EXPLORE

exoplanet orbit research

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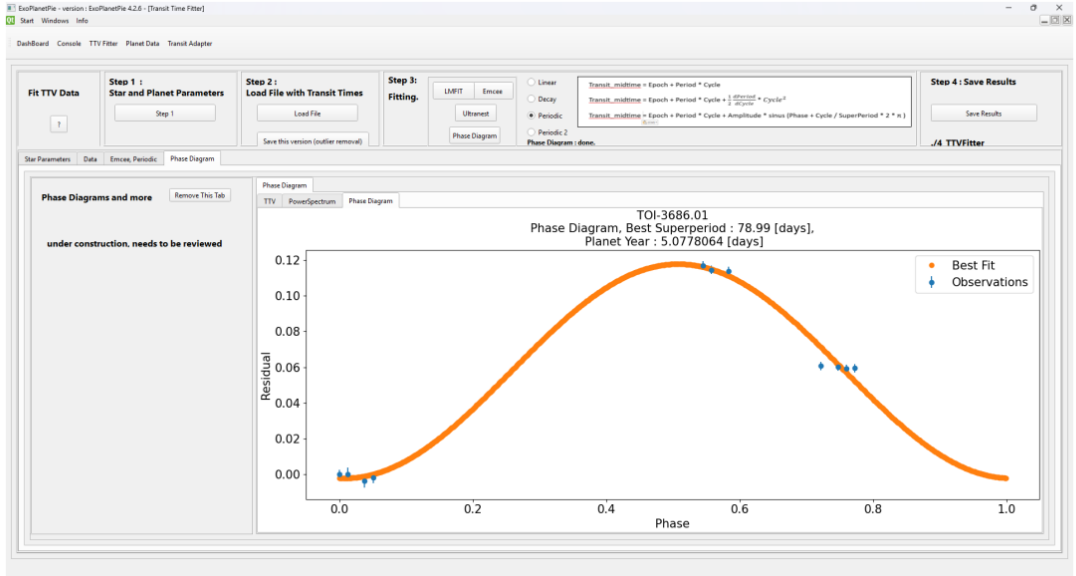


Introduction

Citizen-science project focused on Transit Timing Variations (TTVs)

Main goal: support observations of exoplanets with TTVs

Discovery of multiplanet systems using TTVs

EXPLORE website includes:

- Target lists
- Observing guides & tutorials
- Links to software, papers & presentations

Working Group

- **Active members:**
  - Rodney Buckland The open university, BAA
  - Dennis Conti AAVSO
  - Franky Dubois VVS
  - Roger Dymock BAA
  - Allan Schmitt Caltech
  - Trifon Trifonov University of Heidelberg/Sofia
  - Siegfried Vanaverbeke VVS, KUL
  - Pieter Vuylsteke VVS, KUL

Objectives

Identify planets showing TTVs

- from ExoClock, TESS and other databases

Analyze TTV signals to constrain

- planetary & system parameters
- (Exoplanetpie, LcTools, PlanSim)

Determine possible causes of TTVs

- (extra planets, orbital decay, star-planet interaction, …)

Follow-up promising candidates

- (new exoplanets, variable stars, etc.)

Observation and Analysis Process

Amateur contribution

Target list (mainly ExoClock + TESS…)

Observing guides

Observe & upload to ExoClock / AAVSO/exoFOP

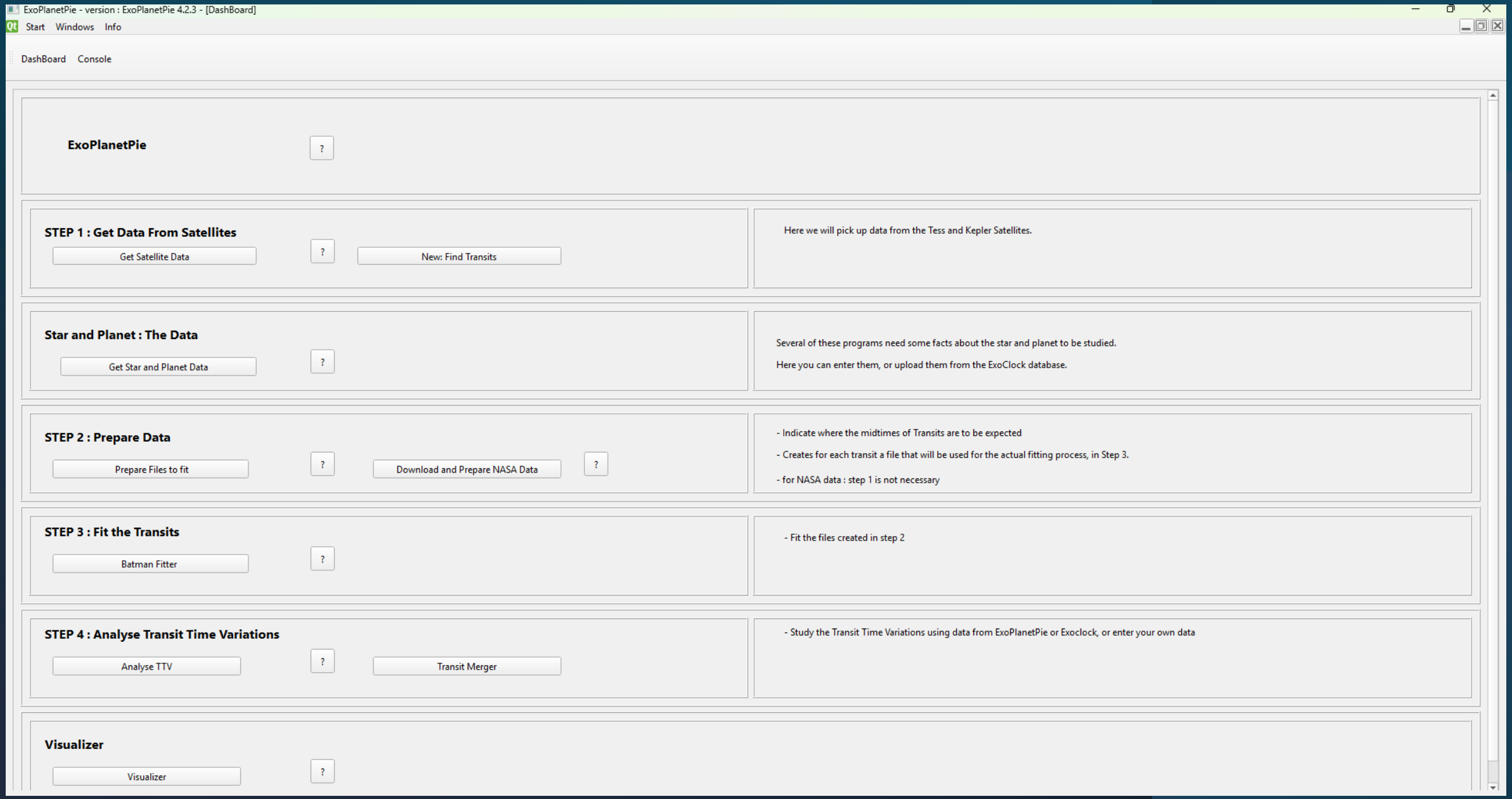
Analysis & modeling

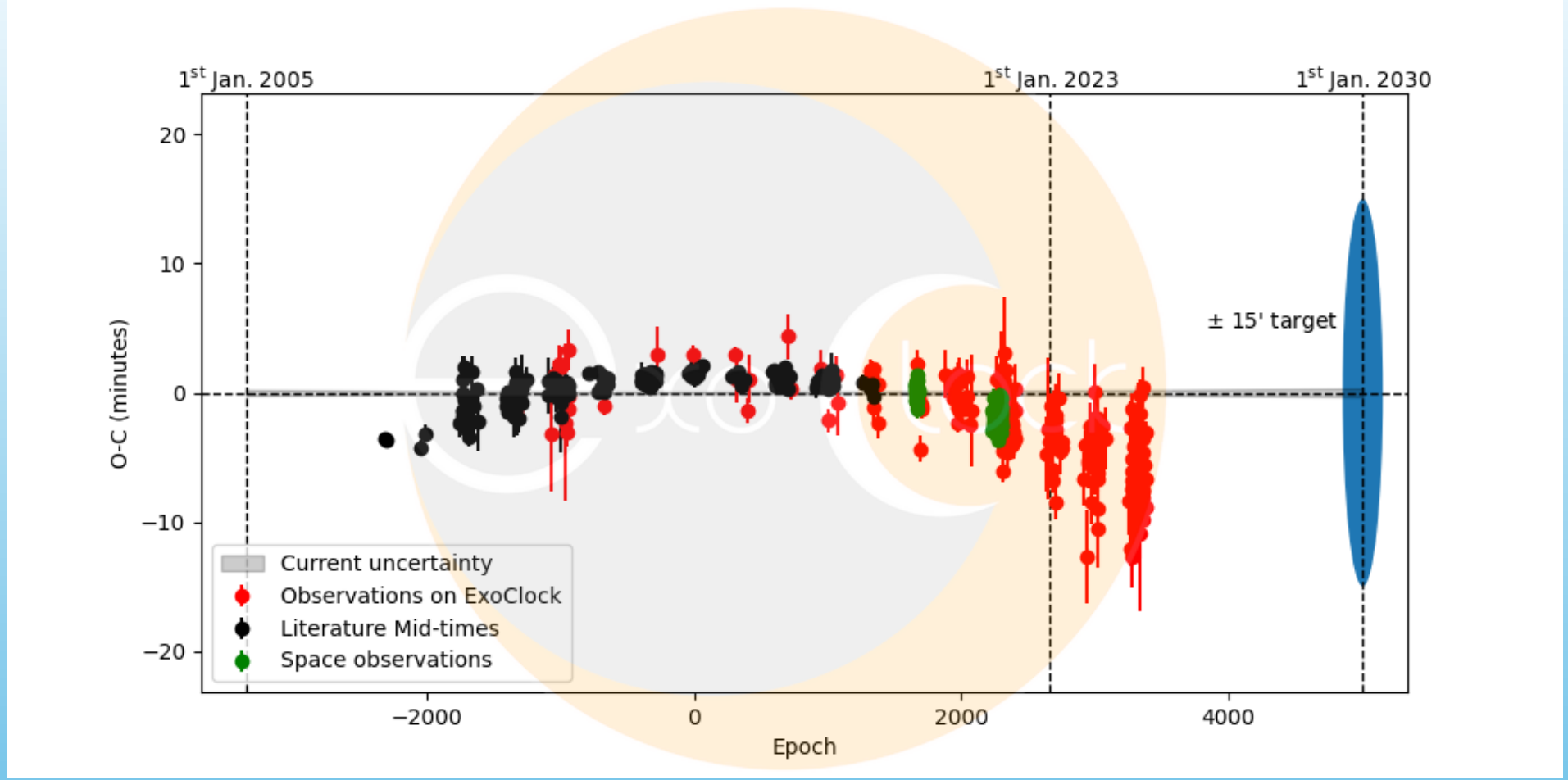
TTV detection (Exoplanetpie, LcTools, PlanSim)

Search for new systems in TESS data

Non-Keplerian effects(e. g. tidal decay in hot Jupiters)

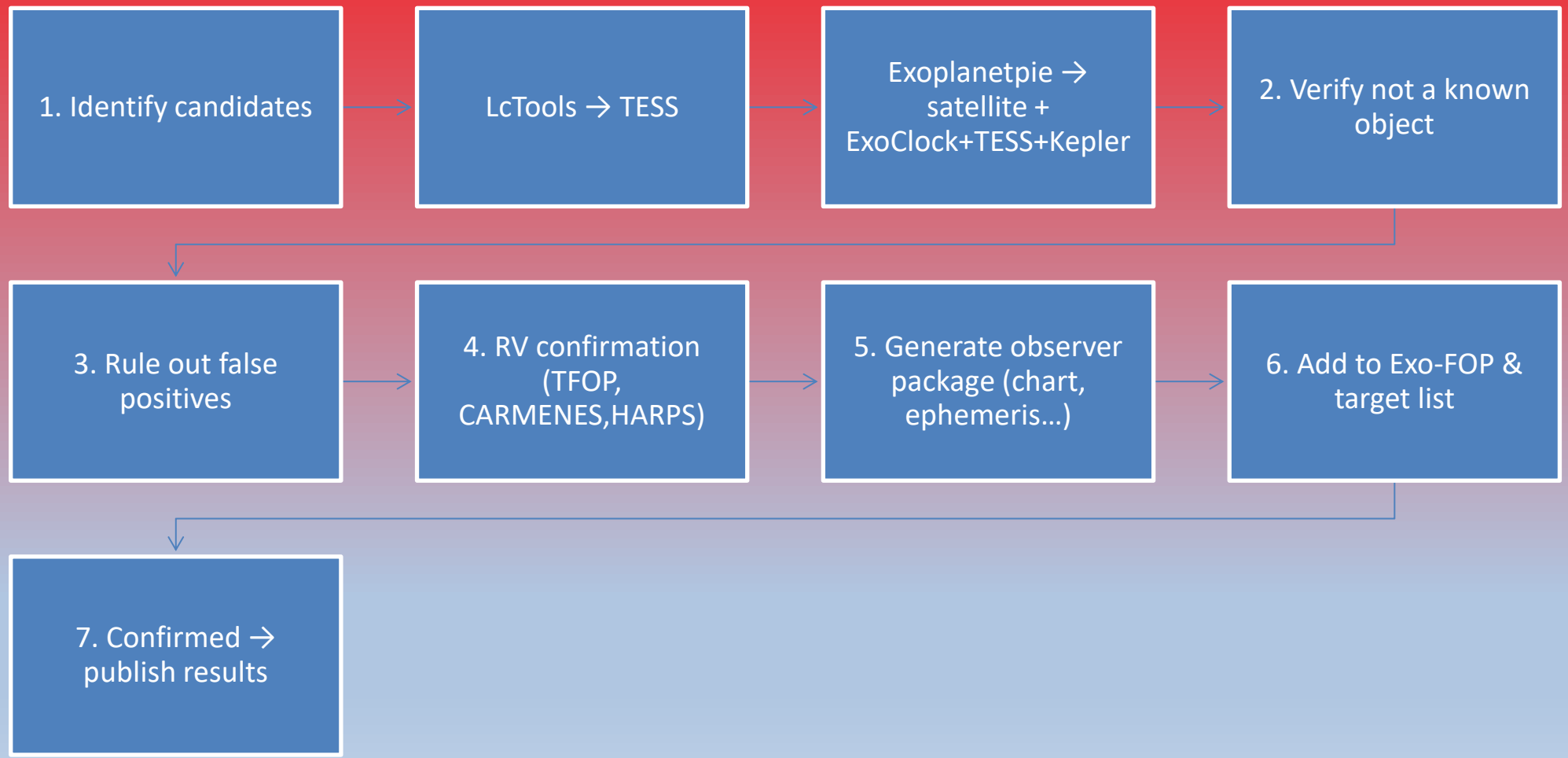
EXOPLANETPIE SOFTWARE GUI





WASP 12b: TTV analysis using exoplanetPie

Discovery Process for new objects

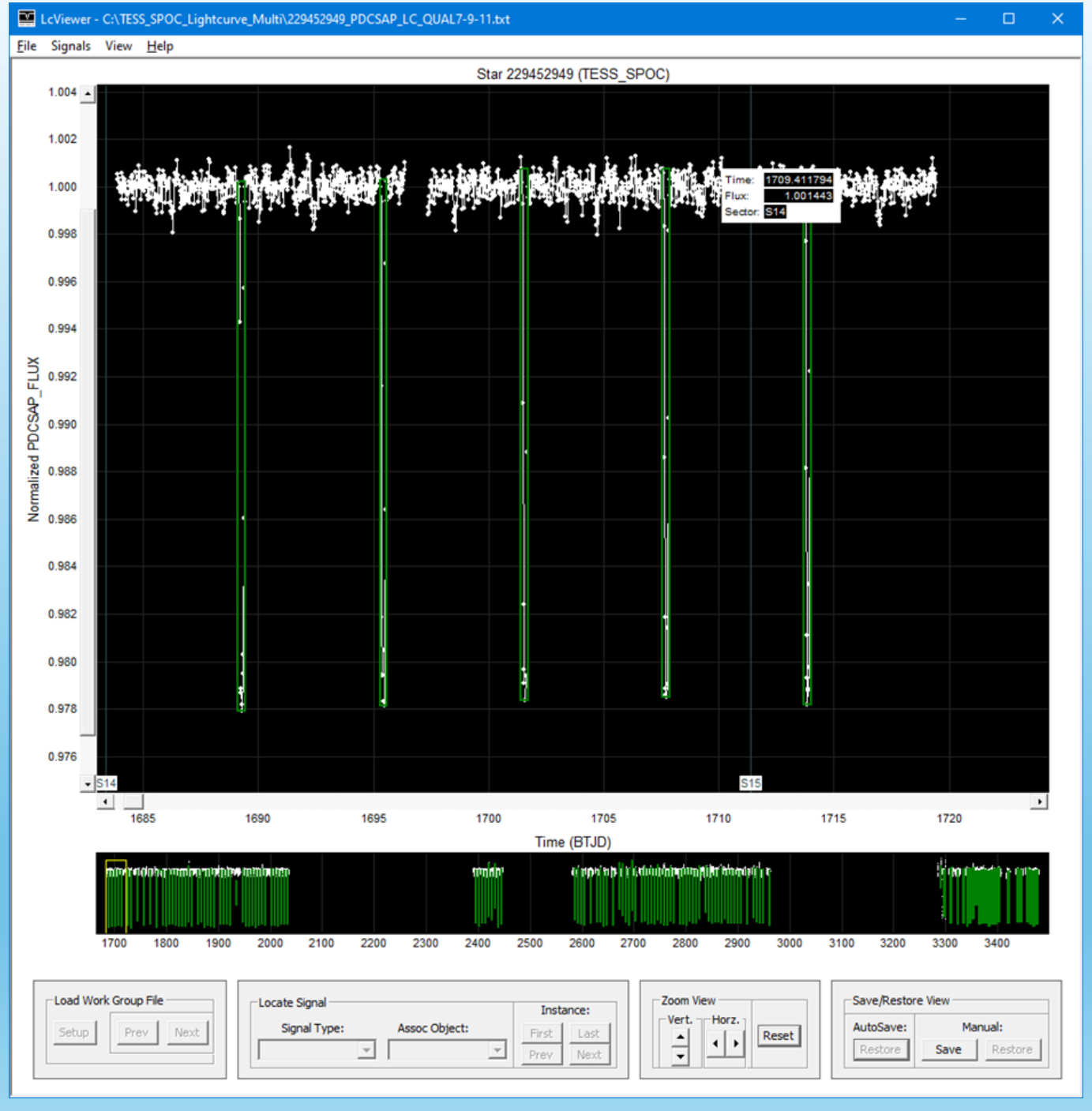


TIC 229452949

The LcTools suite; LcGenerator, LcSignalFinder and LcViewer is being used to analyse TESS SPOC stars observed in multiple sectors. The data is downloaded from the LcTools website.

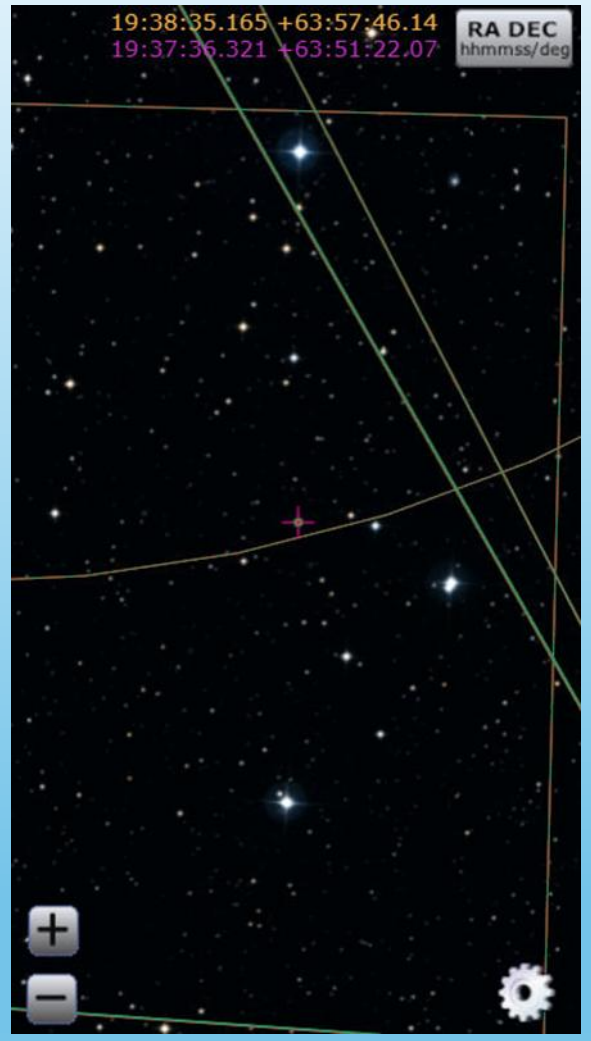
This plot shows multiple transits of possible exoplanet TIC 229452949

RA; 19 37 36.31, Dec; +63 51 22.1
Period; 6.1426970 days
Transit duration; 4.8 hrs
Transit depth; 22.9 mmag

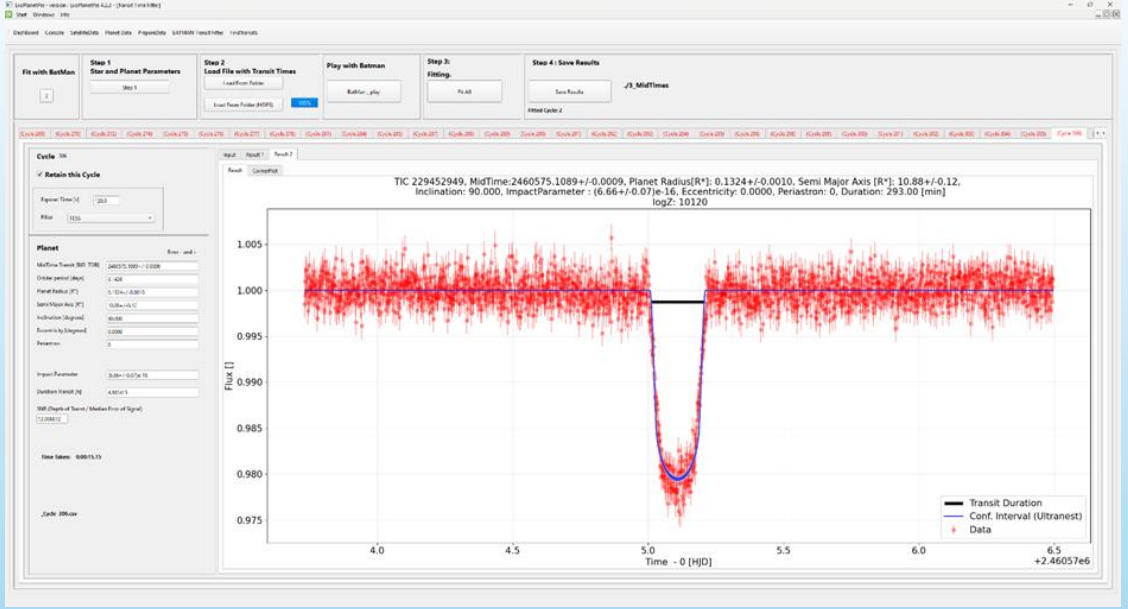


TIC 229452949

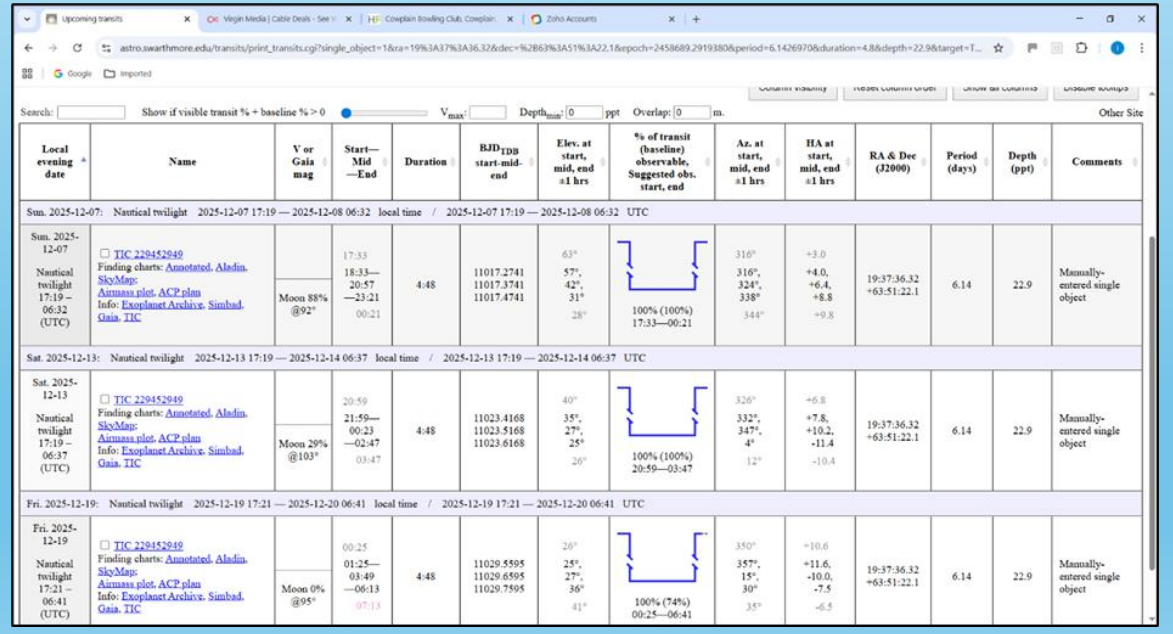
Additional data was obtained from MAST, Exoplanetpie and the Swarthmore Transit Finder.



MAST



Exoplanetpie

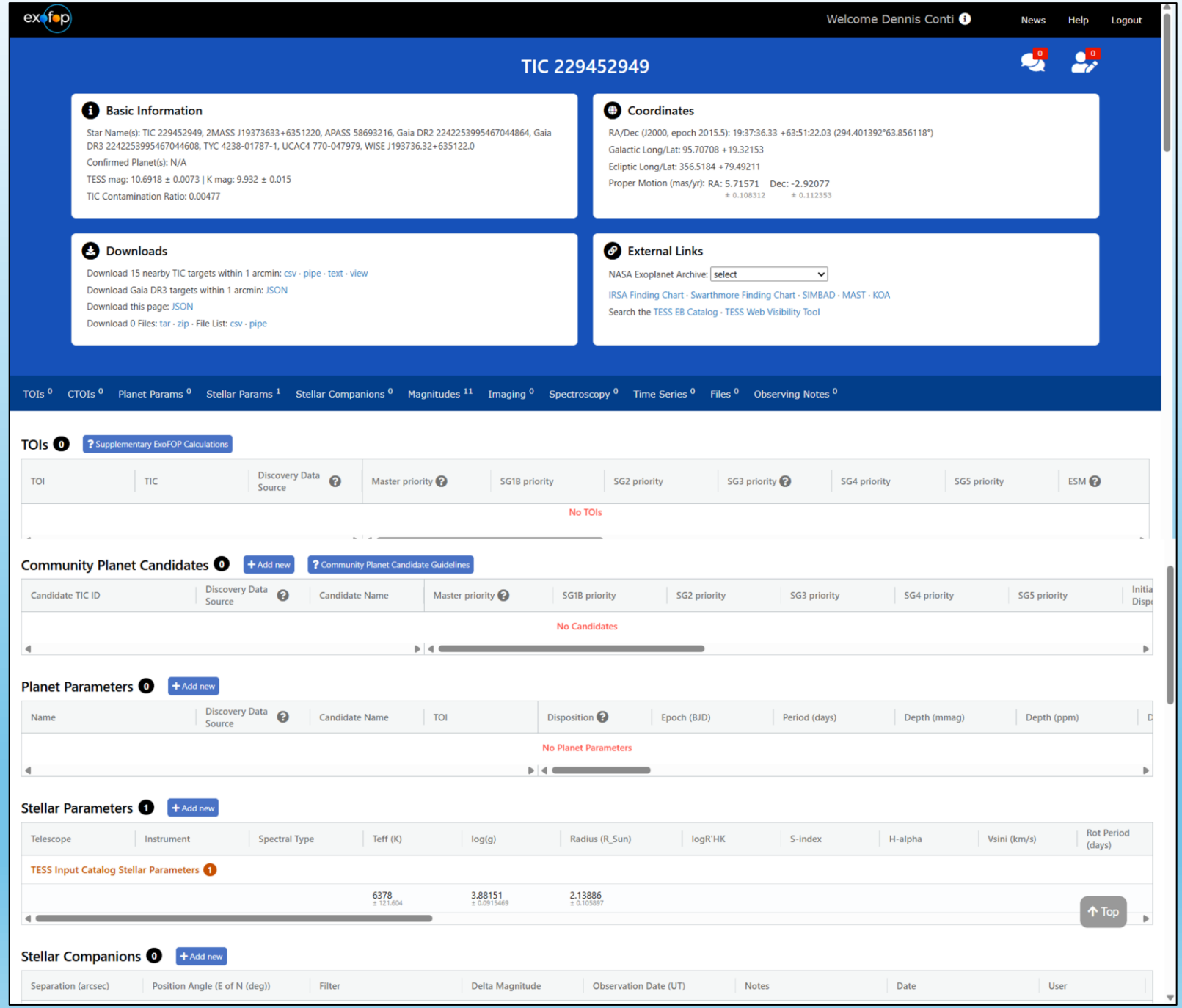


Local evening date	Name	V or Gaia mag	Start—Mid—End	Duration	BJD_TDB start-mid-end	Elev. at start, mid, end ±1 hrs	% of transit (baseline) observable, Suggested obs. start, end	Az. at start, mid, end ±1 hrs	HA at start, mid, end ±1 hrs	RA & Dec (J2000)	Period (days)	Depth (ppt)	Comments
Sun. 2025-12-07: Nautical twilight 2025-12-07 17:19 — 2025-12-08 06:32 local time / 2025-12-07 17:19 — 2025-12-08 06:32 UTC													
Sun. 2025-12-07 Nautical twilight 17:19 – 06:32 (UTC)	TIC 229452949 Finding charts: Annotated, Aladin, SkyMap; Airmass plot, ACP plan Info: Exoplanet Archive, Simbad, Gaia, TIC	Moon 88% @92°	17:33 18:33—20:57—23:21 00:21	4:48	11017.2741 11017.3741 11017.4741	63° 57°, 42°, 31° 28°	100% (100%) 17:33—00:21	316° 316°, 324°, 338° 344°	+3.0 +4.0, +6.4, +8.8 +9.8	19:37:36.32 +63:51:22.1	6.14	22.9	Manually-entered single object
Sat. 2025-12-13: Nautical twilight 2025-12-13 17:19 — 2025-12-14 06:37 local time / 2025-12-13 17:19 — 2025-12-14 06:37 UTC													
Sat. 2025-12-13 Nautical twilight 17:19 – 06:37 (UTC)	TIC 229452949 Finding charts: Annotated, Aladin, SkyMap; Airmass plot, ACP plan Info: Exoplanet Archive, Simbad, Gaia, TIC	Moon 29% @103°	20:59 21:59—00:23—02:47 03:47	4:48	11023.4168 11023.5168 11023.6168	40° 35°, 27°, 25° 26°	100% (100%) 20:59—03:47	326° 332°, 347°, 4° 12°	+6.8 +7.8, +10.2, -11.4 -10.4	19:37:36.32 +63:51:22.1	6.14	22.9	Manually-entered single object
Fri. 2025-12-19: Nautical twilight 2025-12-19 17:21 — 2025-12-20 06:41 local time / 2025-12-19 17:21 — 2025-12-20 06:41 UTC													
Fri. 2025-12-19 Nautical twilight 17:21 – 06:41 (UTC)	TIC 229452949 Finding charts: Annotated, Aladin, SkyMap; Airmass plot, ACP plan Info: Exoplanet Archive, Simbad, Gaia, TIC	Moon 0% @95°	00:25 01:25—03:49—06:13 07:13	4:48	11029.5595 11029.6595 11029.7595	26° 25°, 27°, 36° 41°	100% (74%) 00:25—06:41	350° 357°, 15°, 30° 35°	+10.6 +11.6, -10.0, -7.5 -6.5	19:37:36.32 +63:51:22.1	6.14	22.9	Manually-entered single object

Swarthmore Transit Finder

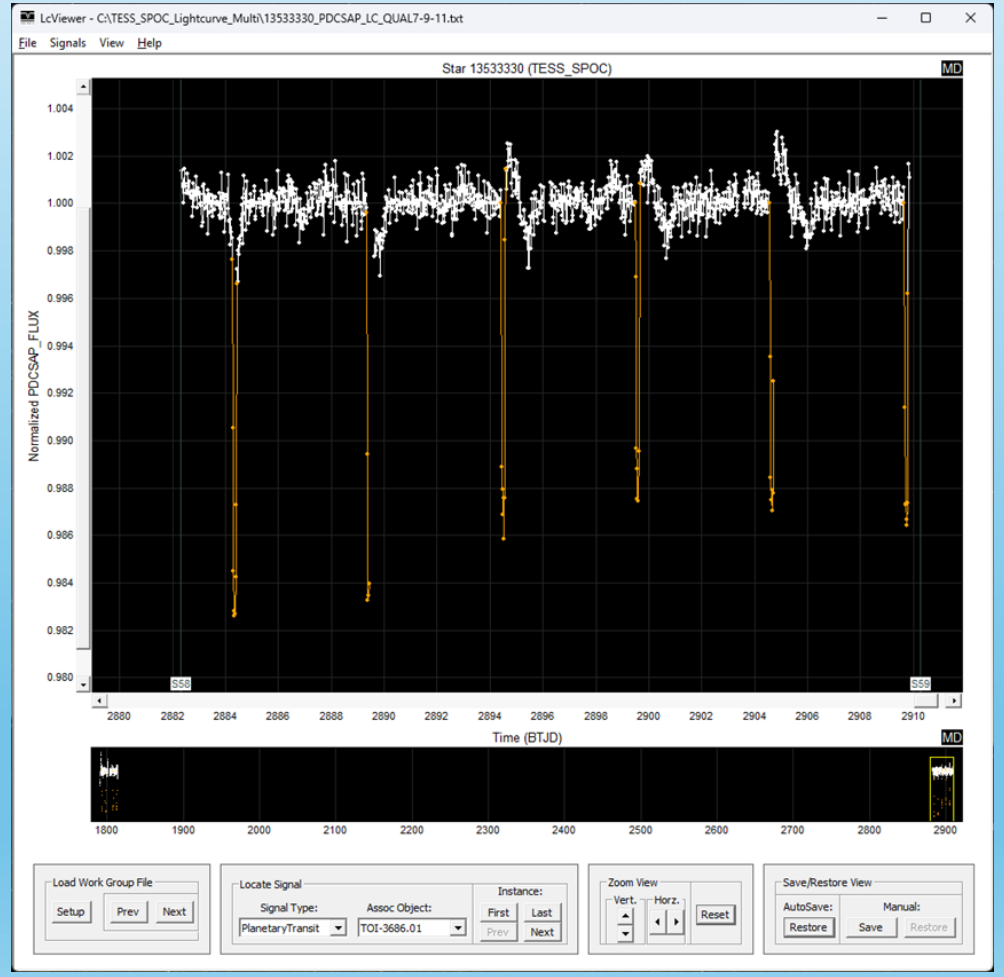
TIC 229452949

ExoFOP database entry for TIC 229452949 showing that it has not yet been identified as a TOI (target of interest)

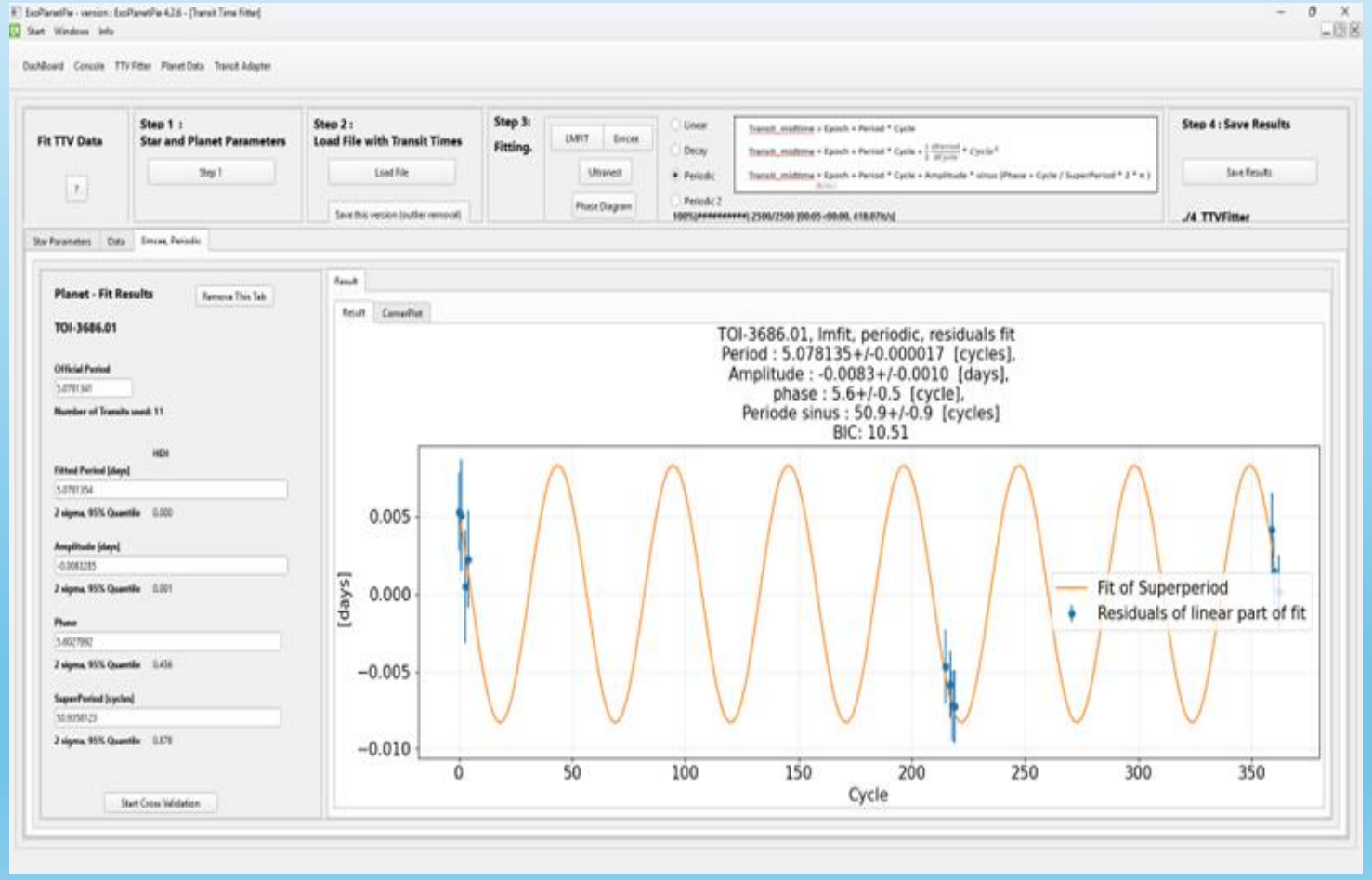


TOI-3686, TIC 13533330

This object exhibits a large TTV of 0.0083 days - 12 minutes. The LcTools data suggests that the variation is cyclical. Possible reasons are; starspots, change in orbital inclination, orbital precession, exomoons or orbital resonances.

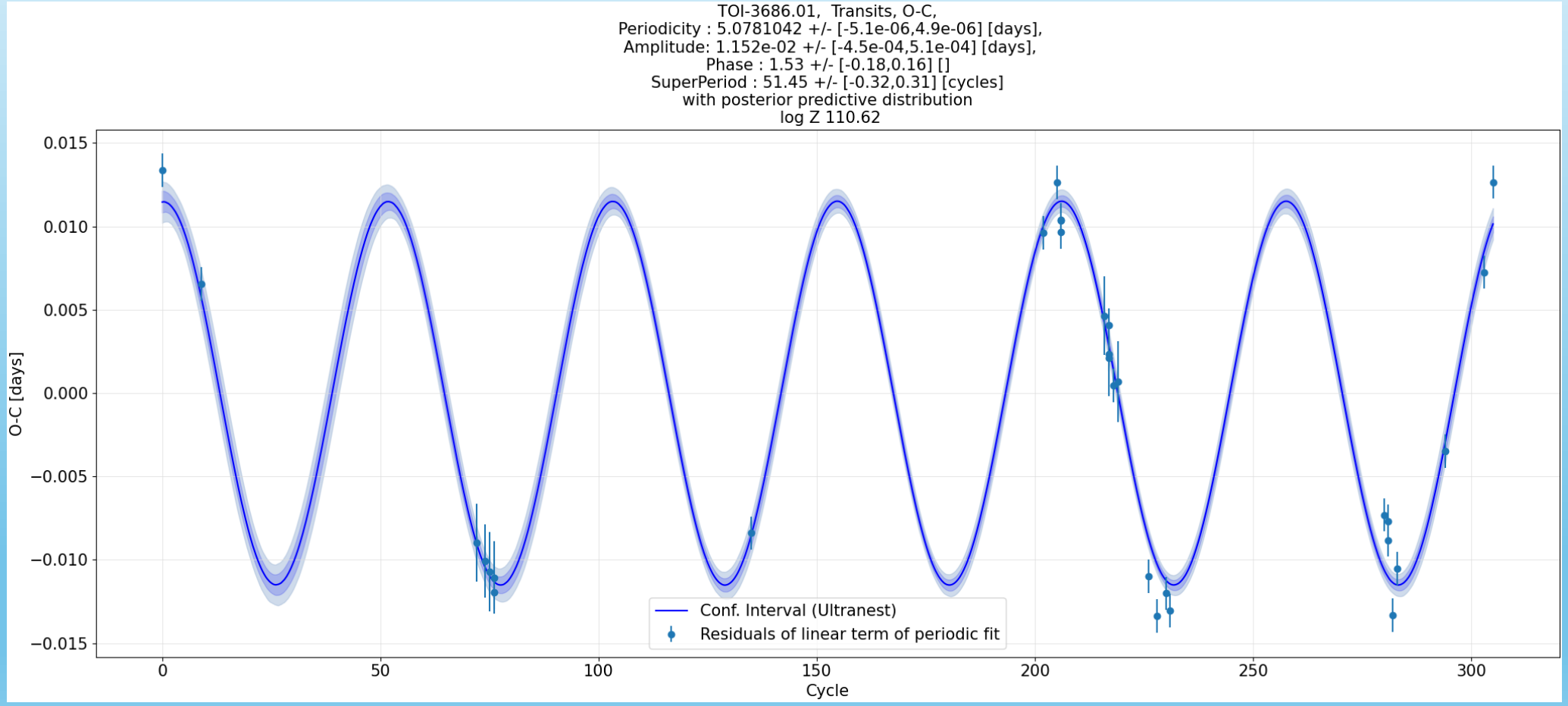


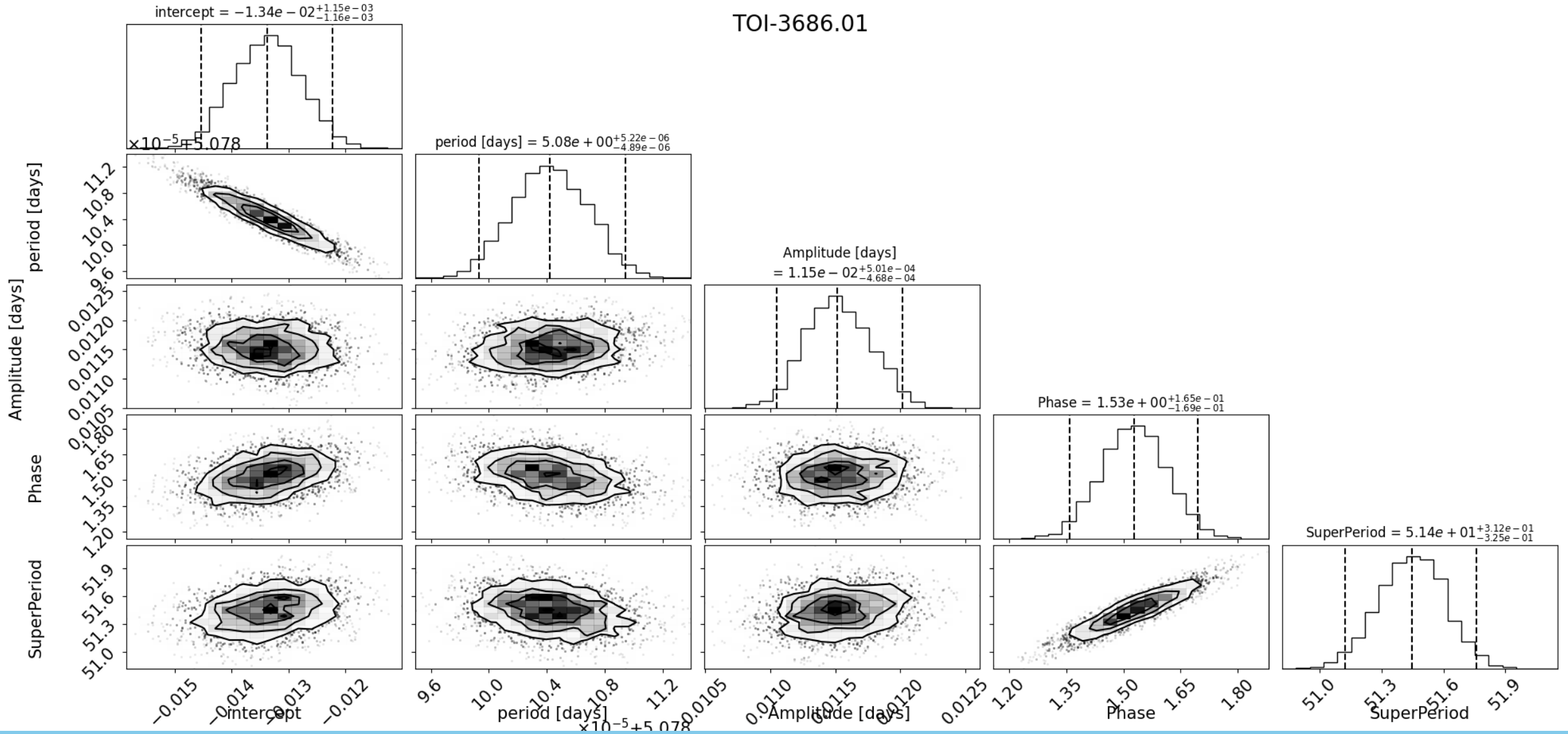
Lc Tools



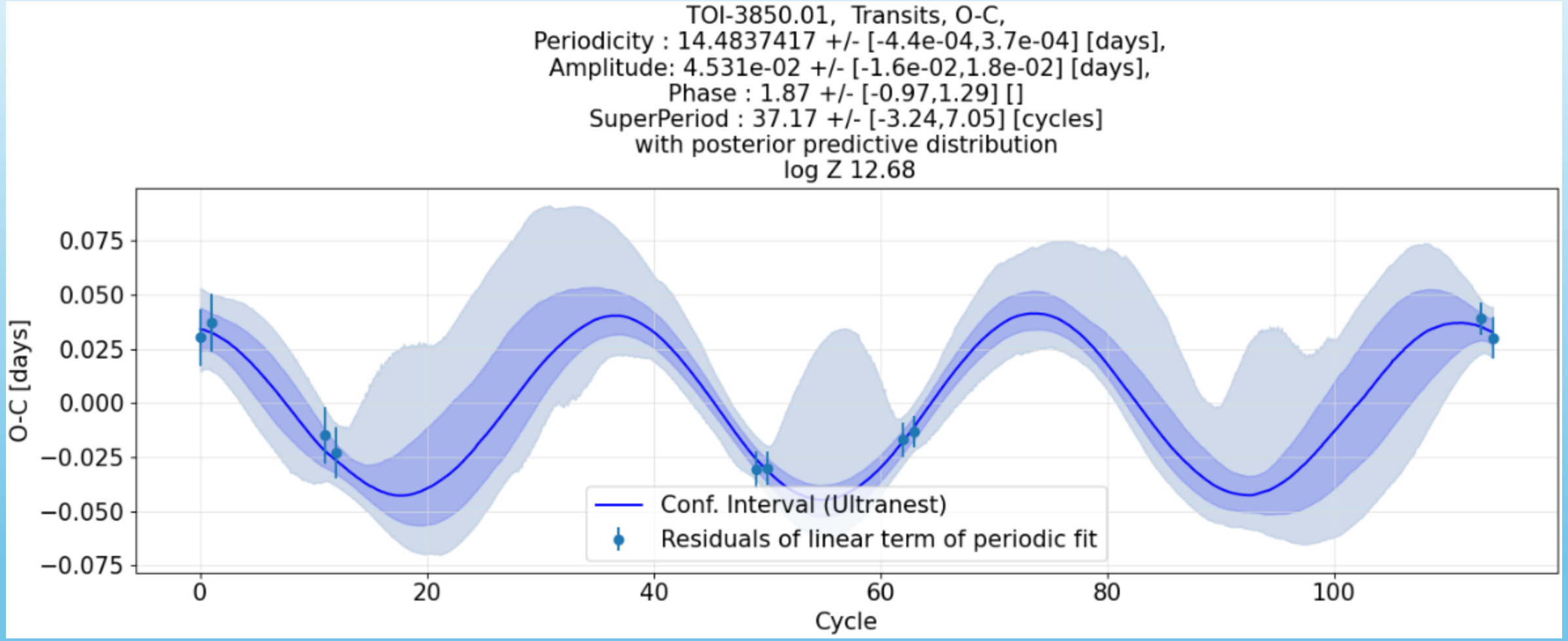
Exoplanetpie

TOI-3686, TIC 13533330

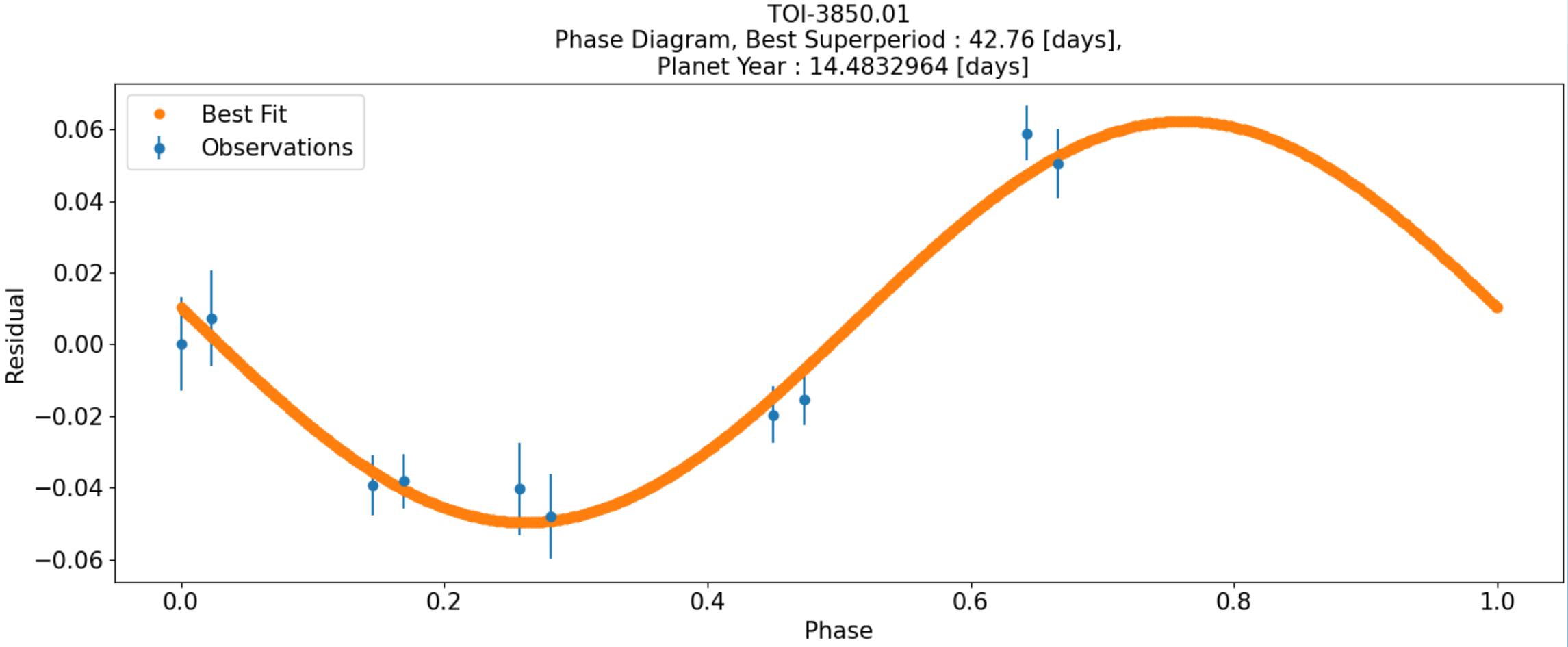



TOI-3686.01
intercept = $-1.34e-02^{+1.15e-03}_{-1.16e-03}$
period [days] = $5.08e+00^{+5.22e-06}_{-4.89e-06}$
Amplitude [days]
= $1.15e-02^{+5.01e-04}_{-4.68e-04}$
Phase = $1.53e+00^{+1.65e-01}_{-1.69e-01}$
SuperPeriod = $5.14e+01^{+3.12e-01}_{-3.25e-01}$
×10⁻⁵+5.078
intercept
period [days]
Amplitude [days]
Phase
SuperPeriod

TOI-3850, TIC 143008050



TOI-3850, TIC 143008050



Further Project Development & Collaboration

Project Development

- 1. Enhance PlanSim for unseen planet parameters
- 2. Use of exostriker(Trifonov) and jaxttv(Matsuda)
- 3. Contiguous (multi-longitude) campaigns
- 4. Future directions to be defined

Collaboration

- **Southern Hemisphere involvement(WINE survey) ?**

Warm vs Hot Jupiters

Warm Jupiters

- Period 10–200 days
- Large TTV signals → good for amateurs

Contiguous campaigns/resonance detection

Hot Jupiters

- Period typically < 10 days
- Small TTV amplitude

Typically long term (tidal ?) effects/companions rare

Contiguous Observations (2026 basis)

Focus: Warm Jupiters (10–200 day periods)	• with large TTV amplitudes
Challenges:	• • Uncertain predictions • • Need multi-time-zone coverage
Planned:	• • Coordinated photometry • • Radial velocity follow-up
Key contacts:	• • Trifon Trifonov (MPIA) • • Siegfried Vanaverbeke (KU Leuven)