### 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 \( \rho \), we can get stellar density \( \rho_* \), as in [1] and [2].

\[
\rho_* = \frac{3n/g(R)^3}{4\pi^2}.
\]

However, when compared to a density independent of the assumption \( e = 0 \), this results in a discrepancy, \( \rho_* - \rho_{\text{true}} = \frac{3}{4}(1 + \sin^2 \omega) e^2 \).

As long as we have two density measures, we can infer \( e \) and \( \omega \) using posterior functions [2].

### Mass-Magnitude, Mann
For our \( \rho_{\text{true}} \) measure, we calculate \( \rho_* \), 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].

**Median of posterior = estimated stellar density!**

### Detrending Problem Times
Measuring \( \rho_{\text{true}} \) 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 \( b = \frac{R_p}{R} \), mid-transit time \( t_p \), and \( \rho_{\text{true}} \).
All of this can be done in [5].

### Eccellent Inferencing
Given \( \rho_{\text{true}} \) and \( \rho_{\text{true}} \), and their standard deviations, we define a measurement distribution \( \rho_{\text{true}} \), and priors [6].

\[
P(e) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{e^2}{2\sigma^2}}, \quad a = 1, \beta = 3; \text{represents RV population}
\]

\[
P(\omega) = \frac{1}{\pi} \text{uniform argument of periastron,}
\]

and joint posterior,

\[
\rho(e,\omega) = \text{PDF} \times \rho_{\text{true}}(e,\omega) \times \text{Pearson}(\text{transit model light curve})
\]

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

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

### 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.

### References

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