

**Connecting Past and Future: The Commonality, Relevance and  
Connection to Stellar Spin of Secular Resonances in the Early Years  
of Exoplanet Systems**

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# Sunlike Stars lose spin diversity with age

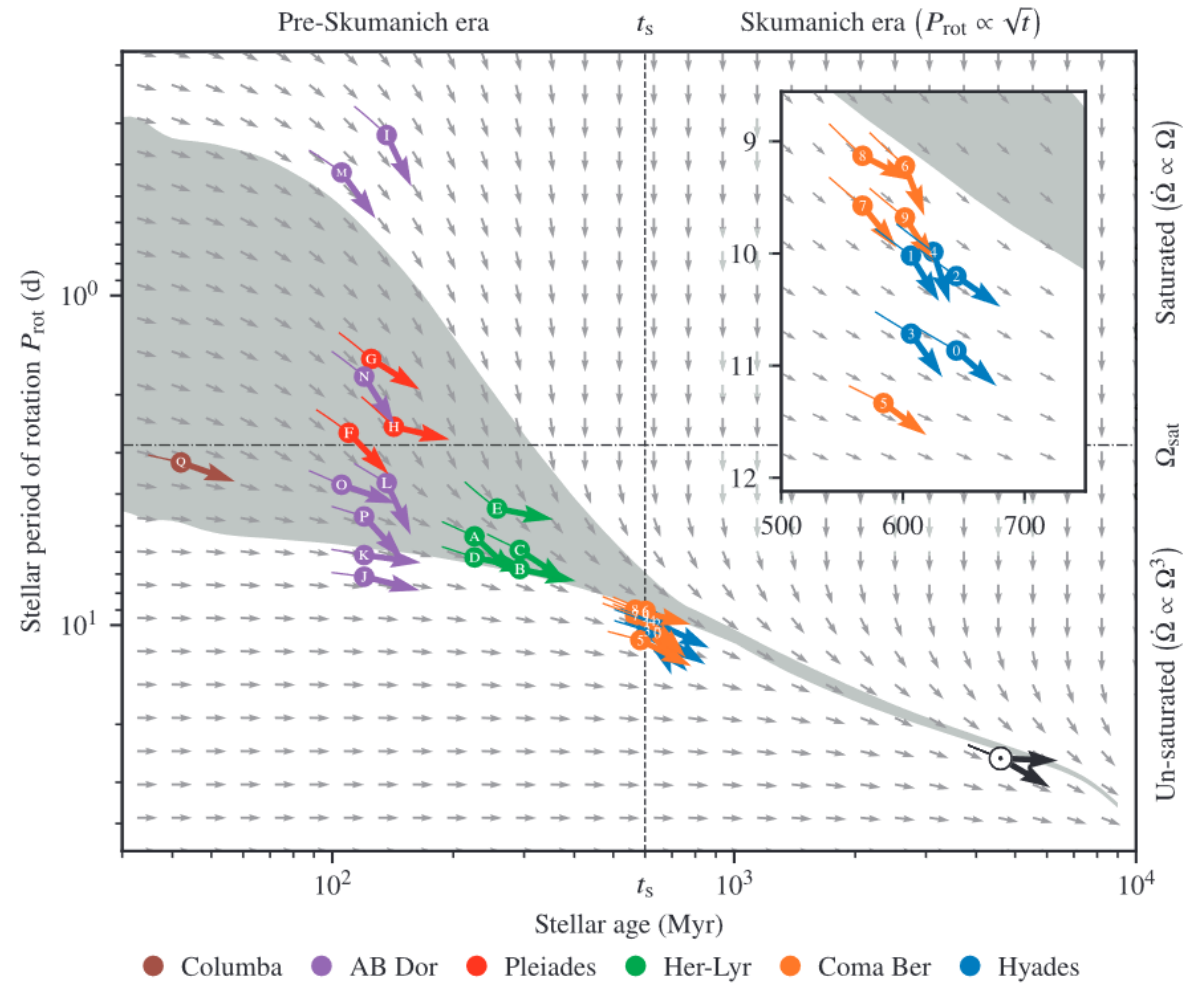


Image: Evensberget & Vidotto (2023)

# Stars' spins make them oblate ( $J_2$ )

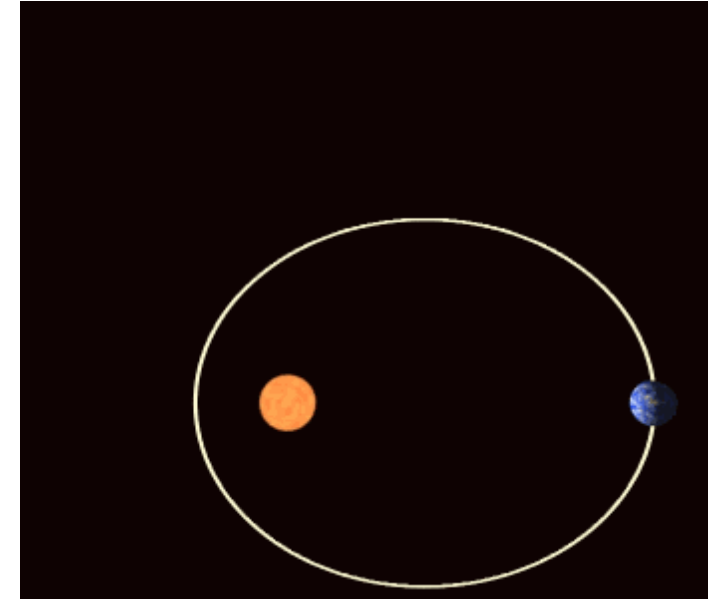
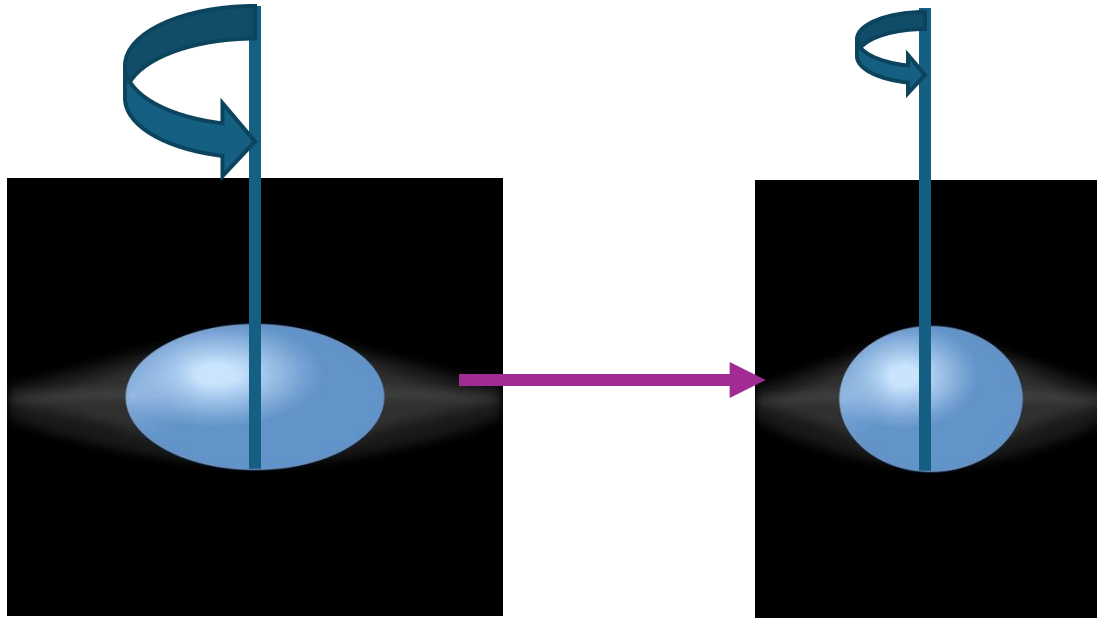


Image: By Lasunncty at the English Wikipedia, CC BY-SA 3.0,

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# $J_2$ Has a Significant Impact!

- $J_2$  misaligns (Ultra) short-period planets
  - e.g., Chen et al (2022), Becker et al (2020), Brefka & Becker (2021), Faridani et al (2023)
  - And mercury Ward (1976)
- Hot Jupiters as well
  - e.g., Spalding & Batygin (2017), Spalding & Millholland (2020)
- Combined with Stellar Obliquity, its effects can be destabilizing
  - e.g., Spalding et al (2018), Spalding & Batygin (2016)

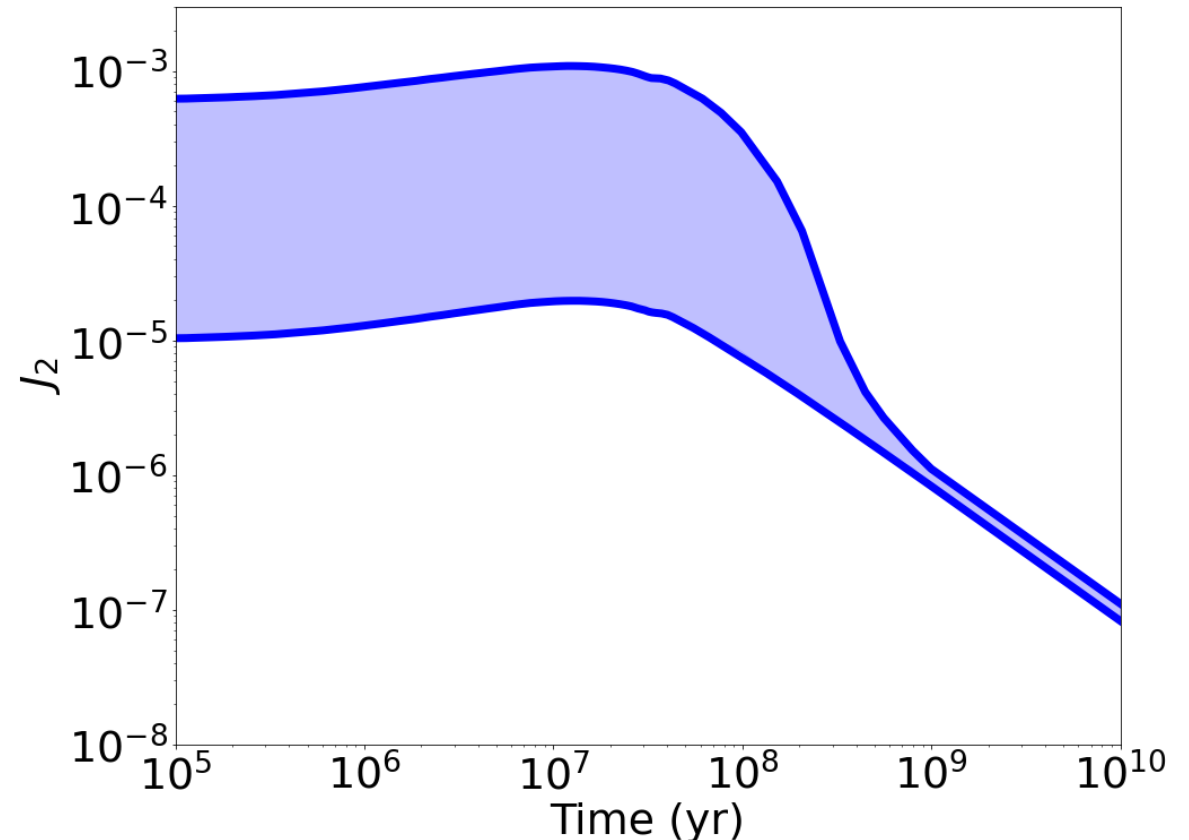


Image: Faridani, et. al., 2024

# Secular Resonances – Precession Commensurabilities Exchange Angular Momentum

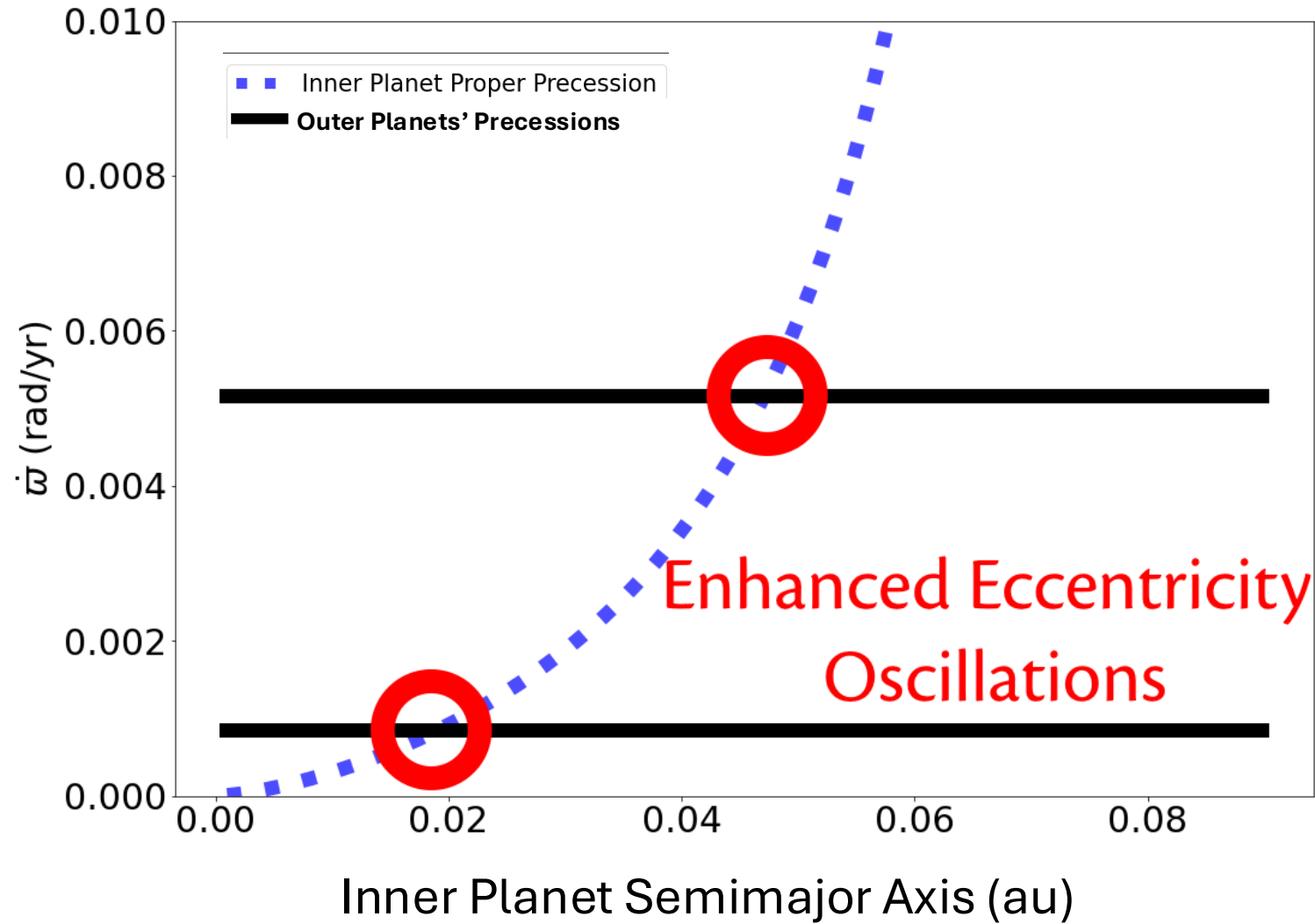
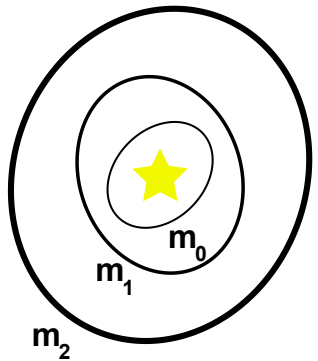


Image: Faridani, et. al., 2023

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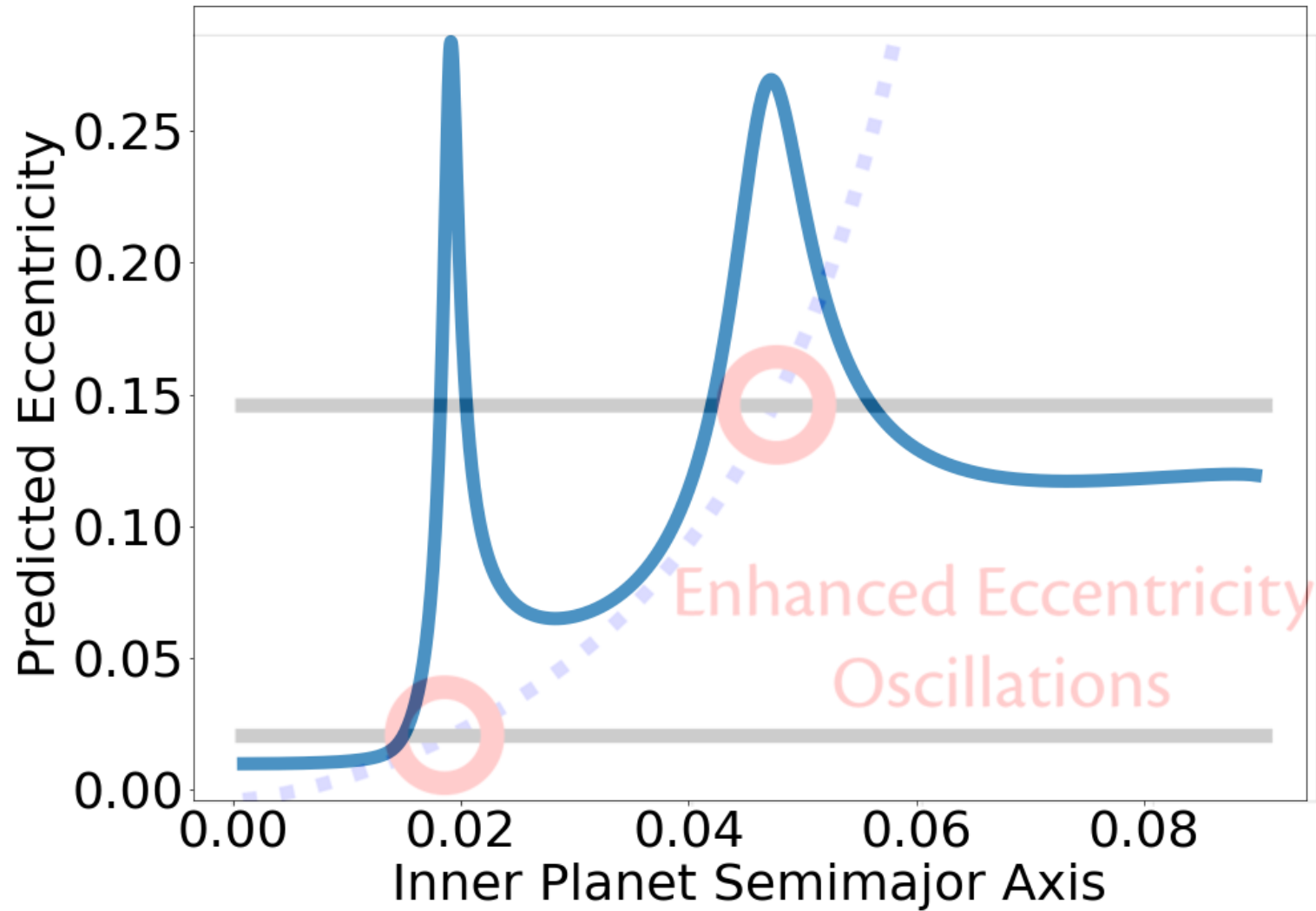
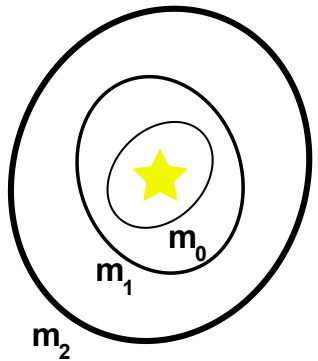


Image: Faridani, et. al., 2023

February 10, 2025

# What Ranges of Semimajor Axis ratios Produce Resonance?

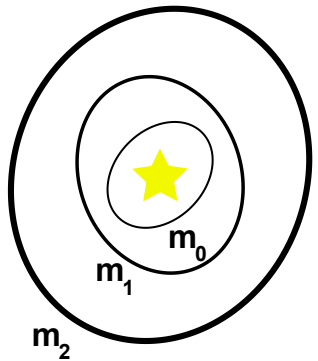
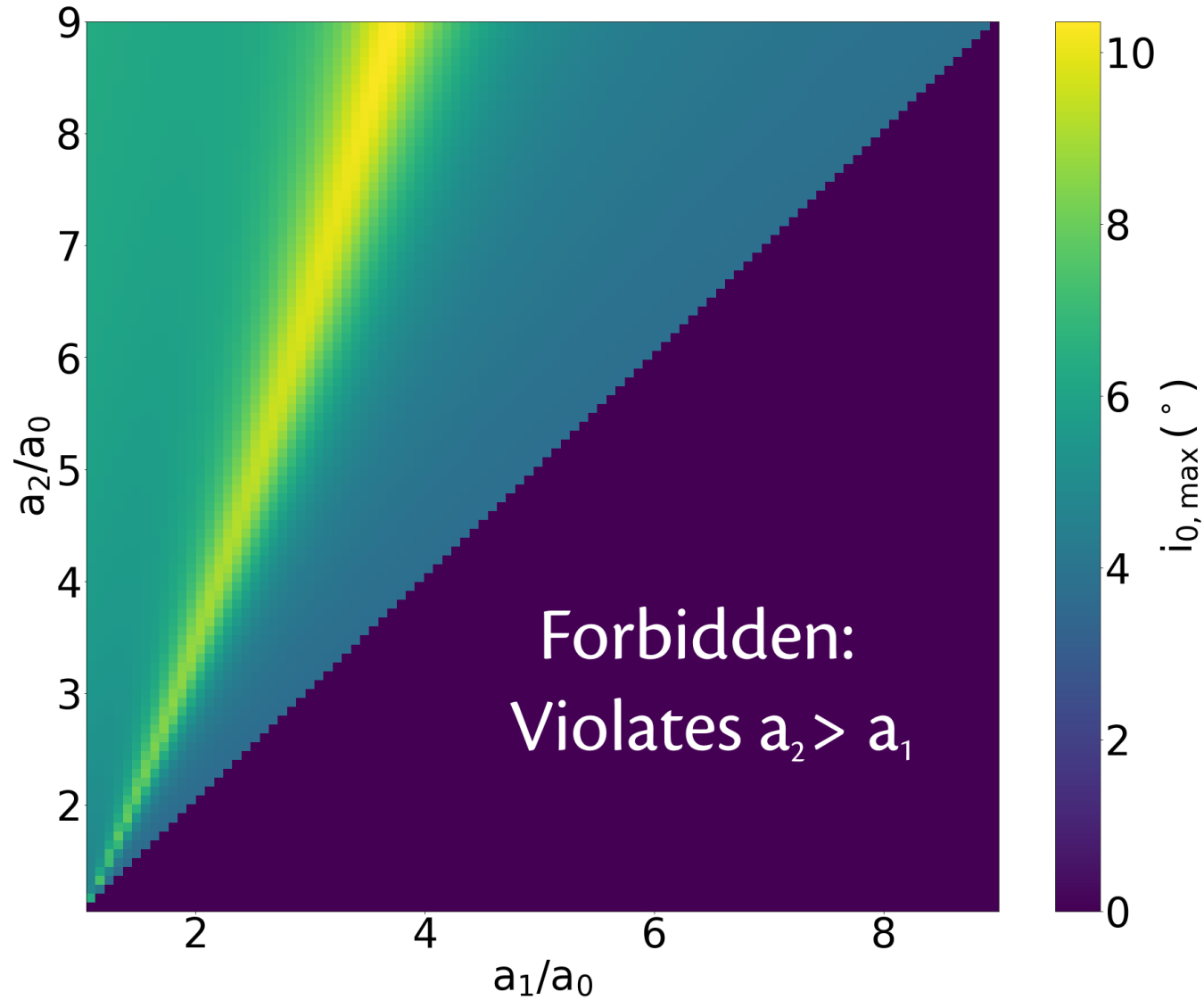


Image: Faridani, et. al., 2024

# How does $J_2$ affect the precessions?

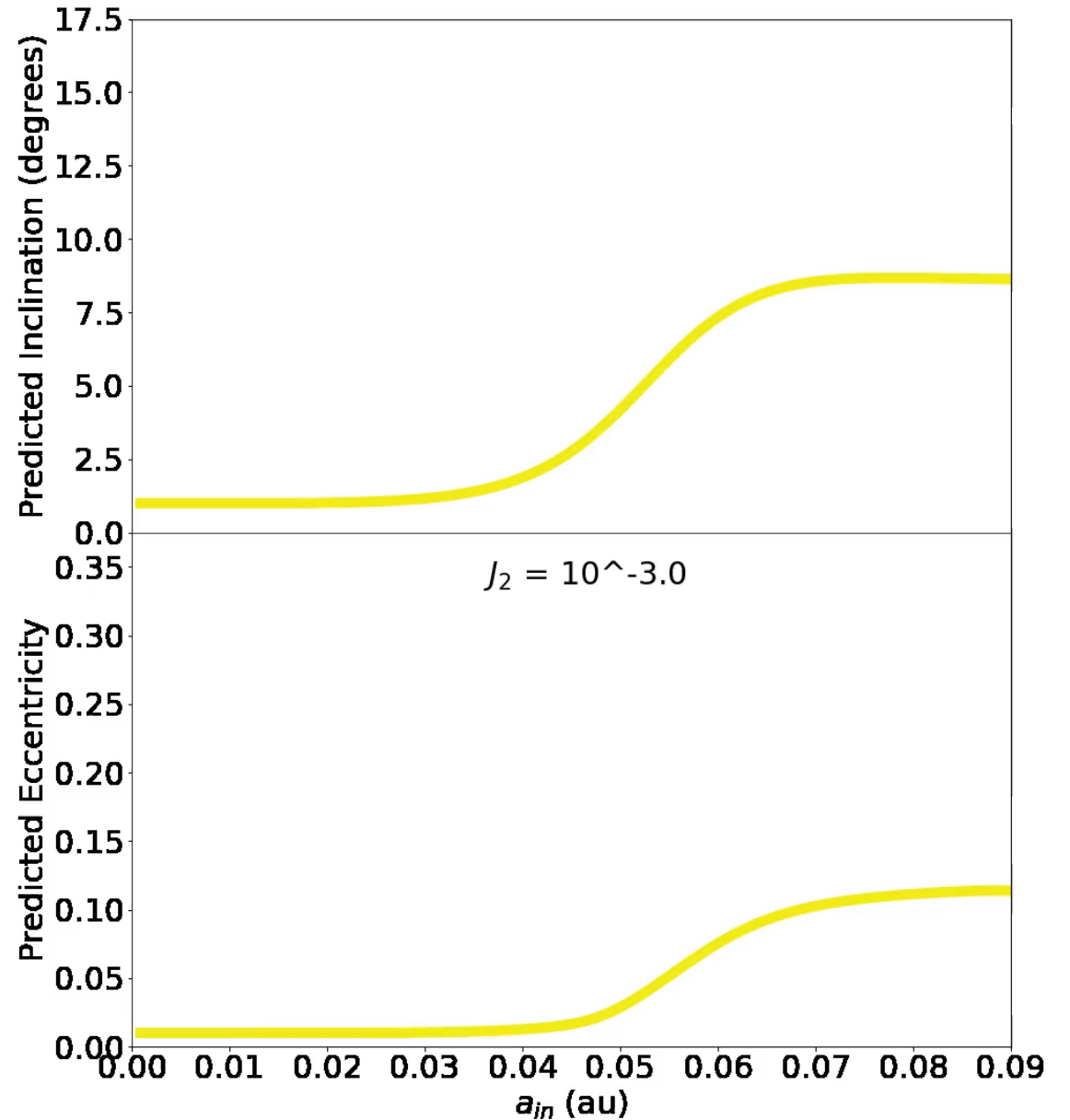
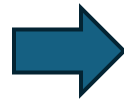
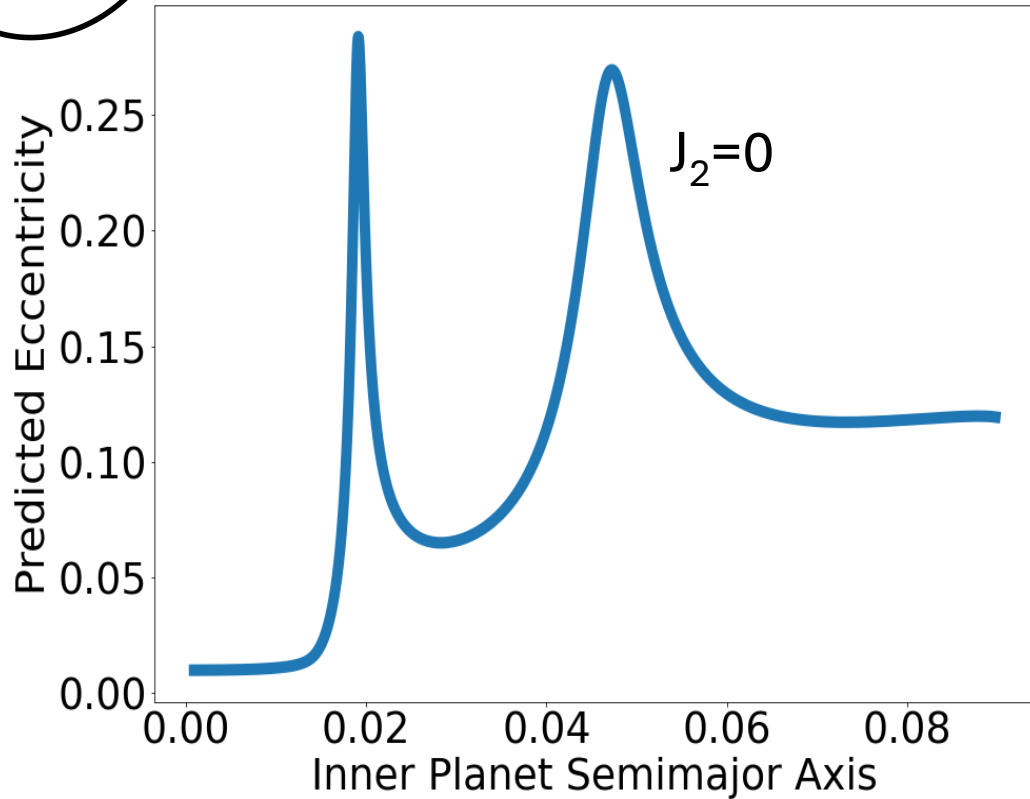
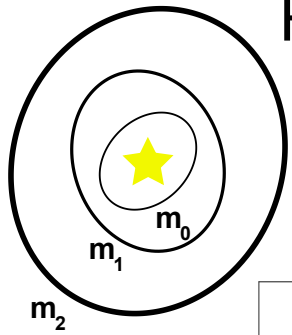


Image: Faridani, et. al., 2023



What effect does  $J_2$  have on these resonances?

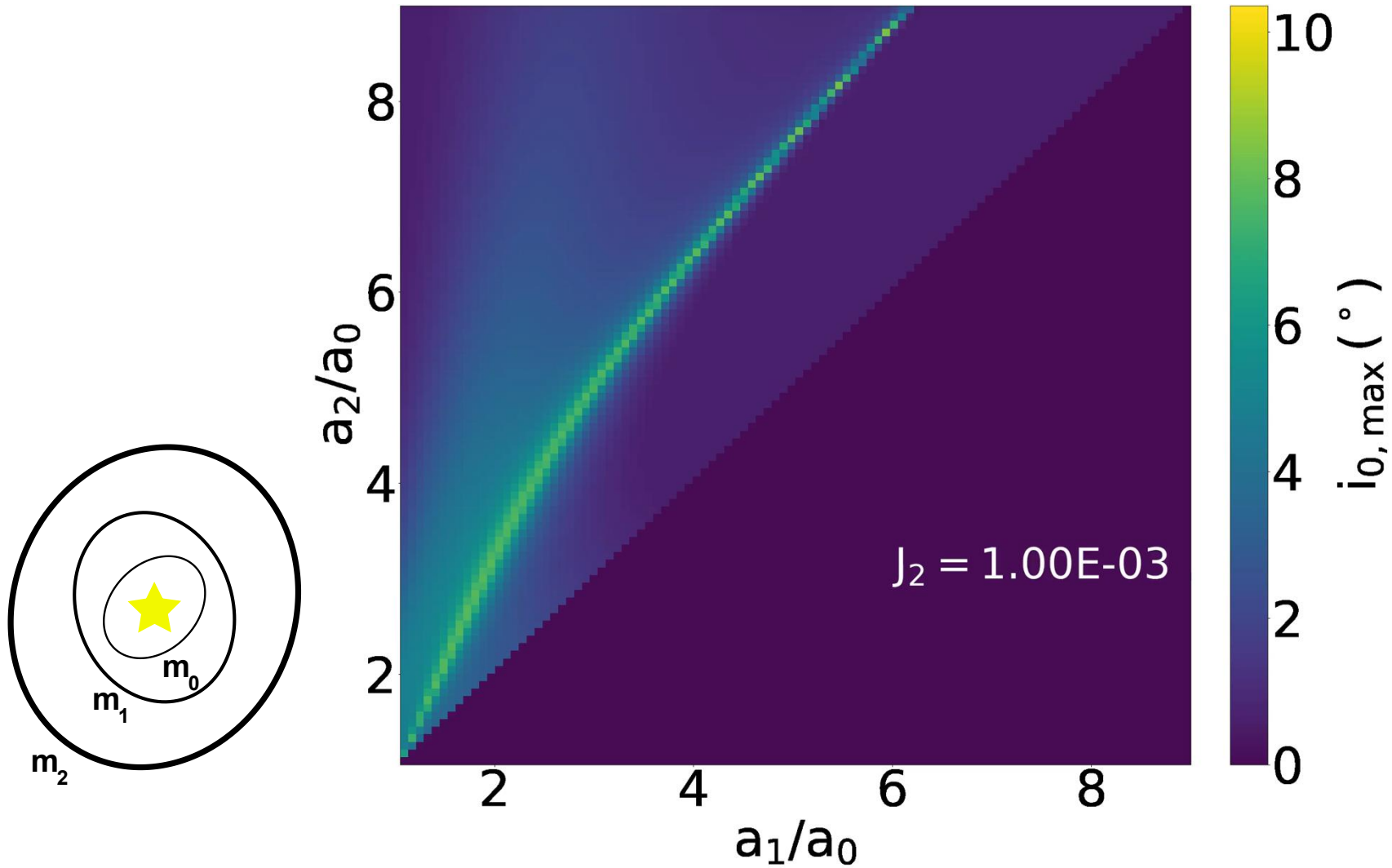


Image: Faridani, et. al., 2025

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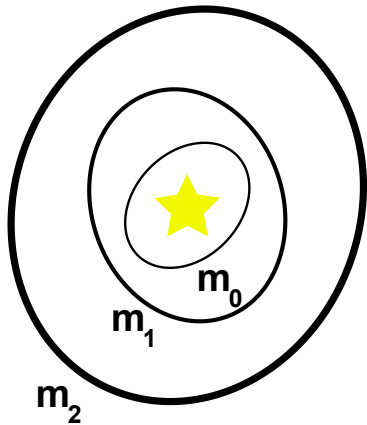
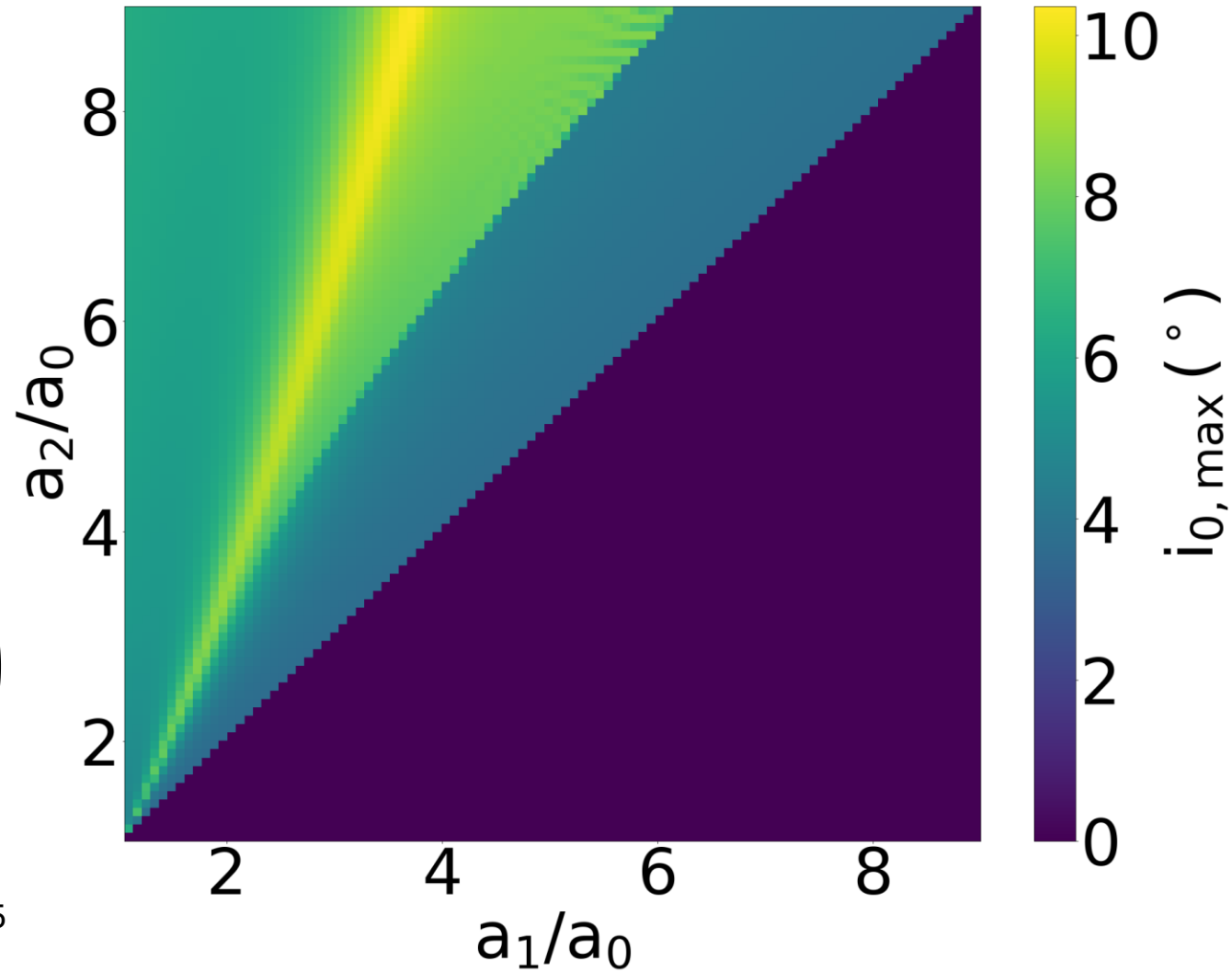


Image: Faridani, et. al., 2025



# What effect do these resonances have on the orbital elements?

- Kepler-9 is a sunlike star with  $1.02 M_{\odot}$  and  $1.05 R_{\odot}$ , and is approximately 2 Gyr old (Borsato et al. 2019)

Name	a (au)	R ( $R_{\oplus}$ )	Citation
Kepler-9 d	0.027	1.64	Torres et al. (2011)
Kepler-9 b	0.143	8.29	Borsato et al. (2019)
Kepler-9 c	0.227	8.08	Borsato et al. (2019)

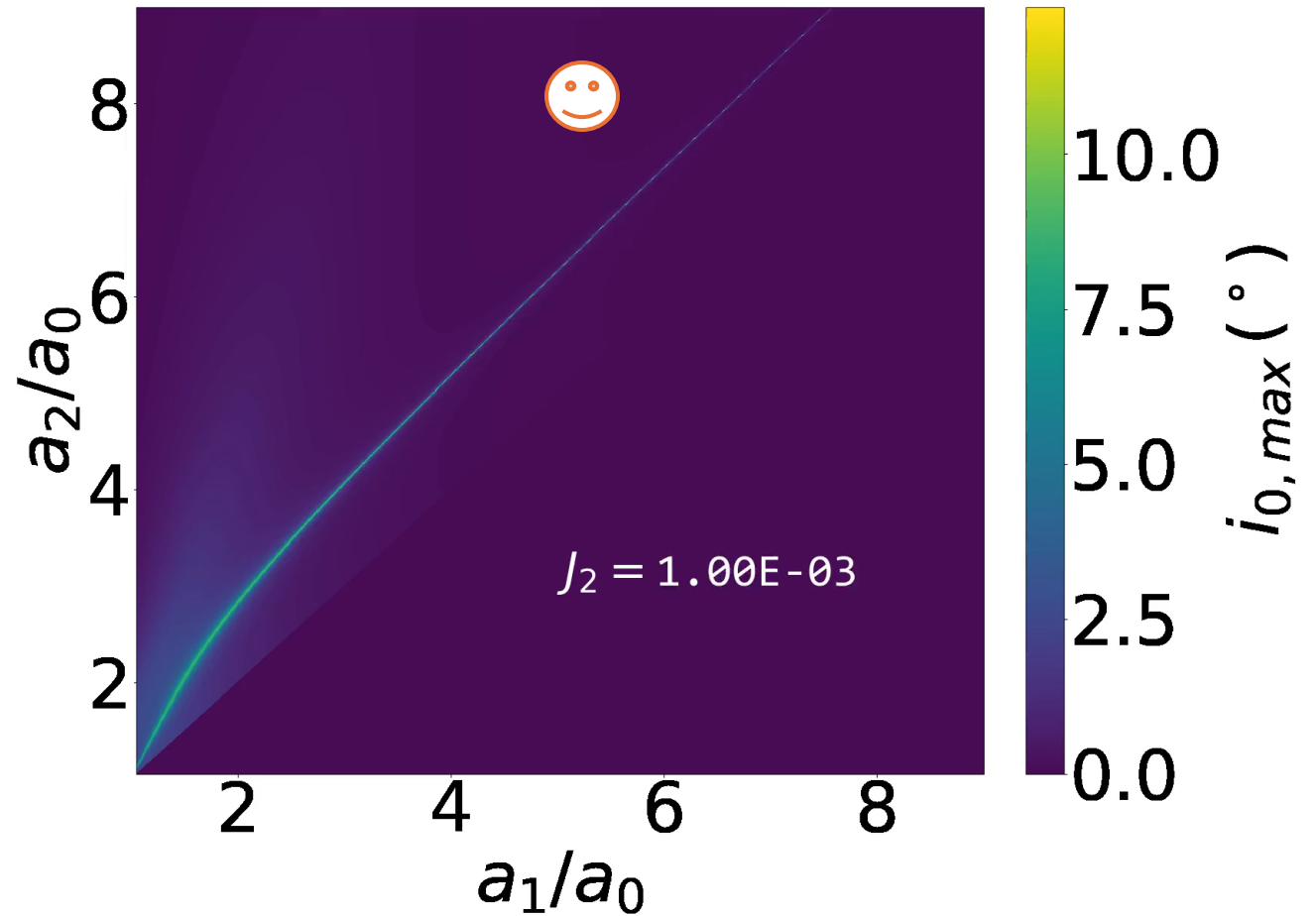


Image: Faridani, et. al., 2025

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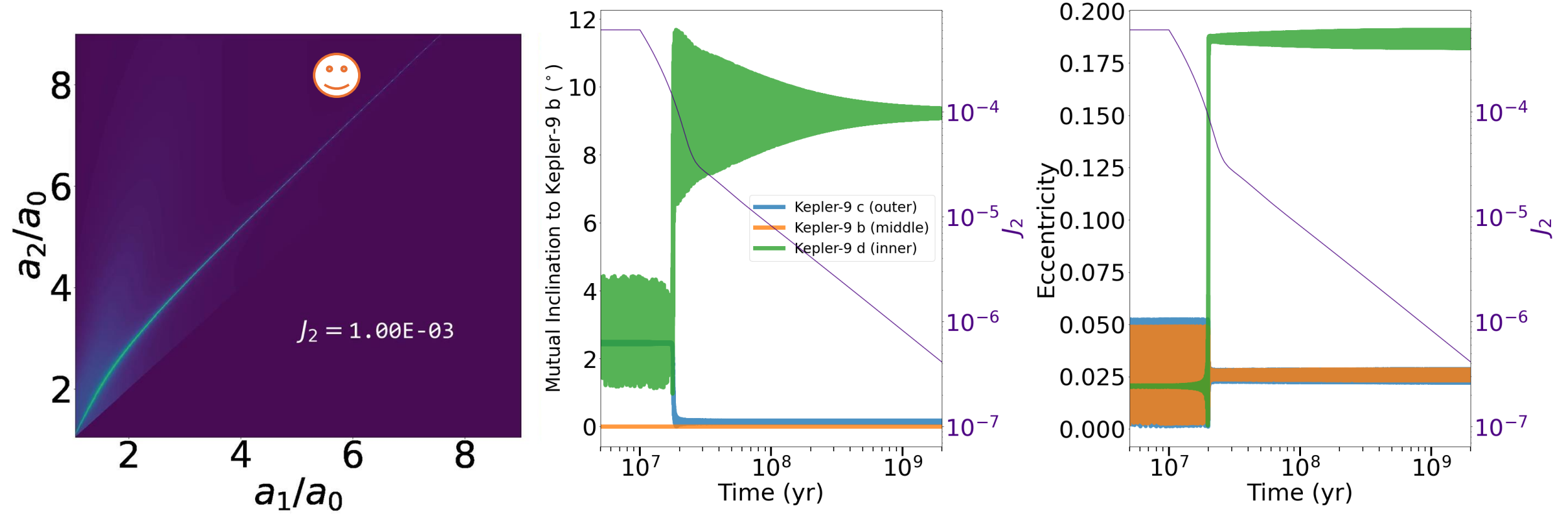
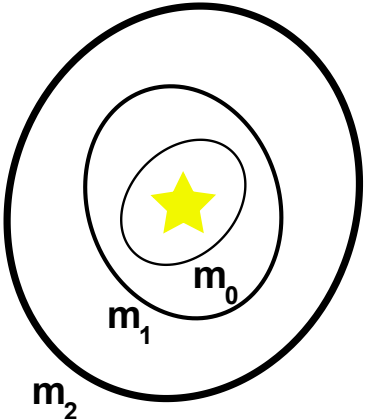


Image: Faridani, et. al., 2025

# Observed Systems?



Outer to Inner  
semimajor  
axis ratio

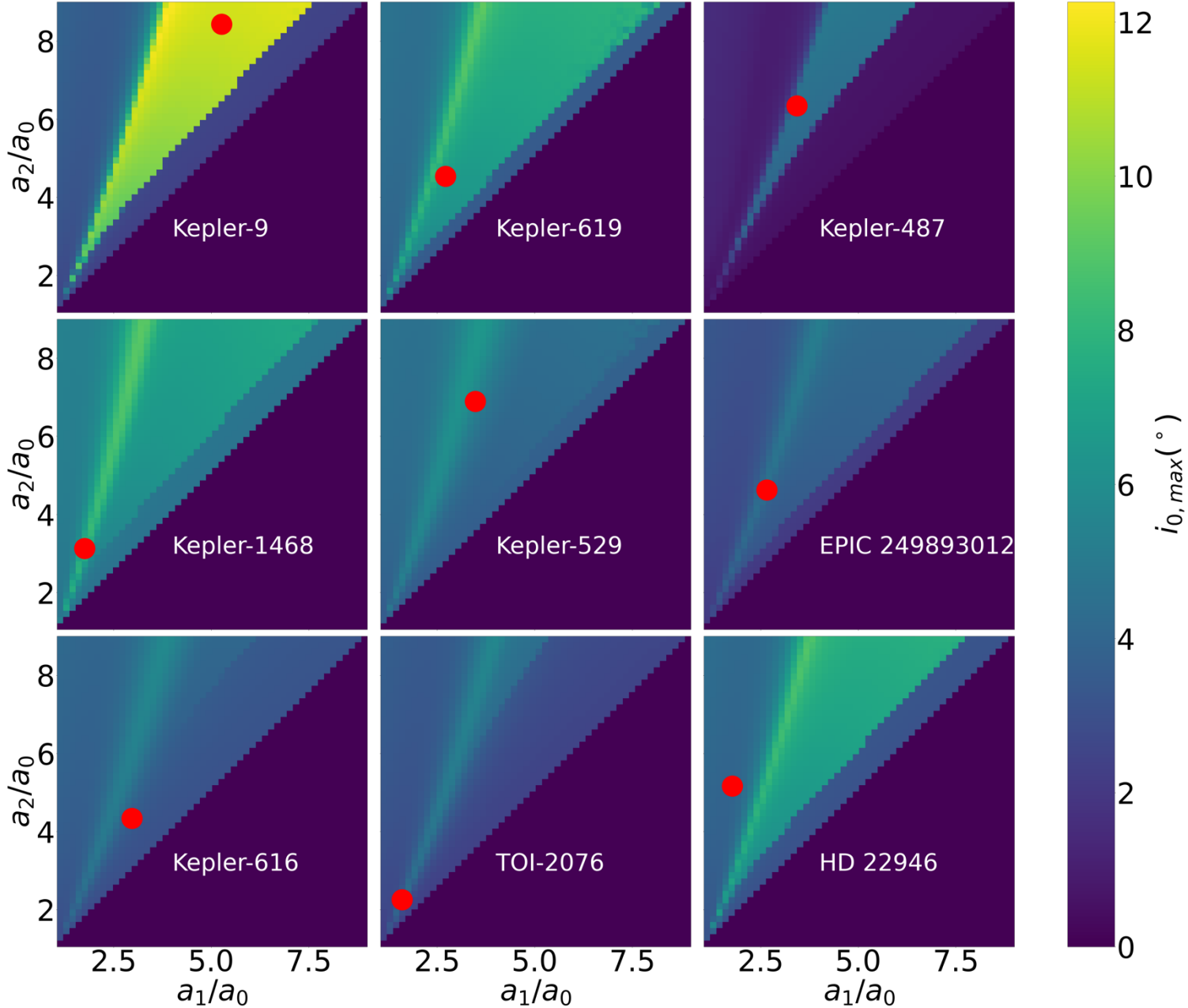


Image: Faridani, et. al., 2025

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Middle to Inner semimajor axis ratio

# How do these resonances affect transit probabilities?

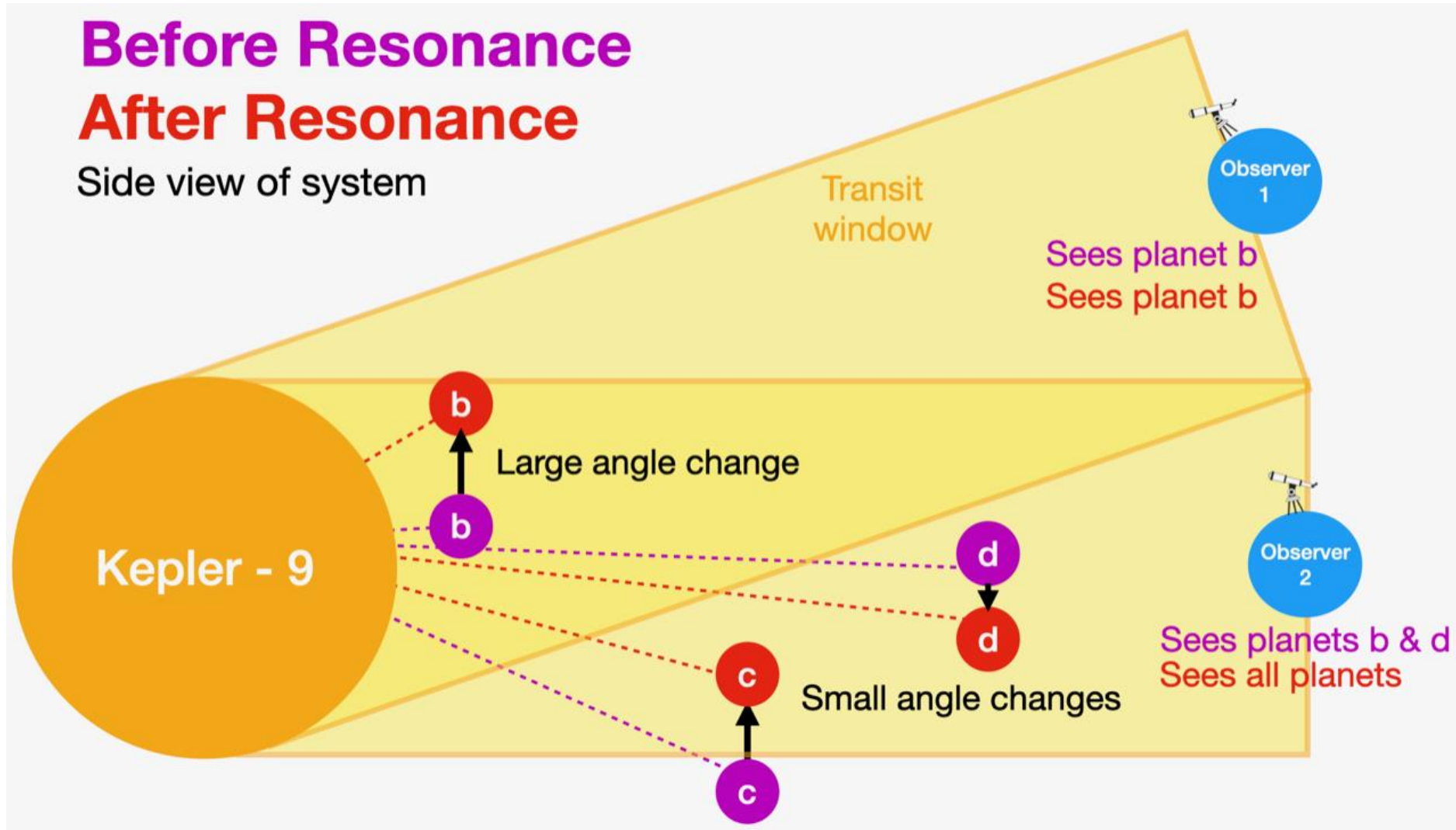


Image: Faridani, et. al., 2025b, in prep



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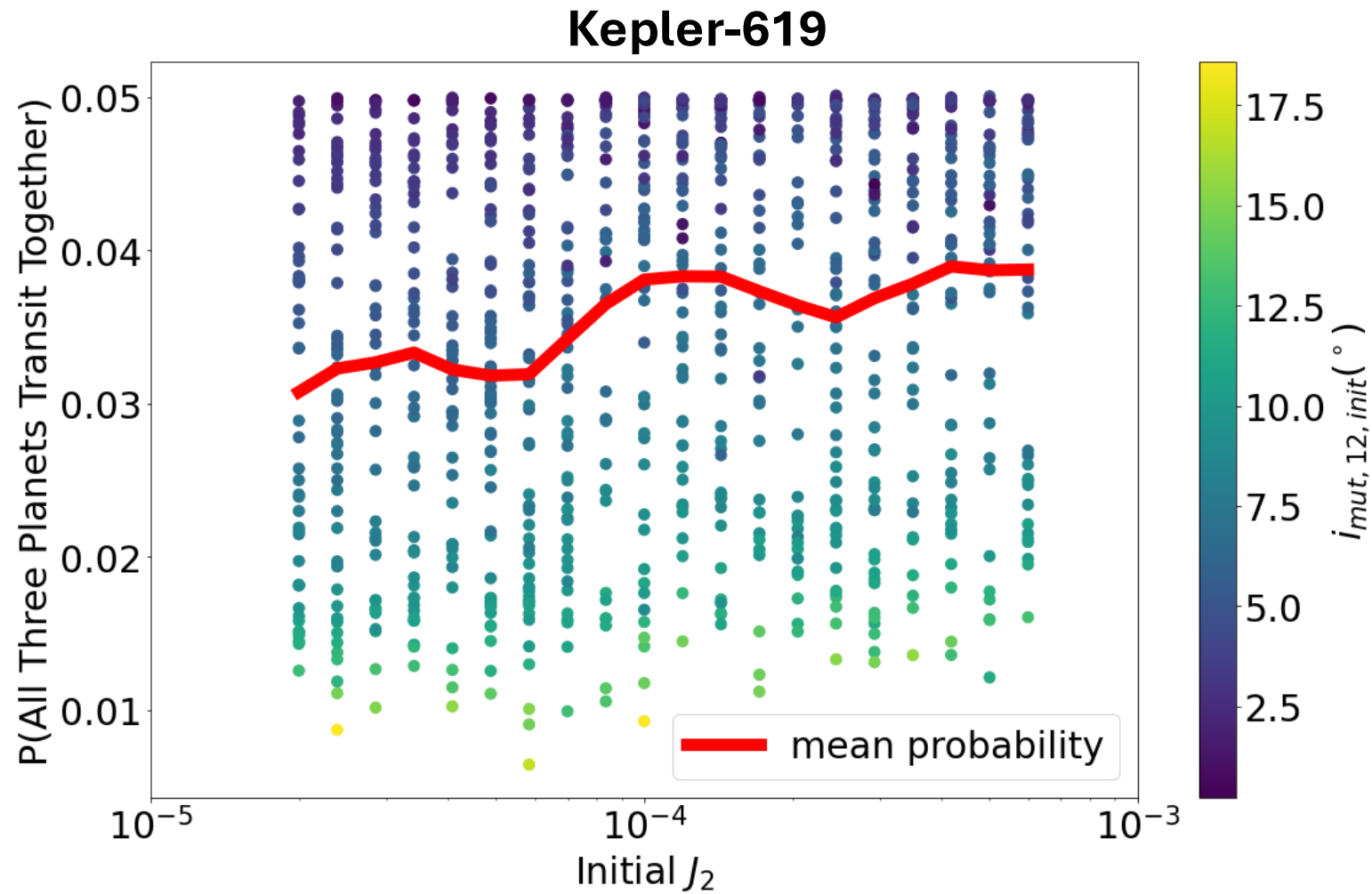
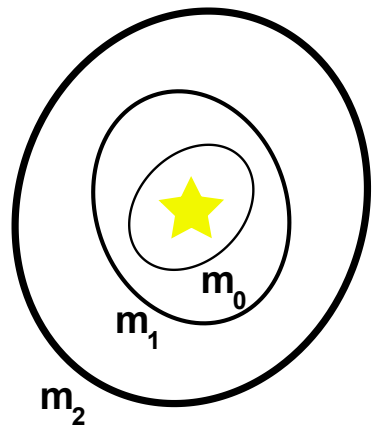


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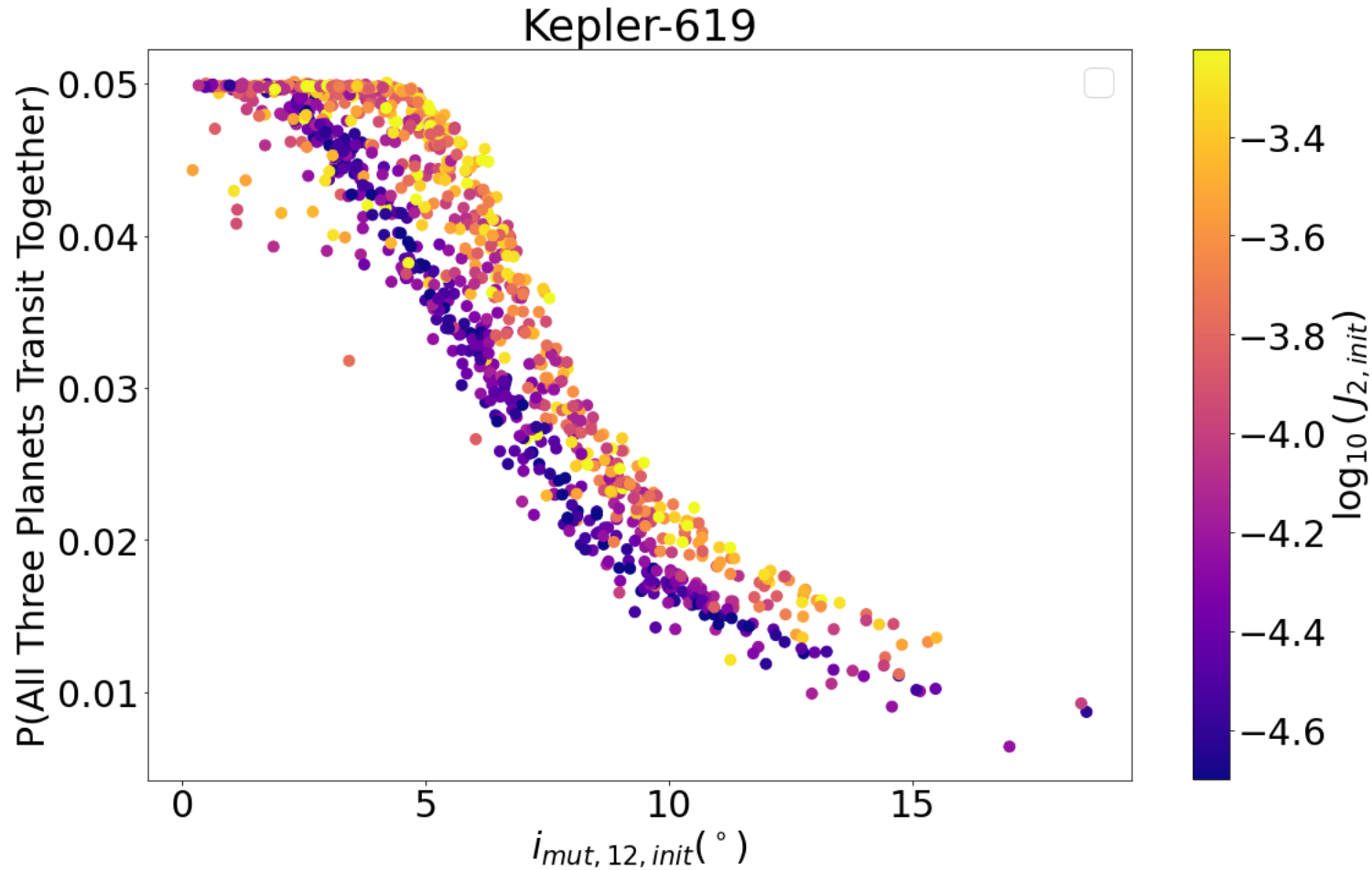
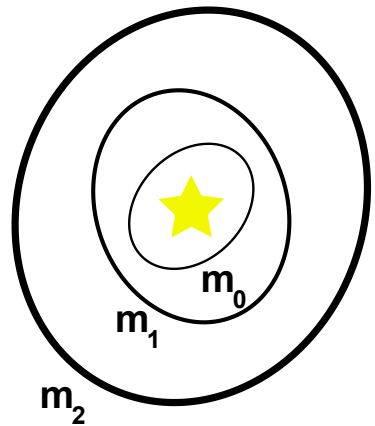


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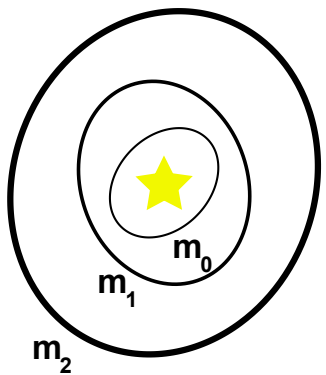
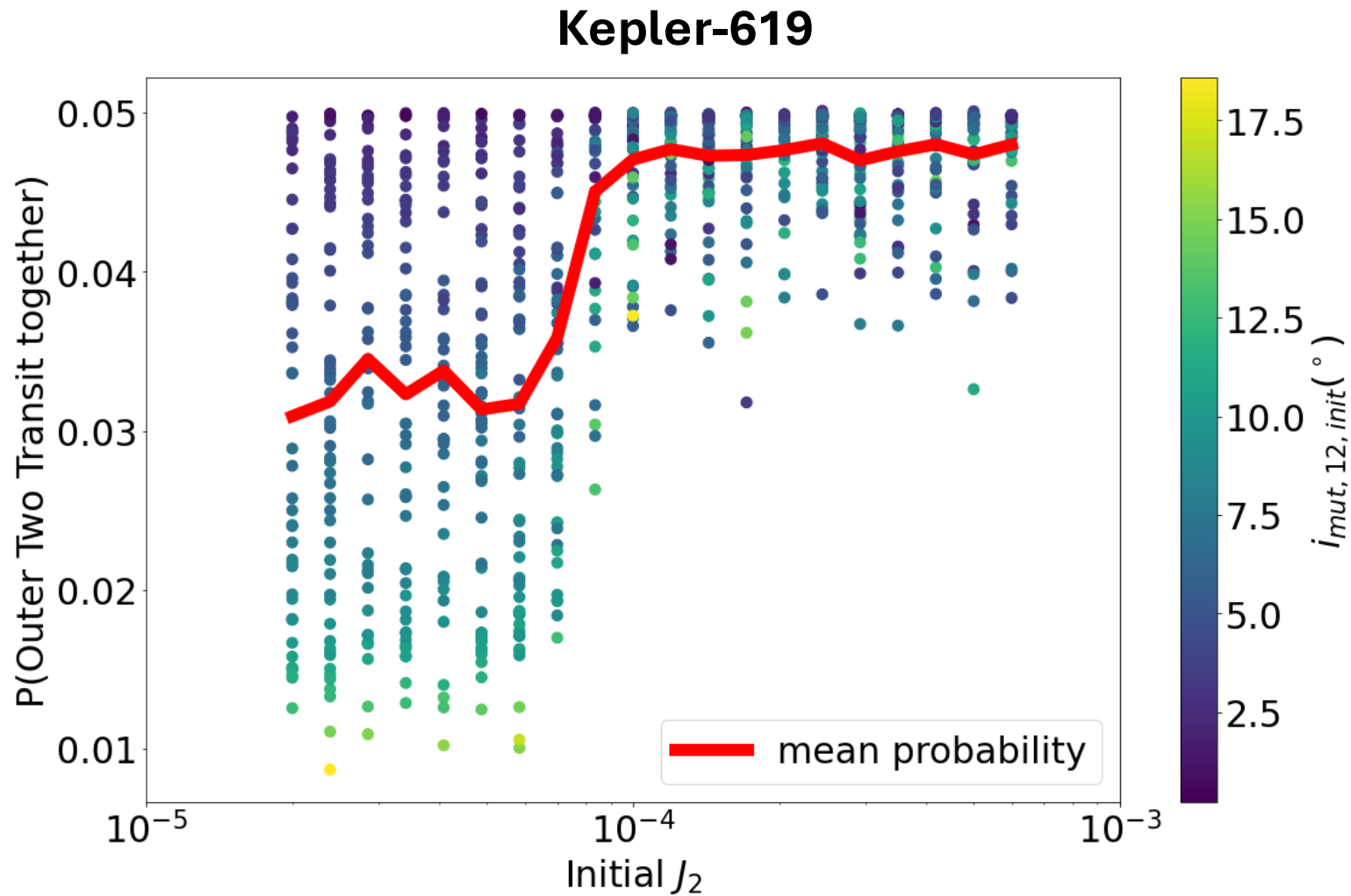


Image: Faridani, et. al., 2025b, in prep



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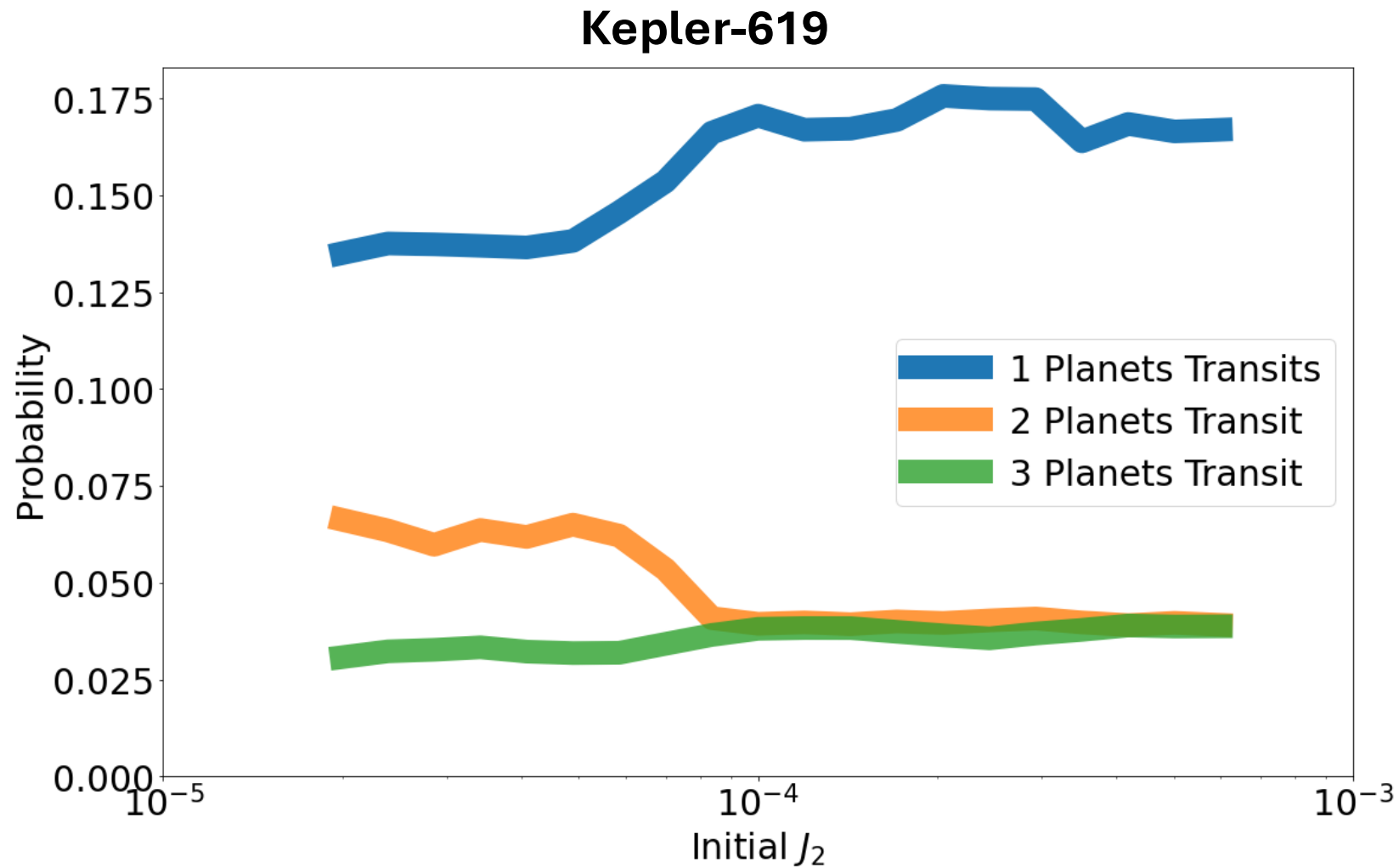


Image: Faridani, et. al., 2025b, in prep



# Let's check on Kepler-9?

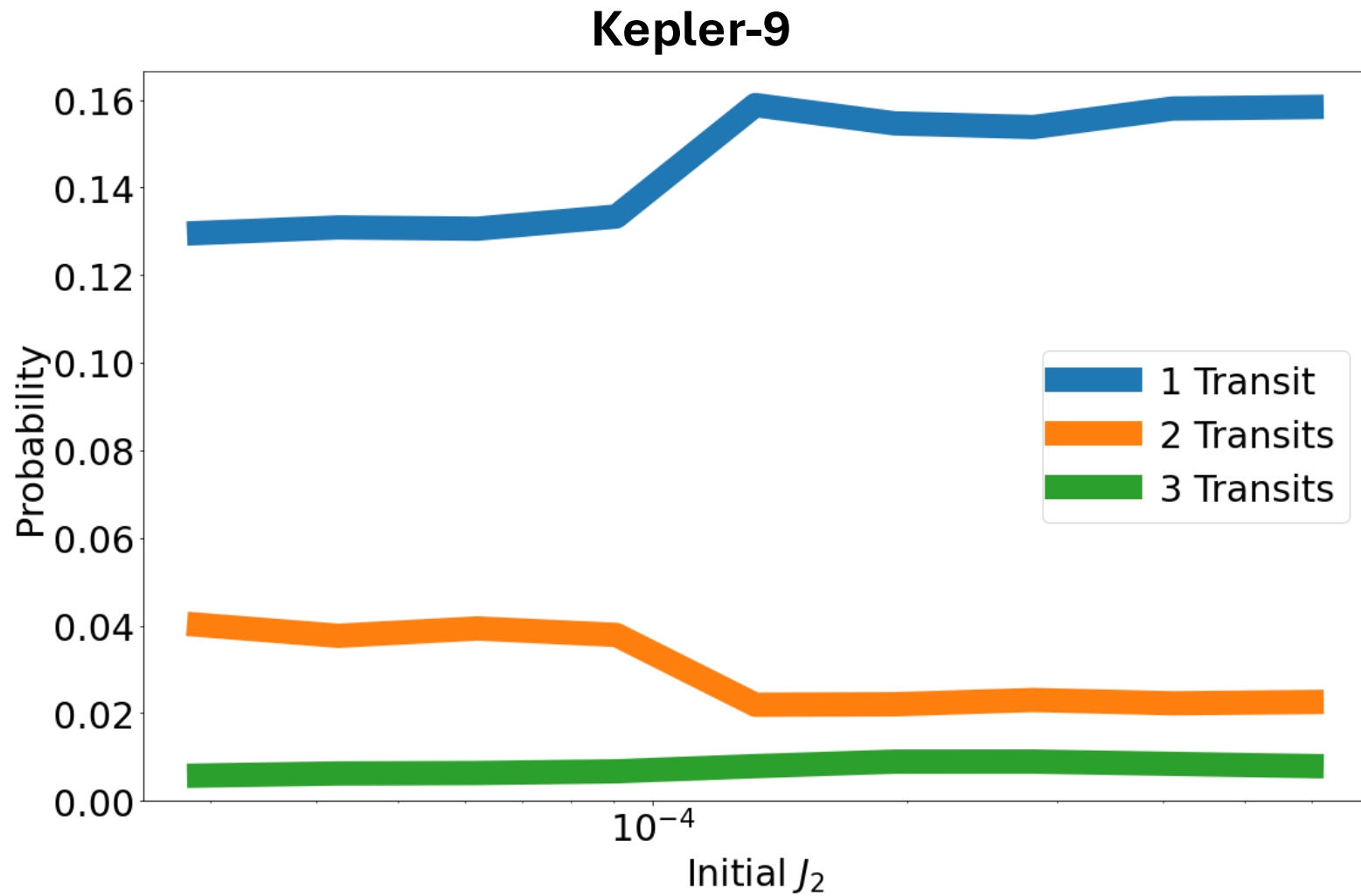


Image: Faridani, et. al., 2025b, in prep



# Summary

- Evolving stellar spin makes secular resonances in 3+ planet systems with a close-in inner planet much more likely than ignoring spin.
- These resonances modestly increase odds of all planets in susceptible 3-planet systems transiting together (~25% increase) by aligning the outer planets at the expense of the inner planet
- However, this significantly reduces the odds of seeing 2 out of 3 planets transit
- Stars born spinning faster  $\rightarrow$  higher fraction of single transits?

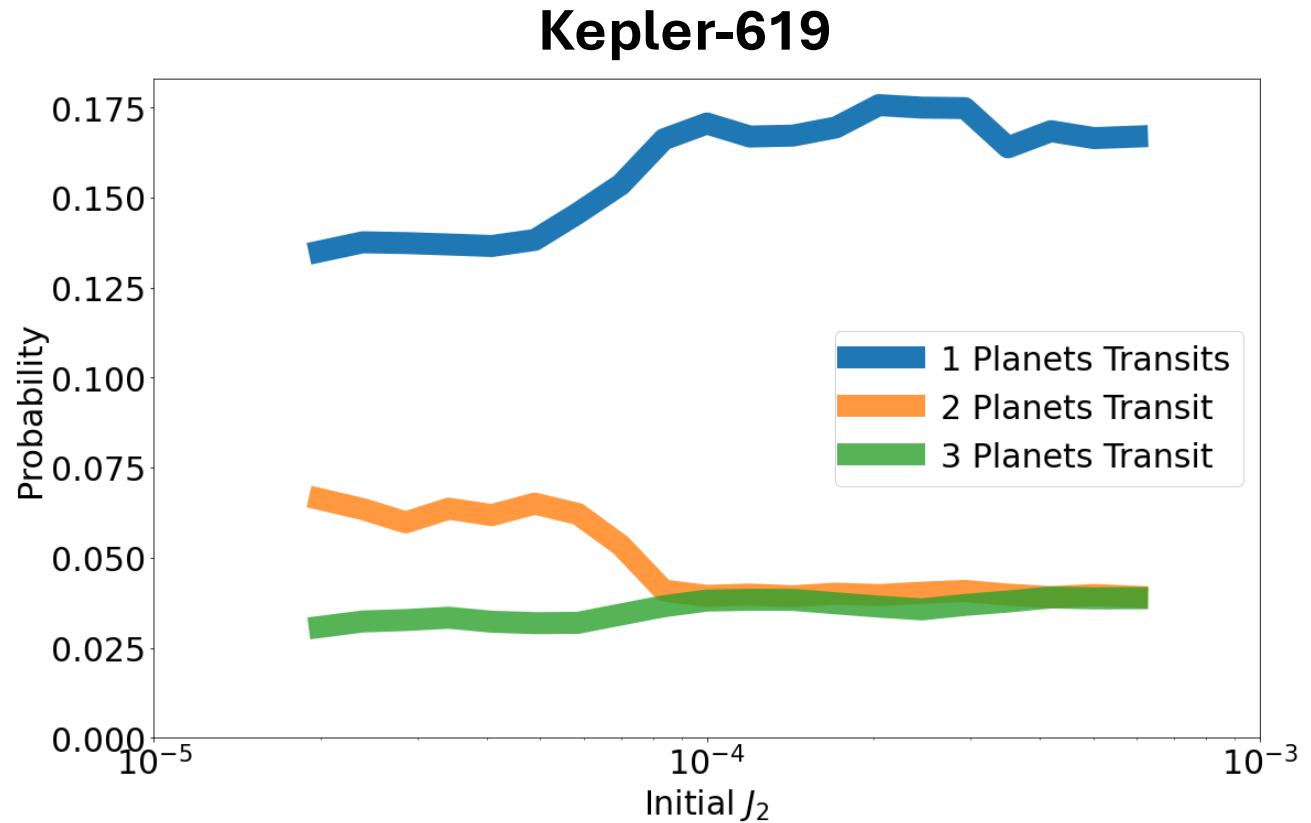


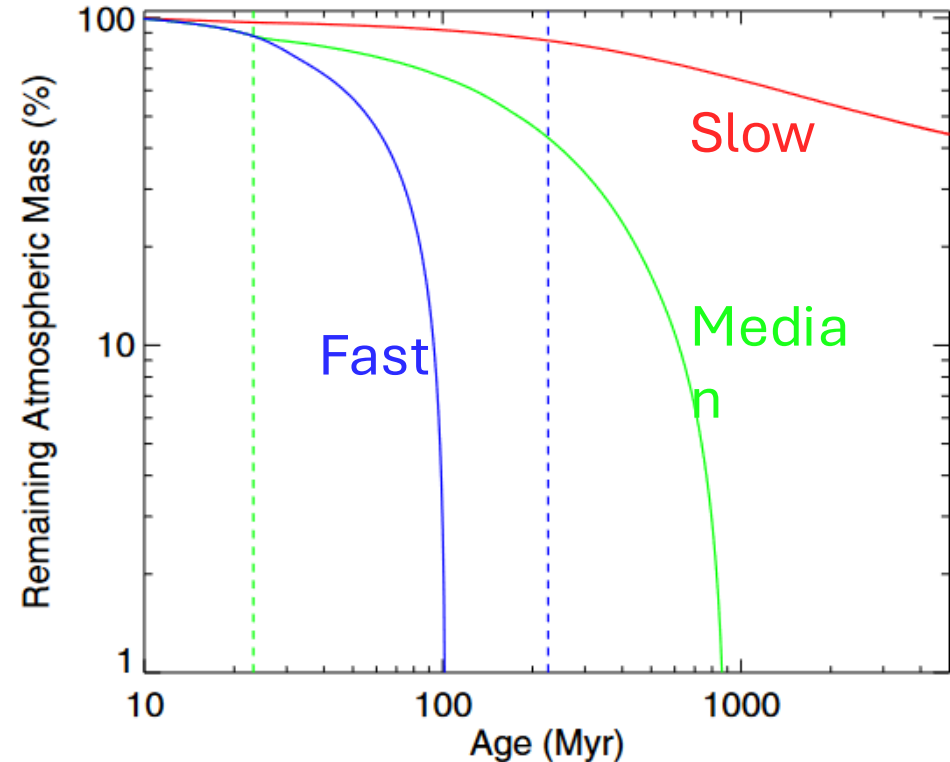
Image: Faridani, et. al., 2025b, in prep

## Observed Systems Our 30-system clean sample

- 5600 planets on the exoplanet archive
- Exclude Binary systems -> 5100 planets
- Planets are in a system with exactly 3 planets -> 561 planets
- Measured star mass + radius -> 239 planets
- FGK main sequence star below kraft break -> 186 planets
- Remove systems with 1 or more nontransiting planets -> 90 planets = 30 systems

# Stellar Spin Impacts the Planets

- The faster a star spins, interactions with the dynamo produce more X-ray and Extreme UV emission
  - (e.g., Wright 2011)
- This can evaporate H/He right off the planet!
  - (e.g., Yelle 2004; Tian et al. 2005; Murray-Clay et al. 2009; Owen & Jackson 2012; Johnstone et al. 2015; Erkaev et al. 2016; Wang & Dai 2018)



# How does $J_2$ affect the precessions?

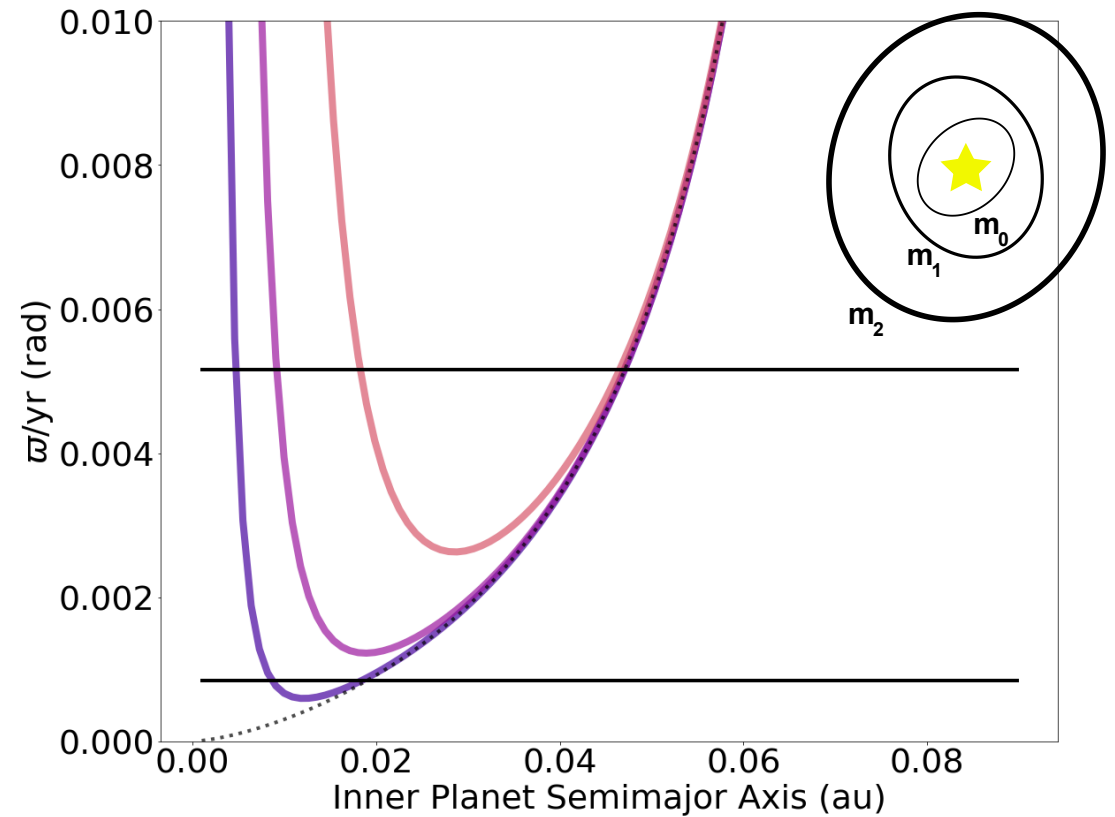
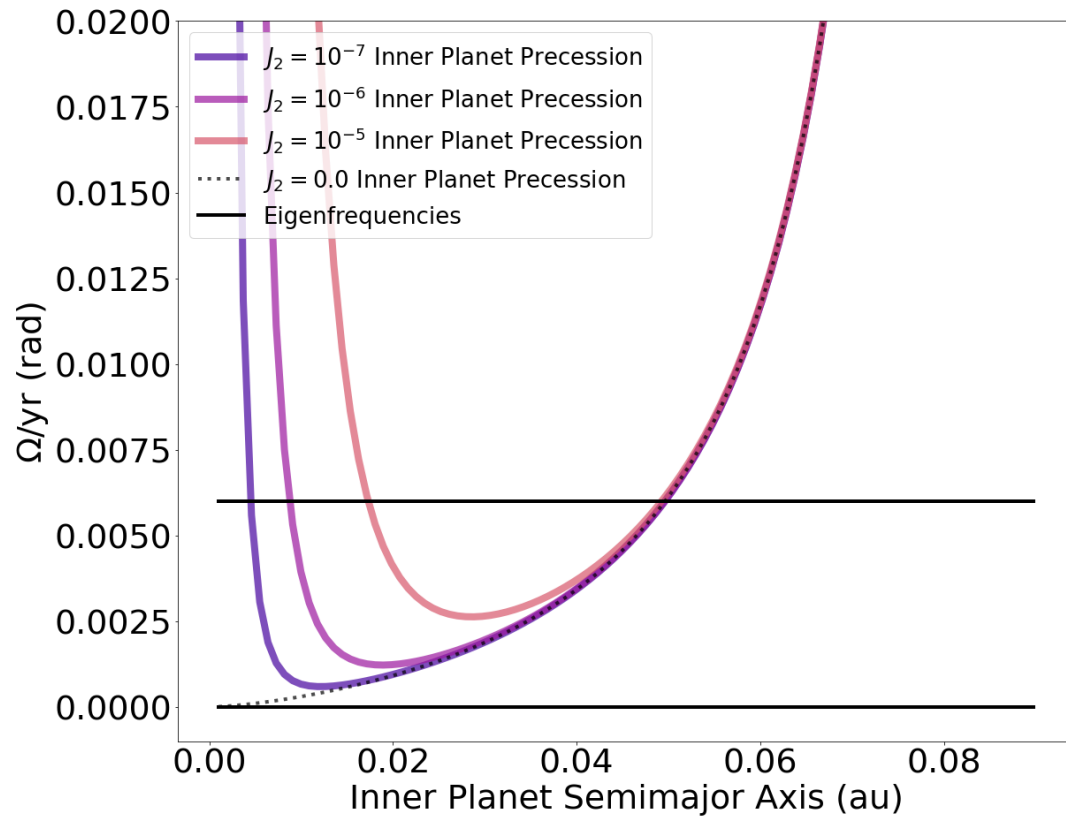


Image: Faridani, et. al., 2023

# How much do these systems misalign?

- Here are the results of 100 orbital evolutions
- Typical Misalignment:
  - Inner planet misaligns from outer planets (high red)
  - Outer planets align with each other (low blue)
- Depends on the initial mutual inclination between the outer two planets!!

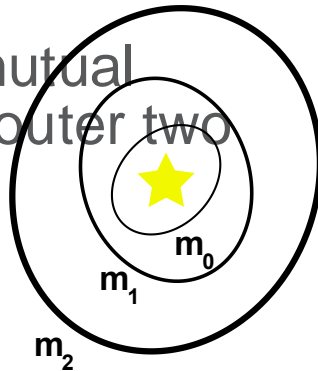
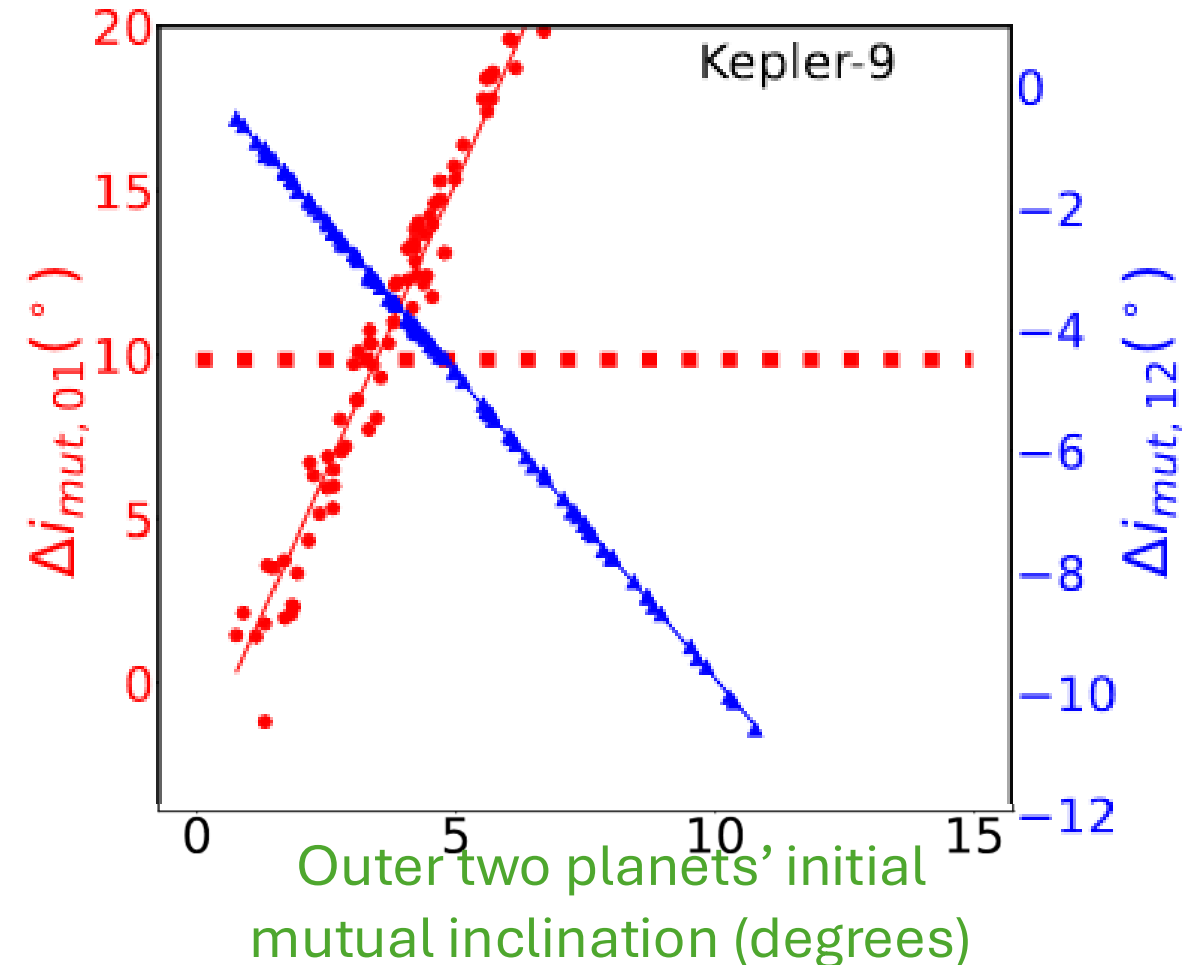


Image: Faridani, et. al., 2024





# How do these systems misalign?

- Typical Misalignment:
  - Inner planet misaligns from outer planets (high red)
  - Outer planets align with each other (low blue)
- Red dotted line: transit detectability limit

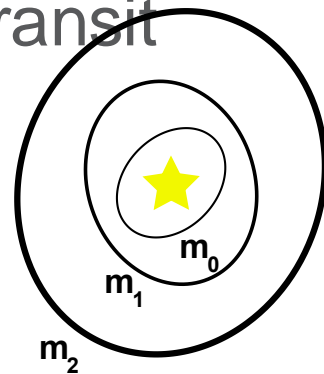
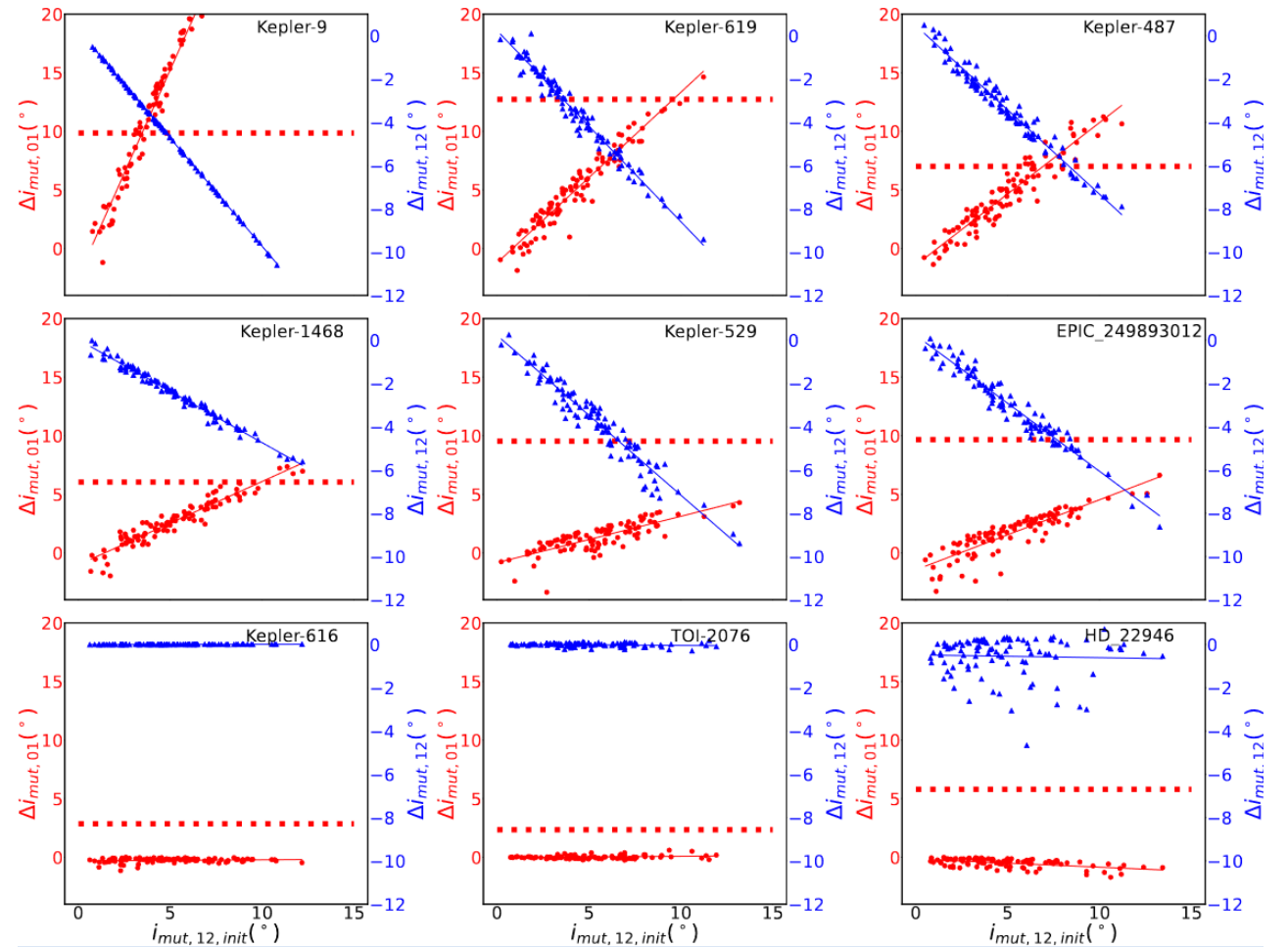


Image: Faridani, et. al., 2024



# How does Mass affect things?

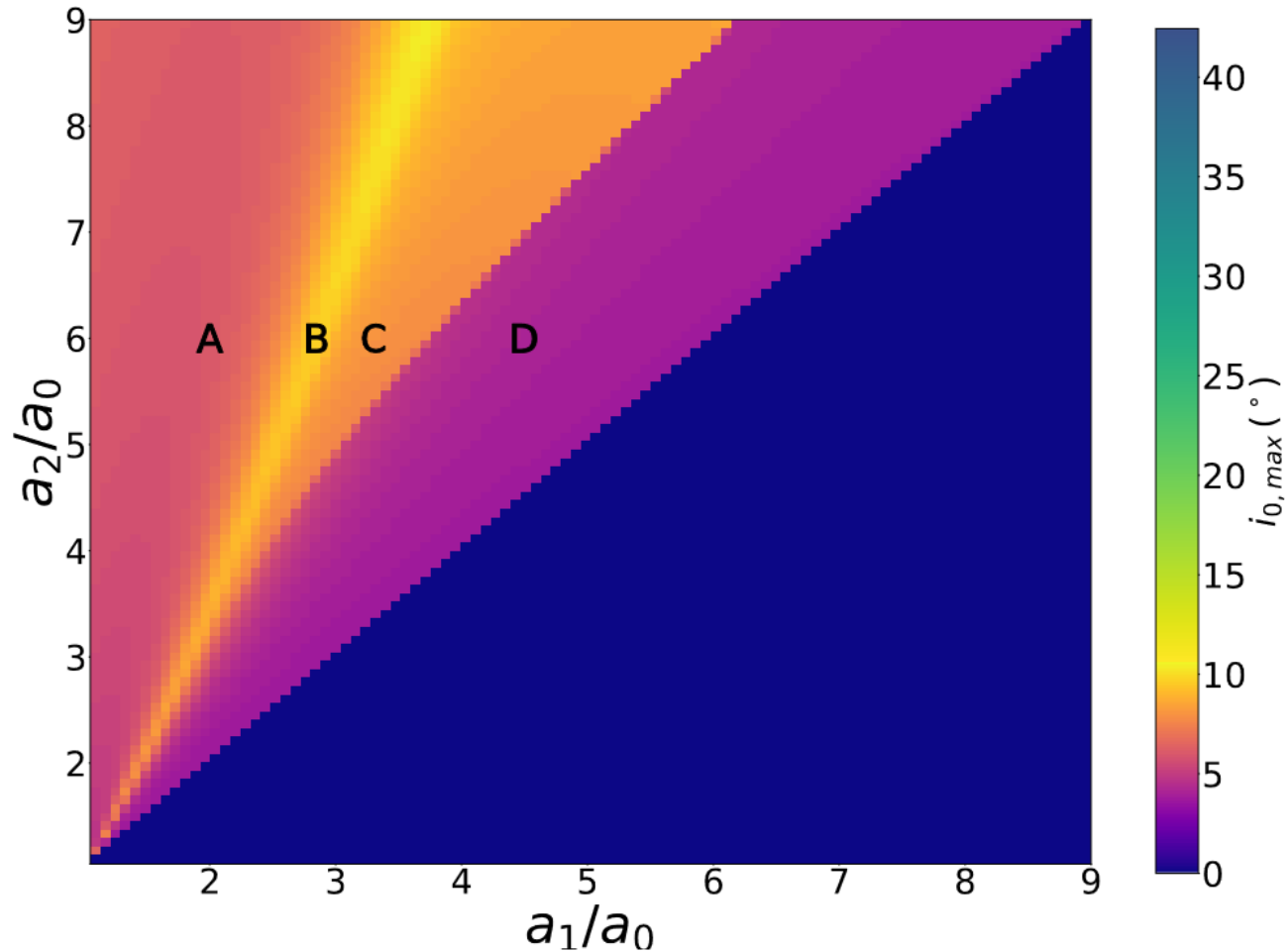


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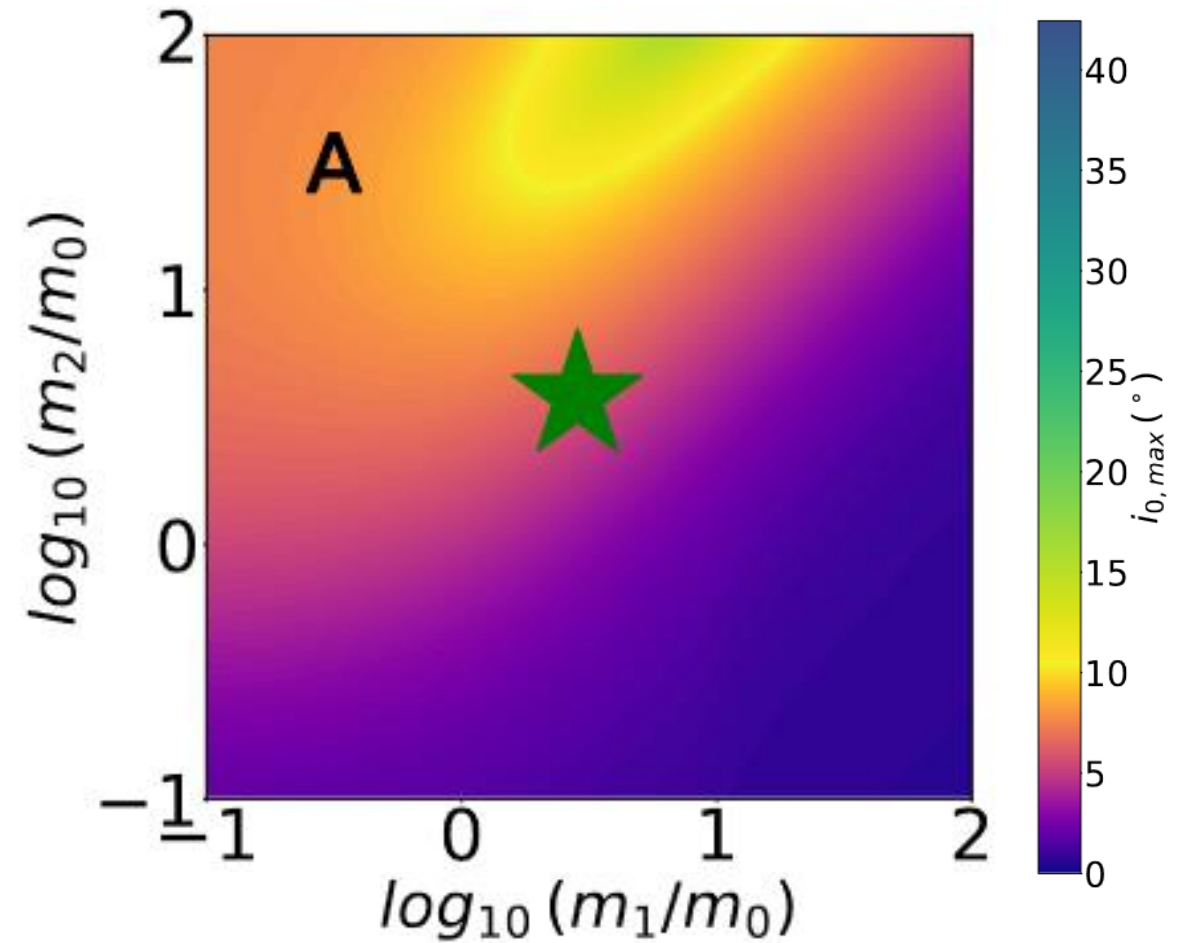
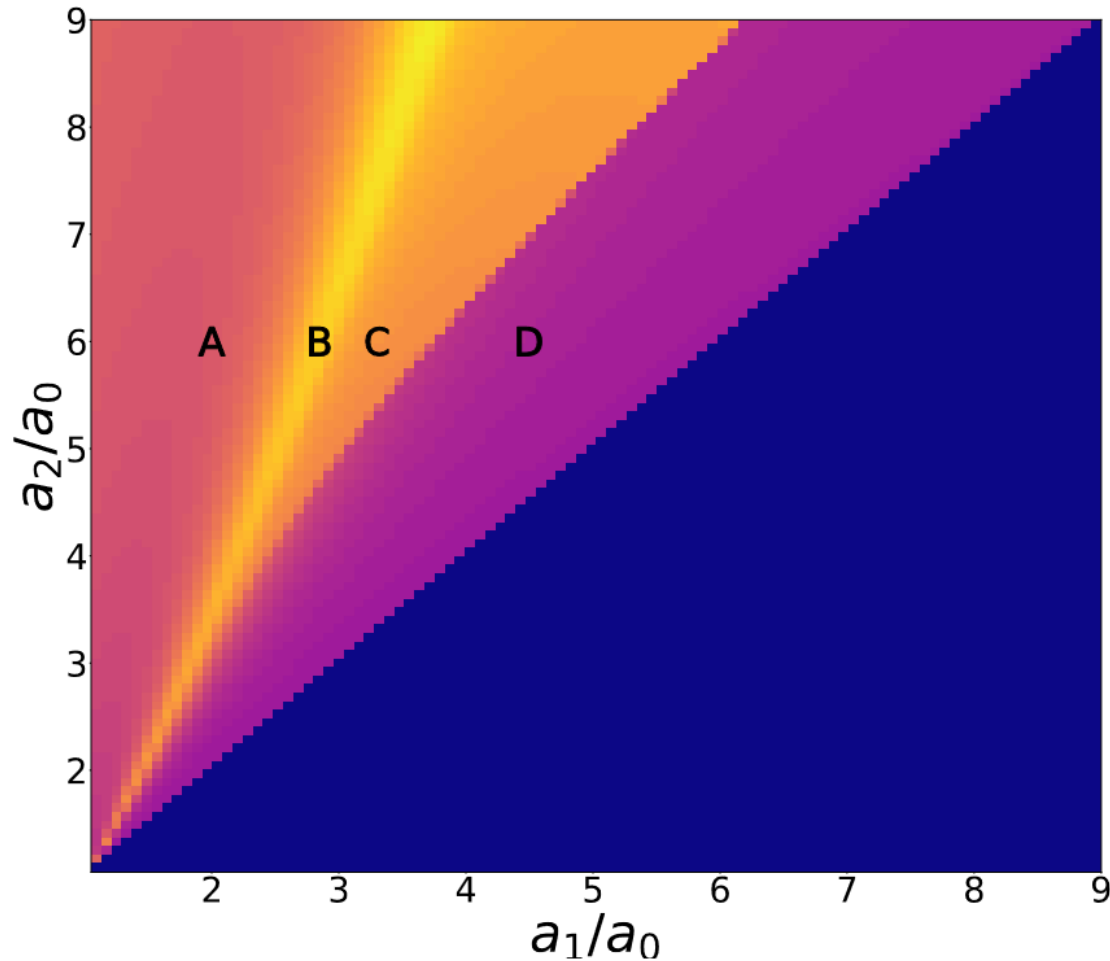


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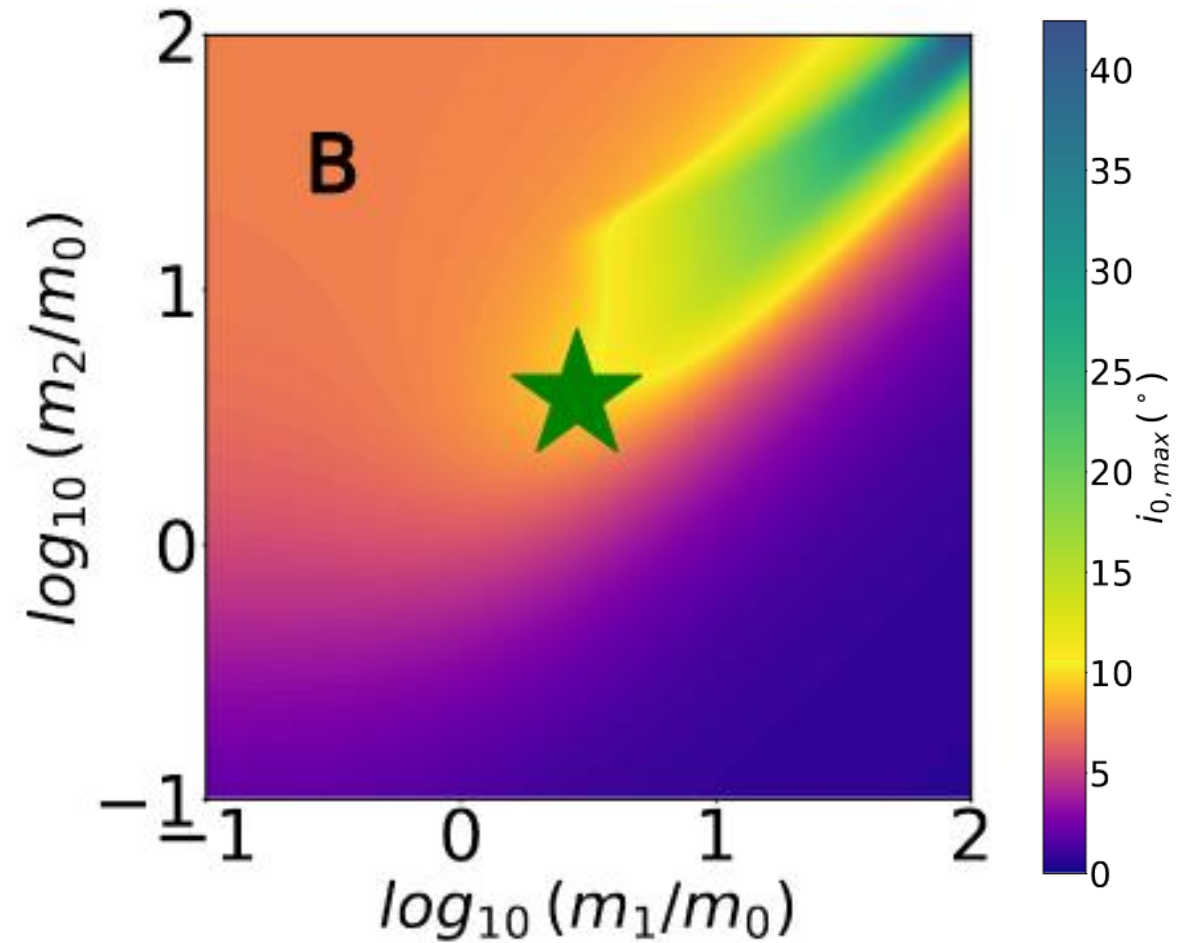
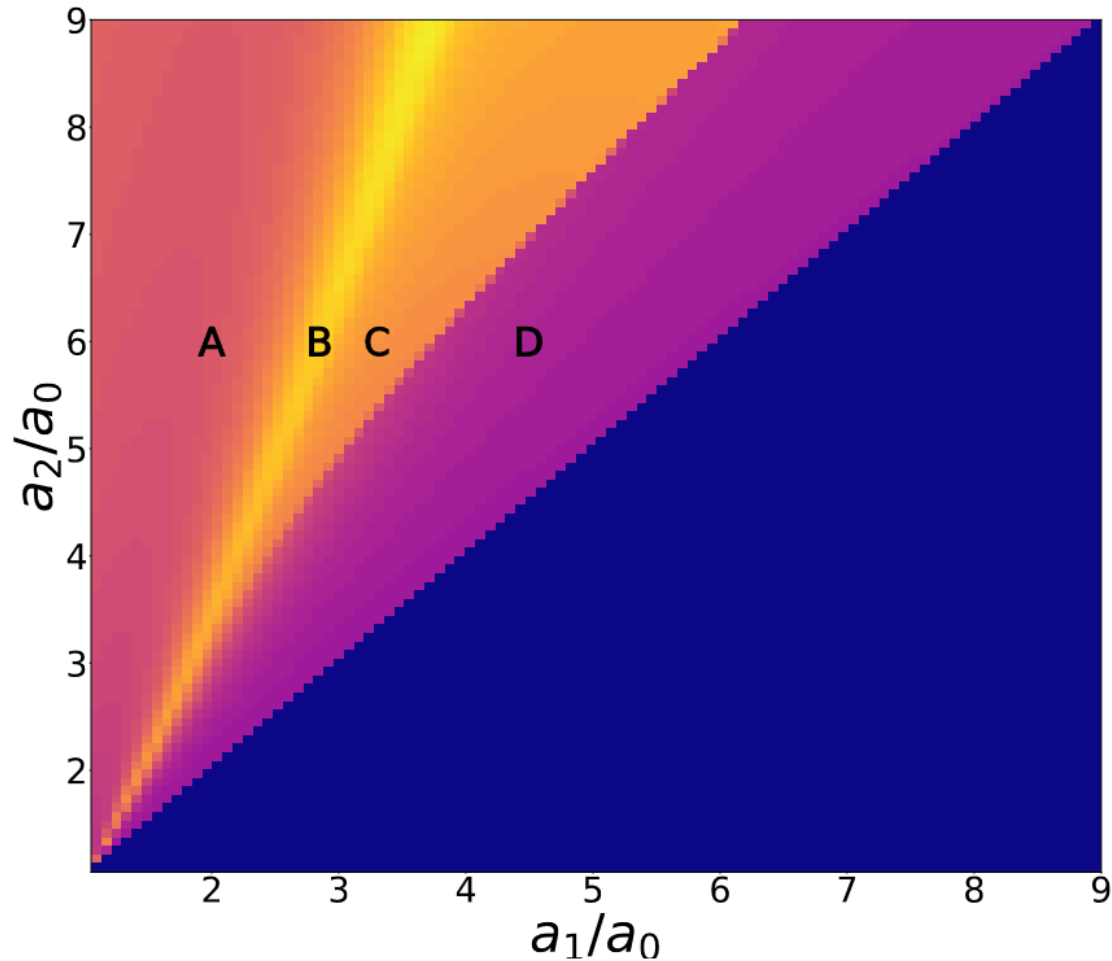


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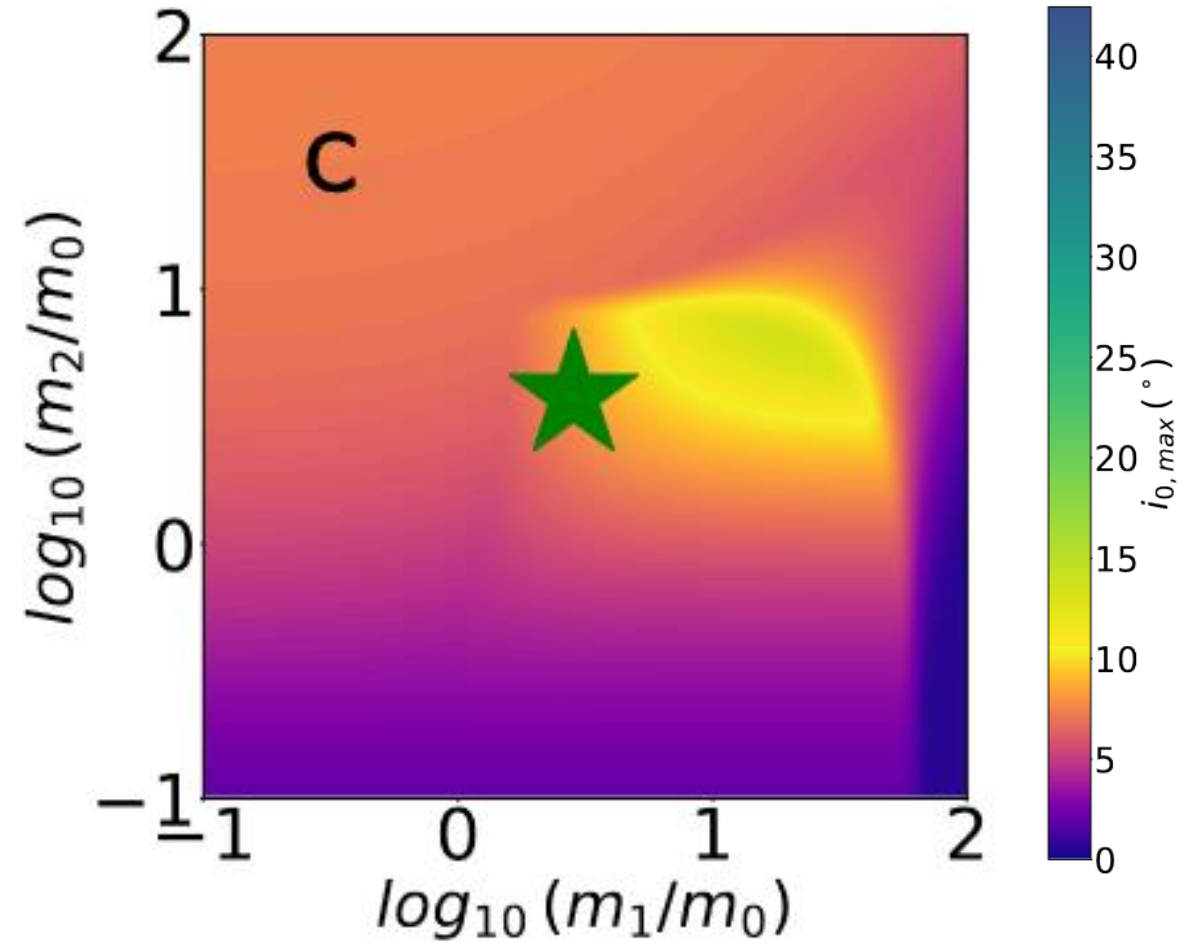
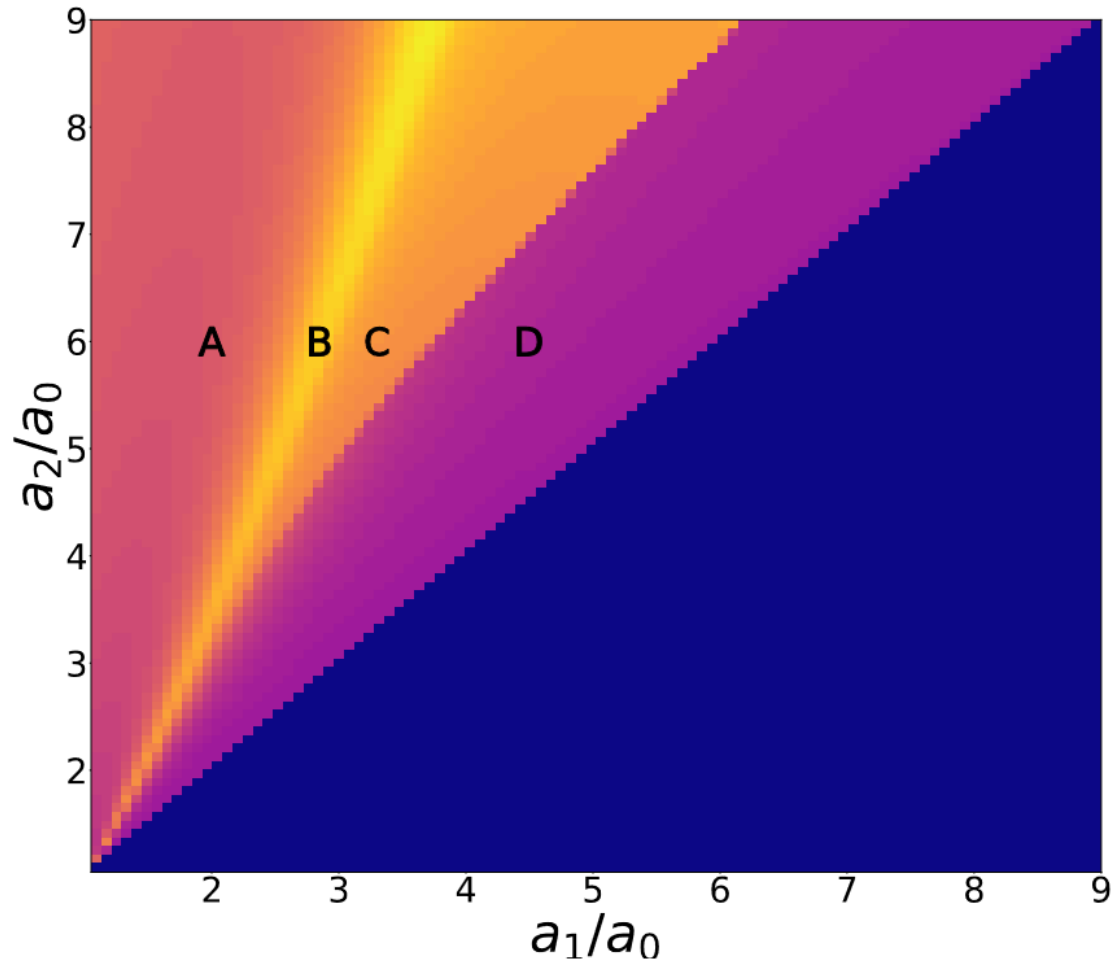


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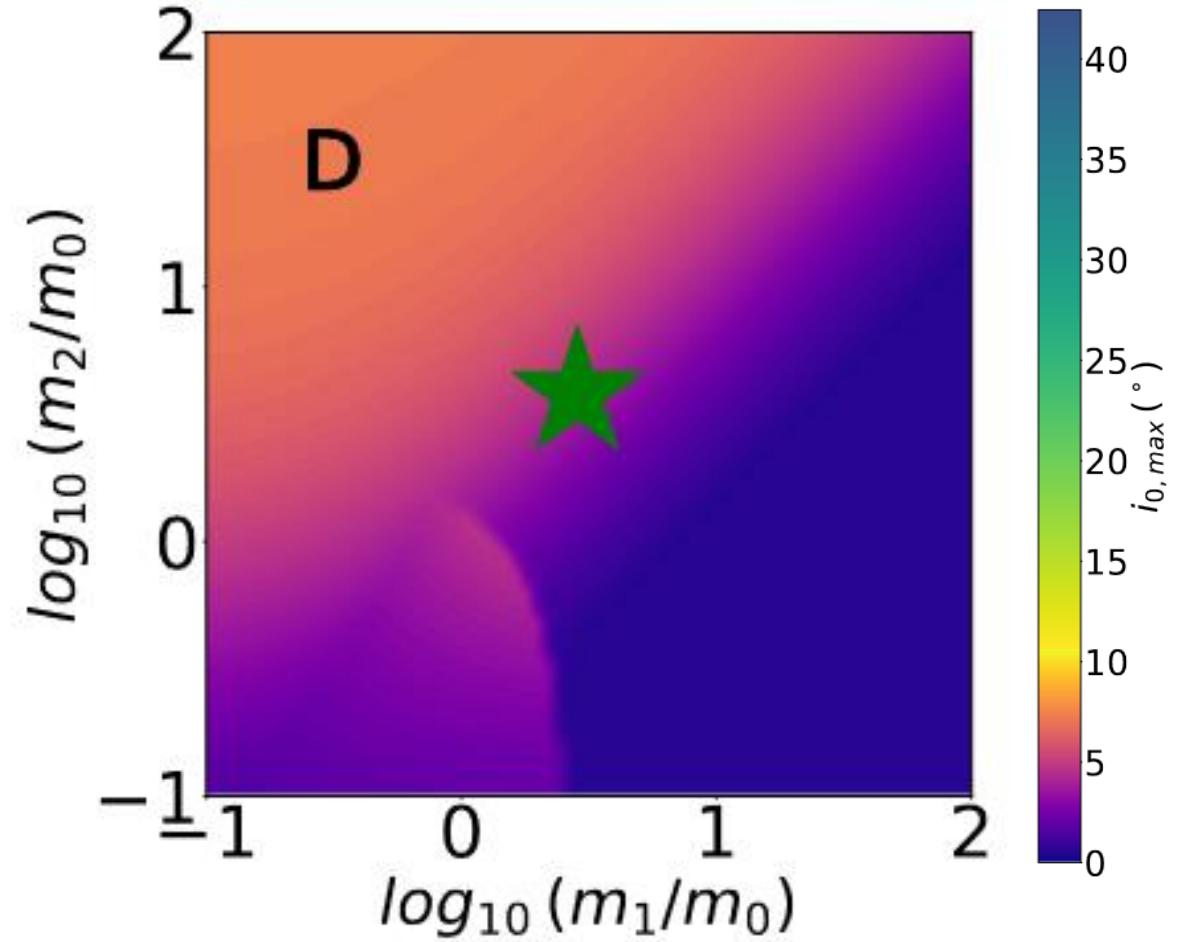
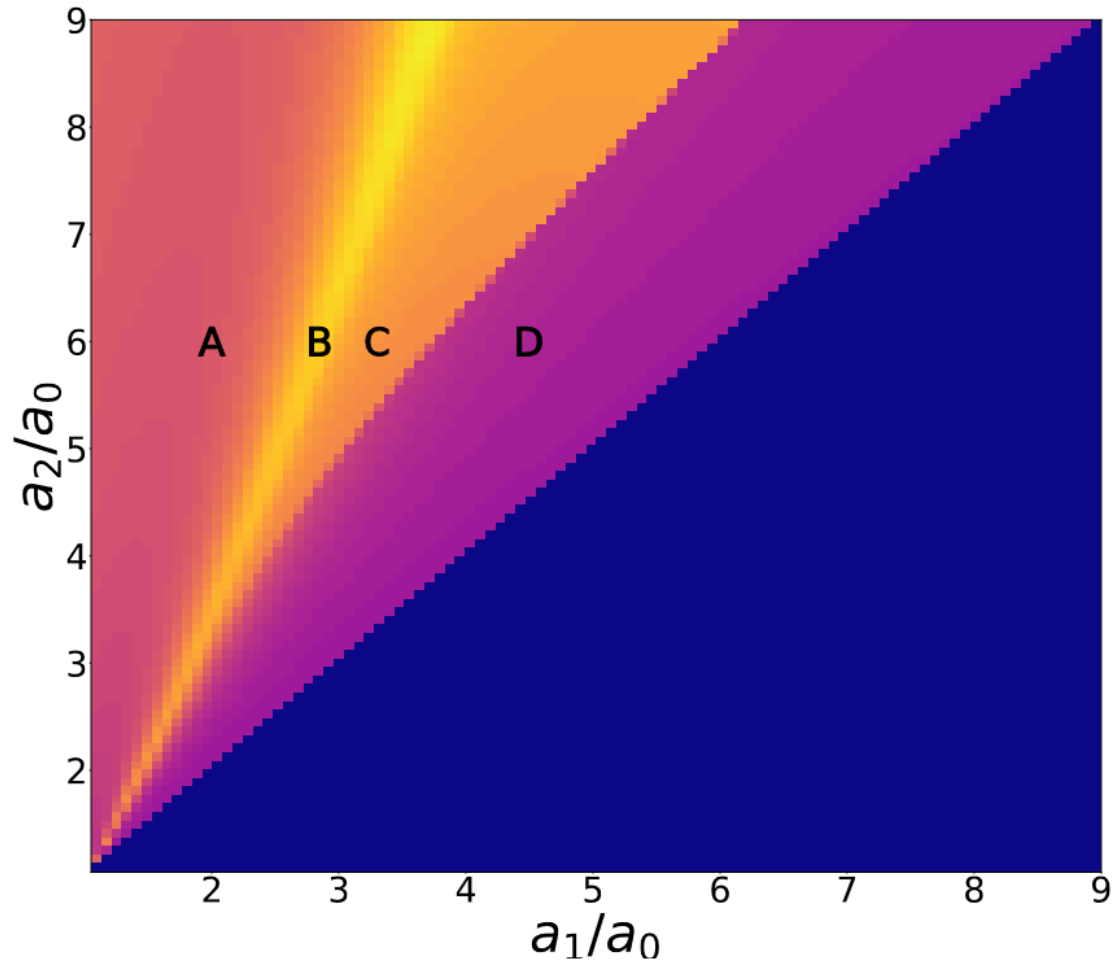
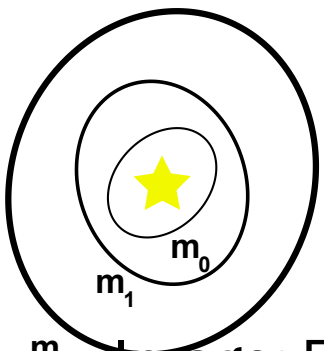
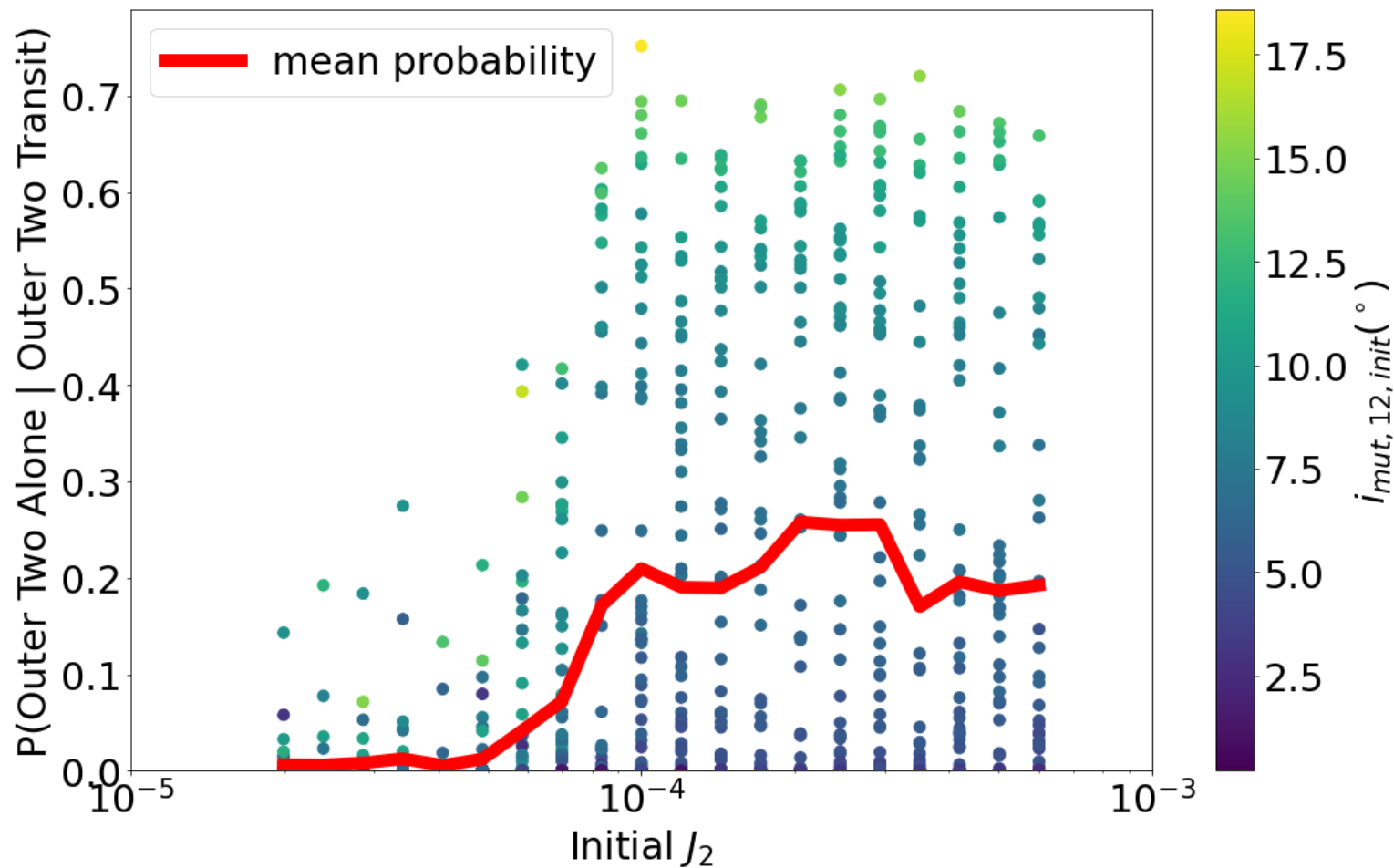


Image: Faridani, et. al., 2024

# How do these resonances affect transit probabilities?

## Kepler-619



$m_2$  Image: Faridani, et. al., 2025b, in prep



# How do these resonances affect transit probabilities?

- High  $J_2$  boosts transit probability slightly
- But Outer two planet's co-transit probability increases by ~50%
  - But at the cost of inclining the inner planet too much in some cases  
They're alone a fifth of the time they transit
- Similarly for the inner planet

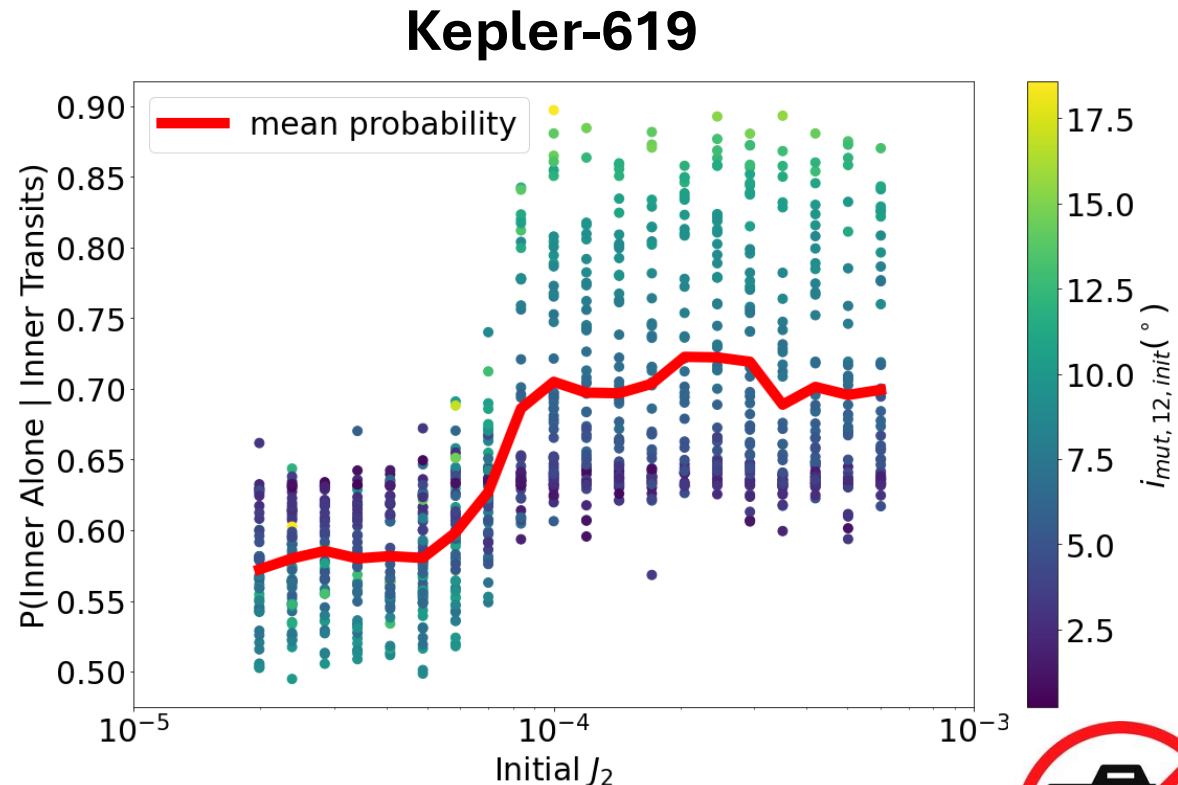
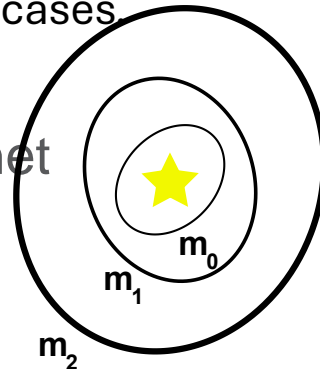


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