Origin of Hot Jupiters

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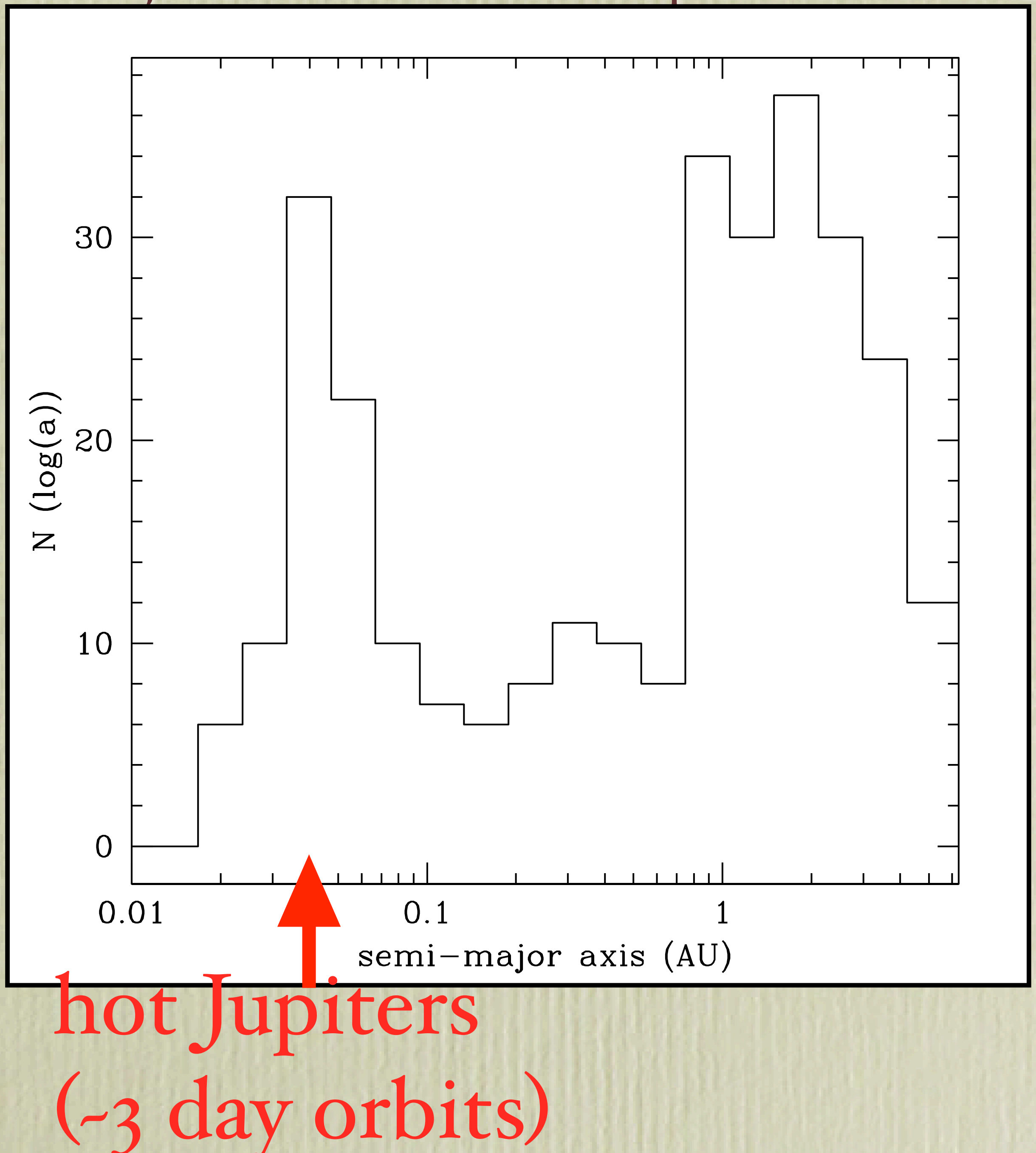
Hot Jupiters

Semi-major axis distribution of planets > 0.1 M_Jup



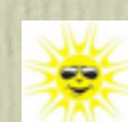
- ~ 1% of FGK stars have hot Jupiters
- How did Jupiters migrate from >1 AU to < 0.1AU?

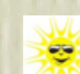
A New Migration Mechanism: Secular Chaos

(Wu & Lithwick 2011)

- Start with a few Jupiters beyond an AU, on widely-spaced, mildly eccentric & inclined orbits

- focus on secular (i.e. orbit-averaged) interactions. Okay if no close encounters or strong resonances.





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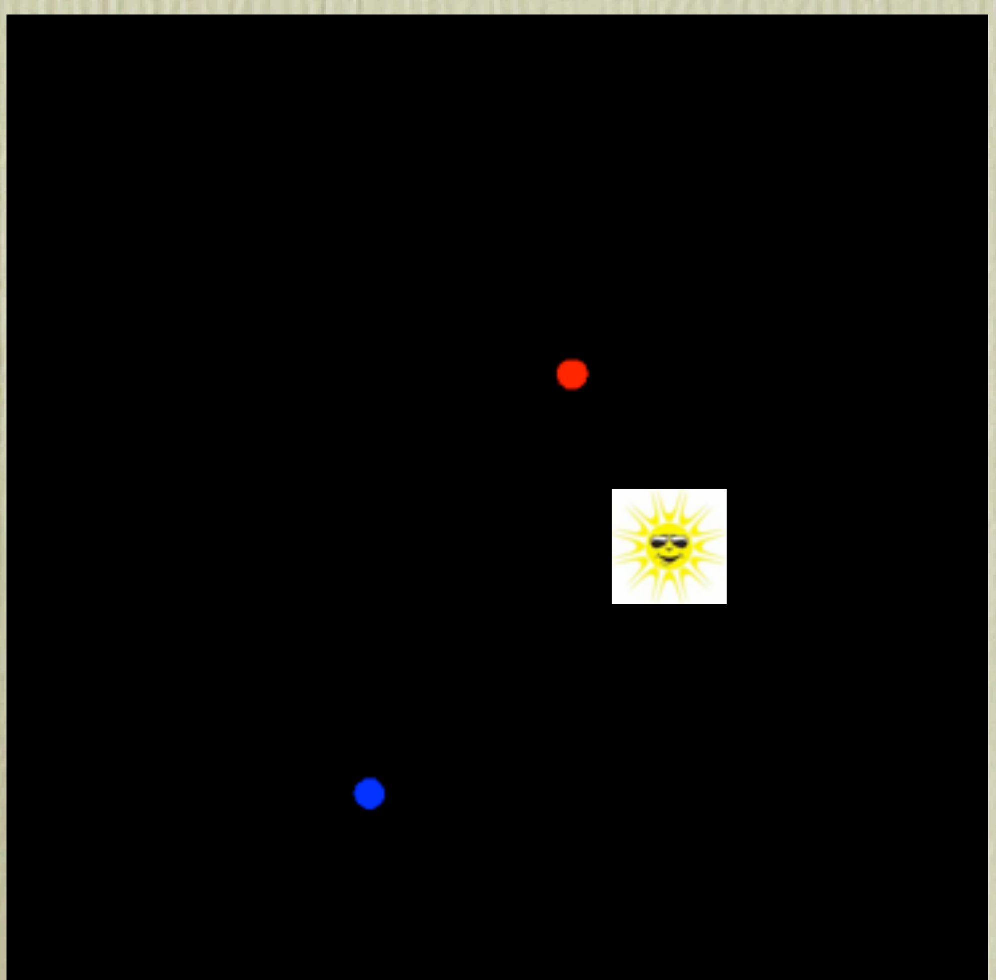

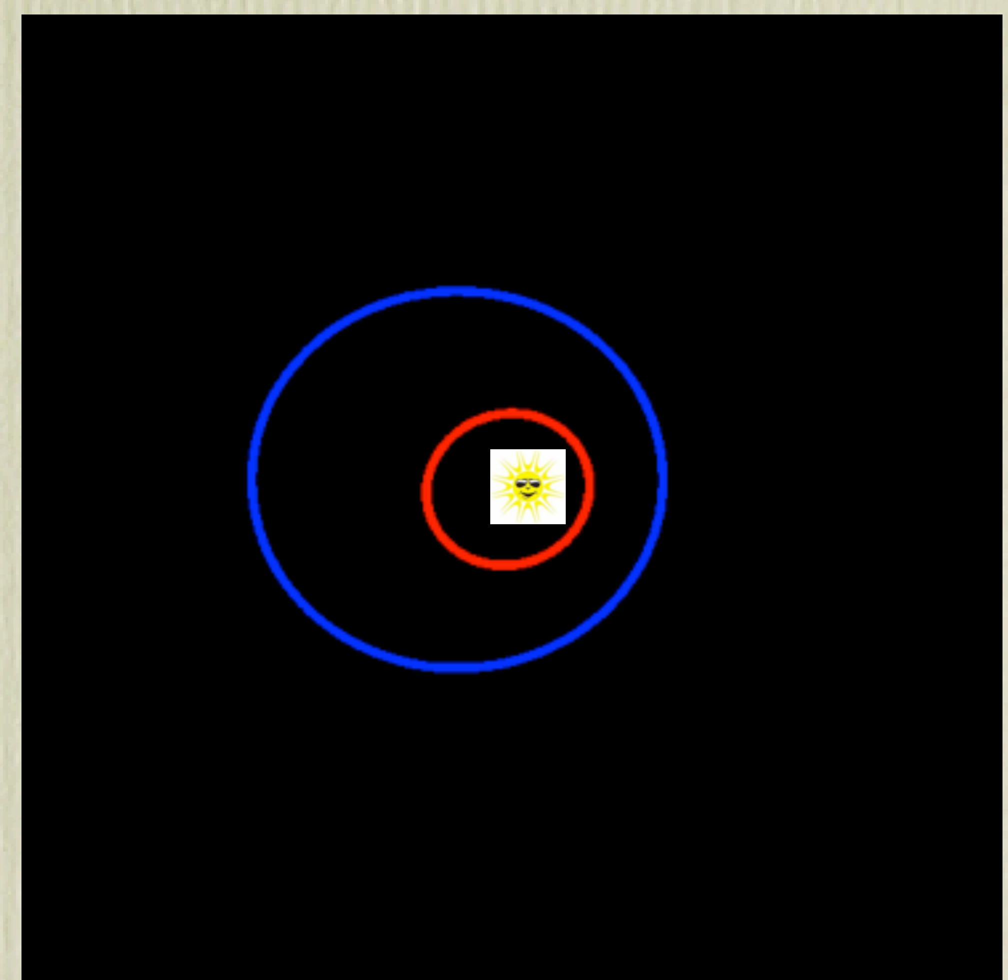

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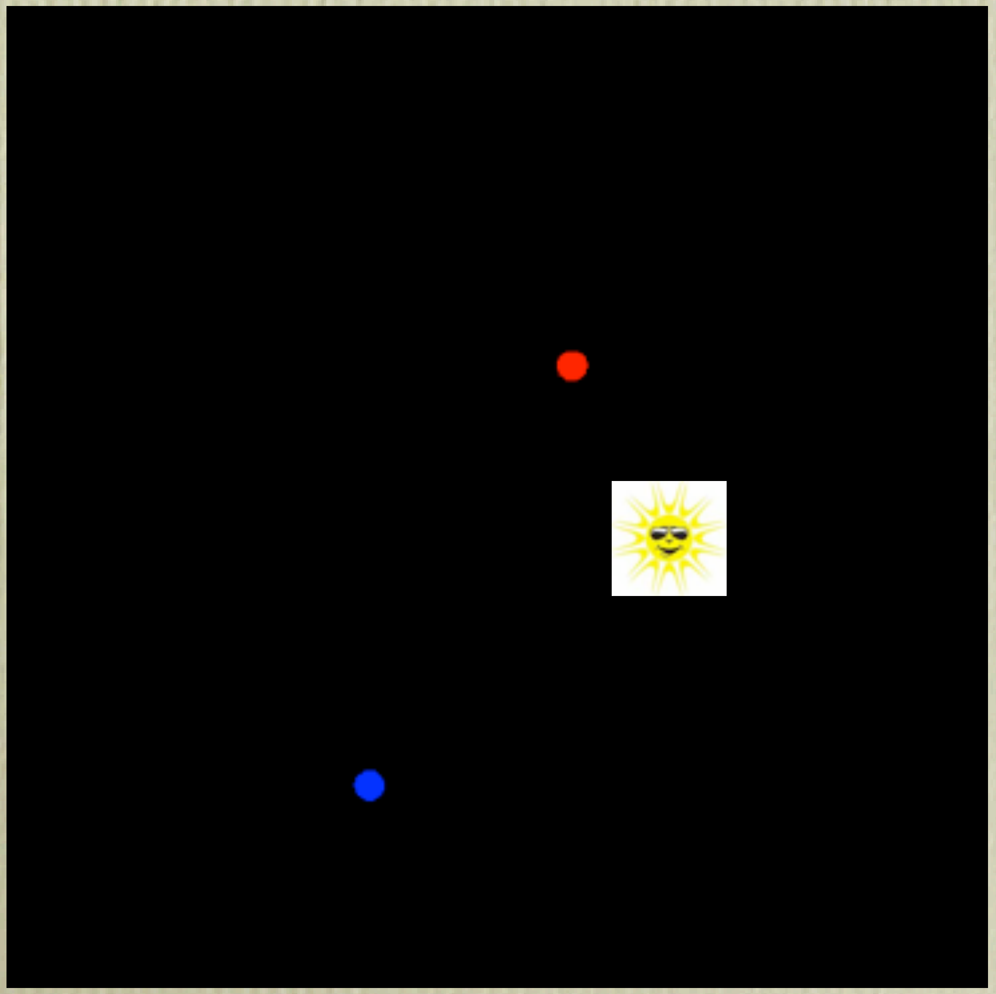
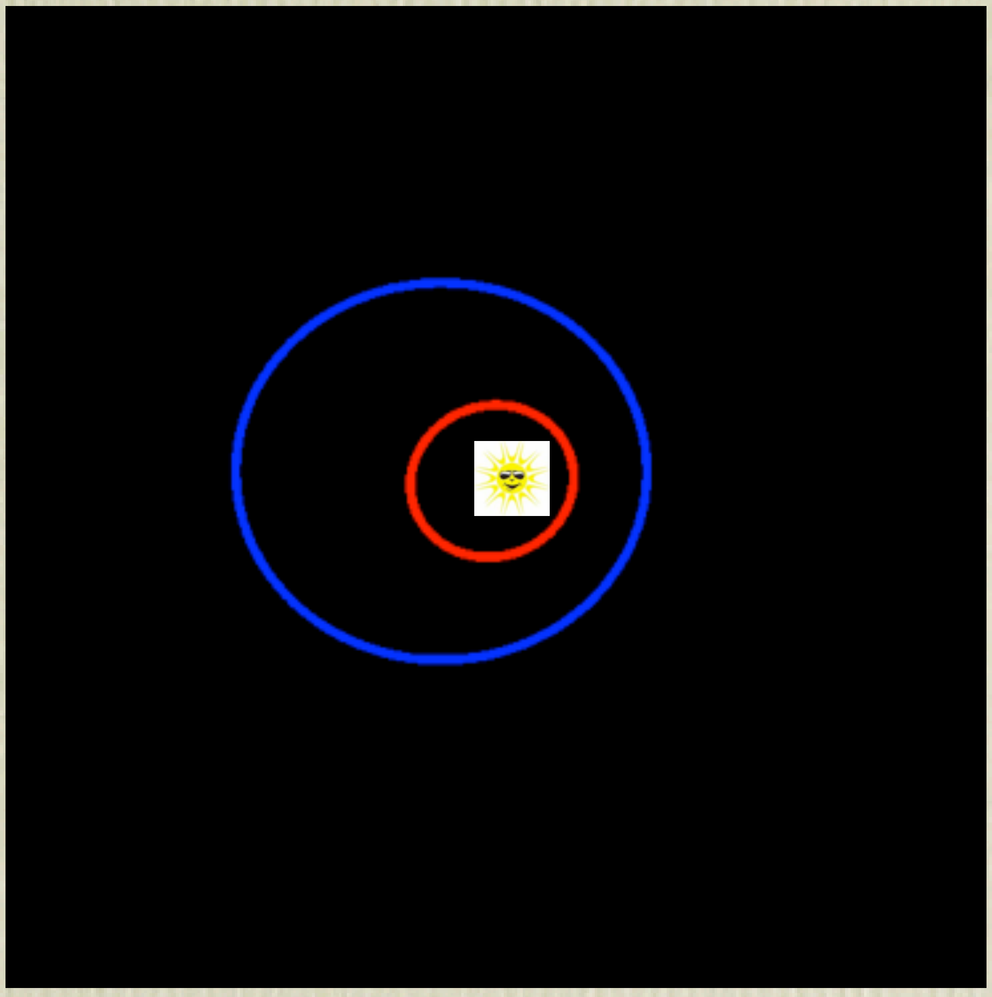
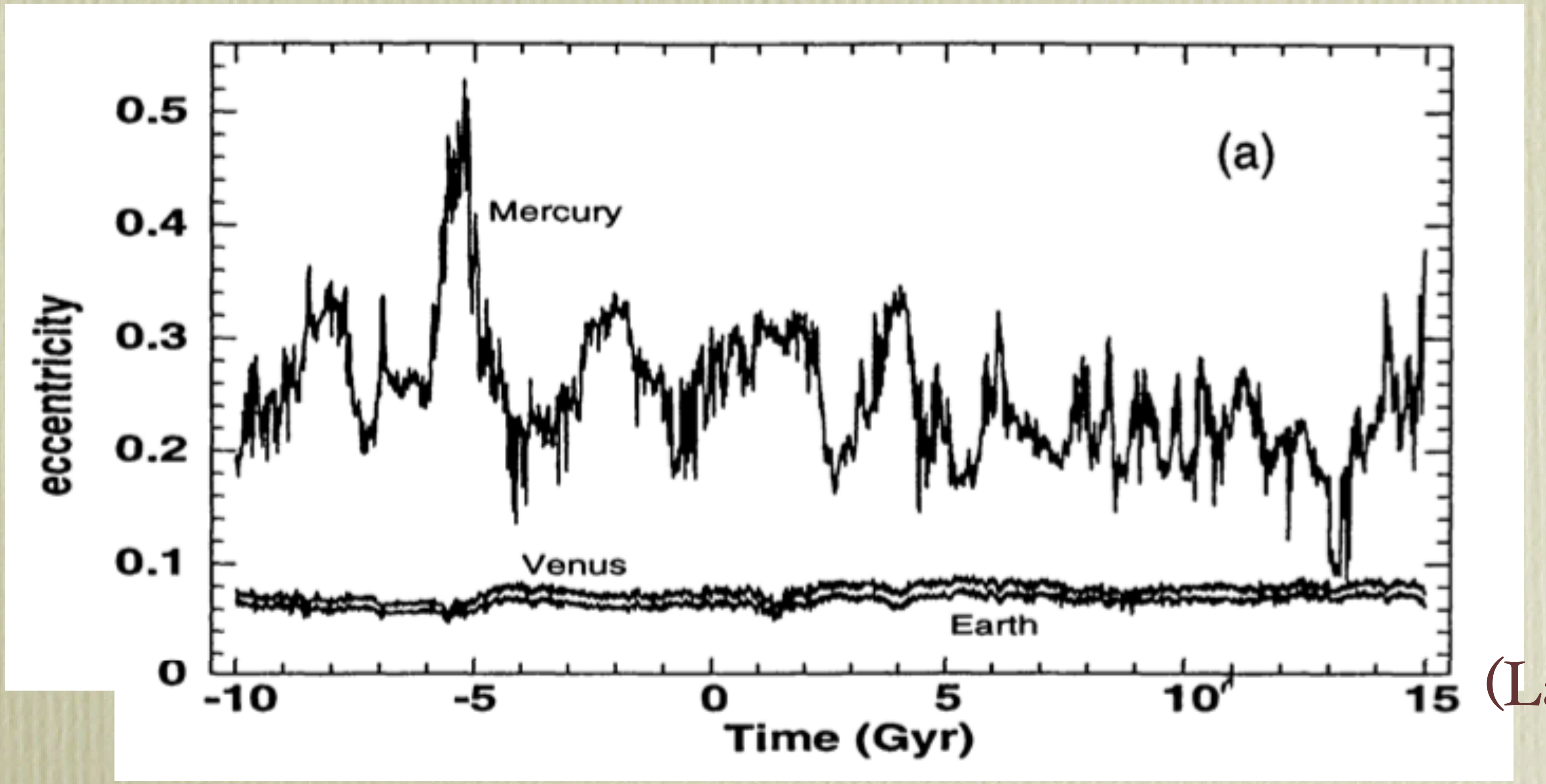




A New Migration Mechanism: Secular Chaos

- secular interactions can lead to chaos

- e.g., terrestrial planets' orbits driven by secular chaos

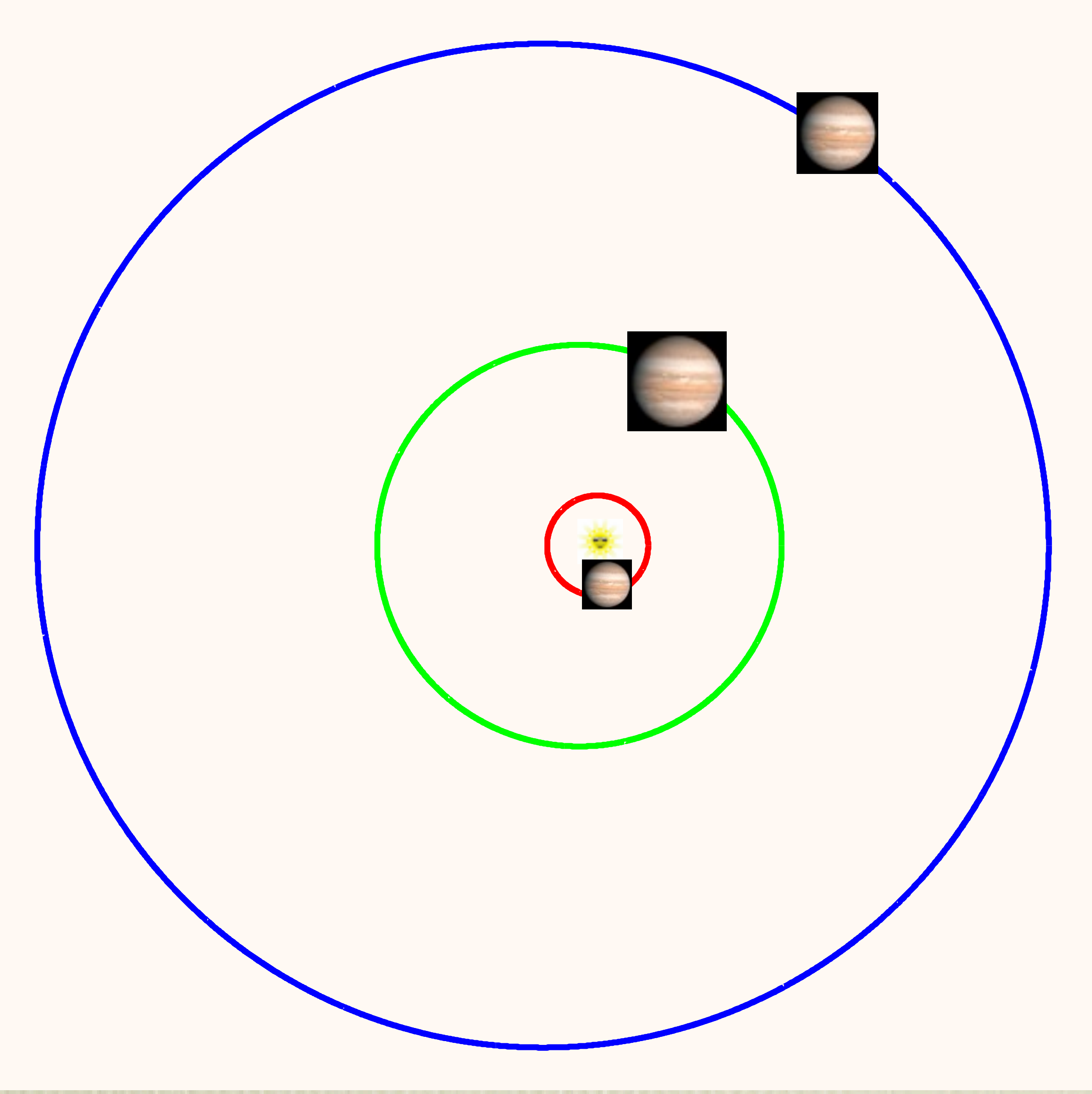


(Laskar '96)

An Example N-body Simulation

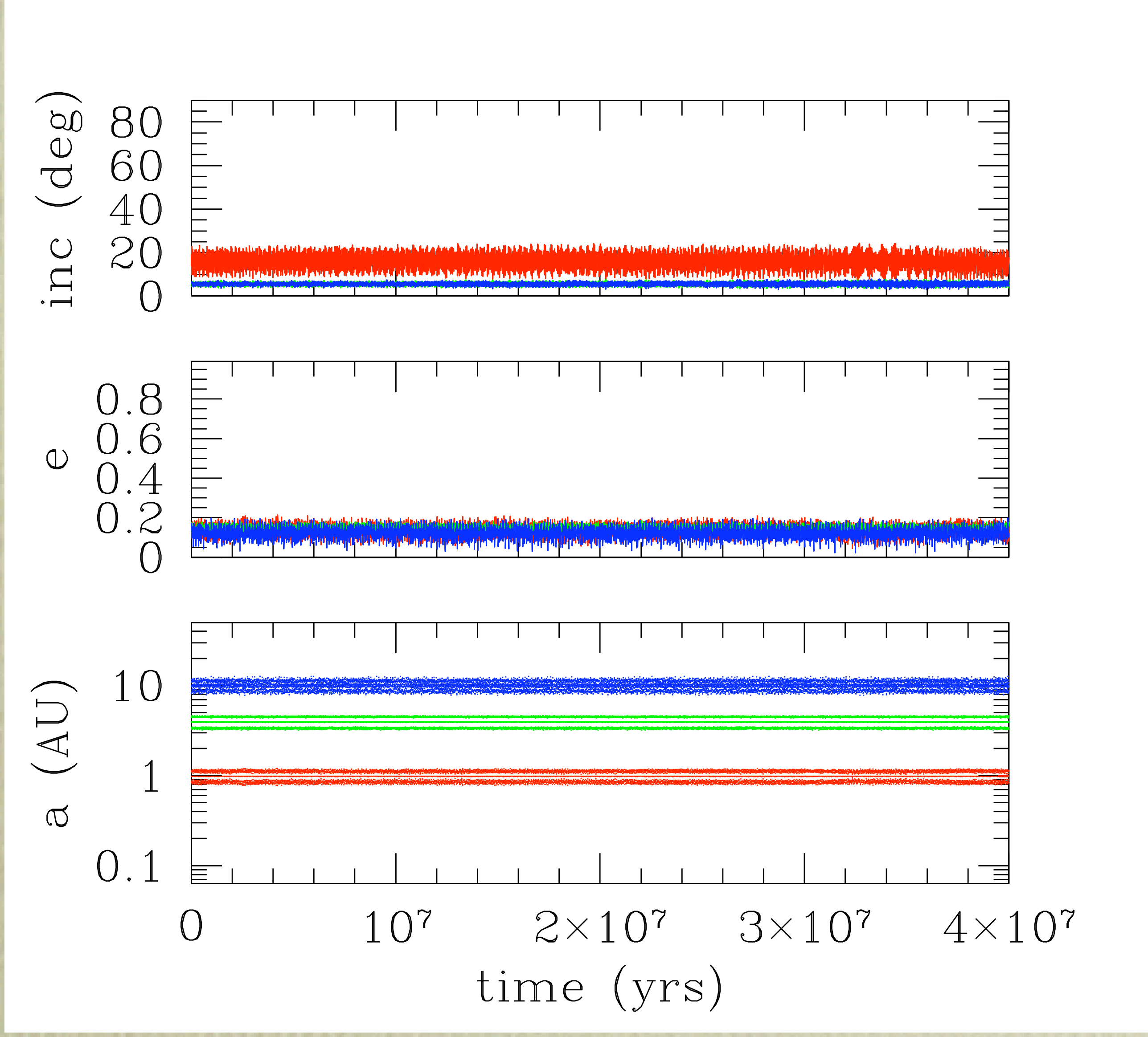
- Initial conditions:

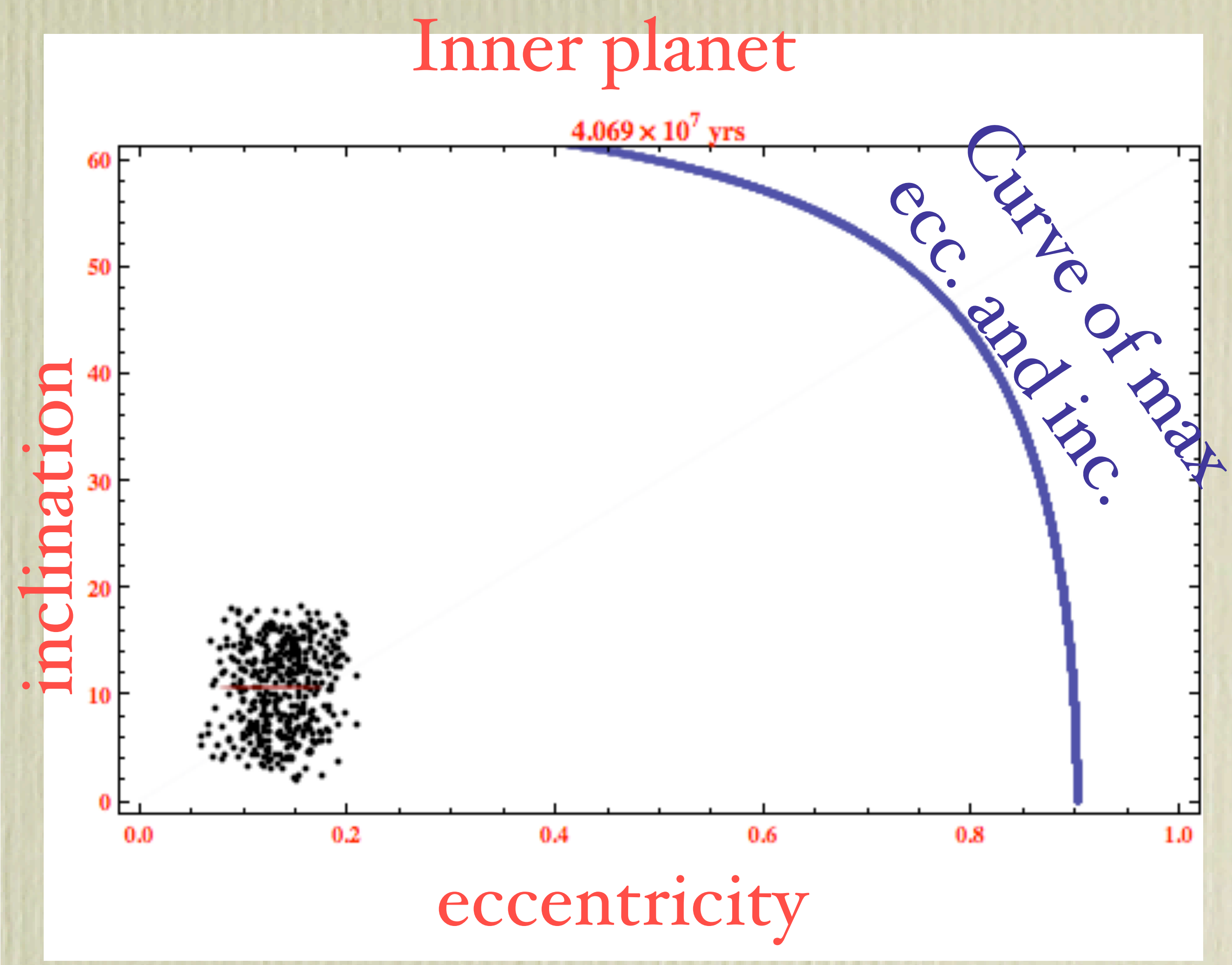
a(AU)	*ecc.*	*inc. (deg)*	*mass (Mjup)*
1	0.12	10	0.5
4	0.12	5	10
10	0.12	5	5



Secular Instability

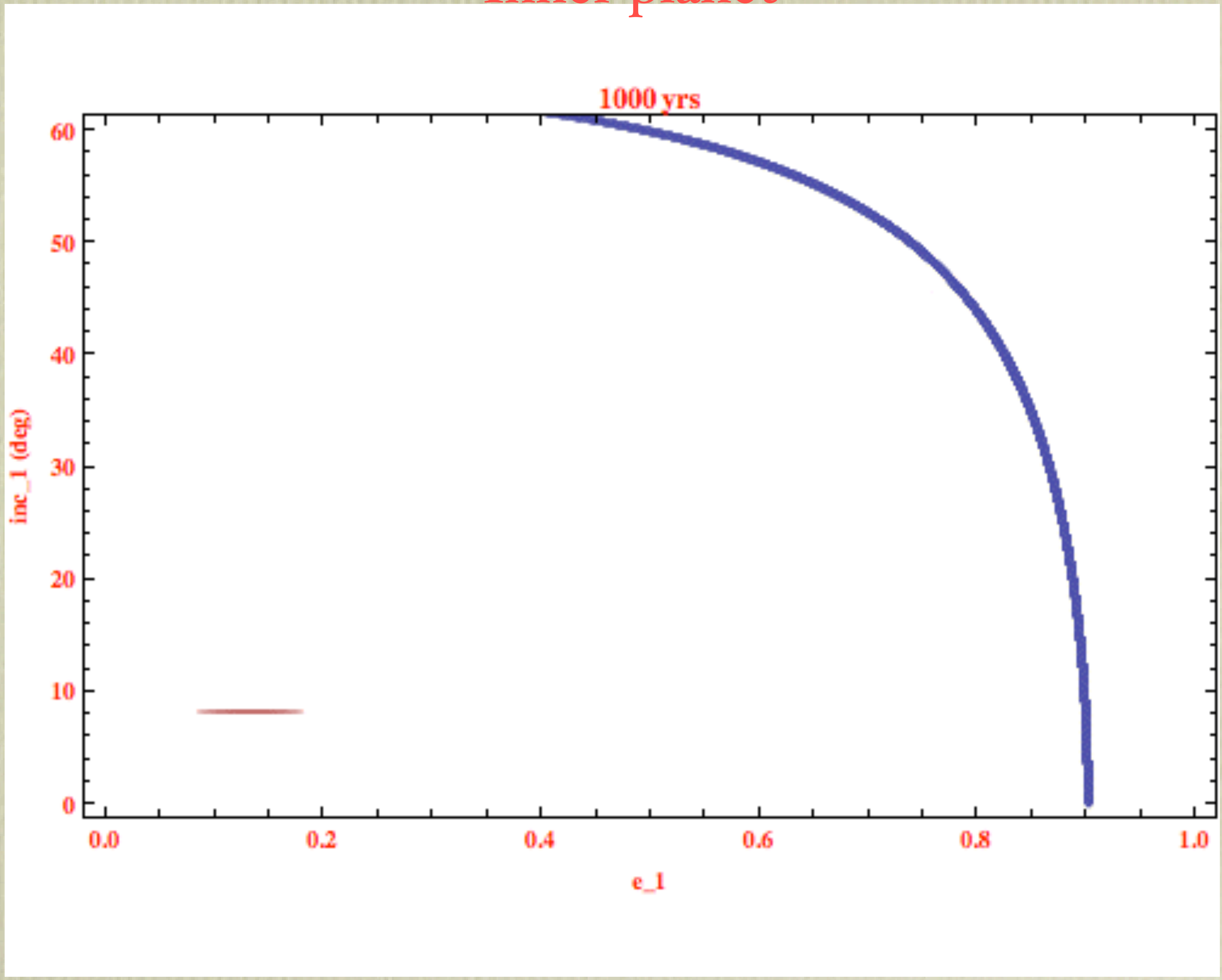
Nothing happens for a long time...





Secular Instability

Inner planet



- Inner planet can reach high eccentricities & inclinations, given enough time

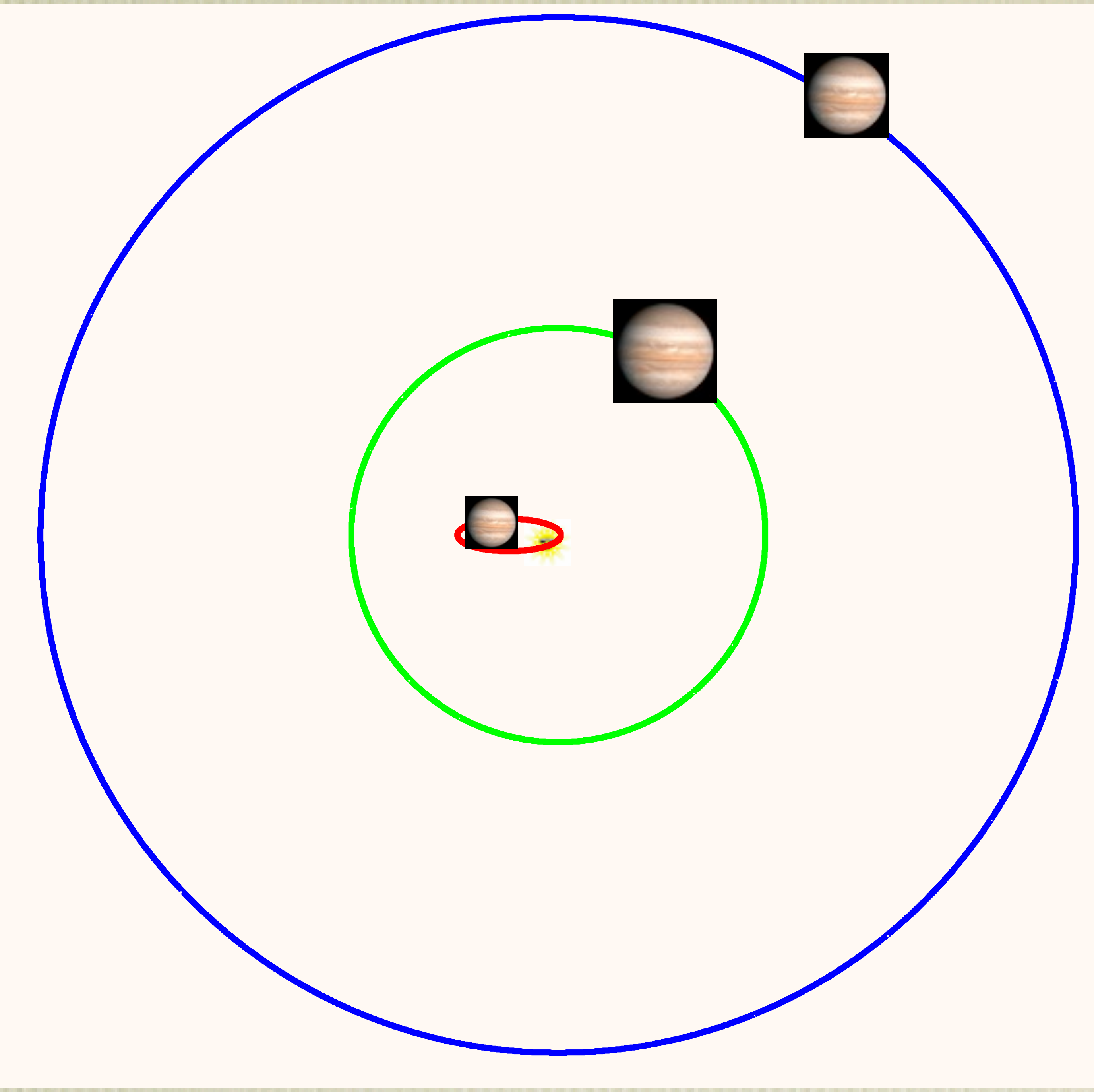
Secular Instability

When inner planet acquires high e,

- pericenter approaches star
- tides raised by star can circularize planet

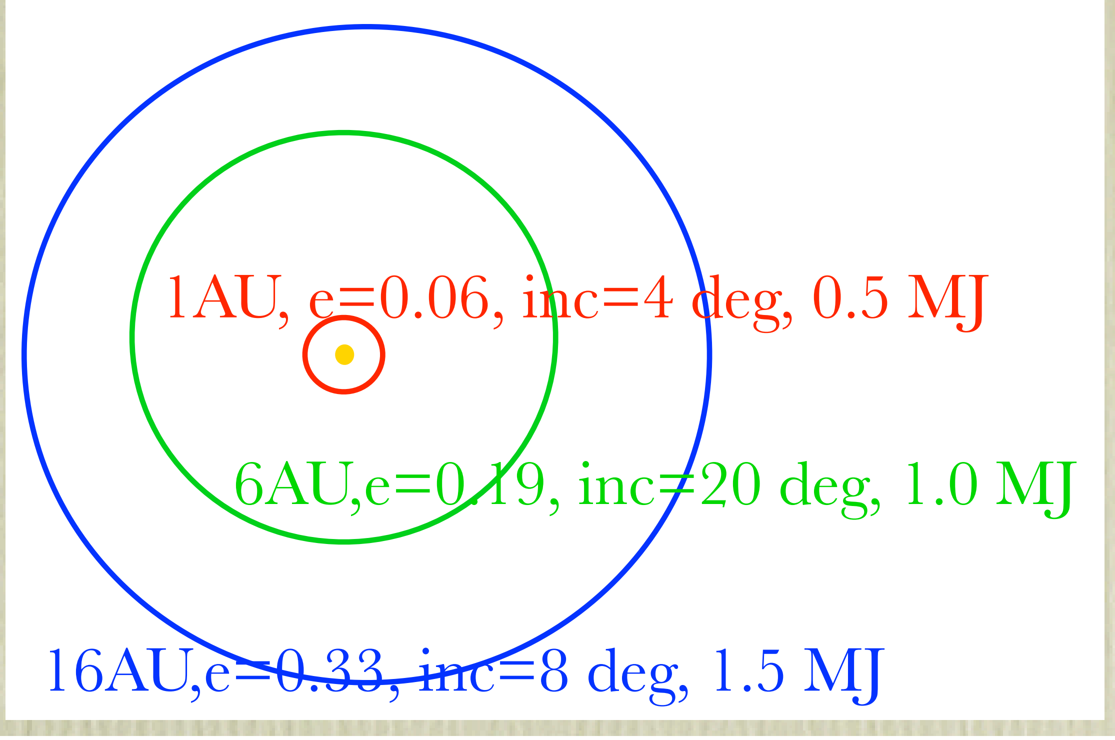
$\Rightarrow$ hot Jupiter

- Inner planet has smallest "inertia" $\Rightarrow$ most likely to be excited

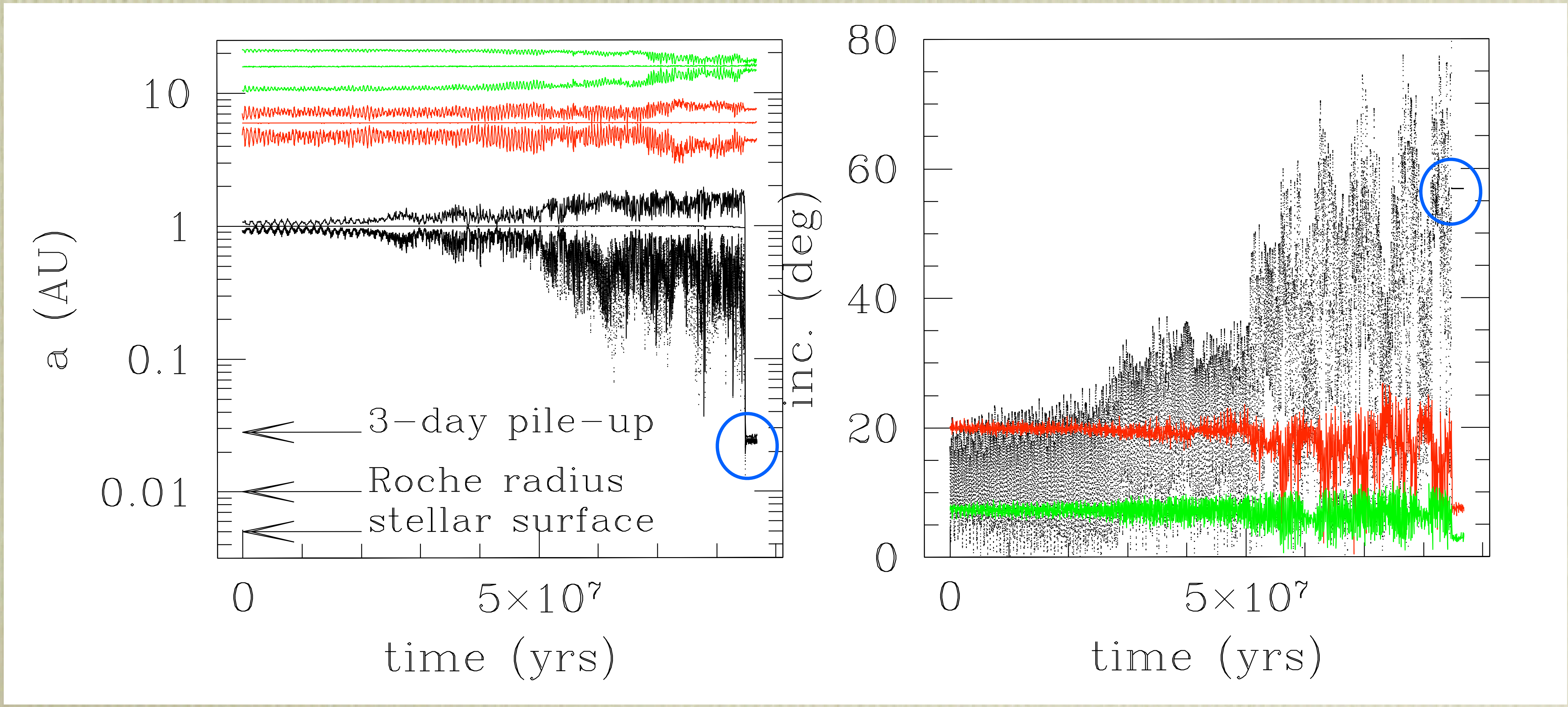


- Note also: remaining planets "cooled"

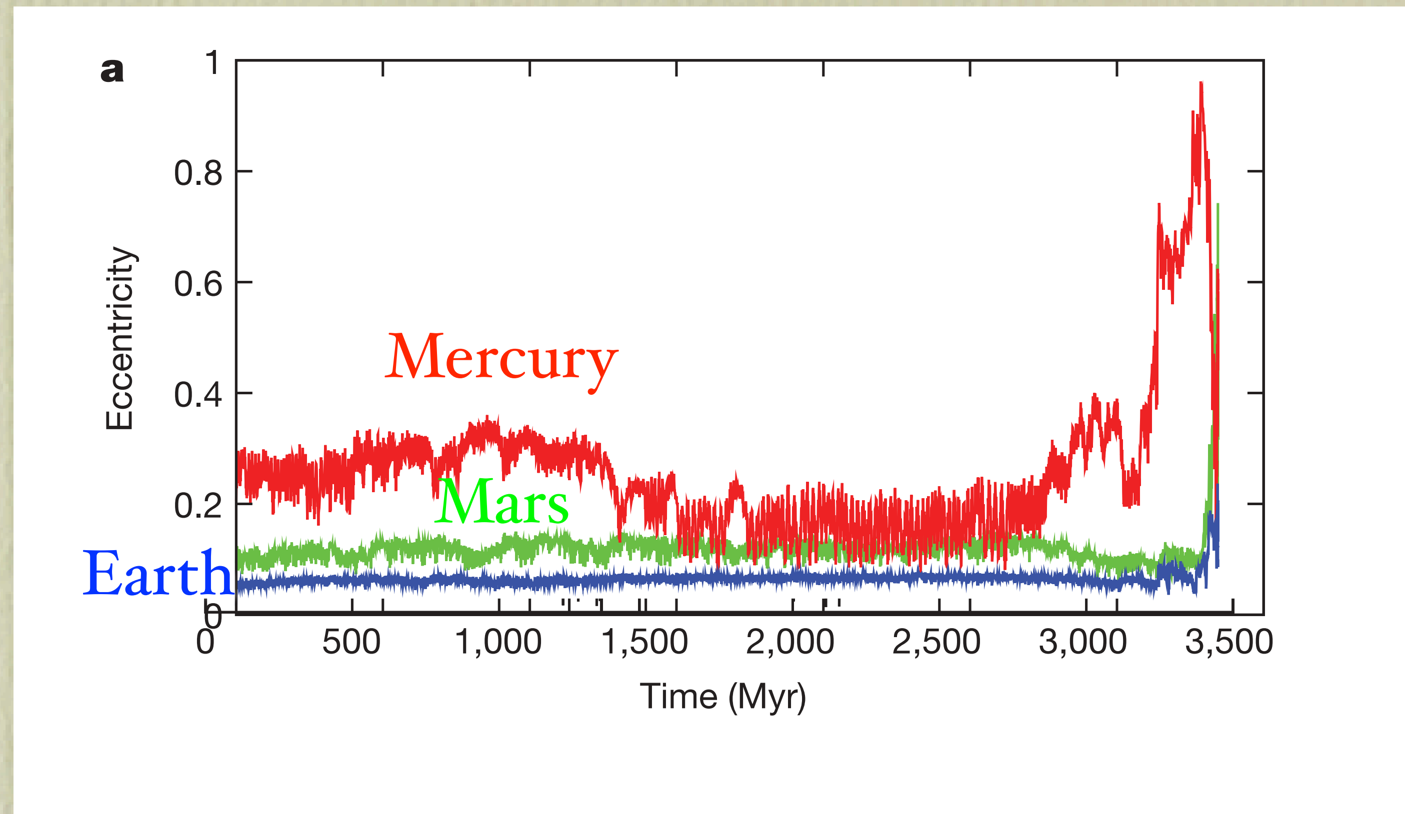
Another system (with tides & GR)



constant a ⇒ secular



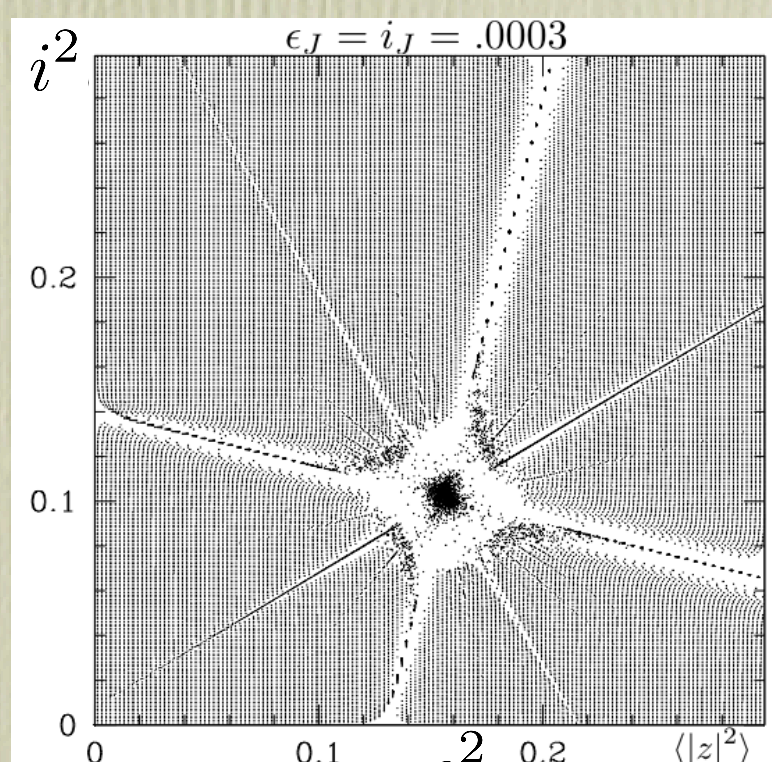
Similar to Mercury's orbital chaos



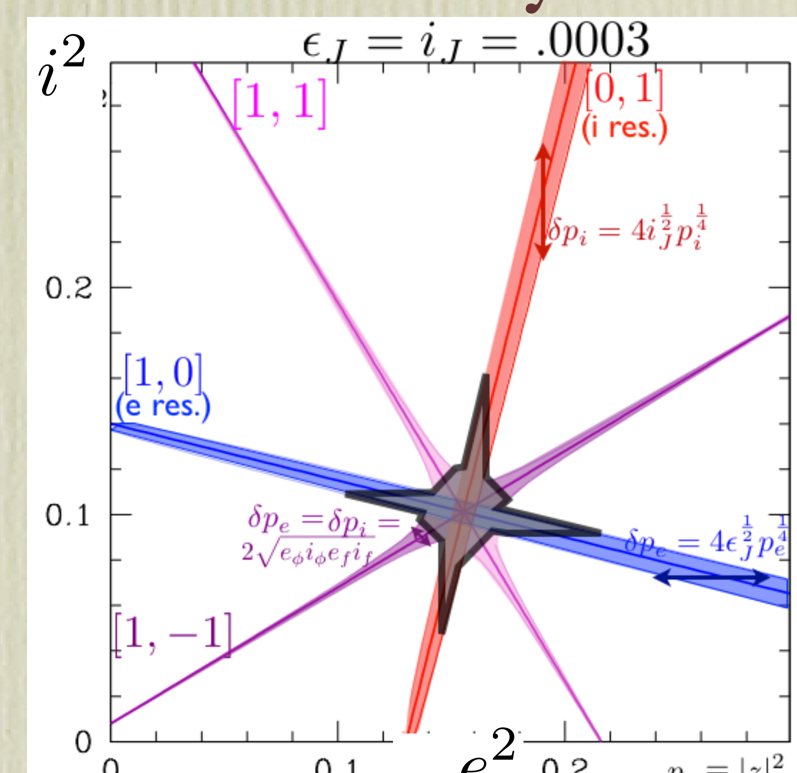
(Laskar & Gastineau `09)

Lithwick & Wu (2011)

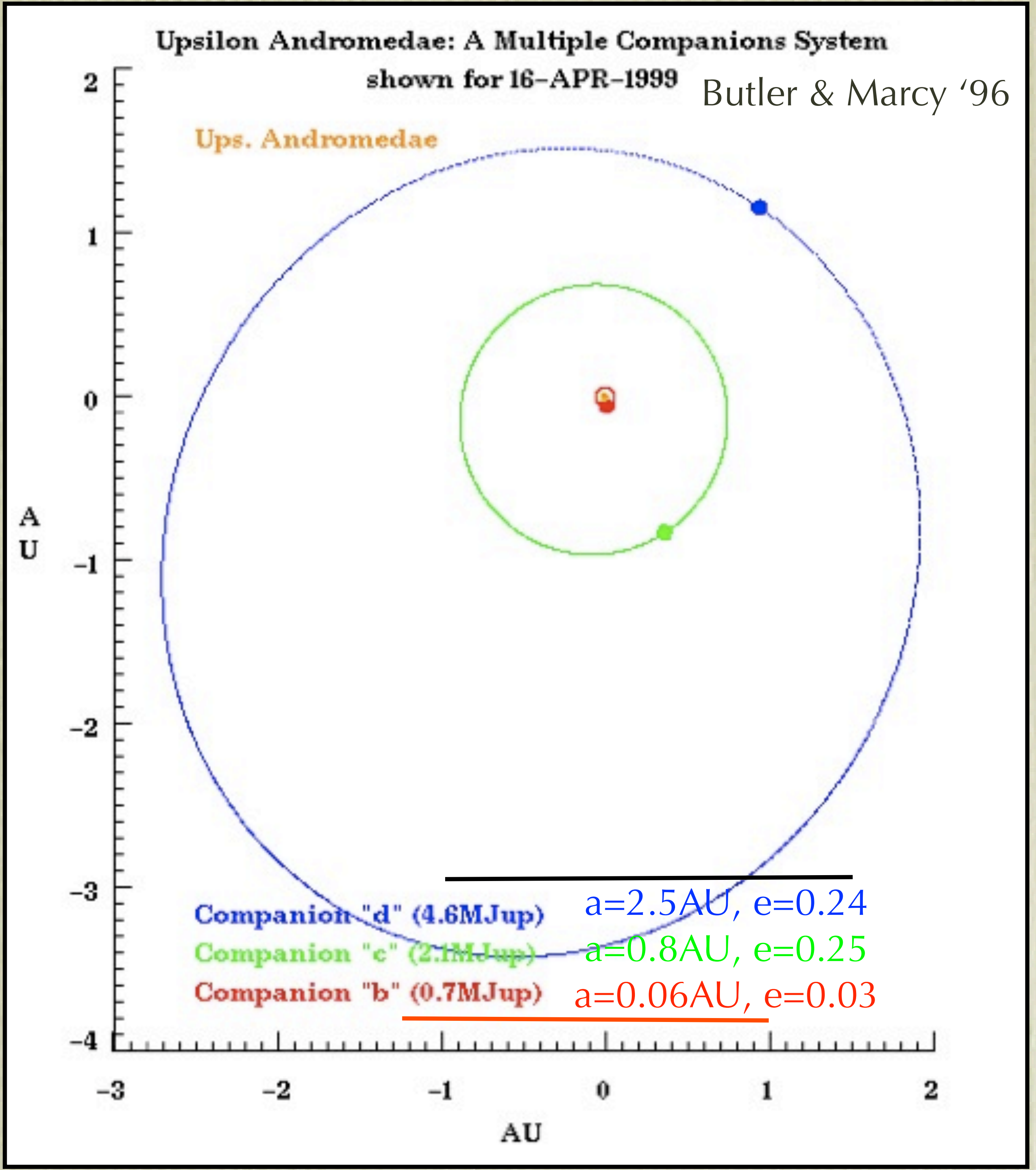
Simulation



Theory



Has it really happened?



Michtchenko & Malhotra '04
Migaszewski & Gozdziewski '08,'09

Comparison with Observations

observation		explanation
3-day pile-up	✓	gradual e-growth (timescale > 10^6 yrs) + tidal dissipation
range of stellar obliquities (R-M)	✓	excite both e and i
lack of close companions	✓	predict: no TTV for hot Jupiters more Jupiters beyond a few AU
Masses lower than average	✓	easier to excite low mass planets

Also predict that fraction of hot Jupiters increases with stellar age ⇒ no hot Jupiter around T Tauri observation

	secular chaos	disk migration	Kozai migration	planet scattering	
3-day pile-up	✓	✗?	✓	✗	
range of stellar obliquities (R-M)	✓	✗?	✓	✓	
lack of close companions	✓	✗	✓	✓	
Masses lower than average	✓	?	✗	✗	
			Also, cannot produce frequency of hot Jupiters (Wu et al.)	Also, initial conditions are artificial	

Secular chaos predicts

$$M \simeq M_J \left(\frac{\text{orbital period}}{1.9\ \text{days}}\right)^{-10/3}$$