Unearthing the dependence of exoplanet populations on stellar parameters

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- *With larger exoplanet sample sets, we can move beyond simple power law scaling relations.*
- We use nonparametric basis sets (Beta density functions) to do so, which –

1. Can model conditional distributions (f(x|y)) that are not Gaussian.
2. Are intrinsically more flexible than power laws.
3. Easier to expand to > 2 dimensions.

Ning et al. (2018), and Kanodia et al. (2019), used these to model the Mass-Radius relationship for FGK and M dwarf planet samples, respectively.

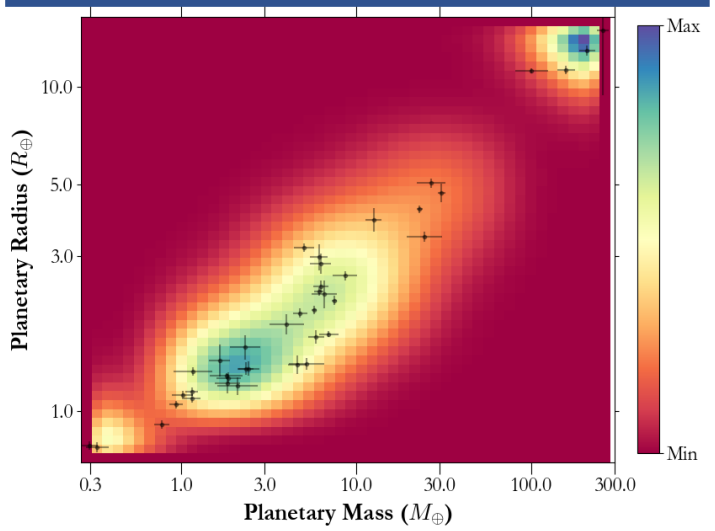
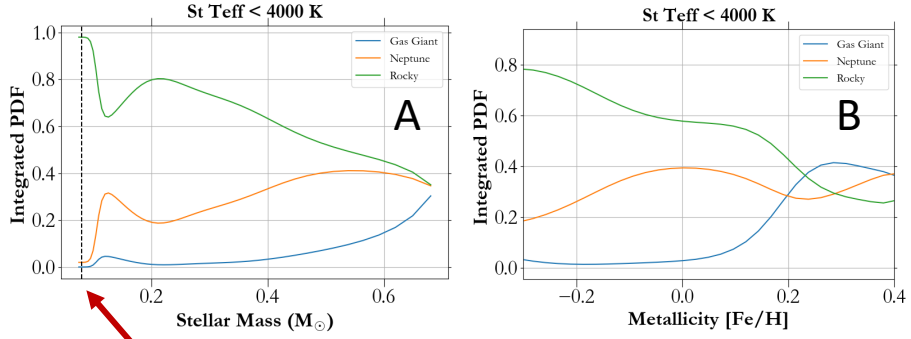


Figure 1: Joint mass-radius (M-R) distribution fit to a sample of M-dwarf planets. The color-scale represents the probability density function (PDF) of the model.

Expanding from Mass-Radius to higher dimensions (Ongoing)

- Expand from Mass-Radius relationships to higher dimensions (3, 4, even 5 dimensions). Such as planetary mass, radius, period, eccentricity, stellar mass, metallicity
- Some example applications –

1. Model the Mass-Radius relationship as a function of Period **(M-R-P)** to include the period dependence of density (especially important for photoevaporation).
2. Then include stellar mass, to probe how the M-R-P space evolves across spectral types **(M-R-P-StM).**
3. Evolution of Radius-Insolation space features for features such as the Radius-gap or Neptune desert with stellar parameters such as metallicity, stellar mass **(R-P-StM-Fe/H)**. Especially important for M dwarfs, where Stellar Mass can change 6-7x between late and early Ms.
4. Correlations between Gas Giant occurrence with Period, Metallicity, Stellar Mass **(R-P-StM-Fe/H)**.



TRAPPIST-1

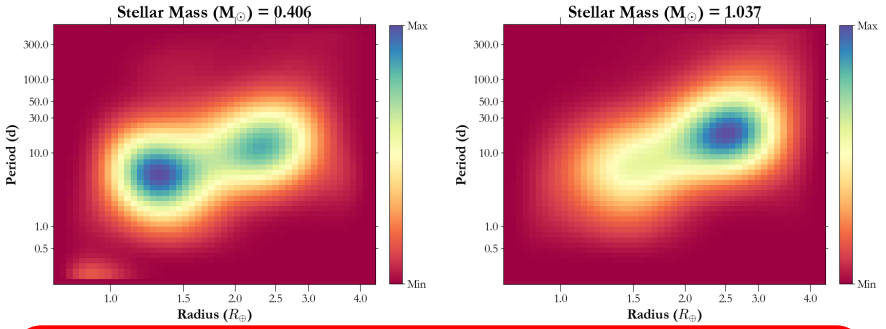


Figure 3: Projections of the joint **R-P-StM** distribution for a sample of FGKM planets. Conditioning on stellar mass allows us to probe how the planet radius-valley (in R-P) changes as a function of the stellar mass.

FUTURE WORK

- Use a combination of TESS + precision RV instruments to find and characterize planets with mass measurements, especially for M dwarfs (currently only about 40 planets.). Example – TOI-1728b (Kanodia et al 2020), TOI-1899b (Canas et al. 2020), TOI-1266b,c (Stefansson et al. 2020).
- Consider science cases which are less sensitive to biases due to selection effects (esp. for non-Kepler samples).
- Account for selection effects to transition from exoplanet samples to populations.
- Include asymmetric measurement errorbars.
- Plot 4+ dimensions in 3 dimensions…

Figure 2: M dwarf sample set. Integrated probability density function (PDF) for the relative occurrence of planets in different size regimes (Rocky, < 2 R_earth; Neptune, 2-4 R_earth; Gas giant, >4 R_earth), as a function of stellar mass **(R-P-StM)** in (A) and host star metallicity (**R-P-Fe/H**) (B).