PROBING ULTRA-LIGHT BOSONS WITH STELLAR TIDAL DISRUPTIONS

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In collaboration with
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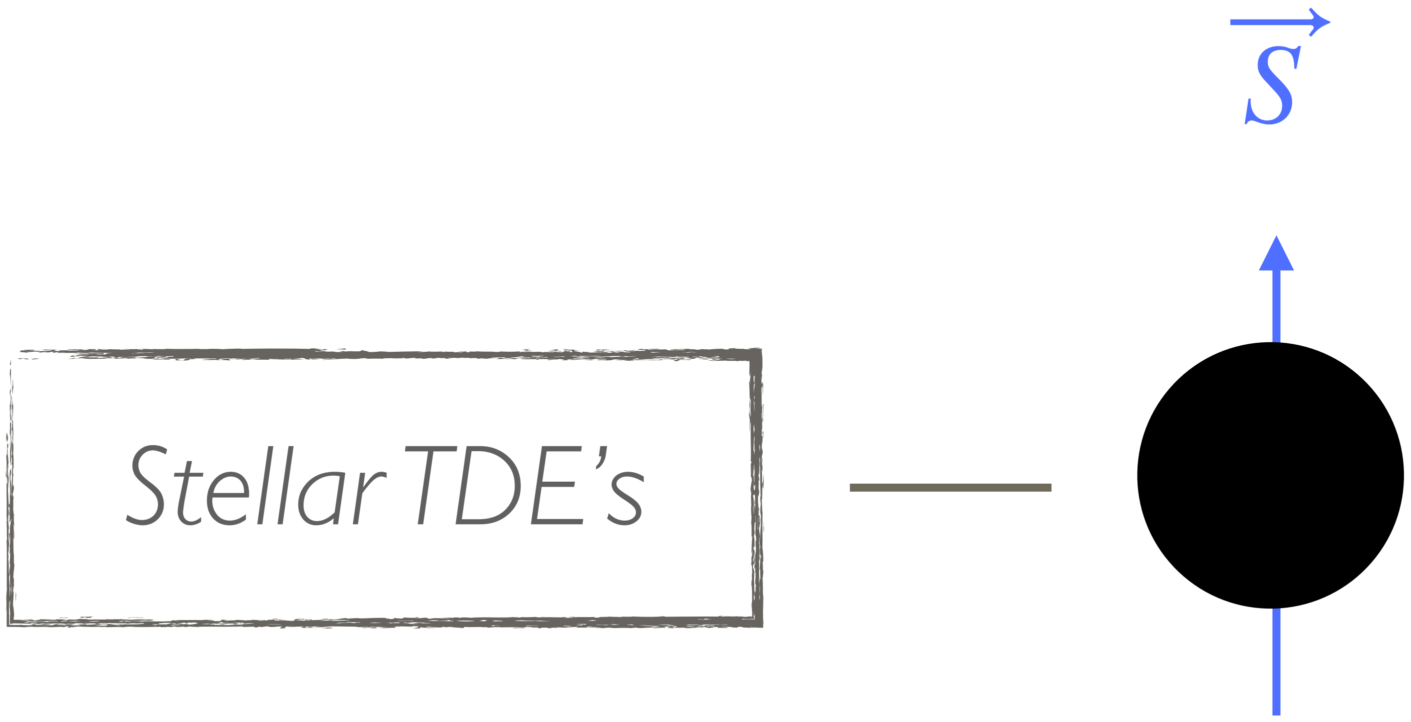
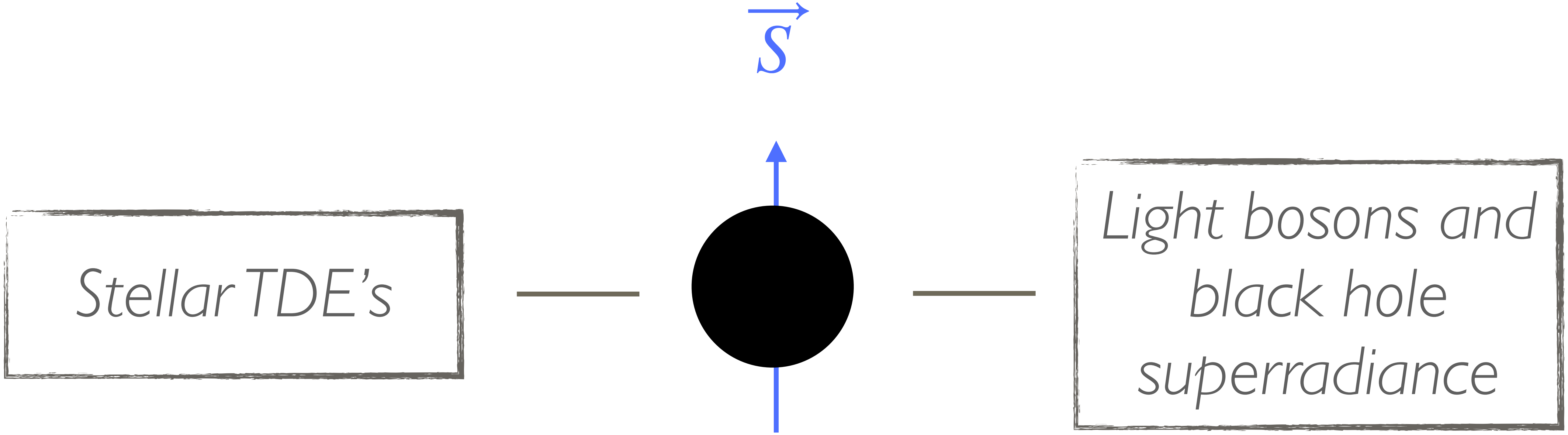
STELLAR TIDAL DISRUPTION EVENTS

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

Credits: DESY, Science Communication Lab

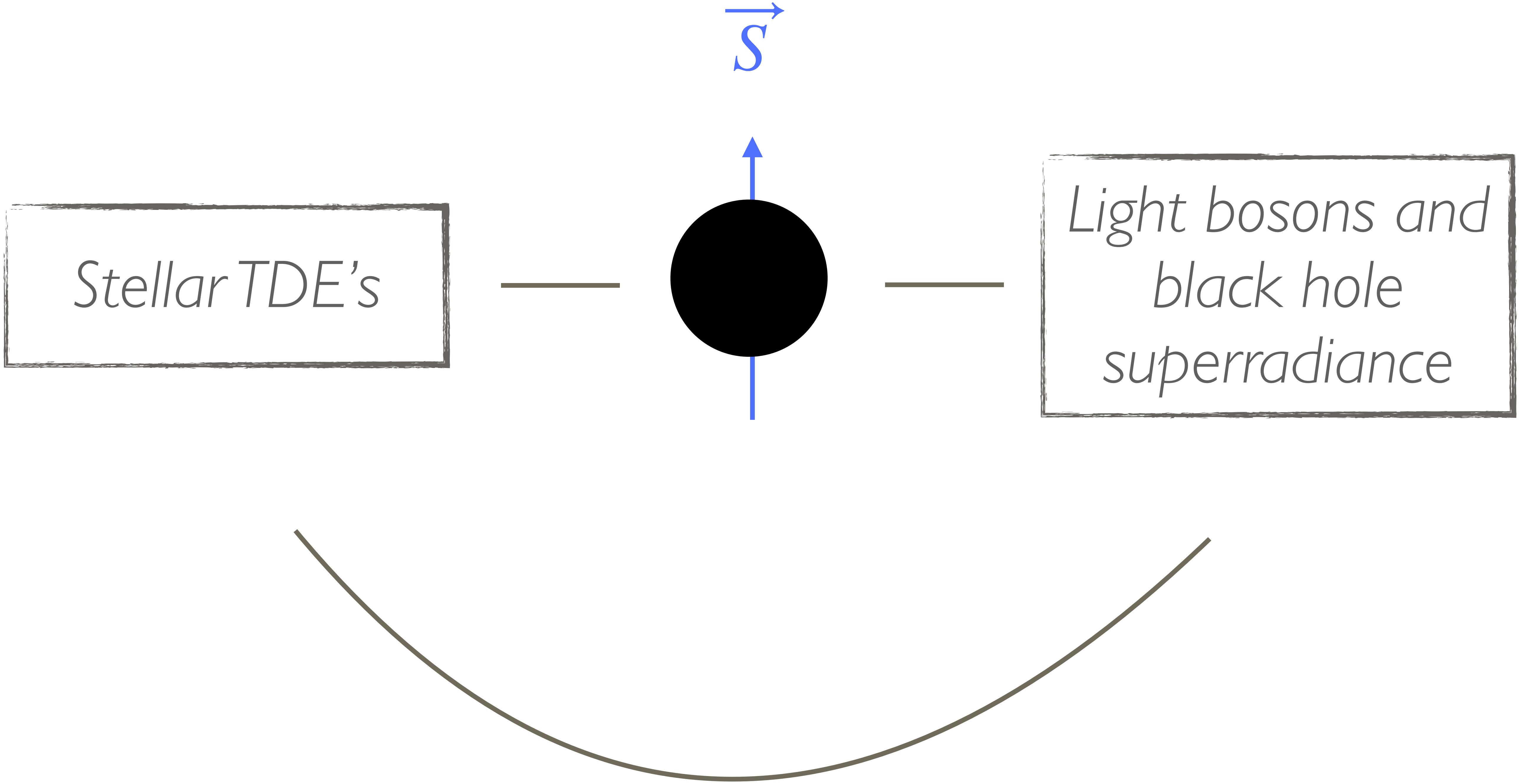


Stellar TDE's



Stellar TDE's

Light bosons and black hole superradiance



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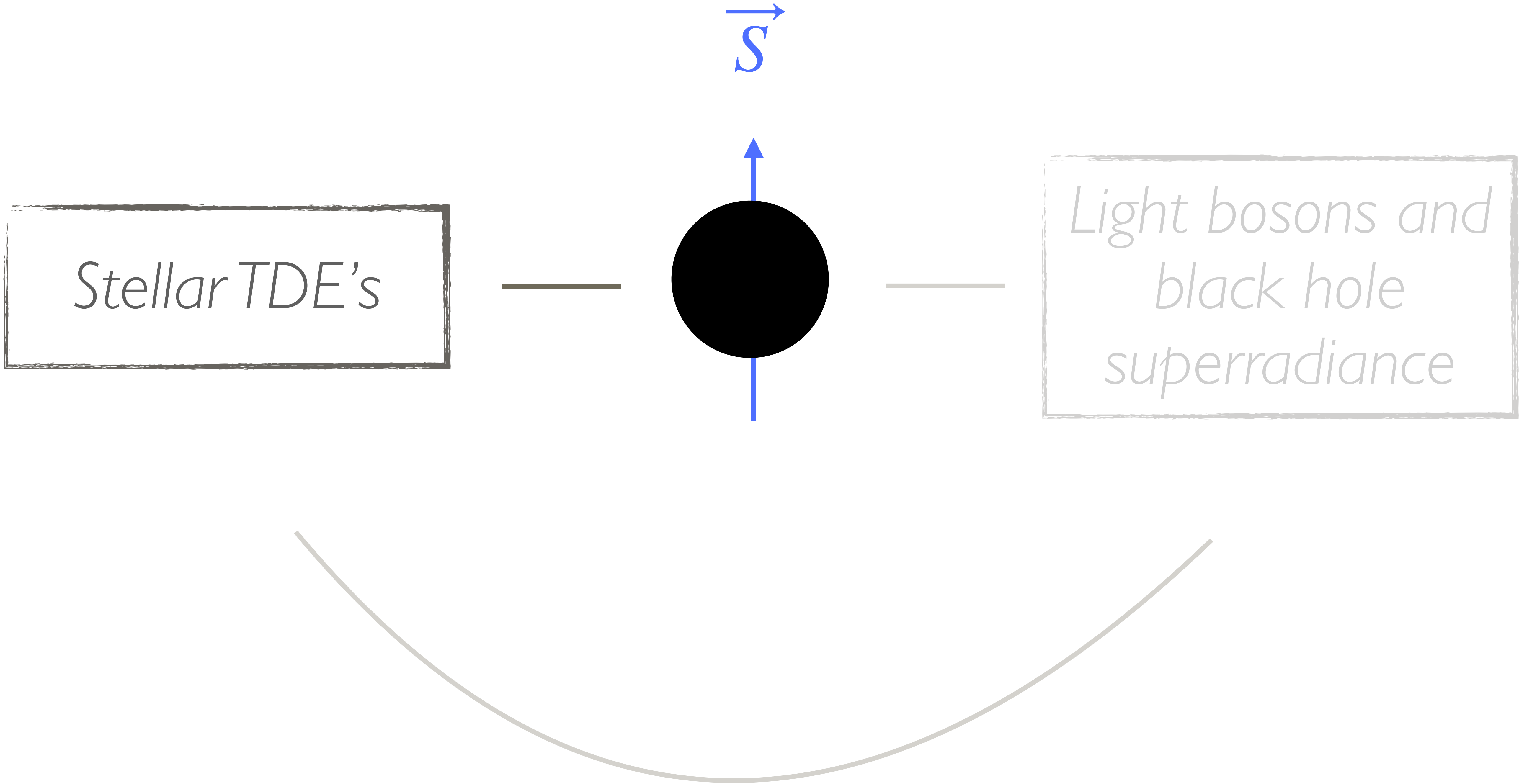
Stellar TDE's

Light bosons and black hole superradiance



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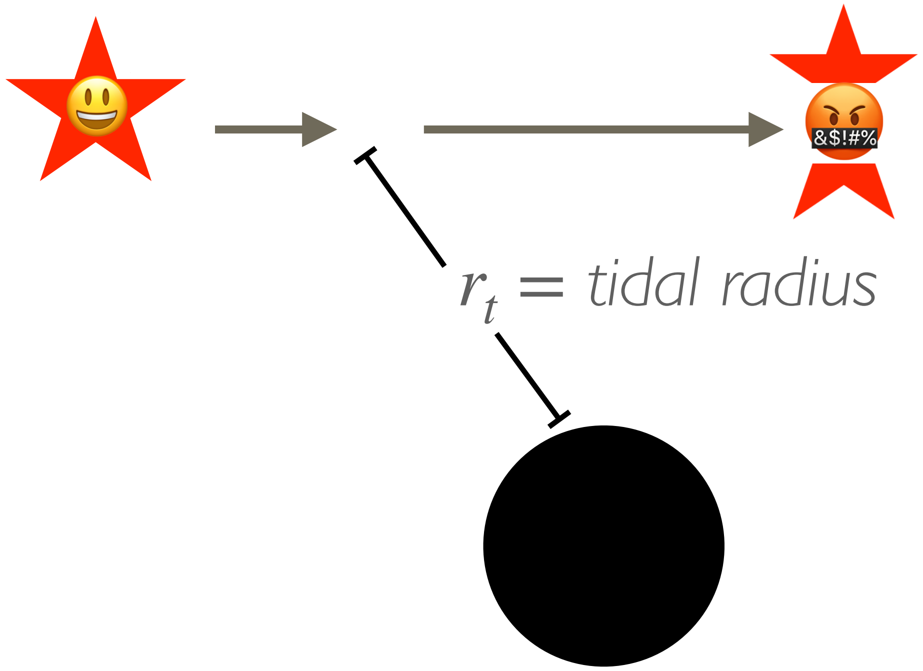
Stellar TDE's

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

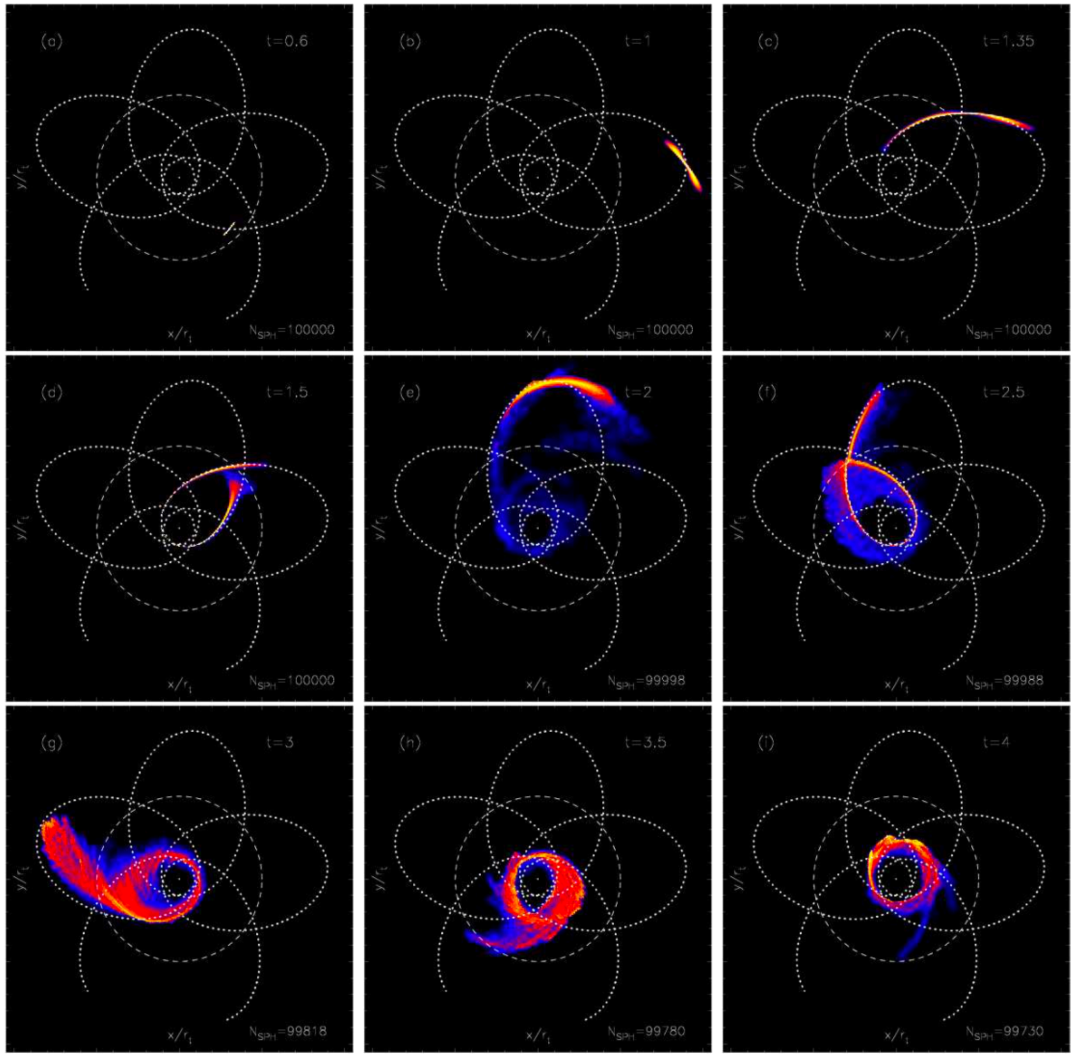


$$r_t = R_\star \left(\frac{M_{\mathrm{BH}}}{M_\star} \right)^{1/3} \sim 10^{-6}\ \mathrm{pc}$$

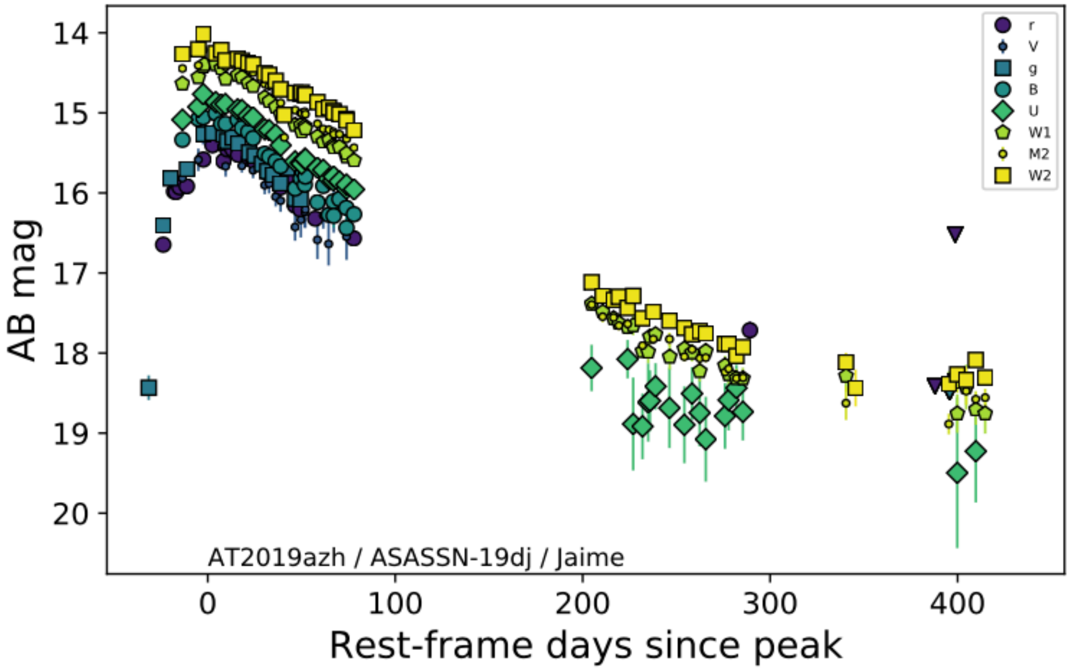
- The disruption is followed by a bright flare due to subsequent accretion of the stellar gas into the black hole

STELLAR TIDAL DISRUPTION EVENTS

Hayasaki et al. 1501.05207



van Velzen et al. 2001.01409
ZTF survey



This behavior was predicted

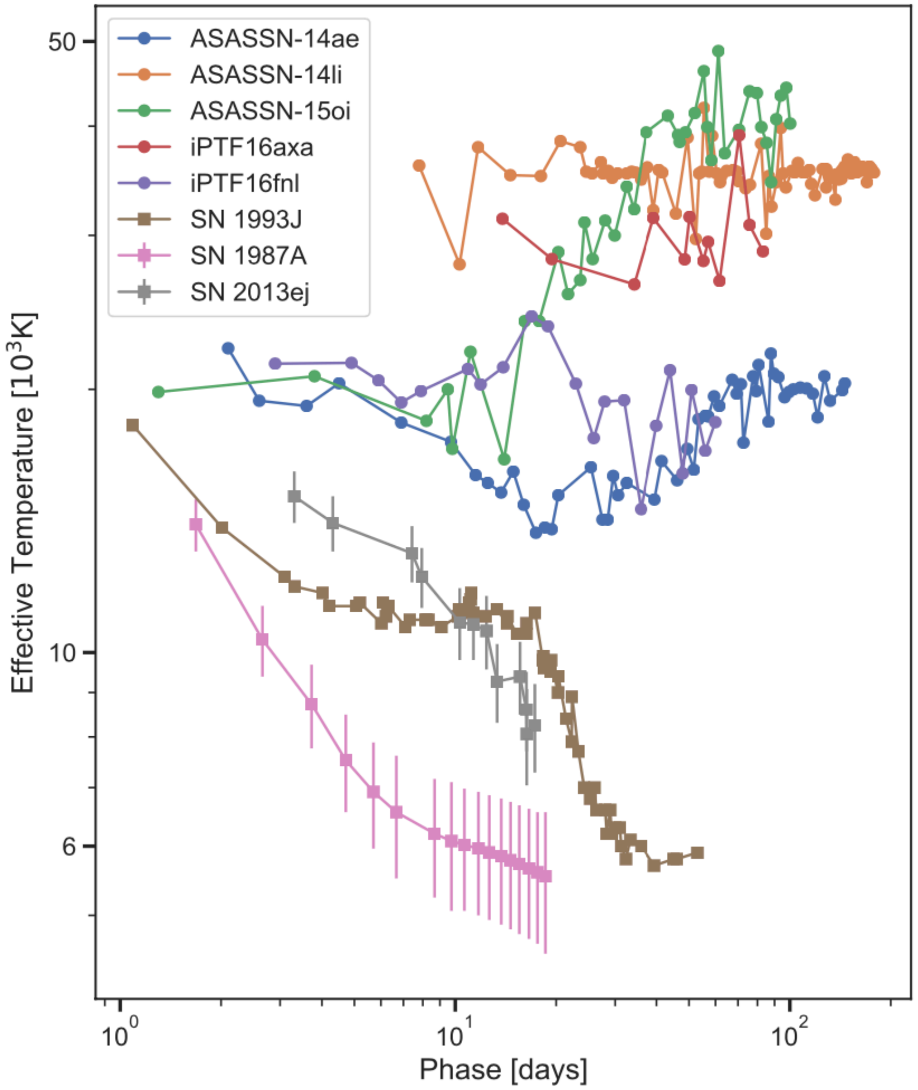
(Martin Rees, Nature 333 91988)

$$L_{bb} = 10^{43}\ \textit{erg/s}\ \text{(peak)}$$

Current status: ~50 optically/UV selected

BASICS OF EVENT SELECTION

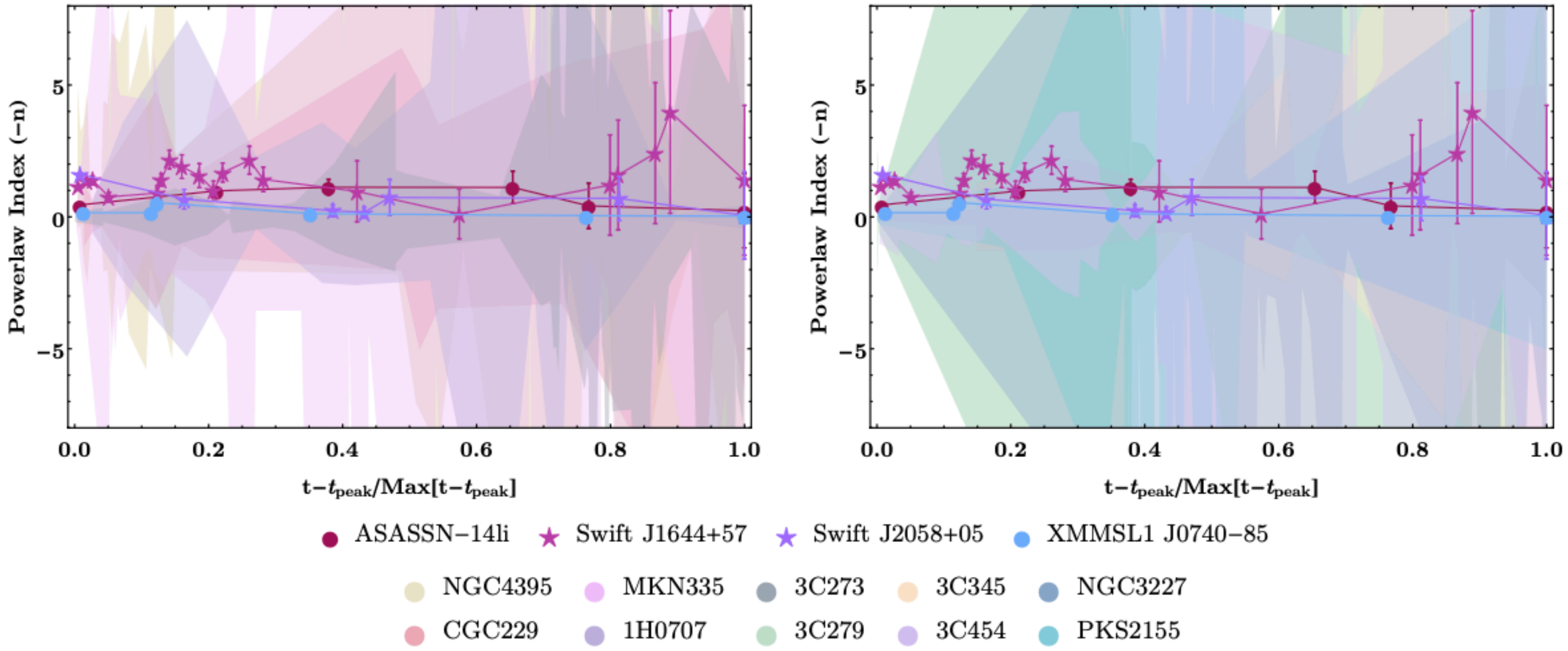
- TDE colors are quite constant in time, differently from SN’s.



Zabludoff et. Al. 2021

BASICS OF EVENT SELECTION

- TDE light curves are smoothly falling, with power-like law behavior.



Auchetll et. Al. 2018

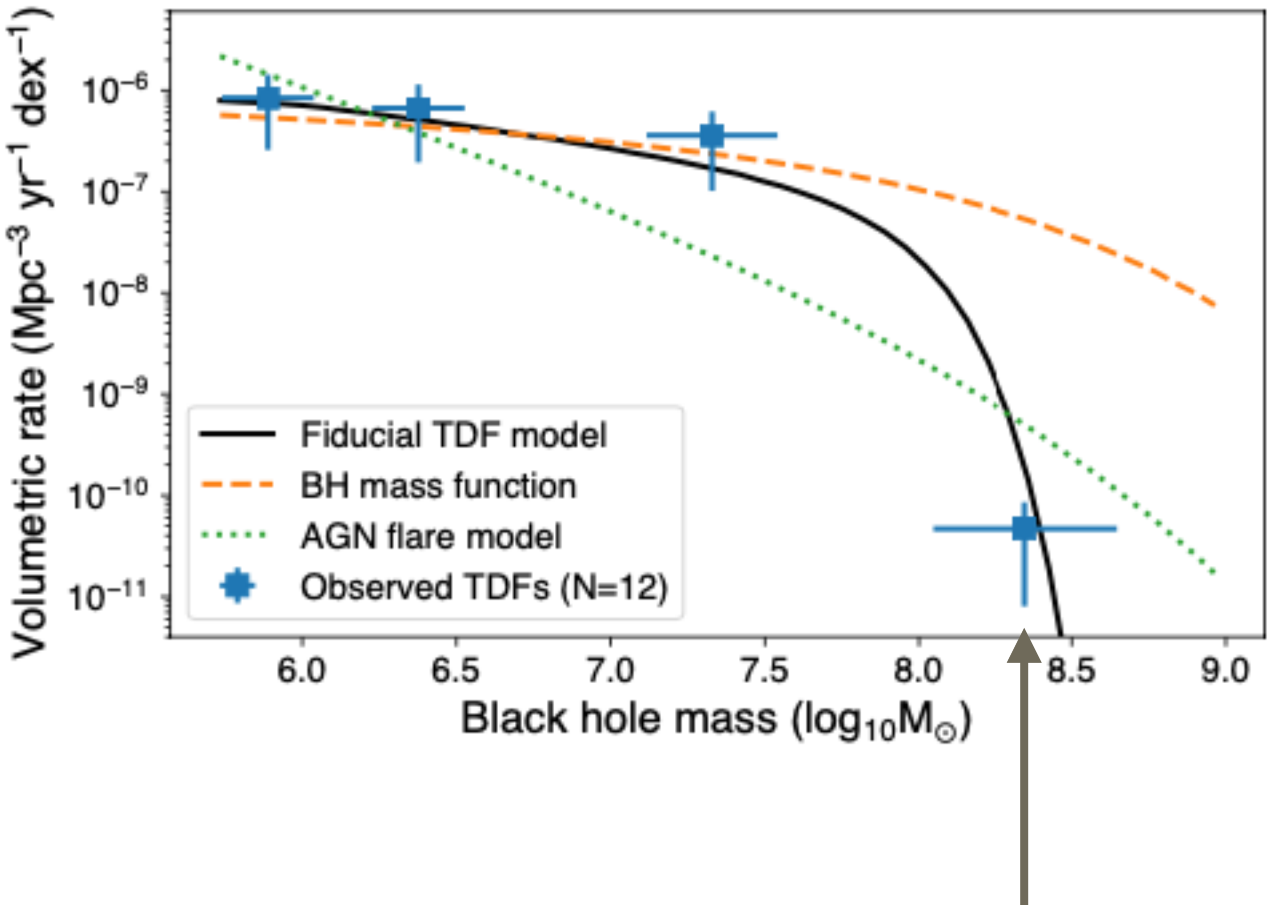
BASICS OF EVENT SELECTION

- 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 and predicted TDE rates:

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

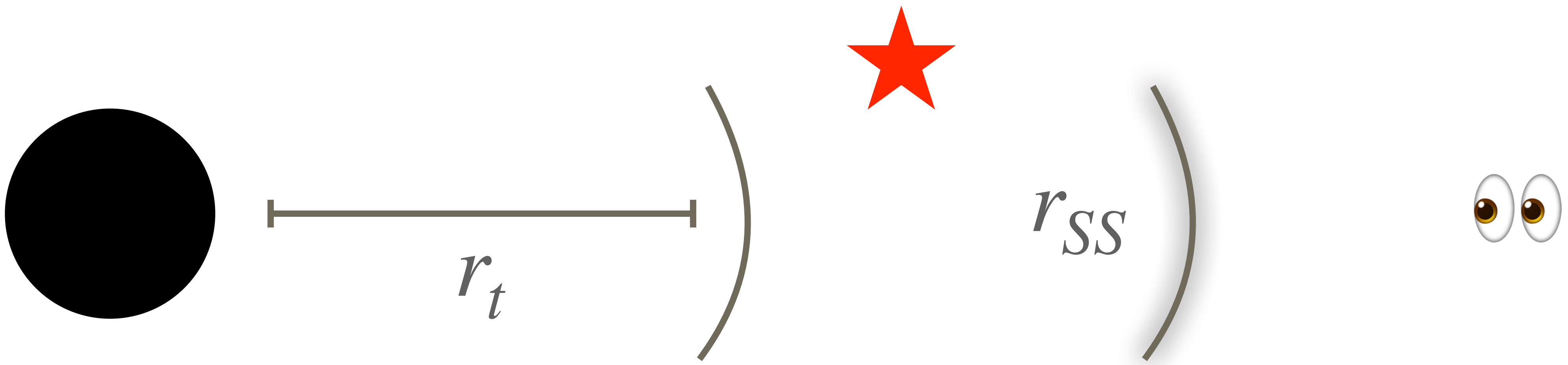


Van Velzen 1707.03458
(see Stone, Metzger
1410.7772 for details)

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.



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

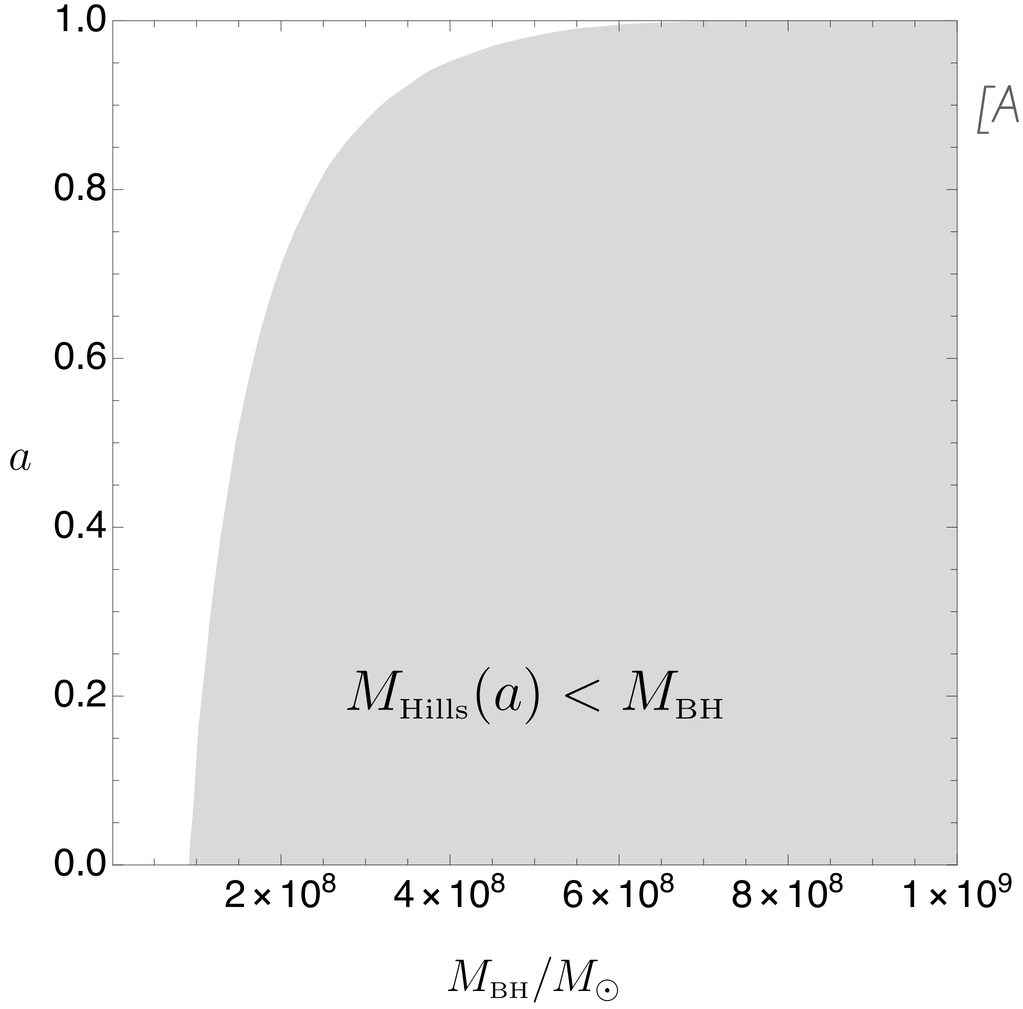
THE HILLS MASS: NON-SPINNING BH

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]

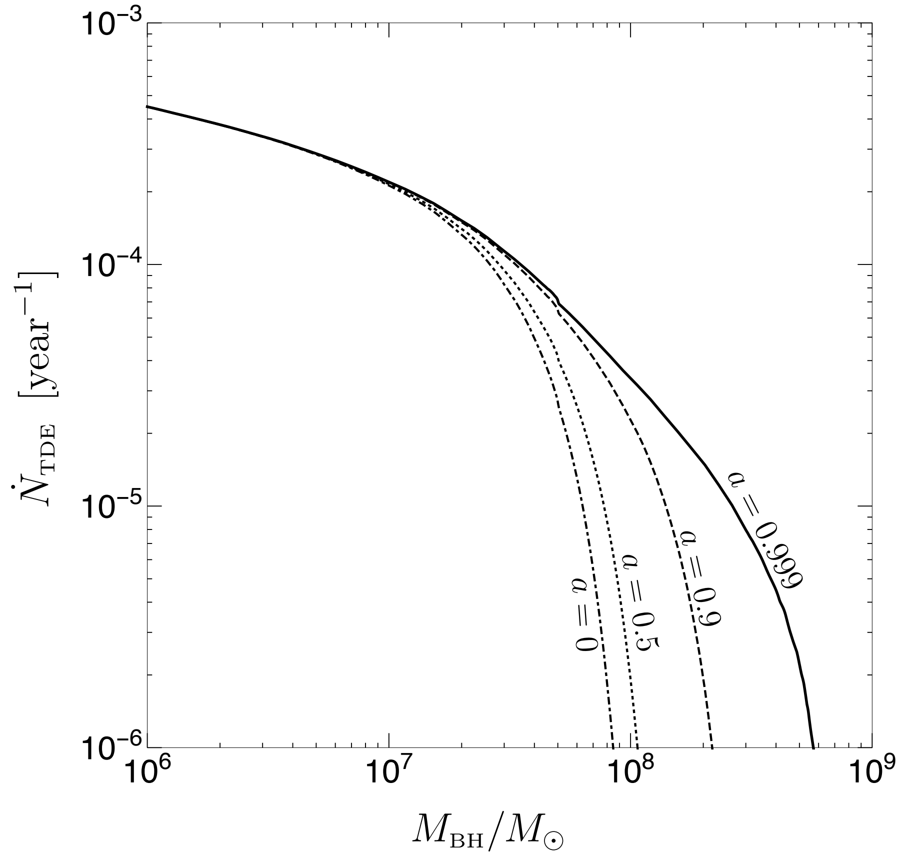
Hills mass for a main-sequence star

Hills mass grows with BH spin

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

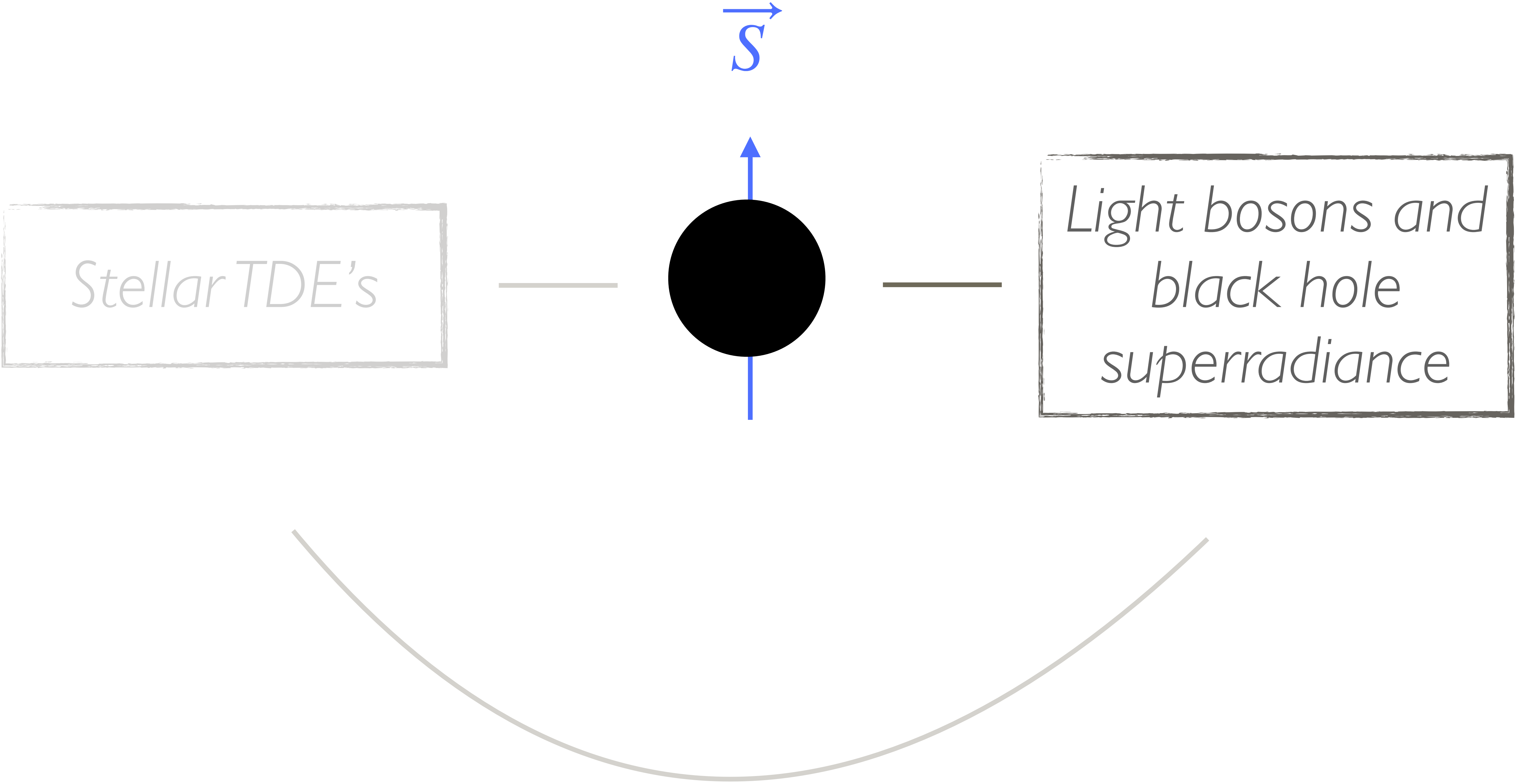
THE HILLS MASS

- 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-



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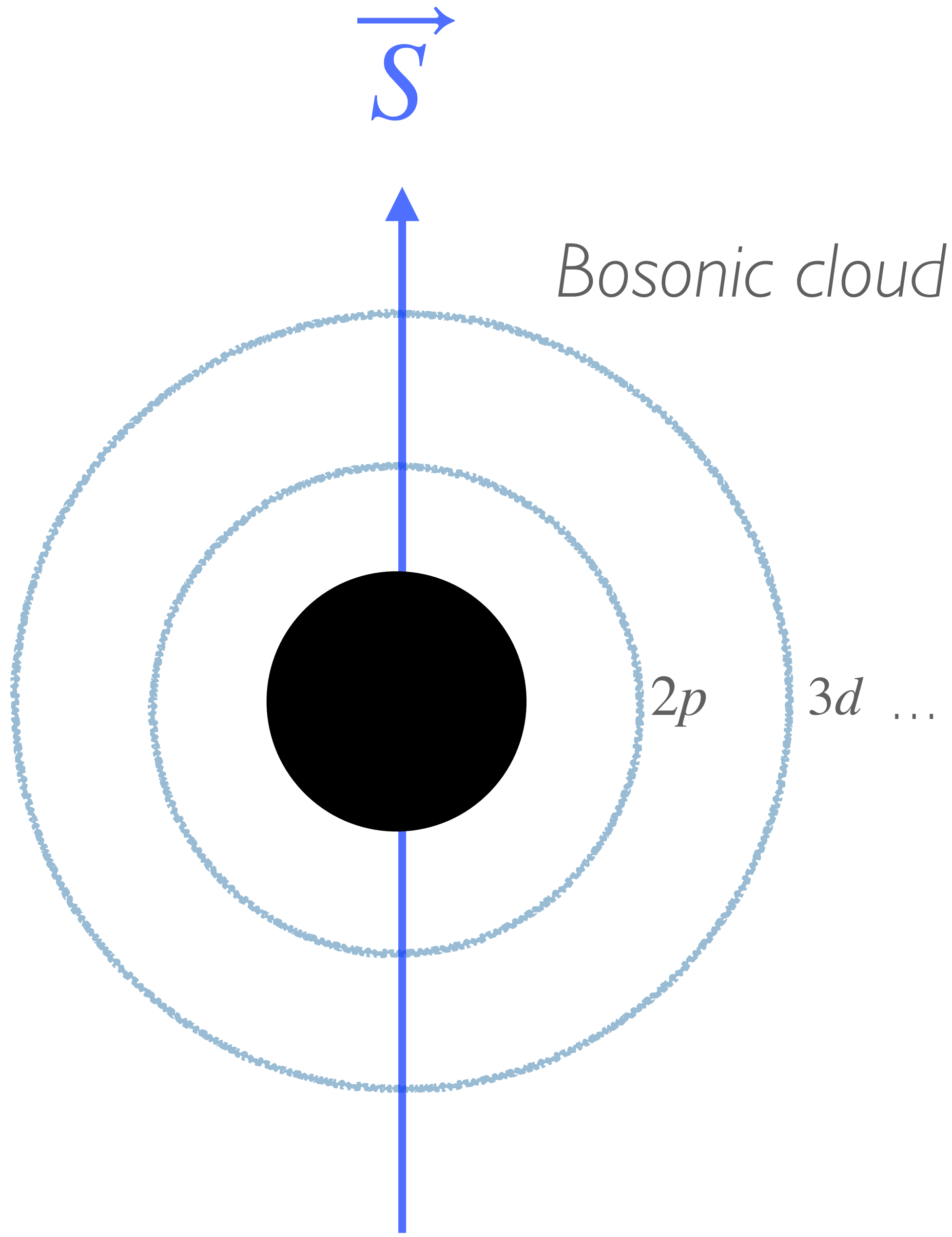
Stellar TDE's

Light bosons and black hole superradiance

If ultra-light bosons exist,
SMBH spins are affected by
the ***superradiant instability***

This would leave very unique imprints
on the observed TDE rates

BLACK HOLE SUPERRADIANCE



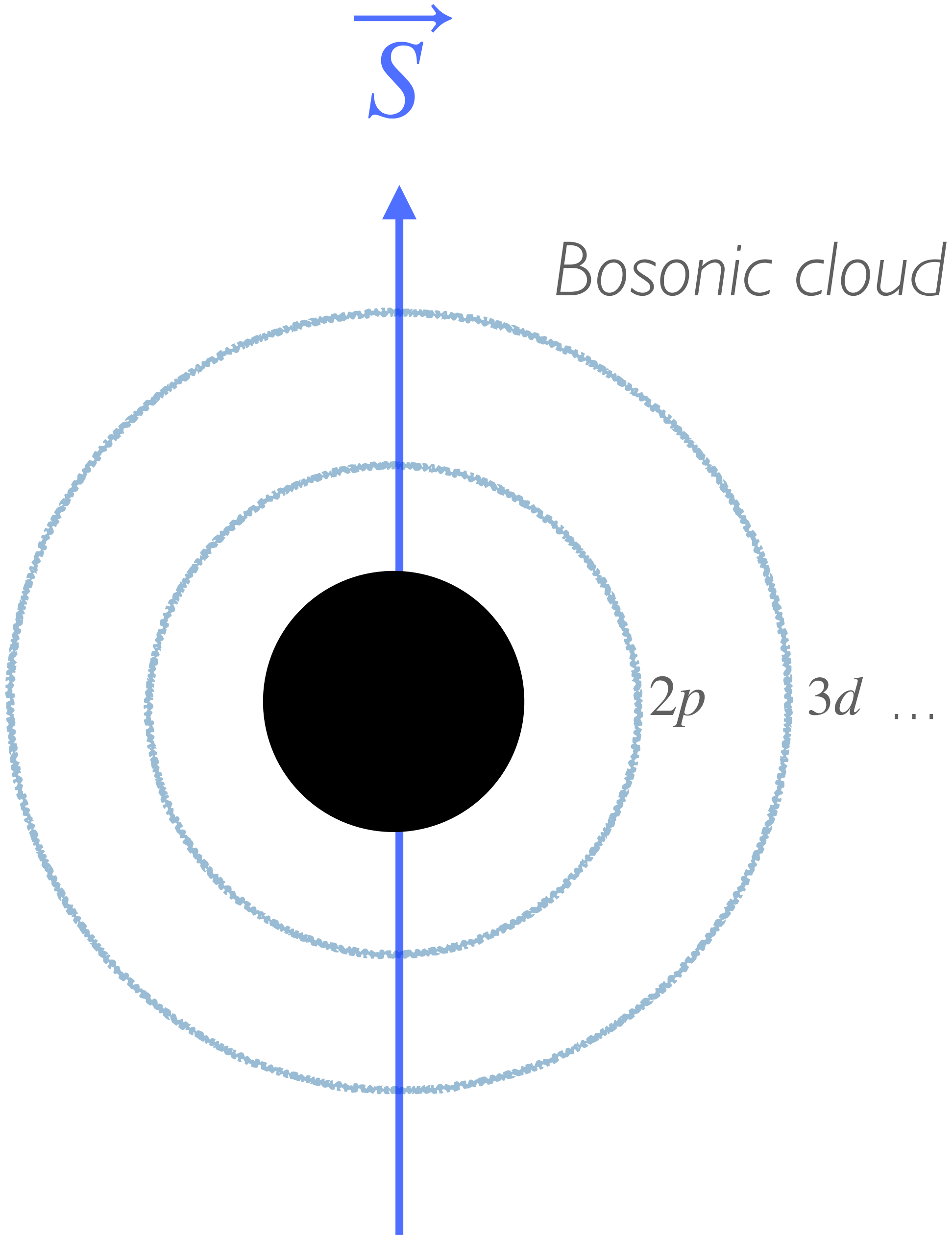
$$\frac{\mu}{m} \lesssim \Omega_{\mathrm{BH}}$$

μ : *Boson mass*

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

Zeldovich JETP Lett. 14 180, 1971
Arvanitaki et. Al. 0905.4720,1004.3558

BLACK HOLE SUPERRADIANCE

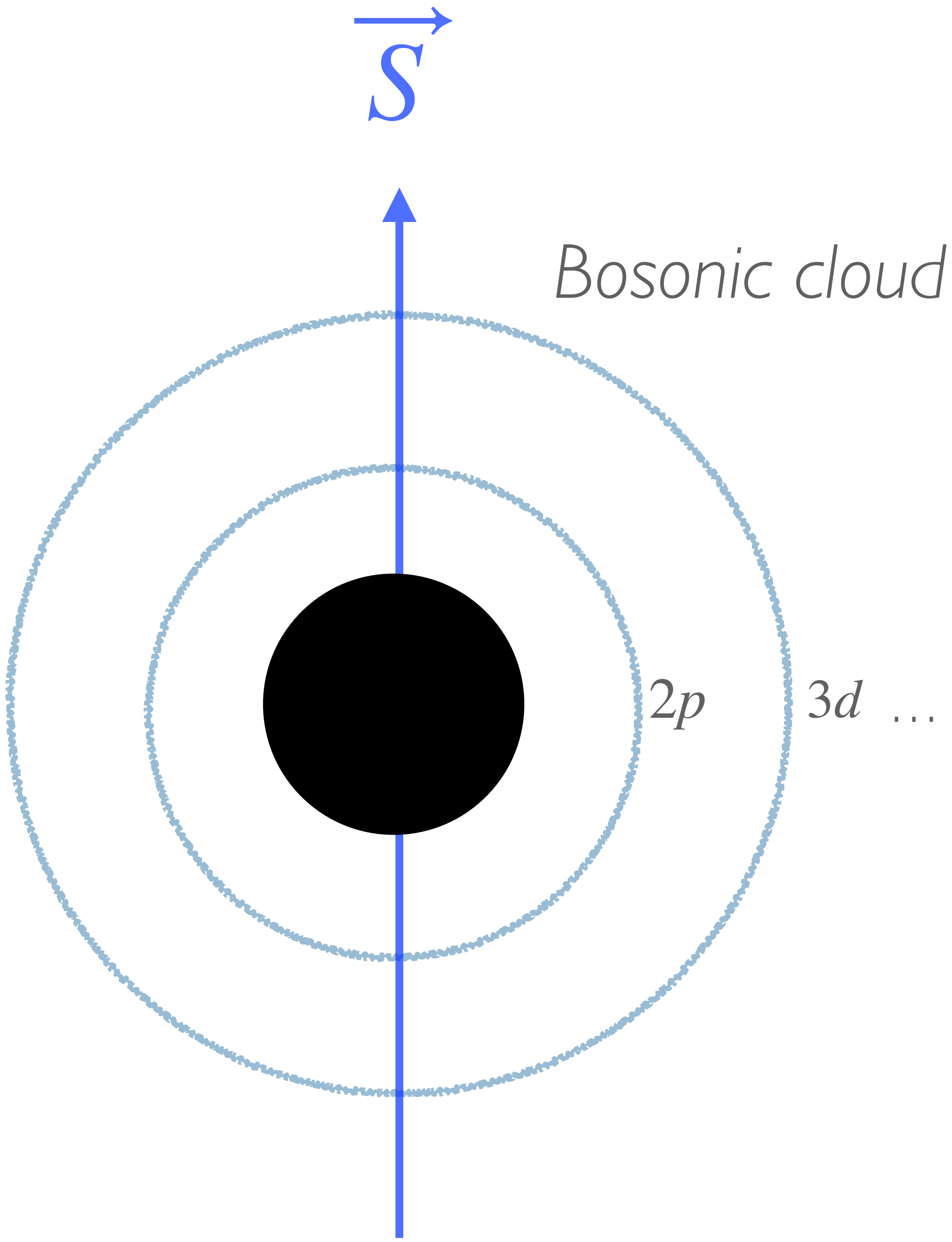


$$\frac{\mu}{m} \lesssim \Omega_{\rm BH}$$

Gravitational coupling

$$\alpha = GM_{\rm BH}\mu$$

BLACK HOLE SUPERRADIANCE



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

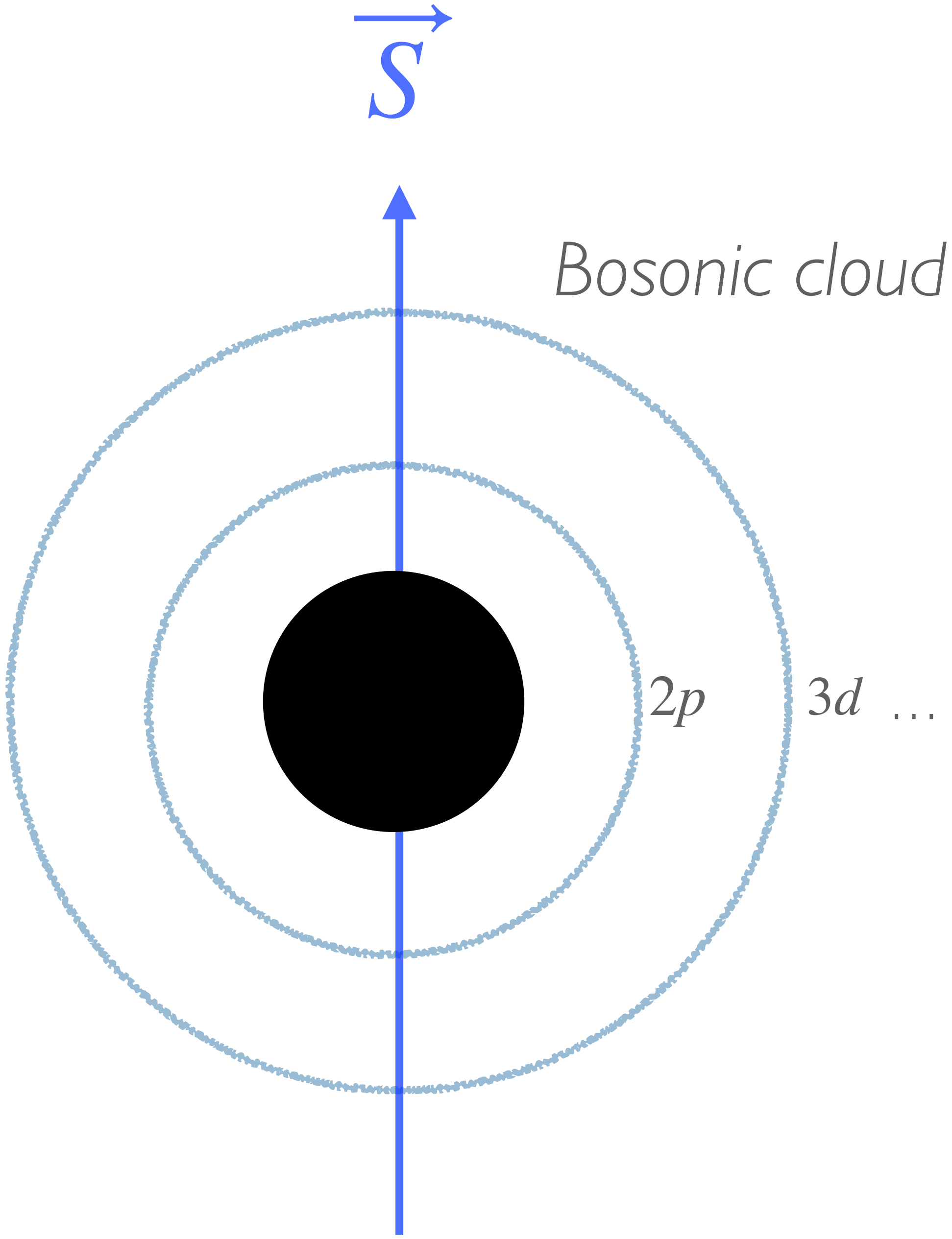
Gravitational coupling

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

Cloud radius

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

BLACK HOLE SUPERRADIANCE



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

Gravitational coupling

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

For <u>maximally spinning</u> 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)

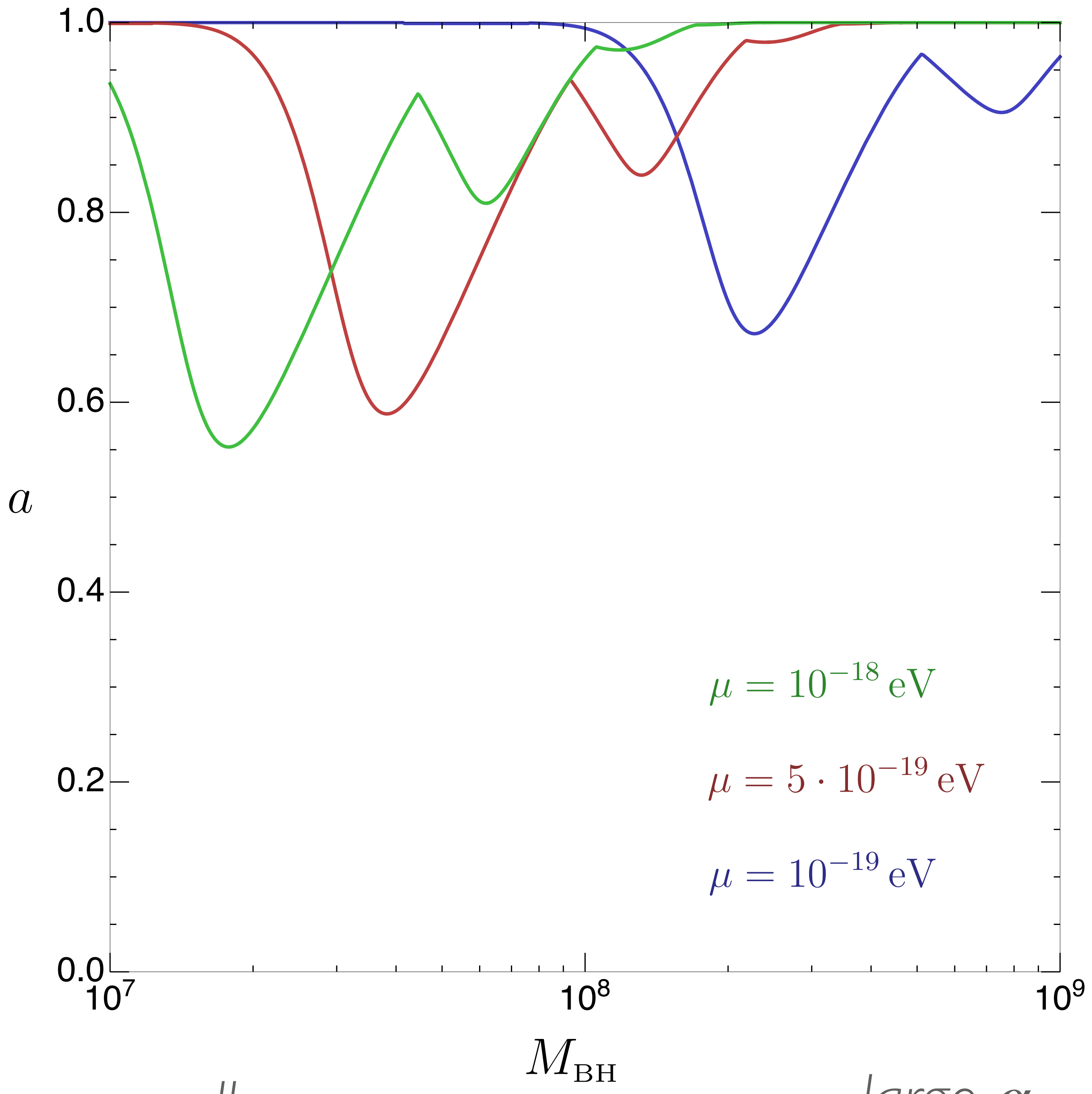
$$\tau_{\rm SR} \sim 10^6\,\textit{years}\left[\frac{\alpha}{0.1}\right]^{-8}\left[\frac{M_{\rm BH}}{10^8 M_\odot}\right]$$

Scalars (axions)

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

$$\mu \sim \frac{1}{GM_{\rm BH}} = \frac{1}{r_g} \sim 10^{-18}\text{eV}\left[\frac{10^8 M_\odot}{M_{\rm BH}}\right]$$

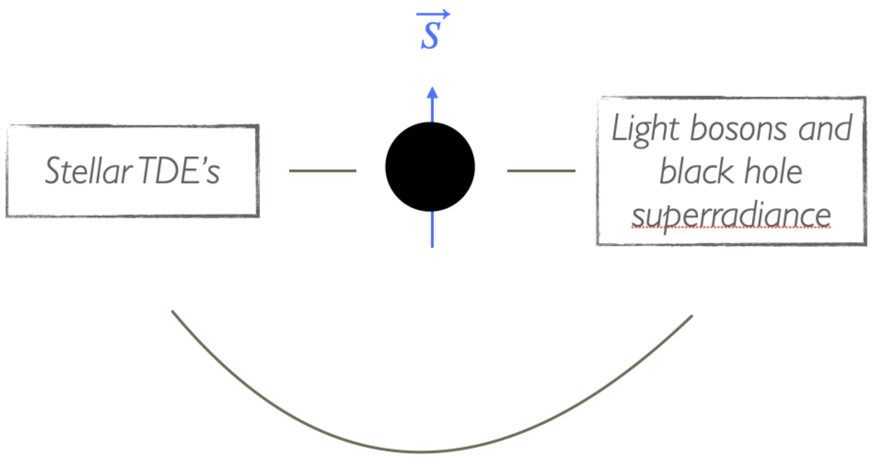
SUPERRADIANT SPIN EXTRACTION



small α *large* α

Spin-0 boson

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



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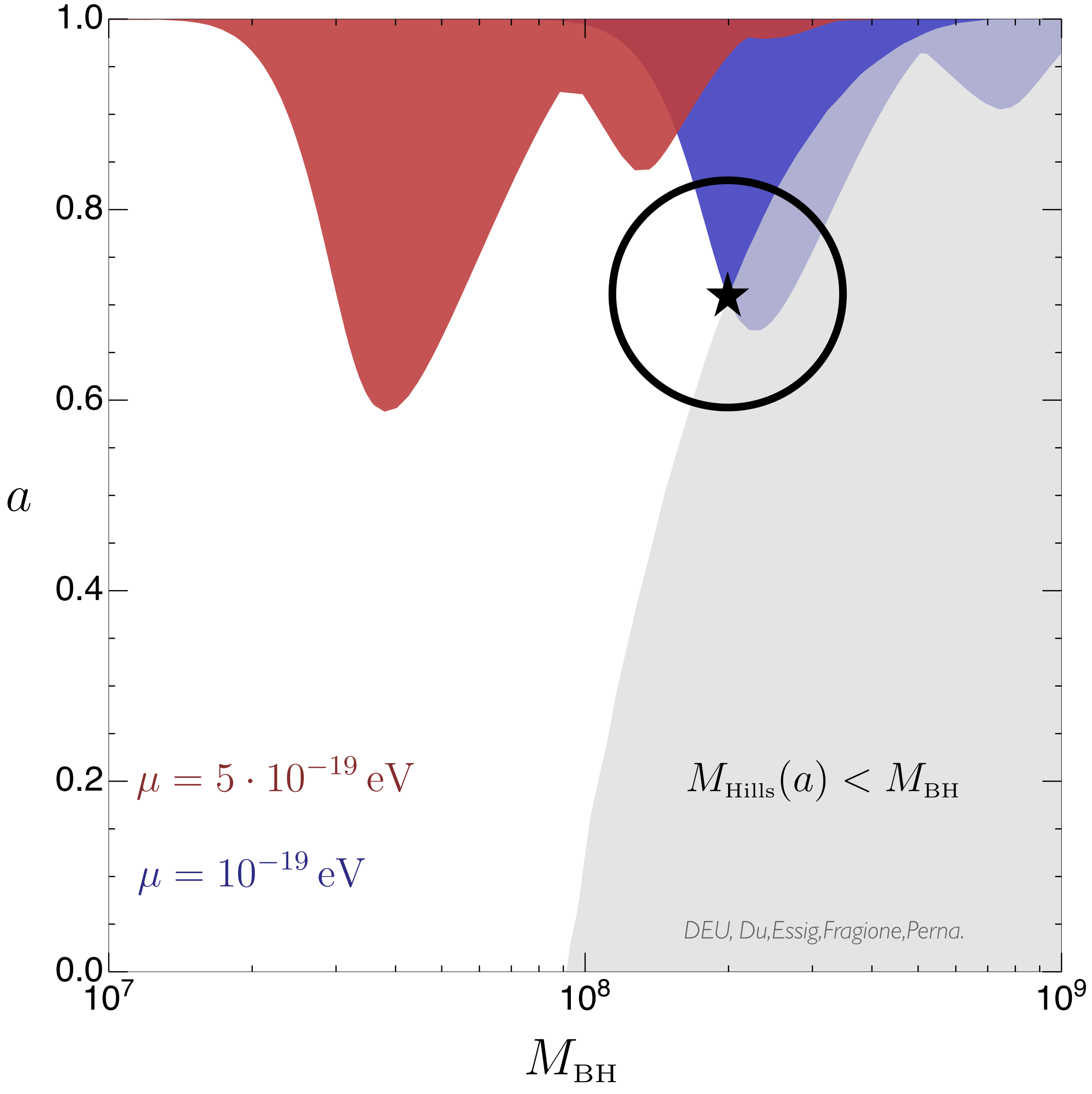
Stellar TDE's

Light bosons and black hole superradiance

The effect of light bosons on TDE event rates

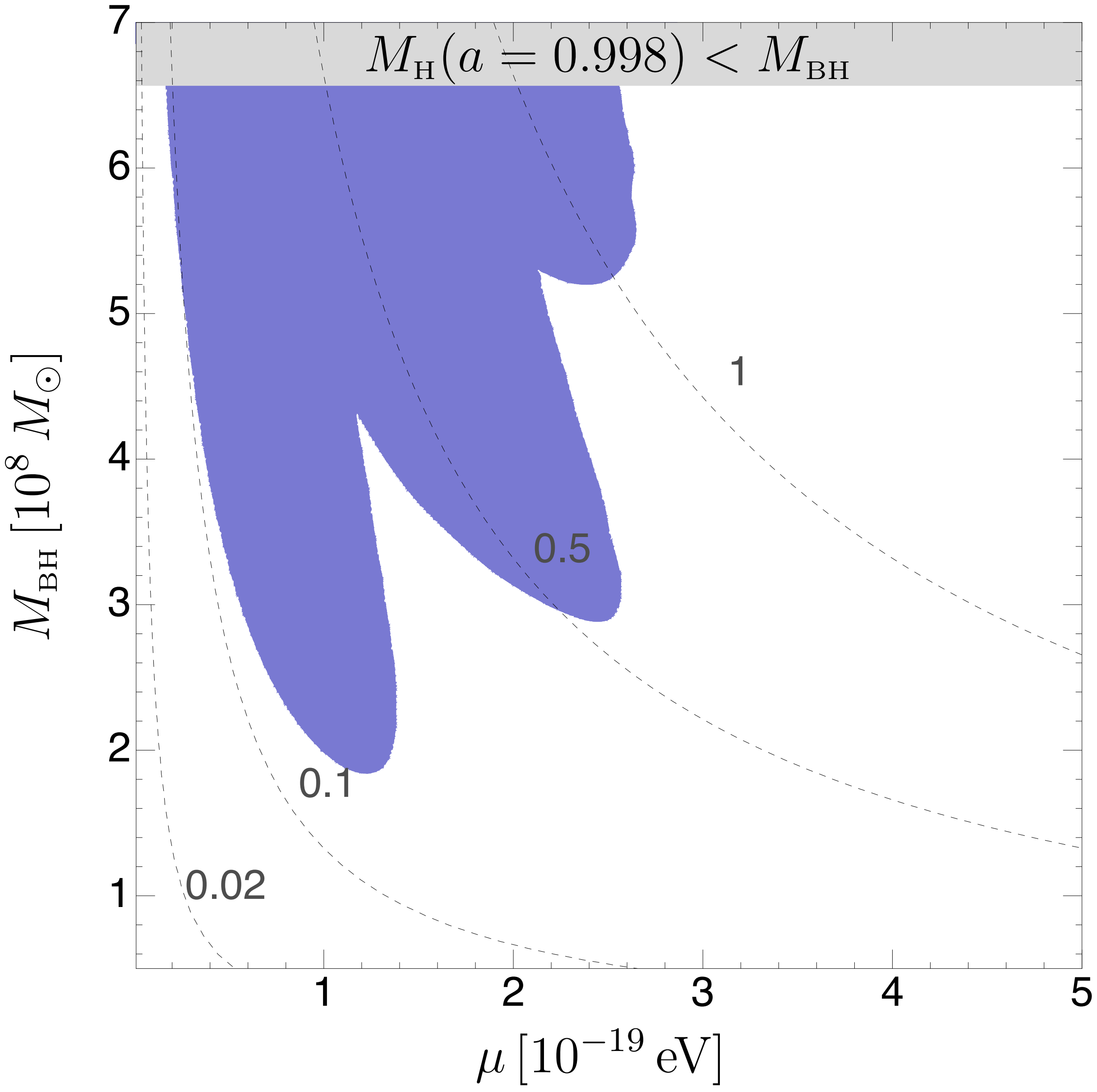
BOSONS DECREASE THE EFFECTIVE HILLS MASS



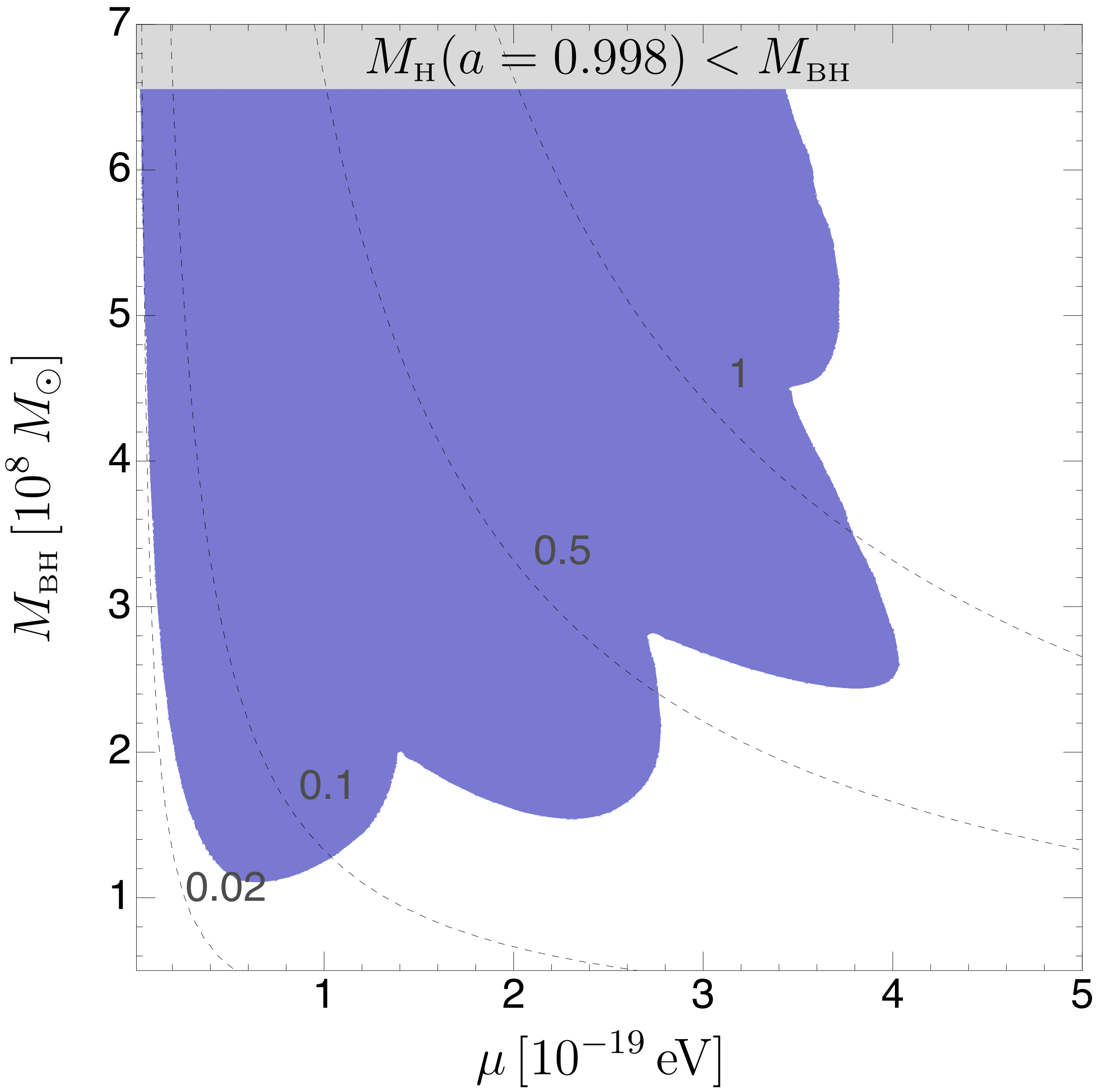
Spin-0 boson

Ultra-light bosons decrease the "effective Hills mass"

THE EFFECTIVE HILLS MASS

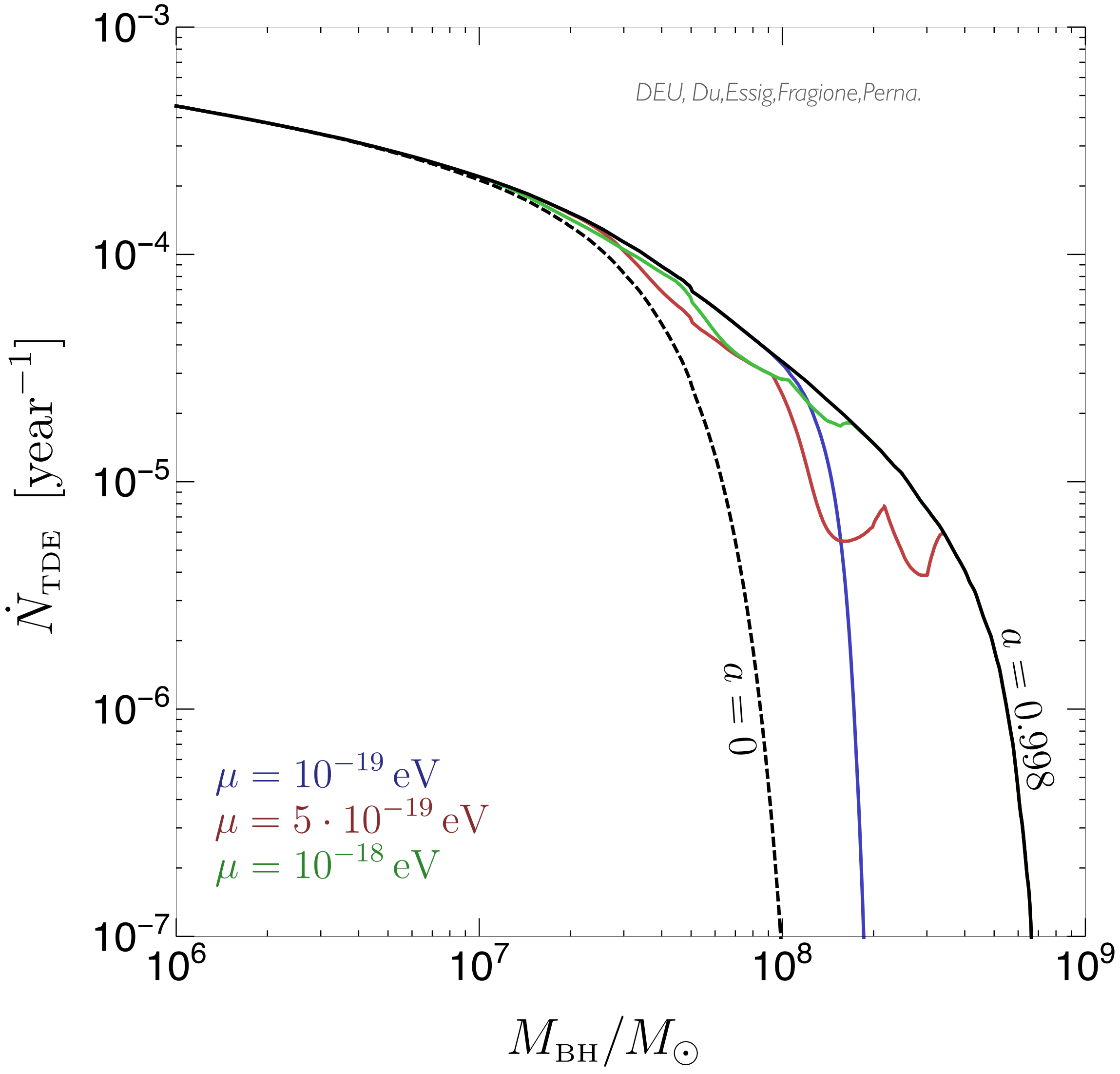


Scalars



Vectors

TDE RATES IN THE PRESENCE OF ULTRA-LIGHT BOSONS



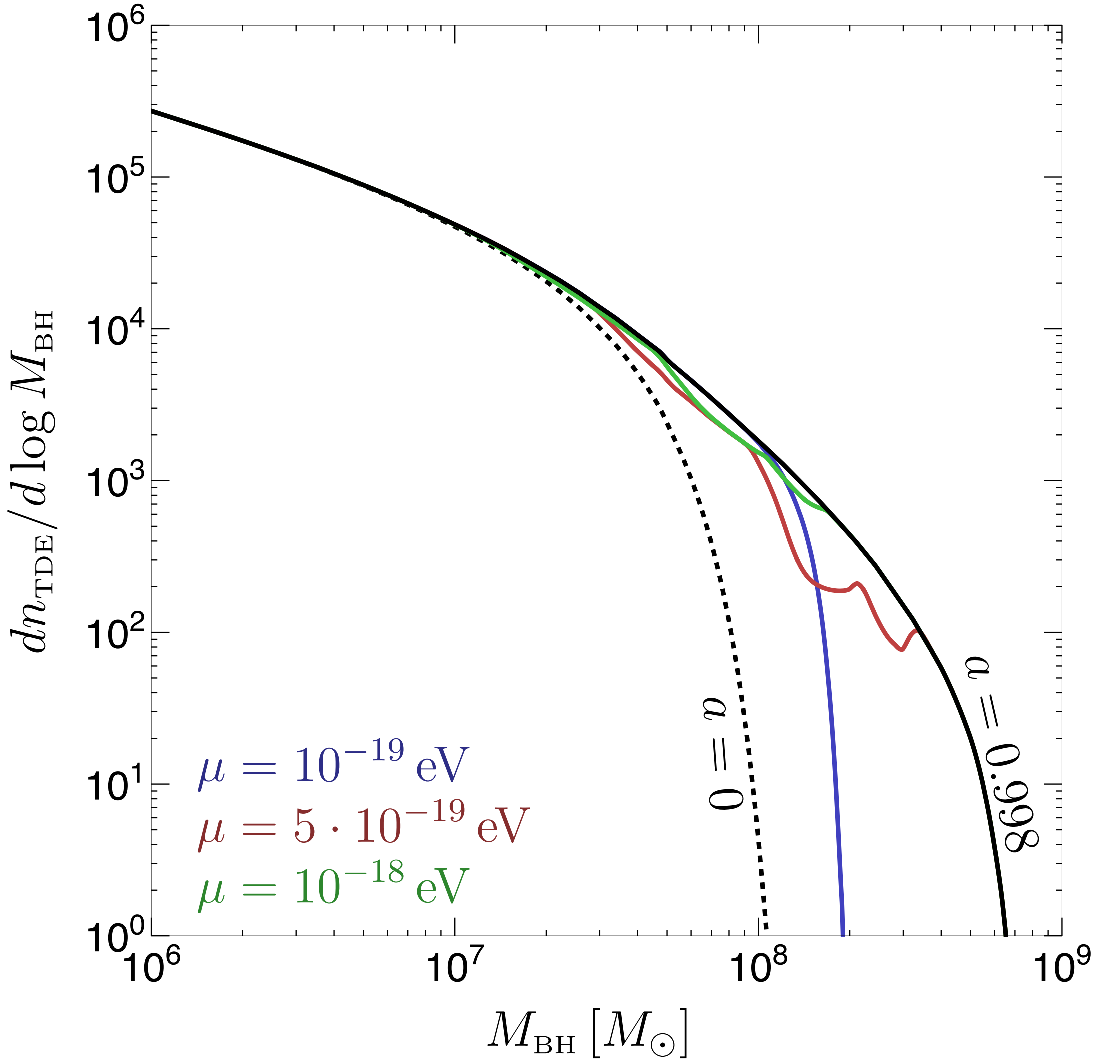
TDE rate

-per galaxy-

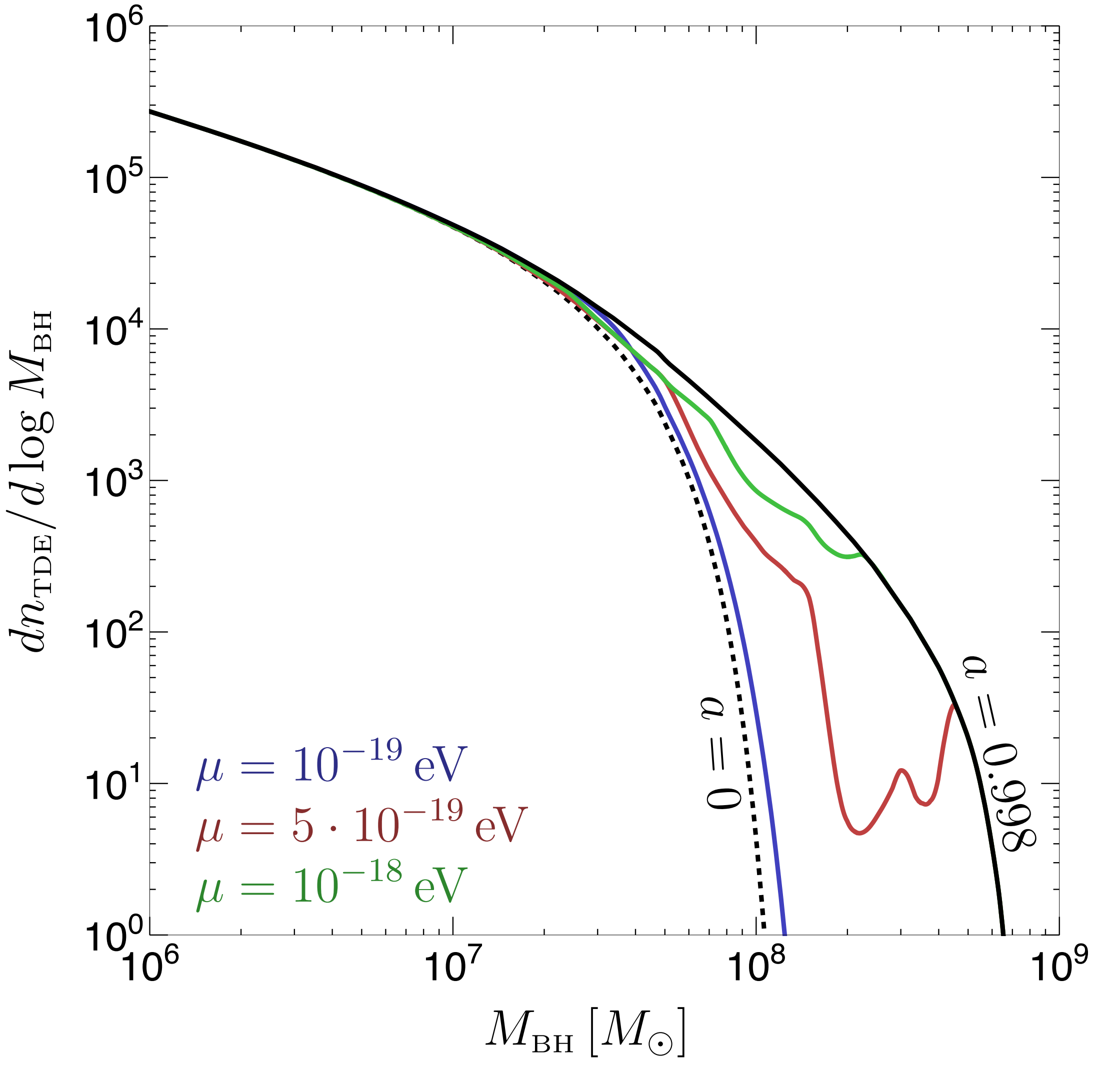
Spin-0 boson

Testing axions and dark photons with LSST measurements of TDE rates

TDE RATE ESTIMATES IN LSST



Scalars

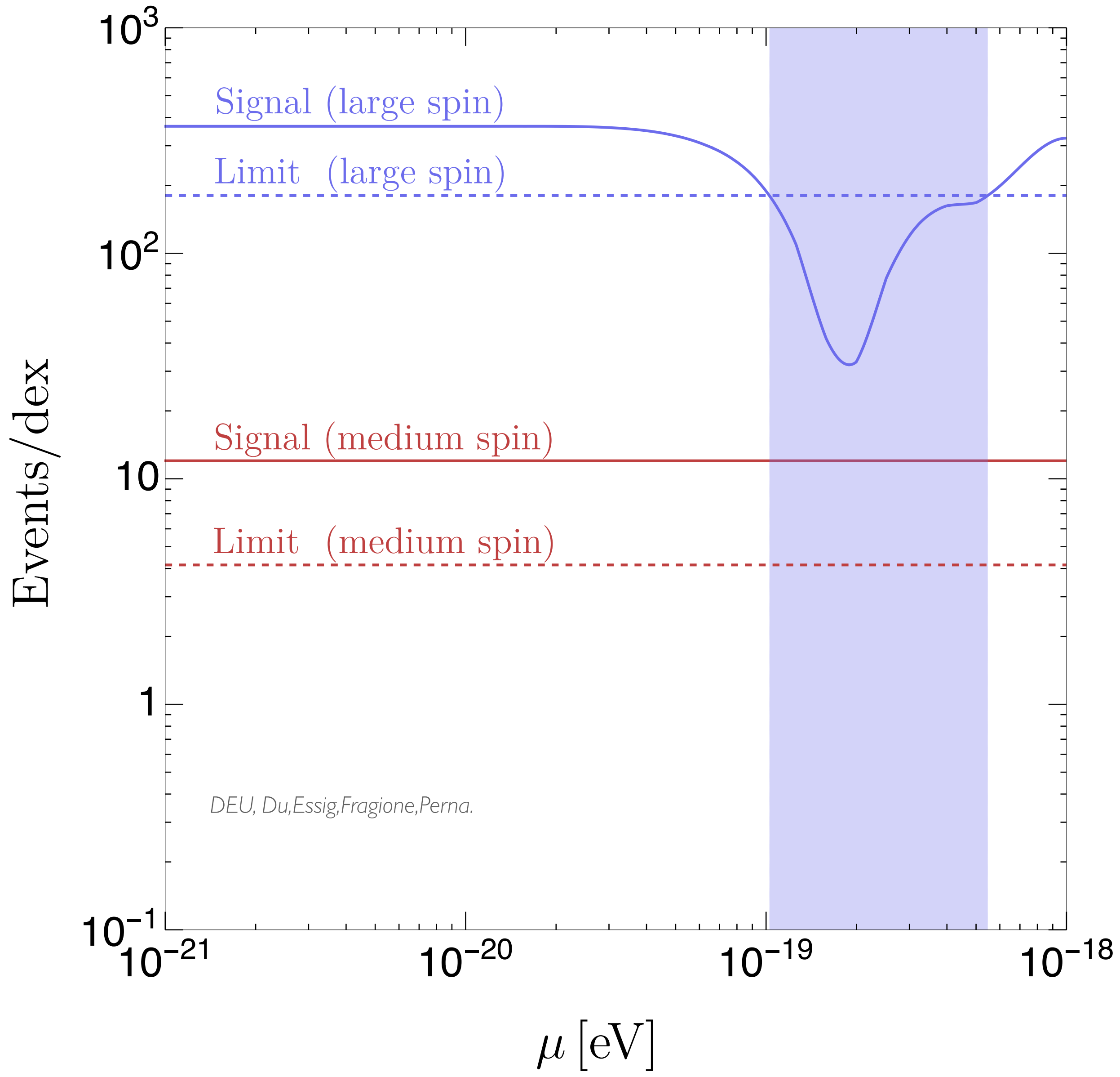


Vectors

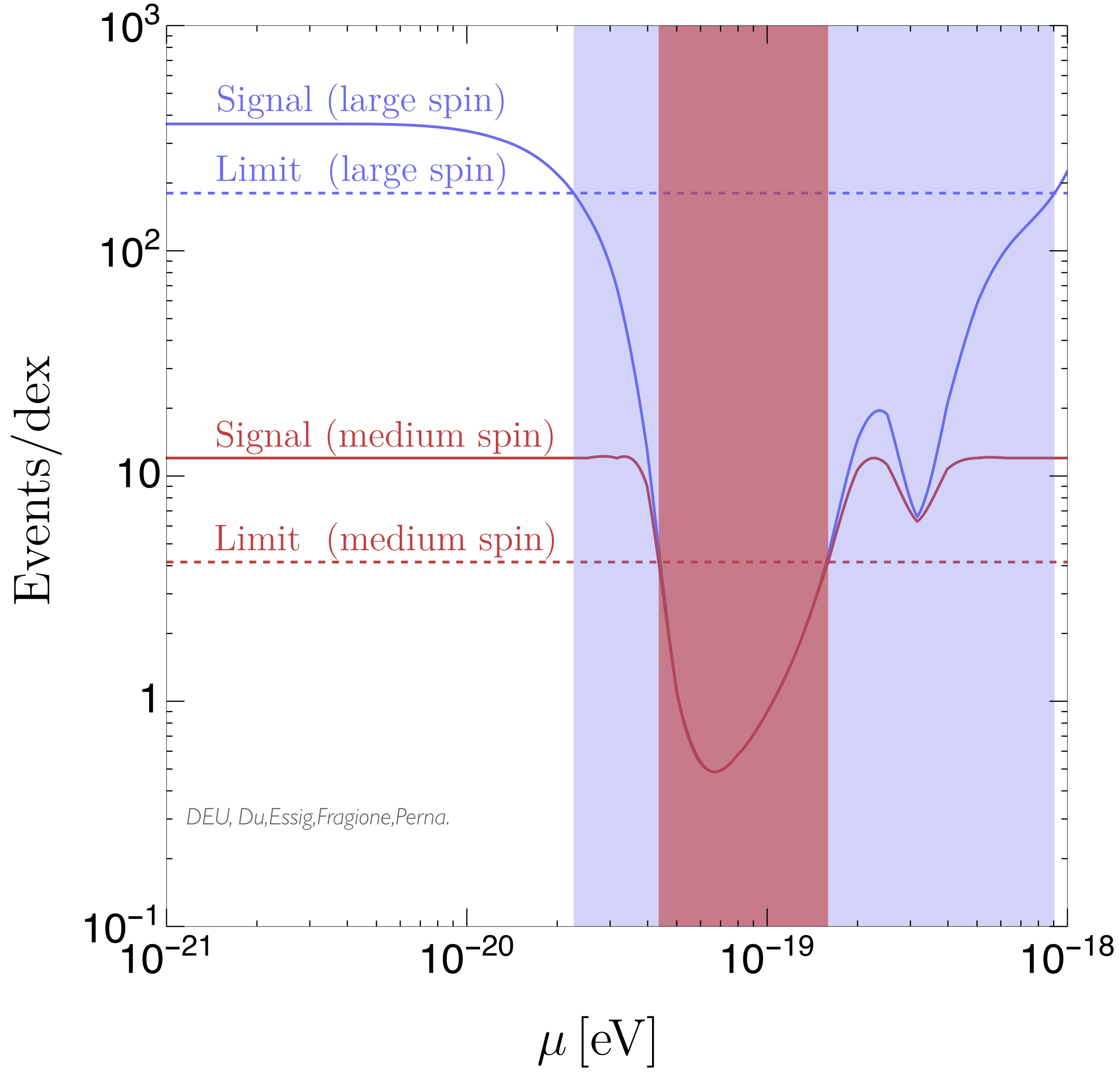
(Our rate estimates in the absence of ultra-light bosons roughly agree with Bricman, Gomboc 1906.08235)

LIMIT PROJECTIONS

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



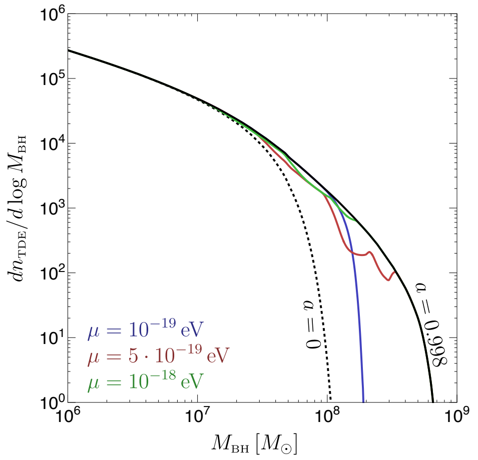
Scalars



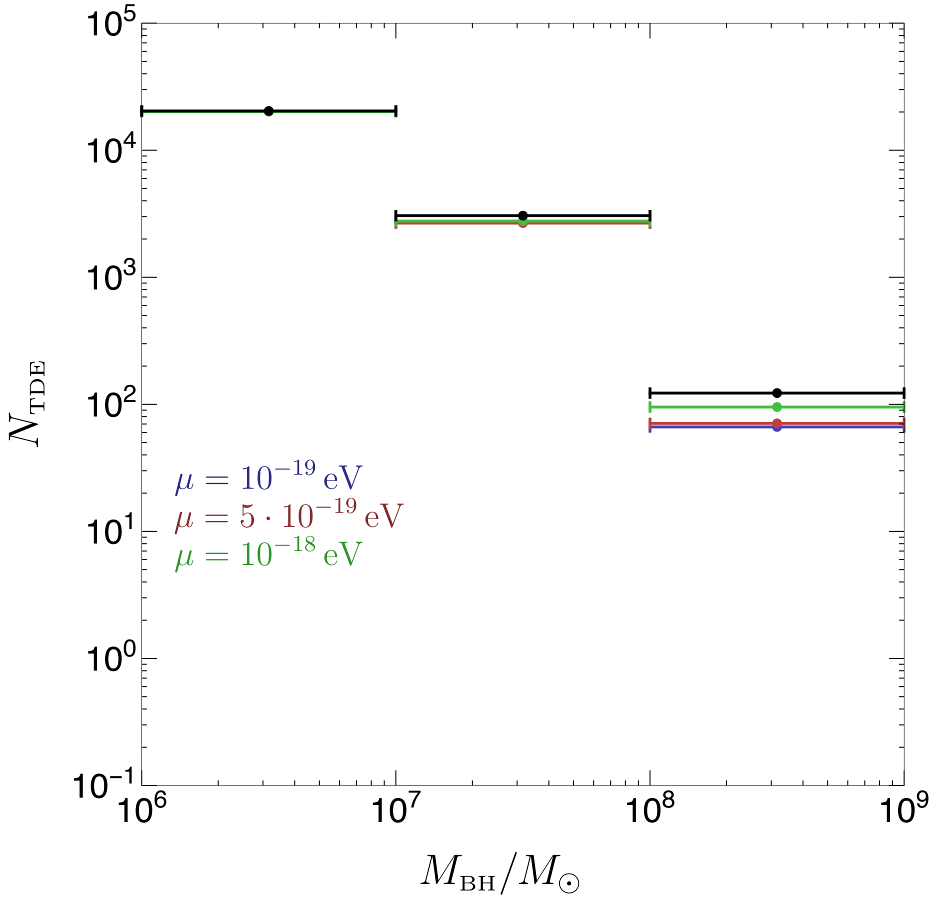
Vectors

SMEARING DUE TO MBH MEASUREMENT UNCERTAINTIES

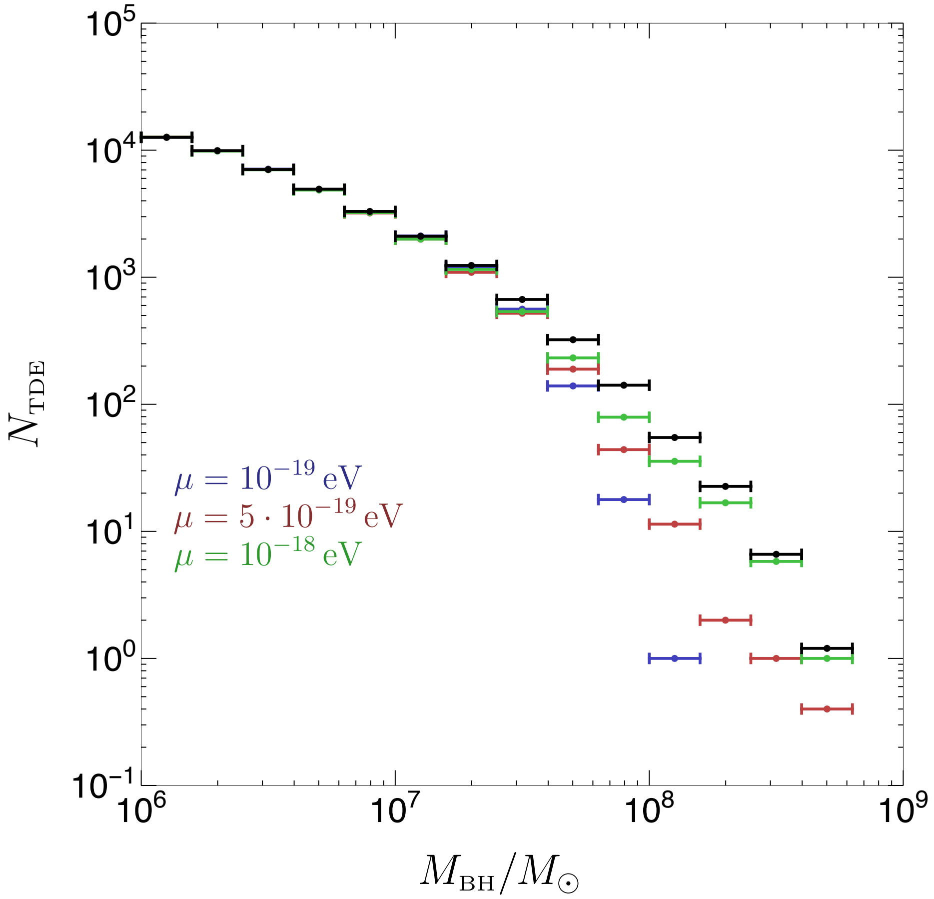
Spin 1



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.