# Inner Edges of Kepler Planetary Systems: Stellar Property Dependence

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## Summary

The position of the innermost planet in a planetary system reflects the relationship of the entire system to the host star. This could provide more potentially important information about planetary formation and evolution processes.

More accurate data enables in-depth investigation. Here we use the Kepler Data Release 25 (DR25) catalog, combined with LAMOST DR9, Gaia DR3, and California-Kepler Survey (CKS) catalog, to analyze and control the influence of stellar age, stellar metallicity, and observational bias to study the correlation between stellar mass and inner edge position.

We find that the inner edges of hot small planet systems decrease with stellar metallicity but increase with stellar mass. After correcting the metallciity dependence, the inner edge exhibits a stronger correlation with stellar mass than previous thought (Mulders et al. 2015), and it is best explained as the dust sublimation radii of actively accreting protoplanetary disks (Alcalá et al. 2014), contrasting with the inner edges of hot Jupiters which are linked to the magnetospheres of protoplanetary disks (Mendigutía et al. 2024).

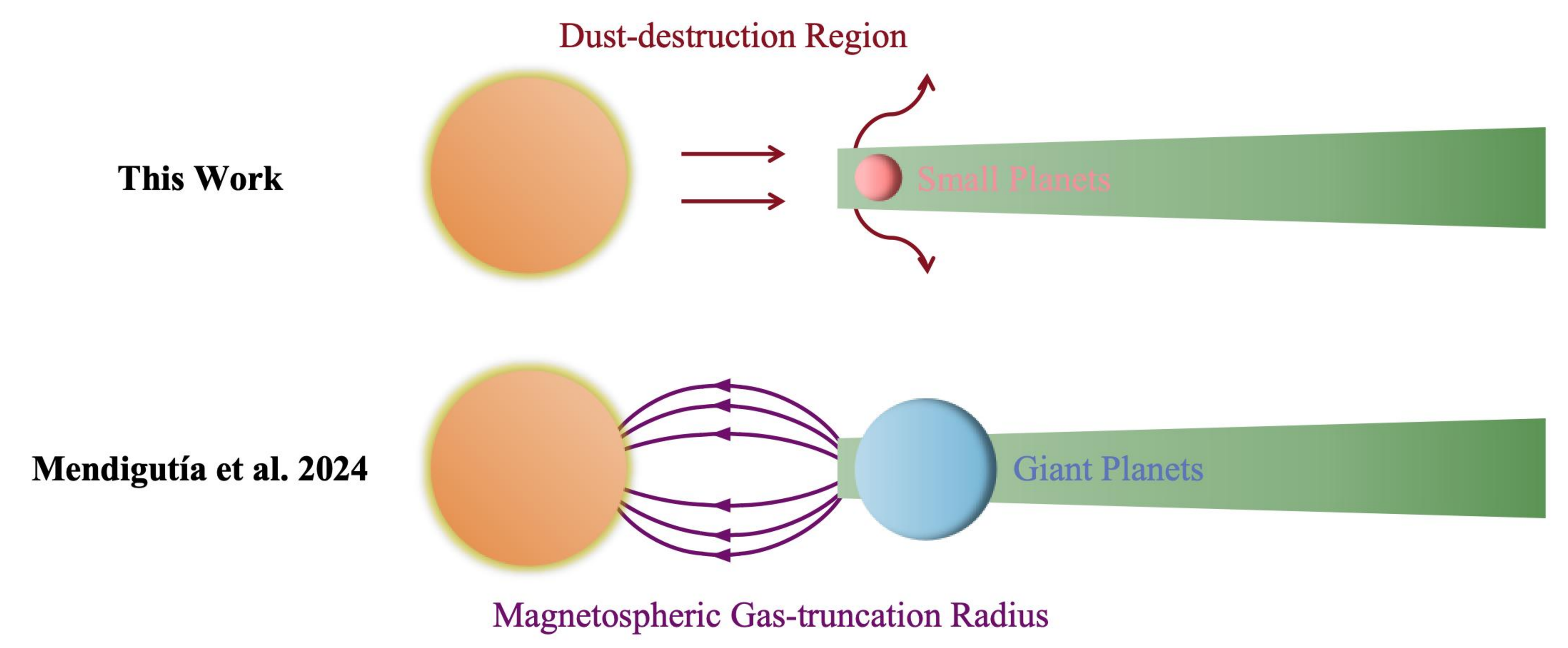


*Figure 1. A comparison of this work with previous studies reveals that the inner edges of different planetary systems correspond to different mechanisms.*

## Methods

### 1. Data and Sample Selection

We match different catalogs and select stars and planets.

**Table 1.** Data Samples

| Match | $N_p$ |
|---|---|
| *Kepler* DR25 | 8054 |
| Berger20b | 186301 |
| PAST II | 34541 |
| CKS | 2025 |
| KBP: *Kepler* DR25 + Berger20b + PAST II | 1749 |
| KB: *Kepler* DR25 + Berger20b | 7467 |
| KBC: *Kepler* DR25 + Berger20b + CKS | 1772 |

**Table 2.** Sample Selection

| Filter | $N_s$ | $N_p$ |
|---|---|---|
| Full sample | 1420 | 1749 |
| Not a false positive | 727 | 1025 |
| Not a binary star | 727 | 1025 |
| Not a giant star | 708 | 1003 |
| $T_{eff} = 3500 - 6500$ K | 634 | 911 |
| 1 day $< P <$ 100 days | 570 | 817 |
| $R_p < 6R_\oplus$ | 536 | 780 |
| ror $> 0.01$ | 386 | 533 |

### 2. Statistical Analysis

We fit the observed data through the following equation:

$$a_{in} = \alpha M_\star{}^\beta \tag{1}$$

✓ **Effect of Stellar Age, Stellar Metallicity and Observational Bias**

We perform statistical tests to access the effects of stellar age, metallicity and observational bias, and find that the correlation between the semimajor axis of the innermost planet ($a_{in}$) and stellar mass ($M_*$) is robust.

### 3. Multiple Linear Regression (LR)

LR model finds the best-fitting straight line to describe the relationship between multiple input variables and the output variable. To better express the relationships between mass, age, metallicity, and inner edge, we provide the following relational equation, a simple power law model in the form, and it is easier to work with in logarithmic space.

$$\frac{\mathrm{a_{in}}}{\mathrm{AU}} = \gamma_0 \left(\frac{\mathrm{M}_\star}{\mathrm{M}_\odot}\right)^{\gamma_1} \exp\left(\gamma_2 \frac{\mathrm{t}}{\mathrm{Gyr}}\right) 10^{\gamma_3 [\mathrm{Fe/H}]} \tag{2}$$

To analyze the impact of the correlation between parameters, we calculate the Variance Inflation Factor (VIF) of the LR model to detect multicollinearity.

## Results

Through the observation data obtained by the above data analysis, we find that there is a clear correlation between the stellar mass and the inner edge. We conduct the above analysis on three datasets (KBP, KB, and KBC) under three different scenarios (all, multiple, and single systems). Eventually, we find that they all exhibit the same result: as the stellar mass increases, the position of the inner edge in the system also increases, showing a correlation of around 0.7 with a power-law relationship.

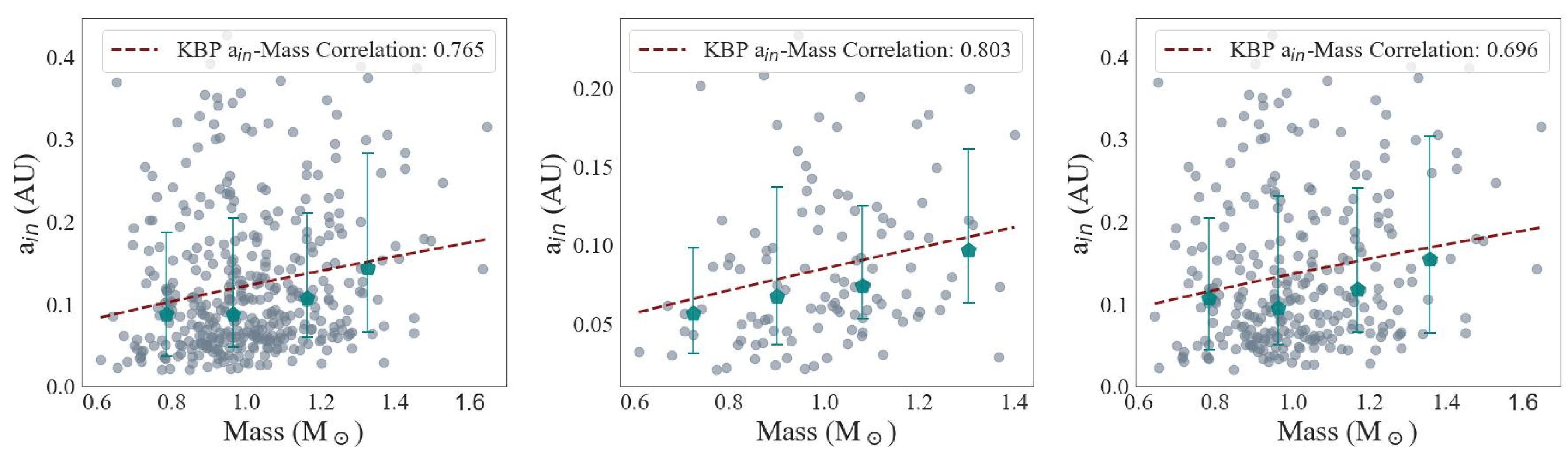


*Figure 2. The observed correlation between stellar mass and inner edge in the KBP dataset is also divided into all systems (left), multiple systems and single systems (right). The gray dots are observation data. The four green pentagons are the median value of each bin and the error bar is 1σ. The red dotted line is the result of fitting the observation data according to Equation (1).*

Building upon this, we further investigate the specific relationship between the inner edge and mass, age, and metallicity by applying LR model using Equation (2). The relationship between age and metallicity with the inner edge aligns with previous research efforts, and it also makes sense how their presence influences the relationship between mass and the inner edge. Ultimately, we find that after removing the effects of age and metallicity, the correlation between mass and inner edge becomes stronger (a correlation of around 1.1 with a power-law relationship).

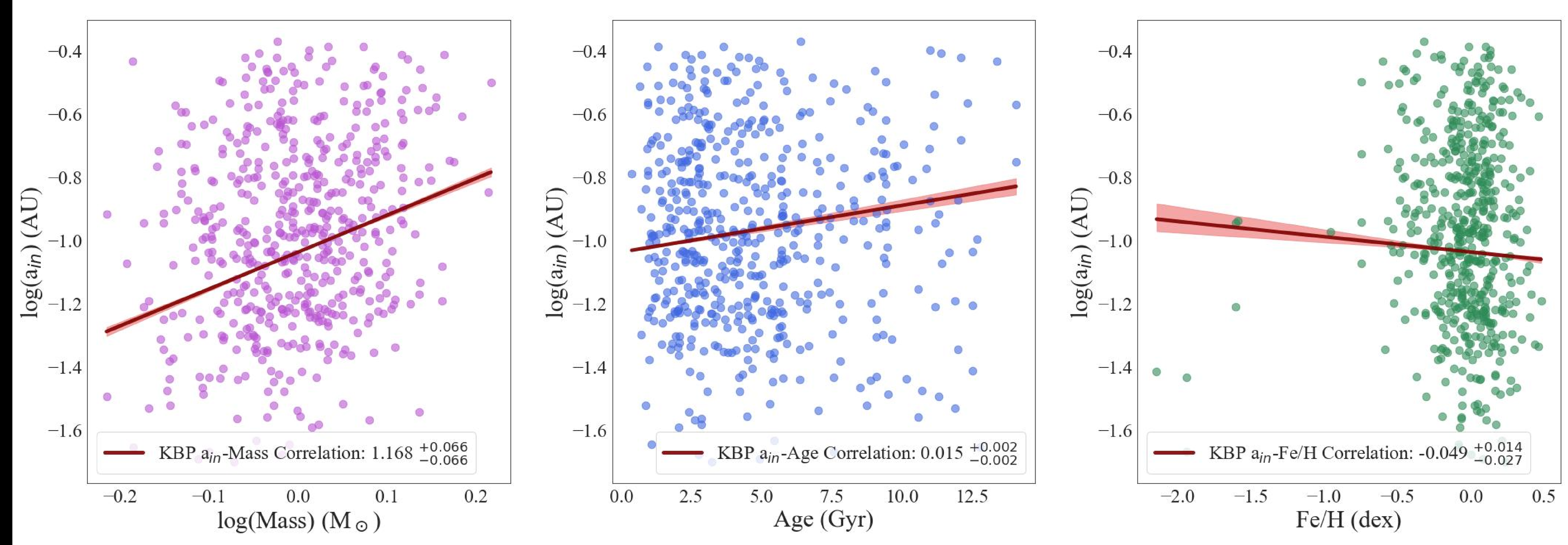


*Figure 3. Comparison of LR model results. Different panels respectively represent the relationships between mass, age, metallicity, and inner edge. It reflects the LR coefficients, with color bands corresponding to 1σ error bars.*

Finally, we compare the observational results with theoretical models (e.g. Mulders et al. 2015). The main models about the pre-main-sequence (PMS) dust sublimation radius of an actively accreting disk with q = 2 and q = 1, show results that best match the slopes of the observed results at the same intercept as the observations.

**Table 3.** Power-law Index of Results and Models

| Dataset and Mechanism | Index |
|---|---|
| KBP All Systems (LR) | $1.168^{+0.066}_{-0.066}$ |
| KBP All Systems | $0.765^{+0.041}_{-0.042}$ |
| KBP Multiple Systems | $0.803^{+0.061}_{-0.060}$ |
| KBP Single Systems | $0.696^{+0.044}_{-0.044}$ |
| Co-rotation Radius | $1/3 \sim 0.333$ |
| Dust Sublimation | 0.700 |
| Viscous Sublimation ($q=2$) | $11/9 \sim 1.222$ |
| Viscous Sublimation ($q=1$) | $7/9 \sim 0.778$ |
| Stellar Tides | $9/13 \sim 0.692$ |
| Planetary Tides | $3/13 \sim 0.231$ |

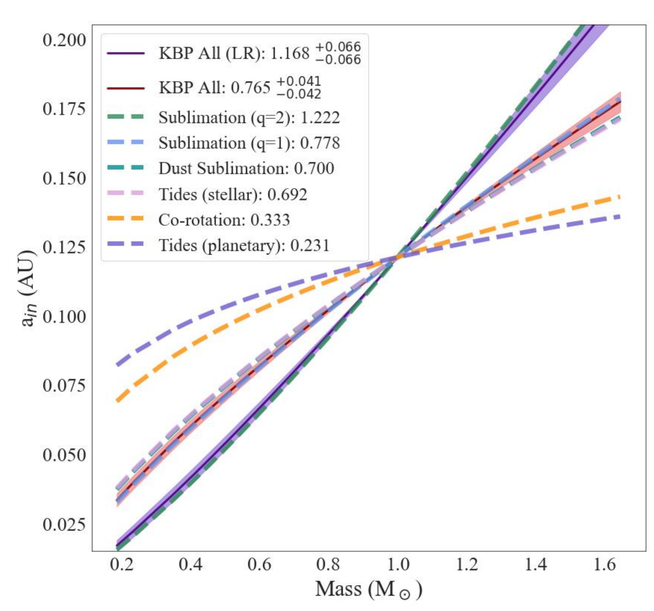


*Figure 4. The correlation coefficients comparison between different models and observational results. The solid line represents the results of the KBP dataset. Dashed lines of different colors represent different models (in descending order). To compare correlation coefficients, the intercepts of the models are standardized with the intercepts of the observational results.*

## References

Alcalá, J. M., Natta, A., Manara, C. F., et al. 2014, A&A, 561, A2
Mulders, G. D., Pascucci, I., & Apai, D. 2015, ApJ, 798, 112
Mendigutía, I., Lillo-Box, J., Vioque, M., et al. 2024, arXiv:2405.00106