INSTITUT D'ASTROPHYSIQUE DE PARIS
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Gravitational-wave detections with ground-base observatories: from O1 to O4

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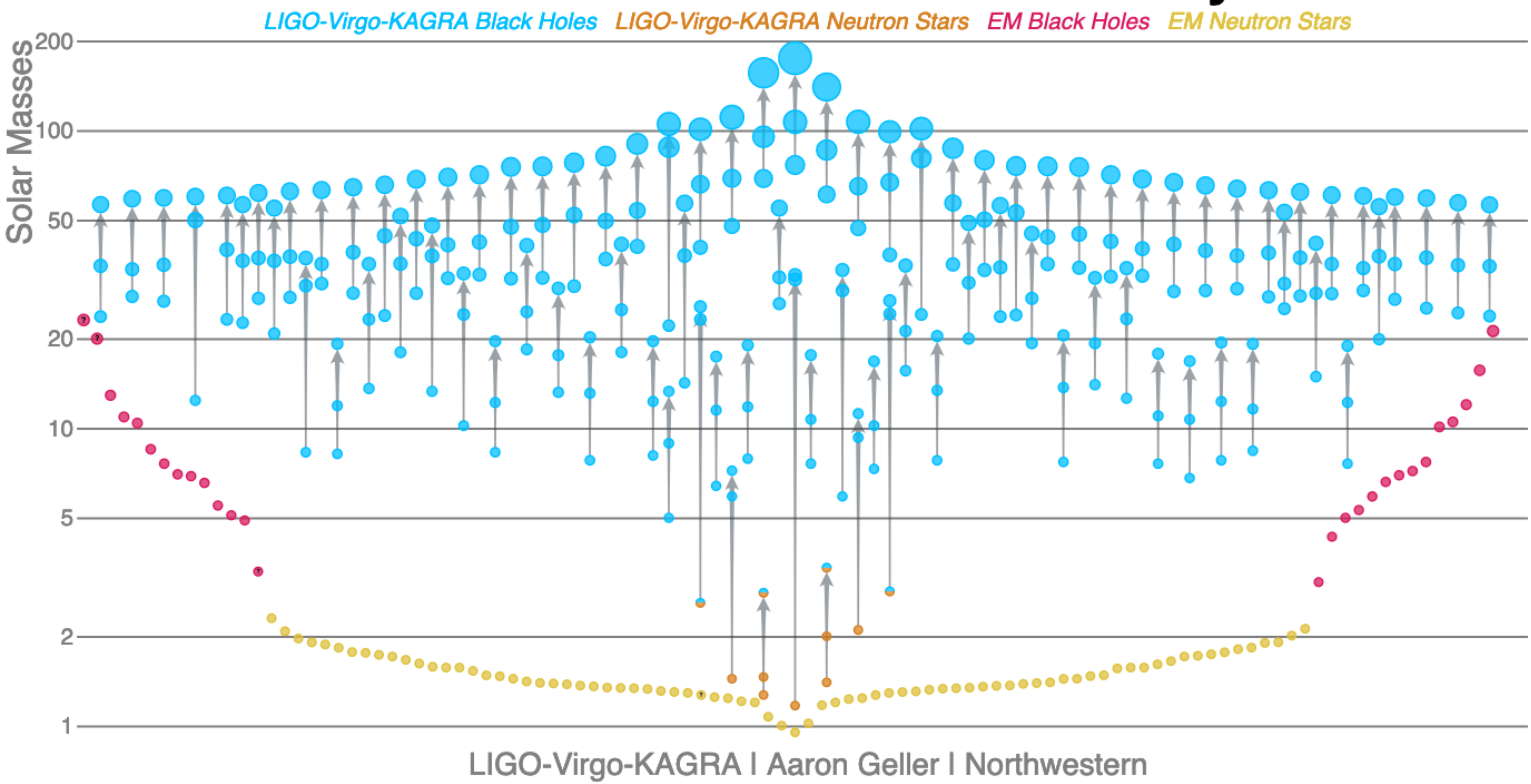
LIGO VIRGO

Journées PNHE 2023, IAP 8 Sept 2023

Masses in the Stellar Graveyard



Abbott et al. 2019, PRX, 9, 031040; Abbott et al. 2021, PRX, 11, 021053;
Abbott et al. 2021, arXiv:2111.03606; Abbott et al. 2021, arXiv:2108.01045

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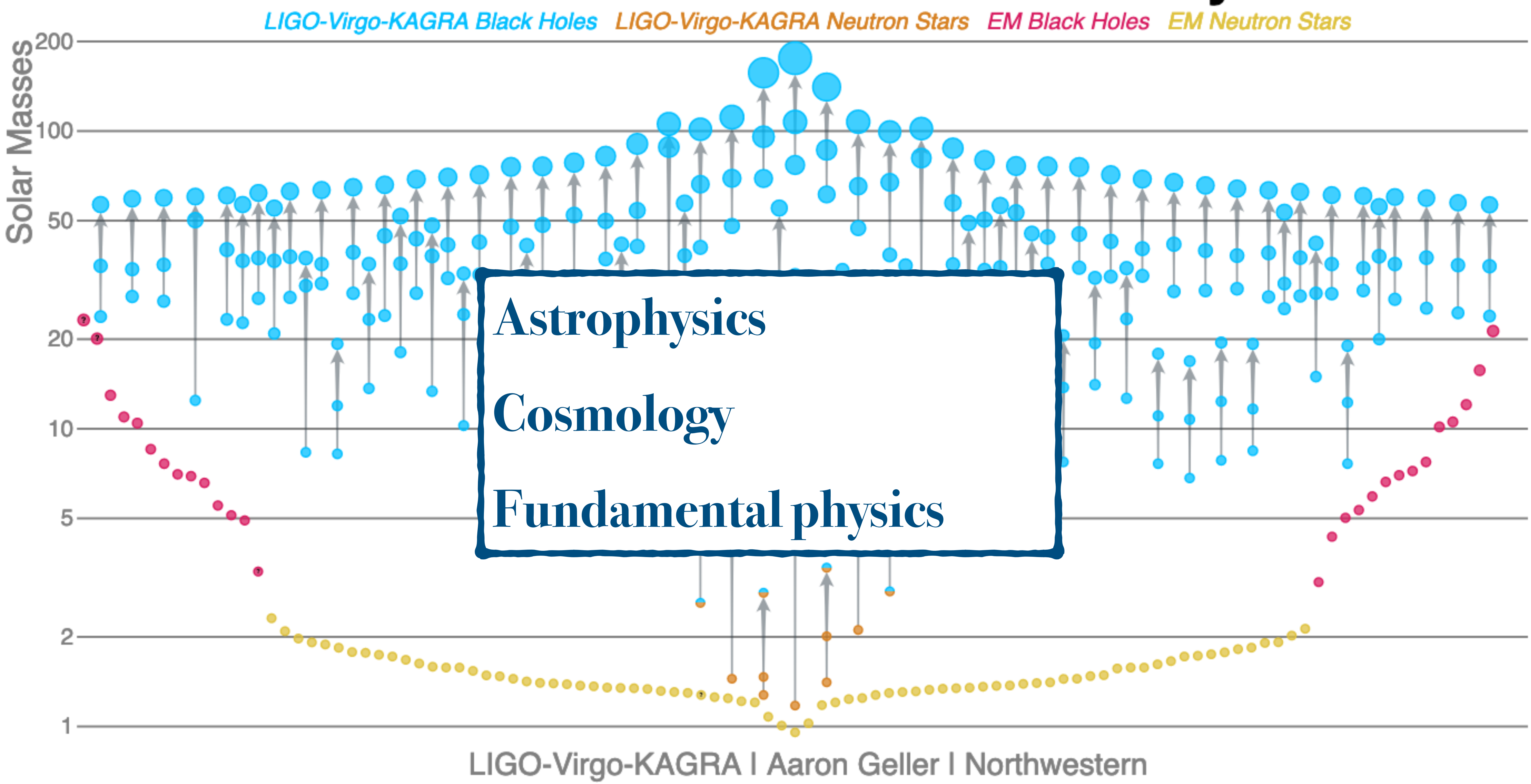

Astrophysics

Cosmology

Fundamental physics

Abbott et al. 2019, PRX, 9, 031040; Abbott et al. 2021, PRX, 11, 021053;
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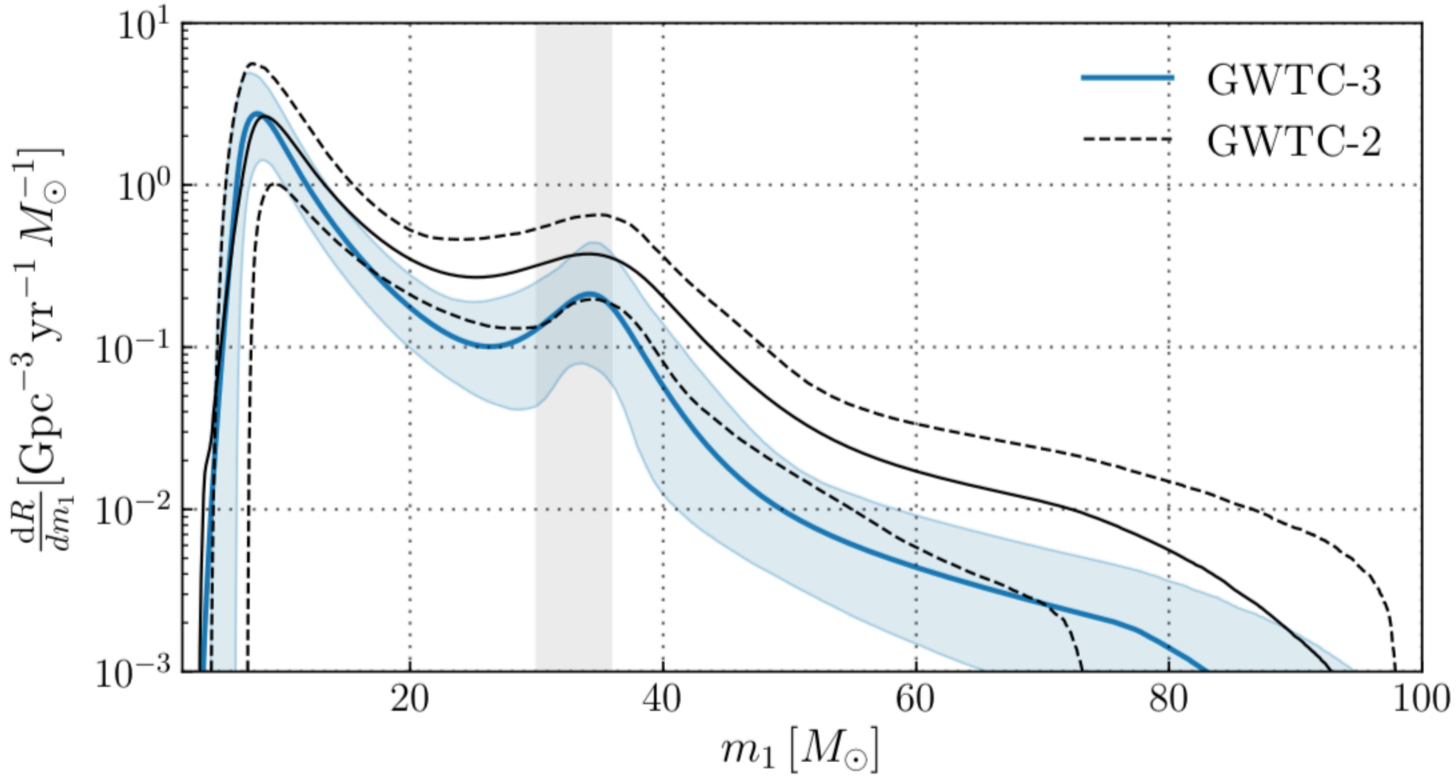
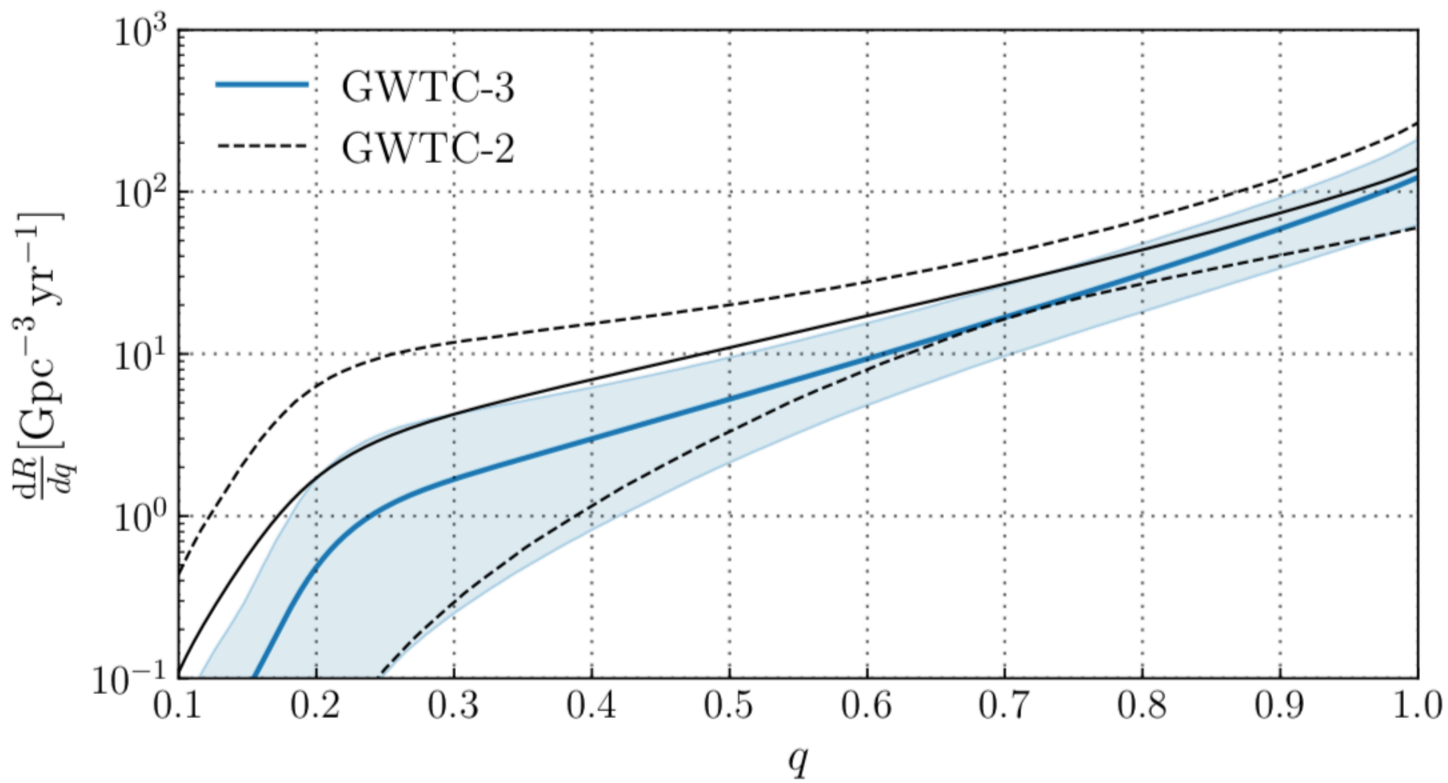
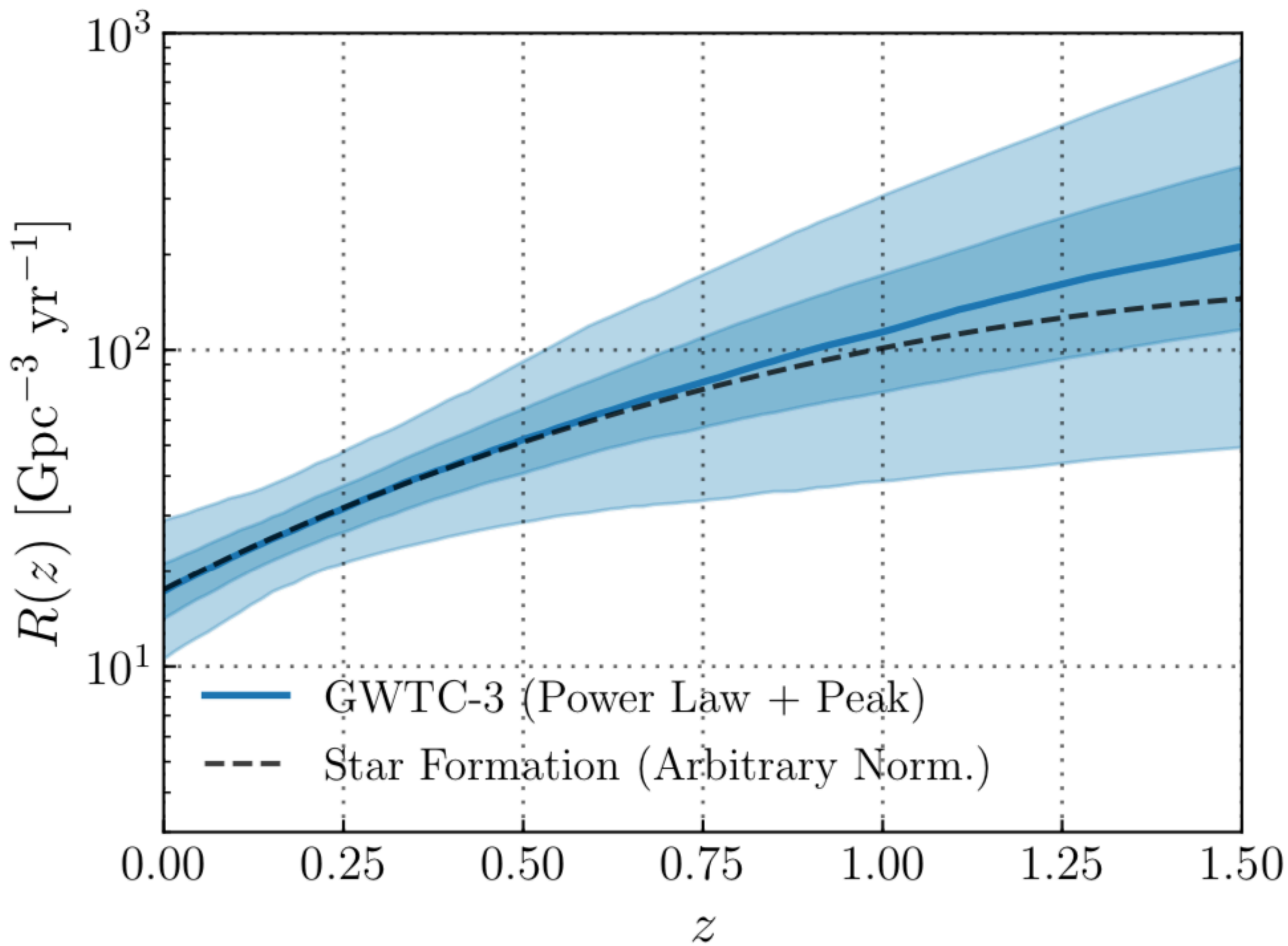
Black hole populations: mass distribution





[Abbott et al. 2023, PRX, 13, 011048]

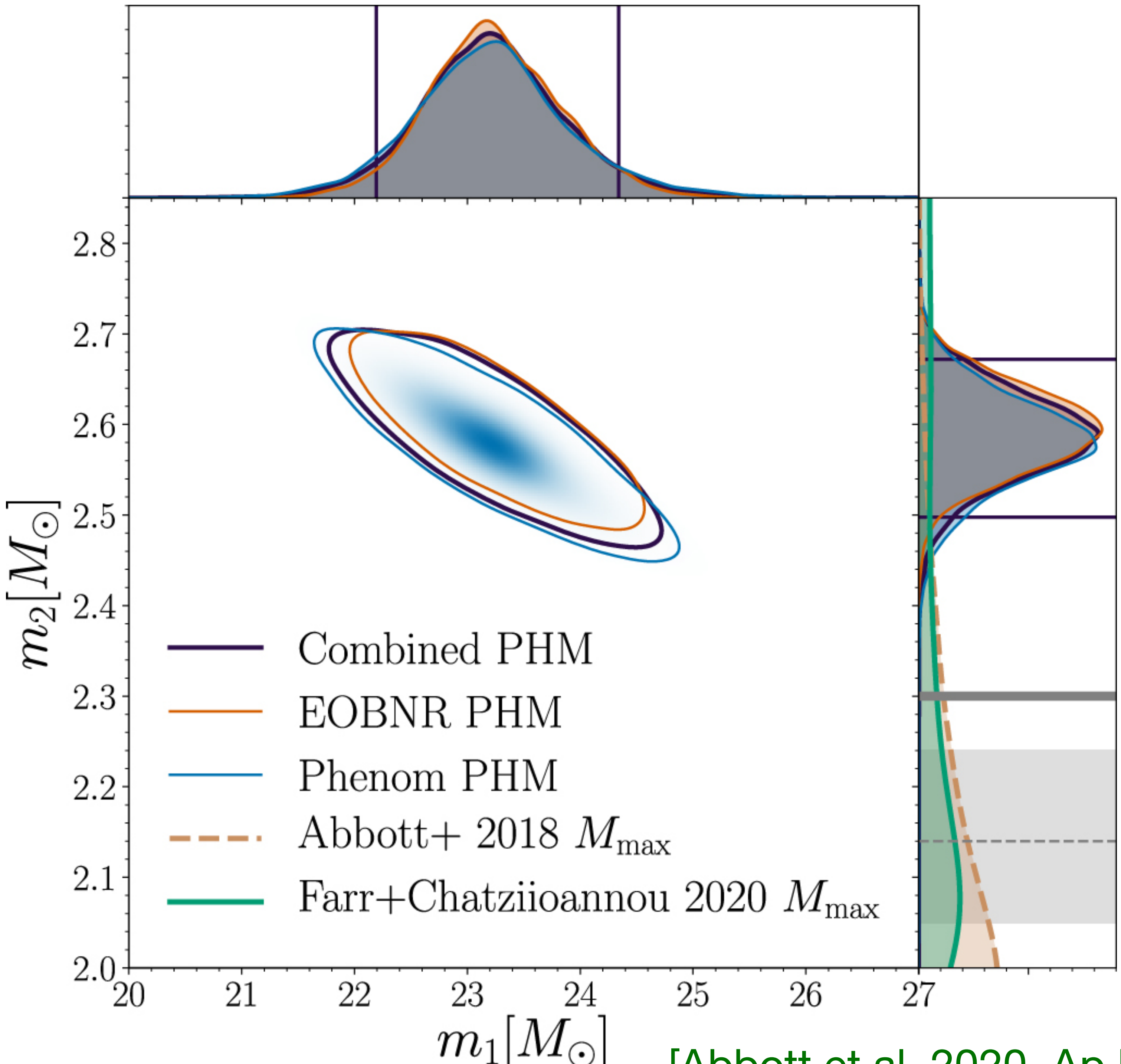
Black hole populations: merger rate evolution



$$R_{BBH}(z = 0.2) = 17.3 - 45 \quad Gpc^{-3}yr^{-1}$$

[Abbott et al. 2023, PRX, 13, 011048]

Black holes in the lower mass gap



GW190814

$$m_1 = 23.3^{+1.1}_{-1.0}\ M_\odot$$

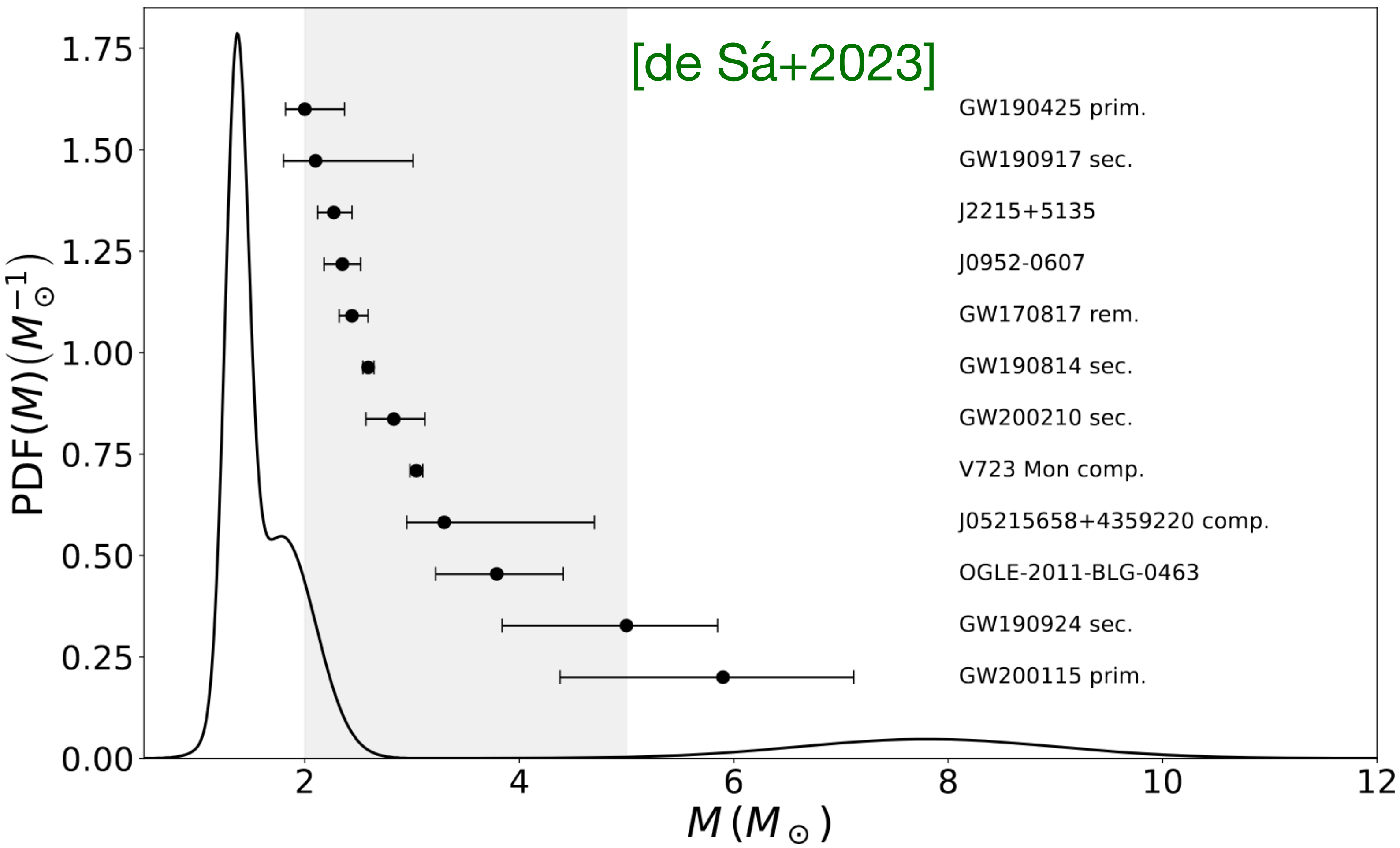
$$m_2 = 2.59^{+0.08}_{-0.09}\ M_\odot$$

Heaviest neutron star?

Lightest black hole?

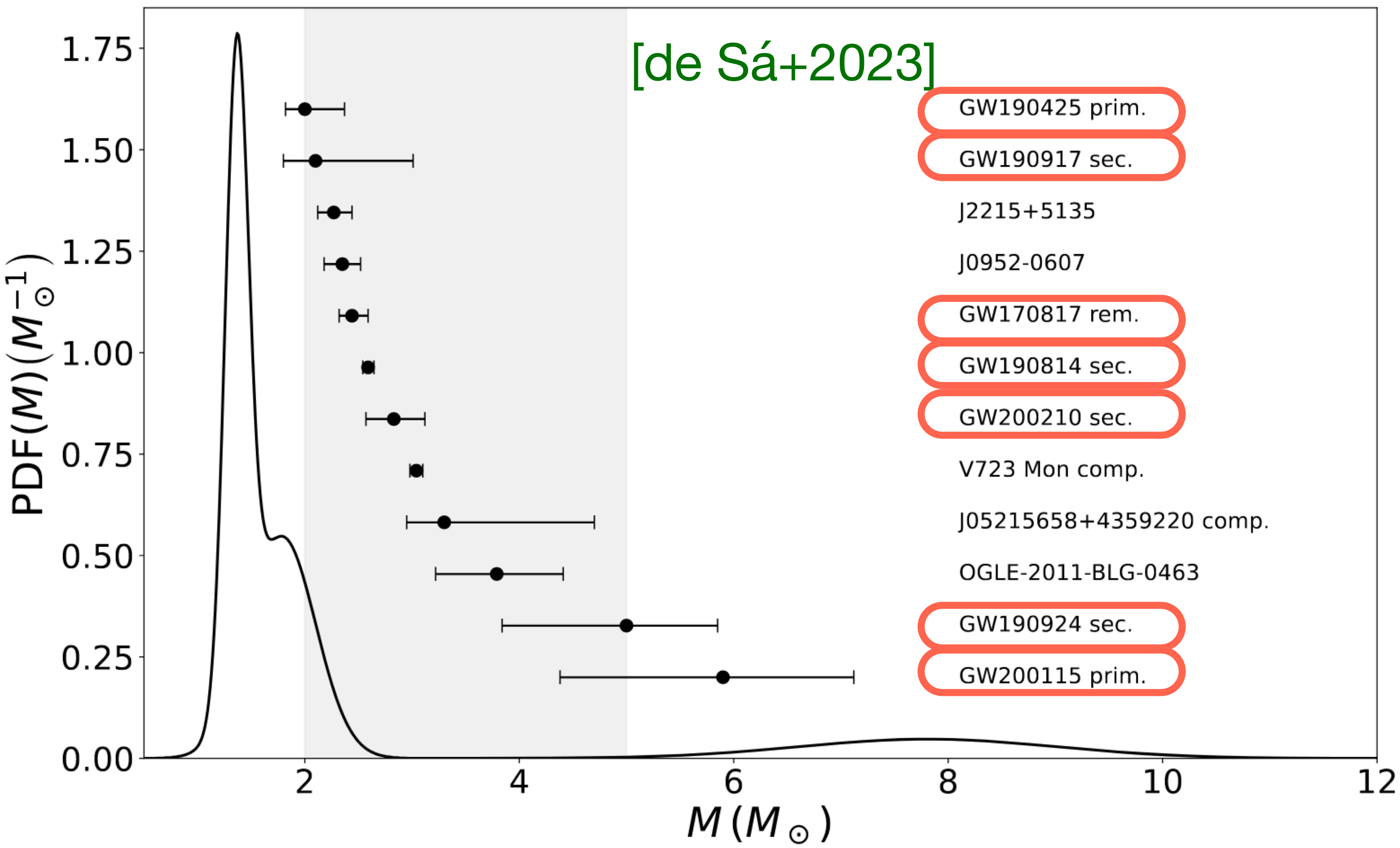
[Abbott et al. 2020, ApJL, 896, 44]

Black holes in the lower mass gap



Is the mass gap real?
Is it an observational effect?

Black holes in the lower mass gap



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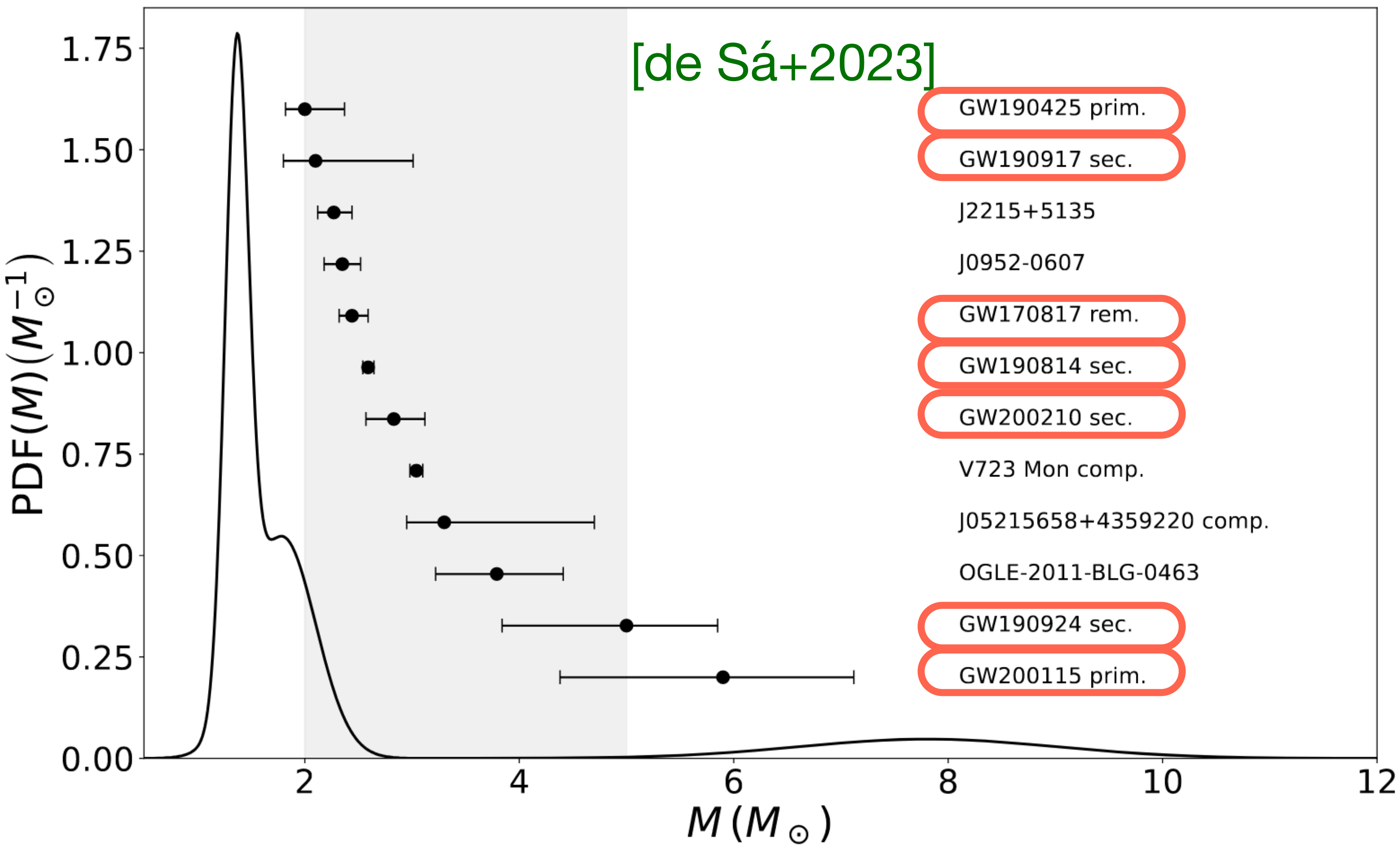
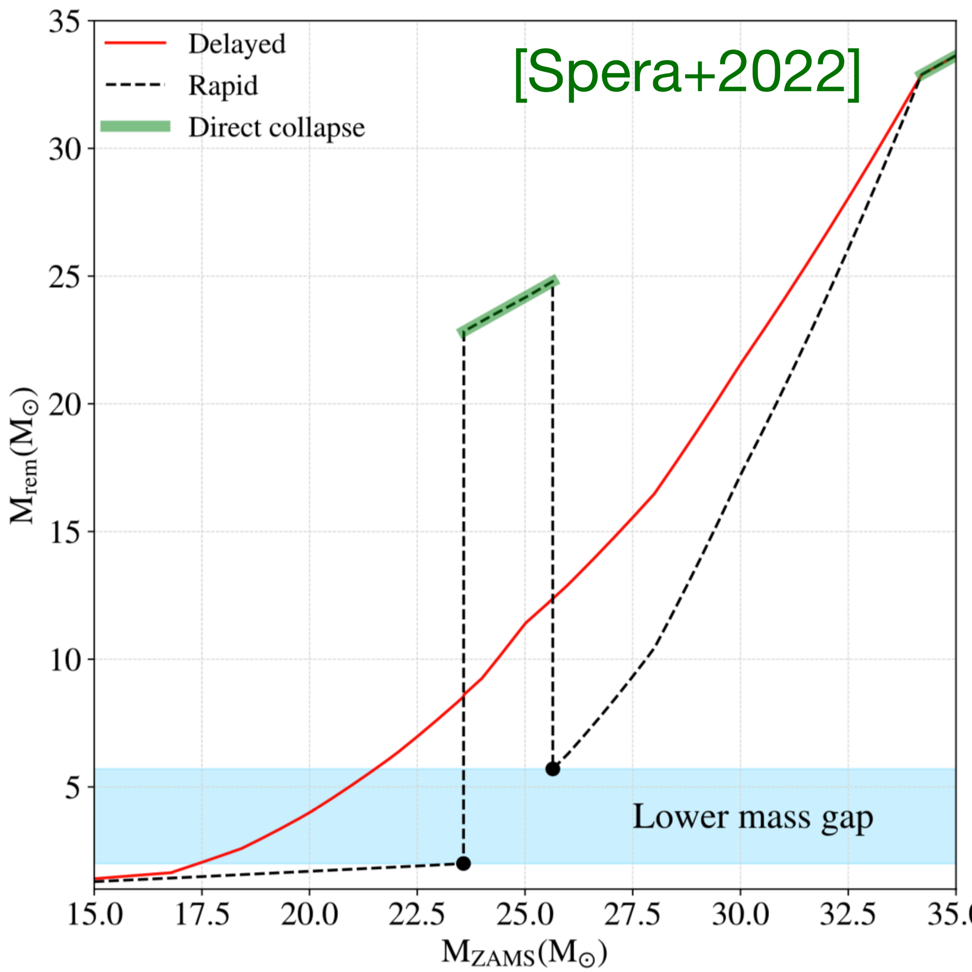
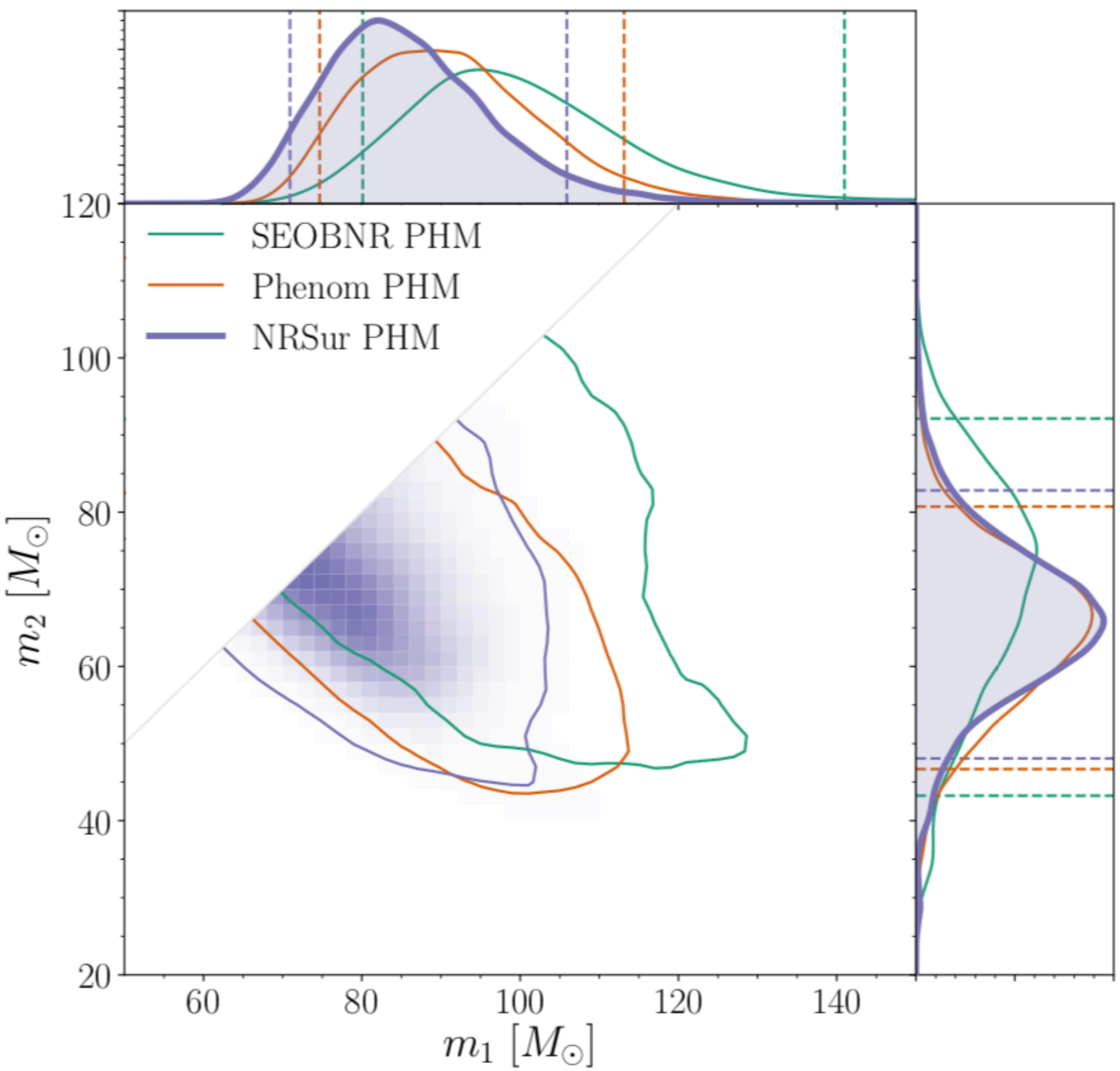




Is the mass gap real?
Is it an observational effect?

Implications for supernova explosion mechanism?

Black holes in the upper mass gap



GW190521

$$m_1 = 85^{+21}_{-14}\ M_\odot$$

$$m_2 = 66^{+17}_{-18}\ M_\odot$$

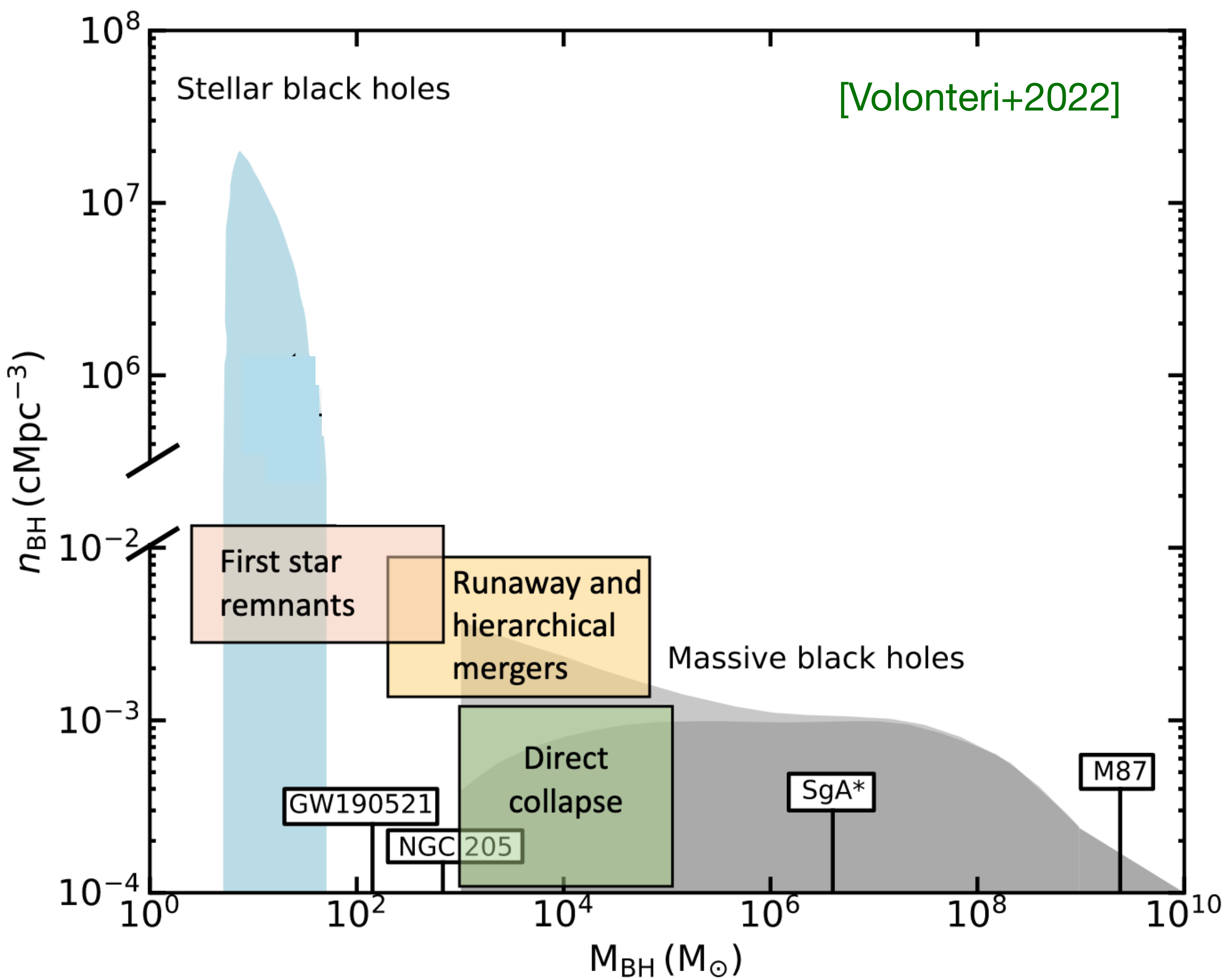
Hierarchical merger?

Black hole formed in the mass gap?

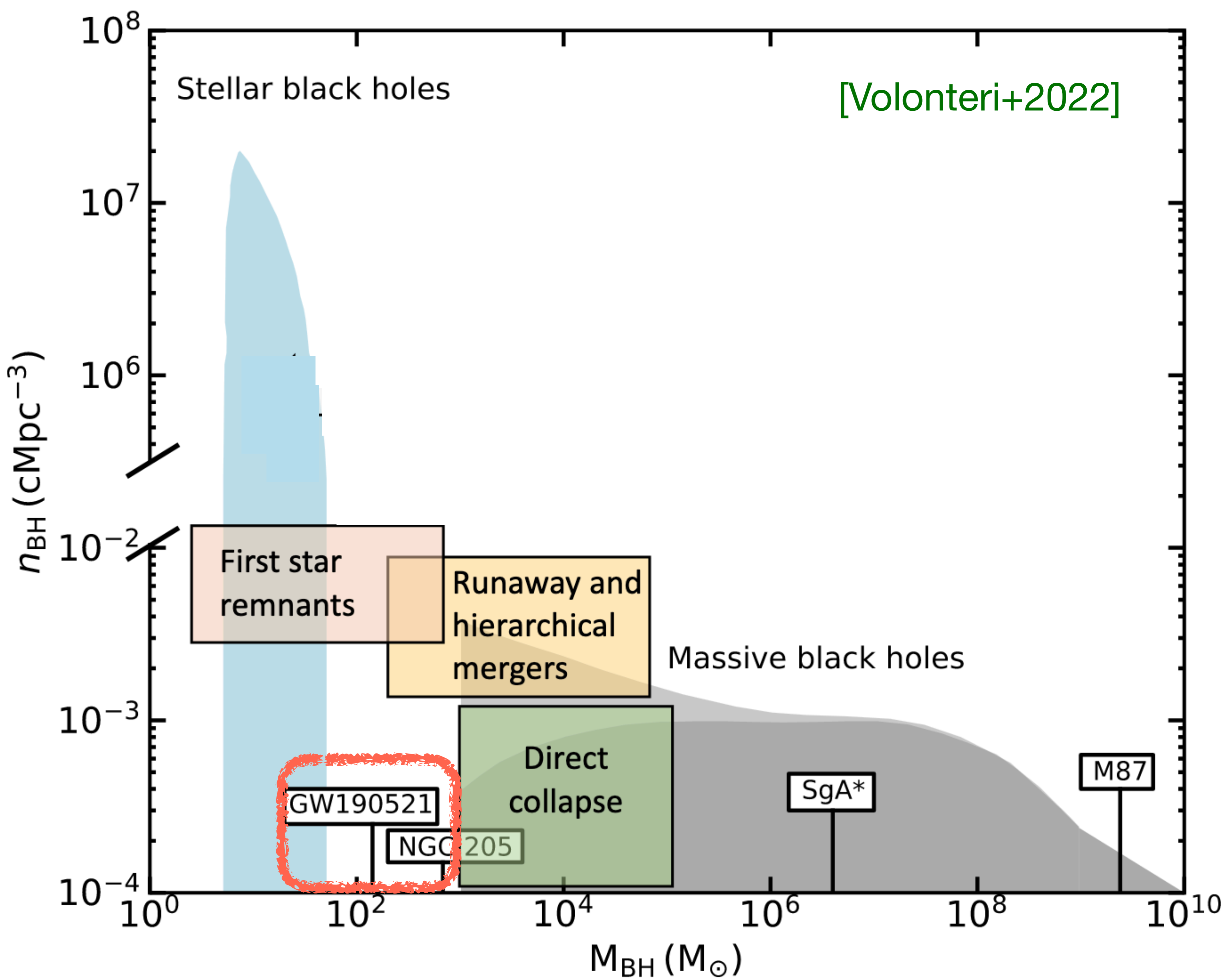
[Abbott et al. 2020, PRL, 125, 101102]

[Abbott et al. 2020, ApJL, 900, 13]

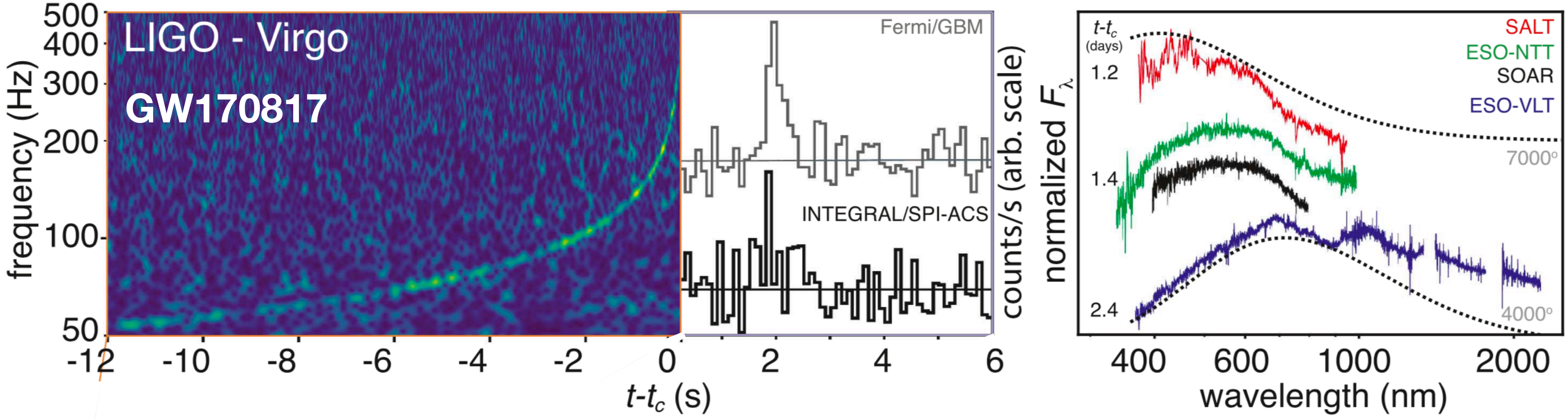
The link between stellar-mass and massive black holes?



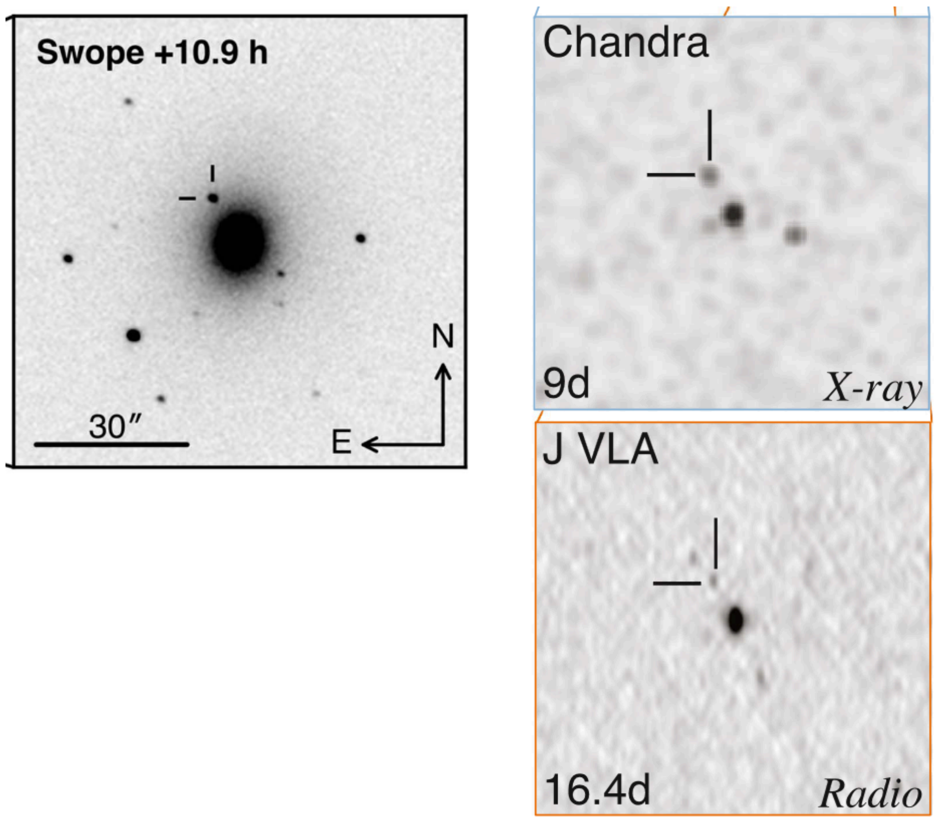
The link between stellar-mass and massive black holes?



Binary neutron stars: multi-messenger observations!

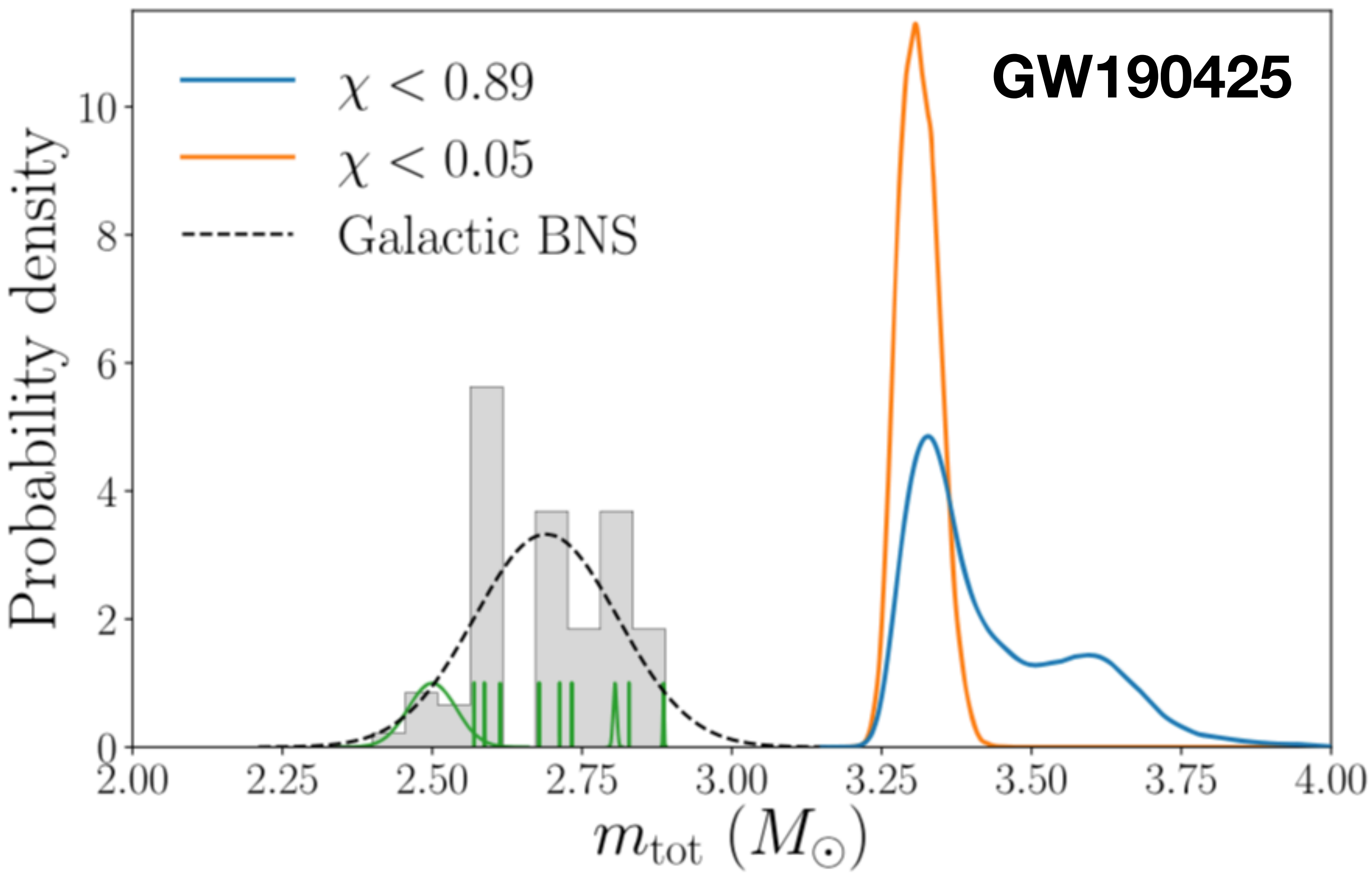


- GW+EM observations
- Connection between BNS merger and short gamma ray bursts (GRB)
- Kilonova: synthesis of heavy elements
- GRB: jet structure
- Identification of host galaxy



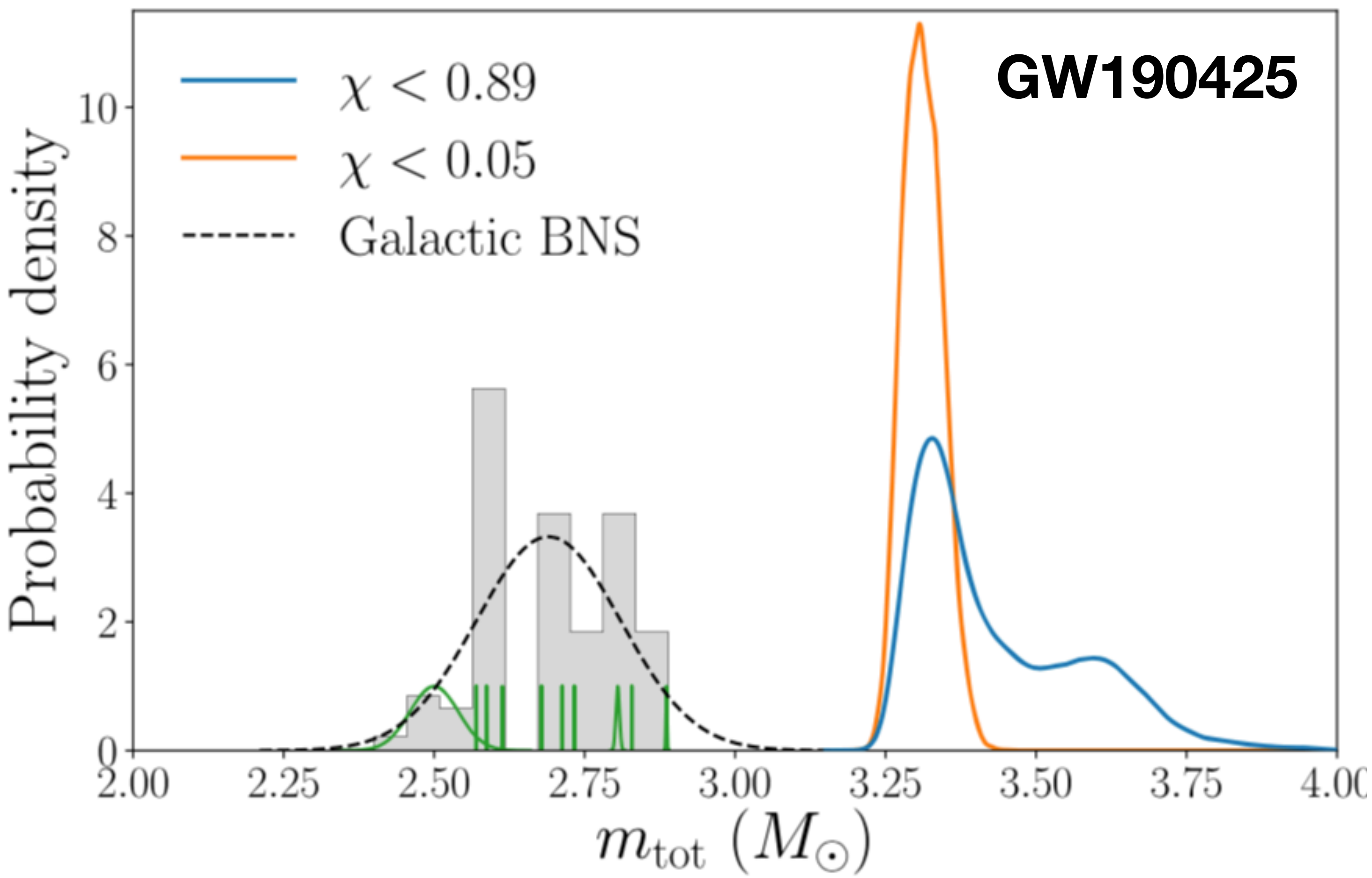
[Abbott et al. 2017, ApJ Letters, 848, 2]

Binary neutron stars: masses



[Abbott et al. 2020, Astrophys. J. Lett. 892, L3]

Binary neutron stars: masses



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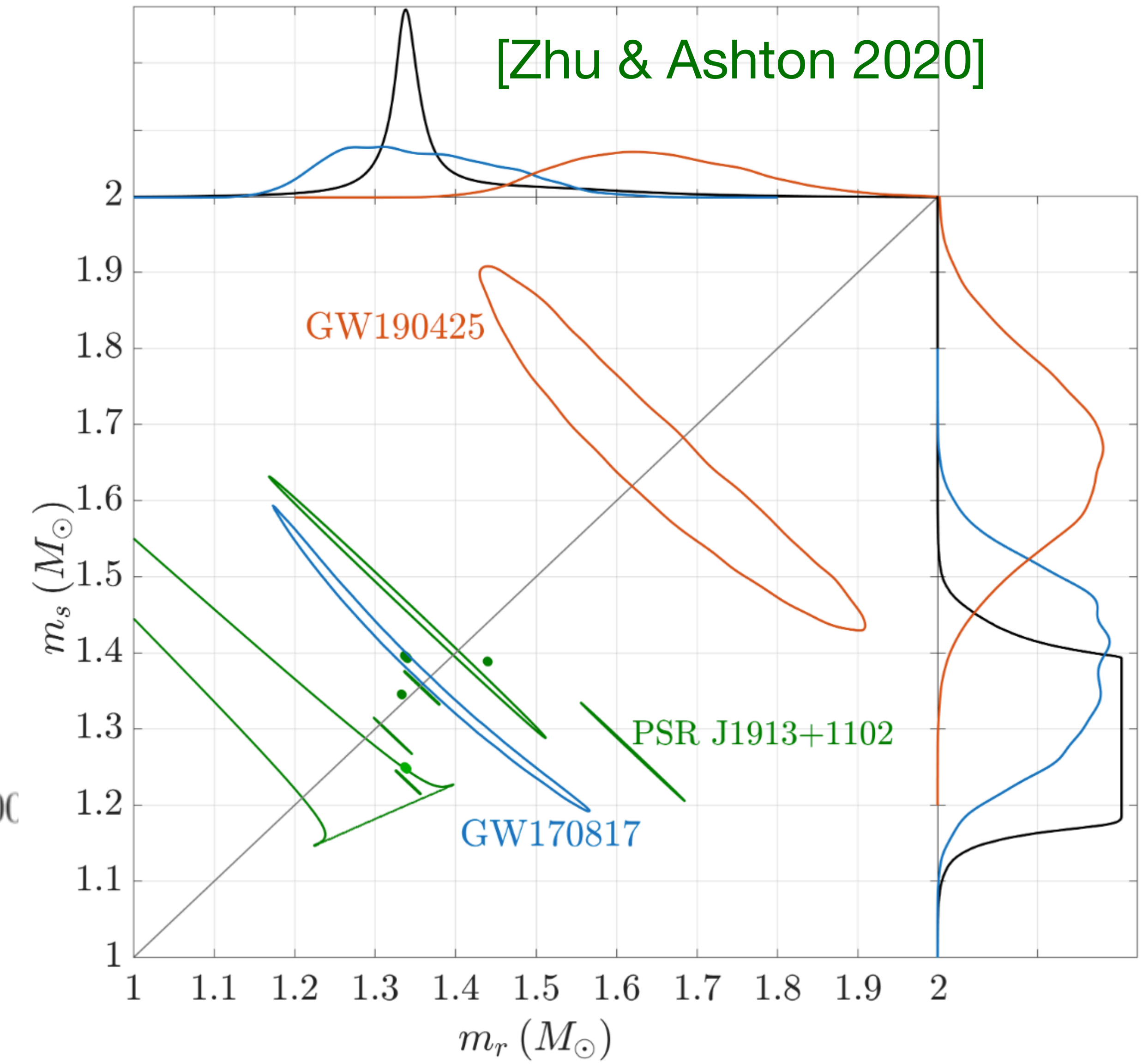
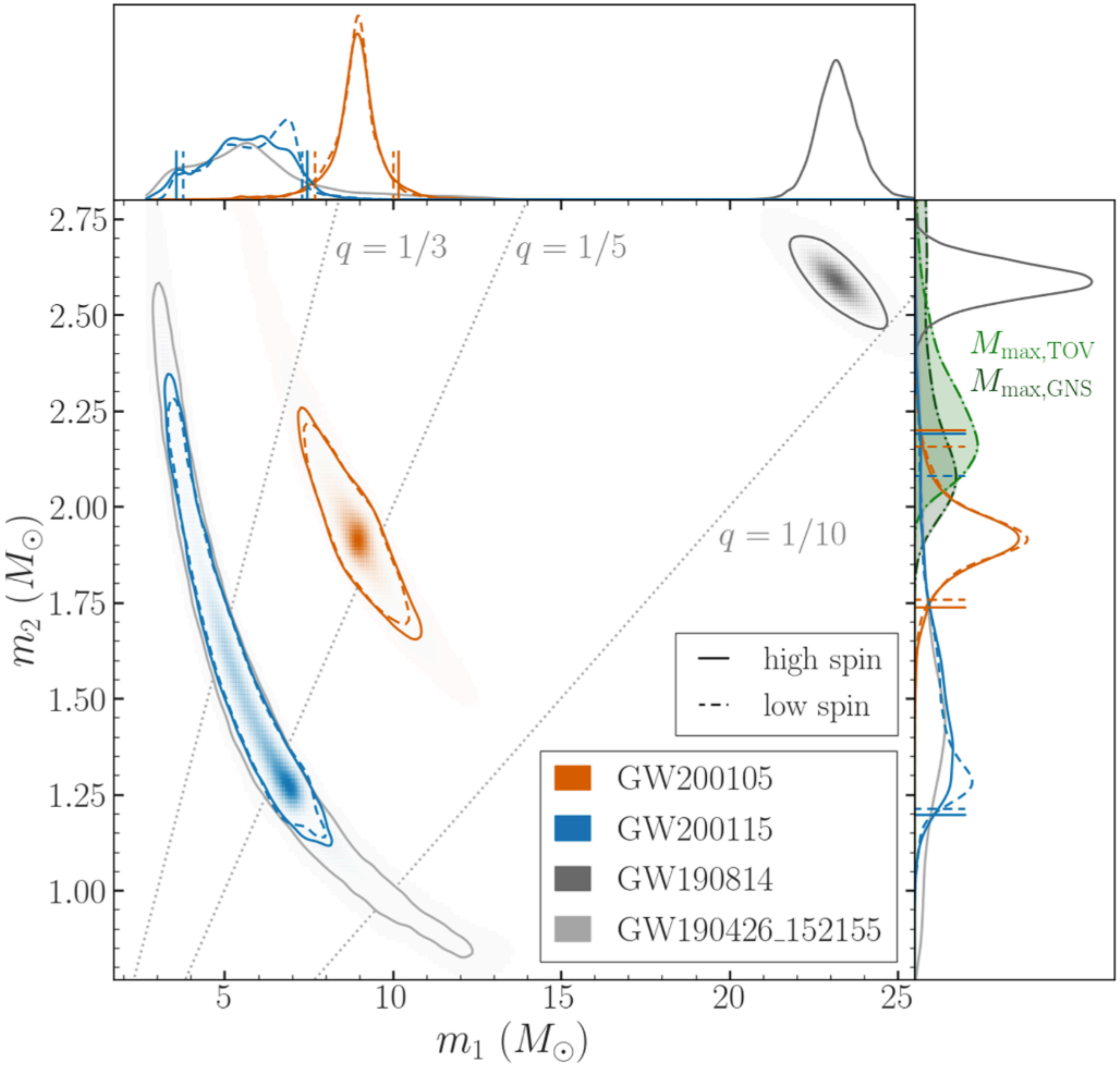


How do binary neutron stars form?

What are the differences between GW sources and Galactic binaires?

Neutron star-black hole: mixed binaries



GW200115

$$m_1 = 5.7^{+1.8}_{-2.1}\ M_\odot$$

$$m_2 = 1.5^{+0.7}_{-0.3}\ M_\odot$$

GW200105

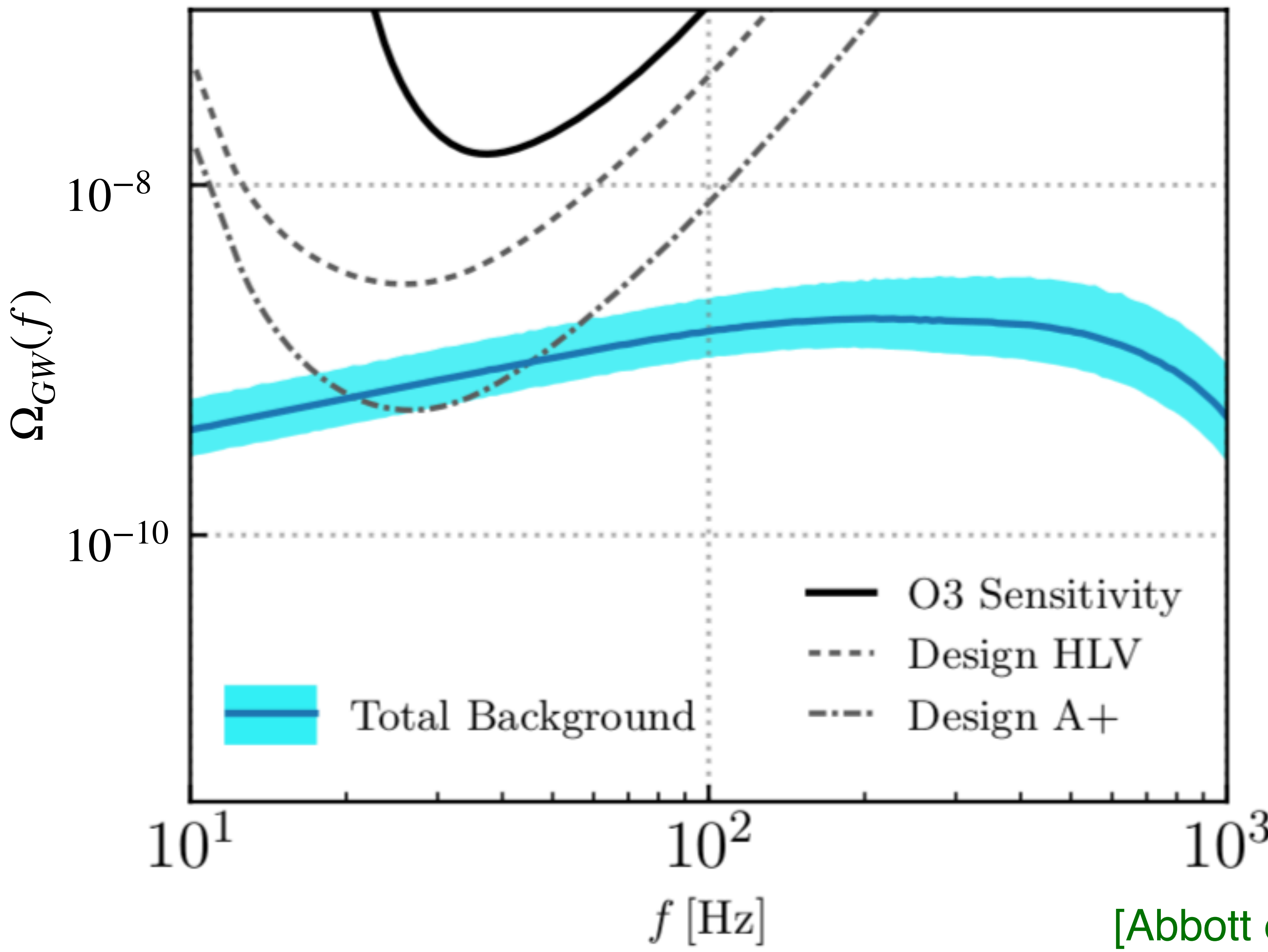
$$m_1 = 8.9^{+1.2}_{-1.5}\ M_\odot$$

$$m_2 = 1.9^{+0.3}_{-0.2}\ M_\odot$$

[Abbott et al. 2021, ApJL, 915, L5]

Stochastic GW background from compact binaries: predictions

Unresolved compact binary coalescences: BBH+BNS+NSBH



Energy density:

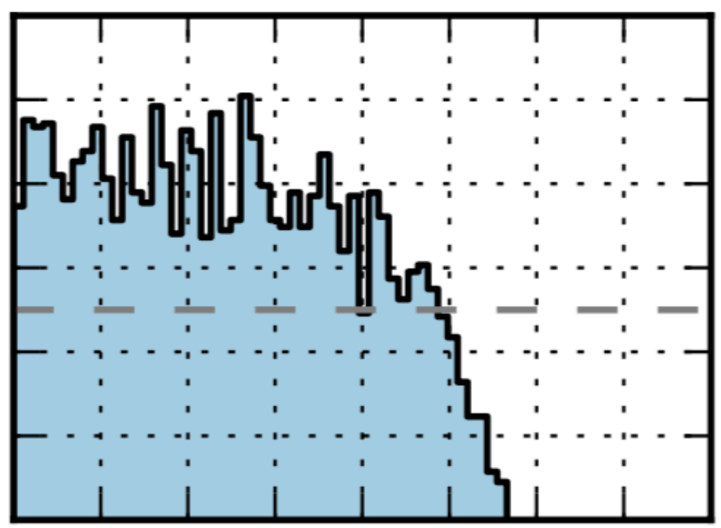
$$\Omega_{GW}(f) = \frac{1}{\rho_c}\frac{d\rho}{d\ln f}$$

Parametrization:

$$\Omega_{GW}(f) = \Omega_{ref}\left(\frac{f}{f_{ref}}\right)^{\alpha}$$

[Abbott et al. 2023, PRX, 13, 011048]

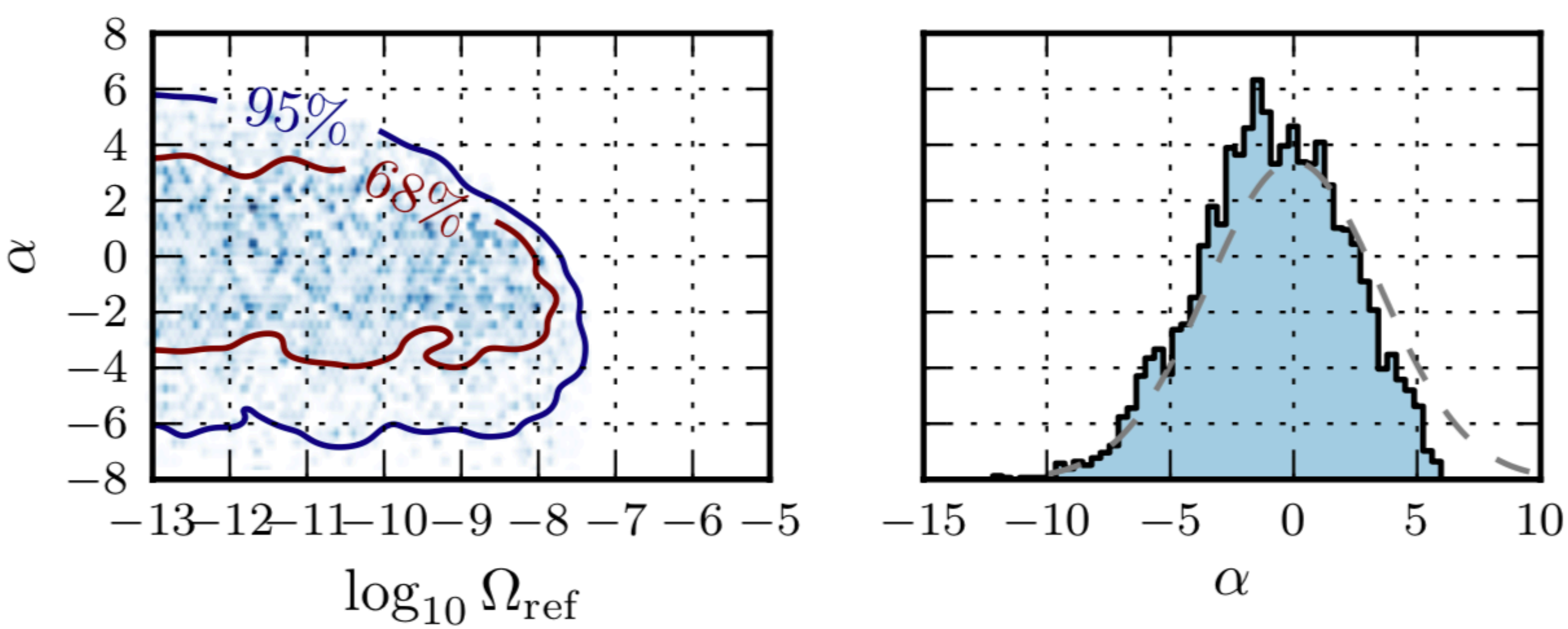
Upper limits on the stochastic GW background



Unresolved astrophysical sources

Cosmological sources (early Universe)

No detection in O3, upper limits on amplitude

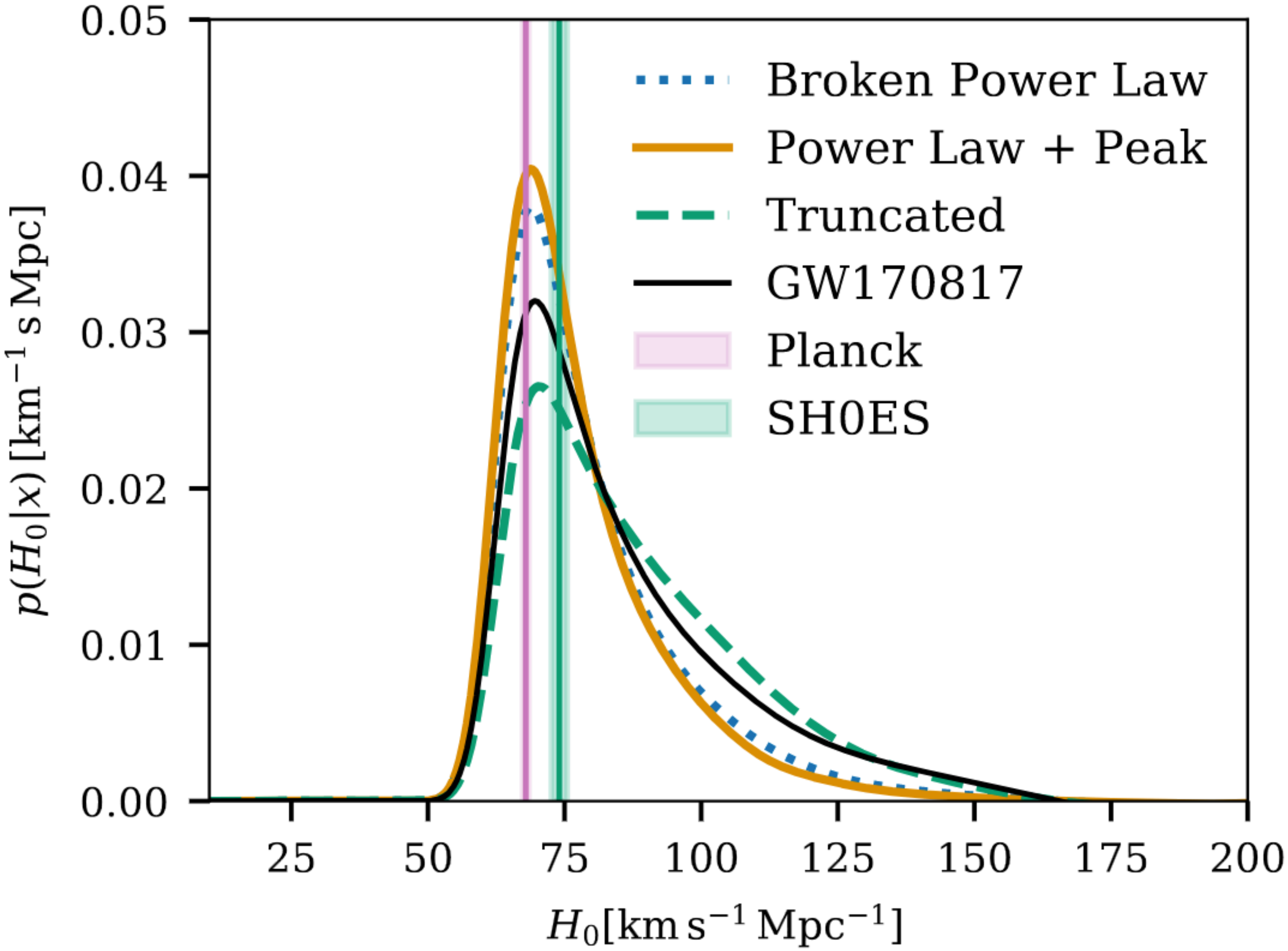


Energy density:

$$\Omega_{GW}(f) = \Omega_{ref}\left(\frac{f}{f_{ref}}\right)^{\alpha}$$

[Abbott et al. 2021, PRD, 104, 022004]

Measuring the cosmic expansion history



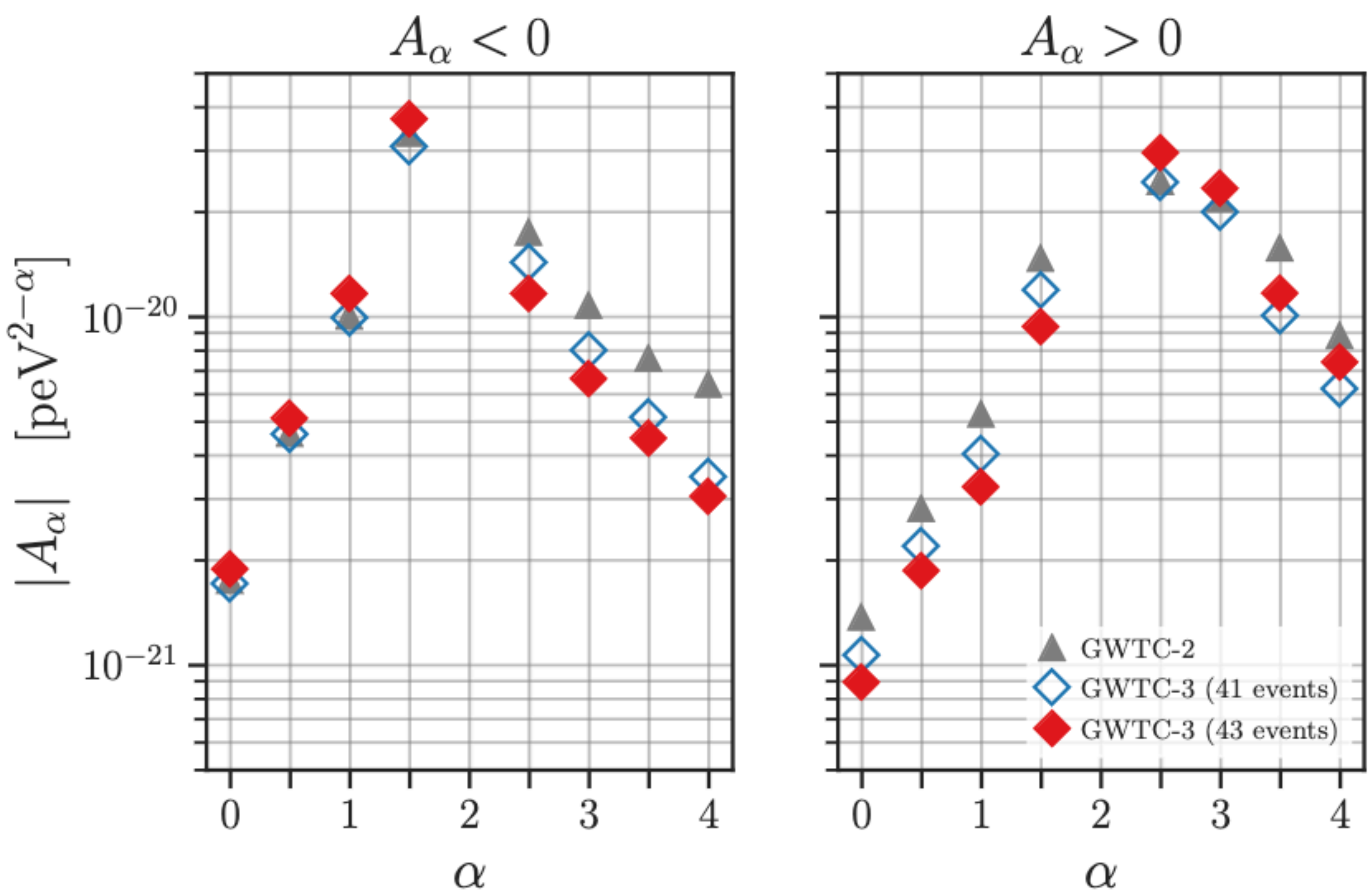
Standard siren: GW170817

Dark sirens: statistical methods

[Abbott et al. 2023, ApJ, 949, 76]

Testing GR: GW dispersion relation

Modified dispersion relation: $E^2 = p^2c^2 + A_\alpha p^\alpha c^\alpha$



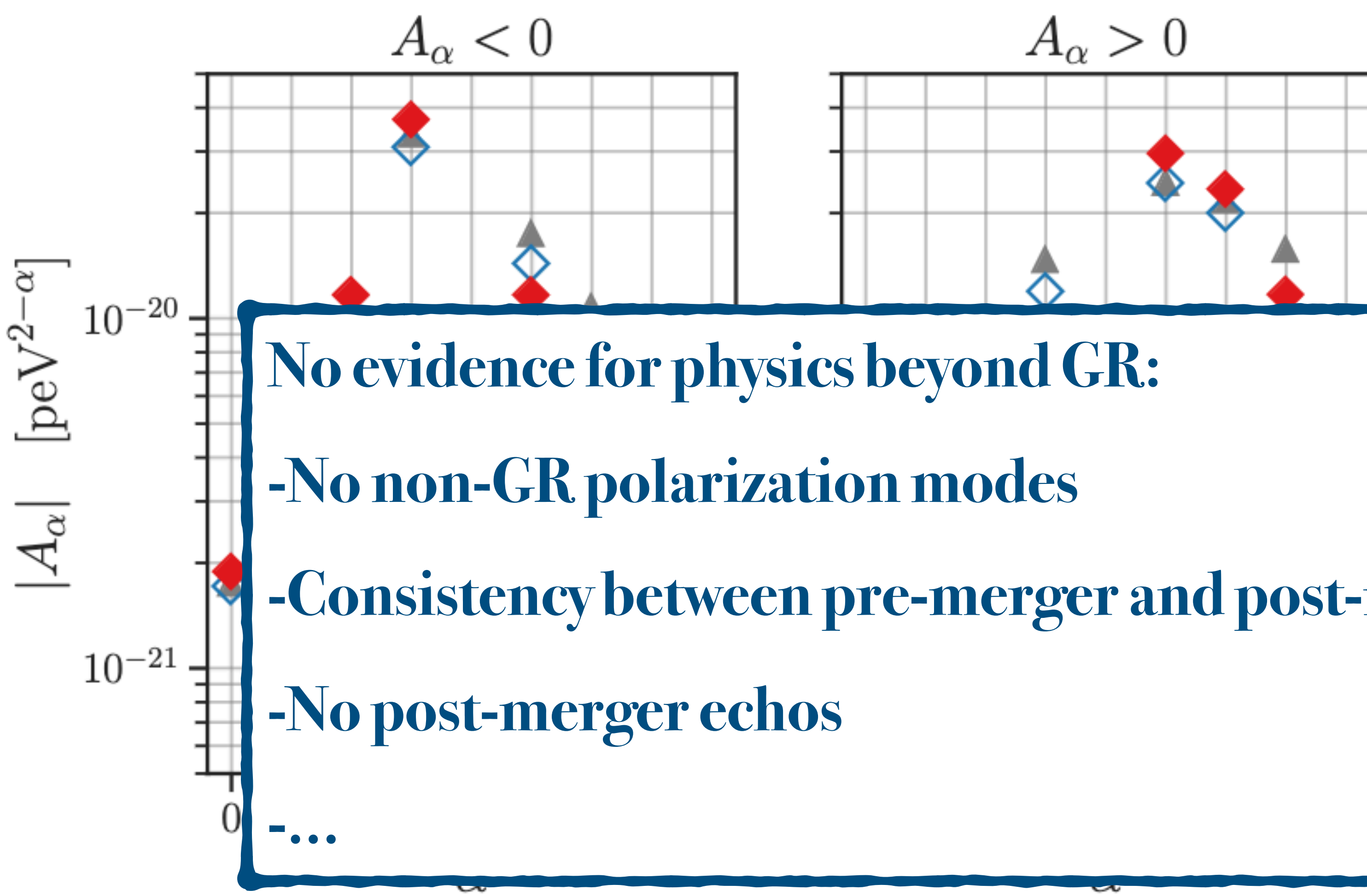
Constraint on graviton mass from A_0:

$$m_g \leq 1.27 \cdot 10^{-23}\ eV/c^2$$

[Abbott et al. arXiv:2112.06861]

Testing GR: GW dispersion relation

Modified dispersion relation: $E^2 = p^2c^2 + A_\alpha p^\alpha c^\alpha$



Constraint on graviton mass from A_0:

c^2

No evidence for physics beyond GR:

-No non-GR polarization modes

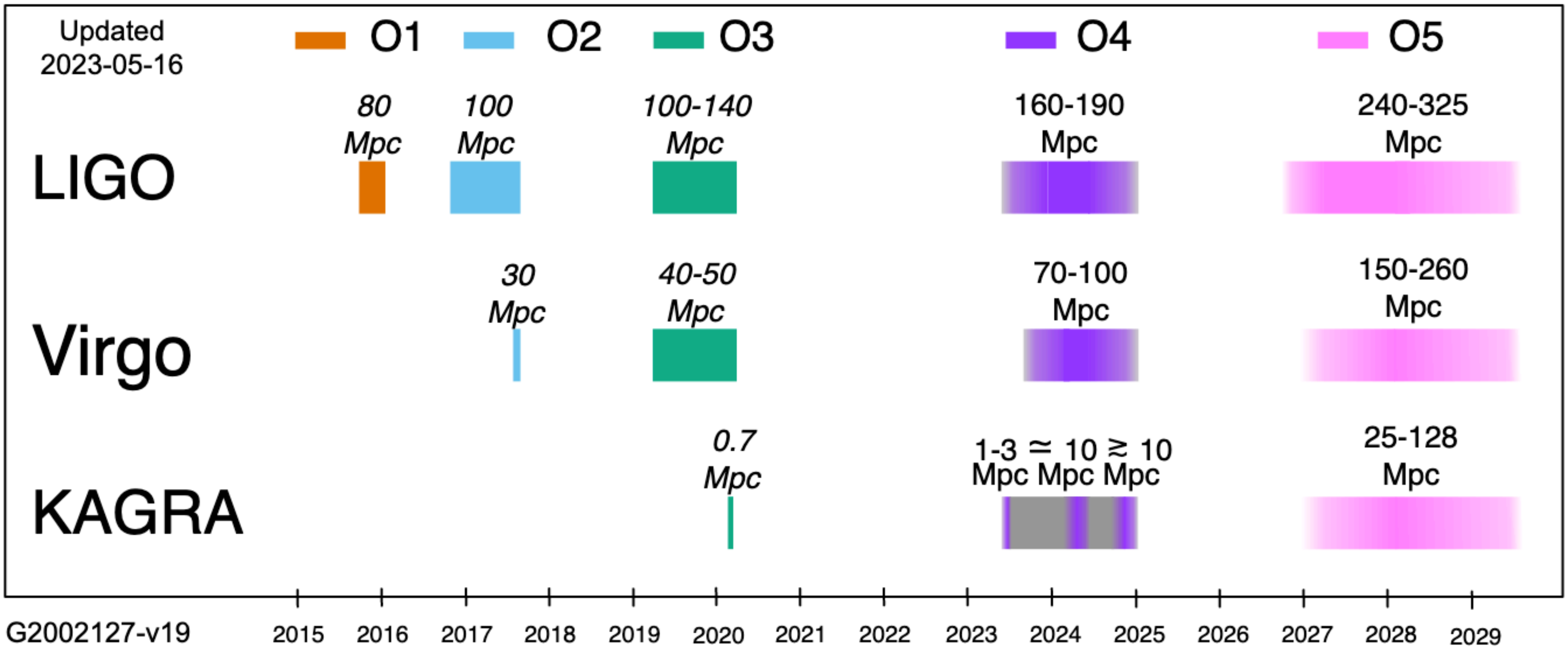
-Consistency between pre-merger and post-merger final mass and spin

-No post-merger echos

-...

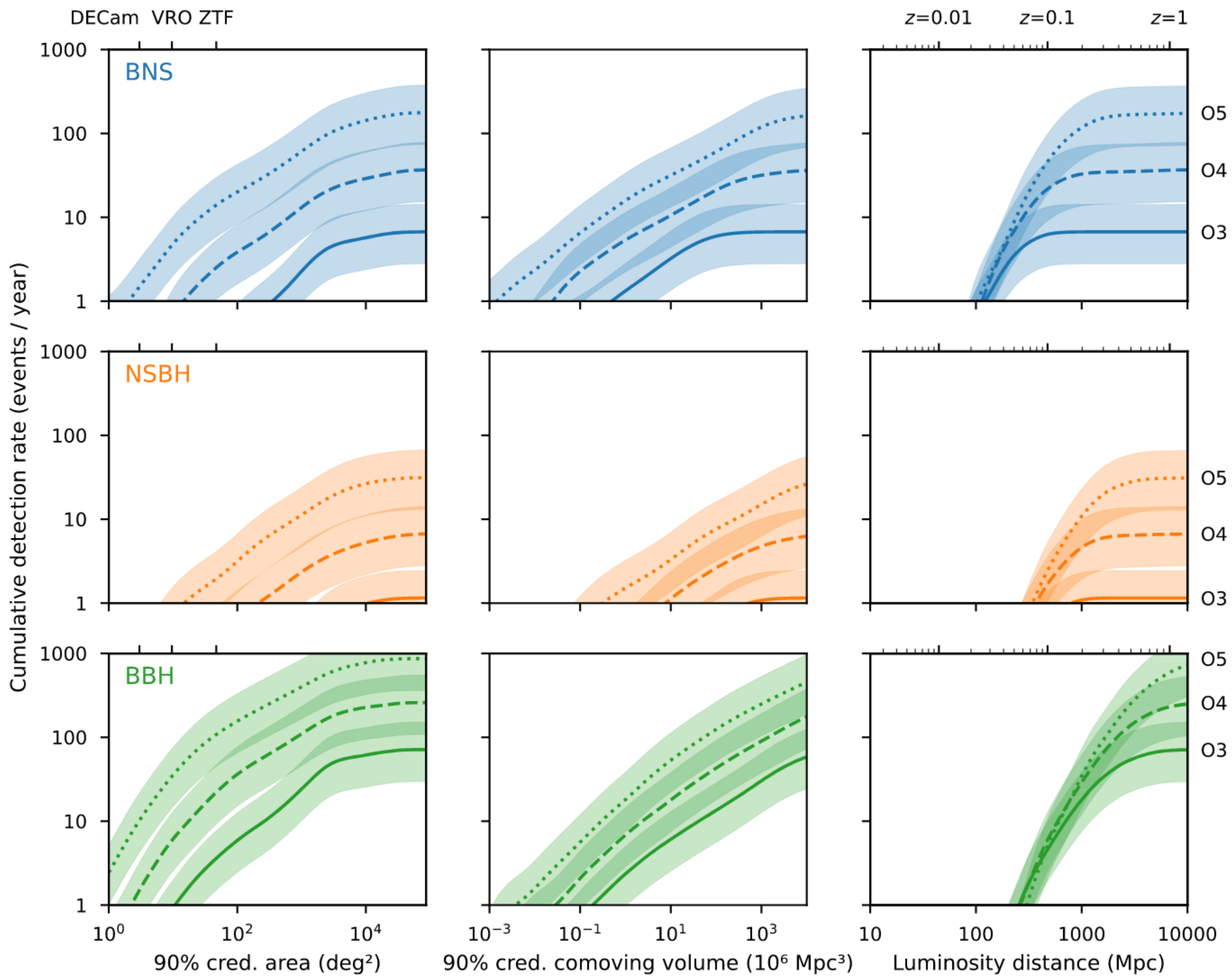
[Abbott et al. arXiv:2112.06861]

Prospects for O4/O5 runs



[LIGO Public User Guide: https://emfollow.docs.ligo.org/userguide/capabilities.html]

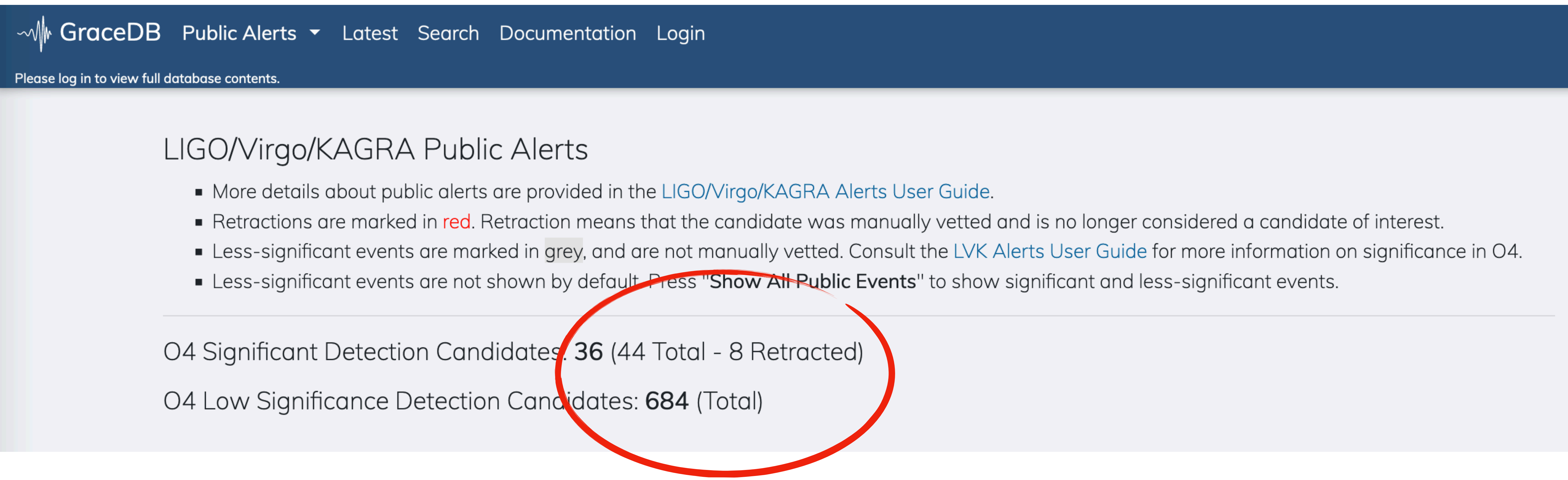
Prospects for O4/O5 runs



[LIGO Public User Guide: https://emfollow.docs.ligo.org/userguide/capabilities.html]

O4 run ongoing…

O4 started on 24 May 2023 and will last 20 calendar months including up to 2 months of commissioning breaks for maintenance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LIGO/Virgo/KAGRA Public Alerts

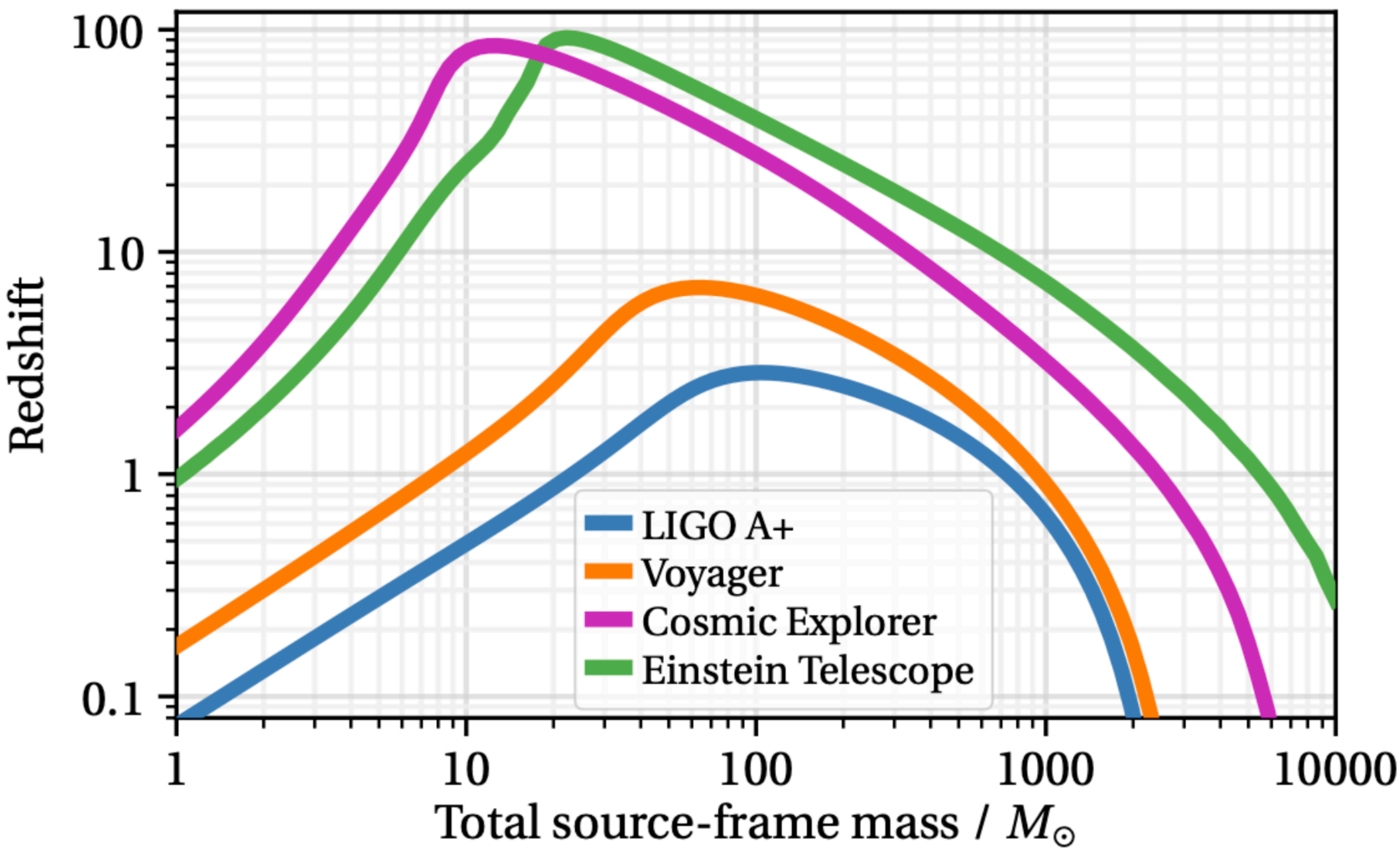
- More details about public alerts are provided in the LIGO/Virgo/KAGRA Alerts User Guide.
- Retractions are marked in red. Retraction means that the candidate was manually vetted and is no longer considered a candidate of interest.
- Less-significant events are marked in grey, and are not manually vetted. Consult the LVK Alerts User Guide for more information on significance in O4.
- Less-significant events are not shown by default. Press "**Show All Public Events**" to show significant and less-significant events.

O4 Significant Detection Candidates: **36** (44 Total - 8 Retracted)

O4 Low Significance Detection Candidates: **684** (Total)

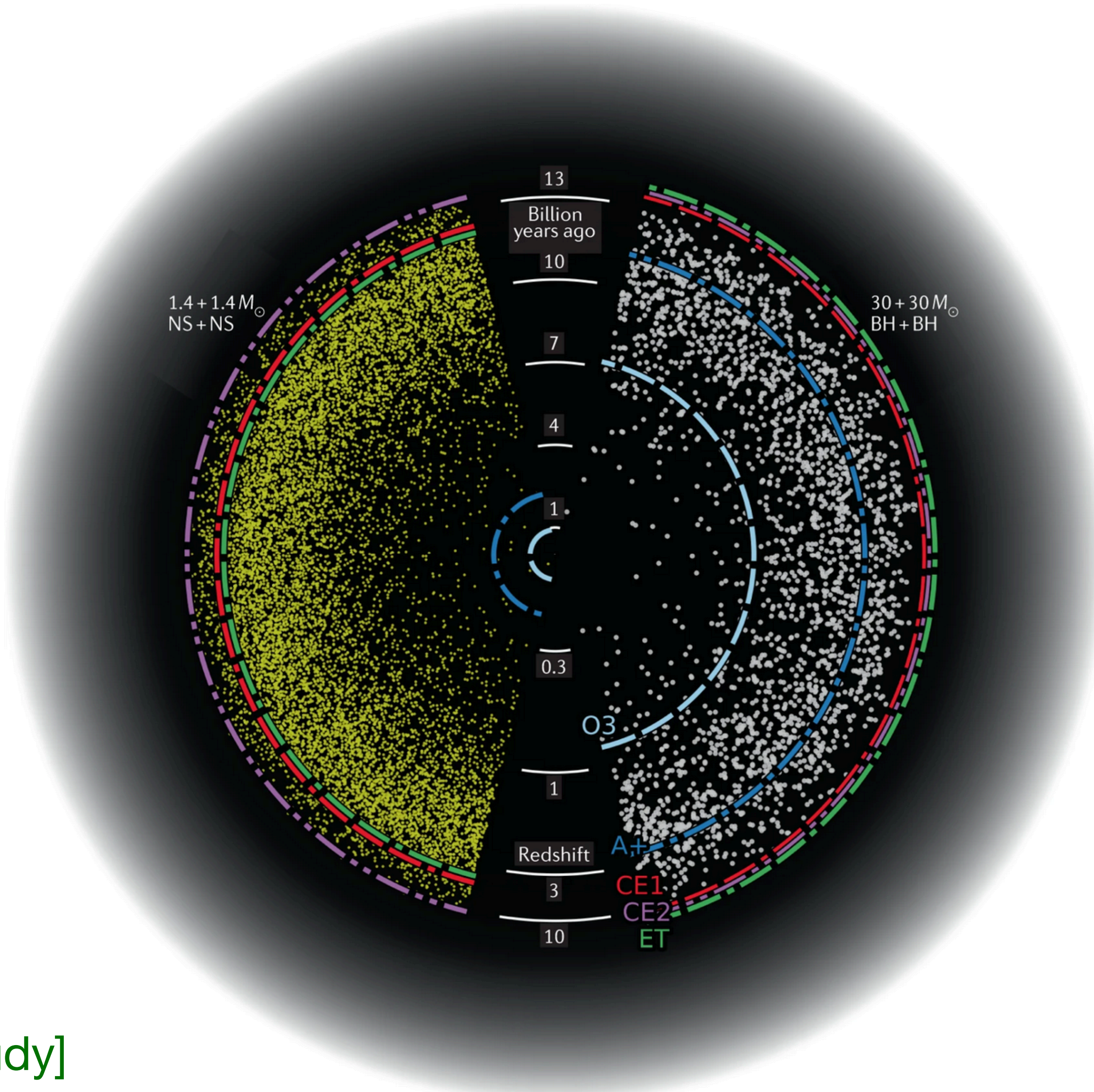
[as of September 1st 2023]

Third generation detectors: Einstein Telescope and Cosmic Explorer



[Evans et al. 2021, Cosmic Horizon Study, arXiv:2109.09882]

Third generation detectors: Einstein Telescope and Cosmic Explorer



[Evans et al. 2021,
Cosmic Horizon Study]

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