In Situ Origins of Hot Jupiter Isolation

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Introduction

- **Outstanding issue:** Hot Jupiters are more observed to be more isolated than warm Jupiters
- **Context:**
  - Widespread prevalence of super-Earths in compact multiple-planet systems
  - Super-Earth pairs packed near the boundary of Hill instability (Pu & Wu 2015)
  - Most exhibit "peas in a pod" structure (Weiss et al. 2018)
  - Many are sufficiently massive to trigger runaway accretion (Lee et al. 2014; Batygin et al. 2016)
- **Our work:** Use *N*-body simulations of mass-boosted super-Earths to demonstrate that in situ formation naturally produces *observationally* isolated hot Jupiters and warm Jupiters with nearby low-mass companions

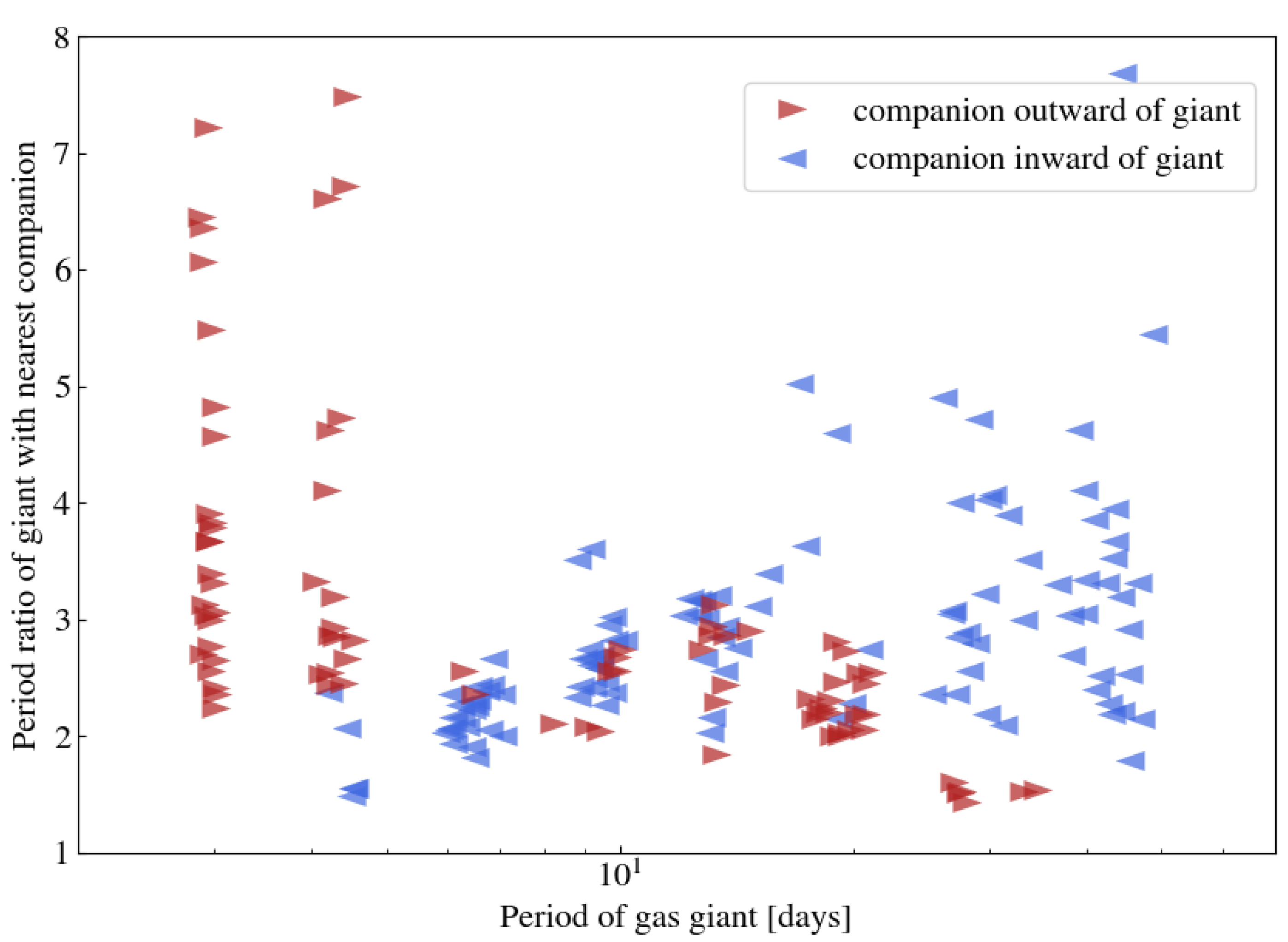
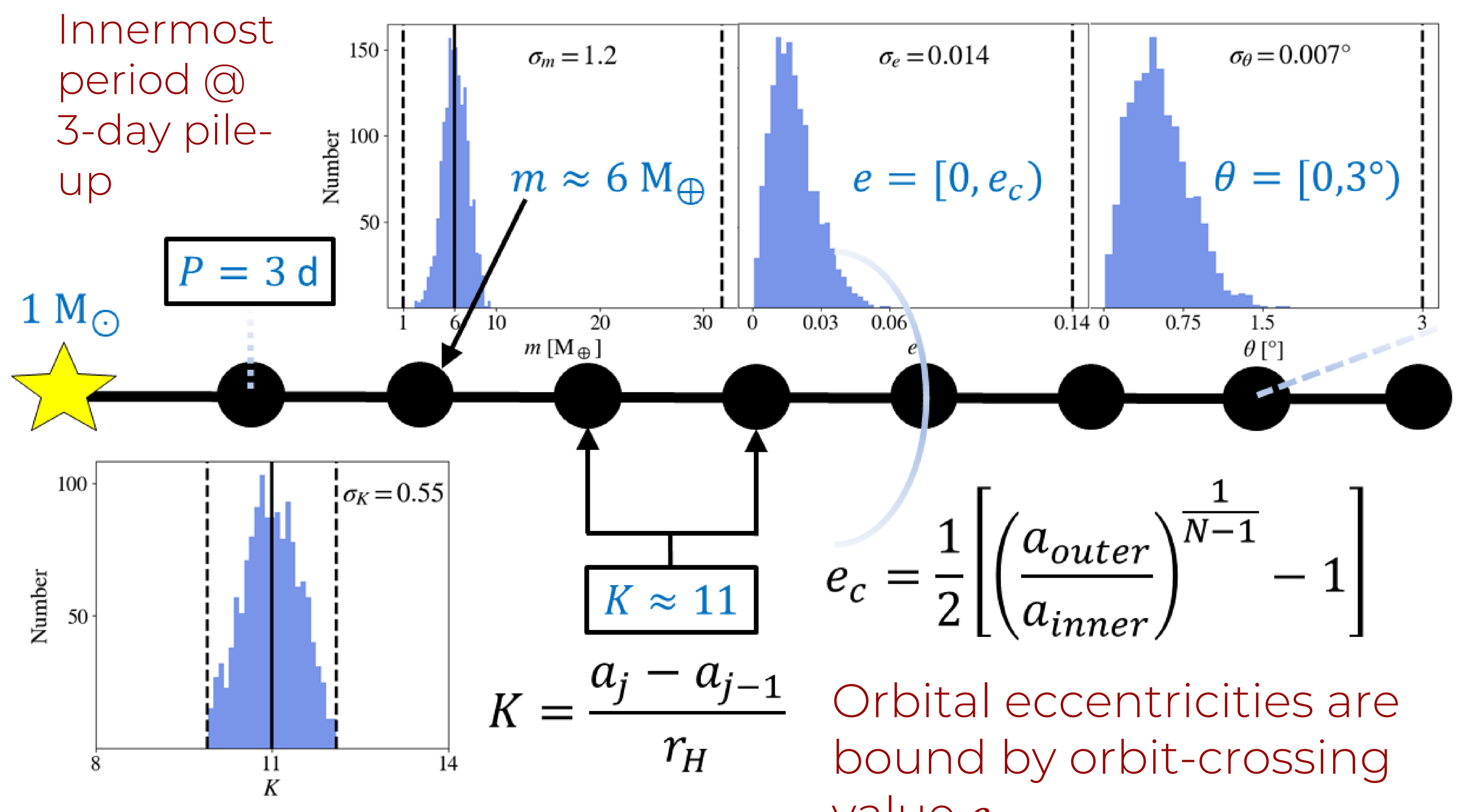


Figure 1. Final giant period ratios with their nearest neighbor as a function of giant period, with orientations indicated (red rightward and blue leftward triangles). The mirror effect between our red and blue triangles may be astrophysical so long as peas-in-a-pod systems become truncated (see Millholland et al. 2022).

N-body Simulation Set-up

We generate 200 peas-in-a pod systems, each with eight super-Earths orbiting a solar mass star. We then boost the mass of one planet per system to 1 Jupiter mass (M_J), driving instability, and integrate to $t = 10$ Myr.

Step 1: Generate Stable Peas-in-a-Pod Systems



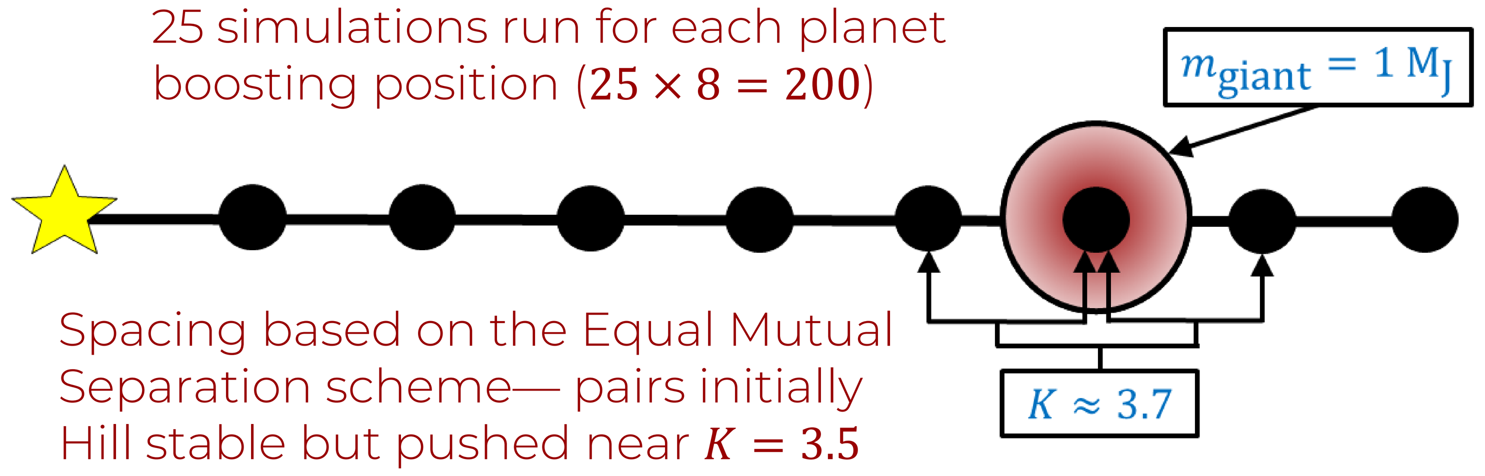
$$e_c = \frac{1}{2}\left[\left(\frac{a_{outer}}{a_{inner}}\right)^{\frac{1}{N-1}} - 1\right]$$

$$K = \frac{a_j - a_{j-1}}{r_H}$$

Orbital eccentricities are bound by orbit-crossing value e_c

Step 2: Provide Mass Boost

25 simulations run for each planet boosting position ($25 \times 8 = 200$)



Spacing based on the Equal Mutual Separation scheme— pairs initially Hill stable but pushed near $K = 3.5$ threshold after mass-boosting

Main Results

Our final systems exhibit three key properties (Figure 1):

1. **Hot Jupiter Isolation.** Period ratios of our hottest Jupiters ($P < 5$ days) relative to their nearest companions are typically larger than those of warm Jupiters (by a factor of ~2). Thus, a large fraction of hot Jupiters' companions would not yet be detectable through transit timing variations or transit searches.
2. **Dynamical Sweet Spot.** Inner companions rarely survive for the hottest Jupiters but are seldom destroyed for hot Jupiters in the dynamical "sweet spot" ($5 < P < 7$ days). This sweet spot marks a dramatic drop in the average period ratio and a transition to inner companion configurations.
3. **Mirrored Architectures.** Our hot and warm Jupiter systems mirror each other—inner companion period ratios steadily increase with giant period while outer ratios tend to decrease.

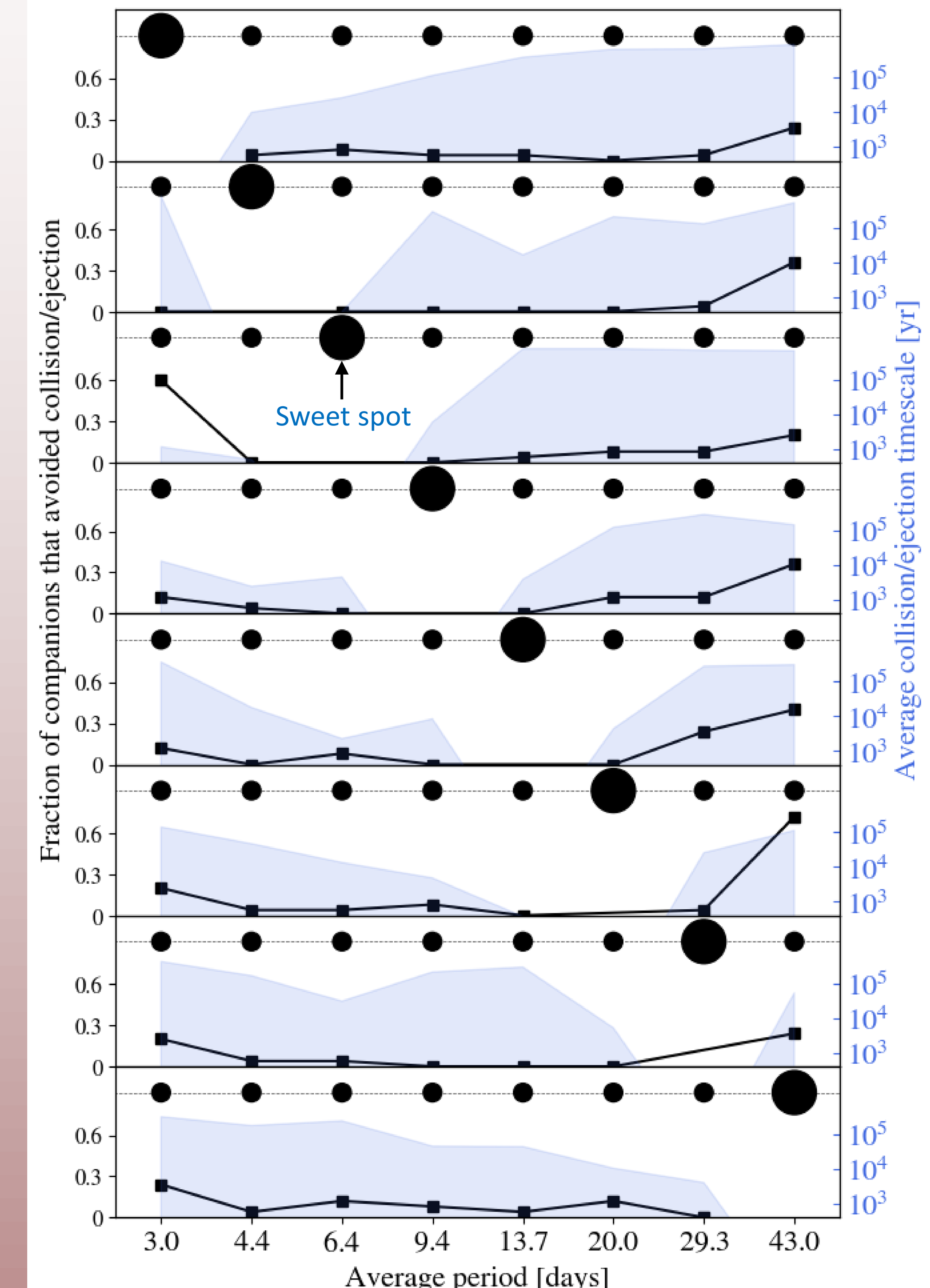


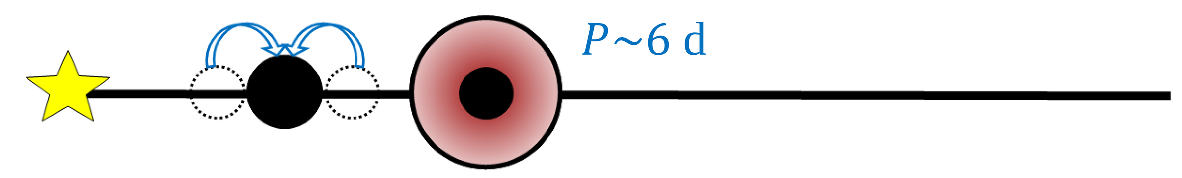
Figure 2. Fraction of companions that avoid collisions & ejections (black squares; left axes) and average timescale for such events (blue shading; right axes) as a function of planet position, stacked for each giant's position. Giant positions are shown schematically at the top of each panel (large black circles).

Dynamics: The giant's position chiefly determines the final configuration since companion-companion collisions dominate (Figure 2).

Hot Jupiter Isolation

A long planet chain exists outside the hot Jupiter, resulting in collisional cascade once two adjacent planets reach $e \approx e_c/2$. The hot Jupiter also merges with its nearest inner companion, leaving it isolated.

Dynamical Sweet Spot



The hot Jupiter has two inner companions which quickly merge and are then Hill stable for all time, since the Jupiter will "filter" e excitation.

Mirrored Architectures

The number of companions on either side of the giant dictates the system's fate, causing a mirrored effect for hot and warm Jupiter configurations.

References: Batygin, K., Bodenheimer, P. H., & Laughlin, G. P. 2016, ApJ, 829, 114; Lee, E. J., Chiang, E., & Ormel, C. W. 2014, ApJ, 797, 95; Millholland, S. C., He, M. Y., & Zink, J. K. 2022, arXiv e-prints, arXiv:2207.10068.; Pu, B., & Wu, Y. 2015, ApJ, 807, 44; Weiss, L. M., Marcy, G.W., Petigura, E. A., et al. 2018, AJ, 155, 48,