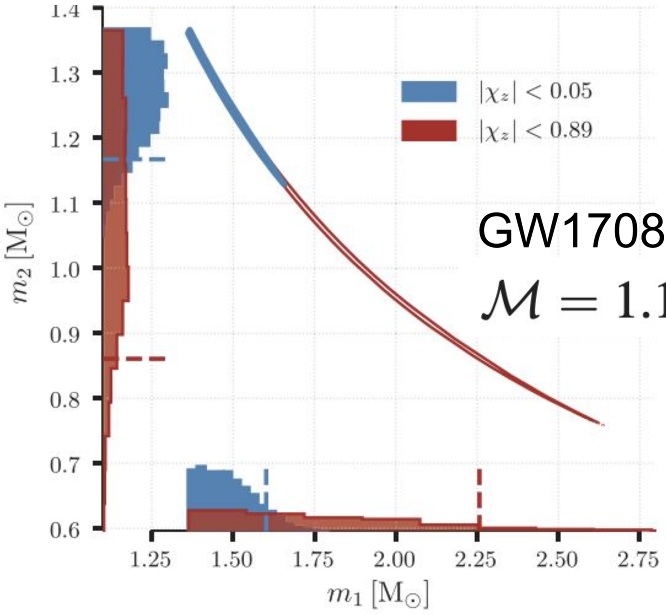
Binned Chirp Mass Information for O4c

Chirp Mass

$$\mathcal{M} = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

Precisely measured from inspiral GW frequency evolution in the low mass regime



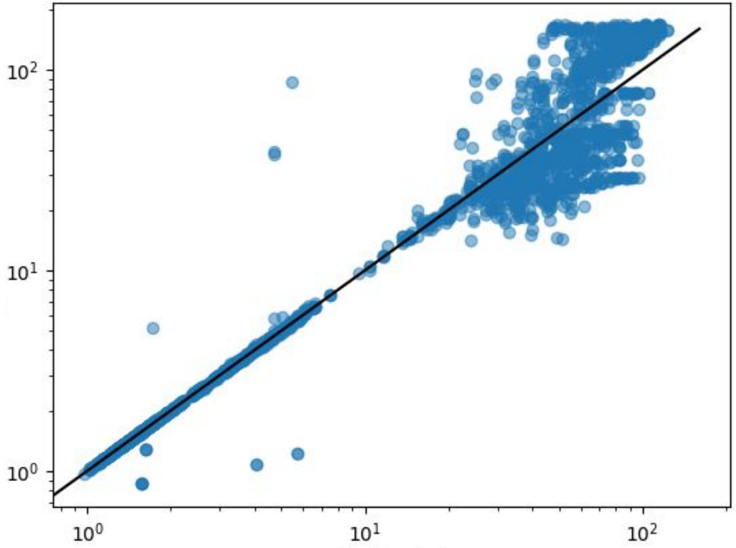
GW170817

$$\mathcal{M} = 1.188^{+0.004}_{-0.002} M_\odot$$

Abbott el al. 10.1103/PhysRevLett.119.161101

Accurately estimated by search pipelines in the low mass regime

Mock Data Challenge simulated signals



$\mathcal{M}$ (Measured)

$\mathcal{M}$ (Injected)

Binned Chirp Mass Information

A new data product providing **source** chirp mass in the form of binned probabilities.

The predetermined bins are the following (in units of solar masses):

[0.1, 0.87, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.7, 1.9, 2.1, 2.3, 3, 5.5, 11, 22, 44, 88, 1000]

The bins are fine in the *HasSSM* and *HasNS* regime where chirp mass is recovered more accurately, and become coarse for higher masses in the BBH regime.

Binned Chirp Mass Information *(HasSSM)*

A new data product providing **source** chirp mass in the form of binned probabilities.

The predetermined bins are the following (in units of solar masses):

[0.1, 0.87, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.7, 1.9, 2.1, 2.3, 3, 5.5, 11, 22, 44, 88, 1000]

Example: A chirp mass of 0.87 $M_\odot$ may correspond to a 1 $M_\odot$, 1 $M_\odot$ merger.

The bins are fine in the *HasSSM* and *HasNS* regime where chirp mass is recovered more accurately, and become coarse for higher masses in the BBH regime.

Binned Chirp Mass Information *(HasNS)*

A new data product providing **source** chirp mass in the form of binned probabilities.

The predetermined bins are the following (in units of solar masses):

[0.1, 0.87, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.7, 1.9, 2.1, 2.3, 3, 5.5, 11, 22, 44, 88, 1000]

Example: A chirp mass of 1.2 $M_\odot$ may correspond to a 1.4 $M_\odot$, 1.4 $M_\odot$ merger.

Example: A chirp mass of 3 $M_\odot$ may correspond to a 1.4 $M_\odot$, 10 $M_\odot$ merger.

The bins are fine in the *HasSSM* and *HasNS* regime where chirp mass is recovered more accurately, and become coarse for higher masses in the BBH regime.

Binned Chirp Mass Information *(BBH)*

A new data product providing **source** chirp mass in the form of binned probabilities.

The predetermined bins are the following (in units of solar masses):

[0.1, 0.87, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.7, 1.9, 2.1, 2.3, 3, 5.5, 11, 22, 44, 88, 1000]

Example: A chirp mass of 8.7 $M_\odot$ may correspond to a 10 $M_\odot$, 10 $M_\odot$ merger.

Example: A chirp mass of 44 $M_\odot$ may correspond to a 50 $M_\odot$, 50 $M_\odot$ merger.

The bins are fine in the *HasSSM* and *HasNS* regime where chirp mass is recovered more accurately, and become coarse for higher masses in the *BBH* regime.

Binned Chirp Mass Information $\mathcal{M}_z = (1+z)\mathcal{M}$

A **.json file containing the probabilities** and a **.png histogram** will be publicly available on **GraceDB** (not included in alert packet)

Just as for em-bright and sky maps, chirp mass information may be present in the initial GCN circular and later updated with an update GCN circular

There are two pathways for estimating the source chirp mass:

1. Low-latency : pipeline point estimate + sky map distance PDF
    - For cWB BBH preferred events there is no distance estimate, we provide "detector frame" chirp mass $\mathcal{M}_z$
2. Medium latency update : Bayesian Parameter Estimation (PE) using Bilby posterior samples

Binned Chirp Mass Information

Provided by
search pipelines/PE

$$\boxed{\mathcal{M}_z} = (1+z)\mathcal{M}$$

A **.json file containing the probabilities** and a **.png histogram** will be publicly available on **GraceDB**

Just as for em-bright and sky maps, chirp mass information may be present in the initial GCN circular and later updated with an update GCN circular

There are two pathways for estimating the source chirp mass:

1. Low-latency : pipeline point estimate + sky map distance PDF
   - For cWB BBH preferred events there is no distance estimate, we provide "detector frame" chirp mass $\mathcal{M}_z$
2. Medium latency update : Bayesian Parameter Estimation (PE) using Bilby posterior samples

Binned Chirp Mass Information

Provided by search pipelines/PE

Provided by Bayestar/PE

$$\boxed{\mathcal{M}_z} = (1 + \boxed{z})\mathcal{M}$$

A **.json file containing the probabilities** and a **.png histogram** will be publicly available on **GraceDB**

Just as for em-bright and sky maps, chirp mass information may be present in the initial GCN circular and later updated with an update GCN circular

There are two pathways for estimating the source chirp mass:

1. Low-latency : pipeline point estimate + sky map distance PDF
   - For cWB BBH preferred events there is no distance estimate, we provide "detector frame" chirp mass $\mathcal{M}_z$
2. Medium latency update : Bayesian Parameter Estimation (PE) using Bilby posterior samples

Binned Chirp Mass Information

Provided by search pipelines/PE

Provided by Bayestar/PE

Source chirp mass reported

$$\boxed{\mathcal{M}_z} = (1 + \boxed{z})\boxed{\mathcal{M}}$$

A **.json file containing the probabilities** and a **.png histogram** will be publicly available on **GraceDB**

Just as for em-bright and sky maps, chirp mass information may be present in the initial GCN circular and later updated with an update GCN circular

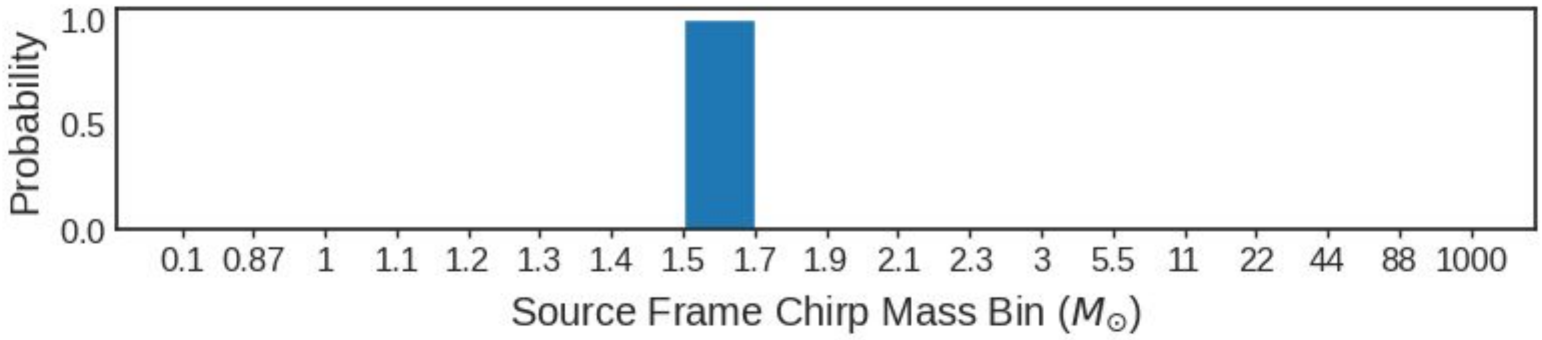
There are two pathways for estimating the source chirp mass:

1. Low-latency : pipeline point estimate + sky map distance PDF
   - For cWB BBH preferred events there is no distance estimate, we provide "detector frame" chirp mass $\mathcal{M}_z$
2. Medium latency update : Bayesian Parameter Estimation (PE) using Bilby posterior samples

Integration into Public Alerts

- **Chirp mass info *not* included in the alert packet** (potential future item)
- The most probable bin is reported in the GCN circular
- .json of all bin probabilities and .png histogram on GraceDB (public)
    - Low-latency estimate available in ~seconds with em-bright+p(astro): **mchirp_source.json**
    - PE estimate available alongside update alert ~hour(s): **mchirp_source_PE.json**


```
{
  "bin_edges": [0.1, 0.87, 1, 1.1, 1.2, 1.3, 1.4, 1.5, 1.7, 1.9, 2.1, 2.3, 3, 5.5, 11, 22, 44, 88, 1000],
  "probabilities": [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0]
}
```

Circular Changes

3.1 Initial Circular

The format of the proposed Initial Alert circular text is the following:

> *"The source chirp mass falls with highest probability in the bin* (`left_bin, right_bin`) *solar masses, assuming the candidate is astrophysical in origin."*

3.2 Update Circular

For Update Circulars, the following text includes mention of the estimate coming from parameter estimation:

> *"The source chirp mass falls with highest probability in the bin* (`left_bin, right_bin`) *solar masses* ***after parameter estimation [citation to Bilby],*** *assuming the candidate is astrophysical in origin."*

3.3 cWB BBH Circulars

For superevents where cWB BBH is the preferred event, the circular specifies that the redshift is assumed to be zero for the low-latency case:

> *"The* ***redshifted (detector frame)*** *chirp mass falls with highest probability in the bin* (`left_bin, right_bin`) *solar masses, assuming the candidate is astrophysical in origin.* ***For cWB BBH events, no distance or redshift information is available in low latency."***

. For updates on cWB BBH preferred events based on `Bilby` parameter estimation, the text will be the same as Sec. 3.2.

SUBJECT: LIGO/Virgo/KAGRA S1234: Identification of a GW compact binary merger candidate

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

We identified the compact binary merger candidate S1234 during real-time processing of data from LIGO Hanford Observatory (H1) and LIGO Livingston Observatory (L1) at 2018-06-28 03:08:04.741 UTC (GPS time: 1214190502.741). The candidate was found by the GstLAL [1], MBTA [2], and PyCBC Live [3] analysis pipelines. An early-warning alert was issued for this candidate, detected by the GstLAL [4], MBTA [2], and PyCBC Live [5] early-warning pipelines.

S1234 is an event of interest because its false alarm rate, as estimated by the online analysis, is 9.1e-14 Hz, or about one in 1e6 years. The event's properties can be found at this URL: https://gracedb.invalid/superevents/S1234

The classification of the GW signal, in order of descending probability, is BNS (95%), Terrestrial (4%), NSBH (1%), or BBH (< 1%).

Assuming the candidate is astrophysical in origin, the probability that at least one of the compact objects is consistent with a neutron star mass (HasNS) is > 99%. [6] Using the masses and spins inferred from the signal, the probability of matter outside the final compact object (HasRemnant) is > 99%. [6] Both HasNS and HasRemnant consider the support of several neutron star equations of state for maximum neutron star mass. The probability that either of the binary components lies between 3 and 5 solar masses (HasMassGap) is 20%.

The source chirp mass falls with highest probability in the bin (3.0, 5.5) solar masses, assuming the candidate is astrophysical in origin.

Two sky maps are available at this time and can be retrieved from the GraceDB event page: * bayestar.multiorder.fits,0, an early-warning localization generated by BAYESTAR [7], distributed via GCN notice about a minute before the candidate event time. * bayestar.multiorder.fits,1, an initial localization generated by BAYESTAR [7], distributed via GCN notice about 11 minutes after the candidate event time.

The preferred sky map at this time is bayestar.multiorder.fits,1. For the bayestar.multiorder.fits,1 sky map, the 90% credible region is 24218 deg2. Marginalized over the whole sky, the a posteriori luminosity distance estimate is 29 +/- 9 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/.

[1] Tsukada et al. PRD 108, 043004 (2023) doi:10.1103/PhysRevD.108.043004 and Ewing et al. PRD 109, 042008 (2024) doi:10.1103/PhysRevD.109.042008
[2] Aubin et al. CQG 38, 095004 (2021) doi:10.1088/1361-6382/abe913
[3] Dal Canton et al. ApJ 923, 254 (2021) doi:10.3847/1538-4357/ac2f9a
[4] Sachdev et al. ApJL 905, 2 (2020) doi:10.3847/2041-8213/abc753
[5] Nitz A. H., Schäfer M., Dal Canton T. ApJL 902, 2 (2020)

https://dcc.ligo.org/P2500123

Looking Ahead

The calculation and data product has been reviewed and we are currently testing the integration of data product into our alert infrastructure.

Release of these estimates is planned in June!

Most Probable Bin

To be concise, we report only the most probable bin in the circular text, while *all* information can be found on GraceDB.

➔ For >85% of events, the highest probability bin contains >80% of the probability

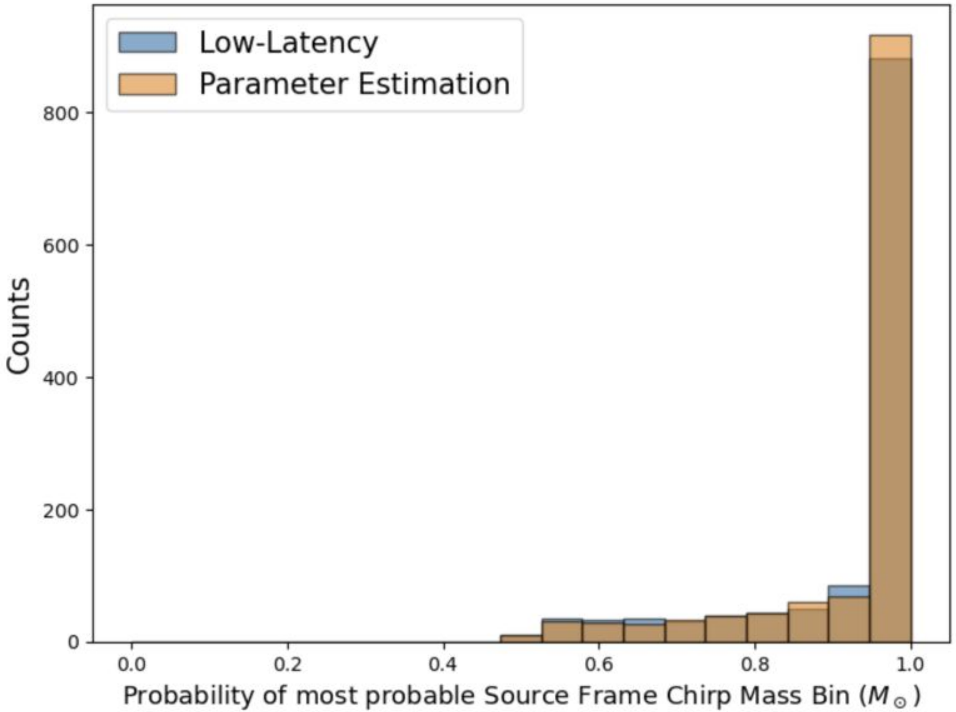


Figure 3: The probability contained in the highest probability bin for the low-latency and `Bilby` parameter estimation $\mathcal{M}$ estimates based on an analysis of MDC11 significant superevents.