The TESS Follow-Up Observing Program (TFOP)

An Opportunity for Citizen Astronomers to Contribute to TESS Exoplanet Discoveries

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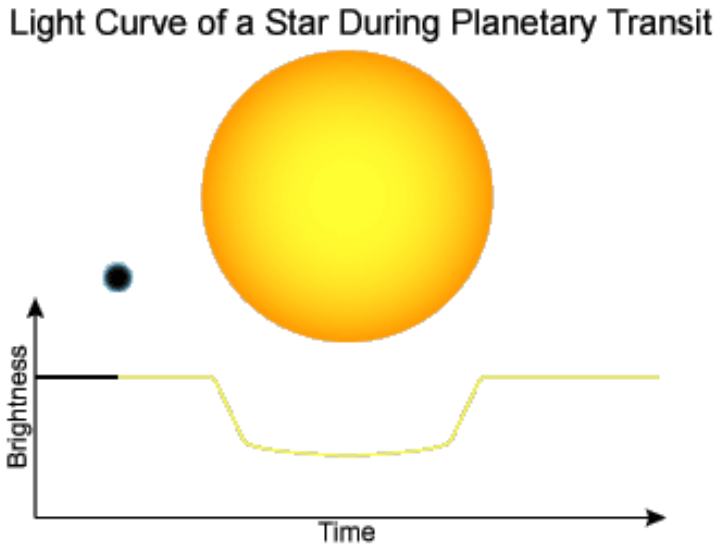
What is an Exoplanet?

- Planets orbiting stars outside our Solar System
- Nearly 6000 exoplanets to-date
- Earth-like to gas giants
- Studied to understand planet formation, evolution, demographics, atmospheres, and the possibility of habitability

- Brown dwarfs and low mass stellar companions are also interesting to scientists

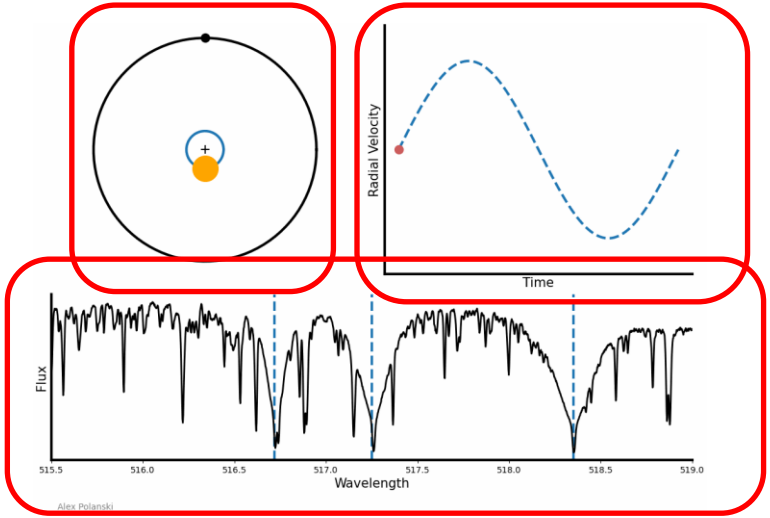
Exoplanet Detection - Transit Method

- A planet passes ('transits') in front of its host star, causing a small, temporary dip in the star’s brightness
- The depth and duration of the dimming reveals the planet’s size (relative to the host star)
- Repeating transits reveal the orbital period



Exoplanet Detection - Radial Velocity Method

- Measures the star's "wobble" caused by the planet's gravity.
- Wobble appears as periodic Doppler shifts in the star’s spectrum.
- Precise instruments can detect velocity changes smaller than a meter per second.

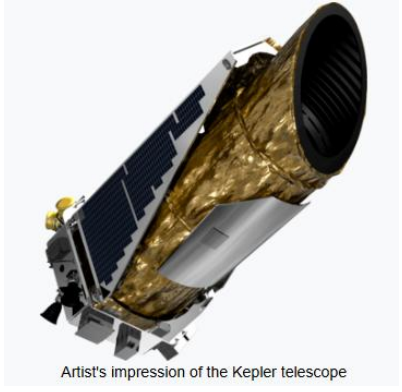


By combining transit data (for planet size) with radial velocity measurements (for mass), we determine the planet’s density and derive constraints on its composition.

Ground and Space-Based Transit Surveys

- **Ground-Based Transit Surveys:**
  - Used/use networks of small-to-medium telescopes (e.g., HATNet, WASP, **KELT**, NGTS)
  - Monitored wide fields for transit events across millions of stars
  - Typically sensitive to larger/closer-in planets due to atmospheric limits
- **Space-Based Transit Surveys:**
  - Satellites above the atmosphere (e.g., CoRoT, Kepler, TESS)
  - Achieve higher photometric precision, no weather or day/night cycles
  - Can detect smaller/longer-period planets
  - Enables statistical studies of exoplanet populations

KELT “Telescope”



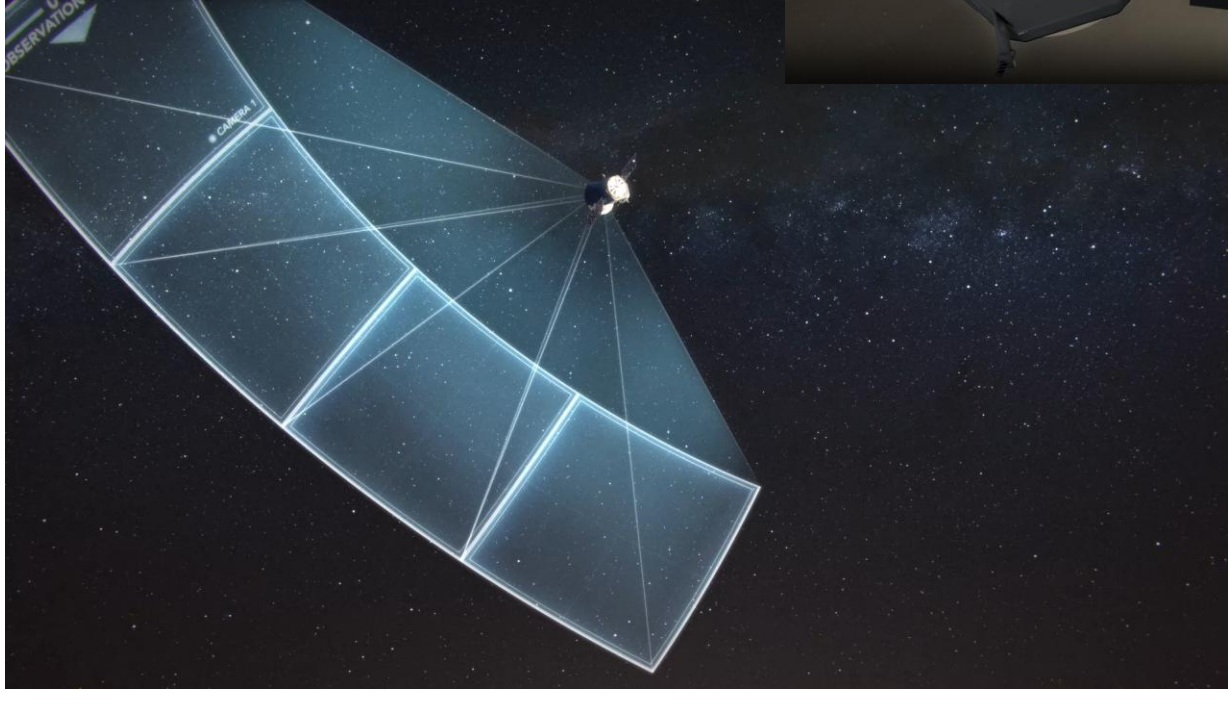
Artist's impression of the Kepler telescope

TESS Mission

- NASA's Transiting Exoplanet Survey Satellite, launched 2018
- Nearly all-sky survey to find planets around bright, nearby stars
- Starting its 8th year of observations (3rd Extended Mission) in October

TESS Observing Strategy

- Uses 4 wide-field cameras covering 24° × 96° per pointing
- Continuously observes 27-day “sectors” to spot transit events
- Observes 13 sectors per year
- Has two continuous coverage zones

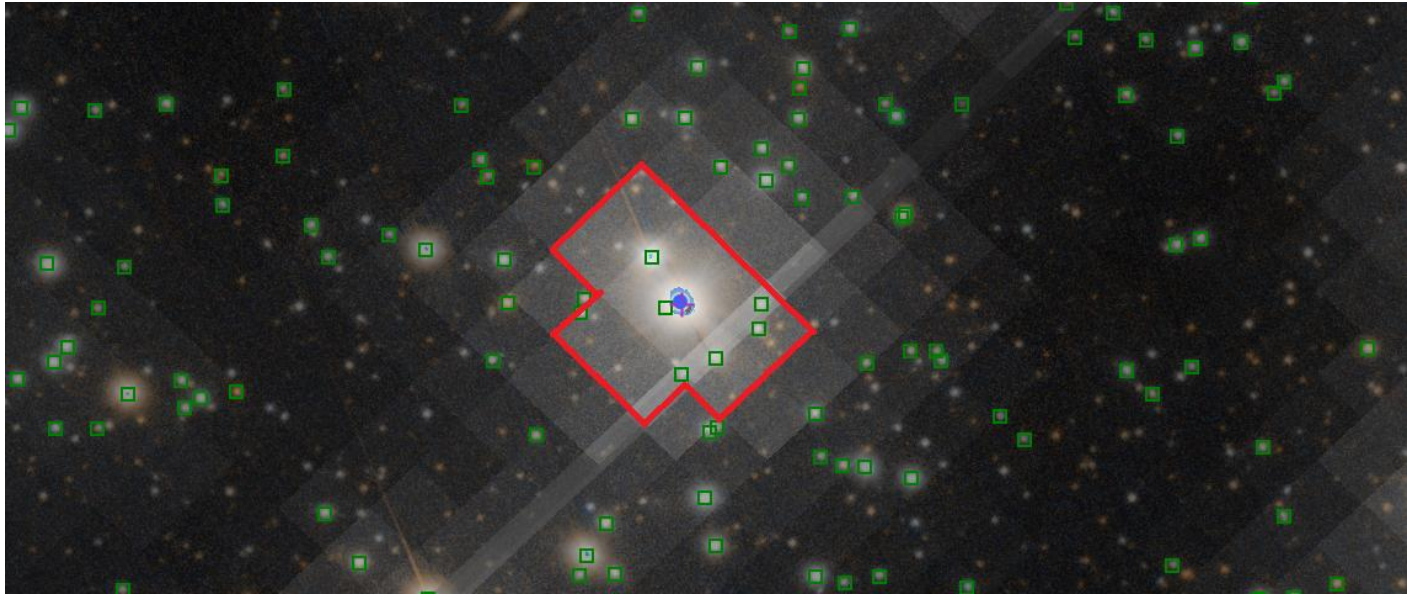


TESS Results So Far

- Over 7500 planet candidates
  (TESS Objects of Interest – TOIs)
- 687 published TESS planet discoveries
- 373 planets smaller than Neptune
- 80 planets smaller than 1.5 Earth radii
- 500 planets with mass measurements
- Prime targets for JWST atmospheric observations

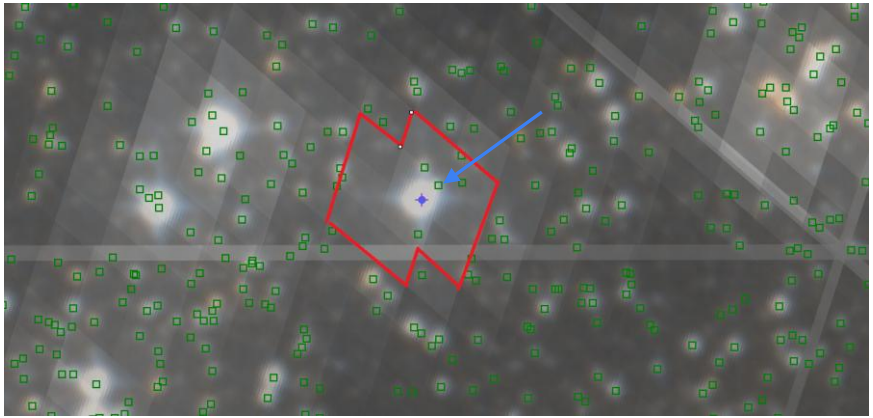
TESS Image Pixel Scale

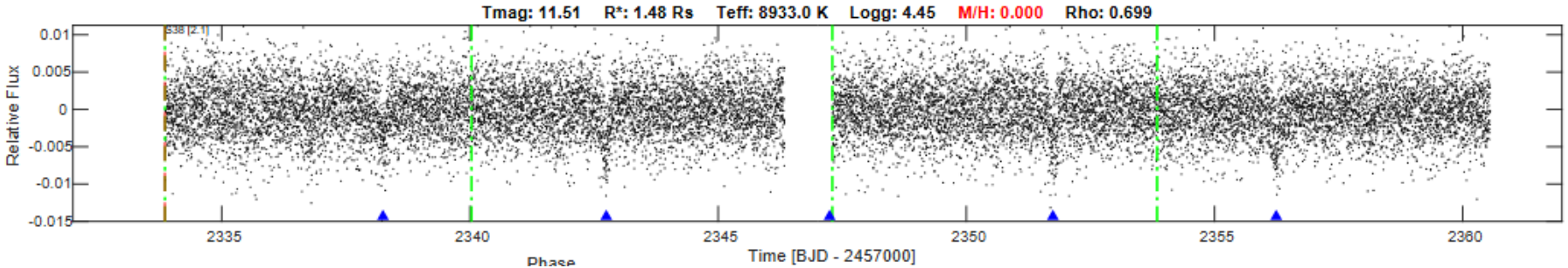
- TESS Pixels are 21” x 21”
- TESS photometric apertures are roughly 60” x 60”
- Multiple stars are typically blended within the TESS photometric apertures



The need for ground-based follow-up

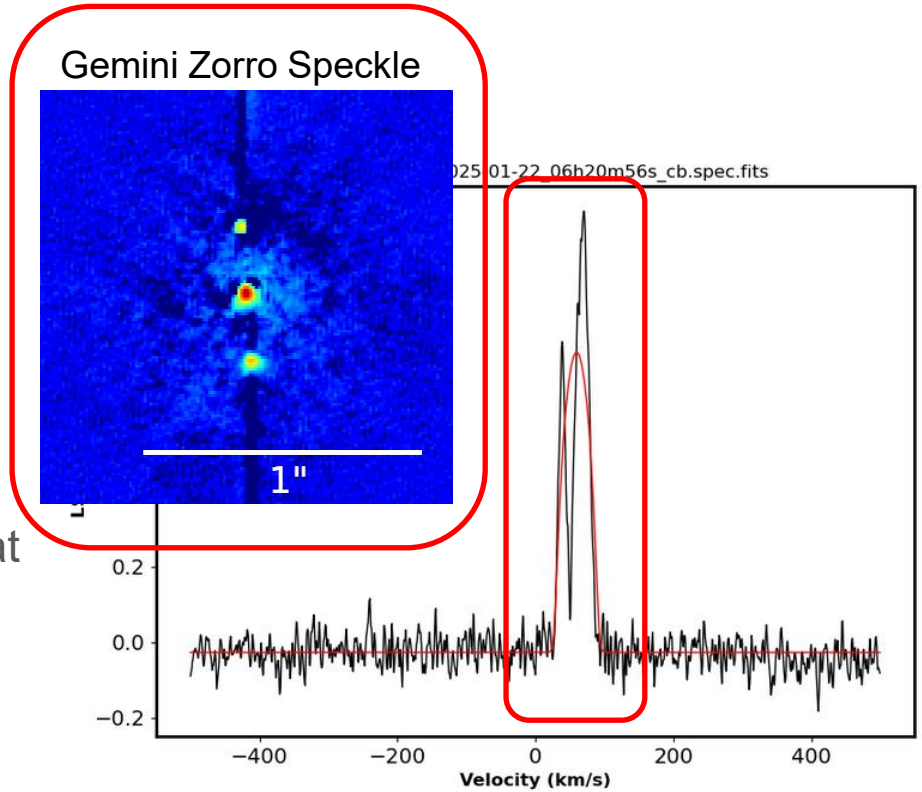
- TESS simply detects variations in a lightcurve of a ~60 arcsec region of the sky
- Higher spatial resolution ground-based lightcurves may be needed to determine the source of the dip in flux





The need for ground-based follow-up

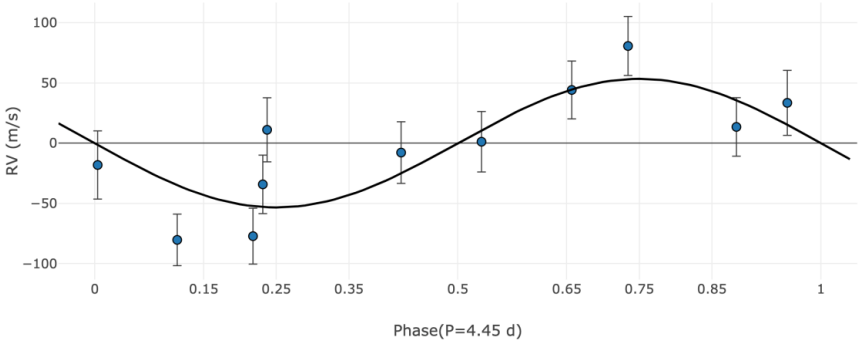
- Seeing limits may hide very close in stellar neighbor
- Adaptive optics and speckle high resolution imaging may reveal < 1” neighbors
- Stellar spectroscopy may reveal even closer in “spectroscopic binaries” that are not otherwise resolved
- Stellar spectroscopy may also find that star is rotating too rapidly for precise radial velocity measurements



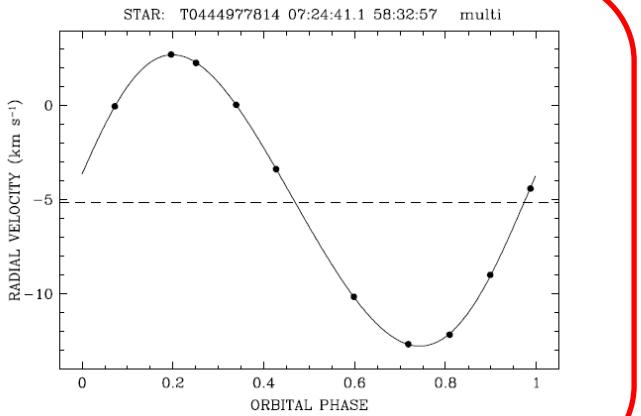
TRES Spectroscopy (LSD profile)

The need for ground-based follow-up

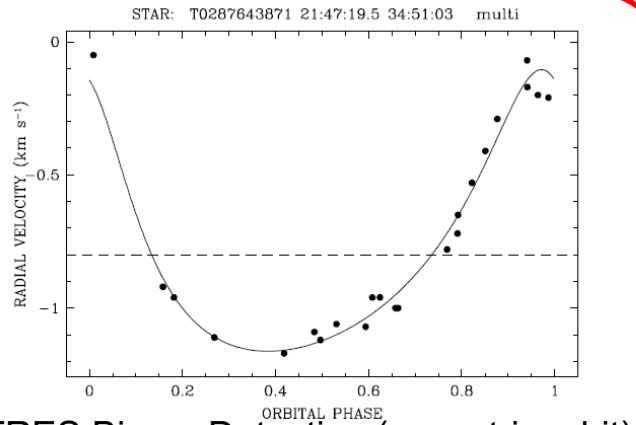
- Mass measurement with precise radial velocities (from spectroscopy)
  - Planet
  - or star
  - Eccentricity of orbit



TRES Planet Detection



TRES Binary Detection



TRES Binary Detection (eccentric orbit)

TESS Follow-up Observing Program (TFOP)

- Led by the Smithsonian Astrophysical Observatory (SAO) as part of the TESS Science Office
- Goal is to foster communication and coordination among the TESS Science Team members and the community:
  - Maximize scientific output
  - Minimize duplication of effort
- The TFOP is organized into five sub-groups (SGs):
  - **Ground-Based Lightcurve Photometry (SG1)** - Karen Collins (lead)
  - Recon Spectroscopy (SG2) - Sam Quinn (lead)
  - High-Resolution Imaging (SG3) - David Ciardi (lead)
  - Precise Radial Velocities (SG4) - David Latham (SG4 and overall TFOP lead)
  - Space-Based Photometry (SG5) - Diana Dragomir (lead; ~~Spitzer~~, CHEOPS, NEOSSAT)
- 700+ registered TFOP members worldwide
- 500+ registered SG1 members
  280+ registered SG1 observatories (suitable for lightcurve follow-up)
- TFOP WG Charter and TFOP WG Publication Policy ensure coordinated publication efforts and intellectual property protections between TFOP members
  - Useful observations are included in TESS planet discovery papers
  - Observers are included as coauthors of planet discovery papers
- Observation results and final TOI dispositions are uploaded to ExoFOP
  (with a 12 month TFOP group proprietary period for uploaded files)

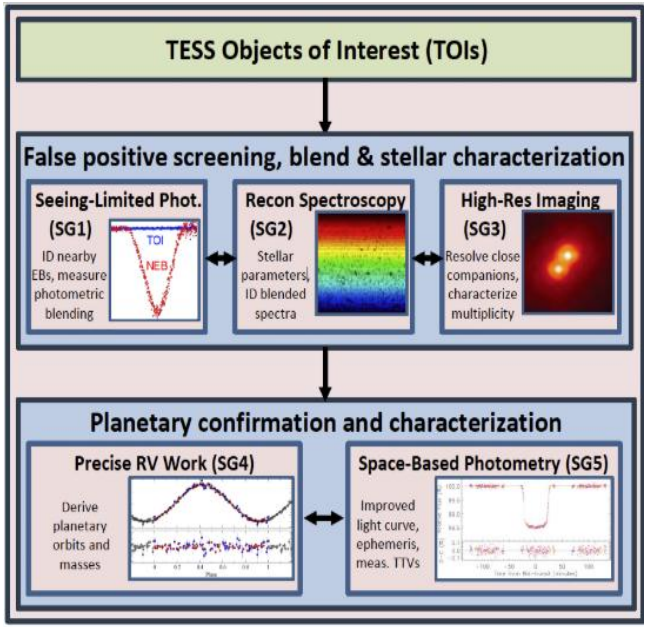


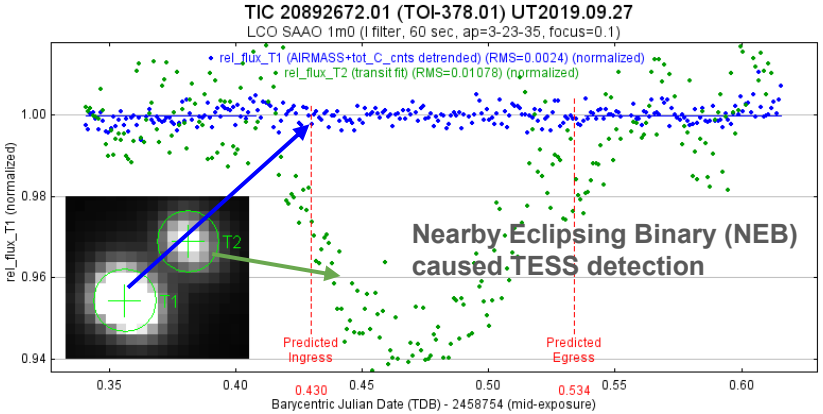
Image credits (clockwise from top left): KELT Survey, NOAO/AURA/NSF, Buchhave et al. (2011), Berta et al. (2012), Malavolta et al. (2016).

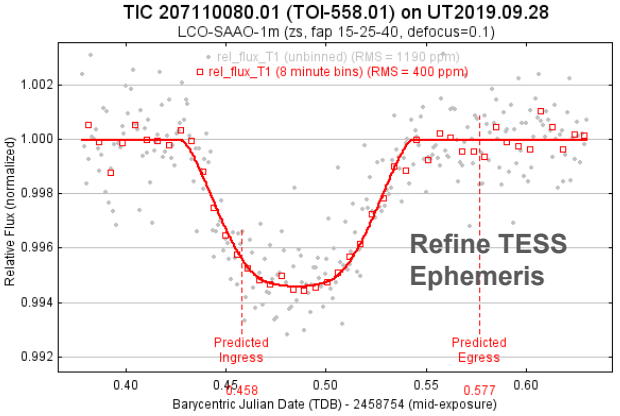
TFOP SG1 Overview

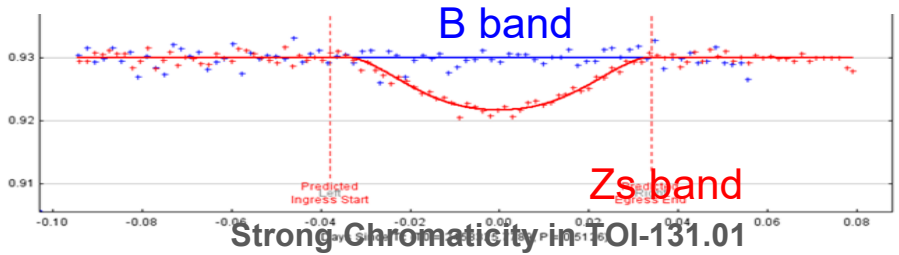
TFOP SG1 conducts ground-based lightcurve photometry

TFOP SG1 goals:

- Determine the true source the TESS transit detection (<1 arcsec px scale vs 21 arcsec TESS px scale)
- Refine the TESS transit ephemeris, depth, and duration
- Check for color dependent depth differences (chromaticity) across optical, IR, and NIR bands
- Conduct long-term TTV observations
- Track down the true orbital period of high uncertainty systems
    a. TOIs with limited TESS time baseline coverage
    b. Period from TESS Single Transit detections + RVs
- Determine the true orbital period of TESS “duo transits”







Strong Chromaticity in TOI-131.01

Duo Transits (Orbital Period Aliasing)

Generally a result of TESS data gaps

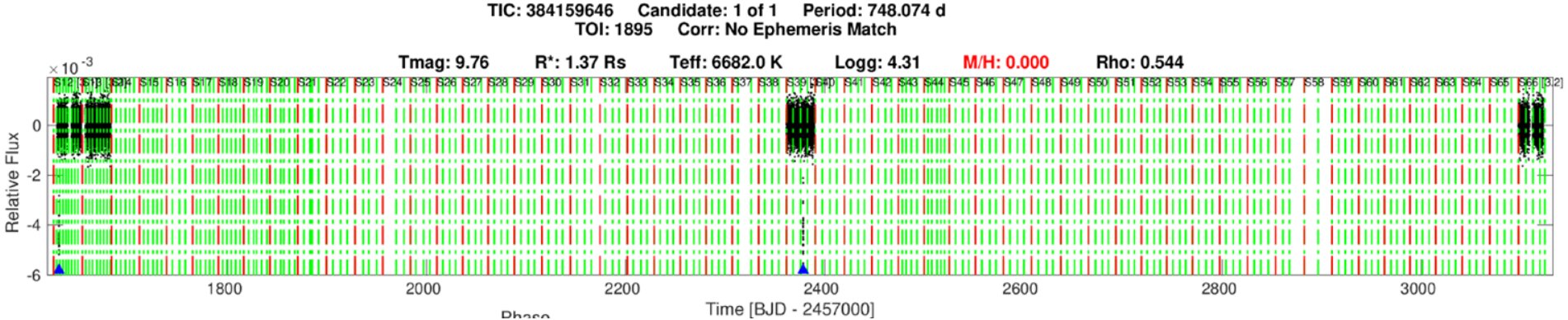
TESS detection is consistent with a family of orbital periods

Upper orbital period limit from two (or more) transit detections

Lower orbital period limit from TESS coverage with no transits

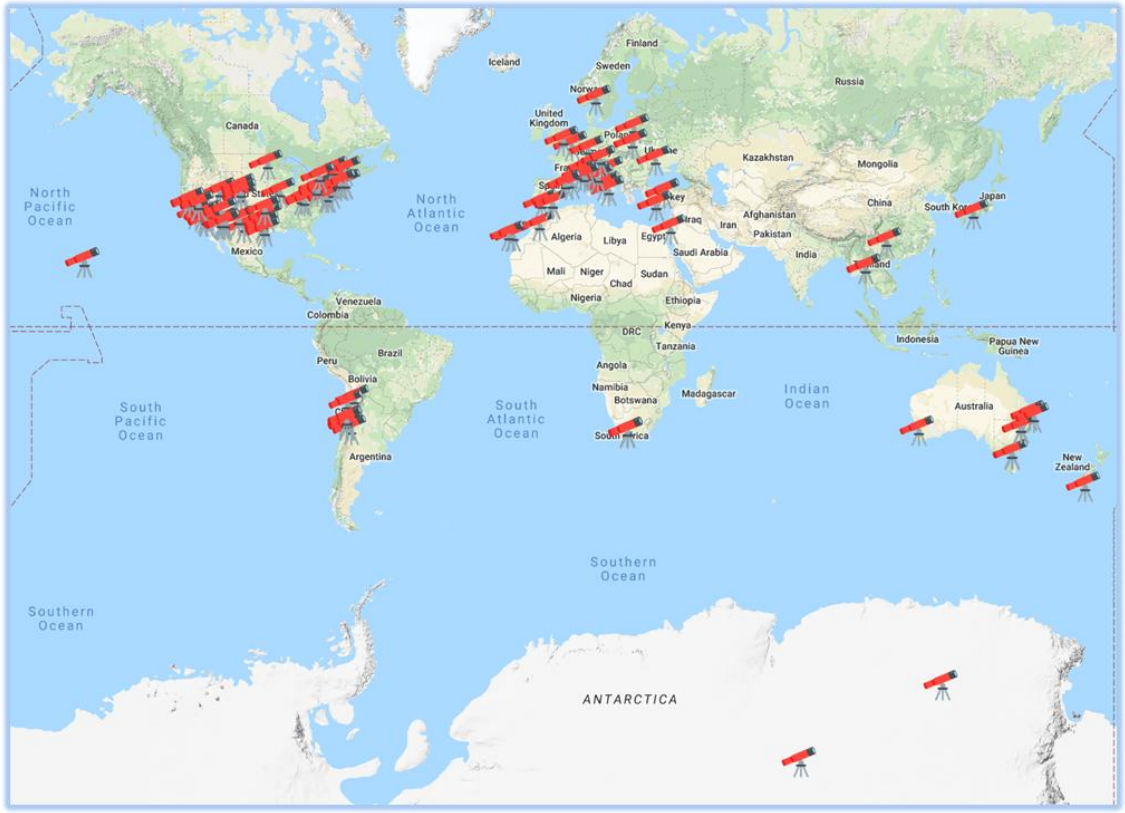
We parameterize as a maximum period and a set of valid alias integers “I_N”

$P_N = P_{MAX} / I_N$



TFOP SG1 Observatories

- 500+ members
- 280+ observatories
- Professional astronomers
- Student astronomers
- Citizen astronomers
- Ground-based surveys



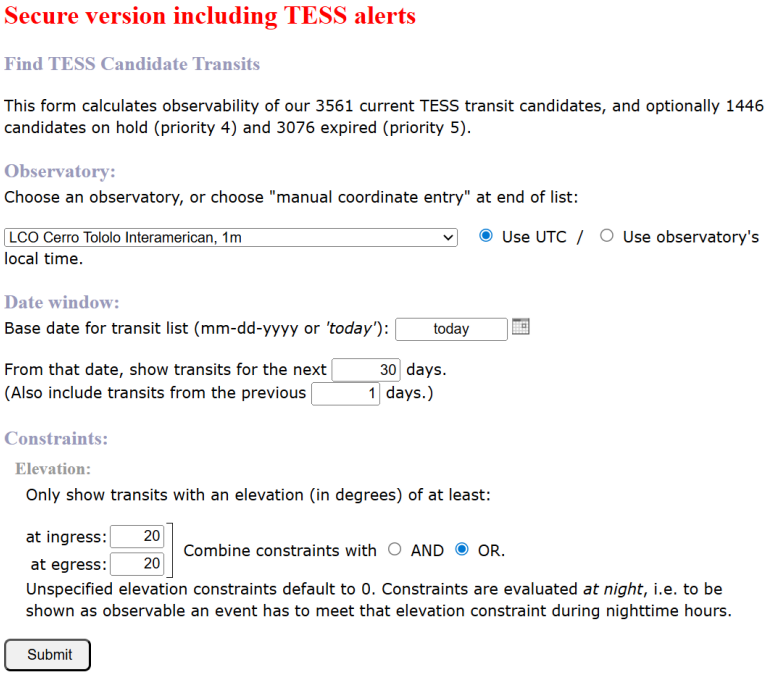
Software Tools Provided to SG1 Team

- TESS Transit Finder (TTF)
  (private to TFOP members)
- SG1 TOI List shared spreadsheet
  (private to TFOP members)
- TESS Observations Coordinator (TOC)
  (private to TFOP members)
- Field of view tool
- Gaia apertures tool
- ExoFOP (reduced data repository and sharing)
- AstroImageJ (data reduction)

TESS Transit Finder (TTF)

Two methods for accessing TTF transit searches:

- User interface mode for interactive searches
- Scripted with output optionally available as csv file for easier parsing



Secure version including TESS alerts

Find TESS Candidate Transits

This form calculates observability of our 3561 current TESS transit candidates, and optionally 1446 candidates on hold (priority 4) and 3076 expired (priority 5).

Observatory:

Choose an observatory, or choose "manual coordinate entry" at end of list:

LCO Cerro Tololo Interamerican, 1m ◉ Use UTC / ○ Use observatory's local time.

Date window:

Base date for transit list (mm-dd-yyyy or *'today'*): today

From that date, show transits for the next 30 days.
(Also include transits from the previous 1 days.)

Constraints:

Elevation:

Only show transits with an elevation (in degrees) of at least:

at ingress: 20
at egress: 20
Combine constraints with ○ AND ◉ OR.

Unspecified elevation constraints default to 0. Constraints are evaluated *at night*, i.e. to be shown as observable an event has to meet that elevation constraint during nighttime hours.

Submit

TESS Transit Finder (TTF)

- Ephemeris prediction tool available to TFOP team for scheduling observations
- Transit predictions based on latest SG1 ephemerides, dispositions, priorities
- Provides feedback to observers:
  - Status of TOI
  - Observation history
  - Type of observation needed next

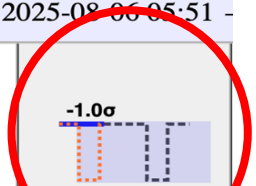
VPC VPC VRV? qlp-s49-219824470 Sectors:[16, 22, 23, 49] SG2:[TRES(18), Vrot=4] SG4:[Ariel, NEID-Yee]: TFOP determined this star (TIC 219824470) is the true source of TOI 1848.01 / TIC 219824469 which has been retired as off-target; Rick Schwarz/LCO-Teid-1m0 analyzed a full on 20240314 in zs and ruled out an on-time 3 ppt event on the original target, but detected an on-time 3 ppt in this star. **No more observations needed, except for a high precision (<1.0 ppt/10 min) full transit in a blue (U, u', B, g') filter to check chromaticity. High-precision (<1.0 ppt/10 min) multi-band observations even better.**

Local evening date	Name	V mag	T mag	% of transit (baseline) observable, Suggested obs. start, end	Start—Mid—End	Priority	Period (days)	Depth (ppt)	Duration	R_{planet} ($R_\oplus$)	Comments and followup status
Fri. 2026-05-01: Nautical twilight 2026-05-01 21:30 — 2026-05-02 06:15 local time / 2026-05-02 02:30 — 2026-05-02 11:15 UTC											
Fri. 2026-05-01 (local date) Nautical twilight 02:30 – 11:15 (UTC)	TIC 219824470.01 (TOI 6972.01) Add to TOC Finding charts: Annotated, Aladin; Info: ExoFOP, Simbad, Gaia, TIC, VSX, All apertures, Vizier phot.; Airmass, ACP plan	11.07 Moon 99% @73°	10.39	100% (55%) 04:19—10:29 65°—36°	04:19 05:43—08:11—10:38 12:02 ±0:09	3	5.48	2.237	4:55 ±0:36	8.4	VPC VPC VRV? qlp-s49-219824470 Sectors:[16, 22, 23, 49] SG2:[TRES(18), Vrot=4] SG4:[Ariel, NEID-Yee]: TFOP determined this star (TIC 219824470) is the true source of TOI 1848.01 / TIC 219824469 which has been retired as off-target; Rick Schwarz/LCO-Teid-1m0 analyzed a full on 20240314 in zs and ruled out an on-time 3 ppt event on the original target, but detected an on-time 3 ppt iin this star. No more observations needed, except for a high precision (<1.0 ppt/10 min) full transit in a blue (U, u', B, g') filter to check chromaticity. High-precision (<1.0 ppt/10 min) multi-band observations even better.

(coming soon)

TTF handling of high ephemeris uncertainty systems

- Typical ephemeris prediction tools require a nominal ingress or egress to be observable
- New TTF version will consider ephemeris uncertainty when listing observable transits

Local evening date	Name	Start—Mid—End	Elev. at start, mid, end ±2 hrs	Duration	% of transit (baseline) observable, Suggested obs. start, end
Tue. 2025-08-05: Nautical twilight 2025-08-05 19:51 — 2025-08-06 05:10 local time / 2025-08-06 05:51 -					
Tue. 2025-08-05 (local date) Nautical twilight 05:51 – 15:10 (UTC)	☐ TIC 277329402.01 (TOI 5851.01) Add to TOC Finding charts: Annotated, Aladin; Info: ExoFOP, Simbad, Gaia, TIC, VSX, AIJ apertures, Vizier phot.; Airmass, ACP plan	08:19 18:21—19:32—20:43 06:45 ±8:02	78° -40°, -51°, -57° 58°	2:22 ±0:18	 100% (86%) 08:19—13:26 78°—25°

SG1 TOI List

A shared google sheet listing data and status for all public and custom TOIs

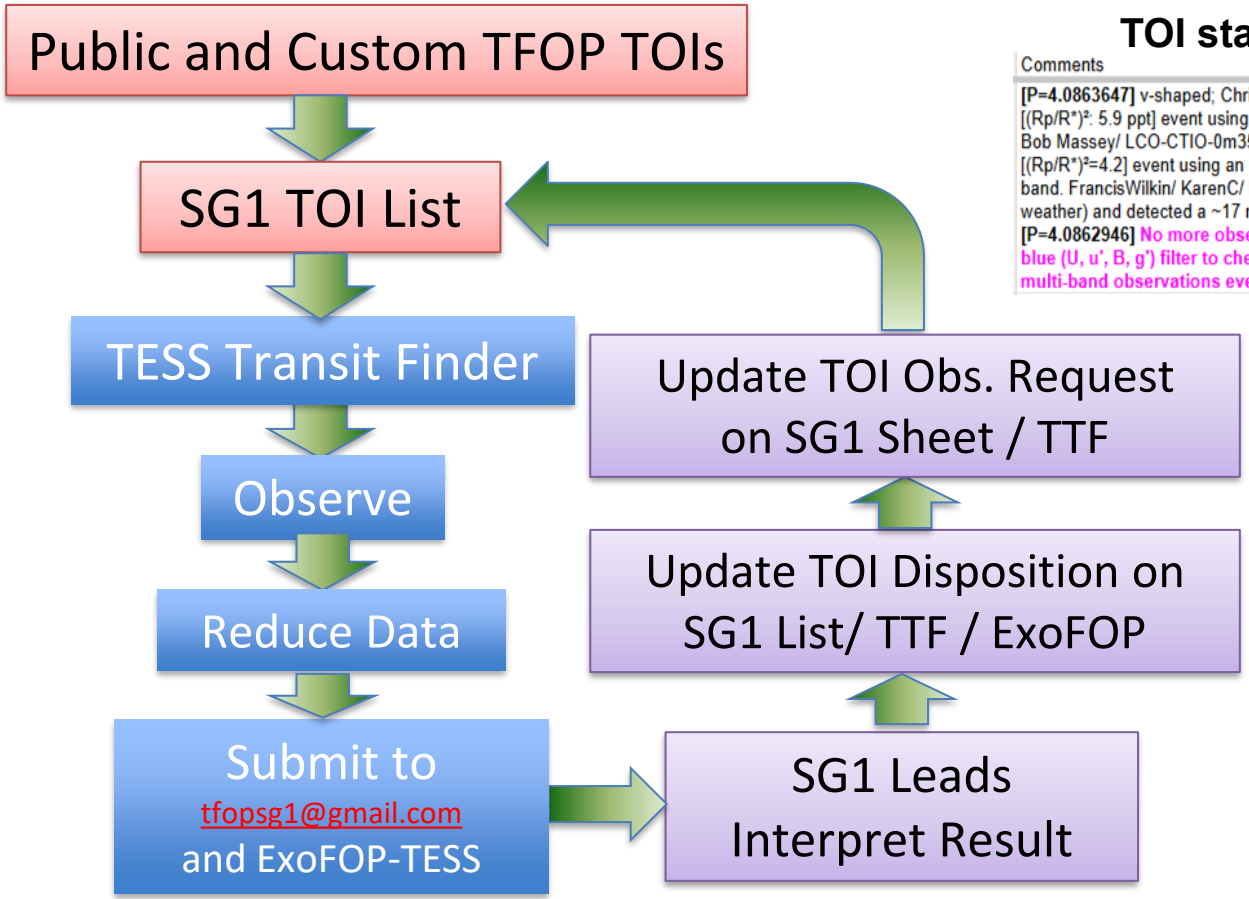
TESS Transit Finder (TTF) reads data from SG1 sheet

Maintained by SG1 leads and trained volunteers

AR	AS	AT	AU	AV	AW	BC	BD	BE	BF	BG	BH	BI	BK	BL	BM	BN	BO	BP
Pipe-line	Sec-tor	Prio rity	Master Disposi tion	Phot Disposi tion	Spec Dispo sition	Tc_BTJD	Tc_Err	P	P_Err	Dura tion (hrs)	Depth (ppm)	Rp (R_ Eart h)	Cur Eph Unc (min)	Dur Unc (min)	Delta Tc (min)	N Obs	Owner/Interest/ Publication Status	Comments
CTOI	S49	3	VPC	VPC	VRV?	2661.0743	0.0025	5.4809114	0.0000215	4.91	2237	8.4	8	36	0	0		TFOP determined this star (TIC 219824470) is the true source of TOI 1848.01 / TIC 219824469 which has been retired as off-target; Rick Schwarz/LCO-Teid-1m0 analyzed a full on 20240314 in zs and ruled out an on-time 3 ppt event on the original target, but detected an on-time 3 ppt iin this star. **No more observations needed, except for a high precision (<1.0 ppt/10 min) full transit in a blue (U, u', B, g') filter to check chromaticity. High-precision (<1.0 ppt/10 min) multi-band observations even better.**

Pipe-line	Sec-tor	Prio rity	Master Disposi tion	Phot Disposi tion	Spec Dispo sition	Tc_BTJD	Tc_Err	P	P_Err	Dura tion (hrs)	Depth (ppm)	Rp (R_ Eart h)	Cur Eph Unc (min)	Dur Unc (min)	Delta Tc (min)	N Obs	Owner/Interest/ Publication Status	Comments	TOI List Eph Unc
SPOC	S78	4	VPC+	VPC+		3434.6862	0.0053	3.0499550	0.0000100	1.82	23466	11.2	8	14	-295	7		[P=3.0513298] no centroid information; slightly v-shaped; **Update from AIJ-s24+s78. [P=3.0498798]** Ferran Grau/ Gemma Domènech/ Kike Herrero/ Jordi Lopesino/ TJO-0m8/ analyzed a full on 20250305 in rp and detected an ~11 min (1.4σ) late, ~20 min longer duration, ~23.0 ppt event using an uncontaminated 4.9" target aperture. **[P=3.0499550]** Dur => 1.82 hr. K. Barkaoui/LCO-Teid-1.0m analyzed a full on 20250425 in gp and detected a ~23 ppt event on target using an uncontaminated 3.5" aperture. ChrisS/LCO-SAAO-1m0 analyzed a full on 20250425 in gp and detected a 5 min (0.6σ) early, 8 min (0.5σ) longer, 22 ppt [(Rp/R*)²: 23.6 ppt] event using an uncontaminated 4.7" target aperture. MuSCAT2 Team observed a nominal full on 20250619 in gp, rp, ip, zs and detected a ~6 min. early 24.4, 24.84, 22.97, 21.22 ppt events using an uncontaminated 5.7" target apertures. **No more SG1 observations needed at this time.**	294

TFOP SG1 Process Overview



TOI status and observation request

Comments

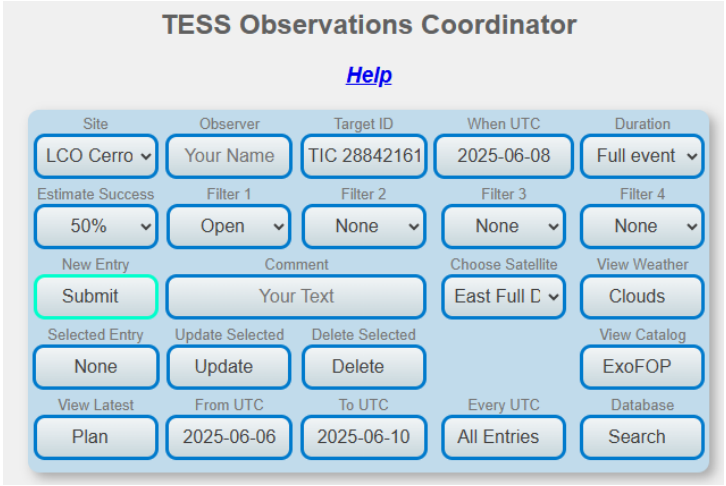
[P=4.0863647] v-shaped; ChrisS/ Hwd observed a full on 20241008 in R and detected an ~on-time ~4.3 ppt [(Rp/R*)²: 5.9 ppt] event using an uncontaminated 5.5" target aperture and cleared the neighbors over the window. Bob Massey/ LCO-CTIO-0m35/ analyzed a full on 20241029 in ip and detected a ~0-10 min (2.5σ) early ~3.2 ppt [(Rp/R*)²=4.2] event using an uncontaminated 5.9" target aperture. This observation checks the depth in a red band. FrancisWilkin/ KarenC/ LCO-CTIO-0m35 on 20250705 in gp an ingress+80% (intended full cut short by weather) and detected a ~17 min early, 4 ppt ingress on target in an uncontaminated 6.0" aperture.
[P=4.0862946] No more observations needed, except for a high precision (<1.0 ppt/10 min) full transit in a blue (U, u', B, g') filter to check chromaticity and refine the timing. High-precision (<1.0 ppt/10 min) multi-band observations even better.

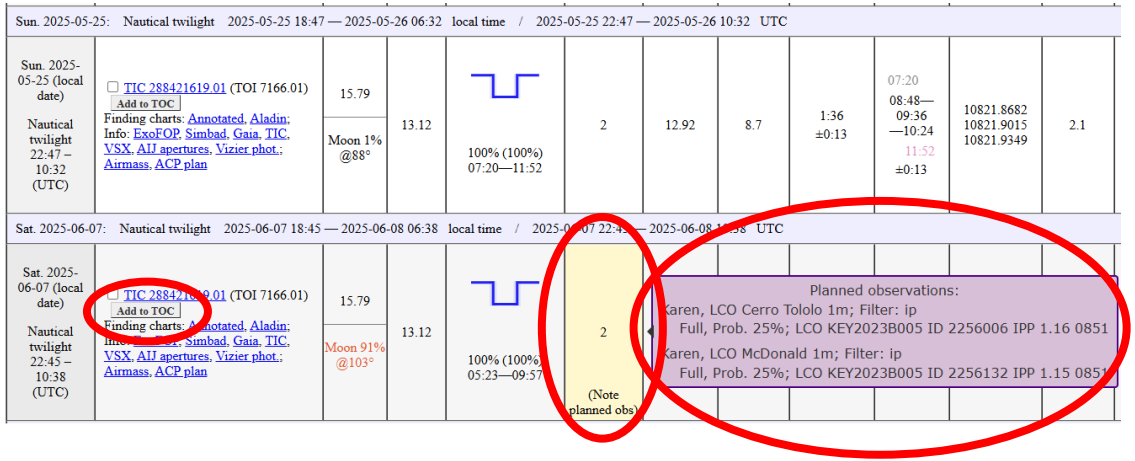
SG1 List Dispositions

Priority	Master Disposition	Phot Disposition	Spec Disposition
4	VPC+	VPC+	VRV
3	VPC	VPC	
1	CPC	VPC?	RVD?
5	SEB1	PC	SEB1
5	NEB	NEB	

TESS Observations Coordinator (TOC)

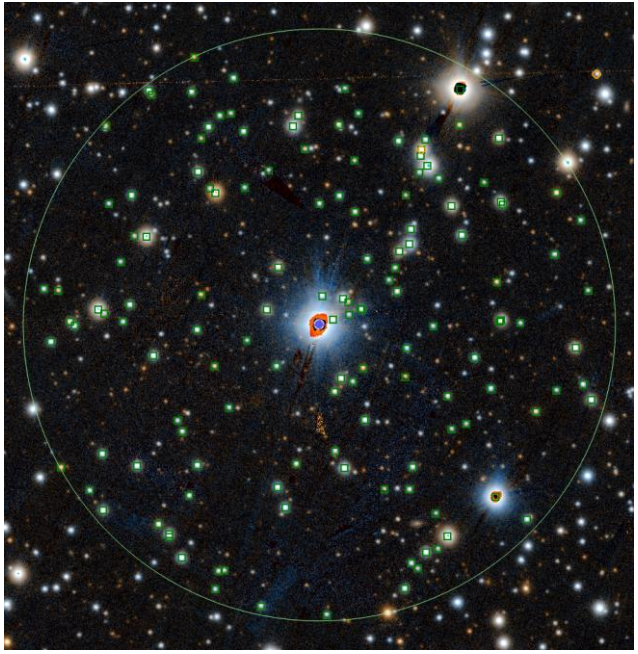
- TTF Provides connection to TOC interface for posting planned observations
- The plans will show up in the TTF output to inform other potential observers
  - For events with planned observation, the priority cell is highlighted in yellow
  - Mouse over to see details
- Can help avoid duplication of observations

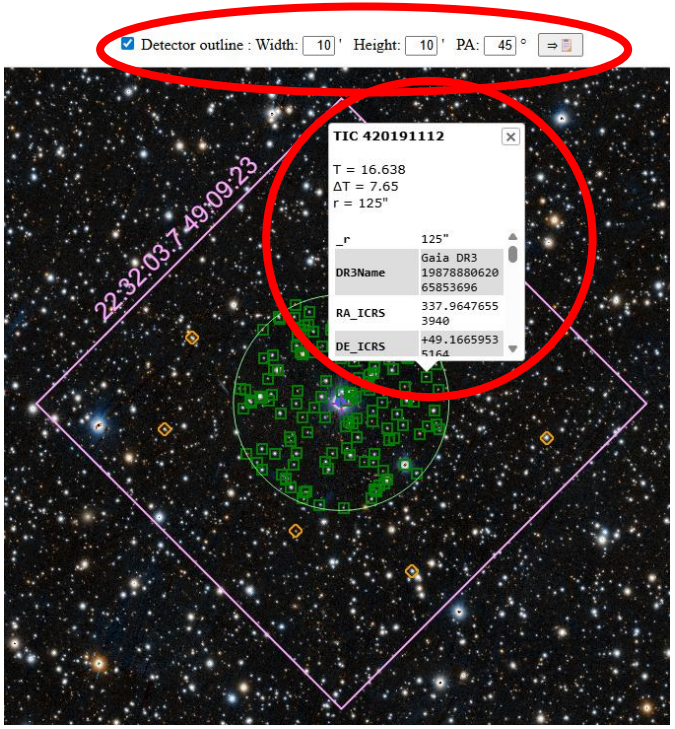




Field of View Tool

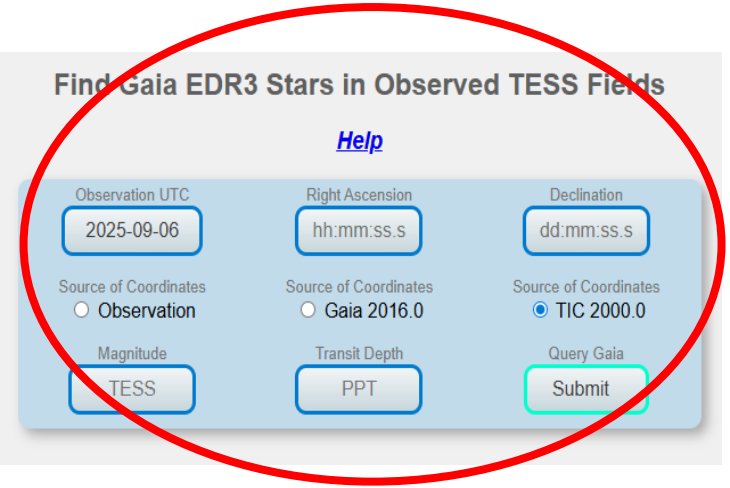
- Shows zoomable field of view using catalog imagery
- Identifies target star
- Green symbols identify all nearby Gaia stars bright enough to host TESS detected signal
- Field of view can be set to match your telescope
- Click symbol for catalog data on each star
- Example field

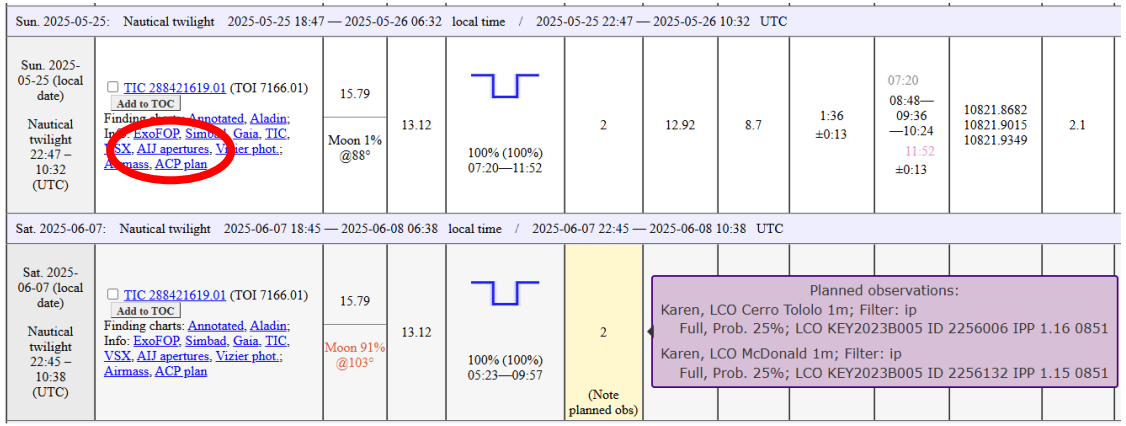




Gaia Apertures Tool

- Provides a list of star locations that should be checked for NEBs
- Star locations provided depend on transit depth
- Link to tool from TTF and SG1 sheet
- User interface auto-filled and bypassed when using TTF link
- Drag and drop file into AstroImageJ





ExoFOP (Provided by NExSci at Caltech)

- Reduced data repository
- Provides list of all observations for each TIC / TOI number
- Hosts reduced data files, with optional 1 year proprietary period for TFOP members
- User interface or scriptable data uploads
- [Main Page]
- [TIC 288421619 Page]

Time Series Observation + Add new

Name	TOI	User	Telescope	Camera	Filter	Pixel scale (arcsec)	Estimated PSF (arcsec)	Photometric Aperture Radius (pixel)	Transit Coverage	Faintest Neighbor delta Mag	Observation date (UT)
TIC 288421619.01	TOI 7166.01	stockdale	LCO-Teid-1m0 (1.0 m)	SINISTRO	ip	0.389	1.55	8	Full		2025-06-21
TIC 288421619.01	TOI 7166.01	collins	LCO-CTIO-1m0 (1.0 m)	SINISTRO	rp	0.389	2.26	7	Egress		2025-07-04
TIC 288421619.01	TOI 7166.01	barkaoui	TRAPPIST-South (0.6 ...	FLI ProLine PL3041-BB	Rc	0.64	2.5	7	Full		2025-06-21
TIC 288421619.01	TOI 7166.01	barkaoui	SPECULOOS-South (1....	Andor ikon-L	zp	0.35	1.8	8	Full		2025-06-21
TIC 288421619.01	TOI 7166.01	schwarz	LCO-CTIO-1m0 (1.0 m)	SINISTRO	gp	0.389	2.26	15	Full		2025-06-21
TIC 288421619.01	TOI 7166.01	barkaoui	SPECULOOS-South (1....	Andor ikon-L	I+z	0.35	3.8	5	Full		2025-06-08
TIC 288421619.01	TOI 7166.01	barkaoui	LCO-McD-1.0m (1.0 m)	SINISTRO	ip	0.389	1.83	9	Full		2025-06-08

Files 58 + Add new

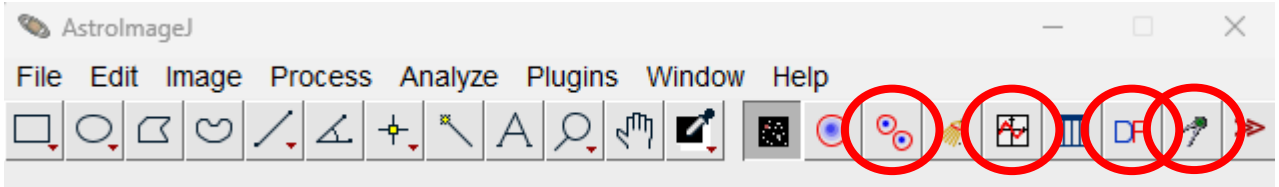
Name	TOI	Type	File Name	Description	Date	User
TIC 288421619.01	TOI 7166.01	Finding_Chart	TOI-7166.01_20250608_SPECULOOS-South-1m0_LCO-McD-1m0_I+z_ip_lightcurves.pdf	T1 Light Curve	2025-06-09 05:08:31	barkaoui
TIC 288421619.01	TOI 7166.01	Light_Curve	TIC288421619-22_20250821_LCO-Teid-1m0_ip_Seeing-Profile.png	AIJ Seeing Profile	2025-08-24 01:07:46	stockdale
TIC 288421619.01	TOI 7166.01	Light_Curve	TIC288421619-22_20250821_LCO-Teid-1m0_ip_Platesolved-Image.fits.fz	AIJ Sample Platesolved FITS Image	2025-08-24 01:07:46	stockdale
TIC 288421619.01	TOI 7166.01	Light_Curve	TIC288421619-22_20250821_LCO-Teid-1m0_ip_Observation-Notes.txt	Observation Notes	2025-08-24 01:07:07	stockdale
TIC 288421619.01	TOI 7166.01	Light_Curve	TIC288421619-22_20250821_LCO-Teid-1m0_ip_8px_Measurements_dmagRMS-plot.png	AIJ dMag RMS Plot	2025-08-24 01:07:07	stockdale
TIC 288421619.01	TOI 7166.01	Light_Curve	TIC288421619-22_20250821_LCO-Teid-1m0_ip_8px_Measurements_8px_NEBcheck.zip	AIJ NEBcheck Plots	2025-08-24 01:07:06	stockdale
TIC 288421619.01	TOI 7166.01	Light_Curve	TIC288421619-22_20250821_LCO-Teid-1m0_ip_8px_Measurements_8px_NEB-table.txt	AIJ NEBcheck Table	2025-08-24 01:07:04	stockdale
TIC 288421619.01	TOI 7166.01	Light_Curve	TIC288421619-22_20250821_LCO-Teid-1m0_ip_8px_Measurements.tbl	AIJ Measurements Table	2025-08-24 01:07:03	stockdale
TIC 288421619.01	TOI 7166.01	Light_Curve	TIC288421619-22_20250821_LCO-Teid-1m0_ip_8px_Measurements.plotcfg	AIJ Plot Configuration File	2025-08-24 01:06:57	stockdale
TIC 288421619.01	TOI 7166.01	Light_Curve	TIC288421619-22_20250821_LCO-Teid-1m0_ip_8px_Measurements.apertures	AIJ Aperture File	2025-08-24 01:06:53	stockdale
TIC 288421619.01	TOI 7166.01	Light_Curve	TIC288421619-22_20250821_LCO-Teid-1m0_ip_8px_Lightcurve.png	AIJ Lightcurve	2025-08-24 01:06:53	stockdale
TIC 288421619.01	TOI 7166.01	Light_Curve	TIC288421619-22_20250821_LCO-Teid-1m0_ip_8px_Field.png	AIJ Field	2025-08-24 01:06:53	stockdale

AstroImageJ

- General astronomical image and data analysis tool (based on ImageJ)
- Image calibration (bias, dark, and flat-fielding)
- Differential aperture photometry
- Lightcurve plotting (with automatic titling and legend capabilities)
- Lightcurve detrending and fitting
- Automatic comparison star selections
- Various aperture options (fixed, auto-fixed, variable size; circular, elliptical, arbitrary shape)
- Automated NEBcheck routine (written by AAVSO's Dennis Conti)
- Automatic optimization of comparison stars and detrend parameters
- Plate solving using astrometry.net (local solver capability on Microsoft Windows)
- Moving object tracking
- Image alignment (if needed)
- TESS image (e.g. TESScut) and SPOC lightcurve analysis

AstroImageJ Toolbar

- Provides access to Astronomy Tools (and underlying ImageJ tools)
- Data Processor (DP; data calibration)
- Multi-Aperture (MA; differential photometry)
- Multi-Plot and lightcurve fitting (MP; plotting facility)
- Coordinate Converter (CC; time format and coordinate conversion)



Data Processor (Image Calibration)

- Create master calibration files
- Bias subtract
- Dark Subtract
- Flat field
- Update FITS headers
- Plate Solve
- Save calibrated files
- Optional run photometry and plotting
- Run in realtime mode while observing to monitor live lightcurve

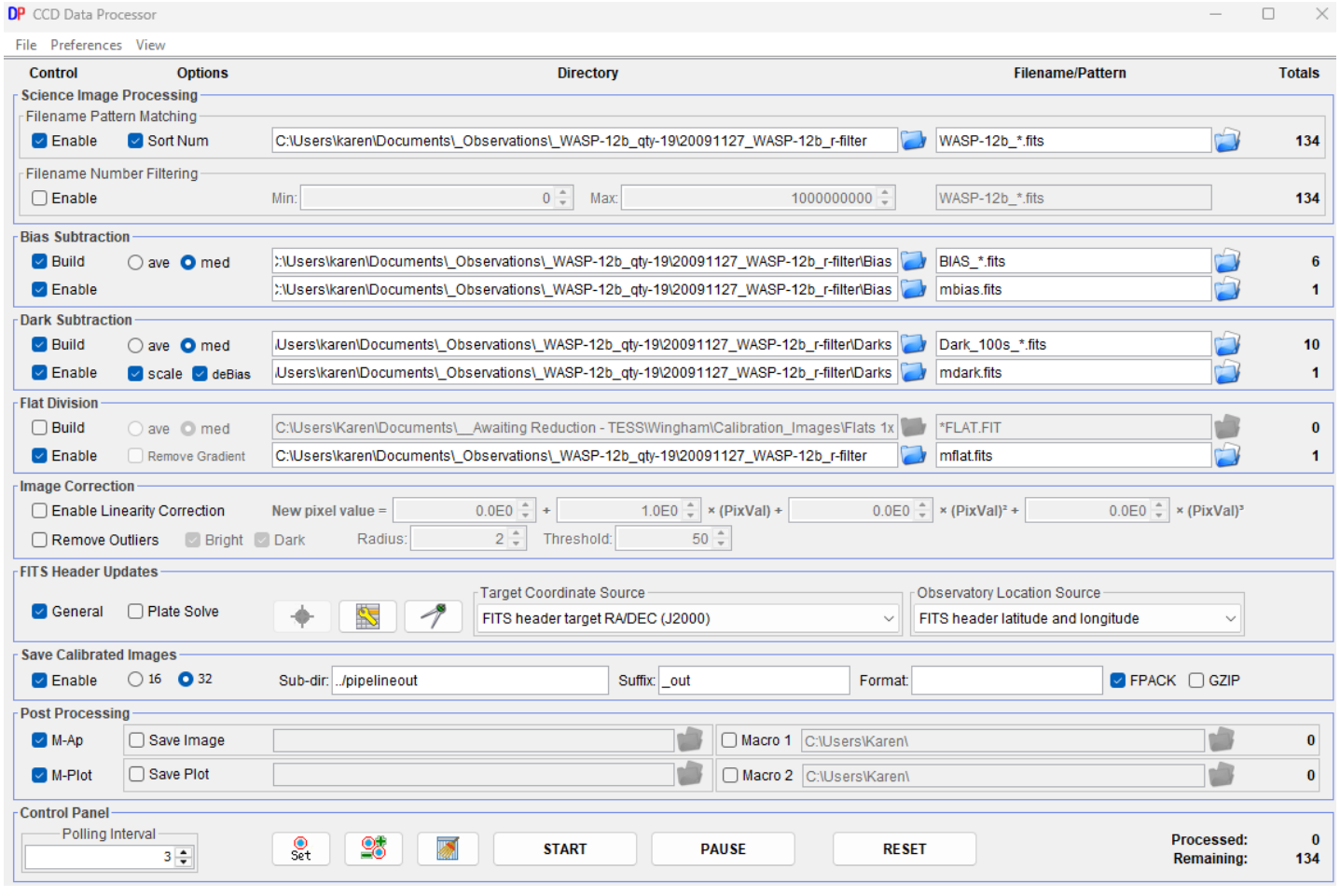
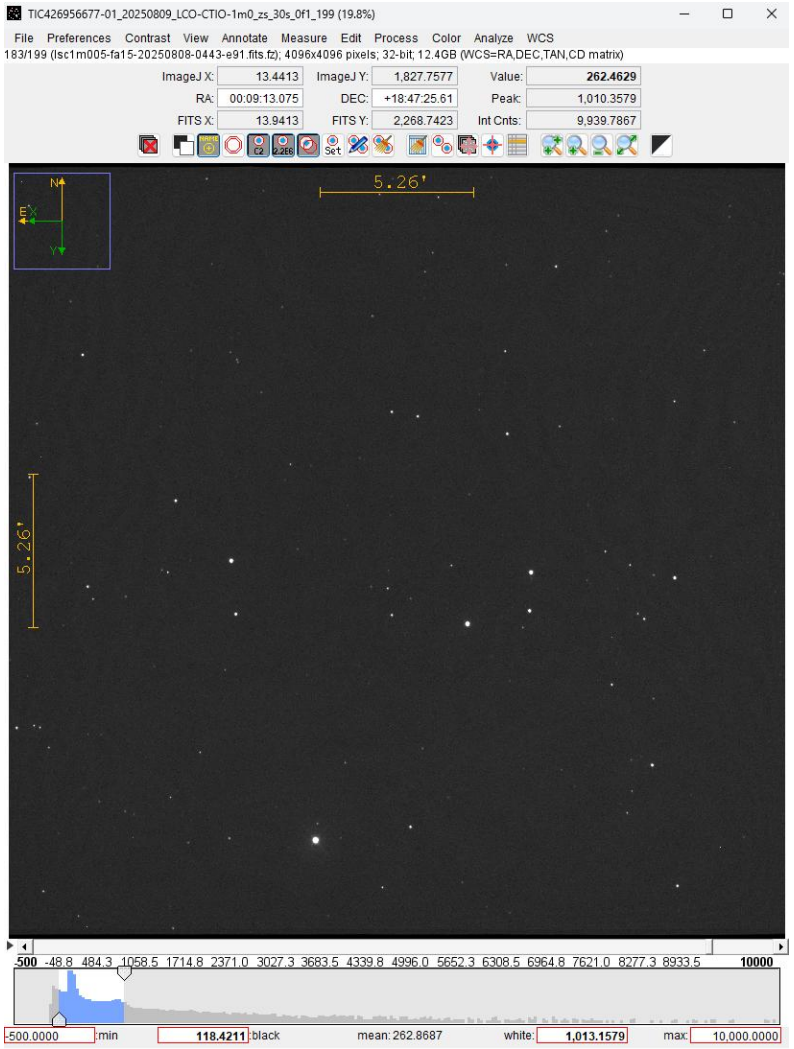


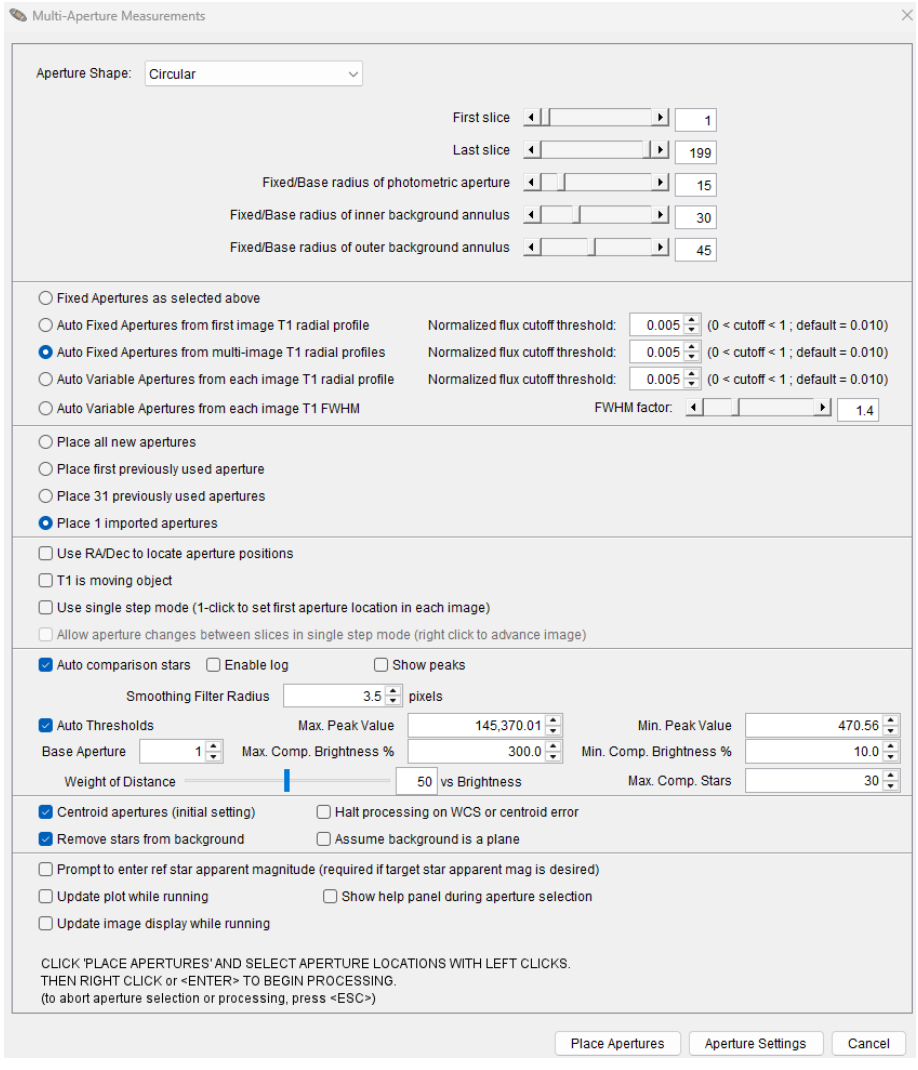
Image Stack Display

- Zoom and pan image with mouse
- Adjust contrast
- Scroll through stack
- Photometer at mouse pointer
- X, Y, East, North, indicators
- Access to all AIJ settings and tools
    - Icons for common settings and tools
    - Menus for all others



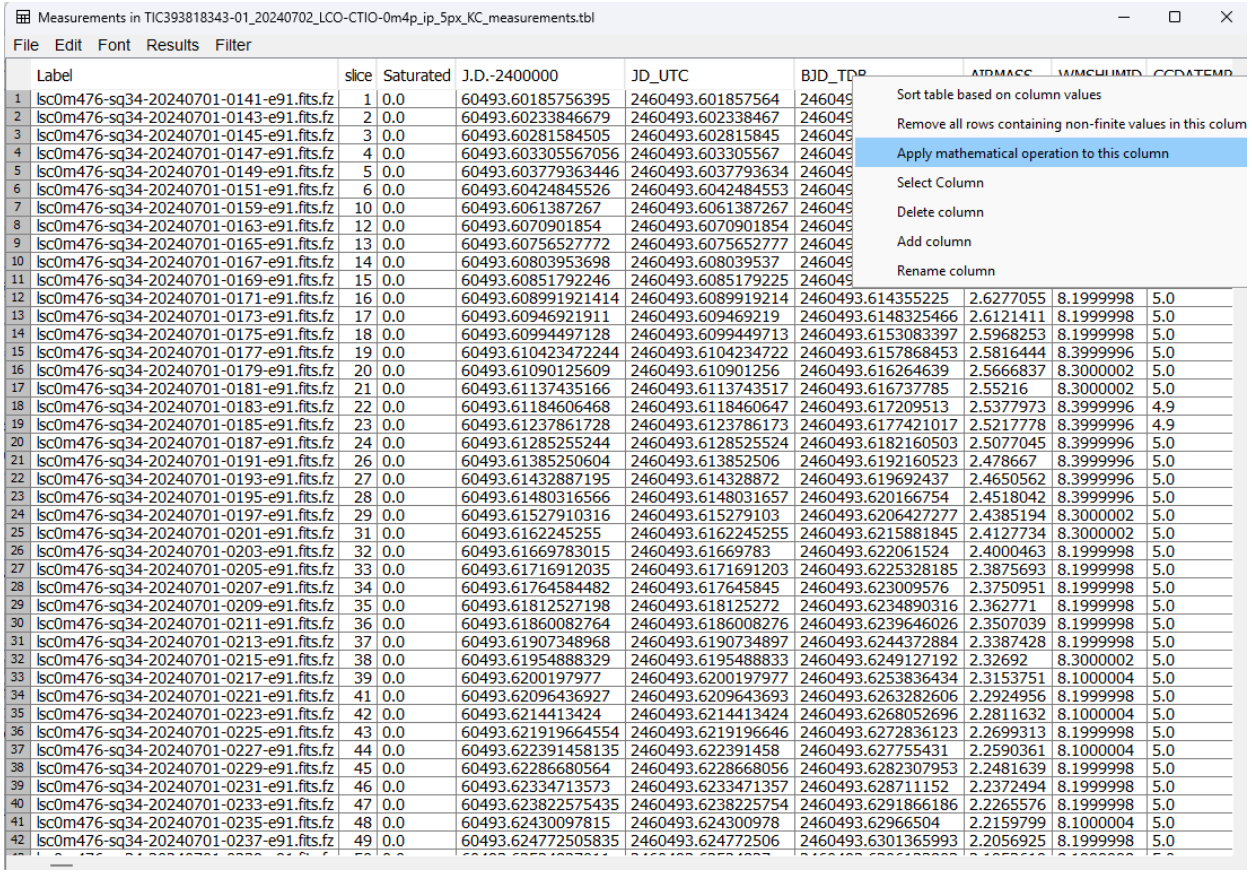
Multi-Aperture

- Select aperture shape
- Select aperture size and size mode
- Select new or saved aperture mode
- Select aperture tracking modes
- Set up auto comp star mode
- Select runtime display options
- Select “Place Apertures” to interactively add, remove, or move apertures in image stack



Measurements Table Display

- Contains all data from multi-aperture run
- Interactive with plotted data
- Searchable
- Sortable
- Editable



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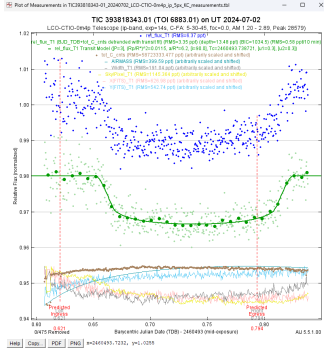
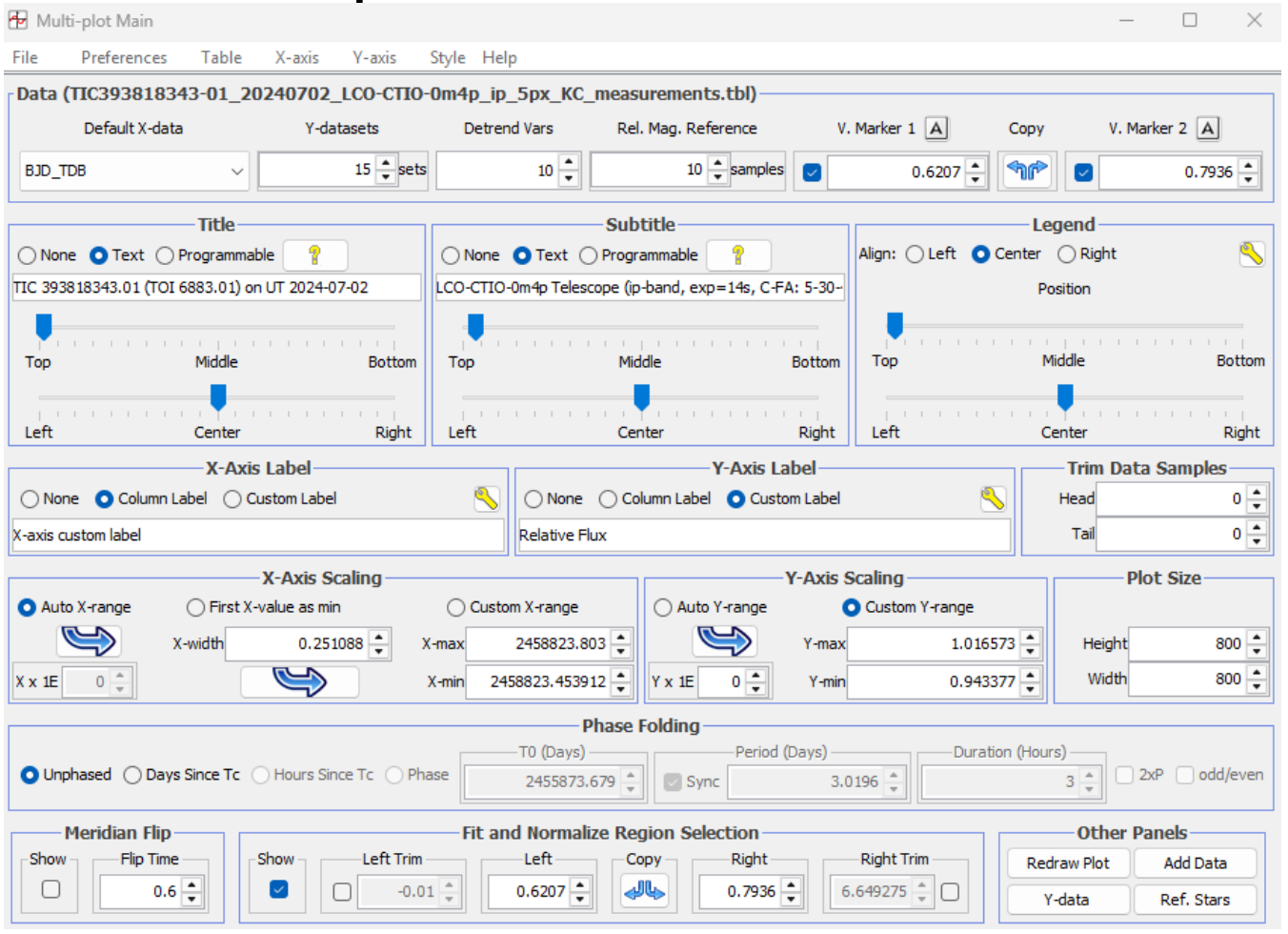
1	lsc0m476-sq34-20240701-0141-e91.fits.fz	1	0.0	60493.60185756395	2460493.601857564	246049			
2	lsc0m476-sq34-20240701-0143-e91.fits.fz	2	0.0	60493.60233846679	2460493.602338467	246049			
3	lsc0m476-sq34-20240701-0145-e91.fits.fz	3	0.0	60493.60281584505	2460493.602815845	246049			
4	lsc0m476-sq34-20240701-0147-e91.fits.fz	4	0.0	60493.603305567056	2460493.603305567	246049			
5	lsc0m476-sq34-20240701-0149-e91.fits.fz	5	0.0	60493.603779363446	2460493.6037793634	246049			
6	lsc0m476-sq34-20240701-0151-e91.fits.fz	6	0.0	60493.60424845526	2460493.6042484553	246049			
7	lsc0m476-sq34-20240701-0159-e91.fits.fz	10	0.0	60493.6061387267	2460493.6061387267	246049			
8	lsc0m476-sq34-20240701-0163-e91.fits.fz	12	0.0	60493.6070901854	2460493.6070901854	246049			
9	lsc0m476-sq34-20240701-0165-e91.fits.fz	13	0.0	60493.60756527772	2460493.6075652777	246049			
10	lsc0m476-sq34-20240701-0167-e91.fits.fz	14	0.0	60493.60803953698	2460493.608039537	246049			
11	lsc0m476-sq34-20240701-0169-e91.fits.fz	15	0.0	60493.60851792246	2460493.6085179225	246049			
12	lsc0m476-sq34-20240701-0171-e91.fits.fz	16	0.0	60493.608991921414	2460493.6089919214	2460493.614355225	2.6277055	8.1999998	5.0
13	lsc0m476-sq34-20240701-0173-e91.fits.fz	17	0.0	60493.60946921911	2460493.609469219	2460493.6148325466	2.6121411	8.1999998	5.0
14	lsc0m476-sq34-20240701-0175-e91.fits.fz	18	0.0	60493.60994497128	2460493.6099449713	2460493.6153083397	2.5968253	8.1999998	5.0
15	lsc0m476-sq34-20240701-0177-e91.fits.fz	19	0.0	60493.610423472244	2460493.6104234722	2460493.6157868453	2.5816444	8.3999996	5.0
16	lsc0m476-sq34-20240701-0179-e91.fits.fz	20	0.0	60493.61090125609	2460493.610901256	2460493.616264639	2.5666837	8.3000002	5.0
17	lsc0m476-sq34-20240701-0181-e91.fits.fz	21	0.0	60493.61137435166	2460493.6113743517	2460493.616737785	2.55216	8.3000002	5.0
18	lsc0m476-sq34-20240701-0183-e91.fits.fz	22	0.0	60493.61184606468	2460493.6118460647	2460493.617209513	2.5377973	8.3999996	4.9
19	lsc0m476-sq34-20240701-0185-e91.fits.fz	23	0.0	60493.61237861728	2460493.6123786173	2460493.6177421017	2.5217778	8.3999996	4.9
20	lsc0m476-sq34-20240701-0187-e91.fits.fz	24	0.0	60493.61285255244	2460493.6128525524	2460493.6182160503	2.5077045	8.3999996	5.0
21	lsc0m476-sq34-20240701-0191-e91.fits.fz	26	0.0	60493.61385250604	2460493.613852506	2460493.6192160523	2.478667	8.3999996	5.0
22	lsc0m476-sq34-20240701-0193-e91.fits.fz	27	0.0	60493.61432887195	2460493.614328872	2460493.619692437	2.4650562	8.3999996	5.0
23	lsc0m476-sq34-20240701-0195-e91.fits.fz	28	0.0	60493.61480316566	2460493.6148031657	2460493.620166754	2.4518042	8.3999996	5.0
24	lsc0m476-sq34-20240701-0197-e91.fits.fz	29	0.0	60493.61527910316	2460493.615279103	2460493.6206427277	2.4385194	8.3000002	5.0
25	lsc0m476-sq34-20240701-0201-e91.fits.fz	31	0.0	60493.6162245255	2460493.6162245255	2460493.6215881845	2.4127734	8.3000002	5.0
26	lsc0m476-sq34-20240701-0203-e91.fits.fz	32	0.0	60493.61669783015	2460493.61669783	2460493.622061524	2.4000463	8.1999998	5.0
27	lsc0m476-sq34-20240701-0205-e91.fits.fz	33	0.0	60493.61716912035	2460493.6171691203	2460493.6225328185	2.3875693	8.1999998	5.0
28	lsc0m476-sq34-20240701-0207-e91.fits.fz	34	0.0	60493.61764584482	2460493.617645845	2460493.623009576	2.3750951	8.1999998	5.0
29	lsc0m476-sq34-20240701-0209-e91.fits.fz	35	0.0	60493.61812527198	2460493.618125272	2460493.6234890316	2.362771	8.1999998	5.0
30	lsc0m476-sq34-20240701-0211-e91.fits.fz	36	0.0	60493.61860082764	2460493.6186008276	2460493.6239646026	2.3507039	8.1999998	5.0
31	lsc0m476-sq34-20240701-0213-e91.fits.fz	37	0.0	60493.61907348968	2460493.6190734897	2460493.6244372884	2.3387428	8.1999998	5.0
32	lsc0m476-sq34-20240701-0215-e91.fits.fz	38	0.0	60493.61954888329	2460493.6195488833	2460493.6249127192	2.32692	8.3000002	5.0
33	lsc0m476-sq34-20240701-0217-e91.fits.fz	39	0.0	60493.6200197977	2460493.6200197977	2460493.6253836434	2.3153751	8.1000004	5.0
34	lsc0m476-sq34-20240701-0221-e91.fits.fz	41	0.0	60493.62096436927	2460493.6209643693	2460493.6263282606	2.2924956	8.1999998	5.0
35	lsc0m476-sq34-20240701-0223-e91.fits.fz	42	0.0	60493.6214413424	2460493.6214413424	2460493.6268052696	2.2811632	8.1000004	5.0
36	lsc0m476-sq34-20240701-0225-e91.fits.fz	43	0.0	60493.621919664554	2460493.6219196646	2460493.6272836123	2.2699313	8.1999998	5.0
37	lsc0m476-sq34-20240701-0227-e91.fits.fz	44	0.0	60493.622391458135	2460493.622391458	2460493.627755431	2.2590361	8.1000004	5.0
38	lsc0m476-sq34-20240701-0229-e91.fits.fz	45	0.0	60493.62286680564	2460493.6228668056	2460493.6282307953	2.2481639	8.1999998	5.0
39	lsc0m476-sq34-20240701-0231-e91.fits.fz	46	0.0	60493.62334713573	2460493.6233471357	2460493.628711152	2.2372494	8.1999998	5.0
40	lsc0m476-sq34-20240701-0233-e91.fits.fz	47	0.0	60493.623822575435	2460493.6238225754	2460493.6291866186	2.2265576	8.1999998	5.0
41	lsc0m476-sq34-20240701-0235-e91.fits.fz	48	0.0	60493.62430097815	2460493.624300978	2460493.62966504	2.2159799	8.1000004	5.0
42	lsc0m476-sq34-20240701-0237-e91.fits.fz	49	0.0	60493.624772505835	2460493.624772506	2460493.6301365993	2.2056925	8.1999998	5.0

Multi-plot Main

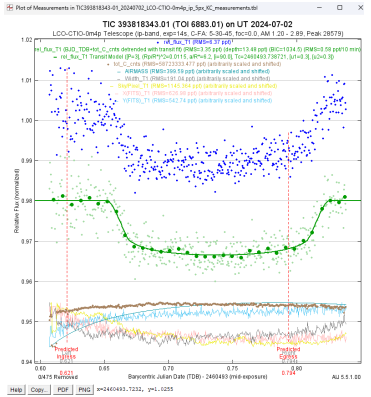
- Controls related to overall plot
- Titling
- Axis labeling
- Axis Scaling
- Legend
- Plot size





Multi-plot Y-data

- Controls related to individual plotted datasets
- Color, symbol shape
- Fitting mode
- Data averaging and binning

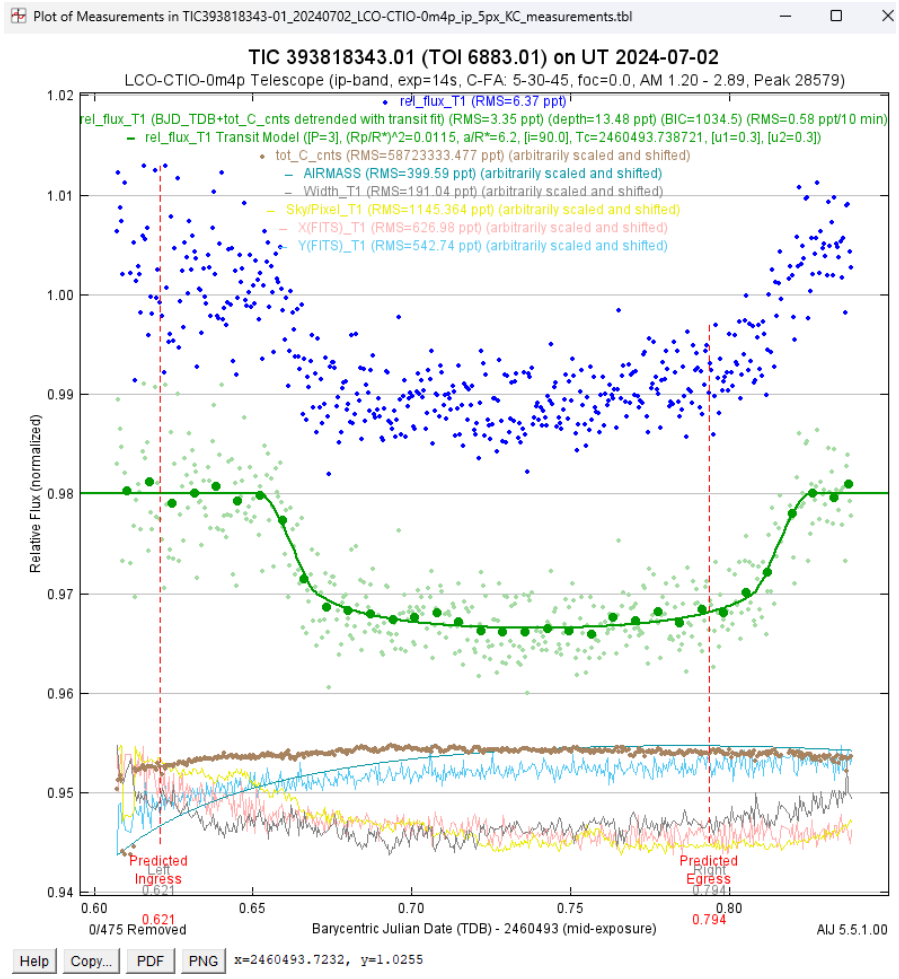


Multi-plot Y-data

Data Set	New Col	Plot	Auto Scale	X-data	Input in Mag	Y-data	Func-tion	Y-operand	Show Error	Color	Symbol	Lines	Input Average	Spline Smooth	Fit Mode	Trend Select	Trend Coefficient	Trend Dataset	Norm/ Mag Ref	Out Mag	Page Rel	Scale	then Shift	Out Bin Err	BinSize (min)
1		☑	☑	default	☐	rel_flux_T1	☐		☐	blue	dot	☐	1	☐			0.0000023			☐	☐	1	0	☐	5
2		☐	☑	default	☐	rel_flux_T1	☐		☐	red	box	☐	5	☐			0			☐	☐	1	-0.008	☐	5
3		☑	☑	default	☐	rel_flux_T1	☐		☐	dark gre...	dot	☐	1	☐			-0.000000	tot_C_cnts		☐	☐	1	-0.02	☑	10
4		☐	☑	default	☐	rel_flux_C2	☐		☐	magenta	X	☐	1	☐	off		-0.0001225			☐	☐	1	-0.04	☐	5
5		☐	☑	default	☐	rel_flux_C3	☐		☐	black	X	☐	1	☐	off		0.0000094			☐	☐	1	-0.045	☐	5
6		☐	☑	default	☐	rel_flux_C4	☐		☐	red	X	☐	1	☐	off		-0.0000517			☐	☐	1	-0.05	☐	5
7		☐	☑	default	☐	rel_flux_C5	☐		☐	purple	X	☐	1	☐	off		-0.0015111			☐	☐	1	-0.055	☐	5
8		☐	☑	default	☐	rel_flux_C6	☐		☐	light blue	X	☐	1	☐	off		0.0000020			☐	☐	1	-0.06	☐	5
9		☐	☑	default	☐	rel_flux_C7	☐		☐	dark gre...	X	☐	1	☐	off		0.0000997			☐	☐	1	-0.065	☐	5
10		☑	☑	default	☐	tot_C_cnts	☐		☐	brown	dot	☐	1	☐	off		0		off	☐	☑	15	-42	☐	5
11		☑	☑	default	☐	AIRMASS	☐		☐	teal	line	☐	1	☐	off		0		off	☐	☑	-15	-42	☐	5
12		☑	☑	default	☐	Width_T1	☐		☐	gray	line	☐	1	☐	off		0		off	☐	☑	15	-42	☐	5
13		☑	☑	default	☐	Sky/Pixel_T1	☐		☐	yellow	line	☐	1	☐	off		0		off	☐	☑	15	-42	☐	5
14		☑	☑	default	☐	X(FITS)_T1	☐		☐	pink	line	☐	1	☐	off		0		off	☐	☑	15	-42	☐	5
15		☑	☑	default	☐	Y(FITS)_T1	☐		☐	light blue	line	☐	1	☐	off		0		off	☐	☑	15	-42	☐	5

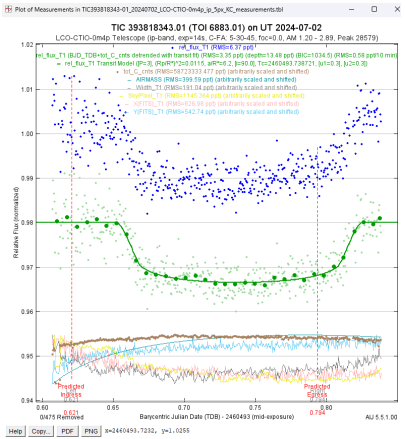
Plot Window

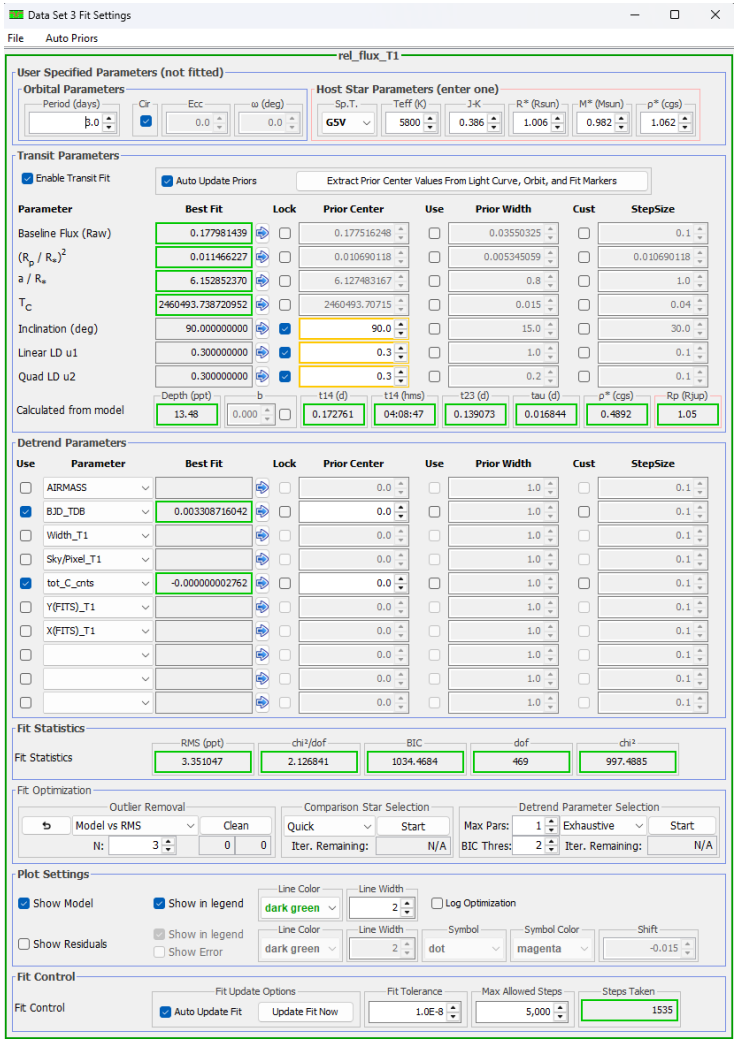
- Displays plotted dataset(s)
- Is interactive with mouse and data table
- Zoom and pan with mouse



Lightcurve Fitting Panel

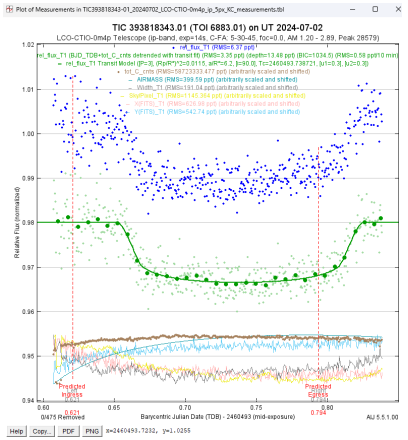
- Set up initial fitting parameters
- View fitted values
- Manually select detrending
- Auto remove bad data points (“clean”)
- Auto optimize comparison stars
- Auto optimize detrending

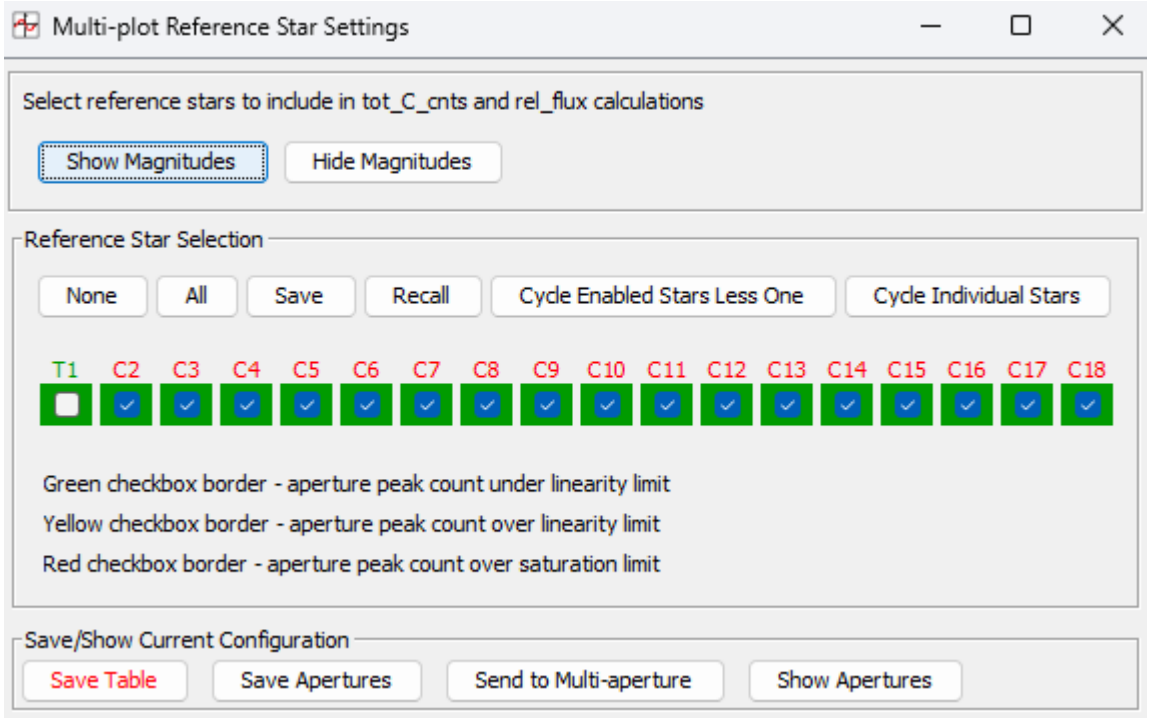




Reference Star Panel

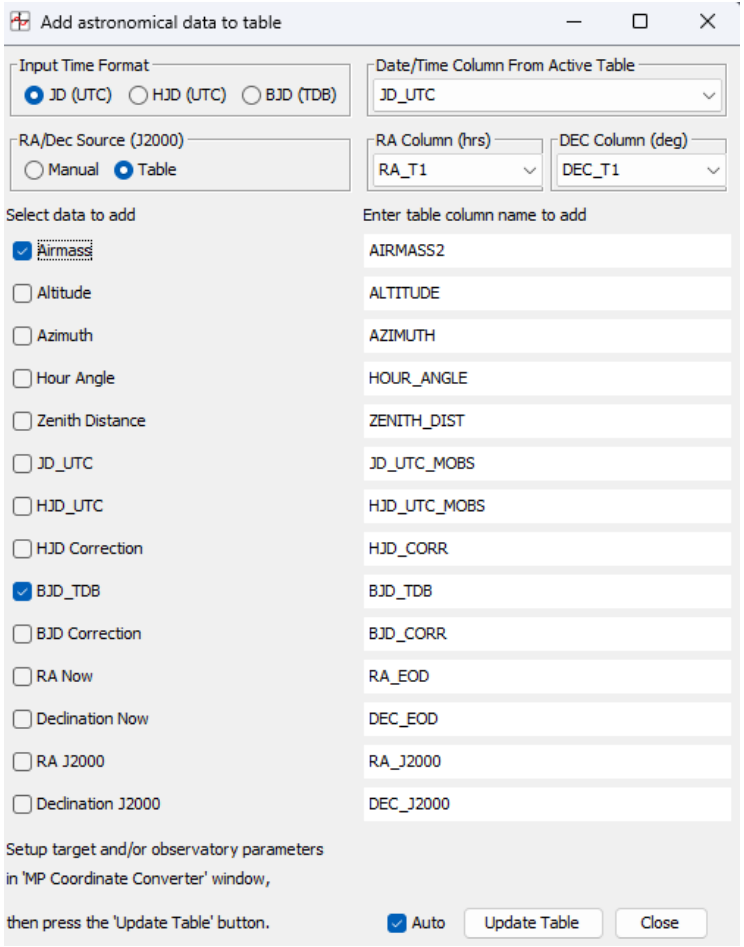
- Interactively change comparison stars
- Add comp star magnitude data (optional)





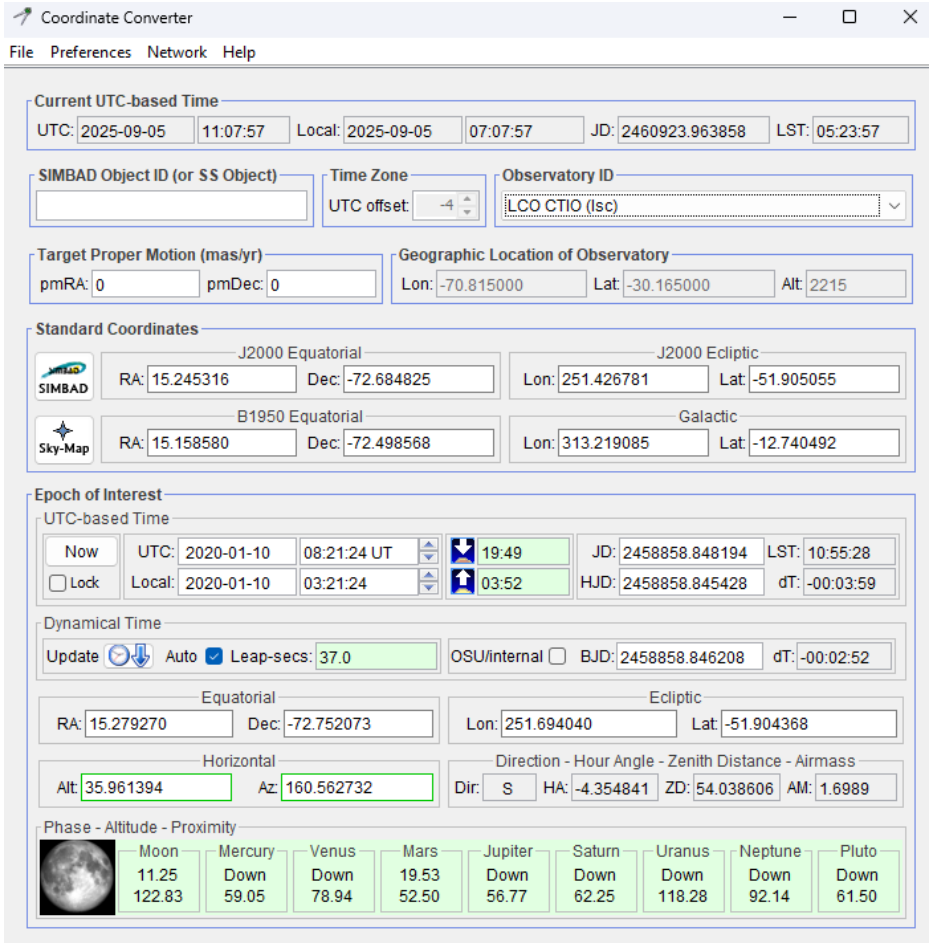
Add Astronomical Data Panel

- Add calculated data to measurements table
- Examples are BJD_TDB, airmass, etc.
- Optionally runs automatically at end of each Multi-Aperture run



Coordinate Converter Panel

- Convert between time formats
- Convert between coordinate formats
- Calculates observability parameters
- Includes leap second calculations
- Manual control or automatic control from:
    - Data Processor
    - Add Data panel



Submit Your Results!

- Use File => “Save All” to save reduced data files
- Run NEBcheck (if still needed)
- Upload reduced data to ExoFOP
- Send summary email to SG1 lead
- Select and observe your next target from the TTF!

Planet Publication Techniques

- Typical methods used for publishing transiting planet discoveries
  - Statistical validation
    - Typically uses TESS and ground-based lightcurves to show <1% chance of false positive
    - May also include spectroscopic stellar parameters, high resolution imaging, and Gaia magnitudes to strengthen results
    - Yields planet size, but not mass
  - Radial velocity mass confirmation
    - Models lightcurve data, precise radial velocities, stellar parameters, Gaia parallax and other catalog data to virtual push the chance of a false positive to near 0%
    - Yields planet size and mass, and thus bulk density and constraints on composition
  - Transit timing variation confirmation
    - Models many transit observations from TESS and ground to characterize TTVs
    - Yields planet size, and often planet mass, and pushes chance of false positive to near 0%

Publication Process

- TFOP lead authors request to post abstract of planet discovery on “TESS Wiki” protected website
- Lead author will review and select data from ExoFOP (SG1 leads will shadow to ensure proper data inclusion when practical)
- You may be asked to provide a short write describing your equipment and observation (SG1 leads attempt to help with this part when practical)
- When your data are useful for a publication, you will be nominated to join the paper as coauthor
- You will need to review the paper and agree to join as coauthor
- Lead author takes paper through peer review process
- Paper will appear in peer reviewed journal, including you as coauthor

Join the Fun!

- If you are new to transit observing, I highly recommend two training approaches
  - Go to Dennis Conti's website and work through his "**A Practical Guide to Exoplanet Observing**"
  - Attend an online AAVSO **"Introduction to Exoplanet Observing"** course, and possibly the more advanced course **"Advanced Use of AstroImageJ for Exoplanet Observing"**
- Apply to join TFOP
  - Dennis Conti (AAVSO) offers a program to qualify AAVSO members to join TFOP
  - Experienced transit observers may opt to apply directly following instructions at https://tess.mit.edu/followup/apply-join-tfop
    - Send email to TFOP SG1 Lead (current me), answering bulleted questions
    - Read and agree to abide by the TFOP WG Charter (7 pages)
    - Read and agree to abide by the TFOP WG Publication Policy (3 pages)