

LVK alert program and IR1 run update

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Outline

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Introduction



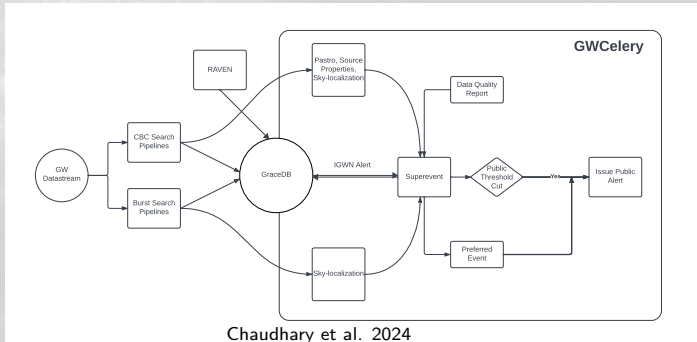
Credit: LIGO-Virgo-KAGRA

- *Four observing runs have already been completed: O1, O2, O3 and O4 (O4 divided in three sub-runs: O4a, O4b and O4c)*
- *Hundreds of GW candidates observed so far*
- *Rapid sharing of GW candidates enables prompt EM and neutrino follow-up*
 - *GW alerts*
 - *GW alerts distributed to MoU partners during O1 and O2*
 - *GW alerts made public since O3*

How does a GW candidate become a public alert?

From GW candidates to public alerts

- Multiple online pipelines continuously analyse the data and upload candidate events to the Gravitational-Wave Candidate Event Database (**GraceDB**)
- The **GWCelery** system is responsible for:
 - **Aggregating** coincident-in-time events into Superevents, assigning a preferred event
 - **Generating alerts** when the preferred event passes the false alarm rate (FAR) cut
 - **Monitoring and correlating** external non-GW events to identify potential coincidences with GW events



What FAR thresholds define a public alert?

Two classes of public alerts, with different thresholds depending on the type of event:

◇ Low Significant GW alerts

- Only automated data quality checks
- CBC events: $1/\text{month} < \text{FAR} < 2/\text{day}$
- Unmodeled burst events: $1/\text{yr} < \text{FAR} < 2/\text{day}$

◇ Significant GW alerts

- Automated data quality checks and human vetting
- CBC events: $\text{FAR} < 1/\text{month}$
- Unmodeled burst events: $\text{FAR} < 1/\text{yr}$

Public alerts user guide: <https://emfollow.docs.ligo.org/userguide/>

What types of alerts exist?

Fully automatic alerts

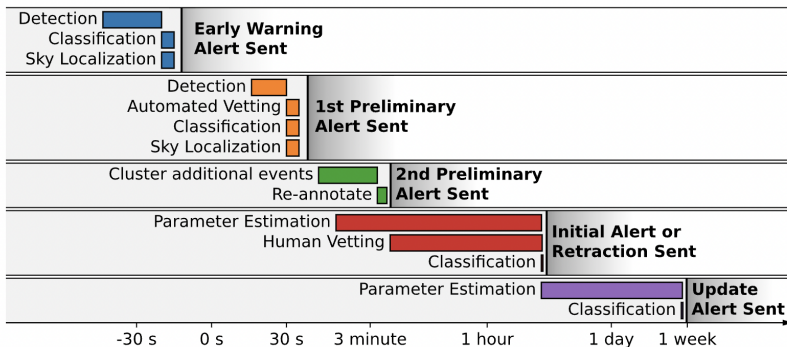
- “Early Warning Alert”: it may be issued for CBC events up to tens of seconds before merger. **O4b novelty!**
- Preliminary alert: typical latency $< 20\text{s}$ (max 30s)
- Final preliminary alert: latency < 5 minutes
after search is completed by all the pipelines

For Significant events: Rapid Response Team decision

- Initial or Retraction Circular
 - Update (1)
 - ...
 - Update (n)
- Update alerts are issued when improved parameter estimation results are available

GW alerts timeline

Time relative to gravitational-wave merger



What is the alert content?

- Estimate of the FAR of the event candidate
- Event time and sky localization (2D skymaps)
- For Burst candidates: central frequency (Hz) and duration (s)
- For CBC candidates:
 - * 3D skymaps with direction-dependent luminosity distance (Singer et al. 2016)
 - * Luminosity Distance marginalized over the whole sky
 - * Source Classification and Properties
 - * Binned Source Chirp Mass (**O4c novelty!**)

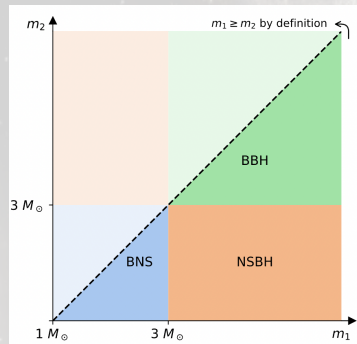
Public alerts: Source Classification

Classification

p_{astro}: Probability that the source is astrophysical.

4 categories:

- BNS
- NS-BH
- BBH
- Terrestrial (i.e., noise)



Public alerts user guide: <https://emfollow.docs.ligo.org/userguide/>

Public alerts: Source Properties

Properties

Under the assumption that the source is not noise:

- **Source classifier (HasNS)**: probability that at least one of the compact objects is a NS
- **Remnant classifier (HasRemnant)**: probability that the system ejected a non-zero amount of NS matter
- **HasMassGap**: probability that one or both the compact objects have a mass that lies in the “mass gap” between NS and BHs ($3 M_{\odot} \leq m \leq 5 M_{\odot}$)
- **HasSSM**: probability that one or both the compact objects have a mass $< 1 M_{\odot}$
→ sub-solar mass (SSM) system

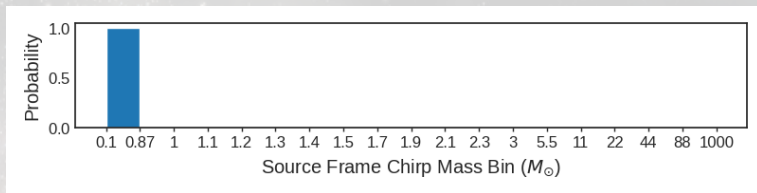
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Public alerts: Binned chirp mass

Binned chirp mass: Probabilities for the chirp mass M_c of the source binary

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

to lie within predefined bins, i.e., a coarse-grained histogram. Example: ([S250818k](#))



Lowest-mass bin up to 0.87 covers cases where at least one component is sub-solar mass

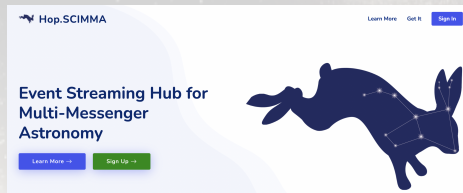
$M_c = 1.2 M_\odot$ may correspond to a $1.4 M_\odot - 1.4 M_\odot$ merger

$M_c = 8.7 M_\odot$ may correspond to a $10 M_\odot - 10 M_\odot$ merger

More details here: [userguide](#)

How were the alerts distributed?

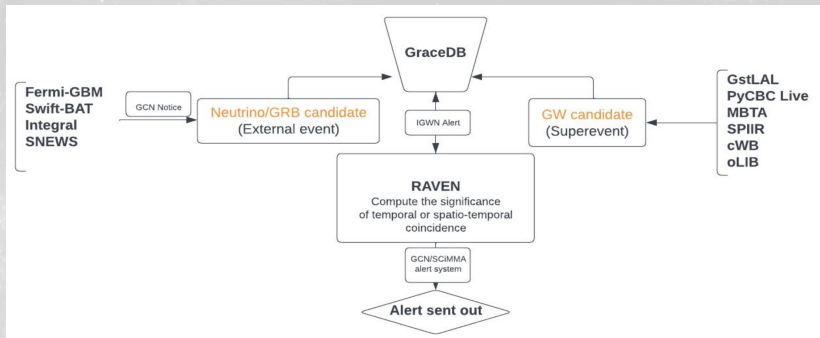
In O4 we had multiple formats and distribution channels for public alerts :



- VOEvent Notices via GCN Classic
- Kafka-based alerts
 - JSON Notices via GCN (see [Receiving Kafka Notices via GCN](#))
 - Avro Notices via SCiMMA (see [Receiving Kafka Notices via SCiMMA](#))

Can we combine GW alerts with other alerts?

Rapid, on source VOEvent Coincident Monitor (RAVEN): low latency identification of coincidences between GWs and GRBs or neutrinos



RAVEN is Fast ($O(s)$ latency) and Autonomous (almost no intervention needed)

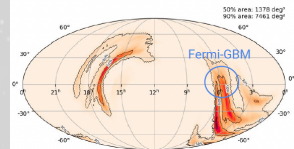
Can we combine GW alerts with other alerts?

Content of RAVEN alerts: Joint significance of the multimessenger event, plus eventually the combined skymap.

This is key for several reasons:

- Identifying joint events early on will help astronomers prioritize interesting events to follow up on
- Combined GW+GRB localizations may help to identify a kilonova counterpart
- Additional sub-threshold GW candidates can be identified, due to the increased, joint significance

Theoretical Example: GW190425



Combined skymap

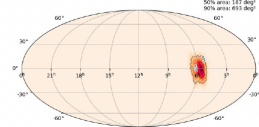
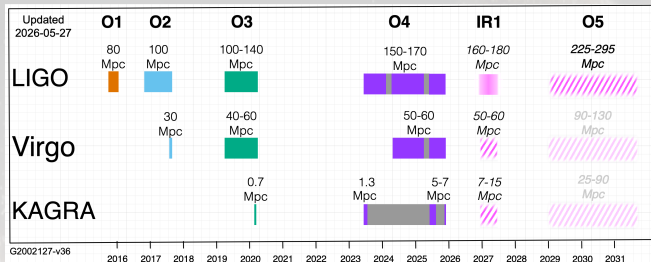


Image Credit: B. Piotrkowski

LVK observing plans



Updated observing run plans at <https://observing.docs.ligo.org/plan/>

- ◆ A six-month observing run (IR1) should begin early- to mid-November of 2026
 - LIGO detectors will be observing
 - Virgo will join but with possible interruptions for maintenance and upgrade
 - KAGRA will join later in the run as available
- ◆ A fifth observing run (O5) is planned to start in a few years

Future changes in the alert system and prospects for IR1

- Alerts will no longer be sent as VOEvents over GCN Classic (see NASA GCN [Announcement](#))
 - JSON and AVRO channels remain the same
- RAVEN:
 - Ingestion of IceCube (high-energy neutrinos), Einstein Probe (X-ray Transients) and CHIME (Fast Radio Bursts) Alerts have been implemented
 - Work in progress to ingest Vera Rubin Alerts (kilonovae)
- Expected alert rate similar to that of O4
 - ~ 1 significant alert every 3 days

Conclusions

- LVK public alerts provide low-latency, progressively refined information for rapid follow-up of GW candidate events
- RAVEN identifies GW coincidences with GRBs, neutrinos and other transients in near real time, helping to prioritise follow-up observations
- A new LVK observing run (IR1) is expected to start in November 2026, with changes in alert distribution (no more VOEvents)

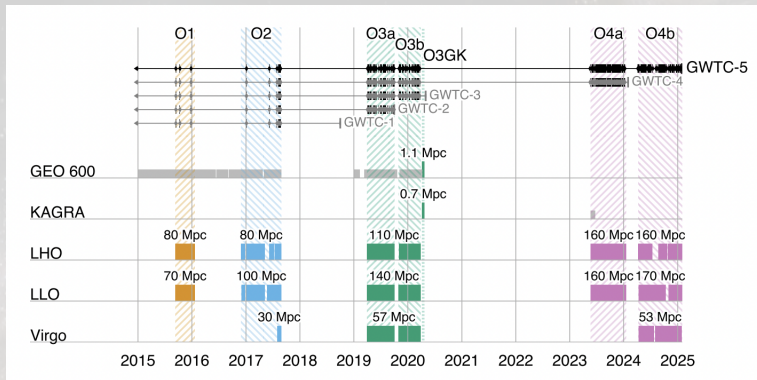
**Many other GW and
possibly multi-messenger discoveries
are expected in the near future ...
stay tuned!**



Backup

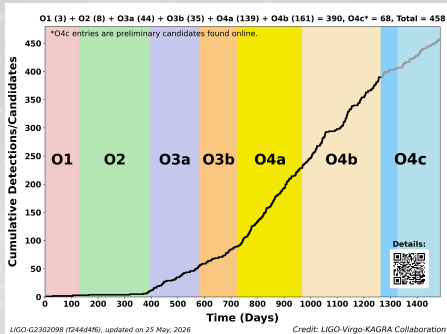
Backup Slides

Where do we stand?



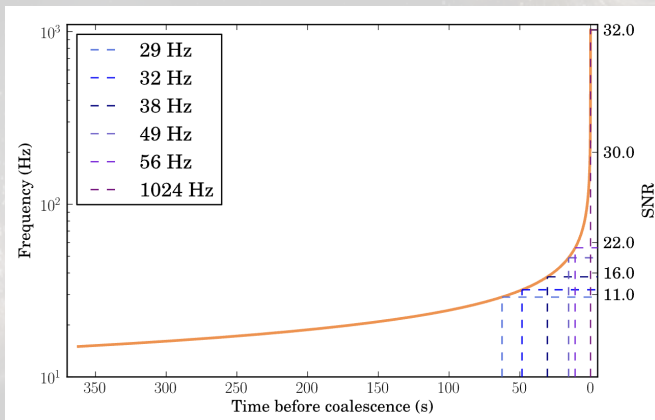
LVK coll. 2026, arXiv:2605.27225

GW detections: O4 summary



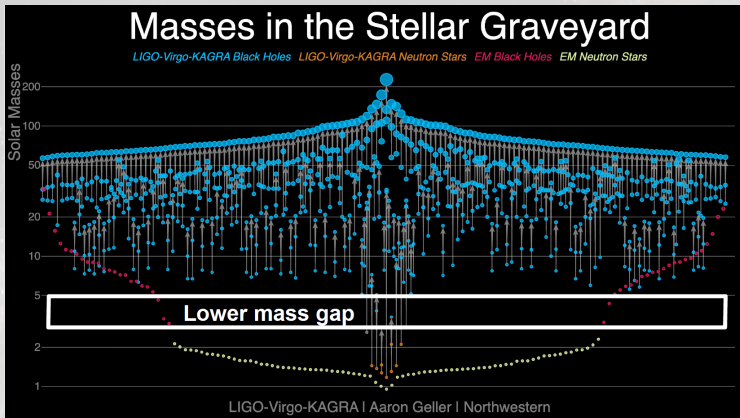
- **O4a:** 139 new GW candidates
- **O4b:** 161 new GW candidates
→ Almost all BBHs; no BNS; two NS-BHs
- **O4c:** 68 significant candidates
→ O4c data release: December 16, 2026

Early Warning Alerts



https://emfollow.docs.ligo.org/userguide/early_warning.html

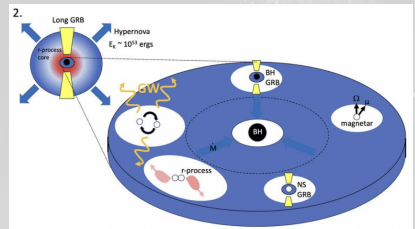
The Lower Mass Gap



Do we expect EM counterparts from SSM events?

Not clear what to expect, but an interesting scenario has been proposed by Brian Metzger (Metzger et al. 2024, ApJL, 971, L34)

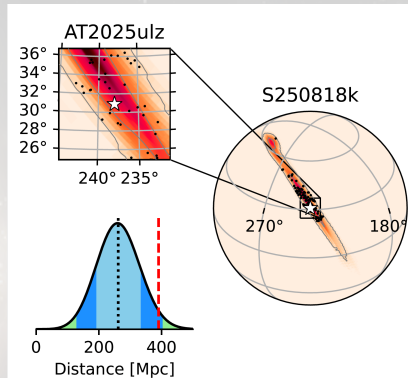
- Collapse of rapidly rotating stars (“collapsars”) leads to the formation of a BH with accretion disk
- In the outer regions of this accretion disk, neutrino cooling might induce fragmentation of the disk into multiple sub-solar (down to $\sim 0.1 M_{\odot}$) NSs (ssNSs)



- GWs expected, e.g. from the merger of two ssNSs;
- EM signals are also expected:
 - Gamma Ray Bursts
 - “kilonova inside a supernova”

S250818k

- Low-significant candidate with a probability of $\sim 30\%$ of being a NS-NS
If astrophysical: very low chirp mass $\rightarrow$ the binary contains at least one sub-solar mass NS ([GCN 41437](#), [GCN 41440](#))
- Possible EM counterpart observed by ZTF:
ZTF25abjmnps/AT2025ulz ([GCN 41414](#))
- Further observations with Keck ([GCN 41436](#))
 - $z=0.0848$, consistent with the GW distance
- **Initial data seemed to be consistent with a kilonova**
- Other EM follow-up campaigns have been performed



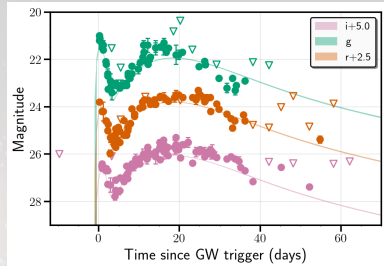
Kasliwal et al. 2025

S250818k



multi-wavelength follow-up of
S250818k/AT2025ulz

- Optical and NIR imaging + spectroscopy and radio observations
- Light curve consistent with a type IIb SN: shock cooling + ^{56}Ni decay-powered emission
- Spectrum also in agreement with early spectra of SNe IIb



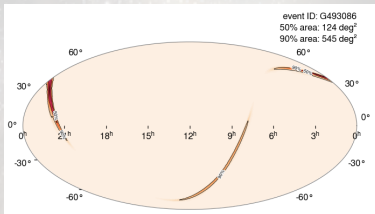
Data favour a type IIb SN interpretation for the source, in chance temporal coincidence with the GW candidate event

ENGRAVE Collaboration, accepted by A&A (arXiv:2605.02639)

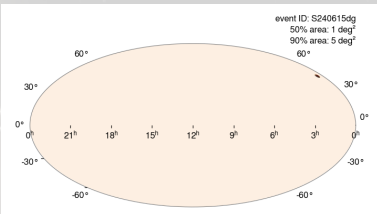
Virgo contribution in O4

- Virgo joined the GW detector network in O4b
- 138 out of 173 total O4b+c events detected by online pipelines received contributions from the Virgo detector (credits: F. Di Renzo)
- **Virgo can have a significant impact on network localization capabilities**

Example: GW240615_113620 (BBH, [GraceDB](#), GCNs [36669](#) and [36704](#))



Early sky localization, Bayestar



Offline sky localization, Bilby

Virgo contribution to sky localization: O4b and O4c

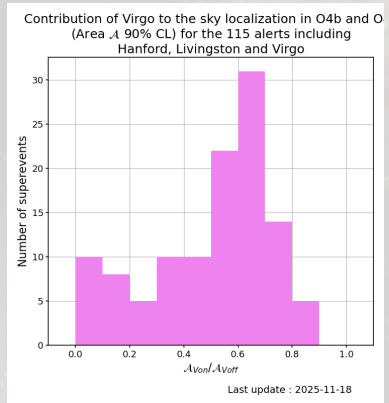
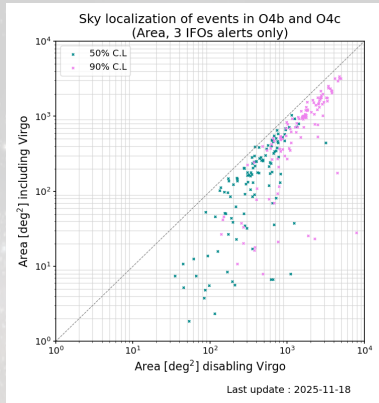


Image Credits: I. Bentara

Transition to IGWN

- **What is IGWN?** The International Gravitational-Wave Observatory Network (IGWN) is an organization anchored by the current network of LIGO, Virgo and KAGRA gravitational-wave observatories
- **Why IGWN?** A unified collaboration, with a single governance structure and a single set of policies and procedures
- **When?** LVK groups are currently joining IGWN; IGWN expected to be fully operational in fall 2027, so **O5 will be an IGWN run.**