Report on the measurement of the magnetic, seismic activities at the KAGRA site

Kazuhiro Hayama, KAGRA detchar,

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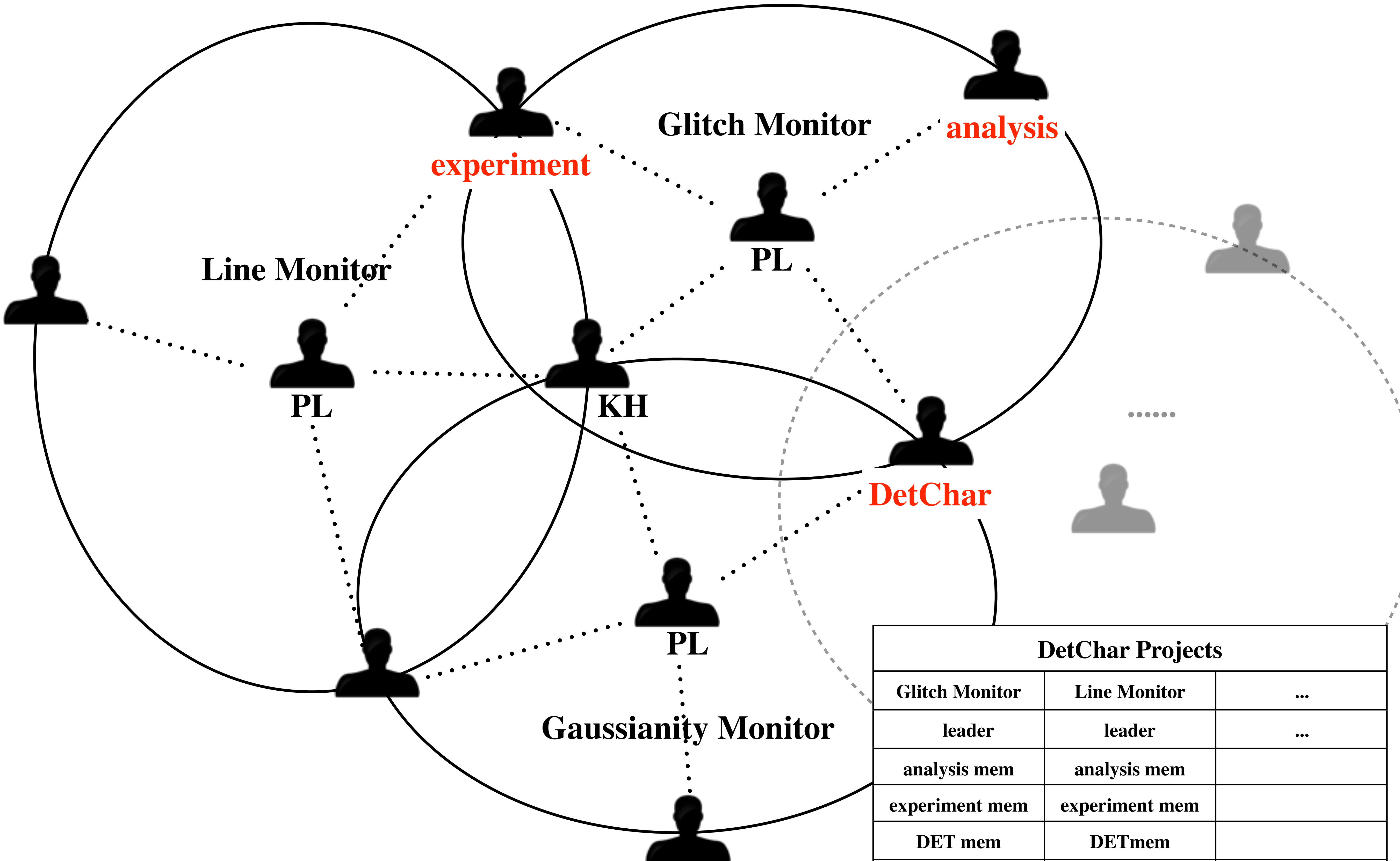
Detector Characterization

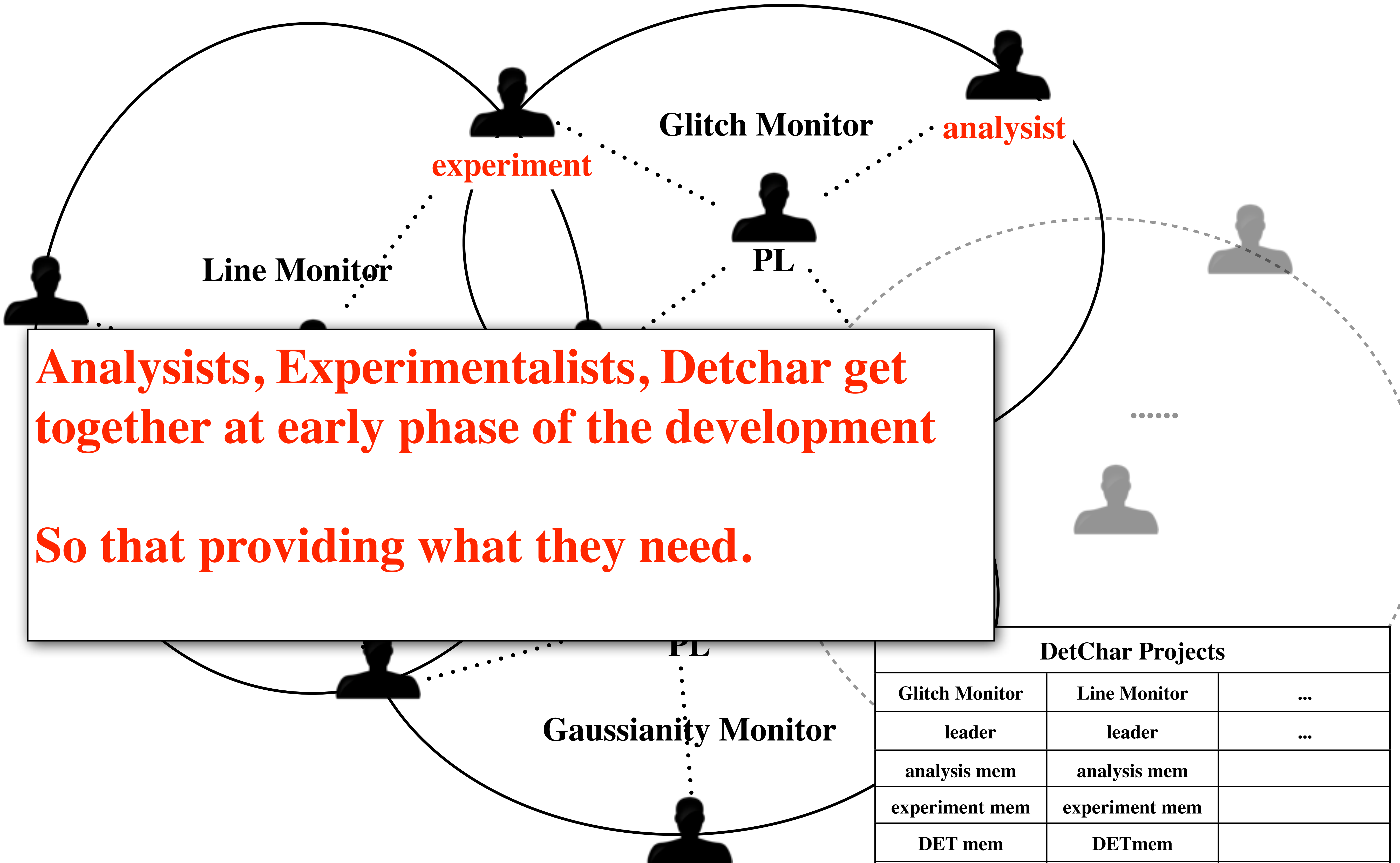
- **Diagnostics system** to know detector conditions, environmental noise, helping for improvement detector operation.
- **Evaluation of data quality** and **Distribution** of the data quality information to collaborators.
- **Veto analysis** to obtain higher-quality scientific results through **noise characterization**.

Structure of the projects



DetChar Projects		
Glitch Monitor	Line Monitor	...
leader	leader	...
analysis mem	analysis mem	
experiment mem	experiment mem	
DET mem	DETmem	

Structure of the projects



Analysisists, Experimentalists, Detchar get together at early phase of the development

So that providing what they need.

DetChar Projects		
Glitch Monitor	Line Monitor	...
leader	leader	...
analysis mem	analysis mem	
experiment mem	experiment mem	
DET mem	DETmem	

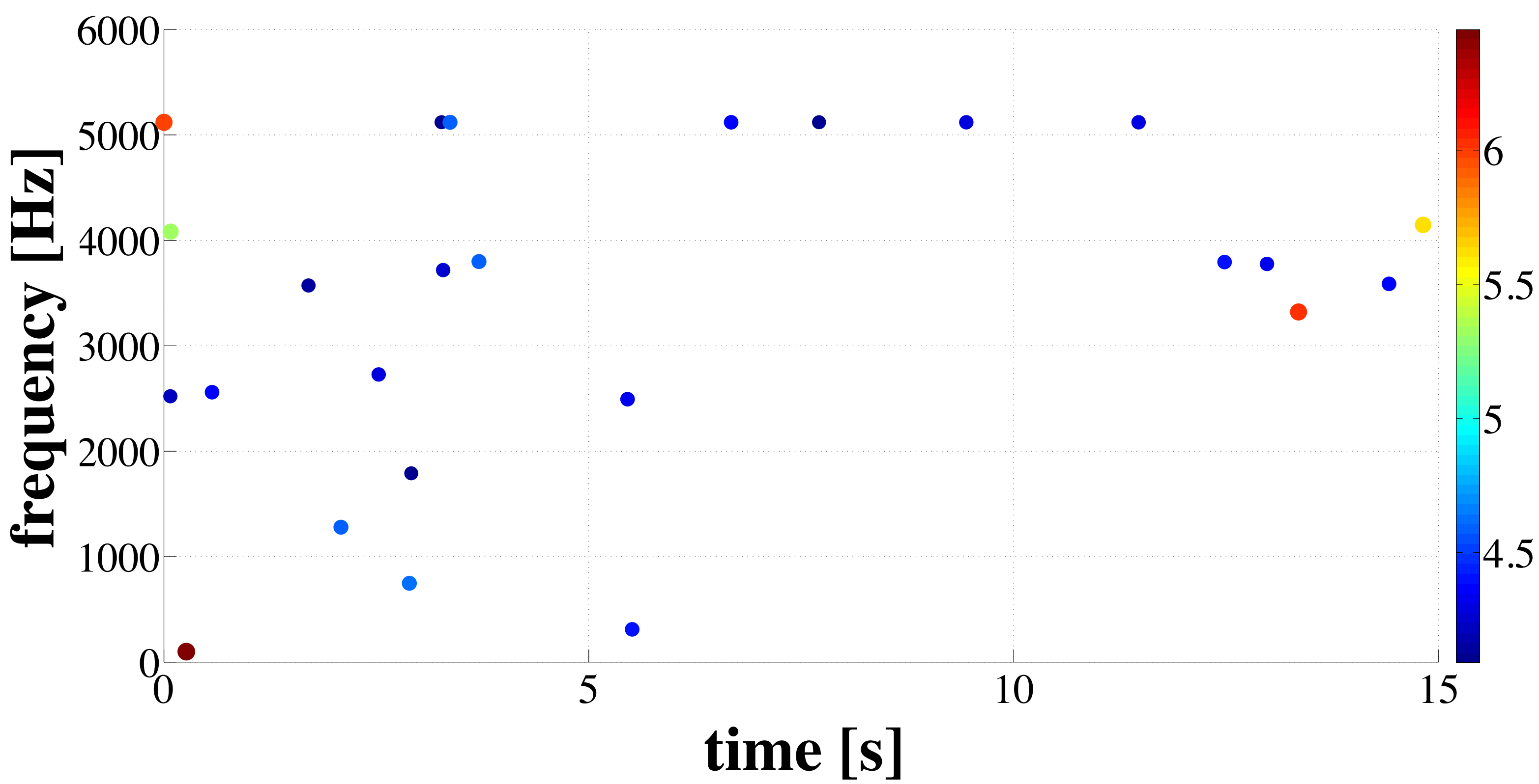
P : Glitch monitors

- Glitch detection
- Statistics (frequency,..)
- Characterization
- Coherency check between channels
- Event display

P : Glitch monitors

- Besides developing our monitor, some monitors are running:
  KleineWelle, ...

- KW is used in LIGO: useful to compare detector conditions with the same algorithm.



XML formatted data

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P : Line monitor

- Line detection
- Statistics (frequency,..)
- Characterization (duration, central frequency, power)
- Coherency check between channels
- Event display

o Useful to find weird oscillation of instruments in subsystems.
o Veto analysis

P : Gaussianity Monitor

- Noise floor tracking
- Power spectrum
- Rayleigh distribution tracking
- Realtime noise modeling
- Monitor display

o Useful to know detector conditions.
o Useful to improve performance of GW search pipelines.

P : Data quality study

Daisuke Tatsumi (NAOJ)

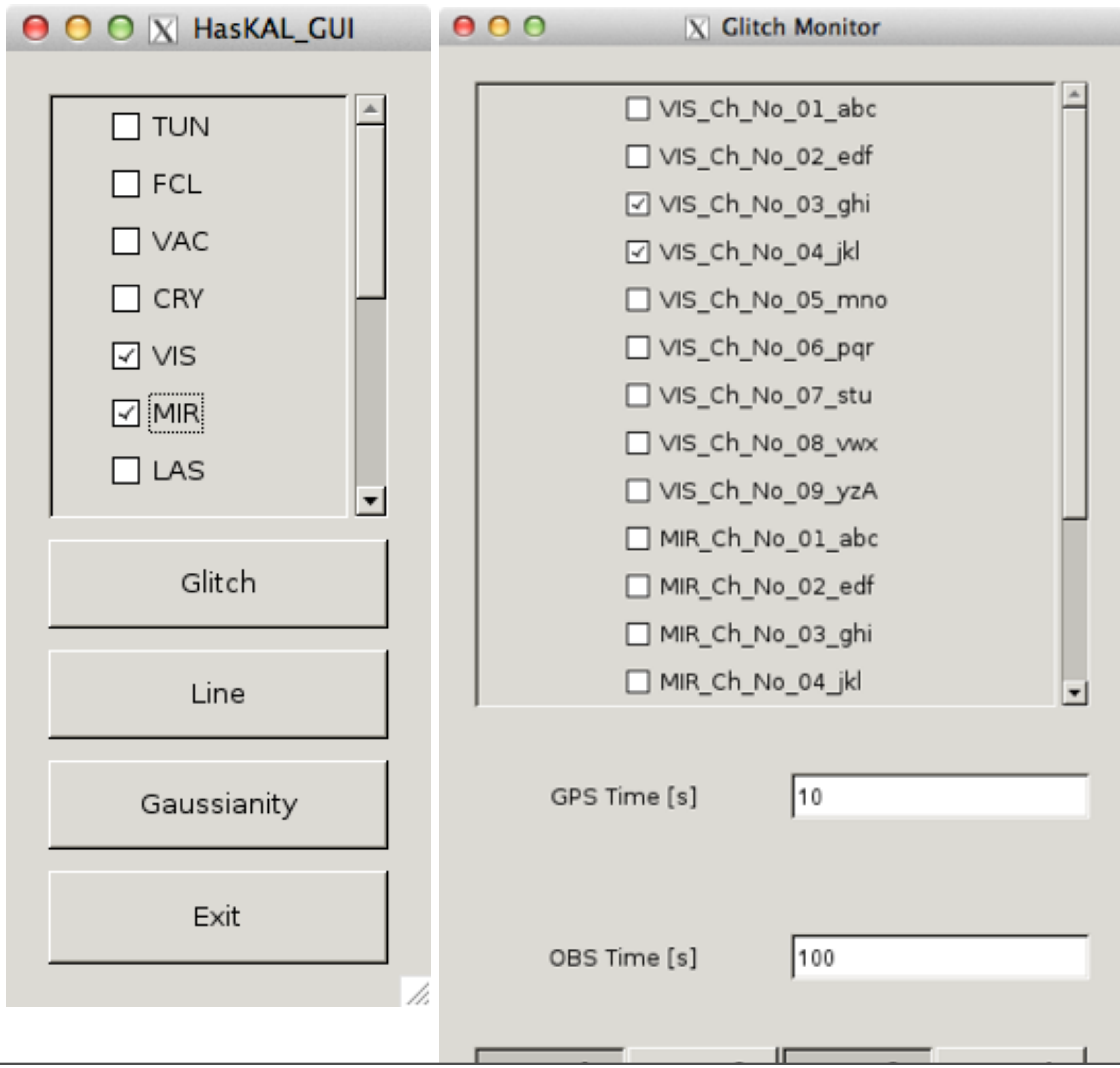
Reduction of cryogenic induced glitches
KAGRA is a unique cryogenic detector in the world.
We are developing a method to quality the data condition.

- **A noise monitoring system for the cryogenic system is developed at TAMA 300.**
- **Our goal is to develop a system to reduce the false alarm rate to 1/month.**

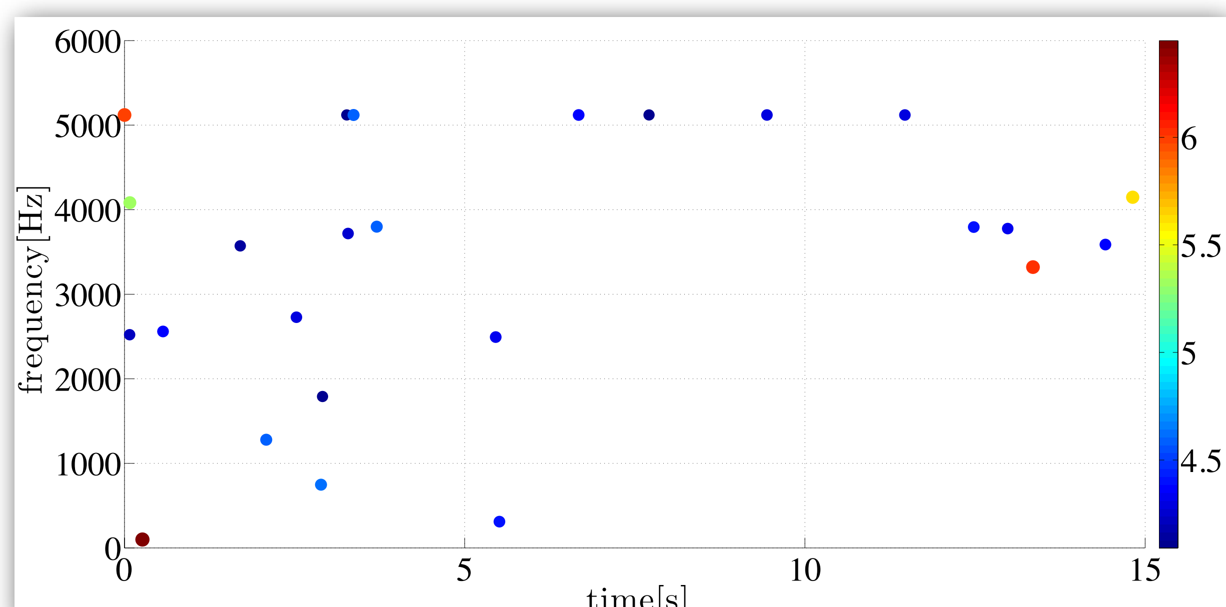
P : Detector characterization system : GUI

Takahiro Yamamoto
(Osaka City Univ.)

- An experimentalist can monitor various channels with the user-friendly GUI system to see what happen in multiple subsystems when he find weird condition of KAGRA.



Glitch display (kleineWelle)



S : Un-supervised glitch clustering

Shuhei Mano
The Institute of Statistical Mathematics, Japan

- From the experience of TAMA300, LIGO, Virgo, there may be glitch families, the number is unknown.
- Identification of glitch families is important to exclude their origins.
- We propose a Bayesian clustering method
  - Dirichlet process Mixture can find how many clusters exist, how they are distributed.
  - Test pipeline are ready to go, now discussing how we construct the input vector.

http://gwwiki.icrr.u-tokyo.ac.jp/JGWwiki/KAGRA/Subgroups/DET/Meet/Agenda20131126?action=AttachFile&do=view&target=gw1311.pdf

S : Supervised glitch clustering

Collaboration with the KGWG detchar group

- Korea group developed the multivariate analysis pipeline, ANN.
- Japan group obtained some PEM data at the KAGRA site.
- We are discussing KAGRA Mock data challenge for detector characterization.
    - The ANN pipeline
    - Simulated KAGRA h-of-t + real PEM data
- A EMD-based event-trigger-generation development using CLIO data

We have to solve man power problem

On going DetChar projects

Primary Projects

- ● To maintain Diagnostics Test Tool(Hayama, Miyakawa)
- ● Detchar GUI (Yamamoto)
- ☐ Detchar Web display(?)
- ● Glitch Monitor (Hayama)
- ● Line Monitor (Itoh, Kokeyama)
- ● Gaussianity Monitor (Hayama)
- ☐ Noise Budget(Hayama, Miyakawa)
- ☐ Health Monitor
- ● Data base

Special Projects

- ● Globally correlated noise (Nishizawa, Hayama, ...)
- ☑ Violin mode(Hayama,Sekiguchi,..)
- ● Multi-Channel Analysis (Hayama with Korea detchar, Mano)
- ● (yellow) Detchar shift plan(Hayama)
- ● (yellow) Newtonian Noise(Agatsuma)

● (green) in progress

● (yellow) in slowly progress

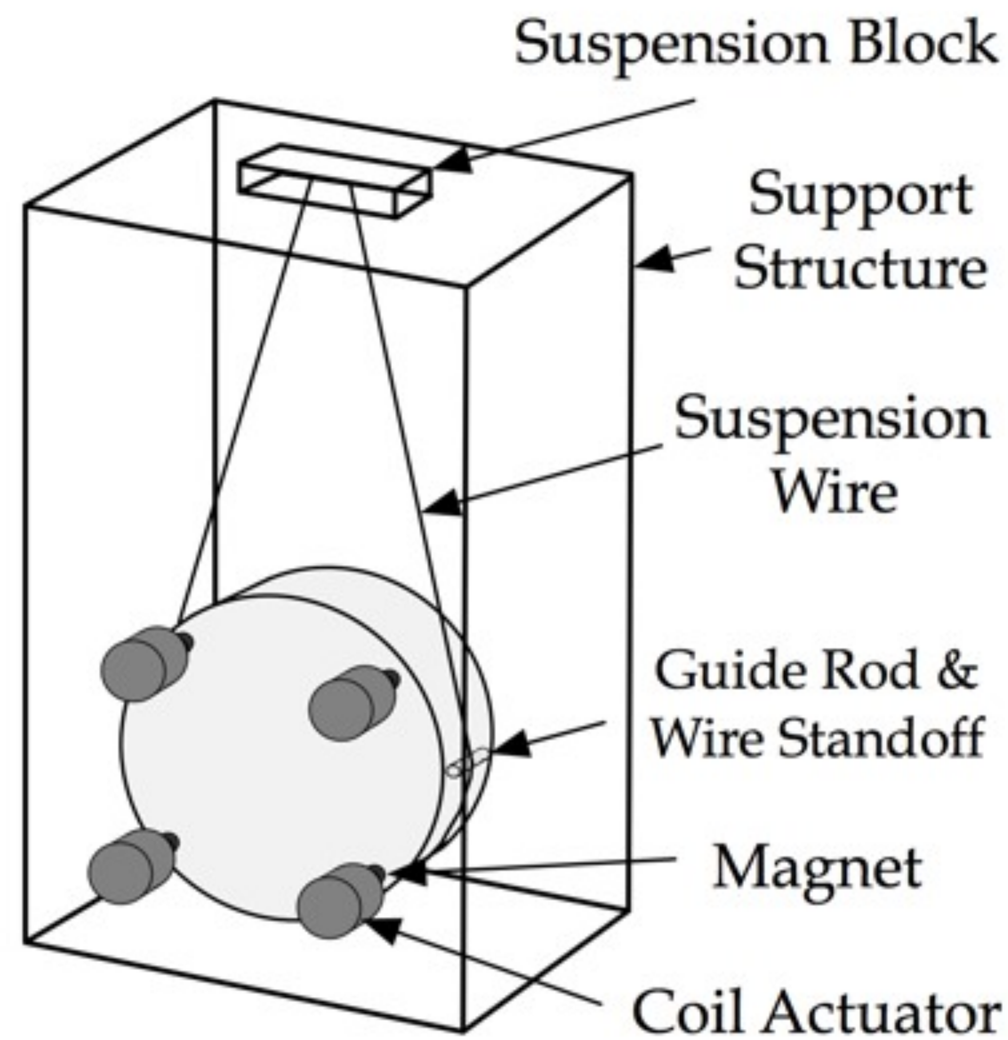
http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/private/DocDB/ShowDocument?docid=1724

Environmental noise characterization

- To know detector condition, and to improve the detector performance, it’s important to study environmental noise around the KAGRA.
  - Seismic noise
  - Magnetic noise

Effect of the magnetic field to KAGRA

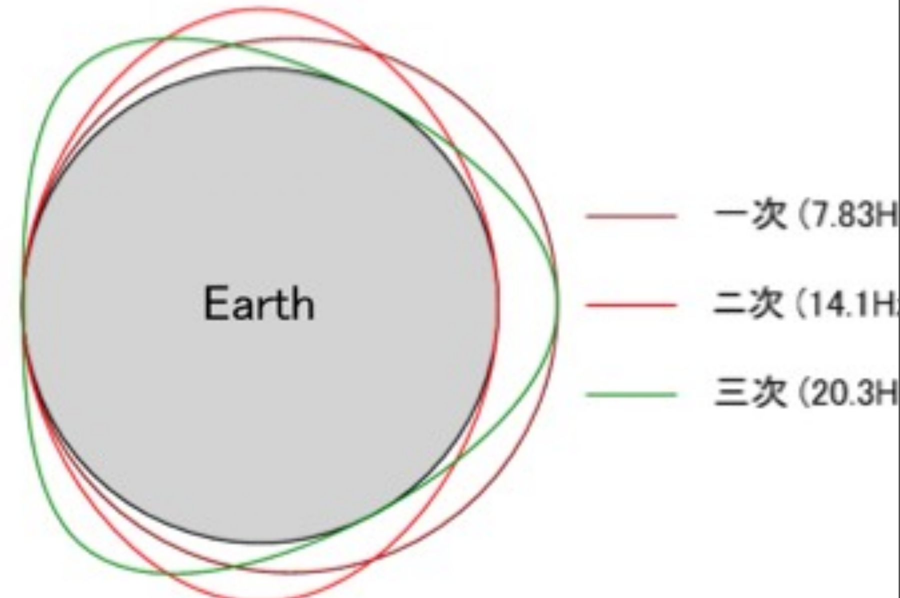
- KAGRA's mirror will be controlled by Magnet-Coil actuator.
- The Magnet-Coil actuator is affected by the environmental magnetic field.

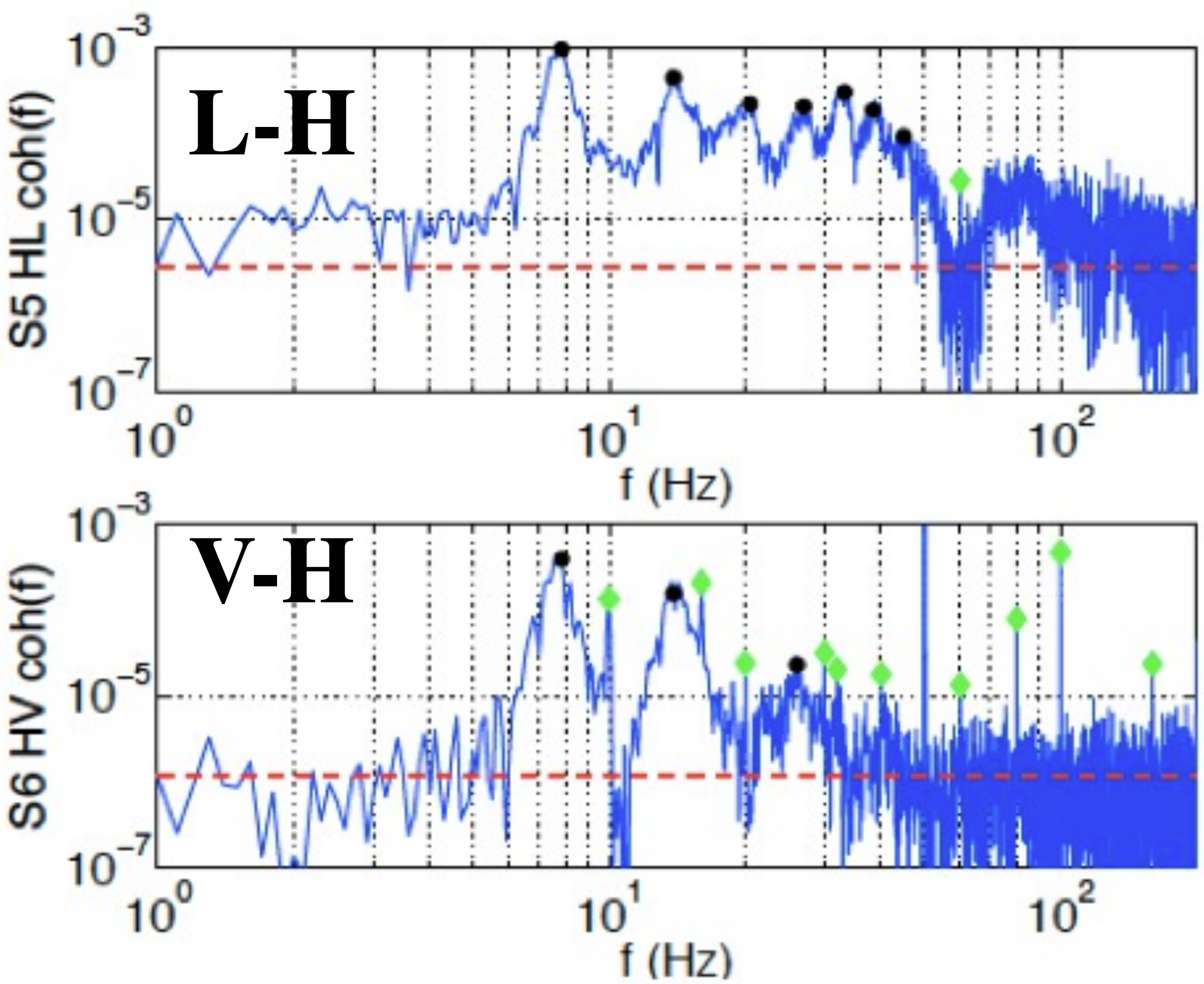


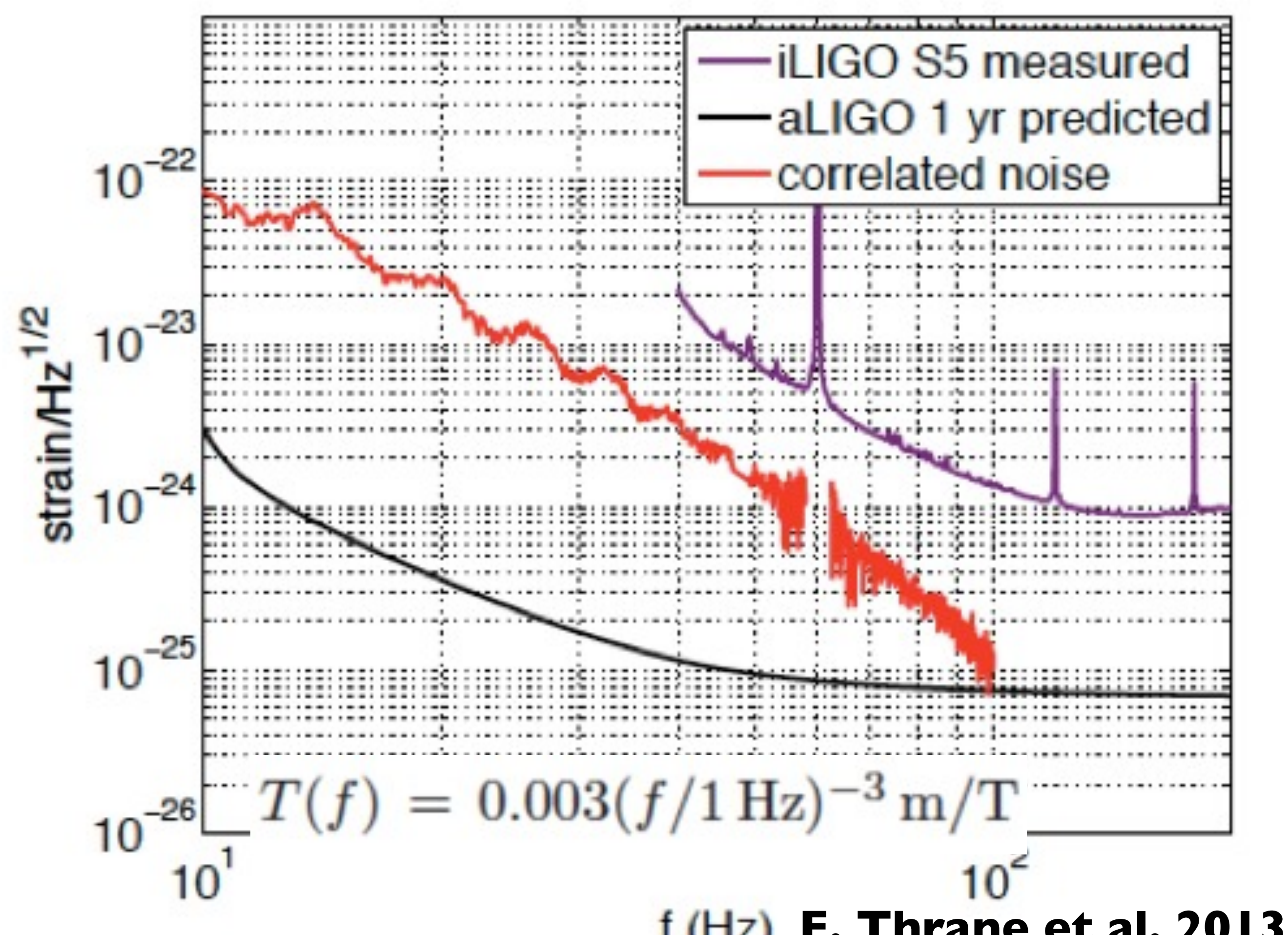
- What size of the magnets can we use without serious influence from the magnetic field?
- How is the magnetic field at the KAGRA site?

Globally Correlated Magnetic Noise

- **Schumann resonance**
  Resonance of the ionosphere due to discharge of thunders, solar wind,...
  - **Very weak (0.5-1E-12T/rHz) (Earth's:1E-5T**
  - **Long coherent length ~1000km**
  - **Correlation appears by 1year integration**







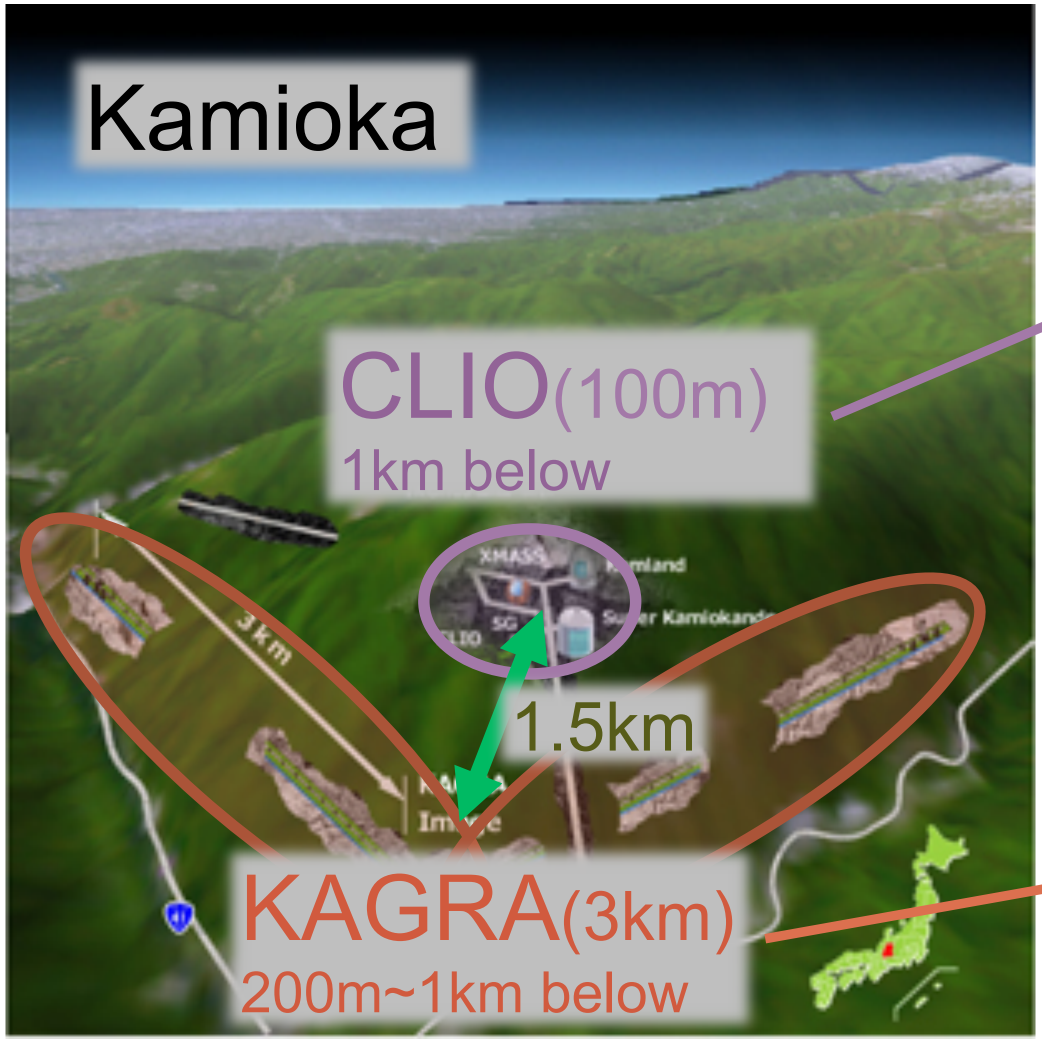
E. Thrane et al. 2013

Globally correlated magnetic noise

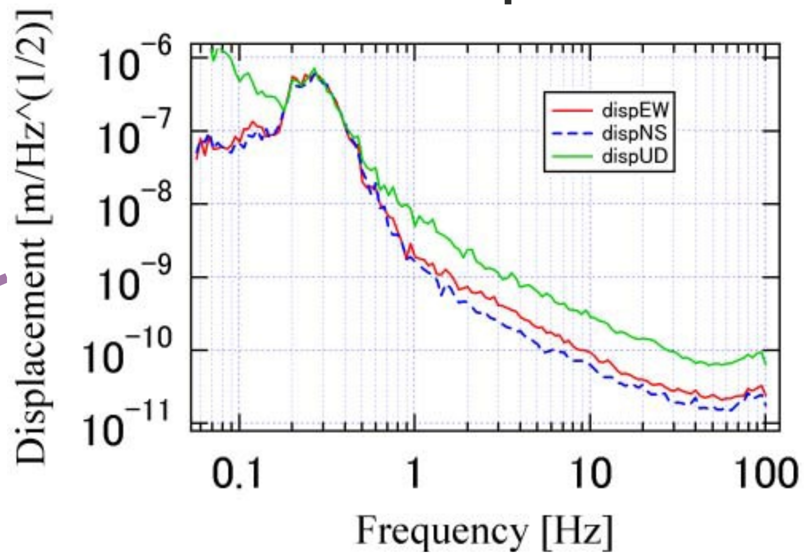
- Impact on sensitivity to GW
  - stochastic : GWB sensitivity is limited at the level of correlated magnetic noise
  - Burst : coincident false events increase and have to put large SNR threshold for the detection

- What about KAGRA's case?
  - Under the mountain is good?

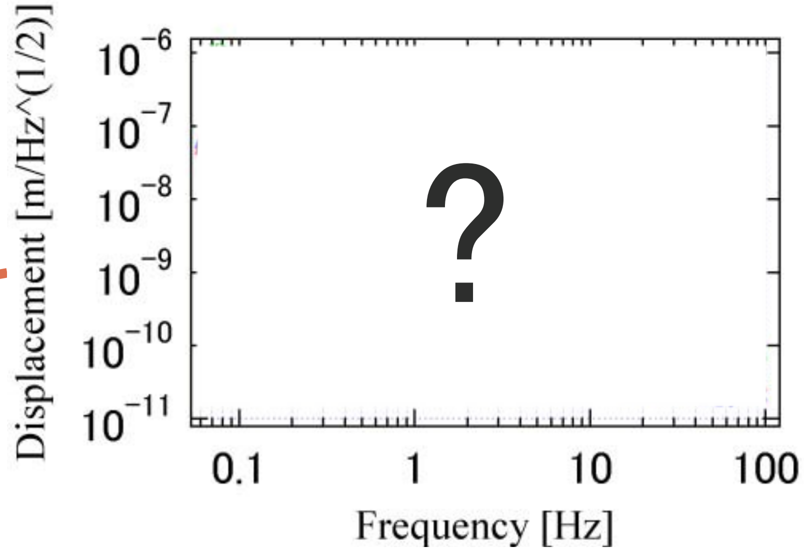
Seismic noise



Seismic spectrum



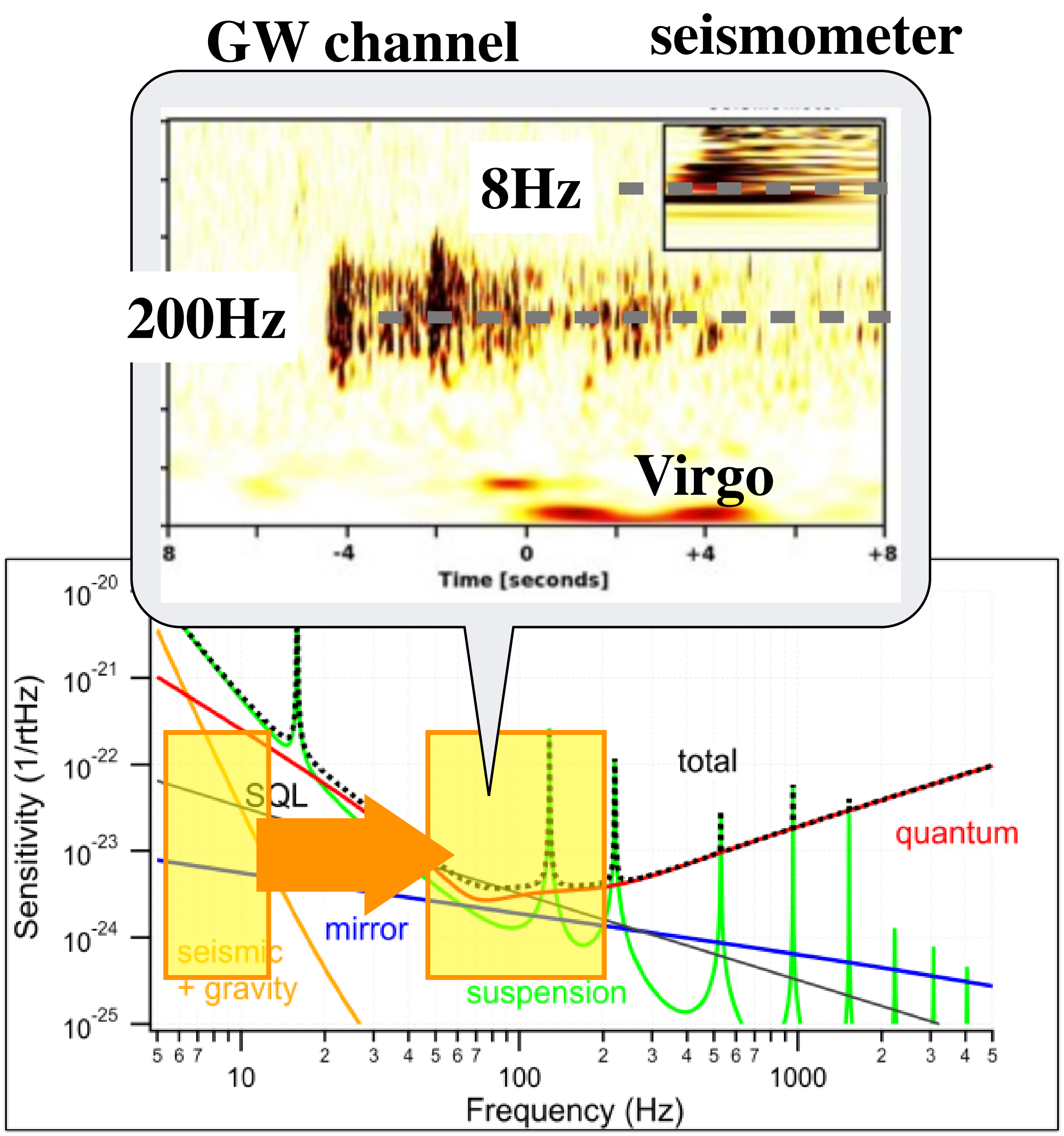
@CLIO



@KAGRA

We didn’t have the seismic spectrum at the KAGRA site

Up-conversion of seismic noise



Sensitivity curve of KAGRA

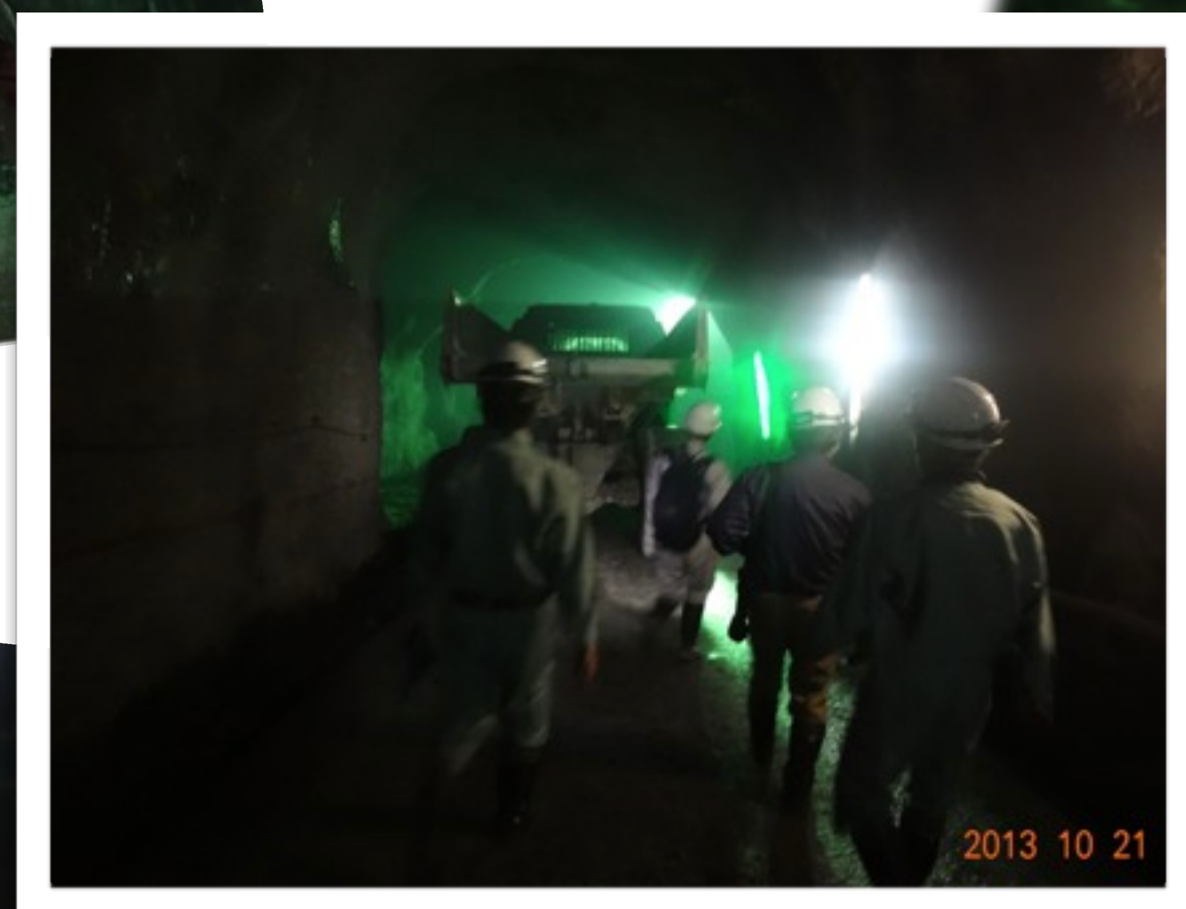
- As TAMA, Virgo, LIGO studied, up-conversion of seismic noise will be glitch sources.
- It's important to know seismic glitch rate at the KAGRA site.

Our motivation of the measurement

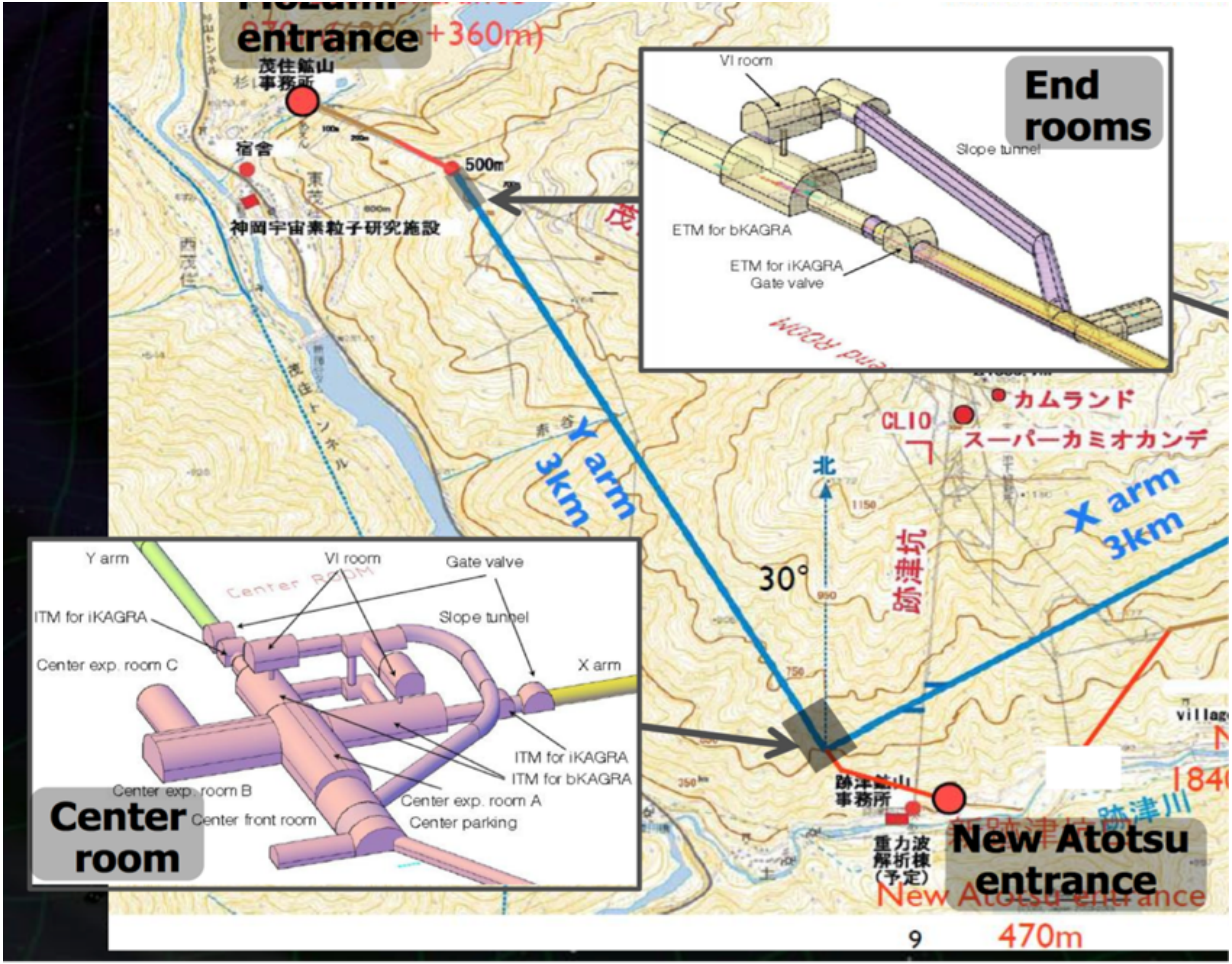
At the KAGRA site,

- How is the magnetic field?
- How is the non-stationarity of the magnetic field?
- How about difference between outside and inside the mountain?
- How are seismic activities

The KAGRA site



Location of the measurement



Location of the measurement

Magnetometer

- Mag649

  made by Bartington instruments

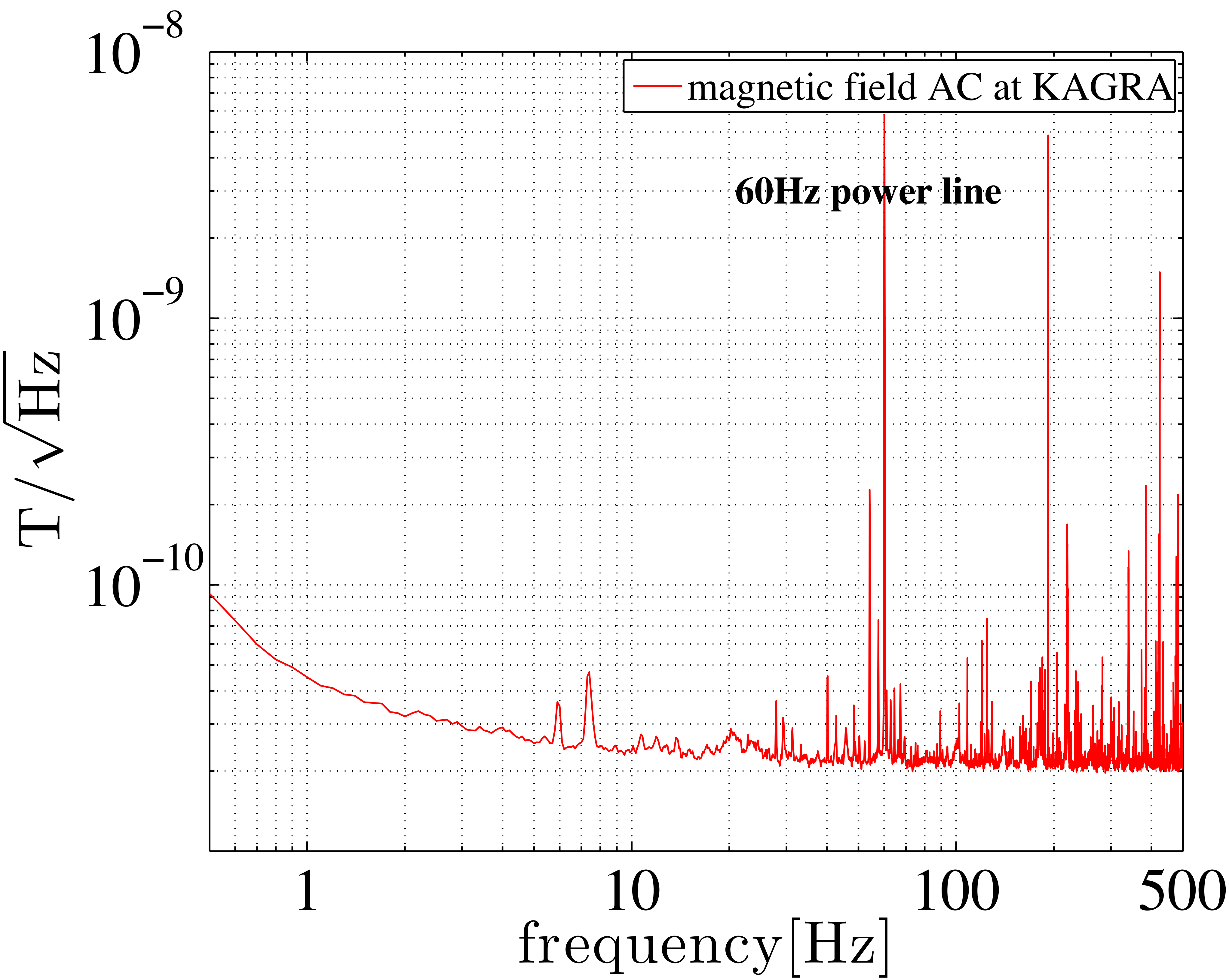
Fluxgate magnetometer

Main spec

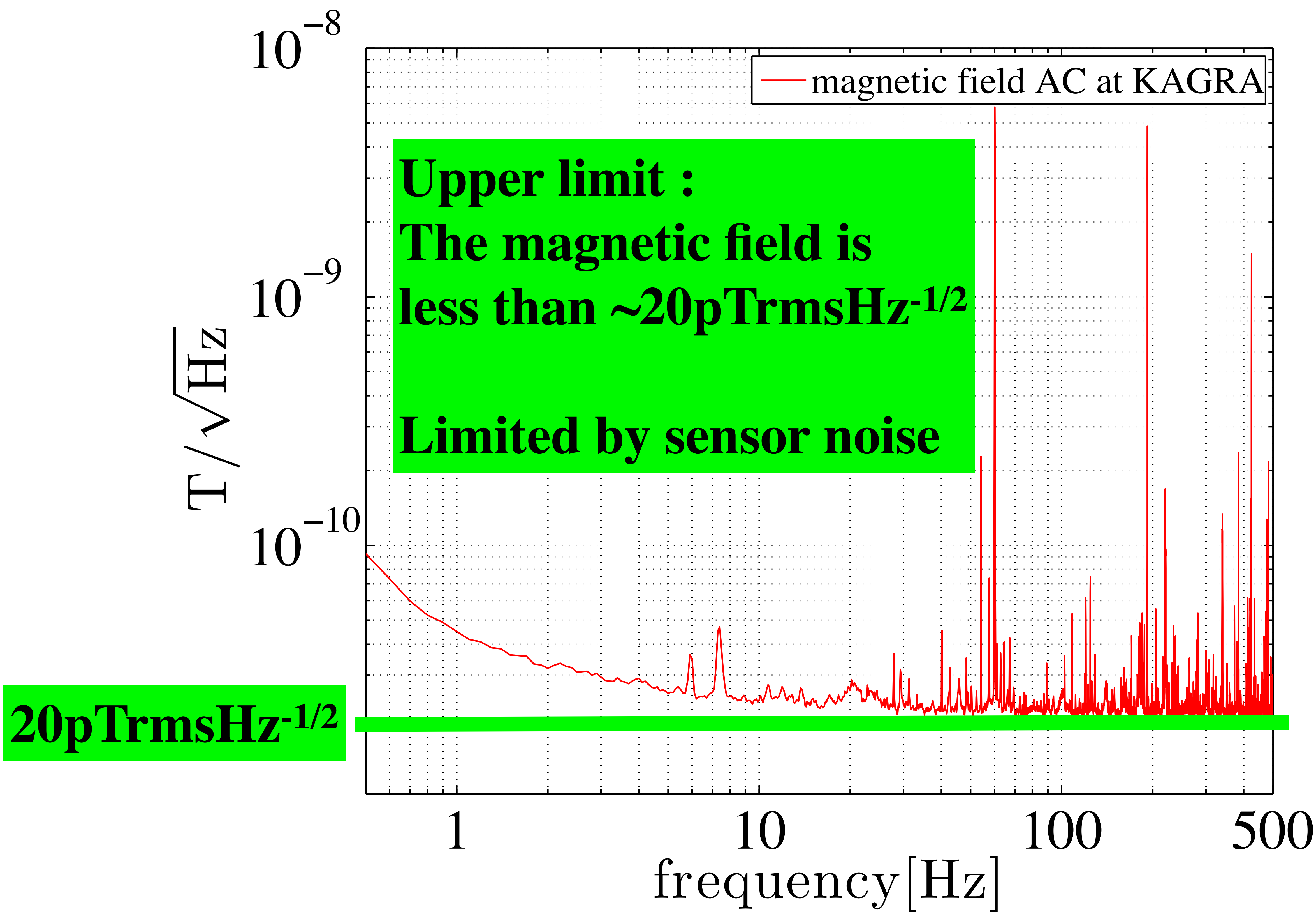
- Number of axis:3(x,y,z)
- Range:±60 μ T
- Bandwidth at -3dB:<1kHz
- standard noise: between 10 and 20 pTrms

External magnetic field change is about ~1pT/√Hz
→we could see “upper limit”

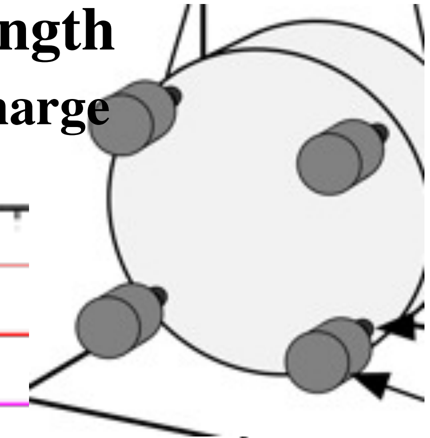
Spectrum of the Magnetic Field



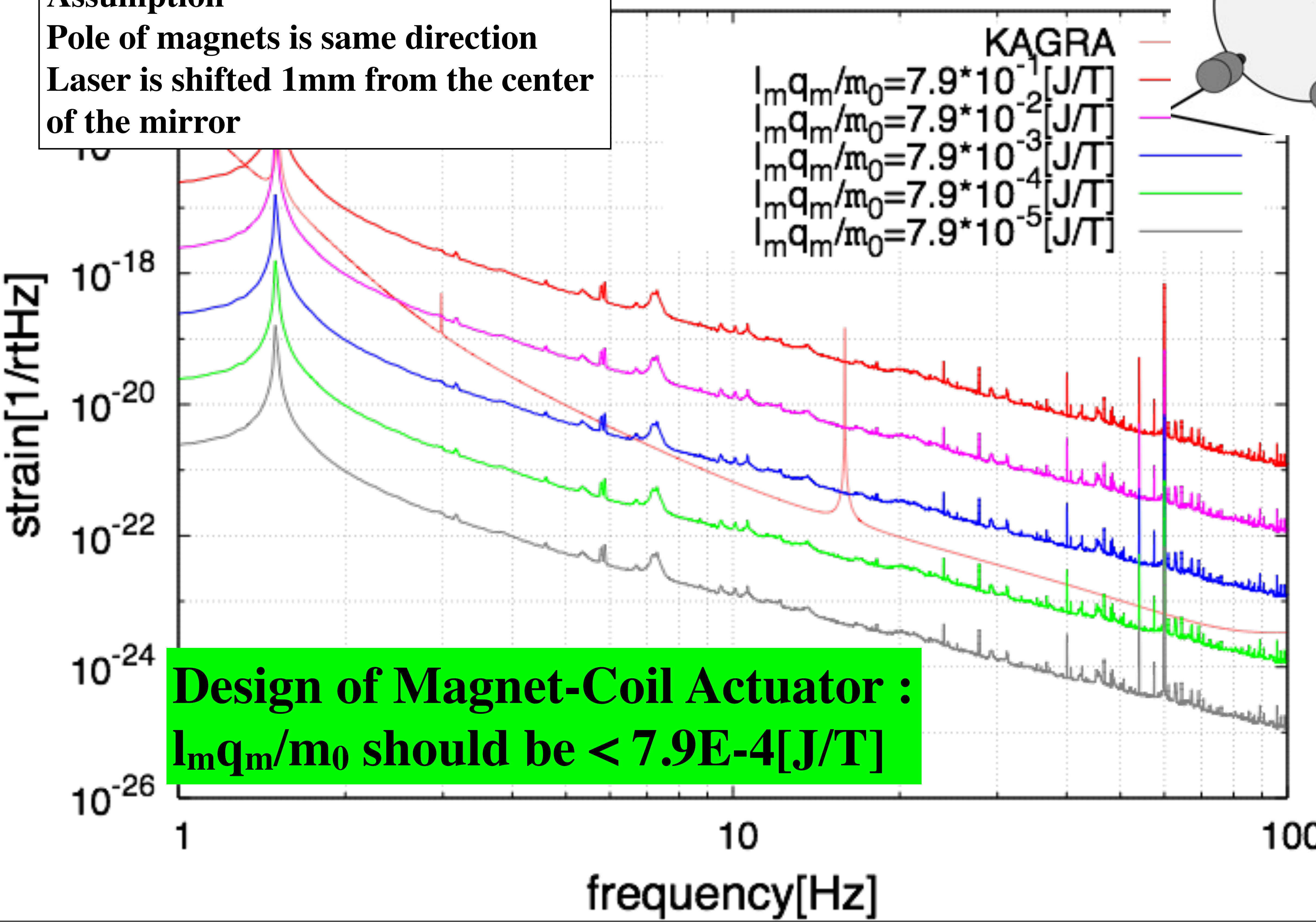
Spectrum of the Magnetic Field



l_m: length
q_m : charge

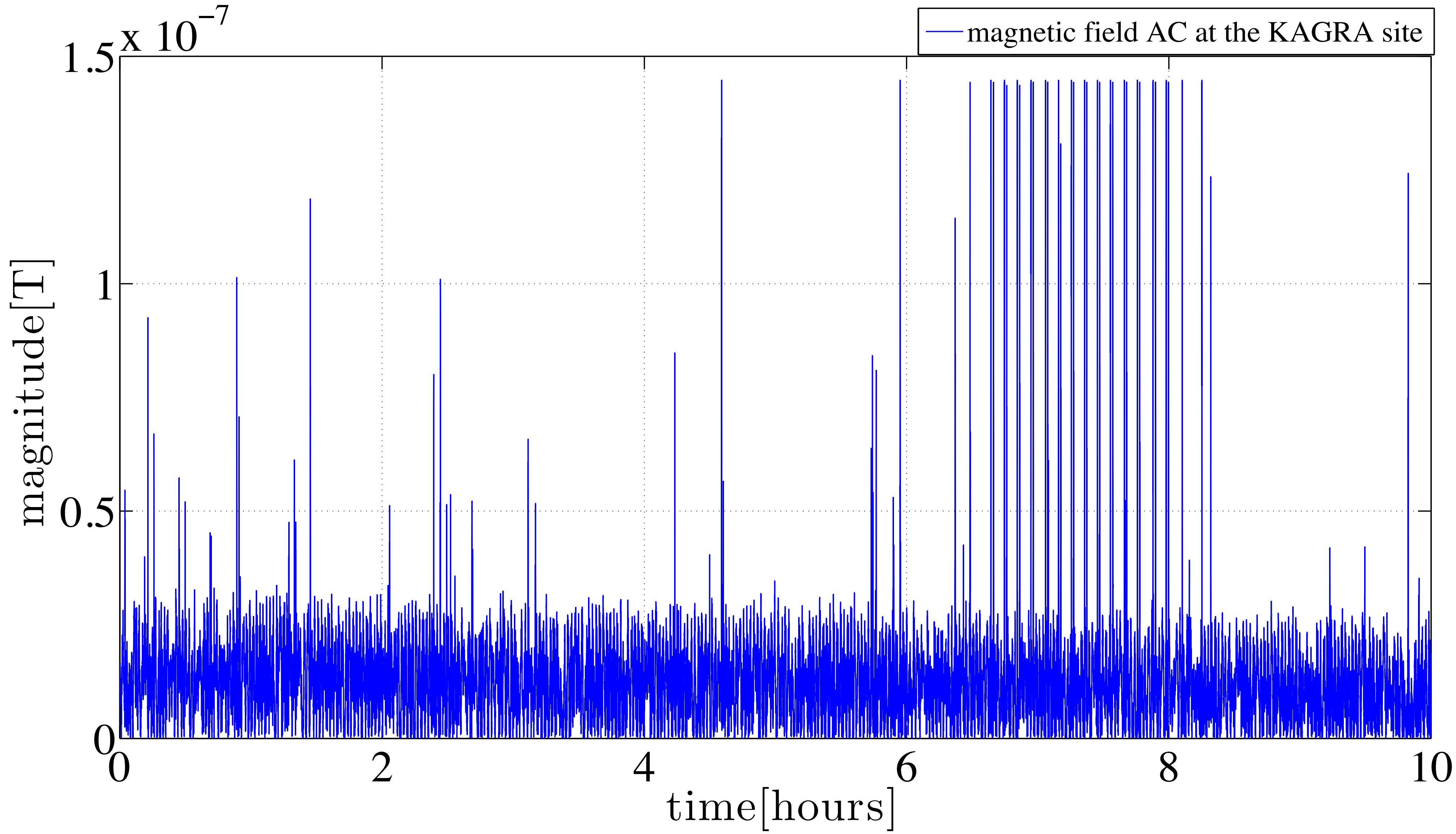


Assumption
Pole of magnets is same direction
Laser is shifted 1mm from the center of the mirror



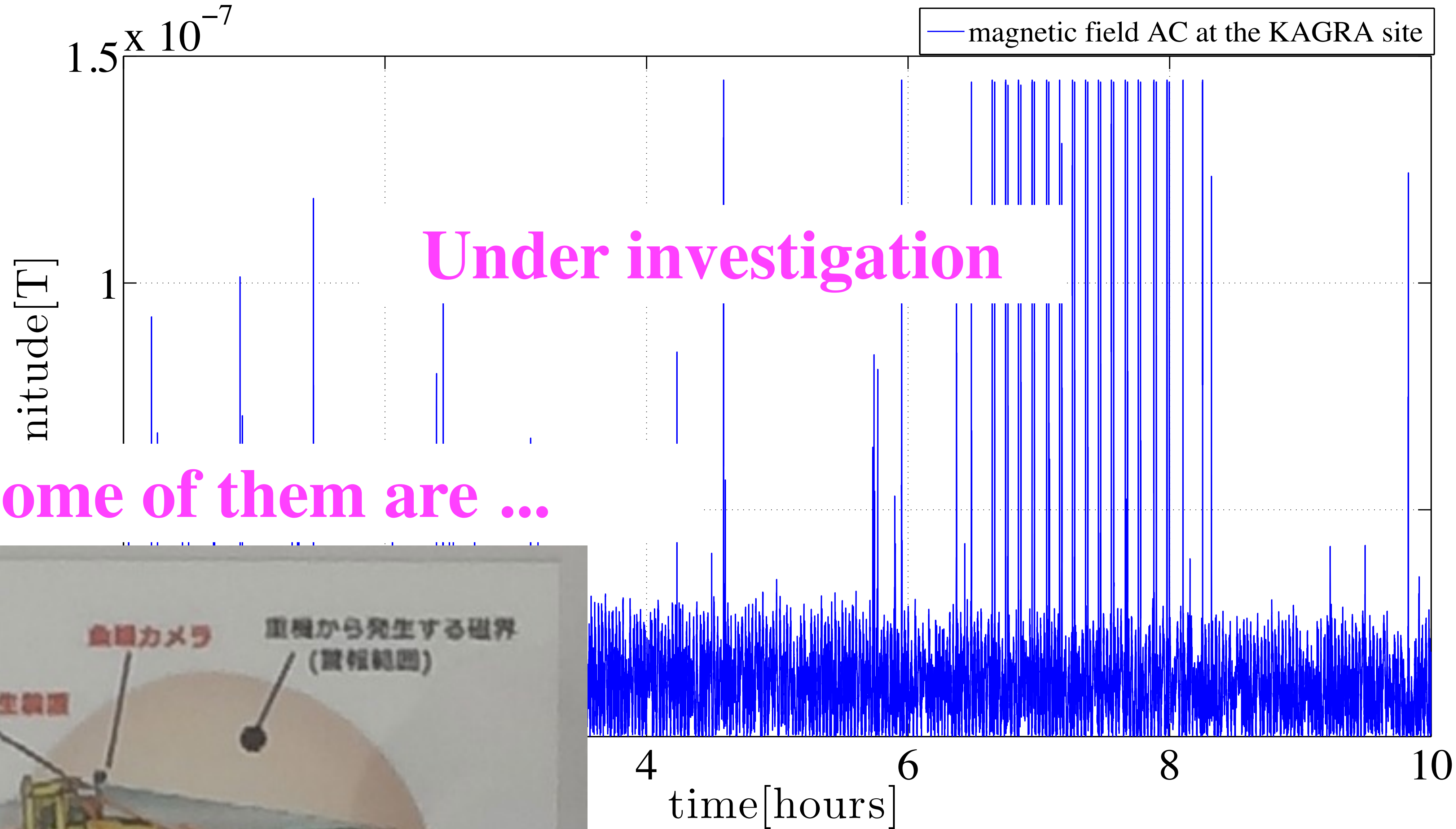
Design of Magnet-Coil Actuator :
l_mq_m/m_0 should be < 7.9E-4[J/T]

Glitches



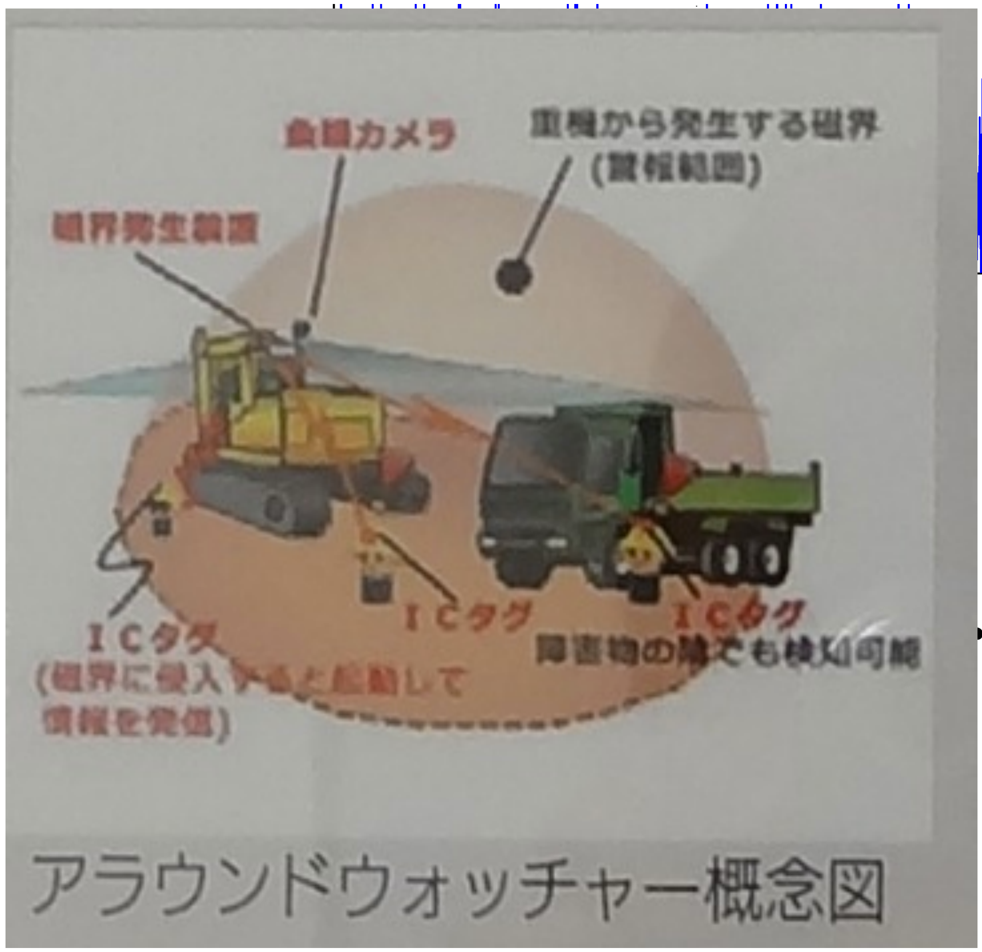
- **4.5 glitch events per hour.**

Glitches



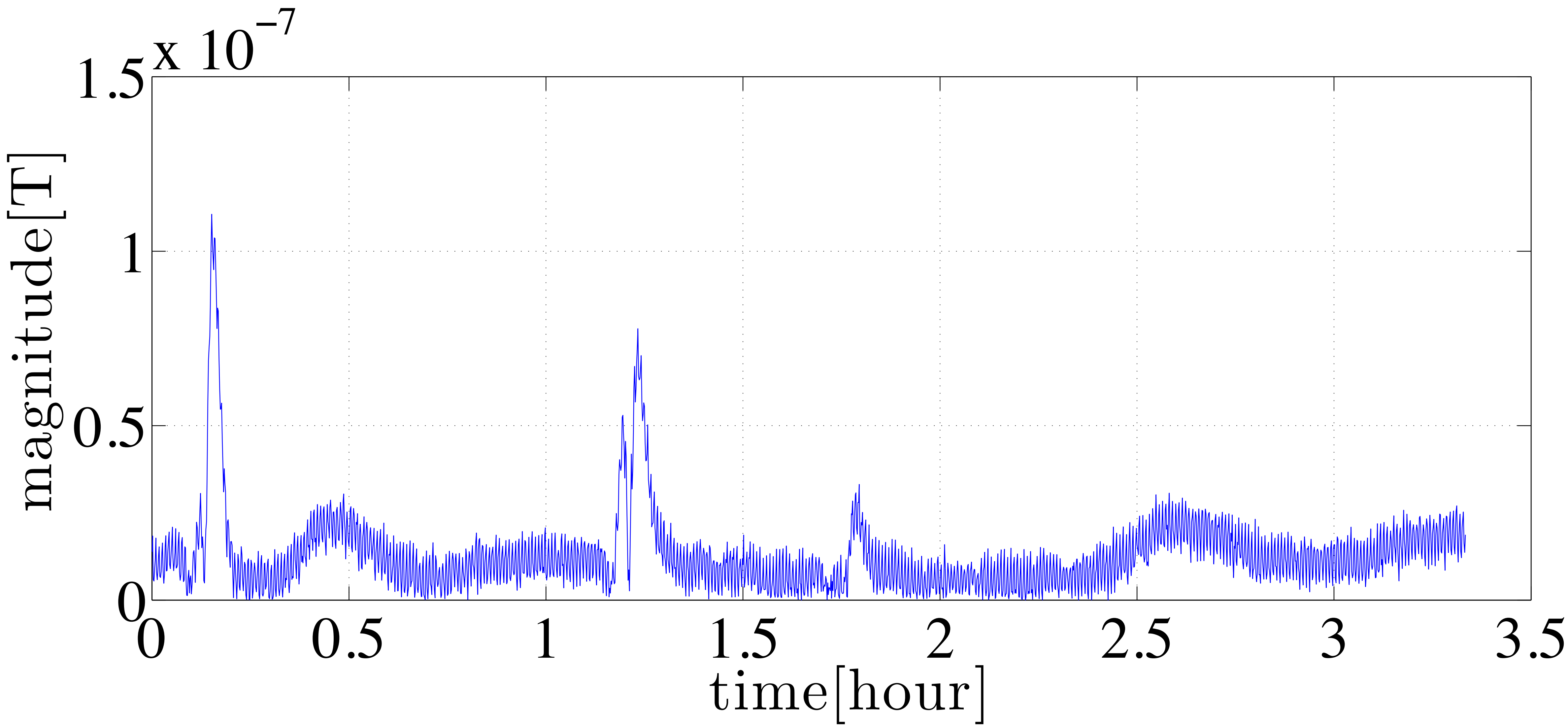
Under investigation

Some of them are ...



hour.

Glitches

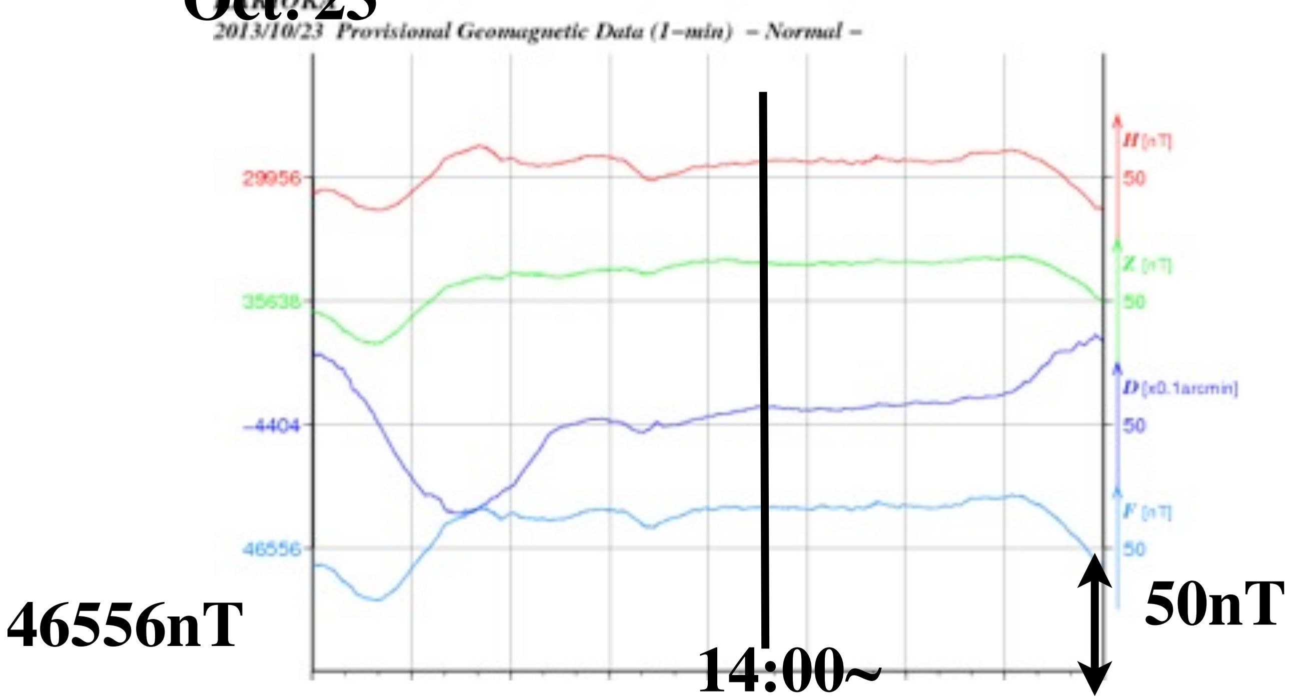


- **4.5 glitch events per hour.**
- **SNR is higher than 5, may appear in obs. band.**

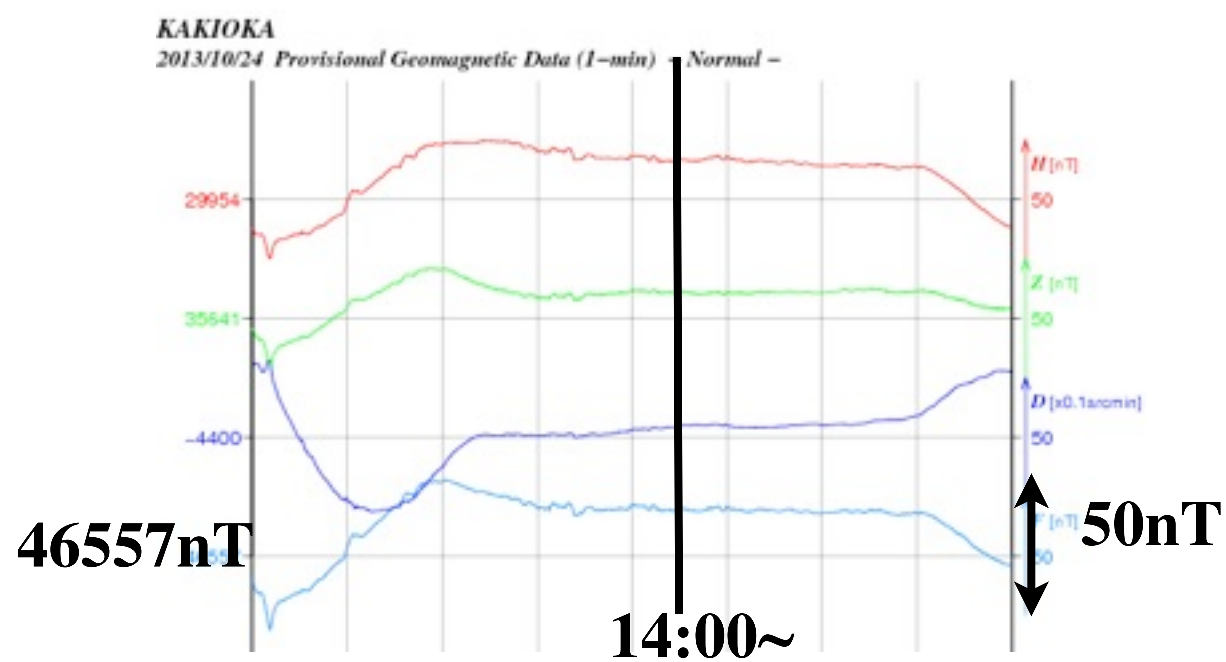
Difference of inside/outside of the Kamioka mine

- Unfortunately one magnetometer was not working.
- We measured DC component at the KAGRA site on 23.
- We measured DC component outside the KAGRA site on 24.
- The geomagnetic variation on 23,24 at 14:00 were within 10nT(< 0.001％)

Oct. 23

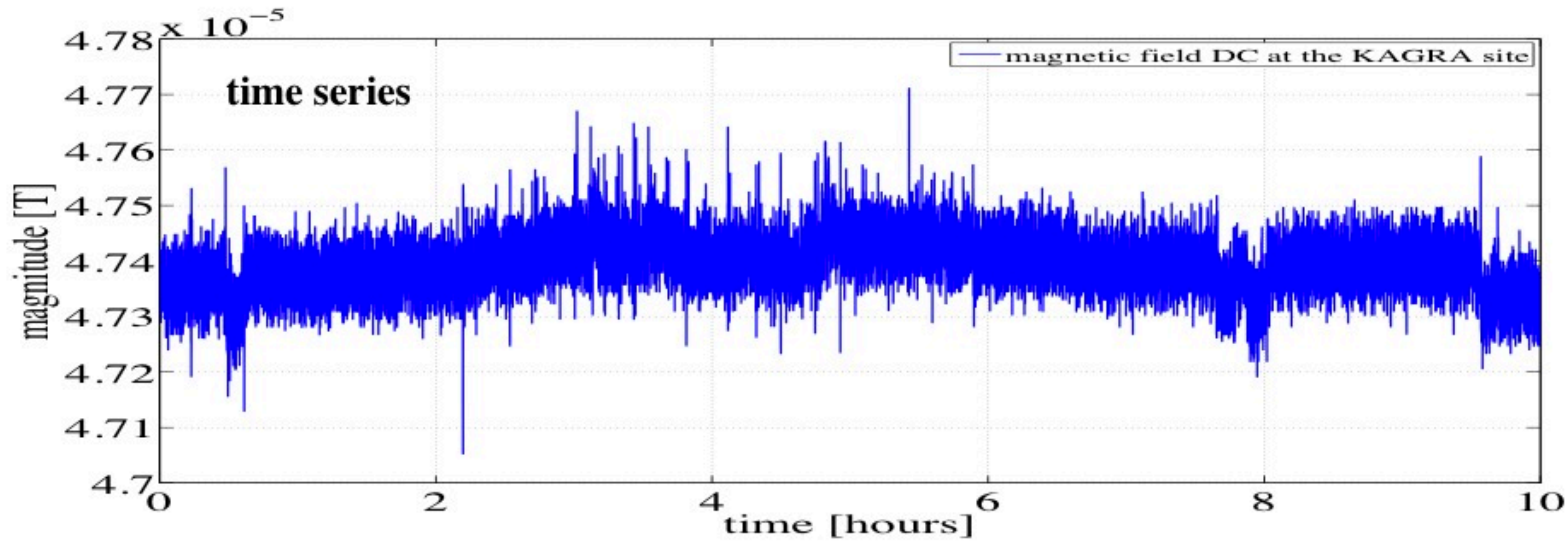


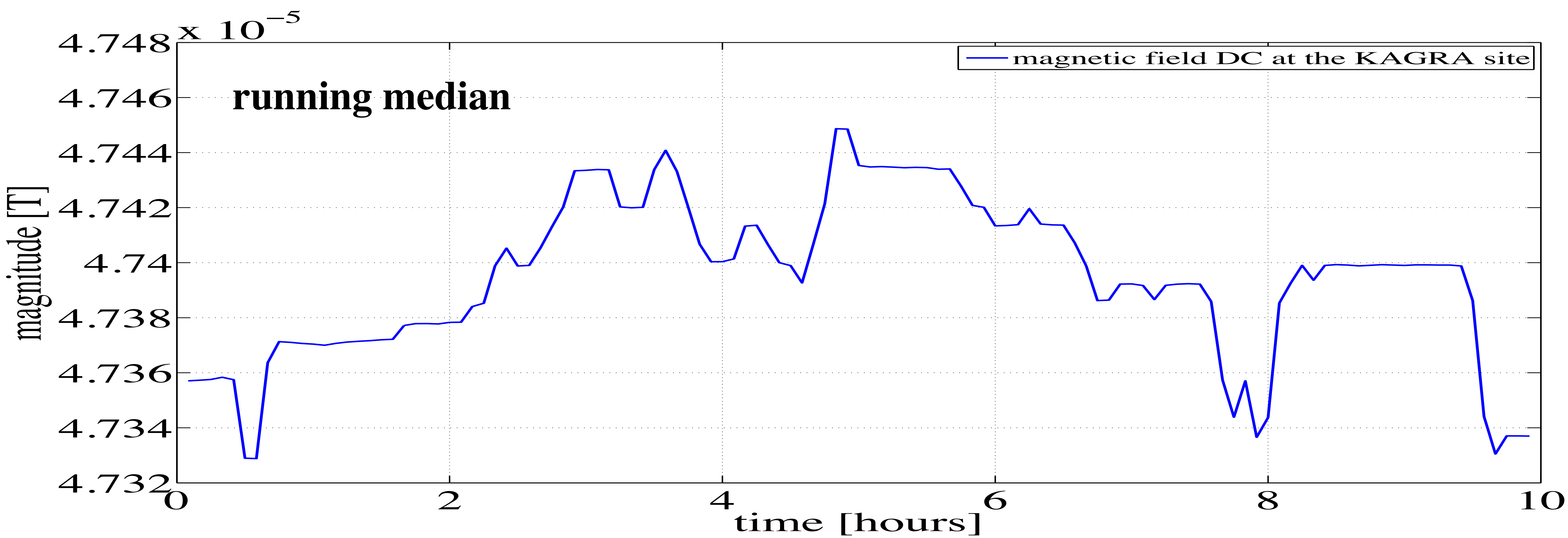
Oct. 24



Geomagnetic variation

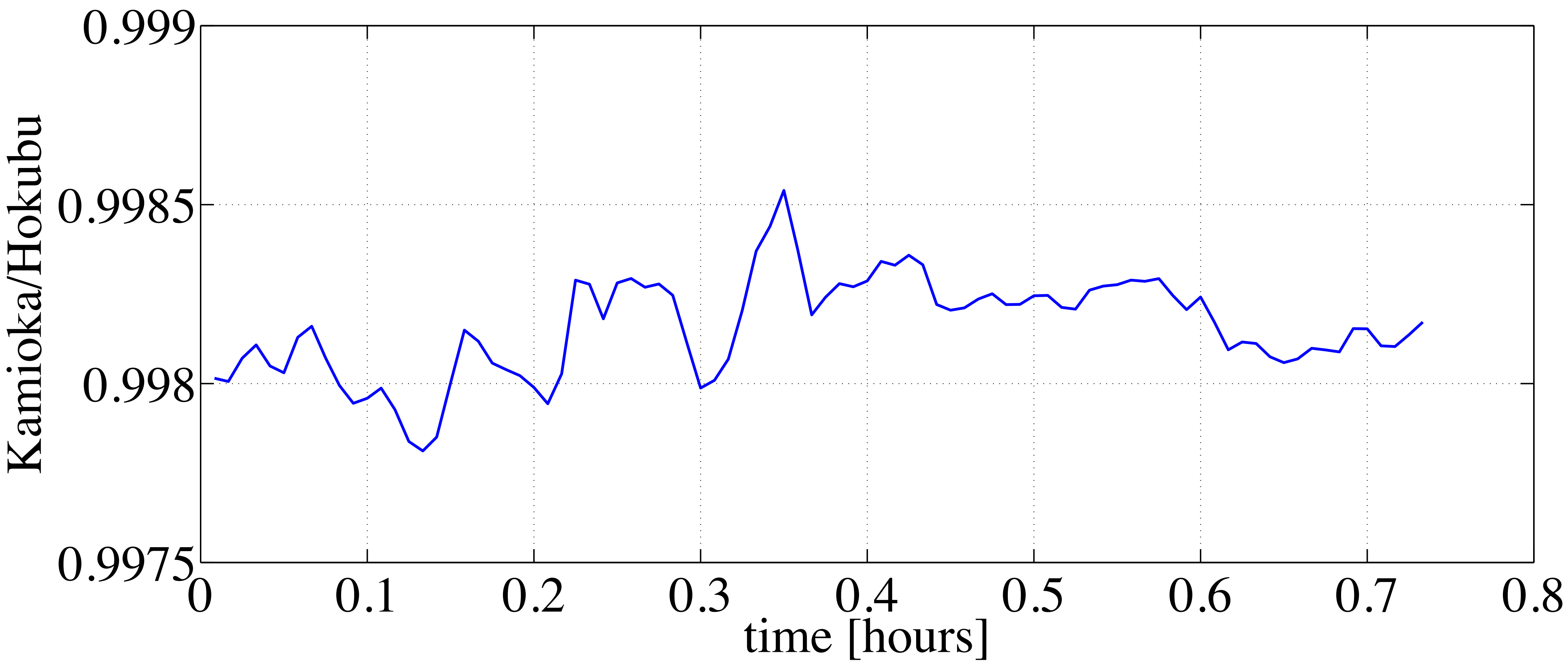
DC component of the magnetic field





Ratio KAGRA/Hokubu

14:00 ~



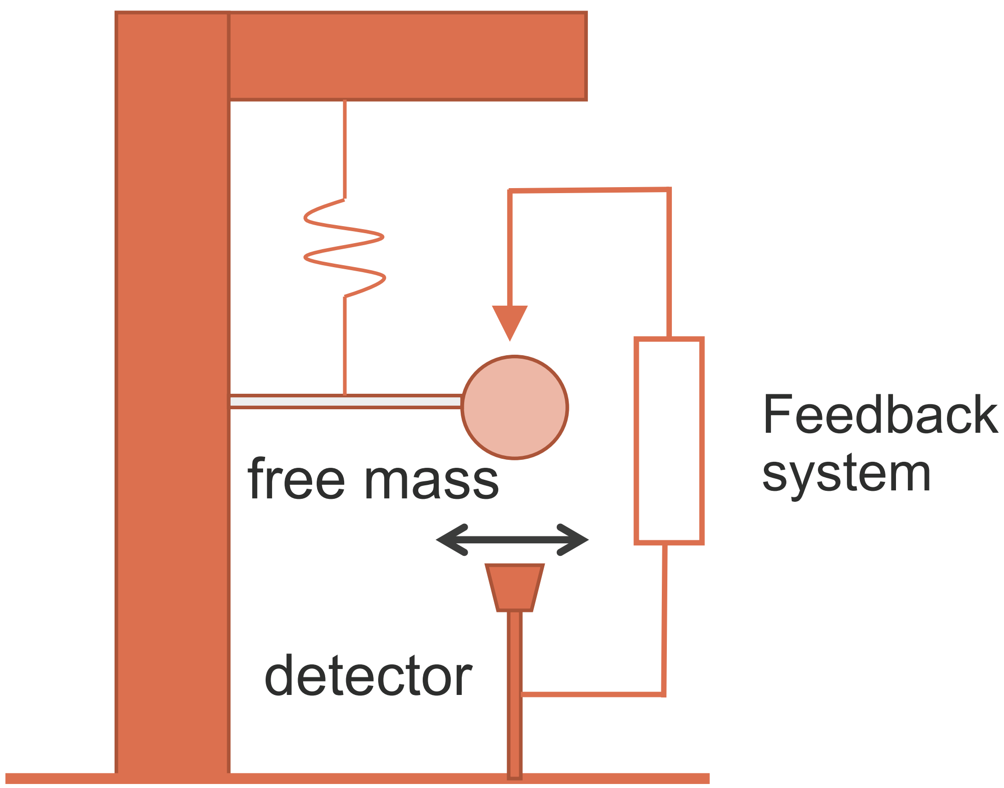
- **The magnetic field at the Kamioka site is ~0.2% smaller than the outside.**

Summary

- How is the magnetic field?
  - We see the upper limit of the magnetic field at the KAGRA sited is ~ 20pTrms/rHz which is sensor noise.
  - Not dominated by unexpected magnetic fields.
  - Need more sensitive measurement, upper limit.
- How is the non-stationarity of the magnetic field?
  - A few events per hour, maybe magnetic flare.
  - Need investigation of origin, taking longer data.
- How about difference between outside and inside the mountain?
  - The DC component at the KAGRA site is ~0.2% smaller than the outside.
  - Need measurement of AC components!

Seismometer

Seismometer



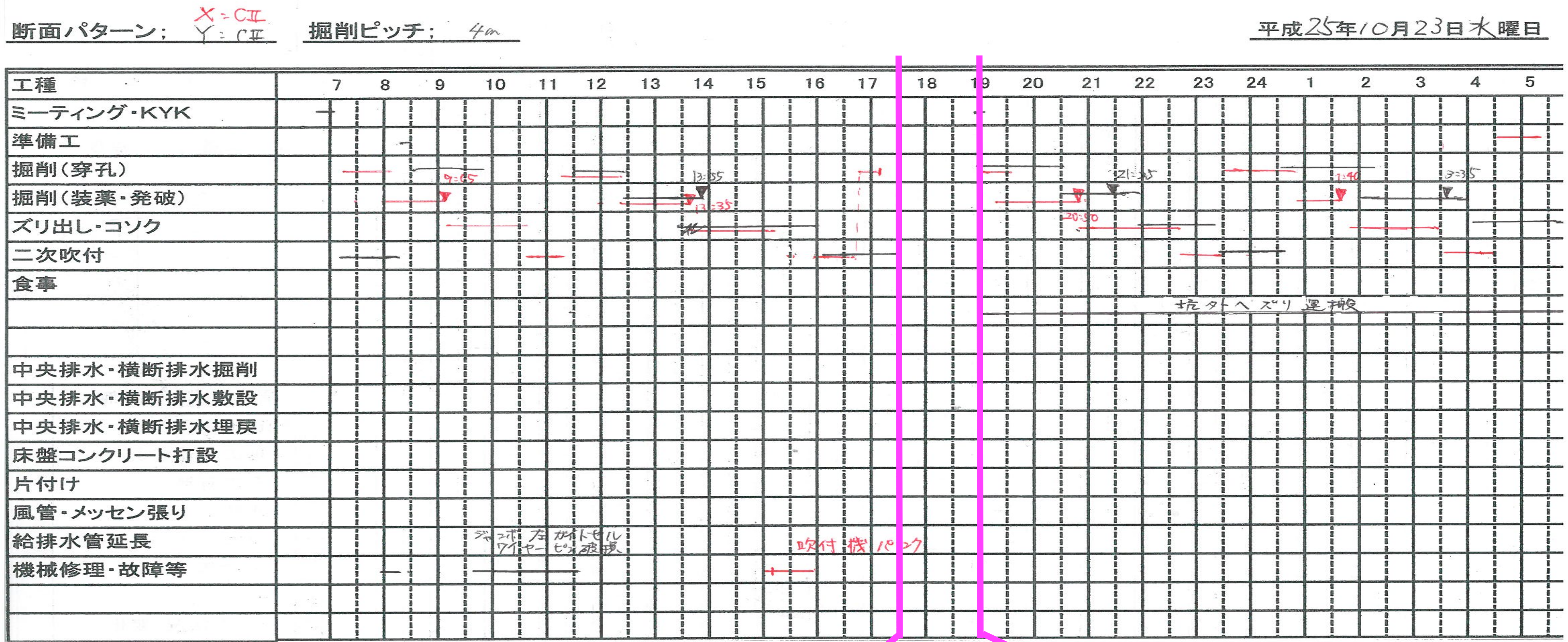
Measure relative displacement

CMG-3T

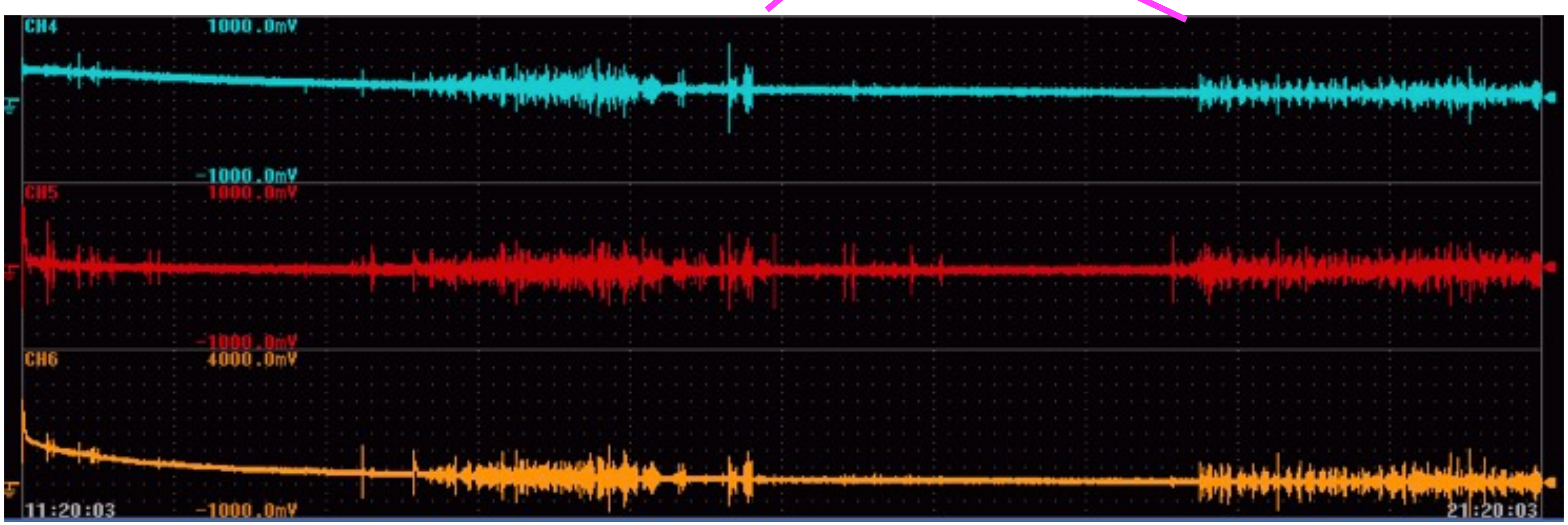
North/South, East/West, Vertical
5mHz ~

Measurement of seismic noise

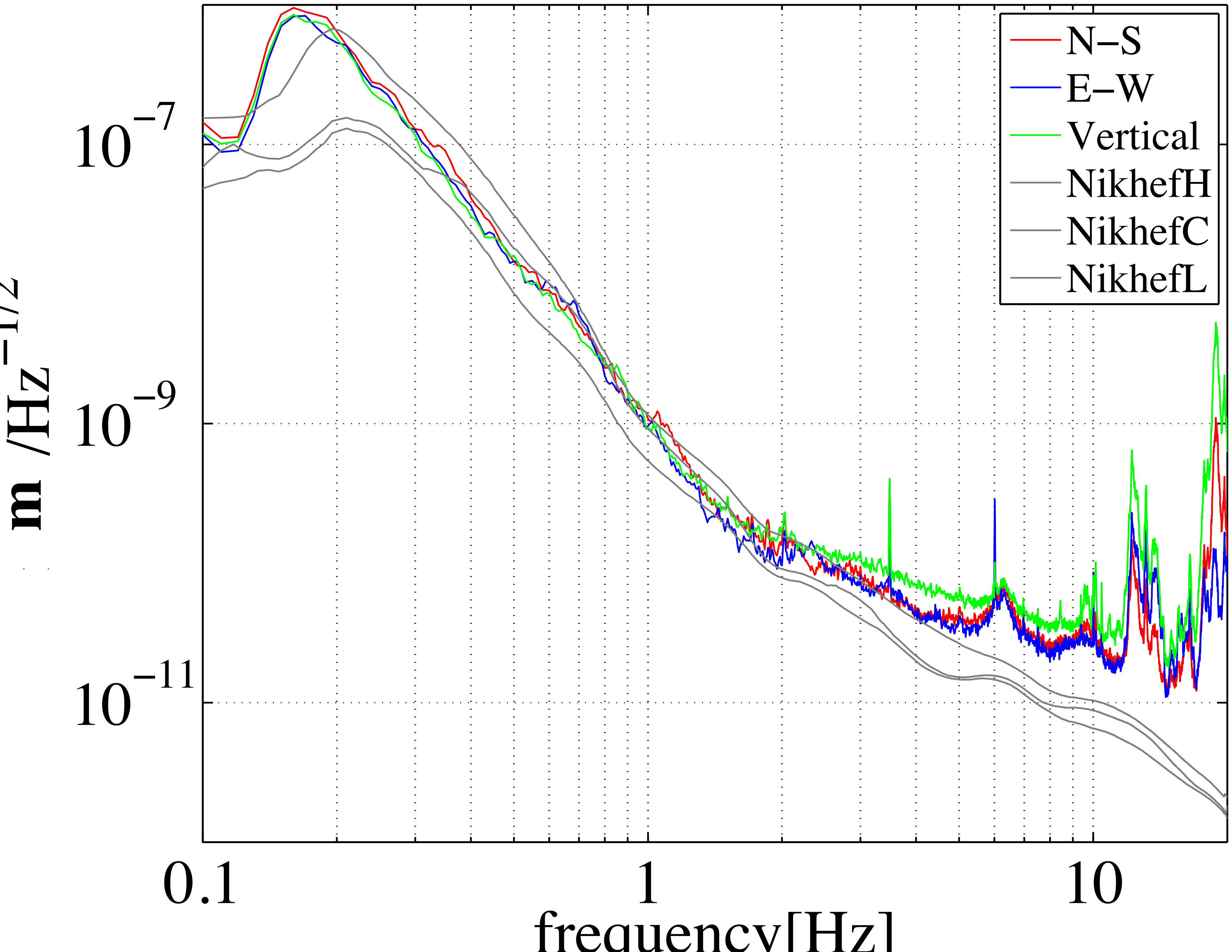
Schedule of excavation of the day



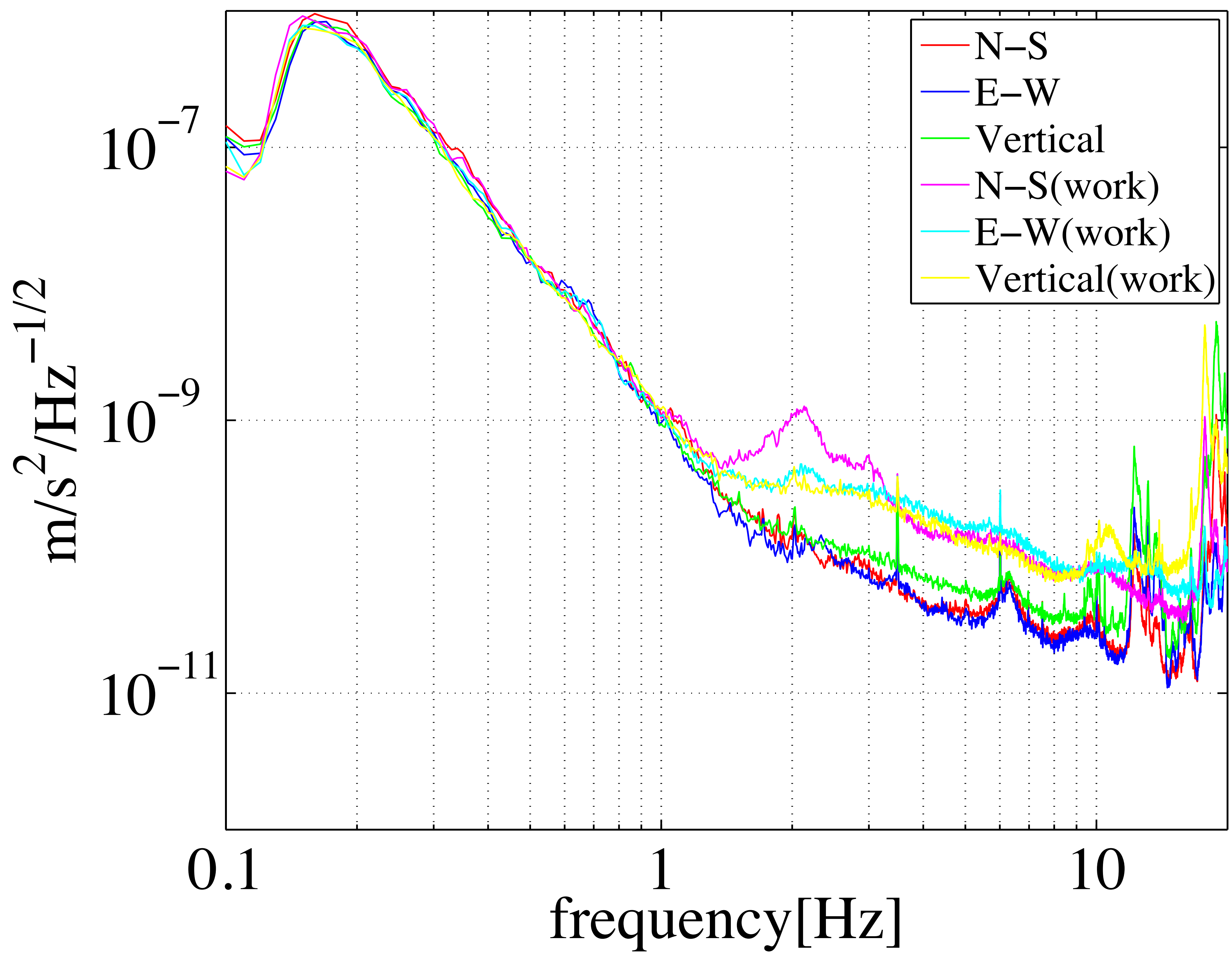
No Work



2013-10-23 Seismic noise at KAGRA 2nd floor.

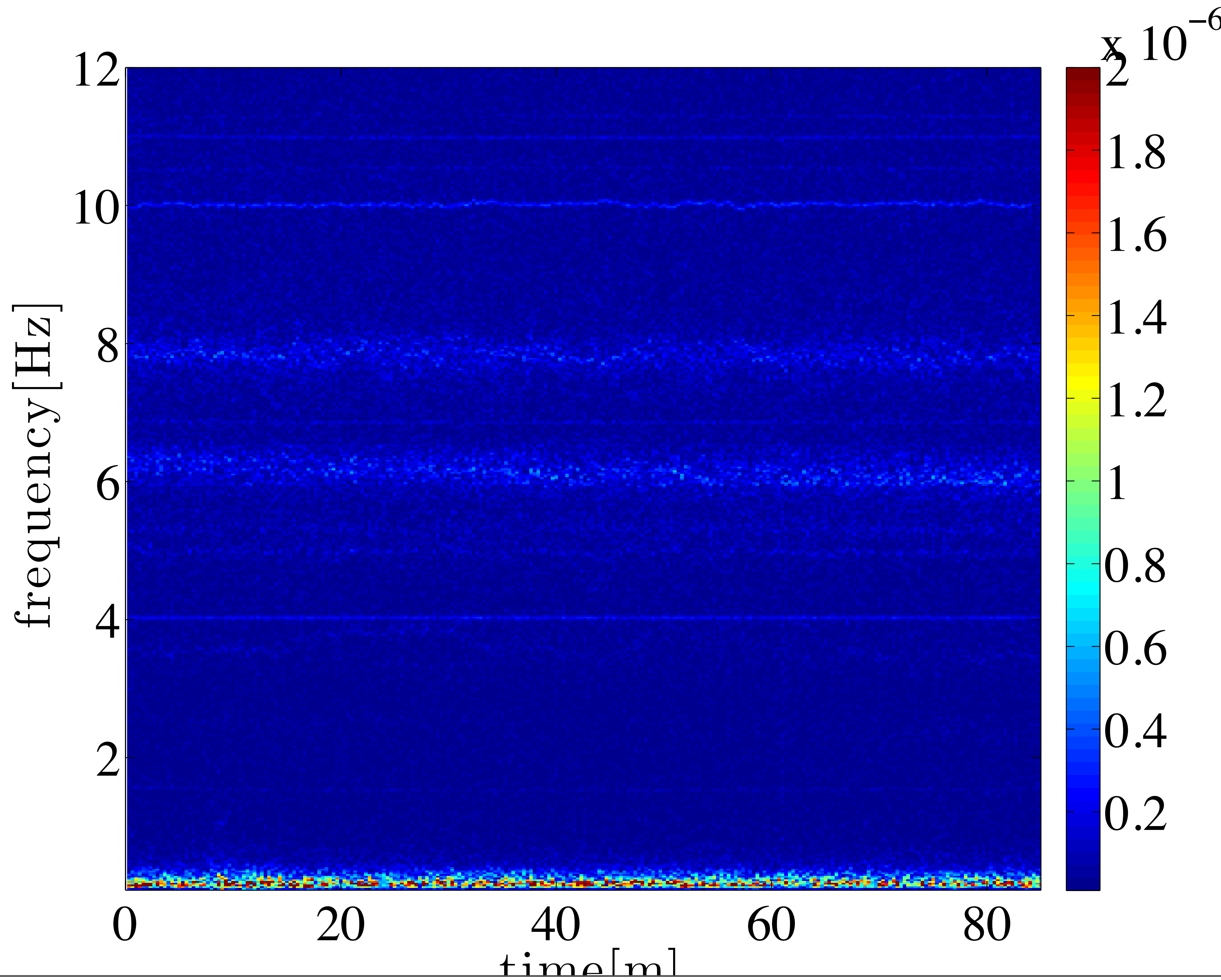


2013-10-23 Seismic noise at KAGRA 2nd floor.

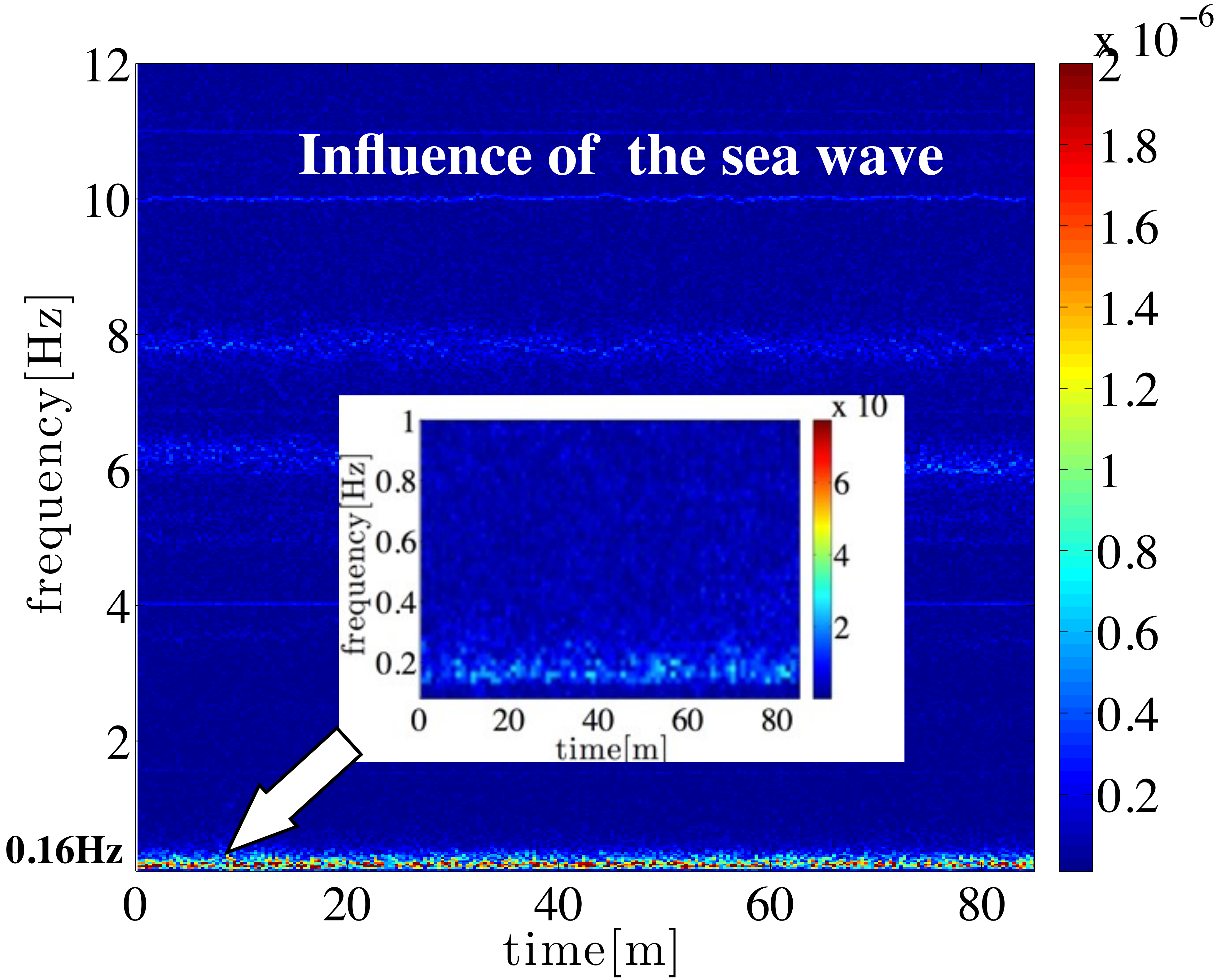


Spectrogram

- **Spectrogram of seismic noise (NS) during the no-work period**



Spectrogram



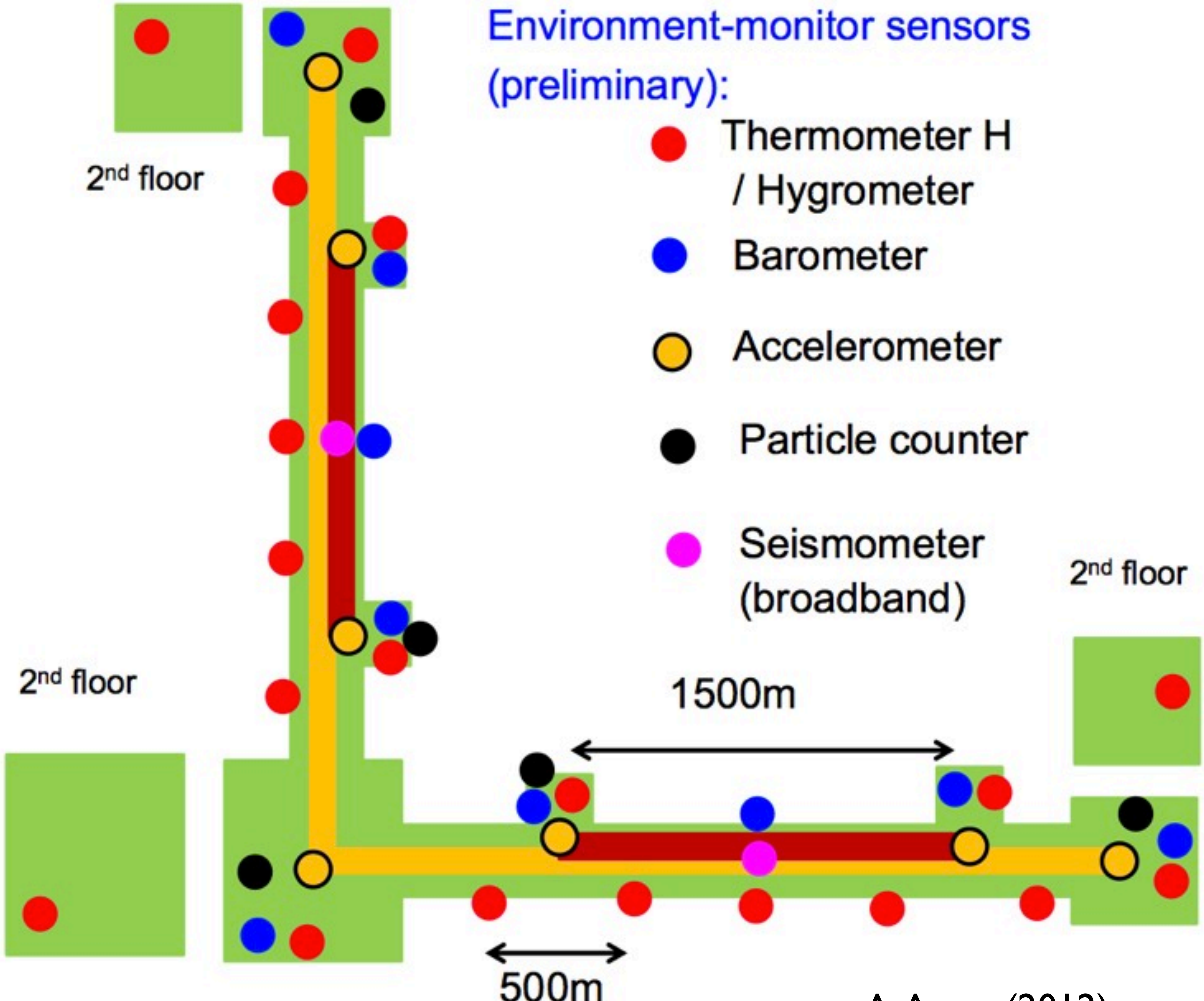
Summary

How are seismic activities

- Below 2Hz, the noise level is consistent with the CLIO site. There is discrepancy at the higher frequency region, we are currently investigating it.
  - The site is still under excavating. We need more measurement when the excavation is completed.
- Nonstationarity:
  - Not bad during no work(85min)
  - we need longer data.

End

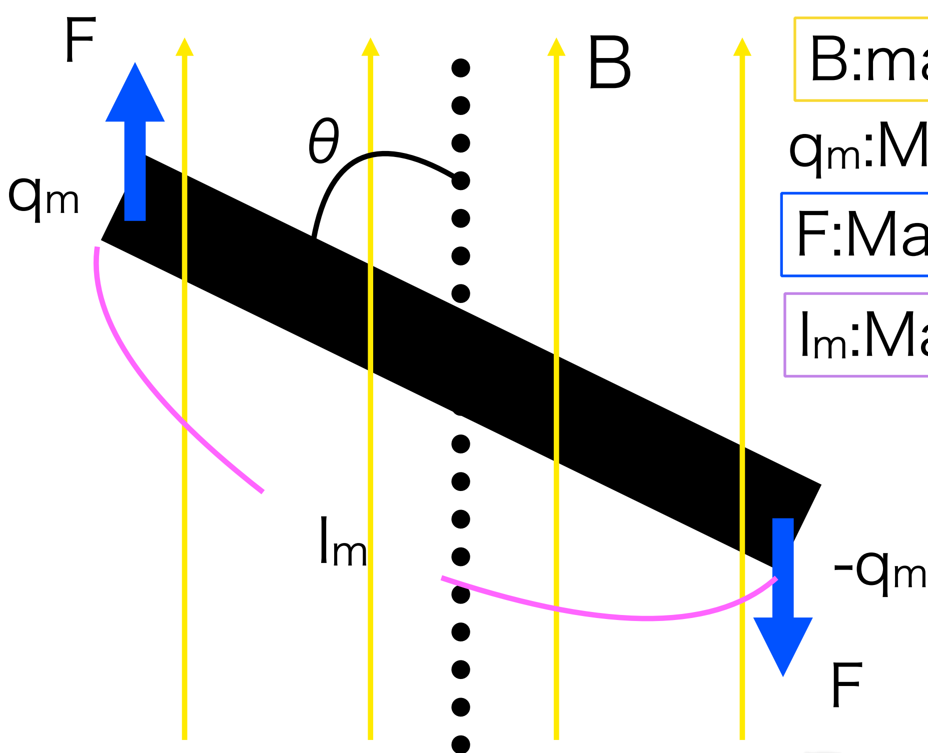
Environmental Monitors



A. Araya (2012)

Moving mirror(upper limit)

Magnet feels "Torque"



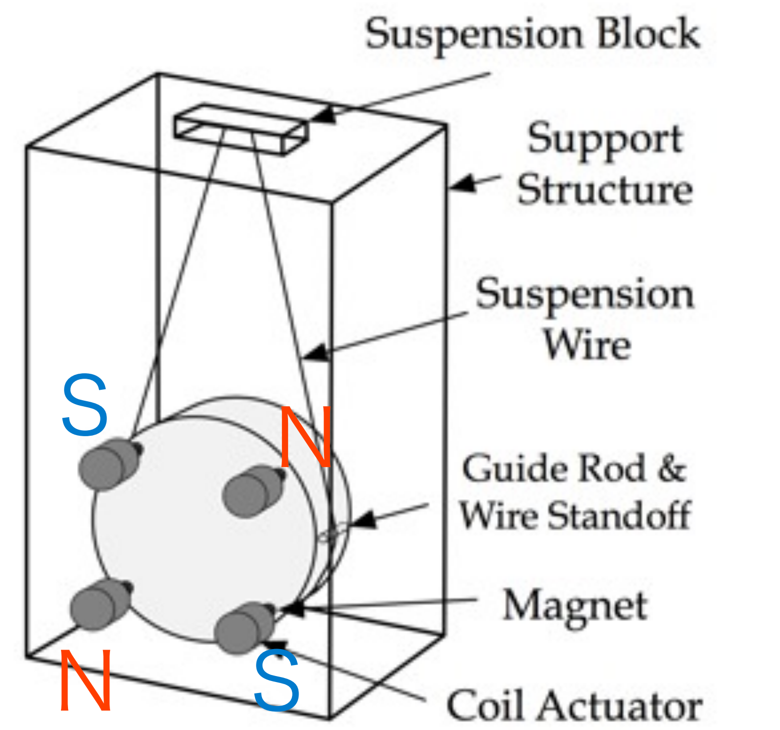
B:magnetic field

q_m:Magnetic charge

F:Magnetic force

l_m:Magnet length

$$F = \frac{q_m}{\mu_0} B$$



$$\mathbf{N} = \mathbf{r} \times \mathbf{F}$$

The number of magnet : 4

$$N = 4\frac{q_m}{\mu_0} l_m B \sin\theta$$

In upper limit, $\sin\theta \sim 1$

EOM of rotation

$$I\frac{\partial^2 \phi}{\partial t^2} = -k\phi + 4\frac{q_m l_m}{\mu_0} B$$

↓ Fourier transformation and Simplify

$$|\tilde{\phi}| = \frac{q_m l_m}{I\pi^2 \mu_0} \frac{1}{f^2 - f_{res}^2} |\tilde{B}|$$

I : moment of inertia

ω : angular velocity

$L = I\omega$: angular momentum

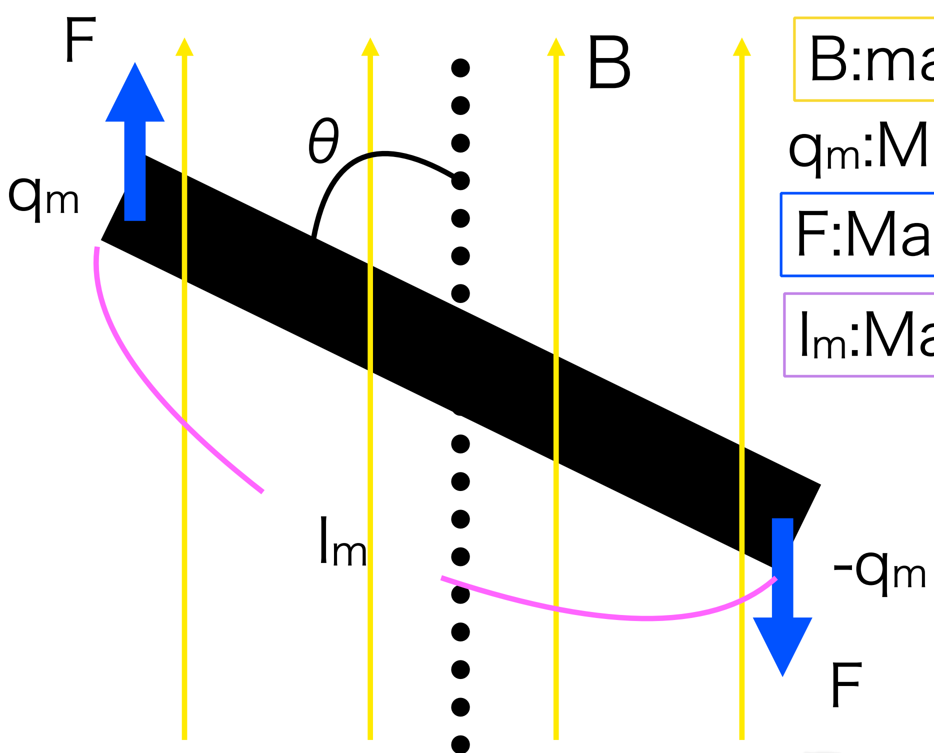
k : coefficient of resilience of mirror

$f_{res} = \frac{1}{2\pi}\sqrt{\frac{k}{I}}$

Ono

Moving mirror(upper limit)

Magnet feels “Torque”



B:magnetic field

q_m:Magnetic charge

F:Magnetic force

l_m:Magnet length

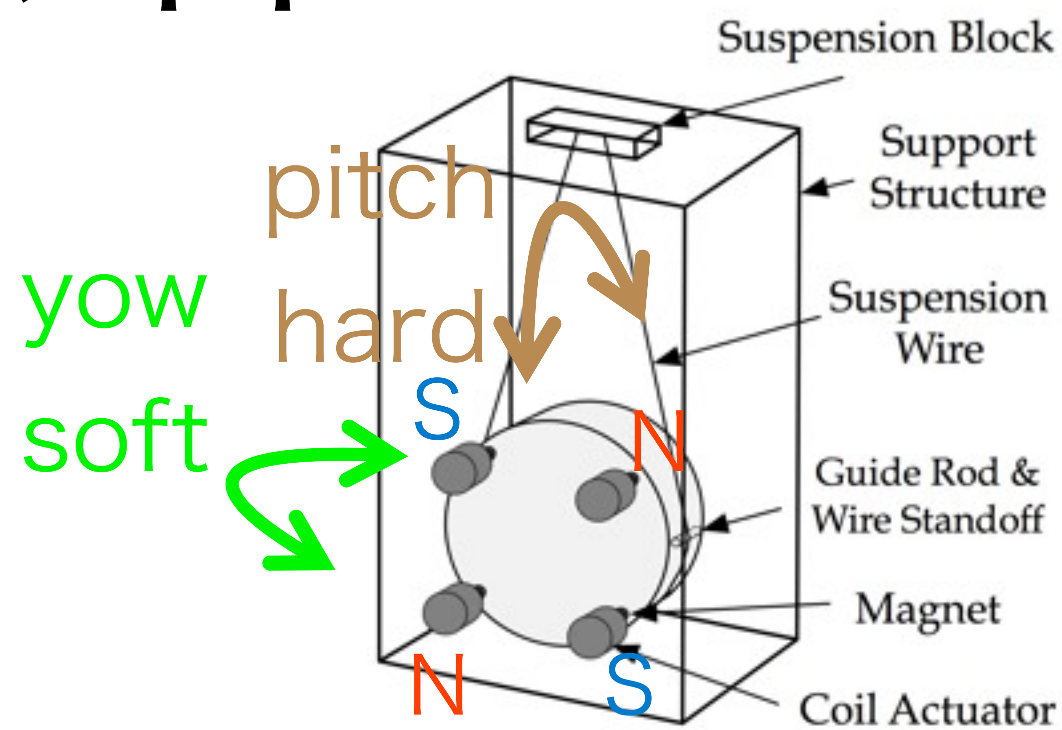
$$F = \frac{q_m}{\mu_0} B$$

$$\mathbf{N} = \mathbf{r} \times \mathbf{F}$$

The number of magnet : 4

$$N = 4\frac{q_m}{\mu_0} l_m B \sin\theta$$

In upper limit, $\sin\theta \sim 1$



EOM of rotation

$$I\frac{\partial^2 \phi}{\partial t^2} = -k\phi + 4\frac{q_m l_m}{\mu_0} B$$

↓ Fourier transformation and Simplify

$$|\tilde{\phi}| = \frac{q_m l_m}{I\pi^2 \mu_0} \frac{1}{f^2 - f_{res}^2} |\tilde{B}|$$

I : moment of inertia $L = I\omega$: angular momentum

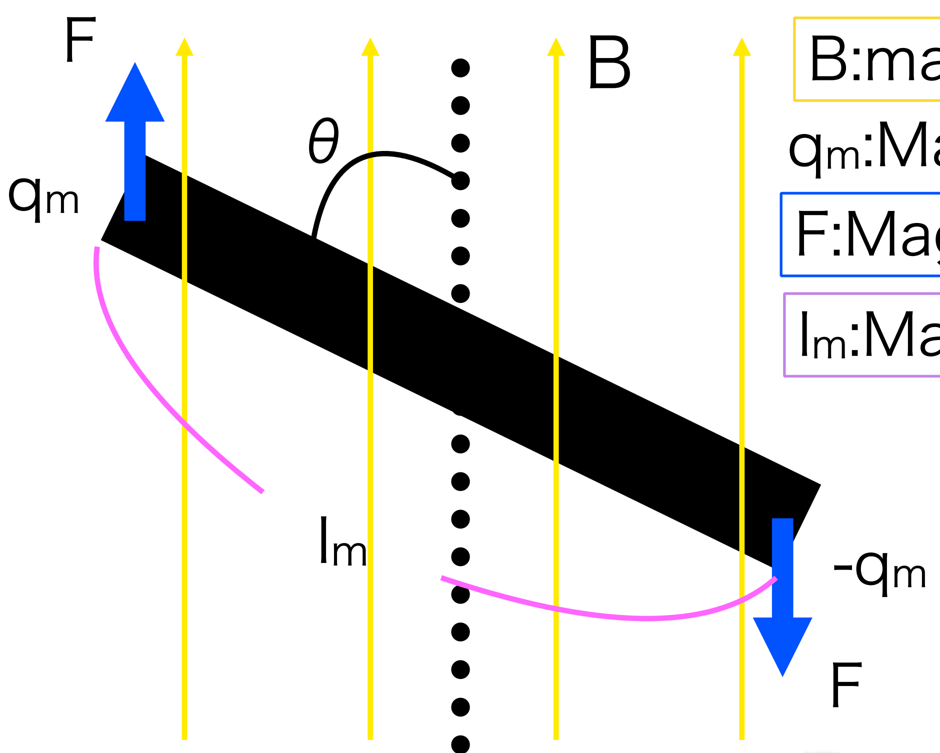
ω : angular velocity k : coefficient of resilience of mirror

$f_{res} = \frac{1}{2\pi}\sqrt{\frac{k}{I}}$

Ono

Moving mirror(upper limit)

Magnet feels “Torque”



B:magnetic field

q_m:Magnetic charge

F:Magnetic force

l_m:Magnet length

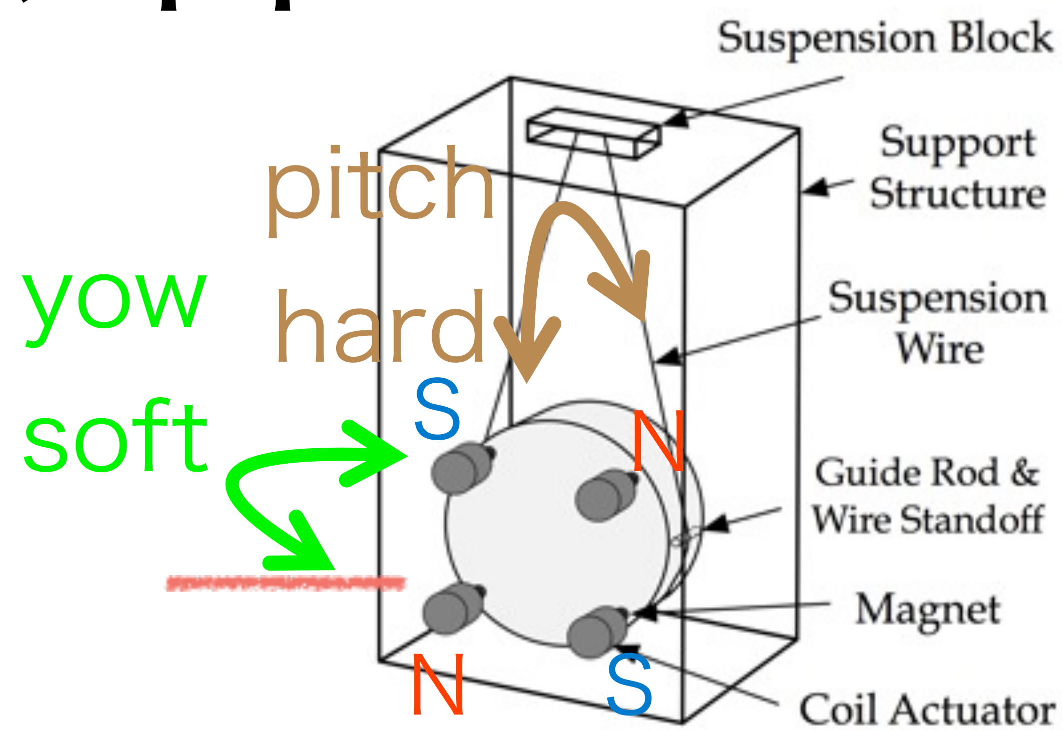
$$F = \frac{q_m}{\mu_0} B$$

$$\mathbf{N} = \mathbf{r} \times \mathbf{F}$$

The number of magnet : 4

$$N = 4 \frac{q_m}{\mu_0} l_m B \sin\theta$$

In upper limit, $\sin\theta \sim 1$



EOM of rotation

$$I \frac{\partial^2 \phi}{\partial t^2} = -k\phi + 4 \frac{q_m l_m}{\mu_0} B$$

↓ Fourier transformation and Simplify

$$|\tilde{\phi}| = \frac{q_m l_m}{I \pi^2 \mu_0} \frac{1}{f^2 - f_{res}^2} |\tilde{B}|$$

I : moment of inertia $\quad L = I\omega$: angular momentum

ω : angular velocity $\quad k$: coefficient of resilience of mirror

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{k}{I}}$$

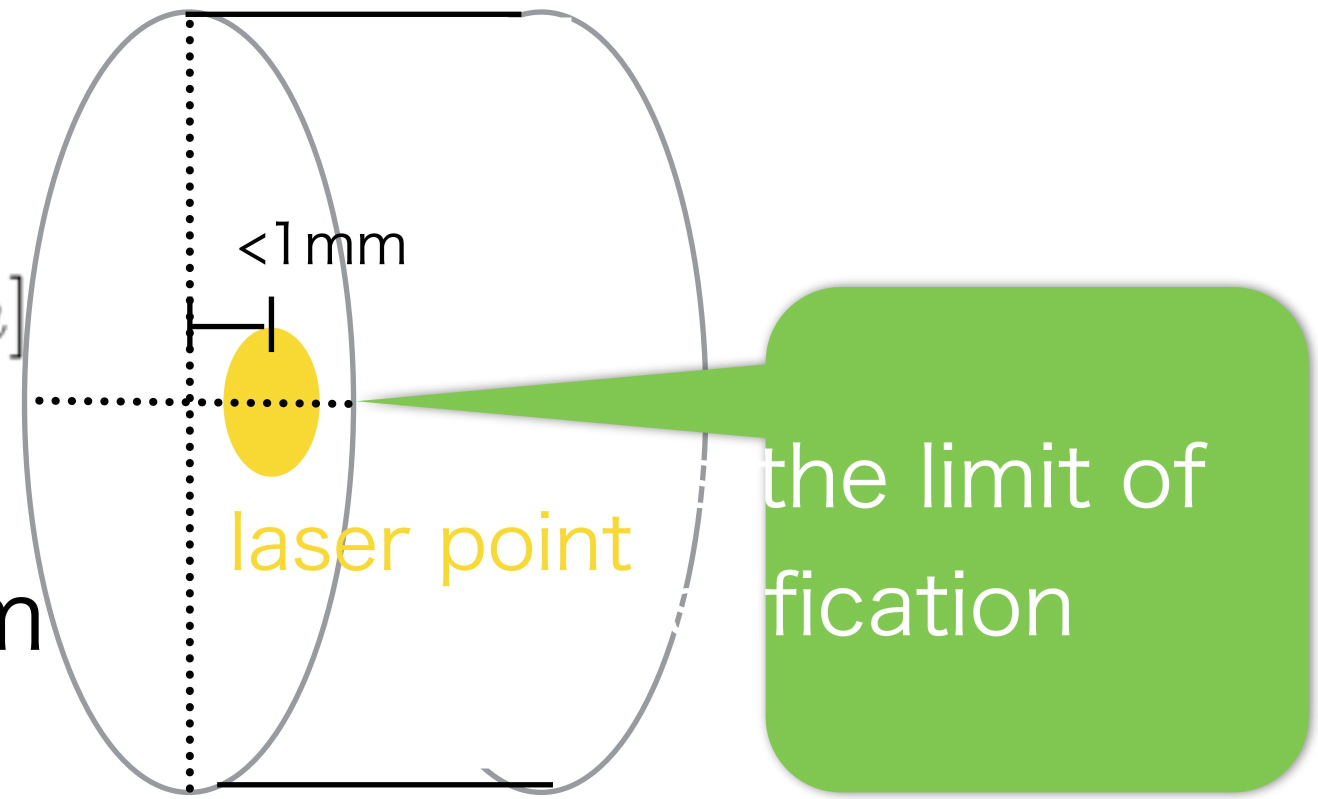
Ono

How much does the magnetic field affect for sensitivity?

Displacement of optical path length is $10^{-3}\phi[m]$

Optical path length:3000m

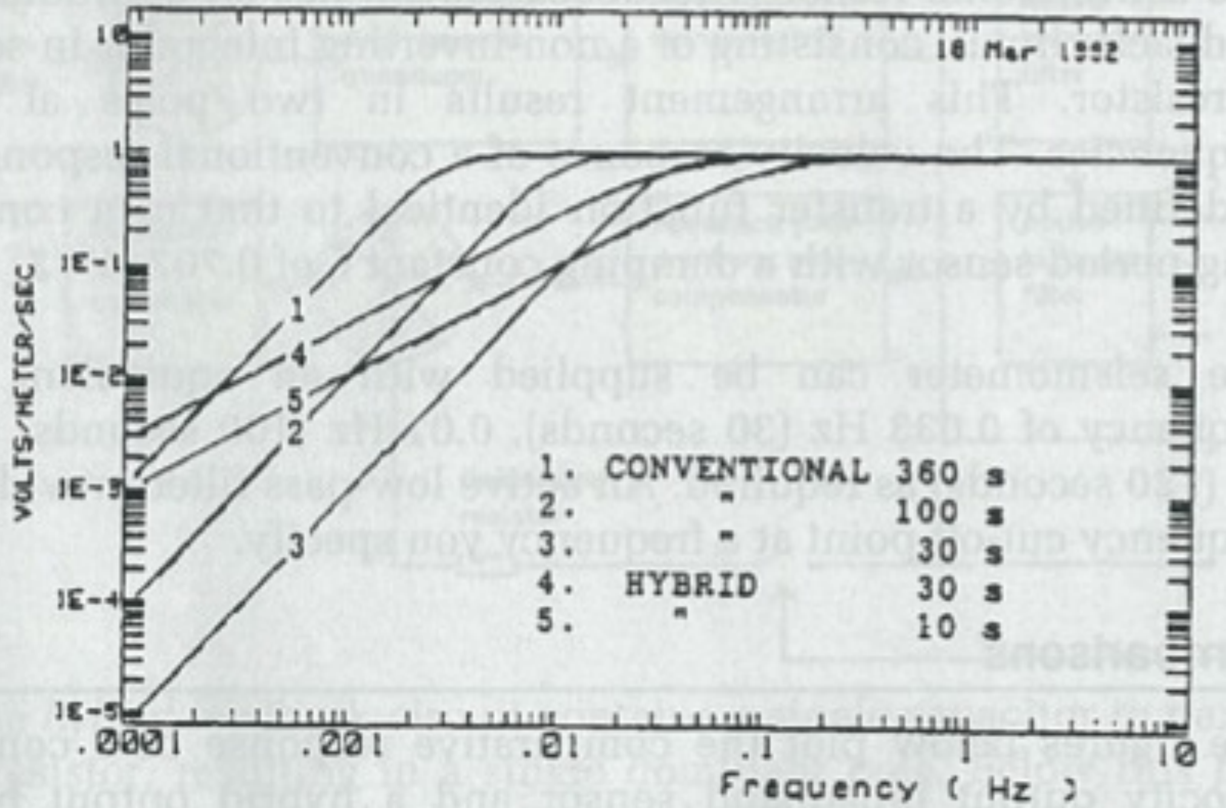
the number of mirror:4



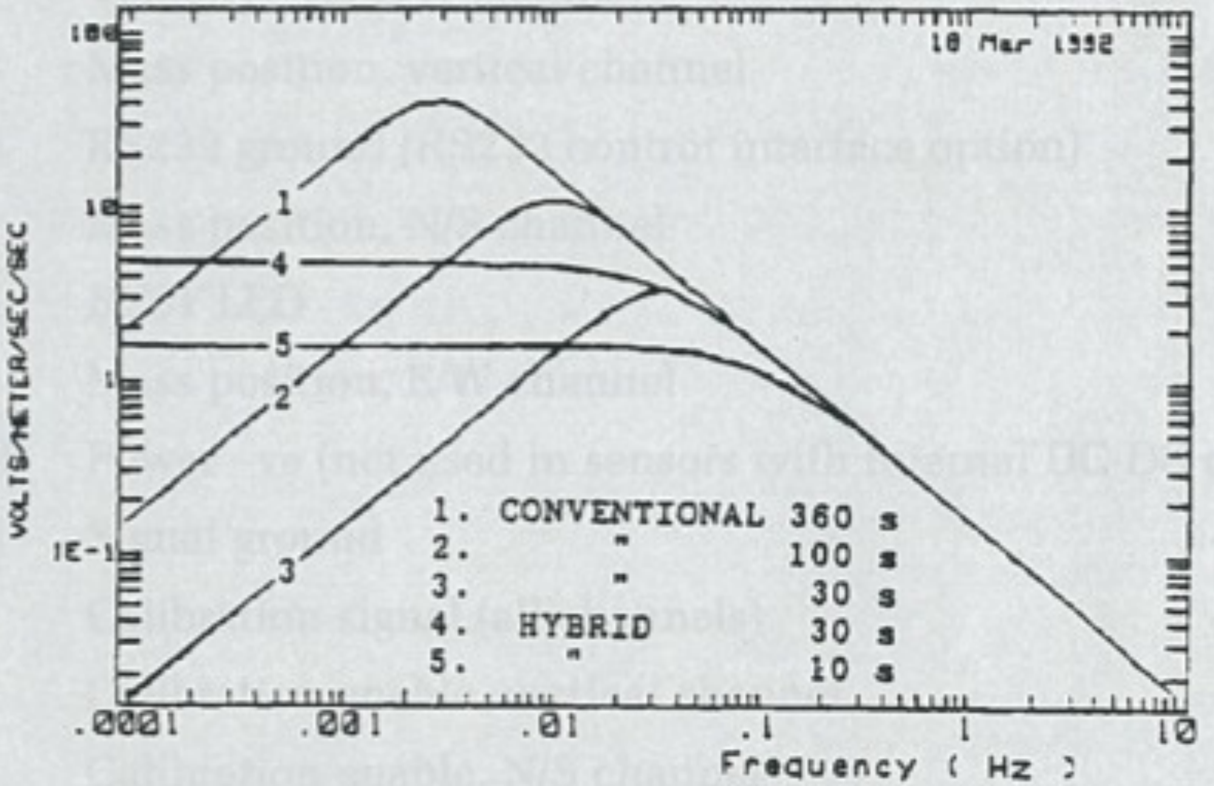
$$h_{\mathrm{magnetic\ \ noise}} = \frac{2}{3}10^{-6}\frac{q_m l_m}{I\pi^2\mu_0}\frac{1}{f^2 - f_{res}^2}|\tilde{B}|\ [1/\sqrt{\mathrm{Hz}}]$$

Ono

Seismometer Frequency Response



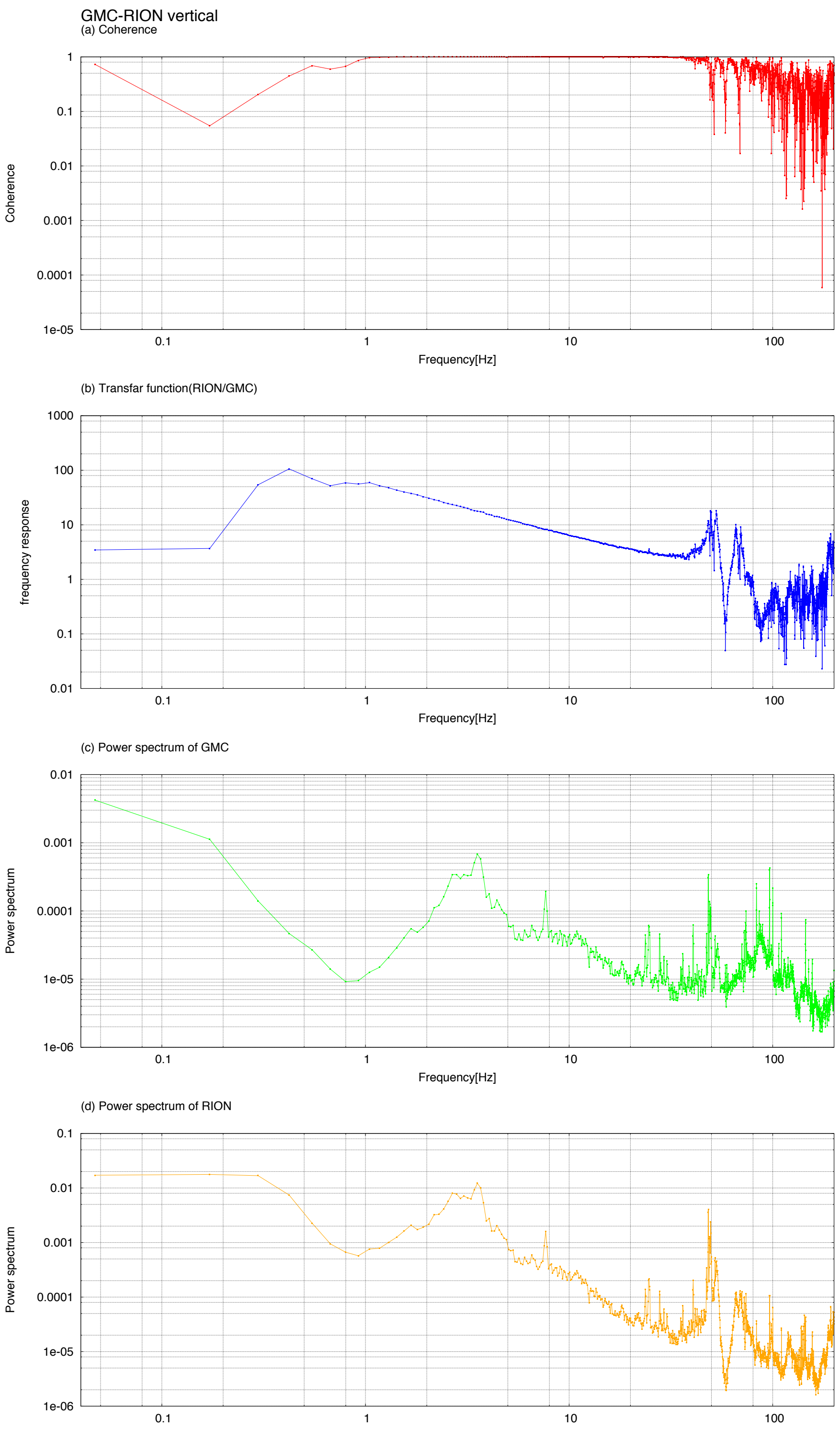
Relative Responses to Ground Velocity.



Relative Responses to Ground Acceleration.

comparison of RION and CMG 3T

horizon



vertical