Crowding Out of Giants: Formation of Terrestrial Planets under the Influence of a Hot Jupiter

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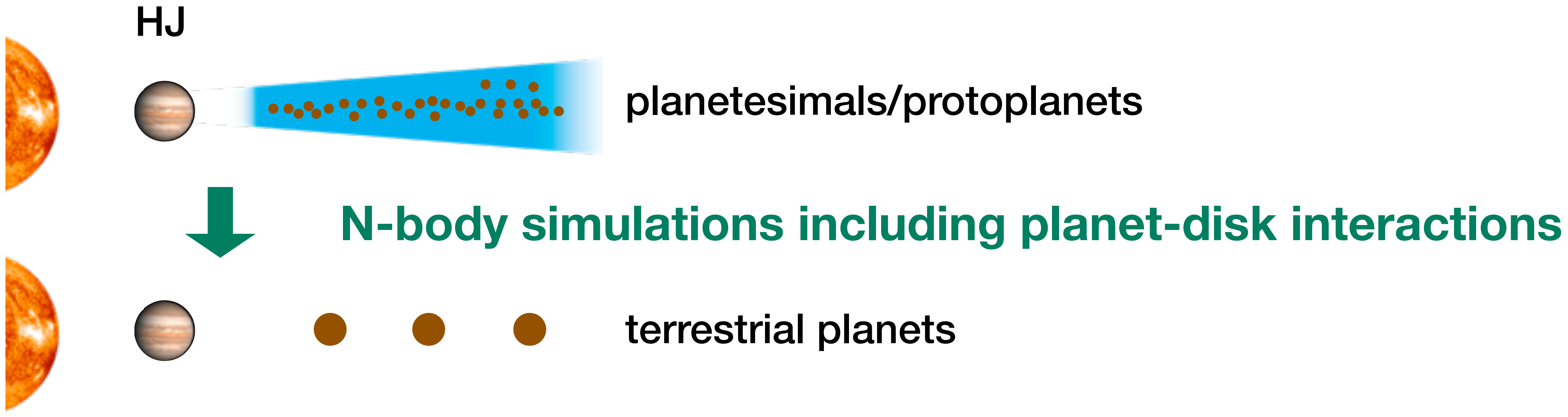

Acknowledgements: Shoichi Oshino, Eiichiro Kokubo, Yasunori Hori

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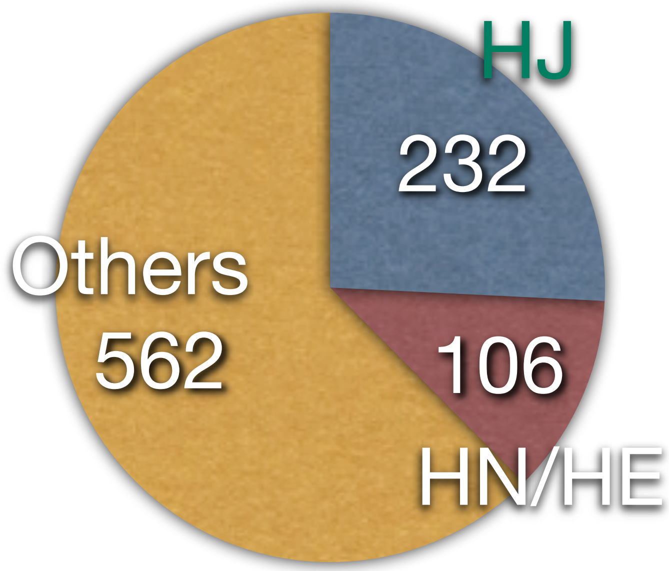
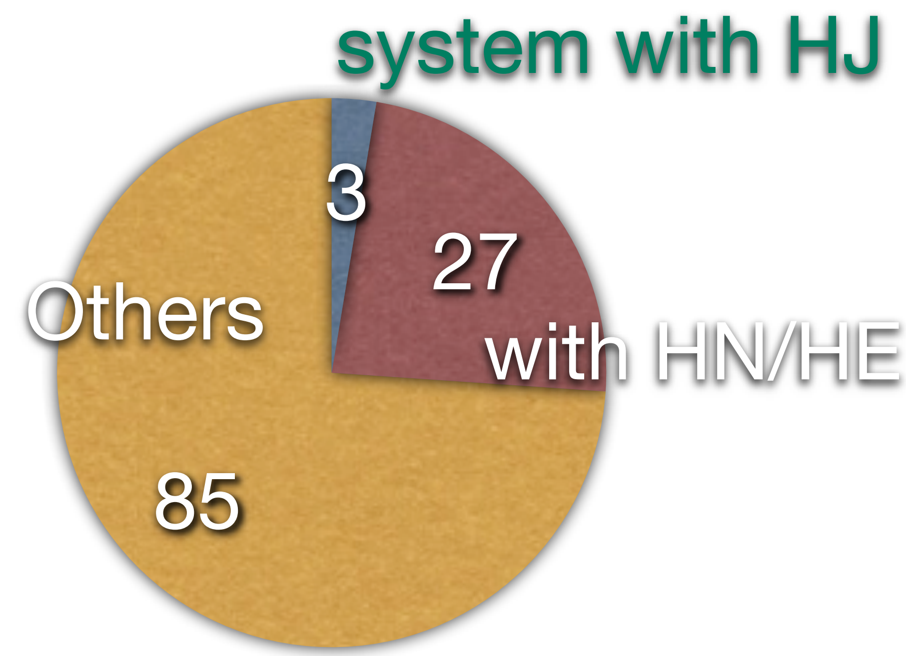
Property of multiple systems

Observational data (exoplanet.eu)

number of exoplanets



number of multiple systems



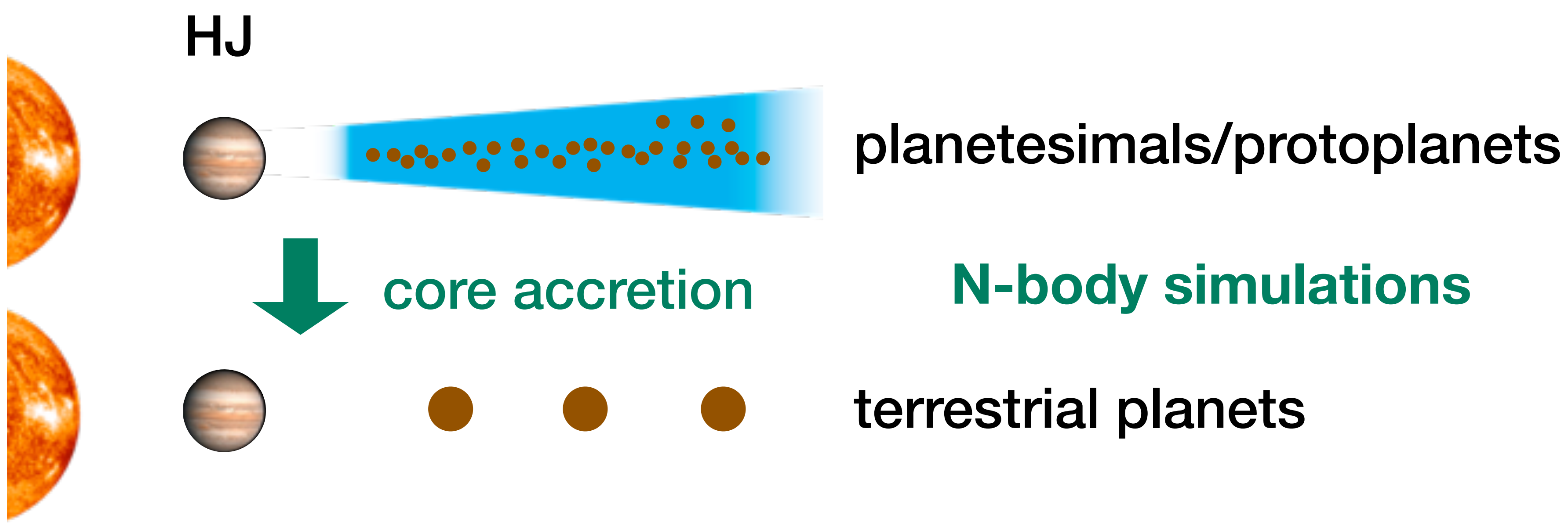
Lack of additional planets in hot Jupiter (HJ) systems

⬇

HJ affects formation of (terrestrial) planet? ***our motivation***

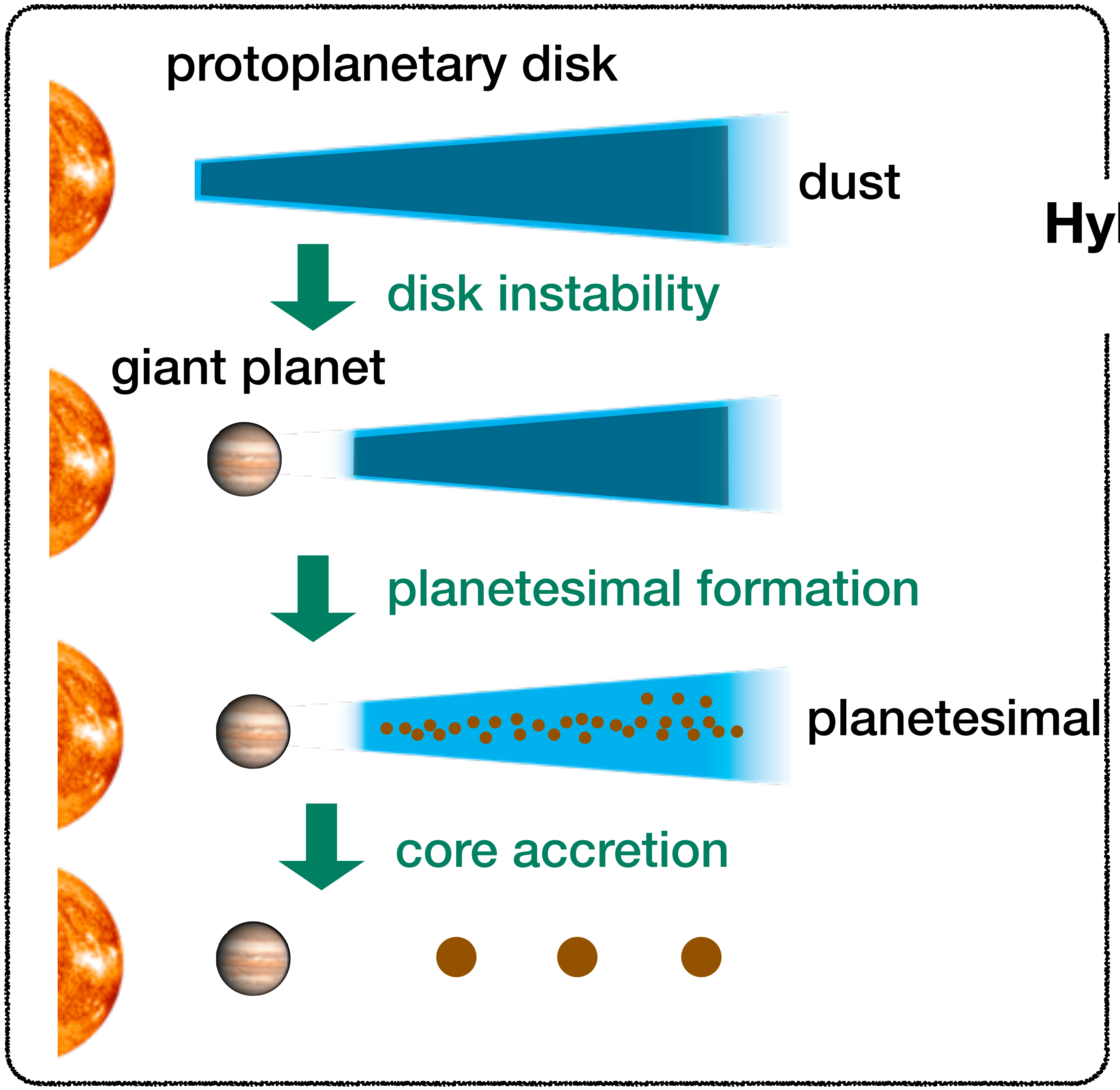
Aim

We investigate formation of (close-in) terrestrial planets under the influence of a HJ using N-body simulations



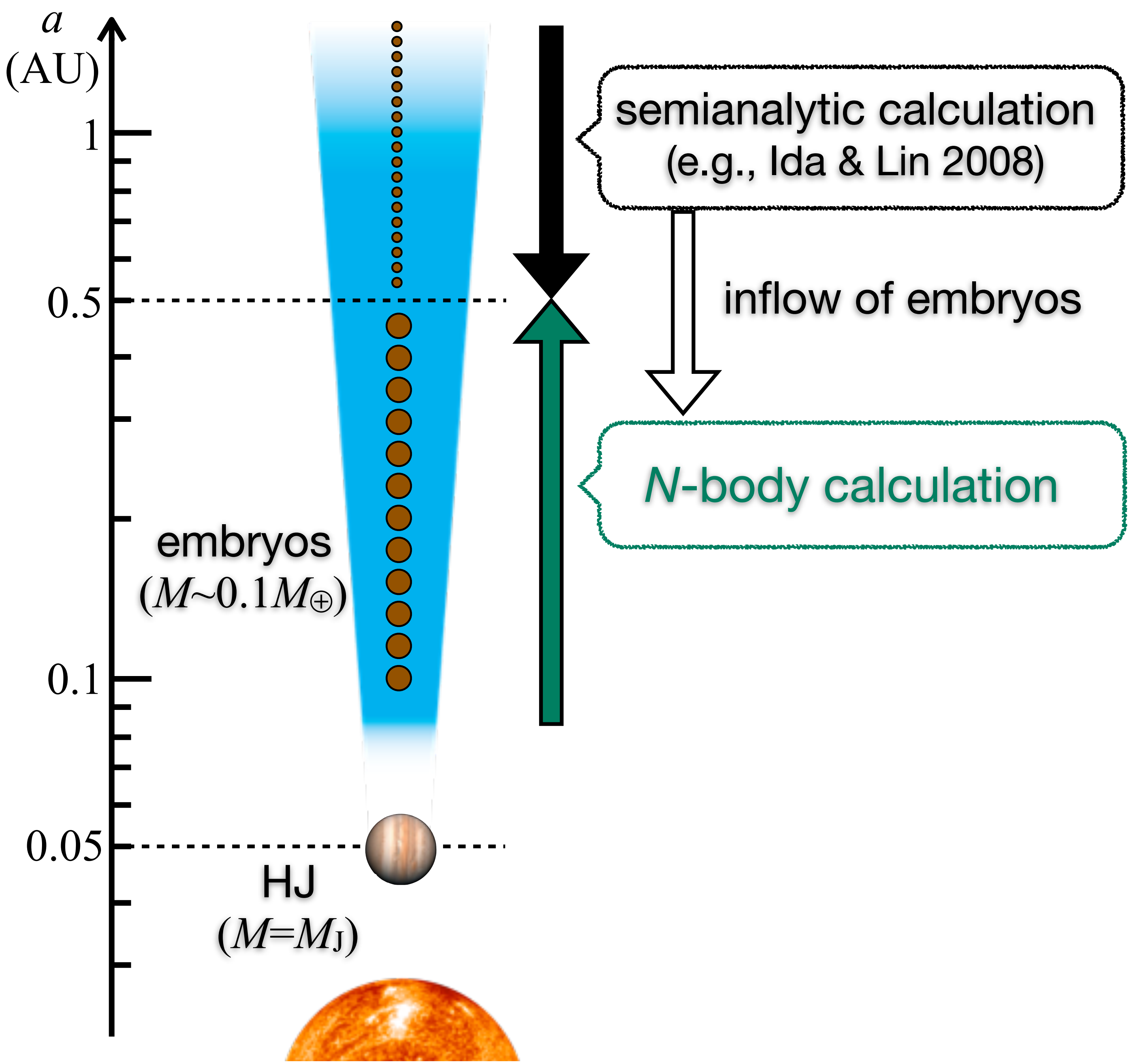
[app.] Aim

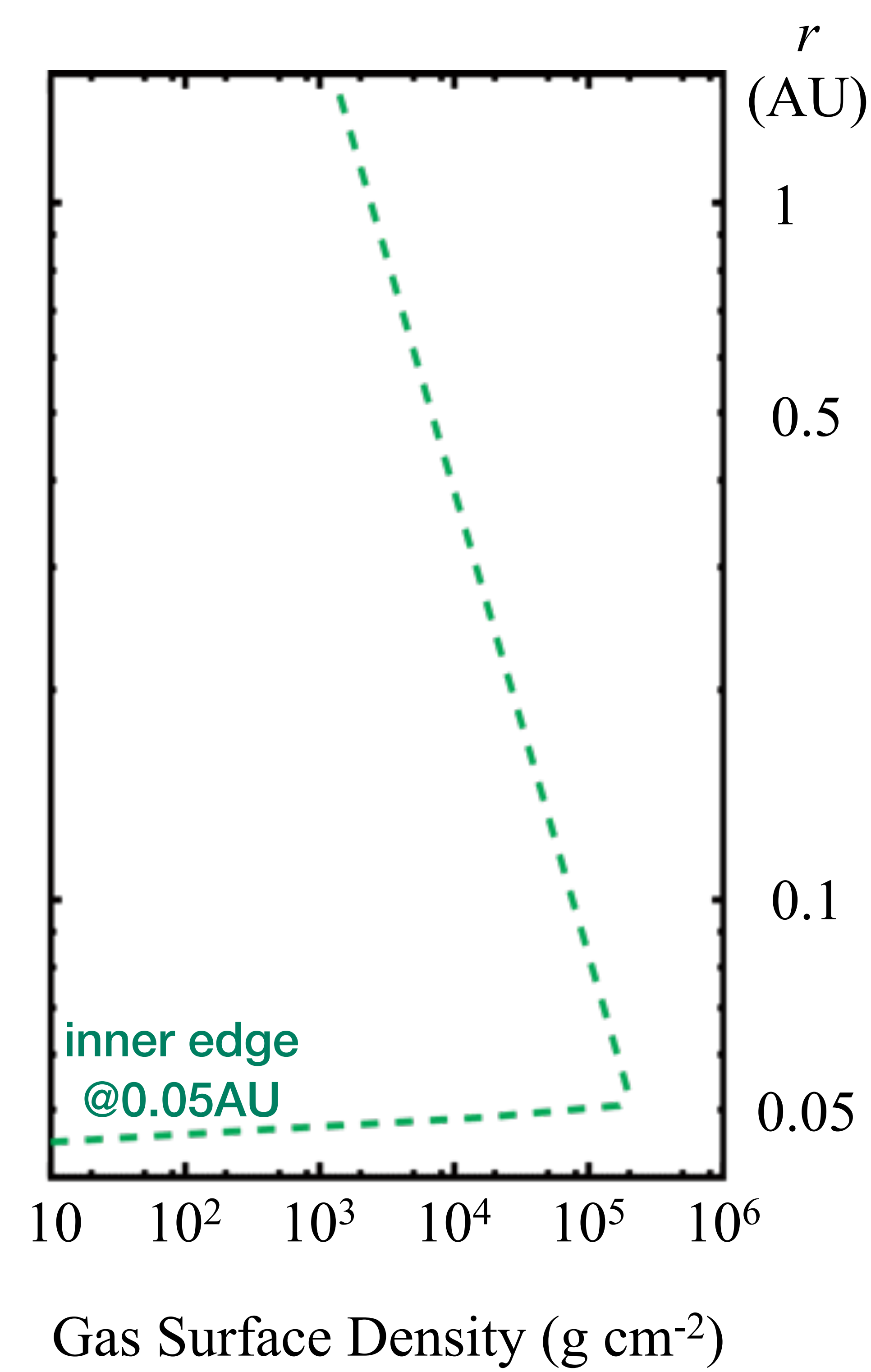
We investigate formation of (close-in) terrestrial planets under the influence of a HJ using N-body simulations



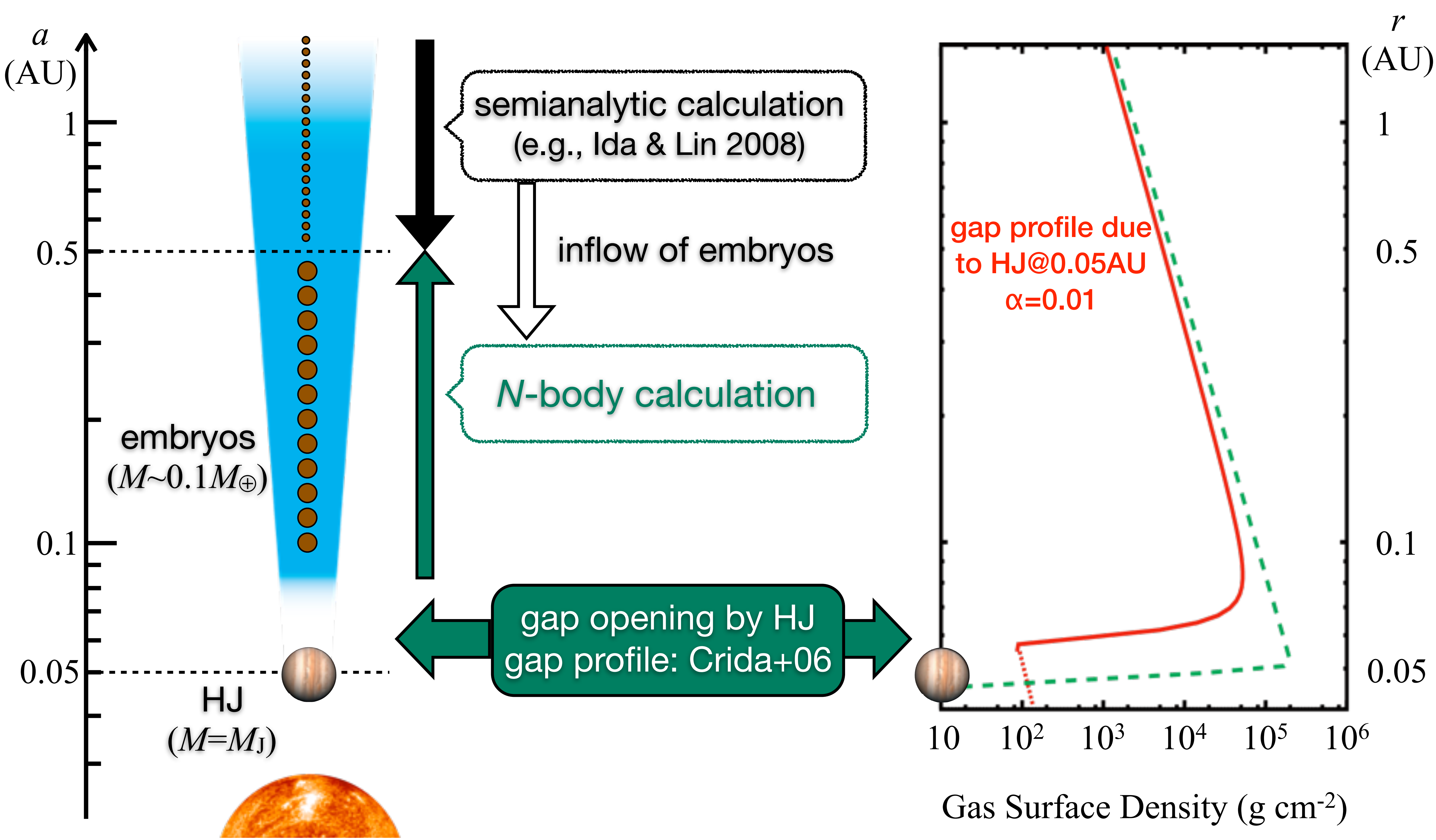
Hybrid scenario of planet formation (Inutsuka 2009)

Numerical model

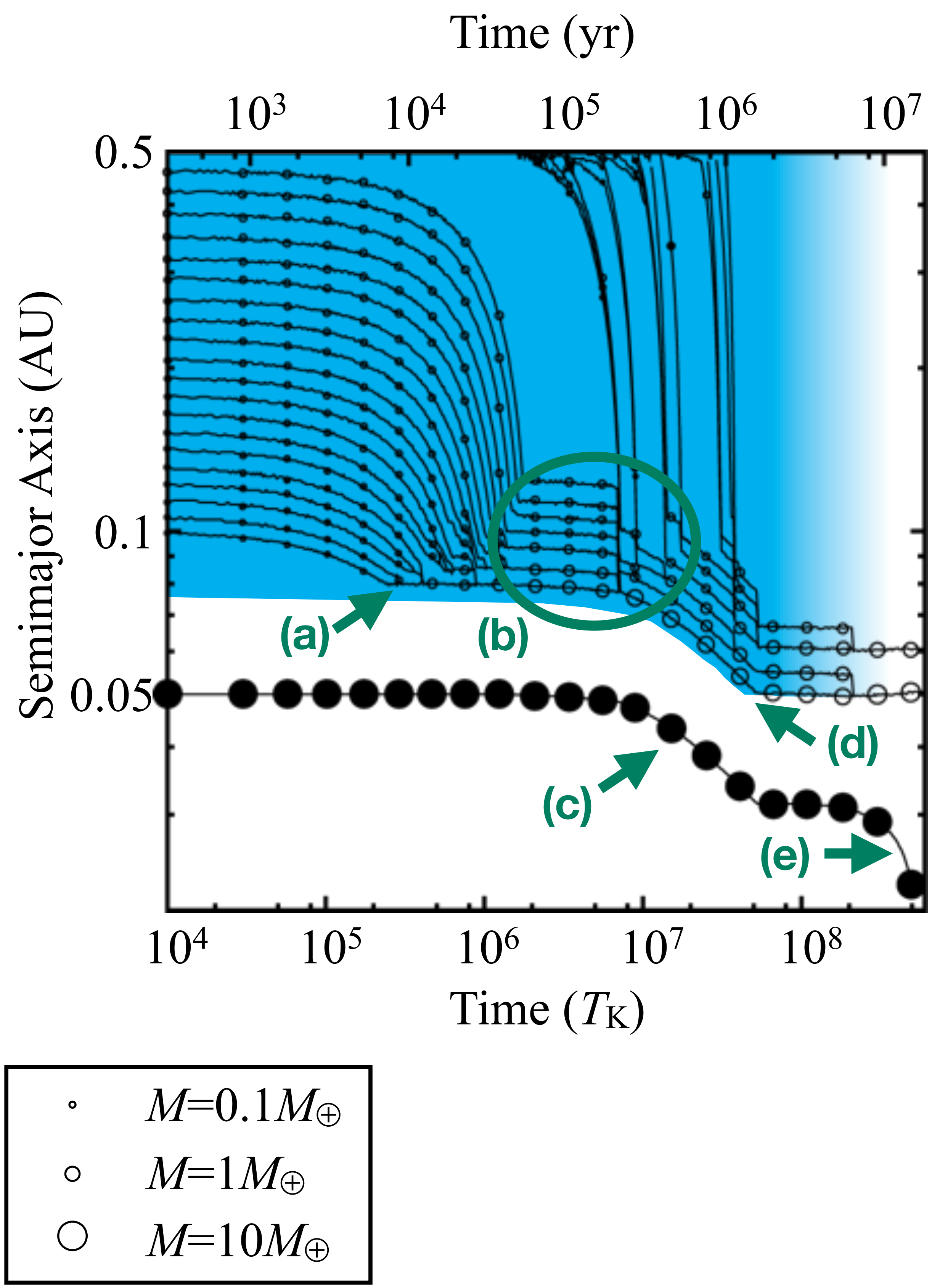




Numerical model



Results: typical results



(a) The innermost planet is captured into the 2:1 MMR with the HJ.

(b) Several planets relax to a quasi-steady state captured in MMRs.

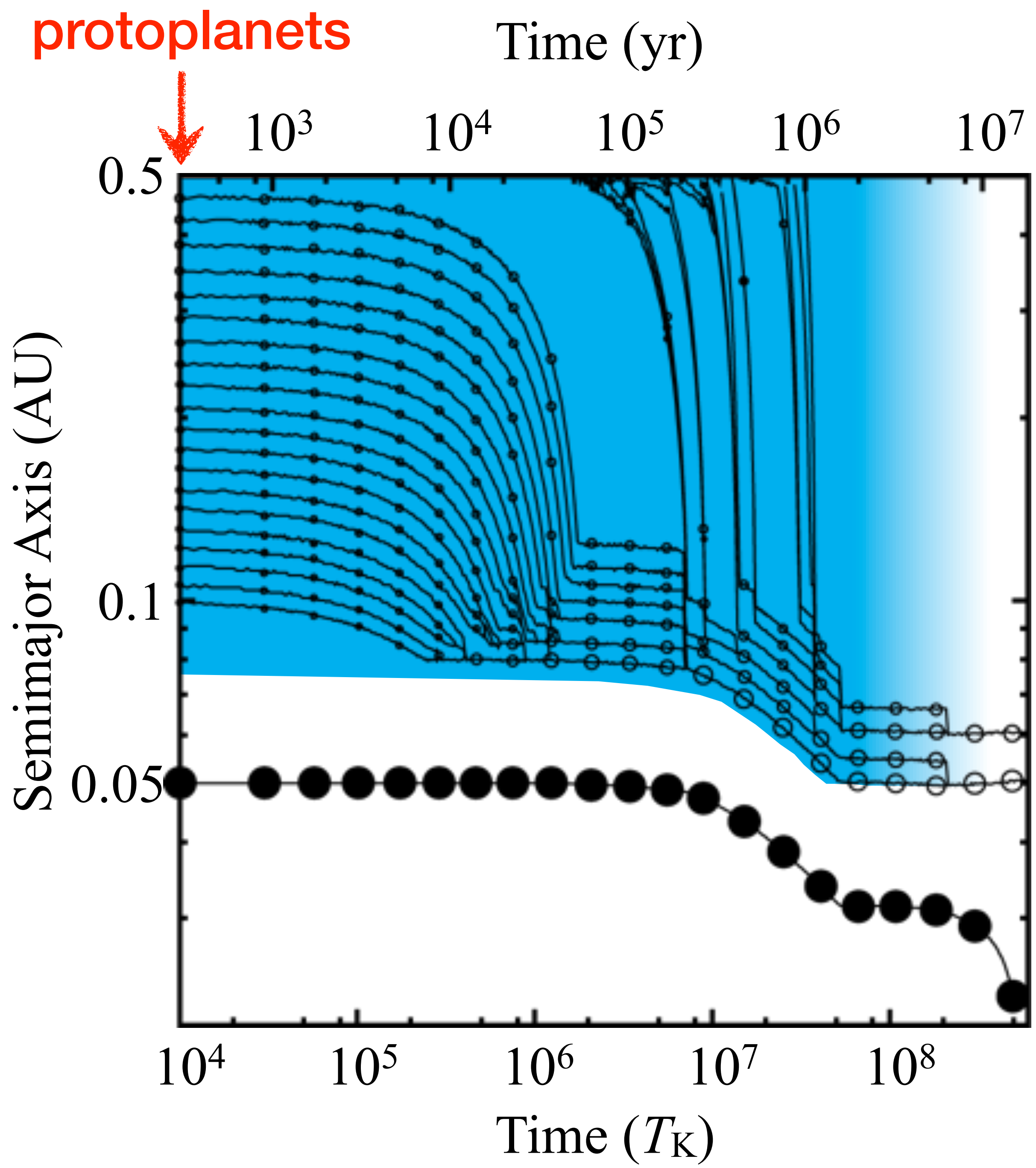
(c) The HJ migrate inward by being pushed in by the resonant chain -> “crowding out”

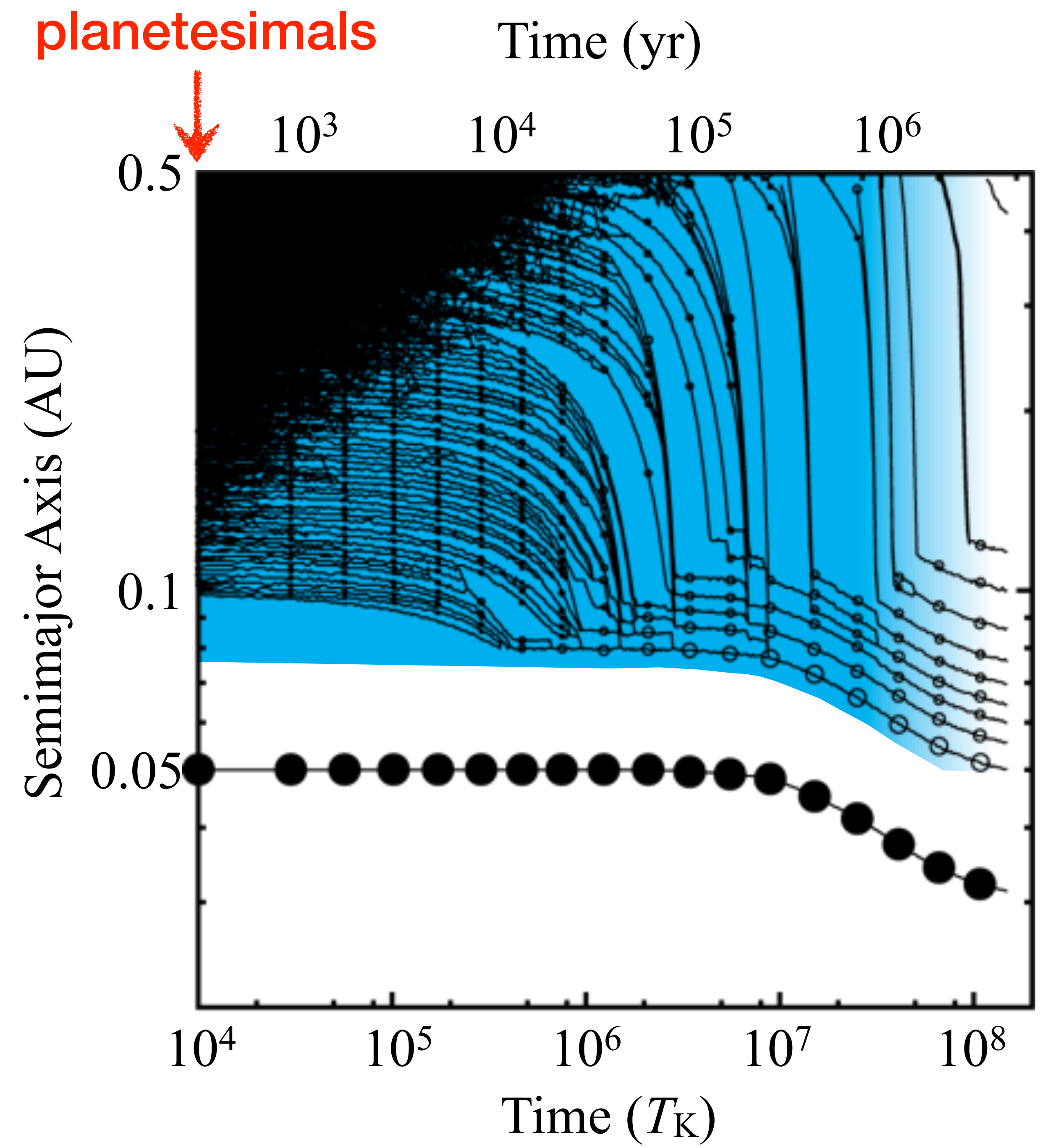
(d) The innermost planet reaches the disk inner edge and experiences the positive torque due to the positive density gradient of the disk (e.g., Masset et al. 2006)

(e) The HJ migrates inward due to the tidal torque from the star

Two planets with masses of ~2.3M⊕ remain at the end of simulation

[app.]Results: dependence on *N*

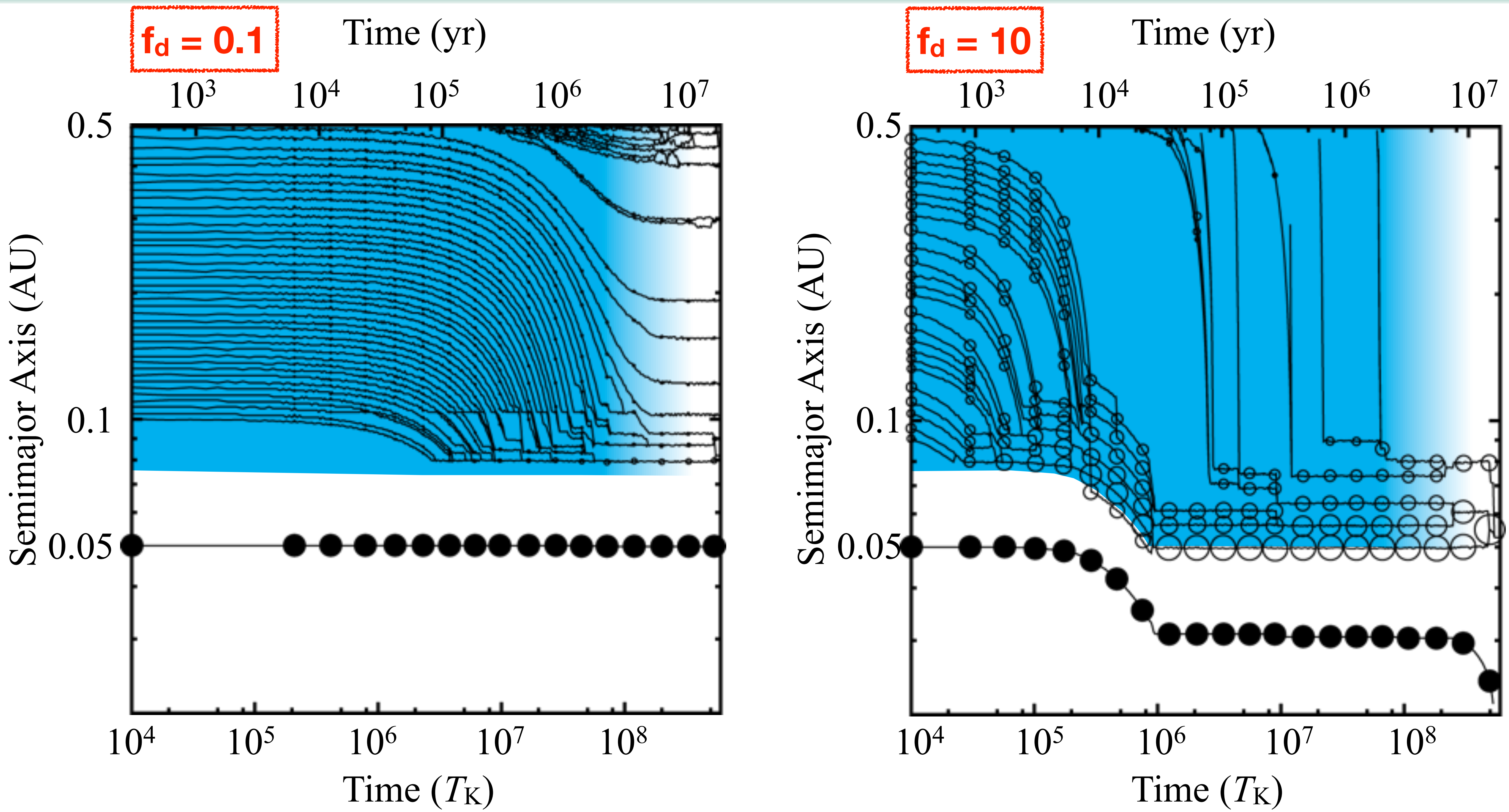




M=0.1$M_\oplus$
M=1$M_\oplus$
M=10$M_\oplus$

no significant difference

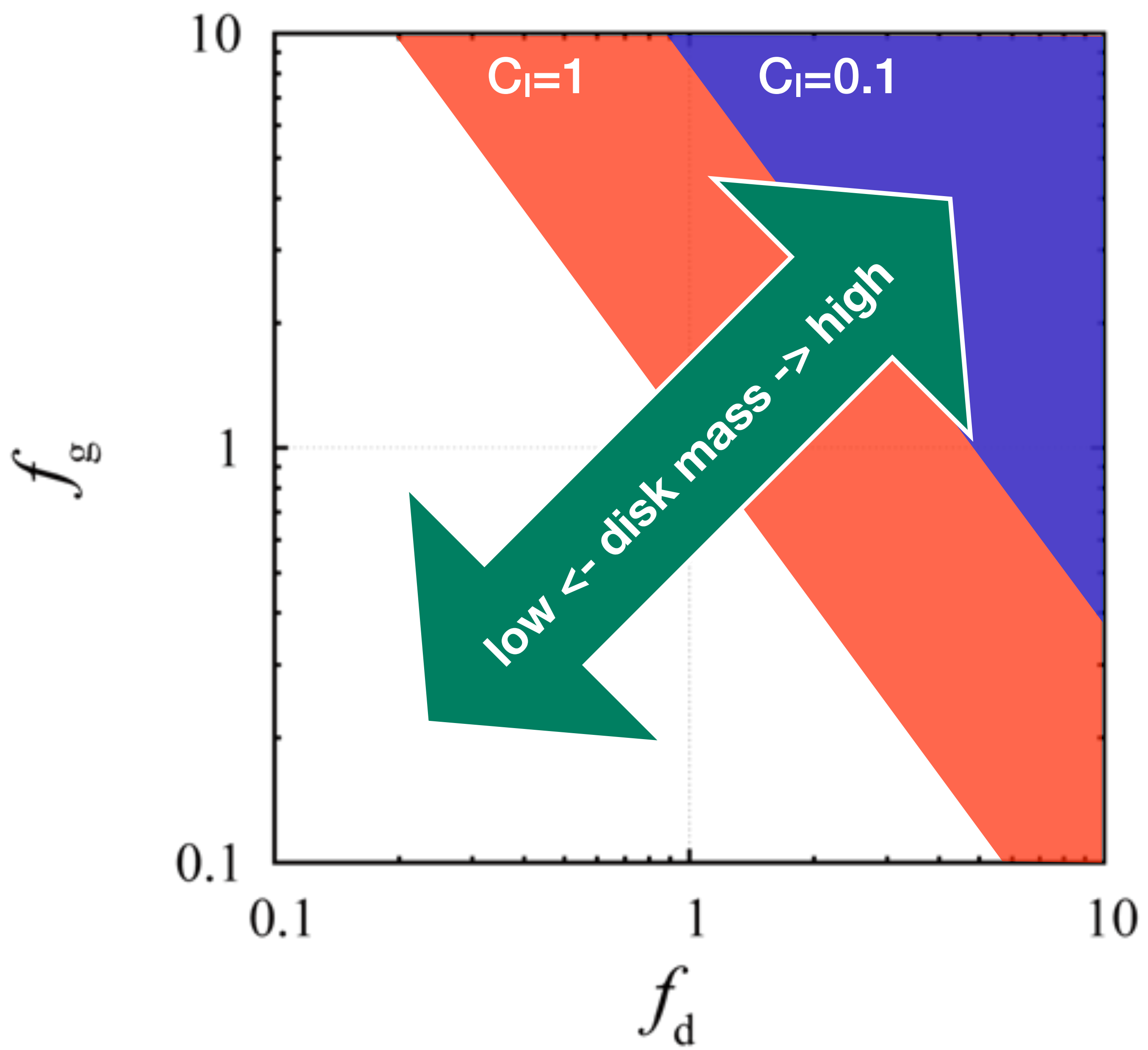
Results: dependence on disk mass



[f_d = 0.1] Small masses of planets -> no crowding out

[f_d = 10] The timescale of crowding out is shortened

Condition for crowding out of HJ



$$\Sigma_g = 2400 f_g \left(\frac{r}{1\ \mathrm{AU}}\right)^{-3/2}\ \mathrm{g\ cm^{-2}}$$

$$\Sigma_d = 10 f_d \left(\frac{r}{1\ \mathrm{AU}}\right)^{-3/2}\ \mathrm{g\ cm^{-2}}$$

NOTE

- **condition for crowding out**

$$t_{a,\mathrm{HJ}} < t_{\mathrm{dep}}$$

(gas depletion time = 1Myr)

- **migration timescale of HJ**

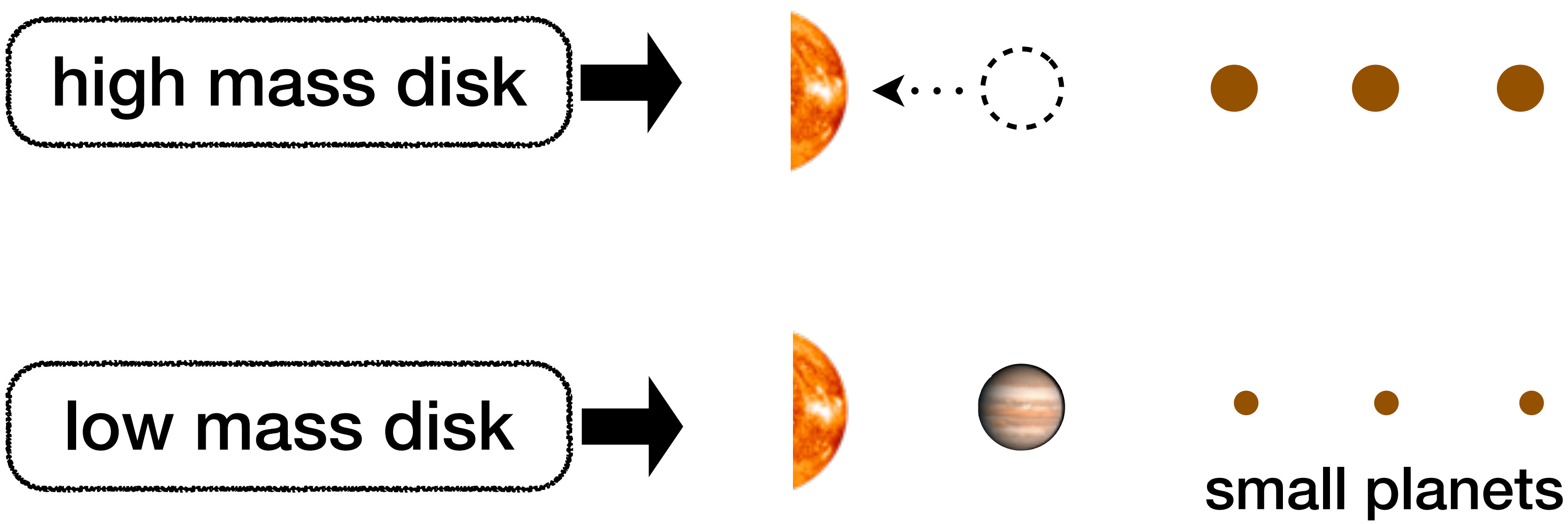
$$t_{a,\mathrm{HJ}} = -\frac{J_{\mathrm{HJ}}}{2T_{\mathrm{chain}}} \simeq t_{a,\mathrm{chain}} \left(\frac{a_{\mathrm{HJ}}}{a_{\mathrm{chain}}}\right)^{1/2} \frac{M_{\mathrm{HJ}}}{M_{\mathrm{chain}}}$$

This depends on disk density (f_d, f_g) and migration efficiency (C_l)

crowding out occurs in massive disk

Implications for observations

- **Explanation for the lack of planets in HJ systems**



HJ is never observed

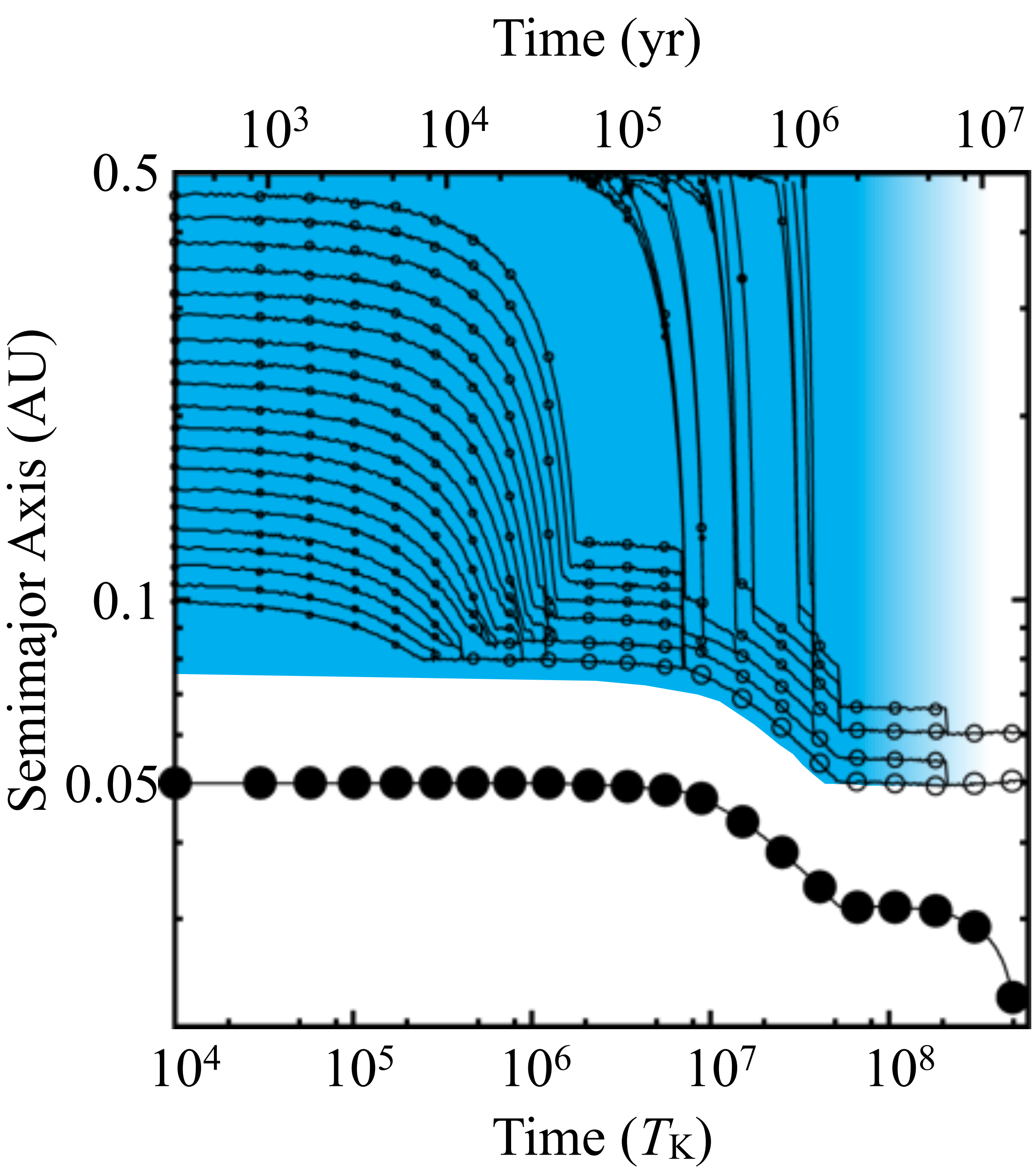
planets are below the detection limit

- **Prediction for future observations**

Future observations reveal additional planets in HJ systems; but, their masses are small.

Summary

We investigate formation of close-in terrestrial planets under the influence of a HJ using N-body simulations



We find a mechanism of pushing the HJ inward by a chain of resonant terrestrial planets

Our simulations naturally explain the lack of additional planets in HJ systems