# The Orbital Eccentricities of the Kepler M dwarf Planets: A Population-Level View of Planet Dynamics around Small Stars

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## The underlying eccentricity distribution of exoplanets around M dwarfs is unknown.

### *Why eccentricities?*

- Orbital eccentricities encode key information about the **formation** and **evolution** of planetary systems
- Distances between host star and planet vary with non-zero orbital eccentricities, potentially affecting habitability

### *Why M dwarf planets?*

- M dwarfs are the **most common** type of star in our galaxy *(Howard et al. 2012)*. M dwarf planets are "typical" Milky Way planets!
- M dwarfs host **small, rocky planets** with high frequency *(Hardegree-Ullman et al. 2019)*
- M dwarfs are the likeliest targets for follow-up surveys to search for life due to their abundance, rate of small planet occurrence, and relative **ease of follow-up investigations** *(Muirhead et al. 2018)*
- Eccentricity may influence **habitability** more significantly around M dwarfs than for FGK stars (due to narrow, close-in habitable zones and tidal heating effects) *(Palubski et al. 2020)*

### *Why hasn't this been done before?*

- Measuring eccentricities typically requires long and costly radial velocity campaigns
- Thanks to **Kepler** and **Gaia**, we now have sufficiently precise data for planets around M dwarfs to circumvent using radial velocities, instead employing the photoeccentric effect

**Using the photoeccentric effect, we derive eccentricity posteriors for ~150 transiting planets around M dwarfs, using Kepler light curves and stellar density priors from spectroscopy and Gaia. Through a hierarchical Bayesian analysis, we derive a population-level eccentricity distribution for planets around early- to mid-M dwarfs.**

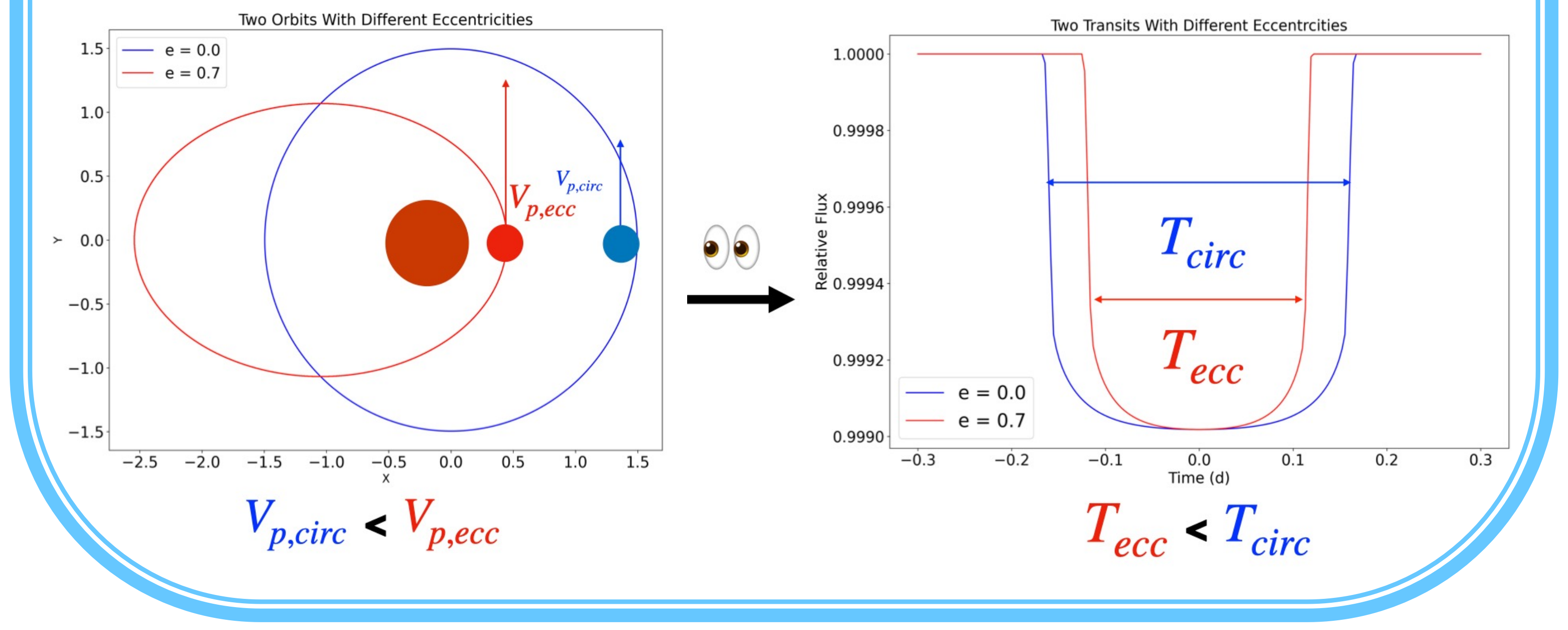
We use the sample of 103 Kepler planet candidate-hosting M dwarfs for which Muirhead et al. (2014) have presented H- and K-band spectra.

## The Photoeccentric Effect

We're using a transiting planet's **light curve** (Kepler) and **stellar density** prior (spectroscopy, Gaia) to constrain eccentricity *(Dawson & Johnson 2012)*.

$$\rho_\star = \frac{3}{G}\frac{P}{\pi^2 T^2}$$

- The duration of equivalent circular and eccentric transits differ.
- The transit duration and Kepler's 3rd law are both linked to the stellar density.
- We first find the best-fit circular transit model with `juliet` *(Espinoza et al. 2019)* and calculate the transit duration.
- We use Kepler's 3rd law (independent of *e*) to calculate $\rho_{circ}$, the "stellar density" in the circular case.
- Comparing $\rho_{circ}$ to the *true* stellar density $\rho_\star$ reveals the difference in transit duration --> eccentricity!



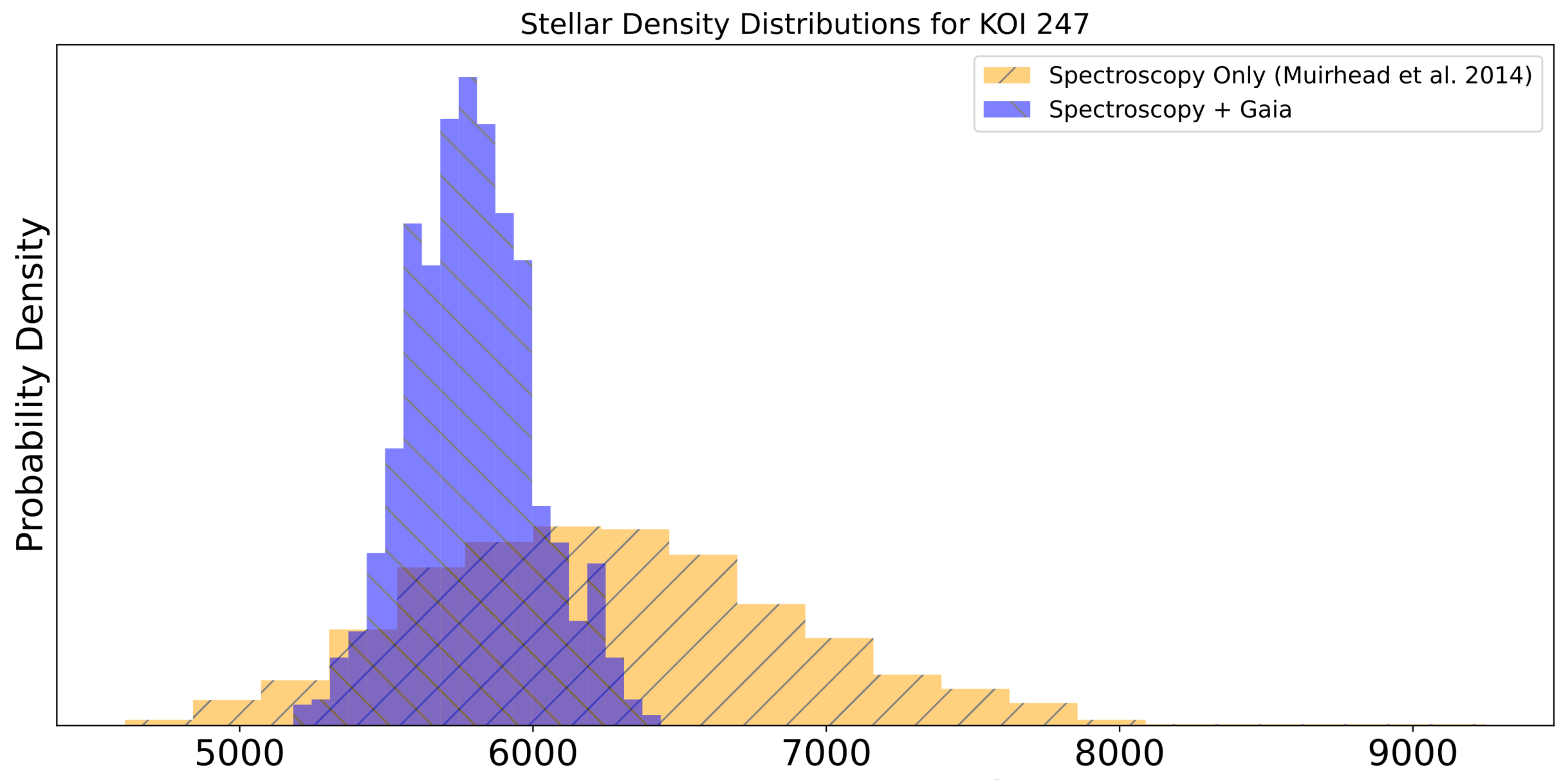
$V_{p,circ} < V_{p,ecc}$ $T_{ecc} < T_{circ}$

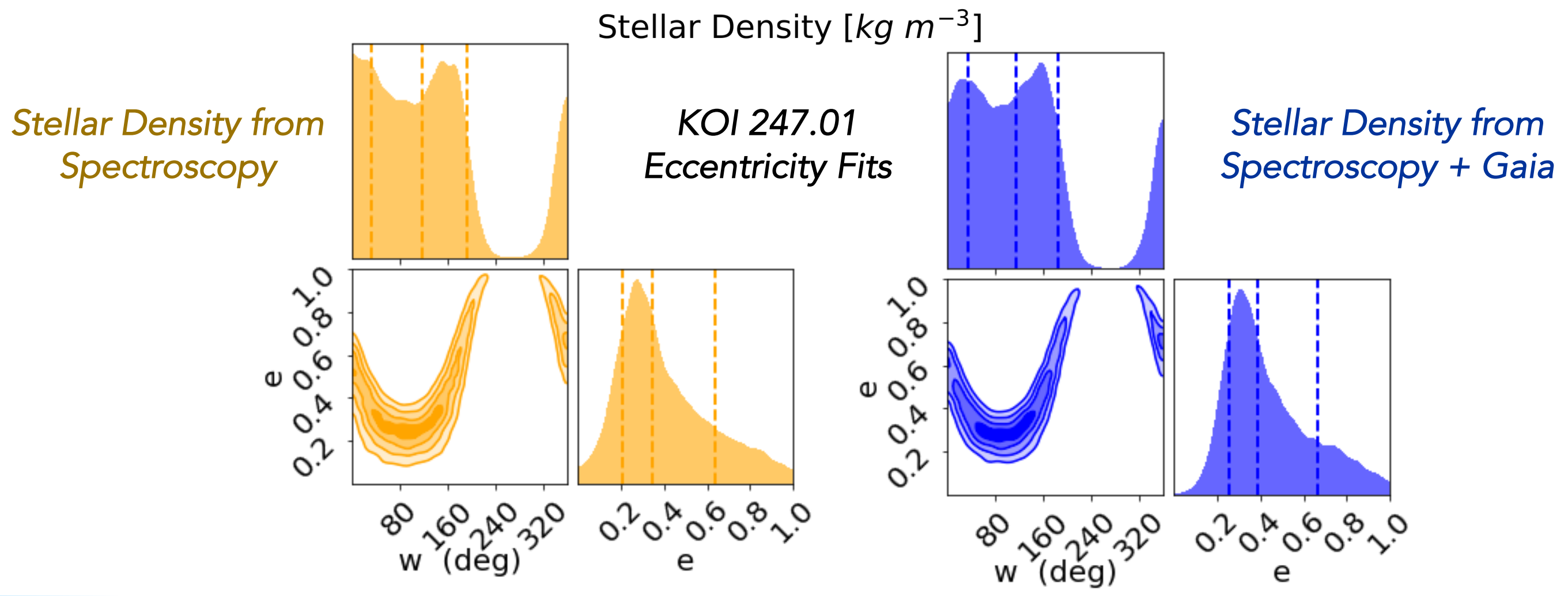
## Constraining Stellar Densities

We constrain stellar densities using a combination of **spectroscopy** and **Gaia** data.

- We use stellar properties calculated from spectroscopy by Muirhead et al. (2014).
- We calculate stellar luminosities using Gaia parallaxes.
- We interpolate stellar properties across MESA stellar isochrones (Choi et al. 2016).

***Incorporating Gaia data allows us to constrain the stellar density even further!***

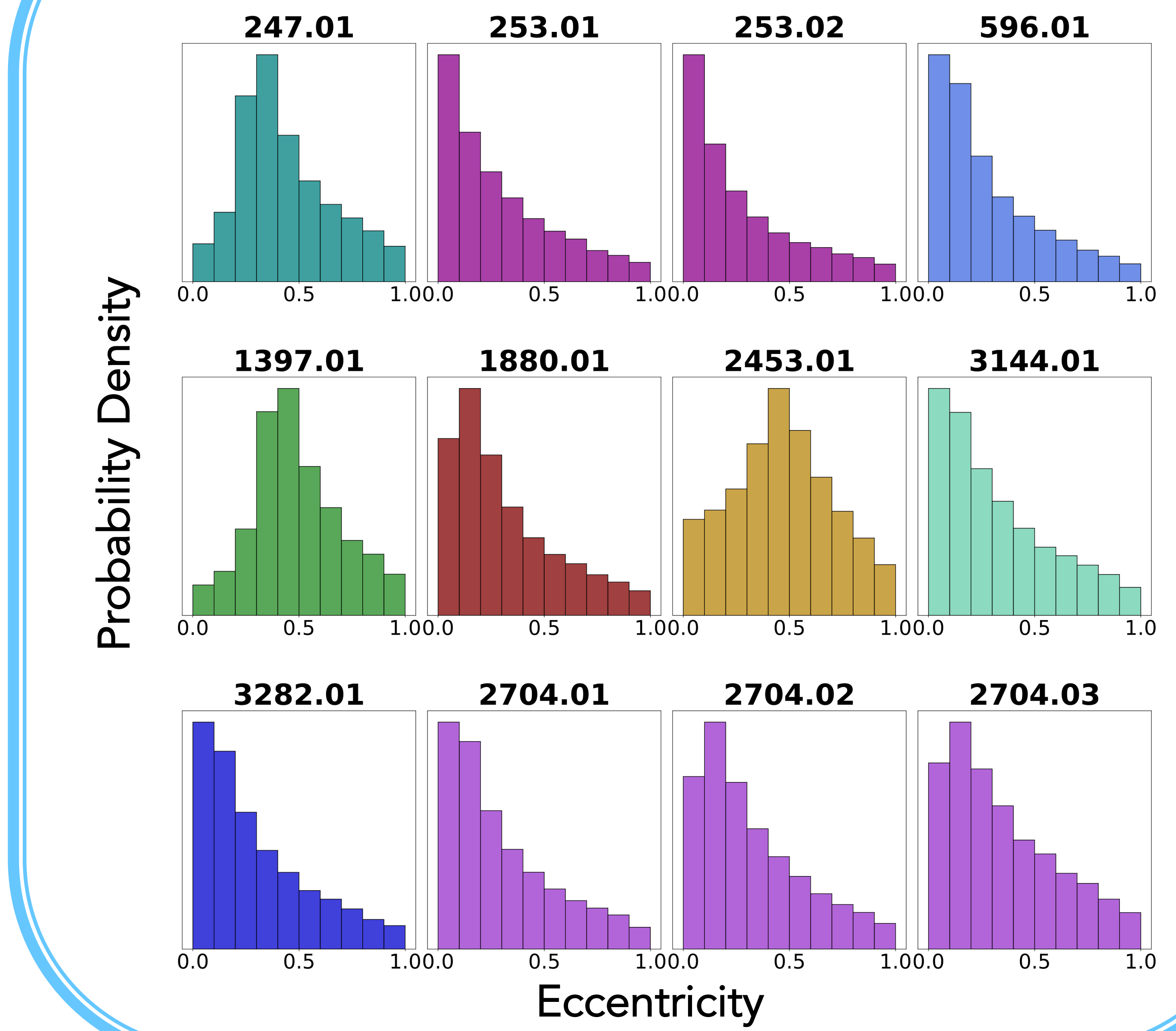




Our open-source Python package **`photoeccentric`** allows you to perform your very own eccentricity fit! Check it out on GitHub:

www.github.com/ssagear/
photoeccentric

## Selected KOI Eccentricity Posteriors



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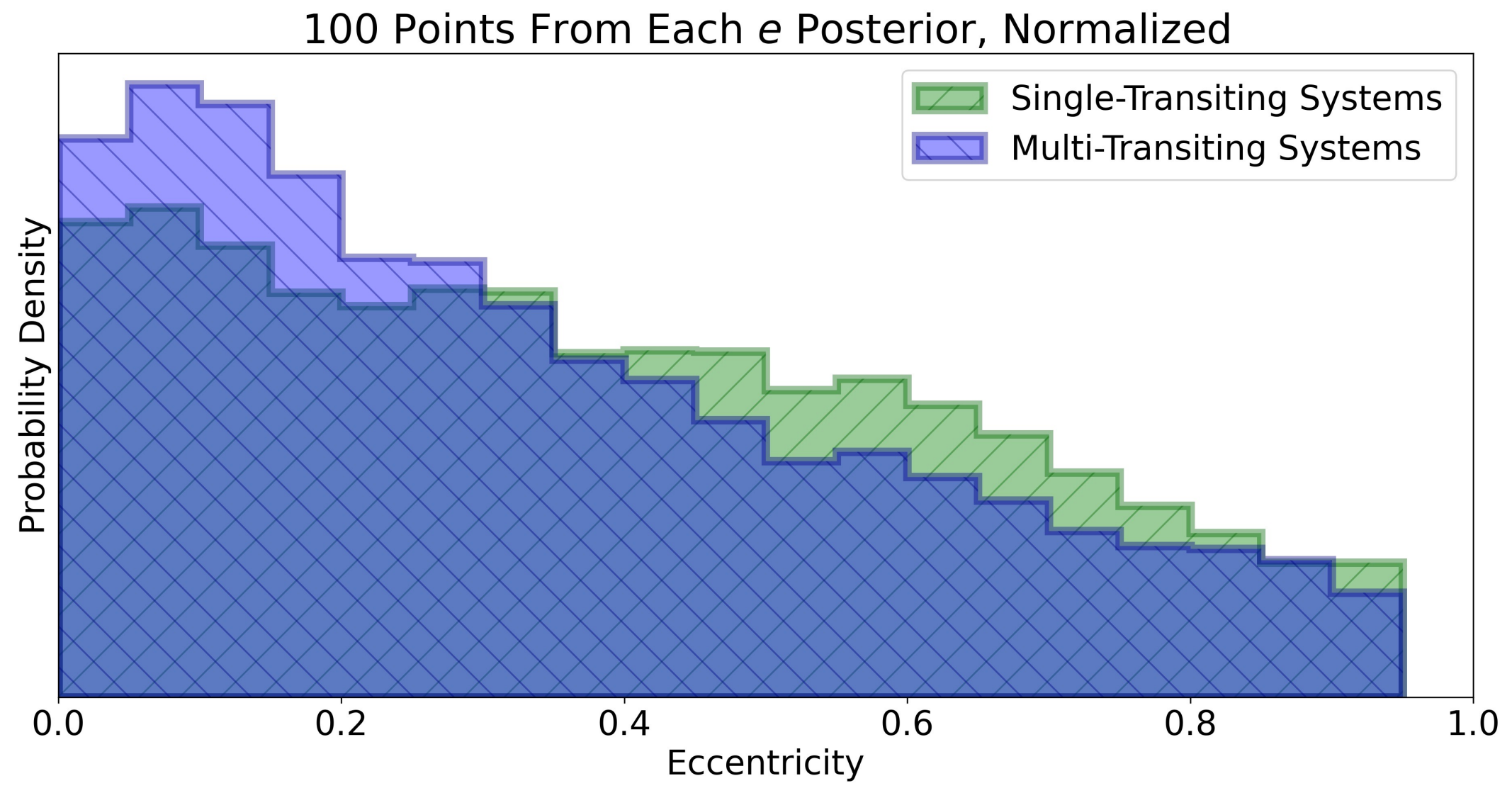
## Combined Planet Eccentricity Posteriors



We combine the eccentricity posteriors for each planet to get an eccentricity posterior for the full sample. We split the sample into single-transiting systems and multi-transiting systems.

## Hierarchical Bayesian Inference

We fit half-Gaussian and Rayleigh distributions to the full sample e posterior.

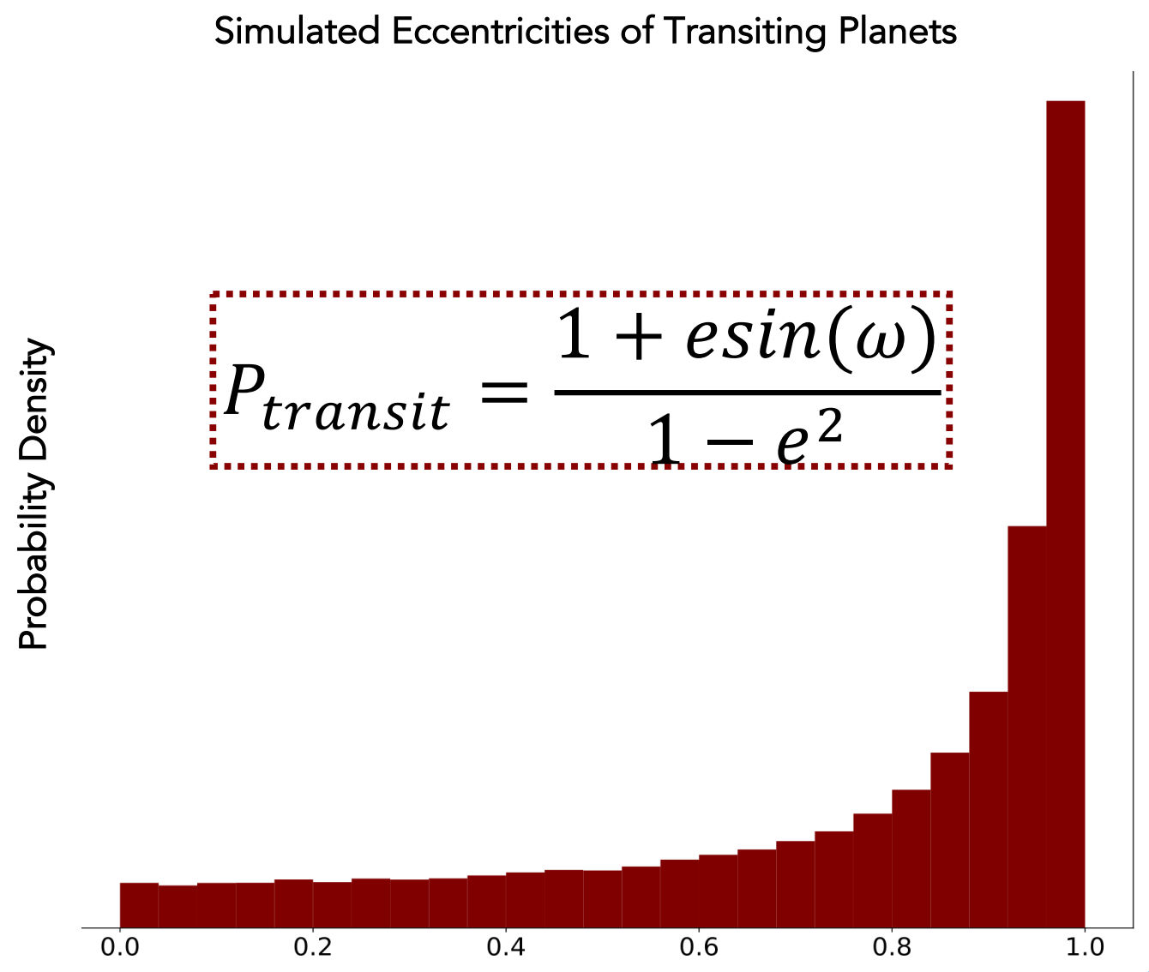
Probability of a *certain e* given a model with parameters θ (e.g. Rayleigh, Beta distributions)

$$p(obs\,|\,\theta) \propto \frac{1}{N}\prod_{k=1}^{K}\sum_{n=1}^{N}\frac{p(e_k^n\,|\,\theta)}{p(e_k^n\,|\,\alpha)}$$

Multiply over all planets in sample

Sum over all posterior values for each planet

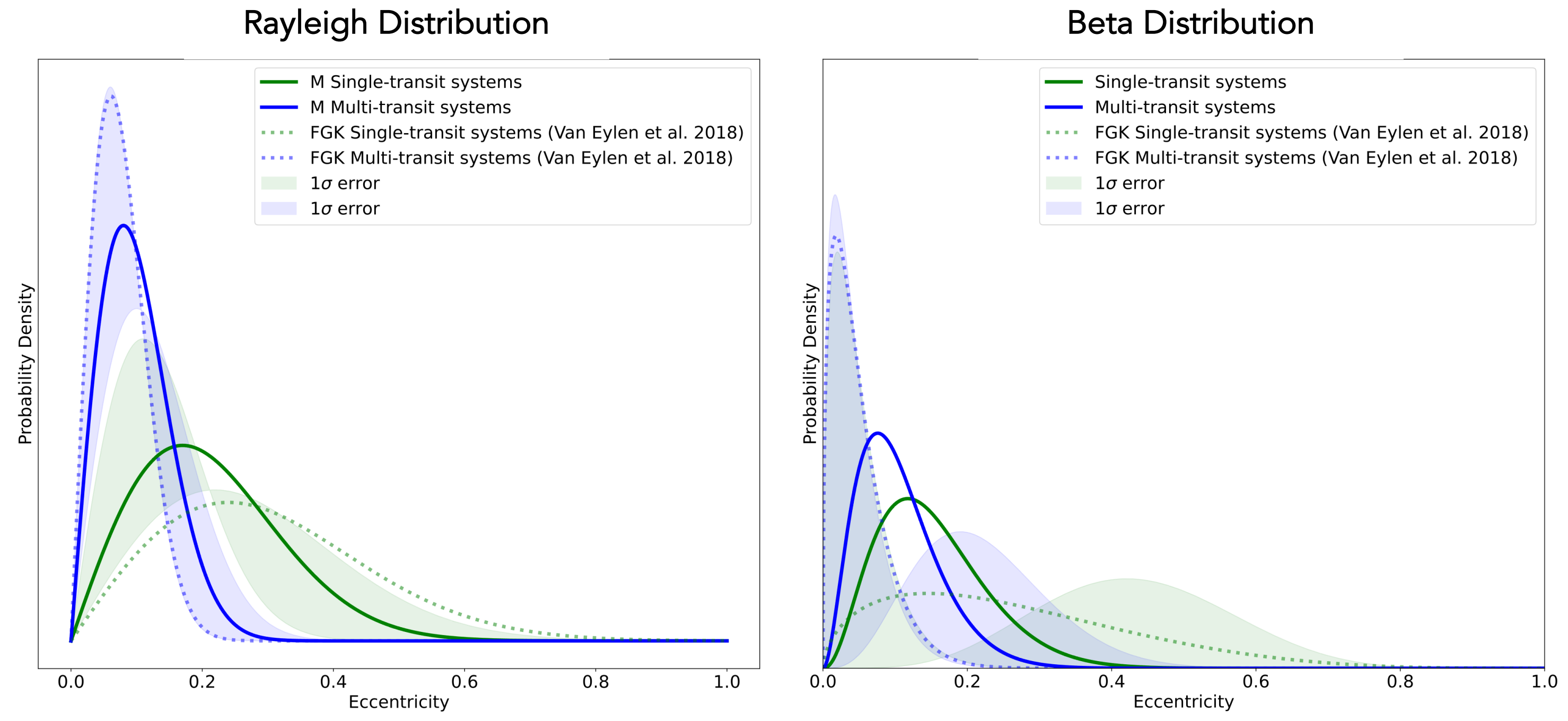
Prior probability of certain distribution parameters (uniform)



$$P_{transit} = \frac{1 + esin(\omega)}{1 - e^2}$$

We account for the higher transit probability of planets on eccentric orbits by de-biasing the combined eccentricity posterior.

## Underlying Eccentricity Distribution



- Preliminary results show the **underlying eccentricity distribution** of M dwarf planets as **best-fit Rayleigh and Beta distributions**. We compare these to similar results from Van Eylen et al. (2018) for planets around Sun-like stars.
- We find that our underlying e posteriors **differ less significantly between single- and multi-transiting systems** than the results of Van Eylen et al (2018).
- An eccentricity dependance on $M_\star$ would favor certain physical mechanisms in shaping planet dynamics. For example, stirring of planets by Jovian companions (strong dependence on $M_\star$) may be more significant than self-excitation among planets (weak dependence on $M_\star$).