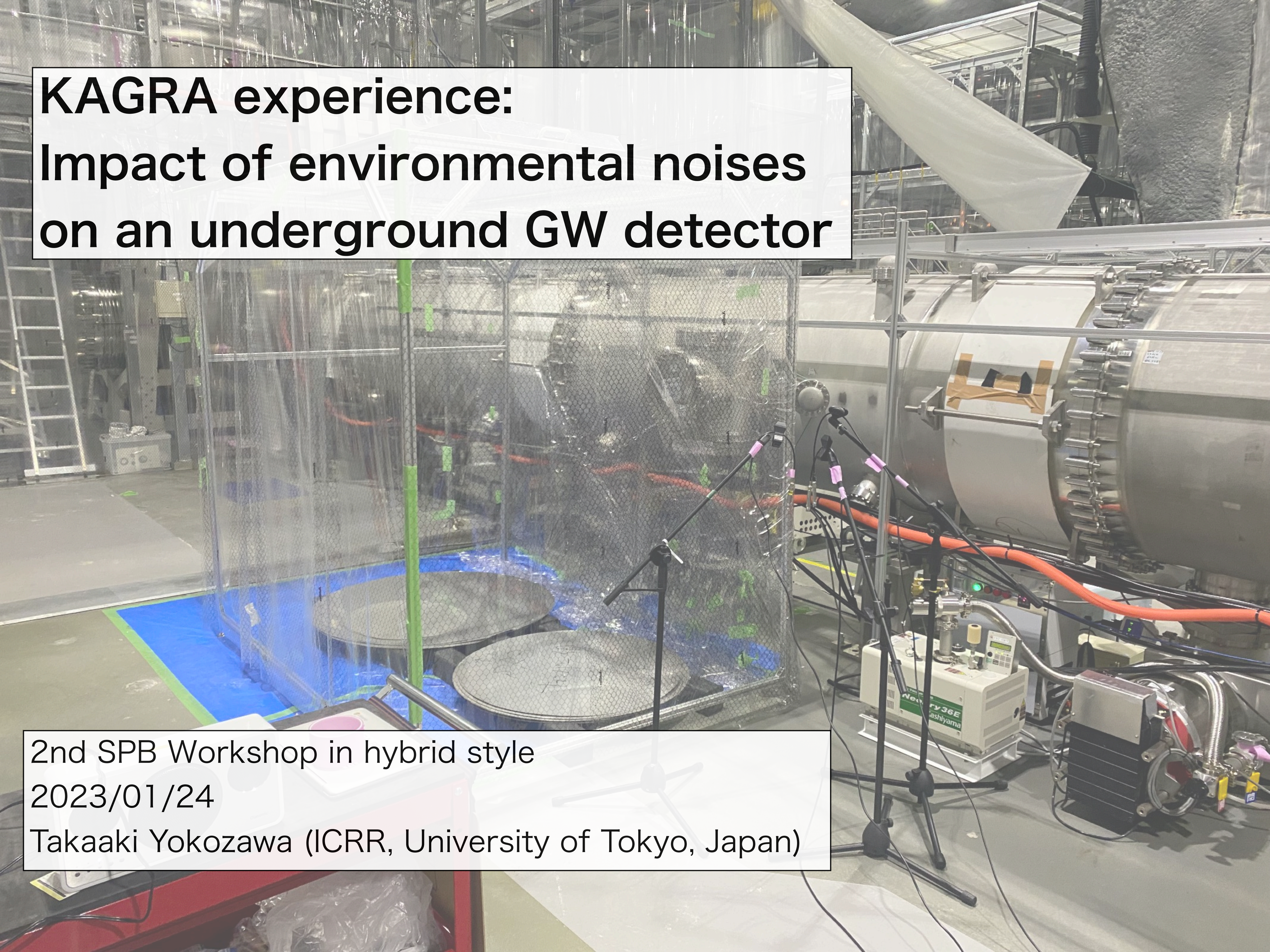
KAGRA experience: Impact of environmental noises on an underground GW detector



2nd SPB Workshop in hybrid style

2023/01/24

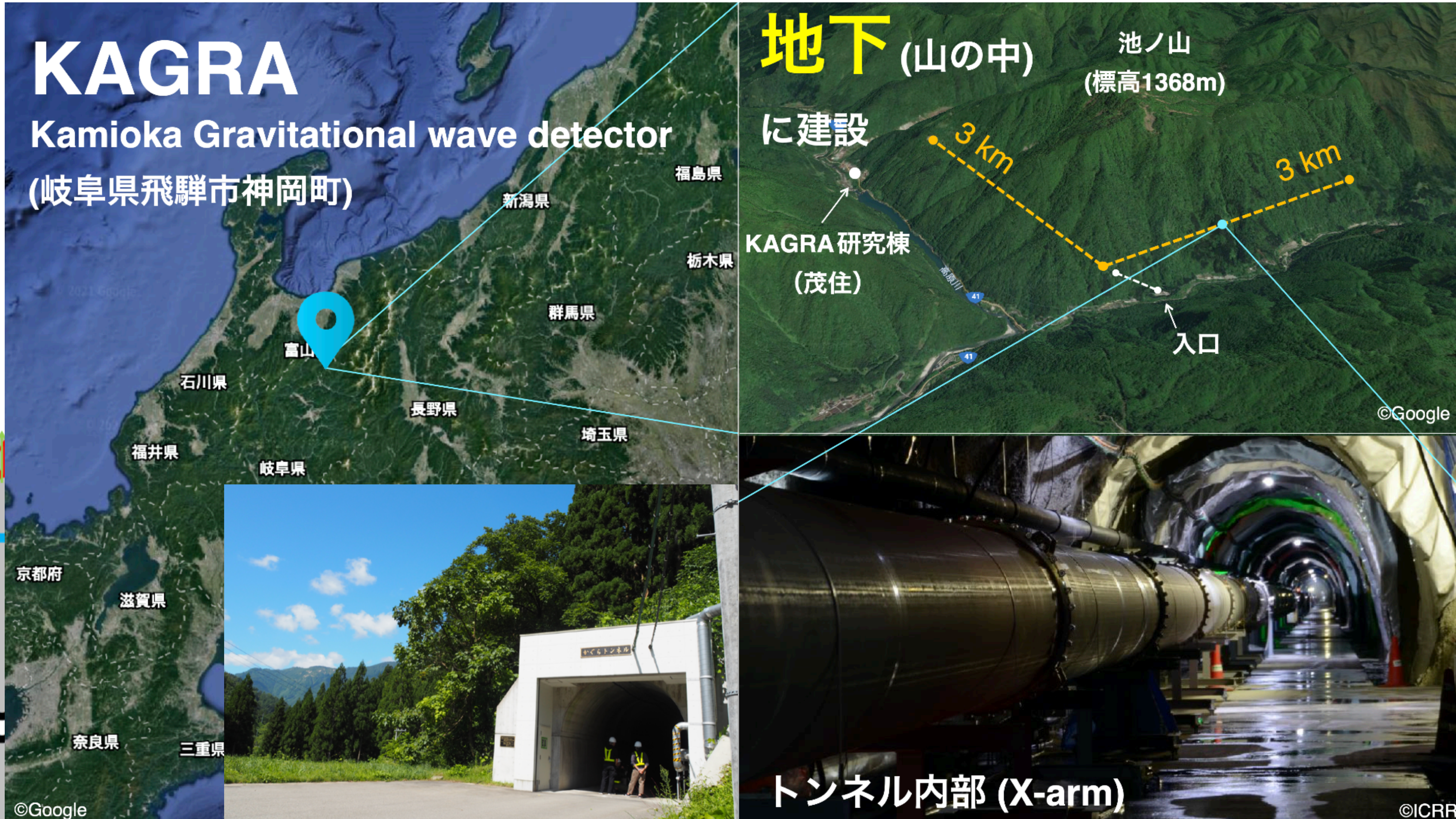
Takaaki Yokozawa (ICRR, University of Tokyo, Japan)

Contents

- Current status of KAGRA experiment (Brief explanation)
  - Upgrade toward the O4
- Underground facility (5 minutes)
  - Good point, difficult point
- KAGRA physical environmental monitors (15 minutes)
  - Past results, ongoing project, future prospect

- Information how to read the JGWDoc
  - https://dcc.ligo.org/LIGO-L2000007
- Infrastructure noise by T.Washimi
  - https://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/private/DocDB/ShowDocument?docid=14176
- KAGRA facility
  - https://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/private/DocDB/ShowDocument?docid=8224

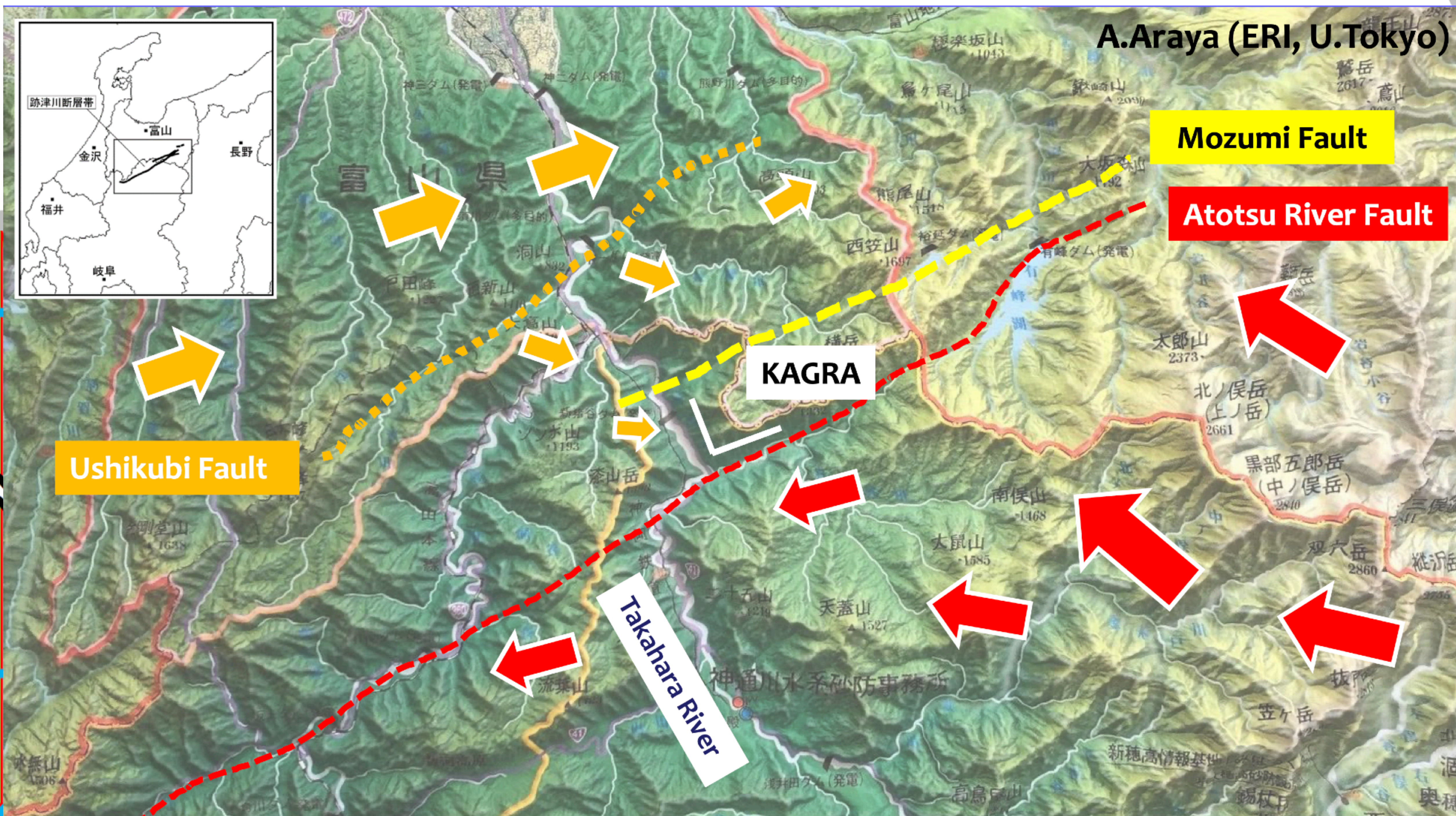
KAGRA detector



- KAGRA (Large(3 km) Cryogenic Gravitational wave Telescope, Japan)
  - Underground experiment
  - Cryogenic experiment

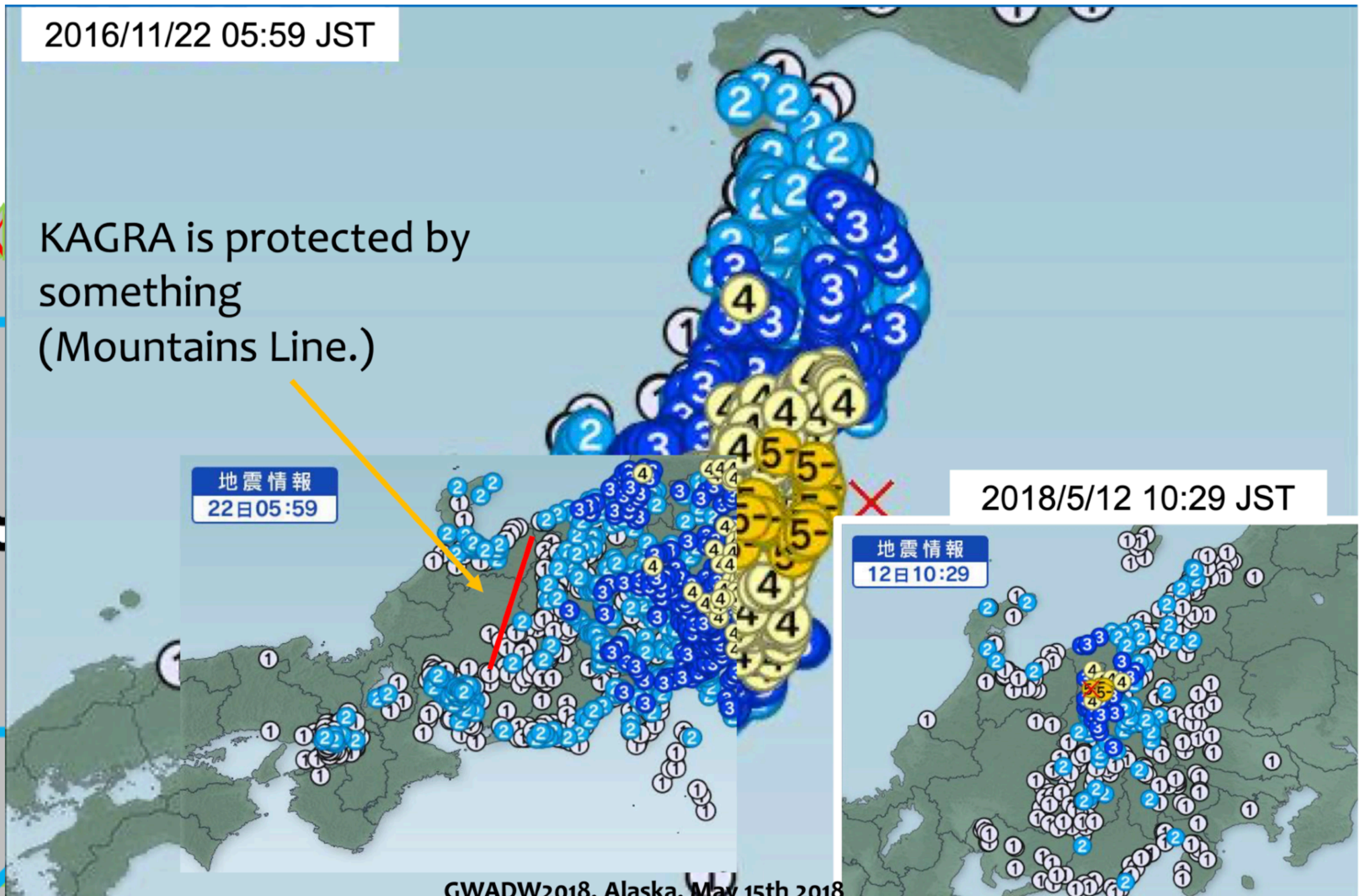
KAGRA facility

- Picked up several interesting topics about KAGRA underground facilities
  - Same mountain with Super Kamiokande, KamLAND, CLIO, …
  - Near the Mozumi and Atotsu River Faults



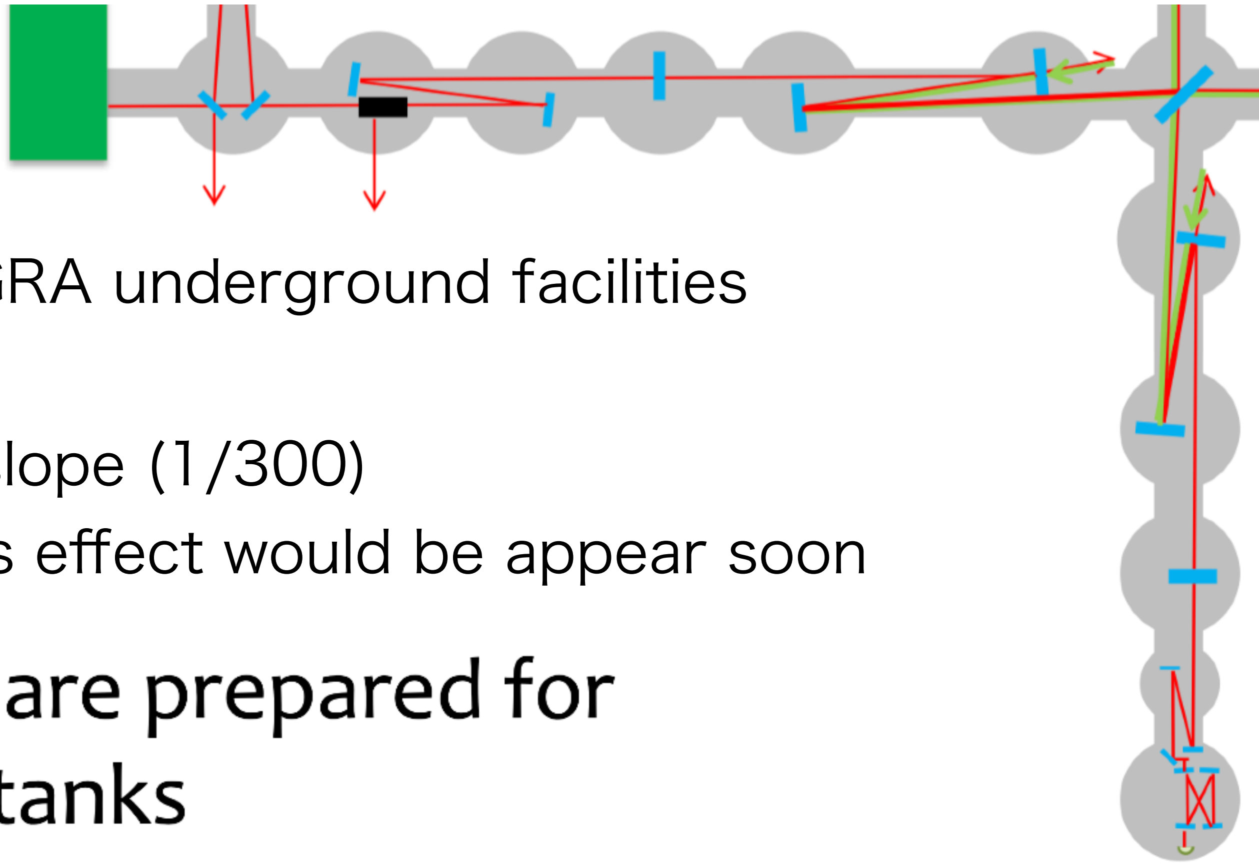
KAGRA facility

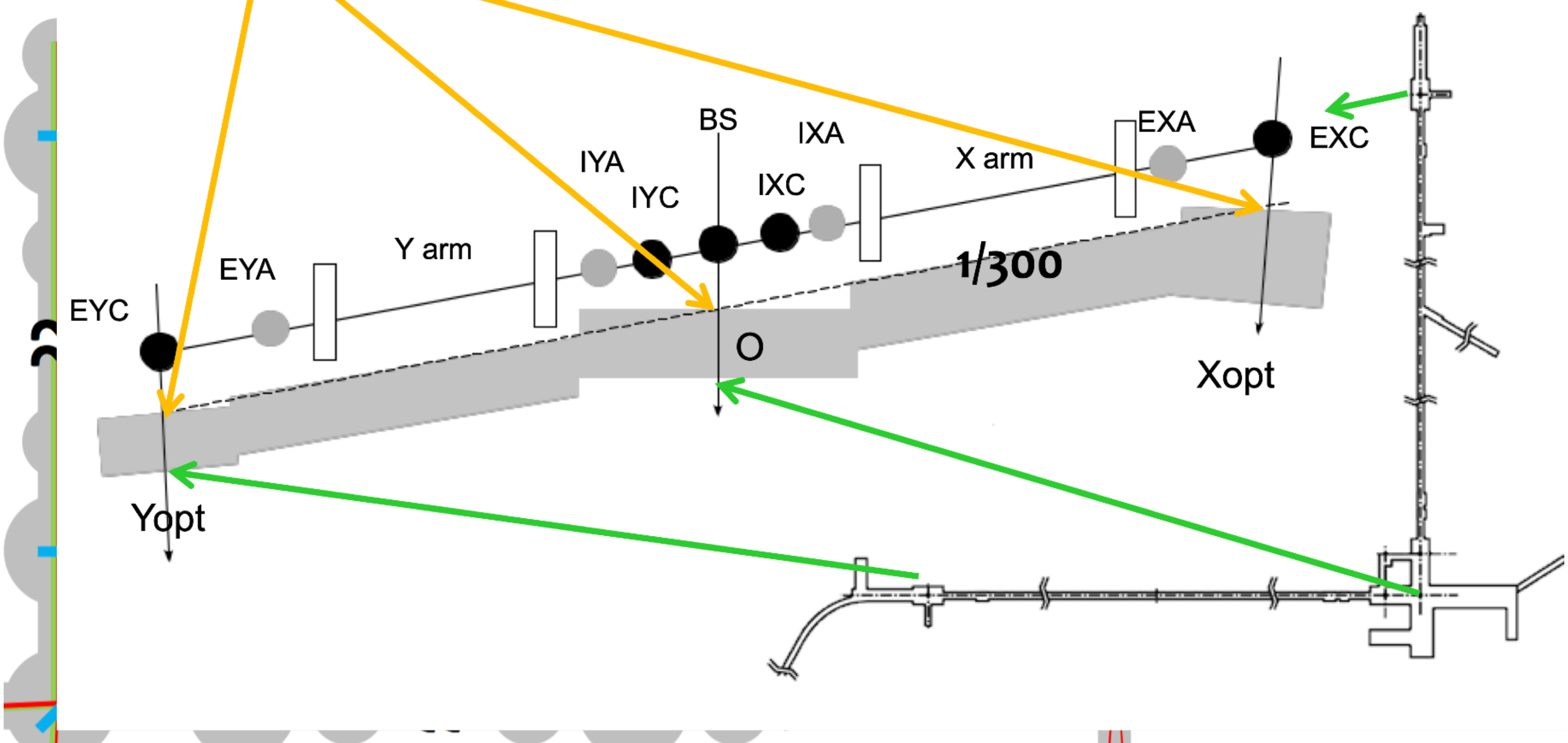
- Picked up several interesting topics about KAGRA underground facilities
  - (Fortunately?) the effect of earthquake would be smaller compared with other Japan area, would be protected by mountains line?
    - From the simulation, low-density(low-velosity) area exit in Hida area



KAGRA facility

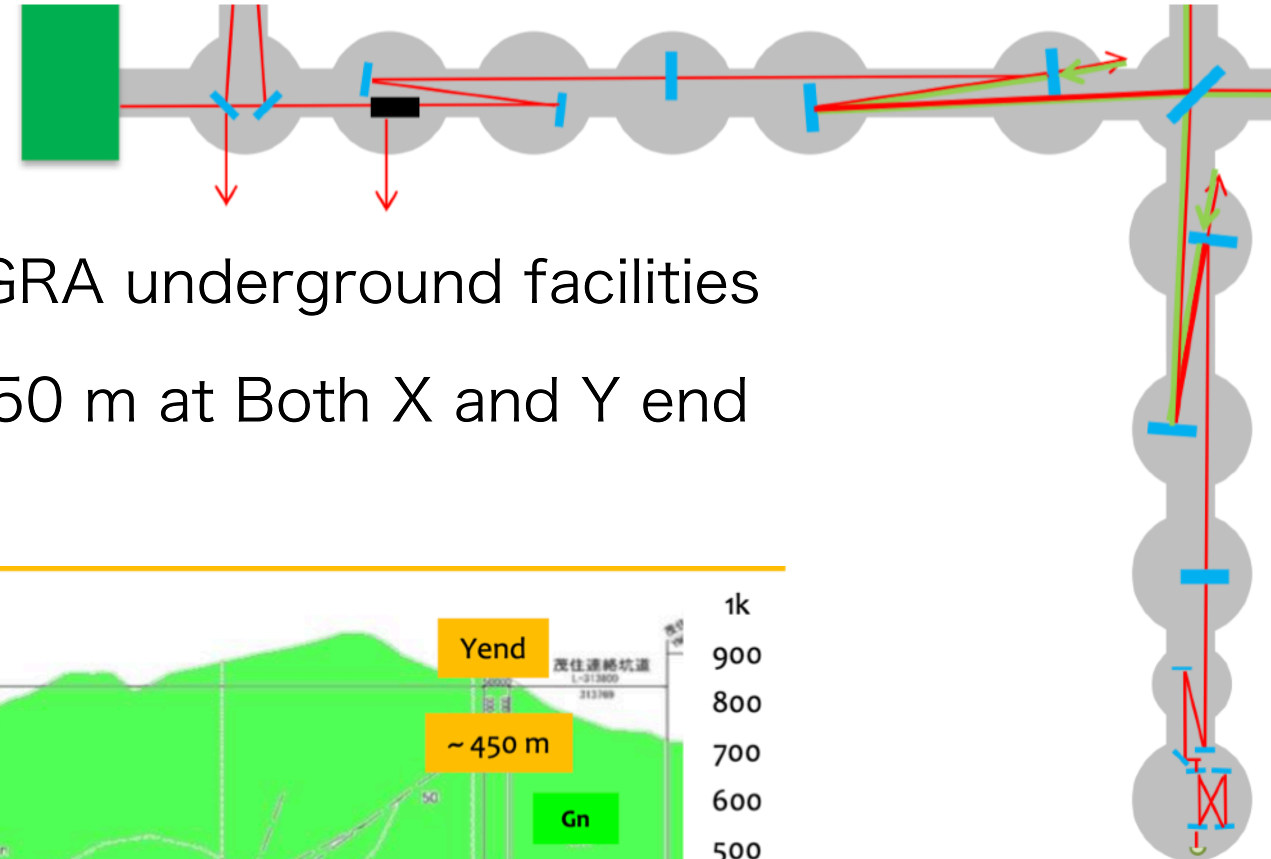
- Picked up several interesting topics about KAGRA underground facilities
  - For draining off the spring water, there are slope (1/300)
    - The more detail of the water drain and its effect would be appear soon
- Horizontal planes for each station are prepared for easiness during installing vacuum tanks

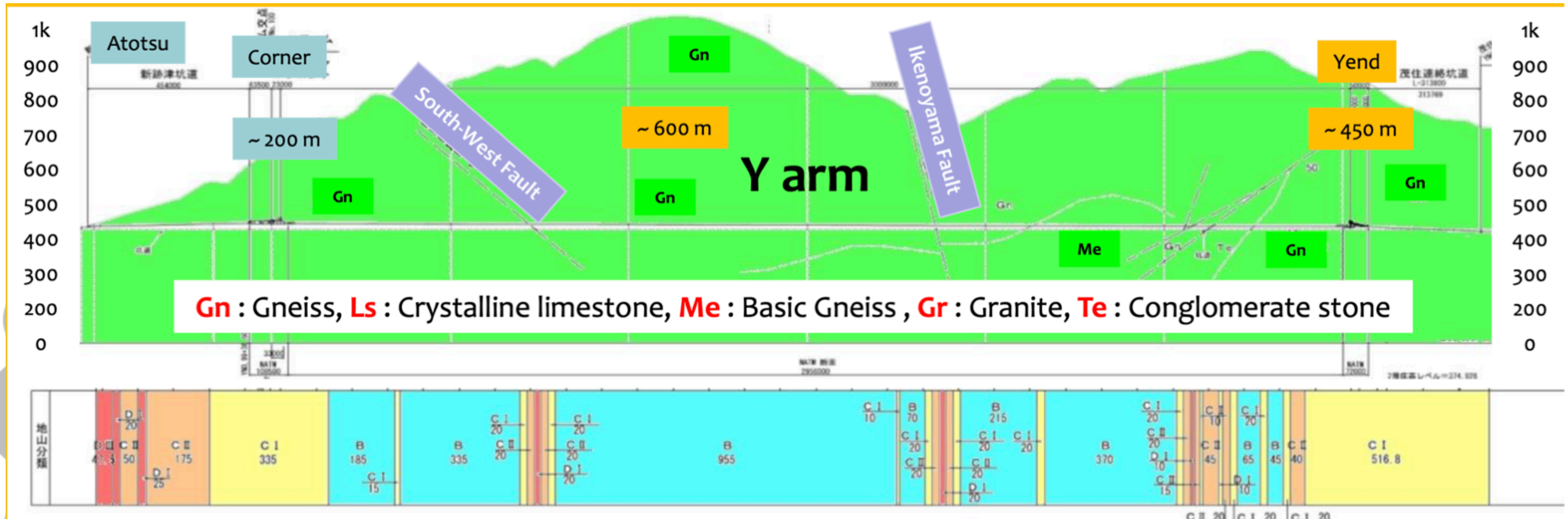


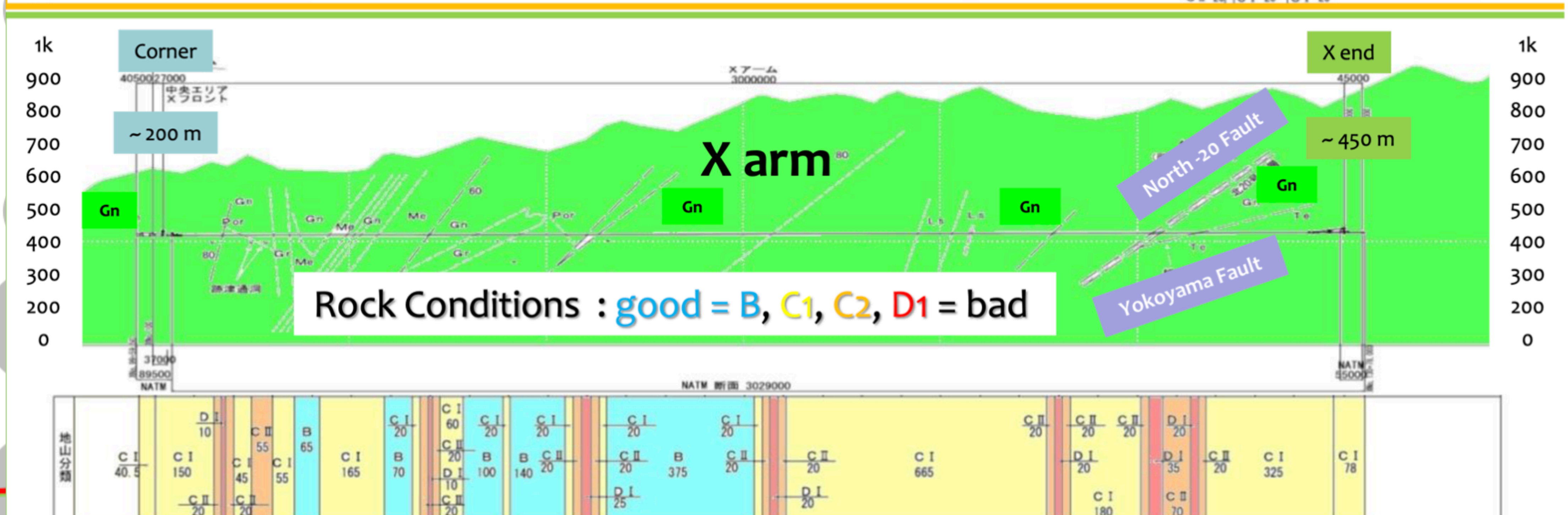


KAGRA facility

- Picked up several interesting topics about KAGRA underground facilities
  - Center area is about 200 m underground, 450 m at Both X and Y end
    - Yend area is close to the dam

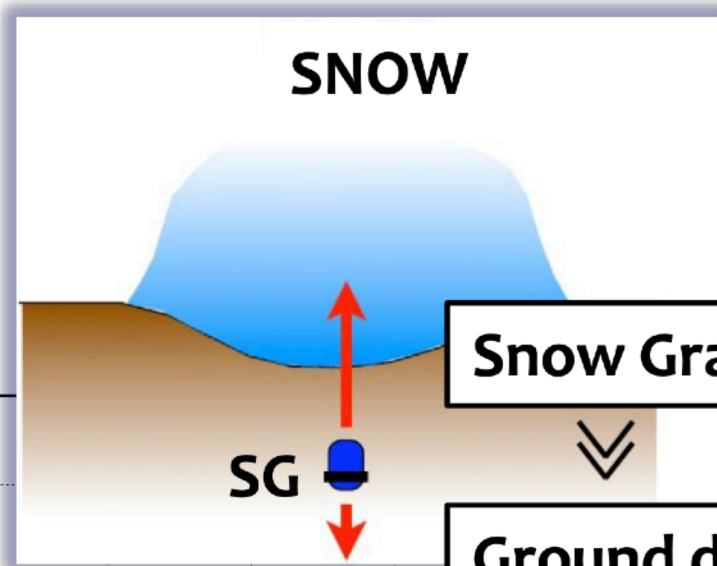




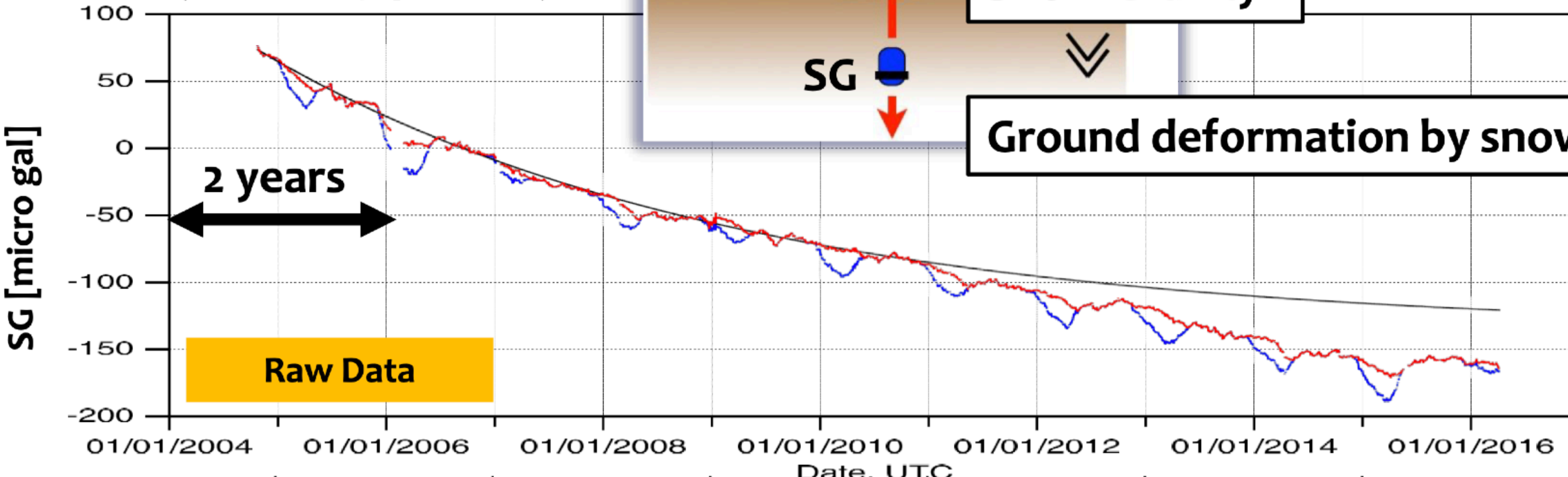


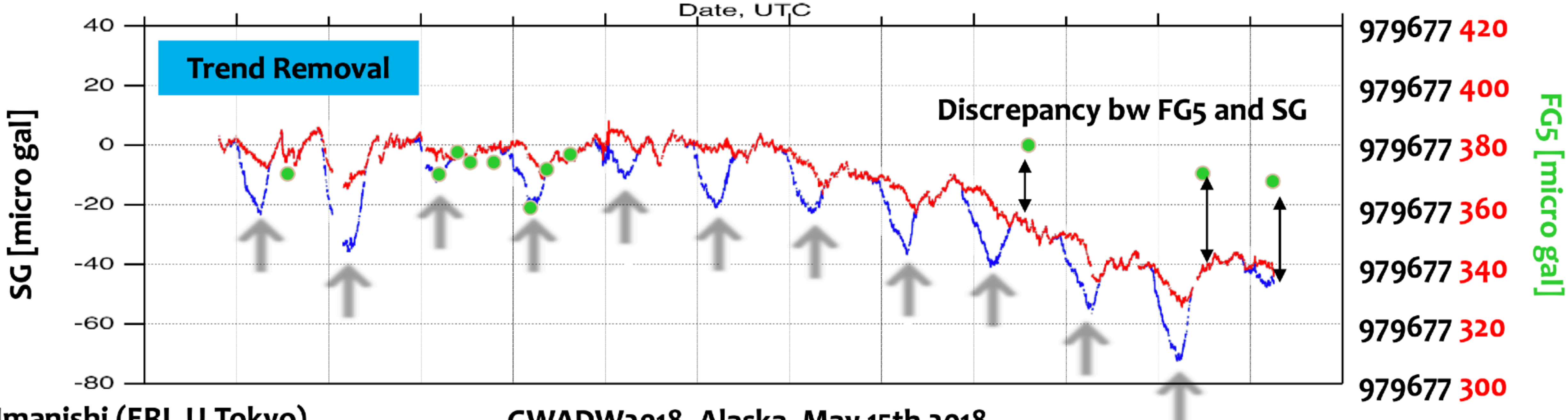
Gravity change by snow

Superconductive Gravity Meter (SG)
In the same mountain With KAGRA
(relatively precise)



Absolute Gravity Meter (FG5)





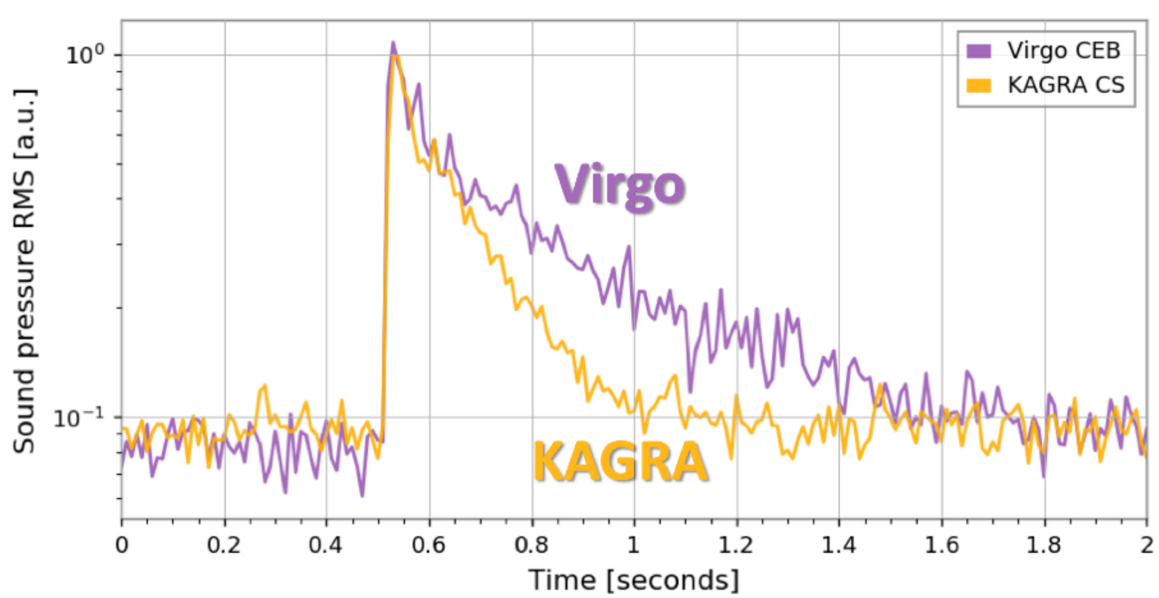
KAGRA facility

- Picked up several interesting topics about KAGRA underground facilities
    - Temperature control
        - Underground environment is more stable than surface, but need costs to keep the temperature: Strongly depending on the working instruments
        - Set many temperature monitors
    - AC/DC power supply
        - Generated DC ±18 V and 24 V at the digital room (outside of experimental area) and bring to inside the experimental area
    - GND issue
        - Difficult to set the earth in underground environment
            - Set outside near the Yend station and connect to center and Xend
            - Search the possible ground at center area

- From now, we presented the status of KAGRA environmental noise investigation, evaluation, and ongoing works
- I cannot explain the result in detail, but if you have interested in each topic, please contact to Yokozawa and Washimi-san

Acoustic reverberation time

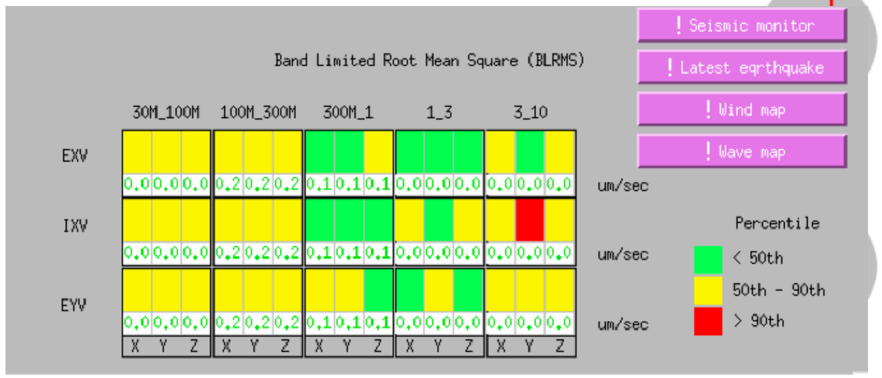
- Reverberation time (decaying time of impulse sound) in the KAGRA site is much shorter than that of LIGO and Virgo
  - Difference in the inner surface of the wall
  - The original aim of this KAGRA's wall design was just to save cost and time

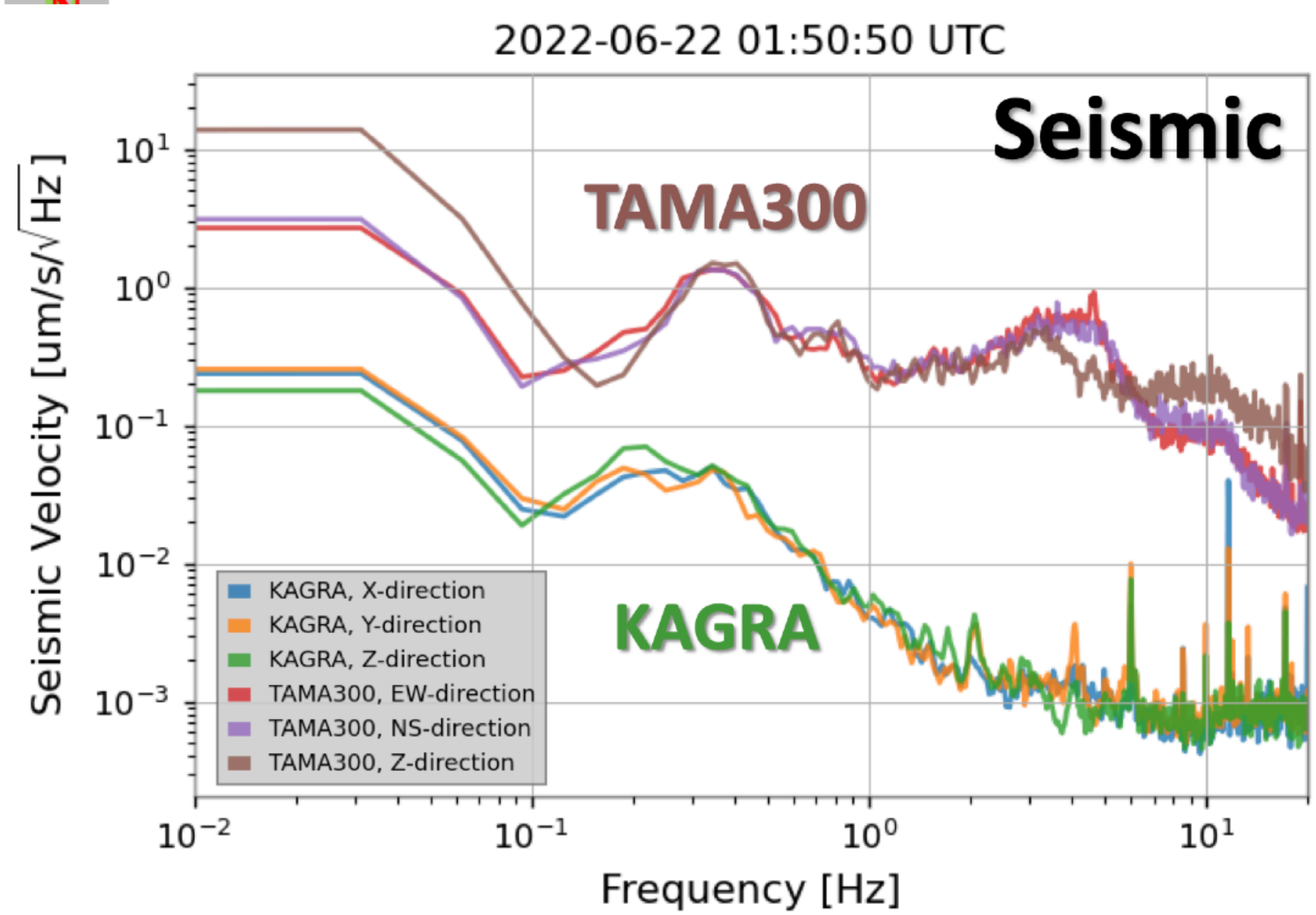


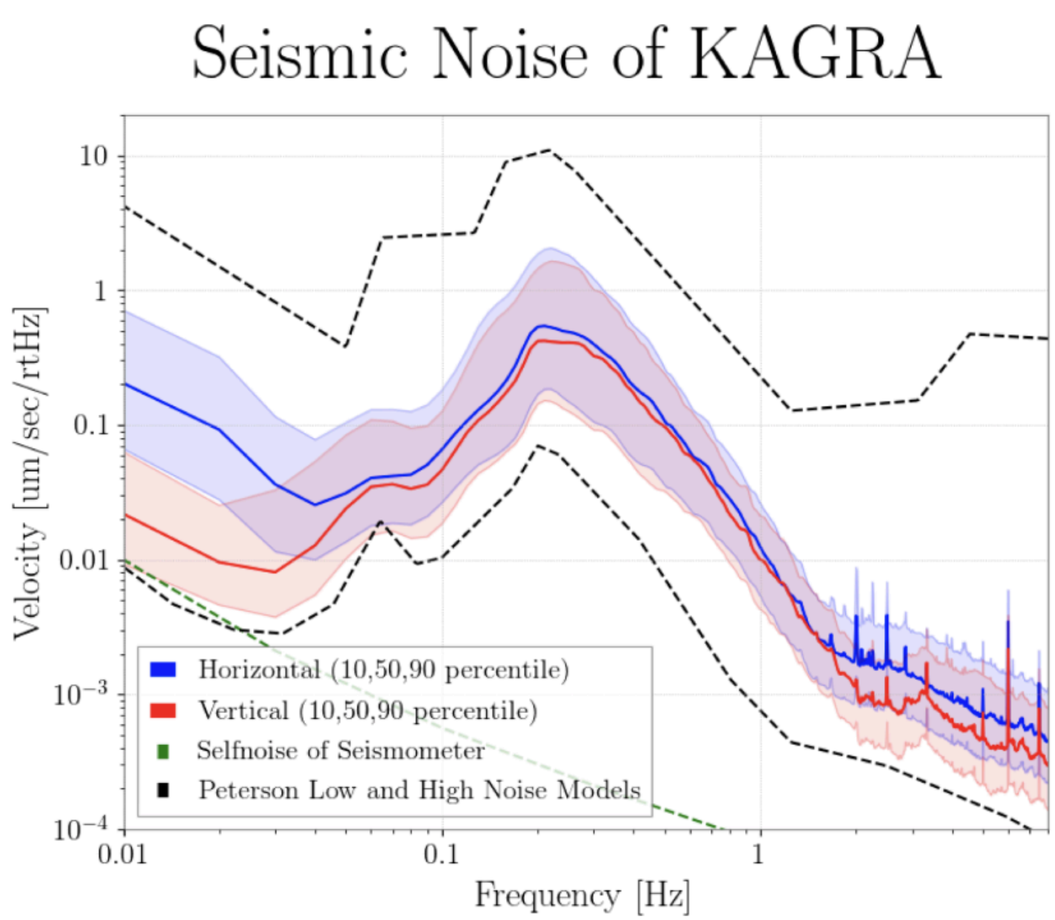
- Some explanation in https://www.mdpi.com/2075-4434/10/3/63
- Paper in preparation

Seismic motion

- There are long history to evaluate the ground motion at KAGRA site
  - Compared with KAGRA and TAMA300 experimental area
  - Seasonal dependence and so on
- Earthquake : Now well investigated yet …
- Vibration from fault : Not well investigated yet …
- Micro-seismic motion : Now preparing paper

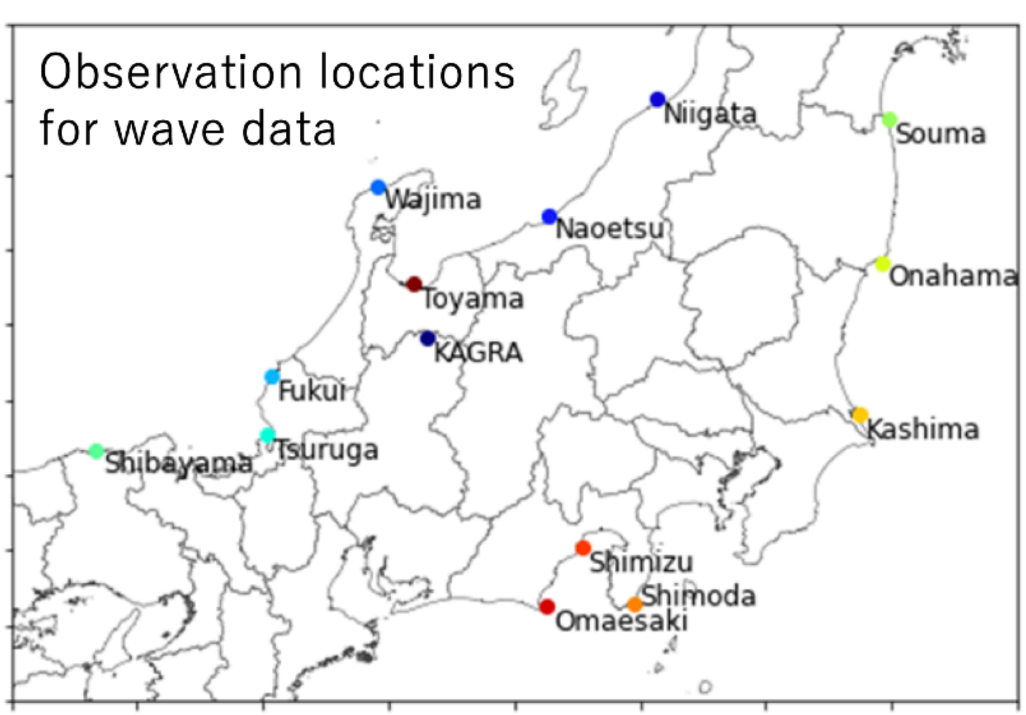




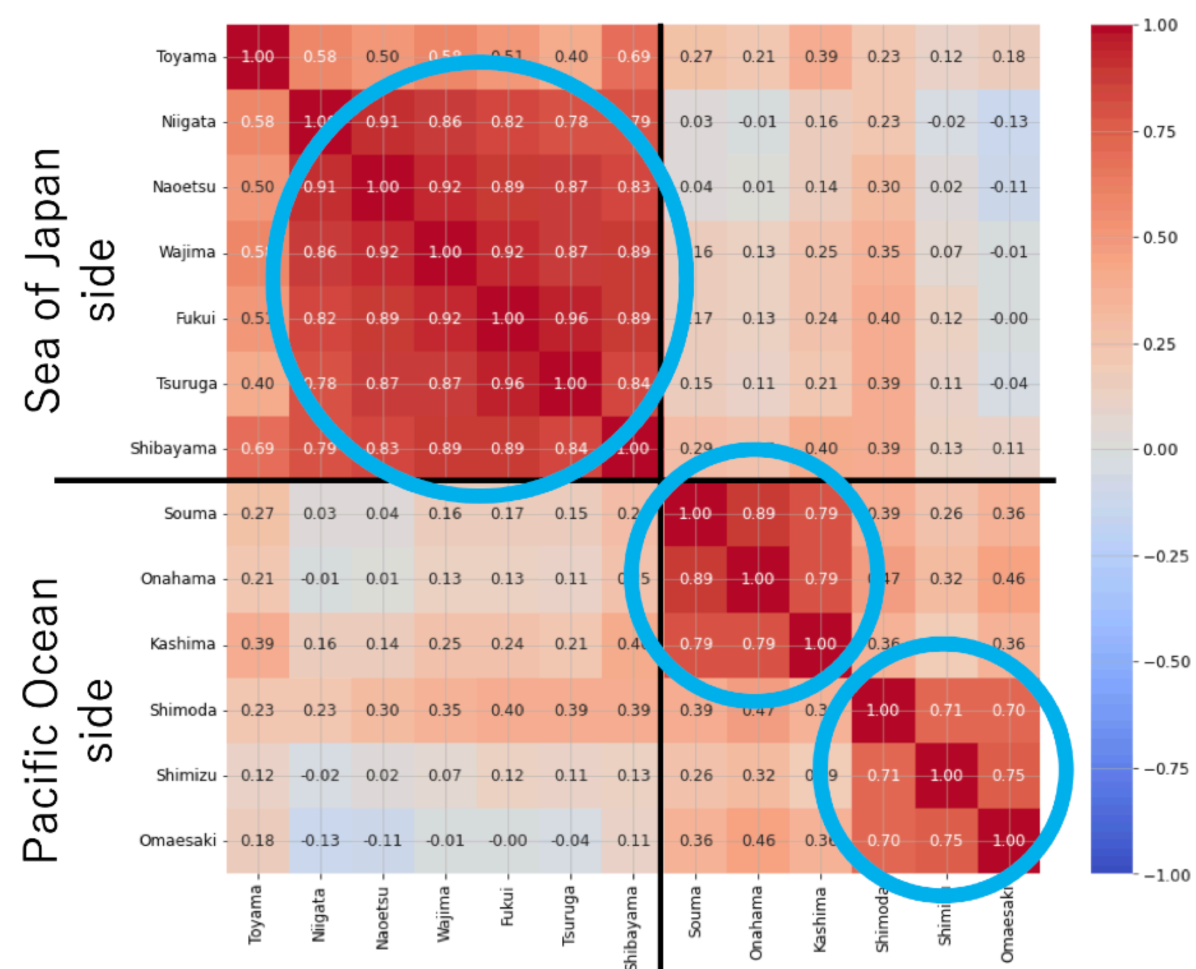


Seismic motion

- Even in underground environment, we could not ignore the micro seismic motion induced by waves in the sea (0.1 - 0.5 Hz)
  - It became difficult to keep the interferometer with lock state
- With reducing the effect by sensor correction, we investigated the characterization of micro seismic motion and we want to forecast
  - Wave data can be obtained from NOWPHAS
  - Check the coherence, characterization by PCA, and connected to KAGRA seismometer data



- Paper in preparation



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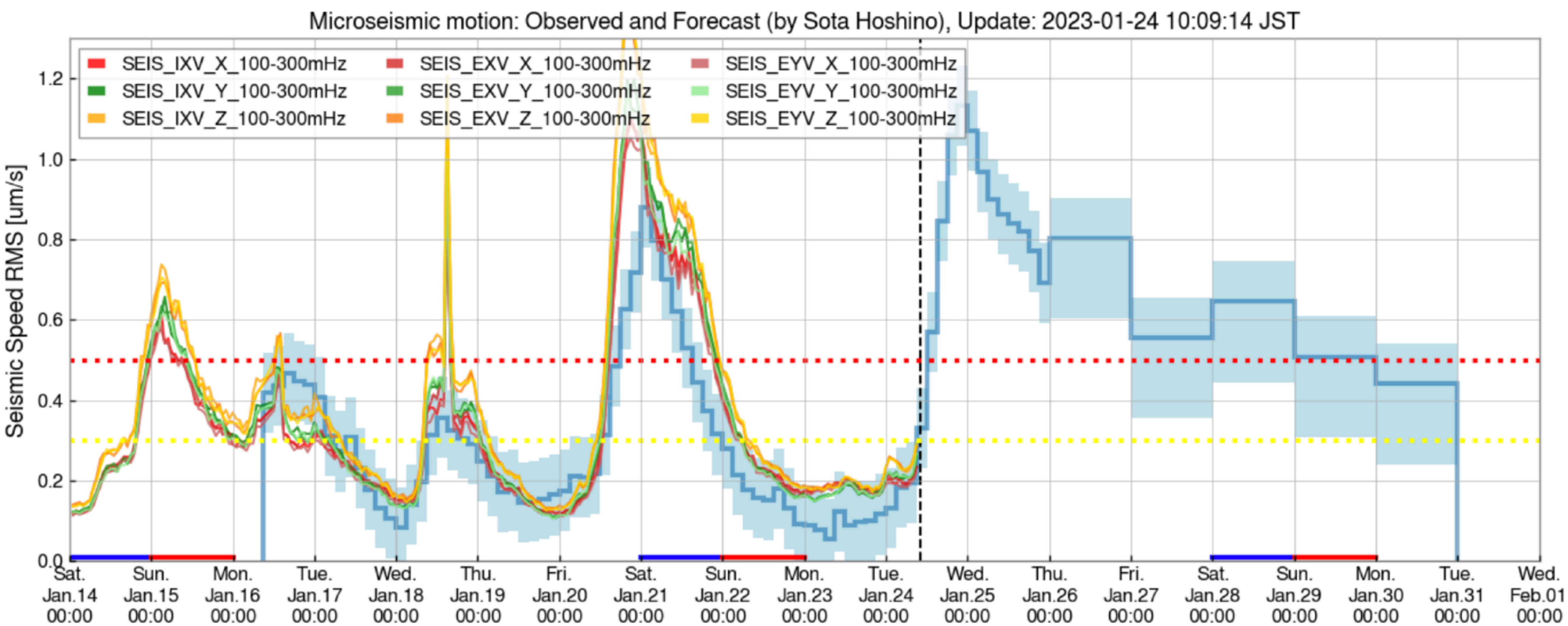
  - It became difficult to keep the interferometer with lock state
- With reducing the effect by sensor correction, we investigated the characterization of micro seismic motion and we want to forecast
  - Wave forecast data can be obtained from otenki.com



- Paper in preparation

Seismic motion

Local Hurst Exponent Computation of Data from Triaxial Seismometers Monitoring KAGRA

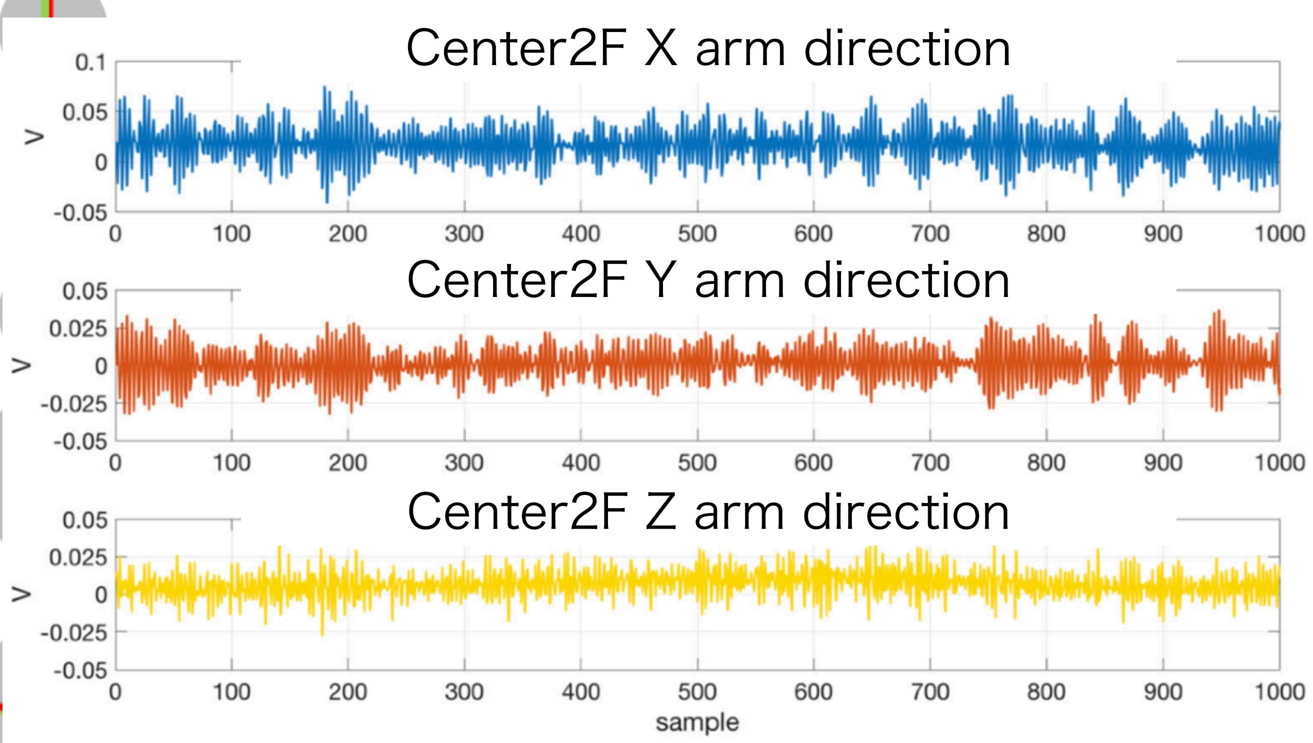
Alessandro Longo,[1] Stefano Bianchi,[6] Wolfango Plastino,[1,2] Kouseki Miyo,[3] Takaaki Yokozawa,[3]
Tatsuki Washimi,[4] and Akito Araya[5]

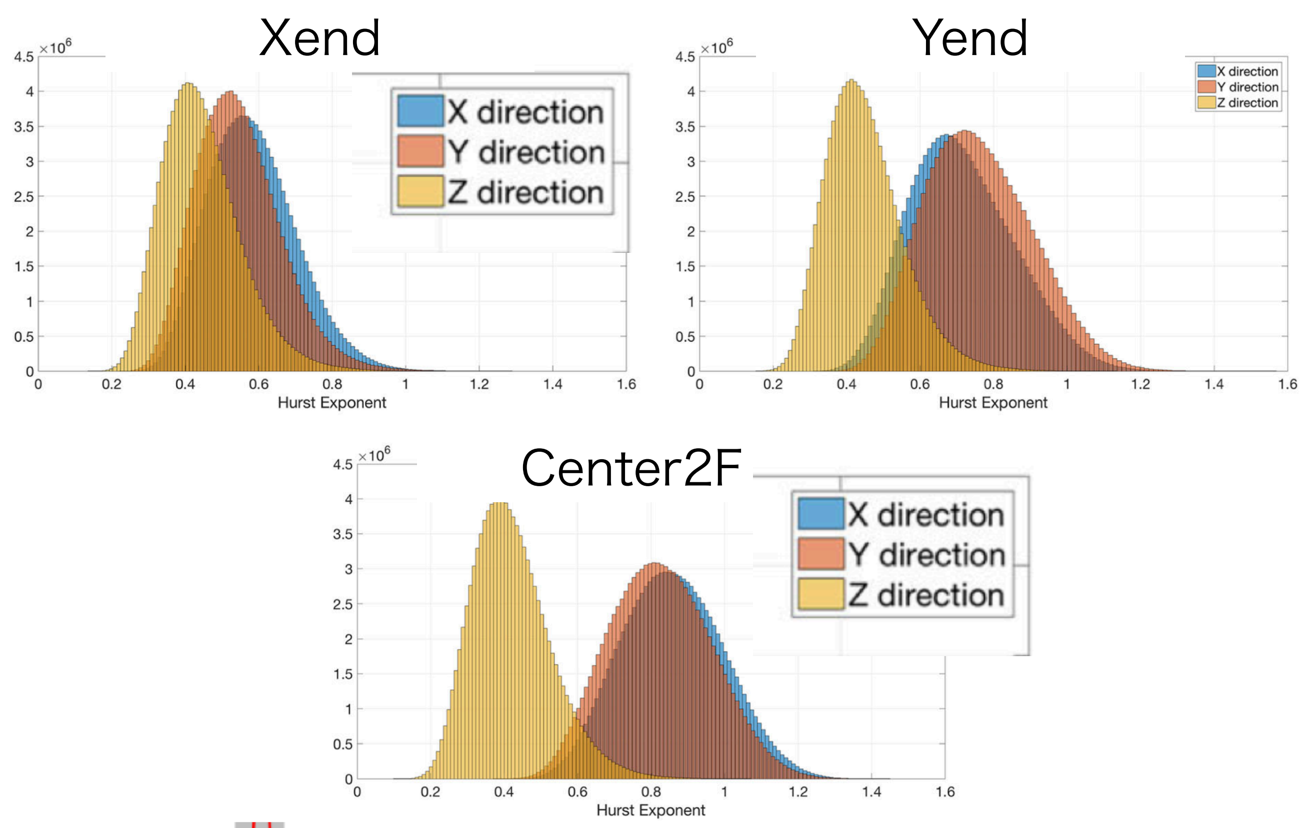
https://link.springer.com/content/pdf/10.1007/s00024-021-02810-2.pdf

- Apply the Local Hurst Exponent filter to KAGRA data and evaluated the color of spectrum
  - The characterization of color behavior is different in each station

$$F_q(n) = \left[\frac{1}{N_{tot}}\sum_{s=1}^{N_{tot}}\left[RMS^2(n,s)\right]^{q/2}\right]^{1/q} \sim n^{h(q)}$$

- Local Hurst : $H = \frac{\beta+1}{2}$ $\quad P(f) \sim f^{-\beta}$





Newtonian noise

KAGRA underground environment and lessons for the Einstein Telescope

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and INFN, Laboratori Nazionali del Gran Sasso, I-67100 Assergi, Italy

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Gravitational Wave Science Project (GWPS), Kamioka branch,
National Astronomical Observatory of Japan (NAOJ), Kamioka-cho, Hida Ciry, Gifu 506-1205, Japan

https://journals.aps.org/prd/pdf/10.1103/PhysRevD.104.042006

- Calculated the directivity of ground motion and newtonian noise using KAGRA seismometers and microphones

Newtonian noise

KAGRA underground environment and lessons for the Einstein Telescope

https://journals.aps.org/prd/pdf/10.1103/PhysRevD.104.042006

- Body wave NN :

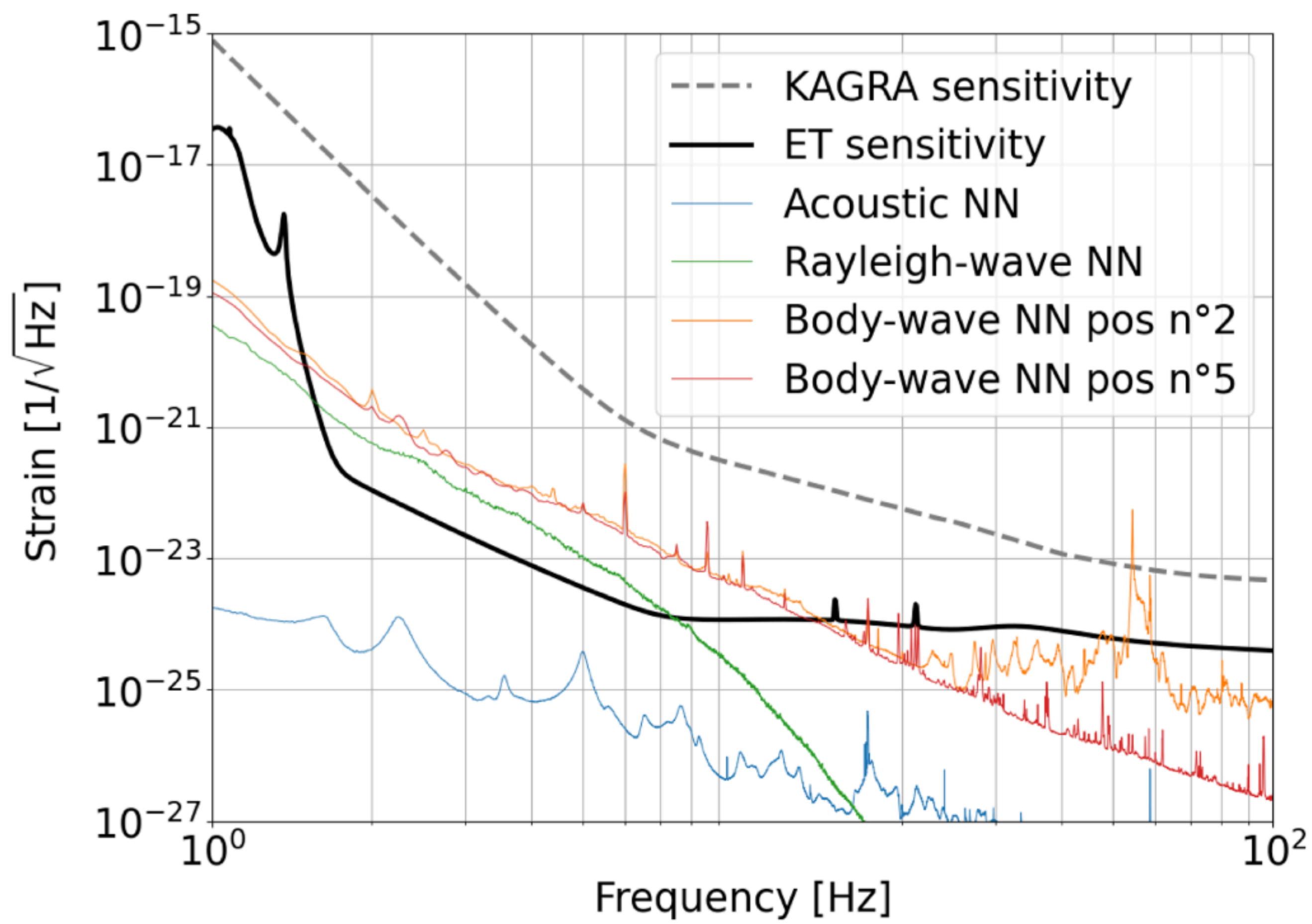
$$S(\delta a^P;\omega) = \left(\frac{8}{3}\pi G\rho_0\right)^2 S(\xi^P;\omega),$$

- Rayleigh wave NN :

$$S^R(\delta a_x;\omega) = (2\pi G\rho_0\gamma(\nu)e^{-h\omega/v})^2 \frac{1}{2} S(\xi^R;\omega),$$

- Acoustic NN :

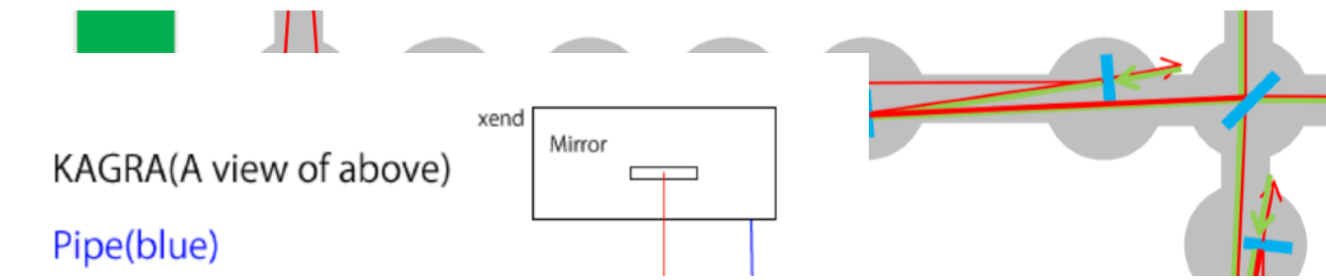
$$S^h_{\mathrm{cav}}(f) = \left(\frac{2c_s G\rho_0\delta p_{\mathrm{cav}}(f)}{p_0\gamma f}\right)^2 \frac{1}{3}(1-\mathrm{sinc}(2\pi fR/c_s))^2 \times \frac{4}{L^2(2\pi f)^4},$$

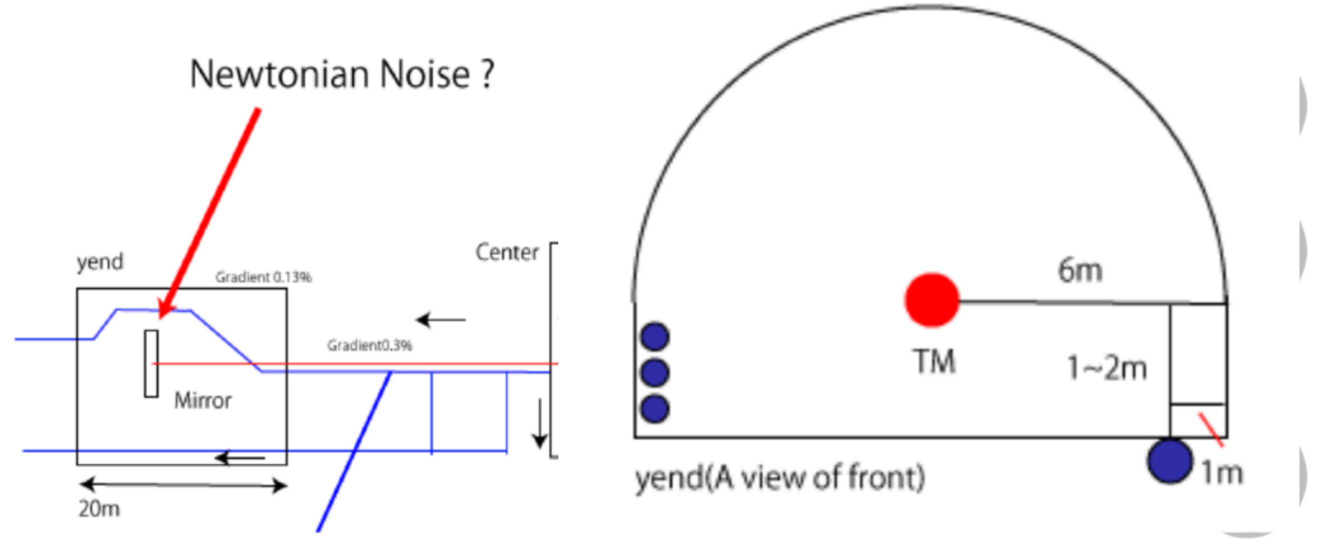


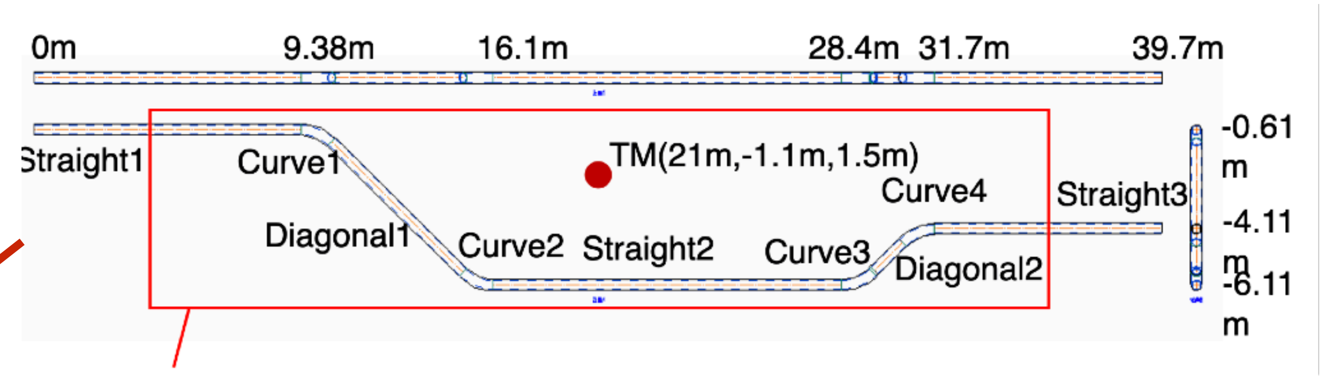
- Body-wave NN contribution seems lager in KAGRA experimental area
- We may not need to care the NN from infrastructure in KAGRA design sensitivity, but we may need in ET design sensitivity

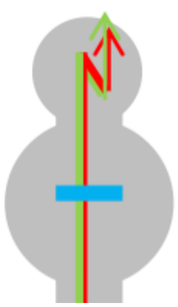
Water fluid and NN noise

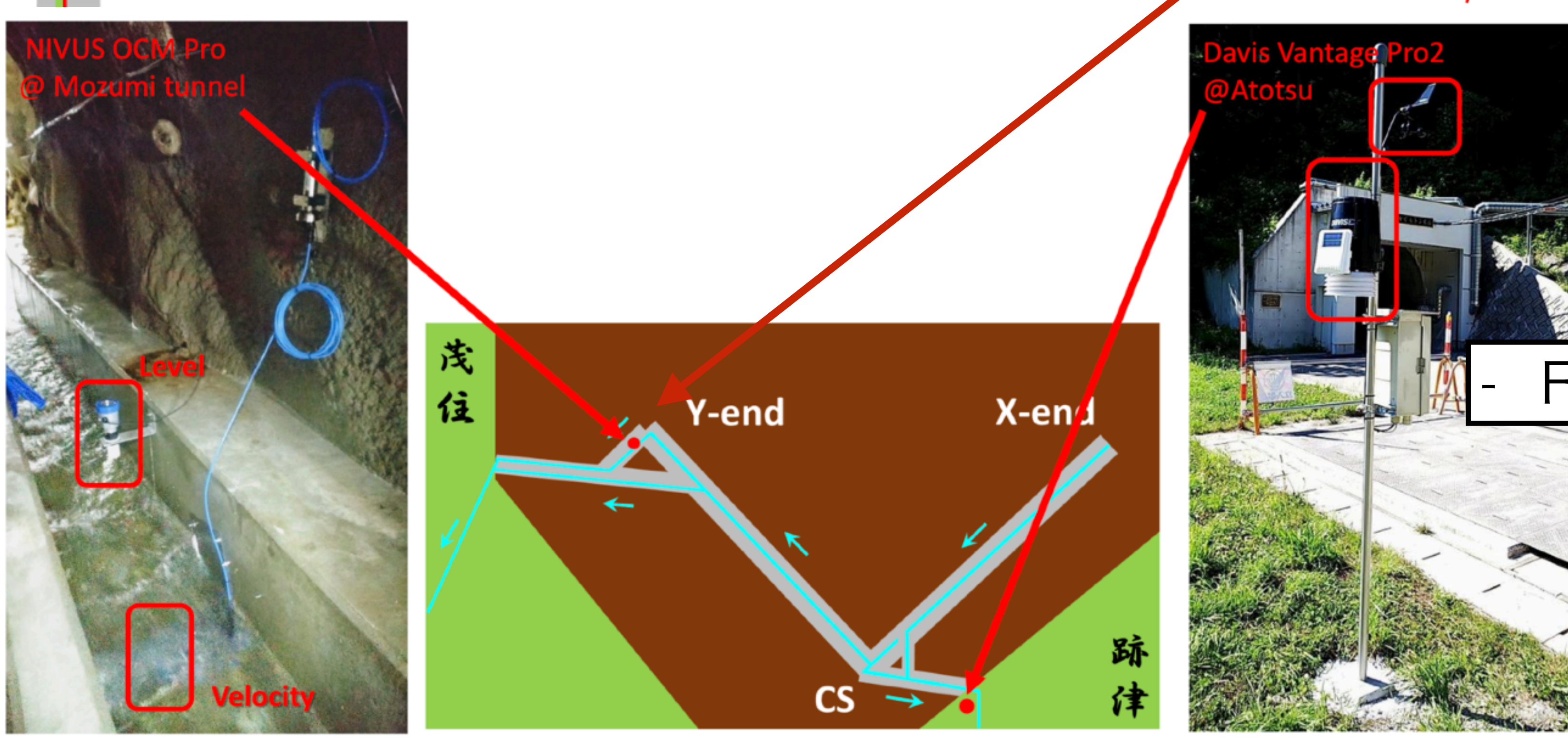
- Water fluid monitor at the Yend
  - Checked the relationship between weather station and water fluid
  - One of the important topic to understand the underground waters
- Newtonian noise evaluation from water
  - Water fluid simulation using FLOW3D

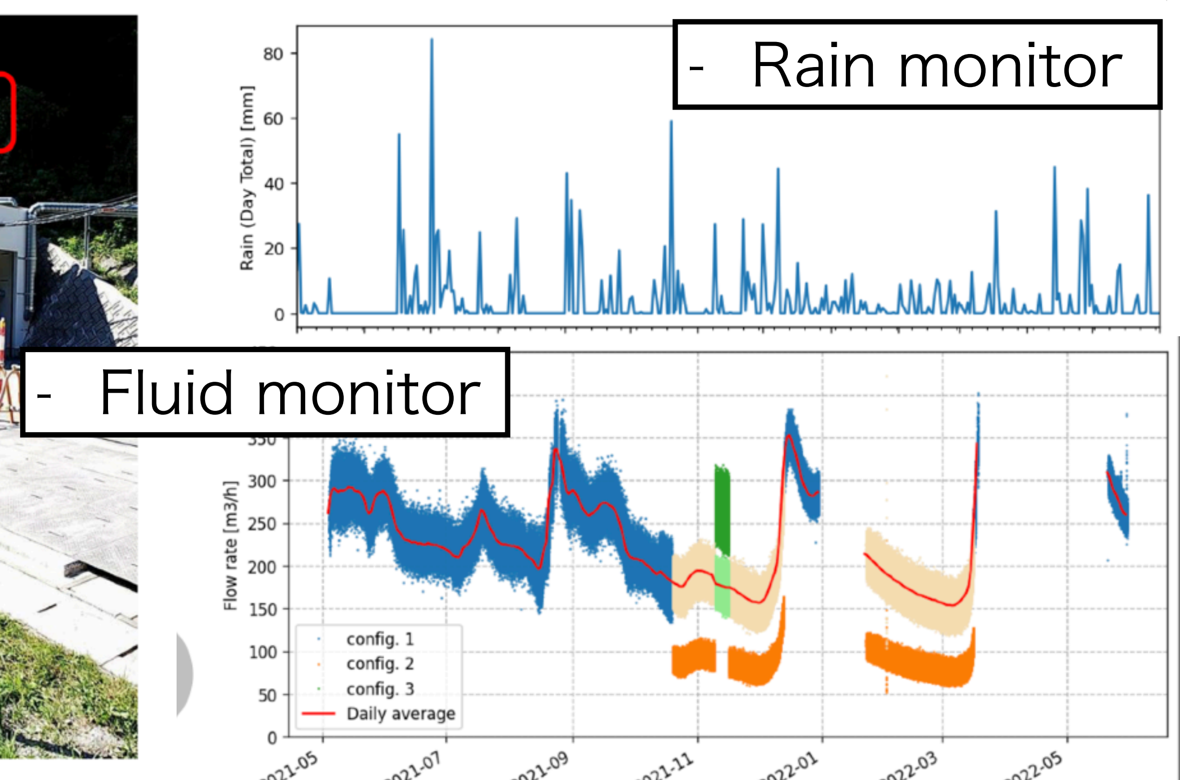




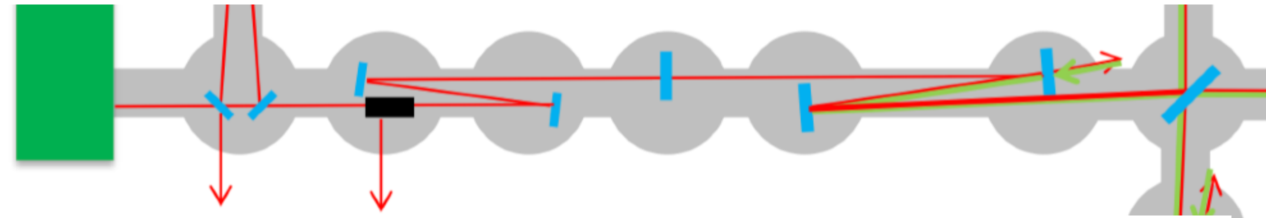


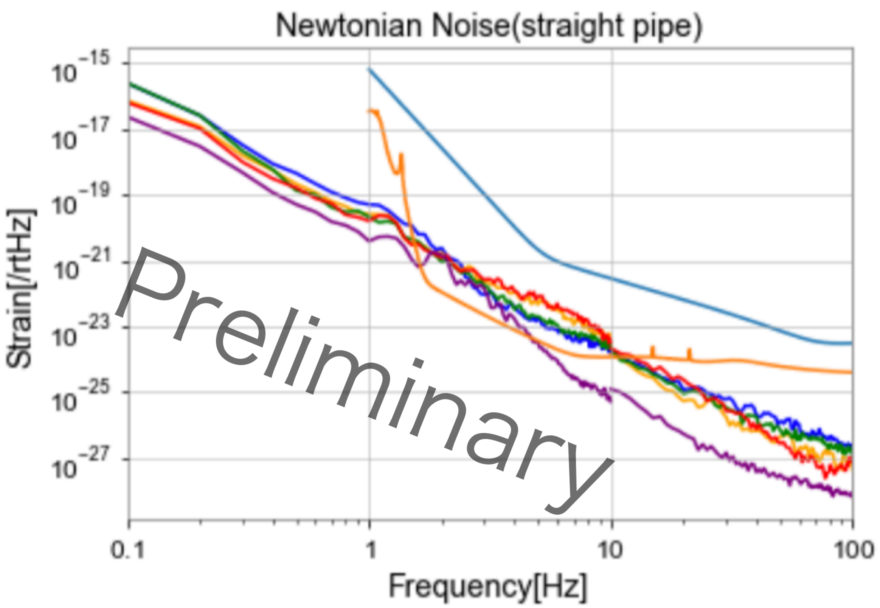


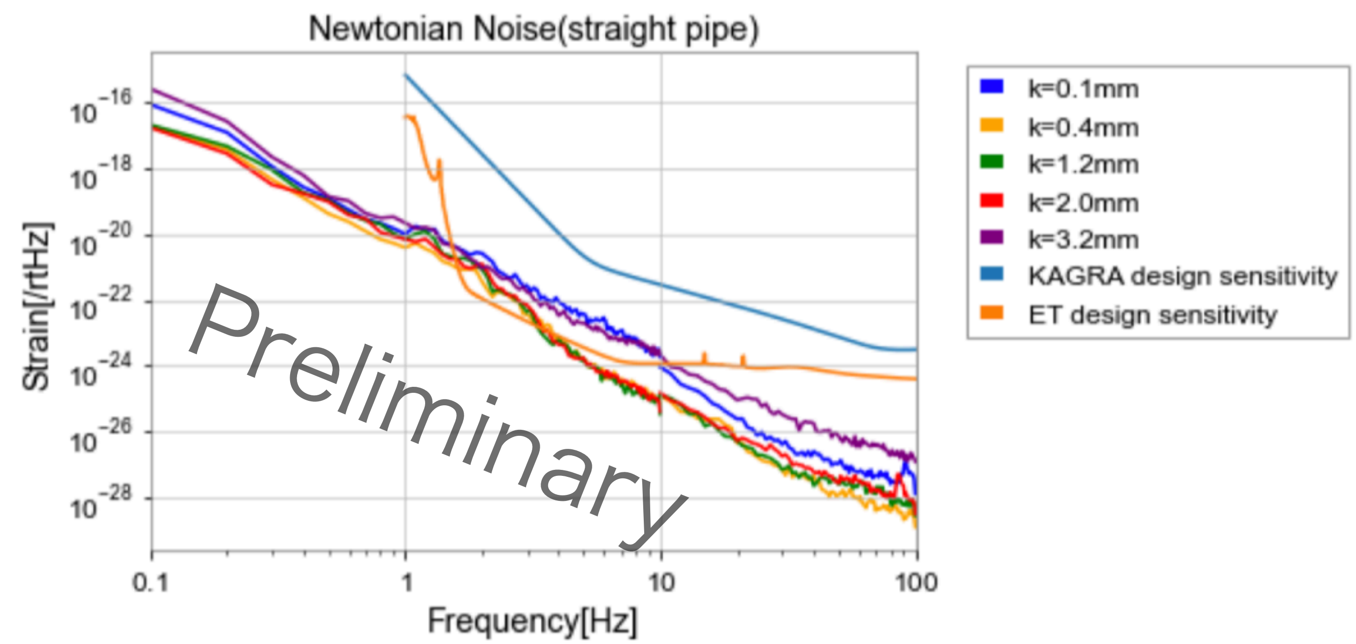




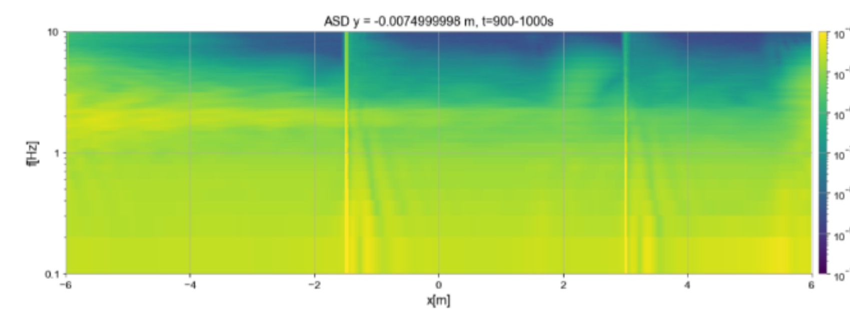
Water fluid and NN noise

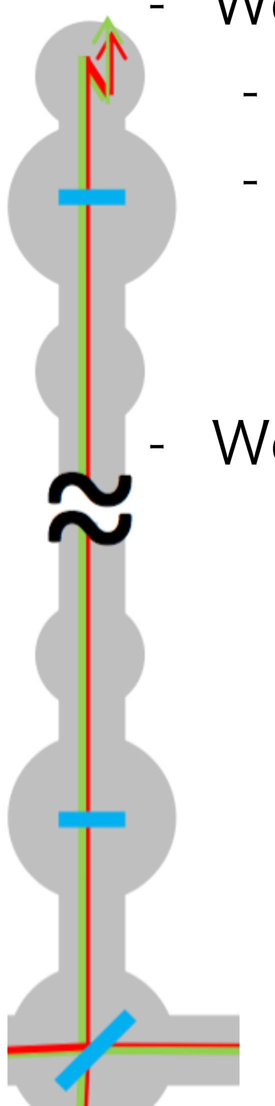


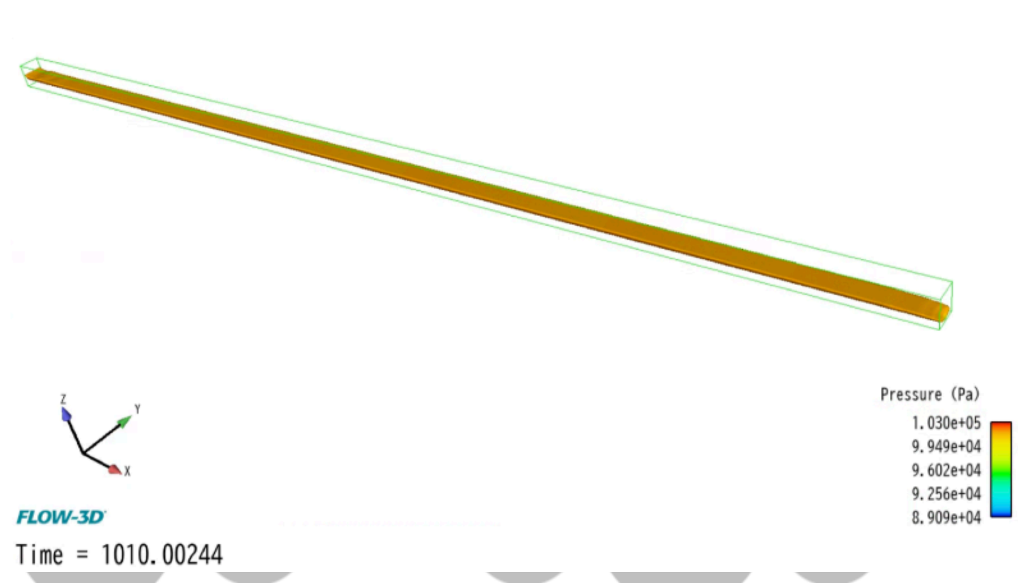


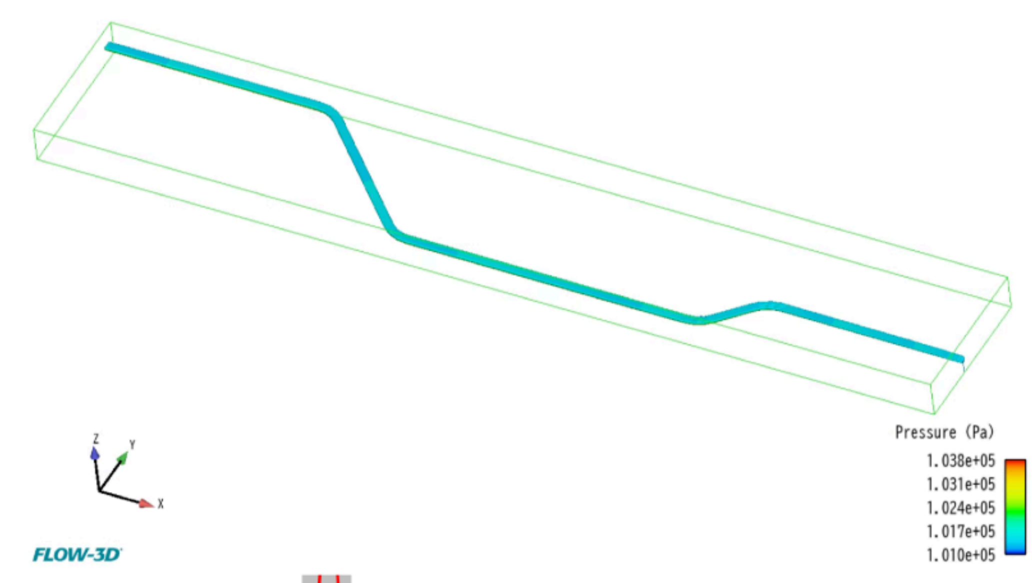


- We simulated several situation for straight pipes
  - Various initial water flow(left), wall roughness(right)
  - We are now final discussion for those results
    - Some treatment need in case of ET sensitivity
      - But, KAGRA water pipes were very close to ETMY…
- We also simulated the realistic shape of water pipe

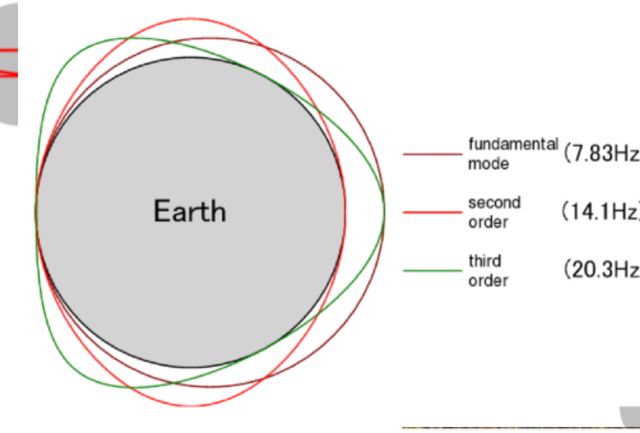




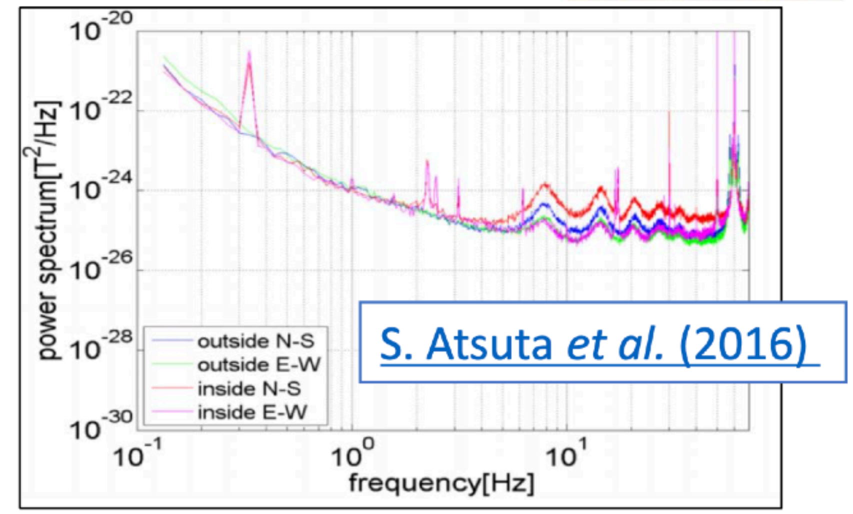


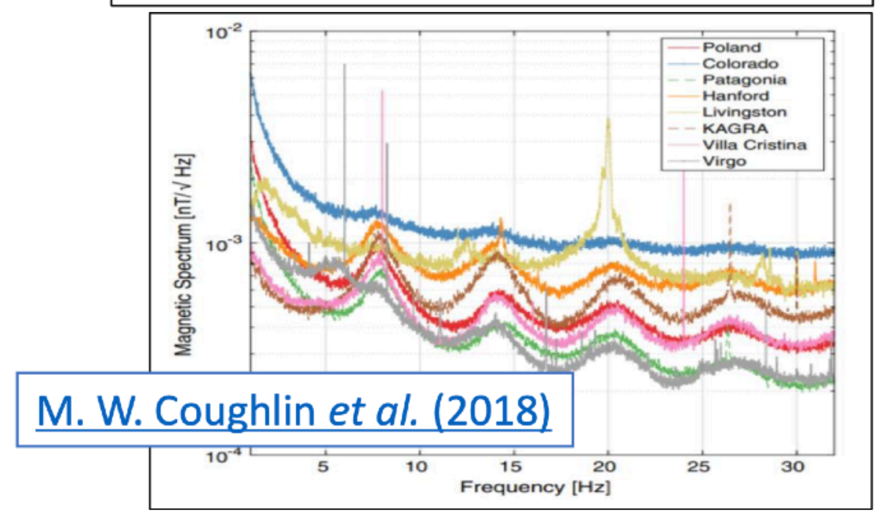


KAGRA Schumann resonance

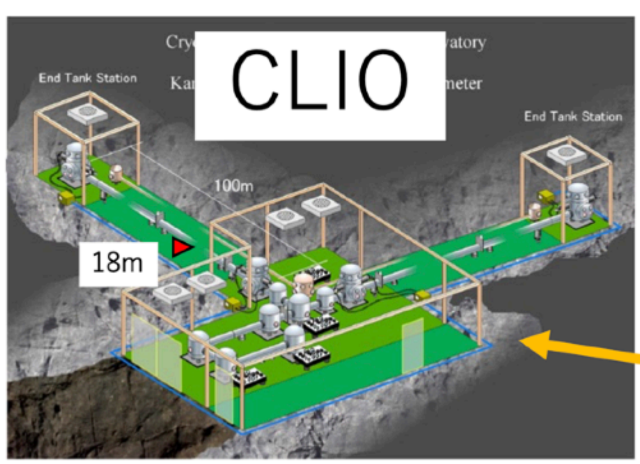


- From the previous study, the amplitude of Schumann resonance at the underground is larger than at the surface(Typically, 1 pT)
- Beginning of July(7/3-7/9), we measured the magnetic field, focusing near the beam duct
  - Y-30m, X-1500m, X-2440m, CLIO Yarm, …
- We took long term magnetic field data outside of KAGRA experimental area
  - August - December

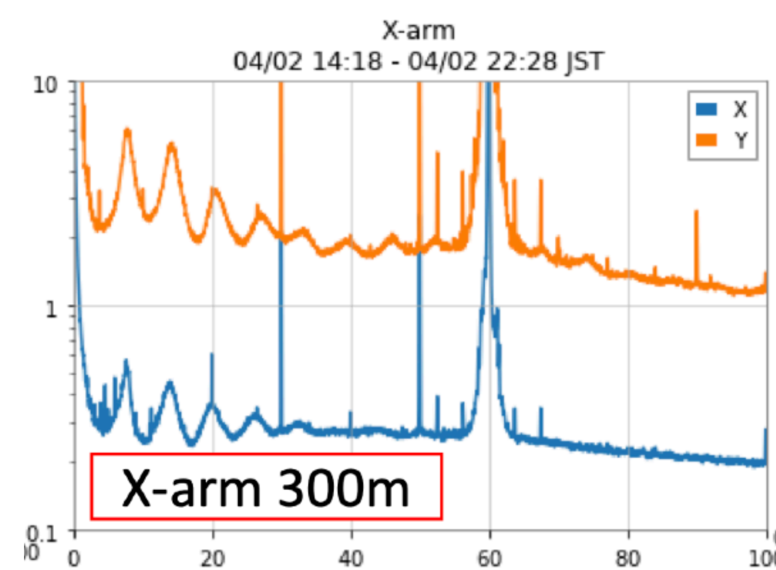




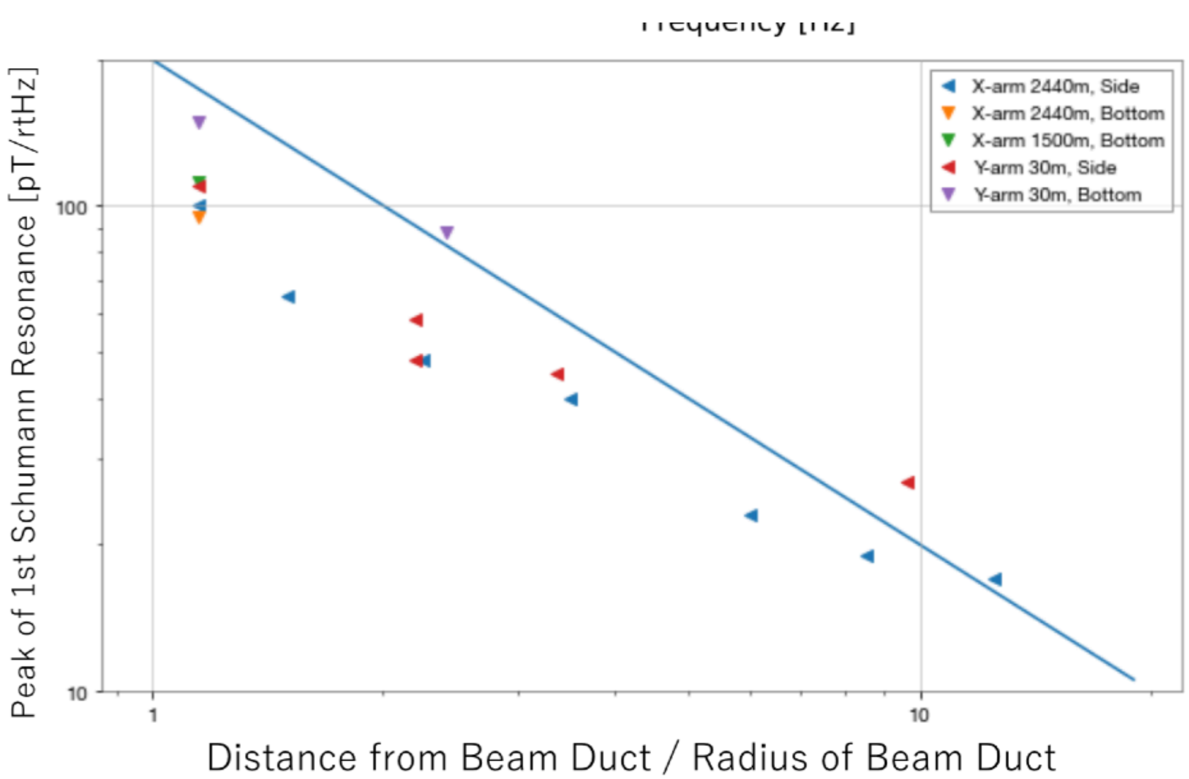
Measurement Location

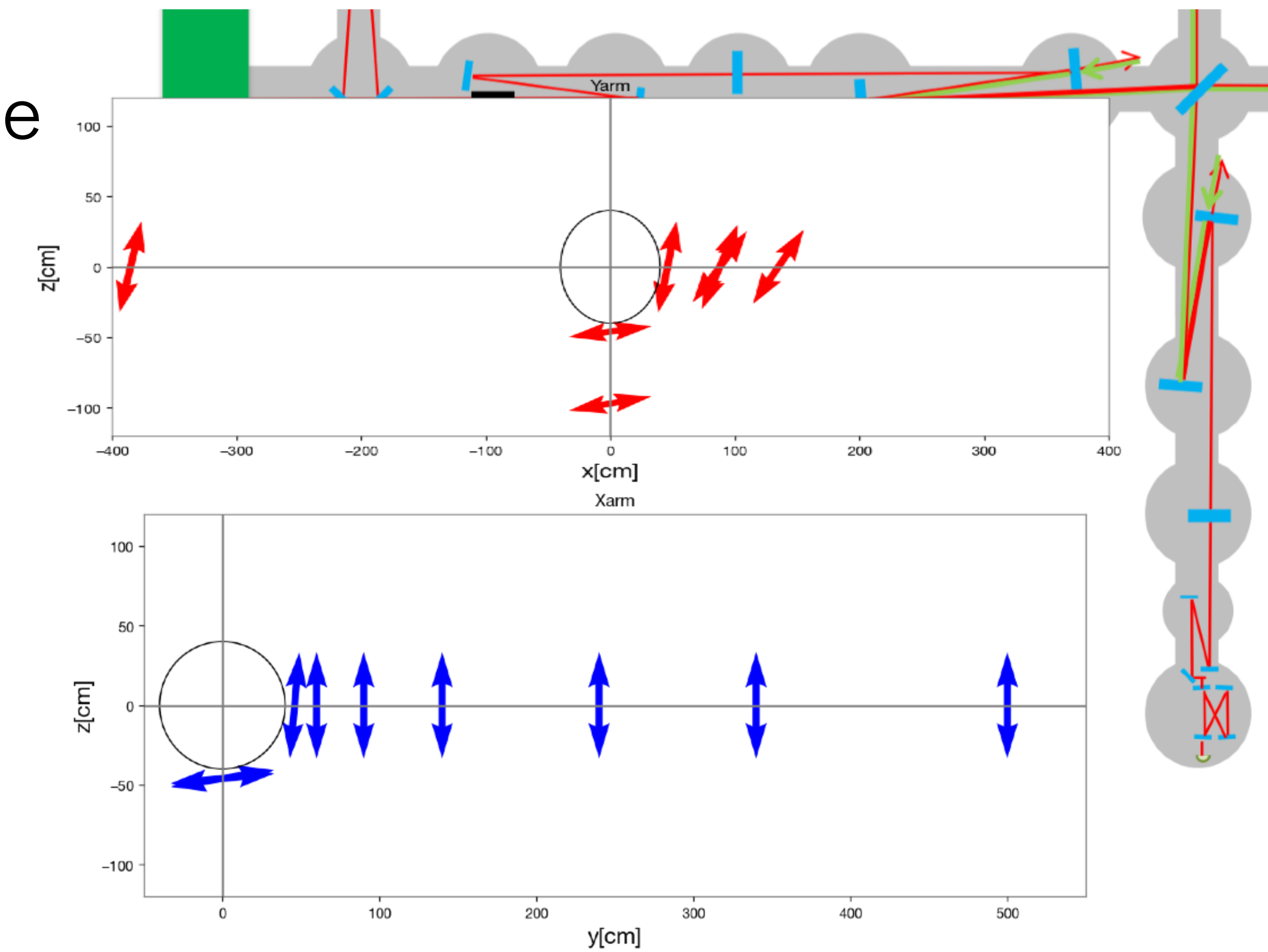


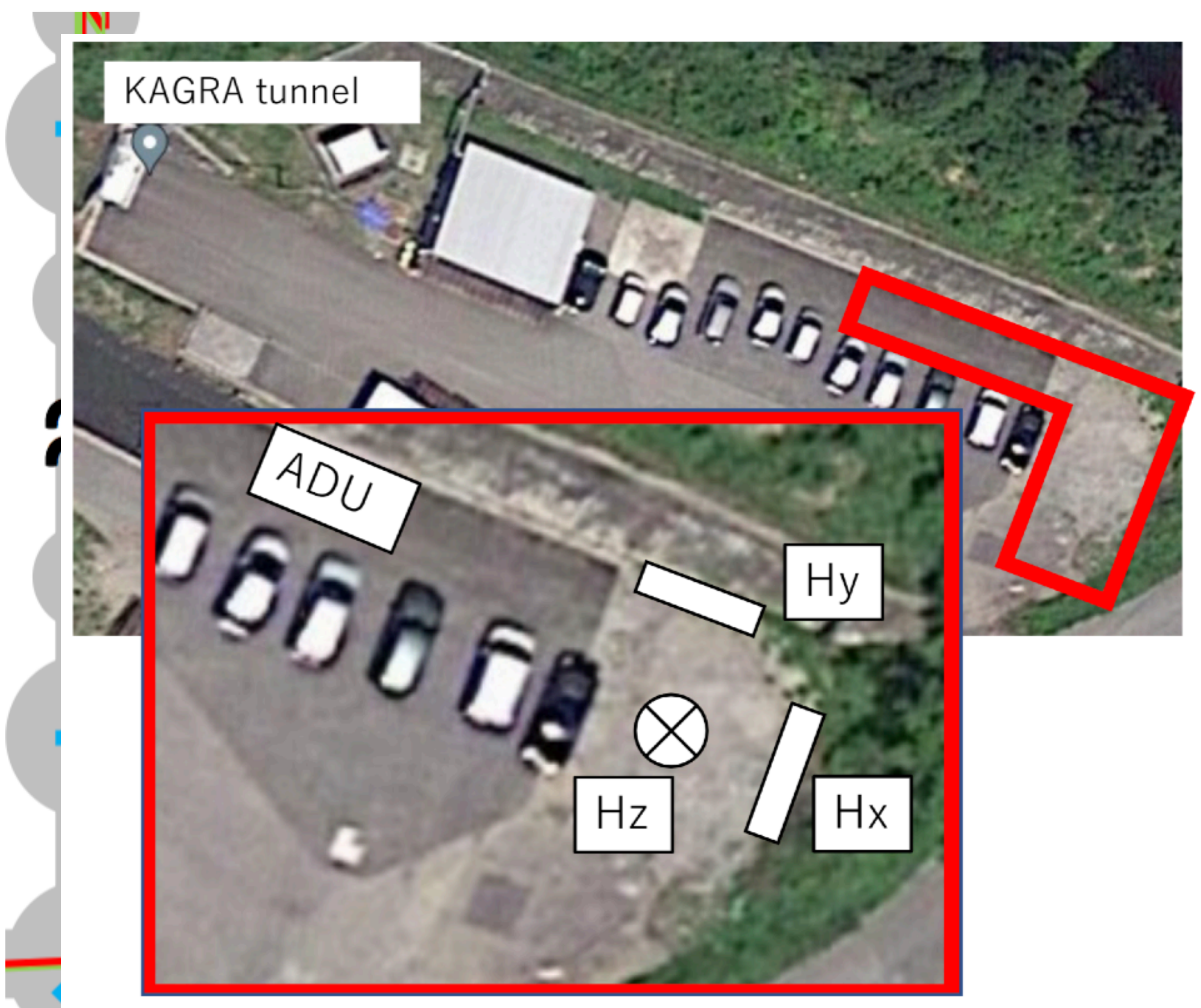
Location
PEM area
Yarm(30m)
CLIO Yarm (18 m)
KAGRA Front room
Xarm(1500 m)
Xarm(2440 m)



KAGRA Schumann resonance





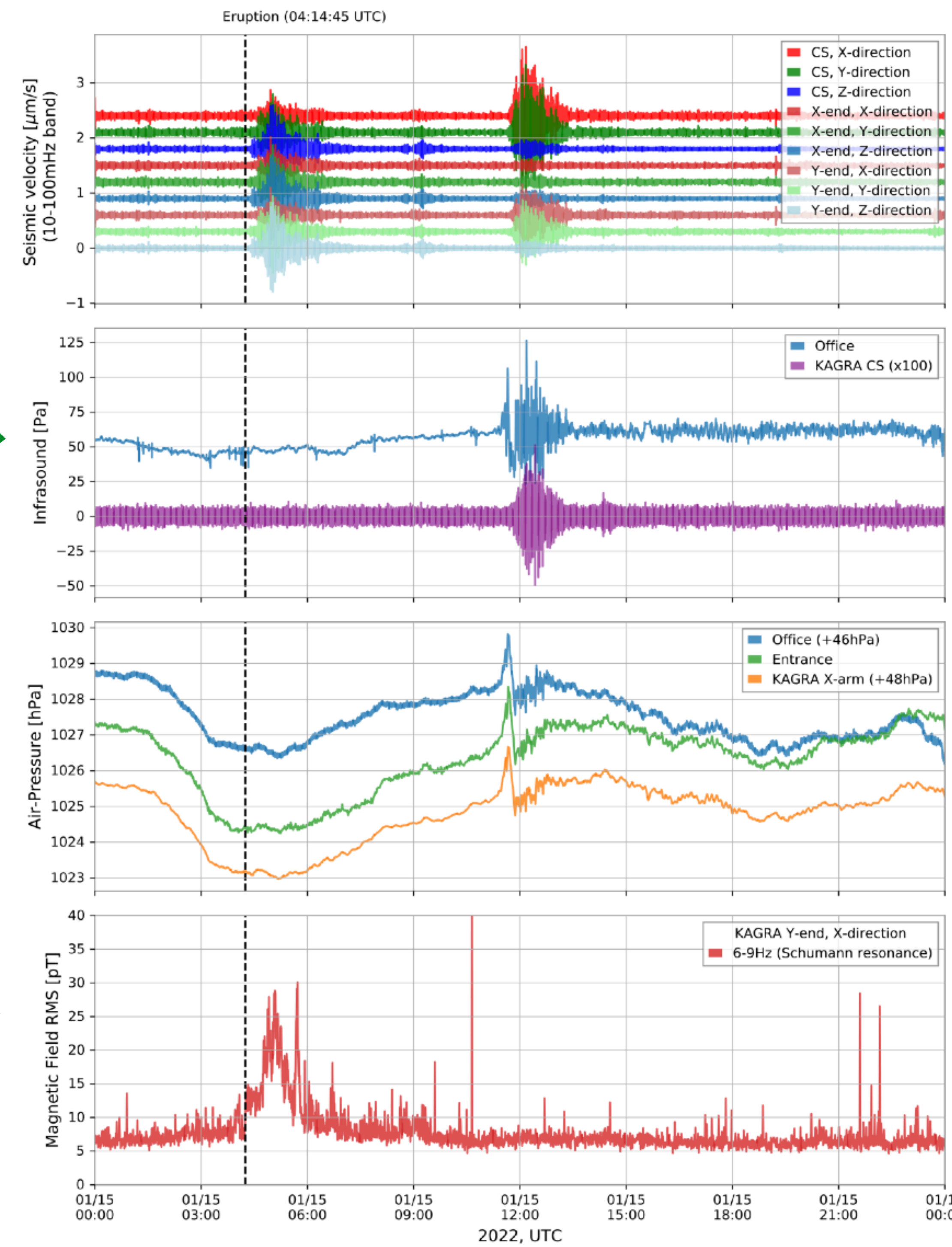


- We found that the amplitude of Schumann resonance have relationship with distance from arm beam ducts.
- Also, we detected the direction dependence around the beam duct.
- Now, we analyzing the long term data
- Also, we measured the magnetic field at Virgo site, this result will appear soon.

Signals from Tonga Eruption

- KAGRA PEM detected several signals from Tonga Eruption
  - https://gwcenter.icrr.u-tokyo.ac.jp/en/tonga-20220115 (ICRR)
  - https://www.nao.ac.jp/en/news/topics/2022/20220210-gwpo.html (NAOJ)
- Accepted by PTEP
  - https://doi.org/10.1093/ptep/ptac093
  - https://arxiv.org/abs/2206.14396

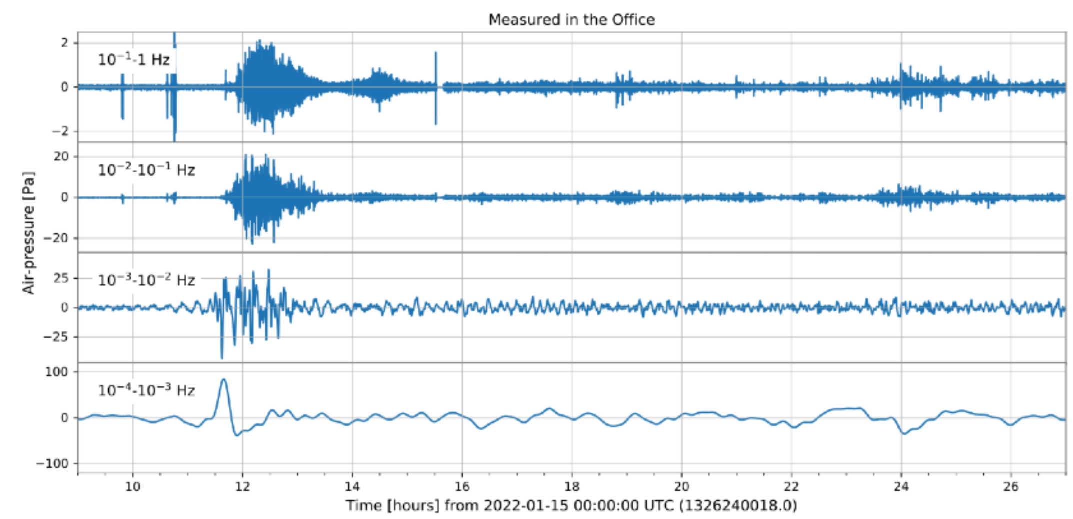
- Seismometers
  - Ground motion (p,s)
  - Air pressure wave
- Infrasound sensors, barometers
  - Air pressure wave
- Magnetometer
  - Increasing the amplitude from Schumann resonance



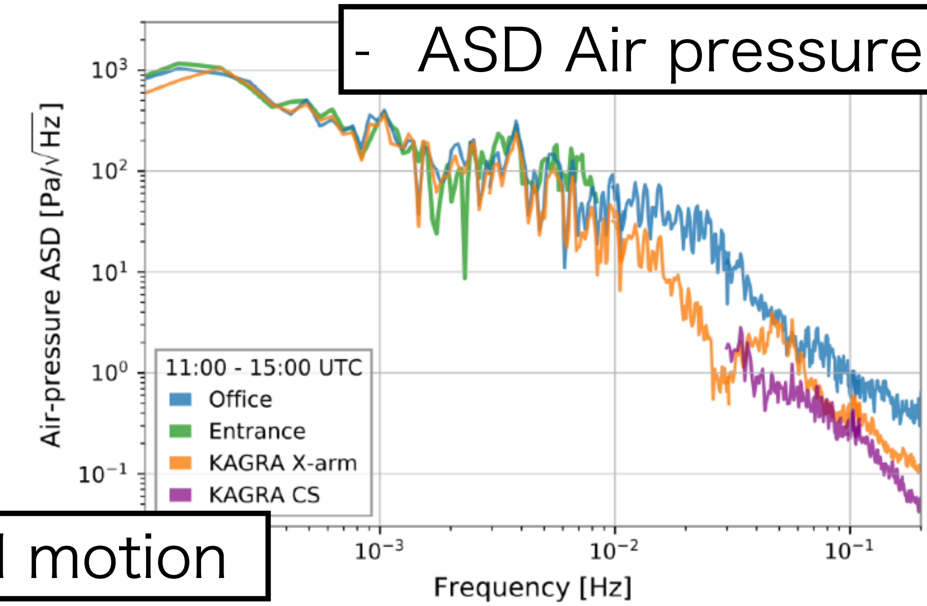
Signals from Tonga Eruption

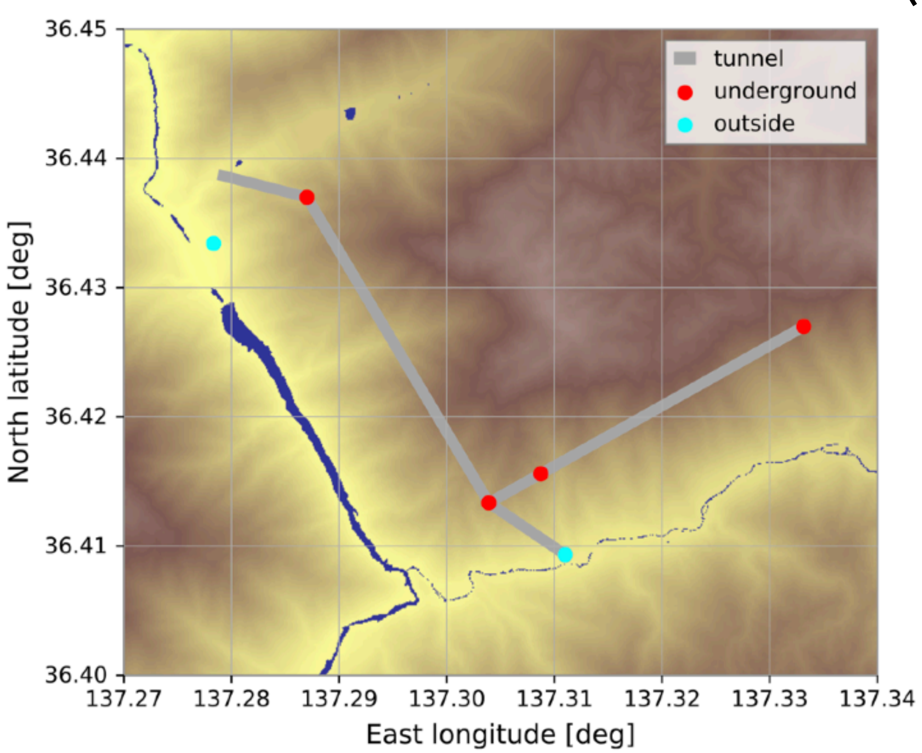
- The detail in JGW14072
  - KAGRA Internal seminar
- Band limited RMS (seismic motion, magnetic field)
- Spectrum analysis
  - With evaluating the sensor noise, calibration
- Transfer function measurement
  - Outside(surface) to underground
  - Velocity of the air pressure wave
  - Center area to X arm
- From this event, we started the rich environment for the infrasound and the air pressure
- See also Takamori-san talk (next talk)

- Band passed Air pressure

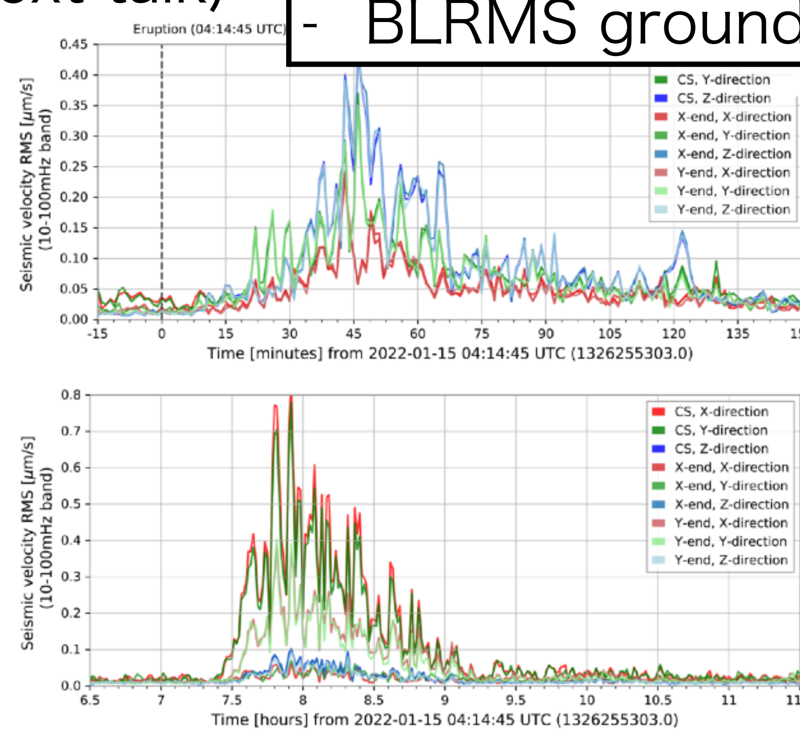


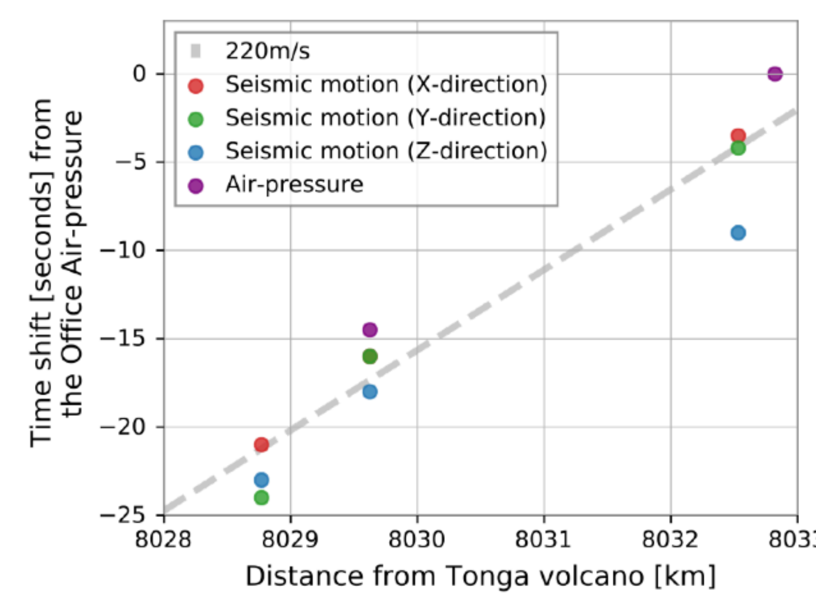
- ASD Air pressure





- BLRMS ground motion





- Time shift Air pressure

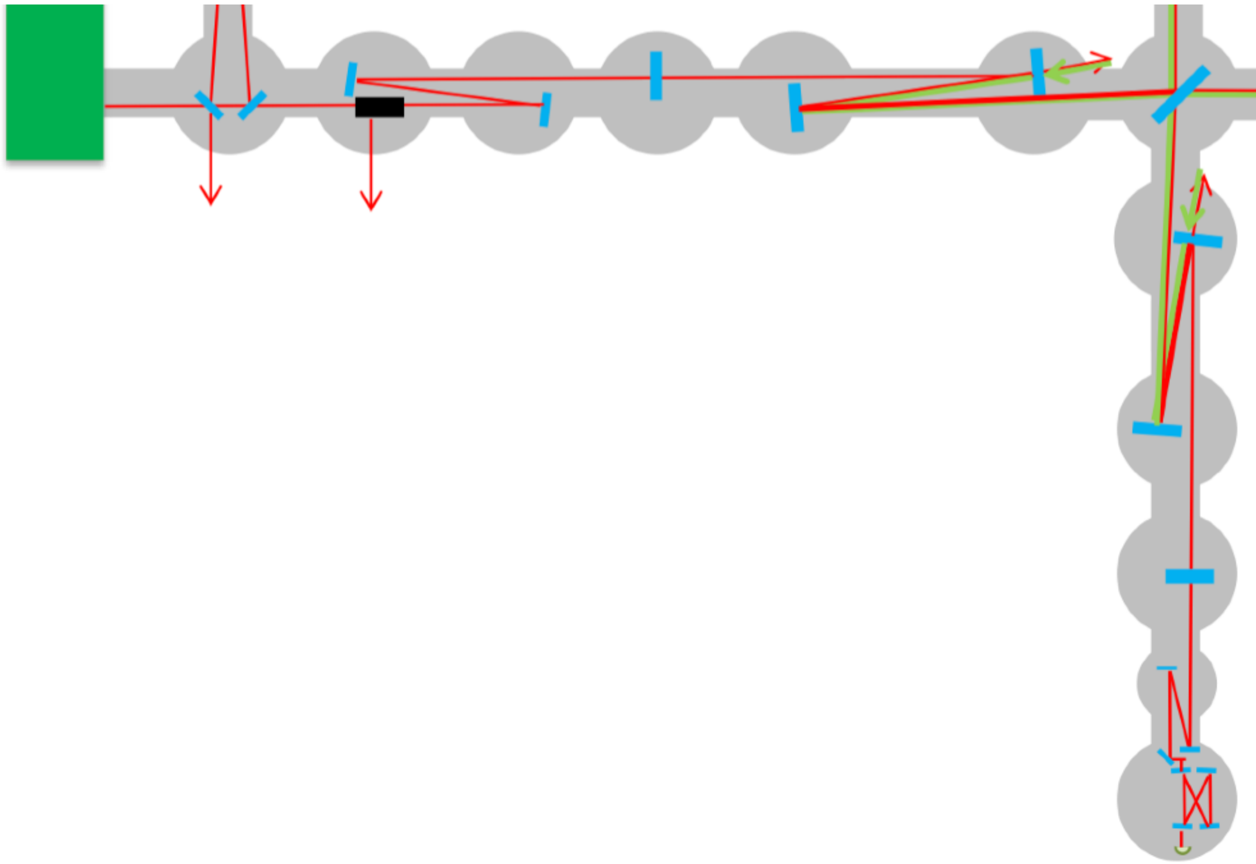
Summary

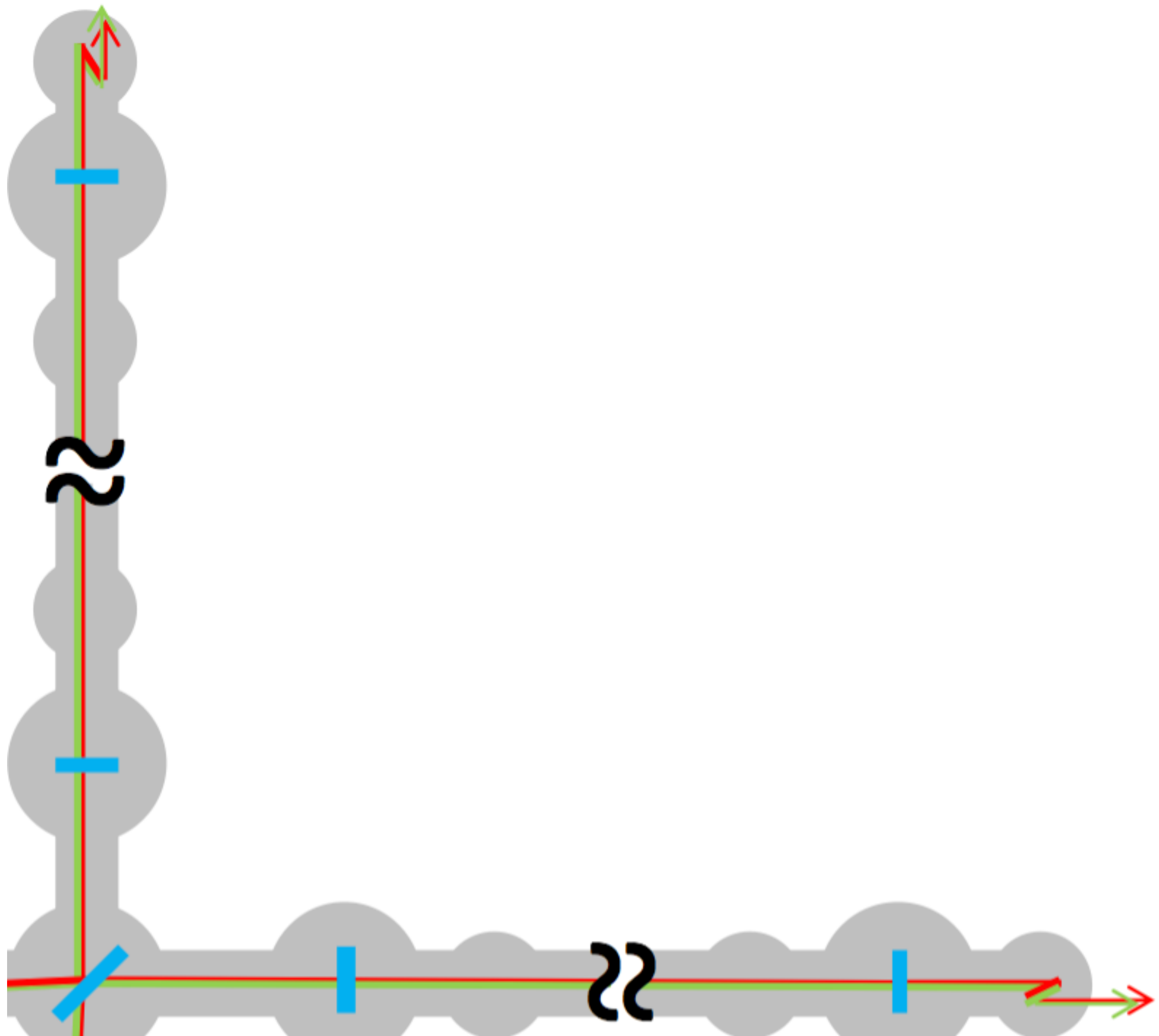
- KAGRA is constructed in underground environment
  - Unique interferometer in 3 km scale
  - For operating the underground interferometer, there are various efforts, and various characteristics exist
- Many projects are ongoing for KAGRA environment
  - Ground motion
  - Newtonian noise
    - Newtonian noise from water fluid
  - Magnetic field
    - Schumann resonance
  - External phenomenon, such as Tonga Eruption

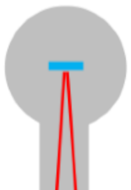
Summary

- Ongoing and future prospect
  - AC/DC and GND investigation in KAGRA experimental area
    - Investigate the 60 Hz and its harmonics
    - Turn on/off the infrastructure and GND level change
  - Study of the weather around KAGRA area and evaluate its effect
    - Calibration of the rain and snow monitor
    - Set new weather station at Analysis building
    - Rain, wind, and so on effect to KAGRA interferometer
    - Lightening effect and wall effect
  - Environmental injection
    - Coupling function evaluation by making new large coil
    - Acoustic noise injection with large speaker

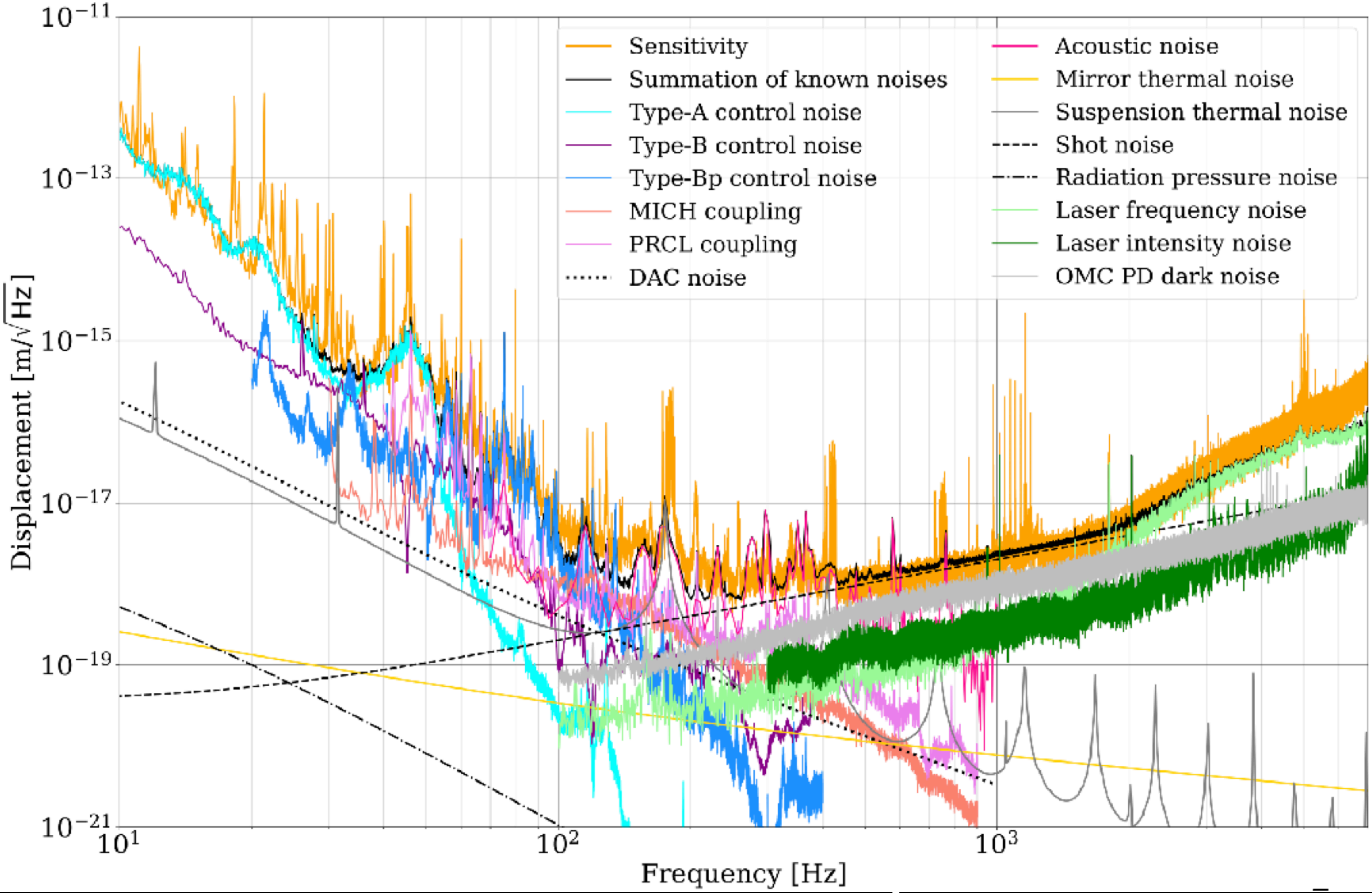
Backups







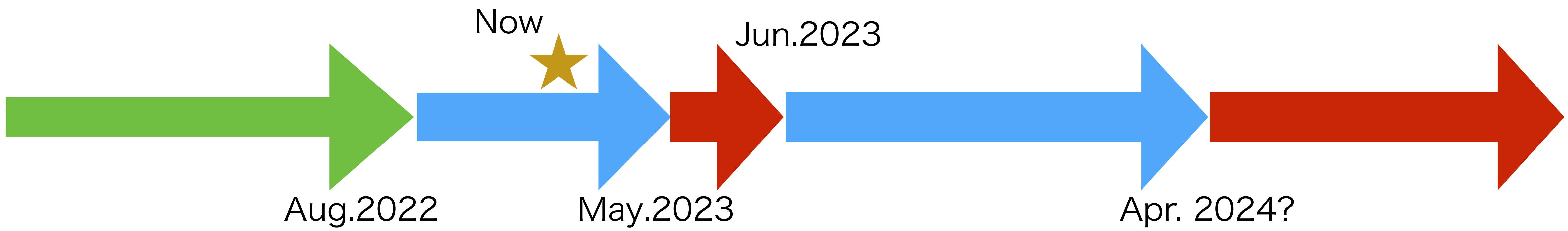
Status of KAGRA



- Sensitivity and noise budget O3GK(Apr. 2020)
  - Low frequency : Suspension control noise
  - Middle frequency : Acoustic and scattered noise
  - High frequency : Shot noise

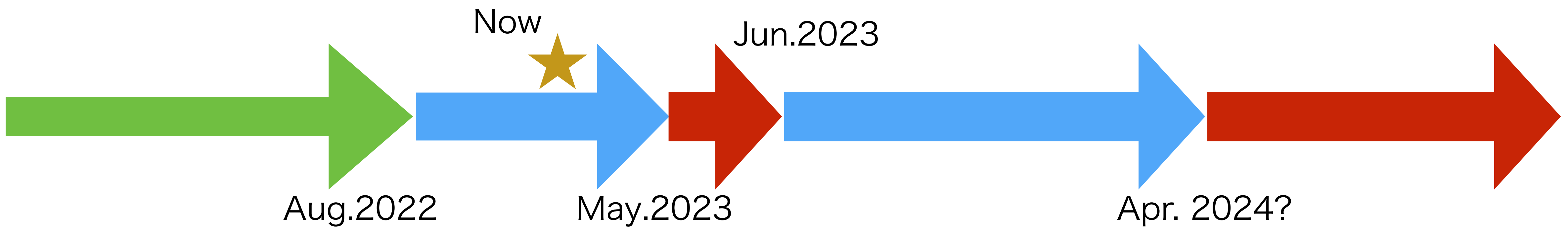
After performing several improvement, closing the camber and pumping down, we performed the lock trial of PRFPMI

Status of KAGRA



- Repair works
  - Suspension upgrade
    - Fixed the malfunction
    - New accelerometers for sensor correction
    - New optical lever for MN/PF
      - Optical lever is strong monitor in underground experimental area
  - Mid-size baffle installation
    - In front of PR's, SR's and BS mirrors
  - Preparing the high power laser
- Commissioning works
  - Lock trial of PRFPMI
    - Stable operation with FPMI done
  - Calibration, Detector characterization and so on

Status of KAGRA



- Joining the O4a run from beginning
  - More than 1 Mpc and continuously 1 month run
  - Open information : https://observing.docs.ligo.org/plan/
- Second commissioning as longer commissioning break
  - Cooling down the cryopayload
  - Optimization of the cryogenic suspension control
  - Noise hunting
  - Operating with the high power laser
  - Alignment sensing and controls
  - Calibration, Detector characterization and so on
- Joining the O4b run from Apr. 2024
  - More than 10 Mpc at Apr. 2024