

Gravitational-wave detections with ground-base observatories

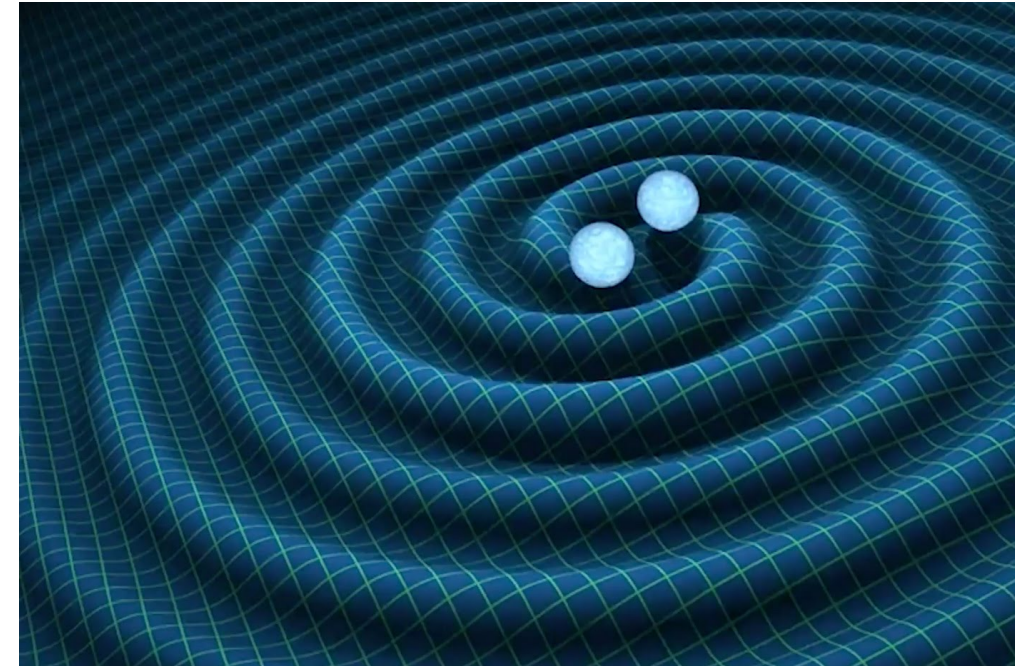
Irina Dvorkin

Institut d'Astrophysique de Paris

Sorbonne Université

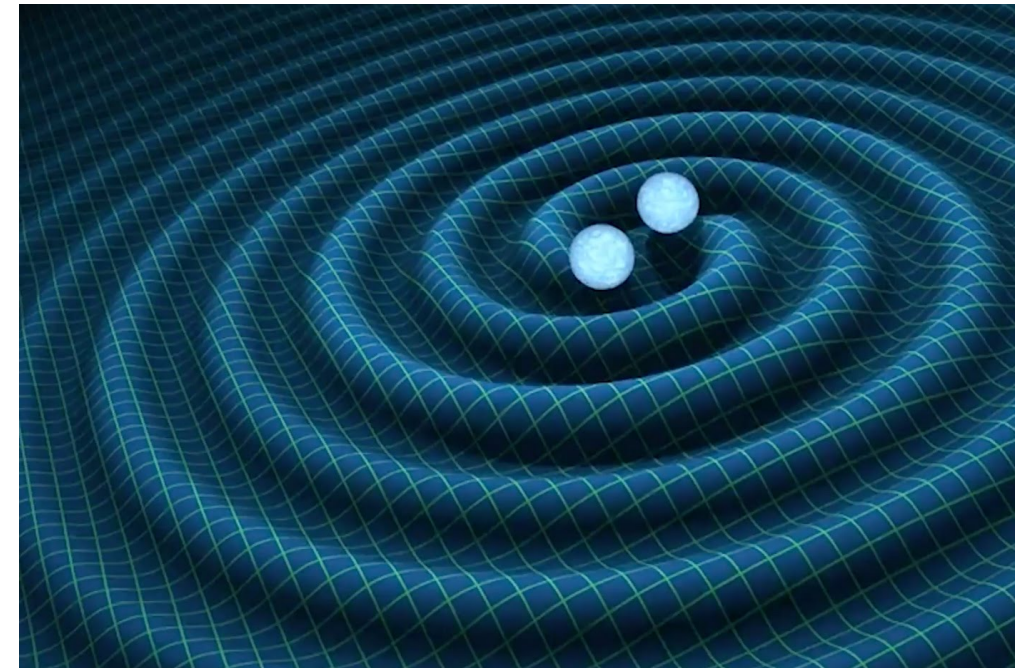
Gravitational-wave astronomy

- Gravitational waves: small perturbations of the metric that propagate with the speed of light
- Sources: compact, non-axisymmetric, accelerating mass distributions
 - compact binaries, rotating neutron stars, core-collapse supernovae...

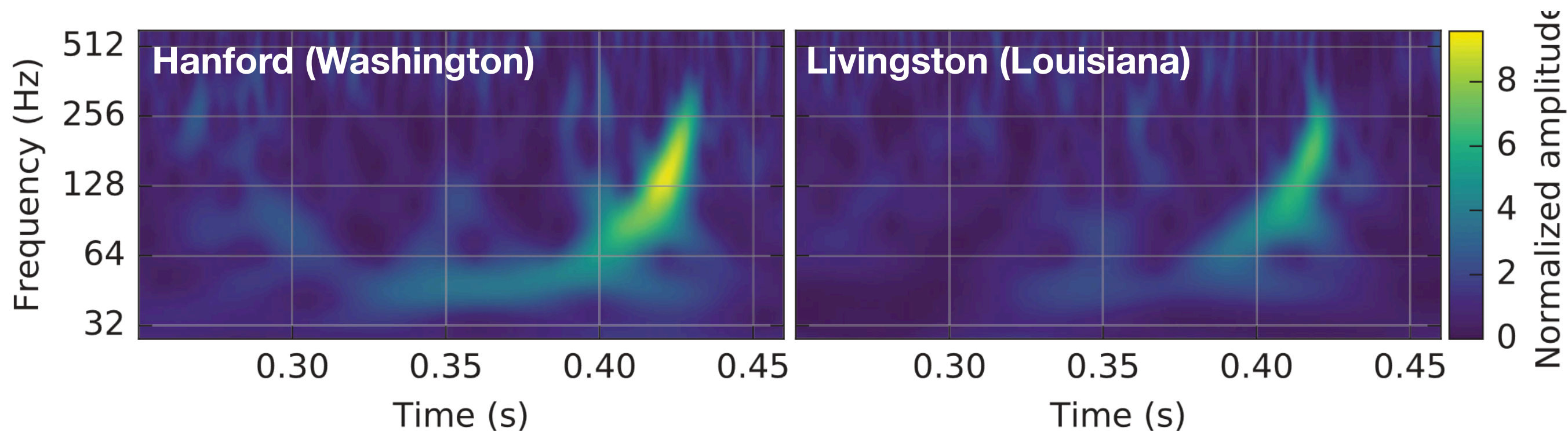


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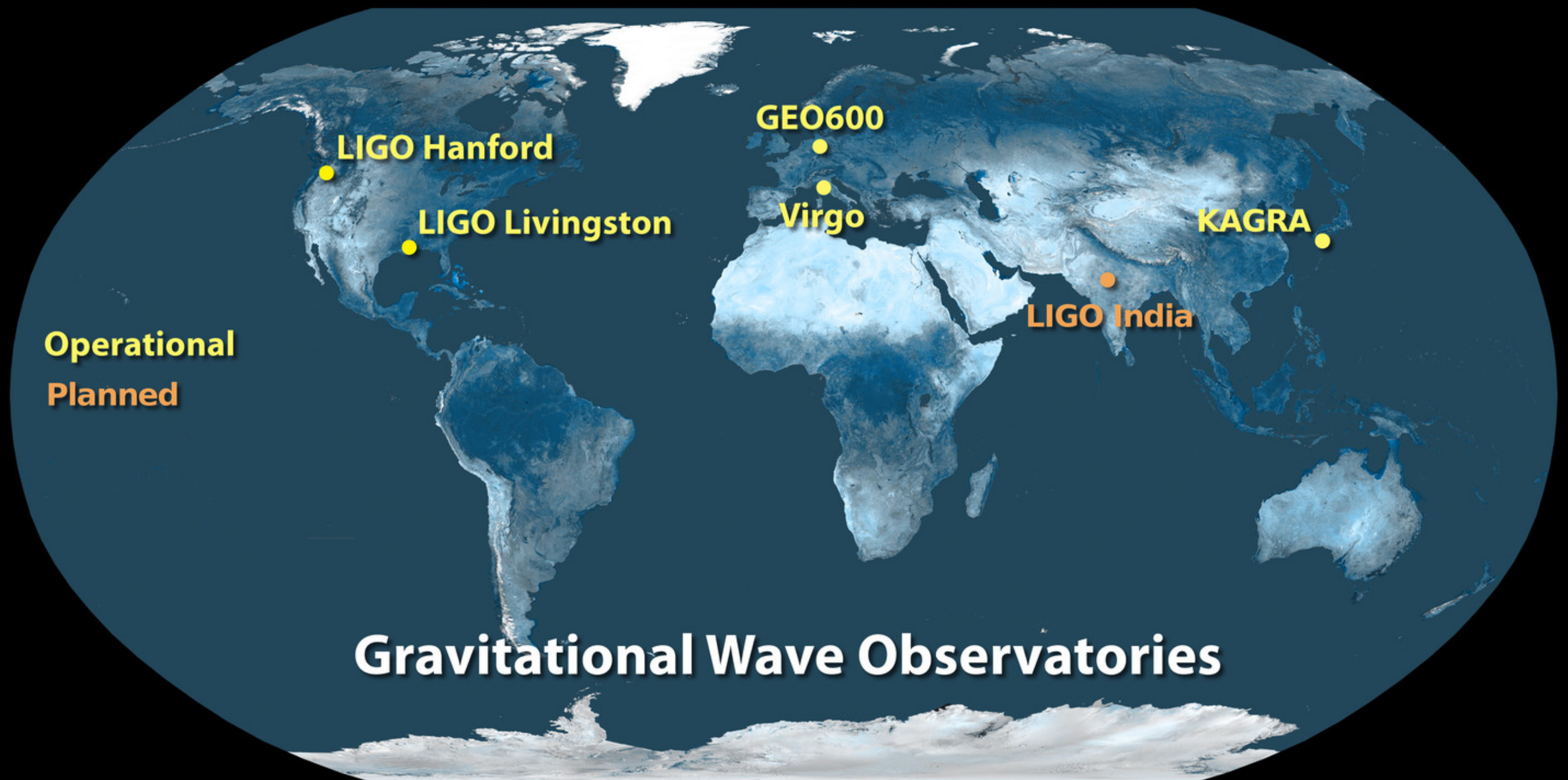


The first detection - GW150914:



[Abbott et al. 2016, PRL, 116, 061102]

Ground-based GW observatories



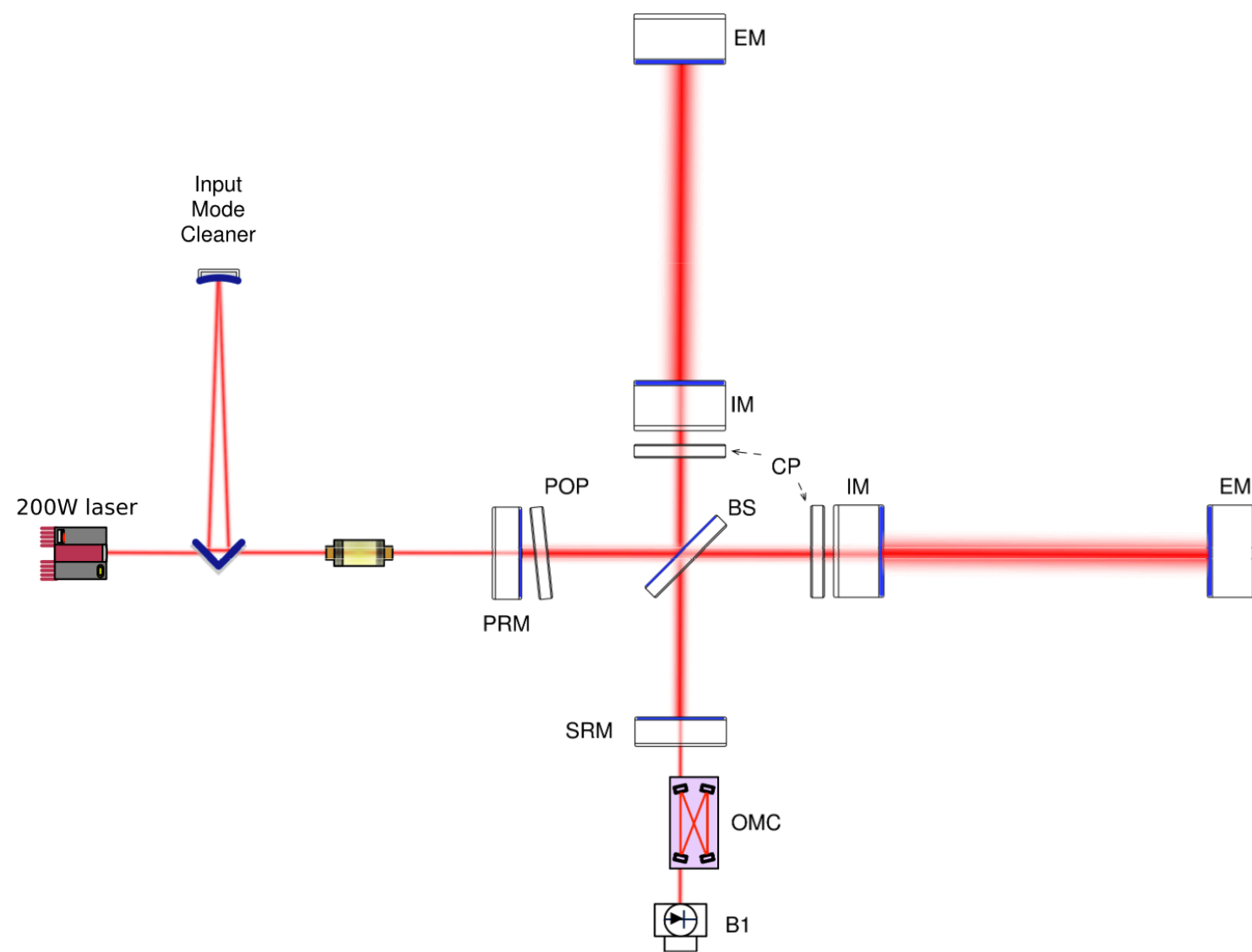
[Credits: Caltech/MIT/LIGO Lab]

Ground-based GW observatories



[Credits: Caltech/MIT/LIGO Lab; Virgo Collaboration]

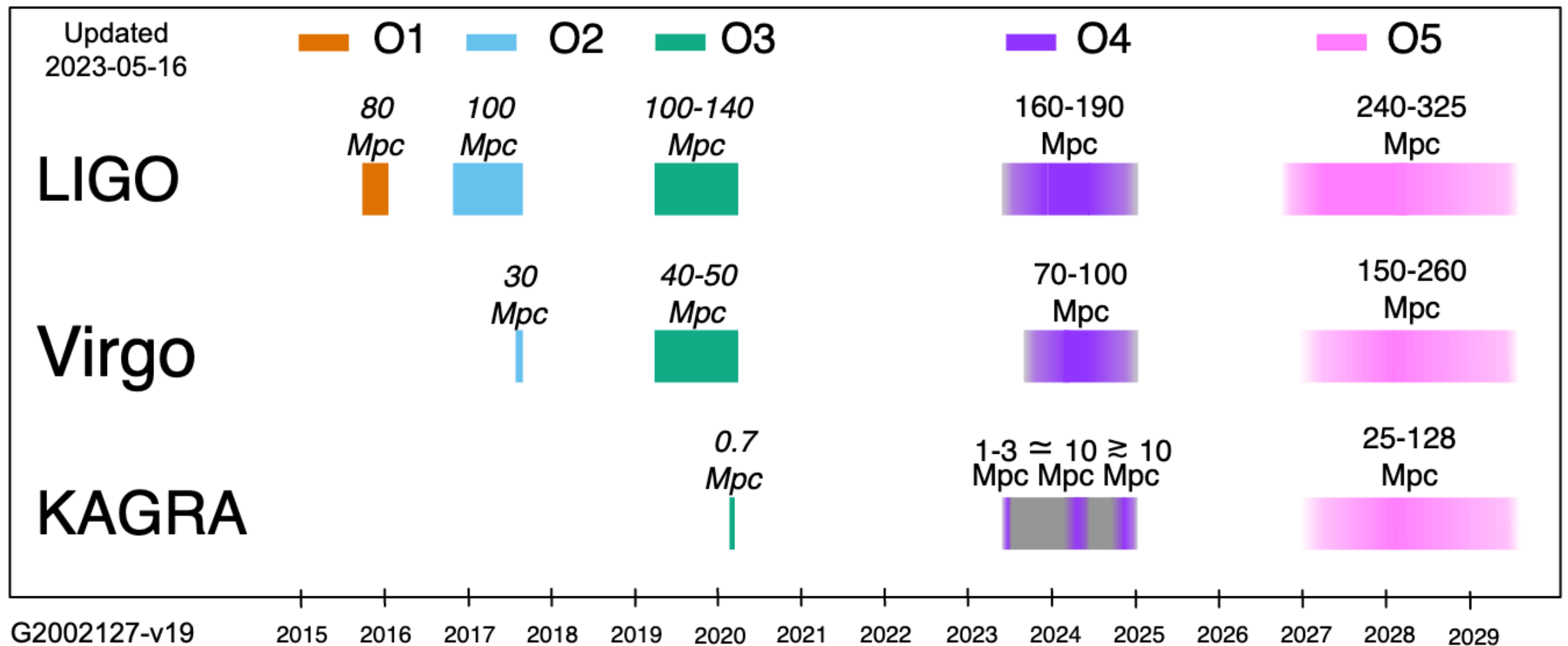
Ground-based GW observatories



[Acernese et al. 2015, CQG, 32, 024001]

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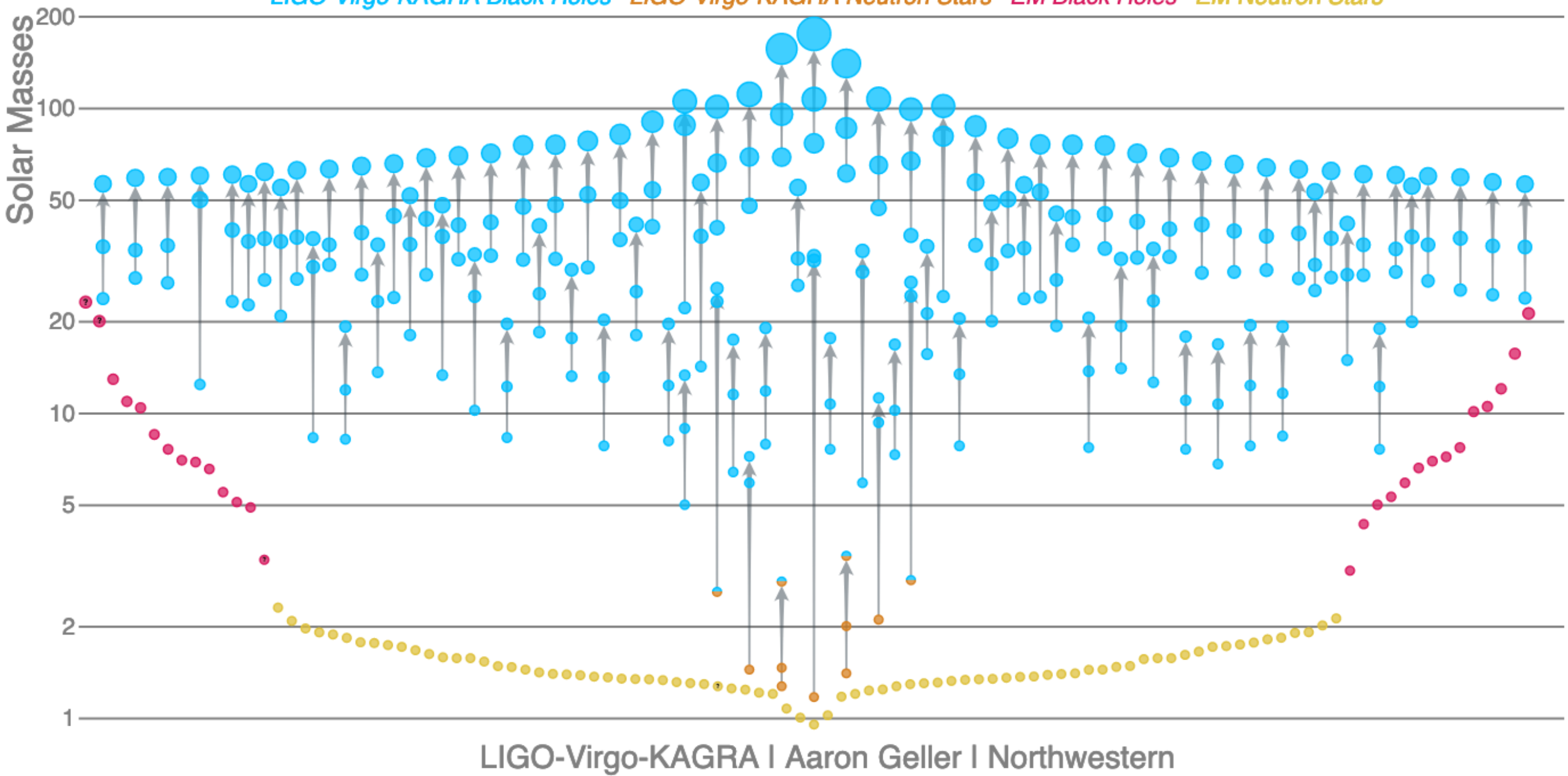
Ground-based GW observatories: detection range for BNS merger



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

Masses in the Stellar Graveyard

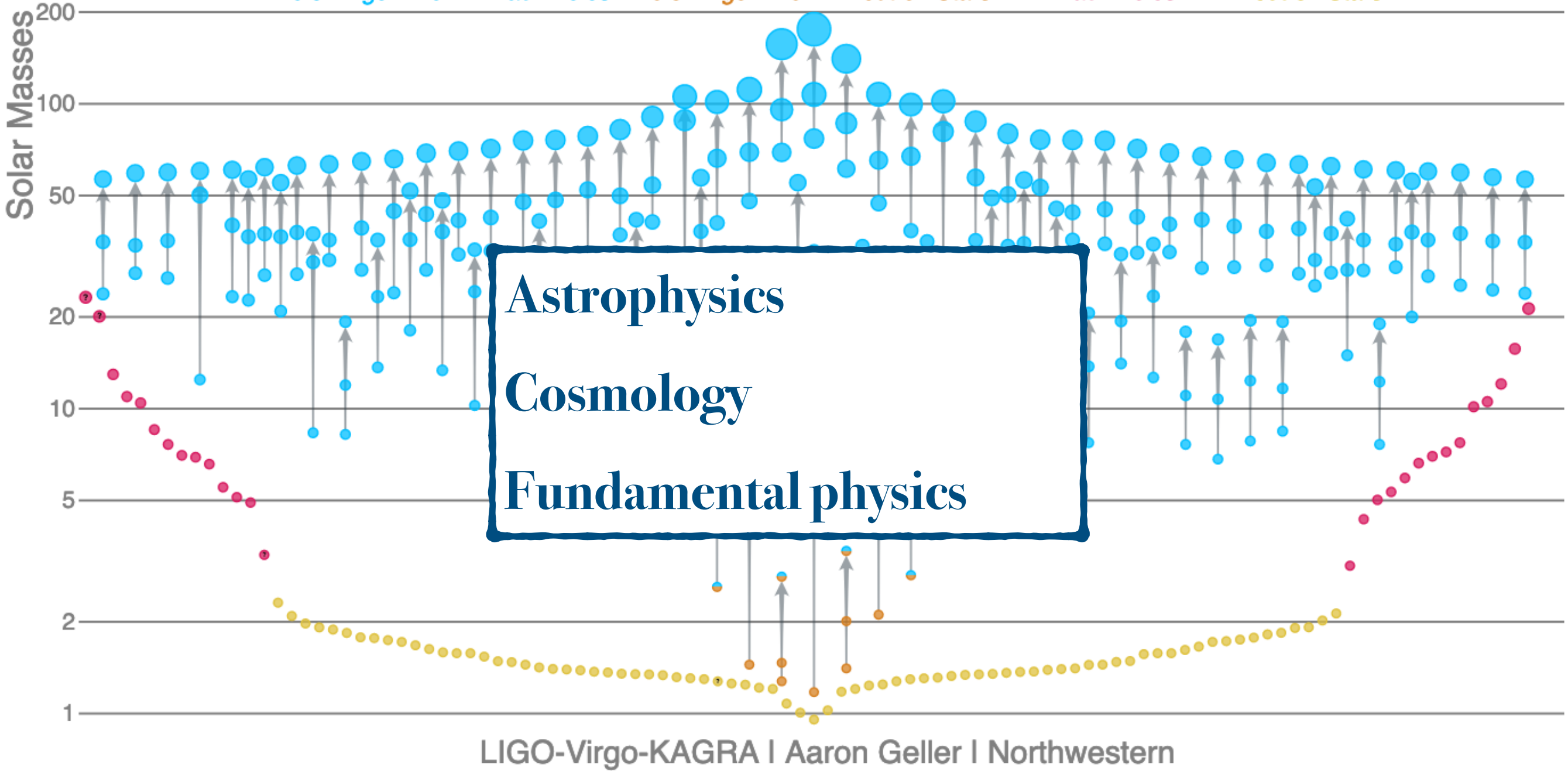
LIGO-Virgo-KAGRA Black Holes *LIGO-Virgo-KAGRA Neutron Stars* *EM Black Holes* *EM Neutron Stars*



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

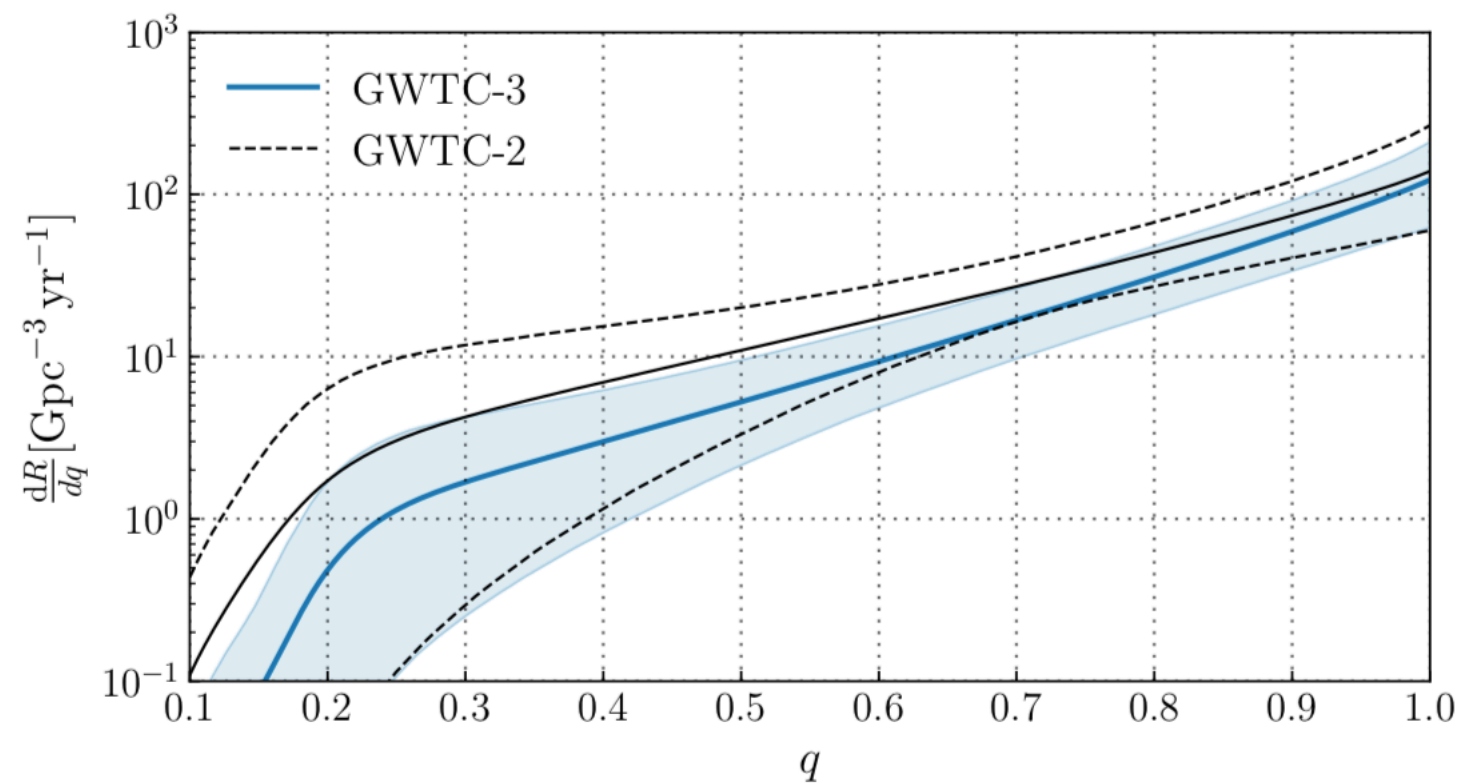
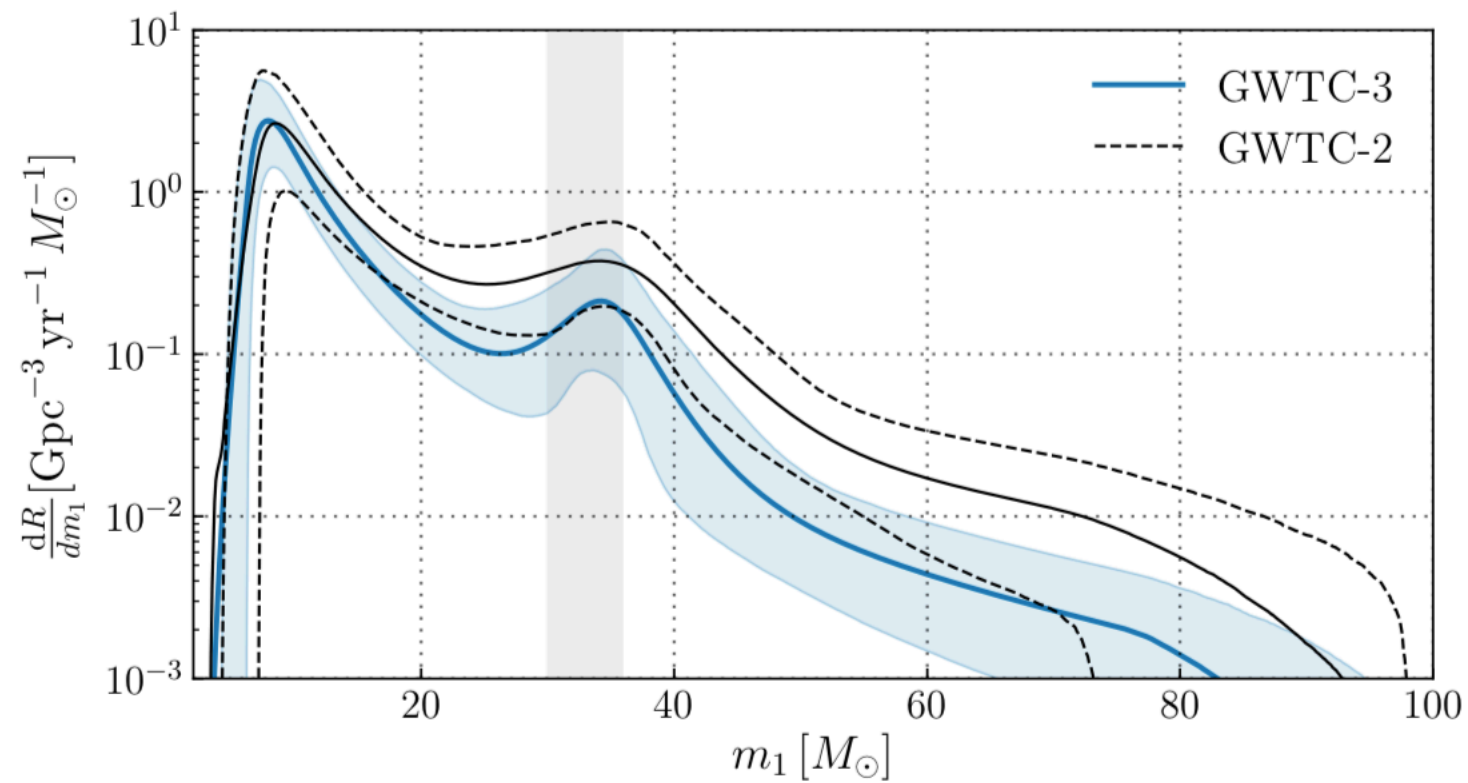
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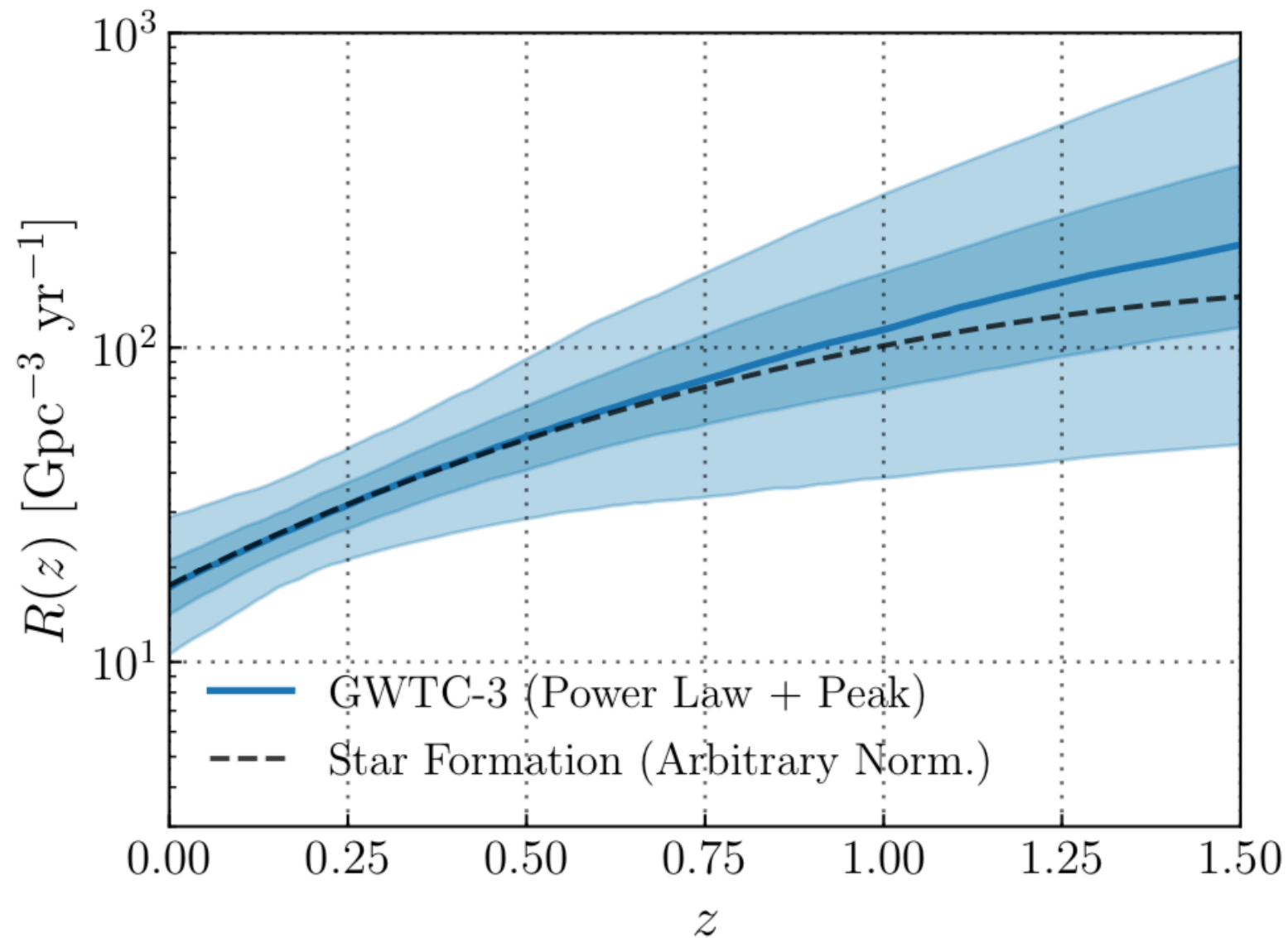
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Black hole populations: mass distribution



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

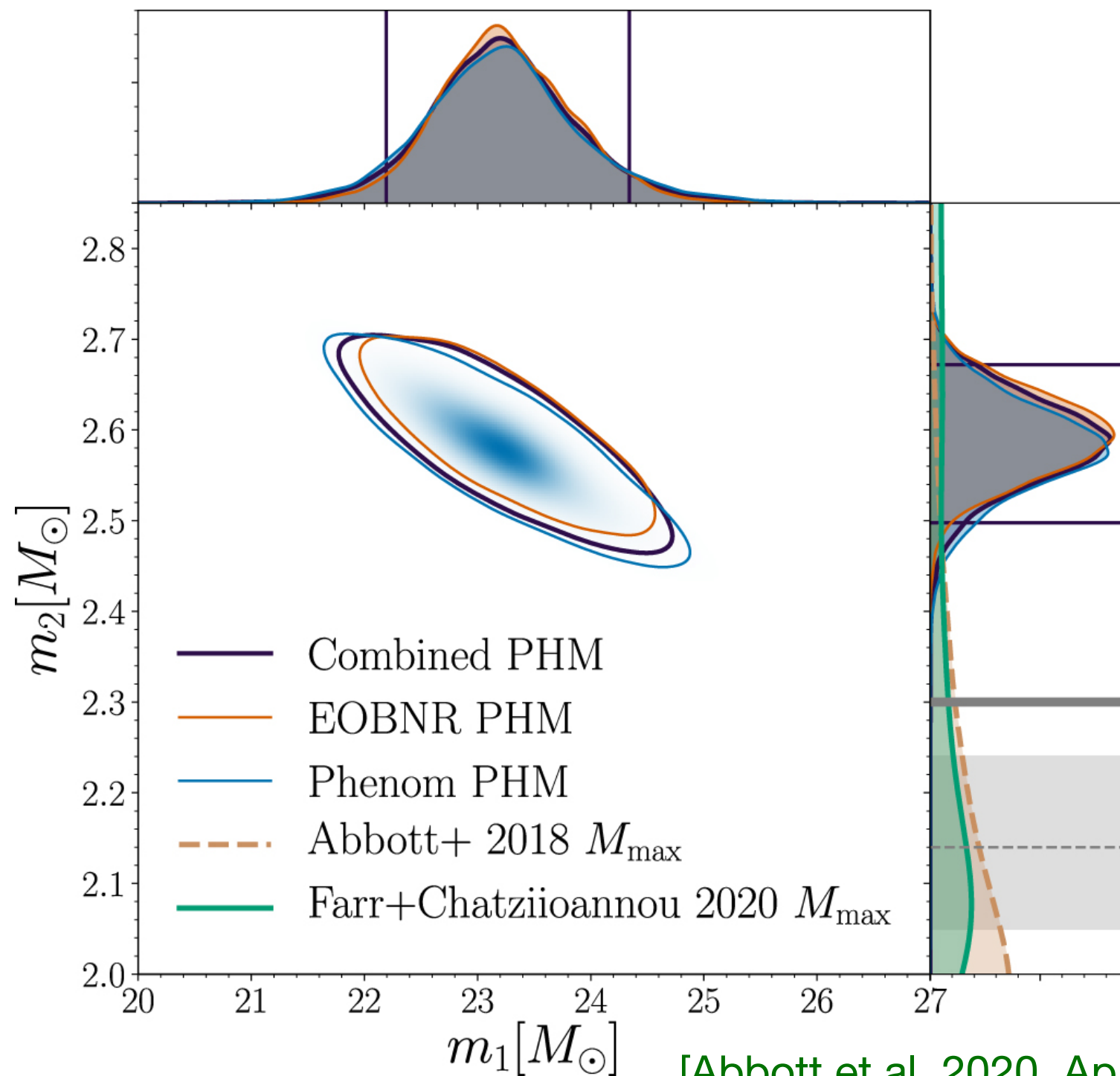
Black hole populations: merger rate evolution



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

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

Black holes in the lower mass gap



GW190814

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

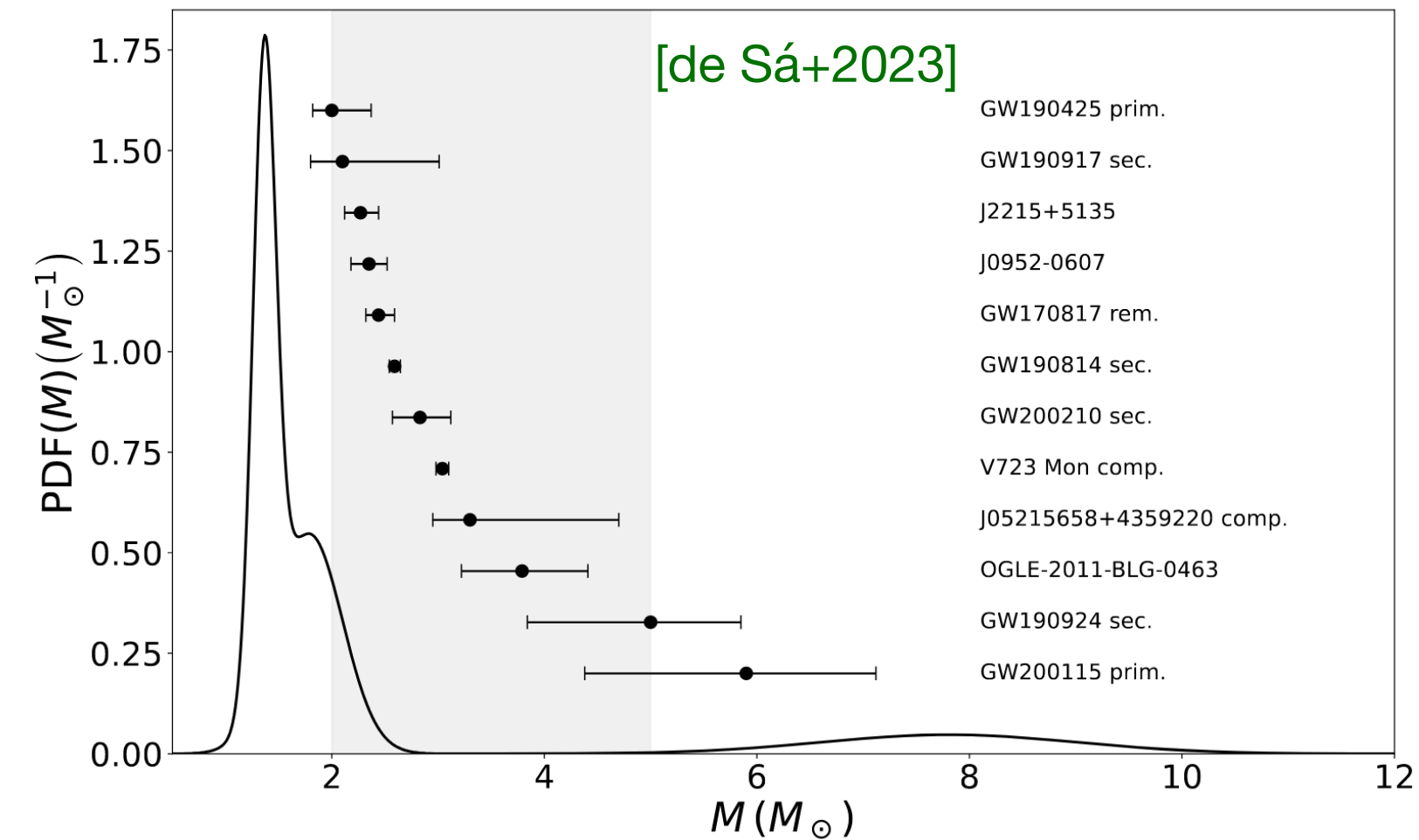
$$m_2 = 2.59^{+0.08}_{-0.09} M_{\odot}$$

Heaviest neutron star?

Lightest black hole?

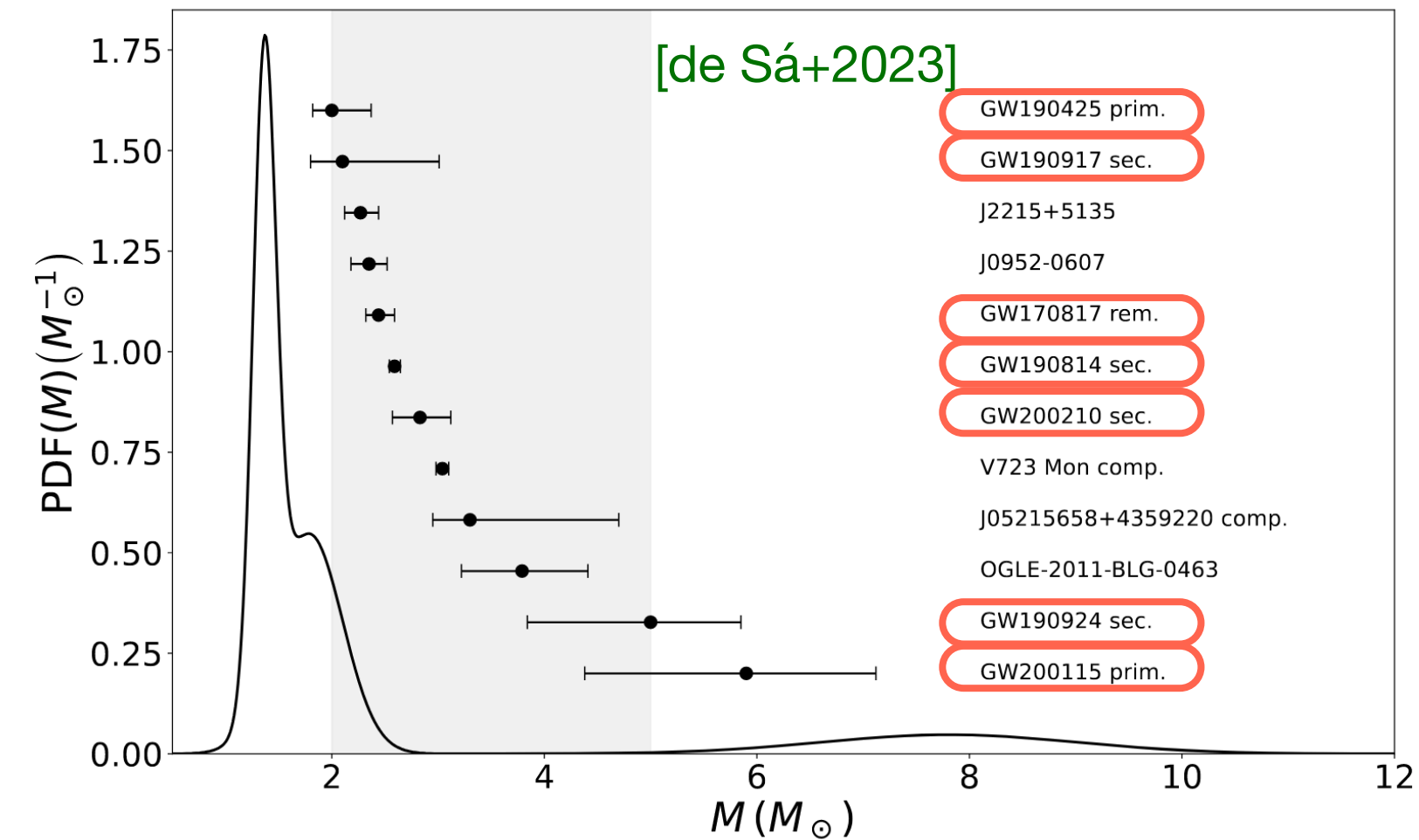
[Abbott et al. 2020, ApJL, 896, 44]

Black holes in the lower mass gap



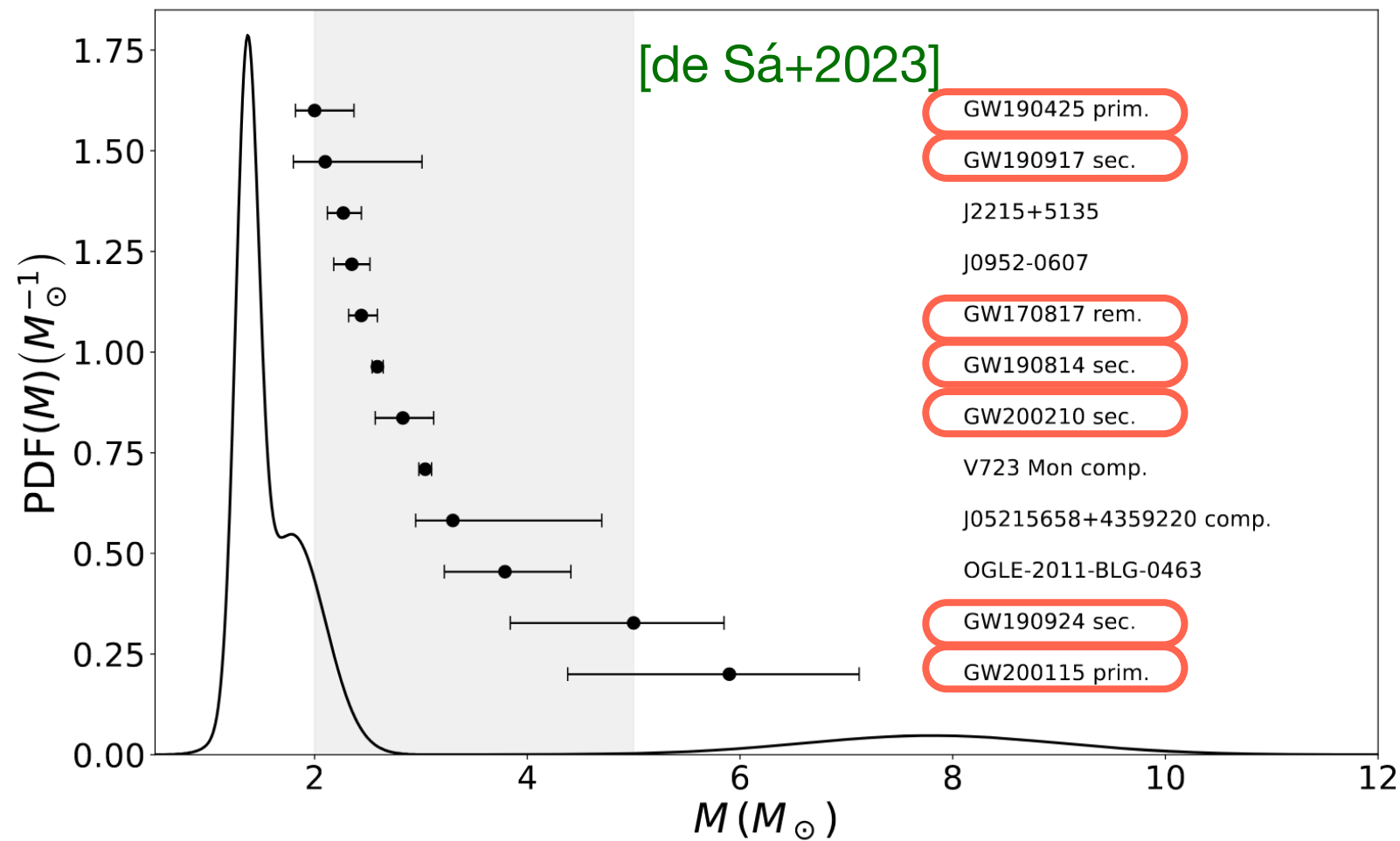
Is the mass gap real?
Is it an observational effect?

Black holes in the lower mass gap

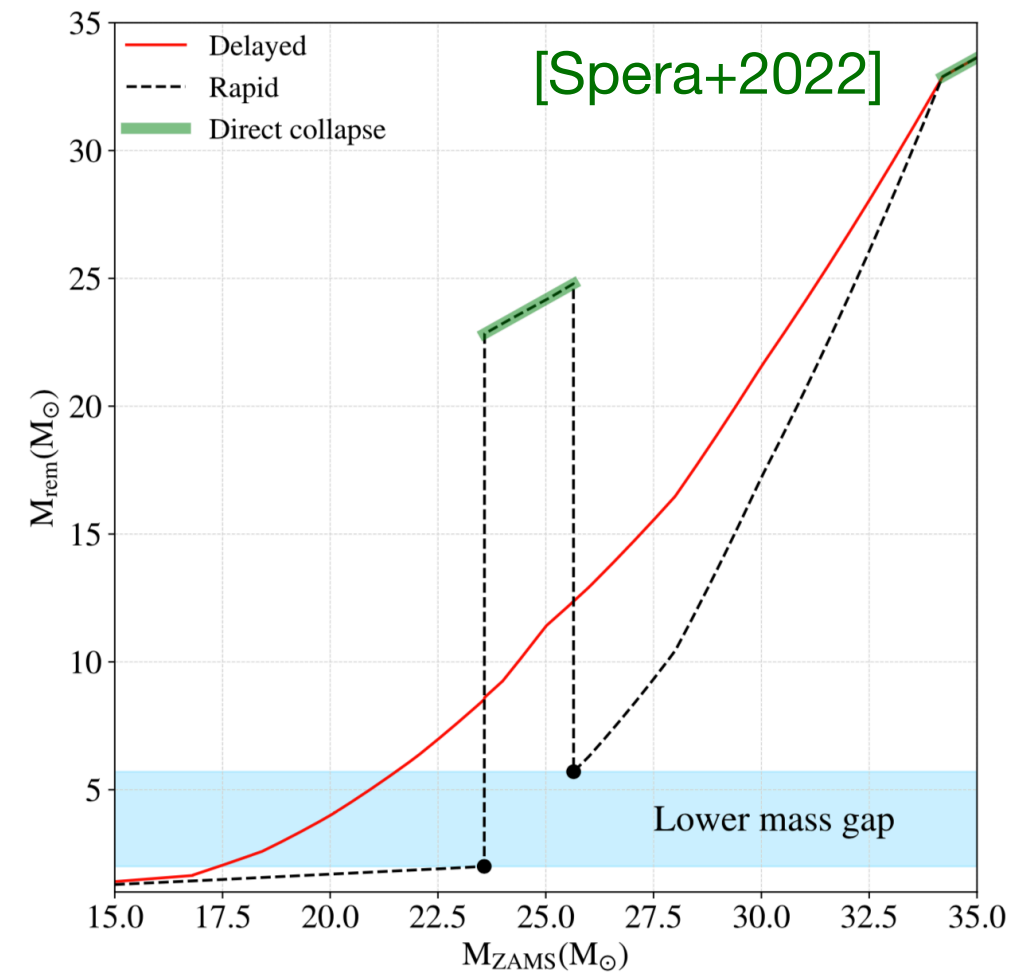


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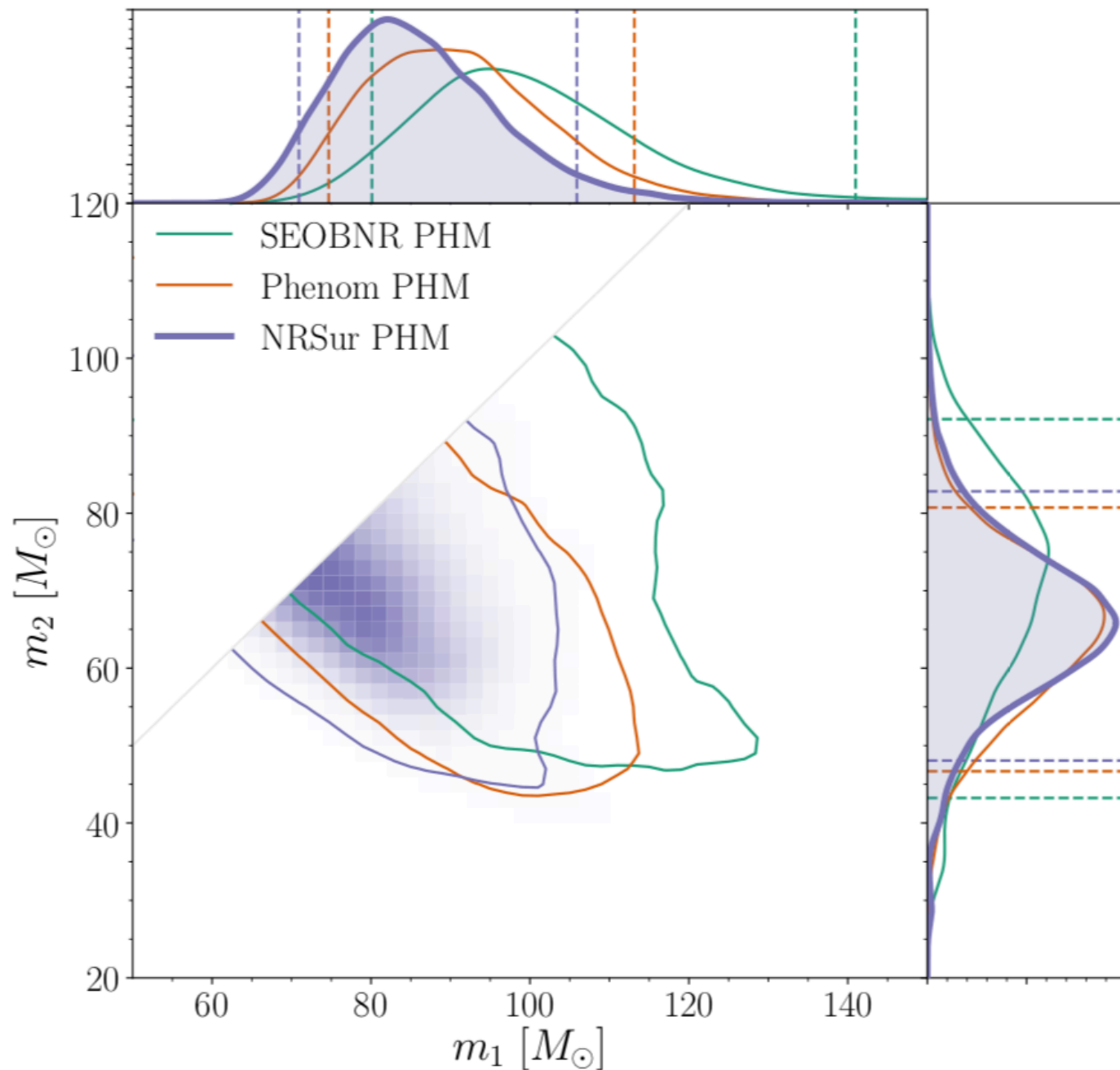


Is the mass gap real?
Is it an observational effect?



Implications for supernova
explosion mechanism?

Black holes in the upper mass gap



GW190521

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

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

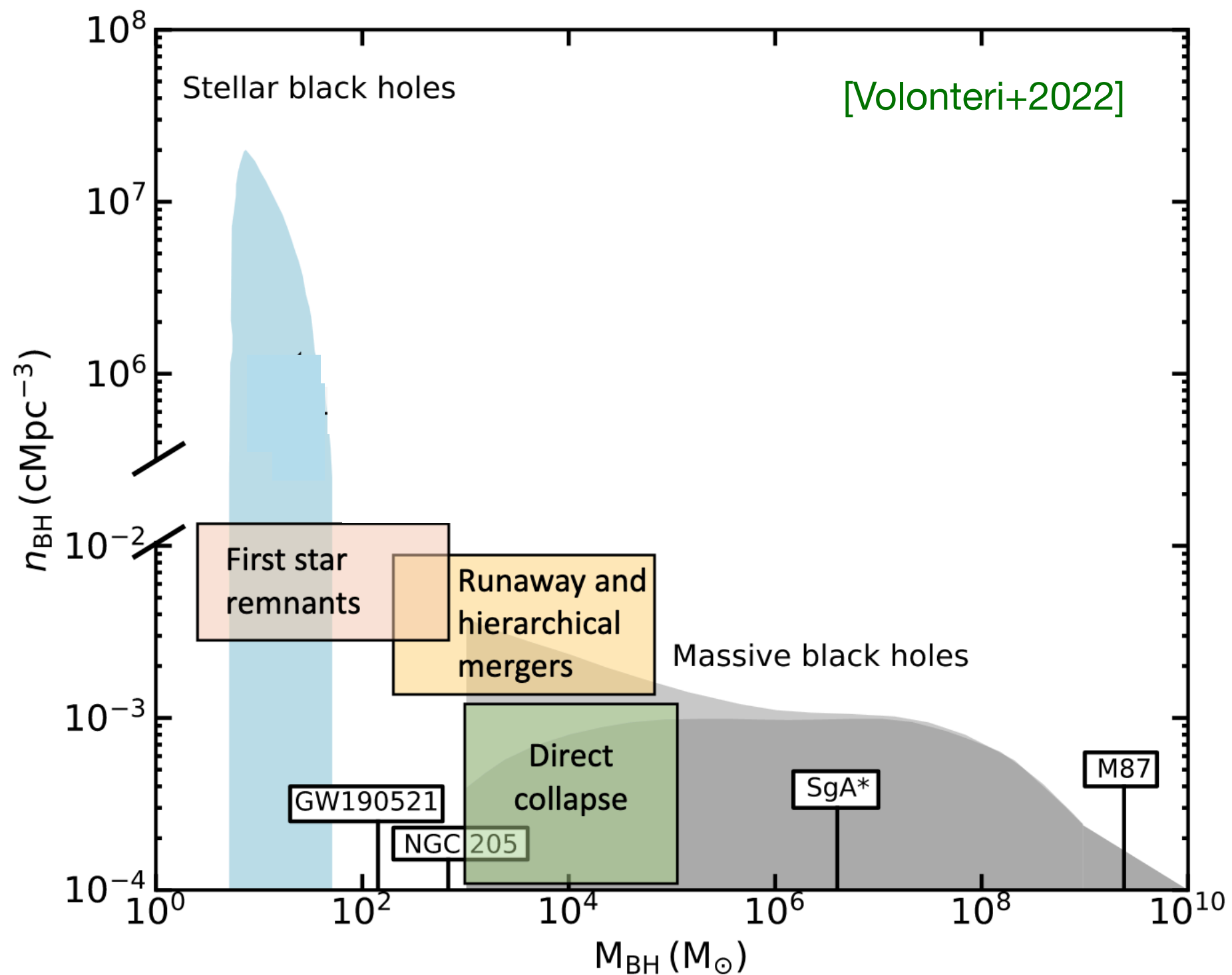
Hierarchical merger?

Black hole formed in the mass gap?

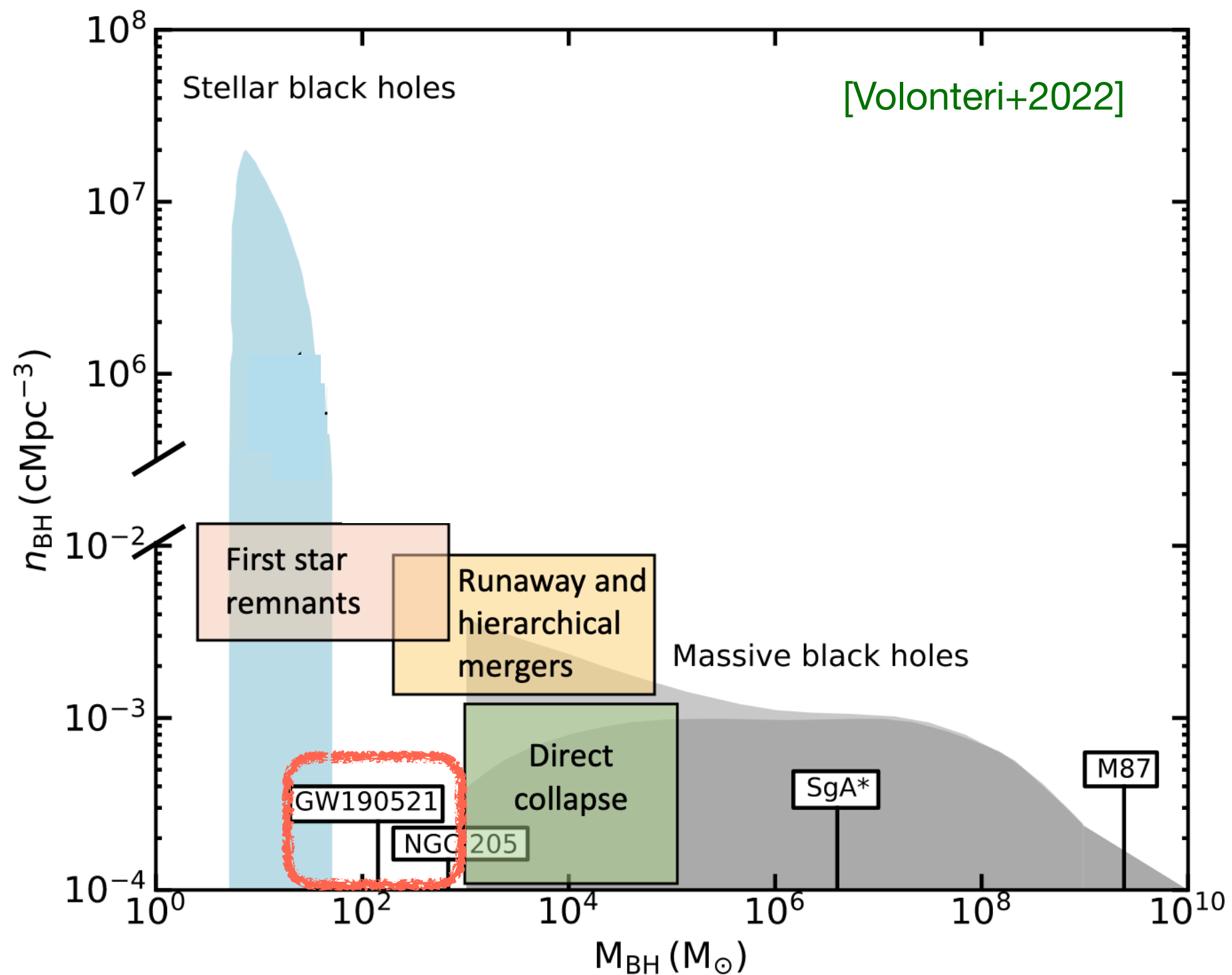
[Abbott et al. 2020, PRL, 125, 101102]

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

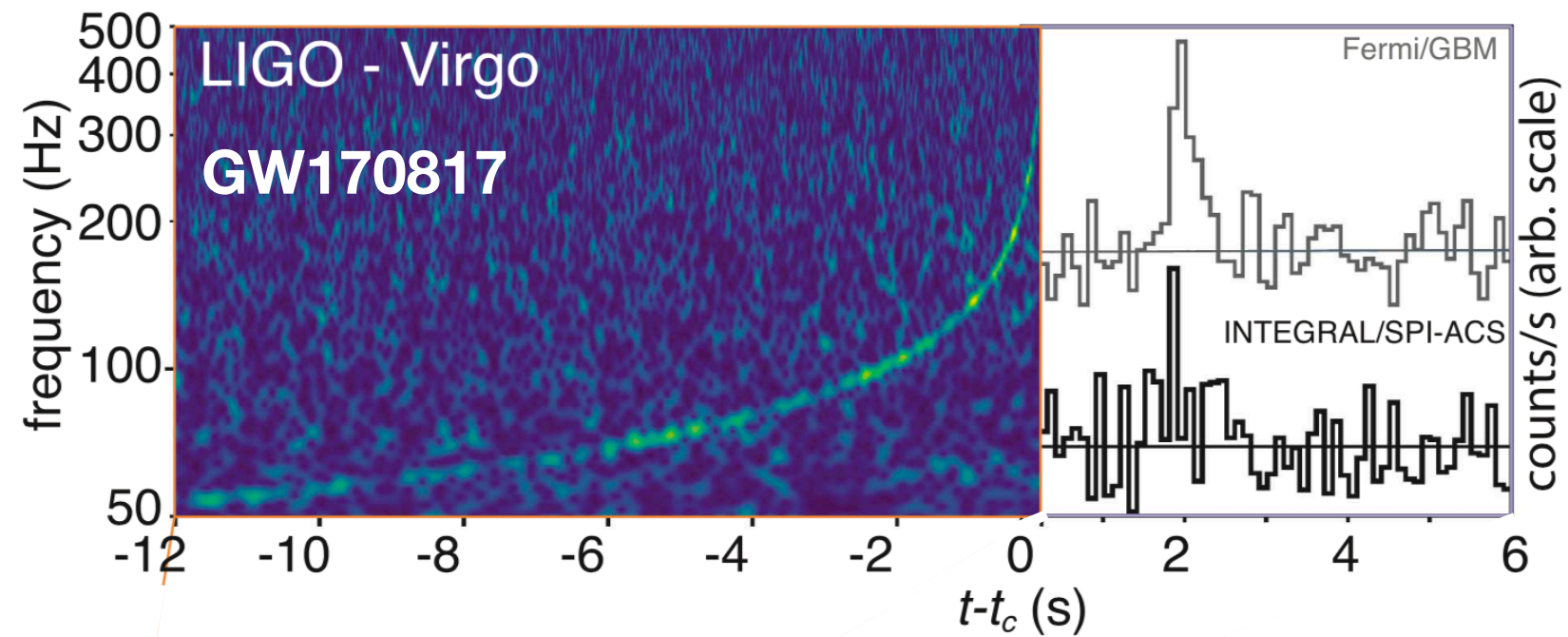
The link between stellar-mass and massive black holes?



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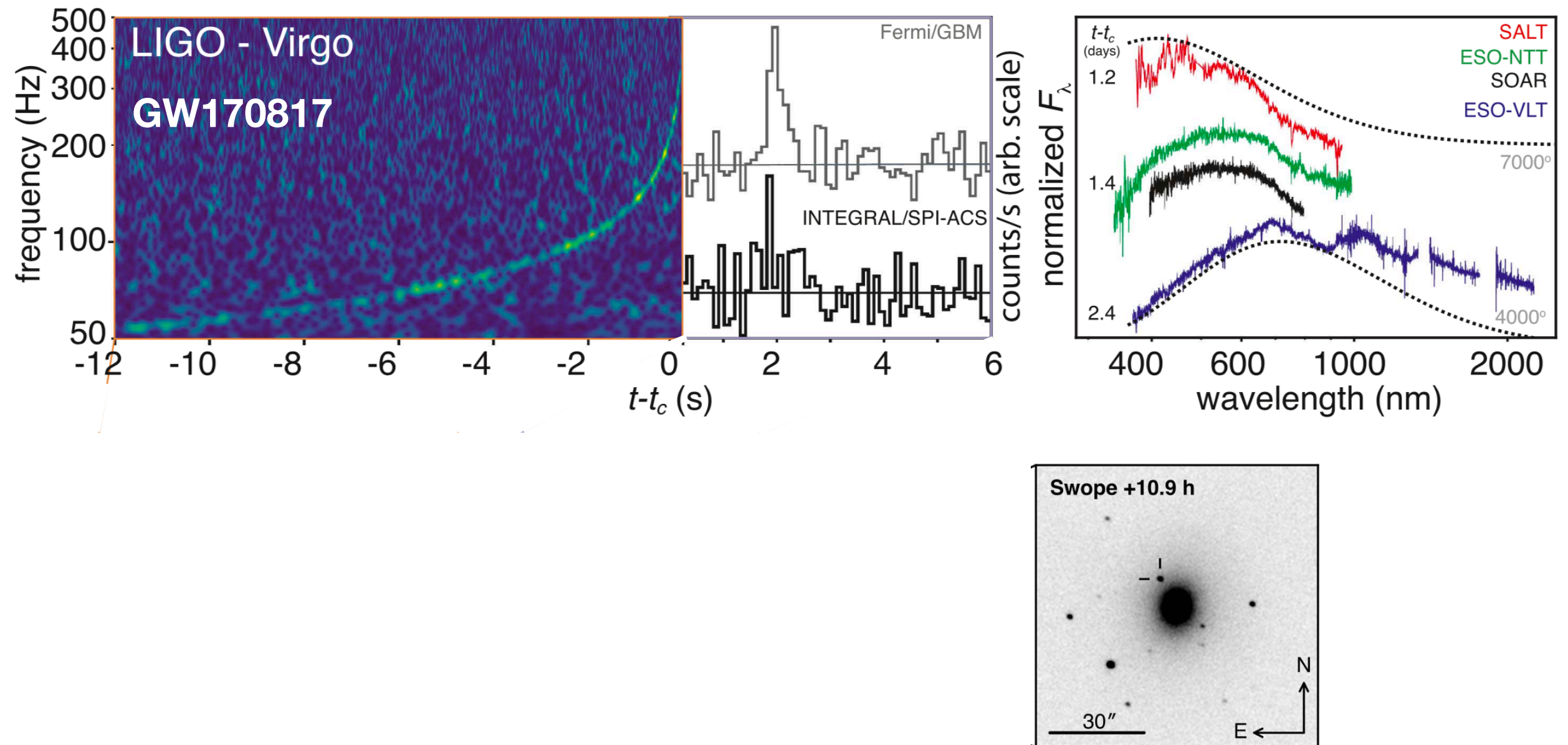


Binary neutron stars: multi-messenger observations!



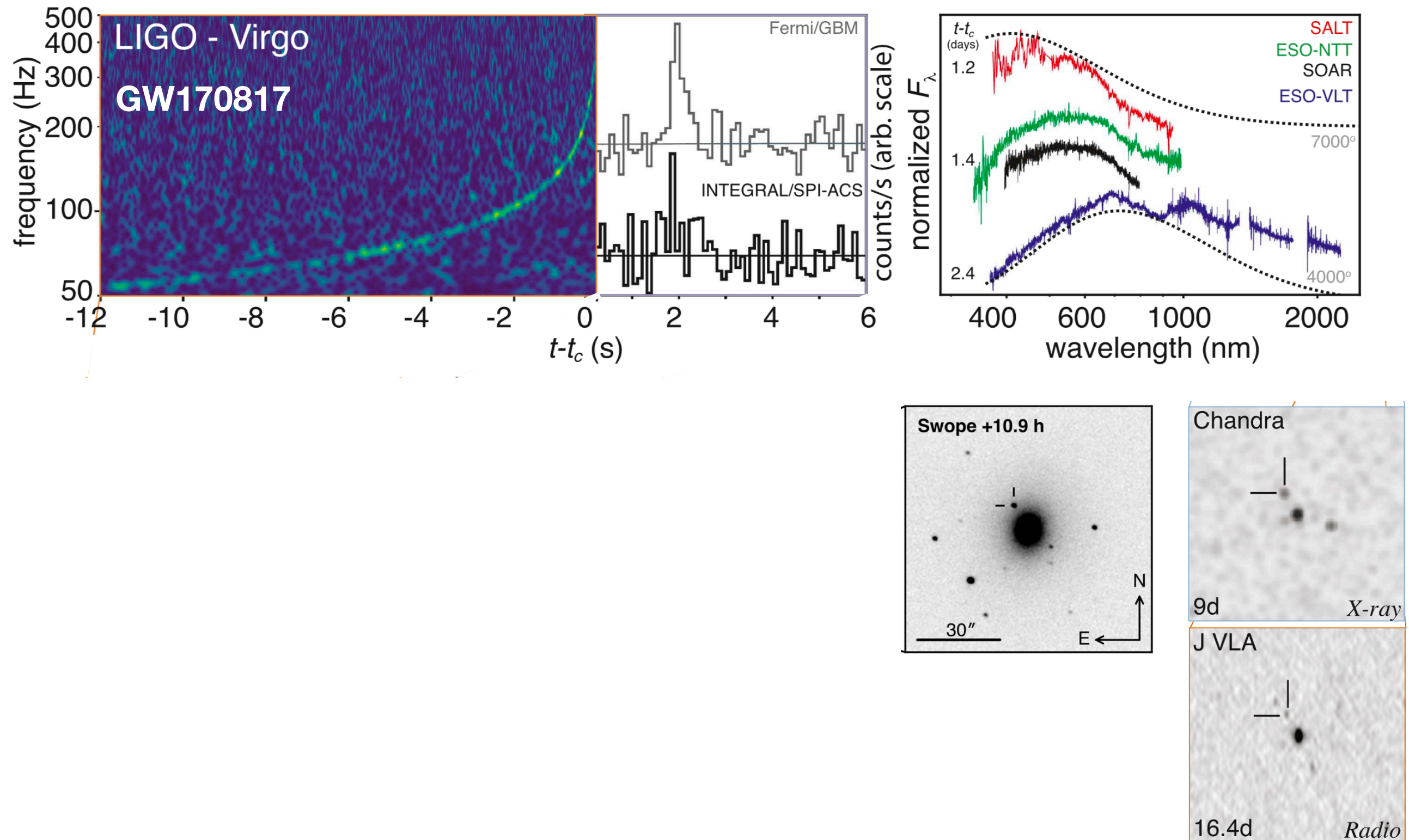
[Abbott et al. 2017, ApJ Letters, 848, 2]

Binary neutron stars: multi-messenger observations!



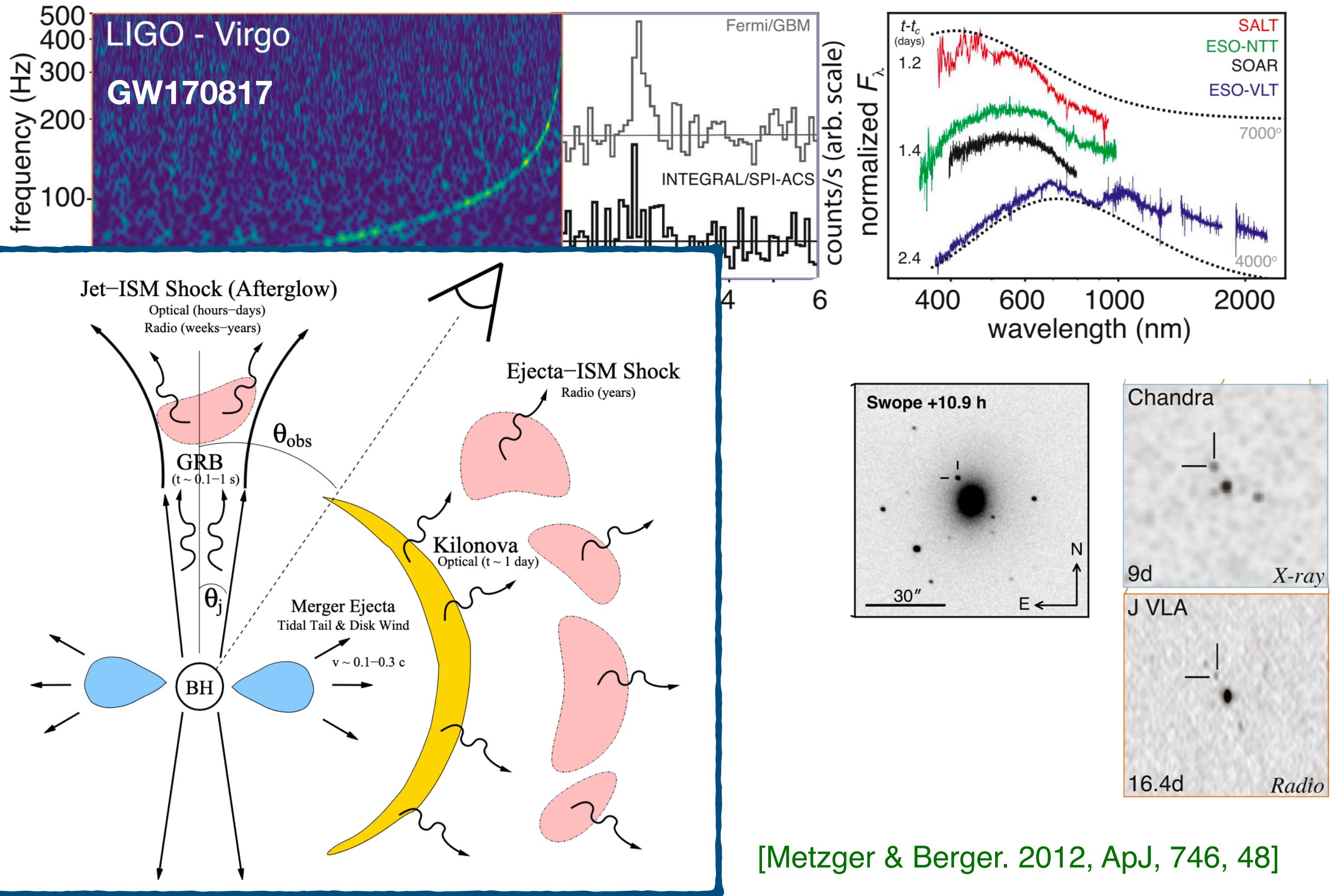
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Binary neutron stars: multi-messenger observations!

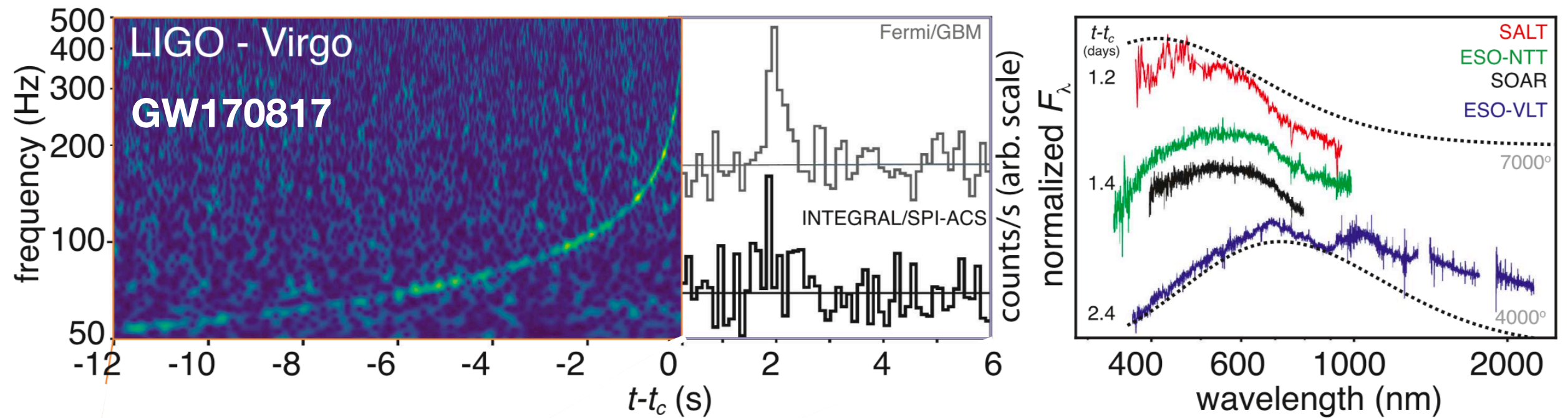


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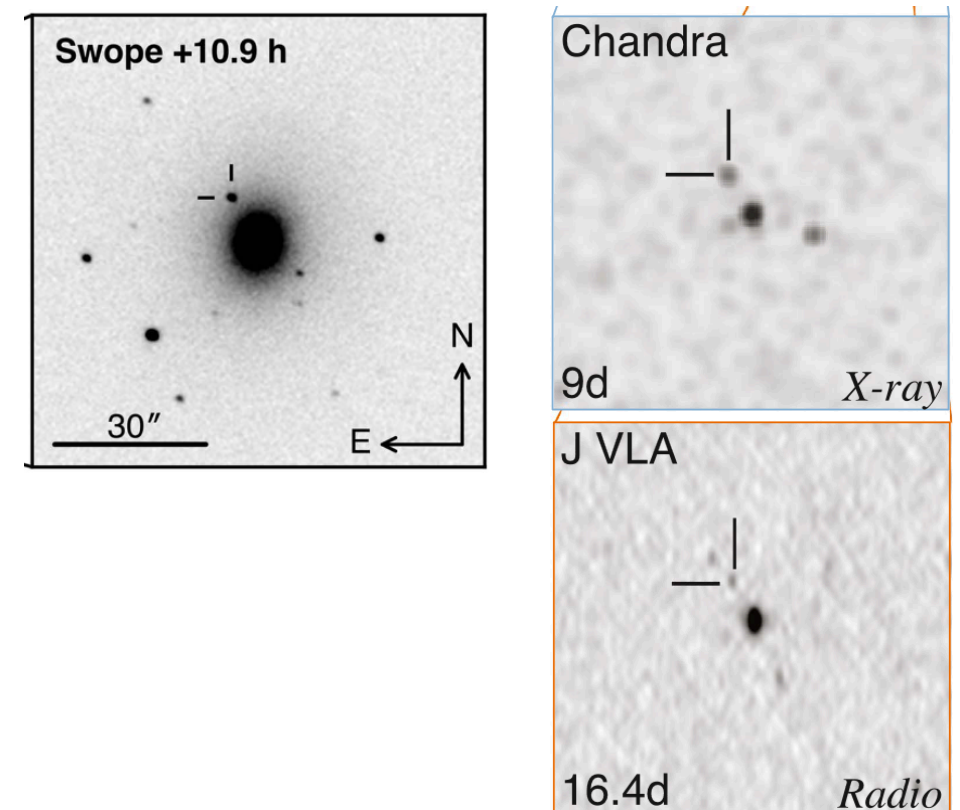
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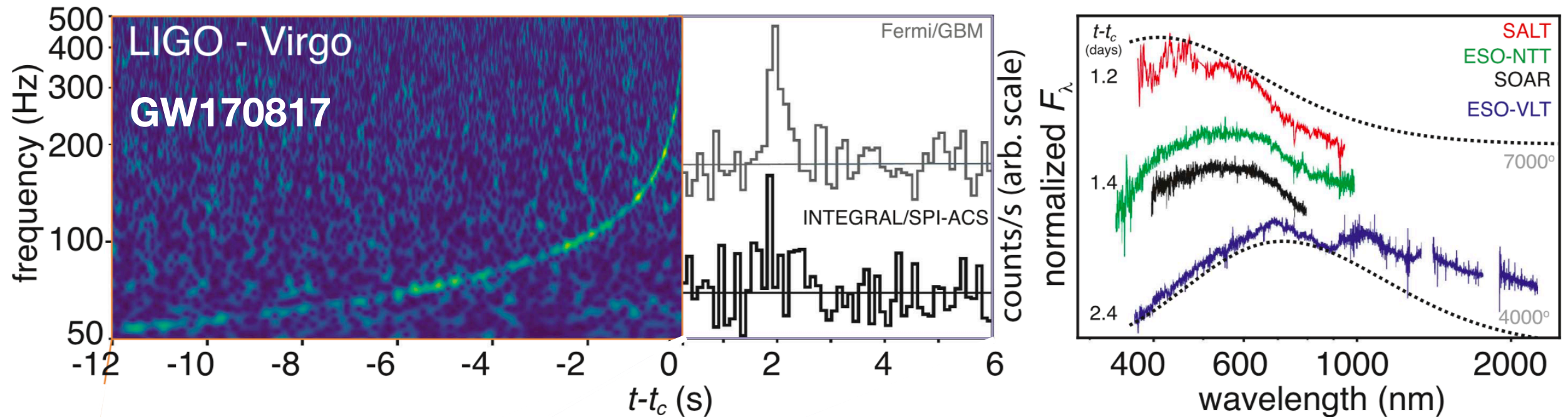


- GW+EM observations
- Connection between BNS merger and short gamma ray bursts (GRB)
- Kilonova: synthesis of heavy elements
- GRB: jet structure
- Identification of host galaxy: 40 Mpc away

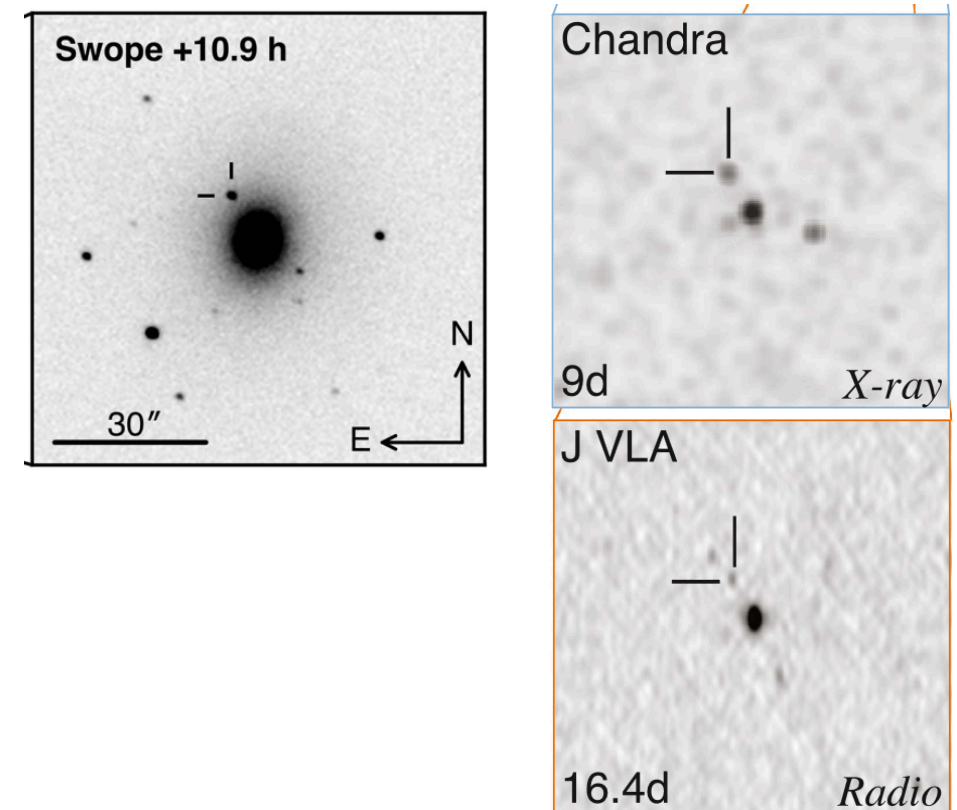


[Abbott et al. 2017, ApJ Letters, 848, 2]

Binary neutron stars: multi-messenger observations!

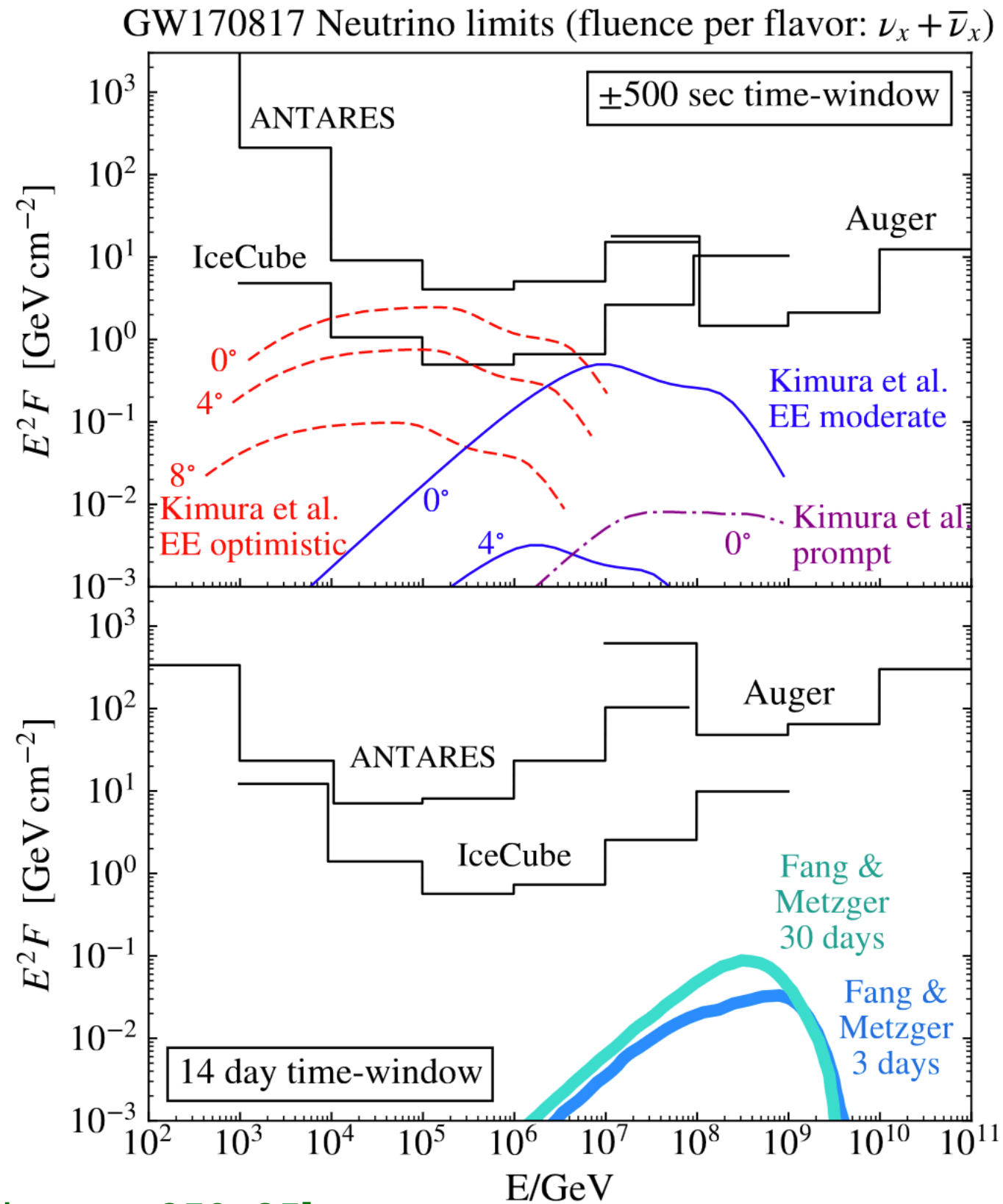


- GW+EM observations
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- **No neutrino detection...**



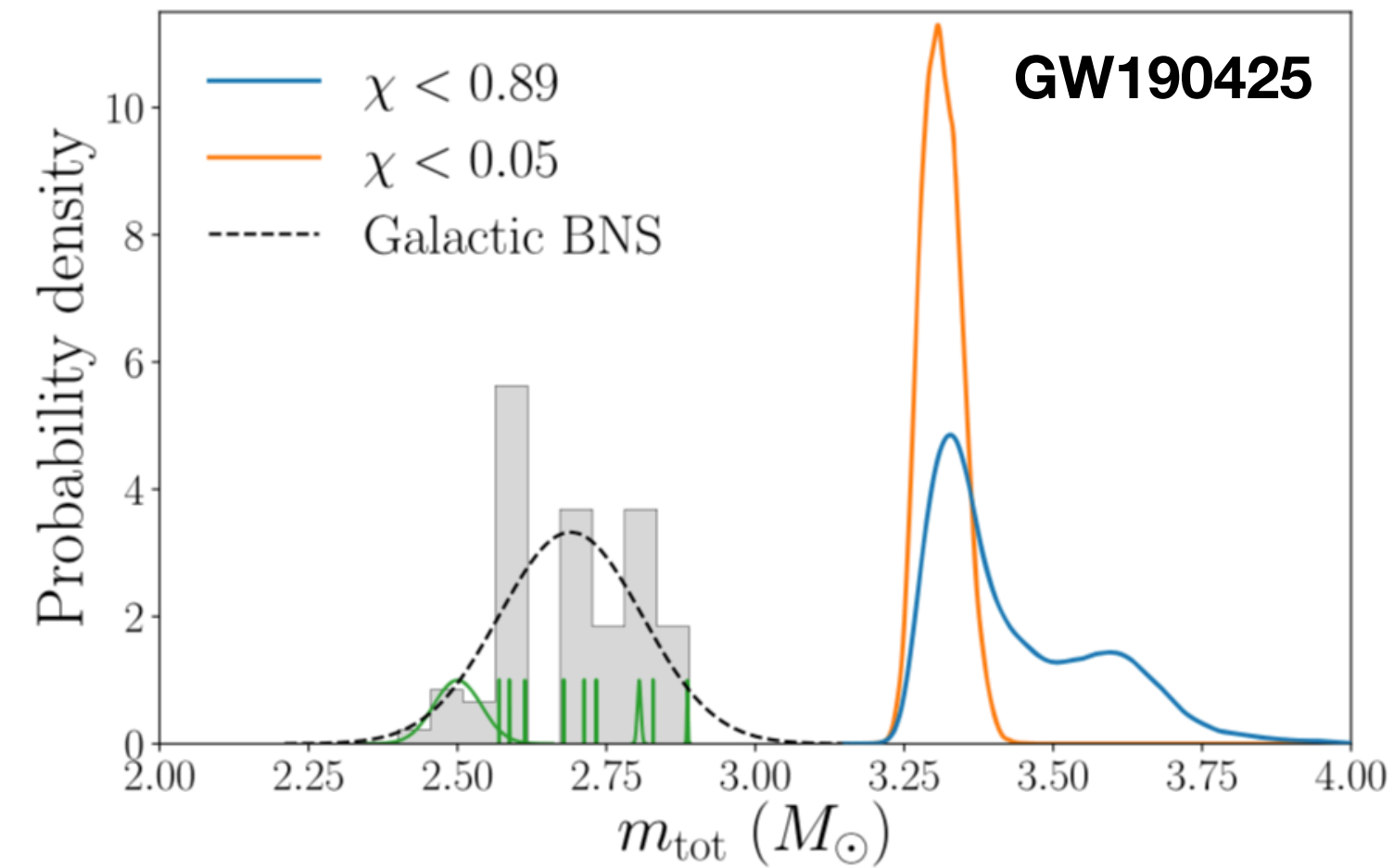
[Abbott et al. 2017, ApJ Letters, 848, 2]

Binary neutron stars: multi-messenger observations... but no neutrinos



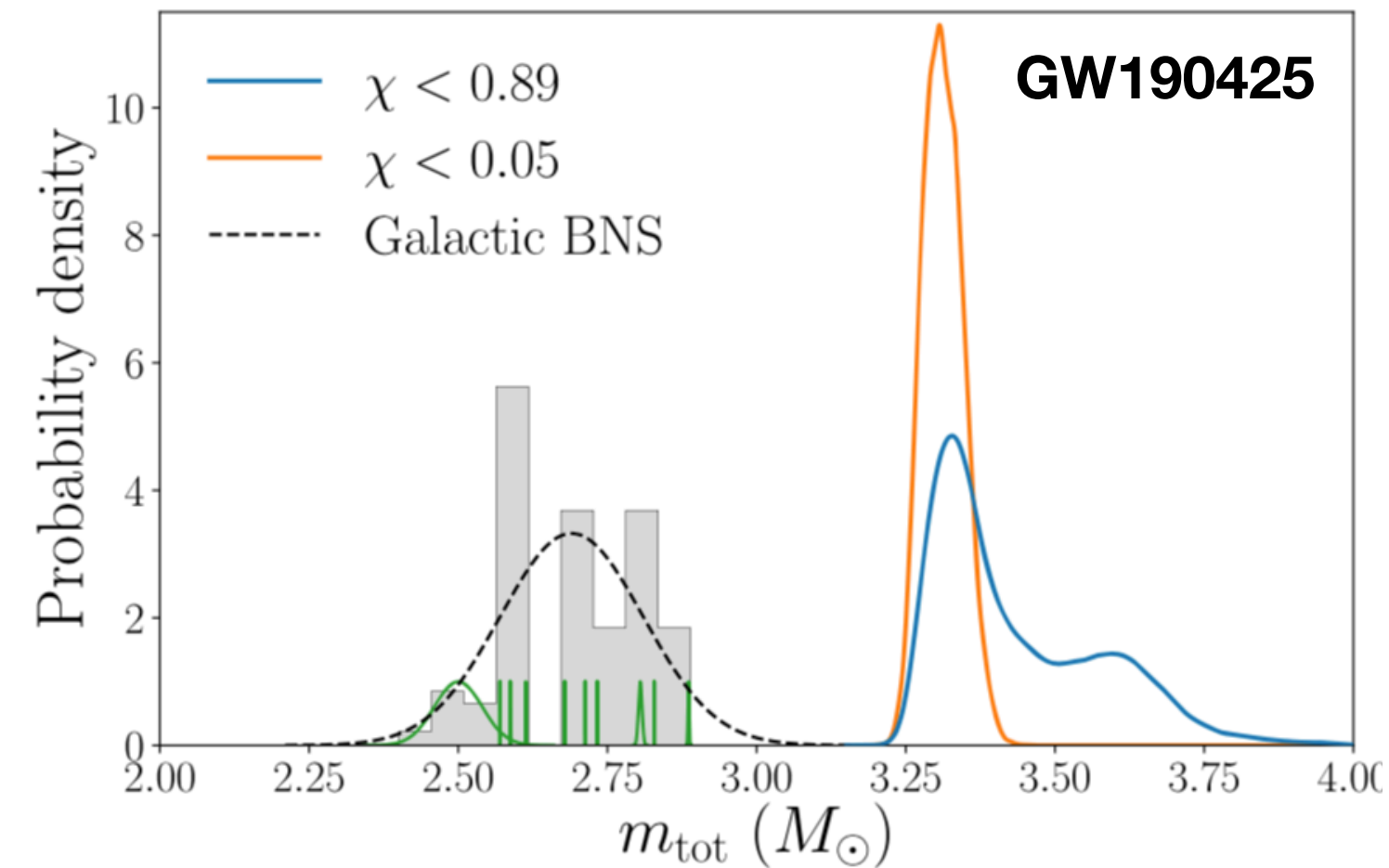
[Albert et al. 2017, ApJ Letters, 850, 35]

Binary neutron stars: masses

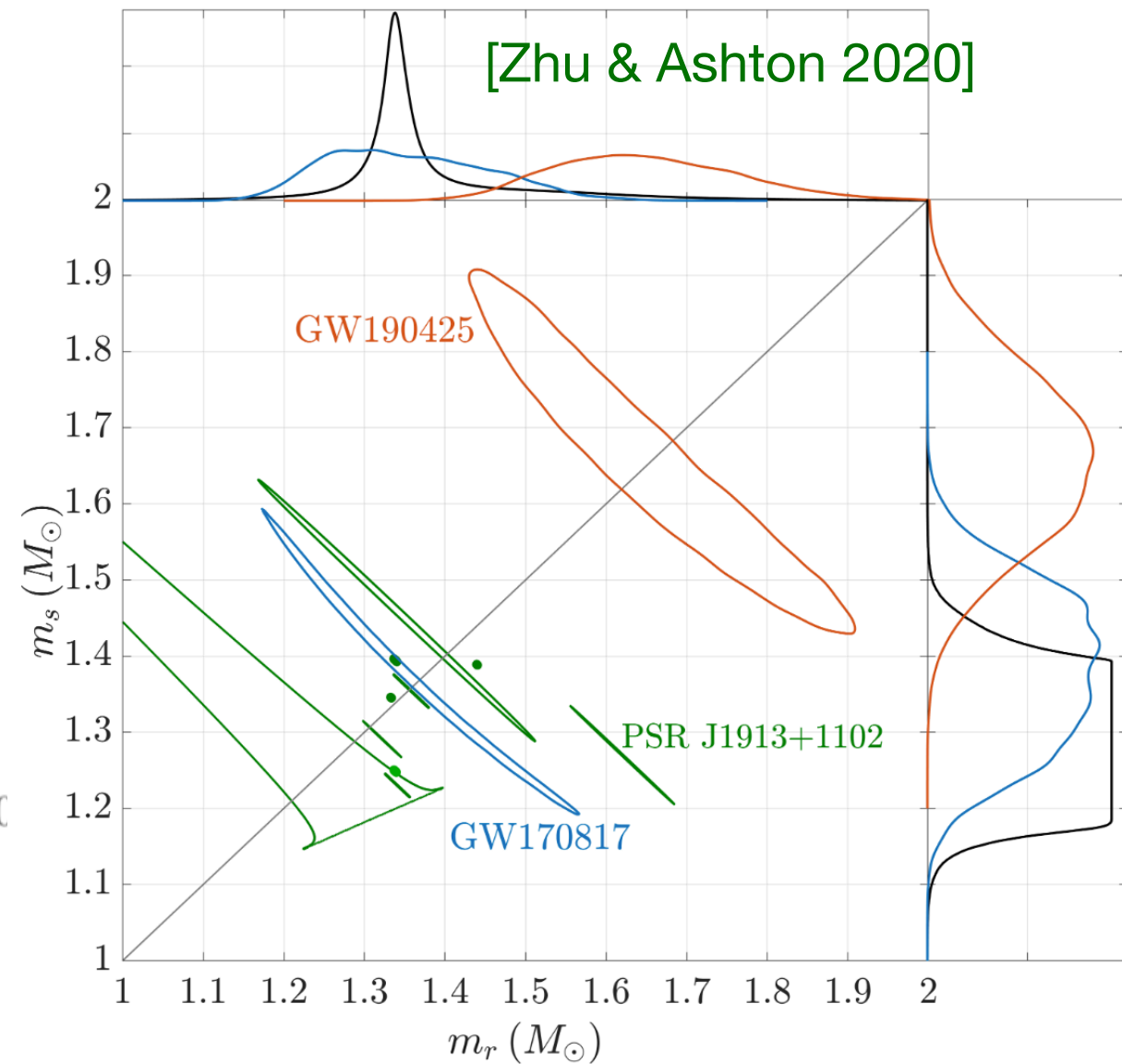


[Abbott et al. 2020, Astrophys. J. Lett. 892, L3]

Binary neutron stars: masses



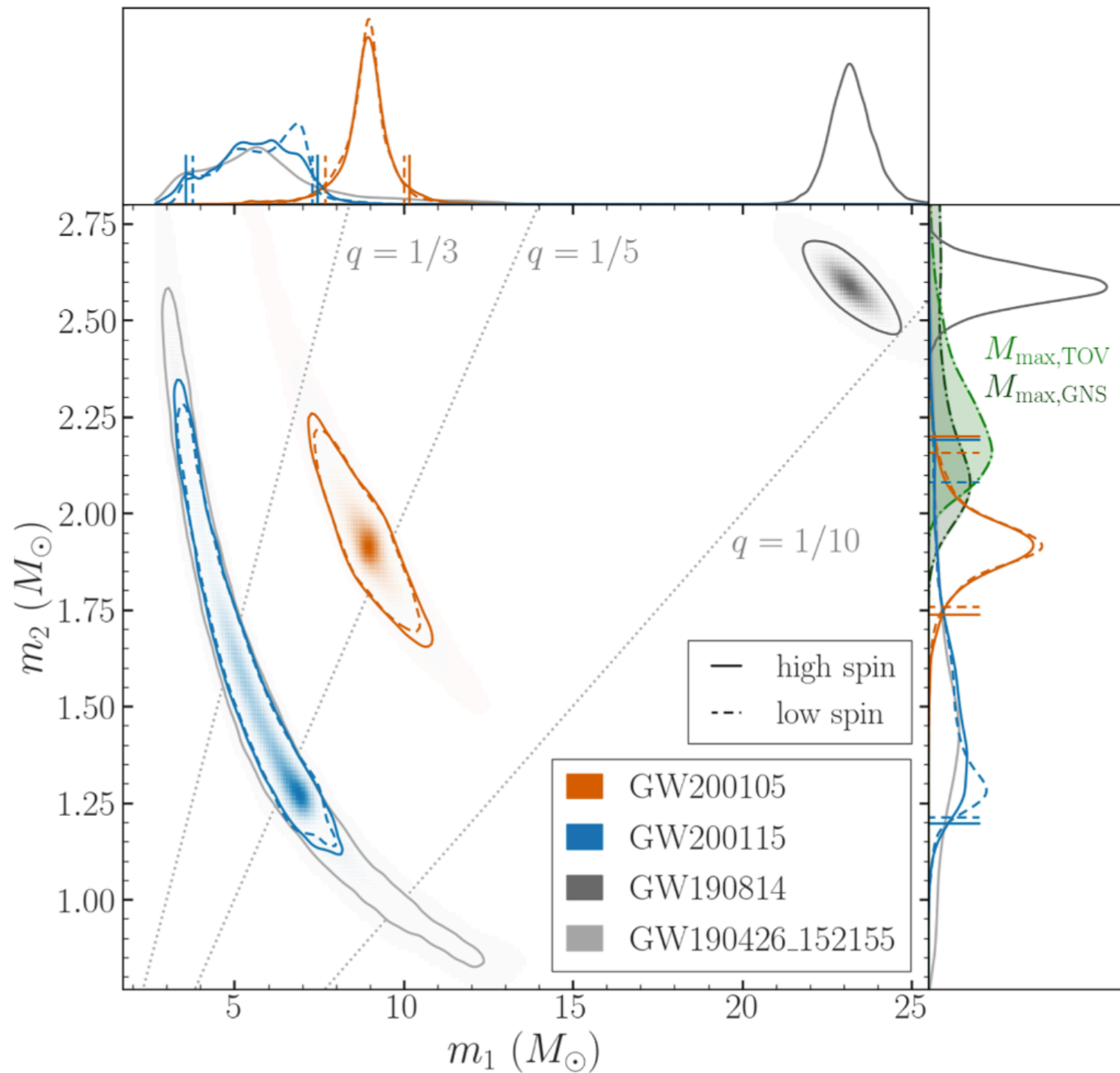
[Abbott et al. 2020, Astrophys. J. Lett. 892, L3]



How do binary neutron stars form?

What are the differences between GW sources and Galactic binaries?

Neutron star-black hole: mixed binaries



GW200115

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

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

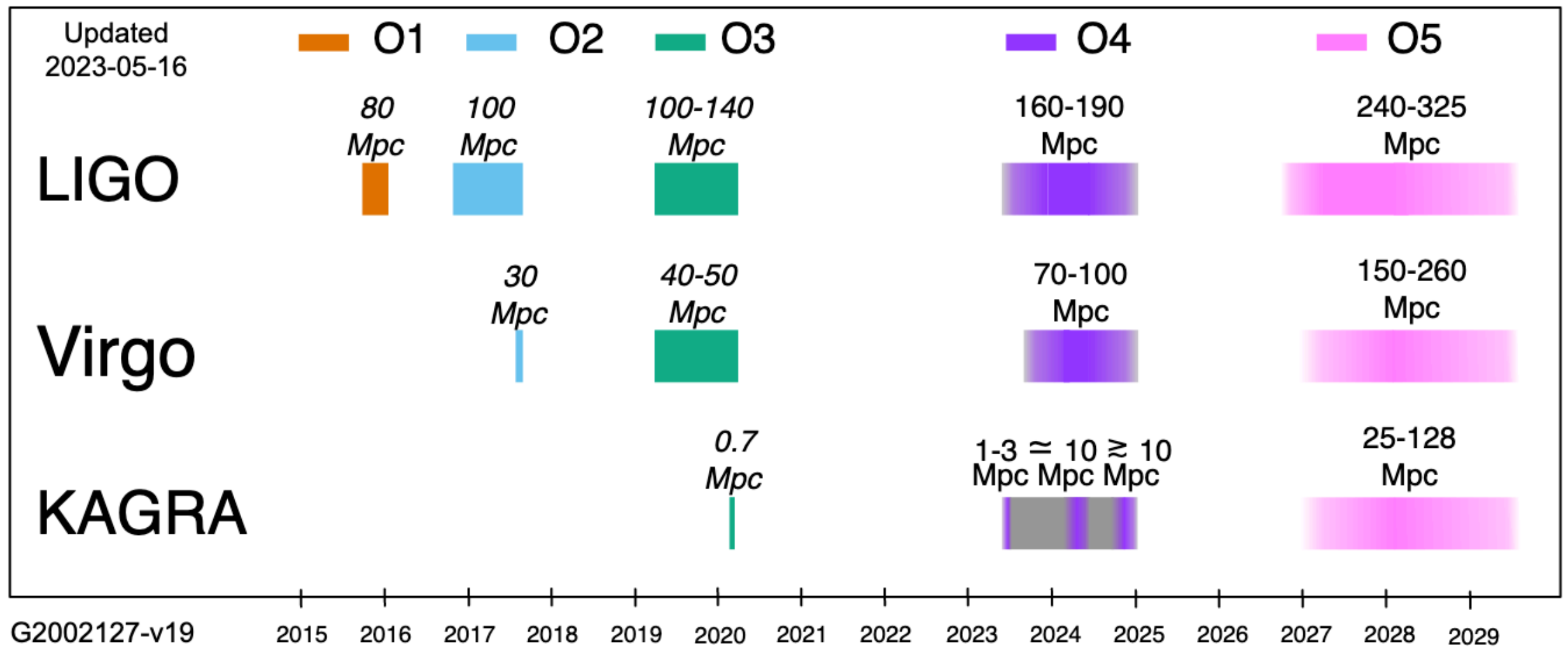
GW200105

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

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

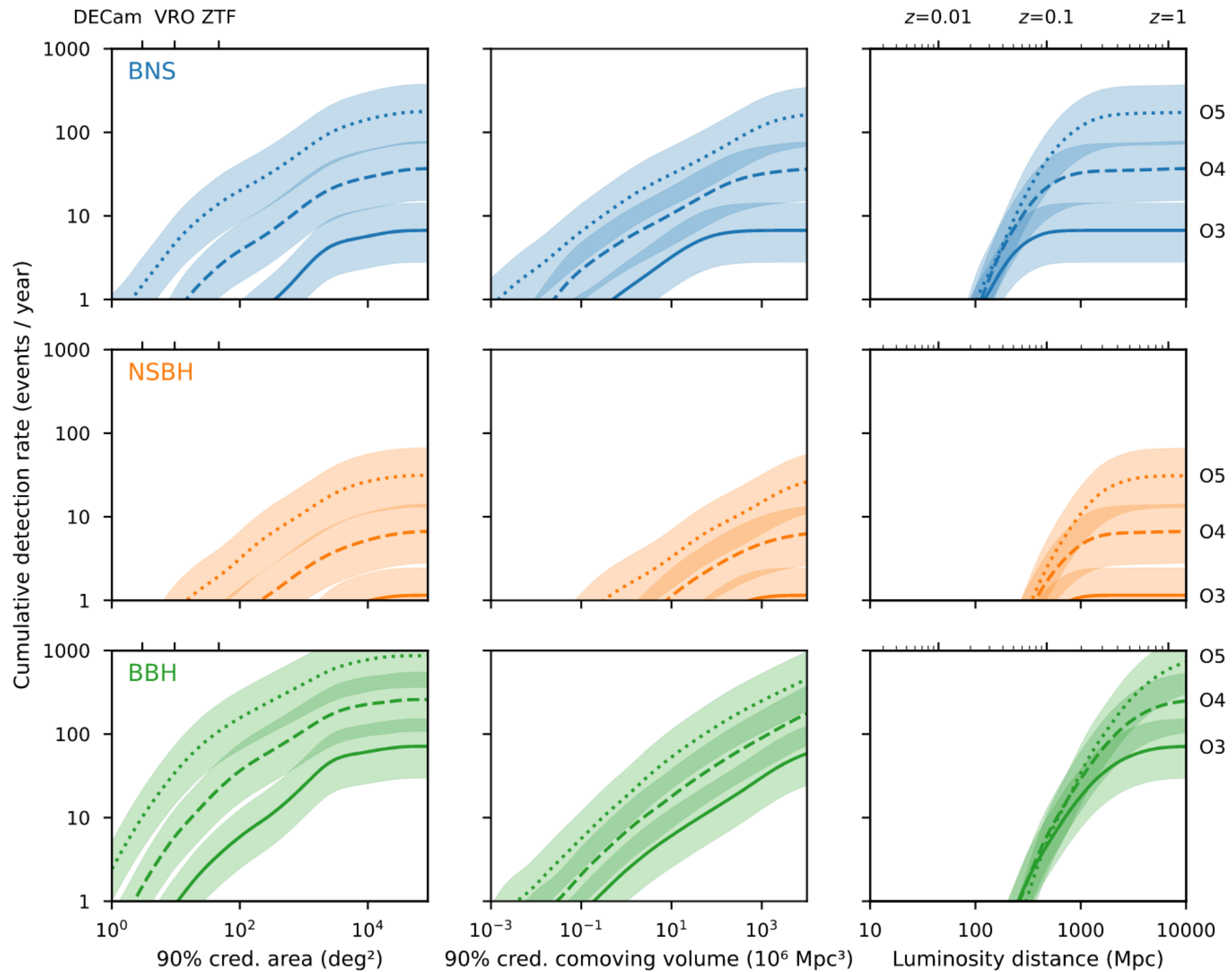
[Abbott et al. 2021, ApJL, 915, L5]

Prospects for O4/O5 runs



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

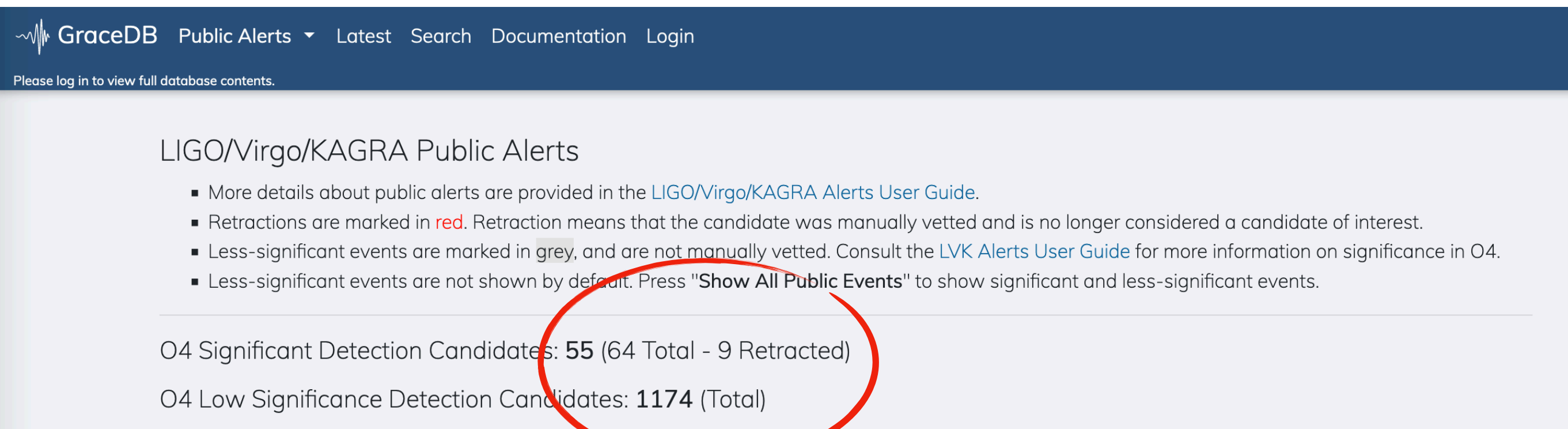
Prospects for O4/O5 runs



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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



The screenshot shows the GraceDB Public Alerts page. The header includes the GraceDB logo and navigation links: Public Alerts, Latest, Search, Documentation, and Login. A message below the header says "Please log in to view full database contents." The main content area is titled "LIGO/Virgo/KAGRA Public Alerts" and contains a list of bullet points: "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.", and "Less-significant events are not shown by default. Press 'Show All Public Events' to show significant and less-significant events." Below this list, two lines of text are displayed: "O4 Significant Detection Candidates: 55 (64 Total - 9 Retracted)" and "O4 Low Significance Detection Candidates: 1174 (Total)". A red circle is drawn around the numbers 55 and 1174.

GraceDB Public Alerts ▾ Latest Search Documentation Login

Please log in to view full database contents.

LIGO/Virgo/KAGRA Public Alerts

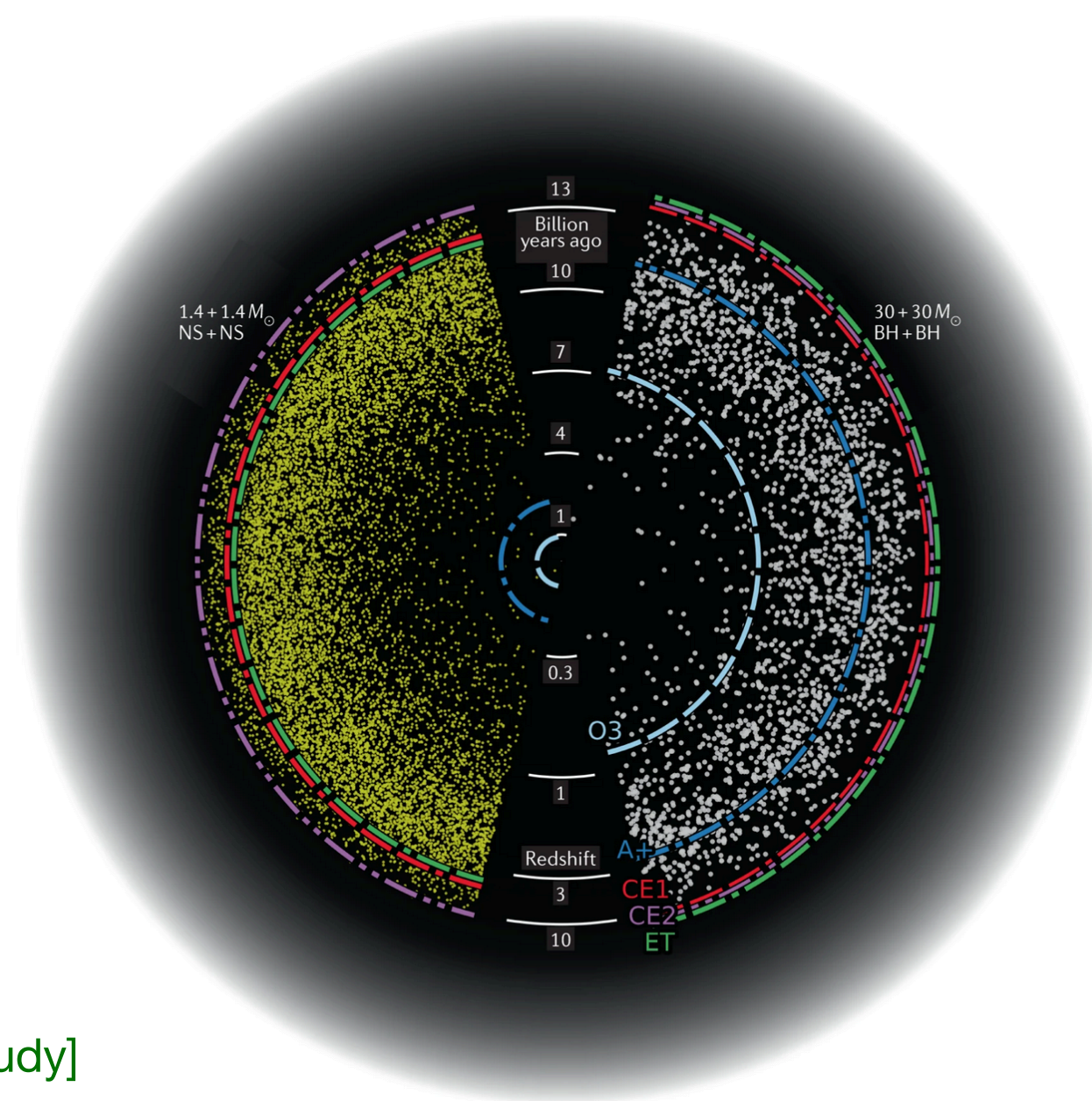
- More details about public alerts are provided in the [LIGO/Virgo/KAGRA Alerts User Guide](#).
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O4 Significant Detection Candidates: **55** (64 Total - 9 Retracted)

O4 Low Significance Detection Candidates: **1174** (Total)

[as of October 25, 2023]

Third generation detectors: Einstein Telescope and Cosmic Explorer



[Evans et al. 2021,
Cosmic Horizon Study]

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