地下から解き明かす宇宙の歴史と物質の進化
Unraveling the History of the Universe and Matter Evolution with Underground Physics

科研費
KAKENHI

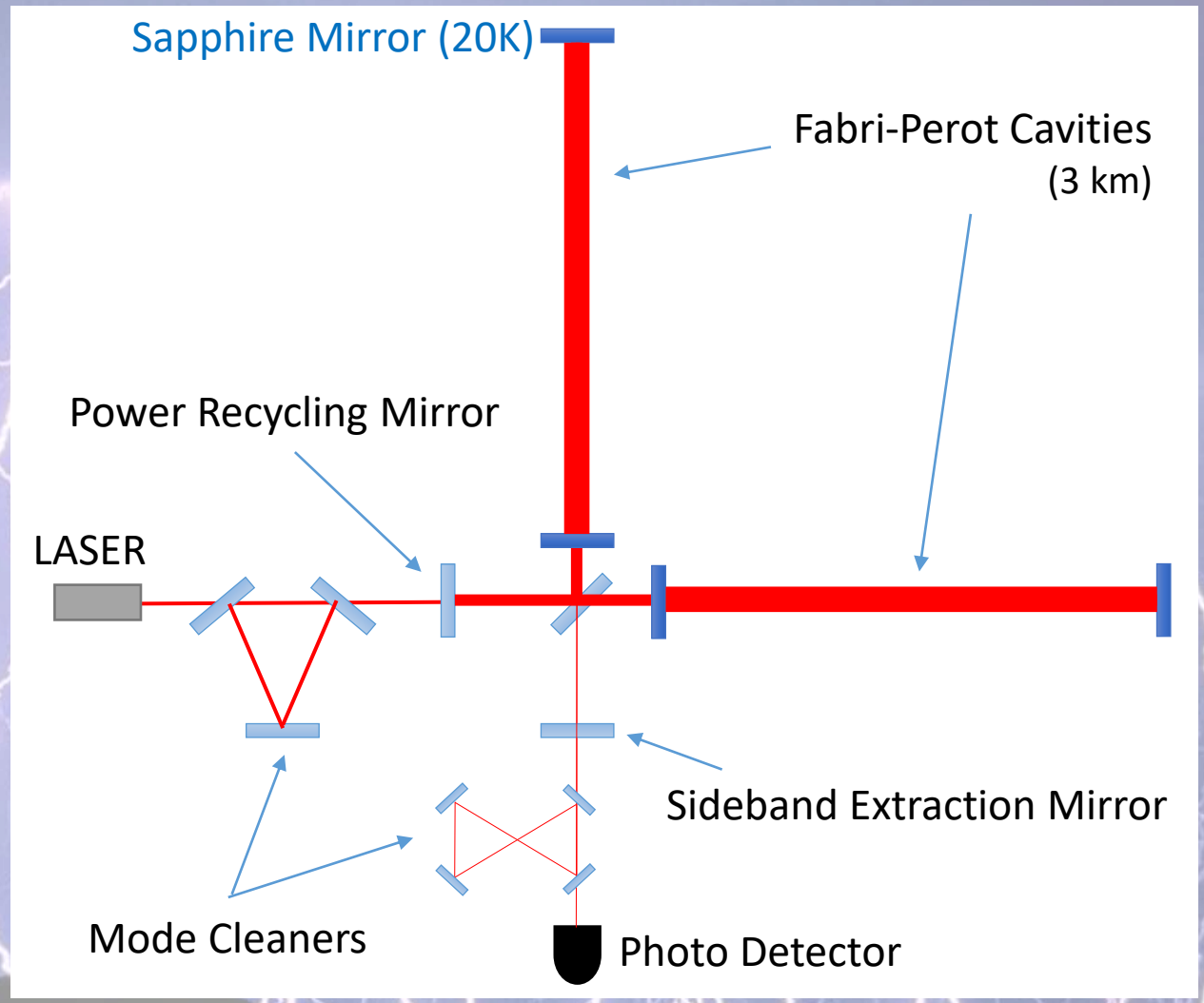
20H05256, 22H04578

Kamioka Lightning & Thundercloud observation and its application for the astroparticle experiments

Tatsuki Washimi (NAOJ)
on behalf of the KAGRA collaboration

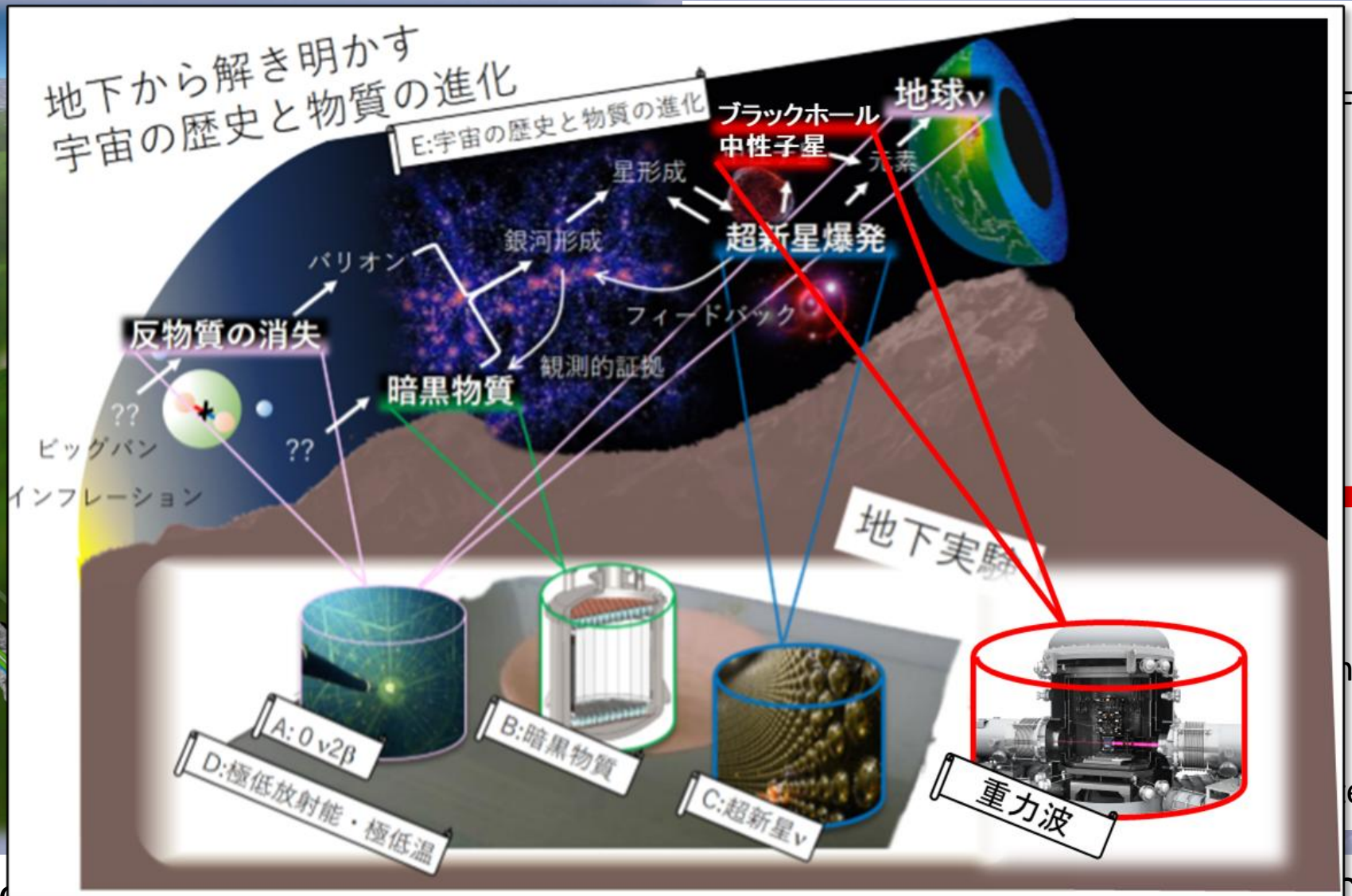
Unraveling the History of the Universe and Matter Evolution with Underground Physics (UGAP2024)
3rd March 2024, Tohoku University, Sendai, Japan.

KAGRA: Kamioka Large-scale Cryogenic GW Telescope



The laser interferometric GW detector constructed at Kamioka underground (200~450 m)

KAGRA: Kamioka Large-scale Cryogenic GW Telescope



Fabri-Perot Cavities
(3 km)

nd Extraction Mirror

ector

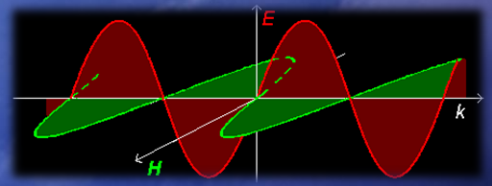
The laser interferometric GW detector constructed at Kamioka underground (200~450 m)

- Also "Underground Physics" for Unraveling the History of the Universe and Matter Evolution

Lightnings and Thunders

Thundercloud
「雷雲」

Light → "Lightning"
「雷光・雷明」



Discharging
↓
"Lightning stroke"
「落雷・雷放電」

Sound → "Thunder"
「雷轟」

Hitting → Lightning strike
「雷撃」

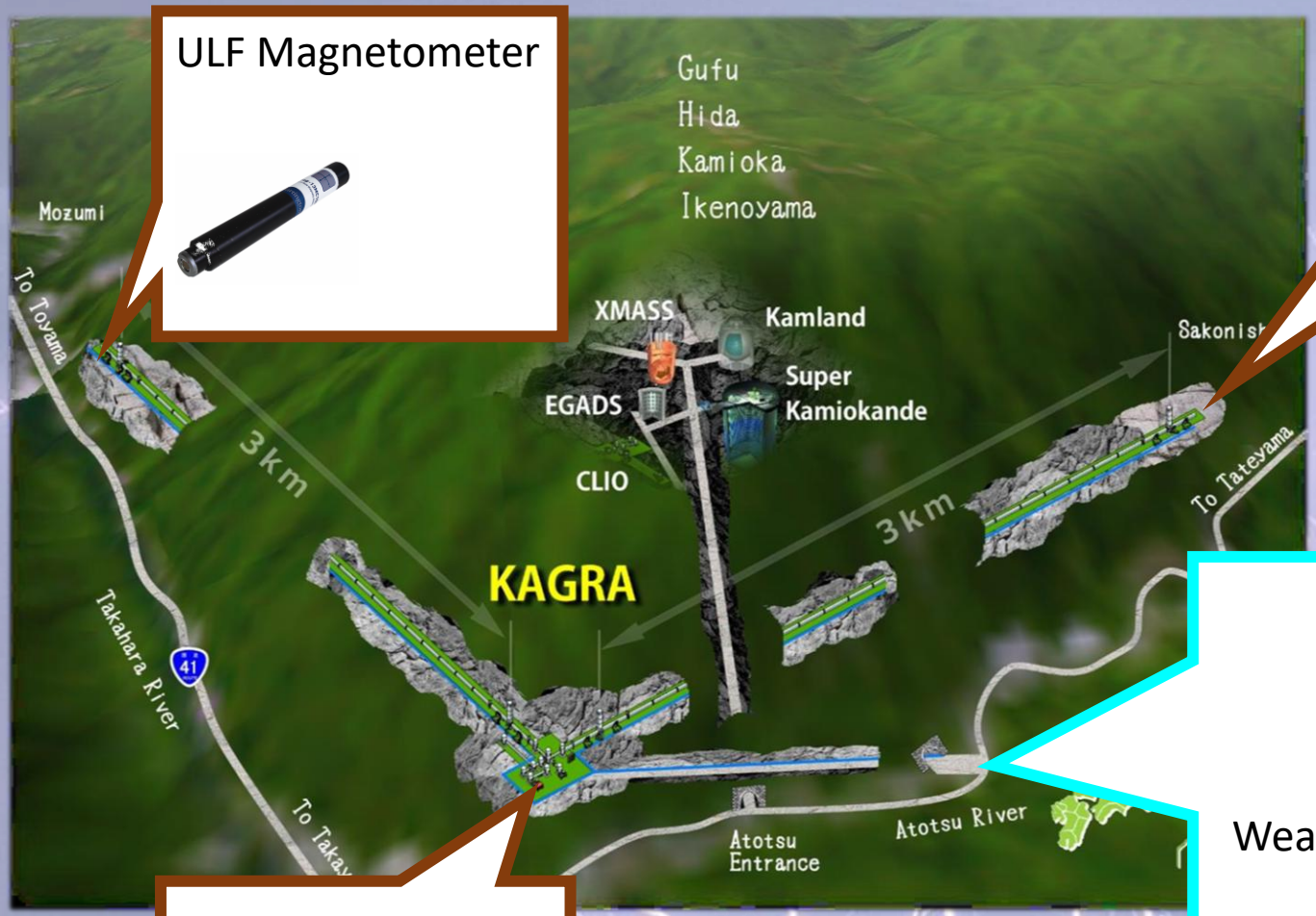
Lightnings and thunders are familiar natural high-energy phenomena.

- They can be noises or backgrounds for the underground experiments.

PEM Sensors for these studies @ KAGRA

2019

Physical Environment Monitoring



ULF Magnetometer

ULF Magnetometer

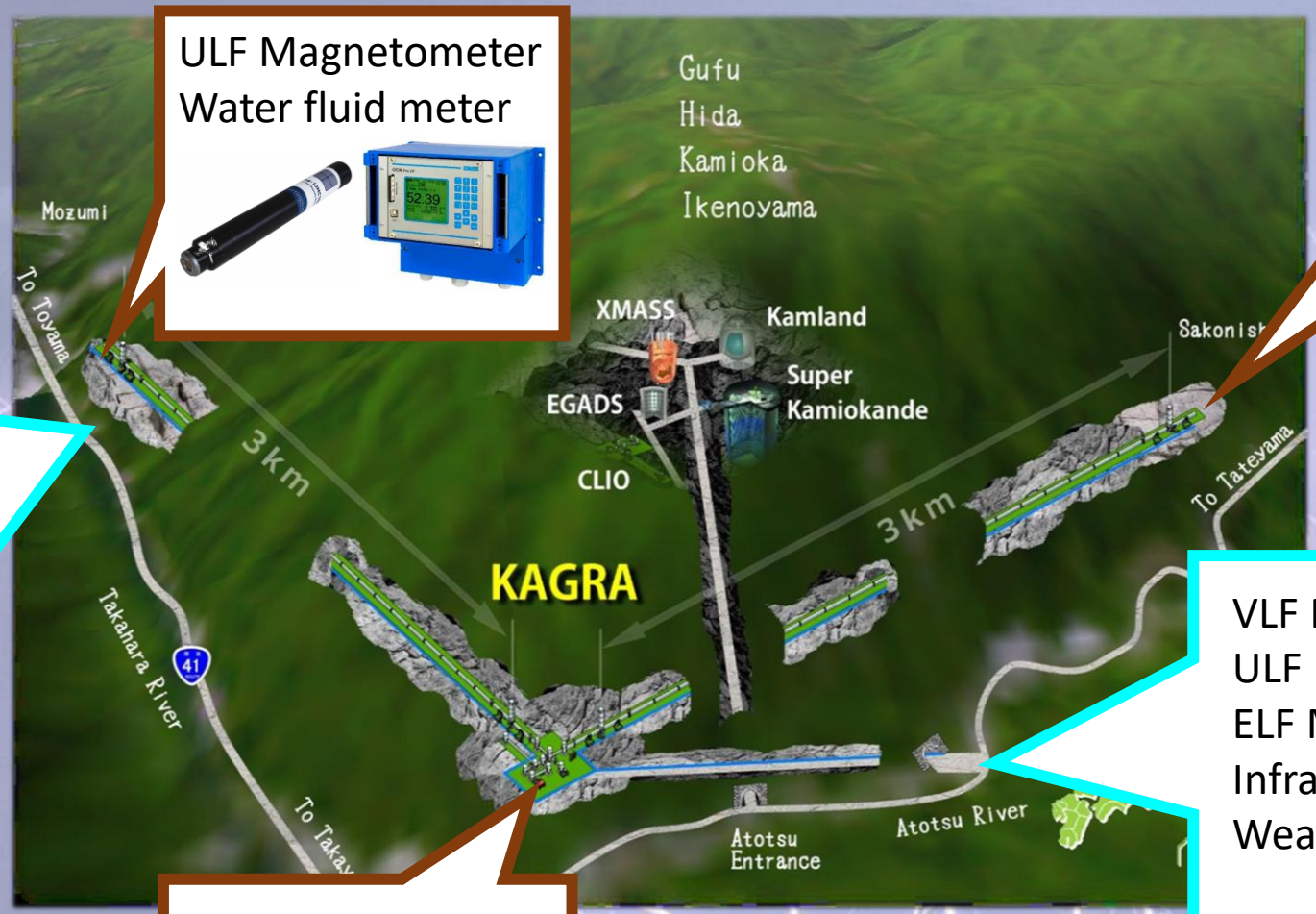
ULF Magnetometer

Weather station

PEM Sensors for these studies @ KAGRA

2024

Physical Environment Monitoring



ULF Magnetometer
Water fluid meter

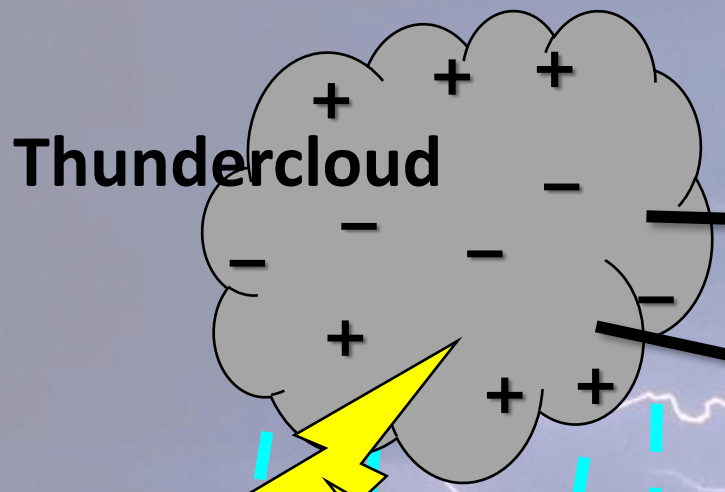
ULF Magnetometer

Infrasound sensor
Weather station
Snow gauge
Gamma-ray detector

ULF Magnetometer

VLF Magnetometer (Blitzortung)
ULF Magnetometer
ELF Magnetometer
Infrasound sensor
Weather station

Observations and Applications



Lightning

Rain

Underground water

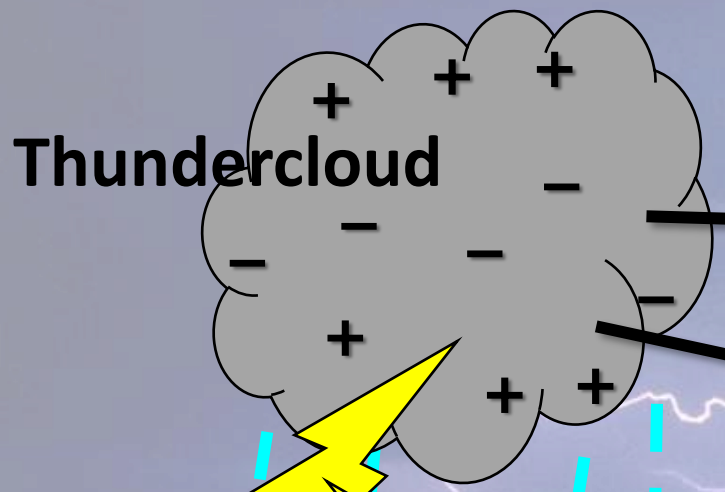
Observations

- Electric Field
- HEP (γ, $e^{\pm}$, n)
- Acoustic wave
- EM wave
- Water

Applications

- Thundercloud v?
- Energy estimation
- Lightning Localization
- Noise monitor for GW
- Neutron flux @ UG

Observations and Applications



Lightning

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Underground water

Observations

Electric Field

HEP (γ, $e^{\pm}$, n)

Acoustic wave

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Applications

Thundercloud v?

Energy estimation

Lightning Localization ②

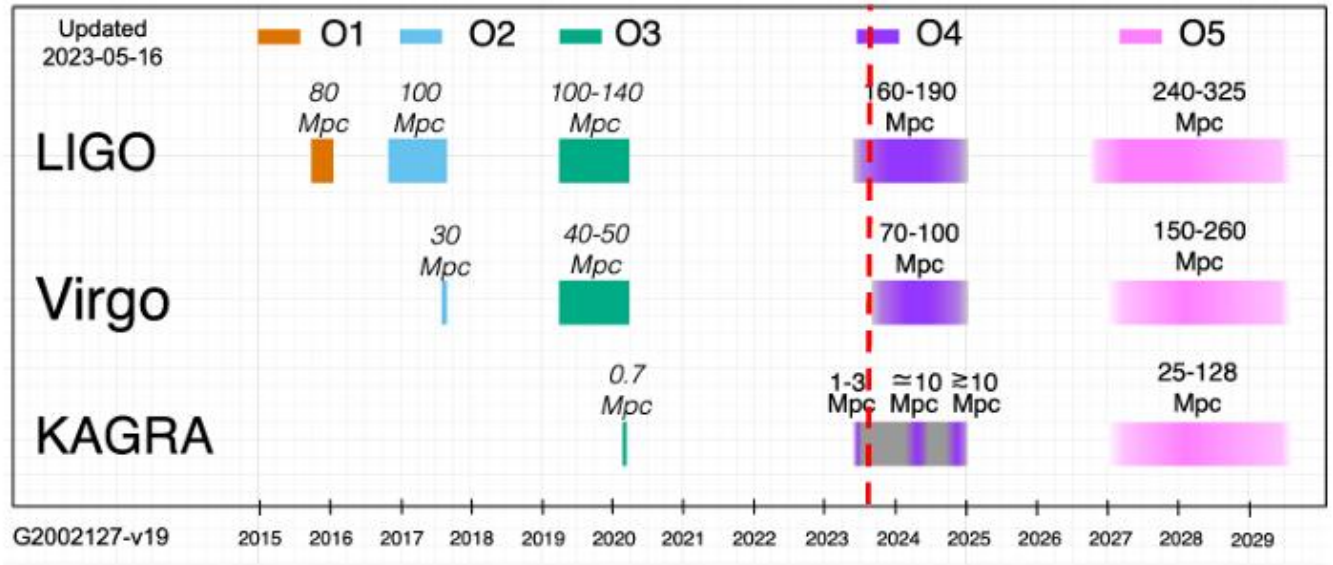
Noise monitor for GW ①

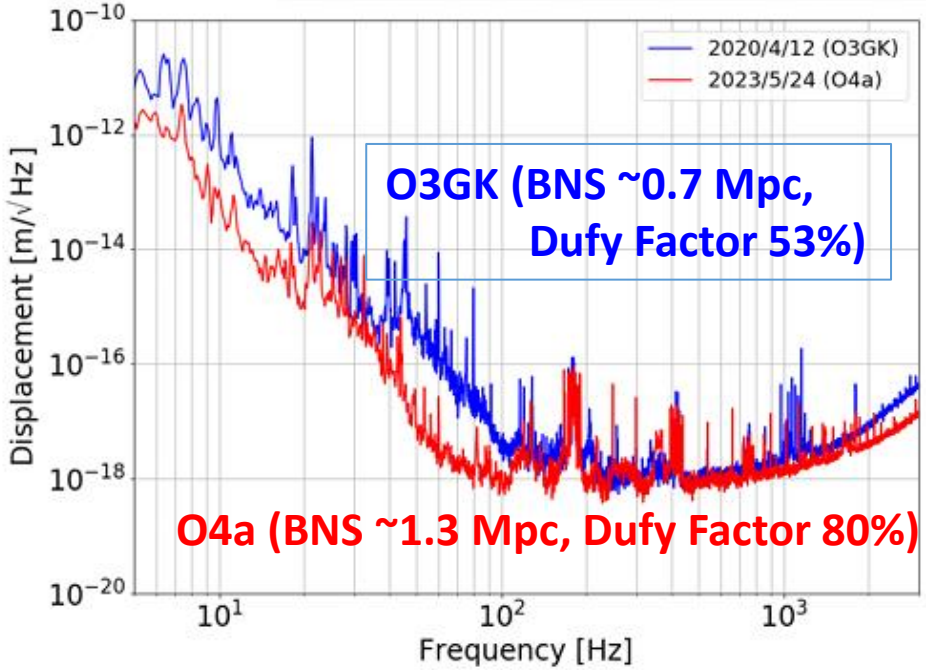
Neutron flux @ UG

Today's Talk

International GW Observation Run (O4a)

T. Ushiba, TAUP2023





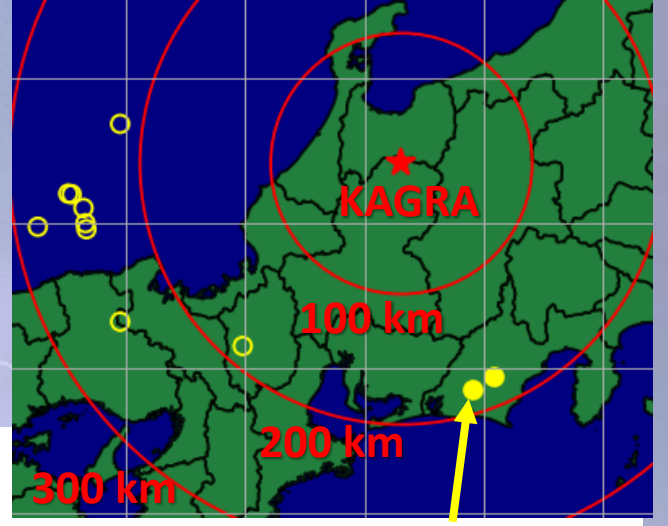
- O4 started from May 24.
- KAGRA joined from May 24 to June 21 with better sensitivity than O3GK.
- KAGRA has commissioning break for improving the sensitivity and ~~will be back to the observing run in next spring.~~

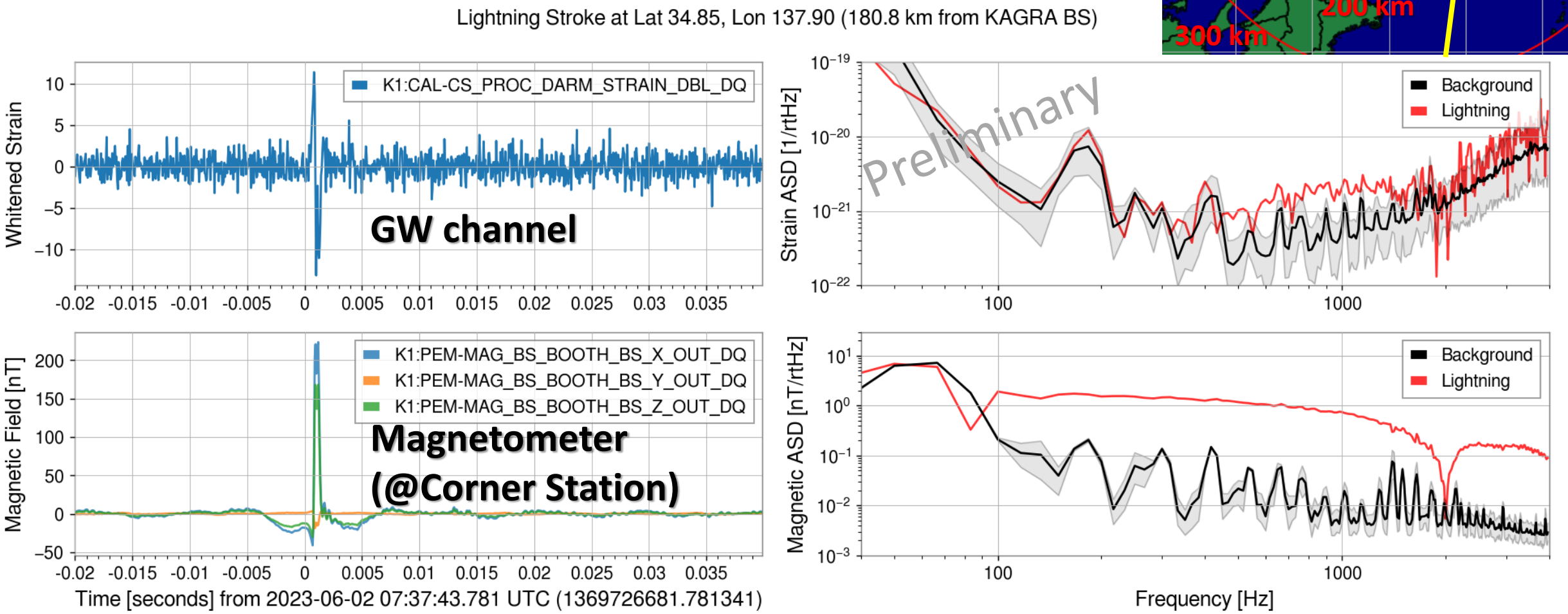
Unclear due to the 1/1 Noto earthquake

Lightning noise event in O4a

In the Blitzortung database, 11 lightnings were recorded (<300km).

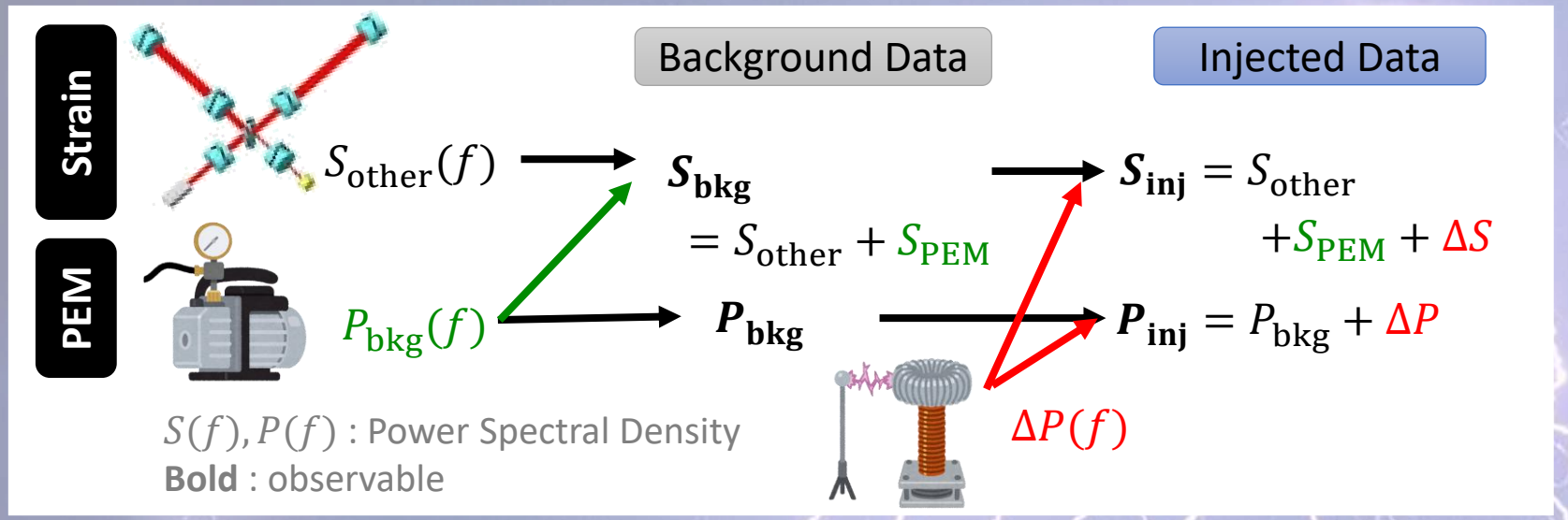
- All events were detected by the underground magnetometers.
- 2 events were found in the GW channel.



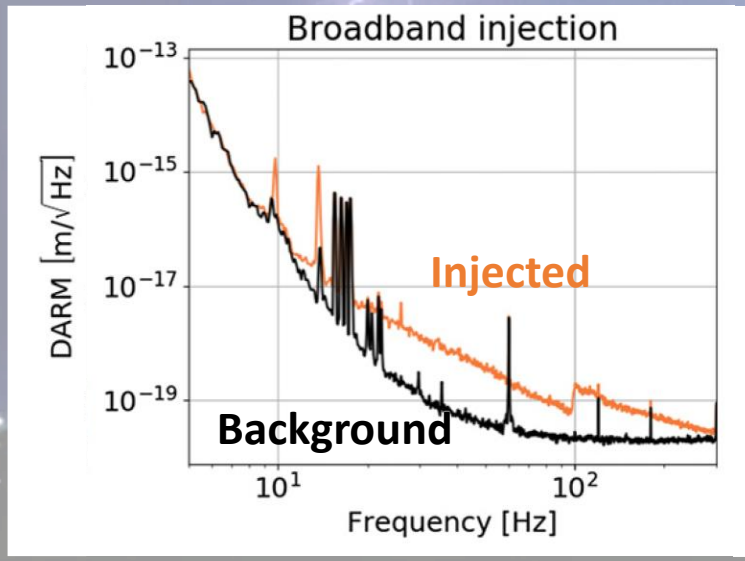


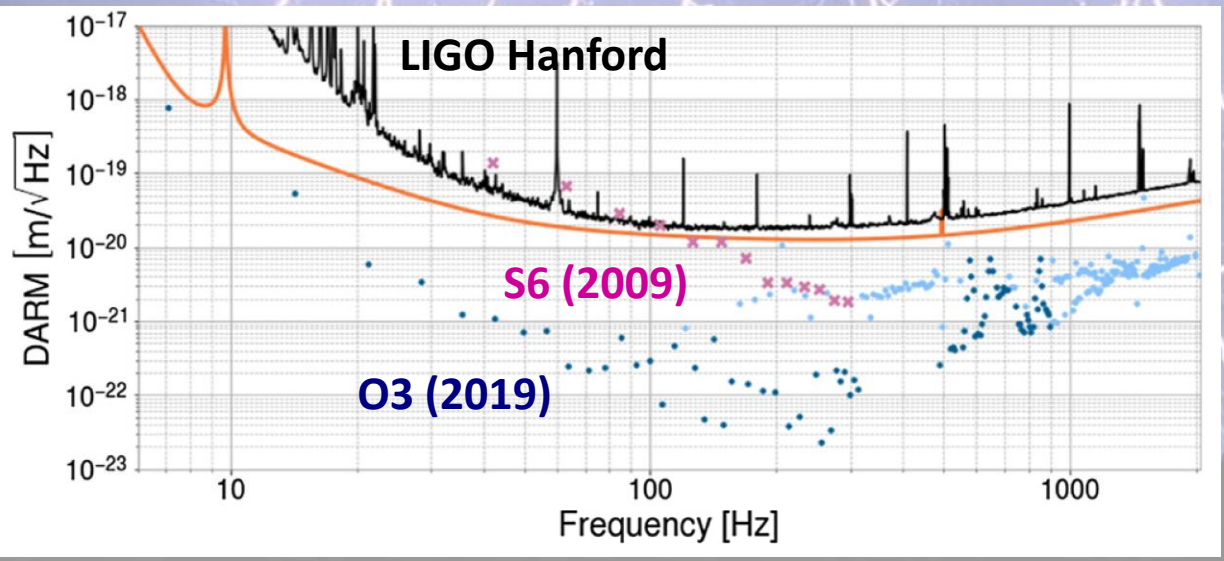
Evaluation of the Ambient Magnetic Noise

PEM injection is a technic to evaluate the ambient environmental noise in the strain signal.



P. Nguyen *et al.*, 2021
CQG **38** 145001



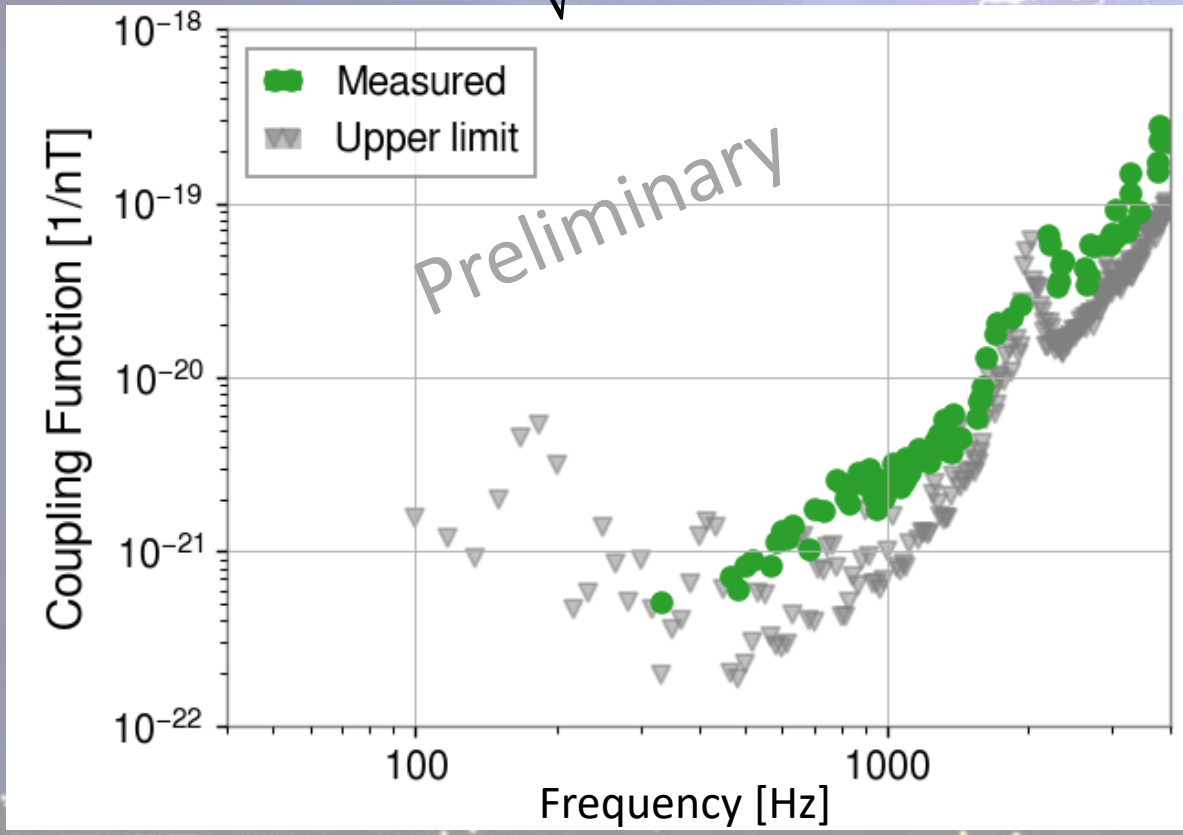


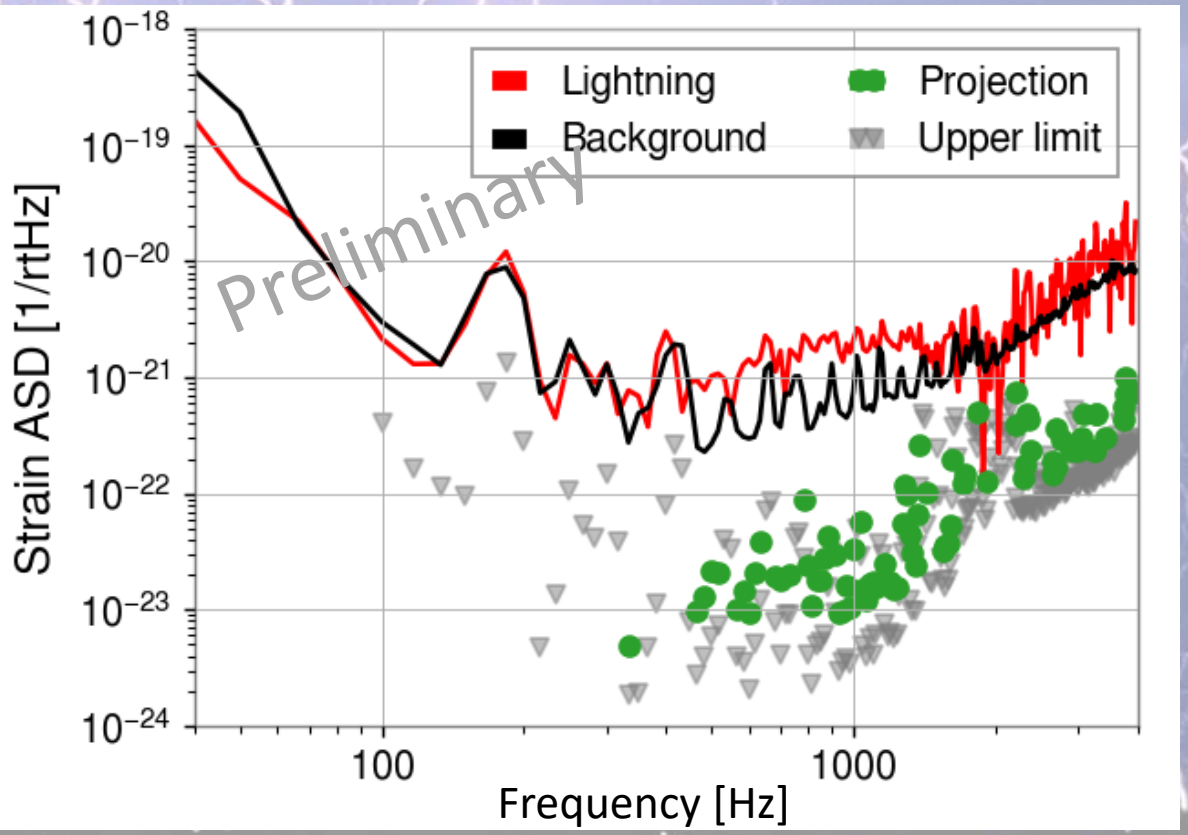
Evaluation of the Ambient Magnetic Noise

I analyzed the lightning noise as PEM injection tests and evaluated the magnetic coupling.

$$CF(f) = \frac{\sqrt{S_{\mathrm{inj}}(f) - S_{\mathrm{bkg}}(f)}}{\sqrt{P_{\mathrm{inj}}(f) - P_{\mathrm{bkg}}(f)}}$$

$$\sqrt{S_{\mathrm{PEM}}(f)} = CF(f) \cdot \sqrt{P_{\mathrm{bkg}}(f)}$$

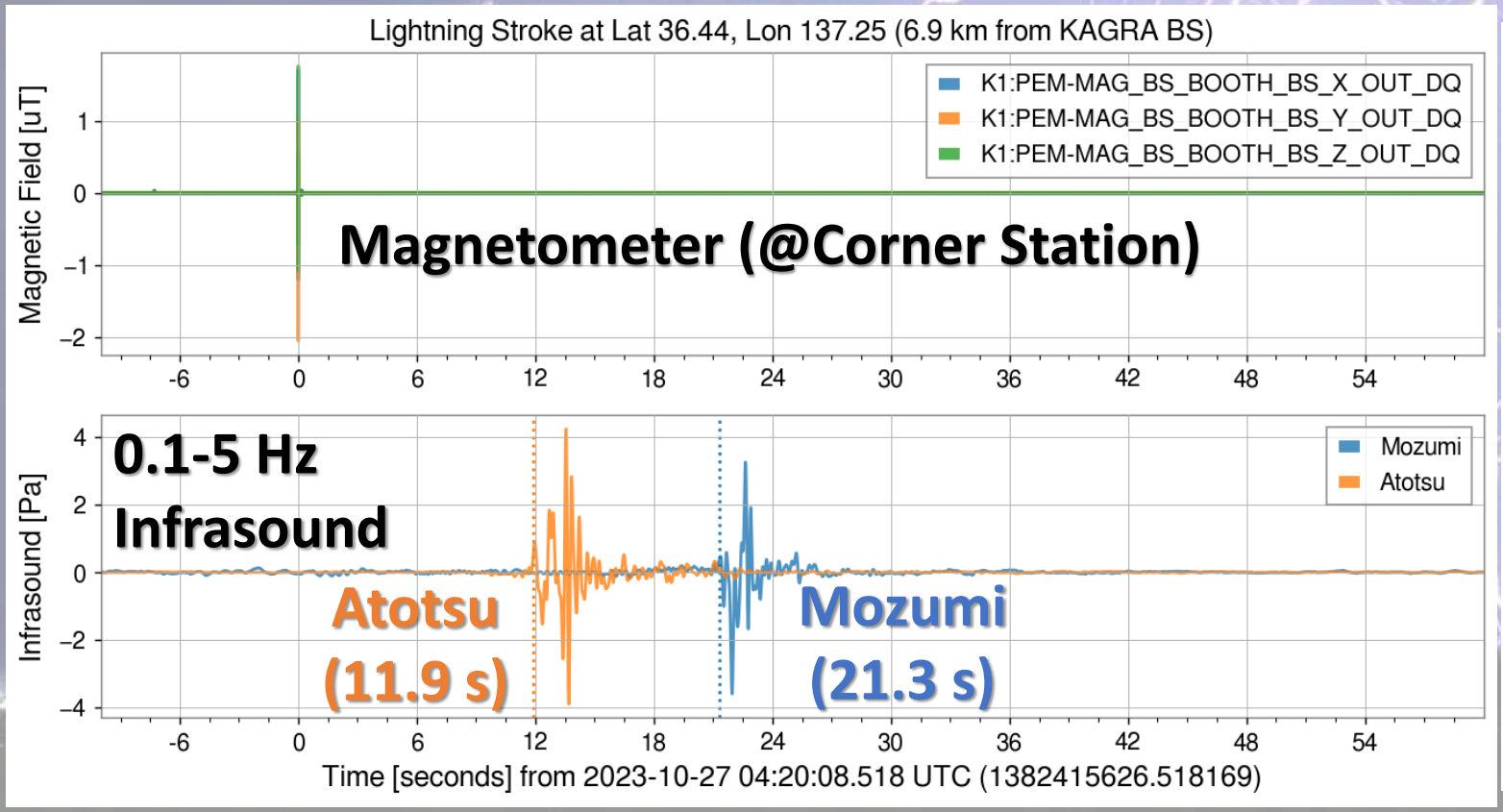


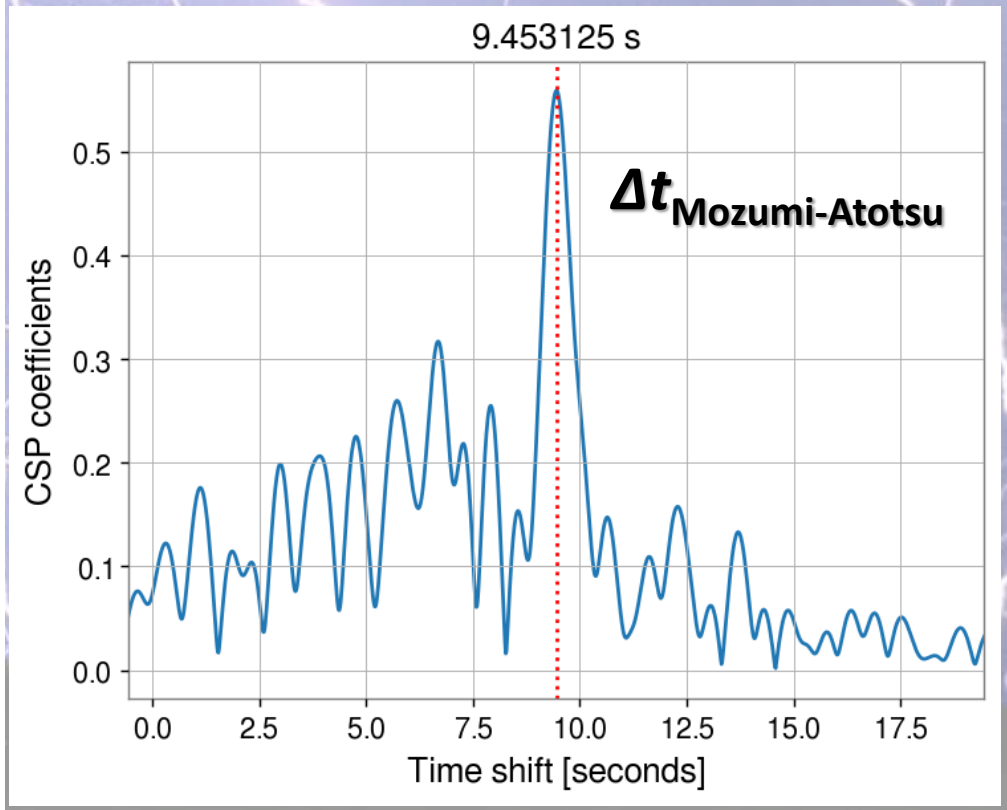


The projected magnetic noise for the normal time was order 1-2 below.

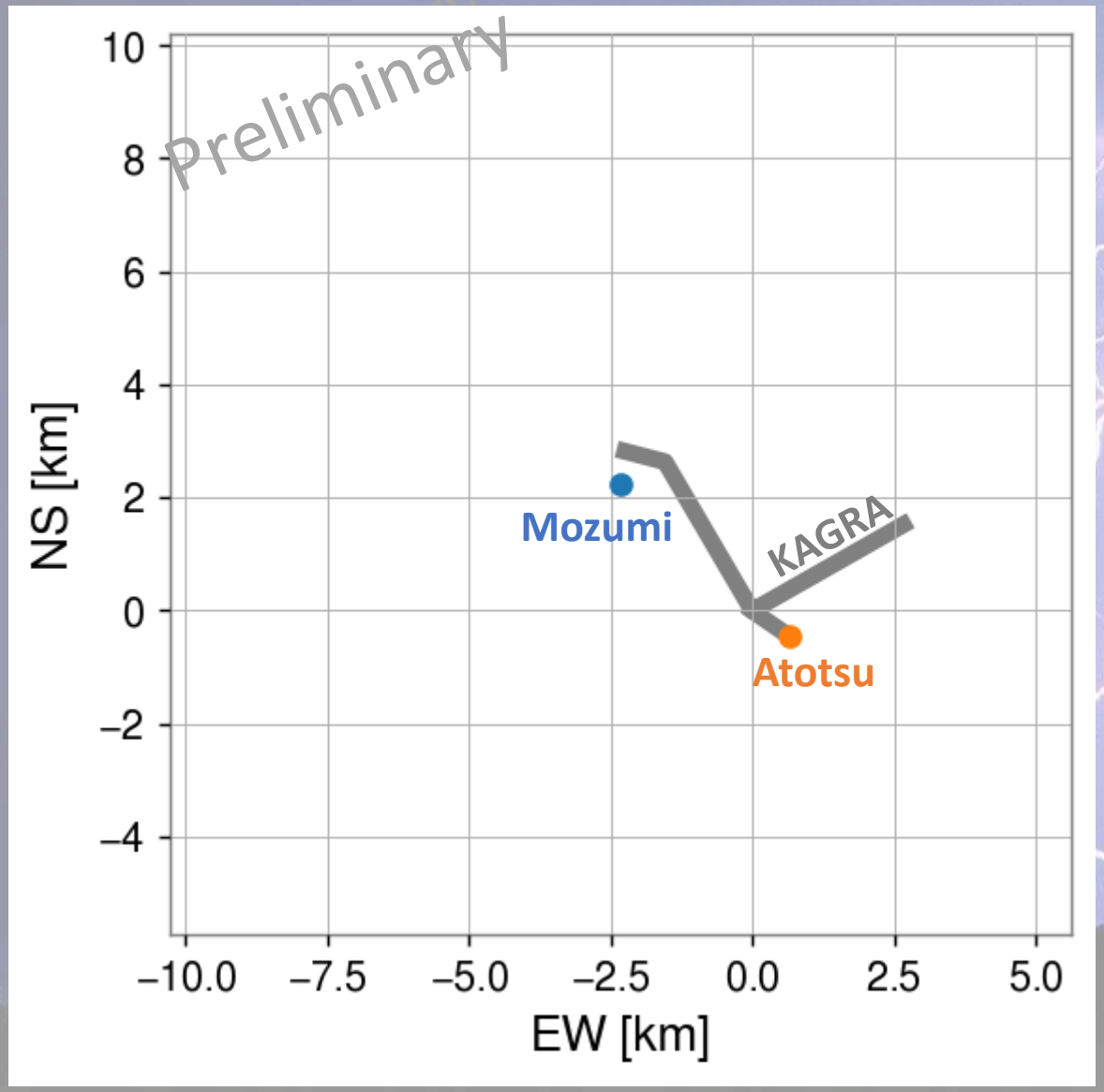
Thunder infrasound (low-frequency sound)

- Thunder is well known as one of the sources of infrasound.
  - Position location and energy estimation using thunder are devised.
  - Better localization accuracy/resolution than EM-wave observation is expected.
- The GW detector (Virgo) on the ground has detected the effects of thunder. [arXiv:2203.04014]
- Infrasound sensors (SAYA INF04) are working at Kamioka surface, Mozumi and Atotsu.





Thunder Localization by the Infrasound signal



Localization for the previous page event.

The major uncertainties are the sound speed and the sound source height

- v_s = 340 m/s in this analysis
- larger circle -> on the ground
- smaller circle -> 3.2 km above

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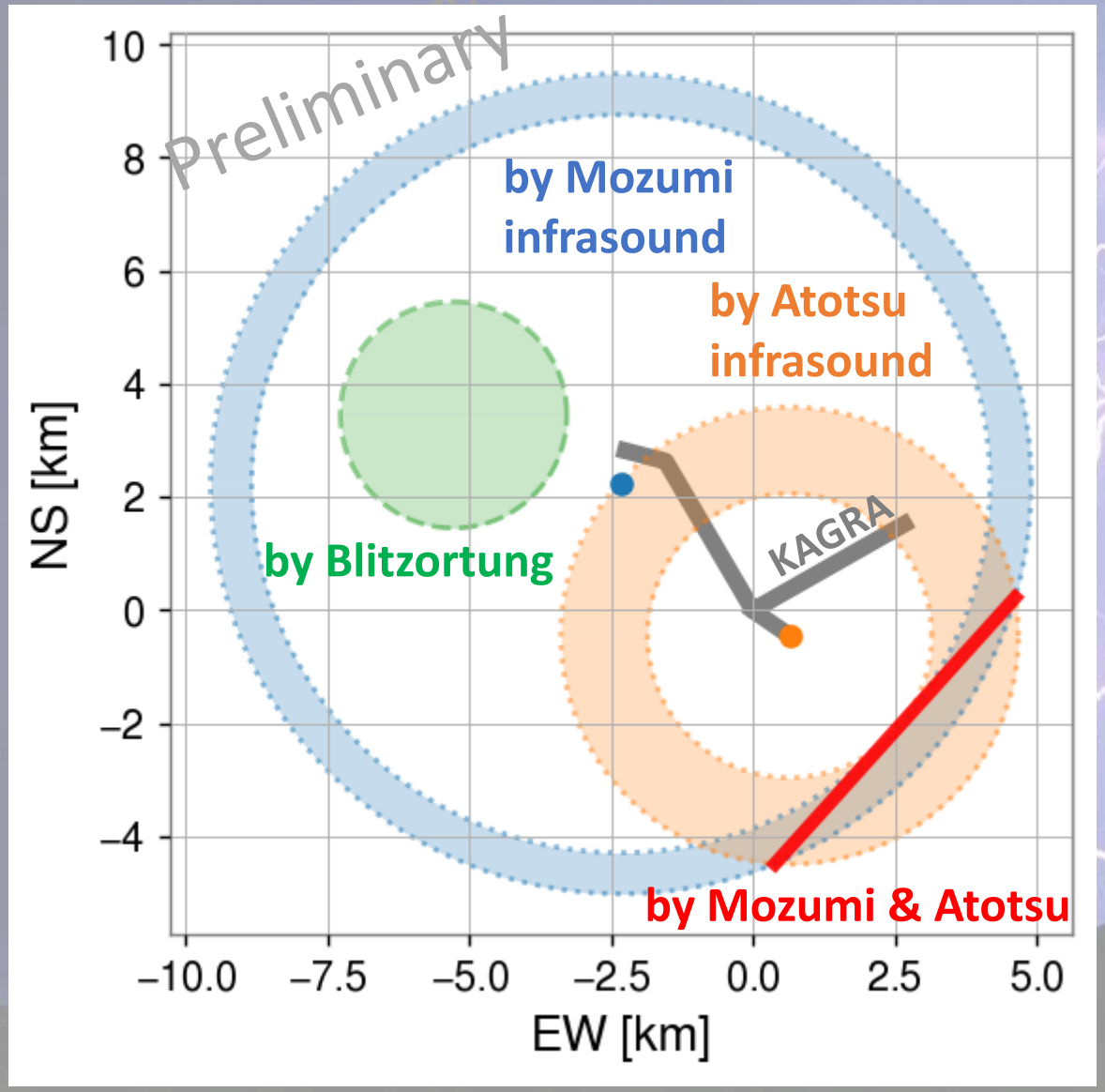

Localization for the previous page event.

The major uncertainties are the sound speed and the sound source height

- v_s = 340 m/s in this analysis
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The estimated position was inconsistent with that of Blitzortung (using VLF EM-wave)

- Some mistake for the measurement and analysis?
- Uncertainty of the Blitzortung (typical error is ±2 km) was larger for this event?
- Emitting positions of the EM-wave and the infrasound were different?

Summary

- ◆Lightnings & thunders are interested phenomena for the underground astroparticle experiments.
- ◆Lightning & thunder monitoring is developed in Kamioka.
  - Two more infrasound sensors have been purchased.
  - A snow gauge and a water fluid meter have been purchased.
- ◆Lightning noise event was found in the KAGRA O4a.
- ◆Thunder localization by infrasound was performed.
- ● About rain, snow, underground water, γ-ray:
  - ➢ Please refer the 9th low-BG tech. workshop (Feb. 2024)