

Surviving type I migration (the old and the new): oligarchic formation of hot Neptunes

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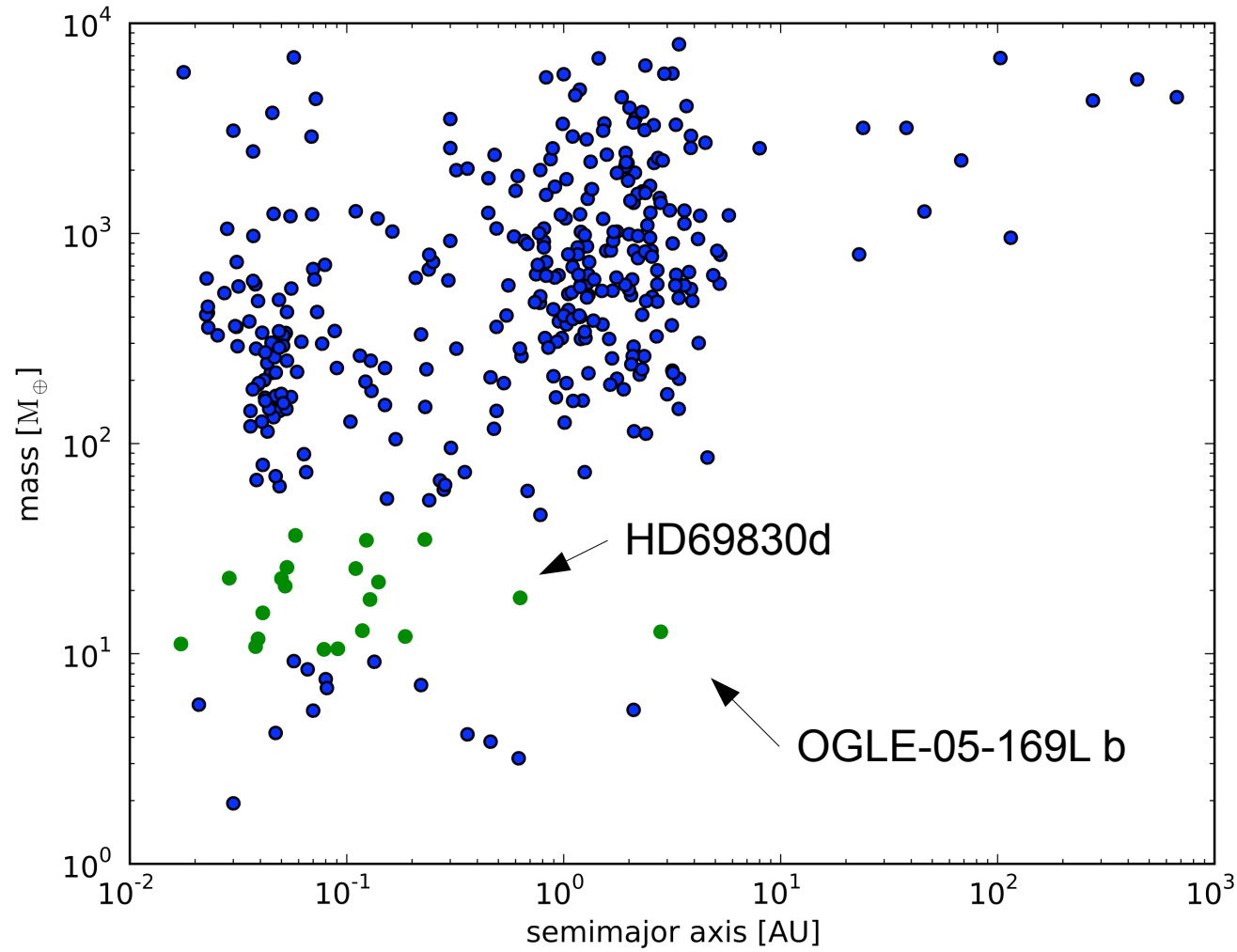
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Overview

- Hot Neptunes, and why we care
- The old migration:
 - Predictions of the simplest classic oligarchy + type I models
- The new Paardekooper migration
 - A simple toy model
 - A more accurate model
- Where we are now

The exoplanet distribution

(as of August 2009)



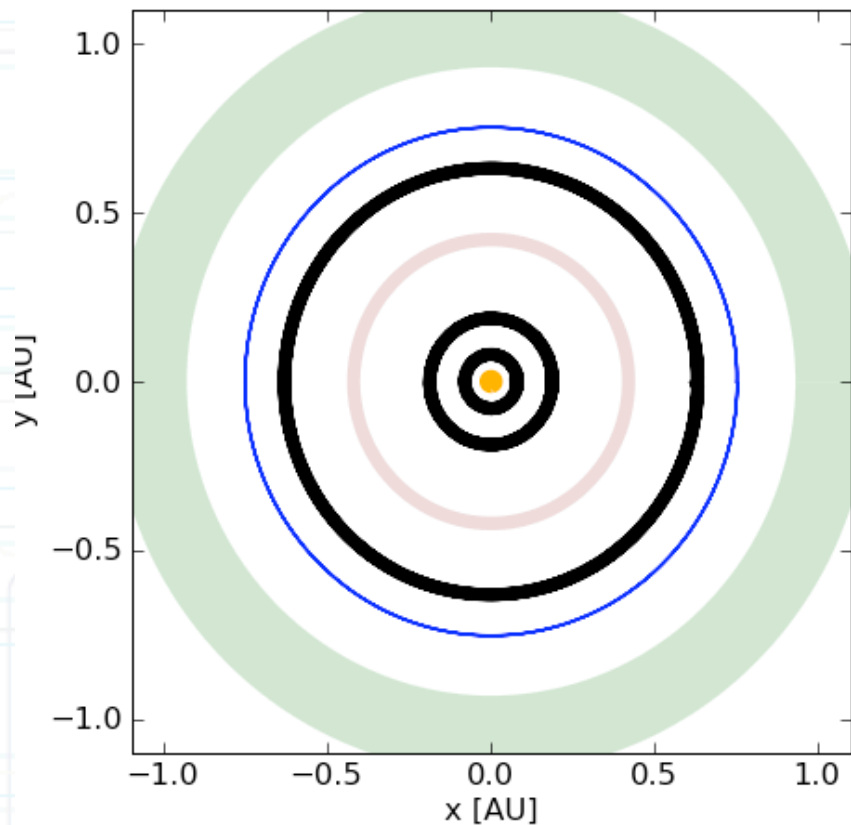
Why are hot Neptunes important?

- large enough to be observable (~20 known)
- large enough to undergo dangerous amounts of type I migration (unlike Earths)
- small enough that they formed via core accretion
- small enough that they can't open a gap and switch to type II

→ excellent probes of type I migration

Our favourite Neptunes

HD69830 (Lovis et al. 2006)



object	mass	a [AU]	ecc.
b	10.5 M_E	0.0785	0.10 ± 0.04
c	12.1 M_E	0.186	0.13 ± 0.06
Beichman et al. (2005) asteroid belt	25 x AB? (22-64) Sedna?	0.42	
d	18.4 M_E	0.63	0.07 ± 0.07
water?		0.72?	
Lisse et al. (2006) debris disc	$> 3 \times 10^{17}$ kg	0.93-1.16	

What does the simplest model (oligarchy + the traditional type I) predict?

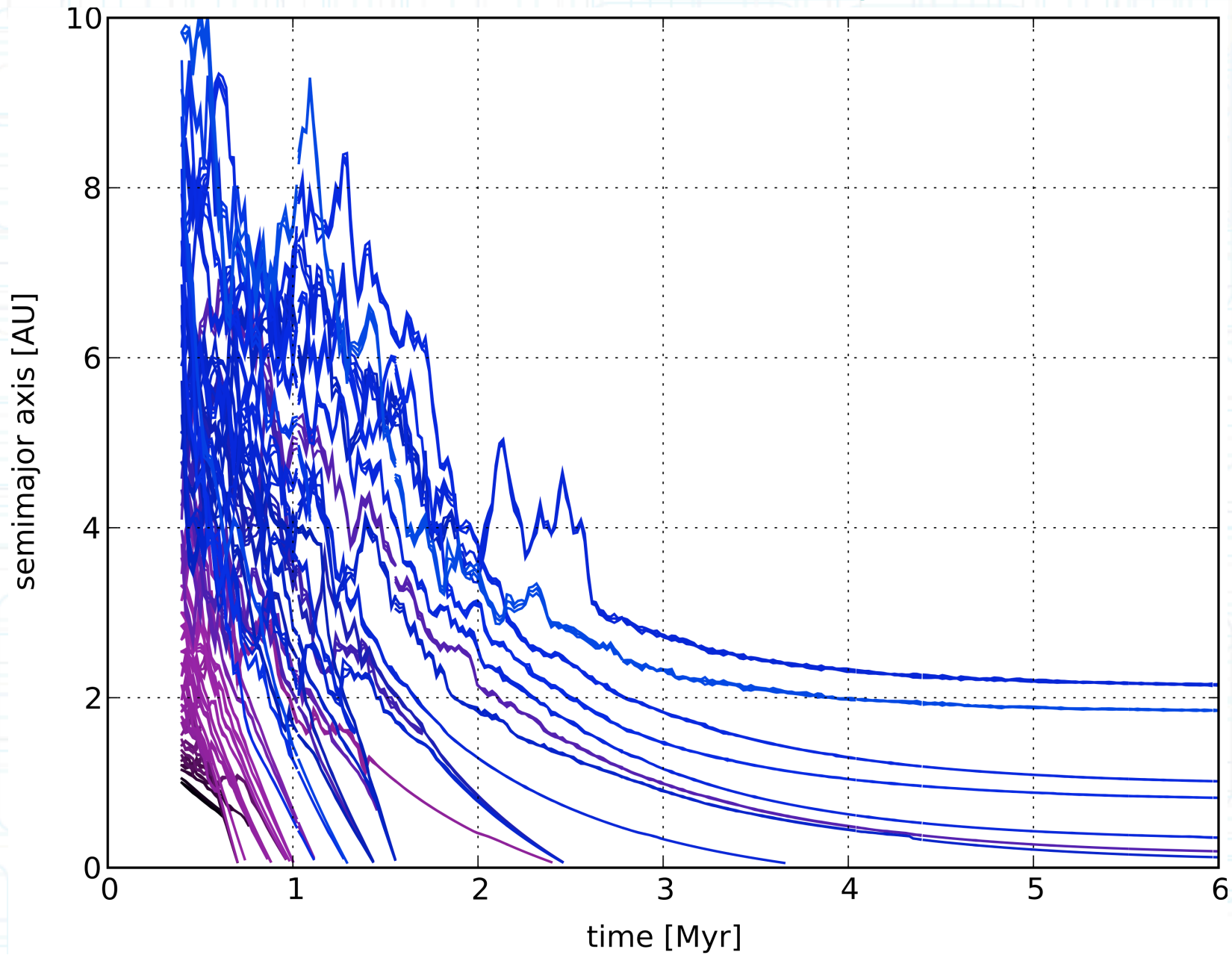
Method: Moderate resolution N-body integrations using multiscale parallel Kepler-adapted symplectic integrator NAOKO [McNeil & Nelson 2009a]

Tanaka et al. (2002) type I torques

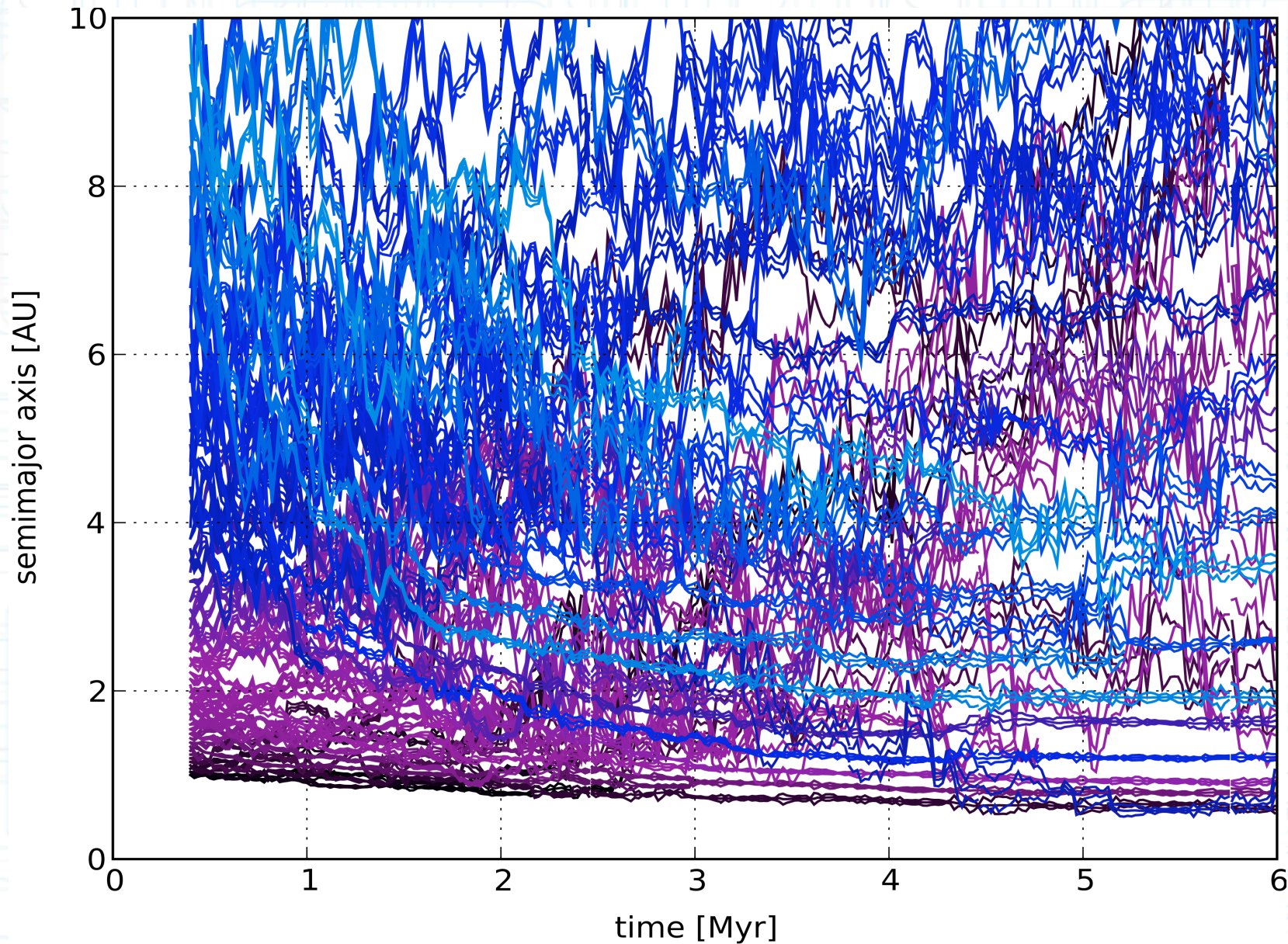
$$\Gamma_{\text{total}}(3\text{D}) = (1.364 + 0.541\alpha) \left(\frac{M_p}{M_c} \frac{r_p \Omega_p}{c} \right)^2 \sigma_p r_p^4 \Omega_p^2$$

$$\Gamma_{\text{total}}(2\text{D}) = (1.160 + 2.828\alpha) \left(\frac{M_p}{M_c} \frac{r_p \Omega_p}{c} \right)^2 \sigma_p r_p^4 \Omega_p^2$$

5x, -1, 1.0, 1 Myr

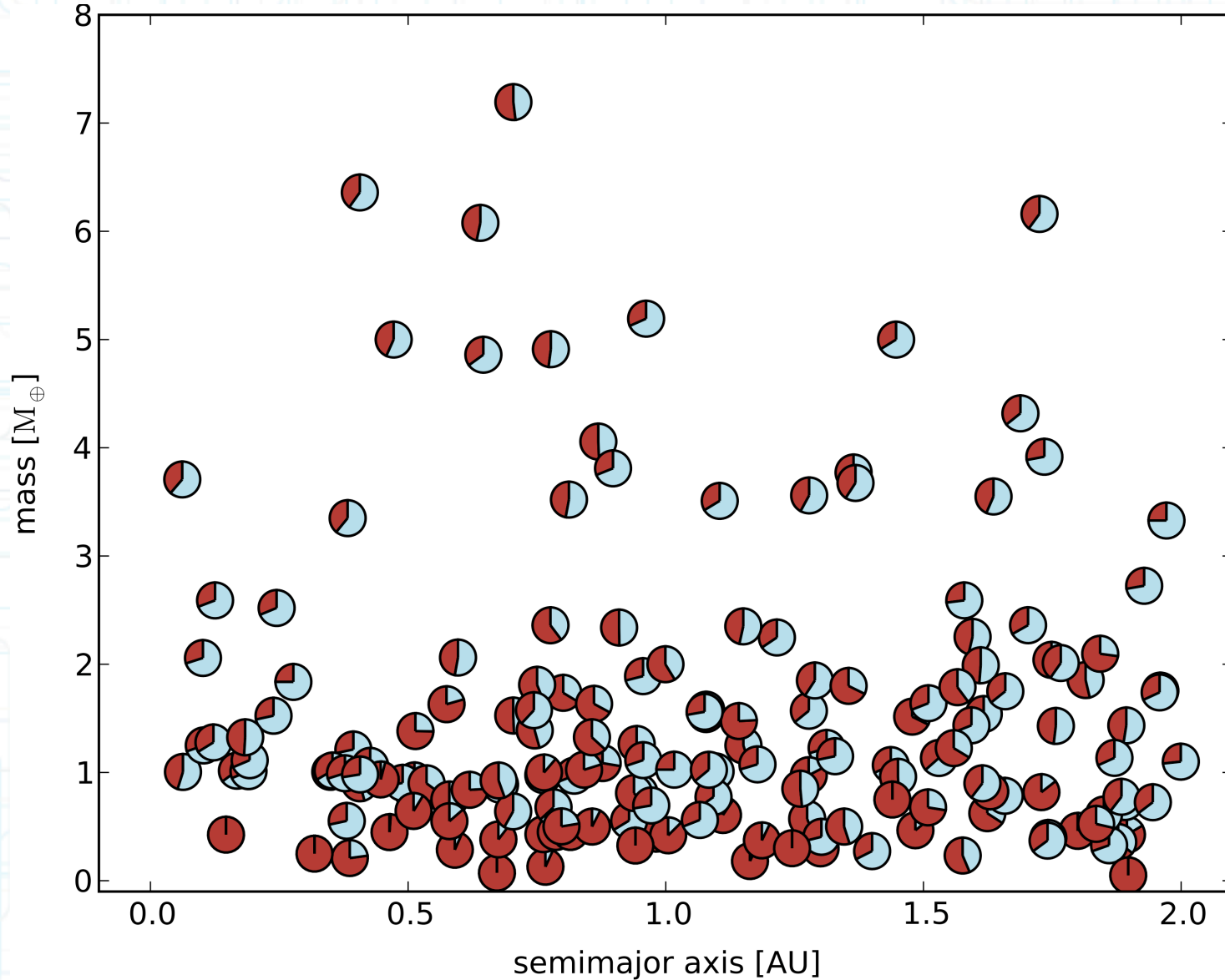


5x, -0.001, 1.0, 1 Myr

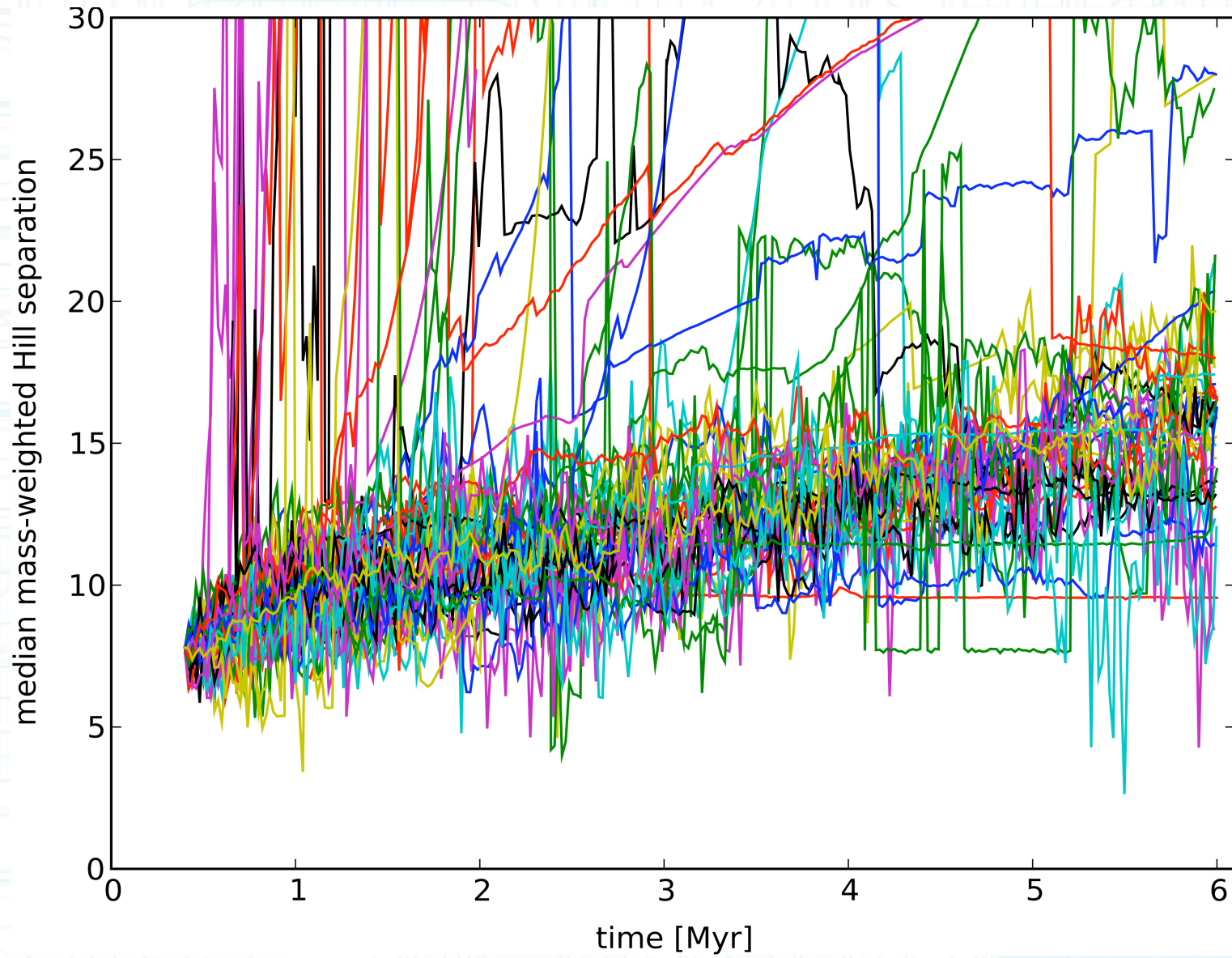


Resulting systems: summary

[McNeil & Nelson 2009b]



\tilde{b} is not 10!



The new type I migration

Paardekooper & Mellema 2006; Baruteau & Masset 2008;
Paardekooper & Mellema 2008; Paardekooper & Papaloizou 2008;
Kley & Crida 2008; Kley, Bitsch, Klahr 2009; Paardekooper et al. 2009

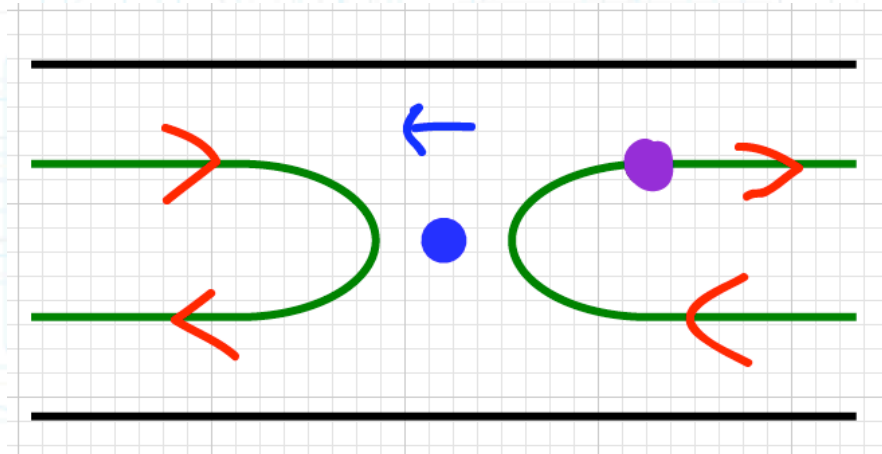
$$\frac{\gamma\Gamma}{\Gamma_0} = \left[-2.5 - 1.7\beta + 0.1\alpha \right] + \left[1.1 \left(\frac{3}{2} - \alpha \right) \right] + \left[7.9 \frac{\xi}{\gamma} \right]$$

Lindblad torques

Barotropic corotation

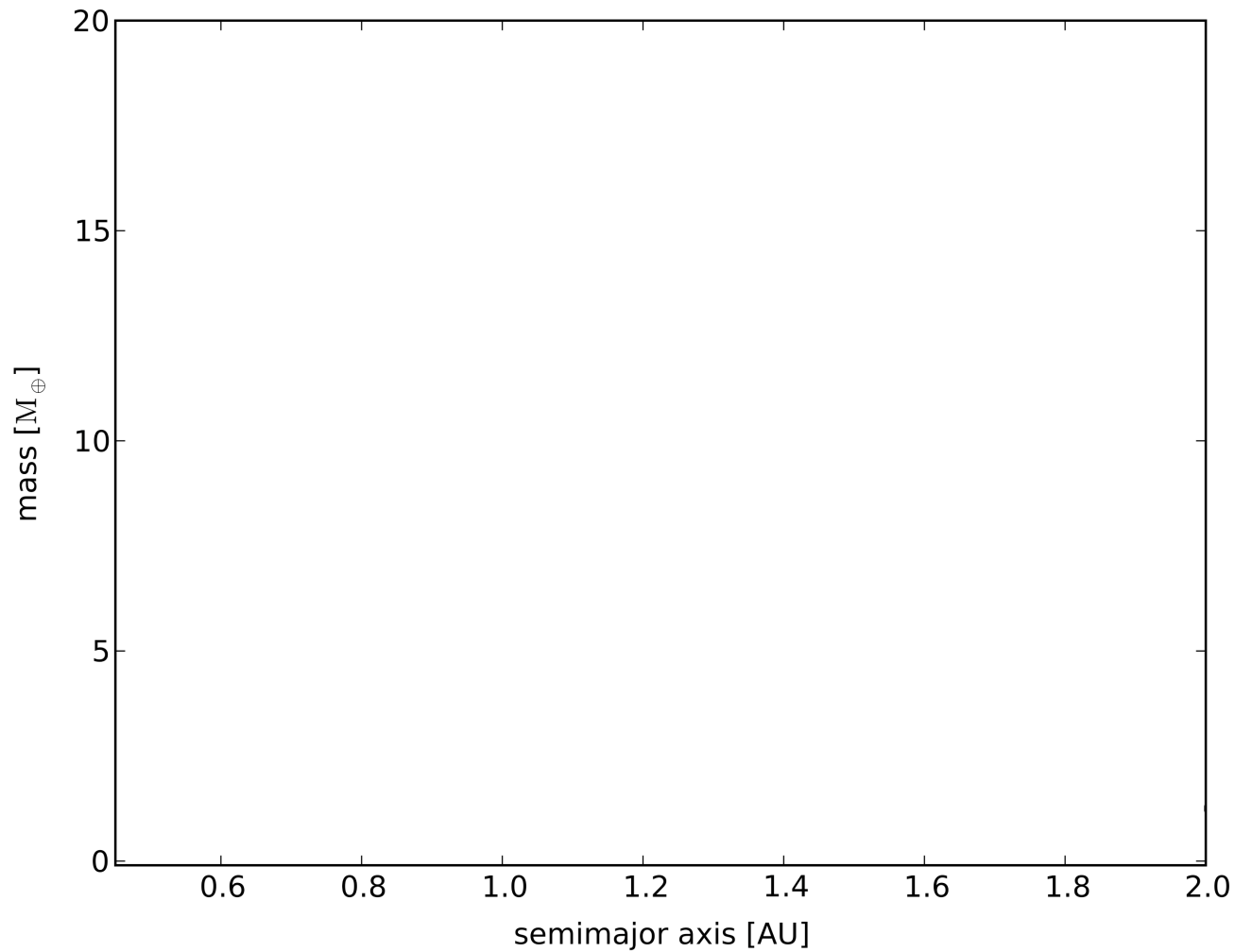
Non-
barotropic
corotation

NBCT can be $>$ LT + BCT \rightarrow outward motion

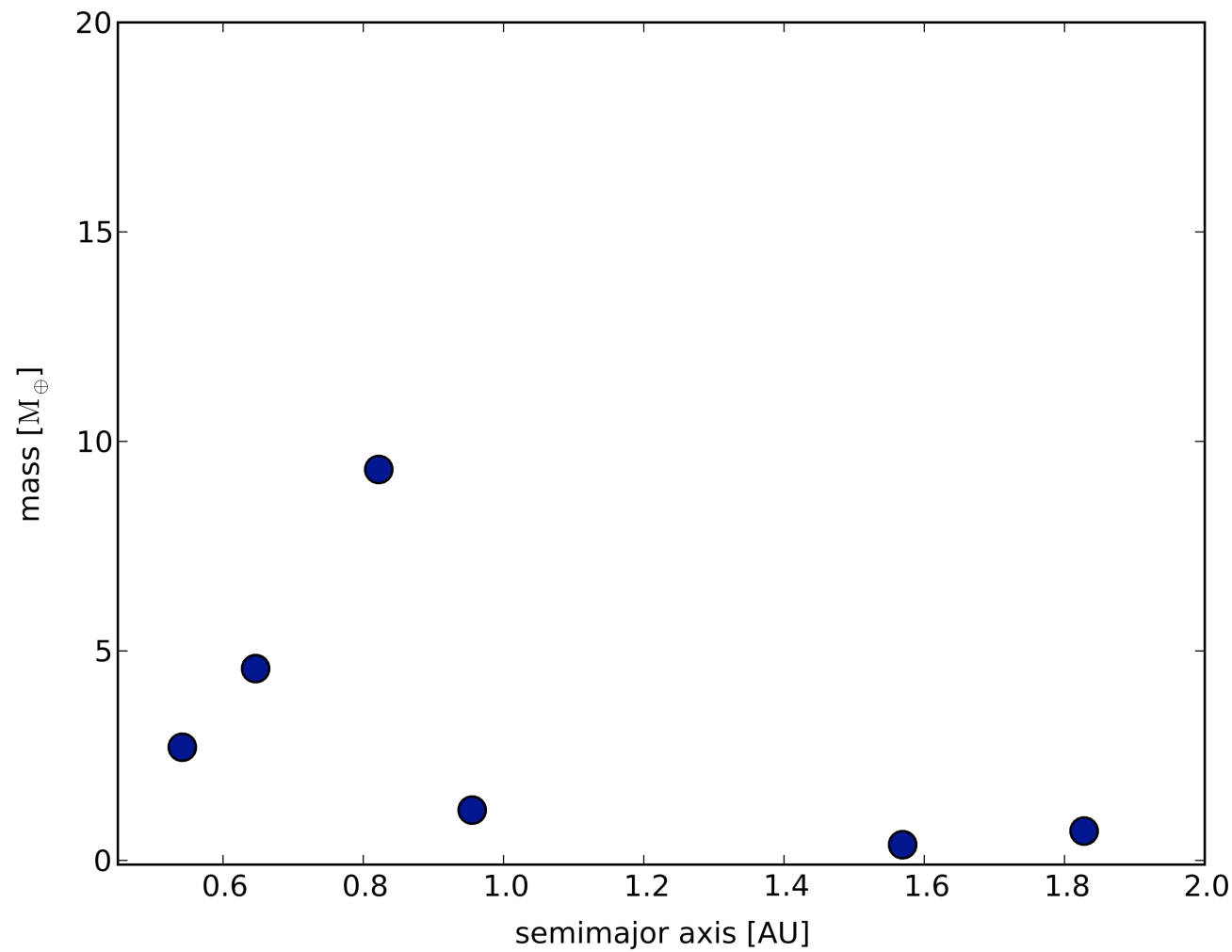


Must avoid
saturation:
 $f[\tau_{\text{lib}}/\tau_{\text{diff}}] = ?$

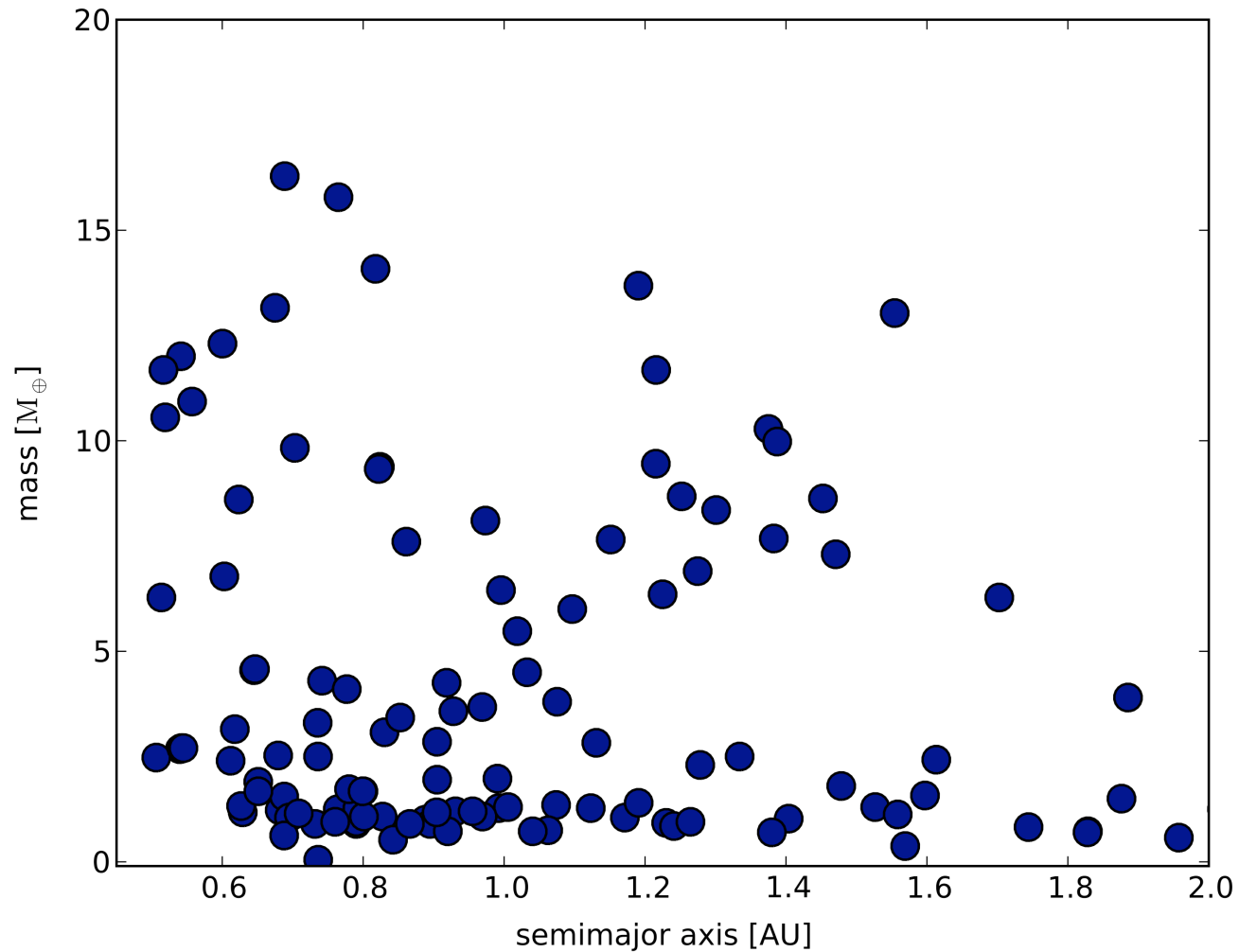
Our first toy model, without NBCT

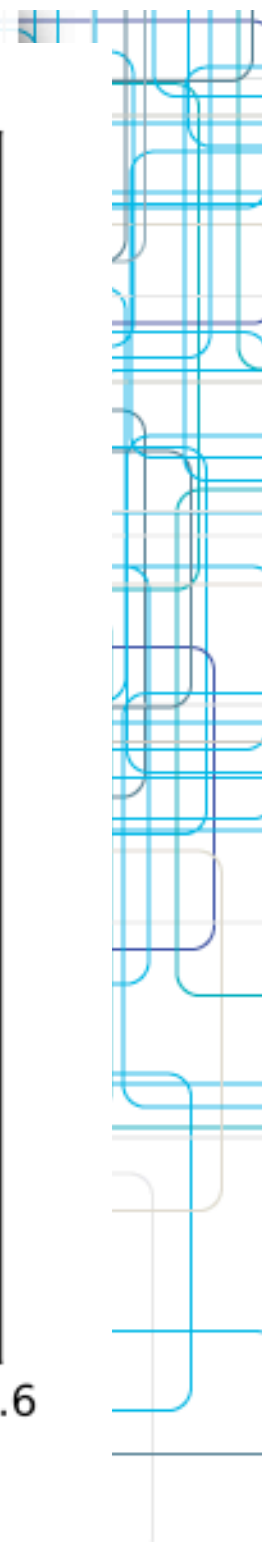
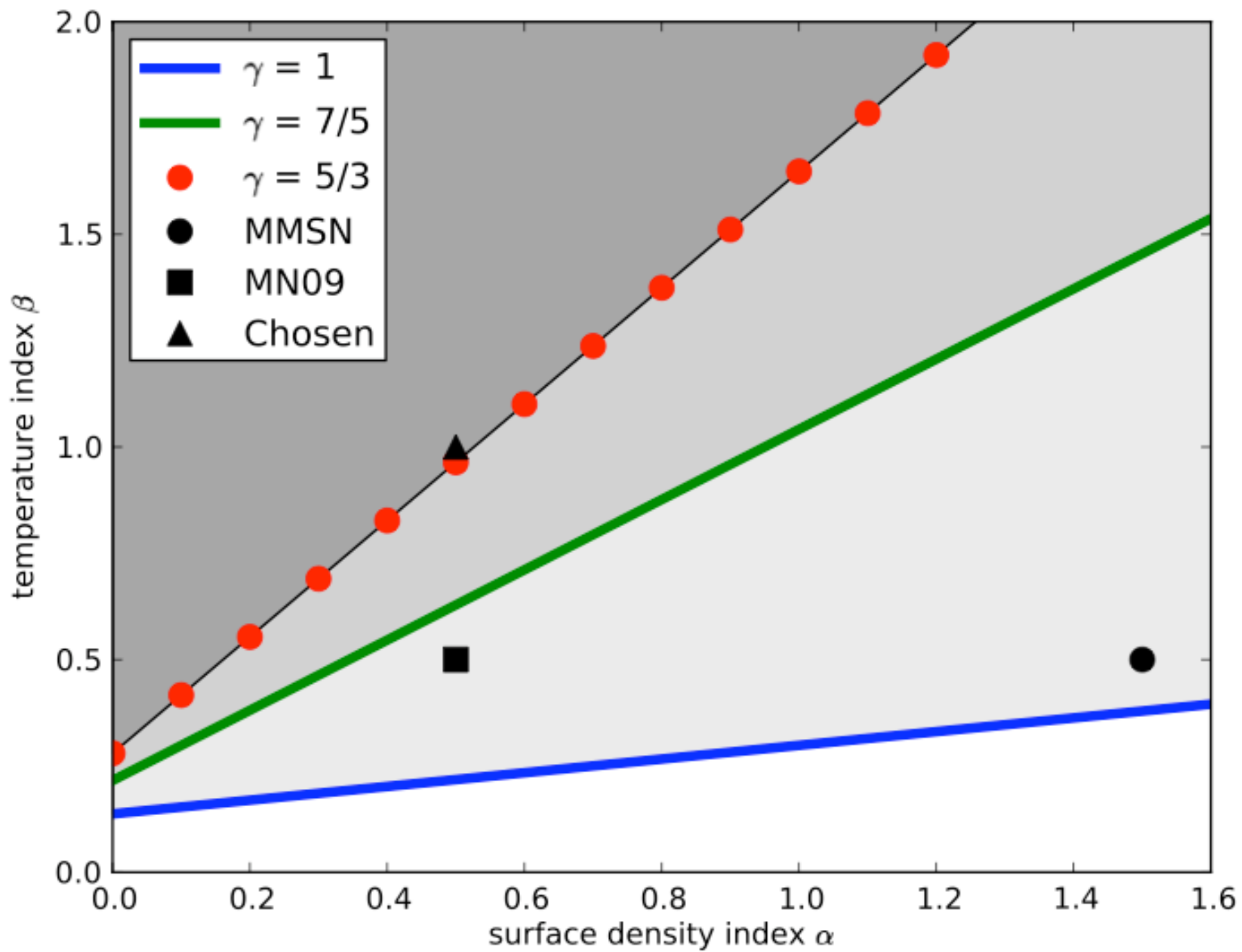


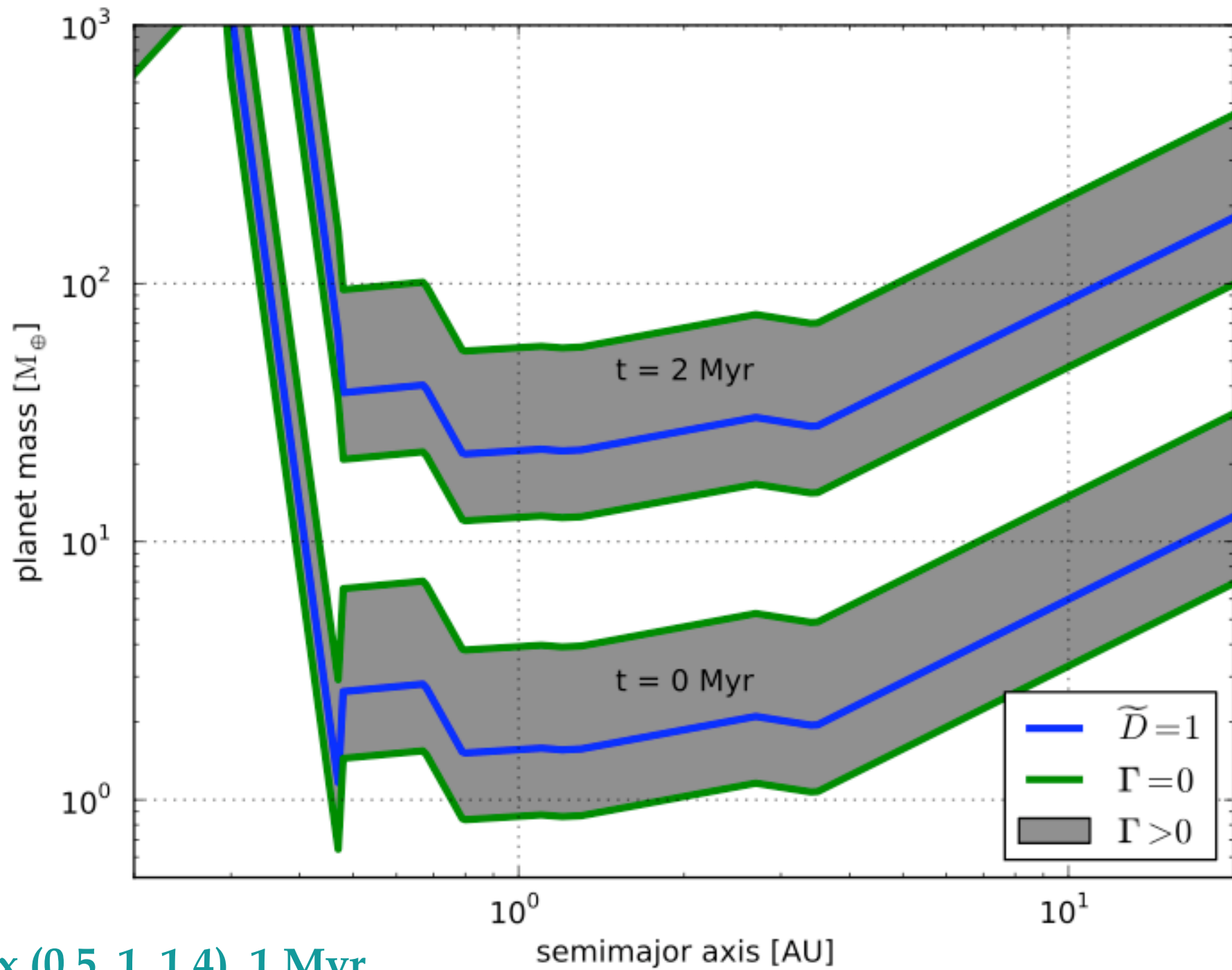
Our very first run with NBCT



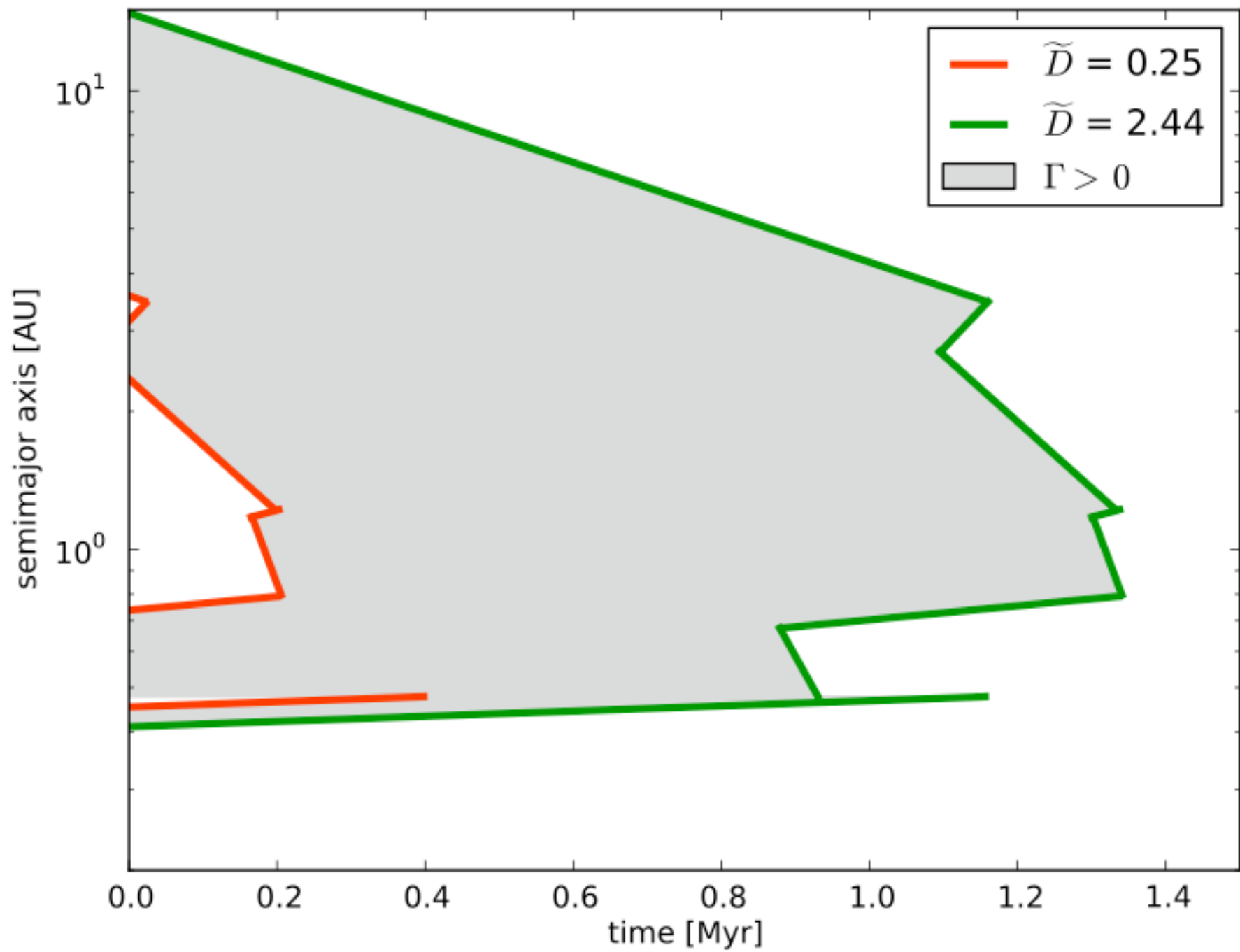
Combined runs with diffusion fudge factor in [0.1..10]

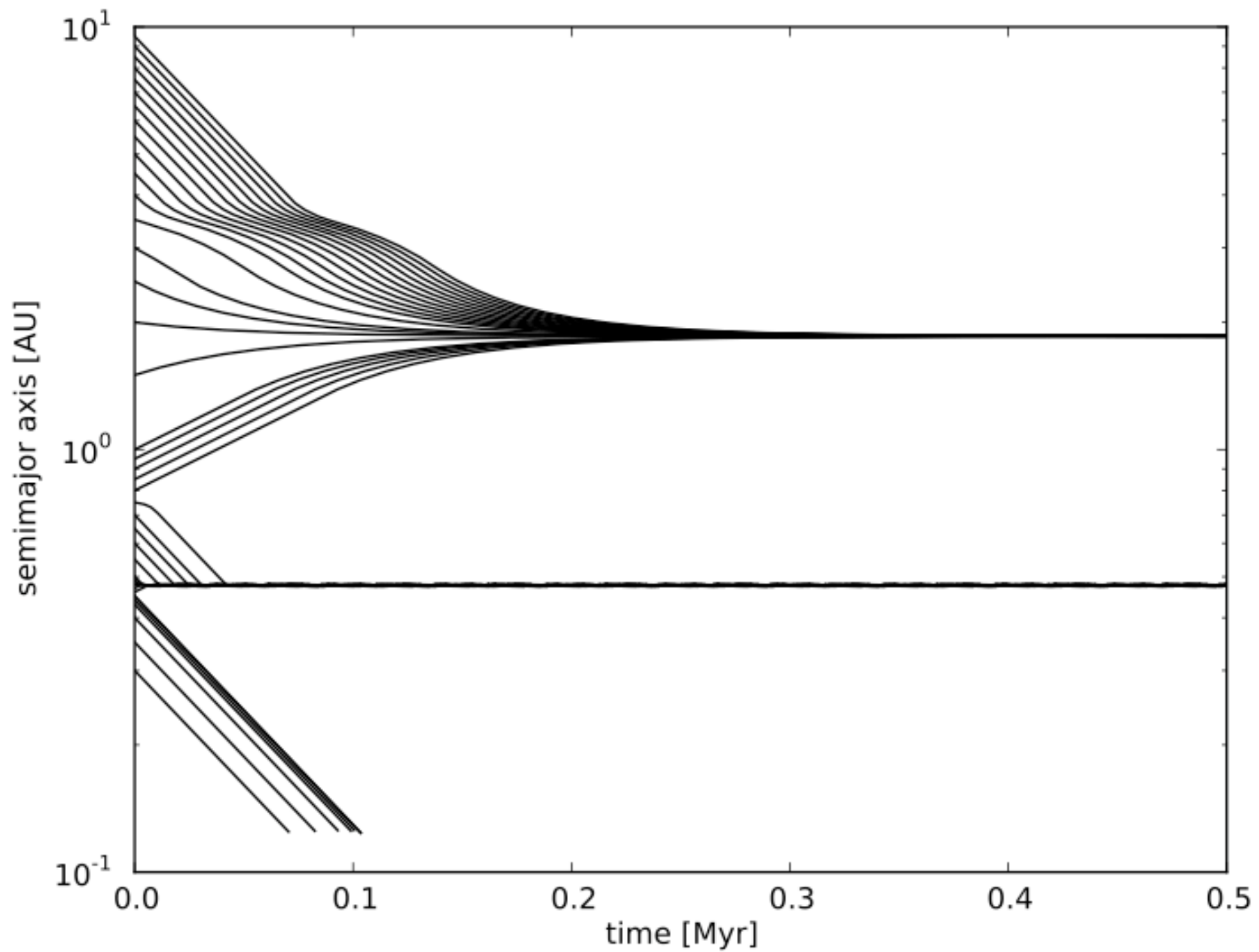


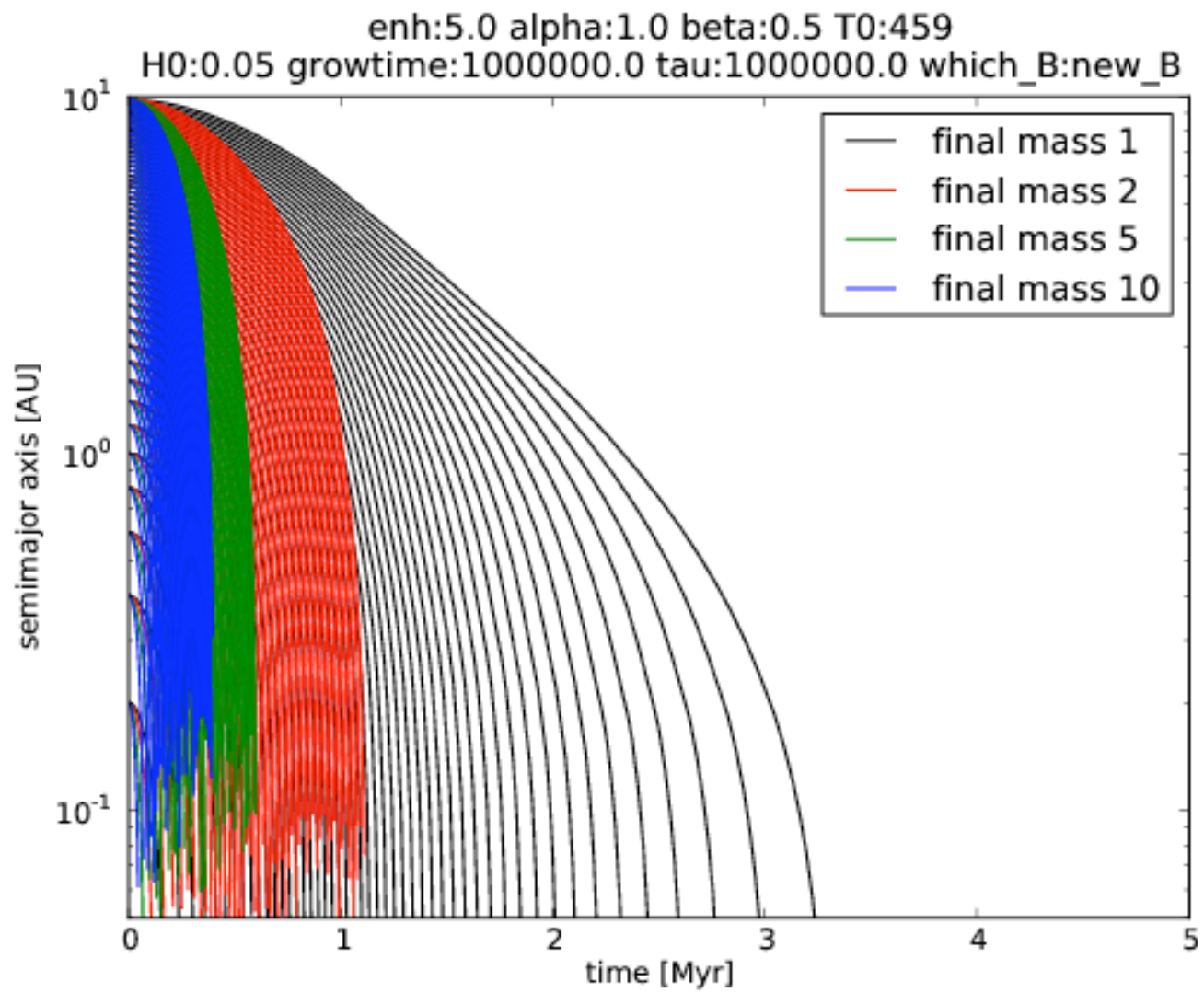


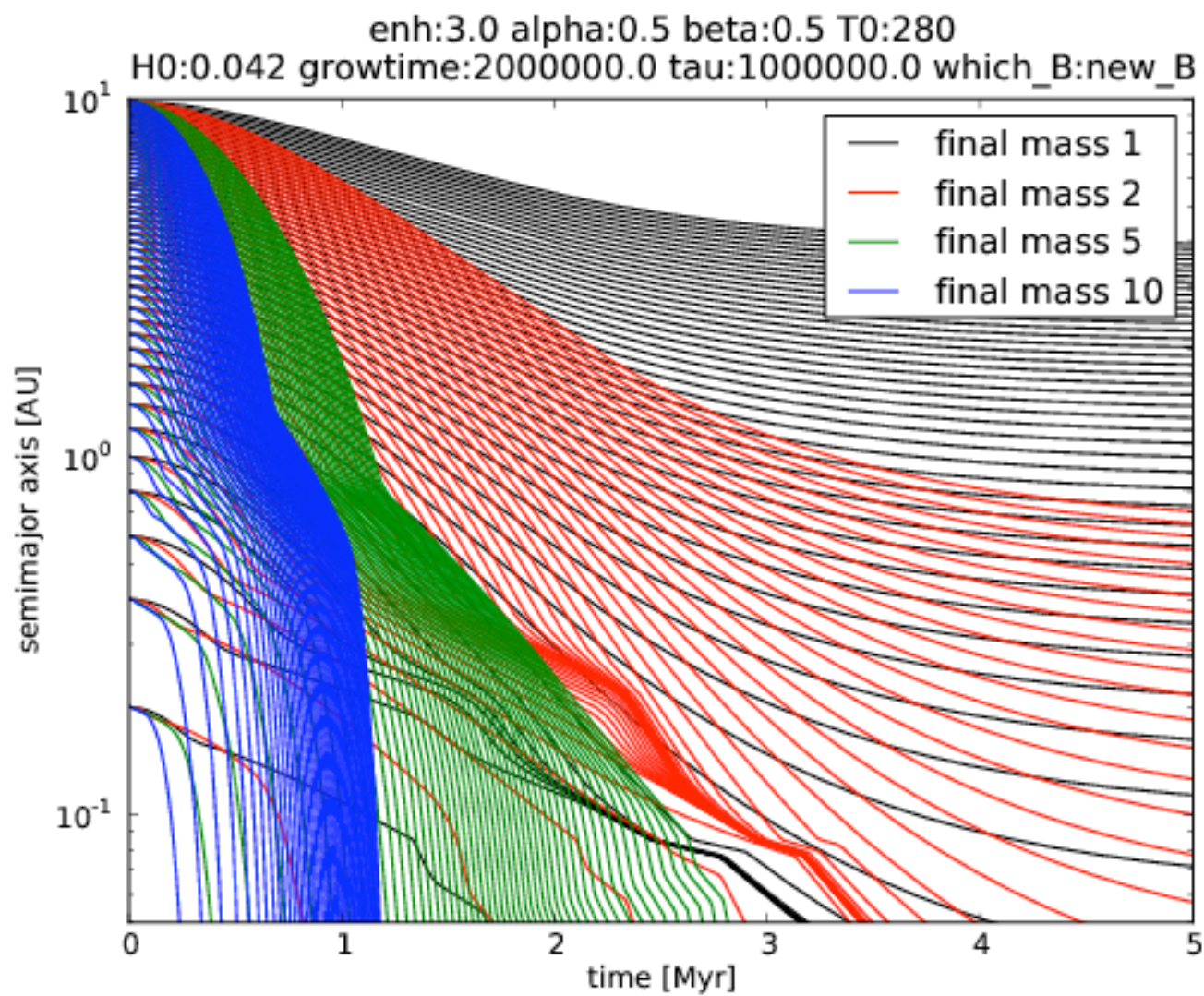


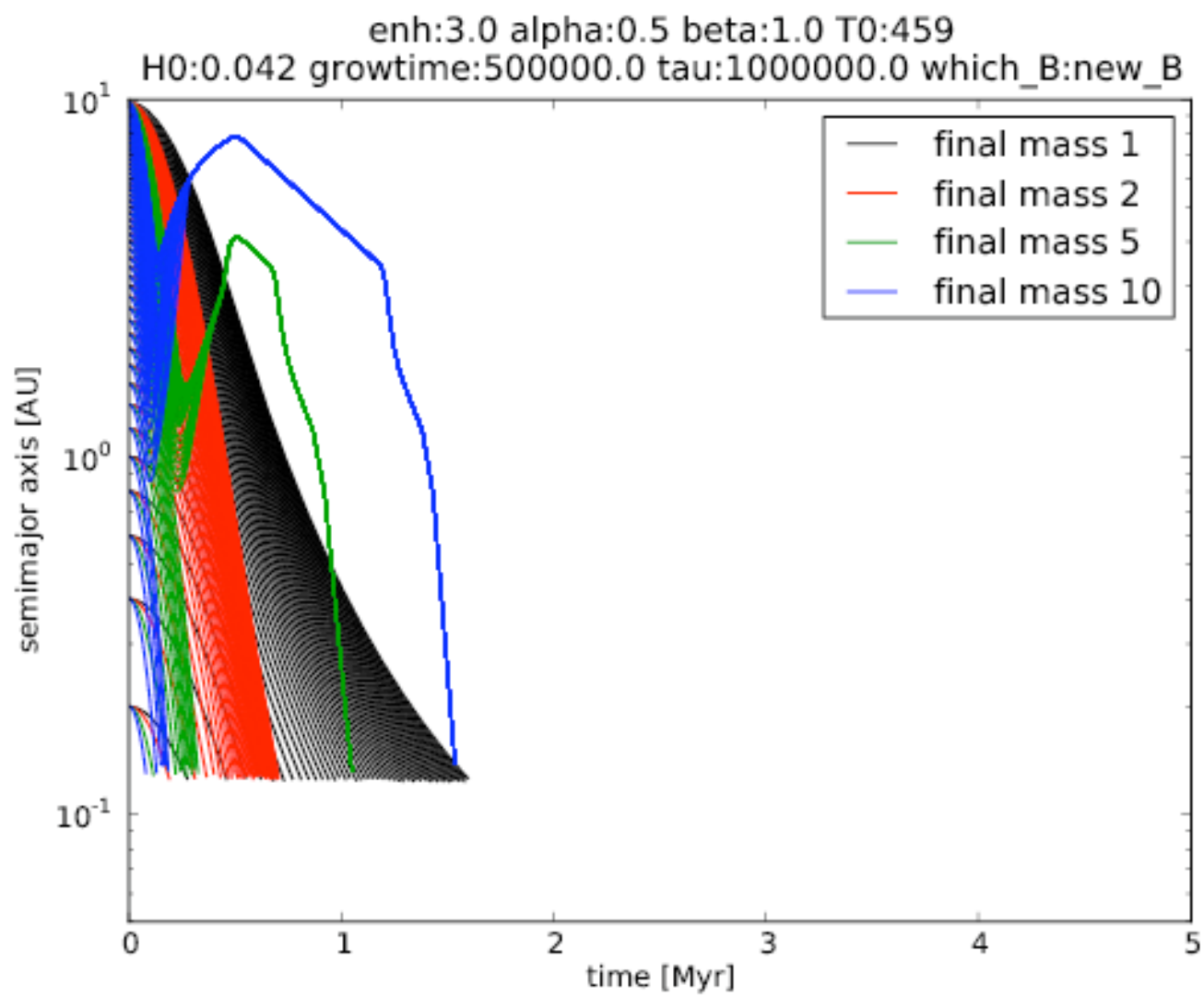
5x (0.5, 1, 1.4), 1 Myr

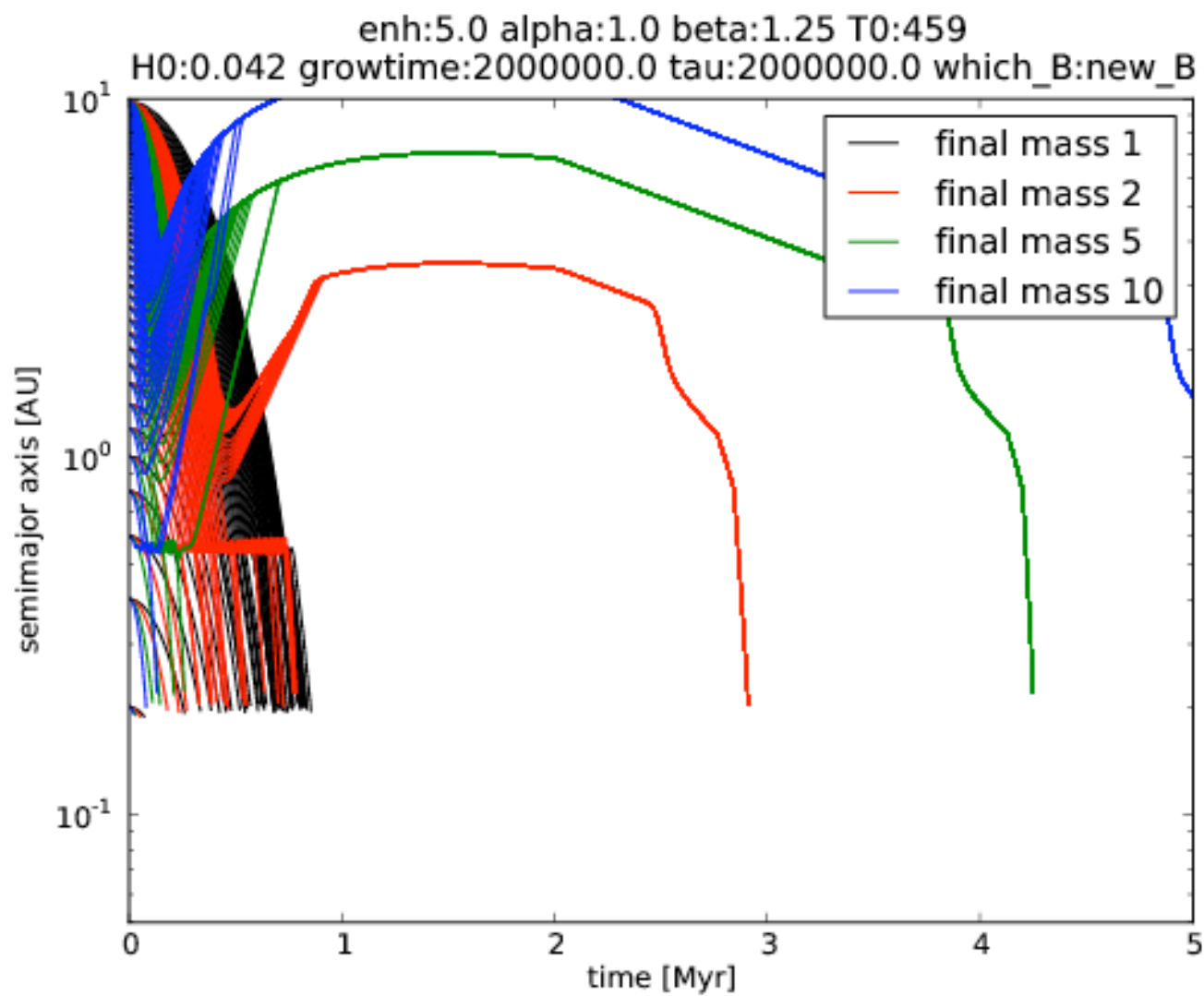


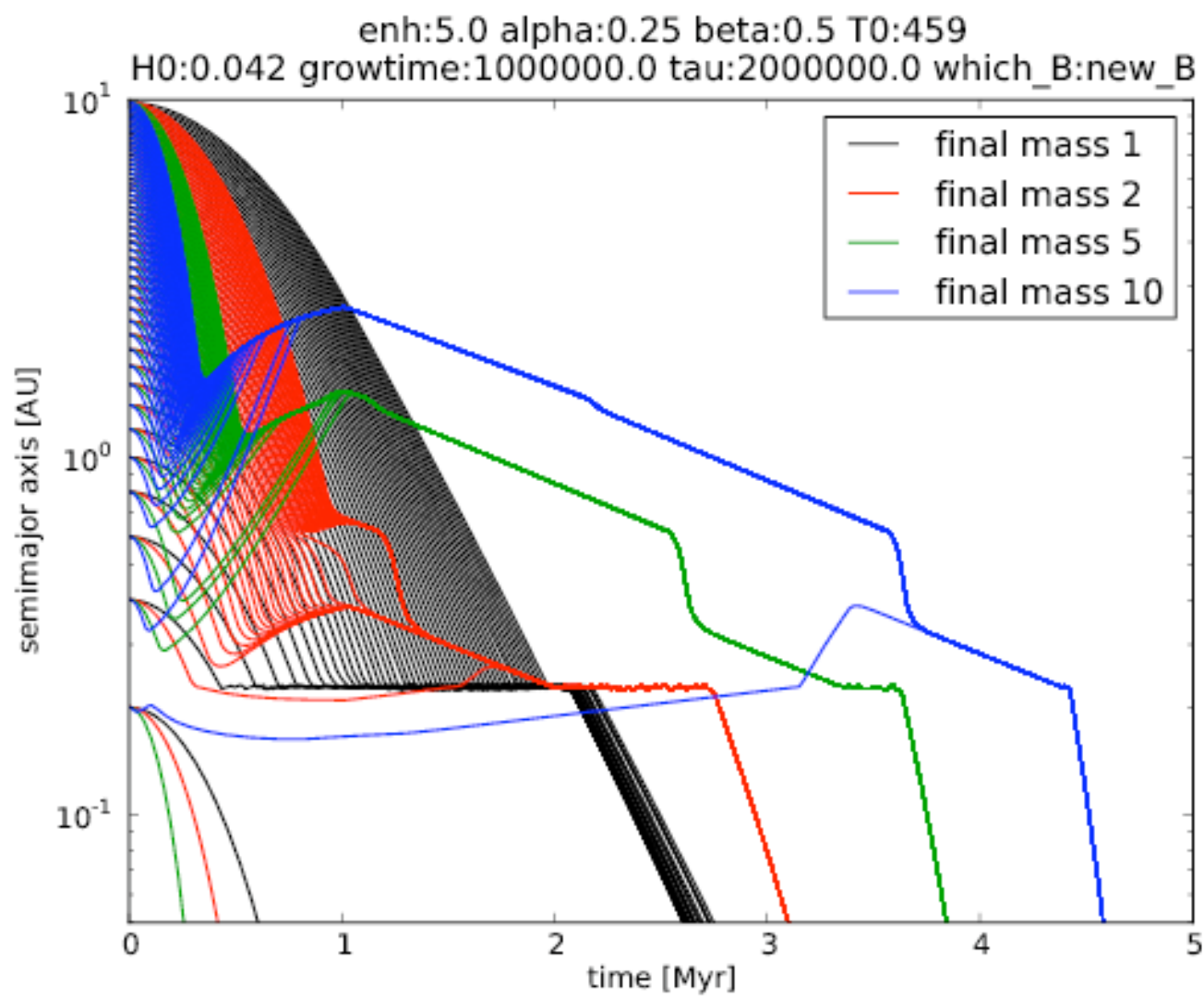












Conclusions

Multiple lukewarm Neptune systems are excellent tests of type I migration physics because they're so hard to form

The simplest oligarchy + TTW type I migration models **fail badly**, dramatically underpredicting the mass

Paardekooper-style type I migration is **very promising** but **frustratingly sensitive** [McNeil & Nelson ~~2009~~ 2010a!]