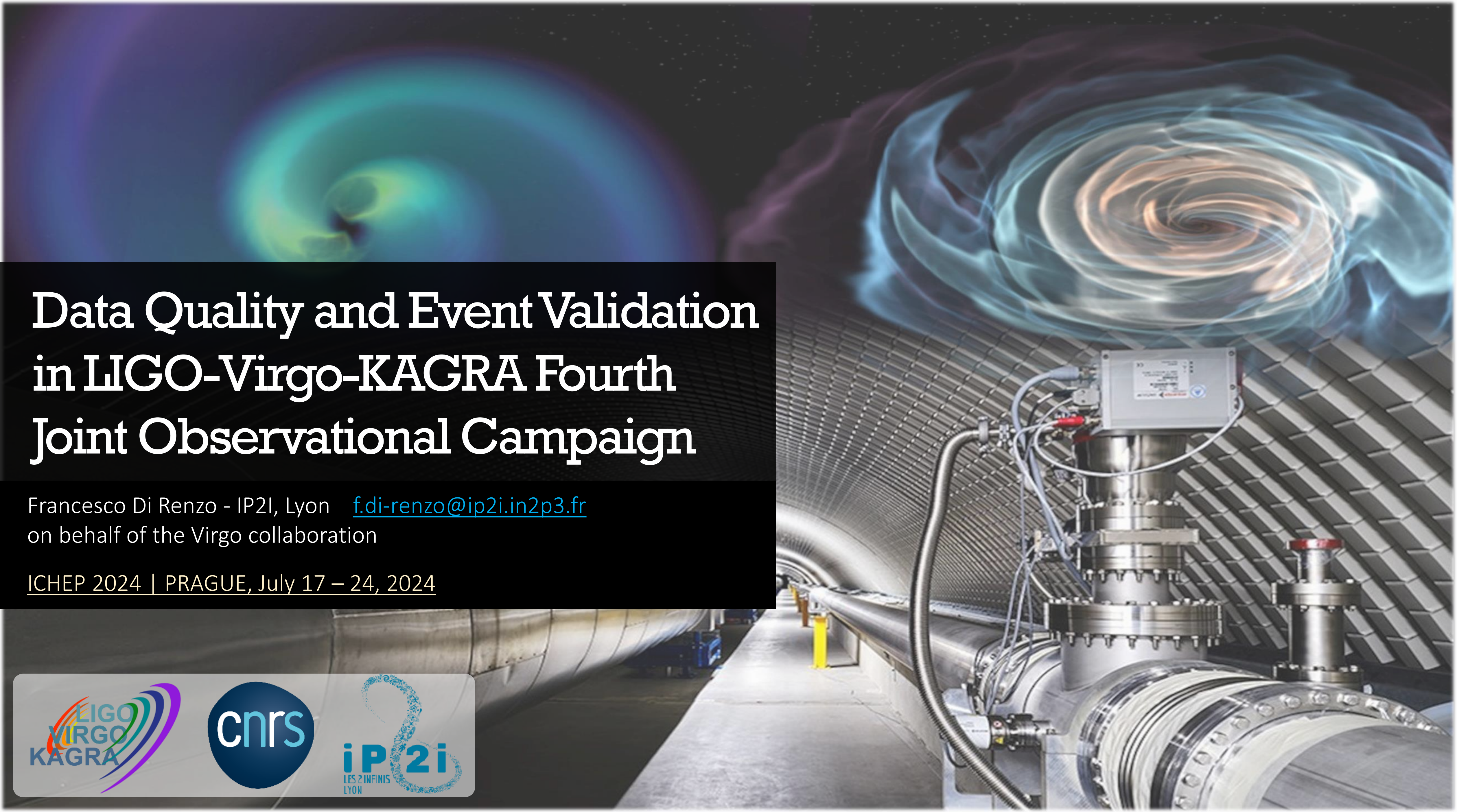


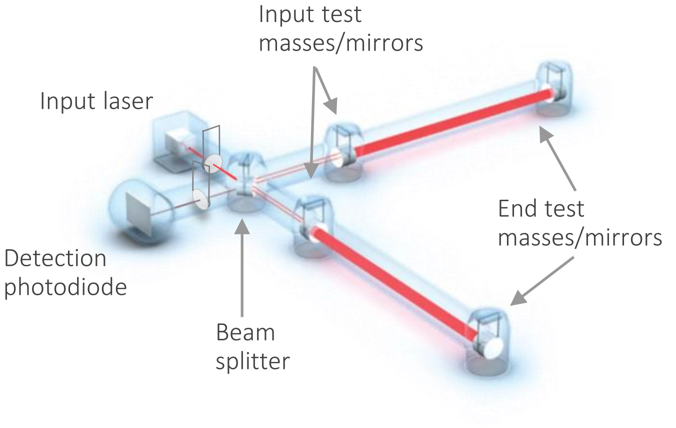
Data Quality and Event Validation in LIGO-Virgo-KAGRA Fourth Joint Observational Campaign

Francesco Di Renzo - IP2I, Lyon   f.di-renzo@ip2i.in2p3.fr
on behalf of the Virgo collaboration

ICHEP 2024 | PRAGUE, July 17 – 24, 2024

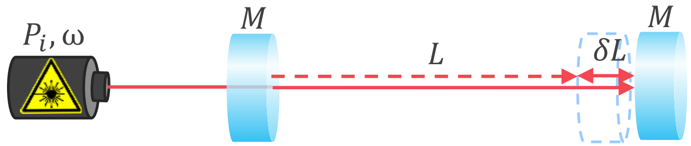
Presentation Outline

Interferometric Gravitational-wave Detectors
Optical Layout and Sensitivity



Optical configuration and detection principle:

- Optical layout based on a modified Michelson interferometer configuration
- The mirrors are the test masses: a GW produces a strain of their relative distances



$$\delta L \propto h\,L, \qquad \delta P \propto \frac{\omega\,L}{2\pi c} P_i\,h$$

- The effect of the GW is measured as a change in the interference pattern (and power) reaching the detection photodiode.

Interferometric Gravitational-wave Detectors
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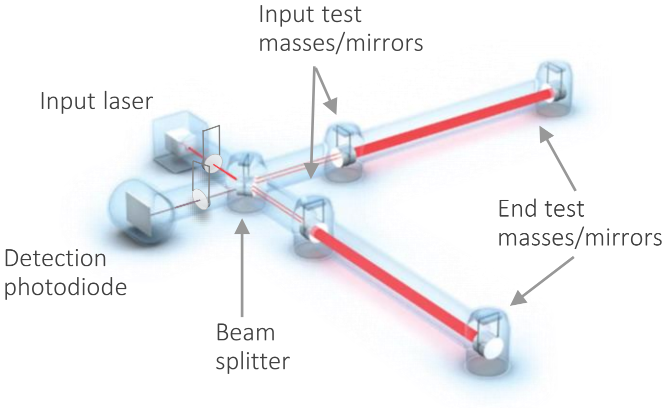

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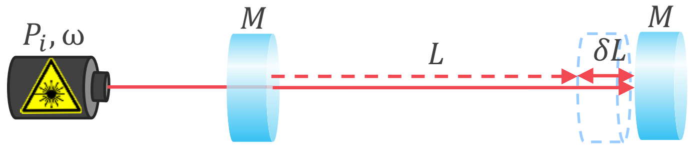

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Detector sensitivity:

- Determined by the strain amplitude due to **noise sources**
- Described in the frequency domain by the Amplitude Spectral Density (ASD), $S_h^{1/2}(f)$, or its square, the Power Spectral Density (PSD)
- Quantum fluctuations:
  - Photon counting: shot noise
  - Position measurement: radiation pressure noise

$$S_h\,(f) = S_{SN}(f) + S_{RPN}(f) = \frac{1}{(4L)^2}\frac{\hbar c^2}{\omega}\frac{1}{P_i} + \left(\frac{4}{M\pi^2}\right)^2 \frac{2\hbar\omega}{f^4}\cdot P_i$$

Strain sensitivity and noise budget

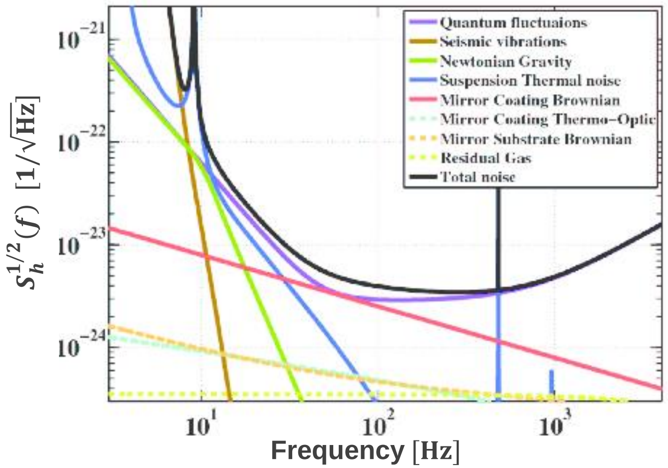
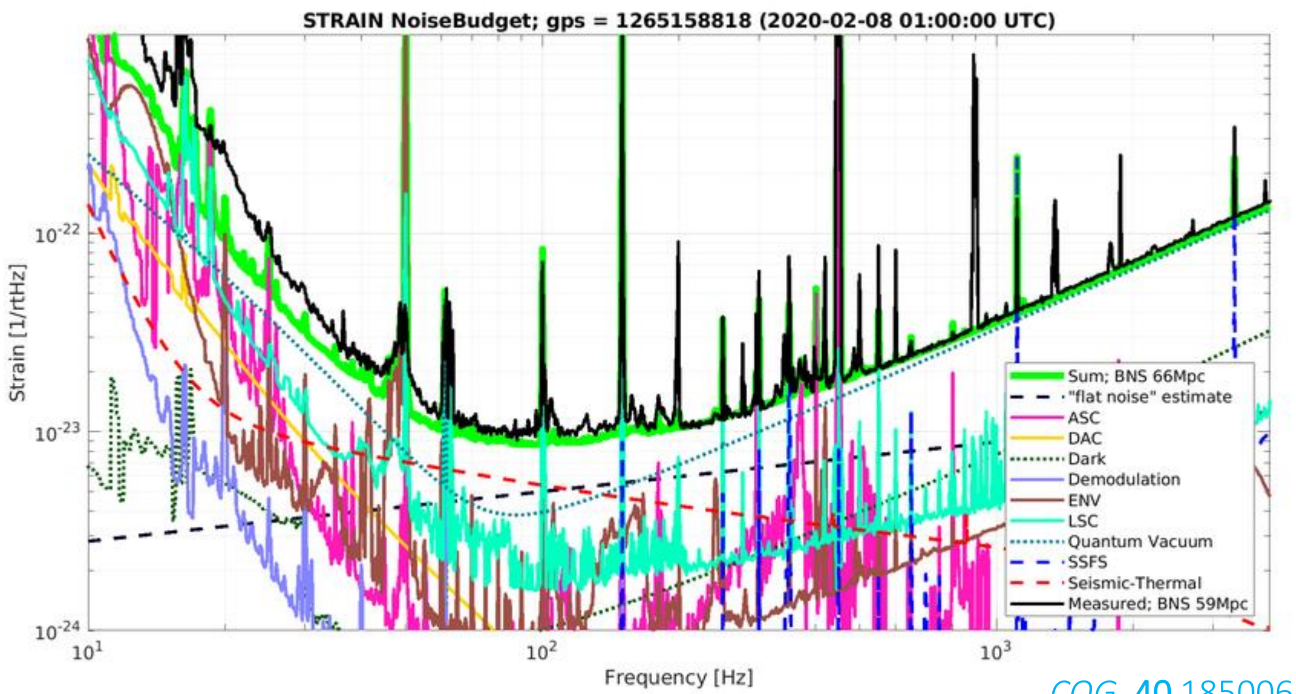


Image created with pygwinc

Improved optical layout

- Fabry-Perot arm cavities: $L \to \mathcal{F}L$
- Power recycling: $P_i \to P_i\, G_{pr}$
- Signal recycling: $P_i\, G_{pr} \to P_i\, G_{pr} \cdot g(f)$
- Squeezed light injections: $S_{SN}\, e^{-2r} + S_{RPN}\, e^{2r}$

Real Detector Noise Budget and Data-quality Issues



CQG. **40** 185006

Many *non-astrophysical* sources can produce an effect similar to a strain at the detector output: noise

- **Fundamental noise:** intrinsic in the detection principle and its practical implementation
- **Technical noise:** from components and controls that are not optimal
- **Environmental noise:** from the detector physical environment

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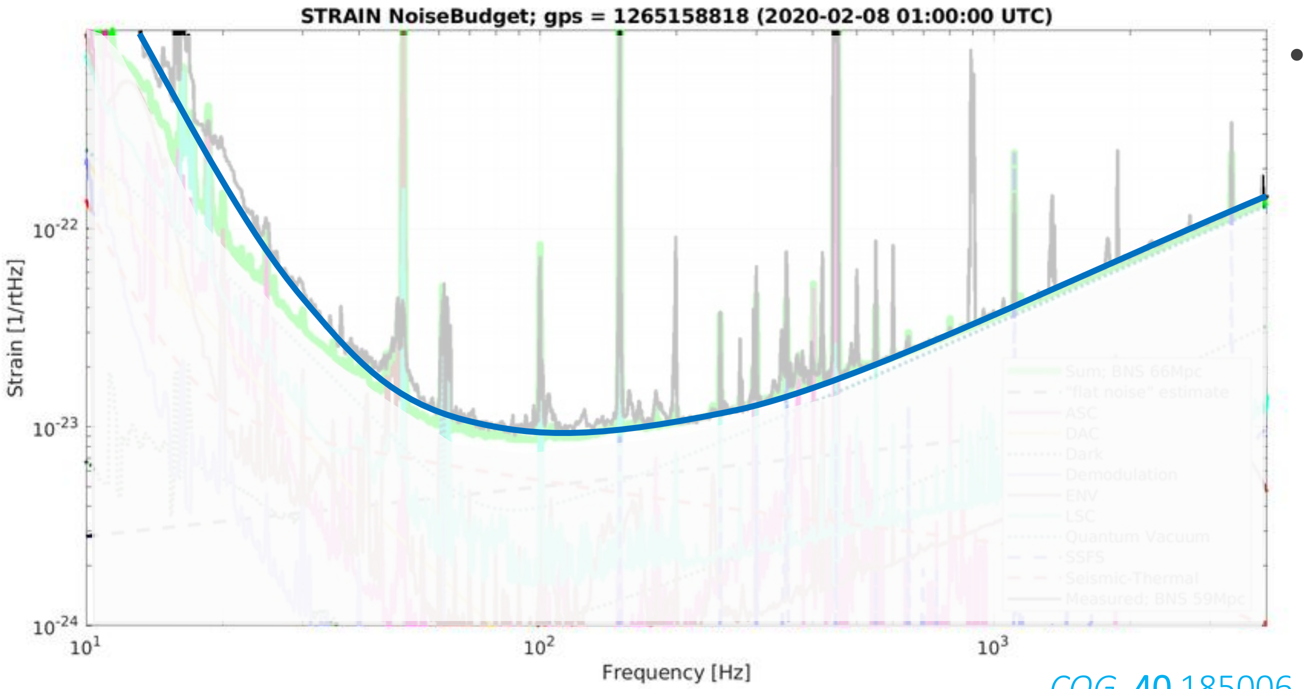

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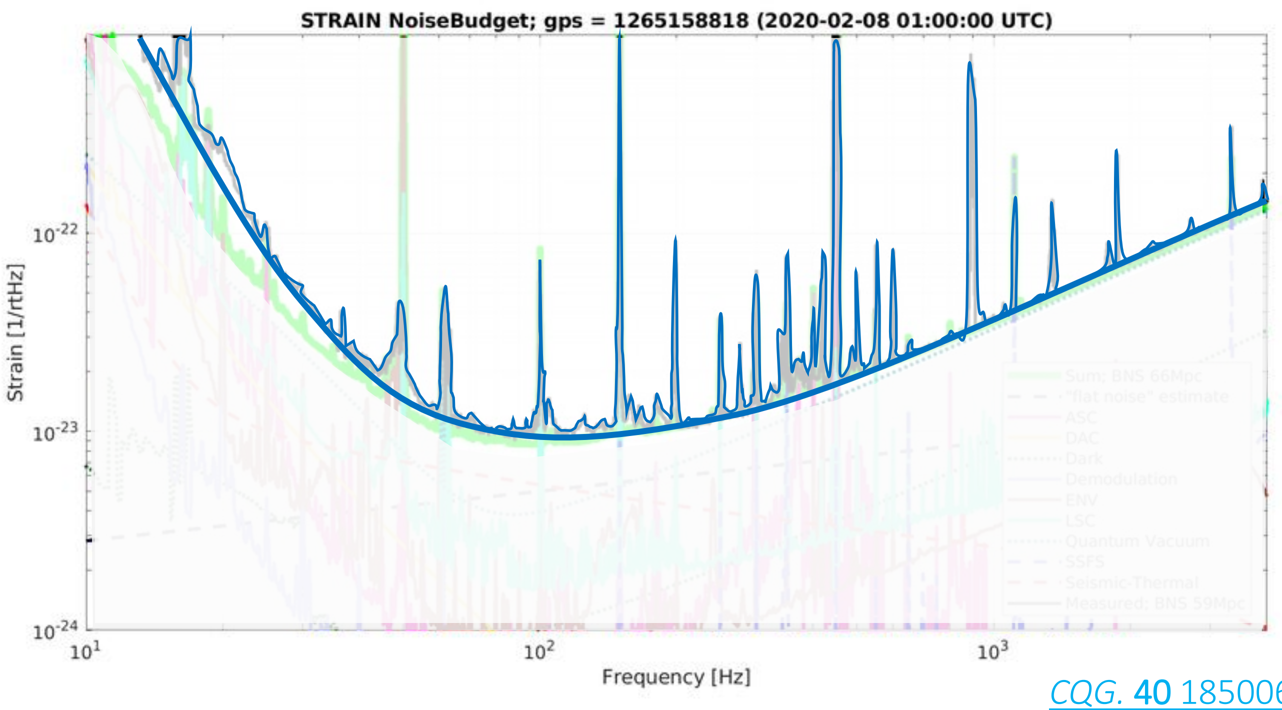

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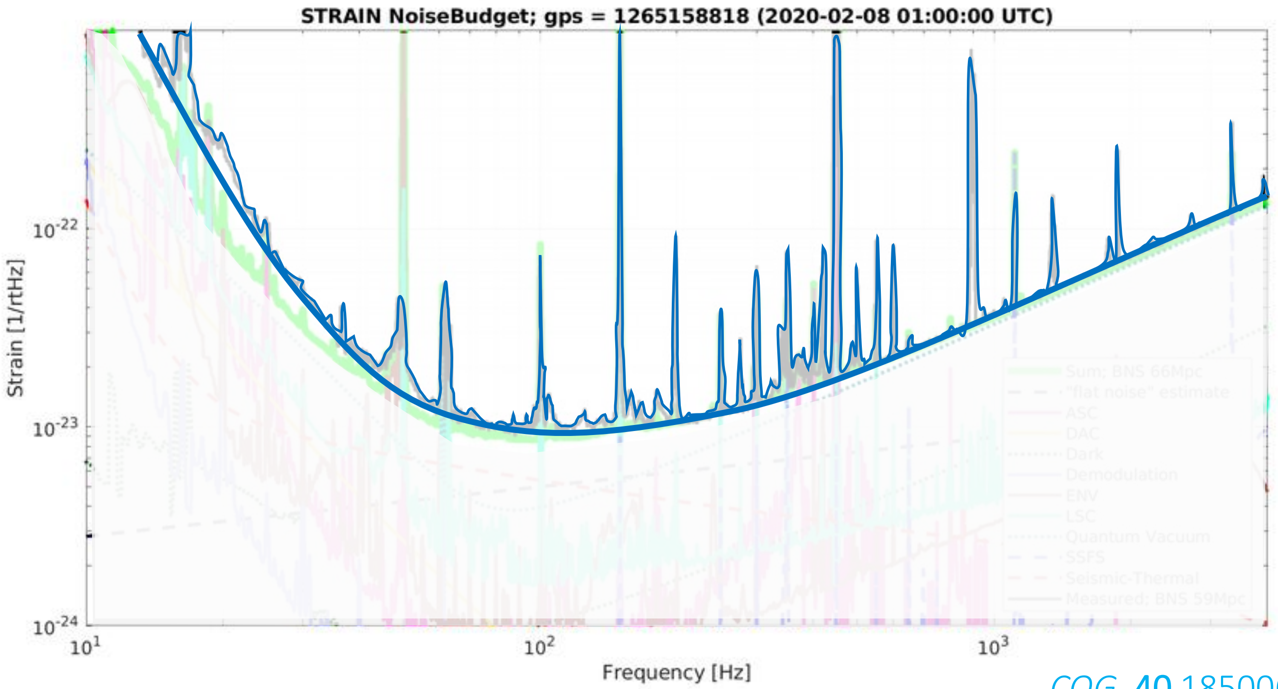

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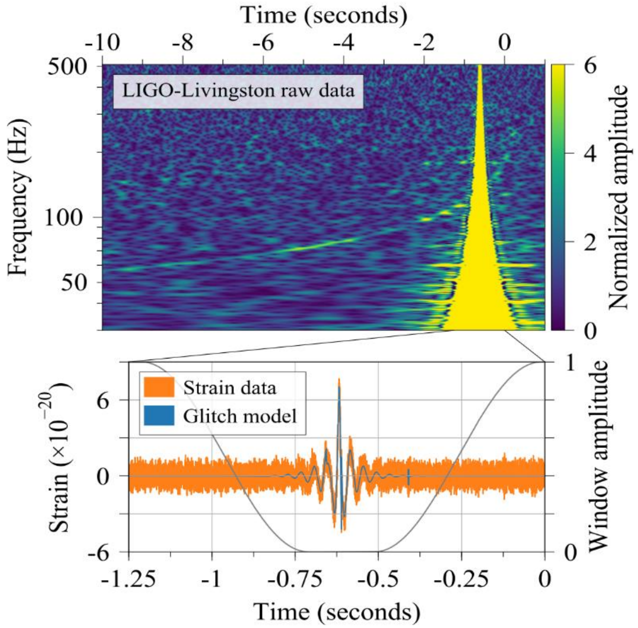
- **Spectral lines** reduce the sensitivity, in particular for narrow-band signals. E.g. continuous wave sources, such as pulsars, or stochastic backgrounds of GWs
- **Transient noise**, colloquially called “glitches,” can mimic transient GW signal or hinder their presence



PRD 98 084016

Effects of Data-Quality Issues on Transient GW Searches

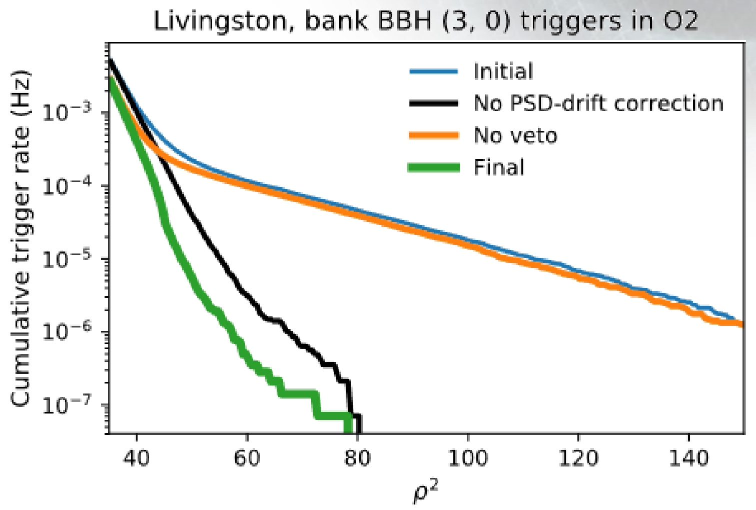
Matched filter based searches:

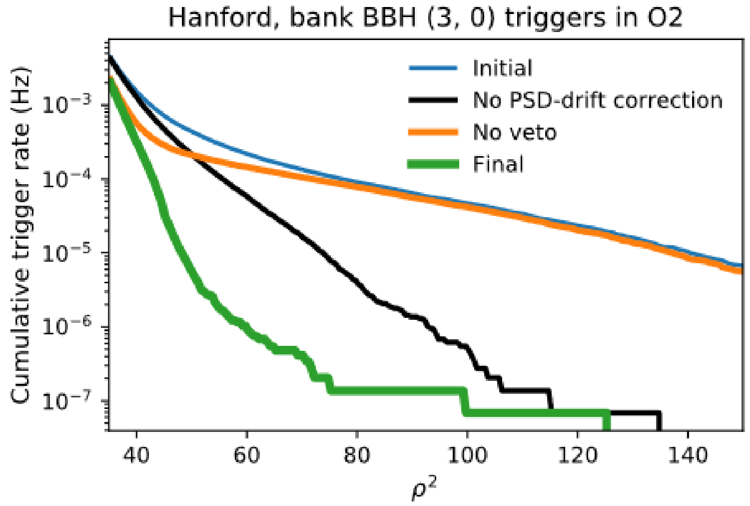
- Signal plus noise model: $\underbrace{x(t)}_{\text{detector data}} = \underbrace{n(t)}_{\text{noise}} + \underbrace{s(t)}_{\text{signal}}$,
- Signal model: $s(t) \approx \varrho h(t)$, with ϱ the amplitude and $h(t) = h(t;\boldsymbol{\theta})$ the waveform model ($(\boldsymbol{h}|\boldsymbol{h}) = 1$)

⇒ **Optimal detection statistic** in stationary and Gaussian data:

$$(\boldsymbol{x}|\boldsymbol{h}) = 4\,\Re \int_0^\infty \frac{\tilde{x}(f)\tilde{h}^*(f)}{S(f)} df$$

$$E[(\boldsymbol{x}|\boldsymbol{y})] = \varrho,\, Var[(\boldsymbol{x}|\boldsymbol{y})] = 1.$$





Phys. Rev. D 104 (2022), 063034

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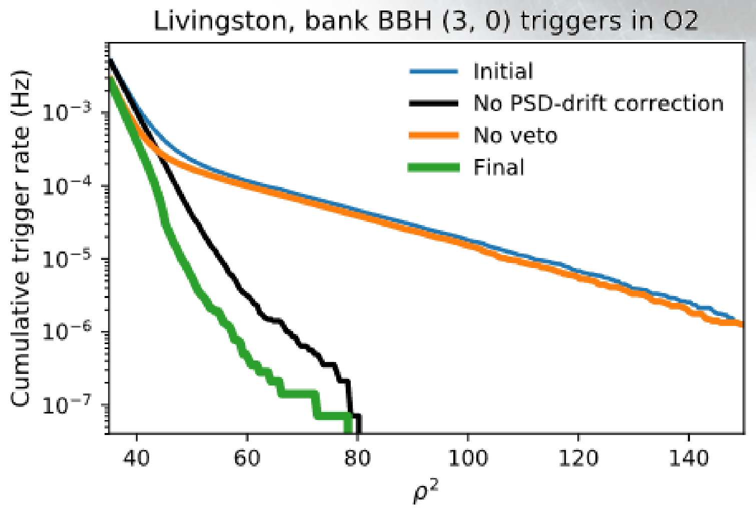
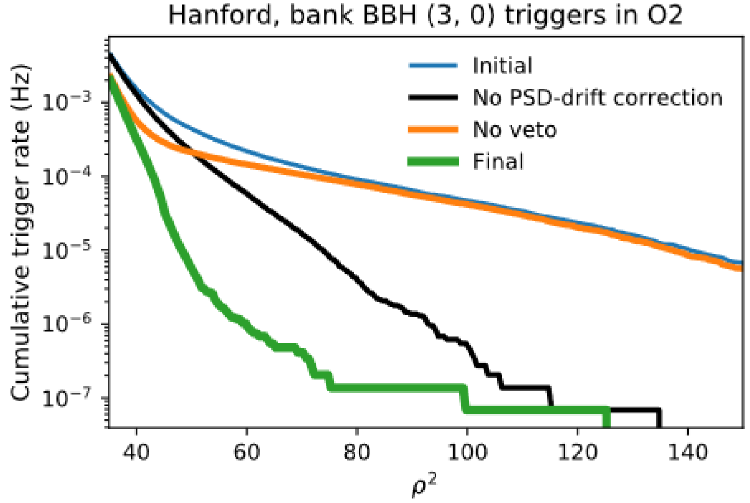
Data-quality issues:

- Increased false alarm rate from non-stationary and non-Gaussian noise
- Non-stationary and non-Gaussian noise ⇒ non-optimal detection statistic:
  - Noise PSD misestimation: $S(f) \to S(f)(1 + \epsilon(f))$
  - Reduced SNR (and significance): $\varrho \to \varrho/(1 + \mathcal{O}(\epsilon^2))$
  - Decreased significance attributed to true astrophysical signals.



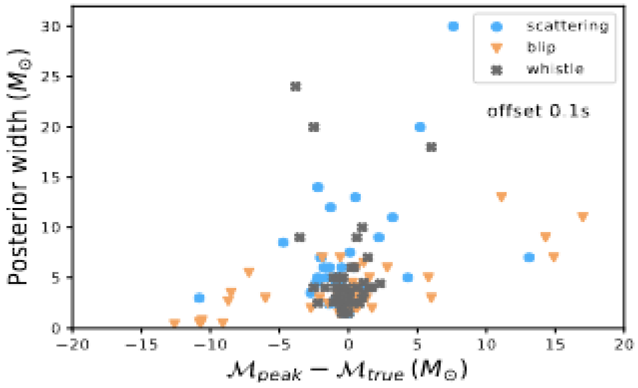


Phys. Rev. D 104 (2022), 063034

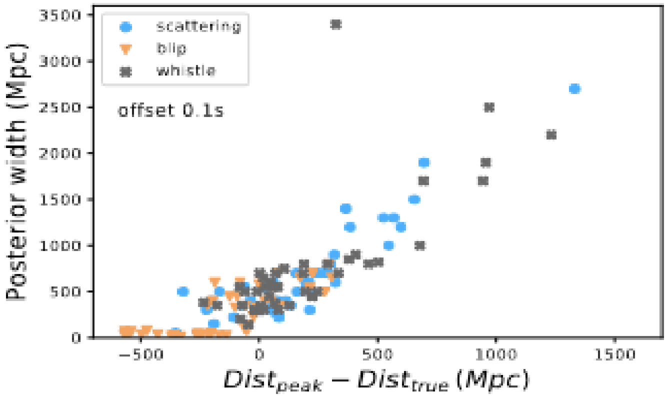
Effects of Data-Quality Issues on Parameter Estimation

Effect on source parameter posteriors

Chirp mass



Luminosity distance



[*Class.Quant.Grav.* 35 (2018) 15, 155017]

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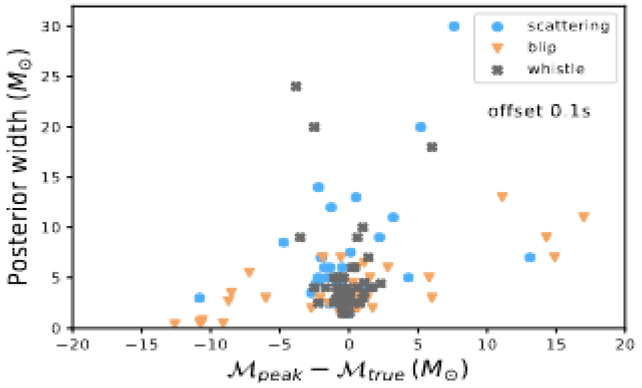

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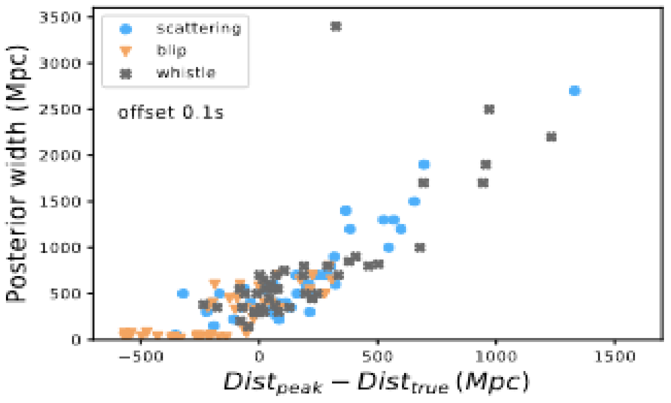
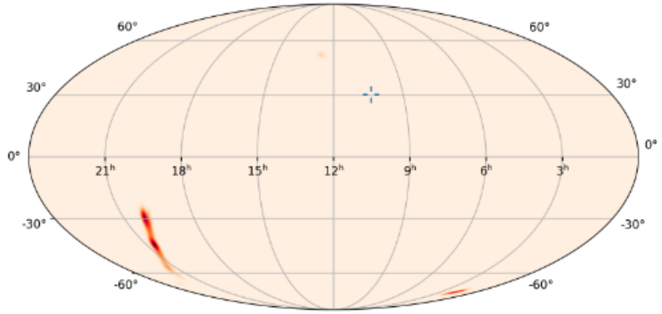


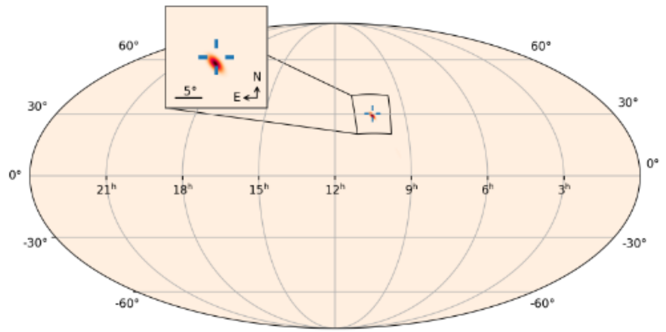
[Class.Quant.Grav. 35 (2018) 15, 155017]

Effect on sky localization

Glitch: 90% credible region 137 deg^2



No glitch: 90% credible region 8 deg^2



Effect on sky-localization of a blip glitch 30 ms after a GW150914-like event.
[Phys.Rev. D 105 (2022) 103021]

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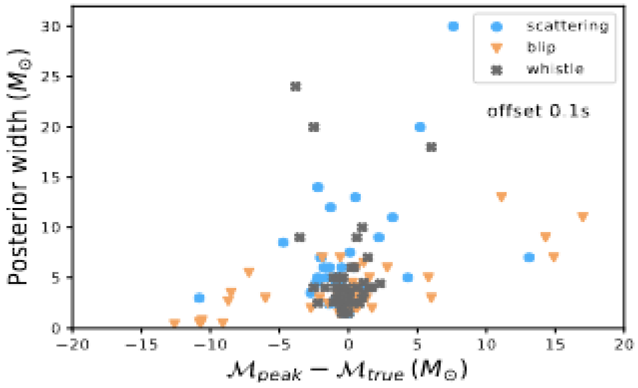

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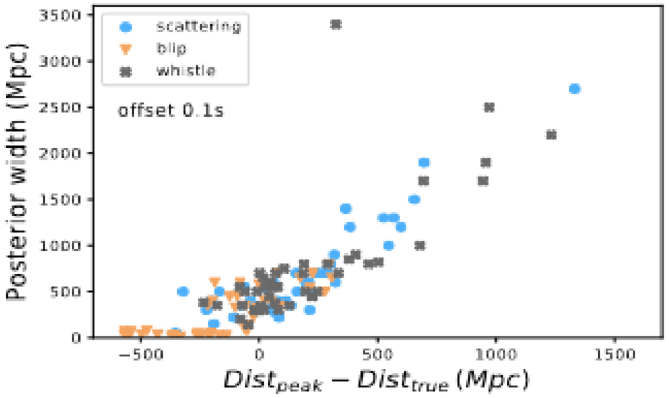

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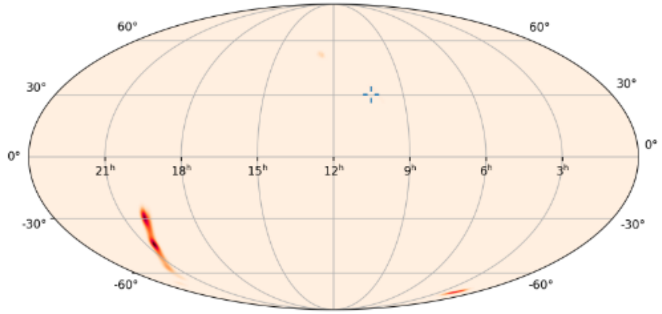

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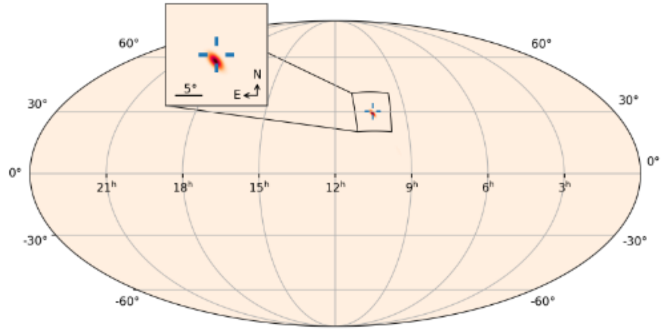

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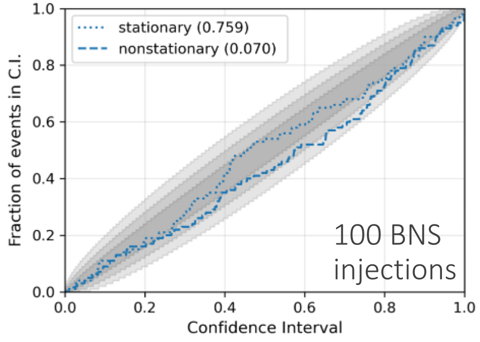
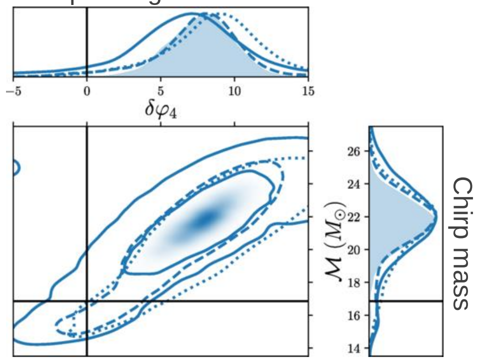
Other parameters affected

- Bias on the measurement of H_0 due to non-stationary noise. [Phys.Rev.D 106 (2022) 4, 043504]



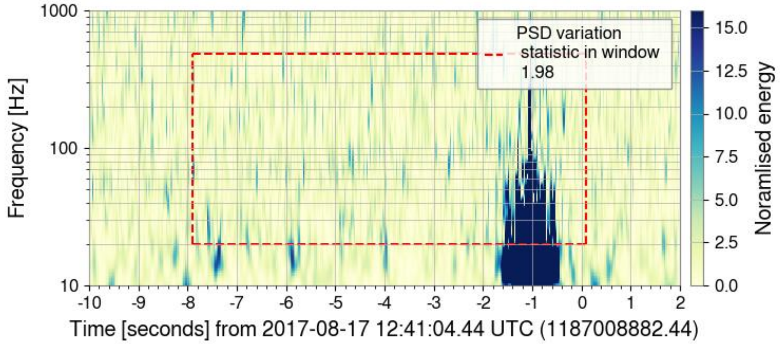
- Bias in parametrized tests of deviations from General Relativity. [Phys.Rev.D 105 (2022) 2, 024066]

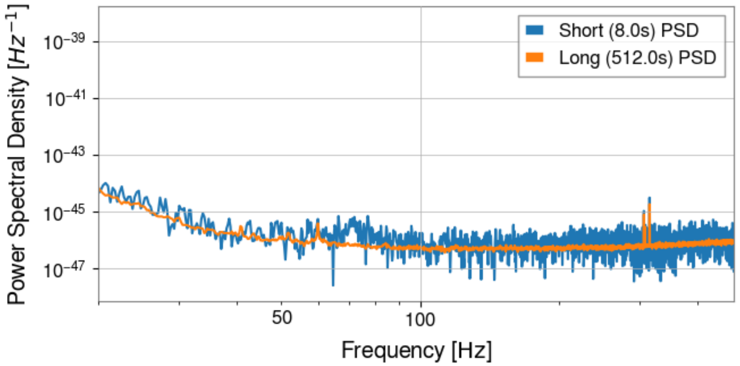


Statistical Tests to Identify Non-Stationarities

Stationarity of the PSD at the time of the event

Check of the consistency of the PSD estimated in a long stretch of data around the time of the event and that in the vicinity of the merger.
[CQG, 37 (2020), 21](CQG, 37 (2020), 21)





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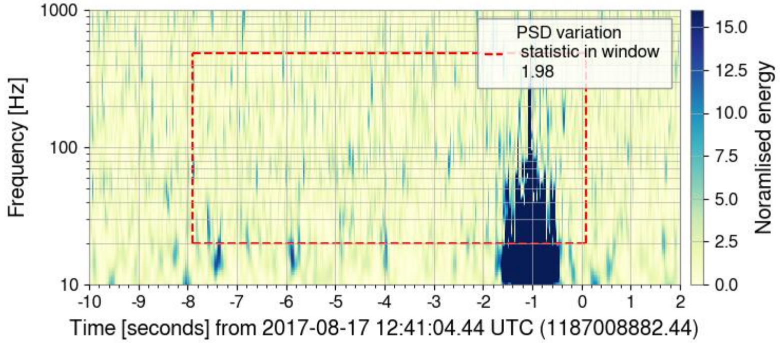
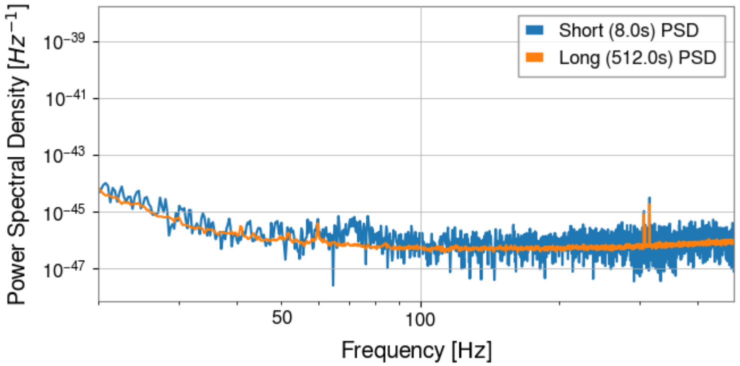
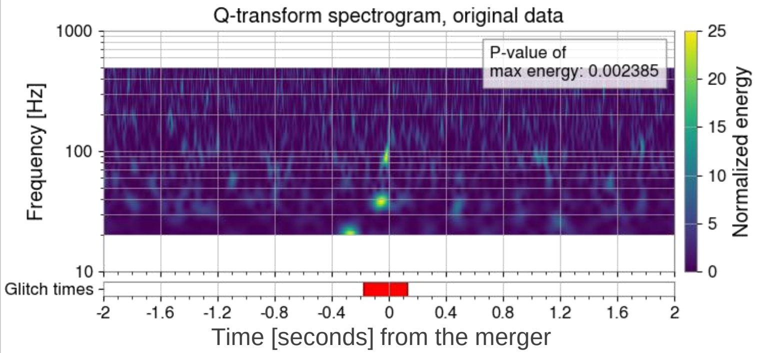
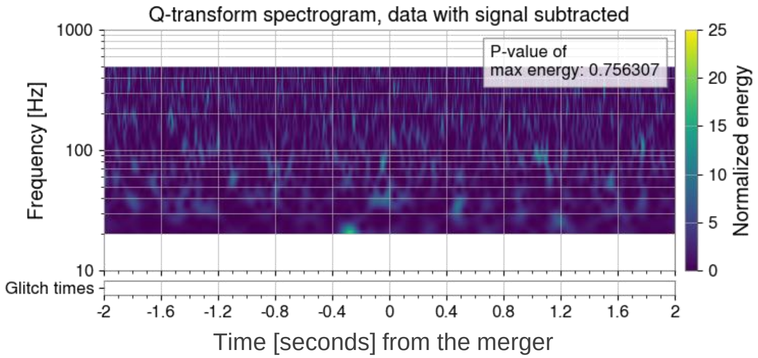




Excess of energy in the spectrograms

- Comparison of the energy with and without the signal template
- For a stationary and Gaussian noise, in the absence of signal the *whiten* spectrogram values should be distributed like a χ_2^2





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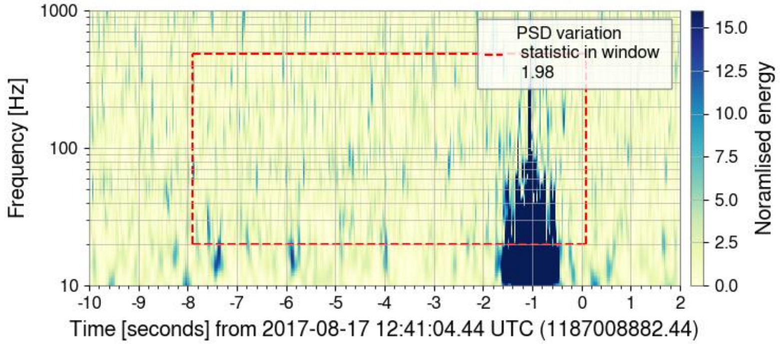

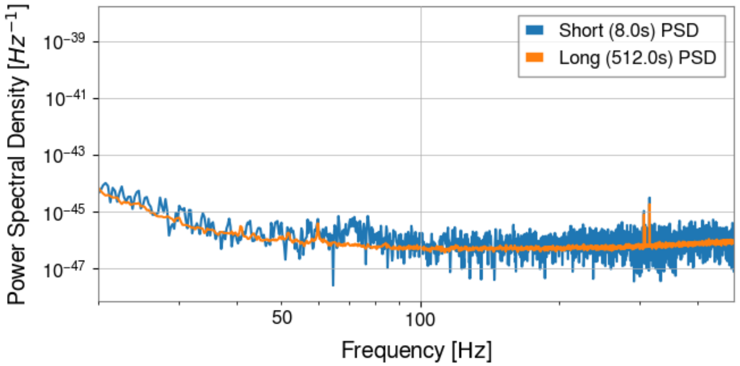

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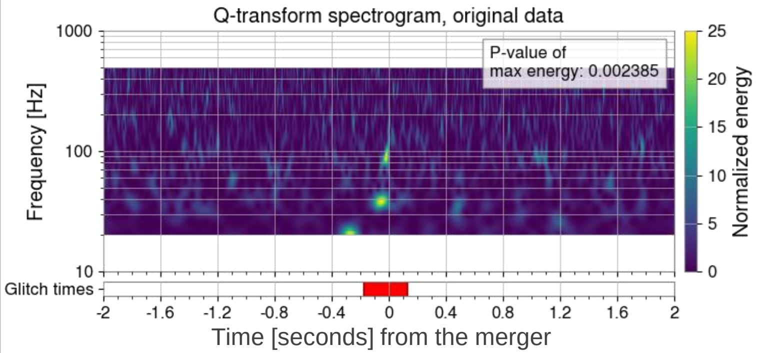
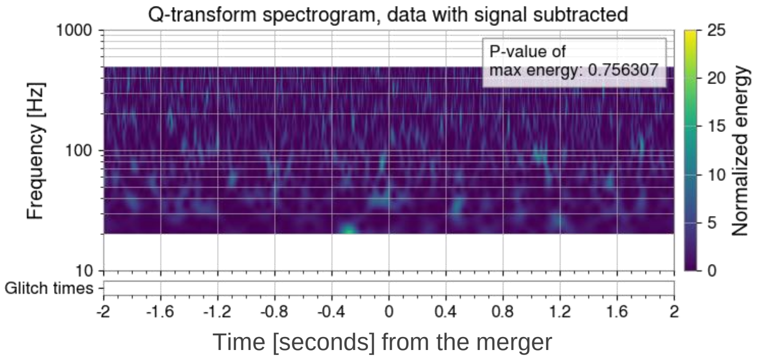
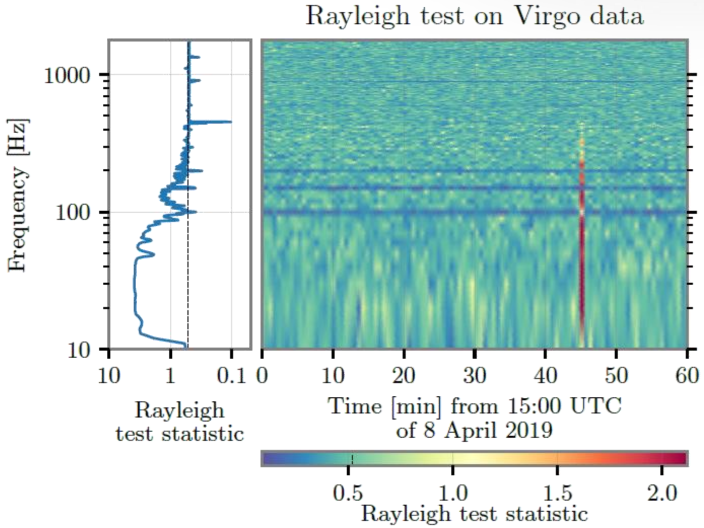
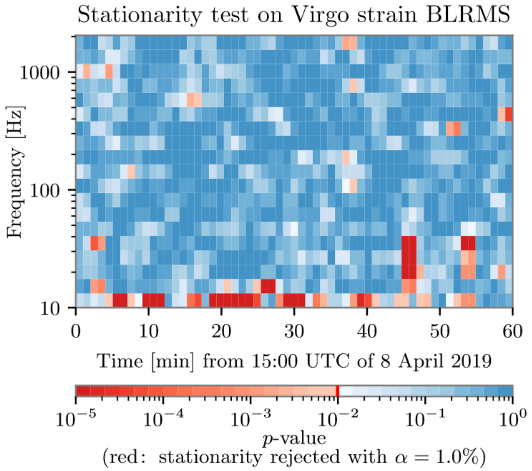




Other stationarity and Gaussianity tests

CQG 40 (2023) 18, 185005

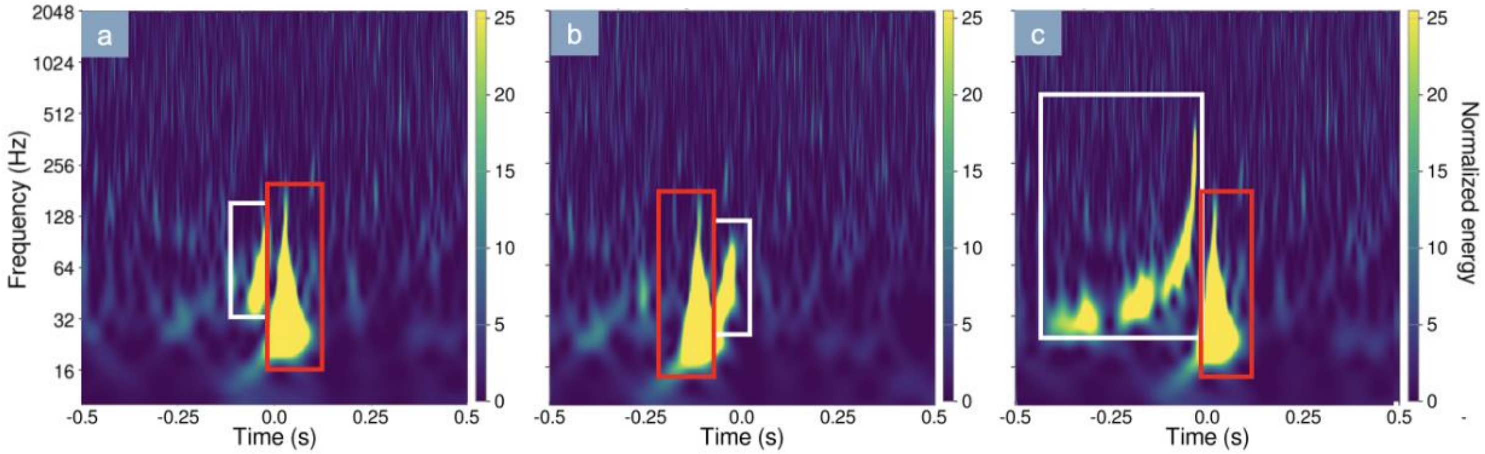




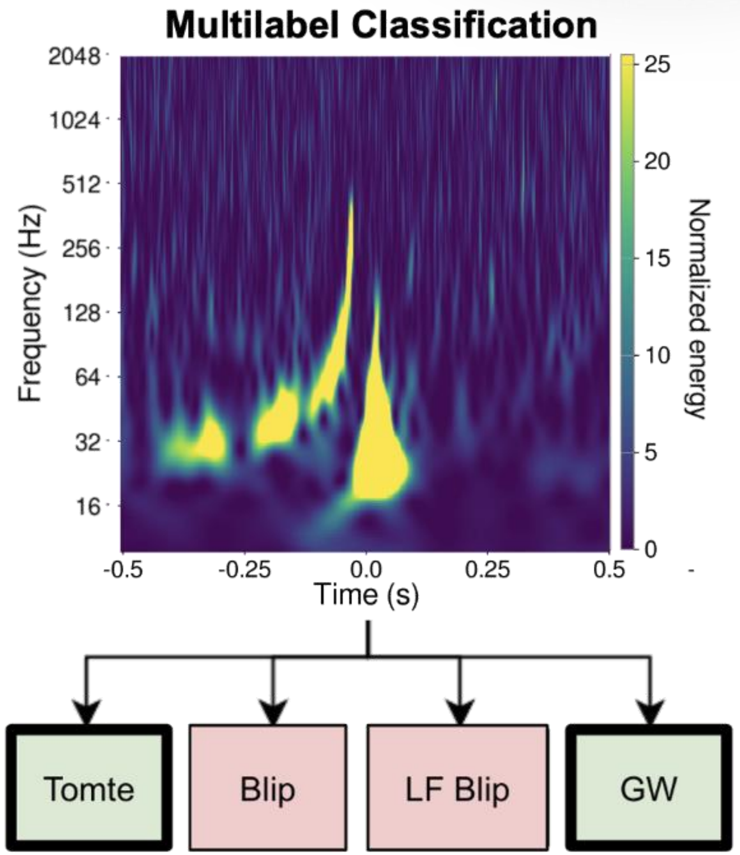
Using Deep Learning to Distinguish Signal and Noise

Multilabel classifier to label excess energy in the spectrogram images and distinguish noise artefacts from GW transients.

- Classification input from citizen science projects like the Gravity Spy and GWitchHunters projects on Zooniverse



Spectrograms of binary black hole signals in the vicinity of some transient noise, colloquially referred to as a "Blip glitch".
CQG 41 (2024) 8, 085007



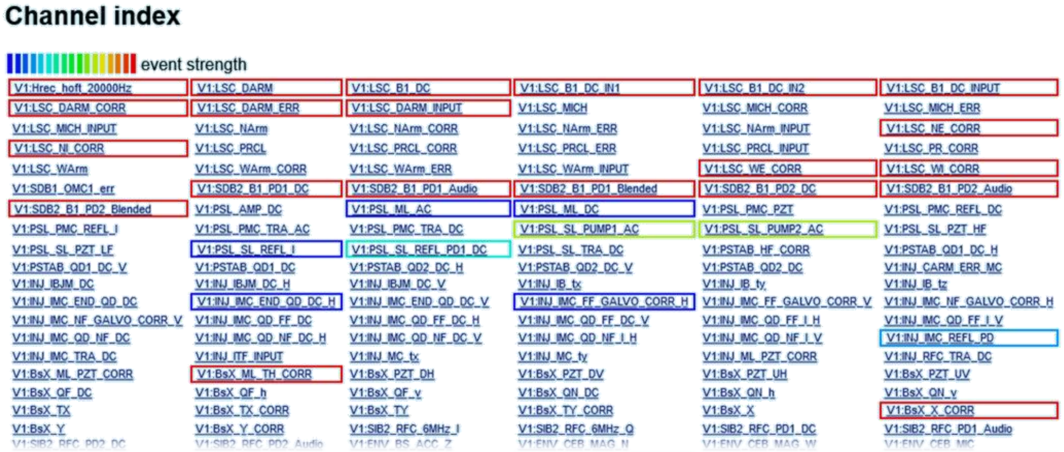
Investigating Correlations

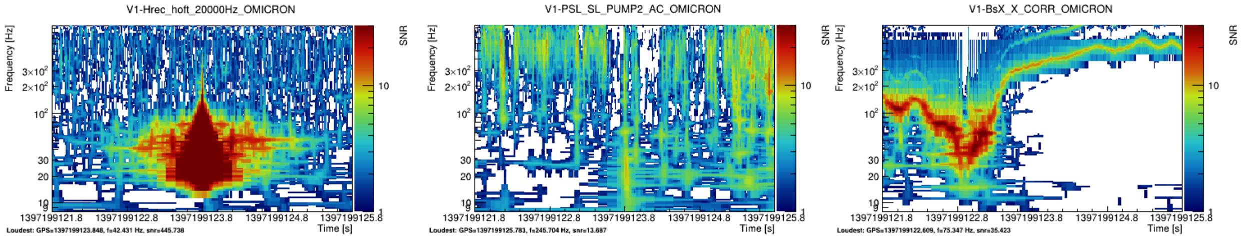
Between the Strain Channel and the Detector Auxiliary Sensors

The detector subsystems and their environment are constantly monitored by thousands of auxiliary sensors.

Investigate simultaneous excess energy at the time of events

- Omicron pipeline SoftwareX, 12 (2020) 100620
- Over 4000 channels are analyzed

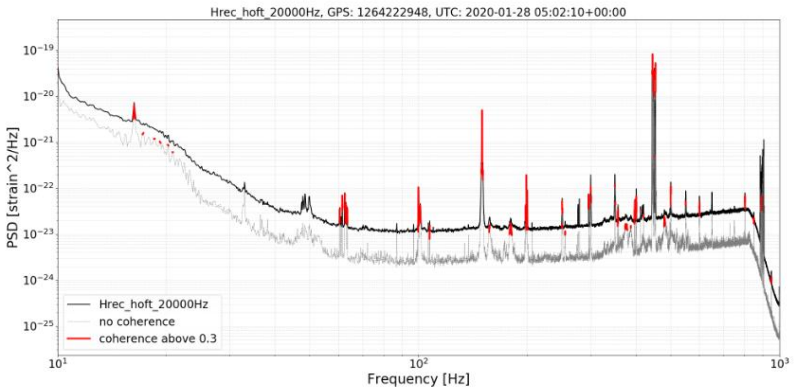




Examine the coherence between the strain and the aux sensors

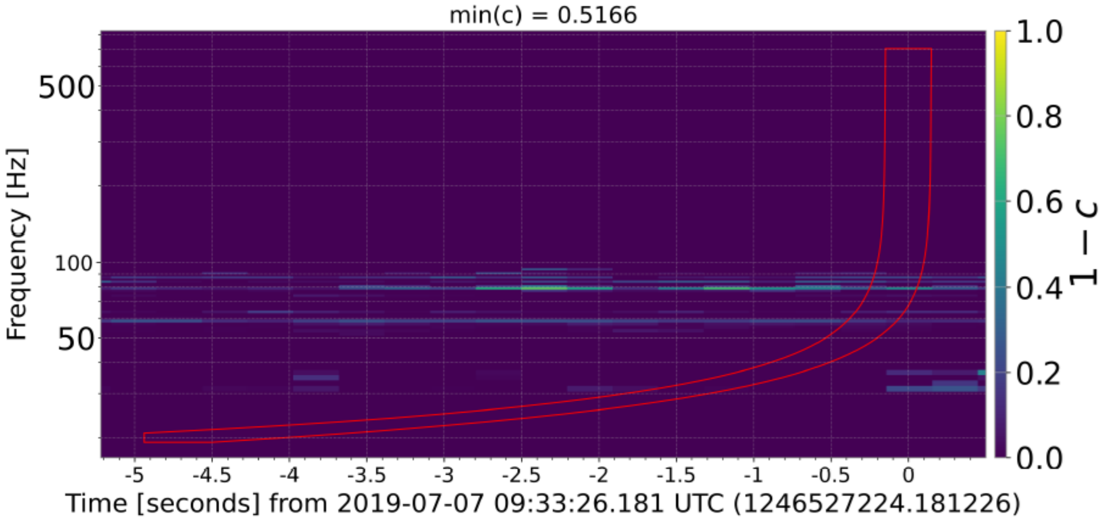
- BruCo pipeline CQG 40 (2023) 18, 185005
- Investigate variations in the results before, during and after the time of the event

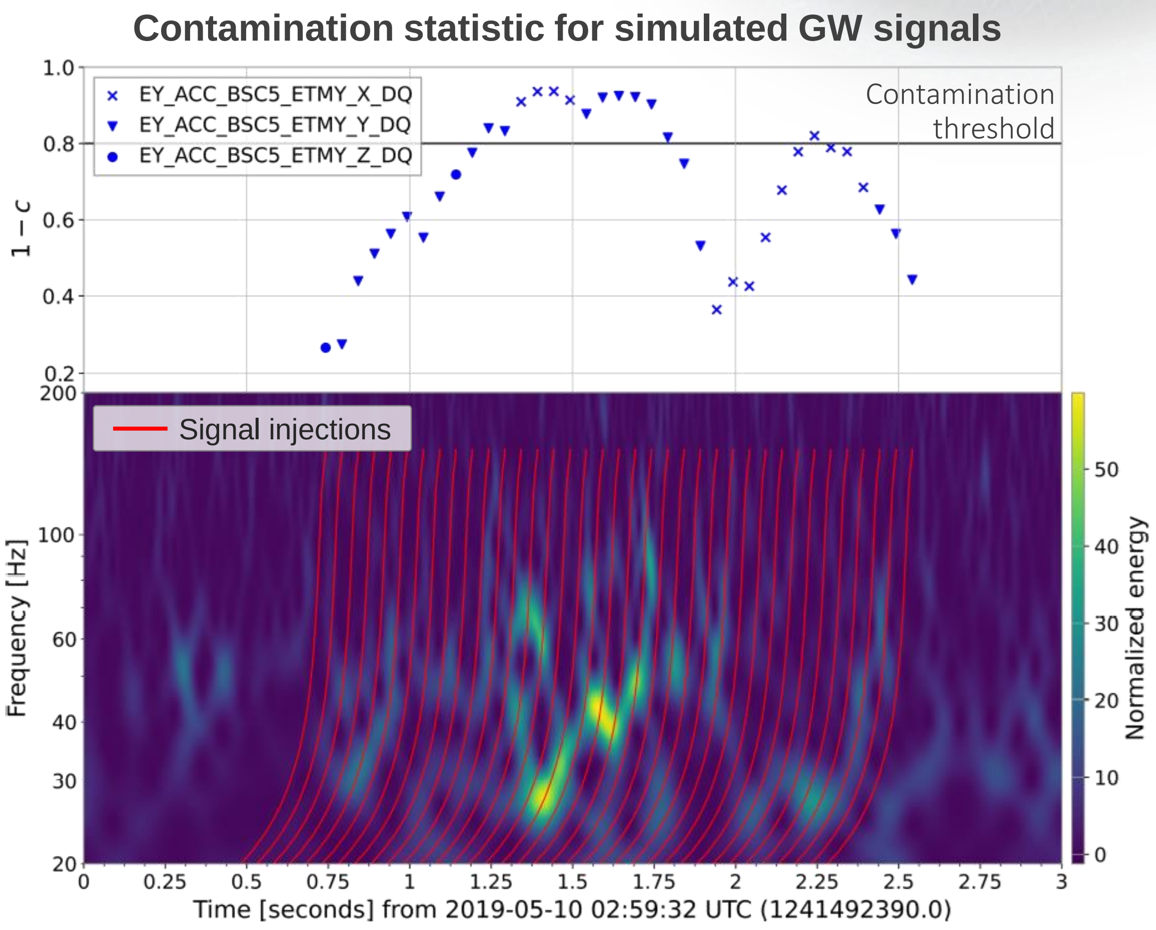
166.88	SDB1_LC_TZ _fb (0.24)	SDB1_LC_TZ _corr (0.24)	SDB1_LC_TZ _err (0.24)	SDB1_LC_TZ (0.24)	SDB1_LC_COIL _FL_V (0.24)
167.00	SDB1_LC_TZ _fb (0.32)	SDB1_LC_TZ _corr (0.32)	SDB1_LC_COIL _FL_V (0.32)	SDB1_LC_COIL _BL_V (0.32)	SDB1_LC_COIL _BR_V (0.32)
167.12	SDB1_LC_COIL _FR_V (0.45)	SDB1_LC_COIL _BL_V (0.45)	SDB1_LC_COIL _FL_V (0.45)	SDB1_LC_COIL _BR_V (0.45)	SDB1_LC_TZ _err (0.45)
167.25	SDB1_LC_COIL _FR_V (0.44)	SDB1_LC_TZ _corr (0.44)	SDB1_LC_TZ _fb (0.44)	SDB1_LC_COIL _BR_V (0.44)	SDB1_LC_COIL _FL_V (0.44)
167.38	SDB1_LC_COIL _BL_V (0.40)	SDB1_LC_TZ (0.40)	SDB1_LC_COIL _FL_V (0.40)	SDB1_LC_TZ _err (0.40)	SDB1_LC_COIL _FR_V (0.40)
167.50	SDB1_LC_COIL _BL_V (0.41)	SDB1_LC_COIL _FL_V (0.41)	SDB1_LC_TZ _err (0.41)	SDB1_LC_TZ _fb (0.41)	SDB1_LC_TZ _corr (0.41)
167.62	SDB1_LC_TZ _err (0.42)	SDB1_LC_COIL _FL_V (0.42)	SDB1_LC_TZ (0.42)	SDB1_LC_COIL _BL_V (0.42)	SDB1_LC_COIL _BR_V (0.42)
167.75	SDB1_LC_TZ _err (0.34)	SDB1_LC_COIL _BL_V (0.34)	SDB1_LC_TZ _fb (0.34)	SDB1_LC_TZ _corr (0.34)	SDB1_LC_TZ (0.34)



Quantifying the Level of Environmental Coupling

- Environmental noise injections campaigns are regularly done to quantify the coupling of the environment with the strain signal. [CQG 39 (2022) 23, 235009]
- The coupling near a GW event candidate is quantified by means of a **contamination statistic**, $c(f)$
- Events with excess of contamination are further investigate to exclude a potential terrestrial origin

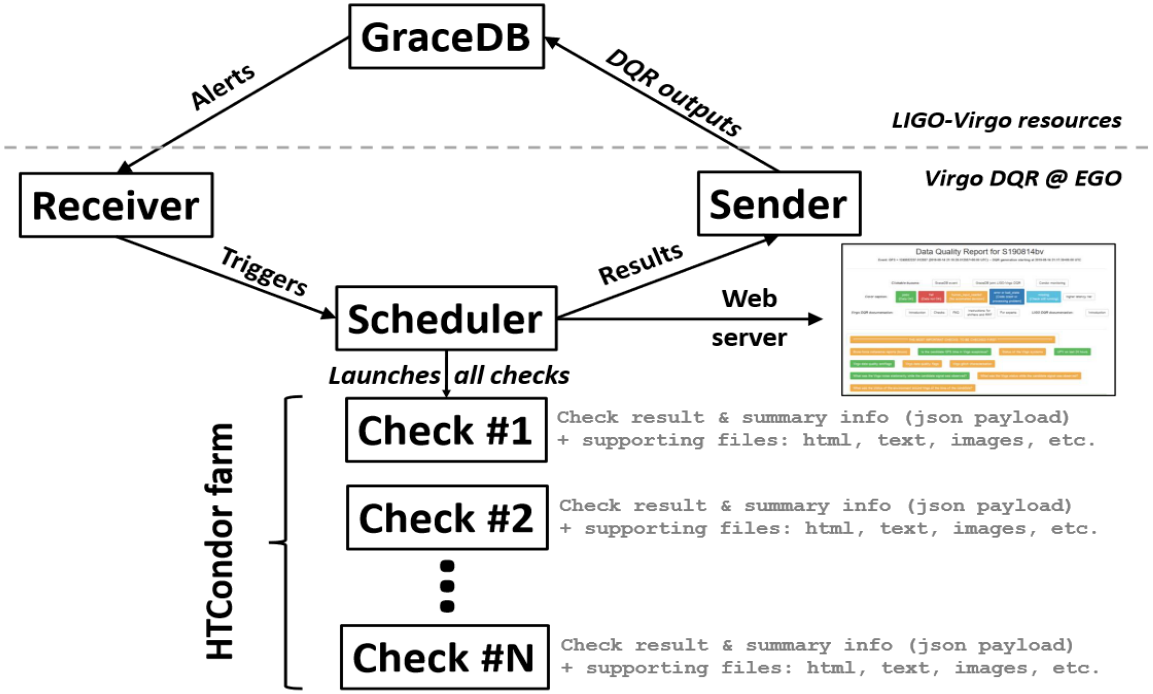




[Class.Quant.Grav. 41 (2024) 14, 145003]

The Data Quality Report Framework

A **Data Quality Report** (DQR) is a framework developed by LIGO and Virgo consisting in a set of DQ checks



Schematics of the Virgo O3 DQR architecture, from CQG **40**, 185006 (2023)

- Two parallel implementations: "Virgo DQR" and "LIGO DQR"
- It is automatically prompted after each significant gravitational-wave candidate is being generated on GraceDB
- The results are uploaded back to GraceDB and used by the **Rapid Response Team** to validate or vet the associated event, and afterwards for the final event validation.

Table: Performance of Virgo DQR during O3b, from CQG **40**, 185006 (2023)

Operation	Time taken [s]		
	Median	Mean	95^{th} percentile
Data acquired → Candidate on GraceDB	52	166	331
Candidate on GraceDB → `LVAlert` trigger	4	4	11
`LVAlert` trigger → Virgo `DQR` configured	331	339	383
Virgo `DQR` configured → Virgo `DQR` started	8	10	21

Operation	Time from start [s]		
	Median	Mean	95^{th} percentile
Quick key checks	374	383	619
Adding `Omicron` trigger distributions	868	816	935
Adding full `Omicron` scans	1740	2159	4690
End	5185	4954	6330

The Data Quality Report Implementations

Virgo DQR

Data Quality Report for SYYMMDD

Clickable buttons: DQR folder contents | GraceDB superevent | GraceDB joint LIGO-Virgo DQR | Condor monitoring

Color caption: pass [Data OK] | fail [Data not OK] | human_input_needed [No automated decision] | error or bad_state [Code crash or processing problem] | missing [Check still running] | irrelevant [Irrelevant check] | higher latency tier

Virgo DQR documentation: Introduction | Checks | FAQ | Instructions for shifters and RRT | For experts

LIGO DQR documentation: Introduction

** THE MOST IMPORTANT CHECKS: TO BE CHECKED FIRST **

- Brute-force coherence reports (bruco)
- Is the candidate GPS time in Virgo suspicious?
- LIGO glitch characterization
- Network
- Status of the Virgo systems
- UPV on last 24 hours
- Virgo data quality flags
- Virgo glitch characterization
- What was the LIGO noise stationarity while the candidate signal was observed?
- What was the Virgo noise stationarity while the candidate signal was observed?
- What was the Virgo status while the candidate signal was observed?
- What was the status of the environment around Virgo at the time of the candidate?

Virgo status (process: virgo_status) (V1)

Virgo state vector (process: virgo_state_vector) (V1)

Long, medium-resolution spectrogram of h(t) (V1) (process: omicronscanhoft_V1_Long) (V1)

LIGO DQR

Network DQR | SYYMMDD | Summary | All tasks | Tasks by IFO | Tasks by Tier | Tasks by Question | Tasks by Computing Center | Links

SYYMMDD results

H1 result: Pass

Task	IFO	Status	P-value	Result
idq	H1	Done	0.00216371	Pass
bristol_H1	H1	Done	0.07608	Pass
glitchfind	H1	Done	0.17375807	Pass
glitchaverage	H1	Done	0.21805393	Pass
omega_overlap	H1	Done	0.25519705	Pass

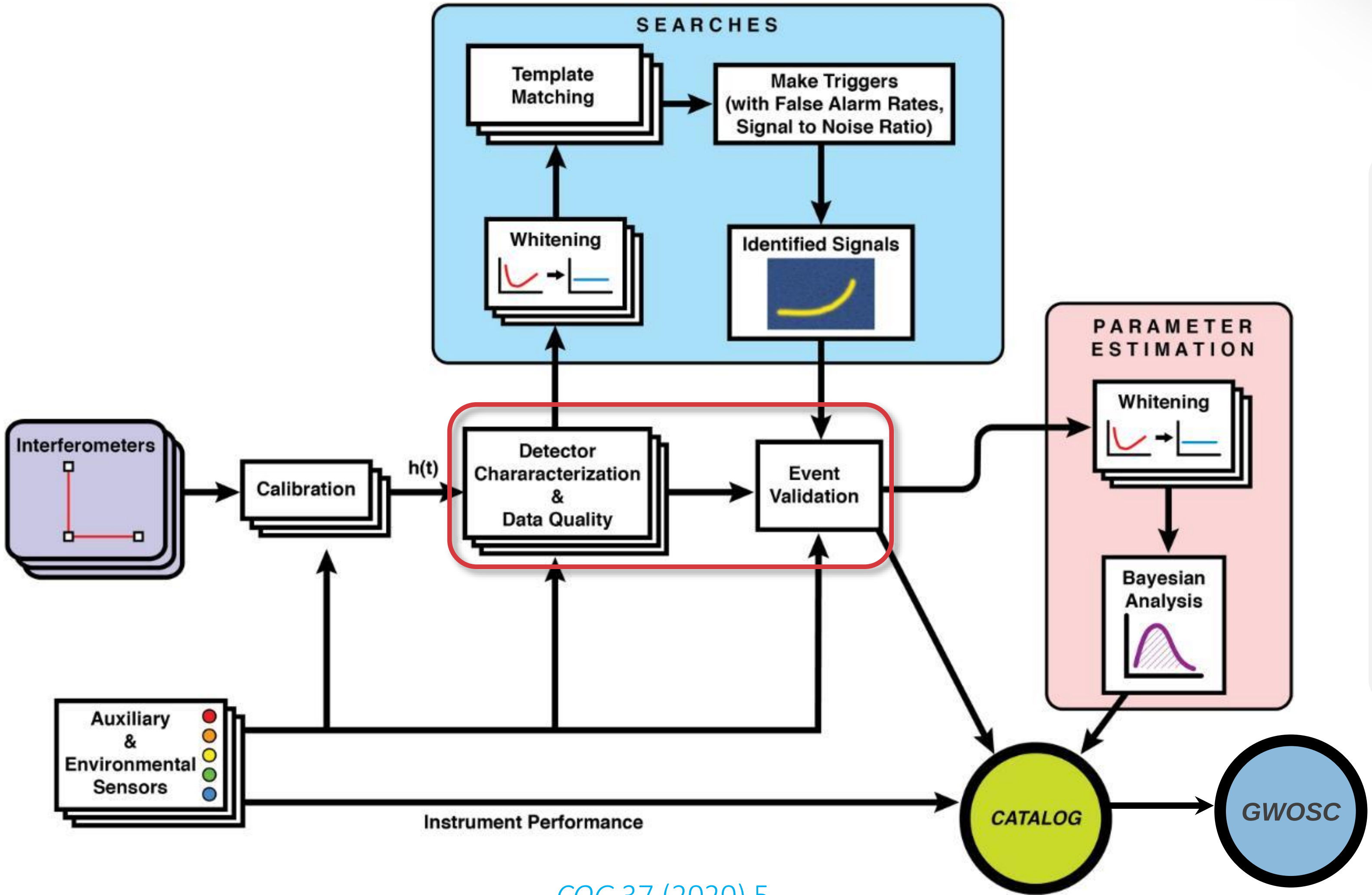
L1 result: DQ Issue

Task	IFO	Status	P-value	Result
bristol_L1	L1	Done	0.02763	DQ Issue
glitchfind	L1	Done	0.10922915	Pass
glitchaverage	L1	Done	0.41935484	Pass
stationarity	L1	Done	0.828125	Pass
omega_overlap	L1	Done	0.97833666	Pass

V1 result: DQ Issue

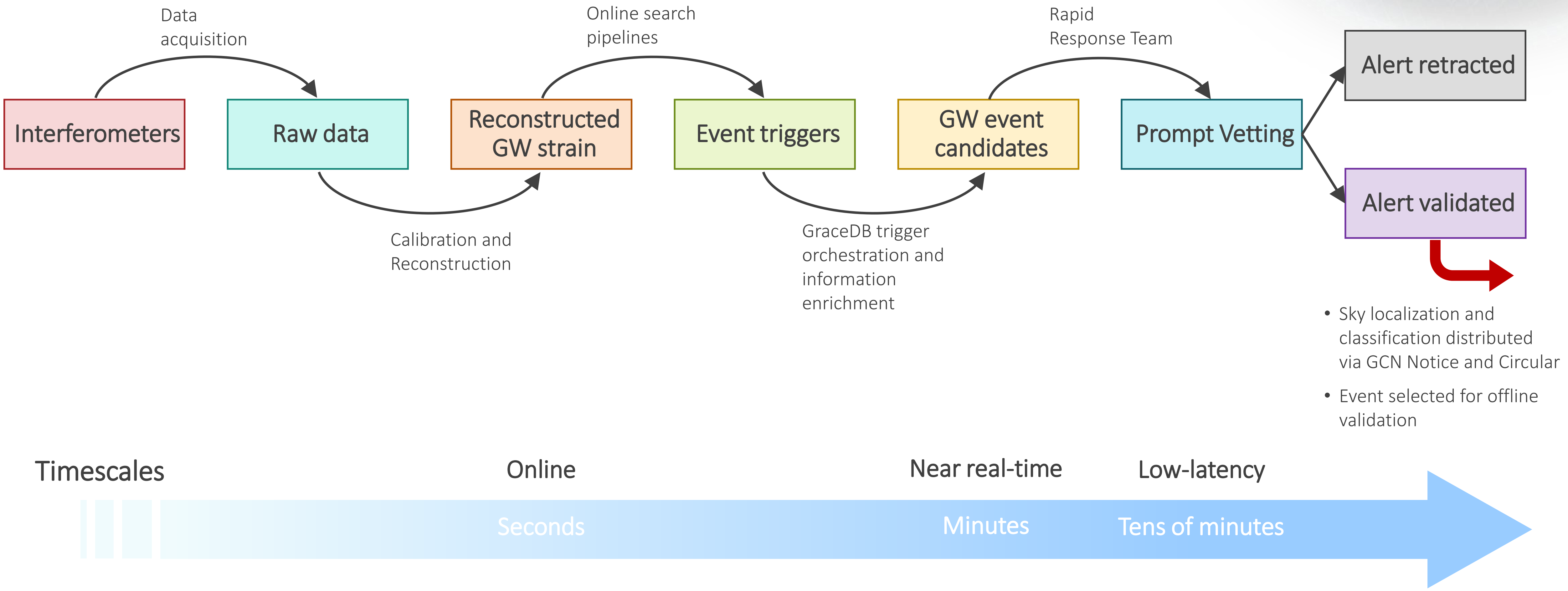
Task	IFO	Status	P-value	Result
bristol_V1	V1	Done	0.01579	DQ Issue
glitchfind	V1	Done	0.02944516	DQ Issue
stationarity	V1	Done	0.96875	Pass
lockcheck	V1	Done	1.0	Pass
virgo_status	V1	Done	1.0	Pass

Data Processing Overview
From Detectors to Publications

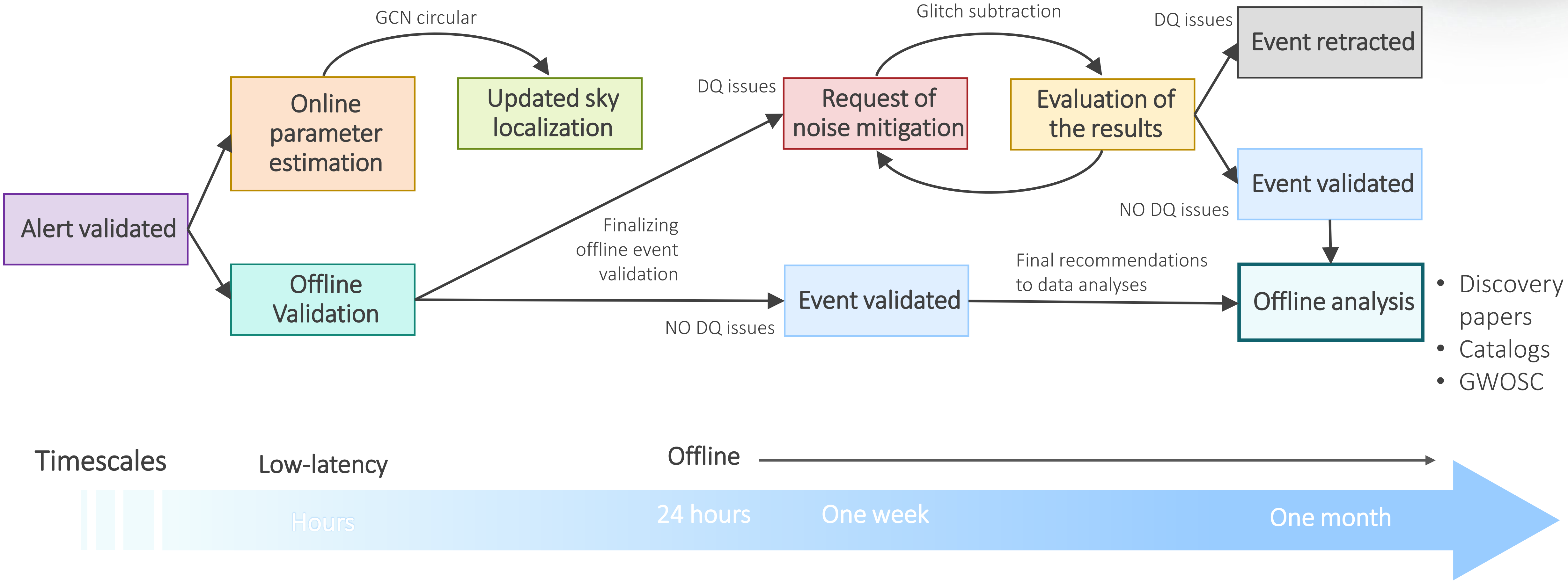


CQG 37 (2020) 5

Online Event Identification and Validation Workflow

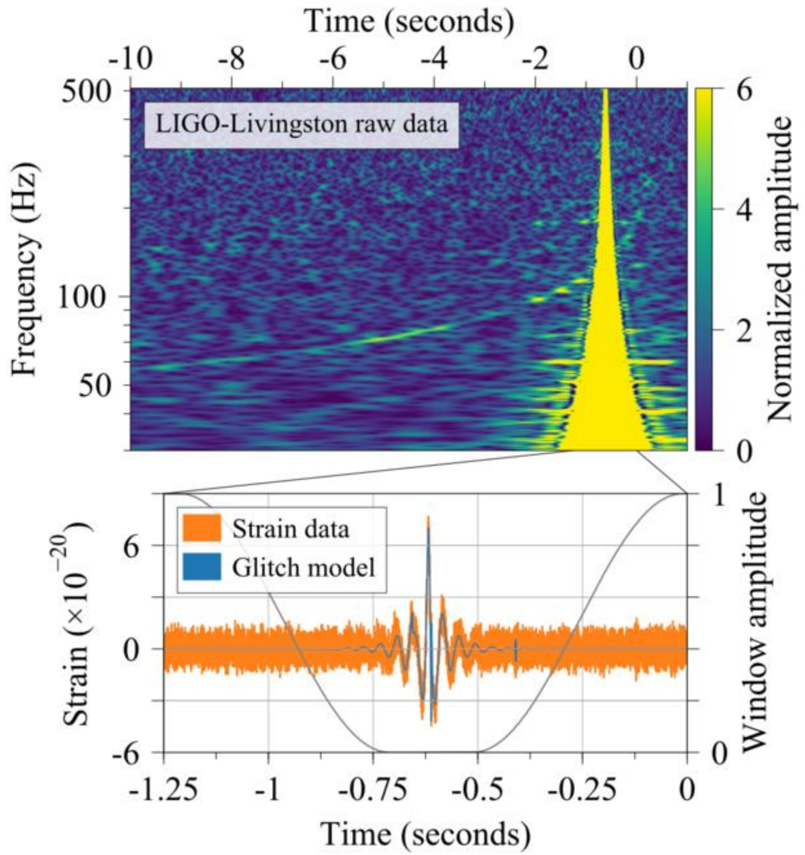


Offline Event Validation



- Discovery papers
- Catalogs
- GWOSC

The Validation of Gravitational-Wave Events



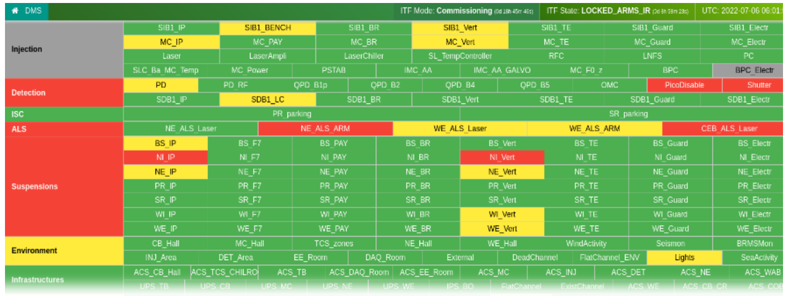
PRD 98, 084016 (2018)

- **Event validation** consists of a set of procedures to verify if **data quality (DQ) issues**, such as instrumental artifacts, environmental disturbances, or anomalies in the search pipelines, can impact the analysis results and **decrease the confidence of a detection**;
- It is applied to all gravitational-wave transient **candidate events** found by both *online* and *offline* search pipelines;
- Typically, candidate events undergo **two stages of validation**:
  - **Prompt validation (RRT, online triggers only)**:

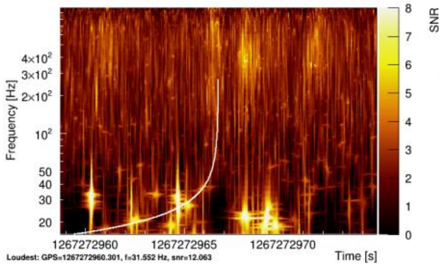
    Accompanies every public alerts and is typically completed within $\mathcal{O}(10 \text{ min})$ from the data acquisition. It has the role to **vet** an event trigger if there is evidence of terrestrial origin or other severe DQ issues;
  - **Offline validation (all)**:

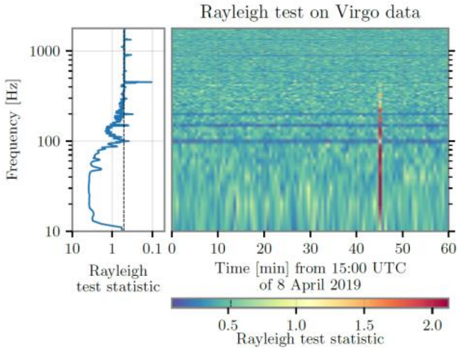
    Completed as a final check before publication for all events found by online and/or offline pipelines. The typical timescale is days or even months after the time of the event.

Prompt Event Validation of Low-Latency Alerts



Example of **Virgo DMS**. From Virgo logbook entry #56363 (NOT a candidate event) VIR-0191A-12





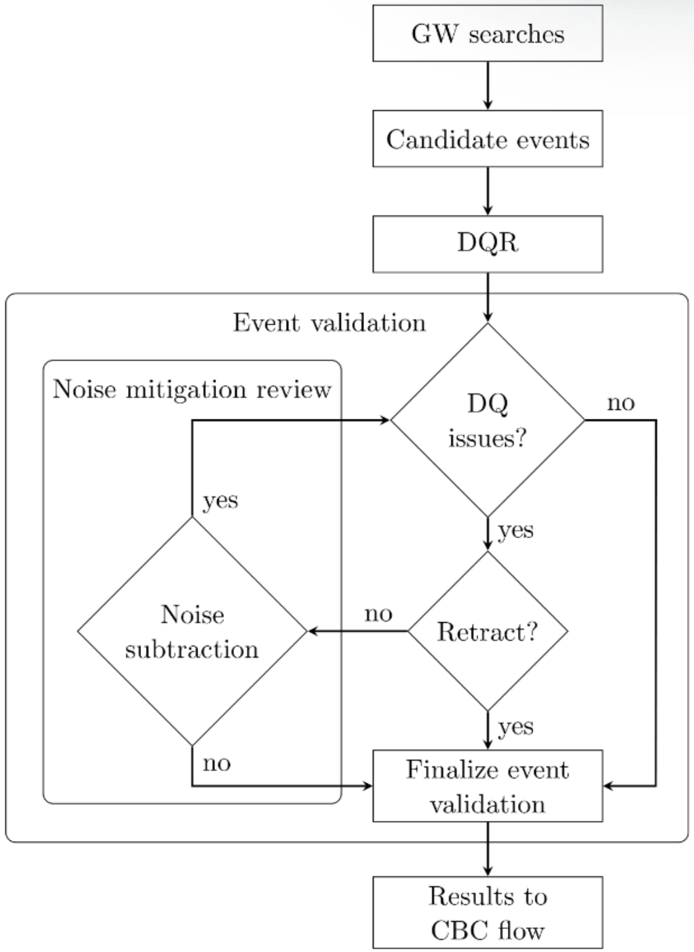
CQG 40 185005

166.88	SDB1_LC_TZ_fb (0.24)	SDB1_LC_TZ_corr (0.24)	SDB1_LC_TZ_err (0.24)	SDB1_LC_TZ (0.24)	SDB1_LC_COIL_FL_V (0.24)
167.00	SDB1_LC_TZ_fb (0.32)	SDB1_LC_TZ_corr (0.32)	SDB1_LC_COIL_FL_V (0.32)	SDB1_LC_COIL_BL_V (0.32)	SDB1_LC_COIL_BR_V (0.32)
167.12	SDB1_LC_COIL_FR_V (0.45)	SDB1_LC_COIL_BL_V (0.45)	SDB1_LC_COIL_FL_V (0.45)	SDB1_LC_COIL_BR_V (0.45)	SDB1_LC_TZ_err (0.45)

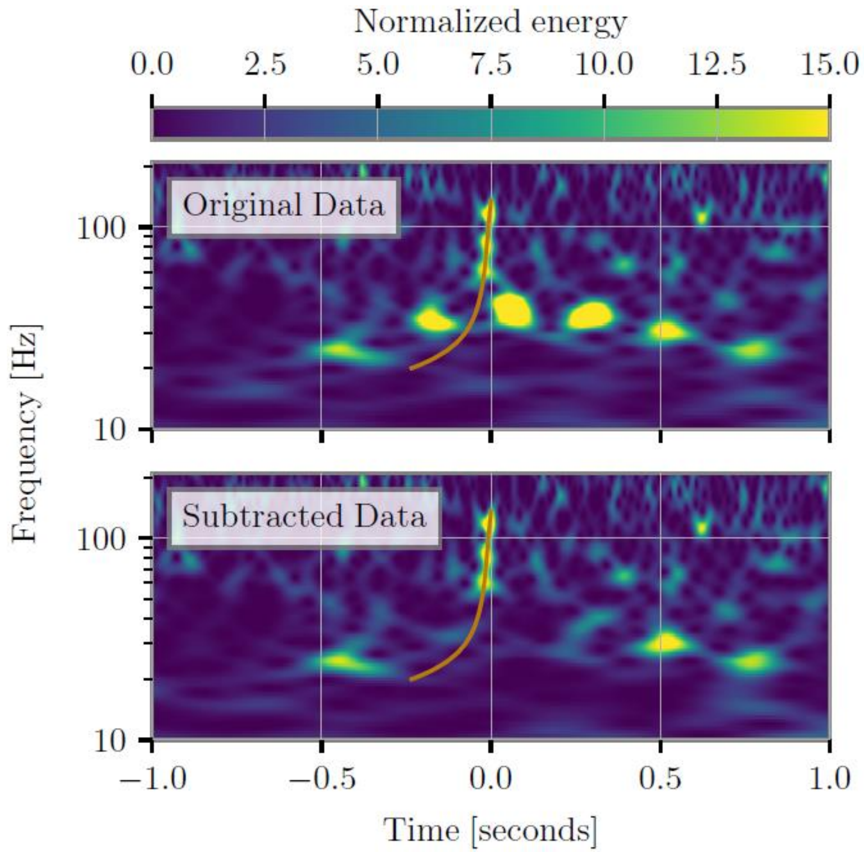
- This stage has the role to **vet those event triggers with severe noise contamination**, for which an astrophysical origin should be excluded
- Otherwise, it serves to enforce the confidence in the event type and **sky-localization** to support multimessenger follow-up.
- The **main DQ checks** based on the DQR are:
  - Operational **status of the detector** and its subsystems at the time of the trigger and around it
  - Scan of the **main DQ flags**: h_{rec} correctly computed, detector observational intent and working condition, injections of spurious signals, etc.
  - **Noise characterization**: stationarity and Gaussianity, including the presence of glitches and their distribution; correlation with auxiliary channels; status of the environment, etc.

Final Validation Before Publications

- **Every LVK publications** (catalogs and exceptional events) undergo a final, comprehensive validation procedure before data analysis reruns
- This includes all the events found online and pre-validated and those found by offline pipelines
- An event validation team is in charge of this procedure. Each event requires $\mathcal{O}(1\ \text{hour})$ per person involved if no DQ issue is found
- The goal is to assess whether the parameter estimation of the astrophysical source can be affected by noise artifacts [*CQG* 35 (2018) 15, 155017]
- If no DQ issue is found, the candidate event is considered validated
- For those events where noise artifacts are found in the vicinity of the putative GW signal, or even overlapping with it, a procedure of **noise mitigation** is implemented. This requires additional time and person power.



Noise Artifacts Mitigation of Gravitational-Wave Detector Data



PRX 11, 021053 (2021)

- Applied to those events flagged to have DQ issues: transient noise, namely **glitches**, superimposing the putative astrophysical signal (orange curve);
- Metric based on the PSD variation to assess the extent of each non-stationary region identified [CQG 37 (2020) 21];
- Deglitched frames mostly produced with BayesWave pipeline [CQG 32 (2015) 13];
- Assessment of subtraction by means of the previous stationarity metric. Parameter Estimation comparison tests to check for bias and systematics;
- **16 events** (≈20%) required glitch subtraction during O3. This process involves lots of human input and slows down downstream analyses.

Summary and Conclusions

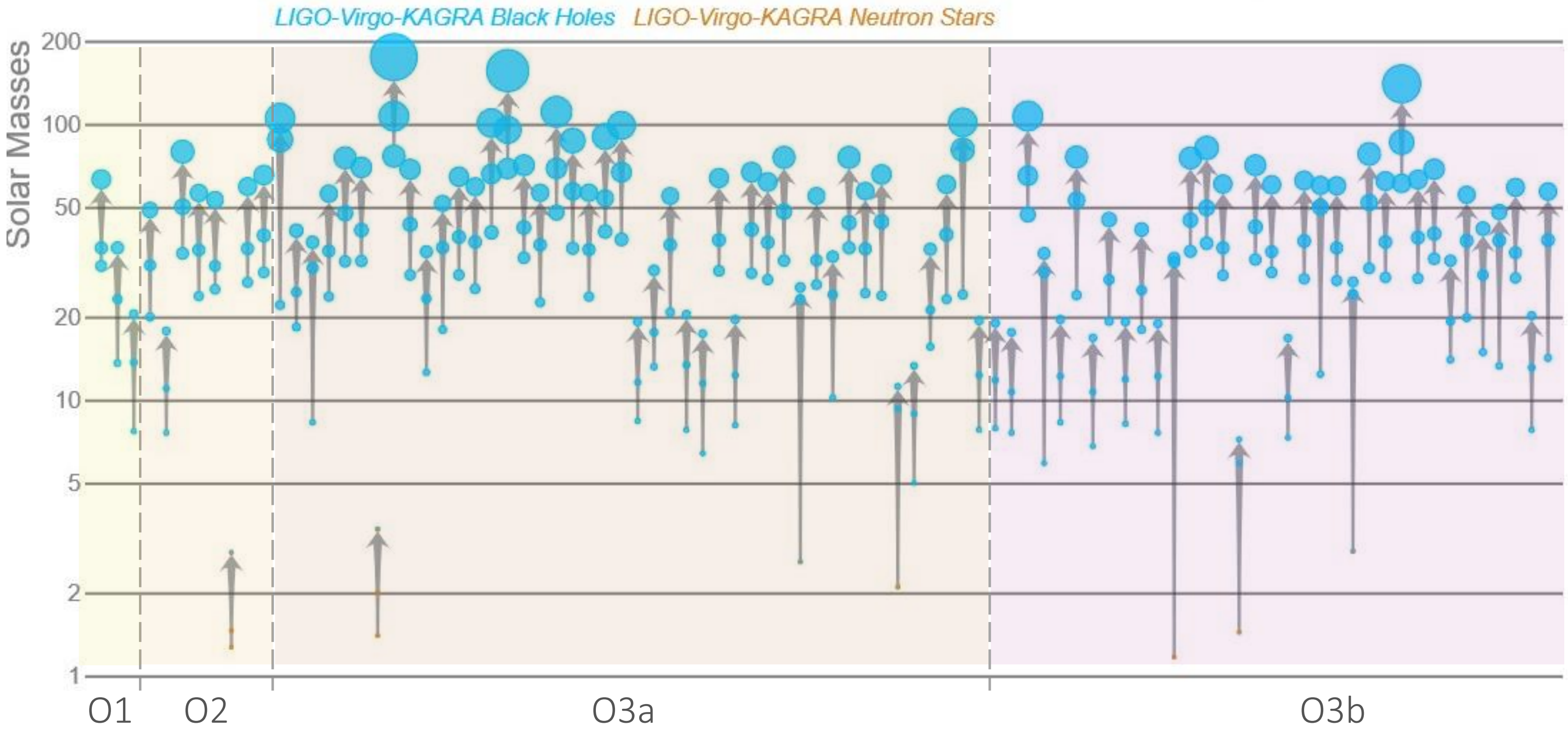
- The sensitivity of gravitational wave (GW) detectors and the reliability of the inferred source parameters can be compromised by **data-quality (DQ) issues**
  - Non-stationary and non-Gaussian noise impact searches for transient GW signals, such as those from the coalescence of binary star systems or other “burst” GW sources
- Numerous statistical tests have been developed to diagnose the presence and impact of DQ issues. These tests are compiled in the **Data Quality Report** framework developed by LIGO and Virgo for transient searches
- **Event Validation** is a crucial part of GW data analysis with the role of reinforcing the confidence in the astrophysical origin of the detected events, and the reliability of the source parameter estimation results
  - Alerts published by the LVK (LIGO-Virgo-KAGRA) in the form of GCN (Gamma-ray Coordinates Network) notices may include warnings if DQ issues are detected near a potential transient GW event candidate
  - For all LVK publications, a thorough validation procedure assesses the impact of DQ issues. If DQ issues affect candidates, noise subtraction techniques can be used to mitigate the effects of transient noise
- Future data collections, with increased sensitivity and a higher rate of detected events, will necessitate further improvements to the validation framework to guarantee effective handling of GW candidate events.

Thanks for the attention!

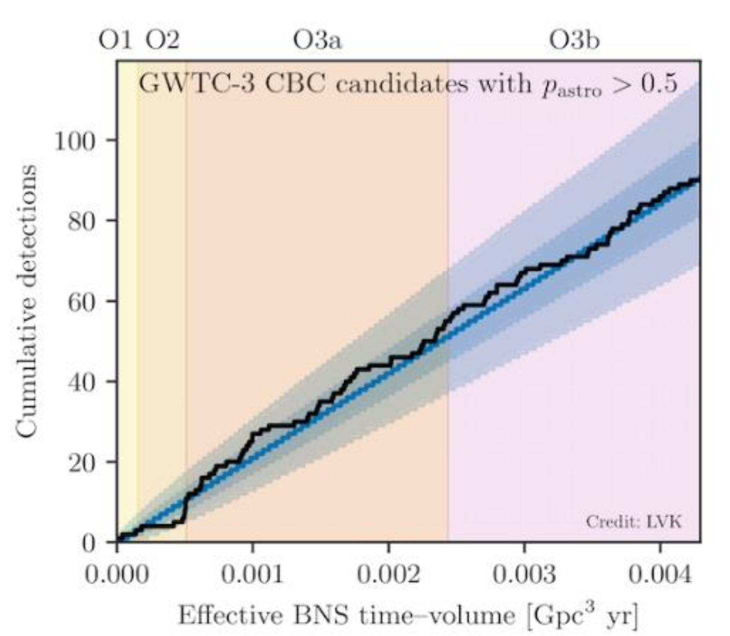
Backup material

Compact binary observations by LIGO and Virgo

Masses in the stellar graveyard

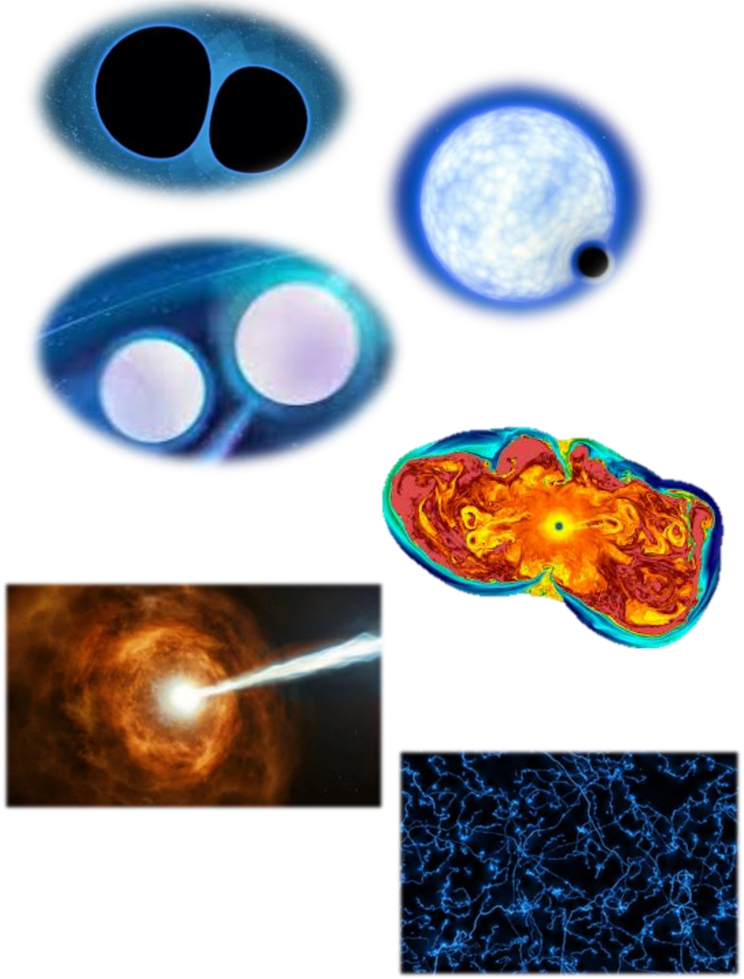


Credit: *Visualization: LIGO-Virgo-KAGRA / Aaron Geller / Northwestern*



arXiv:2111.03606

GW Transient Sources



Compact Binary Coalescences

- Binary star systems made of black holes (BHs) and neutron stars (NSs): BBH, NSBH, BNS. GWTC-3
- Sub-Solar Mass (SSM) objects, MNRAS **524**, 5984 (2023)

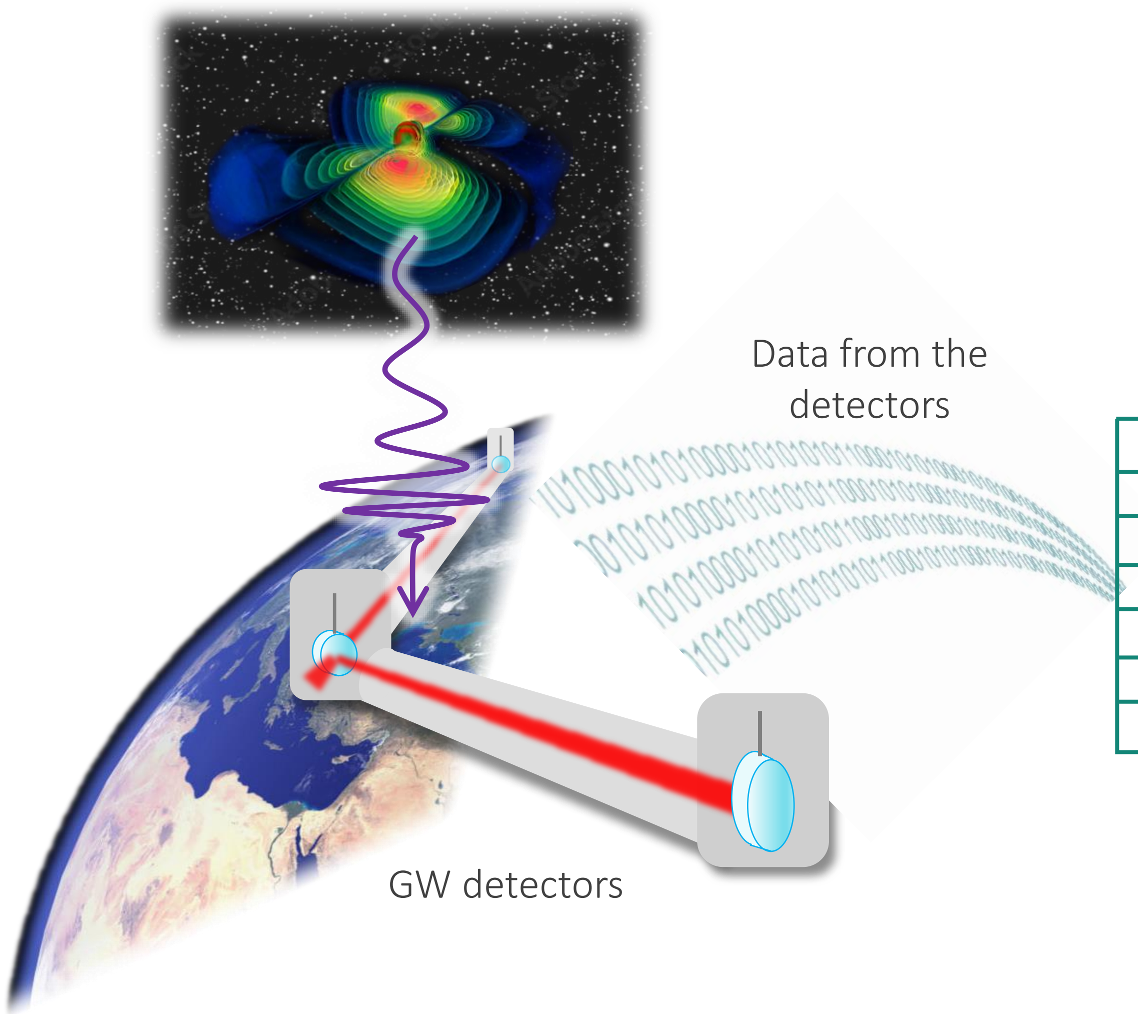
Unmodeled or poorly modeled burst signals

- Core-collapse supernovae (CCSNe)
- Magnetar bursts
- Signals associated with fast radio bursts or gamma-ray bursts
- Cosmic strings cusps and kinks
- …

Online GW Transient Search Pipelines

Search type	Pipeline	Description
Modeled	gstlal	Matched-filter pipeline that evaluates the ratio of the likelihood of a given signal SNR and noise residual over the same quantity for noise only data
	MBTA	Uses the matched filter technique, but splits it in two frequency bands to reduce the computational cost.
	PyCBC	Matched reweighted by imposing the consistency of the signal over various frequency bands. Time-slides method for the background estimate
	SPIIR	Applies GPU empowered summed parallel infinite impulse response (IIR) filters to approximate matched-filtering results
Unmodeled	WB	Searches for coincidences in multiple detectors on the time-frequency data obtained with a wavelet transform
	oLIB	Time-frequency domain search over planes of constant Q factor
Coincident searches	RAVEN	Coincidences between GW events and GRBs and galactic SN alerts
	LLAMA	Combines GW triggers with High Energy Neutrino (HEN) triggers from IceCube

The Low-Latency Pipeline



Online GW search pipelines

- GstLAL
- MBTA
- PyCBC
- SPIIR
- cWB
- oLIB
- RAVEN (GRB, SNE)
- LLAMA (Neutrinos)

GraceDB

GW candidate event database

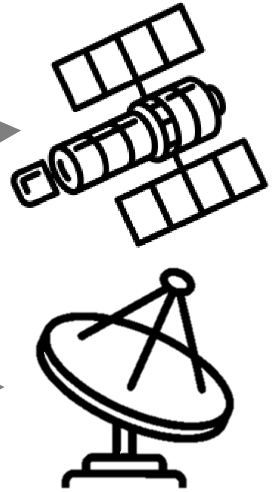
Event vetting

- GWCelery
- Rapid Response Team

Alerts distribution via GCN and SCiMMA

- Notices
- Circulars

Astronomical partners



...

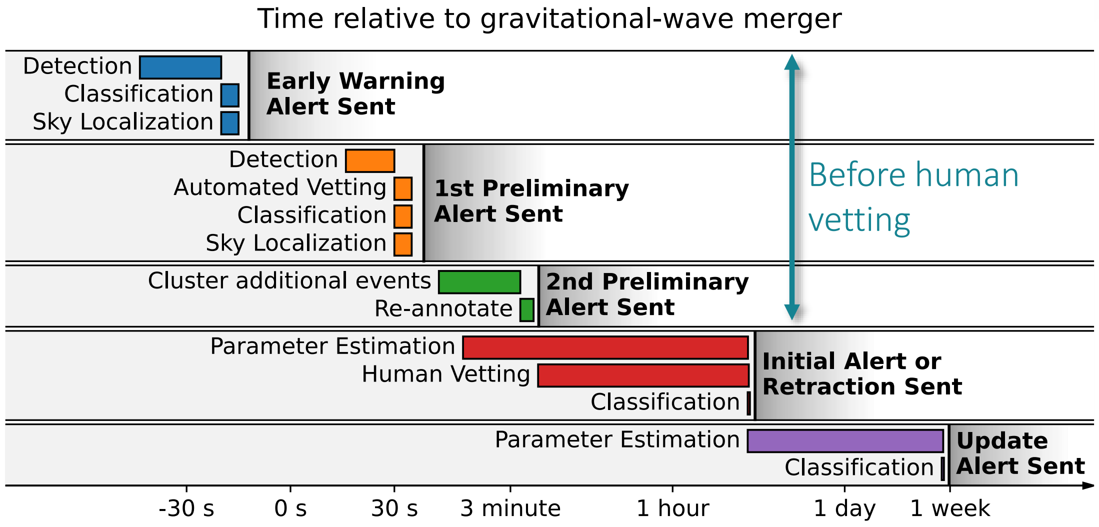
Event Triggers, Superevents and Alerts

- Search pipelines produce Events, with associated **SNR** and false alarm rate (**FAR**), which are uploaded to GraceDB
- **GWCelery** clusters events, possibly from different pipelines, on the basis of coalescence time for modeled searches, and trigger time for unmodeled searches, to Superevents
- The **preferred event** is identified on the base of FAR, SNR and search kind.

Alerts:

- **Low-significance:** preferred event FAR is < 2 per day; a "preliminary alert" is sent out but no human vetting
- **Significant event:** FAR < 1 per month* for modeled CBC candidates and < 1 per year* for unmodeled burst candidates.

Alert timeline



[LVK Public Alerts Open Guide]

* **Alert threshold after trials factor:** to account for the trials factor from the different searches with statistically independent FARs, the event thresholds are corrected to 1 per 6 months and 1 per 4 years for CBC and bursts respectively.

Notices and Circulars, Content of a GCN Alert

```
//////////////////////////////////////////////////////////////////////
TITLE:            GCN/LVC NOTICE
NOTICE_DATE:      Thu 18 May 23 13:38:21 UT
NOTICE_TYPE:      LVC Preliminary
TRIGGER_NUM:      S230518h
TRIGGER_DATE:     20082 TJD;   138 DOY;   2023/05/18 (yyyy/mm/dd)
TRIGGER_TIME:     46748.000000 SOD {12:59:08.000000} UT
SEQUENCE_NUM:     1
GROUP_TYPE:       1 = CBC
SEARCH_TYPE:      1 = AllSky
PIPELINE_TYPE:    15 = pycbc
FAR:              3.219e-10 [Hz]  (one per 35957.2 days)  (one per 98.51 years)
PROB_NS:          1.00 [range is 0.0-1.0]
PROB_REMNANT:     0.00 [range is 0.0-1.0]
PROB_BNS:         0.00 [range is 0.0-1.0]
PROB_NSBH:        0.86 [range is 0.0-1.0]
PROB_BBH:         0.03 [range is 0.0-1.0]
PROB_MassGap:     -1 [range is 0.0-1.0]   VALUE NOT ASSIGNED!
PROB_TERRES:      0.09 [range is 0.0-1.0]
TRIGGER_ID:       0x10
MISC:             0x189A003
SKYMAP_FITS_URL:
https://gracedb.ligo.org/api/superevents/S230518h/files/bayestar.multiorder.fits
EVENTPAGE_URL:    https://gracedb.ligo.org/superevents/S230518h/view/
COMMENTS:         LVC Preliminary Trigger Alert.
COMMENTS:         This event is an OpenAlert.
COMMENTS:         LIGO-Hanford Observatory contributed to this candidate event.
COMMENTS:         LIGO-Livingston Observatory contributed to this candidate event
```

- Trigger time
- Search type
- Source classification
- EM-bright properties
  More details in the EM-follow guide
- Sky localization

GCN Circular 33813

Subject LIGO/Virgo/KAGRA S230518h: Identification of a GW compact binary merger candidate
Date 2023-05-18T14:06:25Z (5 months ago)
From f.di-renzo@ip2i.in2p3.fr

The LIGO Scientific Collaboration, the Virgo Collaboration, and the KAGRA Collaboration report:

We identified the compact binary merger candidate S230518h during real-time processing of data from LIGO Hanford Observatory (H1) and LIGO Livingston Observatory (L1) at 2023-05-18 12:59:08.167 UTC (GPS time: 1368449966.167). The candidate was found by the PyCBC Live [1], GstLAL [2], and MBTAOnline [5] analysis pipelines.

The LIGO detectors are currently operating in an "engineering run" mode prior to the start of the O4 observing run. The data being collected at the time of this candidate is believed to be of good quality based on preliminary checks, but requires further investigation. A decision was made to alert the community promptly, with this caveat, due to the potential significance of this candidate.

S230518h is an event of interest because its false alarm rate, as estimated by the online analysis, is 3.2e-10 Hz, or about one in 98 years. The event's properties can be found at this URL:
https://gracedb.ligo.org/superevents/S230518h

The classification of the GW signal, in order of descending probability, is NSBH (86%), Terrestrial (10%), BBH (4%), or BNS (<1%).

Assuming the candidate is astrophysical in origin, the probability that the lighter compact object is consistent with a neutron star mass (HasNS) is >99%. [3] Using the masses and spins inferred from the signal, the probability of matter outside the final compact object (HasRemnant) is < 1%. Both HasNS and HasRemnant consider the support of several neutron star equations of state. The probability that any one of the binary components lie between 3 to 5 solar mass (HasMassgap) is < 1%.

One sky map is available at this time and can be retrieved from the GraceDB event page:
 * bayestar.multiorder.fits, an initial localization generated by BAYESTAR [4], distributed via GCN Notice about 39 minutes after the candidate event time.

For the bayestar.multiorder.fits sky map, the 90% credible region is 1002 deg2. Marginalized over the whole sky, the a posteriori luminosity distance estimate is 276 +/- 79 Mpc (a posteriori mean +/- standard deviation).

GCN Circular 33813