lisa

GWs from the first BHs

growing cosmological BH binaries from the earliest BHs

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Alberto Mangiagli *(Milano-Bicocca), Federica Sassano (Roma1/INAF-Roma)…*
& the AstroBlack-Italy Group

AstroBlack-Italy Group

Scientific Leaders

AstroWG-Dynamics: Monica Colpi (Milano-Bicocca)
AstroWG-X: Francesco Haardt (Insubria-Como)
AstroWG-EM: Giuseppe Lodato (Milano University)
AstroWG-Catalog: Rosa Valiante (INAF-Roma)

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Primary Science goals

1. Studies of Supermassive Black Holes (SMBHs) and connection to galaxy clustering
2. Studies of seed BHs and their formation mechanisms
3. Analysis of Joint EM+GW SMBH Binary events
4. Studies of stellar BH populations
5. Connection to AGN activity and galaxy mergers

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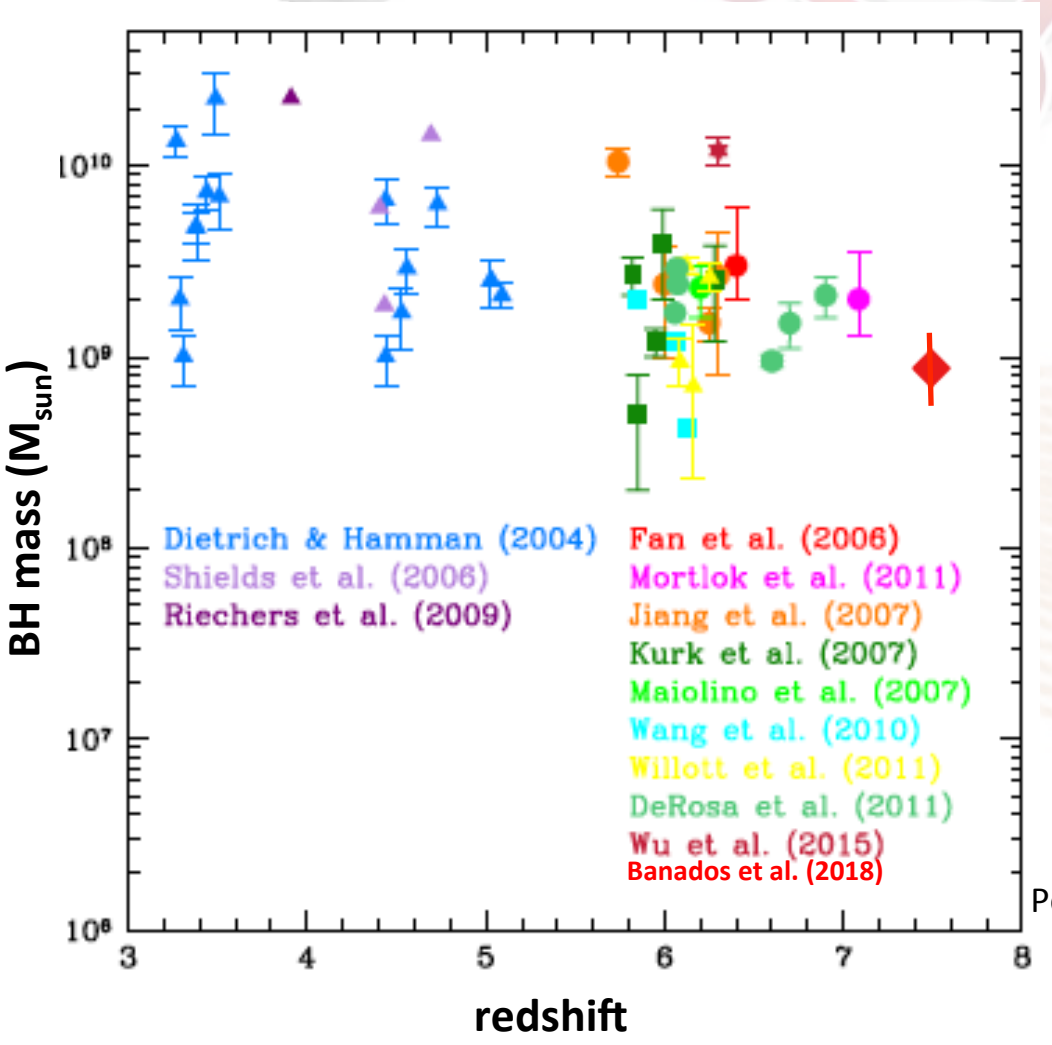
AstroWG-Catalog project

This project aims at contributing to WP8, WP6 and WP5 of the LISA-DAWP document
First goal: this WG commits to deliver a catalog of cosmological BHBs that will produce a mock catalog of waveforms to be injected in pipelines to simulate the LISA sky

Our key questions

When do the first black hole binaries form in the Universe?
Which is the mass (and spin) of the first BHs?
Are the BHs detected at high redshift the “seeds” upon which SMBHs form?

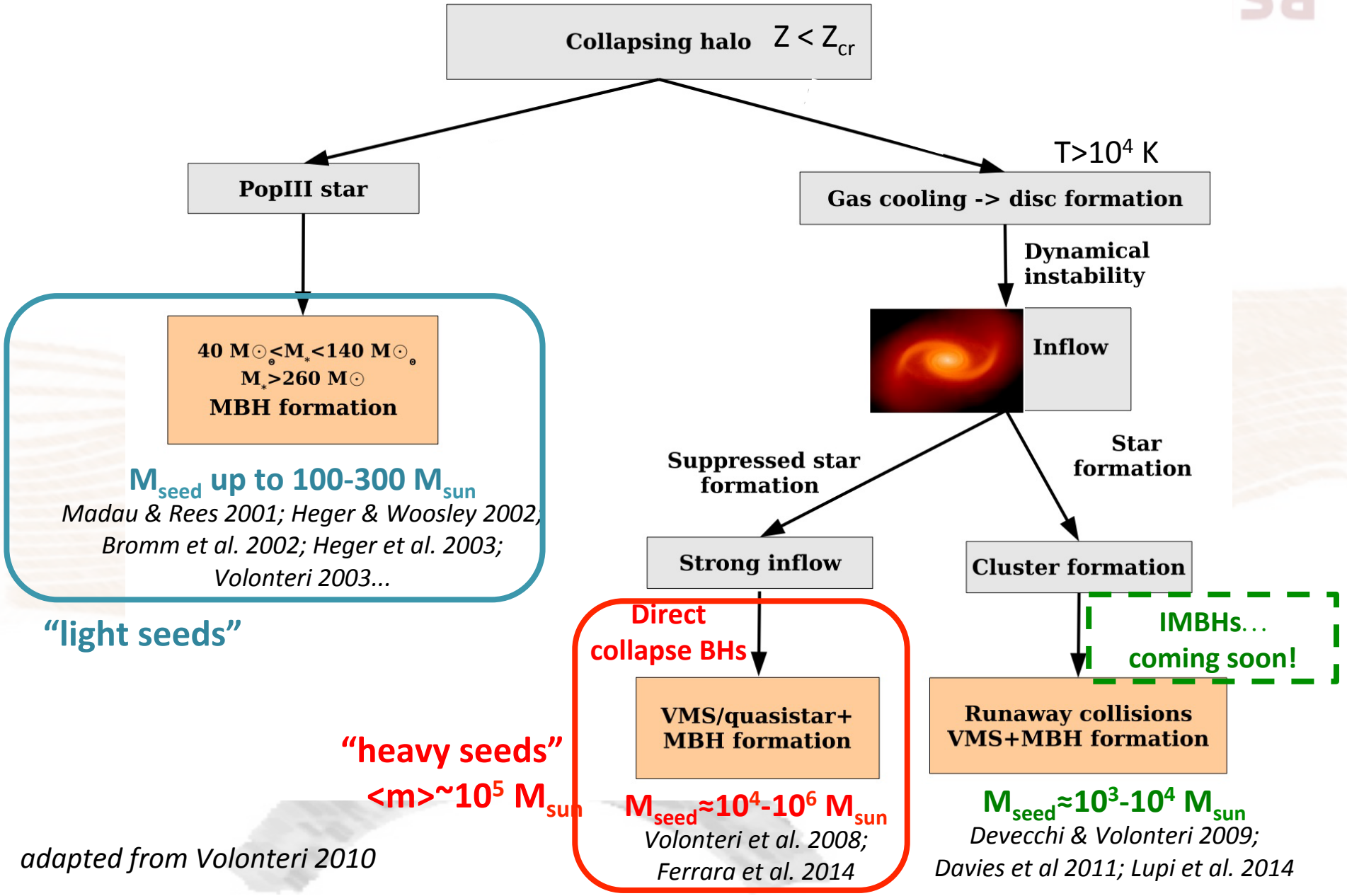
the first (supermassive) black holes



RV, Agarwal, Habouzit, Pezzulli, 2017, PASA revie*w*

The first step toward the BHB catalog: modeling the build-up the first SMBHs tracing seed evolution and BH binaries along the hierarchical assembly of high-z galaxies

how do the (first) BHs form in the Universe?



semi-analytical approach: *GAMETE/QSOdust* (GQd)

data-constrained model + statistical power

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

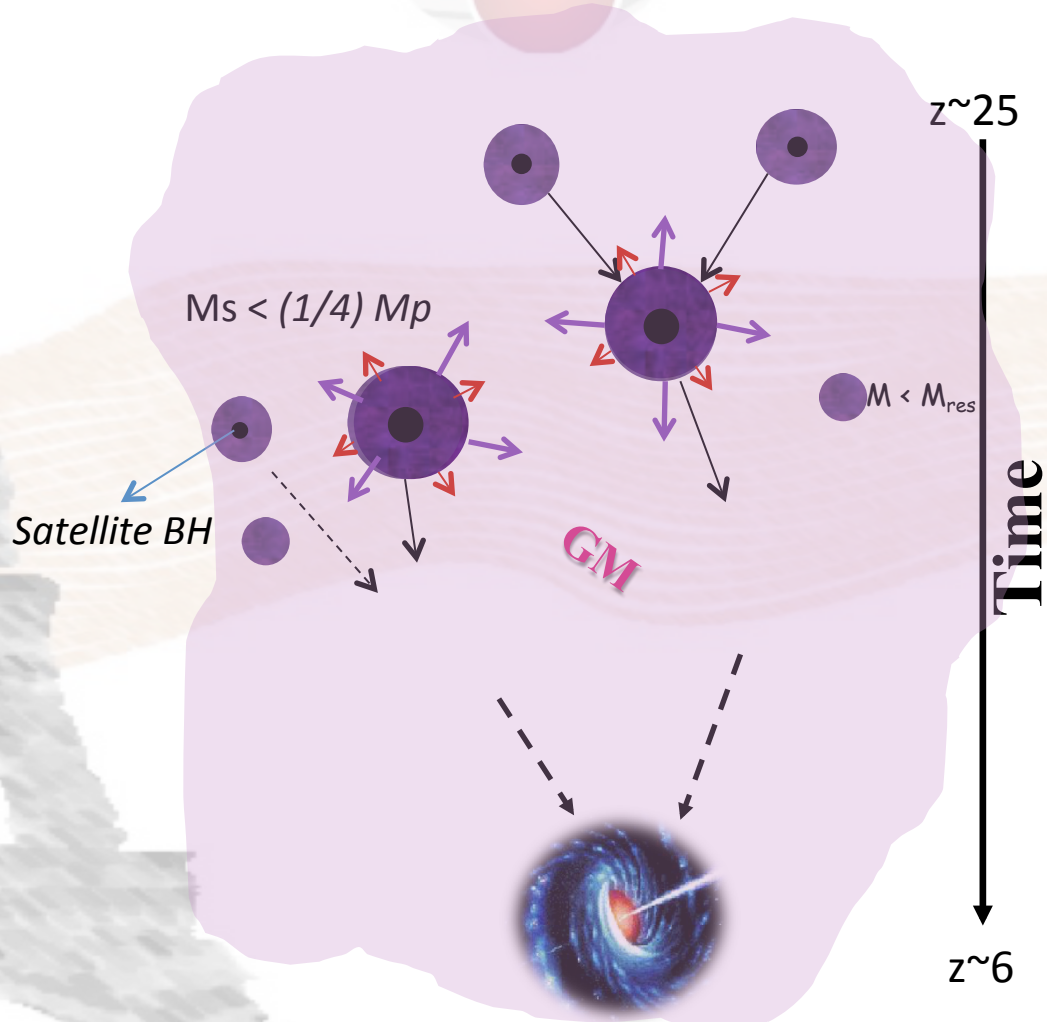
seed BHs formation:
Pop III remnants & DCBHs

BH growth:
Eddington-limited accretion and mergers

mechanical feedback:
BH/SN energy-driven winds

chemical feedback:
dust and metals enrichment

radiative feedback:
stellar and AGN UV emission

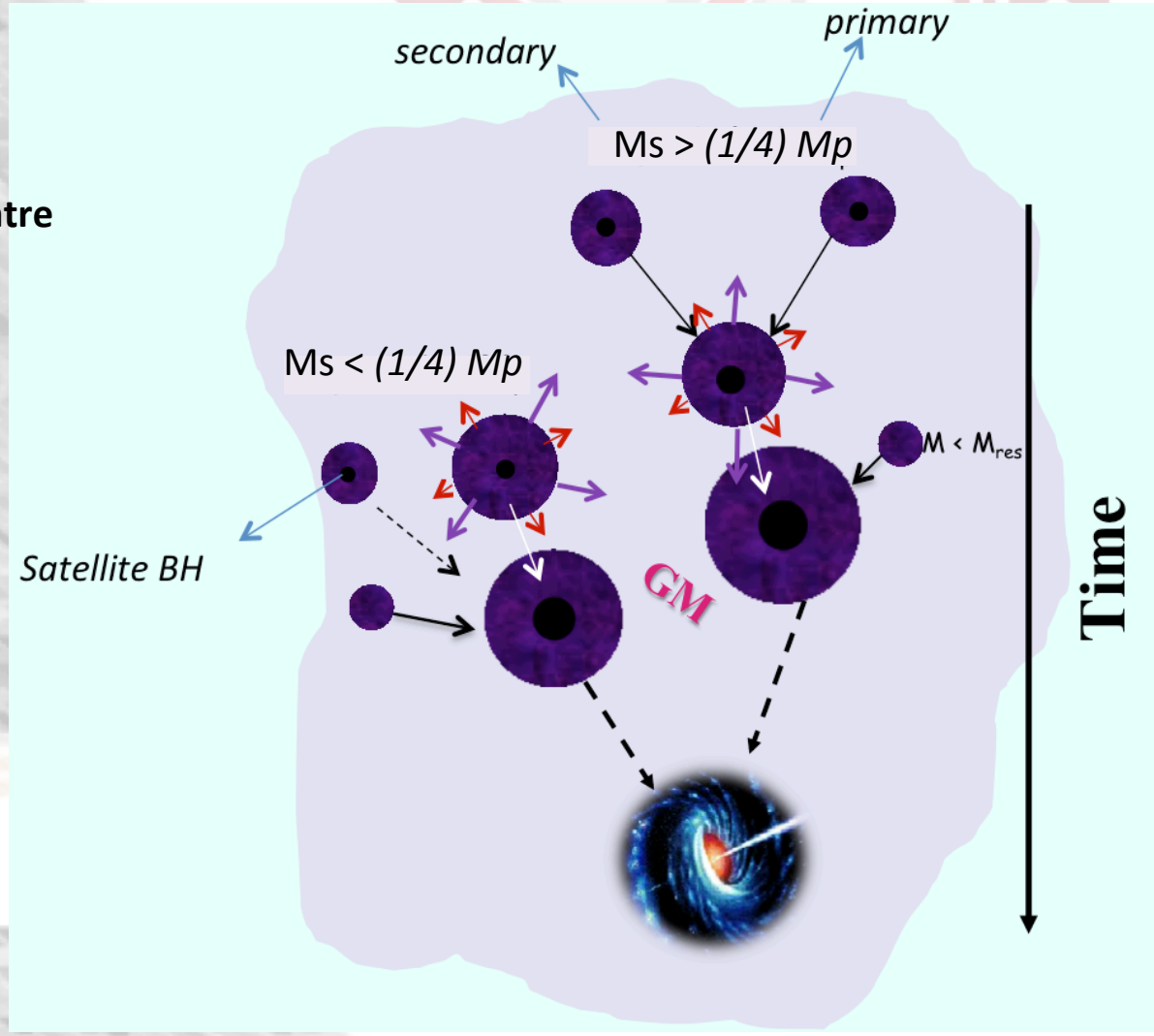


Valiante et al. 2011, 2012, 2014,2016, 2018a,b
Pezzulli, et al. 2016, 2017a,2017b

forming the first BHs in GQd

LIGHT SEEDS

form in metal poor H_2 ($10^{6\text{-}7}$ M_{sun})
and atomic cooling halos ($10^{7\text{-}8}$ M_{sun})
at z>15
The most massive one settles in the centre



RV, Schneider, Volonteri, Omukai. 2016

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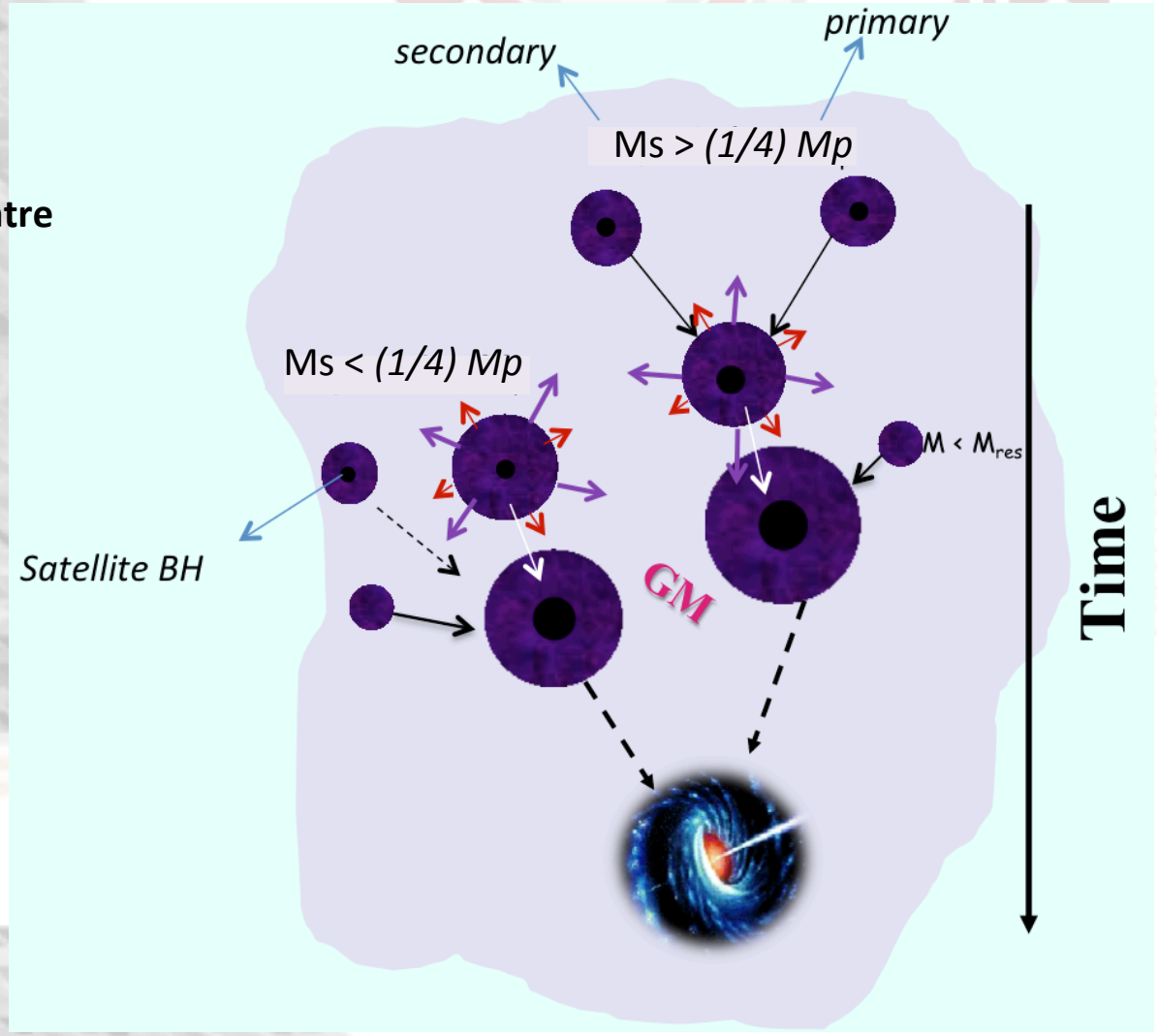
The most massive one settles in the centre

HEAVY SEEDS

form in metal poor atomic cooling halos ($10^{7\text{-}8}$ M_{sun}) when $J_{LW}>J_{cr}$ at 15<z<17

we assume $m_{HS}=10^5$ M_{sun}



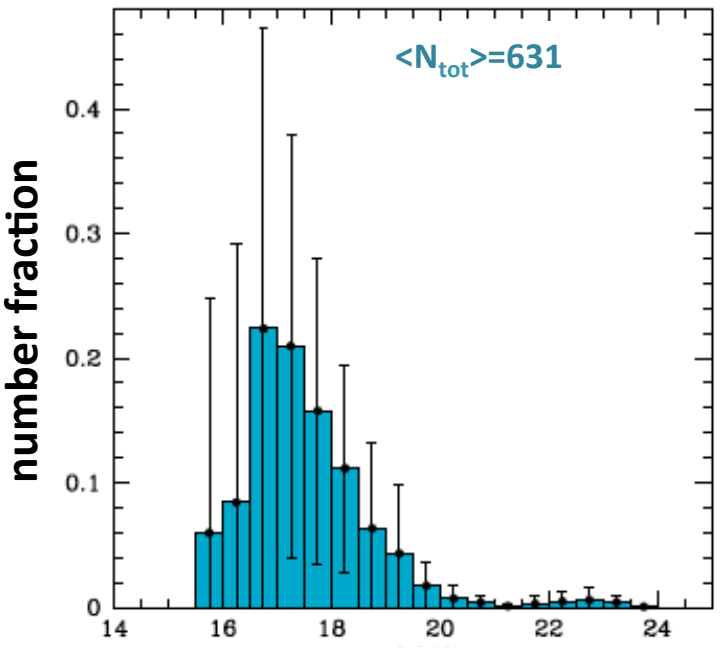
RV, Schneider, Volonteri, Omukai. 2016

light and heavy seeds of a z~6 SMBH

The properties of seeds birth environments are regulated by chemical and radiative feedback

(only final BH progenitors are considered, i.e. no satellite BHs)

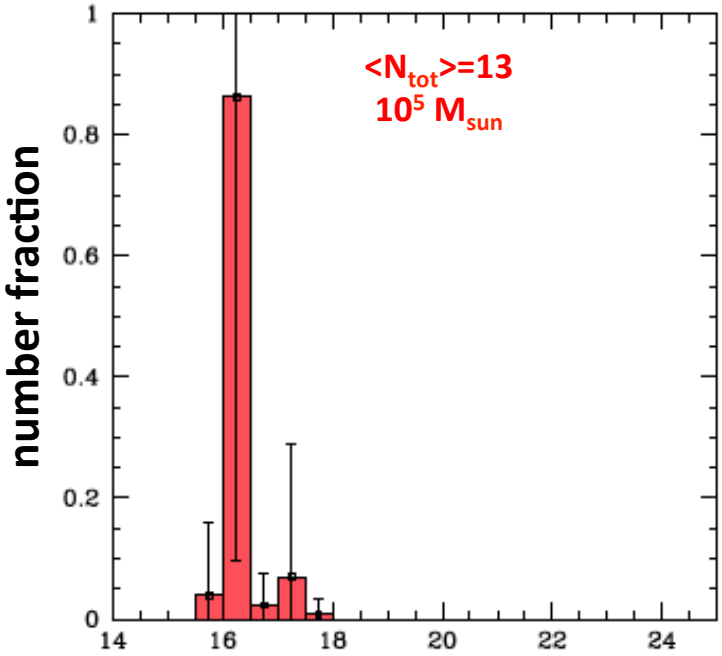
Light seeds number fraction



Light seeds start forming at z≈24 with a peak at z≈17

LS formation stops at z≈15.5 when $Z_{ISM}>Z_{cr}$

Heavy seeds number fraction



Heavy seeds form in a narrow redshift range >80% at z≈16.5 (rare birth environments)

RV, Schneider, Volonteri, Omukai. 2016

the first "cosmological BH binaries" in GQd

LIGHT SEEDS
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and atomic cooling halos (10^{7-8} M_{sun})
at z>15
The most massive one settles in the cent

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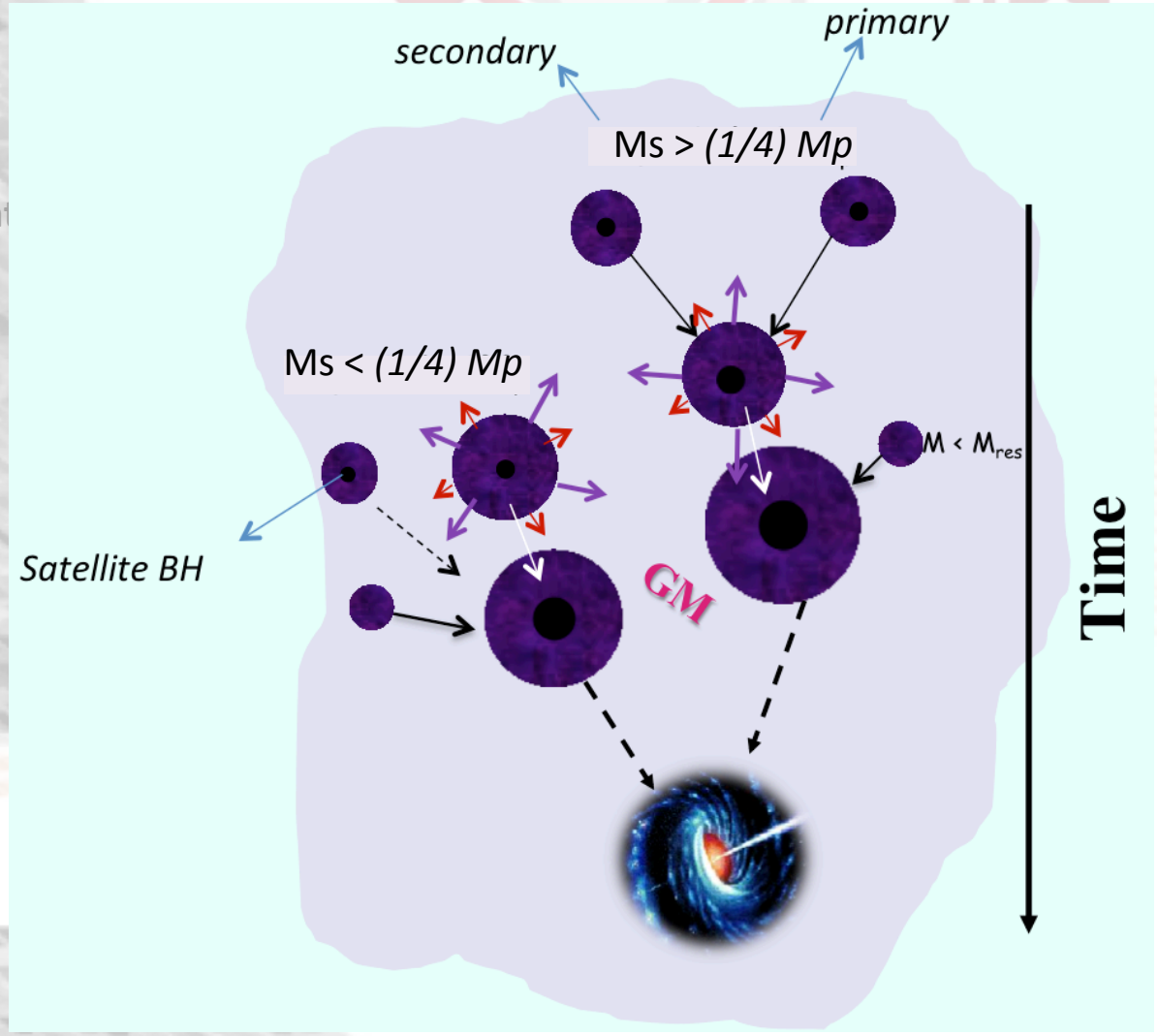
at 15<z<17
we assume $m_{HS}=10^5$ M_{sun}

seeds growth
Eddington-limited accretion and mergers

BH binaries formation
In halo-halo major mergers coalescence over ~0.1-2 Myrs

some of these BHs will end up in the SMBH by z~6



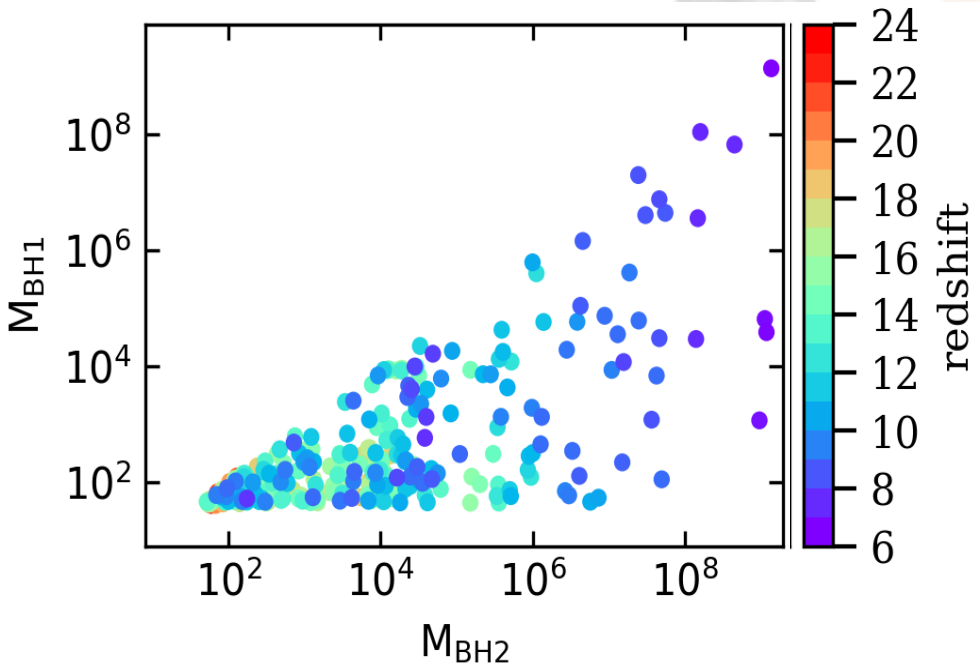
RV, Schneider, Volonteri, Omukai. 2016

the earliest coalescing BHs

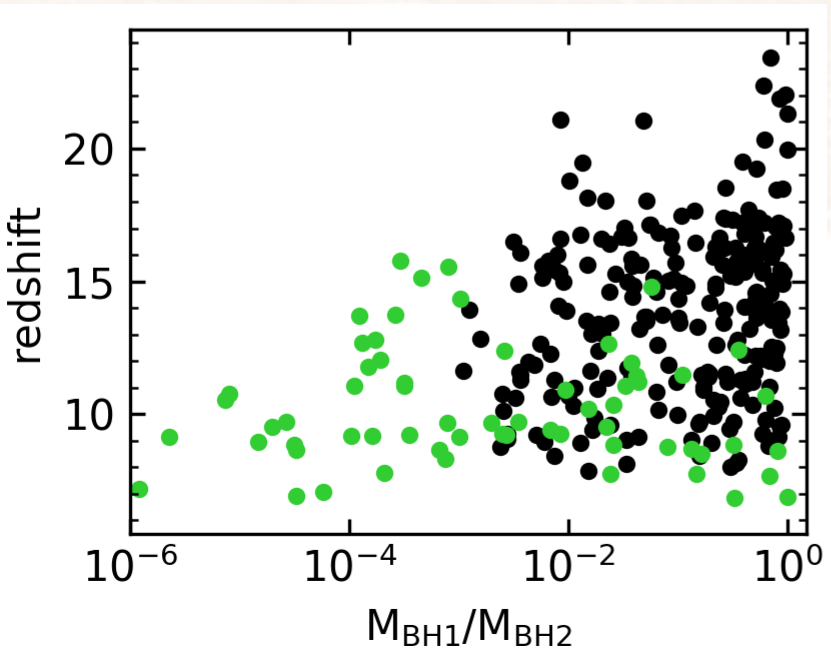
data-constrained model (GQd): forming a >10^9 M_{sun} BH @ z=6 in 10^{13} M_{sun} DM halos

All BH pairs forming in halo-halo major mergers (halo mass ratio >0.25)
one single z~6 galaxy merger tree out of 10 realisations
NB: the redshift indicates the BHBs formation epoch

BH mass



BH mass ratio

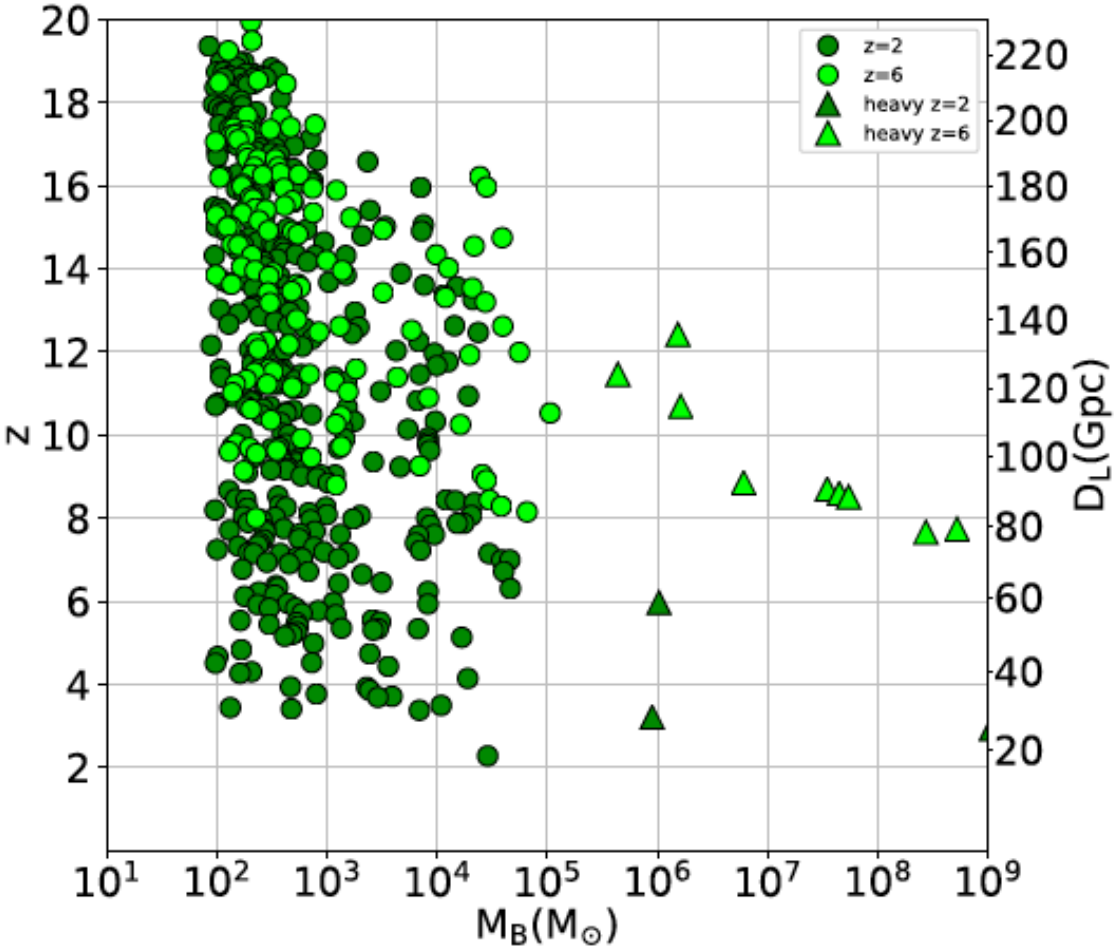


BHs in the cosmological framework

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

BH binaries forming from growing light & heavy seeds

BH Binary formation epoch



merging DM halos
mass ratio > 0.25

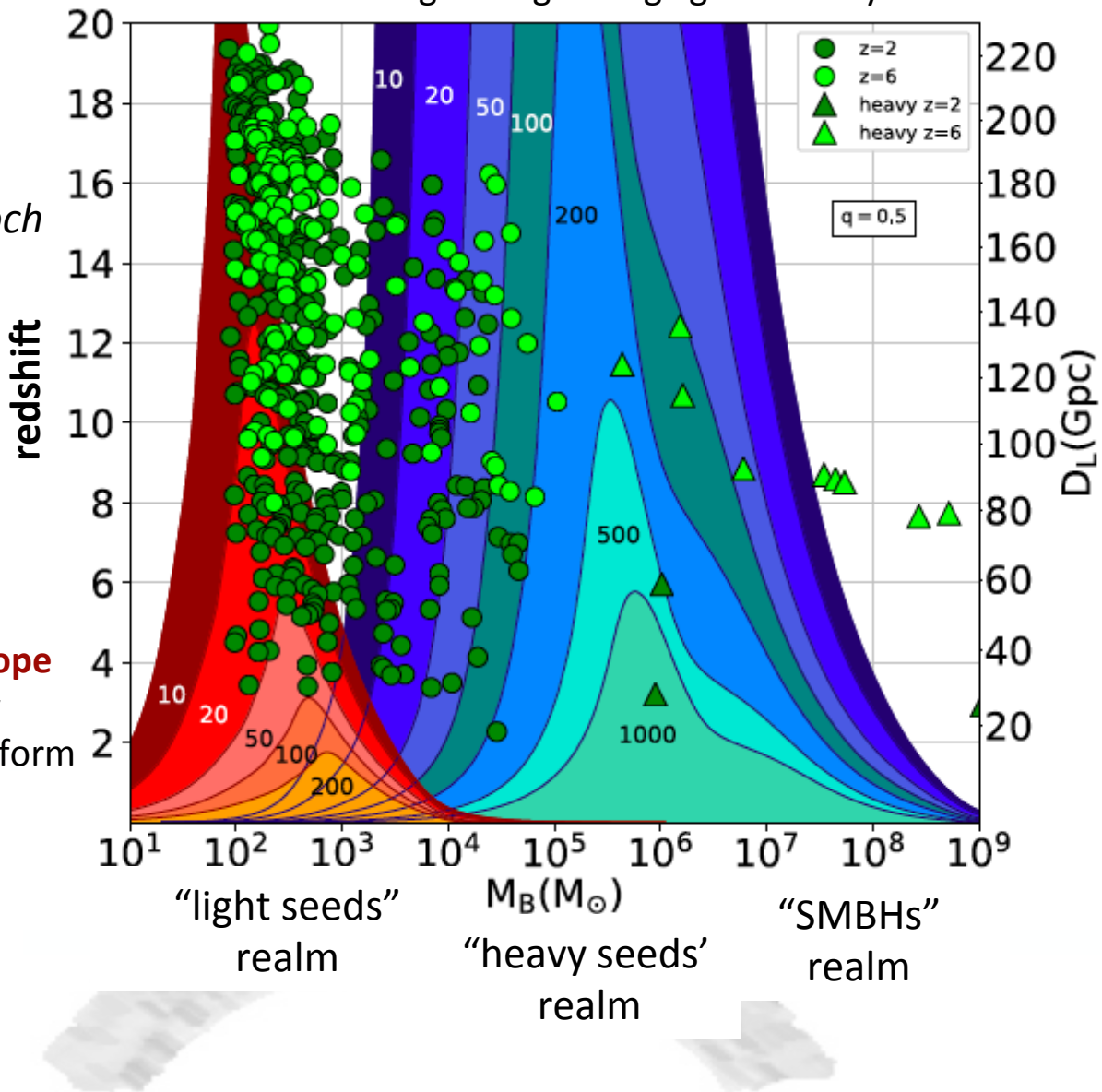
"Cosomological BH binaries"

BHs forming in pristine/metal poor halos and pairing during halo-halo mergers

Black Holes in the Gravitational Universe

BH binaries forming from growing light & heavy seeds

BH Binary formation epoch



z=2
z=6
heavy z=2
heavy z=6

merging DM halos
mass ratio > 0.25

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

LISA
nsitivity curve (q=0.5)
ntamaria et al (2010)

Future prospects

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>10-15

How about "in situ" binaries formation? → AstroWG-Dynamics

<u>These epochs/masses will be accessible to LISA</u>

LISA will see the "heavy seeds" (10^3-10^6 M_{sun}) and the SMBHs (10^7-10^8 M_{sun}) already at z=20

<u>Synergy with 3rd generation GW observatories</u>

3G GW ground-based detectors will reveal "light seeds" (10^2-10^3 M_{sun}), if they exist

LISA+ET will enable to discriminate at statistical level if light seeds contribute significantly to the early growth of supermassive black holes at z~6-7

<u>Multi-messenger (observational) strategies</u>

BH binaries GW source catalog + predicted observational features of accreting BHs/hosts galaxies

SEDs: optical/IR/X-ray emission to support searches for EM counterparts →AstroWG-X and AstroWG-EM in view of the current facilities (e.g. ALMA, SUBARU) and future missions (e.g. JWST, ATHENA, Lynx)