Cosmic Explorer Symposium, April 23 - 25 2024

STRUCTURES
CLUSTER OF
EXCELLENCE

Compact Binaries with Next-Generation GW Detectors

Michela Mapelli

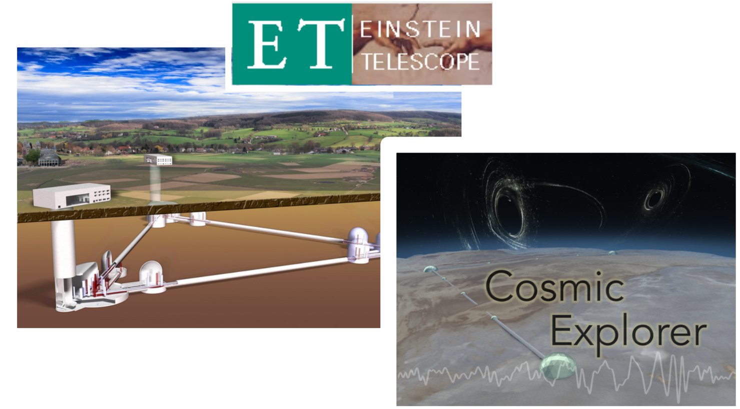
Heidelberg University

Daniel Holz

University of Chicago

Main collaborators: M. Celeste Artale, Yann Bouffanais, Guglielmo Costa, Marco Dall'Amico, Gaston Escobar, Giuliano Iorio, Erika Korb, Elena Lacchin, Benedetta Mestichelli, Carole Périgois, Sara Rastello, Stefano Rinaldi, Filippo Santoliquido, Cecilia Sgalletta, Stefano Torniamenti, M. Paola Vaccaro

1. Laying the ground

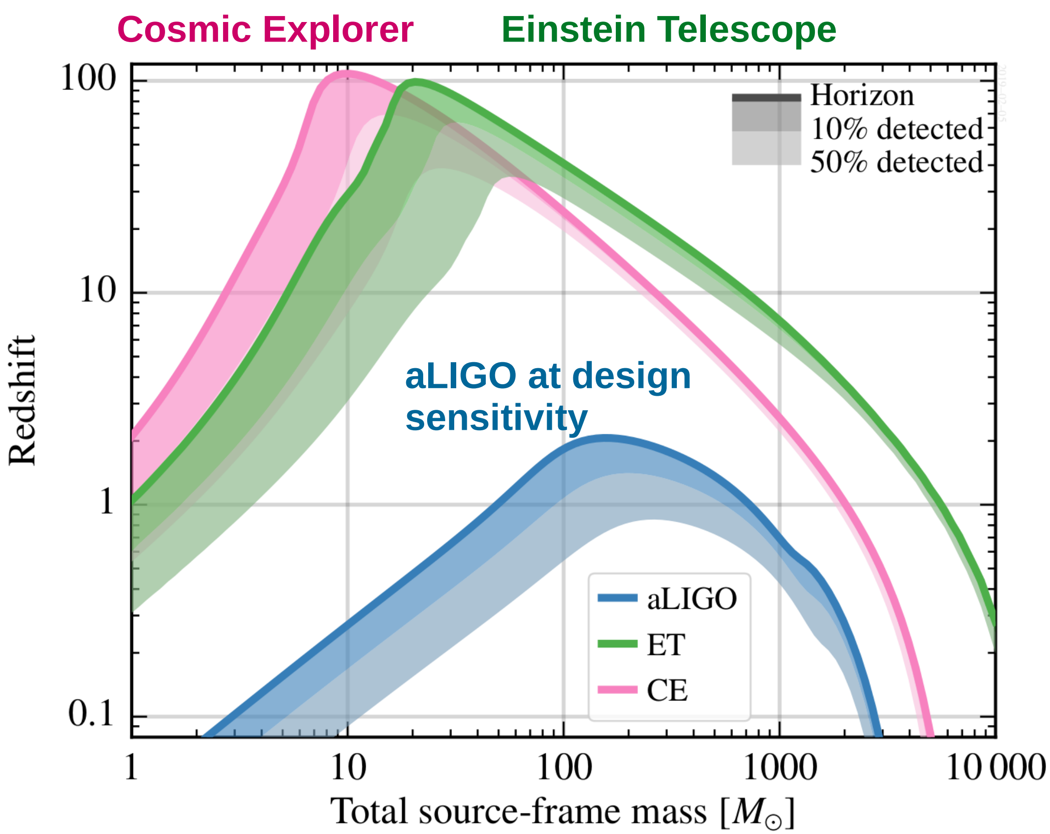


BBH mergers up to z ~ 100

O(200) BBH detections every day
(now 1 every ~3 days)

O(10^3) BBHs with signal-to-noise ratio SNR > 100
(0 with current detectors)

Intermediate-mass black holes (IMBHs) 10^2 – 10^4 Msun
state-of-the art: merger remnant of a few LVK events >10^2 Msun

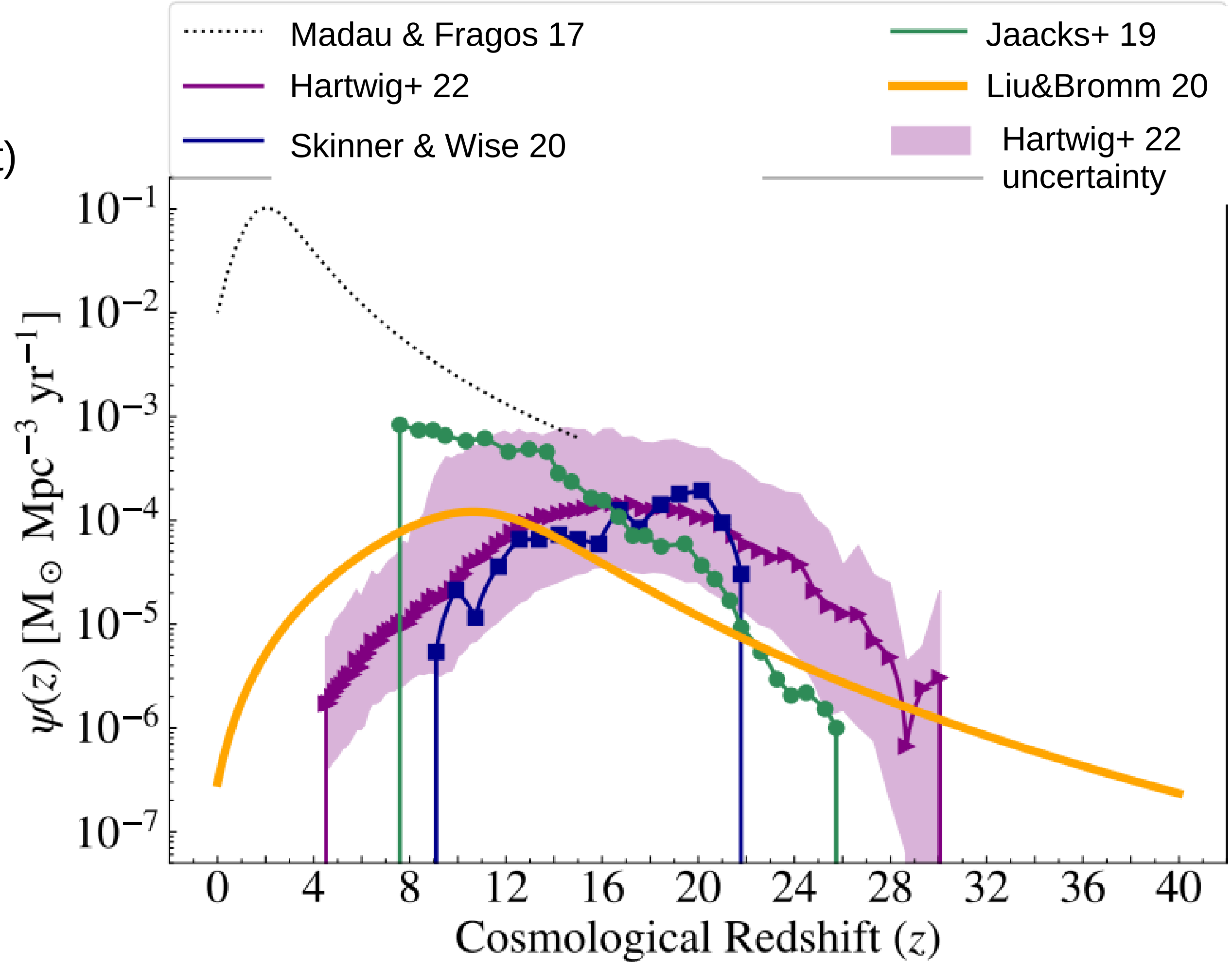


Maggiore+ 2020; Kalogera+ 2021; Branchesi+ 2023

2. What do we expect to find at high redshift? Population III stars

Population III stars:

- Form from **zero-metallicity** gas (H, He, some Li)
- We have **NOT** observed them (yet)
- Their formation rate is uncertain



Santoliquido, MM et al. 2023

Klessen & Glover 2023, for a review

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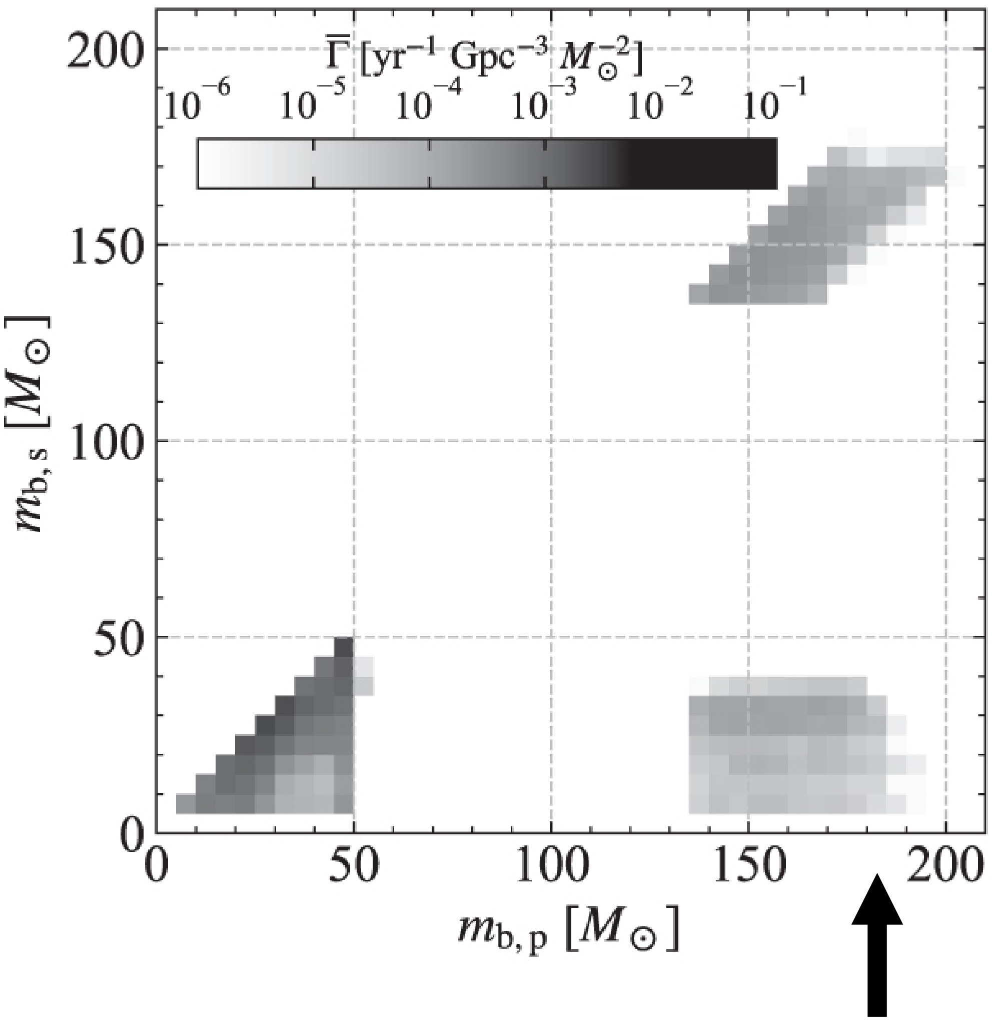
Tanikawa et al. 2021



If Pop III stars evolve with compact radii, many BBH mergers above the mass gap, in the IMBH regime

Tanikawa et al. 2024
Santoliquido, MM et al. 2023
Costa, MM et al. 2023
Tanikawa et al. 2022
Tanikawa et al. 2021
Liu & Bromm 2020
Kinugawa et al. 2016
Hartwig et al. 2016
Kinugawa et al. 2014

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Mestichelli, MM, et al., in prep.

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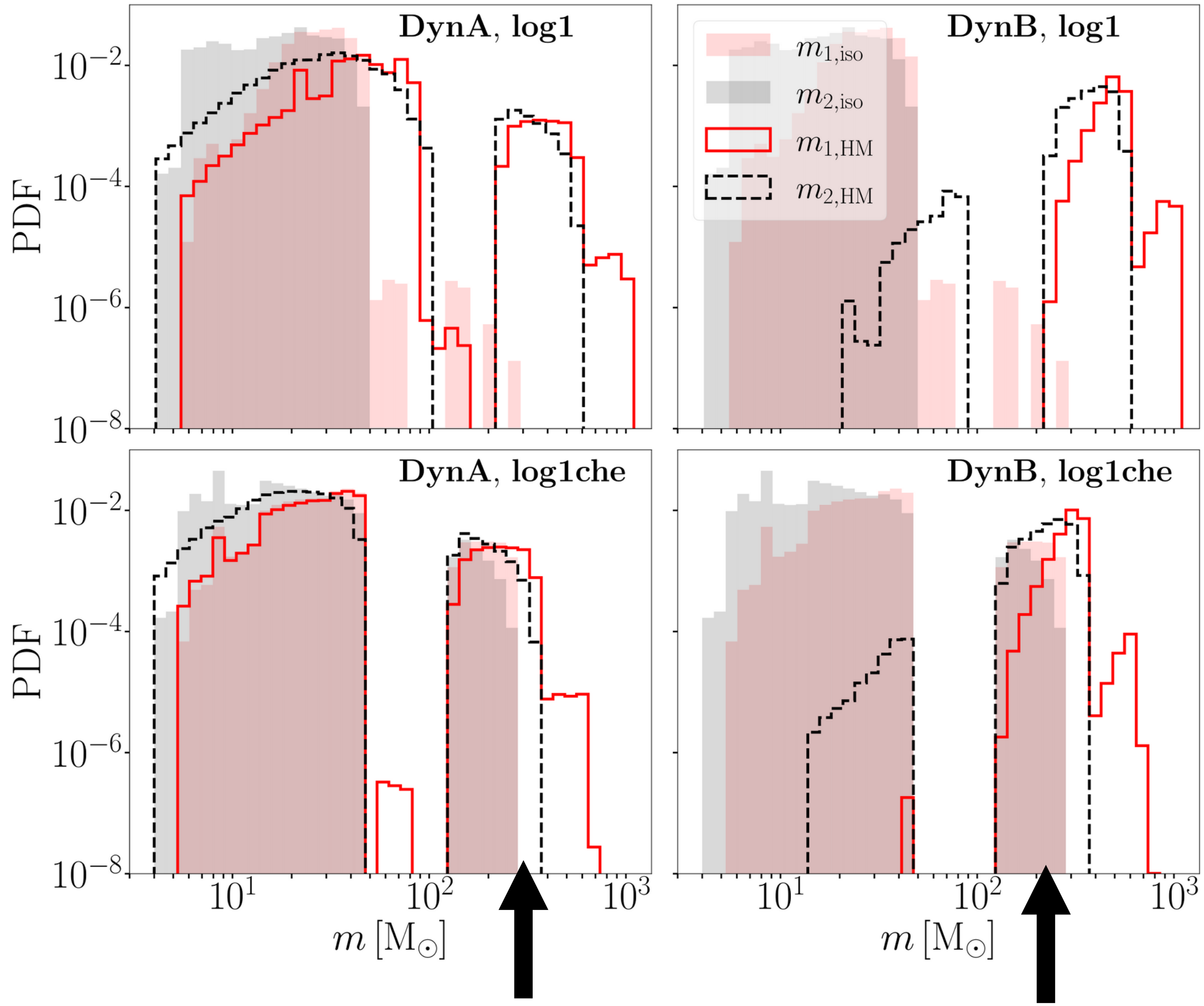

If Pop III stars form in star clusters, many BBH mergers above the mass gap, in the IMBH regime

Tanikawa et al. 2024
Santoliquido, MM et al. 2023
Costa, MM et al. 2023
Tanikawa et al. 2022
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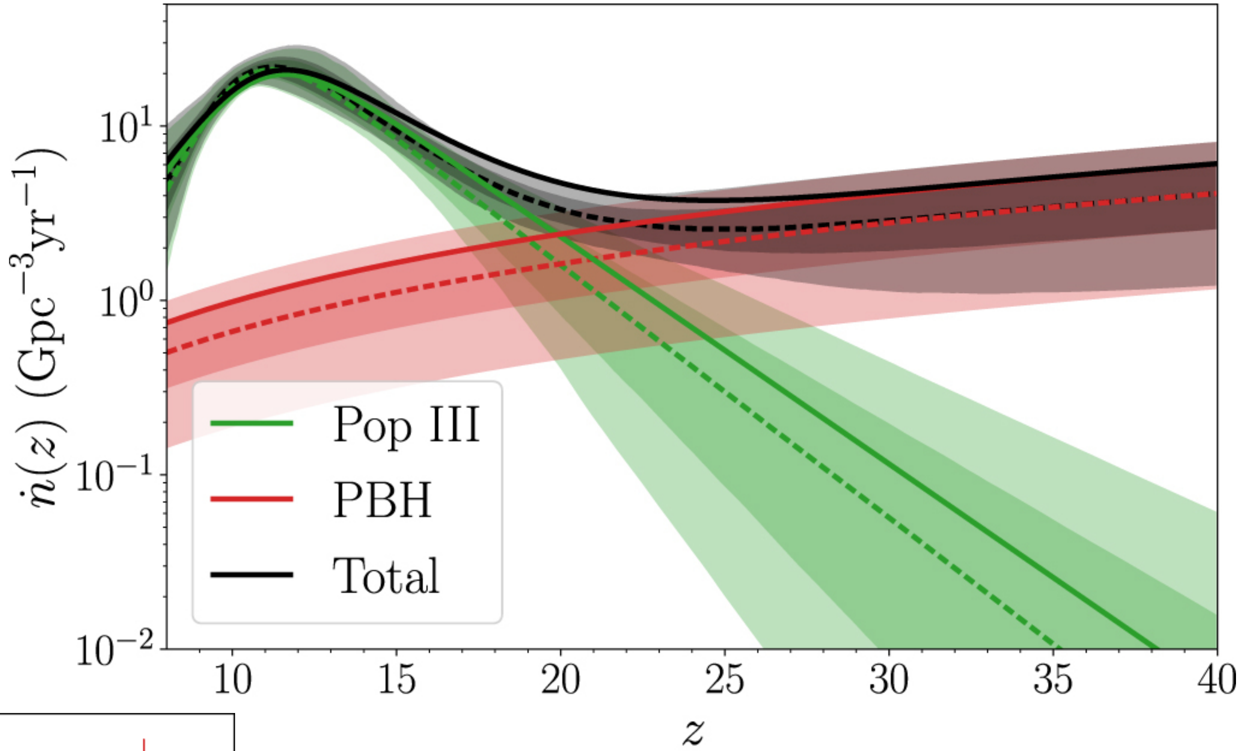
3. What do we expect to find at high redshift? Primordial BHs

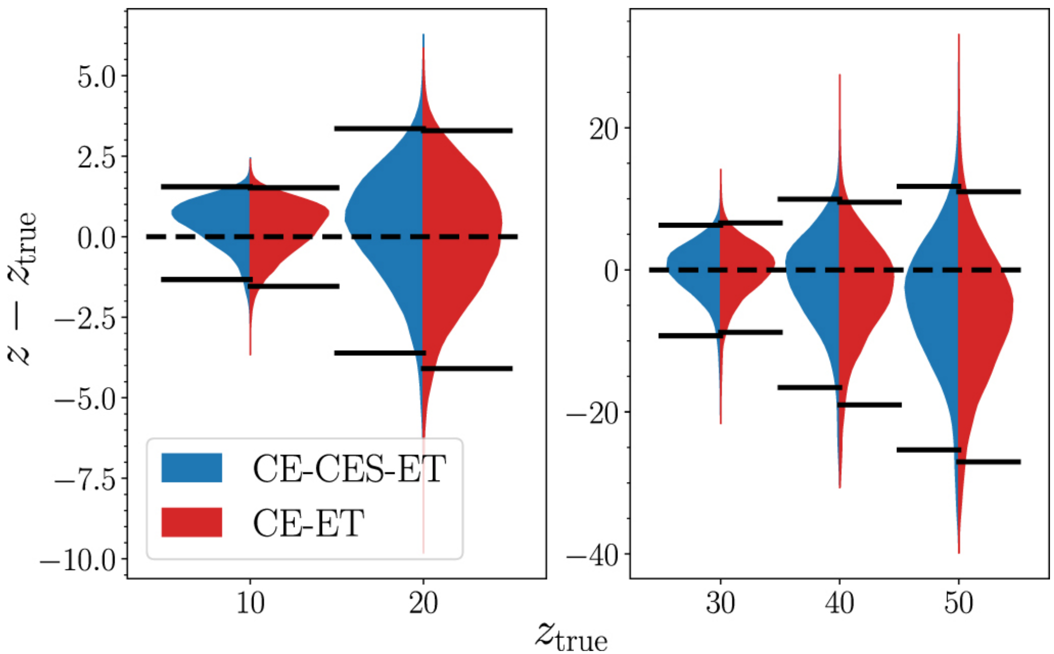
Primordial BHs:

- Collapse of gravitational instabilities in the primordial Universe (Hawking 1971; Carr & Hawking 1974; Sasaki et al. 2018 for a review)

- Unlike Pop III BBHs, their merger rate should increase monotonically with redshift
  → we should be able to disentangle the two populations



Ng et al. 2022a



Ng et al. 2022b

- smoking gun: a single event at z>40, but need CE+ET

4. Why should we care for intermediate-mass BHs (IMBHs)?

IMBHs:

- Almost unavoidable step to form super-massive BHs (SMBHs)

- Evidence for SMBHs already at z~ 11 (JWST, Maiolino et al. 2024)

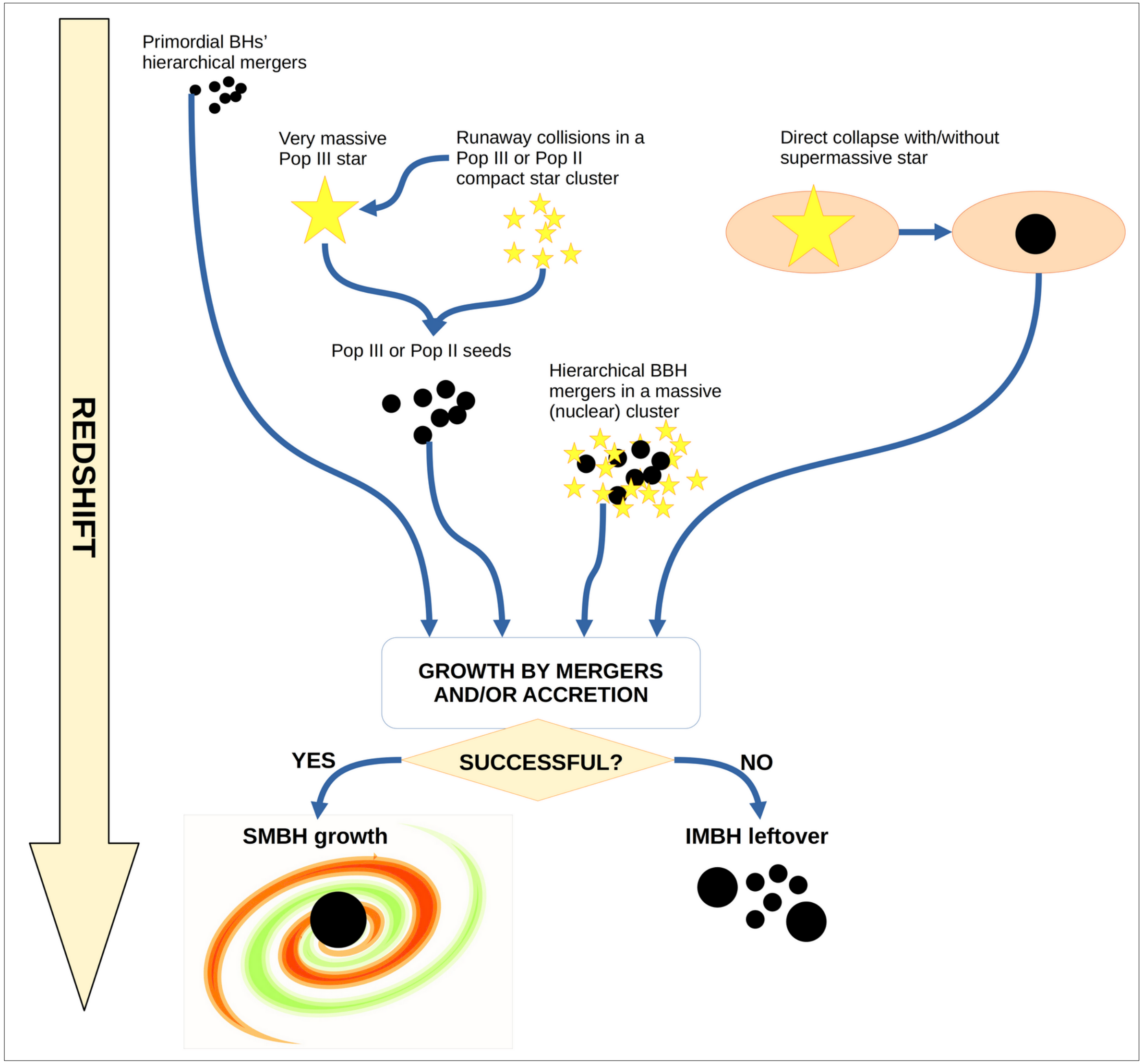
- Electromagnetic observations of IMBHs are scanty (nearly impossible to observe a $10^{3\text{-}4}$ Msun IMBH at high z)

- First detection of IMBHs by LVK: GW190521 (Abbott et al. 2020a, 2020b)

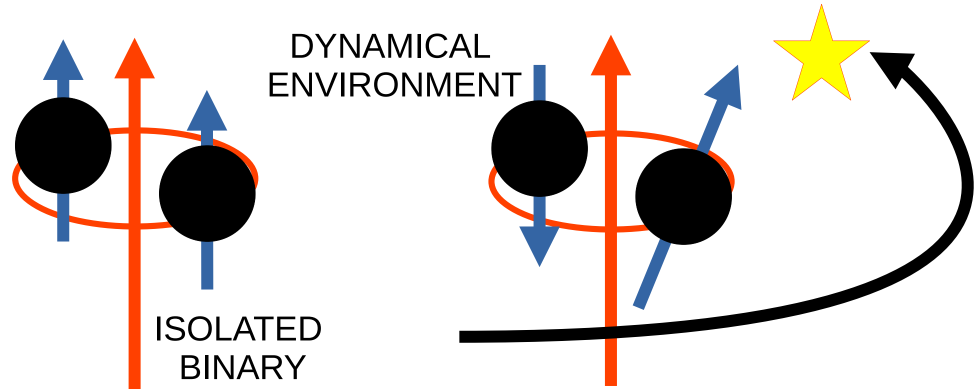
Much better at lower frequency: CE + ET

complementary to LISA

See Volonteri et al. 2021 for a review

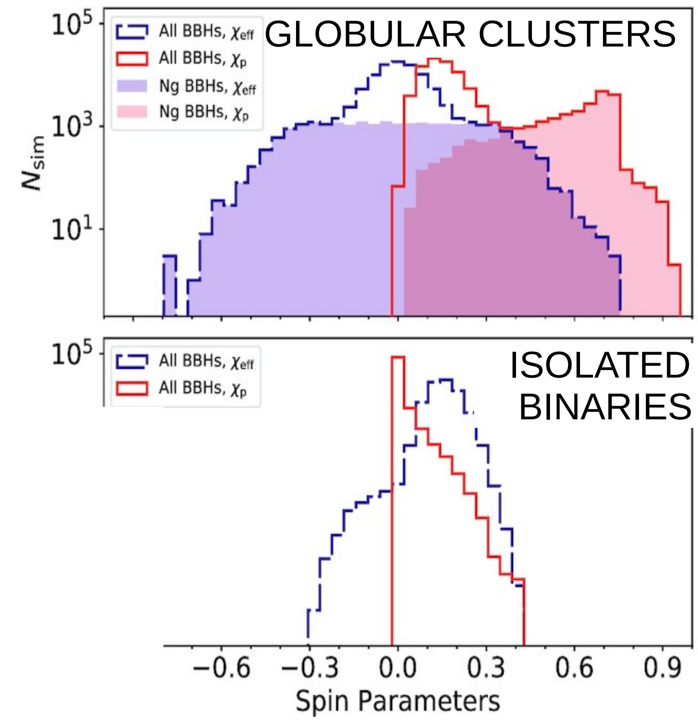


5. What is the advantage of nearby events with SNR>100?



Formation channels of BBHs:

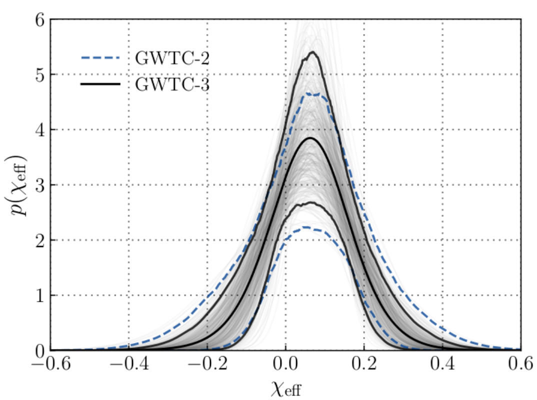
- Spin information is crucial to disentangle formation channels
- Redshift evolution of mass and/or spin?
- Golden binaries to probe astrophysics scenarios



Abbott et al. 2023

Bavera et al. 2022

MM et al. 2022



6. Summary and discussion

Next generation GW detectors & CBCs:

- discover and characterize Pop III stars thanks to their black holes?

- get a smoking gun of primordial black holes?

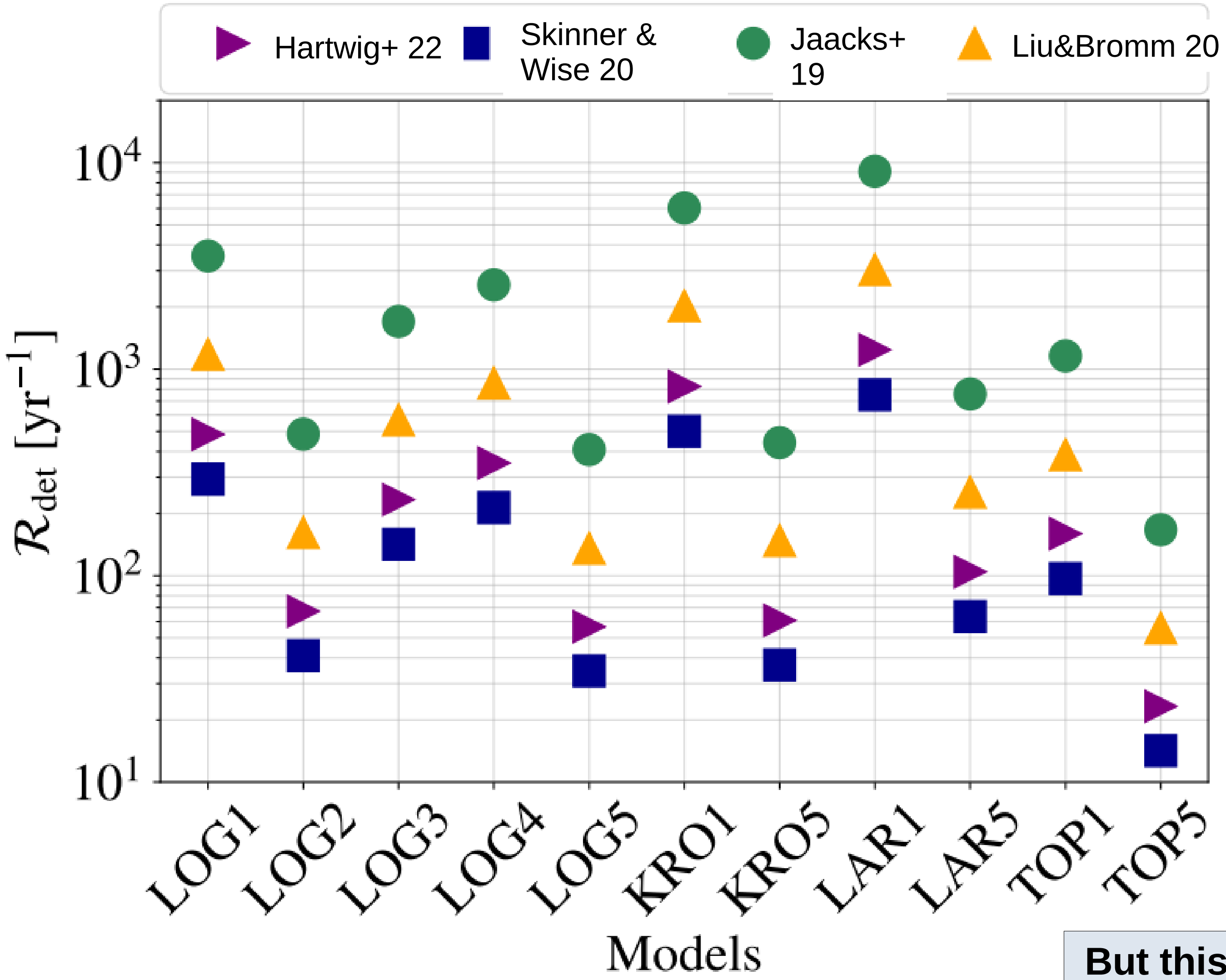
- probe the missing link between stellar-sized and super-massive black holes?

- disentangle the dynamical and isolated BBH scenarios?

QUESTIONS!

2. What do we expect to find at high redshift? Population III stars

Detection rate of Pop. III BBHs with Einstein Telescope only



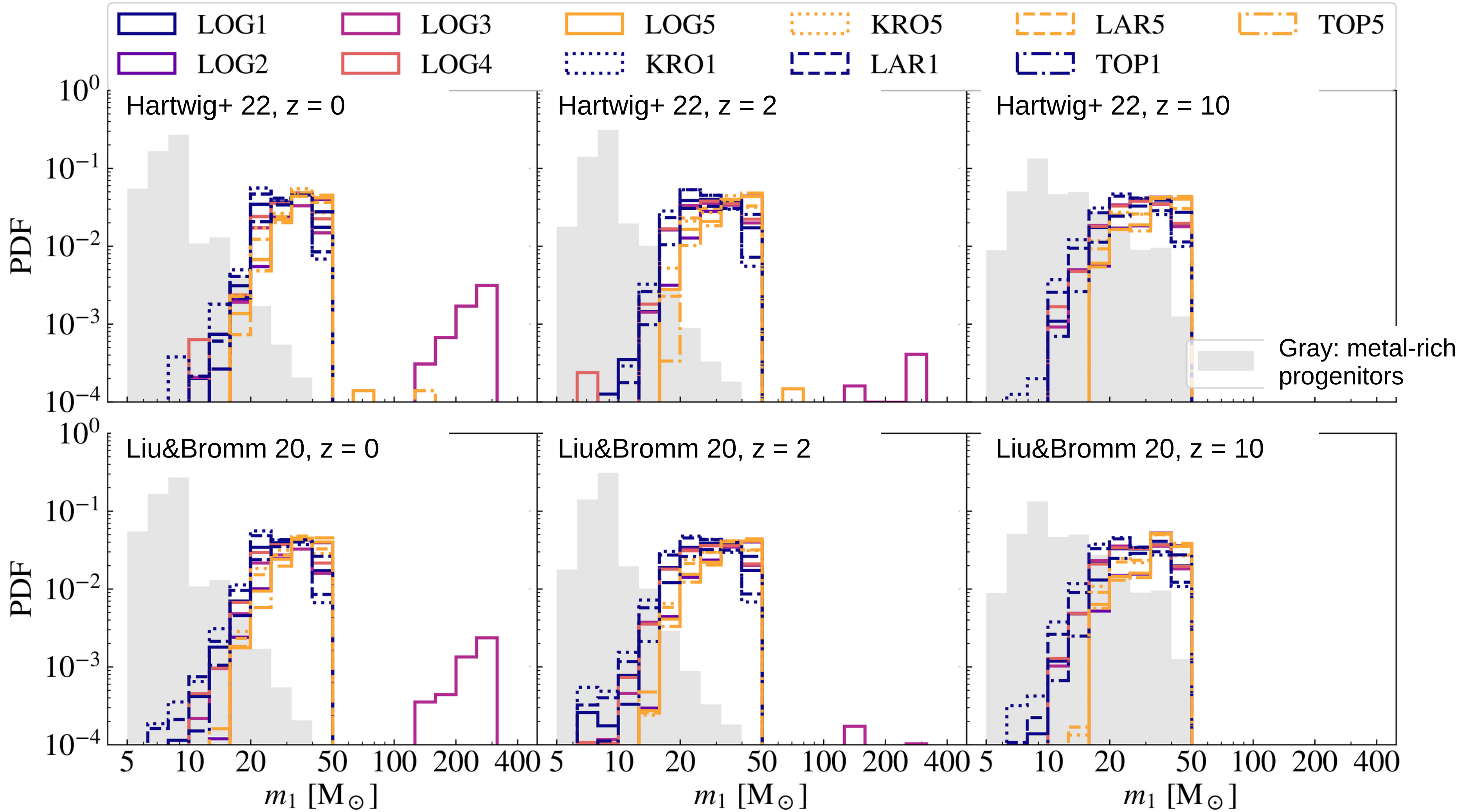
Santoliquido, MM et al. 2023

But this does not mean that we know they are Pop. III BBHs

4. BHs from Pop. III stars and the Einstein Telescope

Mass of Pop. III BBHs peak at 30 – 40 M⊙
Mass of Pop. I BBHs peaks at 8 – 10 M⊙

Evolution with metallicity implies evolution with redshift



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