

# Planet Hunters TESS: people-powered exoplanet discovery in TESS data

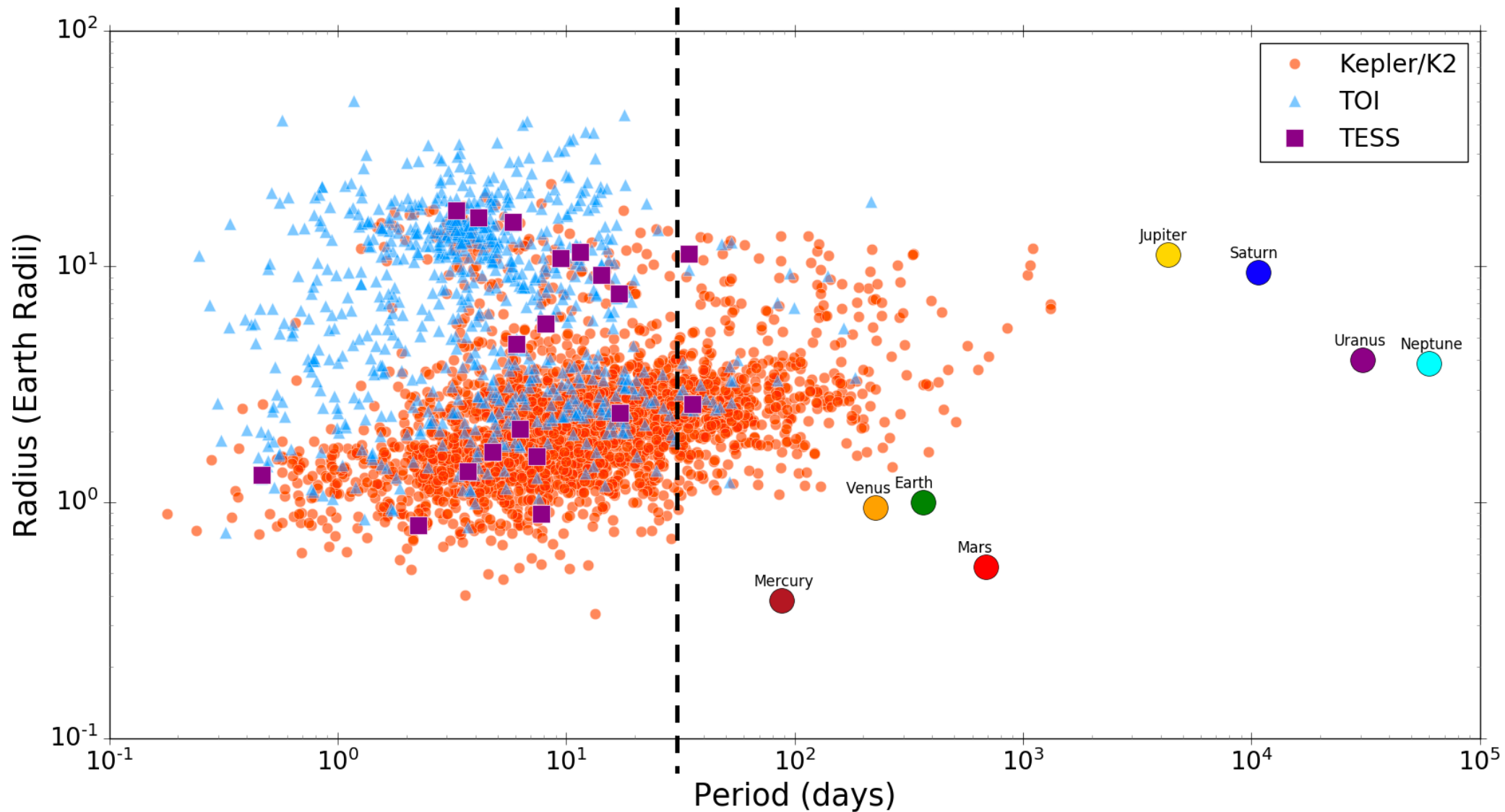
**Nora Eisner**

University of Oxford

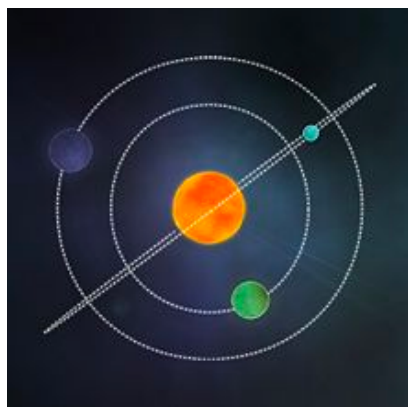
Suzanne Aigrain, Chris Lintott, Oscar Barragàn & the Zooniverse team

TESS Science Conference I, MIT, 30 July 2019

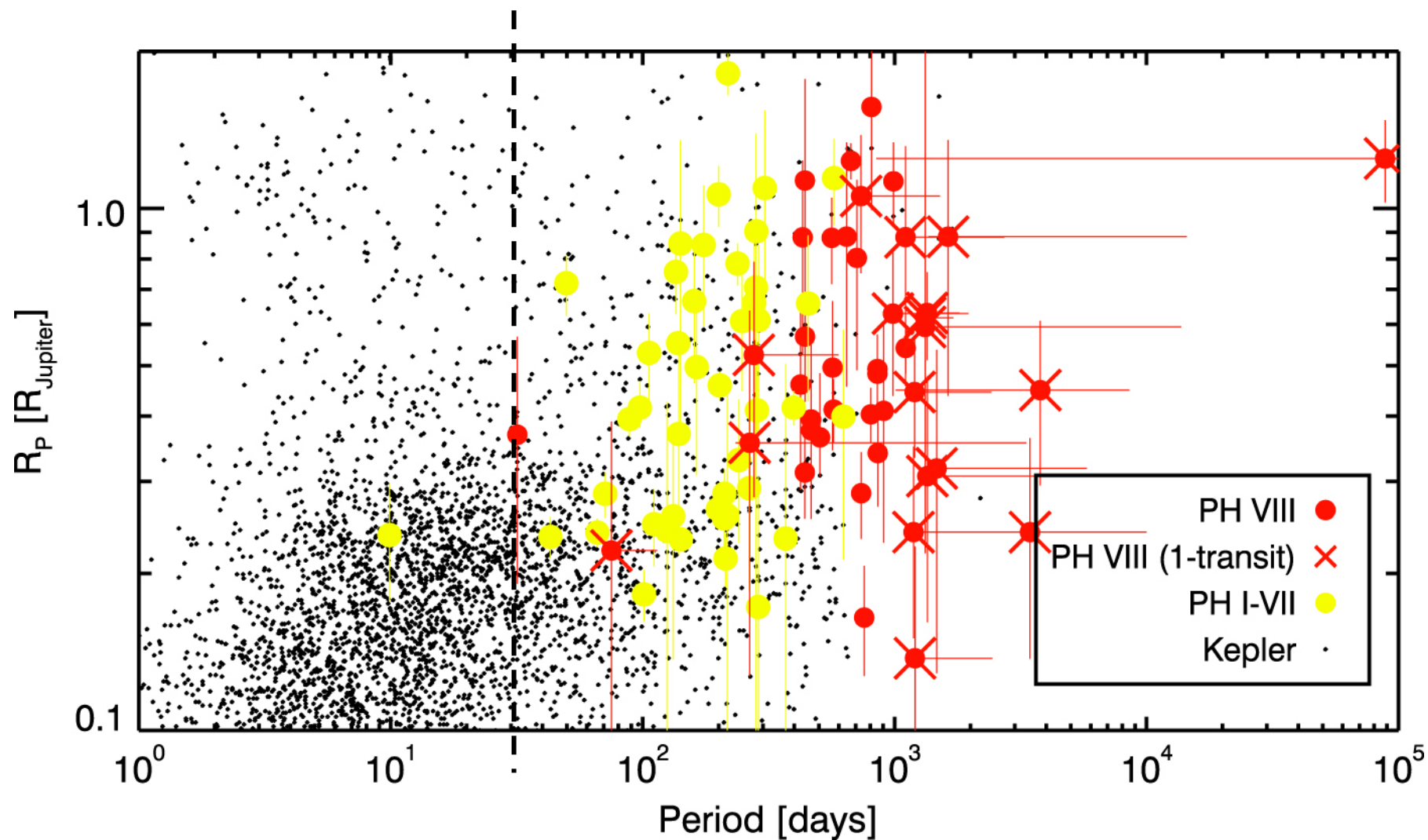
# Kepler + K2 + TESS + TOIs



# Planet Hunters



Kepler Data



# Planet Hunters TESS



[planethunters.org](https://planethunters.org)



# Step-by-Step Summary



## Per Sector:

**20,000**  
Subjects  
each seen  
by 8 - 15  
volunteers



Extract and  
rank new  
planet  
candidates



Top ~500  
looked at by  
science team

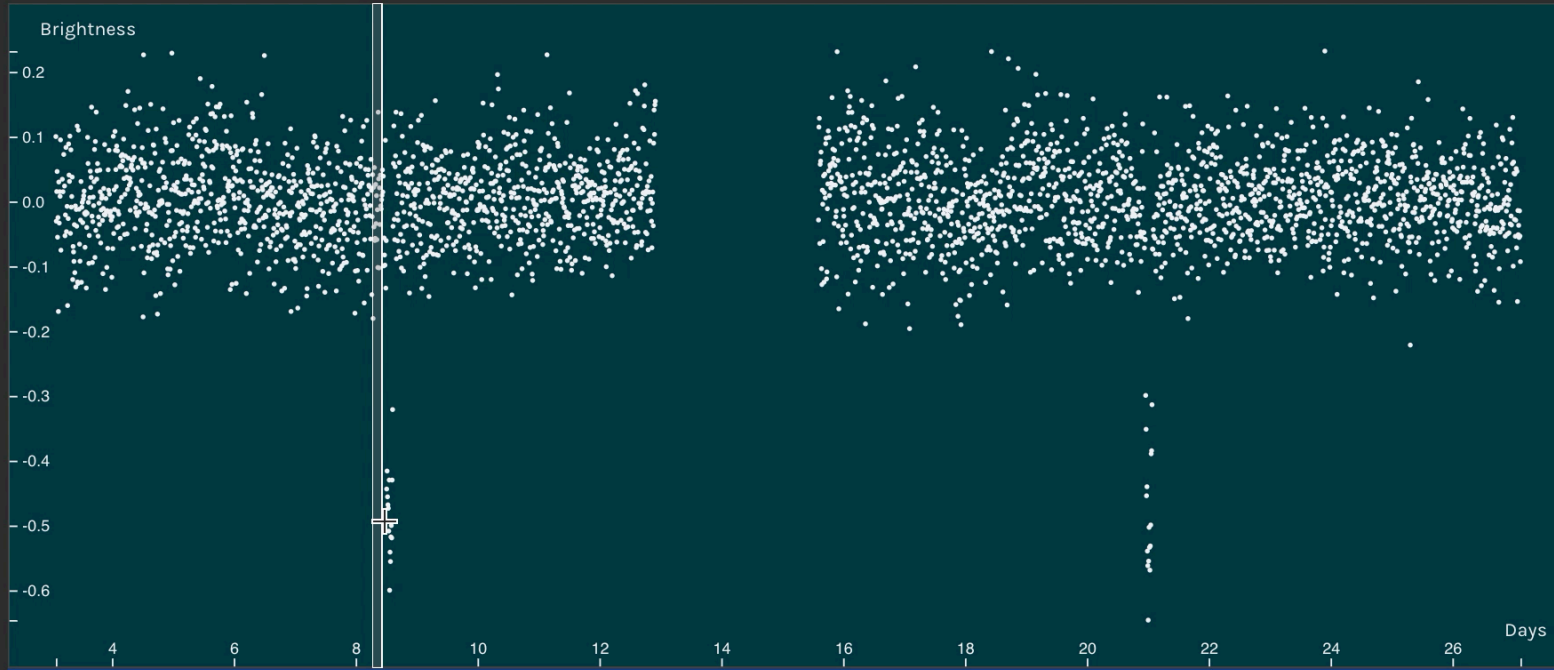


5 - 10 high priority  
candidates



# Planet Hunters TESS

PLANET HUNTERS TESS



- 
- 
- 
- 
- FIELD GUIDE**
- 

SUBJECT INFO ADD TO FAVOURITES ADD TO COLLECTIONS

TASK

TUTORIAL

**Do you spot a transit?** If so, please mark it on the lightcurve to the left!

If you don't see any transits, continue by clicking Done or Done & Talk.

 Transit?

NEED SOME HELP WITH THIS TASK?

SWITCH TO LIGHT THEME

## Finished for the day?

Your answers are saved for the research team while you're working. See the project stats and return to the Planet Hunters TESS home page.

# Simulated Data

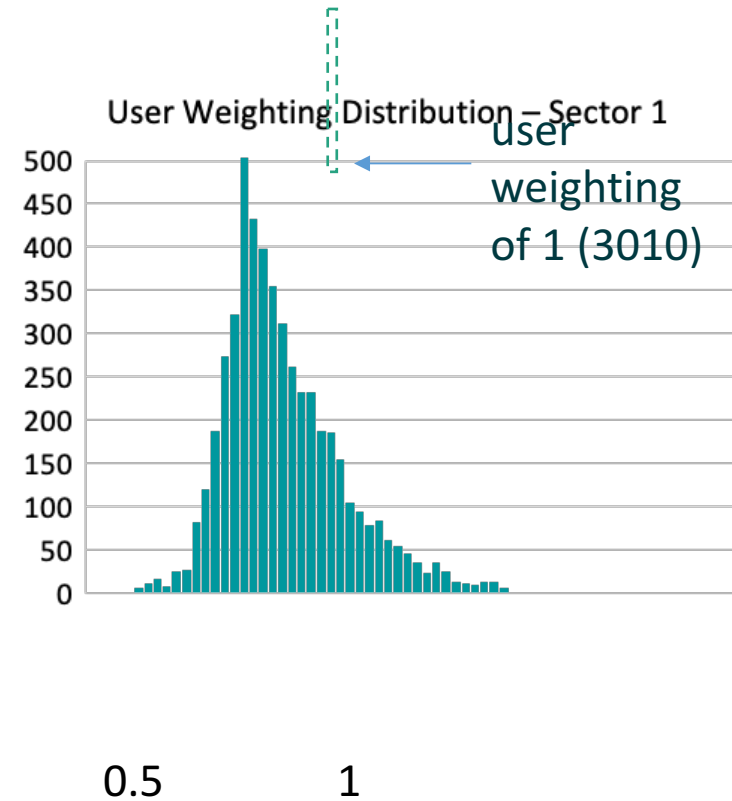


- Inject transits into real lightcurves
  - $\text{SNR} > 7$

Give feedback

Assess project sensitivity

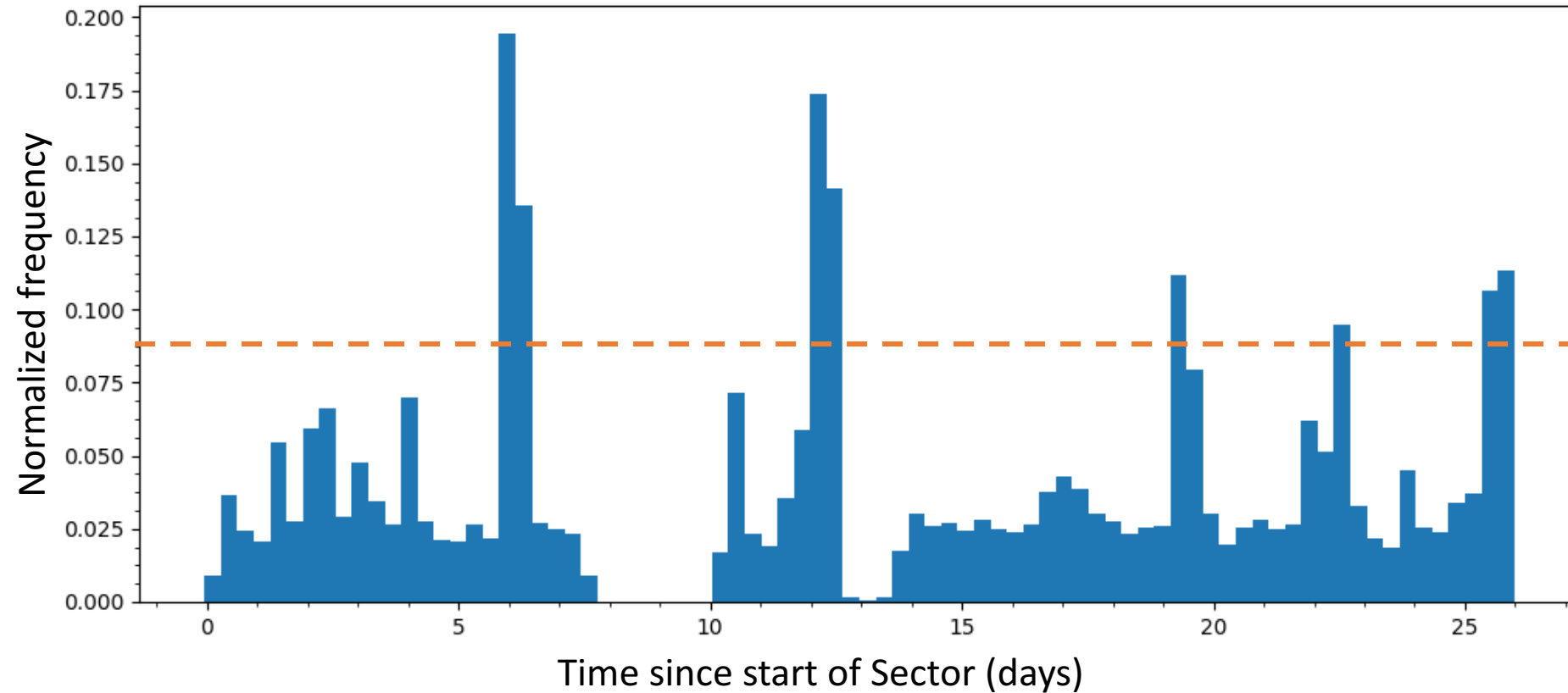
Assess the skill of each volunteer



# Removal of Systematics



Number of markings per time interval for one Sector



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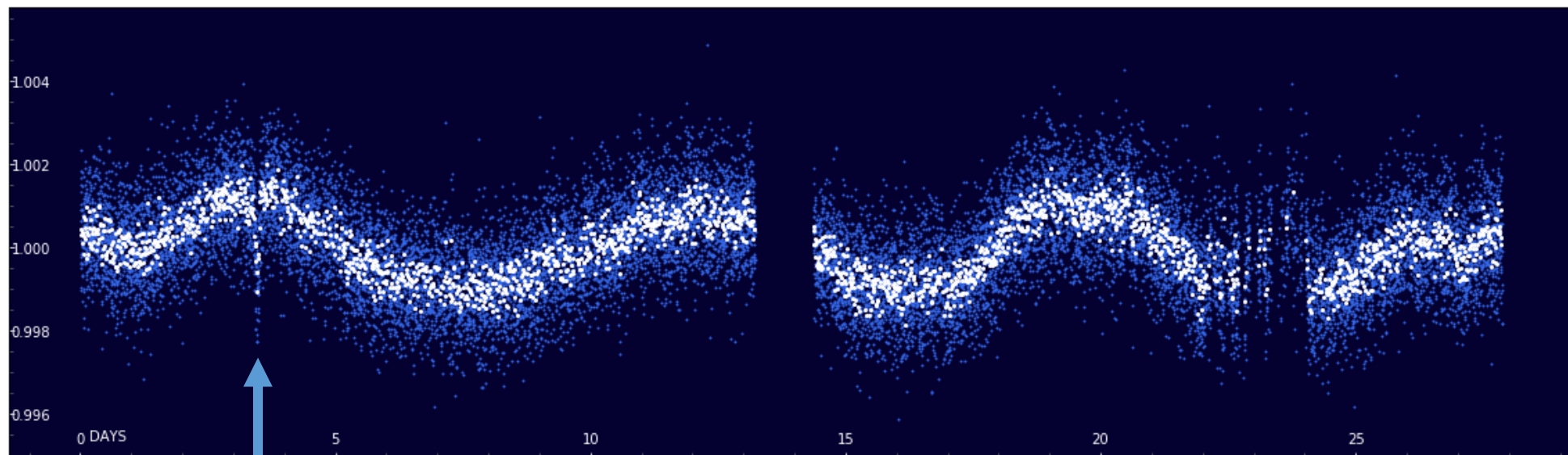


# Density Based clustering



- **DB scan clustering algorithm** : 5 points define a cluster

$$\text{Significance} = \frac{\text{Sum of user weights in the cluster}}{\text{Total user weights of volunteers who saw the subject}}$$



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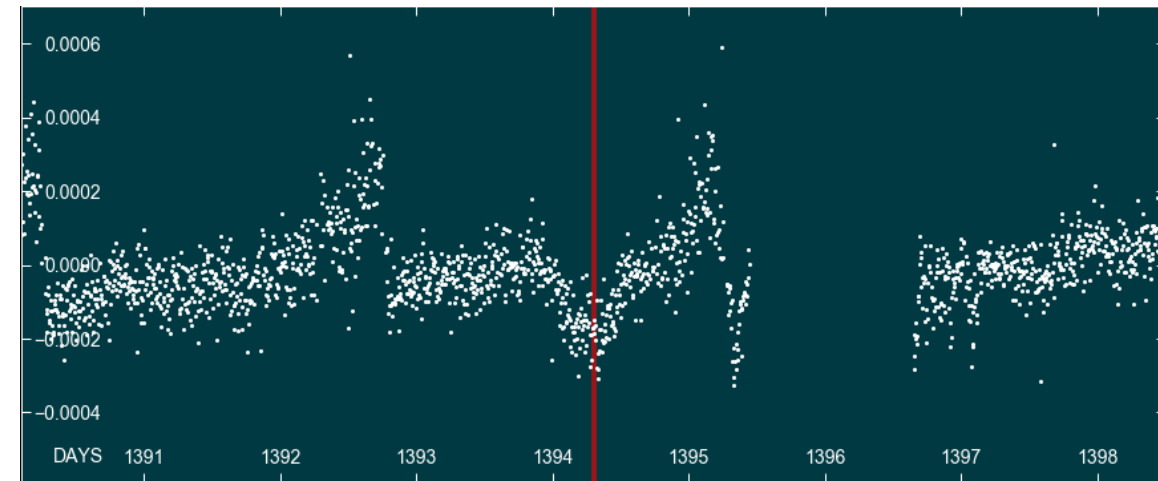
5 - 10 high priority  
candidates

# $\tau$ Ceti



1. Transit-like **signal** in the identified by PHT volunteers

$\tau$  Ceti lightcurve



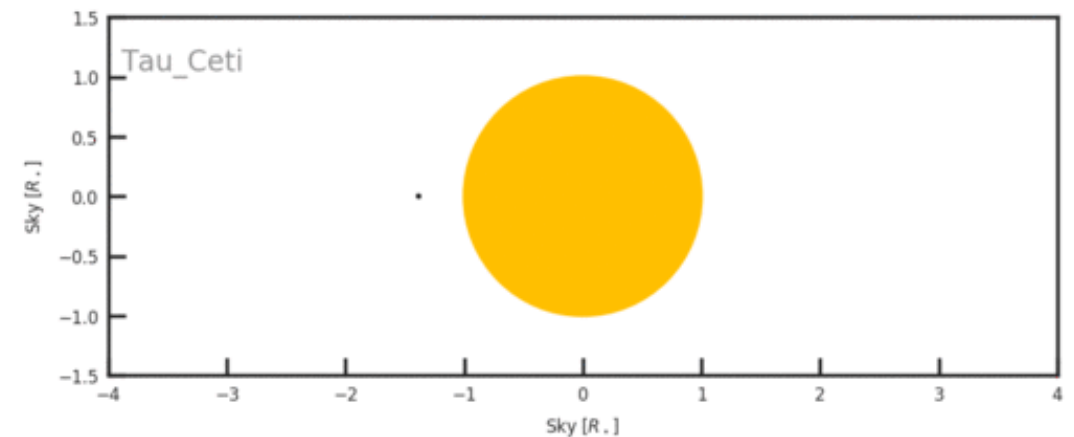
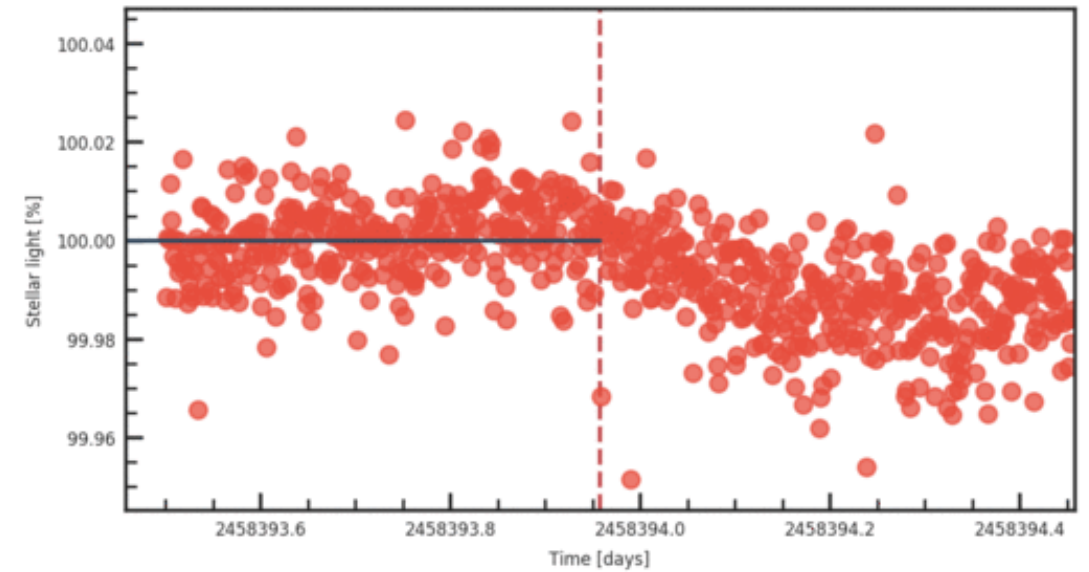
# $\tau$ Ceti



1. Transit-like **signal** in the identified by PHT volunteers

2. **Modelling** suggest

- 0.94 Earth Radii?
- ~225 K?
- Earth like planet?



# $\tau$ Ceti



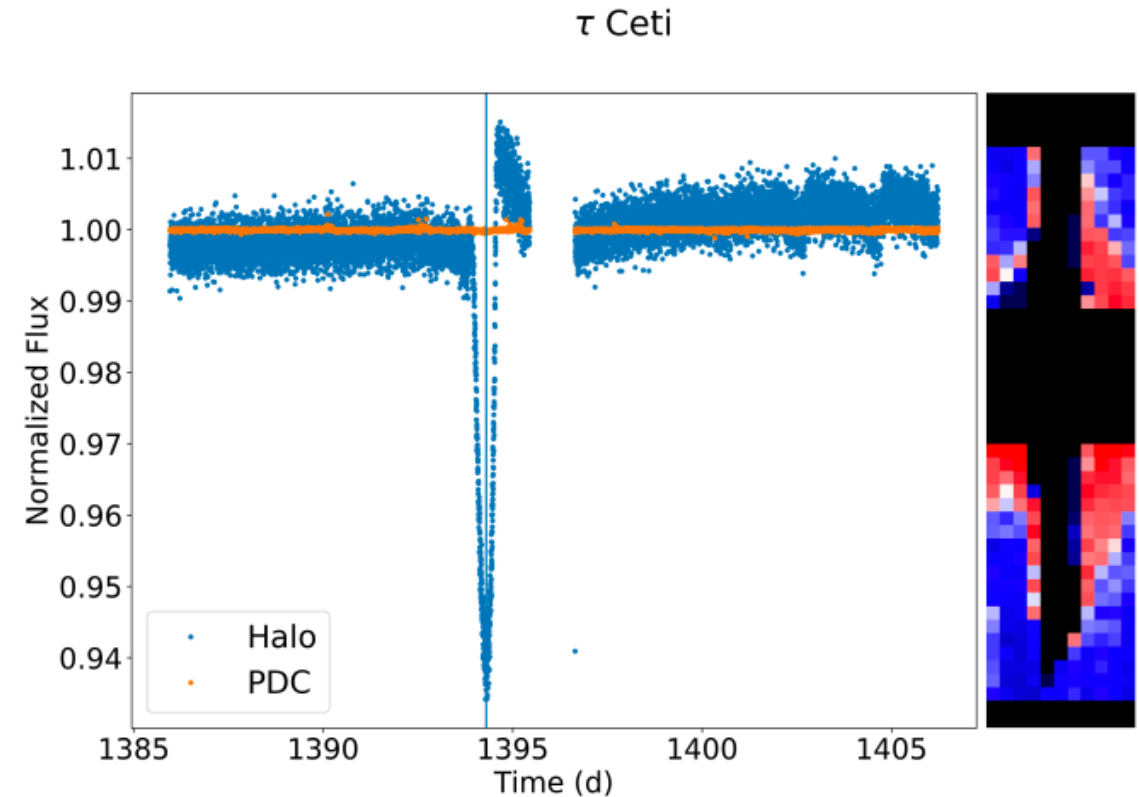
1. Transit-like **signal** in the identified by PHT volunteers

2. **Modelling** suggest

- 0.94 Earth Radii?
- ~225 K?
- Earth like planet?

3. Third magnitude star -> saturated the pixels

- 'halo photometry'



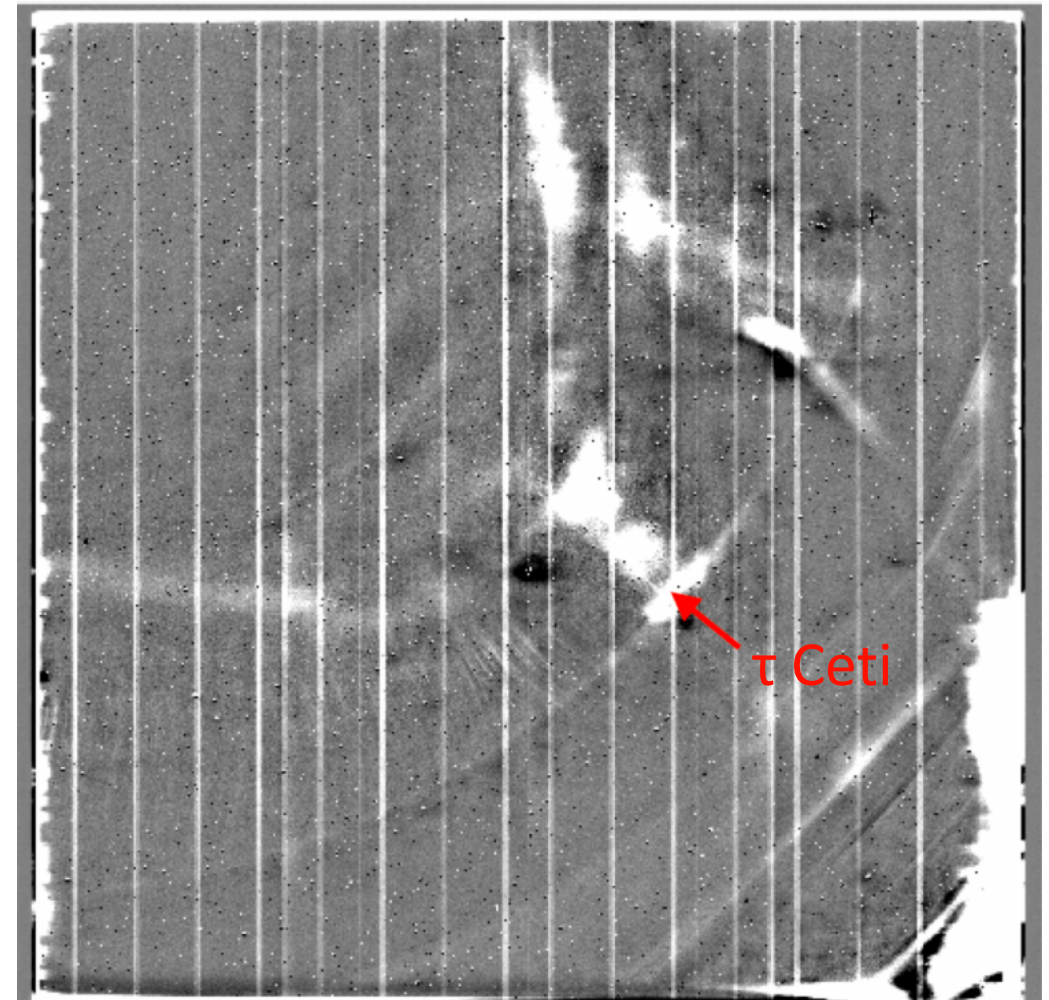


# $\tau$ Ceti



1. Transit-like **signal** in the identified by PHT volunteers
2. **Modelling** suggest
  - 0.94 Earth Radii?
  - ~225 K?
  - Earth like planet?
3. Third magnitude star -> saturated the pixels
  - **'halo photometry'**
4. Full Frame Images
  - background revealed 'ripples'

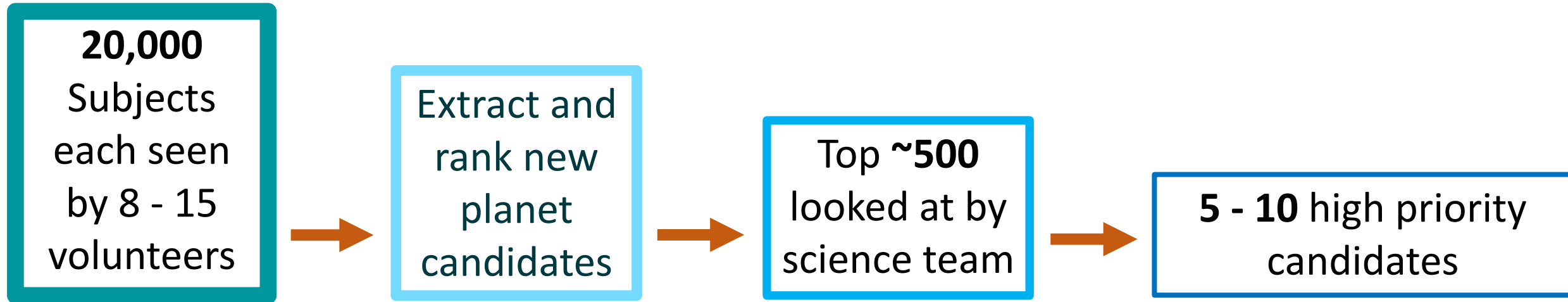
**Conclusion: Found the Earth**



# Step-by-Step Summary



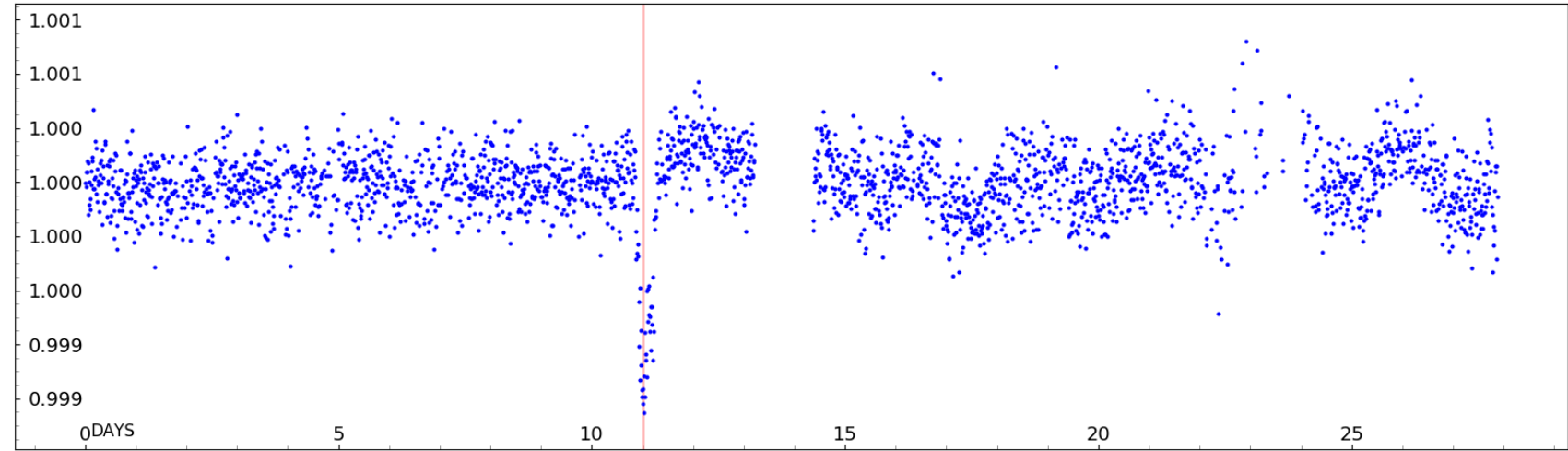
Per Sector:



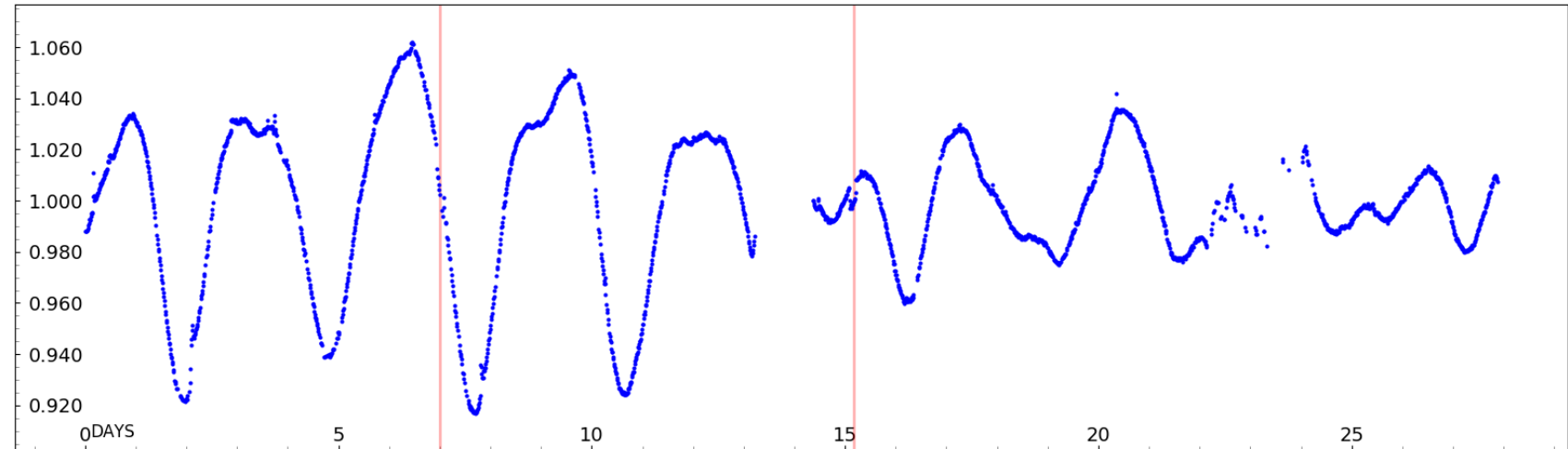
# Candidates



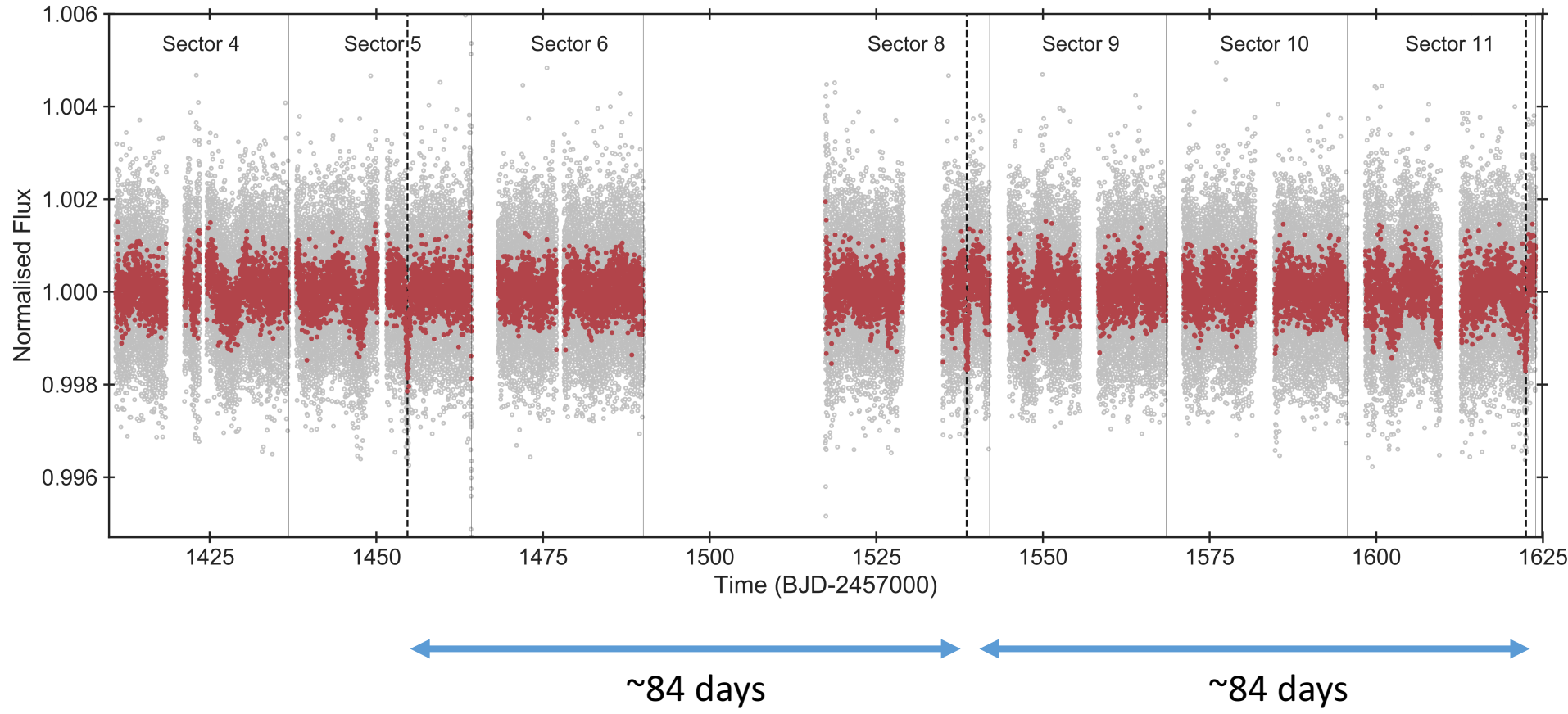
Single Transits (~80%)



Around variable Stars (~20%)



# PHT Candidate



## PHT Volunteers

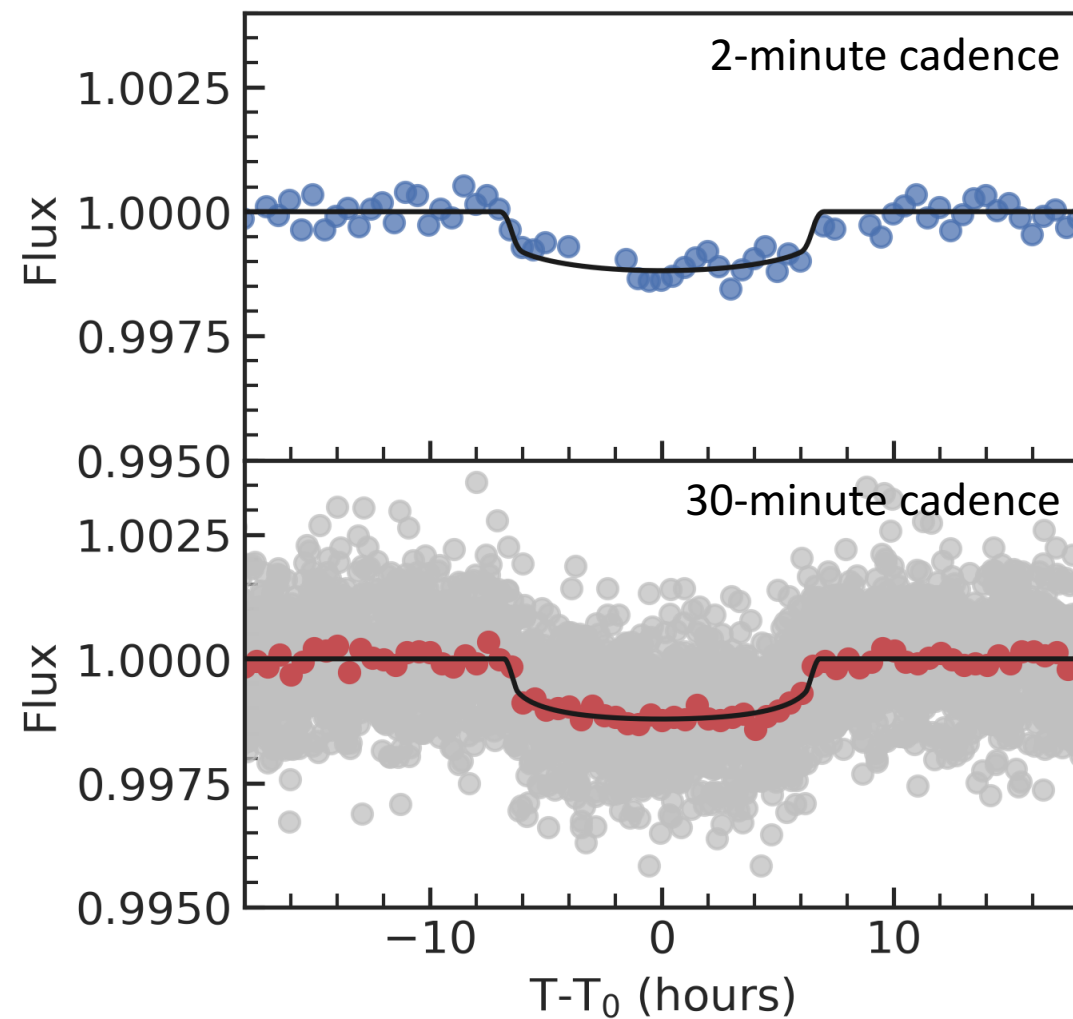
- Andrés Guillermo Stenner
- David Rogers
- Christopher Moore
- Claudia Schuster
- Daniel Ramirez
- David M. Bundy
- Dean Joseph Simister
- Ivan Terentev
- dssmith149
- Jamie Dawson
- kpeltsch
- Larry Melanson
- Marc Hutten
- oregano
- slarish
- Alexander Thzymbal
- S. J. Bean
- Frank Barnet
- Thomas Mitchell
- Christopher Tanner
- zbish

# PHT Candidate: follow-up



- **Bayesian with MCMC sampling**

- ~ 7.1 Earth radii
- ~ 84 day period
- Subgiant host star
- Expected RV signal ~ 6-7 m/s



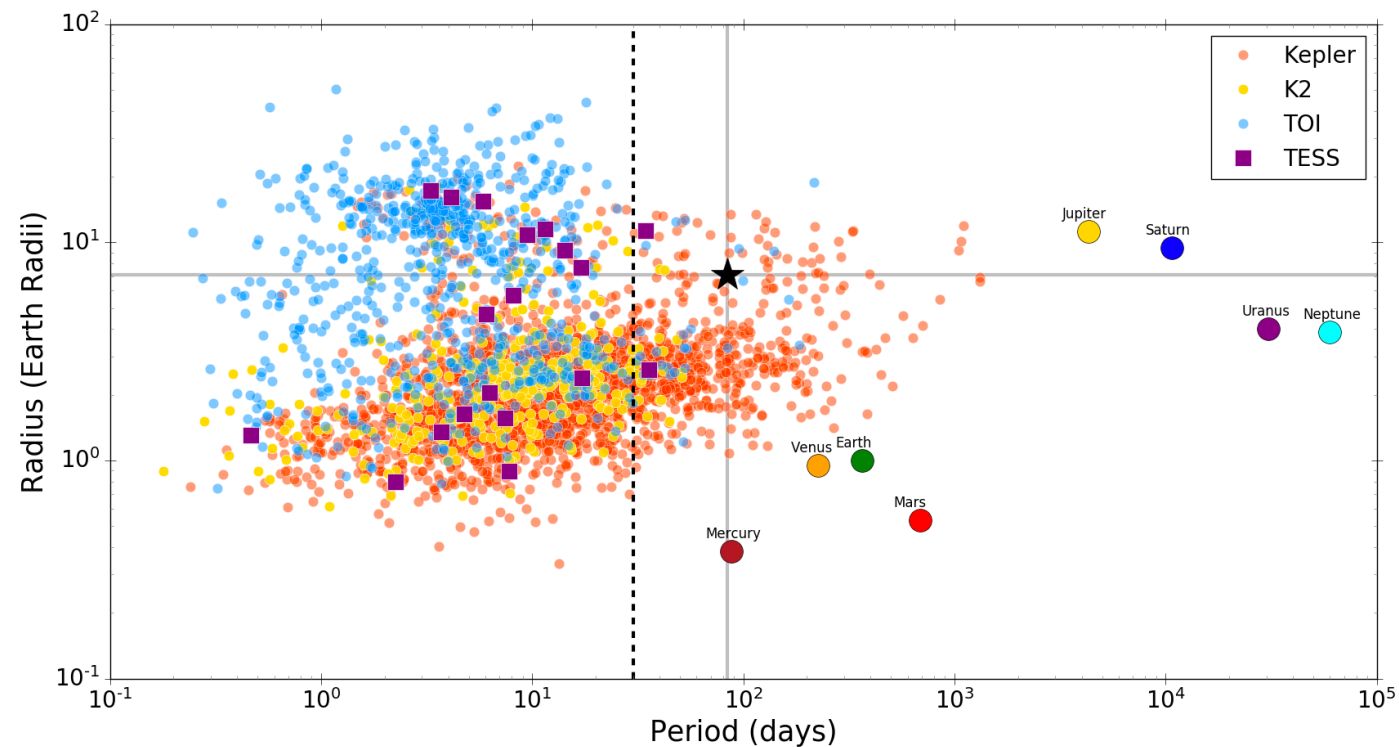


# PHT Candidate : follow-up



- **ANU** reconnaissance spectroscopy
- **HARPS** single high-res spectrum
- **Zorro** speckle imaging

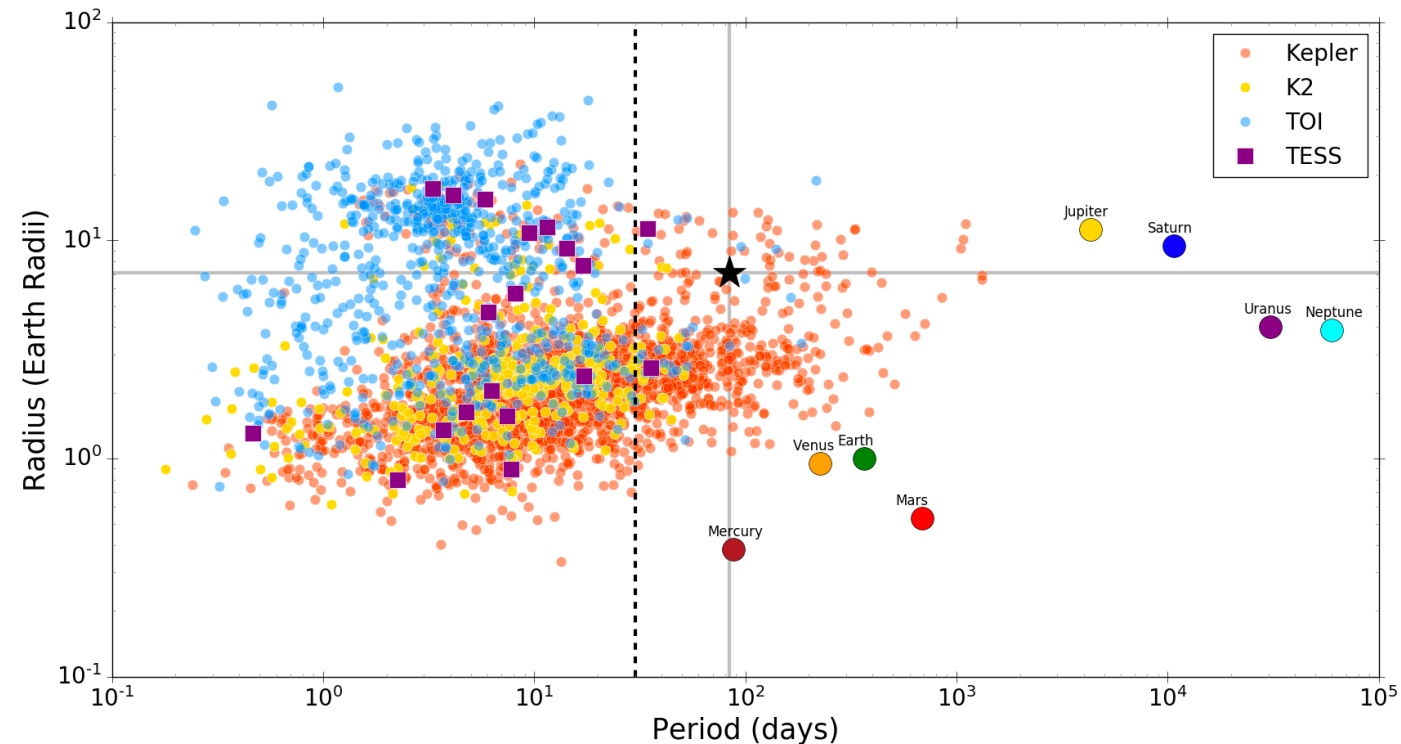
**ALMOST** Statistically Validated



# Longest-Period (almost) confirmed TESS Planet

- **ANU** reconnaissance spectroscopy
- **HARPS** single high-res spectrum
- **Zorro** speckle imaging

**ALMOST** Statistically Validated



## Planet Hunters Analysis Database

TRANSITS | USERS | ABOUT | DOWNLOADS

All Columns

Search

SEARCH

Showing 1 to 10 of 10,301 entries

Subject ID	TIC ID	Center	Width	Weighted Counts	User Count	Date Modified
<a href="#">33846839</a>	<a href="#">25454894</a>	4.12	0.58	6.83	3	2019-06-24 16:01:01.215000
<a href="#">33847111</a>	<a href="#">350858713</a>	15.83	0.22	5.58	3	2019-06-24 16:01:07.721000
<a href="#">33847111</a>	<a href="#">350858713</a>	22.7	0.5	4.86	3	2019-06-24 16:01:07.721000
<a href="#">33847111</a>	<a href="#">350858713</a>	24.89	0.32	5.58	3	2019-06-24 16:01:07.721000
<a href="#">33847111</a>	<a href="#">350858713</a>	11.84	0.32	5.58	3	2019-06-24 16:01:07.721000

<https://mast.stsci.edu/phad/>

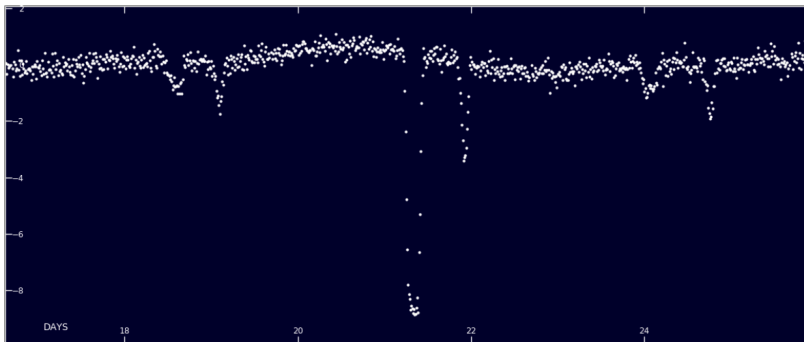
# Planet Hunters TESS: Community



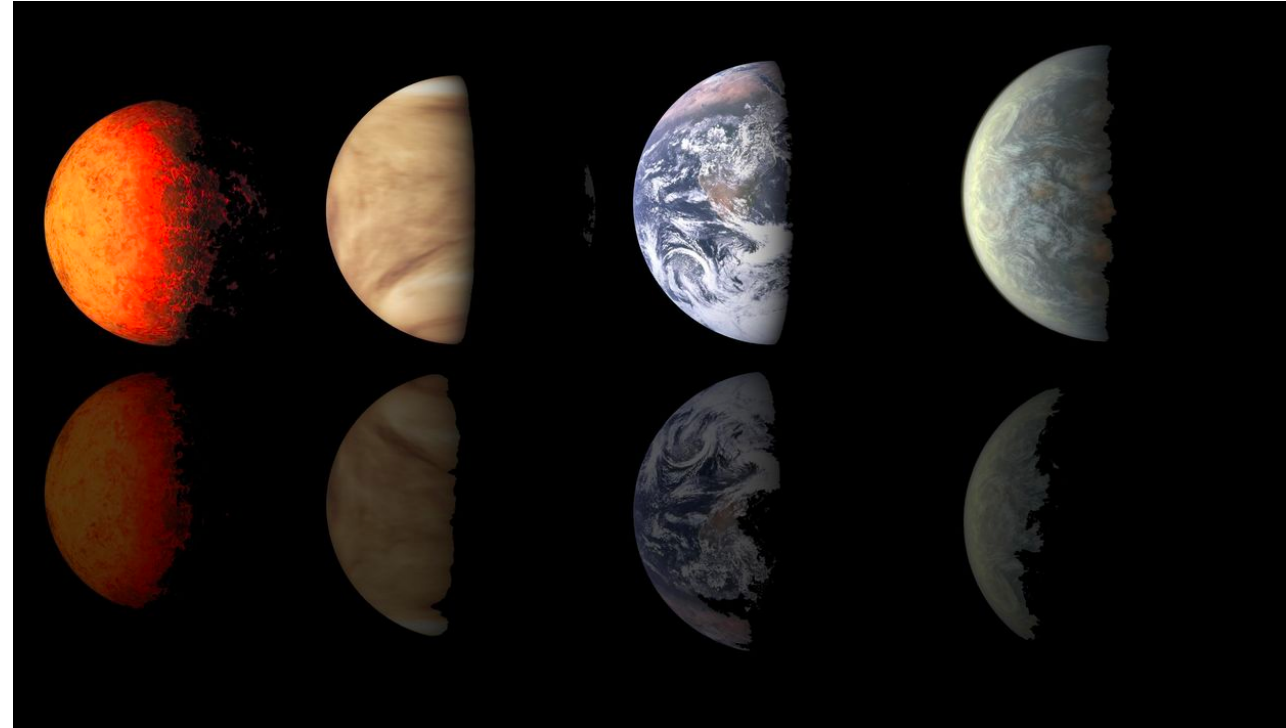
- Over **9 million** classifications since December 2018
- Over **12,000** registered volunteers

“  
An Ultra-Hot Jupiter or a doomed EB around HD 27342?  
- ProtoJeb21

“  
Multi-planetary, or a double binary, or quadruple binary, or a planetary binary system?  
- thaichitsiga



Thank you



[nora.eisner@physics.ox.ac.uk](mailto:nora.eisner@physics.ox.ac.uk)

@planethunters

@eisnernora





# User Weighting

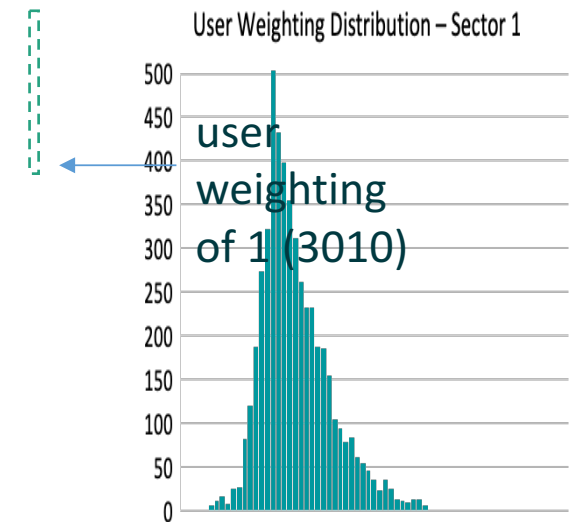
- Difficulty factor per subject:

$$d_i = \frac{1}{\text{Total number of classifications for subject } i} \sum_{\text{subject}, i} \text{'correctly identified'}$$

- For each classification:  $seed_c = d_i \times \text{increment}$

- For each user:  $S_k = \sum_c seed_c$

- User weight:  $w_k = c0 \times (1 + \log(n_{gs}))^{seed/n_{gs}}$

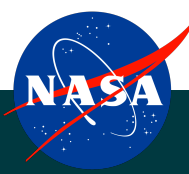




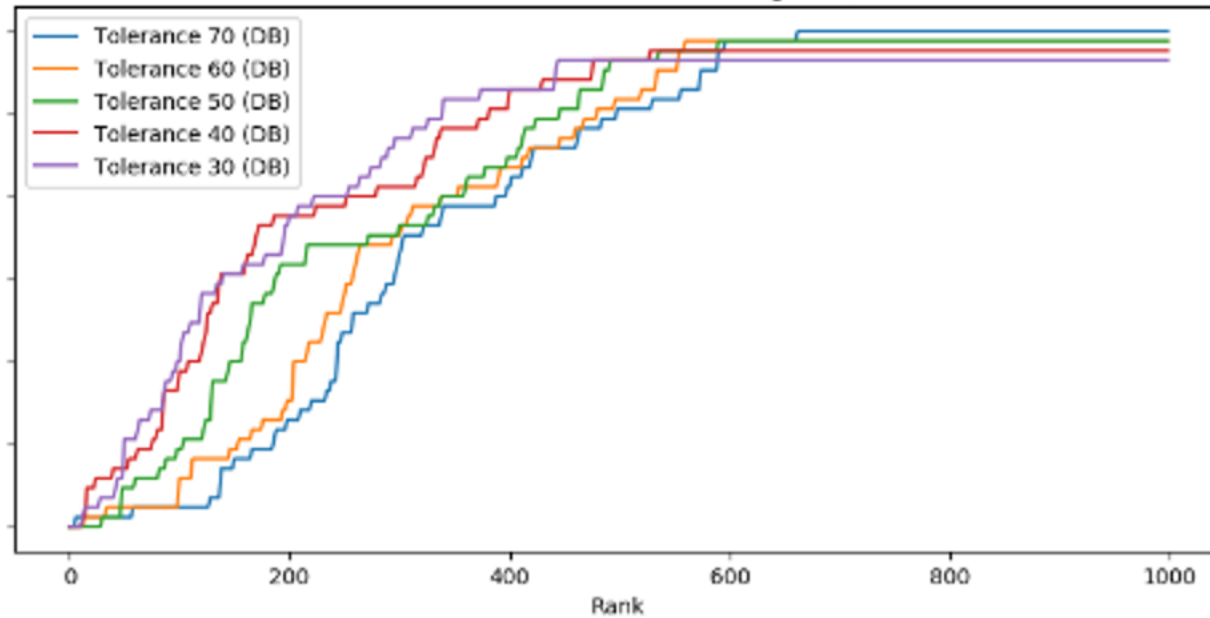
# Follow-up

- Photometric and RV follow-up observations are being carried out
  - 140 hours of LCO
    - SBIG (and some Sinistro) and NRES
  - 4.8 days CTIO
    - CHIRON
- Collaborating with various teams for long term radial velocity follow-up



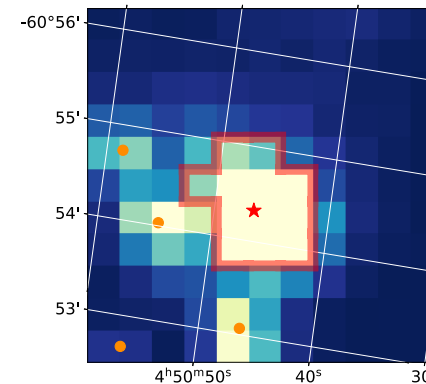
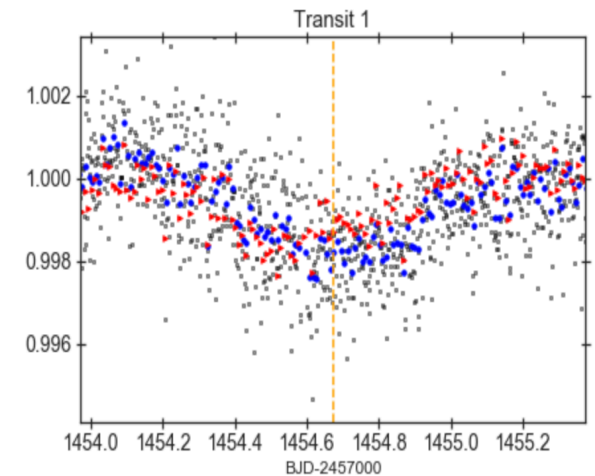
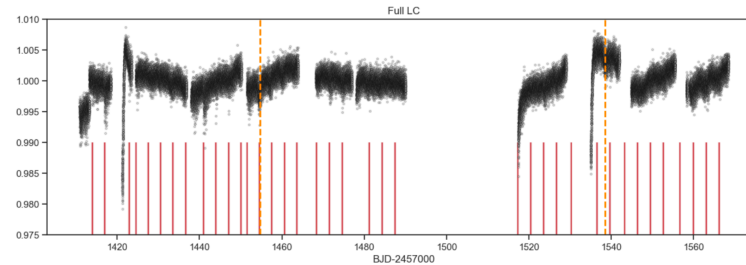
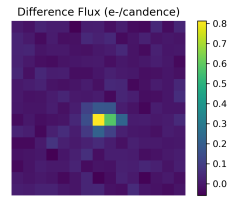
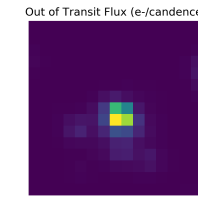
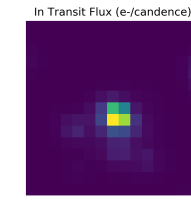
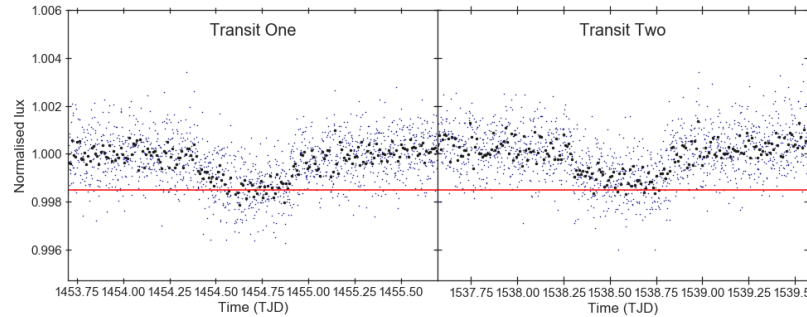


# Fraction of TOIs Recovered



# Longest-period TESS planet: Vetting

- Odd/even transits
- Centroid shifts
- Momentum dumps
- LC in different aperture sizes
- Contamination from nearby stars



# DV report for Citizen Science Found Target TIC 270371513

TOI: --

TCE: YES (check the DV report)

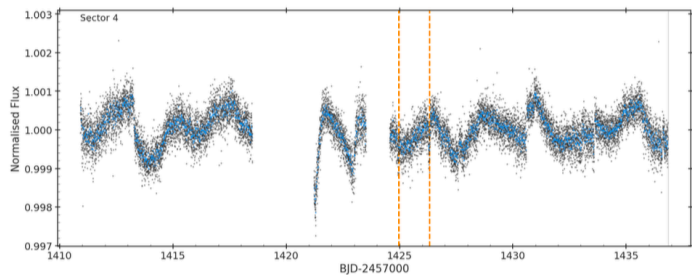


Fig 1. This is the full lightcurve with all the available 2 min cadence data in Sectors: [4]

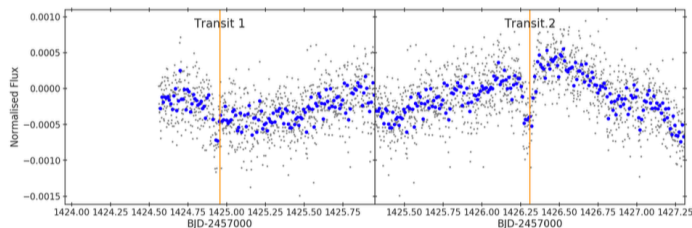


Fig 2. Binned (blue) and unbinned (grey) transit events - if multiple events, check whether they have the same shape and depth.

## Stellar Parameters

Parameter	Value
TIC ID	270371513
RA	32.3425
DEC	5.9864
Radius	1.6961 Solar Radii
Tess Mag	6.5840 Mag
Teff	6720 K

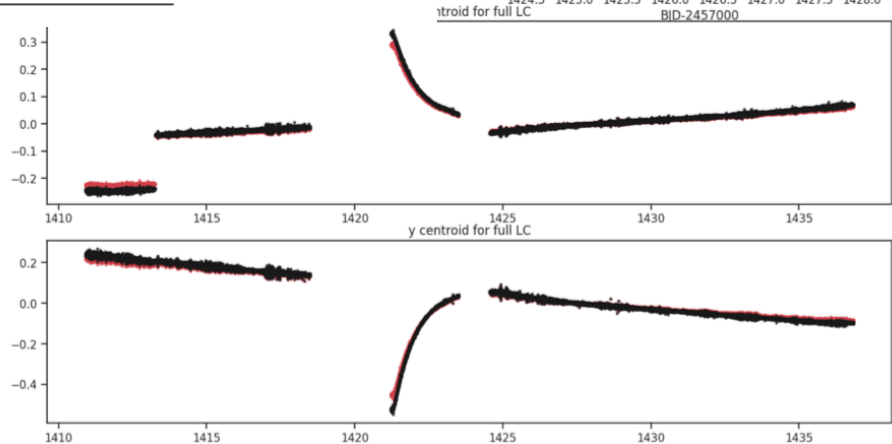


Fig 5. Figures showing the x and y centroid positions (bottom panel).

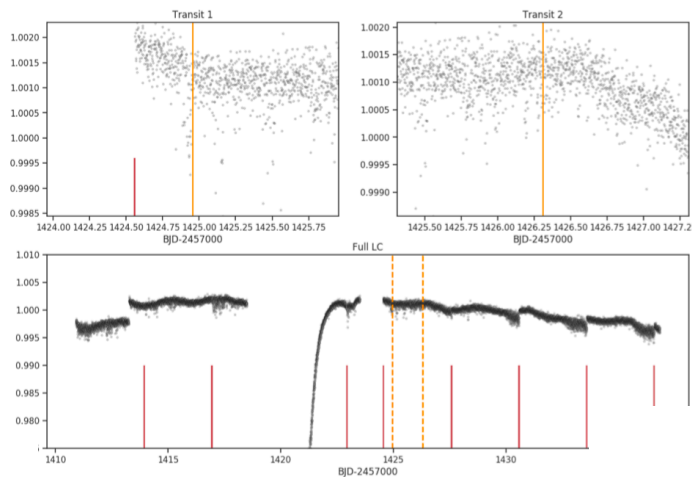
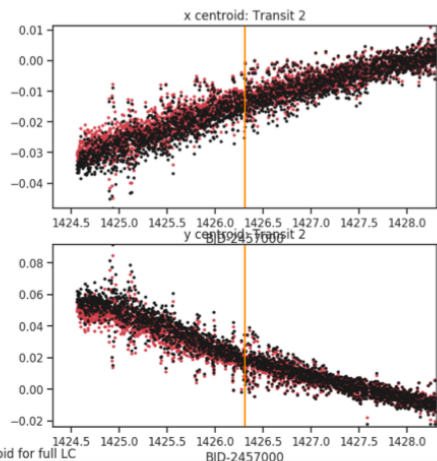


Fig 6. The times of the spacecraft momentum dumps (red lines) and the transit events (red).

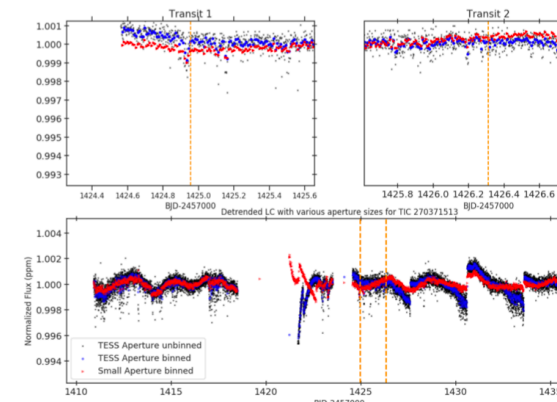


Fig 7. Test to see whether the aperture size affects the transit shape/depth.

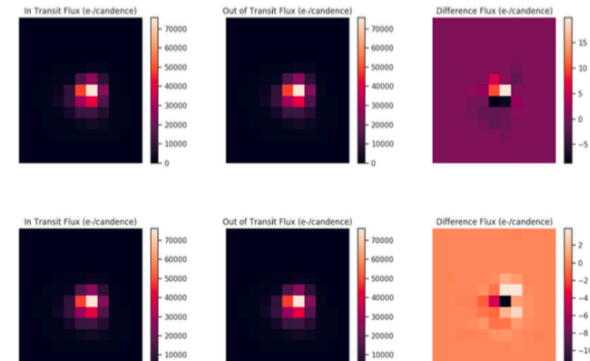


Fig 3. Figures showing the location of stars with mag < 15 (orange circle) within the Tess Cut Out around the target star (red star) for each sector containing a transit event.

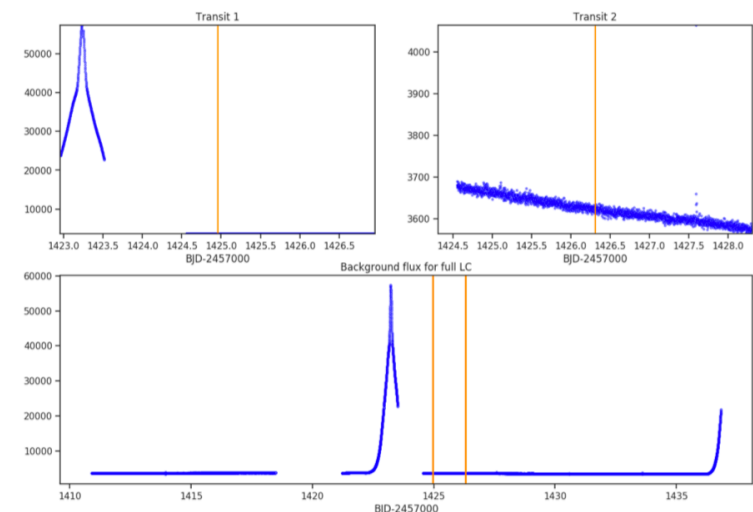


Fig 4. Figures showing the background flux for each transit (top panel) and for the whole lightcurve (bottom panel)

# Kepler/K2's Success

- Multi-Planet Systems  
(e.g., Rowe et al. 2014)
- Quadruple Star System  
(e.g., Schwamb et al. 2013)
- Potentially Habitable Planets  
(e.g., Kaltenegger 2011)
- Water Worlds  
(e.g., Borucki et al. 2013)
- Long-Period Planets  
(e.g., Wang et al. 2015)

