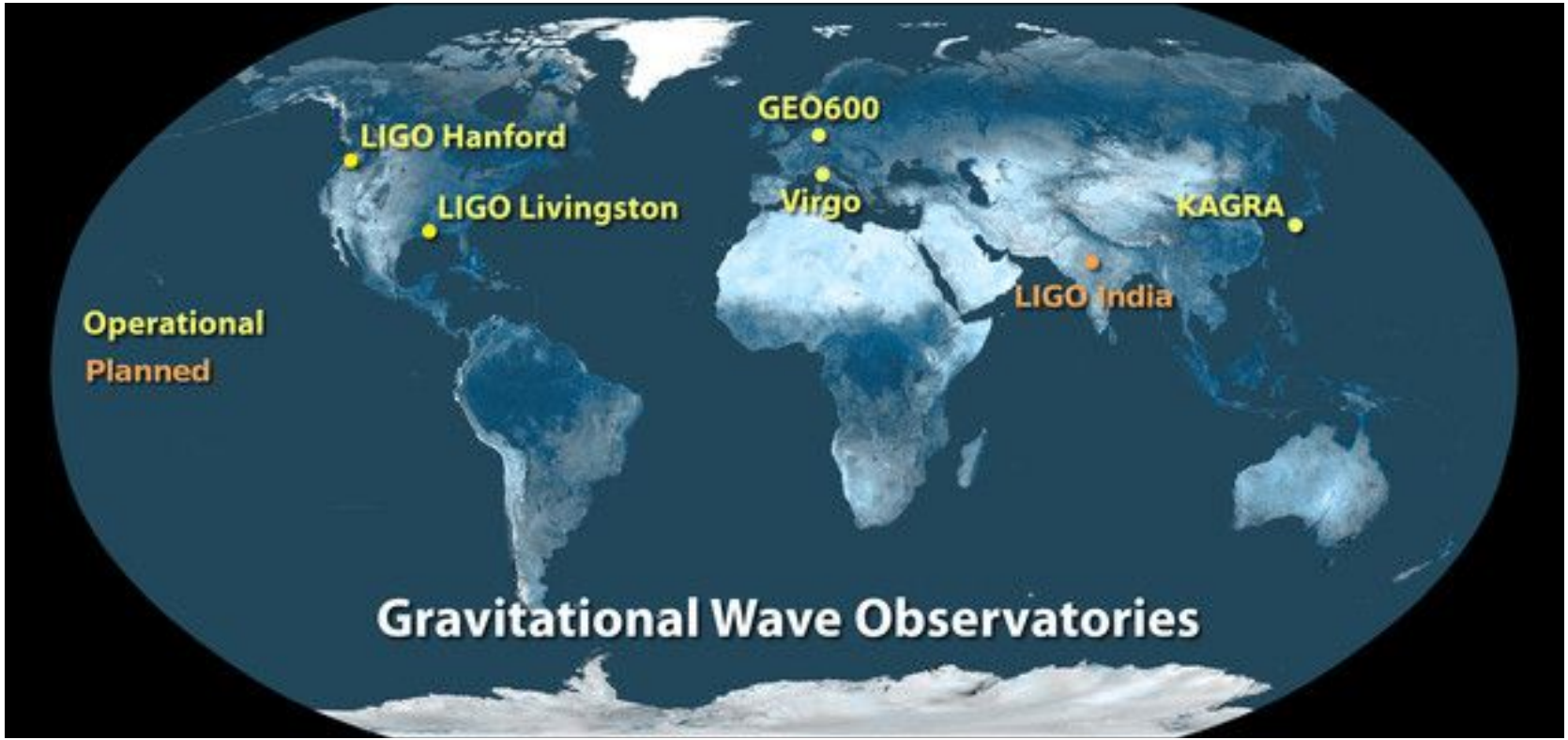
AstroParticle Symposium 2023

Status of the O4 run of LIGO/Virgo/KAGRA

Tito Dal Canton

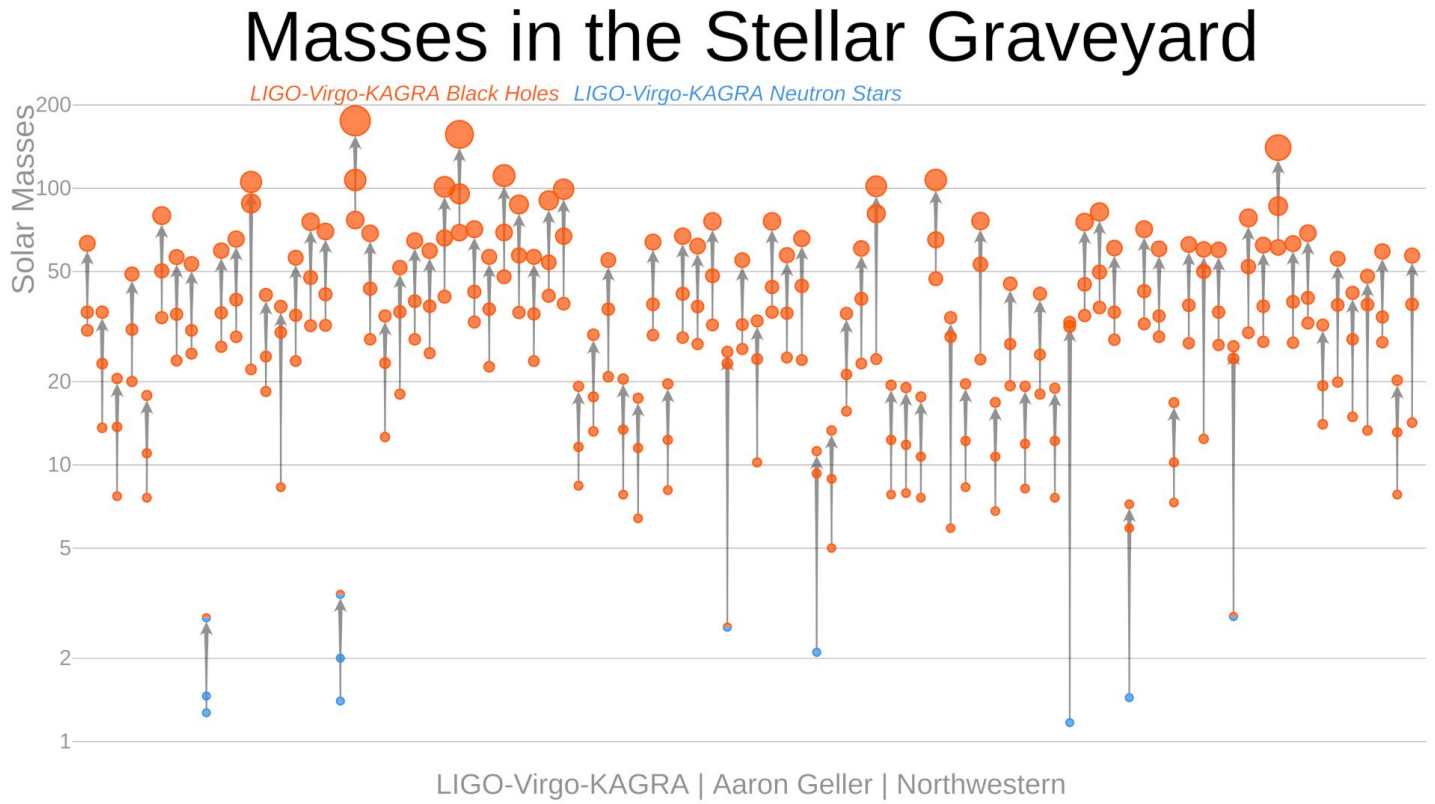
VIR-1037A-23

Ground-based gravitational-wave detectors



Highlights from the previous observing runs

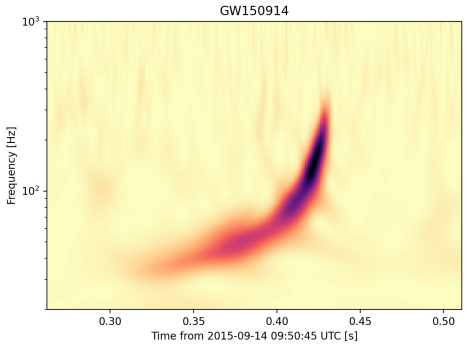
LVK 2020, GWTC-3



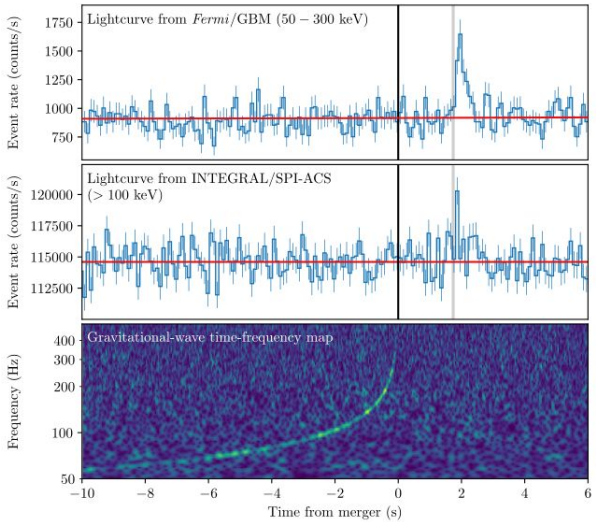
Highlights from the previous observing runs

LVK 2020, GWTC-3

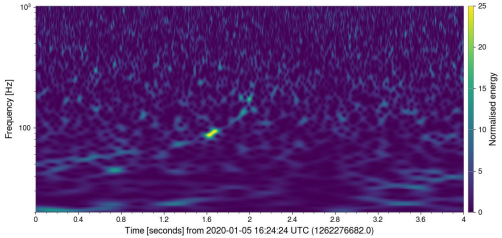
Binary black holes



Binary neutron stars



Mixed binaries

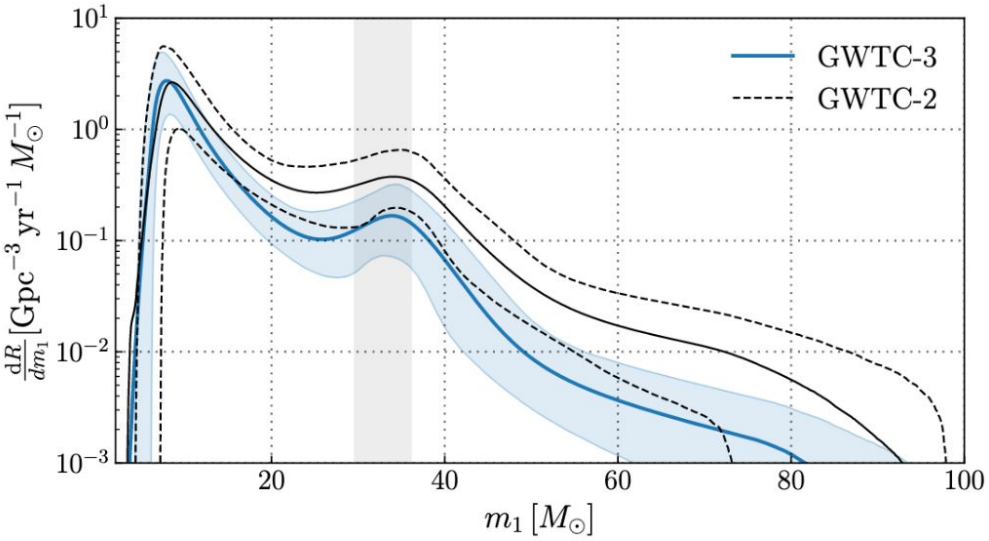


"Surprises": low-mass BHs (GW190814), high-mass BHs (GW190521)

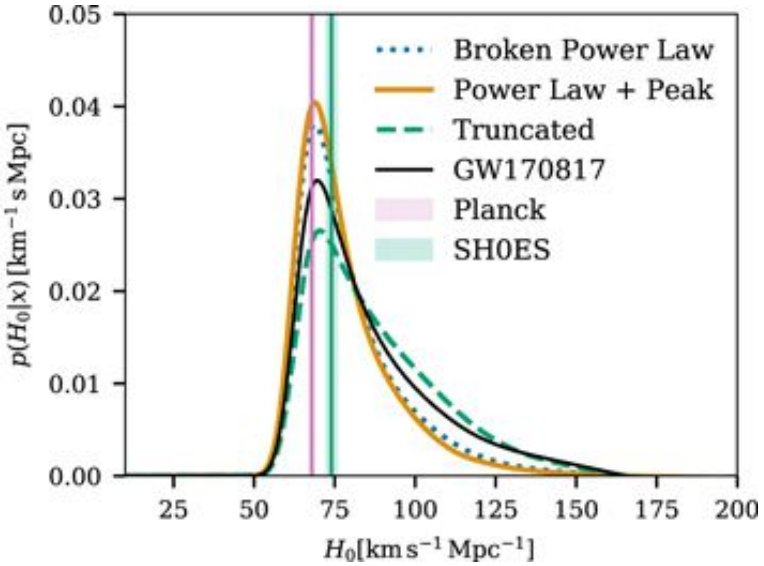
Highlights from the previous observing runs

LVK 2020, GWTC-3

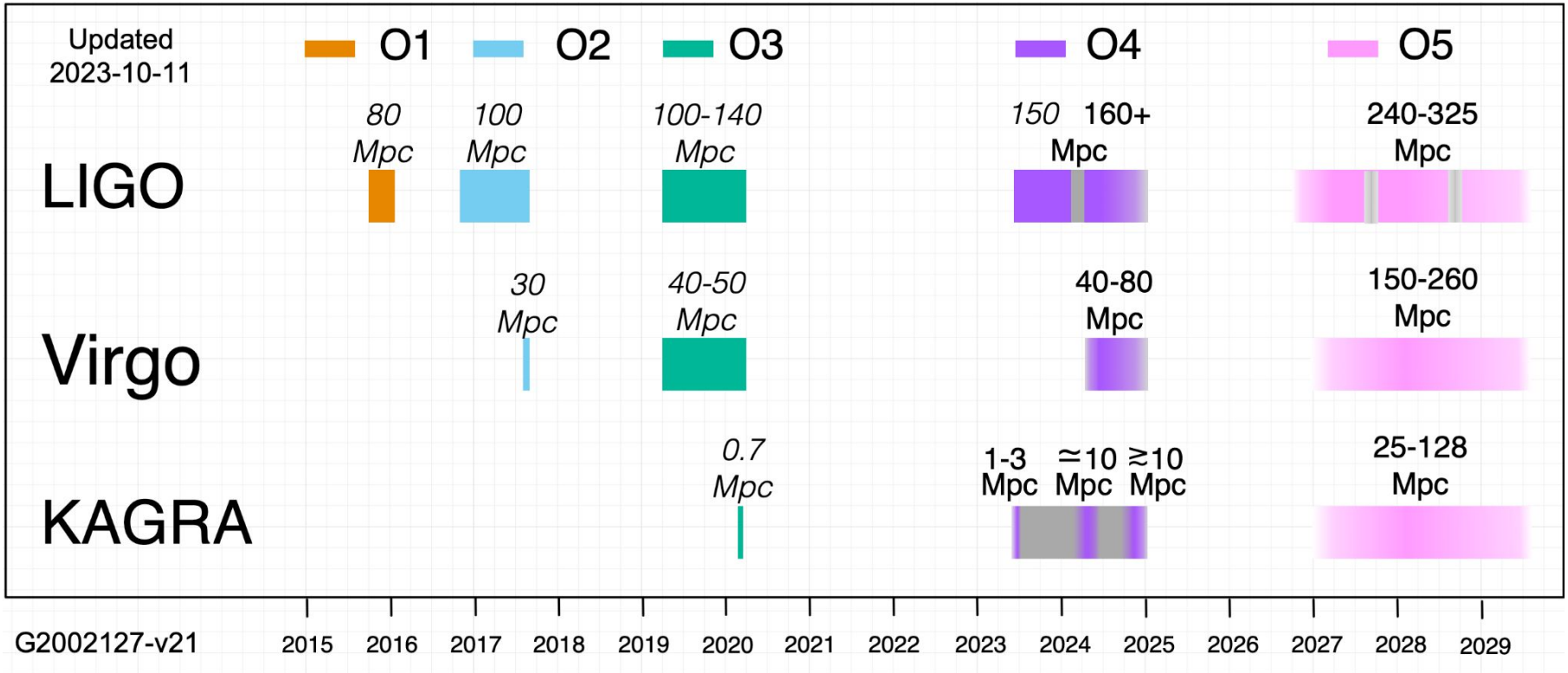
Black hole population properties



Cosmology



Timeline of observing runs



LIGO detector upgrades

Sensitivity improvements at low frequencies

- Stray light baffles

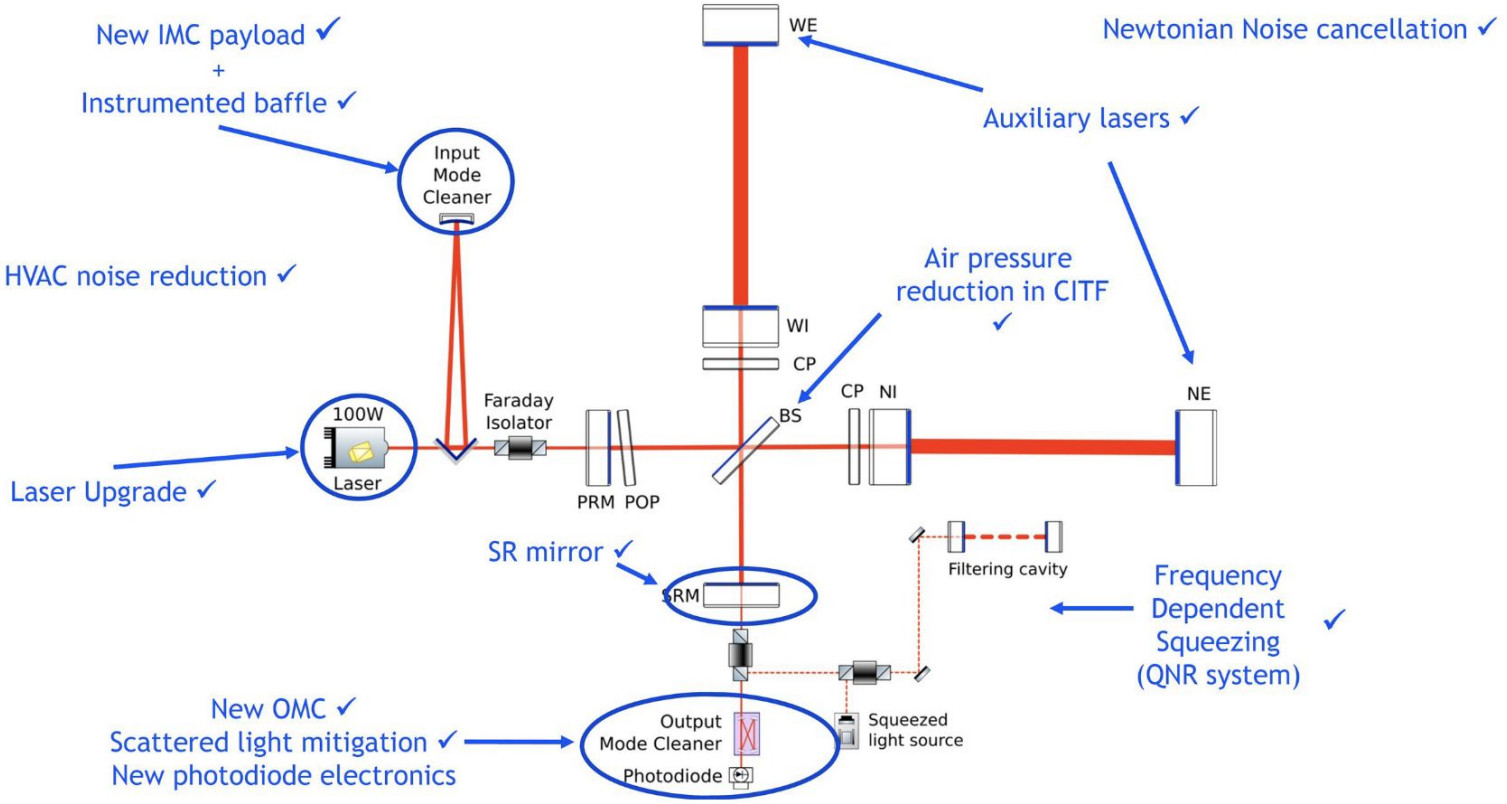
Sensitivity improvements at high frequencies

- New laser amplifier
- Removed point absorbers from mirrors

Broadband sensitivity improvements

- Frequency dependent squeezing
- Adaptive mode matching
- Low-loss faraday isolator

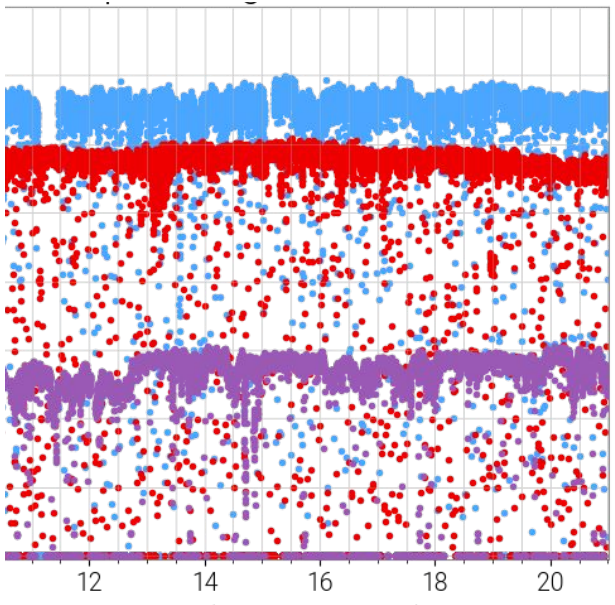
Virgo detector upgrades



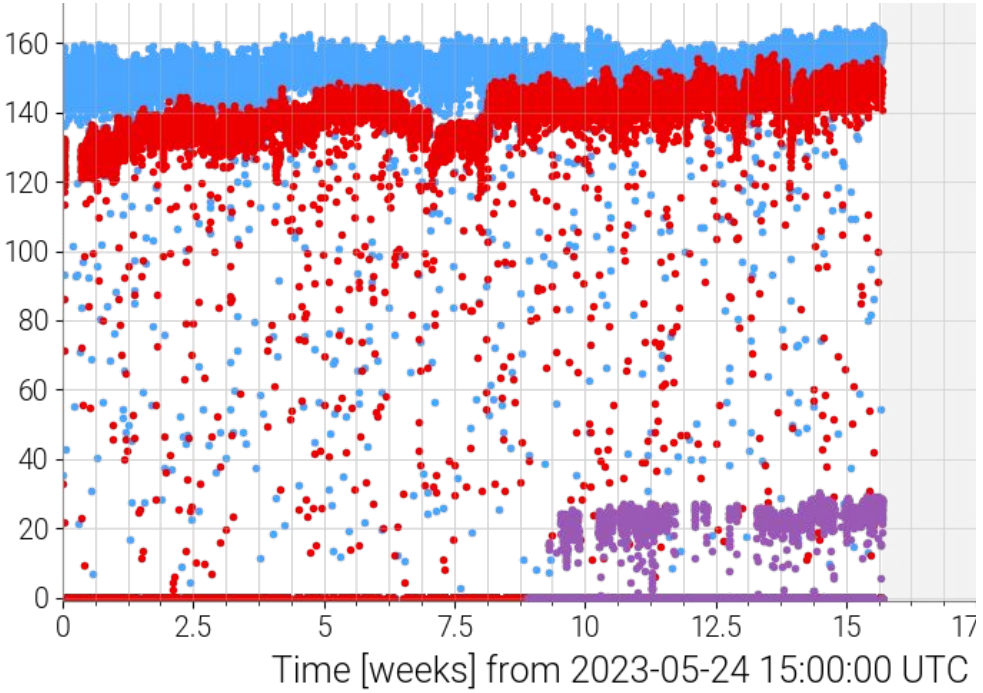
Impact on detector sensitivity

https://gwosc.org/detector_status/O4a/

O3b BNS range (Mpc)



O4a BNS range (Mpc)



LIGO Hanford LIGO Livingston Virgo

Upgrades to the rapid alert system and operations

Early-warning alerts for low-mass compact binary inspirals (Magee+ 2021).

Kafka-based alert distribution (via GCN and SCiMMA).

Lower-significance candidates (FAR < 2/day).

Extra details about each candidate visible on GraceDB (multiple FARs).

Restructuring of the “rapid response team”:
large pool of rapid “non experts” plus smaller pool of experts when needed.

Minor changes to the formatting of the alerts (e.g. HasMassGap).

Automatic parameter estimation for compact binaries.

Low-latency (preliminary) detections in O4

~60 compact binary mergers identified so far.

Most of those consistent with binary black hole mergers.

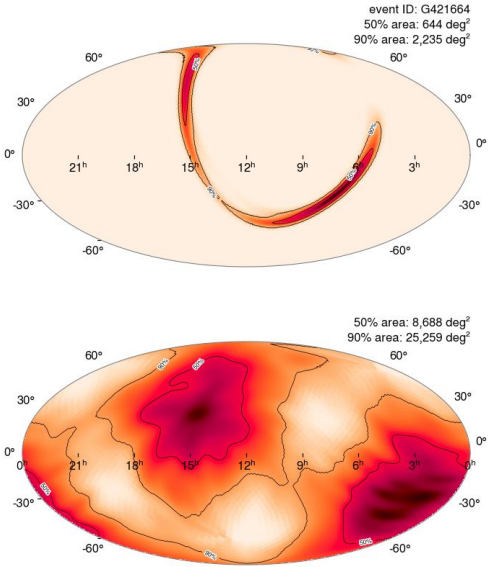
A few might be neutron-star–black-hole mergers!
Looking into those with more precise analyses.

No definite binary neutron star mergers yet.

Sky localizations limited by the lack
of a third sensitive detector.

Very active campaigns to search for counterparts
(electromagnetic and neutrinos).

12 retracted alerts: doing better than O3 so far.



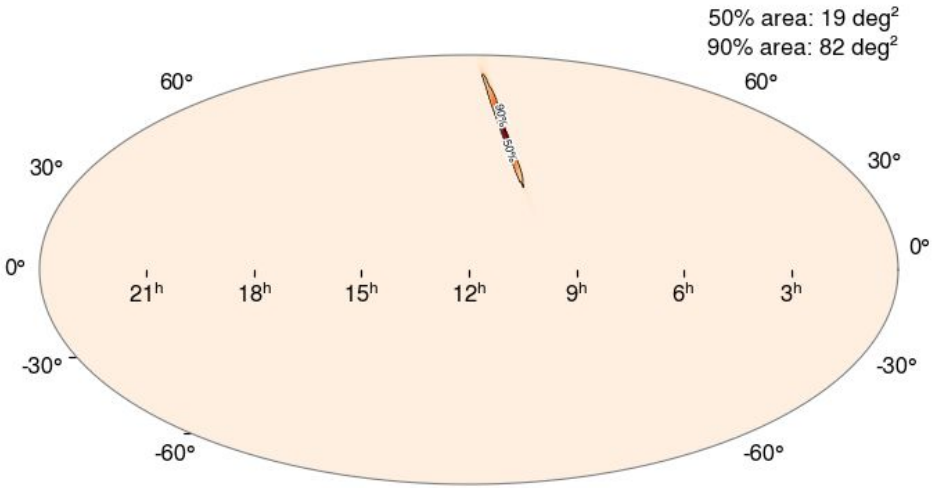
Low-latency (preliminary) detections in O4

S230627c

Best localized compact binary merger so far.

Likely a binary black hole merger.

~300 Mpc.



Post-O5 detector evolution

What to do between O5 (~2028) and 3G (late 2030s)?

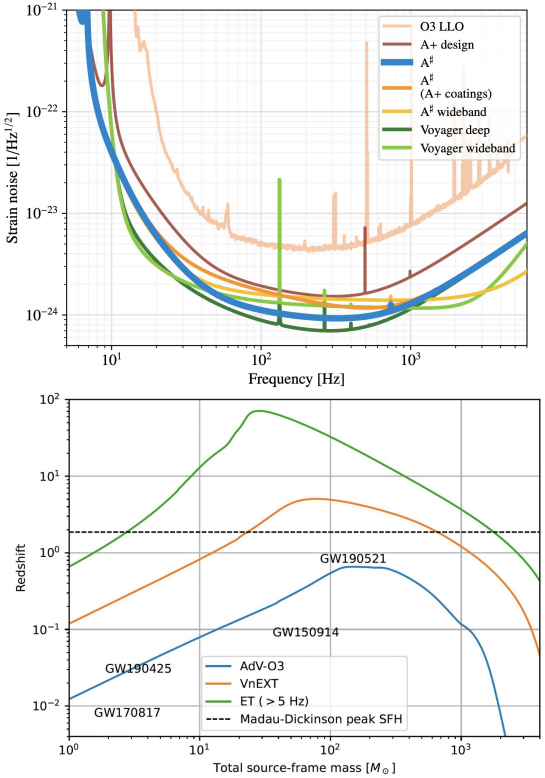
- Push existing infrastructure to their limits.
- Prepare the technology for 3G detectors.

Concepts:

- LIGO A#, Voyager (LSC, 2022)
- Virgo_nEXT

Ideas for improvements:

- Larger test masses (e.g. 40 kg → 100 kg)
- Improved seismic isolation and suspensions
- Higher arm cavity power (e.g. 1.5 MW)
- Increased squeezing



Conclusion

O4 started after a long hiatus in observations.

A few compact binary mergers detected each week now.
Yet to see a definitive multimessenger event, but looking very actively.

Offline analyses underway for compact binaries and other types of signals.

Two-month break planned in early 2024, followed by three-detector observations again.

Stay tuned: gwosc.org, gracedb.ligo.org, Open LVKEM wiki.

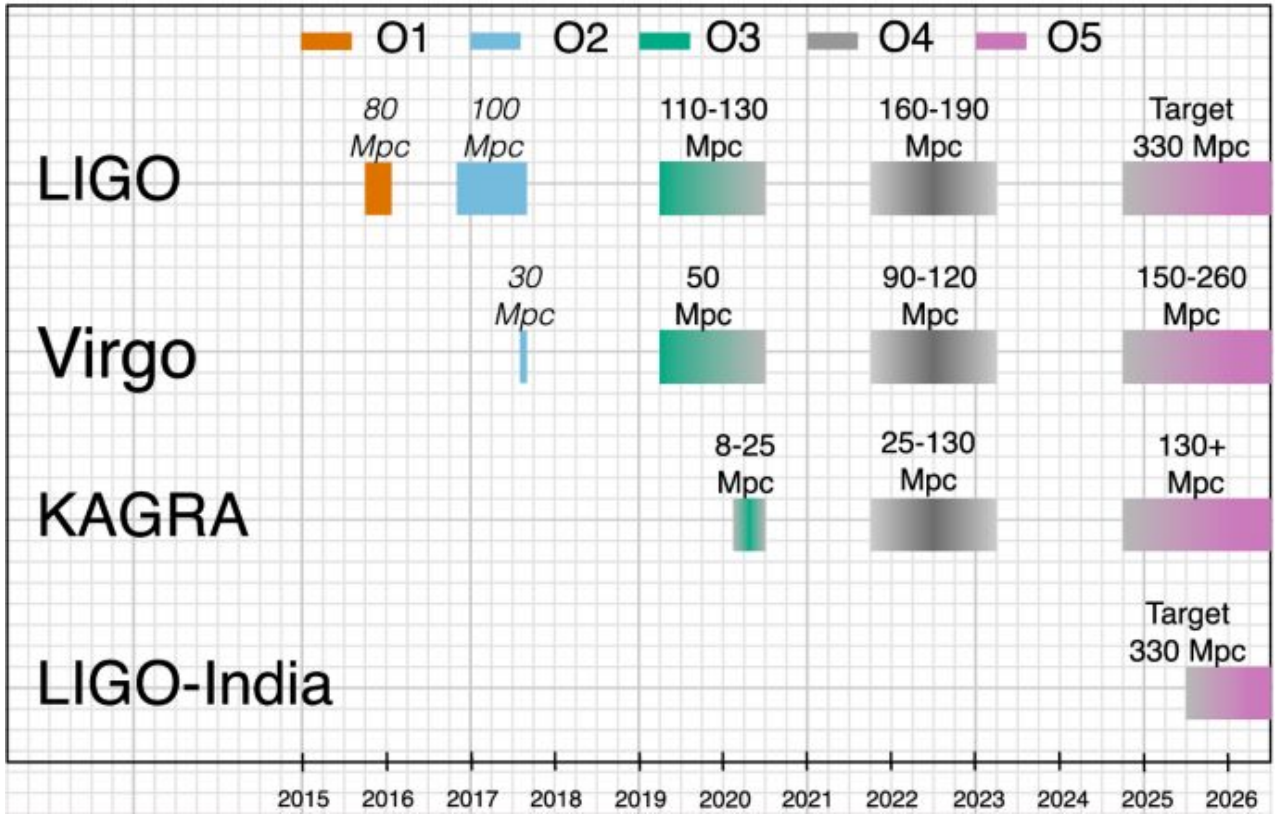
Many of us are working on future detectors.

Thank you for the attention!

Backup

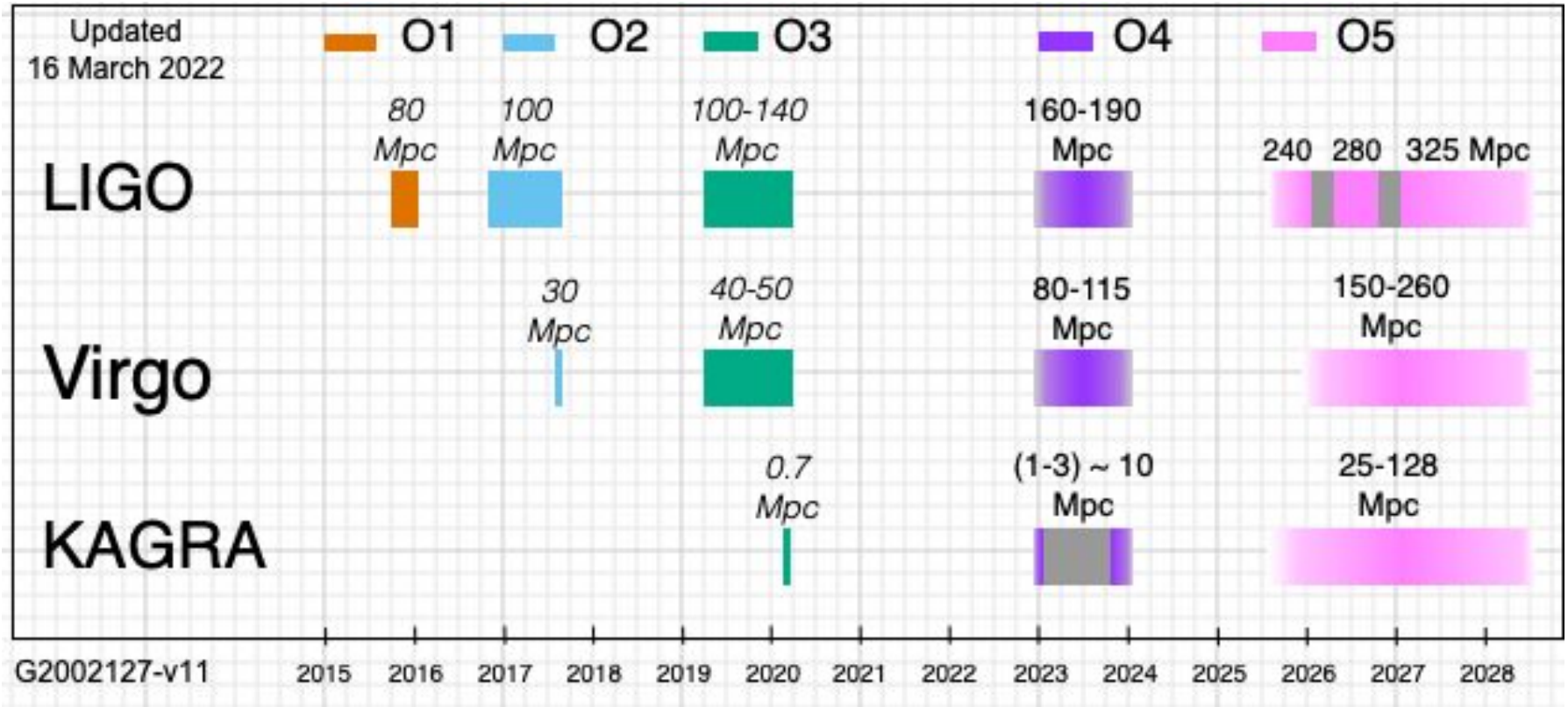
Timeline of observing runs

LVK 2020 observing scenario

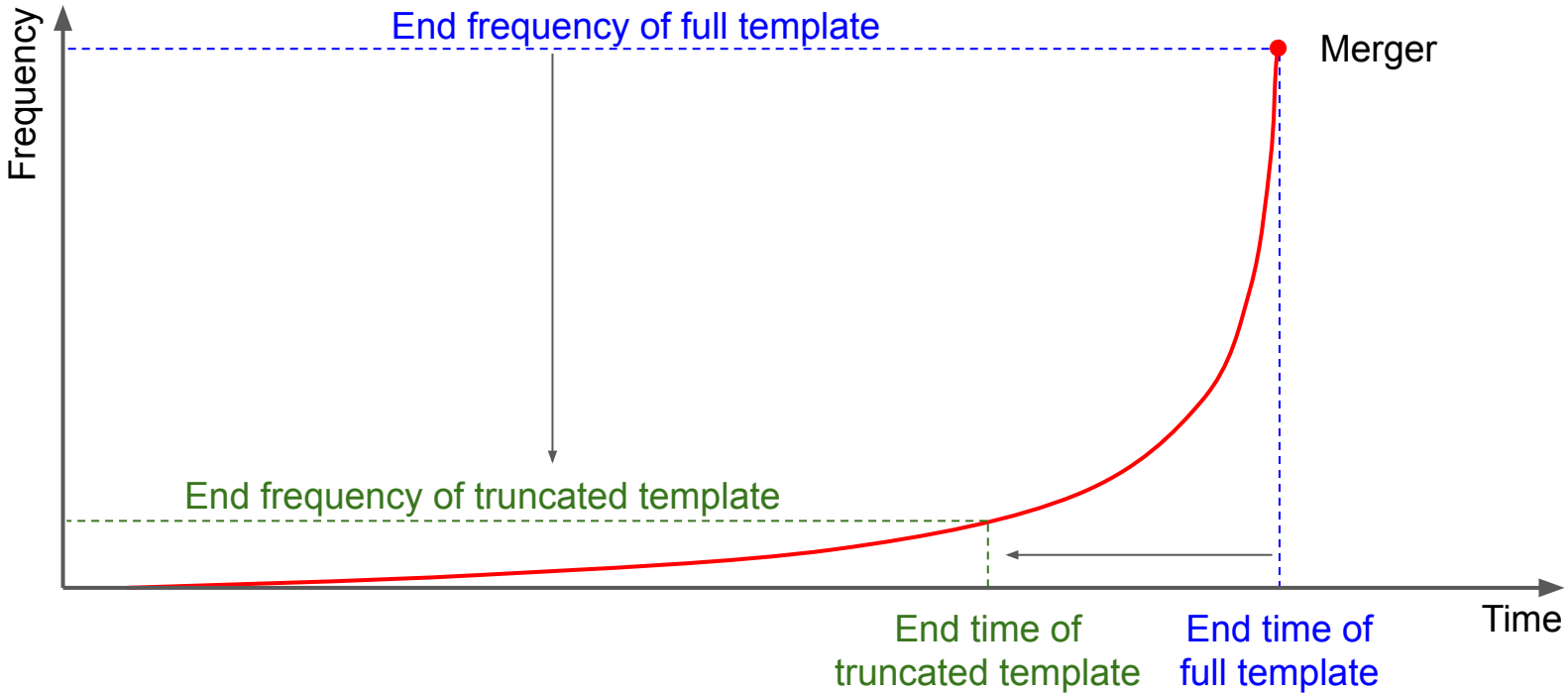


Timeline of observing runs

LVK 2022



Early-warning detection of an inspiral



Preliminary GCN notice

```
TITLE:          GCN/LVC NOTICE
NOTICE_DATE:    Mon 14 Aug 23 23:09:31 UT
NOTICE_TYPE:    LVC Preliminary
TRIGGER_NUM:    S230814ah
TRIGGER_DATE: 20170 TJD;   226 DOY;   2023/08/14 (yyyy/mm/dd)
TRIGGER_TIME: 83341.000000 SOD {23:09:01.000000} UT
SEQUENCE_NUM: 1
GROUP_TYPE:   1 = CBC
SEARCH_TYPE:  1 = AllSky
PIPELINE_TYPE:4 = gstlal
FAR:            1.847e-21 [Hz]  (one per 6265940369012569.0 days)  (one per 17166959915102.93 years)
PROB_NS:        0.00 [range is 0.0-1.0]
PROB_REMNANT: 0.00 [range is 0.0-1.0]
PROB_BNS:       0.00 [range is 0.0-1.0]
PROB_NSBH:      0.00 [range is 0.0-1.0]
PROB_BBH:       1.00 [range is 0.0-1.0]
PROB_MassGap: 0.00 [range is 0.0-1.0]
PROB_TERRES:    0.00 [range is 0.0-1.0]
TRIGGER_ID:     0x10
MISC:           0x1898402
SKYMAP_FITS_URL:  https://gracedb.ligo.org/api/superevents/S230814ah/files/bayestar.multiorder.fits,1
EVENTPAGE_URL:https://gracedb.ligo.org/superevents/S230814ah/view/
COMMENTS:       LVC Preliminary Trigger Alert.
COMMENTS:       This event is an OpenAlert.
COMMENTS:       LIGO-Livingston Observatory contributed to this candidate event.
```

Initial GCN notice

```
TITLE:          GCN/LVC NOTICE
NOTICE_DATE:    Mon 14 Aug 23 23:59:39 UT
NOTICE_TYPE:    LVC Initial Skymap
TRIGGER_NUM:    S230814ah
TRIGGER_DATE: 20170 TJD;   226 DOY;   2023/08/14 (yyyy/mm/dd)
TRIGGER_TIME: 83341.000000 SOD {23:09:01.000000} UT
SEQUENCE_NUM: 3
GROUP_TYPE:   1 = CBC
SEARCH_TYPE:  1 = AllSky
PIPELINE_TYPE:4 = gstlal
FAR:            1.847e-21 [Hz]  (one per 6265940369012569.0 days)  (one per 17166959915102.93 years)
PROB_NS:        0.00 [range is 0.0-1.0]
PROB_REMNANT: 0.00 [range is 0.0-1.0]
PROB_BNS:       0.00 [range is 0.0-1.0]
PROB_NSBH:      0.00 [range is 0.0-1.0]
PROB_BBH:       1.00 [range is 0.0-1.0]
PROB_MassGap: 0.00 [range is 0.0-1.0]
PROB_TERRES:    0.00 [range is 0.0-1.0]
TRIGGER_ID:     0x10
MISC:           0x3898602
SKYMAP_FITS_URL:  https://gracedb.ligo.org/api/superevents/S230814ah/files/bayestar.multiorder.fits,2
EVENTPAGE_URL:https://gracedb.ligo.org/superevents/S230814ah/view/
COMMENTS:       LVC Super Initial Skymap -- a location probability map.
COMMENTS:       This event is an OpenAlert.
COMMENTS:       LIGO-Livingston Observatory contributed to this candidate event.
```

Skymap update GCN notice

```
TITLE:          GCN/LVC NOTICE
NOTICE_DATE:    Tue 29 Aug 23 21:42:37 UT
NOTICE_TYPE:    LVC Update Skymap
TRIGGER_NUM:    S230814ah
TRIGGER_DATE: 20170 TJD;   226 DOY;   2023/08/14 (yyyy/mm/dd)
TRIGGER_TIME: 83341.000000 SOD {23:09:01.000000} UT
SEQUENCE_NUM: 4
GROUP_TYPE:   1 = CBC
SEARCH_TYPE:  1 = AllSky
PIPELINE_TYPE:4 = gstlal
FAR:            1.847e-21 [Hz]  (one per 6265940369012569.0 days)  (one per 17166959915102.93 years)
PROB_NS:        0.00 [range is 0.0-1.0]
PROB_REMNANT: 0.00 [range is 0.0-1.0]
PROB_BNS:       0.00 [range is 0.0-1.0]
PROB_NSBH:      0.00 [range is 0.0-1.0]
PROB_BBH:       1.00 [range is 0.0-1.0]
PROB_MassGap: 0.00 [range is 0.0-1.0]
PROB_TERRES:    0.00 [range is 0.0-1.0]
TRIGGER_ID:     0x10
MISC:           0x4898602
SKYMAP_FITS_URL:  https://gracedb.ligo.org/api/superevents/S230814ah/files/Bilby.offline0.multiorder.fits
EVENTPAGE_URL:https://gracedb.ligo.org/superevents/S230814ah/view/
COMMENTS:       LVC Super Updated Skymap -- a location probability map.
COMMENTS:       This event is an OpenAlert.
COMMENTS:       LIGO-Livingston Observatory contributed to this candidate event.
```

Initial GCN circular

Subject: LIGO/Virgo/KAGRA S230814ah: Identification of a GW compact binary merger candidate
Date: 2023-08-15T00:04:16Z (3 months ago)
From: 최소연 <choisy4044@gmail.com>
Via: Web form

The LIGO Scientific Collaboration, the Virgo Collaboration, and the KAGRA Collaboration report:

We identified the compact binary merger candidate S230814ah during real-time processing of data from LIGO Livingston Observatory (L1) at 2023-08-14 23:09:01.810 UTC (GPS time: 1376089759.810). The candidate was found by the GstLAL [1] analysis pipeline.

S230814ah is an event of interest because its false alarm rate, as estimated by the online analysis, is 1.8e-21 Hz, or about one in 1e13 years. The event's properties can be found at this URL:

https://gracedb.ligo.org/superevents/S230814ah

The classification of the GW signal, in order of descending probability, is BBH (>99%), Terrestrial (<1%), BNS (<1%), or NSBH (<1%).

Assuming the candidate is astrophysical in origin, the probability that the lighter compact object is consistent with a neutron star mass (HasNS) is <1%. [2] Using the masses and spins inferred from the signal, the probability of matter outside the final compact object (HasRemnant) is <1%. [2] Both HasNS and HasRemnant consider the support of several neutron star equations of state. The probability that either of the binary components lies between 3 and 5 solar masses (HasMassgap) is <1%.

Two sky maps are available at this time and can be retrieved from the GraceDB event page:

* bayestar.multiorder.fits,1, an initial localization generated by BAYESTAR [3], distributed via GCN notice about 27 seconds after the candidate event time.

* bayestar.multiorder.fits,2, an initial localization generated by BAYESTAR [3], distributed via GCN notice about 5 minutes after the candidate event time.

The preferred sky map at this time is bayestar.multiorder.fits,2. For the bayestar.multiorder.fits,2 sky map, the 90% credible region is 24222 deg2. Marginalized over the whole sky, the a posteriori luminosity distance estimate is 405 +/- 124 Mpc (a posteriori mean +/- standard deviation).

For further information about analysis methodology and the contents of this alert, refer to the LIGO/Virgo/KAGRA Public Alerts User Guide https://emfollow.docs.ligo.org/userguide/.

[1] Tsukada et al. arXiv:2305.06286 (2023) and Ewing et al. arXiv:2305.05625 (2023)
[2] Chatterjee et al. ApJ 896, 54 (2020)
[3] Singer & Price PRD 93, 024013 (2016)