# Fuelling the first black holes

*— the role of tidal disruption events —*

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Based on: Hamsa Padmanabhan and Abraham Loeb, *A&A, 656, A47 (2021)*

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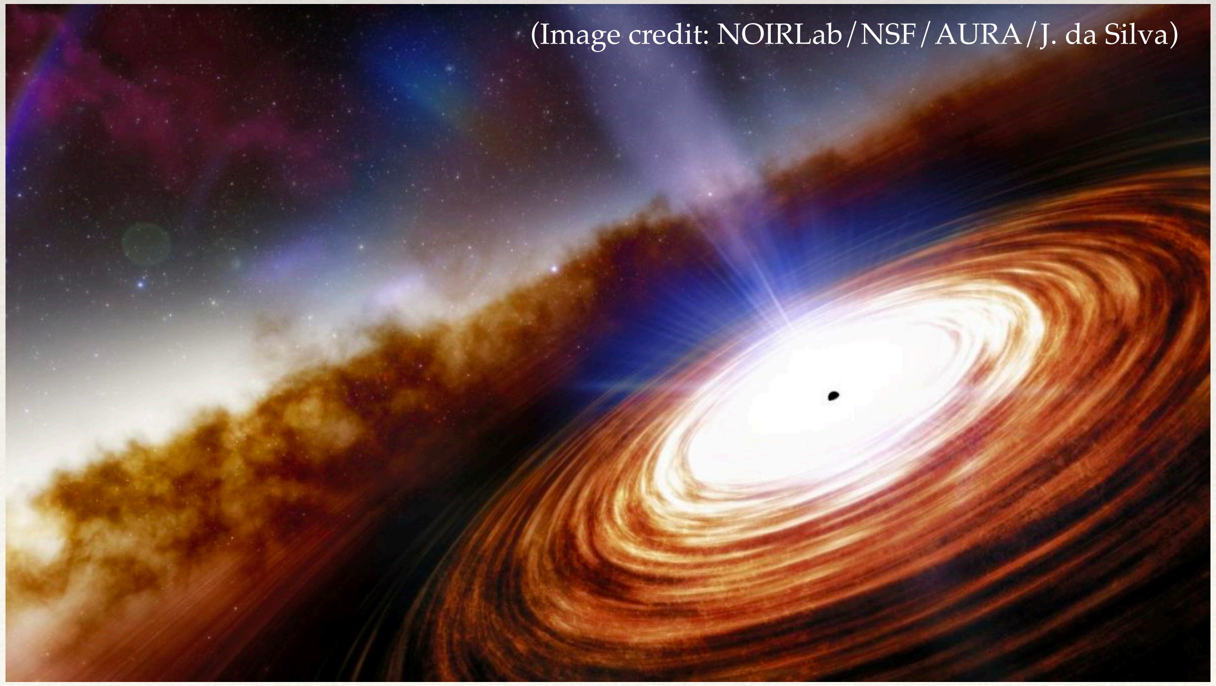
# The first black holes

- Observations of QSOs at z ~ 6 indicate supermassive BH of masses $10^9 - 10^{10} M_\odot$ at $z \gtrsim 6$ [Fan+ (2006), Banados+ (2018)]
- Highest mass predicted to be ~ $10^{10} M_\odot$, also observed … [Haiman & Loeb (2001), Wu+ (2015)]
- … just a few Myr after the first stars [e.g. Barkana & Loeb (2001)]
- Growing a ~ $10^9 M_\odot$ BH from an initial seed of 100 $M_\odot$ needs ~ 1 Gyr of continuous Eddington accretion [Volonteri+ (2010, 2012)]
- Calibration if black holes are **active (= AGN)**
- Most BH at galactic centres dormant (esp. low-luminosity)




Quasar J0313–1806, most distant, z ~ 7.64

# Fuelling and growth of black holes

Two main parameters

Eddington ratio ($\eta_{\rm Edd}$)

Radiative efficiency ($\epsilon$)

$$L_{\rm Bol} = 1.38 \times 10^{38} \eta_{\rm Edd} \left( \frac{M_{\rm BH}}{M_\odot} \right) \ {\rm erg\ s^{-1}}$$

$$M_{\rm BH} = M_{\rm seed} \exp(t_{\rm QSO}/t_S)$$

$$t_{\rm S} = 0.45\,(\epsilon/1-\epsilon)\,(L_{\rm bol}/L_{\rm Edd})^{-1}\ \ {\rm Gyr}$$

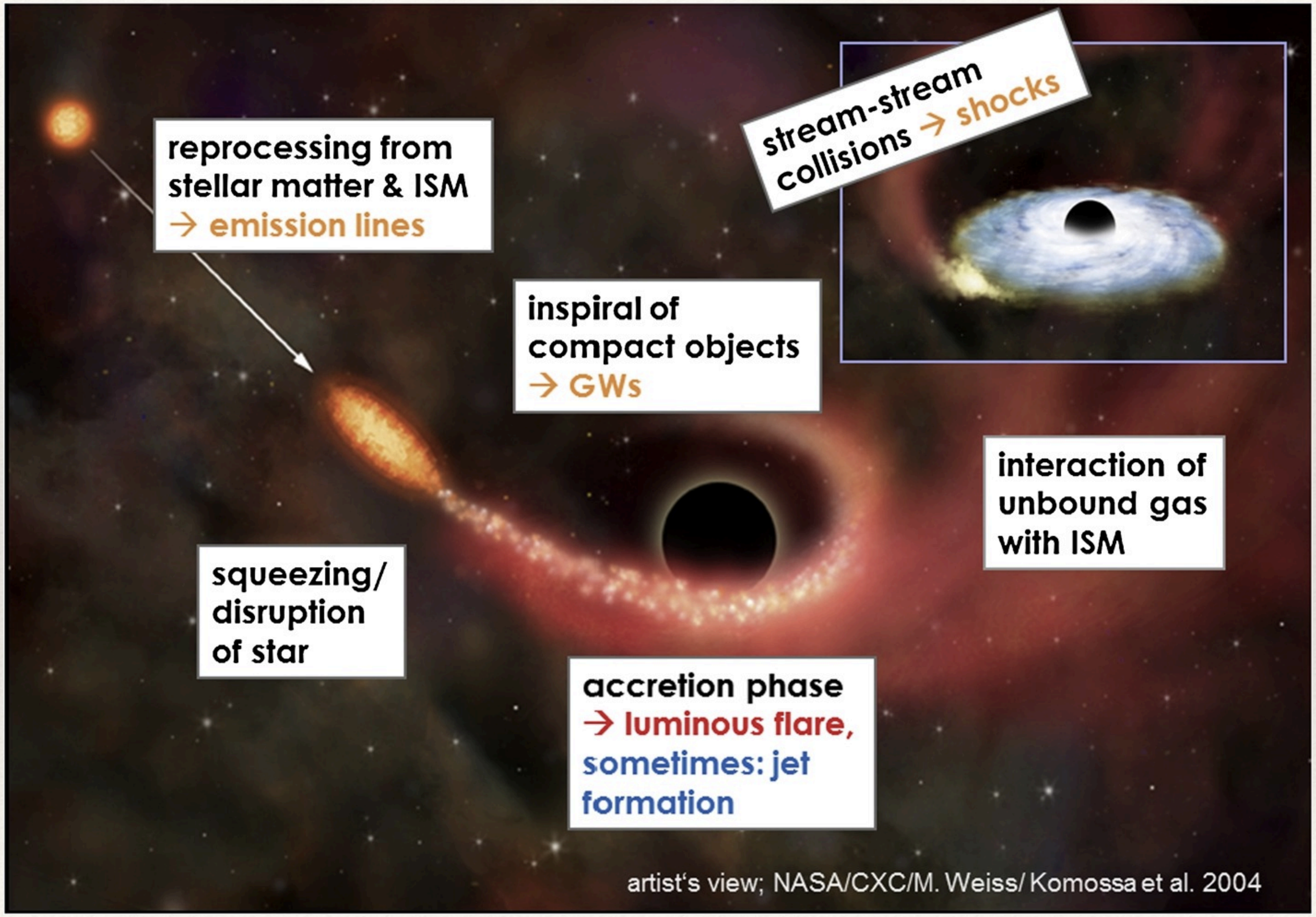
Most high-redshift SMBHs rapidly accreting, $\eta_{\rm Edd} \sim 1$ and $t_{\rm QSO} \sim 10^4 - 10^6$ yrs

[e.g., Willott+ (2015), Trakhtenbrot+ (2017), Khrykin+ (2021), Eilers+ (2020)]

# Fuelling IMBHs and SMBHs

*A promising avenue: tidal disruption events (TDEs)*

[Rees (1988), Hills (1975)]



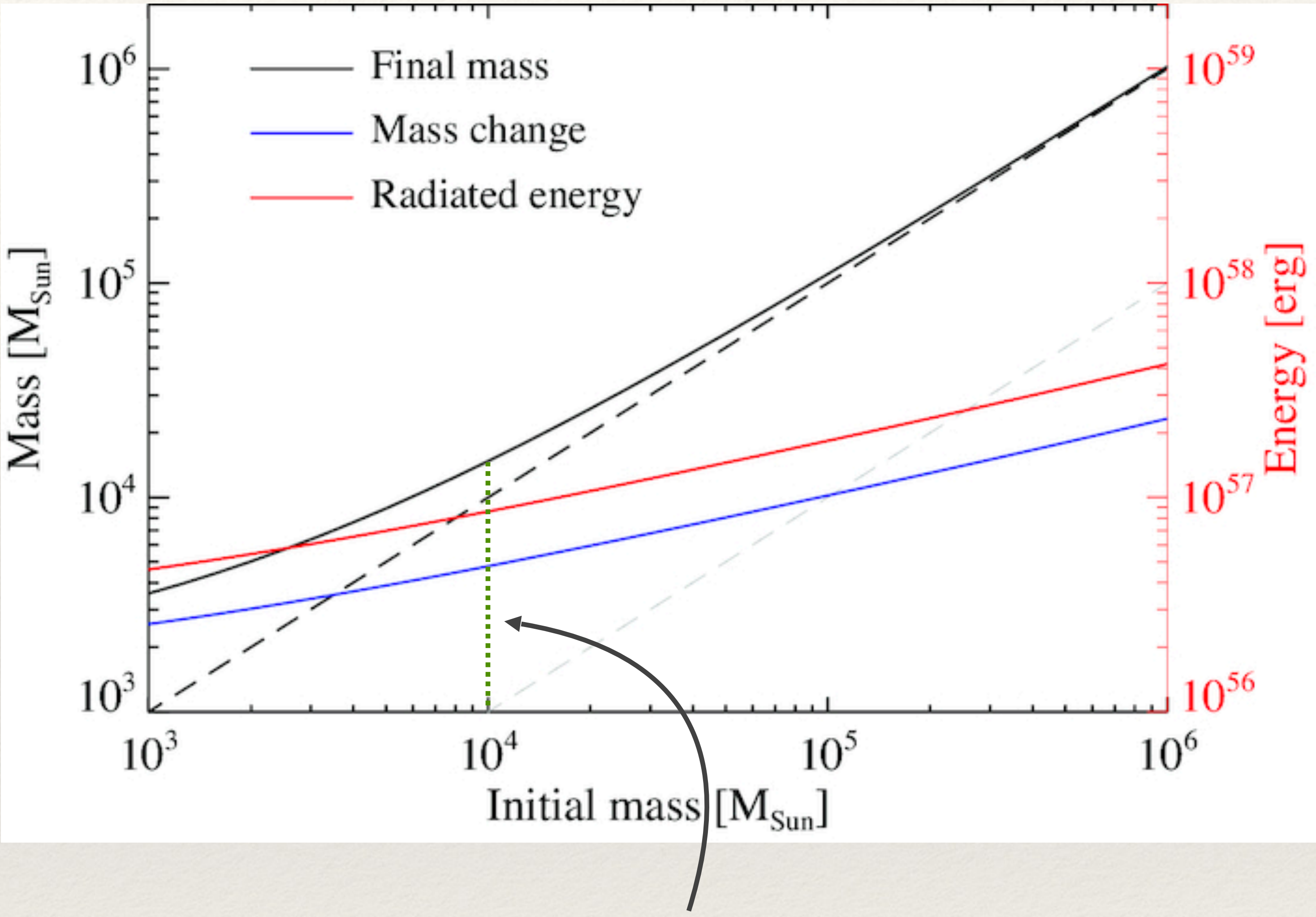

Open TDE Catalog (https://tde.space/), 98 so far

# Intermediate mass black holes (IMBHs)

- 'Missing link' in formation of first supermassive black holes, 100 - $10^6 M_\odot$, e.g., NGC 205, HLX-1

[review: Greene+ (2020)]

- Most black hole mass density at low mass may be built up through tidal capture and TDEs




Growth by factor 1.48 due to TDEs

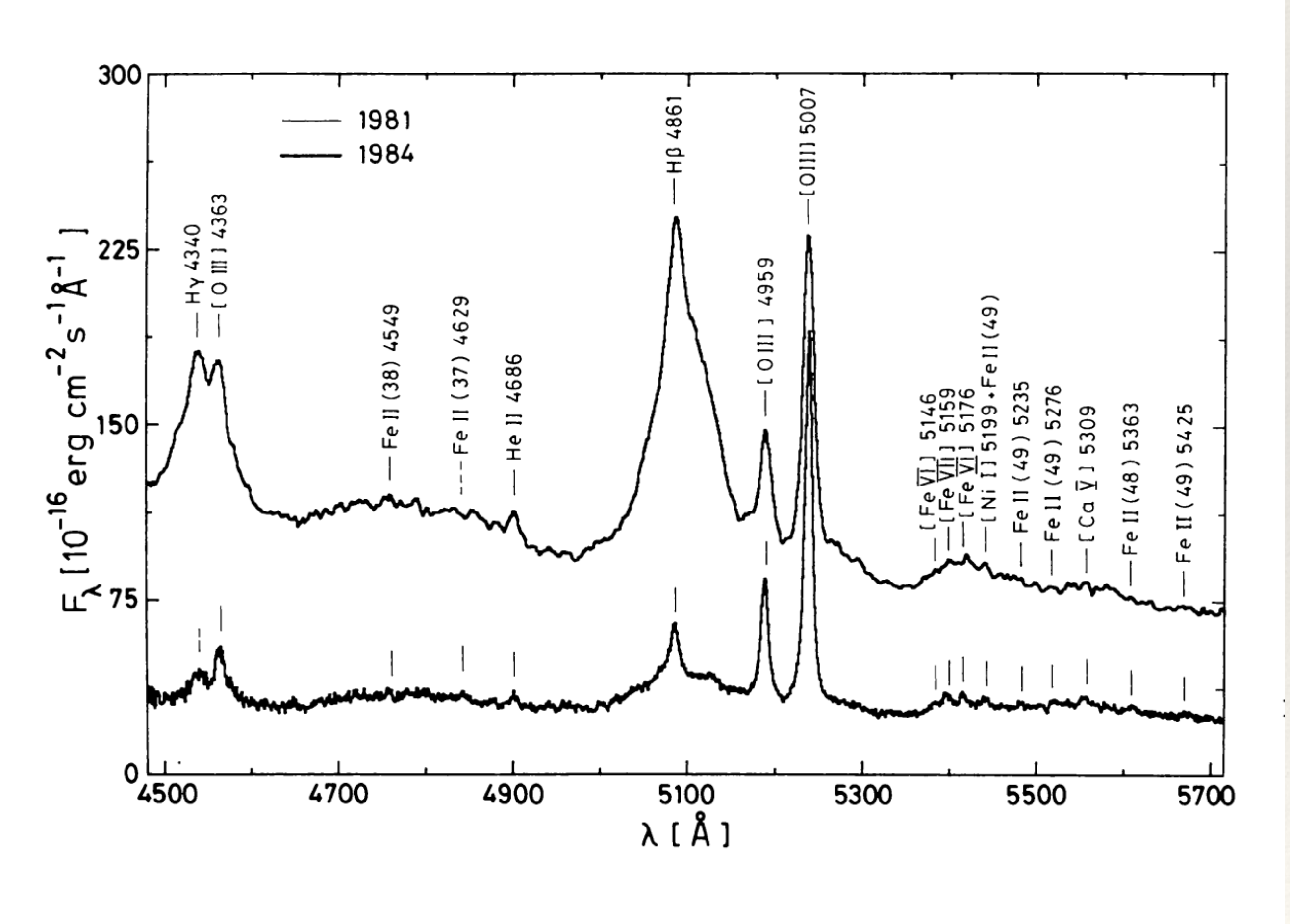
[Zubovas 2019]

[Milosavljevic et al. 2006, MacLeod et al. 2016a, Stone et al. 2017, Zubovas 2019]

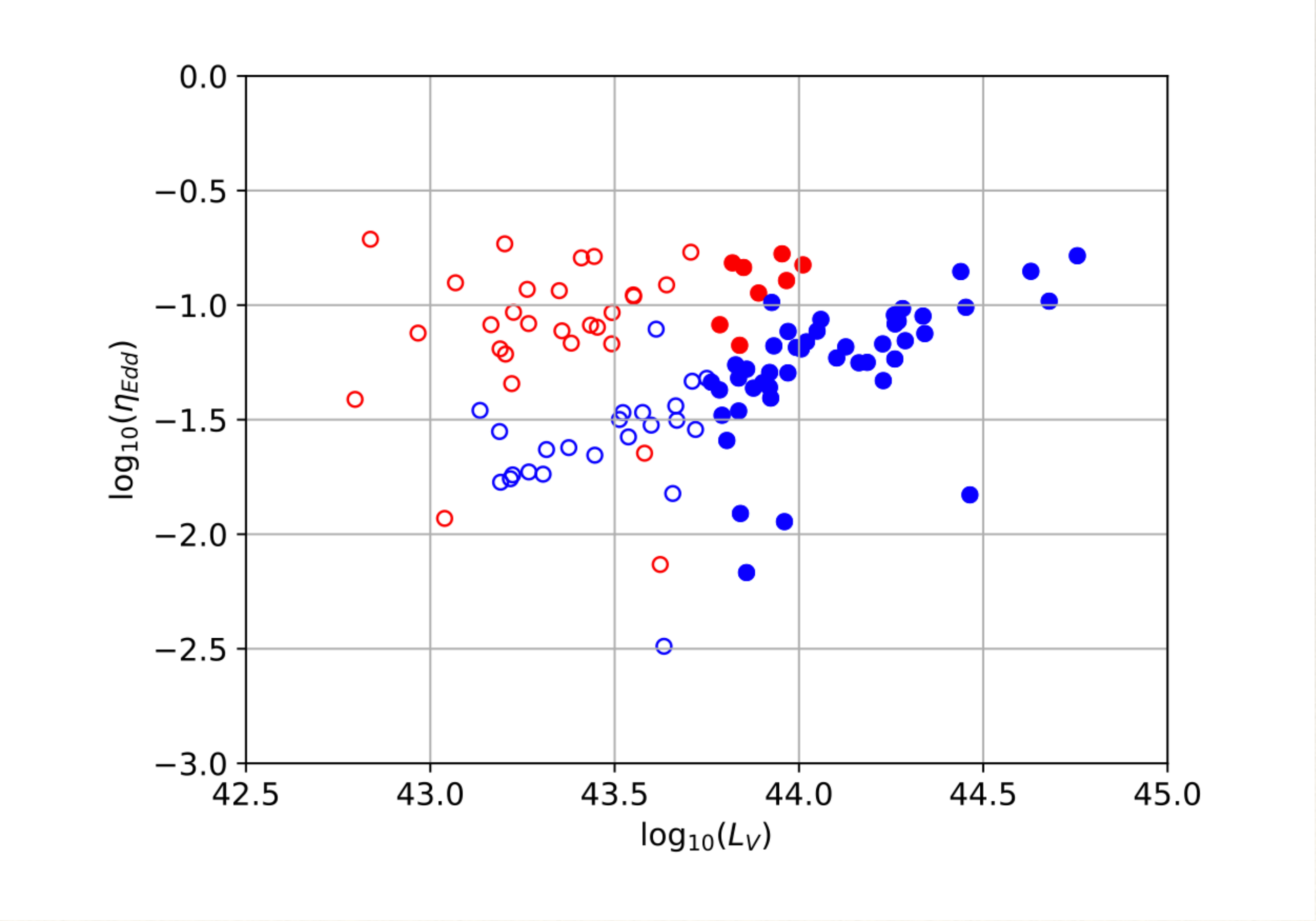
# Changing-look AGN

AGN which exhibit significant changes in optical and mid-infrared luminosity, along with appearance / disappearance of broad emission lines

[Kollatschny & Fricke (1985)]




[Graham+ (2019)]



# Contribution of TDEs to AGN

At $z \sim 0$:

$$p_{\rm TDE}(L_{\rm bol}) = \frac{\Gamma_{\rm TDE} t_{\rm peak}}{\gamma_{\rm TDE}} \exp(-L_{\rm bol}/L_{\rm peak}) \left(\frac{L_{\rm bol}}{L_{\rm peak}}\right)^{-1/\gamma_{\rm TDE}}$$

[e.g., Merloni+ (2015)]

Generalize to high redshifts:

$$\frac{M_{\rm BH}}{10^9 M_\odot} = (0.49^{+0.06}_{-0.05}) \left(\frac{M_*}{10^{11} M_\odot}\right)^{1.16\pm0.08}$$

[Kormendy & Ho (2013)]

$$M_{\rm BH} \propto v_c^4 \; ; \; v_{\rm c} \propto (1+z)^{1/2}$$

[Wyithe and Loeb 2002, Caplar et al. 2015]

$$L_{\rm Bol} = 1.38 \times 10^{38} \eta \left(\frac{M_{\rm BH}}{M_\odot}\right) \text{ erg s}^{-1}$$

# Contribution of TDEs to AGN

Probability of TDEs in AGN with a given bolometric luminosity

$$p_{\rm TDE}(L_{\rm bol}) = \frac{\Gamma_{\rm TDE} t_{\rm peak}}{\gamma_{\rm TDE}} \exp(-L_{\rm bol}/L_{\rm peak}) \left(\frac{L_{\rm bol}}{L_{\rm peak}}\right)^{-1/\gamma_{\rm TDE}}$$

[e.g., Merloni+ (2015)]

$$L_{\rm peak} = 133 \left(\frac{M_{\rm BH}}{10^6 M_\odot}\right)^{-1.5} L_{\rm Edd}$$

Peak luminosity

[e.g., Fialkov & Loeb (2017)]

$$\Gamma_{\rm TDE} = 1.2 \times 10^{-5} \left(\frac{M_{\rm BH}}{10^8 M_\odot}\right)^{-0.247} {\rm yr}^{-1} .$$

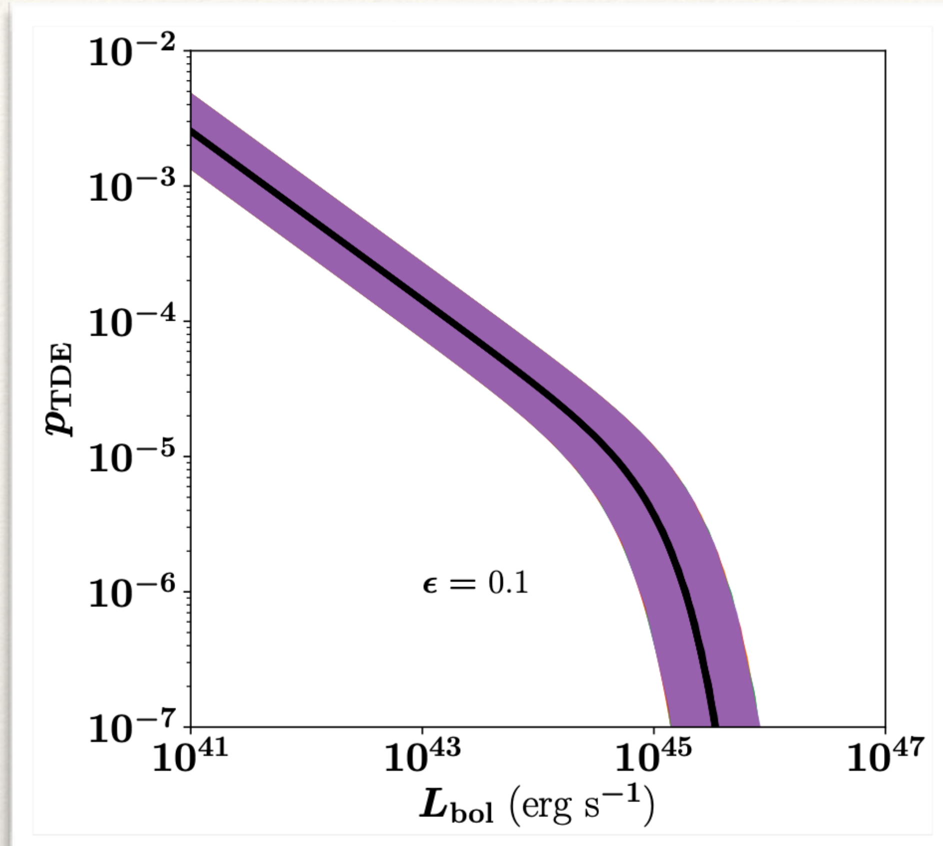
Triggering rate

[e.g., Stone & Metzger (2016)]

$$t_{\rm peak} = 0.5 \epsilon M_\odot c^2 / L_{\rm peak}$$

Event duration

# Contribution of TDEs to AGN

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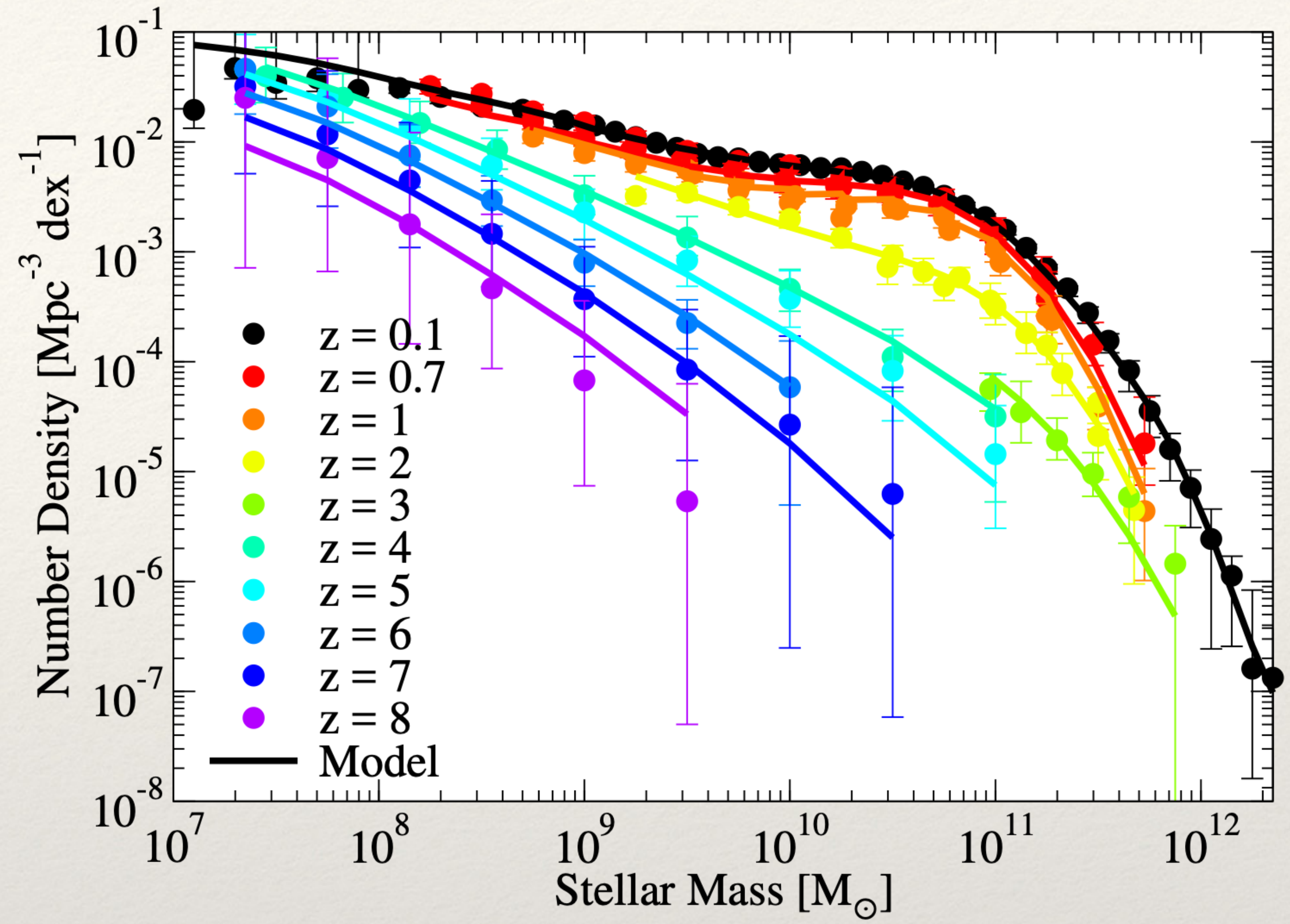
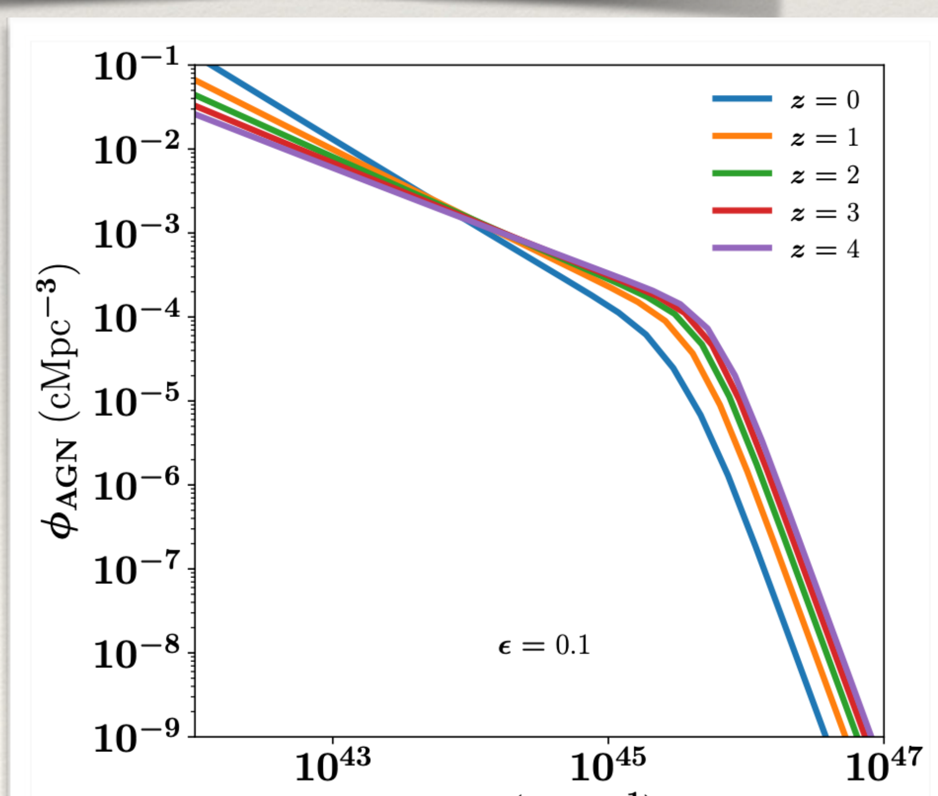



[Aird+ (2012)]

[Behroozi+ (2019)]

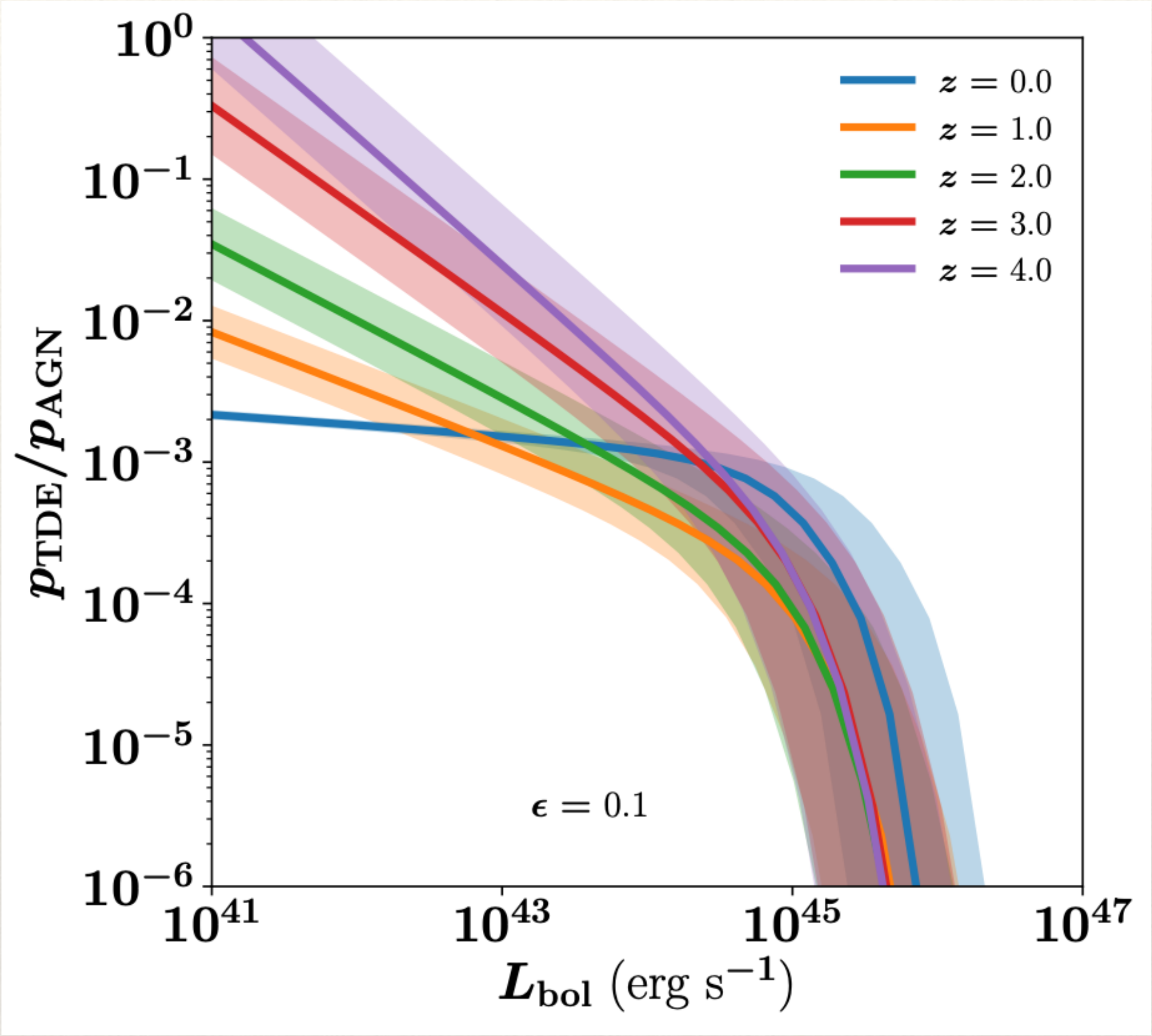
$$p_{\rm AGN} = \phi_{\rm AGN}/\phi_{\rm SMF}$$

Probability of AGN in host galaxy

$$p({\rm TDE}|{\rm AGN}) = p_{\rm TDE}/p_{\rm AGN} \, ,$$

TDE given AGN

# How many AGNs are TDE-triggered?



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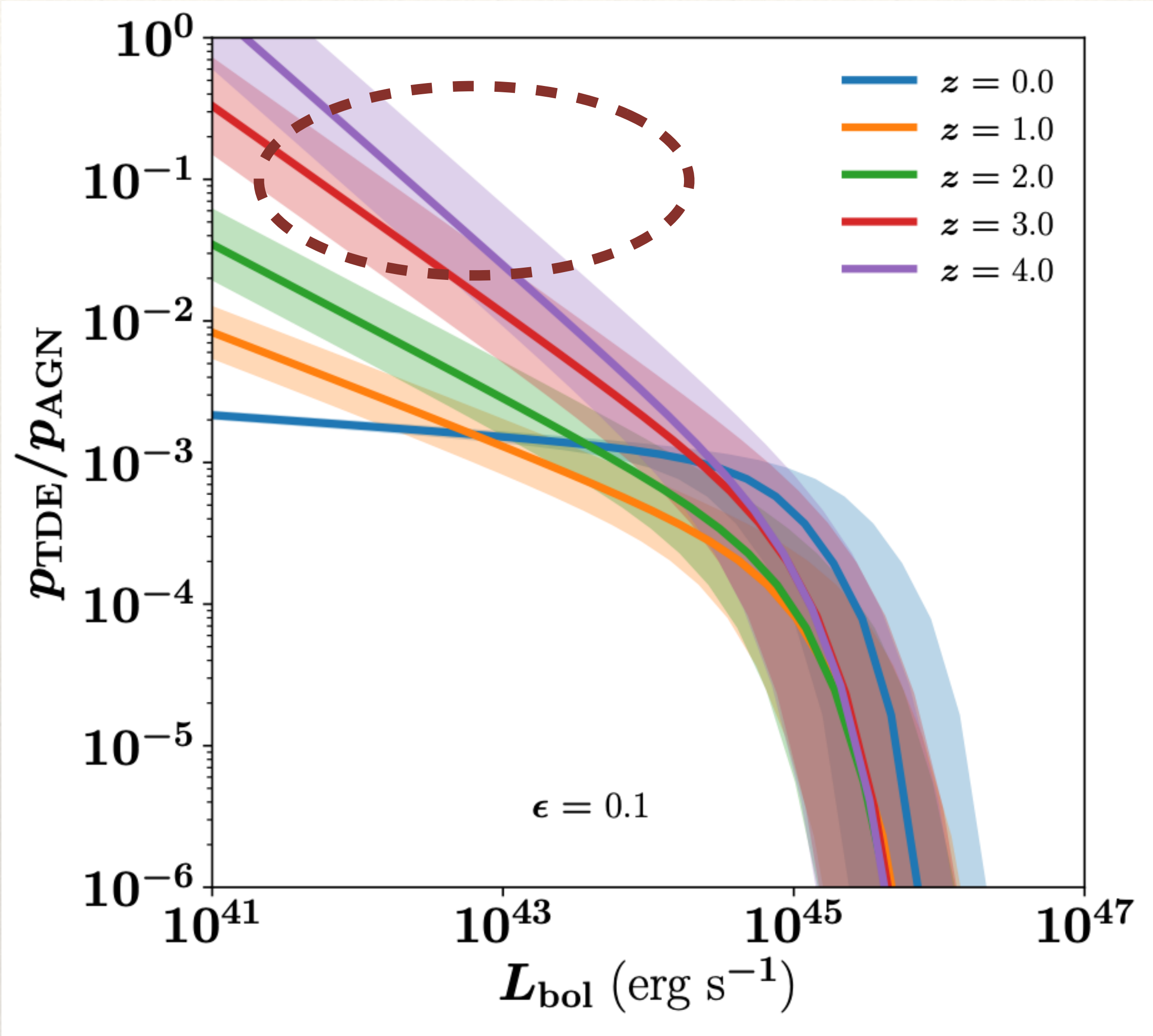


At $z \sim 1$, a maximum of ~ 1%
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AGN may come from TDE flares,
~ 5% of observed CL-AGN abundance

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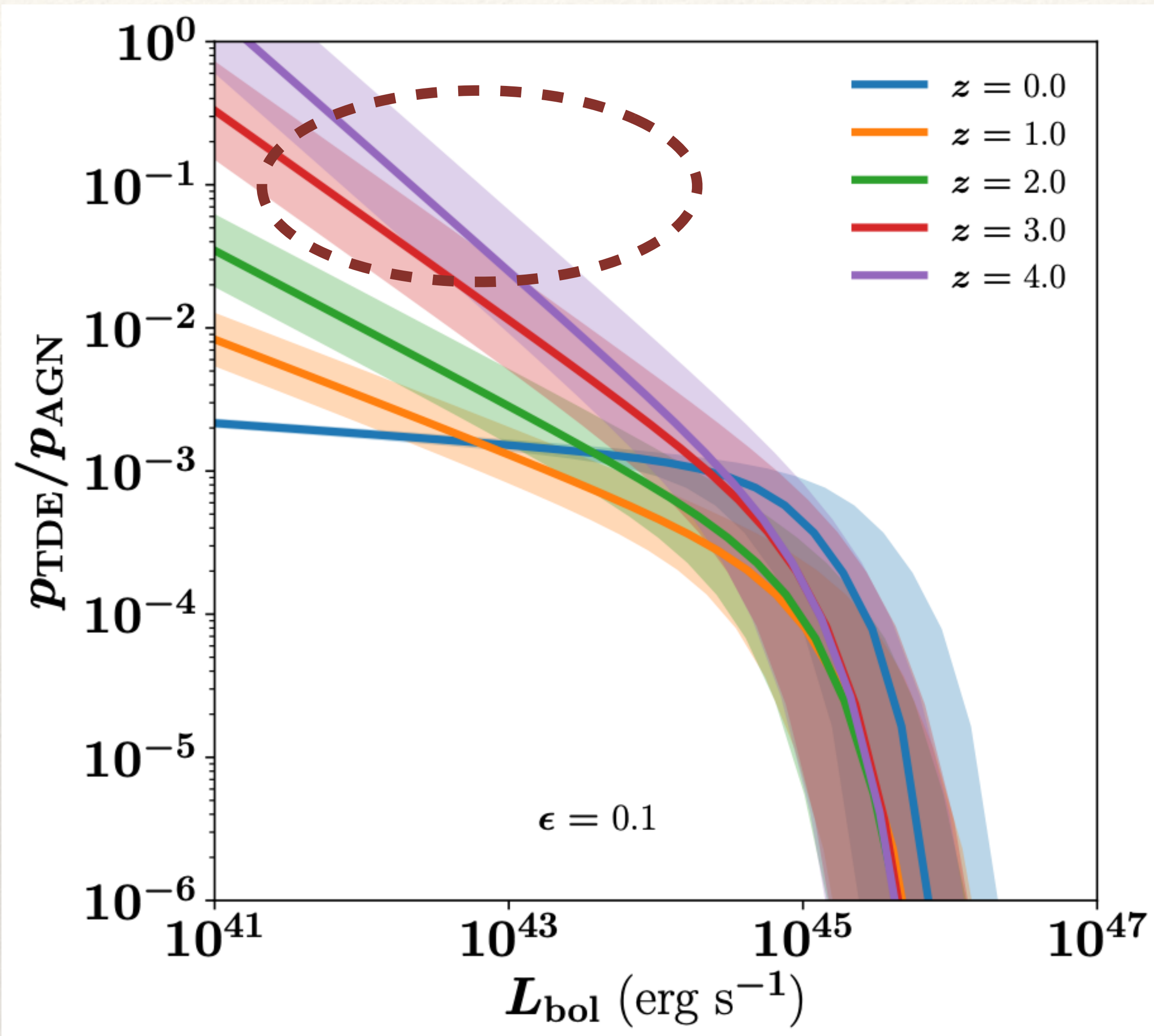


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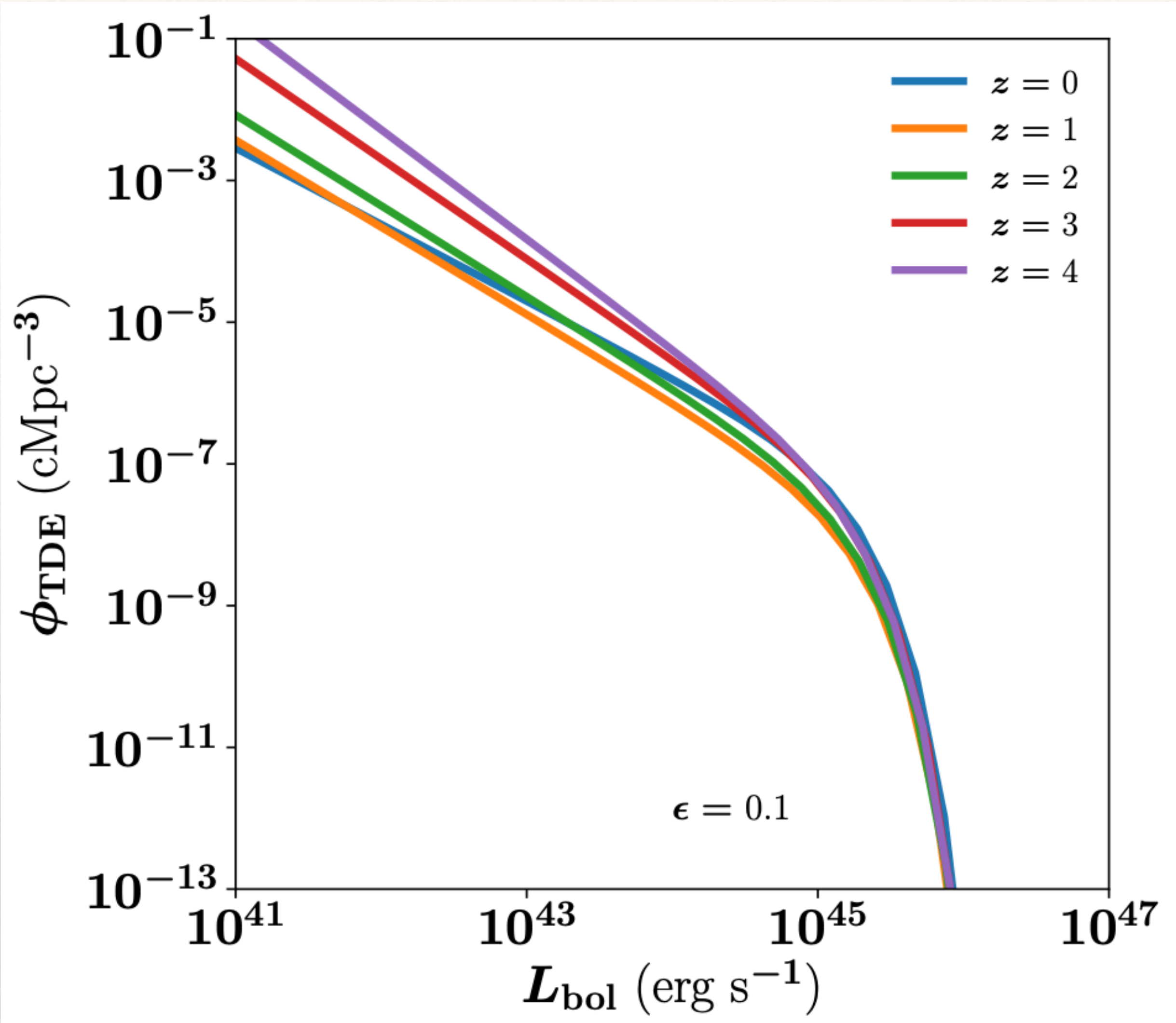



Luminosity function of
TDE-triggered AGN at all $z$;
Lower limit on CL-AGNs

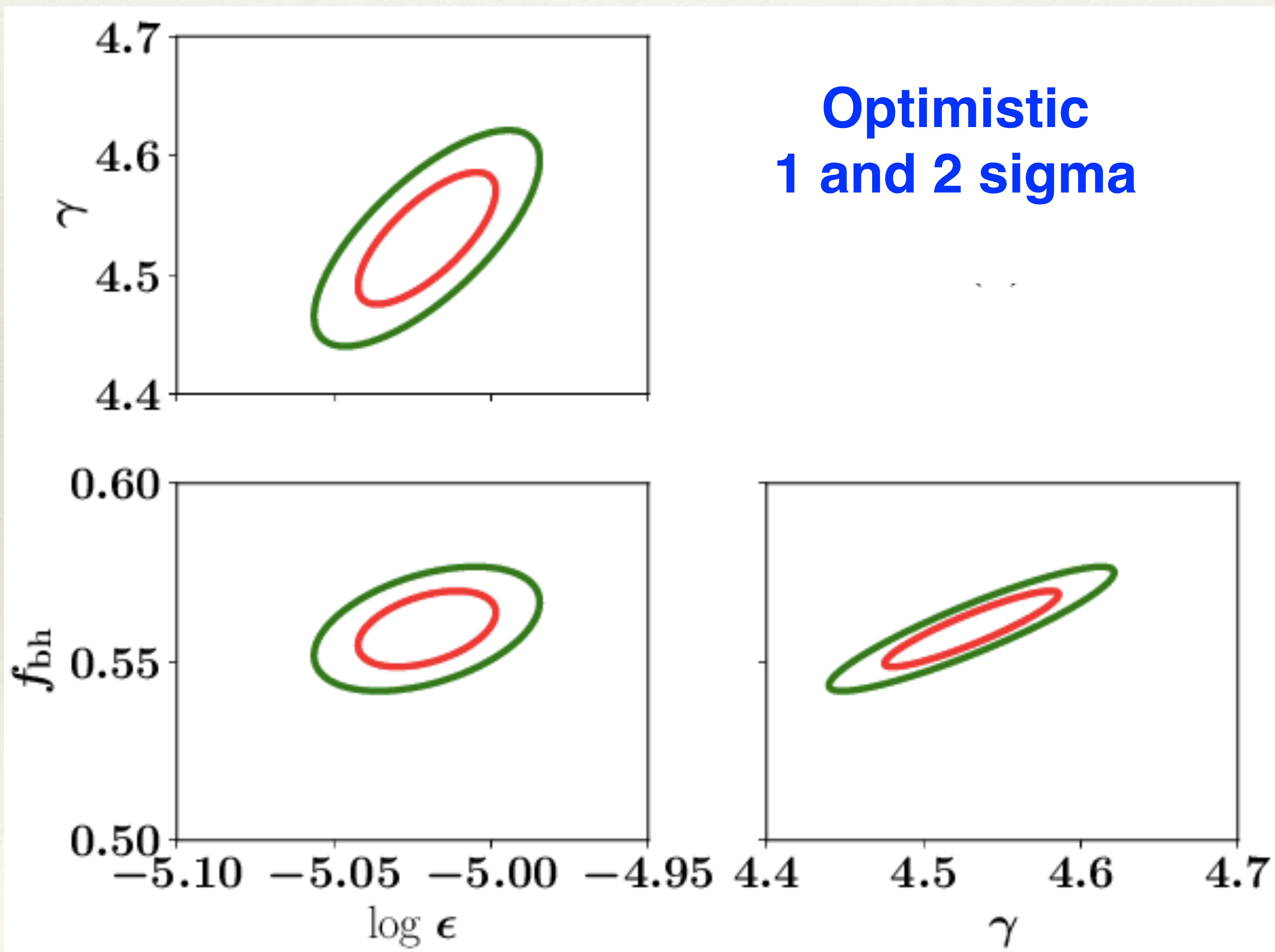
# Follow-up: LISA constraints on IMBHs

Use merger rates of haloes to forecast constraints on BH parameters

**Existing constraints**

[Hughes 2002, Lang & Hughes 2006, 2010]

$$\Delta q/q, \Delta M_{\rm BH}/M_{\rm BH}, \Delta z/z$$




[HP & Loeb, JCAP 11, 055 (2020), arXiv:2007.12710]

## *To summarize …*

- We still don’t know the mechanism by which IMBHs and SMBHs were assembled
- TDEs are a very promising pathway
- At low-z, they may explain a few percent of AGN
- But this can change rapidly by $z > 3$ due to the BH-bulge mass evolution **[HP & Loeb, *A&A, 656, A47 (2021)*]**
- TDEs may account for a significant number of high-z Changing-Look AGN !
- Upcoming observations will soon enable further constraints, as will LISA: IMBH/SMBH mergers

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# Thank you!