PROBING ULTRA-LIGHT BOSONS WITH STELLAR TIDAL DISRUPTIONS

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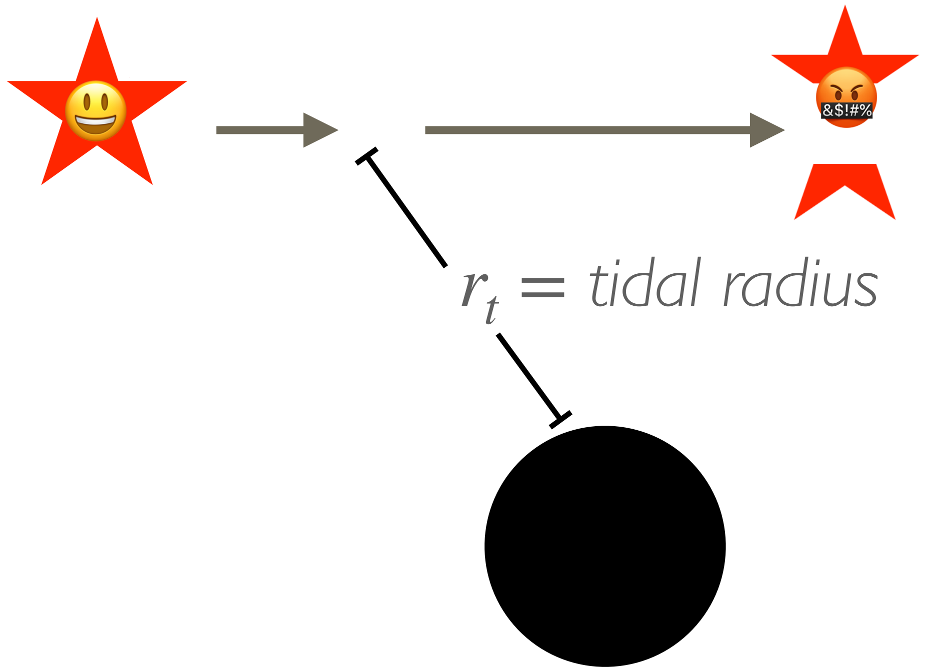
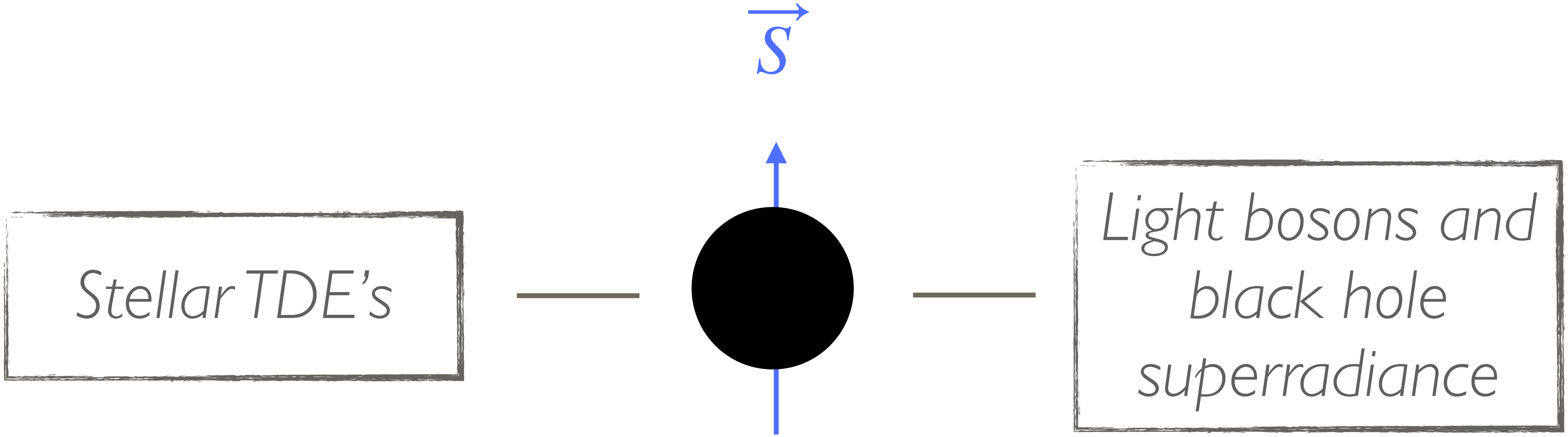
STELLAR TIDAL DISRUPTION EVENTS

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



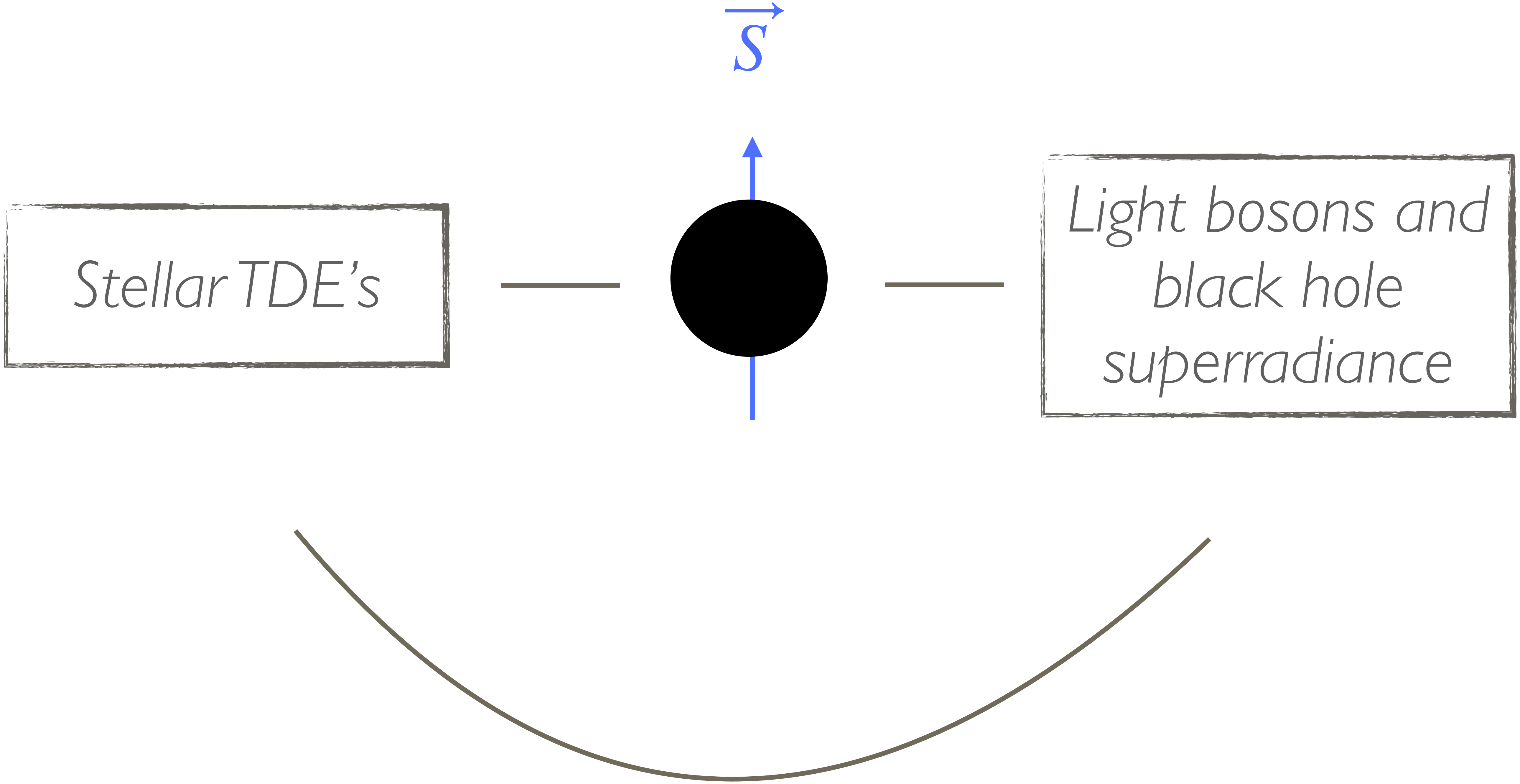
r_t = *tidal radius*

Stellar TDE’s



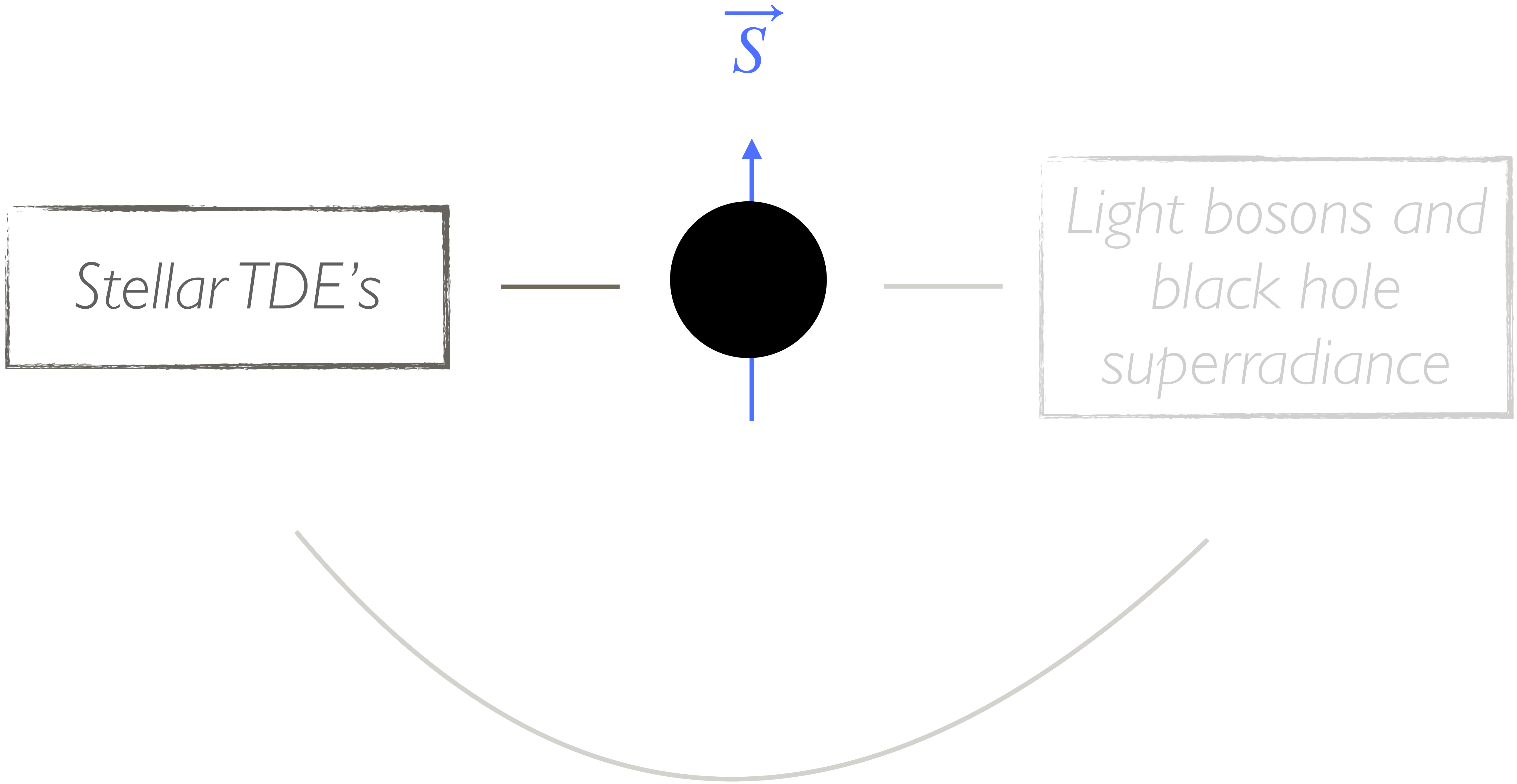
Stellar TDE's

Light bosons and black hole superradiance



Stellar TDE's

Light bosons and black hole superradiance

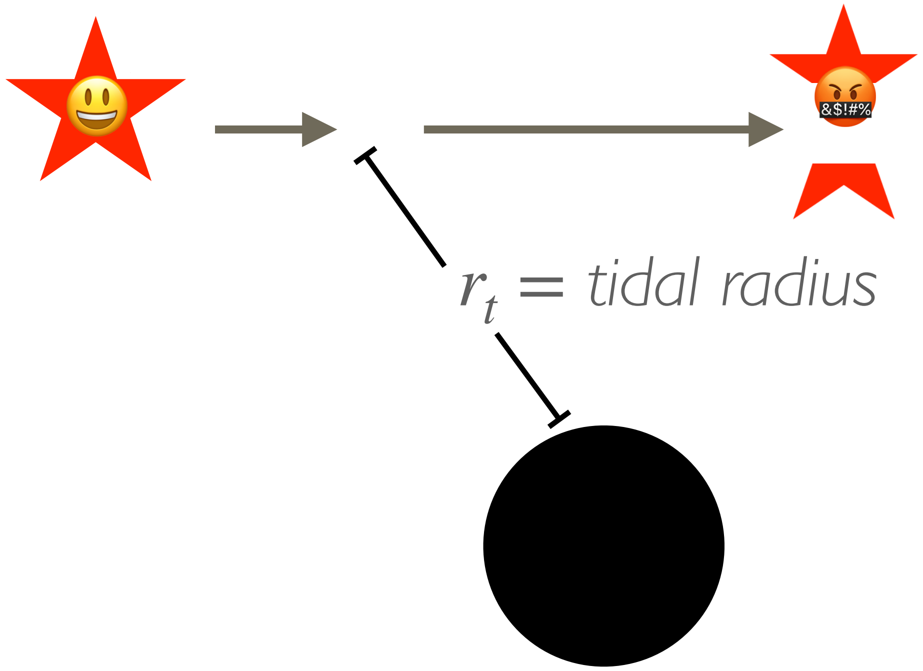


Stellar TDE’s

Light bosons and black hole superradiance

STELLAR TIDAL DISRUPTION EVENTS

- Stars passing close to SMBH's in the center of galaxies can be disrupted by strong tidal forces

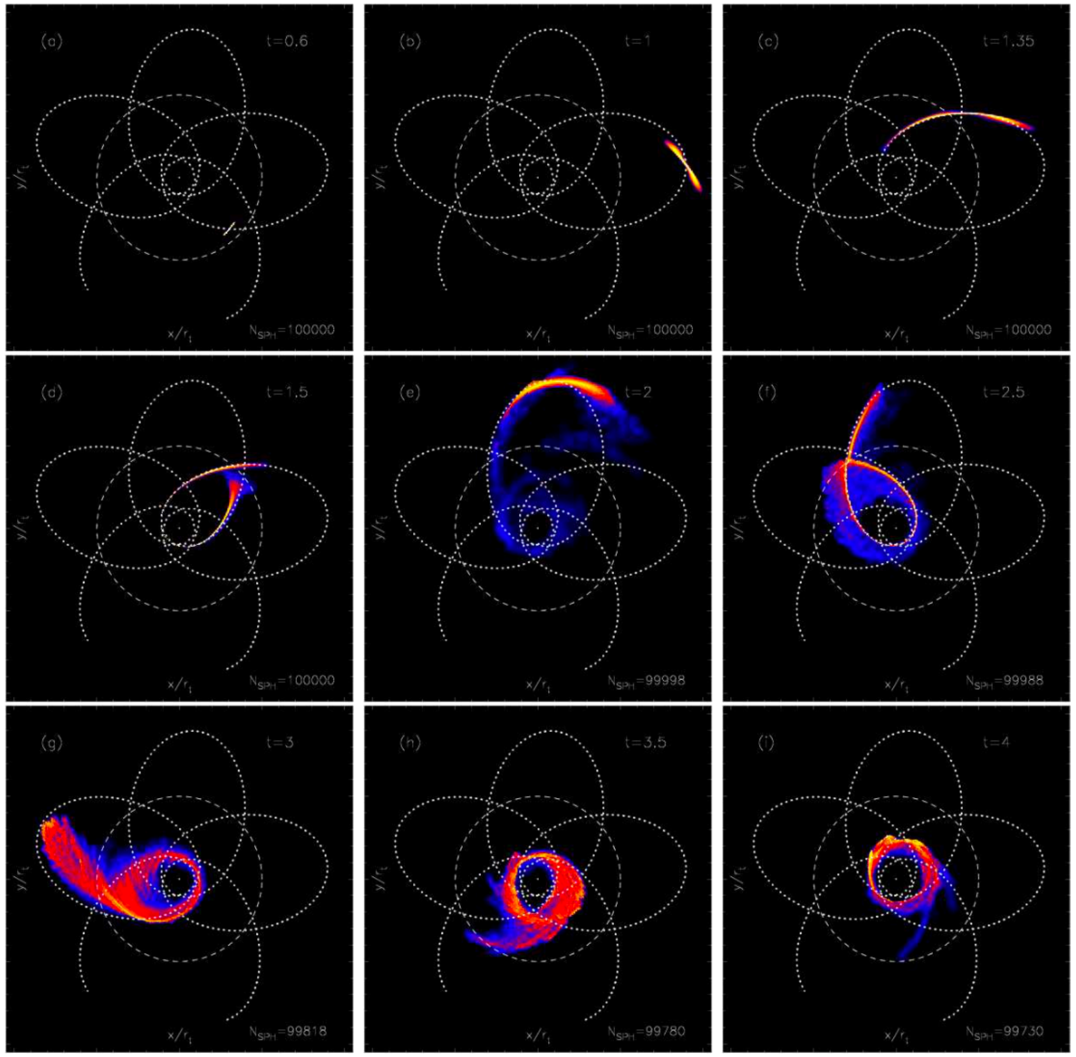


$$r_t = R_\star \left(\frac{M_{\mathrm{BH}}}{M_\star}\right)^{1/3} \sim 10^{-6}\ \mathrm{pc}$$

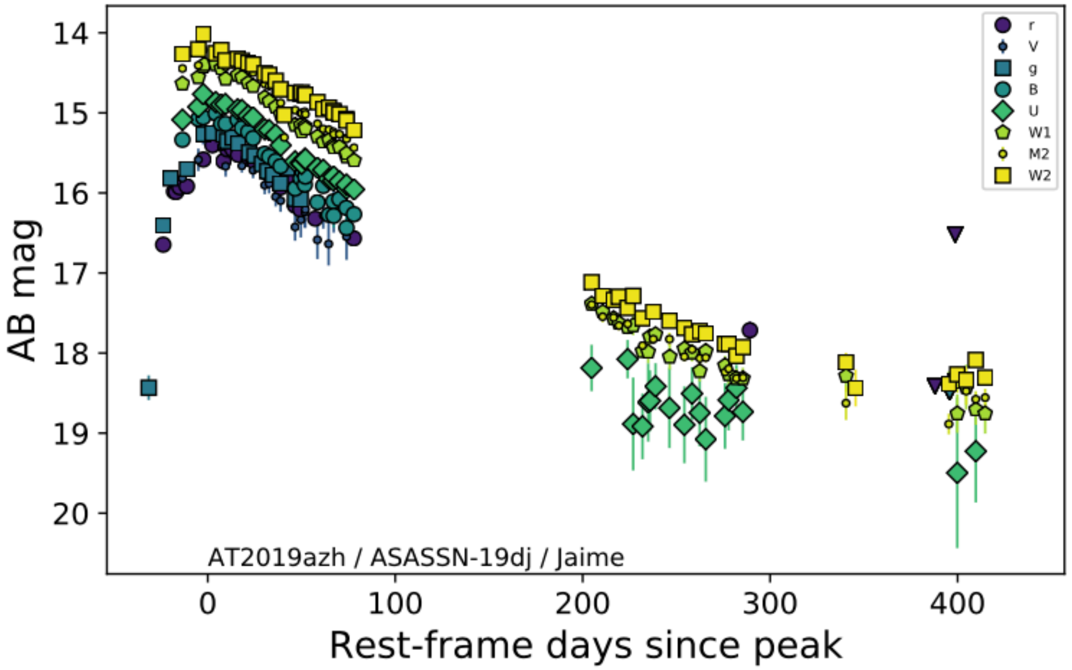
- The disruption is followed by a bright flare due to subsequent accretion of the stellar gas into the black hole

STELLAR TIDAL DISRUPTION EVENTS

Hayasaki et al. 1501.05207



van Velzen et al. 2001.01409
ZTF survey



$L_{bb} = 10^{43}$ *erg/s* (peak)

This behavior was *predicted*

(Martin Rees, Nature 333 91988)

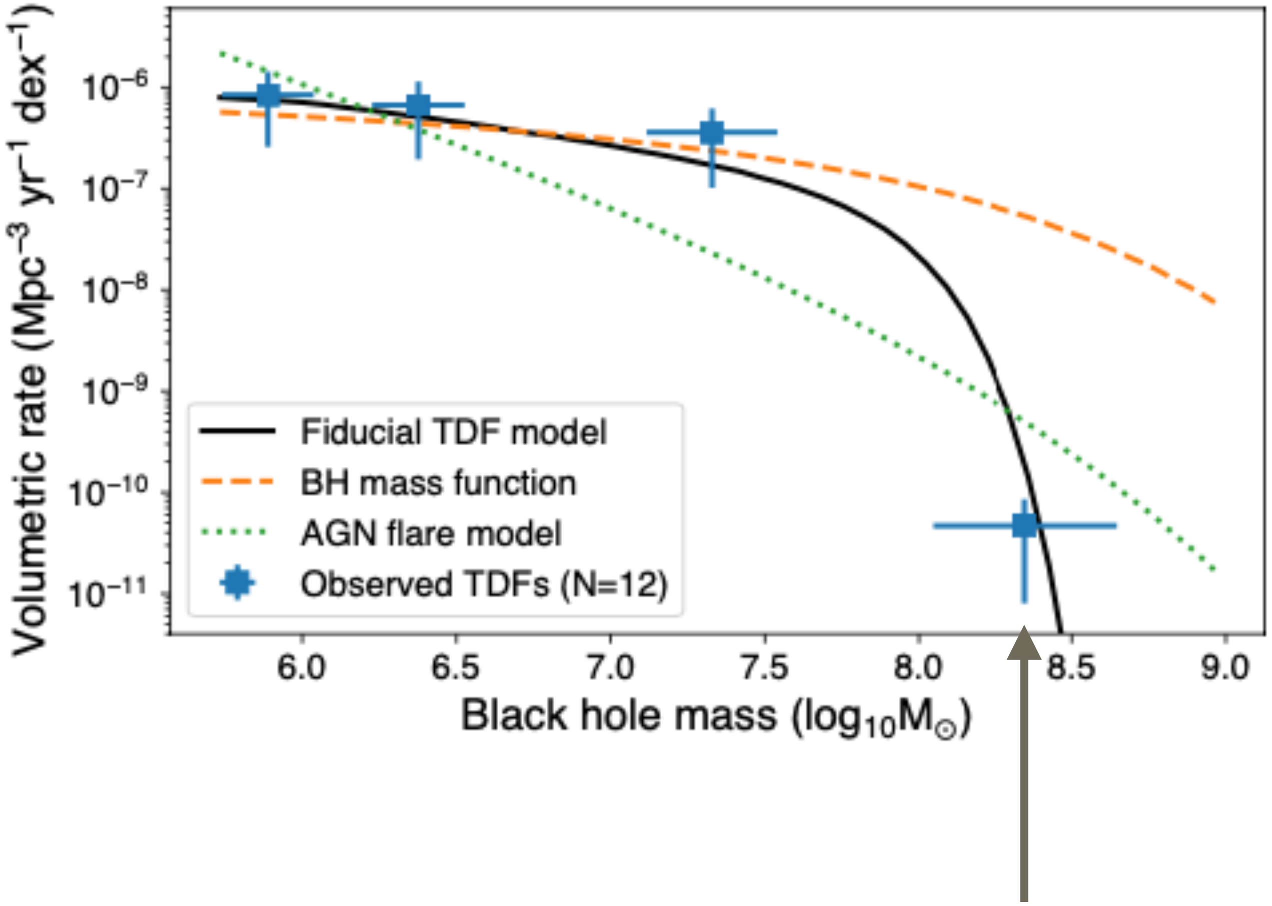
BASICS OF EVENT SELECTION

- TDE's are ultra-bright transient events, with close to or sometimes super-eddington luminosity.
- TDE light curves must be smoothly falling, with power-like law behavior.
- The light-curve fall timescale is of the order of months.
- TDE's are selected only in -quiescent galaxies-. No AGN's in them, and no previous history of accretion.
- TDE colors are quite constant in time, differently from SN's.
- TDE's are quite "blue".
- TDE's spectra are black-body, differently from power-law AGN's.
- TDE's are non-recurrent phenomena, differently from AGN flares.
- TDE's come with some specific atomic emission lines, which were actually predicted!

TDE RATES

Observed <u>and</u> predicted TDE rates:

$$\sim 10^{-4}/\mathrm{galaxy}/\mathrm{year}$$

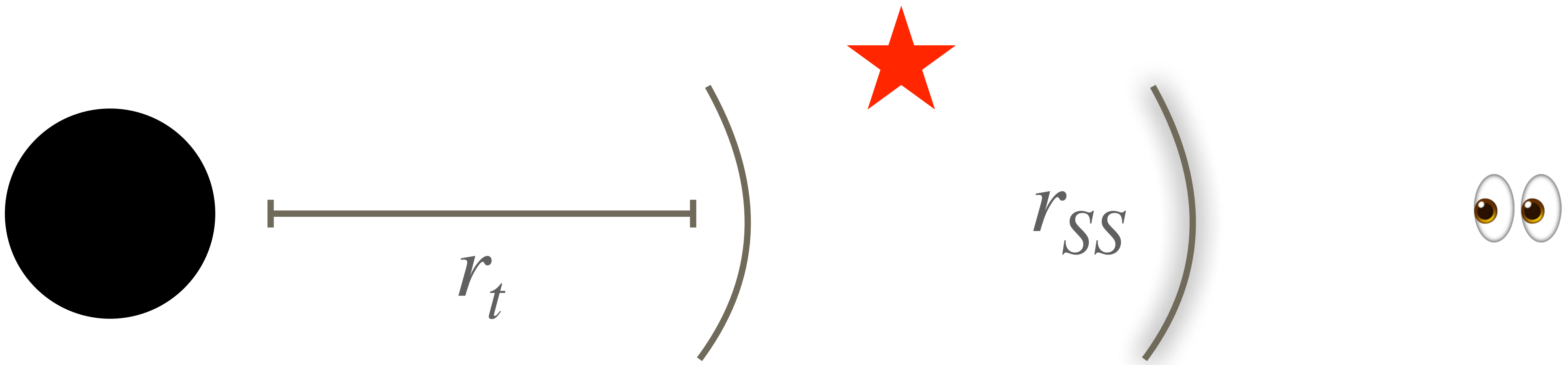


Van Velzen 1707.03458
(see Stone, Metzger
1410.7772 for details)

Sharp cutoff at high masses

THE HILLS MASS: NON-SPINNING BH

- For heavy BH's, the tidal radius falls within the BH horizon, and TDE's become unobservable.



$$r_t = R_\star \left(\frac{M_{\mathrm{BH}}}{M_\star} \right)^{1/3} \qquad r_{SS} = 2GM_{\mathrm{BH}}$$

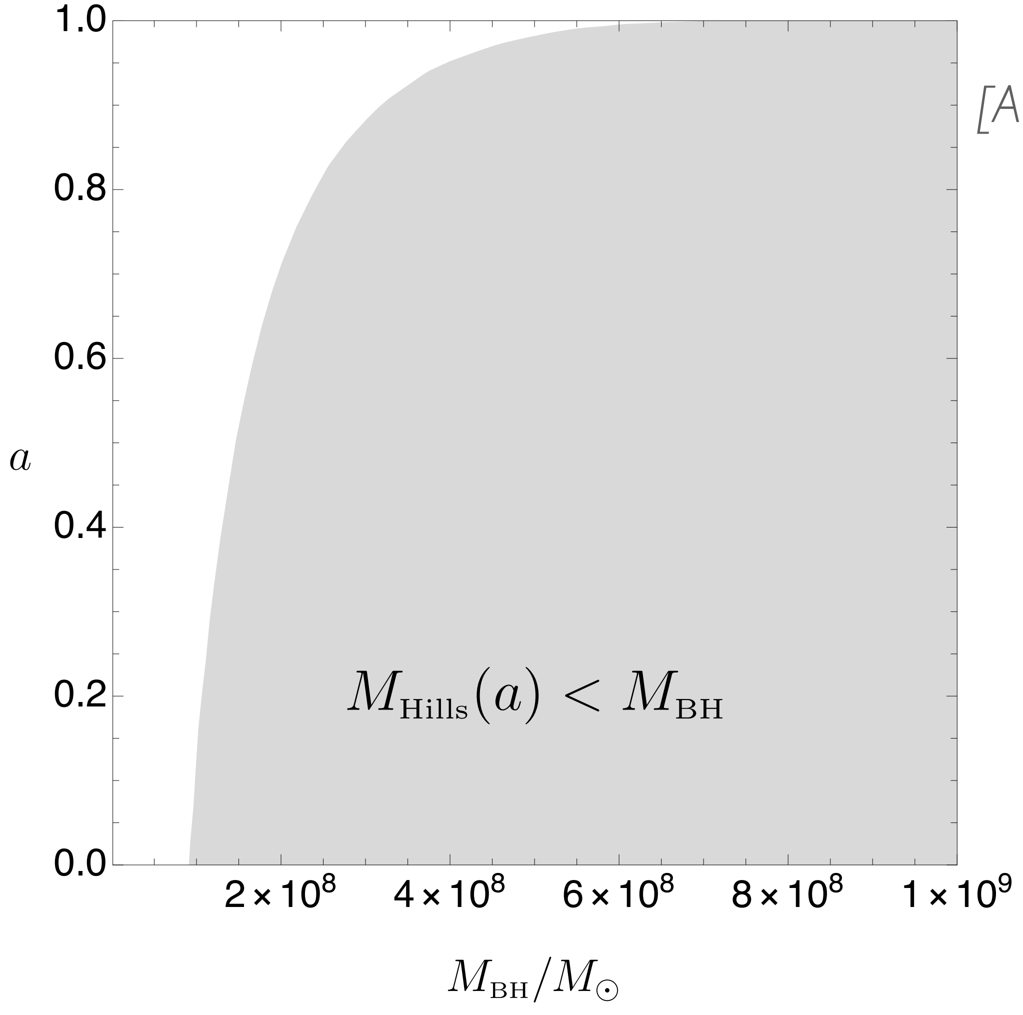
THE HILLS MASS: NON-SPINNING BH

For $r_t > r_{SS}$,

$$M_{\rm BH} \lesssim 10^8 M_\odot \left[\frac{R_\star}{R_\odot}\right]^{3/2} \left[\frac{M_\star}{M_\odot}\right]^{-1/2} \equiv M_{\rm Hills}$$

THE HILLS MASS: SPINNING BH

- The Hills mass depends on BH spin, which modifies the near-horizon geometry.



[Adapted from Kesden 1109.6329]

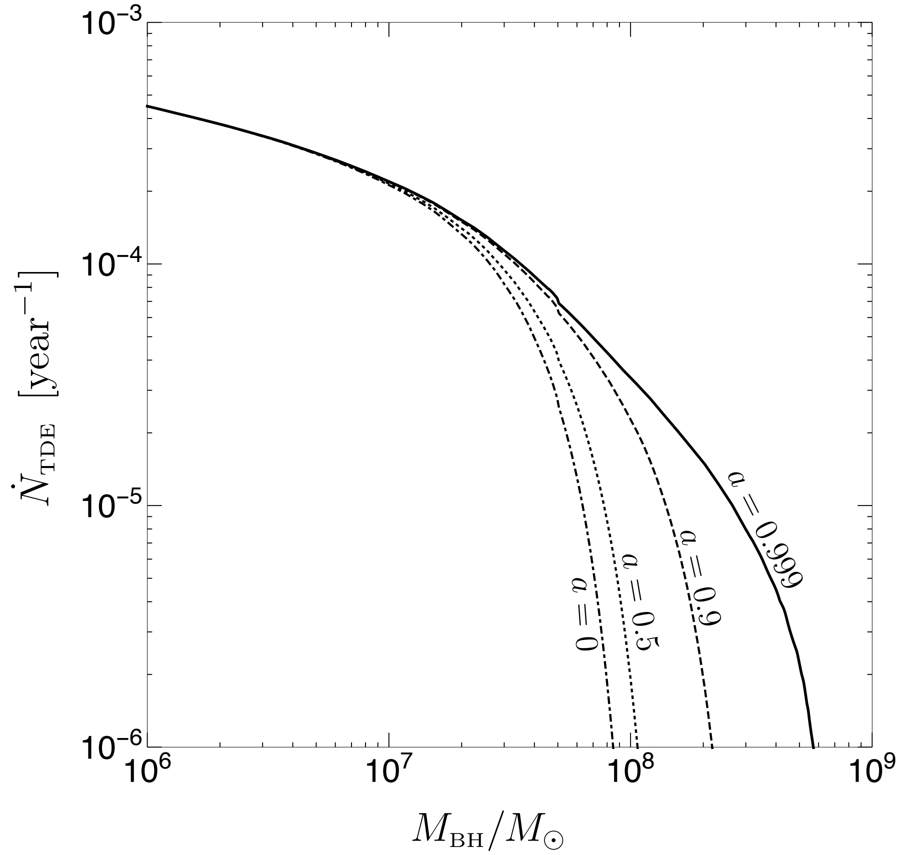
Hills mass for a main-sequence star

Hills mass grows with BH spin

$$M_{\rm Hills}(a \to 1) \sim 10^9 M_\odot$$

THE HILLS MASS

- TDE rates for galaxies with BH's above the Hills mass are strongly suppressed, with a *spin-dependent cutoff*



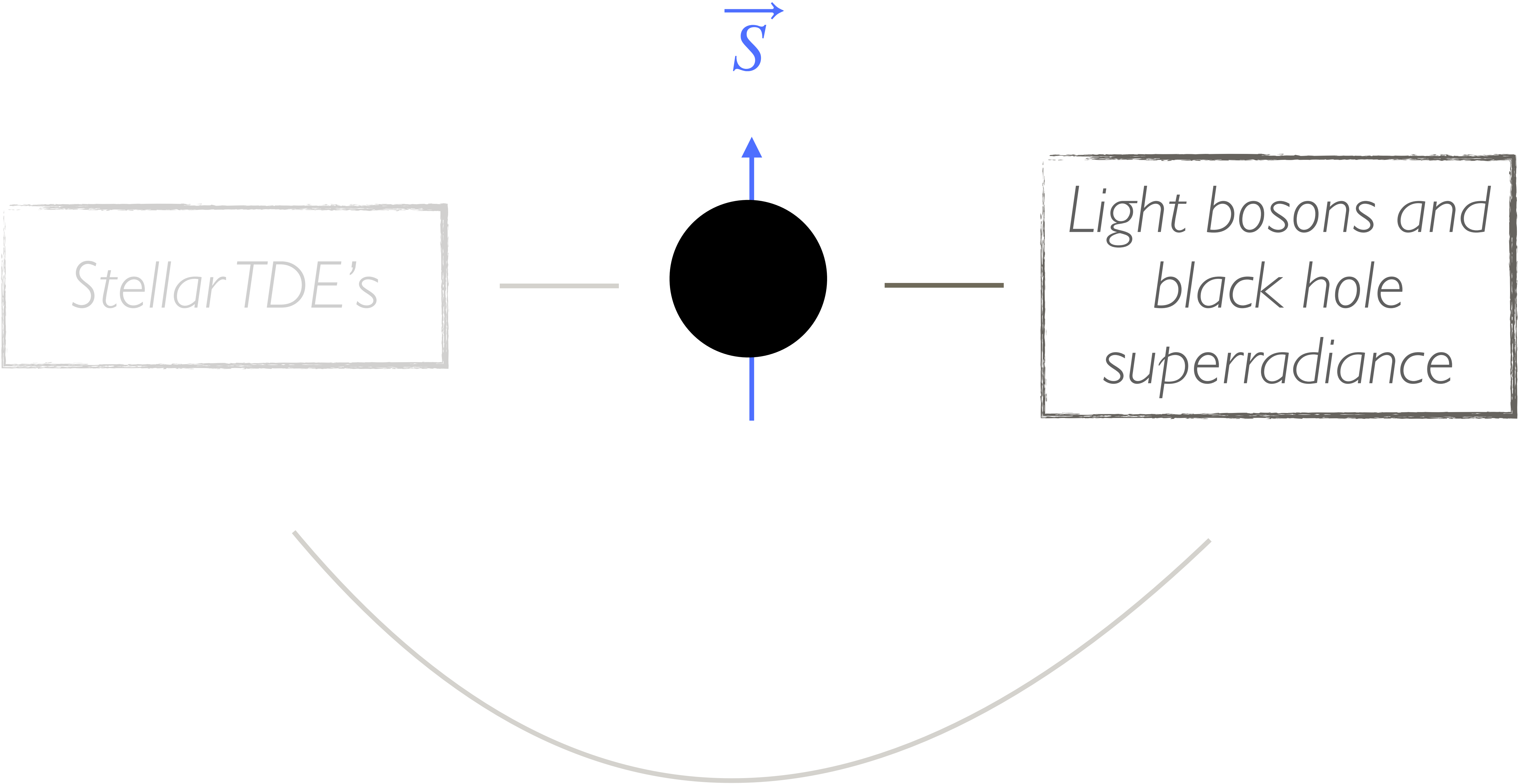
[Adapted from Kesden 1109.6329]

TDE rate -per galaxy-

- Models of accretion in SMBH suggest that in fact, a large fraction of SMBH's *could* have large spins (see e.g. Reynolds 2011.08984, Zhang & Lu 1902.07056)

In addition, if ultra-light bosons exist, SMBH spins are very uniquely affected by the ***superradiant instability***

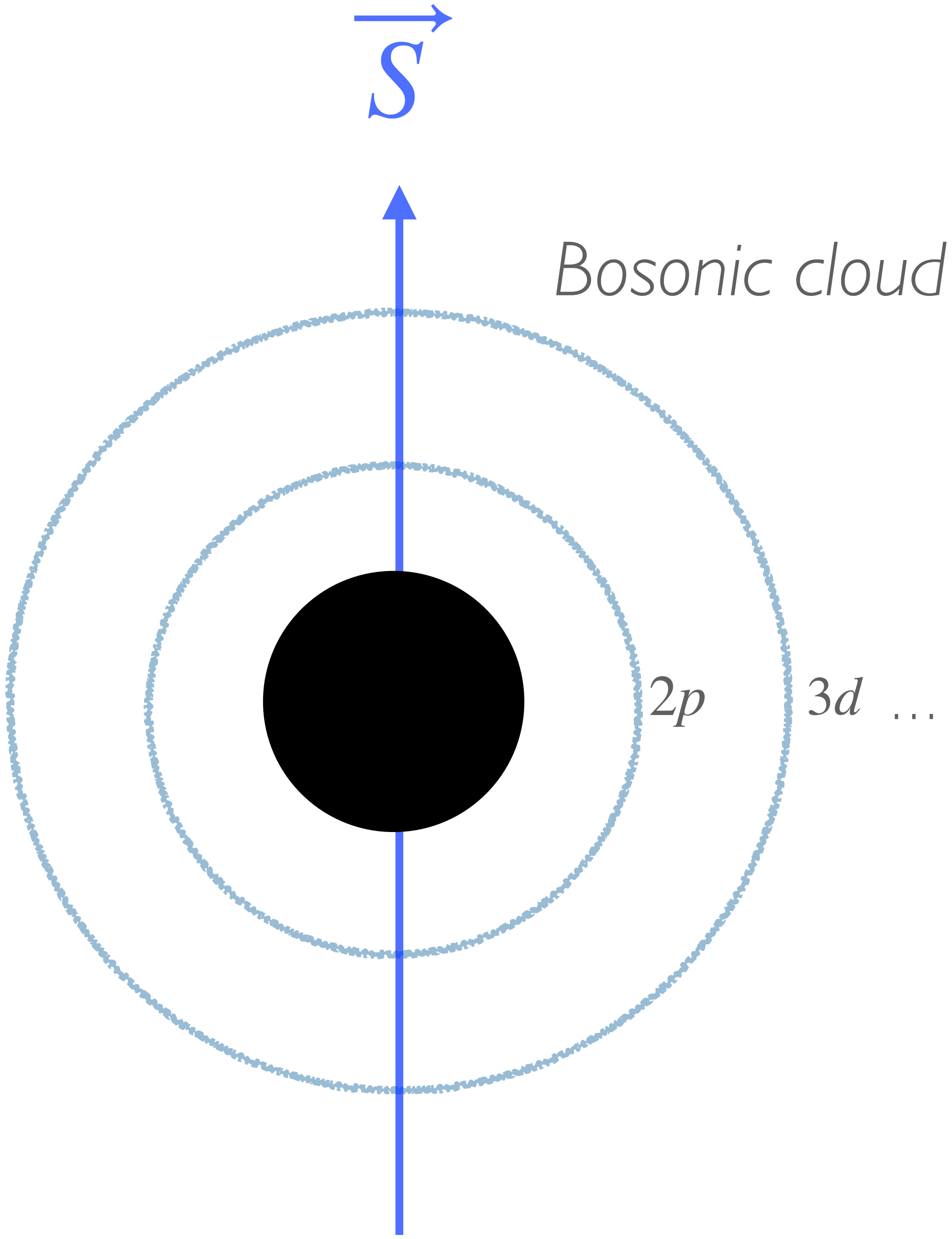
This would leave very unique imprints on the observed TDE rates



Stellar TDE's

Light bosons and black hole superradiance

BLACK HOLE SUPERRADIANCE



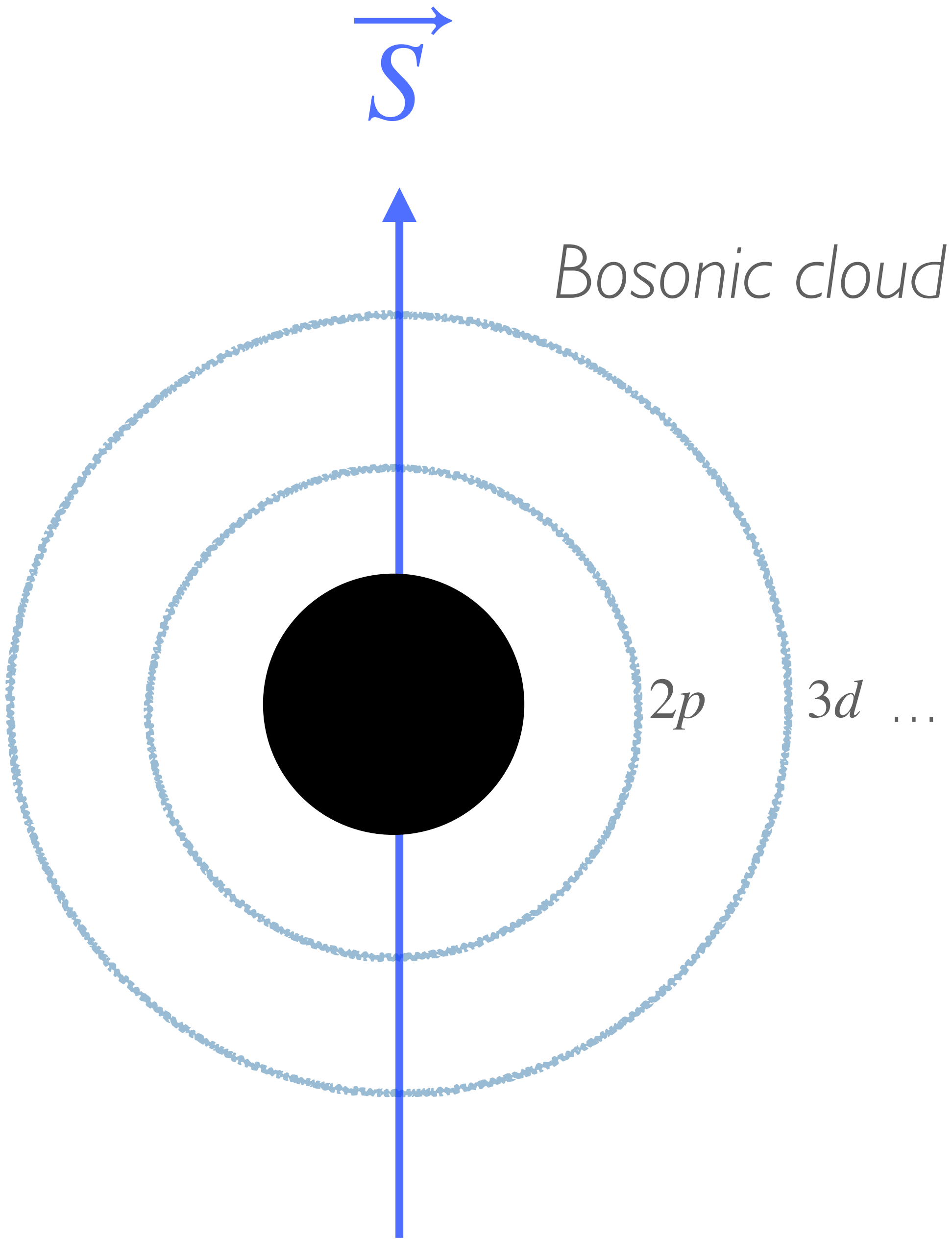
$$\frac{\mu}{m} \lesssim \Omega_{\mathrm{BH}}$$

μ = Boson mass

$$m = -l\,..\,l$$

Zeldovich JETP Lett. 14 180, 1971

BLACK HOLE SUPERRADIANCE

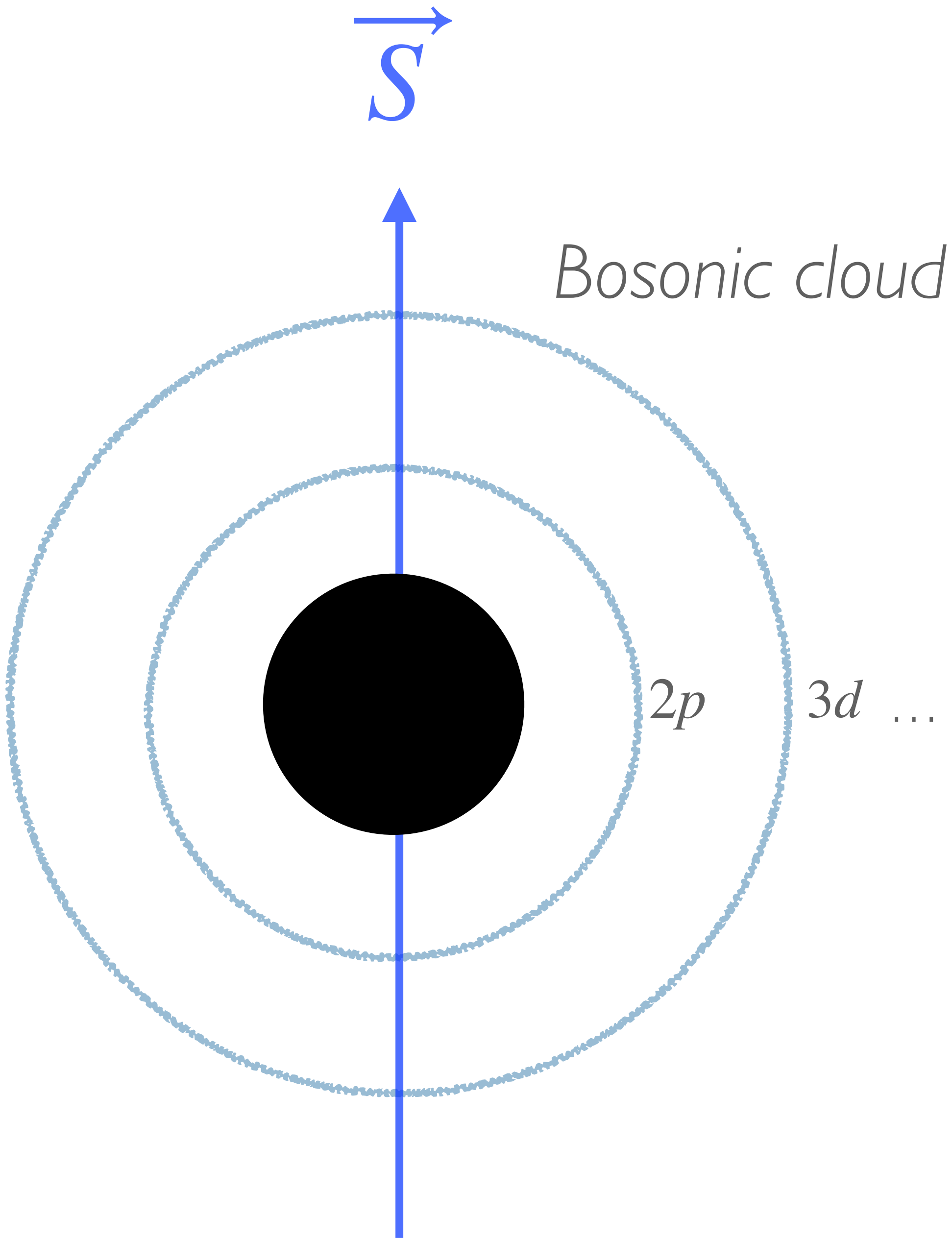


$$\frac{\mu}{m} \lesssim \Omega_{\mathrm{BH}}$$

Gravitational coupling

$$\alpha = G M_{\mathrm{BH}} \mu$$

BLACK HOLE SUPERRADIANCE



$$\frac{\mu}{m} \lesssim \Omega_{\mathrm{BH}}$$

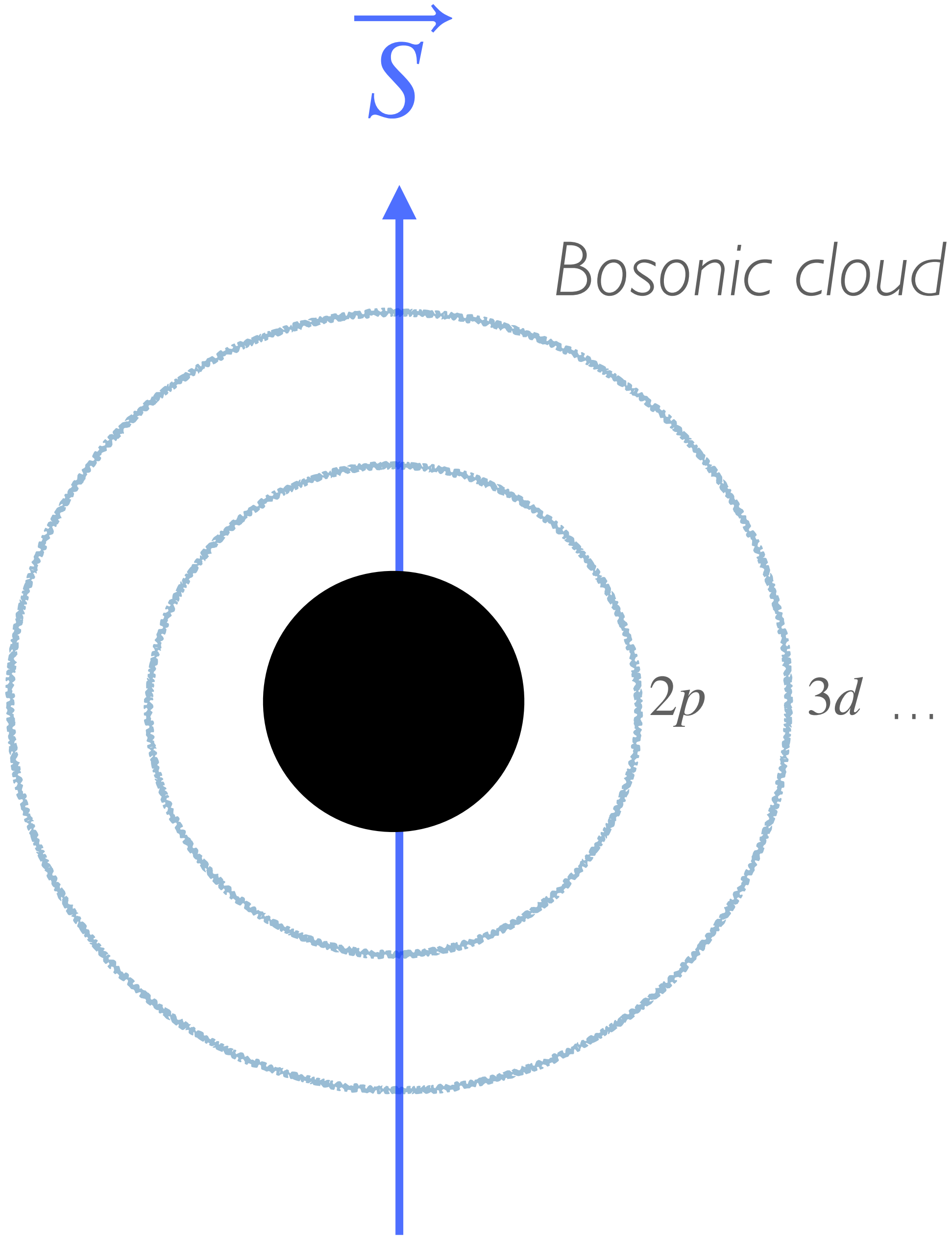
Gravitational coupling

$$\alpha = G\mu M_{\mathrm{BH}}$$

Cloud radius

$$r_{\mathrm{cloud}} \sim \frac{n^2}{\mu\alpha}$$

BLACK HOLE SUPERRADIANCE



$$\frac{\mu}{m} \lesssim \Omega_{\mathrm{BH}}$$

Gravitational coupling

$$\alpha = G\mu M_{\mathrm{BH}}$$

For maximally spinning black holes

$$\frac{\alpha}{m} \leq 0.5$$

BLACK HOLE SUPERRADIANCE

- The SR rates are strongly suppressed at small α

$$\tau_{\rm SR} \sim 100\,\textit{years}\left[\frac{\alpha}{0.1}\right]^{-6}\left[\frac{M_{\rm BH}}{10^8 M_\odot}\right]$$

Vectors (dark photons)

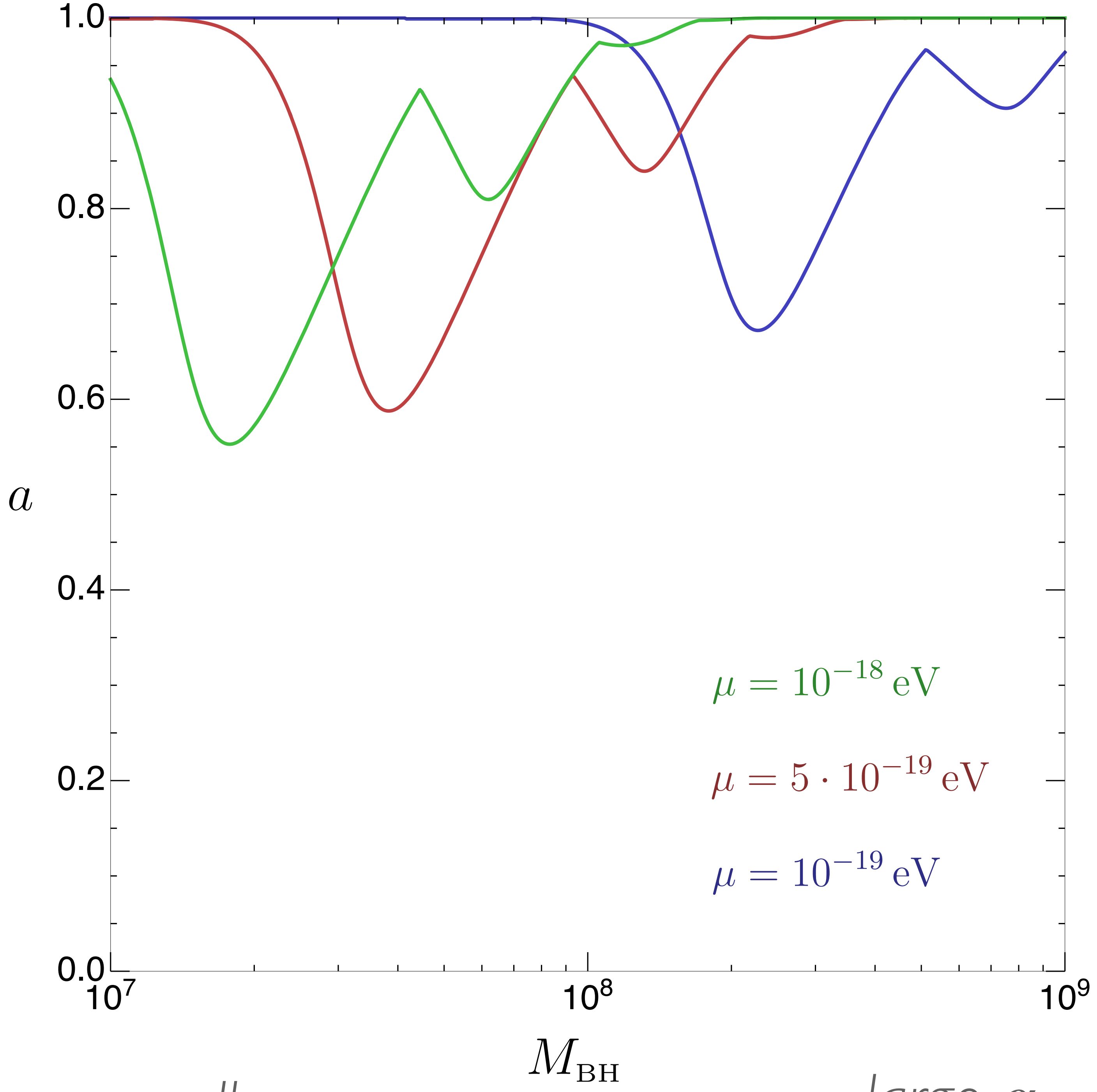
$$\tau_{\rm SR} \sim 10^6\,\textit{years}\left[\frac{\alpha}{0.1}\right]^{-8}\left[\frac{M_{\rm BH}}{10^8 M_\odot}\right]$$

Scalars (axions)

- As a consequence, SR is most effective for $\alpha \sim 0.1 - 1$, or

$$\mu \sim \frac{1}{GM_{\rm BH}} = \frac{1}{r_g}$$

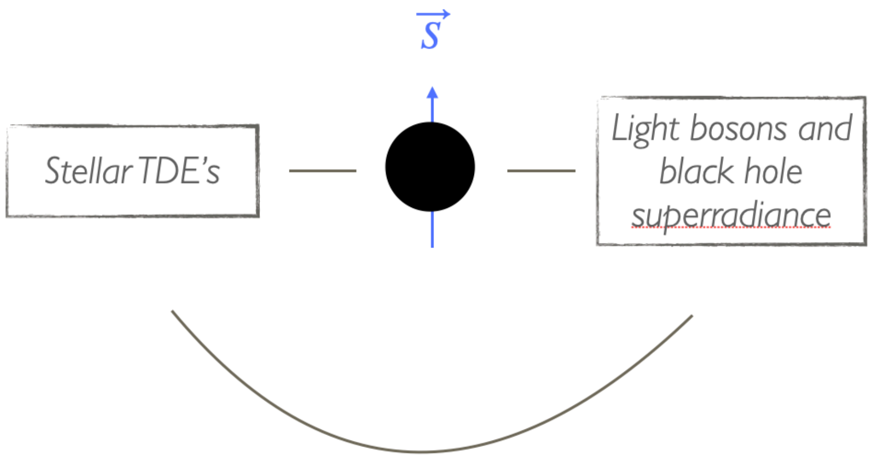
SUPERRADIANT SPIN EXTRACTION



small α large α

Spin-0 boson

Note: if your BH has a low spin to start with, SR is not an observable effect



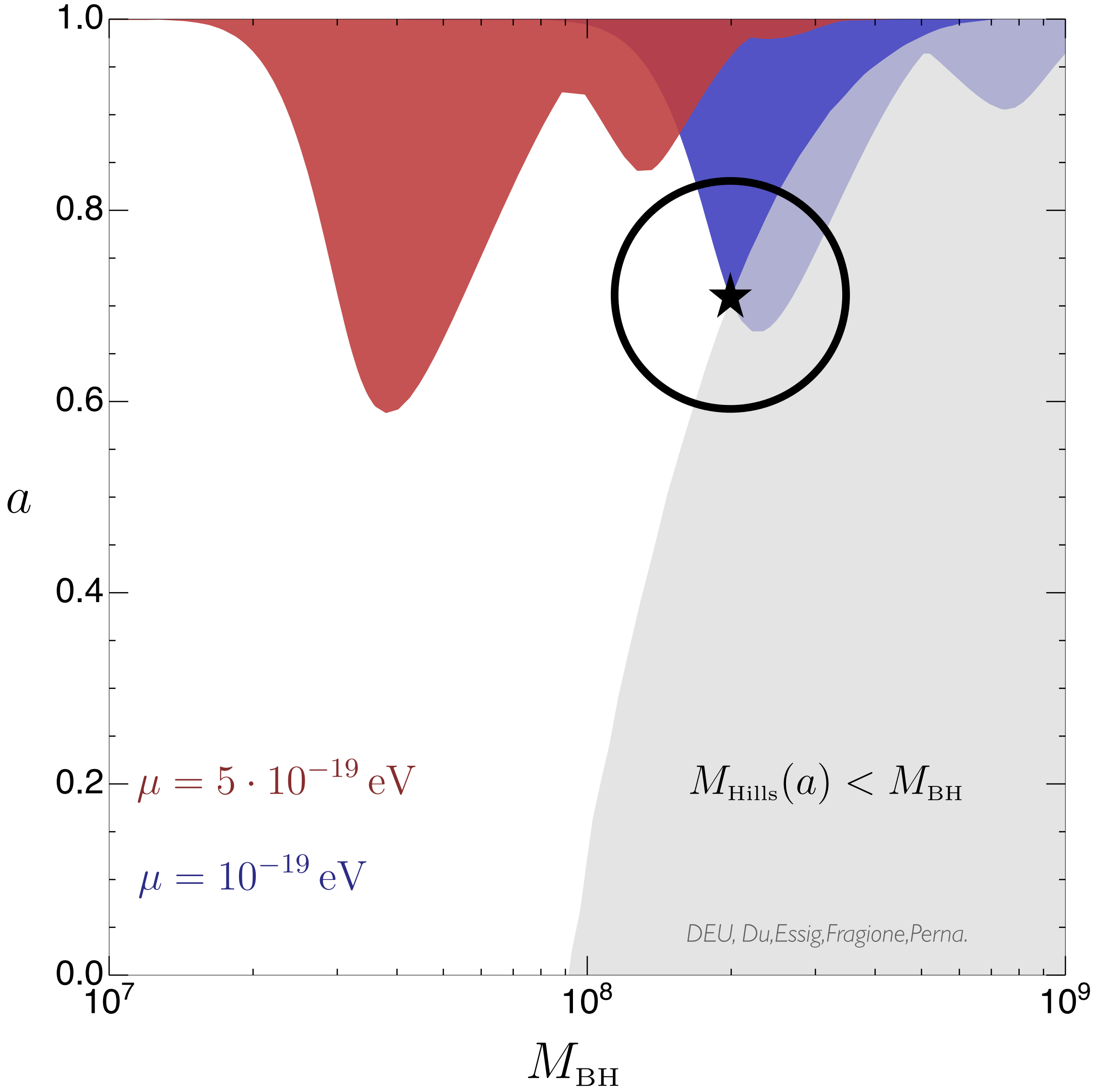
Stellar TDE's

$\vec{s}$

Light bosons and black hole superradiance

The effect of light bosons on TDE event rates

BOSONS DECREASE THE EFFECTIVE HILLS MASS

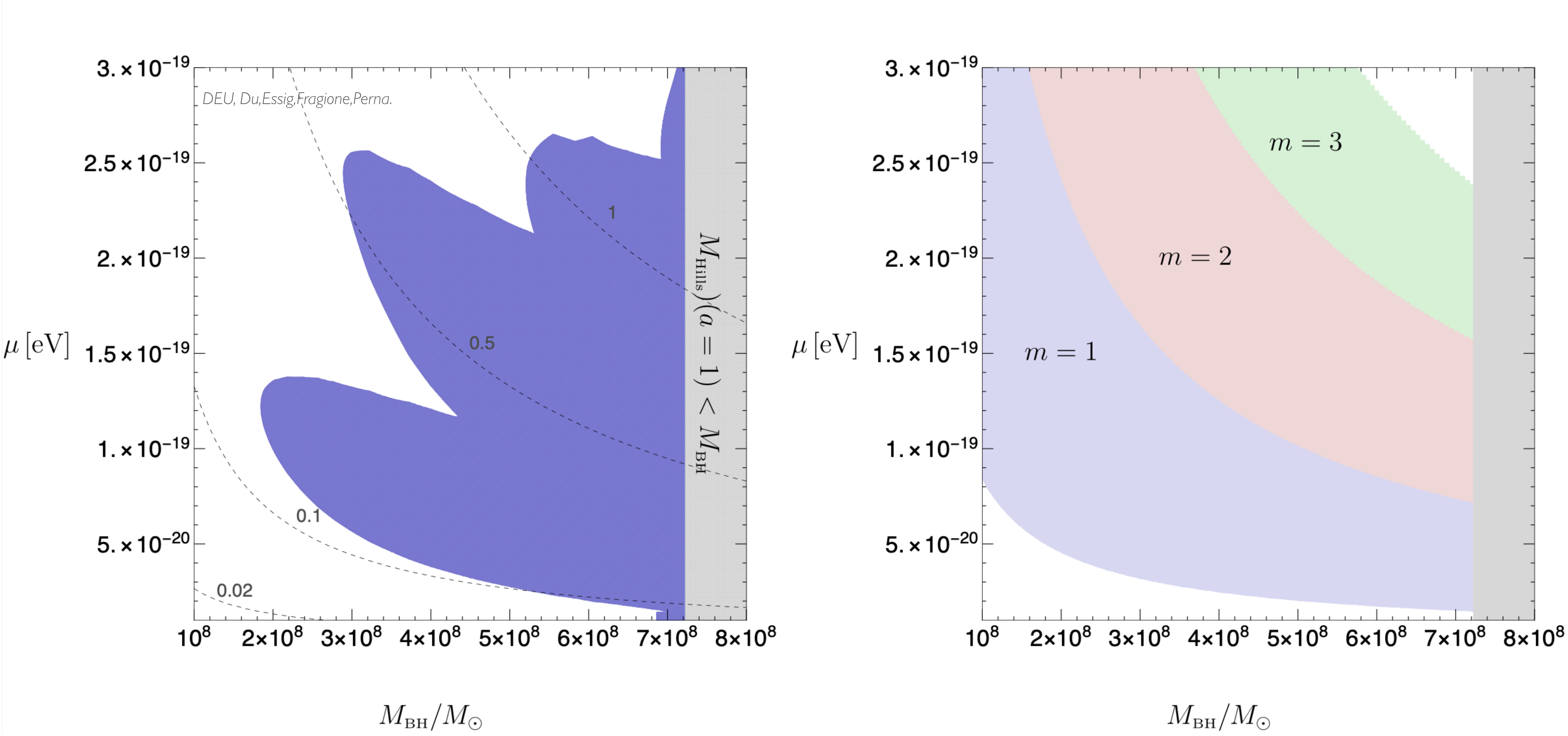


DEU, Du,Essig,Fragione,Perna.

Spin-0 boson

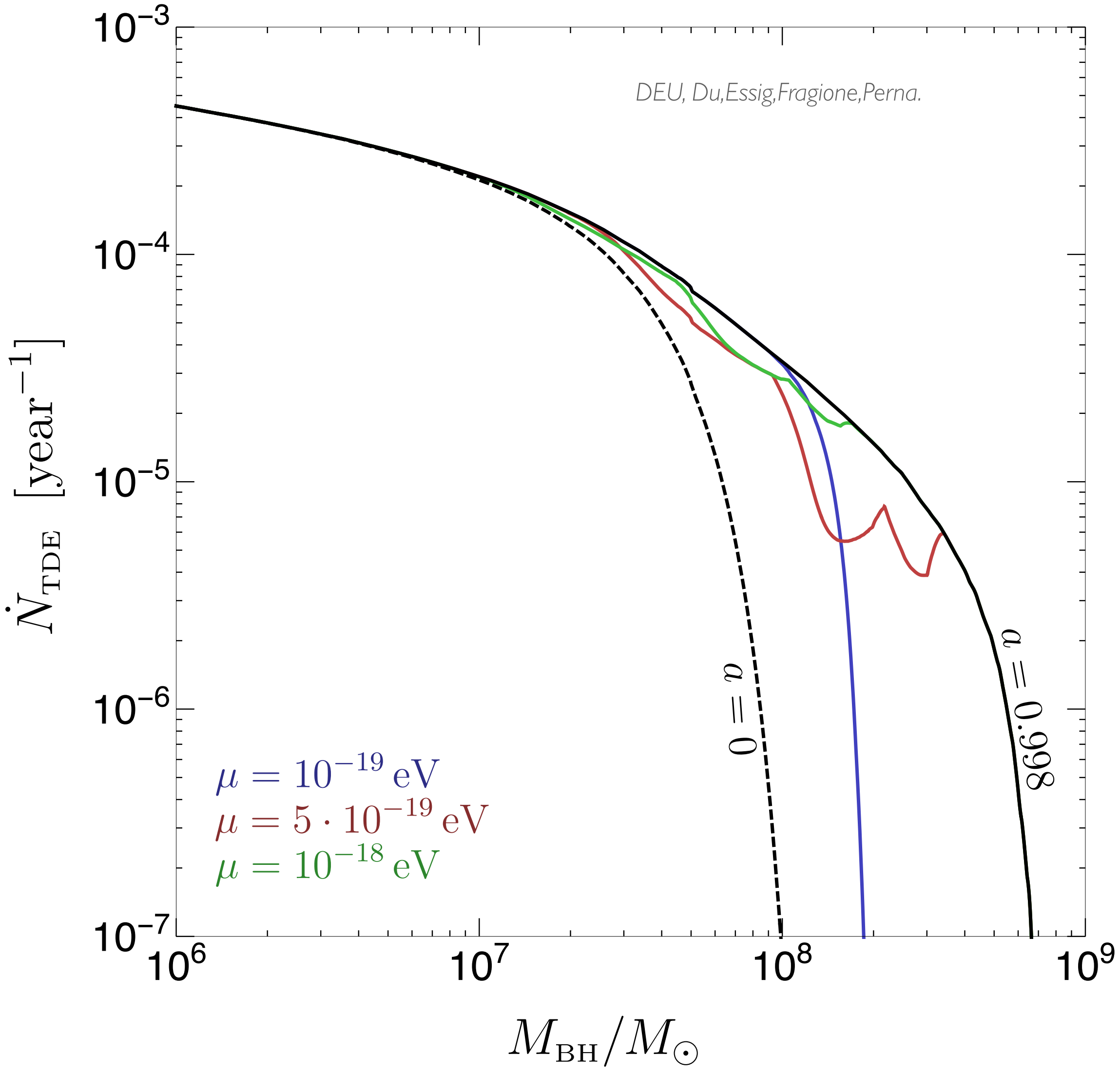
Ultra-light bosons decrease the "effective Hills mass"

THE EFFECTIVE HILLS MASS



Spin-0 boson

TDE RATES IN THE PRESENCE OF ULTRA-LIGHT BOSONS



TDE rate
-per galaxy-

Spin-0 boson

The existence of ultra-light bosons
leaves unique signatures
in the TDE rate distributions

Note that testing ultra-light bosons
by measuring TDE rates
<u>does not require measuring the BH spin</u>

Testing axions and dark photons with LSST measurements of TDE rates

TDE rate per-galaxy ✓

+

SMBH volumetric spin and mass function

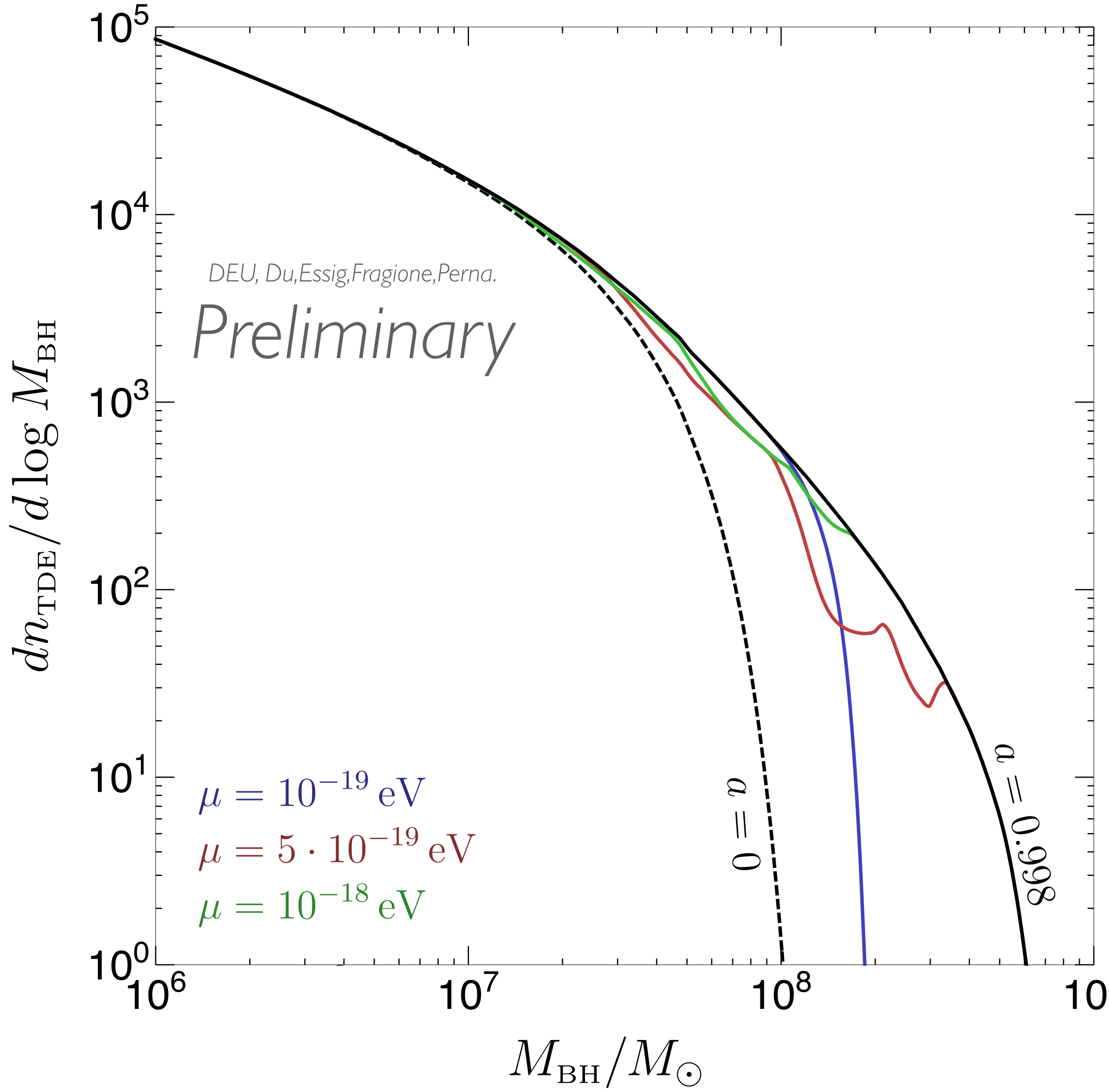
+

TDE luminosity

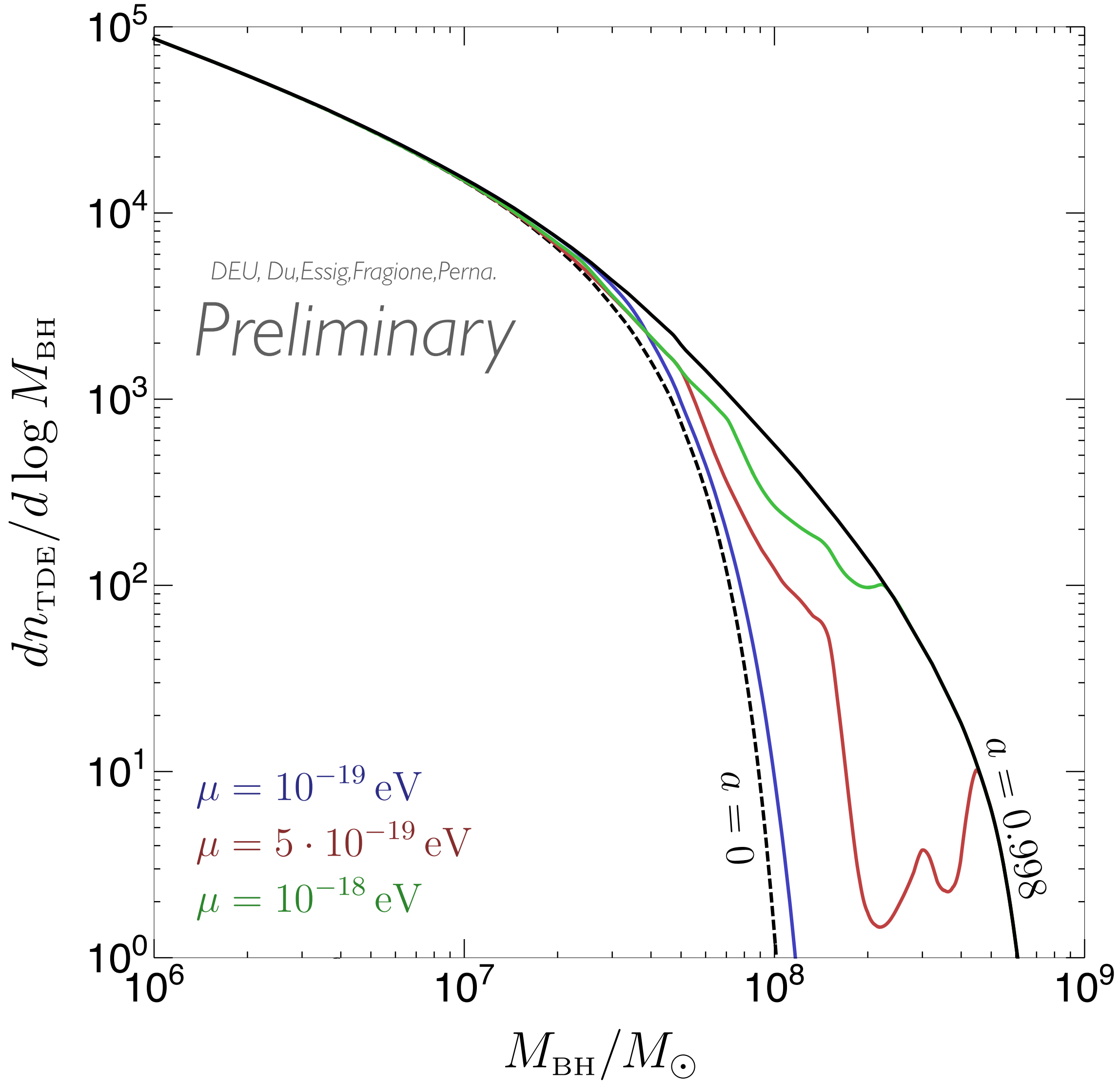
↓

Expected TDE rate
in flux-limited sample

TDE RATE ESTIMATES IN LSST



Spin 0 (axions)

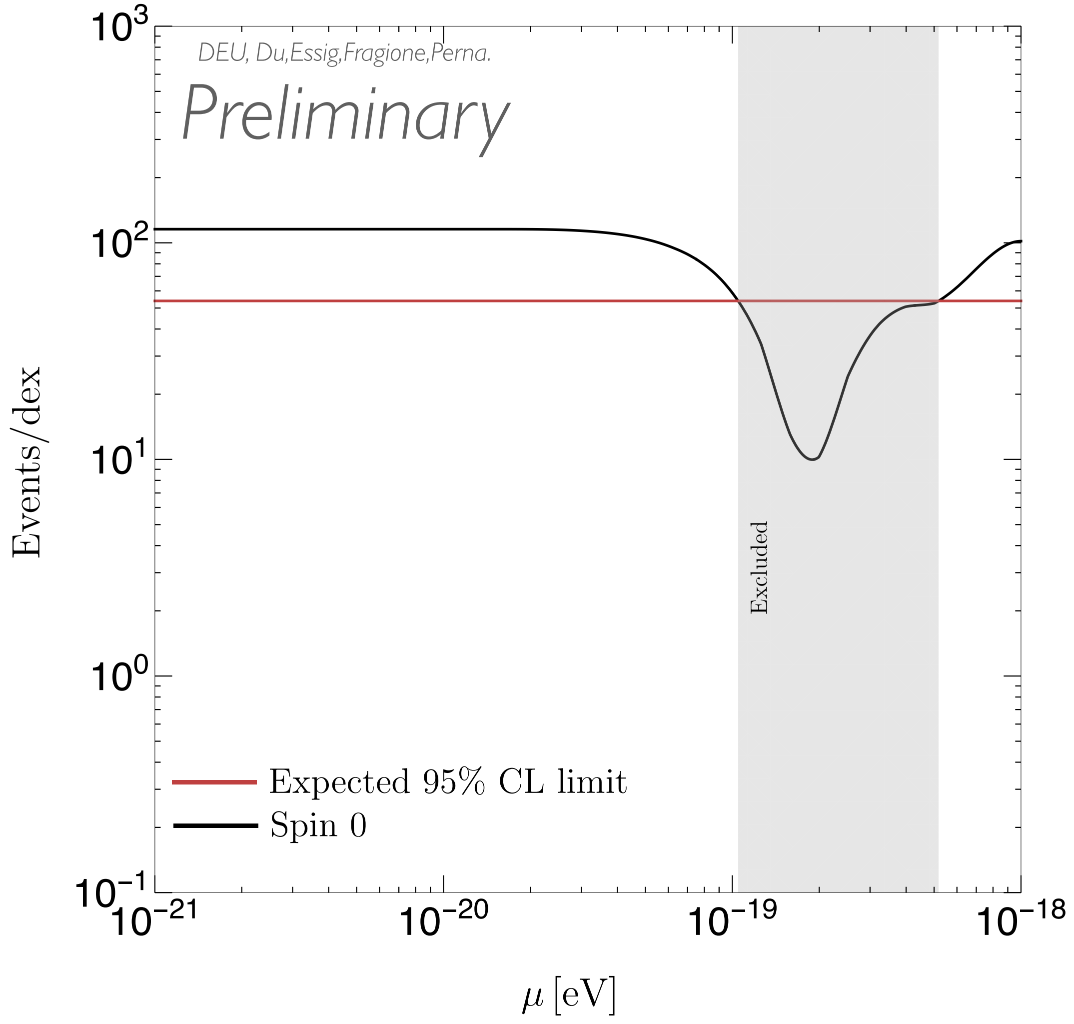


Spin 1 (dark photons)

(Our rate estimates in the absence of ultra-light bosons roughly agree with Bricman, Gomboc 1906.08235)

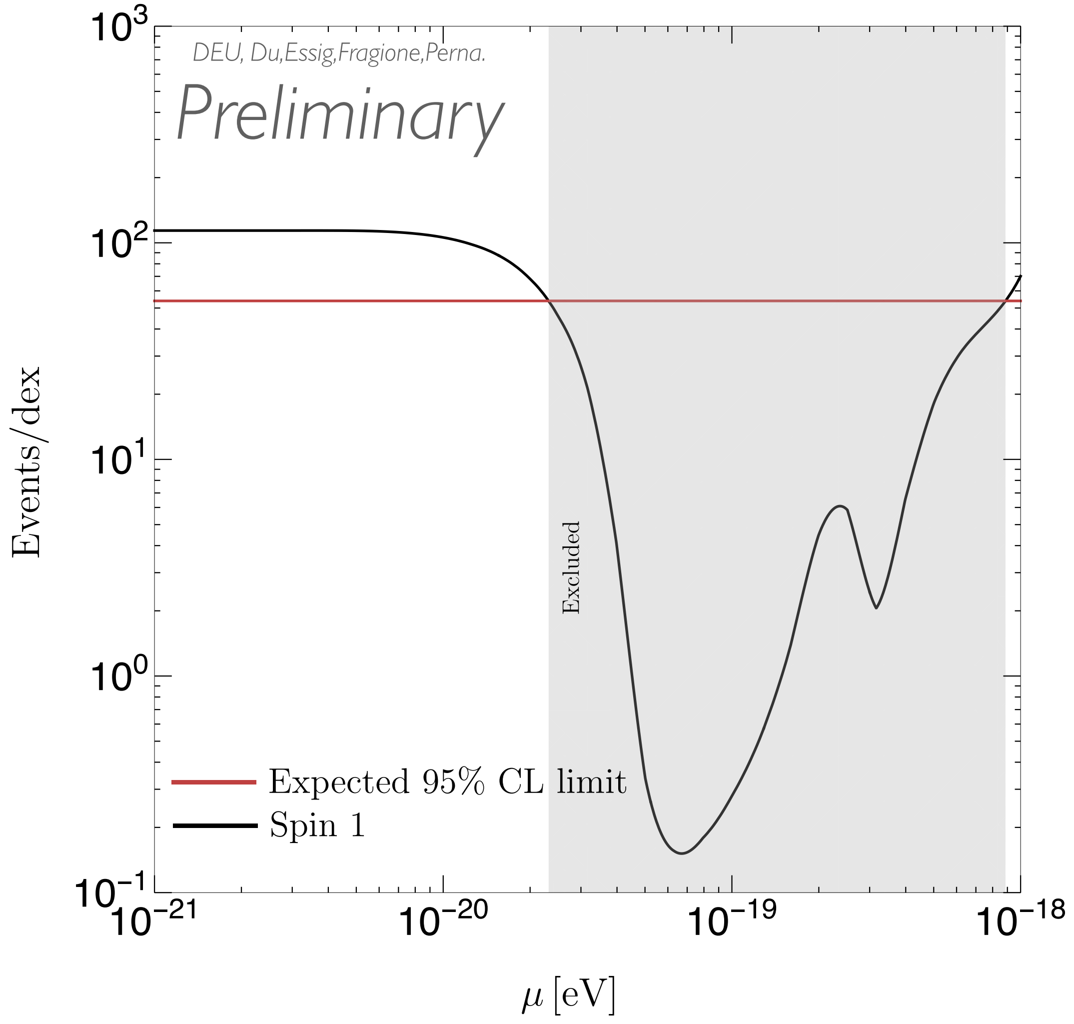
LIMIT PROJECTIONS

Include (arbitrary) **50 %** *systematic on rate*


DEU, Du,Essig,Fragione,Perna.

Preliminary

Spin 0 (axions)

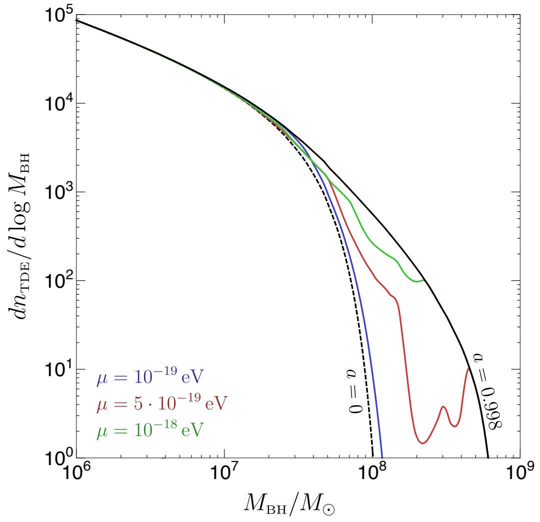

DEU, Du,Essig,Fragione,Perna.

Preliminary

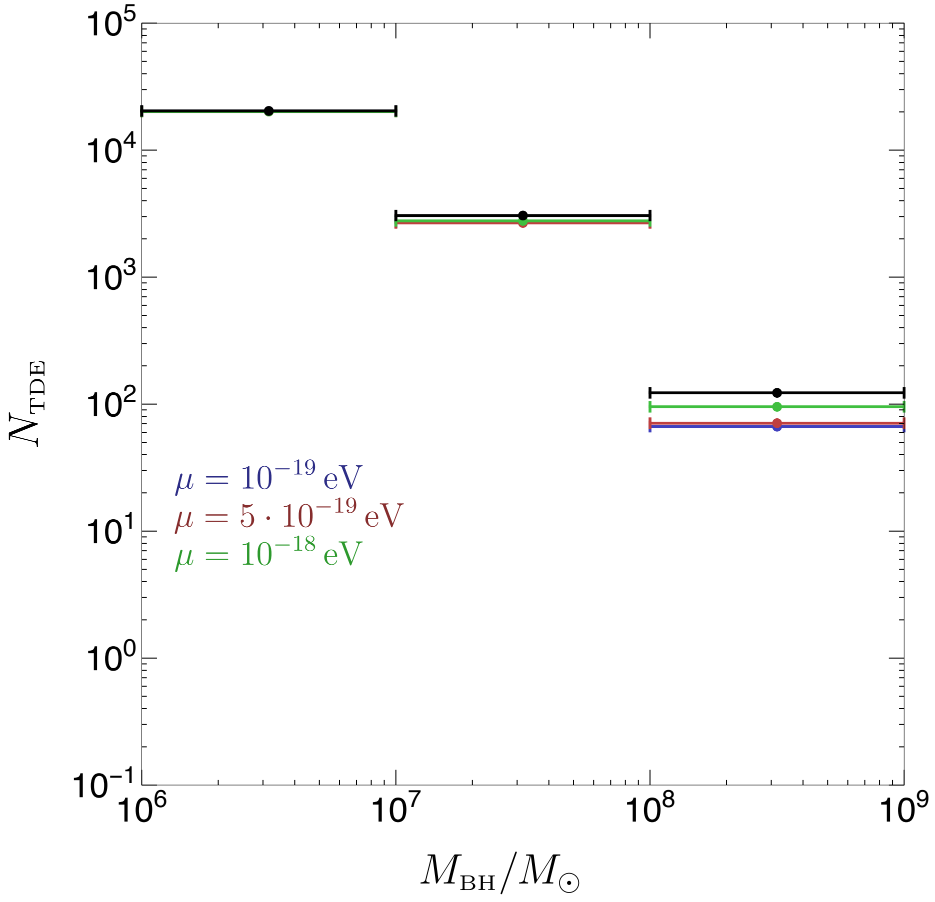
Spin 1 (dark photons)

SMEARING DUE TO MBH MEASUREMENT UNCERTAINTIES

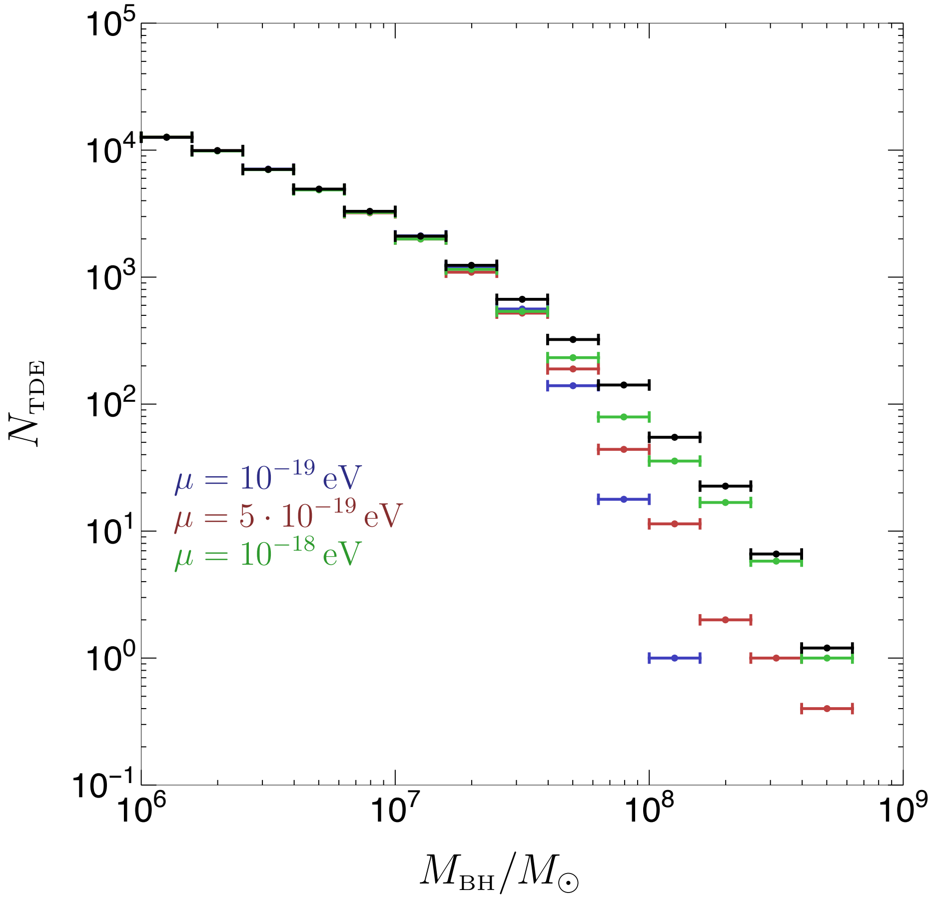
Spin 1



Current



Optimistic? improvements



CONCLUSIONS

- TDE’s rate measurements are a fascinating new probe of BSM physics.

- Ultra-light bosons leave unique imprints in the TDE rate distribution function, at high BH masses.

- In principle, this can be used to either discover or set limits on these BSM theories, but work is required to understand systematics.

- The prospects are encouraging: LSST will select somewhere between 10K-100K TDE’s.