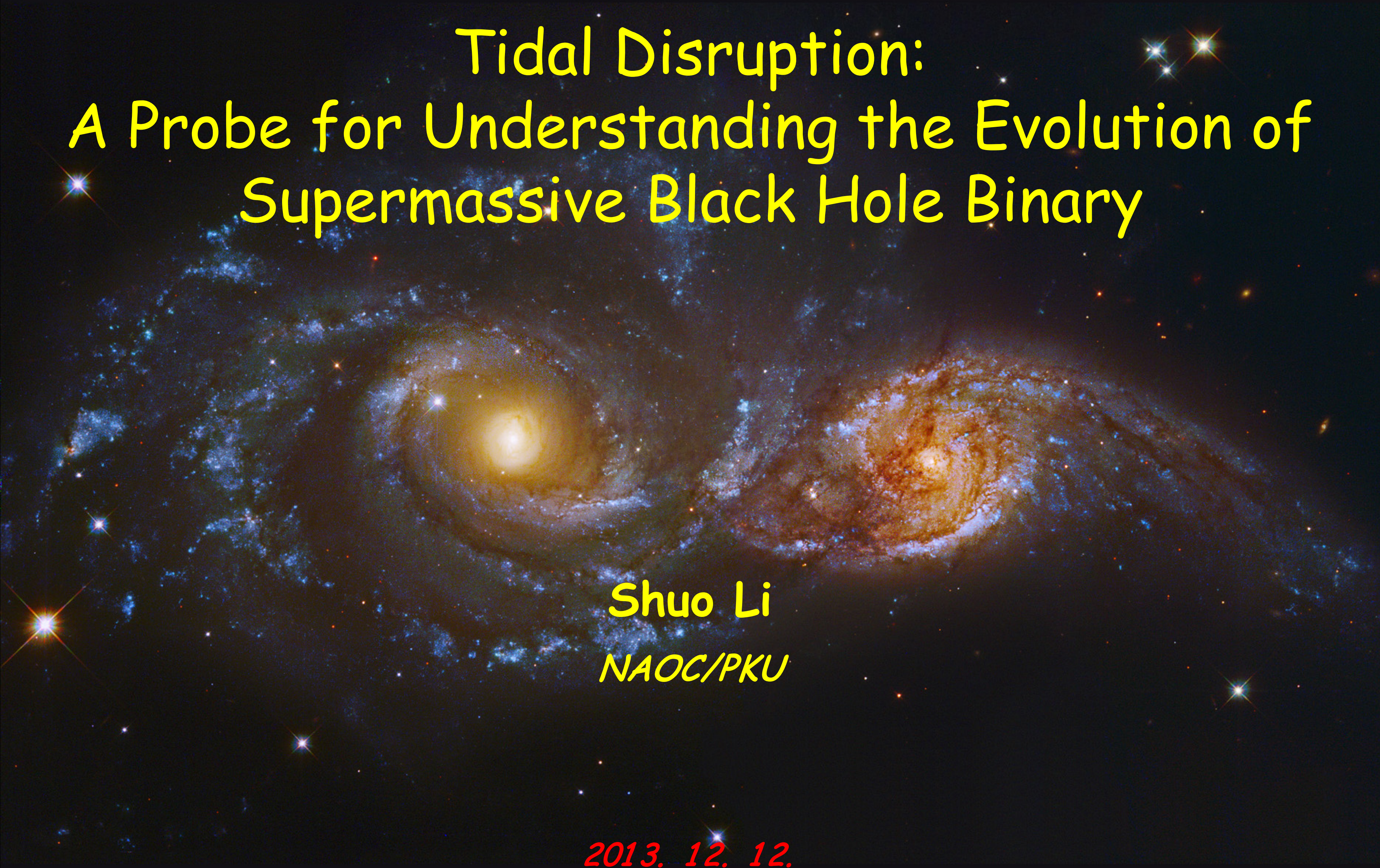


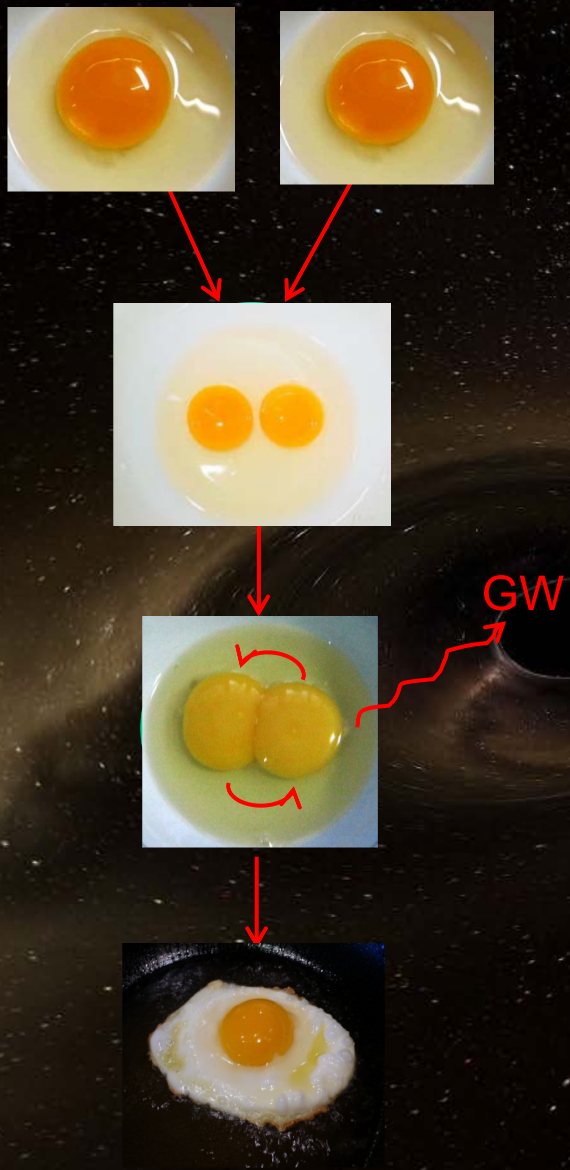
Tidal Disruption: A Probe for Understanding the Evolution of Supermassive Black Hole Binary

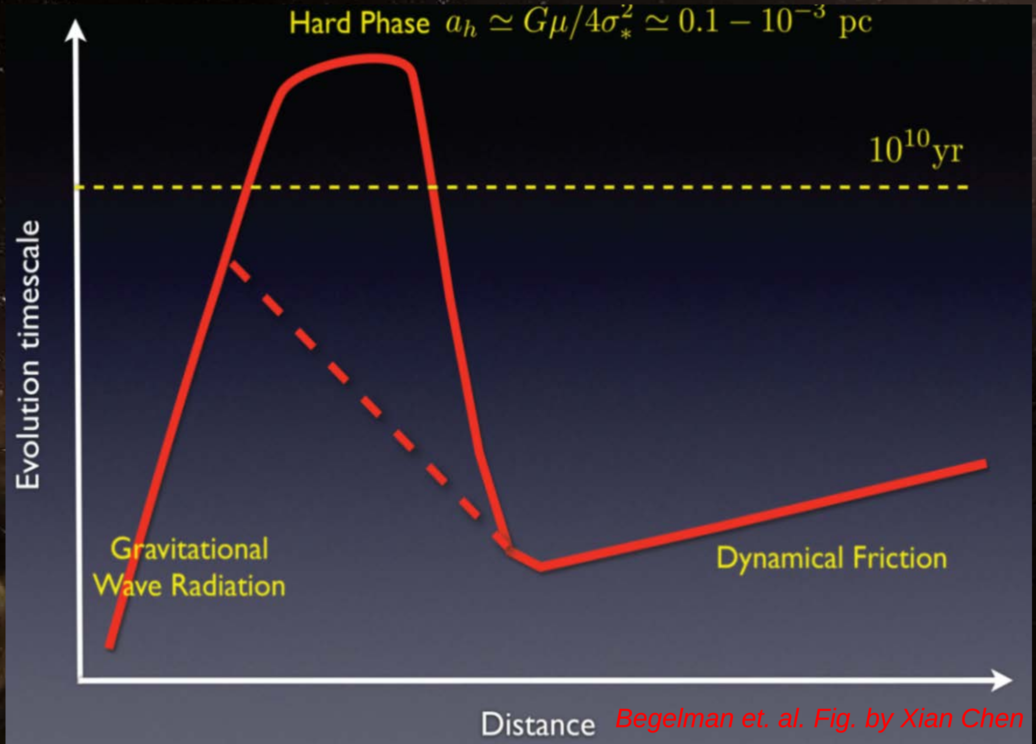
Shuo Li

NAOC/PKU

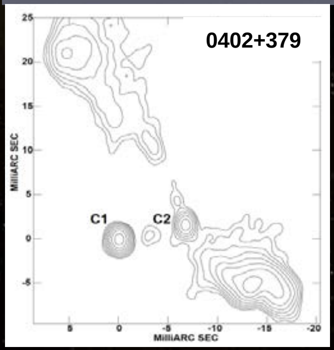
2013. 12. 12.

Evolution of Supermassive Black Hole Binaries



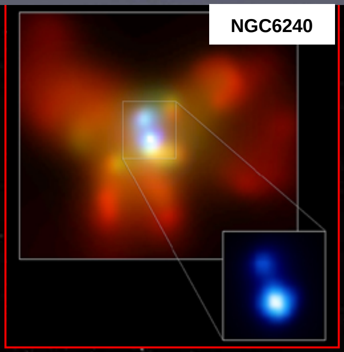


Begelman et. al. Fig. by Xian Chen



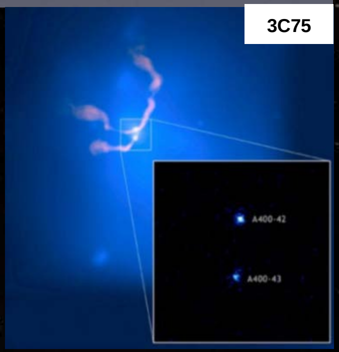
~10pc

Rodrigue et al., 2006



~kpc

Komossa et al., 2003



~10kpc

Hudson et al., 2006

Tidal Disruption

- BH's tidal gravity conquer star's self gravity:

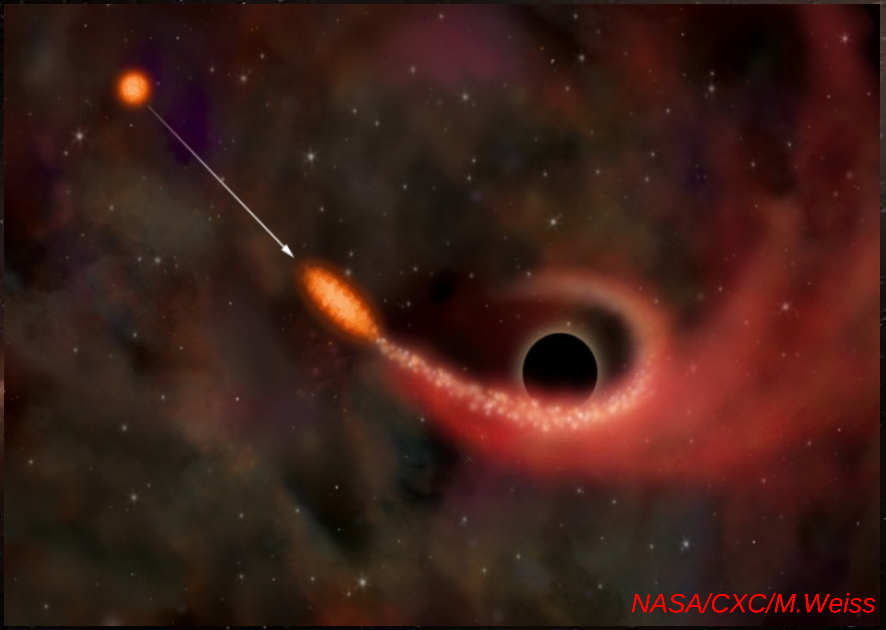
$$\frac{Gm_*}{r_*^2} \sim \left(\frac{GM_{\rm BH}}{r_{\rm t}^2}\right)\left(\frac{r_*}{r_{\rm t}}\right)$$

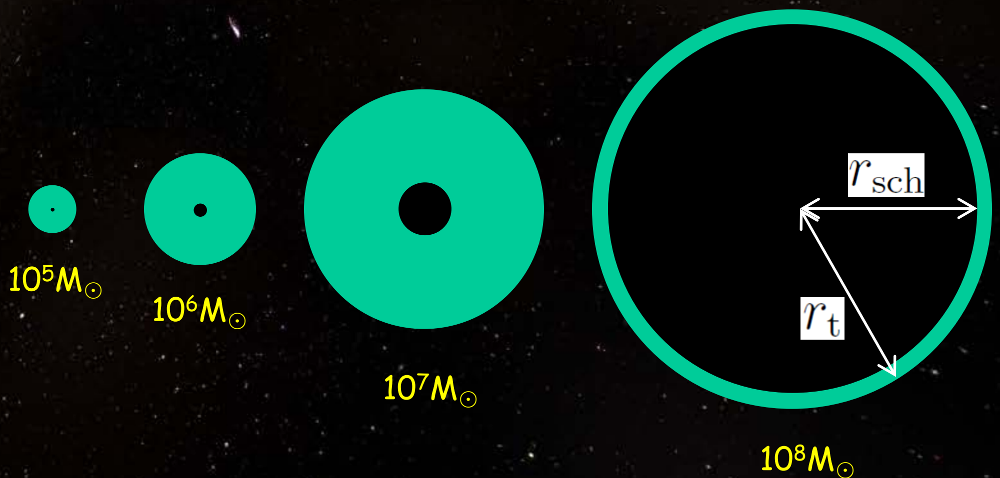
  - *Tidal radius*:

$$r_{\rm t} \simeq \mu r_* (M_{\rm BH}/m_*)^{1/3}$$

$$r_{\rm t} \propto M_{\rm BH}^{1/3}$$

$$r_{\rm sch} \propto M_{\rm BH}$$





Linda Strubbe

Tidal Disruption

- Tidal Flare
  - *Mass distribution during tidal disruption (TD):*

$$\frac{\mathrm{d}m}{\mathrm{d}E} \sim const.$$

  - *Re-falling rate:*

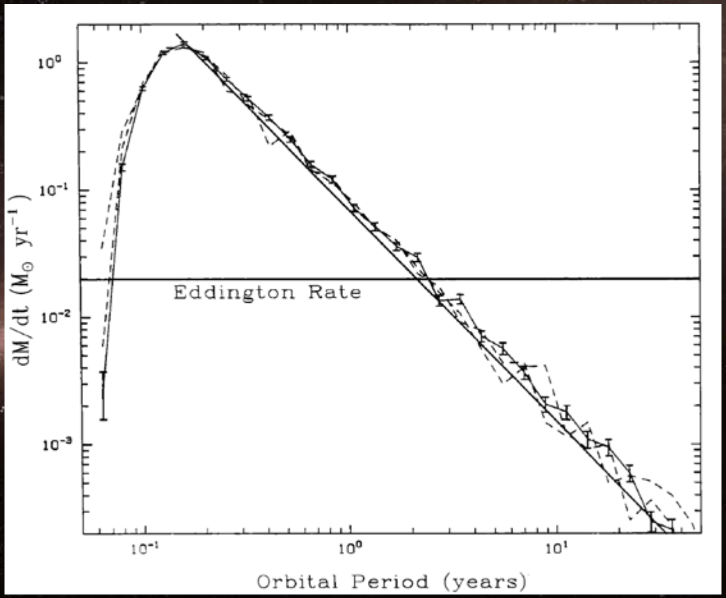
$$\dot{m} = \frac{\mathrm{d}m}{\mathrm{d}t} = \frac{\mathrm{d}m}{\mathrm{d}E}\frac{\mathrm{d}E}{\mathrm{d}t} \propto \frac{\mathrm{d}E}{\mathrm{d}t}$$

$$\dot{m} \simeq \frac{m_*}{3T_{\min}}\left(\frac{t-T_{\mathrm{D}}}{T_{\min}}\right)^{-5/3}$$

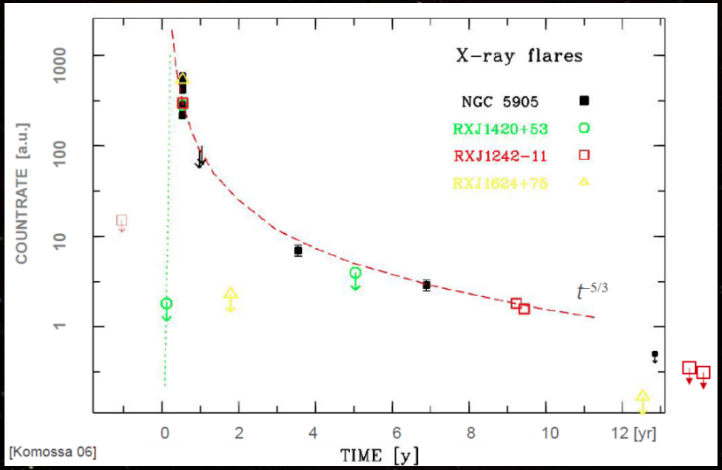
$$\dot{m} \propto t^{-5/3}$$

  - *Luminosity:*

$$L_{\max} = \epsilon \dot{m} c^2$$
$$\simeq (5.6\times10^{45}\ \mathrm{erg\,s^{-1}})\, k^{3/2}\left(\frac{M_{\mathrm{BH}}}{10^7\,\mathrm{M}_\odot}\right)^{-1/2}\left(\frac{\epsilon}{0.1}\right)\left(\frac{r_*}{\mathrm{R}_\odot}\right)^{-3/2}\left(\frac{m_*}{\mathrm{M}_\odot}\right)^2$$



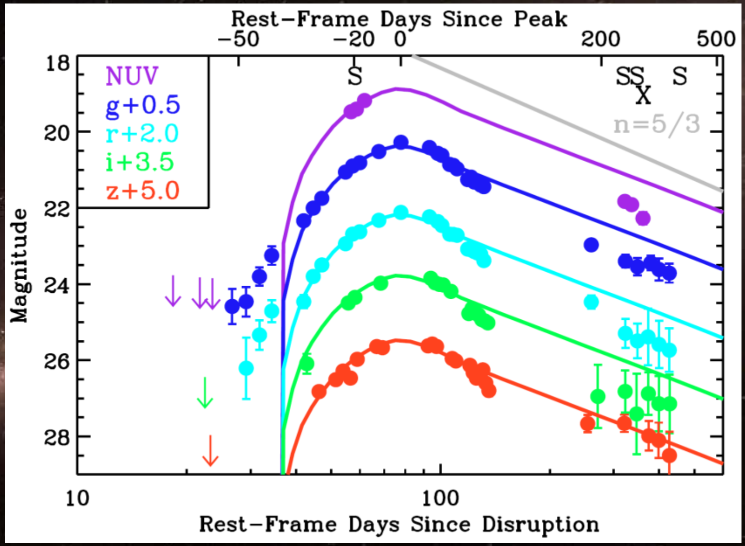
Evans et.al., APJ 1989, 346 L13



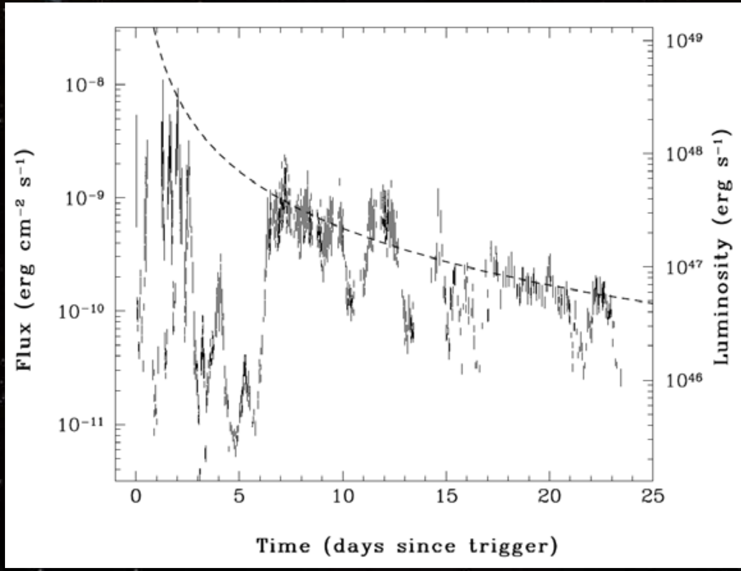
Tidal Disruption

- Flare in Observation
  - *Peak in X-ray(~10^{44} erg/s), flatter in UV and optical;*
  - *Some of them have relativistic jets: J1644+57 , J2058+05…*
  - *More complicated than theoretical predictions;*

- Implications
  - *A probe of galactic core;*
  - *A probe of jet formation;*
  - *A probe of stellar dynamics in galactic nuclei;*
  - *A tool for testing predictions of GR;*
  - *Understand the growth of SMBHs;*
  - *Search for recoiling SMBHs and SMBHBs ……*



PSI-I0jh Gezari et.al., Nature 2012, 485, 217



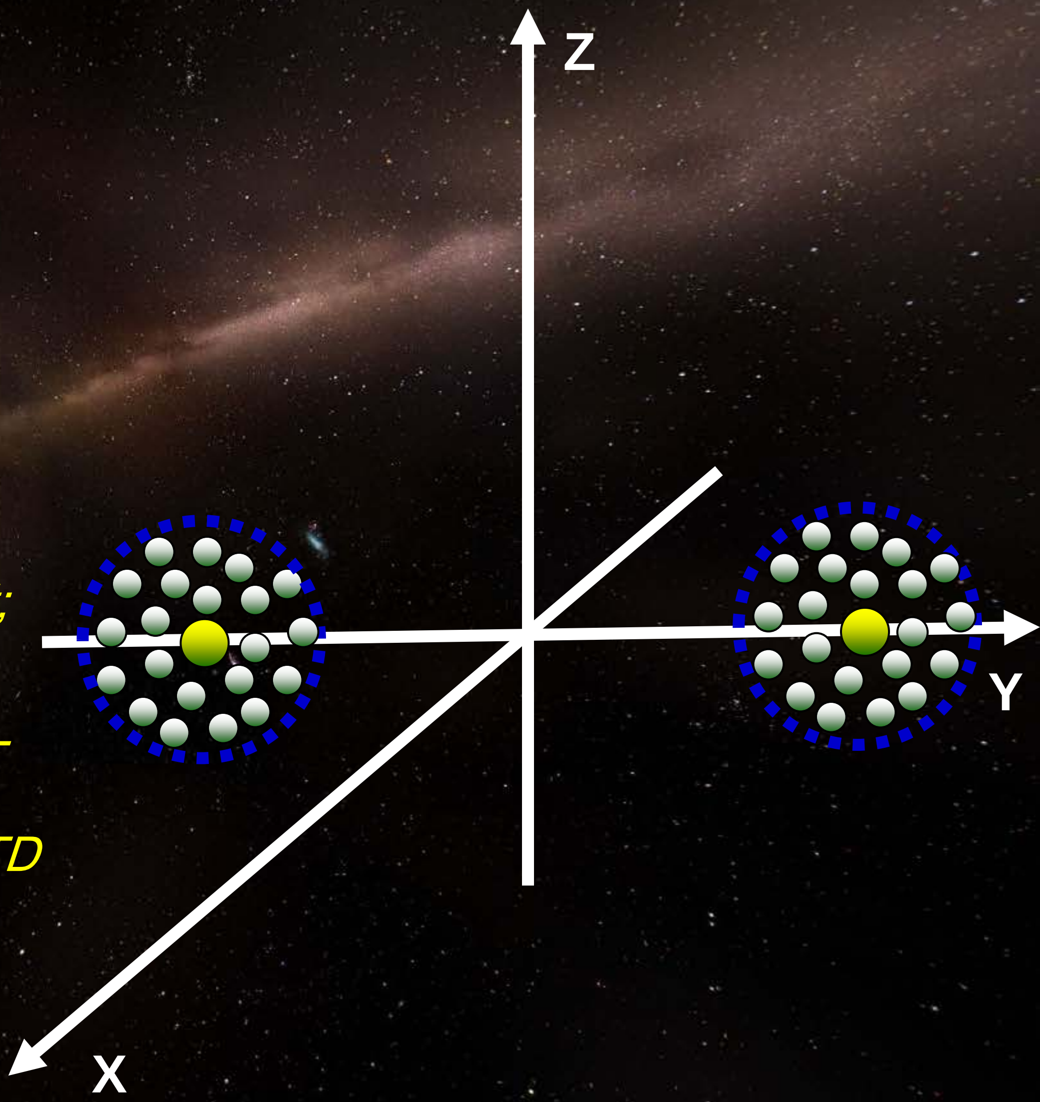
J1644+57 Burrows et.al., Nature 2011, 476, 421B

TD during Galaxy Merger

- Model for galaxy merger:
  - *Stellar distribution:*

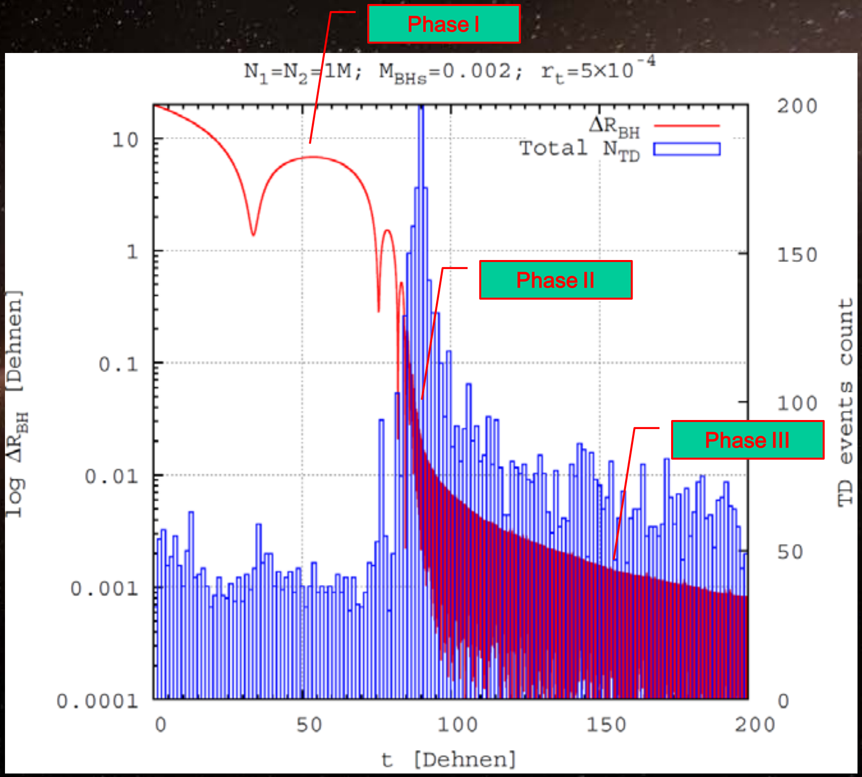
$$\rho(r) = \frac{3-\gamma}{4\pi}\frac{Ma}{r^{\gamma}(r+a)^{4-\gamma}}$$

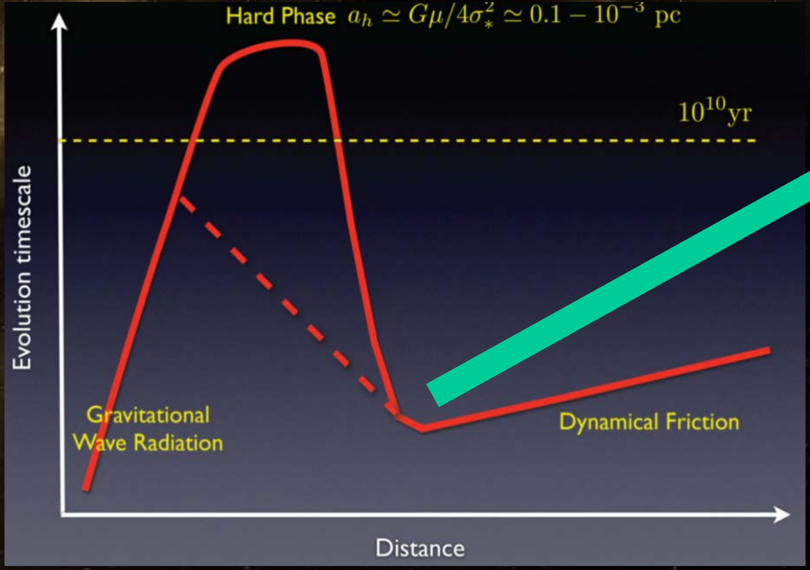
  - *$M_1=M_2=10^{-3}$, $M_{tot}=2$;*
  - *$\gamma=0.5, 1.0, 1.5$;*
  - *N=50kx2, 100kx2, 250kx2, 500kx2;*
  - *$r_{bh0}=20, r_{p0}=1$, in parabolic orbit;*
  - *$r_t=5x10^{-5}, 10^{-4}, 5x10^{-4}$;*
  - *Large particle number direct N-body simulation (phi-GRAPE/GPU) with simplified TD scheme;*



TD during Galaxy Merger

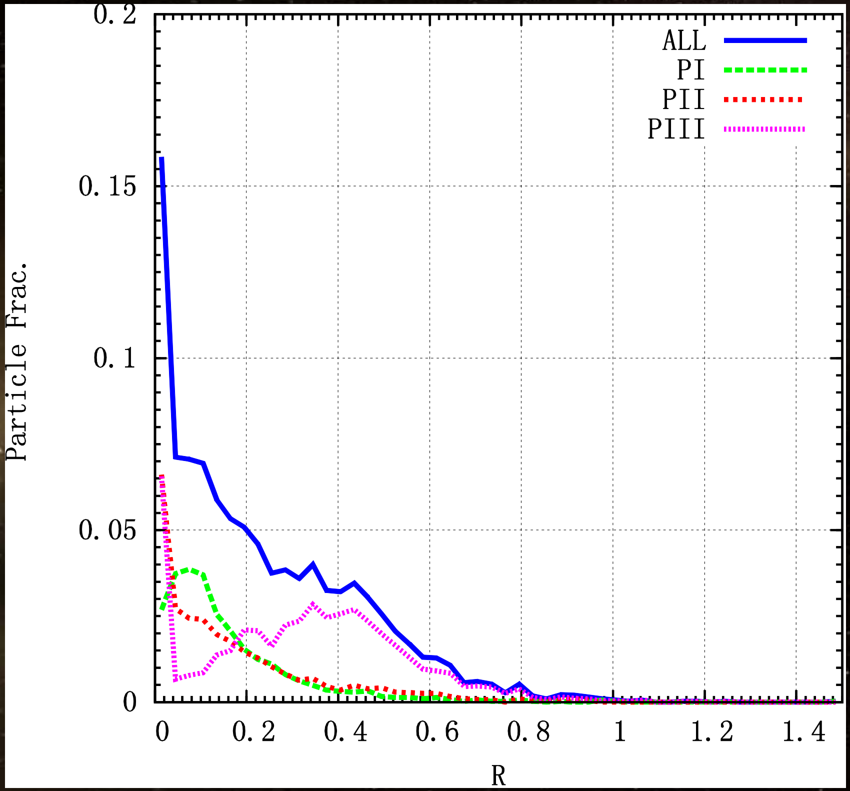
- Preliminary results for tidal disruption in merging galaxies:
  - *Boosted rate around the bound system formation;*

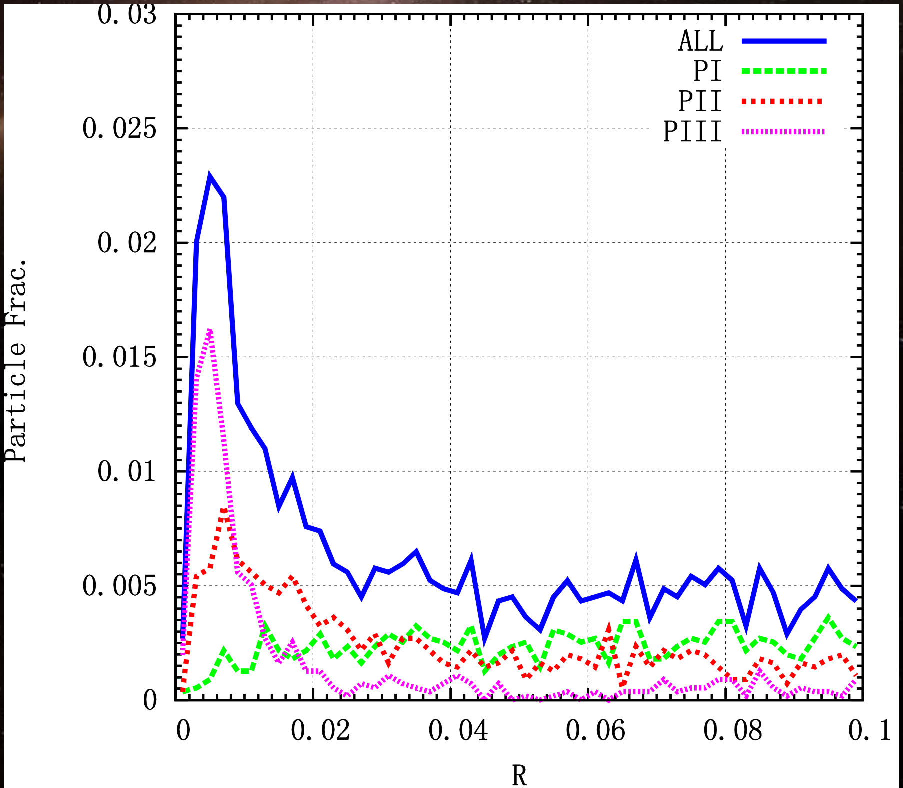




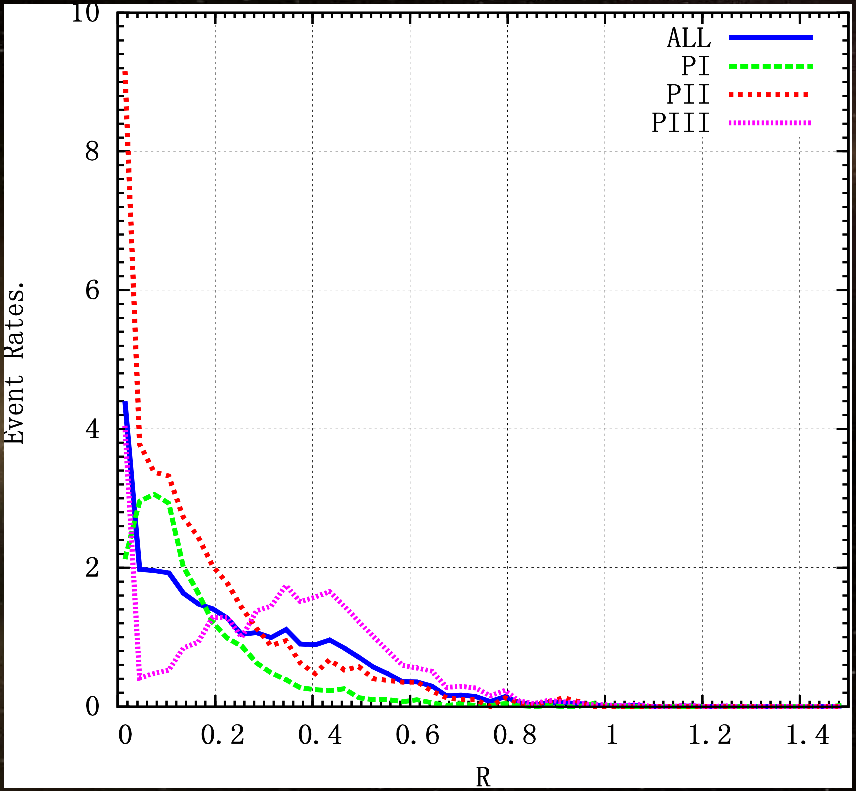
TD during Galaxy Merger

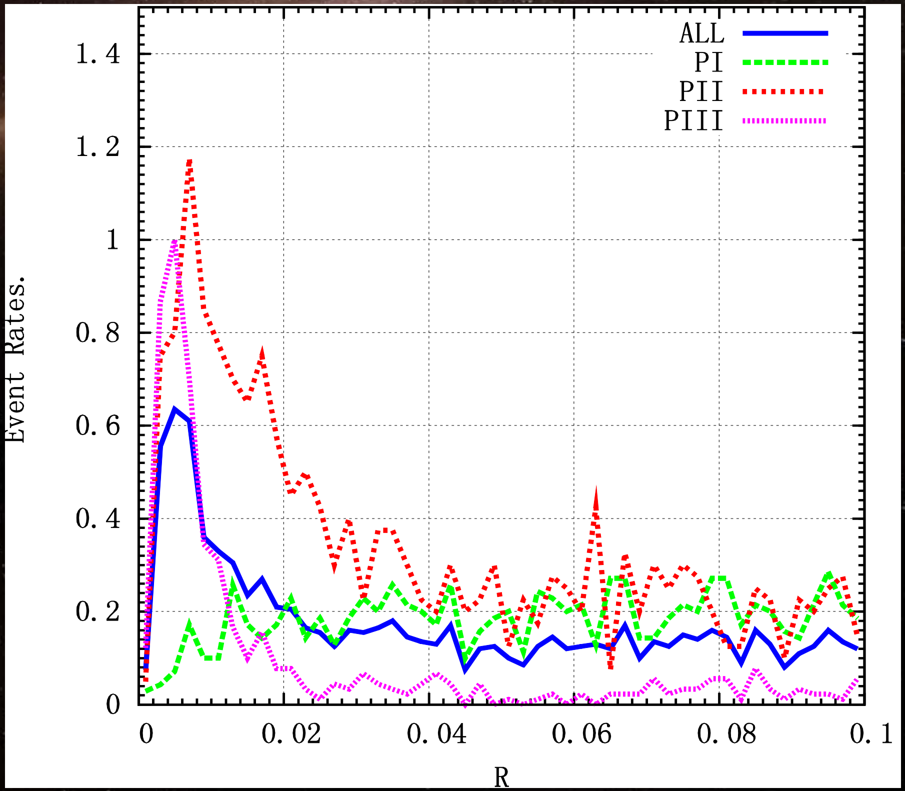
- The last apocenter distribution of disrupted stars:





TD during Galaxy Merger





TD in SMBHB Systems

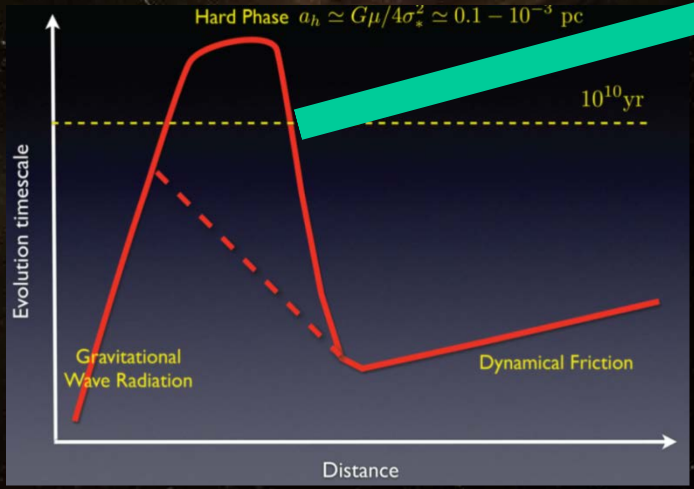
- A triple system is hierarchical and stable when (*Mardling & Aarseth 2001*):

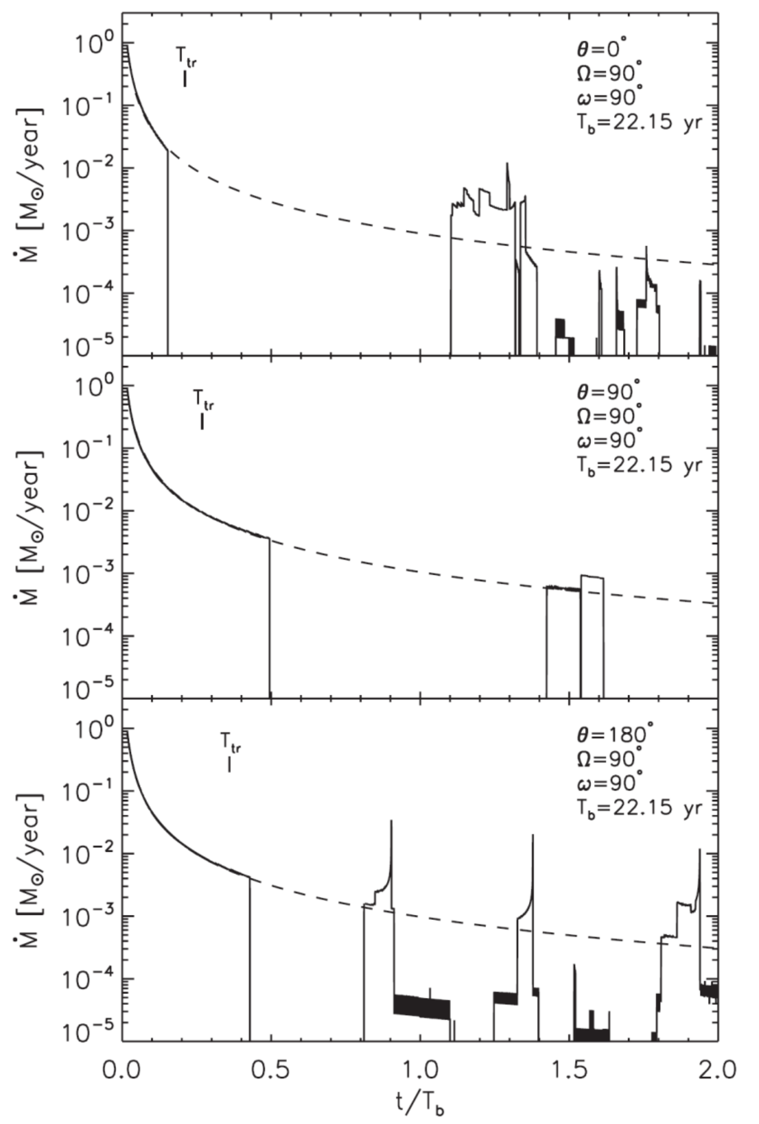
$$a_{\rm out}/a_{\rm in} \;>\; 2.8\,(1+q_{\rm out})^{2/5}\,(1+e_{\rm out})^{2/5} \times (1-e_{\rm out})^{-6/5}\,(1-0.3\theta/180^\circ)$$

- The accretion interrupts at a time T_{tr} :

$$T_{\rm tr} = \eta T_{\rm b} \simeq 6.2\,{\rm yr}\,\sigma_{110}^{-3} M_7 q_{-1}^{3/2} (1+q)^{-2} \left(\frac{\eta}{0.25}\right)\left(\frac{\beta}{10}\right)^{-3/2}$$

$\eta \sim 0.27$ in average theoretically. Our simulation results have $\eta \sim 0.25$.



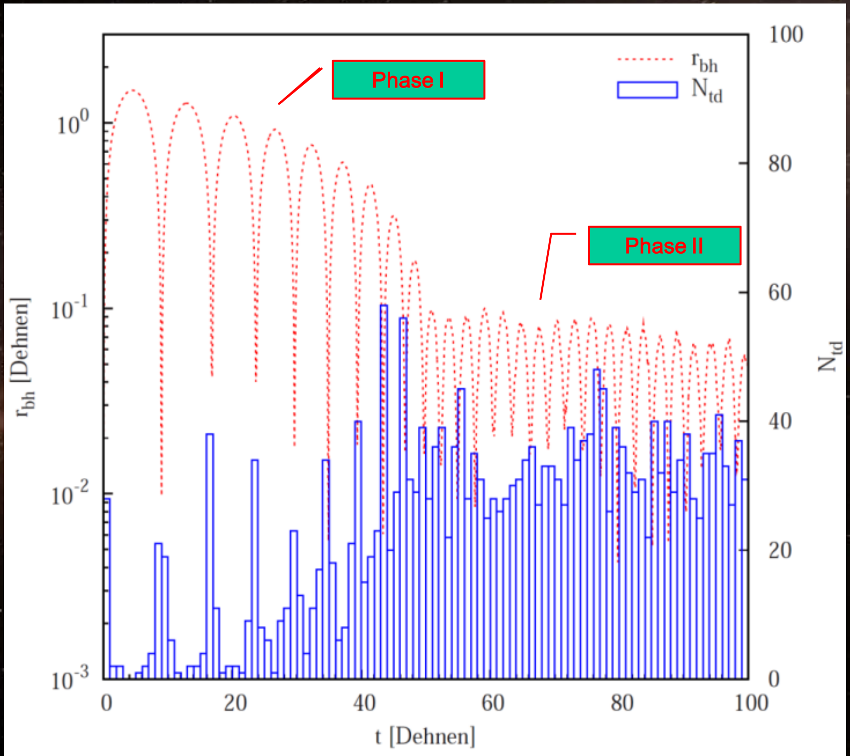


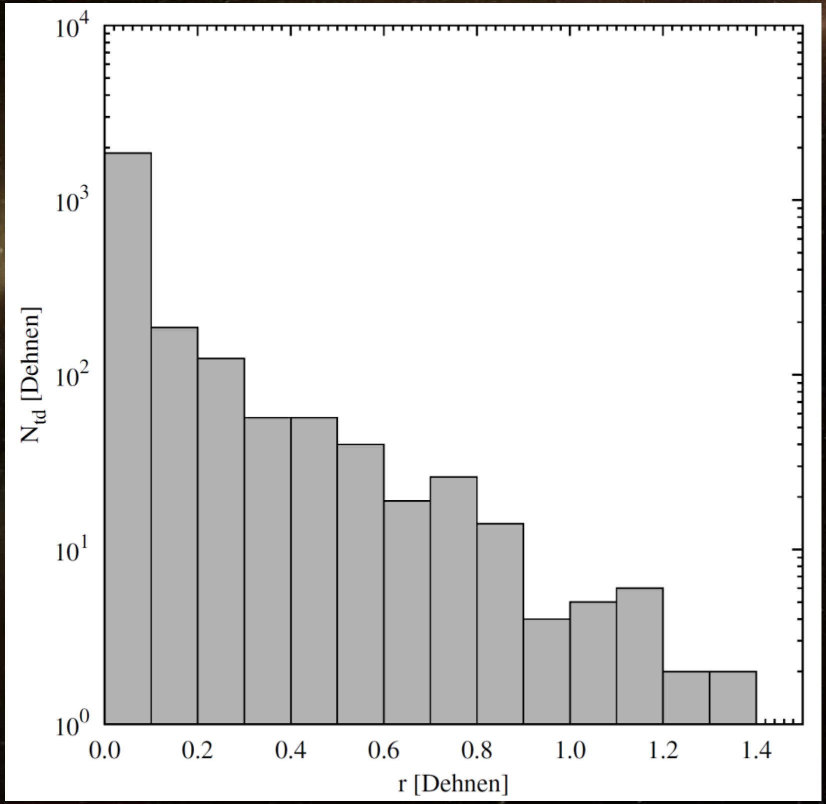
Liu, F. K.; Li, S. & Chen, X., 2009

Tidal Disruption of Recoiling SMBH

- Boosted TD events around density center in phase I:

  Higher stellar density;





Tidal Disruption of Recoiling SMBH

- Boosted TD events around density center in phase I:

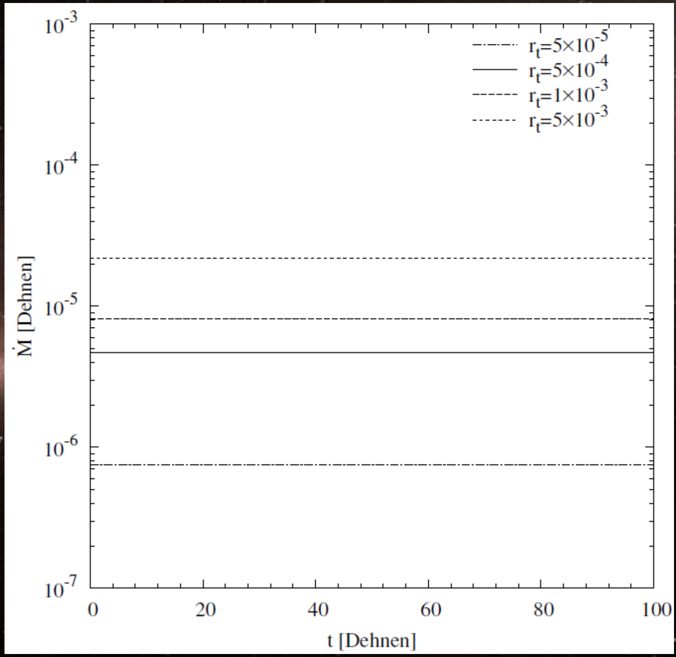
  Higher stellar density;

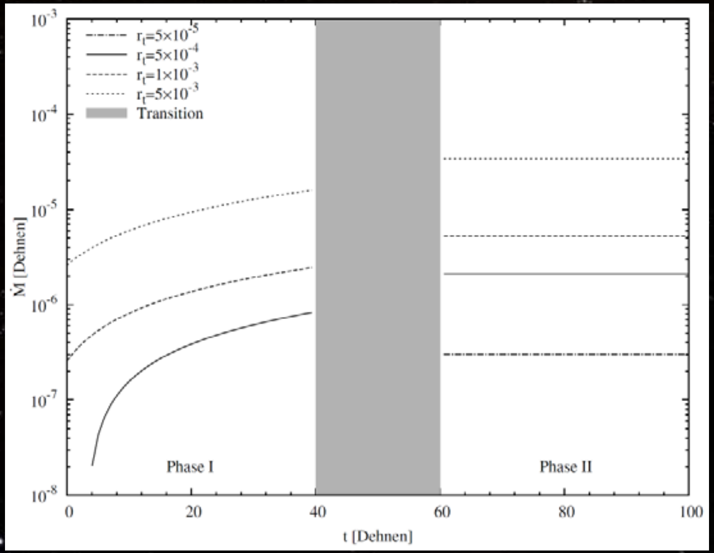
- Monotonic increasing TD rates for recoiling SMBH in phase I:

  $\sim 10^{-6} \mathrm{M}_{\odot}\ \mathrm{yr}^{-1}$

- Constant TD rates for stationary SMBH and recoiling BH in phase II:

  $\sim 10^{-5} \mathrm{M}_{\odot}\ \mathrm{yr}^{-1}$





Summary

- The SMBHBs in normal galaxies are hard to detect;
- TD can be a very powerful tool to study SMBHBs in quiescent galaxies;
  - Boosted TD rates in merging galaxies;
  - The truncation of TD light curve can be used to distinguish SMBHB;
  - Boosted TD rates for recoiling SMBHB passing by galactic center;
- Large scale survey like LSST is very important;
- Long term follow up observation is very important.