The smallest M dwarfs have the highest occurrence rates of close-in rocky planets

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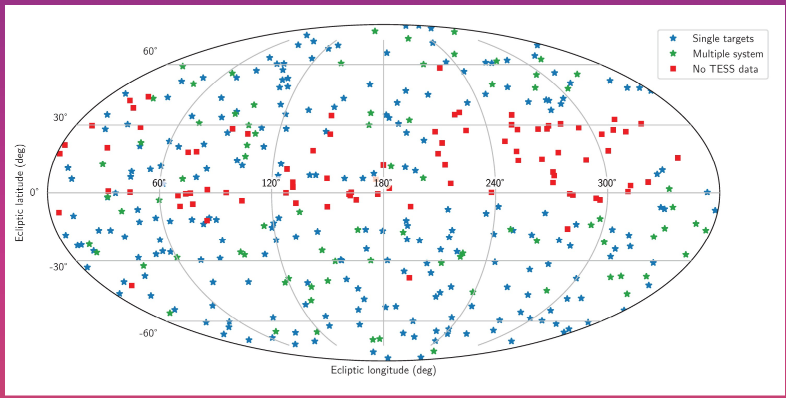
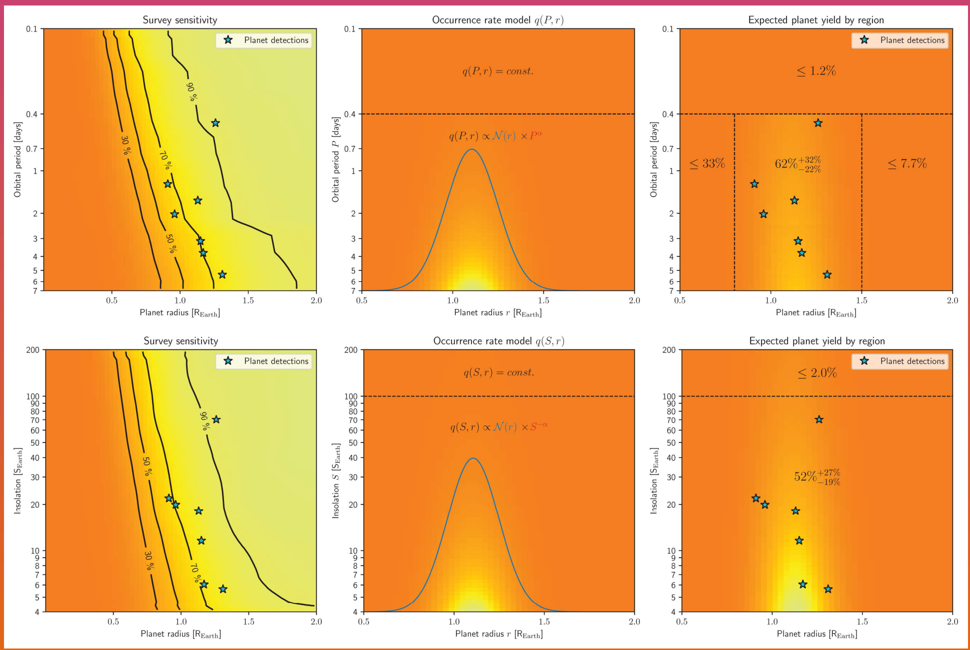
Planet search within a volume-complete sample

There are 512 mid-to-late M dwarfs with masses between 0.1 M_{Sun} and 0.3 M_{Sun} in a volume-complete sample within 15 pc of the Sun (Winters+21, arXiv:2011.09409), shown on the right. We analyze 363 of these stars observed by TESS in Sectors 1 to 42. We search the TESS 2-minute cadence light curves for transiting planets with orbital periods up to 7 days and find a total of 7 small planets with radii varying from 0.91 R_{Earth} to 1.31 R_{Earth}. All of these planets have either been confirmed to be rocky or are highly likely to be rocky based on their size.

Notably, there is a complete absence of an enveloped terrestrial distribution (one of the nearby mid-to-late M dwarfs not yet observed by TESS, GJ 1214, is known to host a mini-Neptune). Furthermore, the searched orbital periods cover a range of 4-200 times the stellar light intensity (insolation) compared to Earth. Around Sun-like stars, the abundance of enveloped terrestrials peaks at similar insolation values (10-100 S_{Earth}, Fulton+17, arXiv:1703.10375). One potential explanation for the dearth of such planets here is the substantially longer period of high XUV activity in the M dwarfs' early evolution, potentially stripping the planets of their volatile atmospheres.





Estimating sensitivity and modeling occurrence rates

We estimate our detection sensitivity individually for each of the 363 targets. We generally find good sensitivity for planets larger than Earth, with a recovery fraction close to unity for sizes above 1.5 R_{Earth}. We also have partial sensitivity for planets with radii between 0.6-1.0 R_{Earth}. We evaluate the overall survey sensitivity as a function of radius versus orbital period and insolation.

We test multiple occurrence rate models and adopt the one with highest integrated model evidence. We model the regions closest to the star (periods below 0.4 days or insolations above 100 S_{Earth}) with a single constant occurrence rate. For the rest of the parameter space, the occurrence rate is the product of a radius-dependent factor (a normal distribution) and a period/insolation-dependent factor (a simple power law).

We find an average of 0.62 [0.40-0.94] planets per star (pps) with orbital periods between 0.4-7 days. We constrain the abundance of mini-Neptunes ($r > 1.5\ R_{Earth}$) to below 0.077 pps (1σ). Intriguingly, we also find a lower rate of at most 0.33 pps (1σ) for planets with radii 0.5-0.8 R_{Earth}, although the discrepancy has a low statistical significance. We estimate a total abundance of 0.52 [0.33-0.79] pps for insolations between 4-100 S_{Earth}.

Cumulative occurrence rates

We extrapolate the period power law from 7 to 10 days and the insolation power law from 4 to 1 S_{Earth} to compare the occurrence rates in our sample (median stellar radius of 0.20 R_{Sun}) to previously estimated values for early-to-mid M dwarfs (Dressing+15, arXiv:1501.01623, median stellar radius: 0.47 R_{Sun}).

For orbital periods of 0.5-10 days, we find a nearly 5-fold increase in the abundance of planets of sizes 1.0-1.5 R_{Earth} for smaller stars compared to early-to-mid M dwarfs, and they also possess sub-Earths at a higher rate. On the other hand, the abundance of mini-Neptunes is at best equivalent or even suppressed in the least massive M dwarfs.

In terms of insolation, we find that the overall abundance of smaller planets ($r < 1.5\ R_{Earth}$) is roughly the same in both early and late M dwarfs; however, the occurrence rates of mini-Neptunes are significantly reduced in late M dwarfs.

Median stellar radius	Range	Occurrence rate (planets per star) by planet radius [1σ]				
		0.5-1.0 R_{Earth}	1.0-1.5 R_{Earth}	1.5-2.0 R_{Earth}	>2.0 R_{Earth}	Total
0.20 R_{Sun}	Orbital period: 0.5-10 days	0.32 [0.14,0.71]	1.06 [0.61,1.81]	0.10 [0.02,0.26]	< 0.19	1.45 [0.84,2.47]
0.47 R_{Sun}		0.18 [0.15,0.23]	0.23 [0.20,0.27]	0.12 [0.09,0.15]	0.18 [0.15,0.23]	0.71 [0.65,0.77]
0.20 R_{Sun}	Insolation: 1-200 S_{Earth}	0.19 [0.07,0.48]	0.64 [0.36,1.23]	0.07 [0.02,0.19]	< 0.25	0.85 [0.49,1.68]
0.47 R_{Sun}		0.31 [0.26,0.38]	0.48 [0.43,0.55]	0.38 [0.33,0.44]	0.58 [0.51,0.67]	1.75 [1.64,1.90]

Takeaways:

1. For orbital periods less than 10 days, the occurrence rates of rocky planets orbiting later M dwarfs (median radius of 0.20 R_{Sun}) are substantially higher compared to early-to-mid M dwarfs (median radius 0.47 R_{Sun}) or Sun-like stars.

2. For insolation values ranging from 4 to 200 S_{Earth}, mid-to-late M dwarfs are severely deficient in enveloped terrestrials (up to a ratio of 15 between rocky and non-rocky planets) compared to early M dwarfs where rocky and non-rocky companions are relatively equinumerous. Furthermore, enveloped terrestrials with similar insolation values are abundant around Sun-like stars (FGK dwarfs) whereas terrestrial planets typically appear at higher insolations there.

3. Around mid-to-late M dwarfs, rocky planets slightly larger than Earth (1.1 R_{Earth}) appear to be the most common. Planets with radii below 0.9 R_{Earth} may in fact be intrinsically less abundant; however, the statistical significance of this statement is currently relatively low due to the small sample size.