Data Analysis Report

Francesco Pannarale – May 28, 2024

STAC Meeting

Preview

- **Updates on pre-O4 papers since the last STAC meeting**
- **Progress on planning and organising O4 papers**
- **Highlights from O4 data**
- **Recent actions and upcoming actions and decisions**
- **Remarks**
  - *Virgo members contribute across all data analysis groups and activities; this includes making the release of public alerts possible and offline analyses, paper writing teams, and review teams*
  - *Almost by definition Observational Science is the division where LIGO, Virgo, and KAGRA are most integrated*

1. Pre-O4 Papers

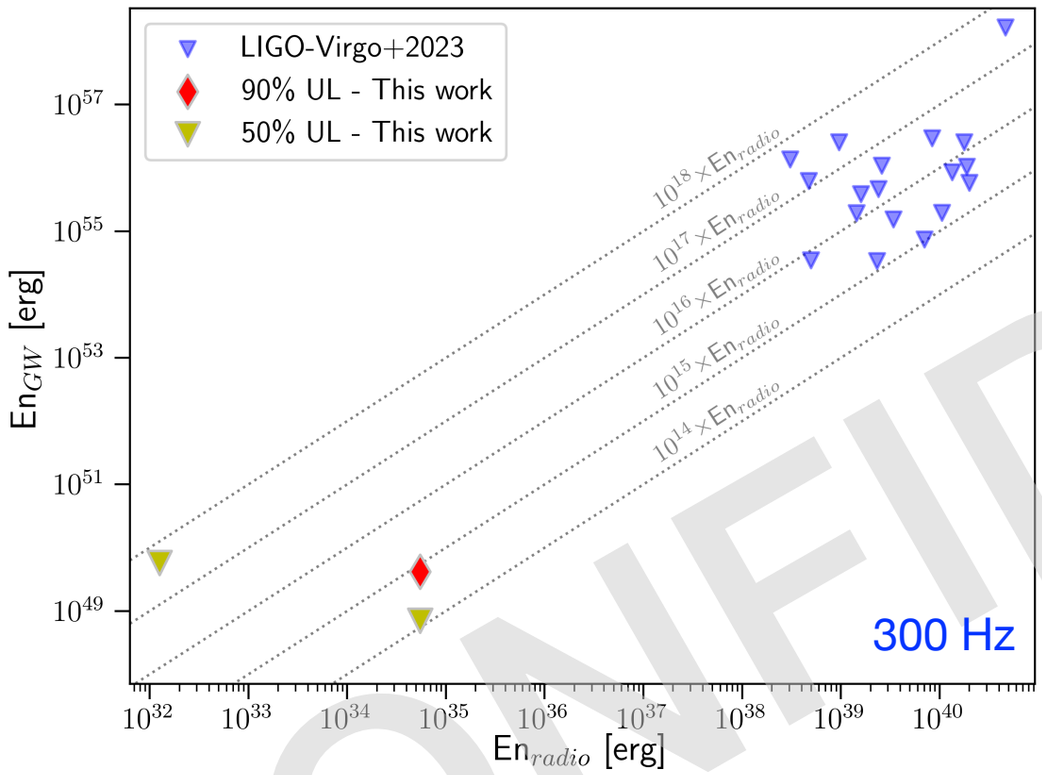
Remaining O3 Full Collaboration Papers (13->9)

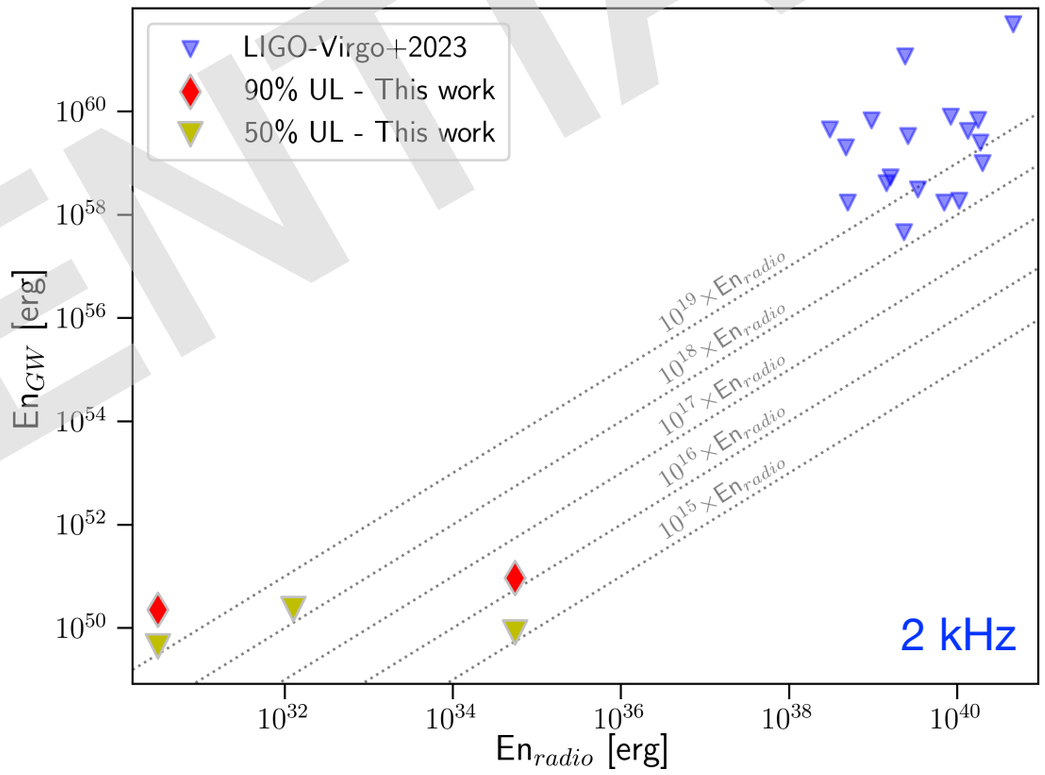
- 4 publications since last meeting
- 4 manuscripts at final stages of interactions with journals/referees
- O3 LVC-Swift sub-thresh GRB
  - Results and paper review completed on May 25, final circulation June 10
- O3 LVC-GBM sub-thresh GRB
  - Initial LVK circulation on May 31
- Post-O3 SGR 1935+2154 FRBs in GEO
  - Group circulation ended on May 16
- O3b FRB triggered search
  - Review of preliminary results starting end of May
- O3 GWHEN sub-threshold search
  - Lead group left the LVK, not IceCube
  - Draft and results approved by IceCube
  - Poor communication and breach of trust between IceCube and ANTARES/KM3NeT : may become an IceCube+LVK paper with the O2+O3 LVK+ANTARES joint analysis needing to find a new “location”

A Search for GWs Coincident with Fast Radio Bursts from the Magnetar SGR 1935+2154

- Magnetar SGR 1935+2154 is the only confirmed known galactic FRB source
- CHIME/FRB and STARE2 observed FRBs in Apr 2020, Oct 2020, and Oct and Dec 2022
- 4 periods analysed in GEO600 data, along with as well as X-ray glitches and bursts detected by NICER and NuSTAR in close to the Oct 2022 FRB
- Adopted distance measurement: 6.6 ± 0.7 kpc (GEO600 BNS range ~ 1Mpc)
- Strictest upper limits on concurrent GW emission from FRBs: 50% (90%) upper limits of 10^{48} (10^{49}) erg for GWs at 300 Hz and 10^{49} (10^{50}) erg at 2 kHz
- Constrain $E_{GW}/E_{radio} \leq 10^{14} - 10^{16}$

A Search for GWs Coincident with Fast Radio Bursts from the Magnetar SGR 1935+2154





2. Planning O4 Papers

Planned O4 Full Collaboration Papers

- 46 “standard” planned papers: all 14 O4a papers already active
- 15 standby papers, 1 of which is pre-generated
- 2 standby papers have been activated by exceptional events
  - S230529ay: released, referee report received on 2024-05-03
  - SN2023ixf: expected release date 2024-06-23

Breakdown by working group

- Burst: 4 O4a + 1 O4b + 7 full run + 7 standby + SN2023ixf
- CBC: 7 O4a + 7 O4b + 5 full run + 9 standby + S230529ay
- CW: 5 O4a + 13 full run + 3 standby
- Stochastic: 5 full run + 4 standby (overall scope of papers is broadened)

Good presence of Virgo Collaboration members in teams set up across all working groups; this includes the exceptional event papers

Memoranda of Understanding for O4 Analyses

- **Standardized, streamlined, and explicitly listing planned papers in a dedicated attachment**
- **8 MOUs for 14 partners fully signed**
    1. CHIME (CBC & Burst)
    2. Fermi Gamma-Ray Burst Monitor and Swift Burst Alert Telescope (CBC & Burst)
    3. Interplanetary Gamma-Ray Burst Timing Network (CBC & Burst)
    4. Pulsar astronomers (CHIME/Pulsar, Argentine Institute of Radio Astronomy, Jodrell, LPC2E Nançay, Neutron Star Interior Composition Explorer, University of Tasmania) providing ephemerides (CW)
    5. KM3Net (CBC & Burst)
    6. IceCube (CBC & Burst)
    7. External partners for interpretations of sub-solar-mass search results (CBC)
    8. CI-Compass (CBC)
- **9th MOU proposed with IReNA and under discussion**

Gravitational Wave Transient Catalog 4 and its Companion Papers as a Focus Issue

- Lots of thought given within the CBC group to redesigning publications, as event rates grow, observing runs become longer, and proprietary periods shorten
- GWTC scoping team proposal: “[...] format where a number of ‘mini-papers’ are published collectively, and periodically updated with each new catalog release […]”
- ApJ provided fastest response and their “focus issue” format is appealing
  - Connects a set of (ApJ, ApJL, ApJS) papers, allowing for a single introduction and minimising repetitions
  - Publications can still be cited individually, and a DOI associated to the whole focus issue is provided
  - The issue can be expanded and updated asynchronously
  - Possibility of updating only new content so that self-plagiarism is not a concern
- An offer from PRL is also on the table
- One focus issue per GWTC-X, with GWTC-X.Y adding on to its GWTC-X focus issue
- Serious chances of adopting this already for GWTC-4, minimising changes to current paper writing teams and adding a layer of coordination across them: **end of May 2024** for a final decision (data release reminders: **2025-08-23** and **2026-05-23**)

Tracking Papers

Improvements to our tool to keep track of paper projects

When MOUs are involved

Specifying roles

People involved

Paper project manager: David Keitel

External partner contacts: Carlos Lousto (IAR), Jim Palfreyman (U Tasmania / Hobart), Wynn Ho (NICER), Patrick Weltevrede (U Manchester / Jodrell Bank)

Analysis team members: David Keitel (transient F-stat), Neha Singh (transient F-stat), Matt Pitkin (cwinpy), Ling Sun (Viterbi (tbc)), Dana Jones (Viterbi (tbc)), Shubhanshu Tiwari (cWB), Dixeena Lopez (cWB), Yumeng Xu (cWB), Raymond Frey (X-pipeline), Matthew Ball (X-pipeline), Kara Merfeld (X-pipeline)

Result reviewer: TBD

PWT/editorial team member: TBD

Internal referee: TBD

Data product producer: TBD

Data product reviewer: TBD

Science summary author: TBD

Journal point of contact: TBD

Interacting with Other Divisions

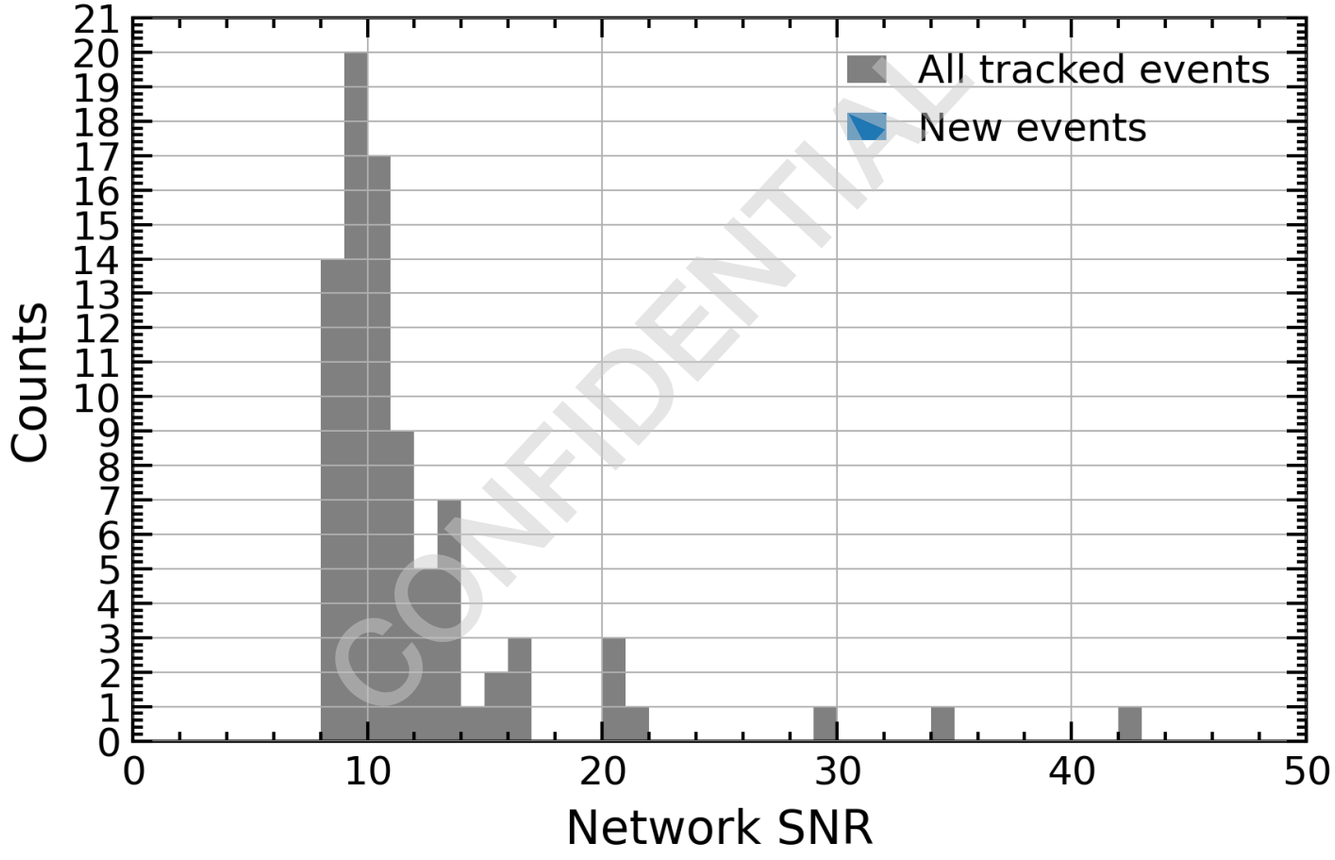
- Once a month the Data Analysis, Operations, Low-Latency Alert Infrastructure, and Computing cochairs have a joint call for collegial decisions and discussions on O4
  - Recently, participation extended to one cochair per Data Analysis working group
  - Cadence is weekly during engineering runs (and possibly in other intense periods)

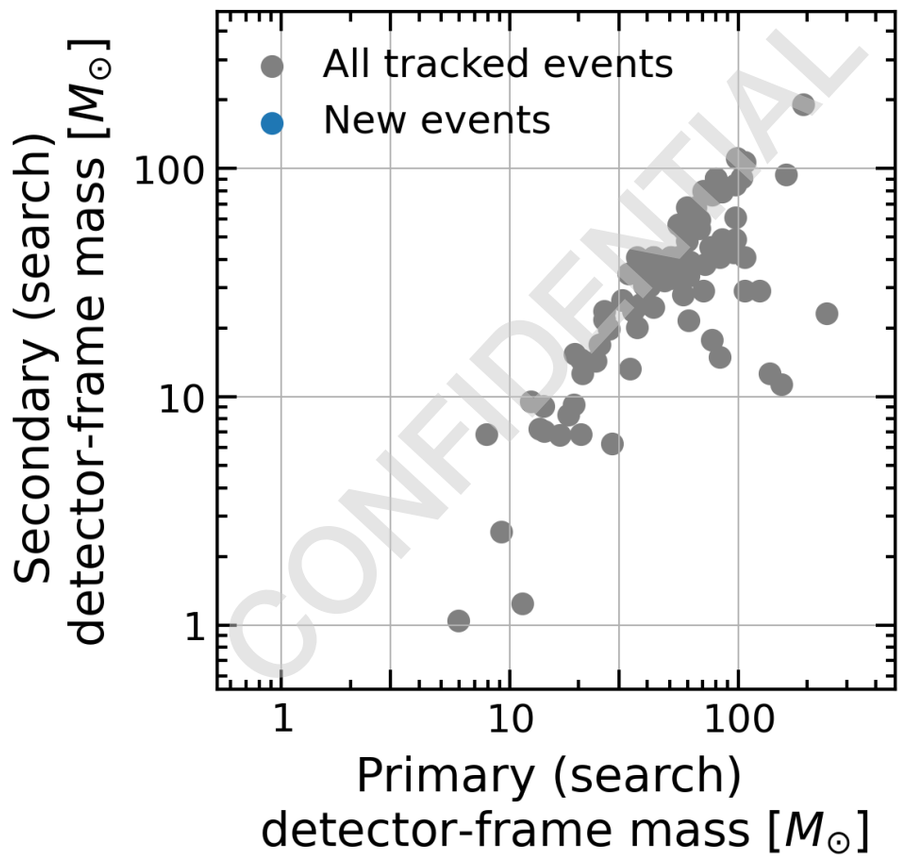
- Formulate(d) O4 Records Of Decision Agreement (RODAs) together and suppressed using wikipages as “official references” in favour of gitlab issues and RODAs
  - Data analysis weekly call alert email contains a reminder of active RODAs of interest for data analysis

- Collecting notes in a shared document for handing over our roles

3. Q4 Highlights

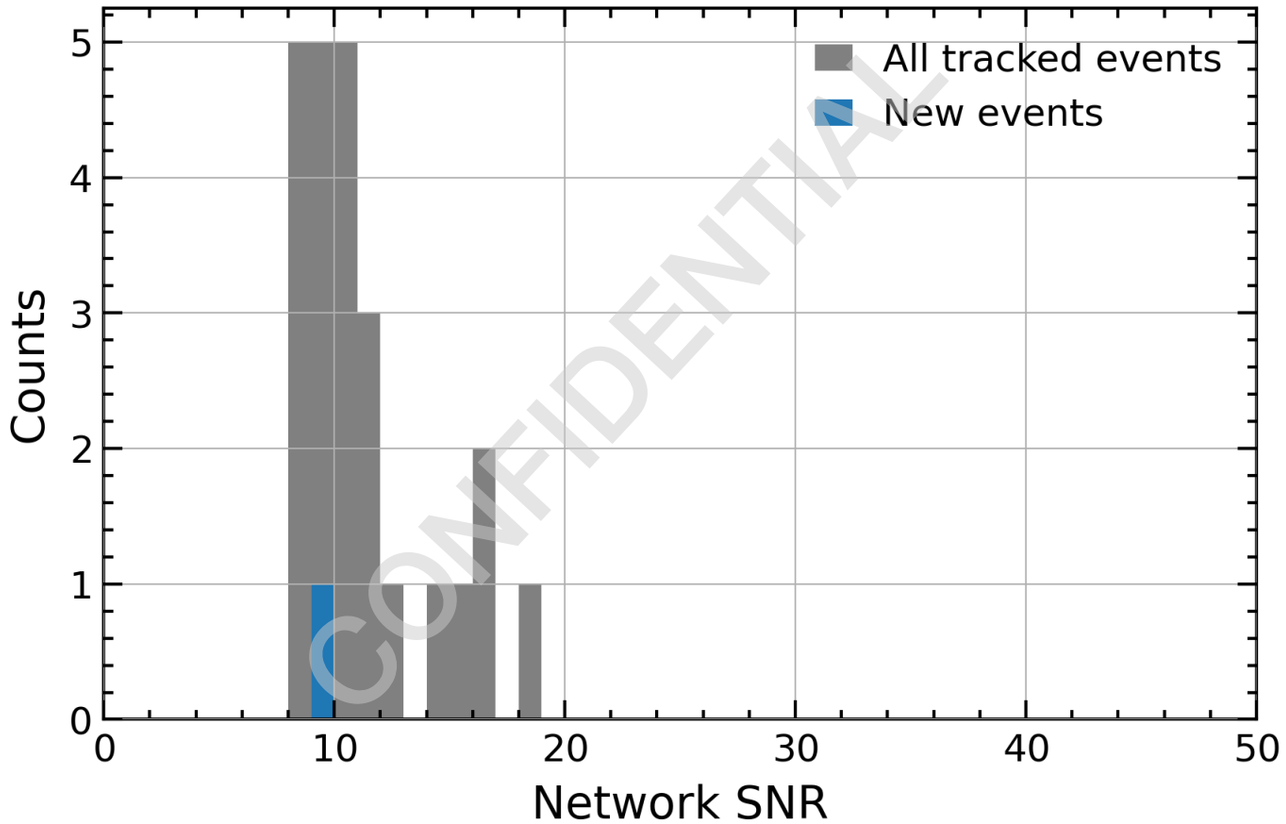
O4a Online Events

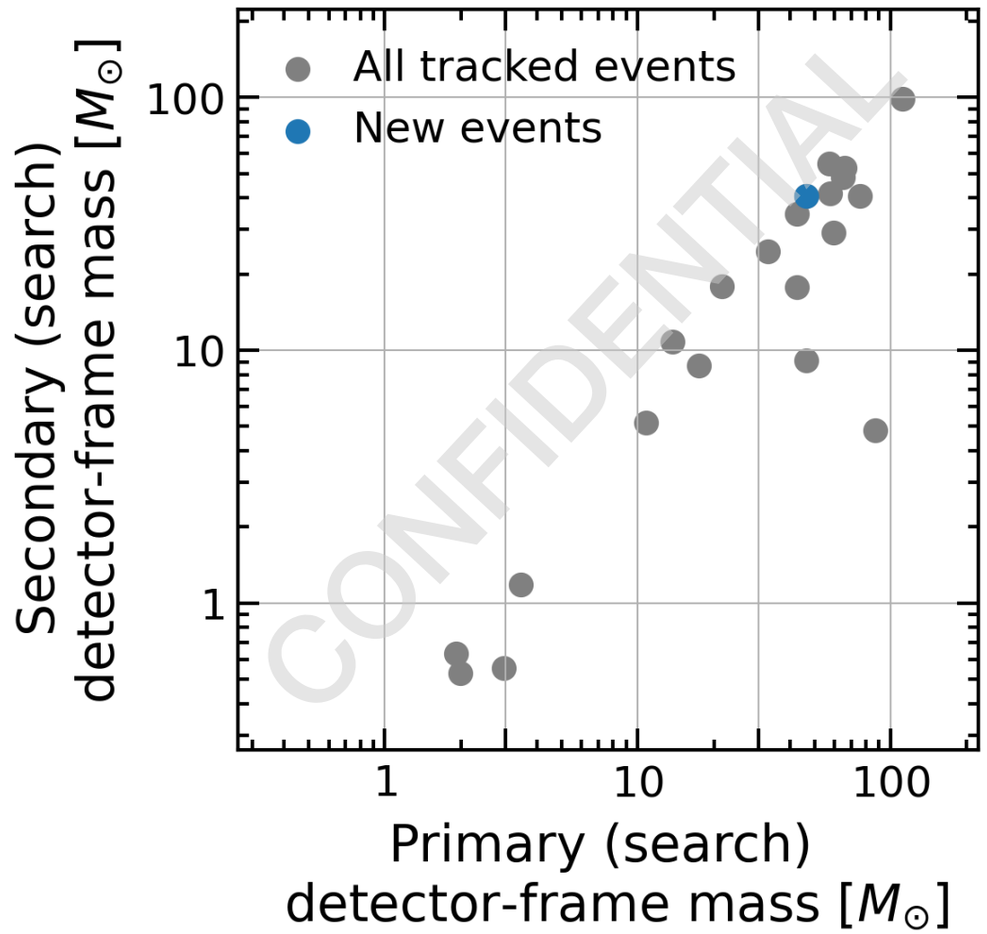




- 81 (+10 retracted) significant alerts [FAR < 1/month for CBC and 1/year for Burst]; BBH dominated
- ~3 events/week

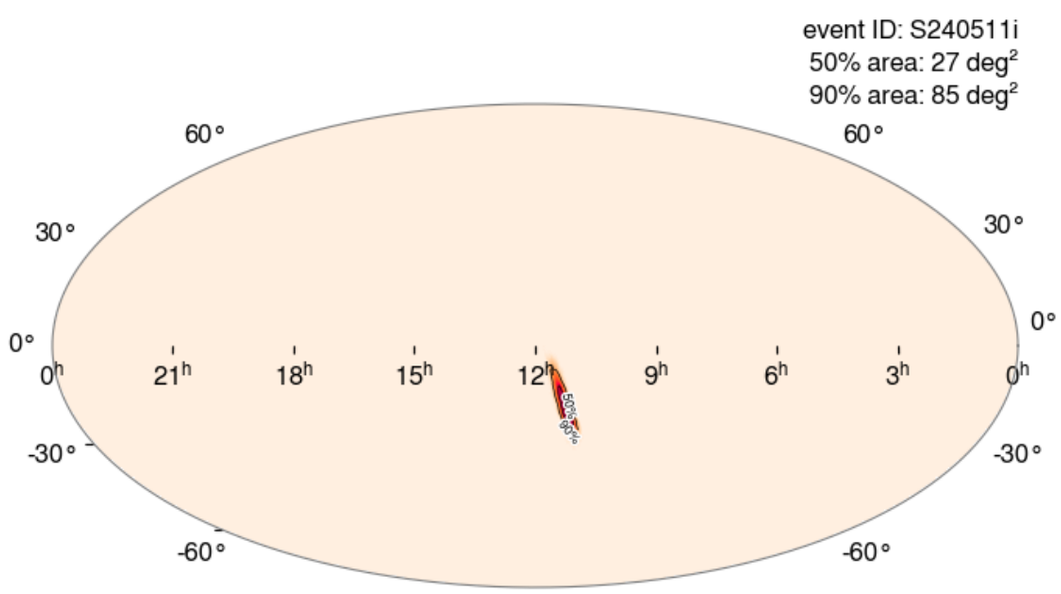
O4b Online Events

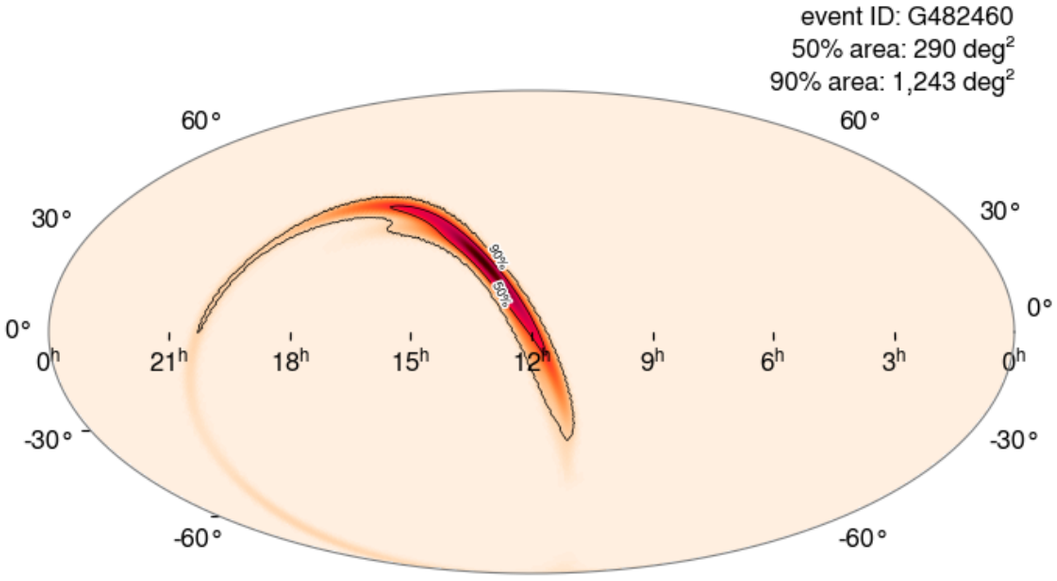




- 20 (+3 retracted) significant alerts [FAR < 1/month for CBC and 1/year for Burst]
- Two obvious statements: there are no error bars in the right hand side plot, the axis changed
- Not all events here become public alerts

O4b Online Events

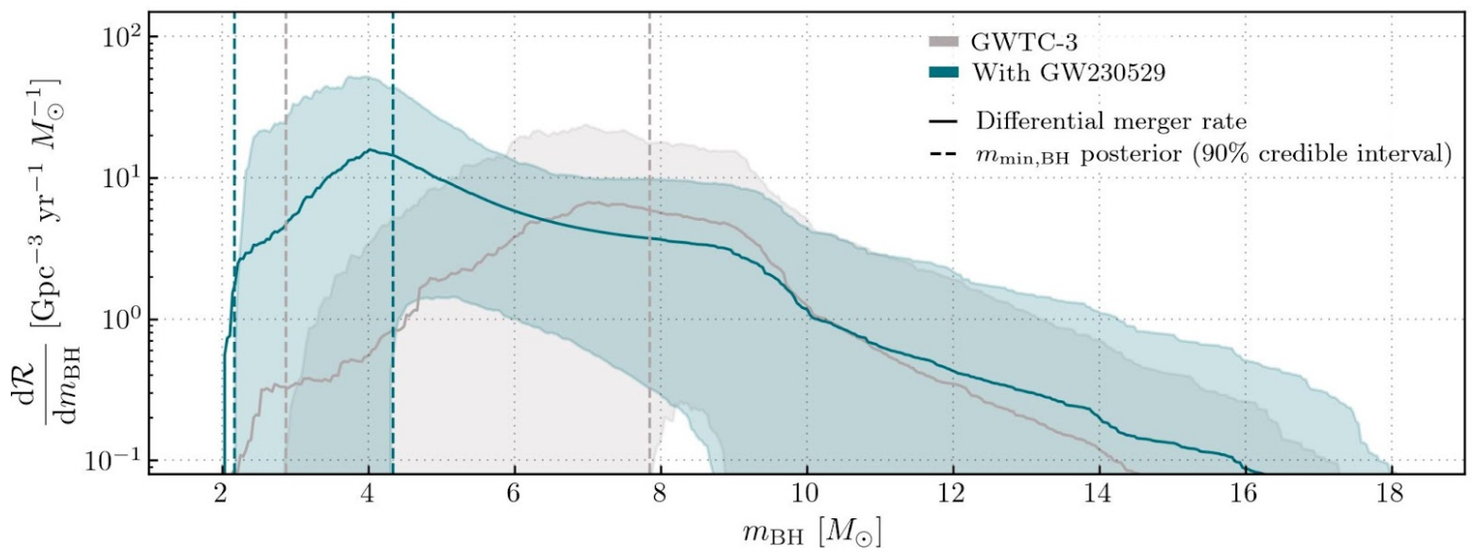


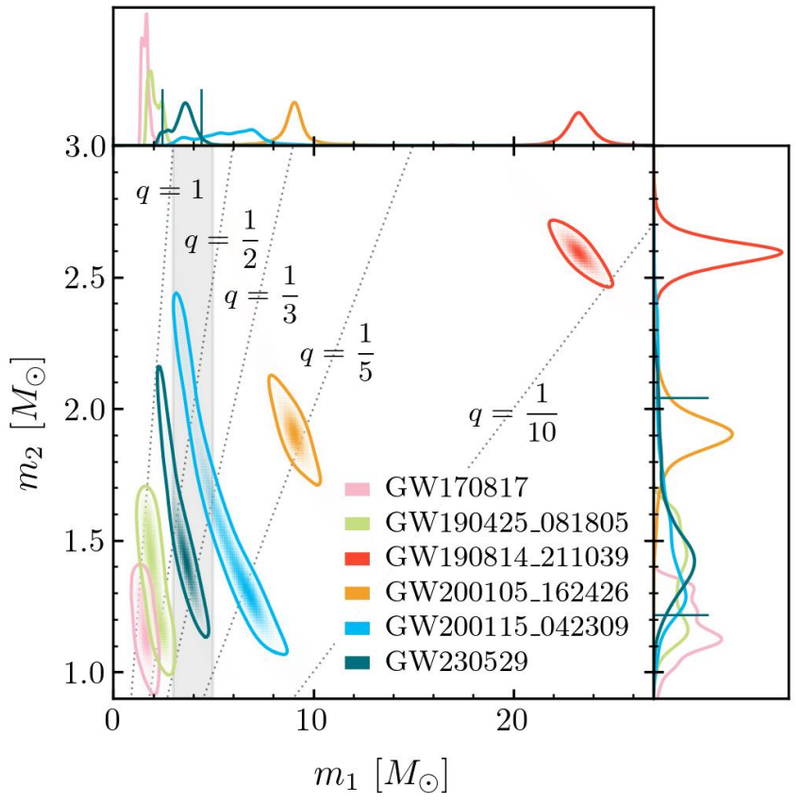


- Virgo data available for localisation in 15 out of 20 public alerts
- Impact can be pretty remarkable, e.g., S240511i

S230529ay Exceptional Event Paper [arXiv:2404.04248]

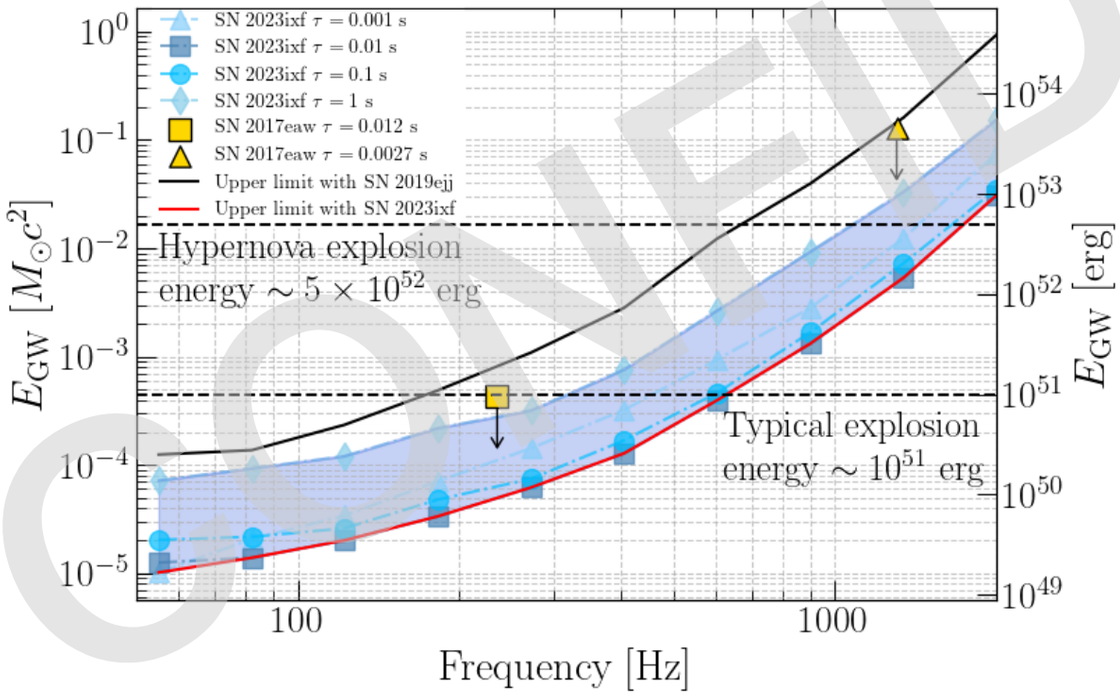
- GCN circular 33889: single interferometer trigger with preferred event SNR = 11.6 and IFAR = 160.4 years (offline IFAR > 1000 years)
- 90% credible level component masses: 2.5–4.5 $M_\odot$ and 1.2–2 $M_\odot$
- This system implies an increase in the expected rate of neutron star–black hole mergers with electromagnetic counterparts and provides further evidence for compact objects existing within the 3–5 $M_\odot$ “lower mass gap” (99% credibility for primary < 5 $M_\odot$)
  - Triggers revisiting core-collapse supernova assumptions radically

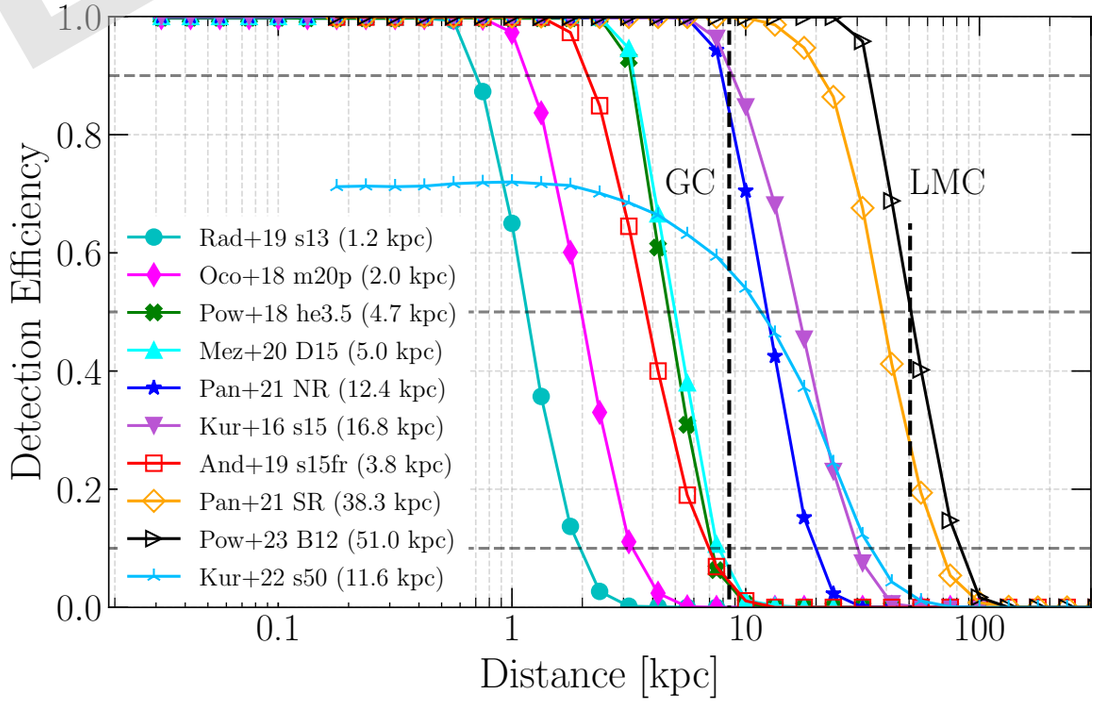




SN2023ixf Exceptional Event Paper

- Type II supernova at 6.7 Mpc (in M101), first observed on May 19, 2023
- H1L1 coincident livetime from the Engineering Run 15 covers 0.8 days, ~14% of the possible on-source window
- Upper limit on the gravitational-wave energy improved by a factor ~10
- **Target release**: 2024-06-23, initial LVK circulation ended on 2024-05-22





Vela Glitched!

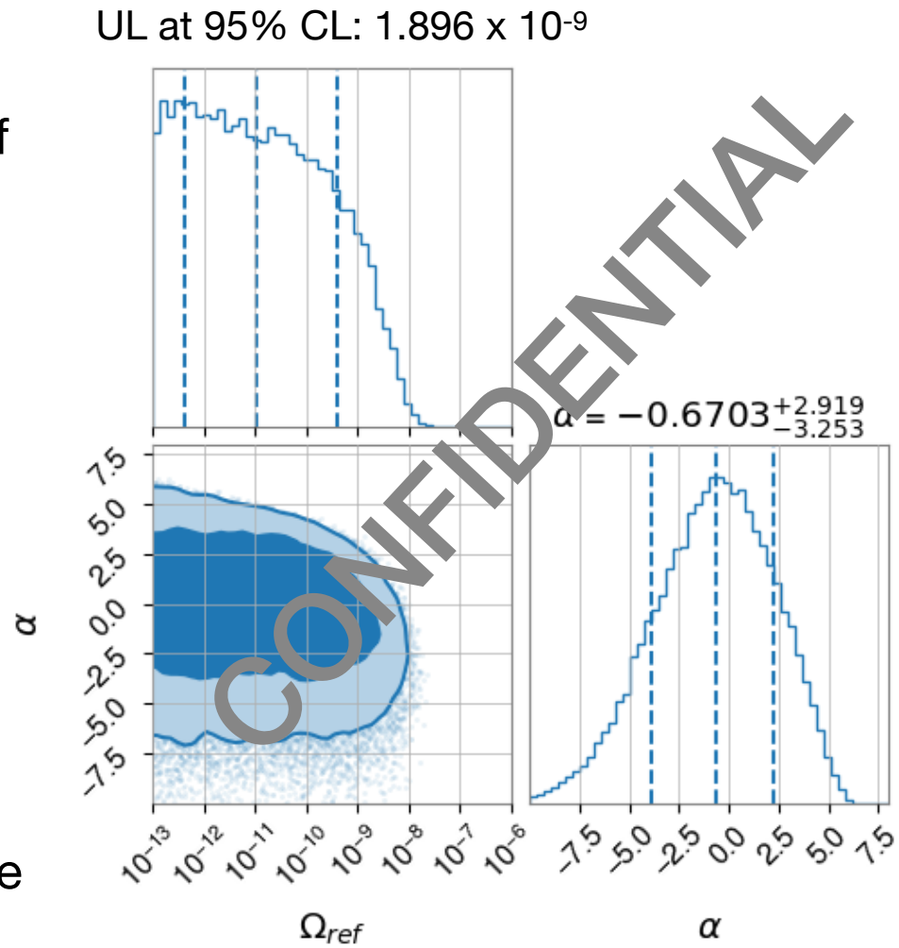
- **ATel #16608: Detection of a new giant glitch in the Vela Pulsar observed from the Argentine Institute of Radio astronomy (see slide on MOUs!)**
  - April 29th at 20:52 UTC +/- barycenter shift
  - ~10 seconds on source window, df/f = 2–3 x 10^{-6}, f = 22 Hz, d = 0.28 kpc
  - Quick estimates yield
    - H1 SNR: 6.8 – 11.0
    - L1 SNR: 13.6 – 21.9
    - V1 SNR: 1.8 – 2.9

- It is likely that a joint Burst - Continuous Wave special event paper will be activated

Stochastic Group

- Proactive, continuous monitoring of data and its quality (weekly shifts to operate data quality pipeline on a daily basis and produce weekly summary reports): a Stochastic group veto definer file is produced and used in O4

- Isotropic analysis
  - O4a results under review, analysis code frozen and will remain frozen for O4b analysis to minimise review time of full O4 results
  - 8.2% data cut (comparable to O3)
  - Data found to be consistently Gaussian
  - Upper limits on amplitude and spectral index of GW background (see posterior plot)
  - Upper limits on non-GR polarizations
  - For this search a cost-benefit decision is pending on inclusion of Virgo data in O4b analysis (considerations are different for anisotropic search where angular resolution matters)

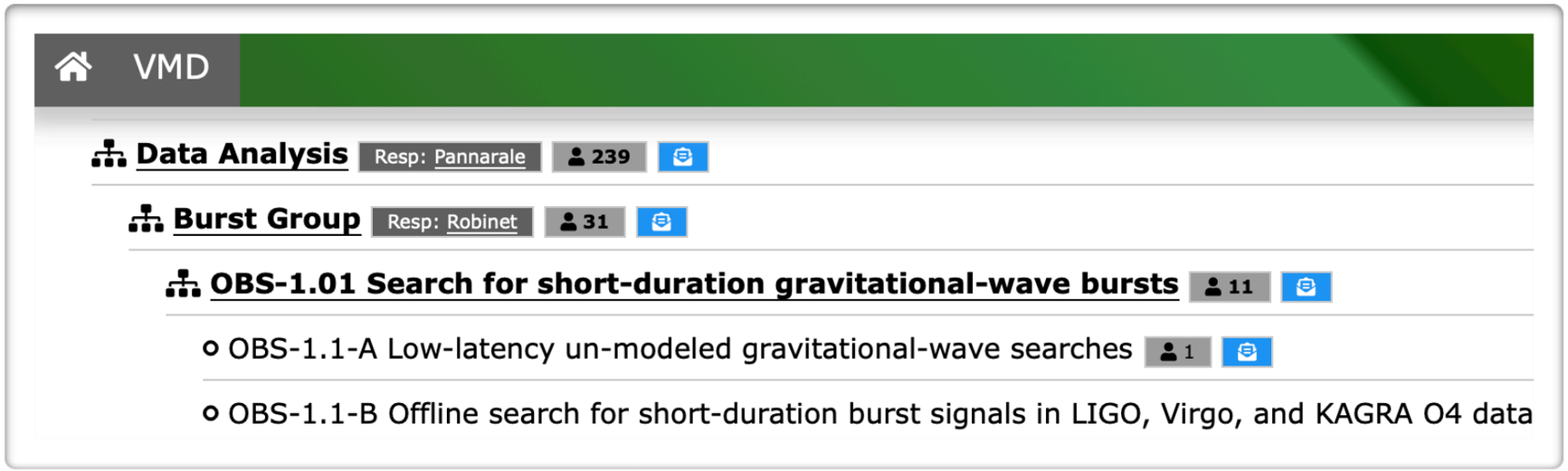


4. Recent Actions

Data Analysis Activities on the Virgo Member Database

- To help with planning, MOA reviews, etc., we need to know what colleagues intend to do and are willing to do, as well as where exactly person power is short

- About a month and a half ago the Data Analysis section of the VMD (with the exception of DetChar) was aligned to the structure of the 2024 LVK Obs White Paper:



Working group
Project
Activity

- **SVAC contributions must be on activities**, not projects or working groups, **with exceptions for the CW group** where lists of activities are explicitly limited to O4

- Budget is gradually repopulating

- Virgo Executive Committee agreed to feed directly into the LVK wide FTE count being set up at wbs.igwn.org

Burst Multiple-Pipeline Policy

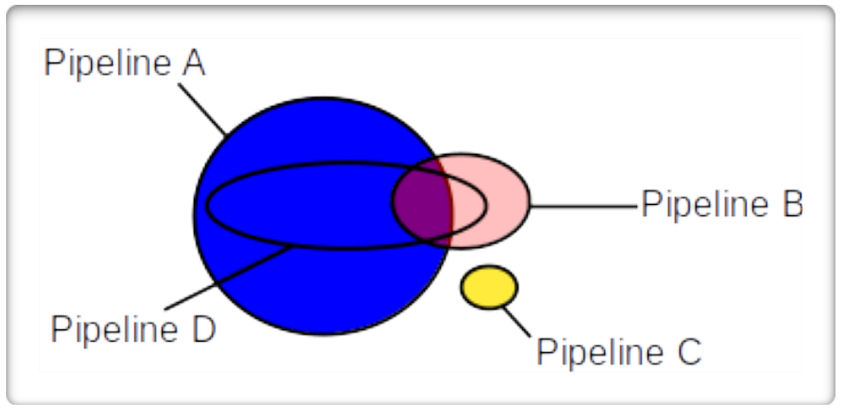
The Burst group established a multiple-pipeline policy to be applied for O4b papers, supported by the Data Analysis cochairs

1. Minimize the number of pipelines in searches associated with LVK publications: LVK papers from the Burst group will only present results obtained with the most sensitive pipelines

2. Avoid penalising the significance of a gravitational-wave candidate

3. Understand the added value of a new/existing search method and optimize the allocation of resources to characterize, operate, review and finally validate a pipeline.

- Search pipelines are qualified iteratively starting with the most sensitive pipeline, the one which detects the largest number of simulated events; subsequent pipelines are qualified if they detect events missed by the pipelines selected at the previous iterations

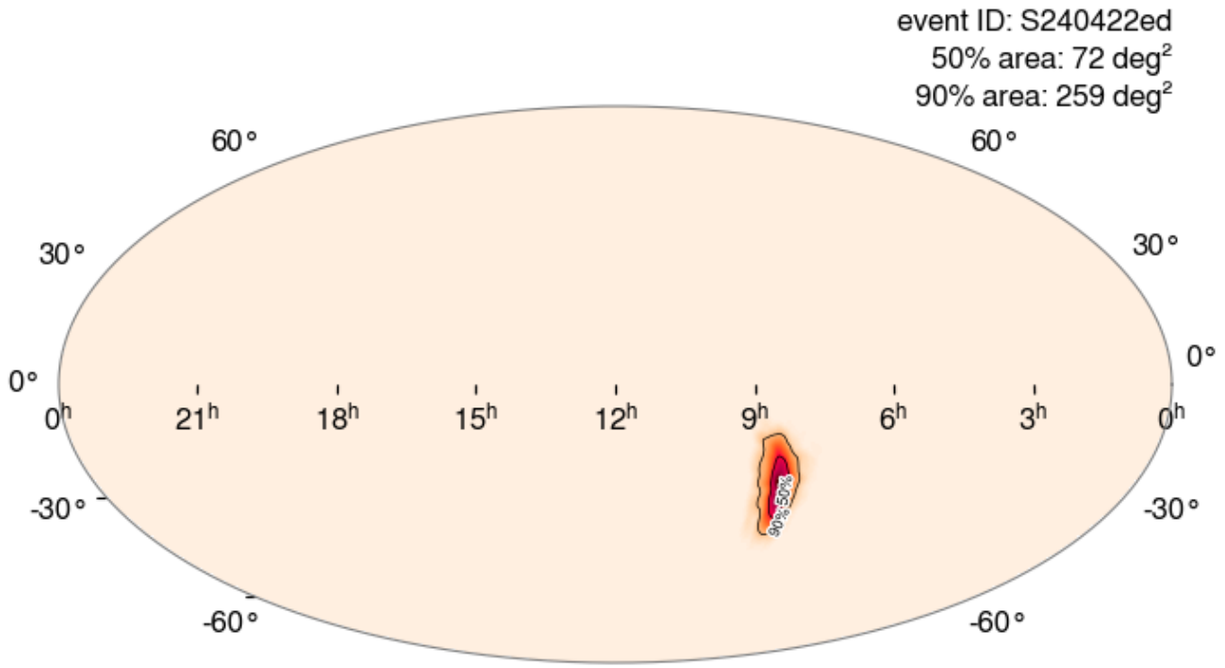


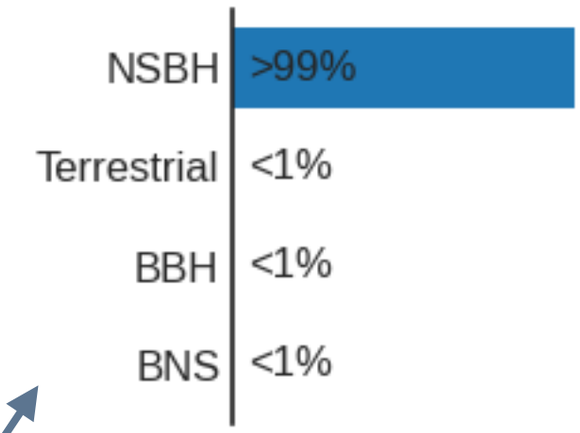
- Burst chairs will set a deadline to freeze the list of qualified pipelines for a given LVK paper, in agreement with the paper timeline

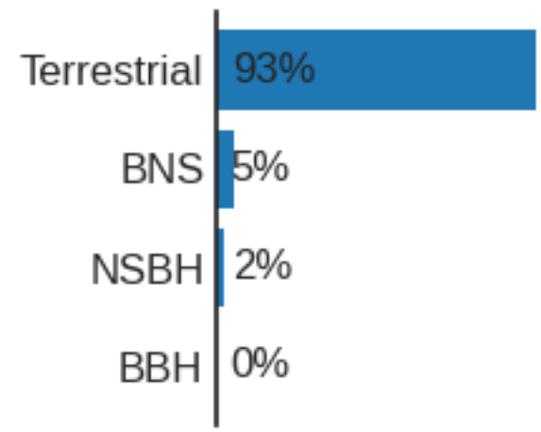
- This policy is considered as a prerequisite for a pipeline to be considered for integration in the low-latency framework

5. Open Points

S240422ed







Per-Pipeline Event Information

UID	Group	Pipeline	Search	gpstime	FAR (Hz)
G476954	CBC	gstlal	AllSky	1397856931.417	3.095e-13
G476957	CBC	pycbc	AllSky	1397856931.431	3.269e-07

- Establishing a way to inform about the status of other pipelines not reported in the supervent
- Issue another circular?

O4 Extension

- Unanimous response from the working groups: do not extend the run without touching the data release plan (i.e., release all of O4 by 2026-05-23)

- O4a + O4b + O4c
  - Add a third release date
  - Simpler to implement on paper
  - Introduces a lot of criticalities for the Continuous Waves group
  - If the extra release date is too far away in time, O5 preparations could be jeopardised

- O4a + extended O4b
  - Delay the full O4 release date, by the duration of the extension or
  - Requires adjustments to the paper plan
  - Does not raise specific issues for the working groups

- Regardless, the Stochastic's group only viable option is to not analyze the extra months
  - Better avoid scooping on O4a results (release 2025-08-23)
  - Then look into publishing a marginal update to O4 at later times

Coarse Grained Mass Information

- Task force charge: work and liaise with the low-latency group on a possible single, consistent approach to releasing coarse-grained mass information for our public alerts. This would be an evolution of the current information carried by the source classification quantities (pBBH/NSBH/BNS) and the CBC source properties (HasRemnant, HasNS, HasMassGap).

- Internal poll suggested several changes: most “positive” response was to add chirp mass values
  - Out of possible additional info, it is the only quantity where we have good control of statistical and systematic errors
  - It may also have impact on followup strategy

> - $0.1 < \mathcal{M}/M_\odot < 0.87$ - Single bin for cases where at least one component is sub-solar mass.
> - $\mathcal{M}/M_\odot = \{0.87, 1, 1.1, 1.2, 1.3, 1.4, 1.5\}$ - Bin boundaries inside which potentially detectable EM emission is expected from BNS mergers.
> - $\mathcal{M}/M_\odot = \{1.5, 2, 2.8, 4, 5.7, 8, 11, 16, 23, 32, 45, 64, 91\}$ - Bin boundaries for general stellar-mass CBC systems, with spacing at powers of $\sim 2^{1/2}$ from $2M_\odot$ upward.
> - $91 < \mathcal{M}/M_\odot < 1000$ - Single bin for high-mass binaries with at least one component above $\sim 100 M_\odot$.