# Run coordinator report

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**European Gravitational Observatory**

## EGO Council open session
## Nikhef – July 2nd, 2024

## VIR-0585A-24

# Foreword

- 21 years ago…



The Virgo detector: status and first experimental results

Nicolas Arnaud     NIKHEF     June 20th, 2003

### Summary

- Many interferometers are currently under developpement
  → Worldwide network in the future

  ✓ All instruments work already although they did not prove yet there can fulfill their requirements
  → Control of complex optical schemes with <u>suspended</u> mirrors

  ✓ All sensitivities need to be <u>significally improved</u> to reach the amplitude of GW theoretical predictions

- Many different GW sources
  ⇒ various data analysis methods in preparation

- In the two last years, the Virgo experiment became real
  ✓ The different parts of the experiment work well together
  ✓ Successful commissioning of the CITF
  ✓ <u>2003:</u> CITF → Full Virgo
  ✓ First 'physically interesting' data expected for 2004 !?!?!

# O4b: setting the stage

- Planning
  - O4b started on Wed. April 10th at 1500 UTC
  - Recently extended up to June 9th, 2025: from "at least 10" to 14 months
    - → Longest continuous data taking period in Advanced detectors era
      - ◆ Various implications for Virgo, but no showstopper

- Virgo data usage in low latency
  - ☒ Not for triggering: sensitivity gap + computing resources
  - ☑ For sky localization: a third detector can significantly reduce the skymap size
    - → Virgo data vet in low latency exactly like LIGO data
      - Virgo Data Quality Report framework works fine and is integrated with LIGO
    - → O4b overall strategy: maximize 3-detector uptime
      - Requires more, continuous, coordination at the LVK level
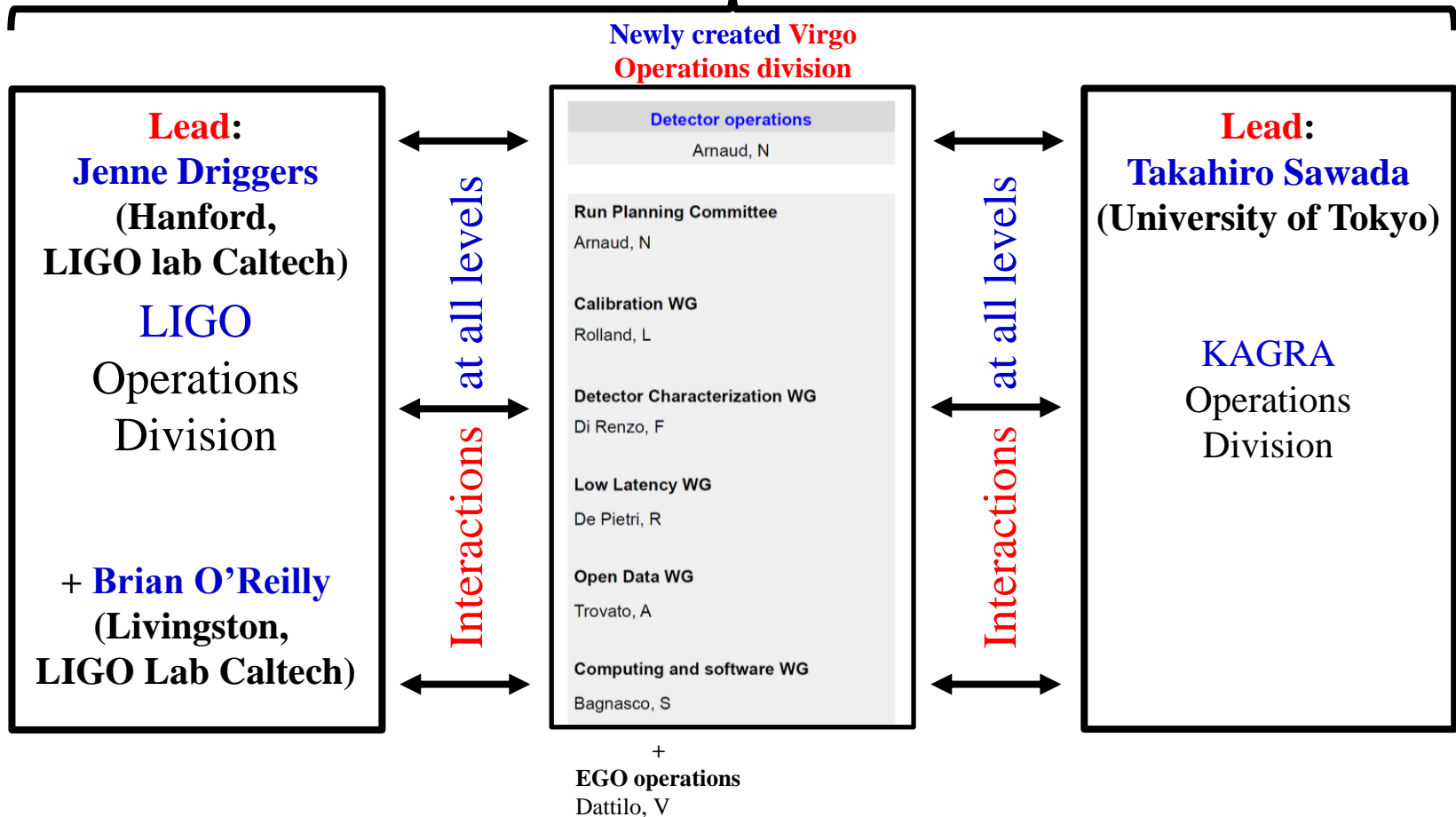        - ◆ In particular: align known, weekly recurring, downtimes

- Dual O4b coordination foreseen by the new Virgo Bylaws
  - Run coordinator ⎫ Smooth management: regular interactions
  - Commissioning coordinator ⎭ and quick info transmission both ways

→ More / complementary info in Michal Was' talk – next in the agenda

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# Run coordination: from Virgo to LVK

## Joint LVK Rapid-Response Team (RRT)

**Newly created Virgo Operations division**

| LIGO | Virgo Operations division | KAGRA |
|---|---|---|
| **Lead:** **Jenne Driggers** **(Hanford, LIGO lab Caltech)** LIGO Operations Division + **Brian O'Reilly** **(Livingston, LIGO Lab Caltech)** | **Detector operations** Arnaud, N | **Lead:** **Takahiro Sawada** **(University of Tokyo)** KAGRA Operations Division |

Interactions at all levels ← → (left)
Interactions at all levels ← → (right)

Virgo Operations division content:

**Detector operations**
Arnaud, N

**Run Planning Committee**
Arnaud, N

**Calibration WG**
Rolland, L

**Detector Characterization WG**
Di Renzo, F

**Low Latency WG**
De Pietri, R

**Open Data WG**
Trovato, A

**Computing and software WG**
Bagnasco, S

+
**EGO operations**
Dattilo, V

- Virgo Operations division approved at June 2024 VSC
  - → Twofold goal
    - ◆ Help coordinating work within Virgo: improve interfaces and liaisons
    - ◆ Have more weight in discussions at LVK level

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# Day to day operations



- EGO operations team
  - 7 operators + 1 manager
  - 3 8-hour shifts / day (7:00 / 15:00 / 23:00) 7 days / week
    - → Full 24/7 coverage in control room
  - Steer the detector
  - Support subsystems and working groups
    - → Training sessions organized prior to the start of O4b
  - First level of response in case of alarms on the Detector Monitoring System

- Daily meetings Monday to Friday in the control room
- Weekly Virgo operations division meetings to be (re)started soon

- LVK Organization
  - Weekly Operations meeting                                                    [Open]
  - Weekly site advocates meeting
  - Monthly joint coordinator meeting with RRT                        [Closed]
  - Monthly joint coordinator meeting with data analysis and RRT

→ Many working group meetings, LVK mailing lists and chat channels

→ Virgo: lead run coordinator 1/3rd of the time, DetChar expert 50% of the time          5

# O4b Virgo status

- Rough start with a handful of new (and unrelated) hardware problems
  - First two weeks: duty cycle ~60%
  - → All fixed

- Since then (two months): duty cycle much higher and still growing in average
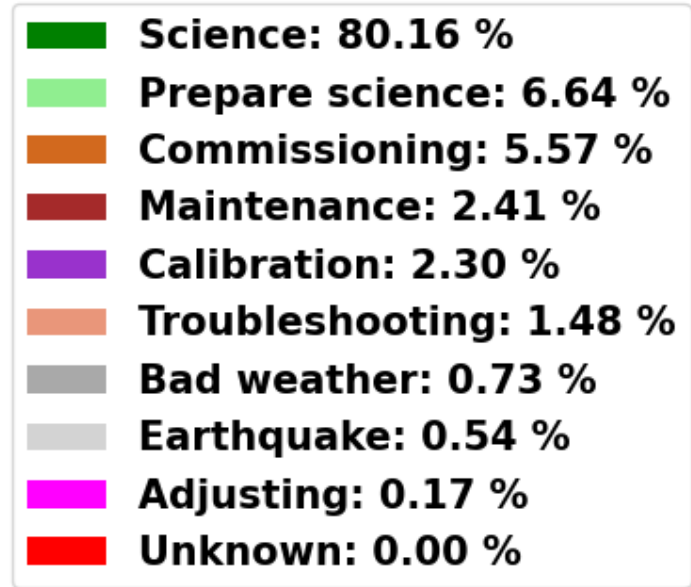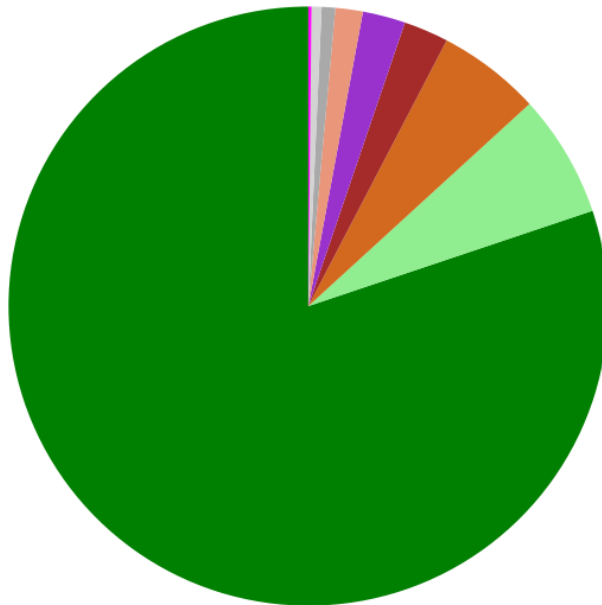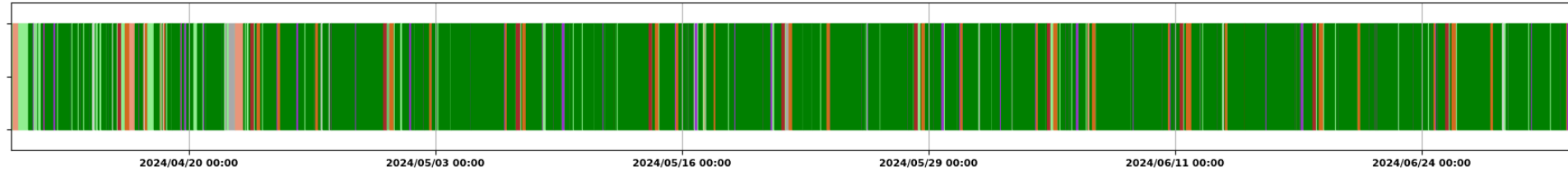  - → No hardware problem, continuous monitoring of transient issues, good weather



**Duty cycle (average: 80.15%) for network configuration V1**
**1396796418 [2024-04-10 15:00:00+00:00 UTC] -> 1403902820 [2024-07-01 21:00:02+00:00 UTC]**
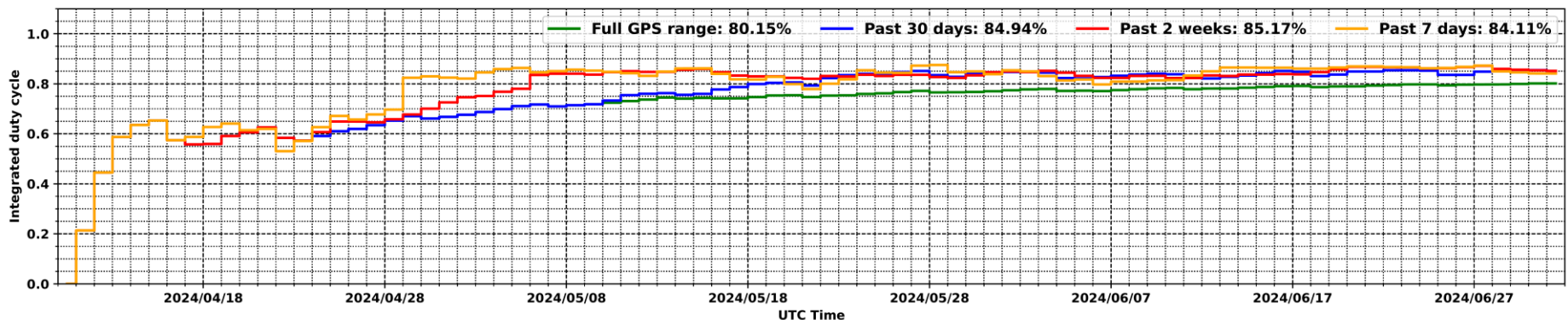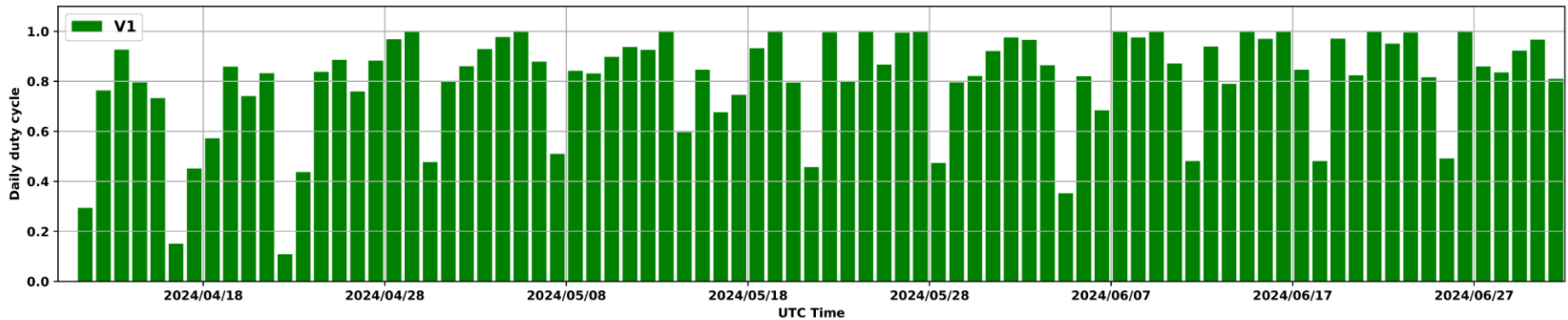
# O4b Virgo status

- Duty cycle summary

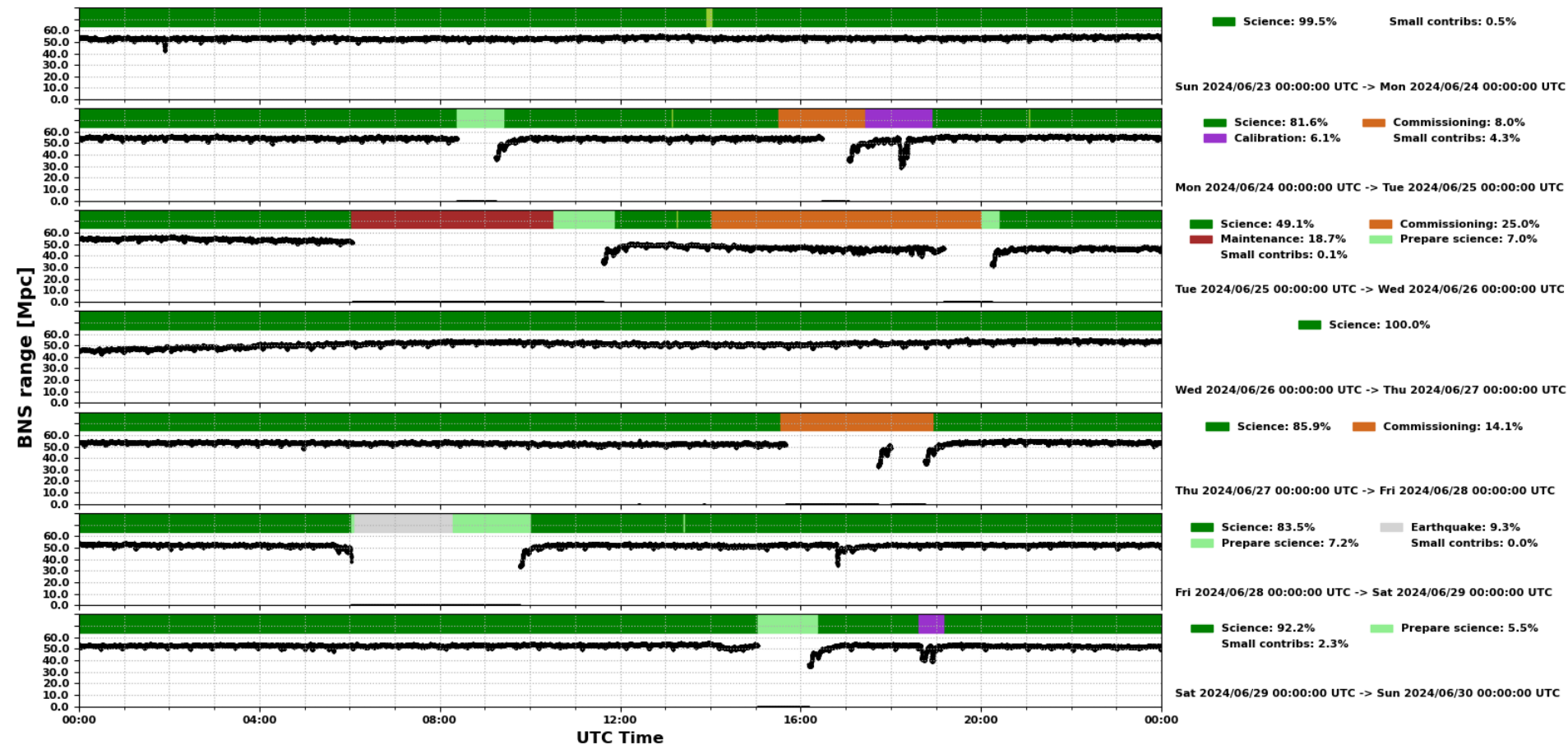**Status of channel V1:DQ_META_ITF_Mode -- time range: 2024/04/10 15:00:00 UTC -> 2024/07/01 21:55:02 UTC**





- Science: 80.16 %
- Prepare science: 6.64 %
- Commissioning: 5.57 %
- Maintenance: 2.41 %
- Calibration: 2.30 %
- Troubleshooting: 1.48 %
- Bad weather: 0.73 %
- Earthquake: 0.54 %
- Adjusting: 0.17 %
- Unknown: 0.00 %

→ Planned weekly downtimes add to about 10% of the wall-clock time

→ With ~80 days of run and a duty cycle of ~80%,
   more than 4 days of continuous operations needed to gain 1% of duty cycle

# A typical O4b week

- High duty cycle: > 80%
- Expected downtime pattern: Monday, Tuesday, Thursday and Saturday



Weekly summary plot: 2024/06/23 00:00:00 UTC -> 2024/06/30 00:00:00 UTC -- S-events: 0 ADVOK, 0 ADVNO

Science: 99.5%     Small contribs: 0.5%
Sun 2024/06/23 00:00:00 UTC -> Mon 2024/06/24 00:00:00 UTC

Science: 81.6%     Commissioning: 8.0%
Calibration: 6.1%     Small contribs: 4.3%
Mon 2024/06/24 00:00:00 UTC -> Tue 2024/06/25 00:00:00 UTC

Science: 49.1%     Commissioning: 25.0%
Maintenance: 18.7%     Prepare science: 7.0%
Small contribs: 0.1%
Tue 2024/06/25 00:00:00 UTC -> Wed 2024/06/26 00:00:00 UTC

Science: 100.0%
Wed 2024/06/26 00:00:00 UTC -> Thu 2024/06/27 00:00:00 UTC

Science: 85.9%     Commissioning: 14.1%
Thu 2024/06/27 00:00:00 UTC -> Fri 2024/06/28 00:00:00 UTC

Science: 83.5%     Earthquake: 9.3%
Prepare science: 7.2%     Small contribs: 0.0%
Fri 2024/06/28 00:00:00 UTC -> Sat 2024/06/29 00:00:00 UTC

Science: 92.2%     Prepare science: 5.5%
Small contribs: 2.3%
Sat 2024/06/29 00:00:00 UTC -> Sun 2024/06/30 00:00:00 UTC

BNS range [Mpc] — UTC Time

Science: 84.6% (5d:22h:2.7m)     Commissioning: 6.7% (0d:11h:18.1m)     Prepare science: 3.4% (0d:5h:45.4m)     Maintenance: 2.7% (0d:4h:29.6m)
Earthquake: 1.3% (0d:2h:13.2m)     Calibration: 1.2% (0d:2h:1.5m)     Adjusting: 0.1% (0d:0h:9.6m)

# O4b Virgo status

- BNS range
  - Data from the new version of GWIstat: online.igwn.org [Public website]
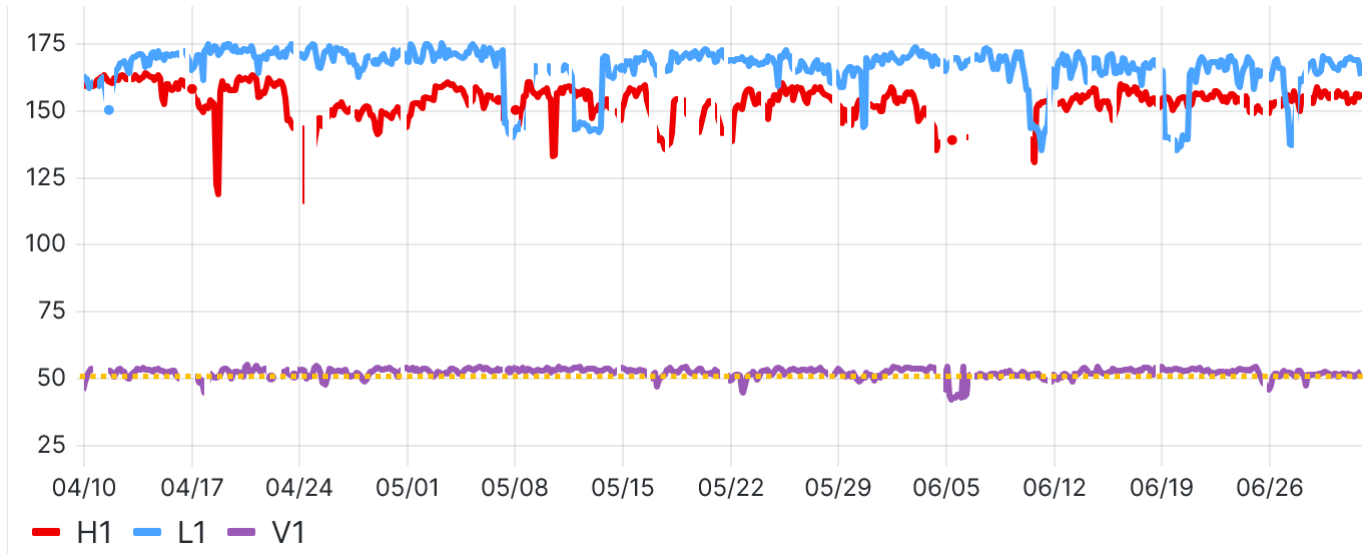


→ Virgo range quite stable
   between 50 and 55 Mpc
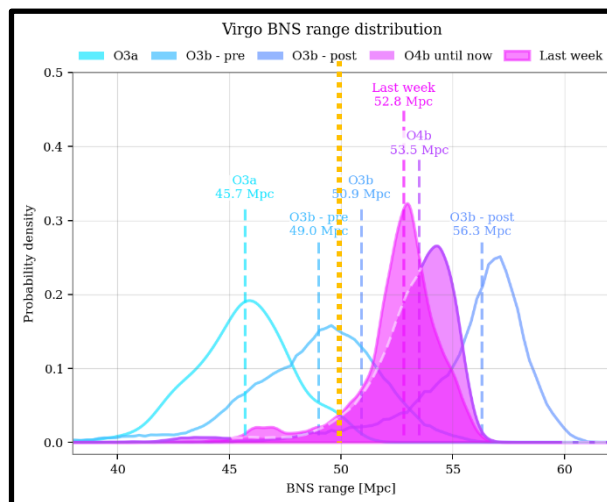
# Data quality: transient noises ("glitches")
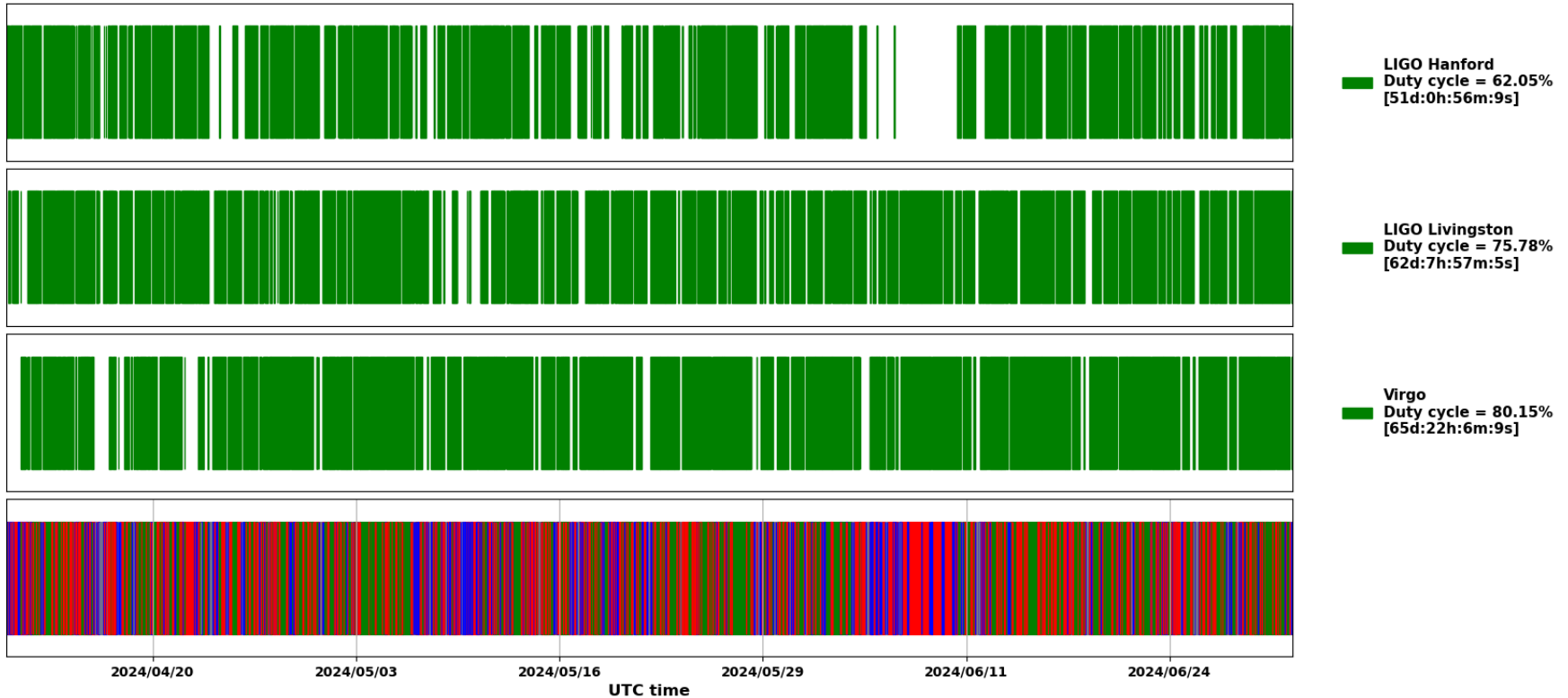
- Reduced glitch rate compared to O3
  → 0.10/minute vs 1.11/minute

- Only two known families of glitches
  - 25-minute glitches
    - Impacted Virgo data for a recent event
      → Investigations to continue via a dedicated taskforce, now that the start of O4b is behind us
  - Scattered light
    → Only during bad weather
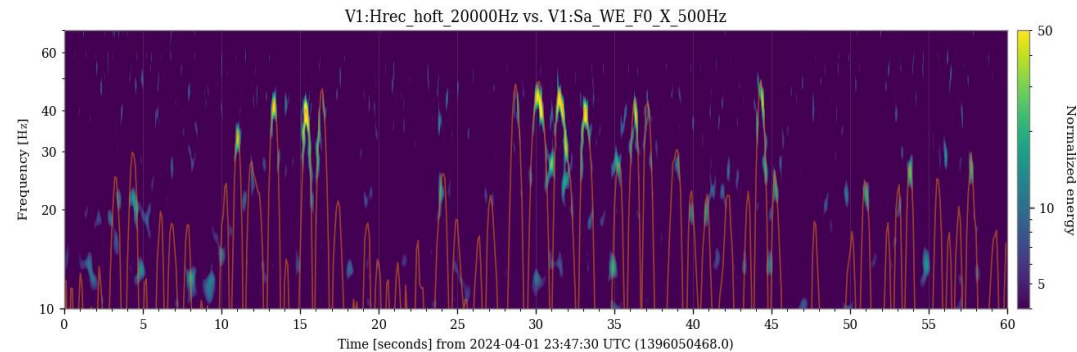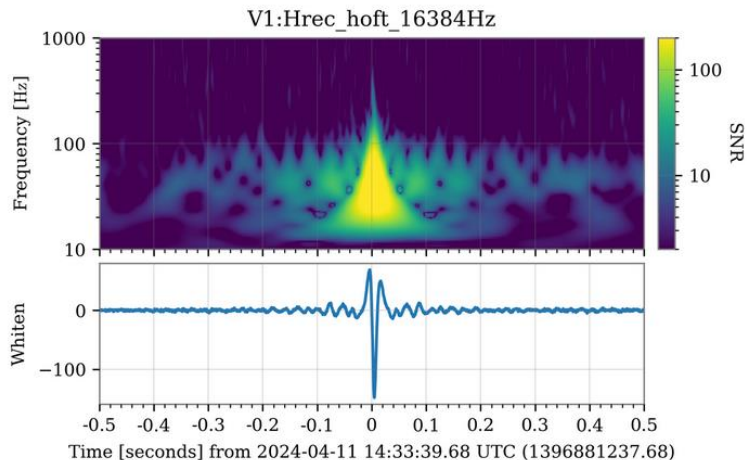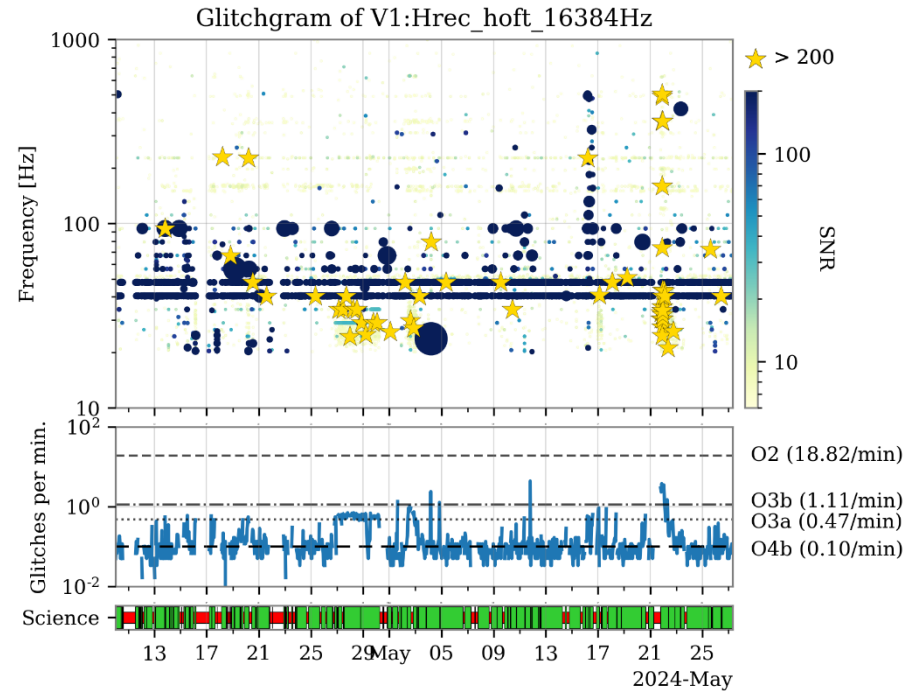
# O4b LVK network

- Duty cycle



**H1-L1-V1 network: 2024-04-10 15:00:00+00:00 UTC -> 2024-07-01 21:00:02+00:00 UTC -- science segments**

**LIGO Hanford**
**Duty cycle = 62.05%**
**[51d:0h:56m:9s]**

**LIGO Livingston**
**Duty cycle = 75.78%**
**[62d:7h:57m:5s]**

**Virgo**
**Duty cycle = 80.15%**
**[65d:22h:6m:9s]**

UTC time

0/3: 8.55% [7d:0h:45m:45s]
1/3: 10.26% [8d:10h:27m:17s]
2/3: 35.86% [29d:11h:48m:54s]
3/3: 45.34% [37d:6h:58m:6s]

# O4b LVK network

- Duty cycle



H1-L1-V1: 45.34 %
H1-L1: 7.40 %
H1-V1: 7.48 %
L1-V1: 20.98 %
H1: 1.83 %
L1: 2.07 %
V1: 6.35 %
None: 8.55 %
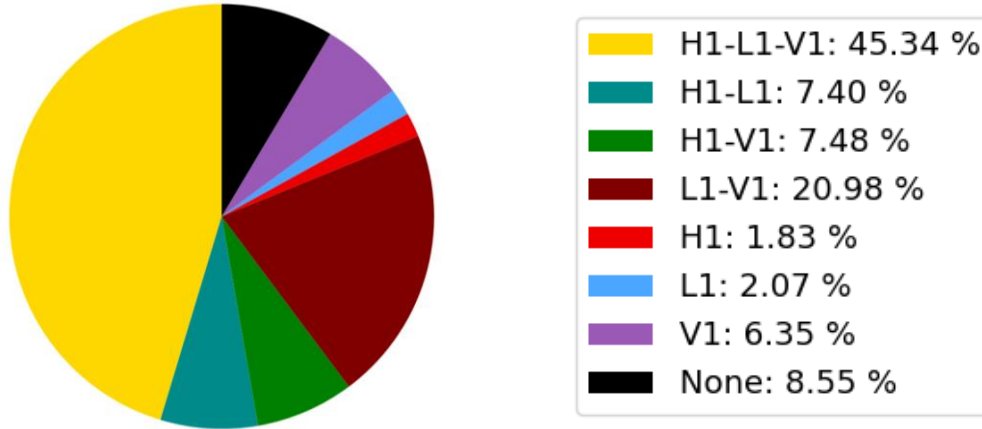
**Monthly duty cycles**
1396796418 [2024-04-10 15:00:00+00:00 UTC] -> 1403902820 [2024-07-01 21:00:02+00:00 UTC]
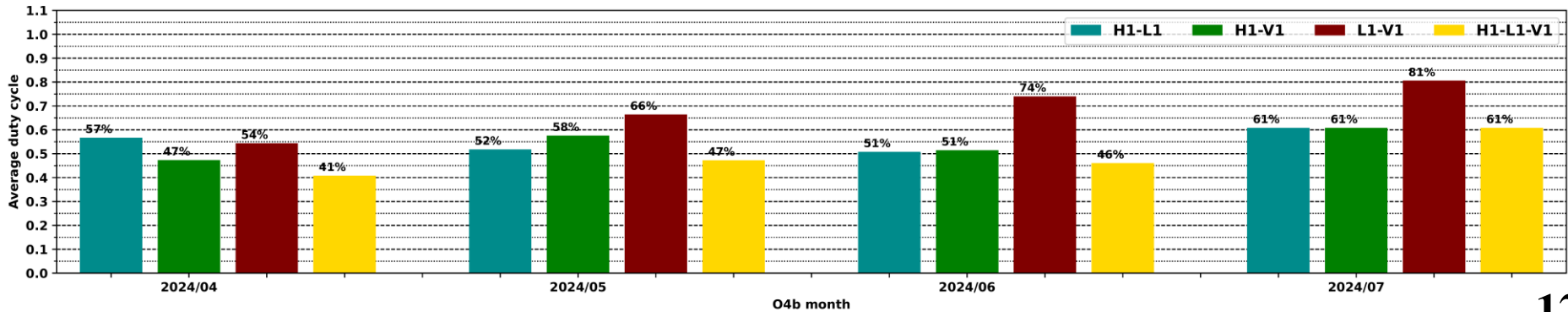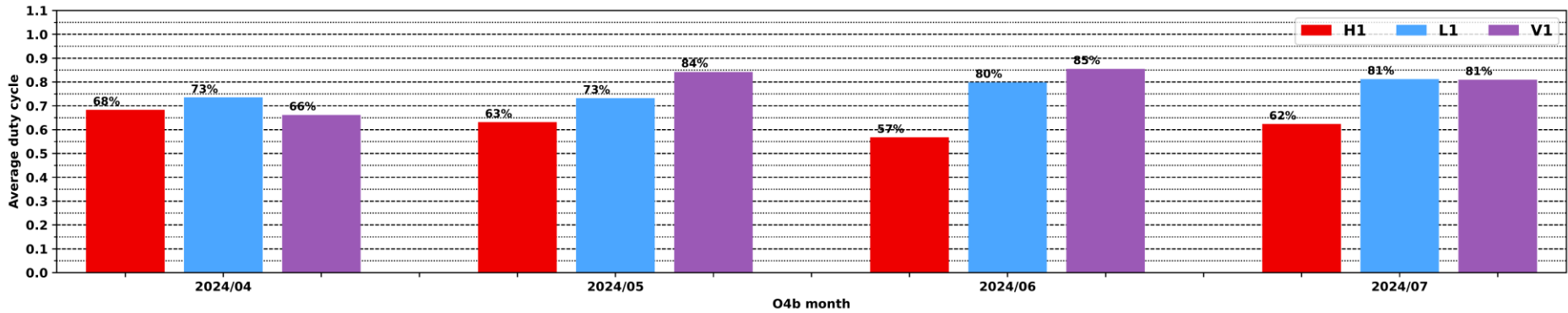
# O4b LVK network

- "Presence" of a detector:
  (3-instrument duty cycle) / (duty cycle of the 2-instrument network w/o that detector)
  - → The higher the better
  - → Reflects both the (good) performance of that detector
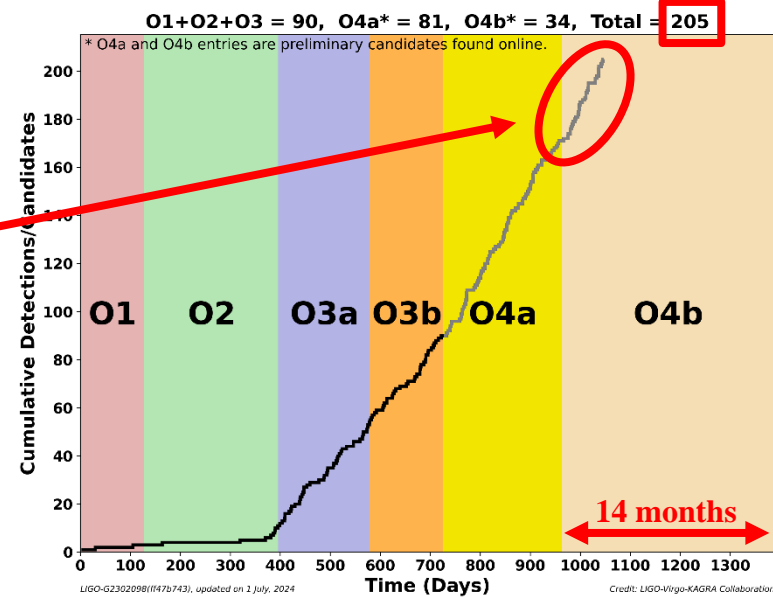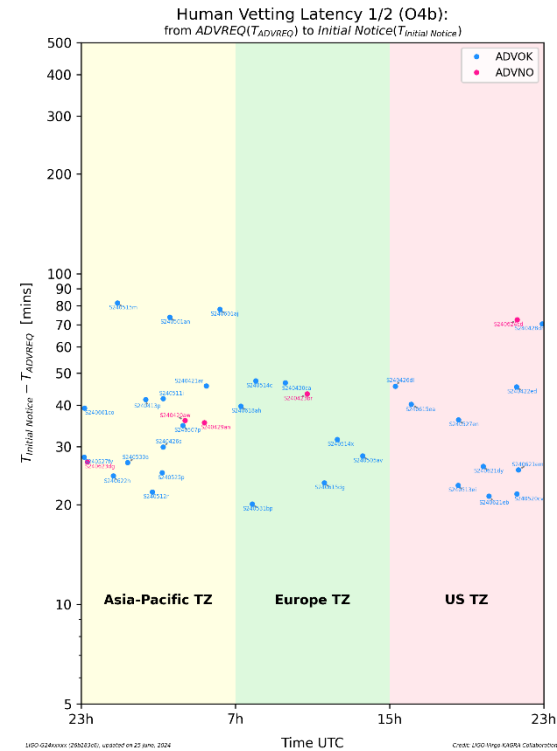    and  the (bad) performance of the other two instruments

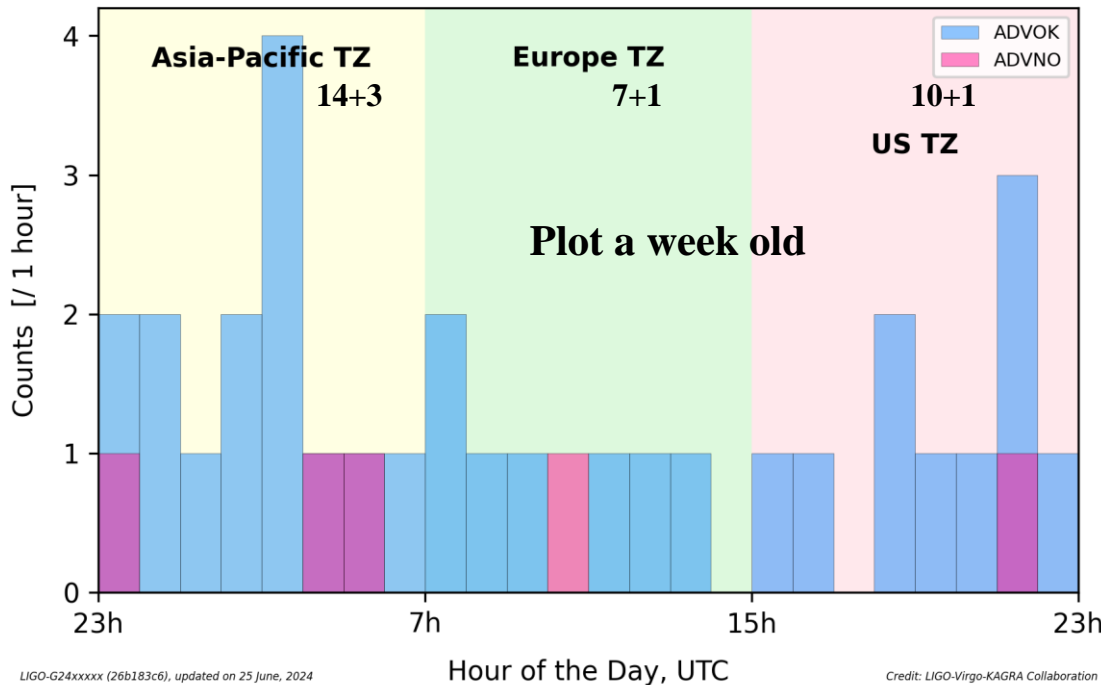**H1-L1-V1 network, monthly presences**
**1396796418 [2024-04-10 15:00:00+00:00 UTC] -> 1403902820 [2024-07-01 21:00:02+00:00 UTC]**

# Public alerts



O1+O2+O3 = 90, O4a* = 81, O4b* = 34, Total = 205
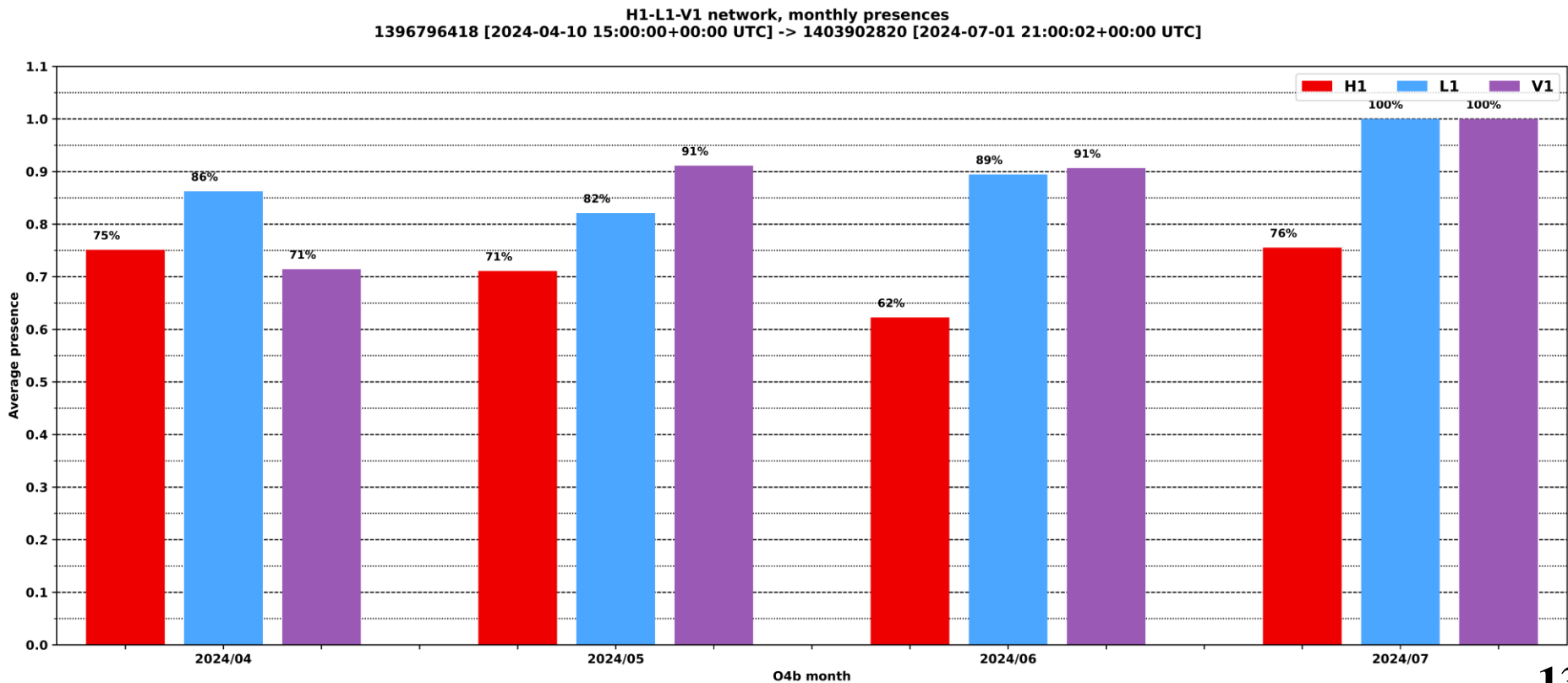
- O4b significant detection candidates: 34
  - 39 [total] – 5 [retracted]

→ https://gracedb.ligo.org/superevents/public/O4b
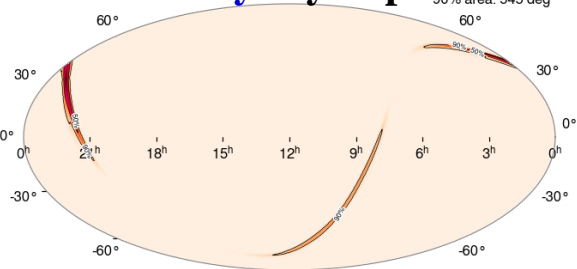
- Rapid Response Team (RRT)





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# Public alerts

- 27/31 (87%) with Virgo data available
  - 4 missed: 3 during Virgo maintenance slots (4 hours on Tuesday mornings)
    + 1 while recontroling the detector in between two Science segments

- Skymaps benefit from the addition of Virgo data to the LIGO trigger
  - Impressive improvement for loud events with favorable "source" sky location
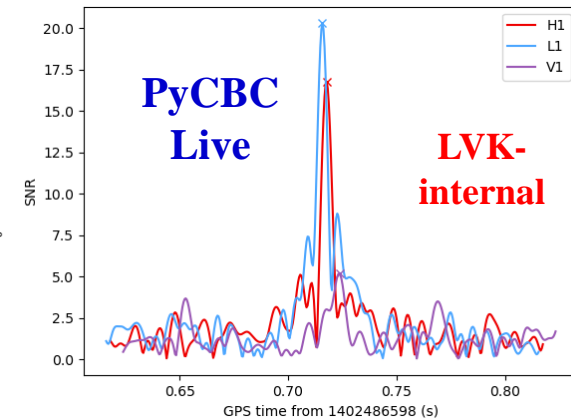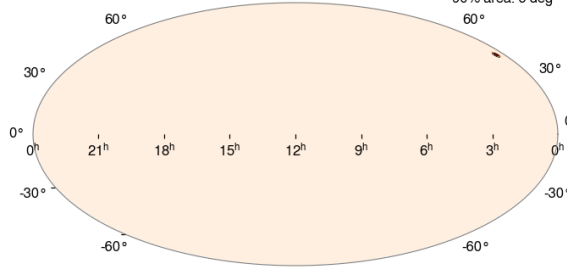    → Record so far: S240615dg



**LIGO-only skymap**
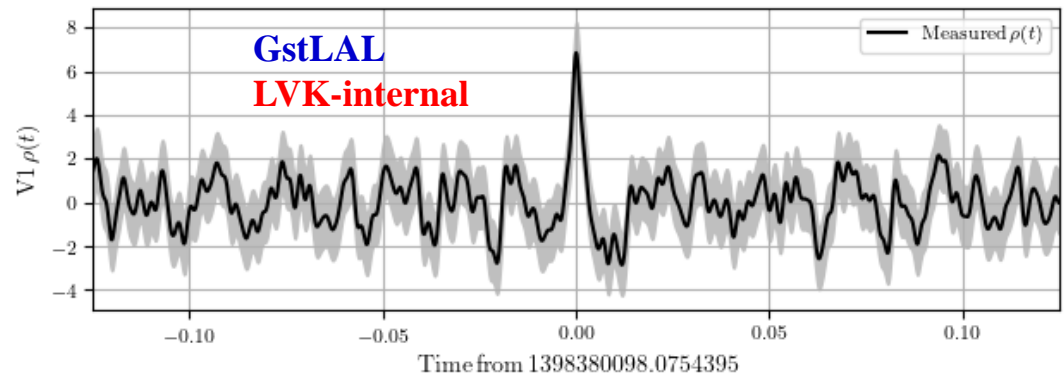event ID: G493086
50% area: 124 deg²
90% area: 545 deg²

**3-detector skymap**
event ID: S240615dg
50% area: 2 deg²
90% area: 6 deg²

**PyCBC Live**

**LVK-internal**

- S240428dr
  - Trigger: Hanford-single
    ◆ Livingston down
  - Virgo SNR: 6.9
    → A record for Virgo
      if event confirmed offline

**GstLAL LVK-internal**

# Rapid Response Team highlights

- Rapid Response Team
  - 3-tier system: Lv0 (on shift) → Lv1 (experts) → Lv2 (full team)
  - Coordination shared by geographical regions (by collaborations in practice)
    - Europe (+ Africa): Francesco DR for Virgo
      → 1/3$^{rd}$ of the time since O4a started
    - Asia/Pacific: KAGRA
    - Americas: LIGO

- Solid infrastructure and excellent overall performance
  - Relying on group contributions for shift coverage and mentorship of colleagues

- 93 individuals from 22 Virgo groups participated in O4a
  - 70% are Early Career Researchers: PhD and Postdocs

- 161 people on the O4b rota from 26 institutions
  → Significant increase, coinciding with Virgo being part of the run

- Challenge ahead of us: keep that commitment high until the end of O4b
  → Will require participation from all Virgo groups
  → Shifts to be taken regularly during the run to ease global management

# DetChar highlights

- Organization: solid infrastructure inherited from O3 plus some novelties
  - Weekly meeting                                       Wiki pages
  - Two, recently started, gitlab projects
    - Tasks: monitor ongoing activities and ping DetChar intervention
      → Foster interactions among Data Analysis and Commissioning groups
    - Help for newcomers: request assistance from experts or discuss common issues

- O4b core activities
  - Continue the support to Commissioning and detector Operations
    - Monitoring and investigation of known issues
    - Prompt investigation of new noise sources
  - Data-quality products for low-latency and offline searches – including final dataset
  - Event validation – jointly with LIGO (and KAGRA)

- Personpower: still the main issue
  - Recent update of the Virgo Member Database
    → Size of the group decreased – but probably more realistic now
  - Individual commitment lower than in other Virgo activities
  - DetChar people scattered in many groups
  → Reduced knowledge transfer and limited mentoring possibilities

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# Calibration and h-reconstruction highlights

- Improved calibration and h-reconstruction methods
  - Uncertainties reduced and better estimated, bias accurately controlled
  - Better noise subtraction methods
  - Newtonian calibrators are complementing the photon calibrators

- Online monitoring + regular automated calibrations – both daily and weekly

- Preparation of the (offline) Analysis Ready frames
  - Improved uncertainties compared to online h(t)
  - Option to update bias
  - First month of O4b to be reprocessed – then only if needed
  - → Joint activity with DetChar

- Publications in preparation

- R&D activities focusing on h(t)-reconstruction in the time domain
  - Potentially a much lower latency

# Low latency highlights

- Virgo technical contributions limited by lack of personpower
  - LVK working group co-chair
  - Co-chair of the low-latency alert infrastructure review committee
  - → Low-latency framework is extremely complex

- Various ongoing developments
  - But difficult (and very time-consuming) to complete these projects and get ready to deploy them in production
  - Hard to find the balance between the will to use new functionalities and the need to protect the framework against unwanted consequences of updates
  - → Ongoing effort at the LVK level to document better and clarify the procedures
    - ◆ More versatile, less monolithic

- Virgo pipelines or pipelines with significant Virgo contributions all work well
  - cWB, MBTA and PyCBC Live

- 3 significant gravitational-wave alerts / week
  - 9 subthreshold events / day

- Latency of the automated alerts
  - 20 to 60 seconds for the first preliminary ▪ About 5 minutes for the second one

# Computing highlights

- Production software frozen before the start of O4b
  - Limited improvements and developments as needed

- Low latency data distribution up and running in production mode
  - Low-latency h(t): focus on latency spikes and monitoring

- Raw data transfer: data flowing with good performances at CNAF and CCIN2P3
  $\rightarrow$ Common efforts to reduce the raw data flux have helped in achieving this result

- Bulk data distribution
  - Prepared OSDF/CVMFS Louvain origin infrastructure working as expected and transitioned successfully to Rucio technology for aggregated h(t) data transfer
  - After dedicated tests with the Calibration group, ready to support the Analysis Ready files (for offline analyses) transfer, using the same infrastructure

- Low Latency pipelines
  - MBTA and cWB are running nominally and contributing to events discovery

- CVMFS-based file network system at EGO to improve performance

- Offline computing: nothing critical – no major resource contention seen nor expected
  - Data distribution infrastructure evolution $\Rightarrow$ shift towards distributed computing

# Open data highlights

- 7th GWOSC workshop took place mid-April
  - https://gwosc.org/odw/odw2024
    - → Internal "lessons learnt" document

- Data releases
  - To accompany the GW230529 article
  - Preparation of the O4a data release – and associated article

- Technical developments
  - Internal to ease the preparation of the next catalog issue GWTC-4
  - GWOSC website
  - Desktop app
  - …

- Discussion about whether the GWOSC website should host non-LVK catalogs

→ Small working group but very active, and with a lot of projects
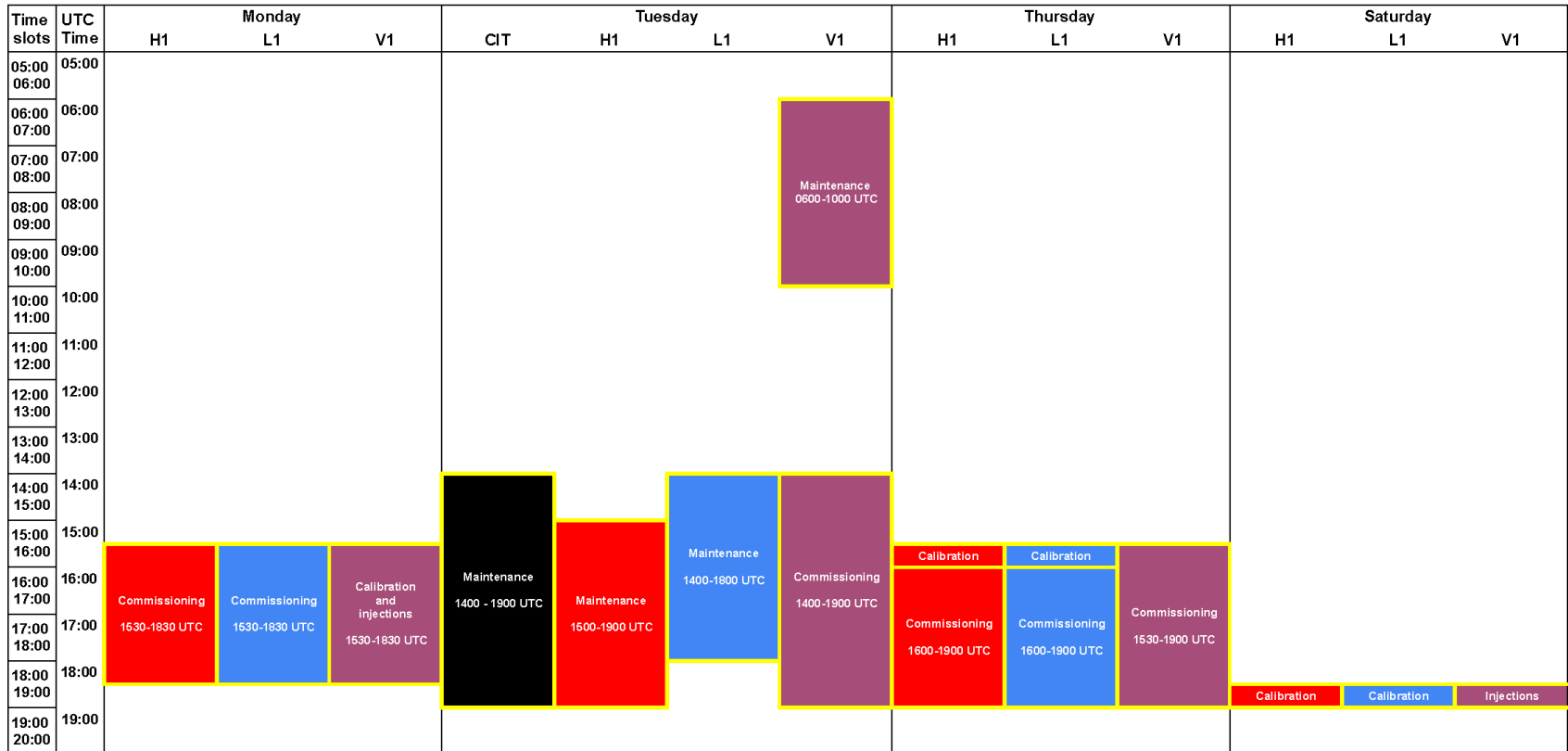
# To watch out: lessons learned so far

- Low-latency h(t) reconstruction at EGO for online gravitational-wave searches
  - Need to provide h(t) frames in a timely way even when the detector is down
    - → Direct (thus sensitive) interface with LIGO through the low-latency pipelines
  - Monitor latency + study its fluctuations + mitigate/fix their causes
  - Check low-latency h(t) frames when leaving the DAQ
    - → Immediate alert if latency too high or frame contents corrupted

  - Enforce rules to act on that (and other) critical part(s) of the Virgo framework
    - ◆ Any work should be announced and cleared
      by control room / coordinators before it may start
    - ◆ Use test systems/dataflows to not interfere with production Hrec
    - ◆ Once the activity is completed, monitor the system
      until back to nominal Science data taking

- Follow-up on errors done while steering Virgo, software bugs or features
  - Update documentation, improve procedure, implement protections, etc.

- Complexity of the low-latency system
  - → Difficulties to implement changes coherently

# Outlook

- Virgo started O4b on time and is committed to be part of the whole data taking period
  - The run has been extended by 4 months
    - → Manageable but complicated by the personpower limitation

- Excellent duty cycle so far
  - Virgo Science data available for most low-latency alerts
    - → Improve sky localization
  - Optimized LVK / run + commissioning planning to maximize 3-detector uptime
    - ◆ "Drawback": no detector observing up to ~10% of the time

- Focus on monitoring performance and improving things where possible

- All run-related working groups performing well

- Personpower remains limited but some balance has been found
  - Focus on critical areas
  - Priorities driven by issues identified and investigations done during the run

→ We'll see what the coming months bring us, but Spring hasn't been bad!

# LVK planning

- **Downtimes aligned** as much as possible among the three detectors
  - **Priority**: 3-detector data taking



| Time slots | UTC Time | Monday | | | Tuesday | | | | Thursday | | | Saturday | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | H1 | L1 | V1 | CIT | H1 | L1 | V1 | H1 | L1 | V1 | H1 | L1 | V1 |

Maintenance 0600-1000 UTC (V1, Tuesday)

Commissioning 1530-1830 UTC (H1, Monday)
Commissioning 1530-1830 UTC (L1, Monday)
Calibration and injections 1530-1830 UTC (V1, Monday)

Maintenance 1400 - 1900 UTC (CIT, Tuesday)
Maintenance 1500-1900 UTC (H1, Tuesday)
Maintenance 1400-1800 UTC (L1, Tuesday)
Commissioning 1400-1900 UTC (V1, Tuesday)

Calibration (H1, Thursday)
Calibration (L1, Thursday)
Commissioning 1600-1900 UTC (H1, Thursday)
Commissioning 1600-1900 UTC (L1, Thursday)
Commissioning 1530-1900 UTC (V1, Thursday)

Calibration (H1, Saturday)
Calibration (L1, Saturday)
Injections (V1, Saturday)

**Downtimes / week**

- **Maintenance**: 4 hours (2.4%)
- **Calibration**: 3 hours max. (1.8%)
- **Commissioning**: 8.5 hours max. (5.1%)
- **Injections**: 0.5 hour max. (0.3%)

→ **Up to 10% of duty cycle**

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# Data quality: spectral lines

- Spectral lines identification
  - Inputs from different, complementary tools
  - → O4b Catalog in progress





- Characterization of bilinear noise
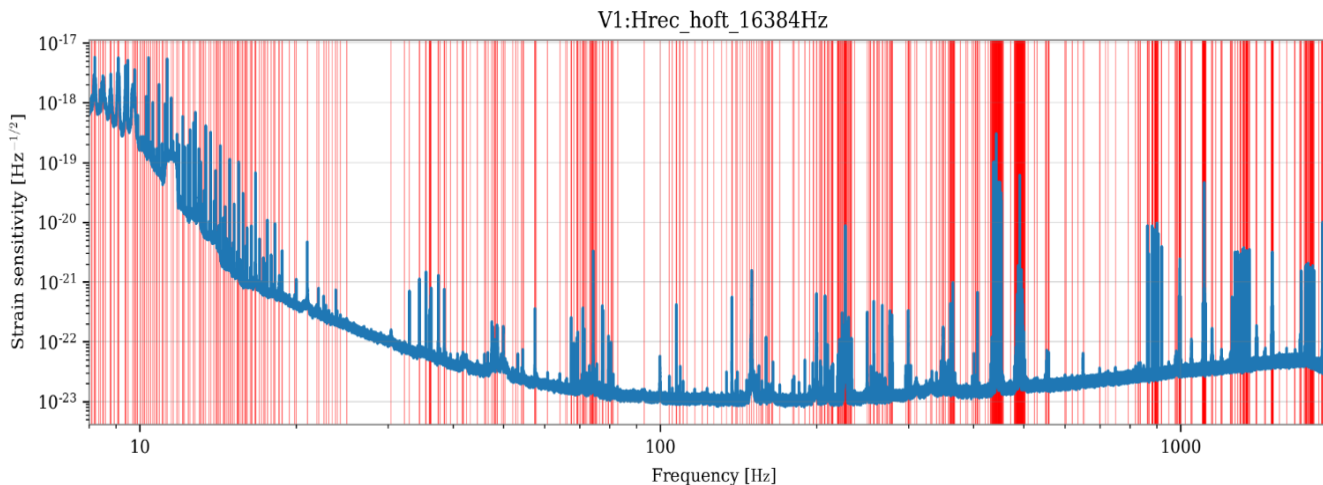  - Sidebands
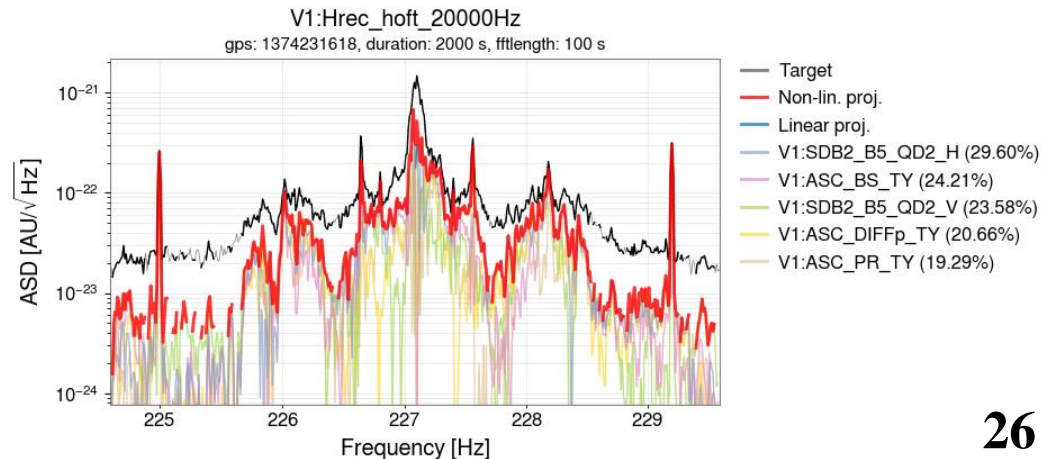
# Public alerts

- **Low-latency alert workflow**



A *significant* GW signal candidate is found by online search pipelines

A **GCN alert** is sent to astronomers in order to search for counterparts (EM waves or neutrinos)

The **RRT** provides rapid **human vetting of low-latency alerts**

- Foster multimessenger searches
- Trigger event validation and all downstream analyses
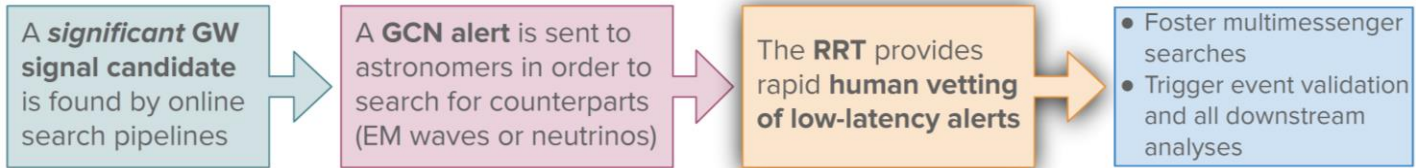
- **LVK data analysis framework**
  - ▪ Applies mostly to low latency as well

- **From detectors to alerts**
  [Old plot]