Searching for a population of Primordial Black Holes with the ET

Mostly based on [arXiv:2304.03160]

with F. Iacovelli, M. Mancarella, M. Maggiore, P. Pani, A. Riotto

+ COBA

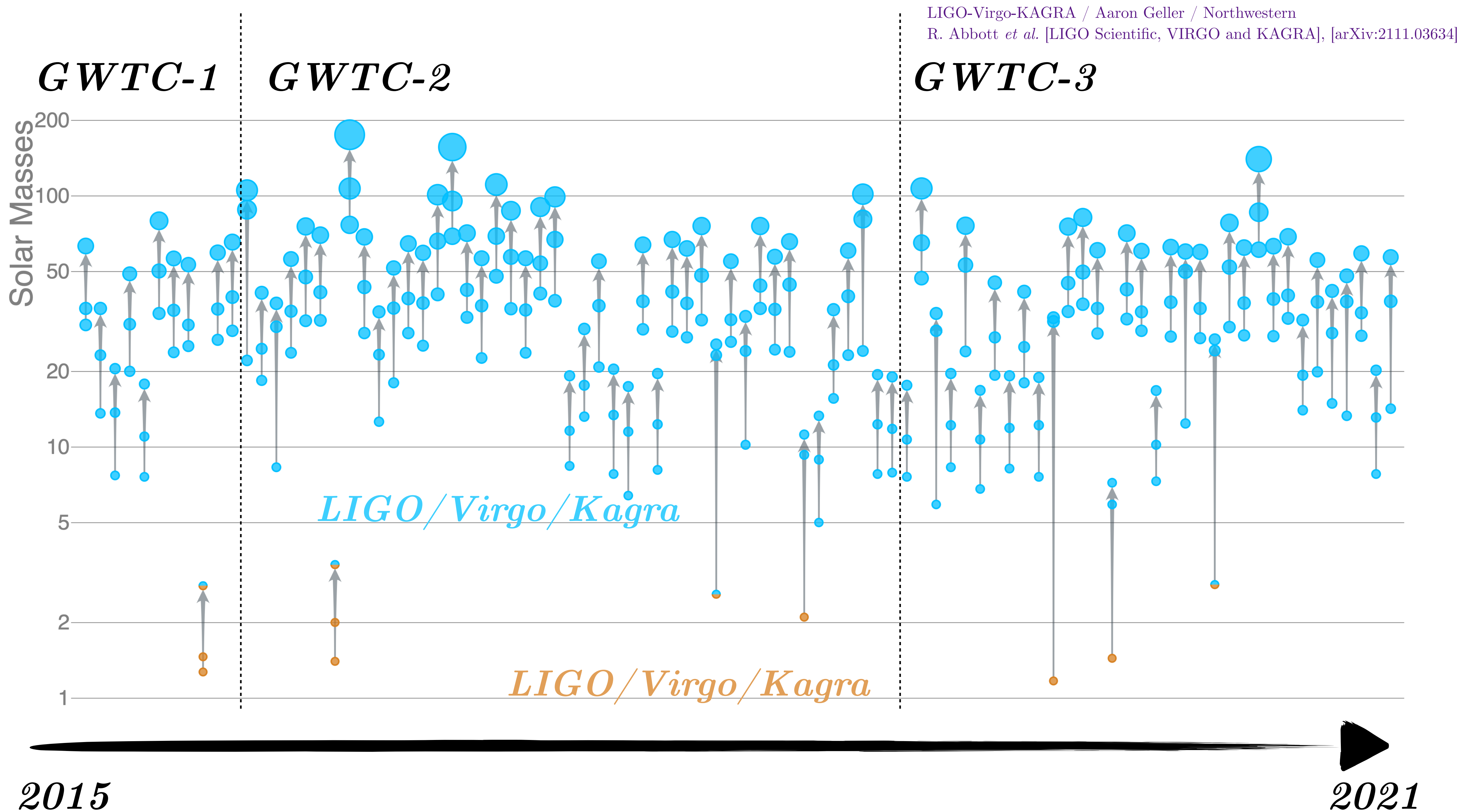
Gabriele Franciolini

XIII Einstein Telescope Symposium - Cagliari

8-12/05/2023

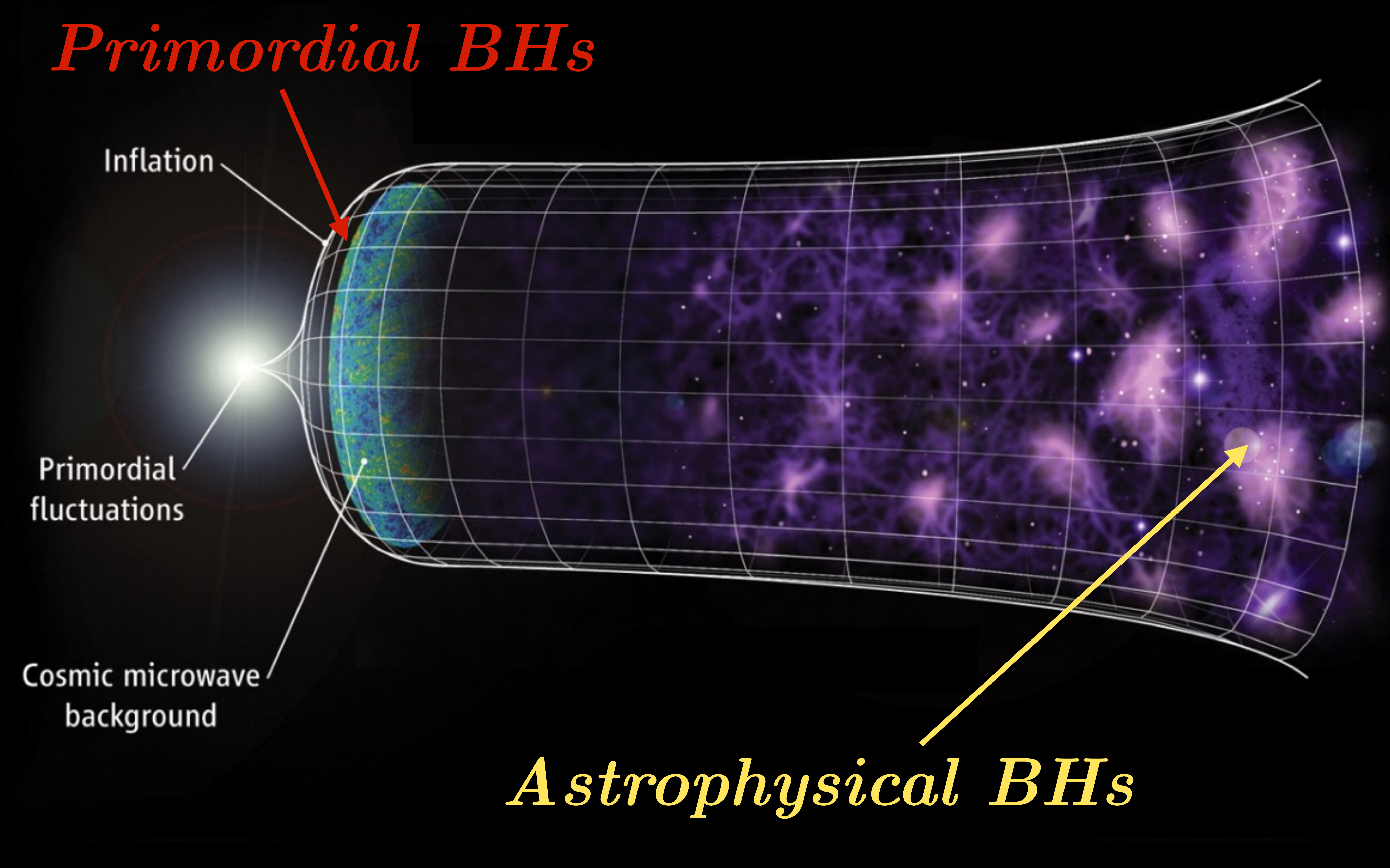
Population(s) of mergers

- *More than 90 events, up to millions in the Einstein Telescope era!*



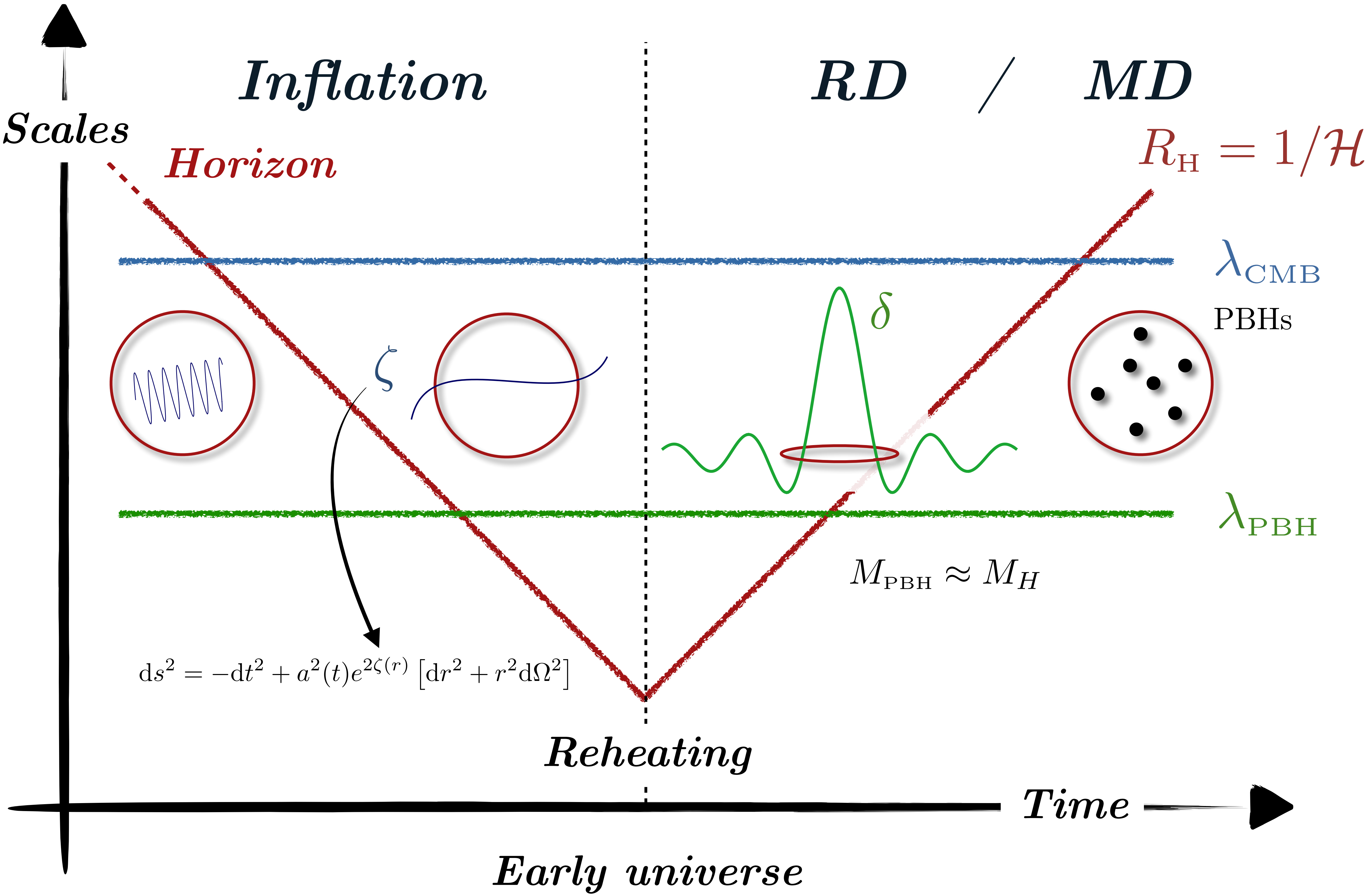
- *We want to understand the population properties, and where they come from*

Where do BHs come from?



A very quick intro to the PBH model

PBH formation timeline

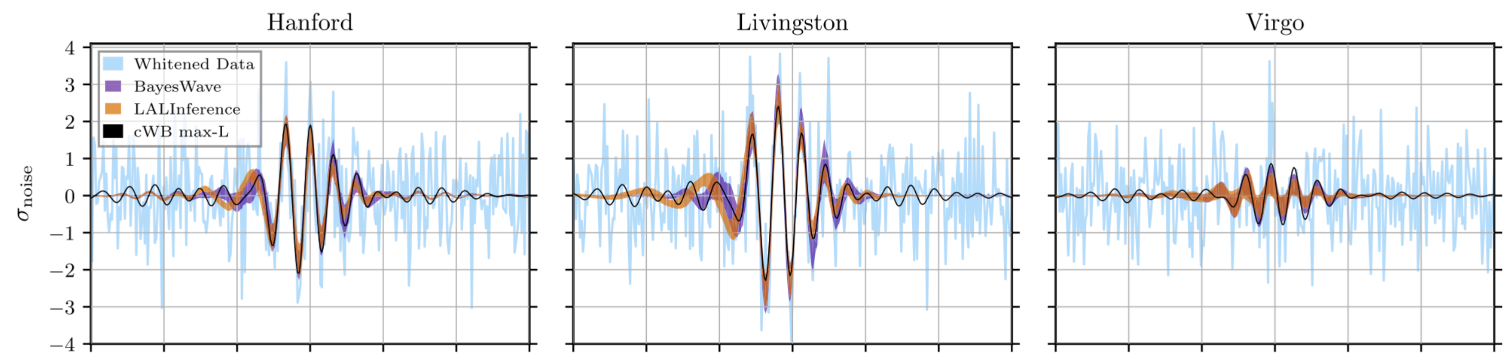


Are PBHs useful?

Yes, if they exist...

- *They could be a significant fraction of the dark matter in our universe;*
- *Form the SMBH seeds;*
- *Possible contribution to current LVKC detections;*

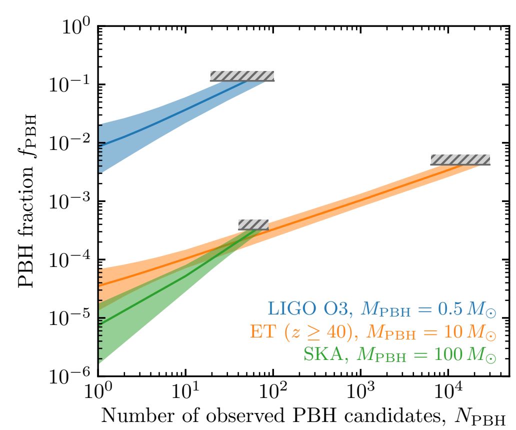
R. Abbott *et al.* [LIGO Scientific and Virgo], Phys. Rev. Lett. **125**, no.10, 101102 (2020) [arXiv:2009.01075]

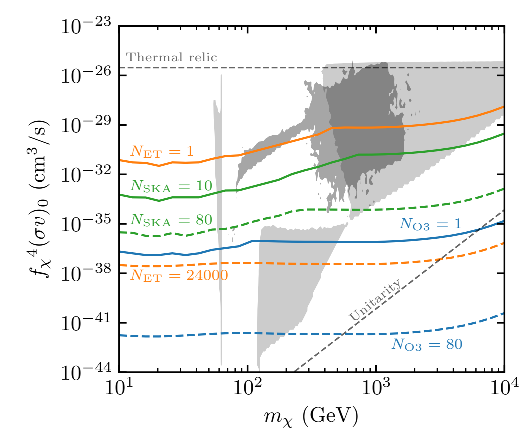


- *They are largely incompatible with other particle DM candidates;*

J. Adamek, C. T. Byrnes, M. Gosenca and S. Hotchkiss, Phys. Rev. D **100**, no.2, 023506 (2019) [arXiv:1901.08528]

G. Bertone, *et al.* Phys. Rev. D **100**, no.12, 123013 (2019) [arXiv:1905.01238]



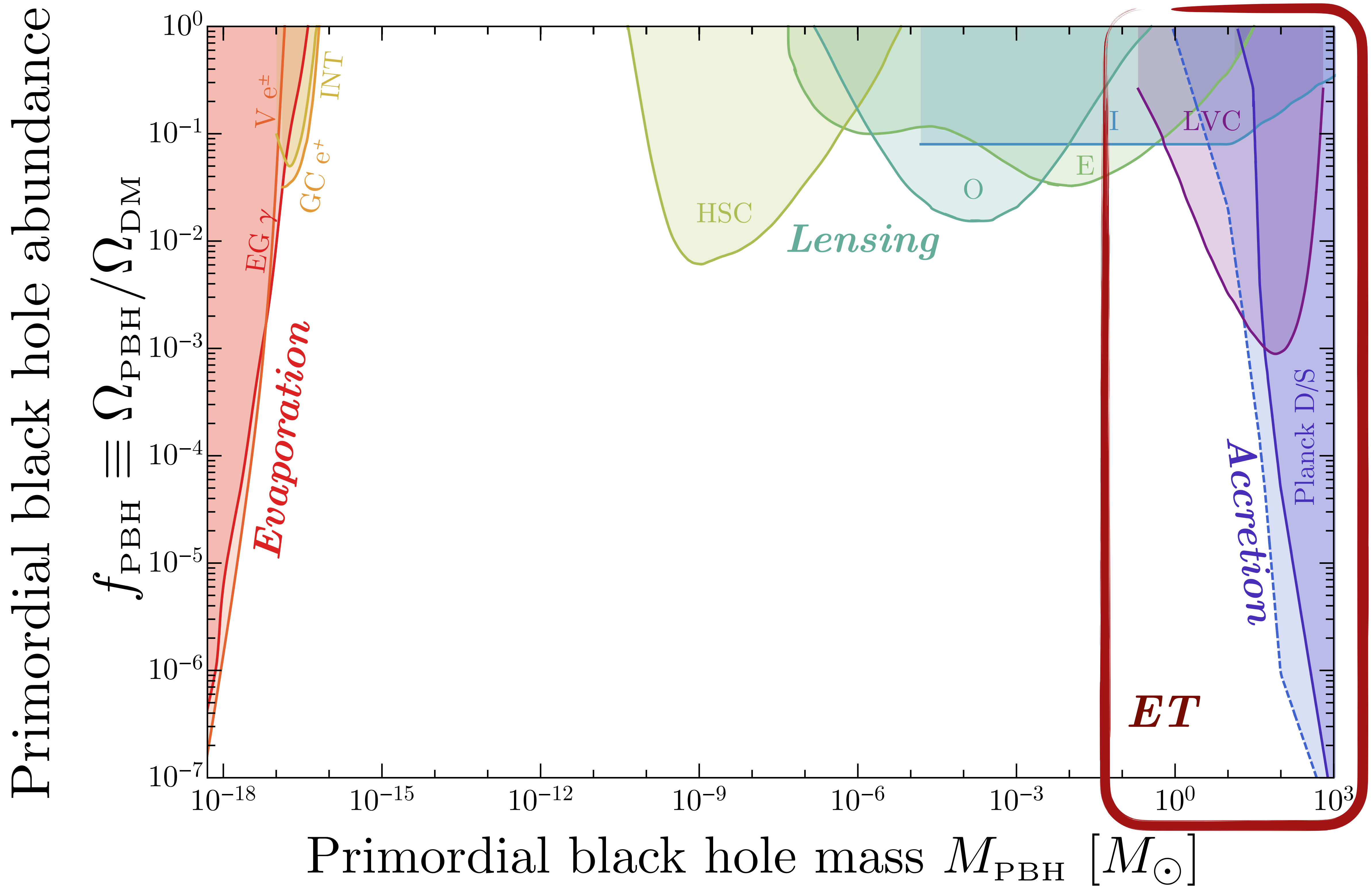


Yes, if they didn't exist...

- *They allow to set constraints on the early universe.*

Constraints on the PBH abundance

Review: B. Carr, K. Kohri, Y. Sendouda and J. Yokoyama, Rept. Prog. Phys. **84**, no.11, 116902 (2021) [arXiv:2002.12778]



PBH abundance

- ***PBH abundance expressed in terms of the dark matter***

$$f_{\rm PBH} \equiv \Omega_{\rm PBH}/\Omega_{\rm DM}$$

(can be thought as a proxy for the average PBH number density)

- ***The abundance controls the merger rate:*** $R \propto f_{\rm PBH}^2$

T. Nakamura, M. Sasaki, T. Tanaka, and K. S. Thorne, Astrophys. J. Lett. 487, L139 (1997), [arXiv:9708060]
K. Ioka, T. Chiba, T. Tanaka, and T. Nakamura, Phys. Rev. D 58, 063003 (1998), [arXiv:9807018]

LVK measurements set a bound on the PBH abundance in the stellar mass range

$$f_{\rm PBH} \lesssim 10^{-3} \quad \text{for} \quad M_{\rm PBH} \approx [1 \div 10^2] M_\odot$$

How to identify PBH mergers?

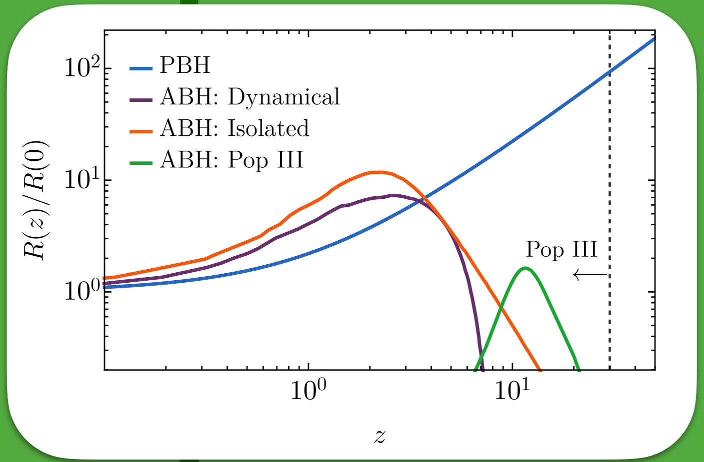
Astro vs Primordial origin

PBHs

ABH — ***Astro Mass Gap (?)*** — ***ABH***

Chandrasekhar limit

- ***Mass distribution***
- ***Spin distribution***
- ***Merger rates evol. (z)***
- ***....***



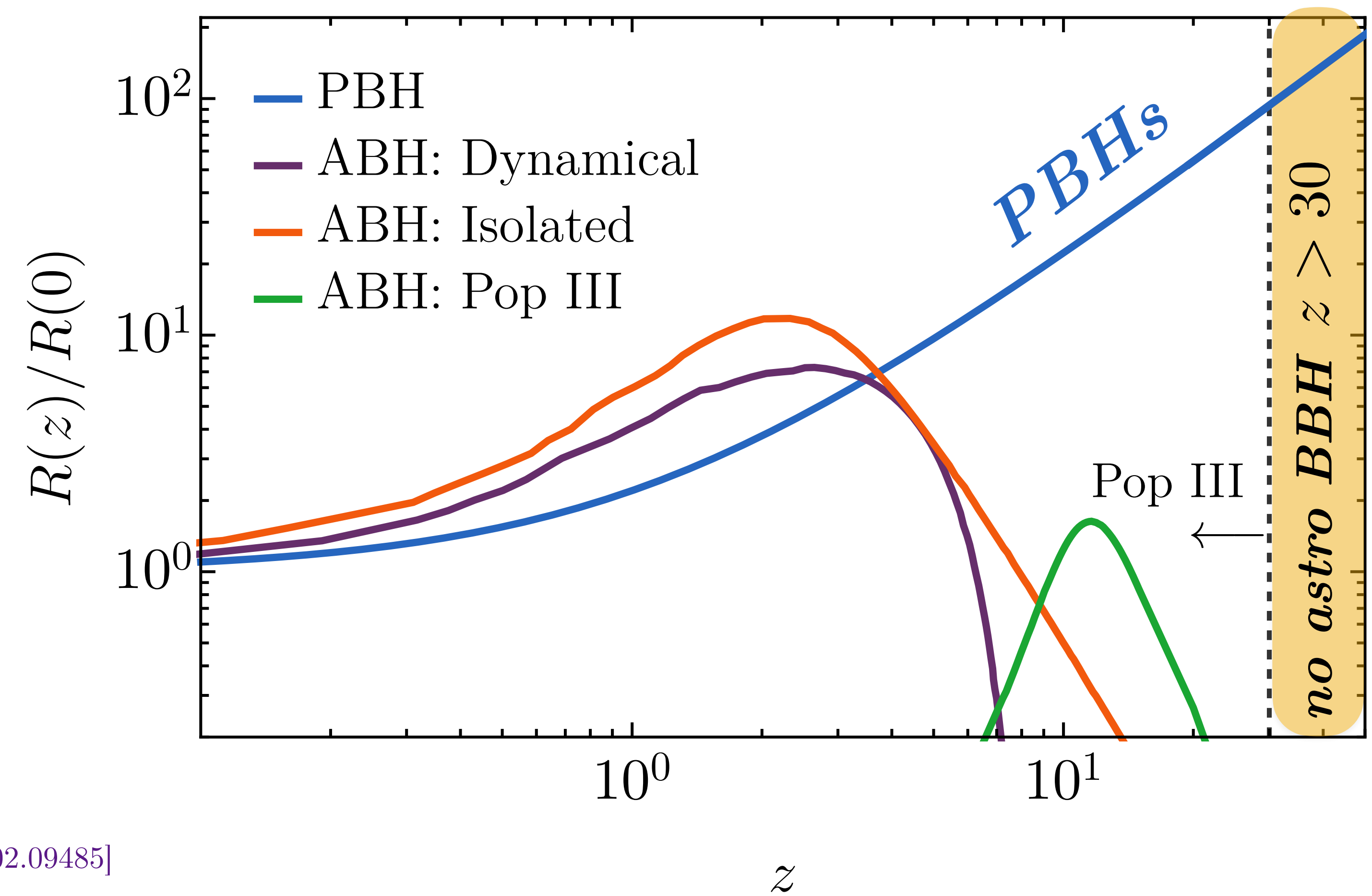
$\approx M_\odot$

Merger rate evolution with redshift

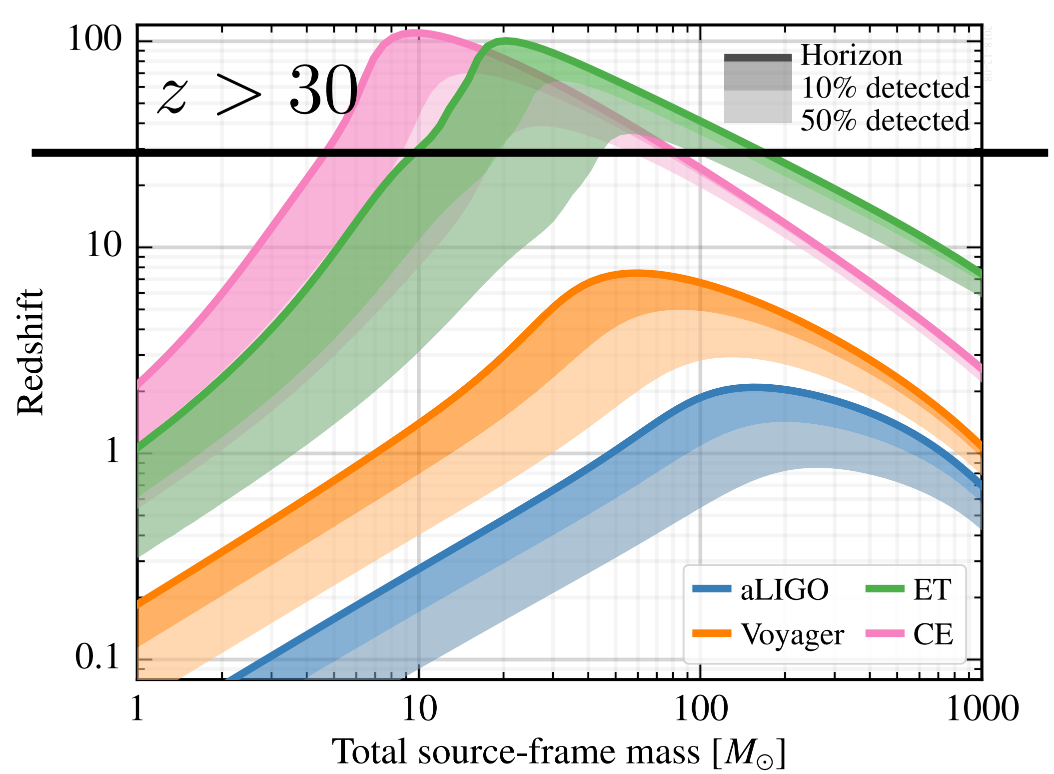
Monotonic growth up to $z \gtrsim 10^3$

$$R \approx t^{-34/37}$$

K. Ng, et al. Astrophys. J. Lett. **913**, no.1, L5 (2021) [arXiv:2012.09876]



E.D.Hall and M.Evans, Class. Quant. Grav. **36**, 22, 225002 (2019) [arXiv:1902.09485]



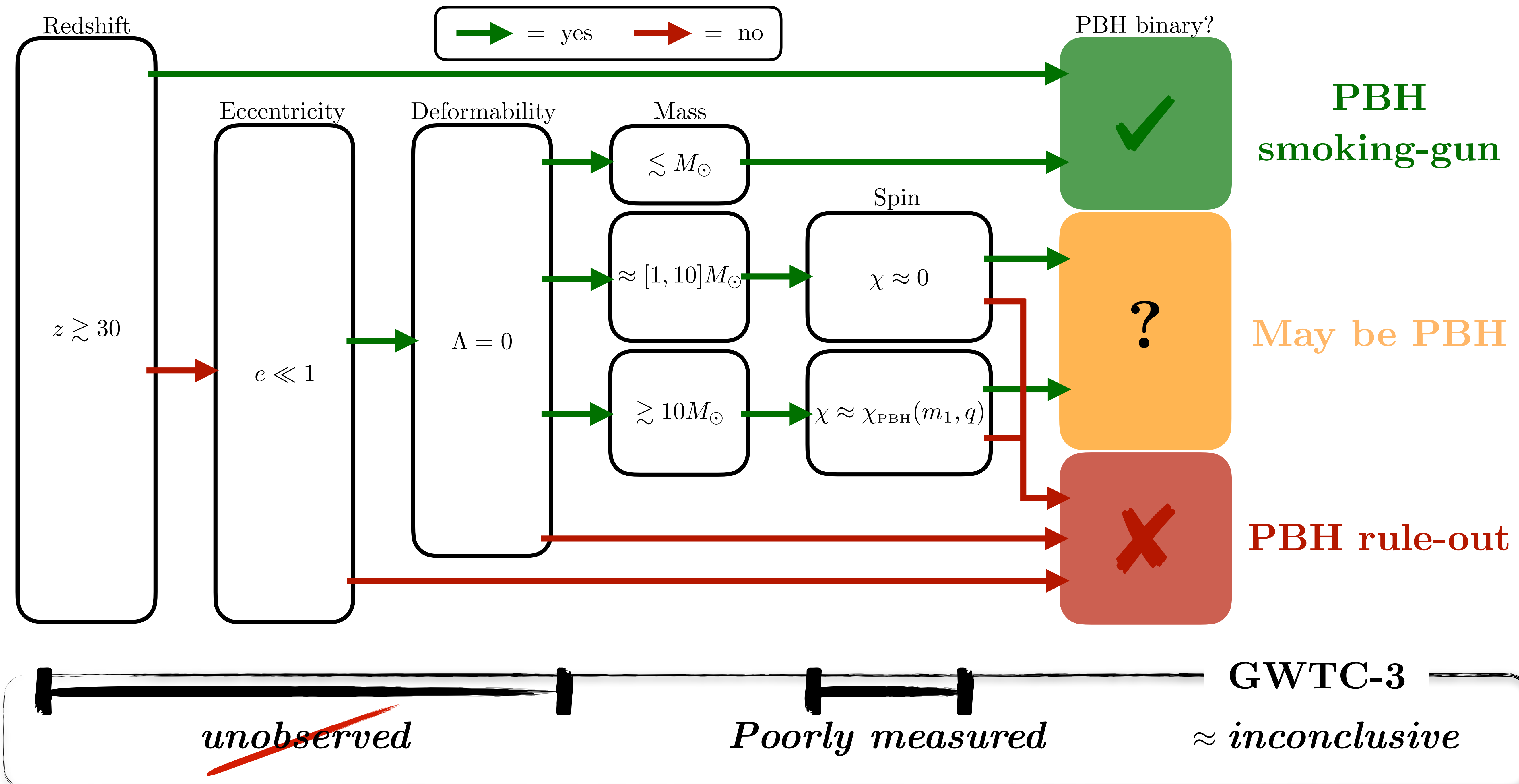
- ***No astro contamination above redshift*** $z \approx 30$

T. Nakamura, *et al.* PTEP **2016**, no.9, 093E01 (2016) [arXiv:1607.00897]
S. Koushiappas and A. Loeb, Phys. Rev. Lett. **119**, no.22, 221104 (2017) [arXiv:1708.07380]
....

- ***3G detectors could observe these sources!***

Properties of PBH binaries

G. Franciolini, R. Cotesta, N. Loutrel, E. Berti, P. Pani and A. Riotto, Phys. Rev. D **105**, no.6, 063510 (2022) [arXiv:2112.10660]



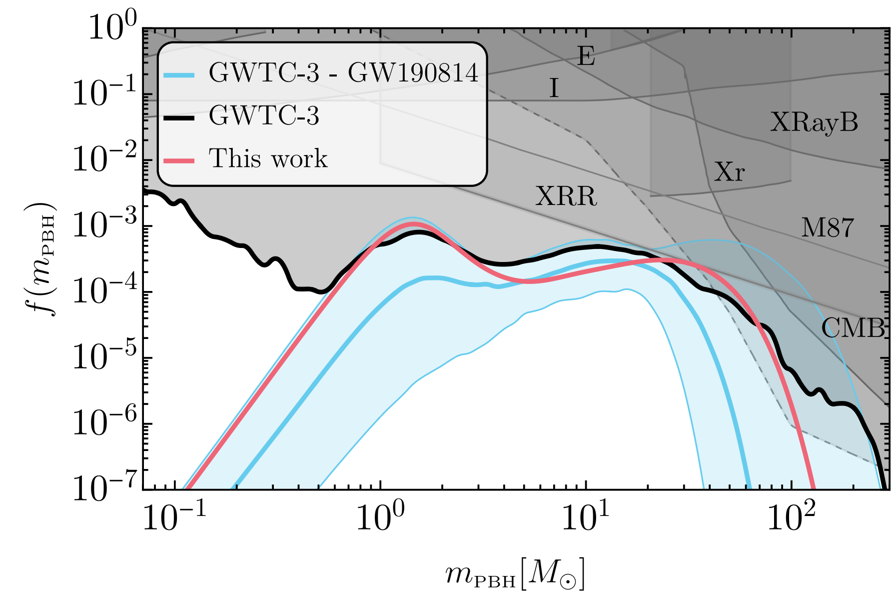
Large precision improvements with the Einstein Telescope!

Population studies

How many events can we hope for?

Conservative upper bound from GWTC-3

	$N_{\rm PBH}^{\rm det}$	$N_{\rm PBH}^{\rm det}({\rm SS})$	$N_{\rm PBH}^{\rm det}({\rm LMG})$	$N_{\rm PBH}^{\rm det}({\rm UMG})$
O1-O3	[0.8, 22.4]	[0.0, 0.6]	[0.1, 2.3]	[0.0, 6.1]
O4	[1.9, 43.7]	[0.0, 1.3]	[0.3, 13.0]	[0.0, 13.1]
O5	[10.3, 216.7]	[0.0, 8.6]	[0.8, 25.2]	[0.0, 47.3]



From LVK to Einstein Telescope

Configuration	$N_{\rm det}^{\rm tot}$	$N_{\rm det}^{\rm SS}$	$N_{\rm det}^{z>10}$	$N_{\rm det}^{z>30}$	$N_{\rm det}^{\rm LMG}$	$N_{\rm det}^{\rm UMG}$
△-10km-HFLF-Cryo	13 347	1650	336	17	2638	235
△-15km-HFLF-Cryo	30 912	4281	1099	91	6443	376
2L-15km-45°-HFLF-Cryo	24 900	3345	824	66	5132	332
2L-15km-0°-HFLF-Cryo	26 585	3580	940	65	5517	356
2L-20km-45°-HFLF-Cryo	35 524	5206	1434	140	7550	374
2L-20km-0°-HFLF-Cryo	45 650	6745	1962	187	9809	465
1L-20km-HFLF-Cryo	22 852	3019	698	37	4656	310

+ other configurations...

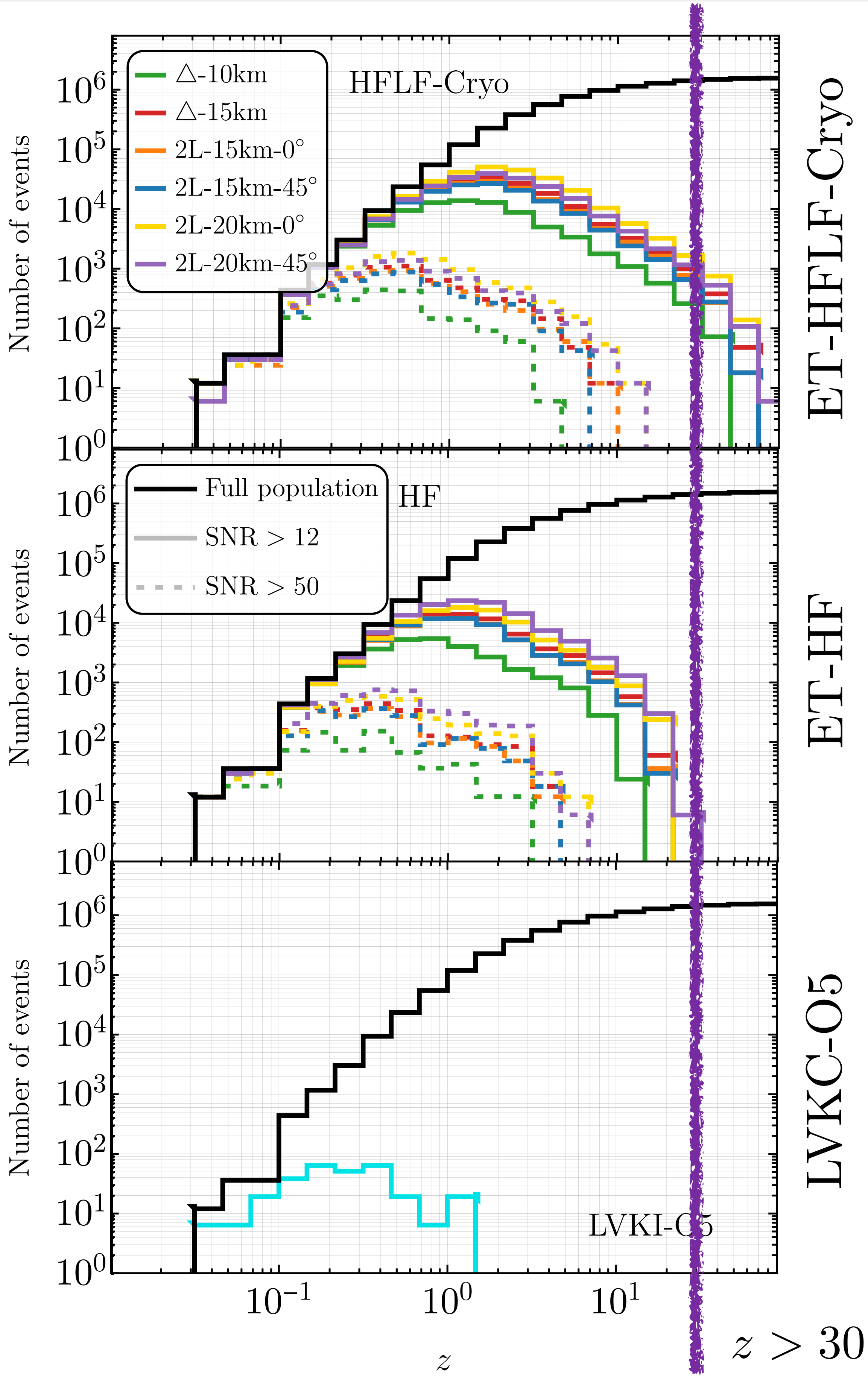
Subsolar

High-z

Mass gaps

G.F., F. Iacovelli, *et al* [arXiv:2304.03160]

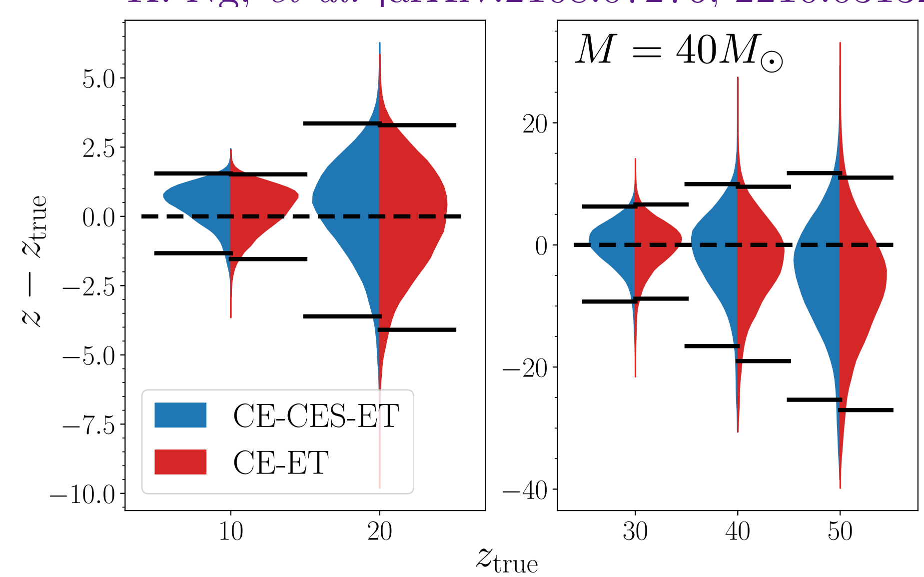
High-z population study



G.F., F. Iacovelli, *et al* [arXiv:2304.03160]

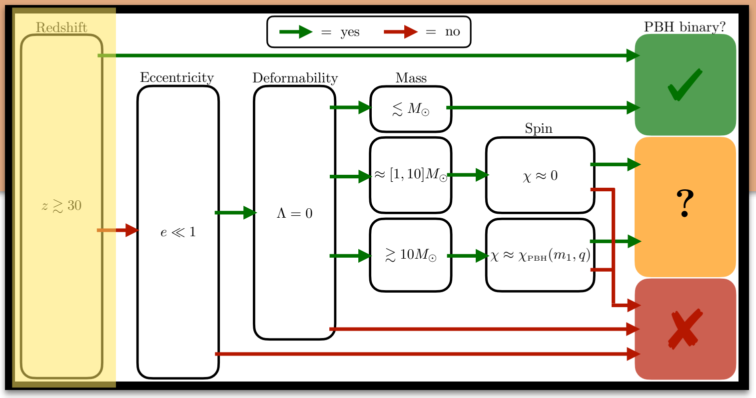
- ***Huge jump compared to LVK***
- ***Cryo design (low-frequencies) crucial for high redshift sources***
- ***Beware of high redshift z-uncertainties***

K. Ng, *et al.* [arXiv:2108.07276, 2210.03132]



High-z population study

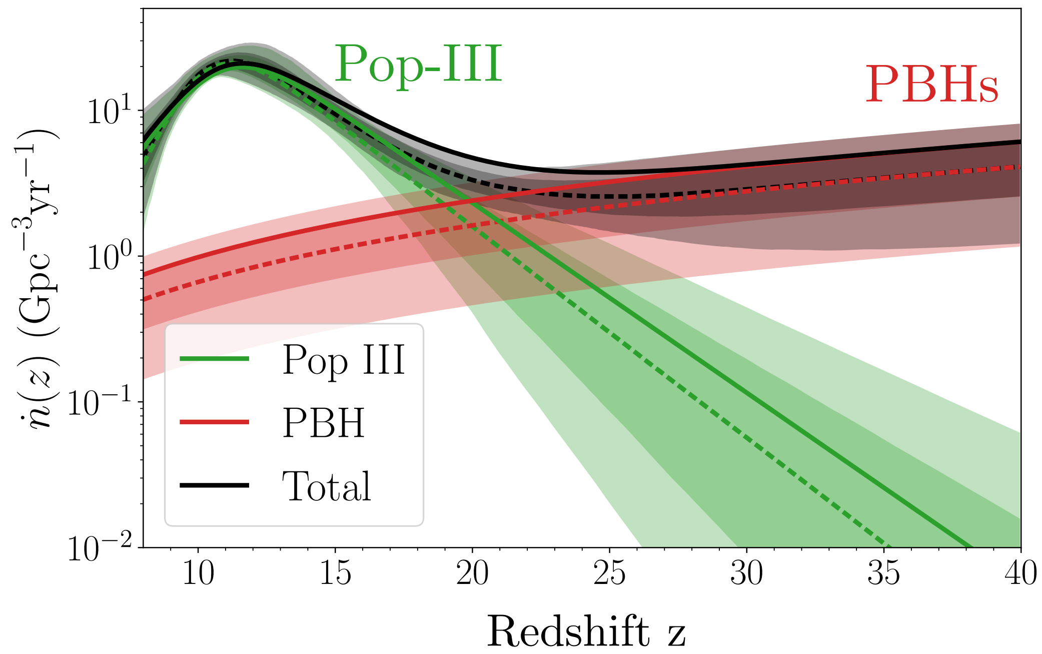
K.Ng, G.Franciolini, E.Berti, P.Pani, A.Riotto and S.Vitale,
Astrophys. J. Lett. **933** (2022) no.2, L41 [arXiv:2204.11864]

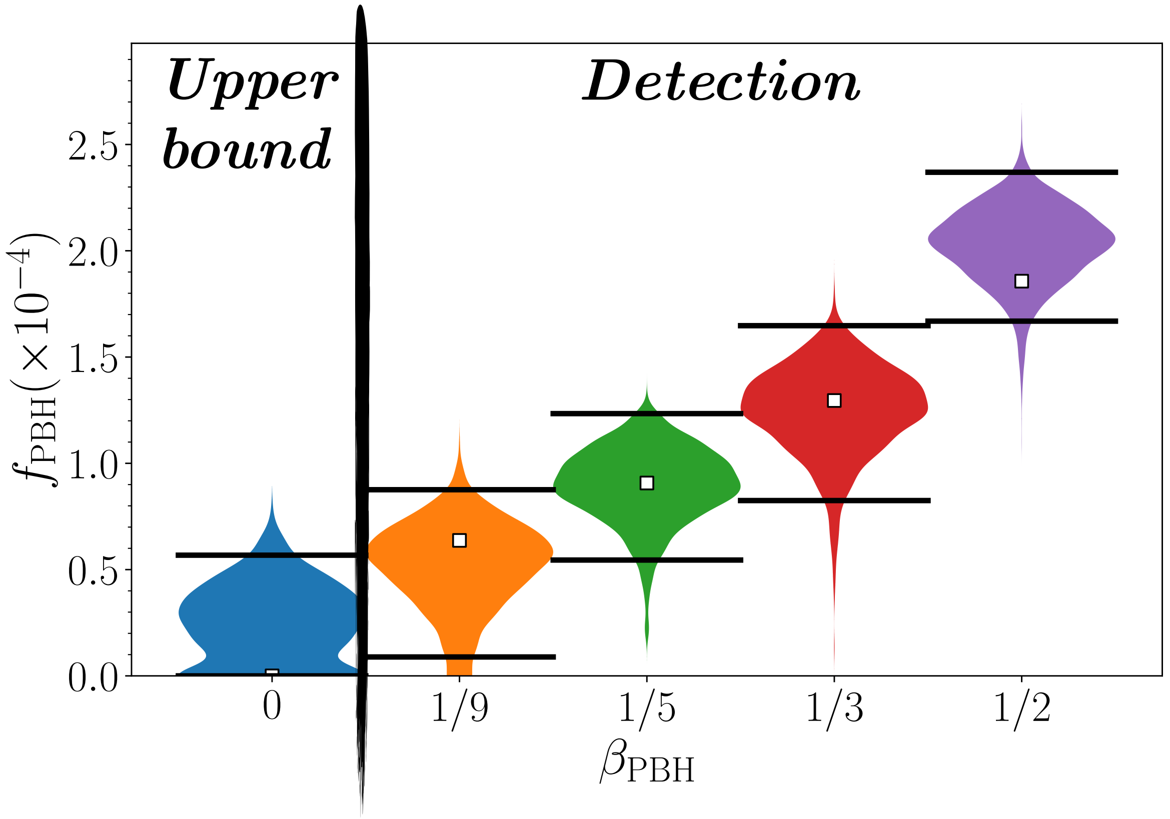


- ***Reconstructing the merger rate*** $z \gtrsim 10$
- ***Conservative assumptions on Pop-III rate***

K. Belczynski, *et al.* Mon. Not. Roy. Astron. Soc. **471**, no.4, 4702-4721 (2017) [arXiv:1612.01524]

- ***Simulated 4 months of data at CE-ET***





Within the mass range

$$M_{\rm PBH} \approx [10, 50] M_\odot$$

ET have the unique potential to discover a PBH population

or

Set the most stringent constraint on the PBH abundance in the stellar mass range

Thanks!

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