Tidal and magnetic interactions between a hot Jupiter and its host star within a protoplanetary disk

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Outline

- Motivation
  - How the orbital evolution of a young hot Jupiter inside a magnetospheric cavity depends on the *cavity size*, *planet mass*, and *orbital eccentricity.*
- Description of the model
- Result
- Conclusion

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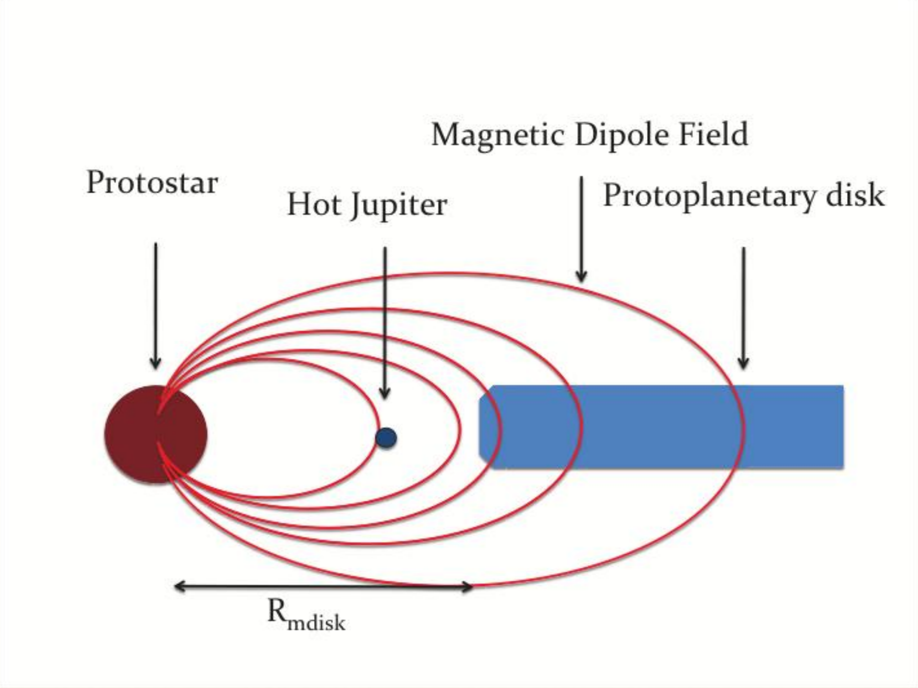
Illustration of our simple model



Summarize the equations for the simulation

- circularization
- Star-planet magnetic linkage
- Thermal adjustment
- Stellar tide
- Disk locking
- Mass loss

$$\frac{de}{dt}=\boxed{g_p+g_*}$$

$$\frac{dR_p}{dt}=\boxed{\left(\frac{\partial R_p}{\partial t}\right)_{\dot{M}_p=0}}+\boxed{\alpha\left(\frac{R_p}{M_p}\right)\dot{M}_p}$$

$$\frac{d\Omega_*}{dt}=-\frac{1}{I_*}\left\{\boxed{\dot{I}_*\Omega_*-T_{disk}}-\boxed{\langle T_{planet}\rangle}+\boxed{\dot{M}_p\left[GM_*a\left(1-e^2\right)^{1/2}\right]}\right\}+\boxed{\dot{\omega}_*}$$

$$\frac{da}{dt}=\boxed{\frac{2ae\dot{e}}{1-e^2}}-\boxed{\frac{2\varepsilon\langle T_{planet}\rangle}{M_p an\sqrt{1-e^2}}}+\boxed{\frac{2a\dot{J}_*}{J_0}}-\boxed{\frac{2\dot{M}_p a}{M_p}}$$

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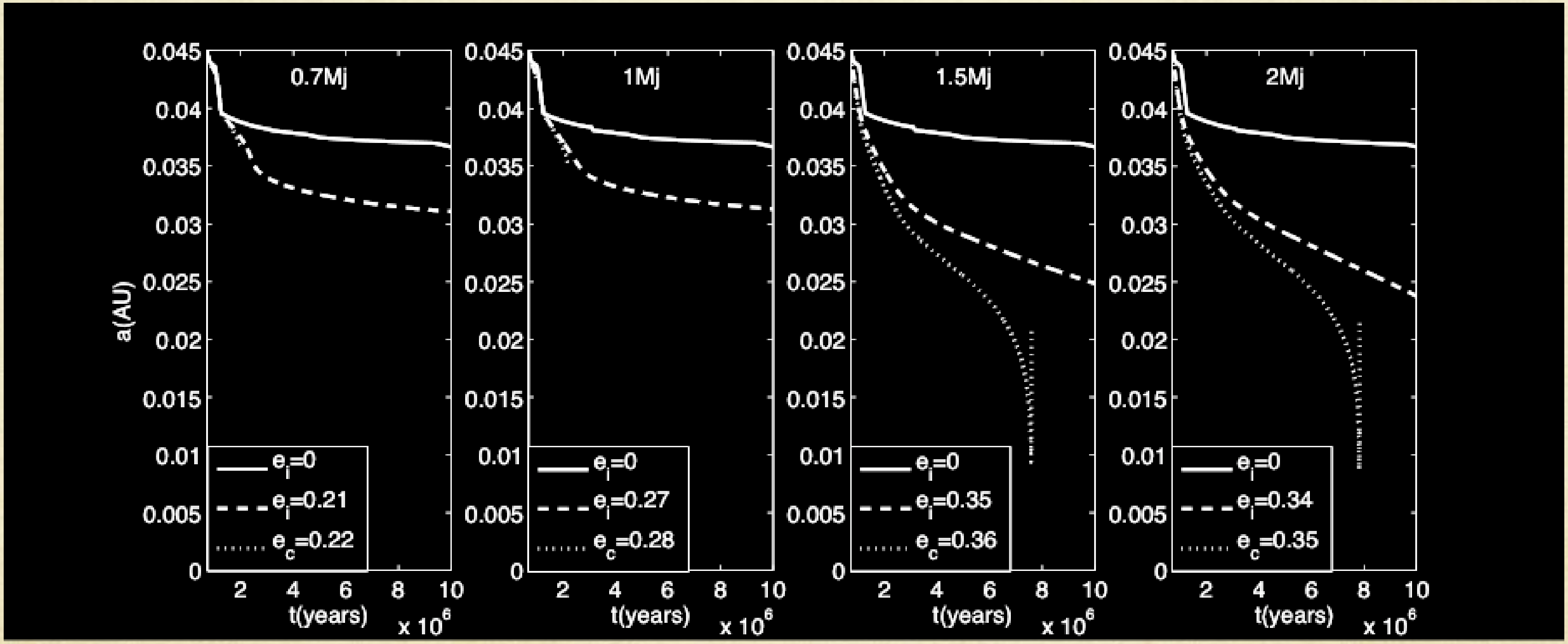
- Description of the model
- Result
- Conclusion and discussion

Setting

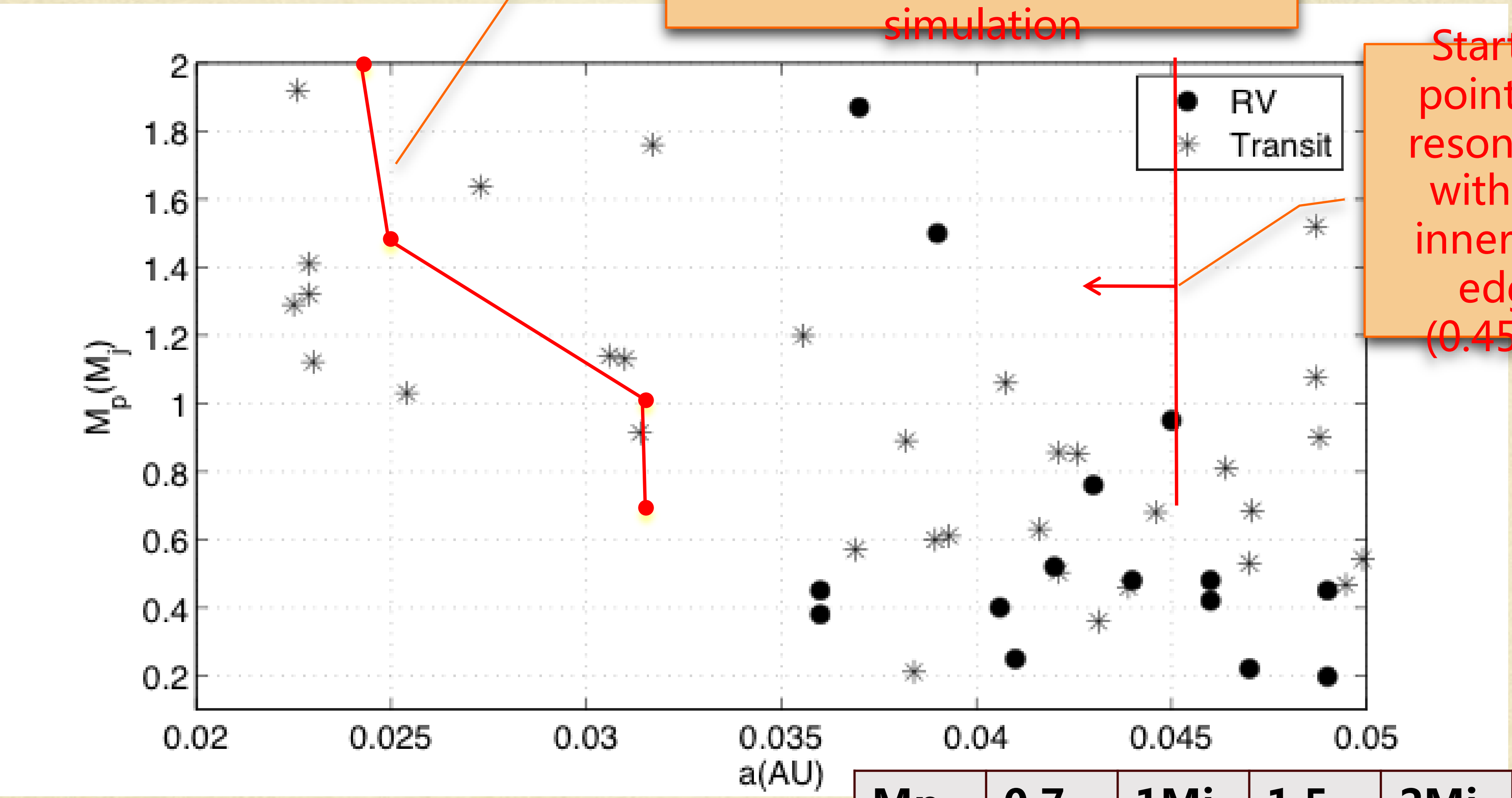
- The orbital evolution of the planet is focused from **$7*10^5$ yr** to **10^7 yr**.
- Fixed parameter:
  - M_*=1Msun
  - Q_*' =**$3*10^5$**
  - Q_p' =**10^6**
- Varied parameter:
  - B_0: **1500G** (larger cavity), **500G**(smaller cavity)
  - M_p: **0.7Mj, $1M_j$, $1.5M_j$, $2\ M_j$**
  - Eccentricity: **e_c**
  - ε=**1** (upper limit of the magnetic torque on the planet)
    =**0** (absence of the mangetic torque)

Result

- Big cavity &ε=**1**



Result: $e_i = e_c - 0.01$

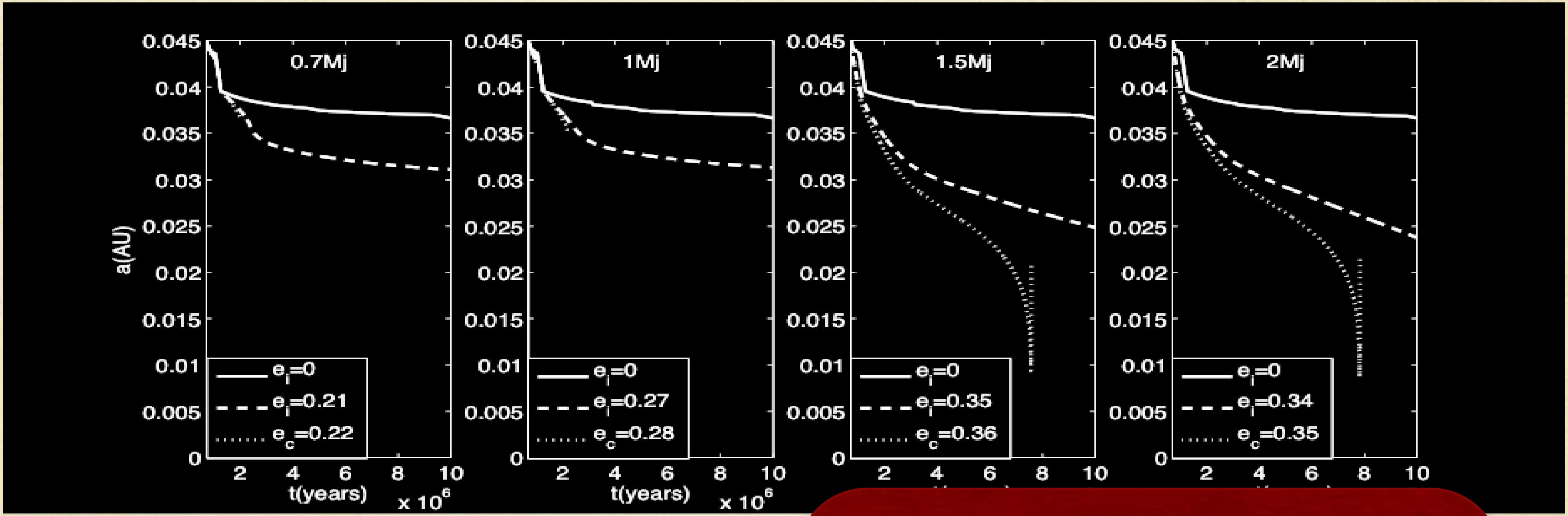


The position they can migrate the farthest in the end of the simulation

Starting point: 2:1 resonance with the inner disk edge (0.45AU)

Mp	0.7 Mj	1Mj	1.5 Mj	2Mj
e_c-0.01	0.21	0.27	0.35	0.34

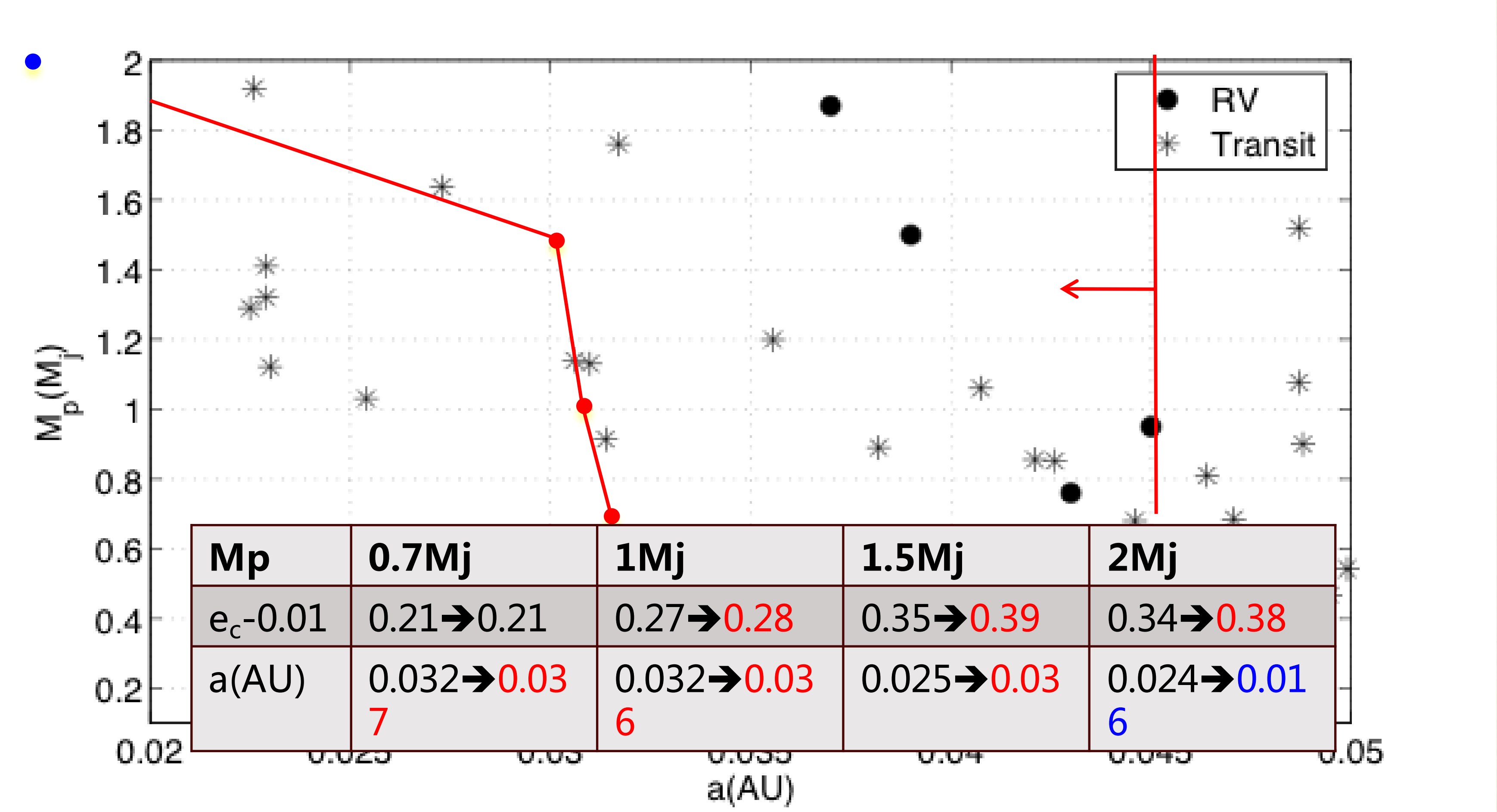
Result: $e_i=e_c$



•Mp<=1Mj:
Tidal inflation faster than inward migration
➔Overflow large Roche lobe at large a
+Degeneracy is high
➔ Runaway mass loss

•Mp>1Mj:
Migrate inward without significant tidal inflation
➔Overflow small Roche lobe at small a; Stable L1 overflow
➔Migrate outward;
When the lighten planet gets larger
➔ High degeneracy : Runaway

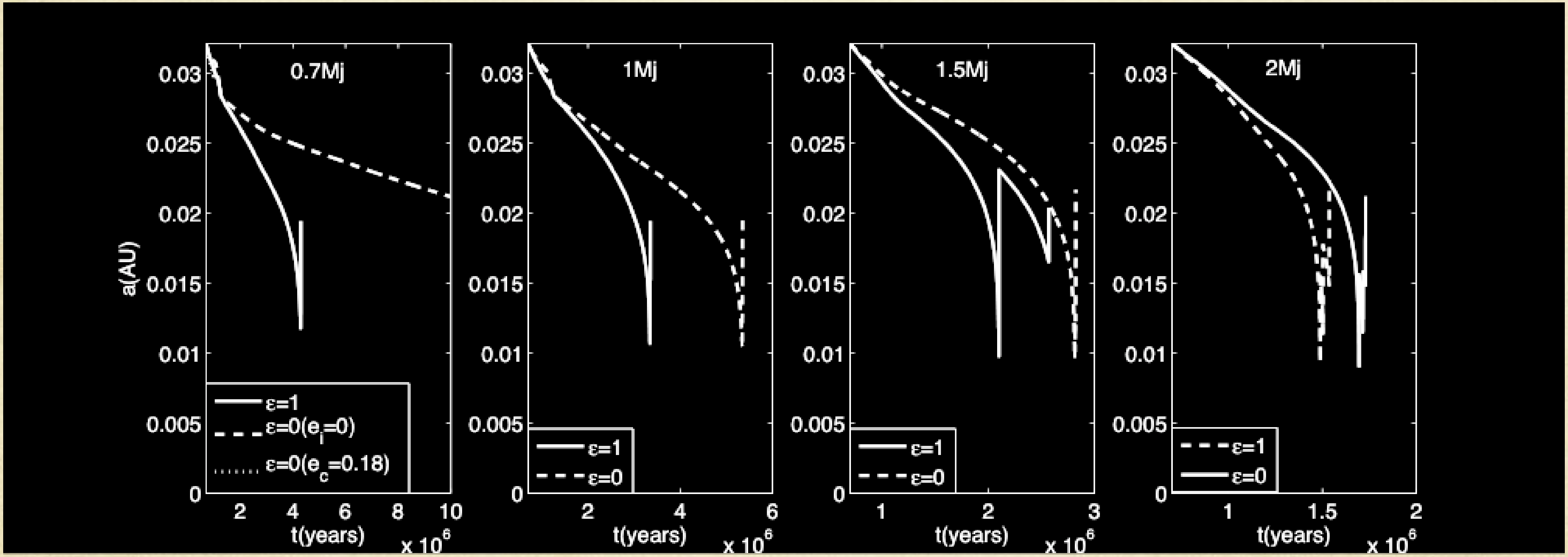
Big cavity & $\varepsilon=0$



Mp	0.7Mj	1Mj	1.5Mj	2Mj
e_c-0.01	0.21→0.21	0.27→0.28	0.35→0.39	0.34→0.38
a(AU)	0.032→0.037	0.032→0.036	0.025→0.03	0.024→0.016

Result

- Small cavity ➔ $a_{2:1} \approx 0.032$AU



Tidal and magnetic interaction

- The migration of less massive planets is more sensitive to the magnetic interaction, which is enhanced by their easily inflated radii.
- The migration of massive planets is more sensitive to the tidal interaction.
- Planets overflow with high degeneracy cause runaway mass loss.

Thanks for your
attention !

Introduction

- Hot Jupiter: Jupiter-mass planets; Locate < 0.1 AU
- Hot Jupiters have formed at larger orbital radii in the protoplanetary disk and then moved inward to their current locations via the disk-planet interactions (e.g. Lin et al. 1996)
- Magnetic fields of CTTS are strong enough to truncate the inner regions of protoplanetary disk to the corotation radius and create an inner magnetospheric cavity.
  - The migration due to planet-disk interaction is expected to slow dramatically once a hot Jupiter passes the inner disk edge. ➔ Hot jupiters pile up at ≈0.04 AU. (Gaudi et al. 2005)

Lin, D. N. C., Bodenheimer, P., & Richardson, D. C. 1996, Nature, 380, 606

Introduction

- Rice et al. (2008): planet's entry into the magnetospheric cavity ➔orbital eccentricity e🡅
  - Provide a mechanism to pump up e ➔afffect the orbital evolution via the tidal interactions between the star and planet.
- The magnetic interaction between Jupiter and the Galilean satellites (Zarka 2007, and reference therein) ➔planet-star magnetic interaction

Lin, D. N. C., Bodenheimer, P., & Richardson, D. C. 1996, Nature, 380, 606

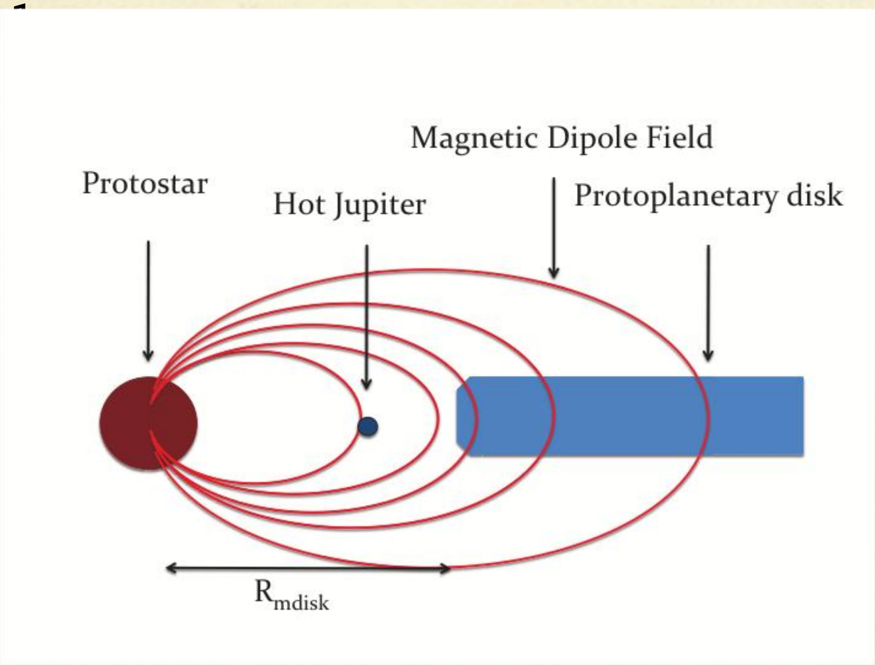
Description of the model

- Magnetic interaction
  - Star-disk magnetic linkage ➔ Disk locking
  - Star-planet magnetic linkage ➔ Orbital evolution
- Tidal interaction ➔ Circularization
  - Tides on the planet
    - Thermal inflation of the planet
  - Tides on the star
    - Orbital evolution
    - Evolution of the stellar spin

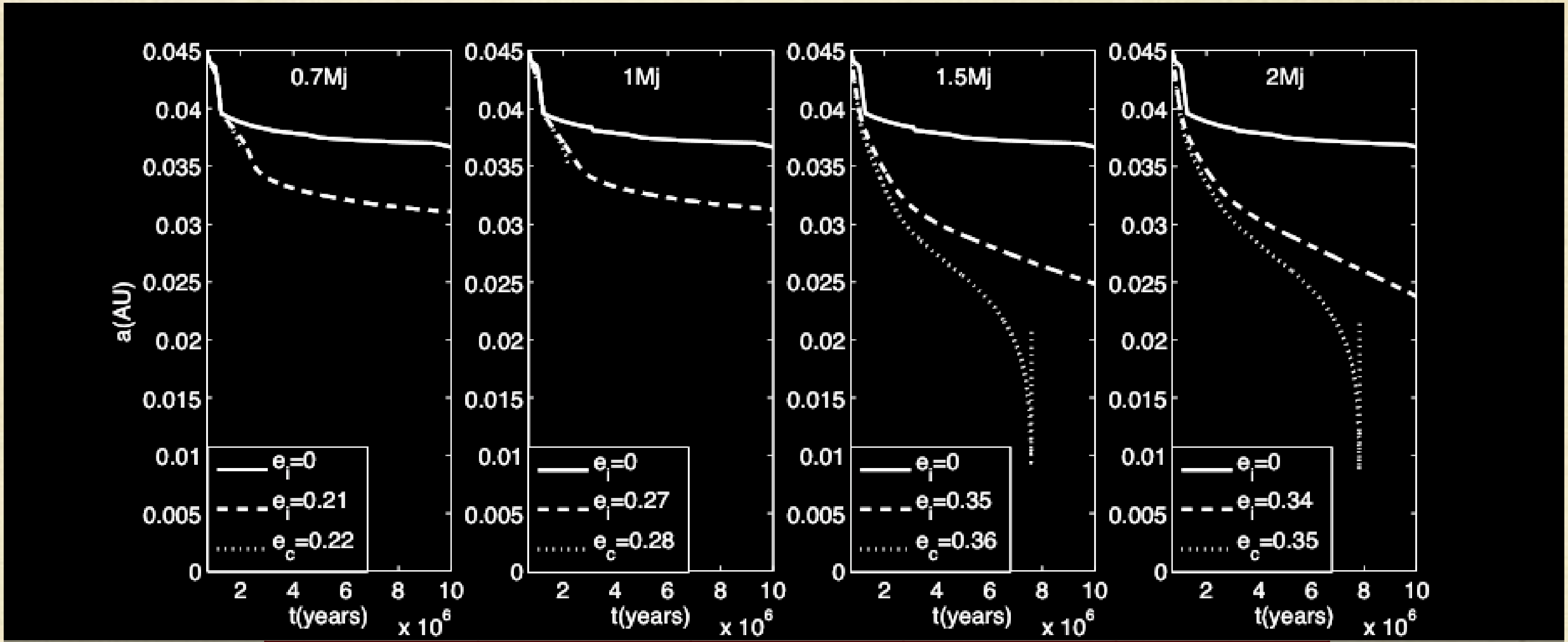
Gu, P. G., Lin, D. N. C., & Bodenheimer, P. 2003, ApJ, 588,509

Illustration of our simple model

- The dipole fields of CTTS truncate the inner regions of protoplanetary disk and create an inner magnetospheric cavity.
- When the inner edge of the disk extends inward making $a>a_{2:1}$, then the planet is moved inward artificially to maintain $a=a_{2}$



Big Cavity➔$a_{2:1}$~0.45AU; $\varepsilon=1$



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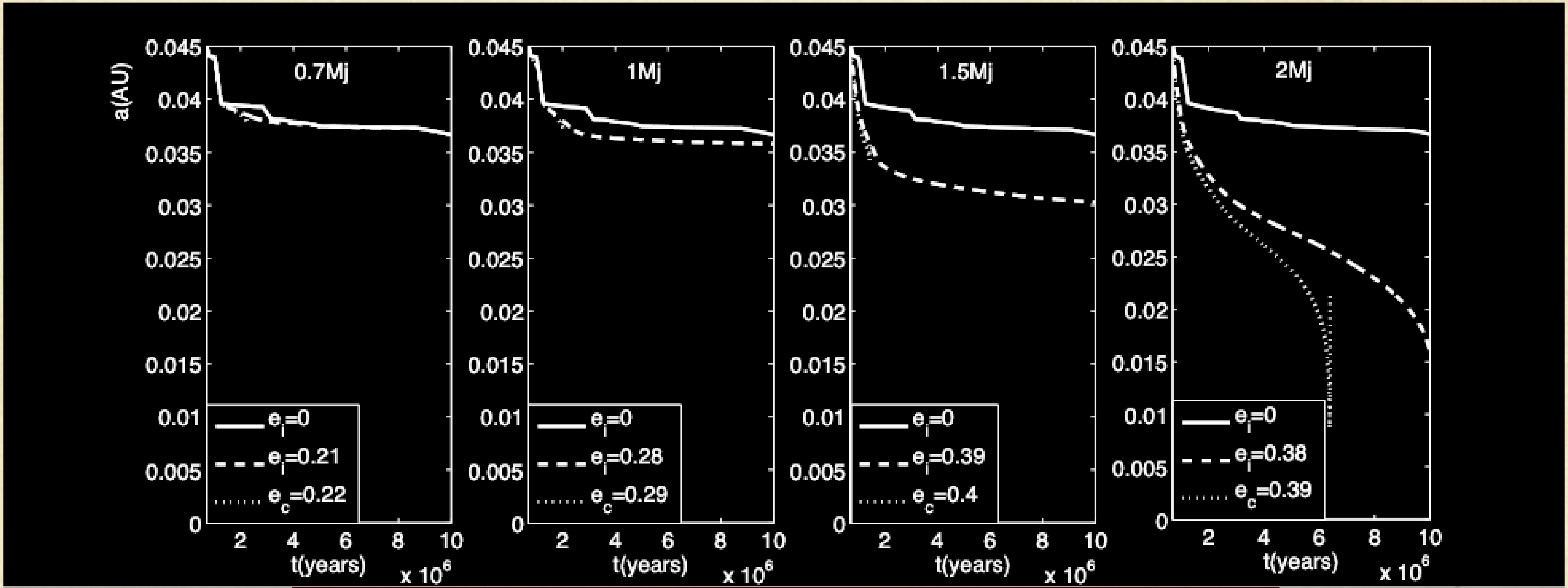
Big Cavity→$a_{2:1}$~0.45AU; ε=0



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