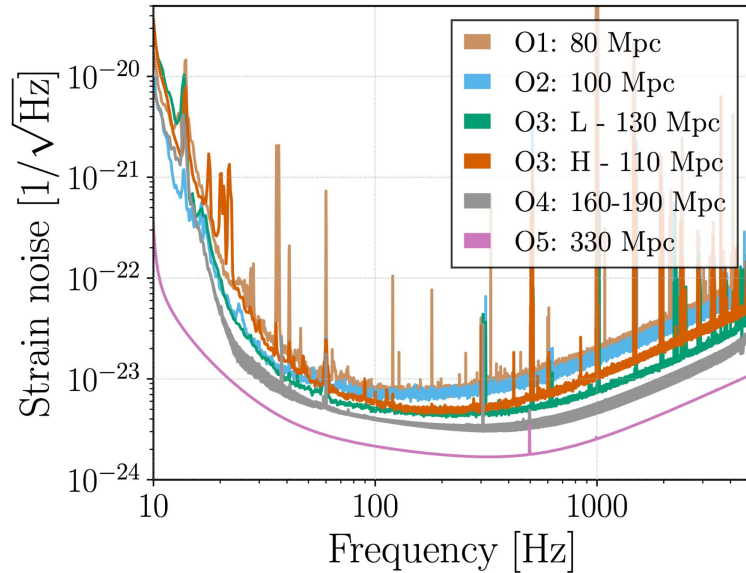


# Alerts during O4

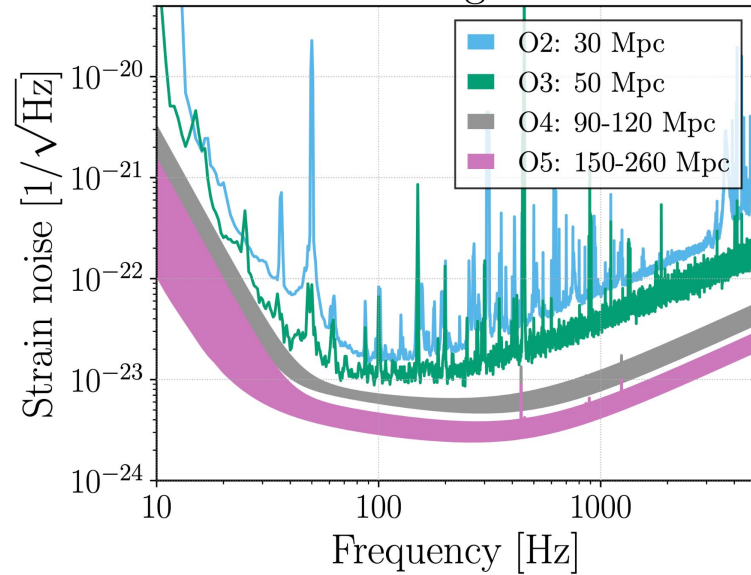
Nicolas Leroy - IJCLab  
Session **Prédiction et suivi des signaux multi-messagers**  
journées de la SF2A 2023

# Initial plan

LIGO



Virgo



# Expected number of alerts

If we take all possible alerts ie 1 to 4 detectors alerts

We could expect more than 1 evt/day even in O4

Possibly one GRB event in common with GW emission (using short GRBs in O3)

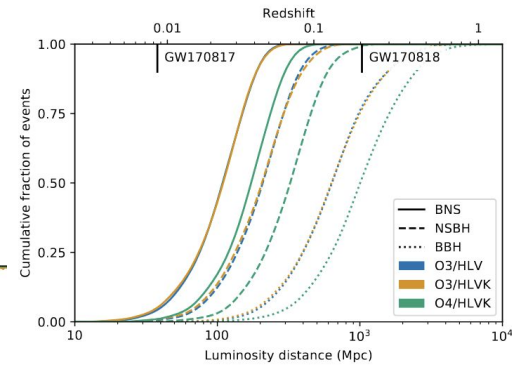
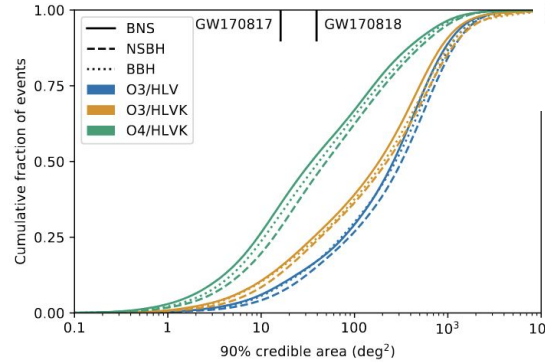
KN peak magnitude > 20.5 mag for a BNS merger within 200 Mpc

| Observing run  | Network | Source class         |                      |                      |
|--|---------|----------------------|----------------------|----------------------|
|  |         | BNS                  | NSBH                 | BBH                  |
| <b>Annual number of public alerts</b><br>(log-normal merger rate uncertainty × Poisson counting uncertainty) |         |                      |                      |                      |
| O4   | HKLV    | $36^{+49}_{-22}$     | $6^{+11}_{-5}$       | $260^{+330}_{-150}$  |
| O5   | HKLV    | $180^{+220}_{-100}$  | $31^{+42}_{-20}$     | $870^{+1100}_{-480}$ |
| <b>Median luminosity distance</b><br>(Mpc, Monte Carlo uncertainty)  |         |                      |                      |                      |
| O4   | HKLV    | $398^{+15}_{-14}$    | $770^{+67}_{-70}$    | $2685^{+53}_{-40}$   |
| O5   | HKLV    | $738^{+30}_{-25}$    | $1318^{+71}_{-100}$  | $4607^{+77}_{-82}$   |
| <b>Median 90% credible area</b><br>(deg <sup>2</sup> , Monte Carlo uncertainty)                              |         |                      |                      |                      |
| O4   | HKLV    | $1860^{+250}_{-170}$ | $2140^{+480}_{-530}$ | $1428^{+60}_{-55}$   |
| O5   | HKLV    | $2050^{+120}_{-120}$ | $2000^{+350}_{-220}$ | $1256^{+48}_{-53}$   |

# Expected number of alerts

If we limit to 2 to 4 detectors alerts

- We could expect up to 1 evt/day
- O5 will be 2 times more sensitive -> 10 times more sources

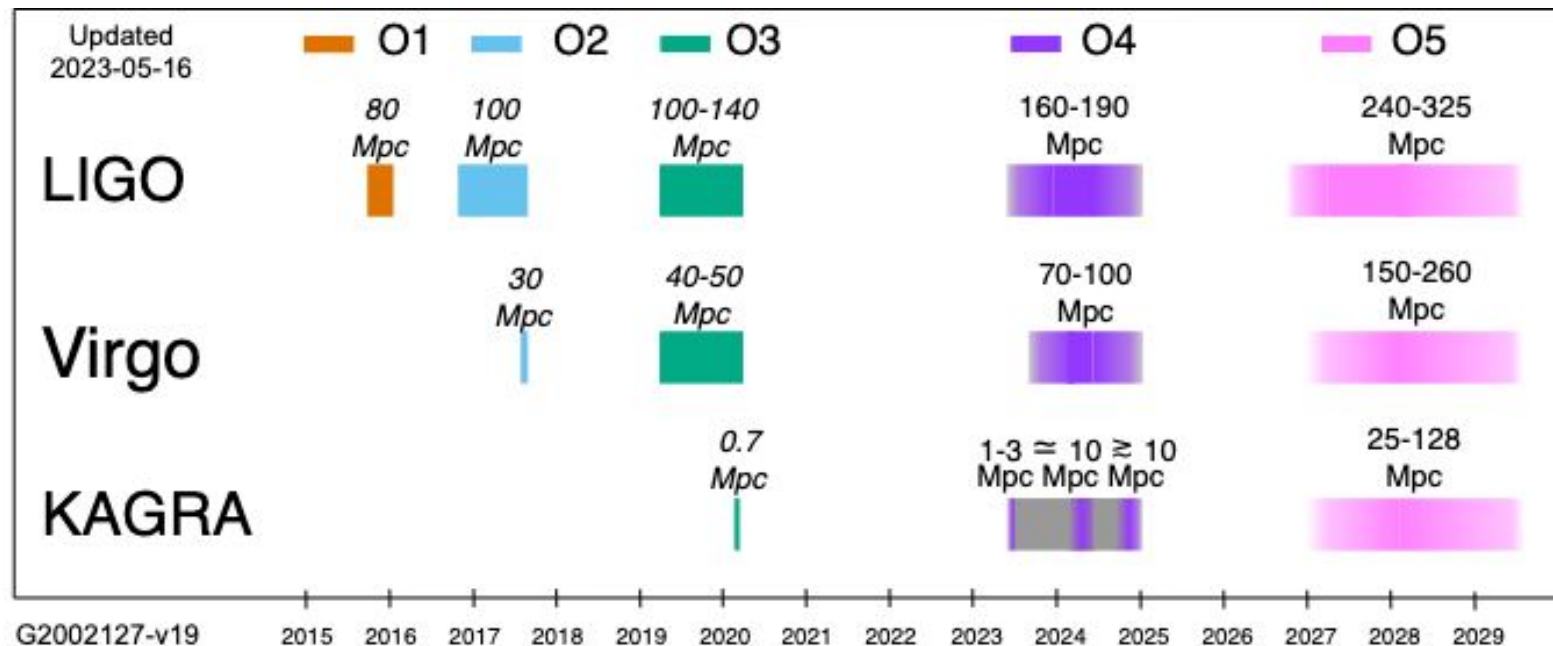


| Observation Run | Network | Expected BNS Detections              | Expected NSBH Detections             | Expected BBH Detections              |
|-----------------|---------|--------------------------------------|--------------------------------------|--------------------------------------|
| O4              | HLVK    | $10^{+52}_{-10}$                     | $1^{+91}_{-1}$                       | $79^{+89}_{-44}$                     |
|                 |         | Area (deg <sup>2</sup> )<br>90% c.r. | Area (deg <sup>2</sup> )<br>90% c.r. | Area (deg <sup>2</sup> )<br>90% c.r. |
| O4              | HLVK    | $33^{+5}_{-5}$                       | $50^{+8}_{-8}$                       | $41^{+7}_{-6}$                       |

# Where do we stand

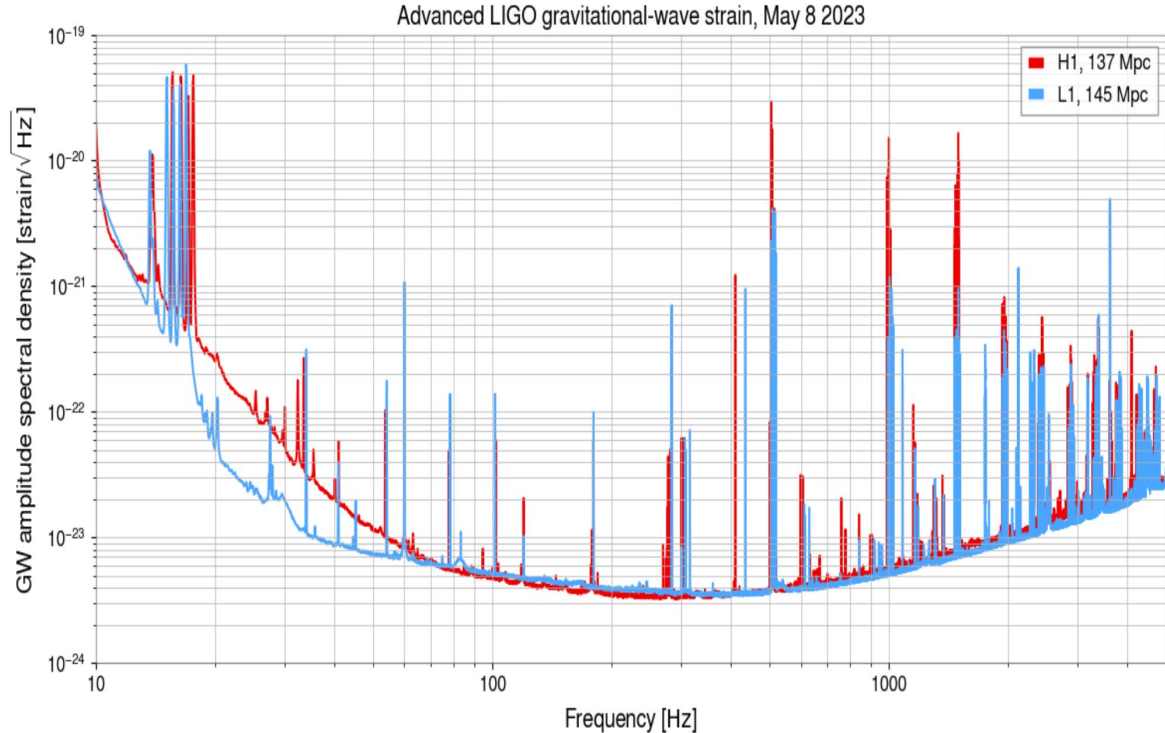
- Some difficulties to achieve good sensitivity on (part of) LVK detectors delay start of O4 to 24th of May 2023 - Engineering run started one month before
  - KAGRA will spend most of the time in commissioning mode to solve problems observed
  - Virgo has been delayed due to some technical problems, see later
- O4 duration has been extend to 20 months ie end of 2024 (beginning of 2025)
  - allow to study some possibilities for O5
  - will also increase the possibility to have EM counterpart (from 70 to 90 %, compare to a 12 months run)
  - will be interleave with 1 to 2 months commissioning phases
  - Goal is to have 18 months of data taking

# Timeline



# LIGO

- 88.5 % with at least one interferometer locked
  - Mainly driven with L1
- Averaged BNS range
  - 135 Mpc for H1
  - 150 Mpc for L1

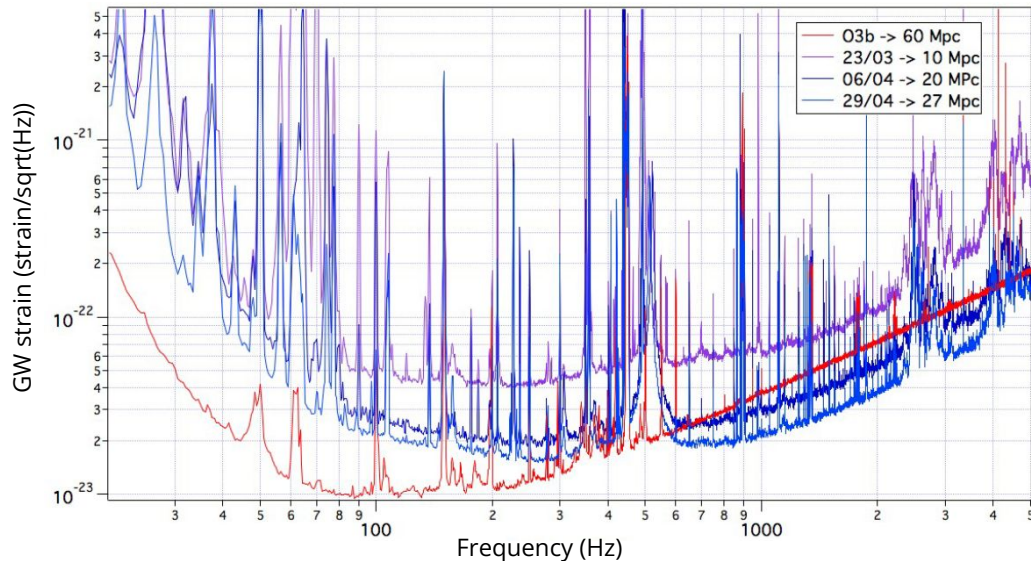


# Virgo

With the new optical configuration, we only reach half of the averaged horizon we had during O3 (27 instead of 60 Mpc)

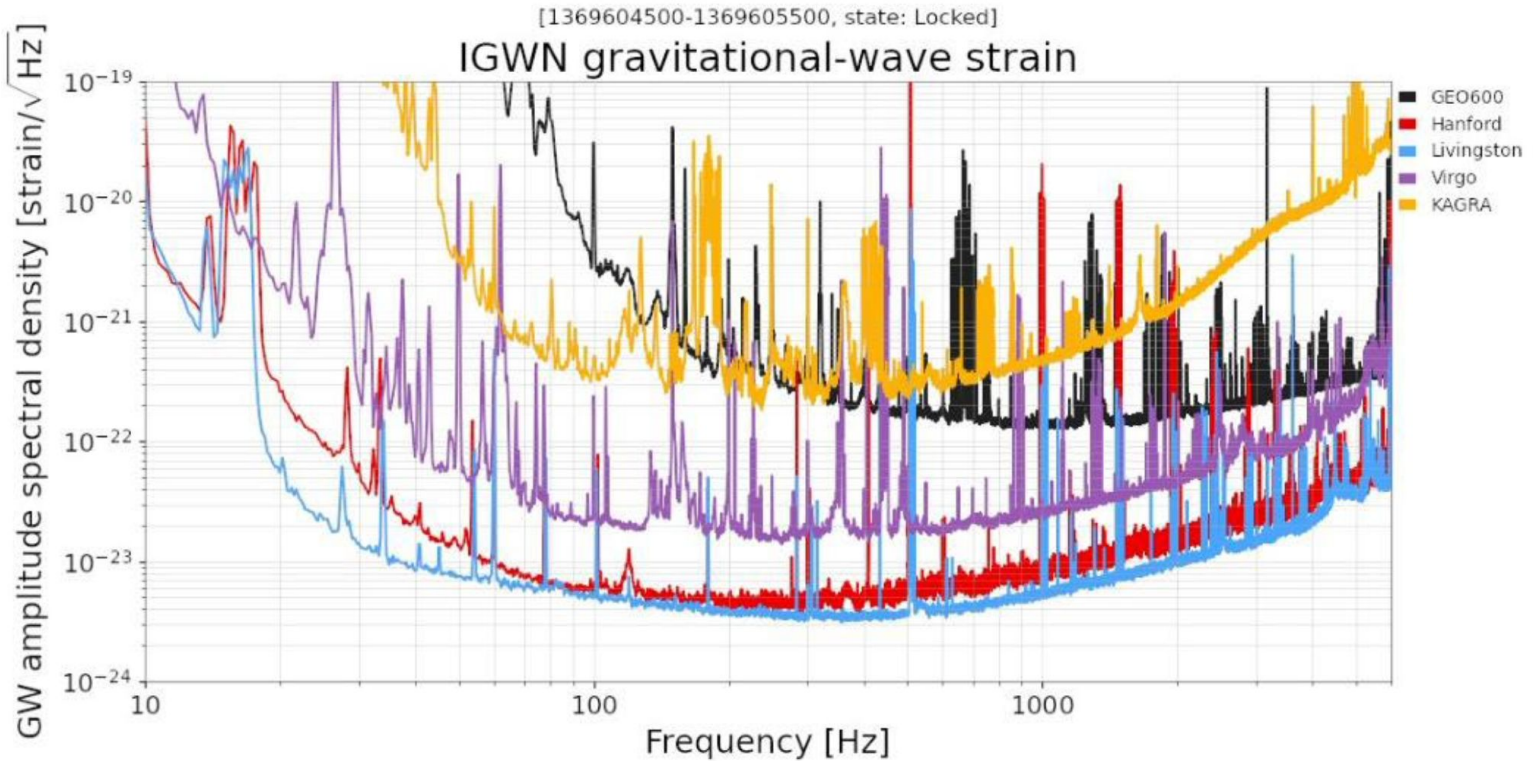
We have several actions possible to try to improve the situation

- A clear peak around 500 Hz due to moving magnet on of the mirror
  - Action performed in the mirror, peak removed !
- One of the mirror showed a large degradation in its contribution between tens and hundreds of Hz
  - Mirror exchanged
  - Recovery of the interferometer in progress since last Monday
- Hope to join O4 by end of August, beginning of September - target for O4 start 60-70 Mpc





# Full network

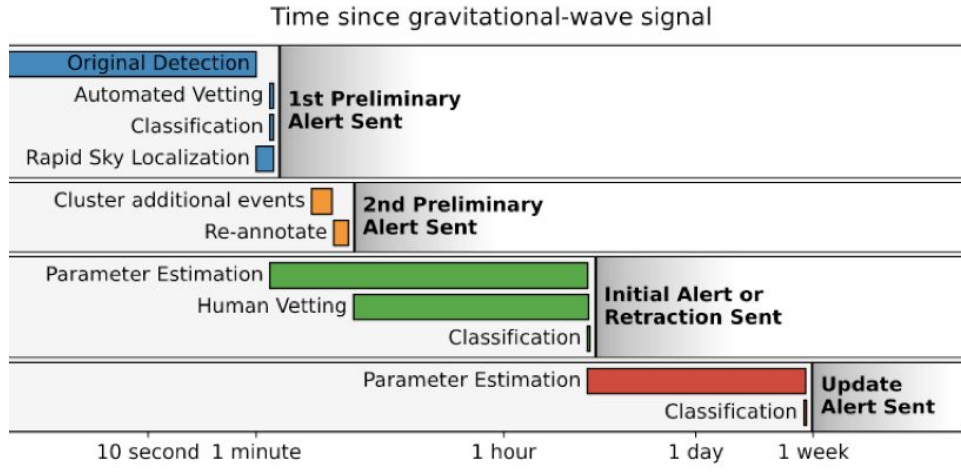


31st of May 2023 - 5 interferometers locked at the same time for one of the first time !

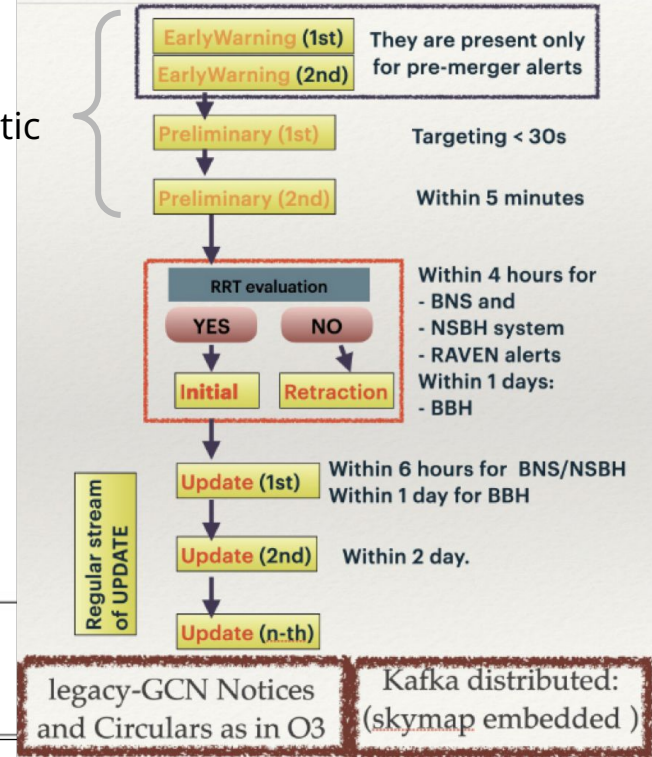
# Low latency network

For each alert we will have a bunch of notices

- early warning - up to 30 secs before
- Preliminary
- Initial/Retraction
- Update



Fully automatic



Using 2 types of formats/protocols

# Public alerts

2 types of pipelines

- Bursts (excess power) - 2 pipelines
- Compact binaries coalescence signals - 4 pipelines

Threshold (including trial factors):

- Significant events
  - FAR < 1/month CBC
  - FAR < 1/year for bursts
- Low significance - ie subthreshold
  - FAR > 1/month CBC
  - FAR > 1/year for bursts

There will be no update/retraction/human checks for those events

# Alert content

1. Time
2. FAR
3. Significance tag
4. instruments
5. pipeline-search
6. P-astro (classification)
7. EM-Bright (properties)
8. Skymap (embedded)
9. EM coincidence

```
{
  "alert_type": "PRELIMINARY", "time_created": "2023-05-22T15:31:02Z",
  "superevent_id": "S230522n",
  "event": {
    "time": "2023-05-22T15:30:33.391Z",
    "far": 6.479128493829593e-09, "significant": true,
    "instruments": ["L1"], "group": "CBC",
    "pipeline": "gstlal", "search": "AllSky",
    "classification": {
      "BBH": 0.9931377623662752,
      "BNS": 1.5857295164144167e-16,
      "NSBH": 1.1696821003800253e-14,
      "Terrestrial": 0.006862237633713075},
    "properties": {"HasNS": 0.0, "HasRemnant": 0.0, "HasMassGap": 0.00410658...},
    "duration": null, "central_f": null,
    "Skymap": "..byte of multiorder.fits file.. embedded..."
  },
  "external_coinc": null,
  "urls": {"gracedb": "https://gracedb.ligo.org/superevents/S230522n/view/"}
}
```

For sub-threshold events we do not expect, in general, to have (strong) consistency between classification and properties.

# Skymaps and format

We generally provide localizations in two HEALPix formats, distinguished by file extension:

## **\*.fits.gz**

A subset of the standard HEALPix-in-FITS format (see semi-official specifications [from the HEALPix team](#) and [from the gamma-ray community](#)) that is recognized by a wide variety of astronomical imaging programs including [DS9](#) and [Aladin](#). It uses HEALPix [implicit indexing](#) and the [NESTED numbering scheme](#). **This is the primary and preferred format, and the only format that is explicitly listed in the GCN Notices and Circulars.** See the section [Working with Sky Maps](#) for details.

## **\*.multiorder.fits**

A new variant of the HEALPix format that is designed to overcome limitations of the `*.fits.gz` format for well-localized events from three-detector operations and future gravitational-wave facilities (see rationale in [LIGO-G1800186](#)). It uses HEALPix [explicit indexing](#) and the [NUNIQ numbering scheme](#), which is closely related to [multi-order coverage \(MOC\) maps](#) in Aladin. This is the internal format that is used by the LIGO/Virgo low-latency alert pipeline. **This is an experimental format, and it is currently recommended only for advanced users.** See the section [Multi-Order Sky Maps \(For Advanced Users\)](#) for details.

Both formats always use celestial (equatorial, J2000) coordinates.

All sky localization FITS files for CBC events are three dimensional: they include both the sky probability map and a directionally dependent distance estimate. This can be useful for identifying possible host galaxies using a galaxy redshift catalog.

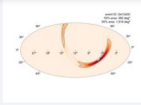
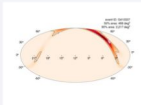
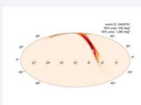
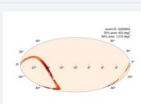
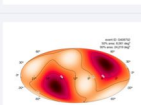
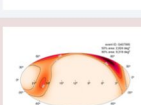
# News on O4

ER 15 :

- 4 significant
- 2 subthresholds

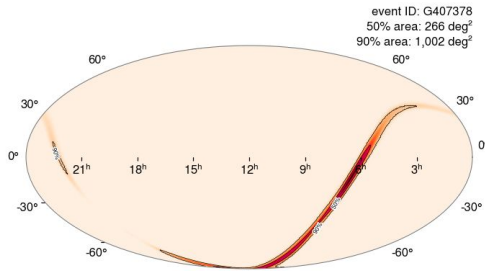
O4  
(06/22/19, 16:15 UTC) :

- 8 significant  
(2 retracted)  
Latency < 60s  
for Preliminary
- 82 subthresholds

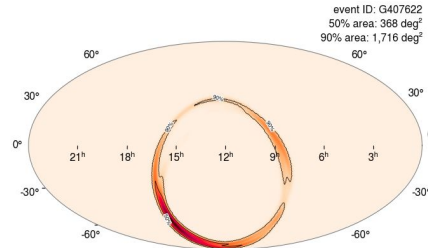
|                           |  |     |                              |  |   |                        |           |
|---------------------------|--|-----|------------------------------|--|---|------------------------|-----------|
| <a href="#">S230609u</a>  | BBH (96%), Terrestrial (4%)                | Yes | June 9, 2023<br>06:49:58 UTC | <a href="#">GCN Circular</a><br><a href="#">Query</a><br><a href="#">Notices</a>   <a href="#">VOE</a> |  | 1 per 3.1557 years     |           |
| <a href="#">S230608as</a> | BBH (>99%)                                 | Yes | June 8, 2023<br>20:50:47 UTC | <a href="#">GCN Circular</a><br><a href="#">Query</a><br><a href="#">Notices</a>   <a href="#">VOE</a> |  | 1 per 231.43 years     |           |
| <a href="#">S230606d</a>  | BBH (>99%)                                 | Yes | June 6, 2023<br>00:43:05 UTC | <a href="#">GCN Circular</a><br><a href="#">Query</a><br><a href="#">Notices</a>   <a href="#">VOE</a> |  | 1 per 2.7789 years     |           |
| <a href="#">S230605o</a>  | BBH (99%), Terrestrial (1%)                | Yes | June 5, 2023<br>06:53:43 UTC | <a href="#">GCN Circular</a><br><a href="#">Query</a><br><a href="#">Notices</a>   <a href="#">VOE</a> |  | 1 per 7.0086 years     |           |
| <a href="#">S230601bf</a> | BBH (>99%)                                 | Yes | June 1, 2023<br>22:41:34 UTC | <a href="#">GCN Circular</a><br><a href="#">Query</a><br><a href="#">Notices</a>   <a href="#">VOE</a> |  | 1 per 1.8492e+07 years |           |
| <a href="#">S230529ay</a> | NSBH (62%), BNS (31%),<br>Terrestrial (7%) | Yes | May 29, 2023<br>18:15:00 UTC | <a href="#">GCN Circular</a><br><a href="#">Query</a><br><a href="#">Notices</a>   <a href="#">VOE</a> |  | 1 per 160.44 years     |           |
| <a href="#">S230524x</a>  | BNS (75%), Terrestrial (25%)               | Yes | May 24, 2023<br>20:22:41 UTC | <a href="#">GCN Circular</a><br><a href="#">Query</a><br><a href="#">Notices</a>   <a href="#">VOE</a> |  | 2.2799 per year        | RETRACTED |

# News on 04

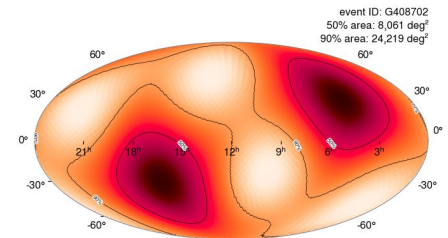
- Mainly BBH as expected
- 2 potentials NSBH
- But 2 interferometers skymap will make the search for EM counterpart a tricky game !
  - From 1000 deg<sup>2</sup> to 24 000 deg<sup>2</sup>



NSBH @ 200 Mpc



BBH @ 2Gpc



NSBH @ 200 Mpc

# Data release plan

- Calibrated strain data will be released in 2 periods:
  - a. First 10 months released August 2025
  - b. Following 11 months, May 2026
- Gravitational Wave Open Science Center <https://www.gw-openscience.org>



# Conclusions

- O4 started the 24th of May will only 2 detectors which will have strong impact on EM follow-up - error region is quite large 😊
- The run will finally last for a total of 20 months and 18 months of data taking - already 6 high confidence events (+4 during ER15)
- Virgo is aiming to join by the end of the summer
- New thresholds for automatic notice - 2/day, increase the rate by a factor 10

Thanks for your attention