Exploring the Radius Valley among the lowest mass stars with TESS

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Introduction

The close-in transiting exoplanets observed by Kepler provided evidence for the photoevaporation of atmospheres, revealing a radius valley in the distribution of exoplanets around sun-like stars[1]. Later, through this feature, a linear mass dependence between the planet and stellar mass was observed[2]. To further understand this scaling around low-mass stars and their exoplanets, we turn to the Transiting Exoplanet Survey Satellite(TESS) mission. With its sensitivity to redder wavelengths, it has observed ten times more low-mass stars, significantly enhancing planet detections around M dwarfs.

Low mass stars

For our study, we cross-matched all TESS Objects of Interest (TOIs) planet candidates with the Bioverse catalog[3] using GAIA IDs. This process yielded approximately 720 planet candidates and 400 confirmed planets. We chose to focus on the planet candidates to gain a better understanding of the radius valley. Our dataset includes around 280 M dwarfs, 260 K dwarfs, and 150 G dwarfs within 120 parsecs, all with precise stellar masses and radii.

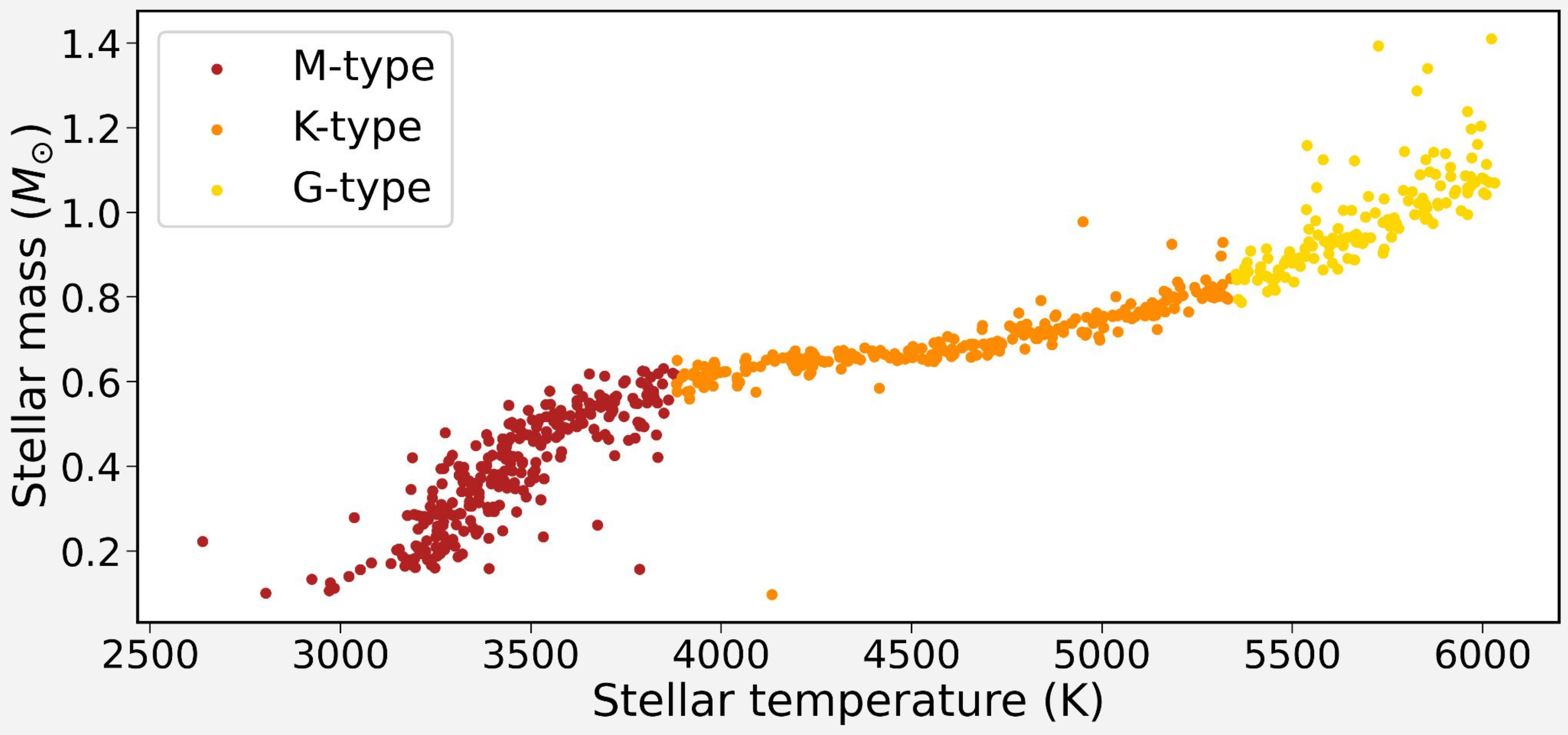

Figure 1: Stellar mass vs stellar temperature of the entire low mass star sample in the study.

Planet radius distribution

After calculating the planet radii using the updated stellar parameters from the Bioverse catalog[3], we observed the radius valley through histograms and Kernel Density Estimation (KDE). To accurately measure the radius valley, we applied a Gaussian Mixture Model (GMM) to fit the bimodal distribution of TESS planets.

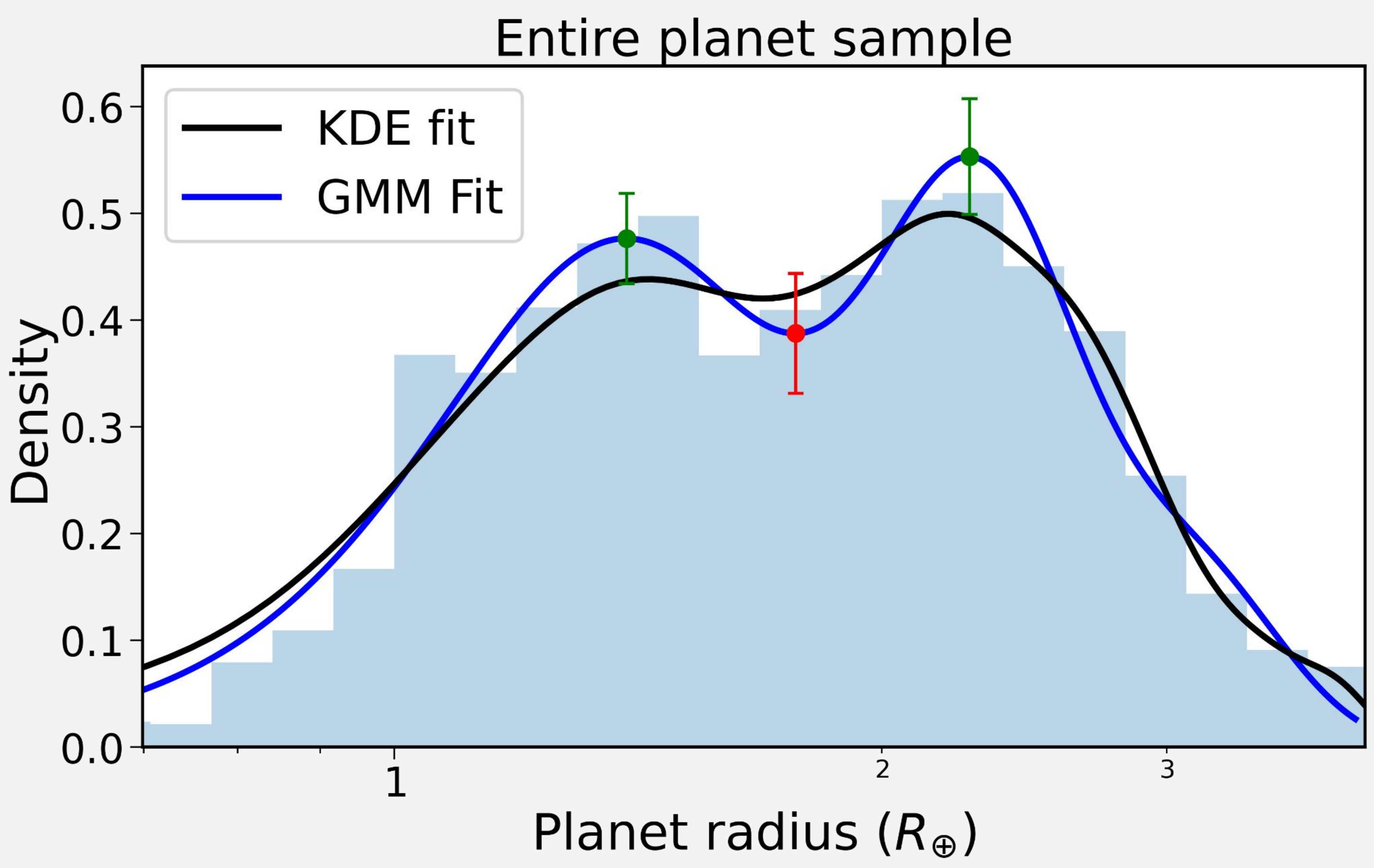

Figure 2: Planet radius distribution of all the low-mass stars in our sample shows a bimodal distribution, as seen in the histogram, KDE, and GMM fits. The Super-Earth and Mini-Neptune peaks are indicated by green points, while the radius valley is marked by a red point, all with their respective uncertainties.

Stellar dependence

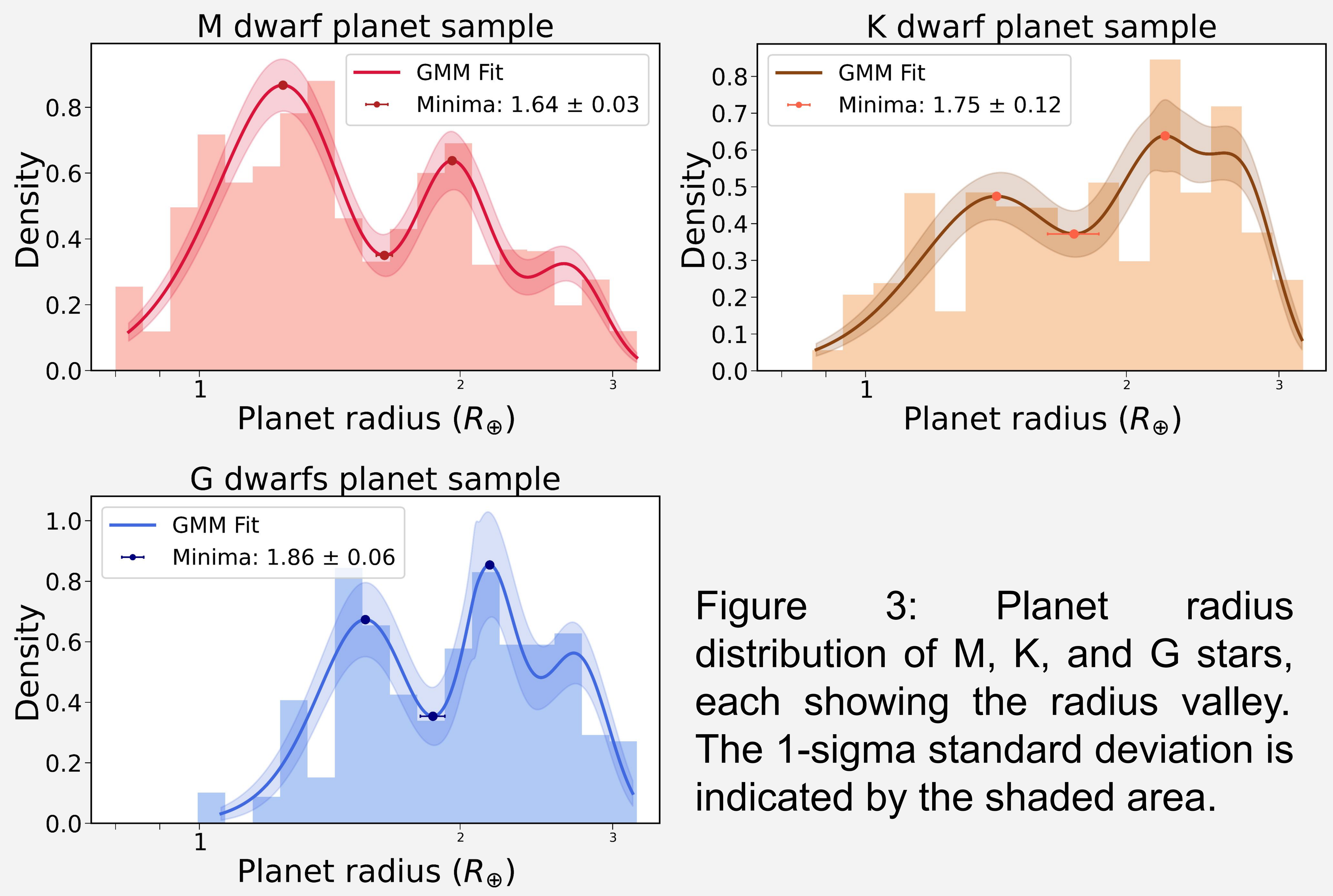

Figure 3: Planet radius distribution of M, K, and G stars, each showing the radius valley. The 1-sigma standard deviation is indicated by the shaded area.

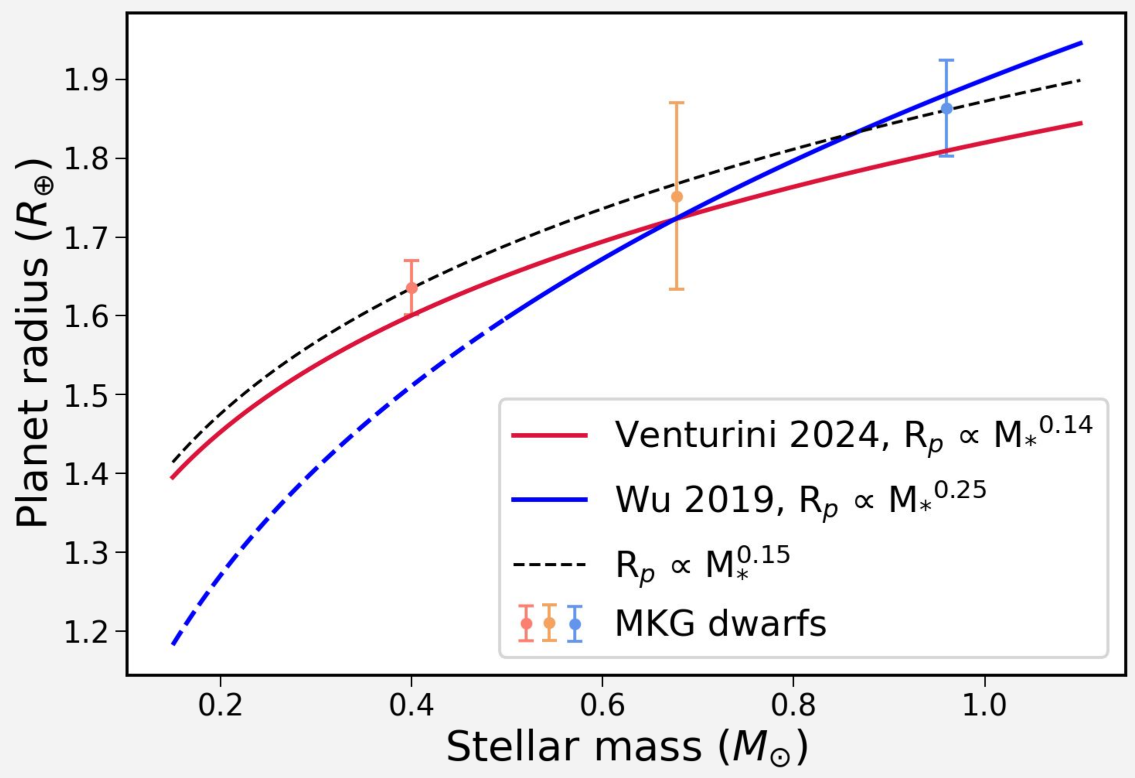

Figure 4: The radius valley among low-mass stars shift to the right with increasing stellar mass. The observed linear dependence fits better with the pebble accretion models[4] (Red line) rather than the photoevaporation model as seen before among the Kepler FGK planets[2] (Blue line).

Conclusions and Future work

We measure the position of the radius valley among the TESS M dwarfs and observe a linear dependence between planet size and host star mass, suggesting that mechanisms shaping the radius distribution around FGK stars—such as photoevaporation or core-powered mass loss—also extend to M dwarfs. However, we observe a flatter scaling (Figure 4) than predicted by photoevaporation models, with results more consistent with pebble accretion theories that include the formation of water worlds[4].

However, our study[5] includes TOIs that encompass both confirmed and candidate planets, which may contain false positives. Additionally, we did not correct for detection efficiency, indicating that super-Earths are likely underrepresented compared to mini-Neptunes. This underrepresentation appears to most strongly affect the detection of the radius gap in K dwarfs. To improve the precision of the radius valley measurement, we plan to combine K2 and TESS stars and include a detection bias correction in future work.

References

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