Acoustic injection in the KAGRA site

2020-12-19, 7th KAGRA International Workshop

Tatsuki Washimi (NAOJ) on behalf of the KAGRA PEM

Physical Environmental Monitors (PEM)

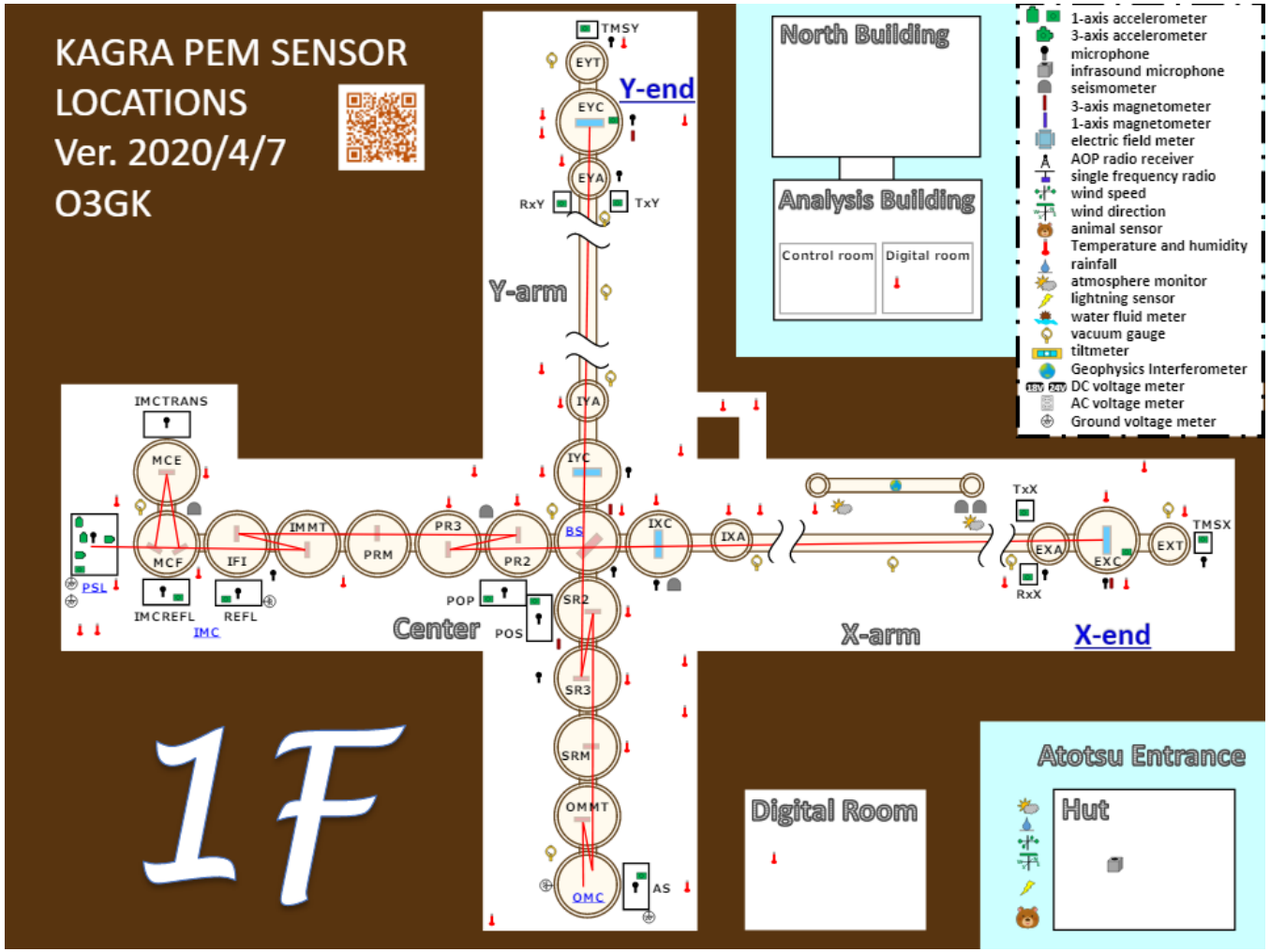
https://www.icrr.u-tokyo.ac.jp/~washimi/KAGRA/PEM/PEMmap/archives/O3GK/

GW detector is exposed to much environmental noise, such as :

- mechanical vibration, seismic motion
- acoustic field
- magnetic field, electrical noise, RF

It's important to
①measure, ②reduce, ③shield, and ④subtract them for the GW observation.

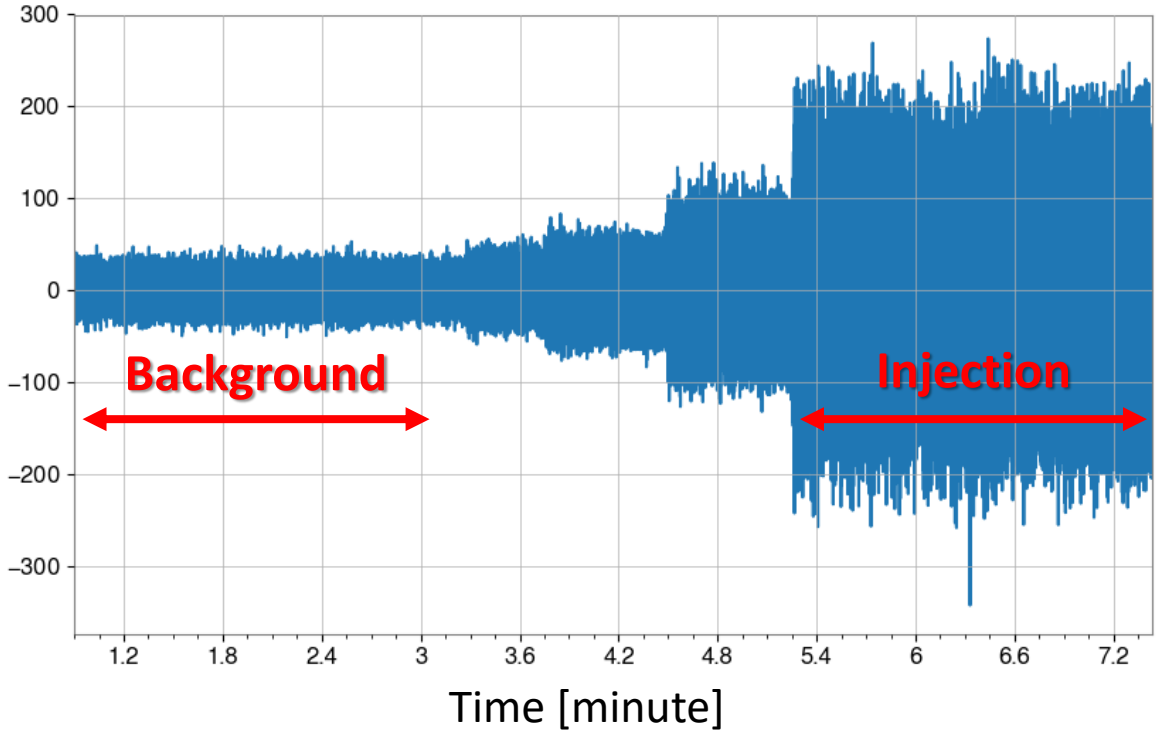
← We held "LVK PEM meeting" in KAGRA.



Details of KAGRA PEM was presented by T.Yokozawa [ID29]

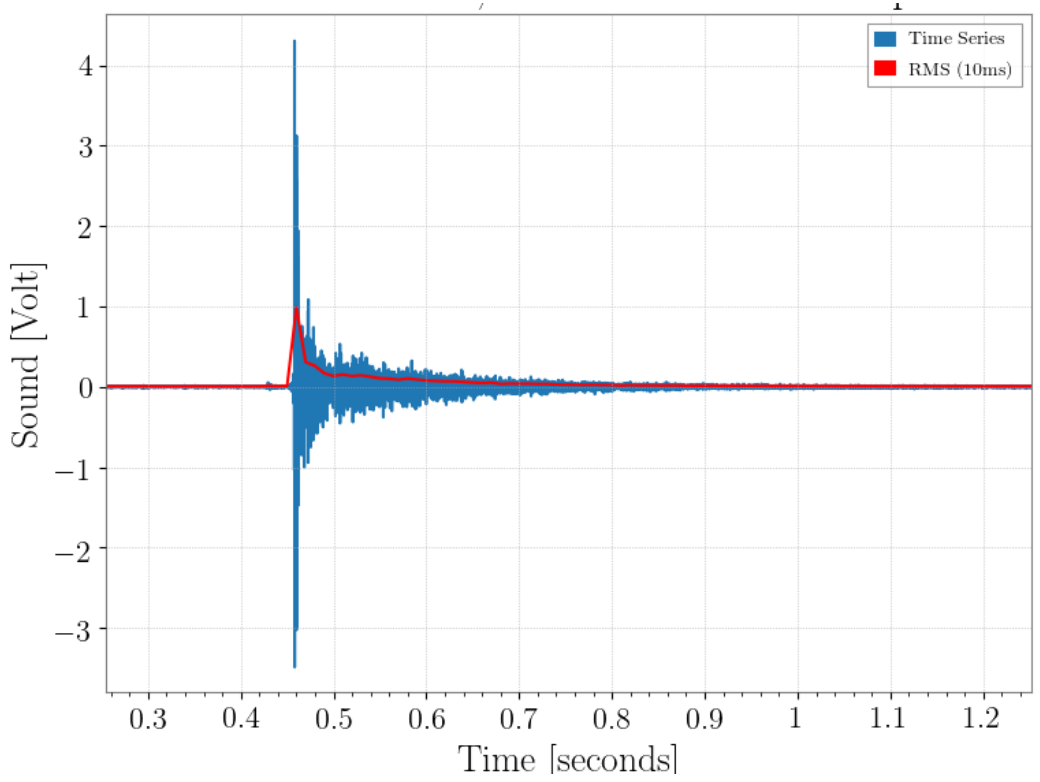
Two types of acoustic injection

① Continuous wave



- Noise budget of the interferometer
  [Details are shown in arXiv:2012.09294]

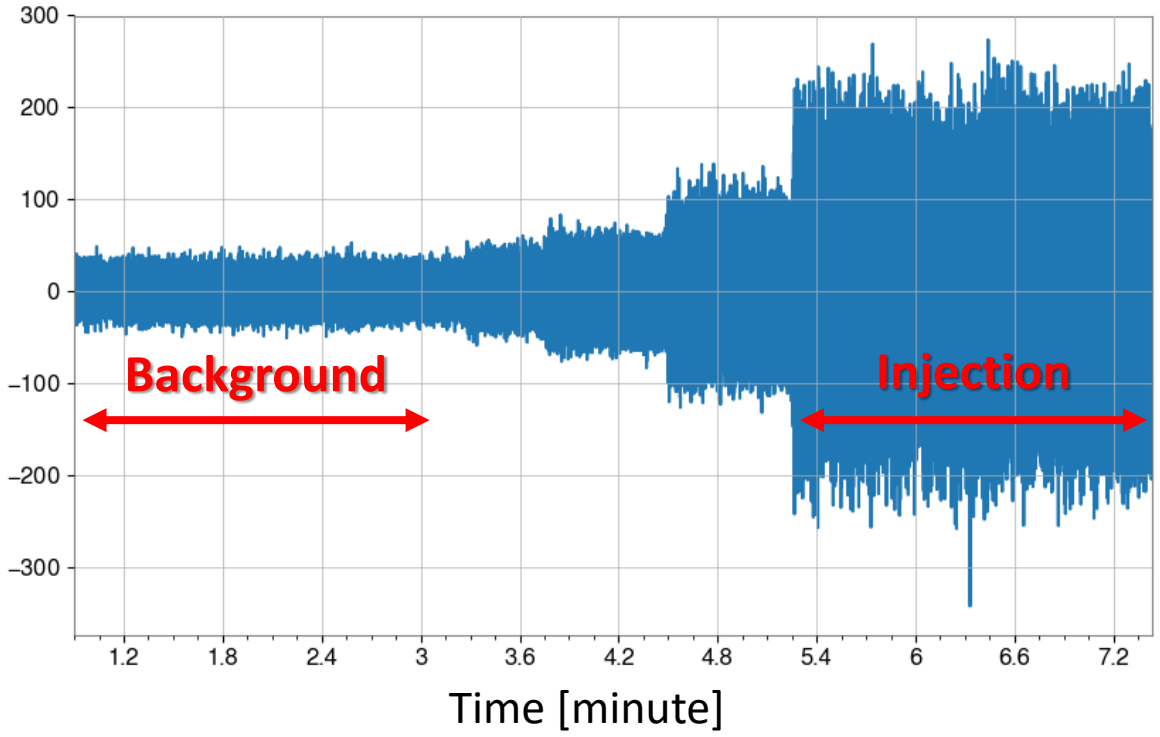
② Impulse wave



- Investigation of the Newtonian noise

Two types of acoustic injection

① Continuous wave



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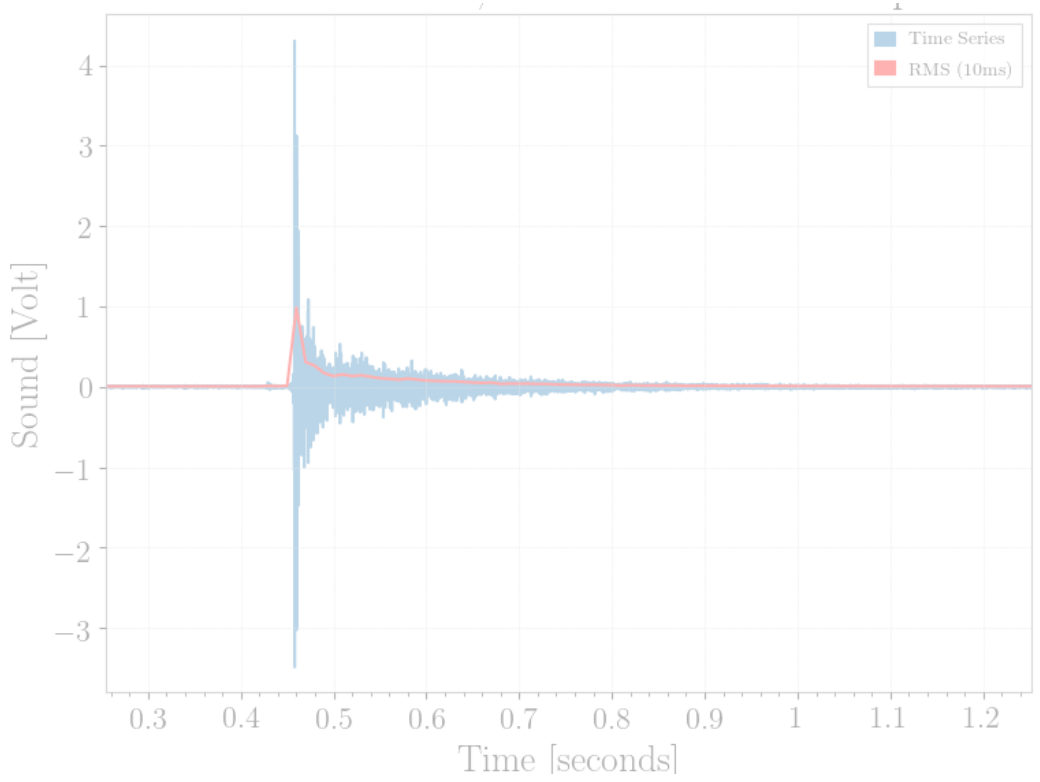
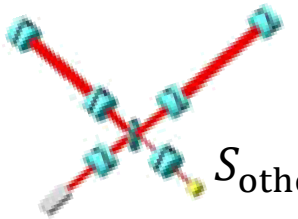


- Investigation of the Newtonian noise

Noise Projection by PEM Injection

A technic to evaluate the ambient environmental noise in the GW channel.



Background Data

Injected Data

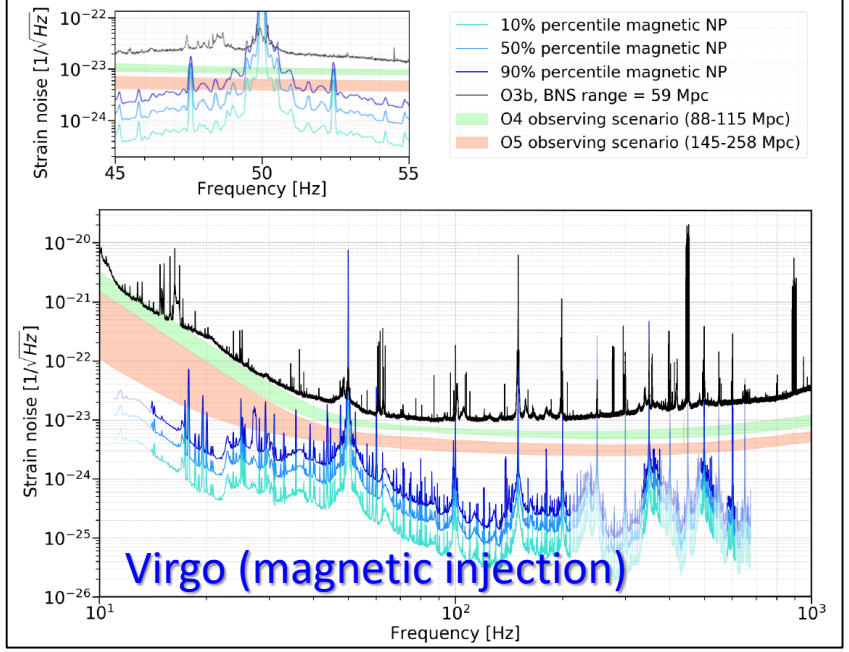
$S_{\mathrm{other}}(f)$ → $\boldsymbol{S_{\mathrm{bkg}}} = S_{\mathrm{other}} + S_{\mathrm{PEM}}$ → $\boldsymbol{S_{\mathrm{inj}}} = S_{\mathrm{other}} + S_{\mathrm{PEM}} + \Delta S$

$P_{\mathrm{bkg}}(f)$ → $\boldsymbol{P_{\mathrm{bkg}}}$ → $\boldsymbol{P_{\mathrm{inj}}} = P_{\mathrm{bkg}} + \Delta P$

$\Delta P(f)$

S(*f*), *P*(*f*) : Power Spectrum Density
Bold : observable

I.Fiori, T.Washimi *et.al.*, Galaxies **2020**, 8, 82



Coupling Function Model

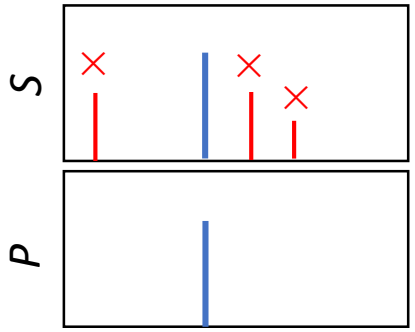
: Currently used in LIGO, Virgo, and also in KAGRA (before O3GK).

$$S_{\mathrm{PEM}}(f) = C^2(f) \times P(f) = \frac{S_{\mathrm{inj}}(f) - S_{\mathrm{bkg}}(f)}{P_{\mathrm{inj}}(f) - P_{\mathrm{bkg}}(f)} \times P(f)$$

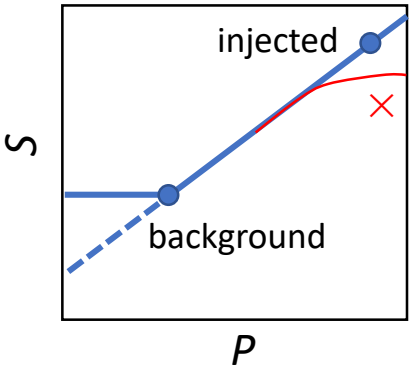
This model is based on the following hypothesis :

- No frequency conversion
- Linearity of the power
- Stability of interferometer

Frequency conservation



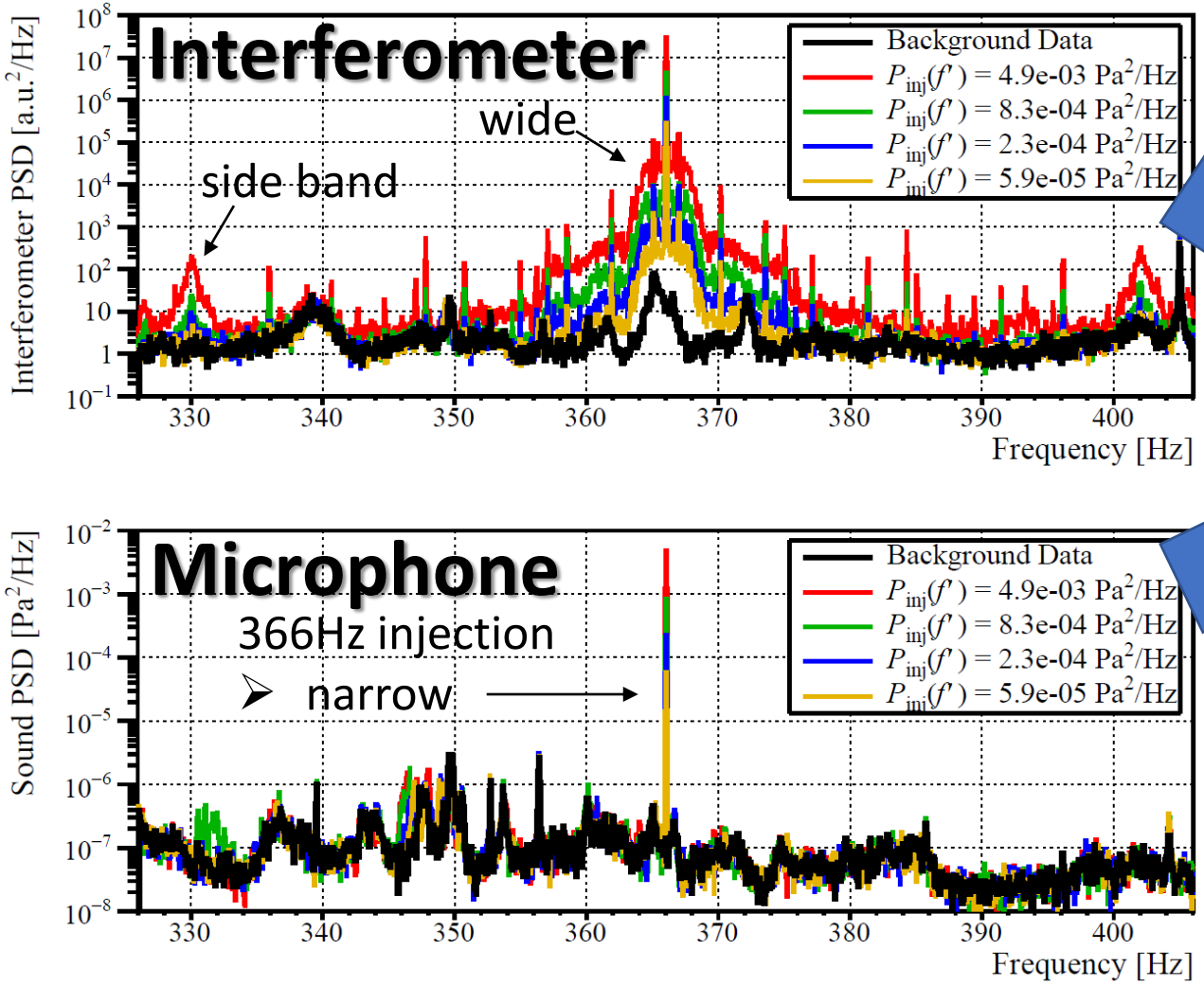
Linearity



We verified it after the O3GK

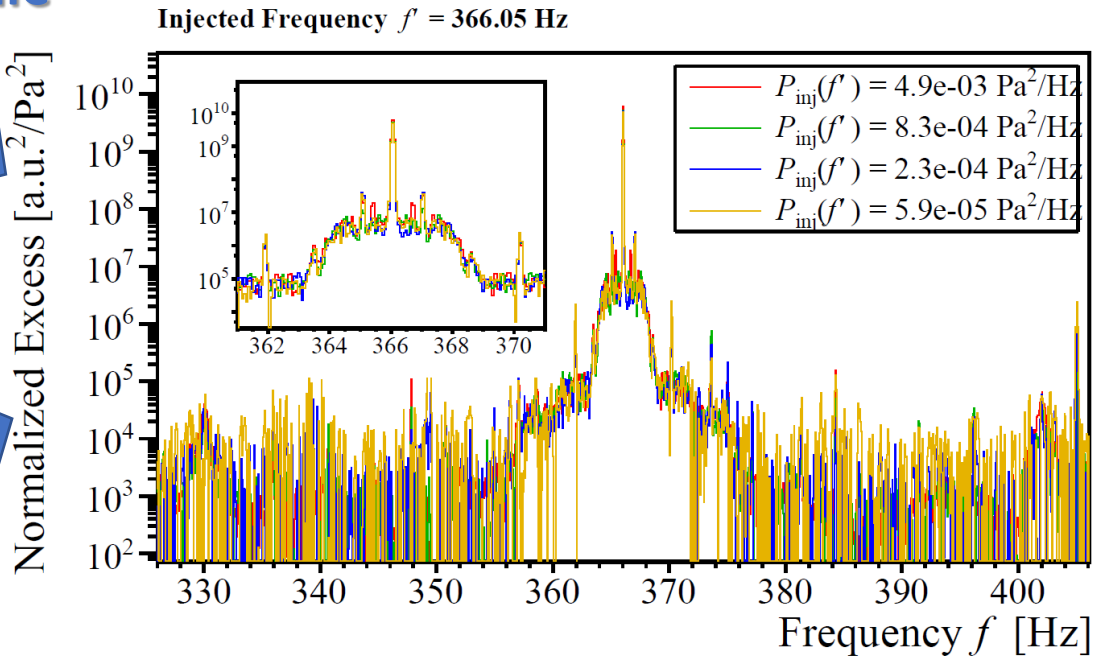
Single Line Acoustic Injection

At first, we checked the hypnosis by single line injection.



Normalized by MIC

$$\left.\frac{S_{inj}(f) - S_{bkg}(f)}{P_{inj}(f') - P_{bkg}(f')}\right|_{f'=366\mathrm{Hz}}$$



- ✓ **Frequency conversion -> Observed**
- ✓ **Linearity of the power -> Confirmed**

also checked for other frequencies

New Model for the PEM Injection Analysis

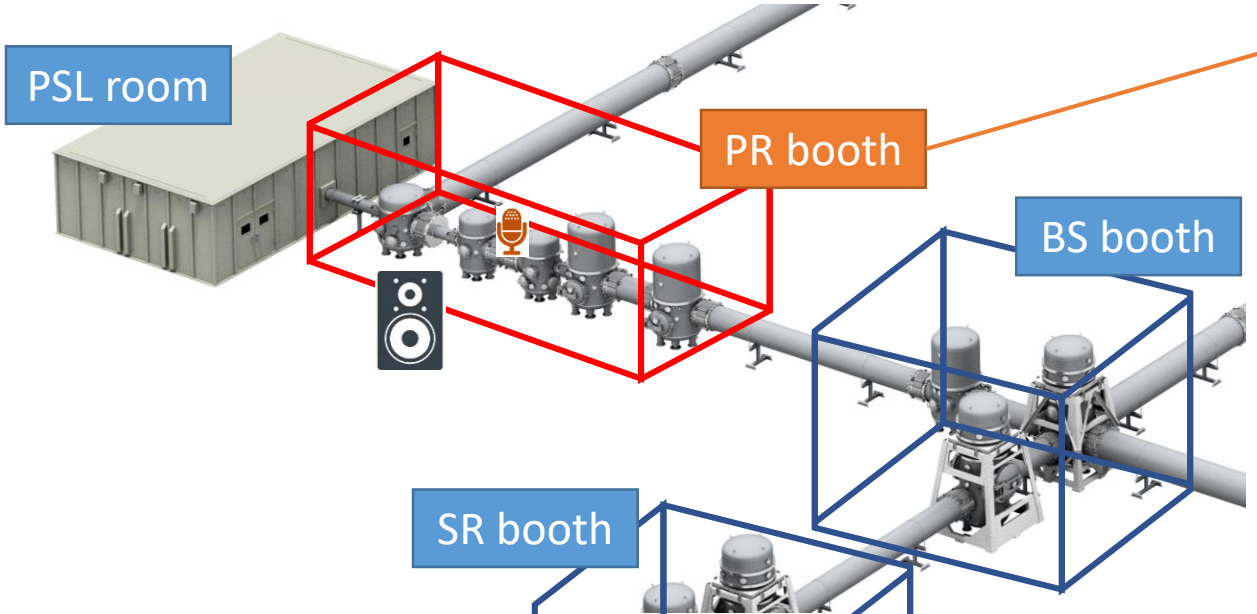
We developed a new model including frequency conversion.

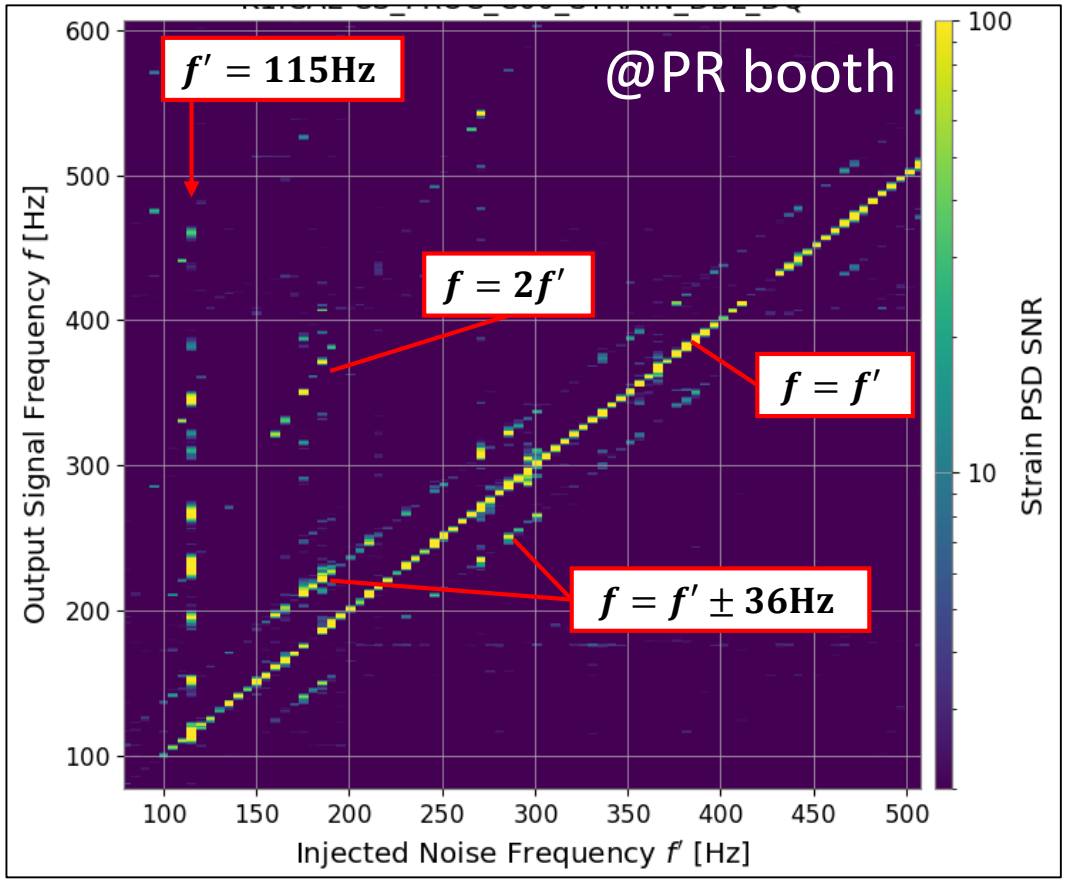
Current $S_{\mathrm{PEM}}(f) = \boldsymbol{C^2}\ (\boldsymbol{f}) \times P(f)$

New $S_{\mathrm{PEM}}(f) = \int [\boldsymbol{R(f, f')} \times P(f')]\mathrm{d}f'$

f' : frequency of the PEM signal

$R(f, f')$: Response function

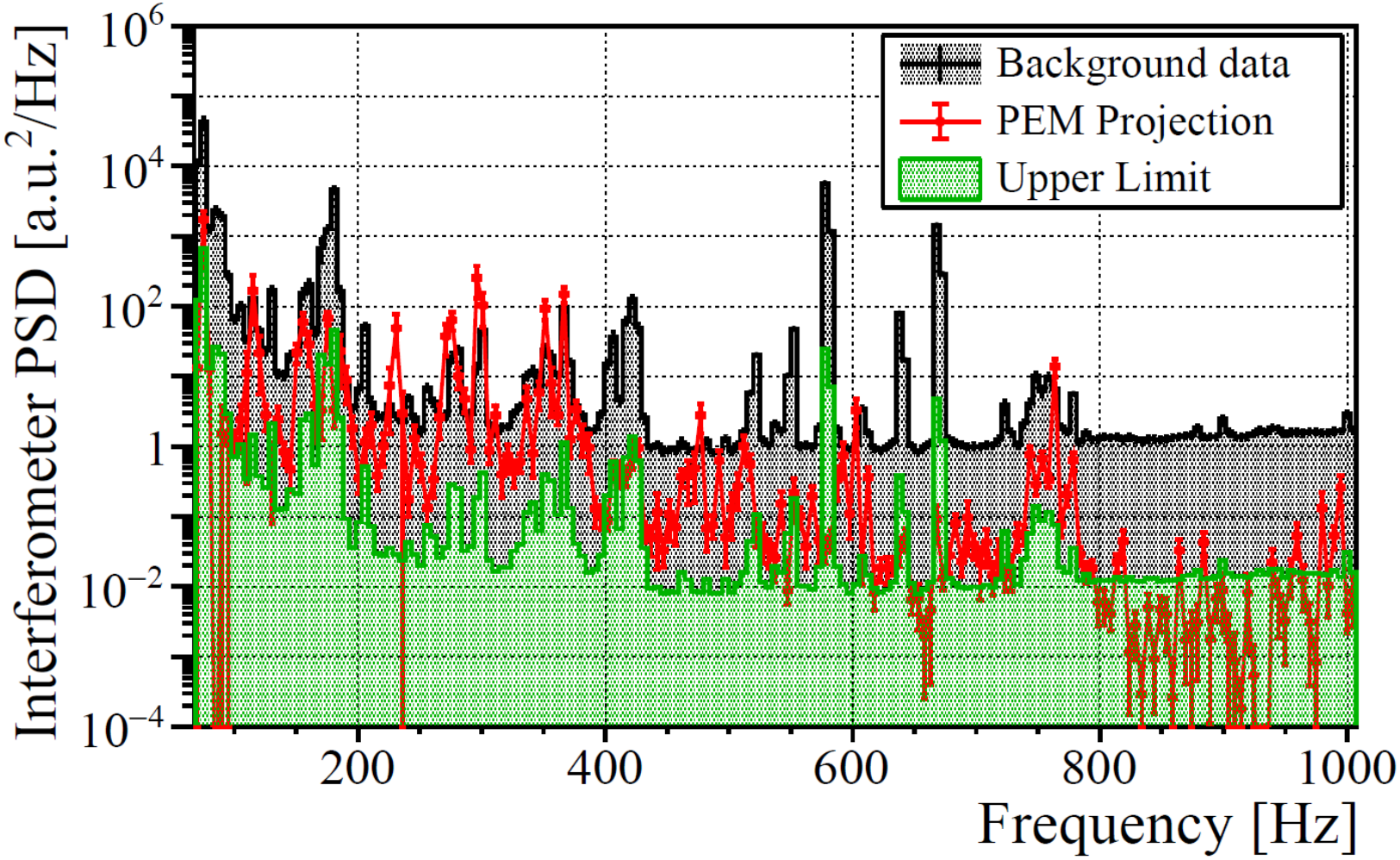




Response function is derived by swept sine injection.

$$R(f, f') = \frac{S_{\mathrm{inj}}(f) - S_{\mathrm{bkg}}(f)}{P_{\mathrm{inj}}(f') - P_{\mathrm{bkg}}(f')} \cdot \frac{1}{\Delta f'}$$

PEM Projection for the Background Data

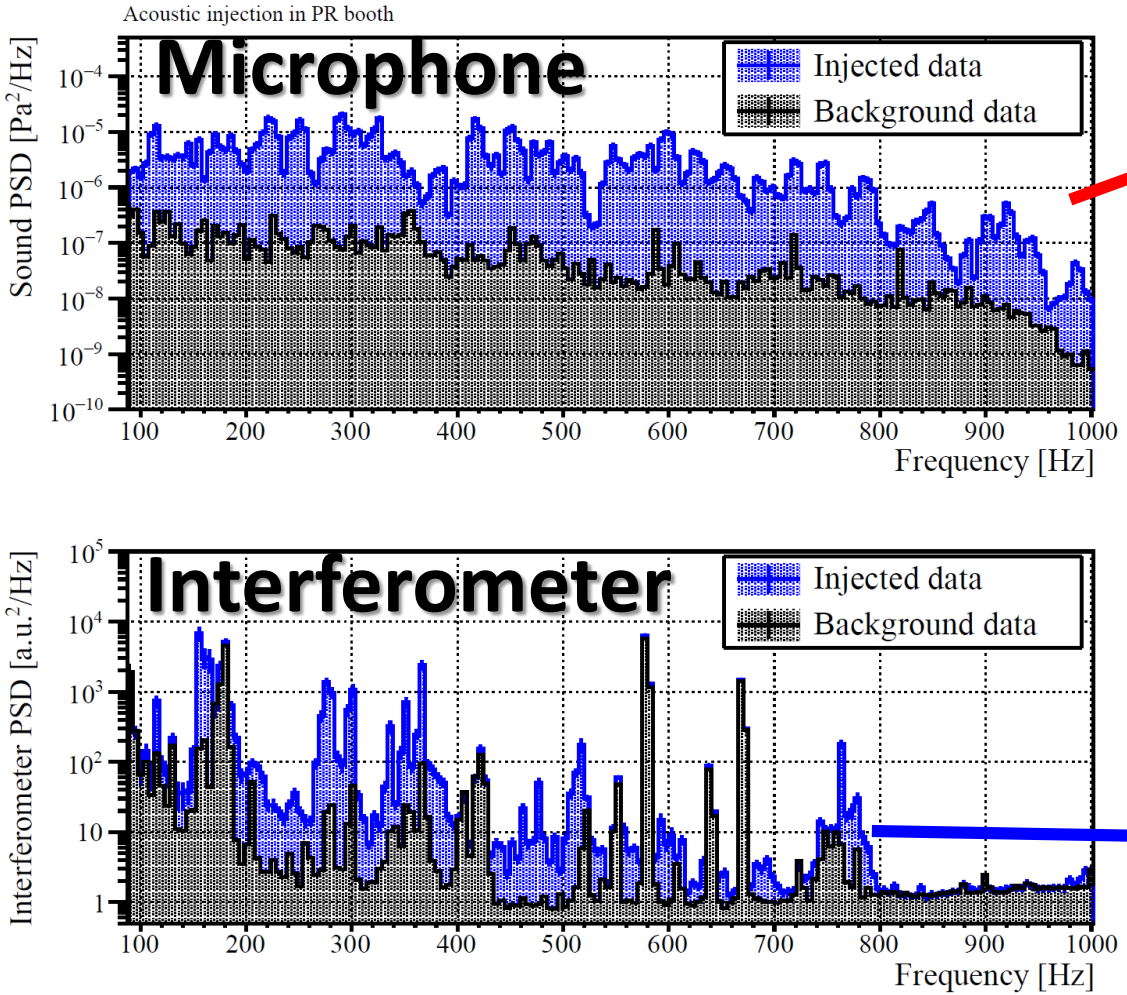


Acoustic noise propagated to the strain sensitivity was dominant about 200-400 Hz.

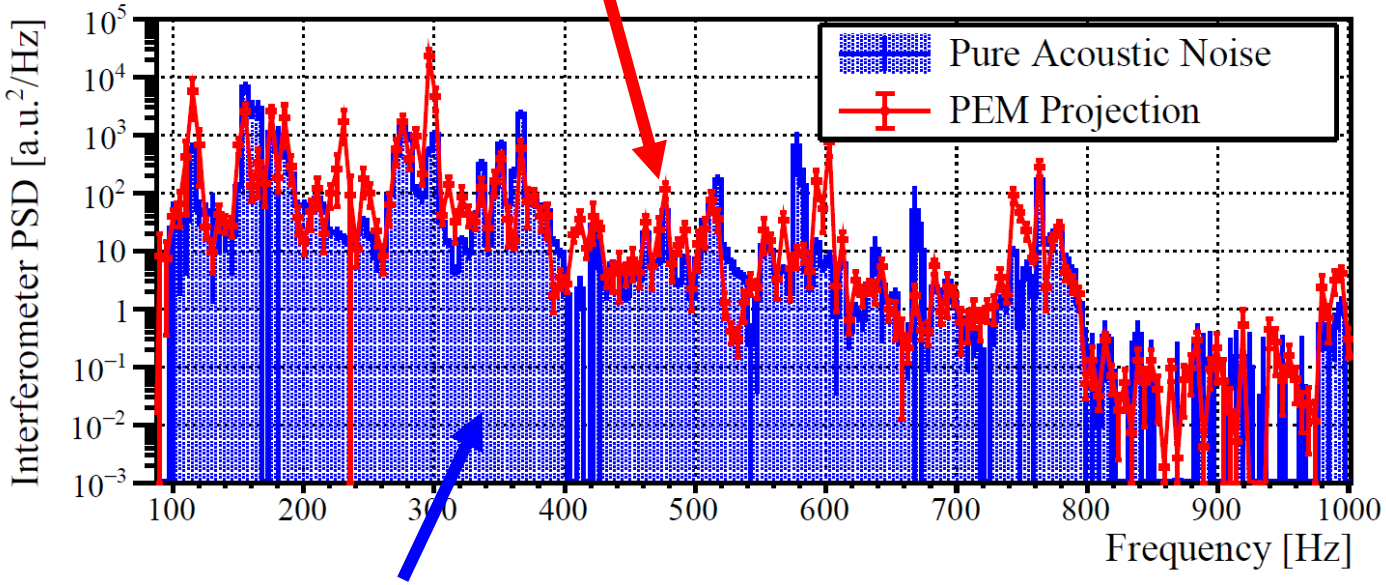
- KAGRA O3GK Noise budget -> K.Kokeyama [ID36]
- Offline noise subtraction -> J.Kume [ID41]

PEM Projection for the “Pure Acoustic Noise”

Check the validity of this analysis by the broadband injected data.



$$\int R(f,f')\{P_{\mathrm{broad}}(f') - P_{\mathrm{bkg}}(f')\}\mathrm{d}f'$$

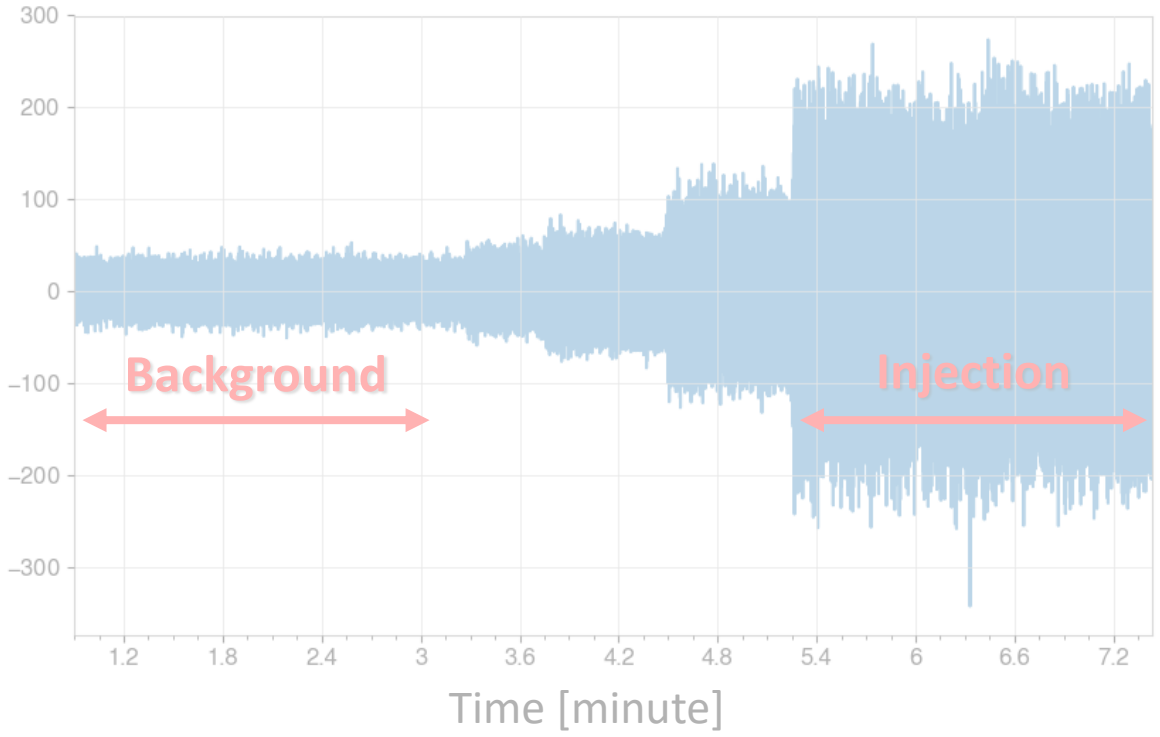


$$S_{\mathrm{broad}}(f) - S_{\mathrm{bkg}}(f)$$

“Pure acoustic noise” (excess in the interferometer signal) is almost consistent!

Two types of acoustic injection

① Continuous wave



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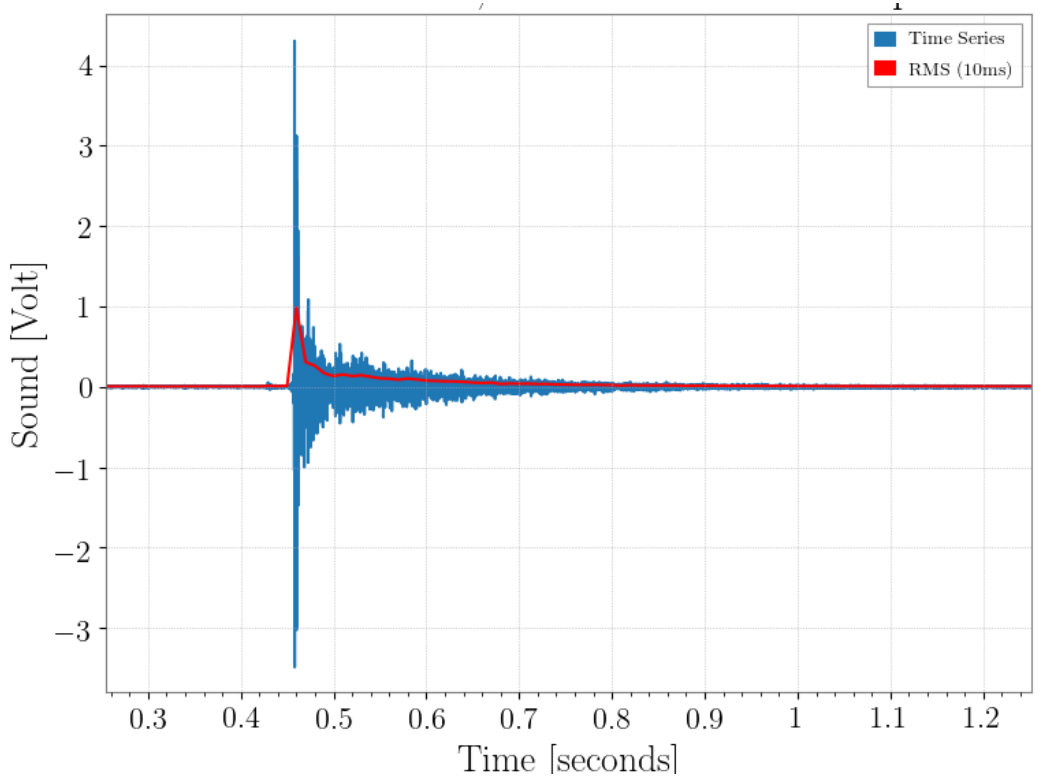
② Impulse wave



- Investigation of the Newtonian noise

Reverberation time for an Impulse sound

"RT60" is a parameter to explain the acoustic character of a room, widely used in the field of the Acoustic engineering

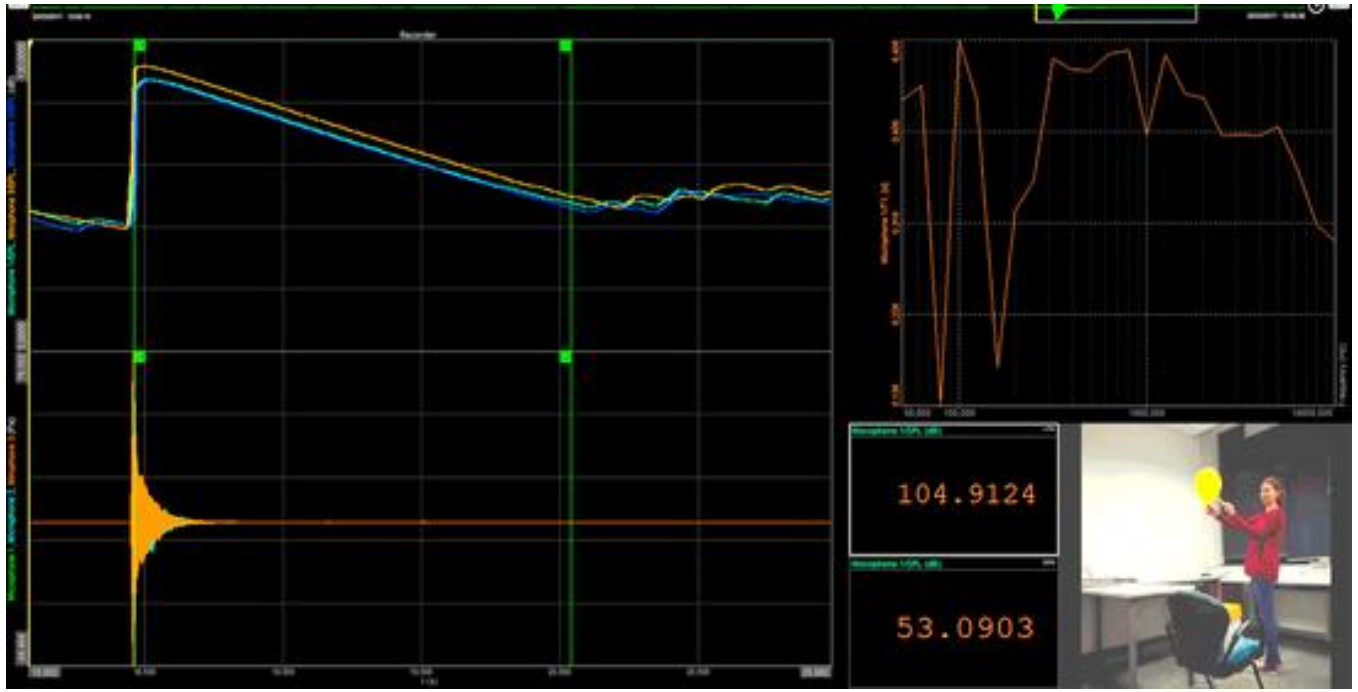
$$SPL(t = \mathrm{RT60}) - SPL(t = 0) = -60\mathrm{dB}$$

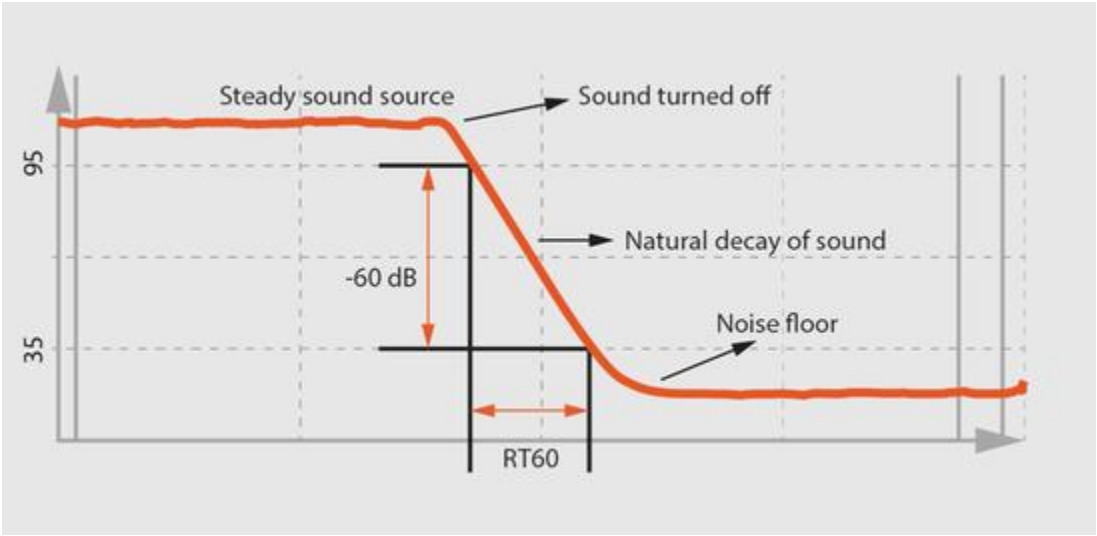
$$SPL = 10\log_{10}(P_{\mathrm{sound}}/P_0)^2$$
$$P_0 = 20\mu\mathrm{Pa}$$

Eyring's formula:

$$\mathrm{RT60} = 0.16\,\mathrm{s/m} \times \frac{V}{S\ \log_e(1-\alpha)^{-1}}$$

V : volume of the room
S : total area of room surface
α : absorptance on surface





https://www.dewesolutions.sg/reverberation-time-rt60.html

Schroeder frequency & Newtonian Noise

Schroeder frequency

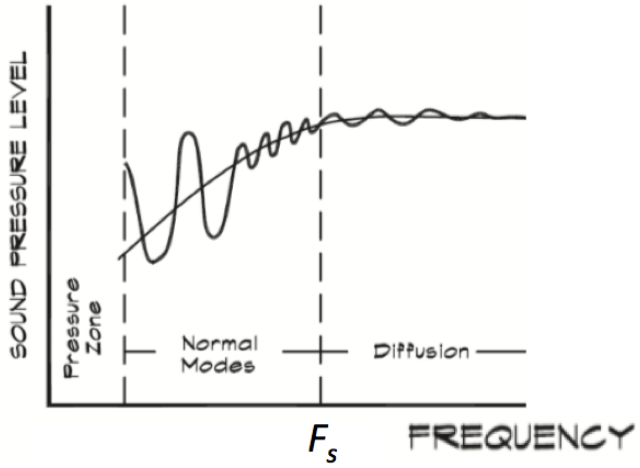
M. R. Schroeder, *J. Acoust. Soc. Am* **34**, 1819 (1962)

$$f_s = 2000\sqrt{\frac{RT60}{V}}$$

$f > f_s$: Diffuse case, $\lambda_{sound} \ll L_{room}$

$f < f_s$: Modal case, $\lambda_{sound} \simeq L_{room}$

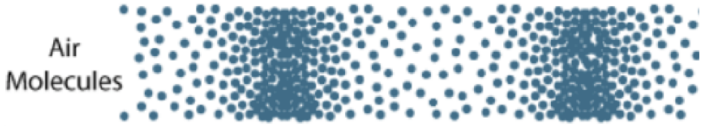
➢ Induce the Infrasound NN



S. M. Luisa, GWADW2019

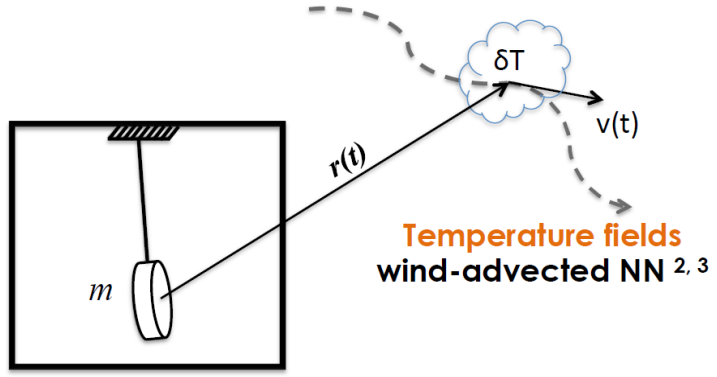
Atmospheric Newtonian Noise (NN)

Sources of atmospheric density perturbations[1]



Pressure fields
e.g. infrasound waves producing infrasound NN [2, 3, 4]

Air humidity field
wind-advected NN [3]

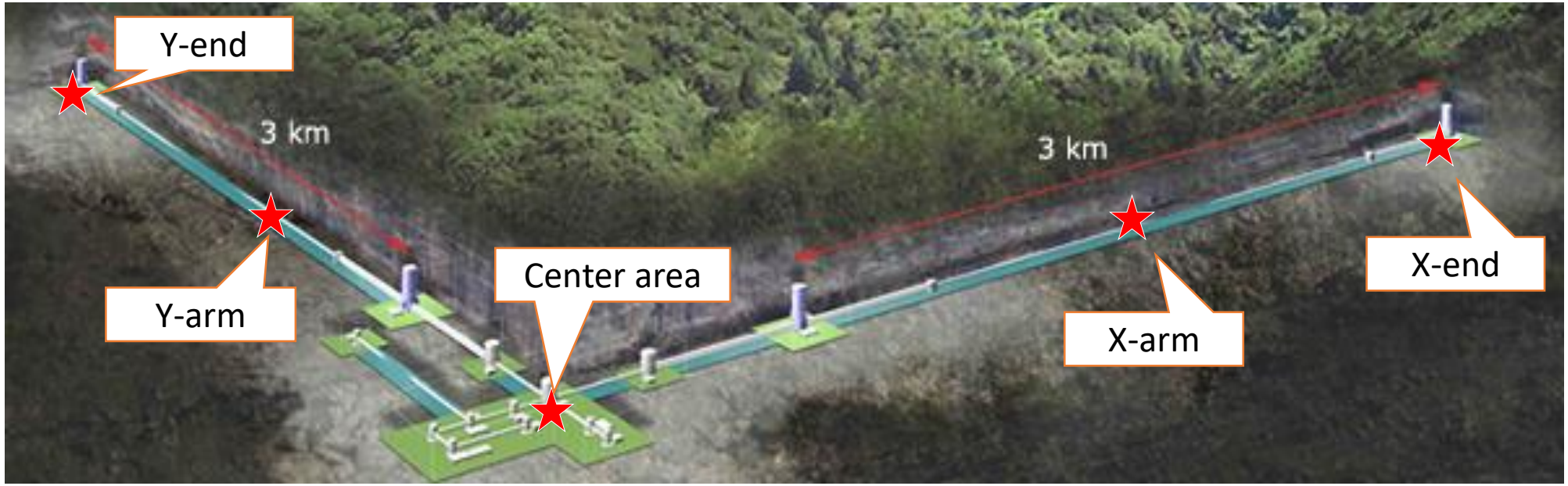


Temperature fields
wind-advected NN [2, 3]

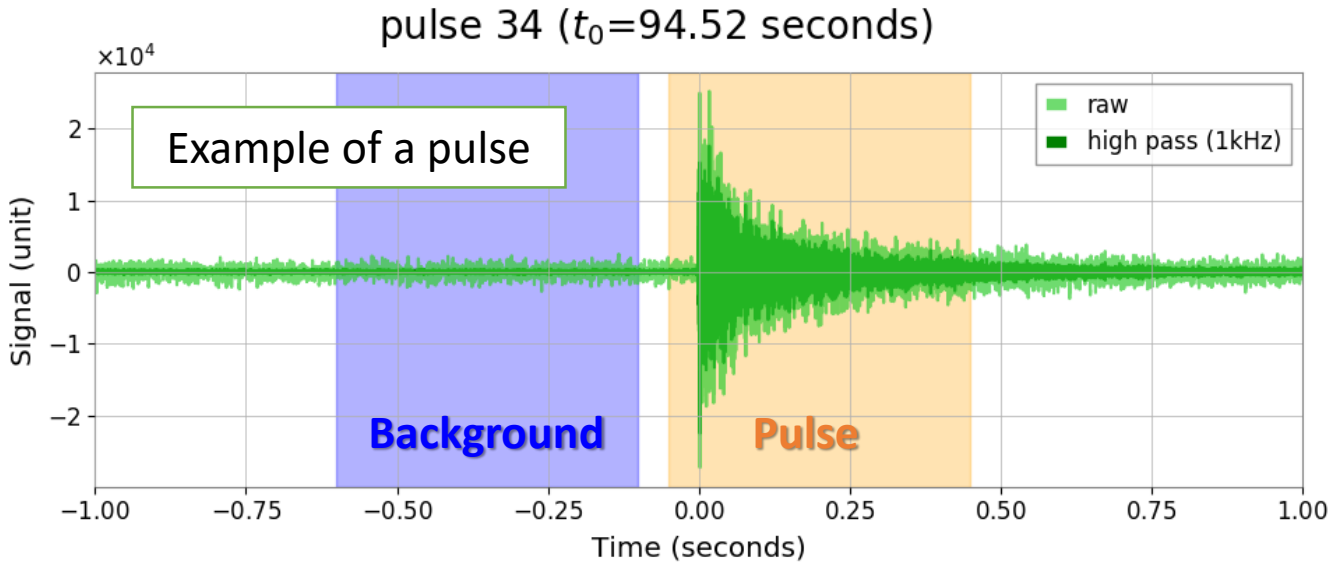
[1] Stull, Meteorology [2] Saulson Phys. Rev. D **30**, 732, [3] J. Harms Terrestrial Gravity Fluctuations, [4] Creighton CQG. **25** (2008) 125011, C.Cafaro, S. A. Ali arXiv:0906.4844 [gr-qc] [2]

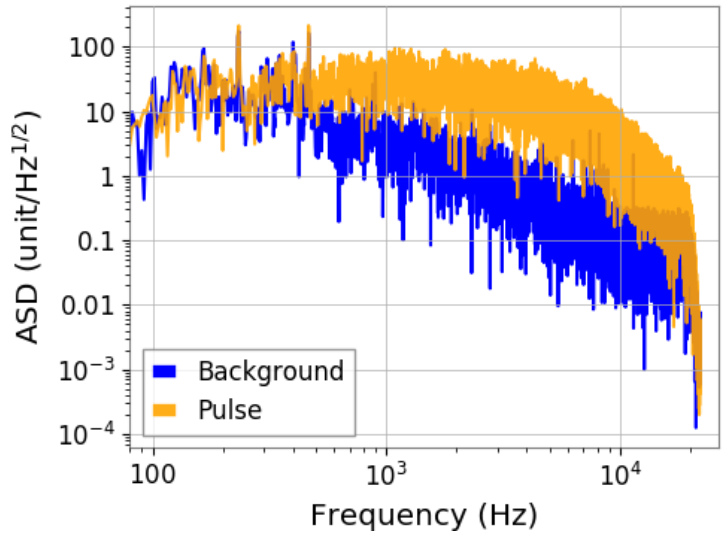
➢ We can estimate the cut-off frequency of the infrasound NN toward future observation or G3.

Measurements in KAGRA site

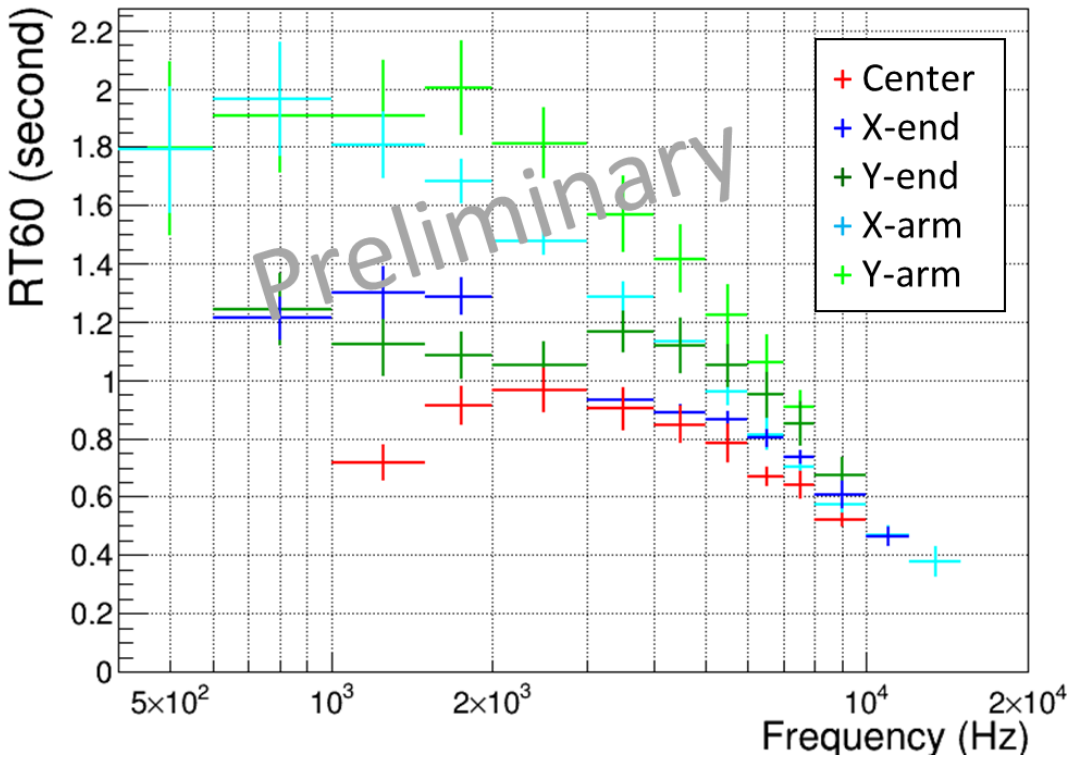


sound source





Results of RT60 and Schroeder frequency in KAGRA



Frequency dependence is coming from the absorptance on surface

$$\mathrm{RT60} = 0.16\,\mathrm{s/m} \times \frac{V}{S\ \log_e(1-\alpha)^{-1}}$$

By using the plateau,

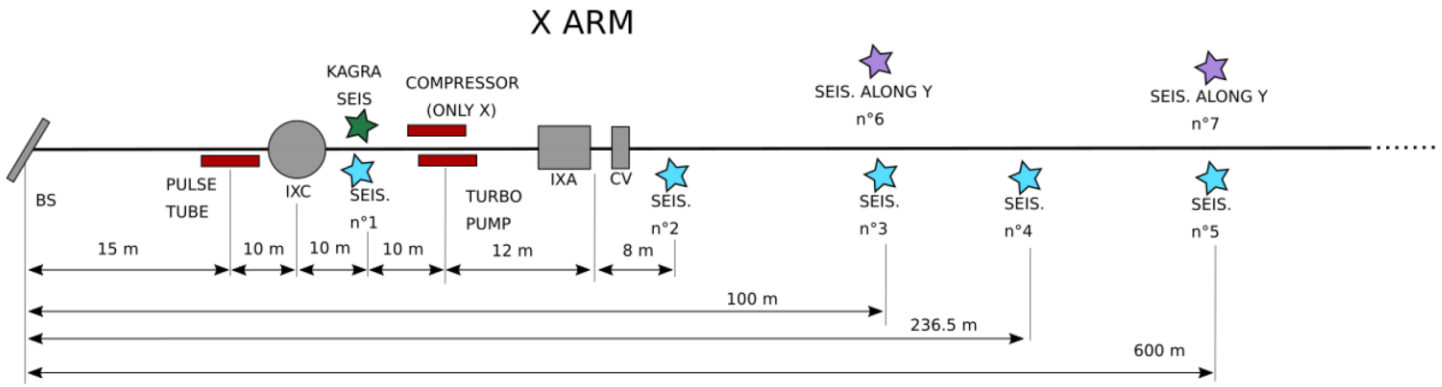
	$RT60$ [s]	V [m^3]	f_s [Hz]
Center	~ 1.0	25,000	13
X/Y end	~ 1.2	10,000	22
X/Y arm	~ 2.0	46,000	13

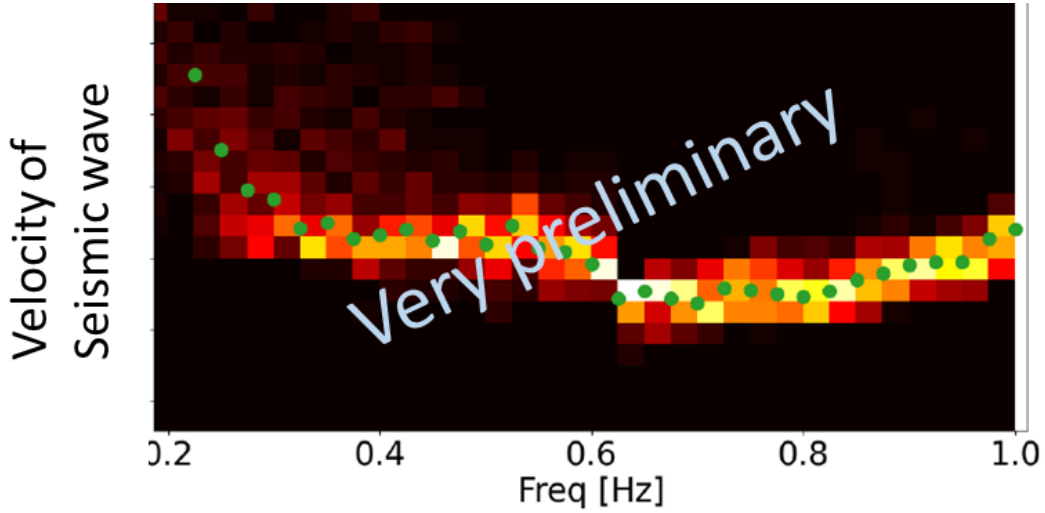
- We performed the same measurements in Virgo.
- The journal paper is in preparation.

Other activities for the Newtonian Noise in KAGRA

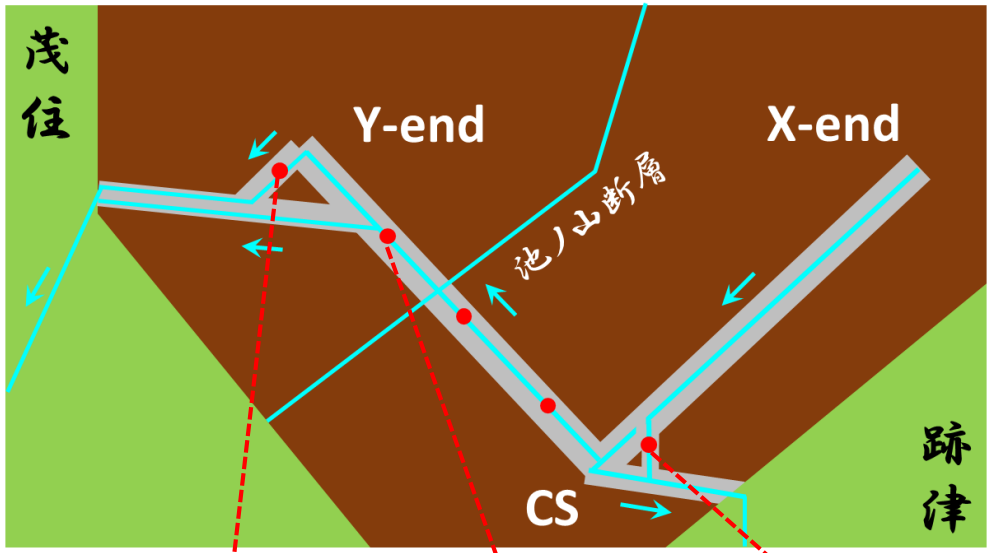
KAGRA PEM is also working on the other types of Newtonian noise in underground environment.

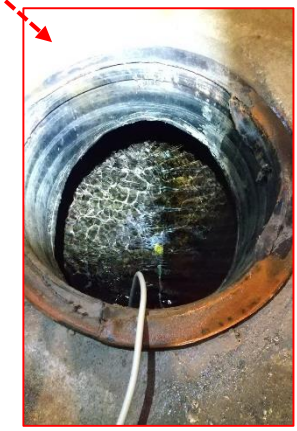
Seismic NN





Water fluid NN



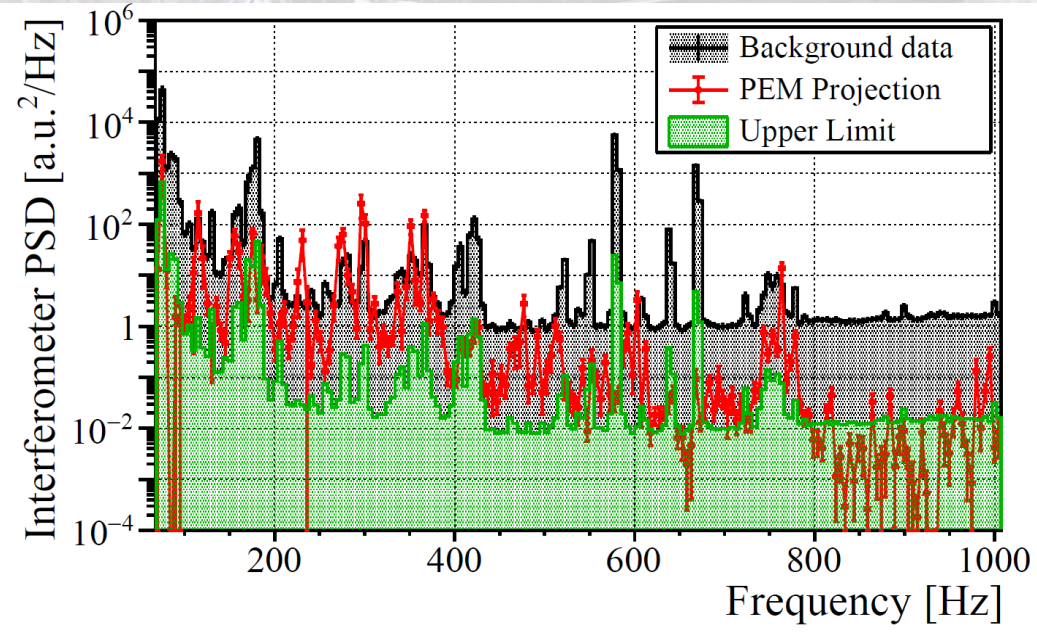


Summary of KAGRA Acoustic Injection

① Continuous wave

✓ We investigated the response of KAGRA interferometer to the acoustic field.

➢ a part of O3GK Noise budget



② Impulse wave

✓ We evaluated the reverberation time in KAGRA observatory.

➢ investigation of a Newtonian noise