

# Data Monitoring and DQ Flags for GW Analysis

**Brennan Hughey**

**GW - Detector Characterization Workshop**

**IUCAA – Pune**

**December 19, 2025**

# Introduction

- About the speaker
  - Current physics and astronomy department chair at Embry-Riddle Aeronautical University in Prescott Arizona
  - Has been involved in production of data quality flags in O2, O3, and O4 (most heavily in O3 and O4a)
  - Co-chair of the LIGO DetChar group for 3 years 2020-2023
  - Engaged with real-time vetting of GW transient candidates throughout O4
  - A couple notes on completeness
    - Speaker is coming at things from a LIGO-specific perspective
    - I'm mentioning some names throughout this talk; I've presumably forgotten some
- Other good points of contact: Francesco Di Renzo and Evan Goetz are good contacts who are at this workshop. Nicolas Arnaud, Derek Davis, Jane Glanzer, Laura Nuttall, are other good contacts in IGWN regarding the issues discussed here

# Data Quality Flags

- Detector Characterization will ideally work with commissioners to mitigate data quality issues so they don't continue affecting data, but:
  - Some data will already be contaminated once an issue is fixed
  - Fixing data quality issues can be difficult and time consuming
- A small percentage of each run's data is discarded (vetoed) in a time domain basis (e.g. specific seconds of data are thrown out).
  - Evan Goetz will talk about frequency domain data removal
  - It is painful to throw out data required at substantial expense & effort, but statistical significance of detections is increased when the worst data is thrown out

# Categories of Data Quality Flags: CAT 1

- **Category 1** flags define periods of data which should not be analyzed. Generally these include
  - The same definitions for each search group
    - exceptions have been made
  - Seconds to hours in larger chunks that don't break up data
    - (pre-lockloss flags are shorter than most Category 1 but don't break up data chunks)
  - Removal of specified data before analysis is conducted
  - Typically, at least 1 subsystem is not operating in its nominal configuration
  - This data is not made available publicly as part of GWOSC

# Categories of Data Quality Flags: CAT 2+

- **Category 2** flags define typically shorter and more numerous periods removed from results after analysis has been conducted
  - Stochastic and Continuous Wave searches have not used this category since it breaks up data into too many chunks
  - Compact Binary Coalescence searches have discontinued the use of category 2 flags since it is possible to detect Gravitational Waves in noisy data (noise subtraction, etc.) and the morphology of CBCs is distinct against backgrounds. Some analyses use iDQ instead
  - Burst transient searches, in which the signal can more closely resemble background, continue to use Category 2, but at a reduced rate due to limits in personpower and the development of other veto methods
- **Category 3 and 4** flags (advisory and hardware injection) existed in previous runs but are no longer relevant to gravitational wave analysis

# Standards for Defining Data Quality Flags

- Category 1 flags can be defined when data is acquired but the detector isn't properly functioning as an interferometer
  - e.g., Beckhoff chassis alignment problem in O3
- In most cases, efficiency/deadtime ratio is used to evaluate the efficacy of vetoes
  - Efficiency is percentage of strain channel triggers surviving (omicron or other ETG)
  - Deadtime is percentage of total analysis time vetoed by flag
- Safe\* auxiliary witness channels should be used to construct data quality flags for all Category 2 flags (based on known and understood couplings) and where that makes sense for Category 1

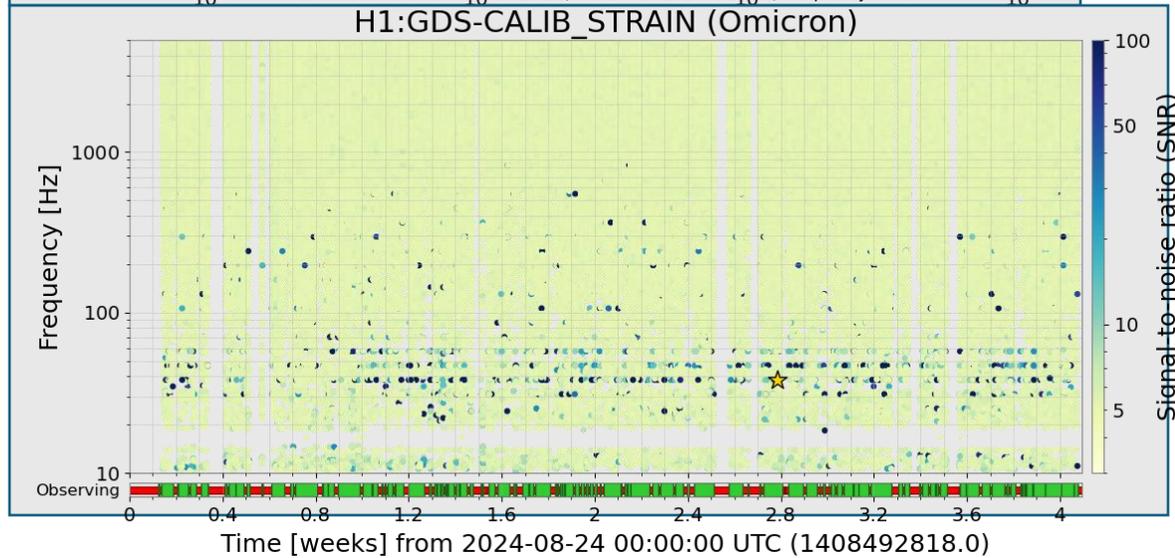
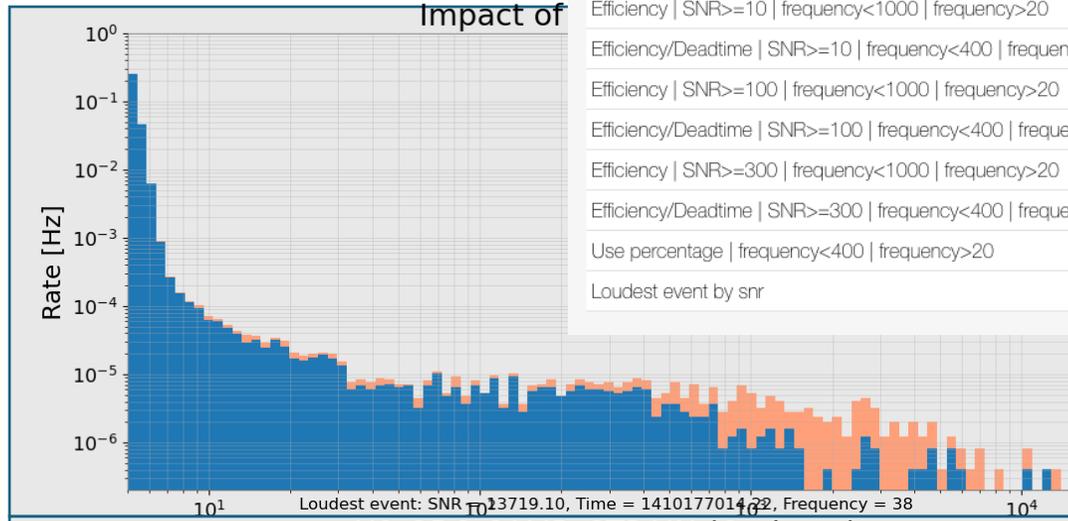
## \*Channel Safety

- Some auxiliary channels also witness gravitational wave signals. It needs to be established on a statistical and logical basis that actual gravitational waves do not produce signals in an auxiliary channel used for flag production

# Veto Evaluation Testsuite: VET

## Flag performance summary

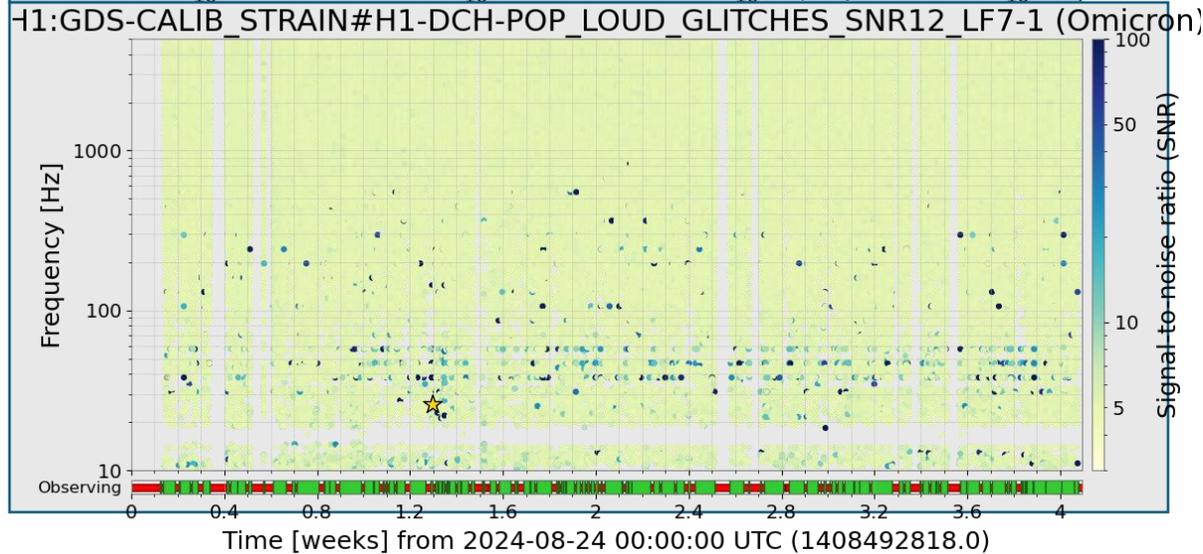
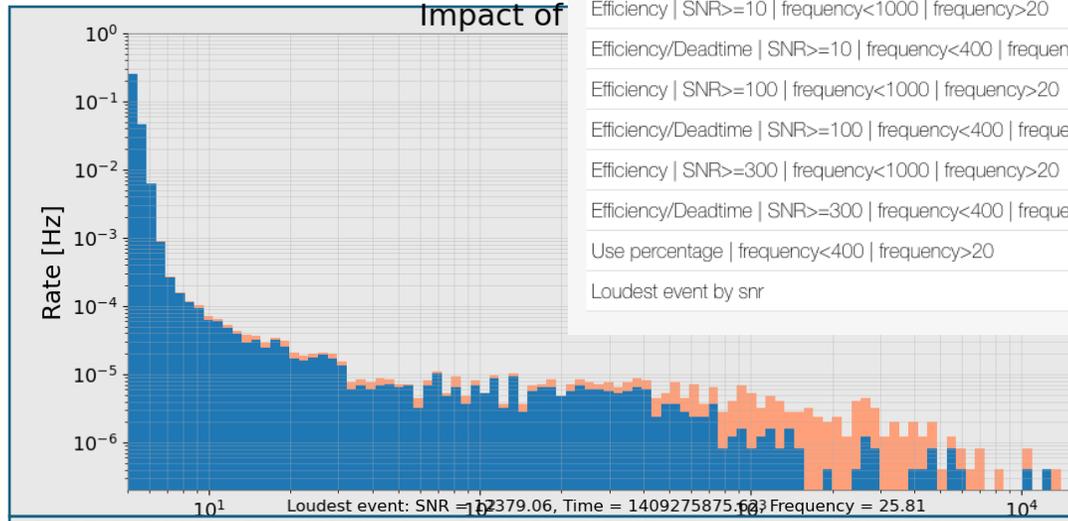
Metric	Result	Description
Deadtime	0.21%	The active duration of a given set of segments
Efficiency   frequency<400   frequency>20	0.88%	The decimal fraction of events vetoed by the given segments (frequency < 400.0) (frequency > 20.0)
Efficiency/Deadtime   frequency<1000   frequency>20	2.40	The ratio of efficiency to deadtime (frequency < 1000.0) (frequency > 20.0)
Efficiency   SNR>=10   frequency<1000   frequency>20	17.18%	The decimal fraction of events vetoed by the given segments (SNR >= 10.0) (frequency < 1000.0) (frequency > 20.0)
Efficiency/Deadtime   SNR>=10   frequency<400   frequency>20	86.81	The ratio of efficiency to deadtime (SNR >= 10.0) (frequency < 400.0) (frequency > 20.0)
Efficiency   SNR>=100   frequency<1000   frequency>20	41.42%	The decimal fraction of events vetoed by the given segments (SNR >= 100.0) (frequency < 1000.0) (frequency > 20.0)
Efficiency/Deadtime   SNR>=100   frequency<400   frequency>20	212.50	The ratio of efficiency to deadtime (SNR >= 100.0) (frequency < 400.0) (frequency > 20.0)
Efficiency   SNR>=300   frequency<1000   frequency>20	59.15%	The decimal fraction of events vetoed by the given segments (SNR >= 300.0) (frequency < 1000.0) (frequency > 20.0)
Efficiency/Deadtime   SNR>=300   frequency<400   frequency>20	303.11	The ratio of efficiency to deadtime (SNR >= 300.0) (frequency < 400.0) (frequency > 20.0)
Use percentage   frequency<400   frequency>20	51.93%	The decimal fraction of segments that are used to veto triggers (frequency < 400.0) (frequency > 20.0)
Loudest event by snr	9.77%	Percentage reduction in the amplitude of the loudest event by snr



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# Flag Construction

- Utilizes GWpy framework
- Can be based on BLRMS, ETG generation from an auxiliary etc.
- Script repository is available here:  
[https://git.ligo.org/detchar/veto-definitions/-/tree/master/scripts?ref\\_type=heads](https://git.ligo.org/detchar/veto-definitions/-/tree/master/scripts?ref_type=heads)
- One of Derek Davis's notebooks documenting construction is here: [https://ldas-jobs.ligo-wa.caltech.edu/~derek.davis/detchar/O4/flag\\_investigations/cal\\_lines\\_broken/test\\_flag\\_config.html](https://ldas-jobs.ligo-wa.caltech.edu/~derek.davis/detchar/O4/flag_investigations/cal_lines_broken/test_flag_config.html)

# Automated procedures: iDQ

iDQ and other algorithms may be used in an automated way to produce vetoes or downweighting

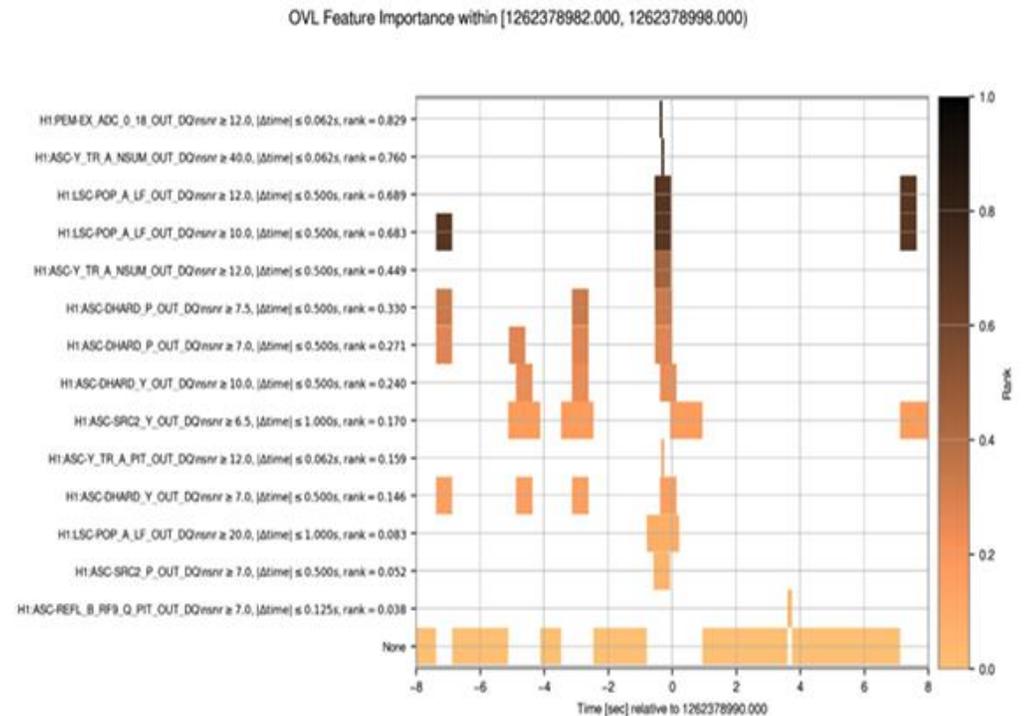
<https://dcc.ligo.org/LIGO-G2300585>

<https://arxiv.org/abs/2412.04638>

Hveto and other ETGs

have also been used in a similar capacity for vetoes in the past

<https://arxiv.org/abs/1107.2948>



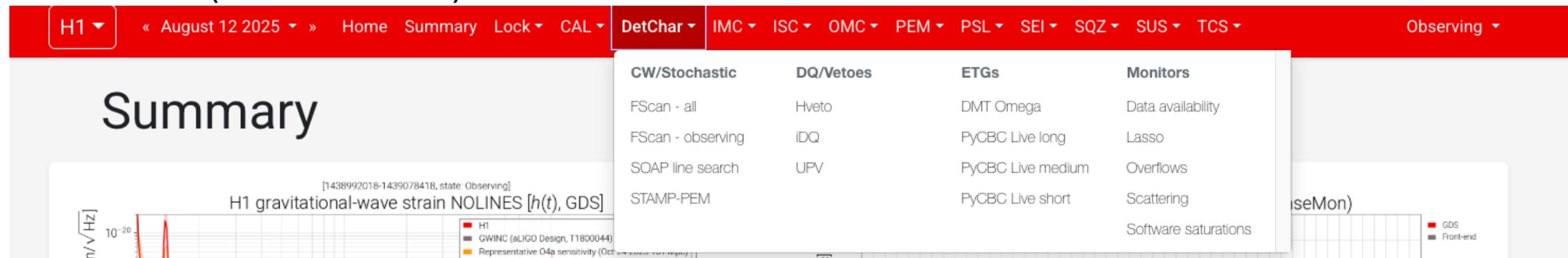
# How is the data monitored and the need for data quality flags identified? (1)

- Analyses can report issue, either from online analysis or early offline running
- Monitoring of alogs
  - <https://alog.ligo-la.caltech.edu/aLOG/>
  - <https://alog.ligo-wa.caltech.edu/aLOG/>
- Direct notice from commissioners
  - <https://chat.ligo.org/ligo/channels/detchar-llo>

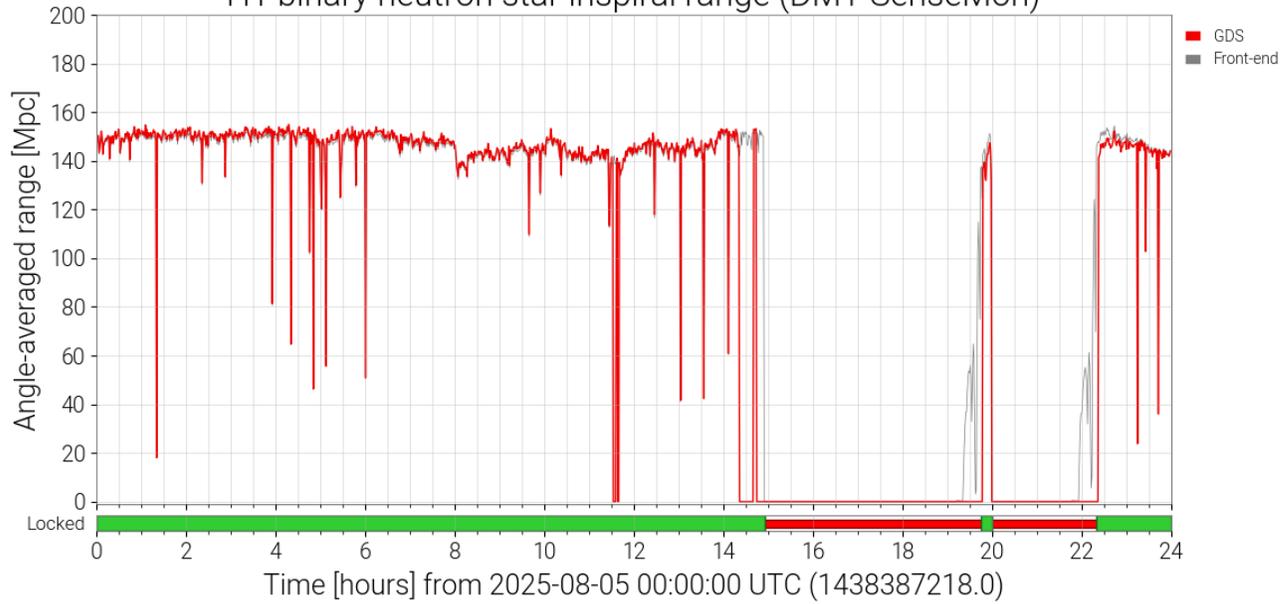
# How is the data monitored and the need for data quality flags identified? (2)

## Issues identified from summary pages

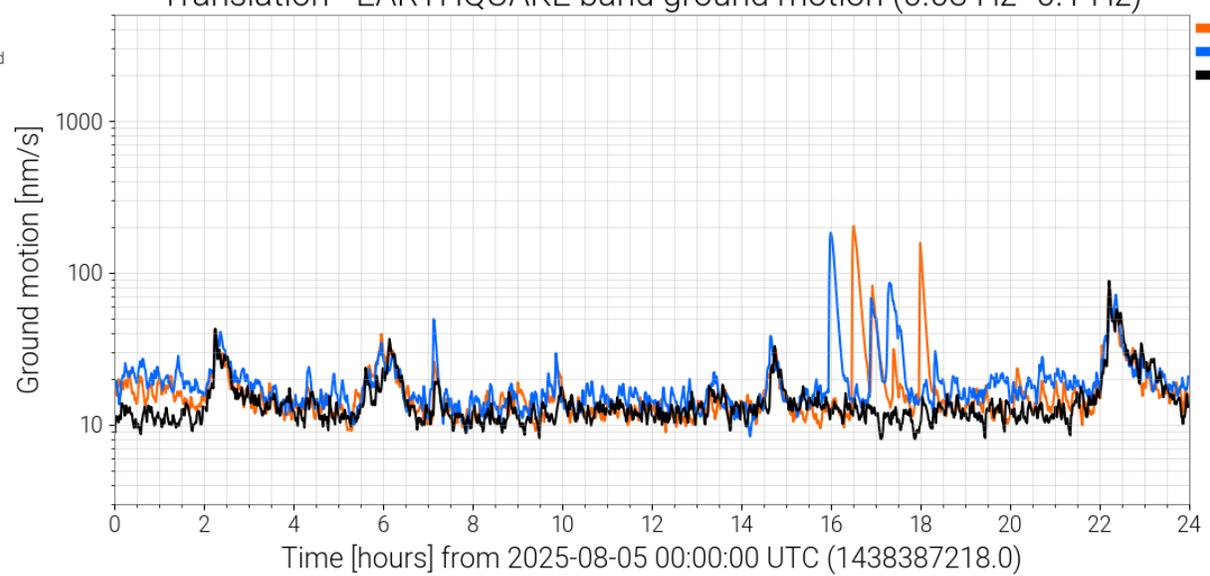
- <https://ldas-jobs.ligo.caltech.edu/~detchar/summary/day/20251215/>
- Sometimes a heads-up from a data quality shift (<https://dcc.ligo.org/LIGO-G2300088> )
- In addition to the frontpage, SEI BLRMS and analysis-specific pages are useful to check
- (see next slide)



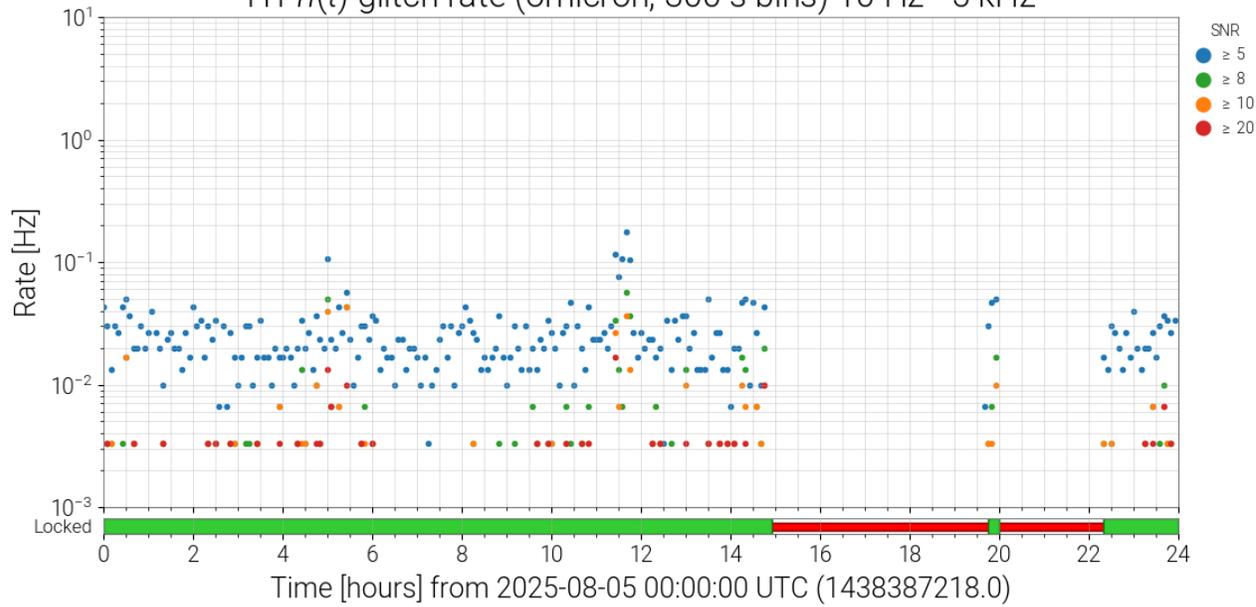
H1 binary neutron star inspiral range (DMT SenseMon)



Translation - EARTHQUAKE band ground motion (0.03 Hz--0.1 Hz)

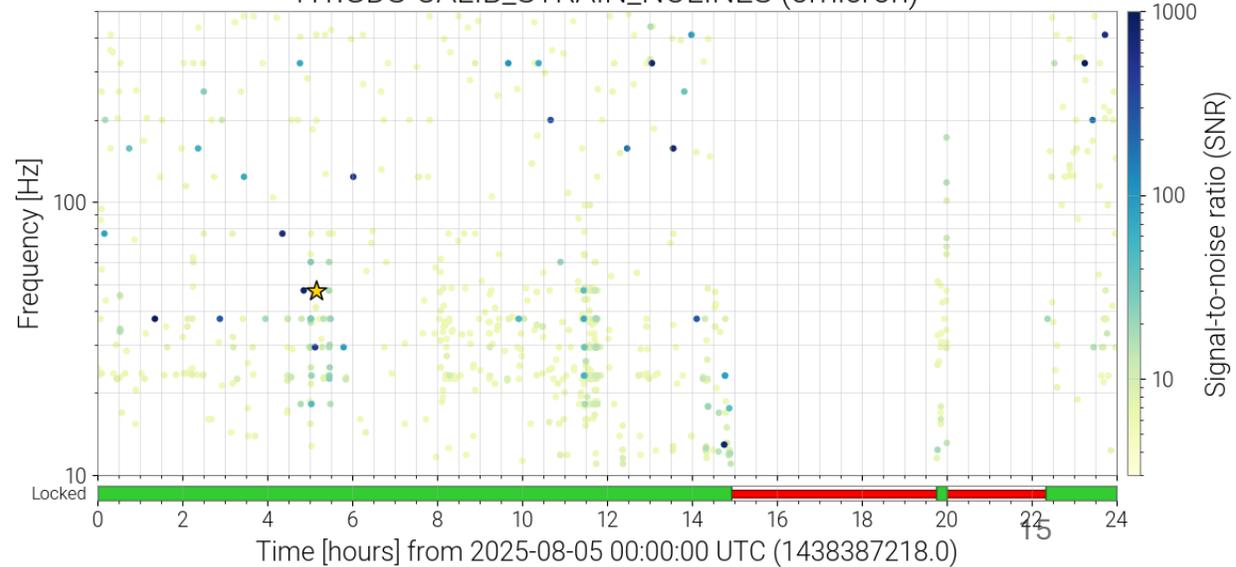


H1  $h(t)$  glitch rate (omicron, 300 s bins) 10 Hz - 5 kHz



Loudest event: SNR = 8047.07, Time = 1438405734.59, Frequency = 47.41

H1:GDS-CALIB\_STRAIN\_NOLINES (omicron)



# Technical infrastructure

- The Data Quality Segment DataBase (DQSegDB) has stored data quality flags since initial LIGO days, with integer-second flag definitions
- LIGO, Virgo, and Kagra flags inserted into same database for utilization in joint analyses
- Permission managed by a grouper group, Robert Bruntz is best contact if you need write access
- Analyses use the appropriate xml-based veto definer file to specify which flags will be applied and over what periods, accessed with GWpy interface

1, "Missing H1 calibrated h(t) data",0,0,"H1","DCS-MISSING\_H1\_HOFT\_C00",1,0,1366556418,1,  
1, "Stochastic hardware injections",0,0,"H1","DMT-INJECTION\_STOCHASTIC",2,0,1366556418,1,  
1, "DetChar hardware injections",0,0,"H1","DMT-INJECTION\_DETCHAR",3,0,1366556418,1,  
1, "Ring-up of PI mode 29 located near 80 kHz",0,1404196636,"H1","DCH-80KHZ\_PI\_MODE\_29\_HIGH",4,0,1369771903,1,  
1, "Segments when DMT-OBS\_INTENT not defined May 10",0,1367798418,"H1","DCH-OBS\_INCORRECTLY\_DEFINED",5,0,1367712018,1,  
1, "Times where the calibration lines are not correctly subtracted by the subtraction pipeline",0,1422118818,"H1","DCH-CAL\_LINES\_NOT\_SUBTRACTED",6,0,1370044818,1,  
1, "ADF servo caused an issue with squeezer performance",0,1387490418,"H1","DCH-SQZ\_ERROR\_ADF\_SERVO",7,0,1387487358,1,  
1, "Broadband excess noise right after two locking periods due to line subtraction problems.",0,1399180518,"H1","DCH-BROADBAND\_LINE\_SUBTRACTION\_NOISE\_MAY7\_MAY8",8,0,1399083266,1,  
1, "Local earthquake near LHO that cause extreme scattering for multiple minutes",0,1397622318,"H1","DCH-LOCAL\_EQ\_20240420",9,0,1397621958,1,  
1, "Broadband low frequency noise from 10 to 100 hz",0,1404134569,"H1","DCH-BROADBAND\_LOW\_FREQ\_NOISE\_10\_100HZ\_JULY4",10,0,1404132468,1,  
1, "SQZ OPO issues at LIGO Hanford causing severe degredation of the range",0,1400246431,"H1","DCH-SQZ\_OPO\_ISSUE\_20240520",11,0,1400242458,1,  
1, "Remove 4 seconds at the end of each lock stretch",0,0,"H1","DMT-PRE\_LOCKLOSS\_4",12,0,1394982018,1,  
1, "10 Khz PI mode ringups",0,1411344018,"H1","DCH-PI\_10KHZ\_MODE\_COMPUTE\_100",13,0,1410566418,1,  
1, "Start-up issues with line subtraction after code update",0,1409427138,"H1","DCH-CAL\_LINE\_SUB\_UPDATE\_ISSUE",14,0,1409424948,1,  
1, "Long duration start up issues with line subtraction",0,1410206178,"H1","DCH-CAL\_LINE\_SUB\_LONG\_DURATION",15,0,1410205078,1,  
1, "Loud, broadband glitching in December at H1 with no known origin; TCS channel was noted to be a valuable witness",0,1417948638,"H1","DCH-DEC\_2024\_BROADBAND\_TCS\_WITNESS",16,0,1417148238,1,  
1, "Loud, broadband noise during active times",0,1418106078,"H1","DCH-SQZ\_GLITCH\_10\_100\_HZ\_13\_DEC",17,0,1418105058,1,  
1, "Loud, broadband noise in higher frequencies that corresponds to SQZ behavior at the start of lock",0,1422098778,"H1","DCH-SQZ\_HIGH\_FREQ\_JAN",18,0,1421094078,1,  
1, "Short jumps in BNS range from OPO temp changes",0,1412778798,"H1","DCH-BROADBAND\_SPECTRUM\_CHANGE\_OPO\_TEMP",19,0,1412692518,1,  
1, "Several locklosses on this day, mostly noted to be due to the rising microseism and FSS glitching.",0,1414640658,"H1","DCH-RANGE\_DECAY\_BROADBAND\_NOISE",20,0,1414639698,1,  
1, "Periods where the line subtraction turns on suddenly mid-lock",0,1411539398,"H1","DCH-MID\_LOCK\_SUBTRACTION\_TURN\_ON",21,0,1410817158,1,  
1, "Start of locks where there was excessive violin modes",0,1412591690,"H1","DCH-EXCESSIVE\_VIOLIN\_RINGDOWN",22,0,1411650716,1,  
1, "Broadband glitching on 2024-12-11 identified by stochnon",0,1417981578,"H1","DCH-BROADBAND\_GLITCHING\_20241211",23,0,1417981278,1,  
1, "Missing L1 calibrated h(t) data",0,0,"L1","DCS-MISSING\_L1\_HOFT\_C00",24,0,1366556418,1,  
1, "Stochastic hardware injections",0,0,"L1","DMT-INJECTION\_STOCHASTIC",25,0,1366556418,1,  
1, "DetChar hardware injections",0,0,"L1","DMT-INJECTION\_DETCHAR",26,0,1366556418,1,  
1, "Segments when DMT-OBS\_INTENT not defined May 11",0,1367884818,"L1","DCH-OBS\_INCORRECTLY\_DEFINED",27,0,1367798418,1,  
1, "Rapid turn on of calibration line subtraction biased estimates of the PSD",0,1383937225,"L1","DCH-CALIBRATION\_LINE\_SUBTRACTION\_ERROR\_NOV13",28,0,1383936925,1,  
1, "Violin mode ring-ups affected time-dependent calibration parameters",0,1388233982,"L1","DCH-CALIBRATION\_ERROR\_FROM\_VIOLINMODES",29,0,1388233979,1,  
1, "Violin mode ringup disturbed DARM and caused lockloss",0,1387905096,"L1","DCH-VIOLIN\_MODE6\_RINGUP\_TO\_LOCKLOSS\_DEC29",30,0,1387905075,1,  
1, "Extreme violin mode ring ups causing non-linear noise artifacts on Jan 2 2024",0,1388233982,"L1","DCH-VIOLIN\_MODE\_RINGUP\_JAN2",31,0,1388233638,2,  
1, "Sporadic data dropouts that caused the line subtraction to fail for short periods in May 2024",0,1400938049,"L1","DCH-CAL\_LINE\_DATA\_DROPOUTS",32,0,1399749384,2,  
1, "L1 lost lock due to a slow ringup of ETMX.",0,1397282131,"L1","DCH-ETMX\_VIOLIN\_MODE\_RINGUP\_APR16",33,0,1397281038,1,  
1, "There was some saturation of photodiodes on ETMX due to some tuning of the violin mode damping.",0,1397396418,"L1","DCH-PD\_SATURATION\_FROM\_VIOLIN\_DAMPING\_APR17",34,0,1397395716,1,  
1, "Remove 4 seconds at the end of each lock stretch",0,0,"L1","DMT-PRE\_LOCKLOSS\_4",35,0,1394982018,1,  
1, "Excess noise due to power issues with PCALY",0,1407989478,"L1","DCH-PCALY\_NOISE\_10HZ\_100HZ\_AUG18",36,0,1407984618,1,  
1, "Loud glitching near 60 Hz due to loose SQZ cable",0,1405868478,"L1","DCH-SQZ\_CABLE\_60HZ\_NOISE",37,0,1405036758,1,  
1, "Start-up issues with line subtraction after code update",0,1409428878,"L1","DCH-CAL\_LINE\_SUB\_UPDATE\_ISSUE",38,0,1409426678,1,  
1, "Start-up issues with line subtraction after PCAL injection swap",0,1408656978,"L1","DCH-CAL\_LINE\_SUB\_SWAP",39,0,1408656669,1,  
1, "Fire drill at L1 which caused a brief moment of high frequency noise",0,1414332558,"L1","DCH-FIRE\_DRILL\_HF\_OCT\_30",40,0,1414332258,1,  
1, "Sharp feature from 10 to 40 hz that causes loud glitches",0,1414641318,"L1","DCH-SHARP\_FEATURE\_10\_40\_HZ\_NOV\_3",41,0,1414640778,1,  
1, "The jump in the range is due to a change in the SQZ phase.",0,1416330018,"L1","DCH-SQZ\_PHASE\_ADJUSTMENT\_NOV\_22",42,0,1416329778,1,  
1, "L1 experience extreme amounts of scattering due to microseism glitching",0,1417967238,"L1","DCH-HIGH\_MICRO\_NOISE\_DEC11",43,0,1417940838,1,  
1, "20 and 30 hz noise flagged by stochnon",0,1423547058,"L1","DCH-STOCHMON\_RINGUP\_20\_30\_HZ",44,0,1418998698,1,  
1, "Updating offline flag DQ\_CAT1\_SATURATION\_SUSP\_OR\_OFFLINE\_04:1",0,1422118818,"V1","DQ\_CAT1\_SATURATION\_SUSP\_OR\_OFFLINE\_04",45,0,1396796418,1,  
1, "Updating offline flag DQ\_CAT1\_LOCK\_LAST\_10S\_OFFLINE\_04:1",0,1422118818,"V1","DQ\_CAT1\_LOCK\_LAST\_10S\_OFFLINE\_04",46,0,1396796418,1,  
1, "Updating offline flag DQ\_CAT1\_SCIENCE\_FALSE\_OFFLINE\_04:1",0,1422118818,"V1","DQ\_CAT1\_SCIENCE\_FALSE\_OFFLINE\_04",47,0,1396796418,1,  
1, "Updating offline flag DQ\_CAT1\_SATURATION\_OMICRON\_OFFLINE\_04:1",0,1422118818,"V1","DQ\_CAT1\_SATURATION\_OMICRON\_OFFLINE\_04",48,0,1396796418,1,  
1, "Updating offline flag DQ\_CAT1\_SATURATION\_B1\_PD1\_OFFLINE\_04:1",0,1422118818,"V1","DQ\_CAT1\_SATURATION\_B1\_PD1\_OFFLINE\_04",49,0,1396796418,1,  
1, "Updating offline flag DQ\_CAT1\_SATURATION\_B1\_PD2\_OFFLINE\_04:1",0,1422118818,"V1","DQ\_CAT1\_SATURATION\_B1\_PD2\_OFFLINE\_04",50,0,1396796418,1,  
1, "Updating offline flag DQ\_CAT1\_SATURATION\_B1p\_PD1\_OFFLINE\_04:1",0,1422118818,"V1","DQ\_CAT1\_SATURATION\_B1P\_PD1\_OFFLINE\_04",51,0,1396796418,1,  
1, "Updating offline flag DQ\_CAT1\_SATURATION\_B1p\_PD2\_OFFLINE\_04:1",0,1422118818,"V1","DQ\_CAT1\_SATURATION\_B1P\_PD2\_OFFLINE\_04",52,0,1396796418,1,  
1, "Updating offline flag DQ\_CAT1\_HREC\_BAD\_QUALITY\_OFFLINE\_04:1",0,1422118818,"V1","DQ\_CAT1\_HREC\_BAD\_QUALITY\_OFFLINE\_04",53,0,1396796418,1,  
2, "Online ETMX ESD DAC Overflow monitor",1,0,"H1","DMT-DQ\_VECTOR\_BIT4\_VETO",54,-1,1368144018,1,  
2, "Online ETMX ESD DAC Overflow monitor",1,0,"L1","DMT-DQ\_VECTOR\_BIT4\_VETO",55,-1,1368144018,1,  
1, "Removing 80 Khz PI mode ringup from July 16 through Sept18",0,1410652818,"H1","DCH-PI\_80KHZ\_MODE\_JULY16\_SEPT18",56,0,1405123218,1,  
1, "Ring-up of PI mode 5 located near 24 kHz",0,1377262472,"L1","DCH-20KHZ\_PI\_MODE\_5\_HIGH",57,0,1377262287,2,  
2, "Persistent high SNR glitches associated with light intensity dips (04a)",1,1389455118,"H1","DCH-POP\_LOUD\_GLITCH\_04",58,-1,1368144018,2,  
2, "Persistent high SNR glitches associated with light intensity dips (04b)",1,0,"H1","DCH-POP\_LOUD\_GLITCH\_04",59,-1,1396797018,3,  
2, "Electrical glitches between 40-100 Hz",0,1378598418,"L1","DCH-ESD24\_EX\_GLITCHES",60,0,1368144018,1,  
2, "Loud glitches witnessed in ASC-X\_TR (04a)",0,1389455118,"L1","DCH-TR\_X\_LOUD\_GLITCH\_04",61,0,1368144018,2,  
2, "Loud glitches witnessed in ASC-Y\_TR (04b)",0,0,"L1","DCH-TR\_Y\_LOUD\_GLITCH\_04",62,0,1396797018,2

Here is the O4 Burst  
Veto Definer File

# Some Takeaways from Definer File: by the numbers

- 62 flags
  - 9 V1, 25 L1, 28 H1
  - 7 Category 2 flags, 55 Category 1
  - 67 total flags in O3 over a shorter run
  - More deadtime during engineering run right before start of run; things settle down after

Deadtime from O4a was less than one-tenth of one percent for CAT1 flags in each LIGO interferometer and  $O(0.1\%)$  for Burst Category 2 in each LIGO interferometer

# Some (More) Takeaways from Definer File

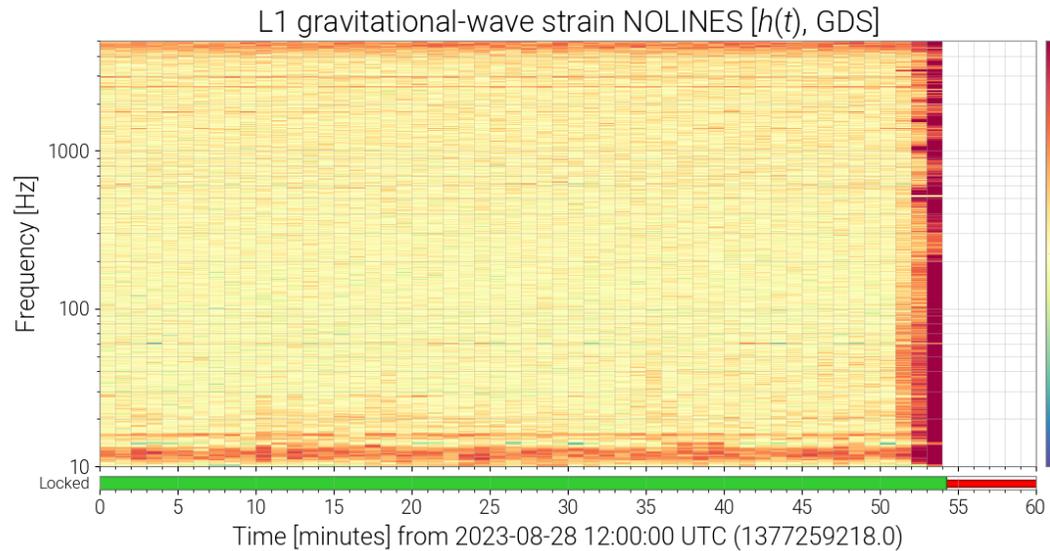
- Some issues requiring multiple flags
  - Parametric Instability modes
  - Issues with squeezer system
  - Violin modes
  - Calibration line subtraction
  - Earthquakes and microseism
  - Once a run or so a fire alarm requires flagging
- Some issues successfully mitigated in O3
  - No RF interference / whistle flagging necessary
  - Light scattering is a much-reduced issue
- More flagging was necessary in engineering run and newer systems like squeezer require more mitigation – LIGO India should expect more upfront need for flags
- **Direct** contributors to flags in O4: Nicolas Arnaud, Robert Bruntz, Derek Davis, Francesco Di Renzo, Jane Glanzer, Evan Goetz, Brennan Hughey, Amber Stuver, Zach Yarborough, Yanyan Zheng

# Some (More) Takeaways from Definer File

- Some issues requiring multiple flags
  - Parametric Instability modes
  - Issues with squeezer system
  - Violin modes
  - Calibration line subtraction
  - Earthquakes and microseism
  - Once a run or so a fire alarm requires flagging
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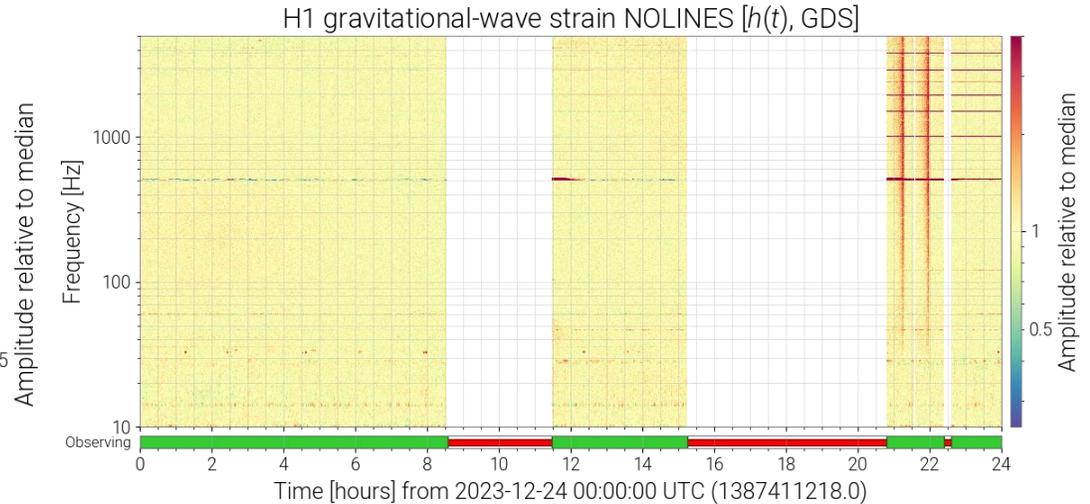
Internal detector issues, though environment (e.g., seismic noises) may be indirect cause

# Visual Representations of 2 CAT 1 issues in O4



Parametric instability

<https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=66978>



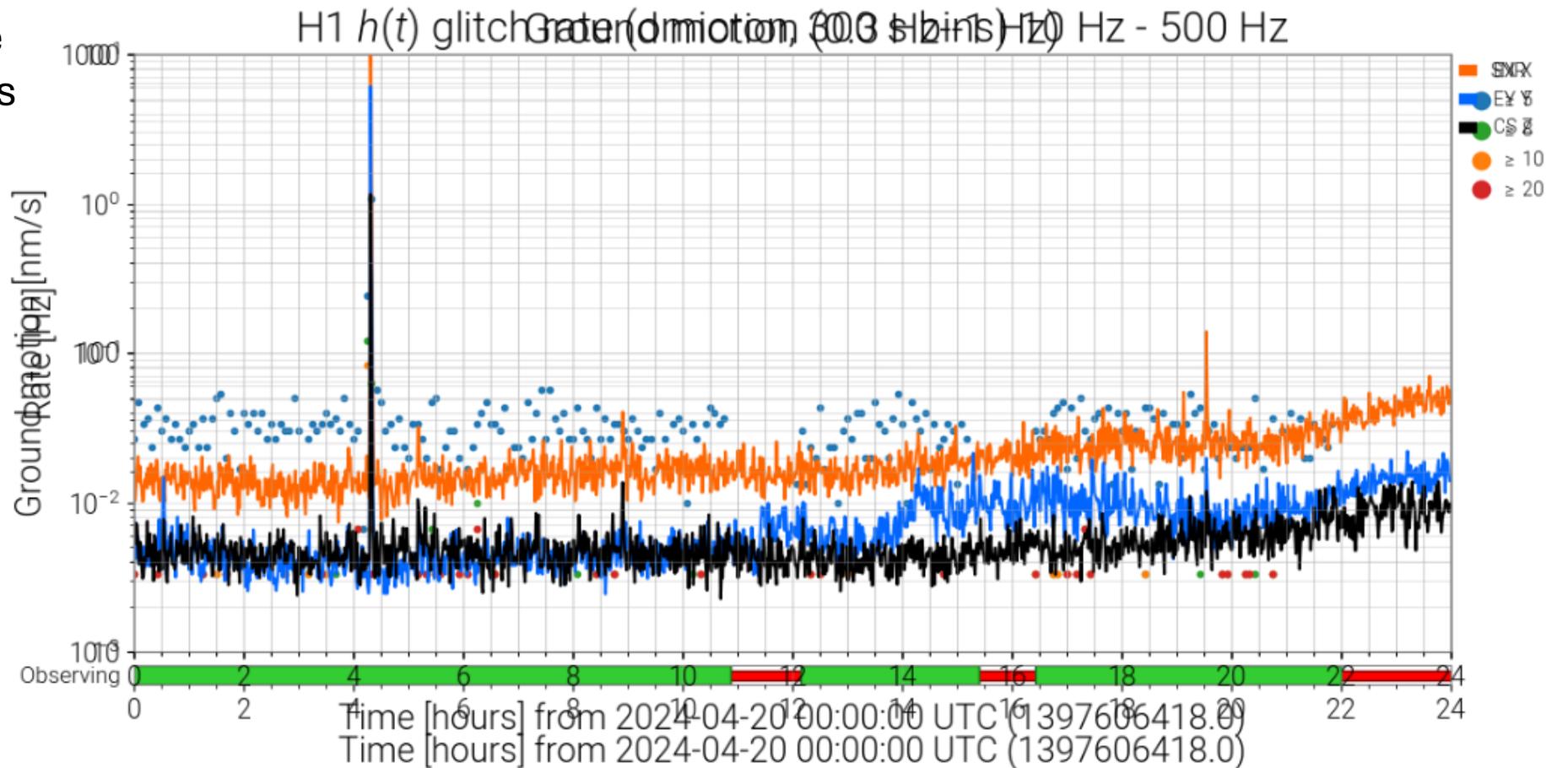
Squeezer issue

<https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=75023>

(Note though that we don't do DetChar just by visual inspection, other issues may visually look as bad and not actually affect analyses. Also make sure the summary pages are only showing Observing mode data)

# CAT 1 Earthquake Flag April 20, 2024

Overlay of trigger rate with seismic monitors



# Issues with the current system

- Recurrent issues with personpower
  - Analyses must wait for Category 1 flags before they can start
  - Hard to assign sufficient personpower to flag development
- Technical debt
  - DetChar computing also suffers from personpower issues
  - Updates to more recent version of Python and integration of SciTokens have happened in this run
- Interface between analysis and commissioners relies on a very few individuals

# Going Forward

- Moving towards increased automation, e.g. iDQ
- Role of data quality flags has gradually reduced as noise subtraction, statistical downweighting and other tools have made it possible to detect GWs in noisy data
- Persistent need for flagging and data quality infrastructure continues to exist

# Resources

- Detector characterization papers
  - LIGO Early O4 <https://arxiv.org/abs/2409.02831>
  - Virgo O3 <https://arxiv.org/abs/2210.15633>  
<https://arxiv.org/abs/2210.15634>
  - LIGO O2 and O3 <https://arxiv.org/abs/2101.11673>

Veto Definitions repository: <https://git.ligo.org/detchar/veto-definitions>

Gwpy interface and data quality(Laura Nuttall)

[https://dcc.ligo.org/DocDB/0176/G2100957/003/gwosc\\_detchar\\_0521.pdf](https://dcc.ligo.org/DocDB/0176/G2100957/003/gwosc_detchar_0521.pdf)

LIGO Flag plans in O4

[https://dcc.ligo.org/DocDB/0187/T2300159/002/DQ\\_flag\\_plan\\_for\\_O4.pdf](https://dcc.ligo.org/DocDB/0187/T2300159/002/DQ_flag_plan_for_O4.pdf)

Public-facing summary of flags applied in O3

<https://dcc.ligo.org/LIGO-T2100045>