Effects of Lightning Strokes on KAGRA Observatory

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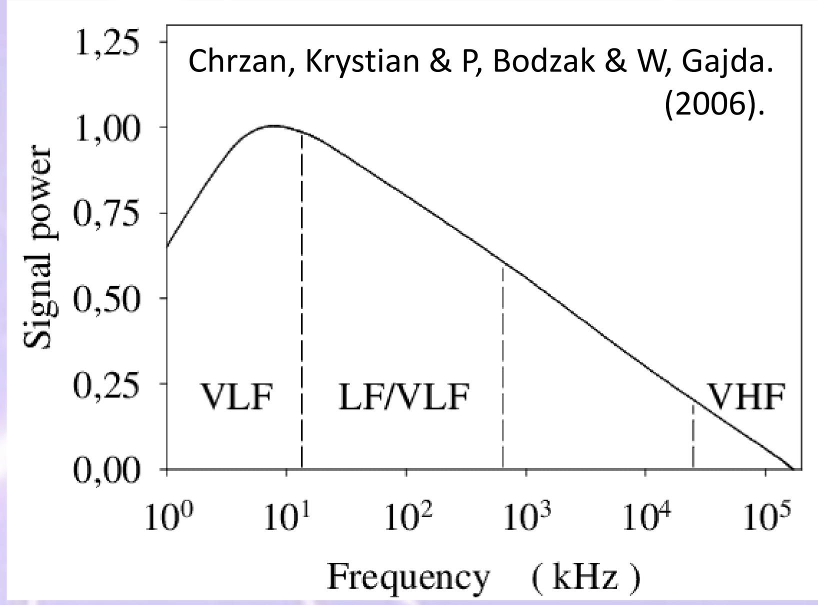
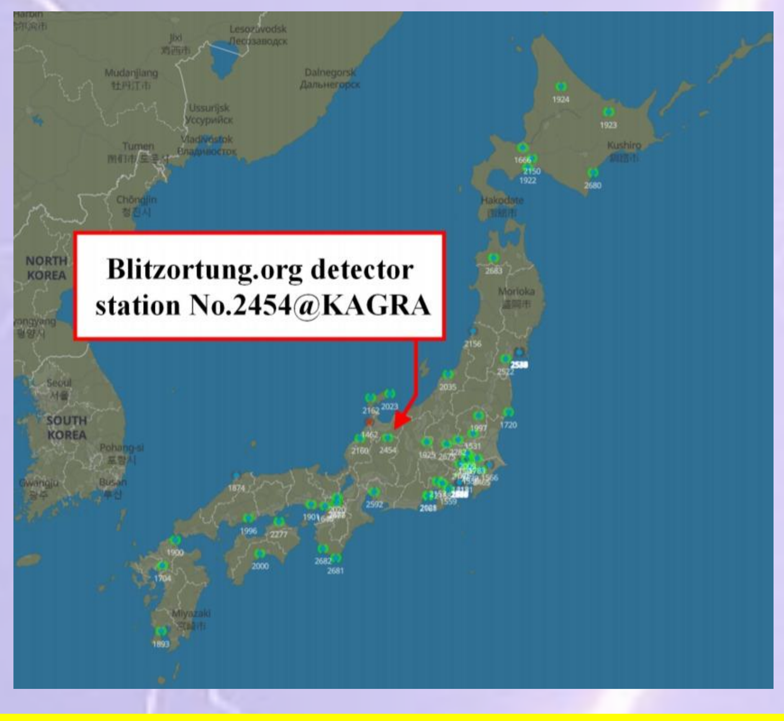
1. Lightning detection system in KAGRA

Lightning generates a large pulse of a magnetic field (it has a peak around 5-10kHz typically) and possibly affects the GW signal by shaking the test-mass mirrors, or incurs electrical noise. However, its effect underground is non-trivial.

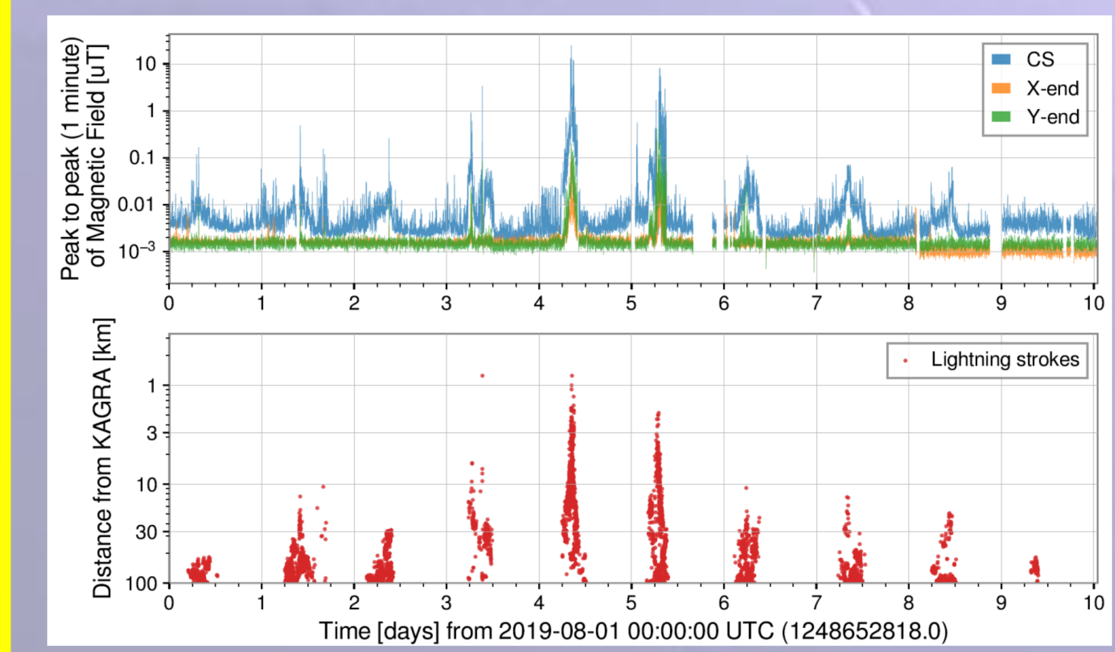


In the KAGRA underground experimental site, there are three 3-axial magnetometers (Bartington Mag-13, DC-3kHz) located in the corner station (CS), and in the X/Y-end. In addition, a lightning detector is located in front of the KAGRA tunnel.



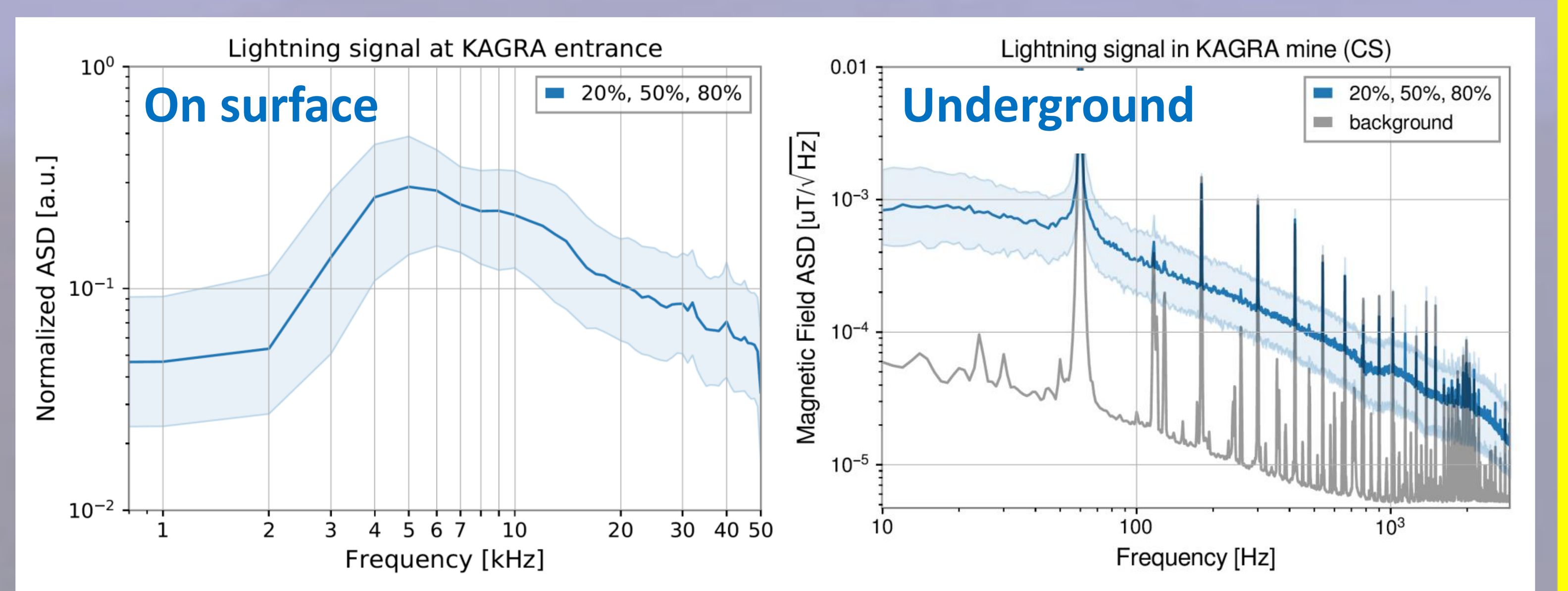
Blitzortung.org is a lightning detection and localization network. A typical detection range for a Blitzortung system-blue detector is about 4000km. Detector station No.2454 is located in front of the KAGRA tunnel. The raw signals of the time series were recorded by a local data logger (GRAPHTEC GL980).

2. Properties of the magnetic field measured inside and outside the KAGRA tunnel

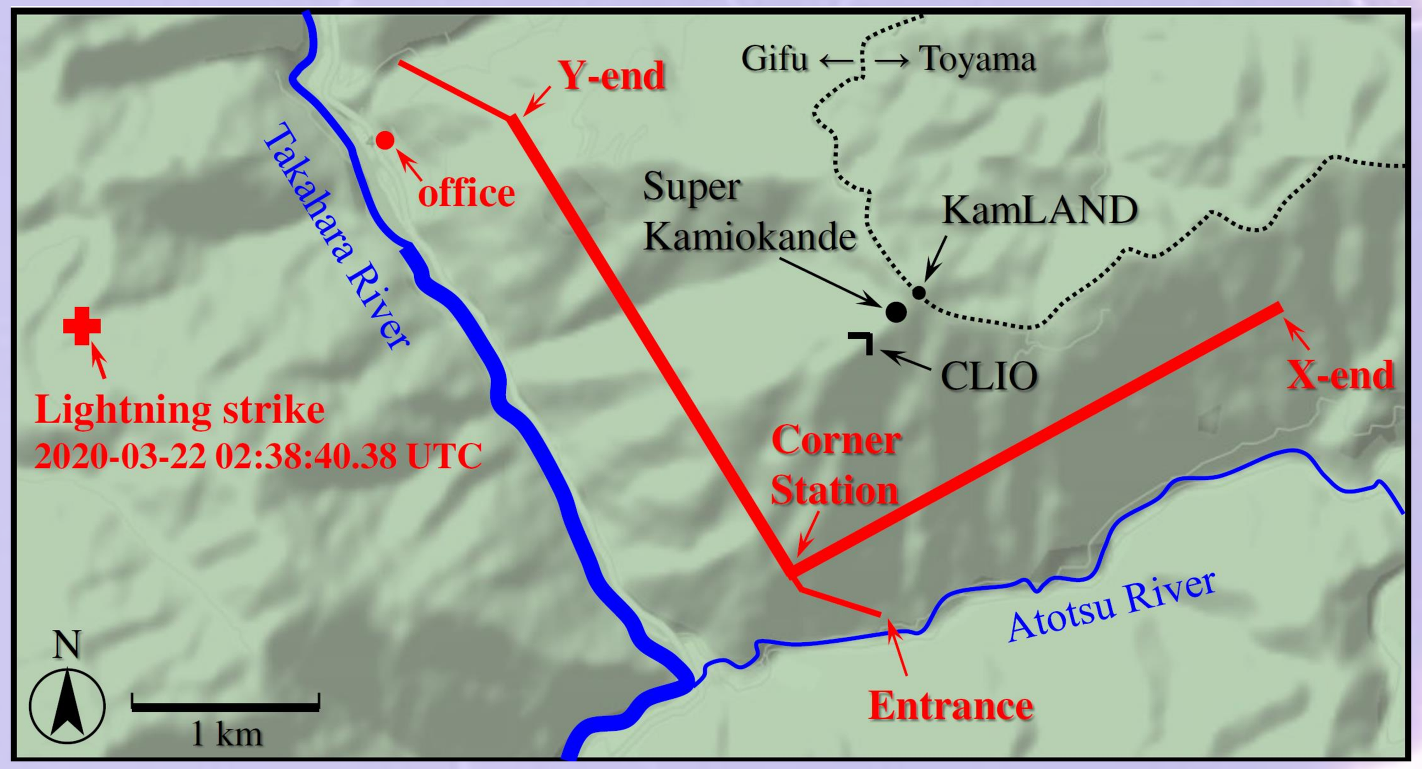


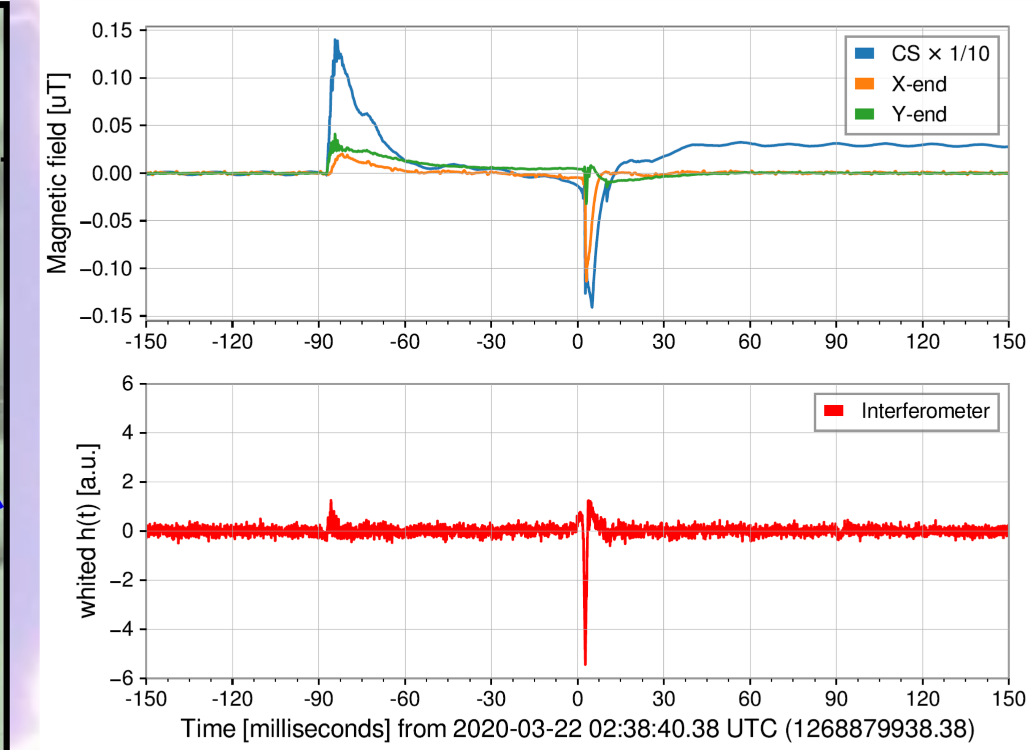
The left figure shows an example of the magnetic field measured in KAGRA tunnel and the distance of lightning strokes from KAGRA. A large magnetic field was observed when lightning strokes occurred near KAGRA. This is because the amplitude of the magnetic wave is decreased in proportion to the path length in the atmosphere. The difference in the magnetic strength between sensor positions can be understood from the results of the skin effect in ground.

The ASDs of the lightning detector (left) and the underground magnetometer (right) for the lightning events are here. There is a peak at ~5kHz for outside, but not for inside. The structure is significantly different between them and is consistent with the skin effect in a qualitative discussion at least in the overlapped frequency of 1-3kHz.



3. Lightning-induced event in the KAGRA $h(t)$ channel





On 2020-03-22 02:38:40.38 UTC, a lightning stroke occurred extremely close to KAGRA. This lightning event was detected by both magnetometers and the GW channel (strain sensitivity, h(t)) of the main interferometer of KAGRA. However, no coincident signals were detected by the other auxiliary channels.

This is the first evidence that a GW detector constructed in an underground facility is excited by lightning strokes in the atmosphere. This means that the lightning will be background events of a burst-GW search, but can be easily identified by the current monitoring system.

4. Summary and Prospects

In the KAGRA PEM, a Blitzortung lightning detector and magnetometers were used to monitor the environmental noise for the GW observation. This system succeeded in monitoring the magnetic field pulses coming from lightning strokes in the atmosphere, both outside and inside the underground experimental site of KAGRA. In addition, it was also confirmed that a lightning-induced event in the GW channel of the KAGRA main interferometer is exhibited, and it can be identified by the current system.

Now we are trying to measure the transfer function of the magnetic pulses from outside to inside the mountain, with locating a magnetometer in front of the tunnel.

References

1. T. Washimi et al., "Effects of lightning strokes on underground gravitational waves observatories", [arXiv:2103.0651], accepted in *JINST*
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3. T. Narita *et al*.,"A study of lightning location system (Blitz) based on VLF sferics", 34th International Conference on Lightning Protection (ICLP), Rzeszow, 2018, pp. 1-7.
4. https://www.blitzortung.org/

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