UC SANTA BARBARA
Kavli Institute for Theoretical Physics

Merging Visions:
Exploring Compact-Object Binaries with Gravity and Light

Massive Black Holes formation and evolution

Growing cosmological BH binaries from the earliest BHs

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growing cosmological BH binaries from the earliest BHs

motivation:

NEXT Generation GW observatories will give us access to the observable Universe at high redshift (up to z=20) and BH mass intervals from few tens up to thousands/millions solar masses

key questions:

When do the first black hole binaries form in the Universe?

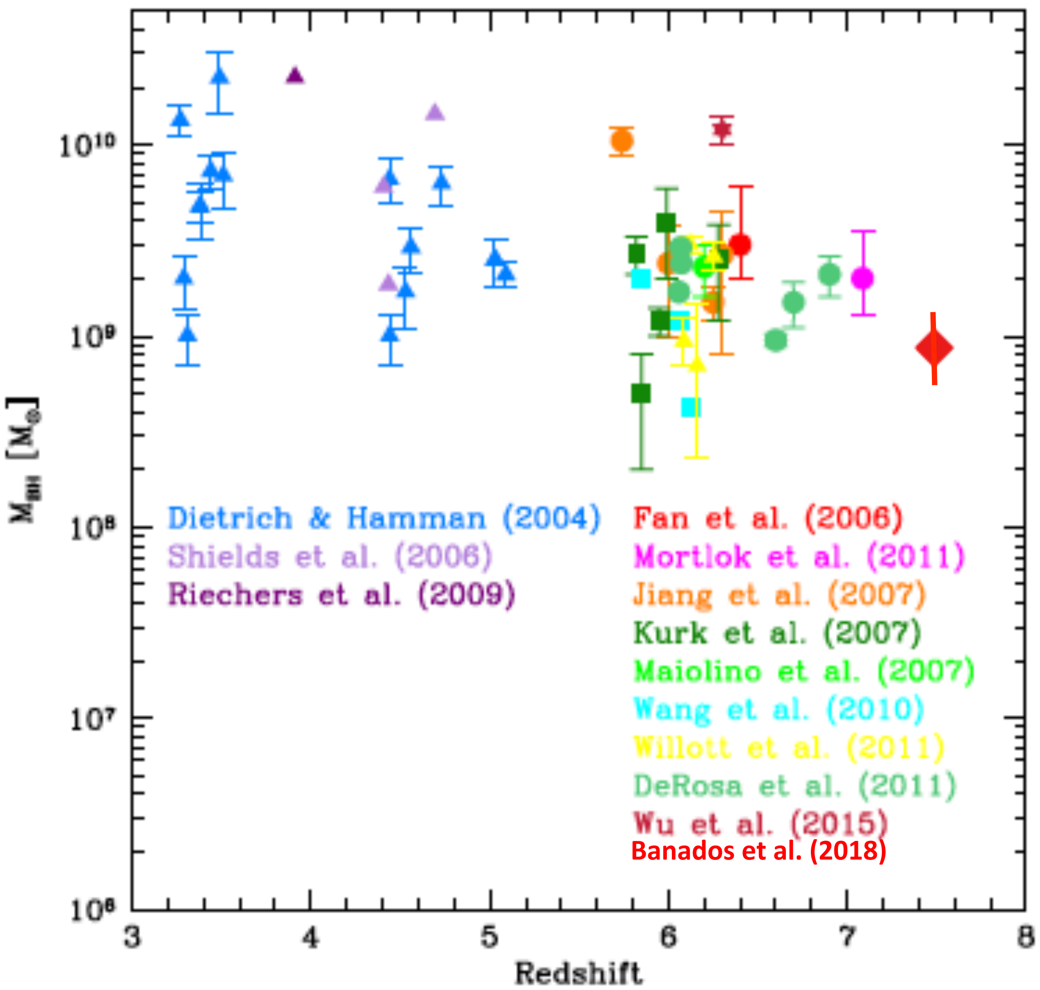
Which is the mass of the first BHs?

Are the BHs detected at high redshift the "seeds" upon which super massive BHs form?

...

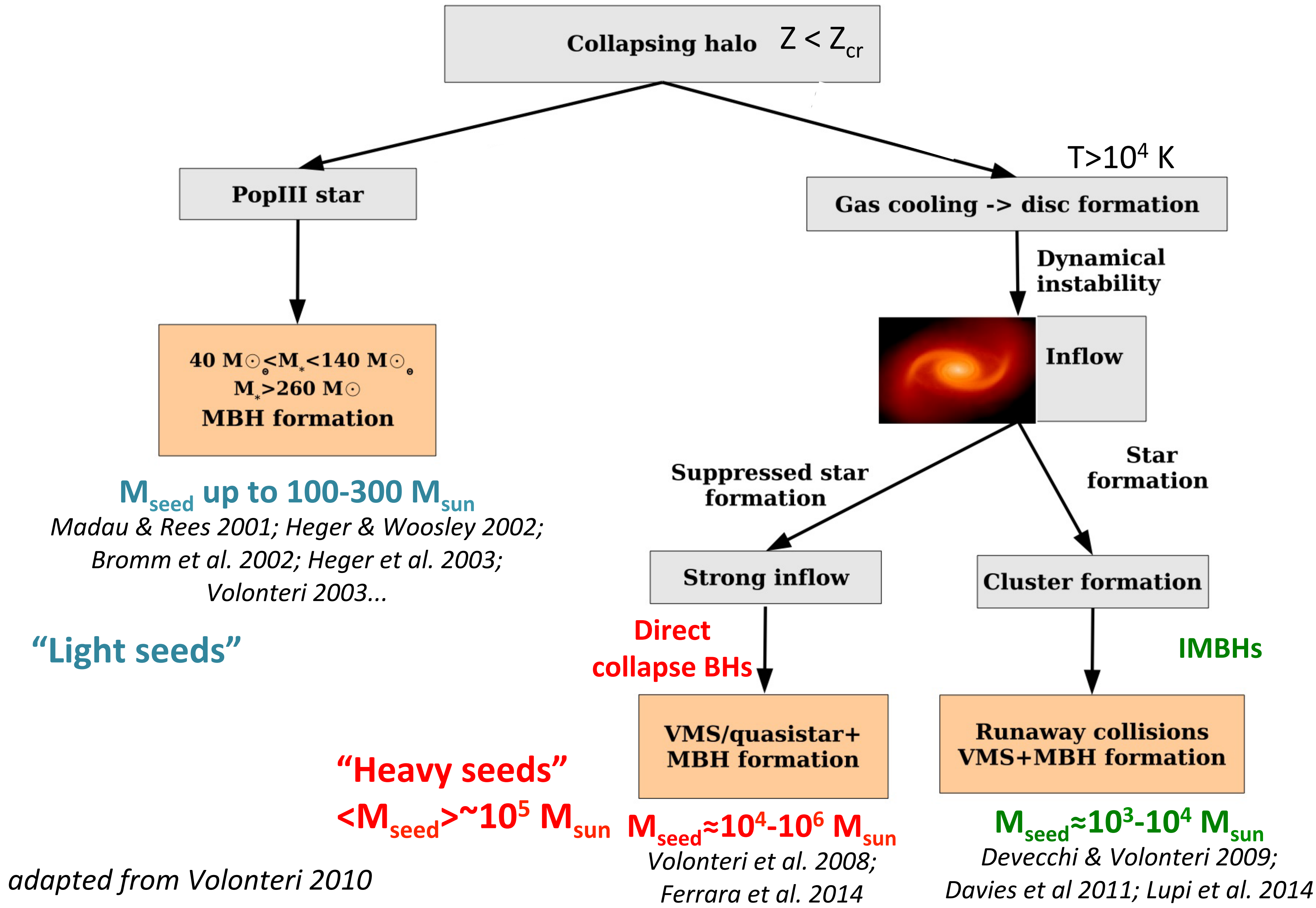
our approach: building-up the first SMBHs

RV, Agarwal, Habouzit & Pezzulli 2017



tracing seed evolution and BH binaries along the hierarchical assembly of high-z galaxies

pathways to the first “seed” BHs



adapted from Volonteri 2010

our method: data-constrained SAM

statistical power

star formation:
PopIII/II SF via quiescent/burst mode
in mini- and Lyα-halos

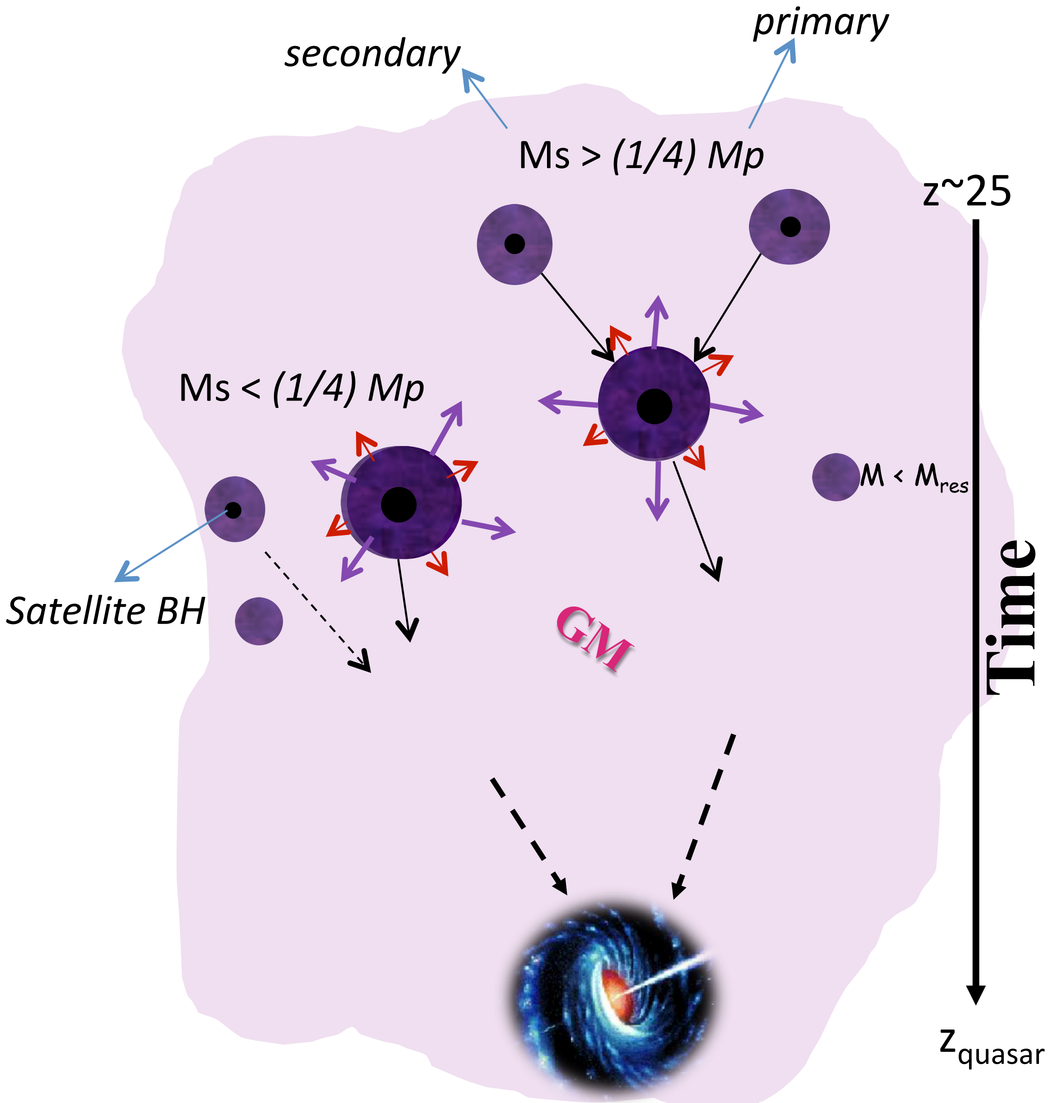
seed BHs formation:
(according to environmental properties)
Pop III remnants &
DCBHs

BH growth:
gas accretion
and mergers

mechanical feedback:
BH/SN energy-driven winds

chemical feedback:
dust and metals enrichment

radiative feedback:
stellar and AGN UV emission



Valiante et al. 2011, 2012, 2014,2016, in prep.
see also Pezzulli, et al. 2016, 2017a, b

forming the first stars

$$\text{IMF} = \Phi(m_*) \propto m_*^{\alpha-1}\ e^{-m_{ch}/m_*}$$
$$\alpha = -1.35$$

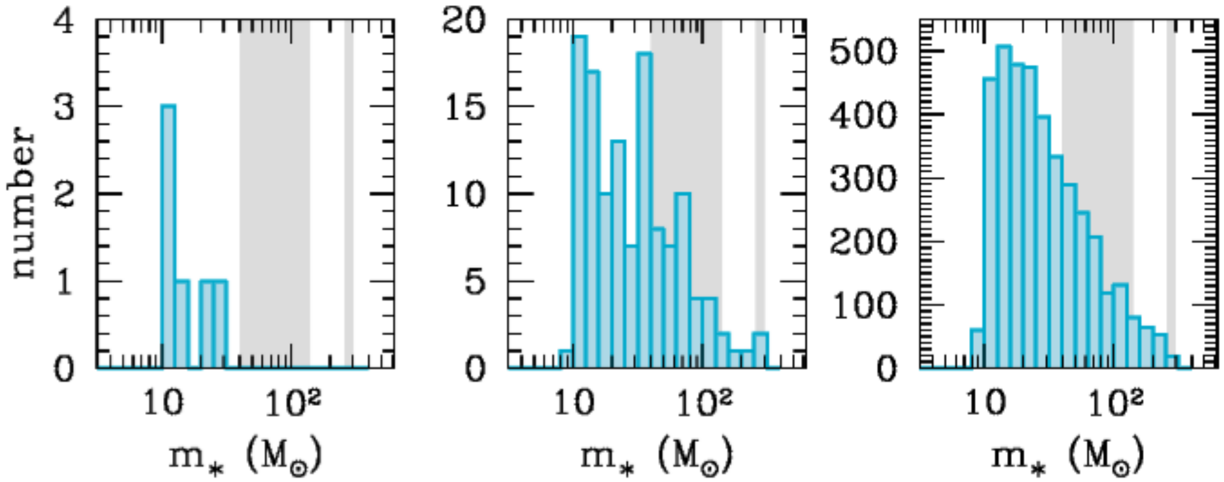
$Z_{ISM} < Z_{cr} \approx 10^{-4}\ Z_{sun}$ → Pop III stars
(Schneider et al. 2001; 2002; 2003)

m_{ch} = 20 M_{sun} and $10 \leq m_\star/M_{sun} \leq 300$

$Z_{ISM} \geq Z_{cr} \approx 10^{-4}\ Z_{sun}$ → Pop II stars
(Schneider et al. 2001; 2002; 2003)

m_{ch} = 0.35 M_{sun} and $0.1 \leq m_\star/M_{sun} \leq 100$

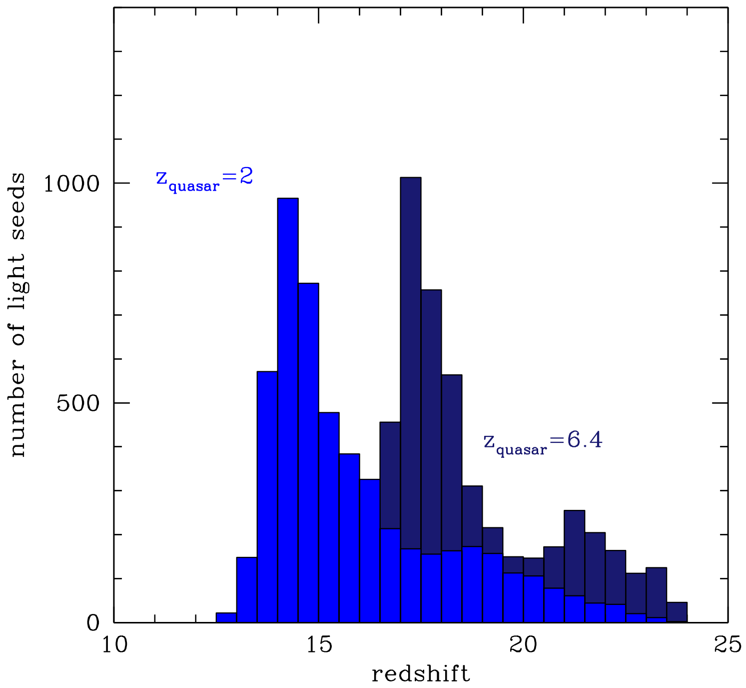
Pop III IMF Stochastic sampling: randomly selected stars



$M_{star} = 10^2\ M_{sun}$ $M_{star} = 5\times10^3\ M_{sun}$ $M_{star} = 1.6\times10^5\ M_{sun}$

RV, Schneider, Volonteri, Omukai. 2016

data-constrained SAM: z≈6 & z=2 quasars

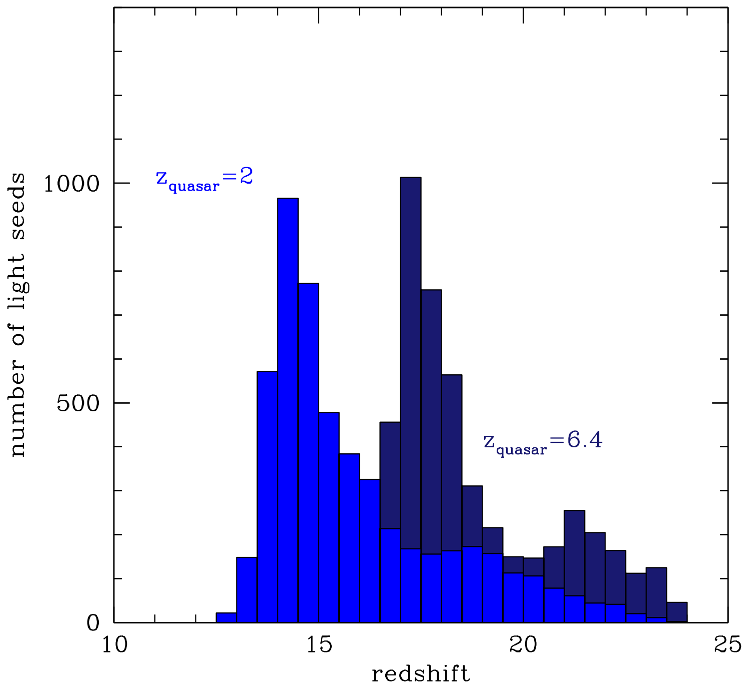


LIGHT SEEDS

form in metal free/poor H_2 (10^{6-7} M_{sun})
and atomic cooling halos (10^{7-8} M_{sun})
the most massive one settles in the centre

Valiante et al. in prep.

data-constrained SAM: z≈6 & z=2 quasars

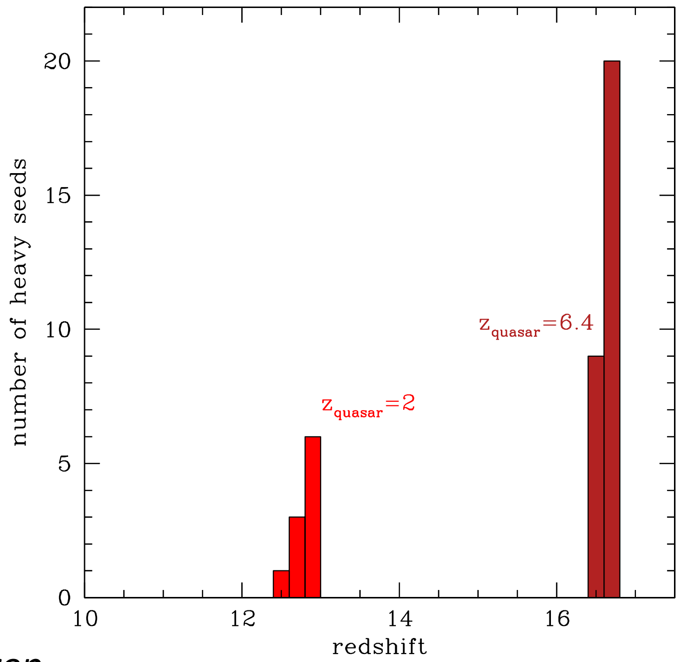


LIGHT SEEDS

form in metal free/poor H_2 (10^{6-7} M_{sun}) and atomic cooling halos (10^{7-8} M_{sun}) the most massive one settles in the centre

HEAVY SEEDS

form in metal free/poor atomic cooling halos (10^{7-8} M_{sun}) when $J_{LW}>J_{cr}$ we assume $m_{HS}=10^5$ M_{sun}



Valiante et al. in prep.

data-constrained SAM: z≈6 & z=2 quasars

LIGHT SEEDS

+

HEAVY SEEDS

↓

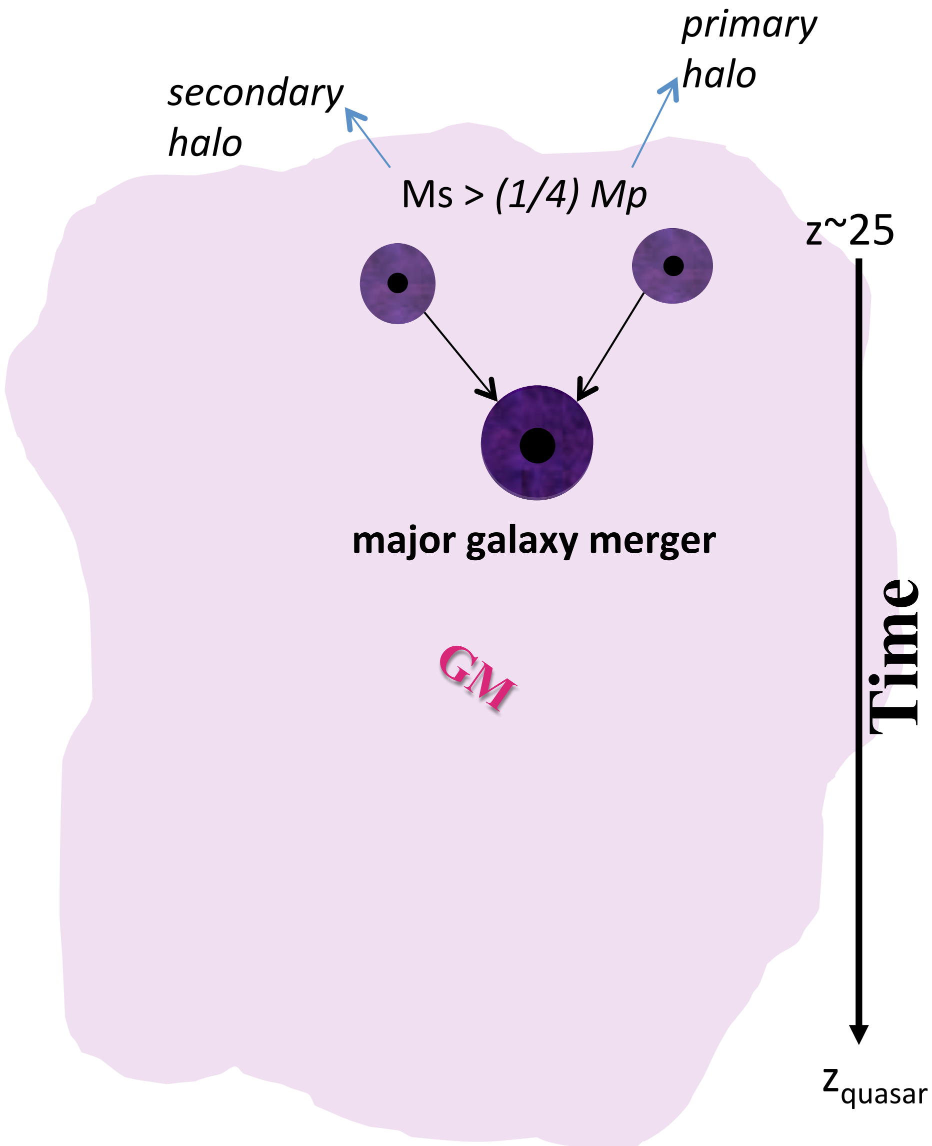
seeds growth

Eddington-limited accretion and mergers

(super-Edd. accretion onto light seeds in Pezzulli et al. 2016)

BH binaries formation

In halo-halo major mergers coalescence over ~0.1-2 Myrs

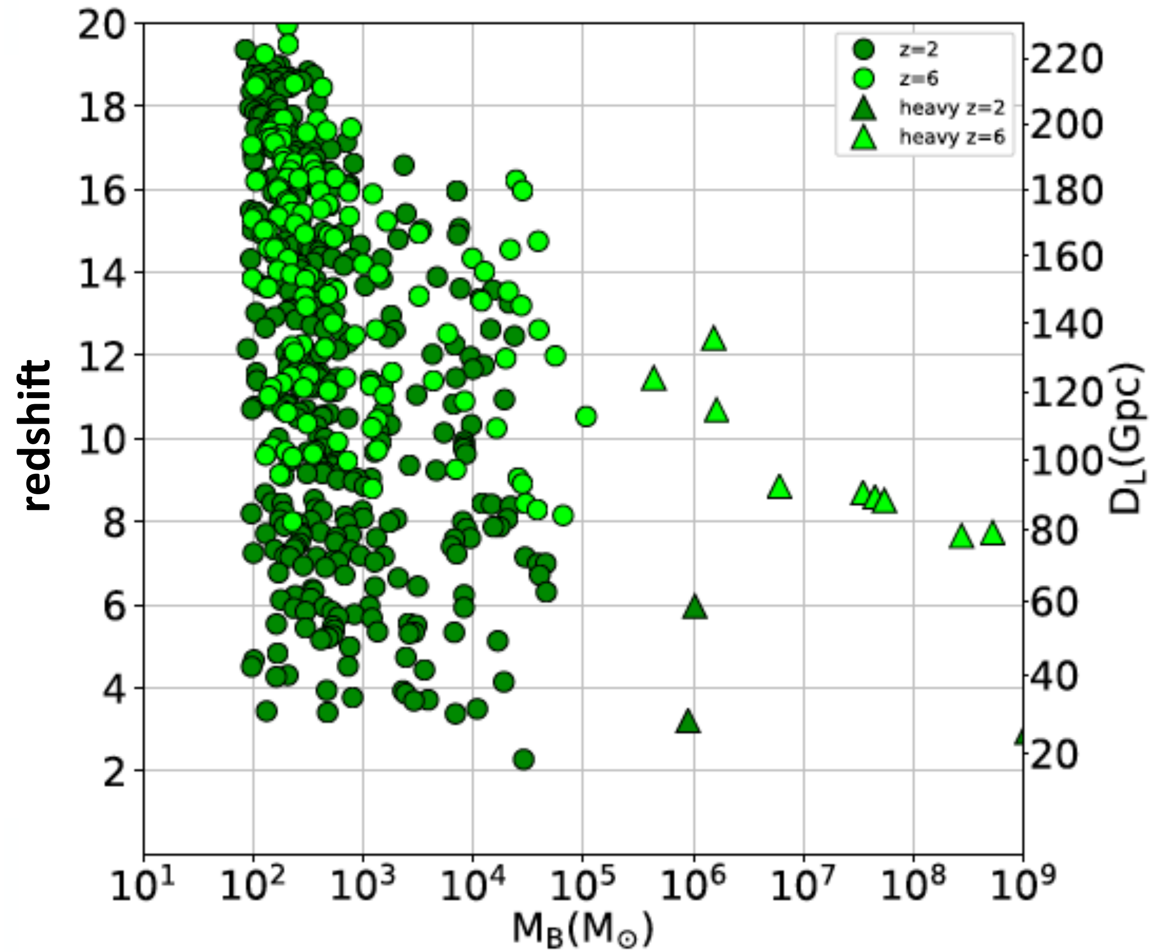


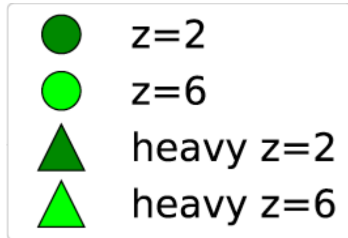
Valiante et al. 2011, 2012, 2014,2016, in prep.
see also Pezzulli, et al. 2016, 2017a,b

BHBs in the cosmological framework

data-constrained models (GQd): >10^9 M_{sun} BH @ z=2 or 6 in 10^{13} M_{sun} DM halos

BH Binary formation epoch





major mergers:
merging DM halos
mass ratio > 1:4

"Cosomological BH binaries"

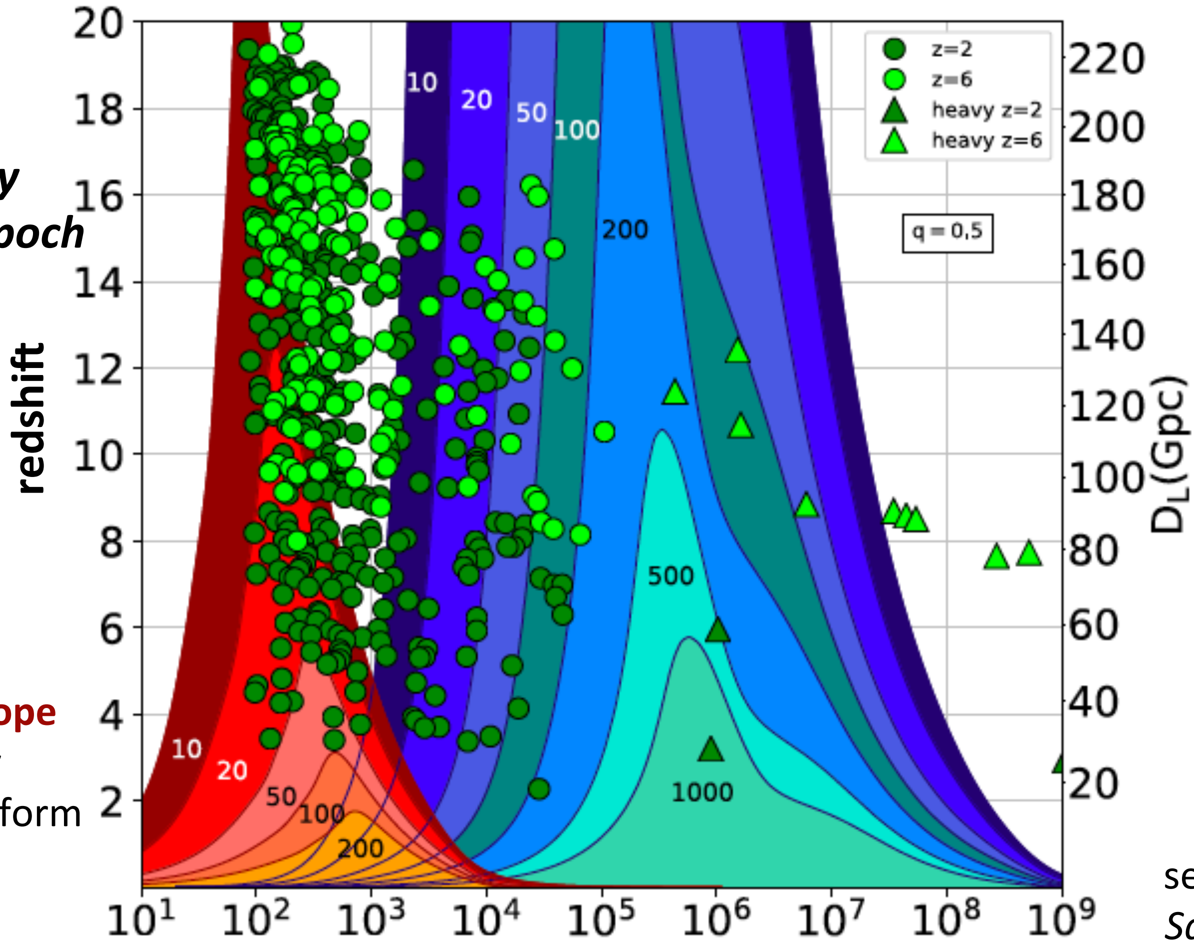
BHs forming in pristine/metal poor halos and pairing during galaxy major mergers

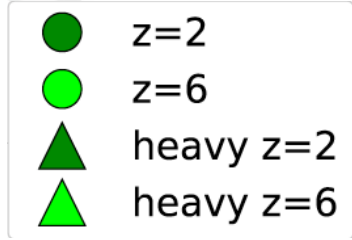
BHBs merge over the hosts merger timescale (few Myr)

BHBs in the Gravitational Universe

BH binaries forming from growing light & heavy seeds: BH mergers follow host galaxies merger

BH Binary formation epoch





major mergers:
merging DM halos
mass ratio > 0.25

Einstein Telescope
ET_D sensitivity
PhenomC waveform
(spin=0, q=0.5)

“light seeds” realm

“heavy seeds’ realm

“SMBHs” realm

LISA
sensitivity curve (q=0.5)
Santamaria et al (2010)

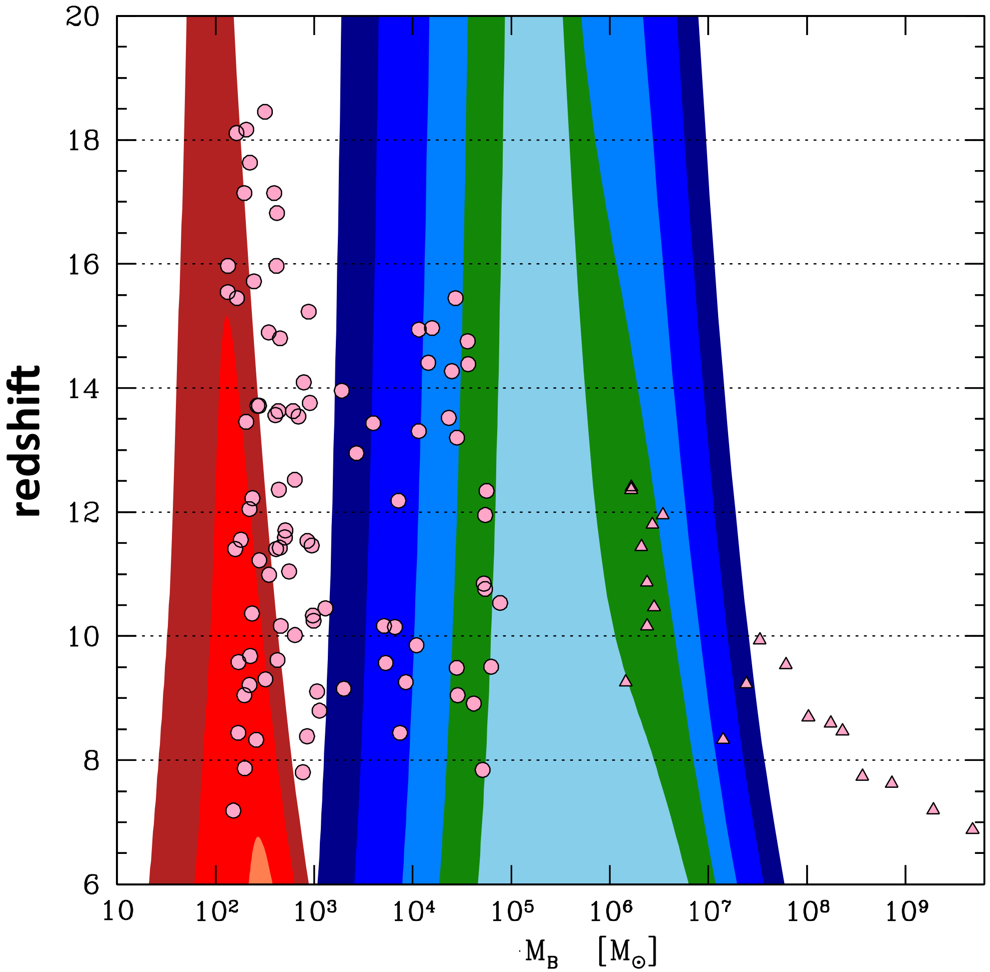
3G-seed team, Mangiagli, Colpi, Valiante, Schneider et al. (in prep)

BHBs in the Gravitational Universe

BH binaries forming from growing light & heavy seeds: **focusing on z>6**

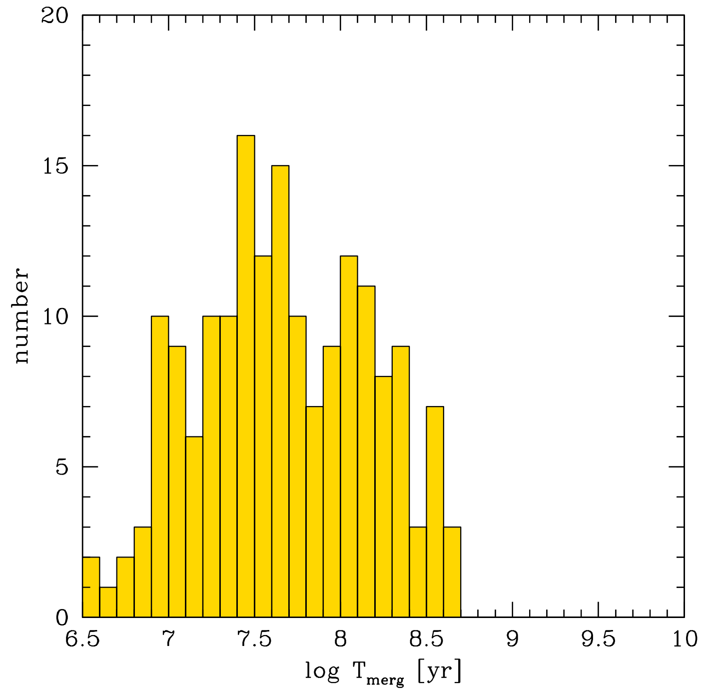
model improvement: "stalled BHBs"

prompt merger (of the two most massive bodies) triggered by multiple BH interactions



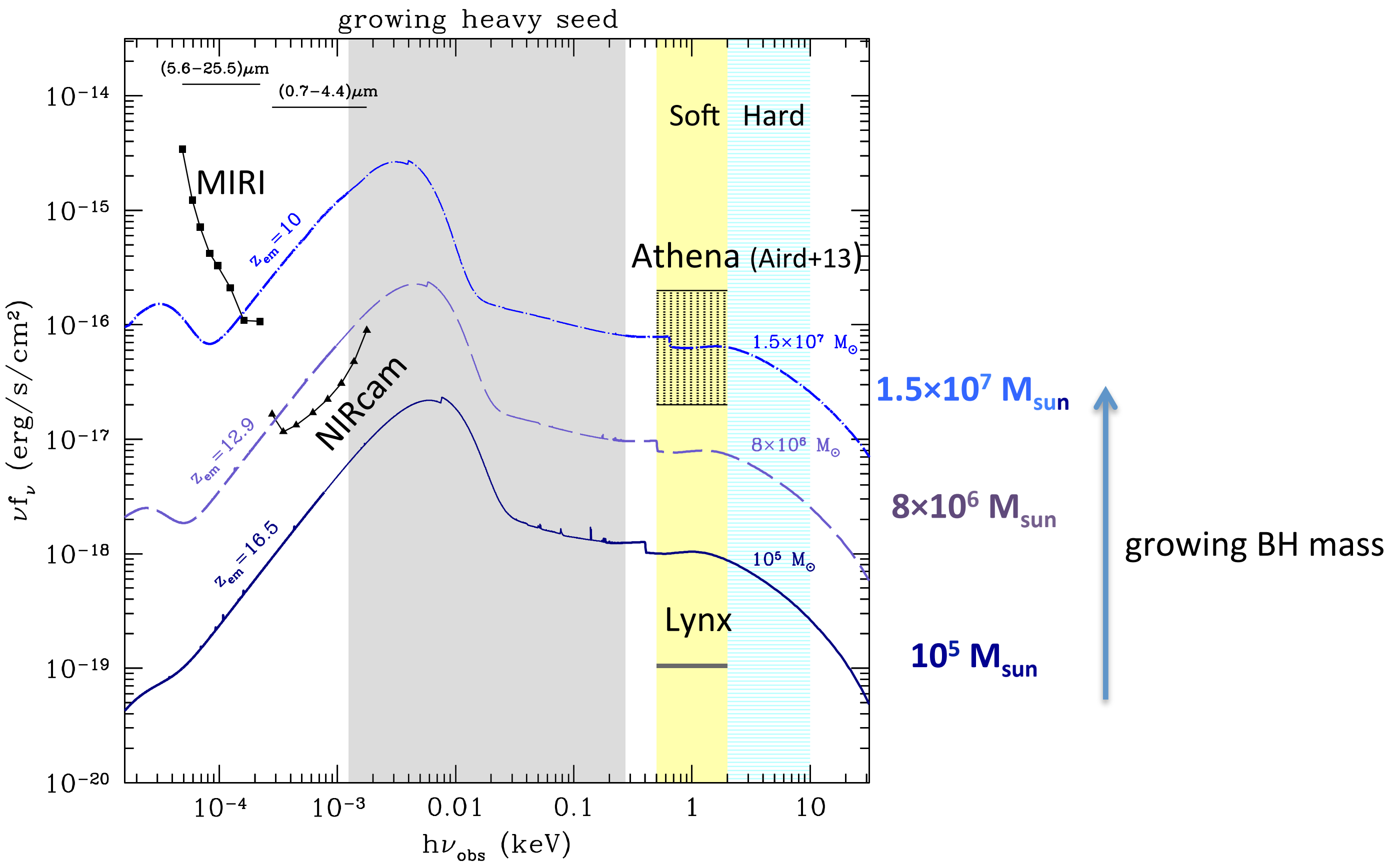
***delays distribution**:*

from BHB formation epoch to triple/quadruple encounter



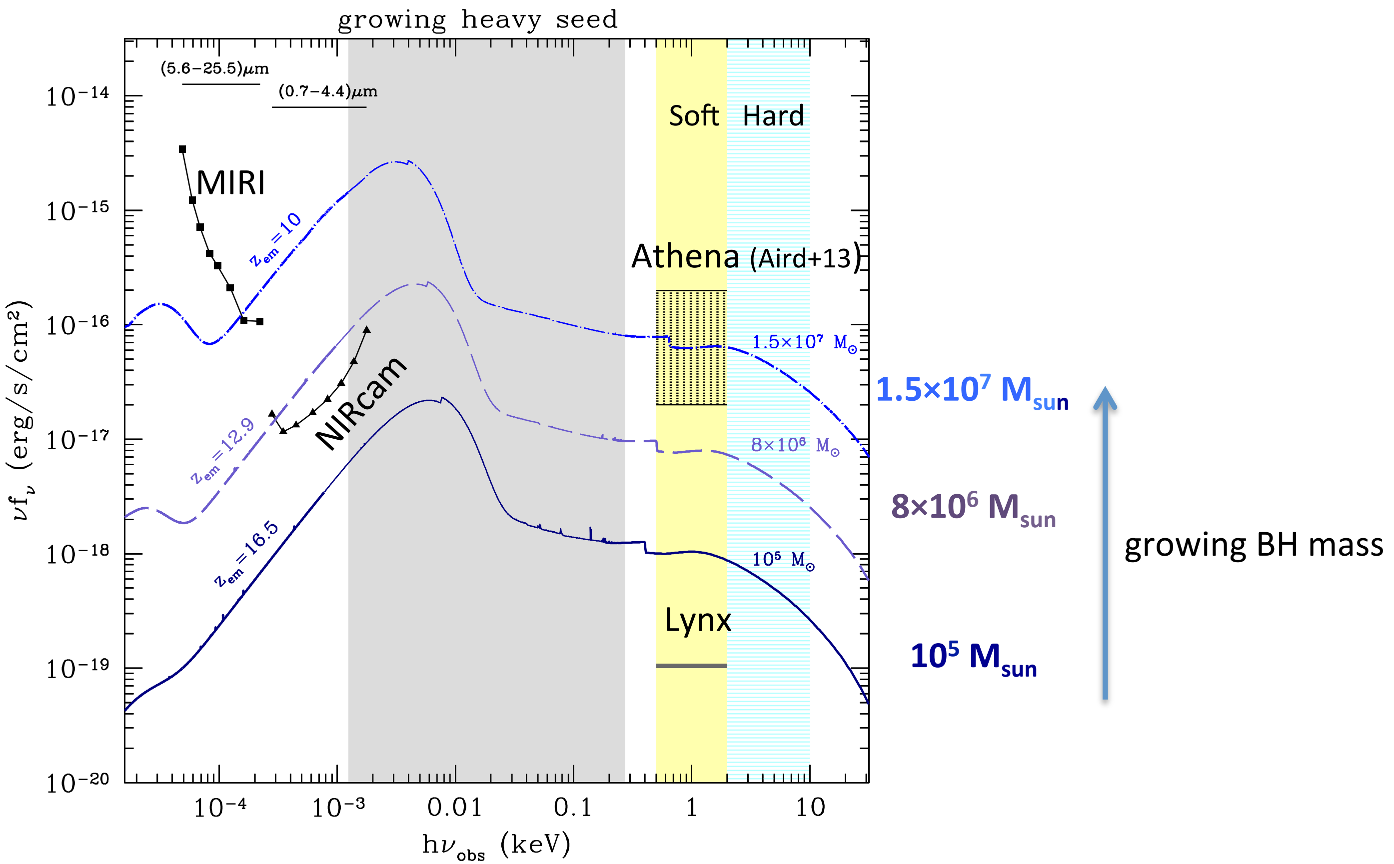
(active) BHs in the EM Universe

(active) BHs in the EM Universe: heavy seeds



3G-seed team, Mangiagli, Colpi, Valiante, Schneider et al. (in prep)

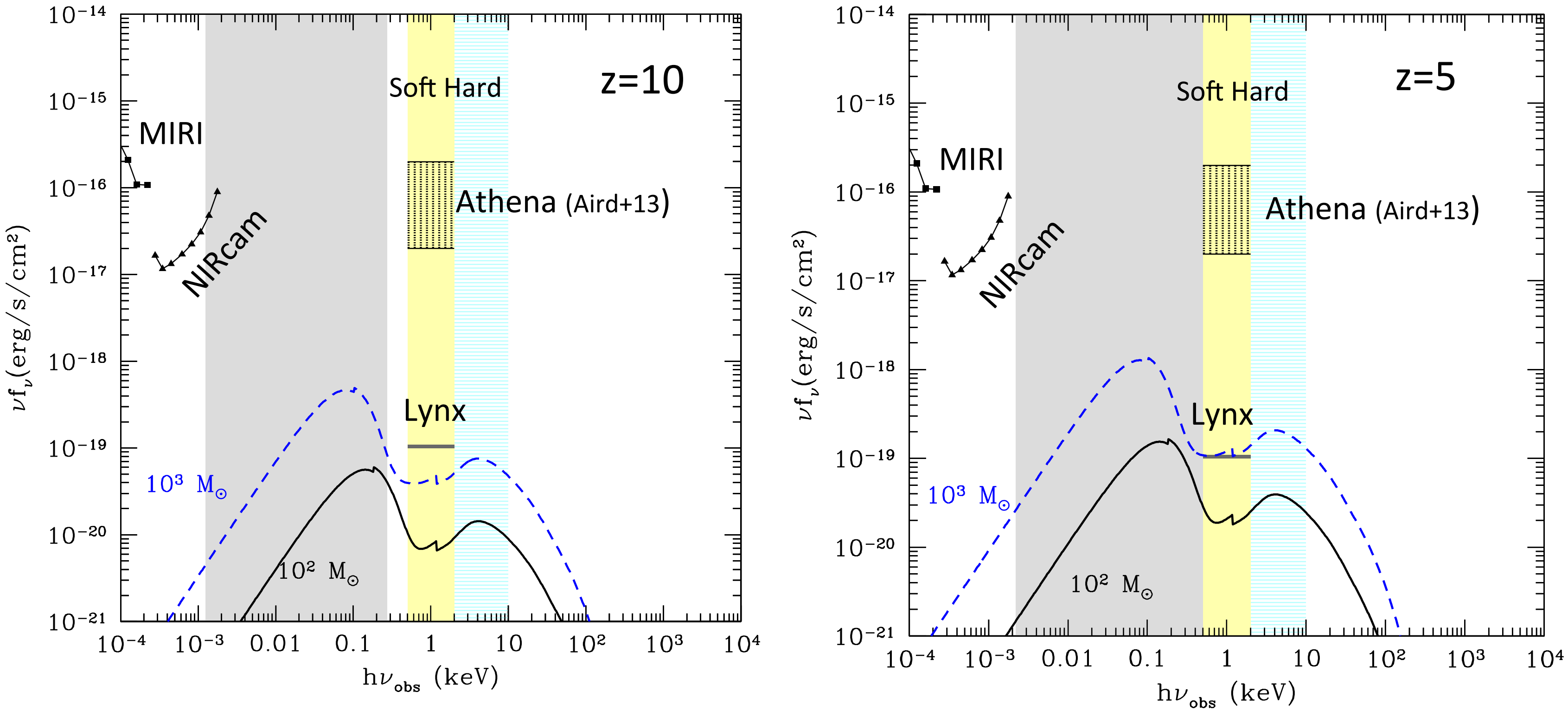
(active) BHs in the EM Universe: heavy seeds



JWST and Athena (and Lynx) will be able to detect the earliest accreting (massive) black holes out to z=15(17)

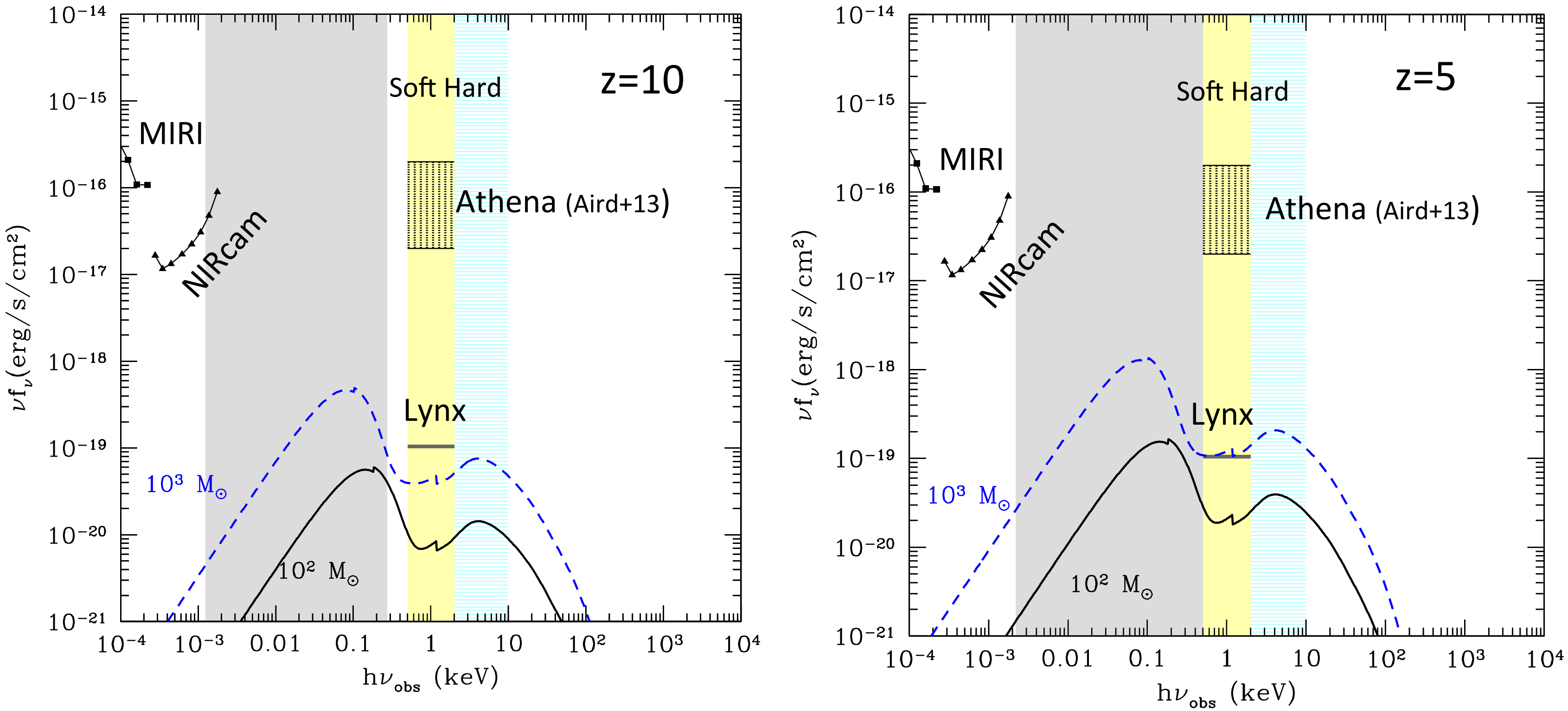
3G-seed team, Mangiagli, Colpi, Valiante, Schneider et al. (in prep)

(active) BHs in the EM Universe: light seeds



3G-seed team, Mangiagli, Colpi, Valiante, Schneider et al. (in prep)

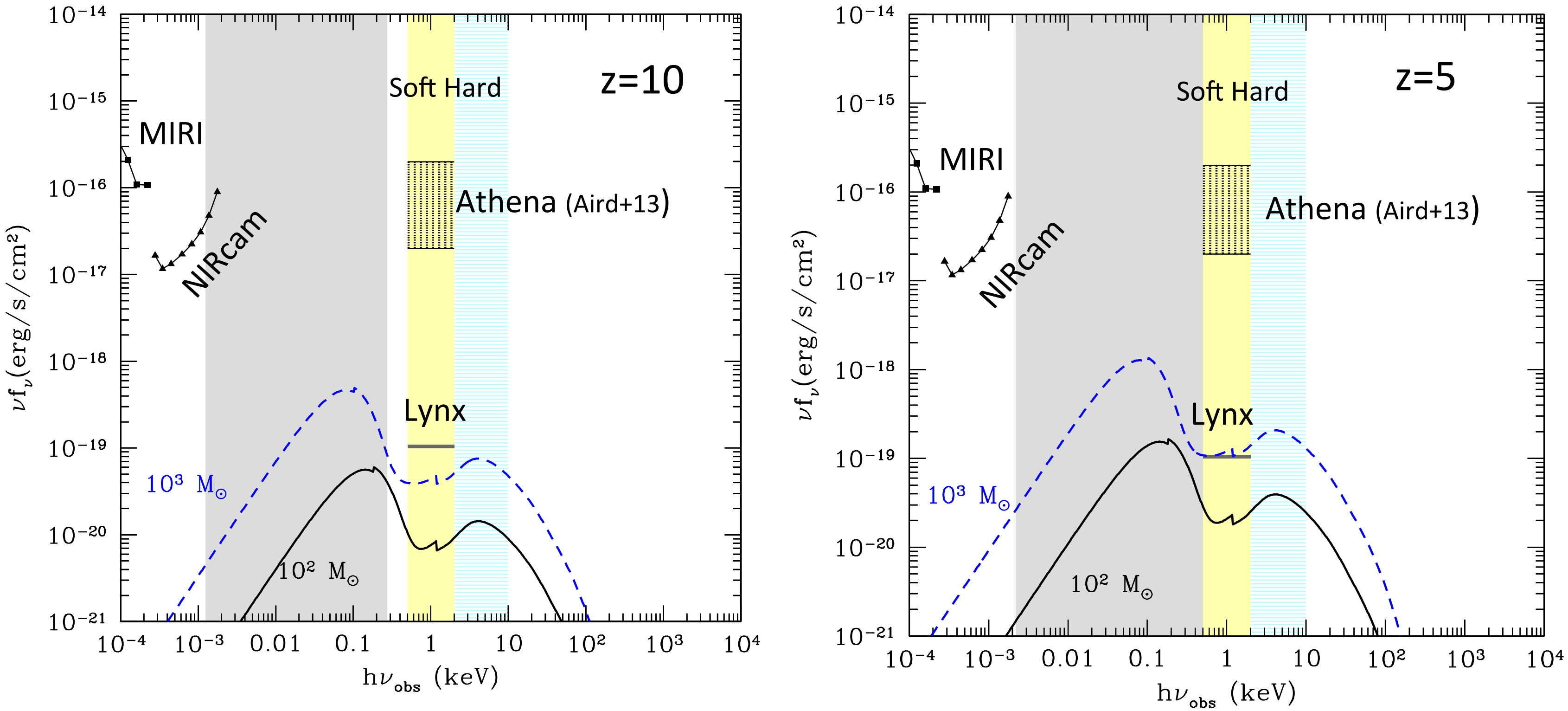
(active) BHs in the EM Universe: light seeds



no accreting light seeds can be detected at z>5 by any EM facility

3G-seed team, Mangiagli, Colpi, Valiante, Schneider et al. (in prep)

(active) BHs in the EM Universe: light seeds



no accreting light seeds can be detected at z>5 by any EM facility
a network of 3G-GW Detectors will be the only instrument that will let us discover light BH seeds (if they exist) forming at cosmic dawn

3G-seed team, Mangiagli, Colpi, Valiante, Schneider et al. (in prep)

Summary

The existence of >10^9 M_{sun} BHs at high redshift implies the formation of lower mass BHs, the "seeds" (10^2-10^6 M_{sun}), and large "cosmological" merger rates already at z>10

These epochs/masses will be accessible to LISA…

LISA will see massive and super-massive BHBs, originating from "heavy seeds" (10^4-10^8 M_{sun}) already at z=15

… and 3G GW observatories

3G GW ground-based detectors will reveal the less massive ones, originating from "light seeds" (10^2-10^3 M_{sun})

Forthcoming and next-gen. facilities, like ATHENA, JWST and Lynx (if in operation), will unveil the dawn of galaxies and accreting (massive) BHs

only 3G GW observatories will be able to discover the lightest (coalescing) early BHs