

Gravitational-Wave Observational Results and Prospects

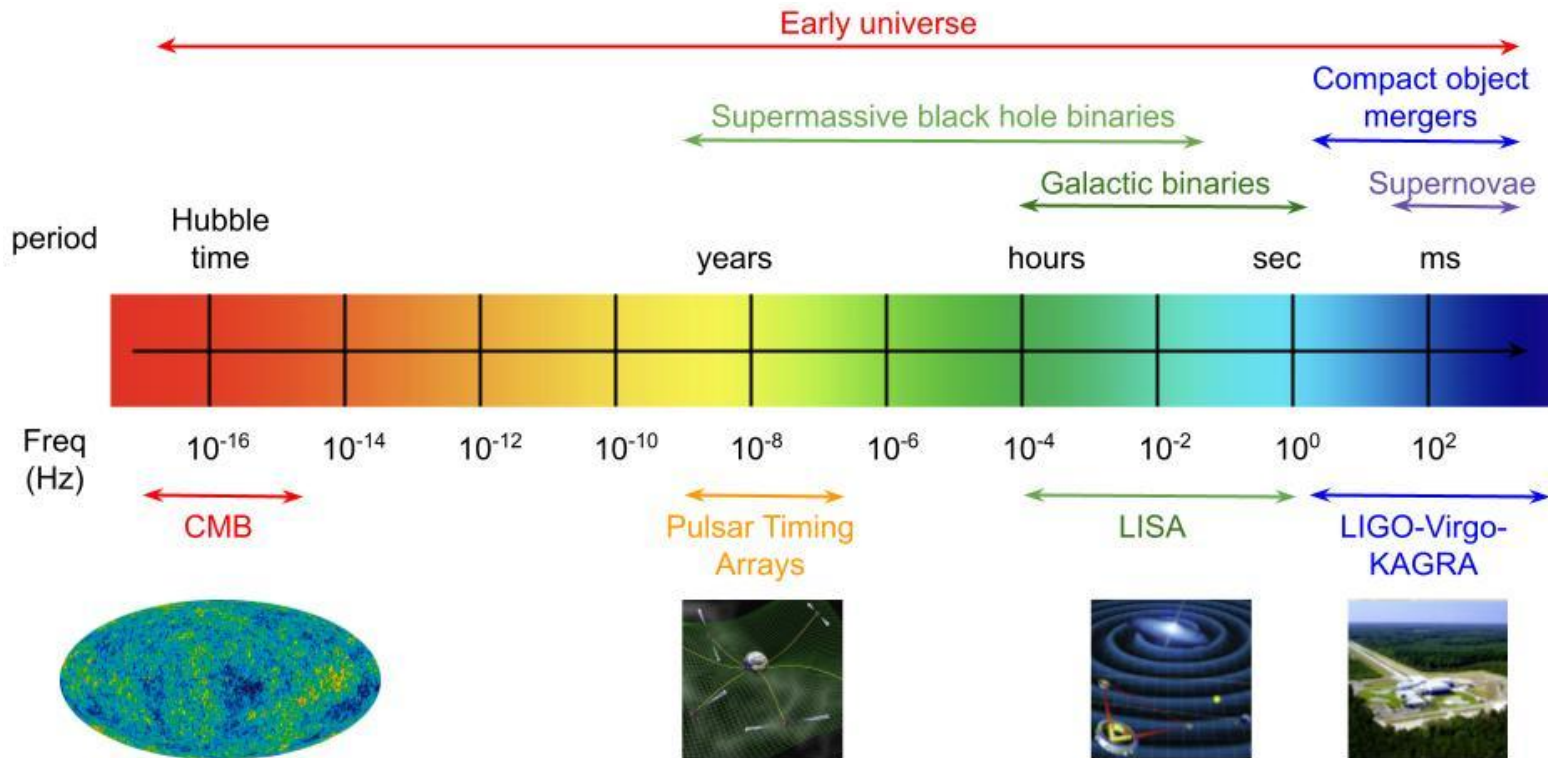
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University of Wisconsin-Milwaukee

TAUP2023
30 August 2023

<https://dcc.ligo.org/G2301194>



Gravitational-wave spectrum



Adapted from: Romano, J.D., Cornish, N.J.
Living Rev Relativ 20, 2 (2017).
<https://doi.org/10.1007/s41114-017-0004-1>

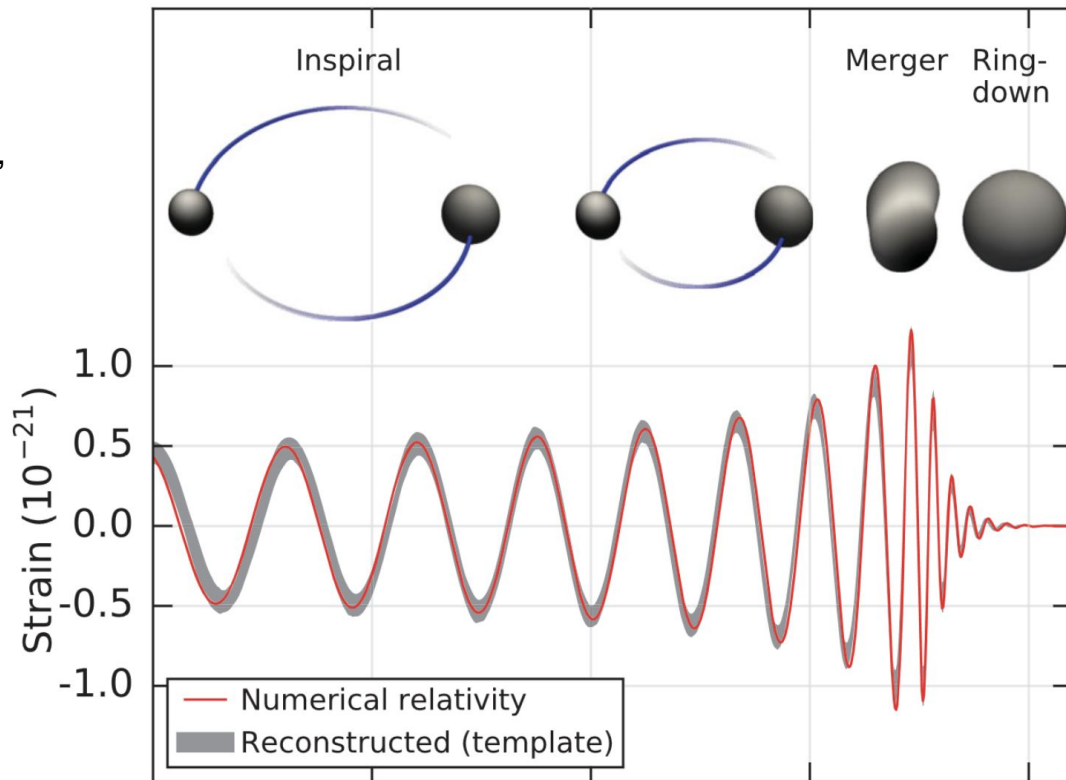
International Gravitational-Wave Observatory Network (IGWN)



Compact object mergers

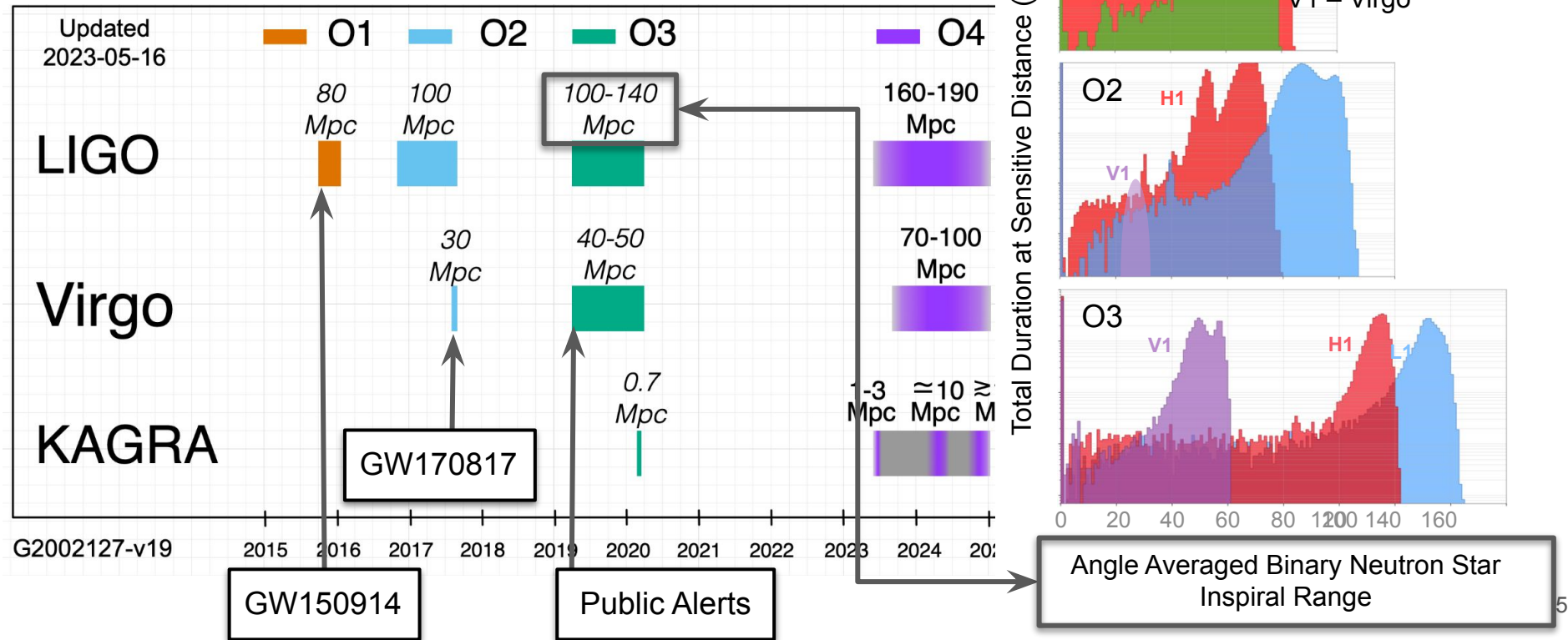
Pairs of stellar-mass black holes,
neutron stars, or a stellar-mass
black hole and neutron star

$$h_{ij} \sim \frac{4GM}{c^4} \frac{v^2}{r}$$



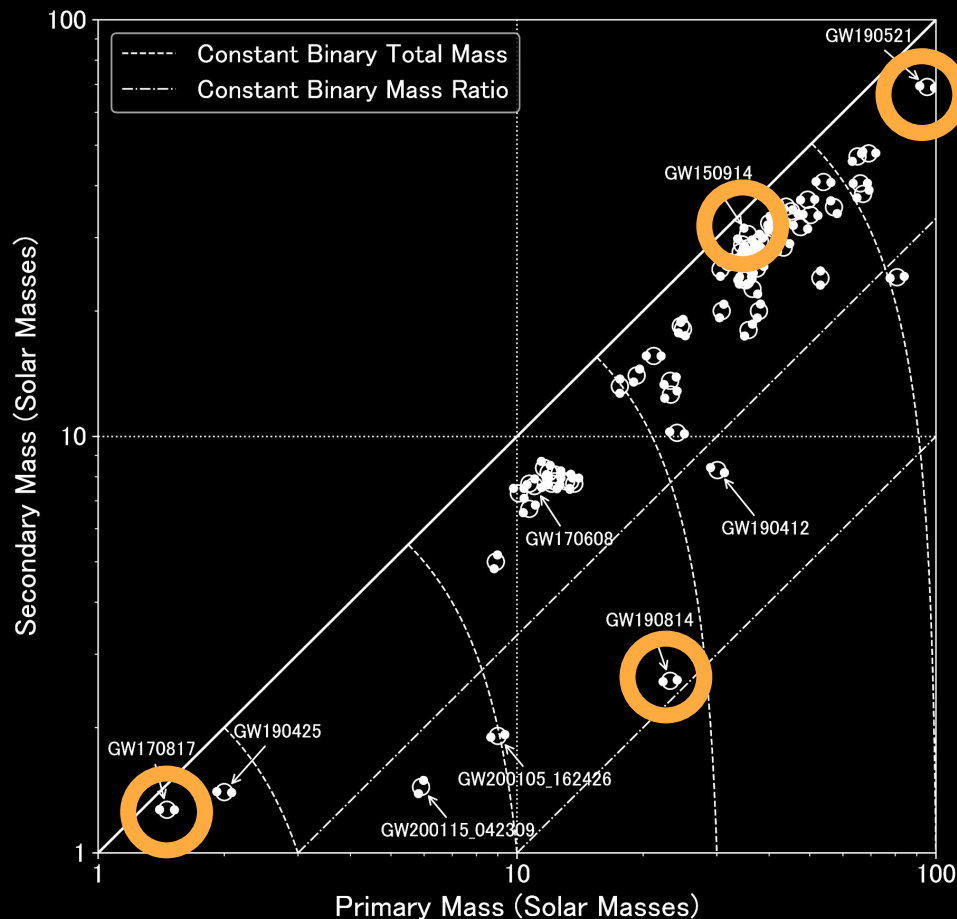
B. P. Abbott et al. Phys. Rev. Lett. 116, 061102

Observing runs

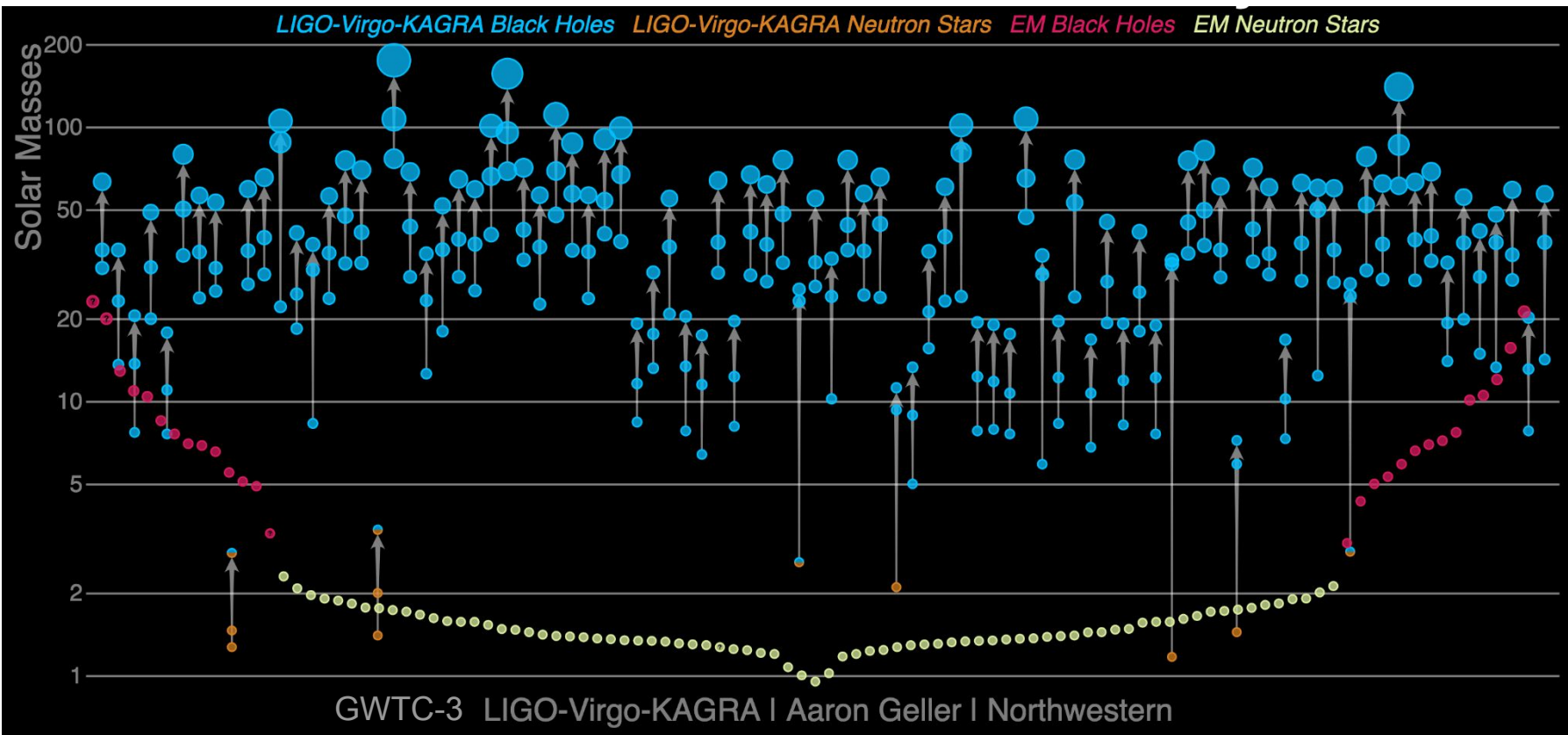


Detections

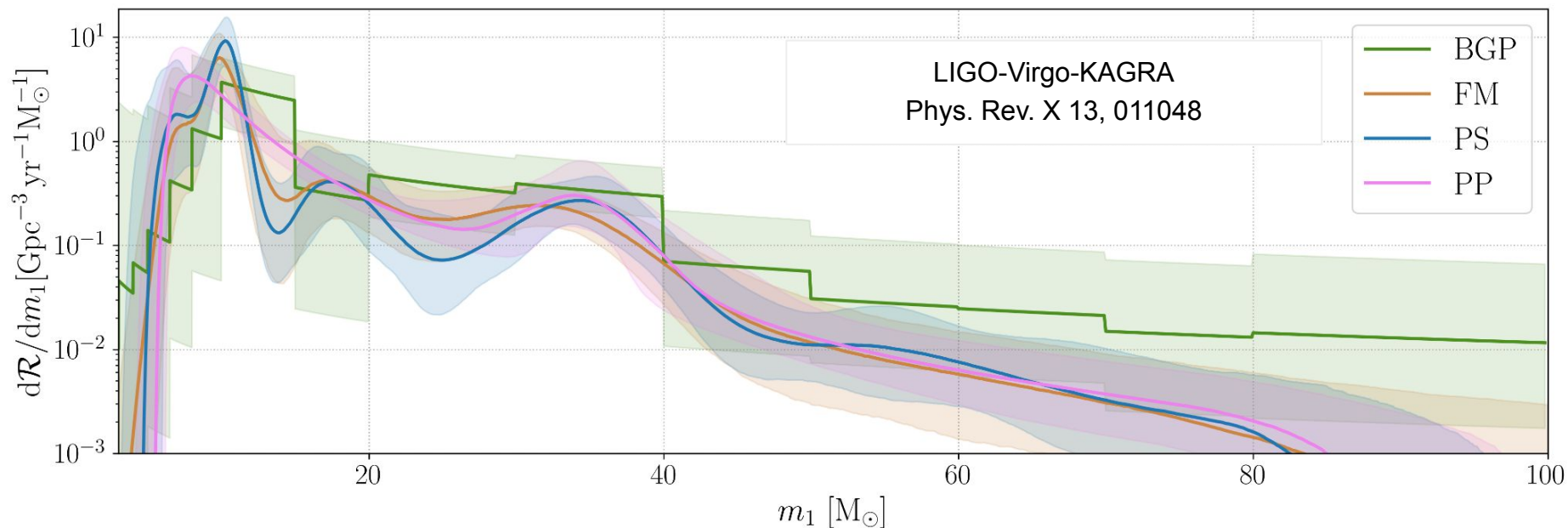
- **GW150914**
 - First astrophysical source
 - Binary black holes exist
- **GW170817**
 - Binary neutron star mergers are gamma-ray burst progenitors
- **GW190521**
 - Black holes exist in pair instability mass gap
- **GW190814**
 - Compact objects exist with masses between 2-5 Msun



Gravitational-Wave Transient Catalog



From one to many: measuring populations

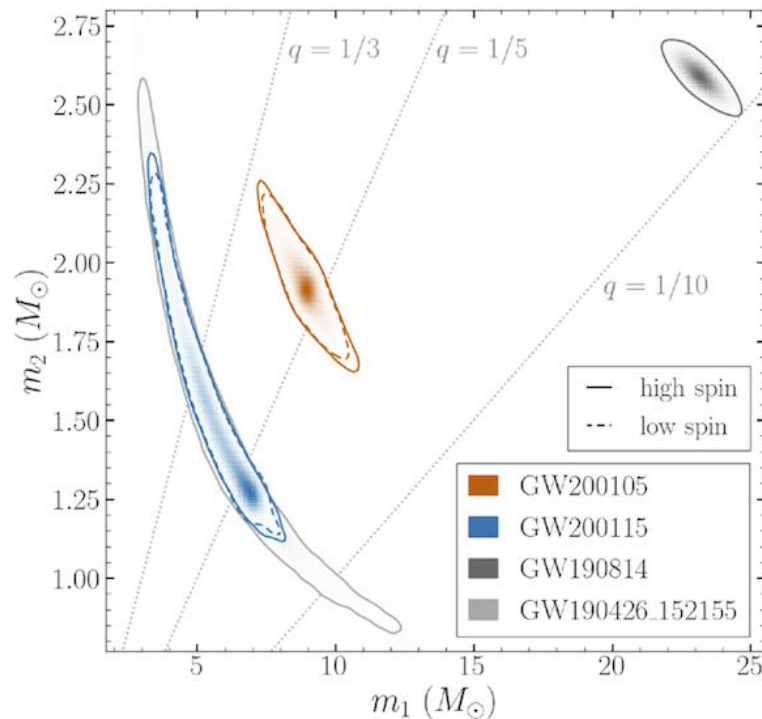


Merger rate density as a function of primary mass using 3 non-parametric models compared to the power-law+peak (pp) model.

Mergers involving neutron stars

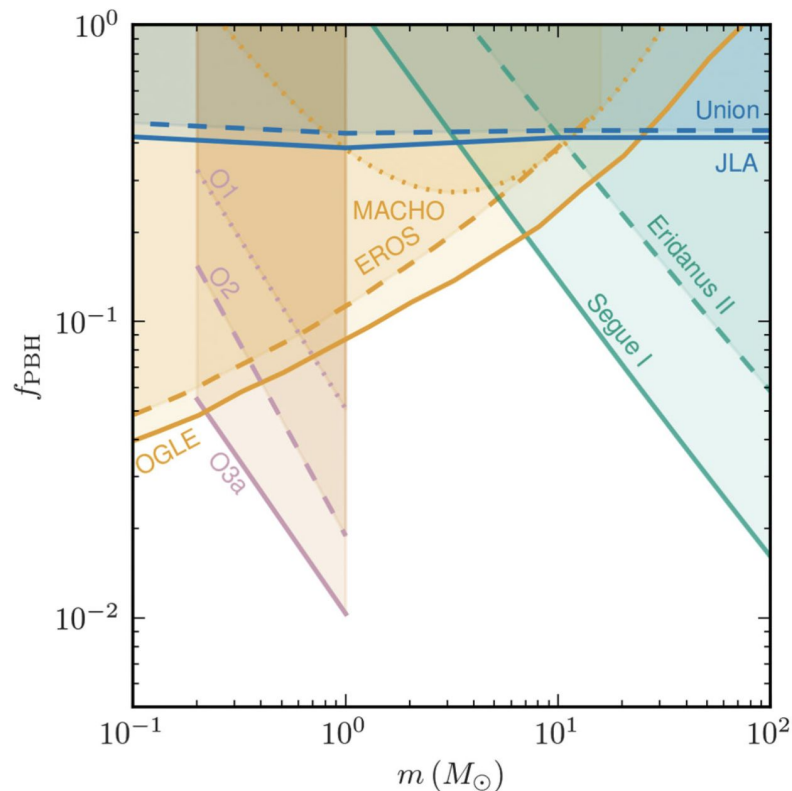
- GW170817 & GW190425
 - Binary neutron star (BNS) merger waves
- GW170817 & GRB 170817A
 - Fractional difference in speed of gravity and the speed of light is between -3×10^{-15} and 7×10^{-16}
- GW170817 & AT 2017gfo
 - Binary neutron star mergers produce kilonova explosions that generate heavy elements

B. P. Abbott et al 2017 ApJL 848 L13



Search for subsolar-mass binaries

- Search for compact binary mergers with at least one object of mass 0.2 - 1 Msun.
- No detections.
- Example constraints on fraction of dark matter in primordial black holes from an isotropic distribution of equal-mass binaries.

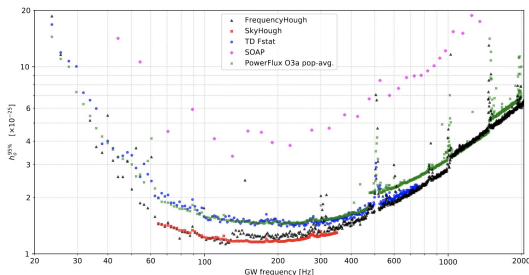


LIGO-Virgo Collaboration
Phys. Rev. Lett. 129, 061104

Many other observational results

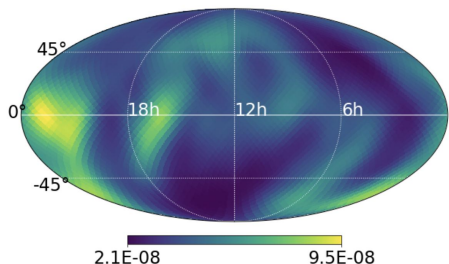
Limits on waves from pulsars

Phys. Rev. D 106, 102008 (2022)



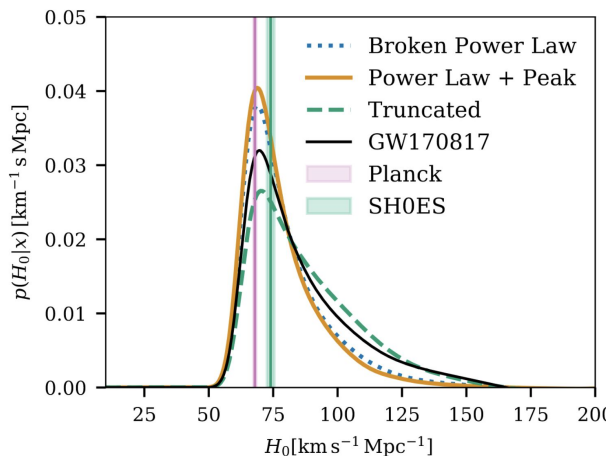
Stochastic background limits

Phys. Rev. D 105, 122002 (2022)



Hubble constant measurements

Astrophys. J. 949, 76 (2023)



And much more!

Back to observing!

- O4 started 24 May 2023: 20 months with up to 2 months commissioning
 - Virgo delayed due to damage to optics; KAGRA renewed commissioning after 1 month.
- Binary detection rates
 - O3 ~ 1 / 5 days
 - O4 ~ 1 / (2.8 days)
- Improved public alerts
 - Localization
 - Classification
 - Latency
 - Early-warning alerts
 - Low-significance alerts
- Improved sensitivity
 - Stay tuned for new results!

GraceDB Public Alerts ▾ Latest Search Notifications Pipelines Documentation Admin Docs Logout

Authenticated as: Patrick Brady





O4 Significant Detection Candidates: **35** (43 Total - 8 Retracted)

O4 Low Significance Detection Candidates: **671** (Total)

[Show All Public Events](#)

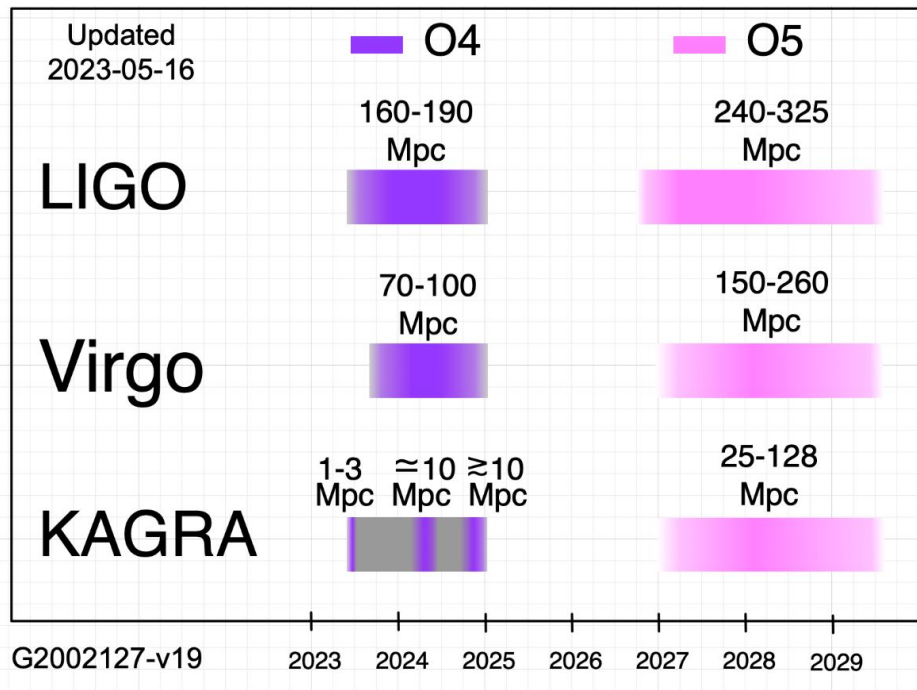
Page 1 of 3. [next](#) [last](#) »

SORT: EVENT ID (A-Z) ▾

Event ID	Possible Source (Probability)	Significant	UTC	GCN	Location	FAR	Comments	Ω Scan
S230830b	NSBH (80%), BBH (20%)	Yes	Aug. 30, 2023 04:21:58 UTC	GCN Circular Query Notices VOE		1 per 275.98 years	RETRACTED	Ω H1 Ω L1 Ω V1
S230825k	BBH (>99%)	Yes	Aug. 25, 2023 04:13:34 UTC	GCN Circular Query Notices VOE		1 per 13.272 years		Ω H1 Ω L1 Ω V1
S230824r	BBH (>99%)	Yes	Aug. 24, 2023 03:30:47 UTC	GCN Circular Query Notices VOE		1 per 1932.8 years		Ω H1 Ω L1 Ω V1
S230823km	BBH (99%), Tapered (1%)	Yes	Aug. 22, 2023	GCN Circular Query		1 per 1,263 years		Ω H1 Ω L1

O5 Observing Run

- Current thinking
 - Start is paced by upgrades after O4: 1.5-2 years gap.
 - Intersperse commissioning and observations
- Binary detection rates
 - O3 ~ 1 / 5 days
 - O4 ~ 1 / (2-3) days
 - O5 ~ 3 / day
- Other science
 - Improved SNR
 - New sources?



<https://observing.docs.ligo.org/plan/>

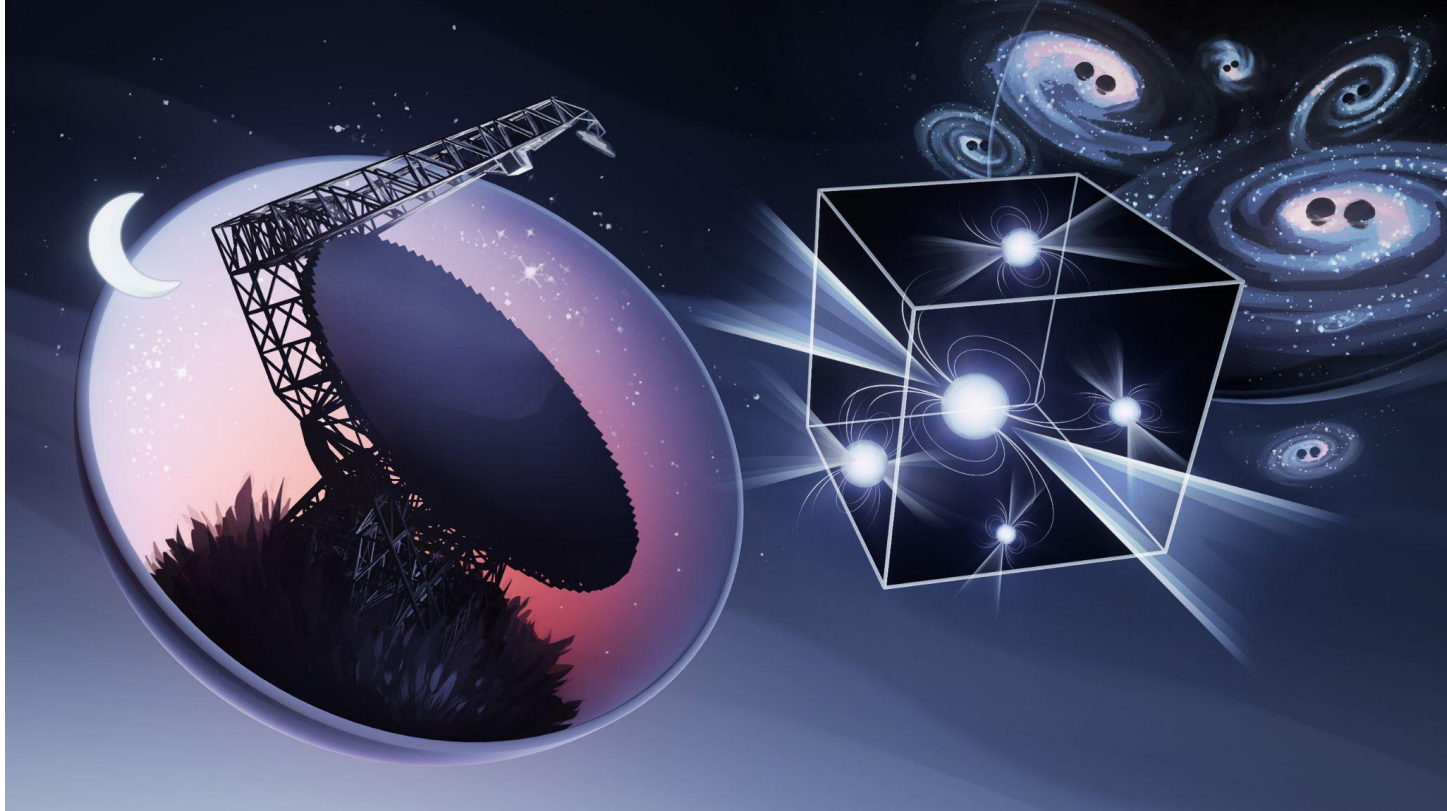
LIGO-Virgo-KAGRA anticipate observing to dovetail with next generation facilities

Early 2030s

- LIGO Aundha Observatory (LAO) is to be constructed in India and operated as part of the LIGO Observatories in the 2030s.
- A[#]: possible targeted improvements to the LIGO detectors
 - Achieve close to a factor of 2 amplitude sensitivity improvement with larger test masses, better seismic isolation, improved mirror coatings, higher laser power, better squeezing ...
 - Begin observing at the end of 2031 and observe for several years.
 - A[#] an engine for observational science and a pathfinder for next-generation technologies.
 - A network including LIGO A[#] detectors would be a cornerstone for multimessenger discovery.
- Virgo has scoped similar improvements, called VirgoNEXT, with similar timetable. KAGRA is focused on reaching its current target.

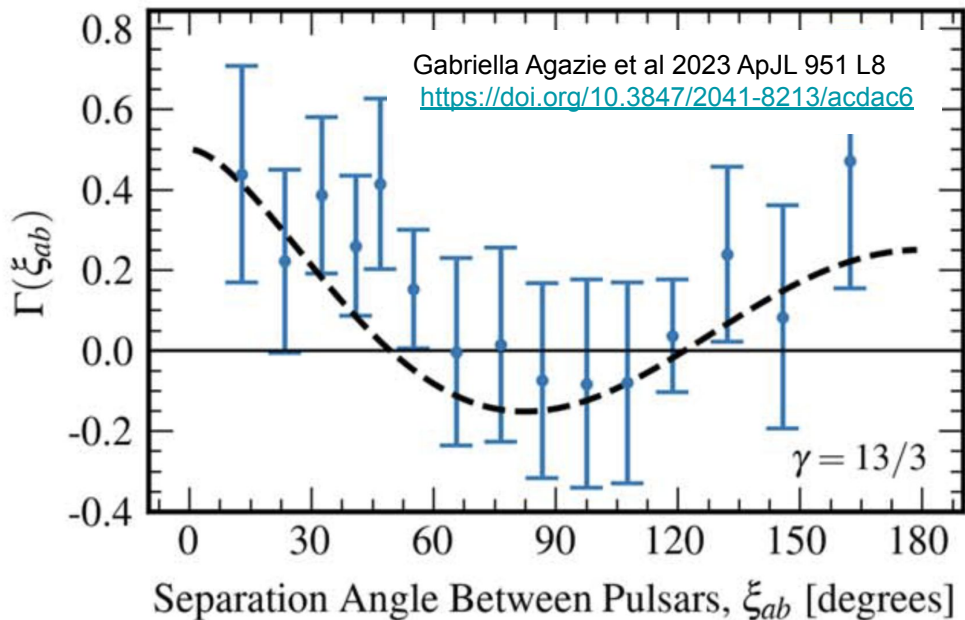
Recent Pulsar Timing Observations

Illustration Credit
Olena Shmahalo for NANOGrav





Recent Pulsar Timing Observations



Hellings-Downs inter-pulsar correlations from a gravitational-wave background.

- Bayesian analysis ~ 3 sigma
- Frequentist analysis ~ 3.5 - 4 sigma

Possibly background from supermassive black hole binaries.

- NANOGrav - G. Agazie et al 2023 ApJL 951 L8
- PPTA - D. J. Reardon et al 2023 ApJL 951 L6
- EPTA and InPTA - J. Antoniadis et al. A&A, to appear
- CPTA - H. Xu et al 2023 Res. Astron. Astrophys. 23 075024

Thank you!