Seed black holes: Synergy between ET and LISA

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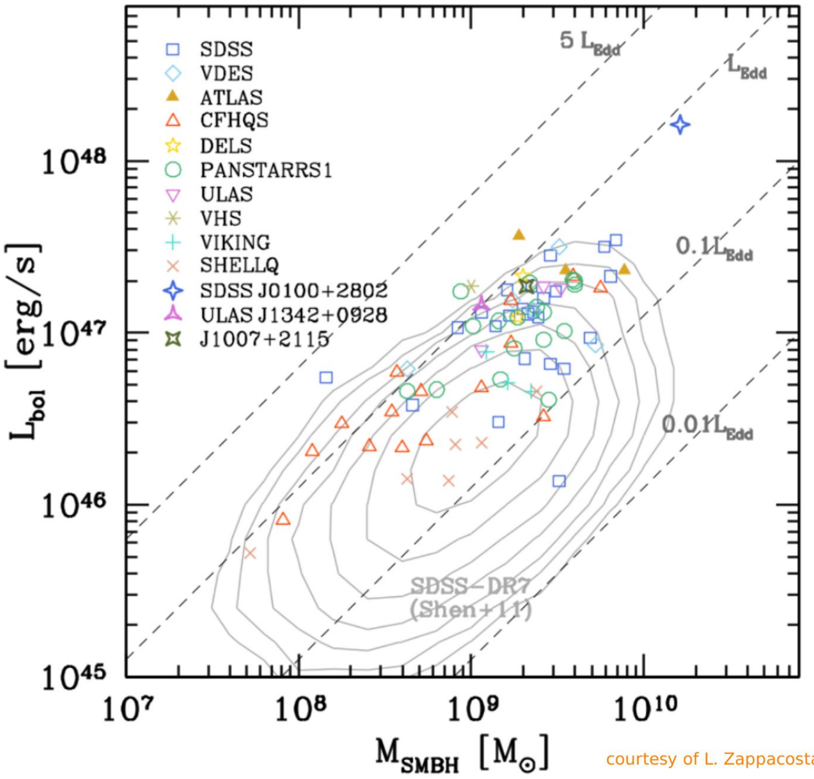
Observation evidences



courtesy of L. Zappacosta

Massive quasars at high redshift

- J0100, $M_{\rm BH} \simeq 10^{10}$ @ $z = 6.3$ (Wu+15)
- J1342, $M_{\rm BH} \sim 10^{9}$ @ $z = 7.54$ (Banados+20)

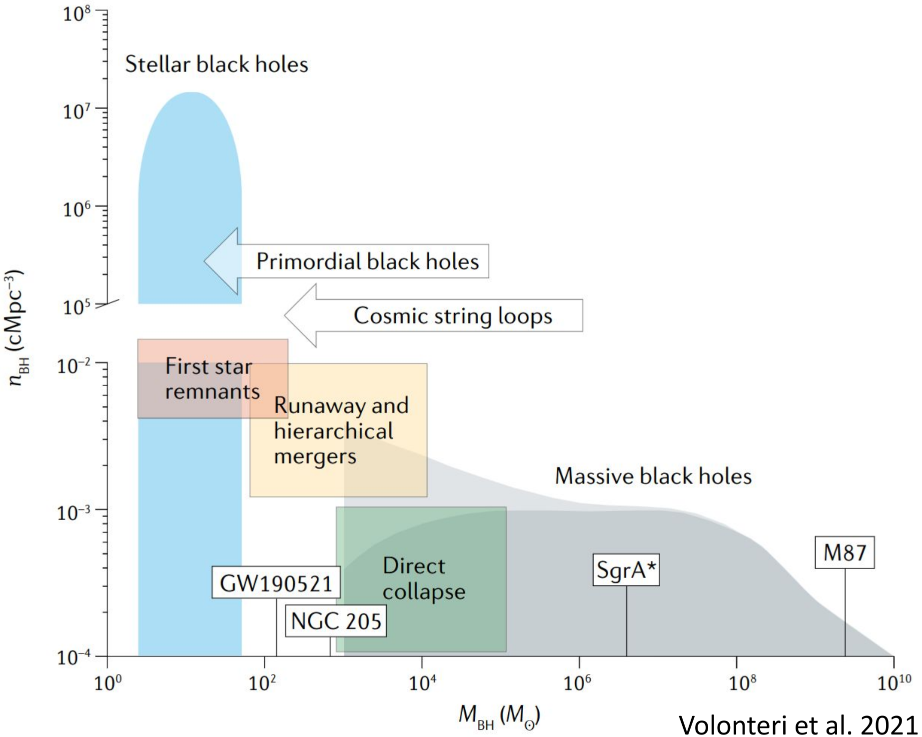
Black hole mass spectrum

- Stellar BHs

$$\begin{cases} M/M_\odot \in [5, 100] \\ \text{Massive stars} \end{cases}$$

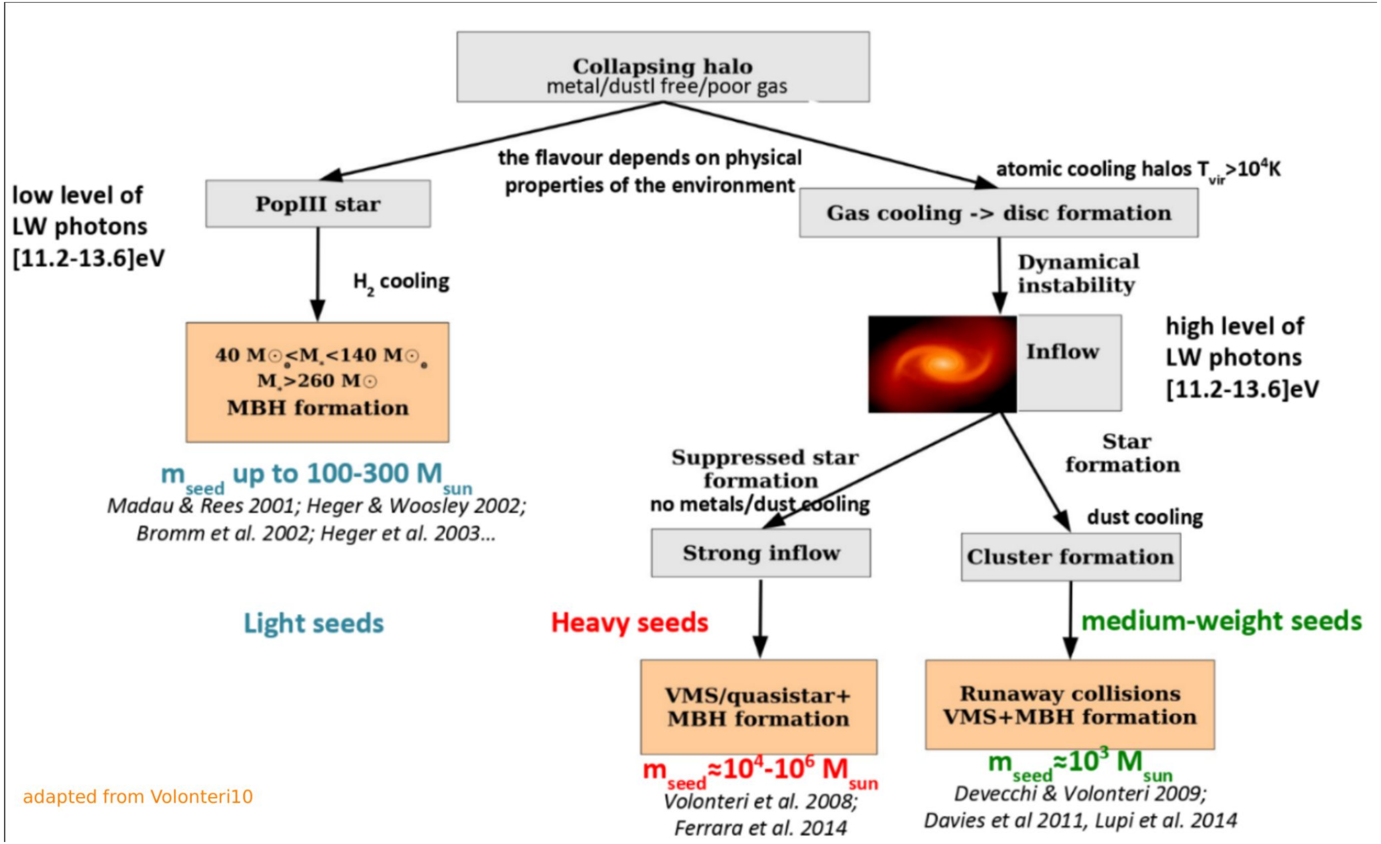
- Massive BHs

$$\begin{cases} M/M_\odot \in [10^5, 10^{10}] \\ \text{Accretion \& growth of DM halos} \end{cases}$$



Volonteri et al. 2021

Seed BHs formation channels



Overview

How can we observe this population of BHs?

- Next generation of EM facilities (SKA, JWST, ELT, Athena, Lynx)
- Third generation GW interferometers (ET, CE)
- Space interferometers (LISA, Decigo, TianQin)

Aims:

- Formation site of first seed BHs
- Growth across cosmic history (accretion/merger)
- Formation of BHBs at high redshift

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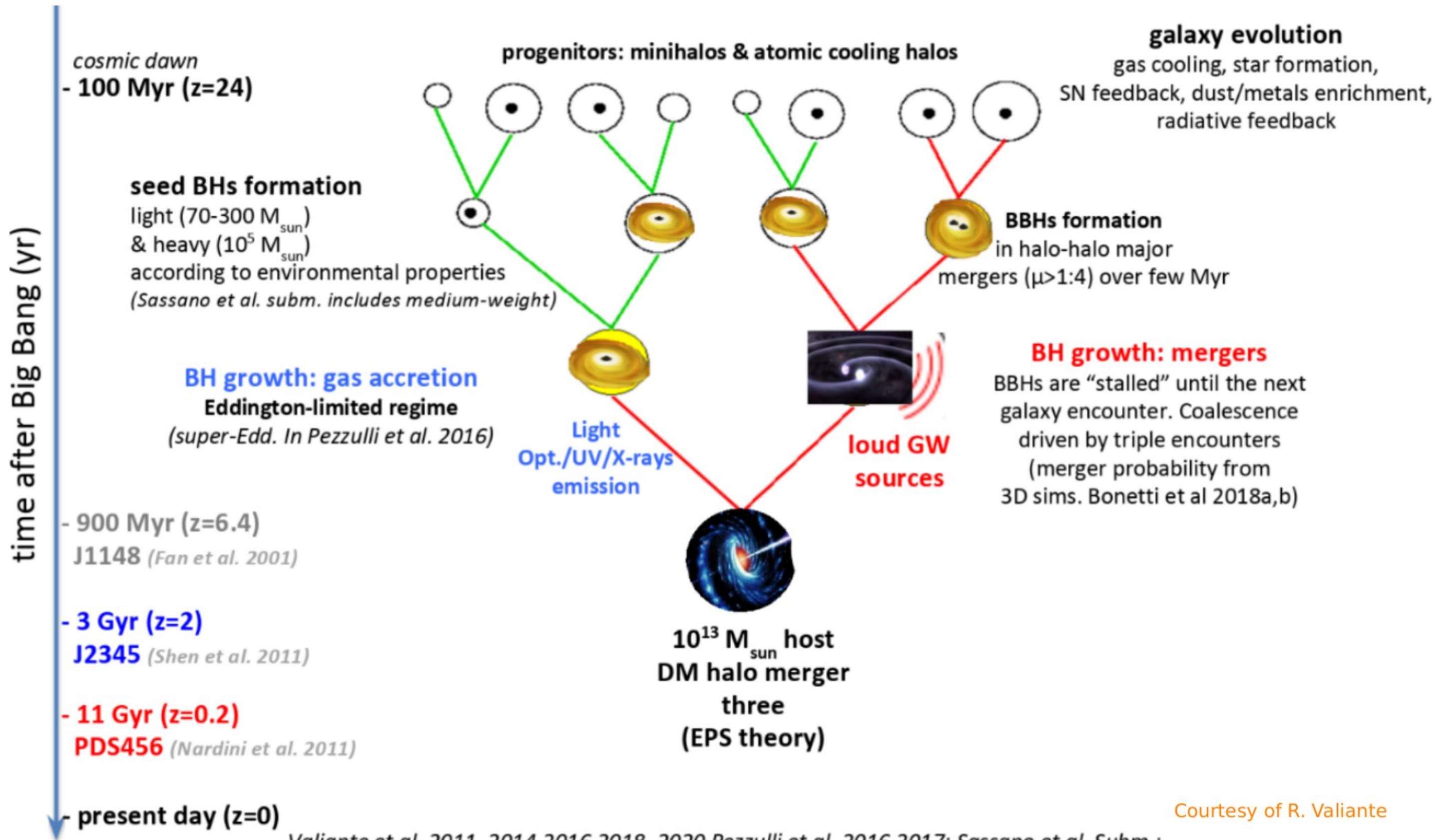
Valiante+21 MNRAS 500, 4095

- Semi-Analytical model GAMETE/QSO DUST (Valiante+16, 18)
- Prescription for dynamics close to merger (Bonetti+16, 18)

General framework

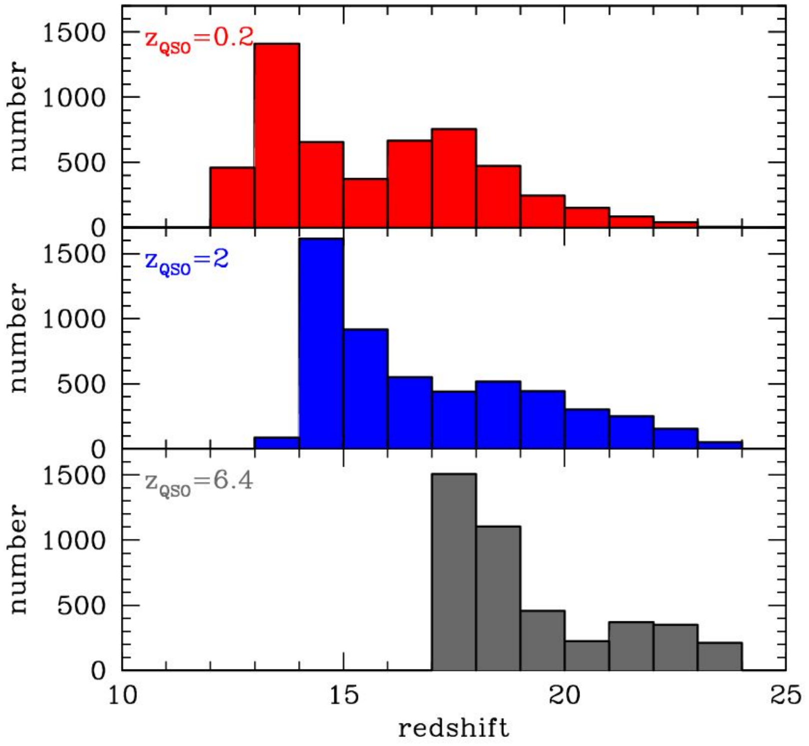


Courtesy of R. Valiante

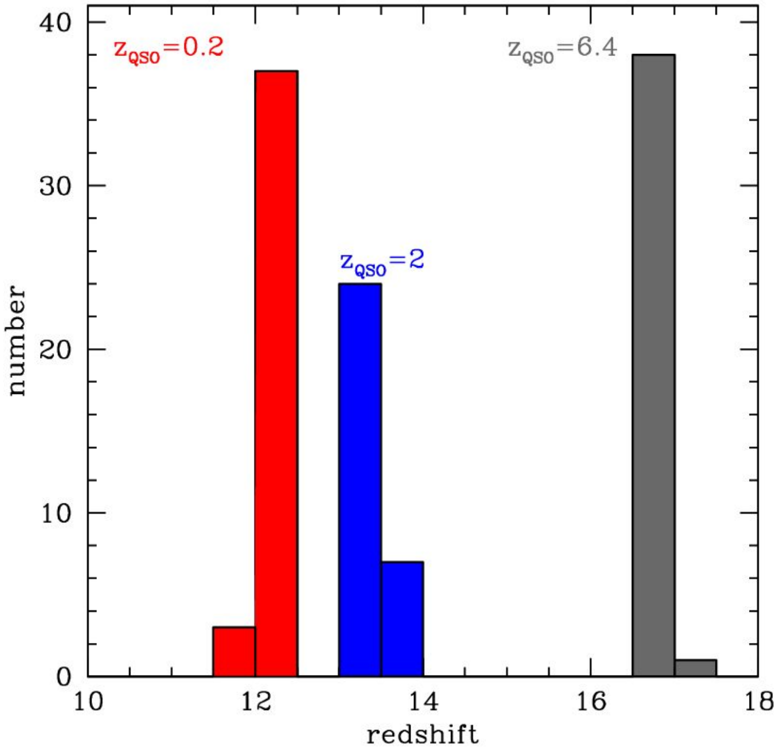
Valiante et al. 2011, 2014,2016,2018, 2020 Pezzulli et al. 2016,2017; Sassano et al. Subm.;

Seeds across cosmic epochs

Light seed $M_{BH} \in [40, 140] - [260, 300] M_\odot$

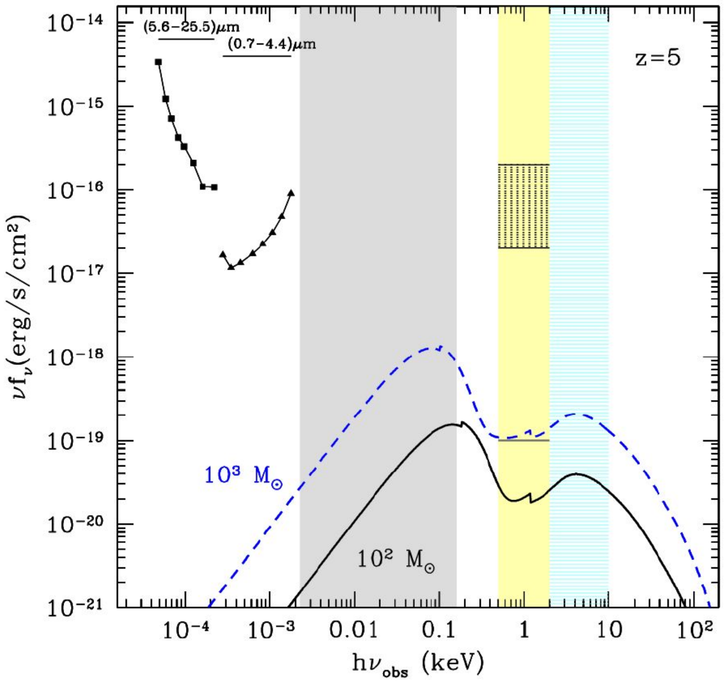


Heavy seeds $M_{BH} = 10^5 M_\odot$



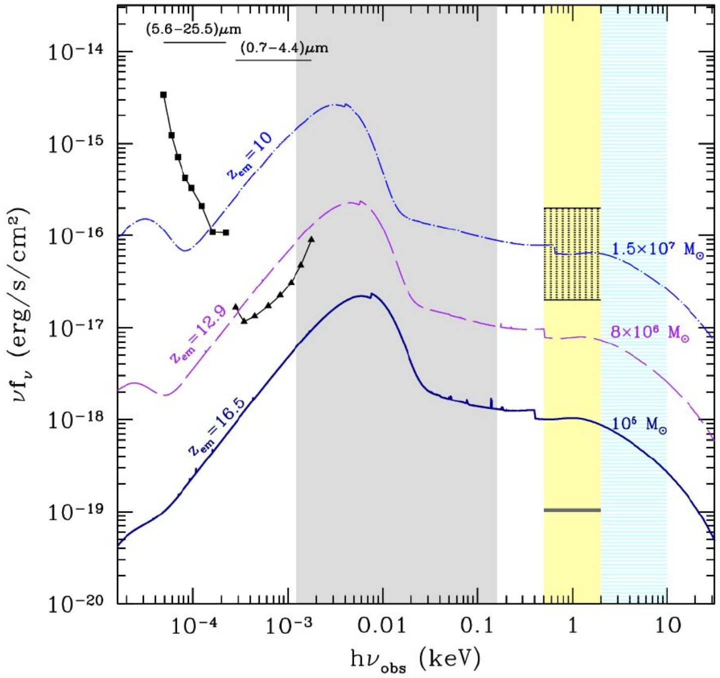
EM emission from seed BHs

Light seeds



No signature at z > 5 by any EM facilities

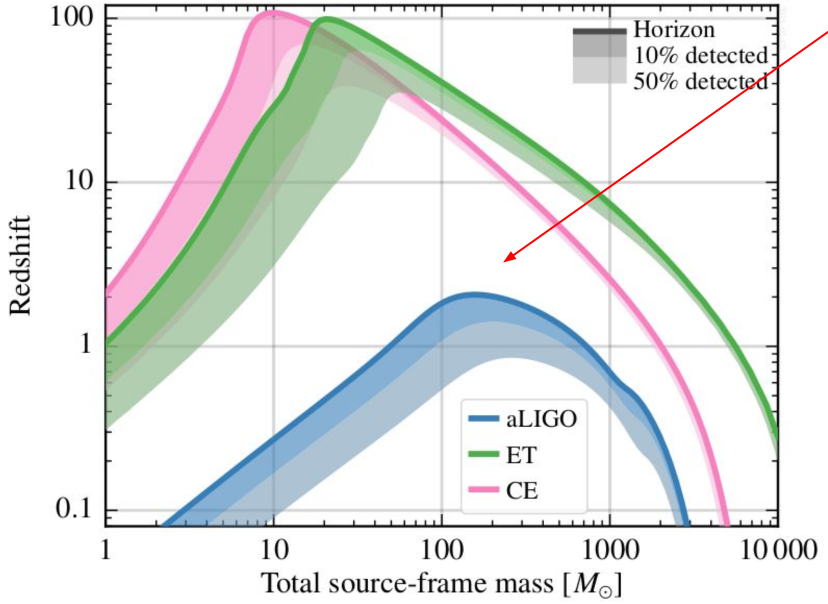
Heavy seeds



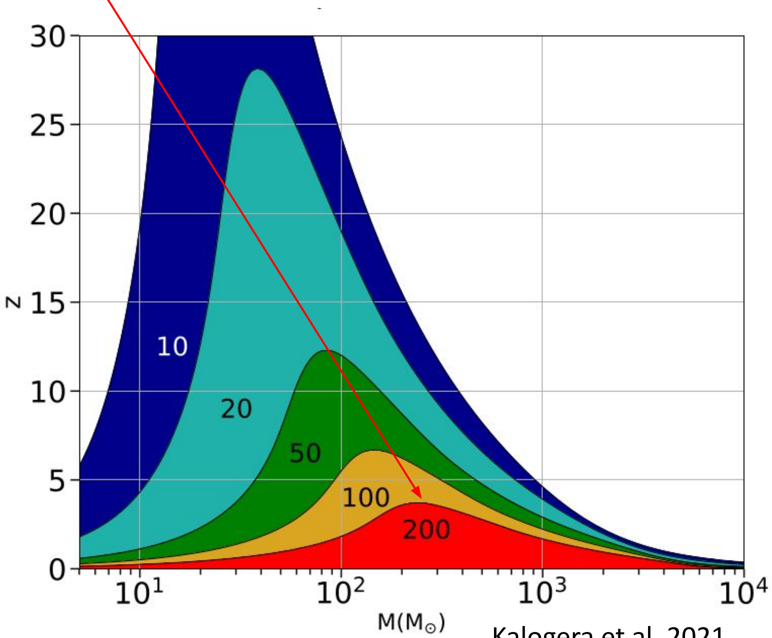
JWST, Athena and Lynx detections out to z ~ 16

ET capabilities

Sweet spot to observe MBH seeds



Maggiore et al. 2020

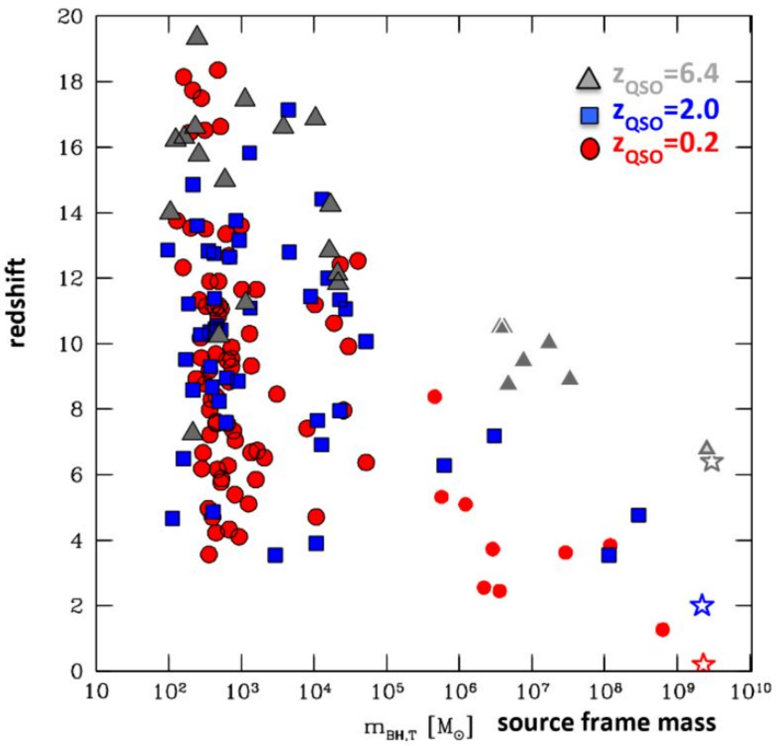


Kalogera et al. 2021

Face on, equal mass binaries at zenith

Average over sky position and orientation

BH binaries at cosmic dawn



Light/heavy seed form in pristine DM halos

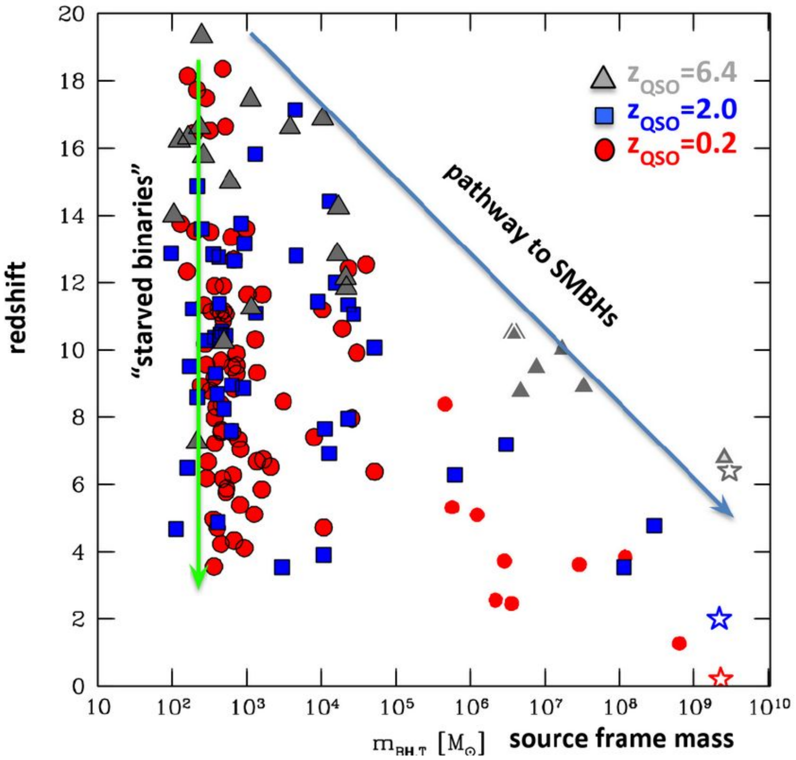
↓

BHs pair during halo major mergers ($\mu > 1 : 4$)

↓

Coalescence after triple interaction with another BHs

BH binaries at cosmic dawn



Light/heavy seed form in pristine DM halos

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BHs pair during halo major mergers (μ > 1 : 4)

↓

Coalescence after triple interaction with another BHs

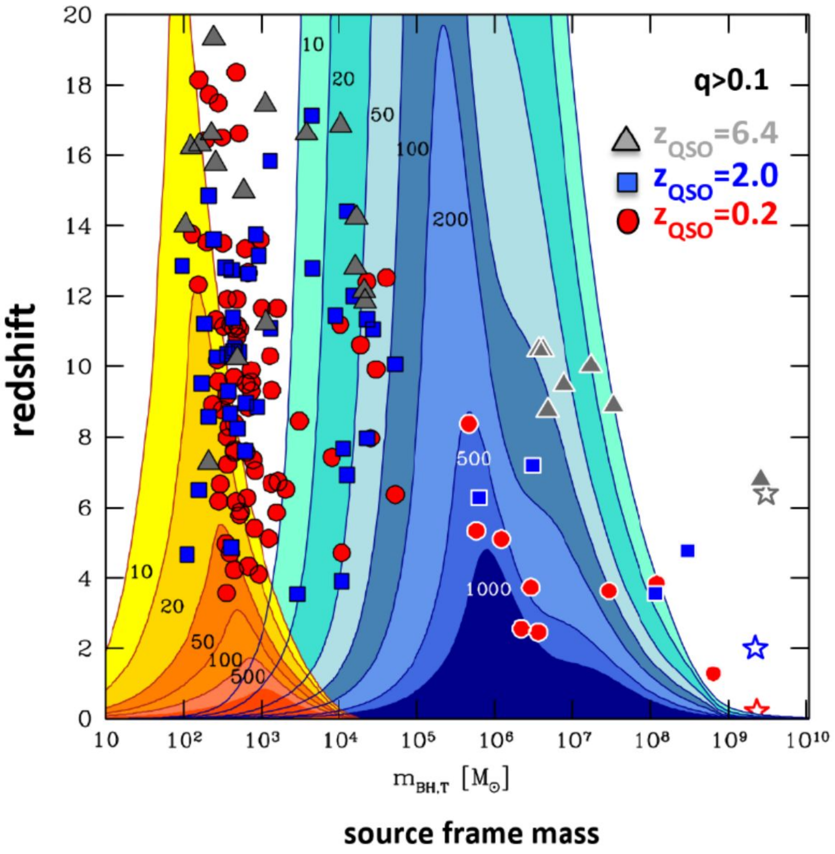
Main findings:

Not-grown light seeds merge down to z = 3

&

MBH binaries along the pathway to SMBH

GW Observations



Detectable with ET and LISA

$$\text{Rates } (S/N > 8) \sim \begin{cases} 11\,\text{yr}^{-1} \text{ for ET} \\ 19\,\text{yr}^{-1} \text{ for LISA} \end{cases}$$

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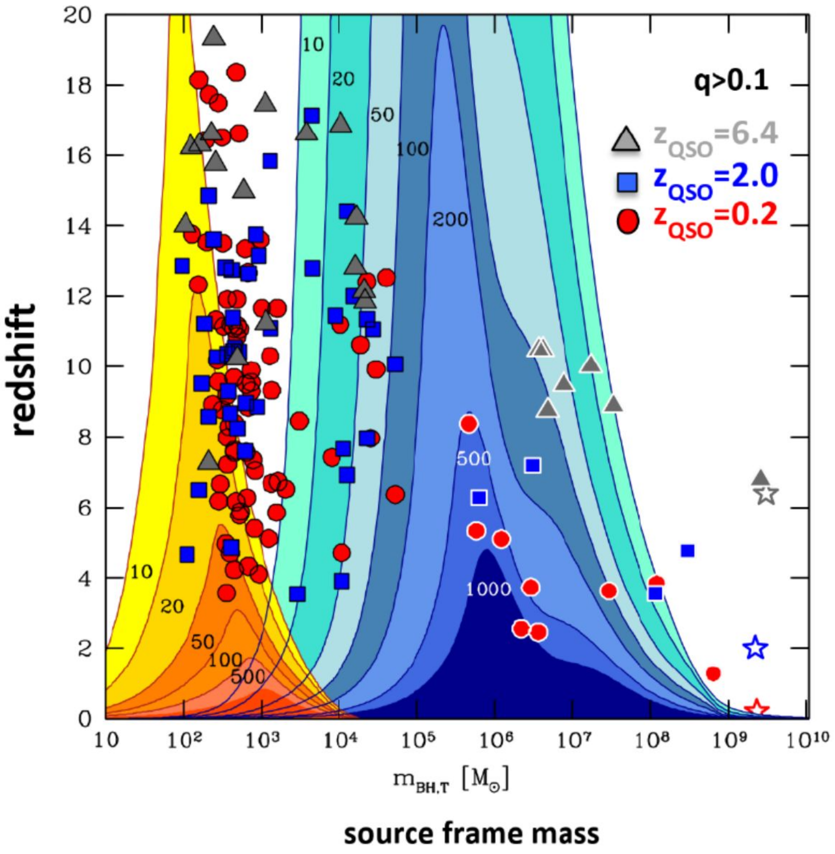

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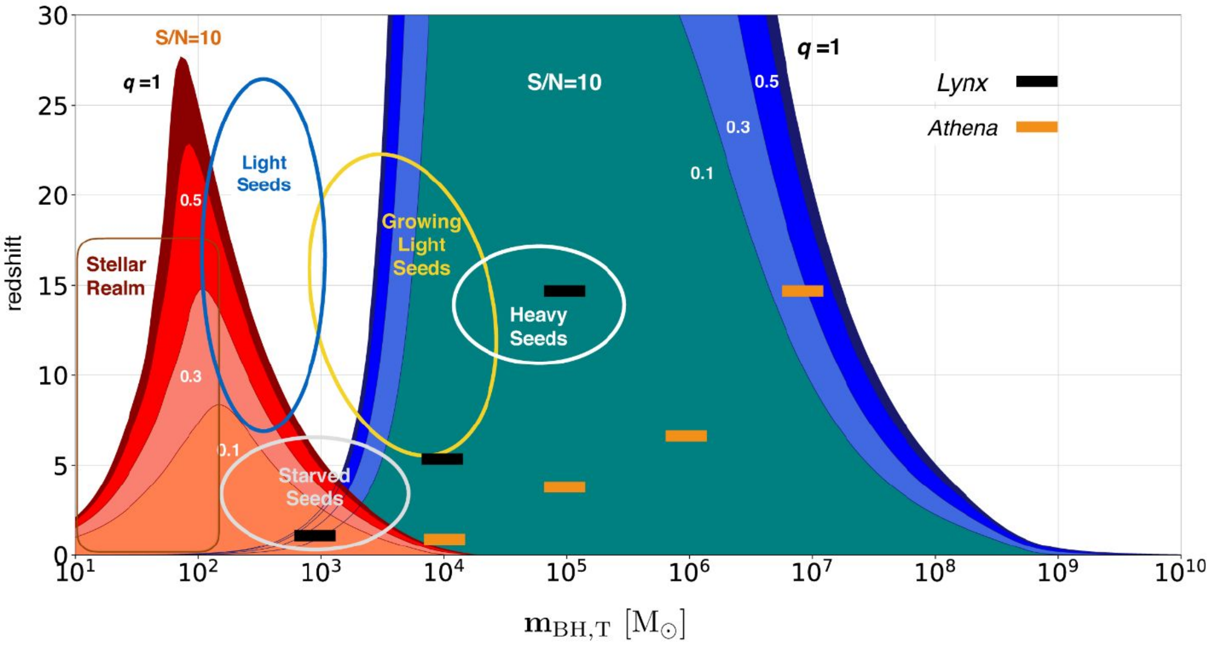
Statistical inference of mass distribution/relative occurrence of earliest BH mergers provided by combined ET and LISA observations will offer unique insight onto the formation and growth history of MBHs

Conclusions

For EM observations . . .

If seed BHs accrete → Athena, JWST and Lynx will detect them



Conclusions

With GW detectors . . .

- LISA will detect MBHBs from heavy seed already at z = 15
- 3G detectors will detect light seeds merging at z > 5

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