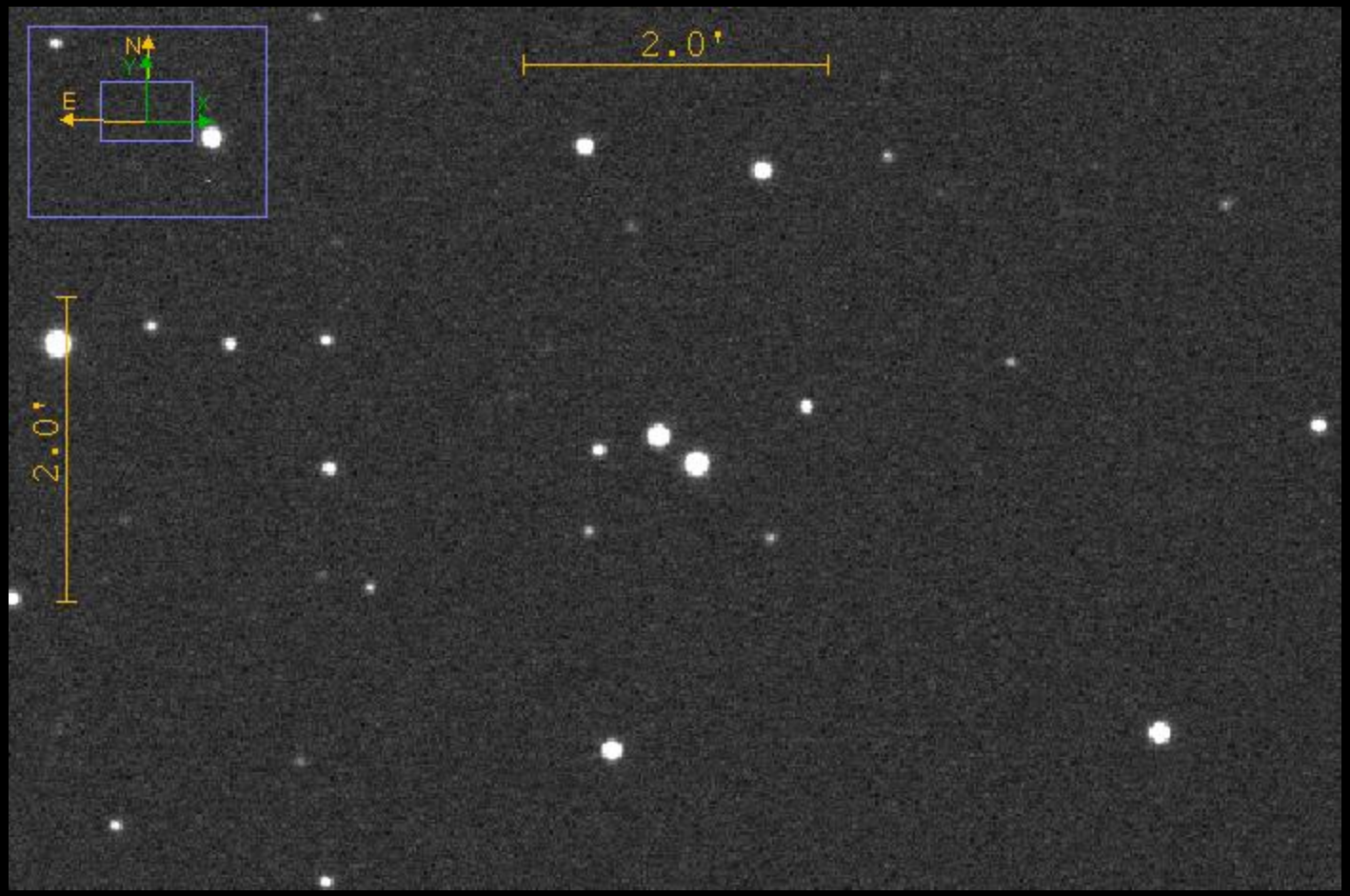
Case 6: Target and an NEB are orbiting each other

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

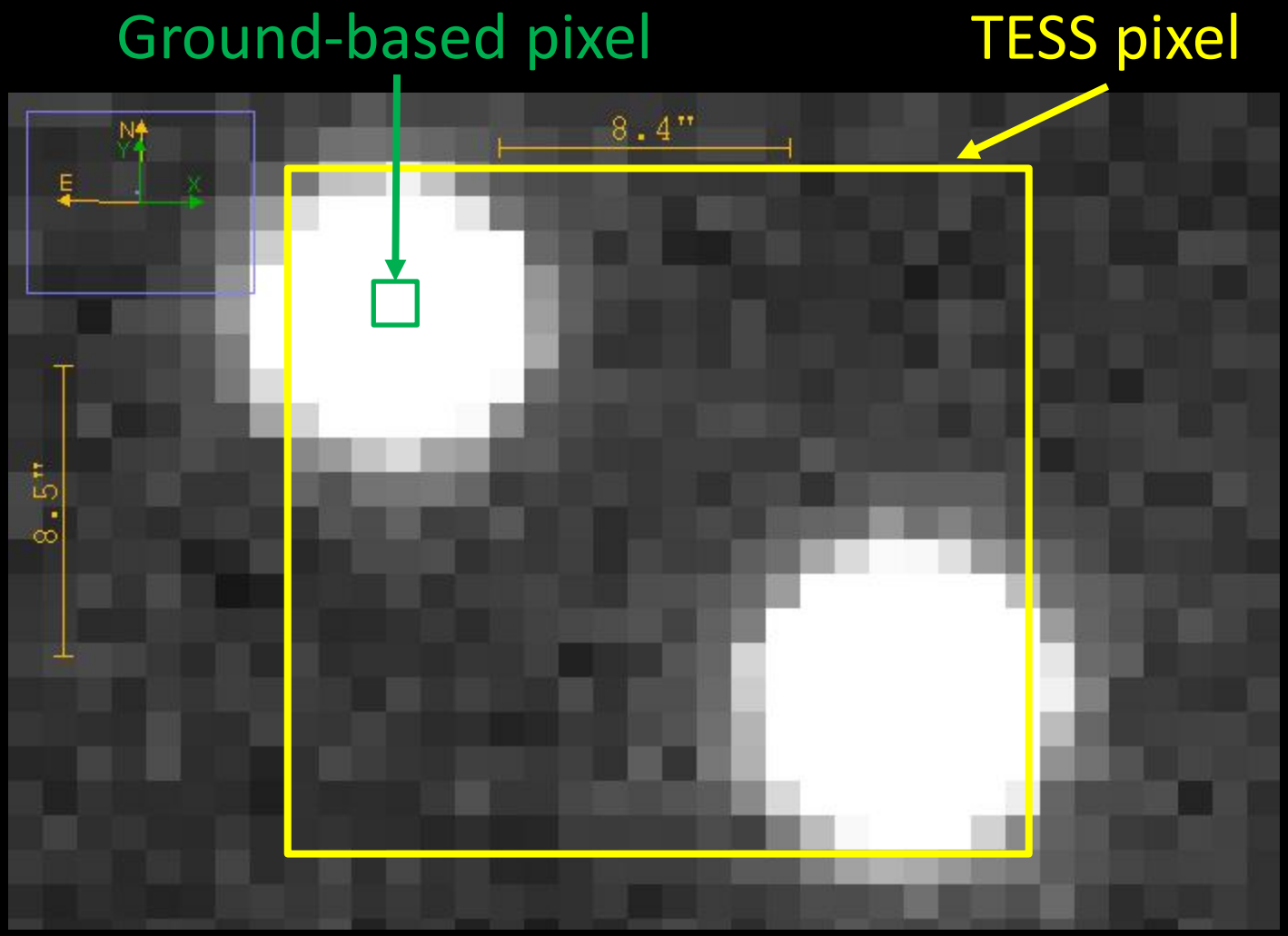
- The light from multiple stars may be blended together
- Thus, dips in light could be caused by either a true exoplanet transit or by a near-by eclipsing binary (NEB)
- Ground-based, follow-up observations are needed to sort out true exoplanet transits from a NEB



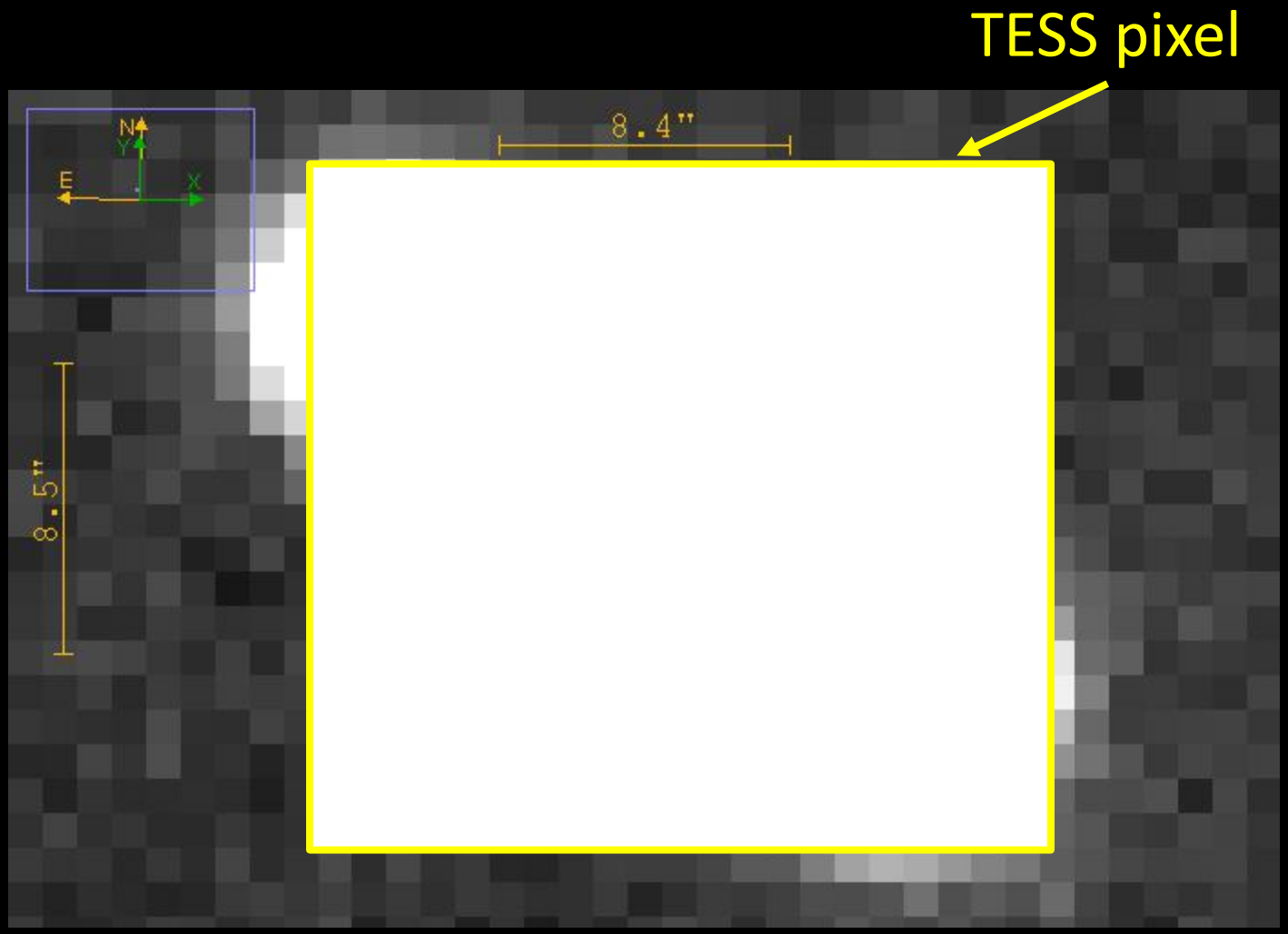
Example: A Typical Ground-Based Image



Pixel Sizes



Pixel Sizes



Exoplanet Observing
vs.
Astroimaging

What's the Same

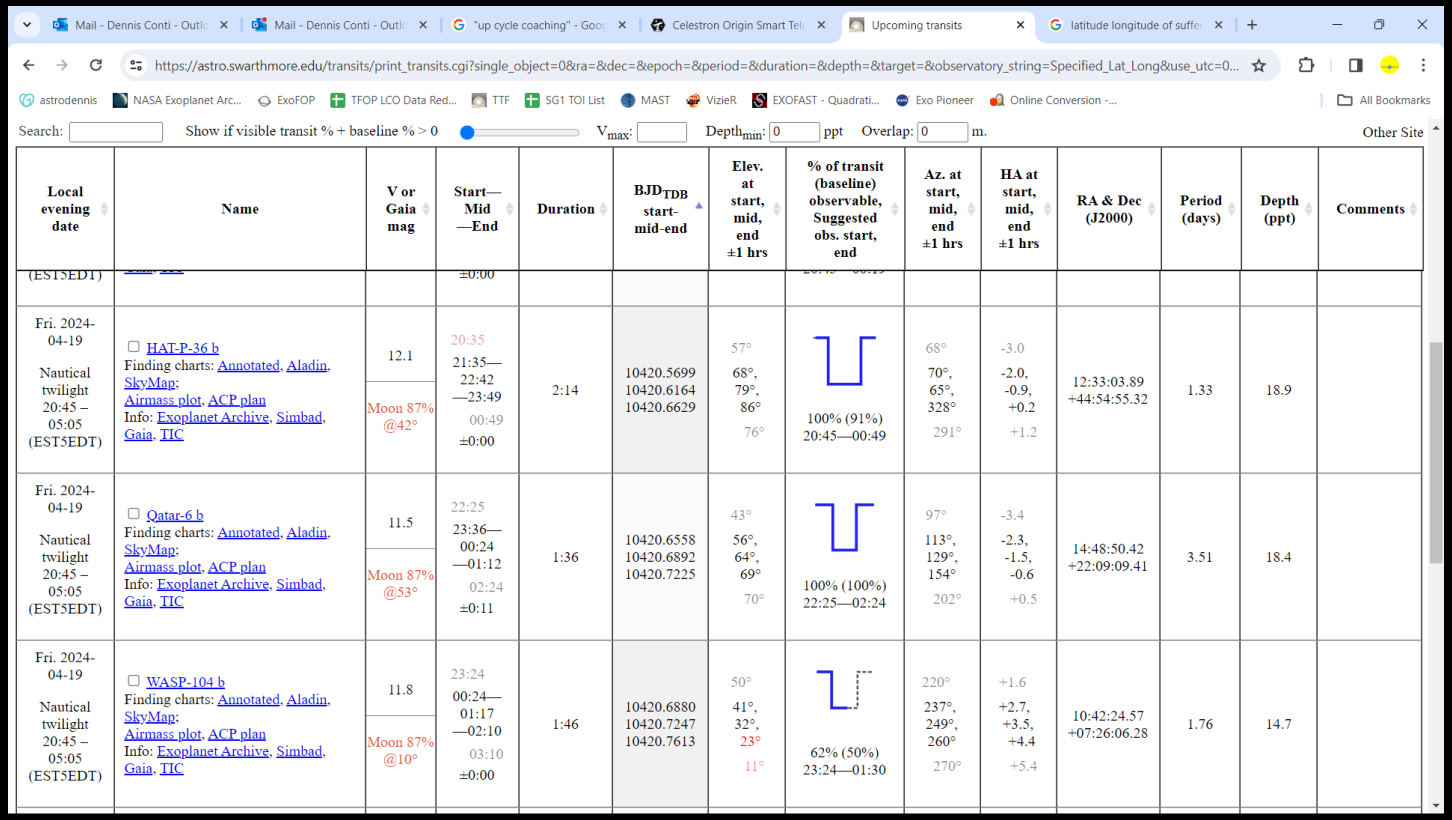
- Same seeing conditions: <5 arc-seconds
- Same gear: mount, optical tube, camera, guide scope, filter wheel
  - Ideally, aperture > 4"
- Same software for navigation, guiding, and auto-scheduling
- Same calibration techniques using bias, darks, flats

What's Different

- Target selection:
  - usually only one target per night
  - either self-selected or part of an organized effort
- Preferred 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



https://astro.swarthmore.edu/transits/print_transits.cgi?single_object=0&ra=&dec=&epoch=&period=&duration=&depth=&target=&observatory_string=Specified_Lat_Long&use_utc=0...

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	

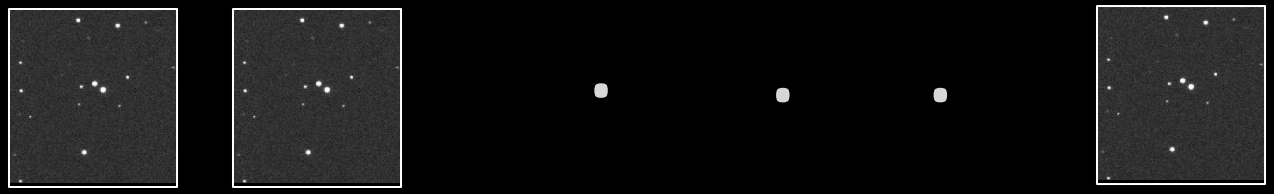
The Process (cont'd)

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

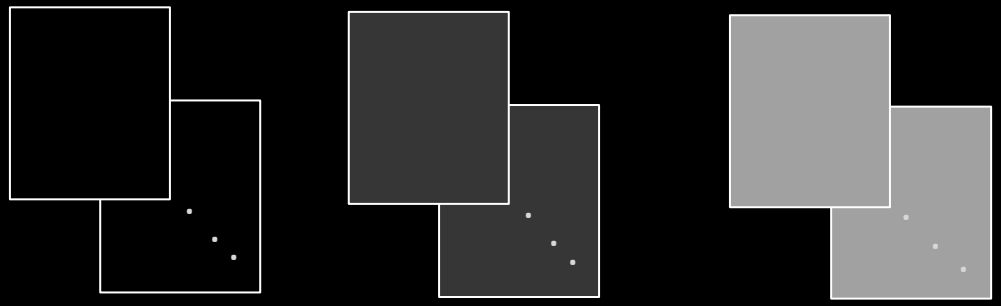
4. Take images of target star from ideally 60 min prior to ingress to 60 min after egress



≈4-6 hours

The Process (cont'd)

5. Calibrate Images



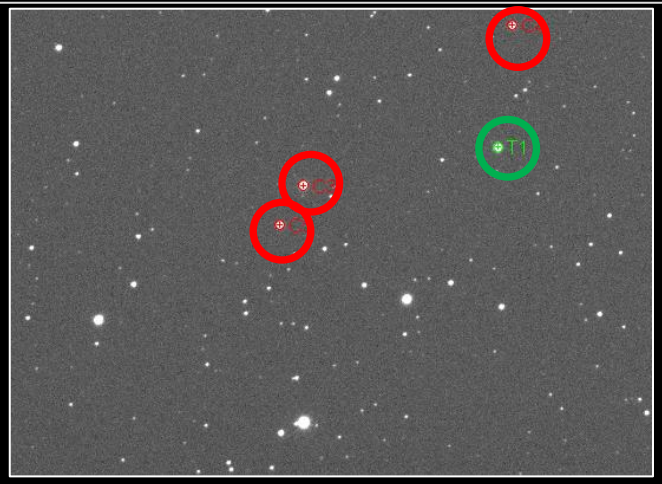
Bias

Darks

Flats

Using AstroImageJ or other software

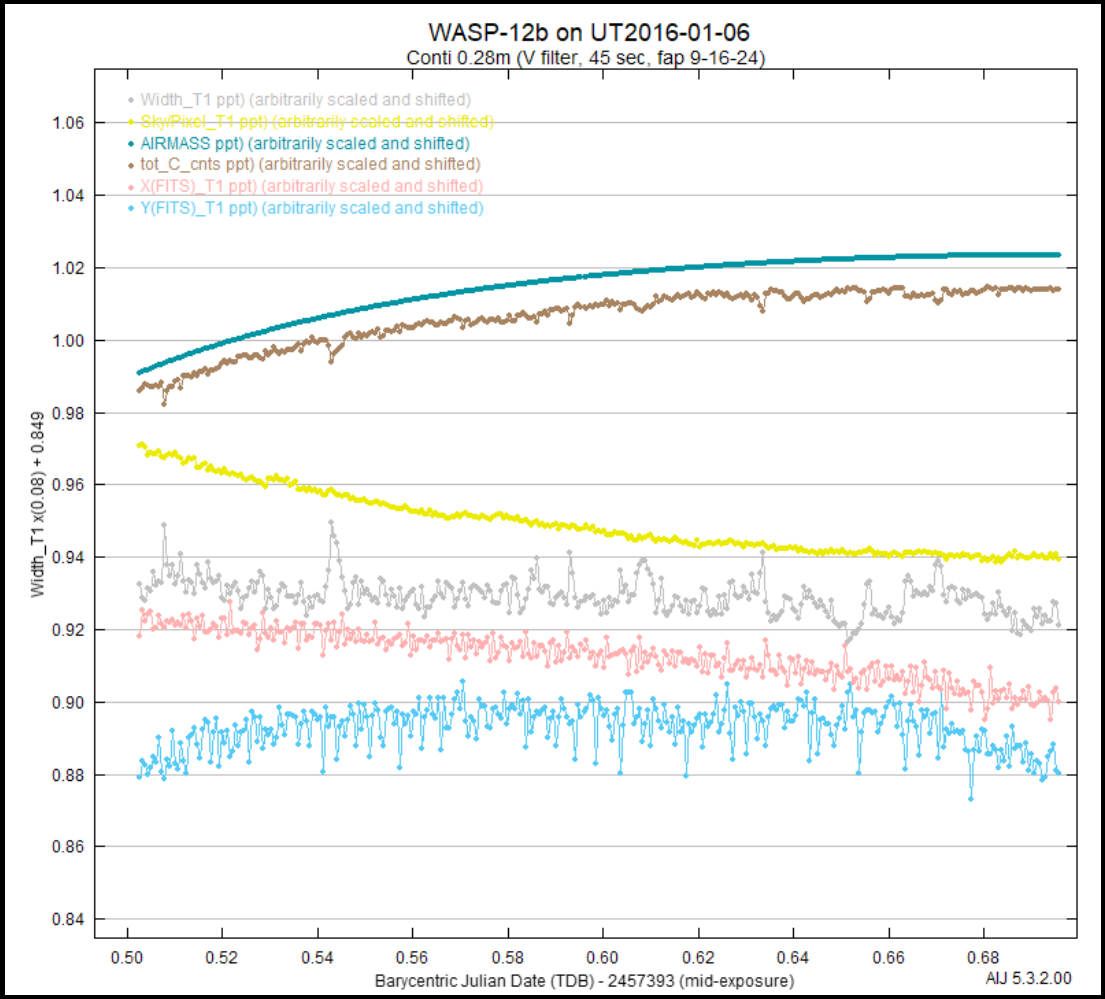
6. Perform differential photometry on calibrated images



Using AstroImageJ

The Process (cont'd)

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



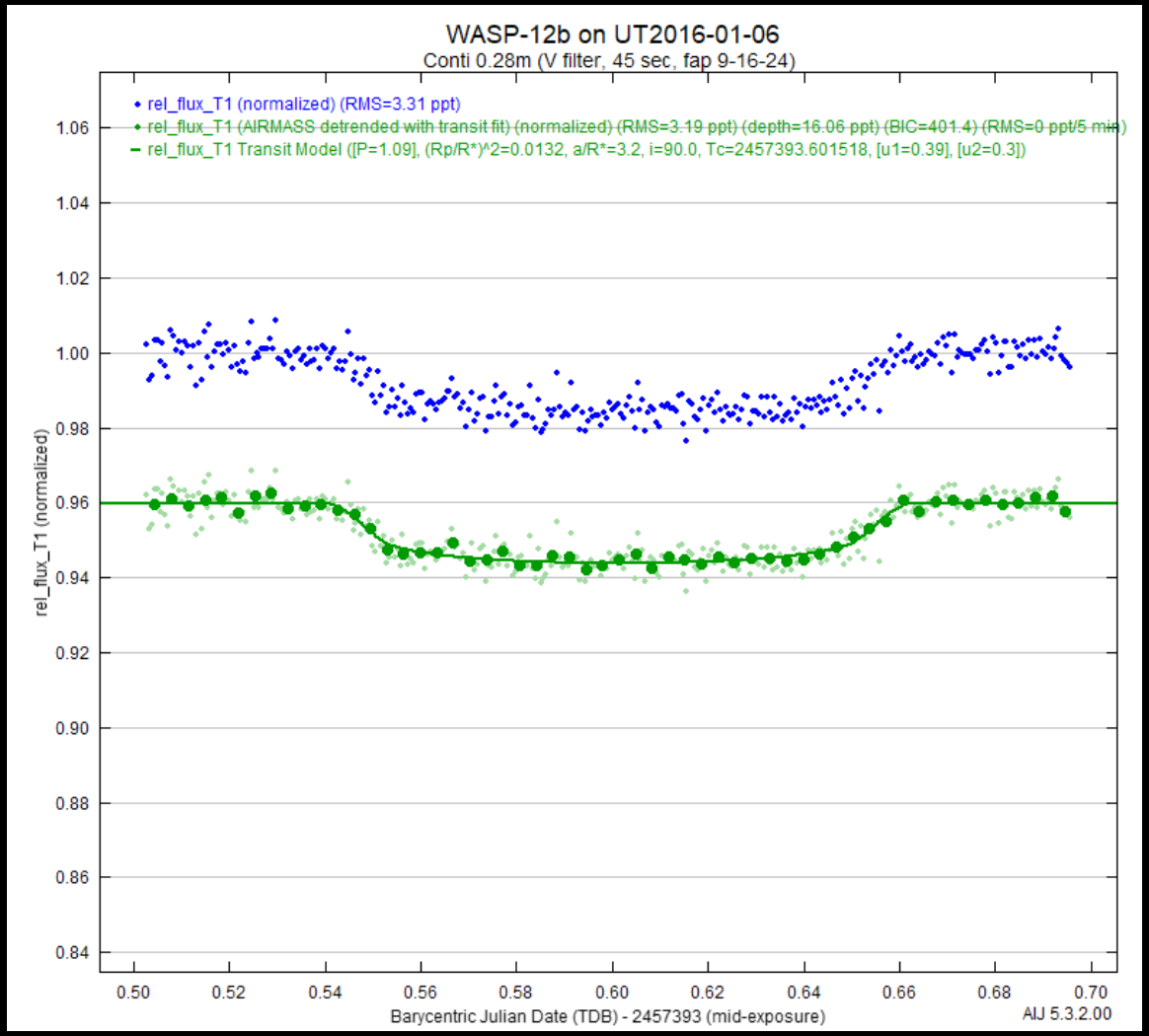
Airmass
Flux of comparison star(s)

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

What practical impact have amateurs had on the success of TESS?

The TESS Confirmation Process

TOI's (Targets of Interest)
are identified from satellite observations

Confirmation Pipeline

SG1

Ground Based Follow-Up

SG2

High-Resolution Imaging

Deep Image of Target Field

High SNR Transit Observation

SG3

Reconnaissance Spectroscopy

Improve Stellar Parameters (T_{eff}, log g, [m/H])

SG4

Precise Doppler Spectroscopy

Doppler Shift

Time

Planet Mass Measurement

Credit: Karen Collins

TOI observations are submitted to ExoFOP database

Exoplanet is "Confirmed"!

Impact Analysis of Amateur Contributions

- Scraped the ExoFOP database for all Time Series observations for TOI-100 to TOI-7900 as of August 4, 2026
  - 8,461 TOI's
  - 21,188 Observations
- Sorted observations by observer:
  - 212 unique observers
- Matched each observer with their affiliation using the ExoFOP directory
- Categorized each user as a professional/academic or amateur astronomer
- Compiled the results

Results

- Observers by category
  - Professional/Academic: 151 (71%)
  - Amateur astronomer: 61 (28%)

    212

- Observations by category
  - Professional/Academic: 10,892 (51%)
  - Amateur astronomer: 10,296 (49%)

    21,188

- Observations per observer ("production capacity")
  - Professional/Academic: 72
  - Amateur Astronomer: 169 (2.3x)

Summary

- Nearly half of all TESS observations were done amateur astronomers
- Amateur astronomers had more than double the "production" capacity of professional/academic observers

AAVSO Contributions to TESS

- Developed "A Practical Guide to Exoplanet Observing"
  - used world-wide by individuals and academic institutions
- Developed the TESS SG1 submission guidelines
- Developed software to help identify false positives due to near-by eclipsing binaries
- Developed a program to train and qualify AAVSO members to join TESS SG1
  - 36 members qualified to-date
  - 28% of TESS observations were done by AAVSO trained/qualified members
- Recently discovered latent errors in EXOFAST, a popular utility for calculating limb darkening coefficients (LDCs)
  - for example, the LDCs for the Sloan i' filter were backwards for the past 15 years
  - helped test a replacement by another amateur for the EXOFAST LDC routine

If you're interested…

- Visit astrodennis.com:
  - review: "A Practical Guide to Exoplanet Observing"
  - download sample images (matches the example in the Guide)

- Join the AAVSO Exoplanet SIG (aavso.org/exoplanet-section)
  - attend regular SIG 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

- Coming soon – a remote site added to AAVSOnet dedicated to exoplanet observing

- Contact me for further information:
  dennis@astrodennis.com