A Bayesian Look at the Planet Occurrence Rate from TESS

Drake Deming
University of Maryland at College Park

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This talk:

Bayesian statistics of TESS planet candidates

just an initial phase, because it's very early

Demographics of TESS planet candidates

as of 7/27, sector 12,
comparison with Barclay et al. (2018)
comparison with Huang et al. (2019) is planned

"Stacking" – and an example from phase curves

Goal: *determine the planet occurrence rate as a function of stellar mass, orbital period, and planet radius*

(using as much Bayesian rigor as possible)

Bayes Theorem:

$$P(p|t) = \frac{P(t|p)\,P(p)}{P(t)}$$

$P(p|t)$ = probability of a planet, given a TOI

$P(t|p)$ = probability that a planet will become a TOI

$P(p)$ = probability that a given star has a (transiting) planet

$P(t)$ = probability that a given star has a TOI

$$P(t) \approx P(p) + P(beb) \quad \text{; valid for small P}$$

Proceed *in two phases:*

$$P(p|t) = \frac{P(t|p)\,P(p)}{P(t)}$$

First phase: adopt P(p) from Kepler results, P(beb) from stellar binary statistics & TRILEGAL galaxy model, calculate P(p|t) – compare to vetting results

Second phase: after vetting of candidates is complete, invert the procedure to calculate P(p), knowing P(p|t)

This differs somewhat from previous methodology (e.g., Fressin et al. 2013; Dressing & Charbonneau 2013)

Many uncertainties:

statistics of stellar binaries – P(beb)

- binary occurrence rate versus mass and period
- secondary mass and radius distribution

galactic stellar populations – matching the TIC

errors in masses & radii of the TIC stars

other sources of false positives

- only using bebs in the same TESS pixel as the host star

incompleteness of false positives

- the TESS team may have eliminated some bebs that I include

imperfections in calculating P(t|p)

- variations in TESS noise from star-to-star
- duty cycle and periods of enhanced noise
- possible selection effects and bias in candidate sample

Method:

P(t|p) is close to 1, for a specific list of candidates

I'm using 993 TOIs from ExoFOP-TESS (7/27 date)

Not using cTOIs, or planets from the ground-based transit surveys

P(t) ≈ P(p) + P(beb)

P(p) from Kepler occurrence rates as a function of planet radius
(Fressin et al; Dressing & Charbonneau)

P(beb) by making binaries using stars from TRILEGAL and:
- accounting for variations in galactic coordinates
- adopting main sequence stars
- binary occurrence rate from Moe & DiStefano (2017)
- uniform distribution of secondary masses

Results *(preliminary)*

for $R \leq 1.8\ R_{\oplus}$:
I predict that 82 ± 3% of the TOIs are planets
(ExoFOP-TESS lists 10% as false-positives)

for $1.8 \leq R \leq 4\ R_{\oplus}$:
I predict that 86 ± 1% of the TOIs are planets
(ExoFOP-TESS lists 10% as false-positives)

TESS has large pixels, so blends will be common
However: the stars are bright,
the TESS team draws on Kepler's experience,
so it's reasonable that most TOIs are planets

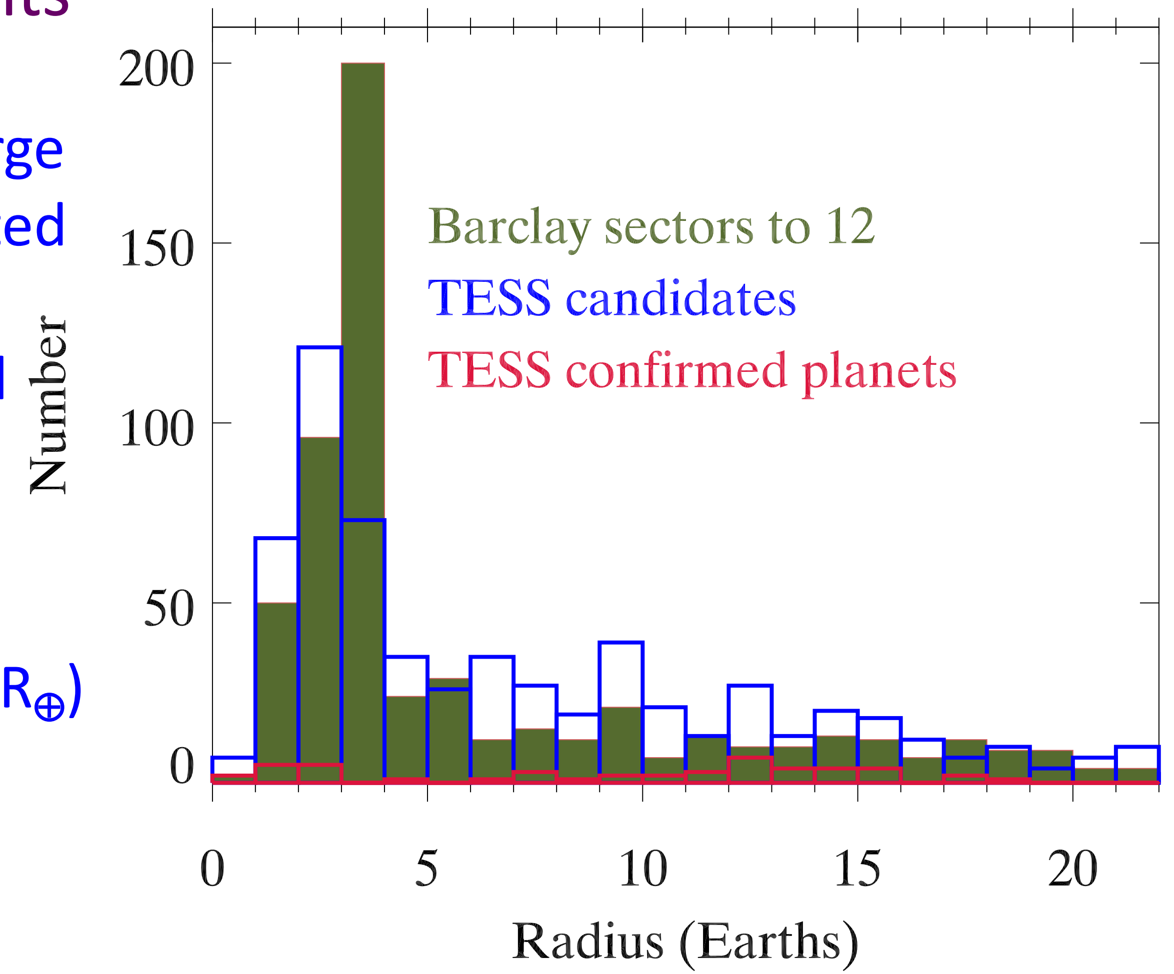
Demographics versus Barclay et al.

comparing TESS candidates to Barclay simulations for the same sky segments

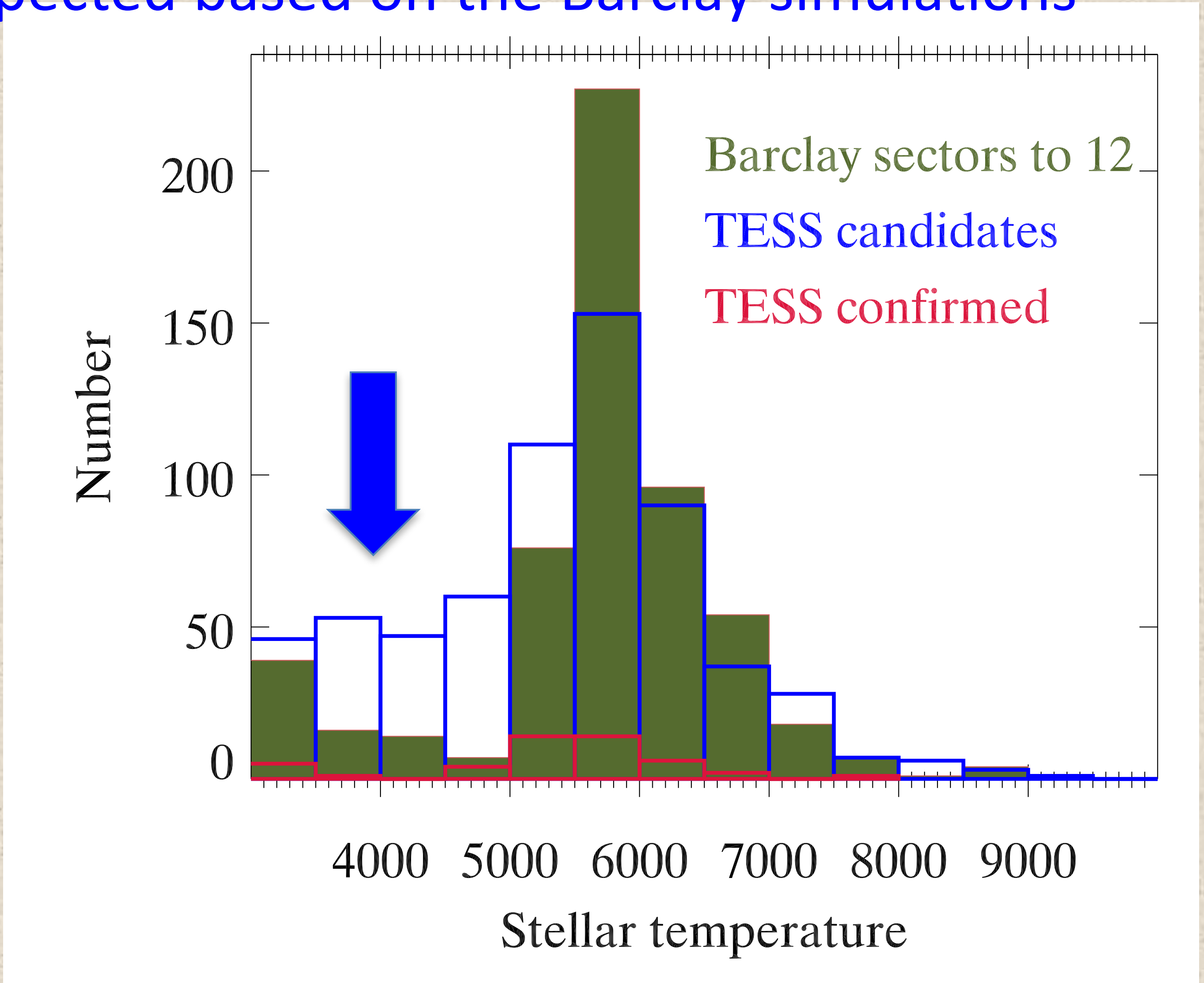
TESS is finding more large candidates than expected

more super-Earths and mini-Neptunes (< $3R_\oplus$) than expected

fewer Neptunes (3 to $4R_\oplus$)

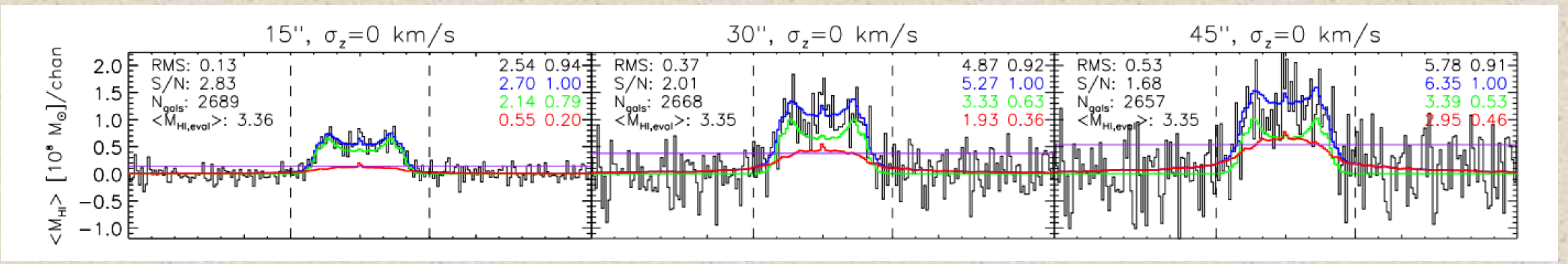


TESS is finding more candidates orbiting K- and M-dwarfs than expected based on the Barclay simulations



Stacking = combining data from different objects to infer a common property

Widely used in astrophysics (*hundreds* of papers), e.g. Elson et al. (2019) stack hydrogen-line spectra of galaxies

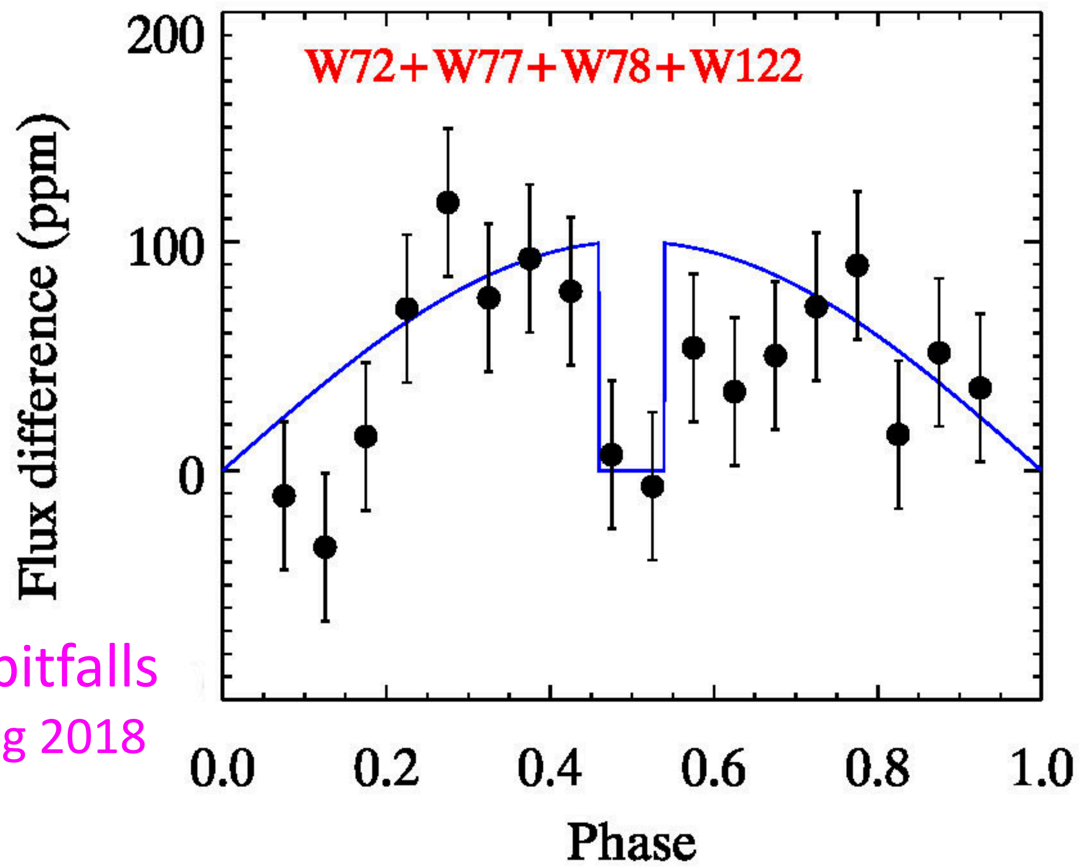


(exoplanets are like galaxies: they are numerous, and many cannot be observed individually with high signal-to-noise)

Potential to stack TESS phase curves

(Jansen & Kipping 2018 stacked Kepler phase curves)

exploits the near-IR response of TESS; potential phase curve shifts & eclipses for planets too cool for individual phase curves



CAUTION:
many subtle pitfalls
Sheets & Deming 2018

Summary

A high fraction of TOIs are planets, potentially as high as 85%

TESS is finding more super-Earths and mini-Neptunes ($< 3R_{\oplus}$) than in the Barclay simulations, and fewer Neptunes (3 to $4R_{\oplus}$)

TESS is finding more candidates orbiting K- and M-dwarfs than the Barclay simulations

Stacking of TESS phase curves has potential to reveal heat circulation on hot Jupiters that are not hot enough for individual analyses