Elevated Tidal Disruption Rates in Post-Starburst Galaxies

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MODEST-18 6/29/18

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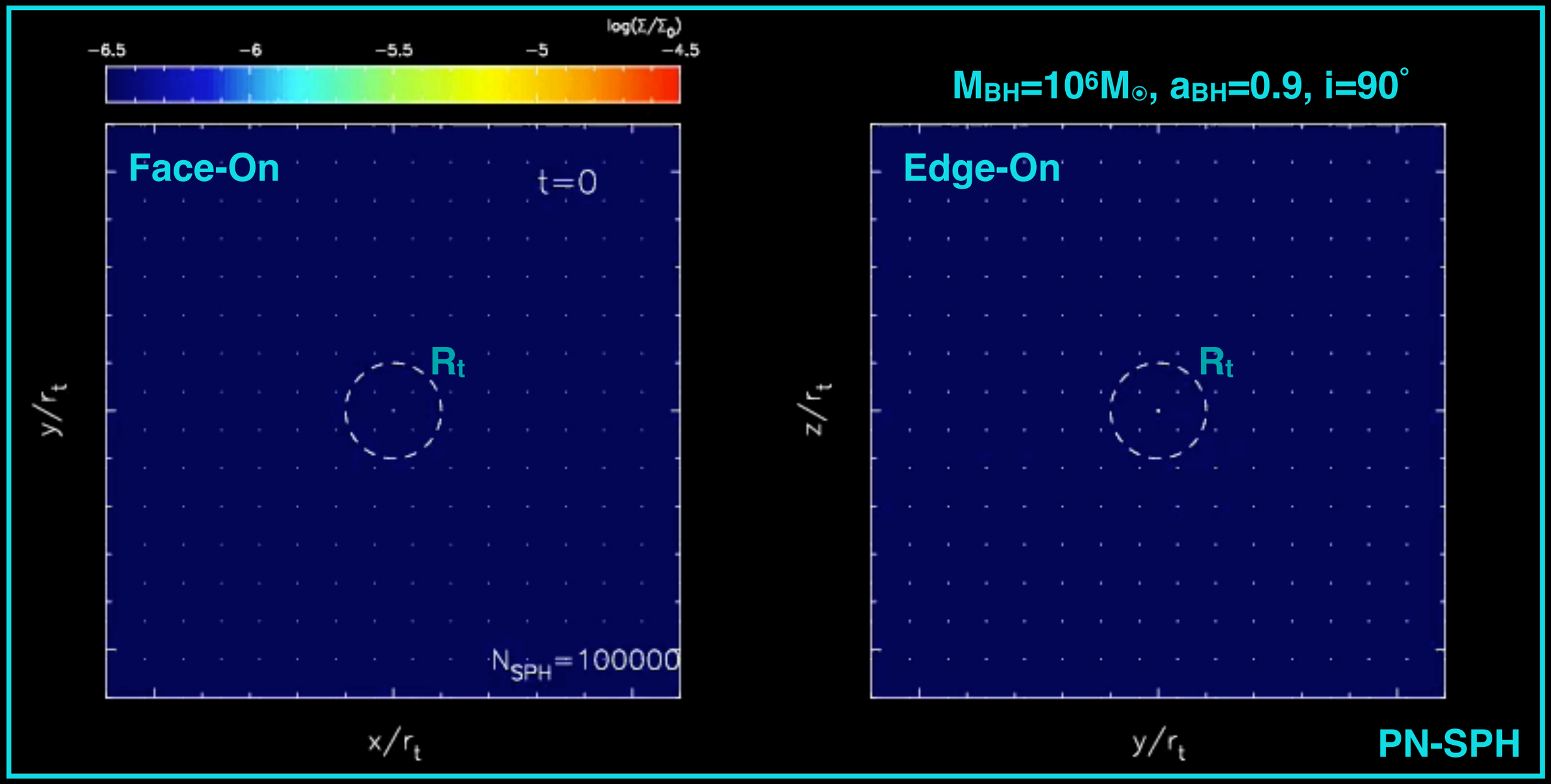
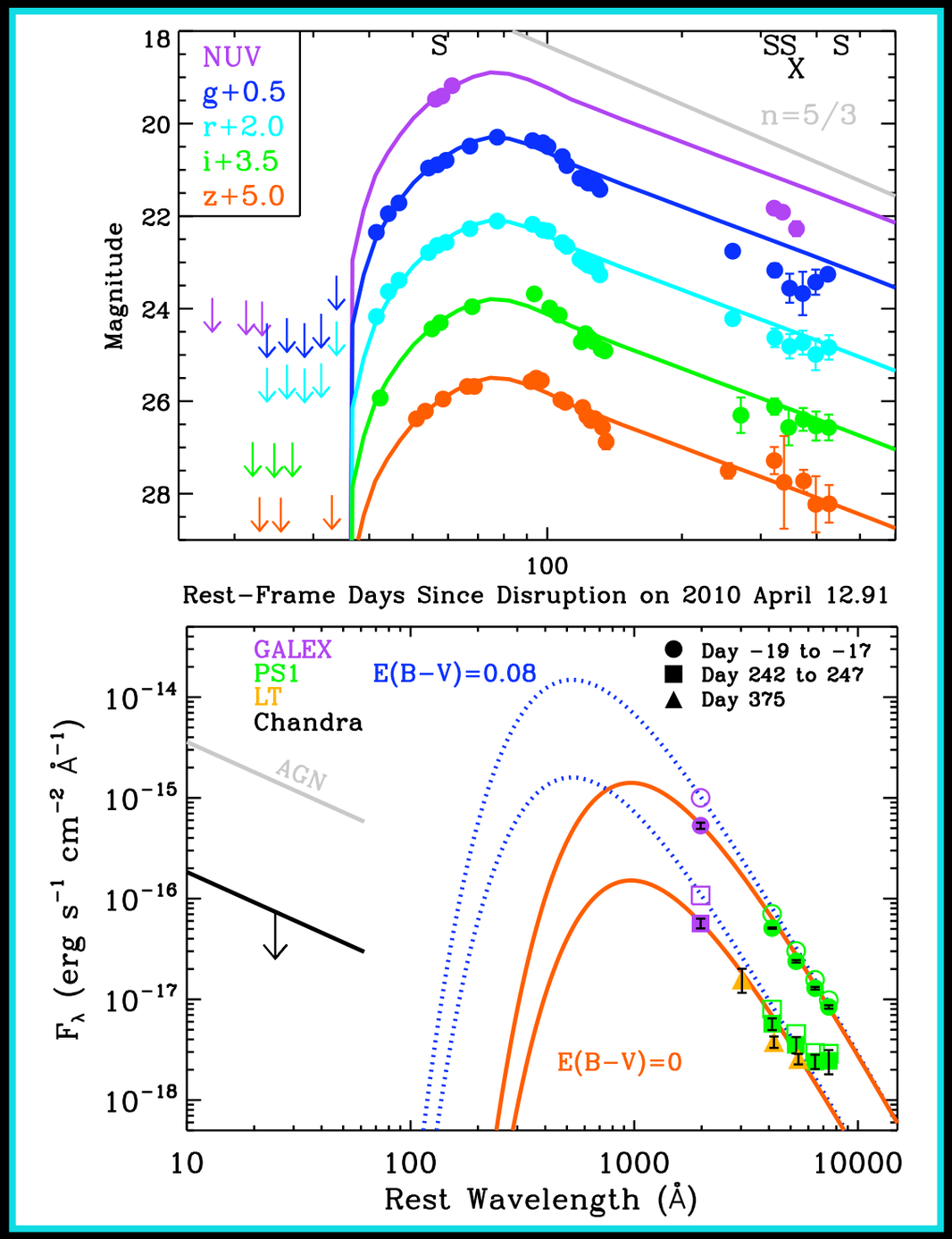
A View to a Kill



(Hayasaki, NCS & Loeb 16)

Tidal Disruption Events

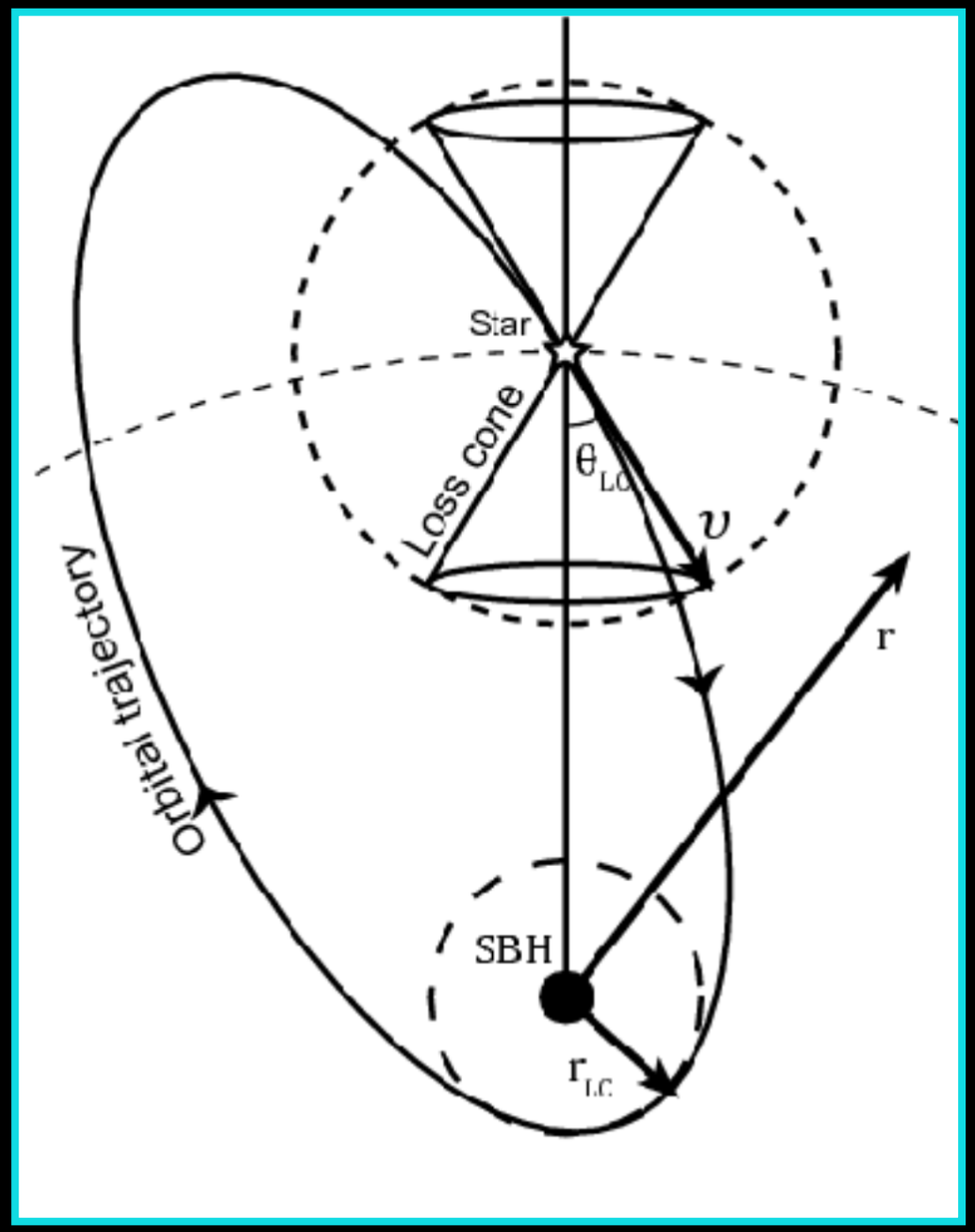
- Empirically:
  - Rare multiwavelength (radio -> hard X-ray) transients
  - Dozens of strong candidate flares (most optical/X-ray)
- Applications:
  - Tools to measure SMBH demography (mass, maybe spin)
  - Super-Eddington accretion laboratories
  - Probes of jet launching physics
  - **Rates encode stellar dynamical processes**



(Gezari+12)

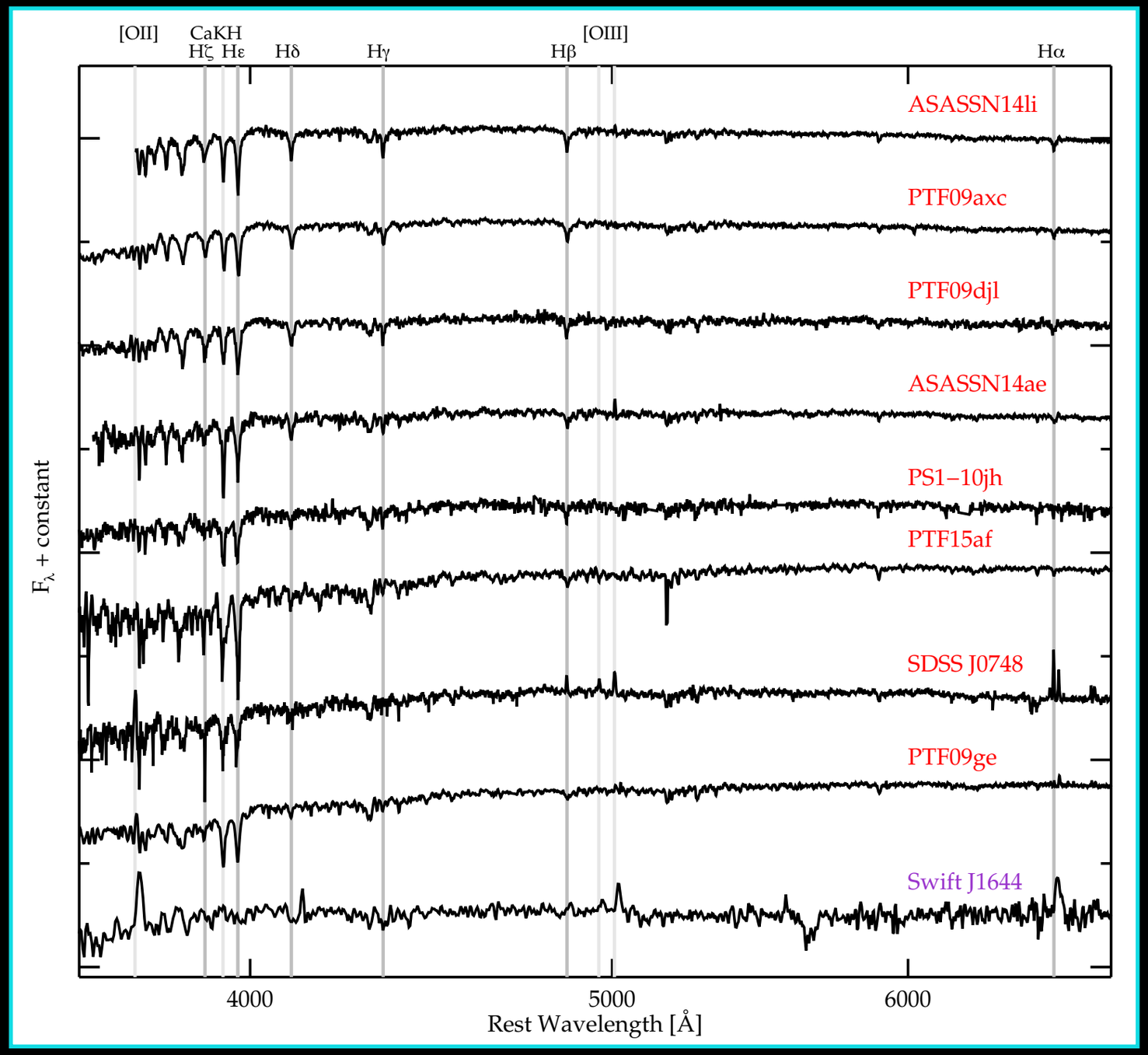
TDE Rates

- TDE rates set by passage of stars into **loss cone**
- Loss cone easily described in terms of angular momentum space
  - ✦ Full vs empty loss cone?
  - ✦ Relaxation (two-body) refills loss cone, sets TDE rate
- **Rate discrepancy?**
  - ✦ $\Gamma_{theory} \sim 2\text{-}10 \times 10^{-4}$/gal/yr >> $\Gamma_{obs} \sim 1 \times 10^{-5}$/gal/yr (NCS & Metzger 16)
  - ✦ Theoretical estimates ~conservative, few dynamical solutions (Lezhnin & Vasiliev 16)
  - ✦ Resolution probably luminosity function (van Velzen 18)



(Freitag & Benz 02)

The Post-Starburst Preference



(French+16)

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)
  - ✦ **Central overdensities**; short relaxation times (NCS & Metzger 16)
  - ✦ **Radial anisotropies**: low angular momentum systems (NCS+17)
  - ✦ **Nuclear triaxiality:** collisionless effects (Merritt & Poon 04)
  - ✦ **Eccentric nuclear disks:** secular instabilities (Madigan 17)
- Useful discriminant: delay time distributions (NCS+17)

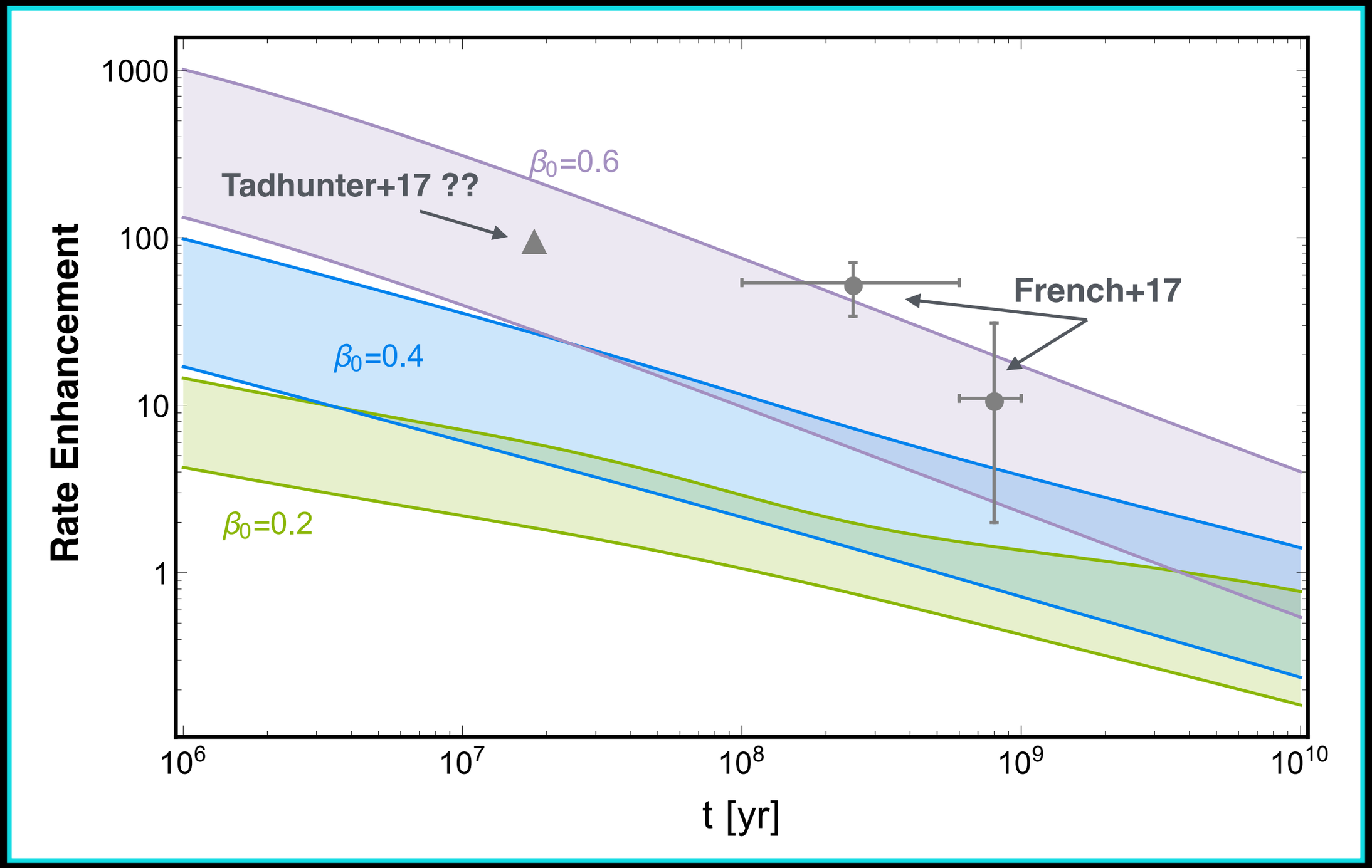
Radial Orbit Anisotropies?

- Simple possibility: anisotropic velocities with radial bias
- Consider constant anisotropy $\beta = 1 - T_\perp / 2T_r$
  - $\beta < \beta_{ROI} \sim 0.6$ 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

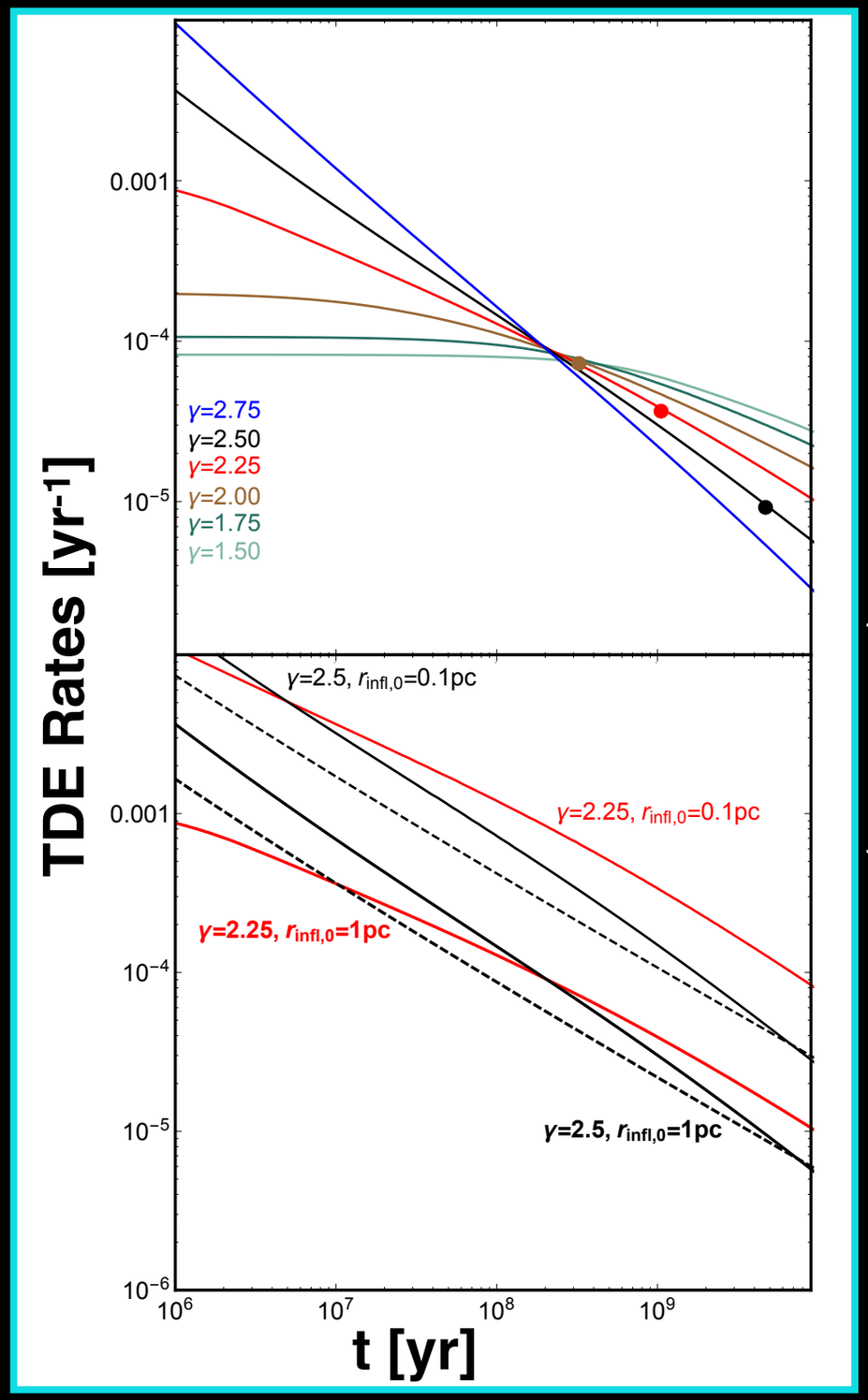
Anisotropic Delay Time Distributions



(NCS+17)

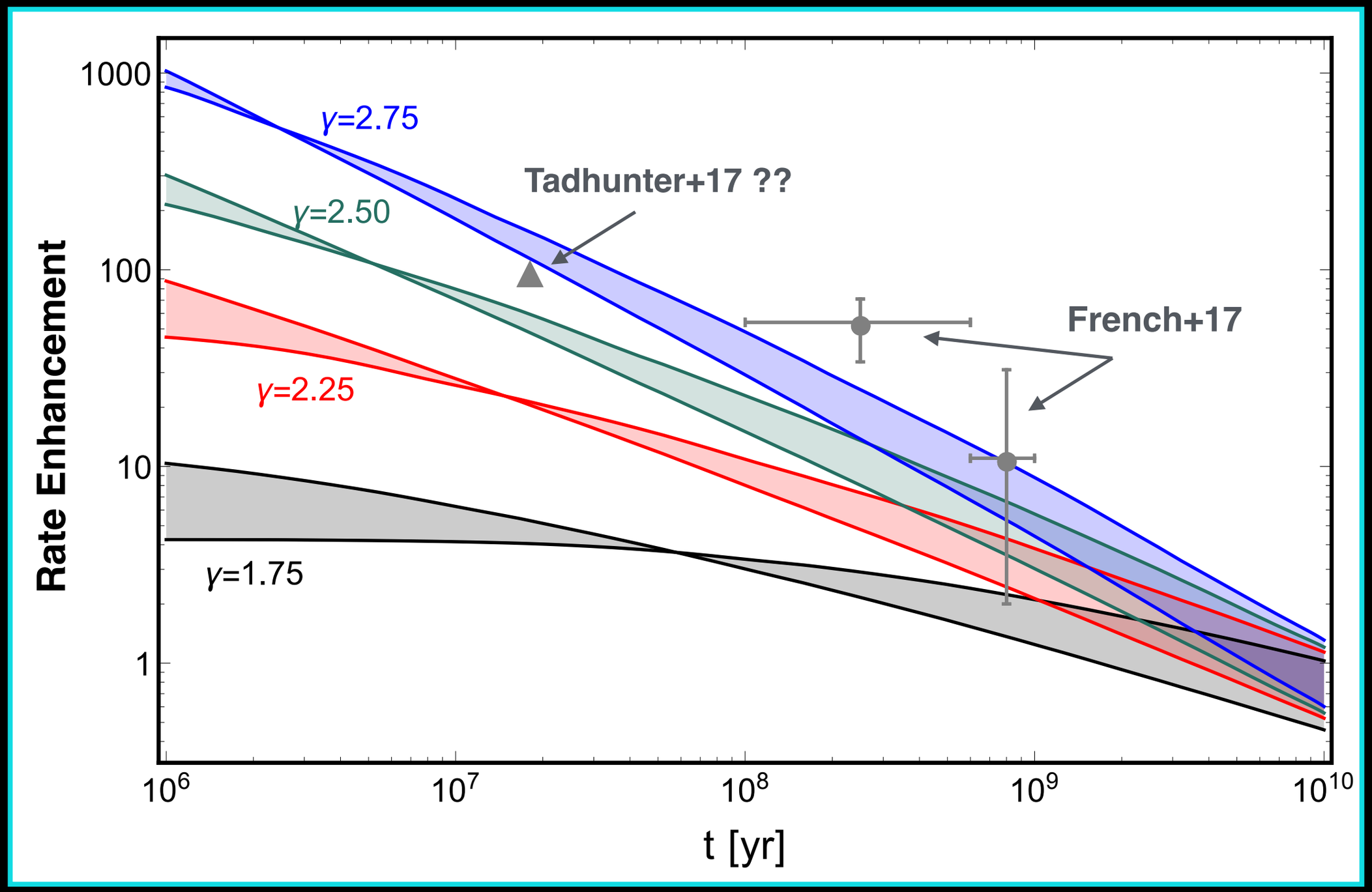
Stellar Overdensities?

- Suggestive evidence: color gradients in E+As (Pracy+13, Law-Smith+17)
- 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
  - TDE rate $\Gamma \propto t^{-(4\gamma-9)/(2\gamma-3)} / \ln(t)$



(NCS+17)

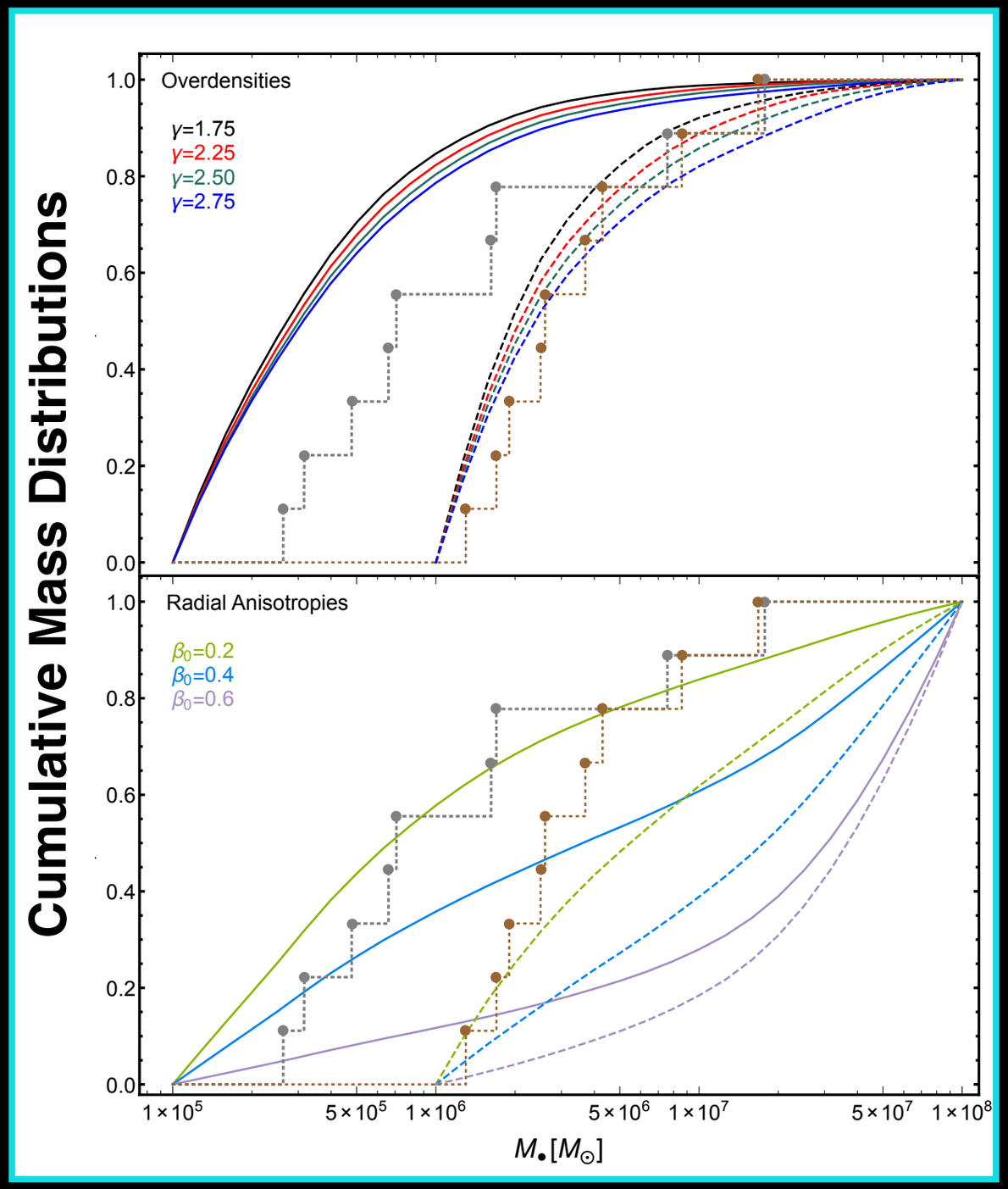
Overdense Delay Time Distributions



(NCS+17)

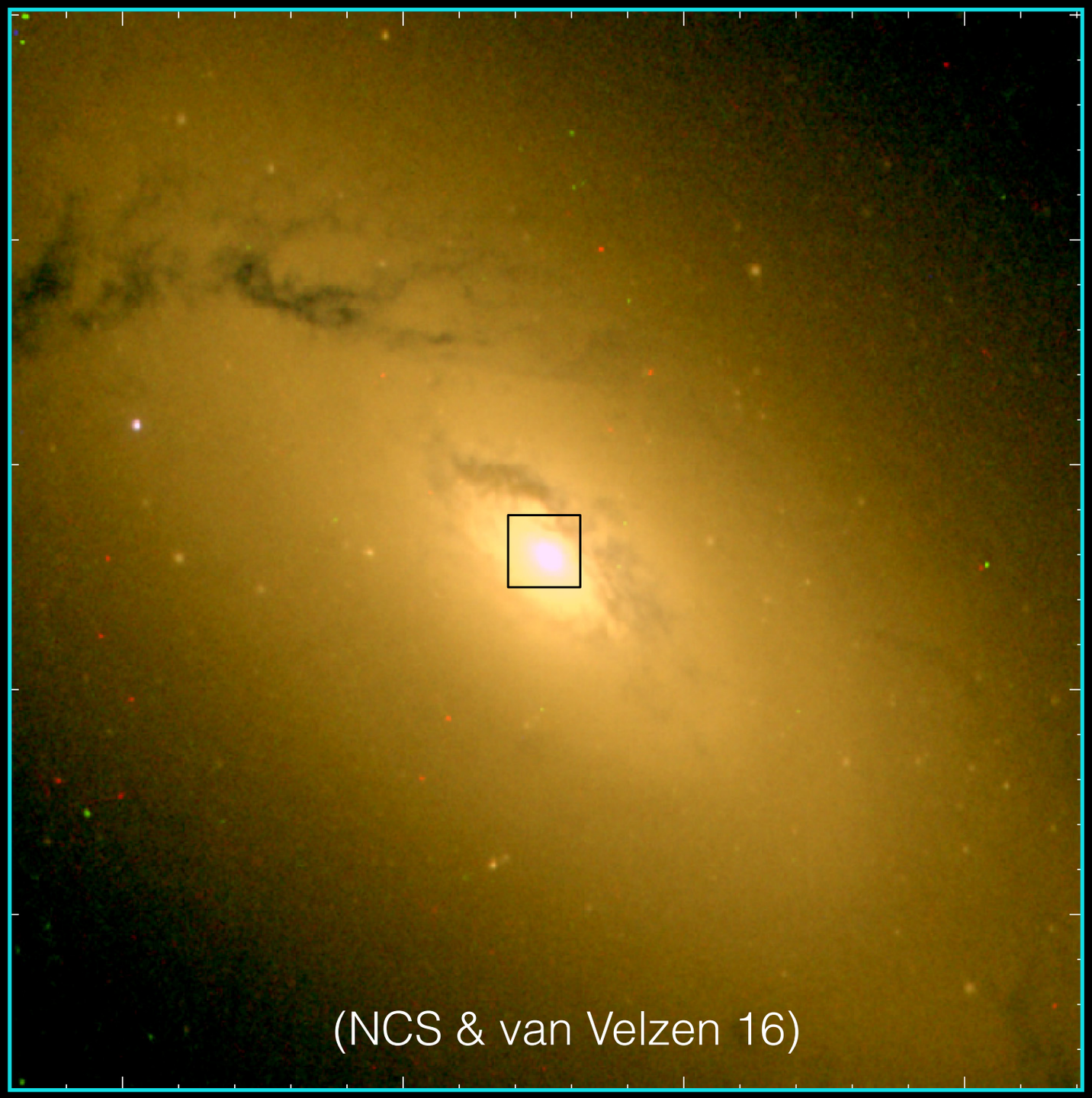
Host Masses

- Host mass distribution uncertain, but useful secondary test
- Observed TDE mass function bottom-heavy
  - In agreement with overdensity scenario
  - In serious tension with radial anisotropies
- Caveat - masses estimated indirectly

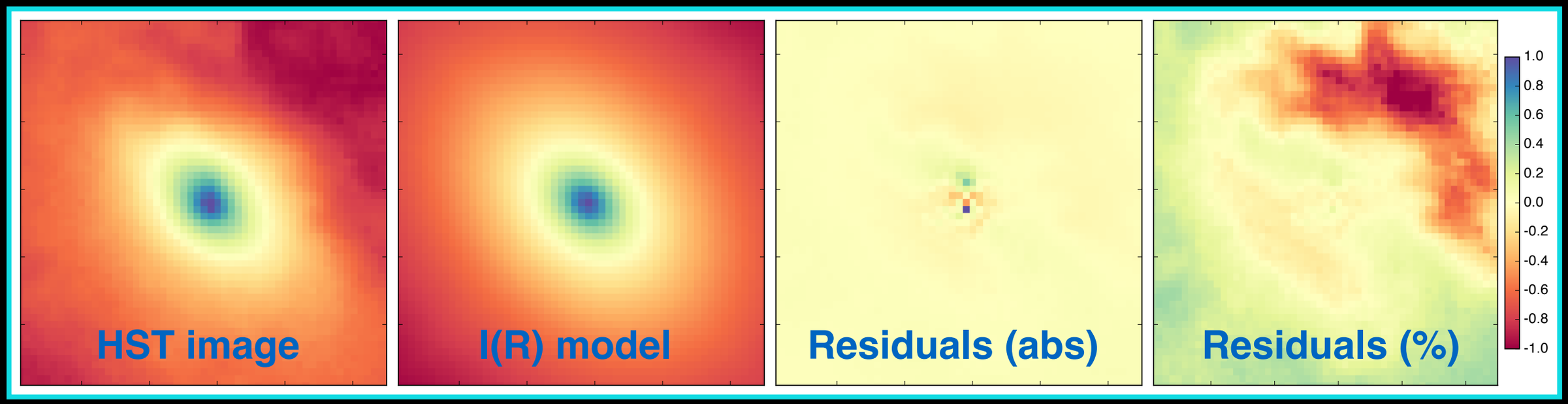


(NCS+17)

NGC 3156: A Nearby E+A



NGC 3156: Modeling



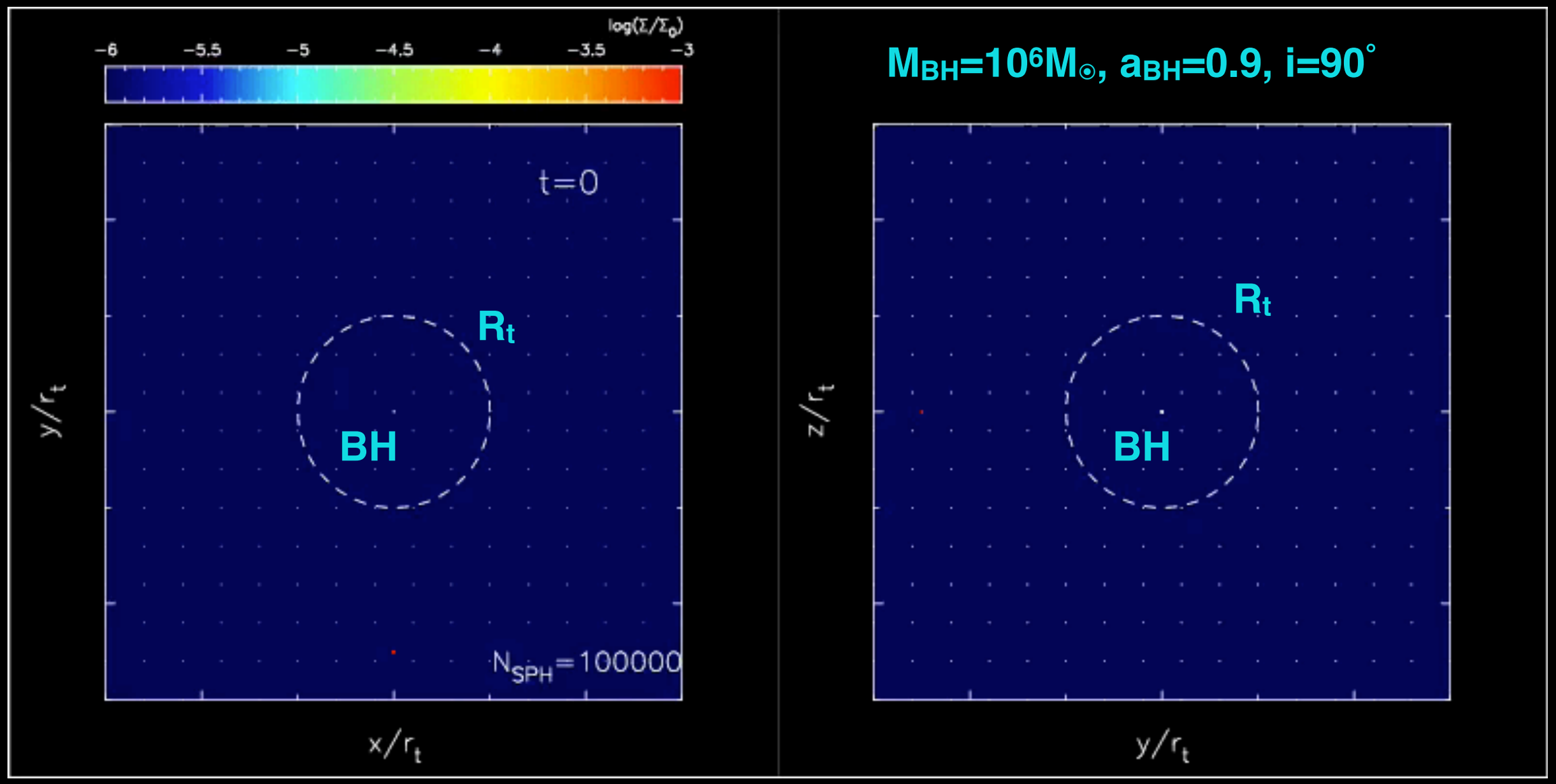
(NCS & van Velzen 16)

- 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: $I(R) \propto R^{-1.3} \rightarrow \rho(r) \propto r^{-2.3}$
- TDE rate $\Gamma \sim 1 \times 10^{-3}$/yr!
  - Currently testing with recent HST observations

Conclusions

- Two-body relaxation sets floor on per-galaxy TDE rate Γ_{theory} $\sim 10^{-4}$/gal/yr
  - Discrepant with old $\Gamma_{obs} \sim 10^{-5}$/gal/yr; discrepancy may be resolved by broad TDE luminosity function
- Several dynamical explanations for the post-starburst preference
  - Radial anisotropies promising for rates, temporal evolution, disfavored by mass function
  - SMBH binaries generally disfavored
  - Overdensity hypothesis most promising, but requires extreme parameter choices
- Delay time distributions powerful future tool - **model selection** and **parameter extraction**

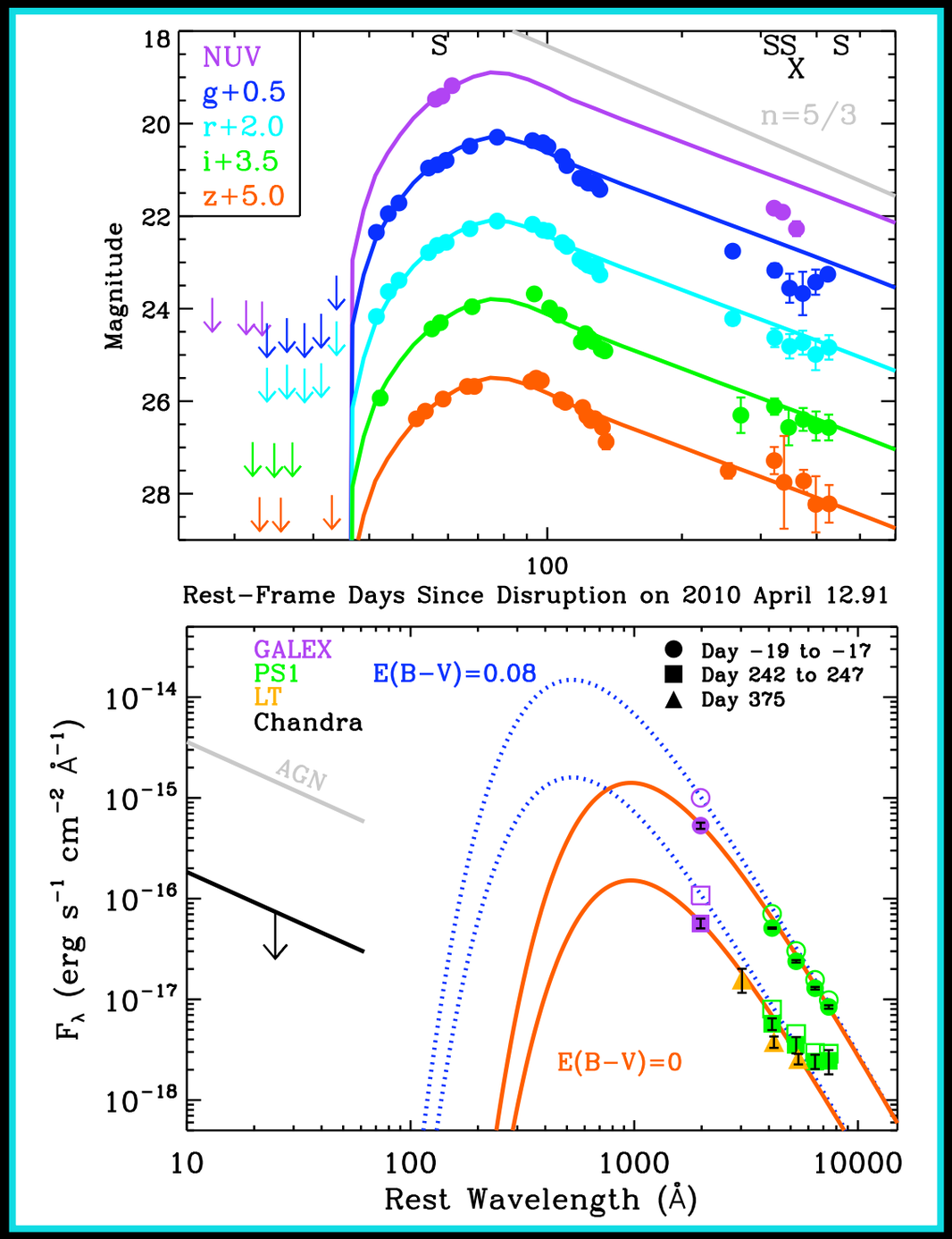
The Wages of Spin



(Hayasaki, NCS & Loeb 16)

Observed TDEs

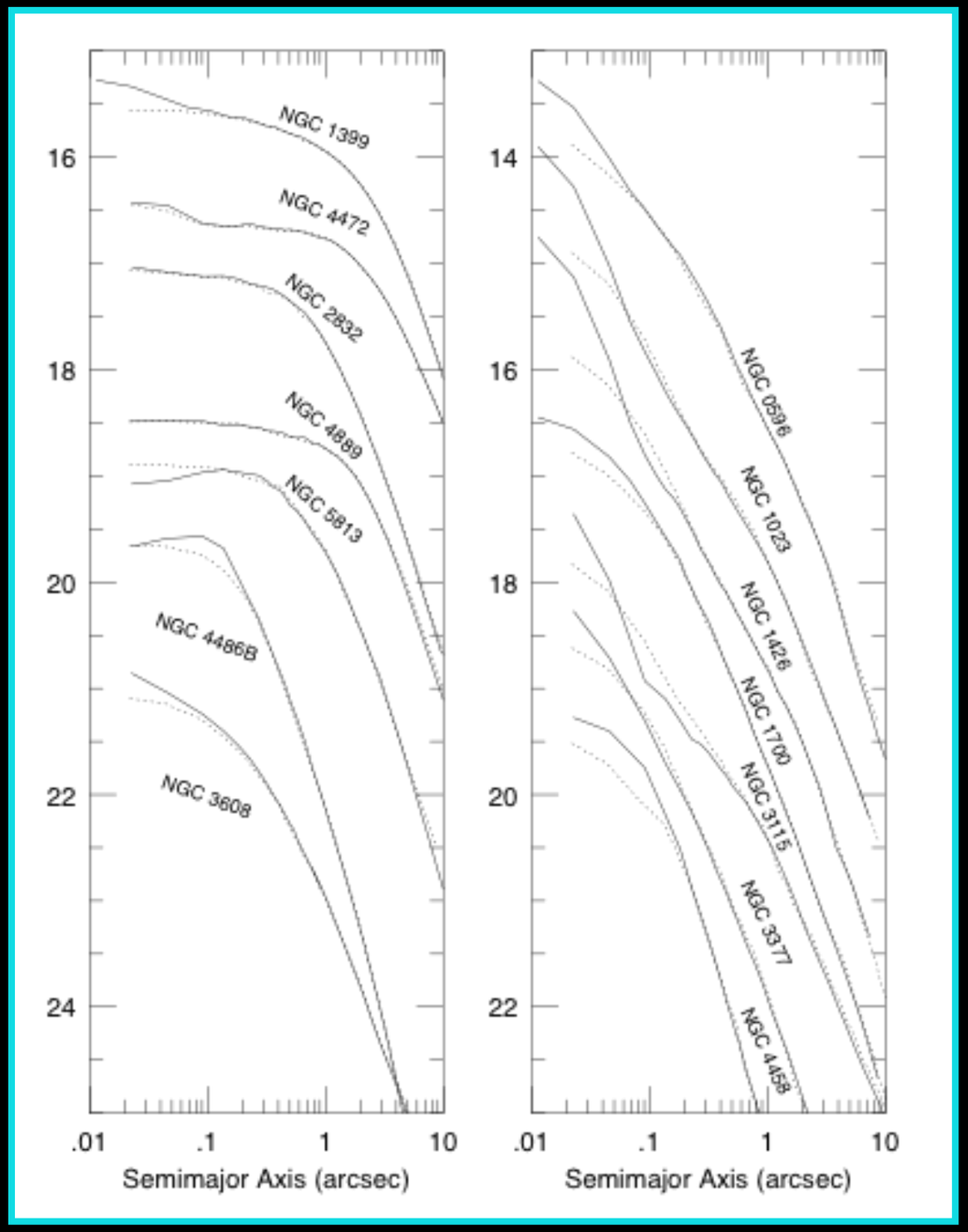
- First TDE candidates found with ROSAT (e.g. Komossa & Bade 99)
  - Later, XMM-Newton, Chandra
- Emission generally consistent with simple theory
  - Light curve follows $t^{-5/3}$
  - Thermal soft X-ray SED consistent with compact accretion disk
- Optical/UV TDEs first found in SDSS (van Velzen+11) and Pan-STARRS (Gezari+12)
  - Also PTF, ASASSN
  - Thermal blackbody emission $>10^2$ x brighter than naive predictions



(Gezari+12)

Realistic TDE Rates

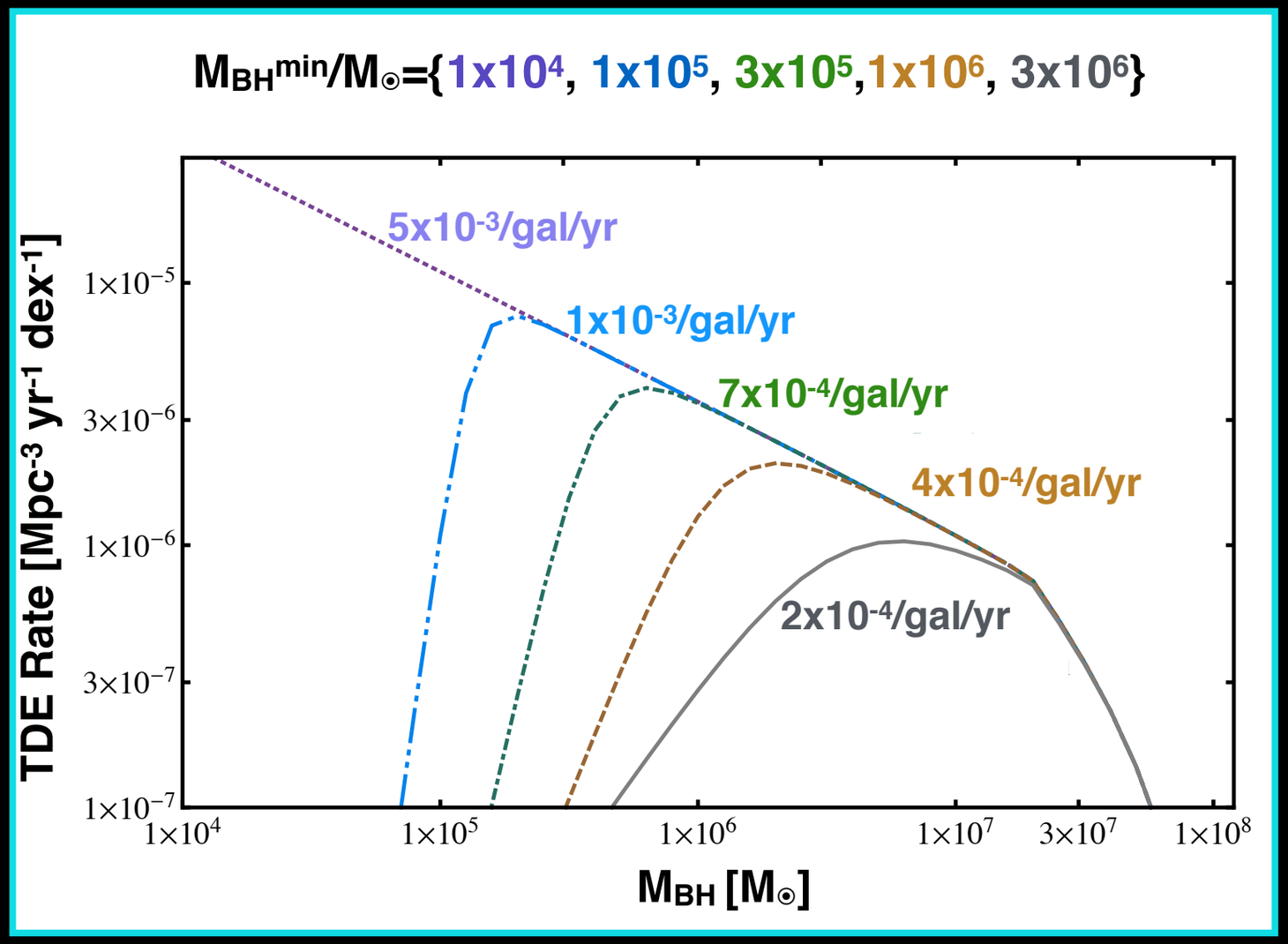
- Theoretical rates calculated semi-empirically (Magorrian & Tremaine 99, Wang & Merritt 04, NCS & Metzger 16):
  - ✦ Take sample of nearby galaxies
  - ✦ Deproject I(R) -> ρ(r) *[assumes sphericity]*
  - ✦ Invert ρ(r) -> f(ε) *[assumes isotropy]*
  - ✦ Compute diffusion coefficients $\langle \Delta J^2(\varepsilon) \rangle$, loss cone flux $\mathscr{F}(\varepsilon)$ *[assumes IMF]*
- Low mass galaxies dominate event rate
  - ✦ $\Gamma_{theory} \sim 2\text{-}10 \times 10^{-4}$/gal/yr



(Lauer+05)

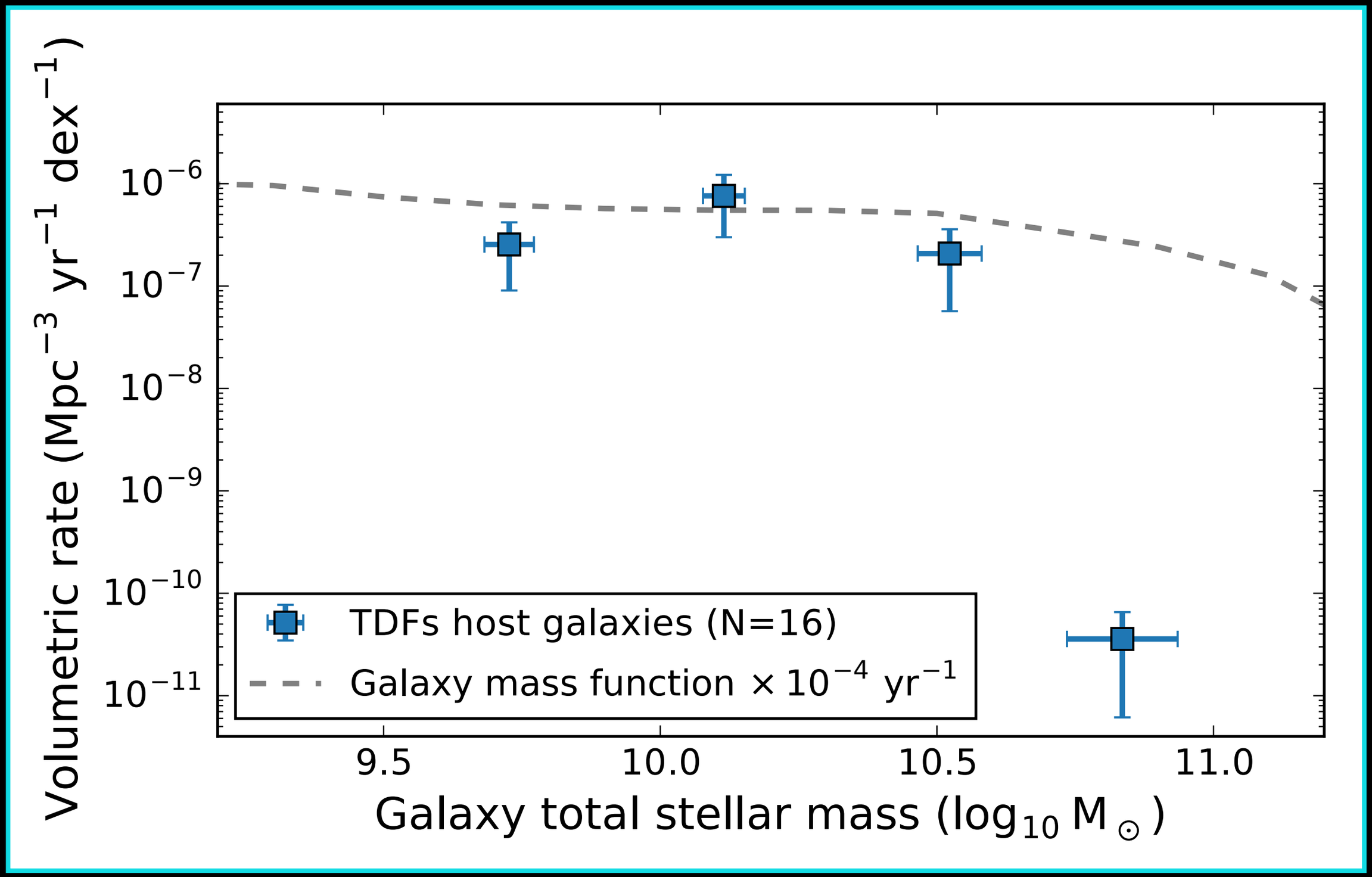
The Rate Discrepancy

- $\Gamma_{obs} \sim 1\times10^{-5}$/gal/yr << $\Gamma_{theory} \sim 2\text{-}10 \times10^{-4}$/gal/yr
- Rate estimates **conservative**
  - See also Lezhnin & Vasiliev 16
- Explanations of discrepancy:
  - ~~1. Dynamical?~~
  - 2. Selection effects?
  - 3. TDE luminosity function



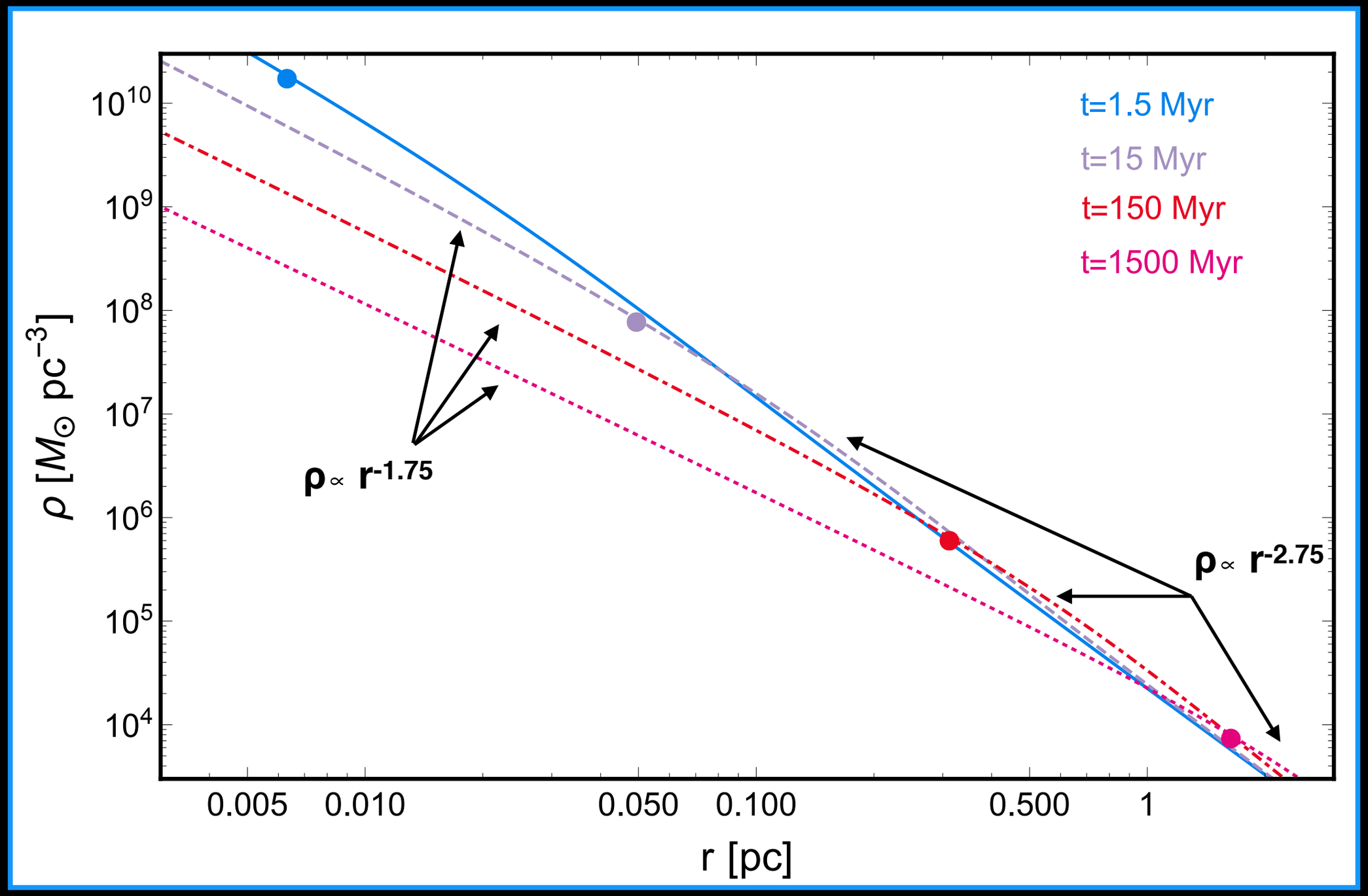
(NCS & Metzger 16)

Rate Discrepancy Resolved?



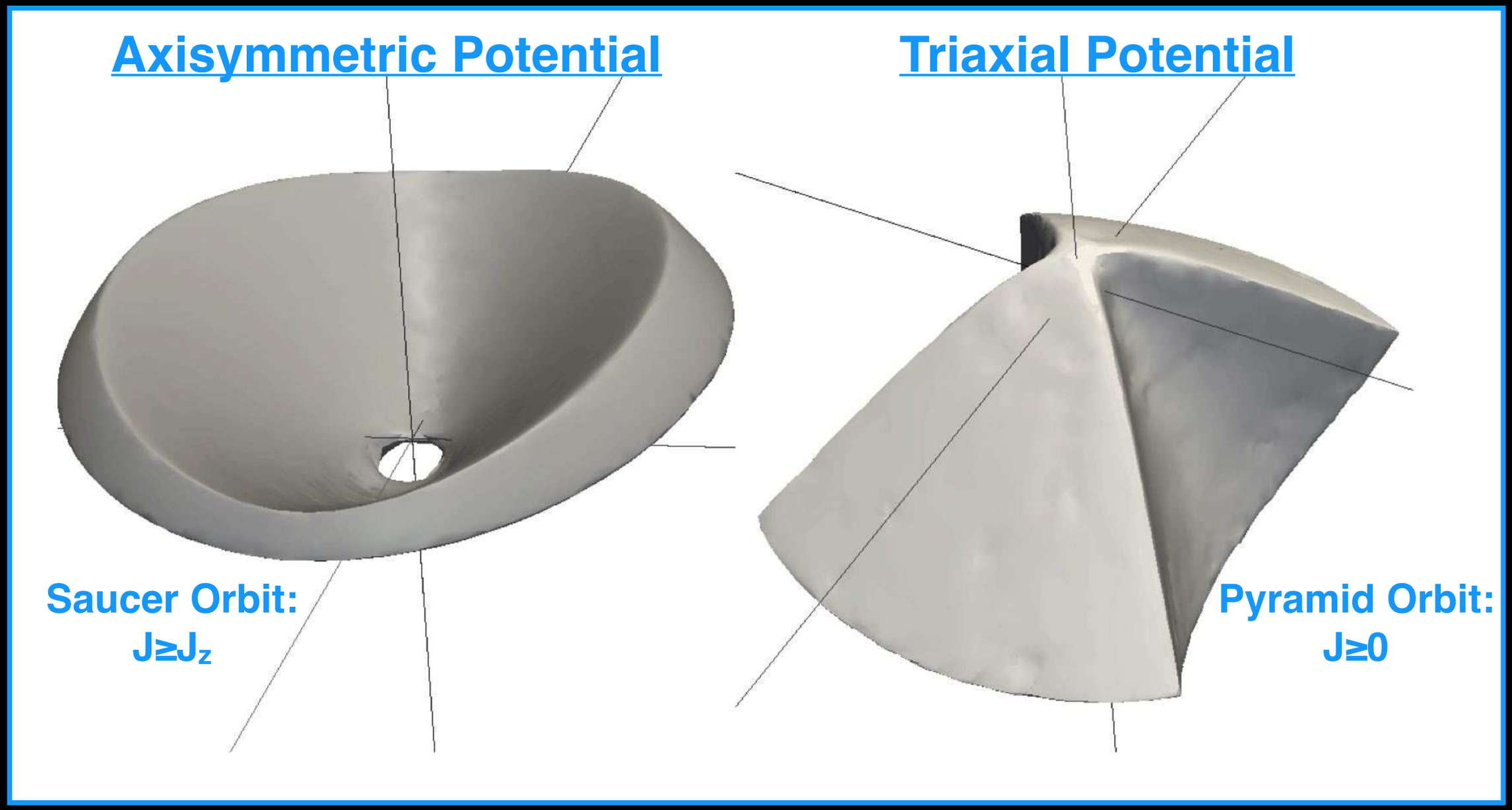
(van Velzen 17)

Birth of a Bahcall-Wolf Cusp



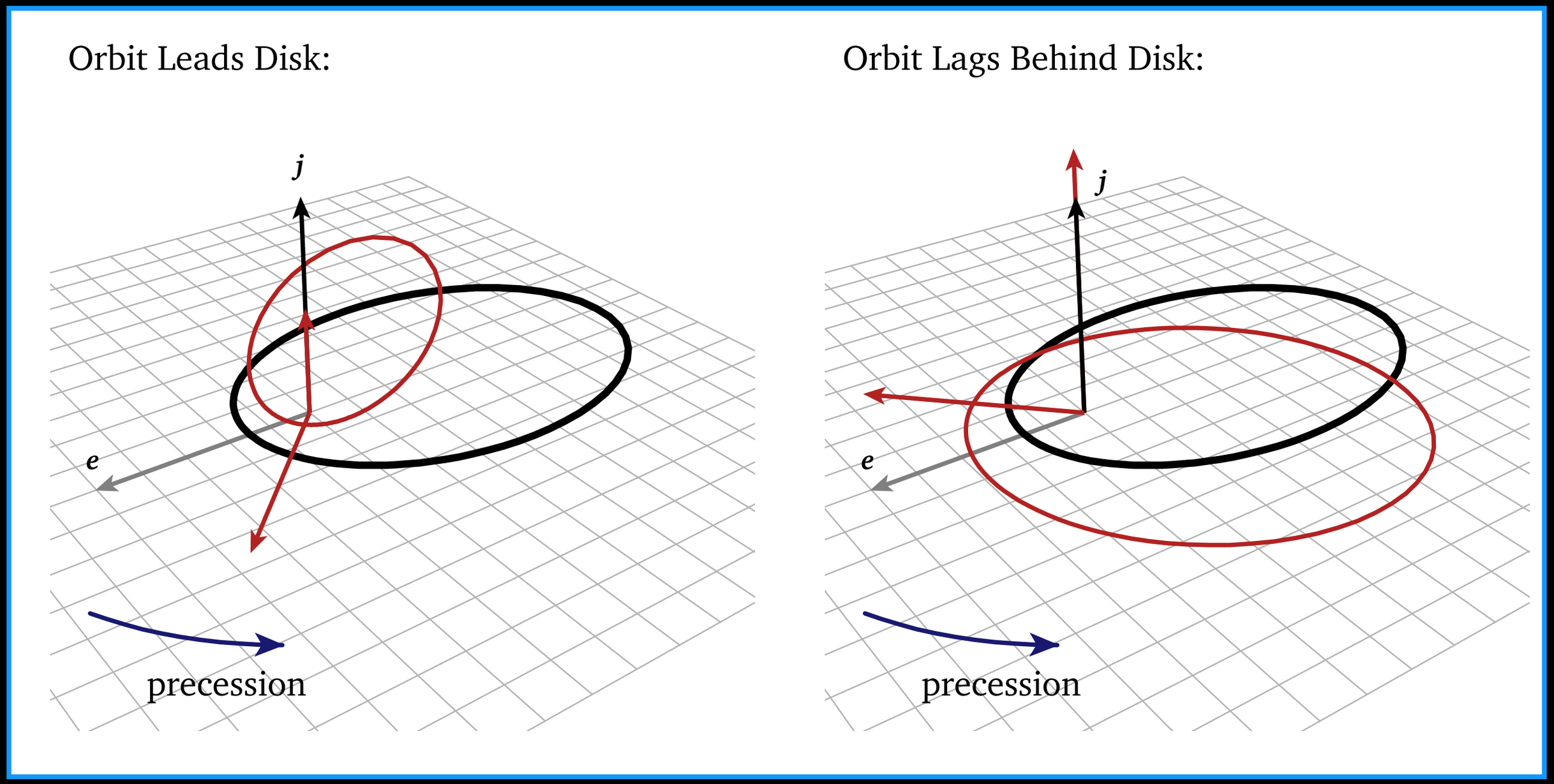
(NCS+17)

Nuclear Triaxiality?



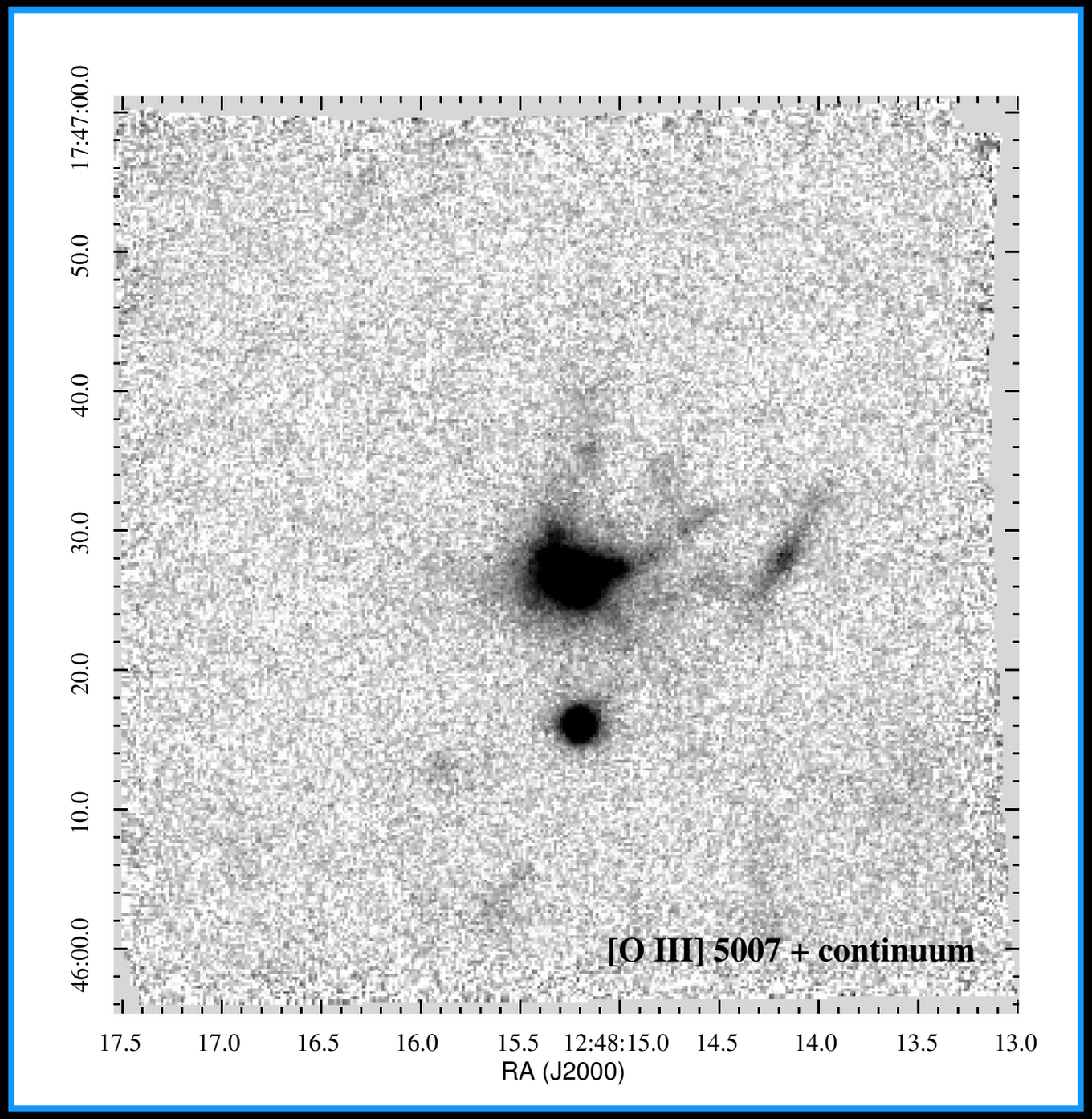
(Merritt+13)

Eccentric Stellar Disks?



(Madigan+17)

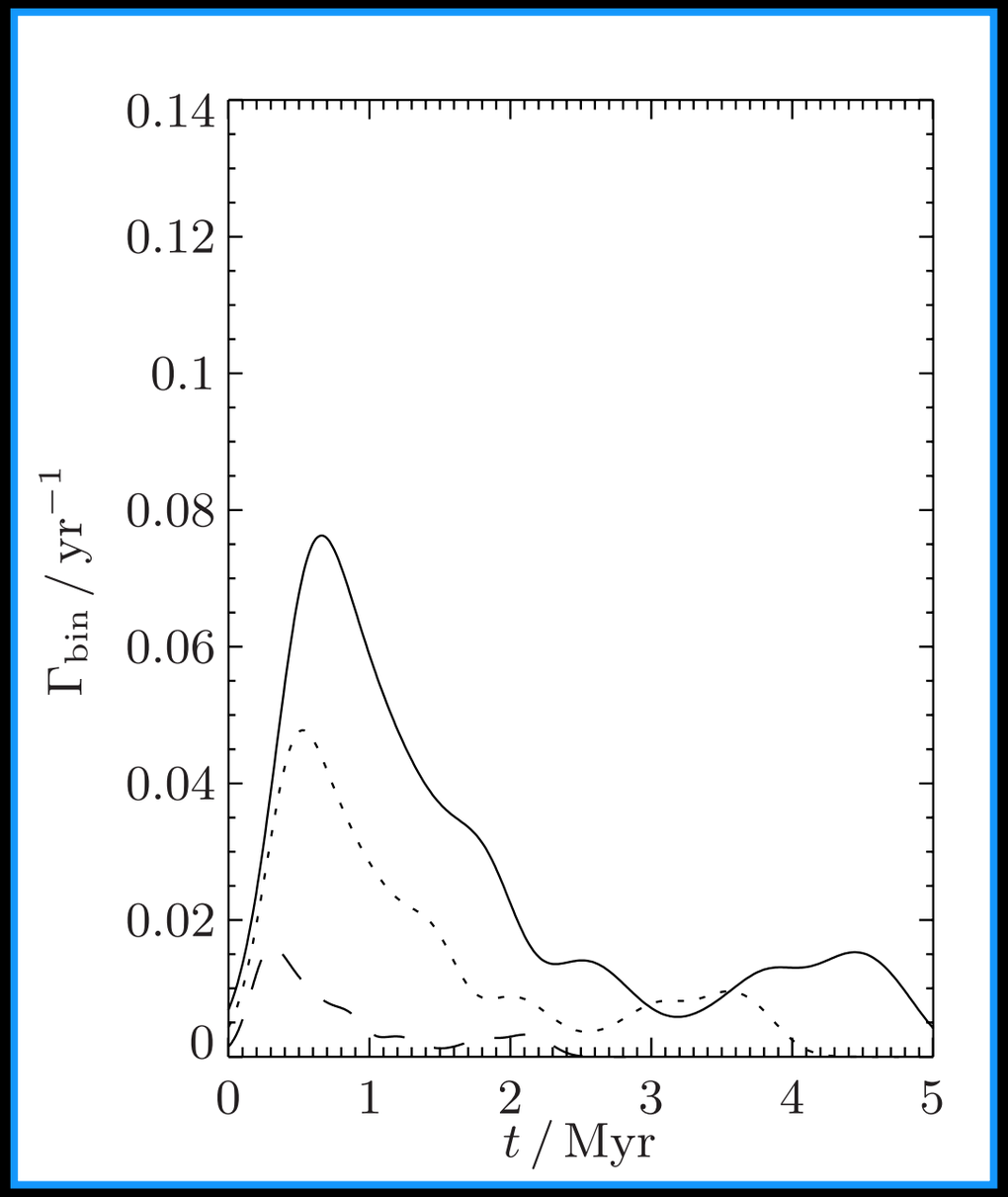
SMBH Binaries?



(Prieto+16)

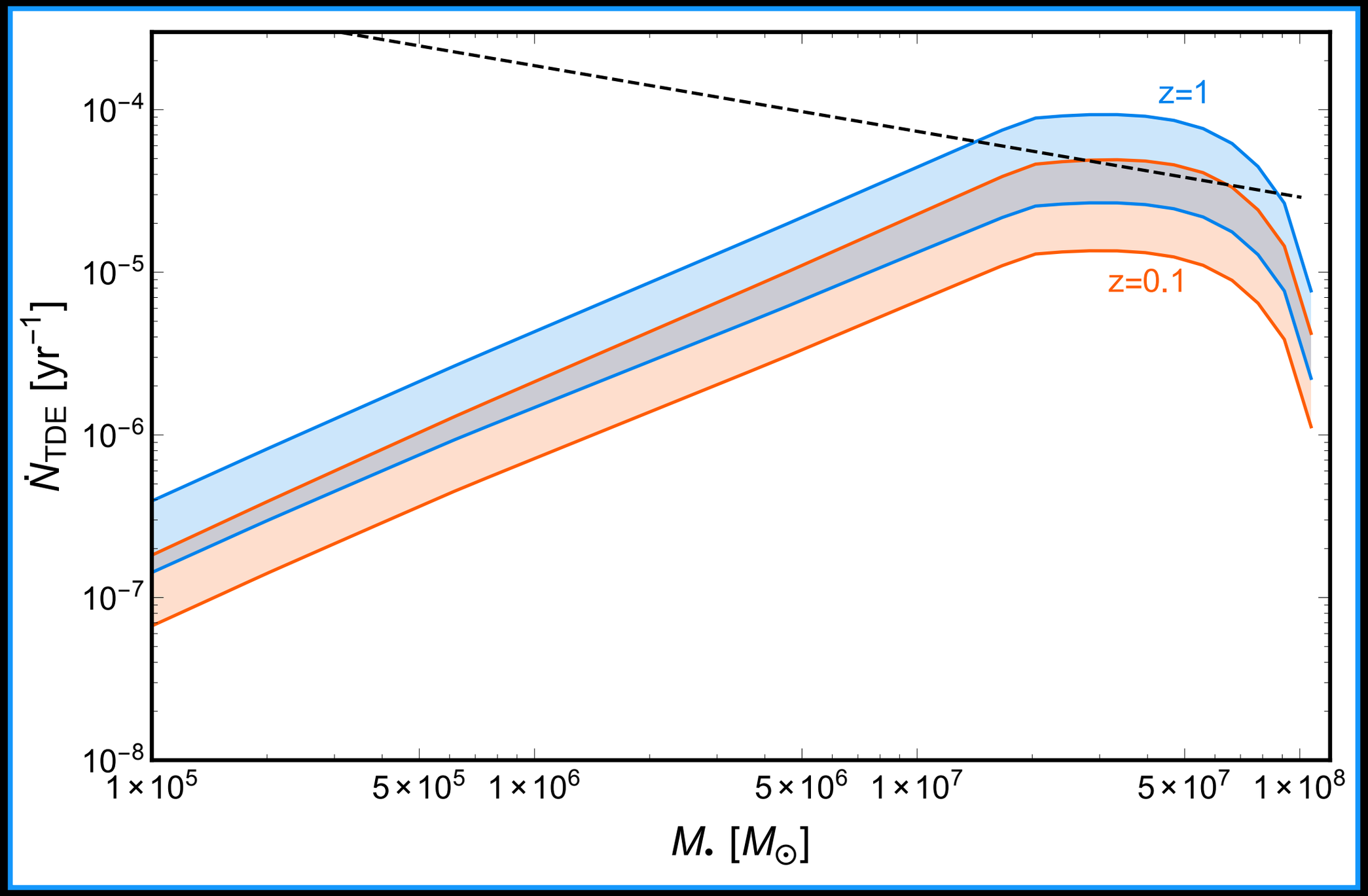
SMBH Binaries

- Nascent SMBH binaries see increase in TDE rate:
  - Kozai effect (Ivanov+05)
  - Chaotic 3-body scatterings (Chen+11, Wegg & Bode 11)
- Enhancement huge ($\Gamma \sim 10_{-1}$/yr) but short-lived ($<10_6$ yr)
  - Occurs before final parsec problem
  - Unique lightcurves? (*Coughlin talk*)
- Possibly disfavored by:
  - Total rate fraction ~3-25% (Wegg & Bode 11)
  - Fine-tuned timescales
  - Mass distribution



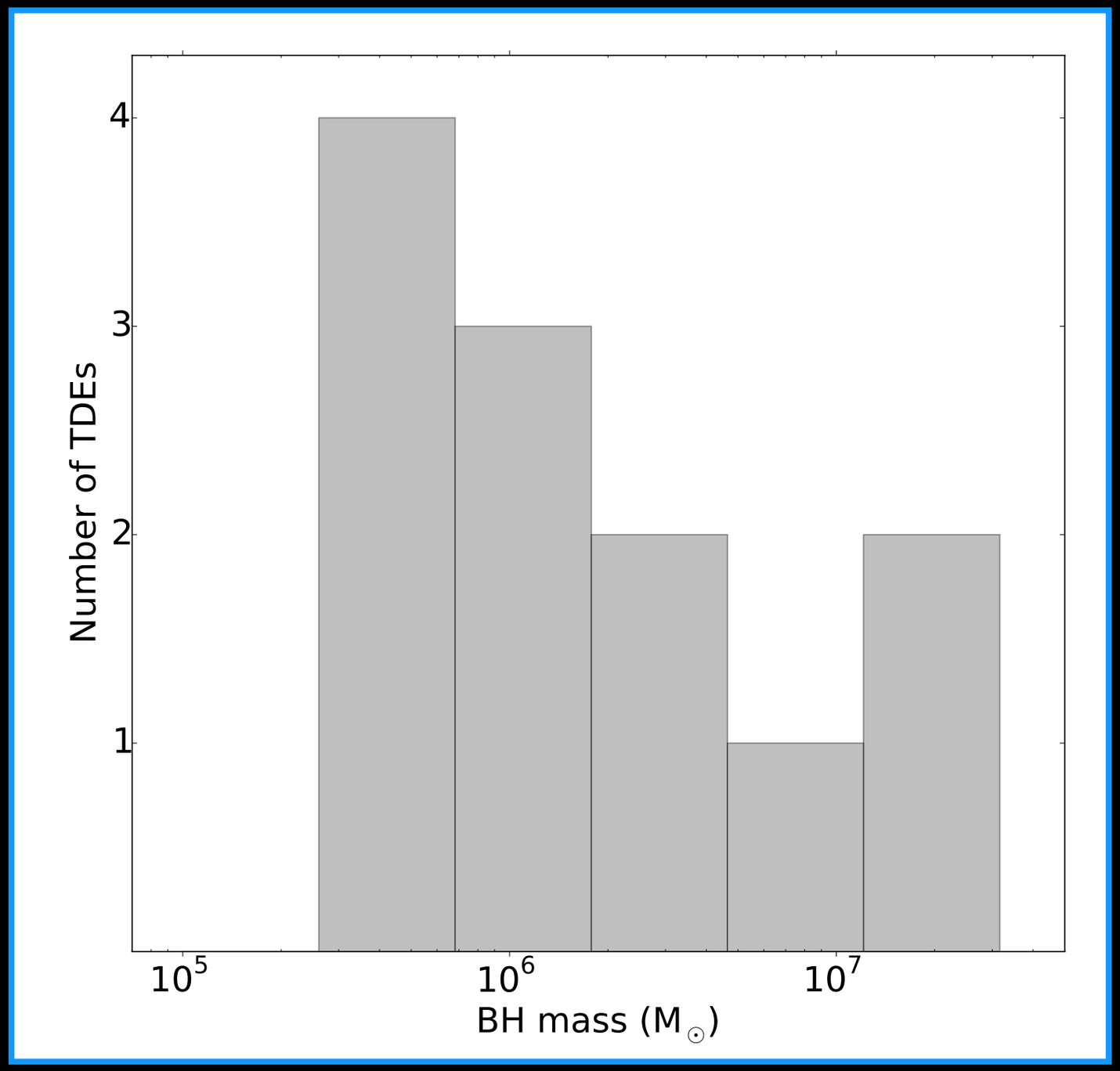
(Wegg & Bode 11)

SMBHB TDE Rates



(NCS+17)

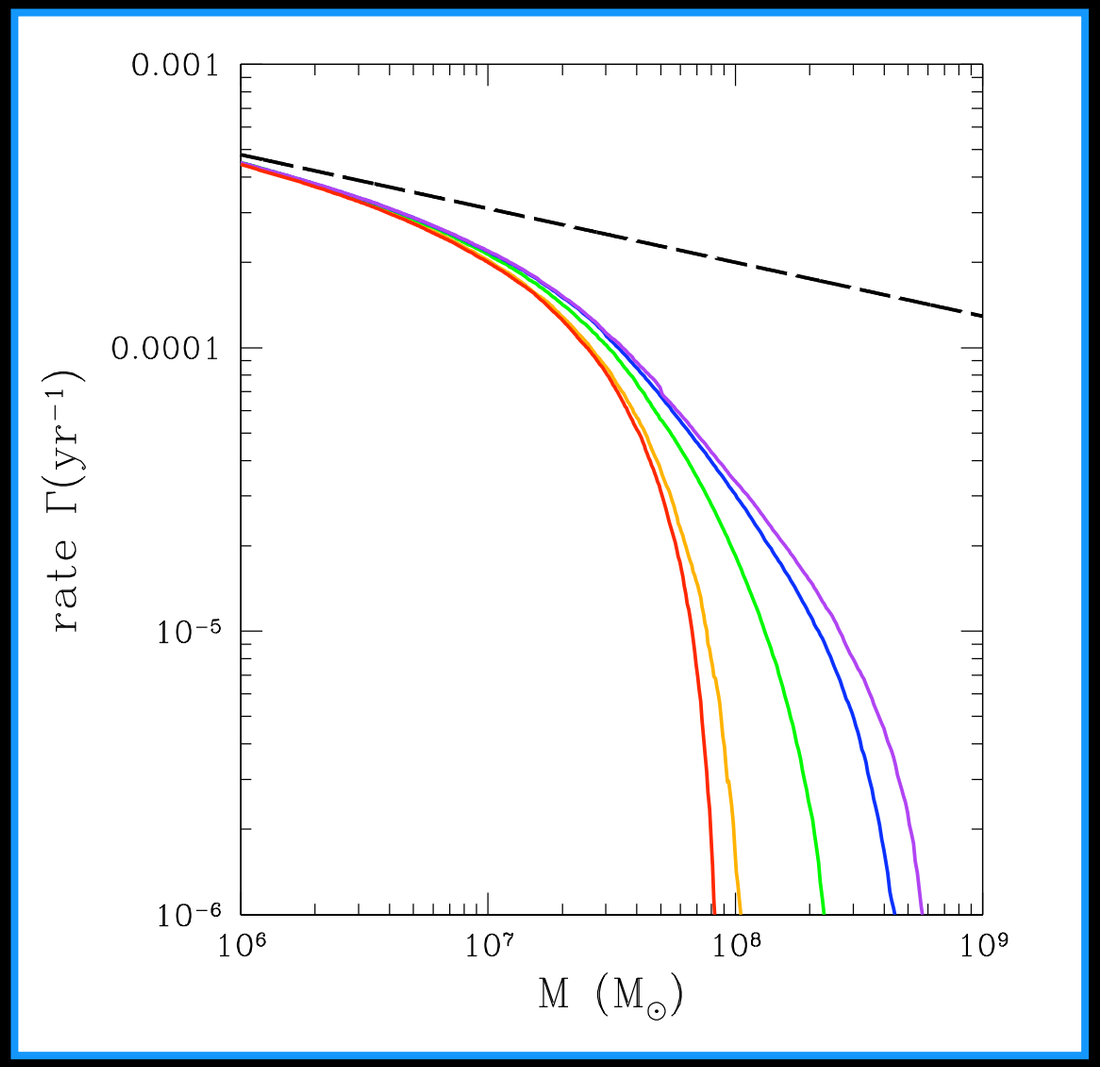
Observed TDE Hosts



(Wevers+17)

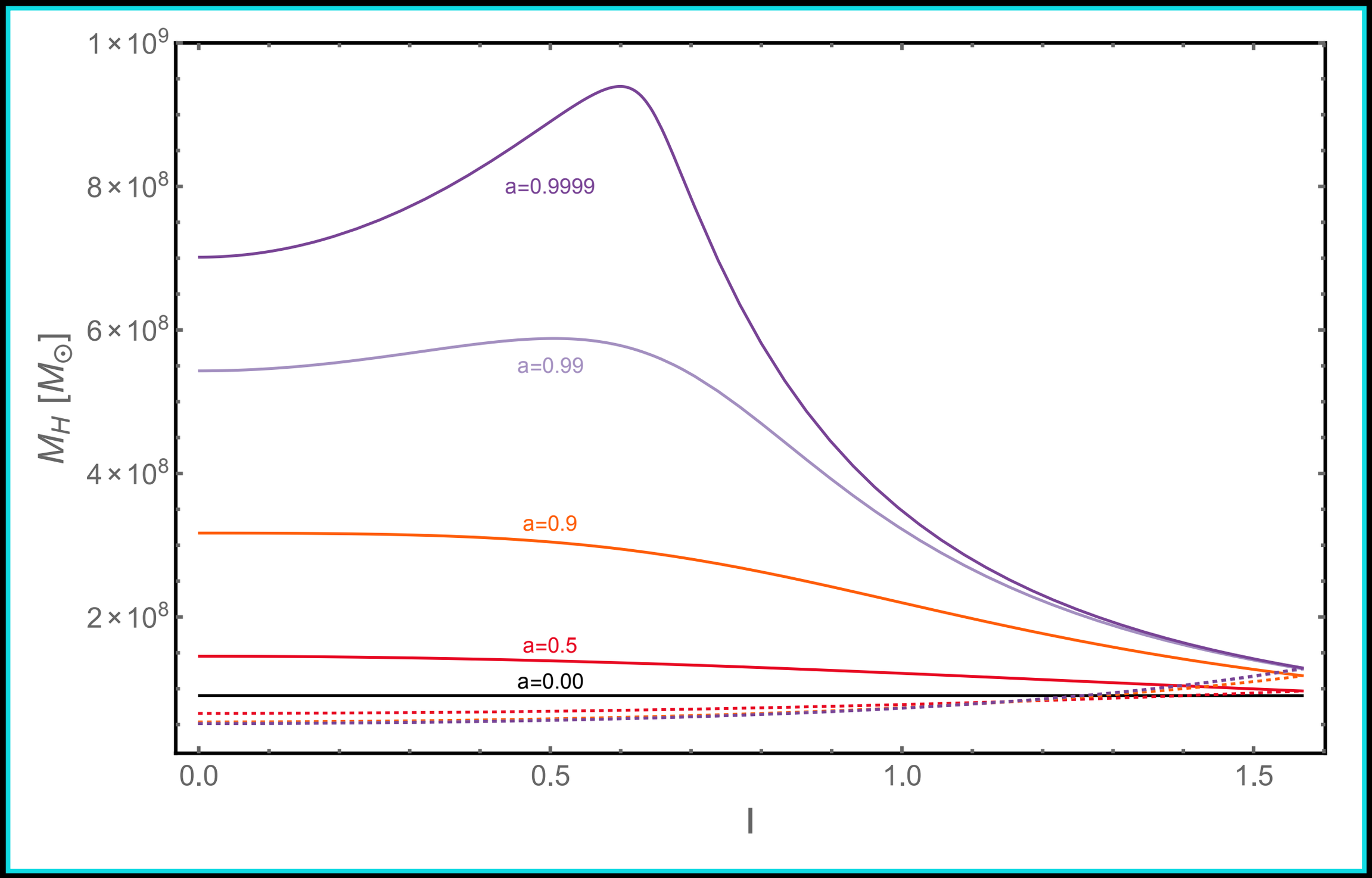
General Relativistic Hills Masses

- Hills Mass: maximum SMBH mass that can produce a TDE
  - $R_t \approx R_\star (M_{BH}/M_\star)_{1/3}$, while $R_g = GM_{BH}/c_2$
  - Above $M_{Hill} \sim 9 \times 10_7 M_\odot$, TDEs impossible…
  - …in Schwarzschild metric
- Quantifiable in exact GR with Fermi Normal Coordinates (Marck 83, Beloborodov+92)
  - Eigenvalues of C_{ij} determine disruption
- M_{Hill} **increases a factor of ~8 as SMBH spin a->1** (Kesden 12)
  - Smaller IBSO (parabolic+inclined ISCO)
  - Stronger tidal tensor



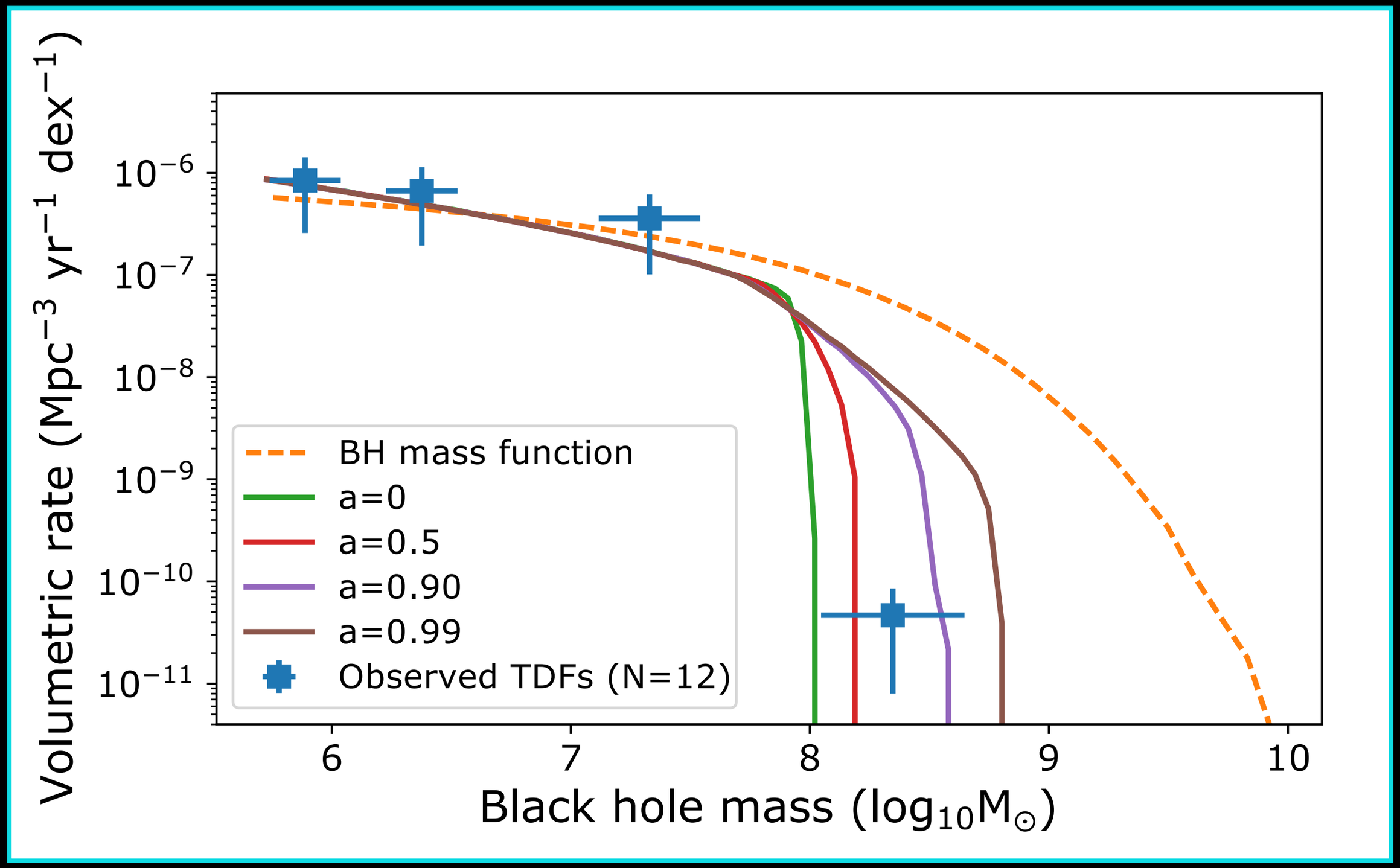
(Kesden 12)

Angle of Approach



(NCS & van Velzen in prep)

TDEs as Integrated Spin Constraints



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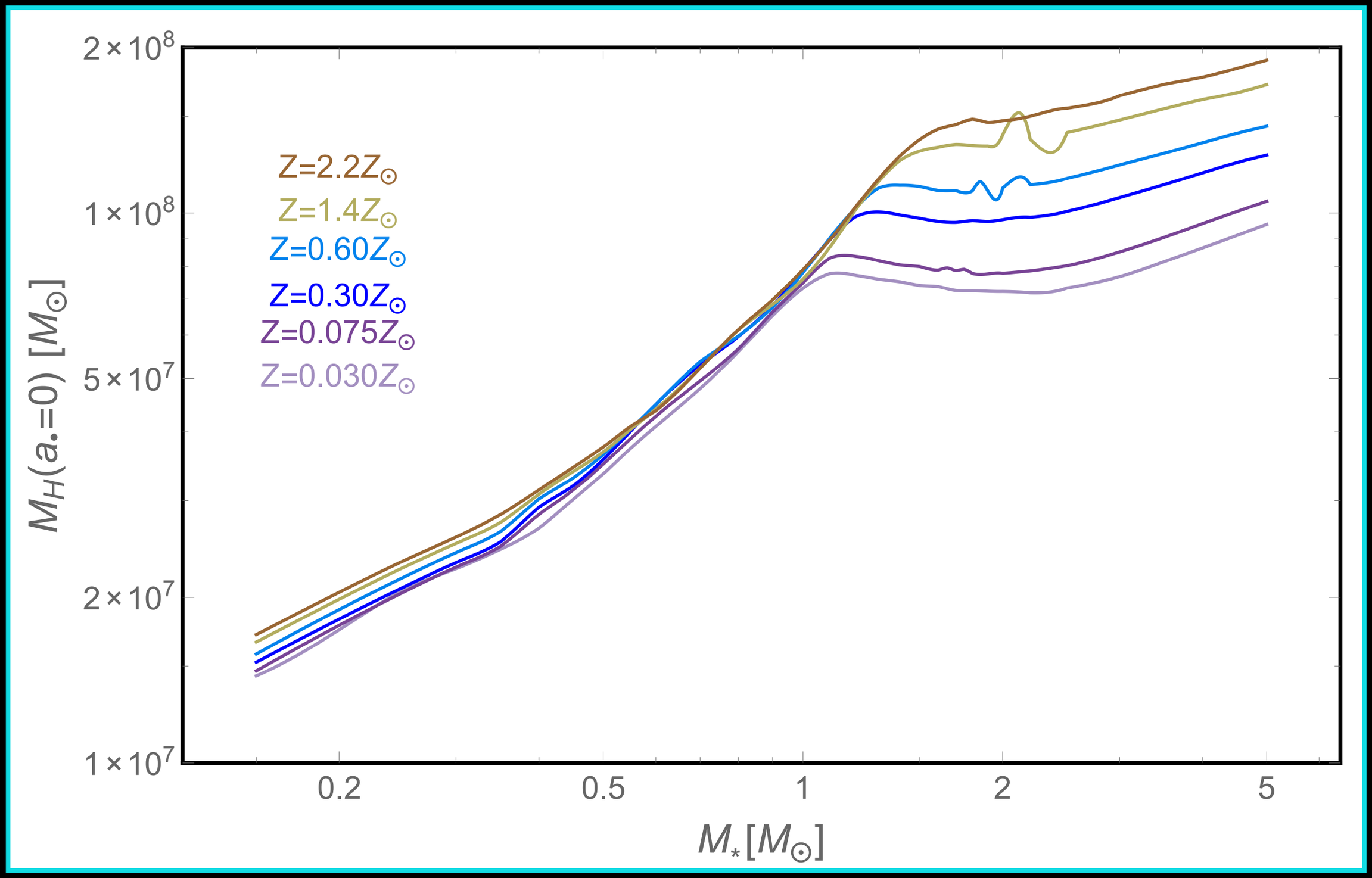
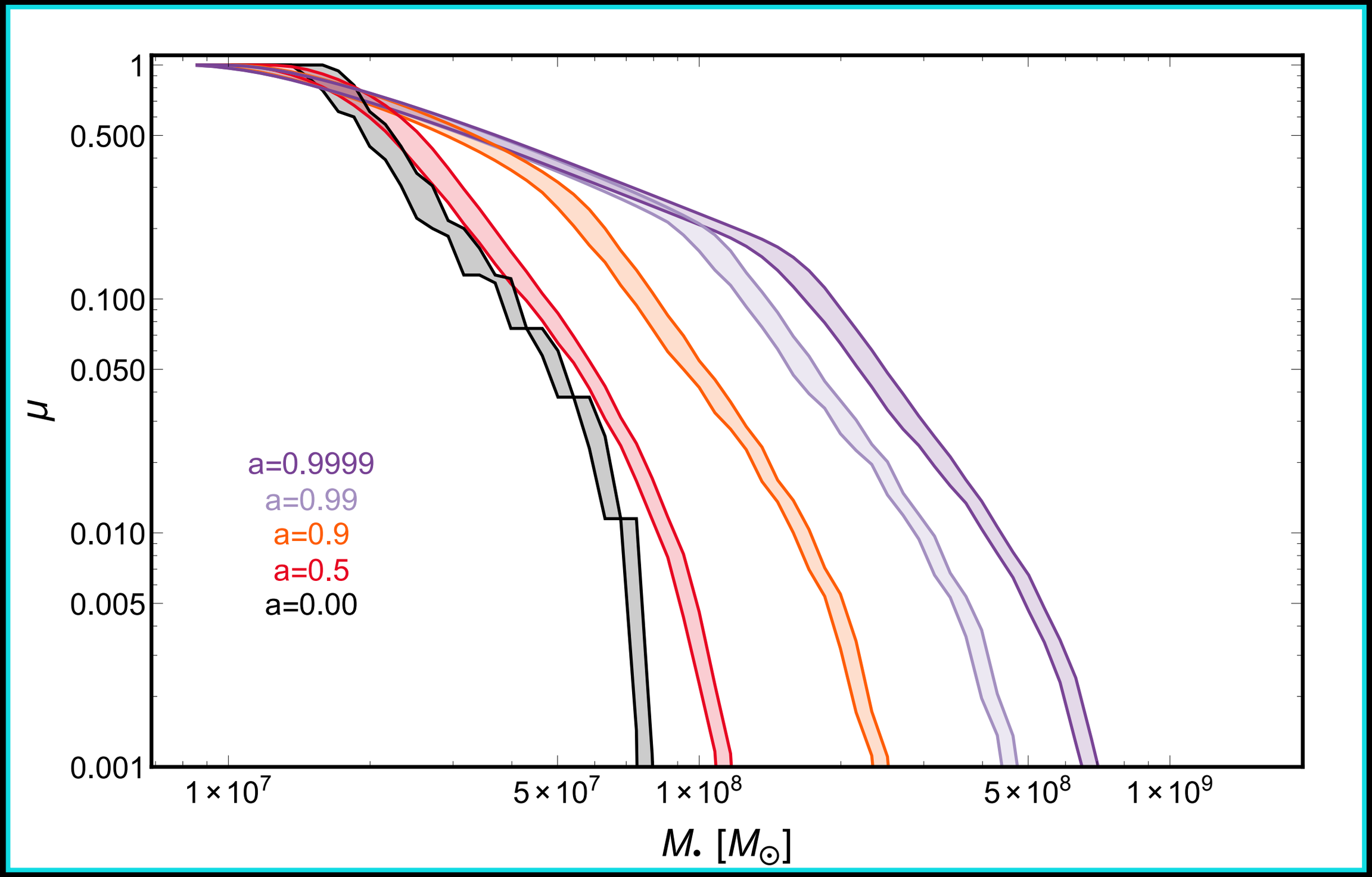
Does Metallicity Matter?



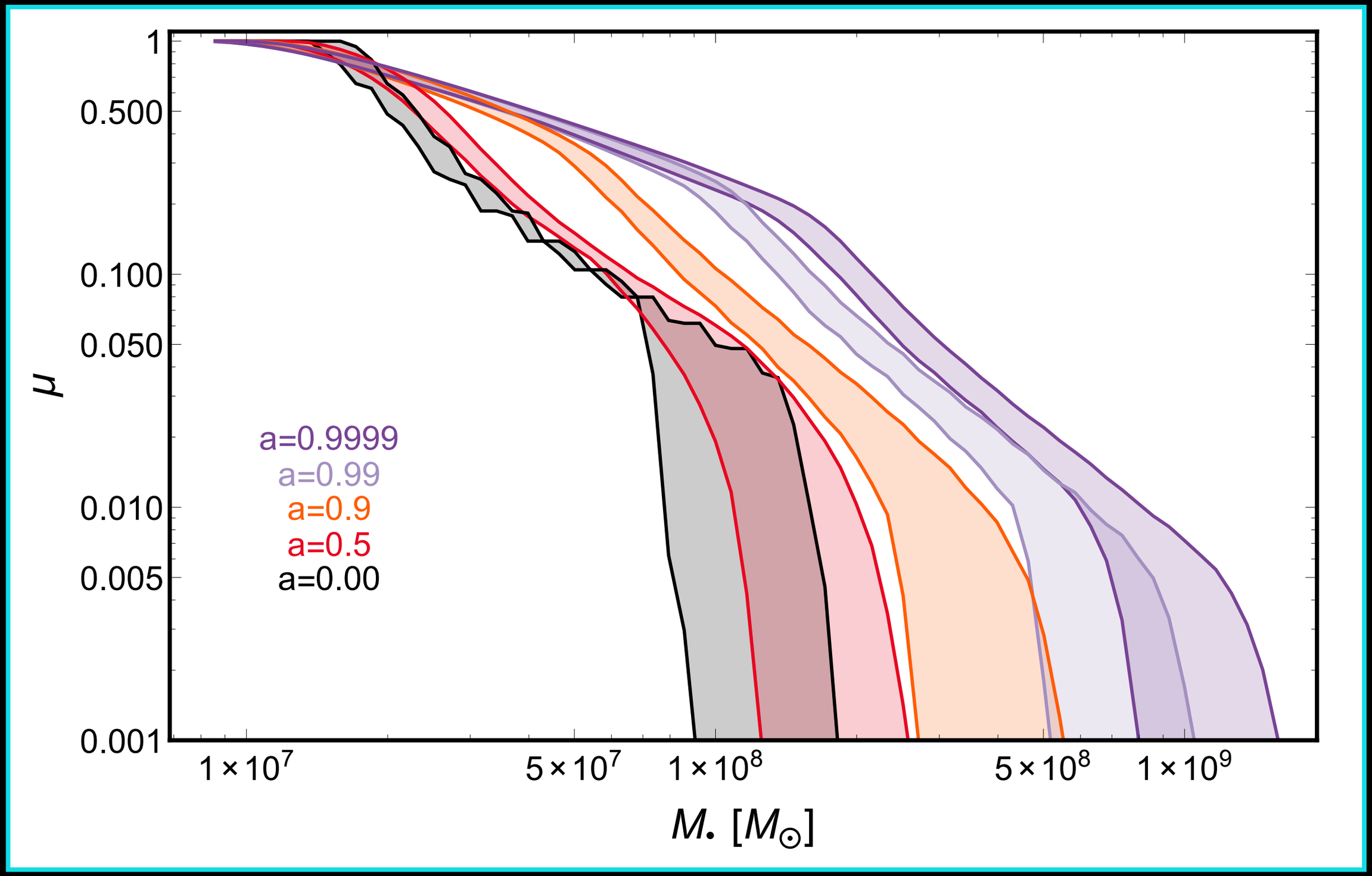
(NCS & van Velzen in prep)

Sometimes not…



(NCS & van Velzen in prep)

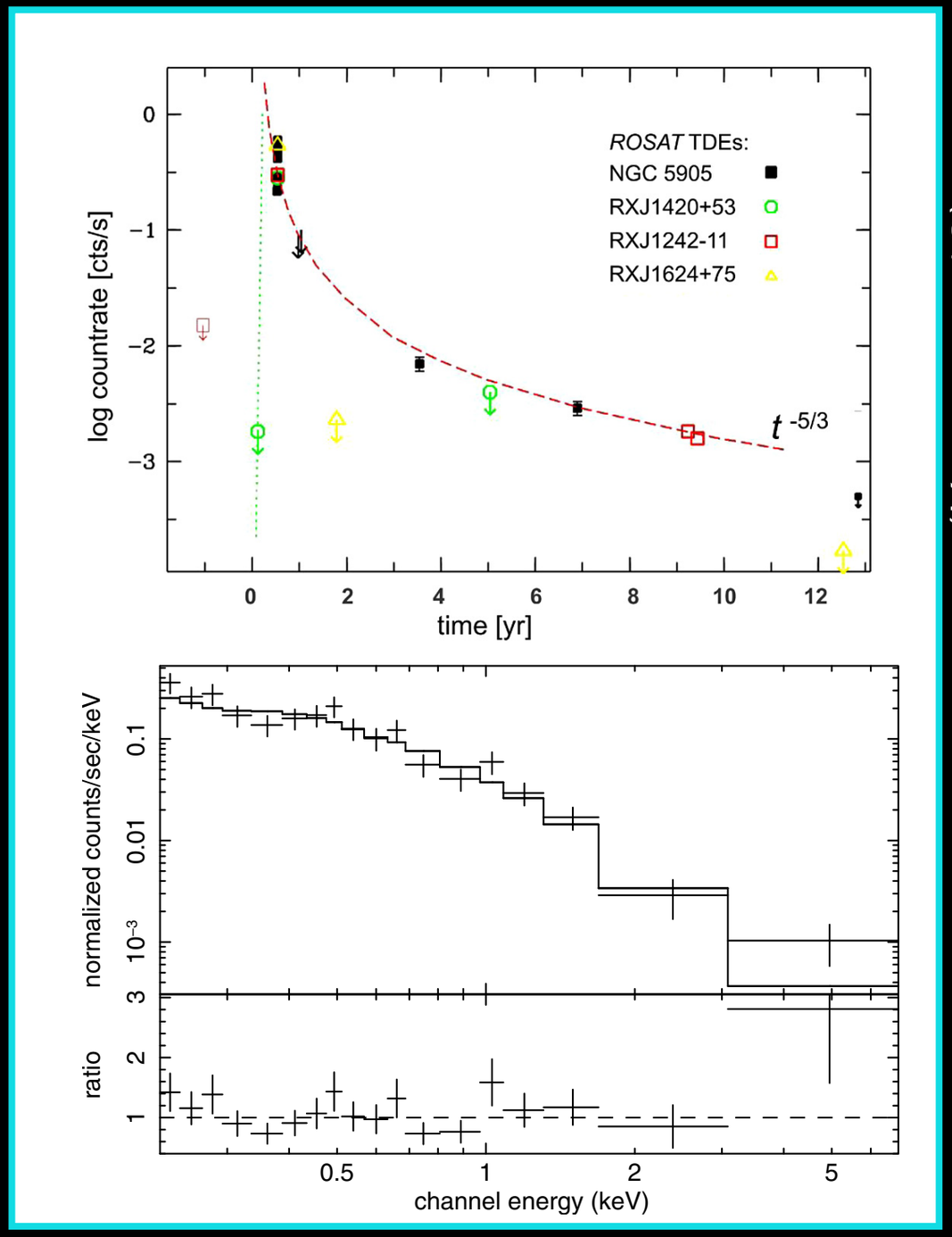
…and Sometimes Yes



(NCS & van Velzen in prep)

X-ray TDEs

- First TDE candidates found with ROSAT (e.g. Komossa & Bade 99)
  - Later, XMM-Newton, Chandra
- Emission generally consistent with simple theory
  - Light curve follows $t^{-5/3}$
  - Thermal soft X-ray SED consistent with compact accretion disk
- Cadence usually poor
- Surprises in nonthermal hard X-rays
  - Three jetted TDEs found by Swift
  - Occasional hard power-law in thermal TDEs



(Komossa 13)

(Esquej+08)

Stellar Dynamics and Tidal Disruption Event Rates

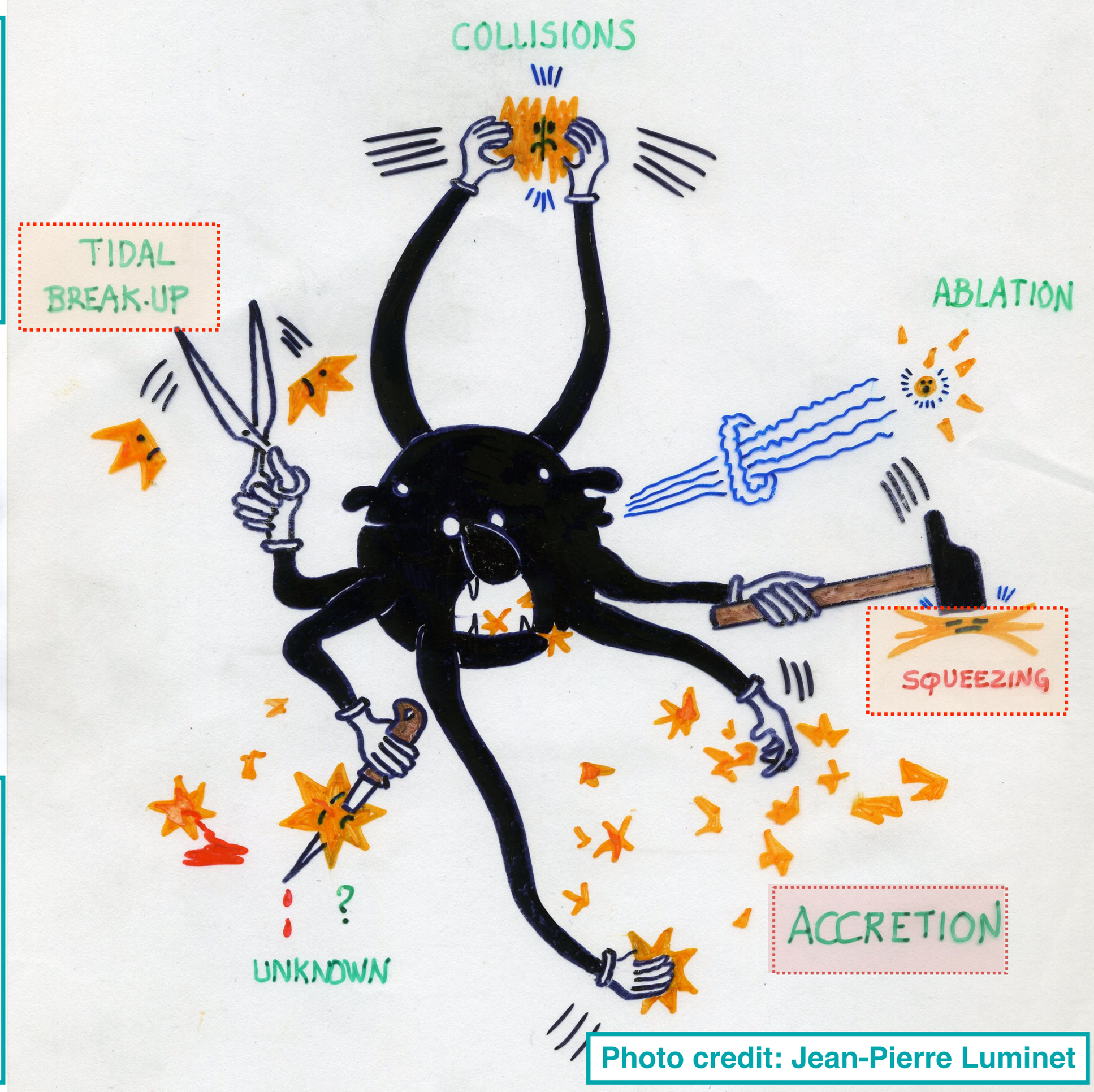


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Photo credit: Jean-Pierre Luminet