Planetary Edge Trends (PET): The Inner Edge – Stellar Mass Correlation

Meng-Fei Sun (Nanjing University)

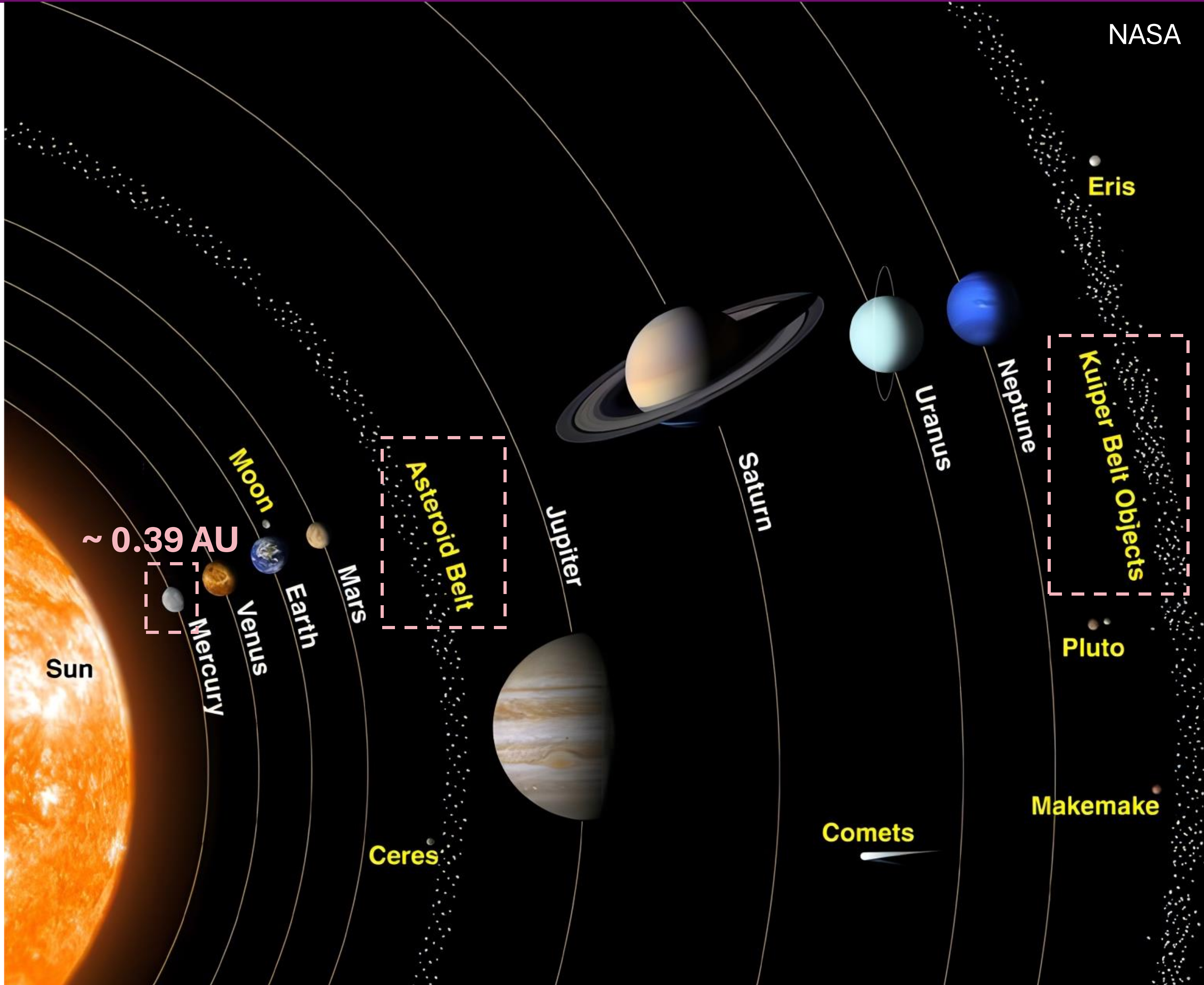
Collaborators: Ji-Wei Xie, Ji-Lin Zhou, Beibei Liu, Nikolaos Nikolaou, Sarah C. Millholland

7 July 2025

Detection and Dynamics of Exoplanets

Boundaries of Planetary Systems

- **Solar System:**
  Structured by Boundaries.
- **Exoplanetary Systems:**
  What Boundaries Exist?



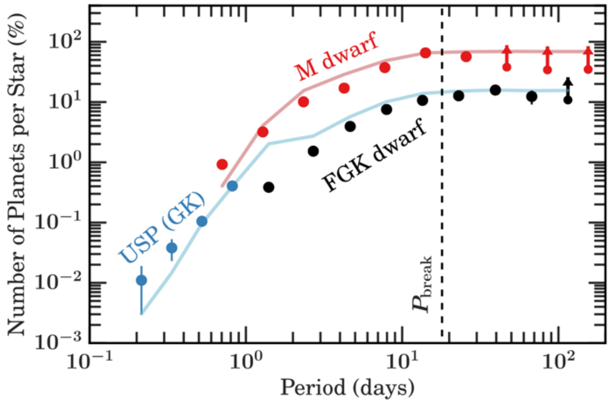
Boundaries of Planetary Systems

Edges in Mature Exoplanetary Systems: Kepler/TESS/RV… (Confirmed > 5900 planets)

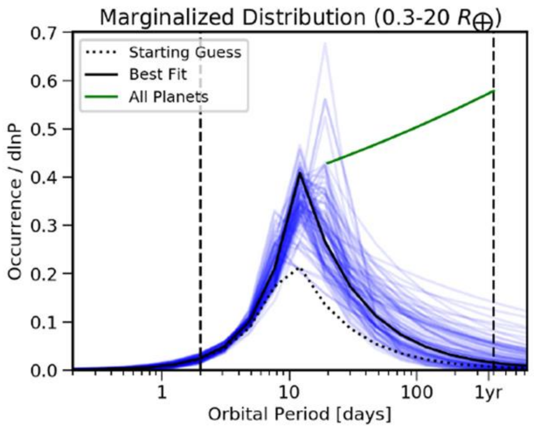
- ✓ Focus on **Inner Edges** of Planetary Systems: positions of **innermost planets**.

- ✓ Innermost exoplanets are closer than Mercury.
- ✓ A peak near 0.1 AU or 10 days.

- ➢ <u>Possible link to stellar properties?</u>
- ➢ <u>Clues to planet formation and evolution?</u>



(Lee & Chiang 2017)

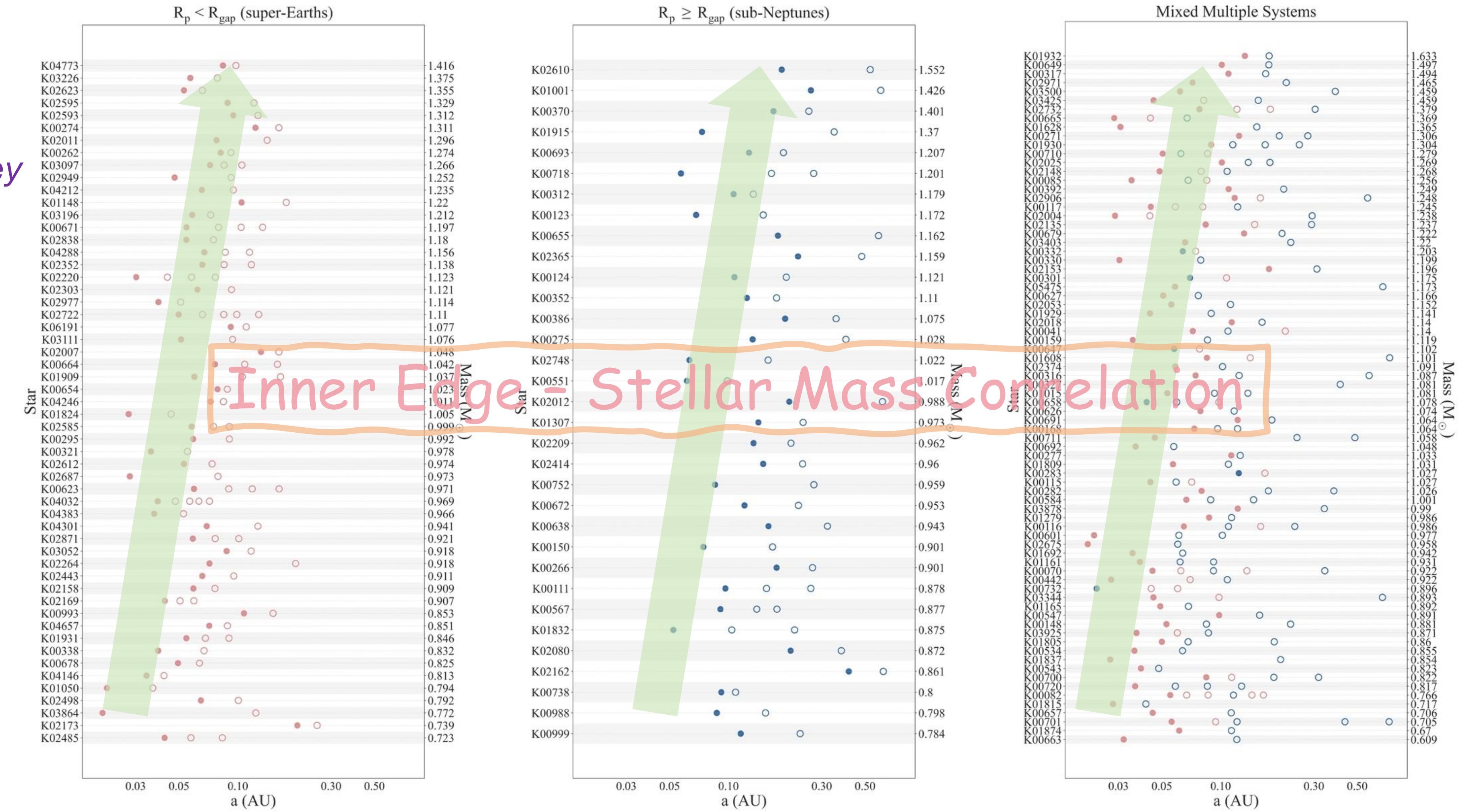


(Mulders et al. 2018)

Planetary Edge Trends

- **Small Planets**: ***Kepler*** Data Release 25 catalog + multiple-planet systems (**N_p > 1**) + main-sequence single stars + **exclude** ultra-short period planets (**P > 1 day**) and giant planets (**R_p < 4 $R_\oplus$**)

Radius Valley



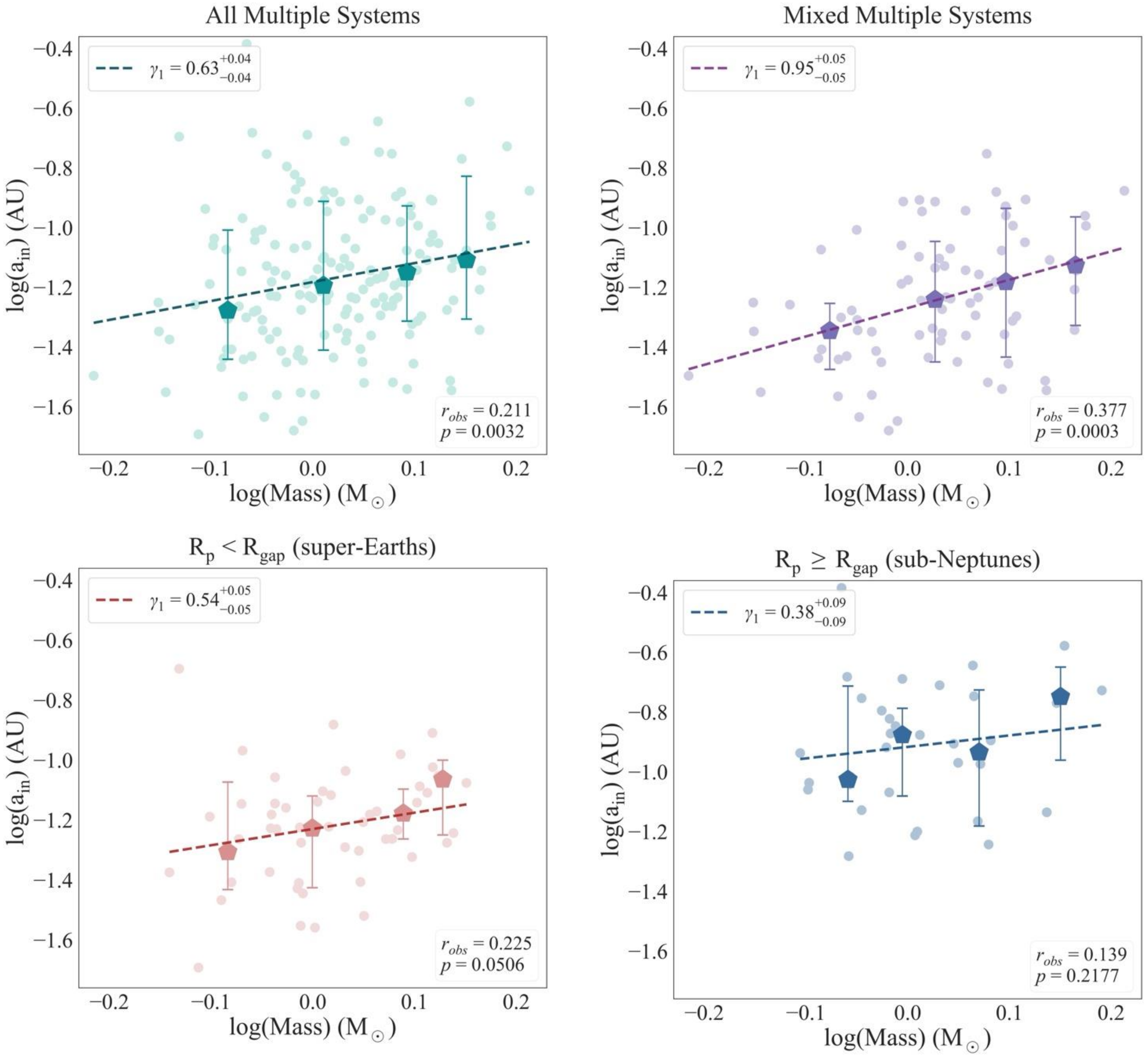
Inner Edge – Stellar Mass Correlation

$$a_{\rm in} = \gamma_{0,am} M_\star^{\gamma_1}$$

- Stellar Mass: ***Gaia*** (Berger et al. 2020)

✓ Significant Positive Correlation Found.
✓ Correlation Strength Varies by Population.

- ☐ All: 166 systems
- ☐ Mixed: 78 systems
- ☐ SE: 55 systems
- ☐ SN: 33 systems

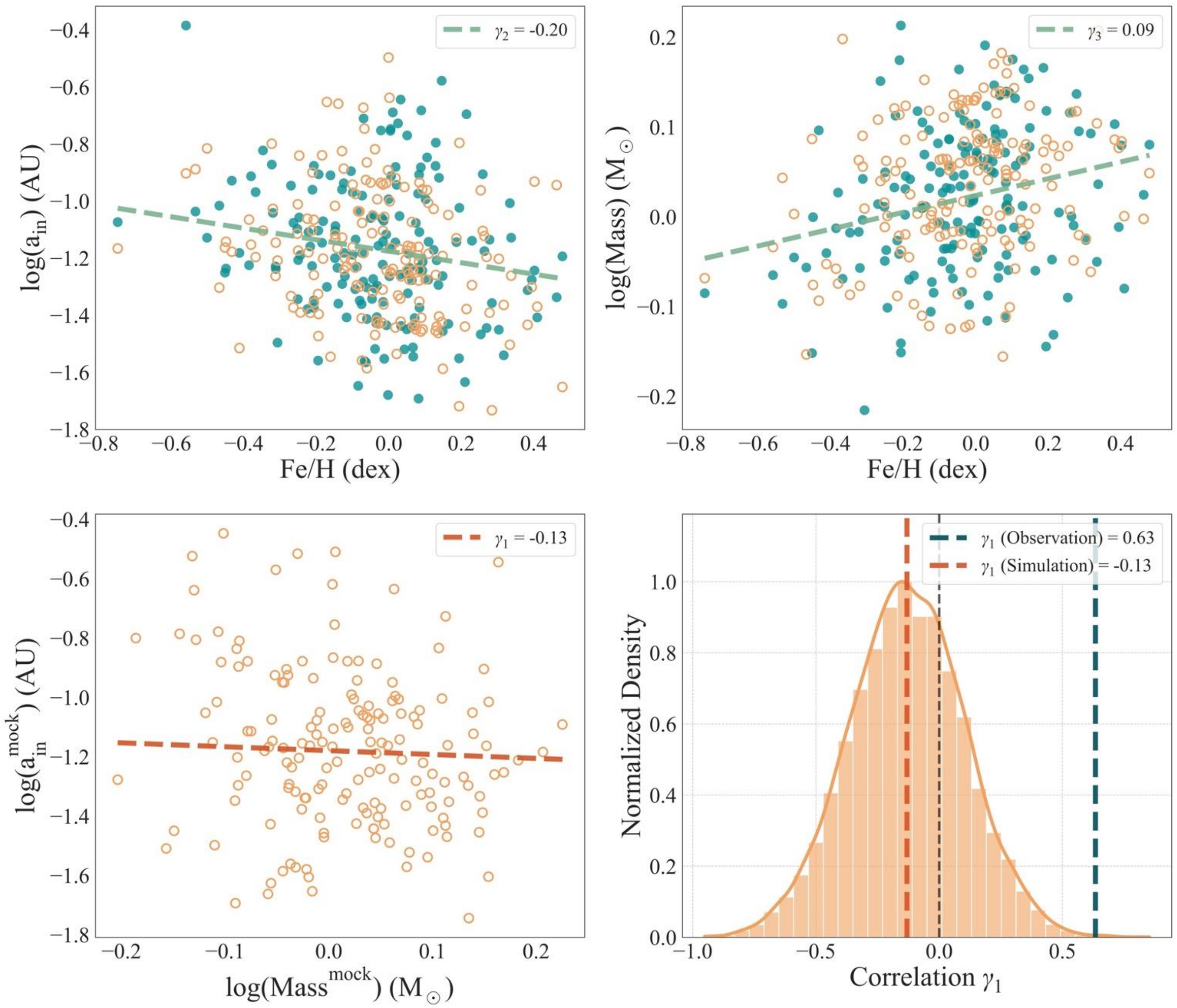


Effect of Stellar Metallicity

- Metallicity Influences Planetary System Architecture. (Beaugé & Nesvorný 2013; Mulders et al. 2016)
- Stellar Metallicity: **LAMOST** (Chen et al. 2021b)

✓ Negative Projection Effect on $a_{in} – M_{star}$ Relation.

➢ Correcting for Metallicity Strengthens the Correlation.



Inner Edge – Stellar Mass Correlation

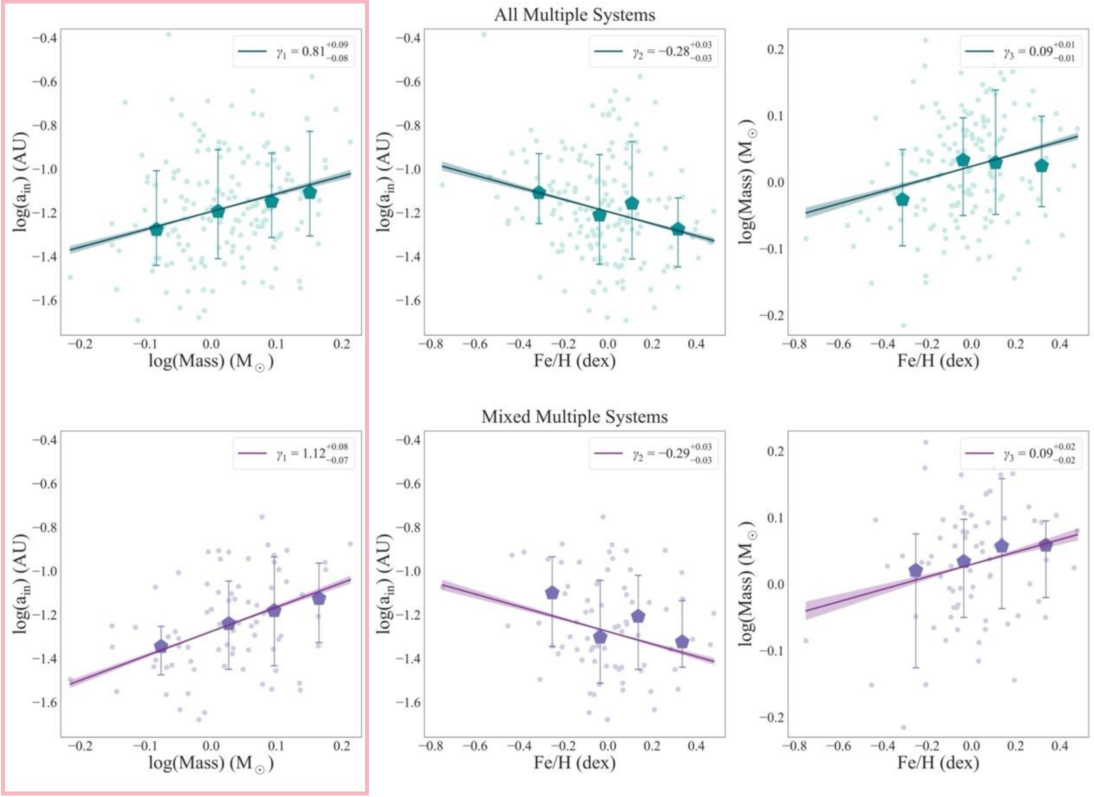
- Multiple Linear Regression

$$\frac{a_{\rm in}}{\rm AU} = \gamma_{0,amf}\left(\frac{M_\star}{M_\odot}\right)^{\gamma_1} 10^{\gamma_2\,[\mathrm{Fe/H}]}$$

γ_1 → 0.6 ~ 1.1

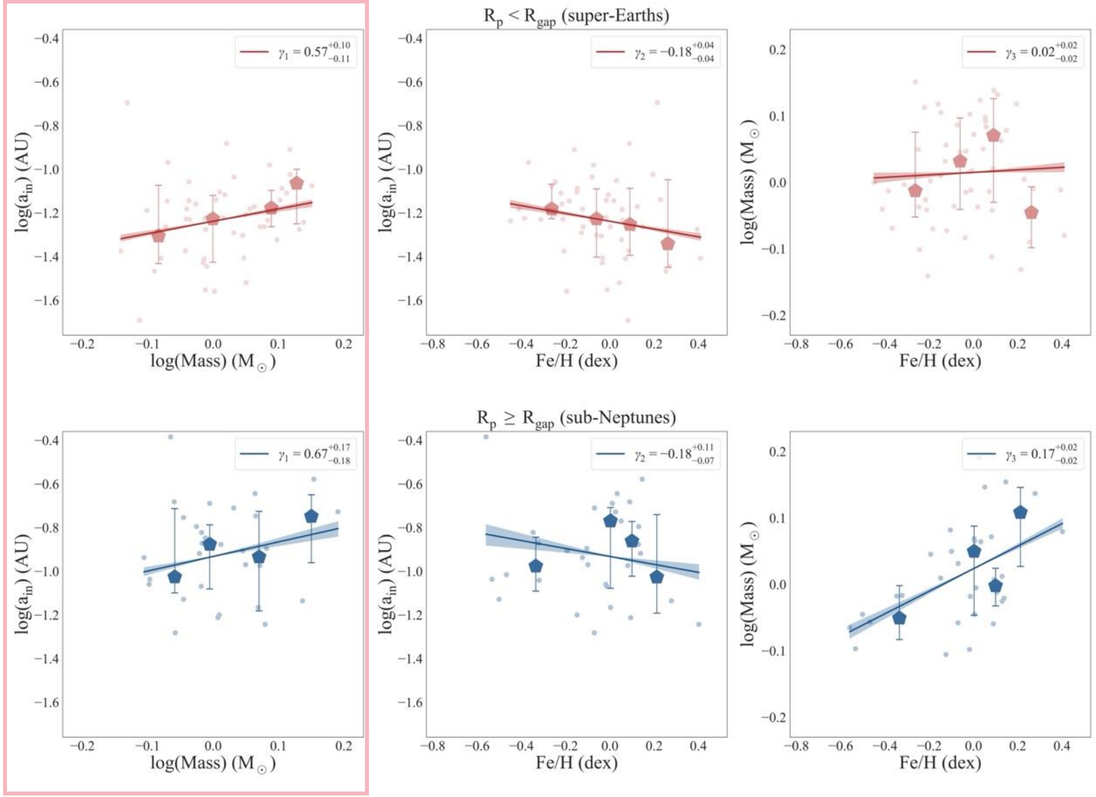
↑ 0.2

↑ 0.2



↑ 0.02

↑ 0.3



Comparison with Observational Results

- Ruling Out Observational Selection Bias.
- **<u>Occurrence Rates</u>** Underestimate the Inner Edge – Stellar Mass Correlation.

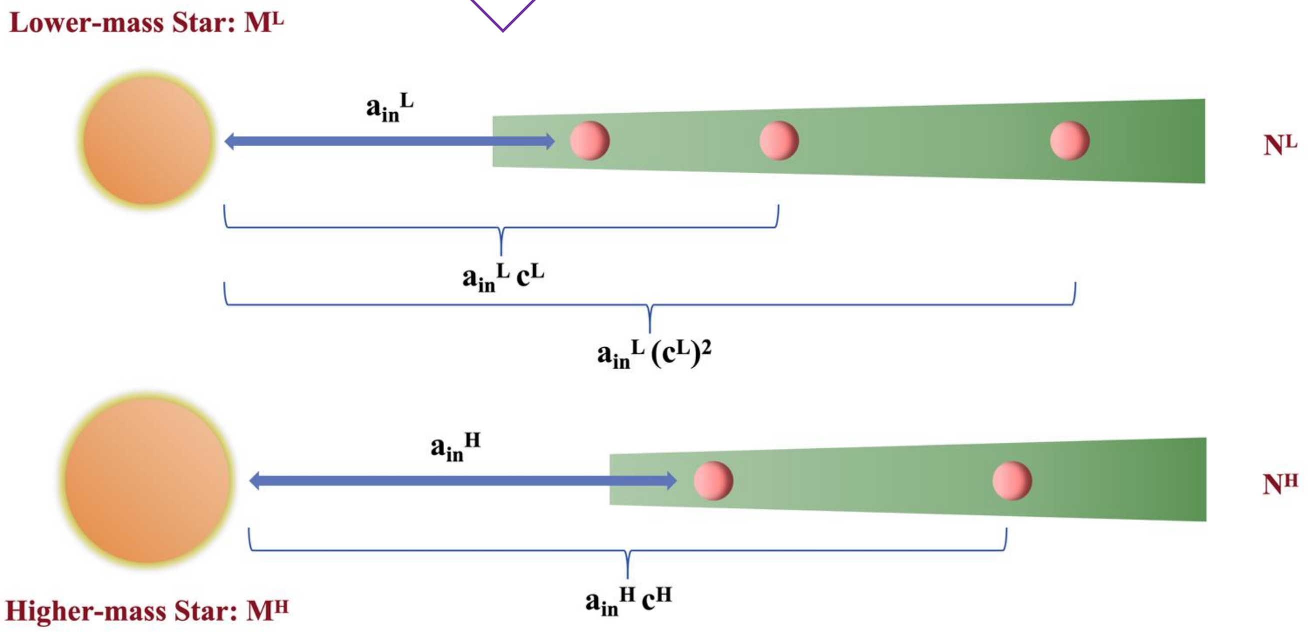
a_{in} - M_{star} : 0.6 ~ 1.1 > 0.3 (using occurrence rates) Mulders et al. 2015

multi-planet systems

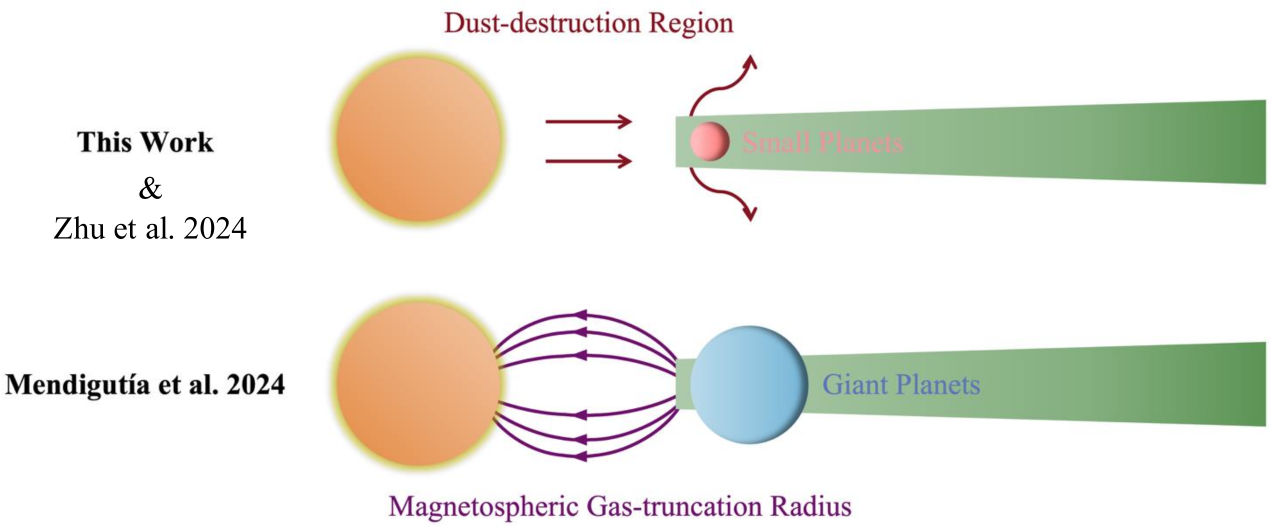
$$\Delta\gamma = \gamma_{occ} - \gamma_1 = \log_{\left(\frac{M^H}{M^L}\right)} \left(\frac{N^L \cdot \sum_{n=0}^{N^H-1} (c^H)^n}{N^H \cdot \sum_{n=0}^{N^L-1} (c^L)^n} \right)$$

- ✓ $M^H = 1.0\, M_\odot \rightarrow N^H = 2$
- ✓ $M^L = 0.5\, M_\odot \rightarrow N^L = 3$
- ✓ $c^L \sim c^H = 2$

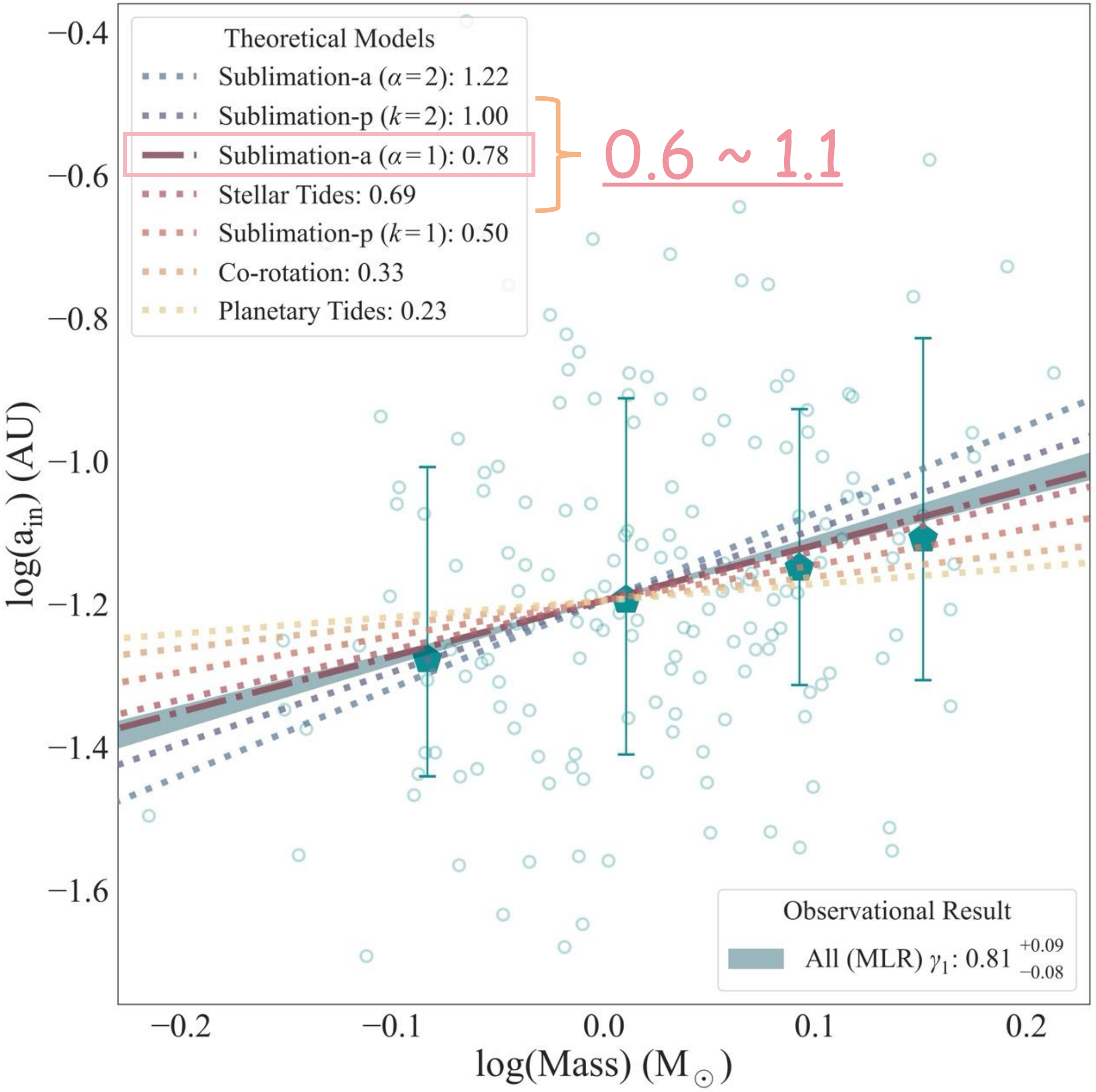
- $\Delta\gamma \approx -0.64$
- $\gamma_1 = 1.0 \rightarrow \gamma_{occ} = 0.36$



Comparison with Theoretical Models



- The innermost orbits of **small planets**: inner dust disk.
- The inner edges of **hot Jupiters**: magnetospheres of protoplanetary disks.
- The inner edges of different planetary populations, such as small planets and giant planets, are shaped by distinct mechanisms.
- In-situ formation or Disk migration.



Summary

- *Kepler* DR25 + *Gaia* (stellar mass) + LAMOST (stellar metallicity): small planets in multis
- As the stellar mass increases, the position of the inner edge in the system also increases.

- ✓ a_{in} – M_{star} power-law index ($\frac{a_{\rm in}}{\rm AU} = \gamma_{0,amf} \left(\frac{M_\star}{M_\odot}\right)^{\gamma_1} 10^{\gamma_2\,[\rm Fe/H]}$): 0.6 ~ 1.1
- ✓ Correcting for metallicity effect strengthens this correlation.
- ✓ Occurrence rates underestimate this correlation.

- ➢ The dust sublimation radius in a pre-main sequence actively accreting disk best matches the slope of our observed correlation.
- ➢ The inner edges of different planetary populations, such as small planets and giant planets, are shaped by distinct mechanisms.
- ➢ Due to the lack of solid material required for in-situ formation, small planets are less likely to be formed within the dust sublimation radius. Small planets migrate inward through disk migration, eventually becoming trapped at the sublimation radius.

Accepted for publication on A&A (arXiv:2501.02215)

Please contact: murphysss@outlook.com