Source classification and properties provided in low-latency by the LVK collaboration

Florian Aubin
Post-doc, IPHC, Strasbourg

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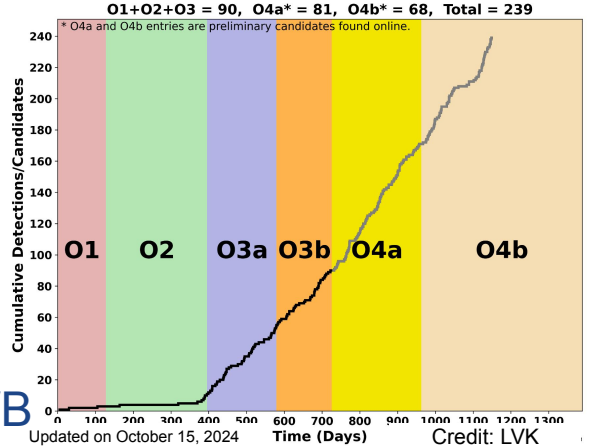
Introduction

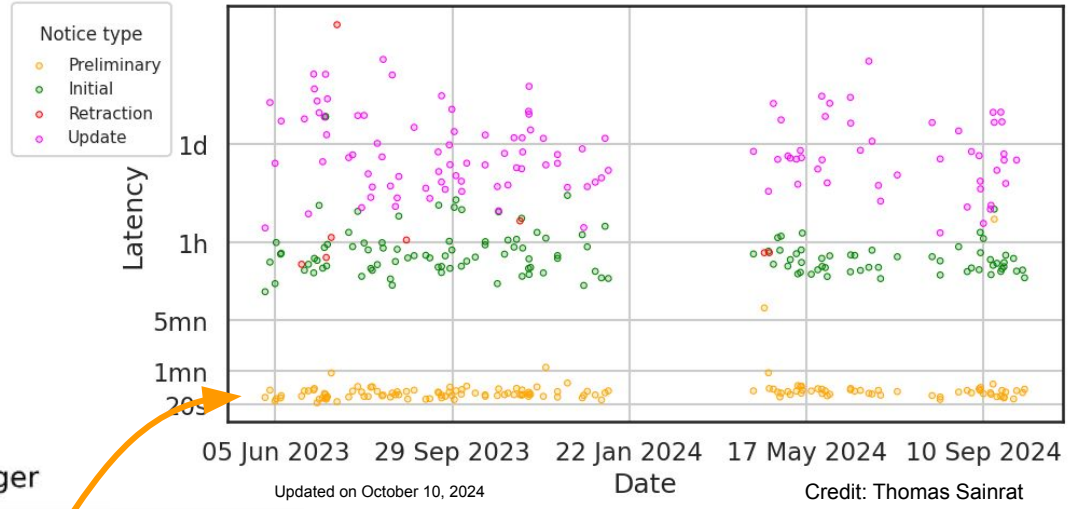


- LVK releases **low latency alerts**
  - Motivation: search for **counterparts**
  - CBC searches: GstLAL, MBTA, PyCBC, SPIIR, cWB
  - Burst searches: cWB

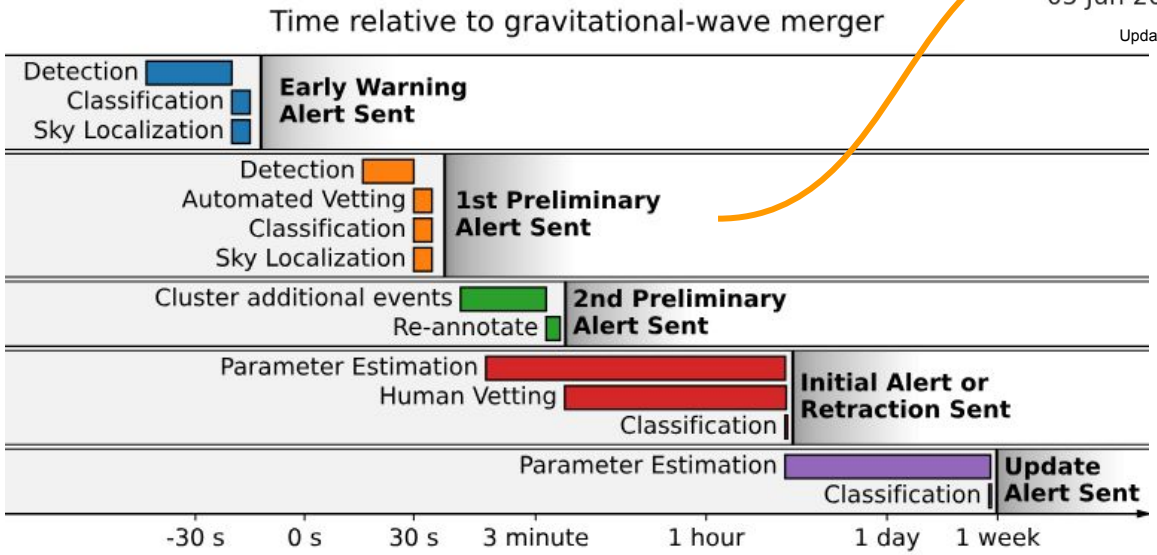
- O4 “significant” candidates: **149** (after **17** retracted)
  - 2500+ “low-significance”
  - O3 “significant” candidates: **56** (after **24** retracted)

➜ Follow-ups are guided by the **source information** provided at low latency

Alert sending process



Credit: Thomas Sainrat



Credit: LVK AlertUser Guide

FAR < 1 / 4 months

FAR < 2 / days
Machine readable only

FAR < 1 / 6 months (CBC)
FAR < 1 / 3 years (burst)
Human readable

Alert content, focus on CBC

- **Human readable** circular
- Same information as in preliminaries
  - Name
  - Instruments involved
  - Search pipelines involved
    - Parameters from highest SNR
  - **Significance: FAR, p_{Astro}**
  - **Source classification: p_{BNS}**
  - **Source properties: "Has…"**
  - Sky localization
  - …
- Add. human **assessment**

S240917cb circular

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

We identified the compact binary merger candidate S240917cb during real-time processing of data from LIGO Hanford Observatory (H1) and LIGO Livingston Observatory (L1) at 2024-09-17 13:02:37.724 UTC (GPS time: 1410613375.724). The candidate was found by the GstLAL [1] and MBTA [2] analysis pipelines.

S240917cb is an event of interest because its false alarm rate, as estimated by the online analysis, is 5.4e-08 Hz, or about one in 7 months. The event's properties can be found at this URL:

https://gracedb.ligo.org/superevents/S240917cb

The classification of the GW signal, in order of descending probability, is BBH (96%), Terrestrial (4%), NSBH (<1%), or BNS (<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%. [3] Using the masses and spins inferred from the signal, the probability of matter outside the final compact object (HasRemnant) is <1%. [3] 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 6%.

Three sky maps are available at this time and can be retrieved from the GraceDB event page:
 * bayestar.multiorder.fits,2, an initial localization generated by BAYESTAR [4], distributed via GCN notice about 2 hours after the candidate event time.
 * bayestar.multiorder.fits,3, an initial localization generated by BAYESTAR [4], distributed via GCN notice about 2 hours after the candidate event time.
 * bayestar.multiorder.fits,4, an initial localization generated by BAYESTAR [4], distributed via GCN notice about 2 hours after the candidate event time.

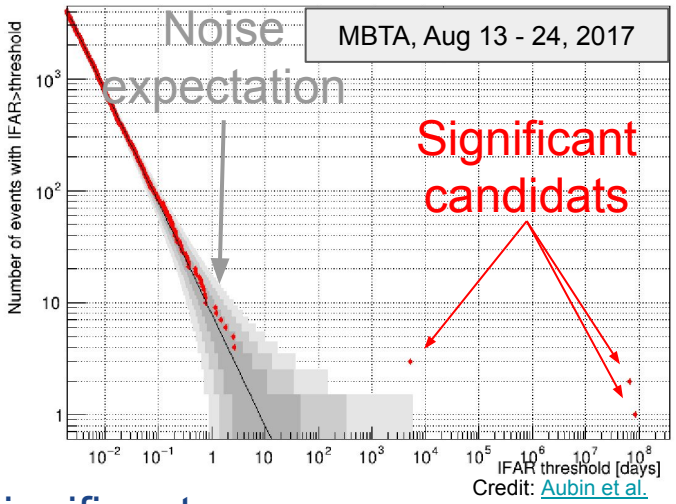
The preferred sky map at this time is bayestar.multiorder.fits,4. For the bayestar.multiorder.fits,4 sky map, the 90% credible region is 3663 deg2. Marginalized over the whole sky, the a posteriori luminosity distance estimate is 8510 +/- 2727 Mpc (a posteriori mean +/- standard deviation).

The first preliminary notice was delayed by a technical issue that also caused the second preliminary notice to erroneously include Virgo data in the alert. The distributed skymap bayestar.multiorder.fits,3 included Virgo data and should be disregarded.

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. (2023) arXiv:2305.05625
[2] Aubin et al. CQG 38, 095004 (2021) doi:10.1088/1361-6382/abe913
[3] Chatterjee et al. ApJ 896, 54 (2020) doi:10.3847/1538-4357/ab8dbe
[4] Singer & Price PRD 93, 024013 (2016) doi:10.1103/PhysRevD.93.024013

Candidat significance



Credit: Aubin et al.

- Pipelines **rank** their triggers
  - SNR and signal consistency checks
- Candidates are associated with the **FAR** value
  - Expected **rate of "noise" triggers** at least as significant
- Significance is also assessed based on $\mathbf{p_{Astro}}$
  - Probability that the candidate is of **astrophysical origin**
  - Based on explicit **astrophysical priors**
  - $p_{terrestrial} = 1 - p_{astro}$

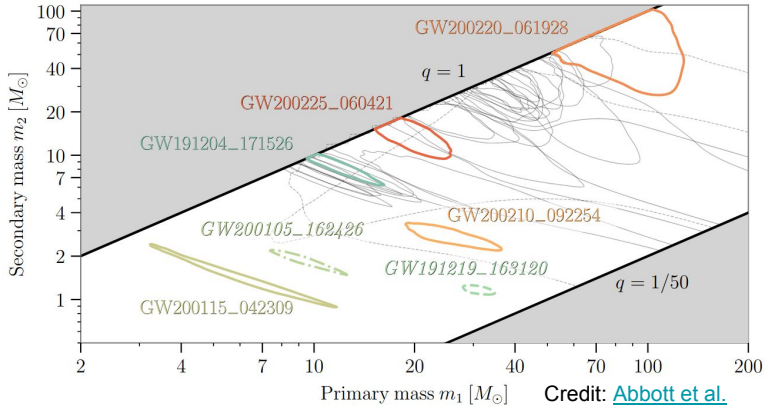
$$p_{astro} = \frac{R_{astro}}{R_{astro} + R_{noise}}$$

Source classification

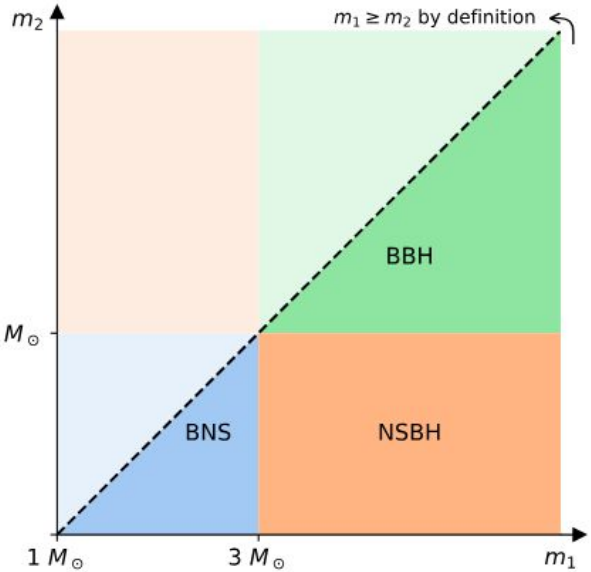
- Poor measurement of m1 and m2
- p_{Astro} is distributed between **three sources**
  - Based on individual masses

$$p_{BNS} + p_{NSBH} + p_{BBH} = p_{astro}$$

- Computed on low latency **by search pipelines**
  - Multiple methods, like:
    - Fraction of parameter space for each source
    - Projected CBC populations on pipeline output
- Refined within hours - days on updated notices
  - Integrated **Parameter Estimation** (PE) posteriors

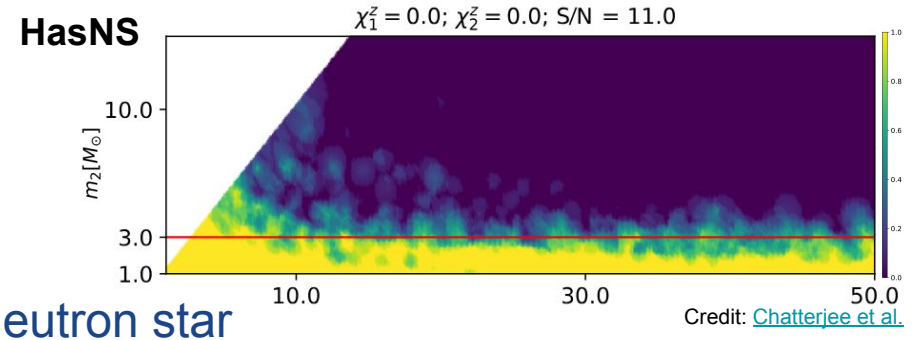


Credit: Abbott et al.



Credit: LVK Alert User Guide

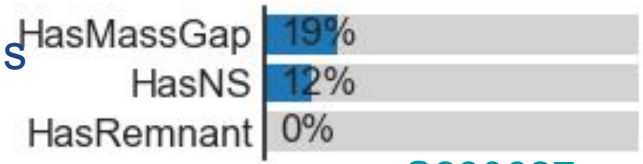
Source properties



Credit: Chatterjee et al.

- **HasNS**
  - A compact object consistent with a neutron star
  - Marginalized over **several equations of state**
- **HasRemnant**
  - Non-zero amount of neutron star material remained
  - Use one **model** (Foucart)
- **HasMassGap**
  - Mass of a compact object between 3 $M_\odot$ and 5 $M_\odot$

- Probabilities computed on low latency
  - **Machine Learning**, trained on simulated signals



S230627c

- Refined within hours - days on updated notices
  - Integrated **PE** posteriors

Possible upgrades on classification and properties

- Provide **more source information** in low latency
  - Chirp masses estimate may be useful to astronomers

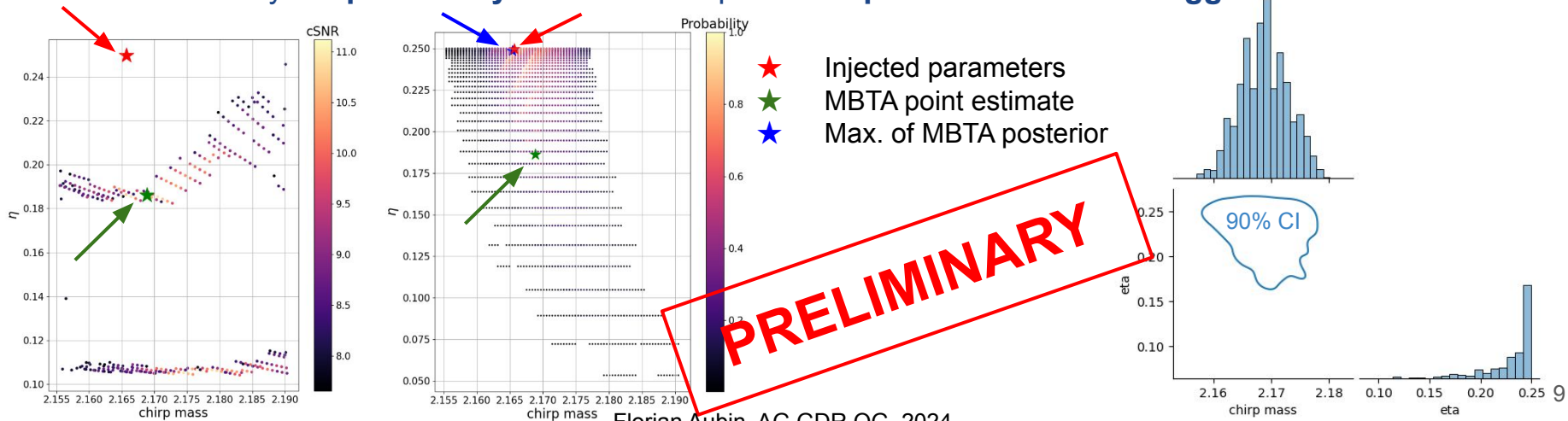
- Release **Sub-Solar Masses** (SSM) candidats in low latency
  - Challenge: BNS/NSBH - SSM degeneracy
  - Need to provide source information

- Speed-up **source parameter estimation**
  - Searches produce point-estimates
  - RapidPE-Rift provides posterior samples within few minutes

Leveraging search results for low latency PE

The MBTA way, method (in development) in a nutshell

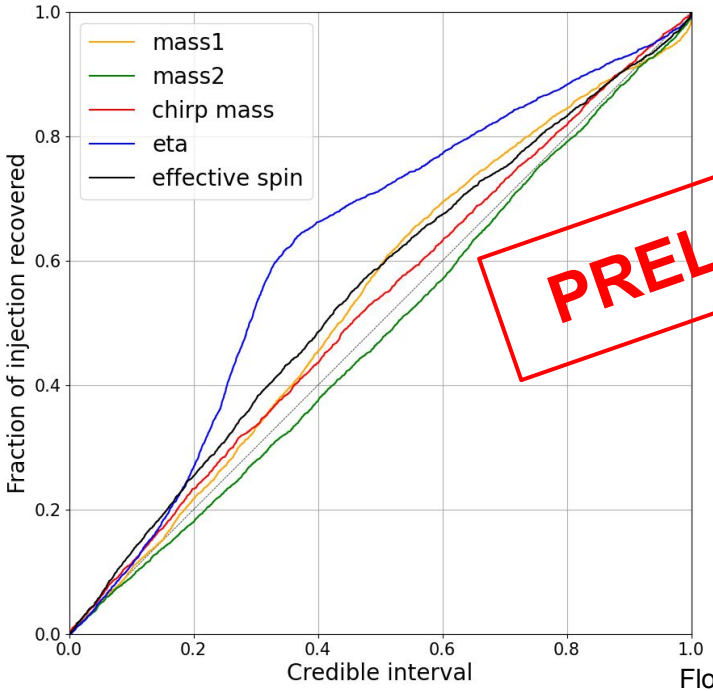
- MBTA filters data with **several simulated waveforms** “templates”
  - **Multiple triggers** associated to each candidate
  - Only the most significant is sent out
- The **trigger collection** provides clues about the **true signal parameters**
- Method
  - Generate **samples** according priors
  - Quantify the **probability** that each sample **could produce the MBTA triggers**



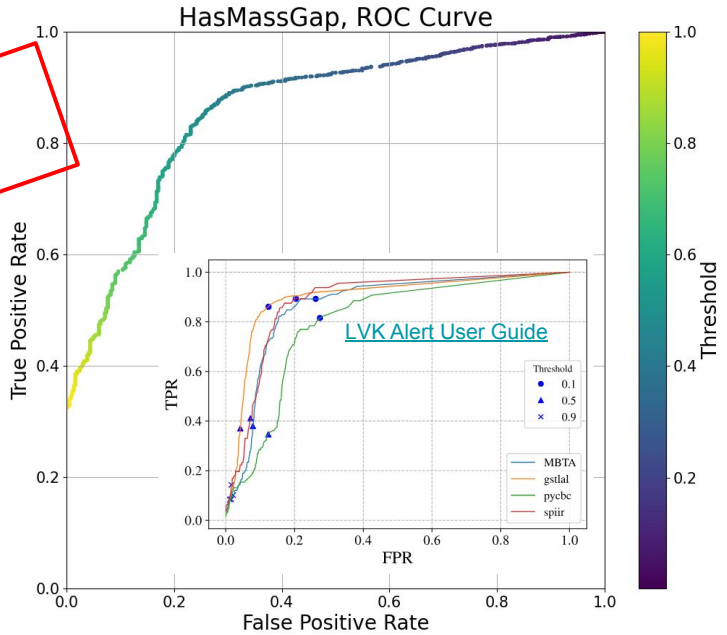
Leveraging search results for low latency PE

The MBTA way, preliminary results

- Runtime ~ **seconds**
- Source properties can be obtained by integrating posteriors



PRELIMINARY



Conclusion

- The LVK collaboration releases **low-latency alerts**
  - Source classification and properties are included

- More alerts expected as detector sensitivity increases
  - **Additional source information** could be provided to facilitate follow-up
    - **New developments** underway