Searching for Ultra-light Bosons with Stellar Tidal Disruption Events

Peizhi Du

C.N. Yang Institute for Theoretical Physics

Stony Brook University

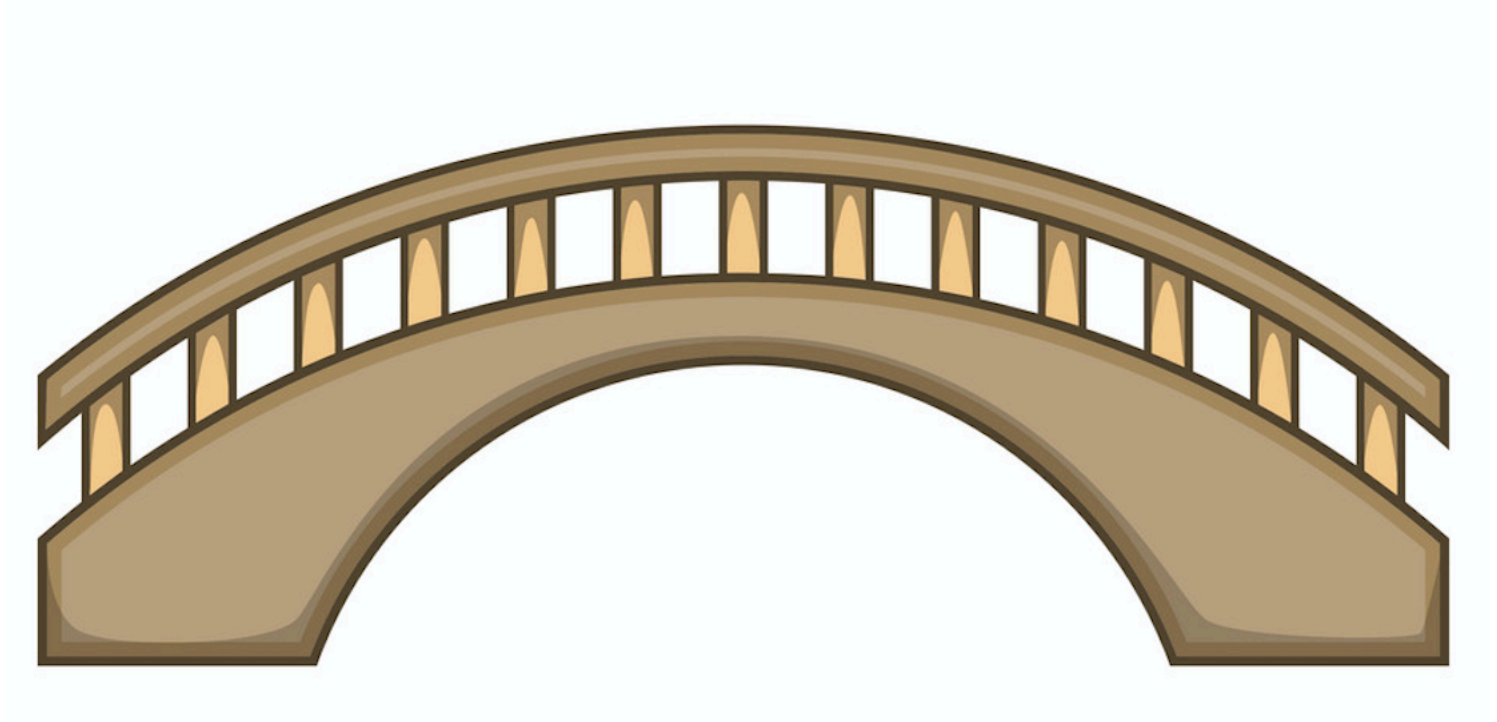
PPC 2022

Washington University in St. Louis

June 8, 2022

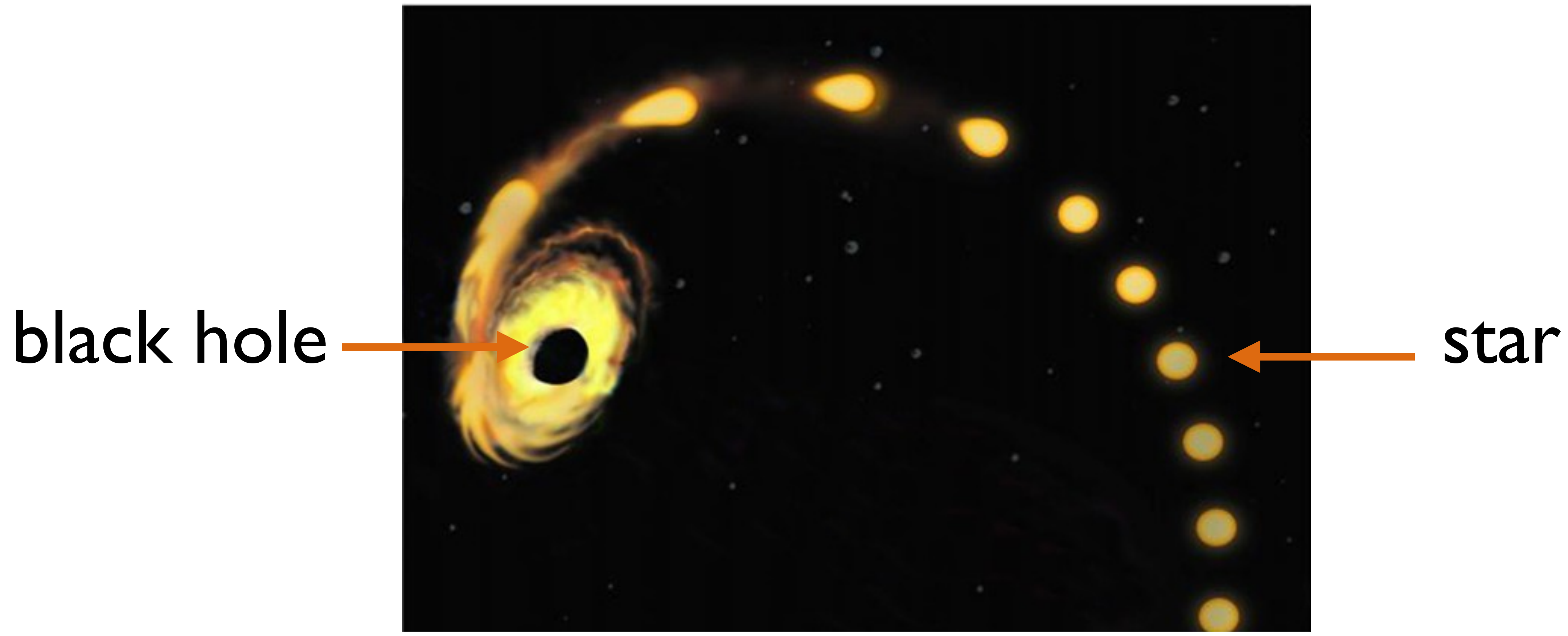
in collaboration with Daniel Egana-Ugrinovic, Rouven Essig, Giacomo Fragione and Rosalba Perna

(arXiv:2202.01215)

Astrophysics  BSM physics

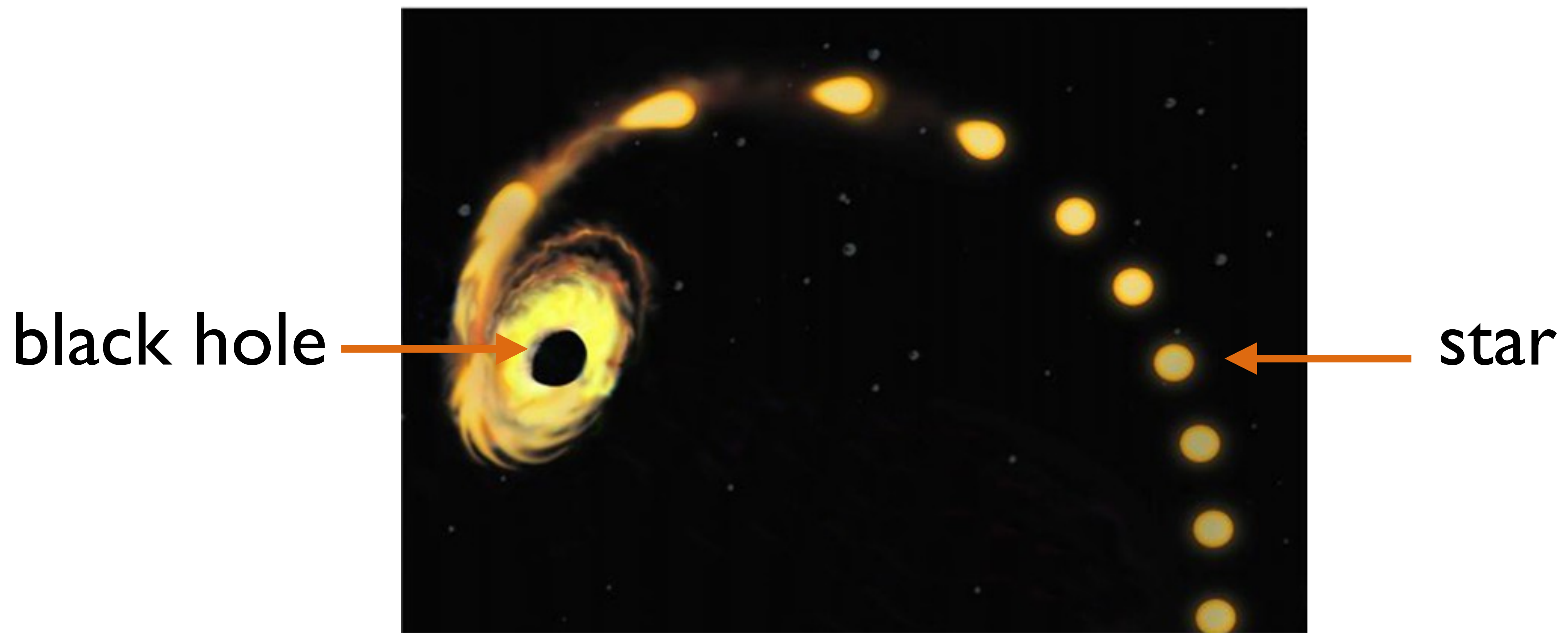
Astrophysics

Tidal disruption events



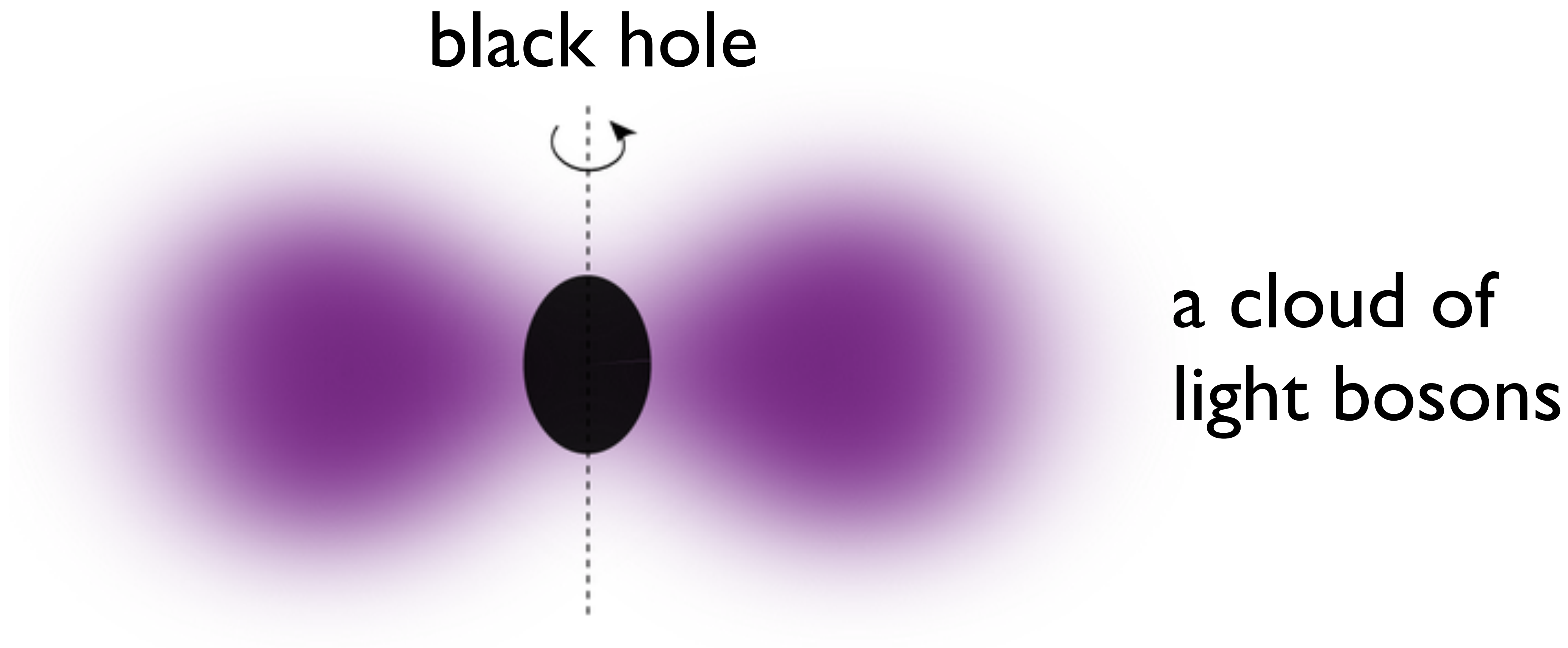
Astrophysics

Tidal disruption events



BSM physics

Ultra-light bosons: axions, dark photon…

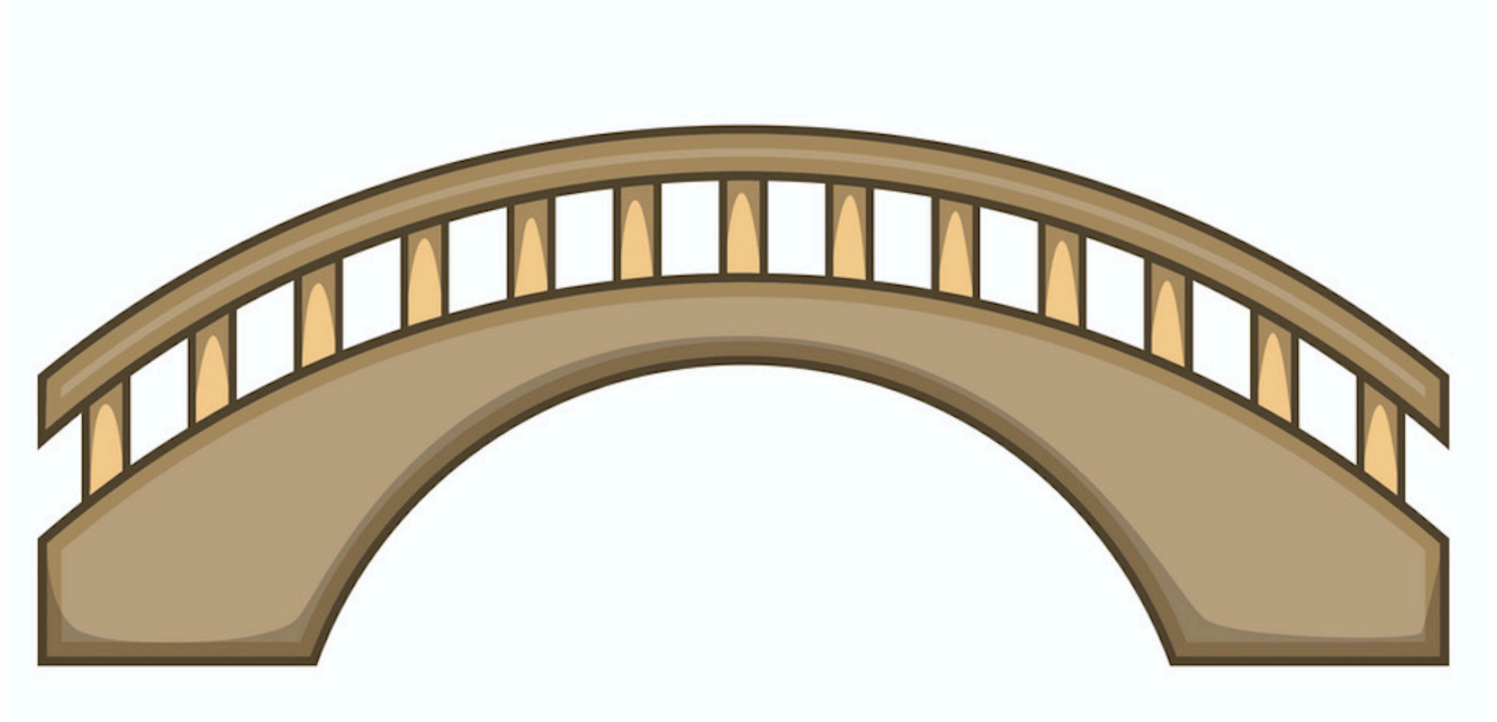


Astrophysics

Tidal disruption events

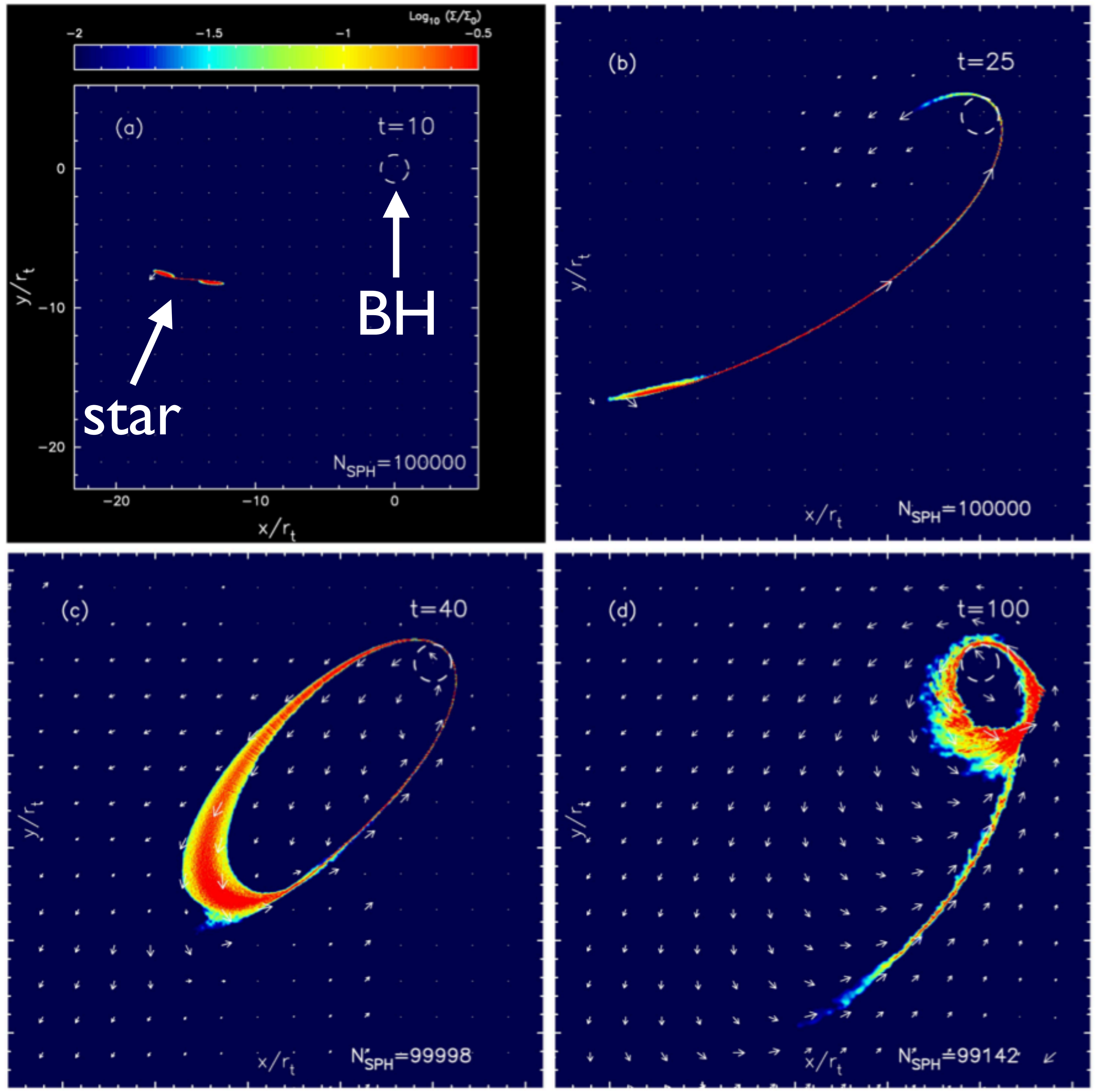
BSM physics

Ultra-light bosons: axions, dark photon…

Astrophysics  BSM physics

Tidal disruption events

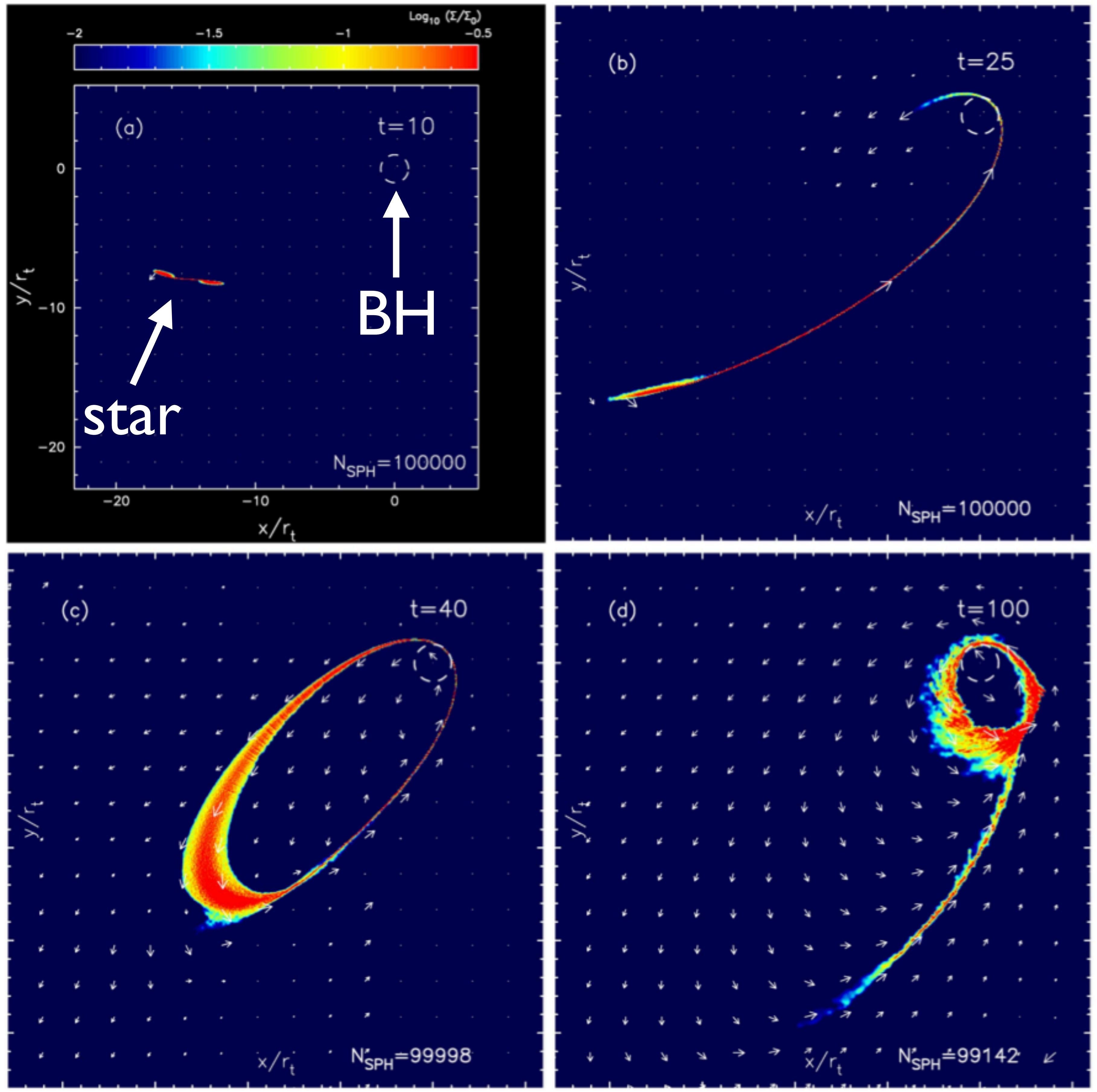
Stars passing close to SMBH can be tidally disrupted by strong tidal forces



Hayasaki, Stone, Loeb, 2016

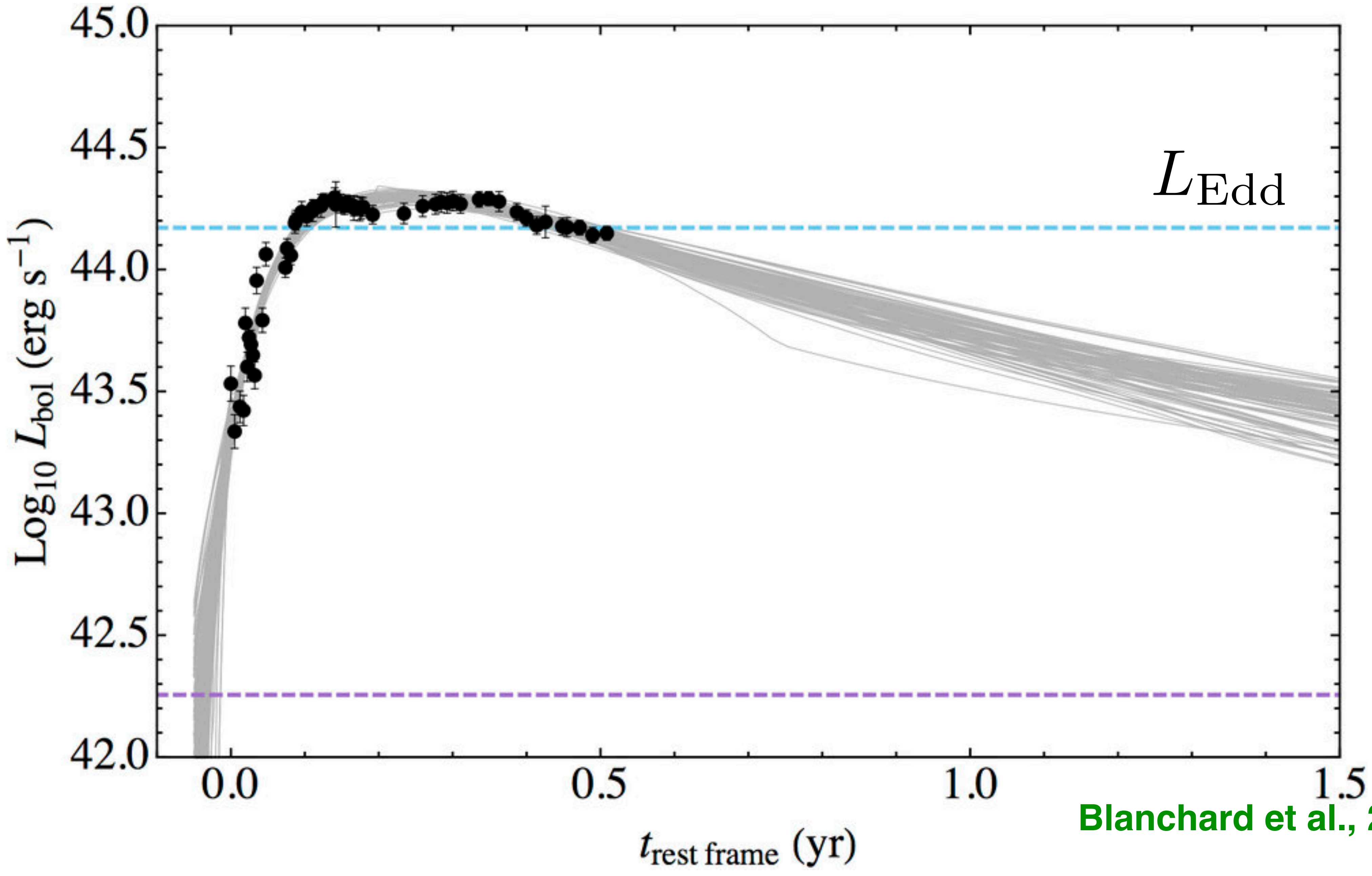
Tidal disruption events

Stars passing close to SMBH can be tidally disrupted by strong tidal forces



Hayasaki, Stone, Loeb, 2016

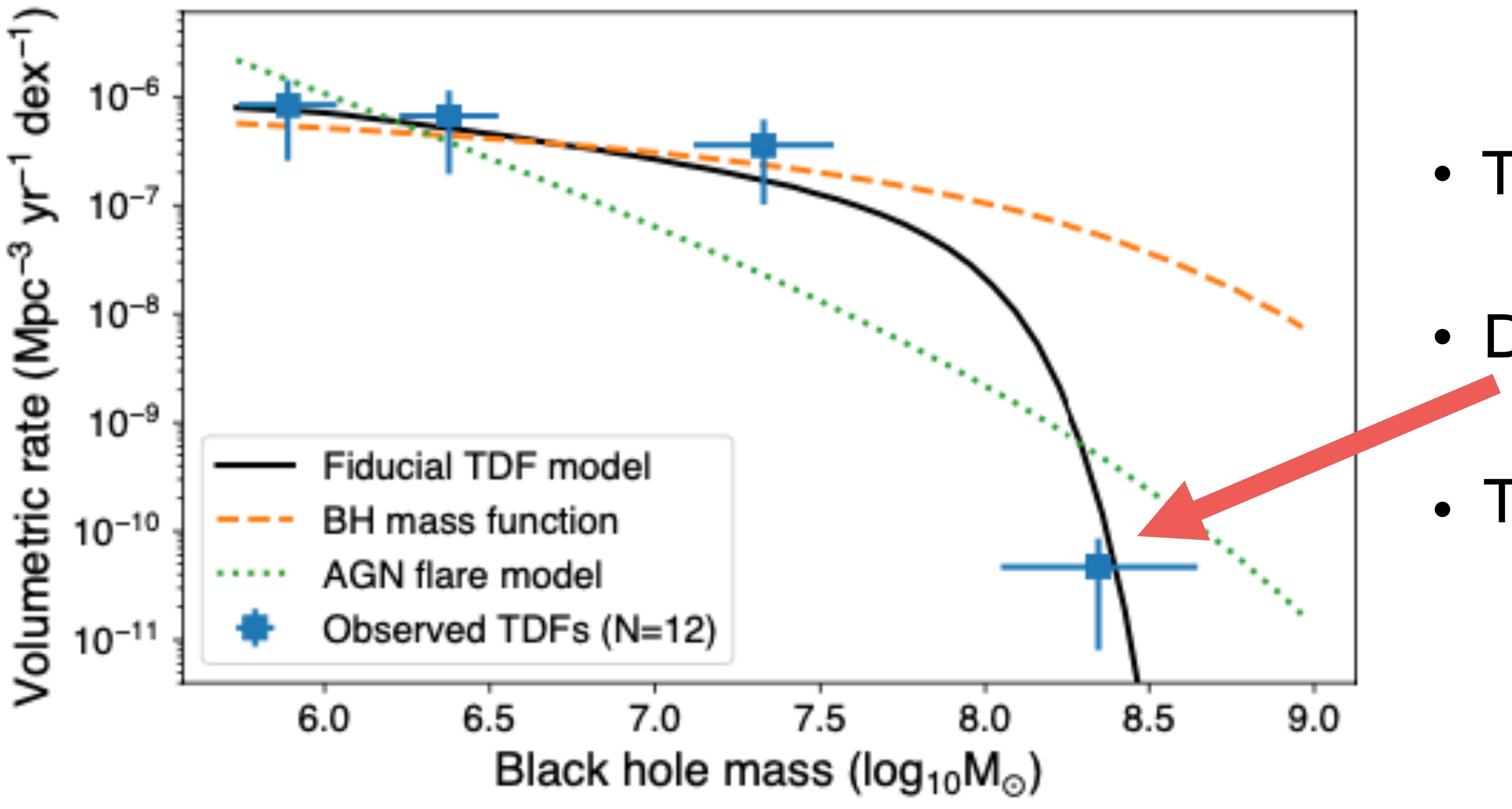
TDE light curve from accretion



Blanchard et al., 2017

- Bright transient events that last O(year)
- Optical to X ray spectrum

TDE rates

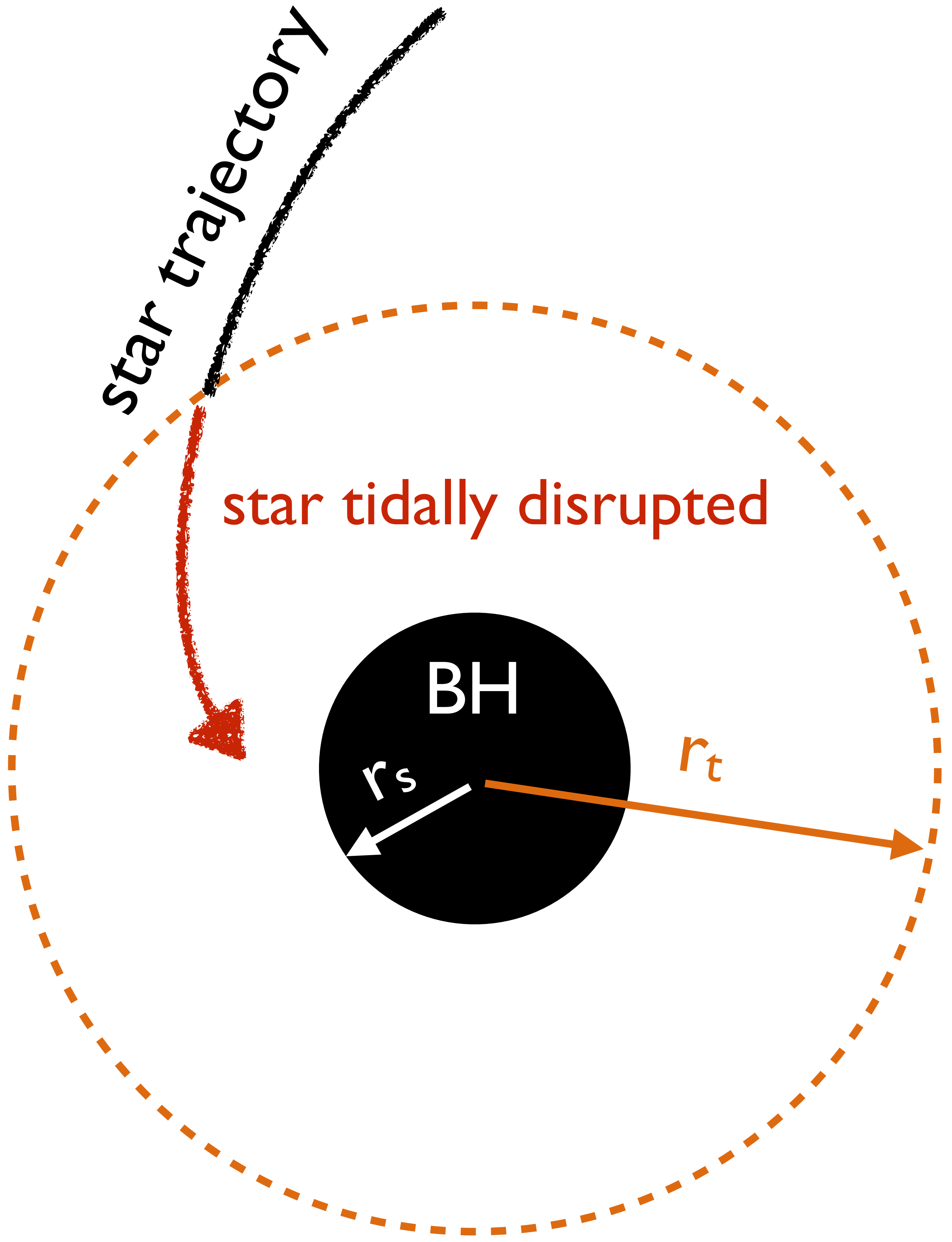


van Velzen, 2018

- Typical rate: $\sim 10^{-4}/\mathrm{galaxy}/\mathrm{yr}$
- Distinct features of TDE: sharp drop at large BH mass
- This drop also depends on BH spin

Hills mass for TDE

Hills, 1975



- TDE happens when the star falls inside tidal radius

Tidal radius: $$r_t \equiv R_* \left(\frac{M_{\rm BH}}{M_*}\right)^{1/3}$$

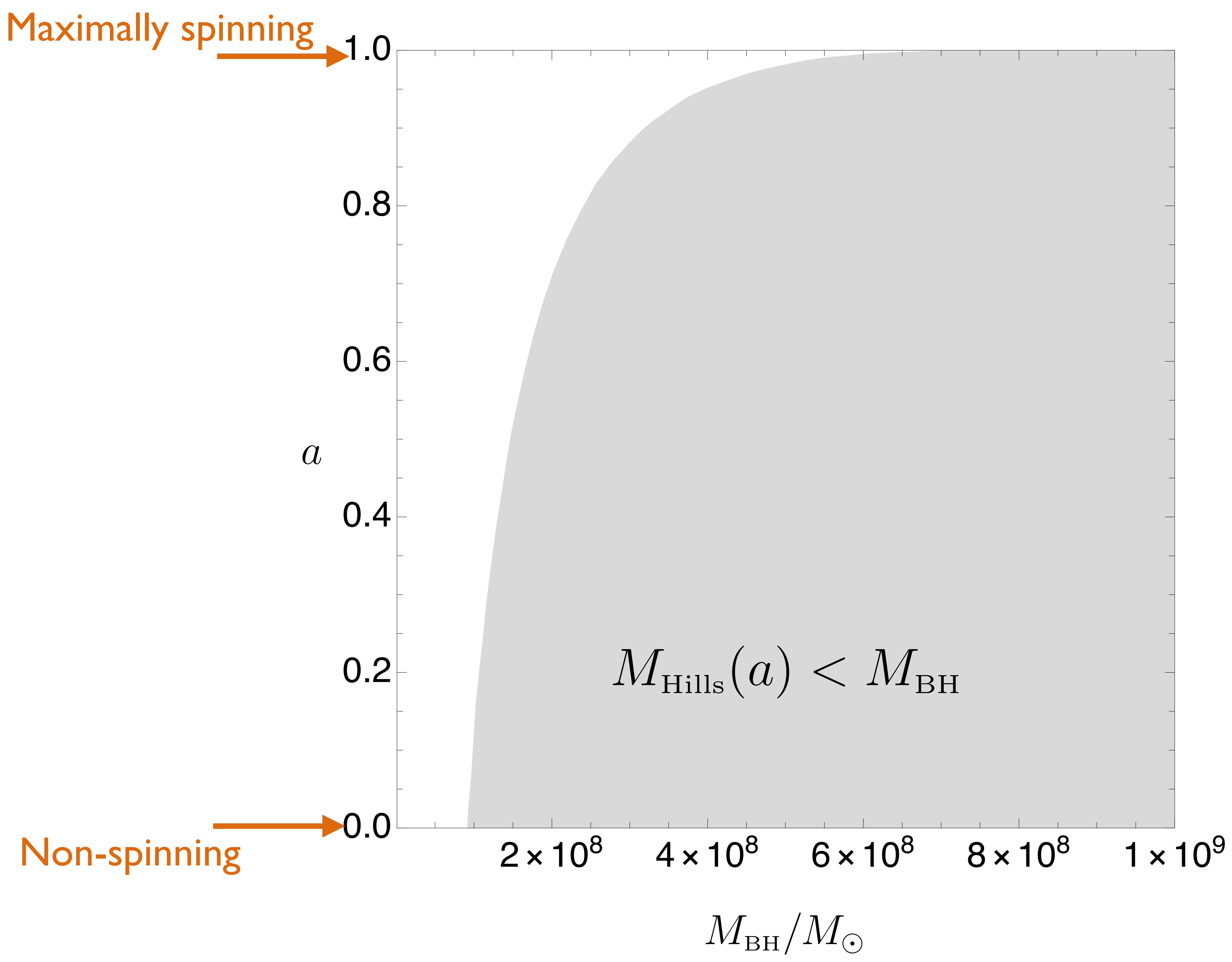
Schwarzschild radius: $$r_s \equiv 2GM_{\rm BH}$$

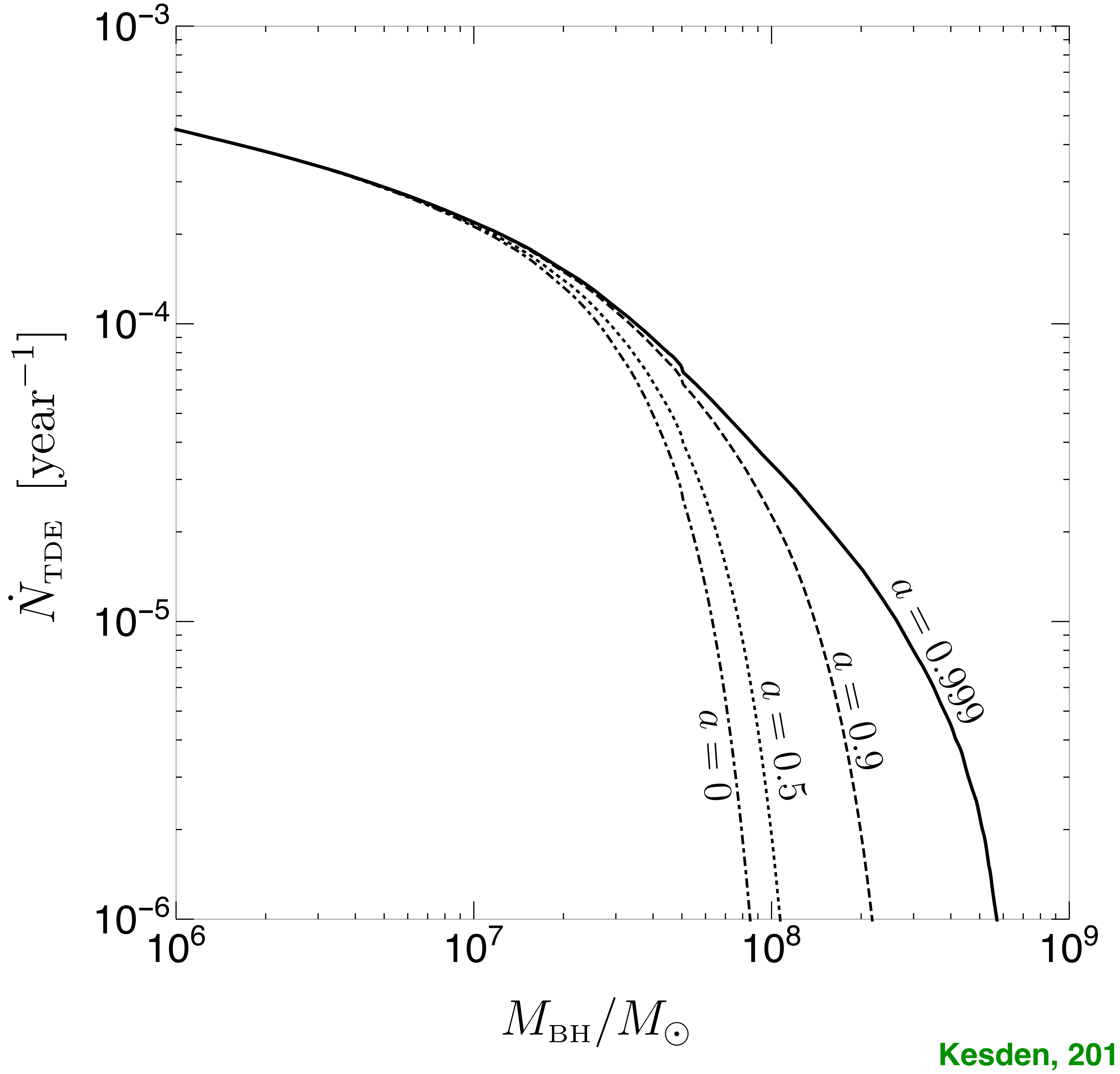
- No observed TDE if $r_s \geq r_t$

$$M_{\rm BH} \geq M_{\rm Hills} \sim 10^8 M_\odot \left[\frac{M_*}{M_\odot}\right]^{-1/2} \left[\frac{R_*}{R_\odot}\right]^{3/2}$$

Hills mass and black hole spin

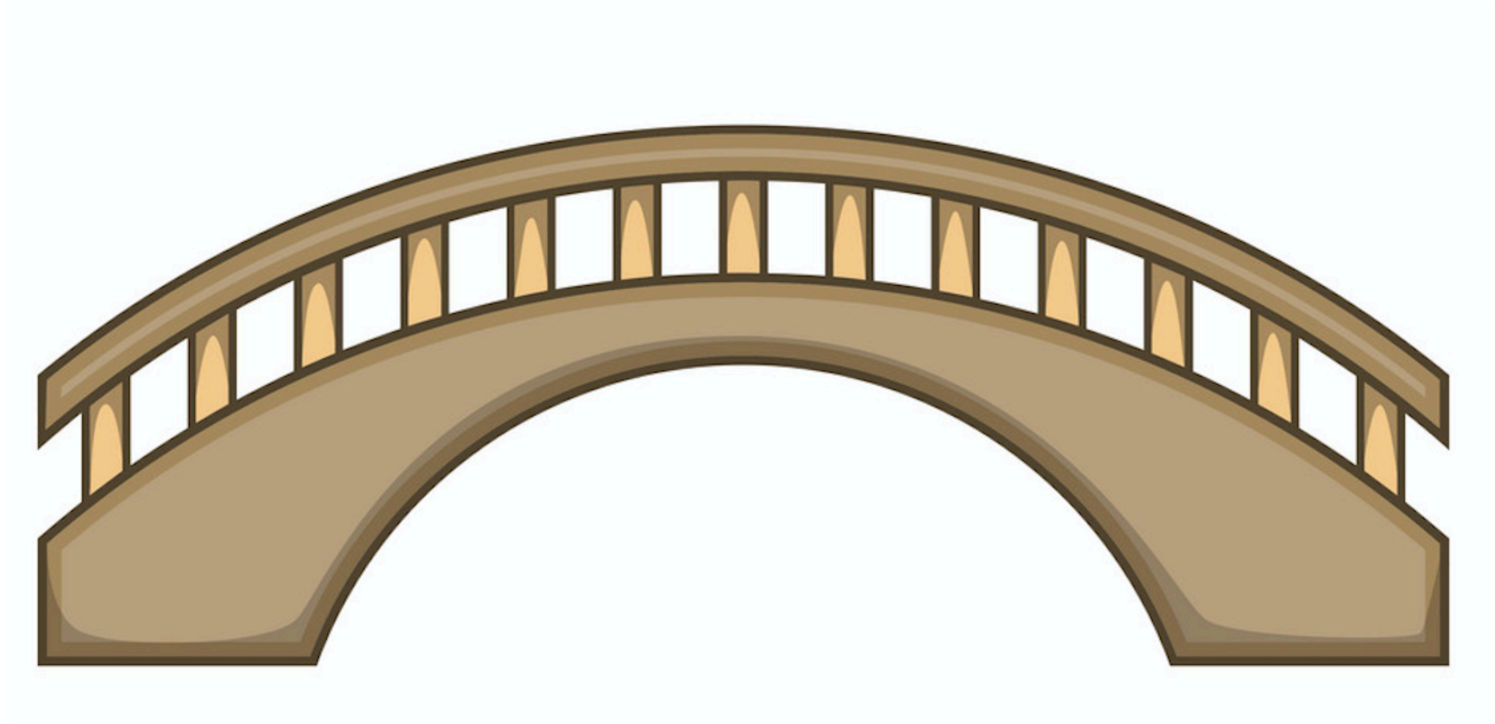
- The horizon and r_t varies with the BH spin, so M_{Hills} depends on BH spin





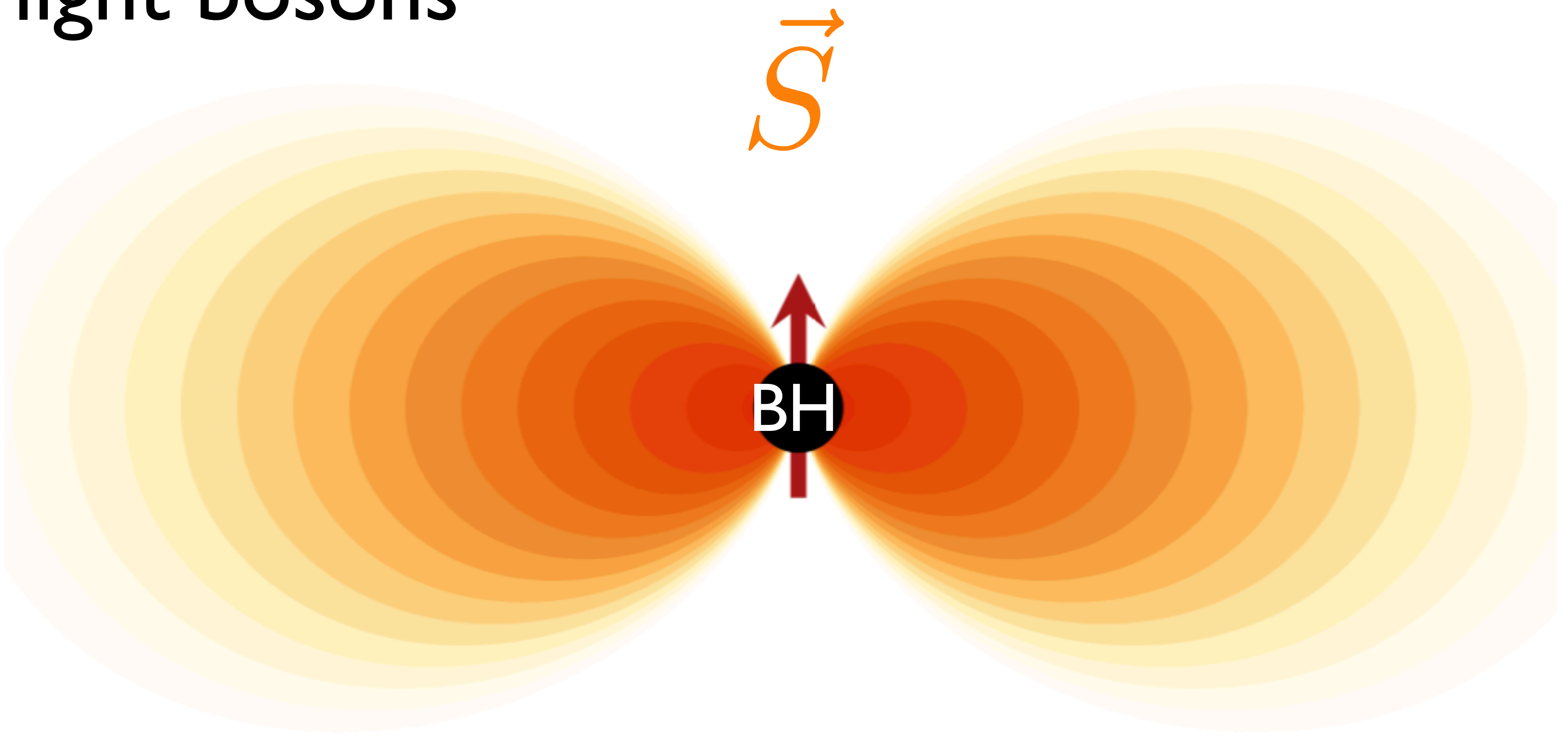
Kesden, 2012

- Measuring TDE rates can determine the BH spin distribution!

Astrophysics  BSM physics

Ultralight bosons and BH superradiance

a cloud of
light bosons



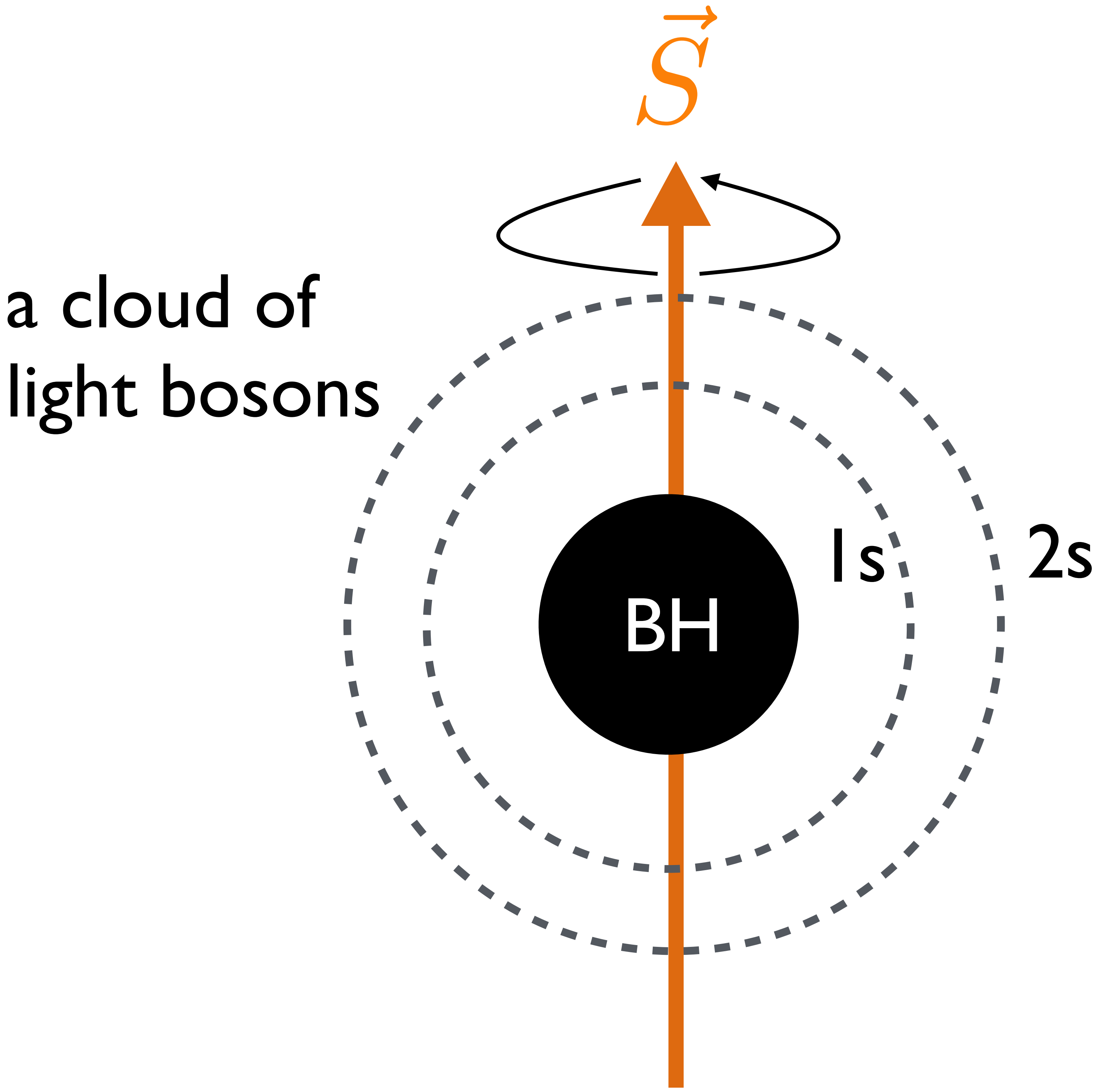
- Large number of light bosons can be produced from rotating BH

Superradiance condition: $\frac{\mu}{m} \leq \Omega_{\mathrm{BH}}$

μ: the mass of the boson

m: the magnetic quantum number

Ultralight bosons and BH superradiance



- Large number of light bosons can be produced from rotating BH

Superradiance condition: $\frac{\mu}{m} \leq \Omega_{\rm BH}$

μ: the mass of the boson

m: the magnetic quantum number

- "Gravitational Atom"

gravitational coupling: $\alpha \equiv G\mu M_{\rm BH}$

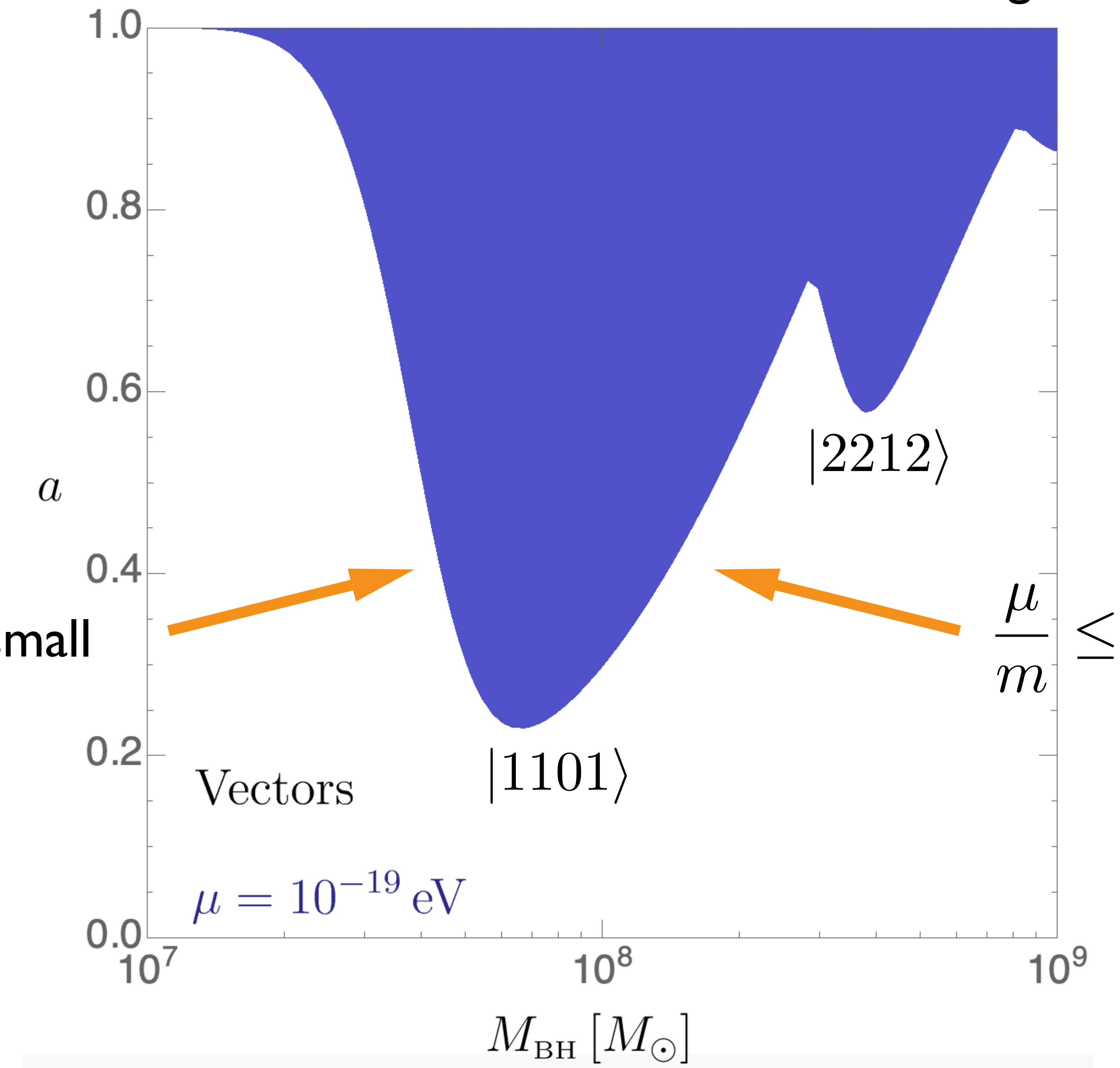
energy levels label by $|njlm\rangle$

BH superradiance

Baryakhtar, Lansenby, Teo, 2017
Baumann, Sheng Chia, Stout, Harr, 2019

- Existence of light bosons spin BHs down due to superradiance

small α   large α



superradiant rate too small

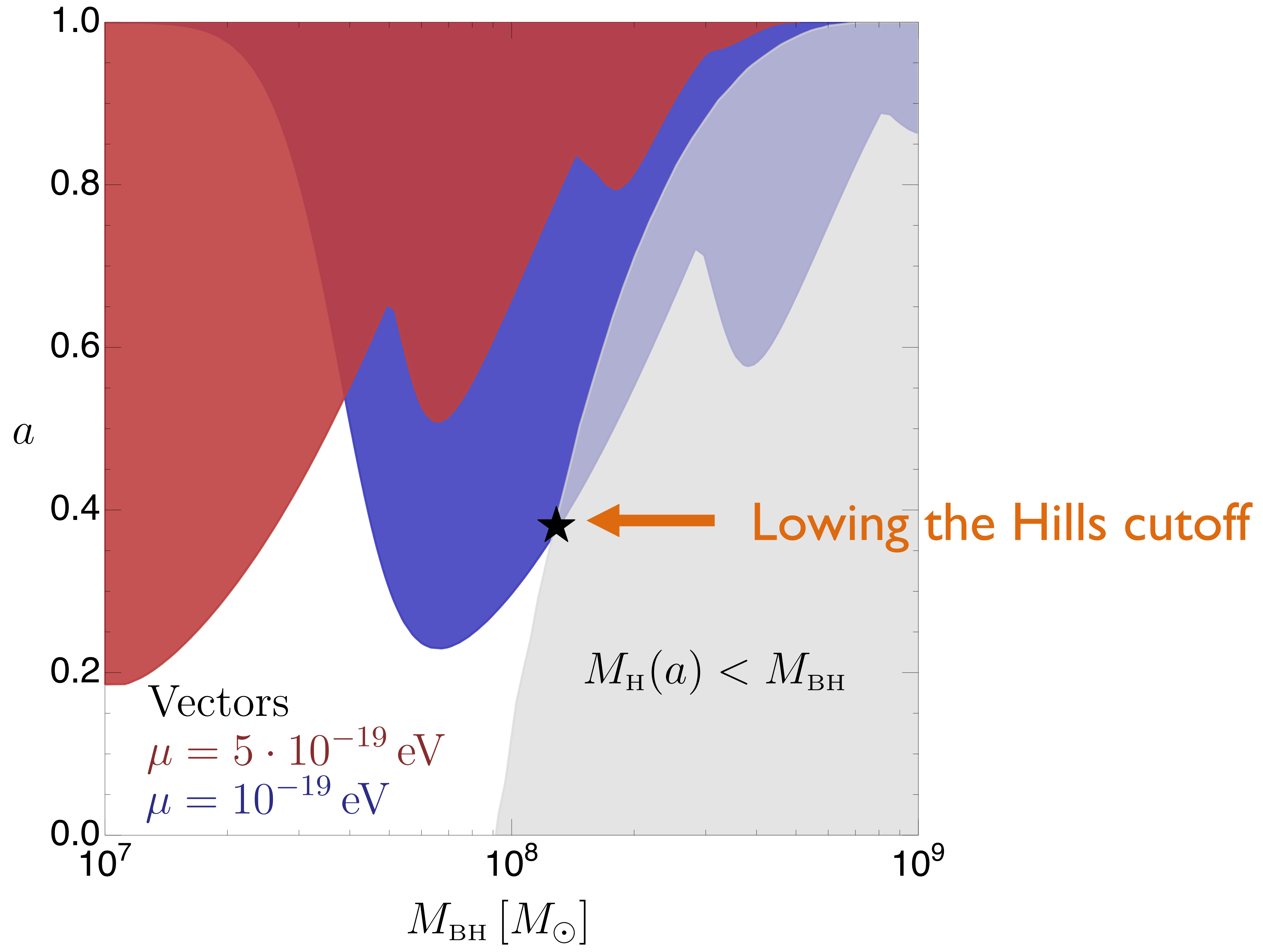
$\Gamma \propto \alpha^6$

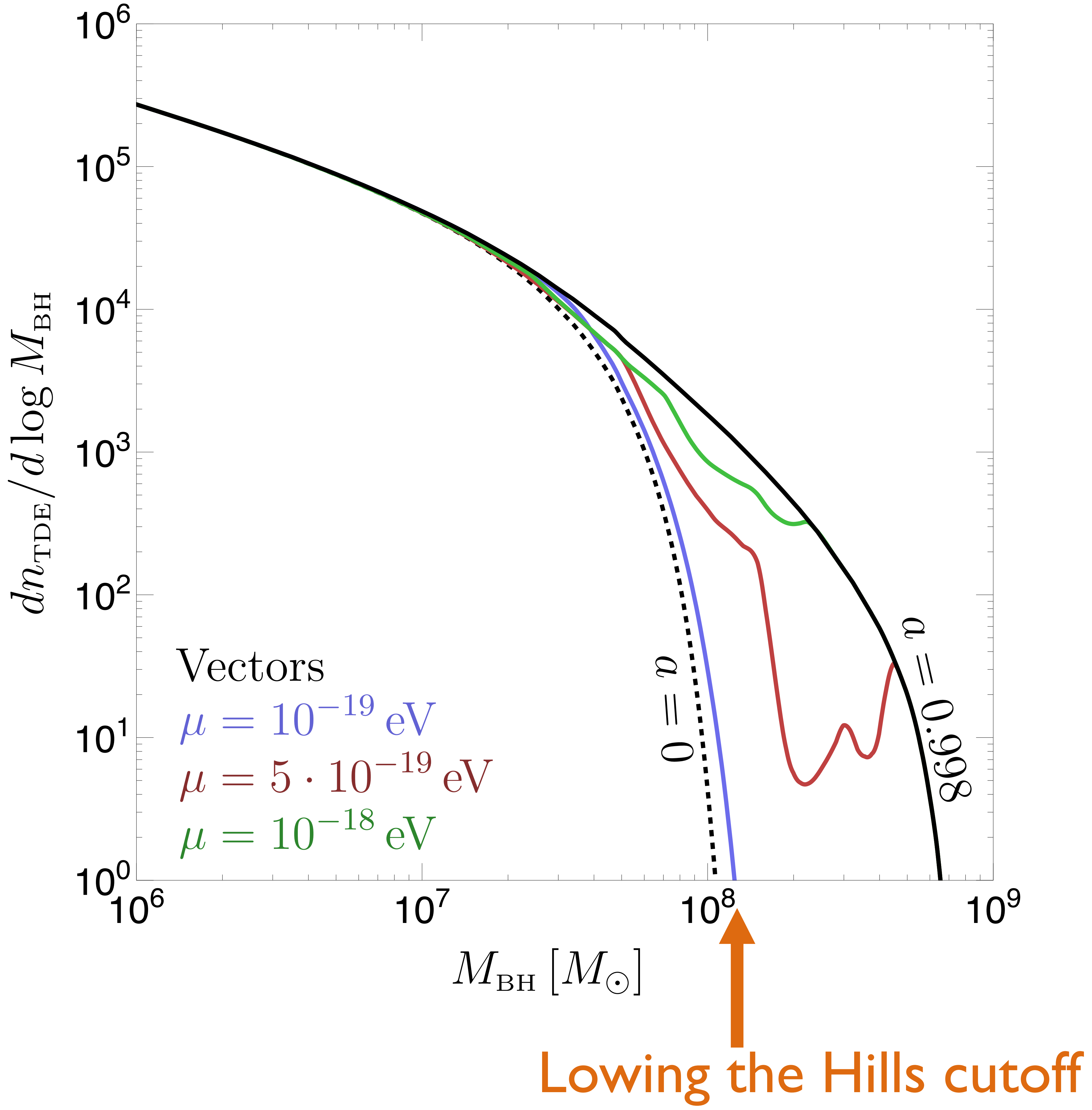
$$\frac{\mu}{m} \leq \Omega_{\rm BH}$$

- Best sensitivity if $\alpha \sim 0.1 - 1$

BH superradiance and TDE rate

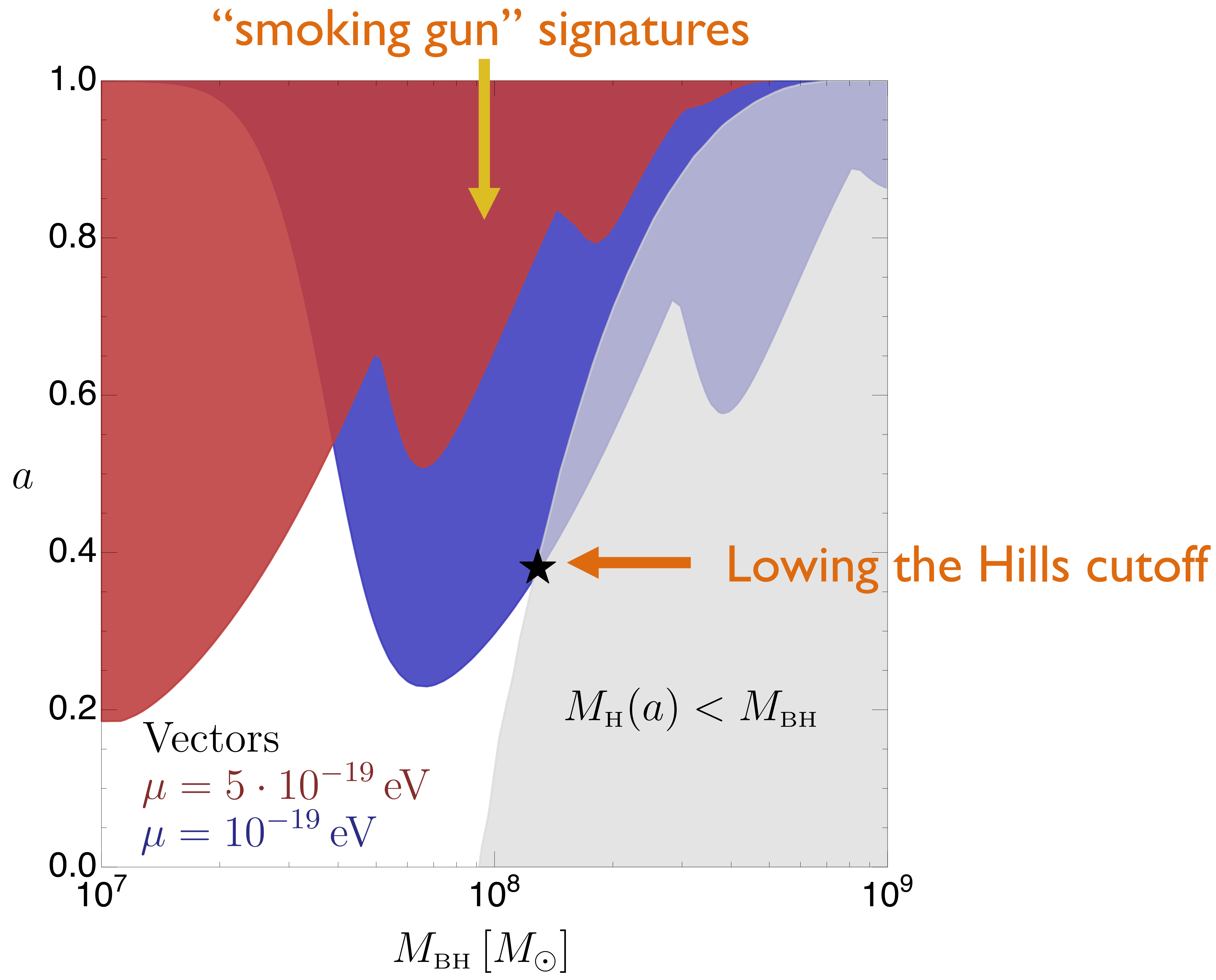
PD, Egana, Essig, Fragione, Perna 2022

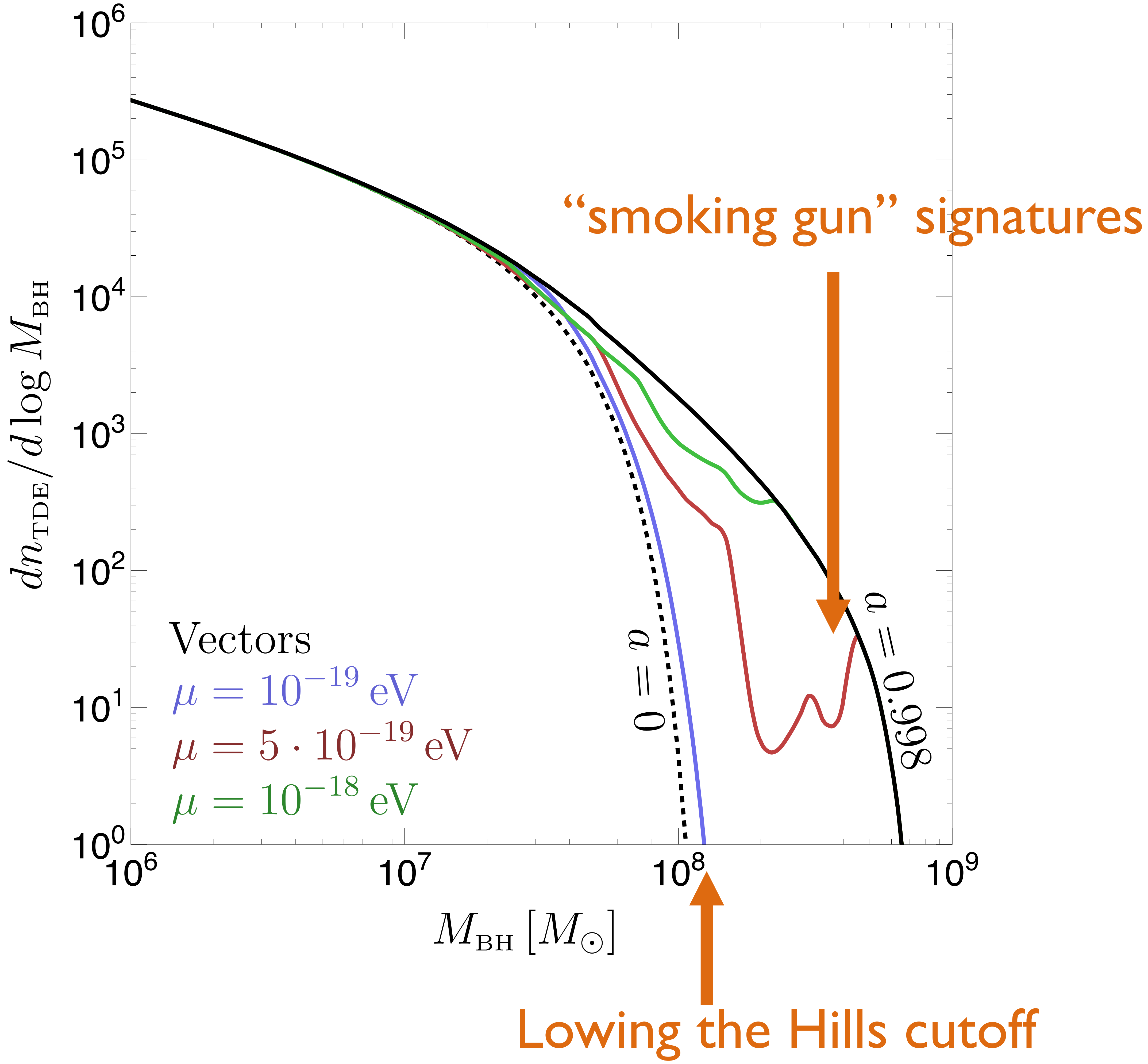




BH superradiance and TDE rate

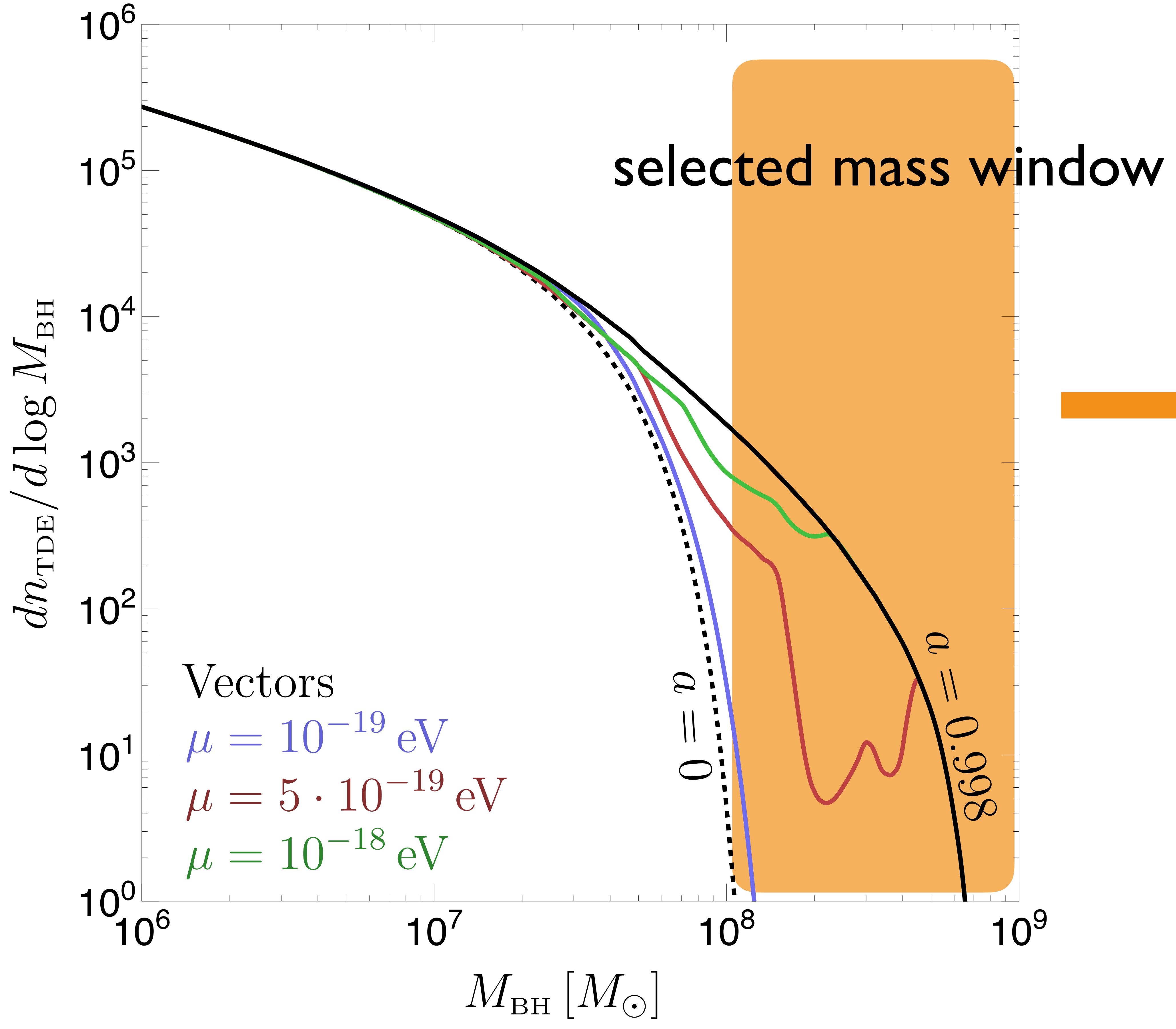
PD, Egana, Essig, Fragione, Perna 2022

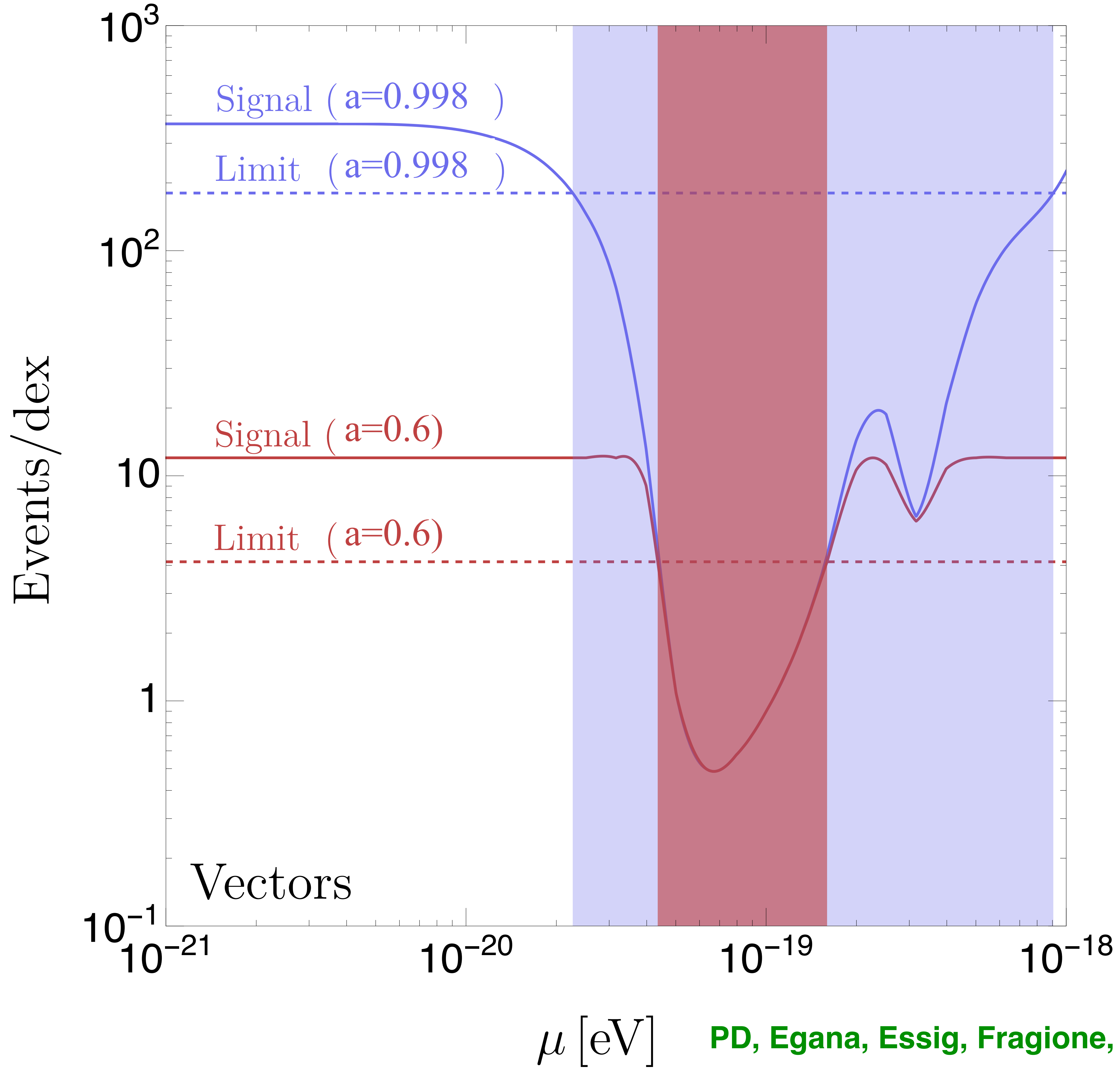




Projected limits from VRO LSST

- VRO LSST is expected to observe up to O(10^5) TDEs! Bricman,Gomboc 2020





PD, Egana, Essig, Fragione, Perna 2022

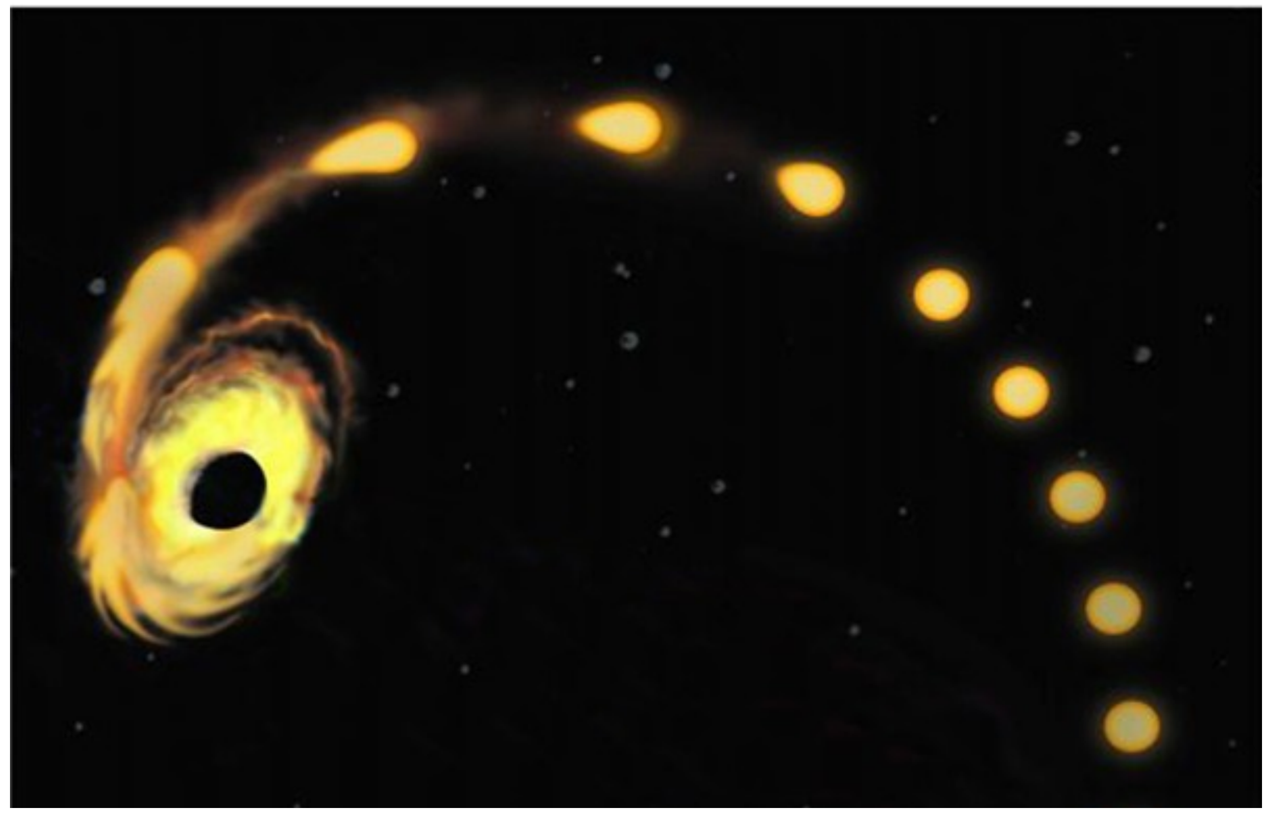
Conclusions

Astrophysics

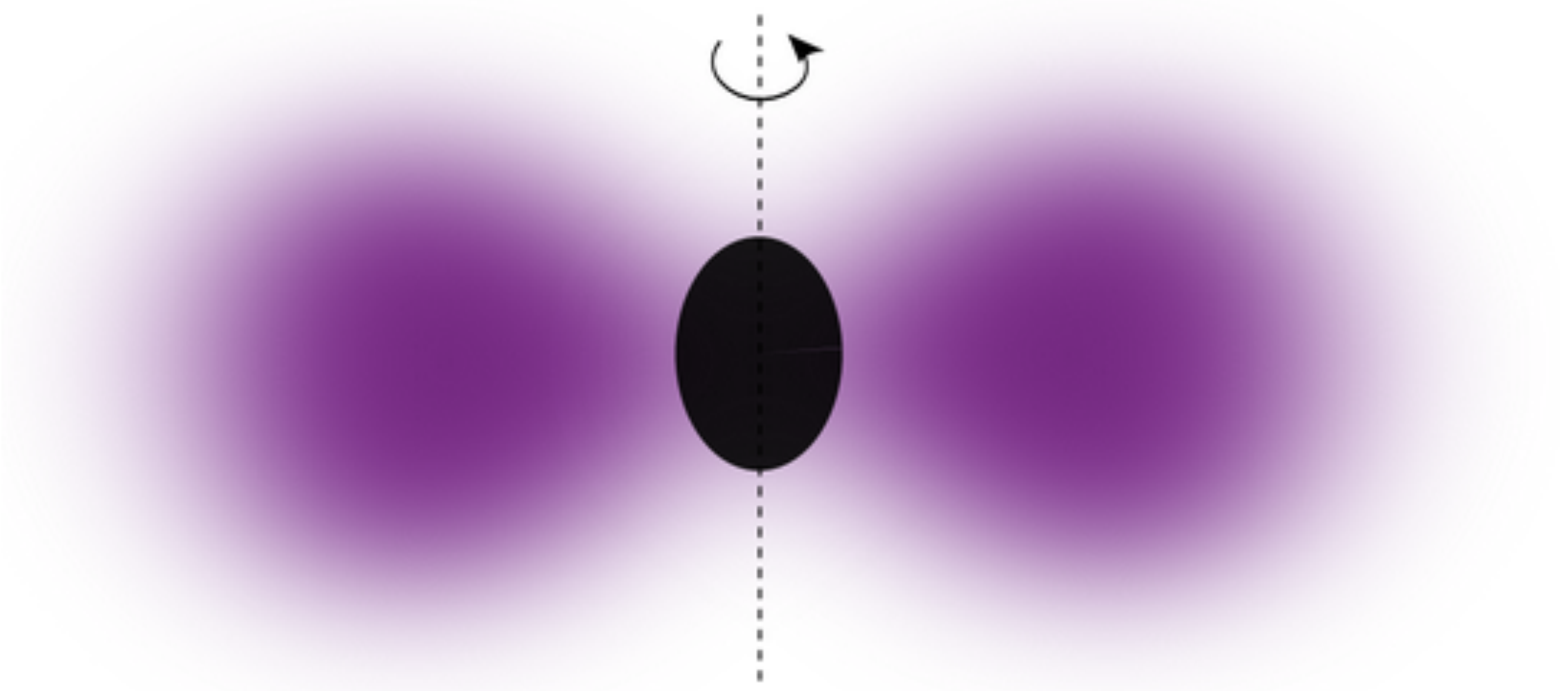
Tidal disruption events

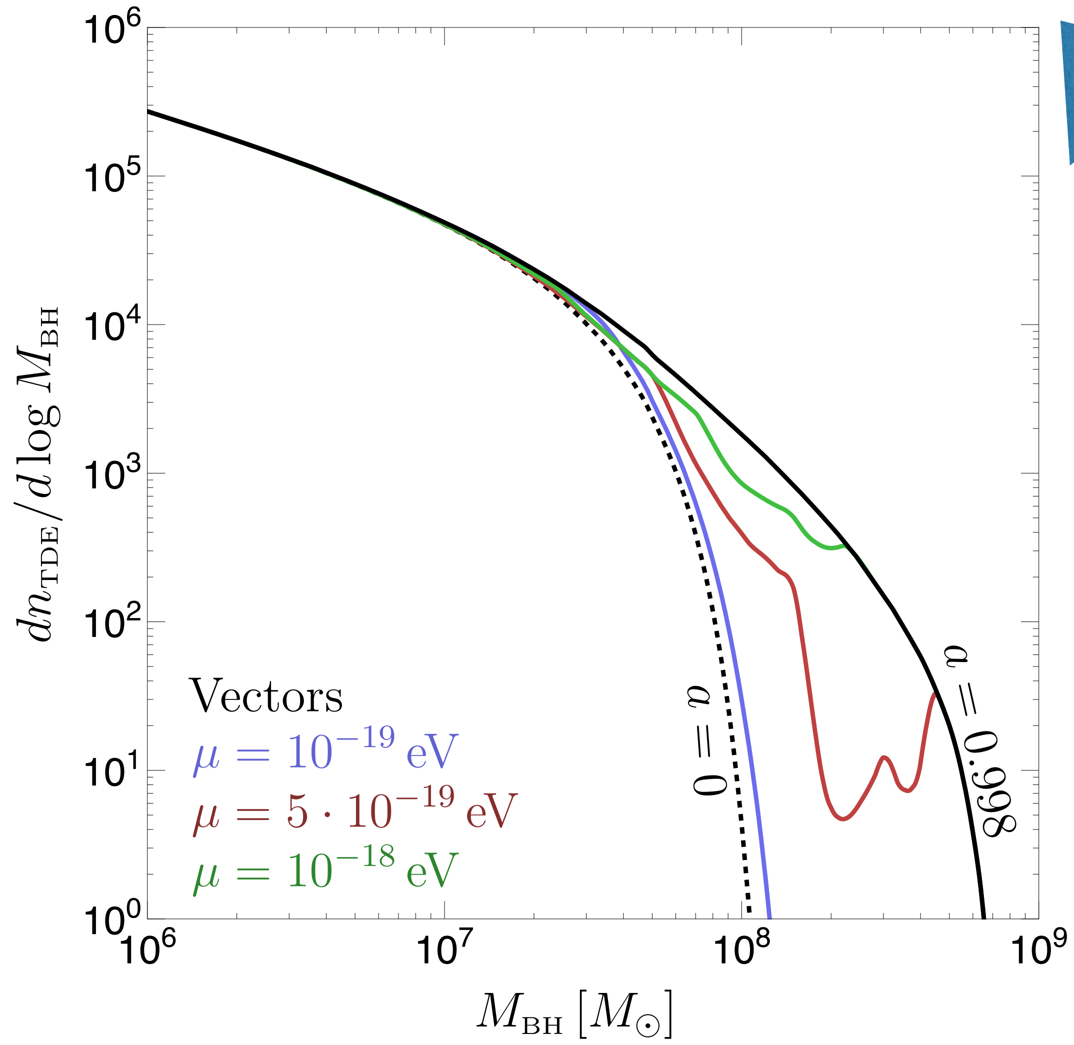
BSM physics

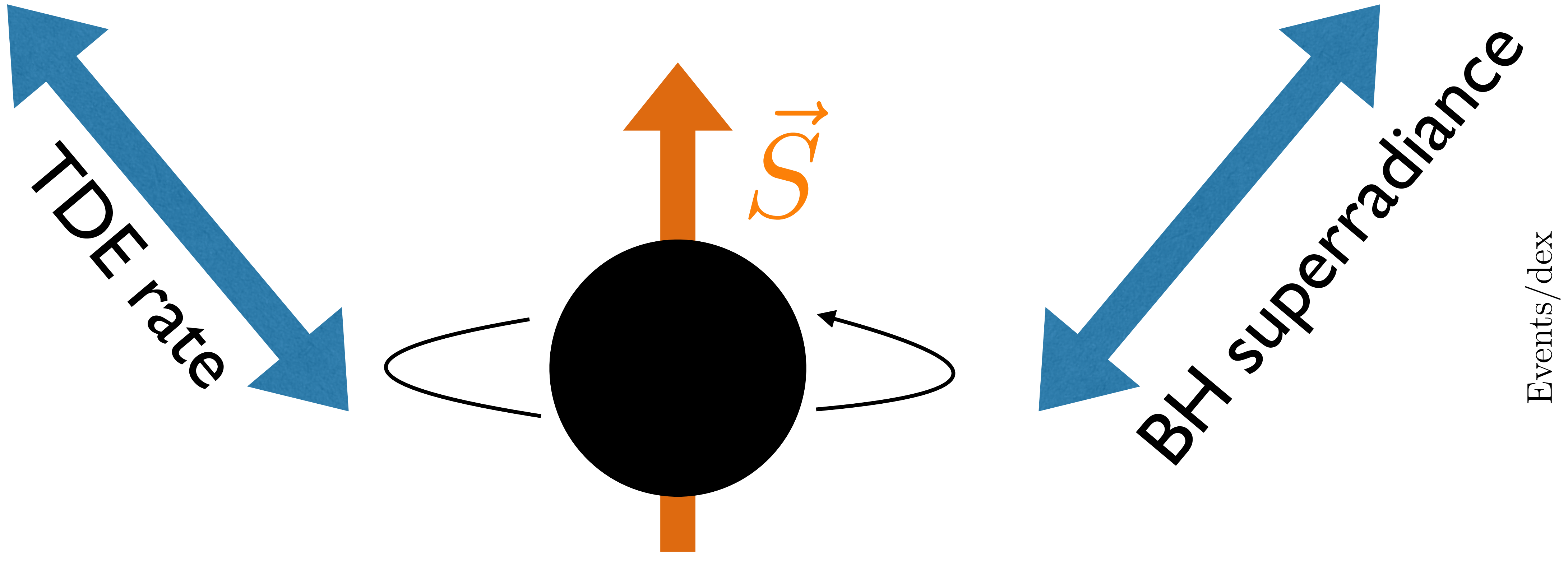
Ultra-light bosons: axions, dark photon…



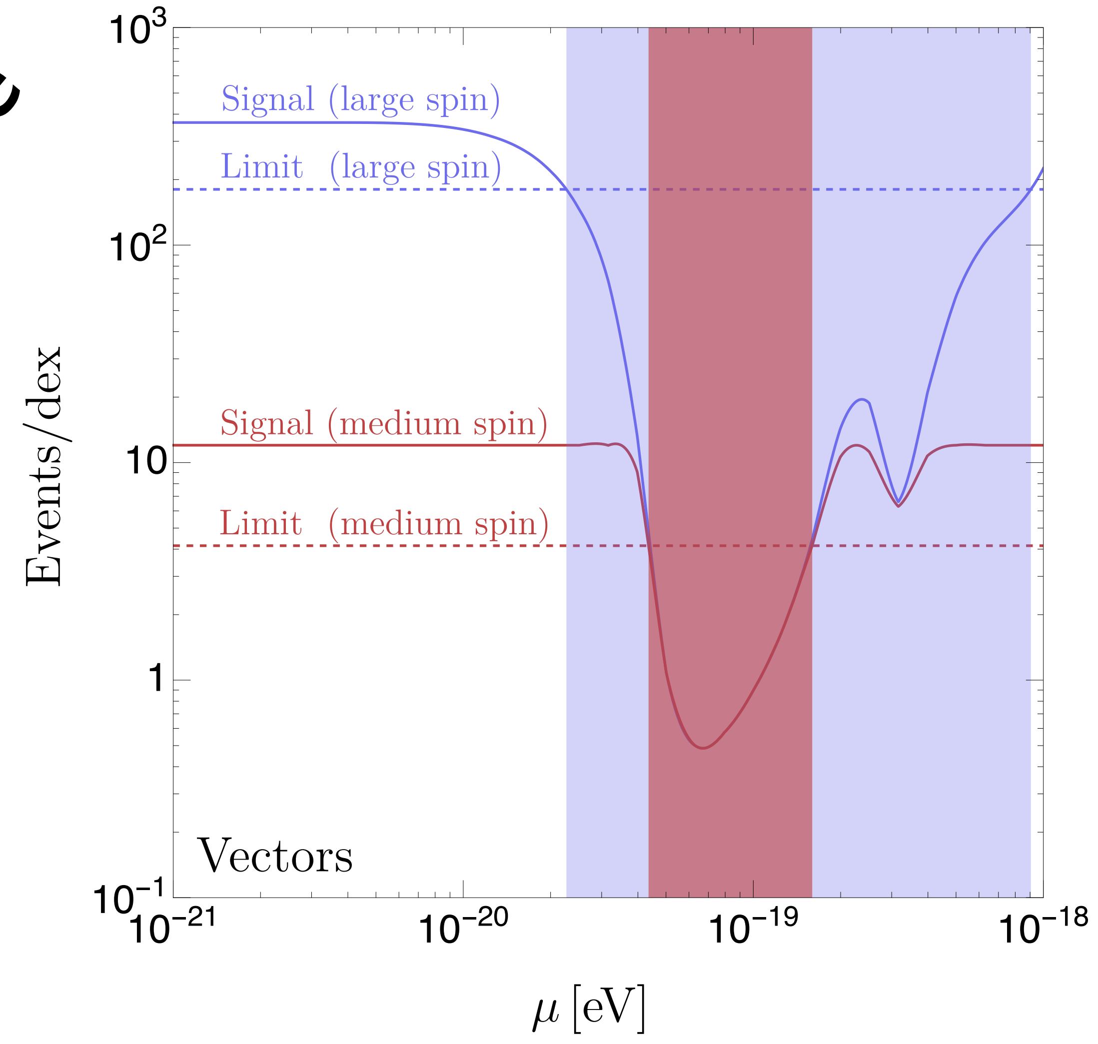
black hole







Black hole spin



Systematic Uncertainties

- Theoretical:

  Spin dependent TDE rate

  BH mass distribution

  dependence on star mass and radius

- Experimental:

  Identifying TDE

  BH mass measurement

- In this work, we take 50% systematic uncertainties in the projection.