The TESS Mission Reaches for Cooler Planets

Diana Dragomir (University of New Mexico)

and the **TESS Single Transit Planet Candidate (TSTPC) team**

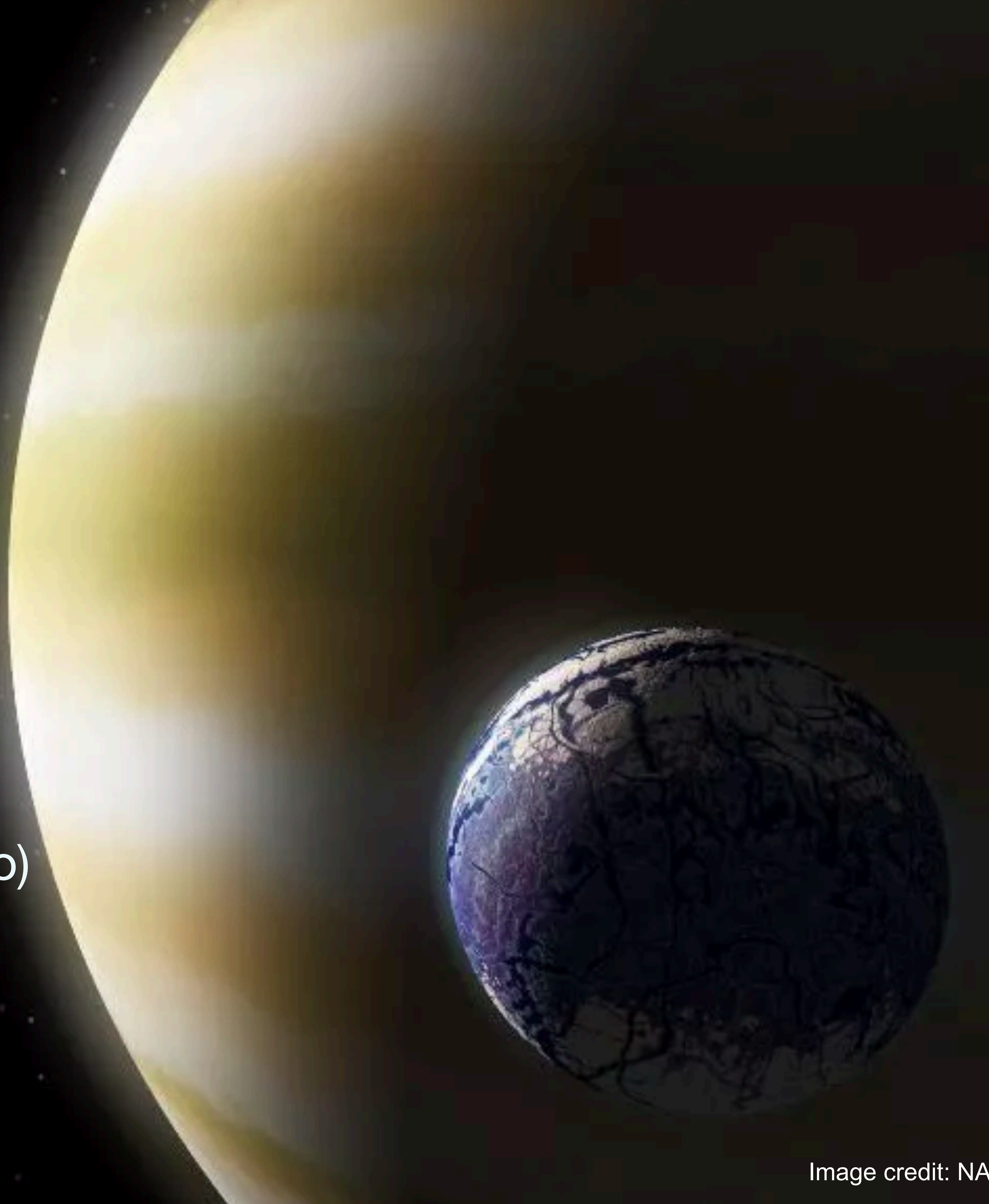
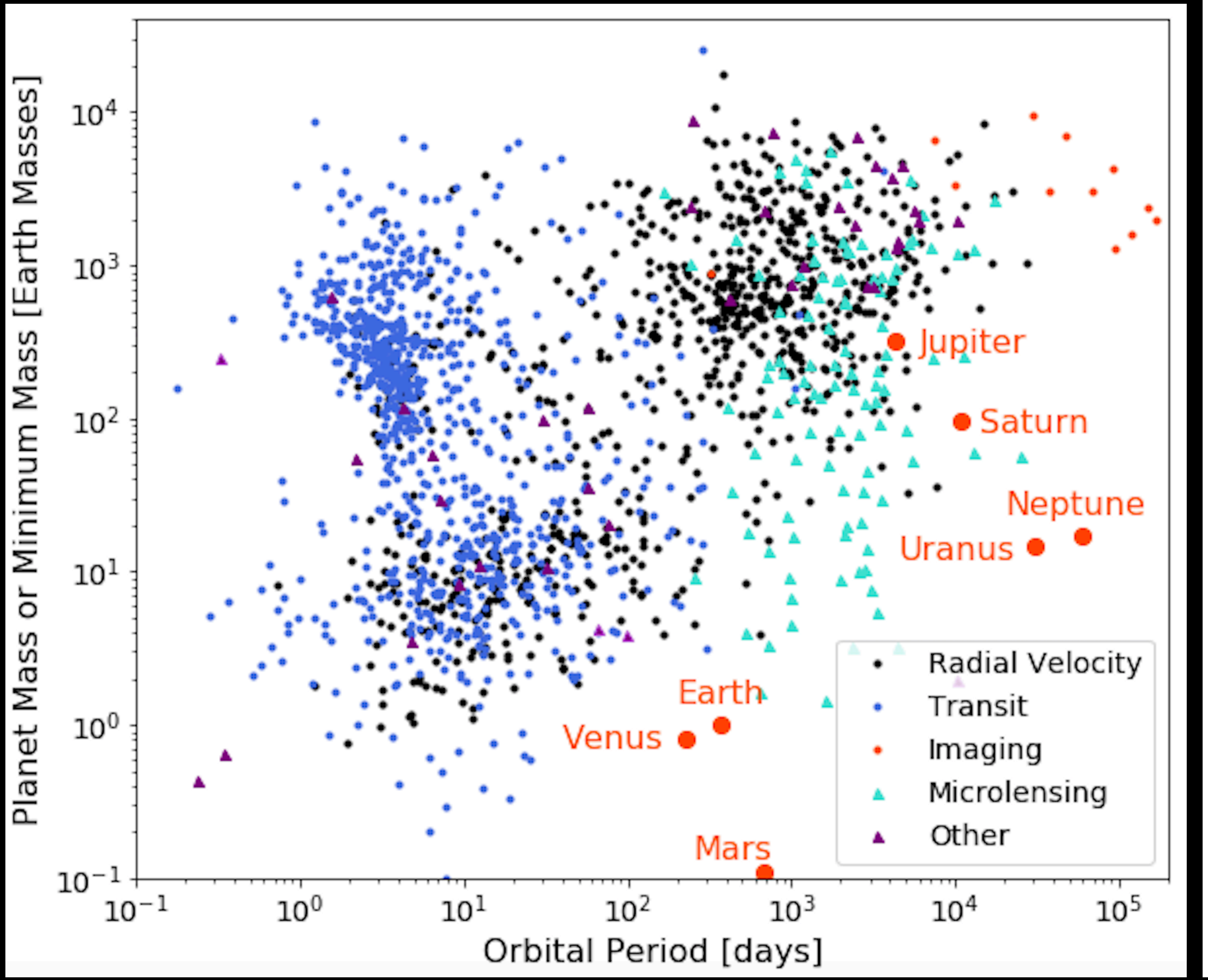


Image credit: NASA/JPL-Caltech

Where is the exoplanet community at?



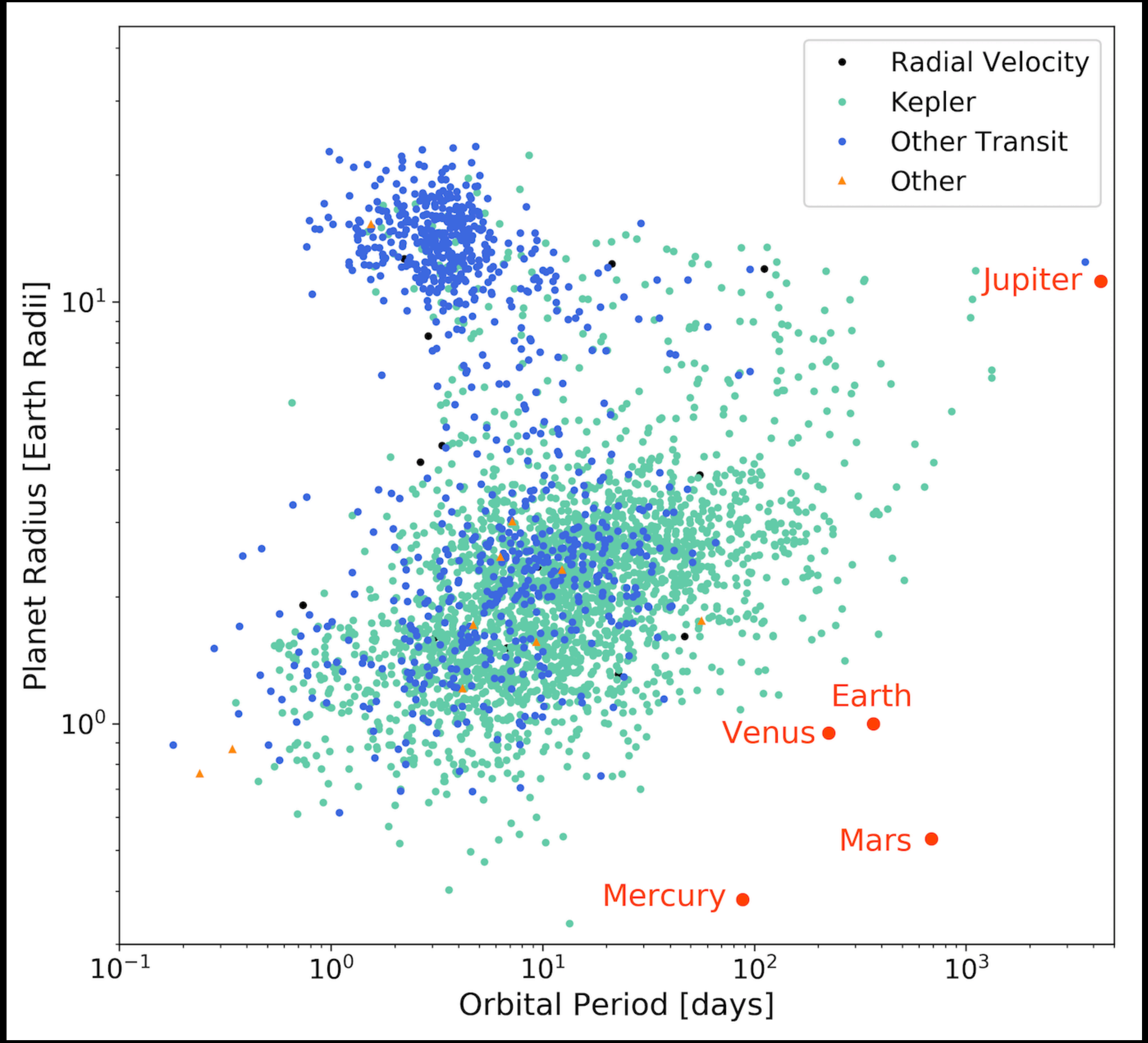
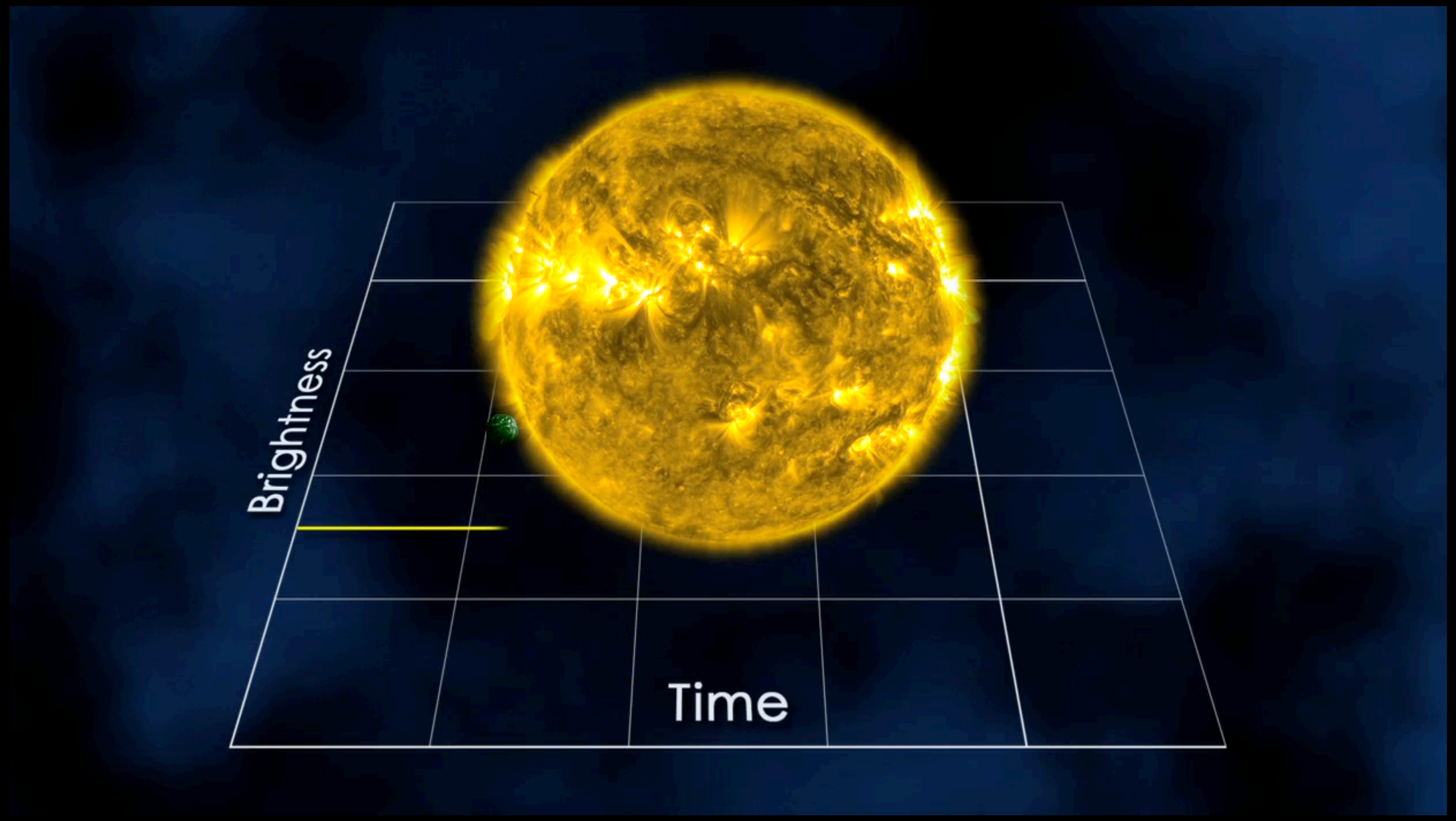


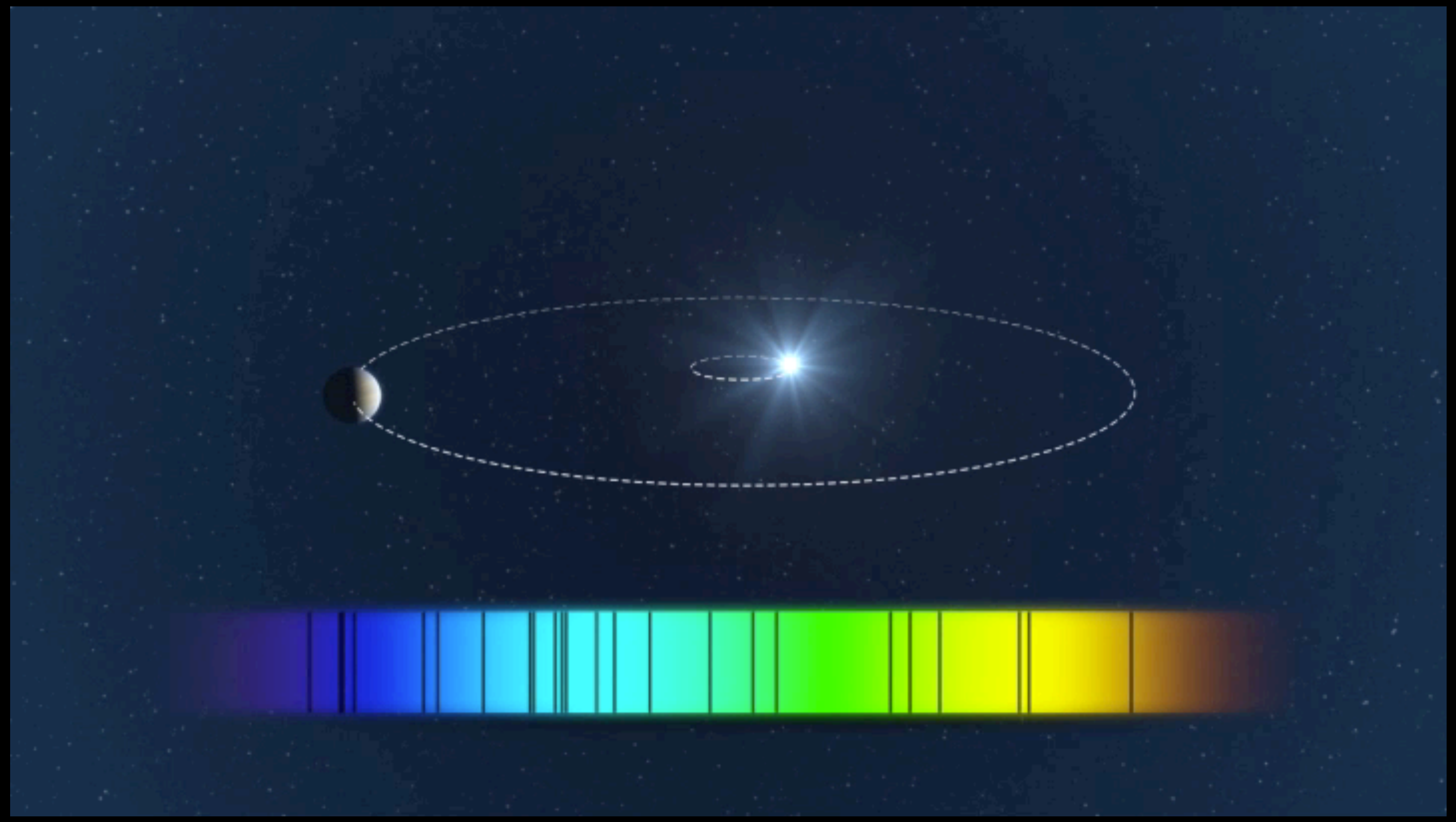
Figure: Gaudi, Christiansen & Meyer (2020)

Exoplanet Detection Techniques

Transits measure the **radius** of an exoplanet.

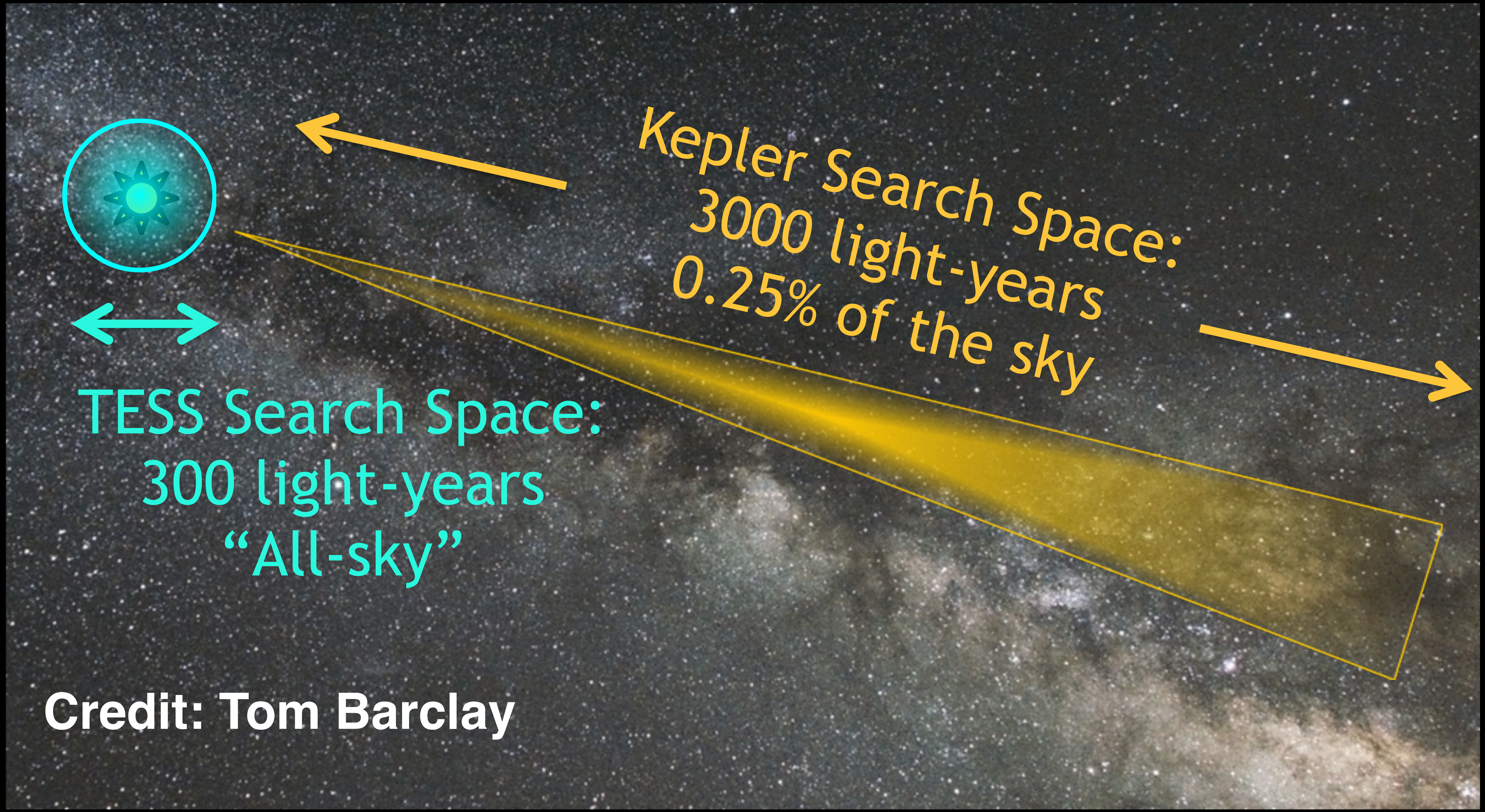


Radial velocities measure the **mass** of an exoplanet.

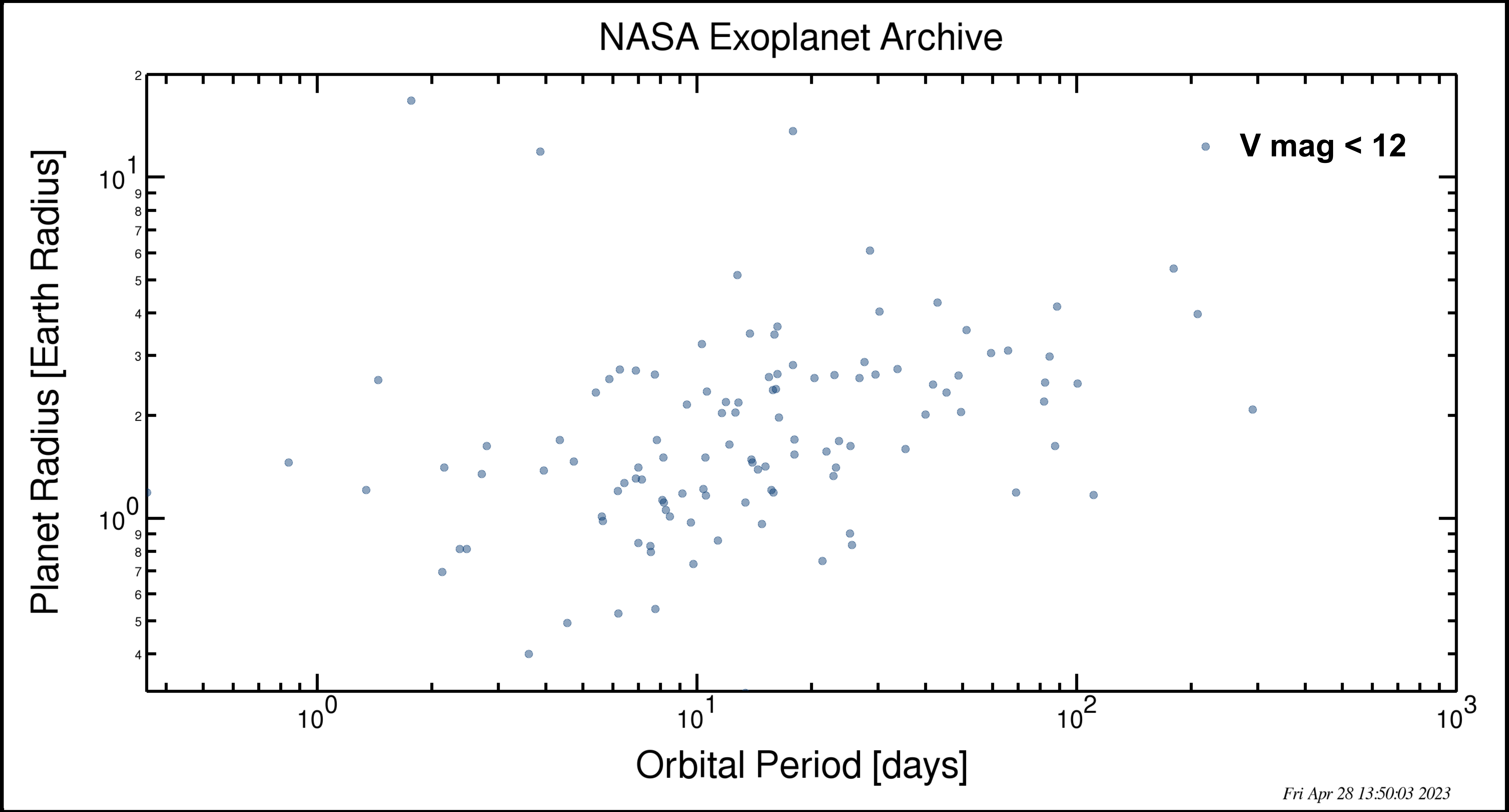


How have we been finding long-period transiting exoplanets?

- **Kepler** - spent 4 years staring at 200,000 stars
  - found ~2700 exoplanets
- But often missing planet mass (and thus density)
  - relatively small sample
  - stars to faint for follow-up transit-based observations (e.g. transmission spectroscopy, RM effect…)



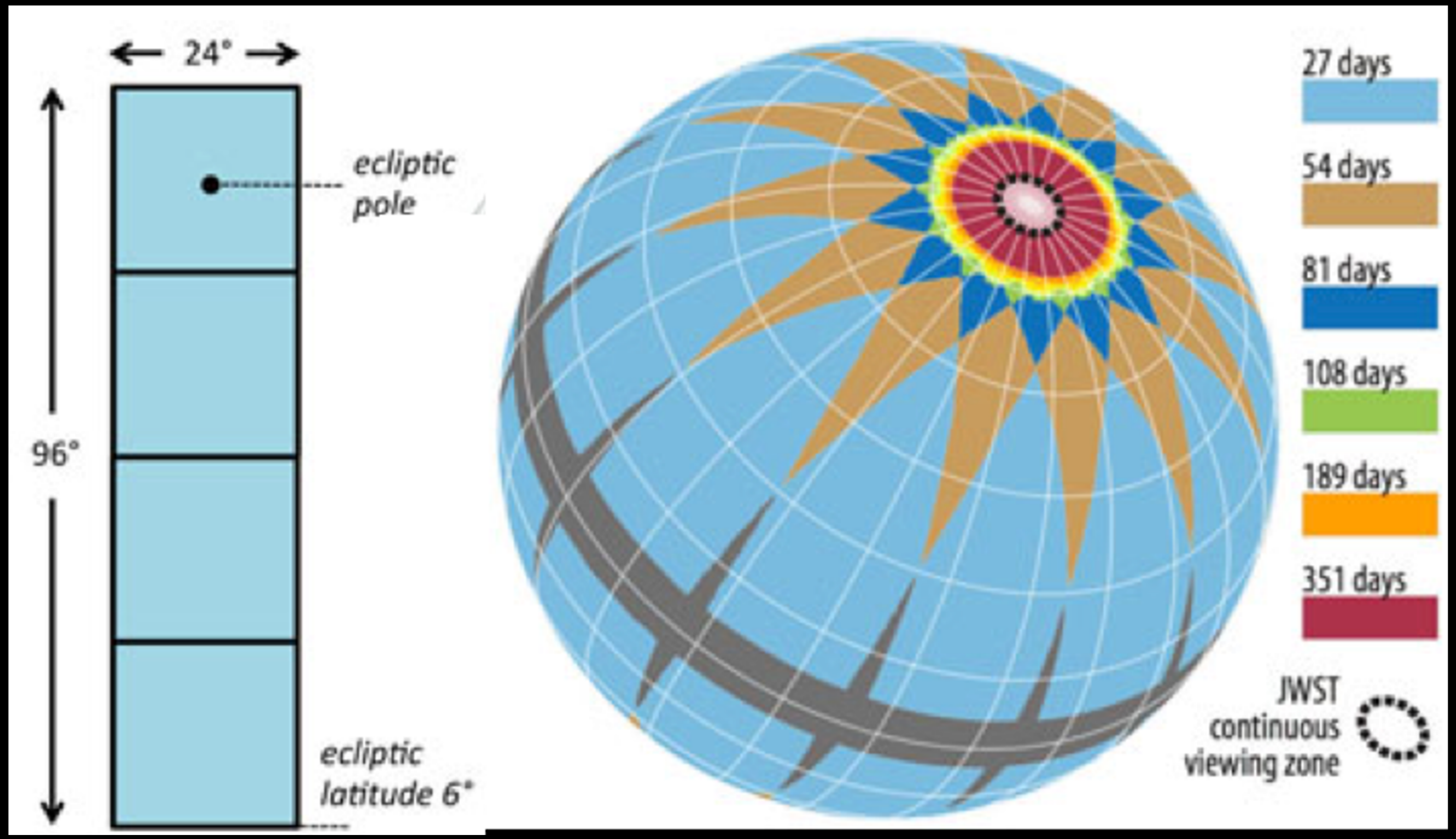
Kepler’s planet yield



The Transiting Exoplanet Survey Satellite (TESS) and its Observing Strategy

- 10 cm aperture
- 600 - 1100 nm
- elliptical 13.7-day Earth orbit
- *searches for transits of exoplanets around nearby, bright stars*

The Transiting Exoplanet Survey Satellite (TESS) and its Observing Strategy



- 10 cm aperture
- 600 - 1100 nm
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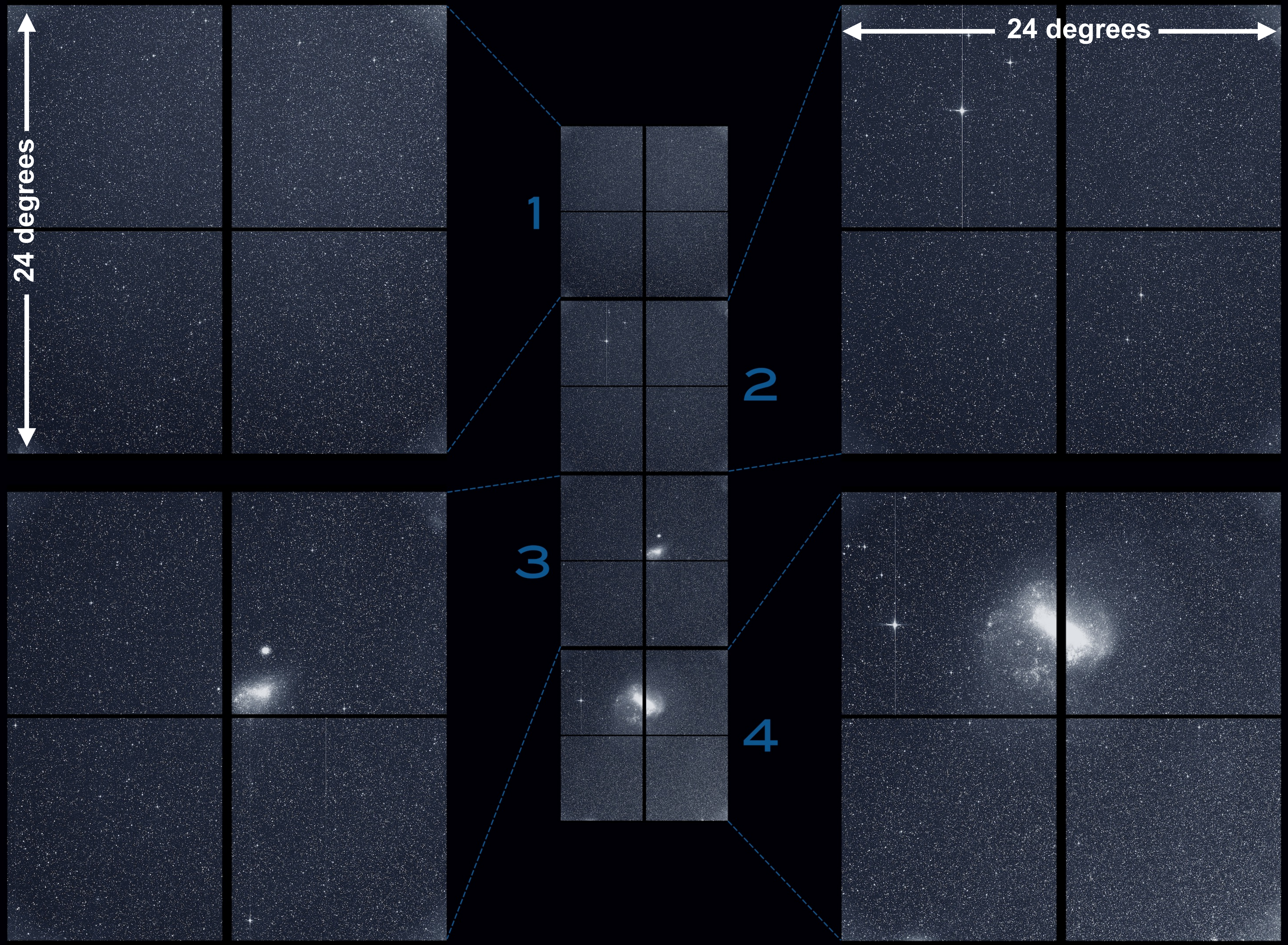
- *searches for transits of exoplanets around nearby, bright stars*


24 degrees
24 degrees
1
2
3
4

TESS Objects of Interest (TOIs)

6867

~~6400 TOIs~~ (so far!)

62 sectors

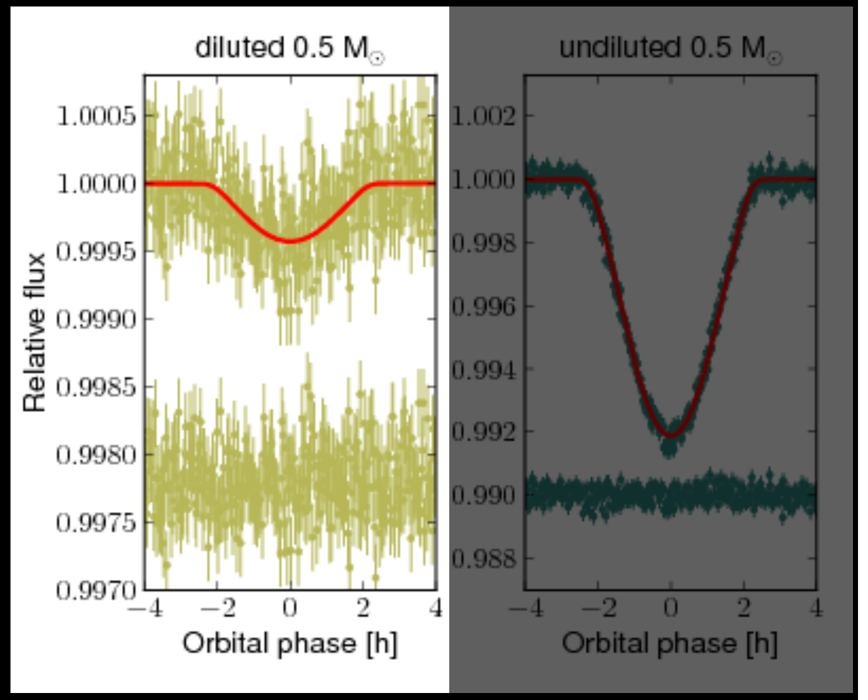
1367 TOIs with TESS Rp < 4 Re

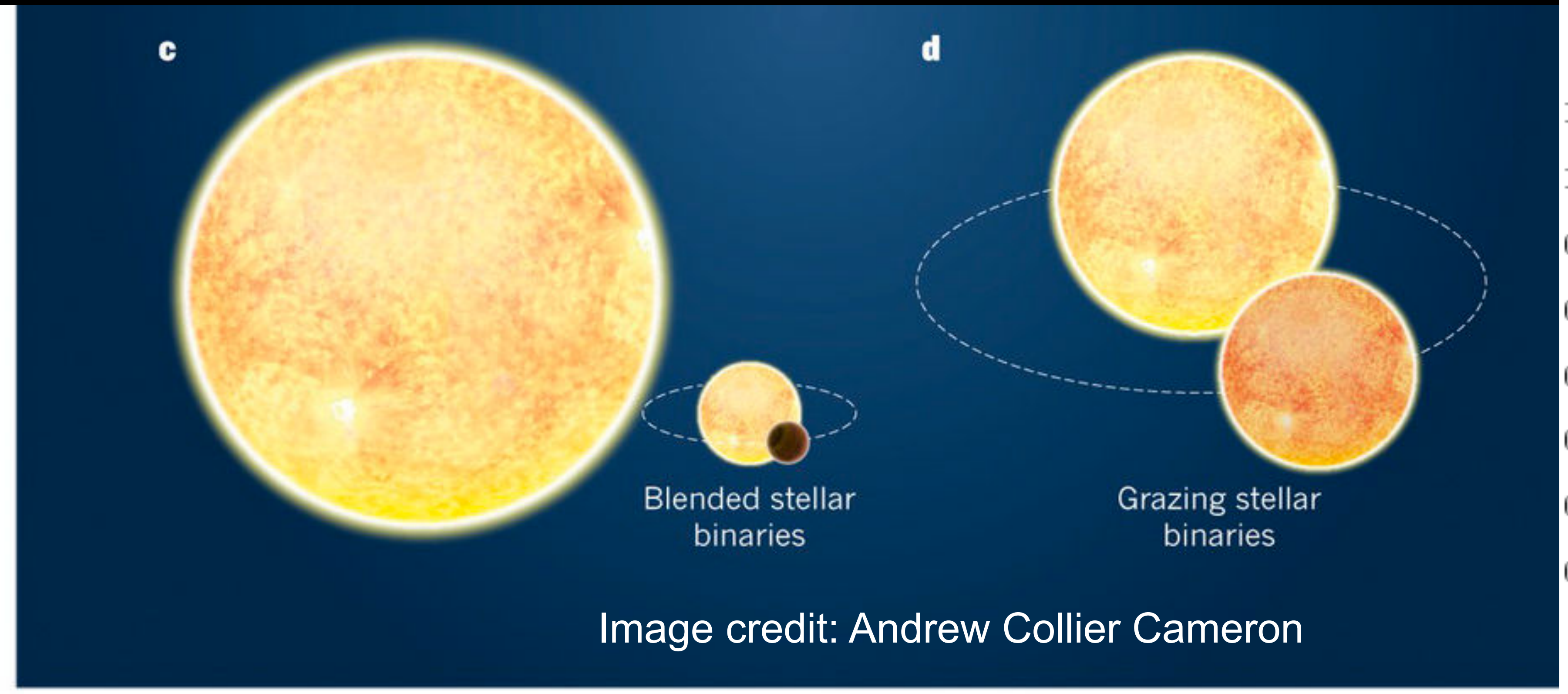
1701 false positives

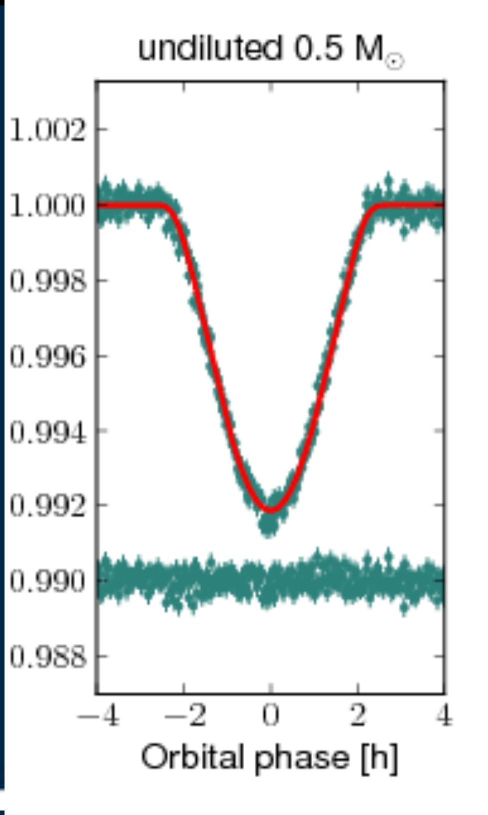
329 confirmed TESS Planets

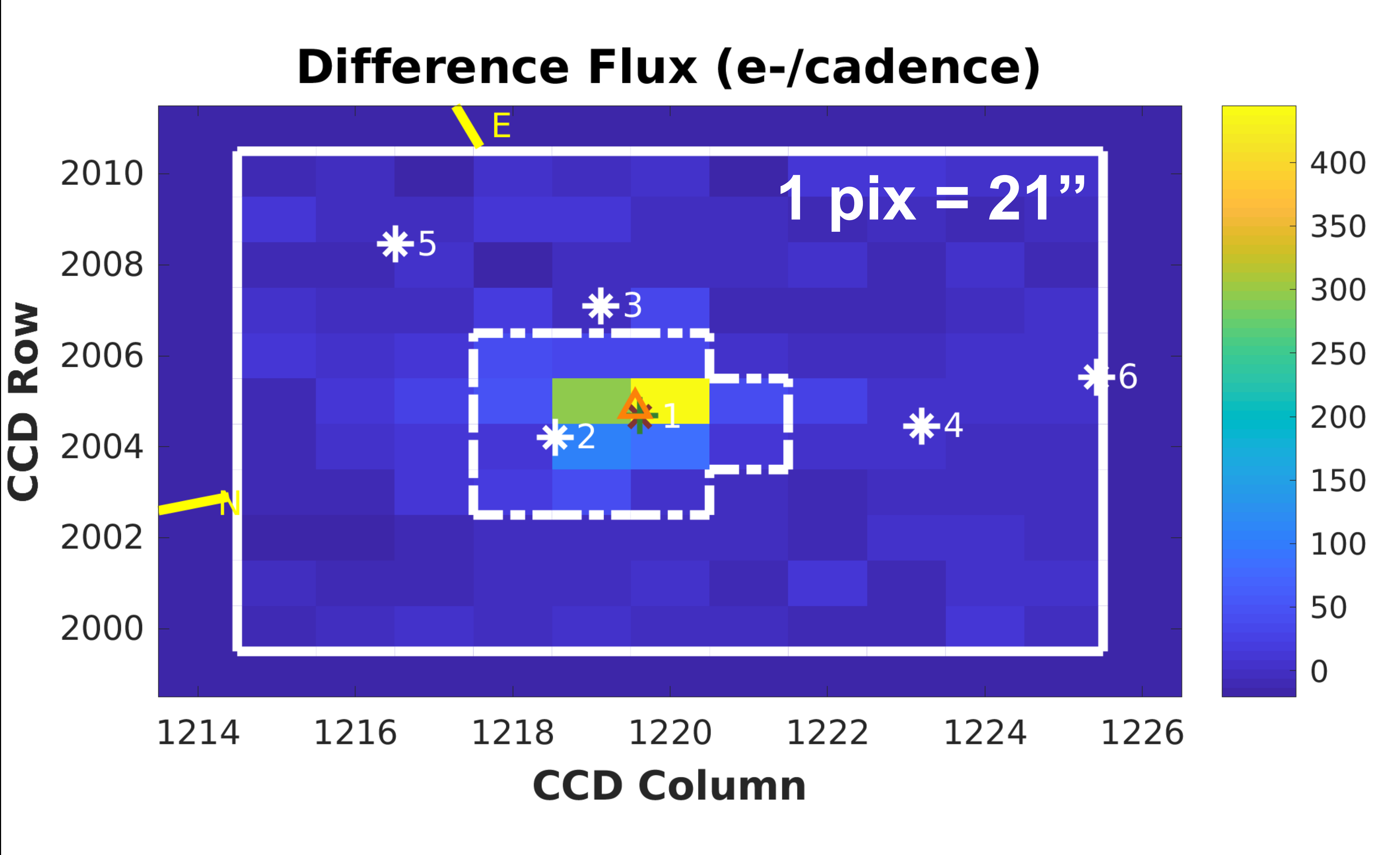
Last updated: 4/13/2023

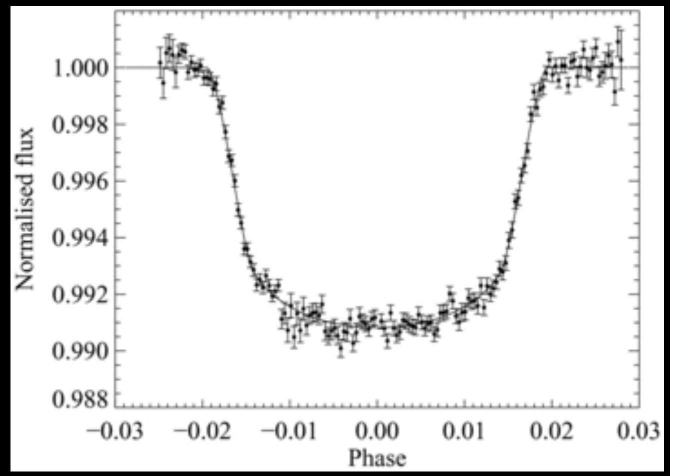
False Positive Vetting

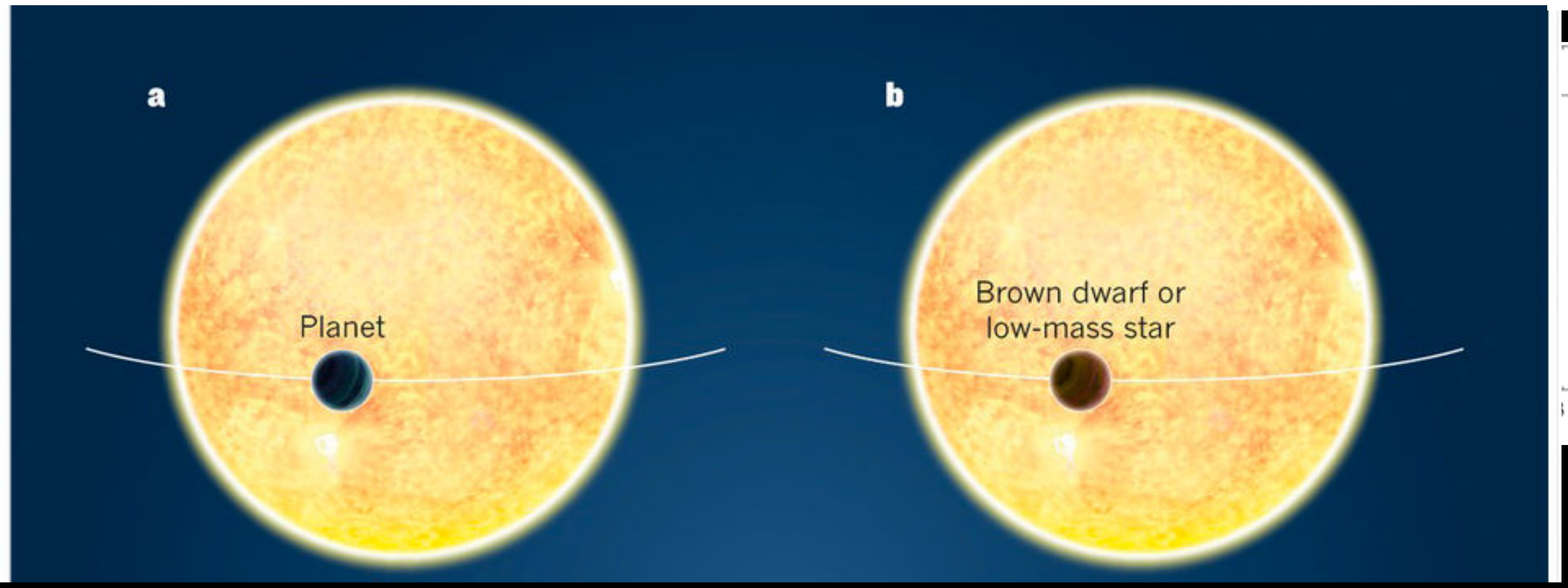


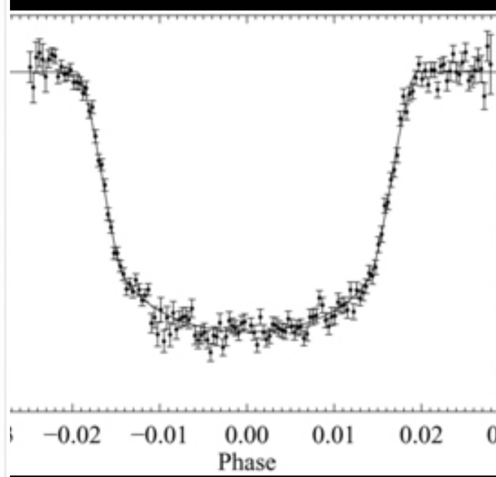




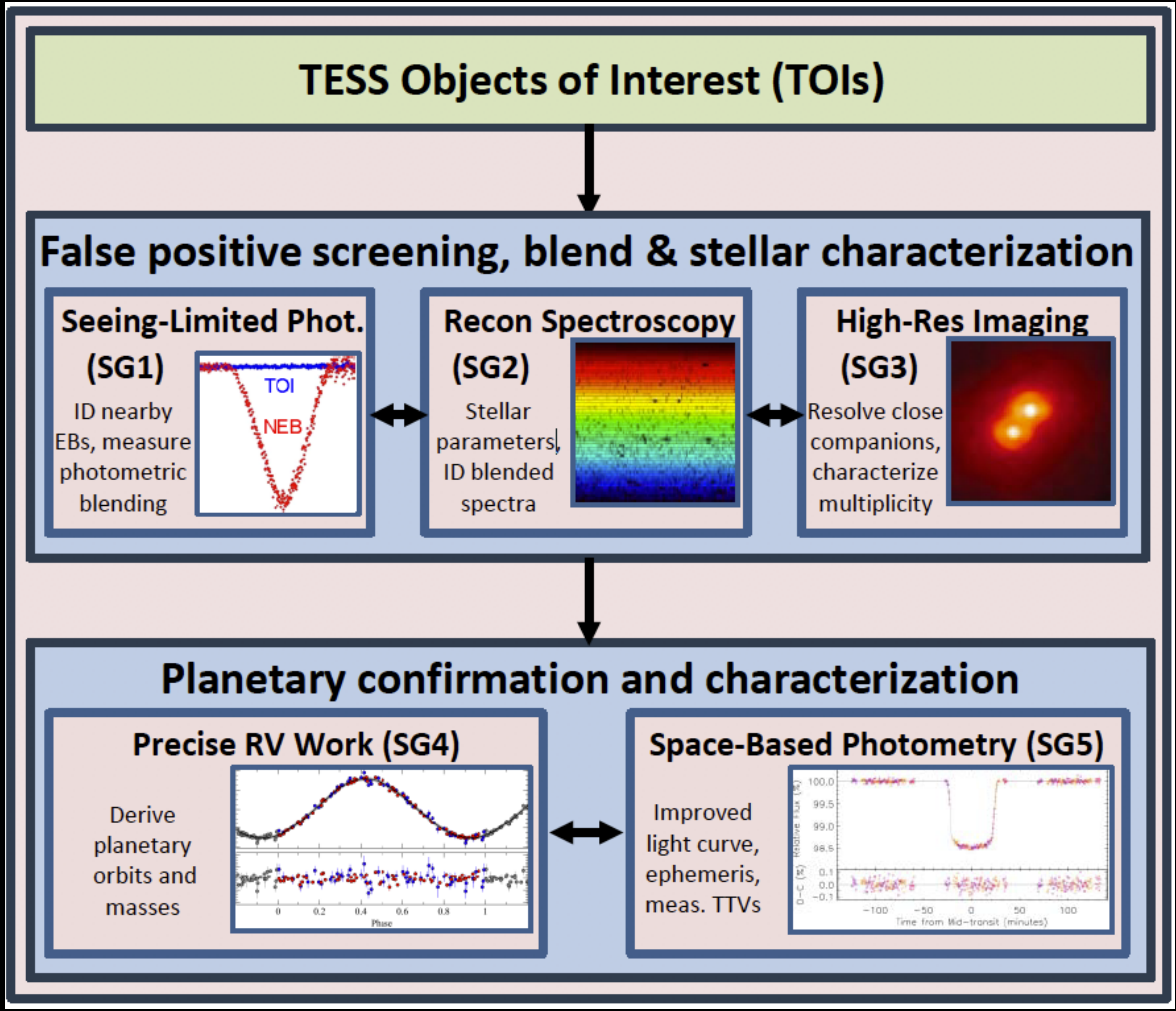




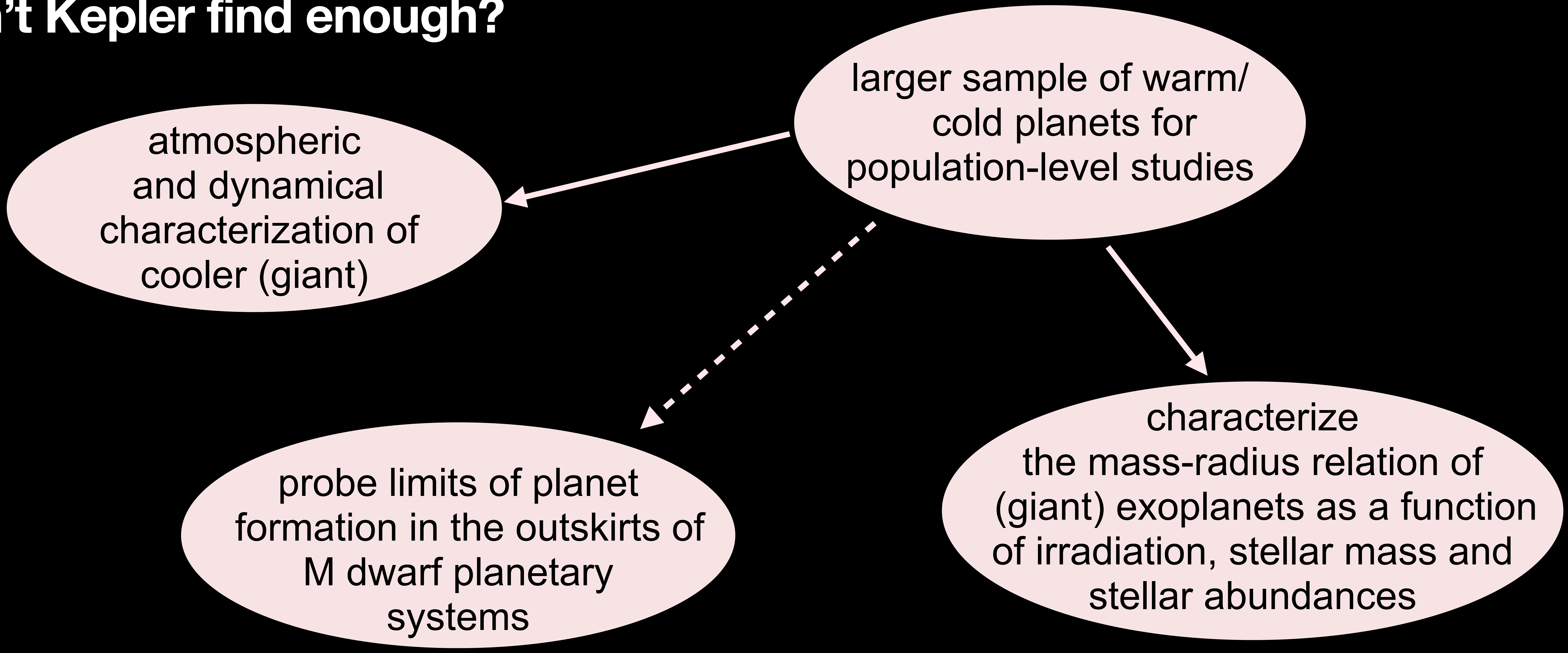




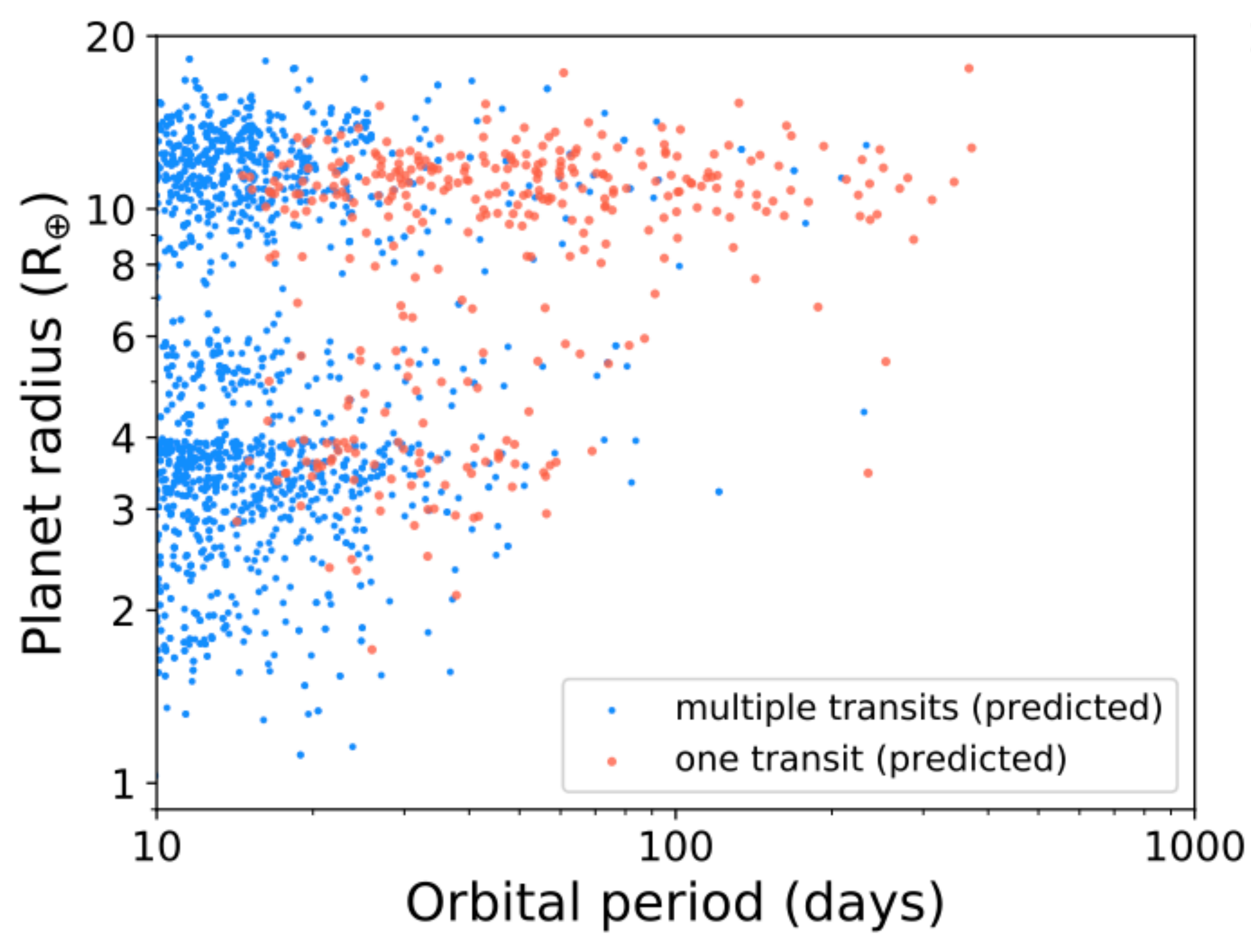
False Positive Vetting through the TESS Follow-Up Observing Program (TFOP)



Why do we want to find transiting long-period exoplanets with TESS? Didn't Kepler find enough?



TESS Expected Yield for Single-Transiting Planets



Predicted Yield
(Villanueva et al. 2019)

How do we find TESS long-period planets?

- search all Tmag < 12 Full Frame Image stars
- use TESS diagnostics for a first pass at false positives
- use TFOP and TSTPC resources to rule out any remaining false positives

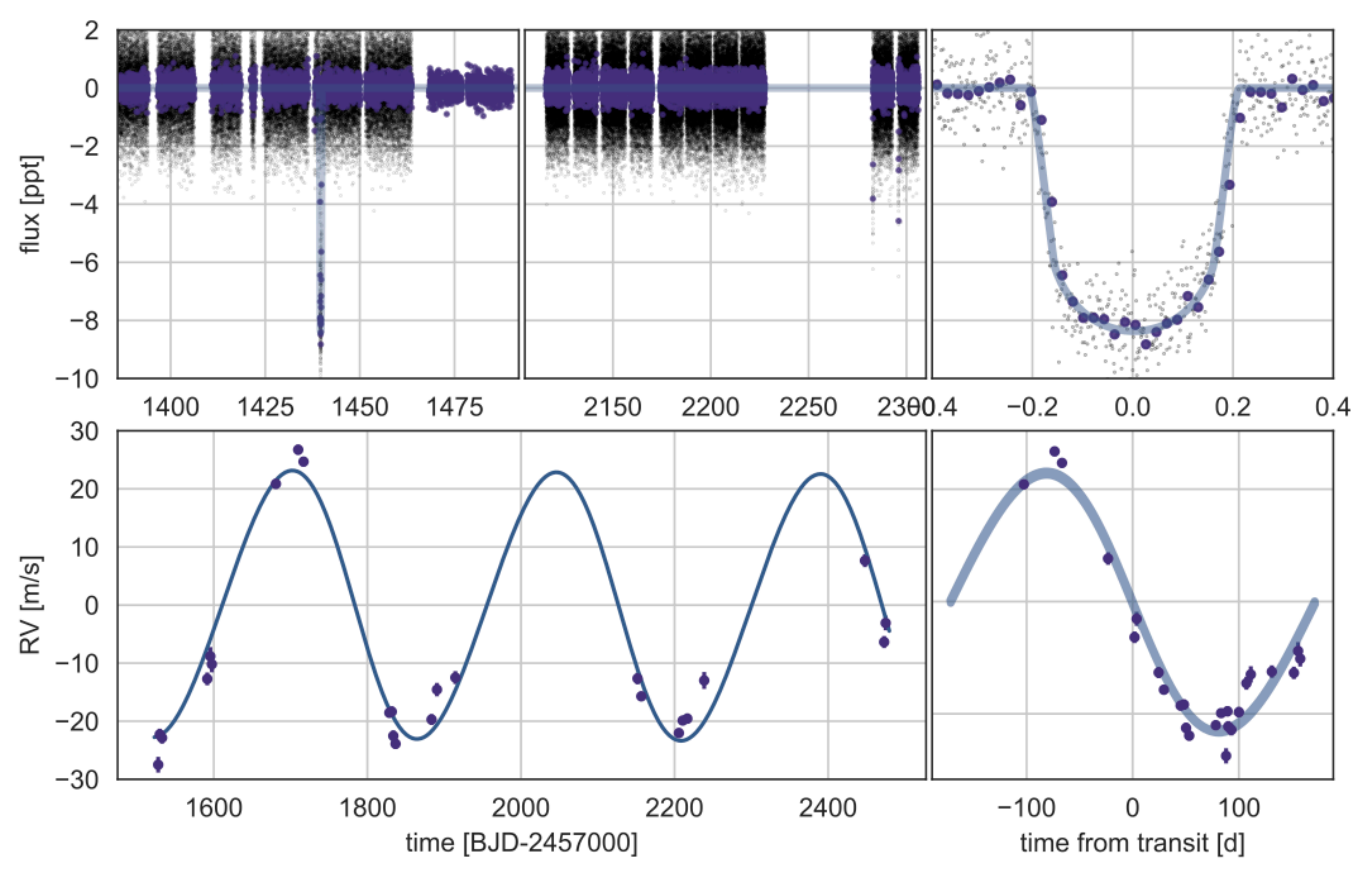
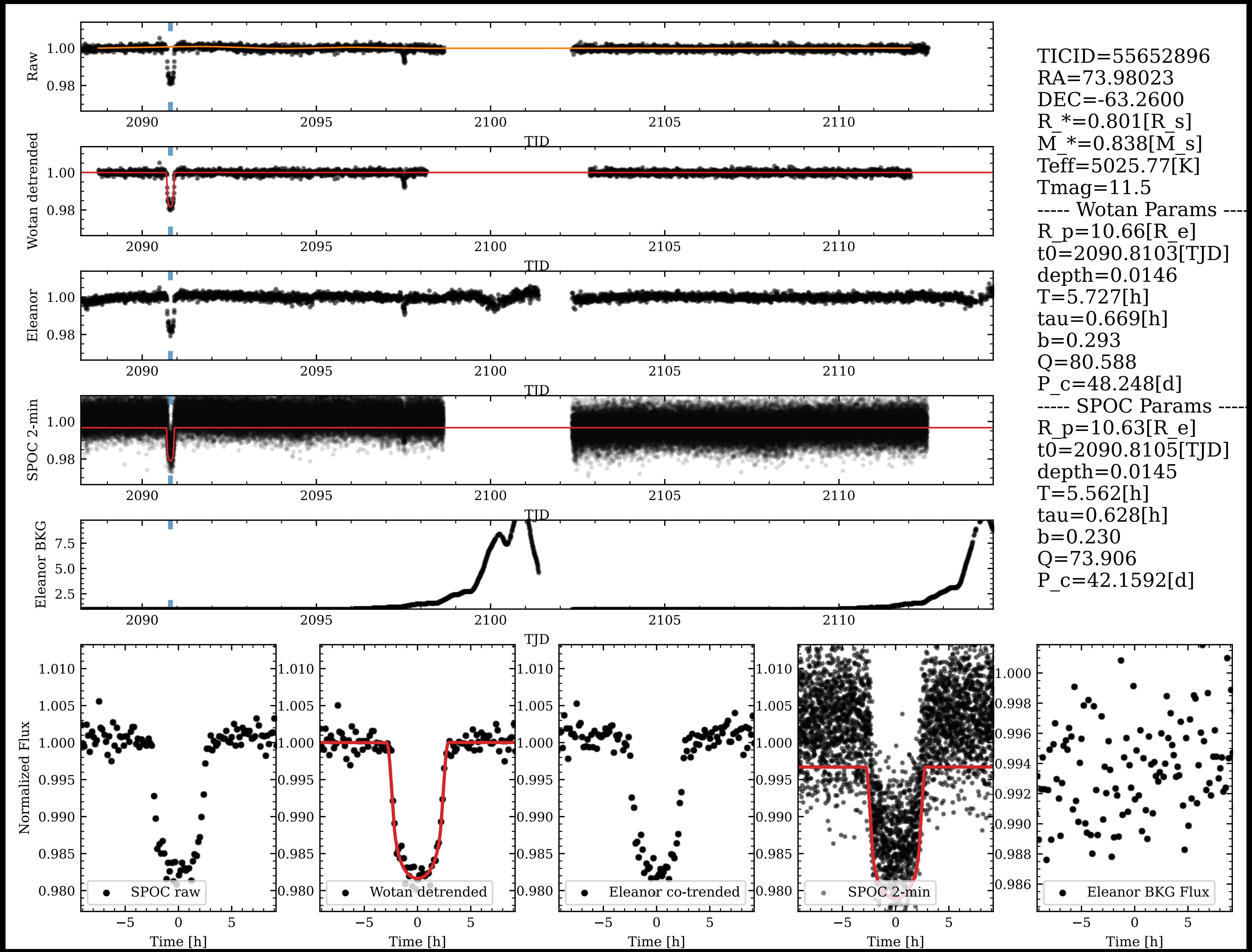
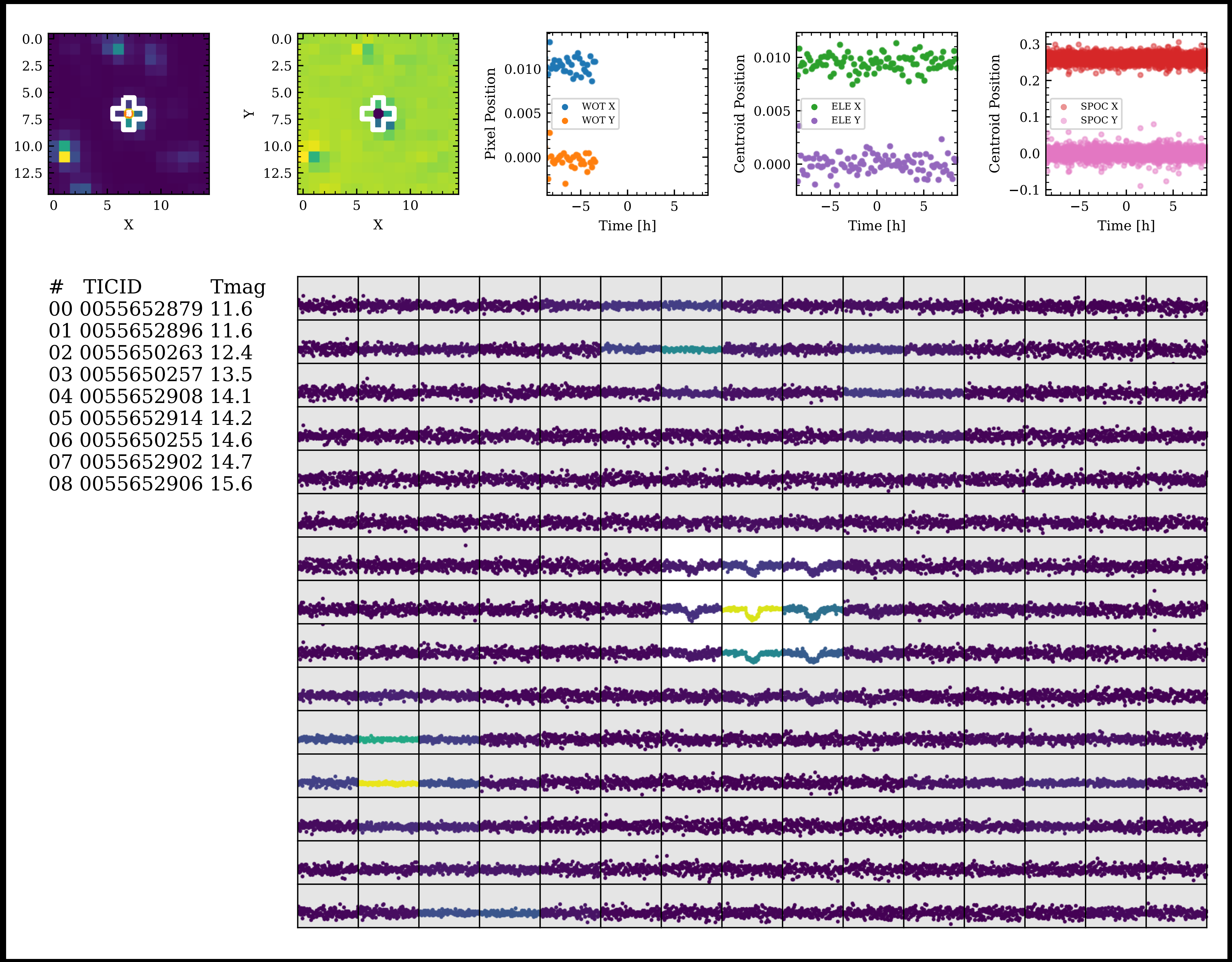


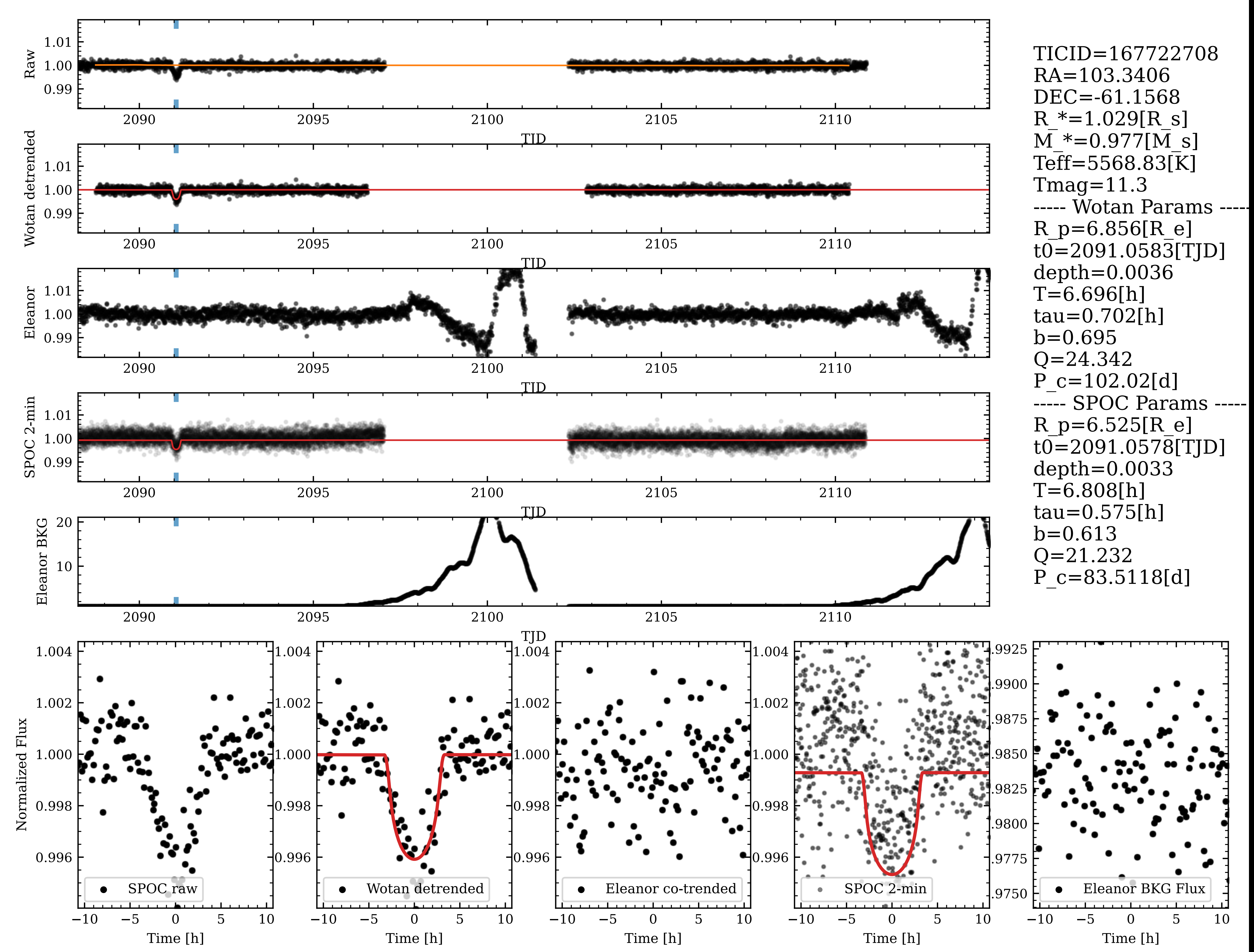
Figure credit: Hugh Osborn
Villanueva et al. (in prep.)

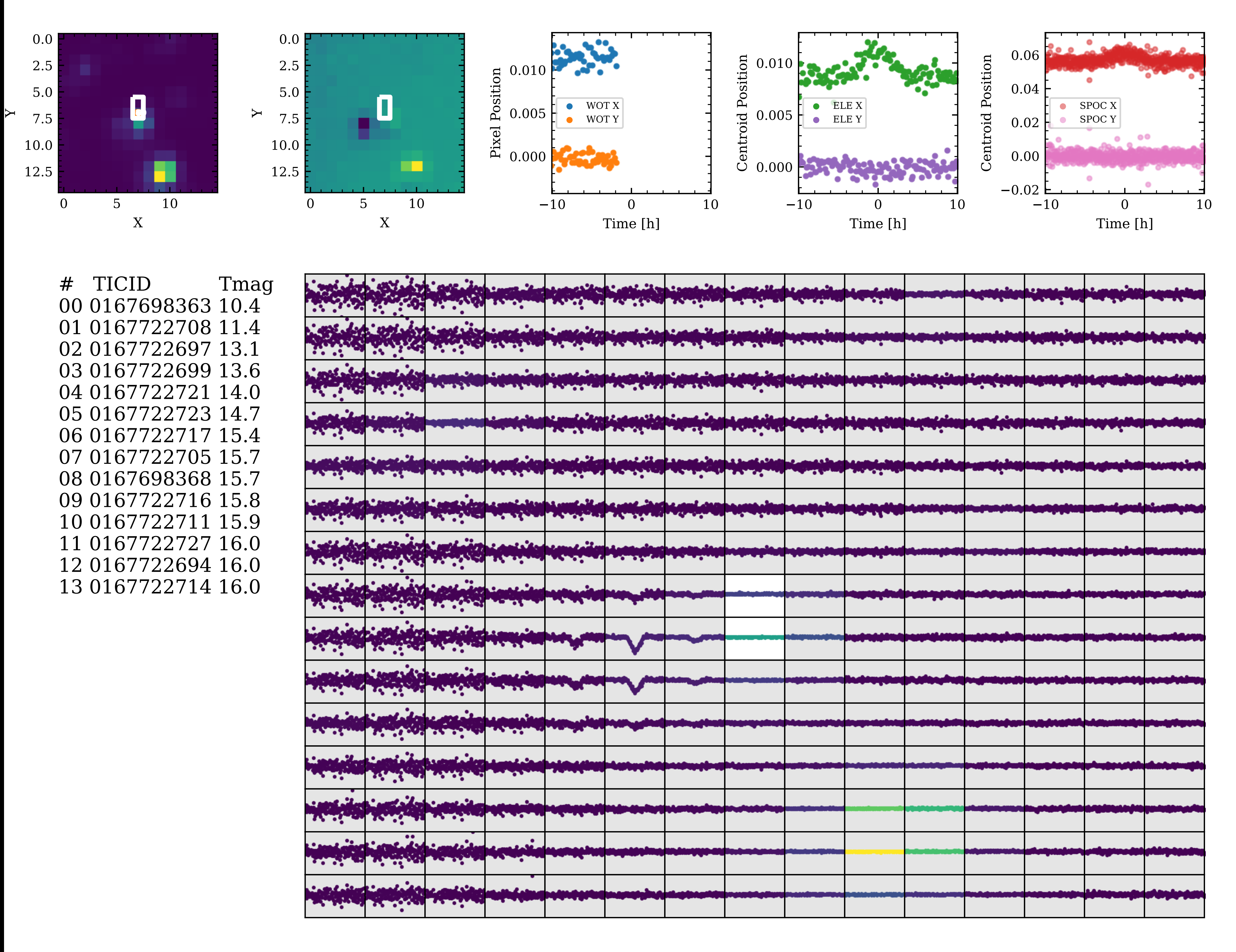
Let’s warm up with some vetting





Let’s warm up with some vetting

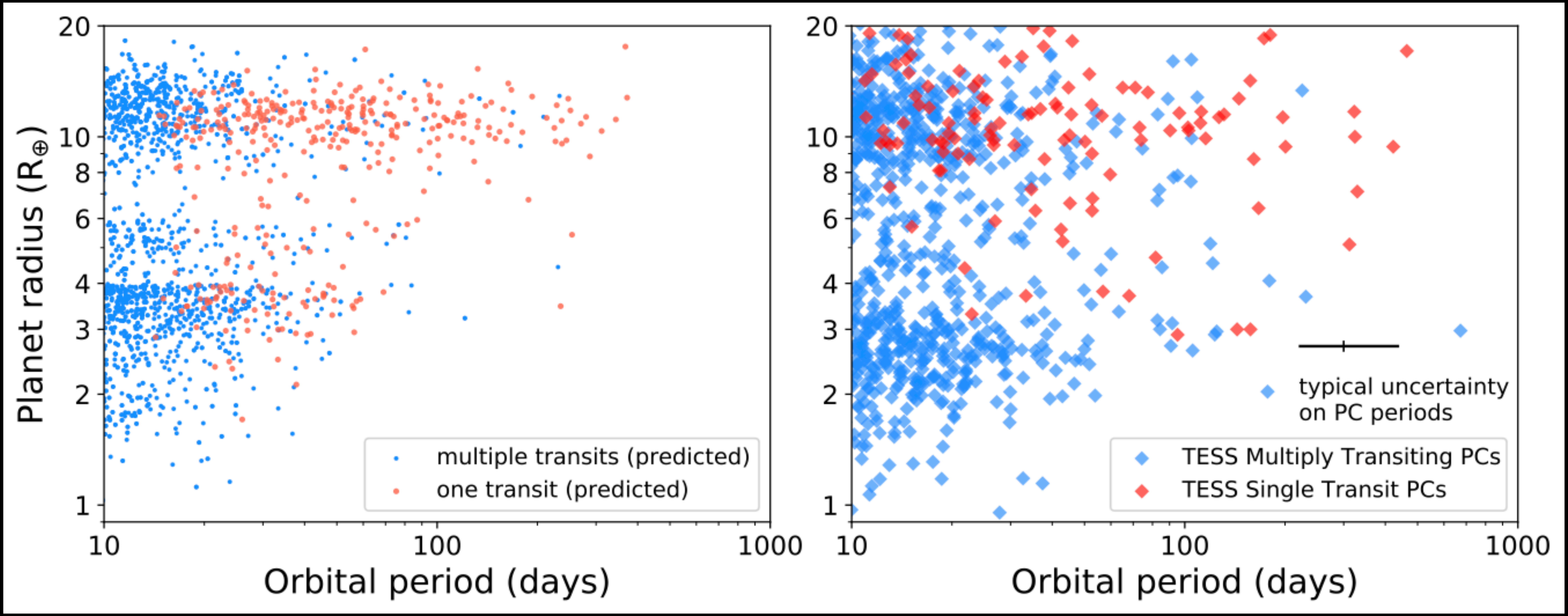




Follow Programs within TSTPC WG

- *RV*
  - APF (PI: P. Dalba)
  - WIYN-NEID (PI: A. Gupta)
  - Magellan-PFS (PI: K. Collins)
  - HARPS-N (PIs: E. Palle and I. Carleo)
  - HARPS (PI: S. Ulmer-Moll)
  - CORALIE (PI: S. Ulmer-Moll)
  - SOPHIE (PIs: G. Hebrard and A. Santerne)
  - CHIRON (PI: J. Rodriguez)
  - VLT-ESPRESSO (PI: K. Hesse)
  - Minerva-Australis (PI: B. Nicholson)
  - TRES (PI: D. Latham)
- *Photometry*
  - CHEOPS (H. Osborn)
  - NEOSSat (C. Mann)
  - LCO (D. Dragomir, K. Collins, et al.)
- SG 1
- **Citizen Science Observers**

“Planet Yield to Date” versus “Expected Planet Yield”

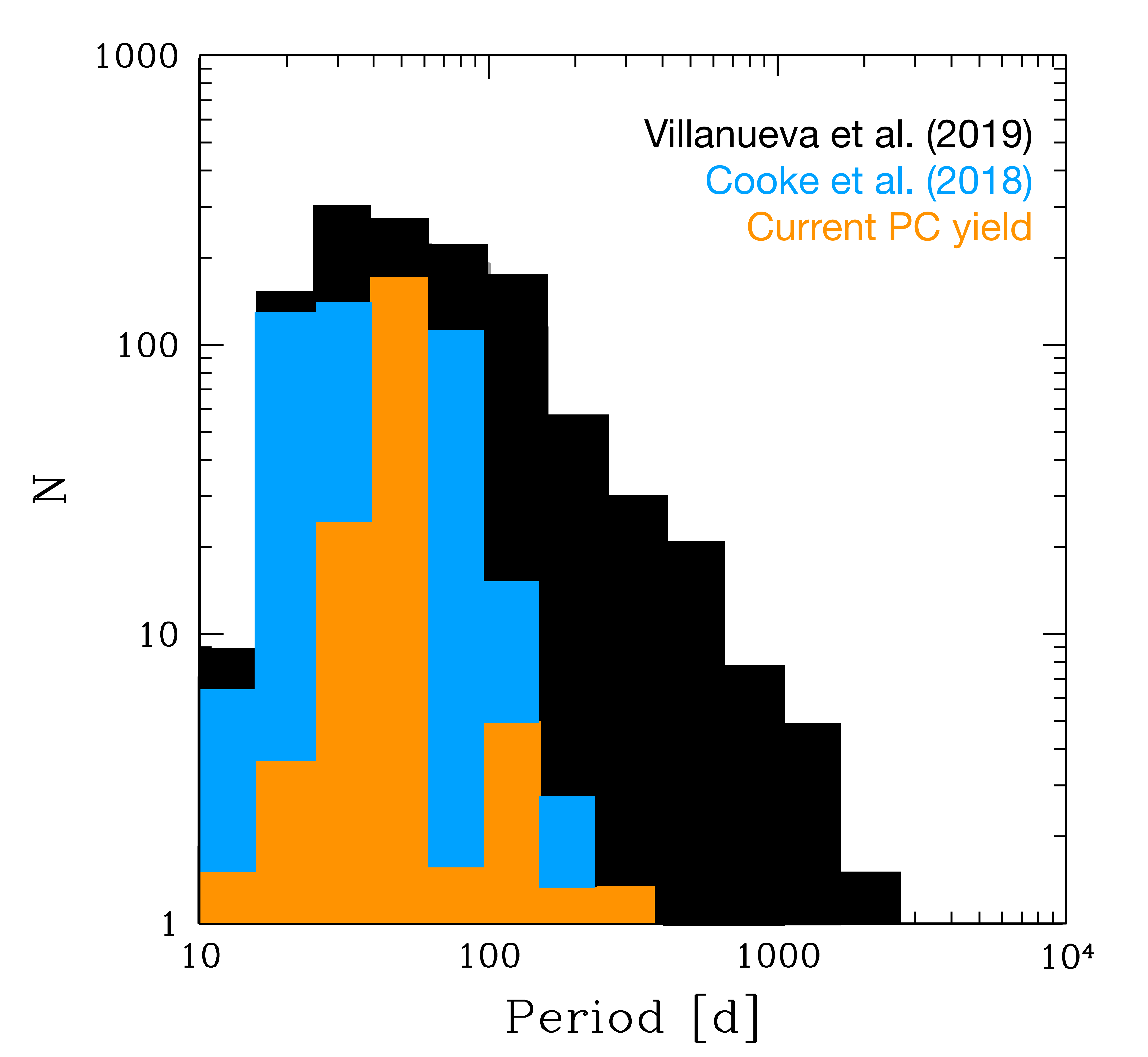


Predicted Yield
(Villanueva et al. 2019)

Yield to Date

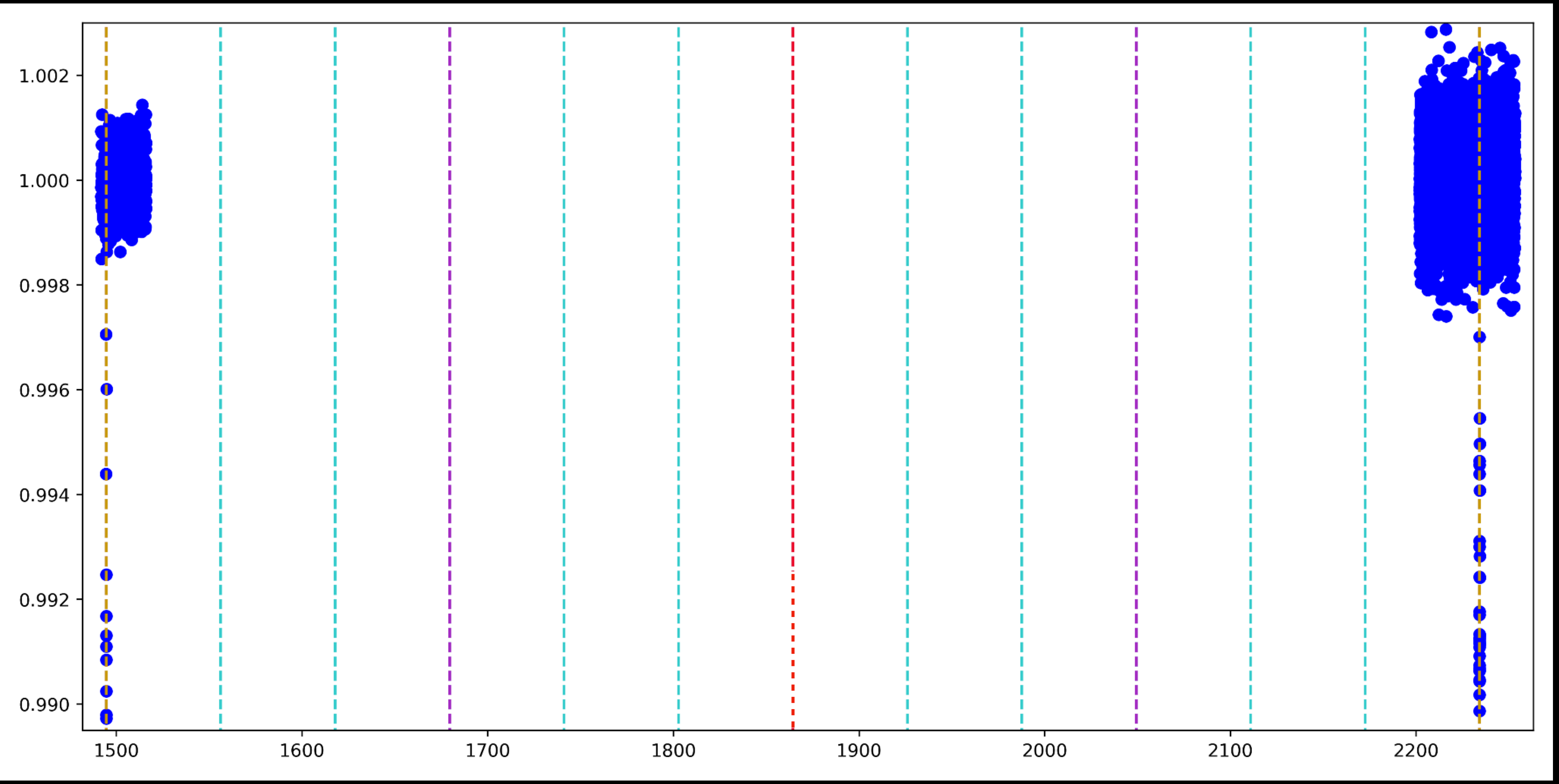
Yield to date

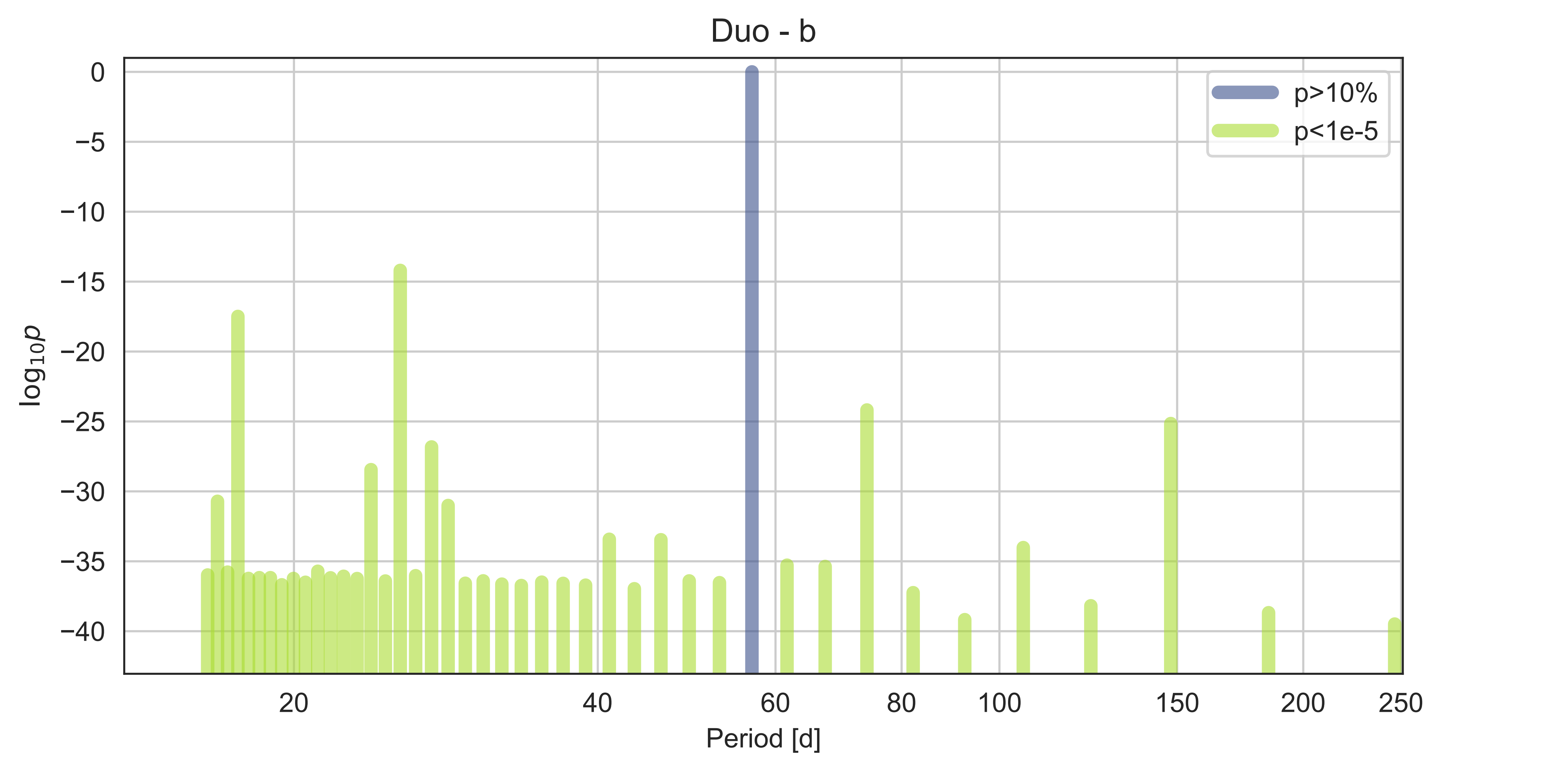
- fewer candidates than predicted, especially at longer periods
- possible reasons:
  - eccentric orbits
  - SNR threshold
  - missed transits (a small fraction) due to e.g. detrending distortions or unaccounted-for gaps



The TESS extended mission(s) opportunity

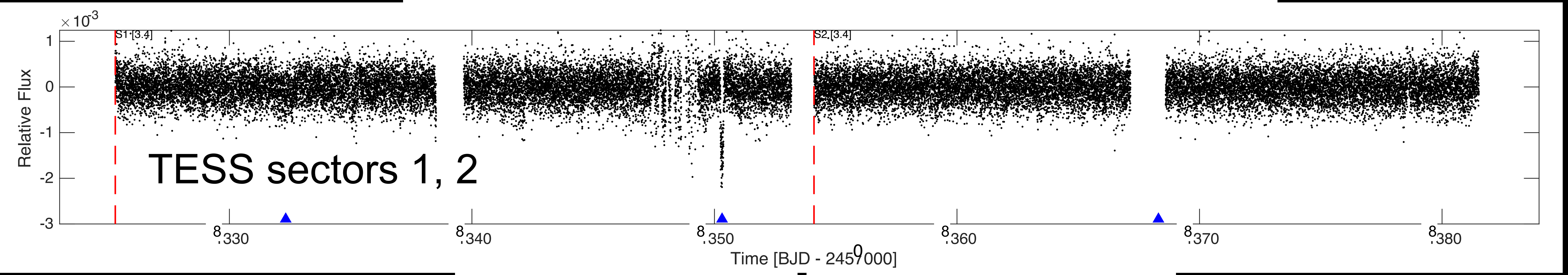
- In EM1, ~60% of all year Primary Mission ST *candidates* transited again, becoming "duos"
- In EM2, over 80% of duos will show a third transit
    - in many of those cases, the period will be uniquely determined with just TESS data



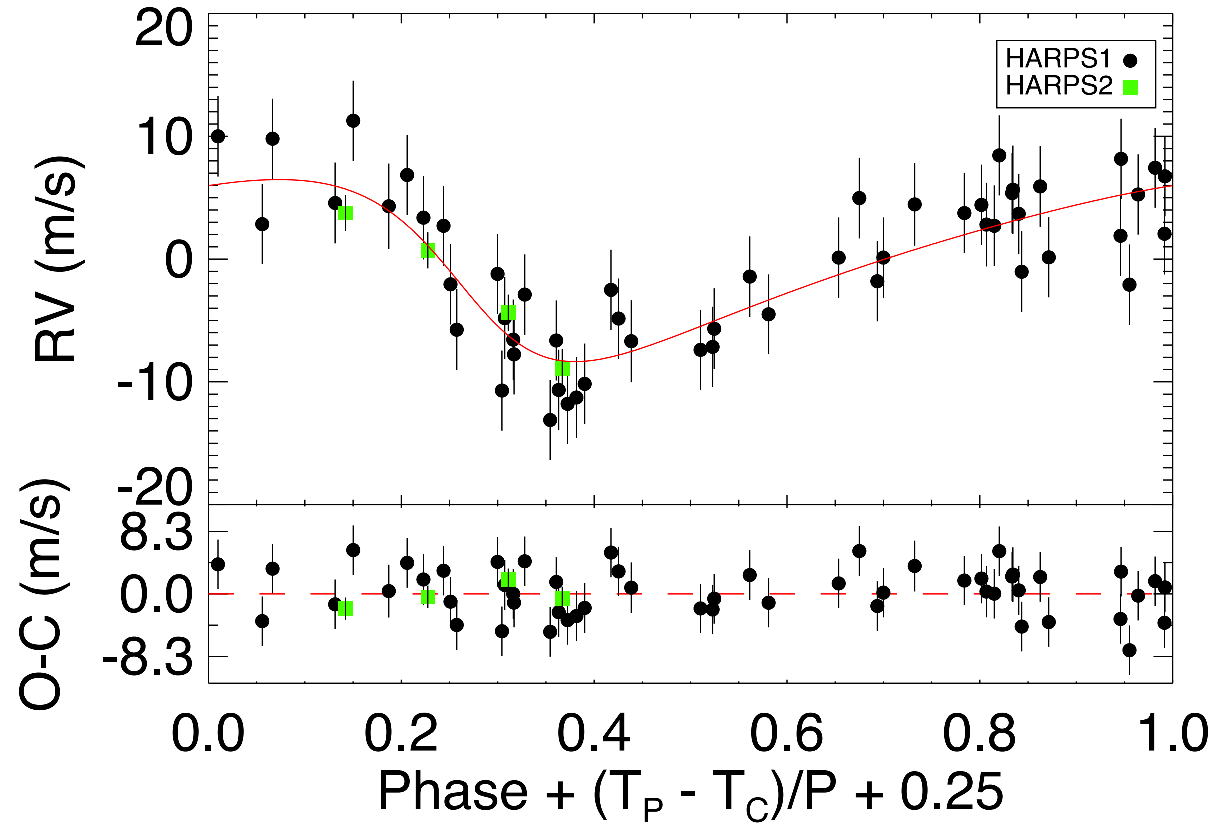


Osborn et al. (2022)

Discovery of HD 21749b (née TOI 186.01)



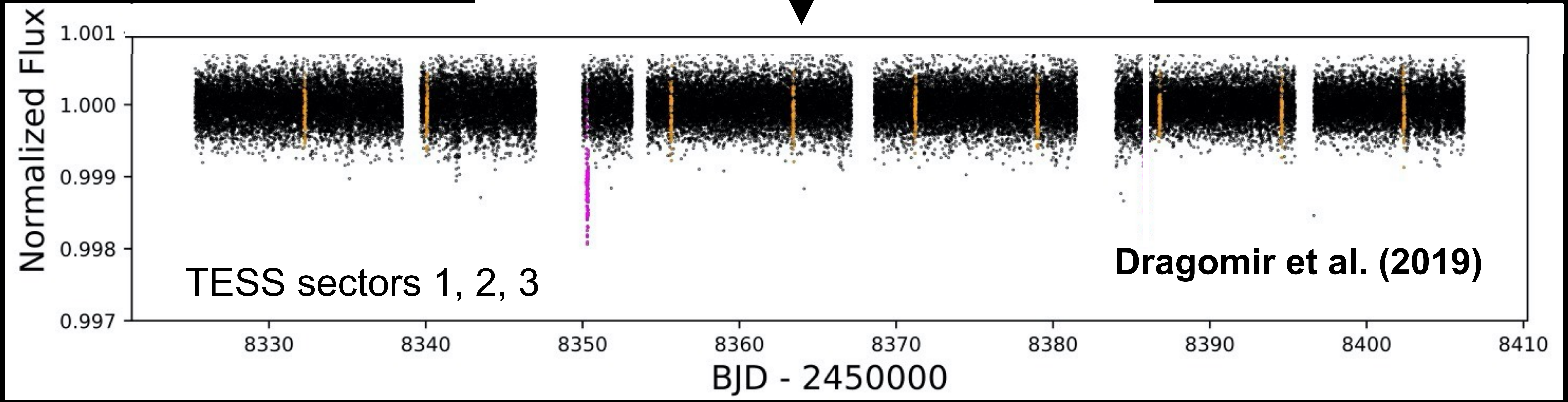
Archival HARPS RVs



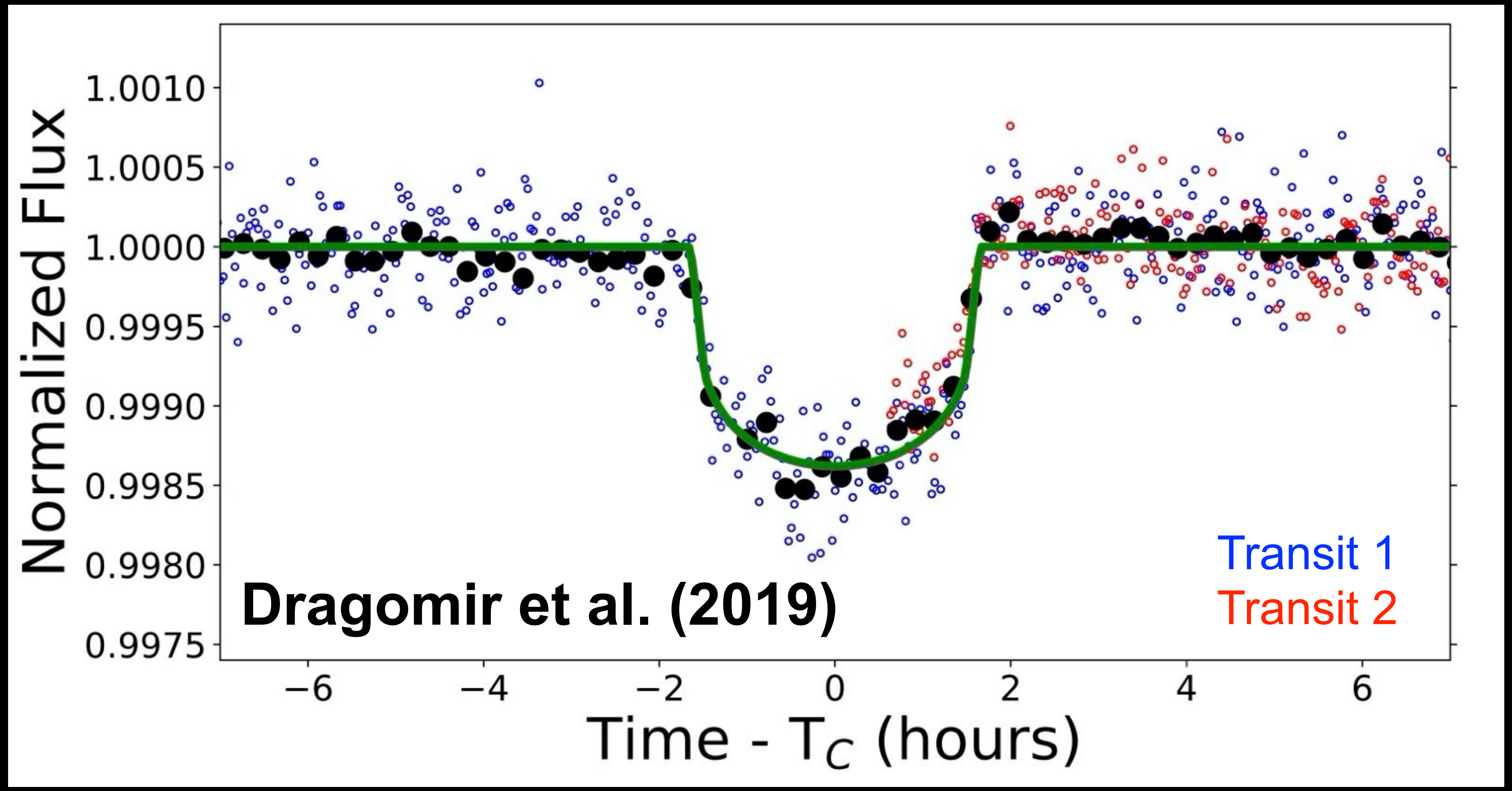
Stellar activity

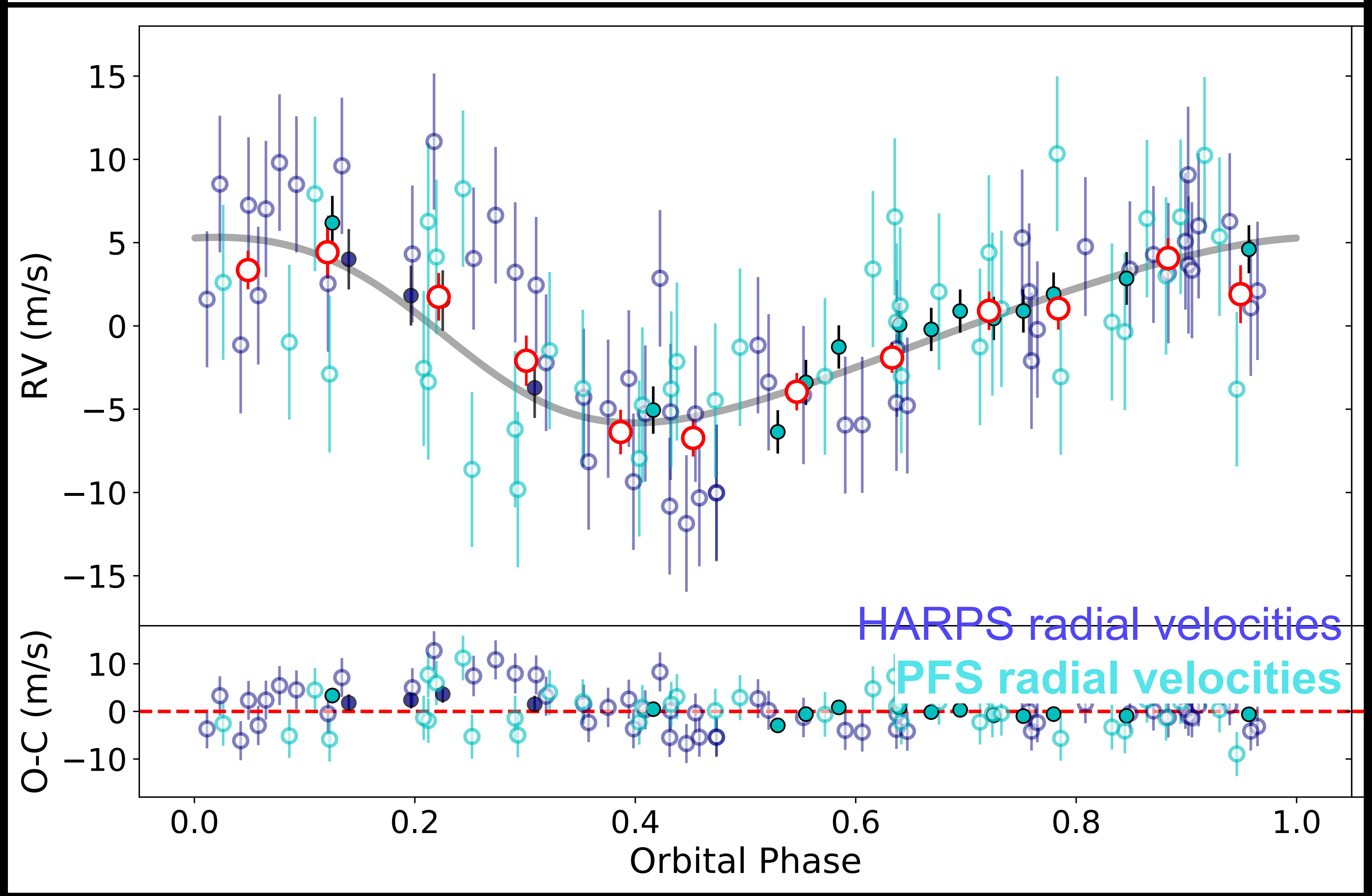
OR

P -> 35.57 days
e -> 0.32
K -> 7.6 m/s



Who is HD 21749b?





- TESS mag: **6.95**
- R_S: **0.69 ± 0.03 R_{Sun}**
- M_S: **0.73 ± 0.07 M_{Sun}**

- Period: **35.6077 ± 0.0014 days**
- Eccentricity: **0.198 ± 0.073**
- R_P: **2.84 ± 0.24 R_{Earth}**
- M_P: **23.2 ± 2.0 M_{Earth}**
- ρ_P: **5.7 ± 1.5 g/cm^3**
- T_{eq}: **423 ± 14 K**

Planets from the TSTPC Working Group

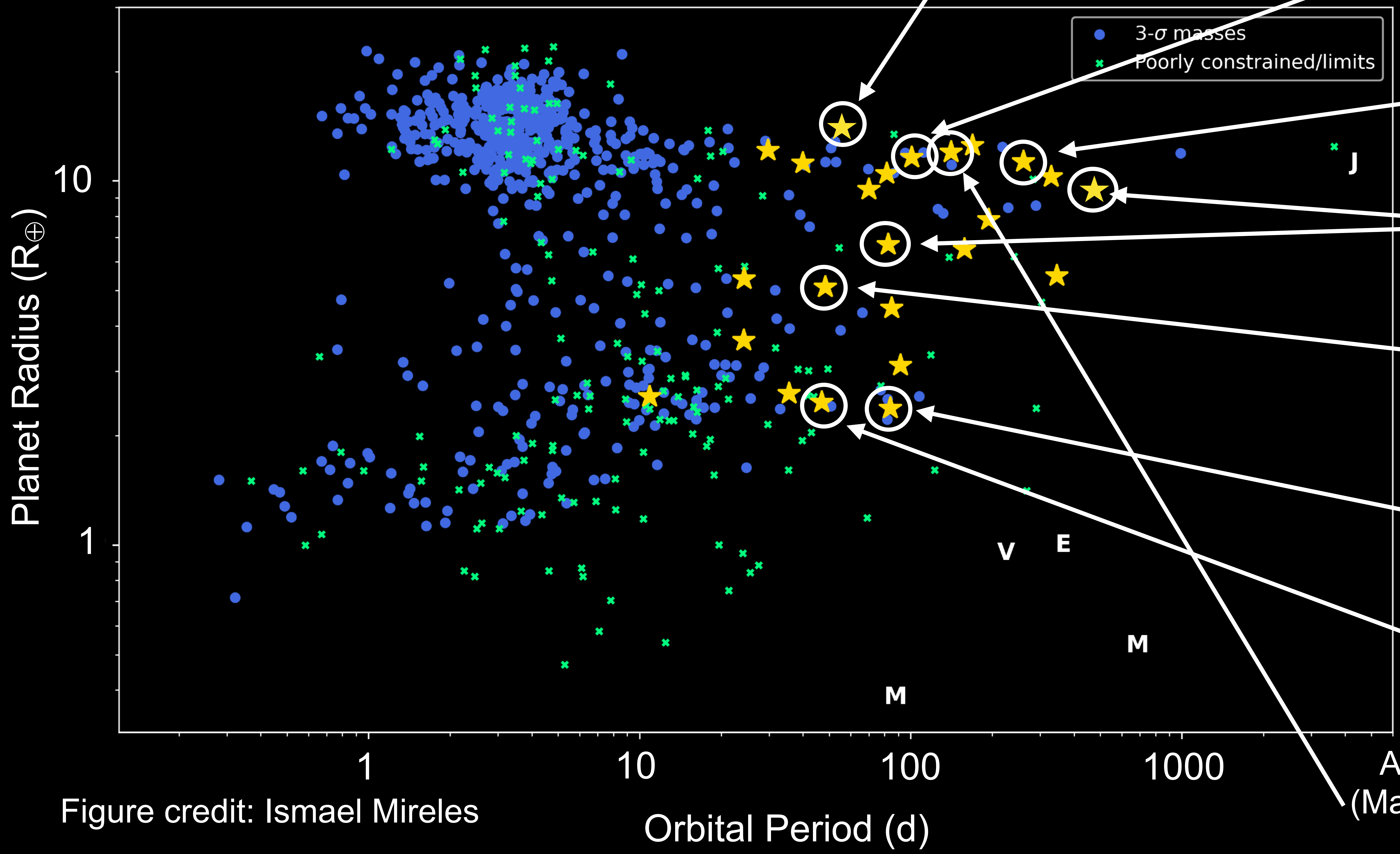


Figure credit: Ismael Mireles

A high-eccentricity warm Jupiter (Gupta et al., in press.; has RV mass)

A dense temperate gas giant (Dragomir et al., in prep.; has RV mass)

An eccentric temperate gas giant (Dalba et al. 2022; has RV mass)

A system of two temperate gas giants (Mireles et al., submitted)

A multi of well-separated planets (Osborn et al., in prep.)

TESS's coldest M dwarf planet (Harris et al., submitted)

A 47-day sub-Neptune (Hesse et al., in prep.; RV mass in progress)

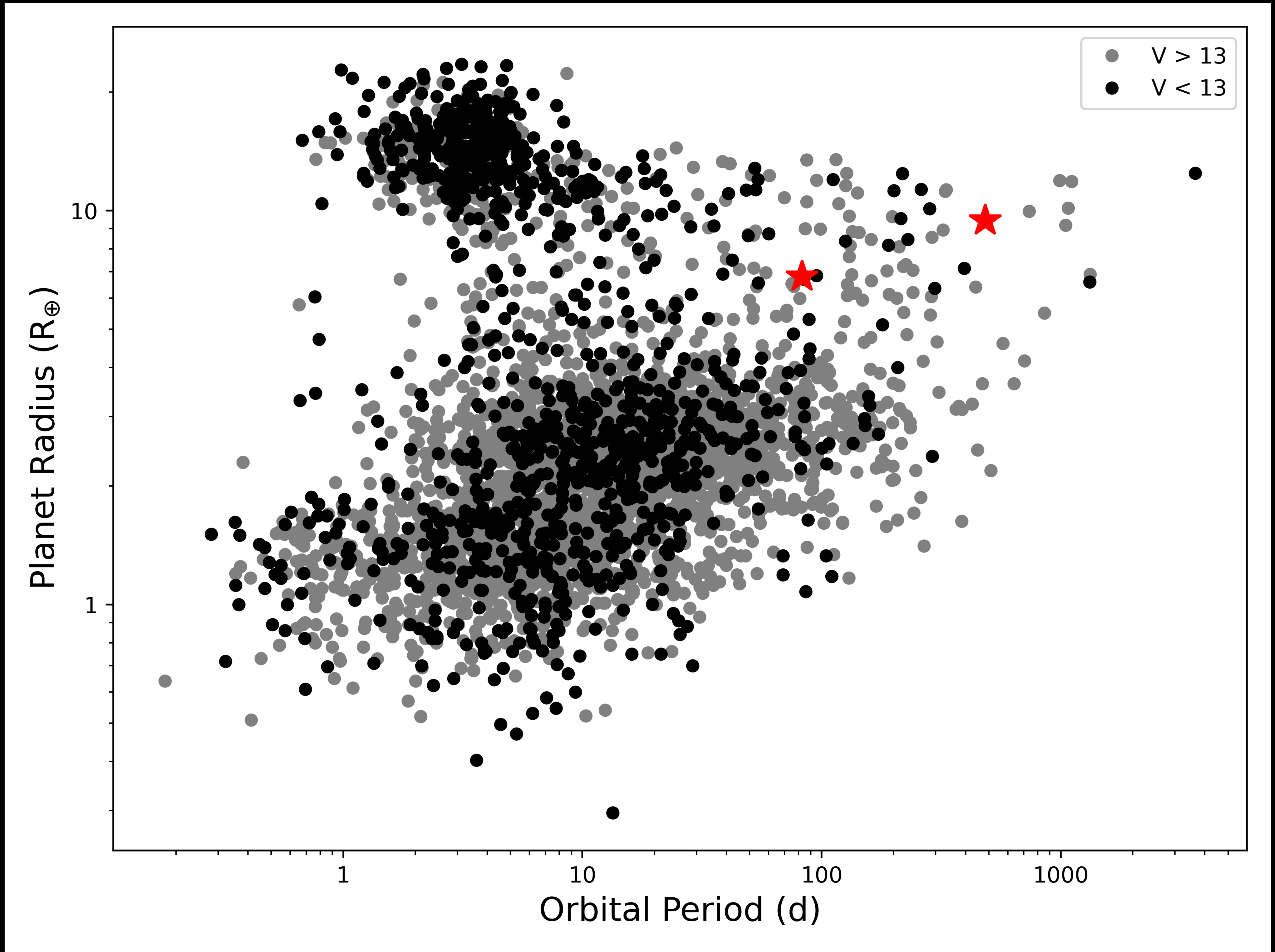
A 141-day Jovian (Mann et al., in prep.; has RV mass)

Why do we want to find transiting long-period exoplanets with TESS?

larger sample of warm/
cold planets for
population-level studies

TOI 4600

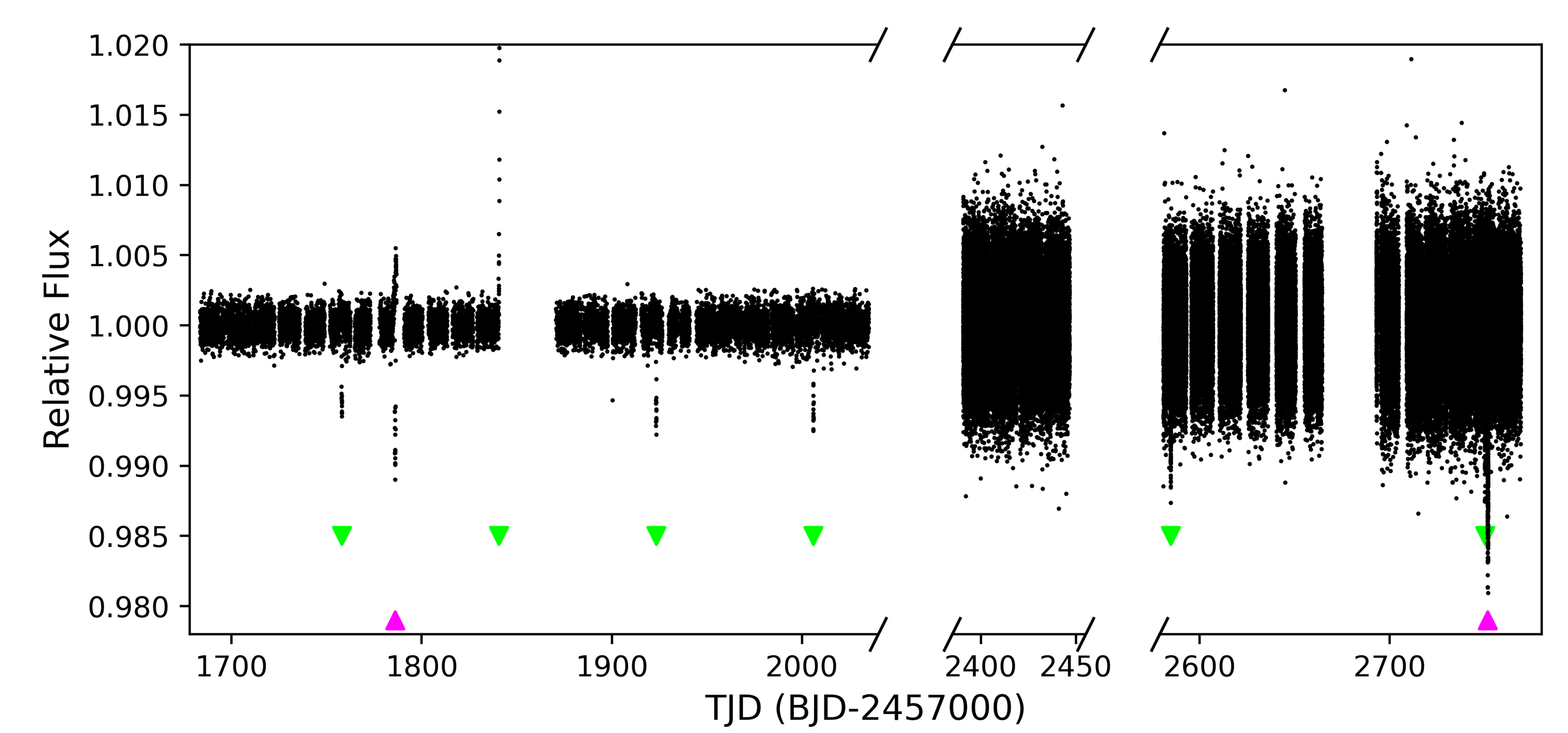
Ismael Mireles - UNM grad student



R_{p1} = 6.8 R_{Earth}
R_{p2} = 9.5 R_{Earth}

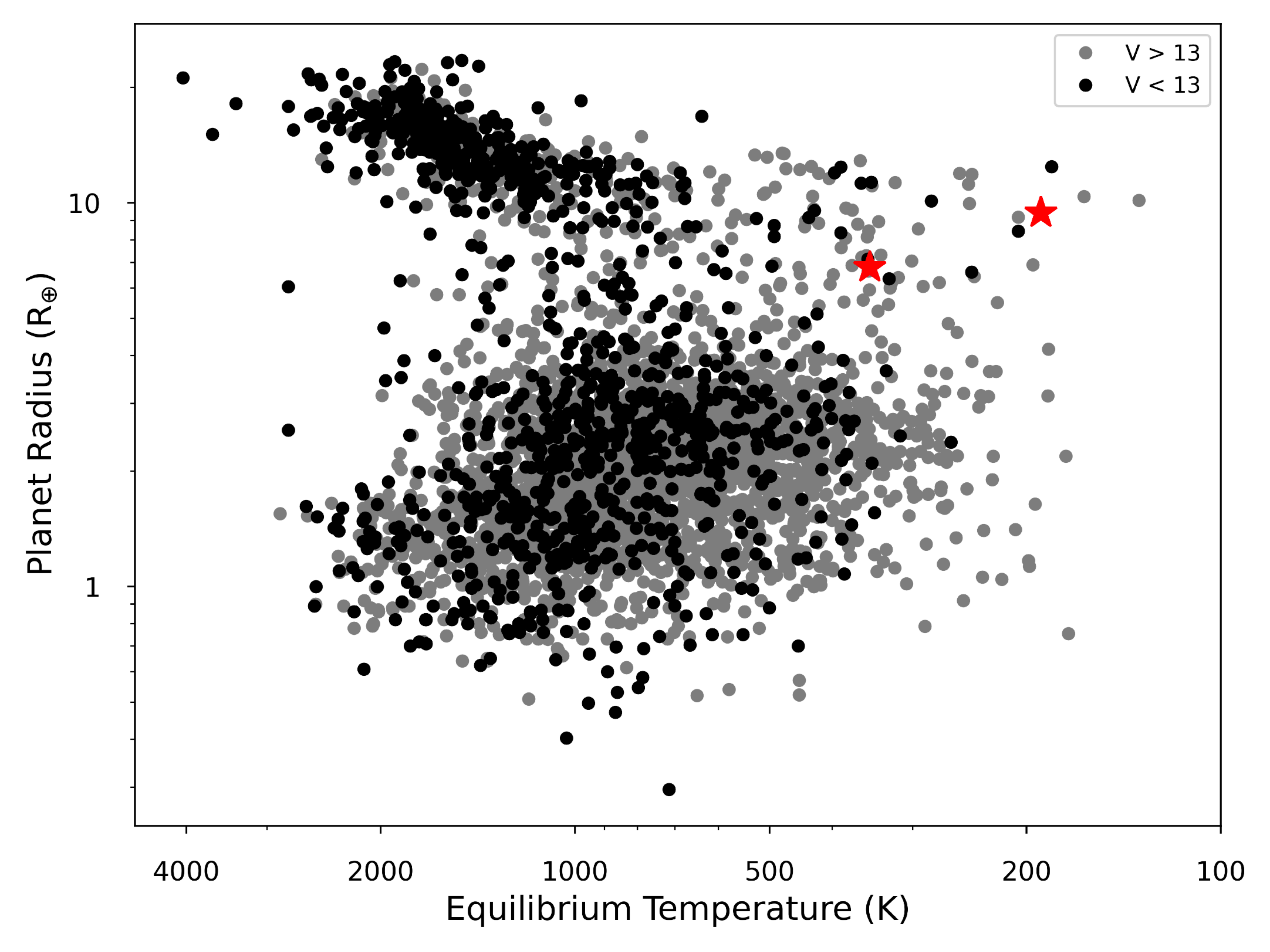
$Period_1$ = 82.7 days
$Period_2$ = 482.8 days

Host: K star
Vmag = 12.6

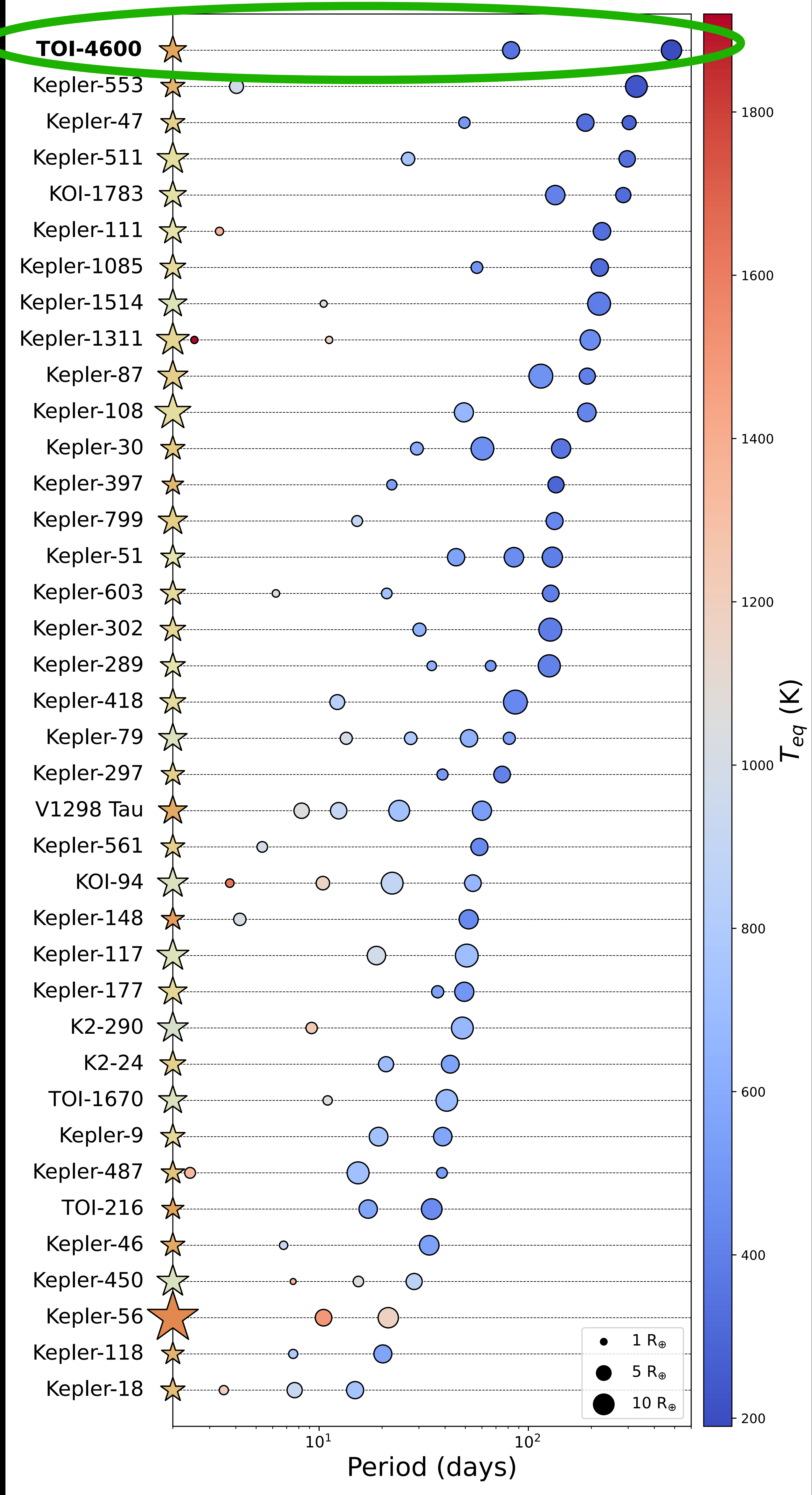


Mireles, Dragomir et al. (2023)

TOI 4600

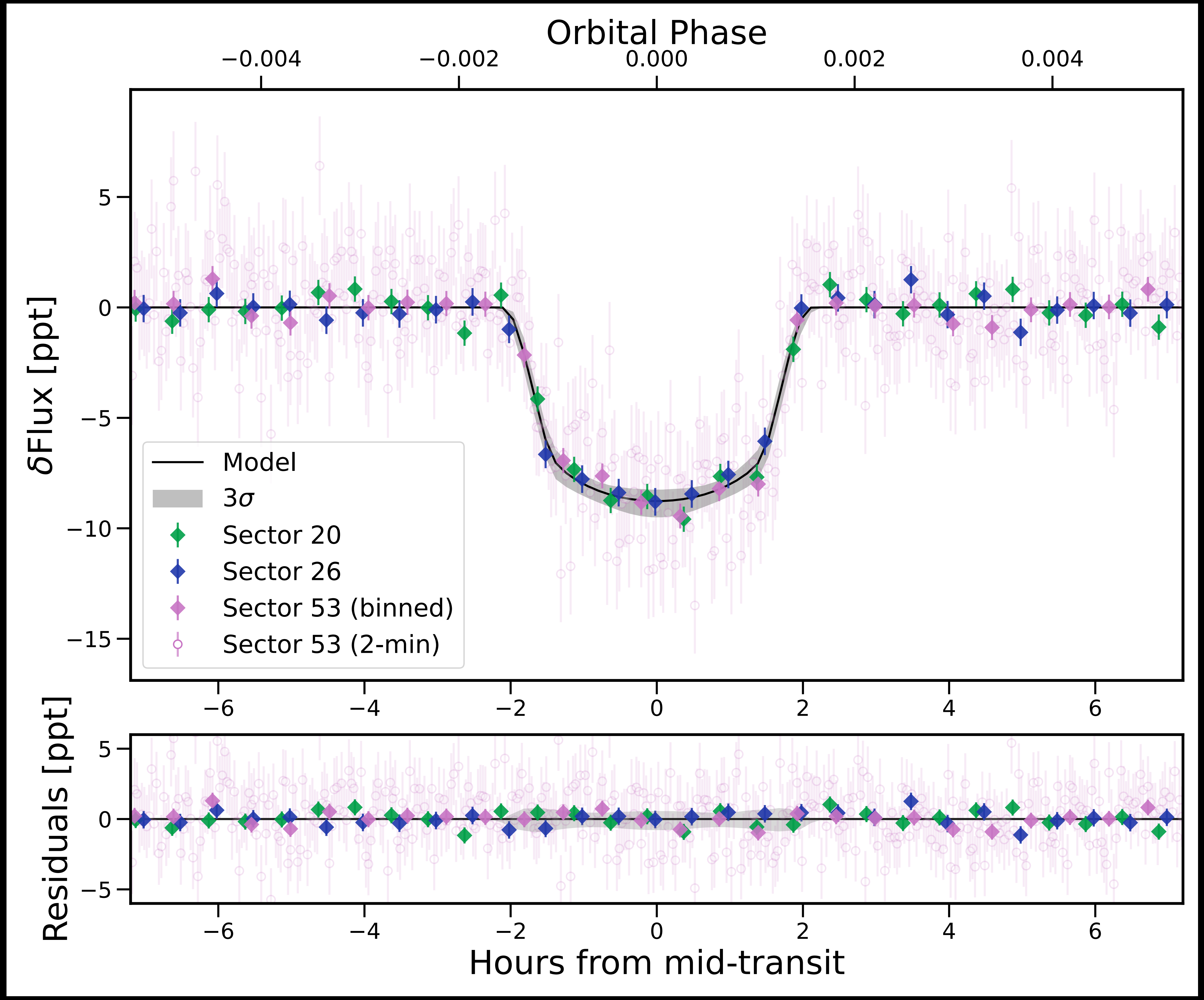


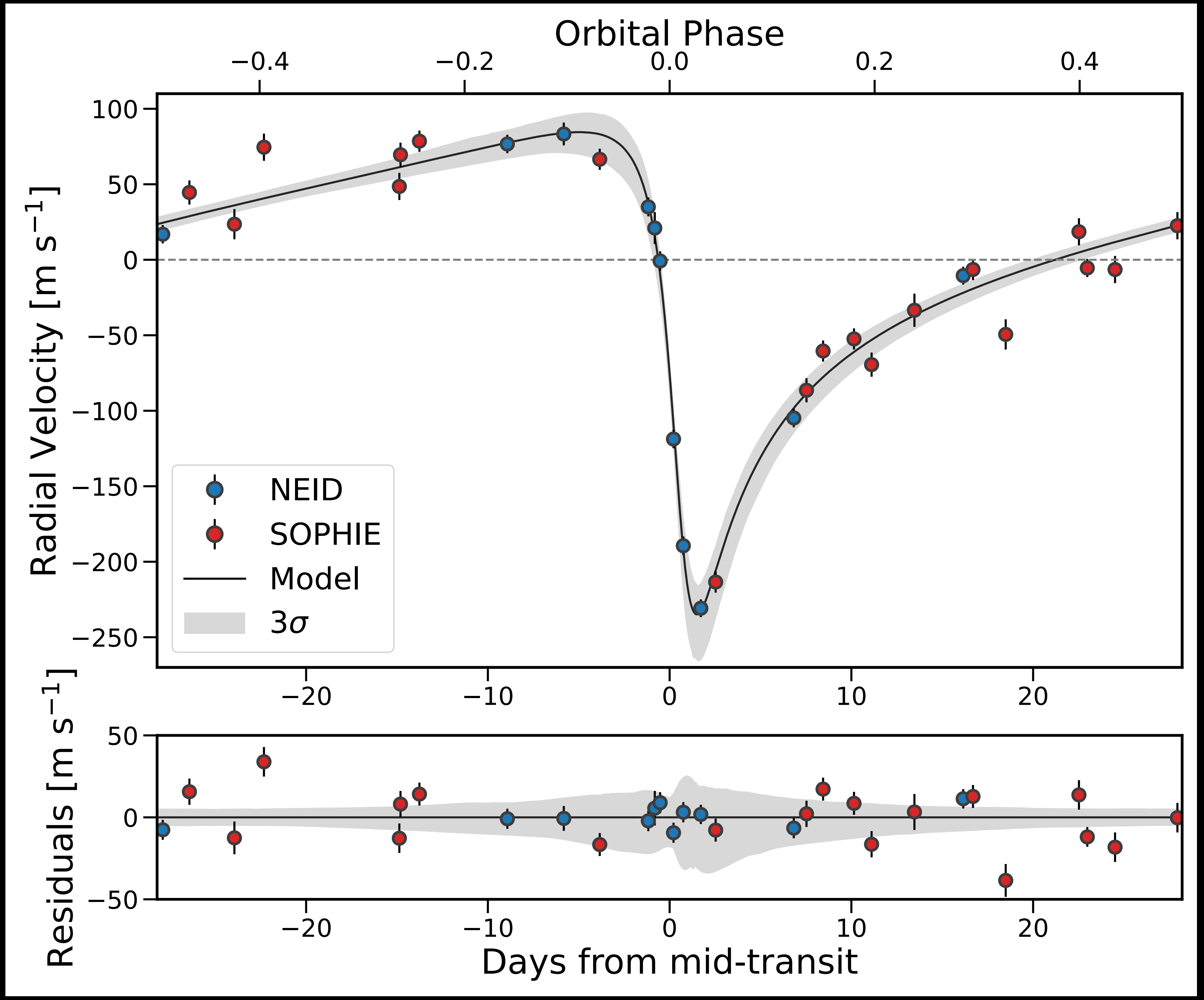
Mireles, Dragomir et al. (2023)



TOI 4127

Gupta et al., submitted





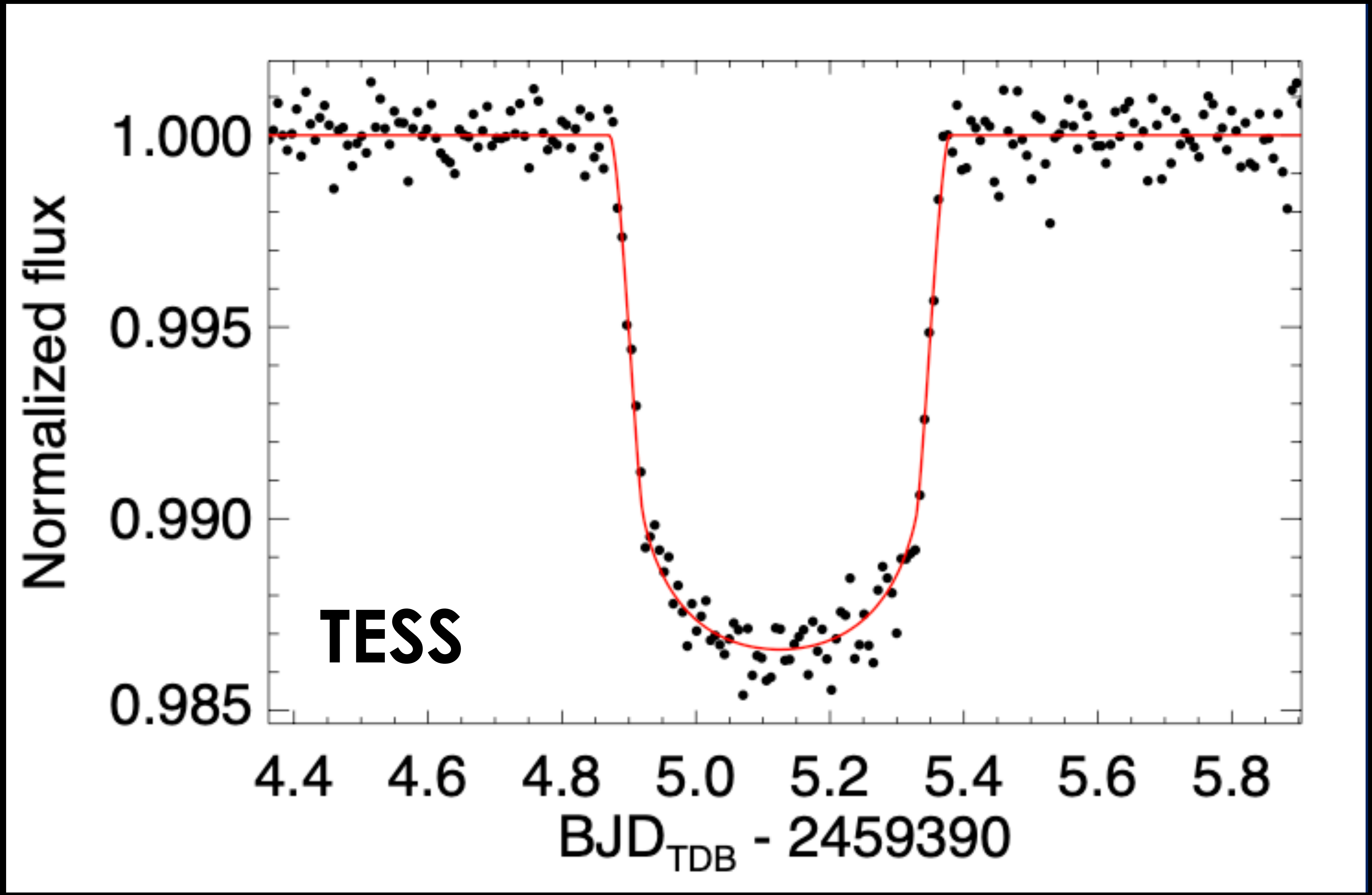
R_p = 1.1 R_{Jup}
Mp = 2.3 M_{Jup}

Period = 56.4 days
Eccentricity = 0.75

Host: late F star

TOI 4465

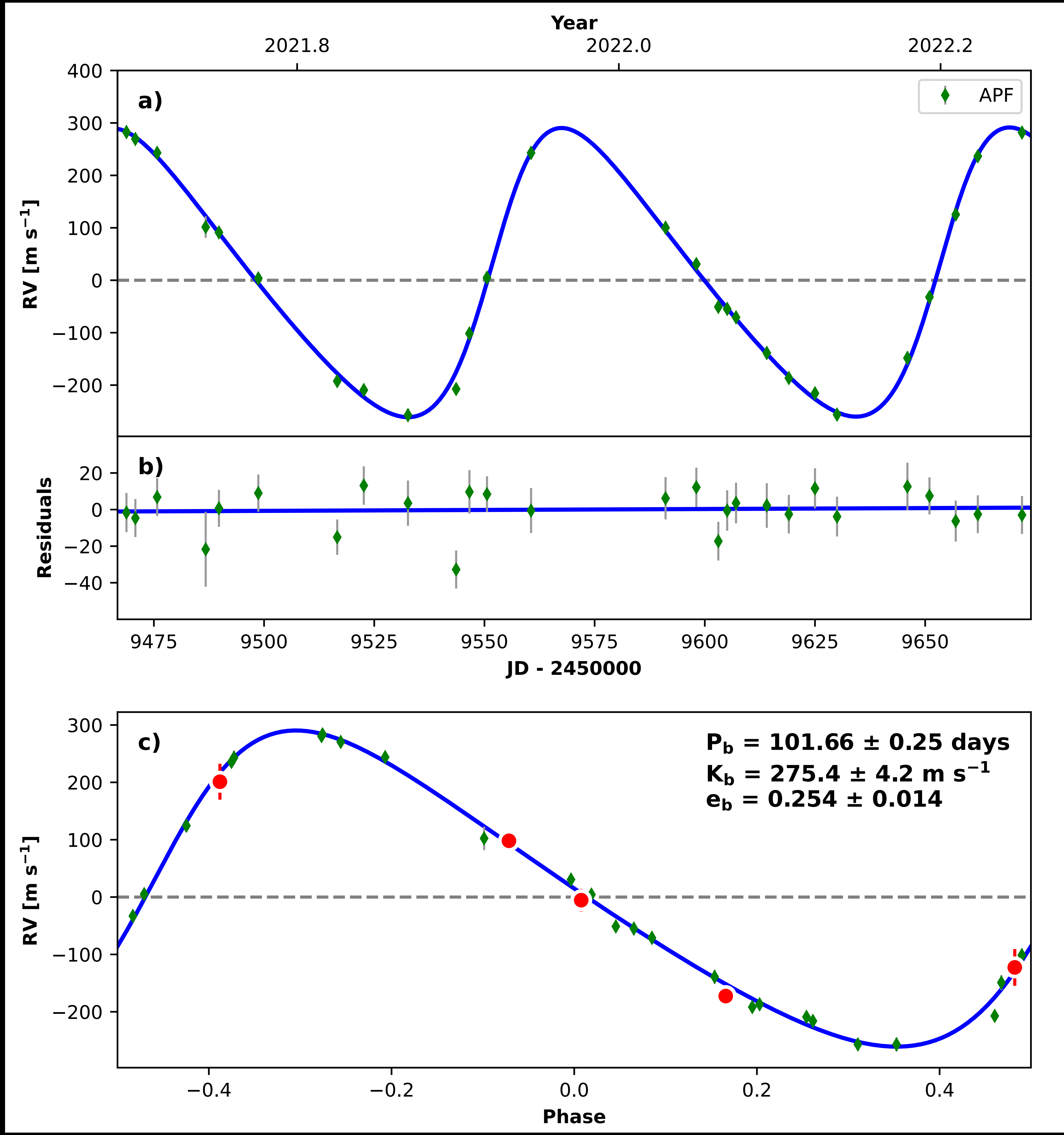
Sector 40 single transit + APF RVs predicted a 3-day 1σ window.



$R_p = 1.02\ R_{Jup}$
$M_p = 5.7\ M_{Jup}$

Period = 101.7 days
Eccentricity = 0.254

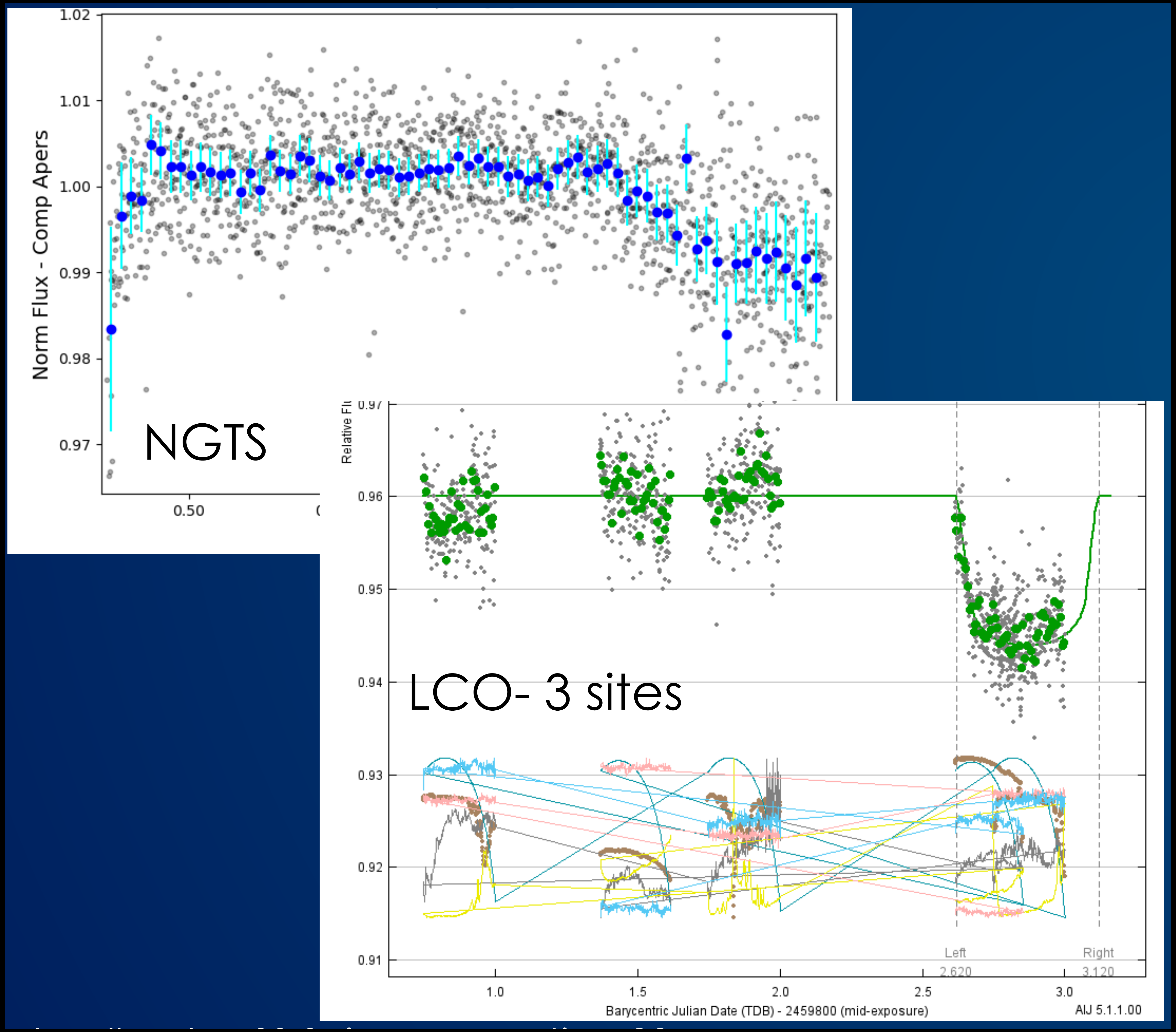
Host: K star
Vmag = 10.4



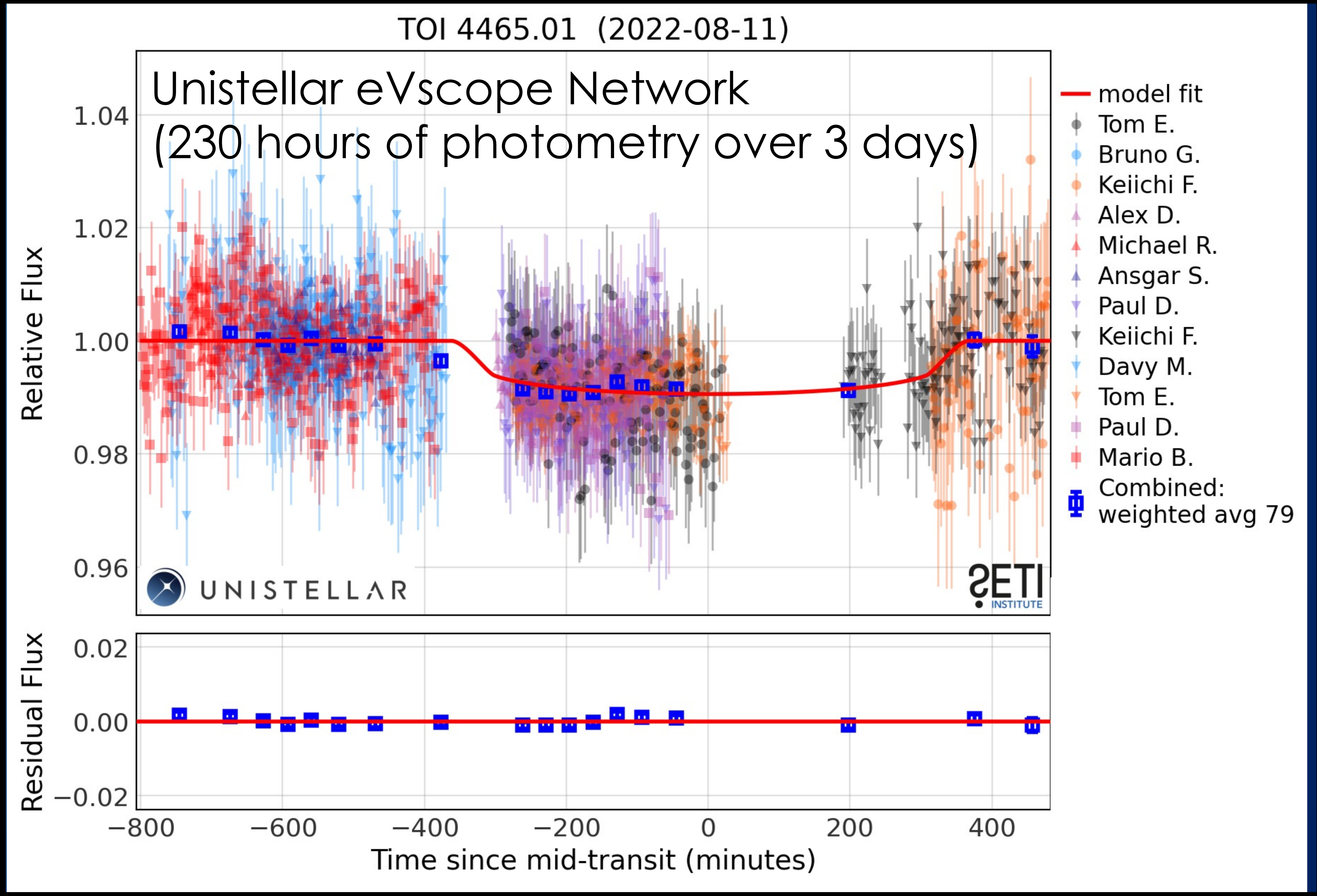
Dragomir et al., in prep.

TOI 4465 - transit recovery planning

TOI 4465 - A successful TSTPC Transit Recovery

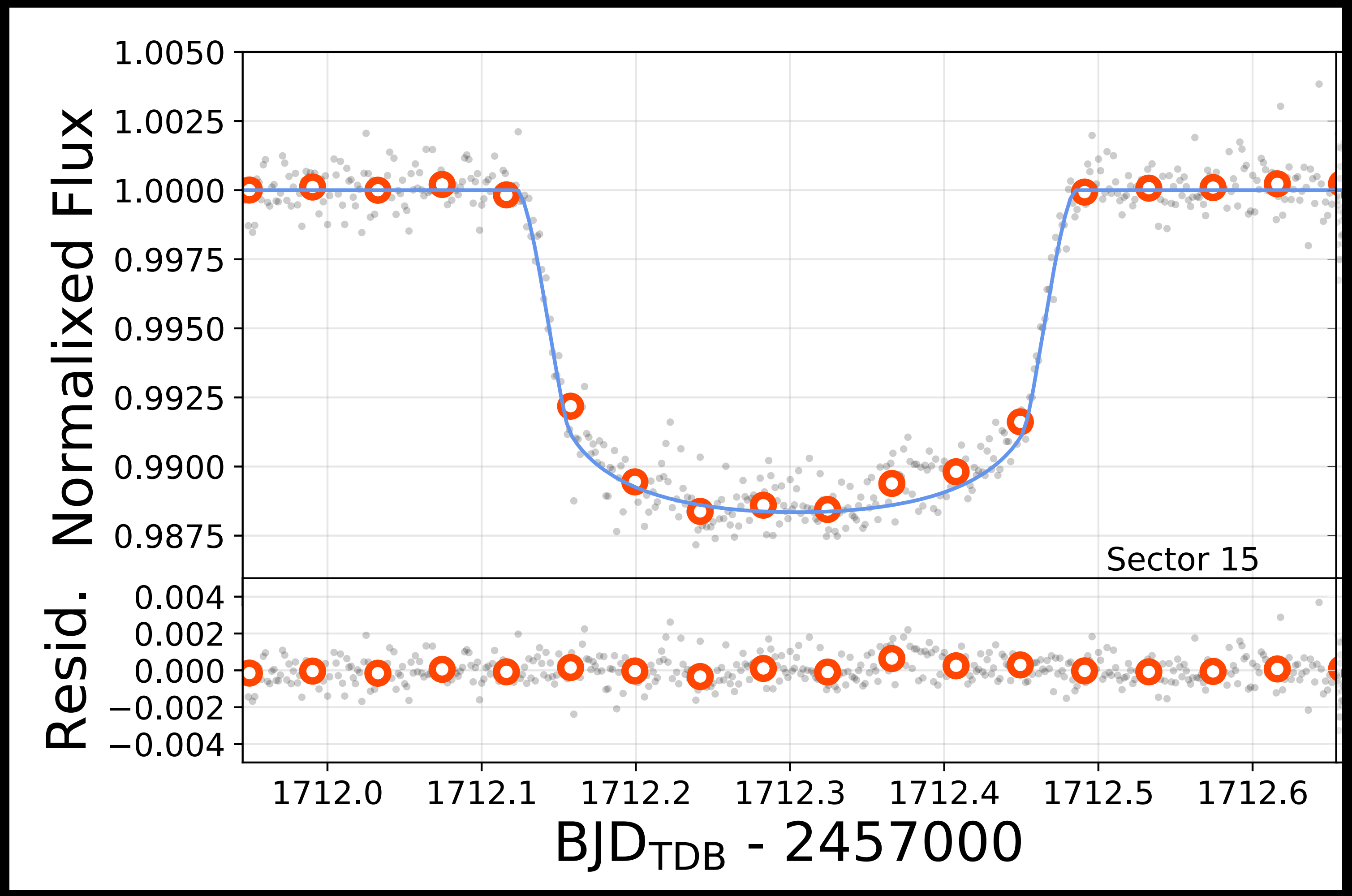


Transit detection from LCO (K. Collins), NGTS (M. Battley) and Unistellar eVscope Network (P. Dalba)

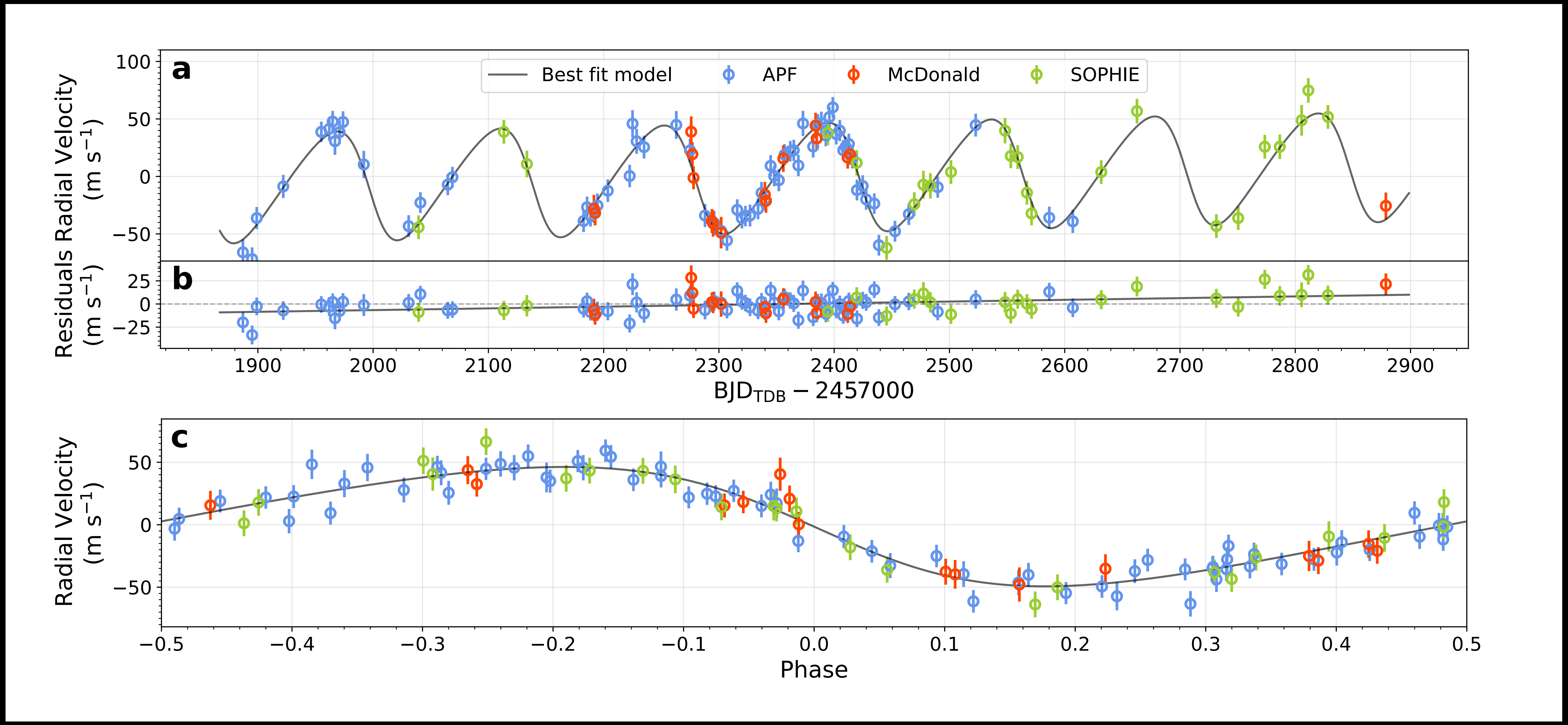


Dragomir et al., in prep.

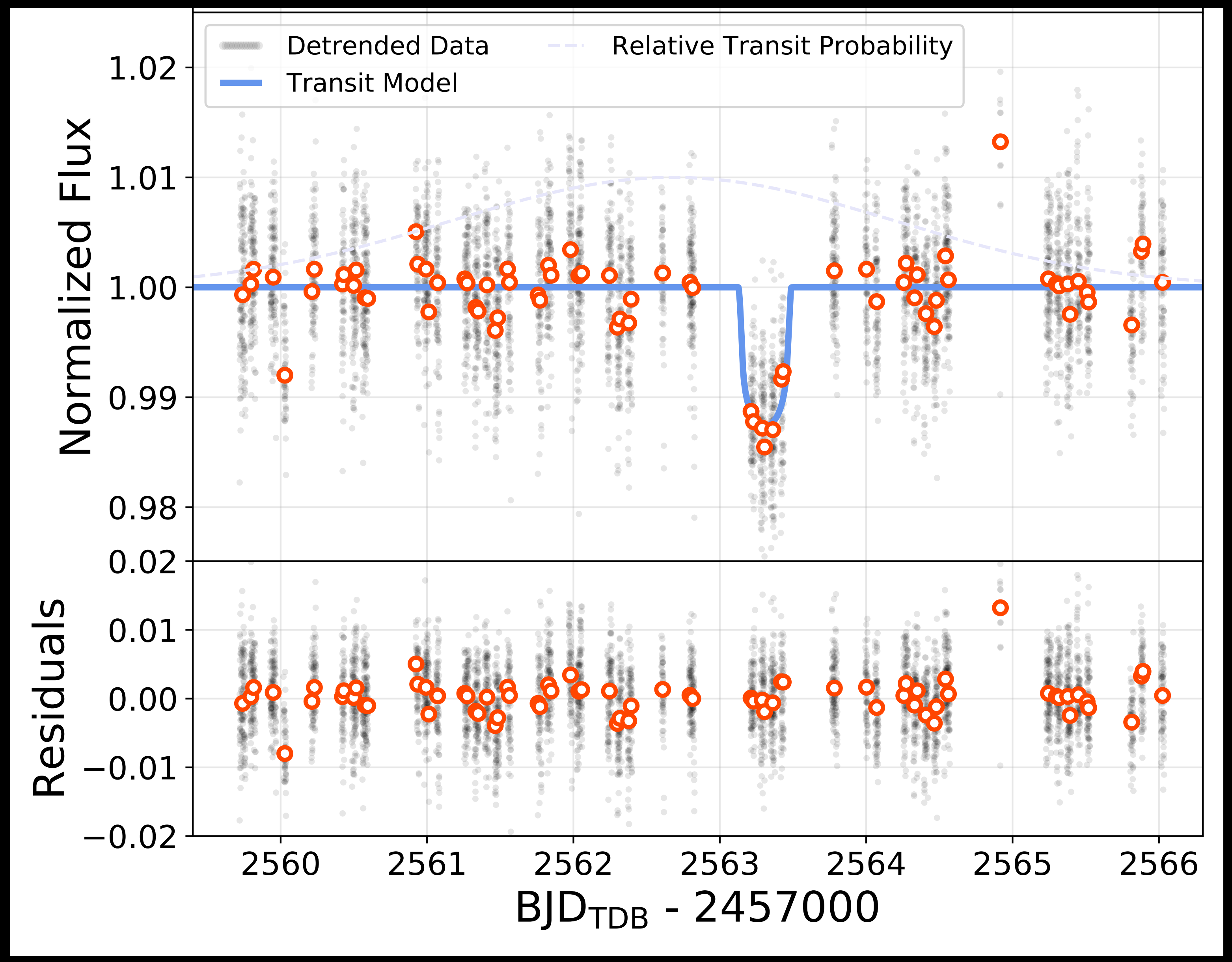
TOI 2010



Mann et al., in prep.



Mann et al., accepted



R_p = 1.29 R_{Jup}
M_p = 1.05 M_{Jup}

Period = 141.8 days
Eccentricity = 0.21

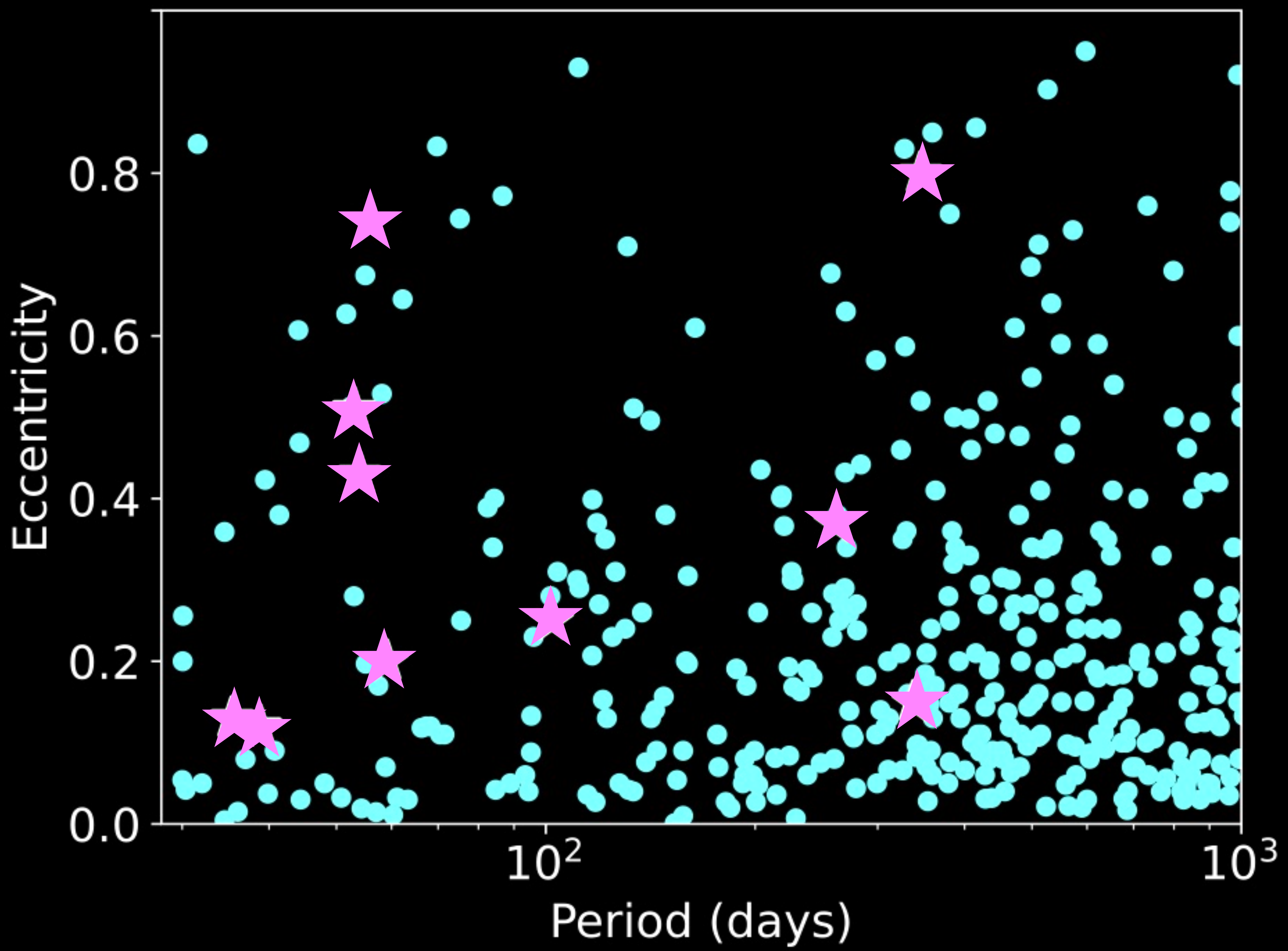
Host: G star
Vmag = 9.9

NEOSSAT observations (PI Chris Mann)

Period-Eccentricity distribution

- All TSTPC orbits measured so far with RVs are at least mildly eccentric

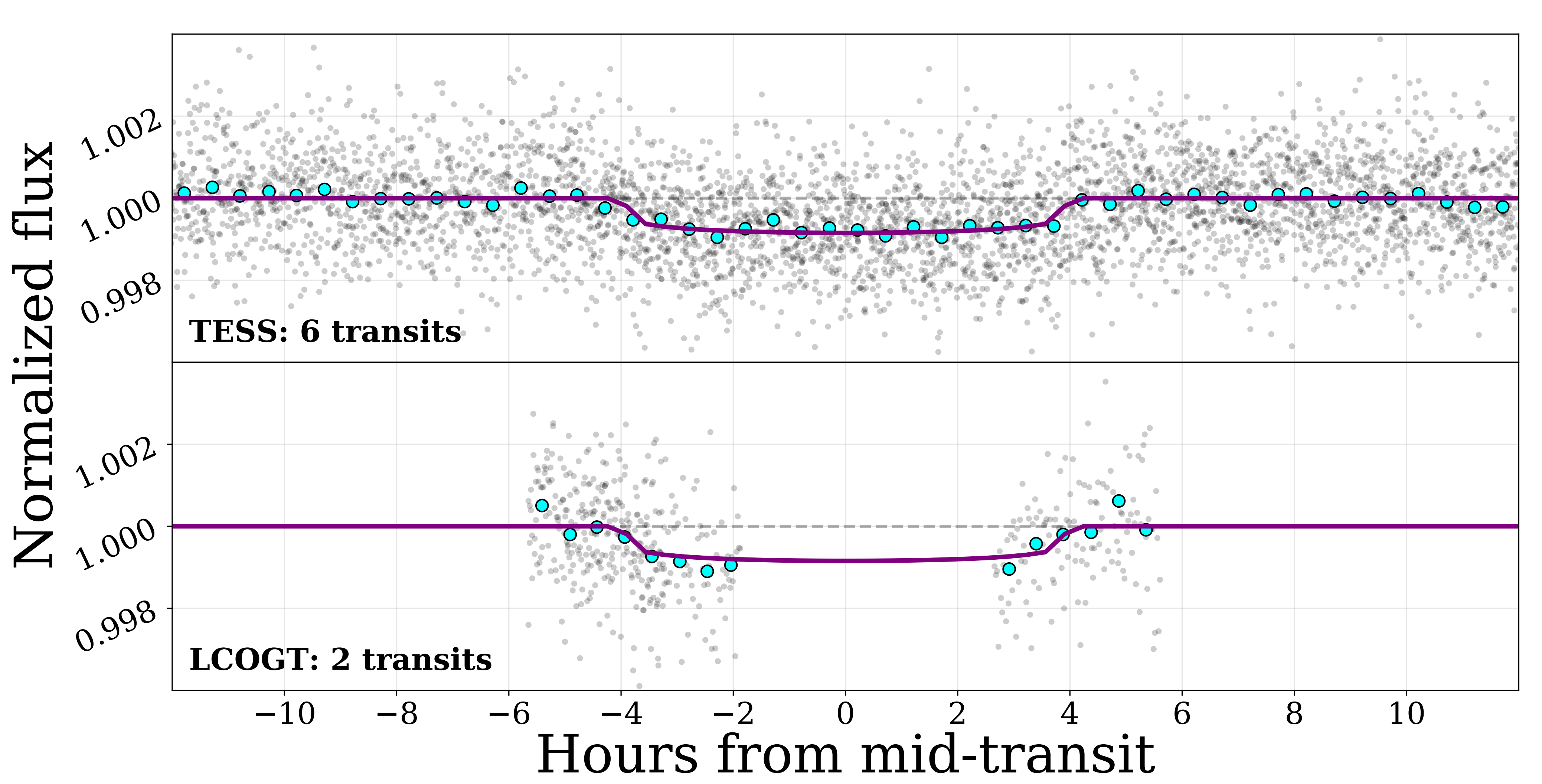
all giant planets with measured eccentricity (majority don't transit)
TESS long-period giant planets with measured eccentricity



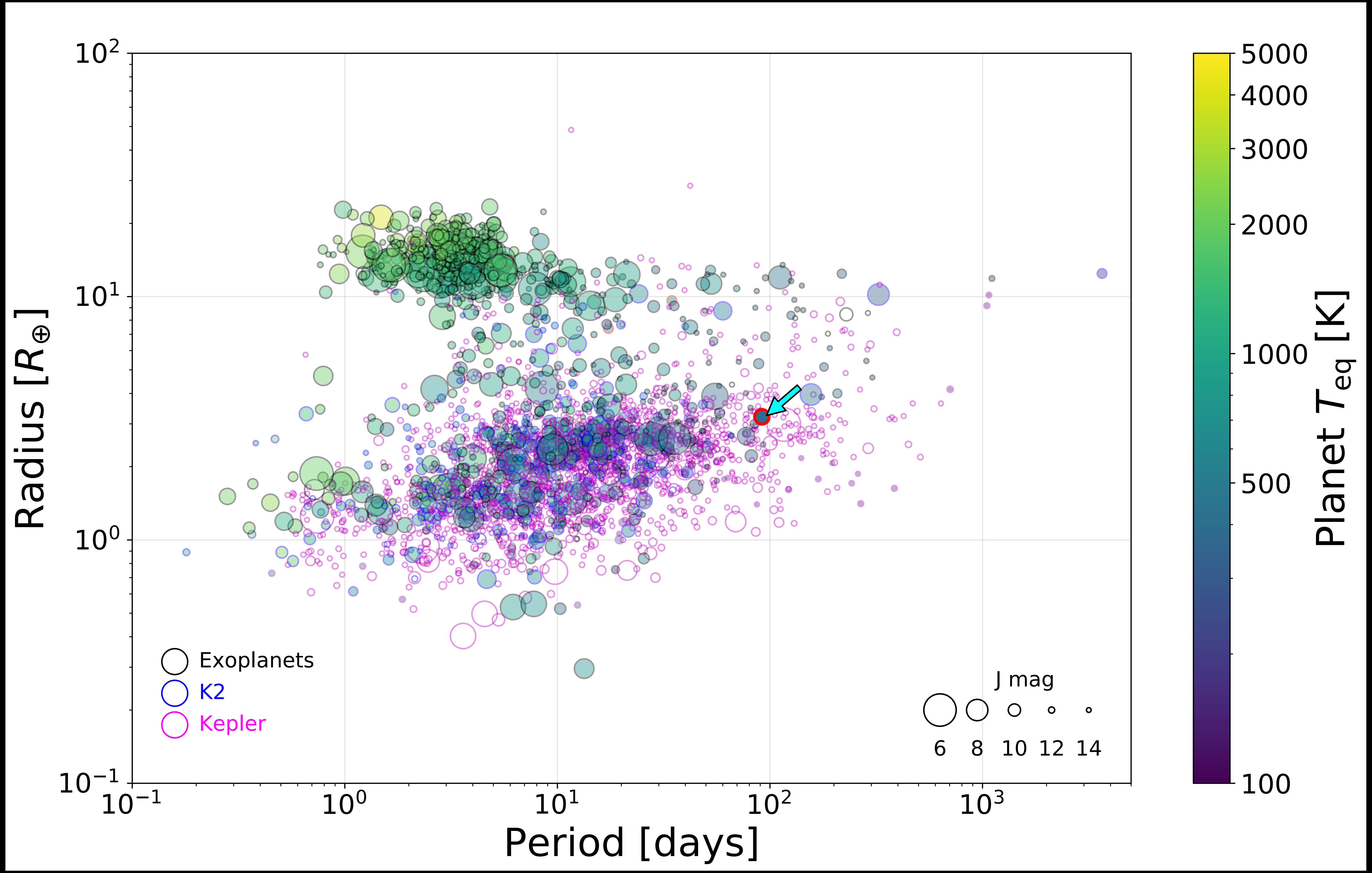
Why do we want to find transiting long-period exoplanets with TESS?

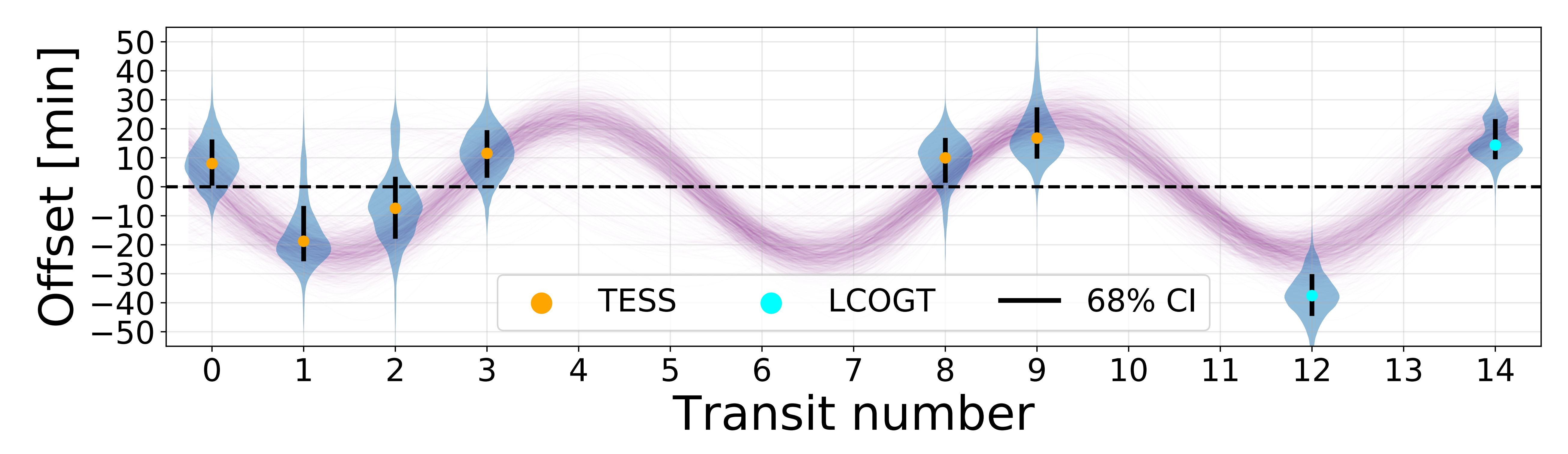
larger sample of *smaller* warm/cold planets for population-level studies

TOI 1221



Mann, Lafreniere, Dragomir et al. (2023)





R_p = 2.9 R_{Earth}

Period = 91.7 days

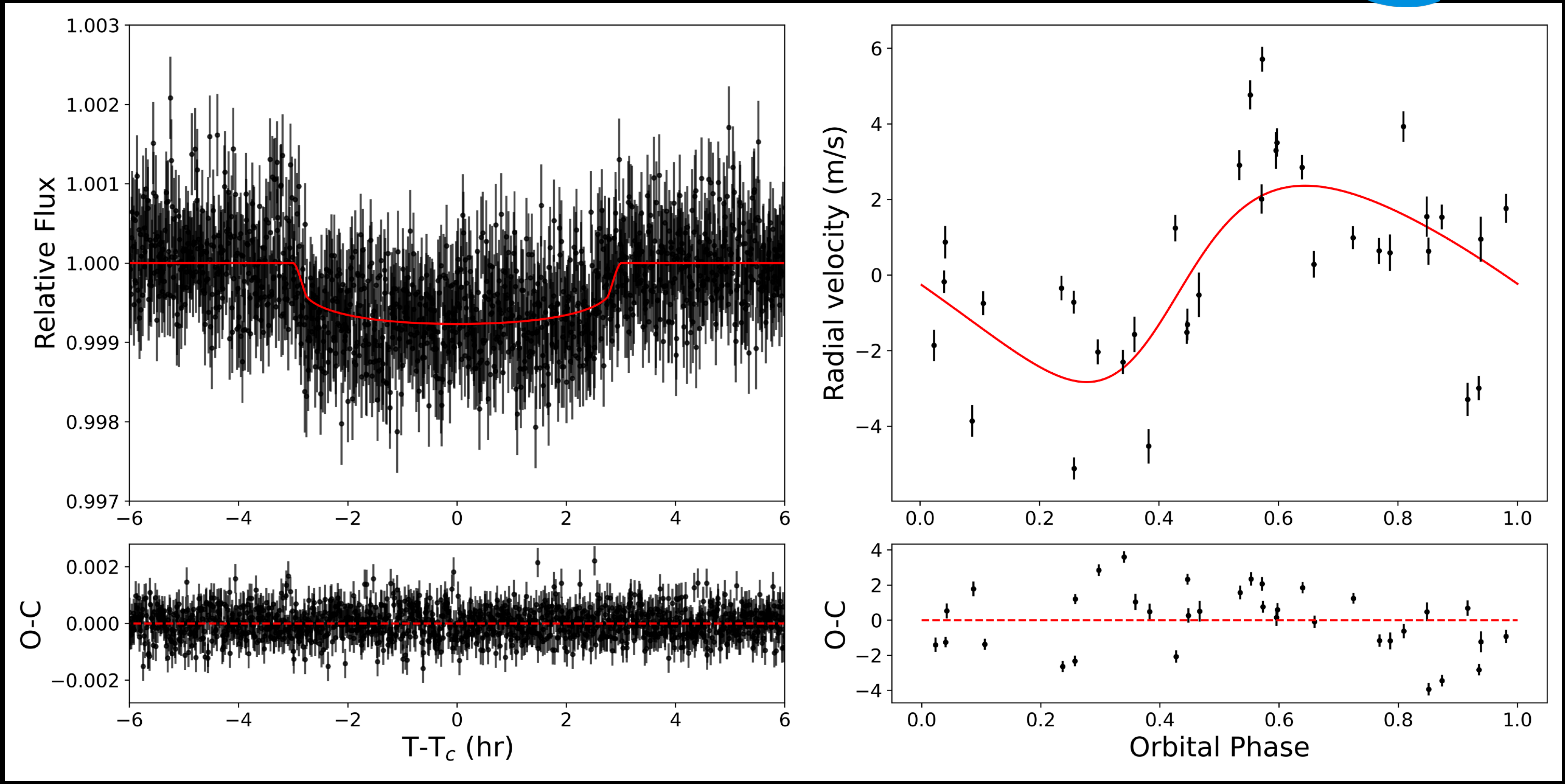
Host: G star
Vmag = 10.5

TOI 4189

R_p = 2.56 R_{Earth}
M_p = 13.8 +/- 2.8 M_{Earth}

Period = 46.96 days
Eccentricity = 0.23 +/- 0.15

Host: G star
Vmag = 9.4



Hesse, Mireles, Dragomir et al., in prep.

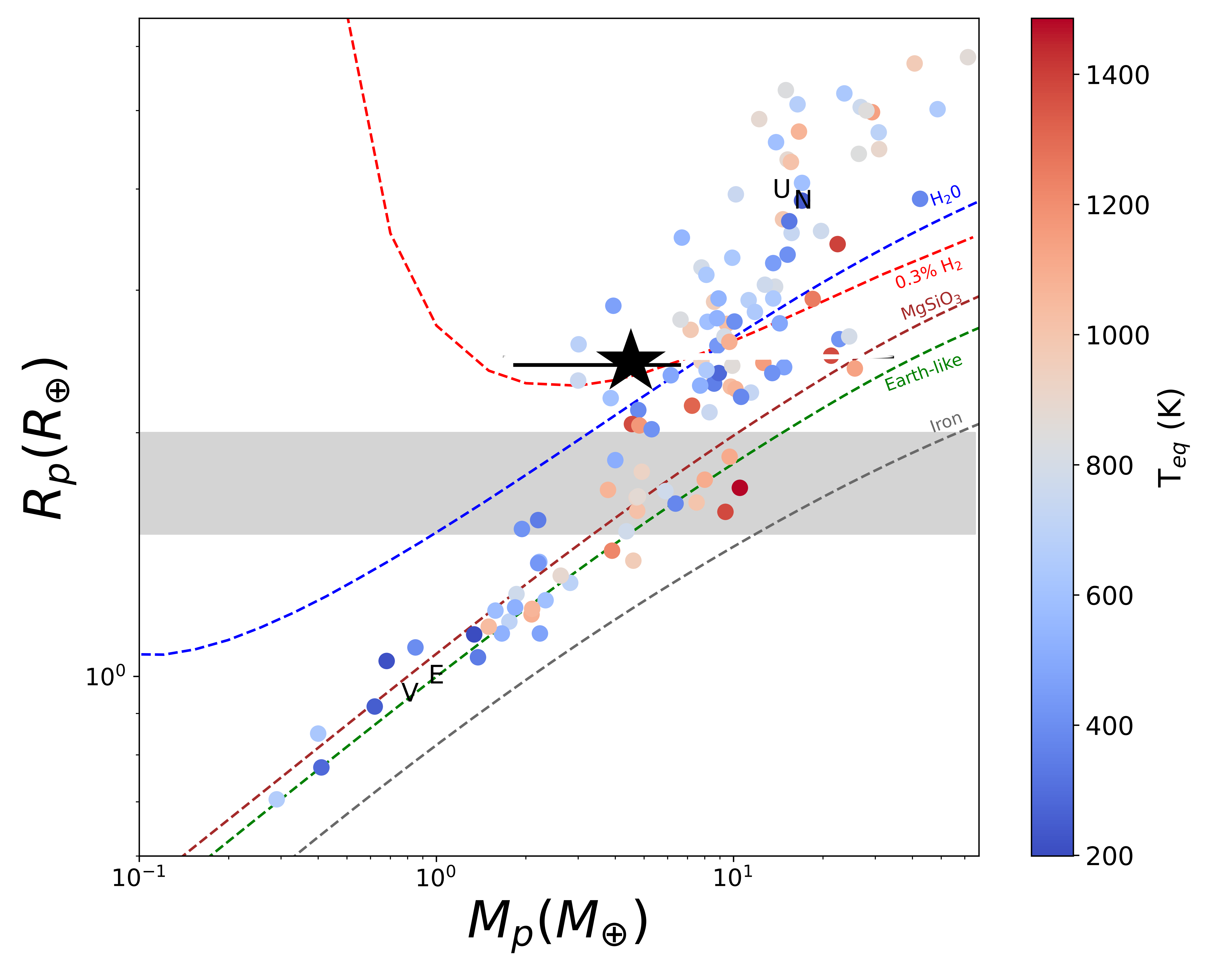
ESPRESSO RVs (PI Katharine Hesse)

TOI 4189

R_p = 2.56 R_{Earth}
M_p = 13.8 +/- 2.8 M_{Earth}

Period = 46.96 days
Eccentricity = 0.23 +/- 0.15

Host: G star
Vmag = 9.4



Hesse, Mireles, Dragomir et al., in prep.

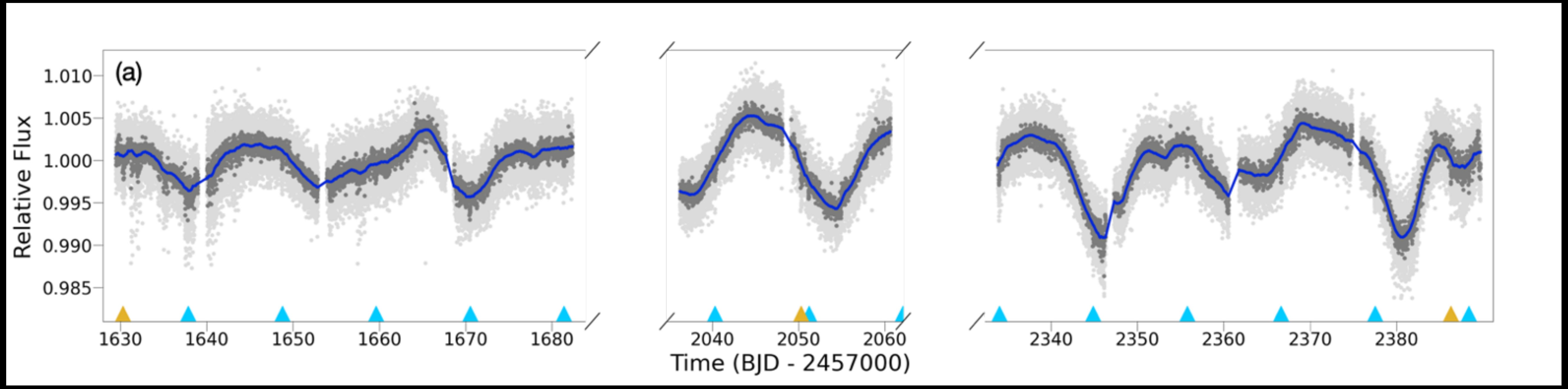
Why do we want to find transiting long-period exoplanets with TESS? Didn't Kepler find enough?

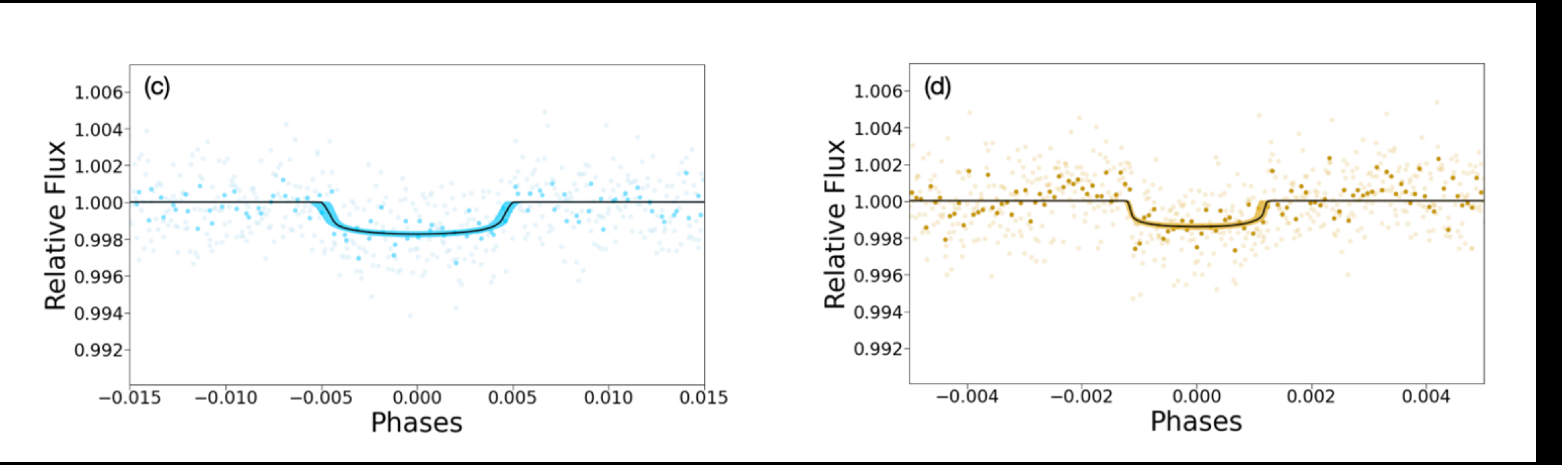
larger sample of warm/ cold planets for population-level studies

probe limits of planet formation in the outskirts of M dwarf planetary systems

TOI 904

Mallory Harris - UNM grad student

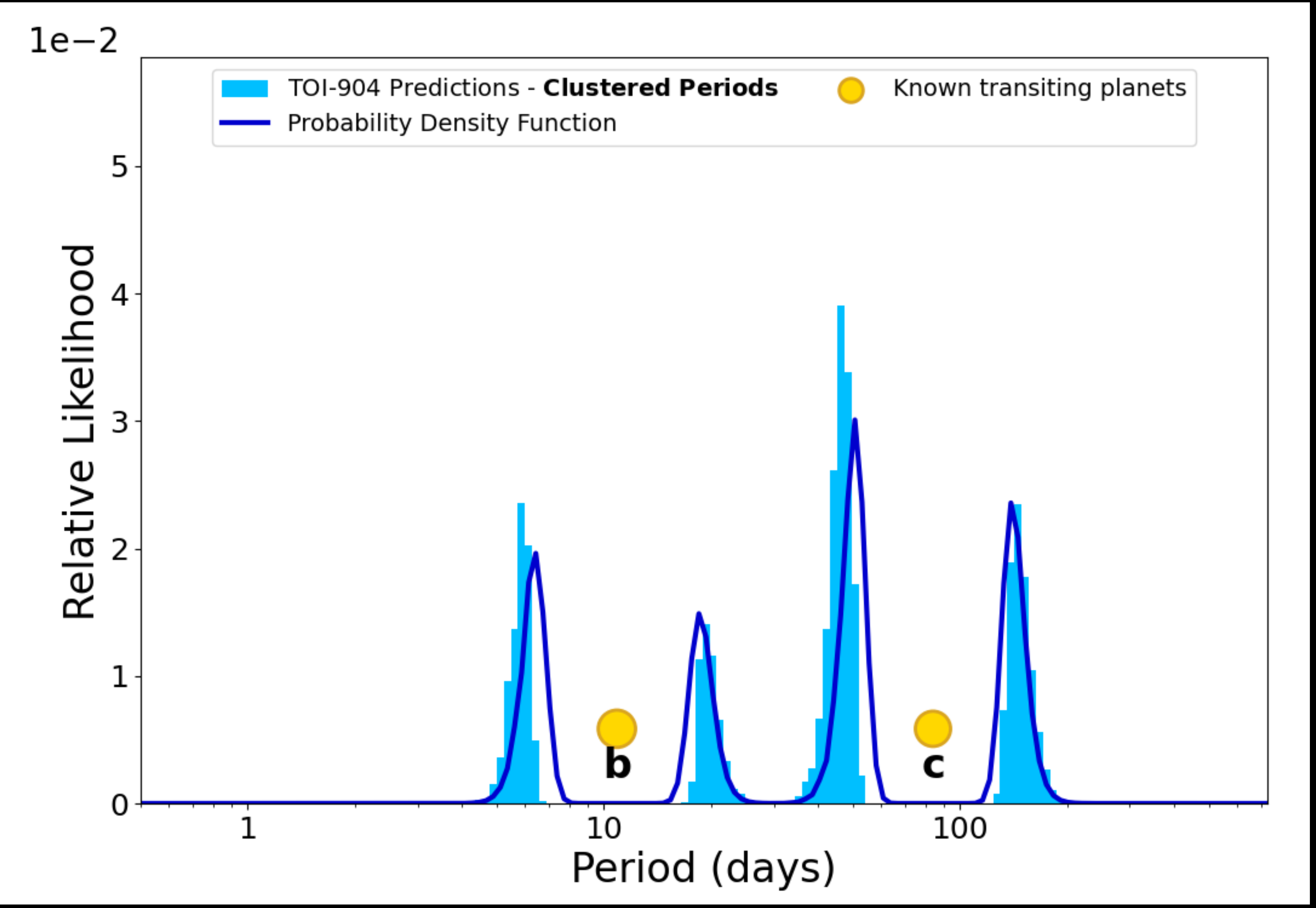




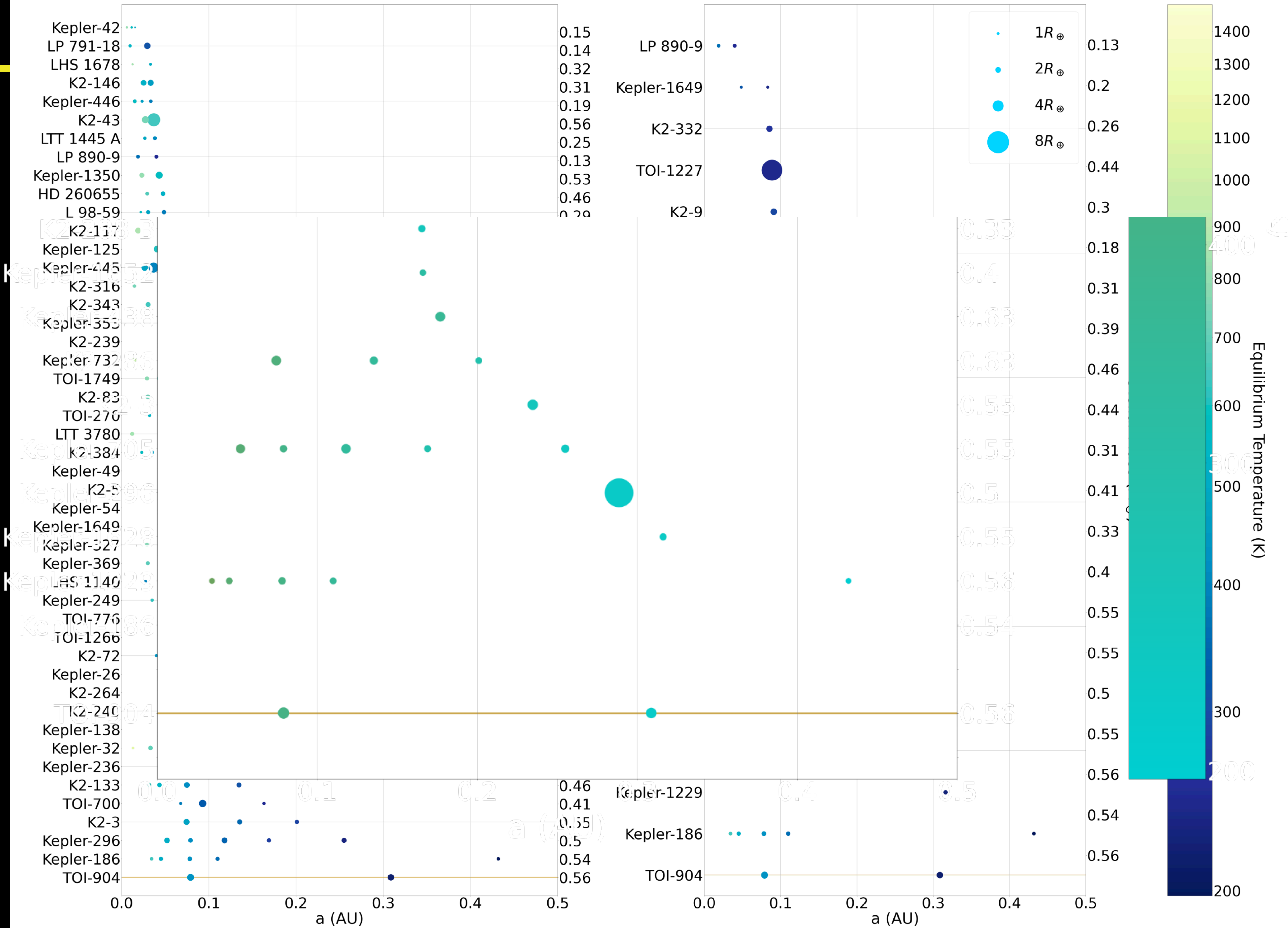
R_{p1} = 2.5 R_{Earth}
R_{p2} = 2.3 R_{Earth}

$Period_1$ = 10.90 days
$Period_2$ = 84 days

Host: M0 star
Vmag = 12.6
Jmag = 9.6

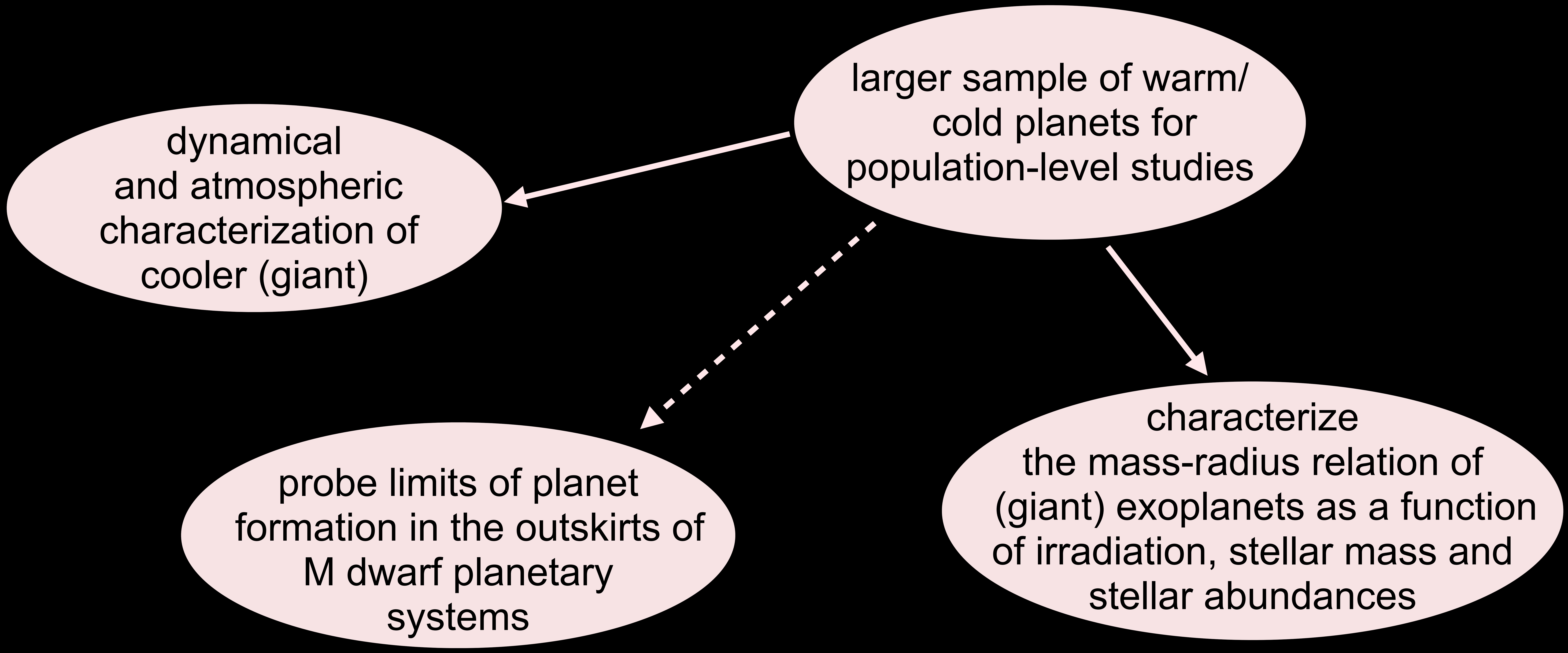


TOI 904



Harris, Dragomir et al., (2023)

Next steps


larger sample of warm/ cold planets for population-level studies
dynamical and atmospheric characterization of cooler (giant)
probe limits of planet formation in the outskirts of M dwarf planetary systems
characterize the mass-radius relation of (giant) exoplanets as a function of irradiation, stellar mass and stellar abundances

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Takeaways

- Finding and characterizing long-period transiting planets is a necessary next step towards placing the Solar System in context
- A large (10s of planets) sample of warm and temperate gas giants will enable studies of:
  - planet density as a function of stellar mass, abundances, and of distance from the star at low irradiation
  - orbital eccentricity as a function of orbital period, system architecture and stellar mass and abundances
- TESS has found 10s of transiting planets and planet candidates with period > 50 days
  - growing the sample of long-period planets transiting M dwarfs
  - already a few with periods in the 200 - 500 day range
  - TESS Extended Mission 2 will solve period ambiguities for many systems, further increasing these yields

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TESS EM2 Key Project award

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