Cosmic Archaeology with LISA and JWST:

seeking the growth of the first black hole seeds

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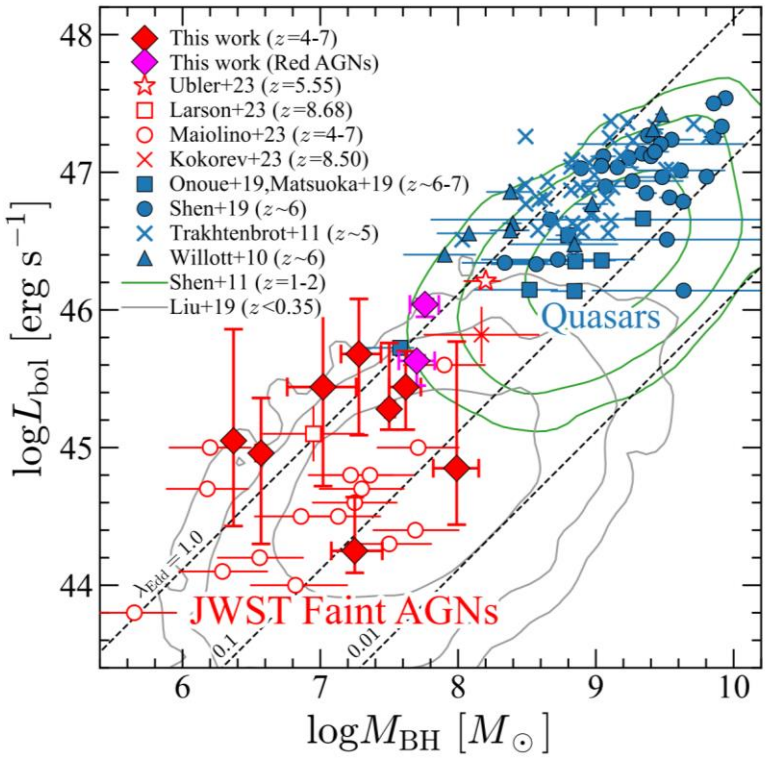
The AGN frontier in JWST era

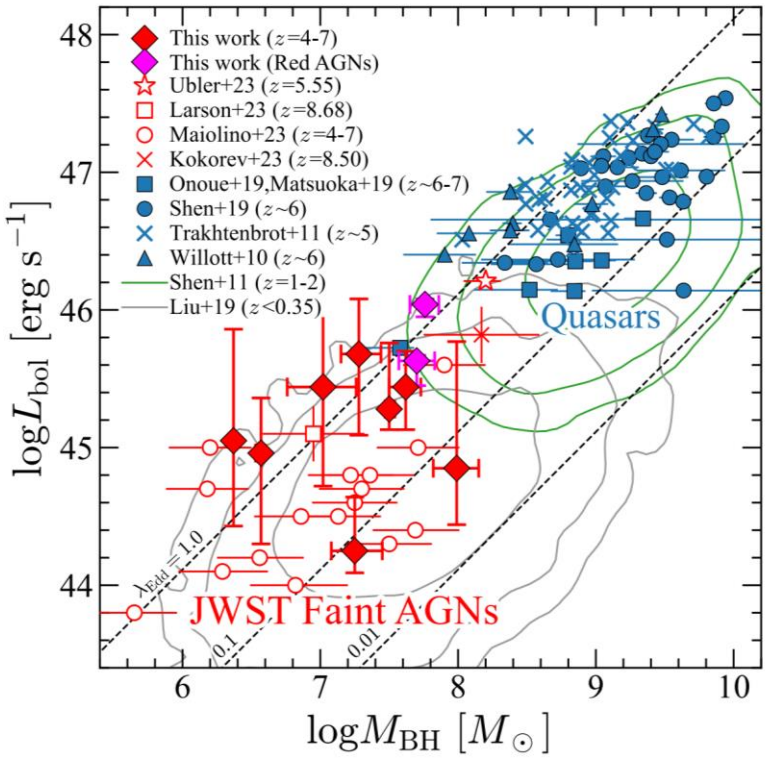
Harikane+2023

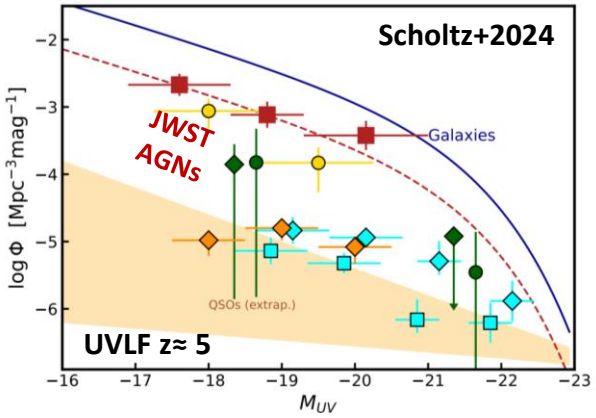


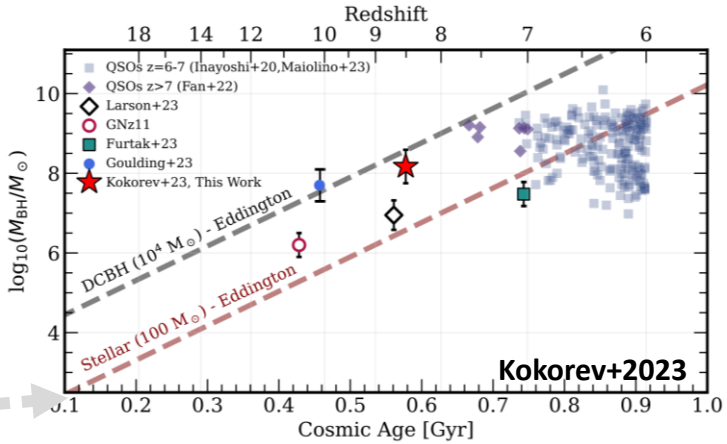
The AGN frontier in JWST era

AGNs more numerous than expected!

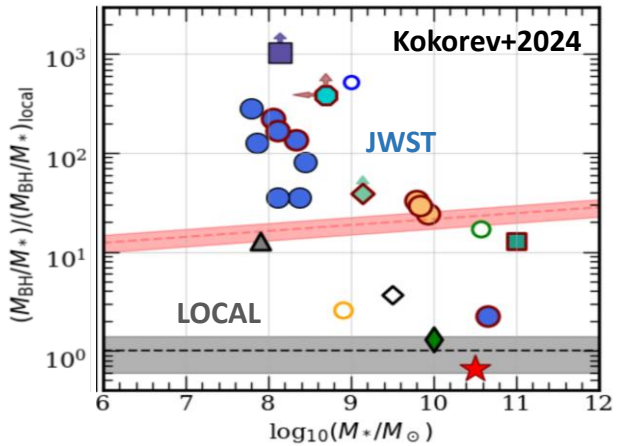
Harikane+2023





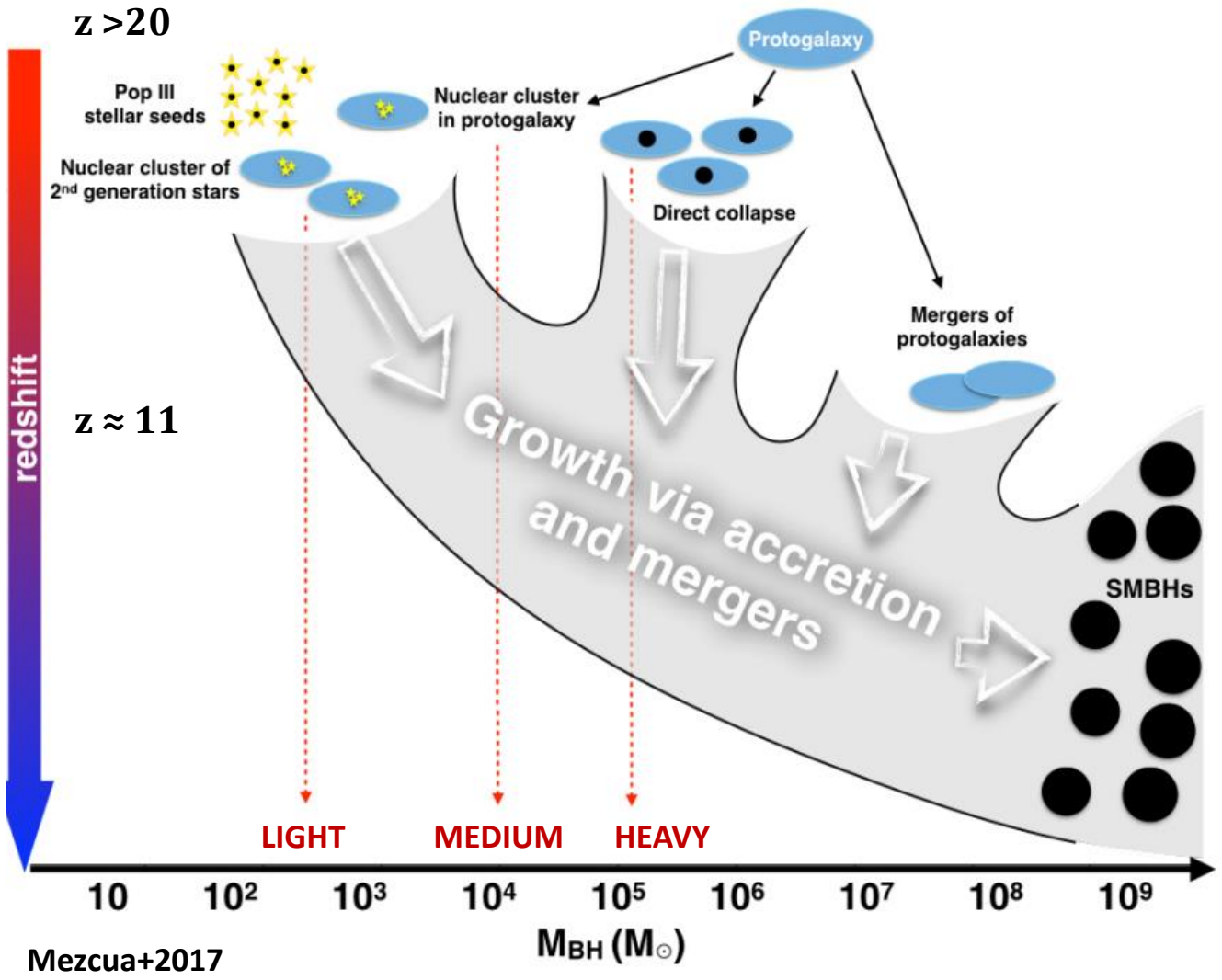


MBHs already in place at z>8!



M_{BH} – M_{star} order of magnitude above the local scaling

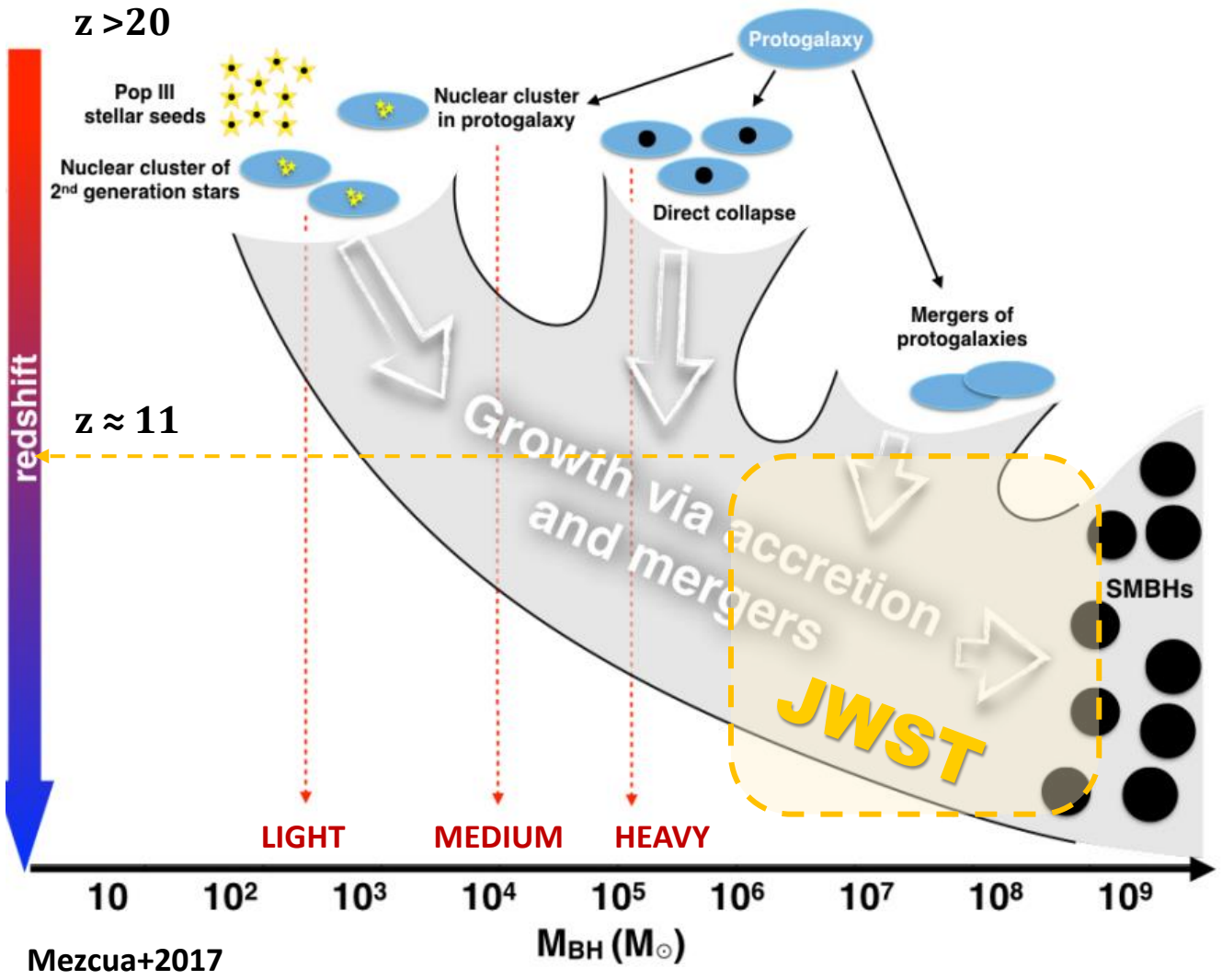
Supermassive Black Holes in the first billion years



Mezcua+2017

- Wide landscape of potential formation scenarios for early BH seeds, **largely unconstrained**.

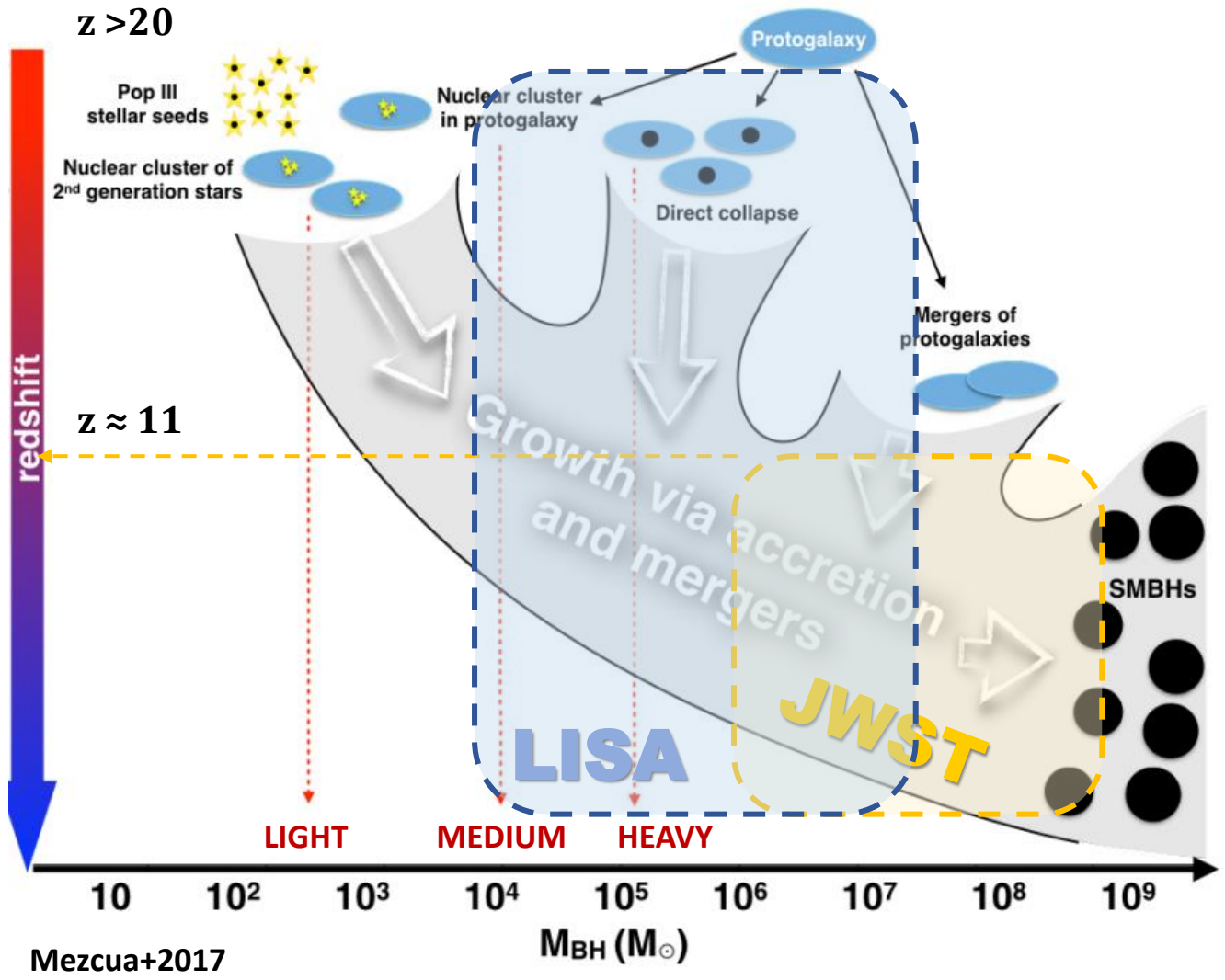
Supermassive Black Holes in the first billion years



Mezcua+2017

- Wide landscape of potential formation scenarios for early BH seeds, **largely unconstrained**.
- JWST will probe especially the **early phases** of (efficient) **BH growth**

Supermassive Black Holes in the first billion years



Mezcua+2017

- Wide landscape of potential formation scenarios for early BH seeds, **largely unconstrained**.
- JWST will probe especially the **early phases** of (efficient) **BH growth**
- Exploiting the **synergy with LISA** will be crucial to investigate the nature of their first progenitors

Versatile tools are needed to predict simultaneously multiple observables for different scenarios of BH seed formation and growth

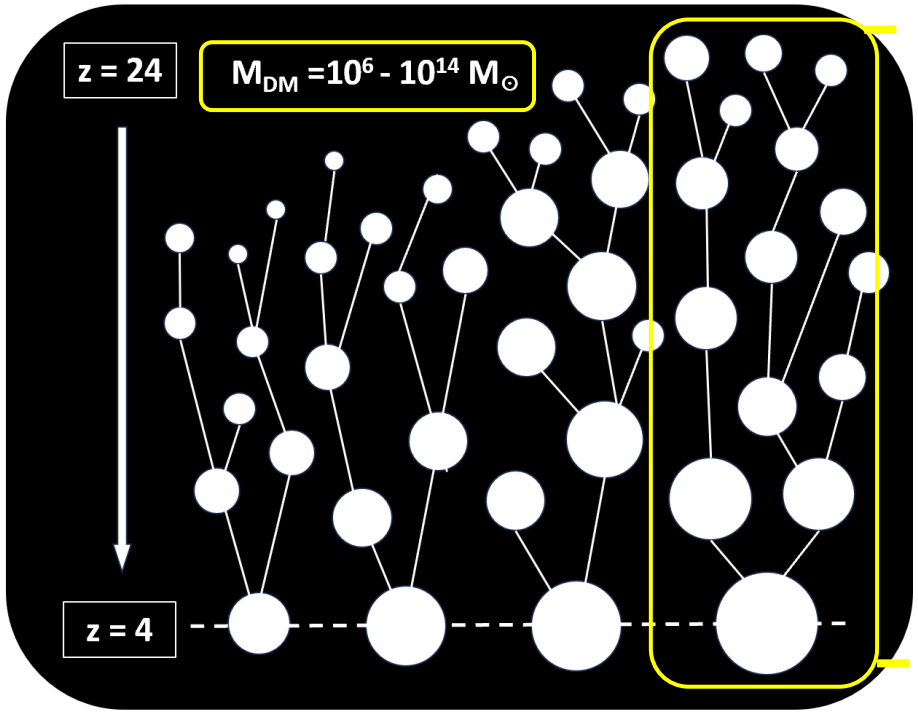
Cosmic Archaeology Tool - CAT

Trinca+2022

Semi-analytical model tailored to track the **early galaxy evolution** and investigate the **interplay between galaxies and their central MBHs** in the first Gyr of cosmic history

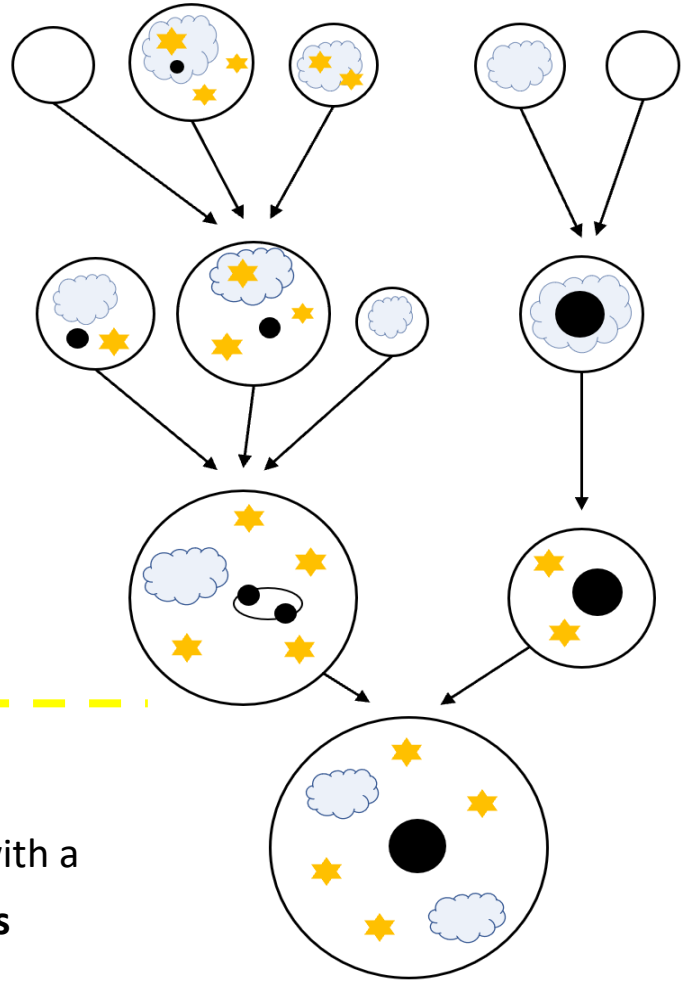
LIGHT SEEDS
(from single Pop III stars)
10^2 - 10^3 M_{sun}

HEAVY SEEDS
(Direct collapse of SMS in pristine atomic cooling halos)
~ 10^5 M_{sun}



DETAILED MODELING OF BH SEEDING

- Multiple stellar populations
- H_2 cooling efficiency
- Self-consistent metal enrichment
- Dust formation and evolution
- Reionization
- AGN and stellar feedback

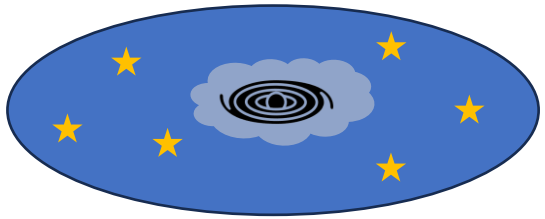


CAT allows for **population studies** for AGNs and galaxies with a broad statistics exploring **different accretion scenarios**

Explore the early Massive Black Hole population

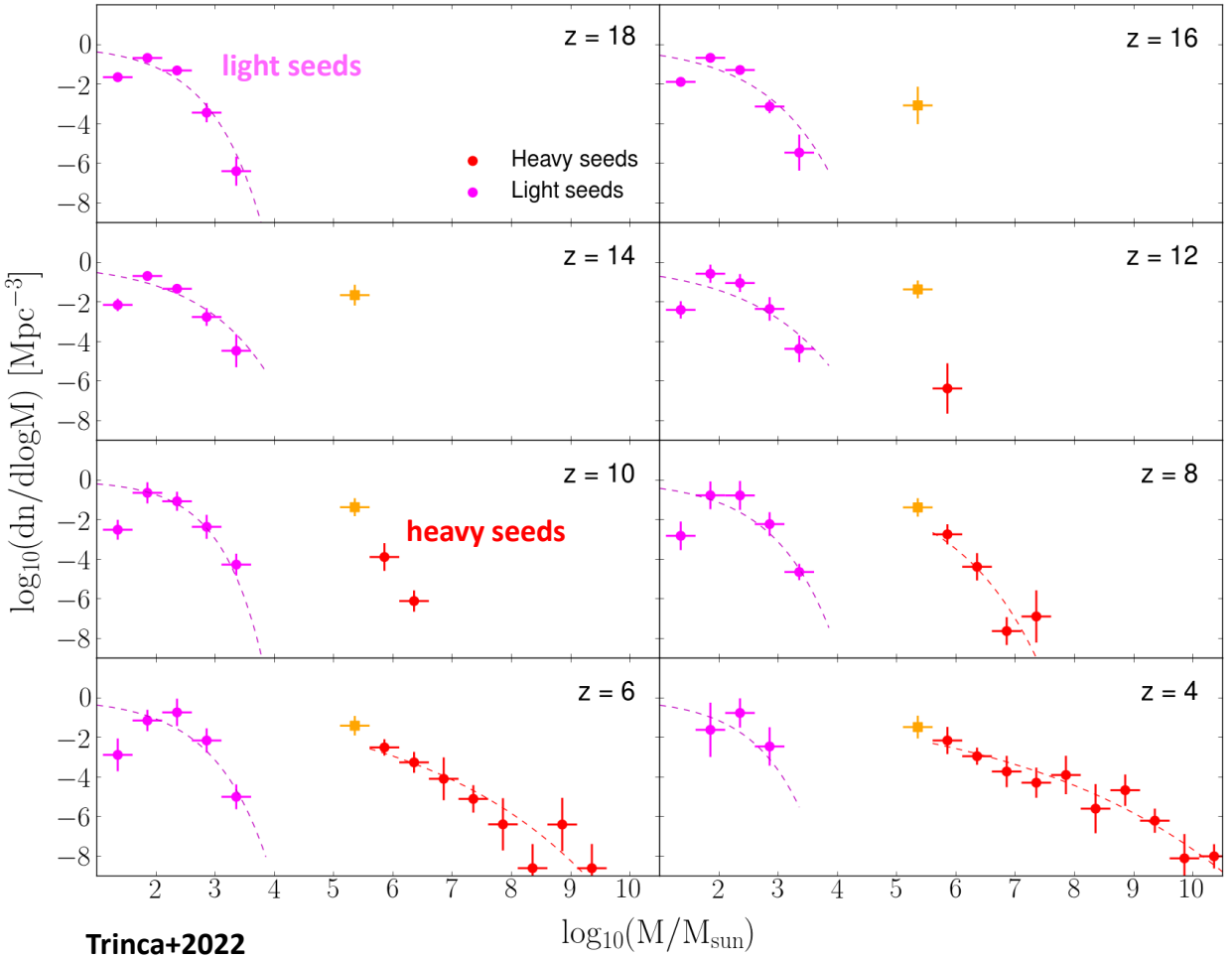
Evolution of the **black hole mass function** in different accretion scenarios:

1) Bondi accretion – Eddington limited



$$\dot{M}_{\rm BHL} = \alpha \frac{4\pi G^2 M_{\rm BH}^2 \rho_{\rm gas}(r_A)}{c_s^3}$$

→ **Heavy** black hole **seeds** drive the building up of the high-mass end



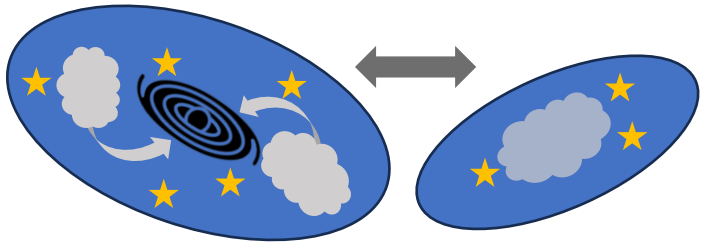
Trinca+2022

Explore the early Massive Black Hole population

Evolution of the **black hole mass function** in different accretion scenarios:

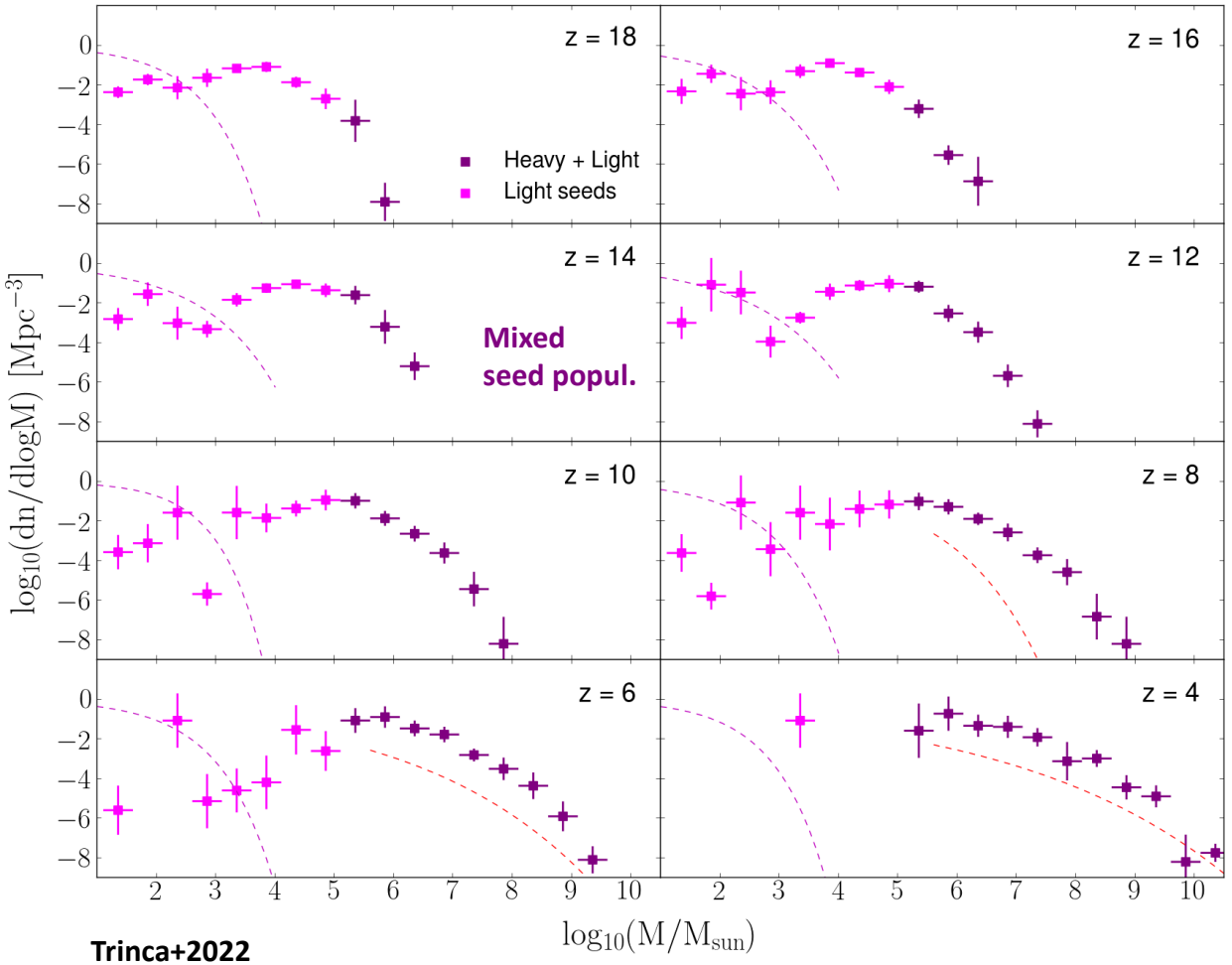
2) Super Eddington growth

Assuming **short burst** of super-Eddington growth **triggered by** host **galaxy major mergers**



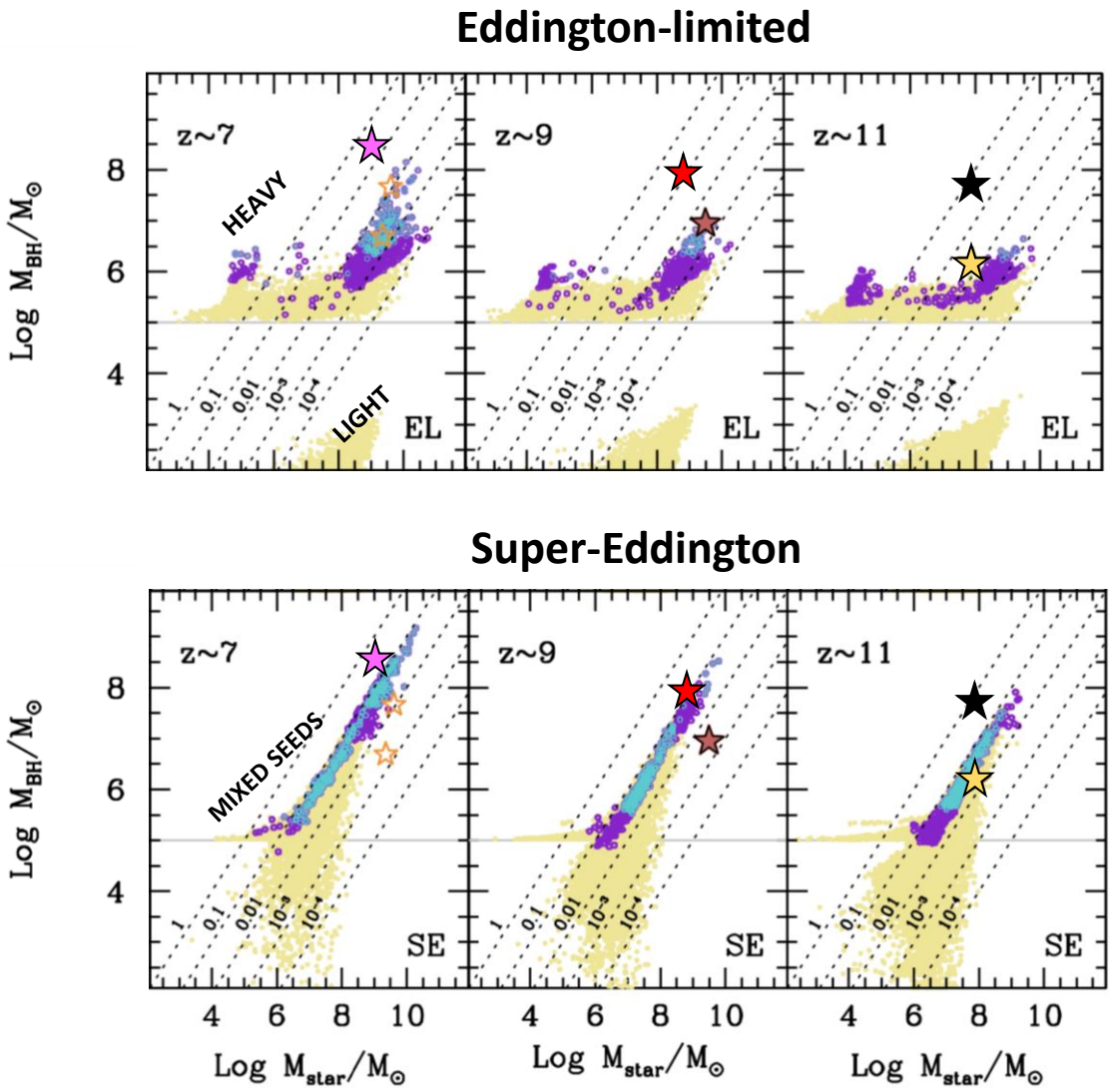
$$\dot{M}_{\rm BH} = \frac{\epsilon_{\rm BH}\, M_{\rm gas}}{\tau_{\rm accr}}$$

→ Early growth of **smaller BH seeds**, strong contribution to the final BHMF



Trinca+2022

Extreme BH candidates at z > 7 with JWST

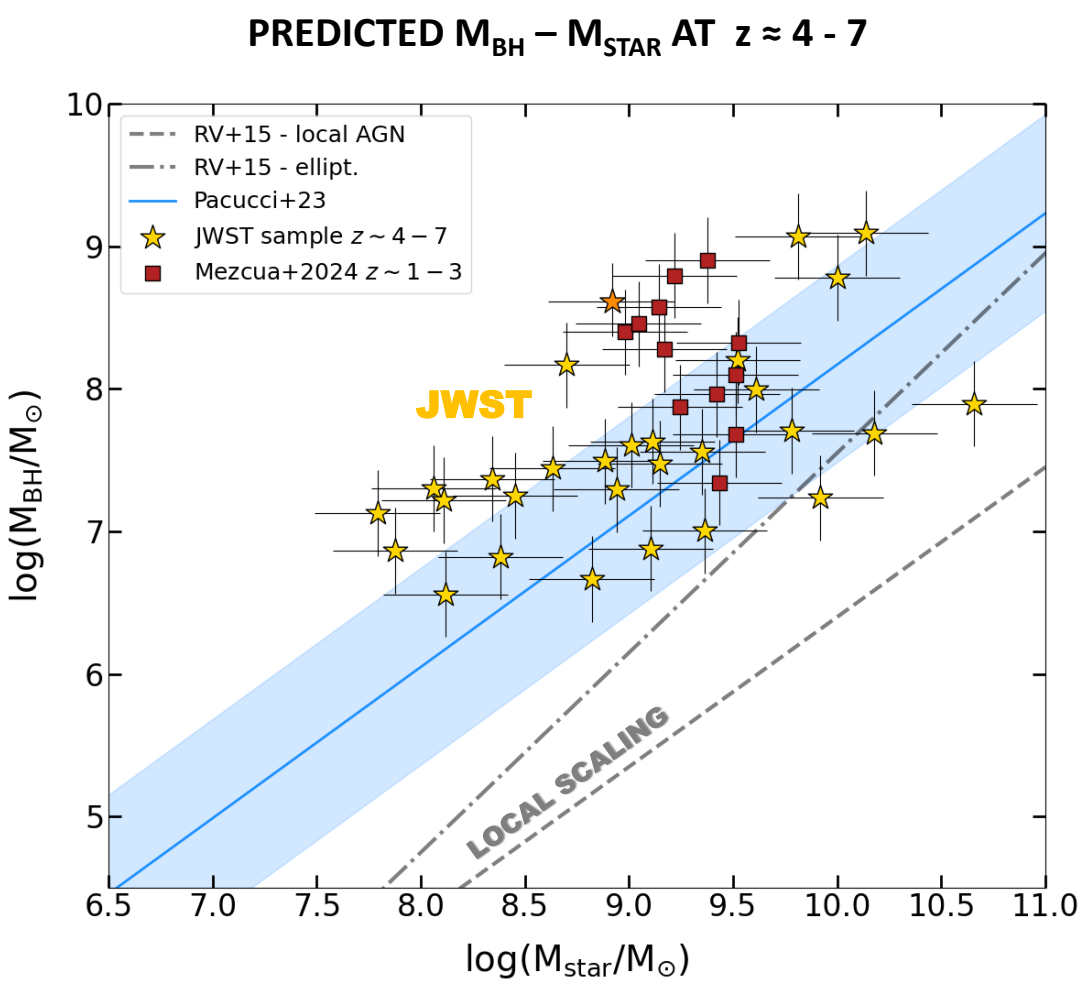


Schneider,AT,+2023

Massive BH candidates (**>10^7 M_{sun}**) detected **up to z ≈ 10**.

If confirmed, strong hint in favor of extremely efficient black hole growth at early cosmic epochs

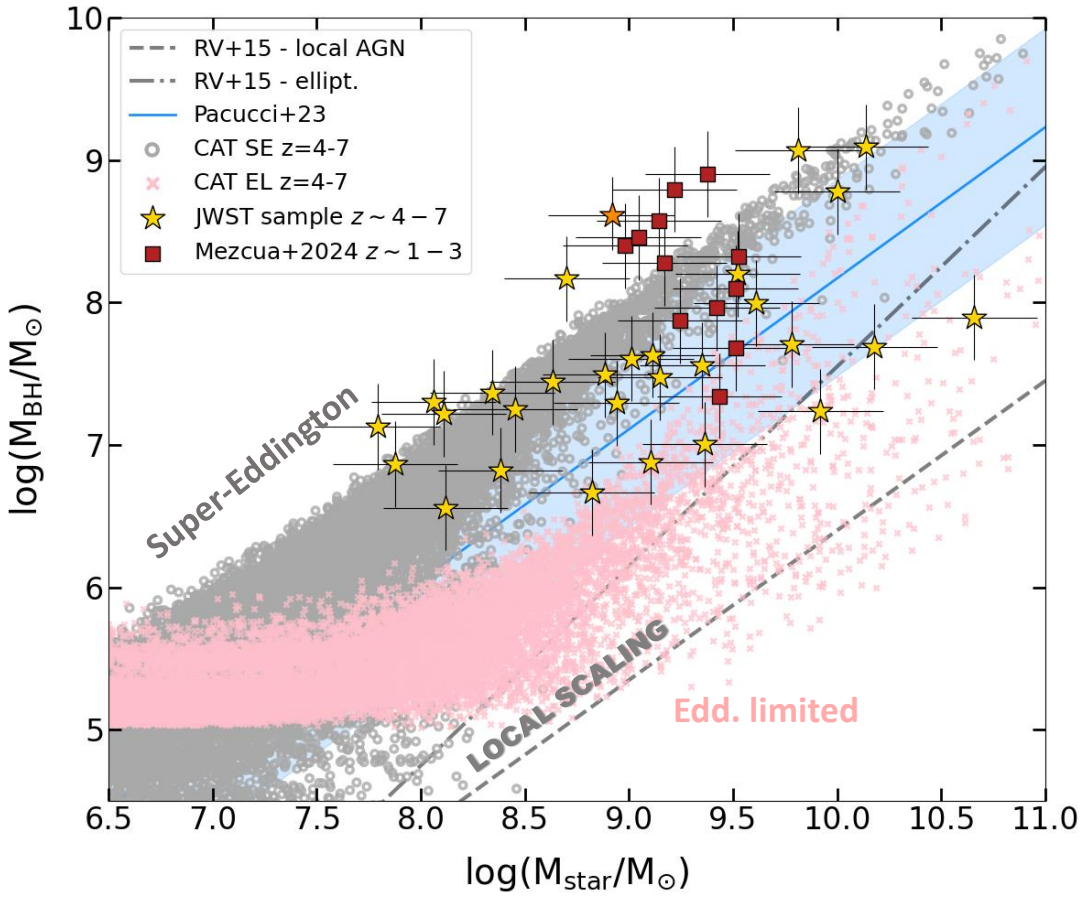
An overmassive black hole population



JWST AGNs show a **BH-to-stellar mass ratio significantly higher** than the local scaling relation.

An overmassive black hole population

PREDICTED $M_{BH} - M_{STAR}$ AT $z \approx 4 - 7$



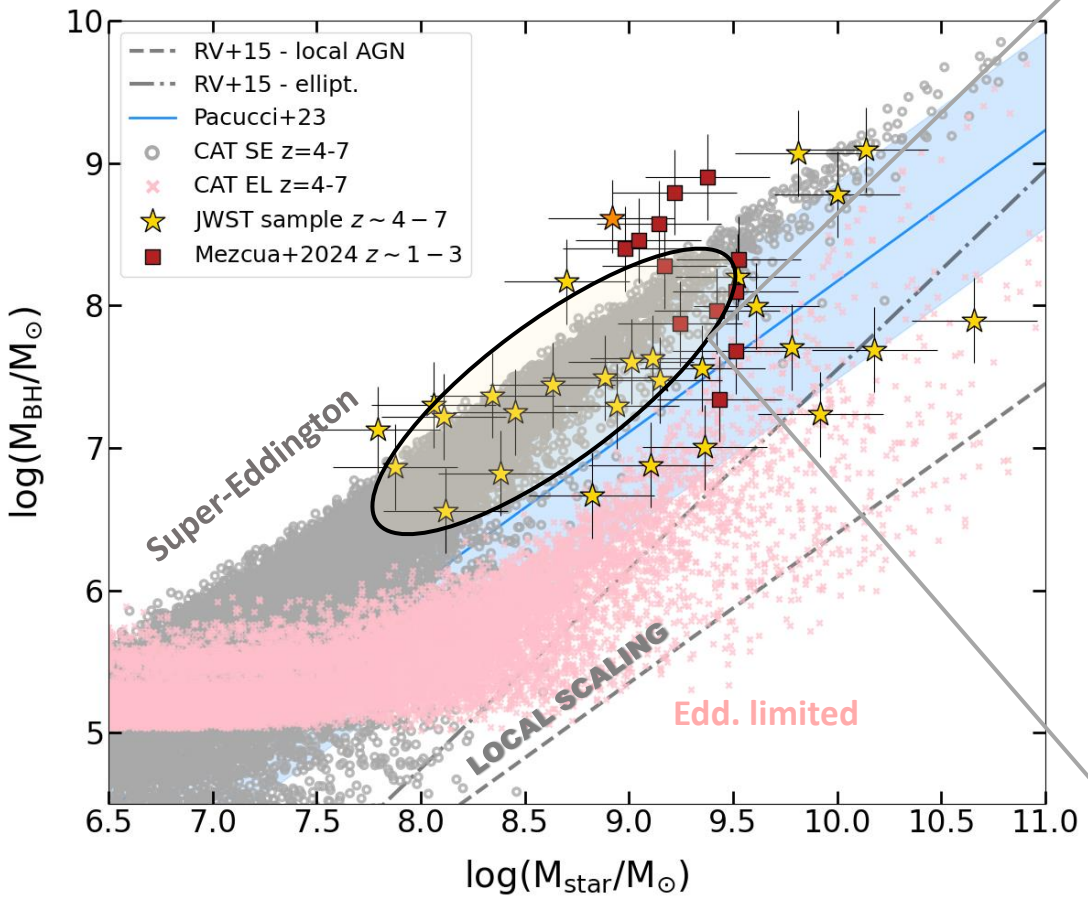
JWST AGNs show a **BH-to-stellar mass ratio significantly higher** than the local scaling relation.

Close agreement with the BH population predicted by CAT **super-Eddington** accretion **scenario**

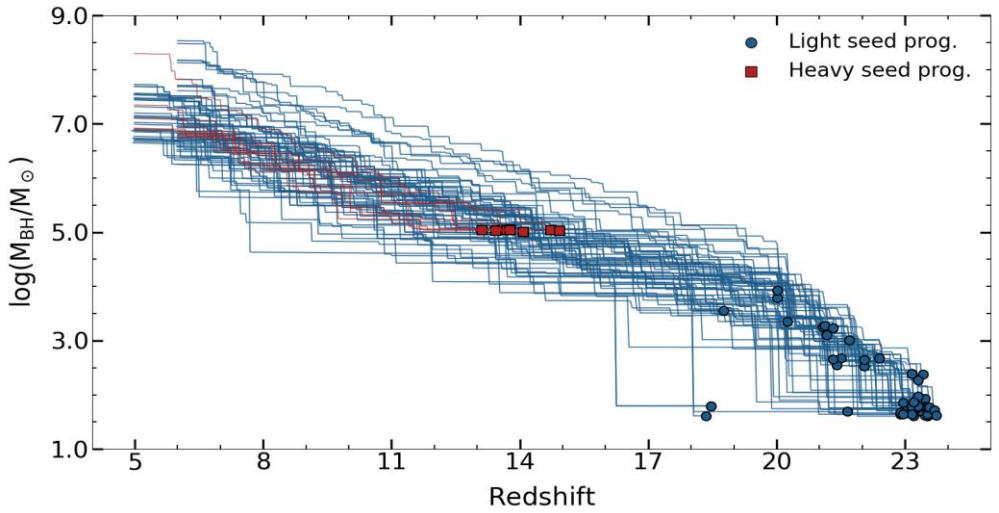
→ implications for the BH and galaxy evolutionary histories?

An overmassive black hole population

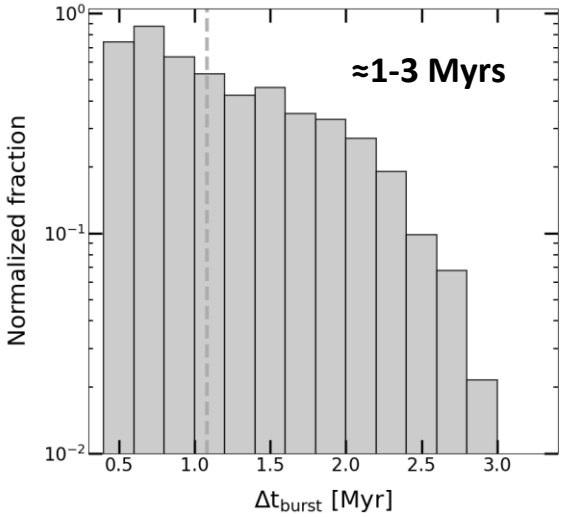
PREDICTED $M_{BH} - M_{STAR}$ AT $z \approx 4 - 7$



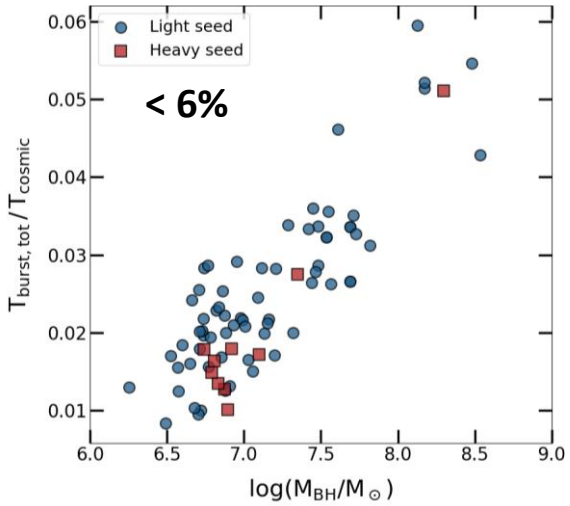
BLACK HOLE EVOLUTIONARY TRACKS



SINGLE BURST DURATION



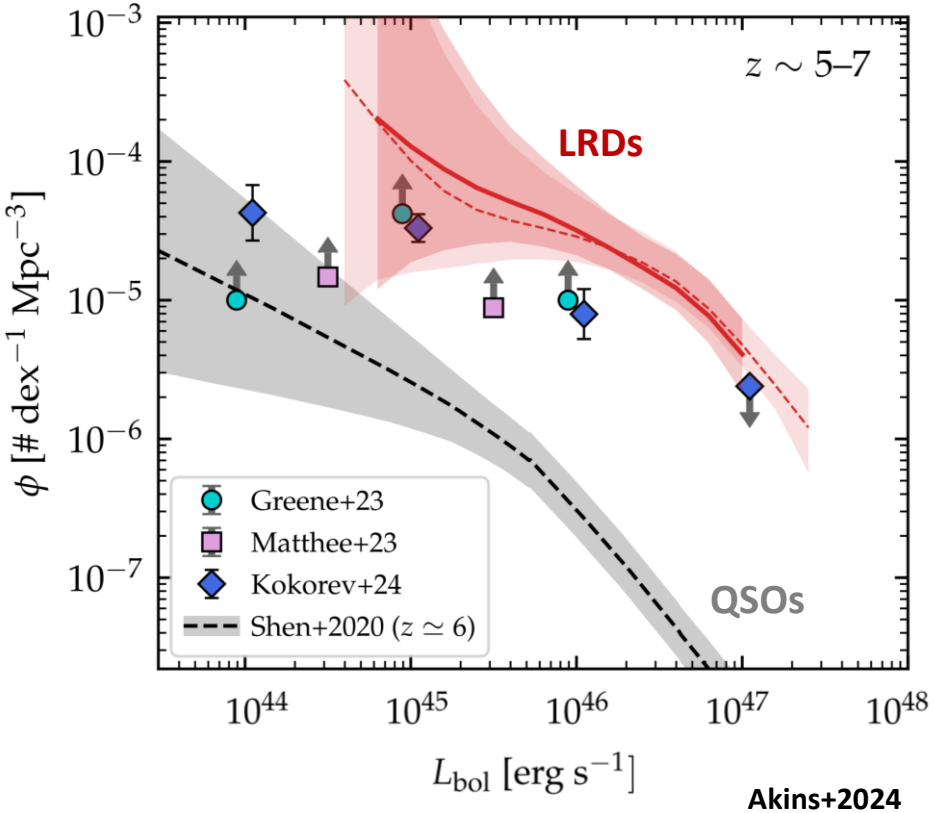
AGN DUTY CYCLE



Trinca+ (to be submitted)

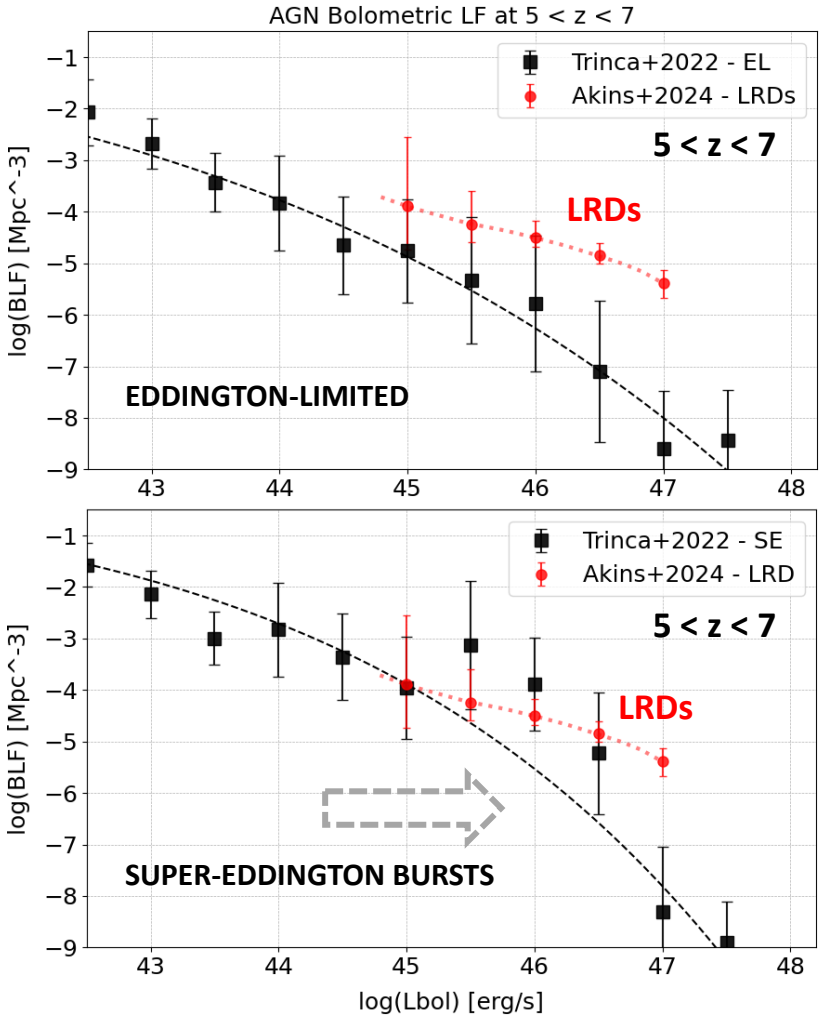
Too many luminous AGNs?

x100 over-abundance of LRDs relative to UV-selected bright quasars



Akins+2024

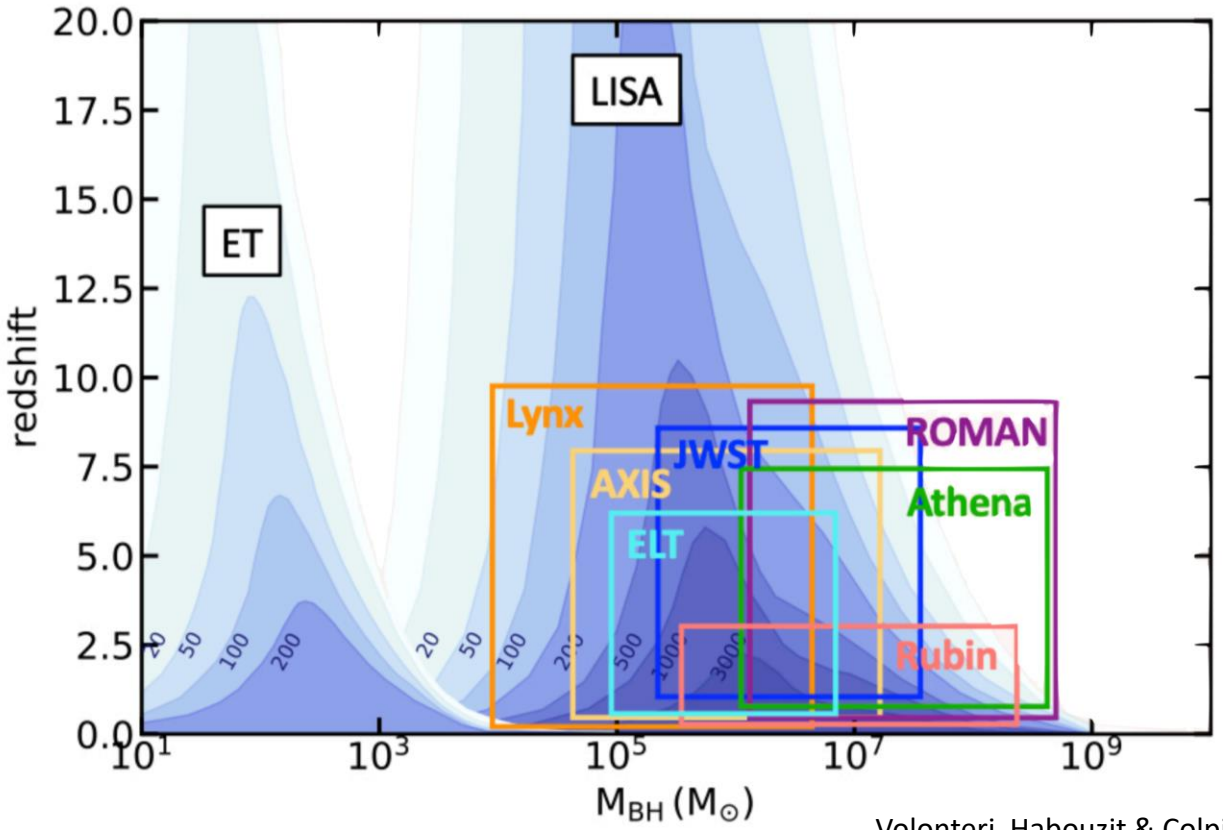
Increase in the bright AGN bolometric LF



Light and Sound from the Cosmic Dawn

The synergy between the next generation of EM and GW observatories will unveil the high redshift Universe up to z=20, revealing black holes spanning from tens to millions solar masses

“the sound”
hints on dynamical properties of BHs

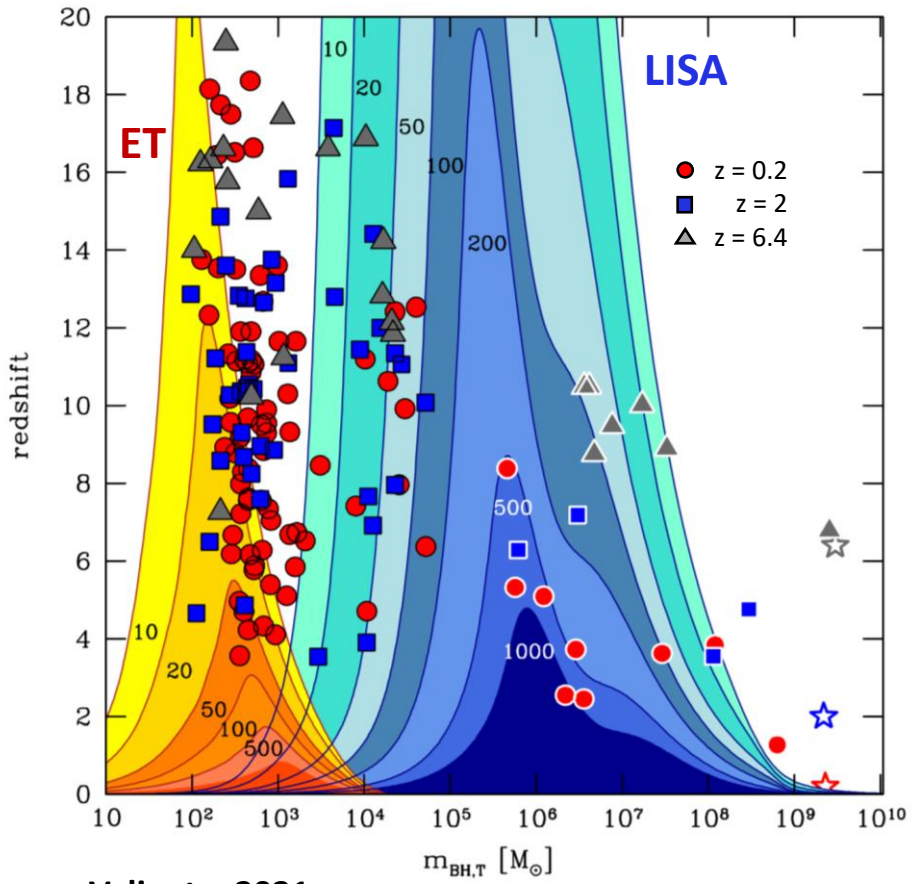


“the light”
hints on early BH growth and host galaxy co-evolution history

Volonteri, Habouzit & Colpi (2021)

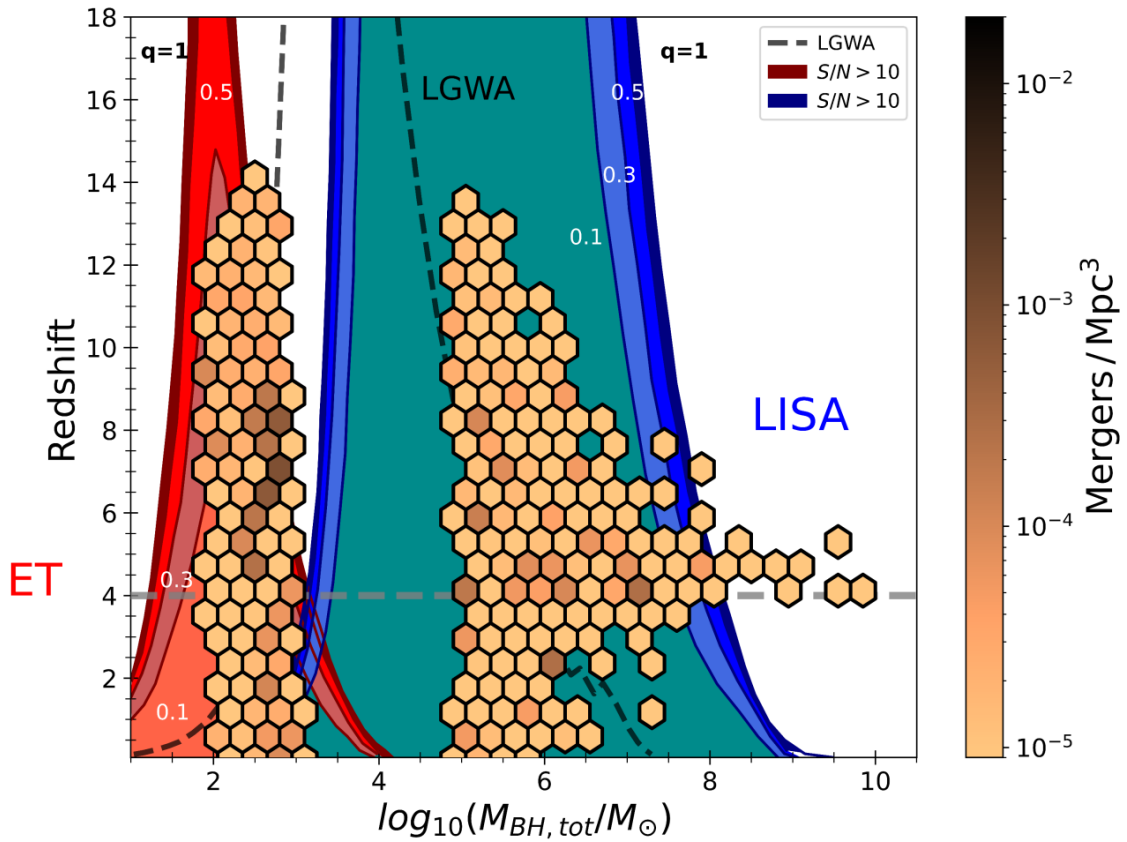
BHBs Merger Rate predictions with CAT

MBHB coalescence events along a **single SMBH** the **evolutionary history**



Valiante+2021

Predicted merger rates for the **overall CAT BH population**

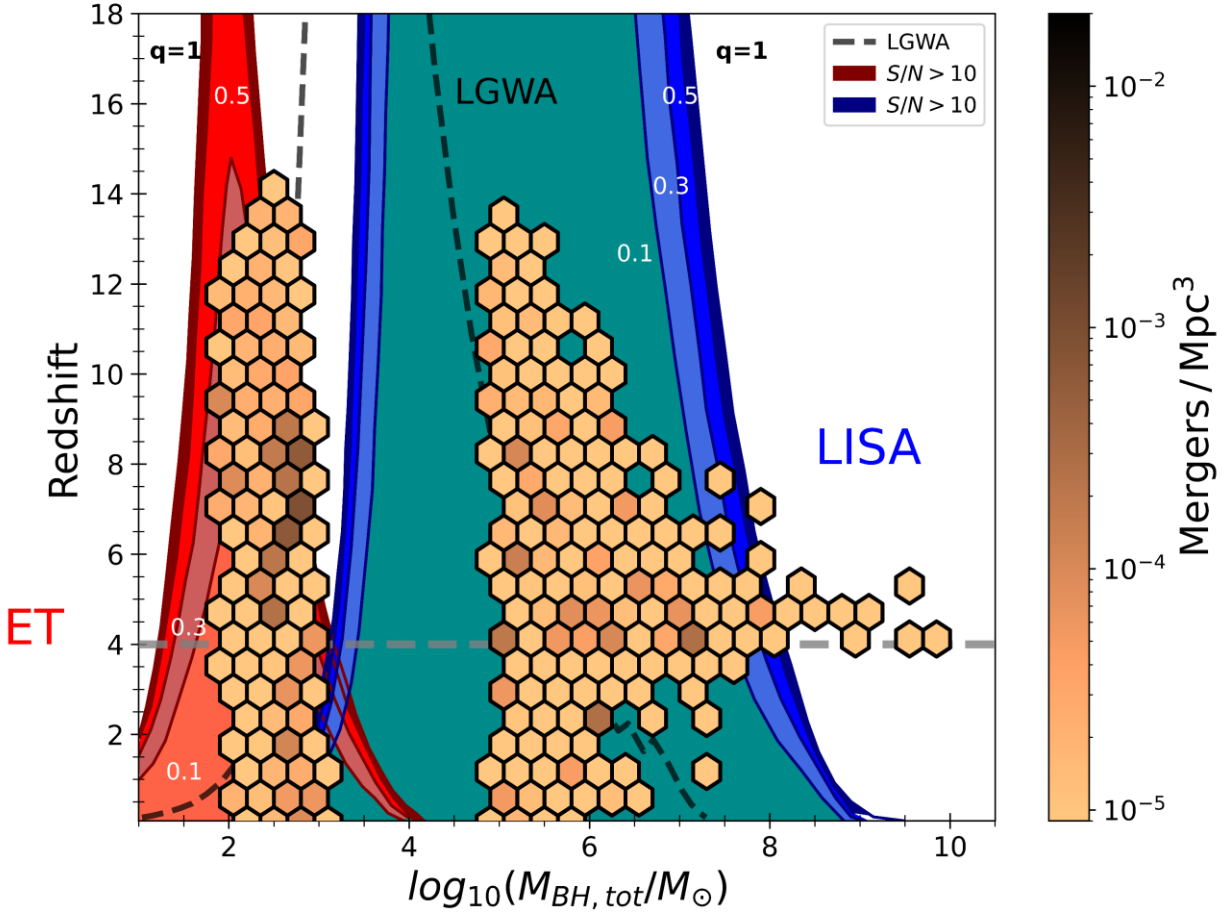


→ Analytical modeling of the **time delays** associated to different BHB evolutionary phases: **dynamical friction** + **stellar/gas hardening**

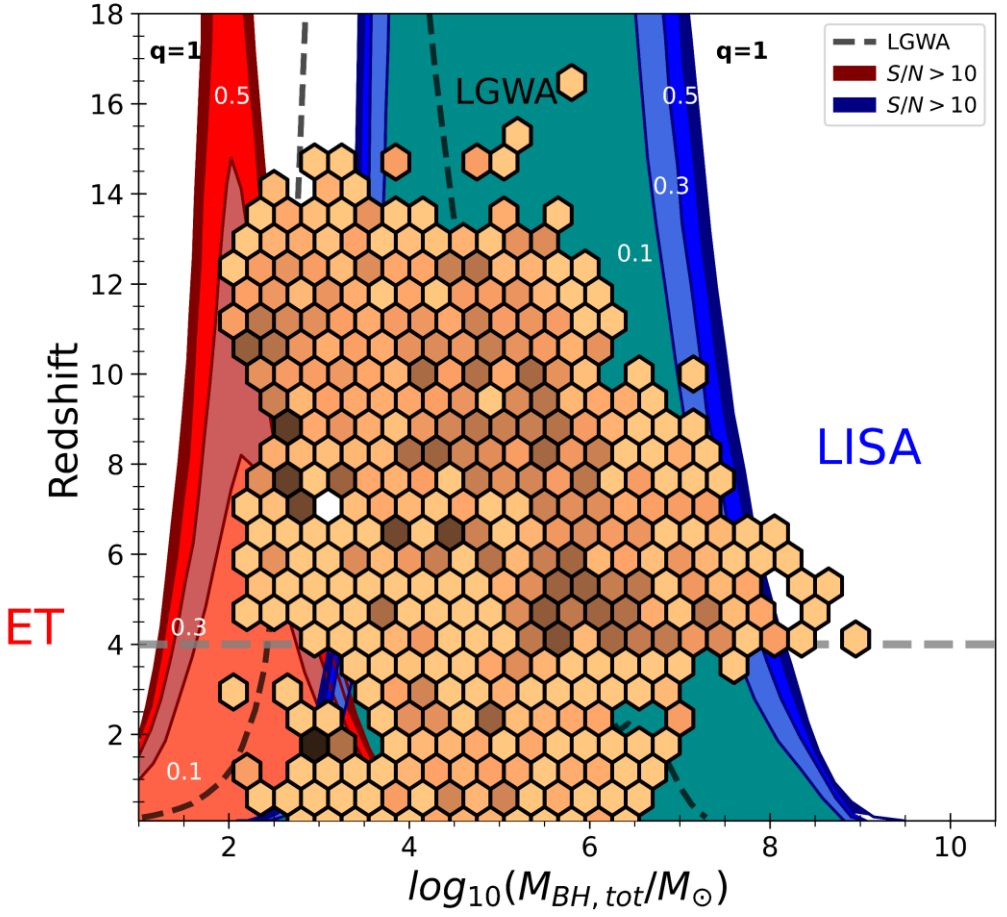
BHBs Merger Rates – Accretion scenarios

Assuming a **different mechanisms of growth** for early BH seeds

EDDINGTON-LIMITED



SUPER-EDDINGTON

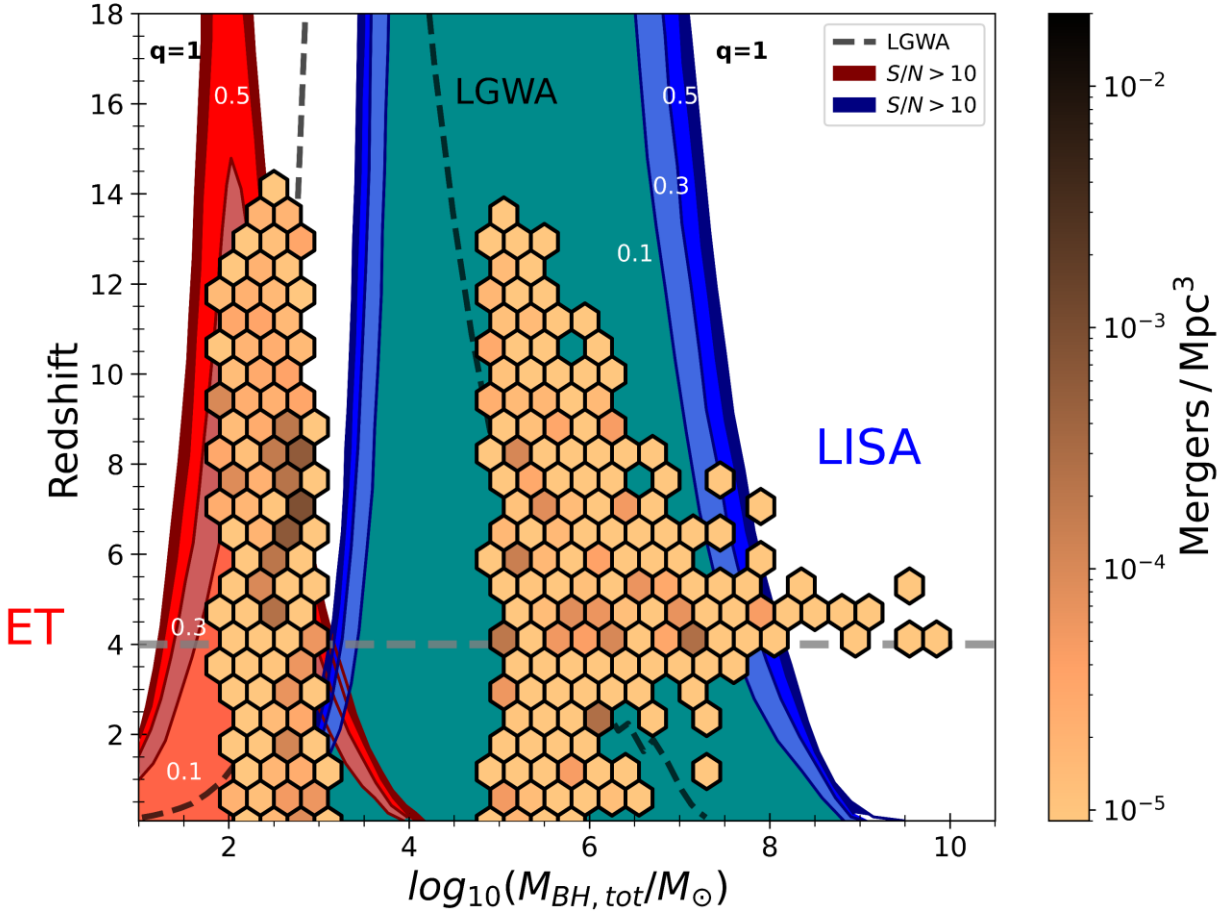


(Trinca+ in prep.)

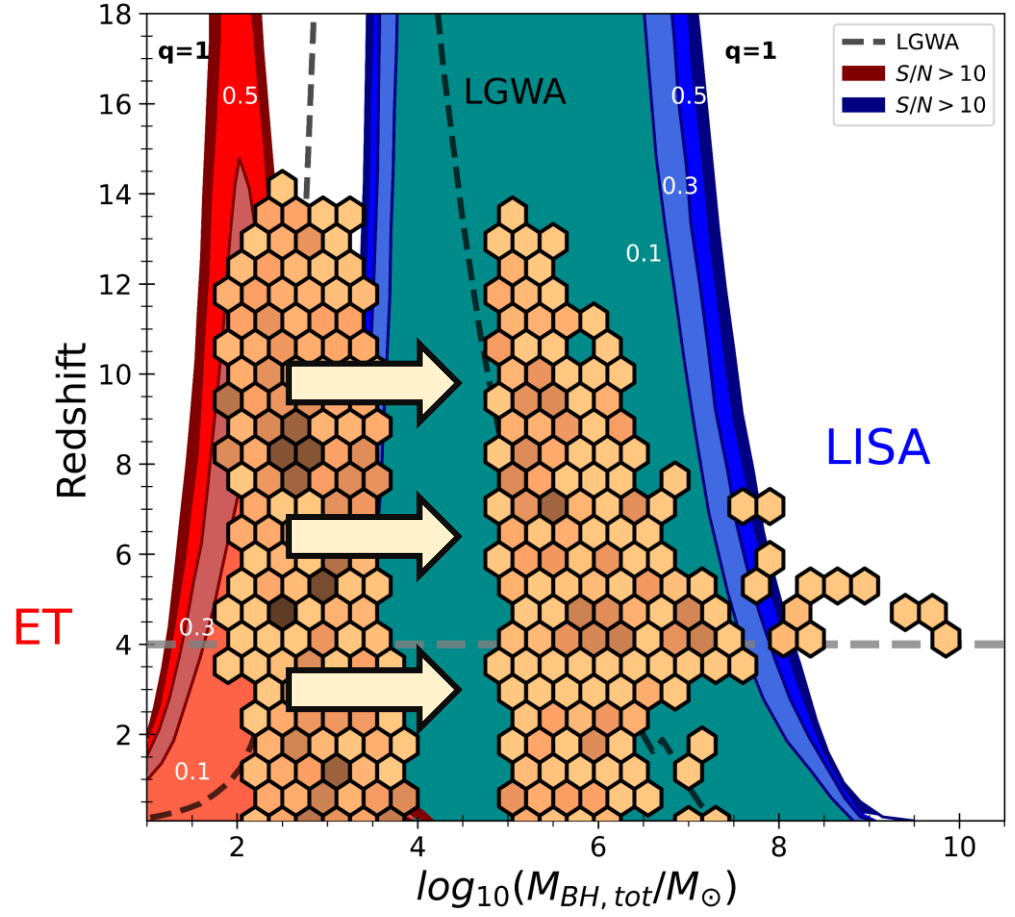
BHBs Merger Rates – Multiple seeding channels

Testing the impact of **additional BH seeding channels**:

Light & Heavy seeds



+ IMBHs from dense nuclear star clusters



WORK IN PROGRESS

(Davari, Valiante, AT+, in prep.)

Conclusions

- → The potential pathways of formation and early growth characterizing the first black hole seeds are diverse and remain largely unconstrained.
- → The Cosmic Archaeology Tool represents a versatile framework to test various evolutionary scenarios, generating extensive catalogs of AGNs and massive black hole binaries.
- → JWST is already uncovering numerous early AGN candidates, whose peculiar properties hint at efficient early black hole growth through short phases of super-Eddington accretion.
- → However, EM survey will be limited to probe the early MBH growth! Developing tools to predict EM and GW signatures for various formation pathways will be essential to unraveling the contributions of accretion processes versus the fundamental nature of the first BH progenitors.

Thank you!

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