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Gravitational-wave detections with ground-base observatories

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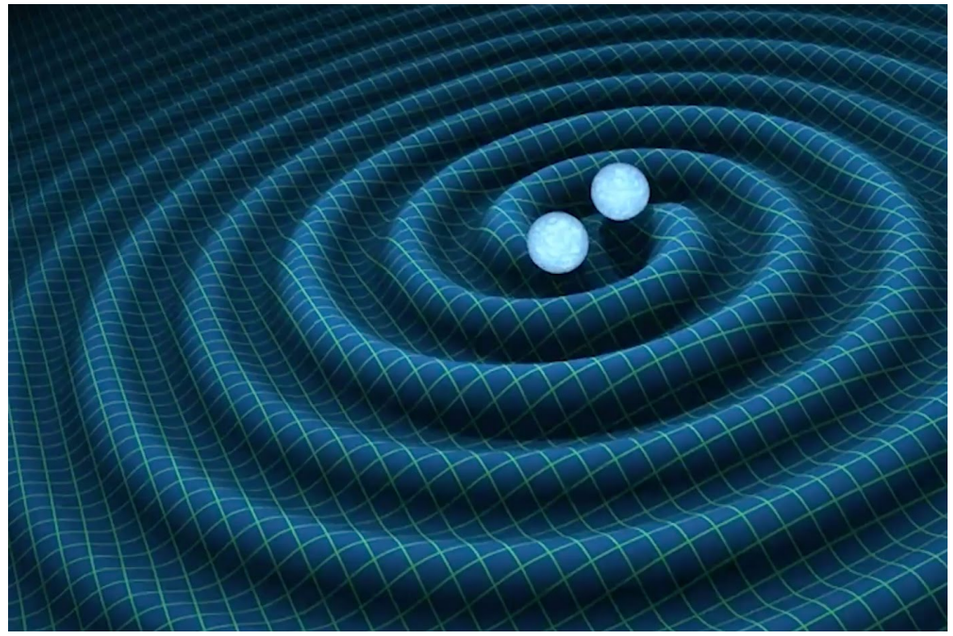
Gravitational-wave astronomy

- 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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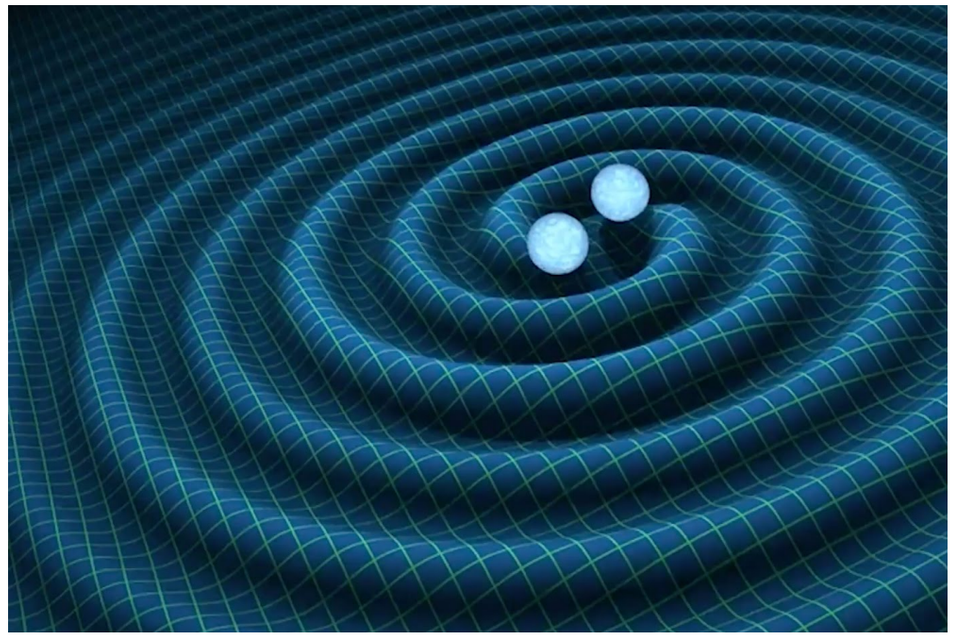
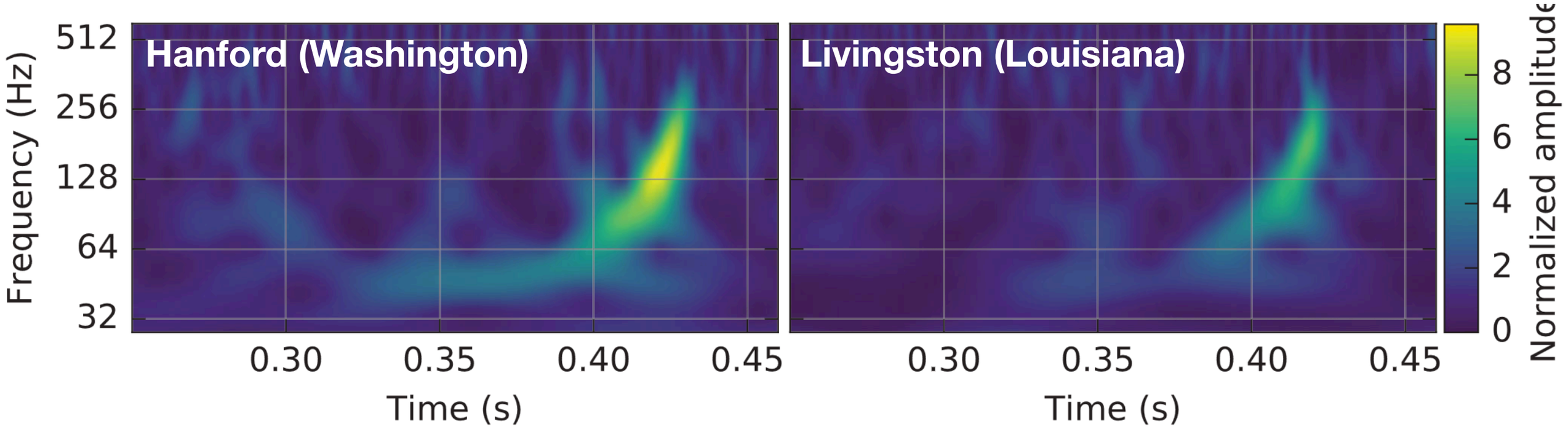
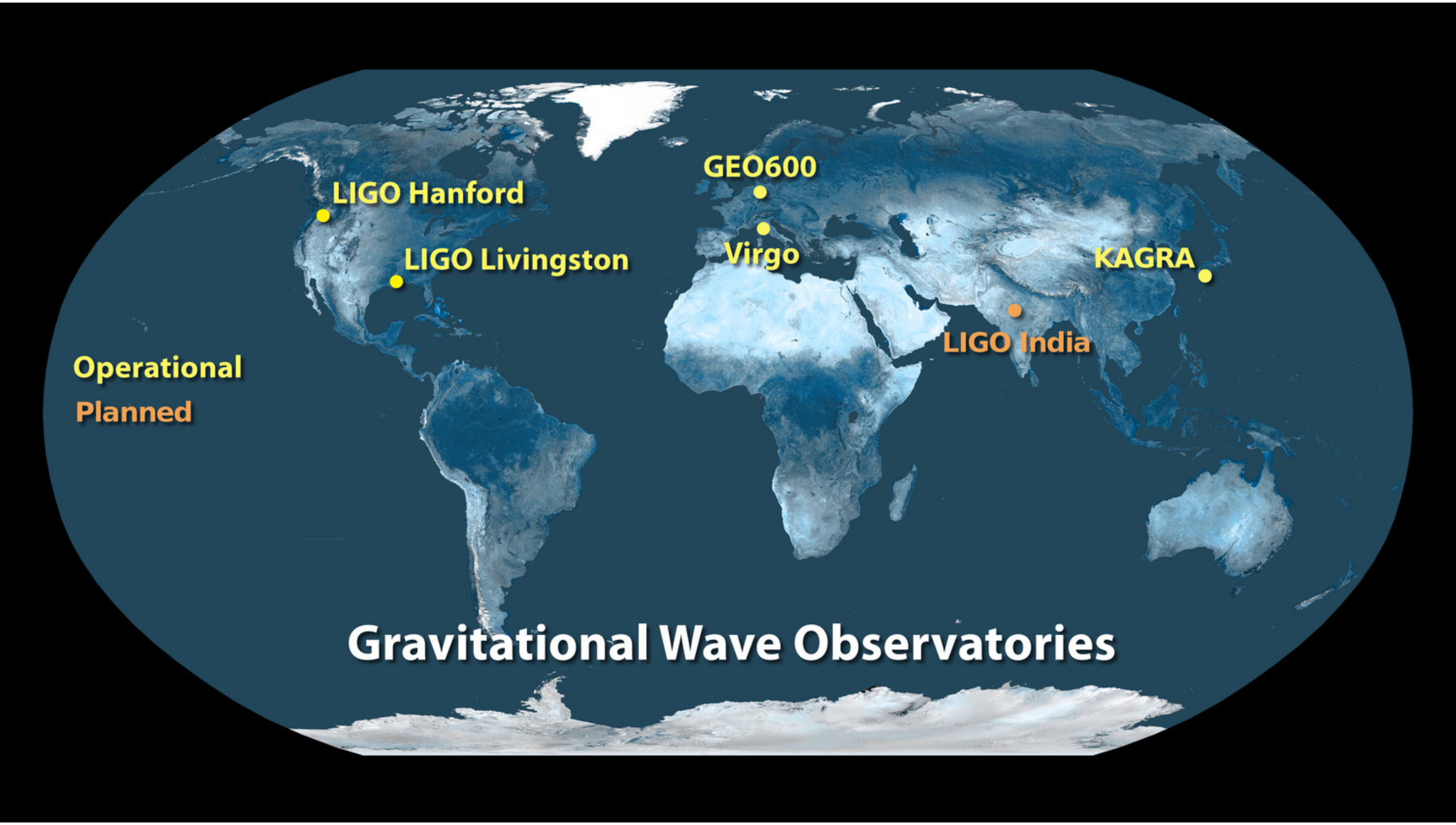


The first detection - GW150914:



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

Ground-based GW observatories



[Credits: Caltech/MIT/LIGO Lab]

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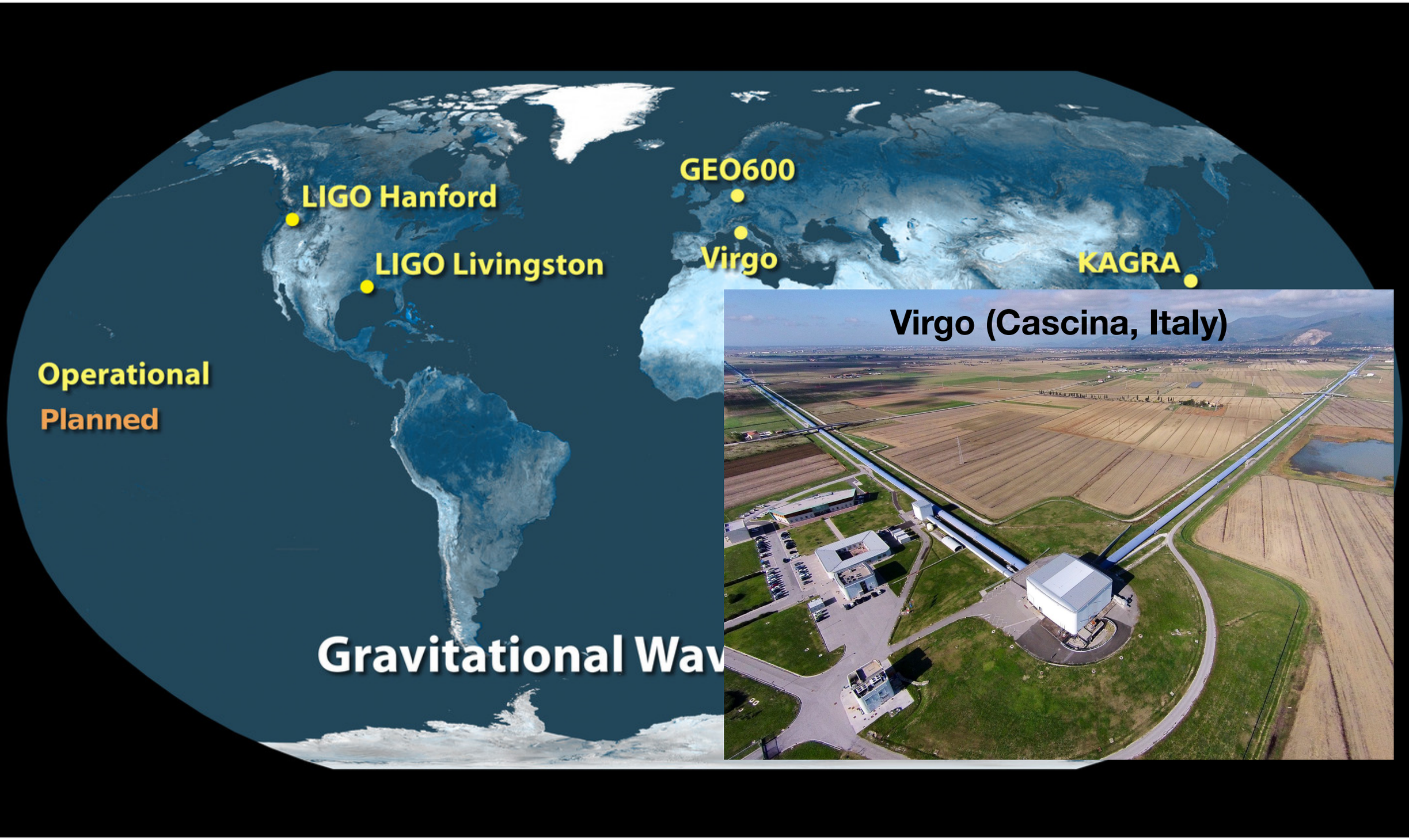

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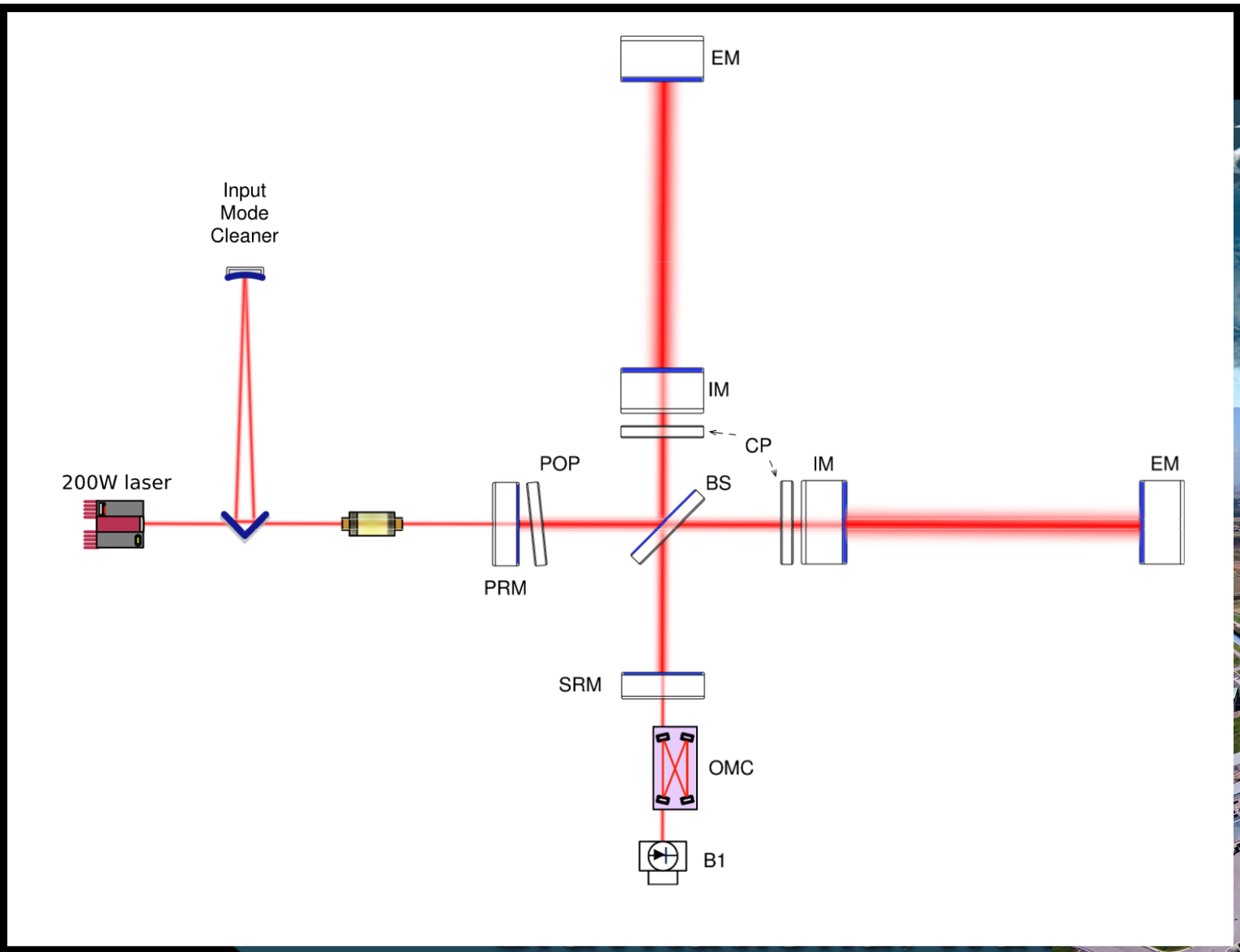
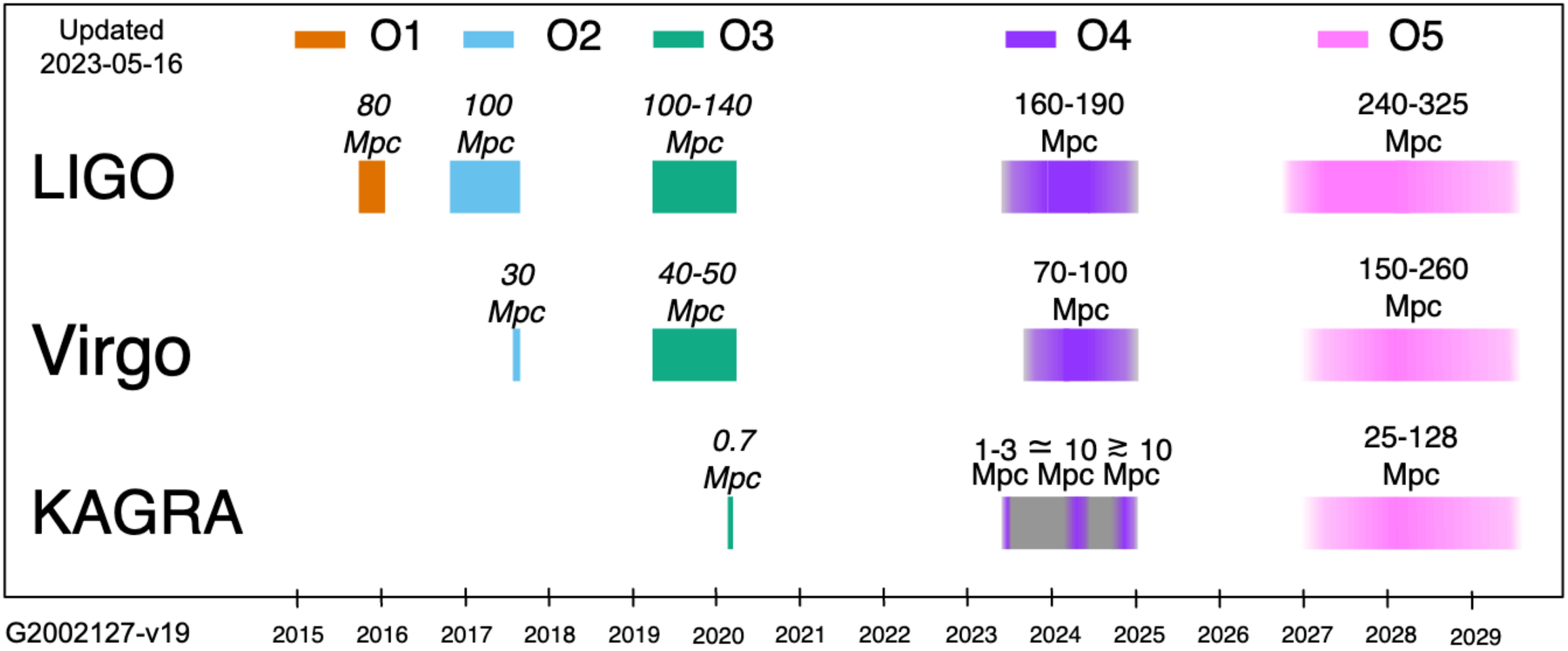


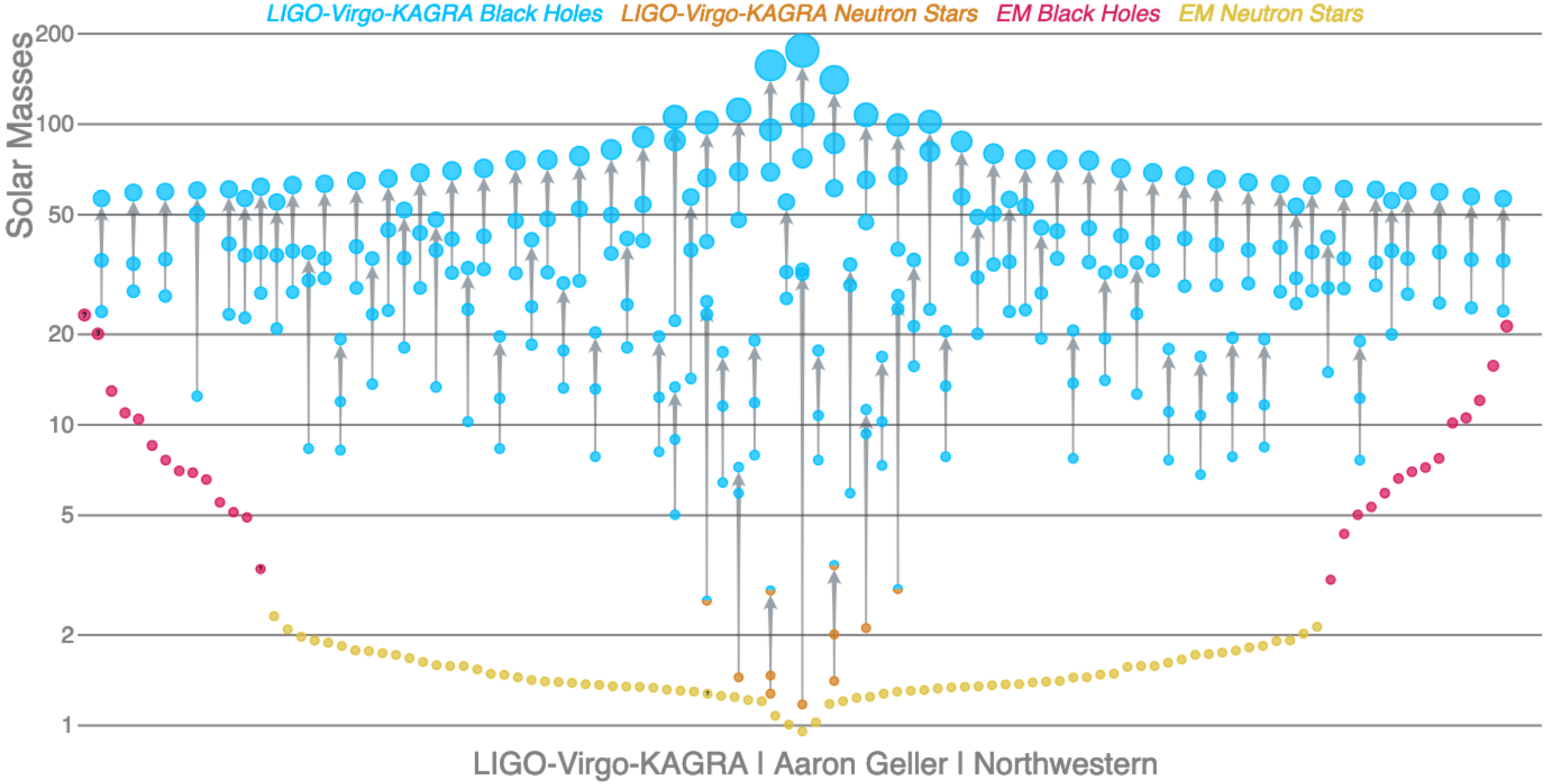
[Acernese et al. 2015, CQG, 32, 024001] [Credits: Caltech/MIT/LIGO Lab; Virgo Collaboration]

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



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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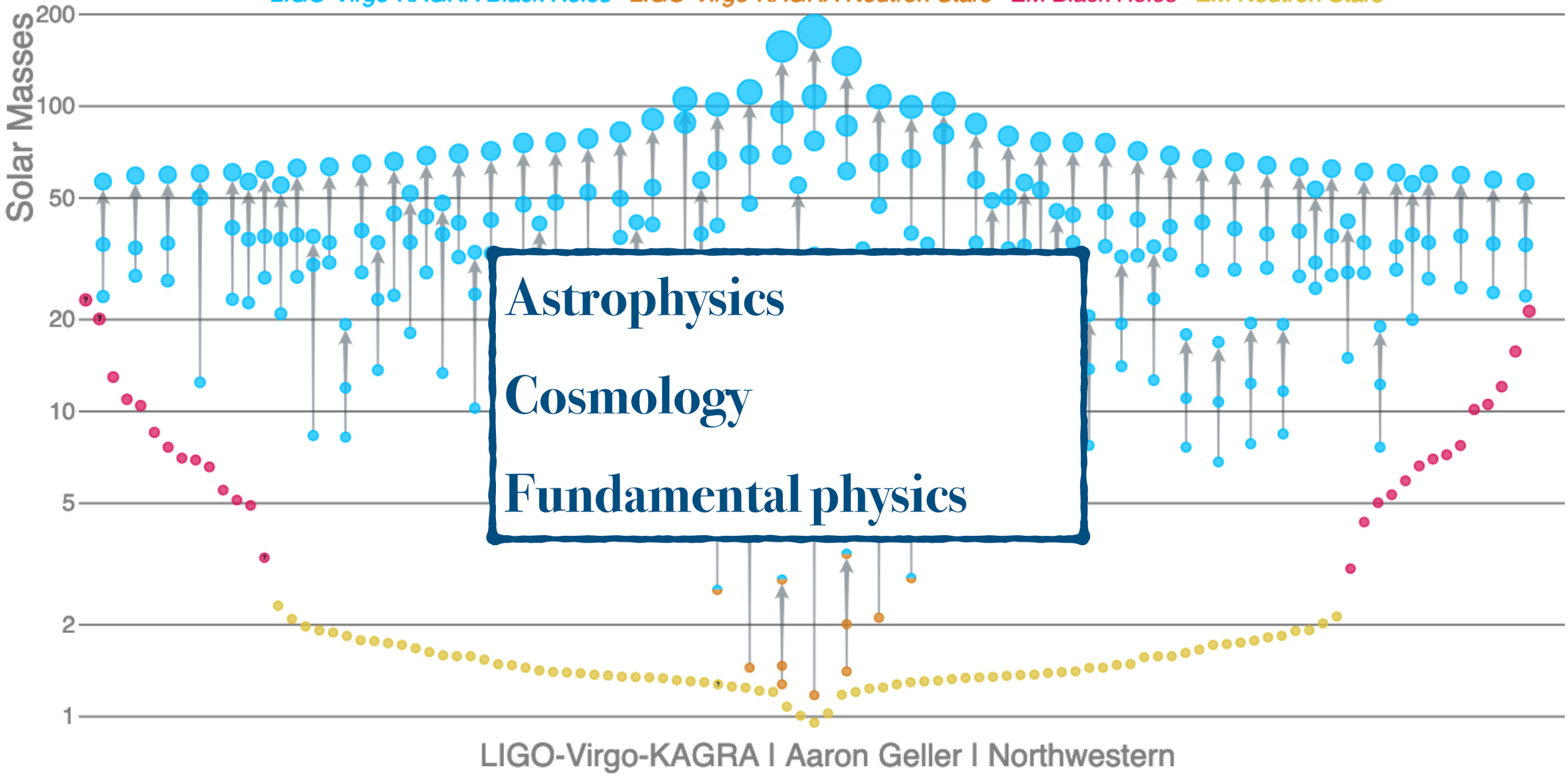

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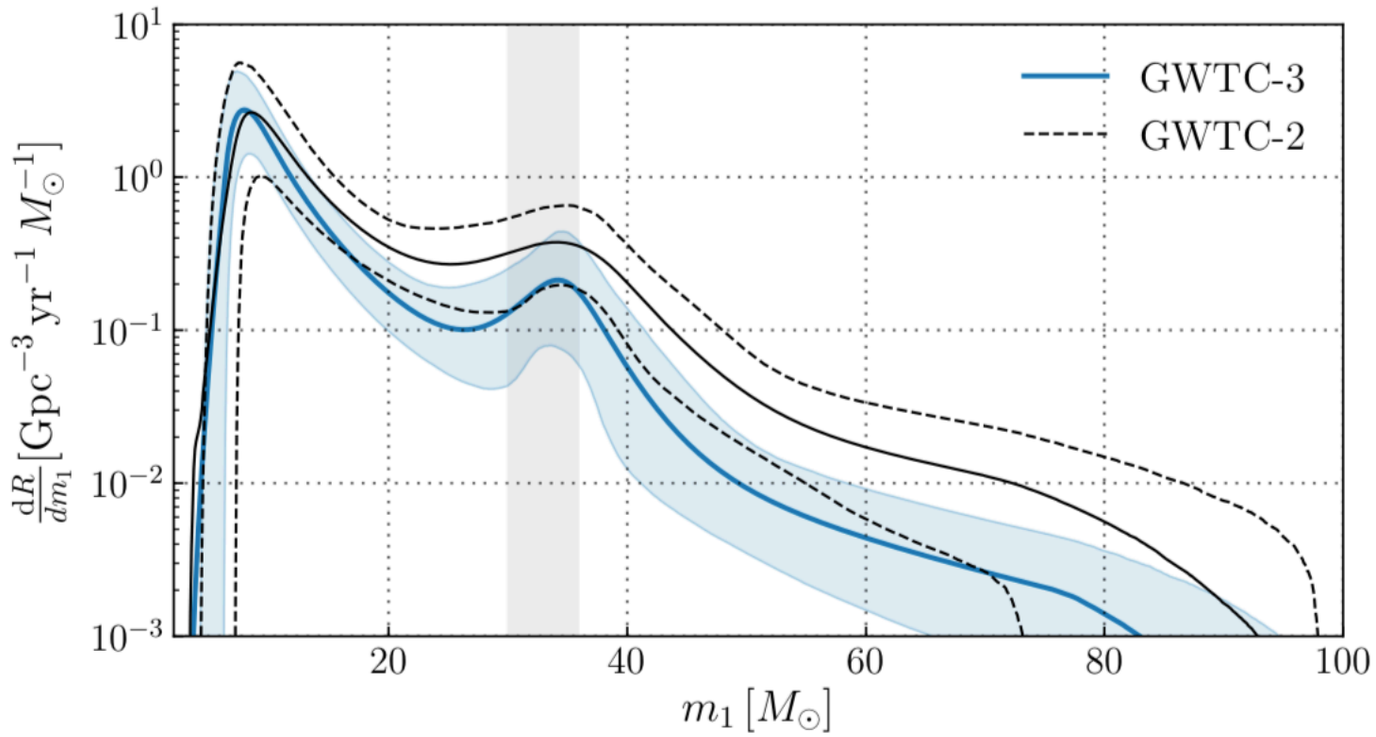
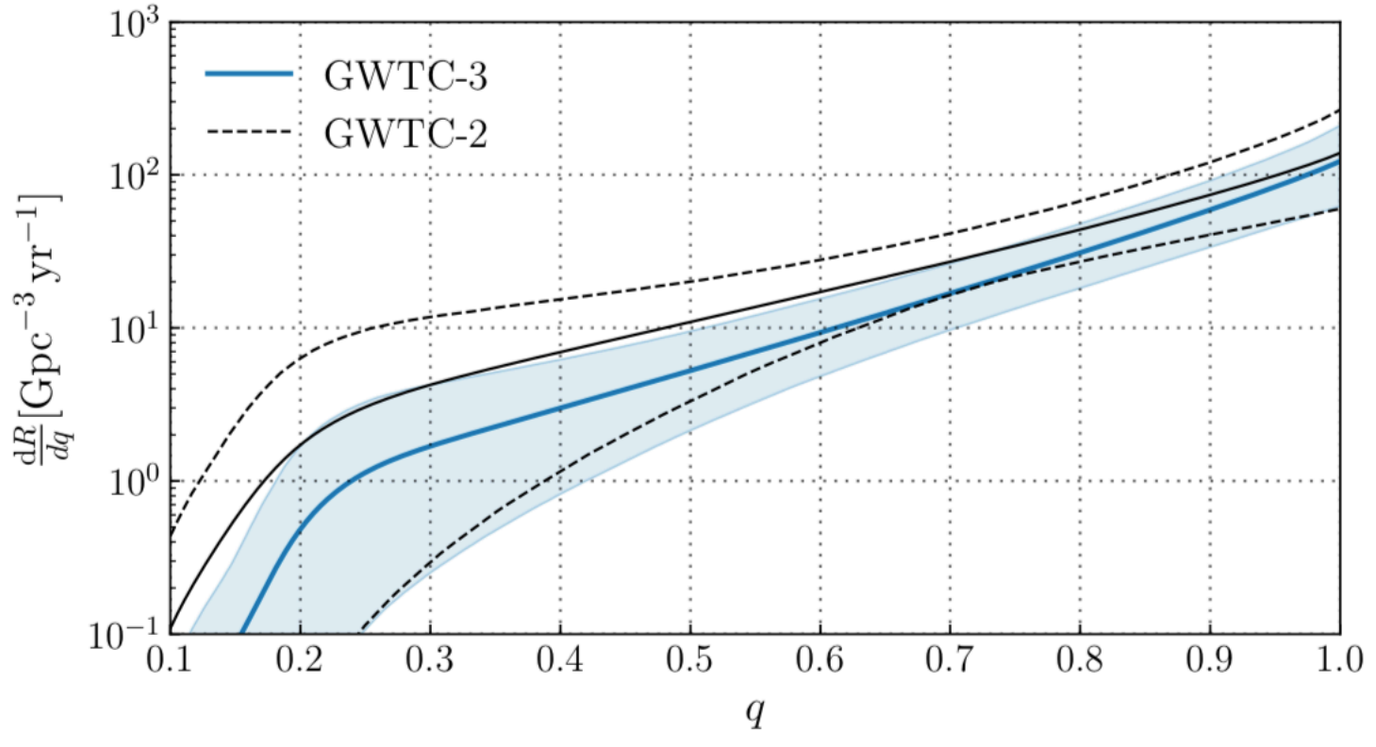
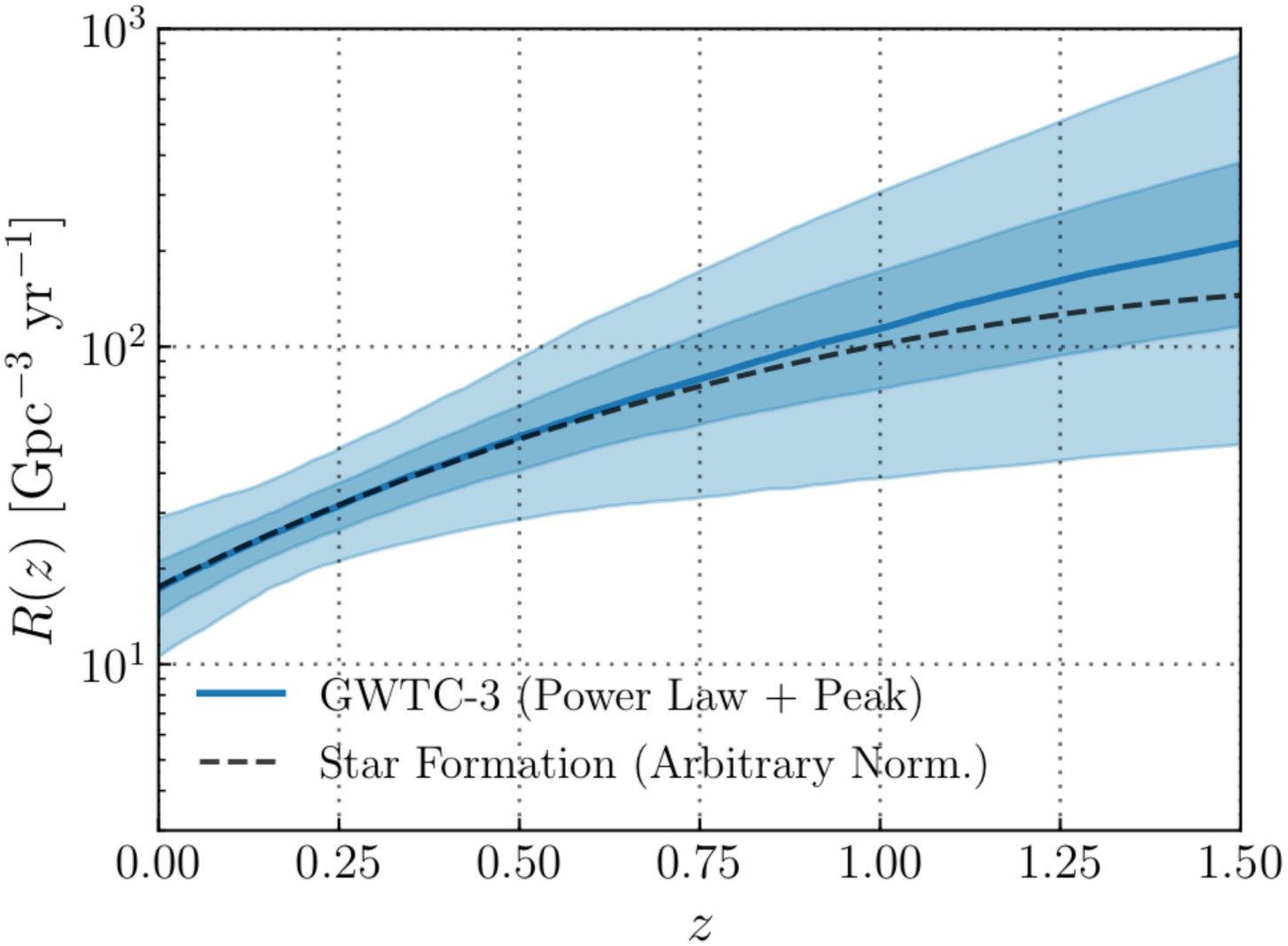
Black hole populations: mass distribution





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

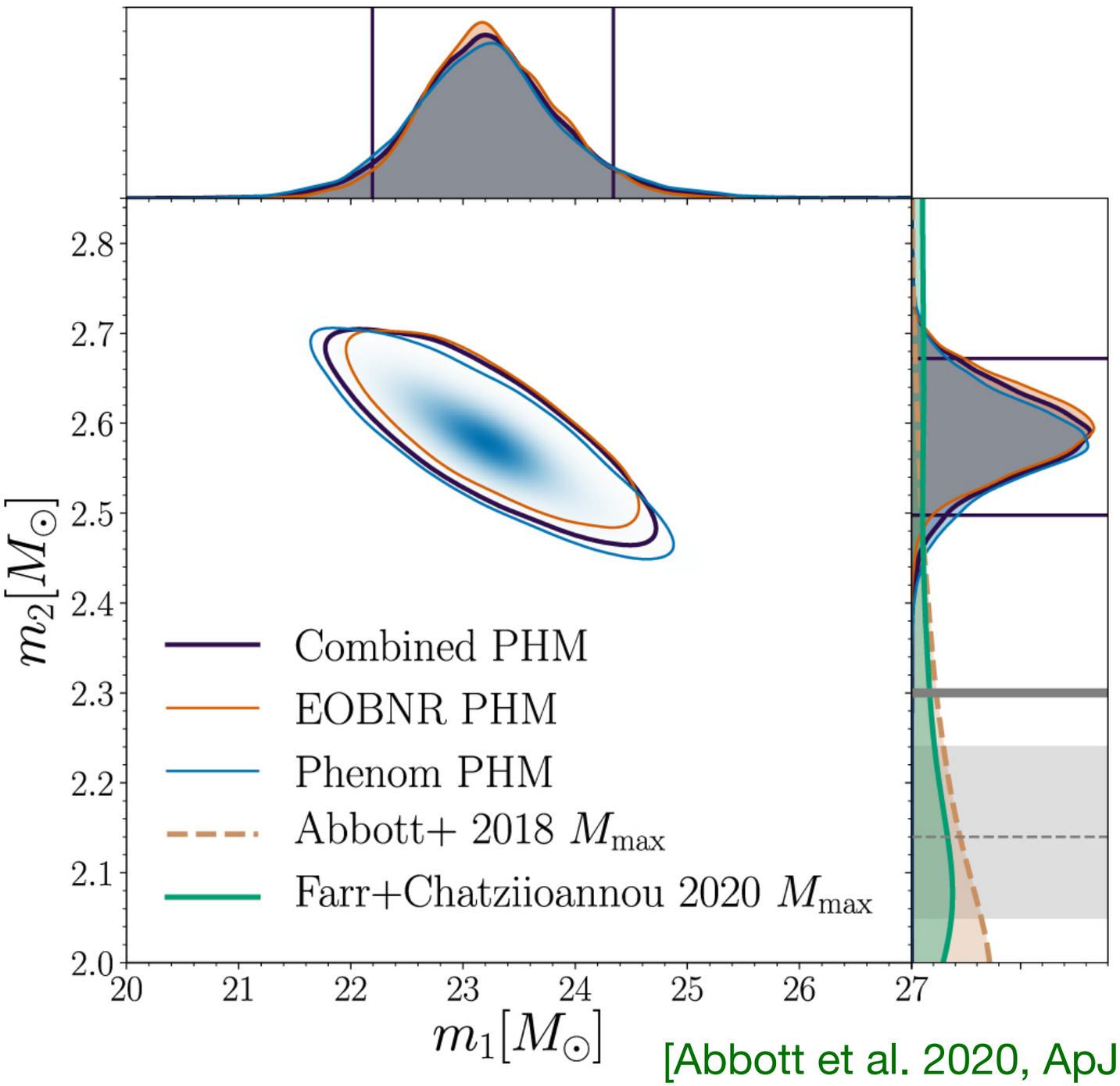
Black hole populations: merger rate evolution



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

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

Black holes in the lower mass gap



GW190814

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

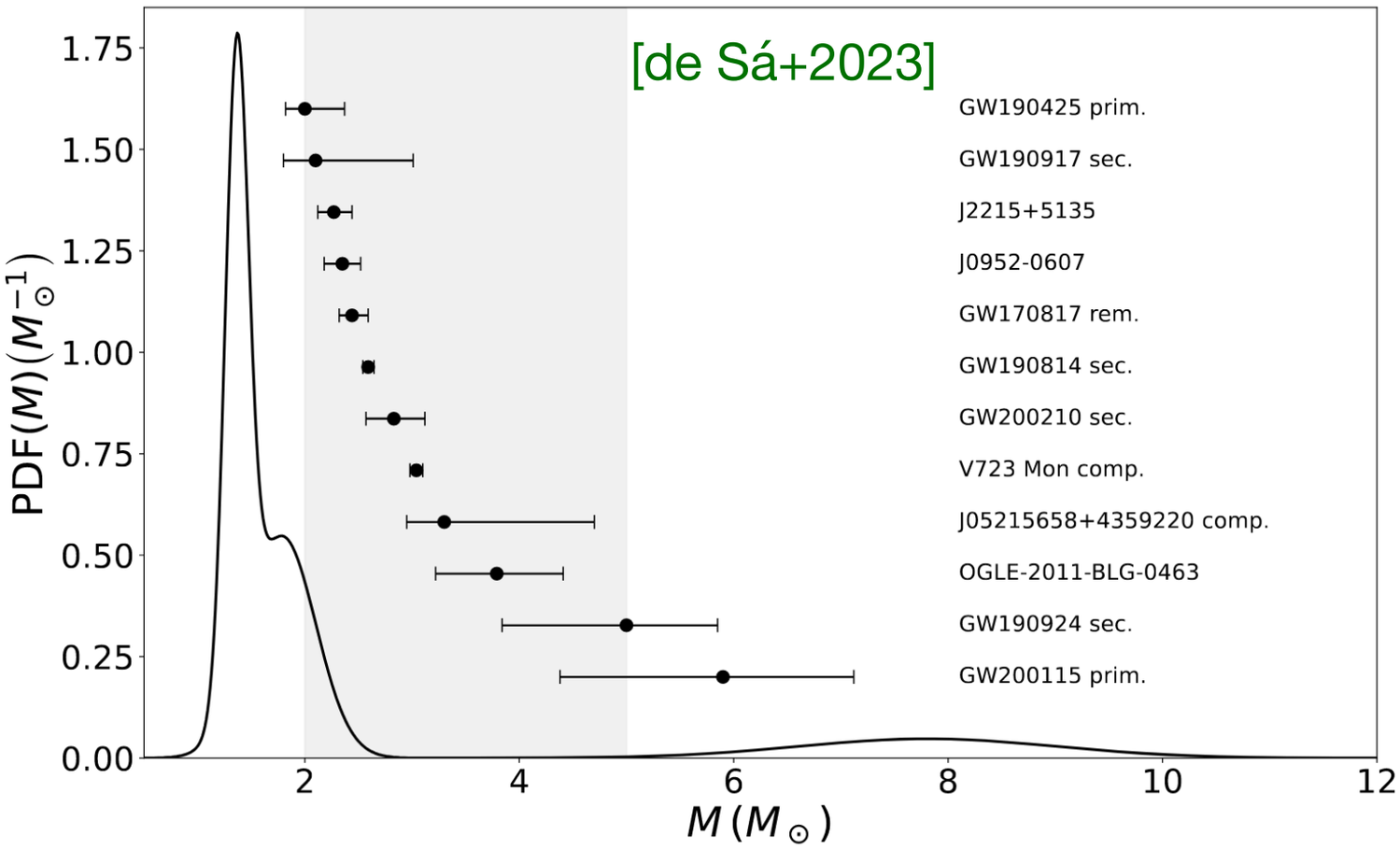
$$m_2 = 2.59^{+0.08}_{-0.09}\ M_\odot$$

Heaviest neutron star?

Lightest black hole?

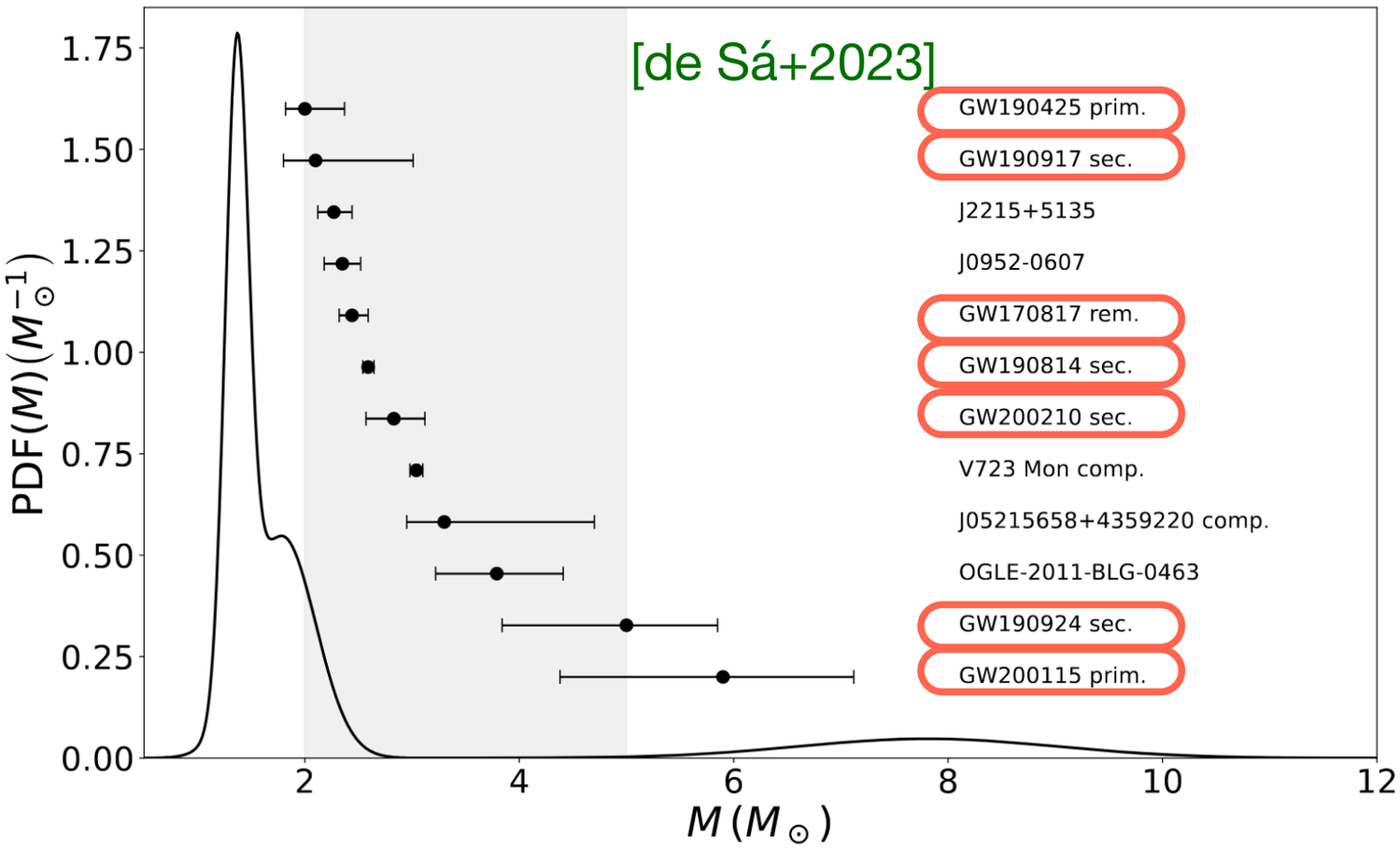
[Abbott et al. 2020, ApJL, 896, 44]

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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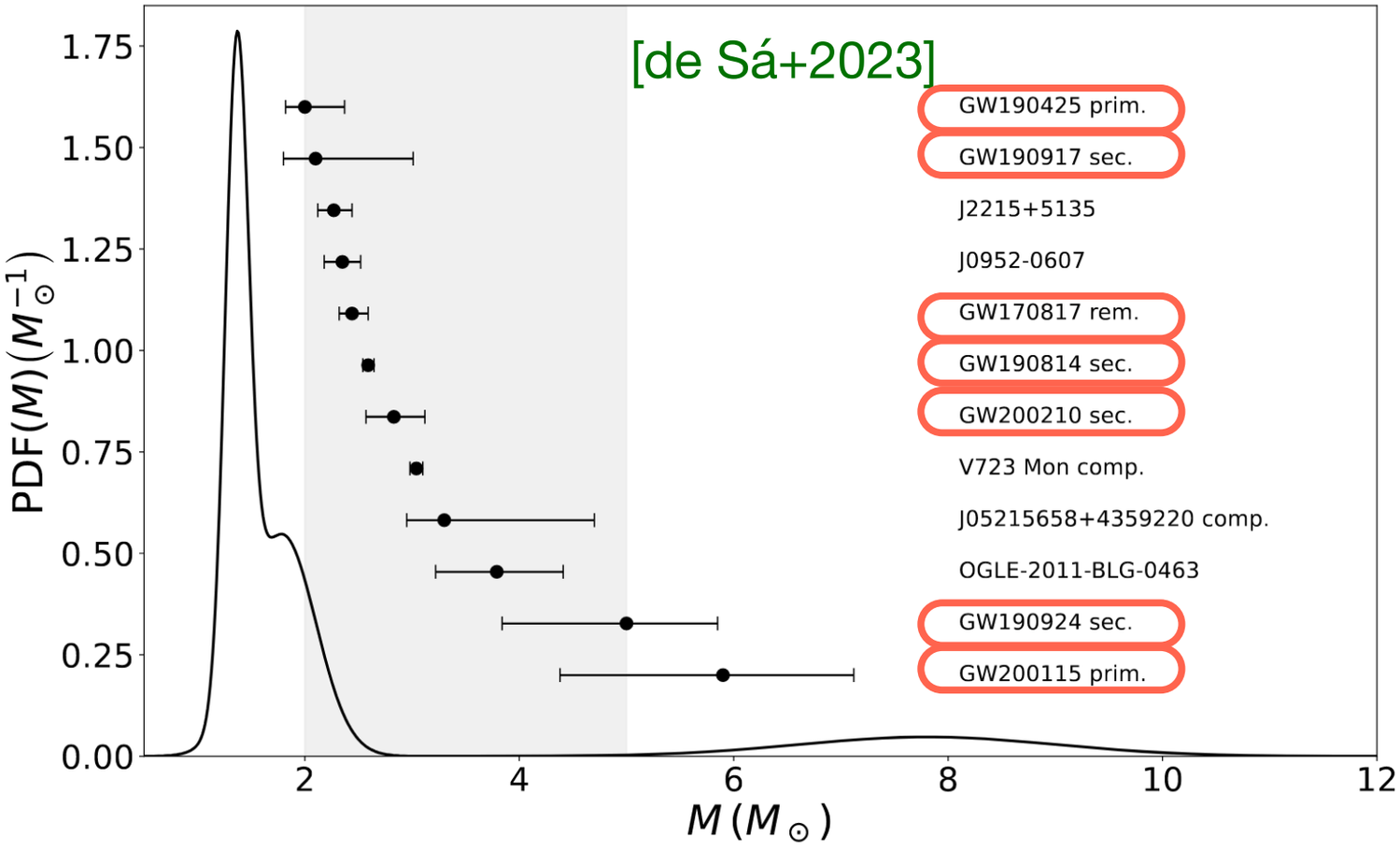
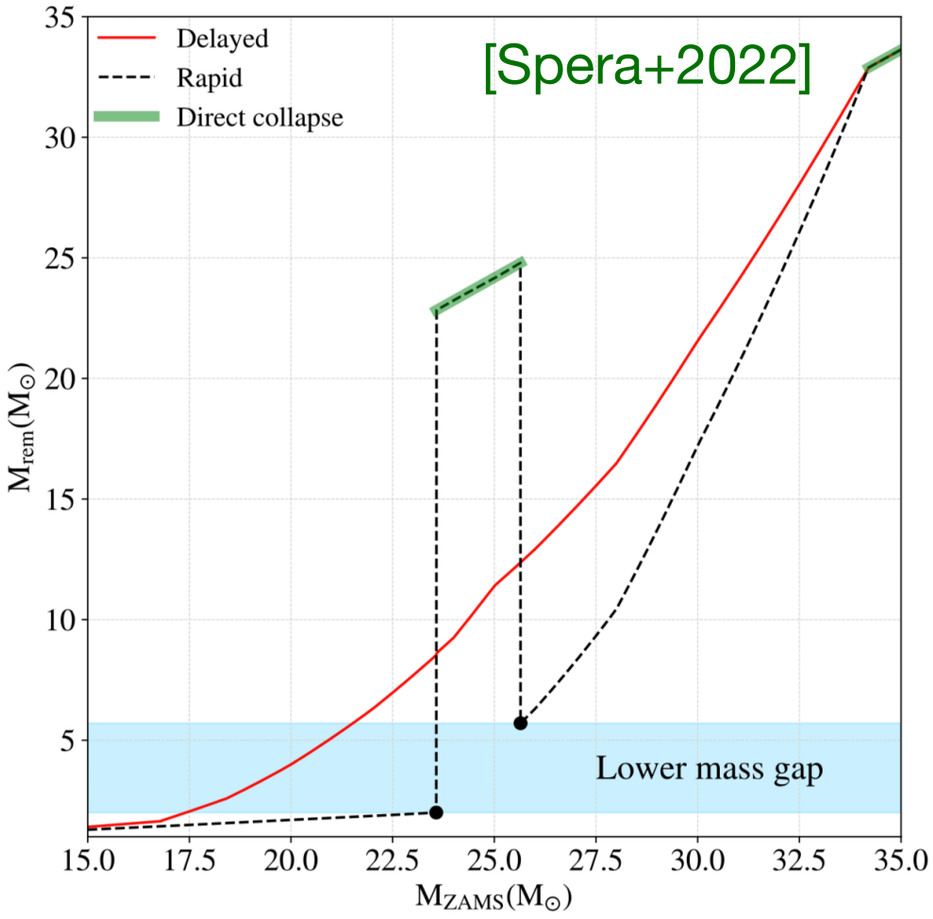
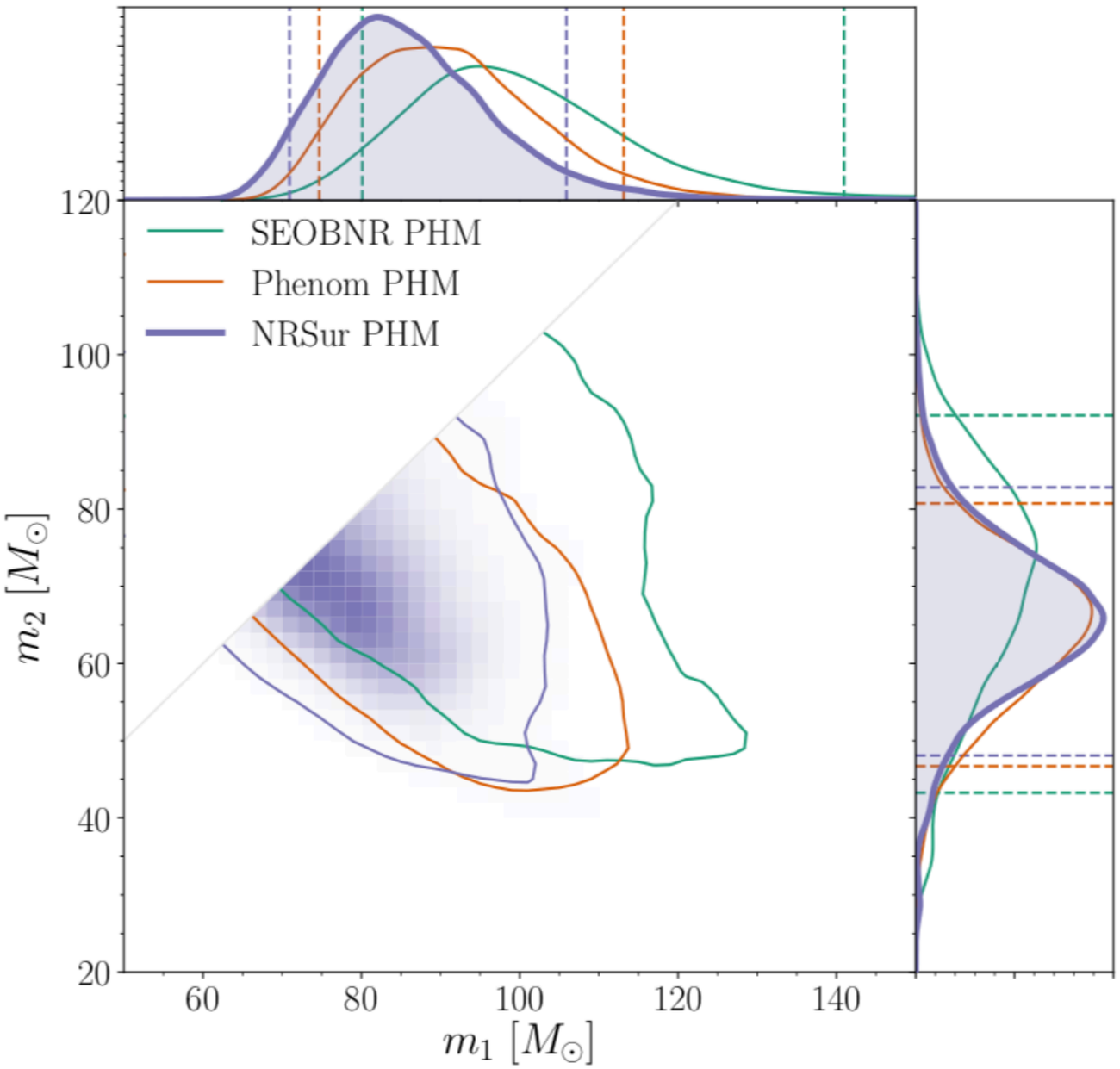




Is the mass gap real?
Is it an observational effect?

Implications for supernova explosion mechanism?

Black holes in the upper mass gap



GW190521

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

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

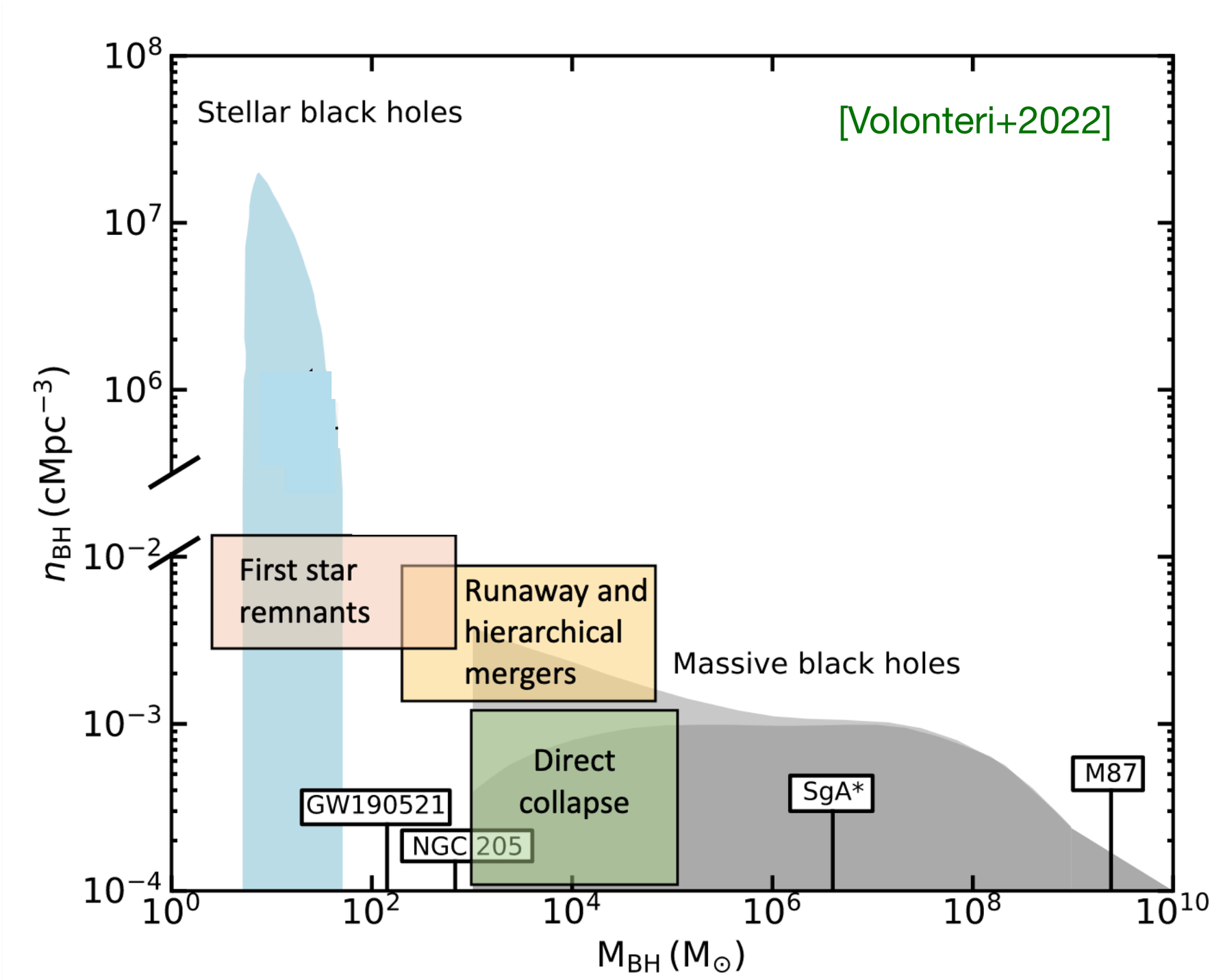
Hierarchical merger?

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?



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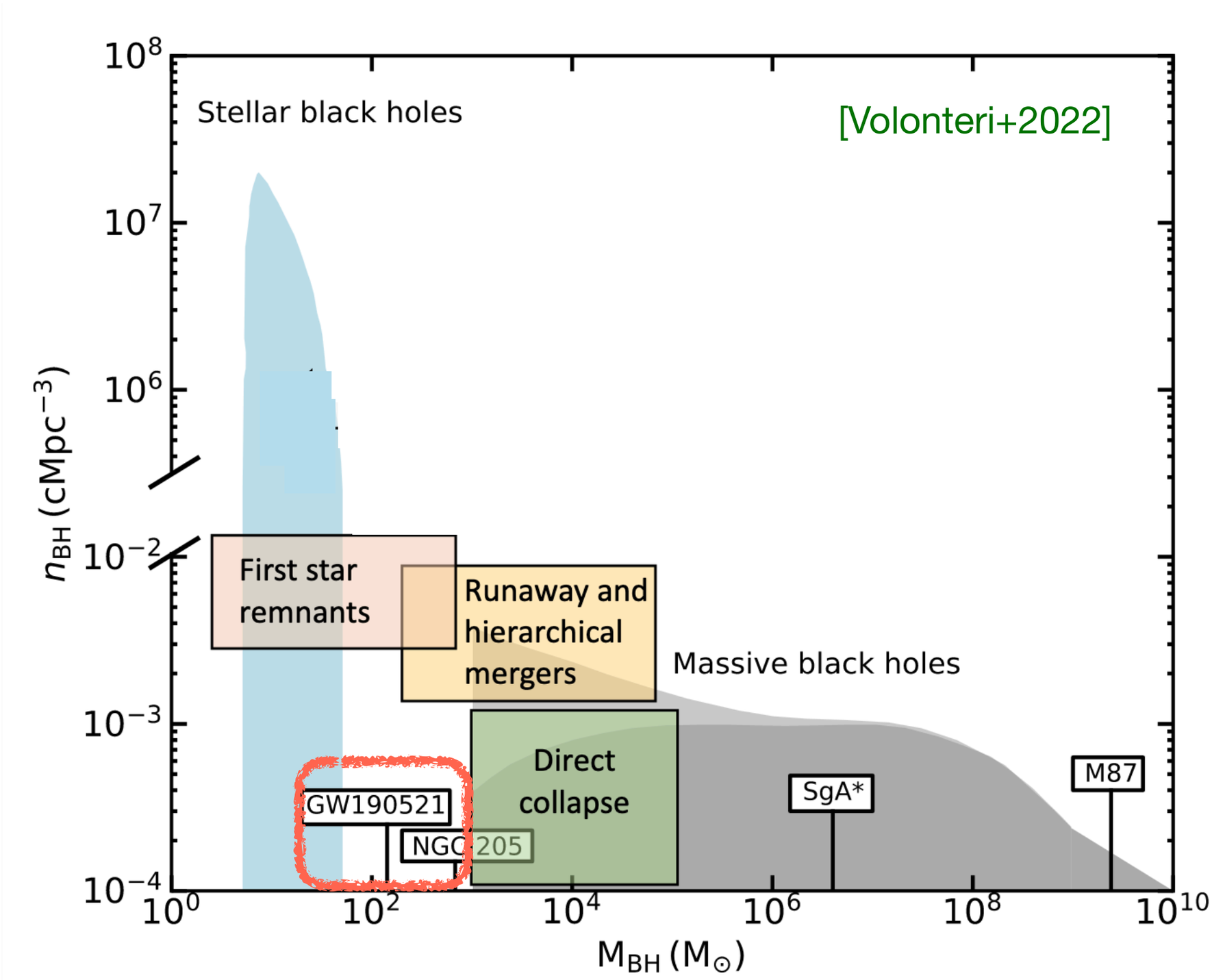
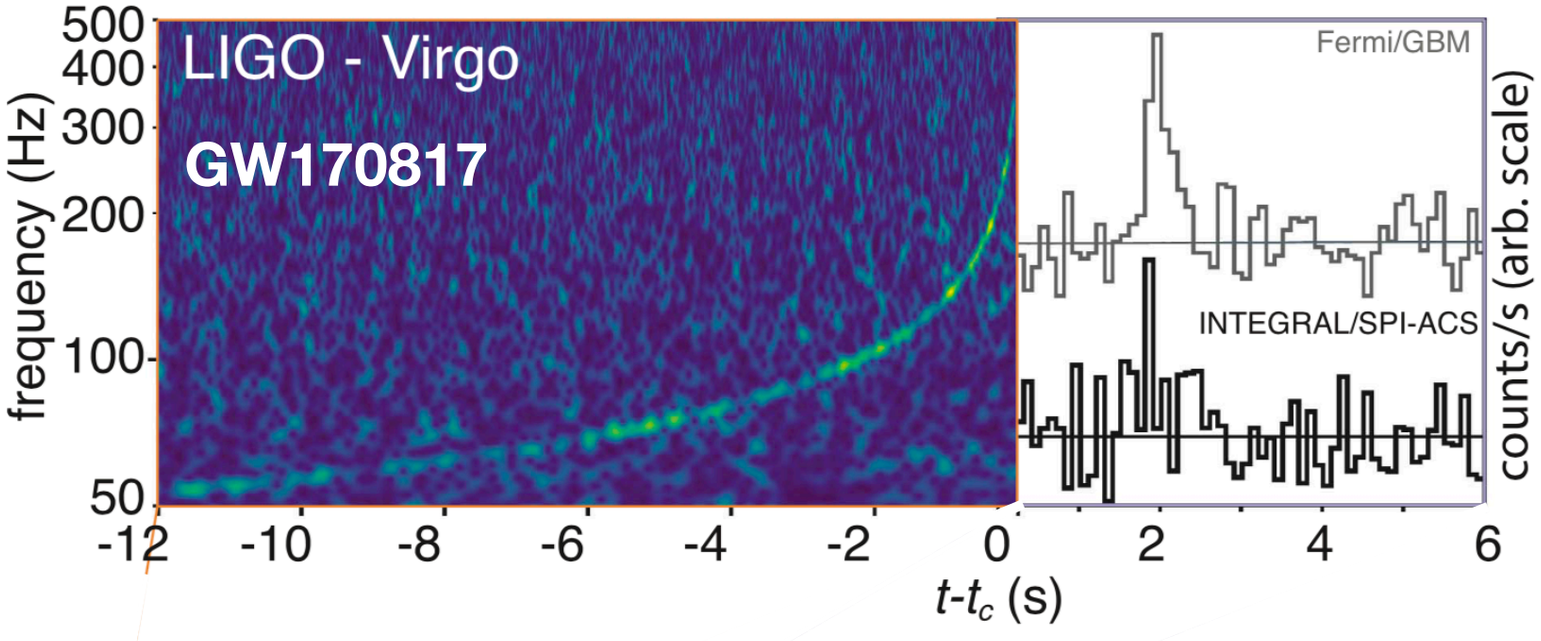


Binary neutron stars: multi-messenger observations!



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

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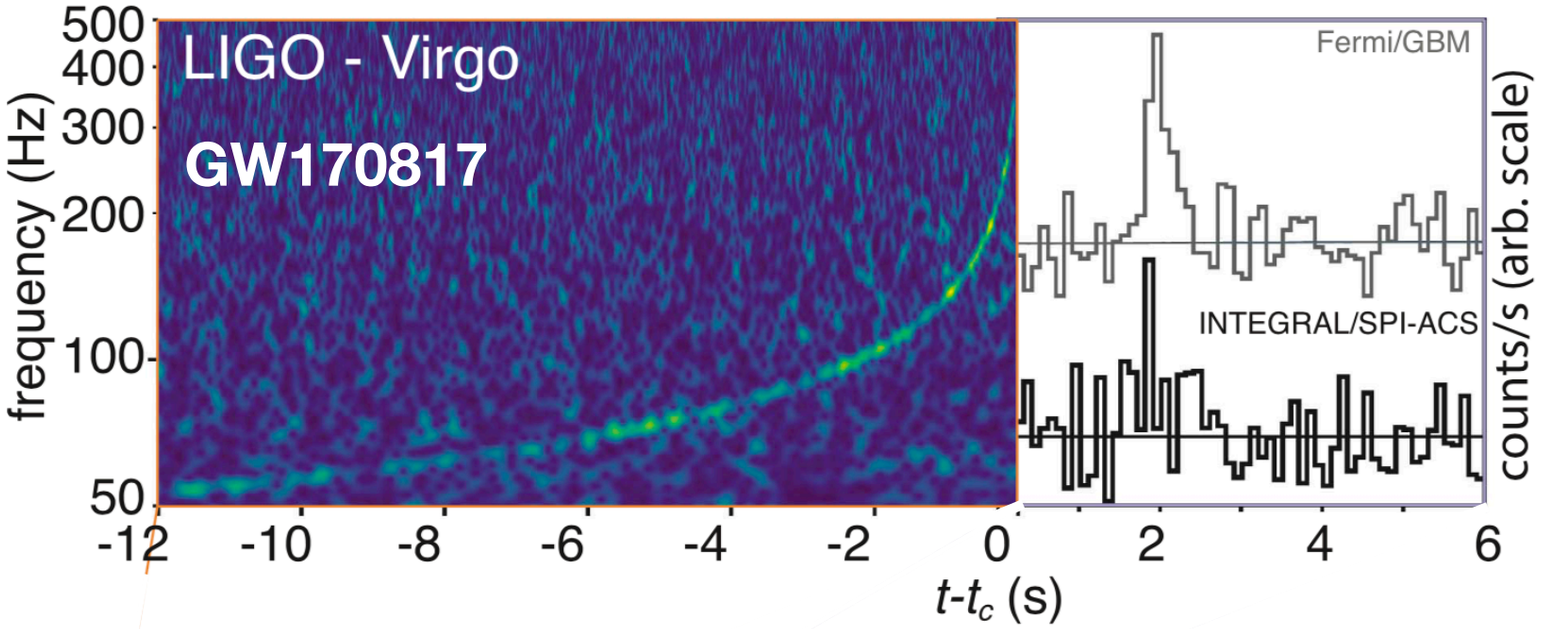

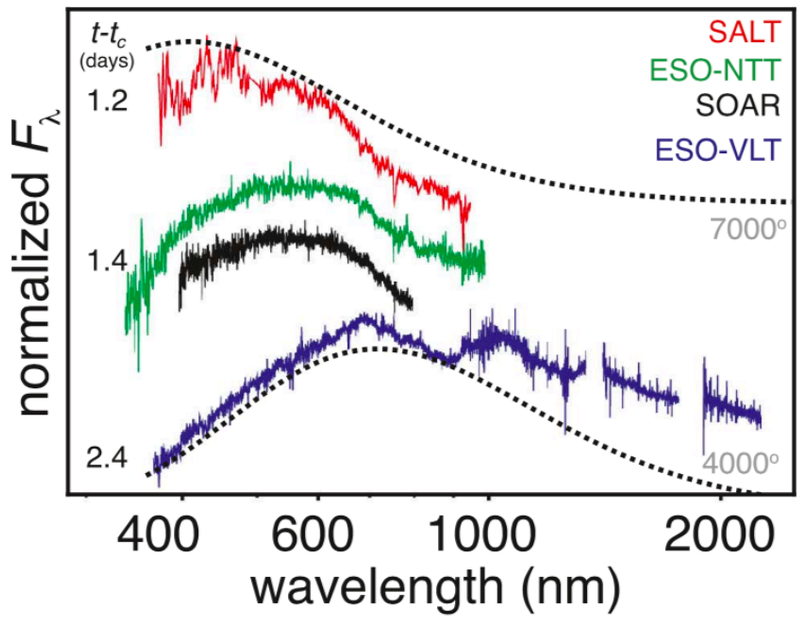

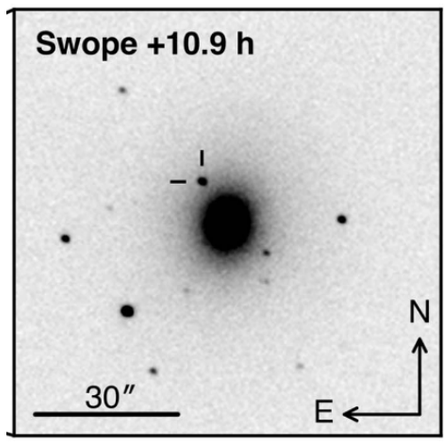

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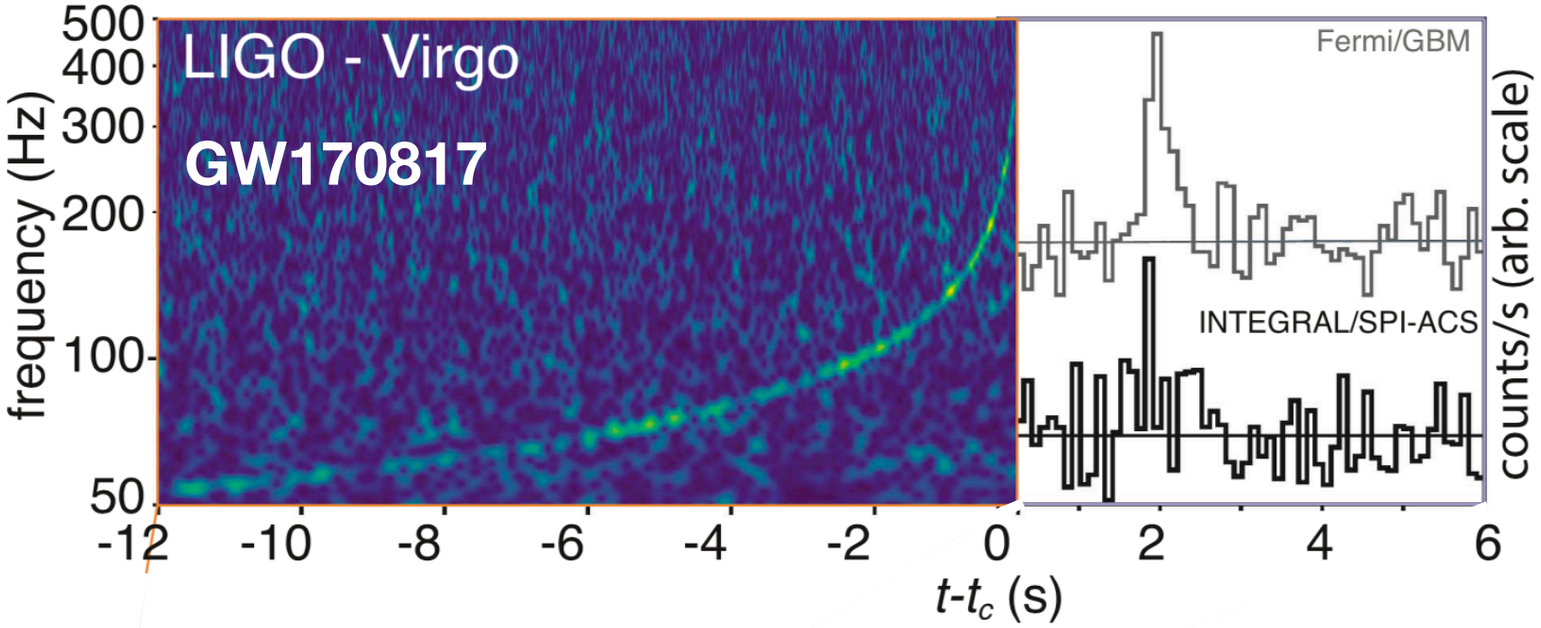

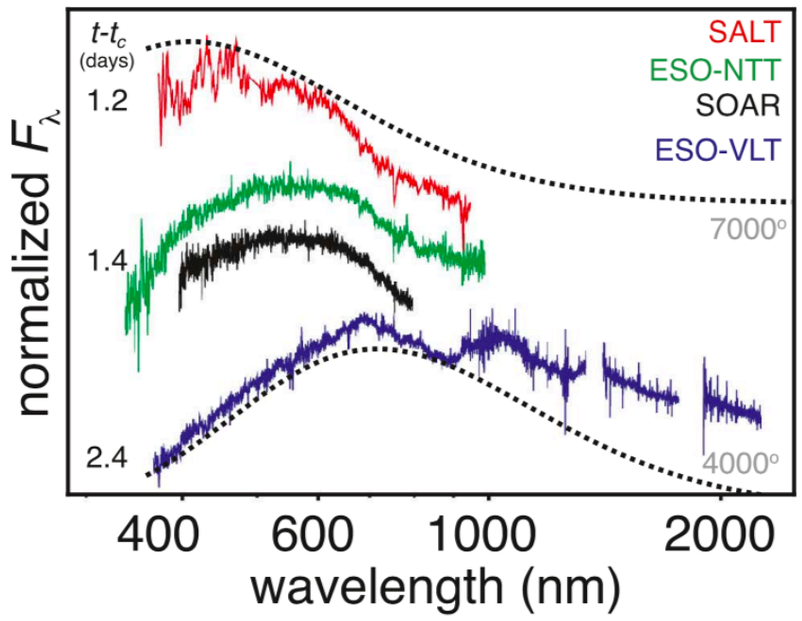

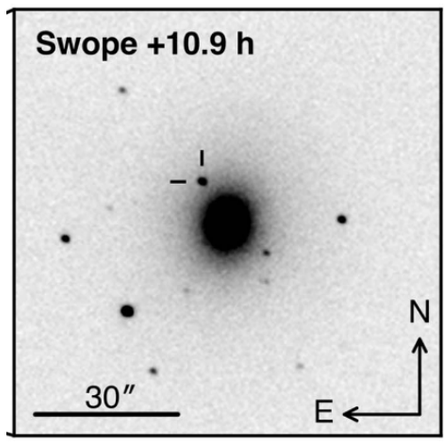

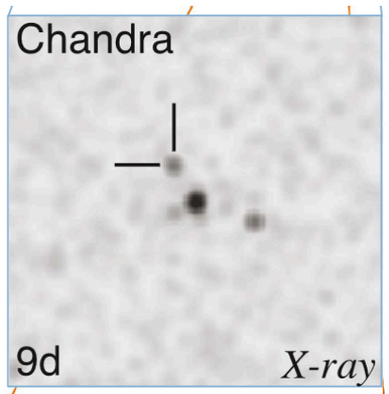

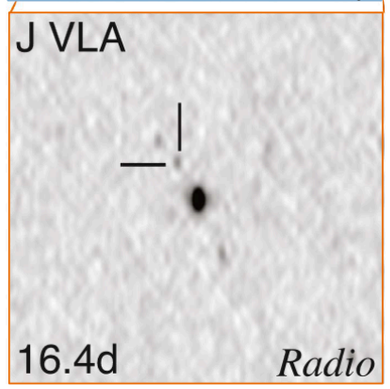

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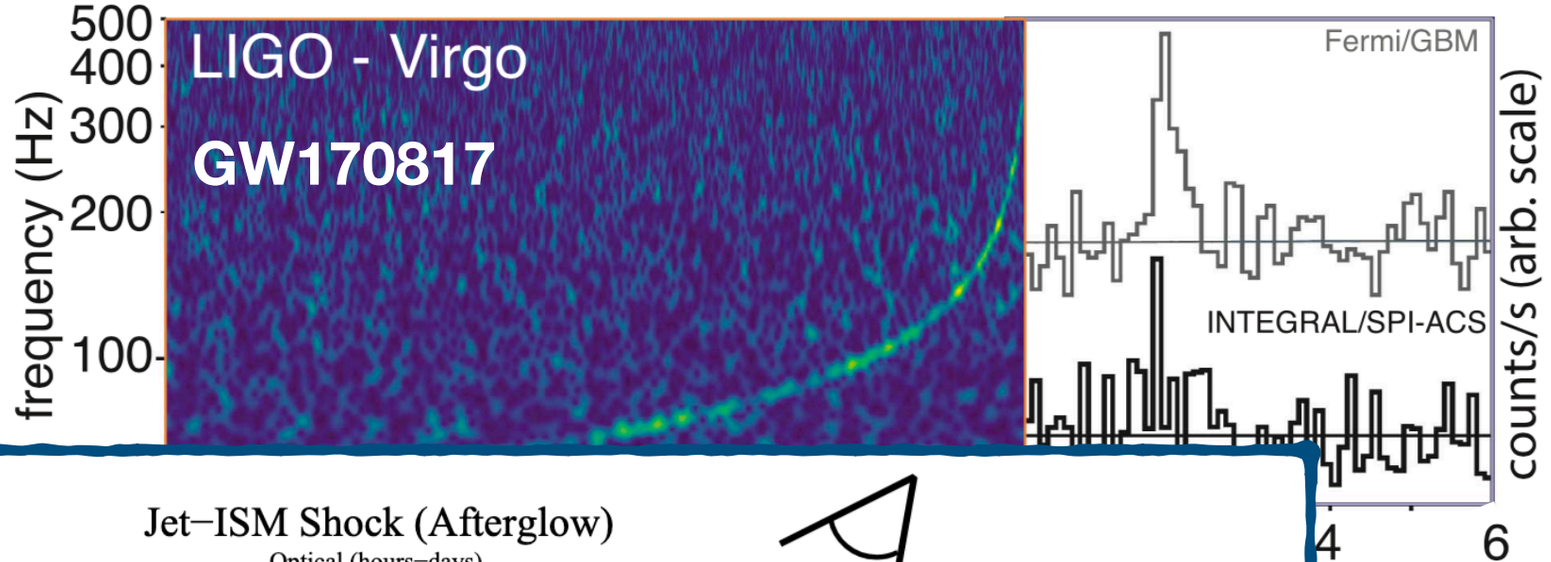

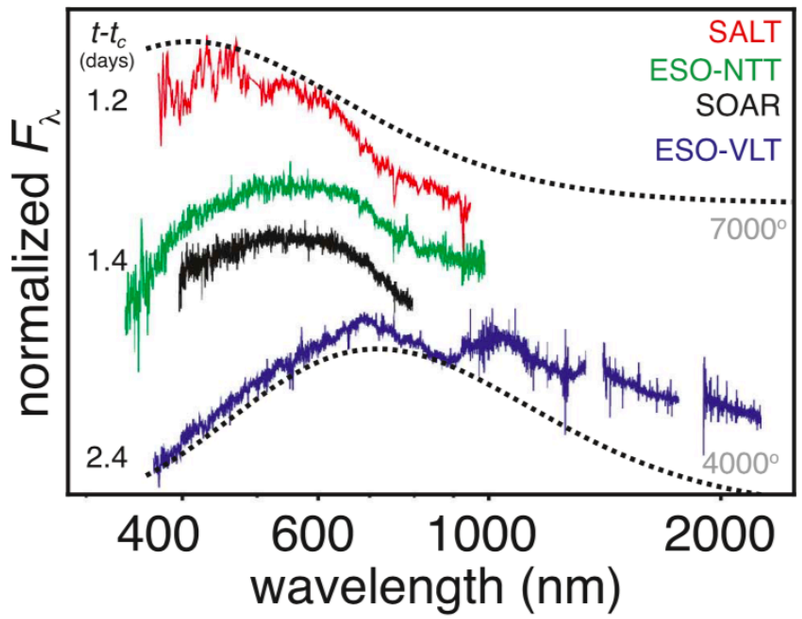

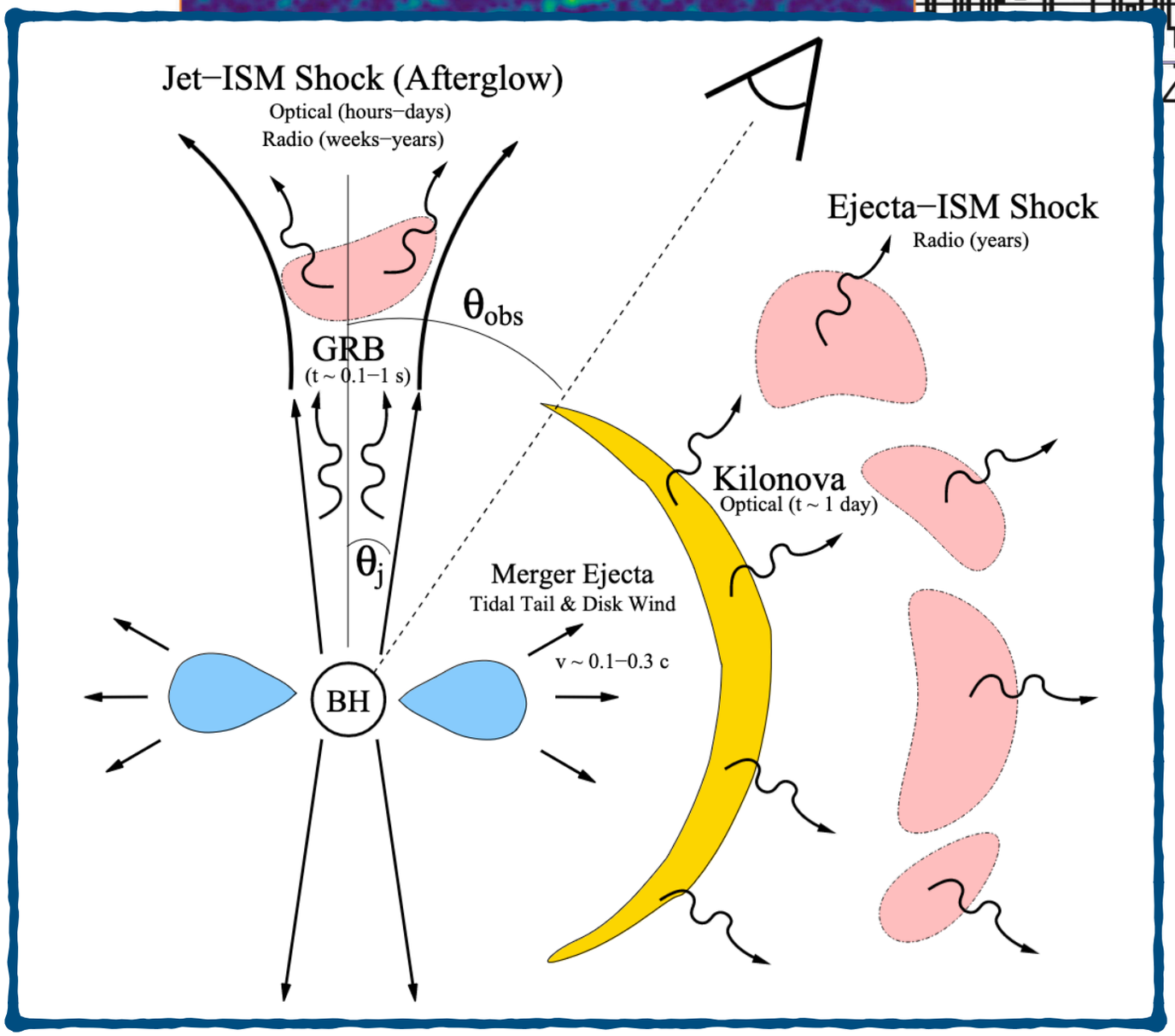

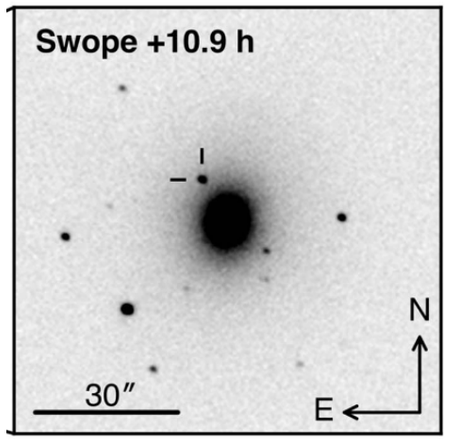

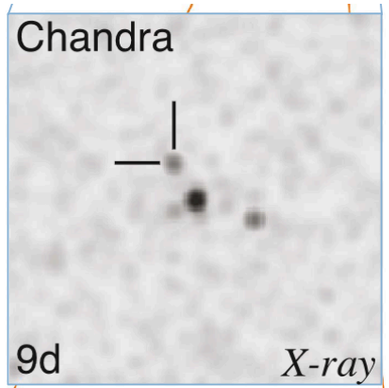

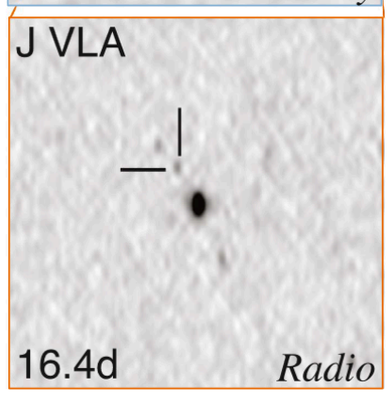

[Metzger & Berger. 2012, ApJ, 746, 48]

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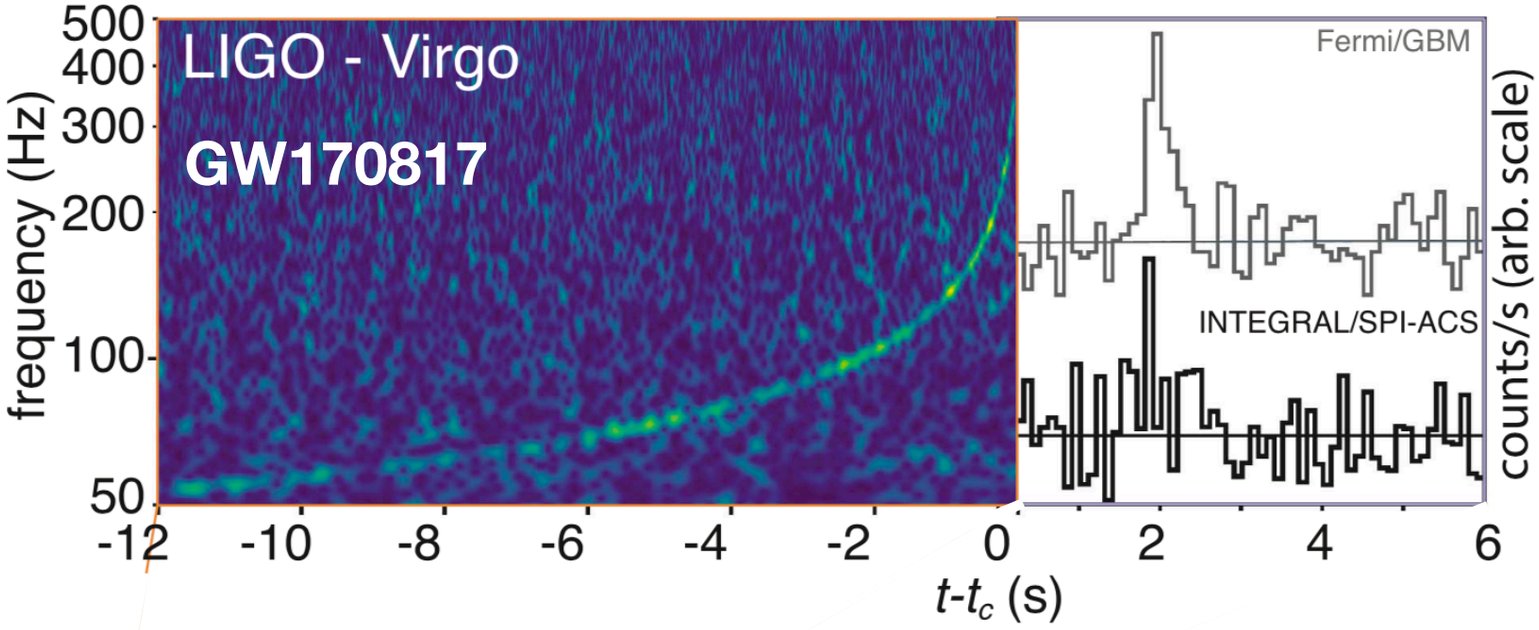
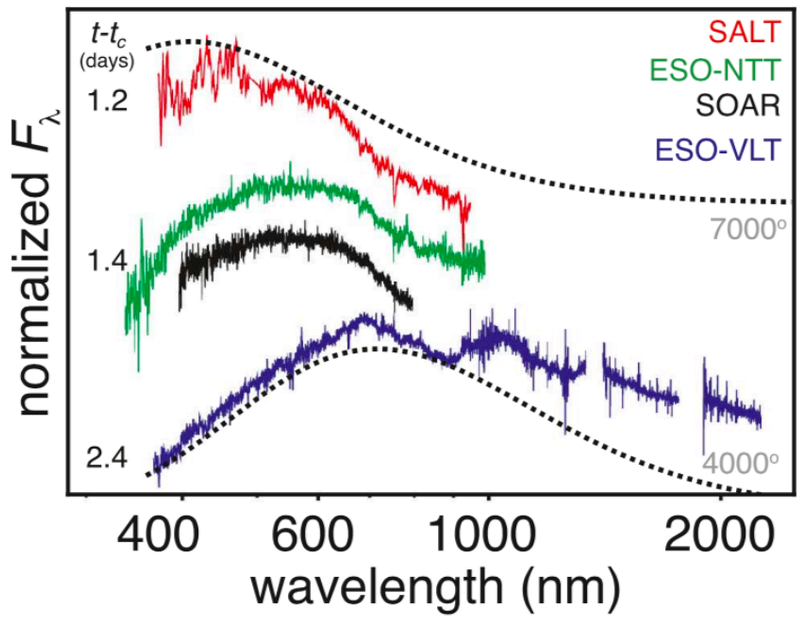
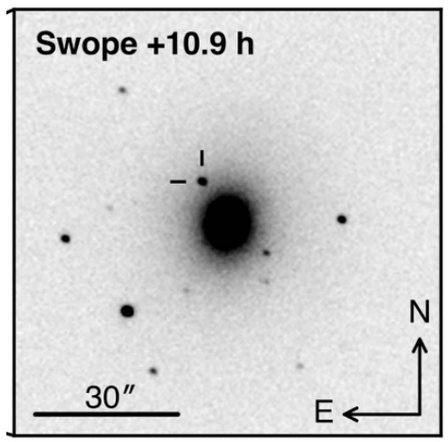
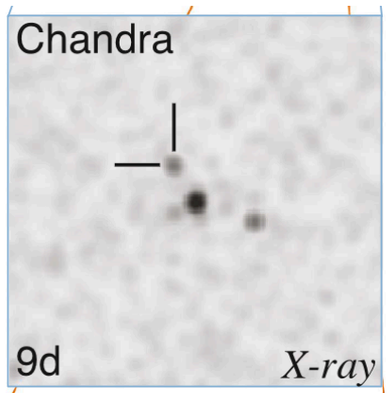
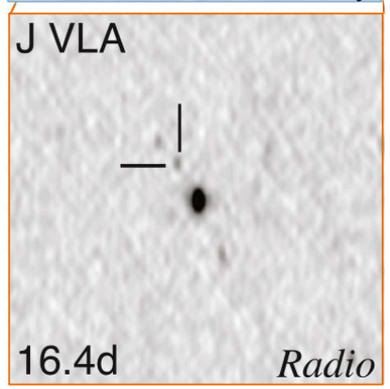




- GW+EM observations
- Connection between BNS merger and short gamma ray bursts (GRB)
- Kilonova: synthesis of heavy elements
- GRB: jet structure
- Identification of host galaxy: 40 Mpc away

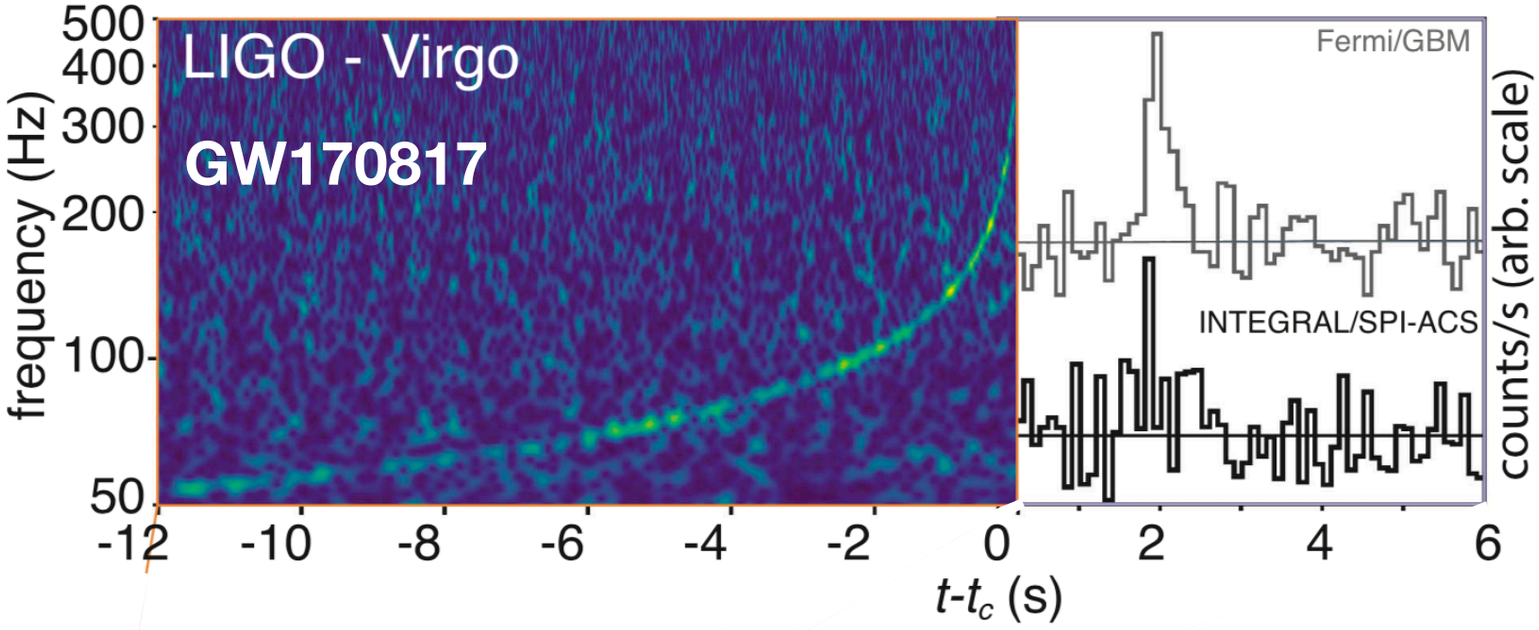


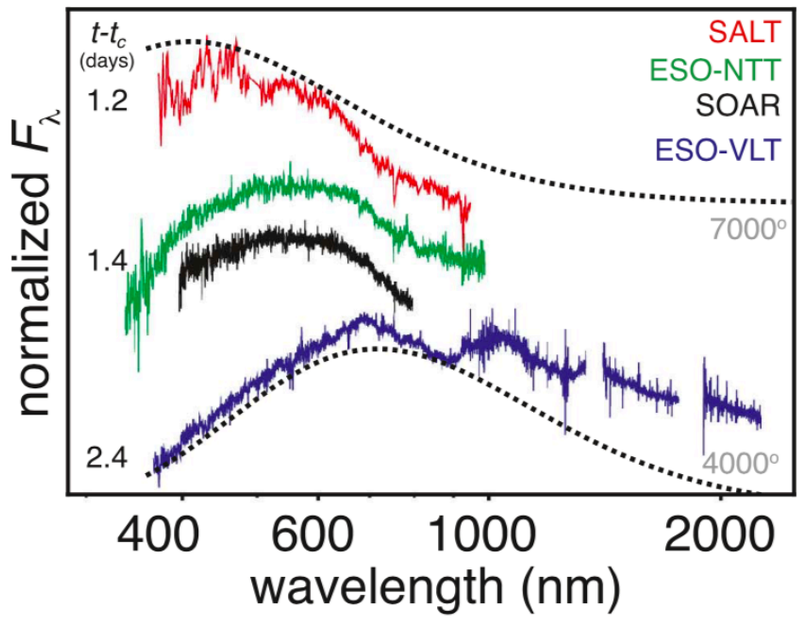




[Abbott et al. 2017, ApJ Letters, 848, 2]

Binary neutron stars: multi-messenger observations!





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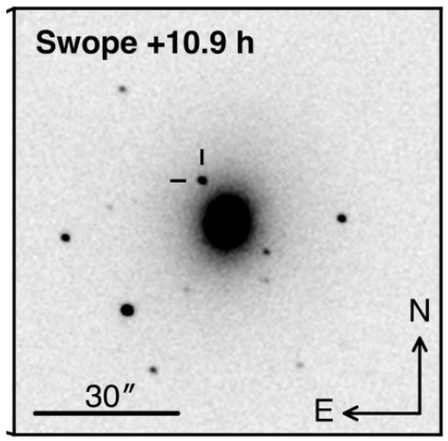
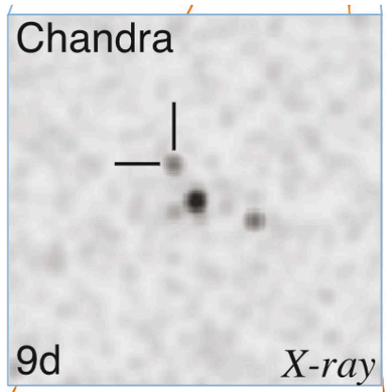
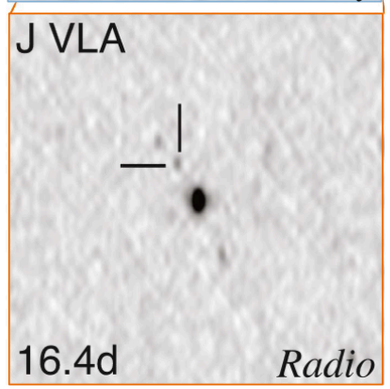
- **No neutrino detection…**

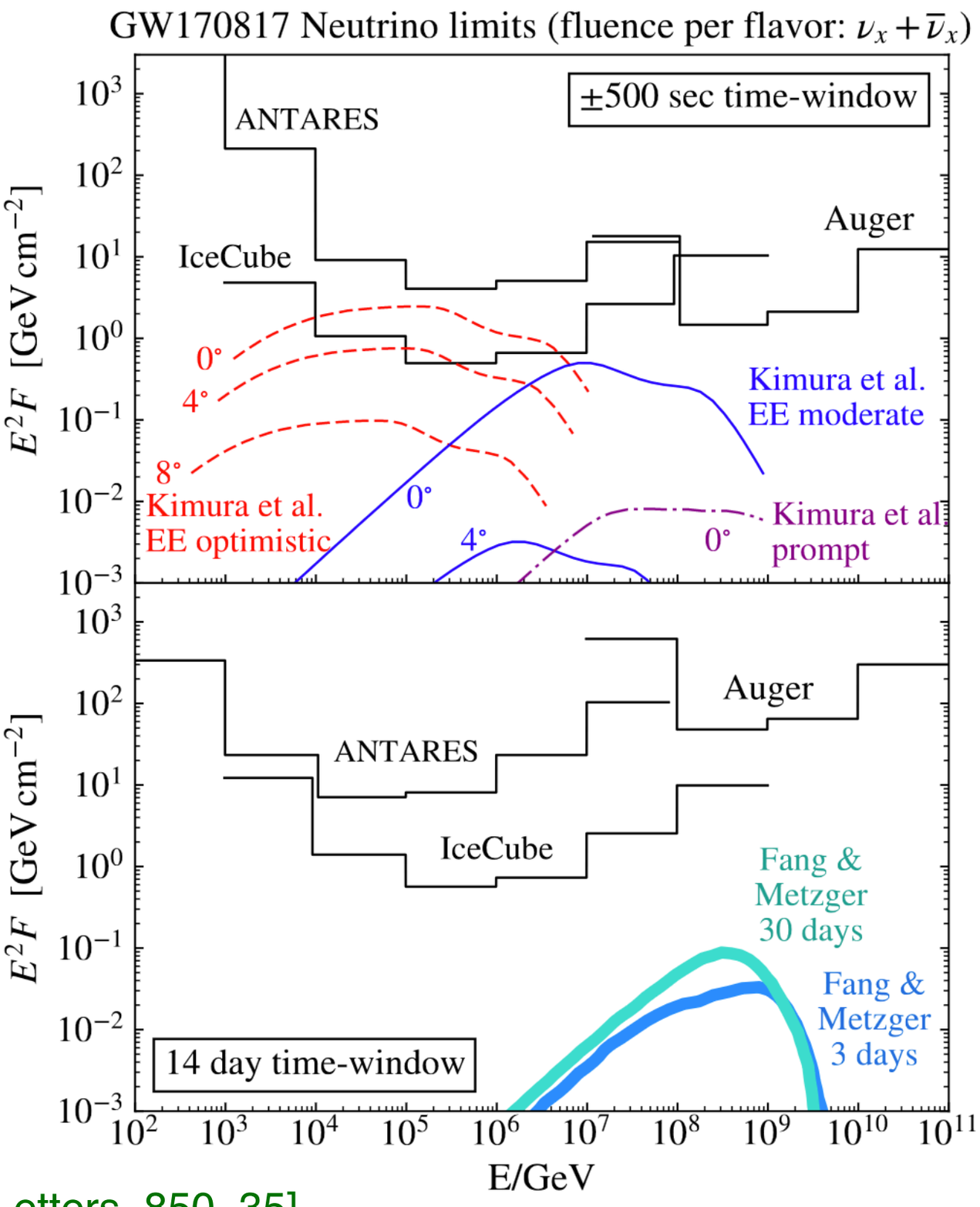






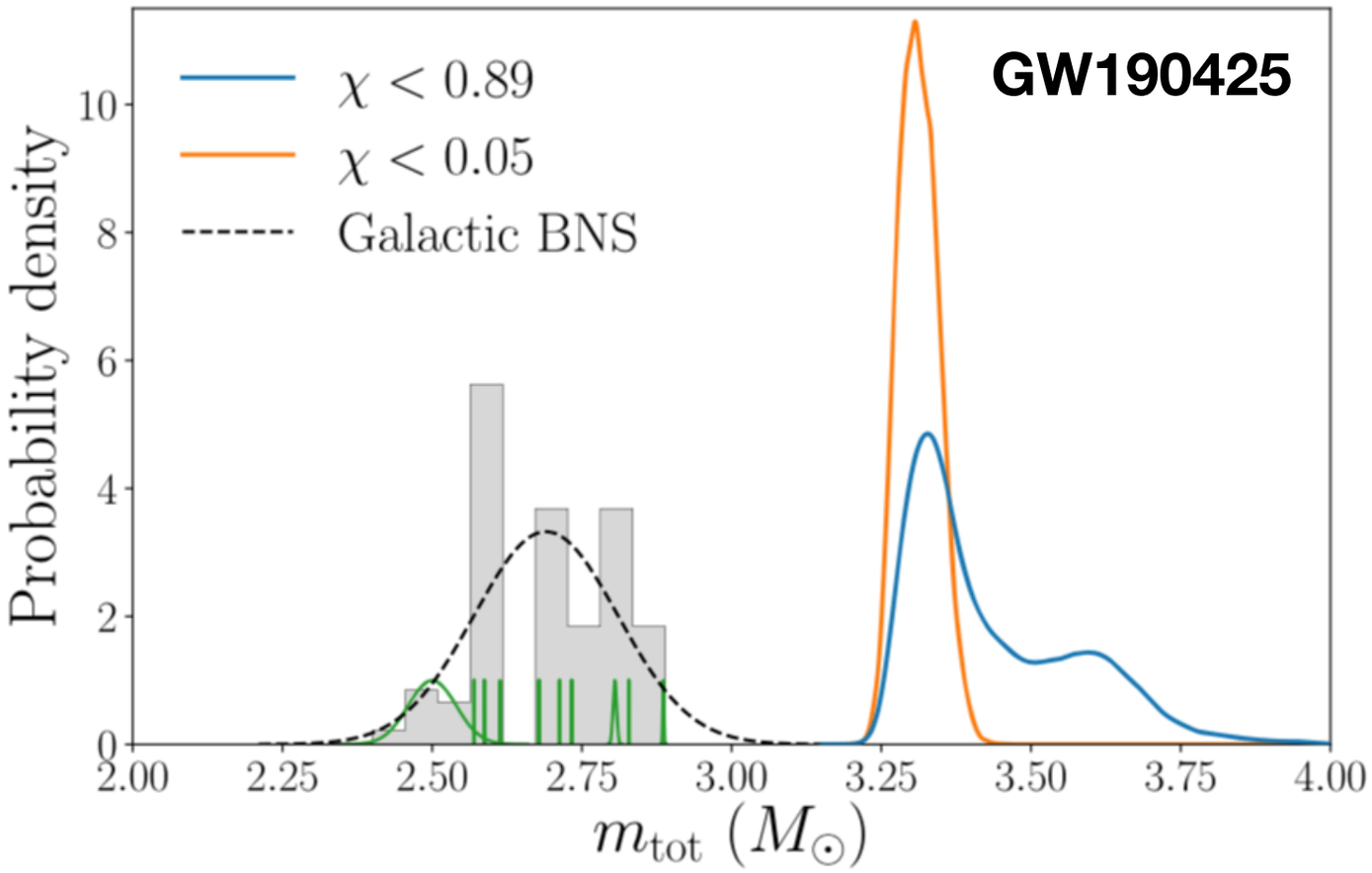
[Abbott et al. 2017, ApJ Letters, 848, 2]

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]

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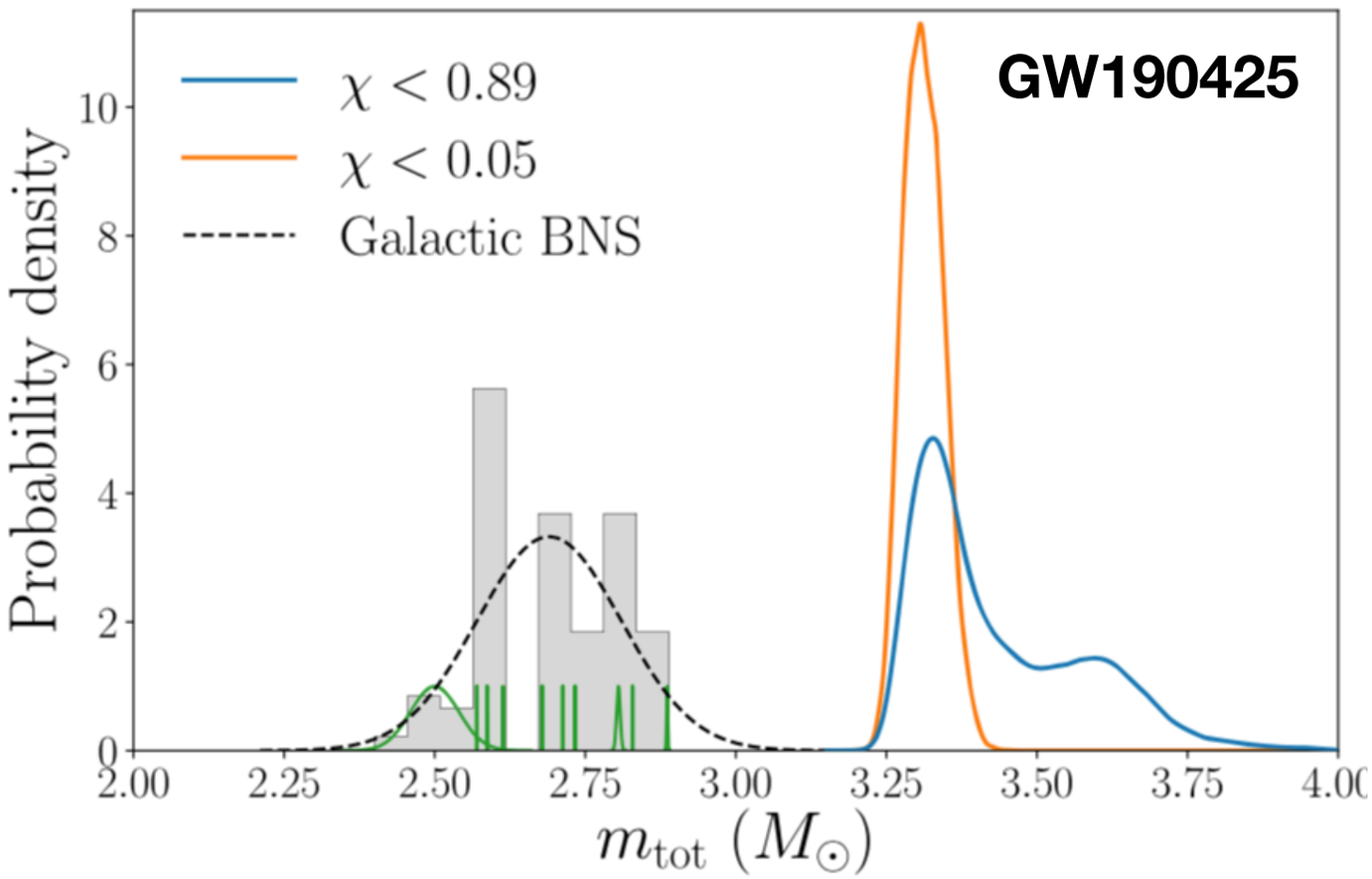

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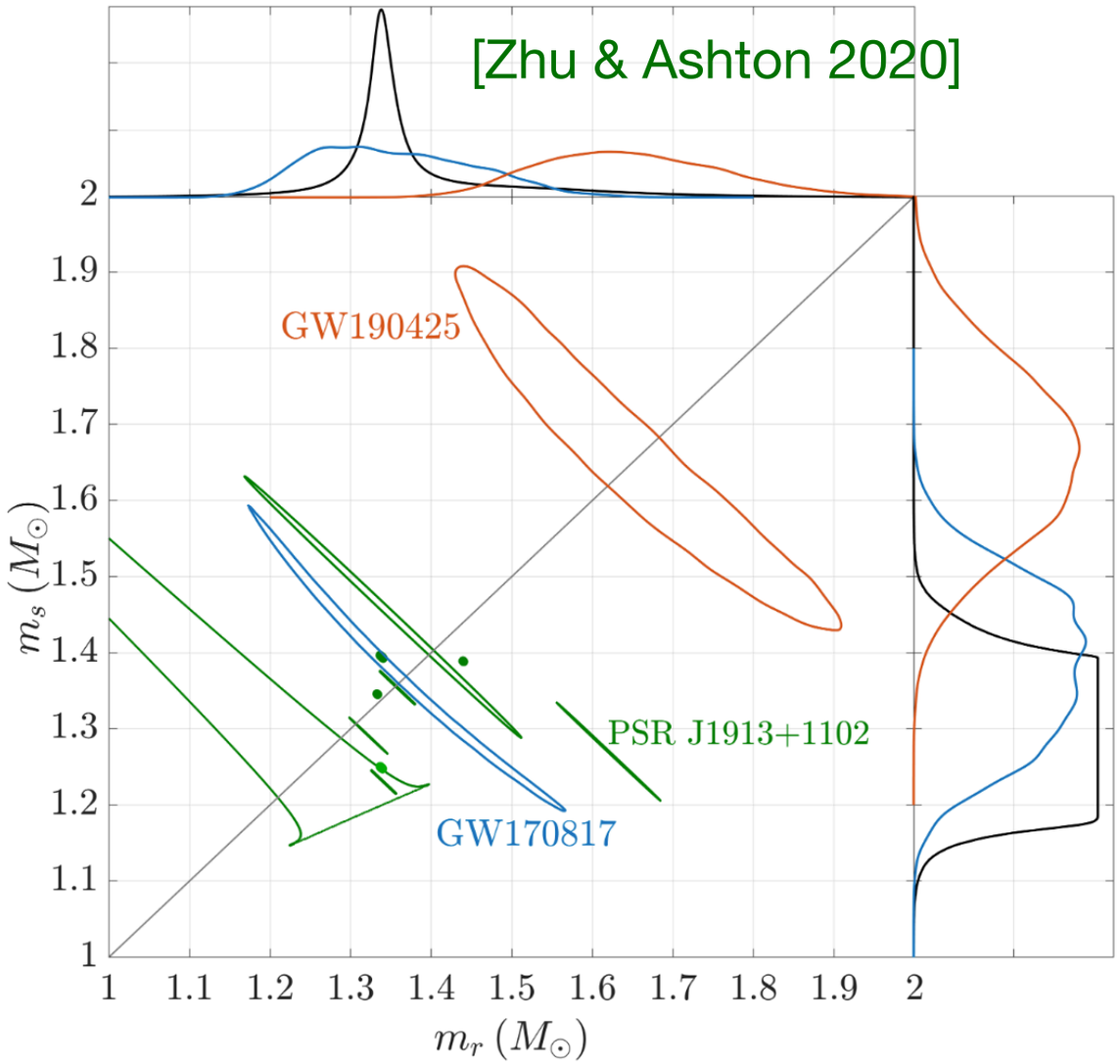
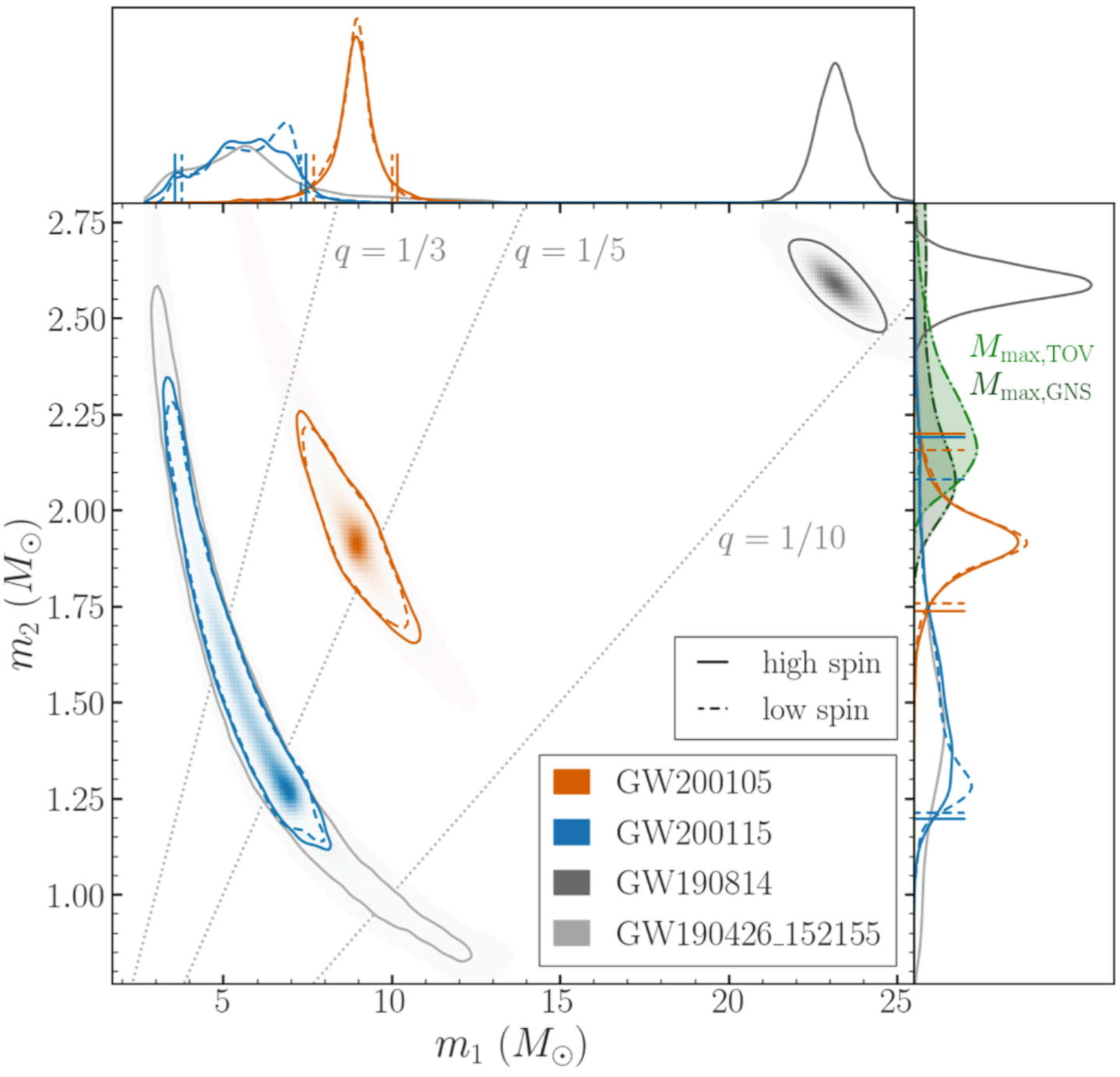


How do binary neutron stars form?

What are the differences between GW sources and Galactic binaires?

Neutron star-black hole: mixed binaries



GW200115

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

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

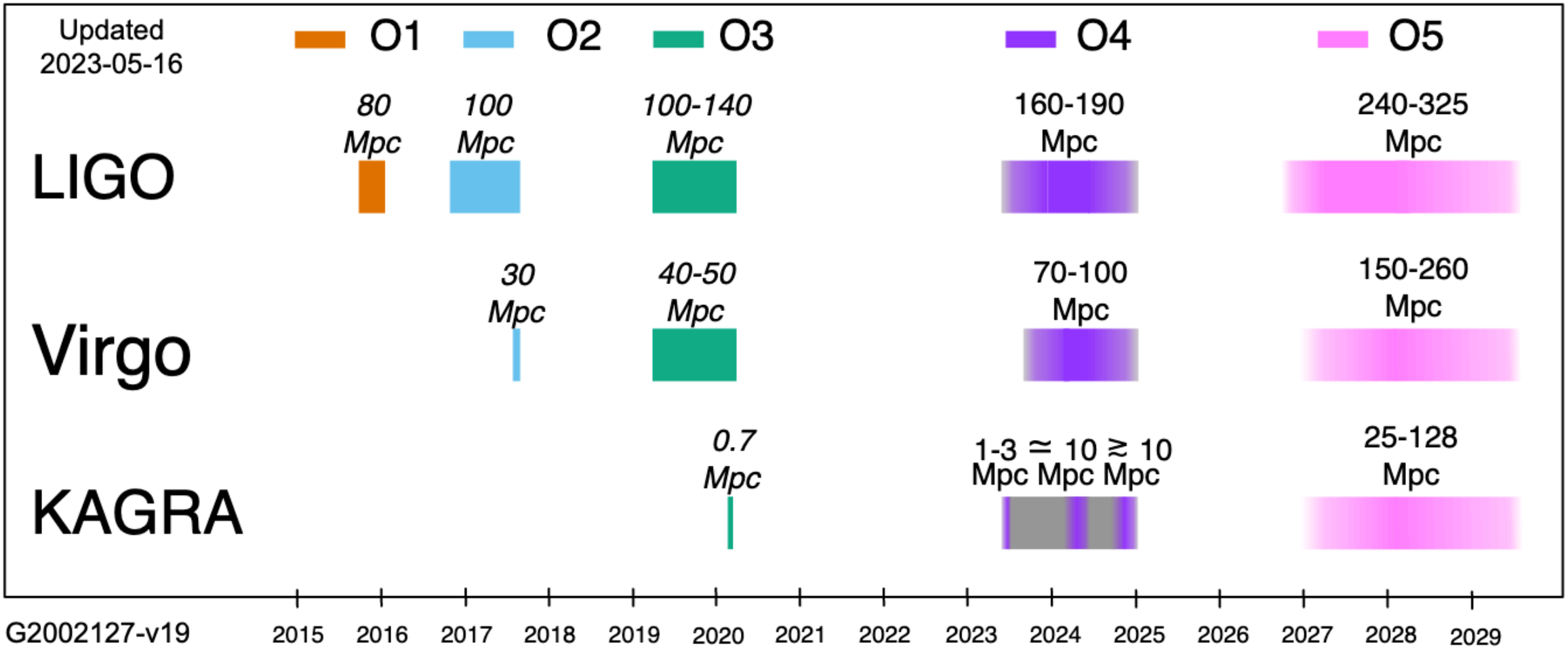
GW200105

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

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

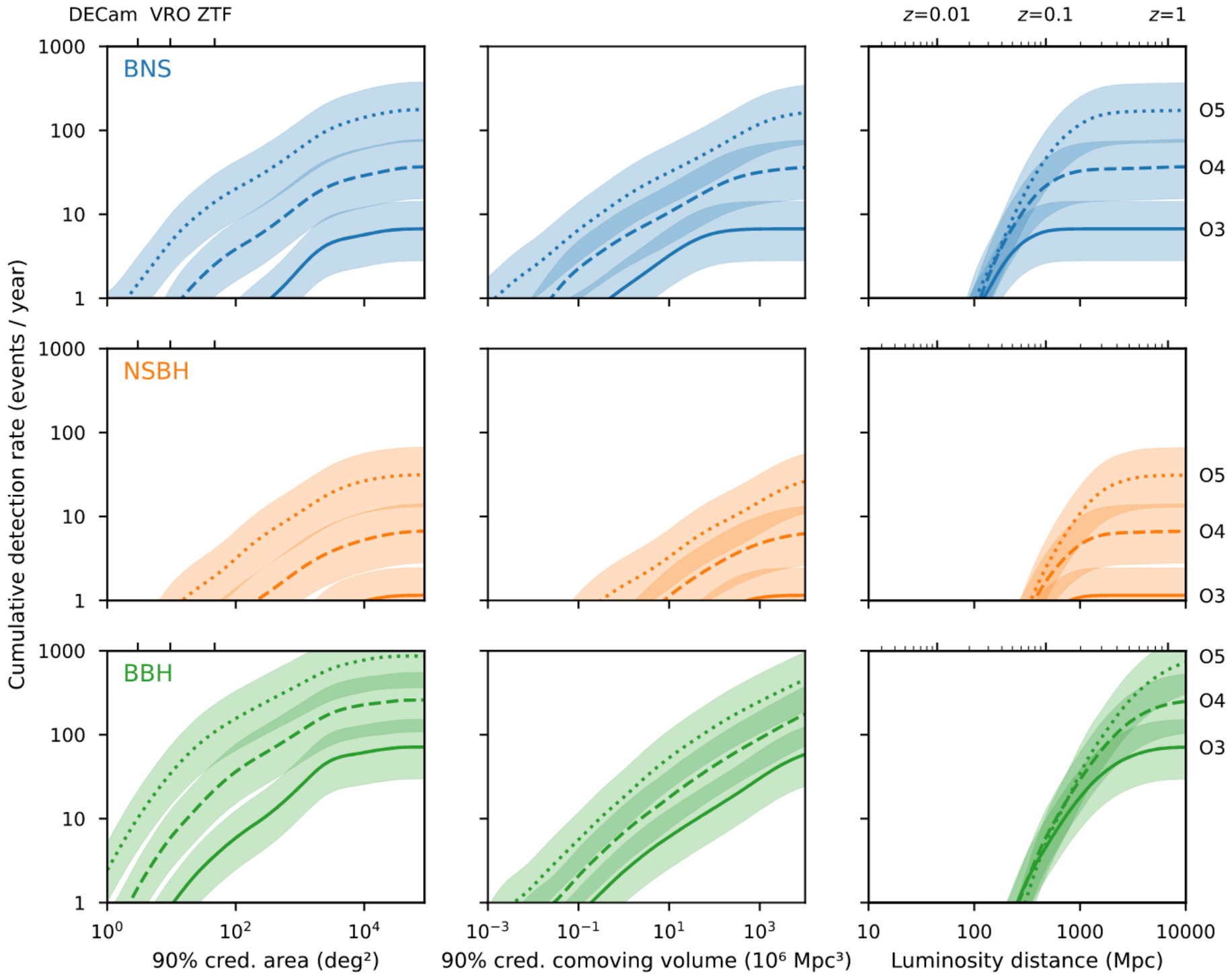
[Abbott et al. 2021, ApJL, 915, L5]

Prospects for O4/O5 runs



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

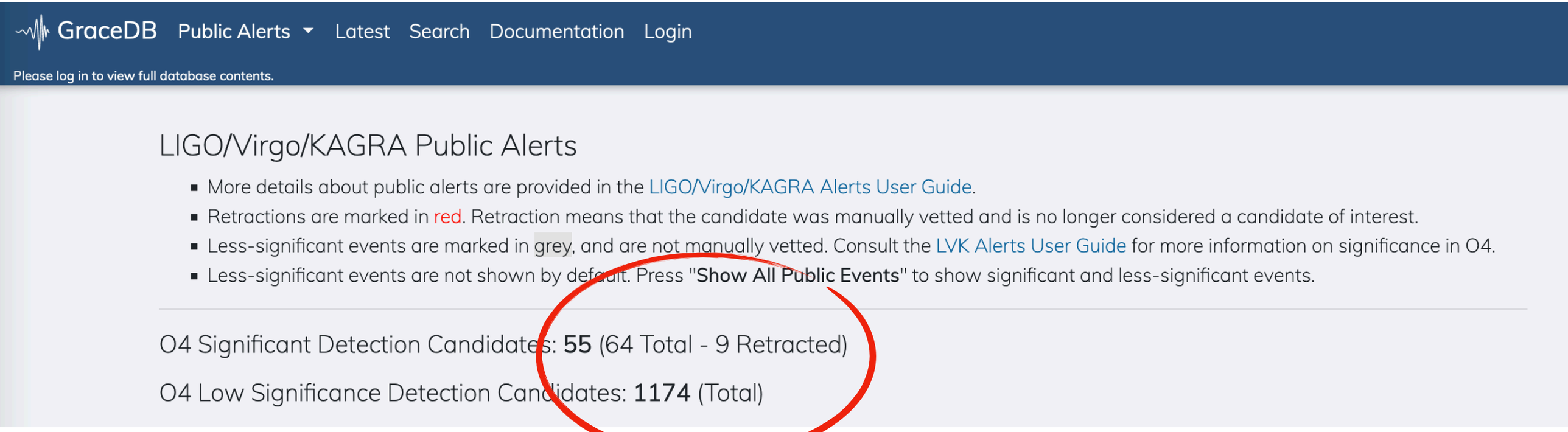
Prospects for O4/O5 runs



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

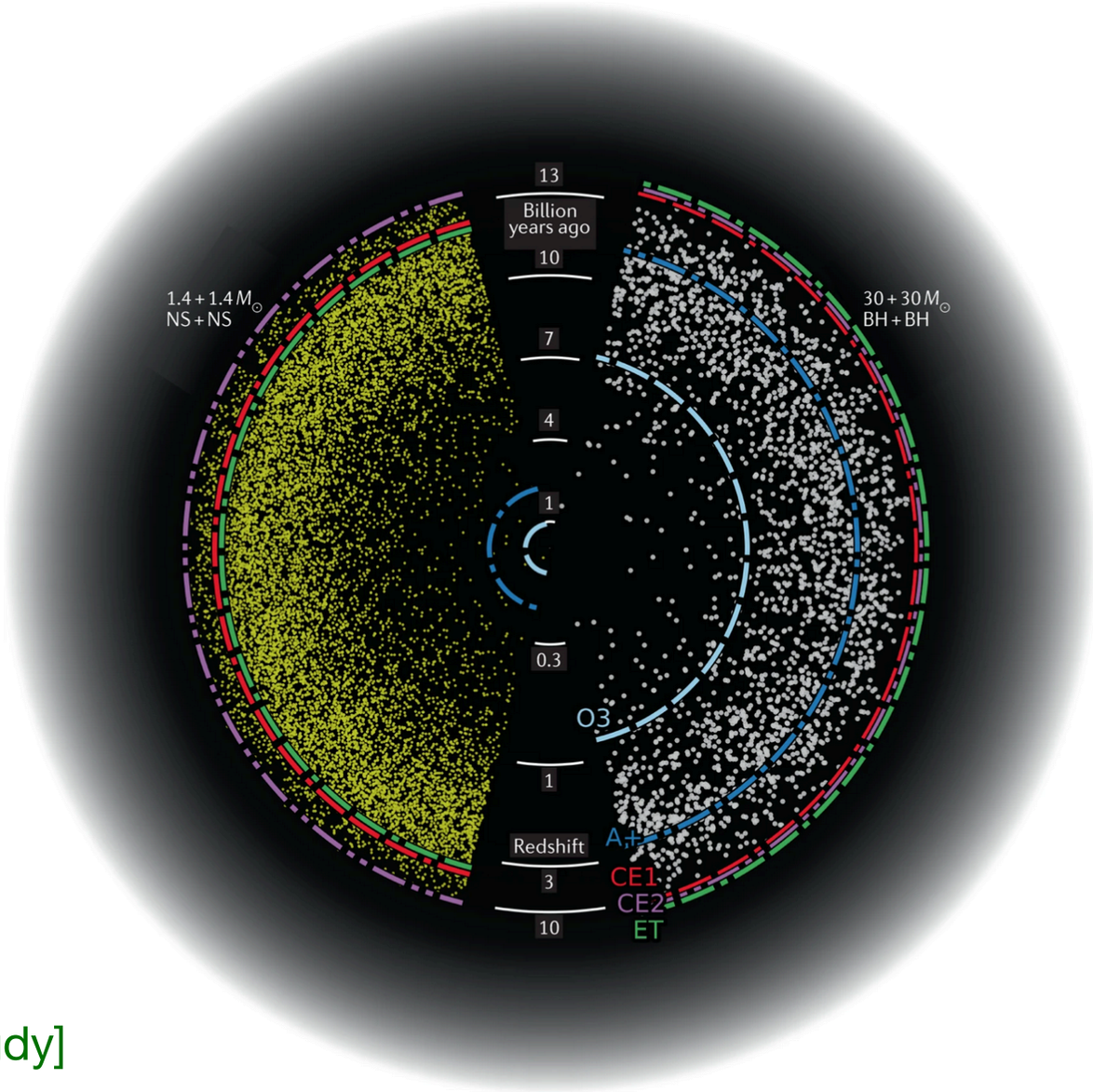
O4 run ongoing…

O4 started on 24 May 2023 and will last 20 calendar months including up to 2 months of commissioning breaks for maintenance



[as of October 25, 2023]

Third generation detectors: Einstein Telescope and Cosmic Explorer



[Evans et al. 2021,
Cosmic Horizon Study]

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