Developing a novel method for finding correlated features between control, environment channels

DetChar Meeting
2014/11/25 (Thus.)

Hirotaka Yuzurihara
Osaka City University

Collaborator : Kazuhiro Hayama, Shuhei Mano,
Takahiro Yamamoto, Atsushi Nishizawa, Nobuyuki Kanda

Table of Contents

motivation - correlation analysis using environmental channels

Goal : search correlated channels between ~10000 environmental channels and finally localize noise sources

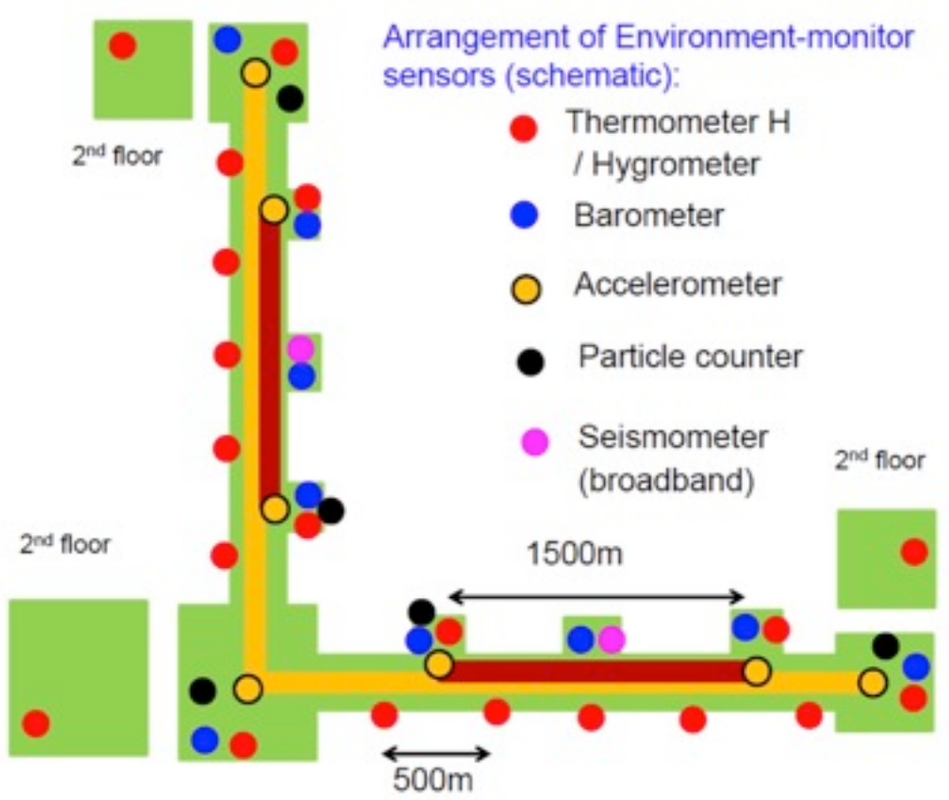
- localization of noise sources reveals noise features
- remove false trigger event generated by GW search pipeline,
  -> increase GW detection efficiency

In this talk, I define
- GW channel
  as sensitive channel to GW

- environmental channel

  as insensitive channel to GW

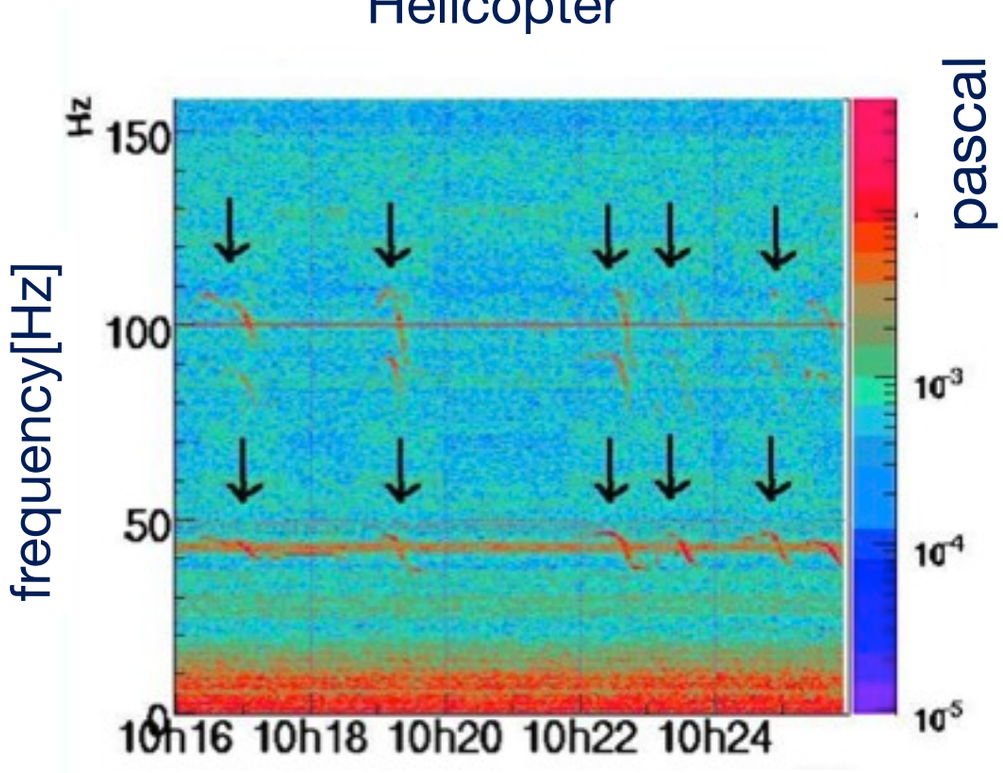
microphone, accelerometer, seismometer, thermometer, barometer, magnetometer so on



Araya (2012)

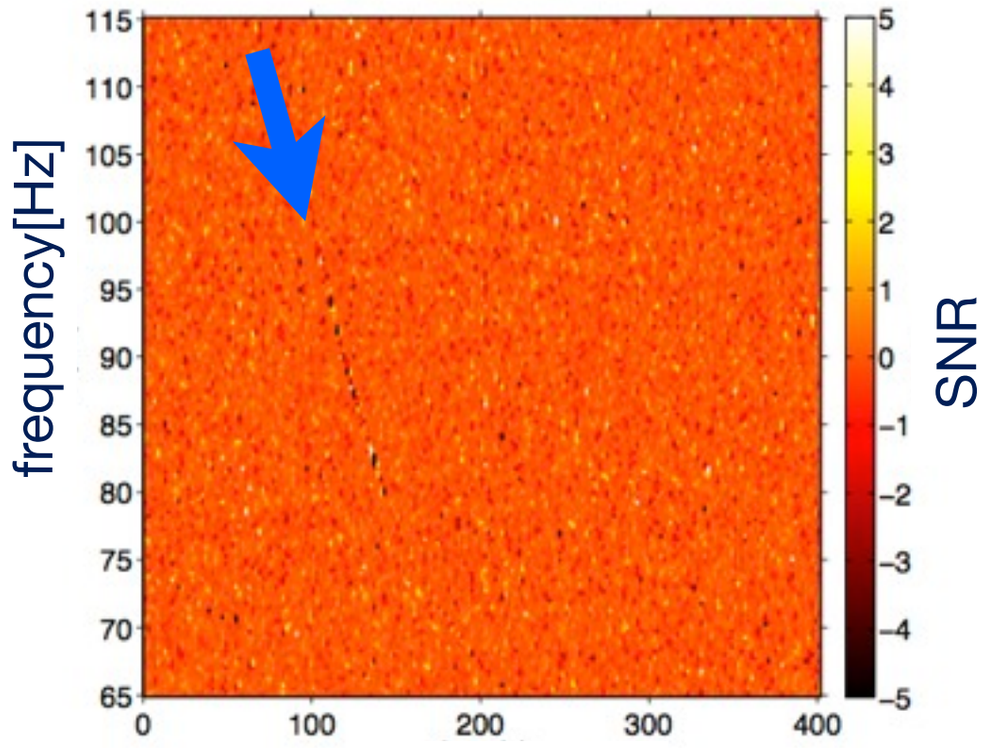
Example of linear correlation observed in LIGO and Virgo

Helicopter



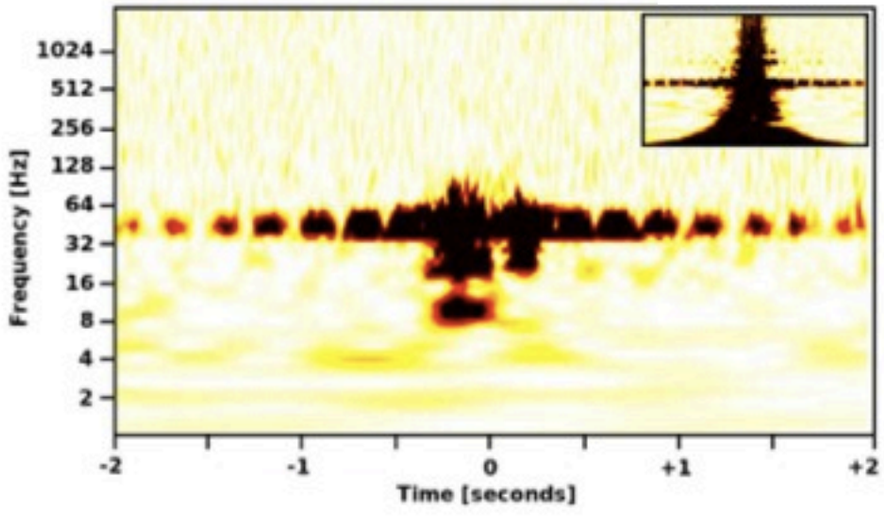
Coughlin et.al (2011)[arXiv 1108.1521]

Airplane



[LIGO-T050174]

GW channel Magnetic sensor



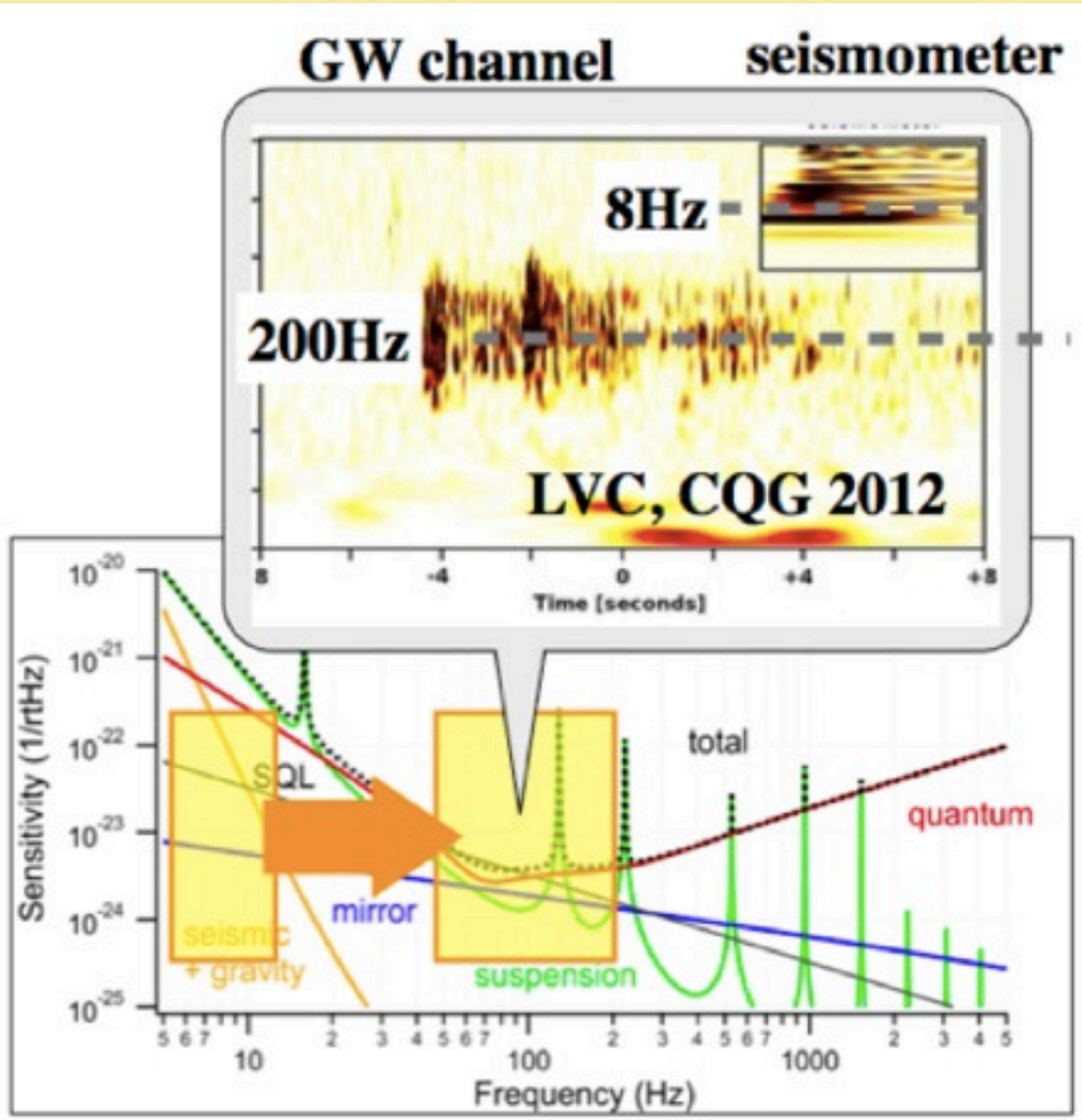
J.Asis et al. (2012) [gr-qc 1203.5613]

Example of non-linear correlation, up-converted noise

Up-converted noise: seismic glitches will excite optical bench motion which cause scattered light noise.
In bad weather day, effect from seismic glitches is strong.
Non-linear correlation over a few Hz ~ a few hundreds Hz in GW channel was observed in detectors.

[Classical and Quantum Gravity 27, 19 (2010) 194011]

http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-20-8-8329



Sensitivity curve of KAGRA

⇒ search correlation between environmental channels

to get information of noise which effect different frequency band

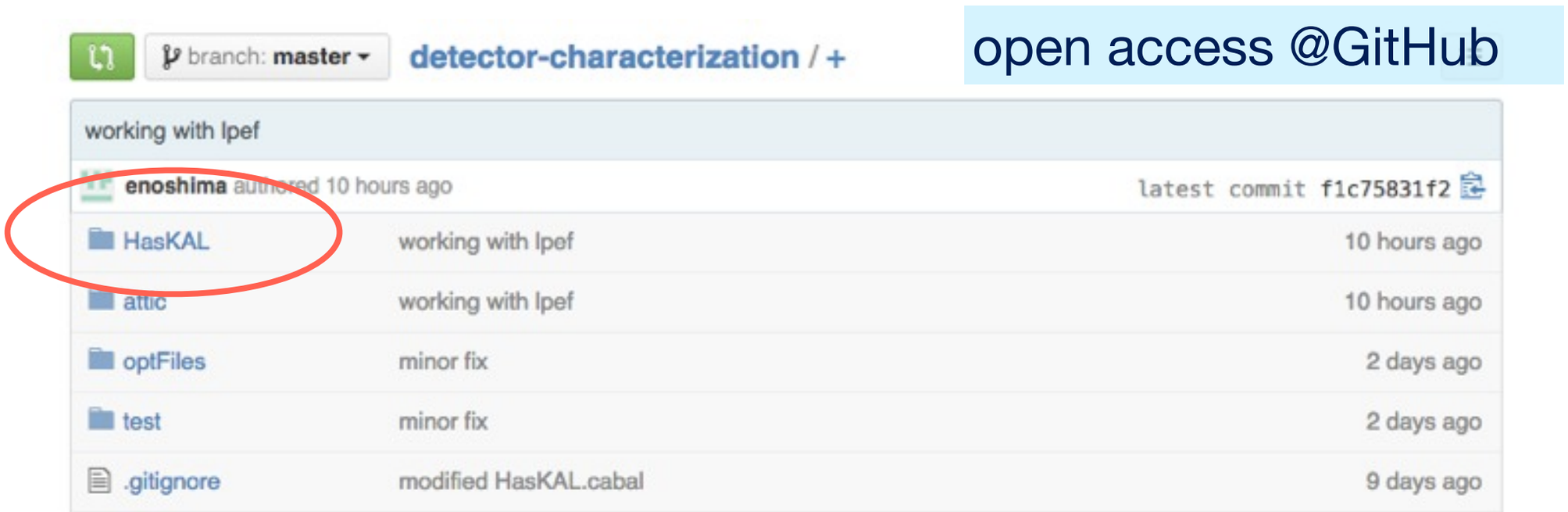
Hayama (2014)
J.Asis et al. (2012) [gr-qc 1203.5613]

Developing monitor tool to search linear & non-linear correlation

- In KAGRA detector commissioning and observation period, efficient tools to localize noises

- Developed software is included in HasKAL
  HasKAL is Haskell-based analysis software package.
  You can easily access from below URL.

https://github.com/gw-analysis/detector-characterization



open access @GitHub

Method to search correlation

- In this study, below two method are used,

  Pearson Correlation Coefficient

  - efficient method to linear correlation $r = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}}$

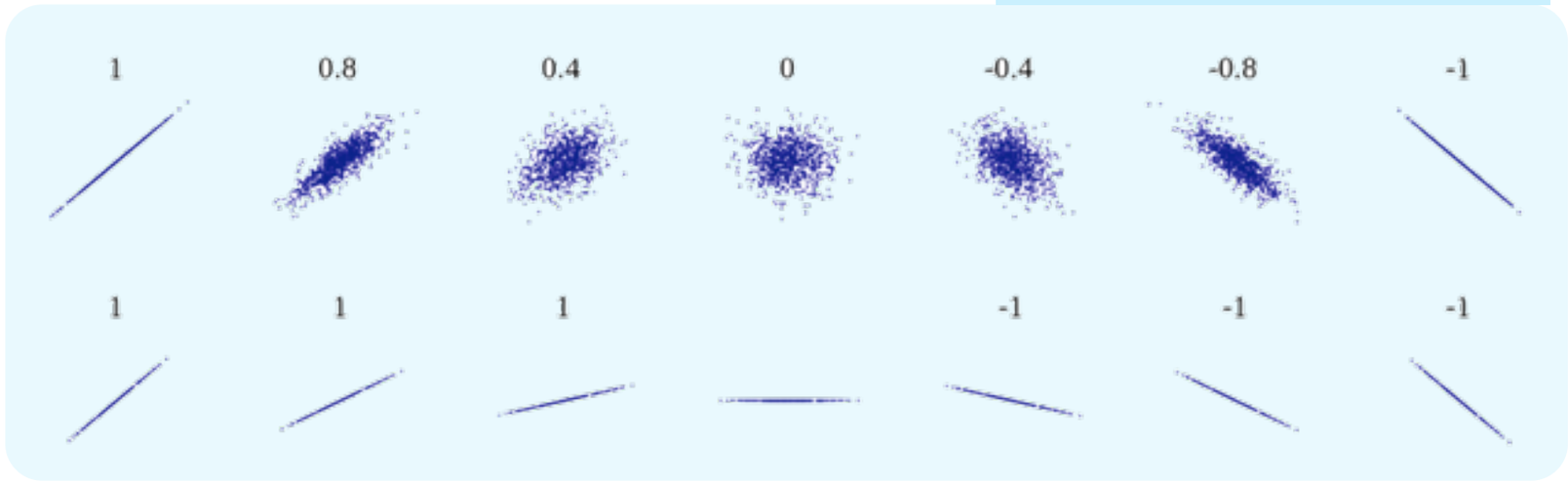
  Maximum Information Coefficient (MIC)

- structure of scatter plot

  → Information of

  noise transfer

linear correlation



non-linear correlation

http://lectures.molgen.mpg.de/algsysbio12/MINEPresentation.pdf

Maximum Information Coefficient (MIC)

[David N. Reshef, et al. Science 334, 1518 (2011)]

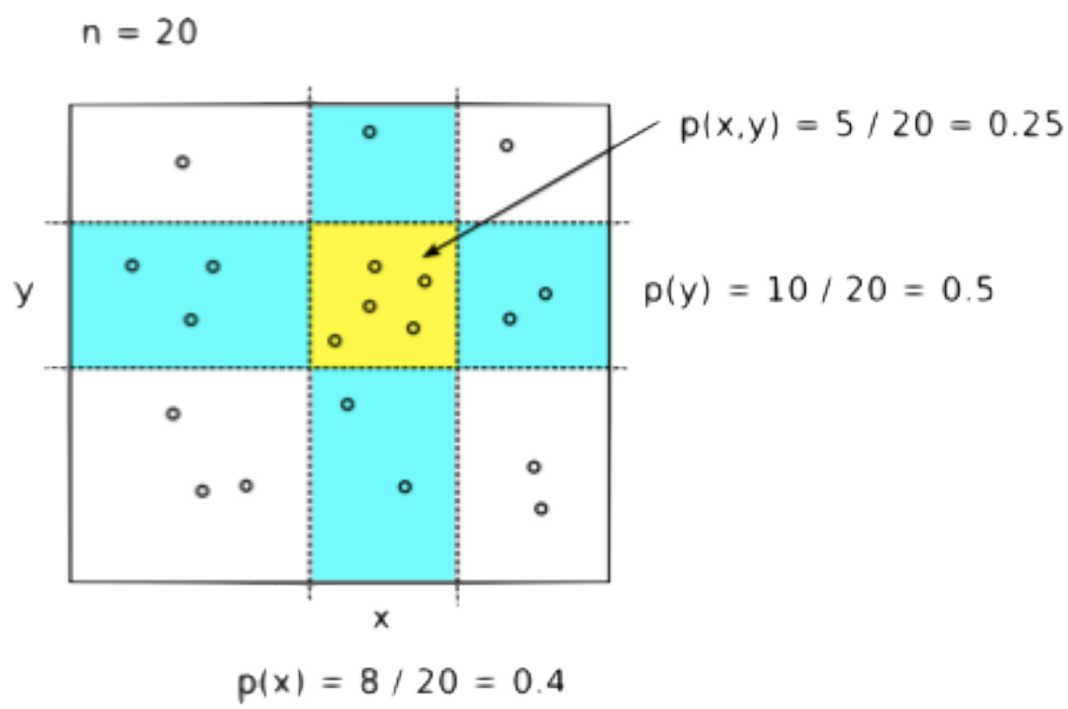
- MIC can detect functional & non-functional dependence.
- If provided sufficient sample size, MIC can detect a wide range of relationship including non-functional types (functional superposition)

- If a relationship exists between two data, a grid can be drawn on the scatter plot of two data that partitions the data to encapsulate that relationship.

Partitioning : For each resolution, MIC finds grid partition placement with highest mutual information

$$I(X;Y) = \sum_{y \in Y} \sum_{x \in X} p(x,y) \log \left(\frac{p(x,y)}{p(x)\,p(y)} \right)$$

X,Y: random variables
p(x,y): joint probability distribution function
p(x), p(y): marginal probability distribution functions

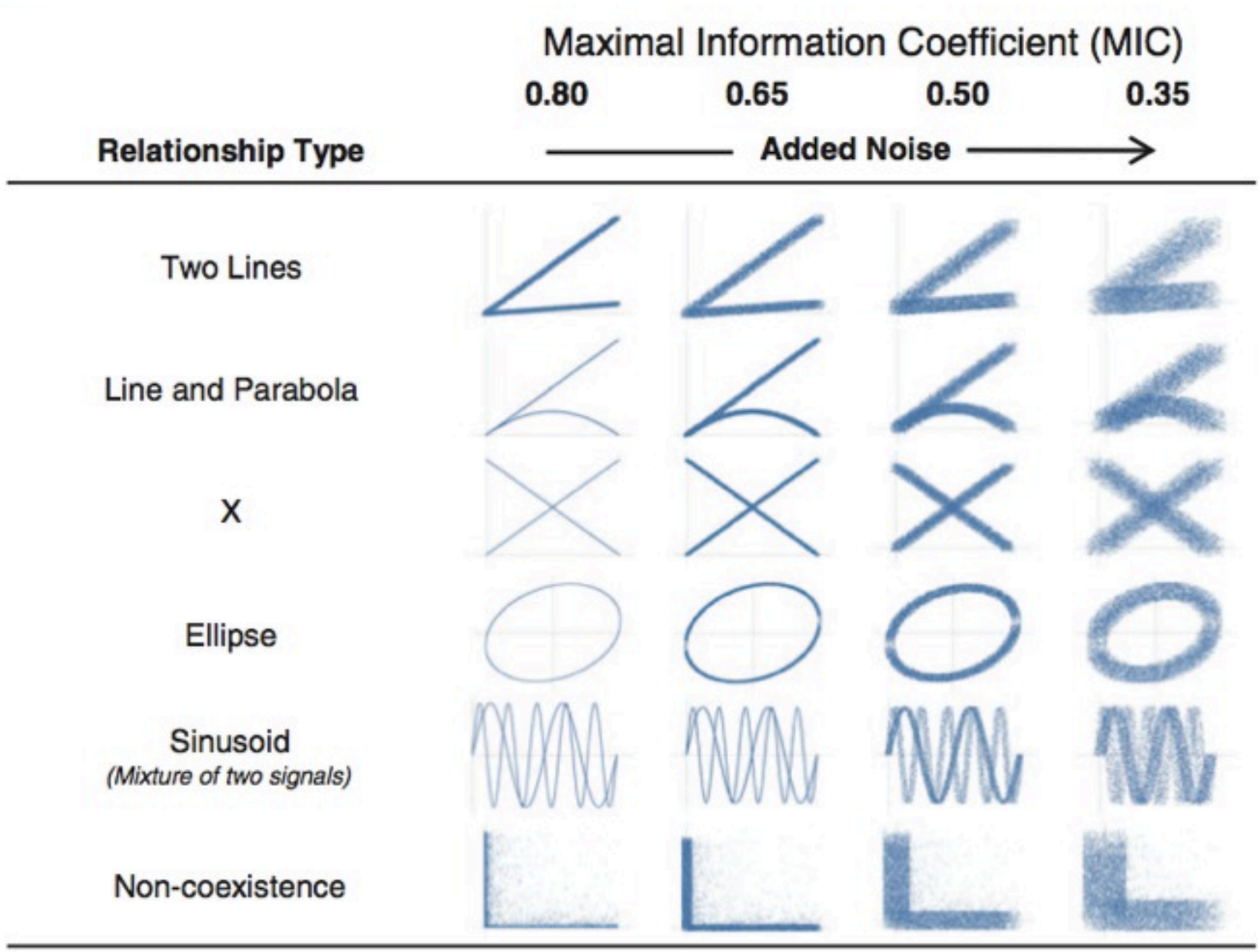


$$p(x,y) \log \left(\frac{p(x,y)}{p(x)\,p(y)} \right) = 0.25 \log \left(\frac{0.25}{0.4 \times 0.5} \right) \approx 0.056$$

http://lectures.molgen.mpg.de/algsysbio12/MINEPresentation.pdf

Which correlation MIC can search?

- MIC can search not only linear but also non-linear correlation.



[David N. Reshef, et al. Science 334, 1518 (2011)]

Operation check using CLIO's channel data

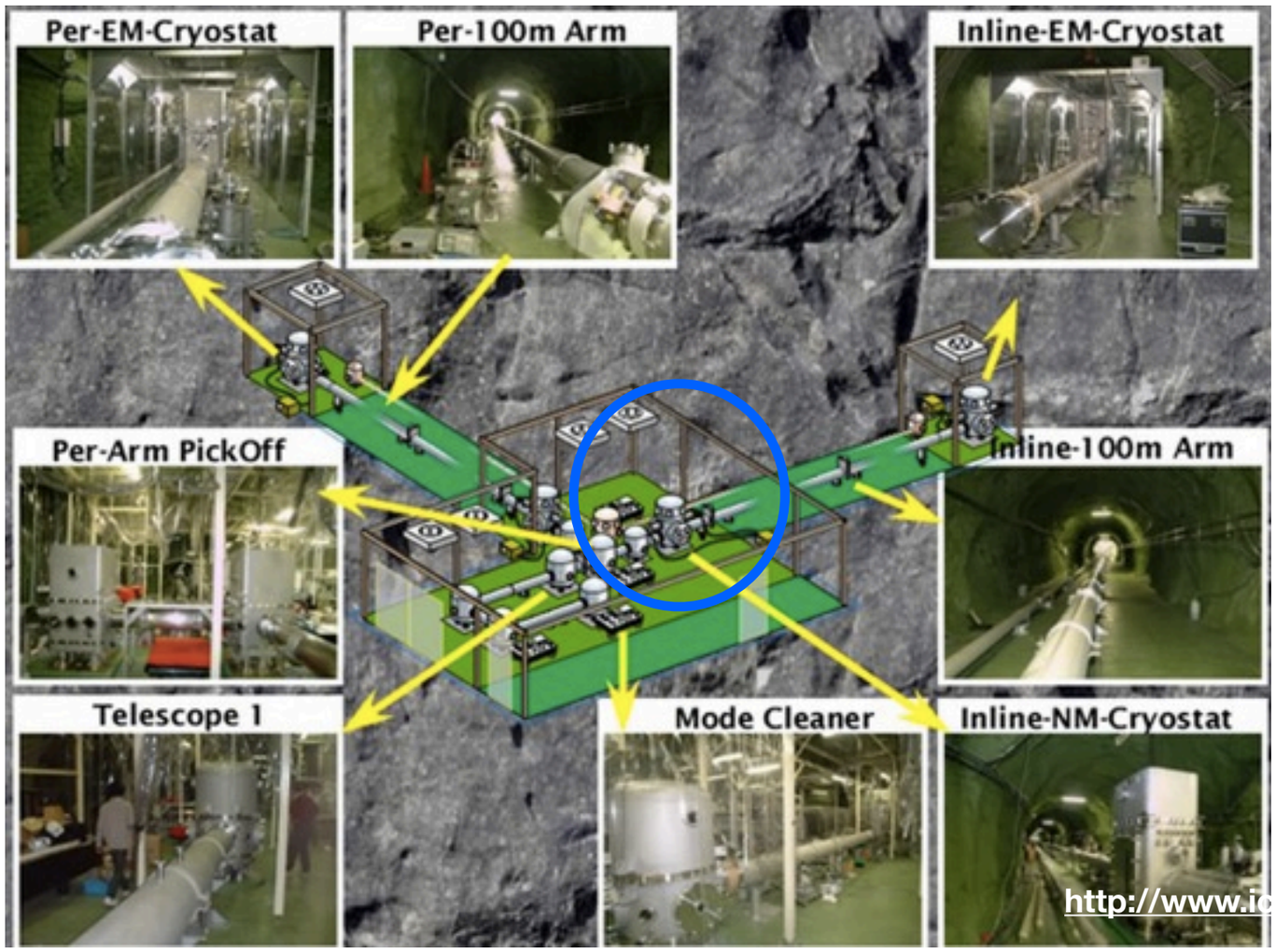
- CLIO detector data recorded at September 2012

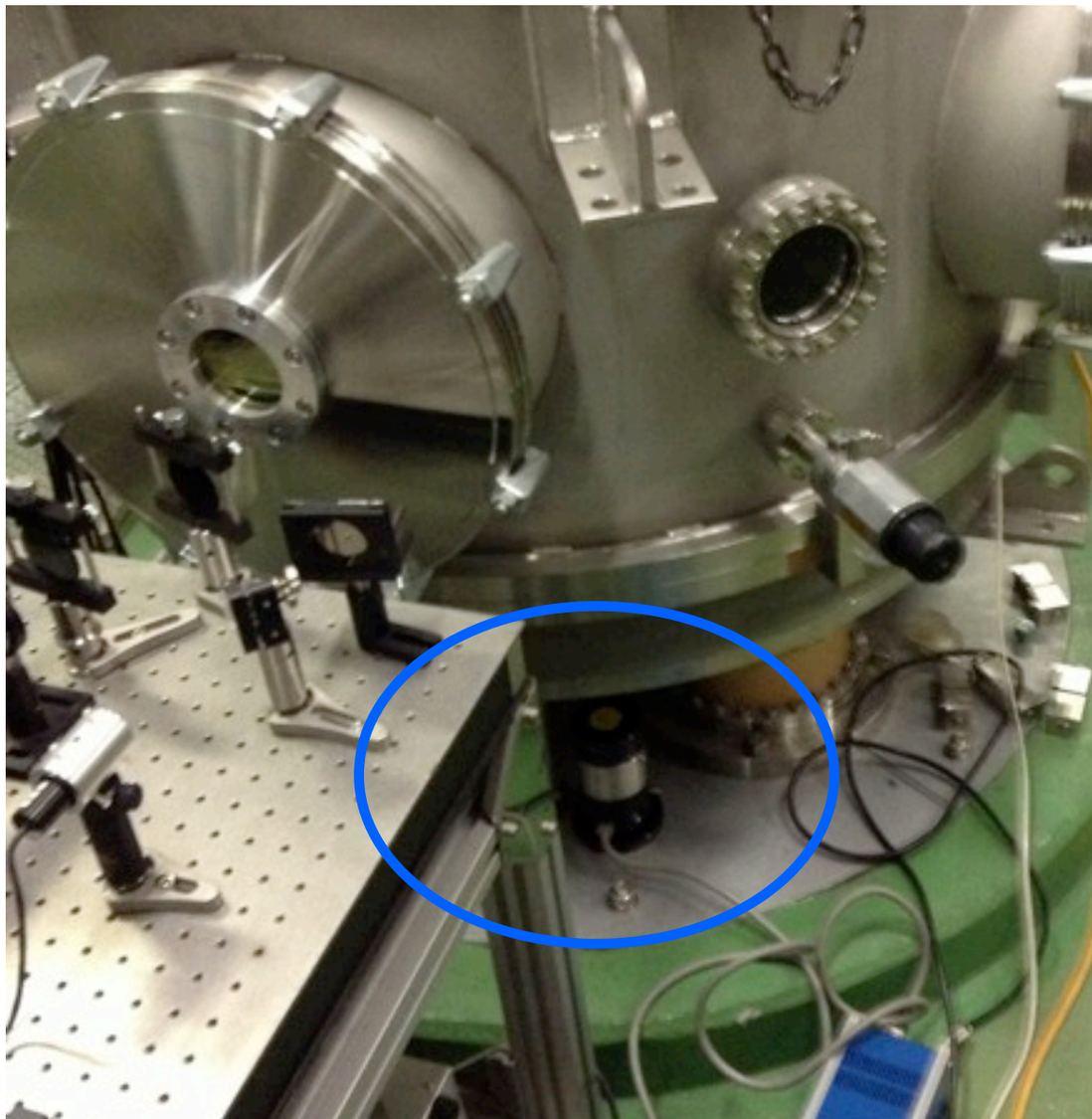
  two channel data : GW channel

  accelerometer channel

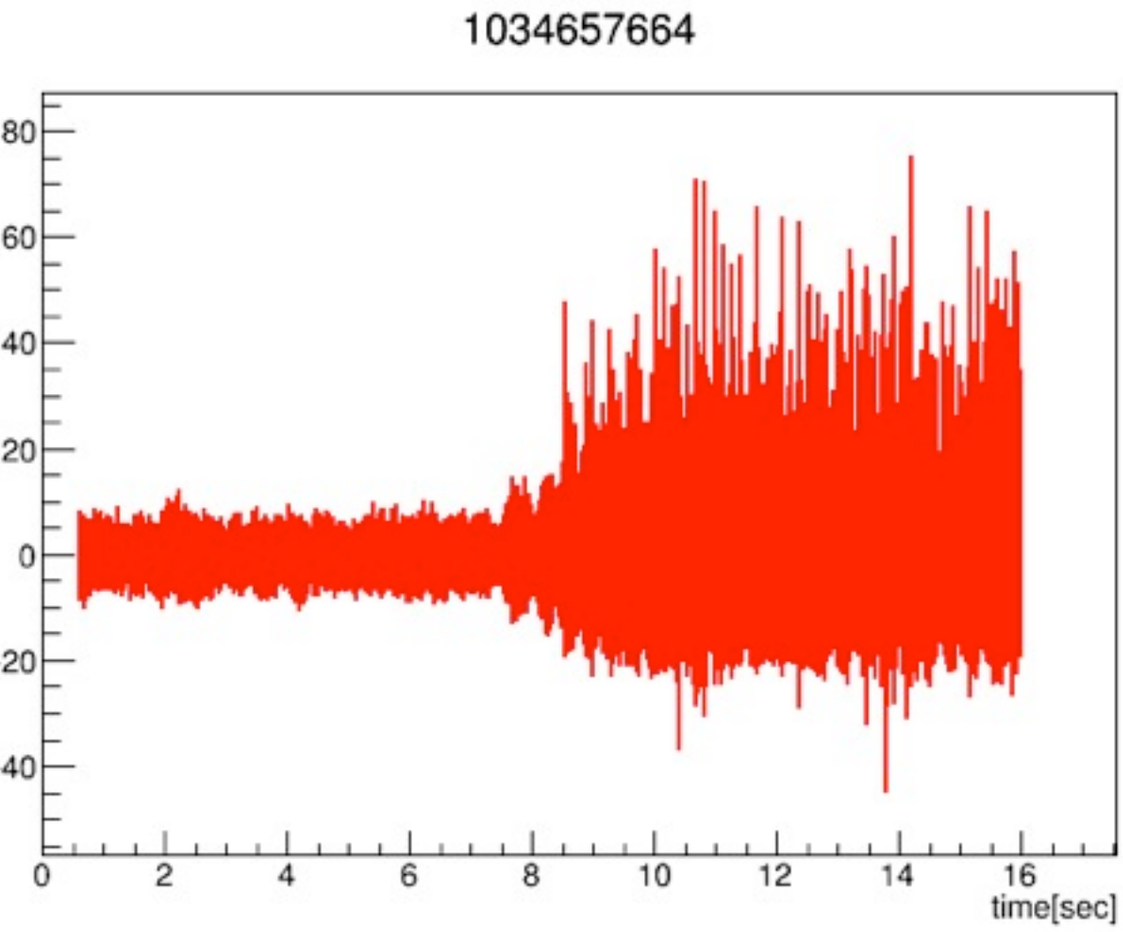
- search for correlation between GW channel and accelerometer channel

Accelerometer is located near front mirror of X-arm.

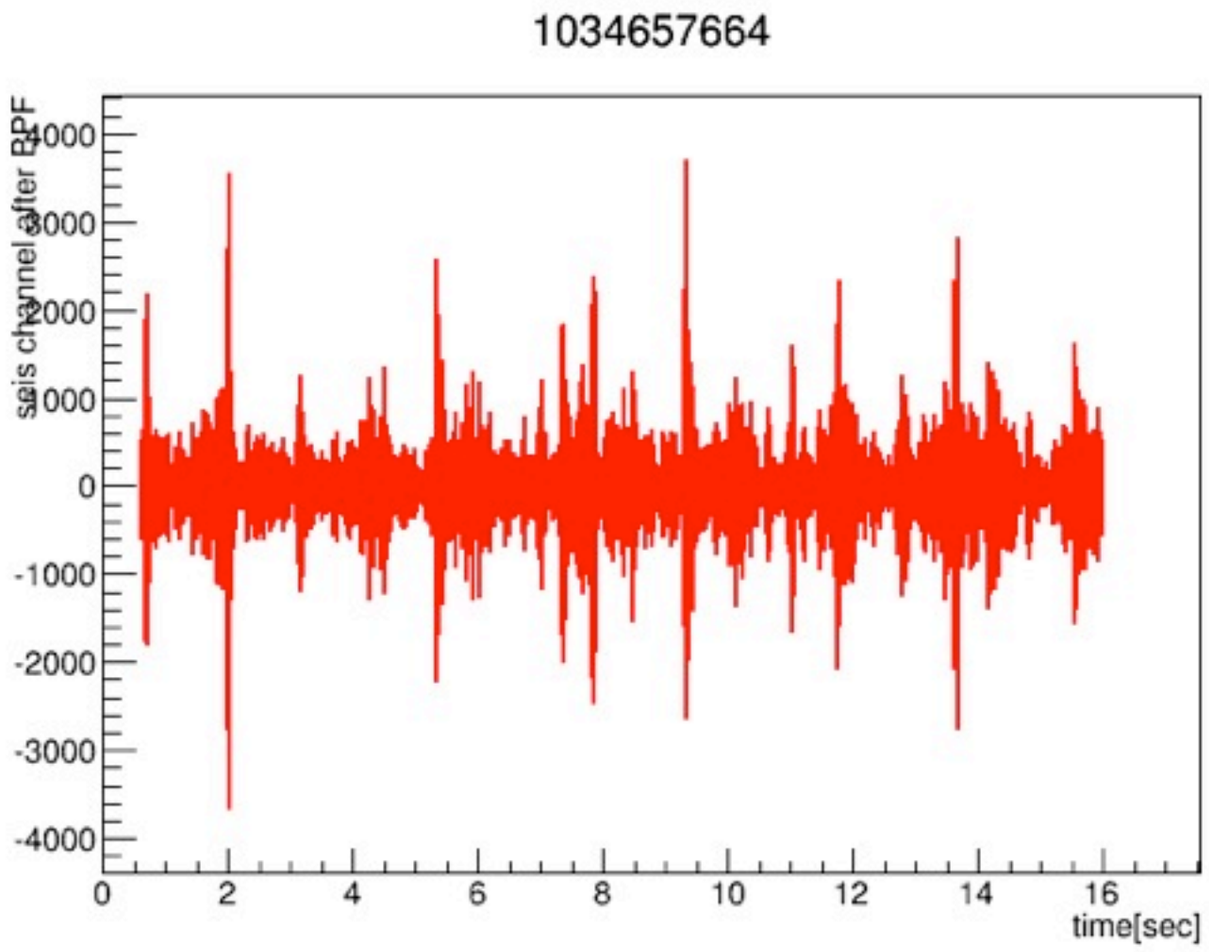




time domain data used to search



GW channel



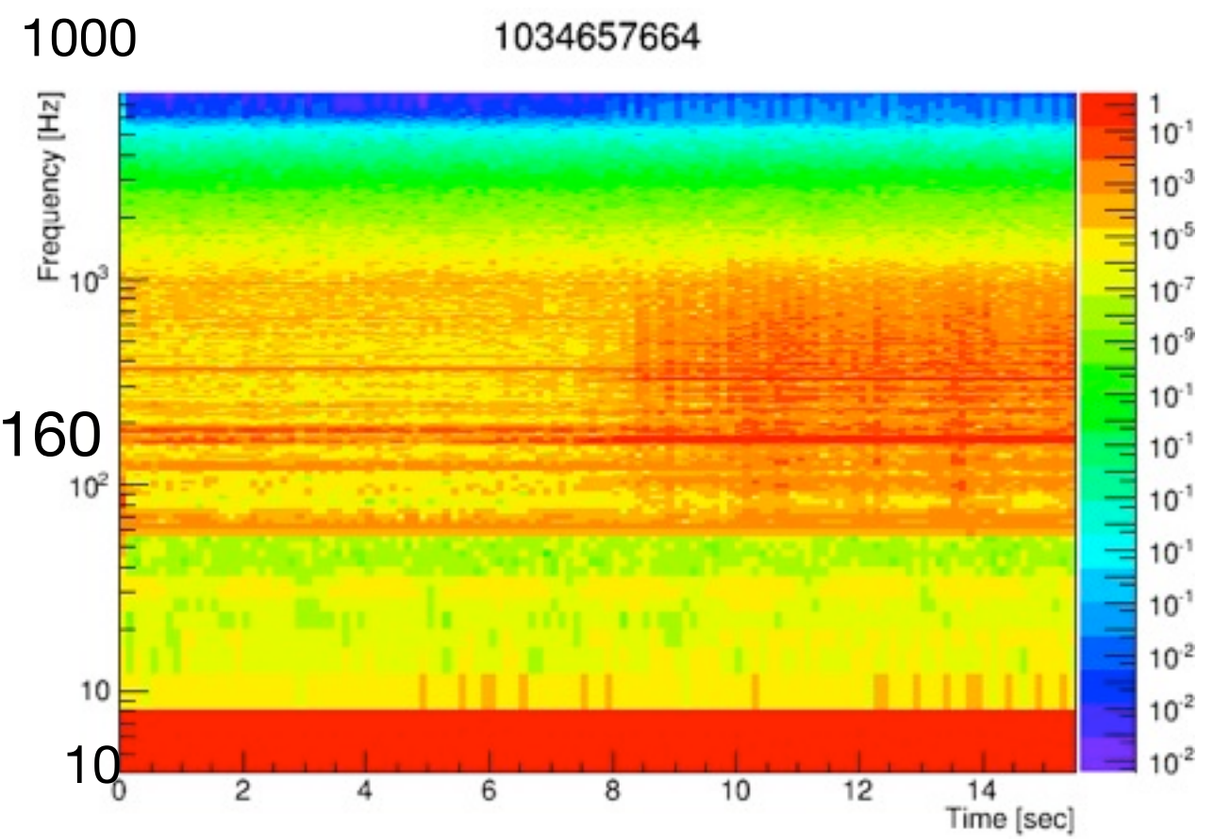
accelerometer channel

It is difficult to draw information of noise

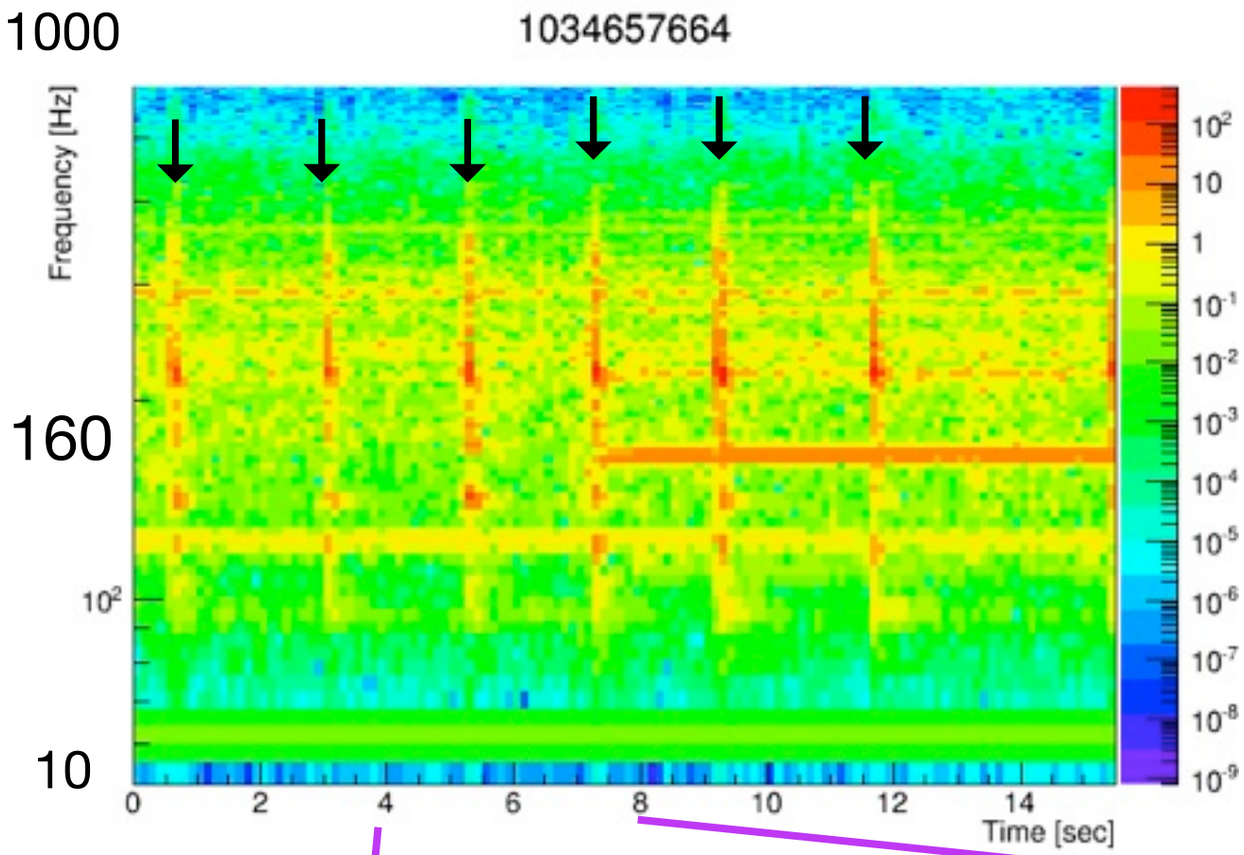
⇒ spectrogram using Short-Fourier Transform

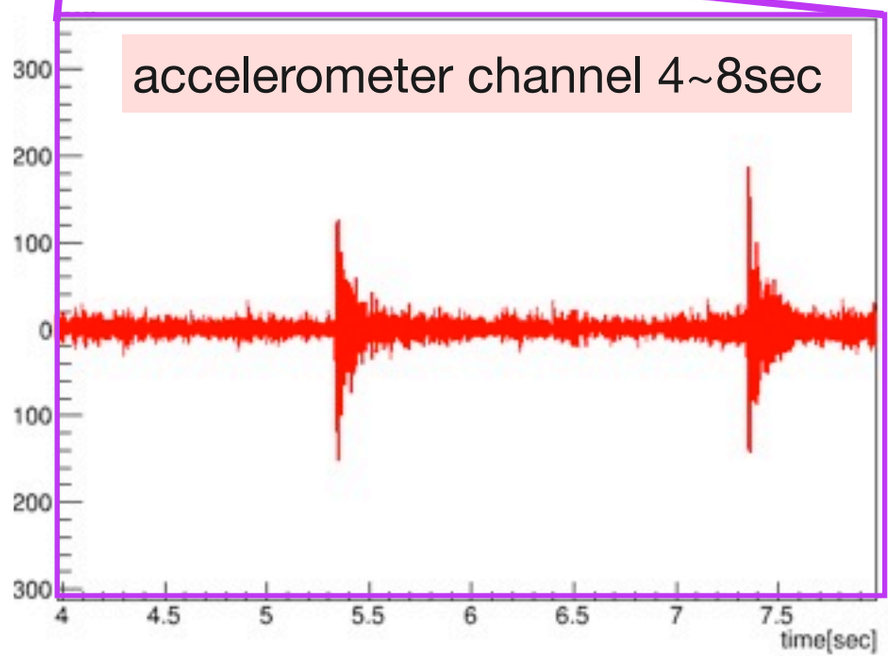
spectrogram of each channel data

GW channel



accelerometer channel



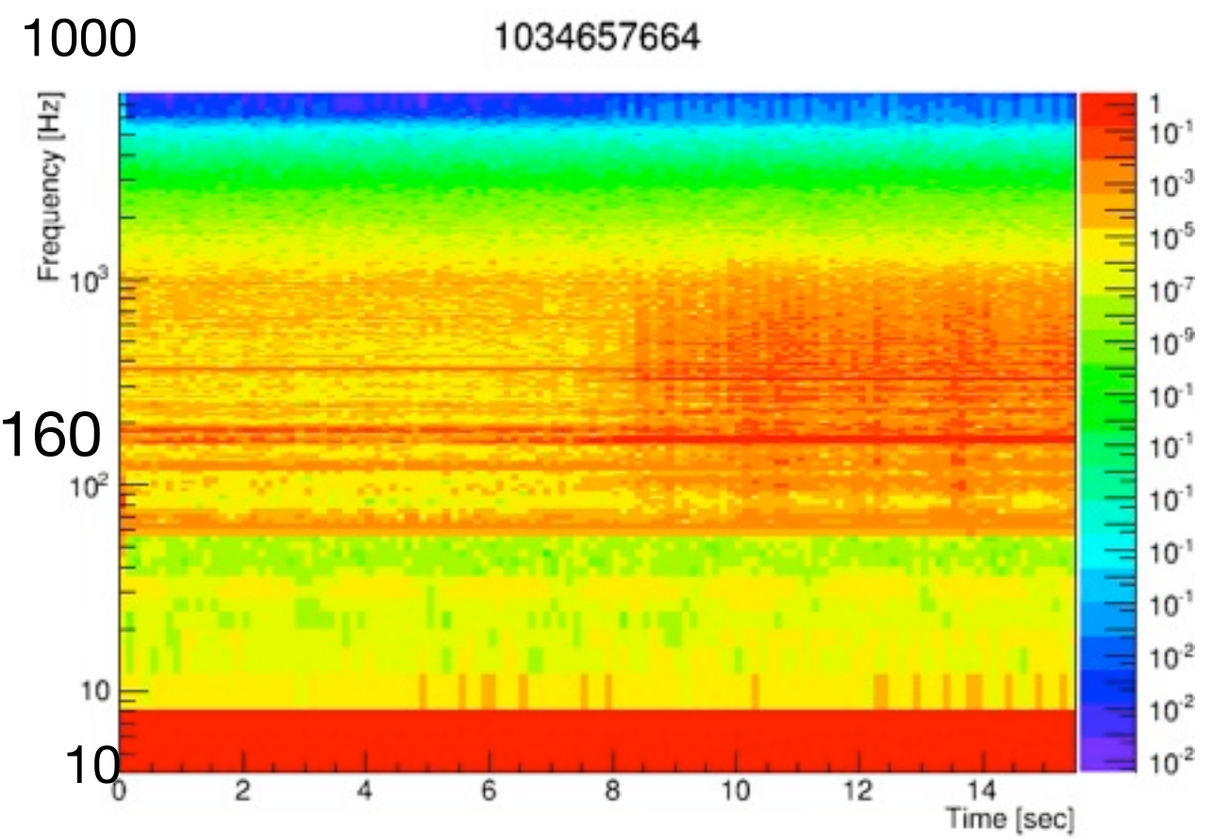


Black arrow in right figure show hardware injection equivalent (shock chamber directly)
⇒ There is this disturbance in GW channel?

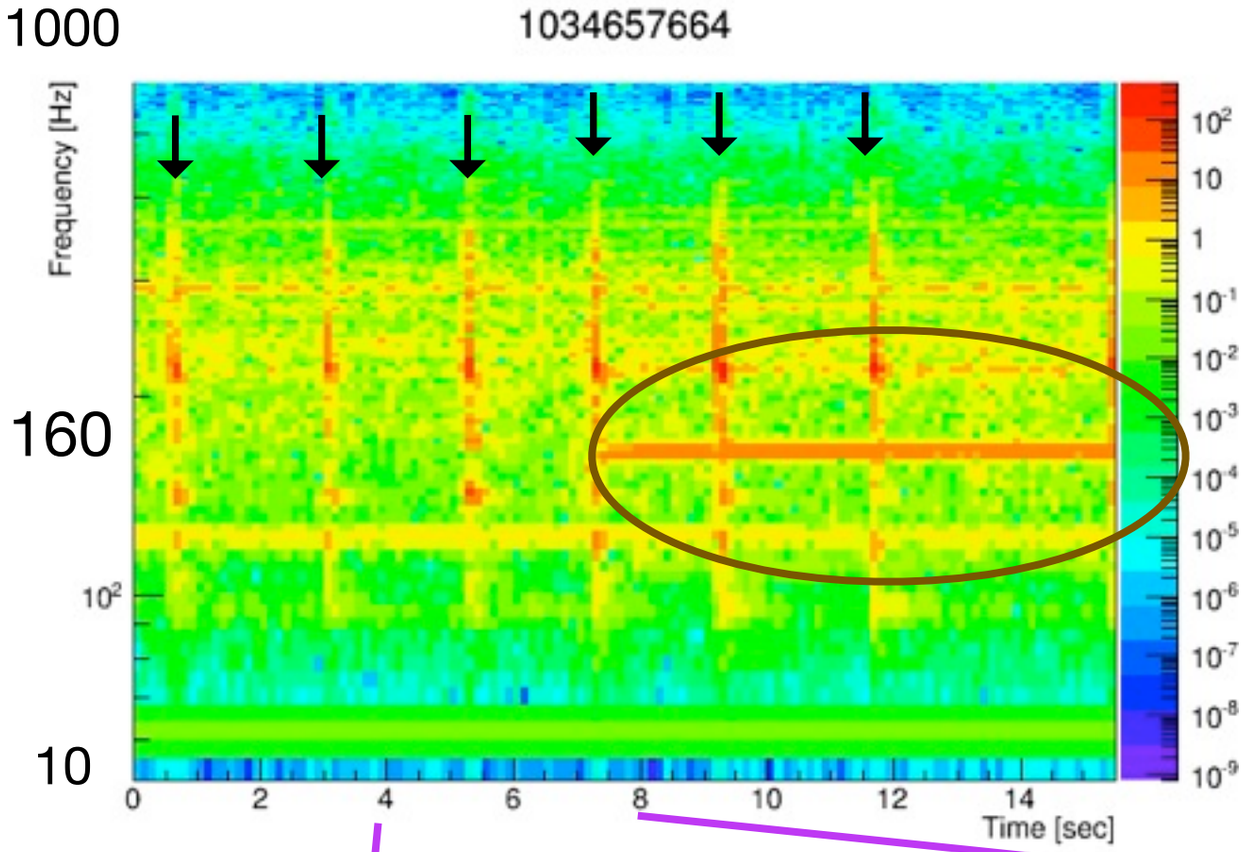
We search correlation using developed correlation monitor.

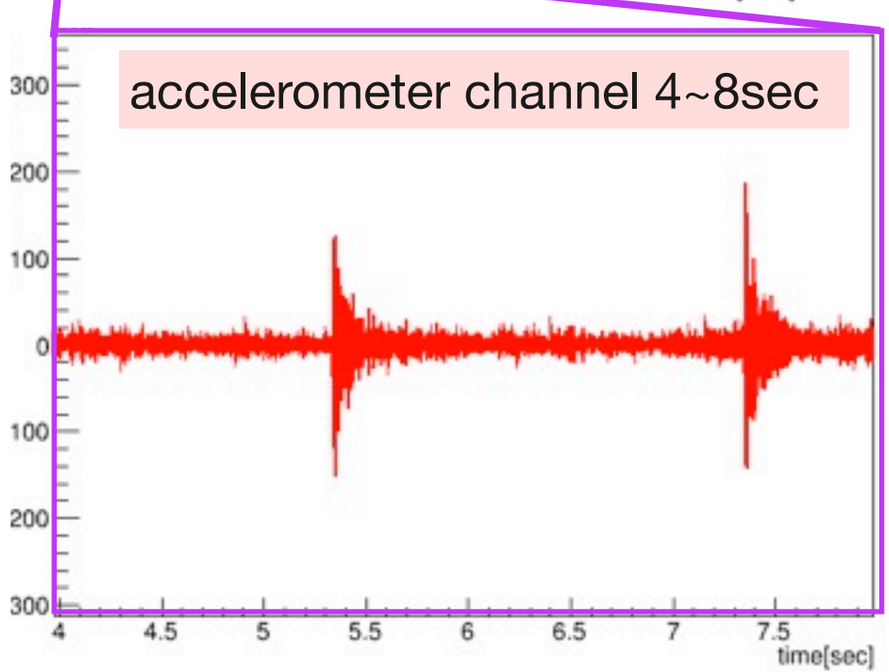
spectrogram of each channel data

GW channel



accelerometer channel





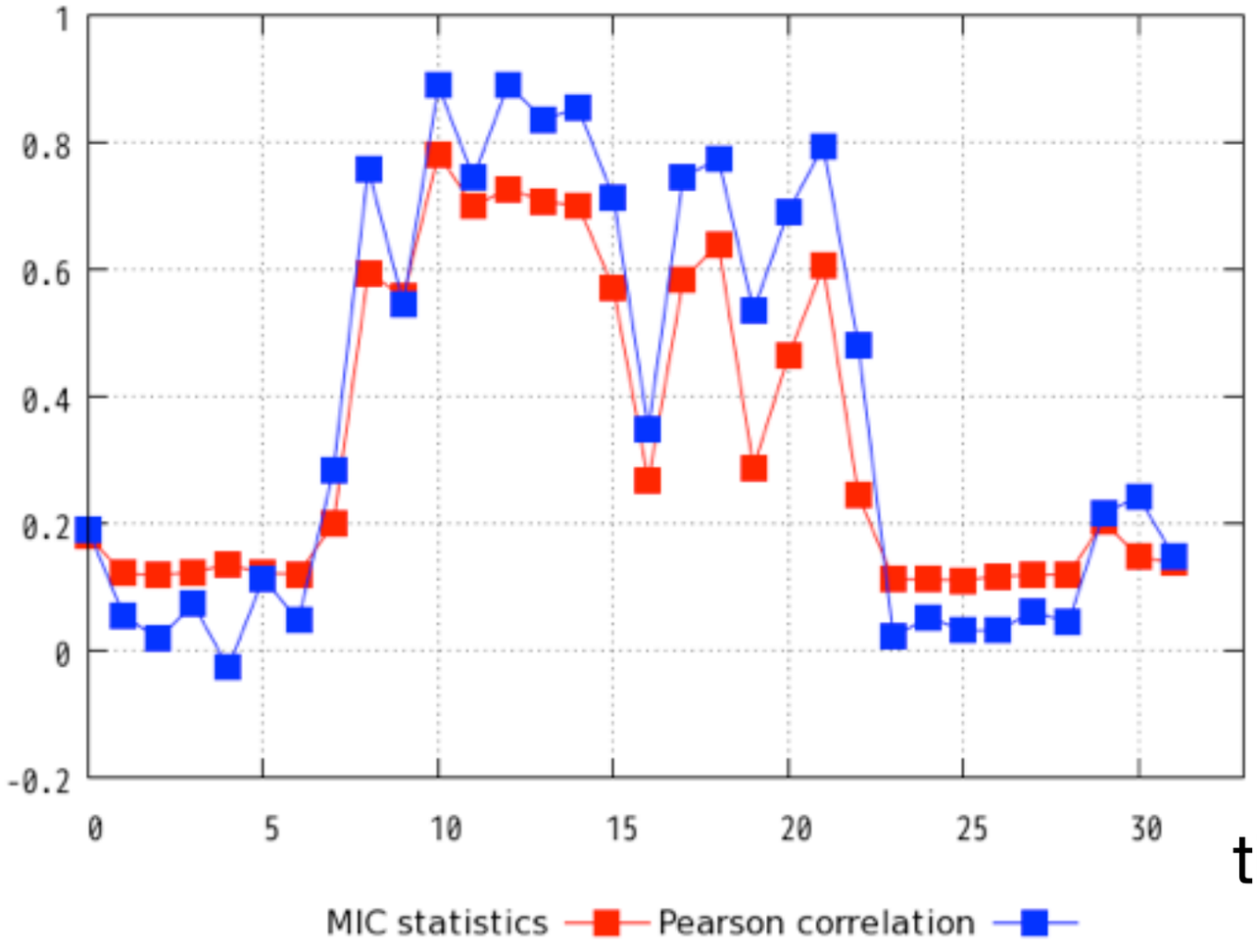
Black arrow in right figure show hardware injection equivalent (shock chamber directly)
⇒ There is this disturbance in GW channel?

We search correlation using developed correlation monitor.

time change of correlation value

We search correlation using data set around hardware injection.
In spectrogram of accelerometer, the signal over 100Hz~200Hz
 -> To pick up only this signal, data is band-pass filtered
 with f_low=100Hz and f_high = 200Hz

correlation value



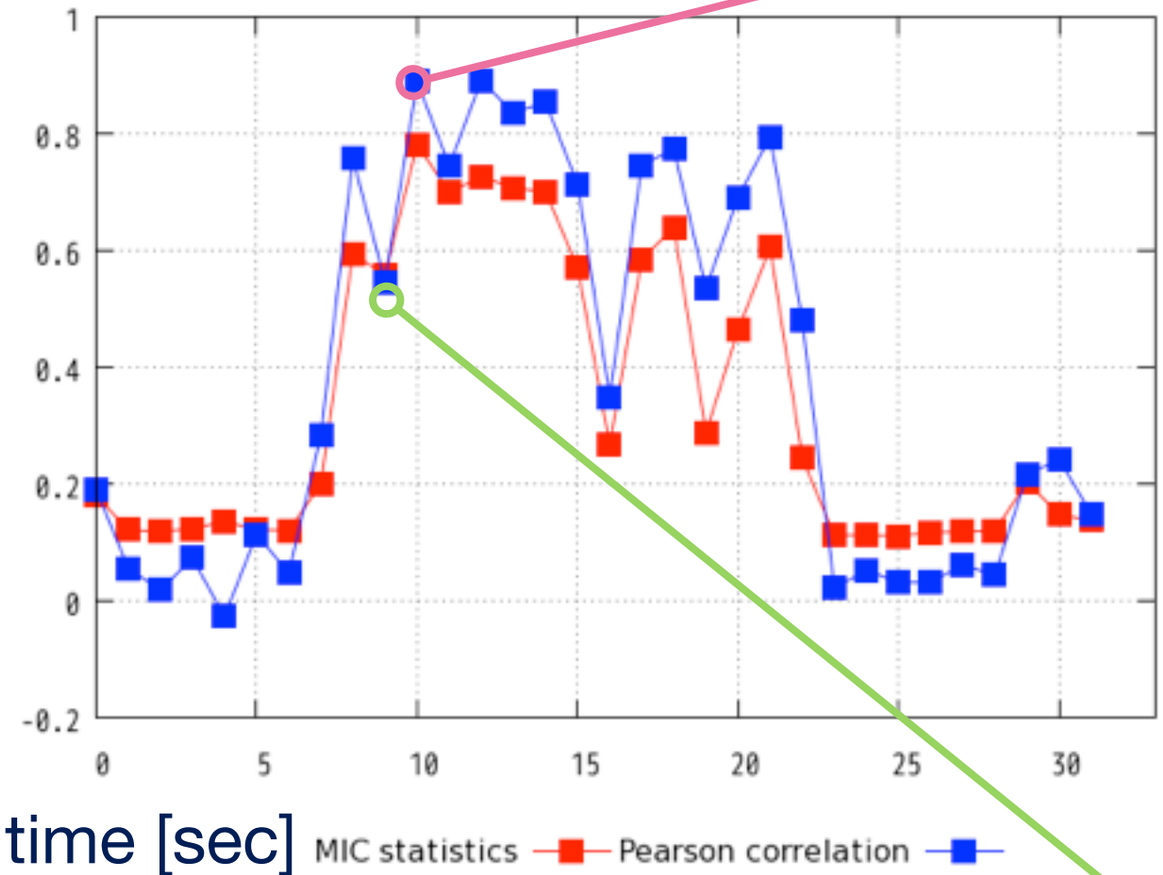
time [sec]

8sec ~ 21sec :
highly correlated value with both Pearson and MIC method

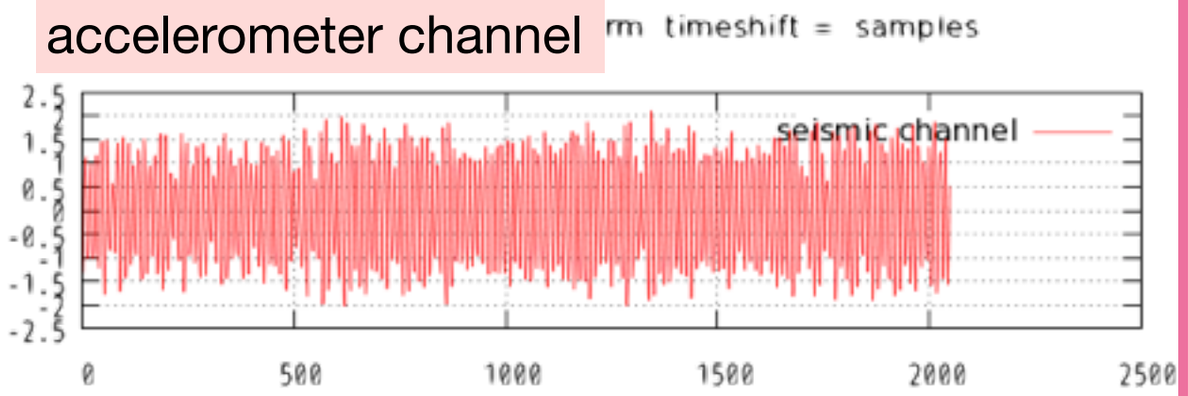
time domain data at each time

data is band-pass filtered with
f_low=100Hz and f_high = 200Hz
and normalized

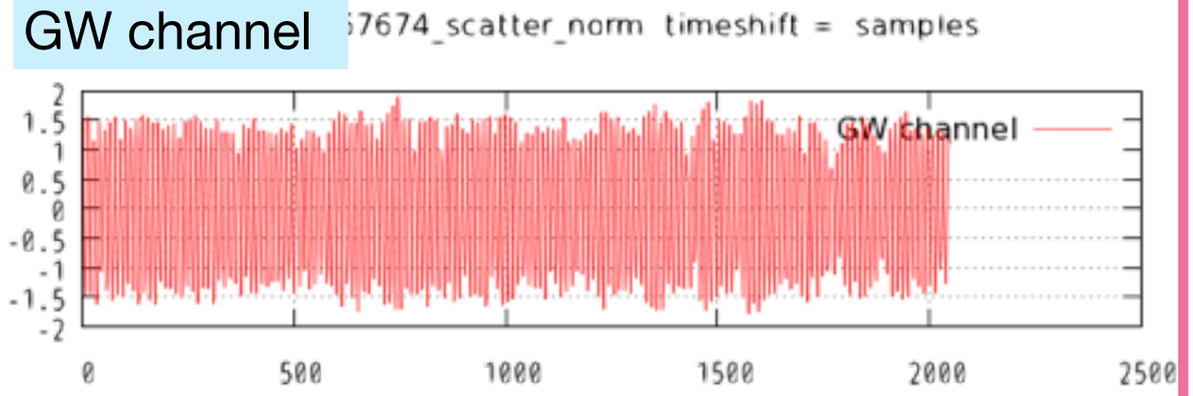
correlation value



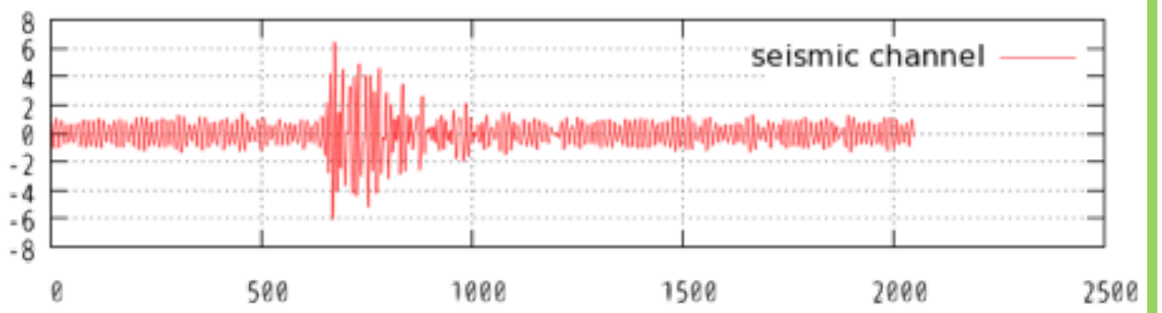
accelerometer channel



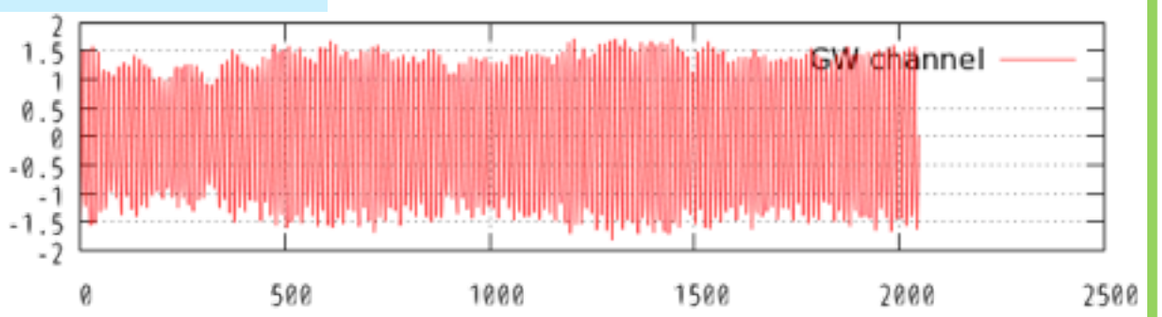
GW channel



accelerometer channel



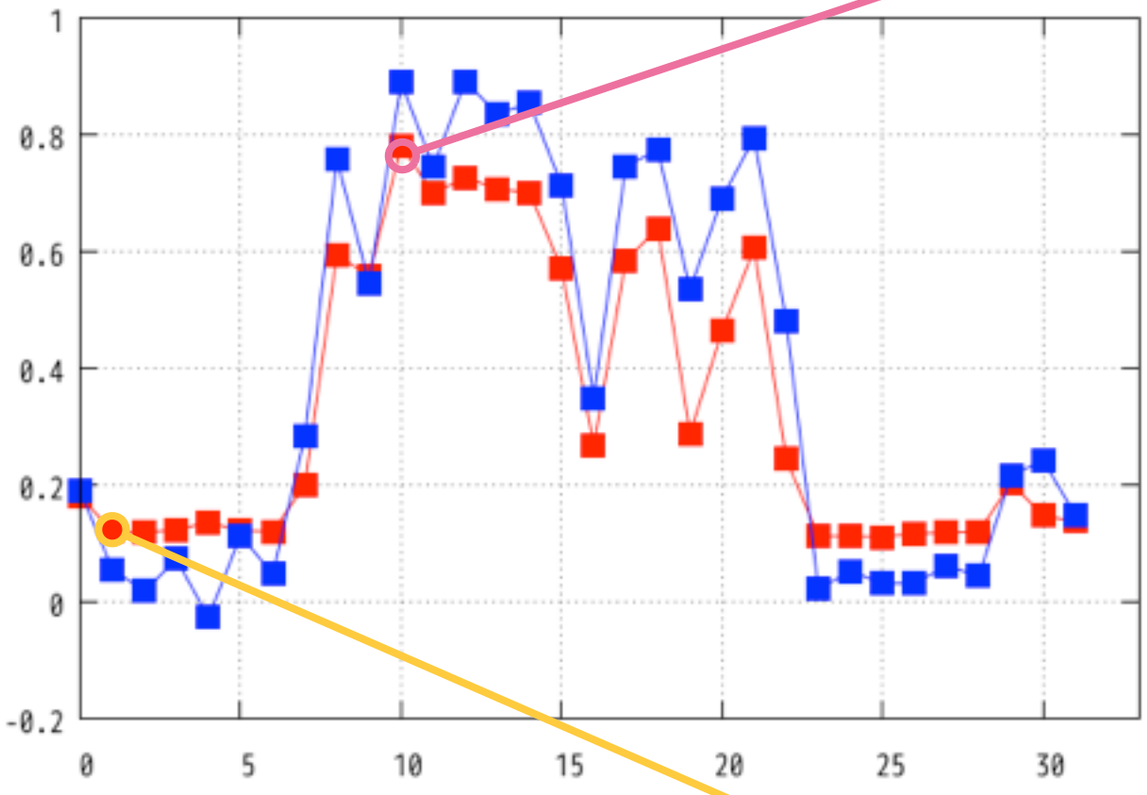
GW channel



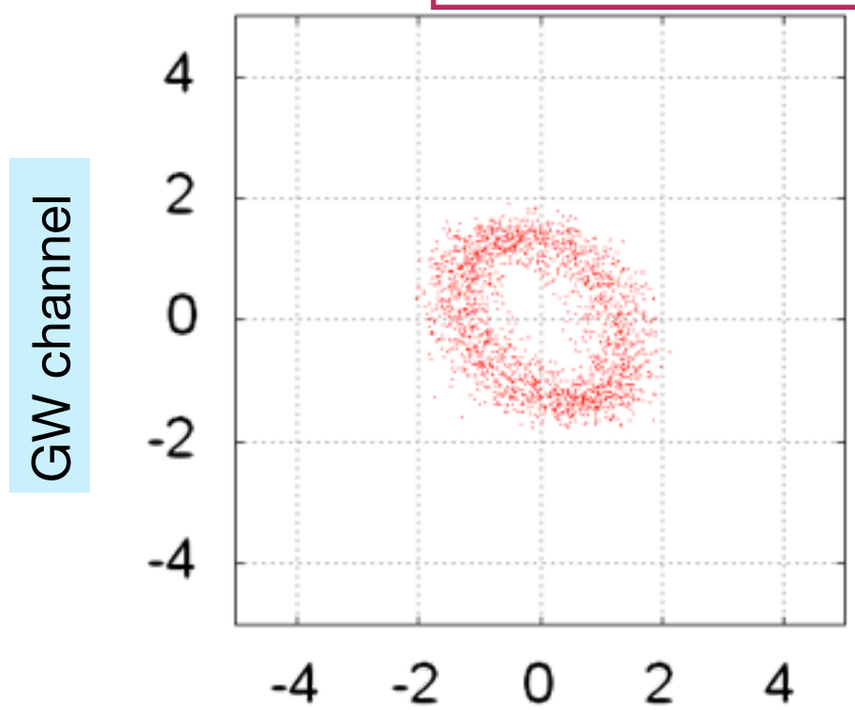
time change of scatter plot

data is band-pass filtered with
f_low=100Hz and f_high = 200Hz
and normalized

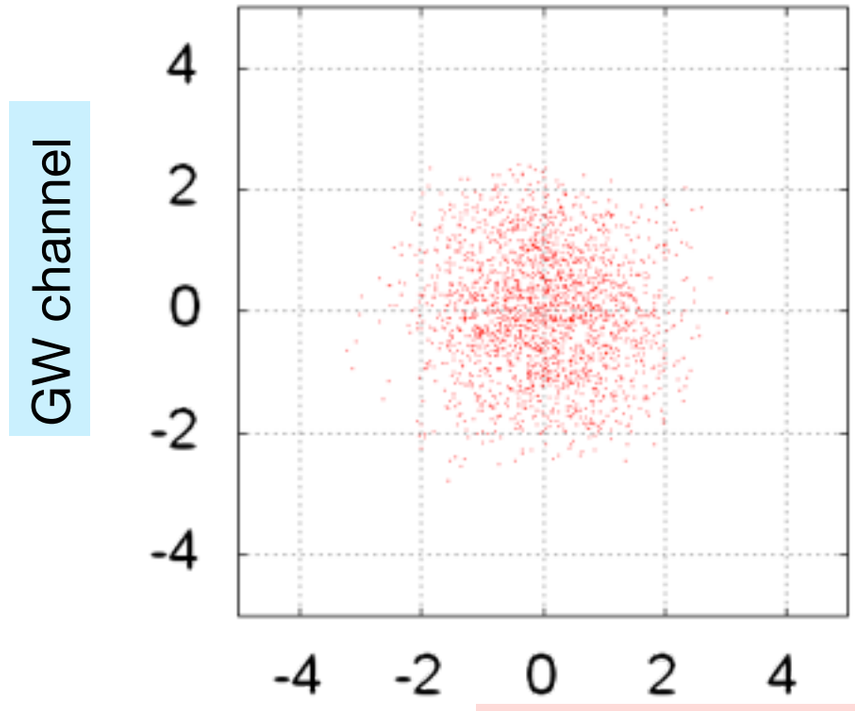
correlation value



correlated data set



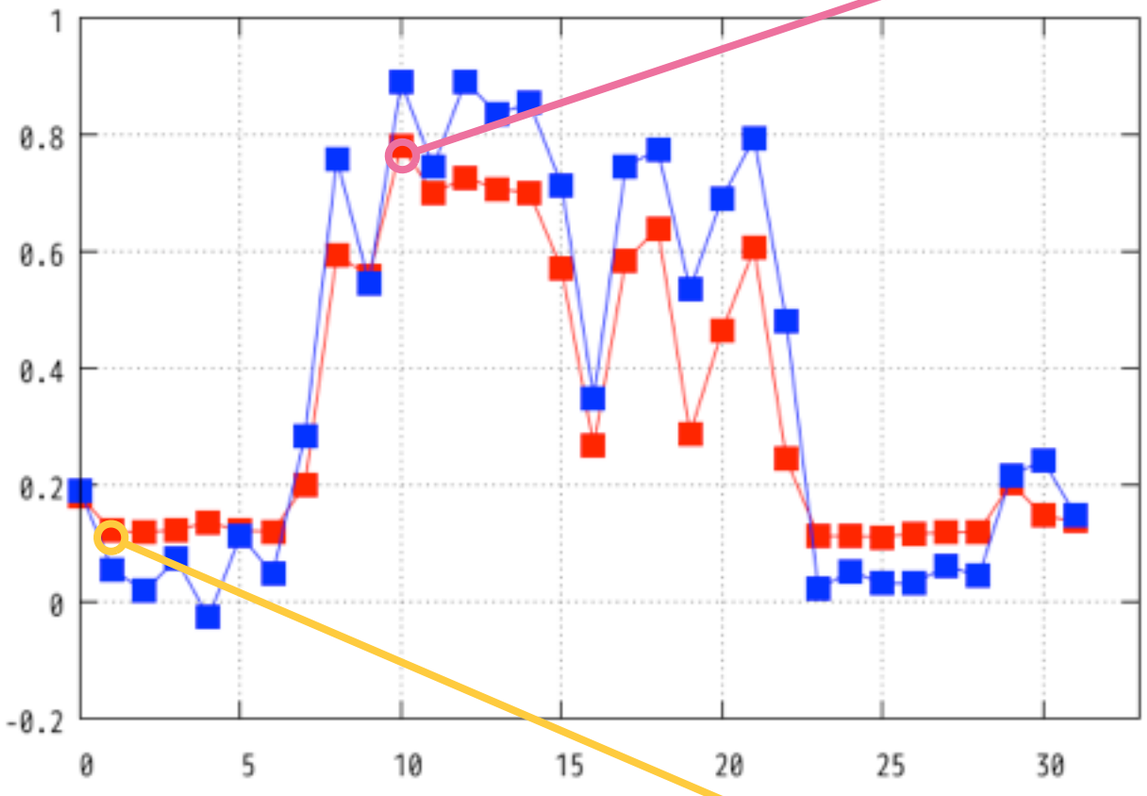
uncorrelated data set



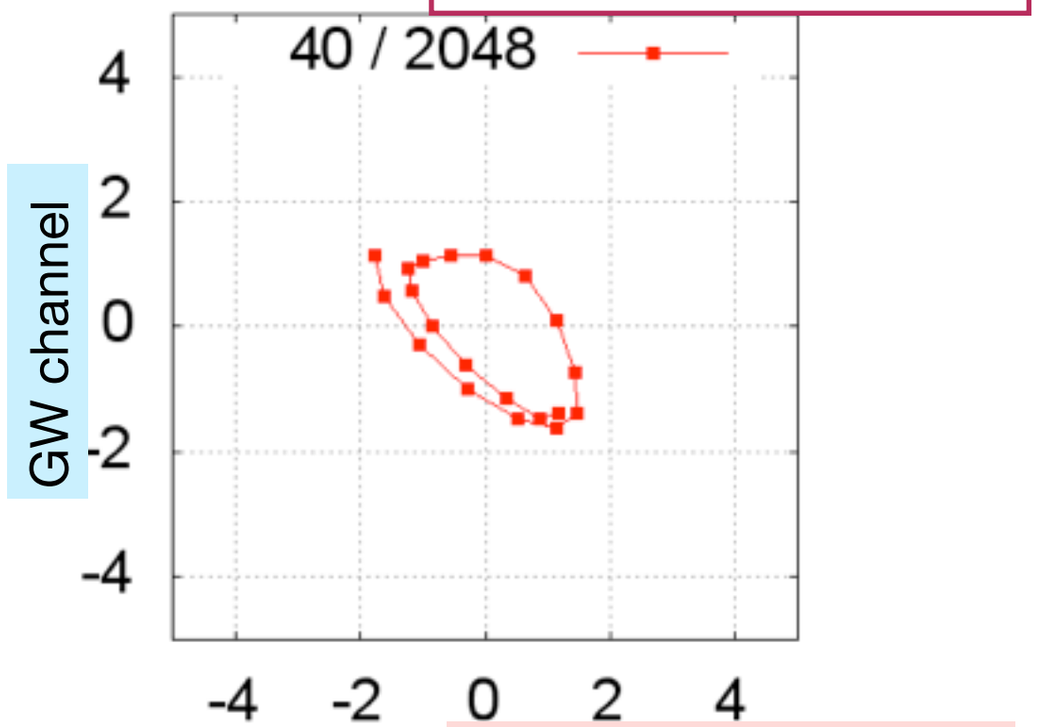
time change of scatter plot

data is band-pass filtered with
f_low=100Hz and f_high = 200Hz
and normalized

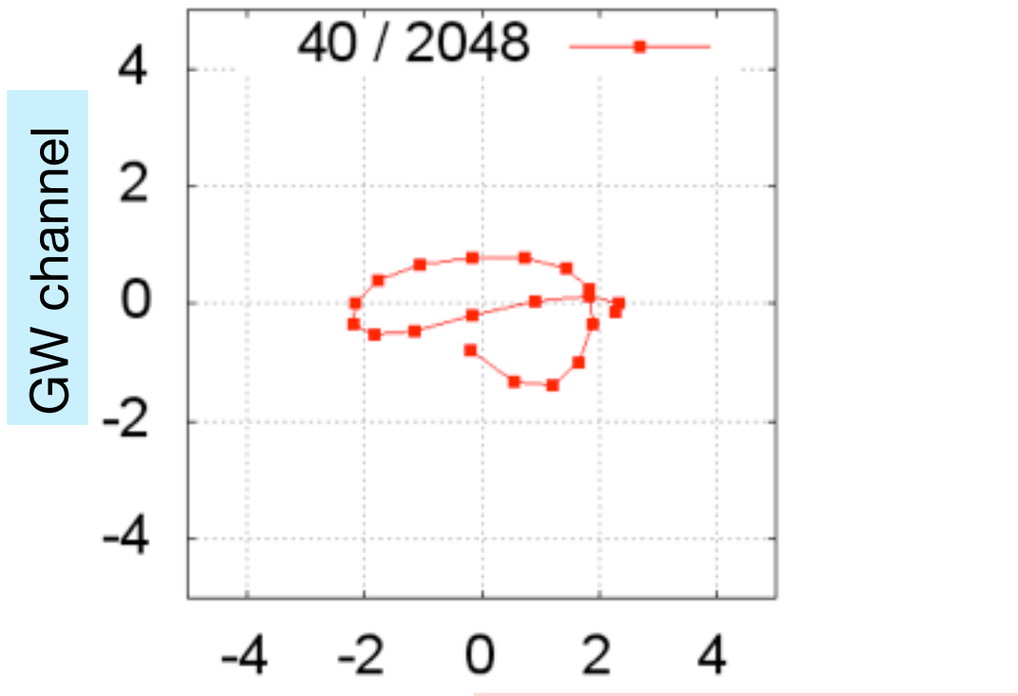
correlation value



correlated data set

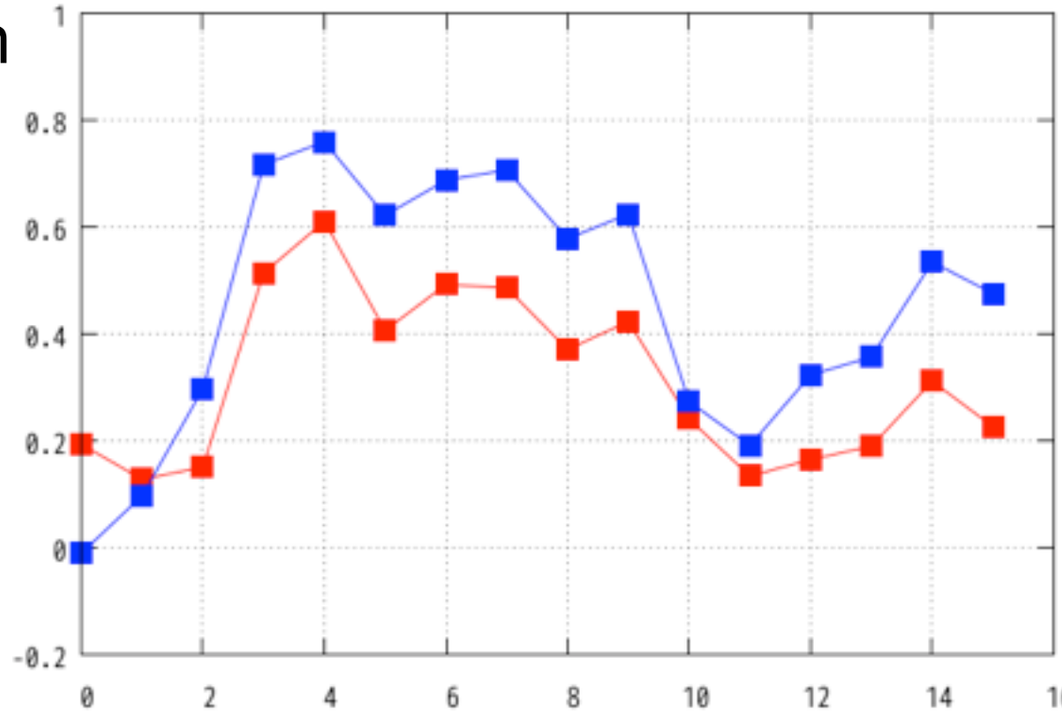


uncorrelated data set



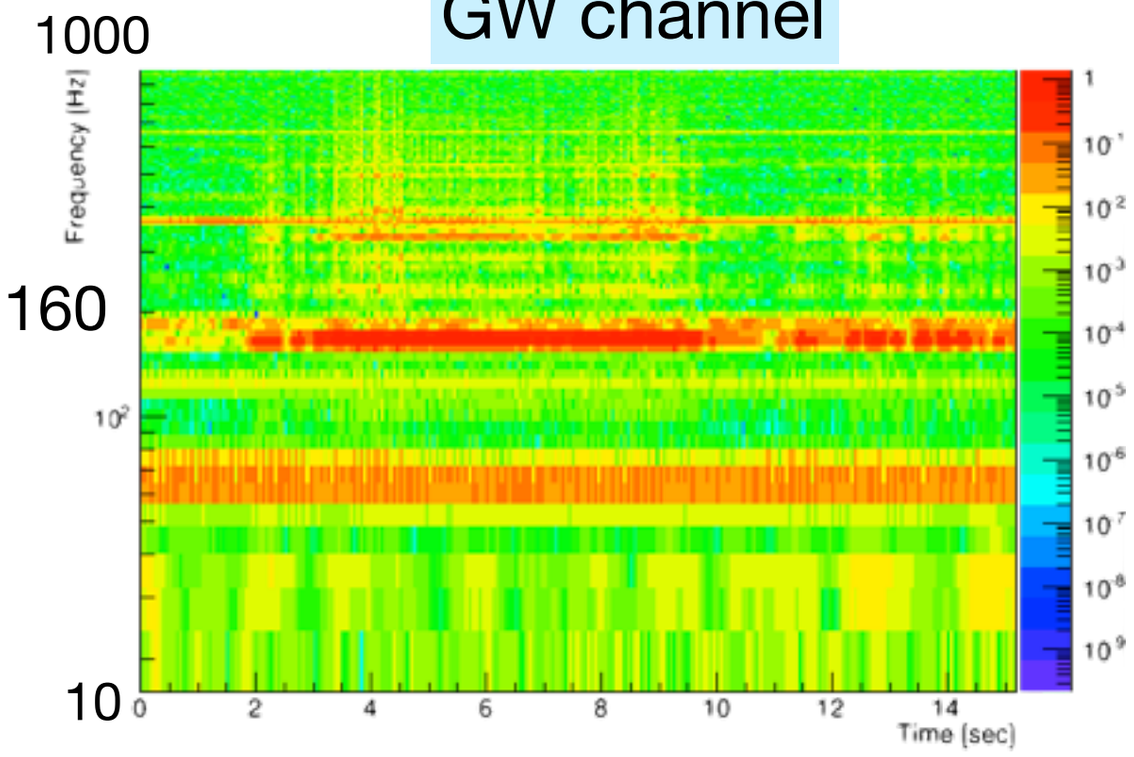
We find same correlation in another data set

correlation value

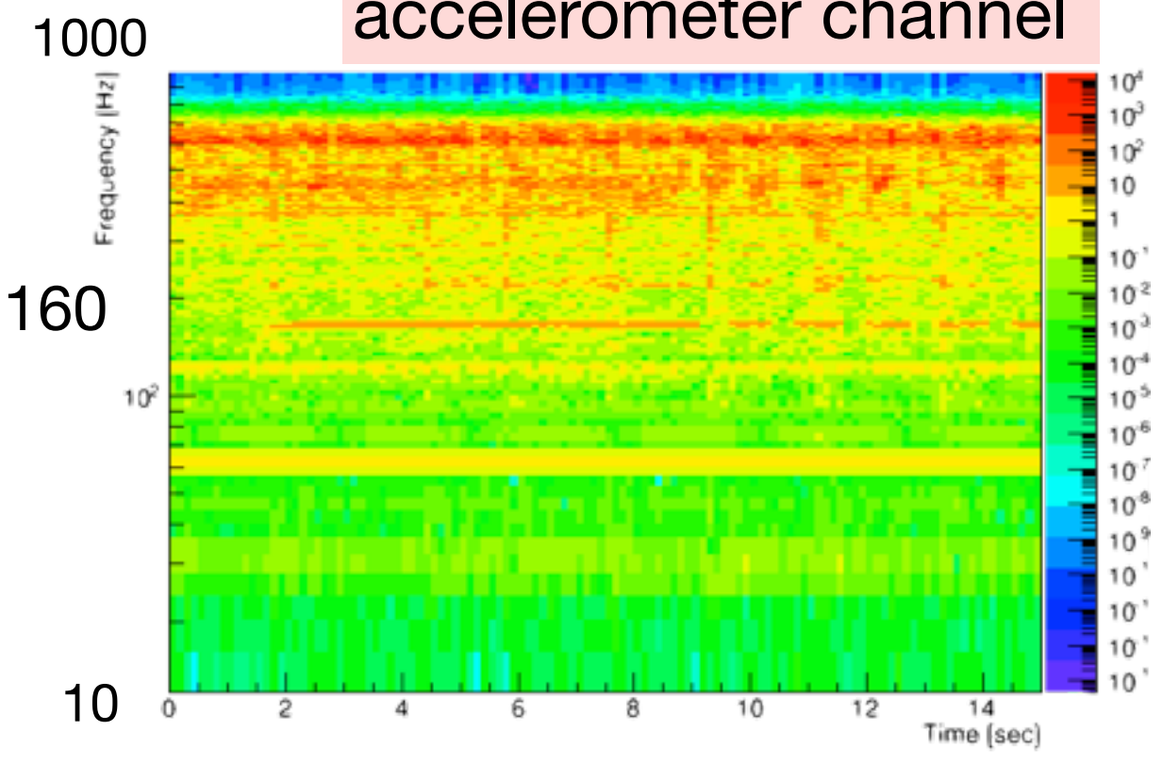


time [sec]

GW channel

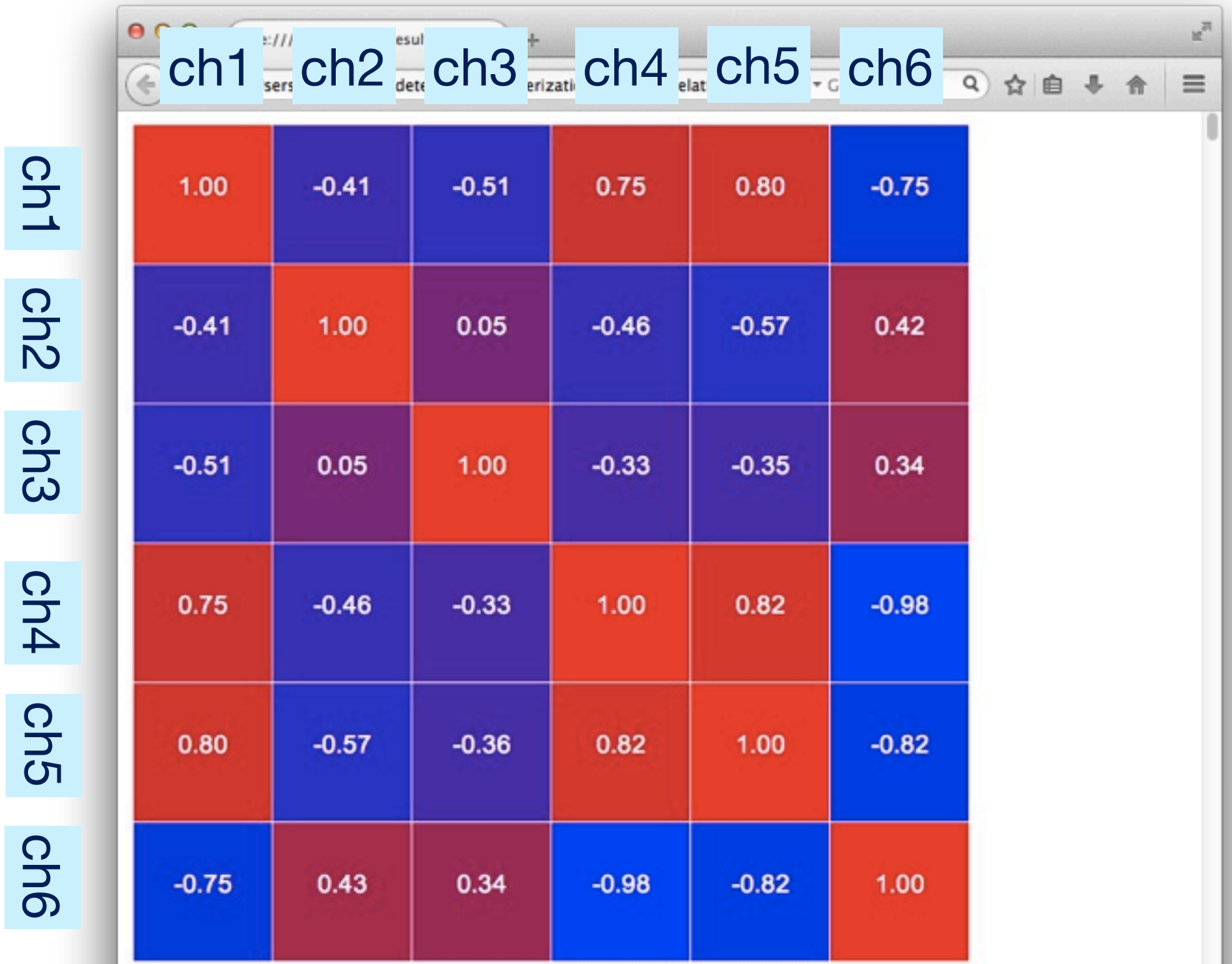


accelerometer channel



correlation map (very preliminary)

In this study, only two channel data is used. But in future, number of channel will increase.
So viewer page was also developed to observe easily which channels are correlated.



Note : Used data is meaningless.

Summary

- Many linear and non-linear correlated noises are observed in LIGO and Virgo.
  These noise limit detector sensitivity.
  Correlation analysis in this study will localize the noise source.
  As a result, false triggers generated GW search pipeline can be removed and increase detection efficiency.

- In KAGRA's commissioning and observation phase, localization of same correlated noise is important.
  In order to detect both linear and non-linear correlation,
  we developed monitor tool using
  Pearson correlation coeddicient
  Maximum Information Coefficient(MIC).
  The monitor tool which cover non-linear correlation is **world-first**.

- Correlation analysis using GW channel and accelerometer of CLIO detector data
  Correlation monitor tool discover a correlation in two channels.