The hot Jupiter period-mass distribution as a signature of in-situ formation

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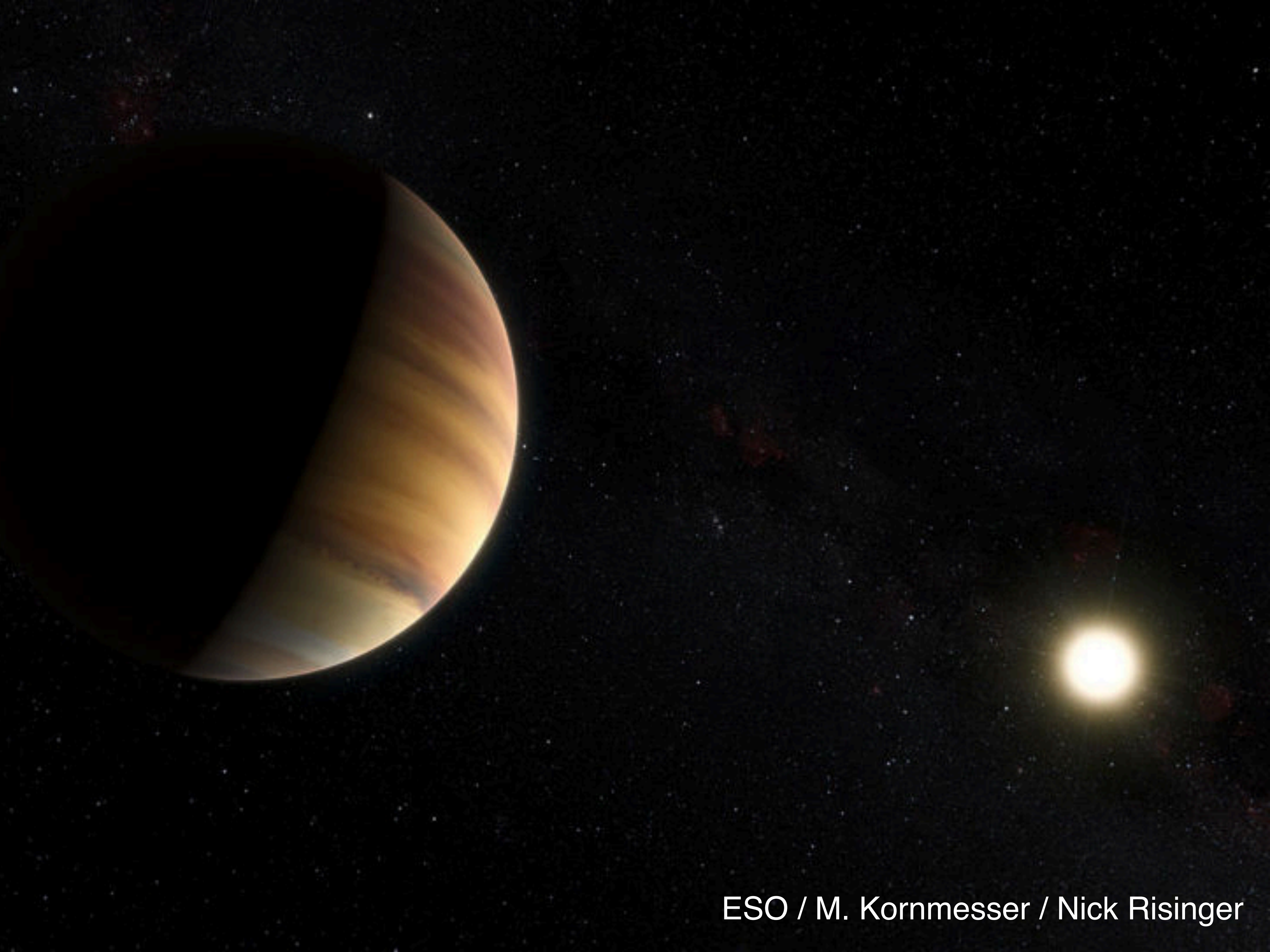
Caltech


ESO / M. Kornmesser / Nick Risinger

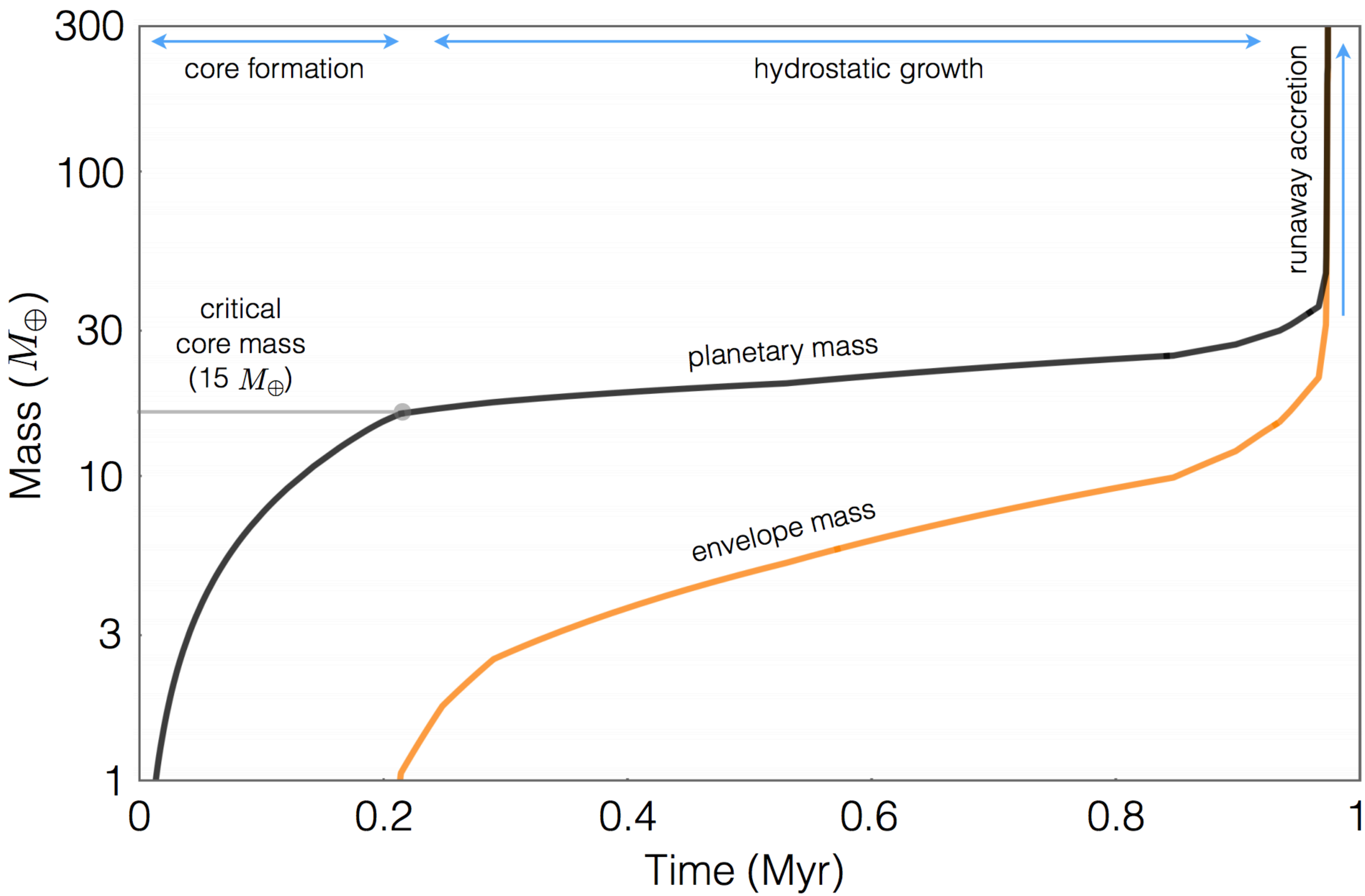
Long-range migration hypothesis

Disk-driven (type-II) migration (Kley & Nelson 2012)

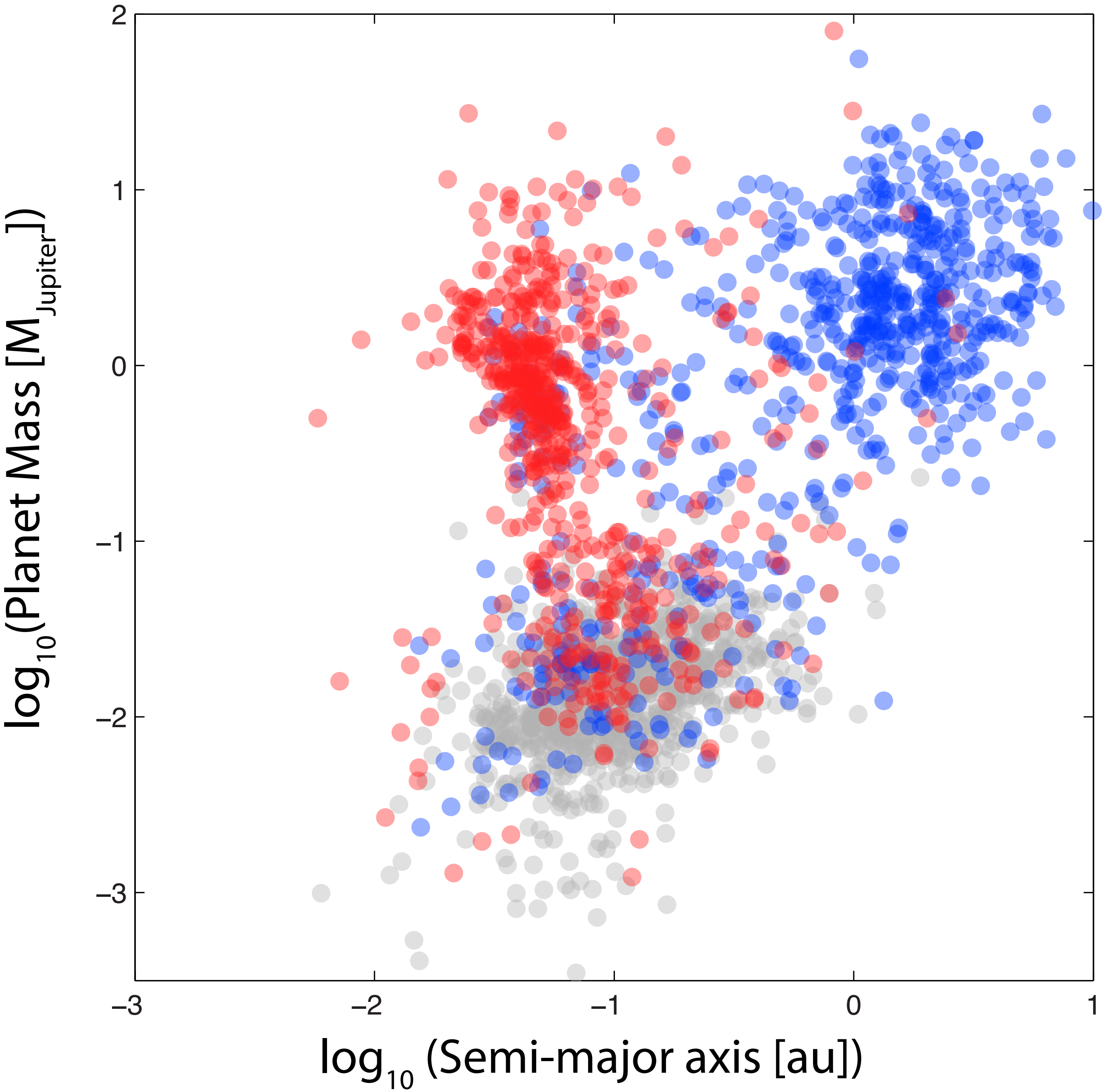
Secular planet-planet interactions (Naoz et al 2011)

Planet-planet scattering (Beauge & Nesvorny 2012)

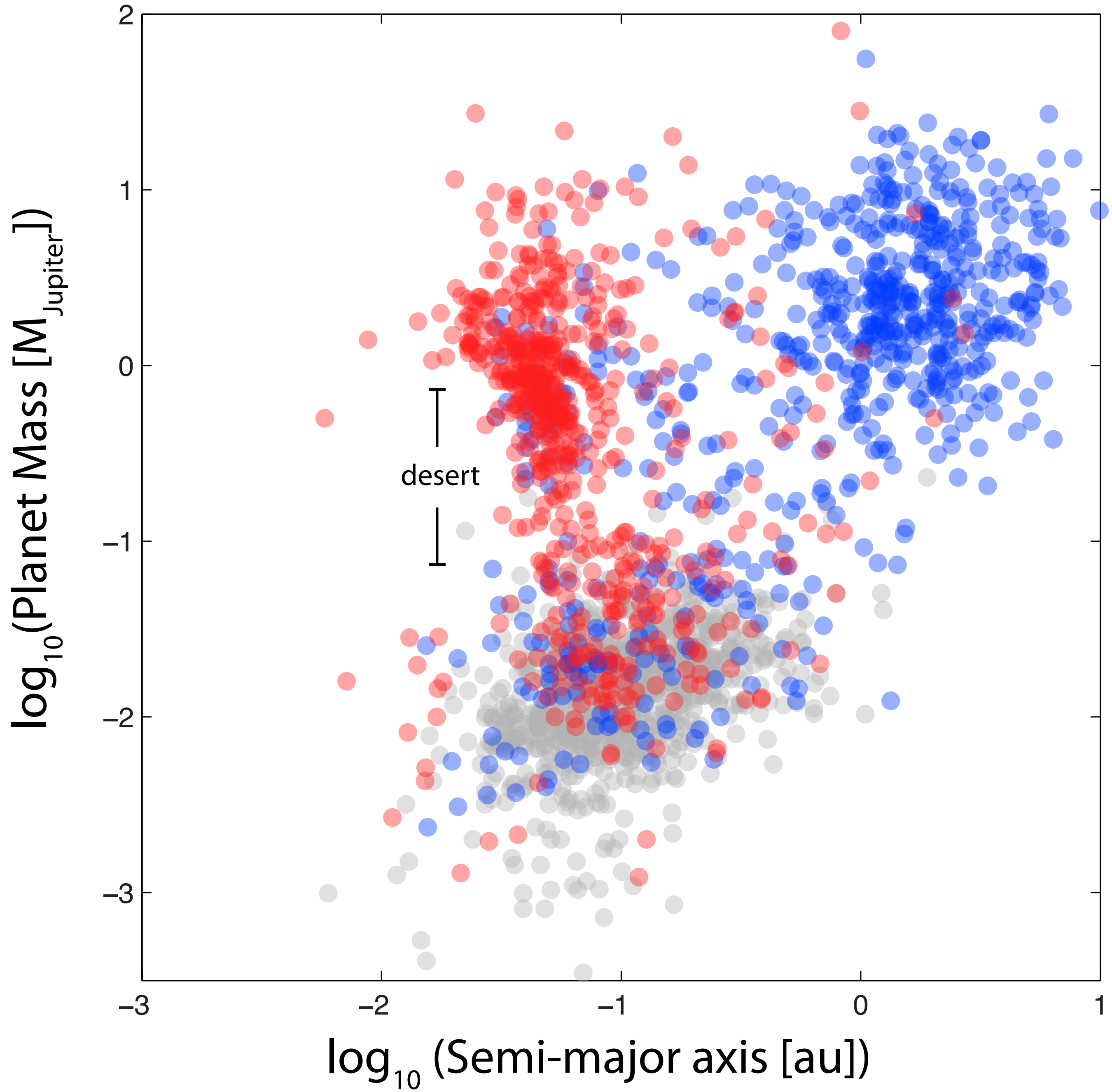
In situ formation hypothesis



Batygin, Bodenheimer, Laughlin 2016



2
1
0
−1
−2
−3
−3
−2
−1
0
1
log10(Planet Mass [MJupiter])
log10 (Semi-major axis [au])



2
1
0
−1
−2
−3
−3
−2
−1
0
1
desert
log10(Planet Mass [MJupiter])
log10 (Semi-major axis [au])

magnetic disk truncation radius

$$R_t \sim \left(\frac{\mathcal{M}^2}{\dot{M}\sqrt{GM_\star}} \right)^{2/7}$$

stellar magnetic moment $\mathcal{M} \equiv B_\star R_\star^3$

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hot Jupiter mass proportional to mass infall rate

$$M_{\rm HJ} \sim \tau \dot{M}$$

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hot Jupiter mass proportional to mass infall rate

$$M_{\rm HJ} \sim \tau \dot{M}$$

$$\dot{M} \sim 10^{-8} M_\odot \ {\rm yr}^{-1}$$

(Hartmann et al. 1998)

$$\Downarrow$$

$$\tau \sim 10^5 \ {\rm yr}$$

magnetic disk truncation radius

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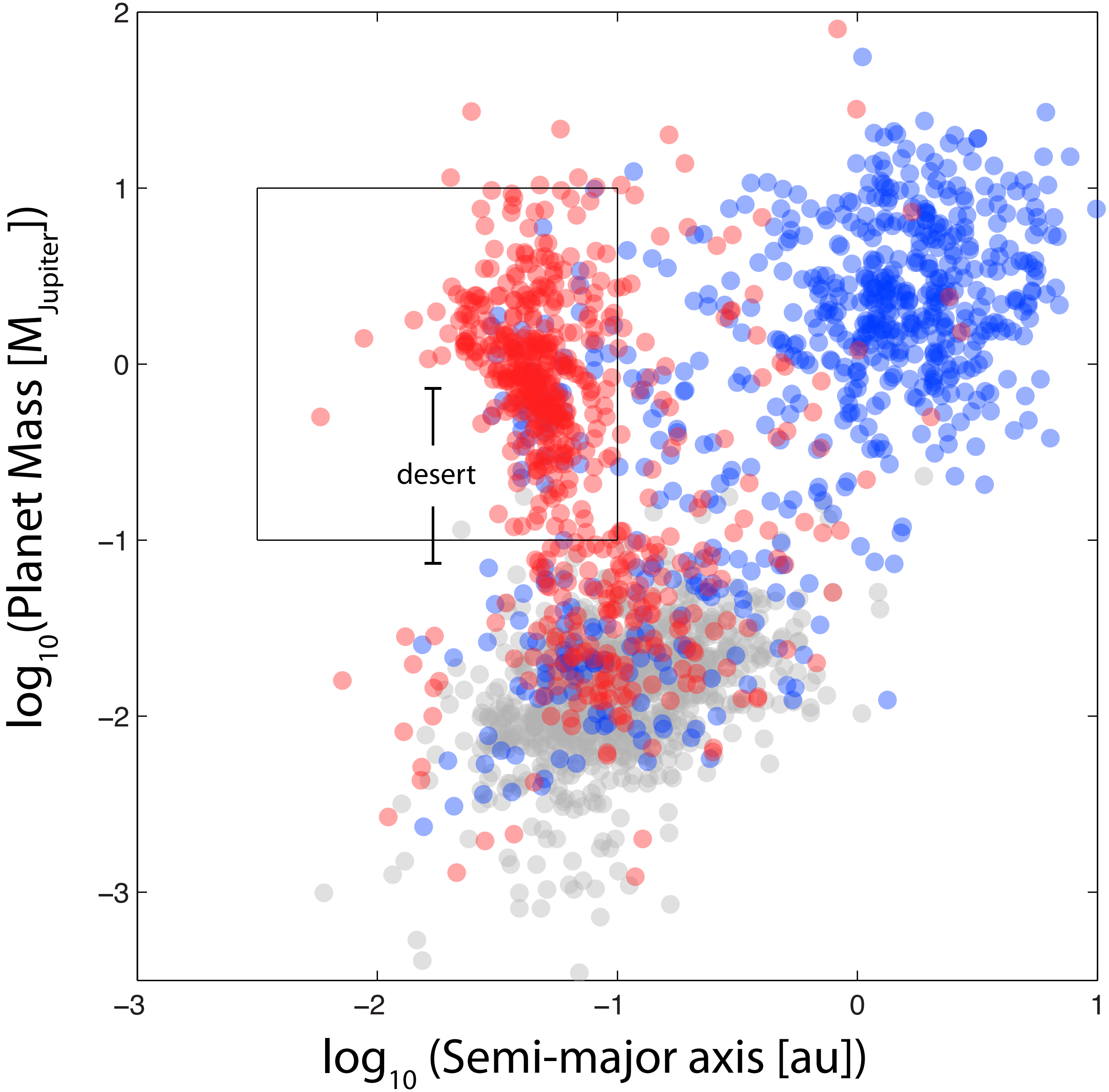
(Hartmann et al. 1998)

$$\Downarrow$$

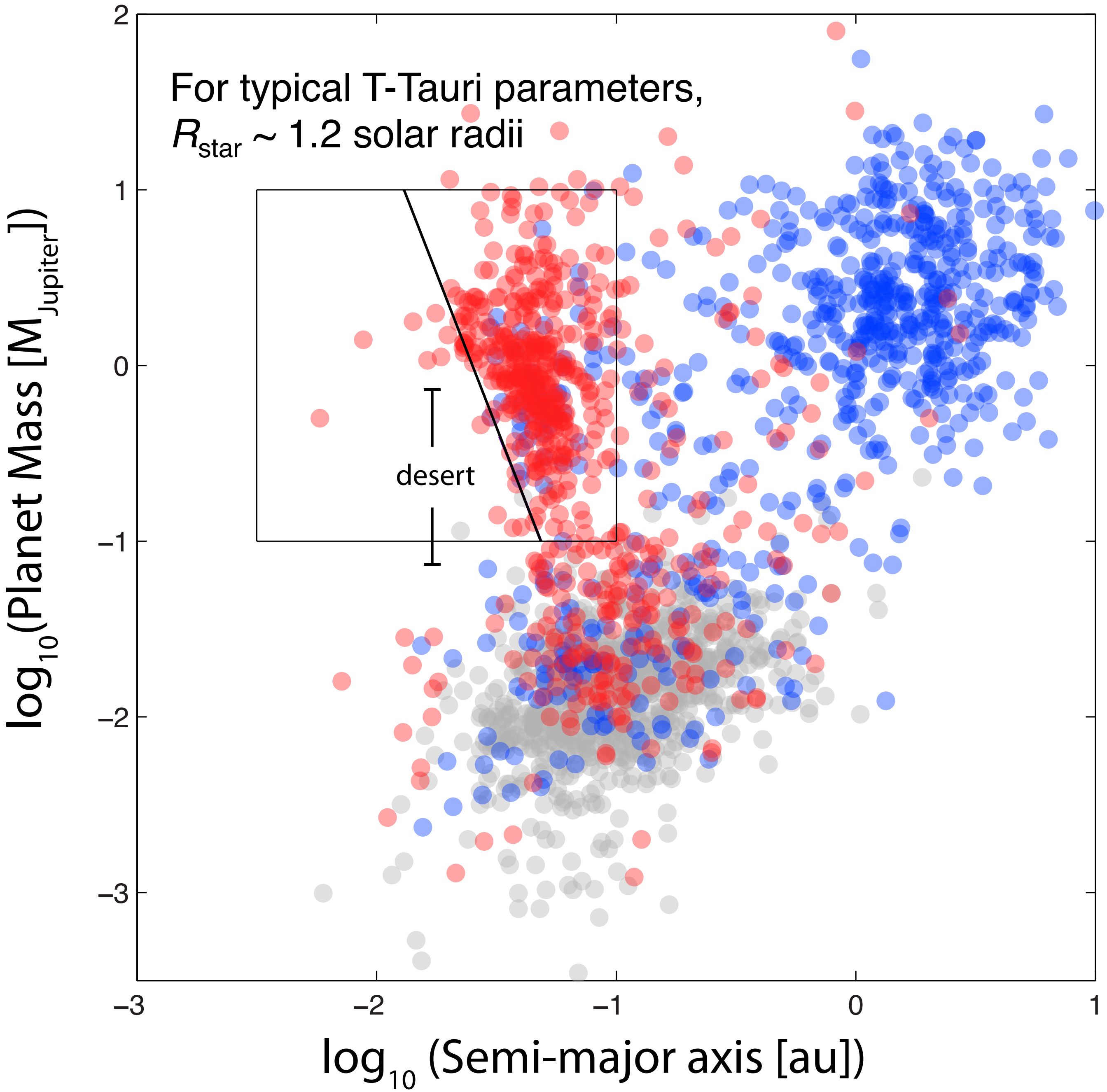
$$\tau \sim 10^5 \ \mathrm{yr}$$

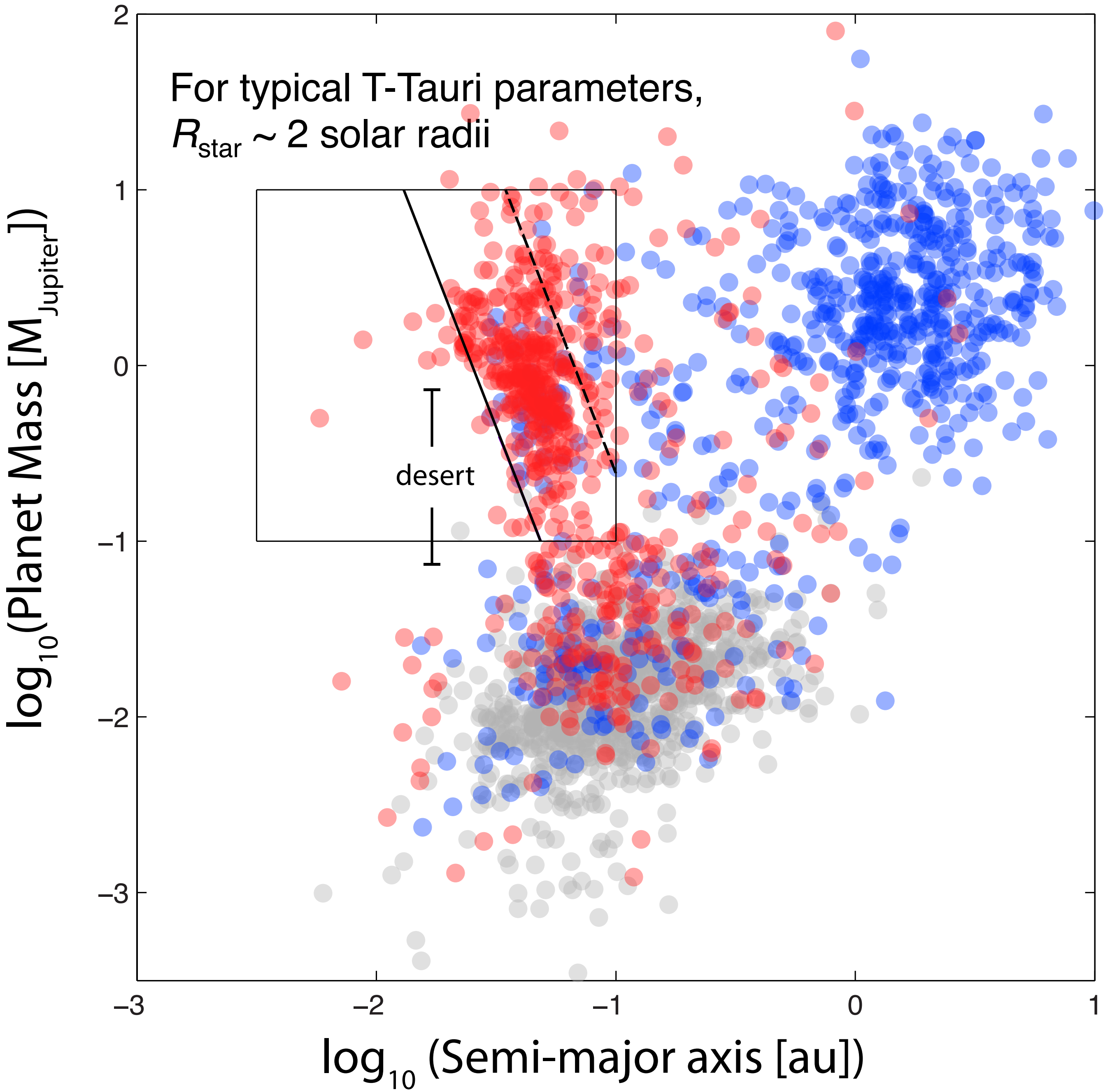
power law prediction
for in situ hot Jupiter formation

$$a \sim \left(\frac{\mathcal{M}^2 \tau}{M_{\mathrm{HJ}}\sqrt{GM_\star}} \right)^{2/7} \propto M_{\mathrm{HJ}}^{-2/7}$$

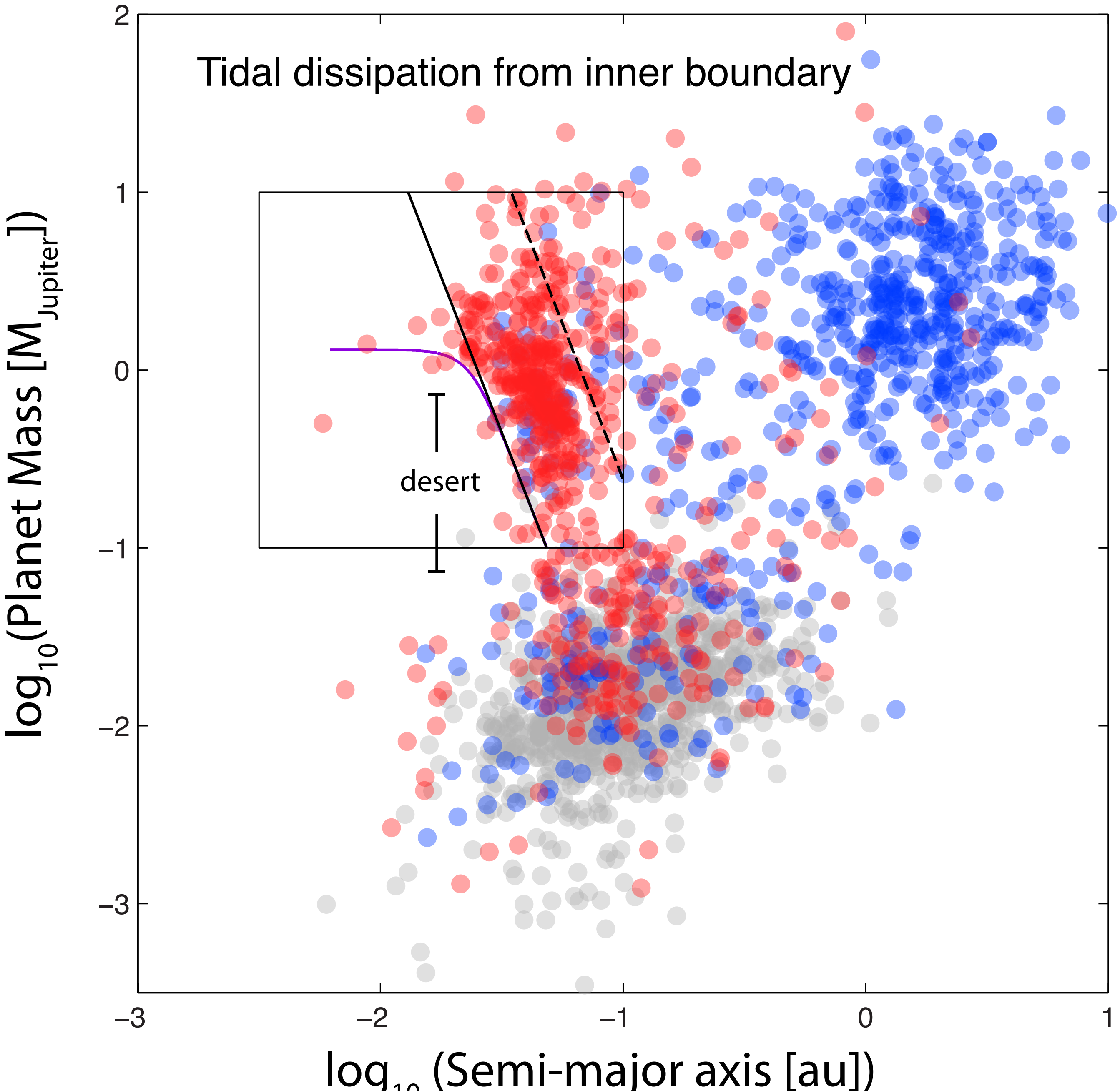


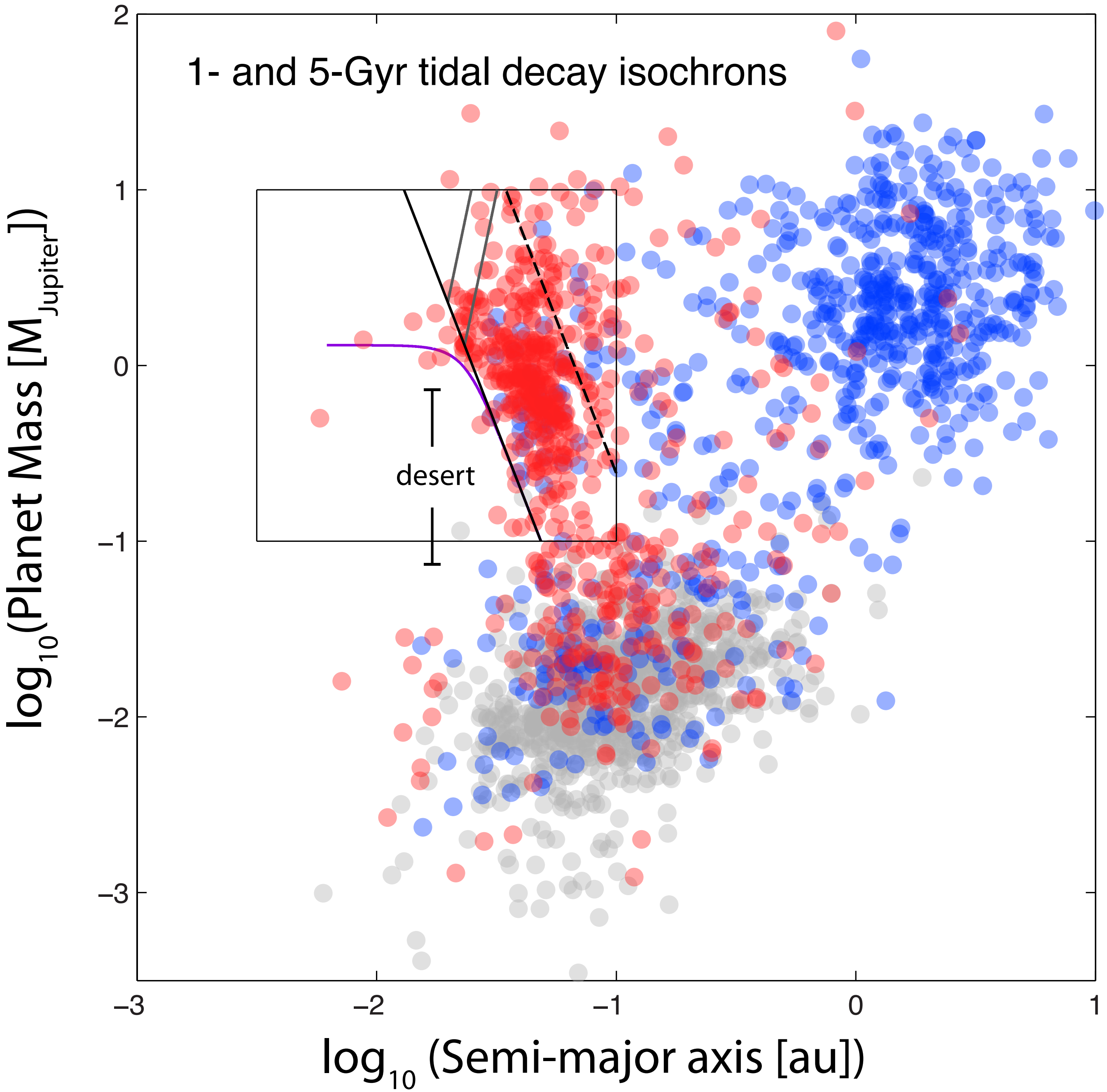
2
1
0
−1
−2
−3
−3
−2
−1
0
1
desert
log10(Planet Mass [MJupiter])
log10 (Semi-major axis [au])


For typical T-Tauri parameters,
R_{star} ~ 1.2 solar radii
desert
$\log_{10}$(Planet Mass [$M_{Jupiter}$])
$\log_{10}$ (Semi-major axis [au])
2
1
0
−1
−2
−3
−3
−2
−1
0
1

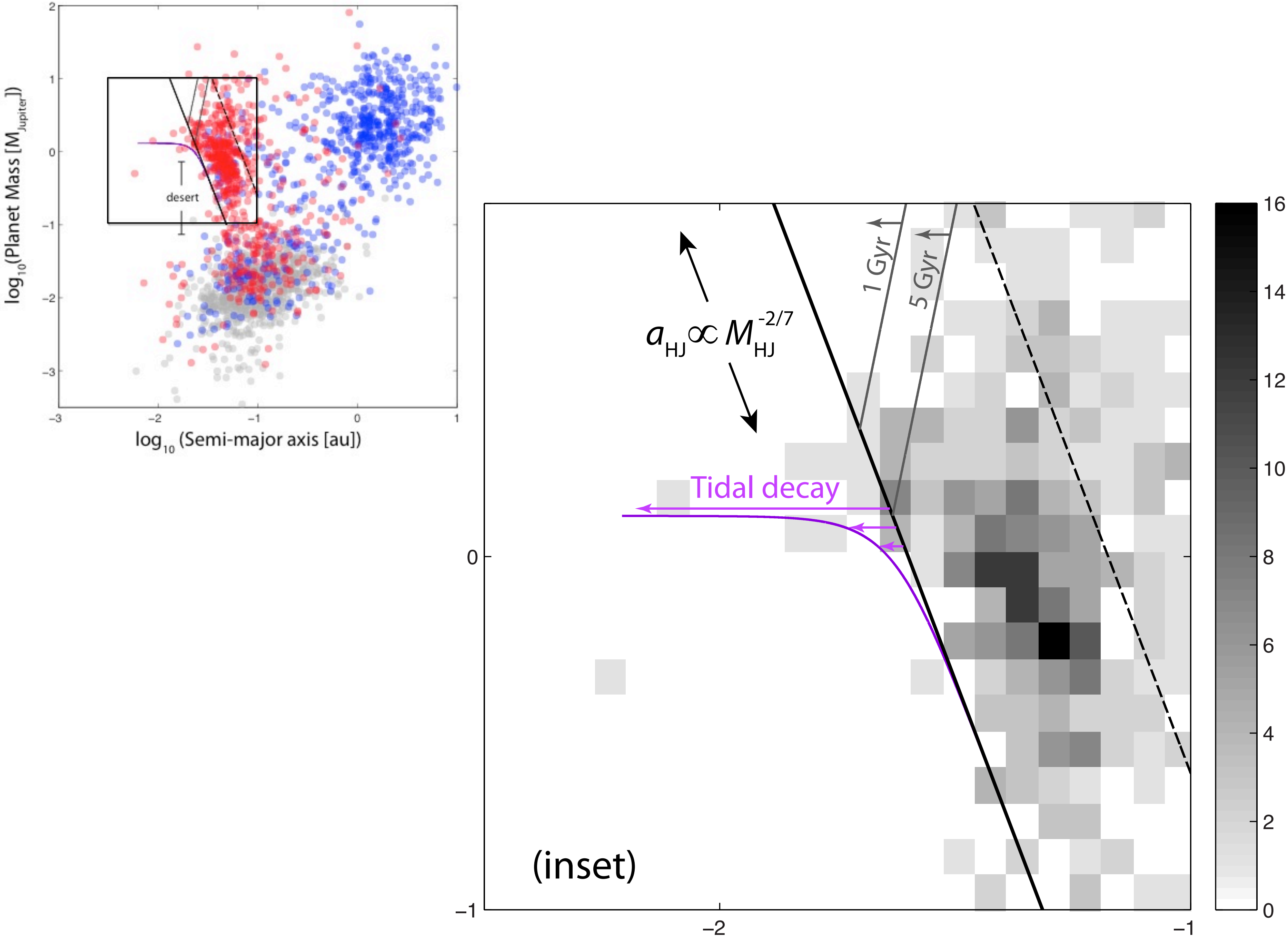


For typical T-Tauri parameters,
R_{star} ~ 2 solar radii
desert
log10(Planet Mass [MJupiter])
log10 (Semi-major axis [au])
2
1
0
−1
−2
−3
−3
−2
−1
0
1


Tidal dissipation from inner boundary
desert
log10(Planet Mass [MJupiter])
log10 (Semi-major axis [au])
2
1
0
−1
−2
−3
−3
−2
−1
0
1



1- and 5-Gyr tidal decay isochrons
desert
log10(Planet Mass [MJupiter])
log10 (Semi-major axis [au])
2
1
0
−1
−2
−3
−3
−2
−1
0
1



log10(Planet Mass [MJupiter])
log10 (Semi-major axis [au])
desert
2
1
0
−1
−2
−3
−3
−2
−1
0
1
1 Gyr
5 Gyr
a_HJ ∝ M_HJ^-2/7
Tidal decay
(inset)
0
−1
−2
−1
16
14
12
10
8
6
4
2
0

Conclusion

Derived $-2/7$ power law + tidal corrections appear to account for the shape of the hot Jupiter population

Suggests in situ formation is dominant mode of formation

Suggests long-range giant planet migration is atypical

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