

# A Planet Hunters Search of the Kepler TCE Inventory

M. E. Schwamb (1), C. J. Lintott (2,3), D. A. Fischer (4), A. M. Smith (3), T. S. Boyajian (4), J. M. Brewer(4),  
M. J. Giguere (4), S. Lynn (3), K. Schawinski (5), J. R. Schmitt (4), R. J. Simpson (2), J. Wang (4)

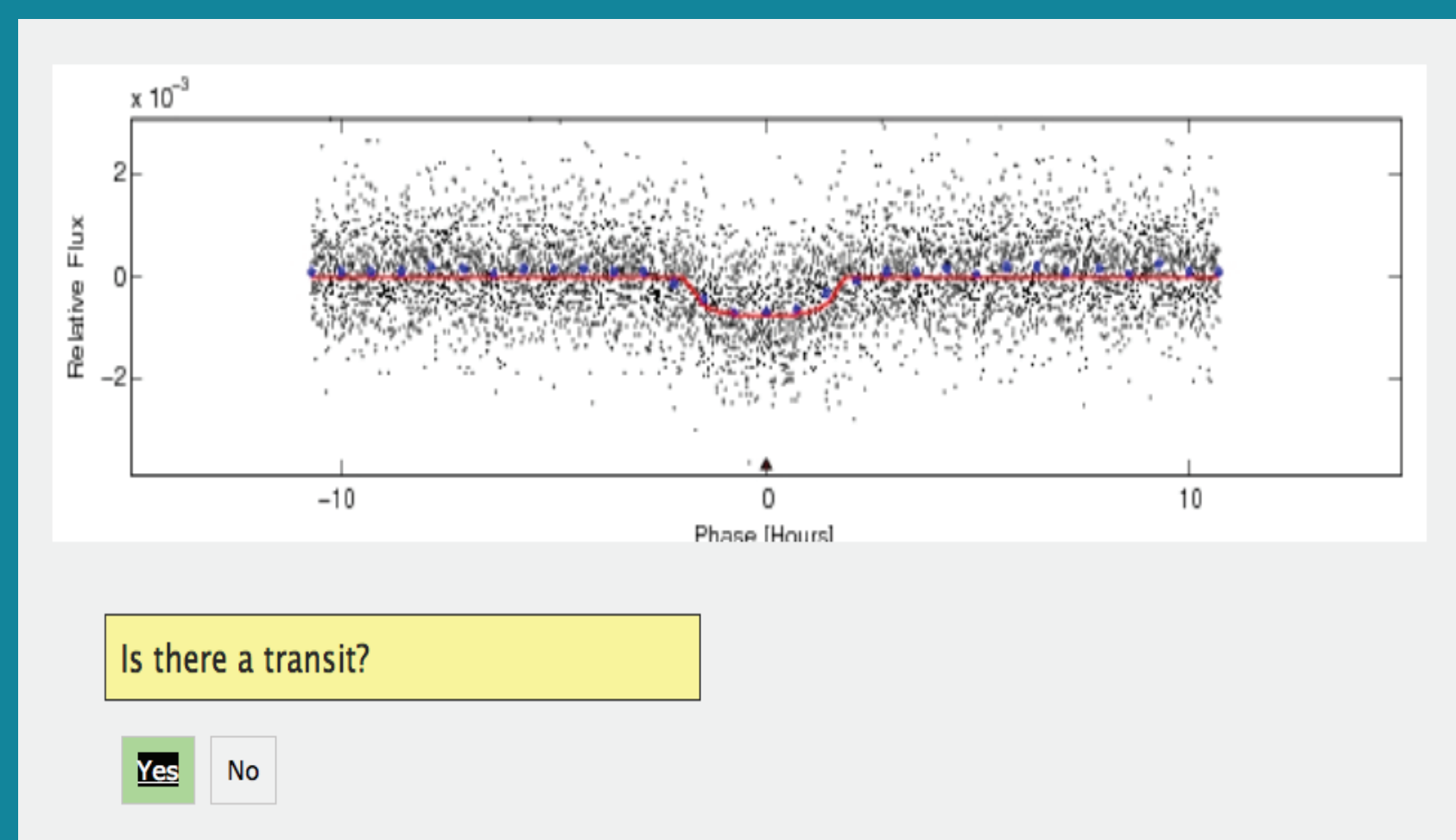
(1) Institute of Astronomy & Astrophysics, Academia Sinica (ASIAA) (2)Department of Physics, University of Oxford, (3) Adler Planetarium  
(4) Department of Astronomy, Yale University, (5) ETH Zurich

## Introduction:

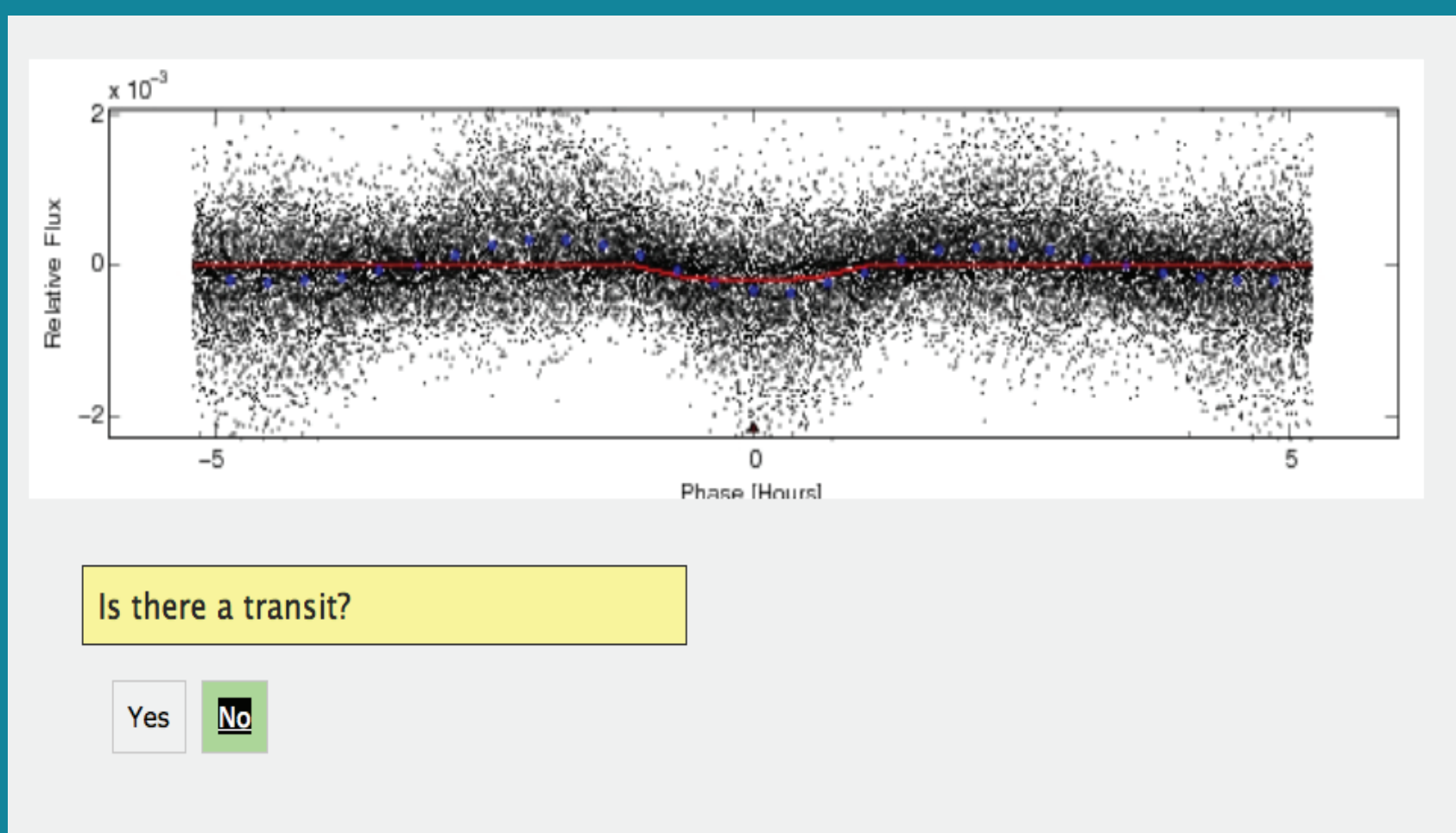
Planet Hunters (<http://www.planethunters.org>), part of the Zooniverse (<http://www.zooniverse.org>) collection of citizen science projects, uses the power of human pattern recognition via the World Wide Web to identify transits in the Kepler public data. We have demonstrated the success of a citizen science approach with the project's over 30 planet candidates not previously identified by the Kepler team, the discovery of PH1b, a transiting circumbinary planet in a quadruple star system, and the discovery of PH2-b, a confirmed Jupiter-sized planet in the habitable zone of a Sun-like star. **The Kepler planet candidate list is produced through expert assessment of the detections from several runs of the automated Transit Planet Search (TPS) algorithm; to test the completeness of this list we have undertaken an independent crowd-sourced effort to perform a systematic search of the 18,406 potential transit signals or threshold-crossing events (TCEs) identified in the first twelve quarters (~1000 days) by TPS. With the Internet we can obtain multiple assessments of each TCE. Planet Hunters volunteers evaluate whether a transit is visible in the Kepler light curve folded on the expected period, with 10 independent assessments per TCE.**

## Classification Interface:

The interface displays the folded zoomed in light curve from the Kepler Data Validation Summary Report. Volunteers are asked to confirm there is a visible transit in the folded light curve identified by TPS ("Is there a transit? yes or no") and determine whether the red line matches the light curve ("Does the red line fit the data? yes or no").



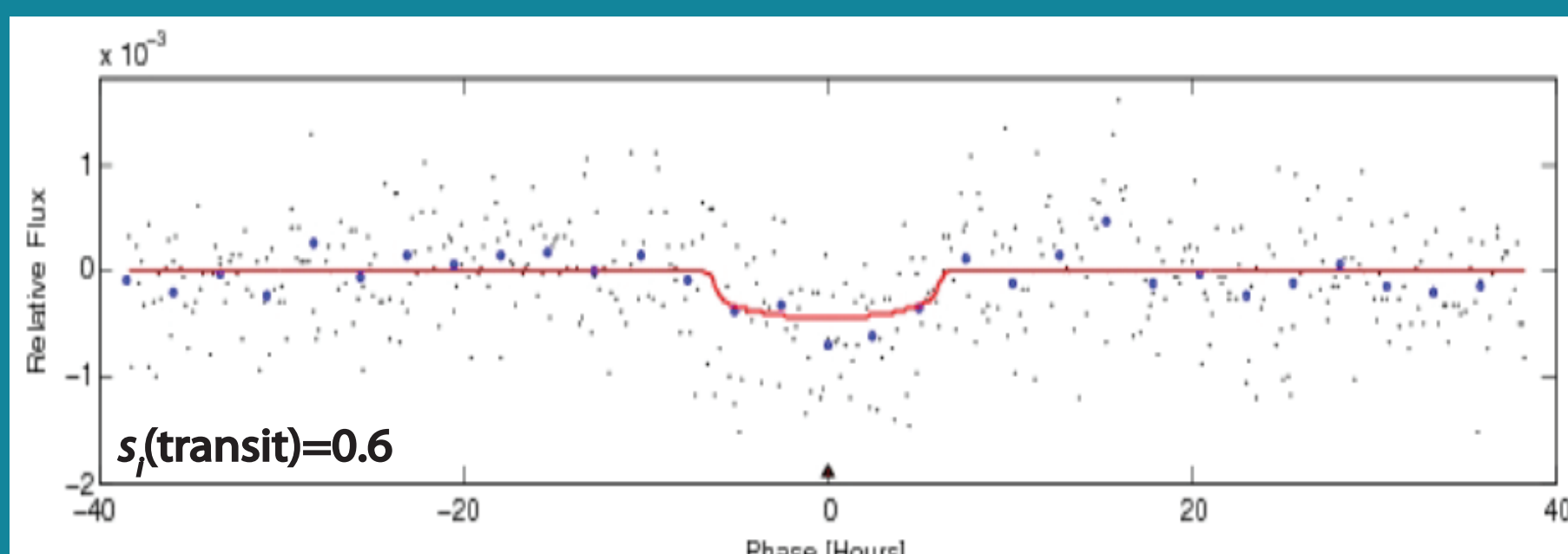
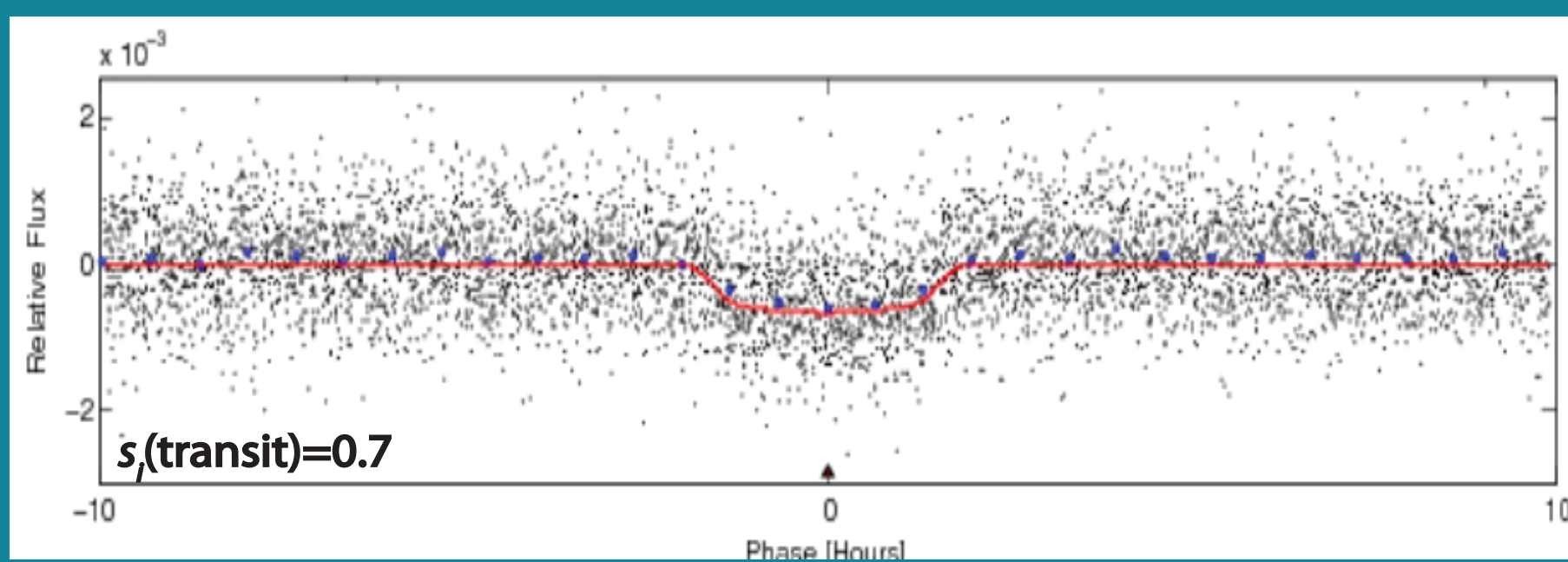
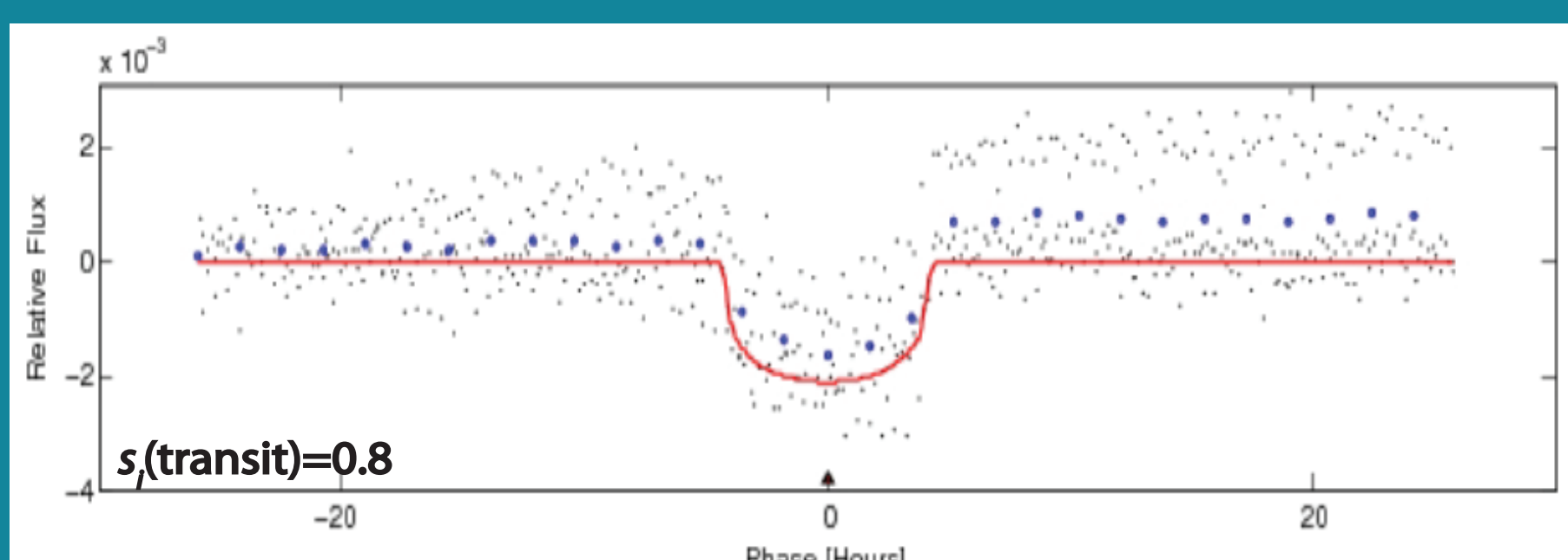
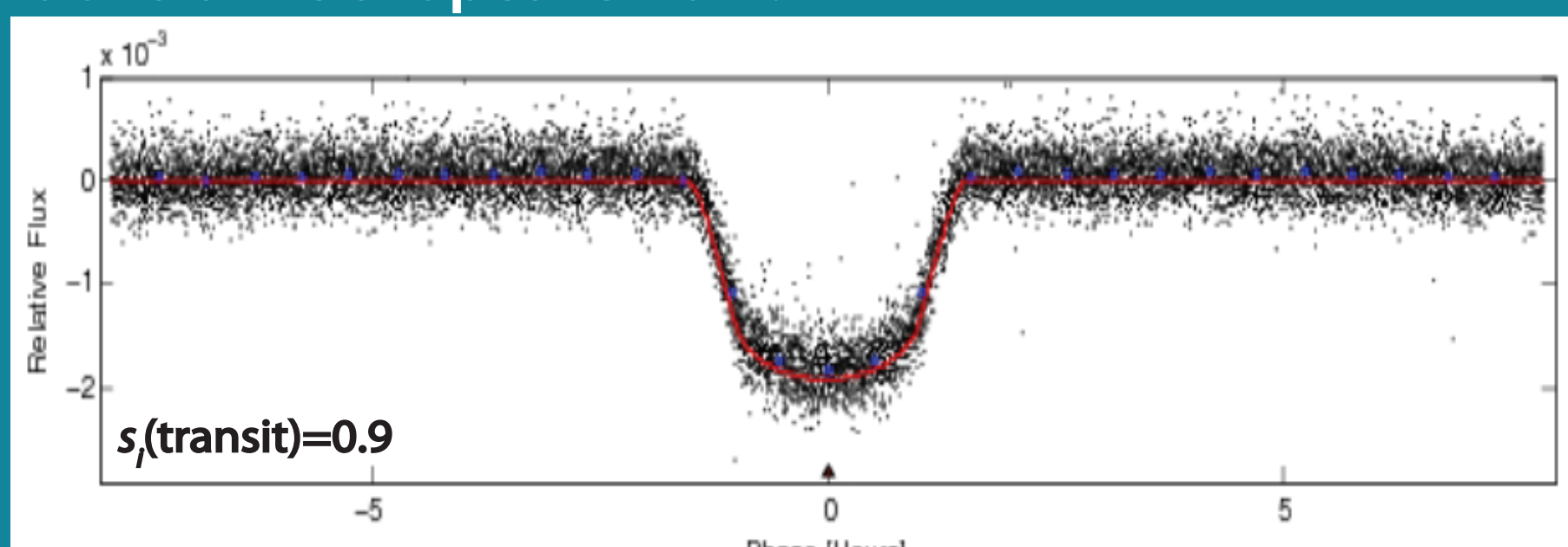
Planet Hunters TCE Review Interface with a transit-like TPS detection



Planet Hunters TCE Review Interface with a TPS false positive detection

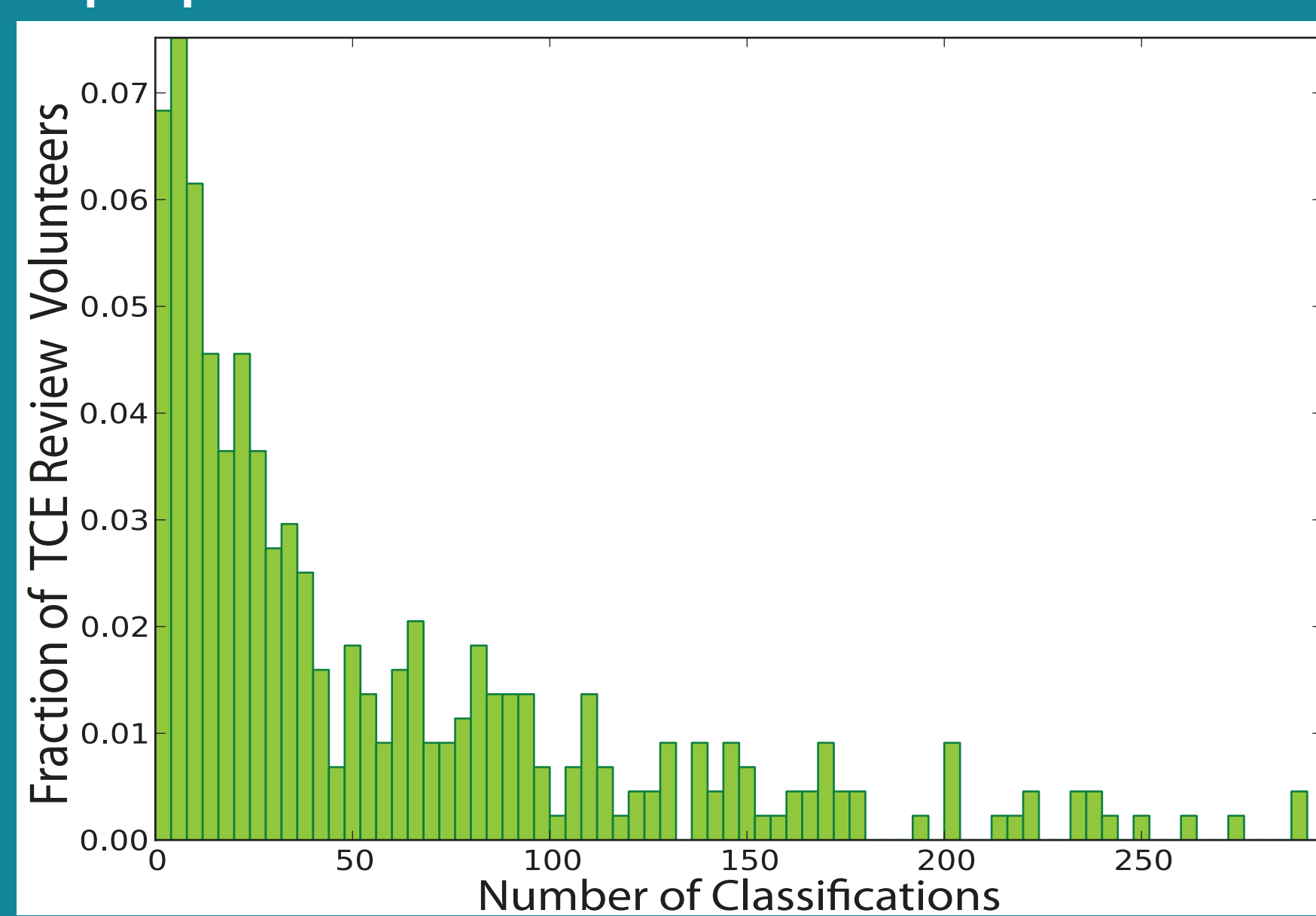
## Transit-shaped TCEs identified:

Applying a cut on  $s_t(\text{transit})$  at 0.5, 4666 TCEs with transit-like shapes remain.



## Classifier Statistics:

**Each of the 18,406 TCEs received 10 independent assessments in the review interface. Classifications were obtained over a 2 month period.** 439 Planet Hunters volunteers contributed classifications to the TCE review with a median of 54 and average of 423 classifications per person.

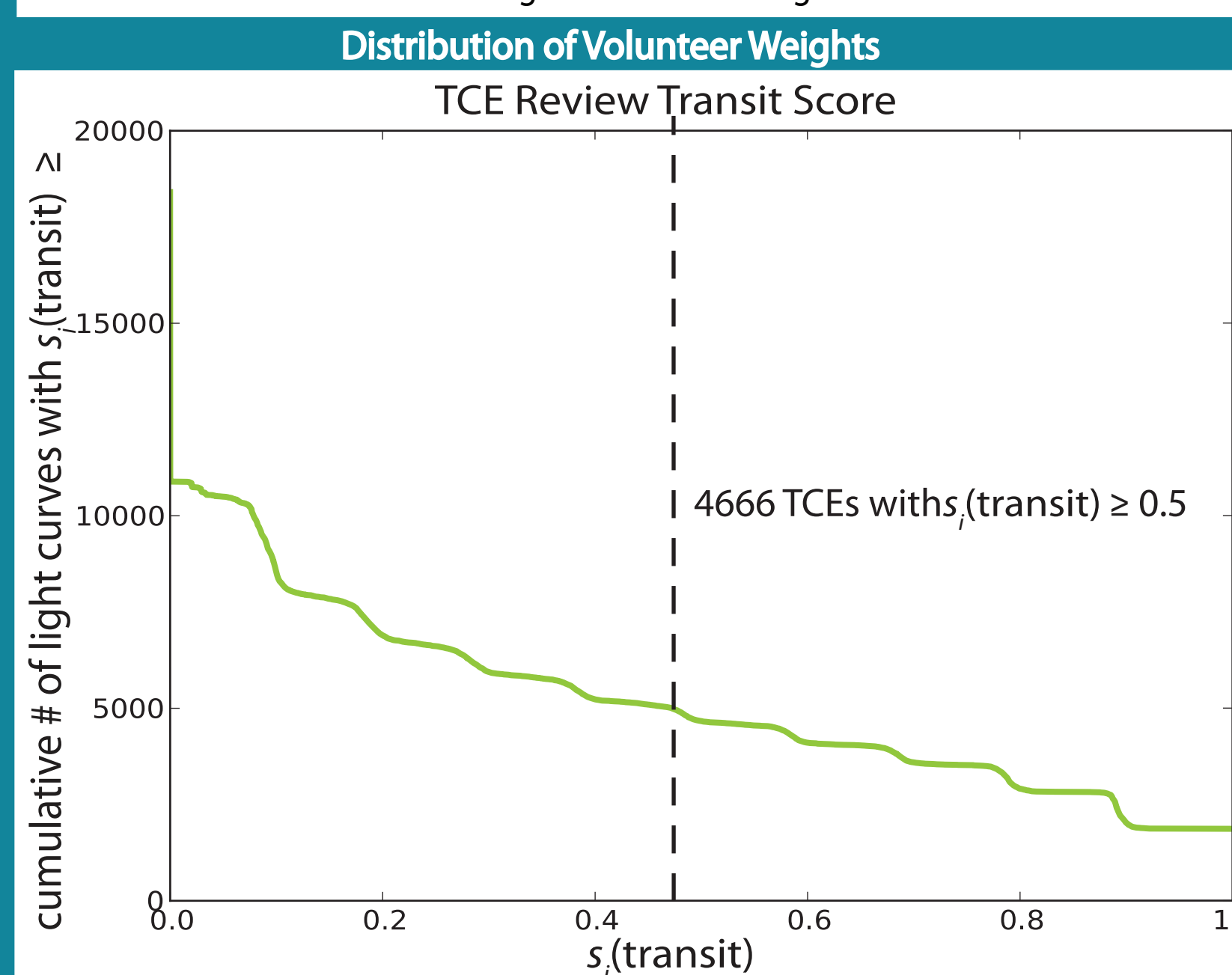
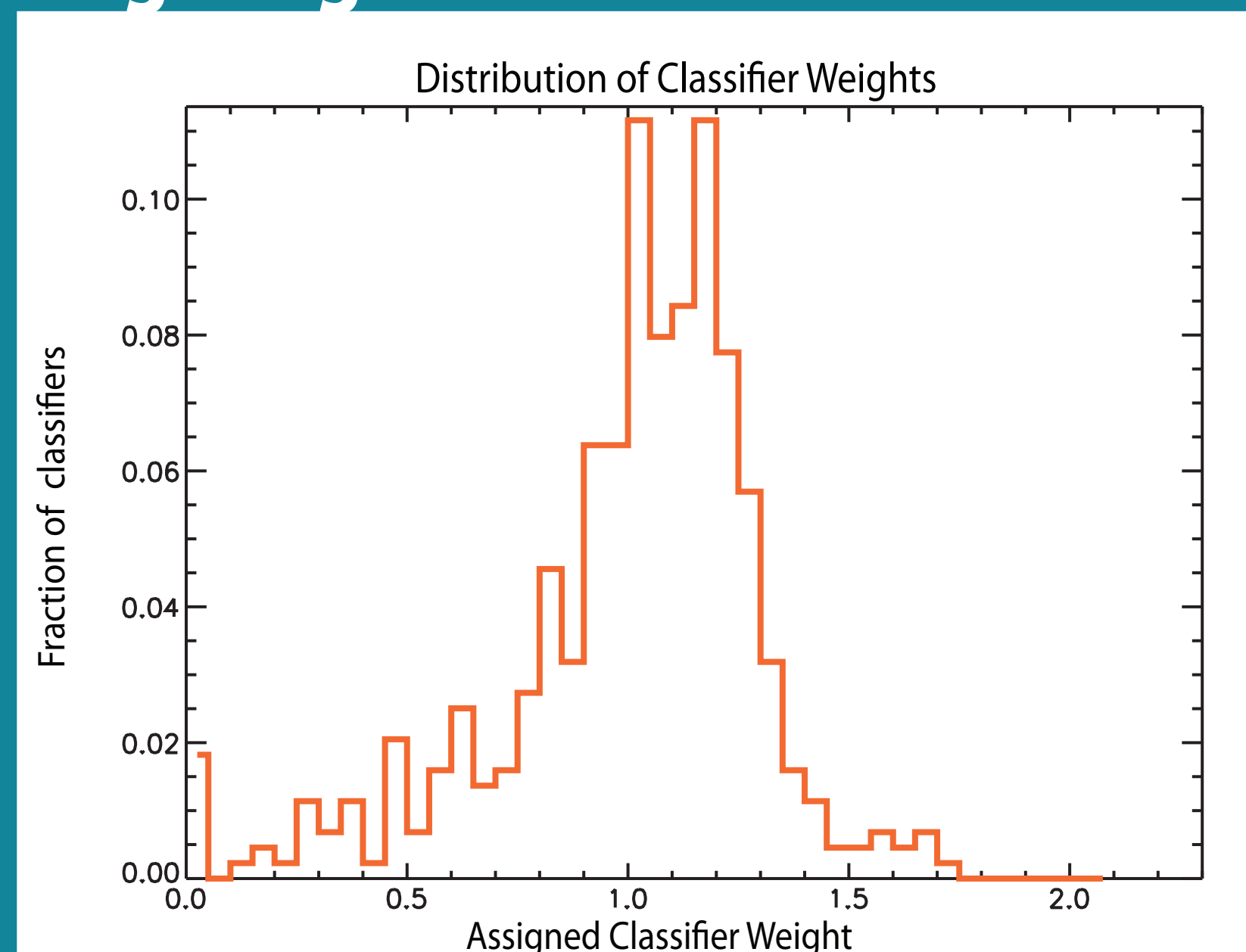


Distribution of classifications used in TCE analysis per registered Planet Hunters volunteer with a bin size of 4. The plotted distribution is truncated at 300 classifications for resolution. Only 20% of all registered volunteers make more than 300 classifications.

## Iterative Weighting Scheme:

The classifications are processed through a pipeline to assess the capabilities of individual classifiers. **Weightings are assigned to individual classifiers, and an iterative process is used to converge on final assessments on whether TCE events are transit-shaped. We assign a transit score  $s_t(\text{transit})$  for each TCE as the sum of the classifier weights who answered yes to the transit question divided by the sum of the weights for all who classified the given TCE.**

## Weighting Scheme Results:



Cumulative Distribution of Transit Scores for Kepler TCEs. Applying a threshold of at 0.5, 4666 TCEs remain on the list

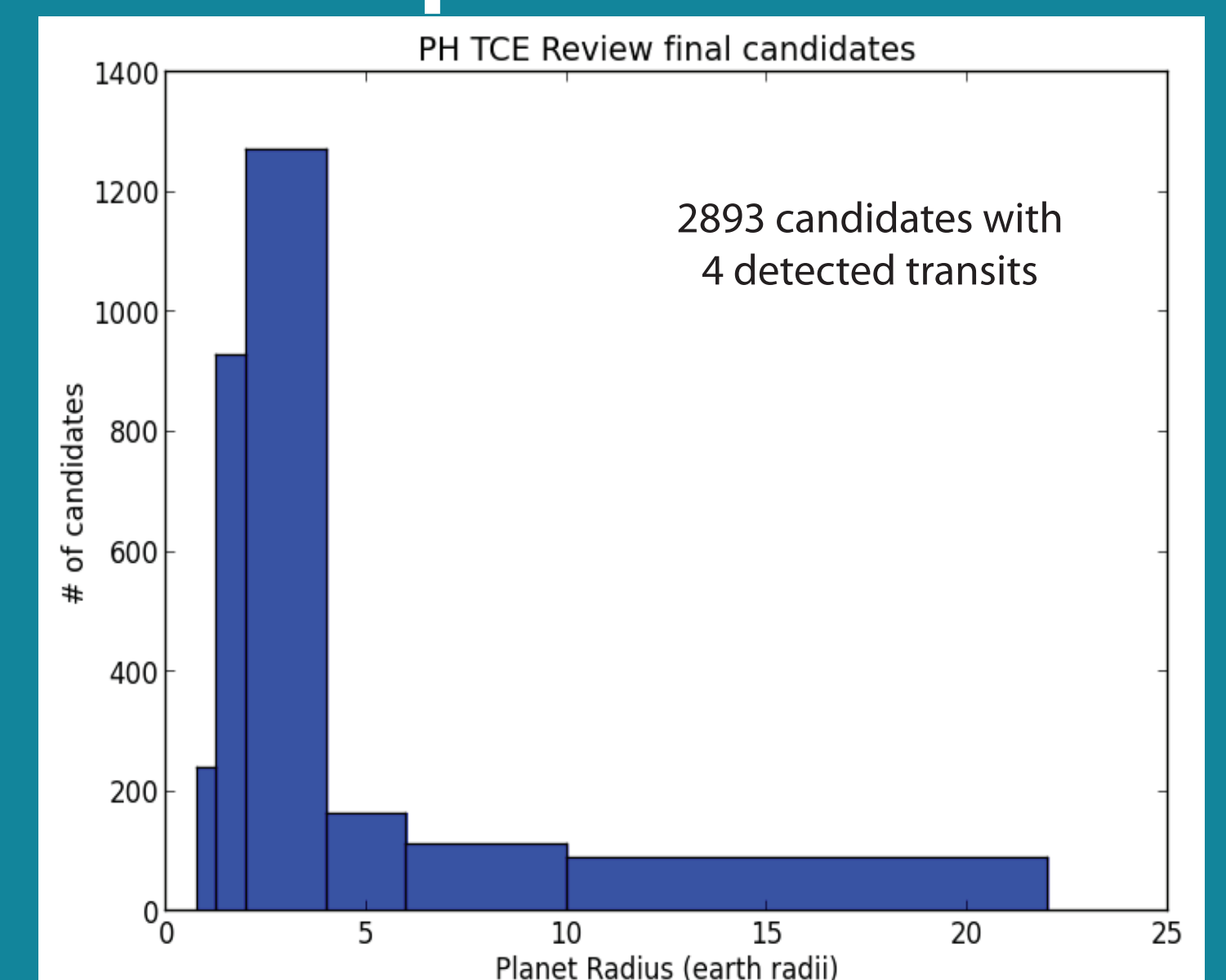
## Transit Model Fit Assessment:

To assess how well the transit model fits the data, we using the previously computed classifier weights. **We assign a transit model score  $s_f(\text{fit})$  for each TCE as the sum of the classifier weights who answered yes to the 'Does the red line fit the data?' question divided by the sum of the weights for all who classified the TCE.** We apply a conservative cut at 0.3 for  $s_f(\text{fit})$  to determine how well the transit model fits the folded light curve. **4261 TCEs remain after this cut.**

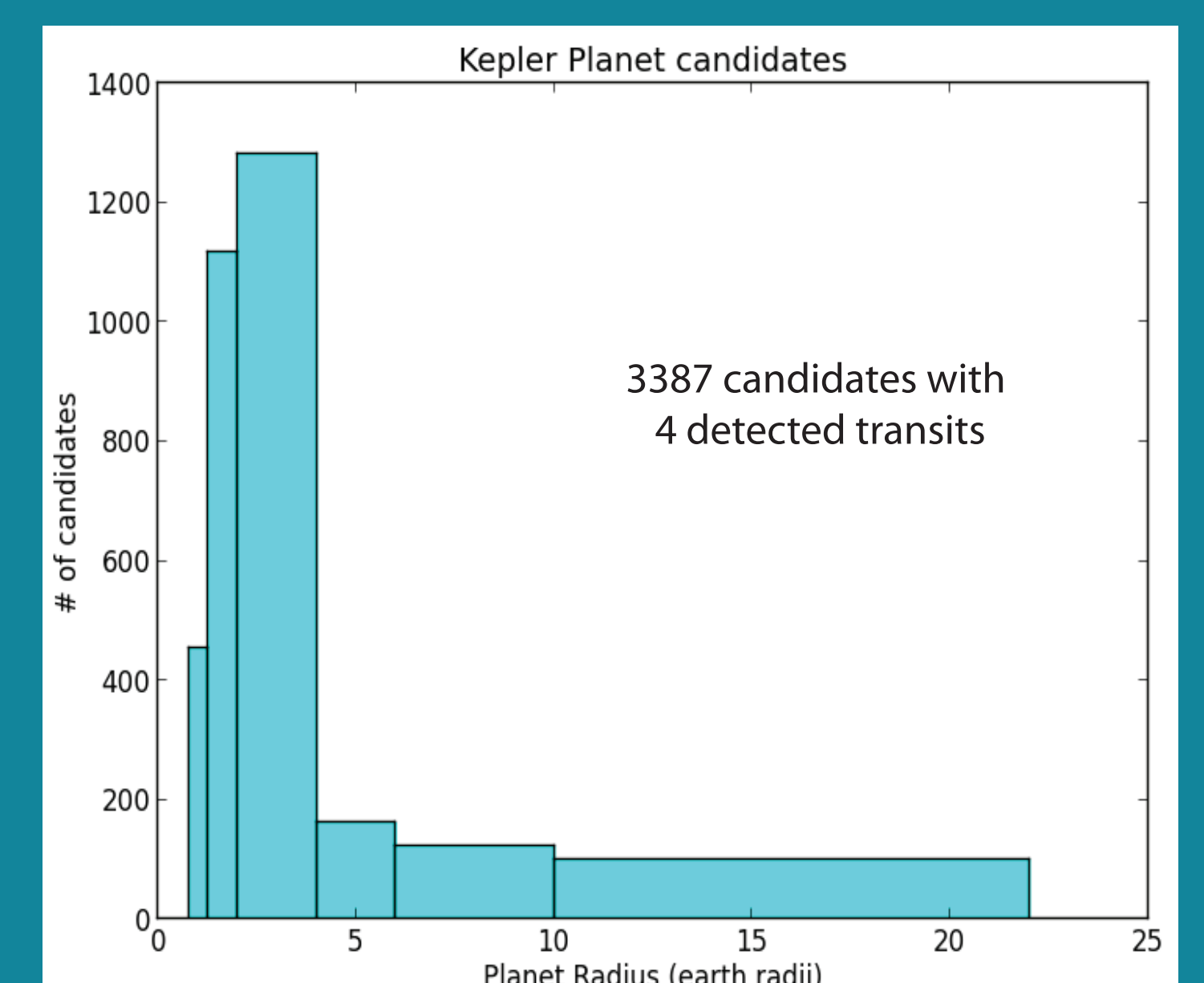
## Refining the Candidate List:

The candidate list is further refined by removing candidates with less than 4 transits, assessing the odd-even transit statistic reported by the Kepler pipeline, removing likely long period detached eclipsing binaries, and checking pixel offsets. Both difference image shifts and relative to star catalog position shifts in and out of transit had to be less than 4-sigma for promotion to candidate status. **2893 planet candidates remain after the cuts.**

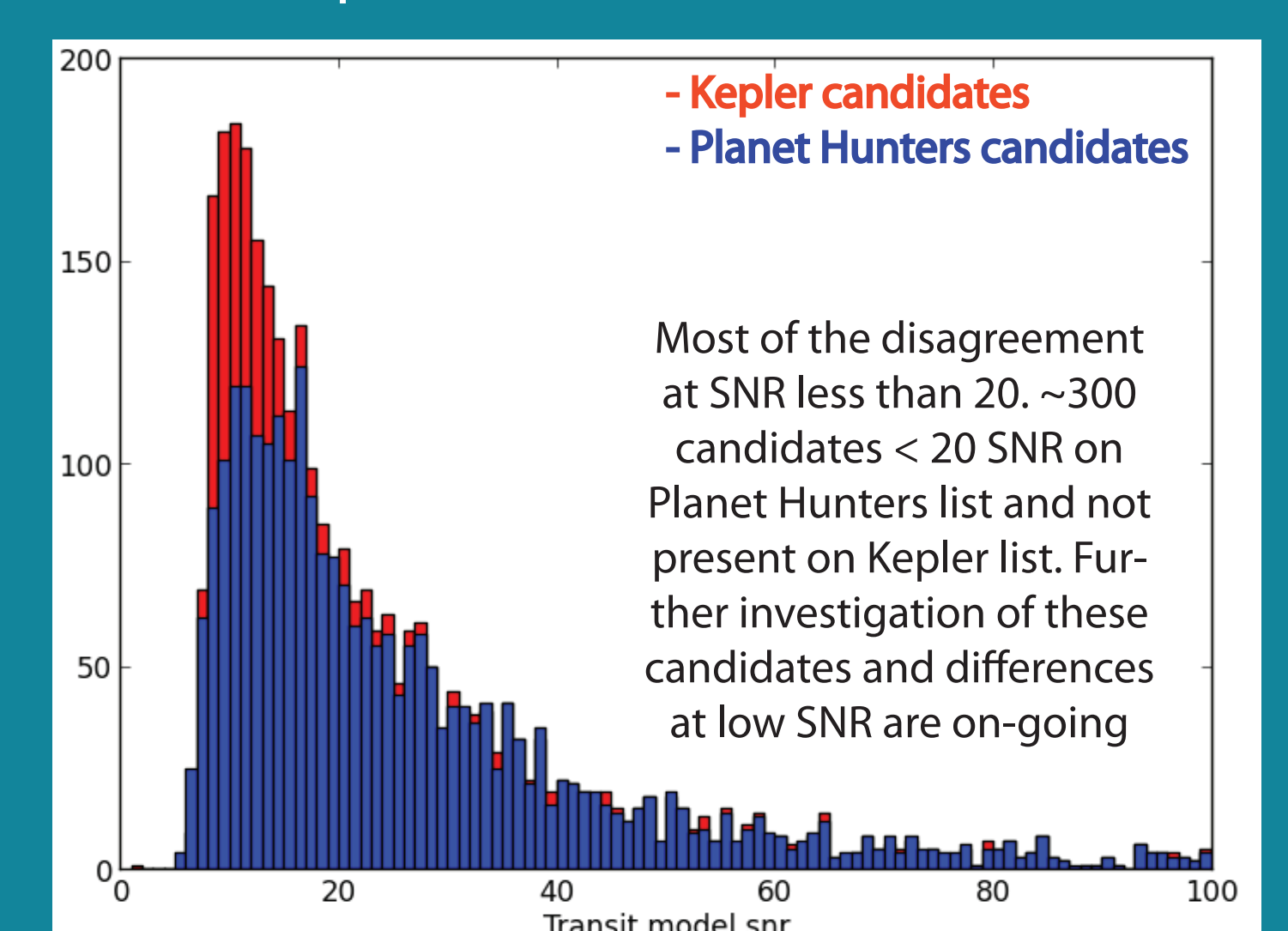
## Candidate Comparison:



Planet Hunters Planet Candidates with 4 detected transits



Q1-Q12 Kepler Planet Candidates with 4 detected transits



planethunters.org

**Acknowledgements:** MES is supported by an Academia Sinica Postdoctoral Fellowship and was supported in part by an NSF Astronomy & Astrophysics Postdoctoral Fellowship under award AST-100325. This research has made use of the NASA Exoplanet Archive