Estimating Exoplanet Eccentricity for M-Dwarfs without RV

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Summary Radial velocity (RV) measurements are lacking for the thousands of planetary candidates detected by TESS, which is needed to calculate eccentricity e, which plays an essential part in habitability. Minimum e constraints can be obtained for candidates orbiting M-dwarfs through the photoeccentric effect, which we demonstrate using TOIs 1634b and 1073b. We obtain $e = 0.117$ for 1634b, in line with the published maximum bound of 0.16. We obtain $e = 0.143$ for 1073b, a strong e constraint for the system.

The Photoeccentric Effect

We cannot directly calculate stellar mass M_* and radius R_* from a transiting planet's light curve, but if we assume $e = 0$ and measure $\frac{a}{R_*}$, we can get stellar density ρ_*

$$\rho_* = \frac{3\pi(a/R_*)^3}{GP^2},$$

as in [1] and [2].

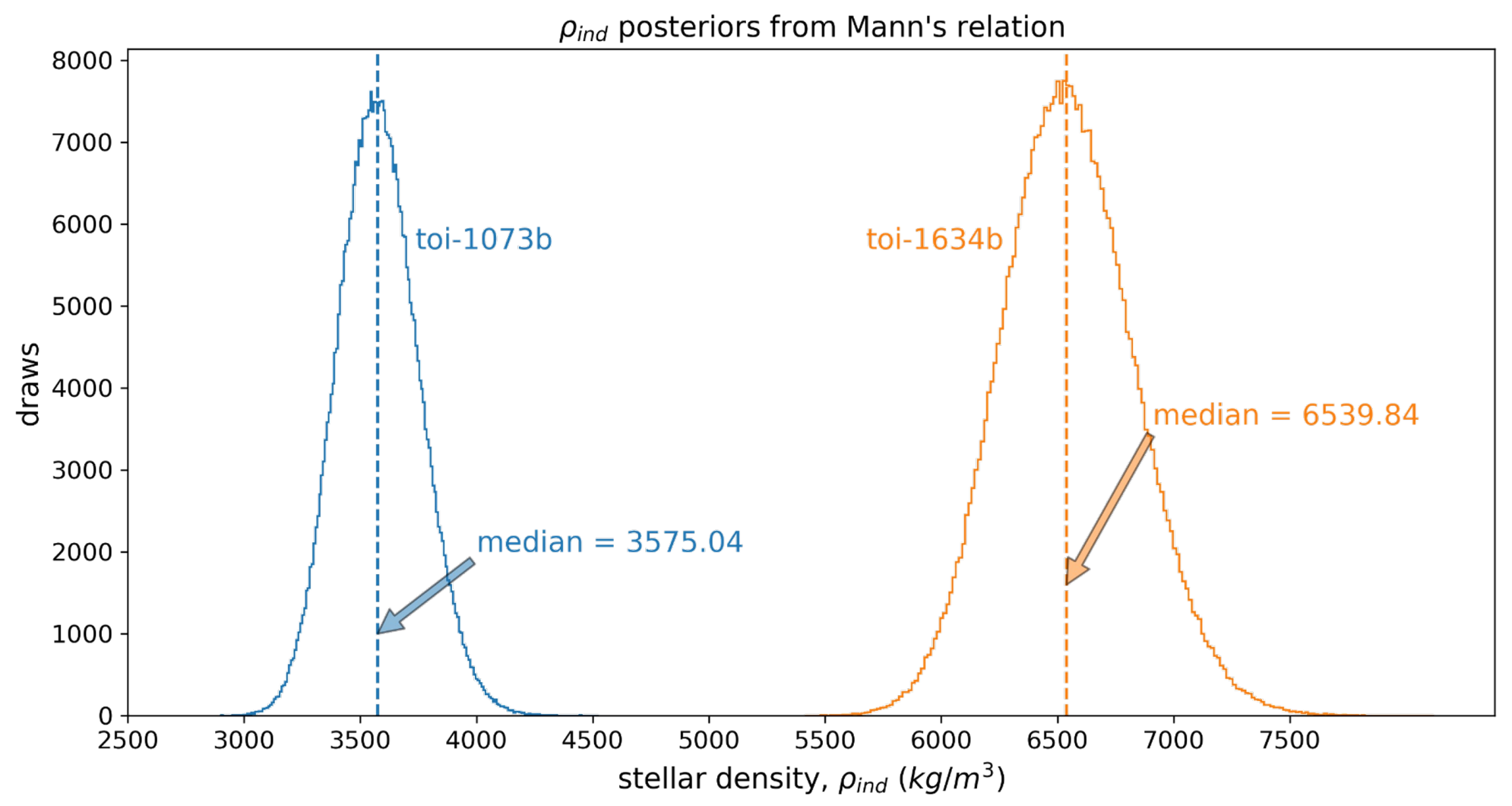
However, when compared to a density *independent* of the assumption $e = 0$, this results in a discrepancy,

$$\frac{\rho_{*,ind}}{\rho_{*,circ}} = \frac{(1 + e\sin\omega)^{\,3}}{(1 - e^2)^{3/2}}.$$

As long as we have two density measures, we can infer e and ω using posterior functions! [2]

Mass-Magnitude, Mann

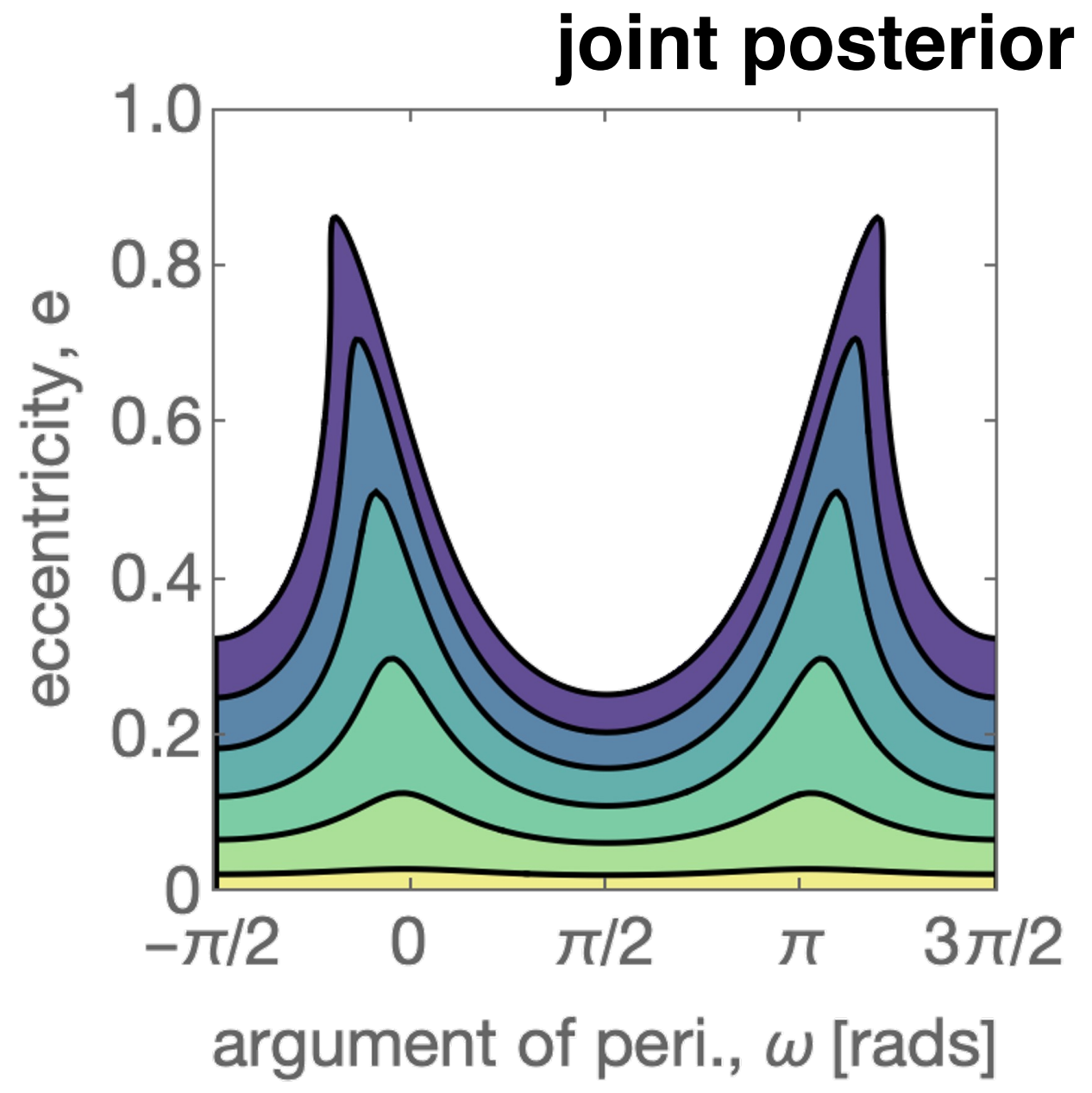
For our $\rho_{*,ind}$ measure, we calculate $\frac{M_*}{R_*}$, which we achieve independently of the light curve by fitting the TOI's GAIA K-band magnitude and stellar distance to Mann's mass-magnitude relation for M-dwarfs [3], generating posteriors for M_*, R_*, and $\rho_{*,ind}$.



Median of posterior = estimated stellar density!

TOI 1634b

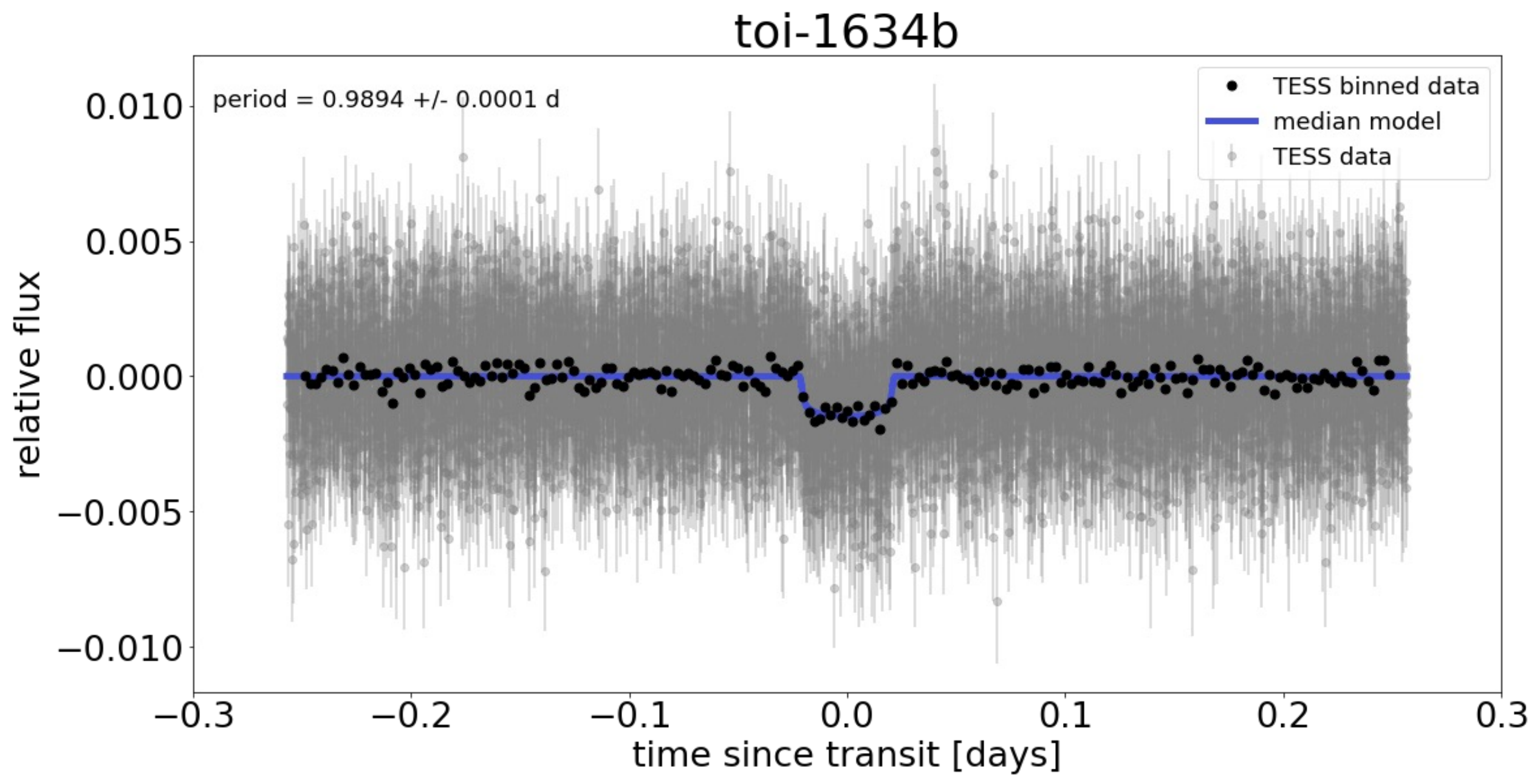
joint posterior distribution



MAP solution in $e - \omega$ joint parameter space:
$e = -4.48348 * 10^{-18} \approx 0,\;\; \omega = \frac{3\pi}{2}\; rads$

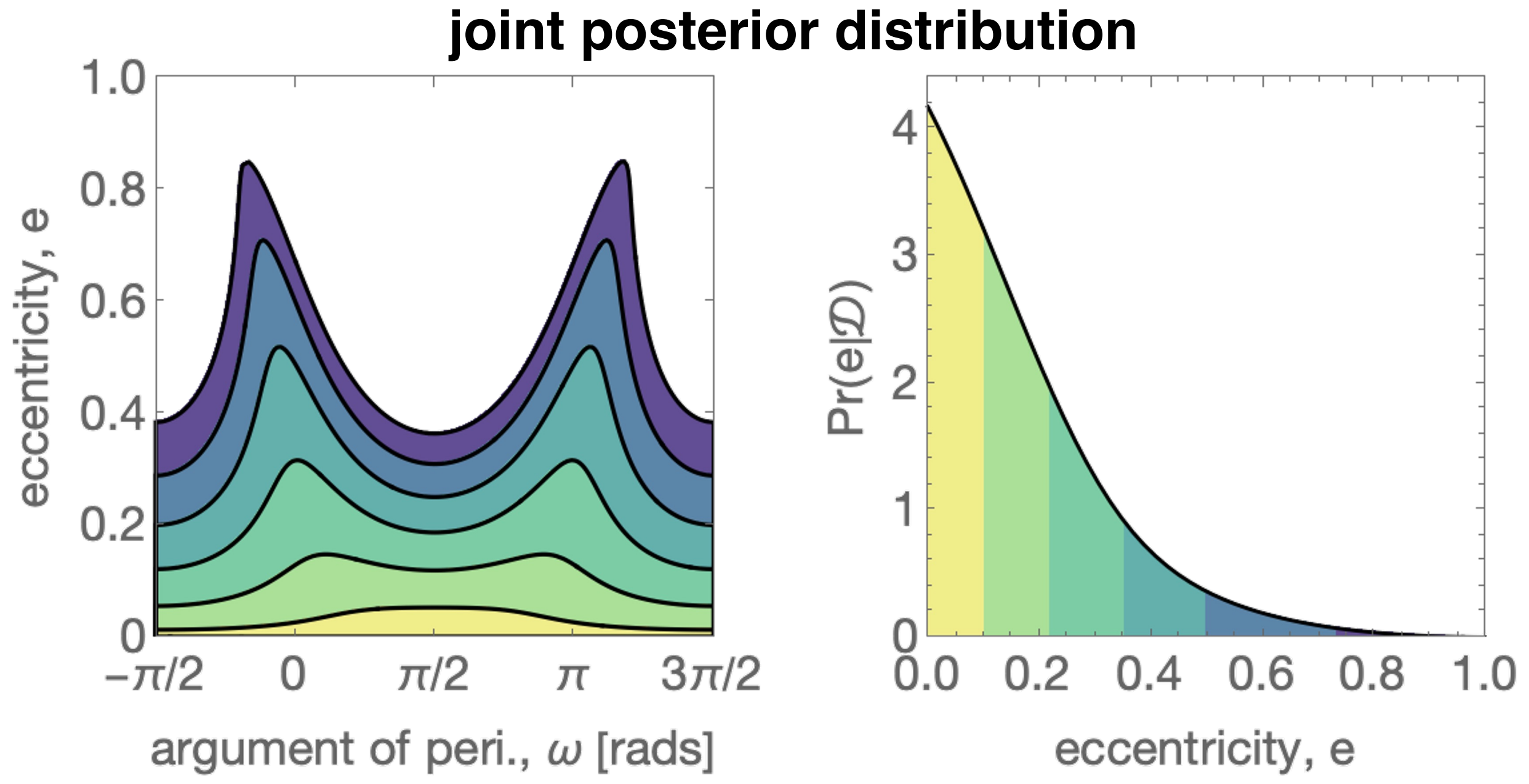
e estimate (median of posterior):
$e = 0.116673 \sim 0.117$

median transit model light curve



TOI 1073b

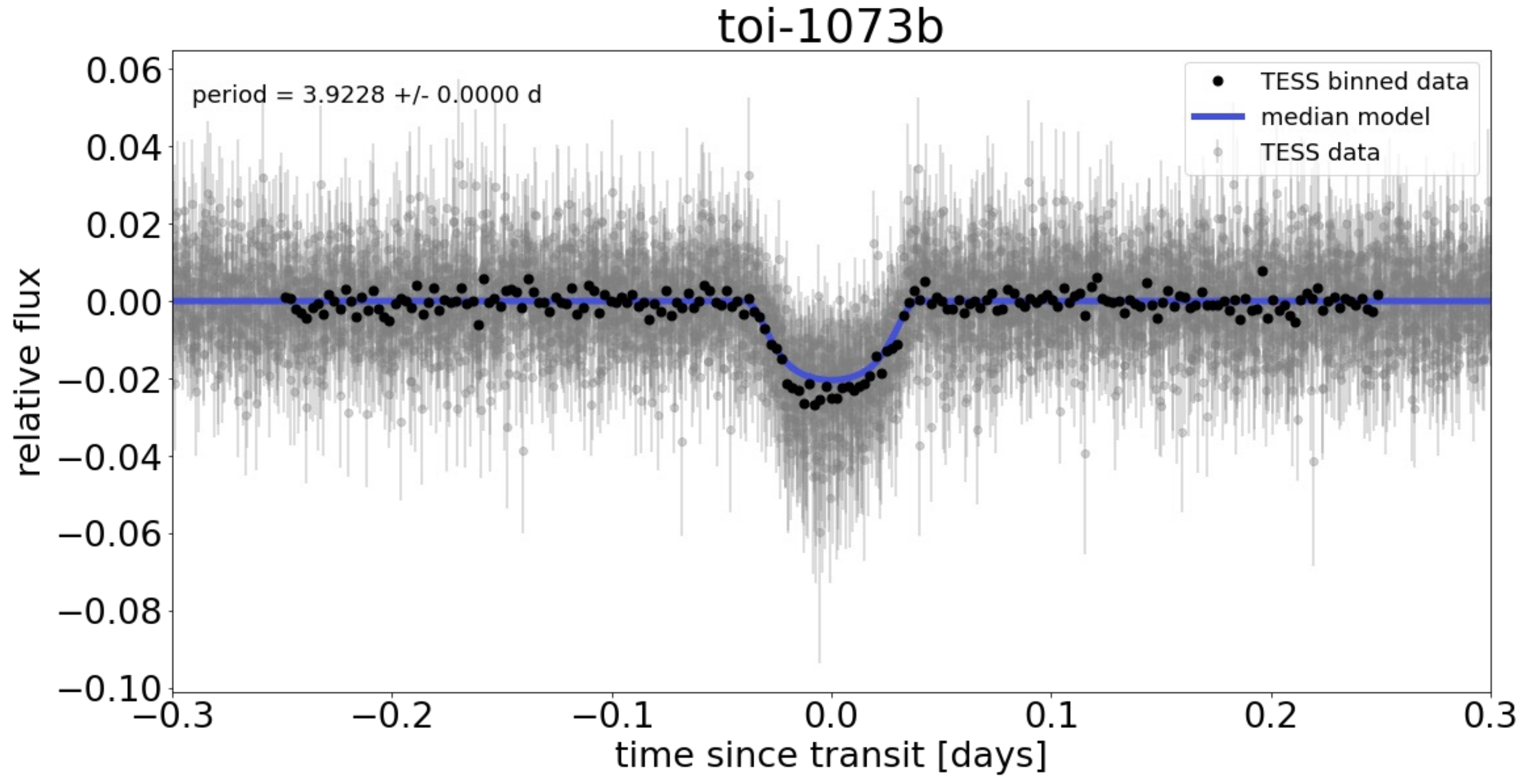
joint posterior distribution



MAP solution in $e - \omega$ joint parameter space:
$e = 0, \omega = \frac{\pi}{2}\; rads$

e estimate (median of posterior):
$e = 0.143175 \sim 0.143$

median transit model light curve



Conclusions

Comparing our e for TOI 1634b to the published maximum e bound of 0.16 [7], which used RV measurements, we can say that our method provides a good e constraint, and can be tested against future RV follow-up studies of TESS objects.

Our estimate 0.143 for TOI 1073b disagrees with the upper bound $e, < 0.088$, in its discovery paper [8], which did have RV data available. This would be an example of RV data confirming or denying an estimate in follow-up studies, although both agree the orbit would be very near-circular.

As Earthlike planets have low eccentricities, our method would be helpful in identifying which planets may be habitable, as it would point towards candidates to prioritize for follow-up RV measurements.

Further Steps

We will produce a catalog of eccentricity estimates for roughly 900 TESS candidates orbiting M-dwarfs, with the goal of making it a public resource for the astronomy community.

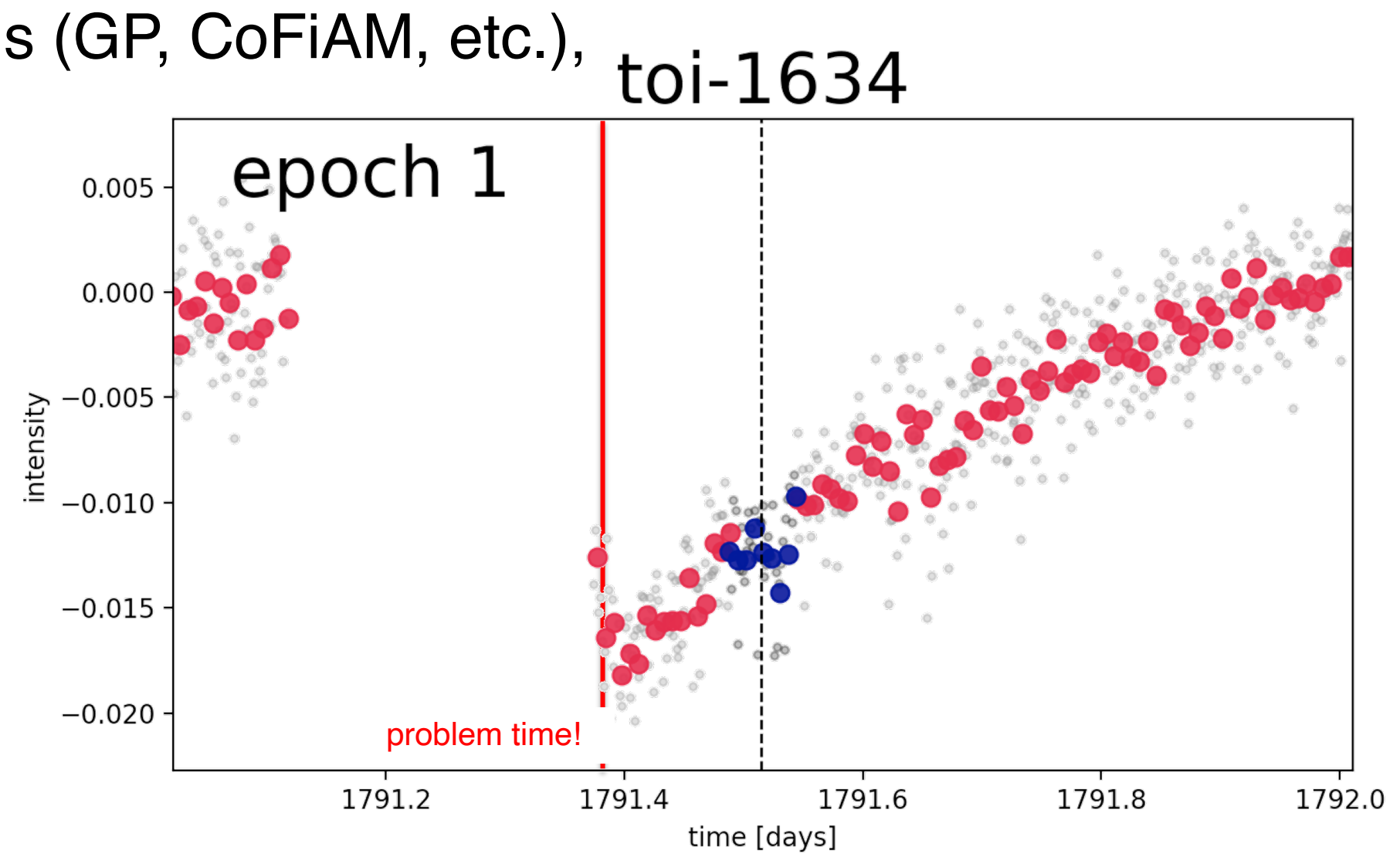
We hope to extend our sample beyond TESS and move on to Kepler objects also orbiting M-dwarfs eventually.

We also intend to study how eccentricities are distributed for this sample.

Detrending Problem Times

Measuring $\rho_{*,circ}$ requires light curves free of structured noise, so we crop out **problem times**, points of discontinuity within non-transit data.
We detrend using various methods (GP, CoFiAM, etc.), the final "clean" data being an agreement between them [4].

We then fit a median transit model with MCMC, optimizing for impact parameter b, $\frac{a}{R_*}$, P, mid-transit time t_θ, and $\rho_{*,circ}$.



All of this can be done in [5]!

Eccellent Inferencing

Given $\rho_{*,ind}$, $\rho_{*,circ}$, and their standard deviations, we define a measurement distribution Λ_{dist}, priors [6],

$$P(e) = \frac{(1-e)^{\beta-1}e^{\alpha-1}}{\mathrm{B}[\alpha,\beta]}, \alpha = 1, \beta = 3;\text{ represents RV population}$$

$$P(\omega) = \frac{1}{2\pi};\text{ uniform argument of periastron,}$$

and joint posterior,

$$\wp(e|\omega) = \mathrm{PDF}\left(\Lambda_{dist}, \sqrt[3]{\frac{\rho_{*,ind}}{\rho_{*,circ}}}\right) \times \frac{P(e|\omega)}{\wp_{normalized}(e|\omega)}.$$

We marginalize and evaluate this posterior, then calculate the median.

This is our estimate for the eccentricity of an exoplanet orbiting an M-dwarf!

References

[1] Seager & Mallen-Ornelas. ApJ., 585 (2003) 1038.
[2] Kipping. MNRAS, 421 (2012) 1166.
[3] Mann, et al. ApJ., 871 (2019) 63.
[4] Teachey & Kipping. SciAdv., 4 (2018).
[5] https://github.com/dyahalomi/TTVs/tree/main/detrend_package (*a work in progress!)*
[6] Kipping. MNRAS, 444 (2014) 2263.
[7] Cloutier, et al. AJ, 162 (2021).
[8] Hartman, et al. AJ, 159 (2020) 173.

Acknowledgements

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