ASTR 405
Planetary Systems
Demographics

Fall 2025

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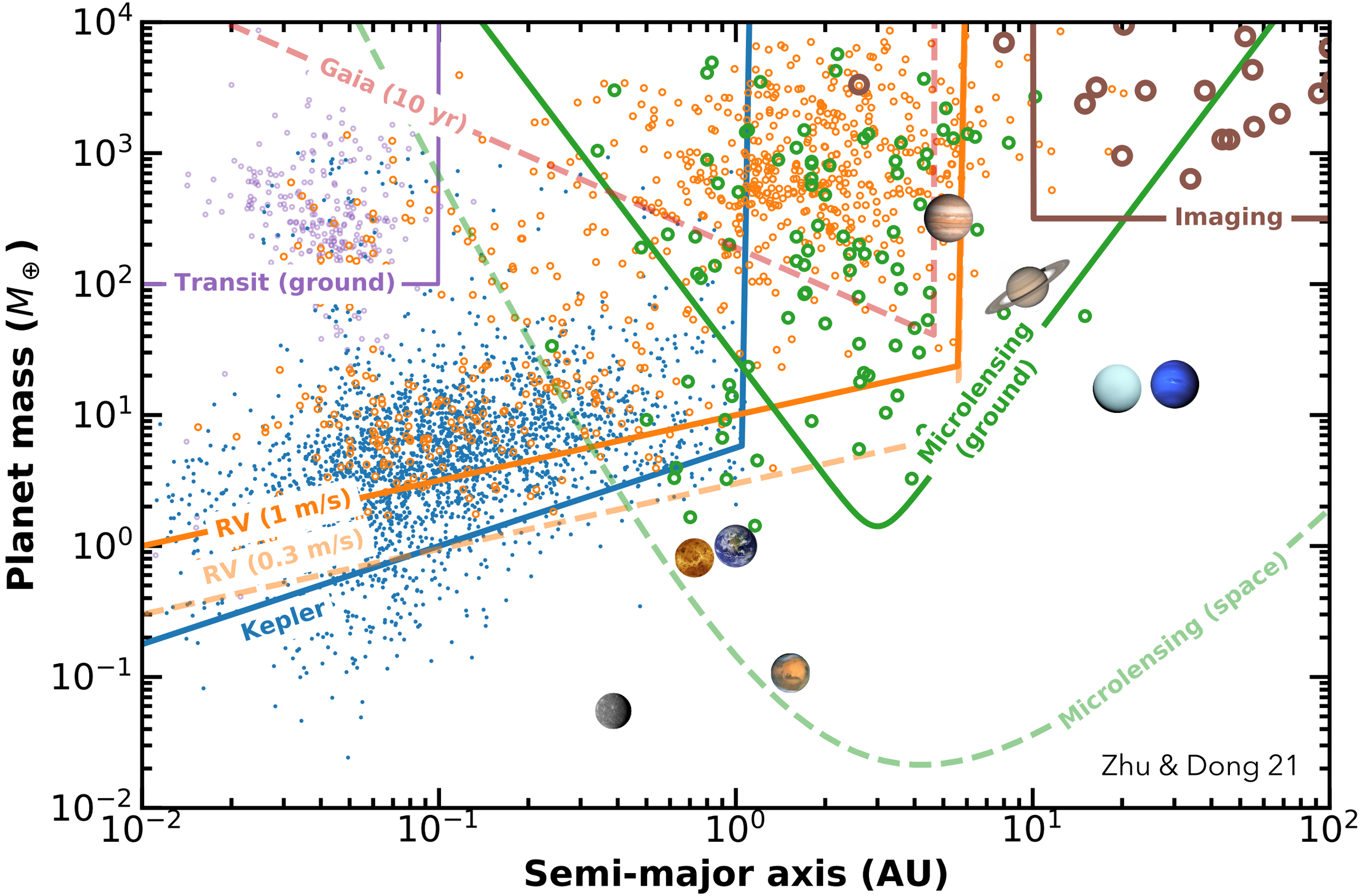
Supplementary Readings: **statistics.pdf** on Canvas

Exoplanet Statistics and Theoretical Implications by Zhu & Dong 2021

Modules

- Part I: Exoplanet Detection Methods
    - Explore the techniques astronomers use to discover planets beyond our solar system
- **Part II: Exoplanet Demographics and Planet Formation**
    - **Investigate the statistical properties of exoplanets and theories of how planetary systems form**
- Part III: Exoplanet Atmospheres, Interiors, and Characterization
    - Examine methods for studying the physical properties and compositions of distant worlds

You will reproduce a plot similar to this in HW4.



Planet Occurrence Rates

- Frequency of planets

$$\bar{n}_p \equiv \frac{\text{Total \# of planets}}{\text{Total \# of stars}}$$

- Frequency of planetary systems

$$F_p \equiv \frac{\text{Total \# of planetary systems}}{\text{Total \# of stars}}$$

- Average multiplicity

$$\bar{m}_p \equiv \frac{\bar{n}_p}{F_p} = \frac{\text{Total \# of planets}}{\text{Total \# of planetary systems}}$$

Inferring Planet Occurrence Rates

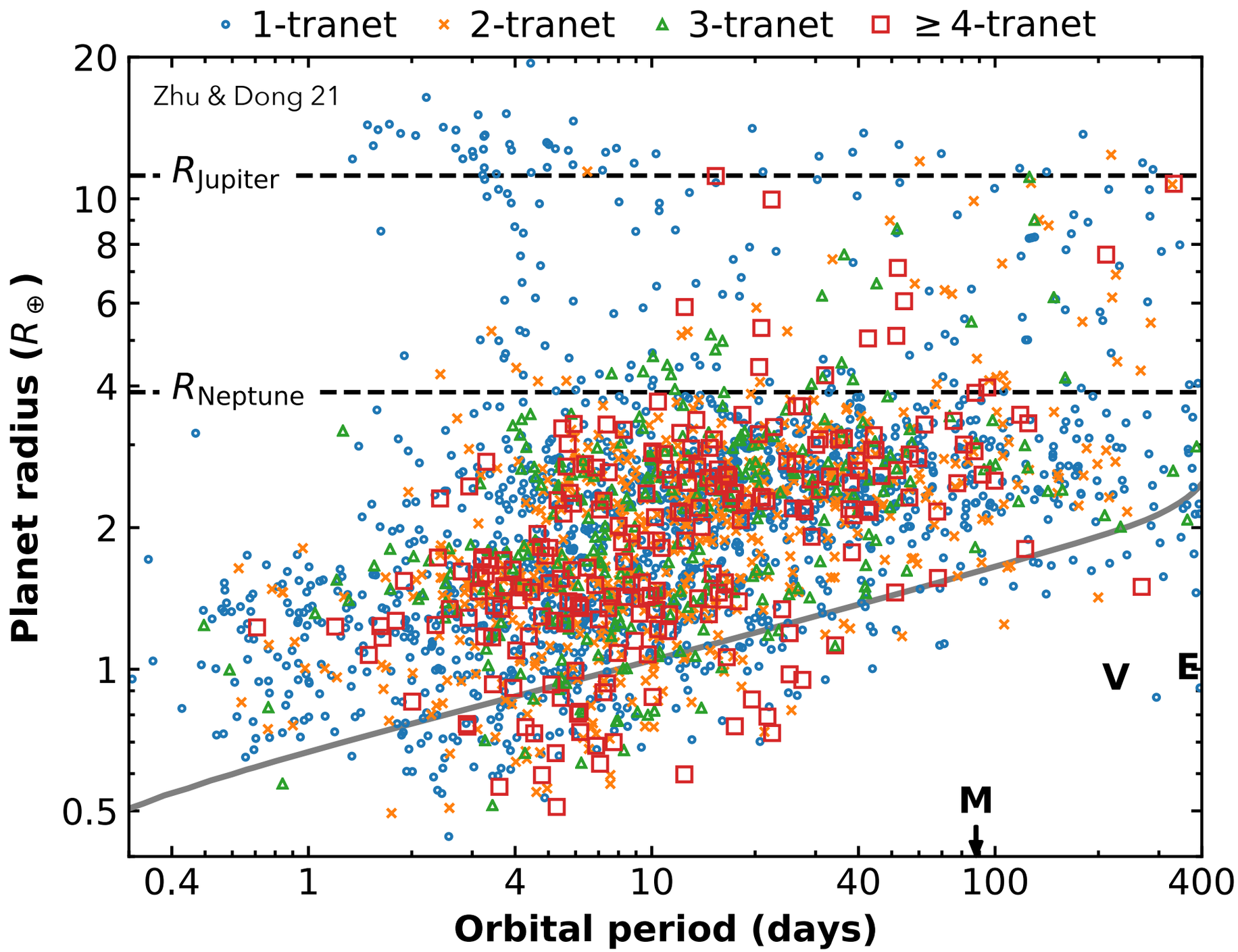
Goal: Find the average number of planets per star ($\bar{n}_p$) from survey detections.

Let's assume

- $N_\star$: total number of target stars
- N_p: number of detected planets
- $\langle p \rangle$: mean detection efficiency across stars

The planet occurrence rate $\boxed{\bar{n}_p = \frac{N_p}{N_\star} \frac{1}{\langle p \rangle}}$

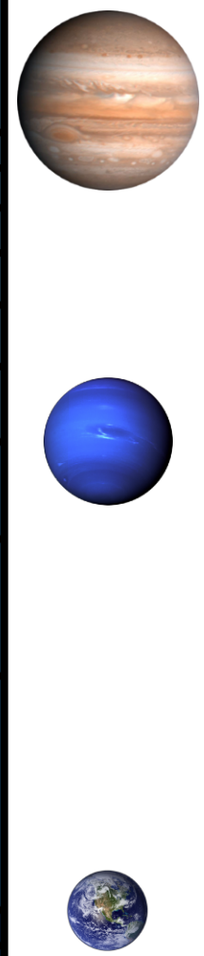
Kepler Exoplanet Sample



Planet Occurrence Rates from *Kepler*

Zhu & Dong 21

Planet radius ($R_\oplus$) \ Orbital period (days)	0.4–1	1–4	4–10	10–40	40–100	100–400
10–20	< 0.009 N/A	< 0.012 N/A	0.022 ± 0.011 0%	0.059 ± 0.021 0%	0.21 ± 0.05 0%	0.18 ± 0.05 0%	0.15 ± 0.05 14%	0.20 ± 0.07 14%	0.17 ± 0.08 25%	0.23 ± 0.10 0%	0.52 ± 0.18 42%	0.44 ± 0.20 25%	1.3 ± 0.4 50%	1.2 ± 0.4 16%	1.7 ± 0.7 33%
8–10	< 0.009 N/A	< 0.012 N/A	< 0.016 N/A	< 0.05 N/A	0.070 ± 0.026 16%	0.19 ± 0.05 15%	0.15 ± 0.05 28%	0.43 ± 0.10 50%	0.45 ± 0.12 50%	0.66 ± 0.18 61%	0.58 ± 0.19 75%	1.5 ± 0.4 50%	1.3 ± 0.4 50%	2.4 ± 0.6 46%	1.7 ± 0.7 33%
4–8	< 0.014 N/A	< 0.012 N/A	0.033 ± 0.013 19%	0.089 ± 0.026 18%	0.37 ± 0.06 25%	1.25 ± 0.13 53%	2.52 ± 0.22 47%	4.3 ± 0.3 46%	6.4 ± 0.5 45%	7.2 ± 0.6 46%	8.1 ± 0.7 41%	6.9 ± 0.8 33%	6.2 ± 0.9 42%	7.5 ± 1.2 27%	6.9 ± 1.5 14%
2–4	0.039 ± 0.011 16%	0.158 ± 0.026 18%	0.20 ± 0.03 20%	0.54 ± 0.07 41%	1.45 ± 0.13 49%	2.97 ± 0.22 44%	4.1 ± 0.3 49%	5.0 ± 0.4 53%	4.6 ± 0.5 37%	4.1 ± 0.6 48%	4.2 ± 0.7 41%	3.1 ± 0.8 46%	4.2 ± 1.3 40%	4.9 ± 1.9 16%	10 ± 3 16%
1–2	0.030 ± 0.011 16%	0.16 ± 0.03 26%	0.17 ± 0.04 13%	0.59 ± 0.10 21%	1.36 ± 0.20 35%	2.9 ± 0.4 53%	4.1 ± 0.6 64%	2.4 ± 0.7 75%	5.2 ± 1.4 61%	4.7 ± 1.9 60%	< 8 N/A	< 12 N/A	< 51 N/A	< 87 N/A	< 555 N/A
0.5–1															



Planet frequencies ($\bar{n}_p$) and the observed multiplicity fractions based on the *Kepler* sample.

Super Earth ($R_p < 4\,R_\oplus$) Prevalence

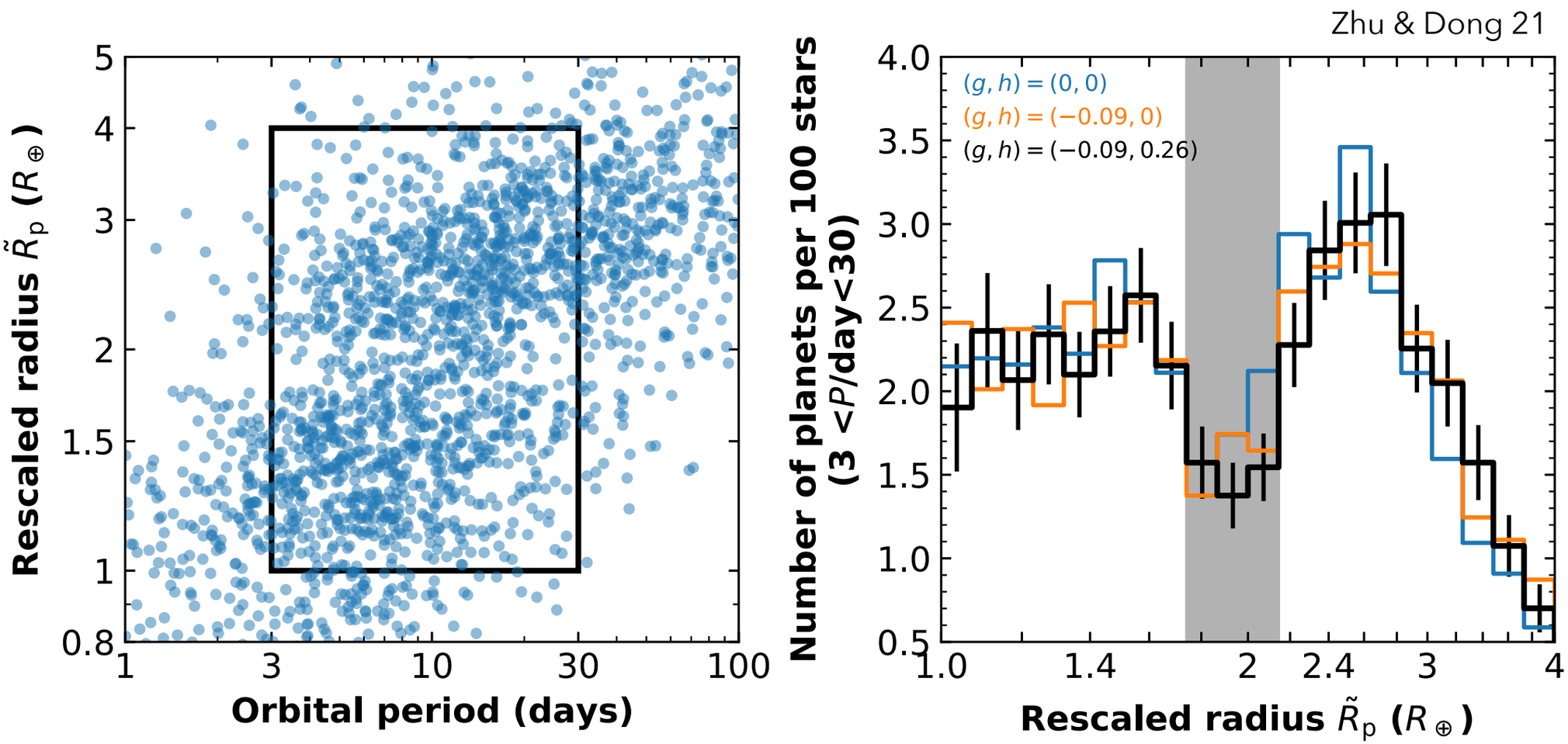
- $F_p \sim 0.3$ of Sun-like stars exhibit at least one detected Super-Earth

- Systems hosting Super-Earths typically contain $\bar{m}_p \sim 3$ such planets

- This implies an average of ~ 1 Super-Earth per star ⇒ **nearly every Sun-like star hosts a super Earth**

Radius Valley

Gap in planet radii at $\sim 2\,R_\oplus$ and periods $\sim 3-30$ days; Separates super-Earths (rocky cores) and sub-Neptunes (with H/He envelopes)



Proposed origins: Photoevaporation by stellar high-energy radiation; Core-powered mass loss (cooling luminosity of the core); Planet formation/migration effects near the ice line

Giant Planets and Inner–Outer System Correlation