Gravitational Waves

Particle Astrophysics Town Hall Meeting

Laura K Nuttall
UKRI Future Leaders Fellow
University of Portsmouth

Gravitational Wave Spectrum

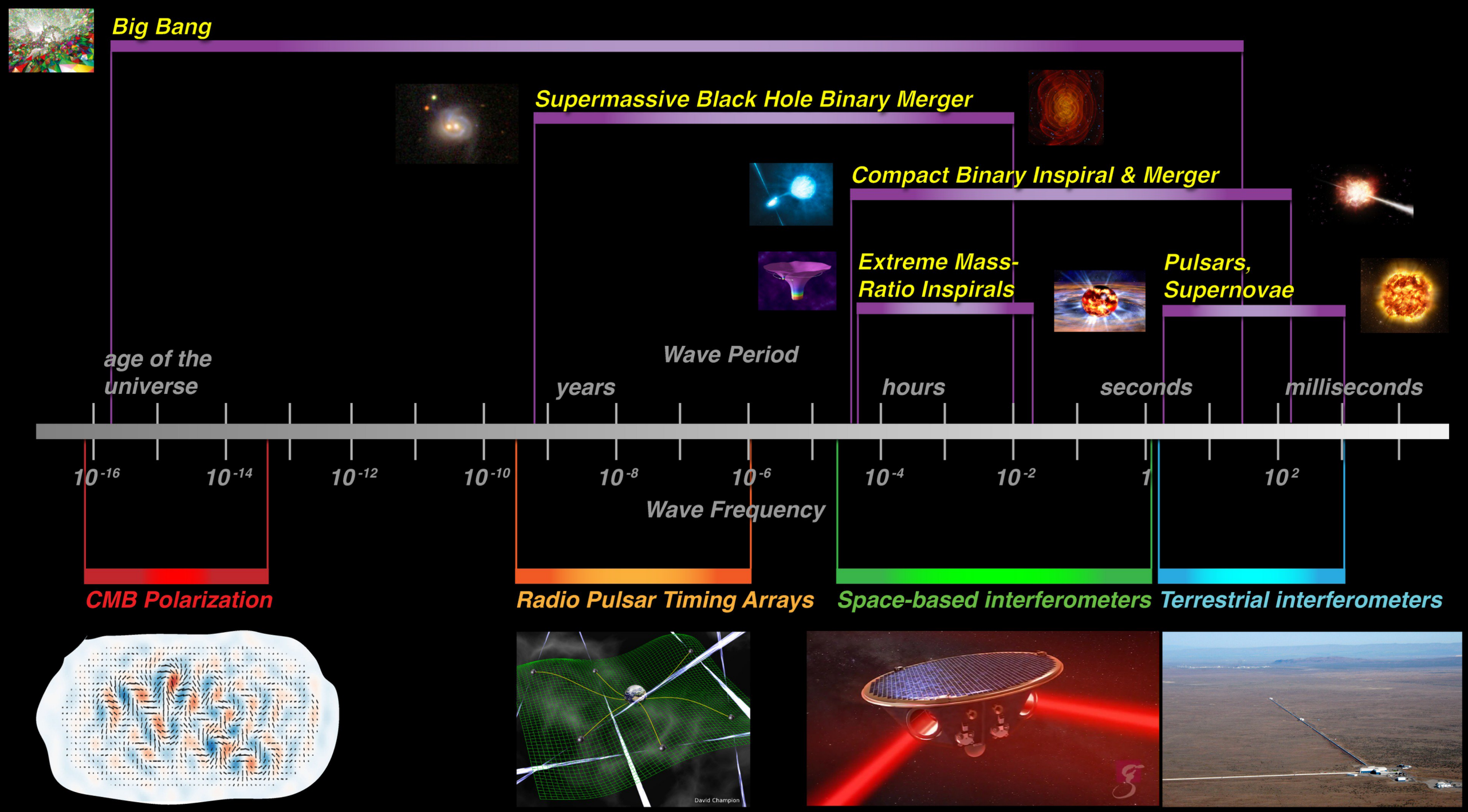
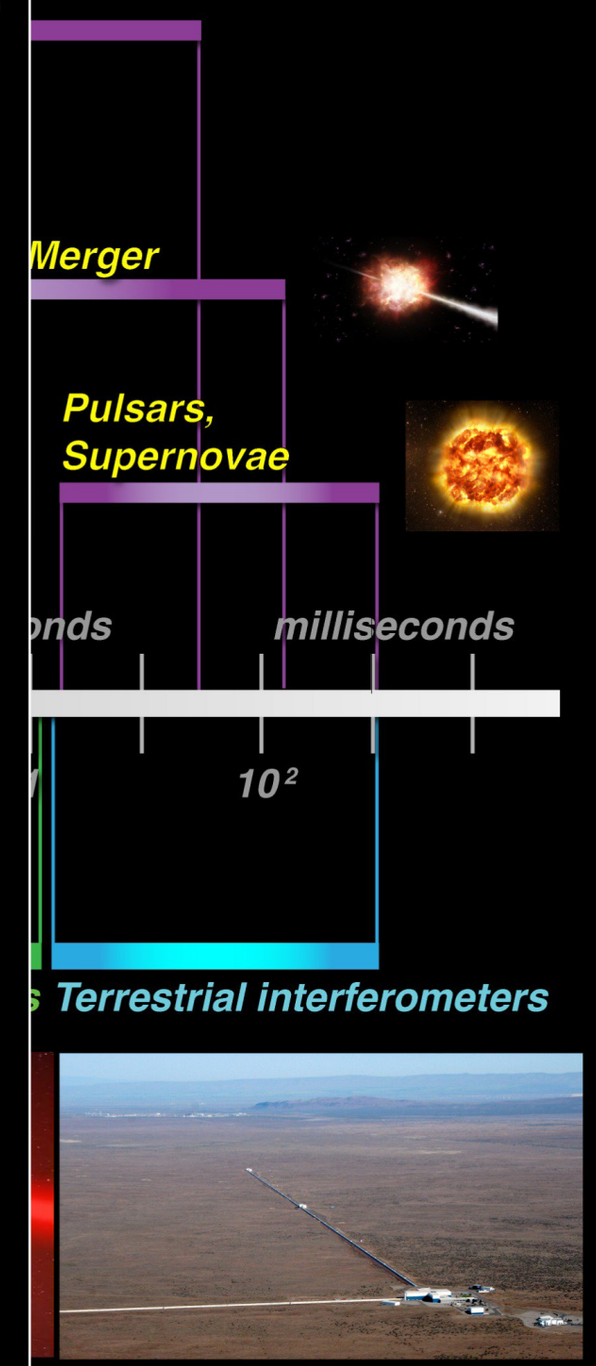


Image credit: Karan Jani/Georgia Tech

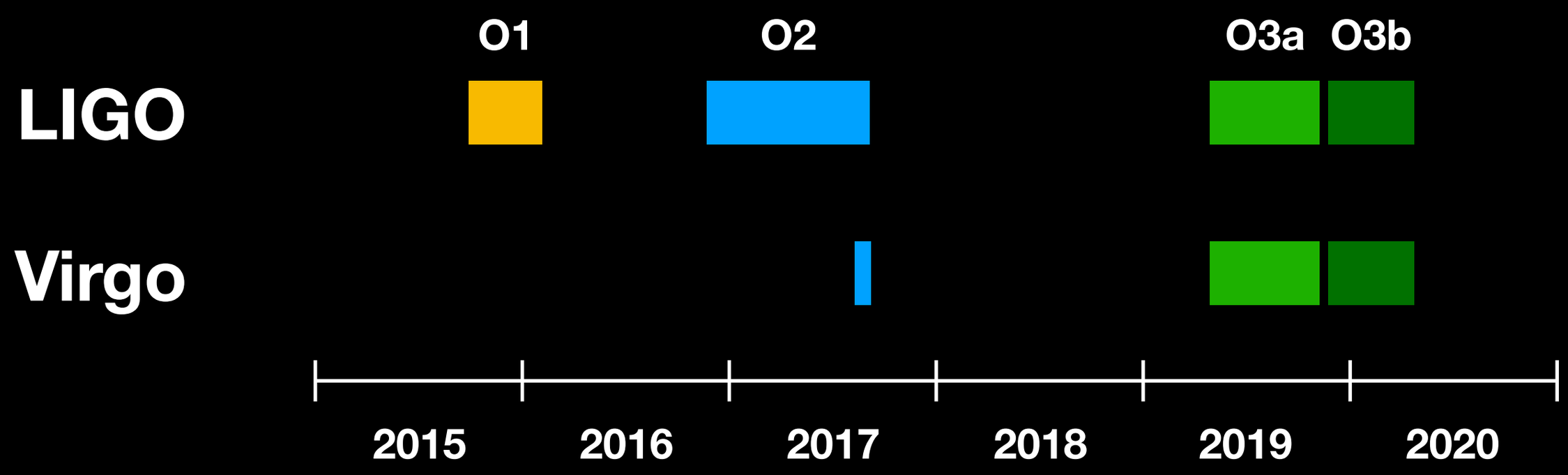
Gravitational Wave Spectrum

~180 scientists in the UK working in the LIGO Scientific Collaboration

University of Portsmouth
University of Strathclyde Glasgow
University of Glasgow
Cardiff University / Prifysgol Caerdydd
University of the West of Scotland UWS
University of Birmingham
University of Cambridge
King's College London
The University Of Sheffield.
Lancaster University
Science & Technology Facilities Council Rutherford Appleton Laboratory



Advanced GW Detector Era - Quick Round Up



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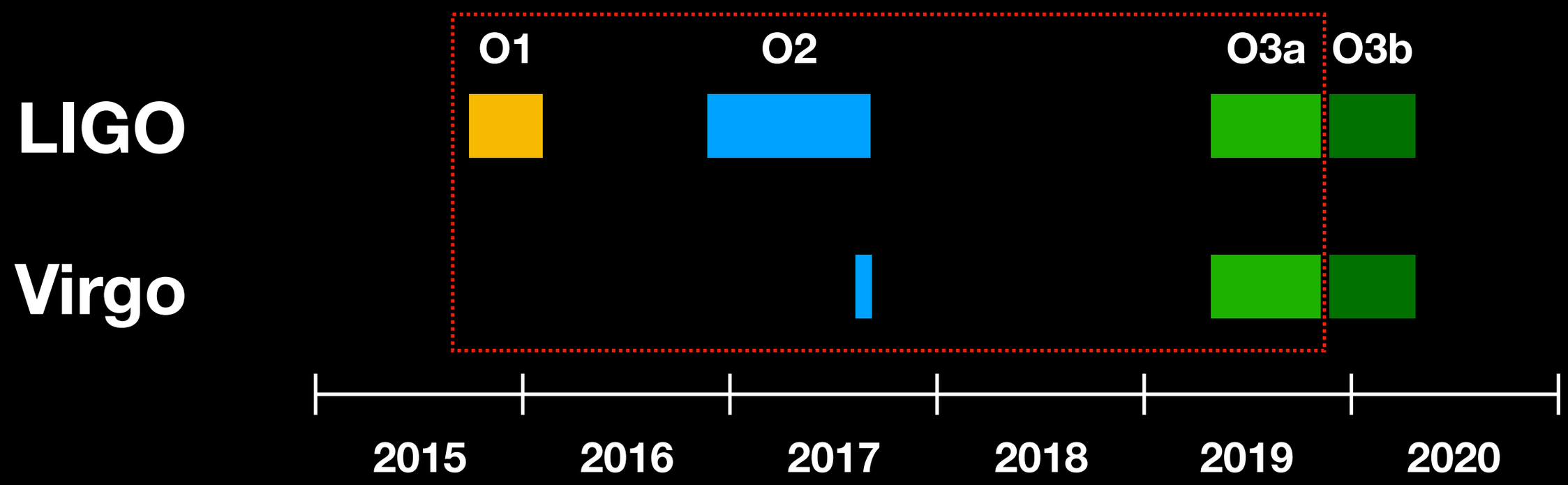

R. Abbott et al., **GWTC-2: Compact Binary Coalescences Observed by LIGO and Virgo During the First Half of the Third Observing Run**, arXiv 2010.14527 (2020)

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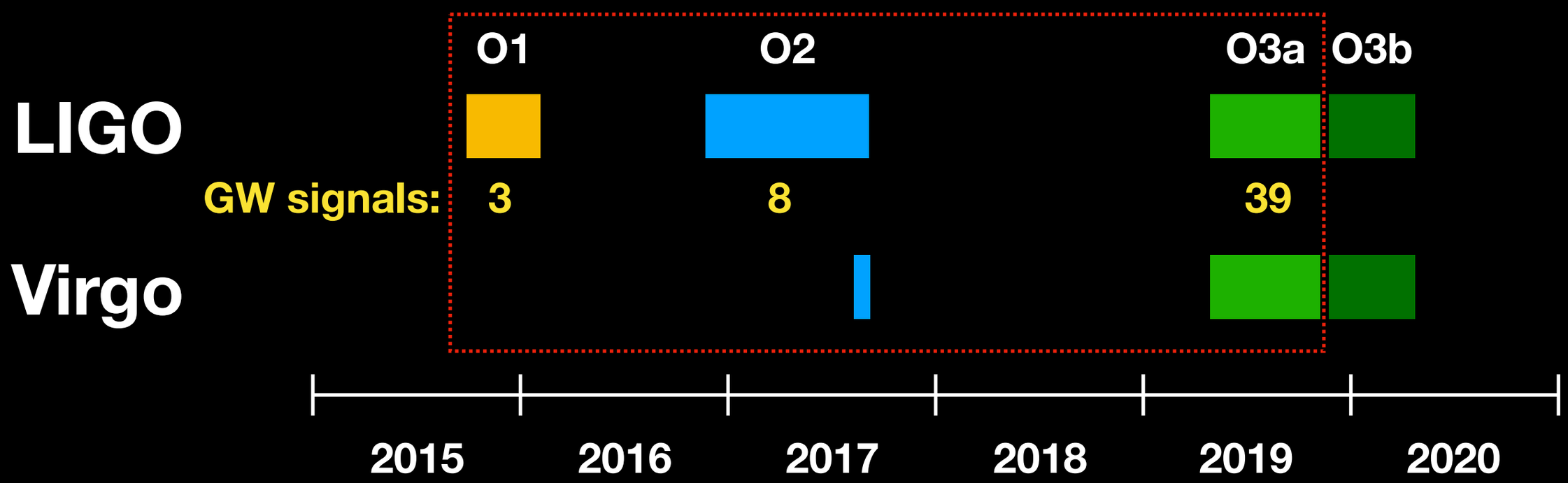

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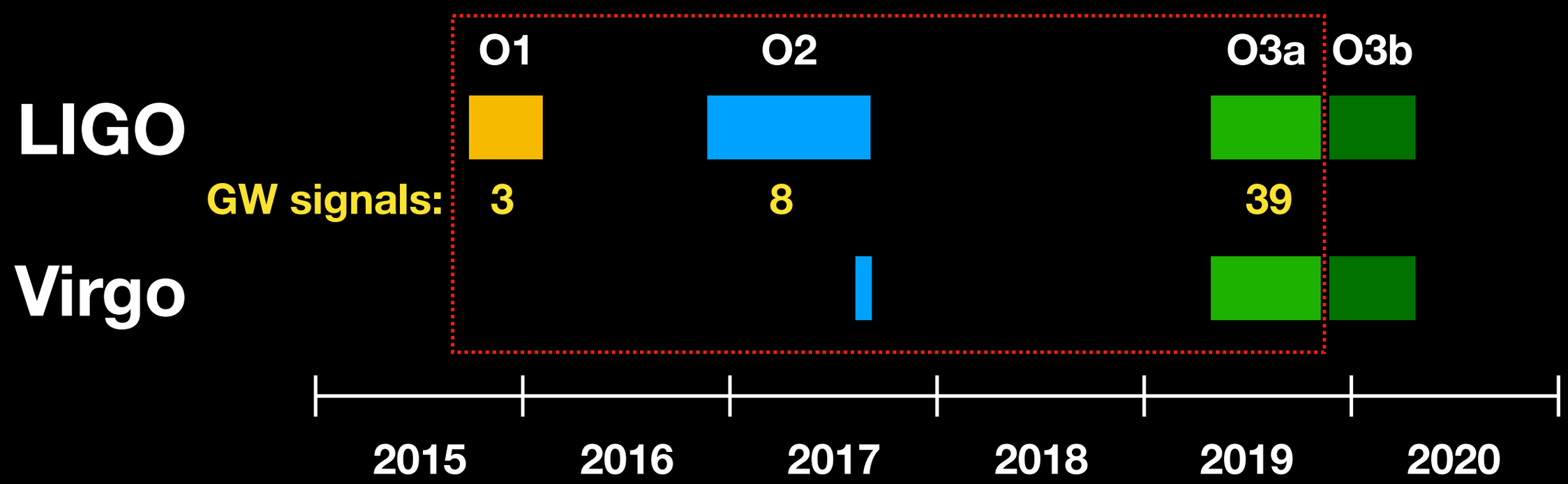

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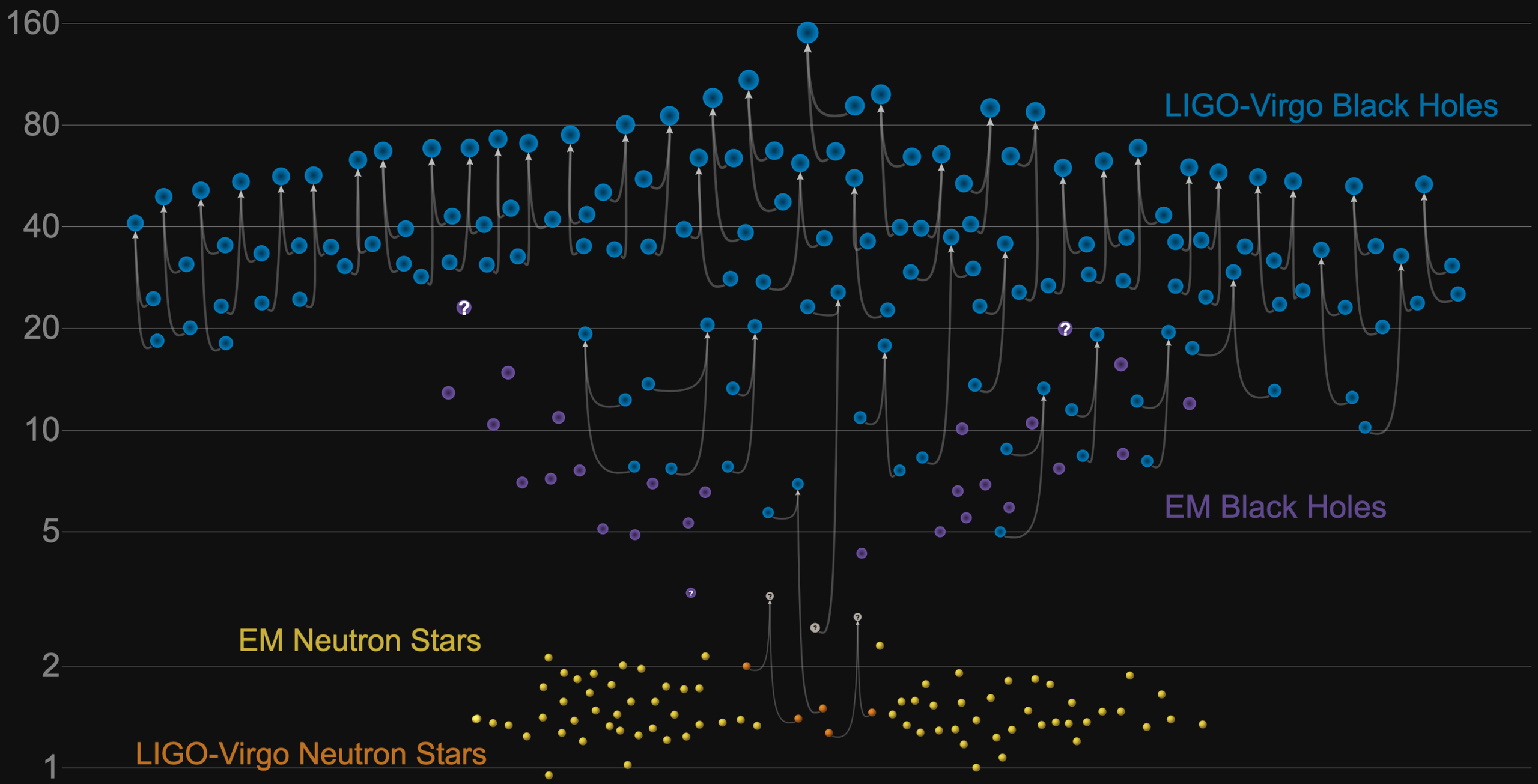
50 GW events

Masses in the Stellar Graveyard

in Solar Masses



GWTC-2 plot v1.0
LIGO-Virgo | Frank Elavsky, Aaron Geller | Northwestern

R. Abbott et al., arXiv 2010.14533 (2020)

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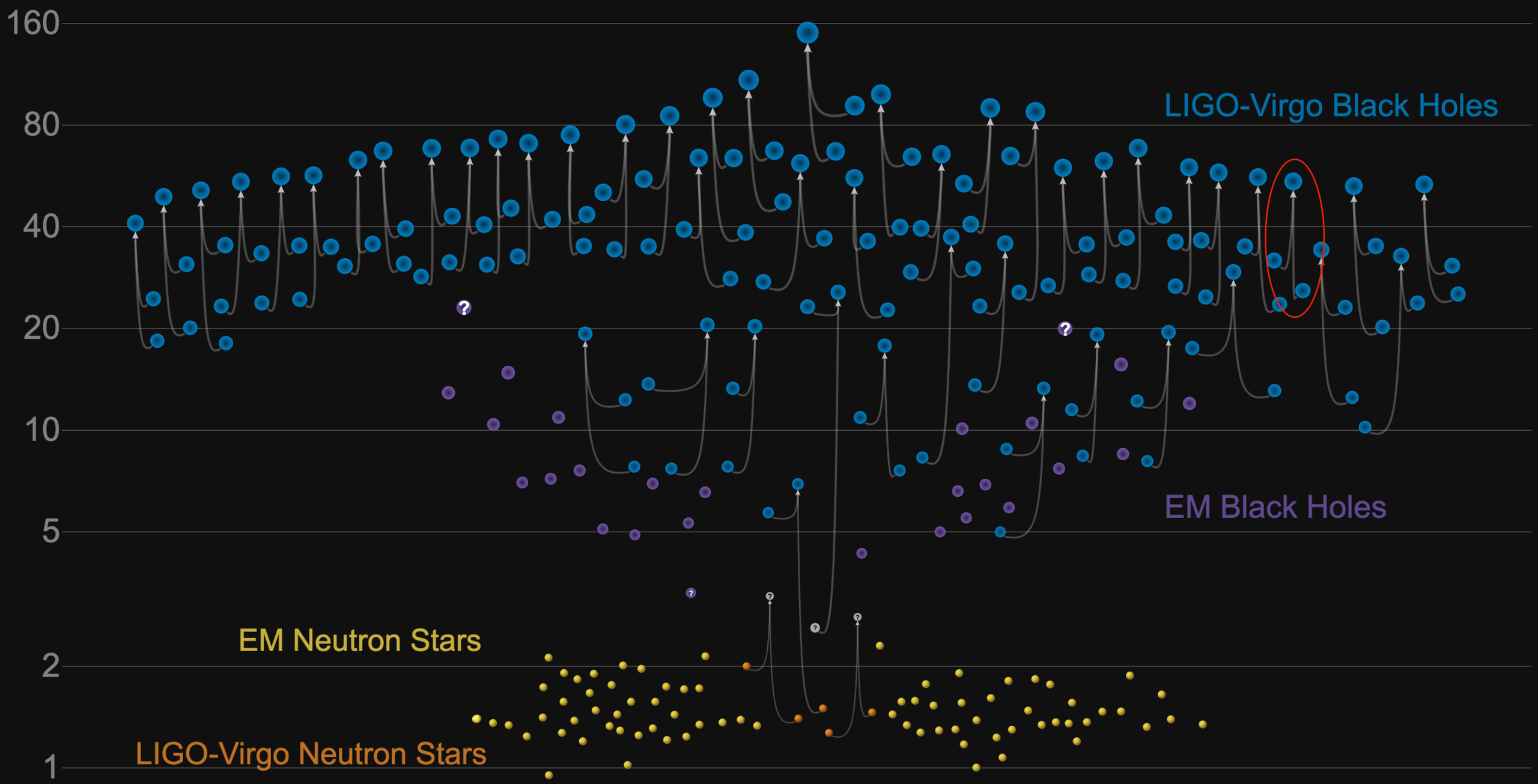

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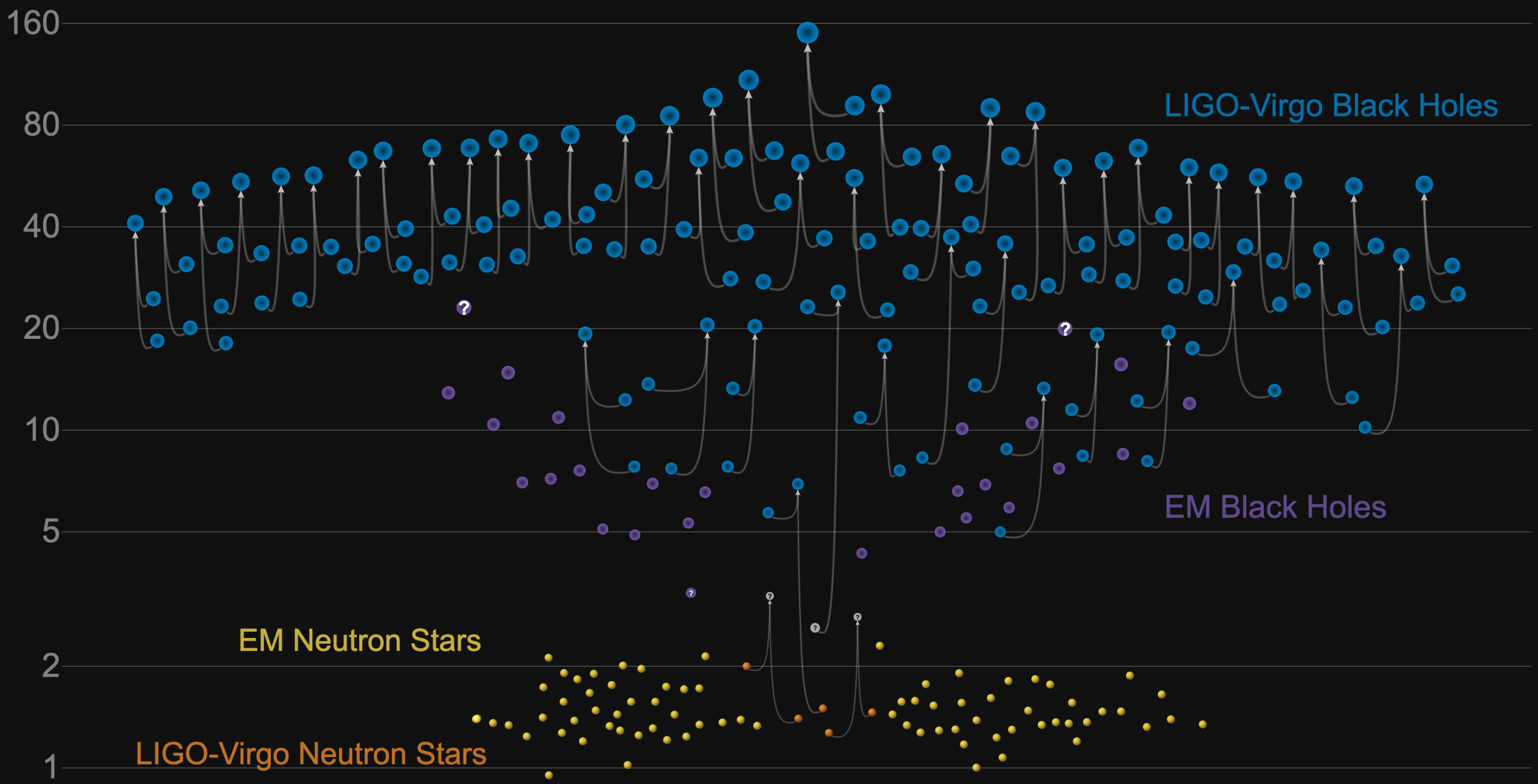

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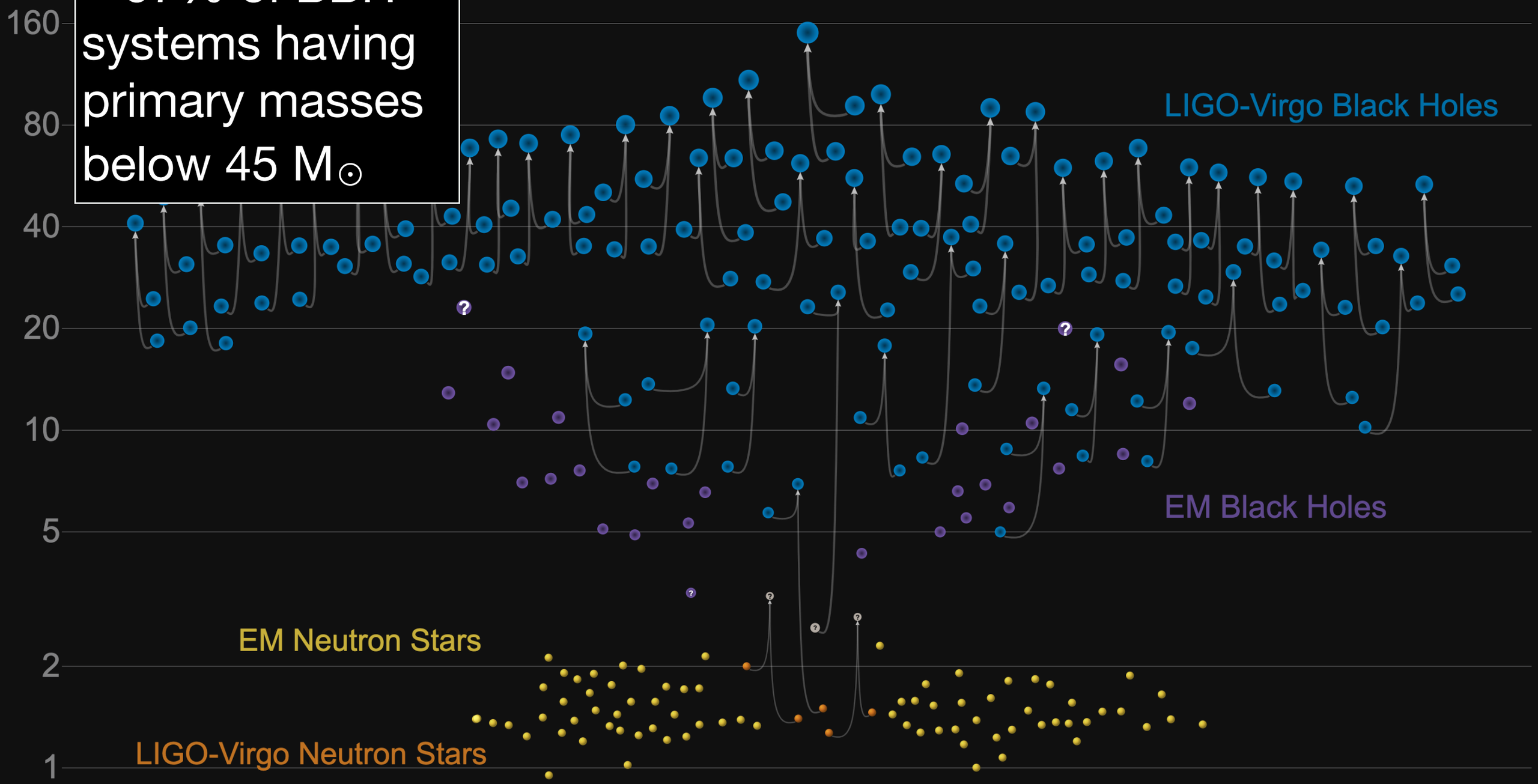
Masses in the Stellar Graveyard

in Solar Masses

~97% of BBH systems having primary masses below 45 $M_\odot$



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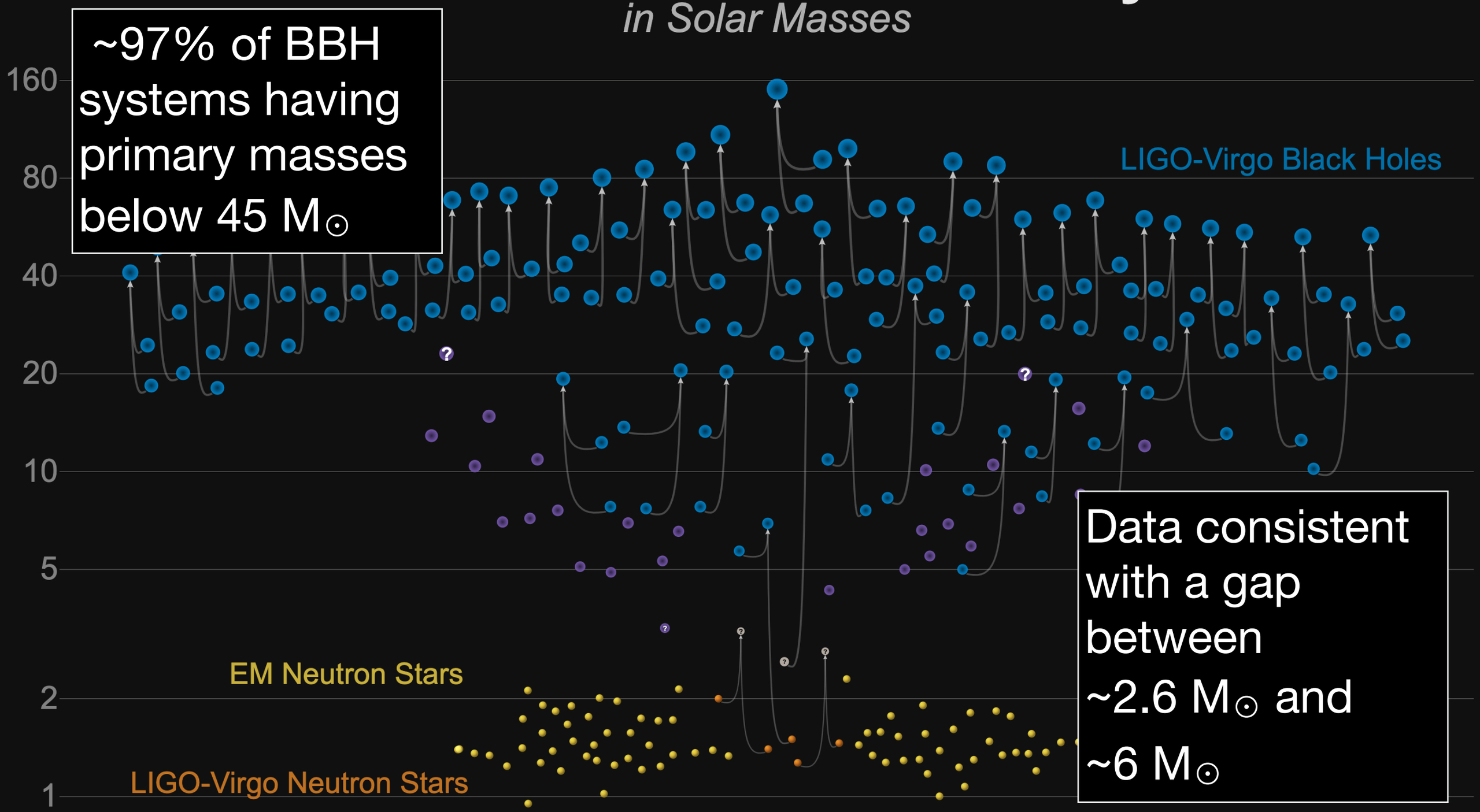

~97% of BBH systems having primary masses below 45 $M_\odot$

Data consistent with a gap between ~2.6 $M_\odot$ and ~6 $M_\odot$

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Masses in the Stellar Graveyard

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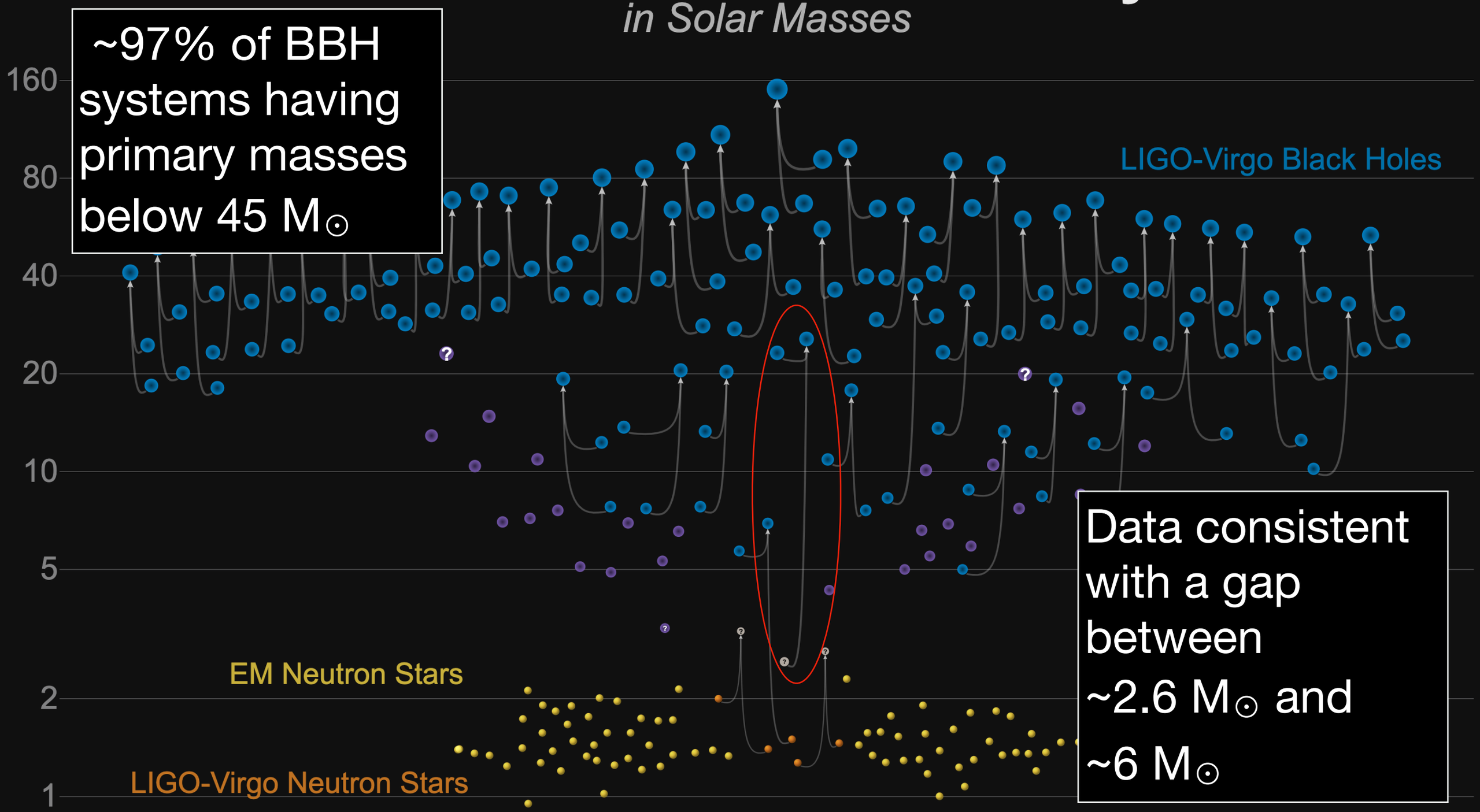

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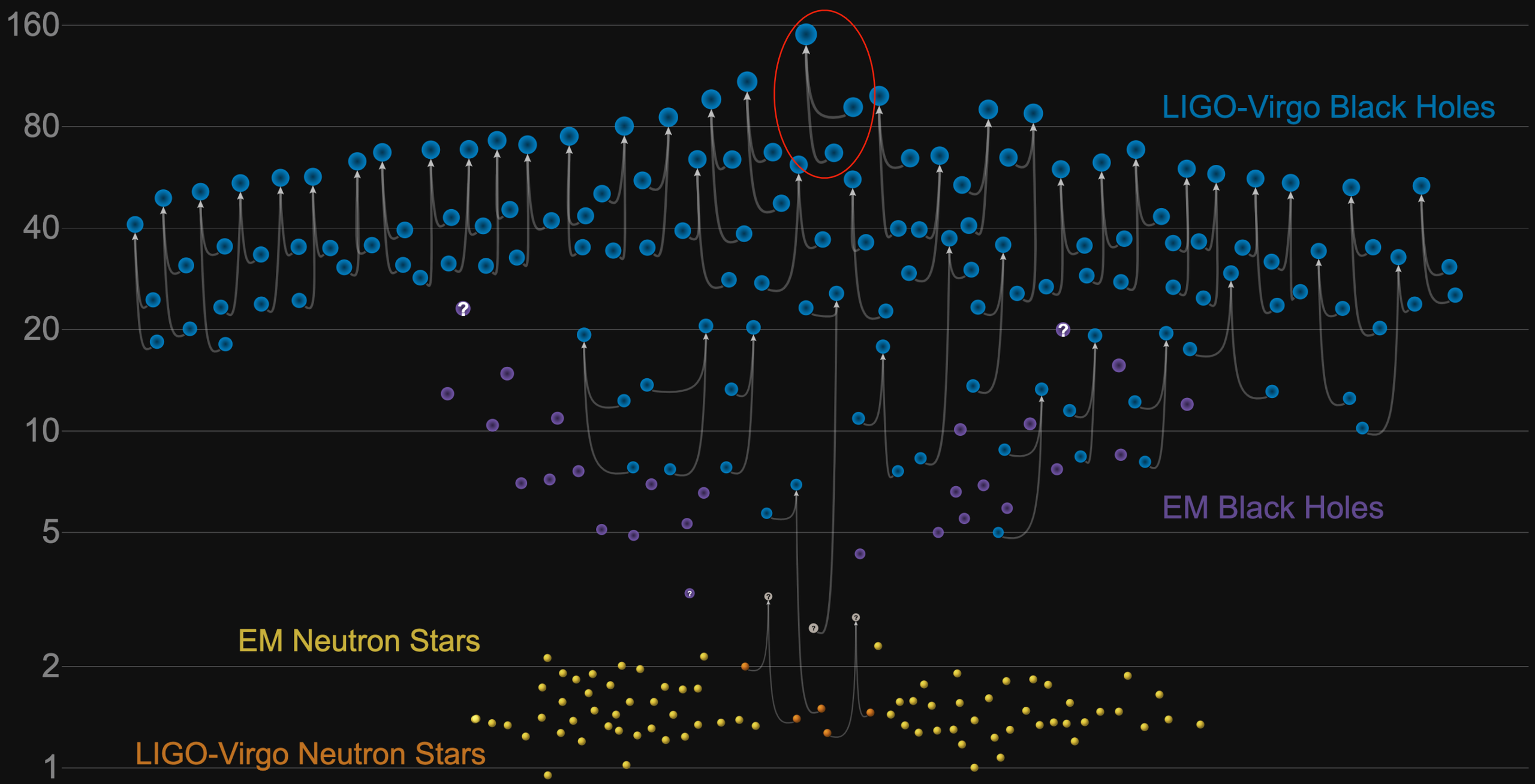

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GW190521: Most massive binary system

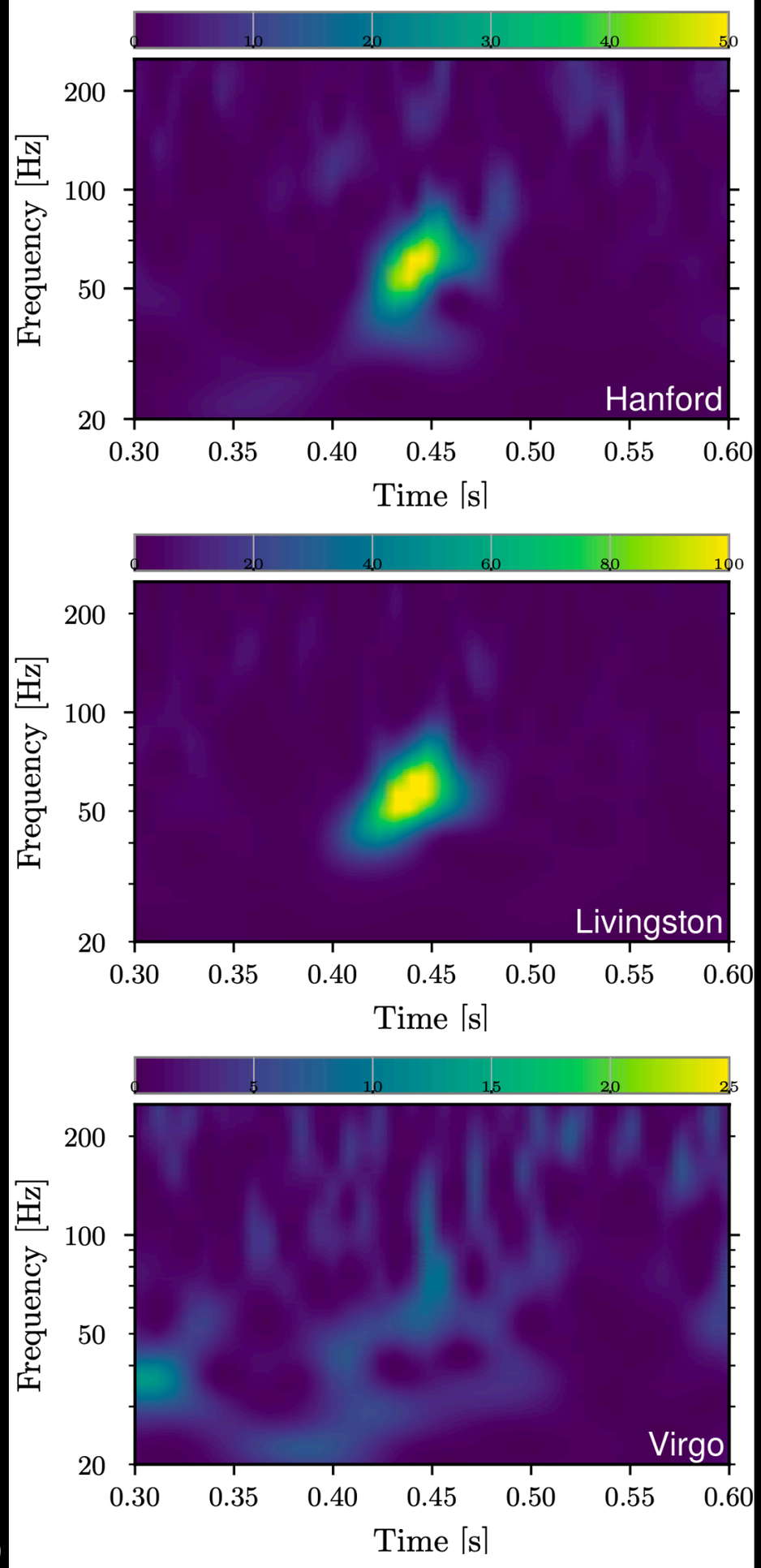
The masses of the two compact objects:
m_1: 73.9 - 120.7 $M_\odot$
m_2: 46.1 - 87.5 $M_\odot$

Remnant mass ~ 150 $M_\odot$
Remnant is an intermediate black hole!

Black holes between ~65 -120 $M_\odot$ cannot form from the collapse of a massive star

Either:
- our understanding of stellar evolution is wrong and stars *can* form high mass black holes
- black hole formed as a result of a previous merger

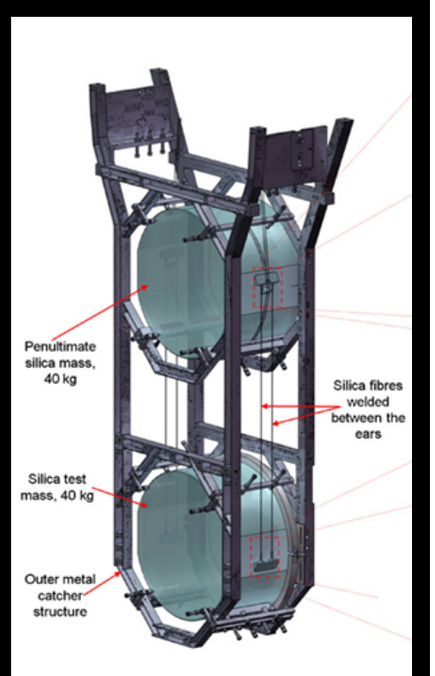
Multiple merger scenario requires the system to form in dense environment with other black holes nearby



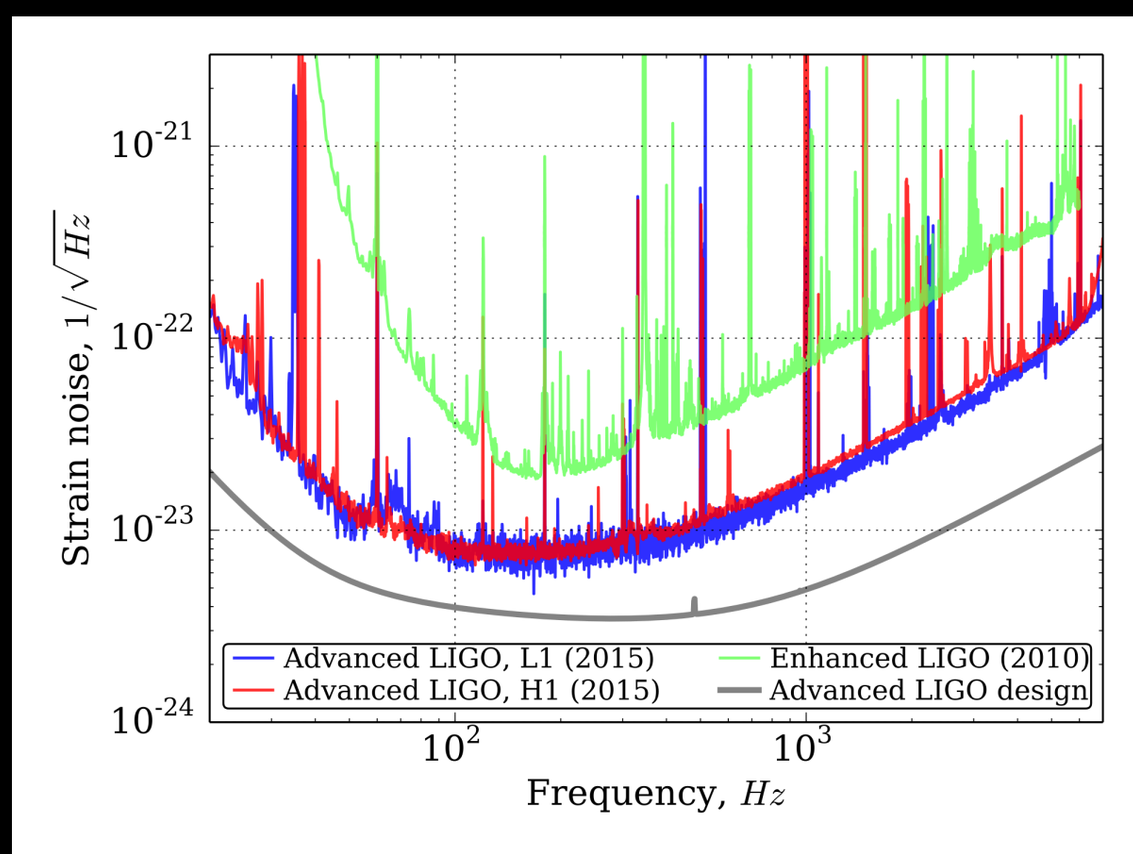
R. Abbott et al., Phys. Rev. Lett. 125, 101102 (2020)

GW190521:
Most massive binary system

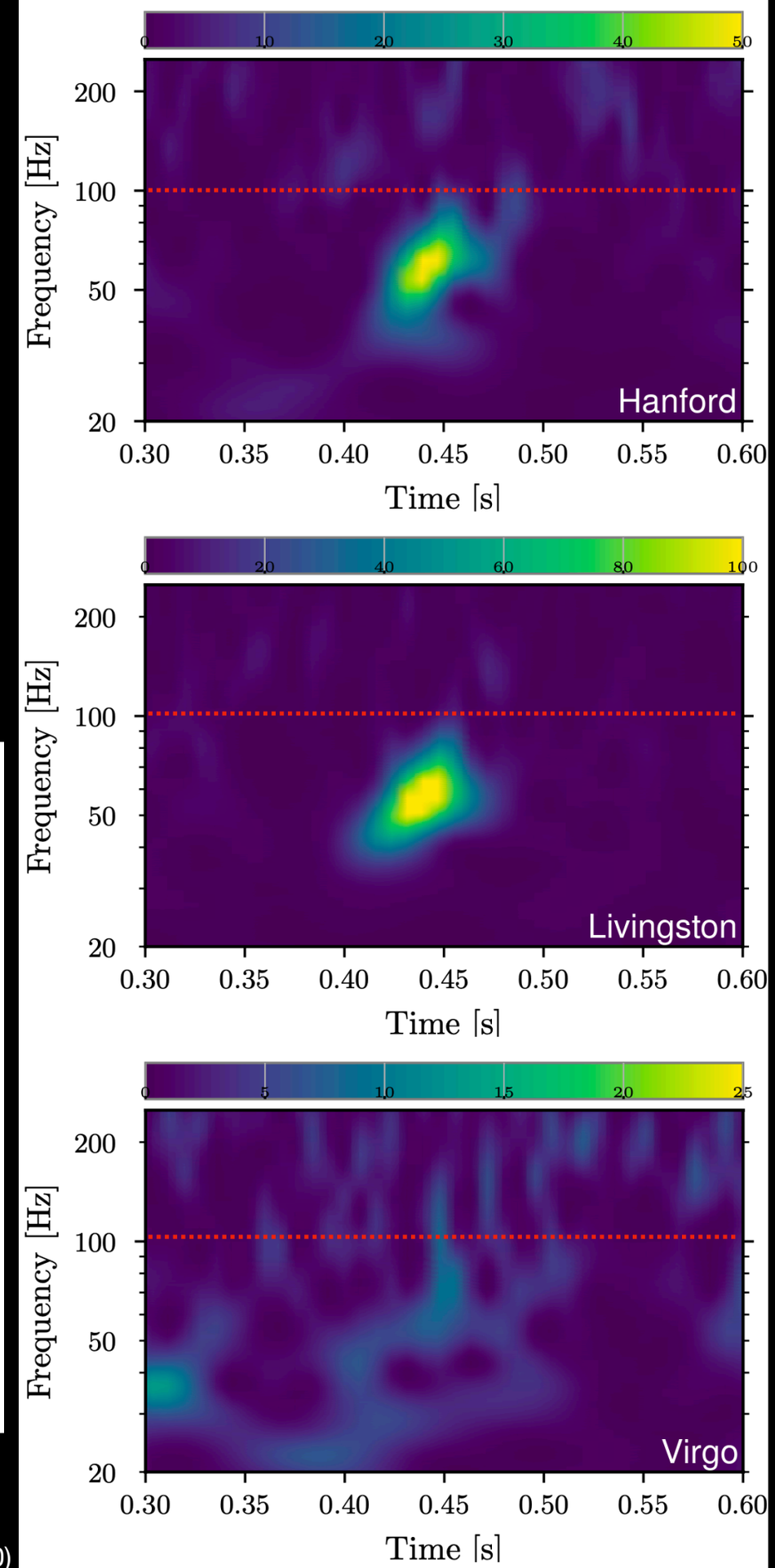
Advanced LIGO UK project provided the core ultra-low noise mirror suspensions based on fused-silica technology



A V Cumming et al., Class. Quantum Grav. **31** 025017 (2014)



D. V. Martynov et al., Phys. Rev. D 93, 112004 (2016)



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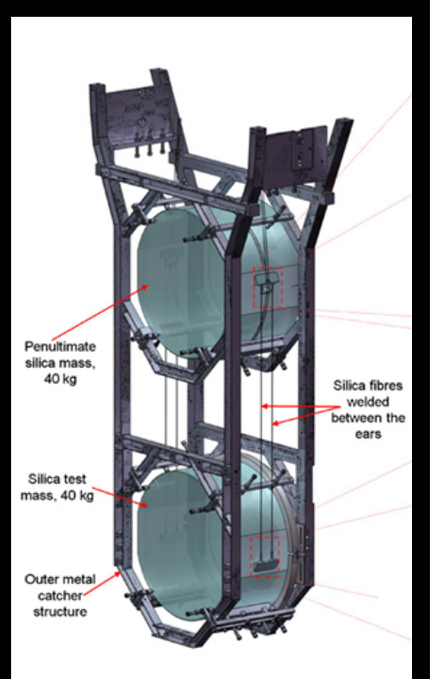
Key to detecting signals where energy is concentrated < 100 Hz



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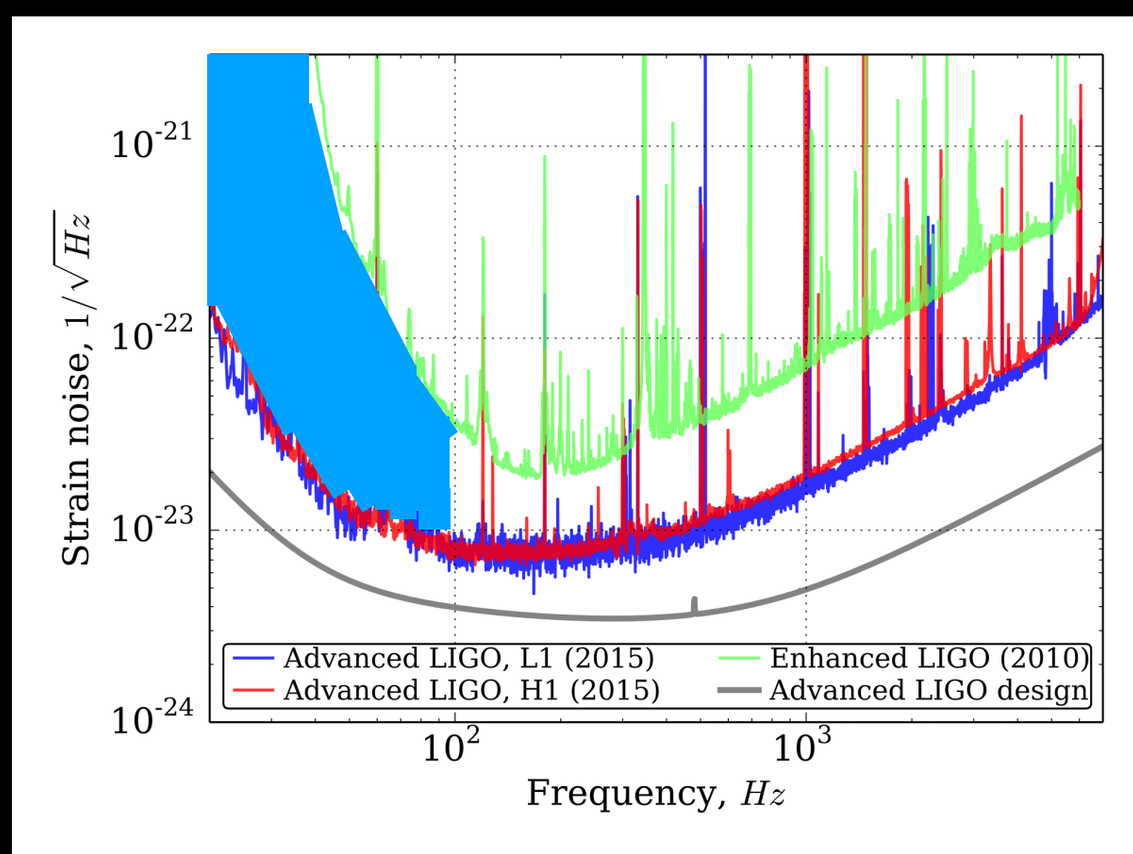

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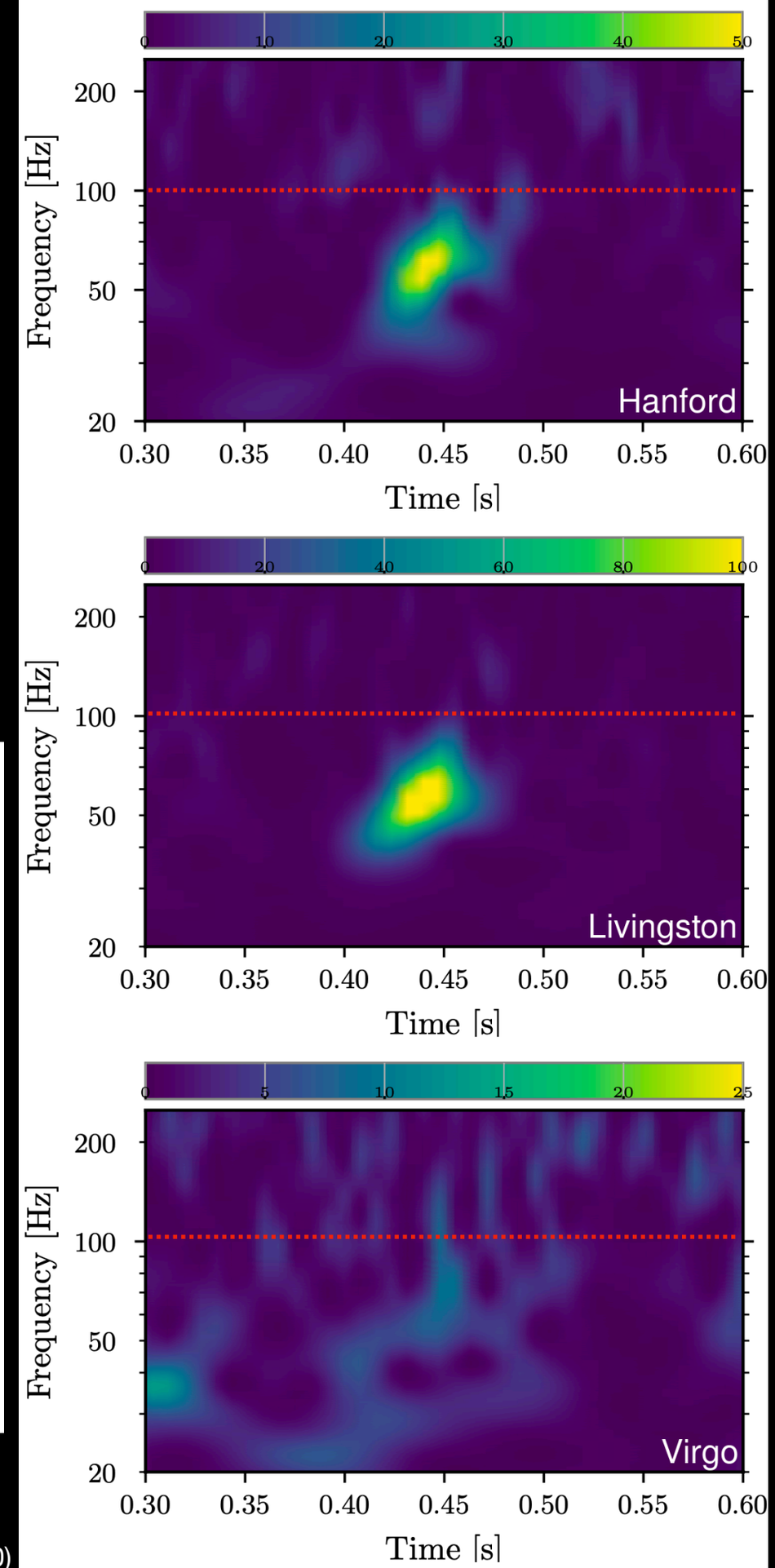

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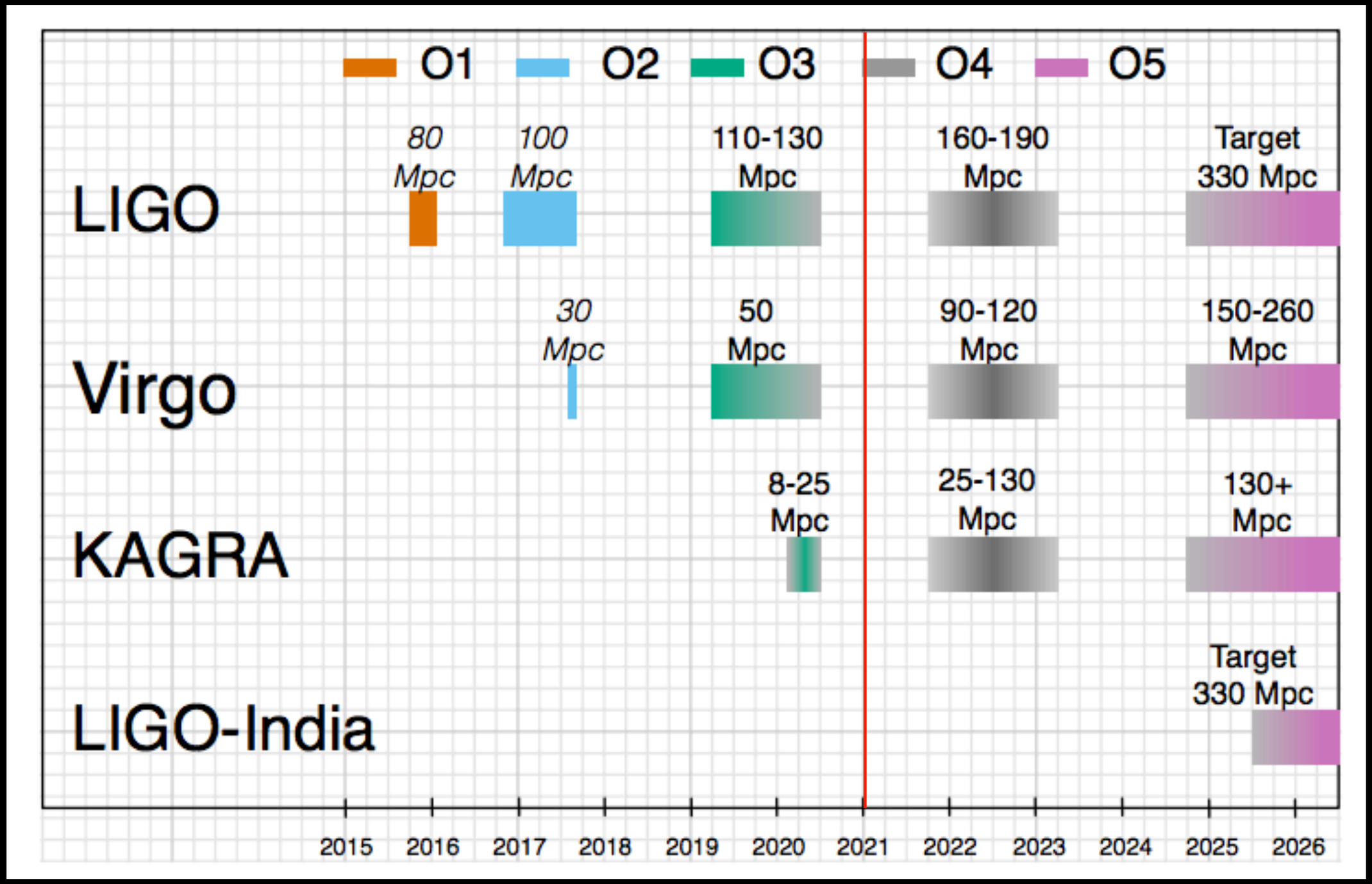
GW Network: the next 5 years



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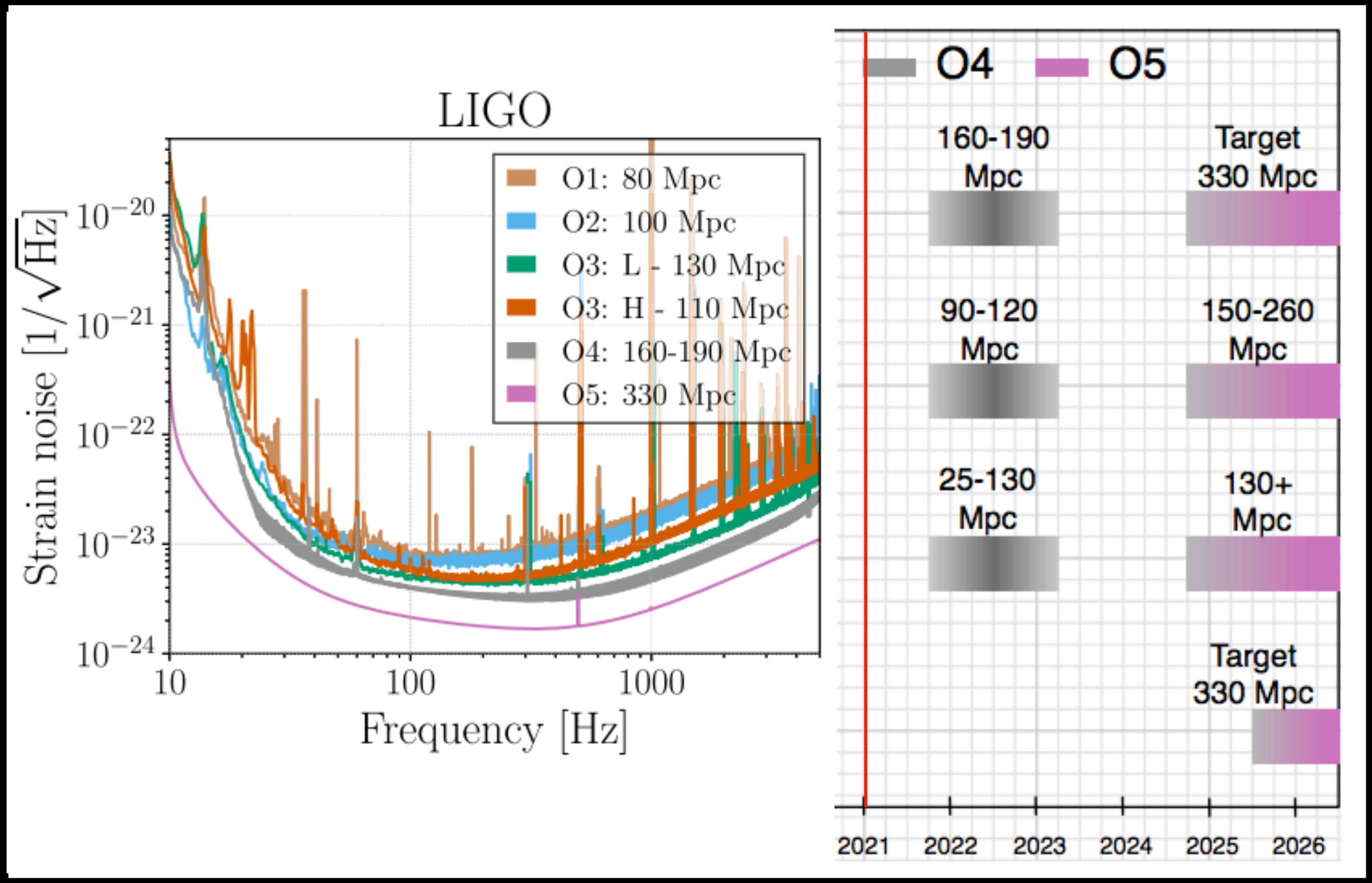

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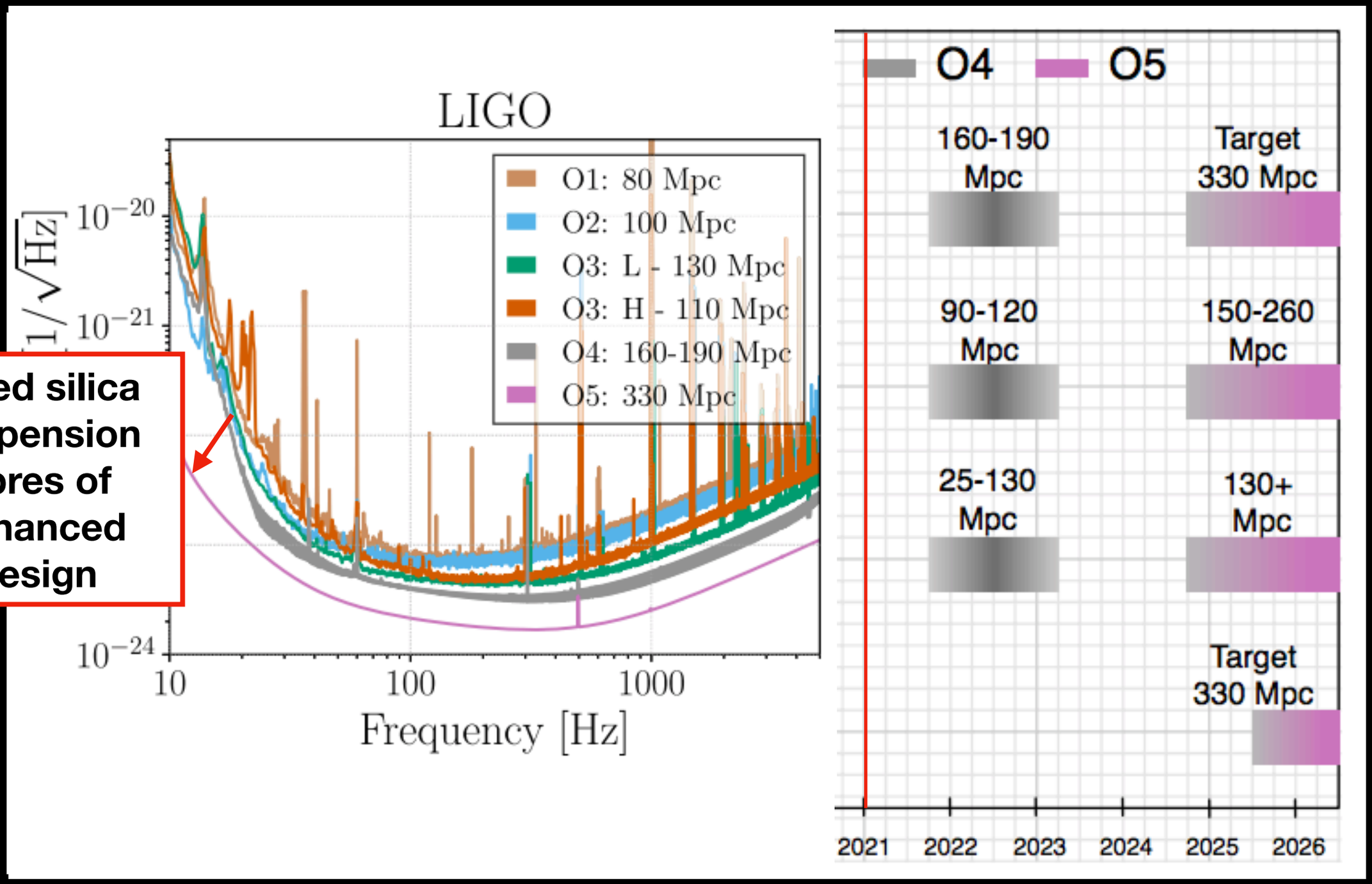

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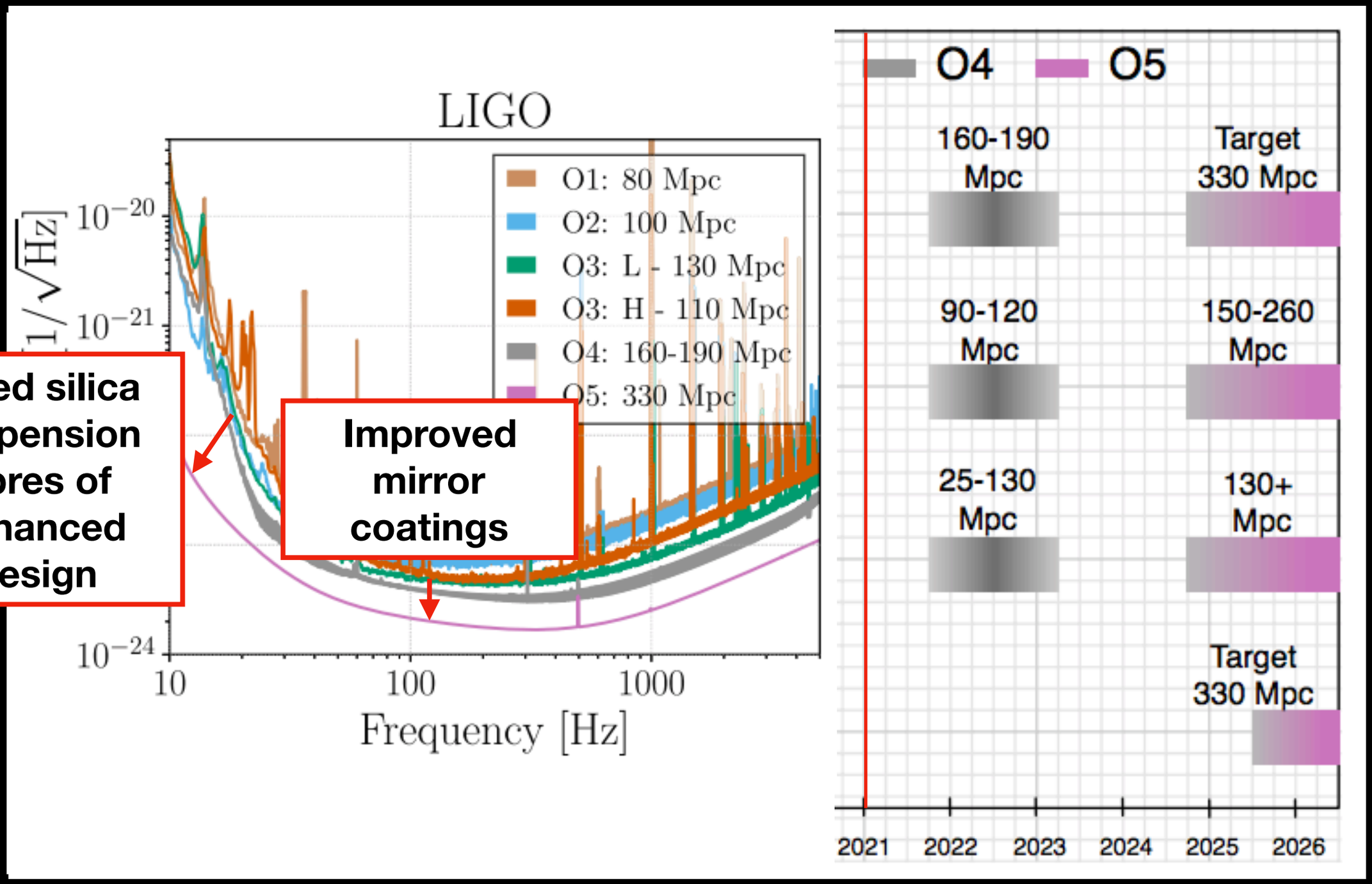

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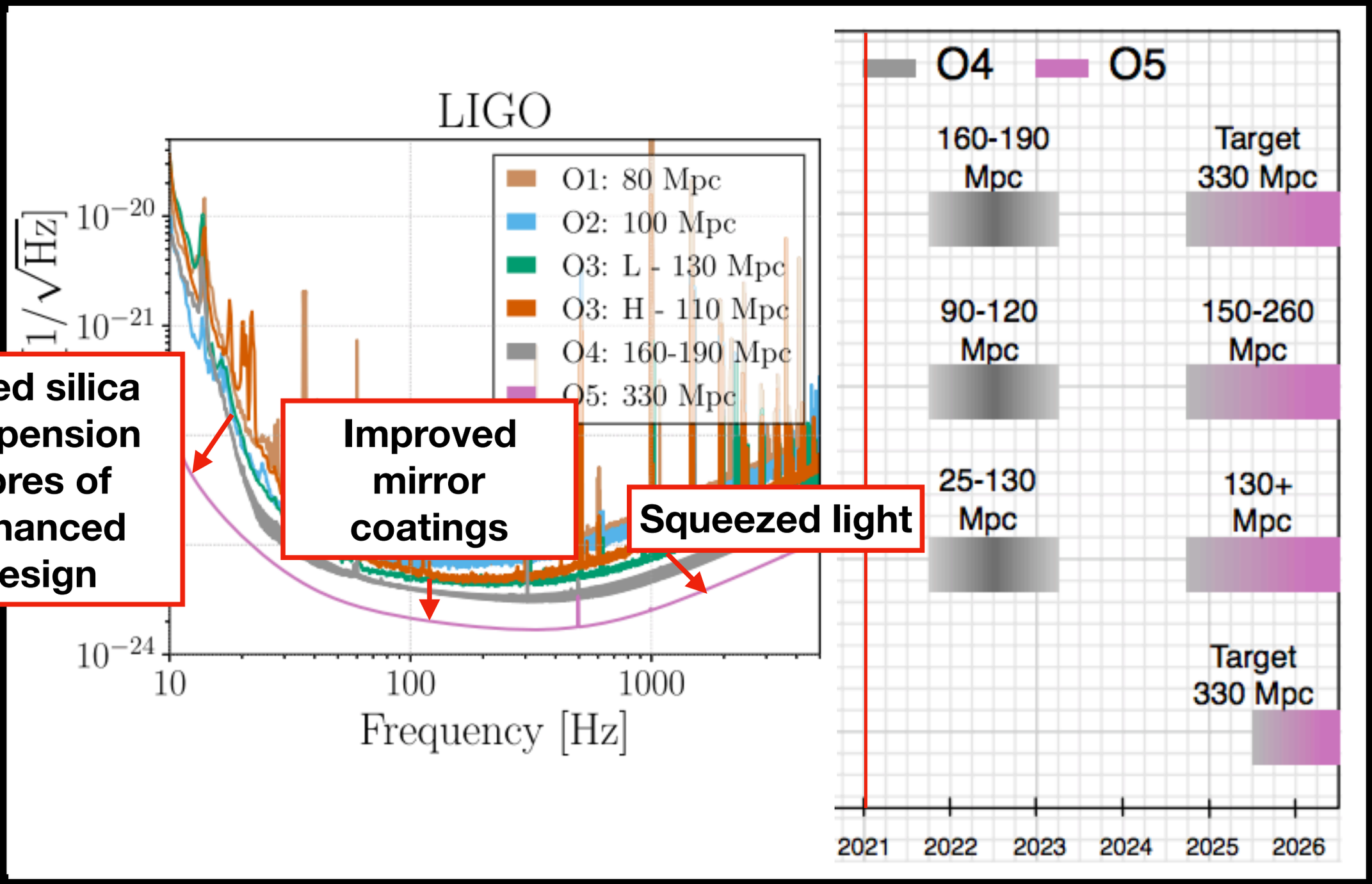

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Exciting Discoveries over the next 5 years

- Multi-messenger Astronomy
  - In O4 (mid 2022) 35-44% of BNS/BBH events are estimated to have a localisation within 20 deg^2
  - EM-GW-Neutrinos?

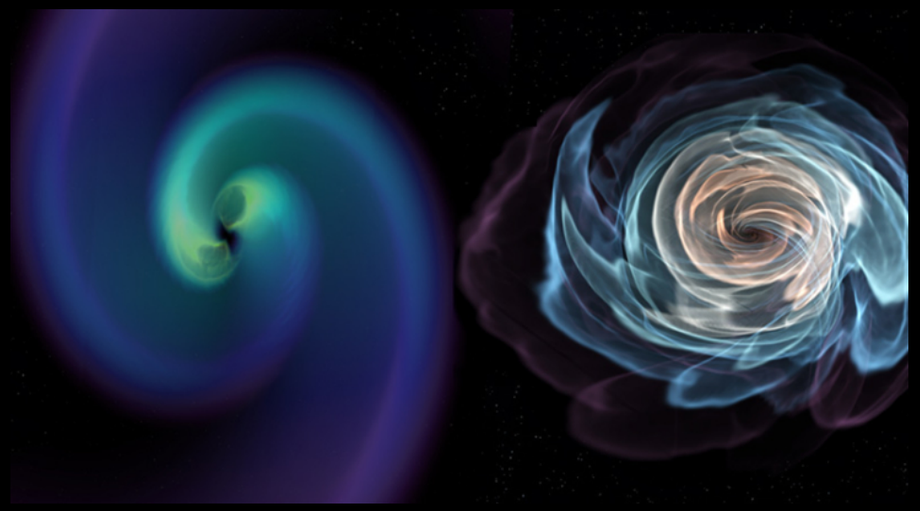


Image credit: Karan Jani/Georgia Tech

- Observing NS-BH systems
- Understand the population of stellar-mass compact binary mergers
  - BBH mass spectrum - do we see features consistent with pair instability supernovae?
  - BBH formation channels - can we distinguish between systems formed in the field and through dynamical interactions?
  - Merger rate with redshift - does it follow the SFR?

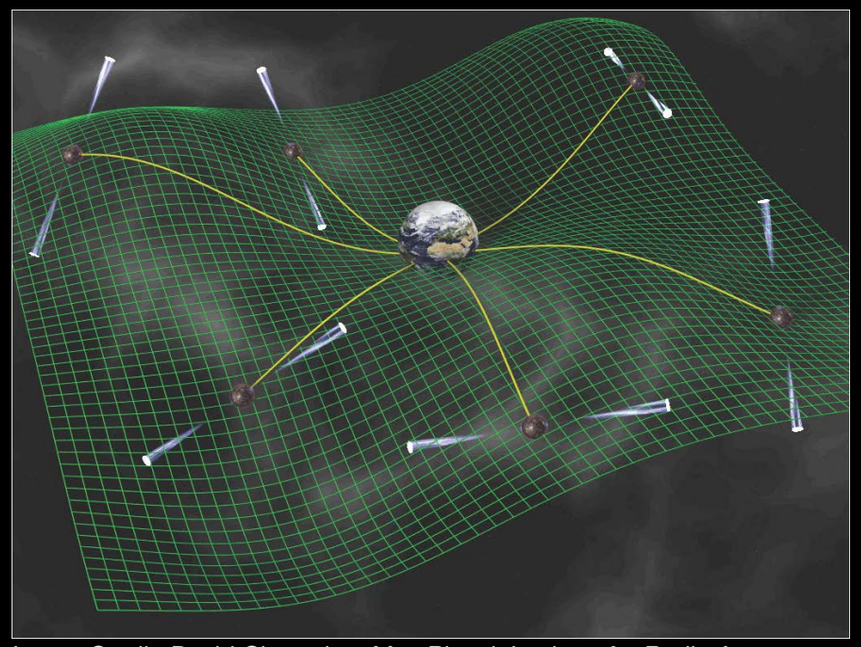


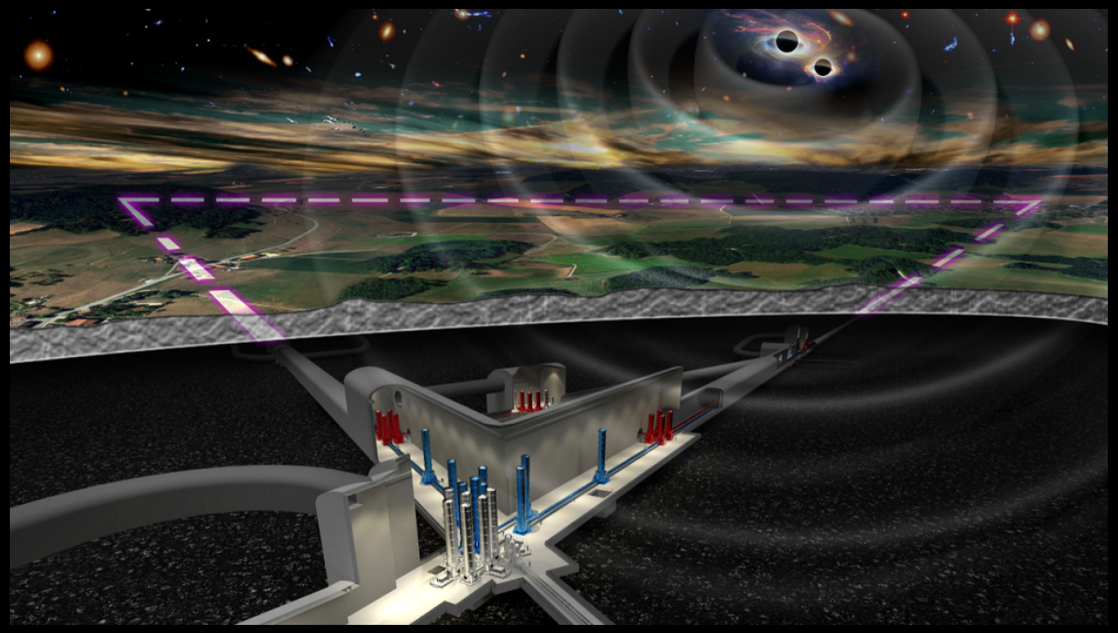
Image Credit: David Champion, Max Planck Institute for Radio Astronomy

- Detection of gravitational waves with pulsars?

10+ years: 3G Detectors

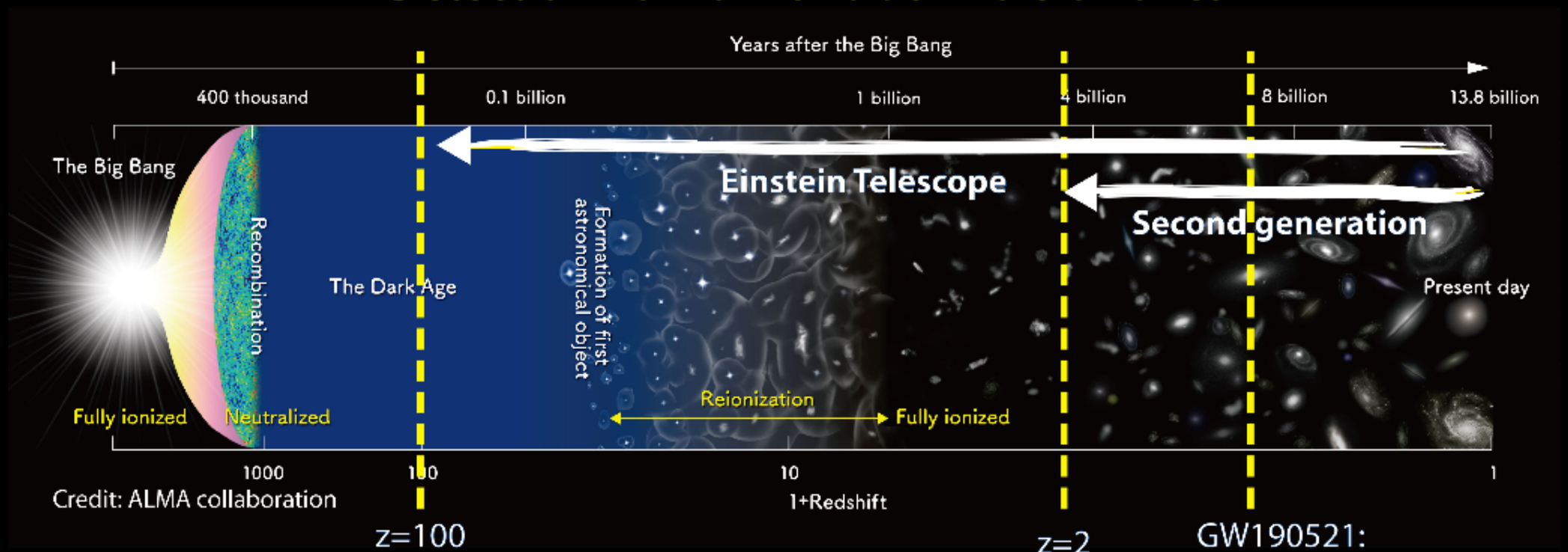
Einstein Telescope (ET)

- European based
- Order of magnitude increase in sensitivity over Advanced LIGO
- Sensitivity: 1Hz - tens of kHz
- 10km arms in a triangle configuration
- Objectives: explore black hole seeds, test gravity with black holes, cosmography, nuclear physics…

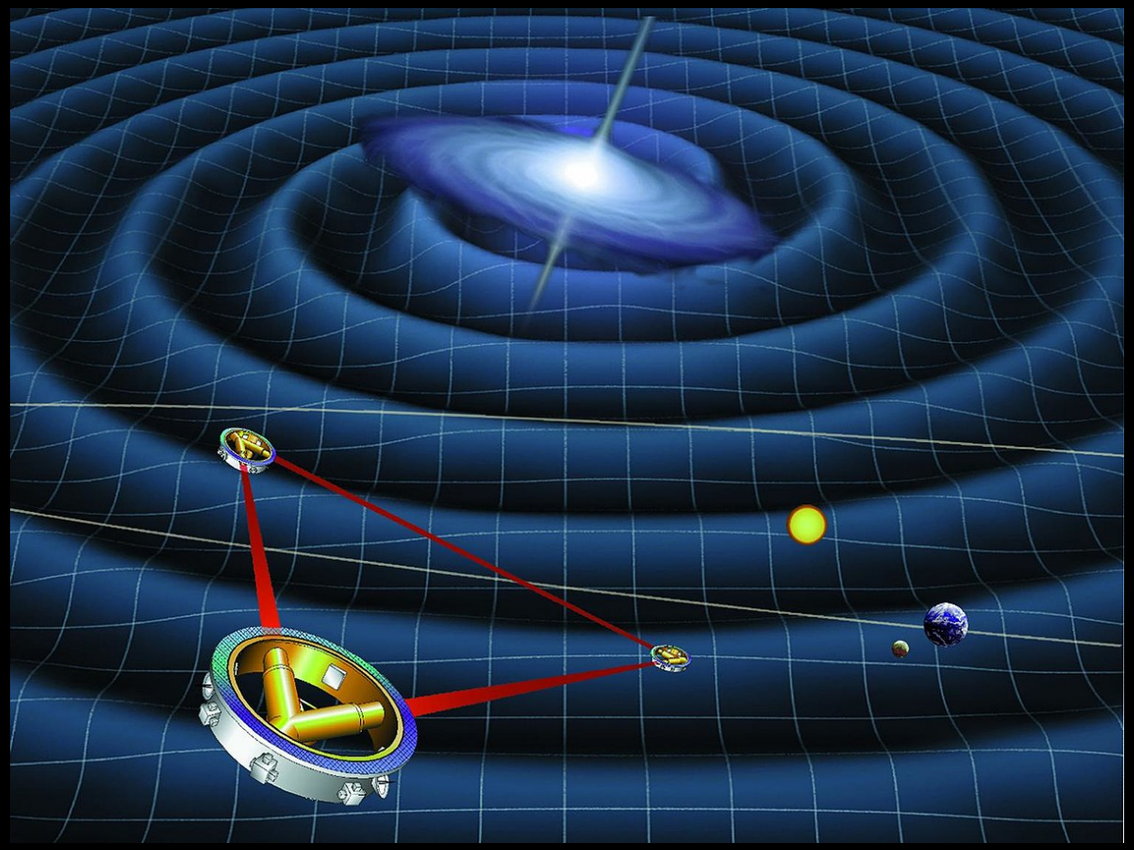


http://www.et-gw.eu/

Detection horizon for black-hole binaries



10+ years: LISA



- Sensitive to the region 10^{-4} to 10^{-1} Hz
- Low frequency -> go after the first seed black holes, exploring z ~ 20
- LISA pathfinder demonstrated key technologies
- 2.5 million km arms
- Launch expected 2034
- Black hole systems with masses from few $M_\odot$ to 10^8 $M_\odot$
- Observe GW150914-like events over many years to < 1 deg^2 and the time of coalescence for ground-based detectors to within a minute!
- Localise 10^6 - 10^7 $M_\odot$ binary black holes at z~2 to ~ 100 deg^2 at least one day prior to merger

Amaro-Seoane et al., arXiv:1702.00786 (2017)


Questions?