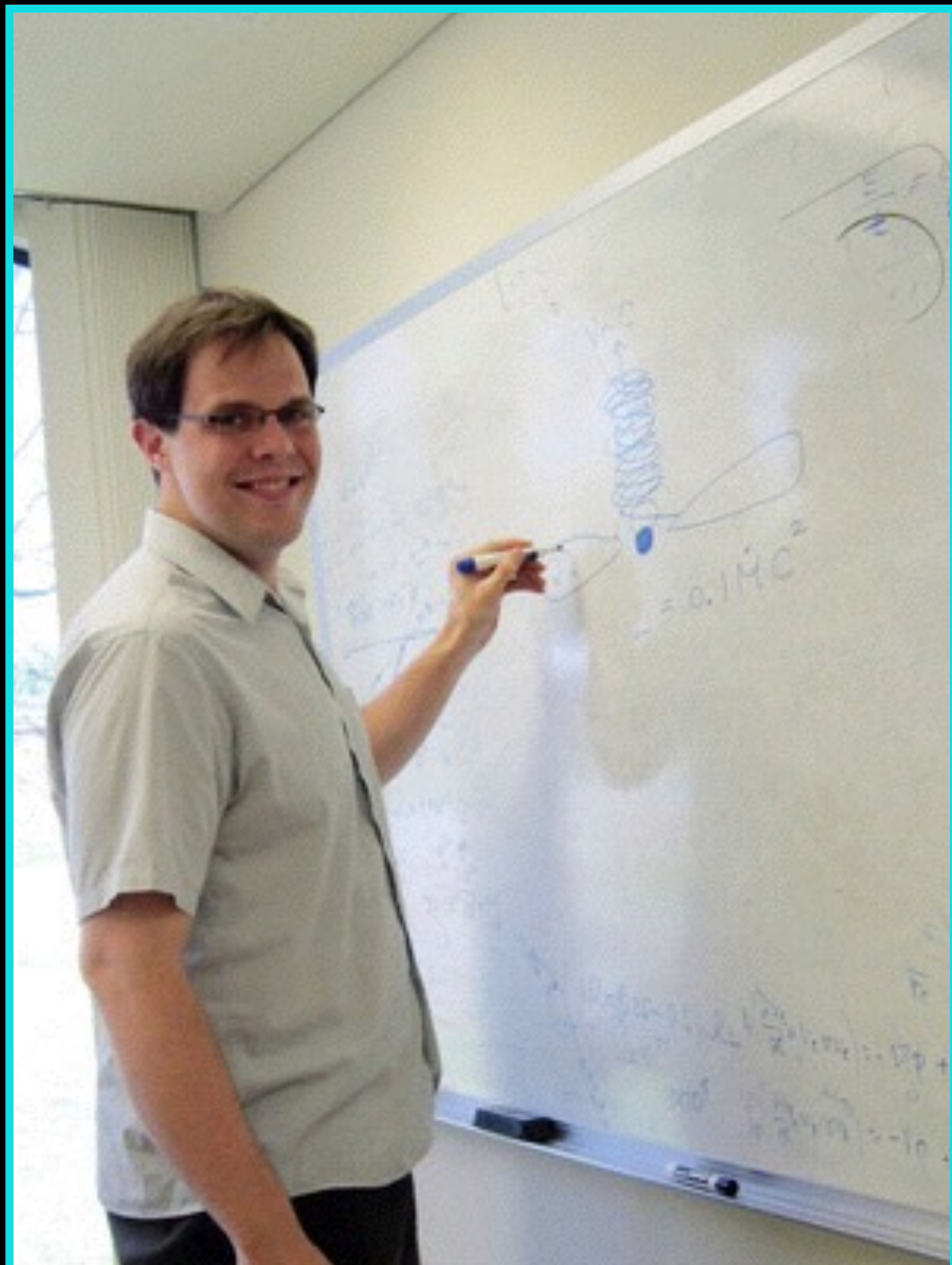
The Delay Time Distribution of Tidal Disruption Events

Nicholas Stone - Columbia University

Einstein Symposium - 10/12/17

arXiv:1709.00423



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(Columbia)

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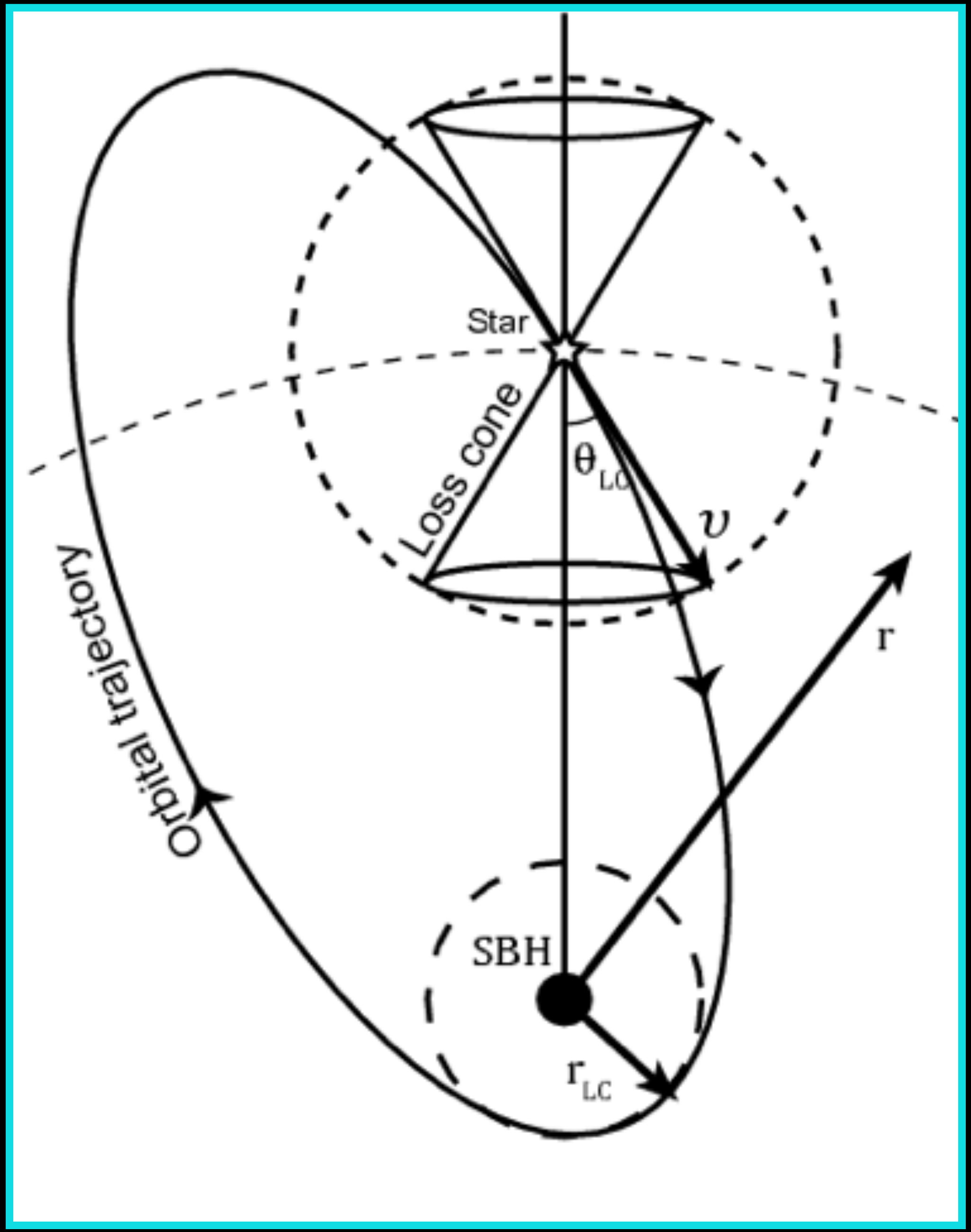
(Columbia)

Tidal Disruption Event (TDE) Rates

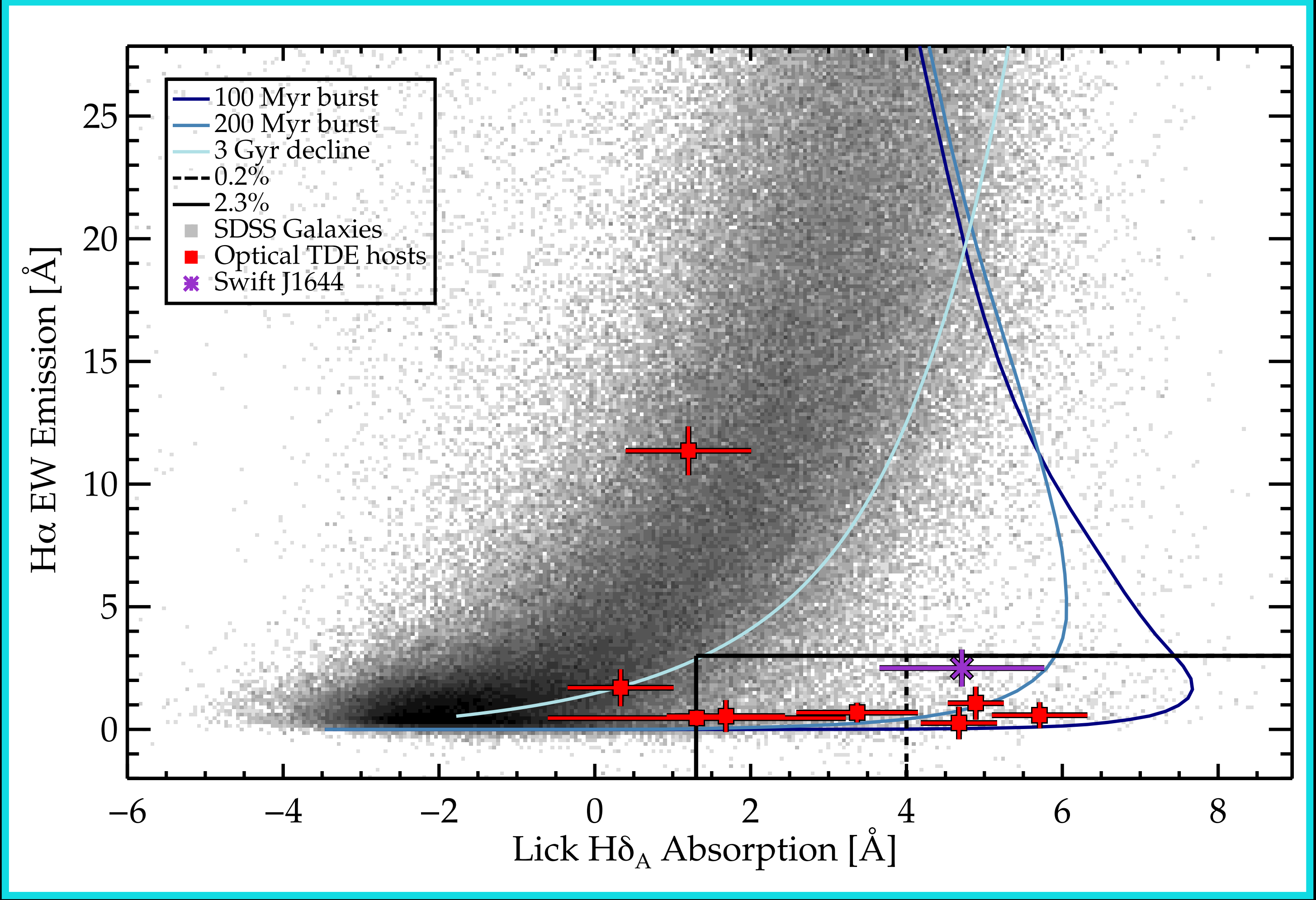
- TDE rates set by passage of stars into **loss cone**
- Loss cone often described in terms of angular momentum space
  - ✦ $J_{LC}^2 \approx 2\ G\ M_{BH}\ r_t$
- TDE rate set by loss cone refilling mechanism: two-body relaxation ubiquitous
  - ✦ Theoretical rate in normal galaxies ~10^{-4}/yr (NCS & Metzger 16)



(Freitag & Benz 02)

Unusual Host Galaxy Preferences

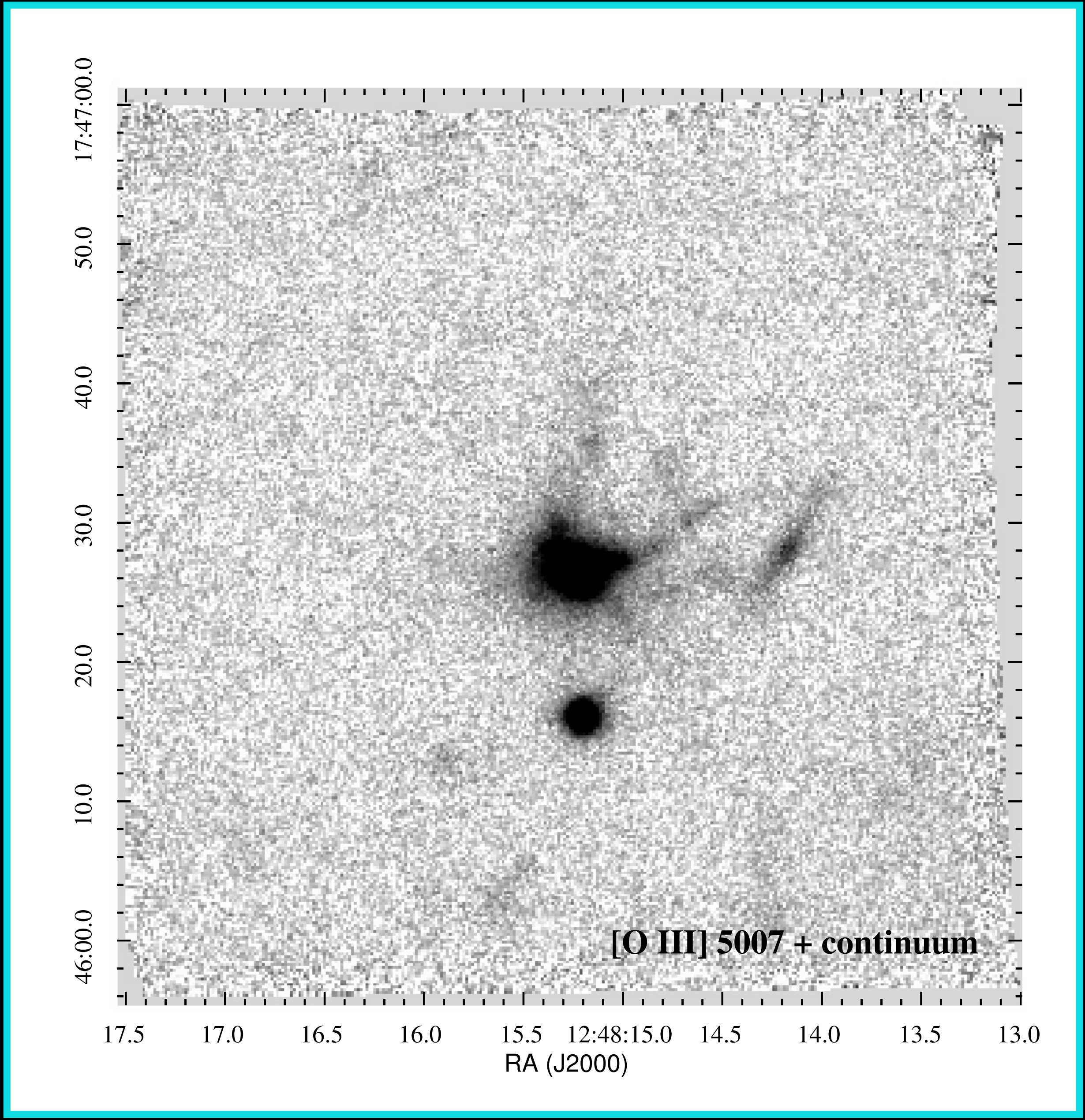
- Many TDEs in **rare post-starburst/ E+A galaxies** (Arcavi+14, French +16, 17, Law-Smith+17, Graur+17)
- Dynamical explanations:
  - ✦ **Binary SMBHs**; chaotic 3-body scatterings (Arcavi+14)
  - ✦ **Radial anisotropies**: low angular momentum systems (NCS+17)
  - ✦ **Central overdensities**; short relaxation times (NCS & Metzger 16)
- Discriminant: **delay time distribution** (DTD; NCS+17)



(French+ 16)

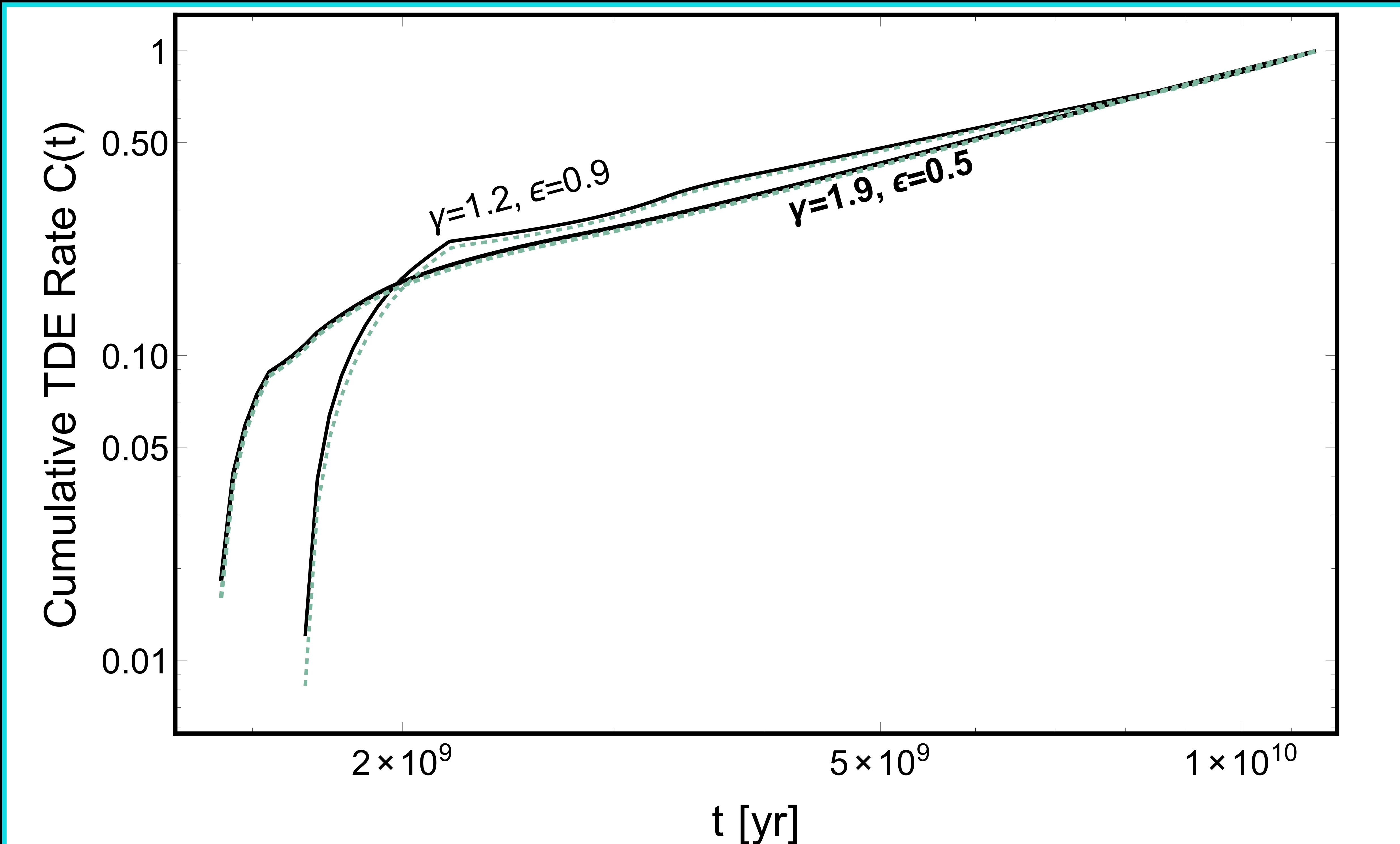
SMBH Binaries?

- Nascent SMBH binaries see increase in TDE rate:
  - Kozai effect (Ivanov+05)
  - Chaotic 3-body scatterings (Chen+11)
- Enhancement huge ($\Gamma \sim 10^{-1}$/yr) but short-lived ($<10^6$ yr)
  - Occurs before final parsec problem
  - Unique lightcurves? (Coughlin+17)
- Possibly disfavored by:
  - Total rate fraction ~3-25% (Wegg & Bode 11)
  - Host mass distribution
  - Fine-tuned timescales



(Prieto+16)

SMBH Binary Cumulative Distribution



(NCS+17)

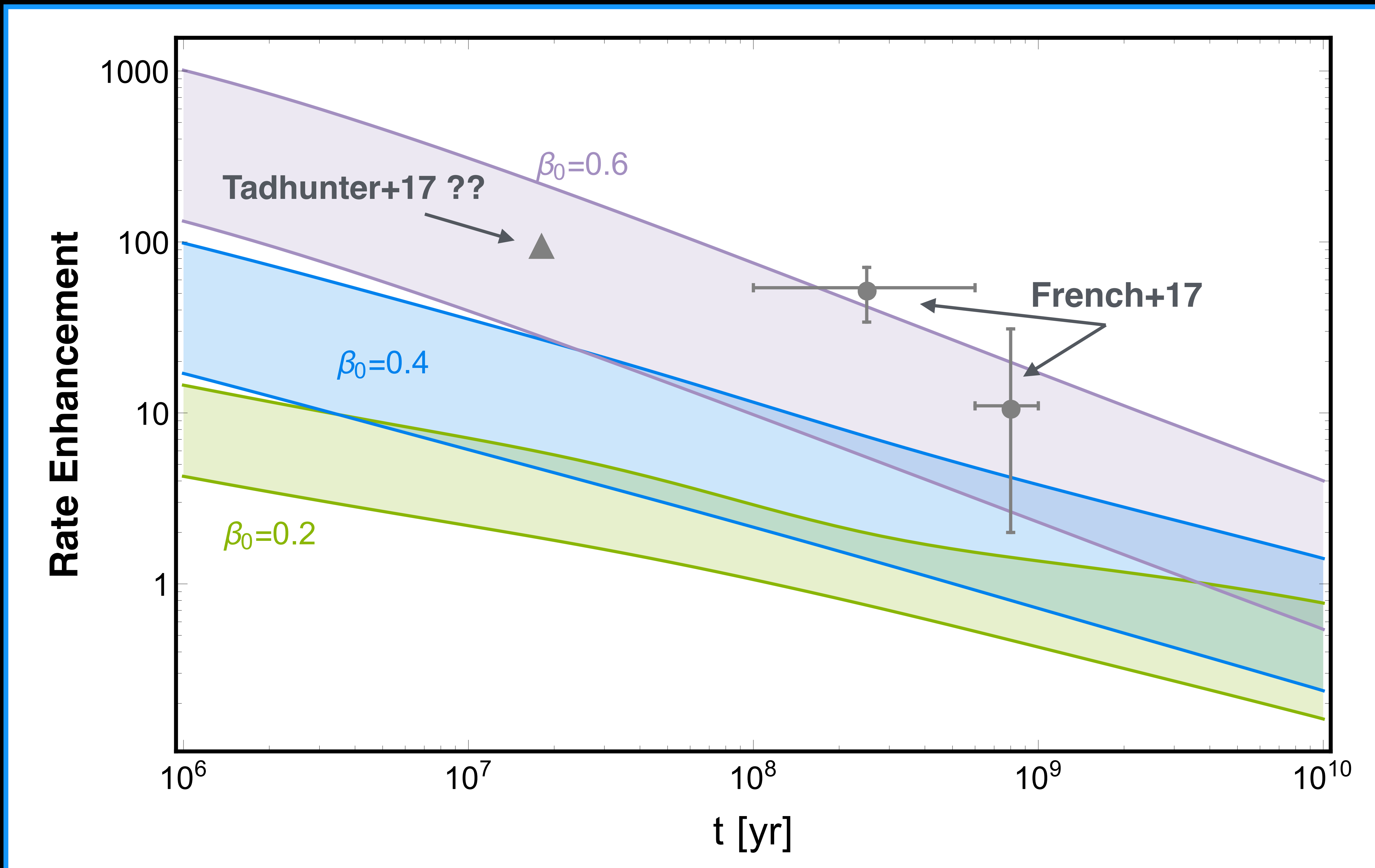
Radial Orbit Anisotropies?

- Another possibility: anisotropic velocities with radial bias
- Consider constant anisotropy $\beta=1-K_{\perp}/2K_r$
    - $\beta<\beta_{ROI}\sim0.6$ to avoid radial orbit instability
- Solve 1D Fokker-Planck equation in angular momentum space:

$$\frac{\partial f}{\partial \tau} = \frac{1}{4j}\frac{\partial}{\partial j}\left(j\frac{\partial f}{\partial j}\right)$$

- TDE rate $\Gamma \propto t^{-\beta}$ in an isotropizing cusp

Anisotropic Delay Time Distributions

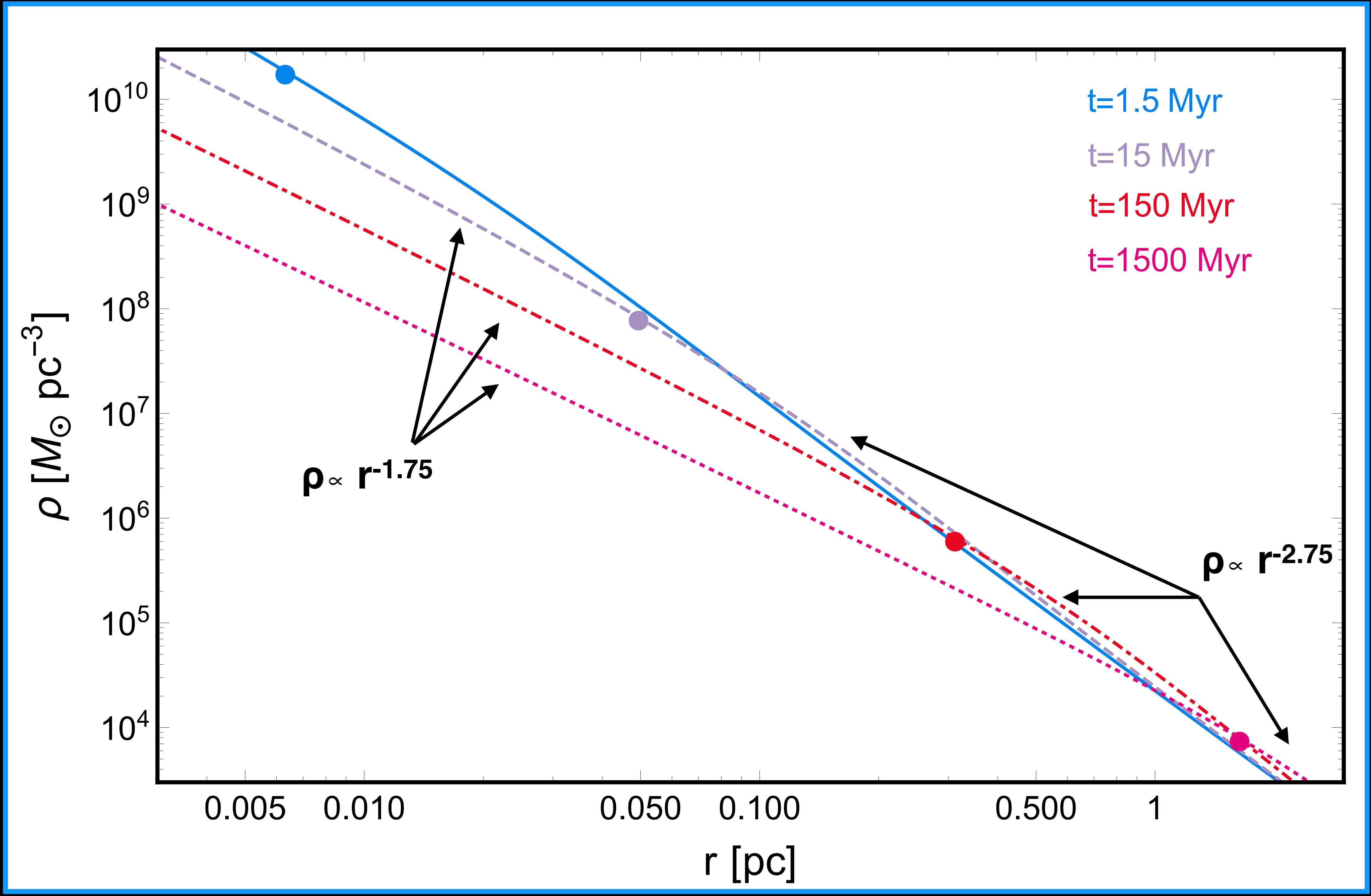


(NCS+17)

Stellar Overdensities?

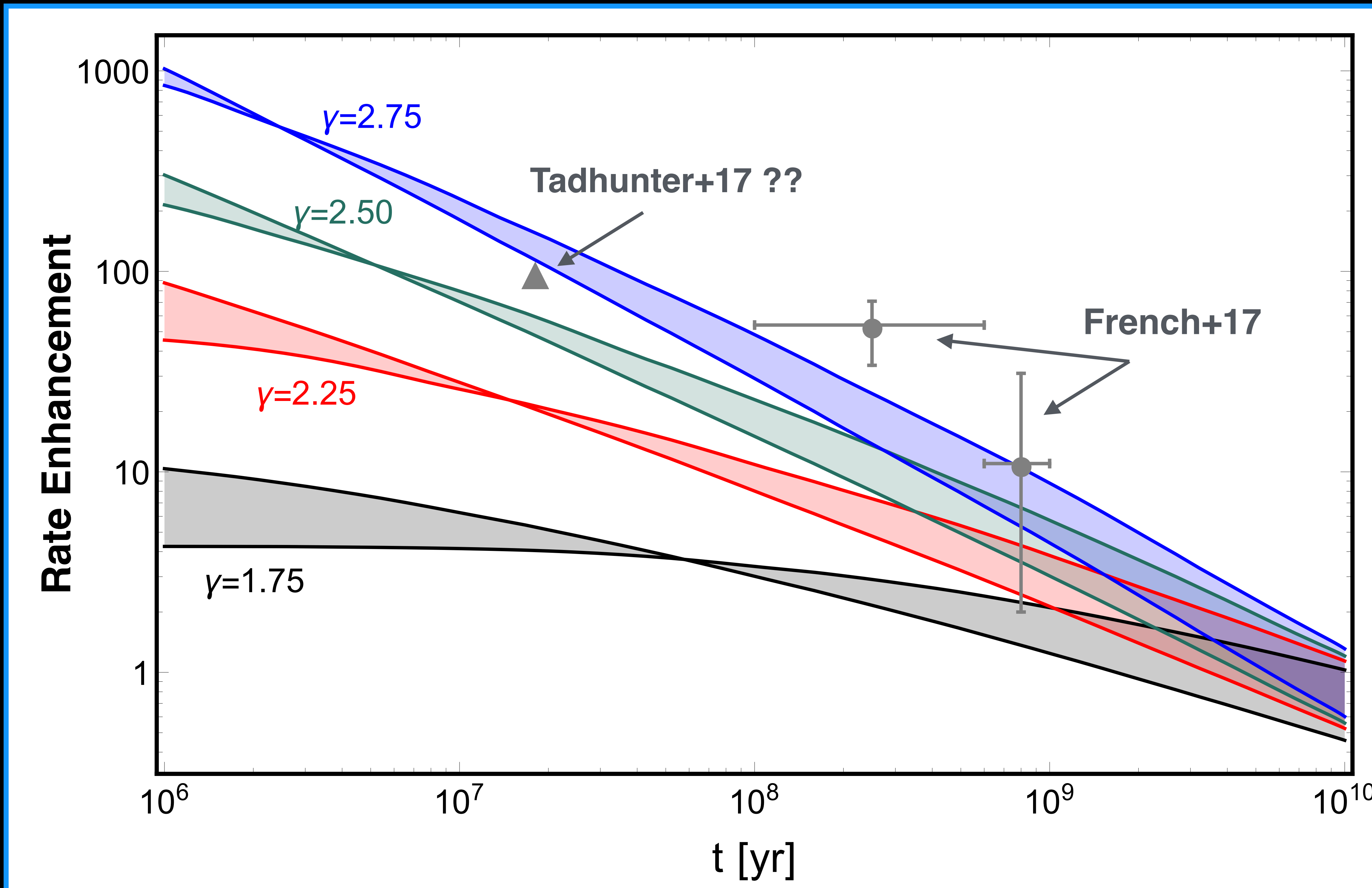
- Suggestive evidence: color gradients in E+As (Pracy+13)
- Overdense nuclei - $\rho(r) = \rho_{infl}(r/r_{infl})^{-\gamma}$ - can have short two-body relaxation times if overconcentrated or ultrasteep
- Overconcentrated (r_{infl} low):
  - High, slowly evolving TDE rate
- Ultrasteep (γ large):
  - If $\gamma>7/4$, profile flattens with time (Bahcall & Wolf 76)
  - If $\gamma>9/4$, TDE rate diverges inward
  - Transition point $r_{BW} \propto t^{1/(\gamma-3/2)}$
  - TDE rate $\Gamma \propto t^{-(4\gamma-9)/(2\gamma-3)} / \ln(t)$

Birth of a Bahcall-Wolf Cusp



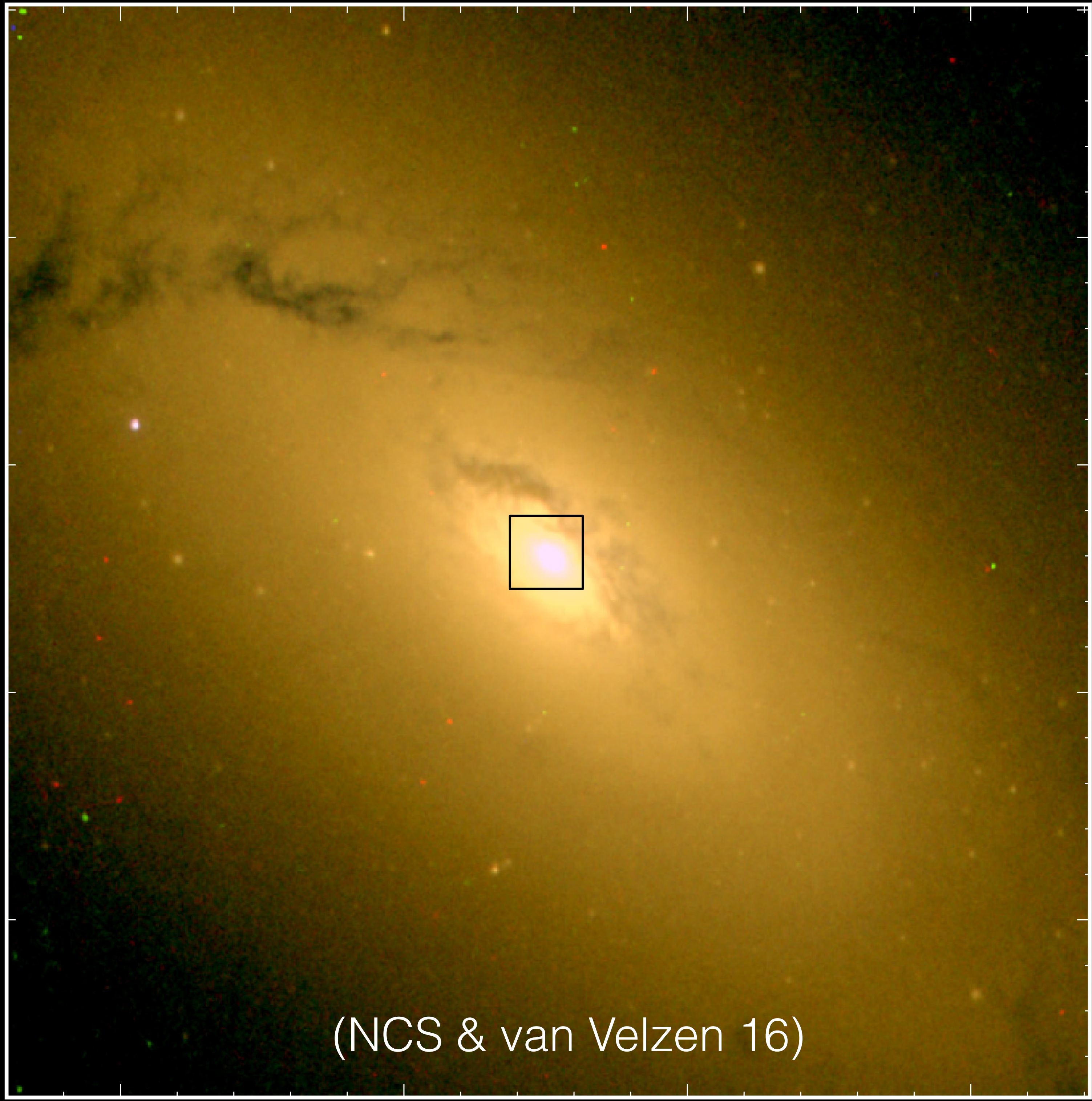
(NCS+17)

Overdense Delay Time Distributions

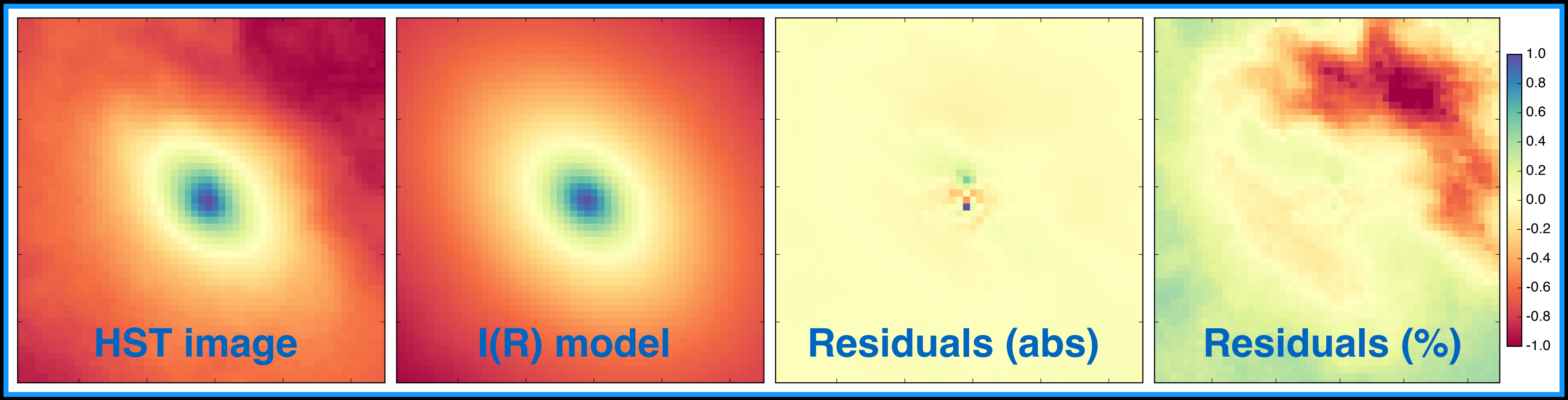


(NCS+17)

NGC 3156: A Nearby E+A



NGC 3156: Modeling



(NCS & van Velzen 16)

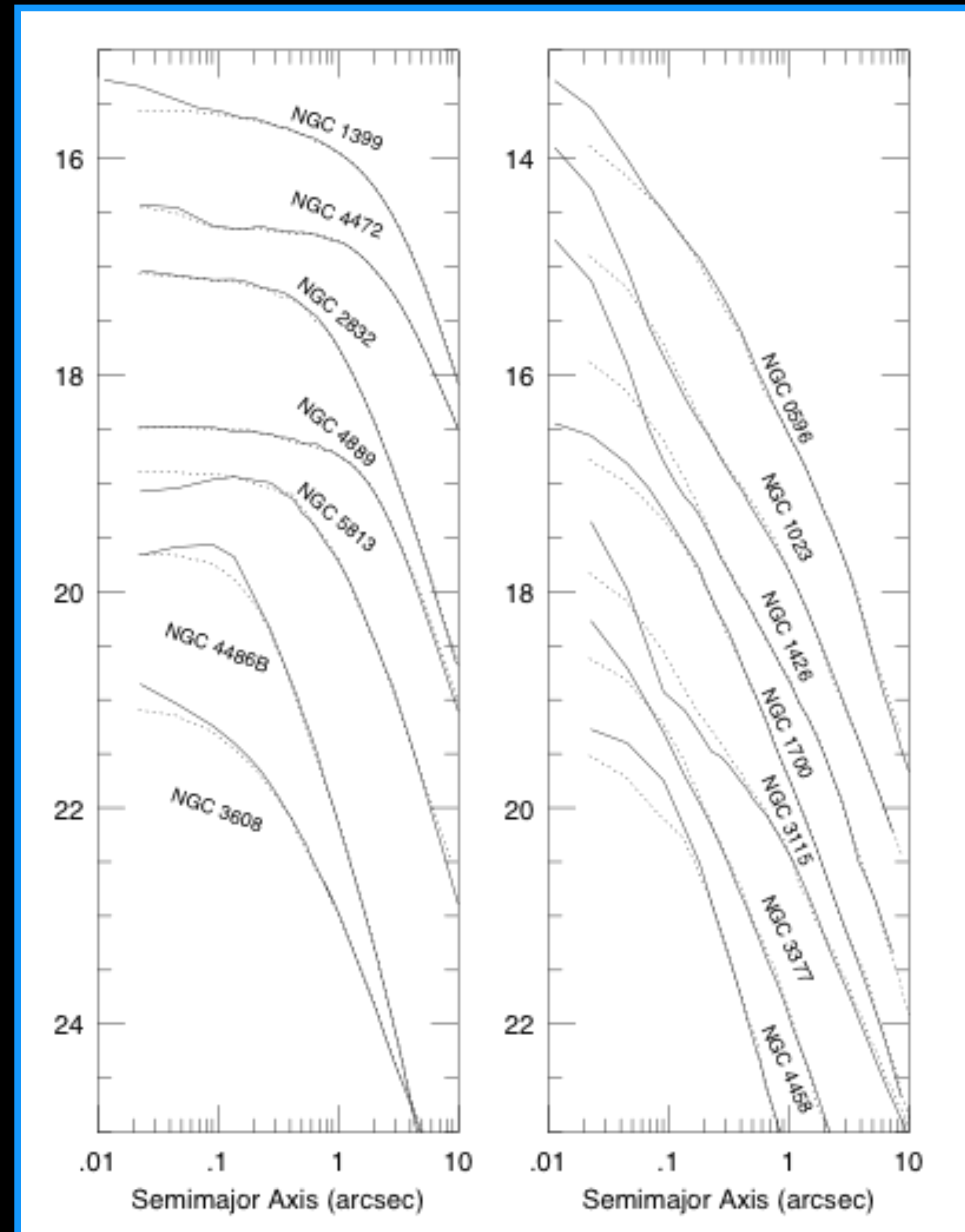
- Optimal target: 22 Mpc, $M_{BH} = 3 \times 10^6\ M_\odot$
- We fit an I(R) model to archival HST observations
  - NGC 3156 **major outlier** in central profile: $I(R) \propto R^{-1.2}$
- TDE rate $\Gamma \sim 1 \times 10^{-3}$/yr!
  - Will test further with upcoming HST observations

Conclusions

- Several dynamical explanations for the post-starburst preference
  - SMBHBs - unlikely
  - Radial anisotropies - possible; DTD requires high $\beta \sim \beta_{ROI}$
  - Stellar overdensities - possible; DTD requires very high γ
- Anisotropy and overdensity hypotheses potentially testable with resolved observations of nearby post-starbursts
- Post-starburst preference important future tool for TDE surveys, validation
- Delay time distributions powerful future tool - **model selection** and **parameter extraction**

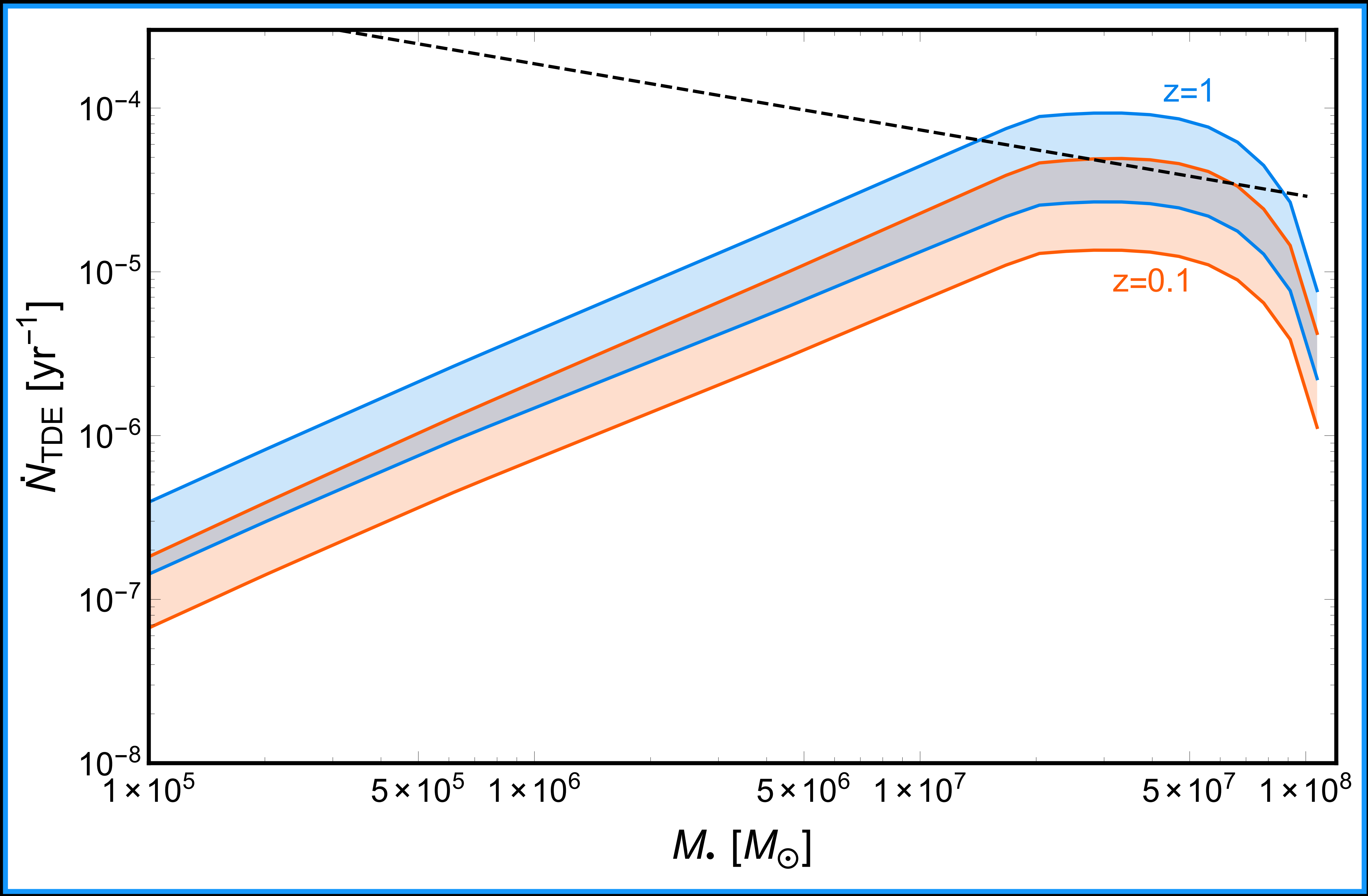
Realistic TDE Rates

- Theoretical rates calculated semi-empirically (Magorrian & Tremaine 99, Wang & Merritt 04, NCS & Metzger 16):
    - ✦ Take sample of nearby galaxies
    - ✦ Deproject I(R) -> ρ(r) *[assumes sphericity]*
    - ✦ Invert ρ(r) -> f(ε) *[assumes isotropy]*
    - ✦ Compute diffusion coefficients $<\Delta J^2(\varepsilon)>$, loss cone flux $\mathcal{F}(\varepsilon)$ *[assumes IMF]*
- $\Gamma_{obs} < \Gamma_{theory} \sim$ few x 10^{-4}/gal/yr ?
    - ✦ But see *Auchettl talk, Saxton talk, Jonker talk*, van Velzen 2017…



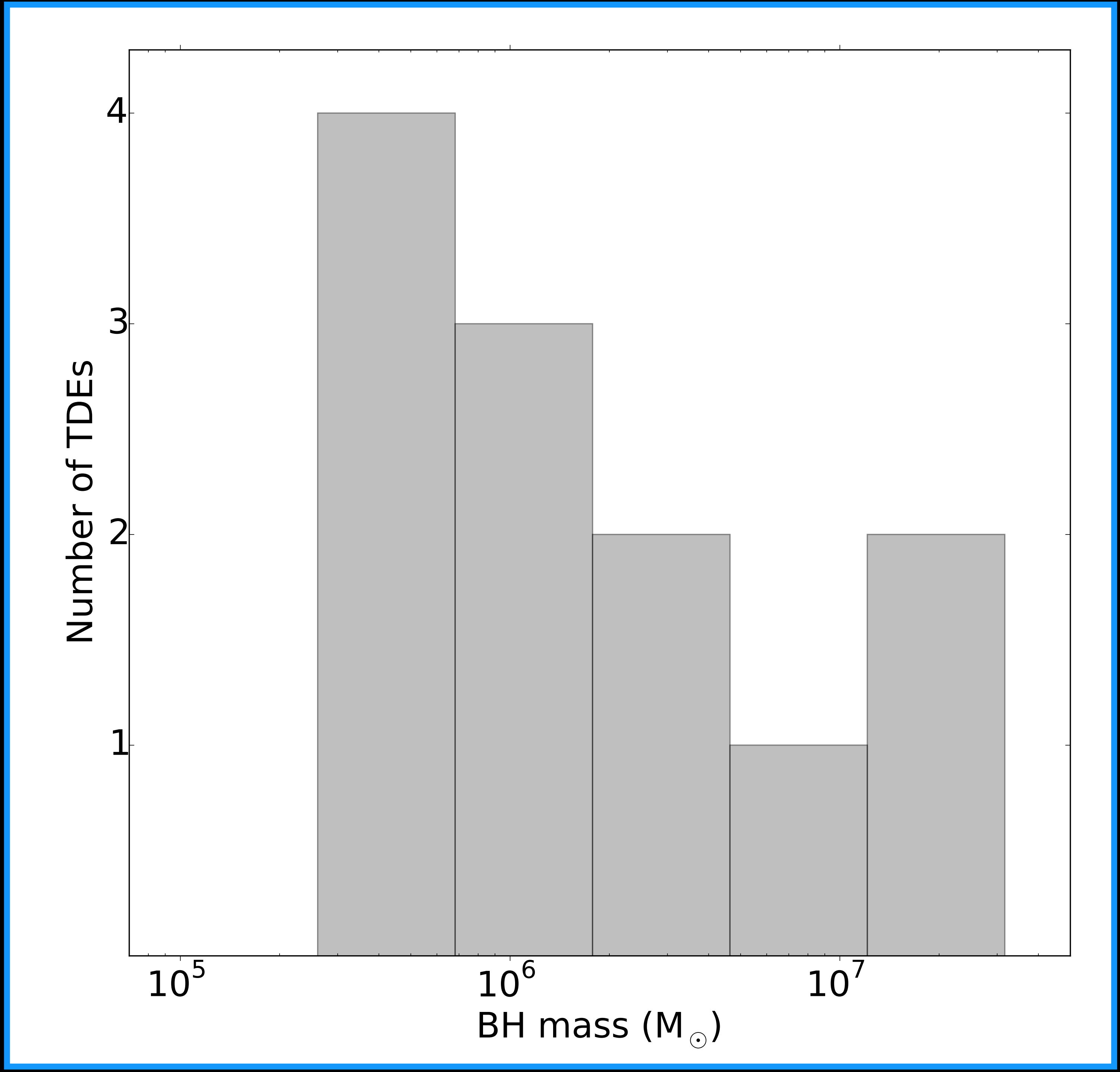
(Lauer+05)

SMBHB TDE Rates



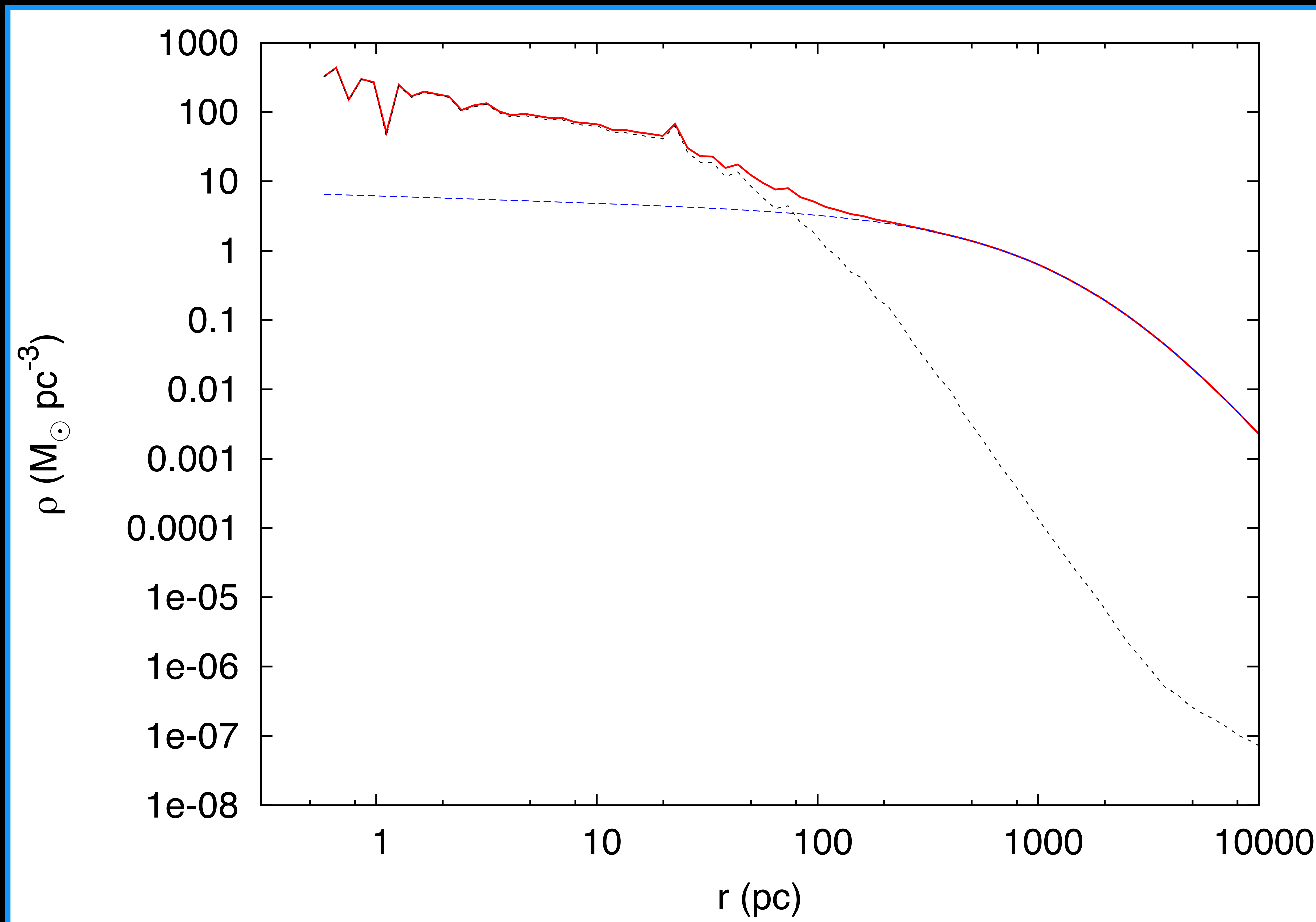
(NCS+17)

Observed TDE Hosts



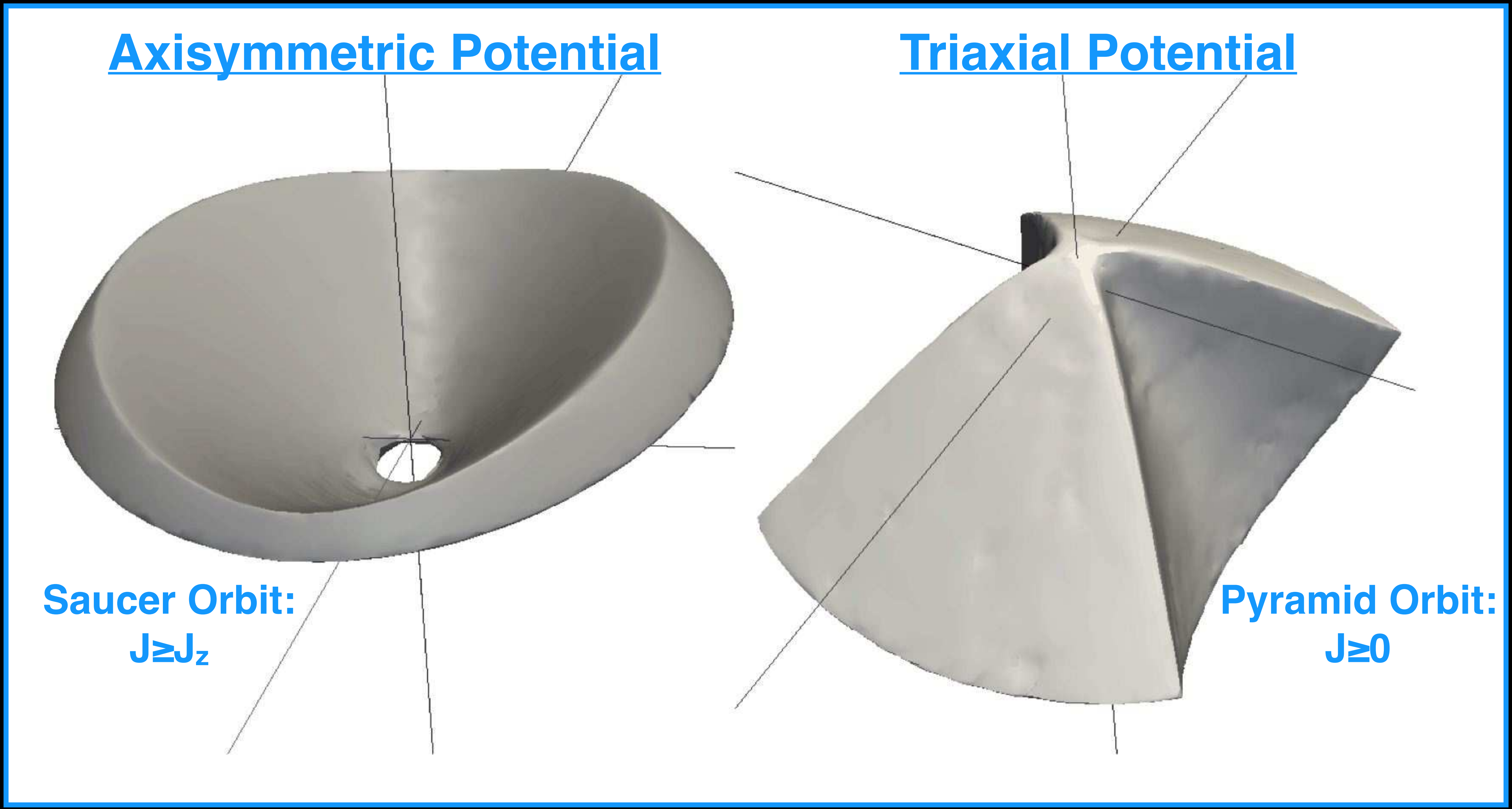
(Wevers+17)

N-Body Simulations



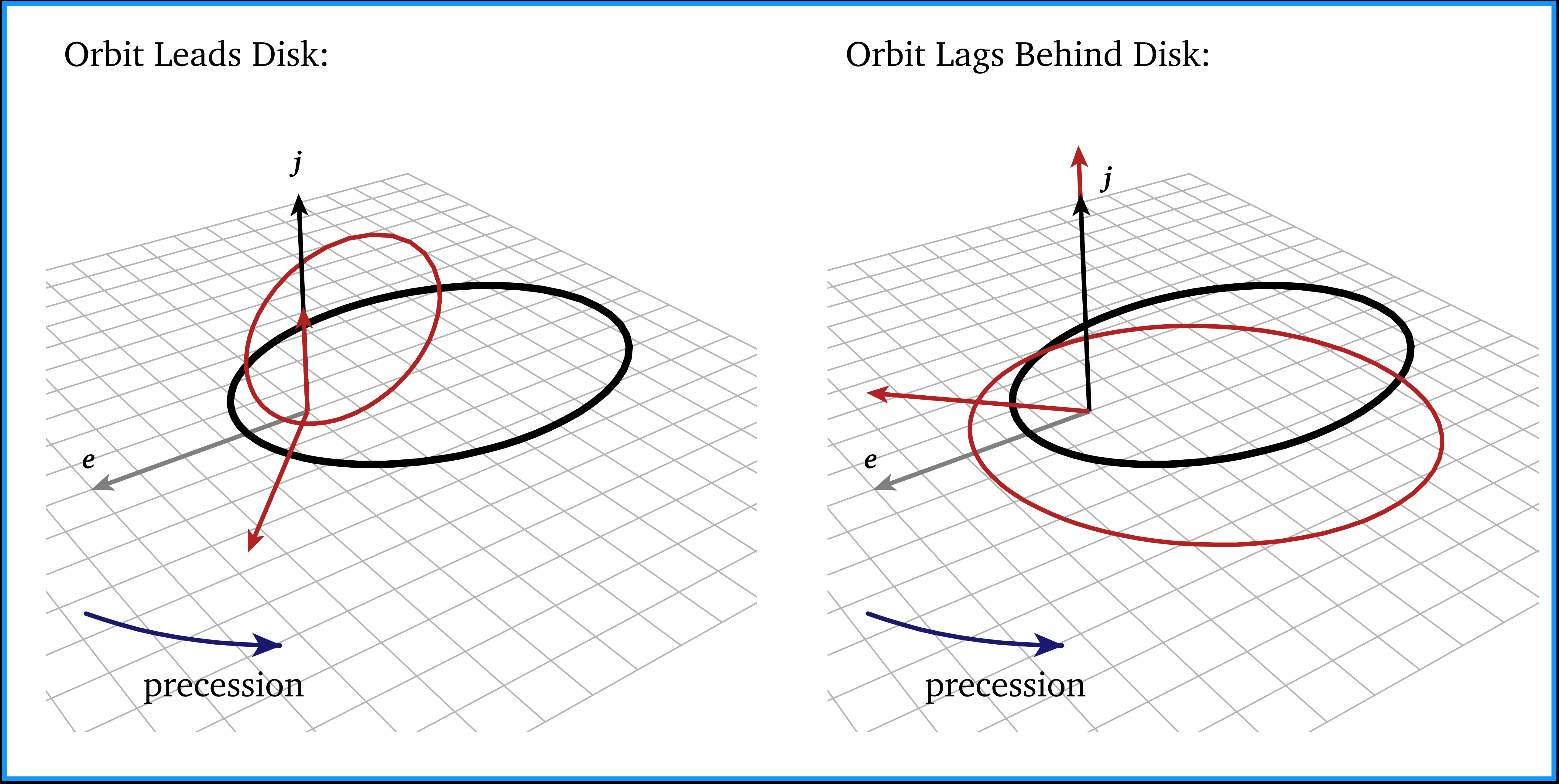
(Arca-Sedda & Capuzzo-Dolcetta 17)

Nuclear Triaxiality?



(Merritt+13)

Eccentric Stellar Disks?



(Madigan+17)