The Orbital Eccentricity—Radius Relation for Planets Orbiting M Dwarfs

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The Orbital Eccentricities of Planets Orbiting M Dwarfs

Sagear & Ballard (2023)

Read the paper in PNAS here!

*We use the **photoeccentric effect** to constrain orbital eccentricities for ~150 Kepler M Dwarf planets.*

Why M dwarfs?

(Early) M dwarfs are the predominant host for small, rocky planets! *(Howard et al. 2012, Muirhead et al. 2018, Hardegree-Ullman et al. 2019)*
M dwarf planets have narrow, close-in habitable zones, making them susceptible to extreme effects from modest eccentricities *(Palubski et al. 2020)*

Why eccentricities?

Orbital eccentricities encode key information about the **formation** and **dynamical evolution** of planetary systems, and can significantly affect planet habitability

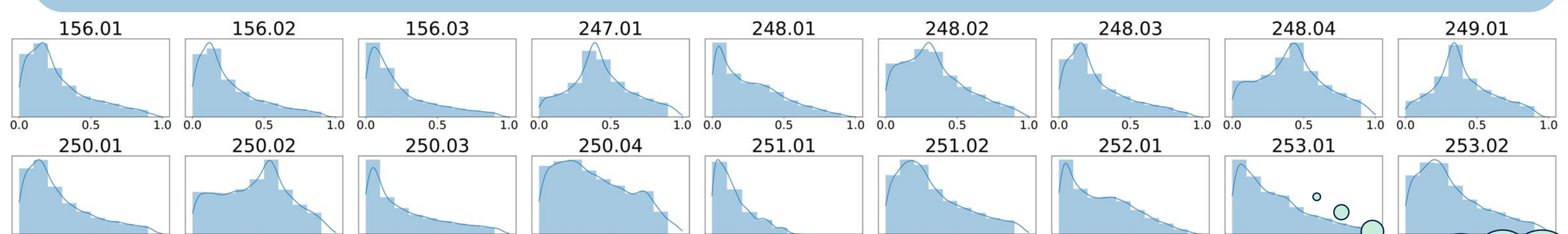
*What is the **photoeccentric effect**?*

(Dawson & Johnson 2012)

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

Eccentric planets change speed throughout their orbits, which directly influences their transit durations.
Combined with knowledge of the **stellar density and Kepler's 3rd law**, we observe transit durations using **Kepler light curves**, and use this to draw out an orbital eccentricity posterior.

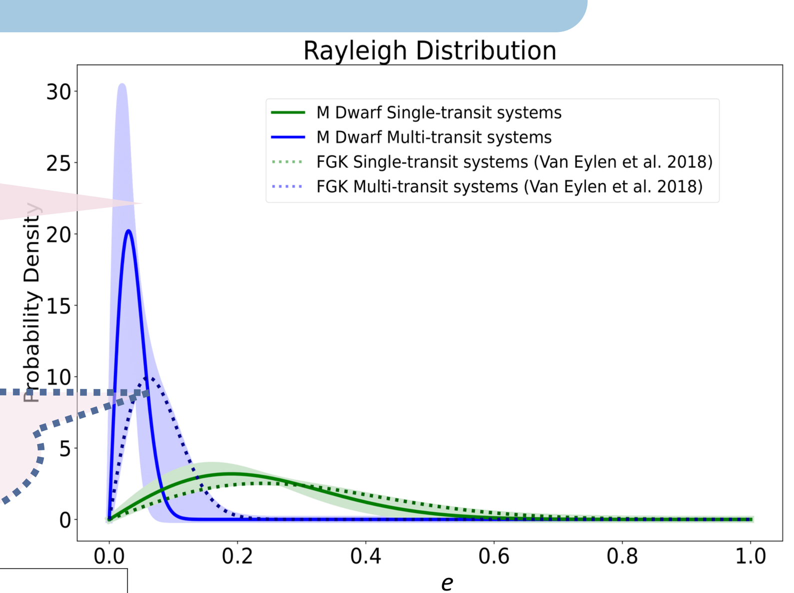
We constrain individual planet eccentricities using Kepler light curves and stellar densities from Gaia + empirical M dwarf metallicity relations.

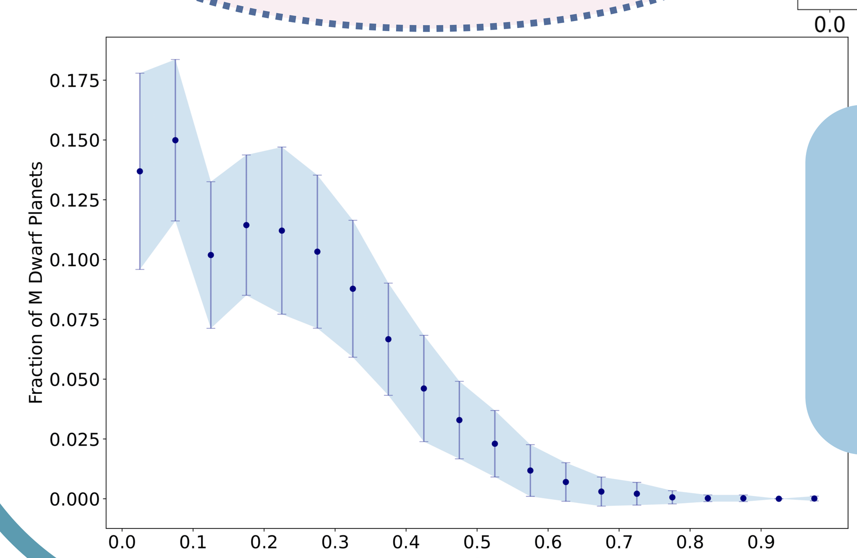


And within a hierarchical Bayesian framework, we draw out the underlying *e* distribution for M dwarf planets.

Splitting up the sample into single—transit and multi—transit systems: the underlying *e* distributions are different!

And our results for M dwarfs are consistent with the underlying *e* distributions for FGK dwarf planets!





Combining with other M dwarf demographic constraints, we estimate the underlying *e* distribution for all nearby M dwarf planets.

The Orbital **Eccentricity—Radius** Relation for Planets Orbiting M Dwarfs

Sagear et al. (in review)

Read the manuscript on arXiv here!

arXiv: 2507.07169

We are motivated by two broad questions concerning planet formation and dynamical evolution:
How do planetary cores and atmospheres evolve?
How do planets interact with their neighbors?

We know that different late-stage planet evolution mechanisms imprint differently on eccentricities. For example…

Planet-planet scattering or giant impacts may excite eccentricity

Disk-driven migration, inelastic mergers may quench eccentricity

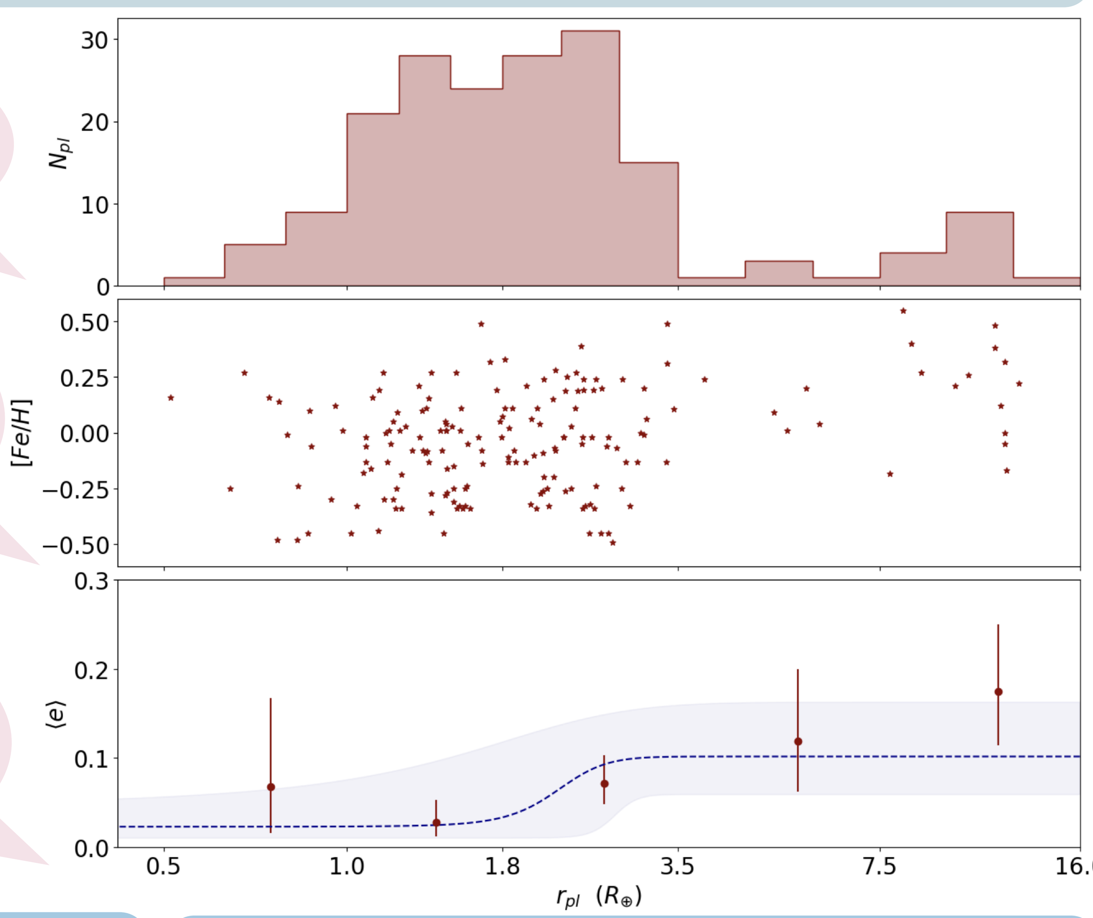
Mass loss driven by stellar luminosity (photoevaporation, core-powered mass loss) may preserve eccentricity at birth

Each of these mechanisms would also have some effect on planet radii. In order to investigate the dominant late-stage dynamical evolution mechanisms for M dwarf planets, we investigate the eccentricity—planet radius relation with ***Kepler*** and ***TESS*** M dwarf planets.

Large (sub-Neptune+) planets around M dwarfs are rare…

And their hosts require higher stellar metallicities.

They also exhibit distinctly higher (~4x) orbital eccentricities!

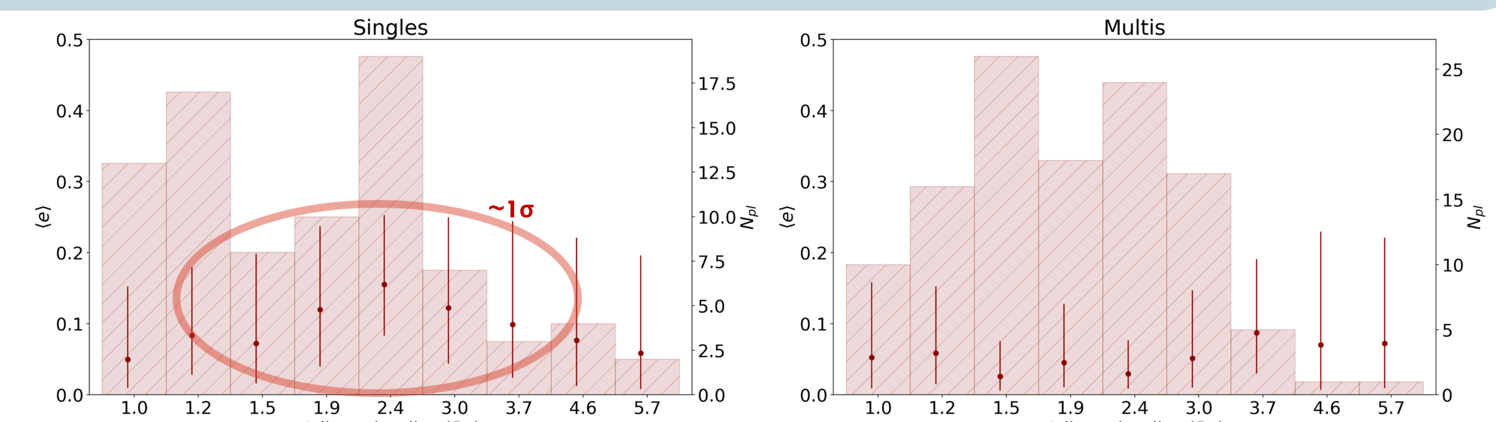


We find an e—r_p relation consistent with that of planets orbiting Sun-like stars *(Gilbert+ 2025)*

There is a "break" in the eccentricity—radius relation at ~3.5 R_e for planets orbiting **FGK stars** and **M stars**, suggesting two distinct evolutionary pathways for small and large planets.

What about eccentricities for planets in the radius gap?

Gilbert+25 see evidence that FGK dwarf planets in the radius gap have eccentricities elevated from those surrounding the radius gap.
We see find that M dwarf ***singles*** potentially have elevated eccentricities (~1σ) but find no such evidence for ***multis***.



This is *not* a detection in itself, but if this effect is physical, the difference could be due to typical mutual Hill spacings of M vs. FGK dwarf systems.
M systems are closely packed and require e~0 for stability, while FGK systems may remain stable with slightly higher eccentricities.

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What about the Galactic context?

We often assume that planets form in stationary isolation—but that isn't true. How might planetary systems be affected by their Galactic environment?

Planets seem to know where they are in the galaxy.

Zink+ 23 (and Chris Lam+ in prep.): The planet occurrence rate appears to decrease with galactic amplitude.

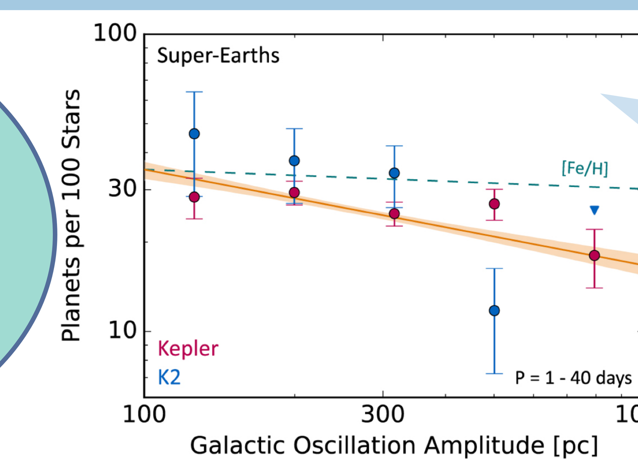
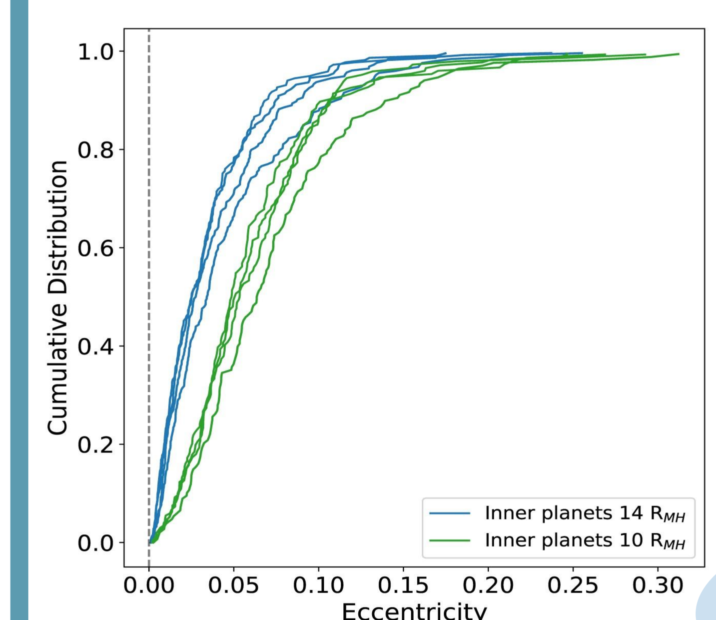


*Figure 12 from **Zink+23**: Lower observed planet occurrence at higher galactic amplitudes (not fully explained by Fe/H)*



Planetary orbits could be perturbed by stellar flybys.

Batygin+ 20, Schoettler & Owen 24, Charalambous+ 25: stellar flybys (on the order of 1000 AU) could dynamically disrupt planetary orbits.

*Figure 8 from **Schoettler & Owen 24**: simulated eccentricities of planets (by separation distance) after simulated stellar interactions*

The flyby interaction radius for significantly disrupting planetary orbits could be 100s or even 1000s of AU.

Can we determine the likelihood of a stellar system to fly by another star throughout its lifetime?
Could this possibly correlate with observable planetary dynamics (i.e. eccentricities)?

We are in a fantastic position to learn more about planet populations in the Galaxy with

1. precise Galactic orbital information for stellar hosts from *Gaia*,
2. planetary orbital eccentricities, and
3. *the power of demographics with **hierarchical Bayesian inference.***