Estimation of Acoustic Newtonian Noise for Underground GW observatories

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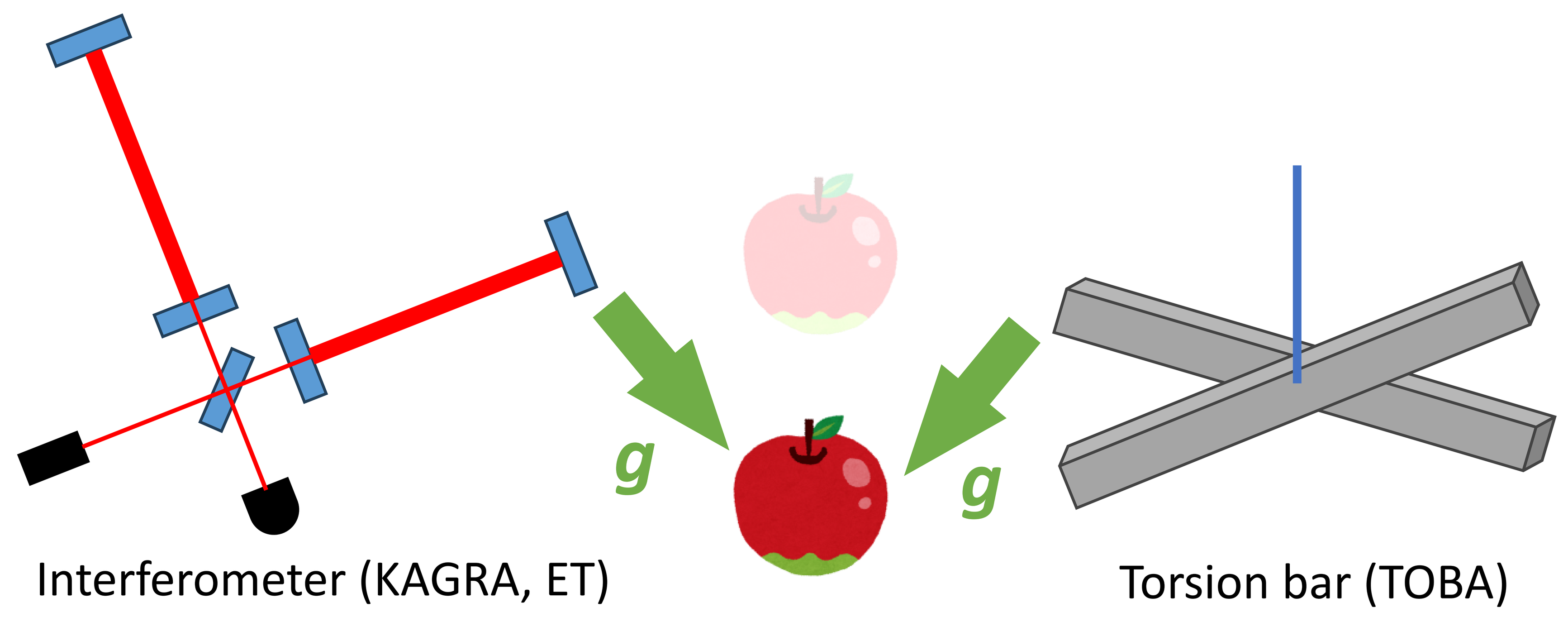
Tatsuki Washimi (NAOJ) on behalf of the KAGRA collaboration

Newtonian noise (or gravity gradient noise) is one of the principal noises for ground-based GW detectors, especially below 10 Hz. In this study, we estimate the NN caused by the acoustic field inside an underground facility for the KAGRA and further detectors based on the infrasound sensors' data at the KAGRA site.

Newtonian Noise on GW detectors

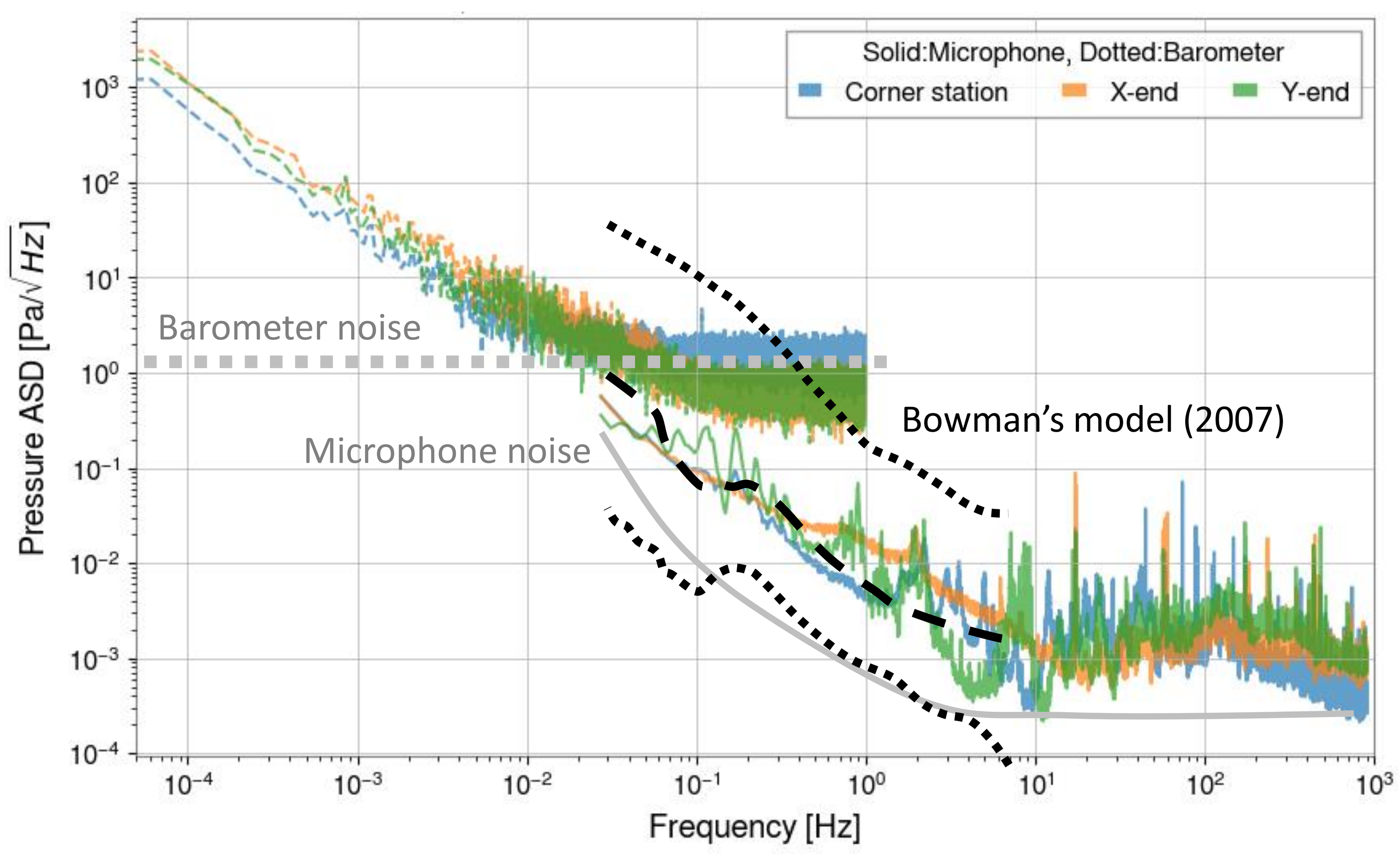
For a ground-based GW detector, improvement of its sensitivity at a lower frequency (below 10 Hz) is necessary, especially for studies of the BSM new physics. Constructing an underground facility to reduce seismic noise is one effective way.

Newtonian noise NN (or gravity gradient noise), caused by a Newtonian gravity force between a test mass of a GW detector and some material around it, is one of the principal noises for ground-based GW detectors, especially at lower frequencies. Because it cannot be shielded, the estimation of the NN in advance and the design of the facility to minimize the NN is quite important.



Origins of NN are assumed *e.g.* seismic waves (body waves, surface waves), mechanical vibration of experimental apparatus, drain water fluid, density fluctuation of are (pressure, temperature), *etc*. In this study, we focus on air pressure waves inside an experimental site of a GW detector facility.

Pressure Spectrum @ KAGRA tunnel

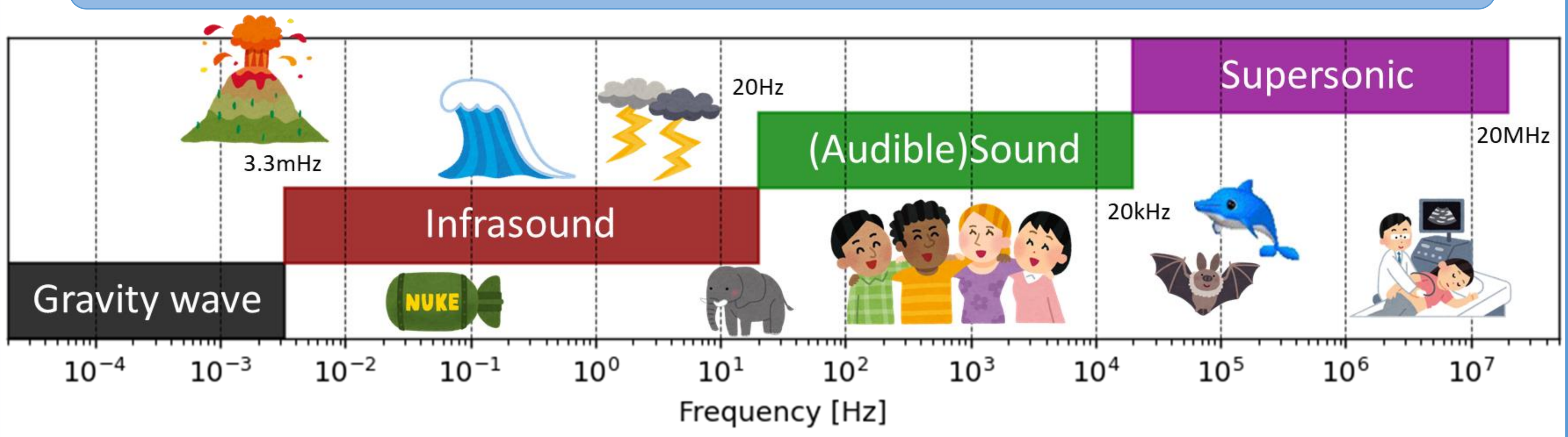


This figure shows the typical amplitude spectral densities (ASDs) of the microphones (ACO4152N + Low-frequency type amplifier, solid lines) and the barometers (Vaisala PTB110, dotted lines) located at each station of the KAGRA underground facility. The gray lines are the noise level of each sensor (include sensor noise and ADC noise).

The infrasound and pressure ASDs below 10 Hz are approximated $\propto f^{-5/4}$, and their amplitude is well consistent with the well-known Bowman's model of ambient infrasound noise[2].

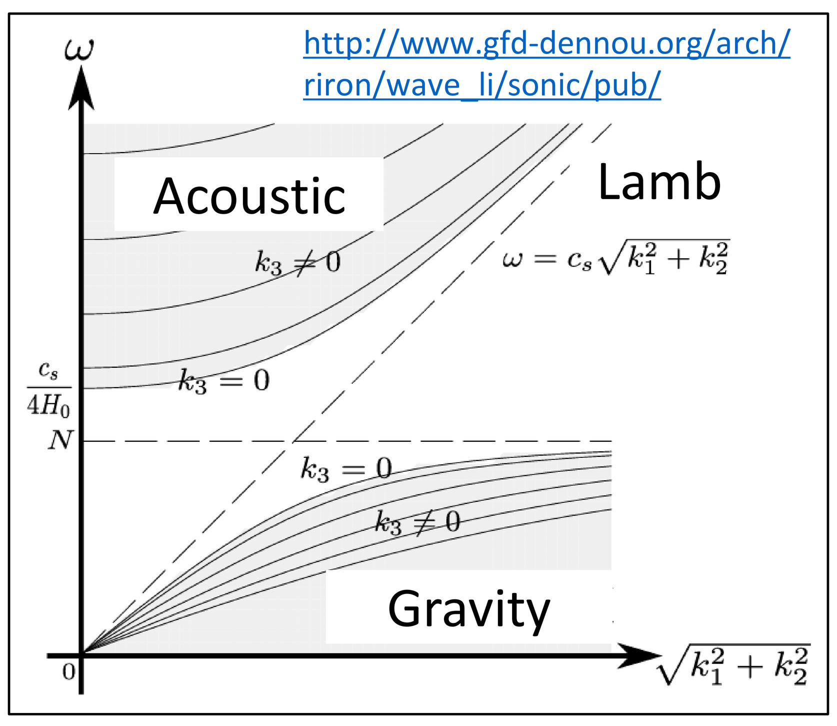
[2] J.R. Bowman *et al.*, Infrasound Technology Workshop (2007)

Air Pressure Waves



Infrasound is acoustic waves (longitudinal waves) in the lower frequency range less than 20 Hz, below the human hearing.
It can be used to understand various geophysical phenomena, such as volcanic eruptions, tsunamis, earthquakes, landslides, meteorites entering the atmosphere, and various man-made noises (windfarm, explosions, nuclear tests, etc.).

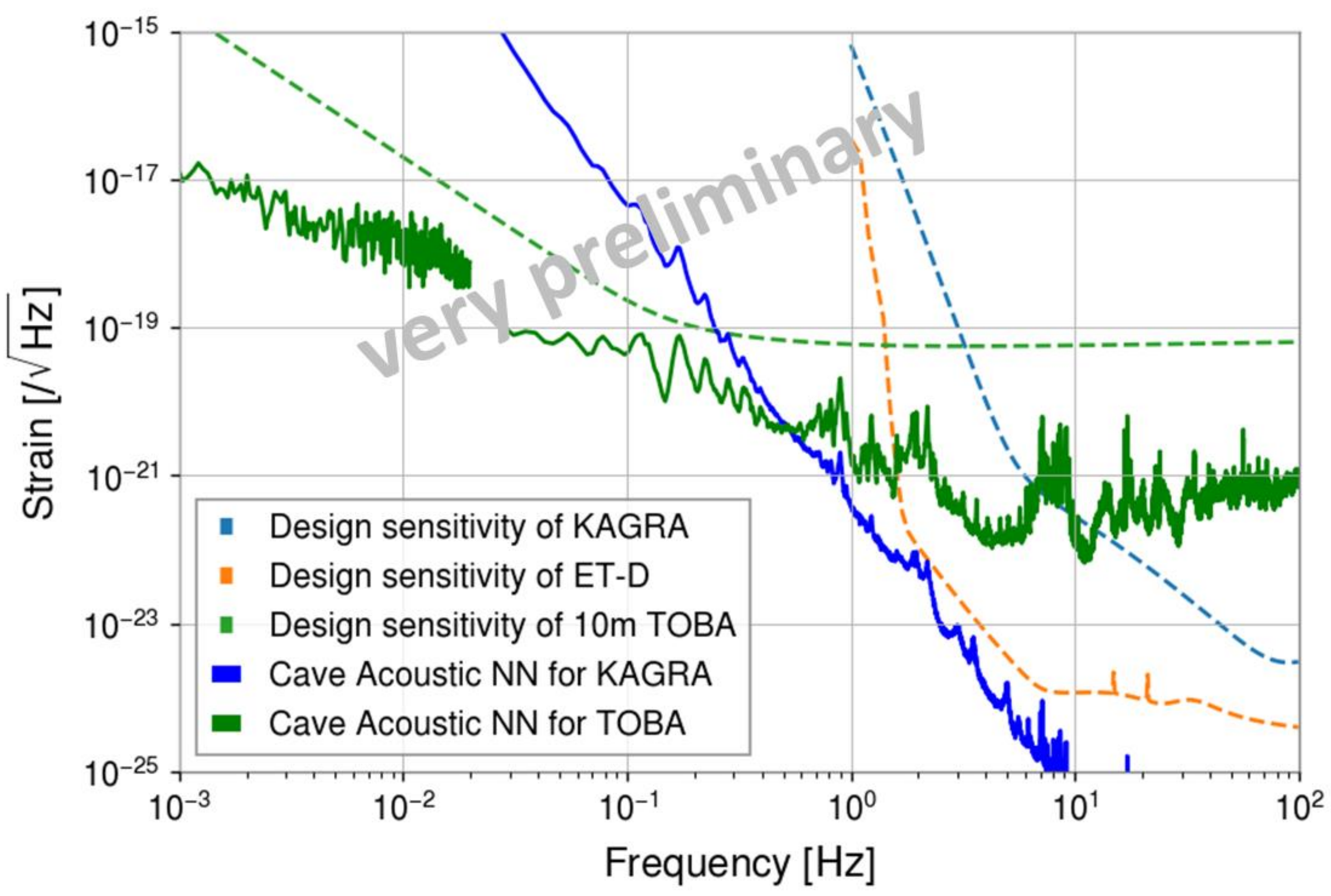
Gravity waves are air pressure waves (transverse waves) that propagate vertical vibrations due to gravity and buoyancy in the air, below a frequency of the acoustic cutoff (3.3 mHz) of the dispersion relation. Note that it is a completely different phenomenon from gravitational waves of the space-time.



We observed the air pressure waves from the Tonga eruption 2022.

[1] T. Washimi et al., *PTEP* 2022, Issue 11, 113H02

Estimation of the Cave Acoustic NN



Here we estimated the NN from cave (in-room) acoustic noise measured in the KAGRA site and compared them to the design sensitivity of the underground GW detectors (KAGRA, ET, and TOBA).
For an interferometric GW detector, we can use the following formula[3]:

$$S_{\mathrm{cave,IFO}}(f) = \sum_{i=1}^{4} \left(\frac{2 c_s G \rho_0 \delta p_{\mathrm{cave},i}(f)}{p_0 \gamma f} \right)^2 \frac{(1 - \mathrm{sinc}(2\pi f R_i / c_s))}{3 L^2 (2\pi f)^4}$$

For a torsion bar type GW detector, the cave acoustic NN contribution is estimated to be 3×10^{-19} strain/Pa, constant over frequency[4].

[3] F. Amann *et al.*, *Rev. Sci. Instrum.* **91**, 094504 (2020)
[4] D. Fiorucci *et al. Phys. Rev. D* **97**, 062003 (2018)

In this study, we measured the air pressure spectrum at each station of the KAGRA underground facility, with microphones and barometers. Based on this data, the acoustic NN inside an underground facility for the KAGRA and the TOBA are estimated. These results are smaller than the design sensitivity of the GW detectors. To make the results more precise, the realistic evaluation of the spatial correlation of the acoustic field based on a simulation and/or a simultaneous measurement with many sensors (10-100) is necessary. Estimation of the acoustic NN contribution from the atmosphere (sky) above the ground is also important.