

By Jove, what a crowd!

Dynamical Sculpting of Giant Planet Populations in Cluster Environments

On the Prevalence of Hot Jupiters in M67

**UK
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CAMBRIDGE**

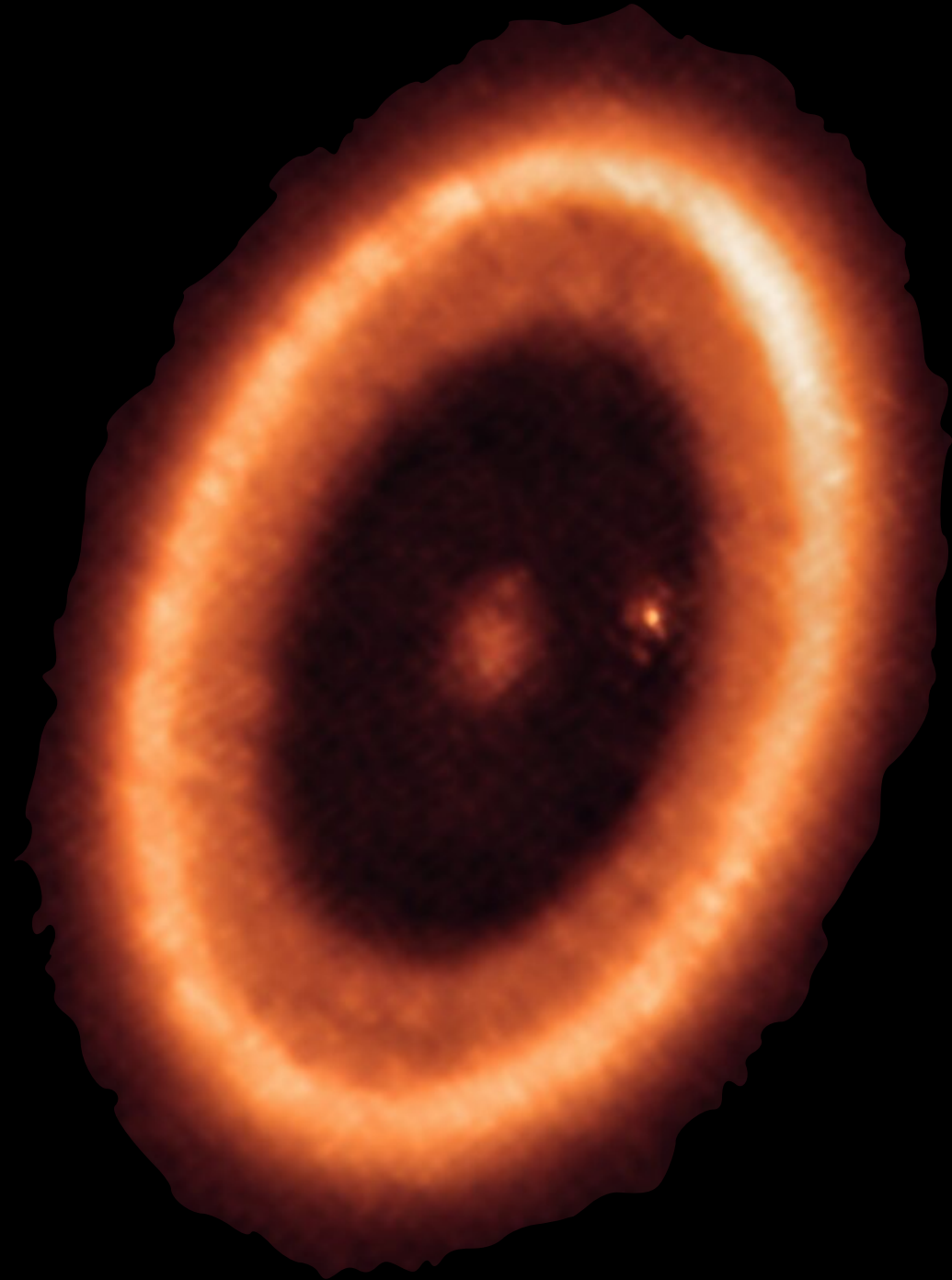
Institute of Astronomy

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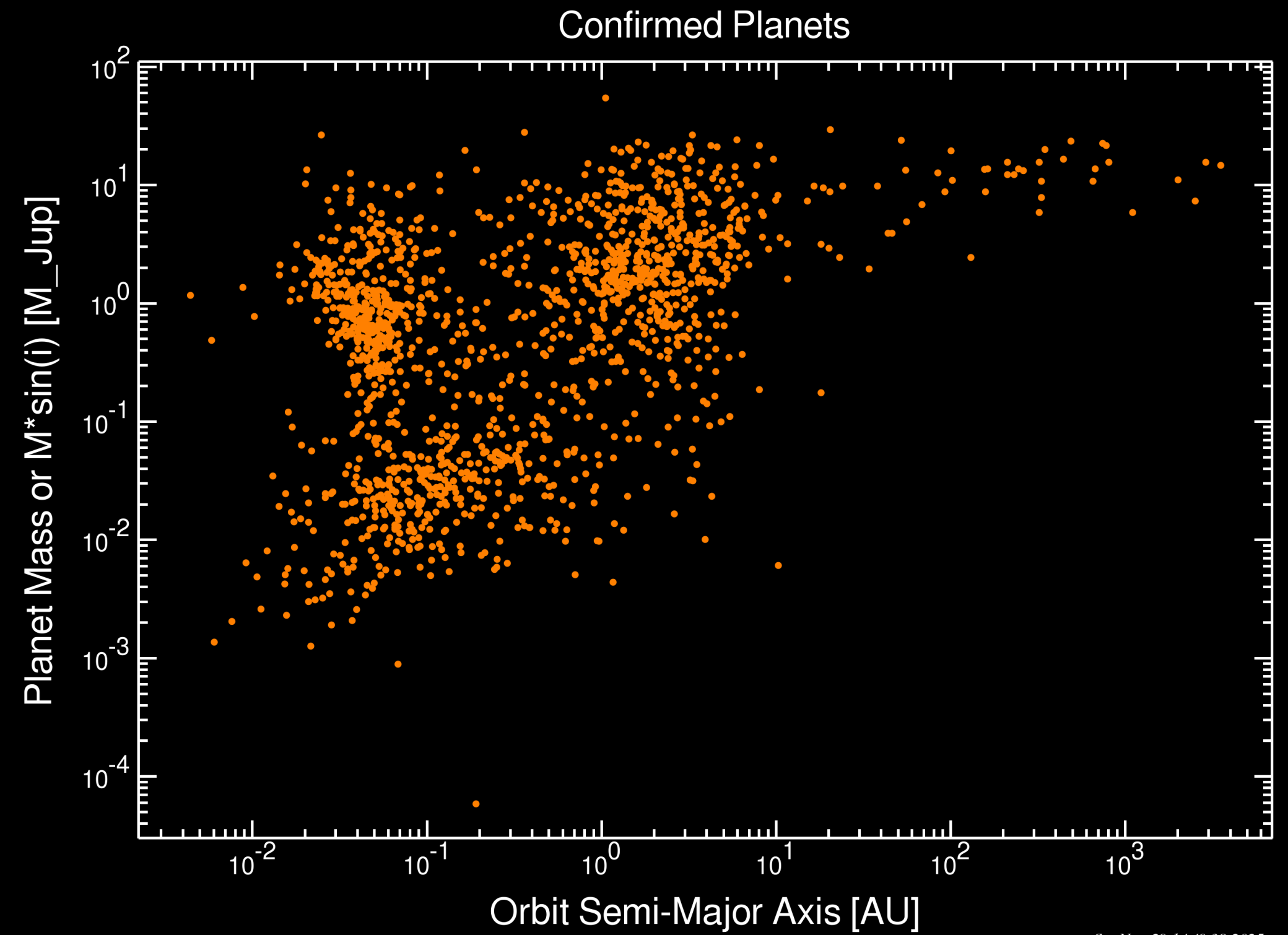
Nordic-Baltic Astronomy Days 2026, Turku, Finland

How it started.



F primordial

How it's going.




Sat Nov 29 14:49:38 2025

?

← →
Dynamical processing?
Environment?

F observed



Hot Jupiter

Definition

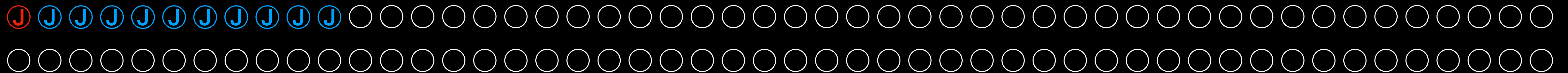
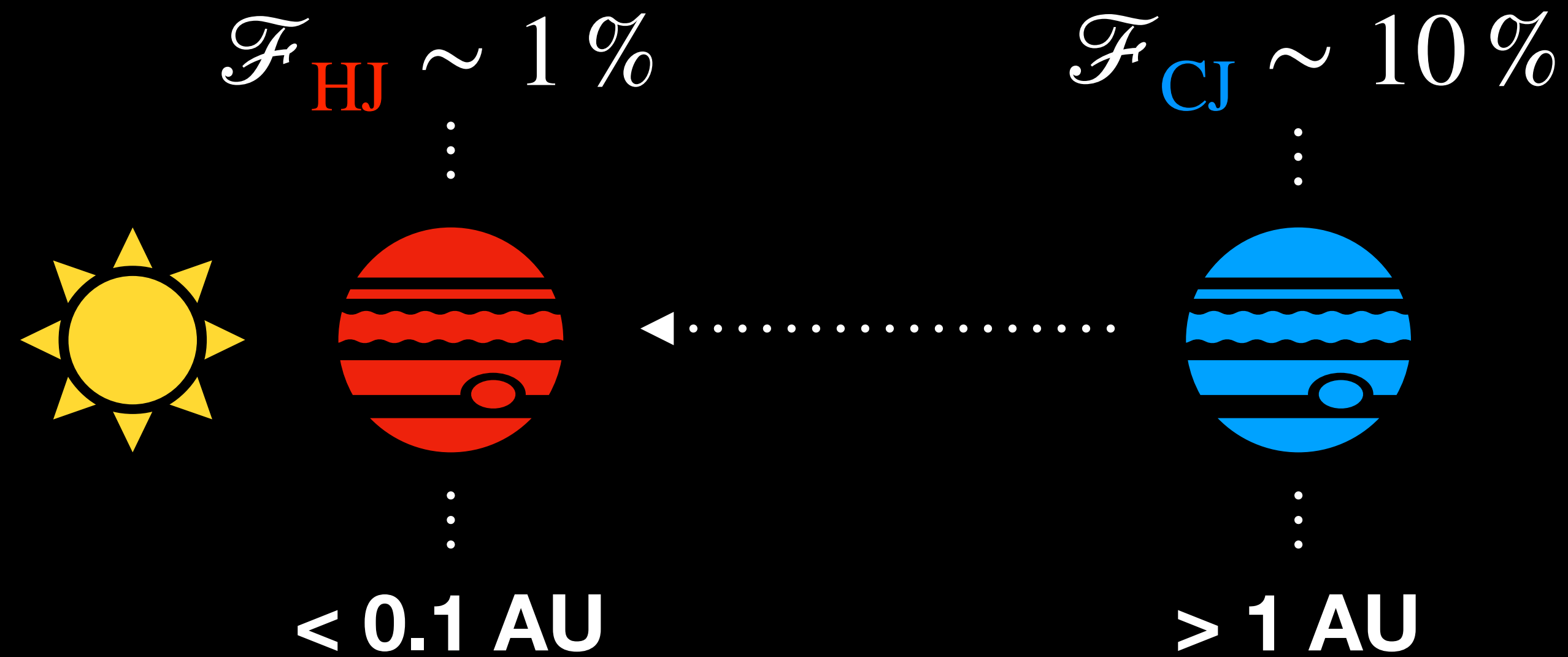
- $M_p > 0.3 M_J$
- $P < 10$ days

Example

51 Pegasi b

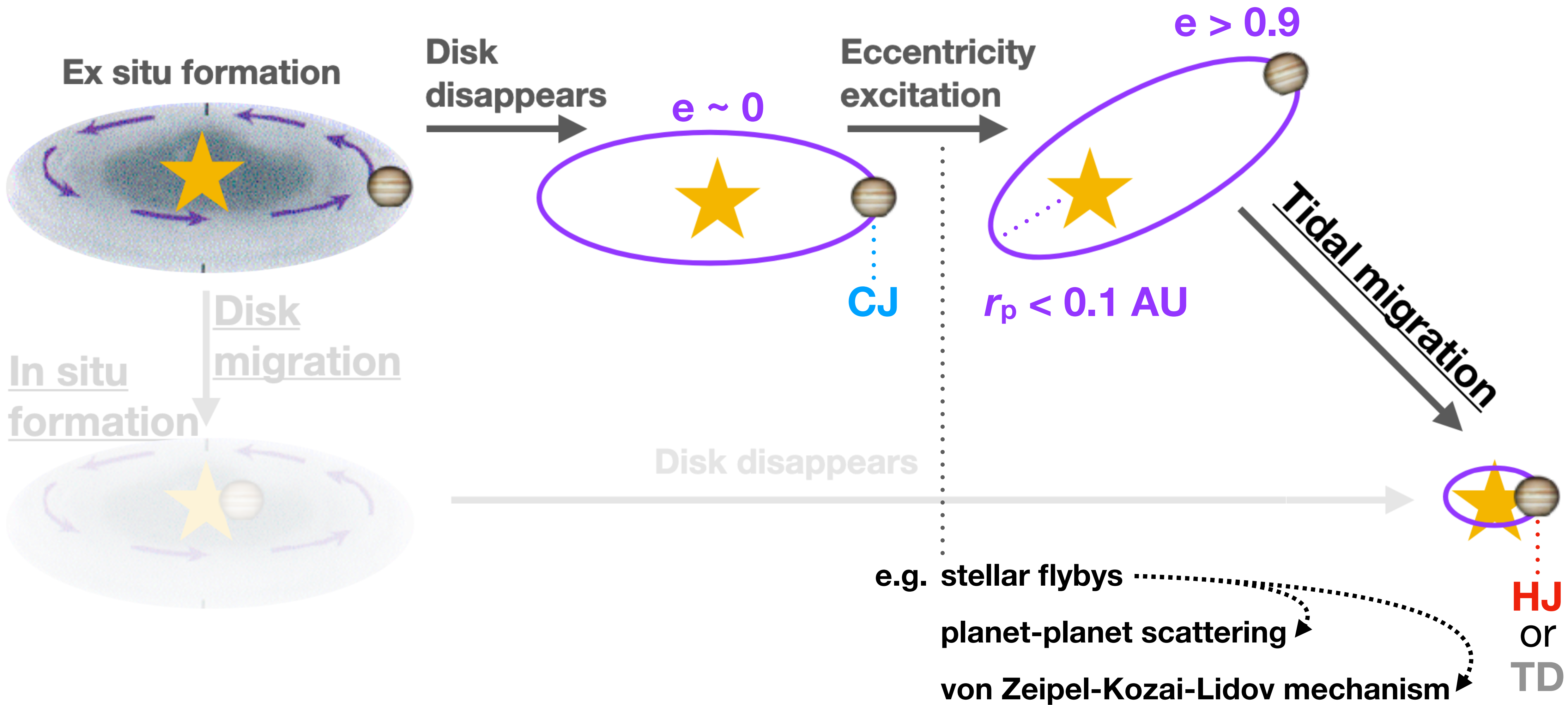
(Mayor & Queloz 1995)

Hot Jupiters likely didn't form in situ.



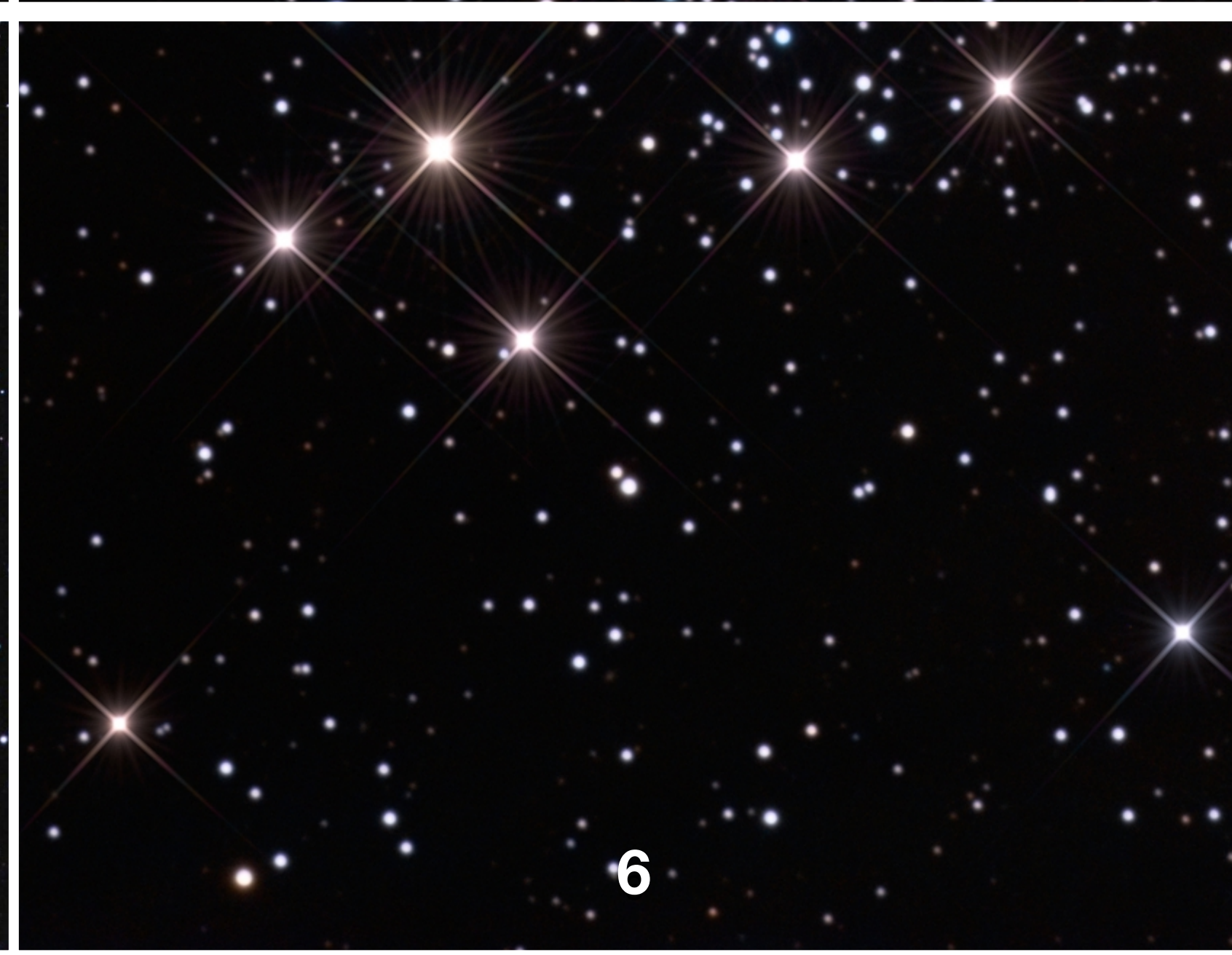
e.g. Beleznyay & Kunimoto 2022, Fulton et al. 2021, Hirsch et al. 2021

High-eccentricity Migration (HEM)



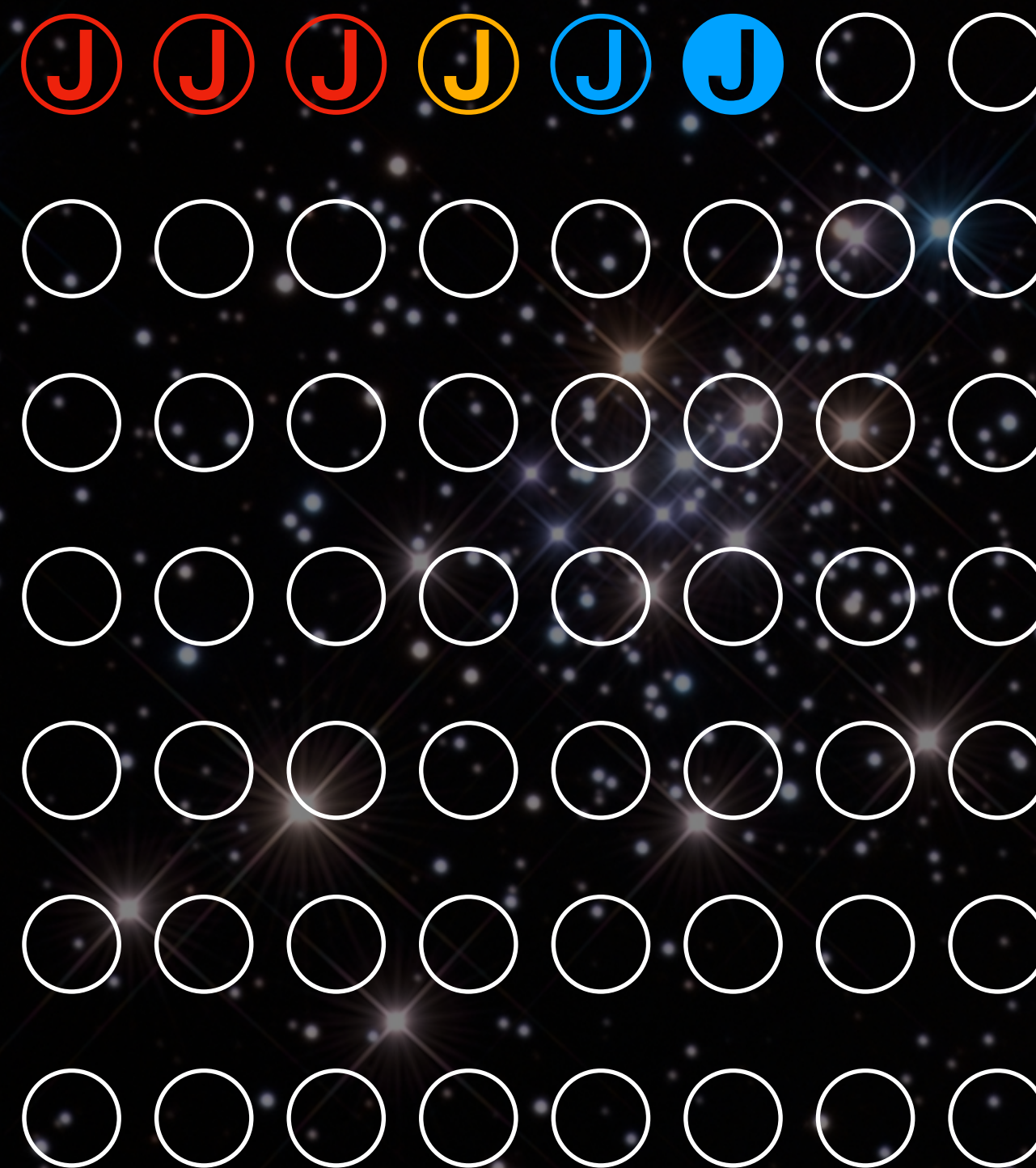


encounter rate $\propto n_{\star}$



M67

(age ~ 4 Gyr, [Fe/H] ~ 0.08)



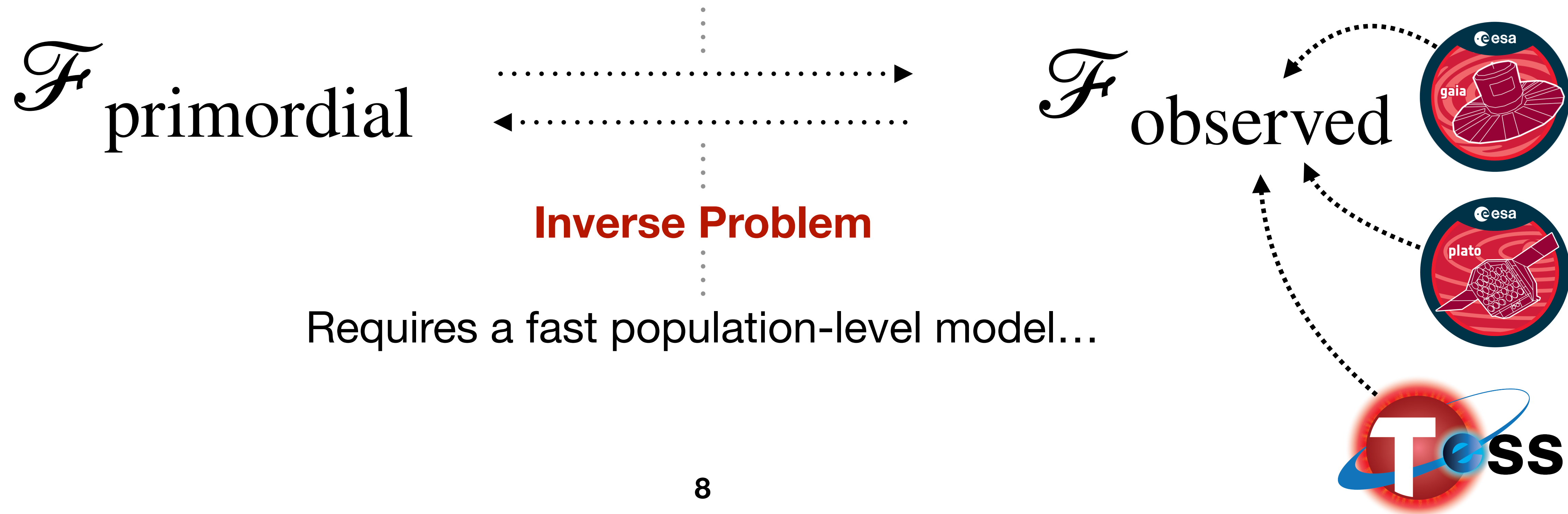
$$F_{\text{HJ}} = 5.4^{+5.1}_{-3.0} \%$$

Previous Work

Limitations: small sample size / limited ICs / extrapolation from single flybys

Shara et al. 2016, Hamers & Tremaine 2017, Li et al. 2020, 2023, 2024,

Wang et al. 2020, 2022, Rodet et al. 2021, Benkendorff et al. 2024



Method

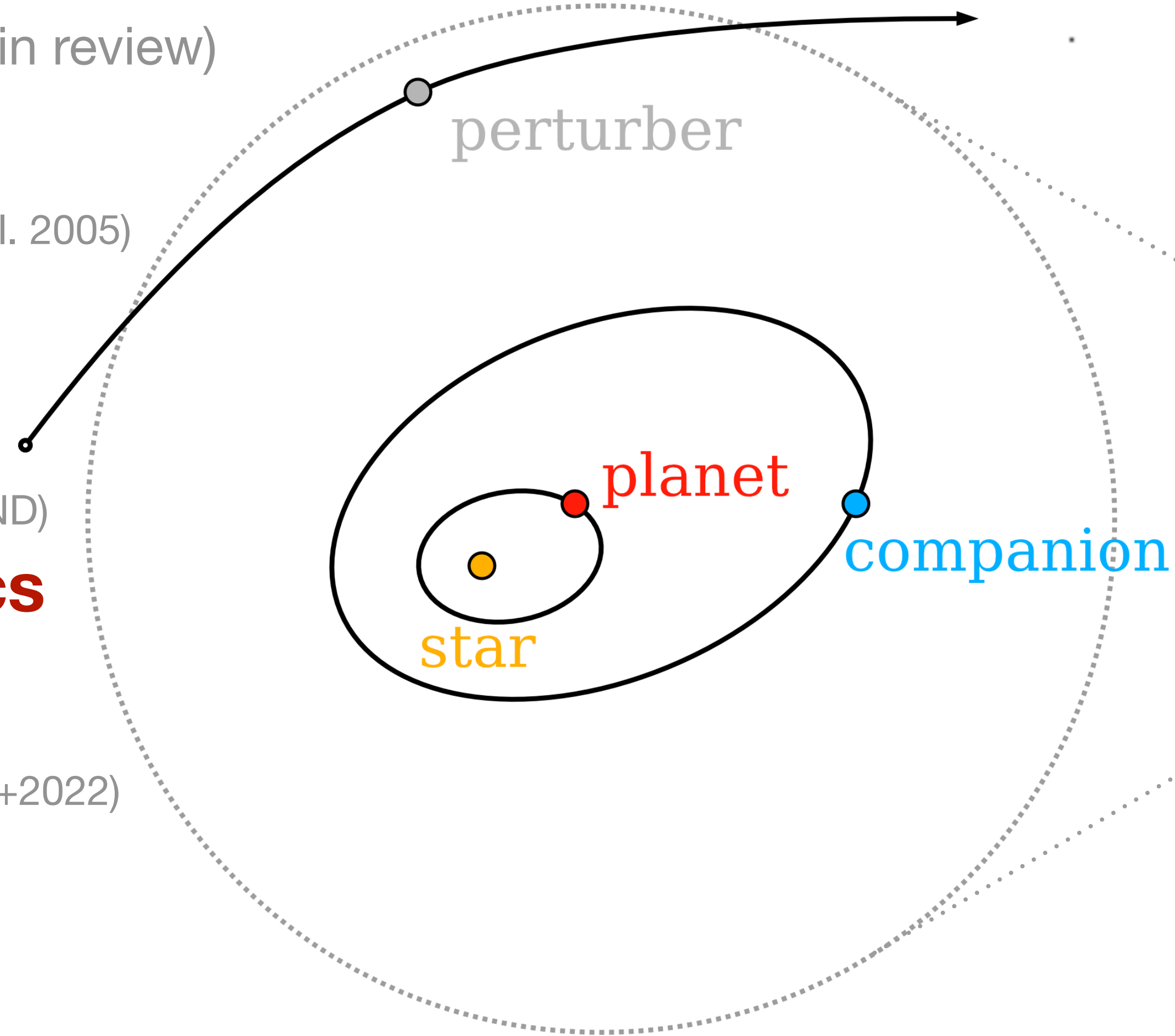
Konttainen, Clarke, & Winter (in review)

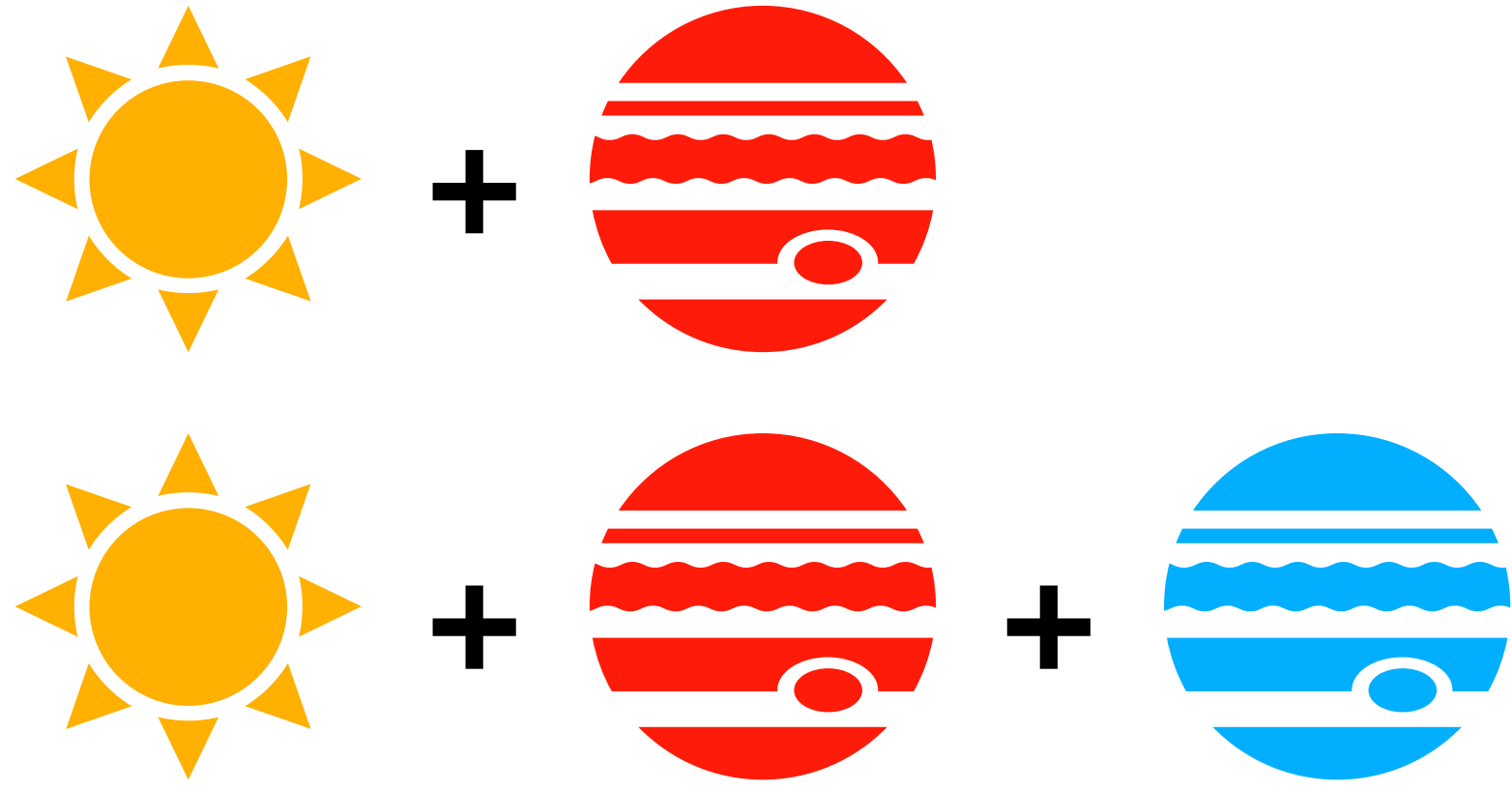
- **Cluster Evolution**
(prescription based on Hurley et al. 2005)
- **Stellar Dynamics**
(Gala, Price-Whelan 2017)
- **Stellar Flybys**
(Heggie & Rasio 1996 \Leftrightarrow REBOUND)
- **Planetary Dynamics**
(secular octupole \Leftrightarrow REBOUND)
- **Tidal Evolution**
(equilibrium \Leftrightarrow dynamical, Rozner+2022)

Hybrid approach:

analytic \Leftrightarrow numerical

→ 1,000s of planetary systems can be evolved over Gyr timescales

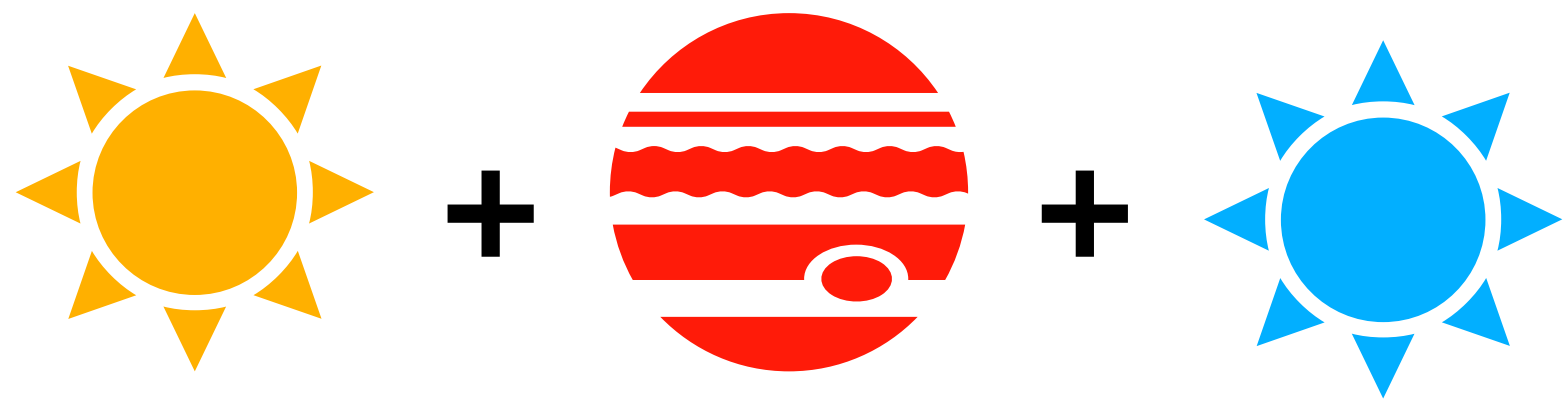




HJ formation in one- and two-planet systems **inefficient...**

BUT

stellar flybys enhance HJ / TD rates by factor **2–3** in wide binaries



Field
 $f_{\text{HJ}} \sim 5.5\%$
 $f_{\text{TD}} \sim 4.1\%$

+ stellar flybys

Cluster Core
 $f_{\text{HJ}} \sim 11.4\%$
 $f_{\text{TD}} \sim 14.6\%$

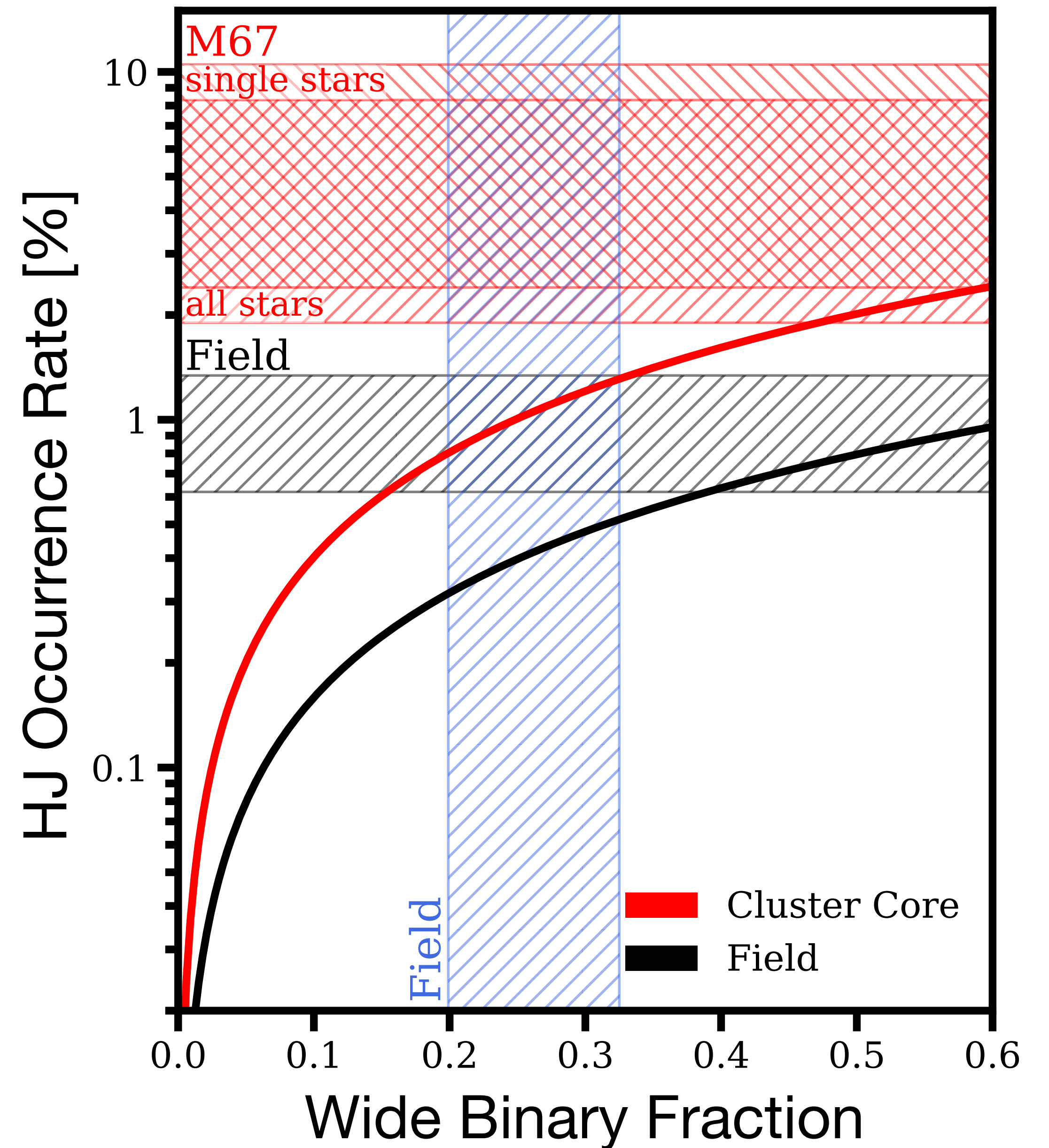
Connection to Observations

$$\mathcal{F}_{\text{HJ}} = f_{\text{GP}} \times f_{\text{bin}} \times (f_{\text{HJ}} + f_{\text{TD}} \times f_{\text{surv}})$$

Field and **M67** HJ occurrence rates reproduced (within uncertainties) by the same agnostic set of ICs

IF

- a fraction of tidally disrupted systems survive as HJs (Weldon et al. 2025)
- primordial wide binary fraction $\sim 50\%$



Implications

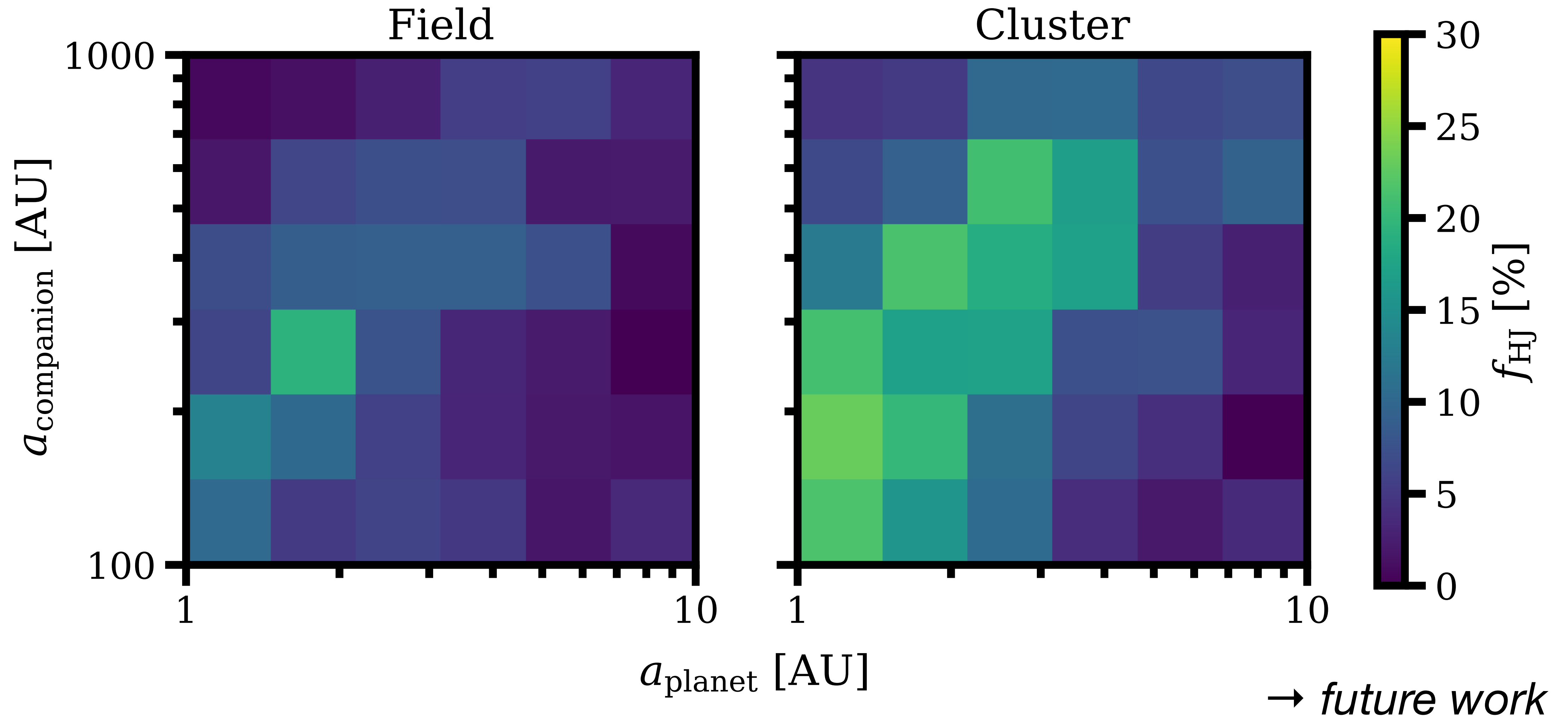
Supports **binary-driven HEM** as a dominant HJ formation pathway (cf. Rice et al. 2022, Weldon et al. 2025)

→ Absence of observed companions to HJs in M67 explained by $\sim 2/3$ of HJ-forming binaries being disrupted by flybys

$\geq 30\%$ enhancement in HJ occurrence among **cluster escapers**

→ Contribution to field population?

Enhancement in f_{HJ} not uniform:



Summary

- Efficient **hybrid method** enables fast modelling of planetary populations in star clusters
→ population synthesis + inference
- In **stellar binaries**, flybys in a cluster environment boost HJ yield x2 and TD rate x3 compared to the field
- Primordial $f_{WB} \sim 50\%$ reproduces both field and M67 rates with otherwise agnostic ICs, hinting at **binary-driven HEM** as a dominant HJ formation pathway



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Thank you!