68TH WORKSHOP ON GRAVITATIONAL WAVES AND NUMERICAL RELATIVITY

CLASSIFICATION AND ANALYSIS OF KAGRA GLITCH USING HVETO DURING O3GK

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- Machine Learning

Motivation

- ✓Glitch classification and analysis is a pre-work required to upgrade data quality(DQ)
- ✓Compared to LIGO and VIRGO, it is necessary to check whether there is a glitch of the same shape and whether there is a characteristic of KAGRA
- ✓However, unlike LIGO and VIRGO, KAGRA is a recent gravitational wave detector, and the accumulated data is incomparably insufficient
- ✓Since KAGRA is a design that can be less affected by environmental factors than other detectors, improving the data quality through these way can yield good results

Detector Characterization

Goal

- Checking and elimination detector noise
- Improved signal detection performance

Tool

- Omicron
- Hierarchical veto (hveto)
- …
- Machine Learning

Omicron

Spectrogram

- Q-transformation
- Hilbert-Huang transformation
- Wavelet transformation

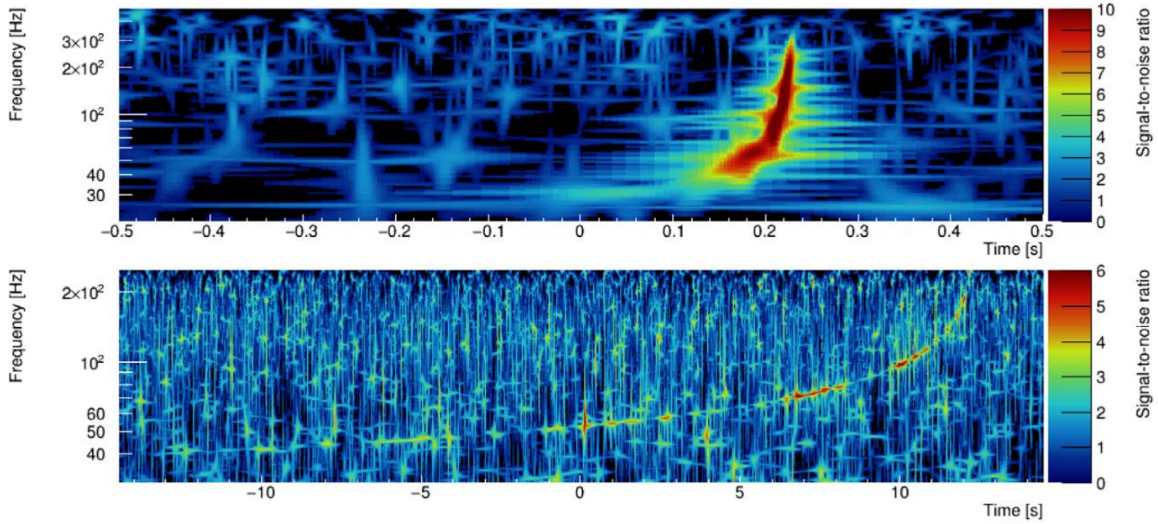


Fig. 3. Top: Omicron spectrogram of LIGO-Hanford detector's data around the time of GW150914. The whitened data is projected in multiple time–frequency planes characterized by a constant Q value and the signal-to-noise ratio is measured for each tile. In this representation, all Q planes are stacked up and combined into one; the tile with the highest signal-to-noise ratio is displayed on top. Bottom: Omicron spectrogram of LIGO-Livingston detector's data around the time of GW170817, using data after glitch subtraction.

Hveto

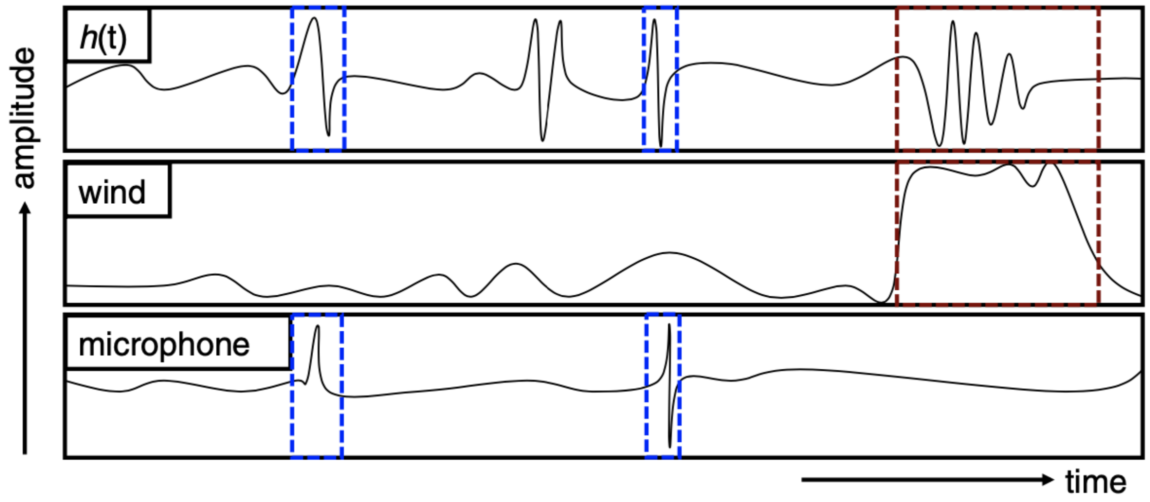
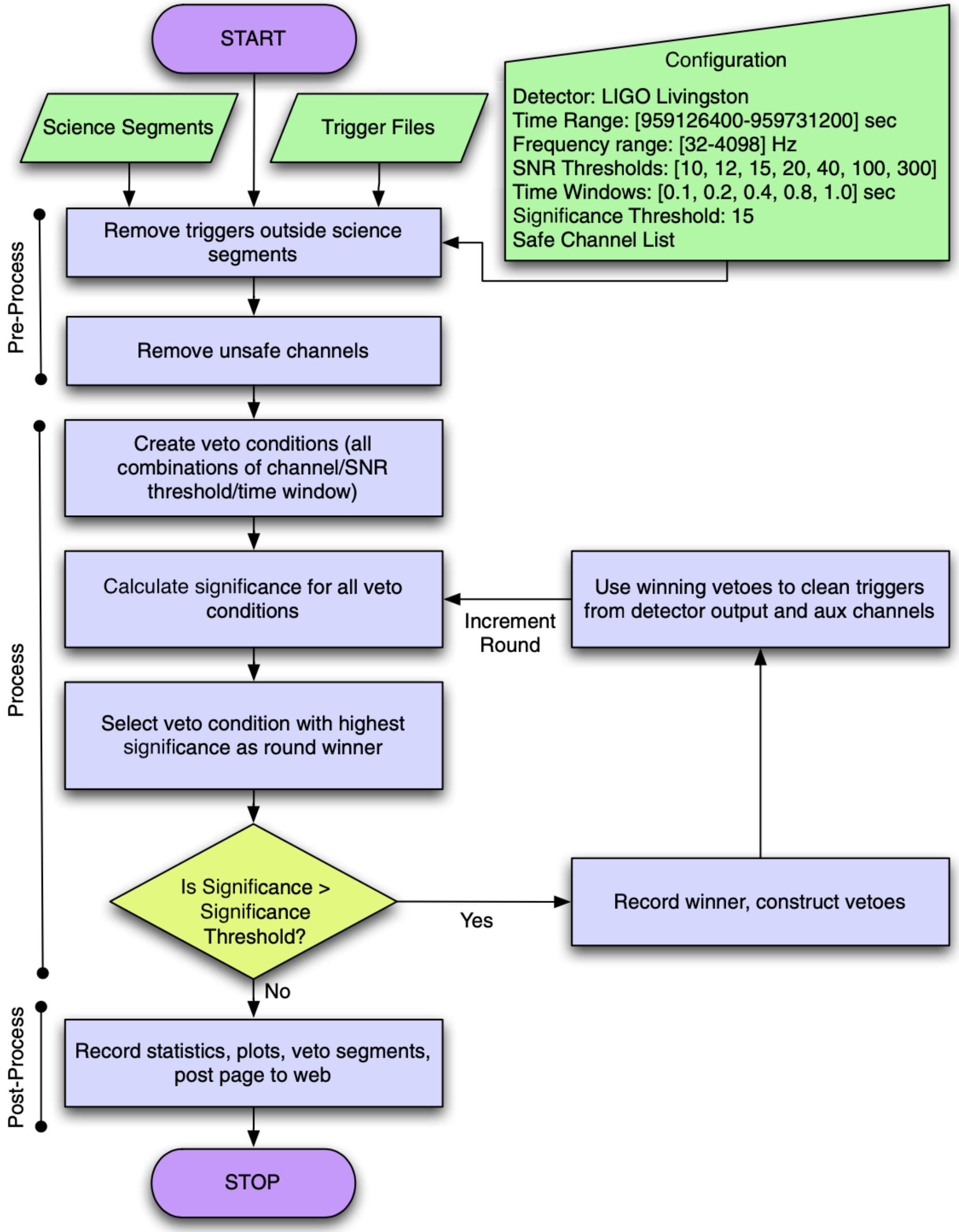


Figure 1. Illustration of the removal of some data from the $h(t)$ channel due to its association with two hypothetical non-astrophysical disturbances, to obtain an improved data stream. The top trace, $h(t)$, represents the $h(t)$ data. The middle trace is a monitor of wind speeds on the detector site, while the lowest trace is a microphone located in one of the detector's buildings. The first and second vetoed period in $h(t)$, between pairs of dashed lines, are removed due to association with sharp glitches in the microphone, while the third period is removed because of high local wind speeds. This data removal would be done after a relationship between these types of disturbances and noise transients in $h(t)$ had been established.



START
Science Segments
Trigger Files
Configuration
Detector: LIGO Livingston
Time Range: [959126400-959731200] sec
Frequency range: [32-4098] Hz
SNR Thresholds: [10, 12, 15, 20, 40, 100, 300]
Time Windows: [0.1, 0.2, 0.4, 0.8, 1.0] sec
Significance Threshold: 15
Safe Channel List
Pre-Process
Remove triggers outside science segments
Remove unsafe channels
Process
Create veto conditions (all combinations of channel/SNR threshold/time window)
Calculate significance for all veto conditions
Increment Round
Use winning vetoes to clean triggers from detector output and aux channels
Select veto condition with highest significance as round winner
Is Significance > Significance Threshold?
Yes
Record winner, construct vetoes
No
Post-Process
Record statistics, plots, veto segments, post page to web
STOP

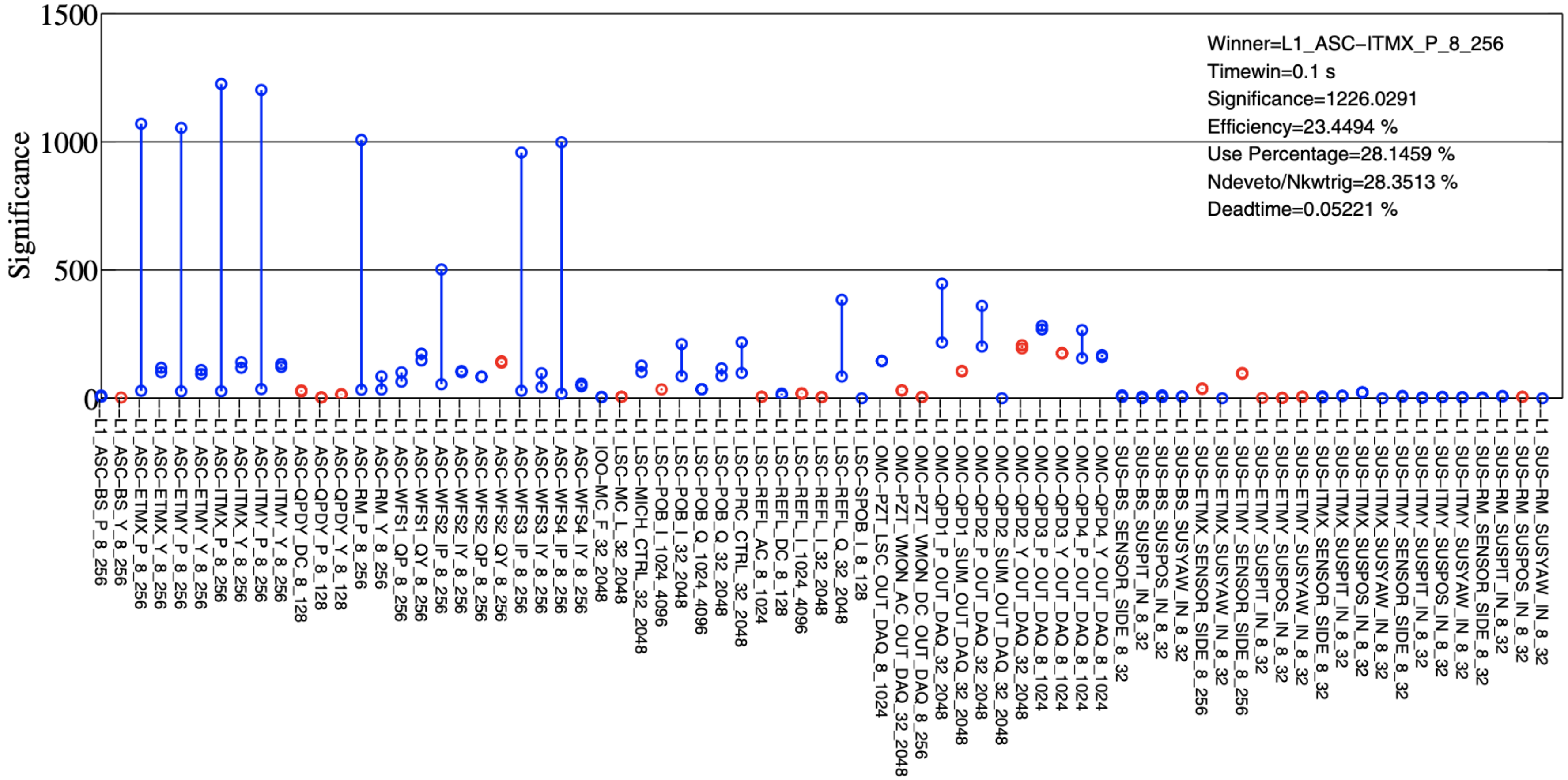
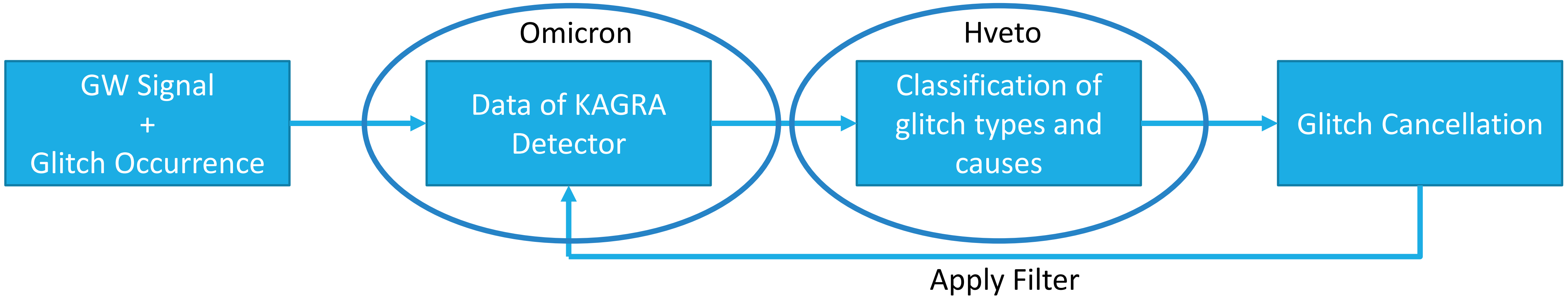


Figure 6. Significance drop plot for the second round, won by ITMX pitch. Each vertical line has two endpoints corresponding to the highest significance for its corresponding channel in a given round, and the following round, respectively. The blue lines indicate that the significance of that channel is lower in the later round, and the red lines indicate the significance is the same or higher. A subset of instrumental sensing and control channels is shown. From left to right, channel prefixes and their general descriptions are ASC: alignment, IOO: frequency, LSC: length, OMC: output mode cleaner and SUS: suspensions.

Methods

- ✓Omicron : tool developed for performing multi-resolution time-frequency analysis of data from gravitational wave detectors
- ✓Hveto : statistically analyzes event correlation between the main channel and hundreds of thousands of auxiliary channels using Omicron



Example: Hveto Results

K1 HierarchicalVeto

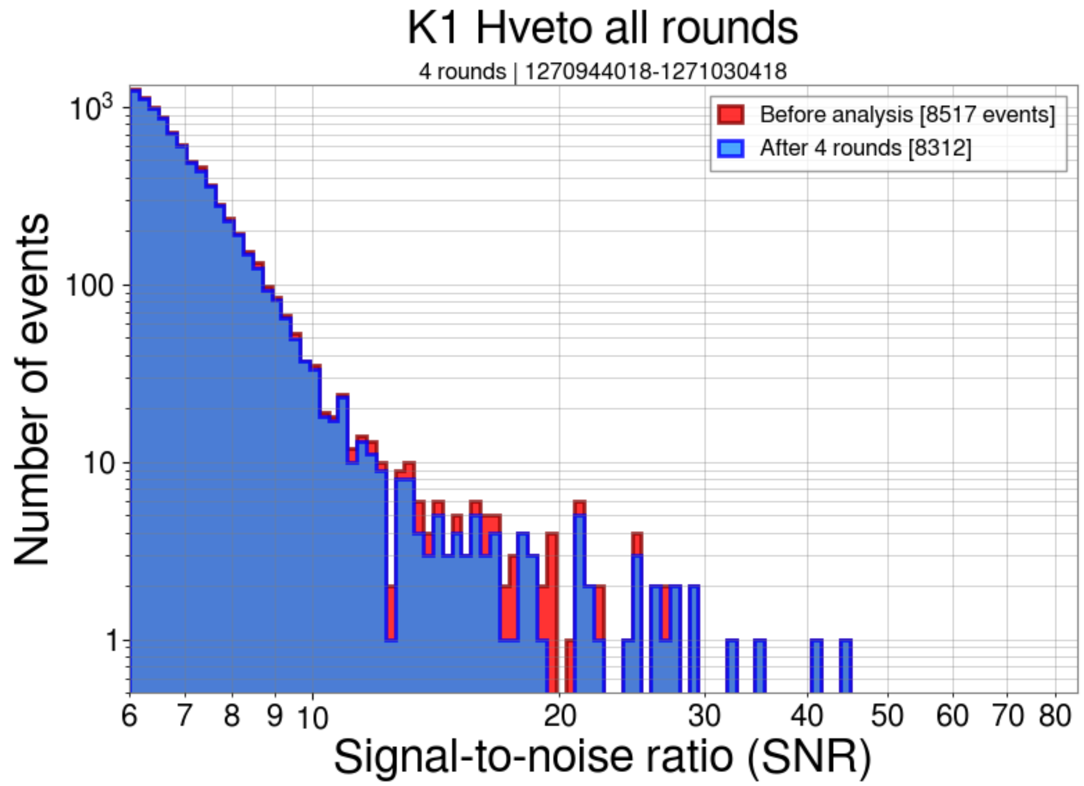
1270944018-1271030418

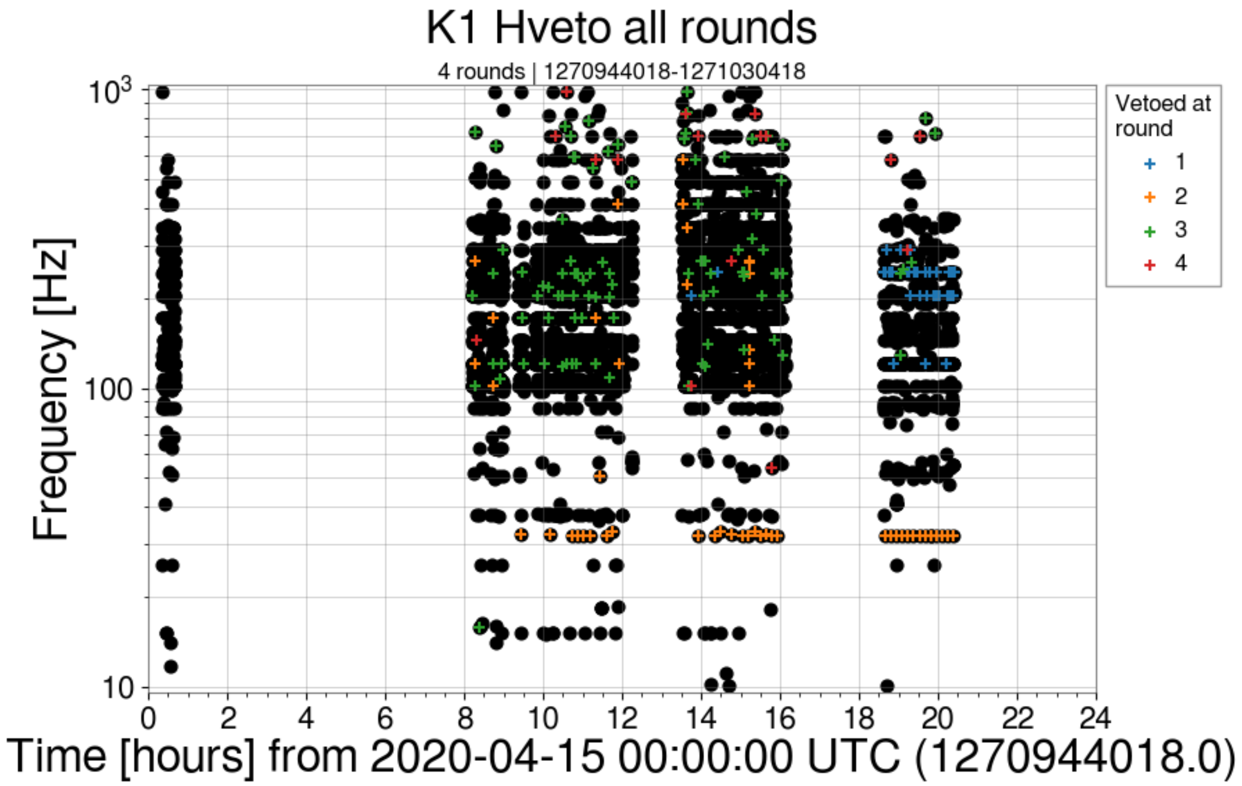
Summary

Summary of this HierarchichalVeto analysis.

Round	Winner	Twin [s]	SNR Thresh	Significance	Use [%]	Efficiency [%]	Deadtime [%]	Cum. efficiency [%]	Cum. deadtime [%]
1	`K1:PEM_MAG_BS_BOOTH_BS_Z_OUT_DQ`	0.01	100.00	64.12	45.57 [36/79]	0.42 [36/8517]	0.00 [0.79/28284.00]	0.42 [36/8517]	0.00 [0.79/28284.00]
2	`K1:VIS-SRM_TM_OPLEV_LEN_YAW_OUT_DQ`	0.80	6.25	11.05	63.77 [44/69]	0.62 [53/8481]	0.19 [54.00/28283.21]	1.04 [89/8517]	0.19 [54.79/28284.00]
3	`K1:LSC-ALS_CARM_OUT_DQ`	0.08	6.00	8.17	4.49 [100/2227]	1.19 [100/8428]	0.63 [178.16/28228.61]	2.22 [189/8517]	0.82 [232.95/28284.00]
4	`K1:PEM_MIC_SR_BOOTH_SR_Z_OUT_DQ`	0.20	20.00	5.11	22.86 [16/70]	0.19 [16/8328]	0.05 [13.55/28050.45]	2.41 [205/8517]	0.87 [246.50/28284.00]

Example: Hveto Results





Example: Hveto Results

Round details

Round 1, Winner = K1:PEM_MAG_BS_BOOTH_BS_Z_OUT_DQ, window = 0.01, SNR thresh = 100.0

Winner: K1:PEM_MAG_BS_BOOTH_BS_Z_OUT_DQ

SNR threshold: 100.0

Window: 0.01

Significance: 64.12

Veto segments: [txt]

Veto triggers: [txt]

Vetoed primary triggers: [txt]

Unvetoed primary triggers: [txt]

Omega scans:

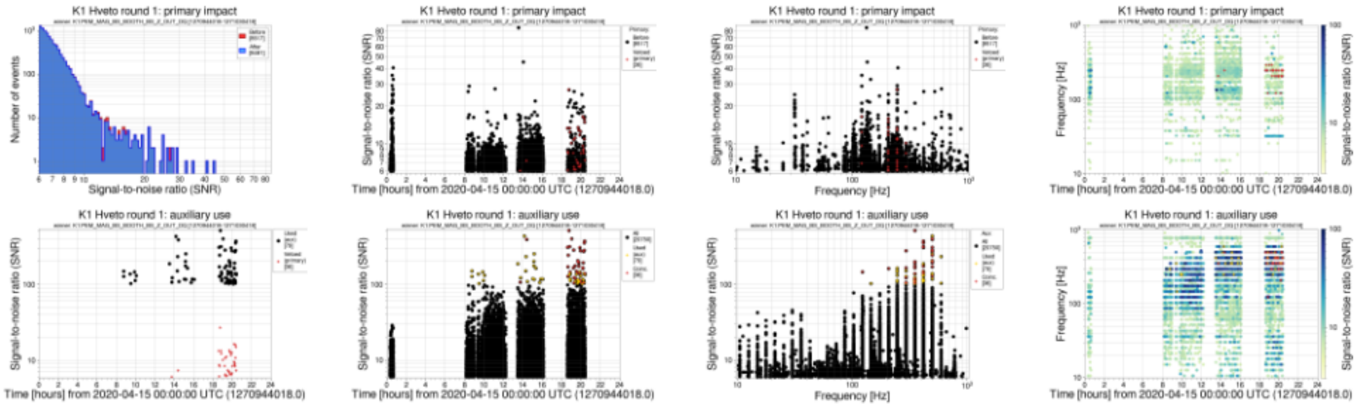
1271015929.516113 [SNR 6.7] [p] [a]

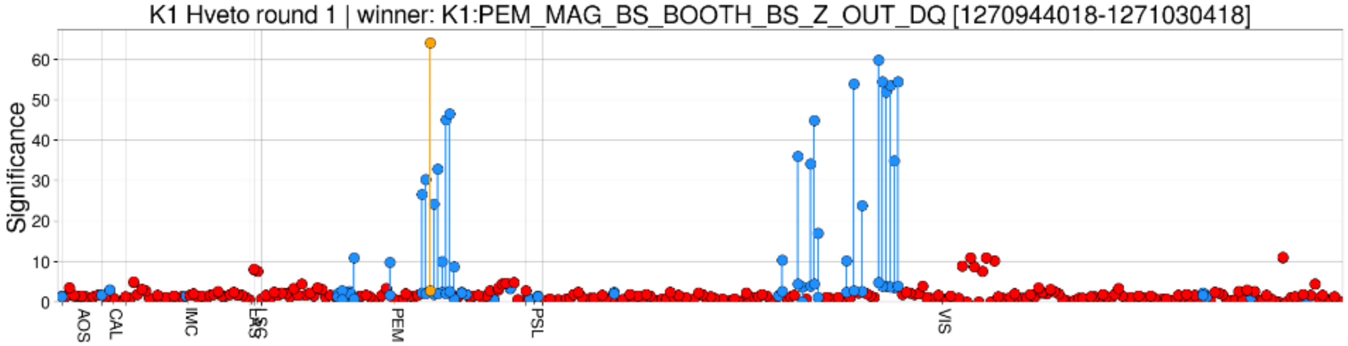
1271011201.643066 [SNR 6.1] [p] [a]

1271014873.354004 [SNR 7.0] [p] [a]

1270995920.657714 [SNR 7.2] [p] [a]

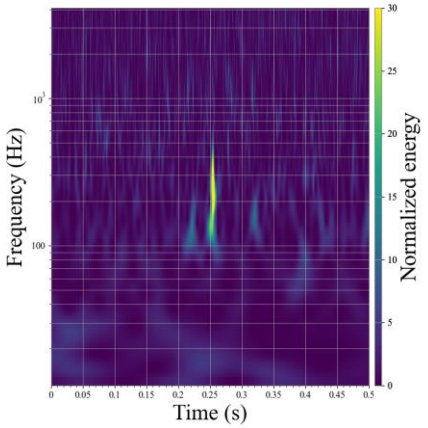
1271013326.818847 [SNR 10.7] [p] [a]



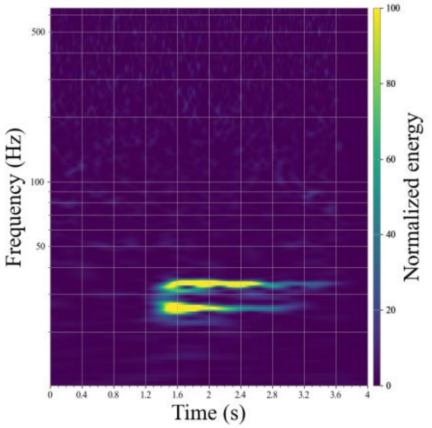


Results: Classification

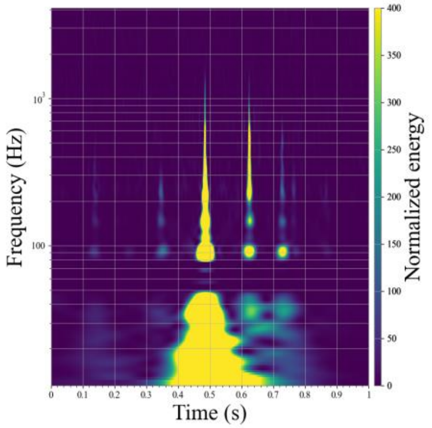
- ✓Glitches are divided into 4 types (Gravity Spy)
  - ✓Blip-like : Blip, Blob, Helix, Jewel, and Whistle
  - ✓Line-like : Power-line, X Hz line, Harmonics, and X hz Scratchy
  - ✓Spire-like : Spire, Fireball, and Weird
  - ✓Low Frequency : Splatter and Low frequency burst



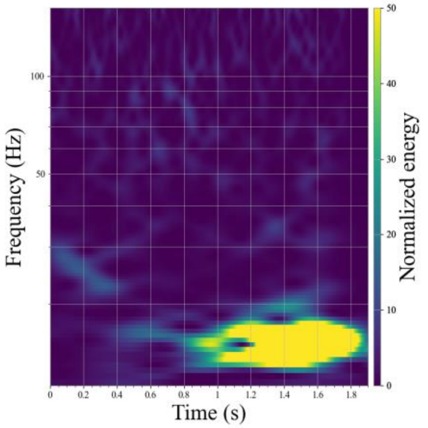
Blip



Harmonics

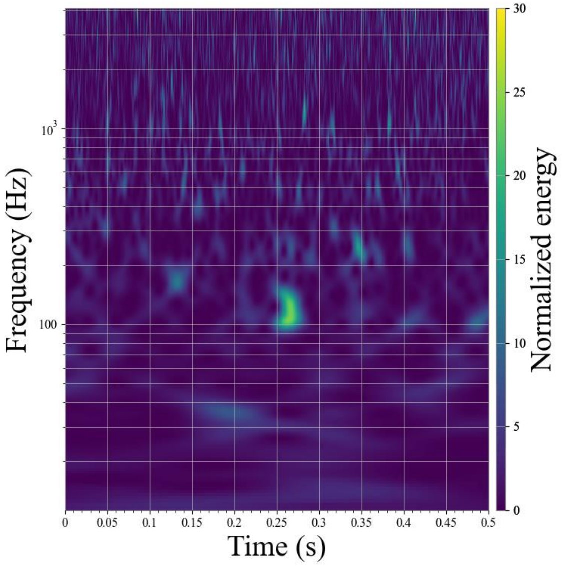


Spire

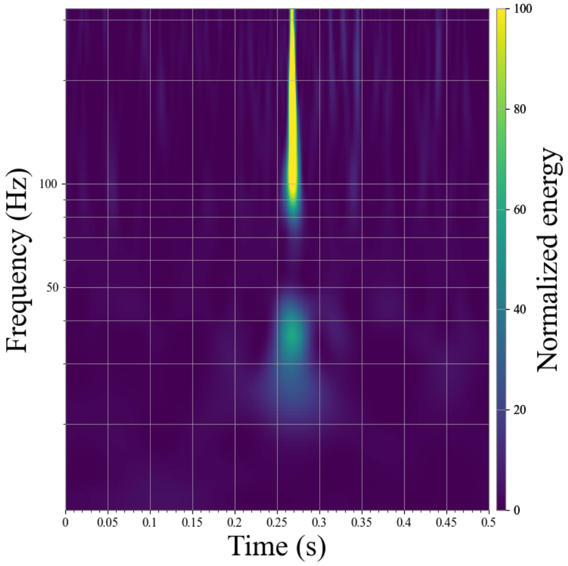


Low frequency burst

Results: Blip



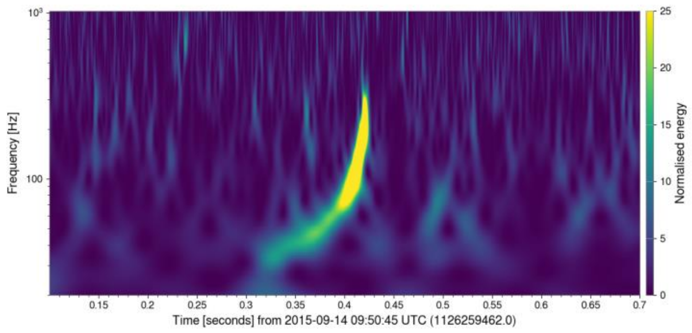
Main channel



Auxiliary channel

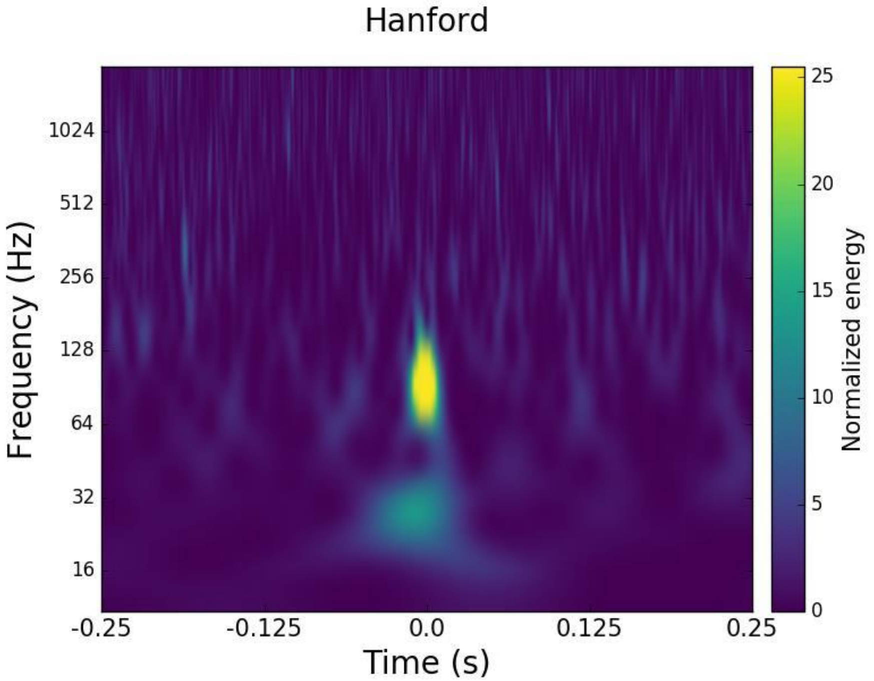
K1:VIS-ITMY_MN_PSDAMP...

- Blip glitch is like the gravitational wave signal from the merging process of binary black hole
- KAGRA's blip appears from 100Hz to 400Hz on the sub channel and comes out in the form of a single character
- When the low frequency falls below 100Hz, the shape of the blip tends to look faint or unclear in the main channel

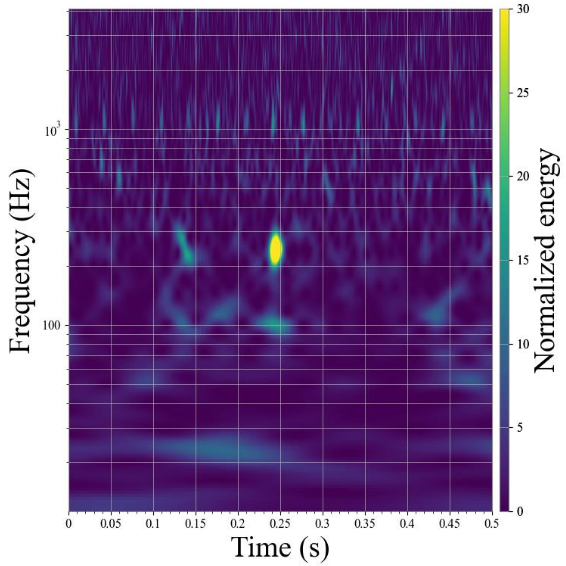


GW150914

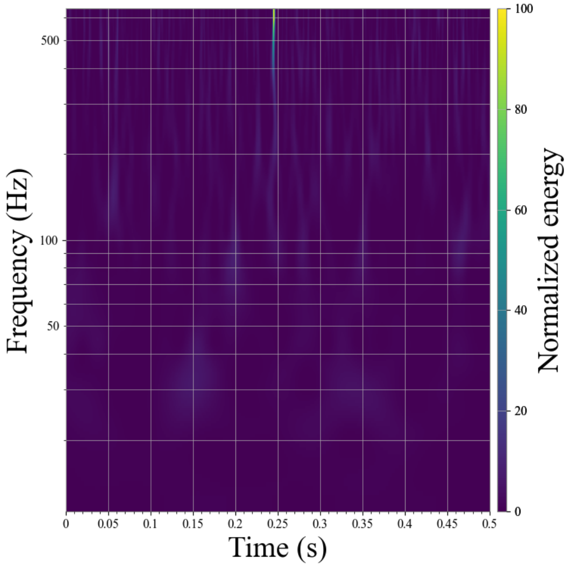
Results: Blob



Example: Blob



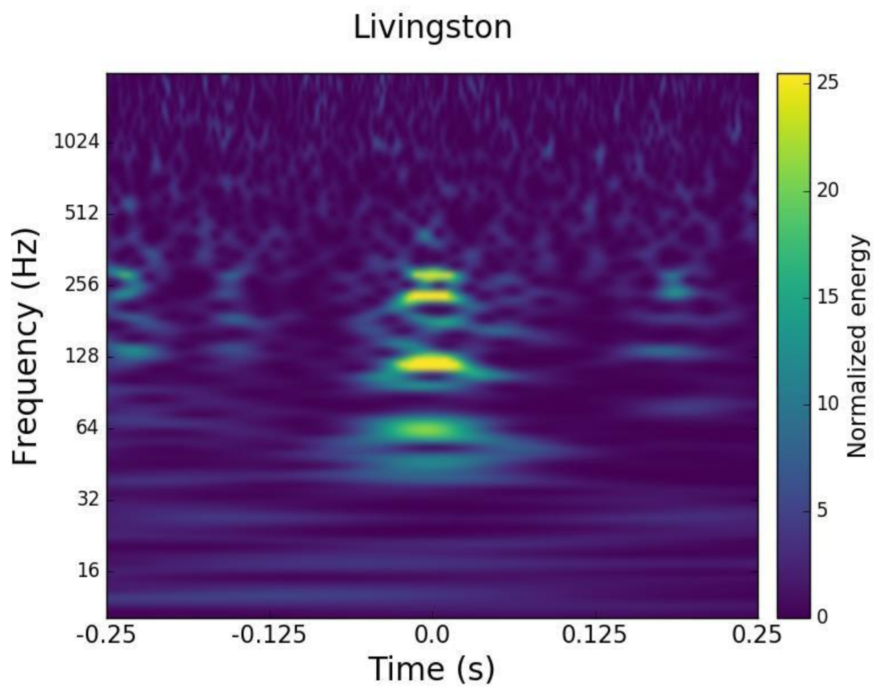
Main channel



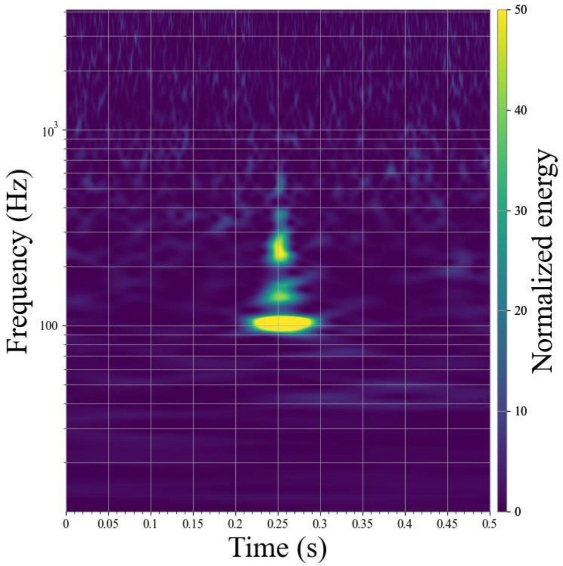
Auxiliary channel
K1:PEM-ACC_OMC_TABLE…

- In KAGRA, a bubble-shaped glitch appeared on the main channel and a blip glitch appeared on the sub-channel at the same time

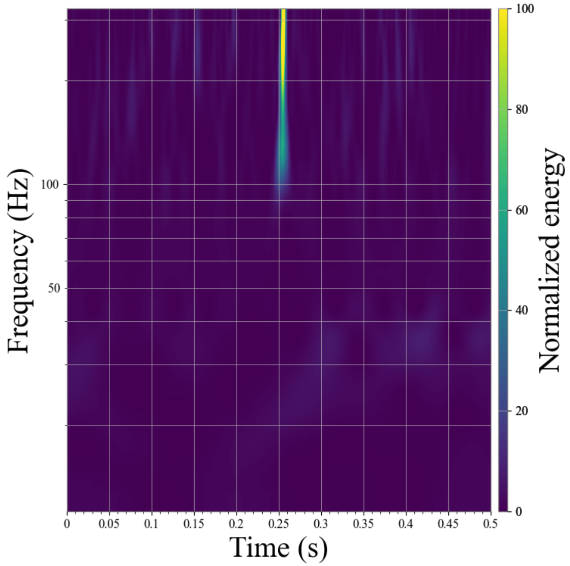
Results: Helix



Example: Helix



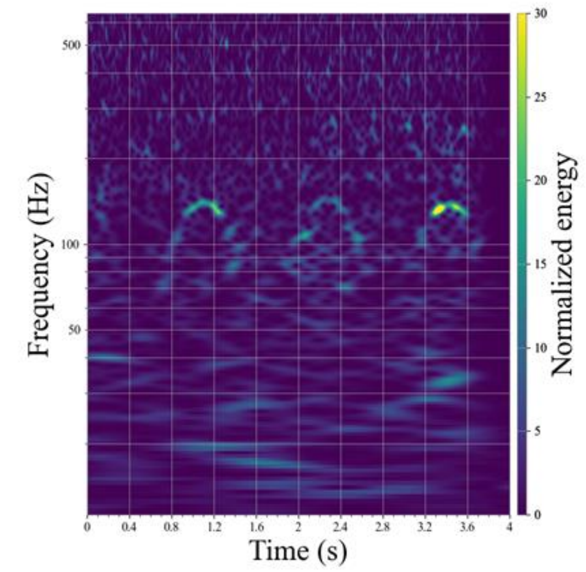
Main channel



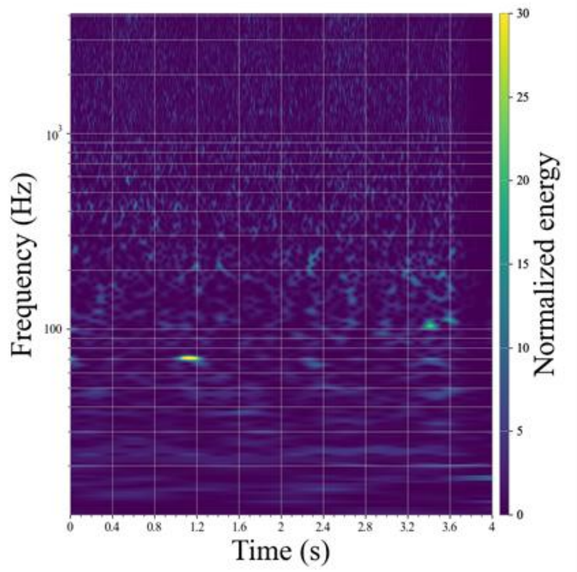
Auxiliary channel
K1:VIS-ITMY_IM_PSDAMP...

- In the case of the helix glitch, a helix appeared in the main channel, but a blip glitch appeared in the sub channel

Results: Whistle



Main channel



Auxiliary channel
K1:LSC-ALS_CARM…

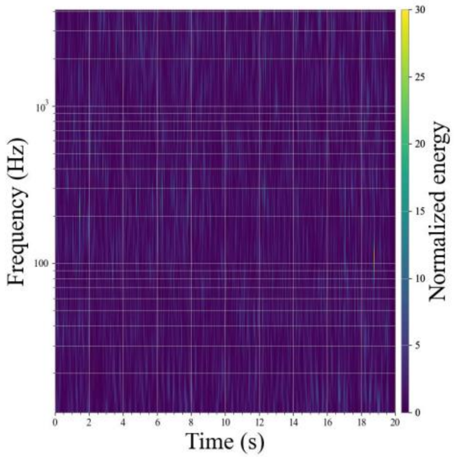
- Whistle-shaped glitches were mainly detected and formed from 100 Hz to 200 Hz
- When the inflection point of the Whistle glitch was near 200Hz, the Whistle strength of the main channel came out strong

Results: Analysis

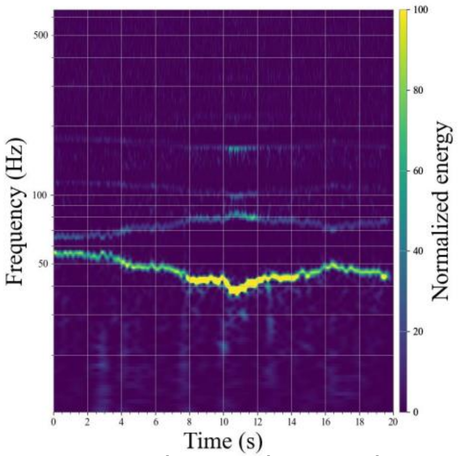
- ✓Blip-like Glitch
  - ✓Blip, Blob, Helix, Jewel, and Whistle
  - ✓The blip glitch is like the gravitational wave signal from the merging process of the Binary Black Hole, which interferes with the detection of the gravitational wave signal
  - ✓KAGRA’s blip appears from 100Hz to 400Hz on the sub channel and comes out in the form of a single character
  - ✓In the case of the blip, when the low frequency falls below 100Hz, the shape of the blip tends to look faint or unclear in the main channel
  - ✓Whistle-shaped glitches were mainly detected and formed from 100 Hz to 200 Hz
  - ✓When the inflection point of the whistle glitch was near 200Hz, the whistle strength of the main channel came out strong

Results: Analysis

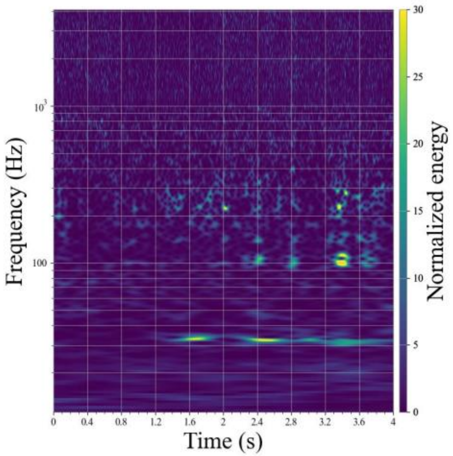
- ✓Line-like Glitch
  - ✓Power Line, X Hz Line, Harmonics, and X Hz Scratchy
  - ✓Power Line glitch: comes out according to the frequency of electricity in each country, and in Japan it comes out between 60Hz
  - ✓Harmonics glitch: Harmonics are multi-line glitches in which the X Hz Line glitch is continuous multiples
    - ✓16Hz, 24Hz, and 32Hz



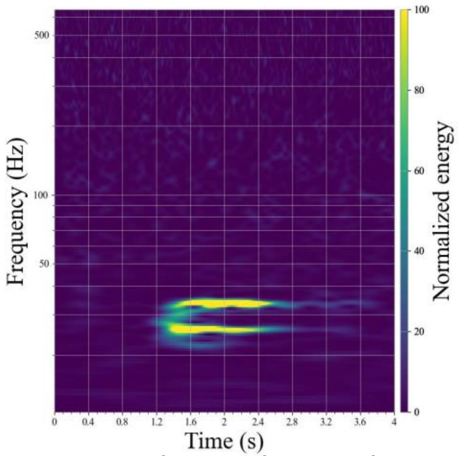
Main channel



Auxiliary channel K1:PEM-ACC_EXC_CHAMBER…

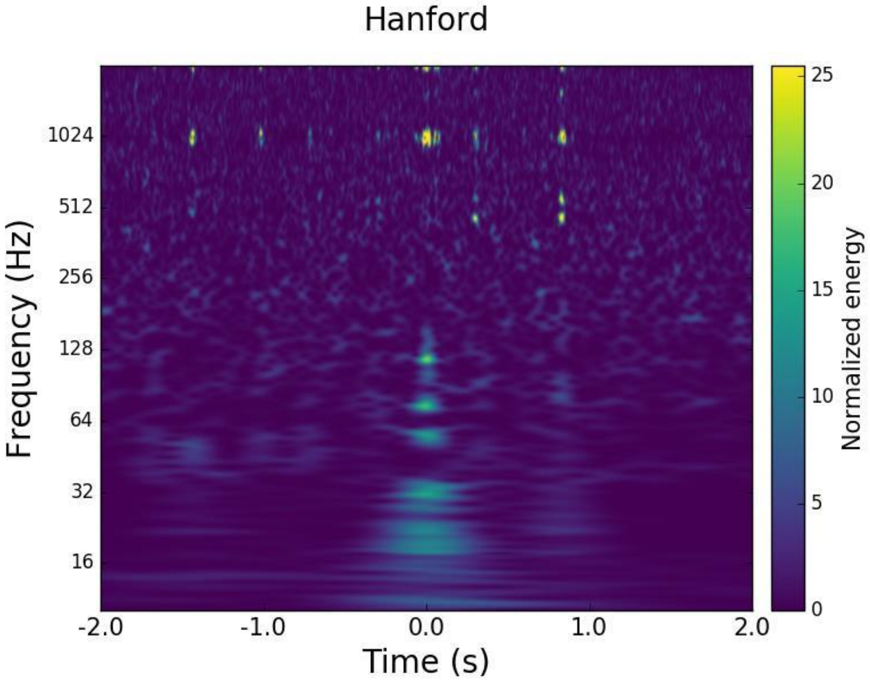


Main channel

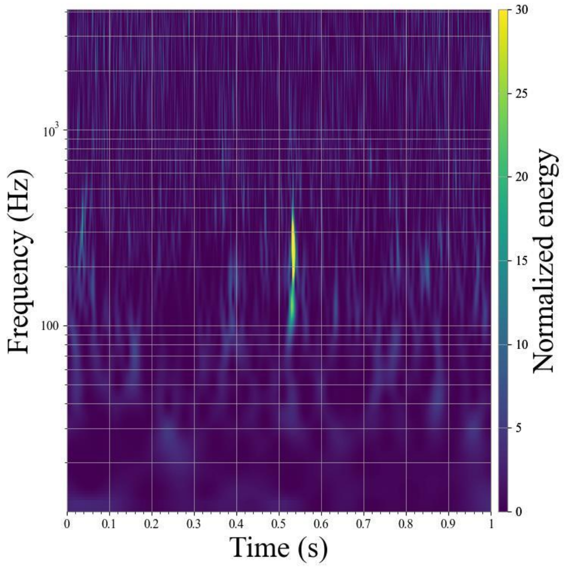


Auxiliary channel K1:VIS-OMMT1_TM_OPLEV

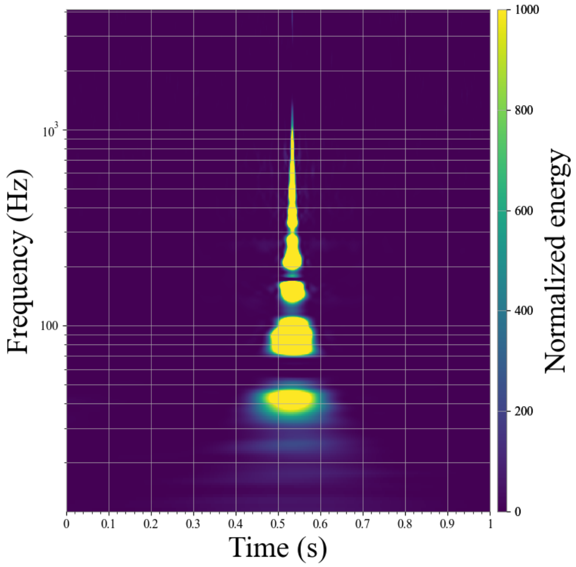
Results: Spire



Example: Spire



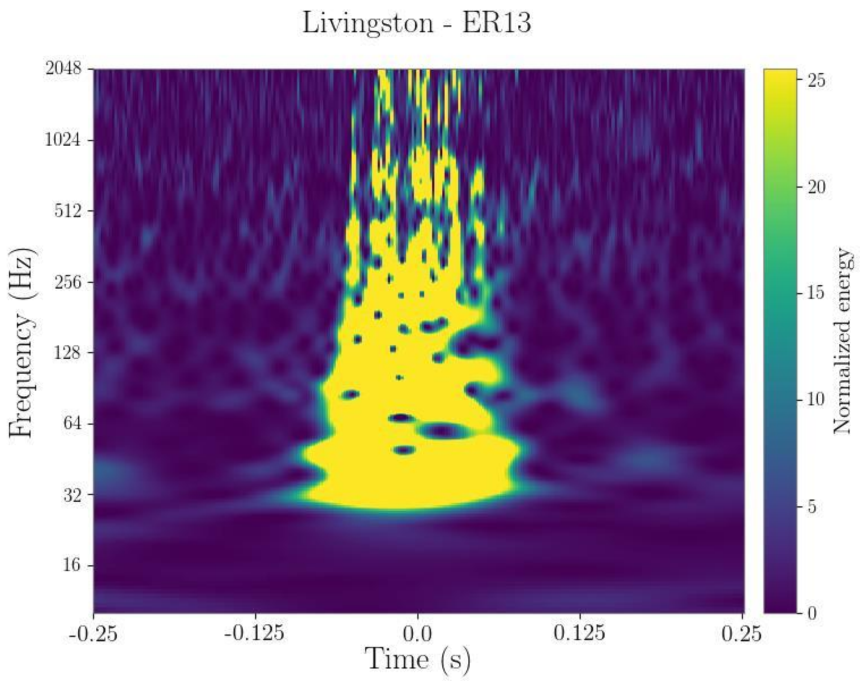
Main channel



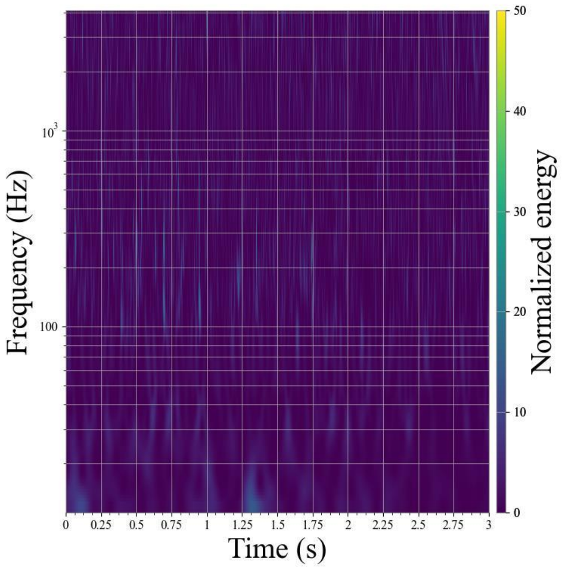
Auxiliary channel
K1:PEM-MAG_BS_BOOTH...

- Spire of KAGRA detector is displayed near 0 to 1000 Hz in the shape of a triangle on the spectrogram
- In the main channel, the blip is shown

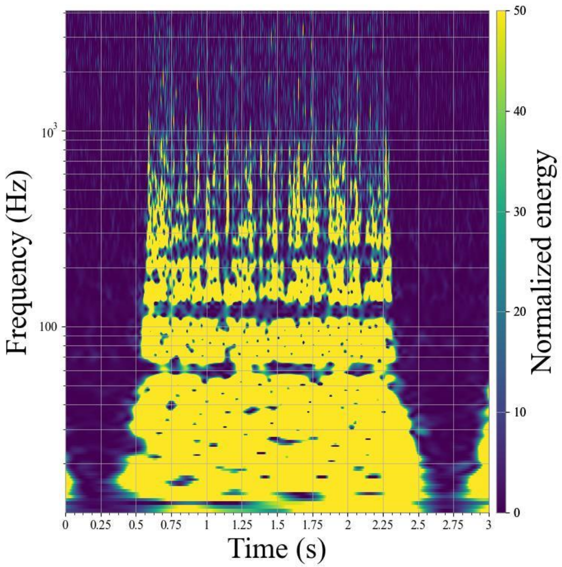
Results: Fireball



Example: Fireball



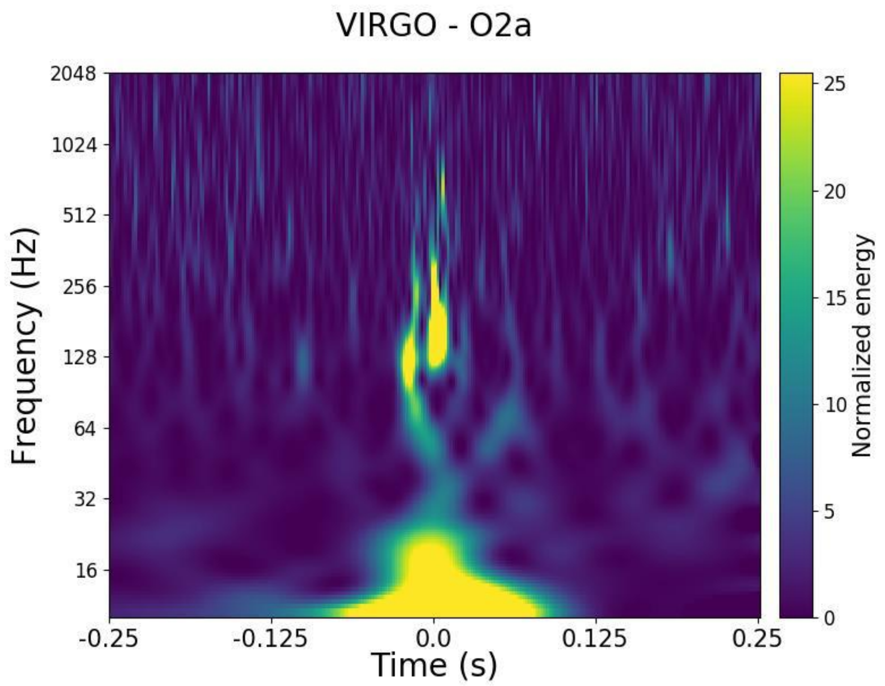
Main channel



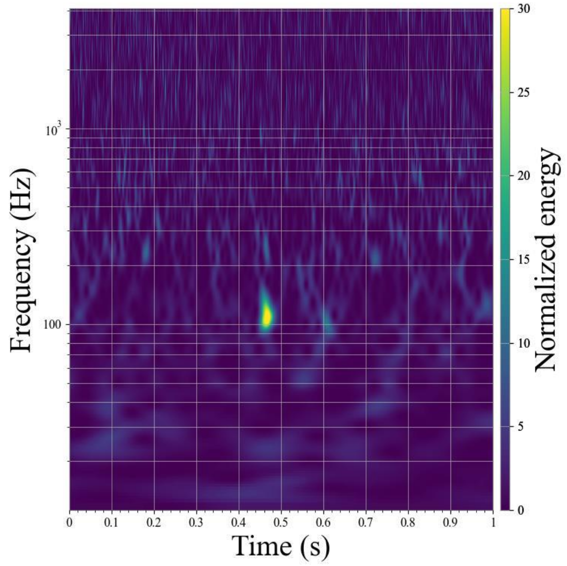
Auxiliary channel
K1:LAS-POW_FIB…

- Fireball glitch shows many spires superimposed
- No glitch in main channel.

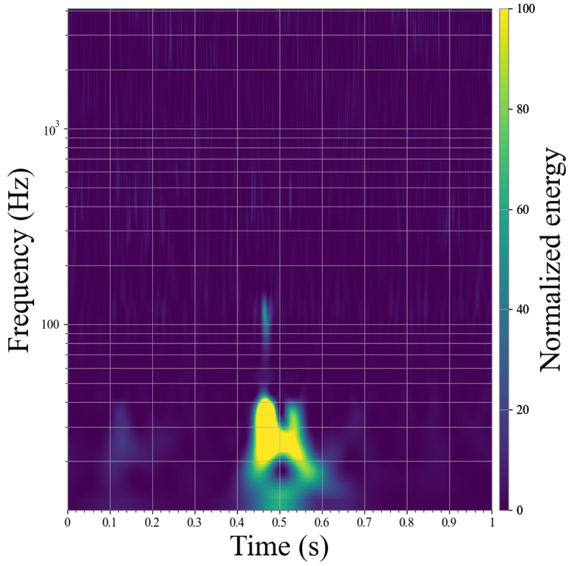
Results: Weird



Example: Weird



Main channel



Auxiliary channel
K1:PEM-MAG_BS_BOOTH...

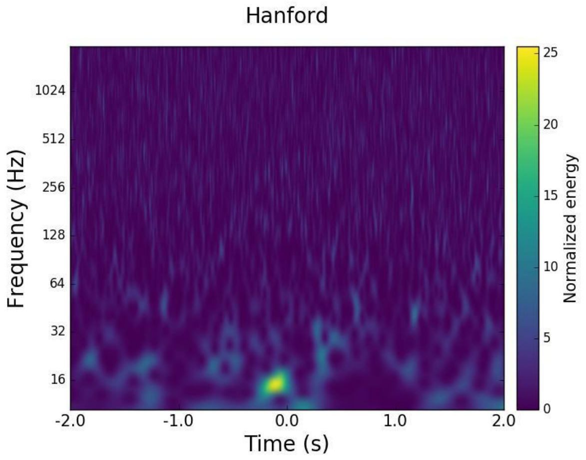
- Weird glitch has a small triangular shape in the low frequency band in sub channel and a glitch like a blip shape around 100Hz in main channel

Results: Analysis

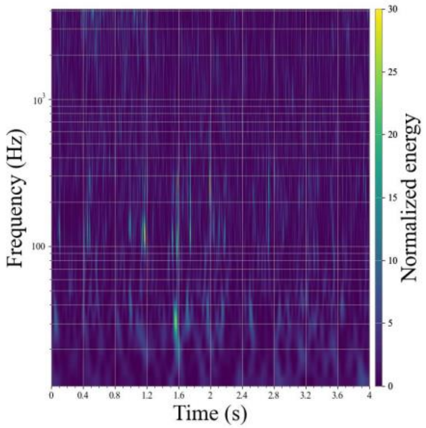
- ✓Spire-like Glitch
  - ✓Spire, Fireball, and Weird
  - ✓Spire-like glitches showed a little correlation between the main and secondary channels
    - ✓Main channel: Blip, Aux channel: Spire-like
  - ✓Spire of KAGRA detector is displayed near 0 to 1000 Hz in the shape of a triangle on the spectrogram
  - ✓Fireball glitch shows many spires superimposed
  - ✓Weird glitch has a small triangular shape in the low frequency band and a glitch like a blip shape around 100Hz
  - ✓The glitch of the sub channel below 100Hz has no effect on the main channel

Results: Analysis

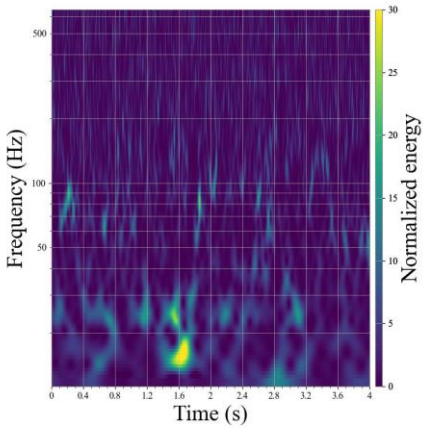
- ✓Low Frequency Glitch
  - ✓Splatter and Low Frequency Burst
  - ✓Looking at the trend of LF glitch, the glitch appearing in the low frequency band in the auxiliary channel does not significantly affect the main channel



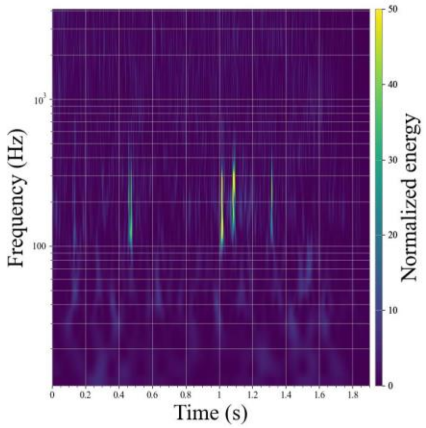
Example: Splatter



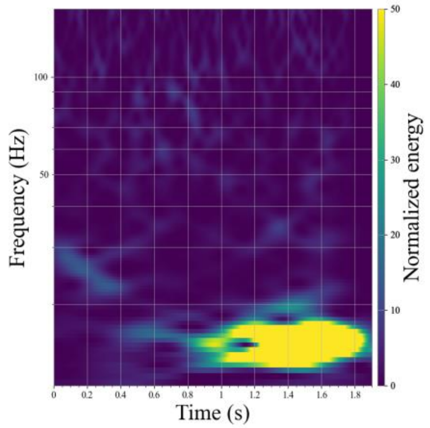
Main channel



Aux channel
K1:AOS-TMSX_IR_PDA1...



Main channel



Aux channel
K1:PEM-SEIS_IXV_GND...

Result: Table & Tree

	Blip-like	Line-like	Low Frequency	Spire-like
AOS	◯	◯	◯	
IMC	◯	◯	◯	
LAS				◯
LSC	◯			◯
PEM	◯	◯	◯	◯
VIS	◯	◯		

Blip-like

- AOS
  - **K1:AOS-TMSX_IR_PDA1_OUT_DQ**
- IMC
  - *K1:IMC-IMMT1_TRANS_QPDA1_DC_YAW_OUT_DQ*
- LSC
  - **K1:LSC-ALS_CARM_OUT_DQ**
  - **K1:LSC-ALS_DARM_OUT_DQ**
- PEM
  - **K1:PEM-ACC_OMC_TABLE_AS_Z_OUT_DQ**
  - **K1:PEM-MIC_SR_BOOTH_SR_Z_OUT_DQ**
- VIS
  - **K1:VIS-ITMY_IM_PSDAMP_R_IN1_DQ**
  - **K1:VIS-ITMY_MN_PSDAMP_L_IN1_DQ**
  - **K1:VIS-ITMY_MN_PSDAMP_Y_IN1_DQ**
  - **K1:VIS-TMSY_DAMP_R_IN1_DQ**

Line-like

- AOS
  - **K1:AOS-TMSX_IR_PDA1_OUT_DQ**
- IMC
  - *K1:IMC-IMMT1_TRANS_QPDA1_DC_PIT_OUT_DQ*
  - *K1:IMC-IMMT1_TRANS_QPDA1_DC_YAW_OUT_DQ*
- PEM
  - *K1:PEM-ACC_EXC_CHAMBER_EXC_Z_OUT_DQ*
- VIS
  - **K1:VIS-OMMT1_TM_OPLEV_PIT_OUT_DQ**
  - **K1:VIS-OMMT1_TM_OPLEV_YAW_OUT_DQ**
  - **K1:VIS-OSTM_TM_OPLEV_YAW_OUT_DQ**
  - *K1:VIS-SR3_TM_OPLEV_TILT_YAW_OUT_DQ*
  - *K1:VIS-SRM_TM_OPLEV_LEN_YAW_OUT_DQ*

Low Frequency

- AOS
  - **K1:AOS-TMSX_IR_PDA1_OUT_DQ**
- IMC
  - *K1:IMC-IMMT1_TRANS_QPDA1_DC_PIT_OUT_DQ*
  - *K1:IMC-IMMT1_TRANS_QPDA1_DC_YAW_OUT_DQ*
- PEM
  - *K1:PEM-MAG_BS_BOOTH_BS_X_OUT_DQ*
  - *K1:PEM-SEIS_IXV_GND_EW_IN1_DQ*
  - *K1:PEM-VOLT_REFL_TABLE_GND_OUT_DQ*

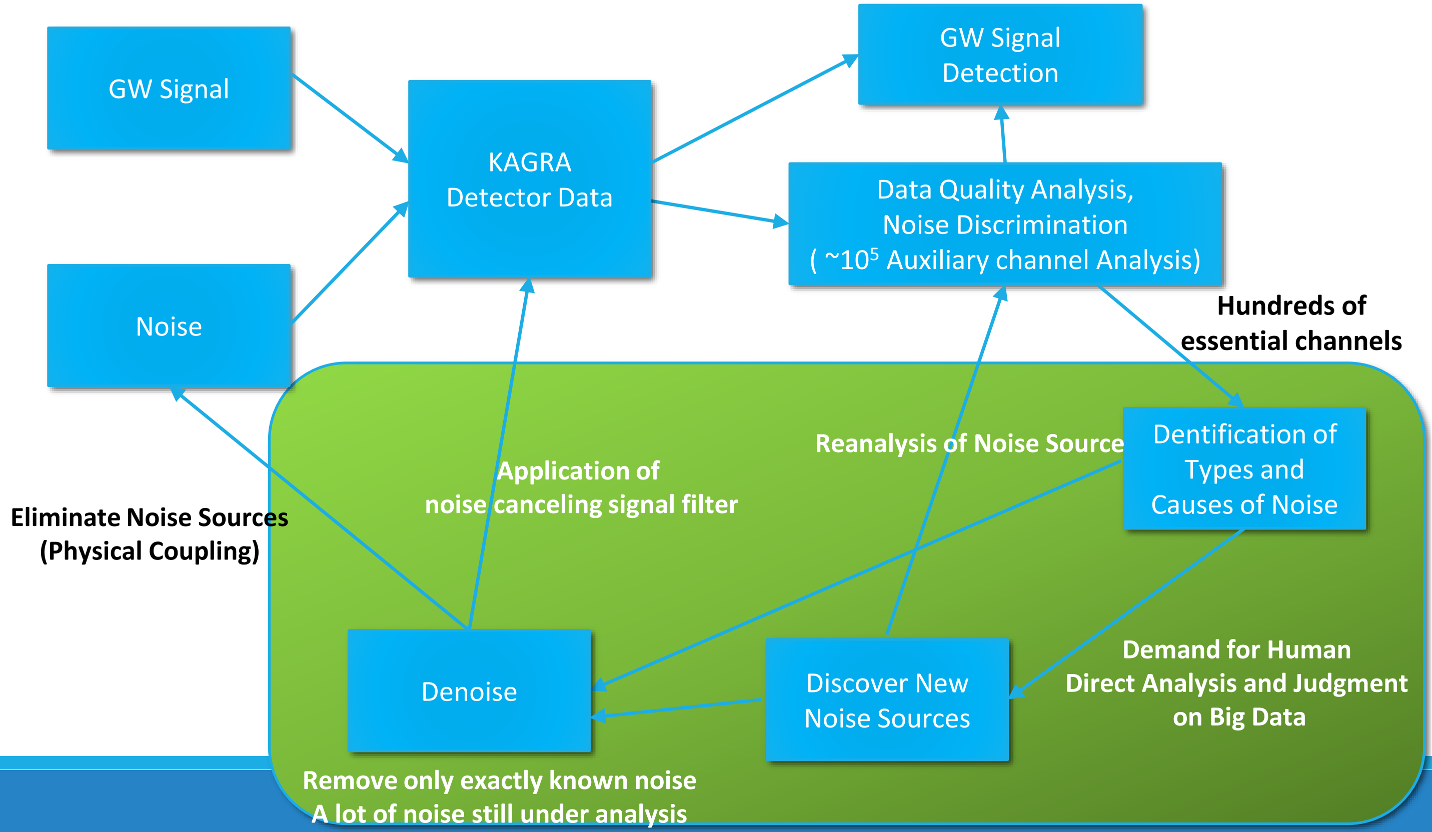
Spire-like

- LAS
  - *K1:LAS-POW_FIB_OUT_DQ*
- LSC
  - *K1:LSC-ALS_DARM_OUT_DQ*
- PEM
  - **K1:PEM-ACC_OMC_TABLE_AS_Z_OUT_DQ**
  - **K1:PEM-MAG_BS_BOOTH_BS_X_OUT_DQ**
  - **K1:PEM-MAG_BS_BOOTH_BS_Y_OUT_DQ**
  - **K1:PEM-MAG_BS_BOOTH_BS_Z_OUT_DQ**

The Need for AI in Glitch Classification

- There is a lot of glitch data coming out, but there is not enough manpower to sort them out visually

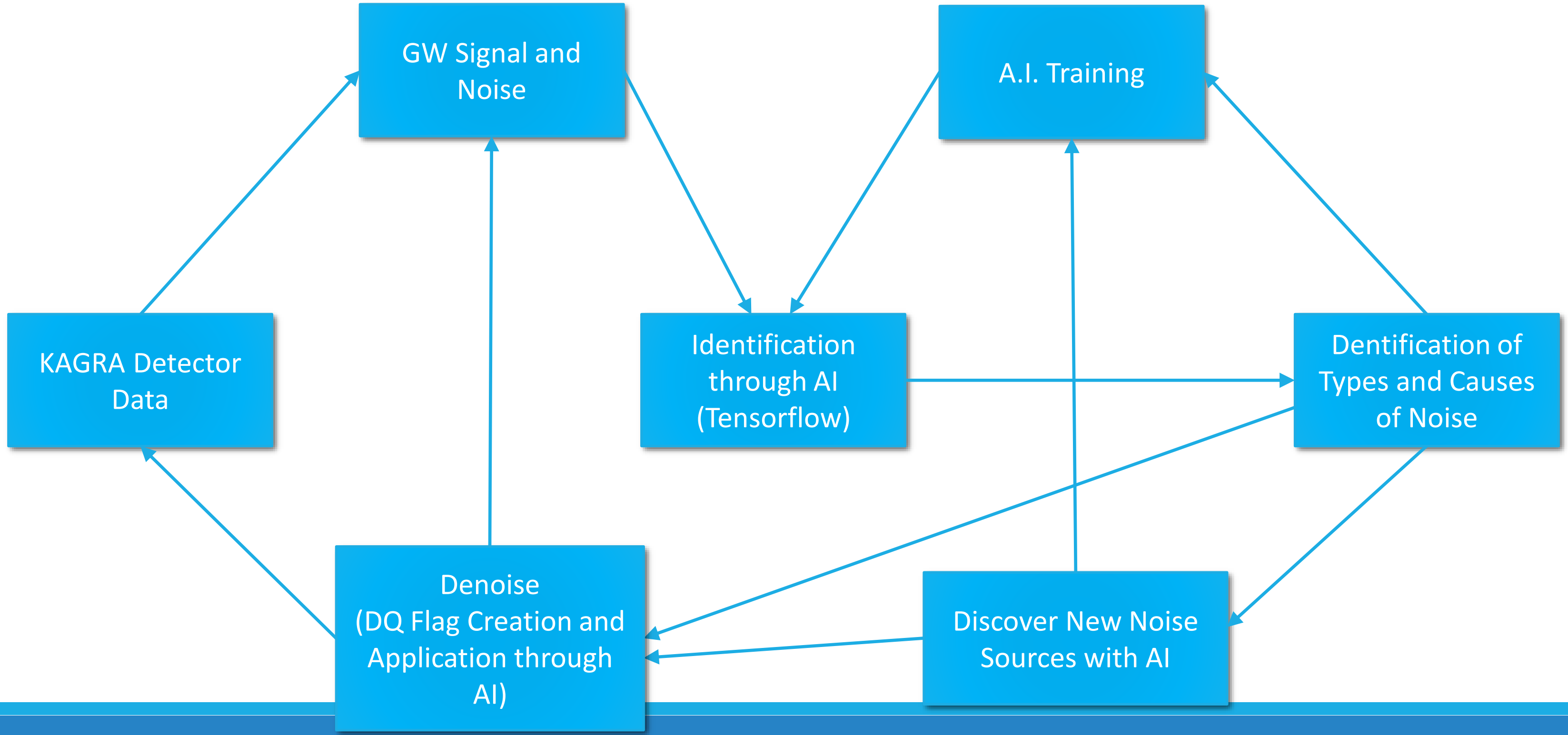
Current Denoising Procedure



The Need for AI in Glitch Classification

- If an AI method is introduced for noise removal, the dependence on manpower can be greatly reduced

Noise Removal Method After Applying AI



Thanks