Tidal Disruption Events in AGN

--AGN regulated TDE rate

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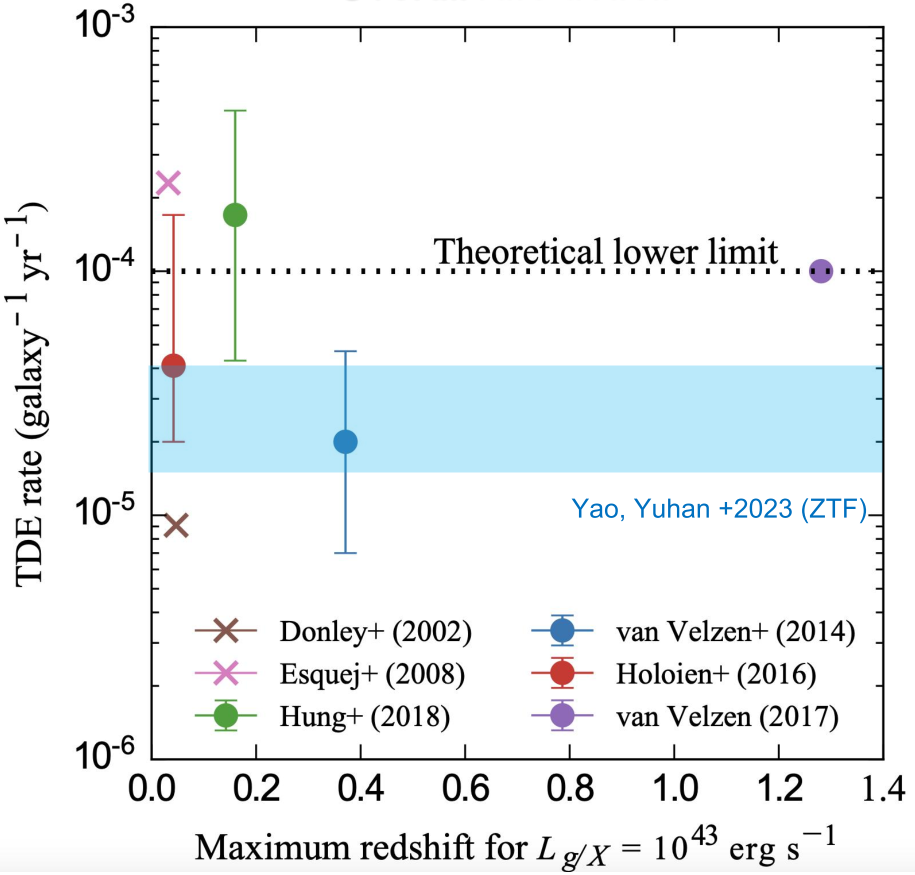
Two long standing problems on TDE rate

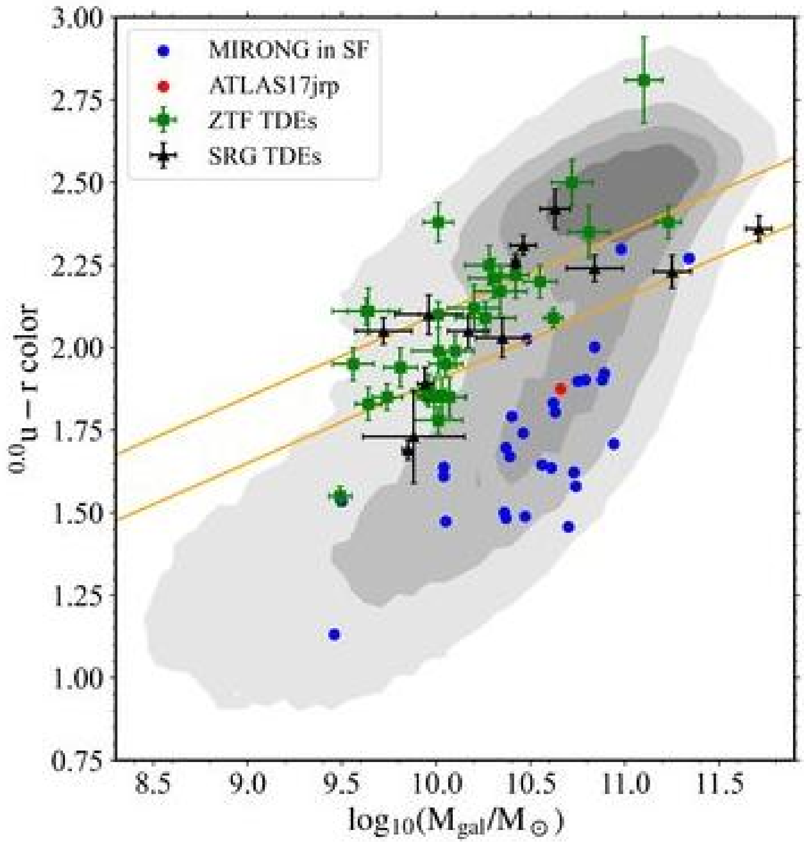
Overall rate deficit



Low luminosity TDEs were missed

Van Velzen 2018

High rate in E+A galaxies



SMBH binaries

Ivanov. et al. 2005
Chen et al. 2011
…

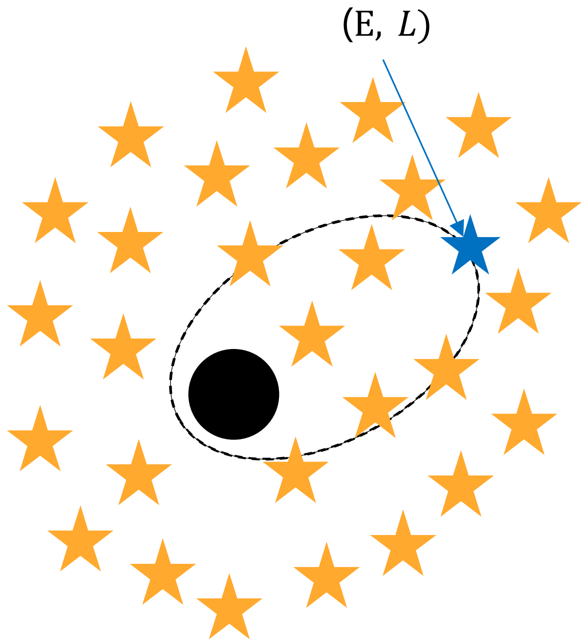
Massive perturbers

Perets et al. 2007
Mastrobuono-Battisti et al. 2014
Hammers & Perets 2017
…

AGN disks

Wang, Ma, Wu & Jiang 2024
Wang, Lin, Zhang & Zhu 2024
Kaur & Stone 2024
…

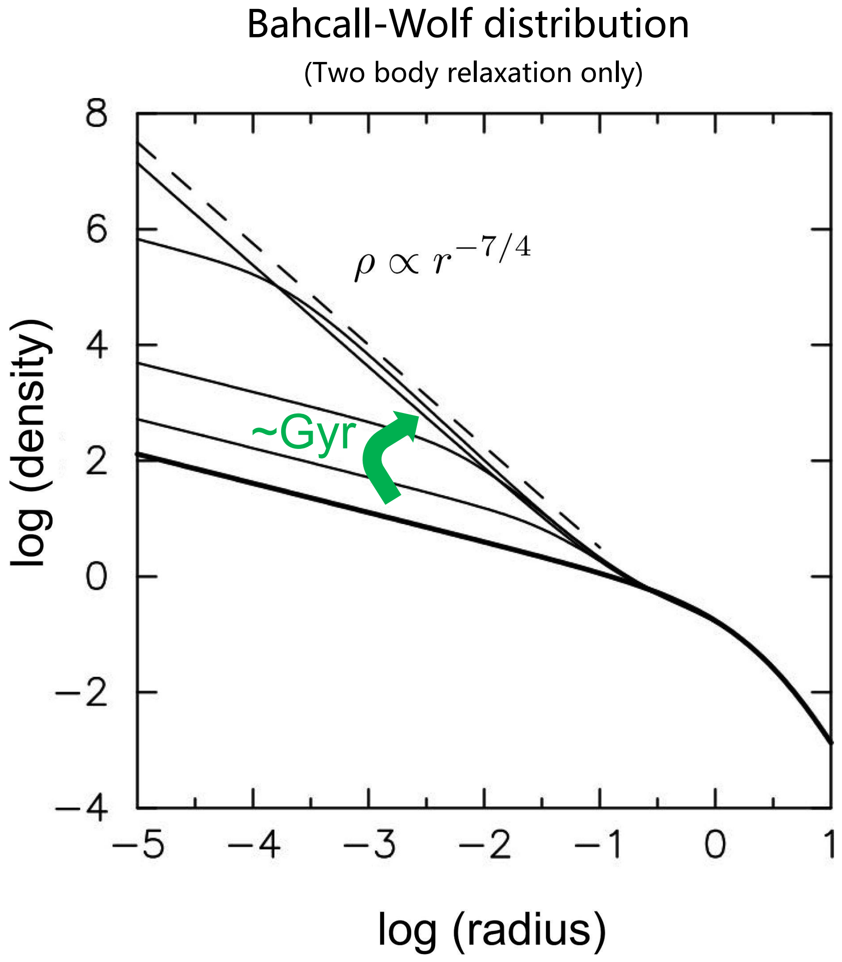
Two-body relaxation in nuclei star cluster



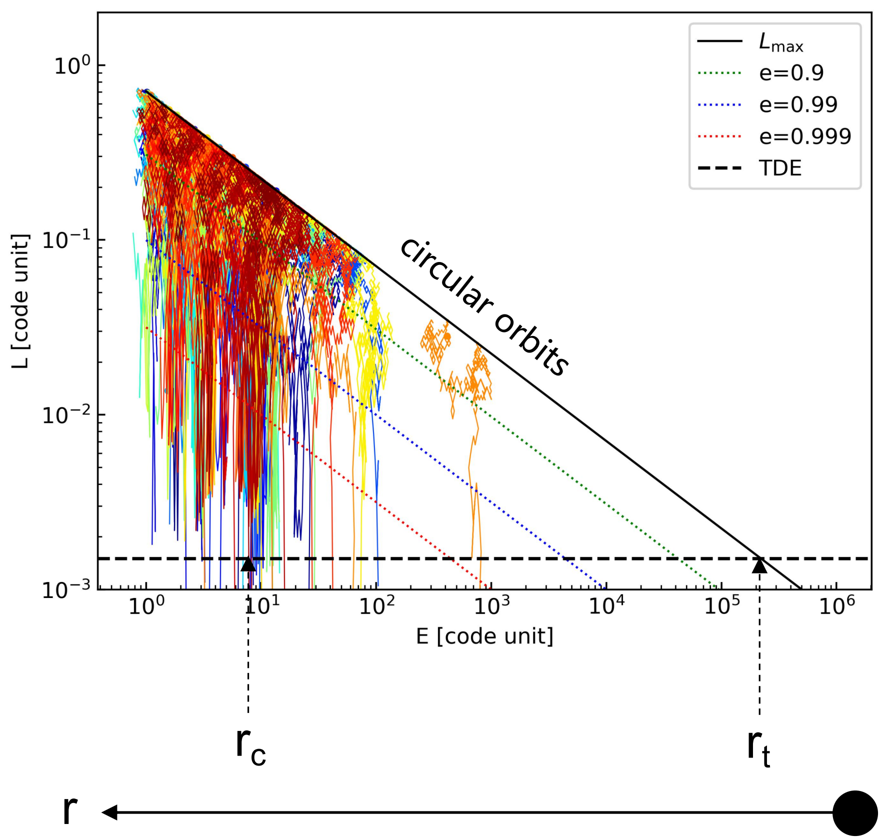
energy fluctuation: $$\frac{\Delta E}{E} \sim \sqrt{\frac{t}{t_{\rm rel}}},$$

angular momentum fluctuation: $$\frac{\Delta L}{L_{\max}(E)} \sim \sqrt{\frac{t}{t_{\rm rel}}},$$

relaxation timescale: $$t_{\rm rel} \sim \frac{M_\bullet^2}{m^2 N \ln\Lambda} T,$$



Spitzer Mote Carlo Method

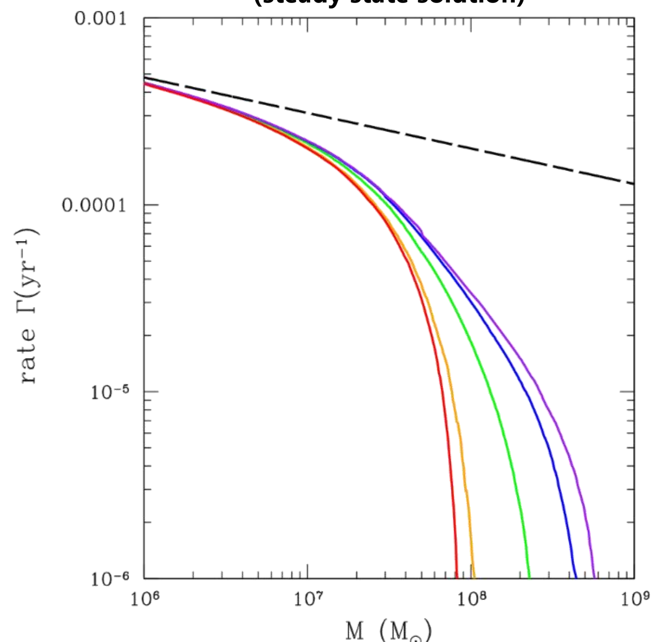


1-D Fokker-Planck equation (isotropic NSC)

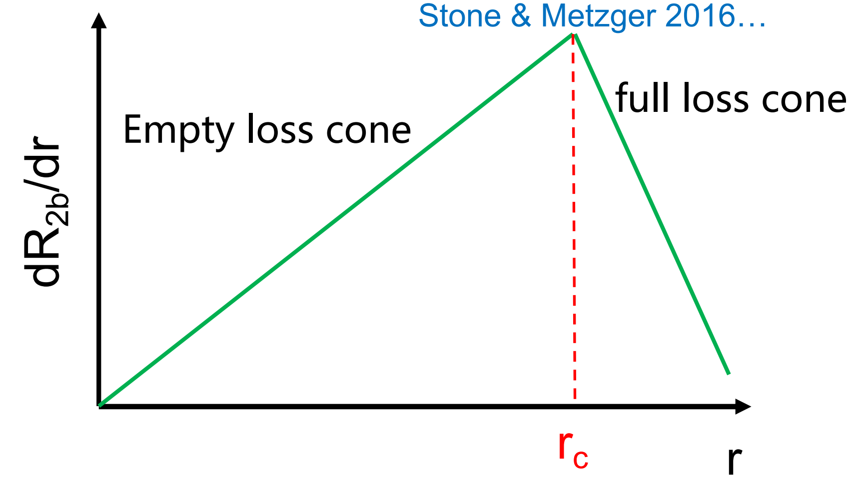
$$\frac{\partial}{\partial t}N(\mathcal{R},t) = \frac{\partial \mathcal{F}}{\partial \mathcal{R}}, \qquad \mathcal{F} \equiv \mathscr{D}(E,\mathcal{R})\,\frac{\partial N}{\partial \mathcal{R}}, \qquad \mathscr{D}(E,\mathcal{R}) \approx \mathcal{D}(E)\,\mathcal{R}.$$

TDE rate as a function of M_{SMBH}

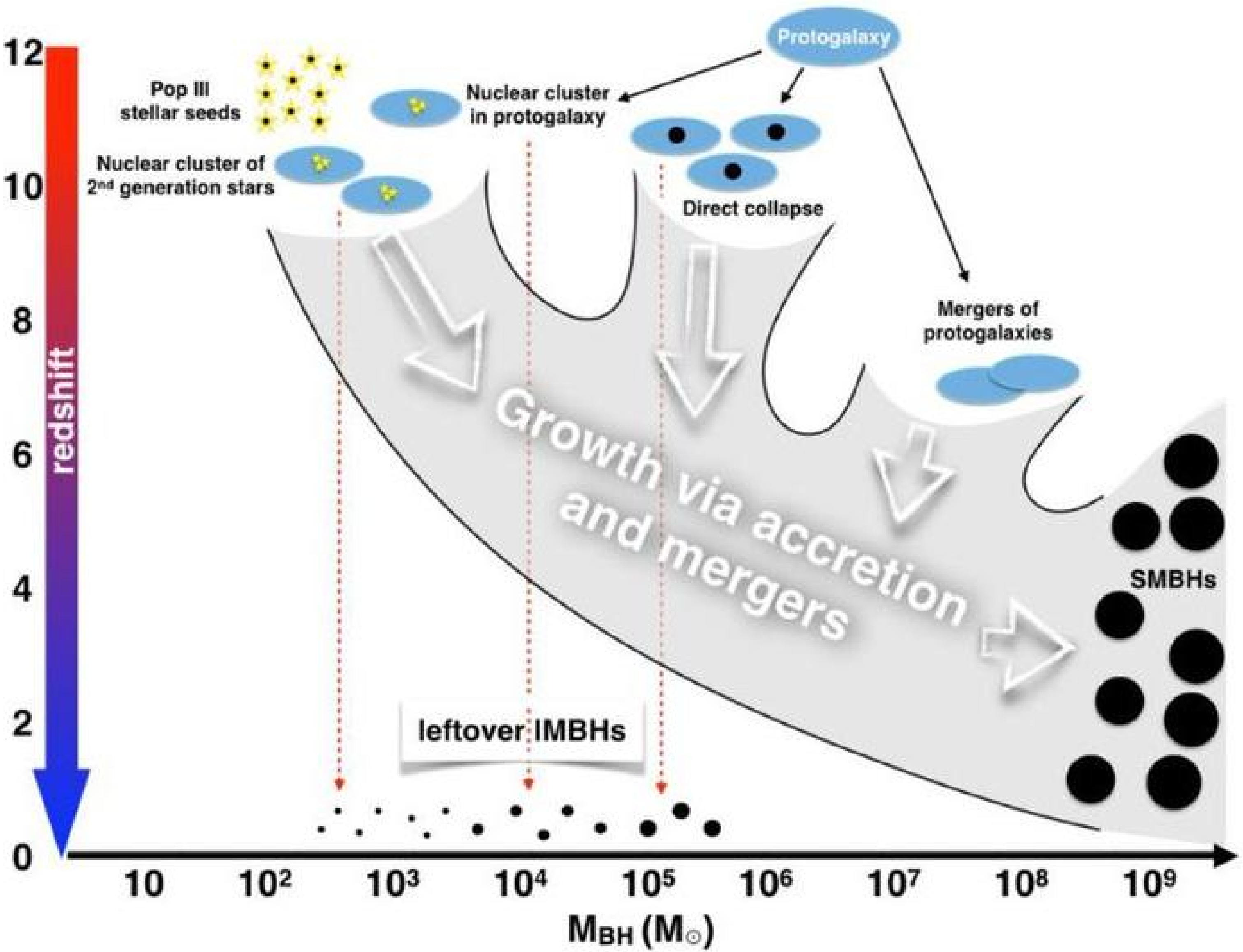
(steady state solution)

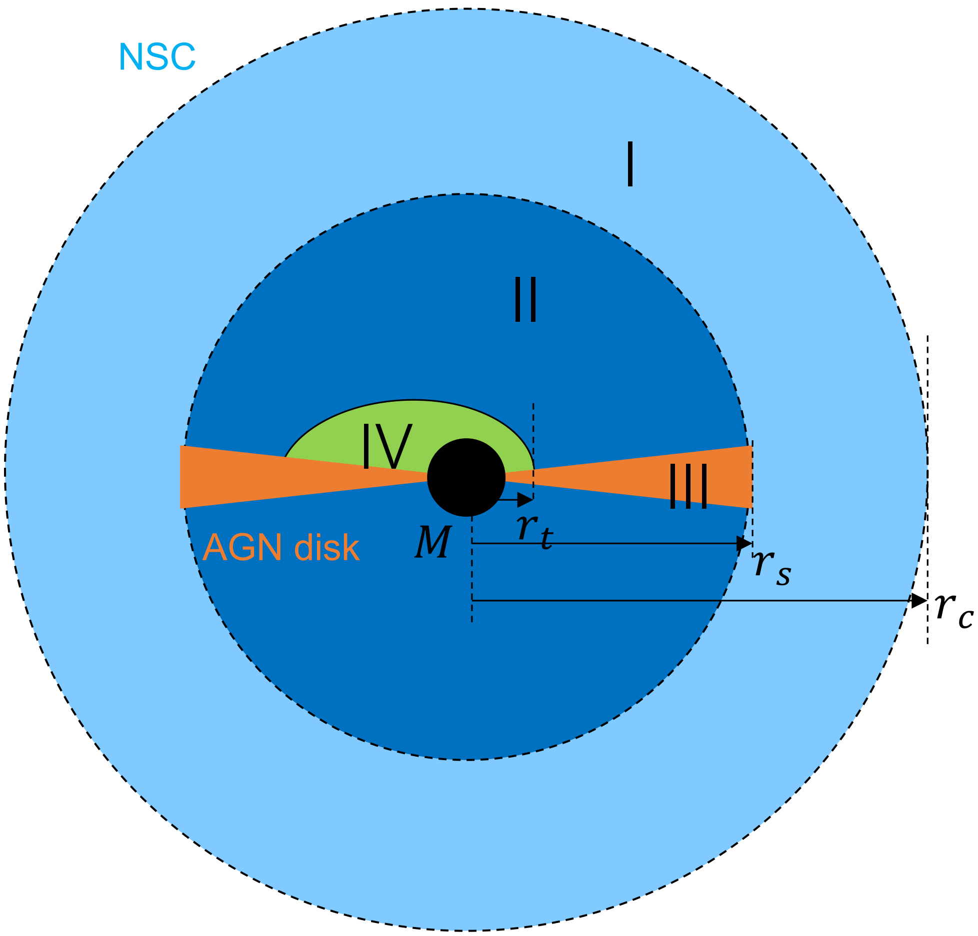


Wang & Merritt 2004
Stone & Metzger 2016…



Growth of SMBH





Three radii:

Tidal radius: $r_t \sim \left(\frac{3M}{m_*}\right)^{\frac{1}{3}} R_*$

Disk radius r_s : $\frac{M_{disk}(r_s)}{M} \sim 1$

Cluster size: r_c

Four regions:

I: relaxation dominated

II: off-disk aerodynamical drag

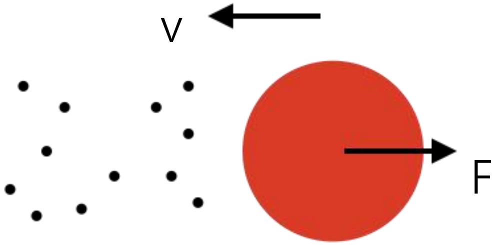
III: Lindblad resonance, in-disk aerodynamical drag

IV: off-disk aerodynamical drag

Disk-star interaction

aerodynamic drag

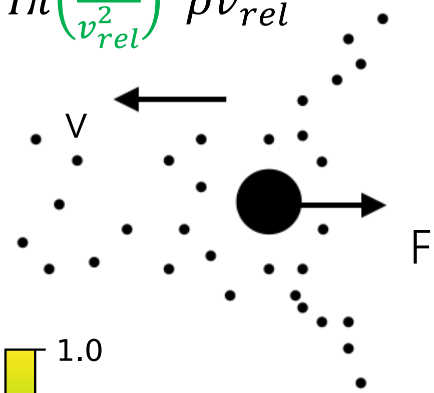
$$F_a \sim \lambda \pi R^2 \rho v_{rel}^2$$

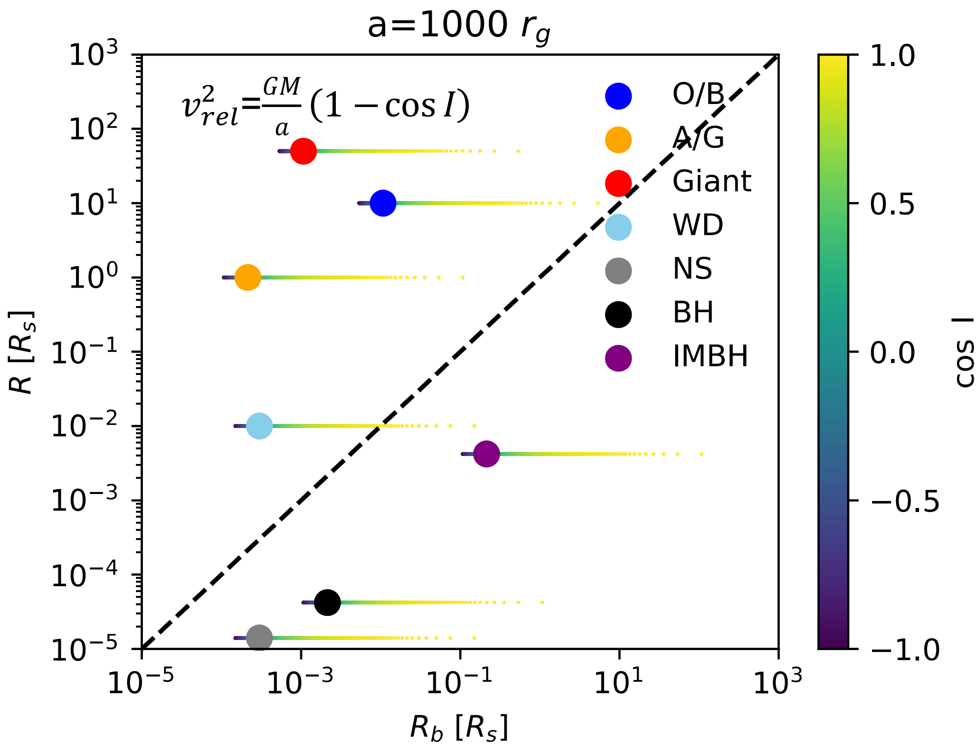


dynamical friction

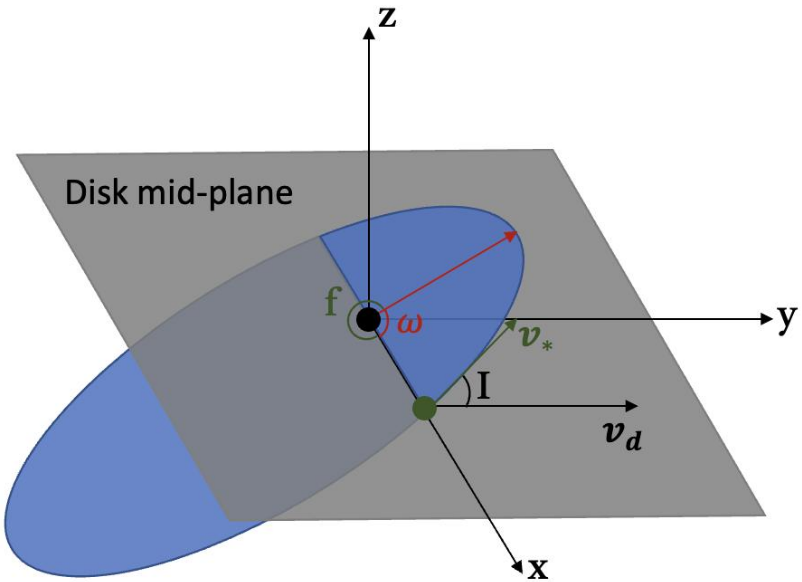
R_b

$$F_d \sim I \frac{4\pi (Gm)^2 \rho}{v_{rel}^2} \sim I\pi \left(\frac{Gm}{v_{rel}^2}\right)^2 \rho v_{rel}^2$$





NSC reshaping by aerodynamic drag



Equation of motion

$$\frac{\mathrm{d}\cos I}{\mathrm{d}(t/T)} = 2\sqrt{2}\alpha\frac{\Sigma}{\Sigma_*}\sin I\sqrt{\delta-\cos I}+\mathcal{O}(\lambda^2)$$

>0: orbital alignment -> angular profile

$$\frac{\mathrm{d}a}{a\mathrm{d}(t/T)} = \frac{4\sqrt{2}}{1-e^2}\bar{\alpha}\frac{\Sigma}{\Sigma_*}\frac{\cos I-\bar{\gamma}}{\sin I}\sqrt{\delta-\cos I}$$

<0: orbital decay -> radial profile

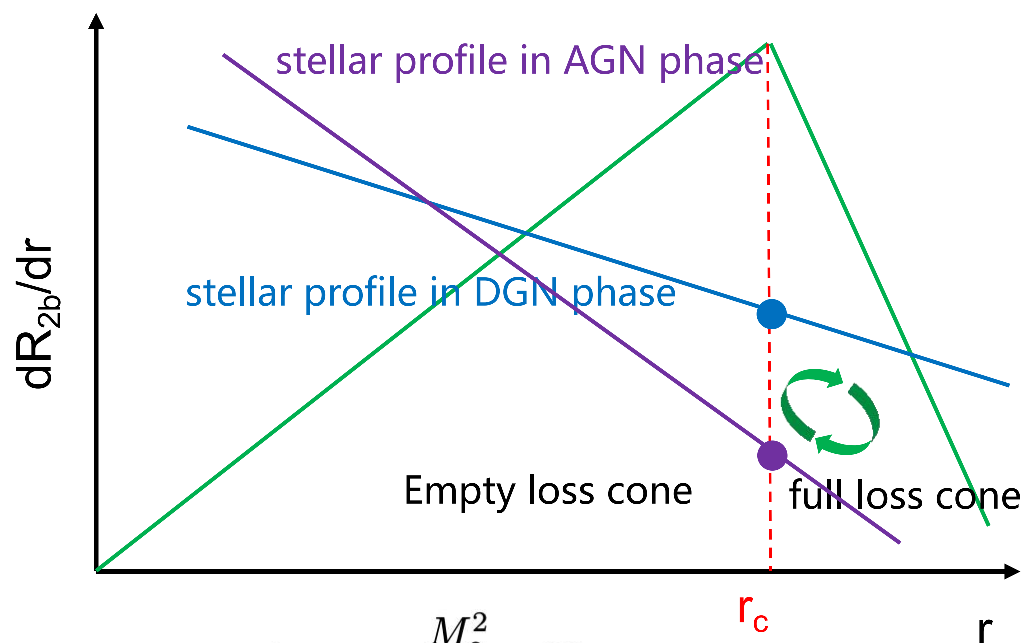
$$\frac{\mathrm{d}e}{e\mathrm{d}(t/T)} = \frac{1}{2e^2}\frac{\Sigma}{\Sigma_*}\frac{4\sqrt{2}}{\sin I}\sqrt{\delta-\cos I}\Big((\bar{\alpha}\cos I-\bar{\beta}) - (1-e^2)(\alpha\cos I-\beta)\Big)$$

<0: circularization -> thermal profile

Does not apply to the BHs!

Wang Y., Zhu Z. & Lin D 2024

NSC profile oscillations



$$t_{\rm rel} \sim \frac{M_\bullet^2}{m^2 N\ln\Lambda}T,\ \sim\text{Gyr}$$

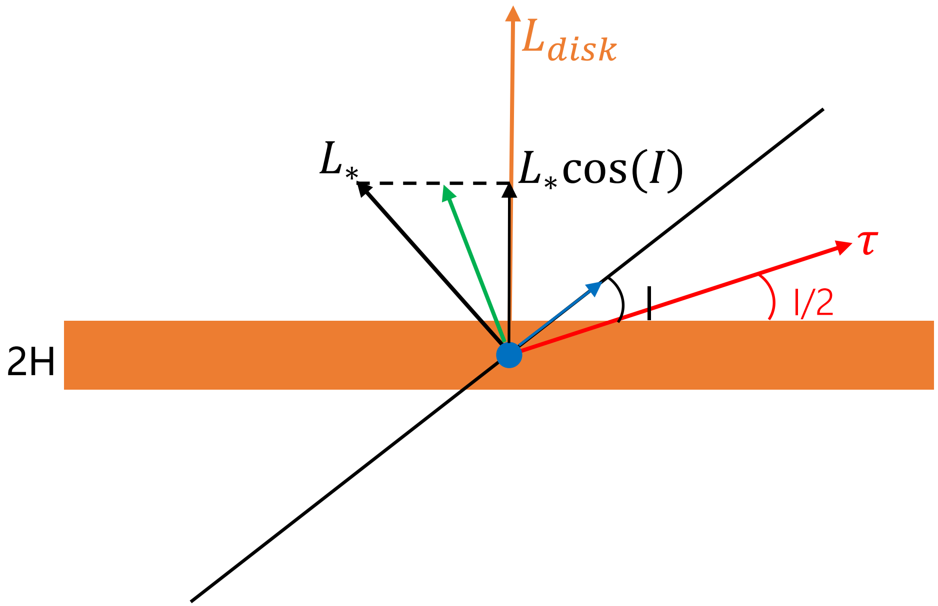
TDE rate from two-body relaxation is oscillating.

Pseudo-integral of motion

$$\boxed{L\cos^2(I/2) = const}$$

Disk model independent!

$$\frac{1}{2}(L + L\cos(I)) = const$$



TDE from direct disk capture

$$\boxed{L\cos^2(I/2) = const}$$

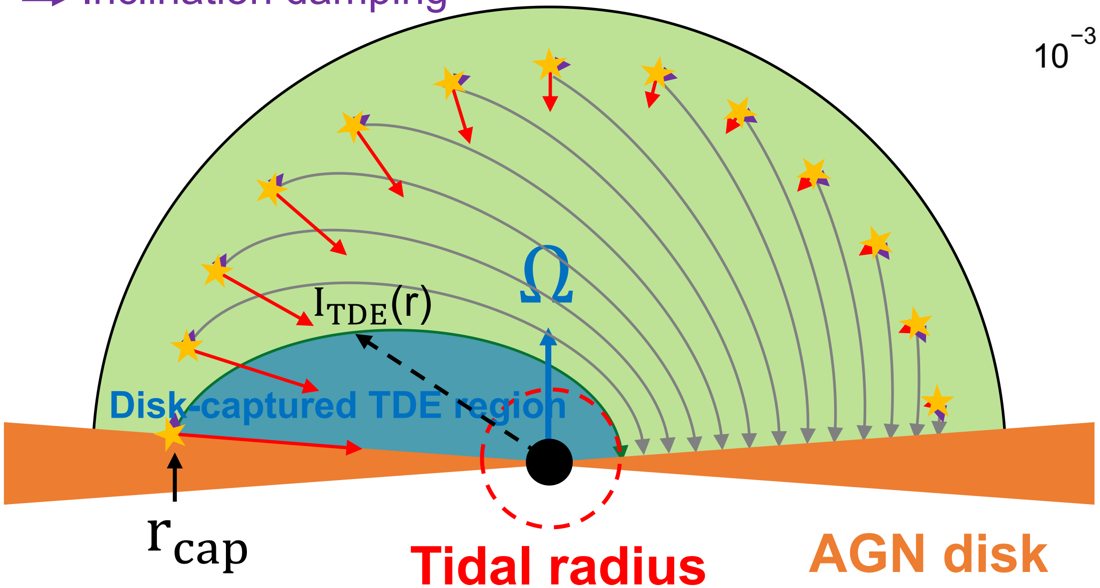
$$L^2 \propto a(1-e^2)$$

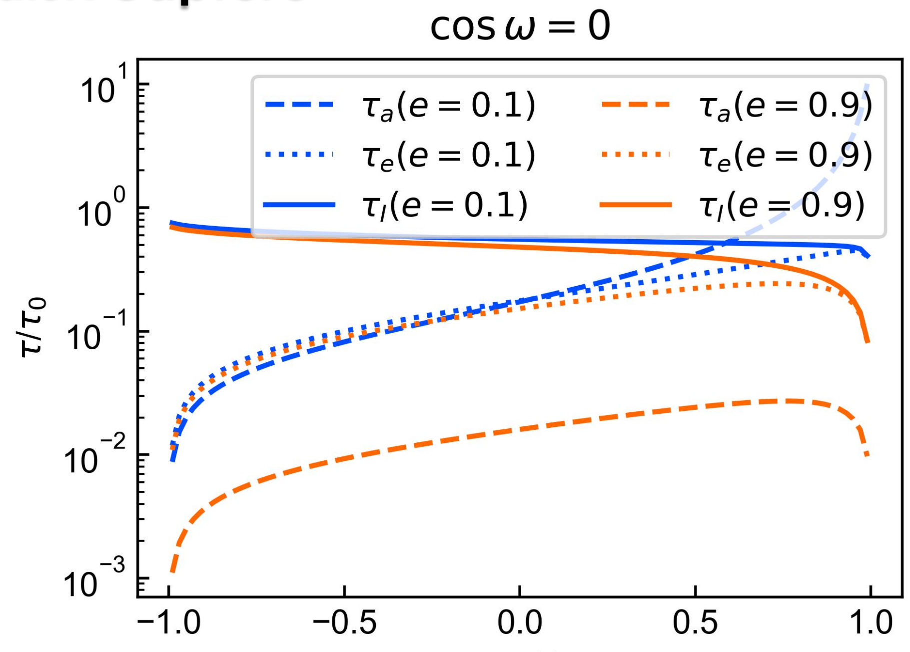
$$a_f = a_0(1-e_0^2)\cos^4\left(\frac{I_0}{2}\right)$$

$$I_0 \to \pi,\ a_f \to 0$$

→ semi-major axis damping

→ Inclination damping





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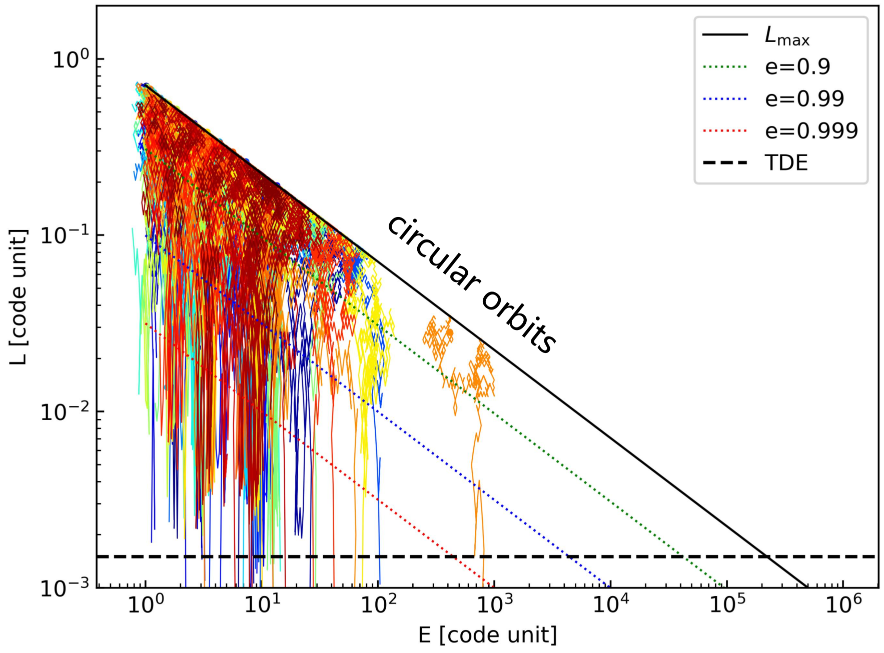
$$\tau_{\mathrm{a,aero}} = \left|\frac{a}{\dot a}\right| = \frac{(1-e^2)\sin I}{4\sqrt{2}\bar\alpha(\bar\gamma - \cos I)\sqrt{\delta - \cos I}}\frac{\Sigma_*}{\Sigma}T$$

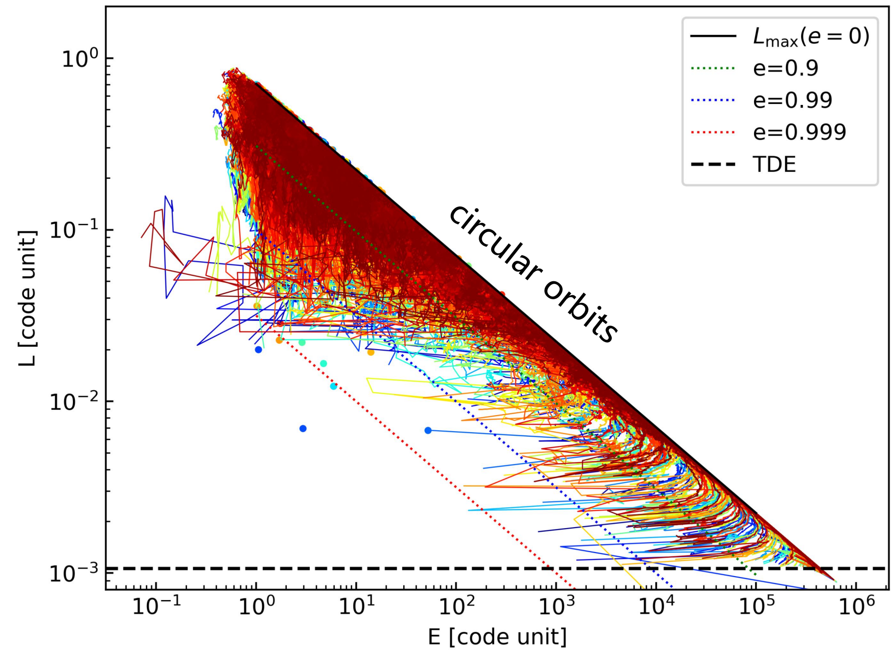
$$\tau_{\mathrm{I,aero}} = \left|\frac{I\sin I}{\dot{\cos I}}\right| = \frac{I}{2\sqrt{2}\alpha\sqrt{\delta-\cos I}}\frac{\Sigma_*}{\Sigma}T$$

$$\tau_{\mathrm{e,aero}} = \frac{2e^2}{(1-e^2)}\left|\frac{1}{\tau_{\mathrm{a,aero}}} - \frac{1}{\tau_{\mathrm{p,aero}}}\right|^{-1}$$

DGN phase



AGN phase



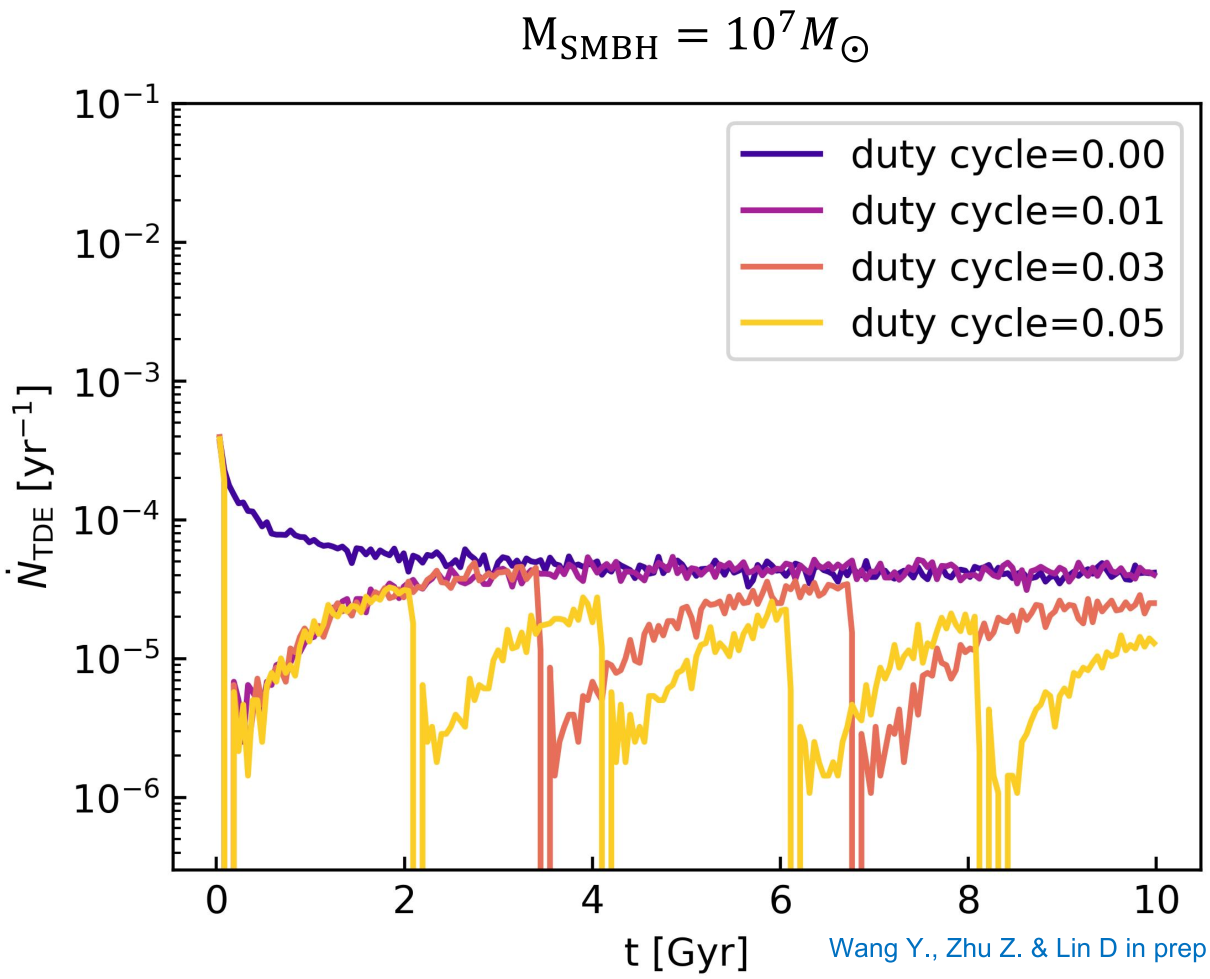
Isotropic two-body relaxation

$$\frac{\Delta E}{E} \sim \sqrt{\frac{t}{t_{\rm rel}}},$$
$$\frac{\Delta L}{L_{\rm max}(E)} \sim \sqrt{\frac{t}{t_{\rm rel}}},$$
$$t_{\rm rel} \sim \frac{M_\bullet^2}{m^2 N \ln \Lambda} T,$$

Axisymmetric disk drift (AGN phase only)

$$\Delta E = \lambda \frac{G M_{\rm tot}}{p}(\eta_\pm^3 \cos I - \sigma_\pm^2).$$
$$\Delta \boldsymbol{L} = \lambda L \left(0, \sin I, \frac{1}{\eta_\pm} - \cos I\right)$$
$$\tau_{\rm a,aero} = \frac{\Sigma_*}{\Sigma} T$$

Evolution of TDE rate with different AGN duty cycles



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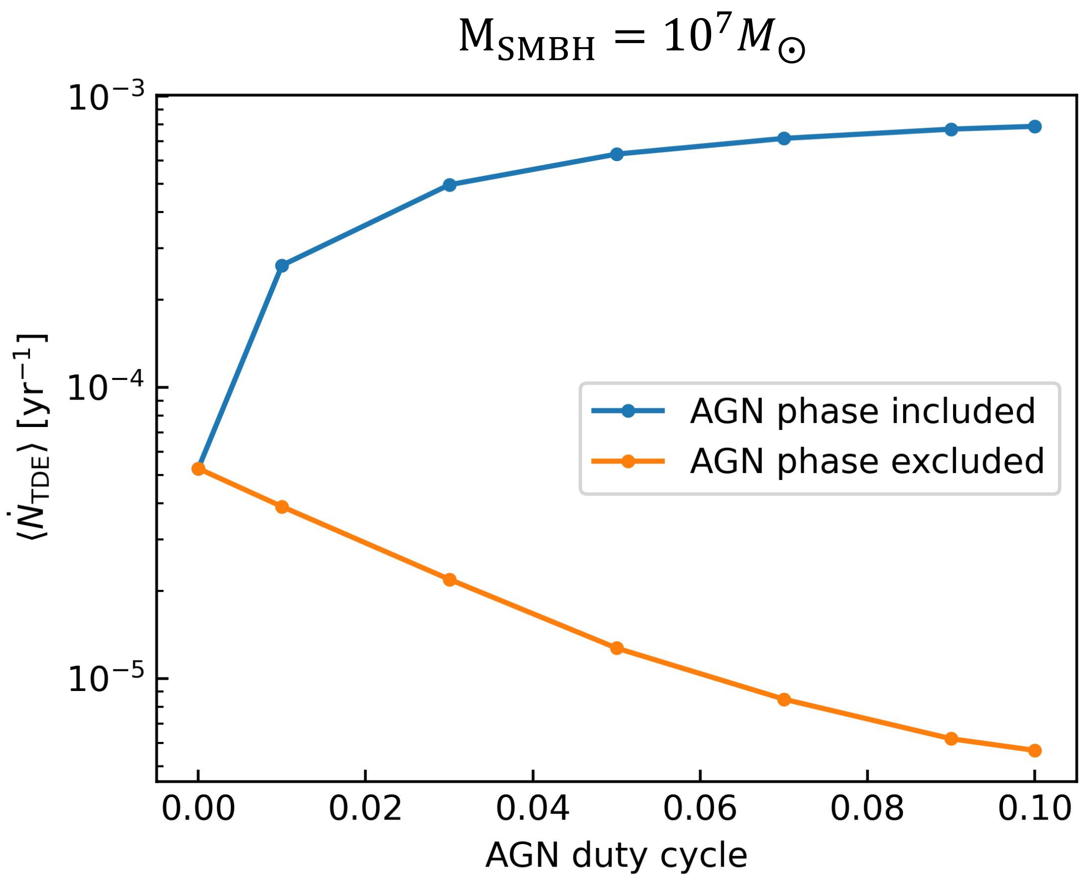

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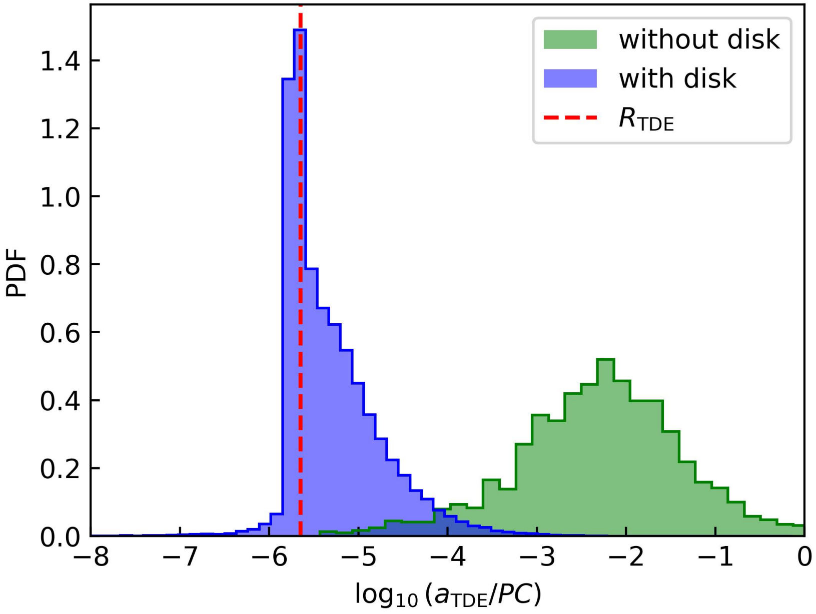
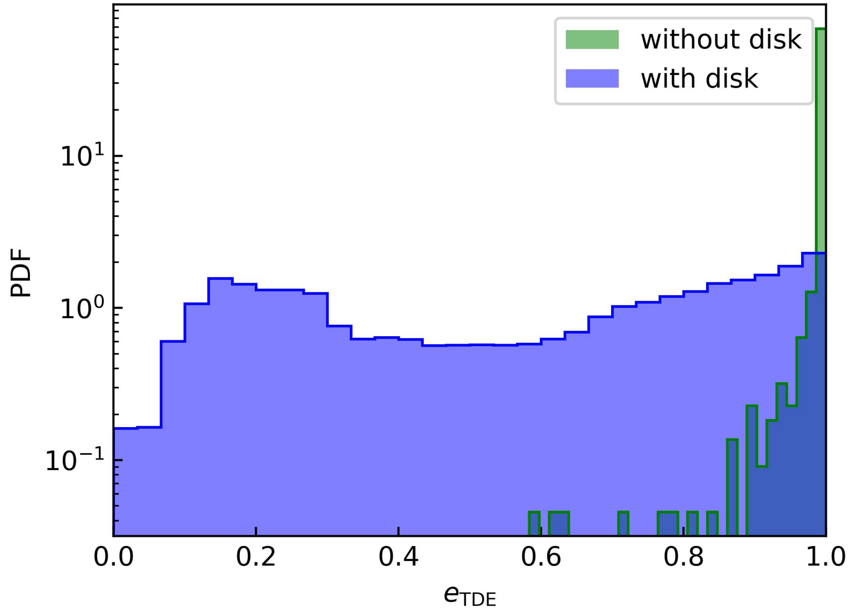
The deficit in TDE rates is caused by the overlooked contribution of AGN hosts and the oscillations of nuclear star clusters induced by disk-star interactions.

TDE orbits in AGN/DGN

Semi-major axis distribution of disrupted stars



Eccentricity distribution of disrupted stars



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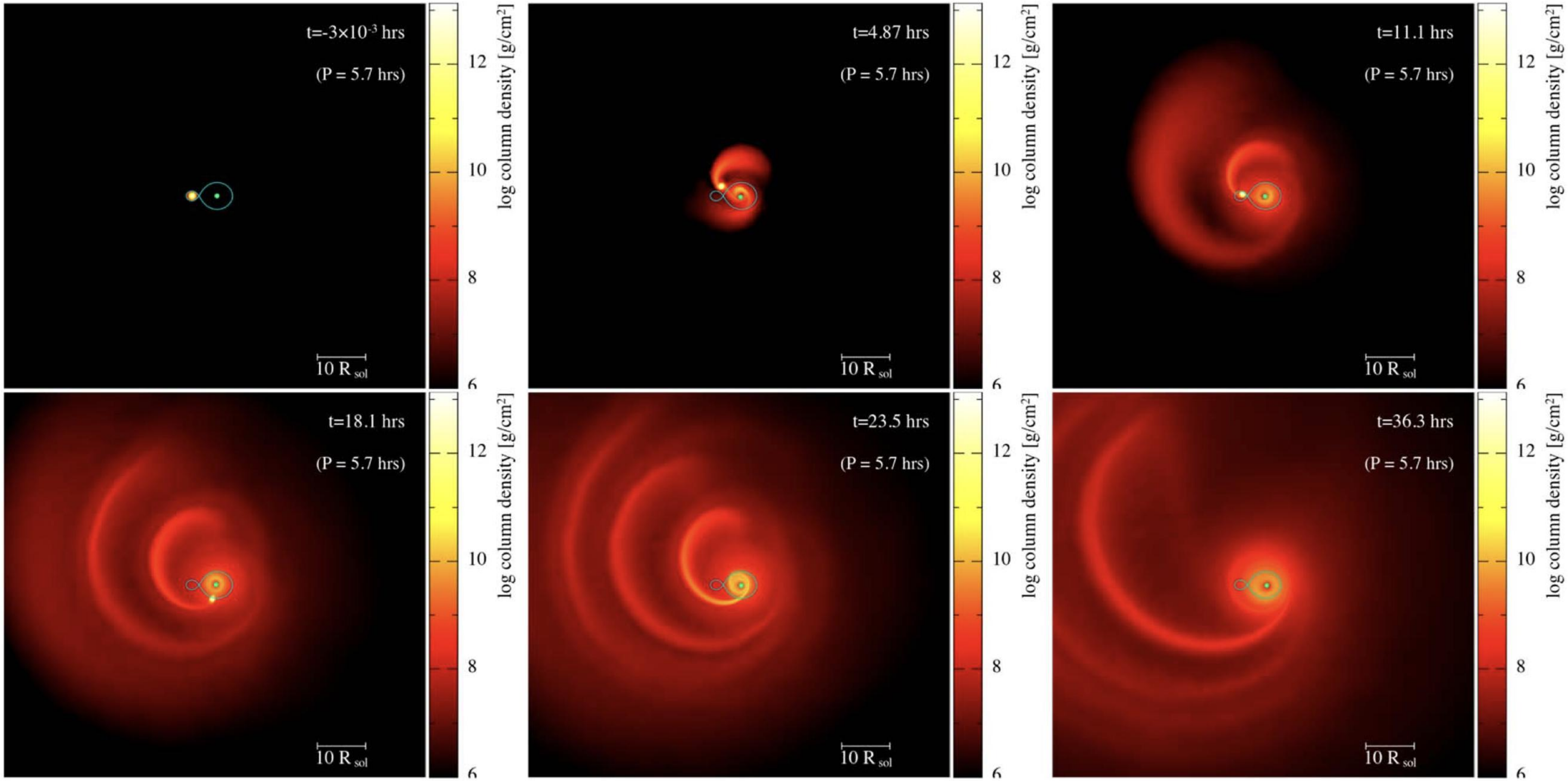
TDEs in DGN: high eccentricity (e~1) from large distances.

TDEs in AGN: low eccentricity from small distances.

Low eccentricity tidal peeling



Xin, Perna, Haiman, Wang& Ryu 2023

Takeaways

1. AGN disks can rapidly transport substantial number of retrograde stars to the vicinity of the SMBH in the early AGN phase, leading to a TDE outburst through direct disk capture.

2. These stars arrive with low eccentricity, in contrast to those parabolic stars delivered by relaxation processes.

3. The AGN phase can reshape the NSC structure by steepening the radial density profile, aligning stellar obits, and altering the thermal distribution of eccentricities, resulting in a deficit in relaxation-driven TDE rates in the DGN phase.

4. The TDE rate (direct capture + relaxation) will oscillate due to the episodic AGN activities.

Gas dynamical friction for BHs

$$\frac{\mathrm{d}\cos I}{\mathrm{d}(t/T)} = 2\sqrt{2}\kappa\frac{\pi m \Sigma p^2}{M_{\rm tot}^2}\frac{\sin I}{\sqrt{\delta-\cos I}}$$

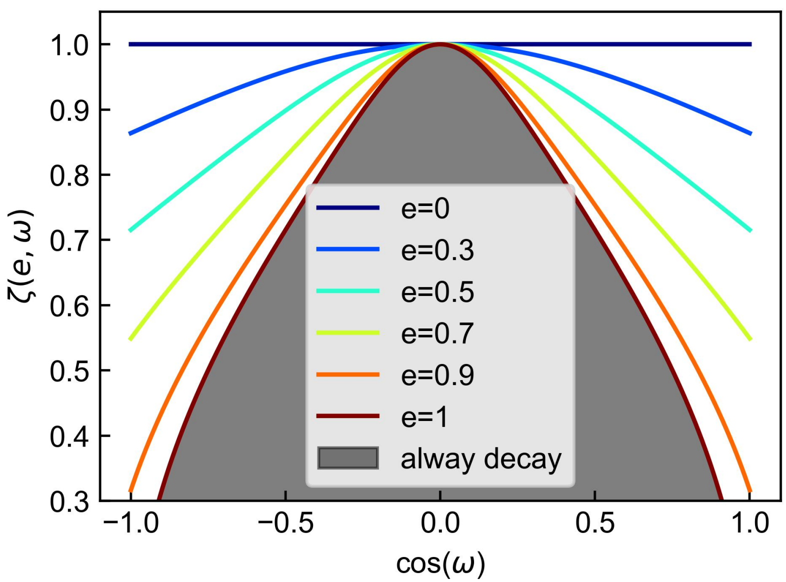
>0: orbital alignment

$$\frac{\mathrm{d}a}{a\mathrm{d}(t/T)} = \frac{4\sqrt{2}}{1-e^2}\bar{\kappa}\frac{\pi m \Sigma p^2}{M_{\rm tot}^2}\frac{\cos I-\bar{\zeta}}{\sin I\sqrt{\delta-\cos I}}$$

?: decay or expand

$$\frac{\mathrm{d}e}{e\mathrm{d}(t/T)} = \frac{1}{2e^2}\frac{\pi m \Sigma p^2}{M_{\rm tot}^2}\frac{4\sqrt{2}}{\sin I\sqrt{\delta-\cos I}} \times \left((\bar{\kappa}\cos I-\bar{\xi})-(1-e^2)(\kappa\cos I-\xi)\right)$$

?: circularization or eccentrilize



timescales

$$\tau_{\rm I,dyn} = \frac{I\sqrt{\delta-\cos I}}{2\sqrt{2}\kappa}\boxed{\frac{M_{\rm tot}}{m}\frac{M_{\rm tot}}{\Sigma\pi p^2}T}$$

$$\tau_{\rm a,dyn} = \frac{(1-e^2)\sin I\sqrt{\delta-\cos I}}{4\sqrt{2}\bar{\kappa}|\cos I-\bar{\zeta}|}\frac{M_{\rm tot}}{m}\frac{M_{\rm tot}}{\Sigma\pi p^2}T$$

$$\tau_{\rm e,dyn} = \frac{2e^2}{(1-e^2)}\left|\frac{1}{\tau_{\rm a,dyn}}-\frac{1}{\tau_{\rm p,dyn}}\right|^{-1}$$

$\cos\omega = 0$