# Implications of the EKL for Stars surrounding SMBHB

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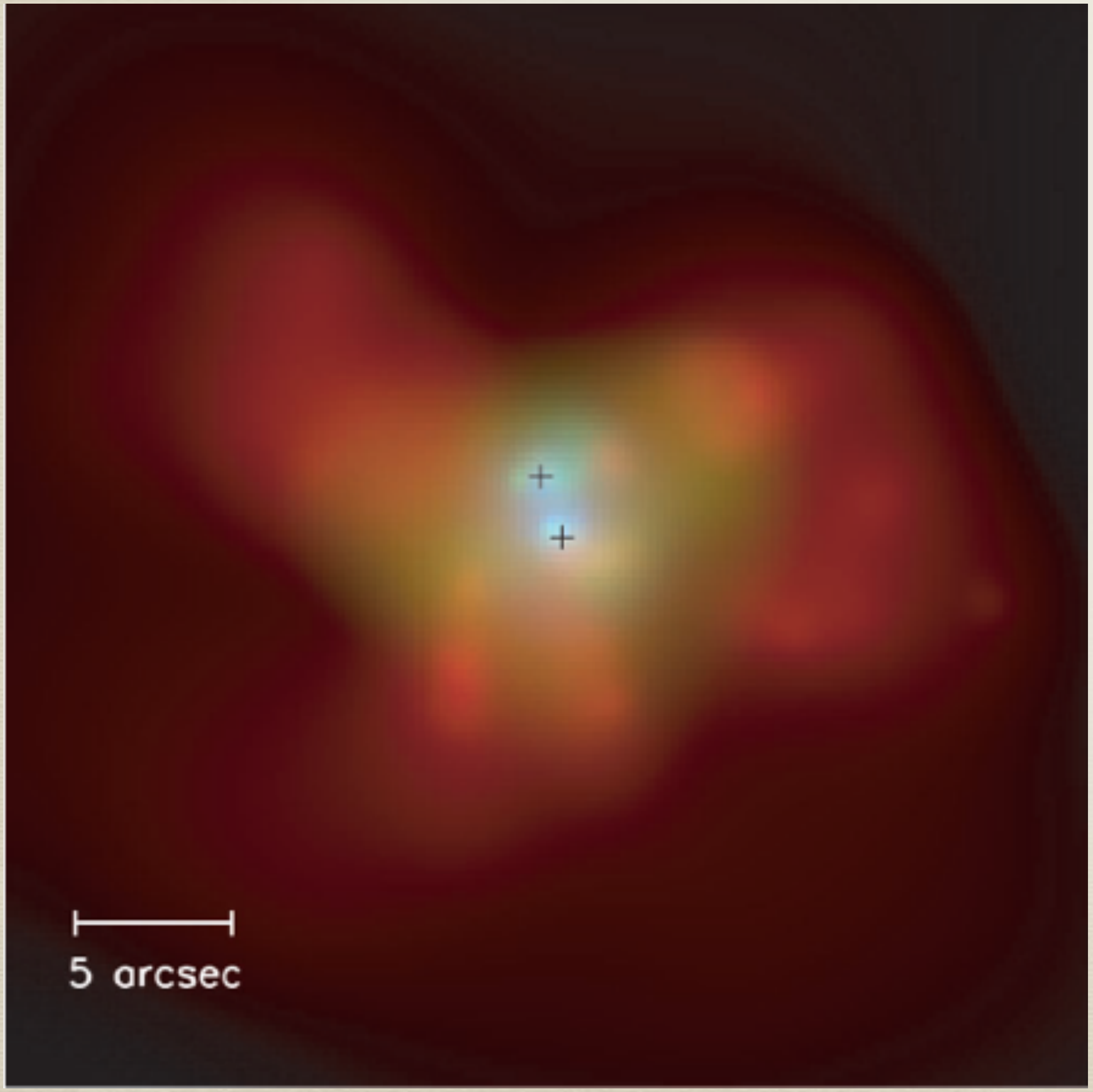
Dynamics and Accretion at the Galactic Center
Aspen, Feb, 2016

# Stars Surrounding SMBHB

- SMBHBs originate from mergers between galaxies.




- SMBHBs with mostly ~kpc separation have been observed with direct imagine.

  (e.g., Woo et al. 2014; Komossa et al. 2013, Fabbiano et al. 2011, Green et al. 2010, Civano et al. 2010, Liu et al. 2010, Rodriguez et al. 2006, Komossa et al. 2003, Hutchings & Neff 1989)

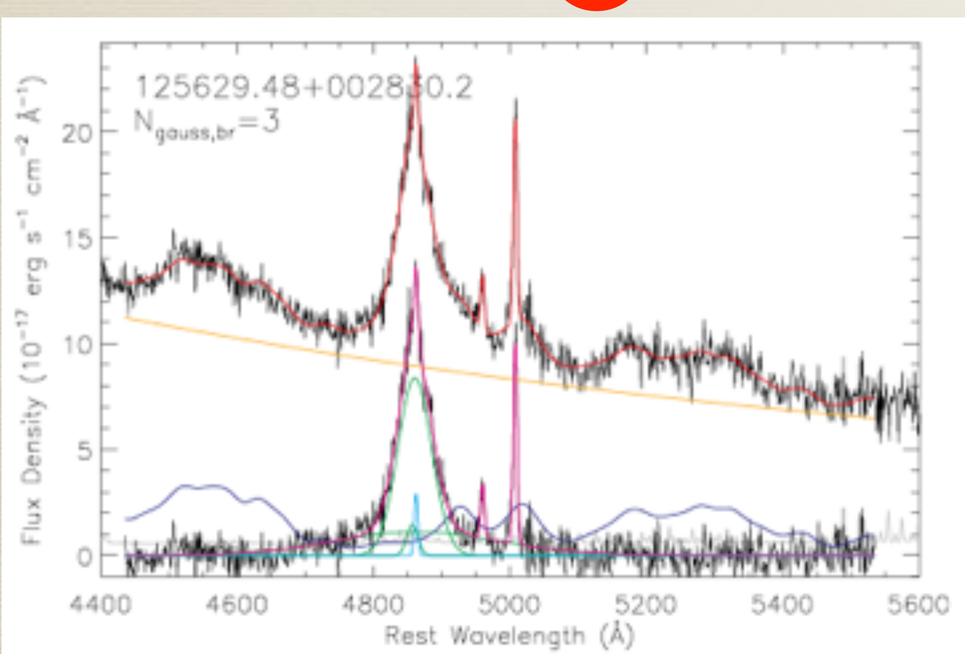
Multicolor image of NGC 6240. Red p soft (0.5–1.5 keV), green p medium (1.5–5 keV), and blue p hard (5–8 keV) X-ray band. (Komossa et al. 2003)

# Stars Surrounding SMBHB

- At ~1pc separation it is more difficult to identify SMBHBs. SMBHBs can be observed with photometric or spectral features.

  (e.g., Shen et al. 2013, Boroson & Lauer 2009, Valtonen et al. 2008, Loeb 2007)

Example of multi-epoch spectroscopy (Shen et al. 2013):


active BH dominates the BL features, multi-epoch BL features => binary orbital parameters

# Stars Surrounding SMBHB

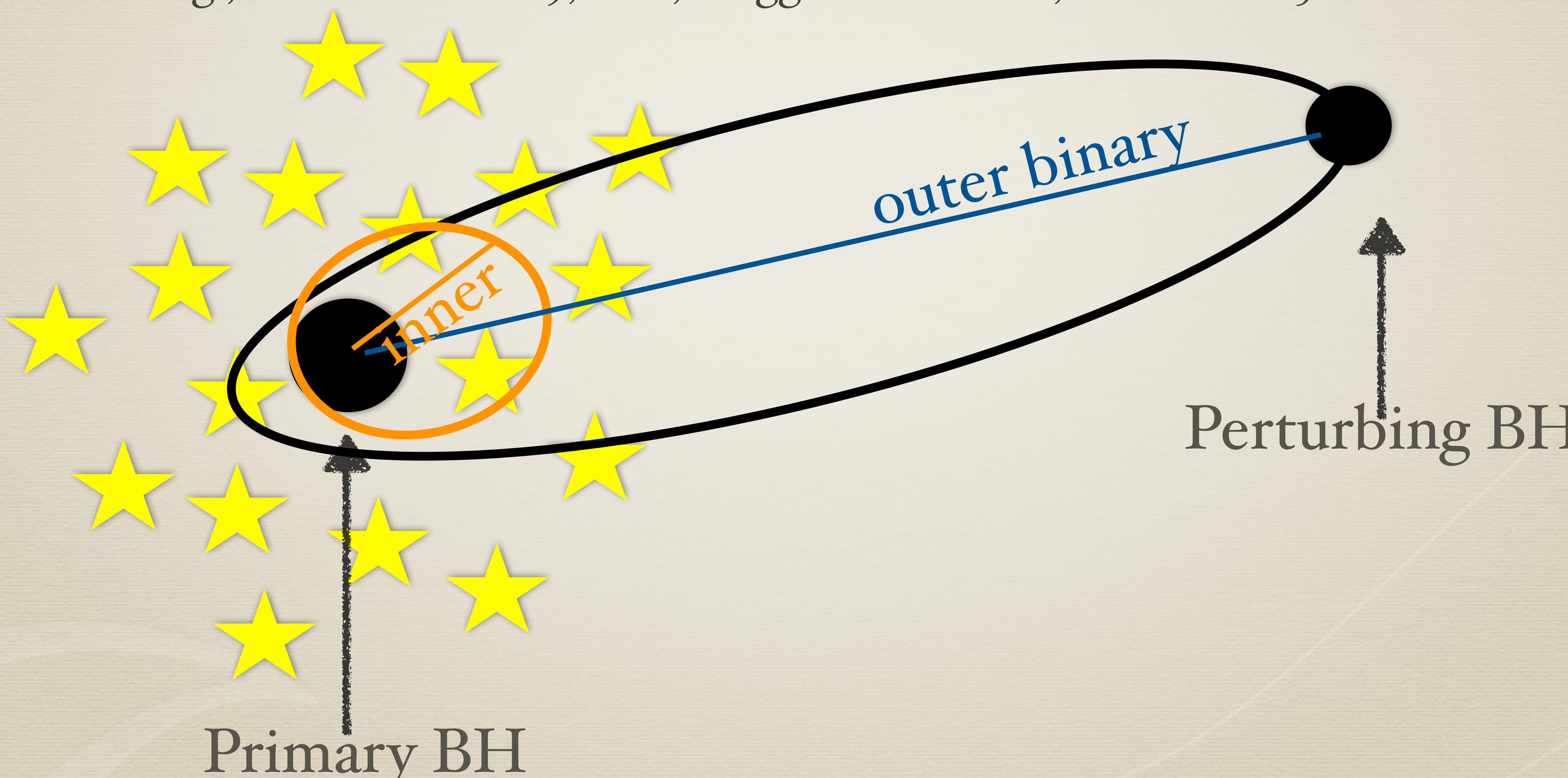
- Identify SMBHB at ~1 pc separation by stellar features due to interactions with SMBHB.

  (e.g., Chen et al. 2009, 2011, Wegg & Bode 2011, Li et al. 2015)

# Perturbations on Stars Surrounding SMBHB

- Identify SMBHB at ~1 pc separation by stellar features due to interactions with SMBHB.

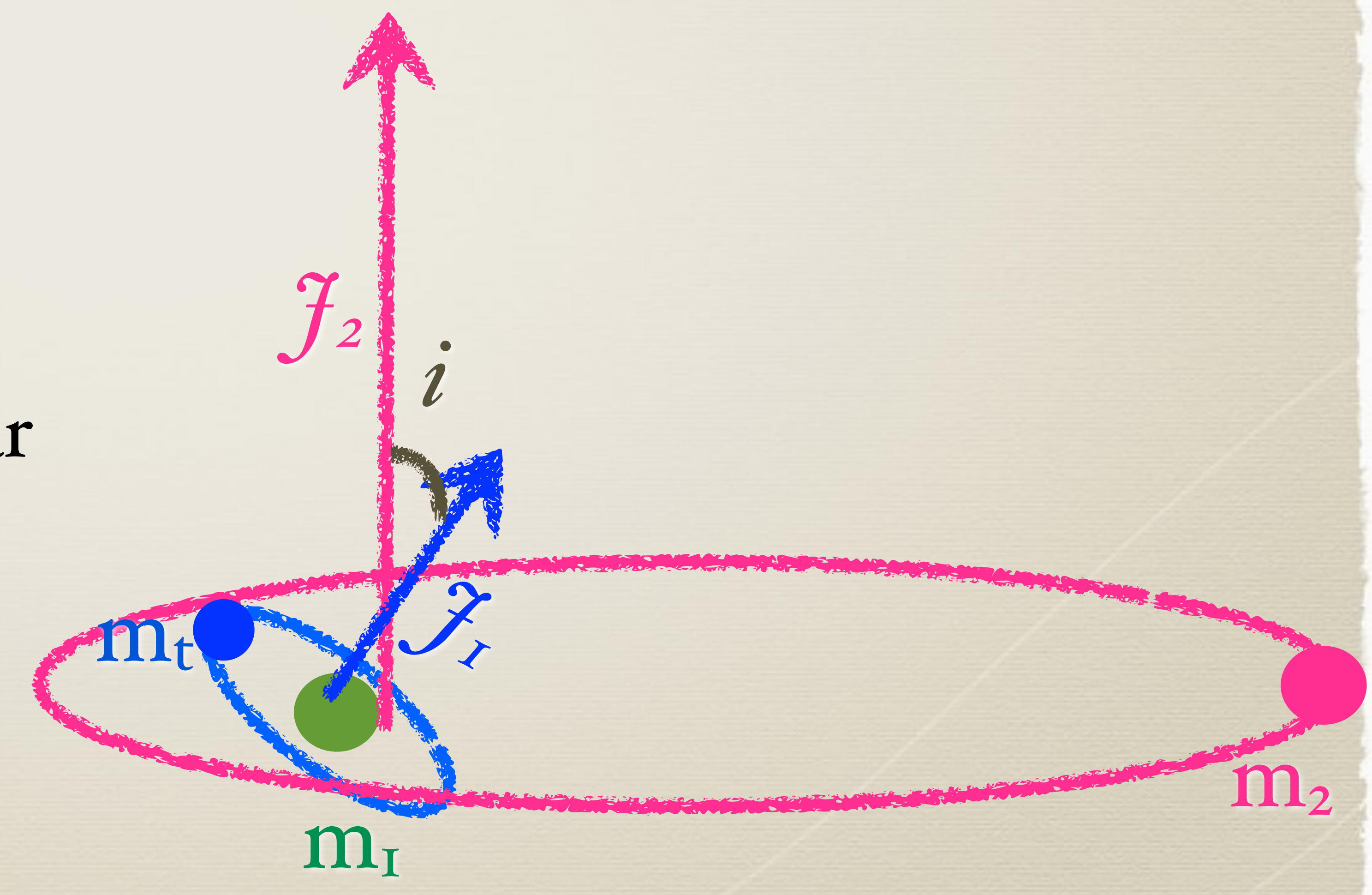
(e.g., Chen et al. 2009, 2011, Wegg & Bode 2011, Li et al. 2015)



# Configuration of Hierarchical 3-body System

System is stationary and can be thought of as interaction between two orbital wires (secular approximation):

- Inner wires (1): formed by $m_1$ and $m_J$.
- Outer wires (2): $m_2$ orbits the center mass of $m_1$ and $m_t$.
- $\mathcal{J}_{1/2}$: Specific orbital angular momentum of inner/outer wire.
- $i$: inclination between the two orbits.



# Kozai-Lidov Mechanism

Kozai-Lidov Mechanism

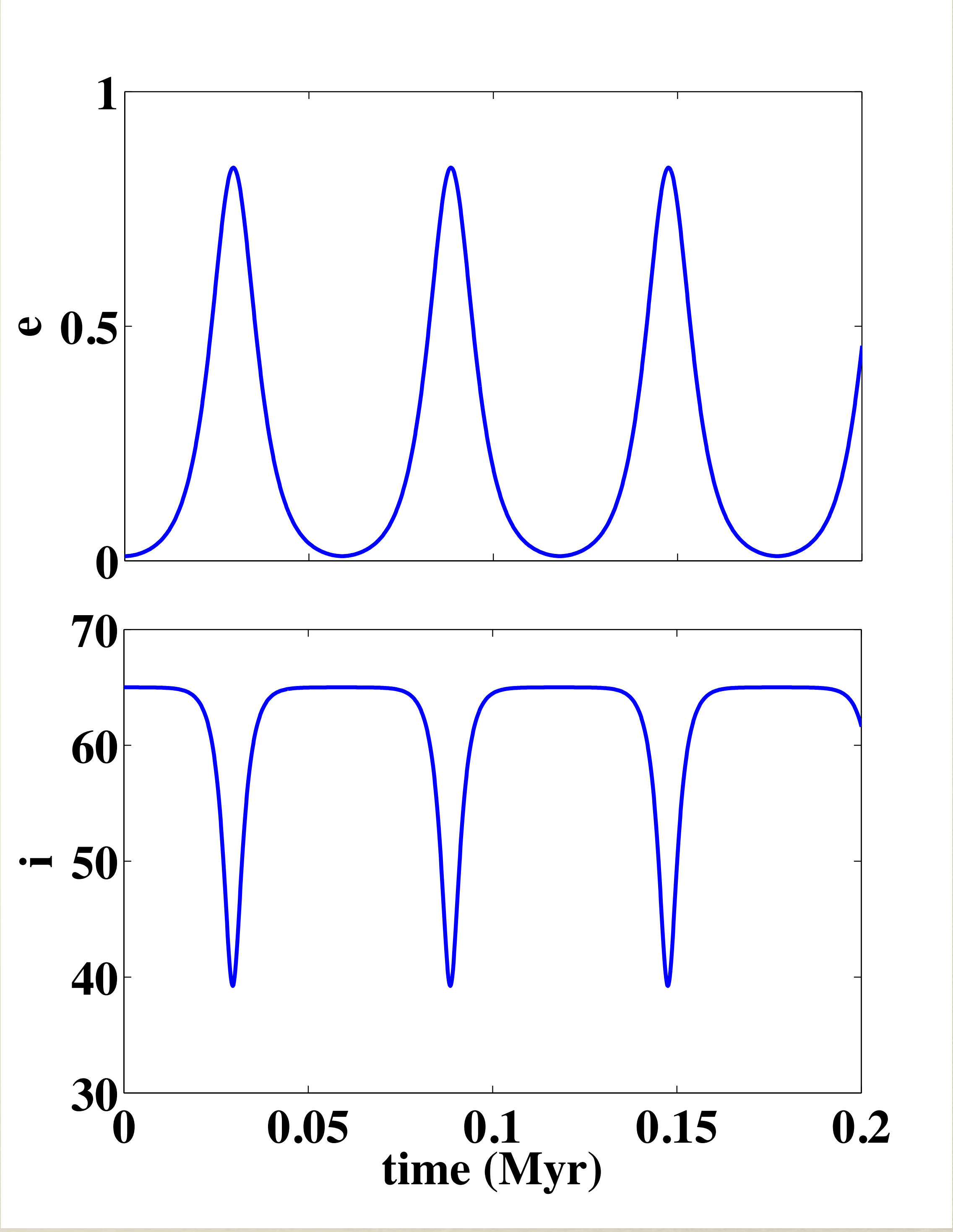
($e_2$ = 0, $m_J \rightarrow 0$)

*(Kozai 1962; Lidov 1962: Solar system objects)*

- Expand Hamiltonian in series of $(a_1/a_2)$.
- Octupole level $O((a_1/a_2)^3)$ is zero.
- Quadrupole level $O((a_1/a_2)^2)$ is sufficient.

=> $Jz = \sqrt{1-e_1^2}\cos i_1$ conserved (axi-symmetric potential).

=> when i>40°, $e_1$ and i oscillate with large amplitude.




Example of Kozai-Lidov Mechanism.

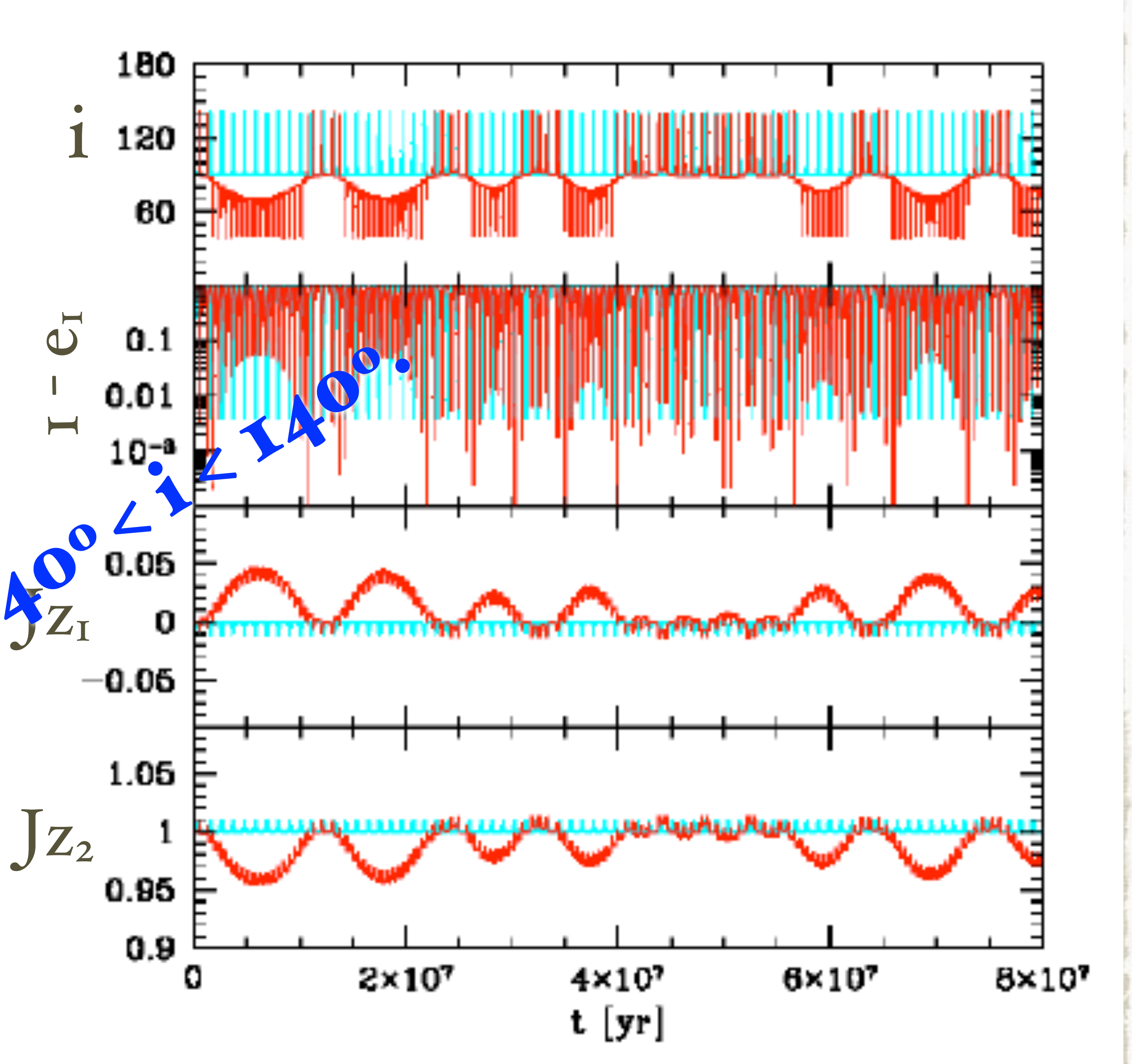
# Octupole Kozai-Lidov Mechanism

- $e_2 \neq 0$ (Eccentric Kozai-Lidov Mechanism) or $m_J \neq 0$:
- (e.g., *Naoz et al. 2011, 2013, test particle case: Katz et al. 2011, Lithwick & Naoz 2011* ):

- Jz NOT constant, octupole ≠ 0.

- when i>40°: $e_1 \rightarrow 1$.
- when i>40°: i crosses 90°

**However, 40° < i < 140°.**

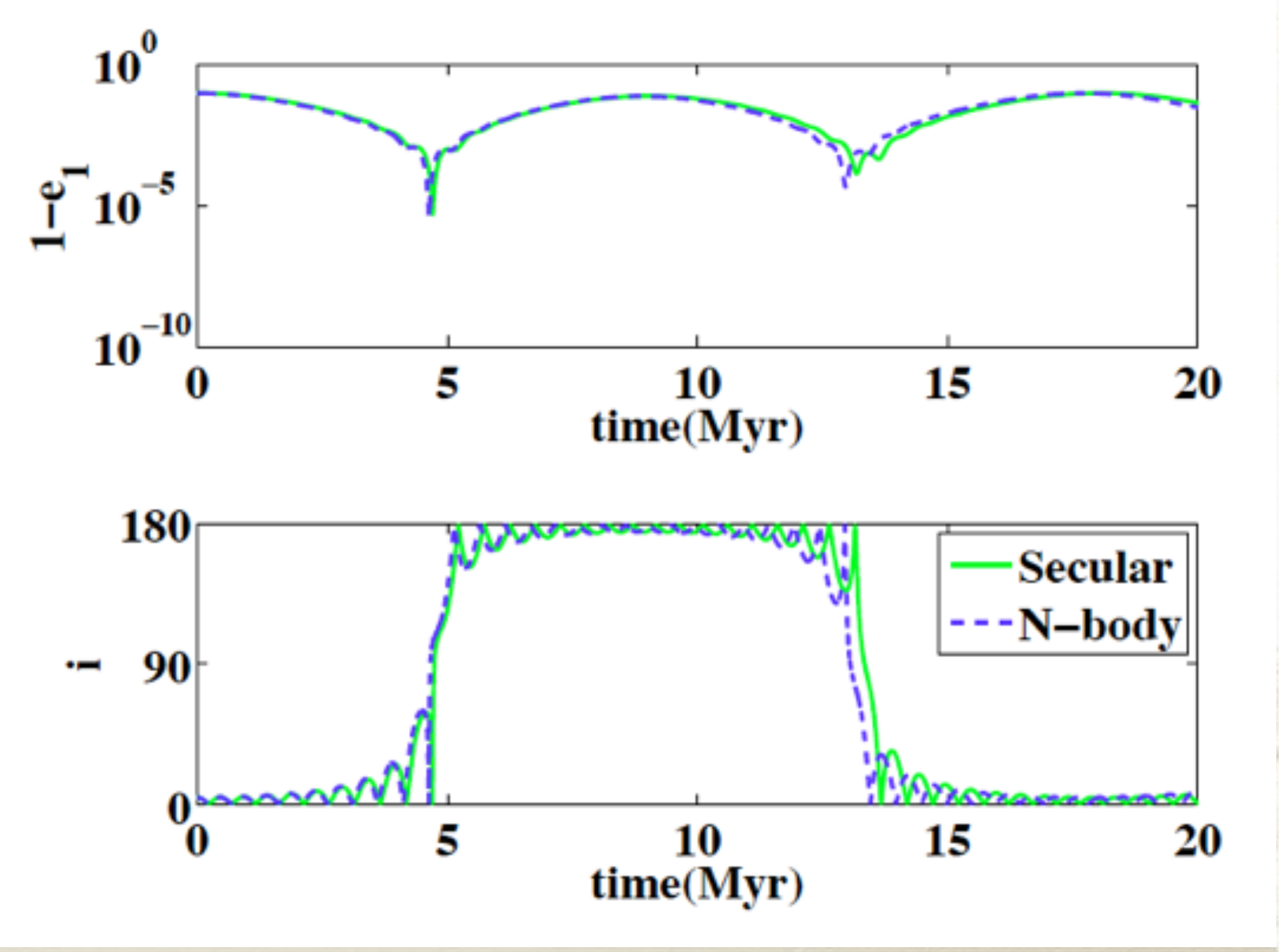



Cyan: quadrupole only.
Red: quadrupole + octupole. Naoz et al 2013

# NEW MECHANISM: Coplanar Flip

- Starting with $i \approx 0$, $e_1 \geq 0.6$, $e_2 \neq 0$:

$e_1 \rightarrow 1$, $i_1$ flips by $\approx 180°$ (*Li et al. 2014a*).



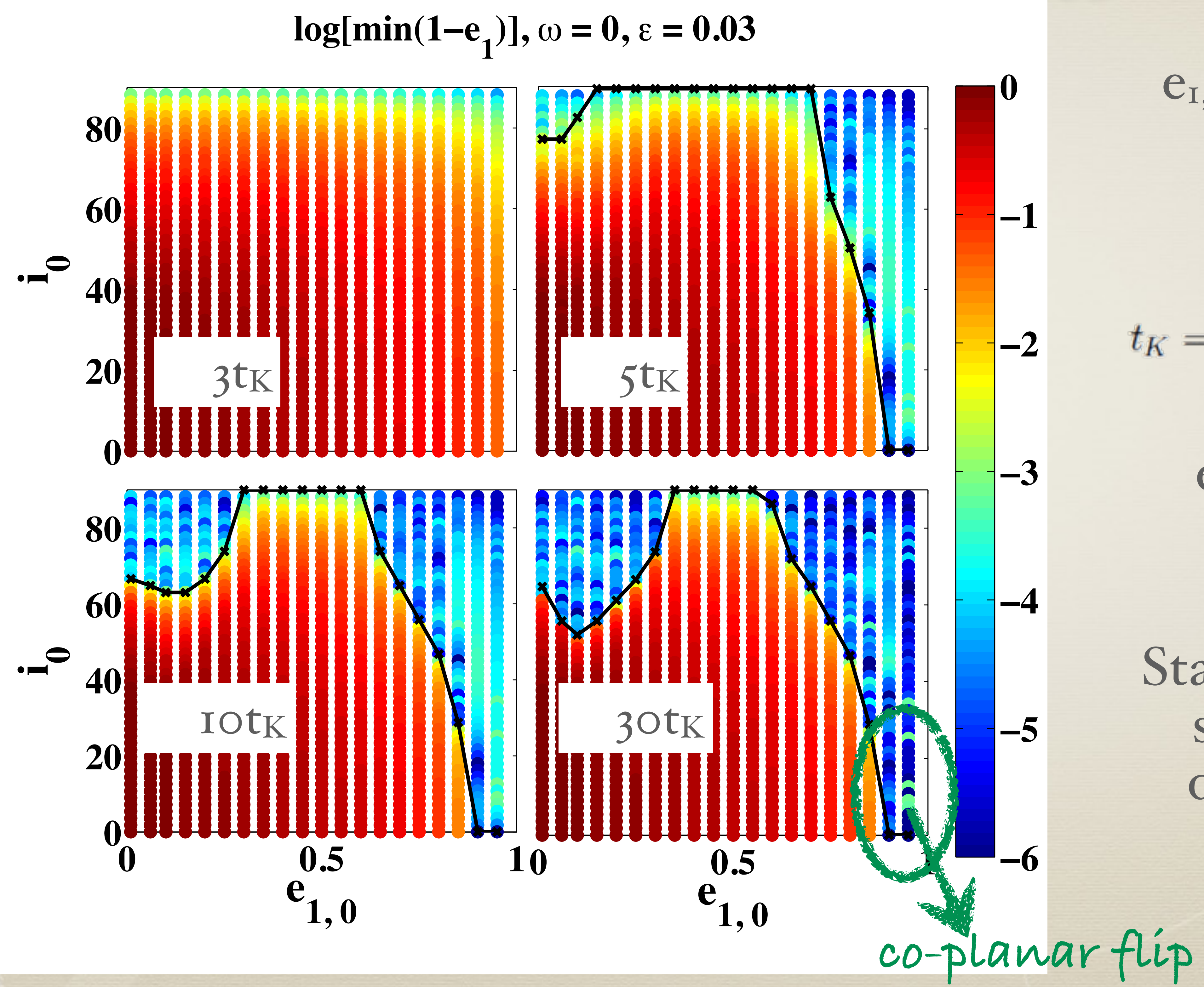

=> Increase the parameter space of interesting behaviors.

=> Produces counter orbiting hot Jupiters.

=> Enhance tidal disruption rates (*Li et al. 2015*).

(Li et al. 2014a)

# Maximum $e_1$: Enhancement of Tidal Disruption Rates




$e_{1,\,max}$ determines the closest distance:

$r_p \propto (1-e_1)$

$$t_K = \frac{8}{3} P_{in} \frac{m_1}{m_2} \left(\frac{a_2}{a_1}\right)^3 (1-e_2^2)^{3/2}$$

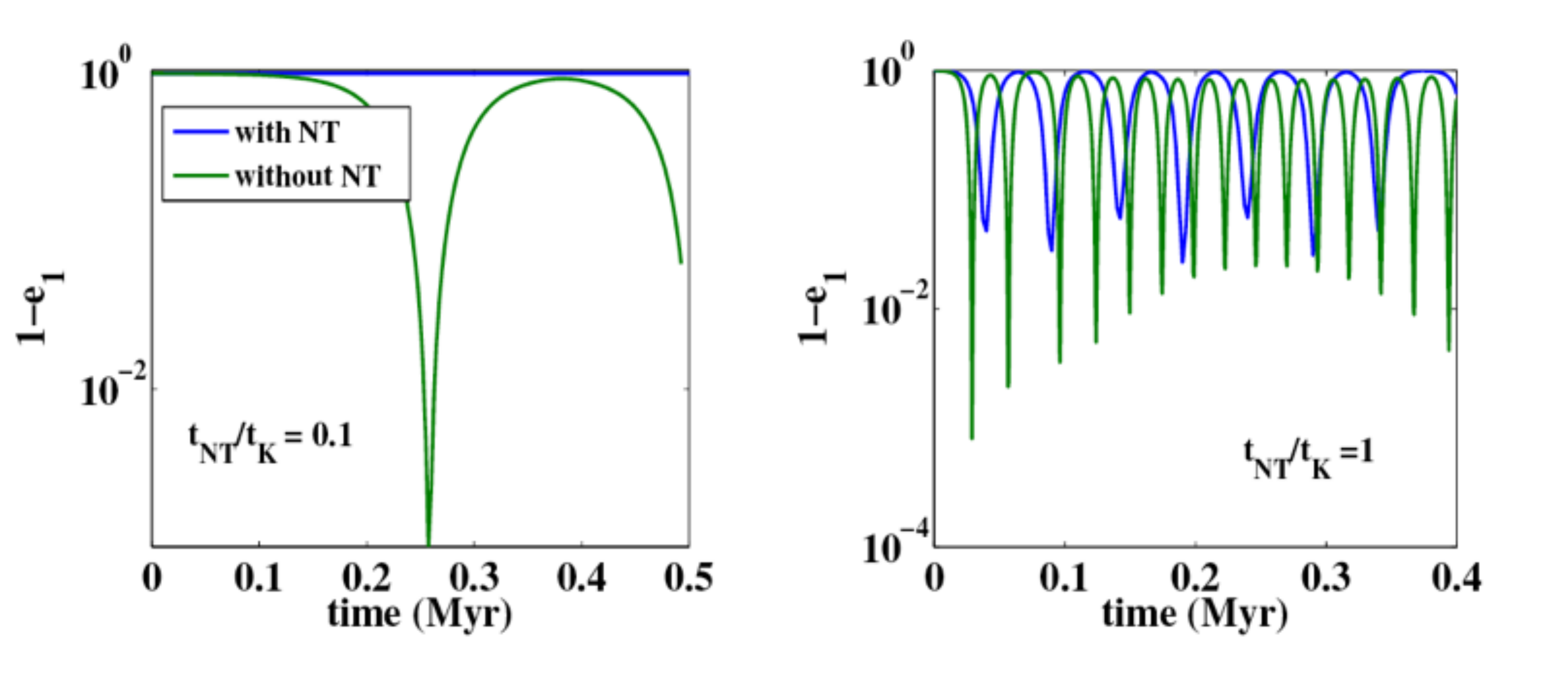
$e_{max}$ reaches $1\text{-}10^{-6}$ over ~$30t_K$

Starting at a~$10^6R_t$, it's still possible to be disrupted in ~$30t_K$!

Li et al. 2014

# Suppression of EKL

- Eccentricity excitation suppressed when precession timescale < Kozai timescale.




$m_0 = 10^7 M_\odot$, $m_2 = 10^9 M_\odot$, $e_1 = 2/3$, $a_2 = 0.3$ pc, $m_1 = 1 M_\odot$, $e_2 = 0.7$. (Li et al. 2015)

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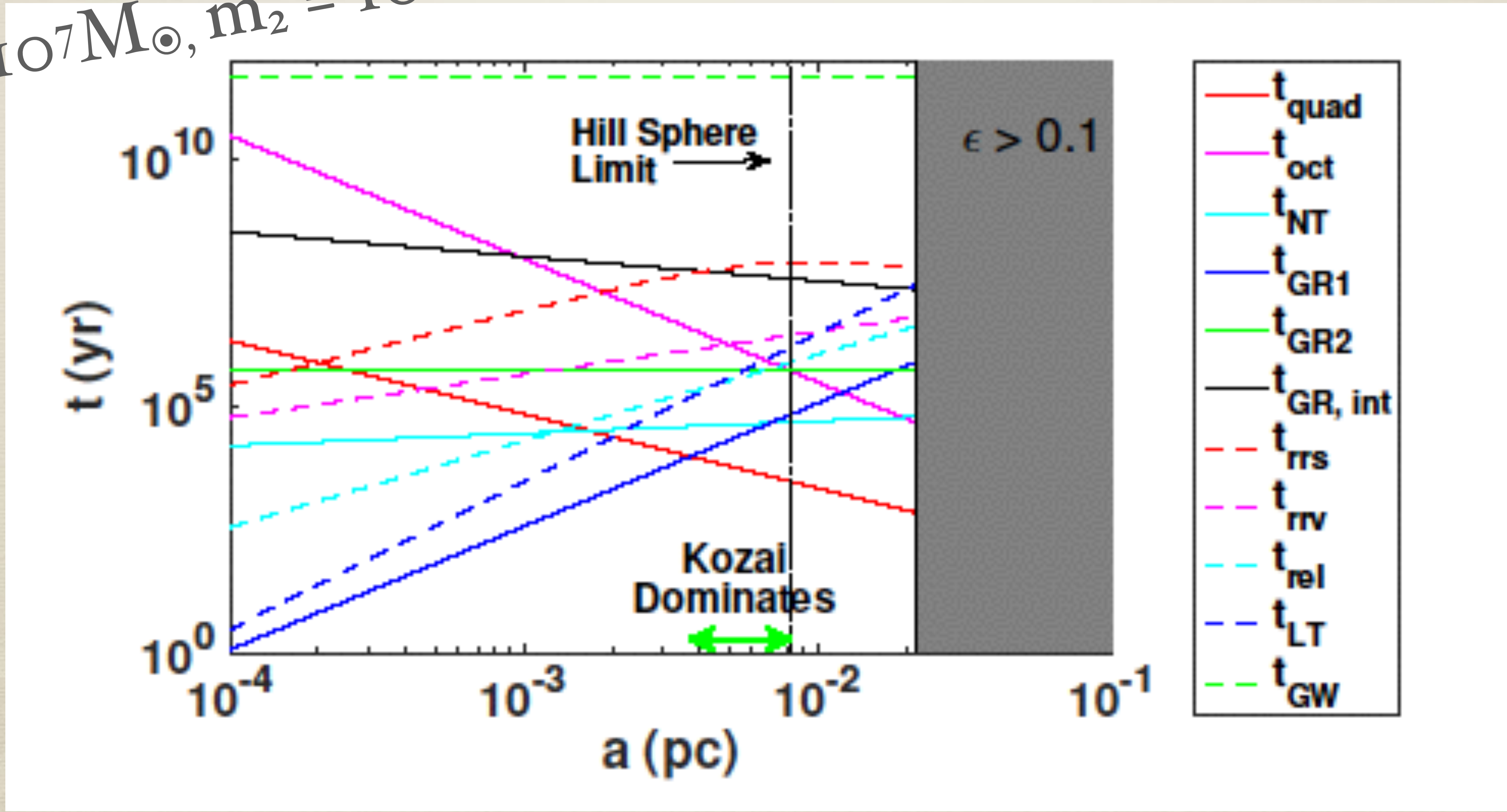


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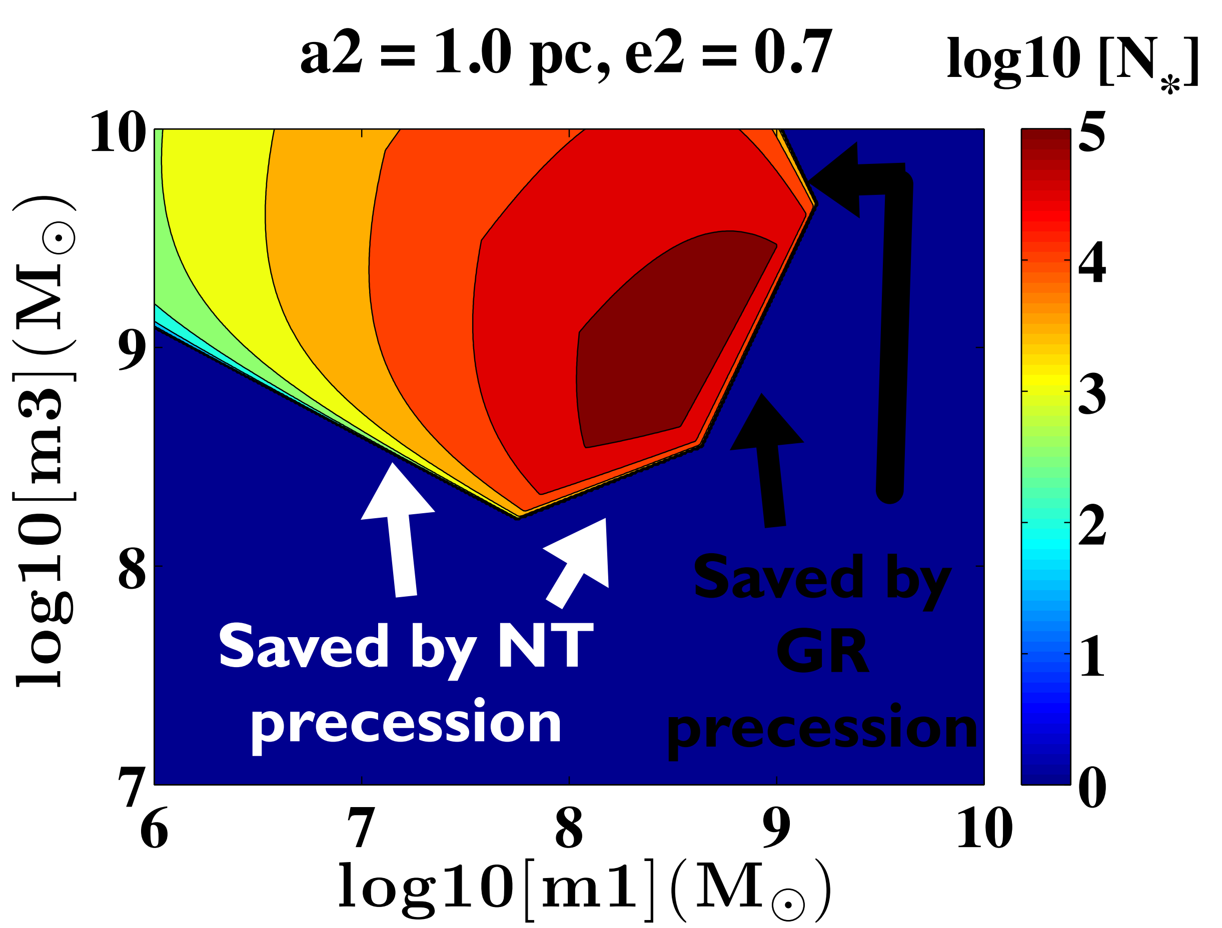
(Li et al. 2015)

# Suppression of EKL

- Eccentricity excitation suppressed when precession timescale < Kozai timescale.
- Stars around SMBHB: GR and NT precession.

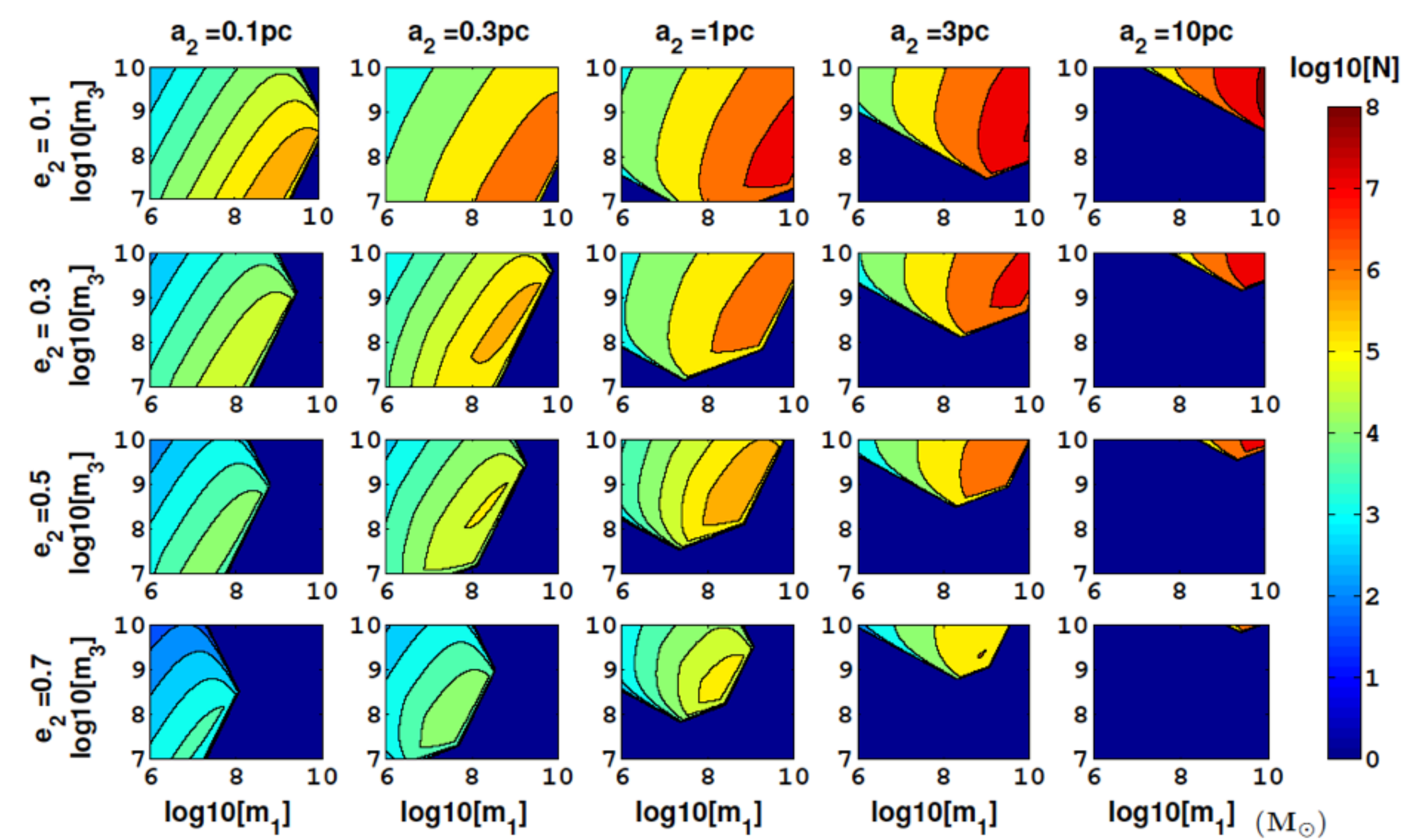
Due to general relativity   Due to stellar system self-gravity




- Kozai affects more stars when perturber more massive.

(Li et al. 2015)

# Suppression of EKL




(Li et al. 2015)

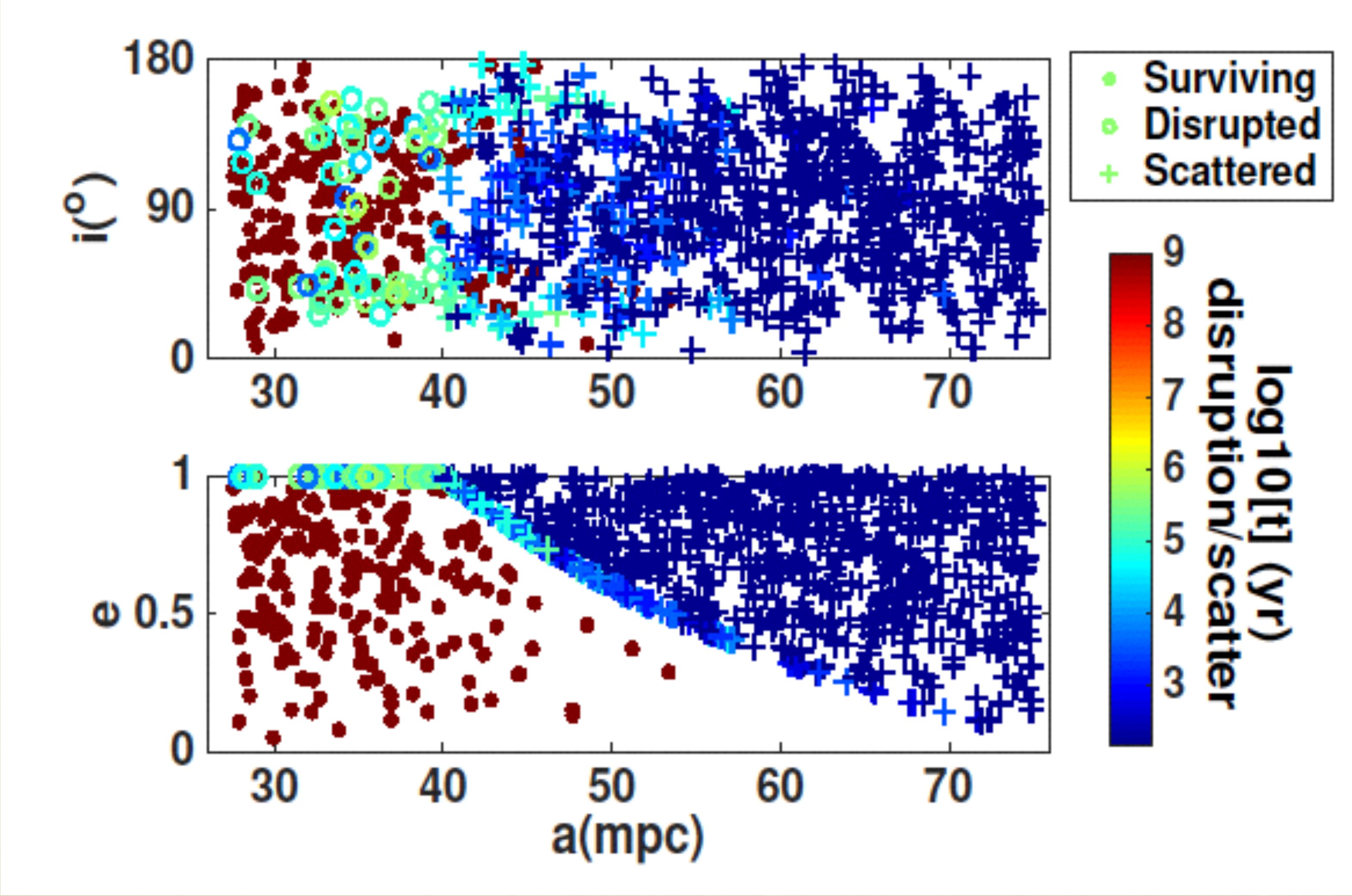
# Effects on Stars Surrounding SMBHB

- Example: $m_1 = 10^7 M_\odot$, $m_2 = 10^8 M_\odot$, $a_2 = 0.5$pc, $e_2 = 0.5$, Run time: 1Gyr.

- 57/1000 disrupted; 726/1000 scattered.

=> Scattered stars may change stellar density profile of the BHs.

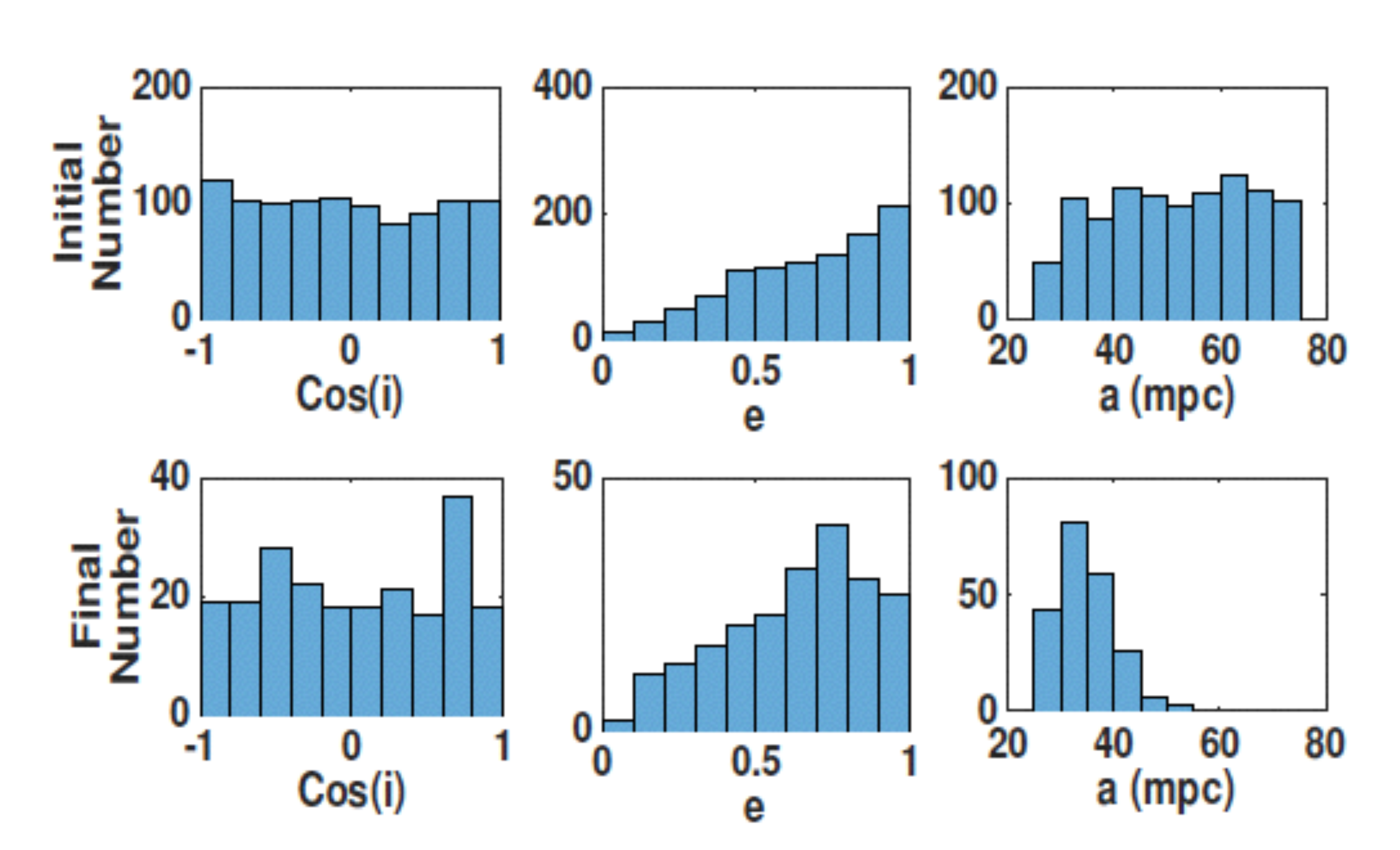
=> Disruption rate can reach ~$10^{-3}$/yr.




(Li et al. 2015)

# Effects of EKM on Stars Surrounding BBH

- Example: $m_1 = 10^7 M_\odot$, $m_2 = 10^8 M_\odot$, $a_2 = 0.5$pc, $e_2 = 0.5$, $\alpha = 1.75$ (Run time: 1Gyr)




(Li, et al. 2015)

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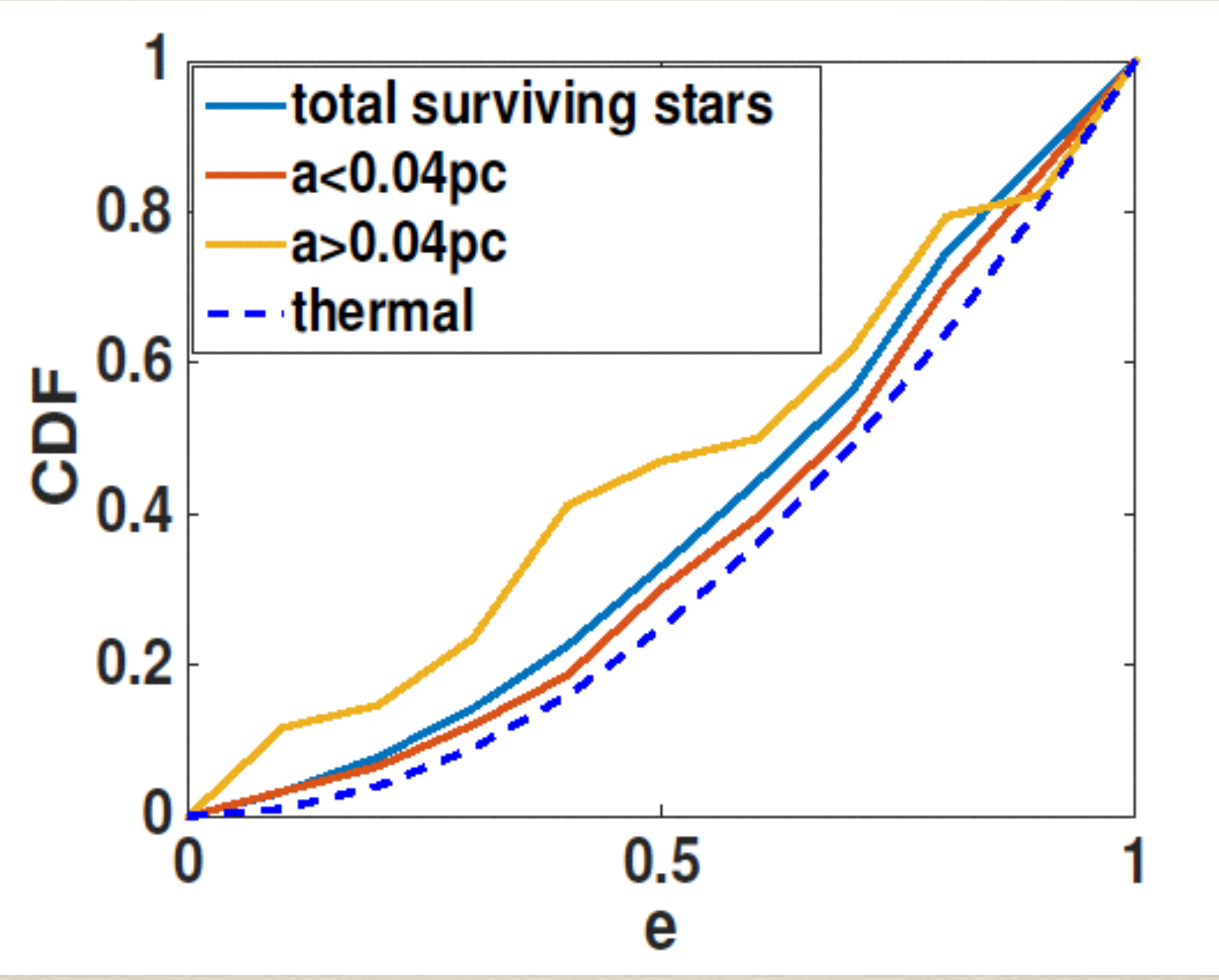


(Li, et al. 2015)

# Effects on Stars Surrounding an IMBH in GC

- Example: $m_1 = 10^4\,M_\odot$, $m_2 = 4\times10^6 M_\odot$, $a_2 = 0.1$pc, $e_2 = 0.7$ (Run time: 100 Myr)

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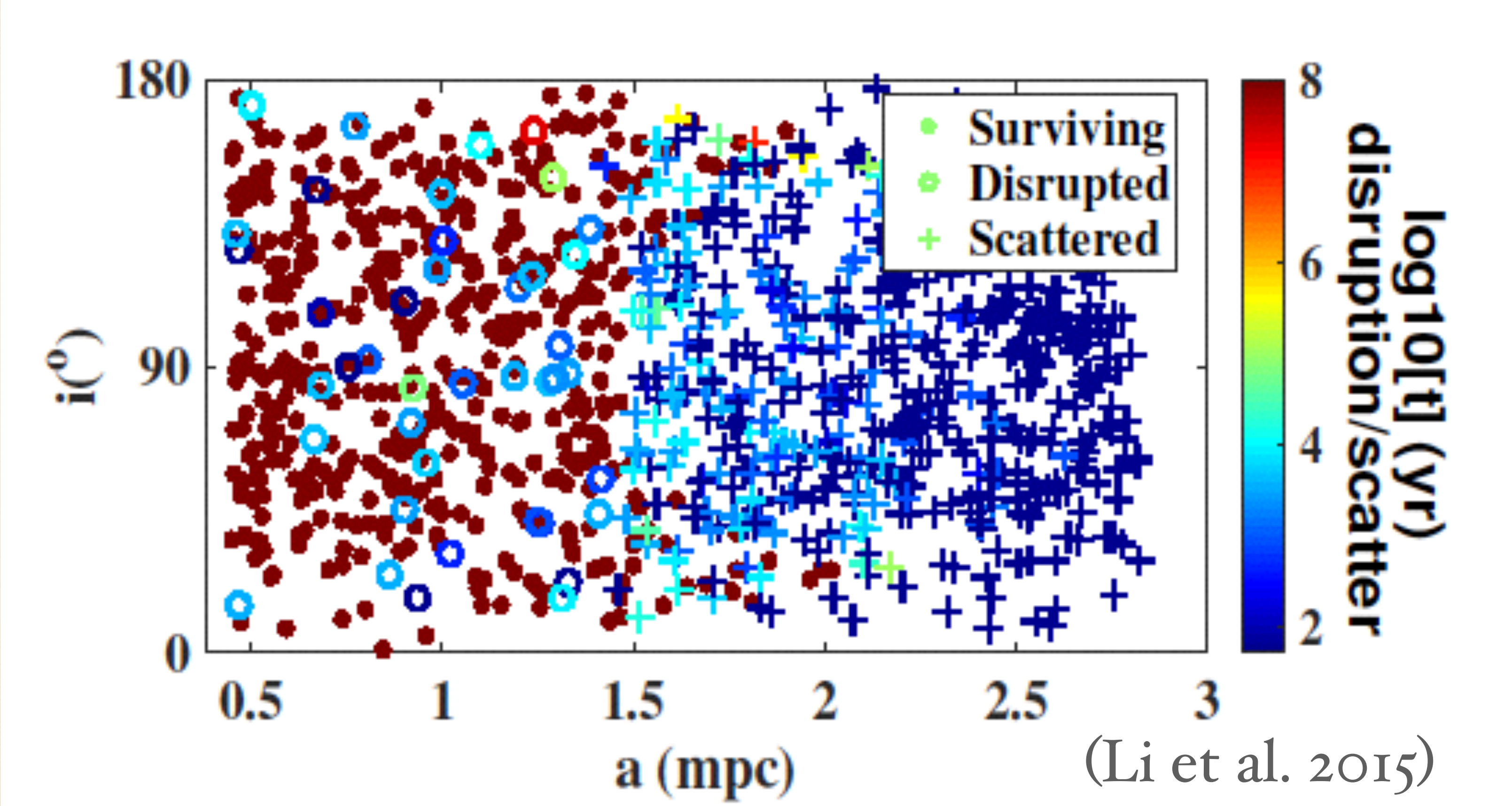


(Li et al. 2015)

- 40/1000 disrupted; 500/1000 scattered.

=> ~50% stars survived.

=> Disruption rate can reach $\sim10^{-4}$/yr.

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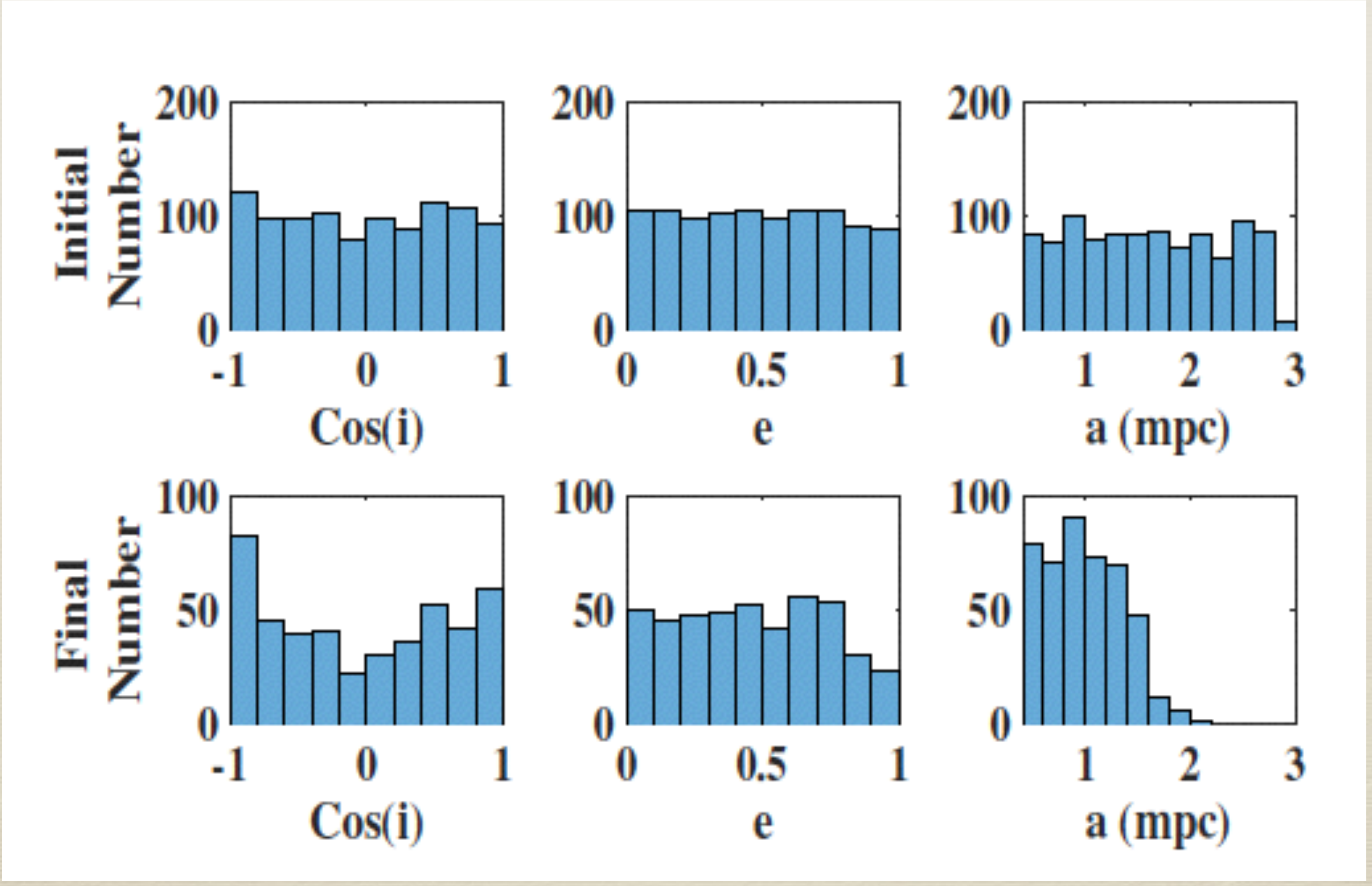


(Li, et al. 2015)

# Take Home Messages

* EKL mechanism drives stars to high e and causes the stars to either scatter off the second SMBH or get disrupted
* For SMBH masses $10^7 M_\odot$ and $10^8 M_\odot$, the TDE rate can reach $10^{-2}$/yr.
* The final geometry of the stellar distribution around the IMBH is a torus.

# Thank you!