Investigation of infrasound noise background at Mátra Gravitational and Geophysical Laboratory (MGGL)

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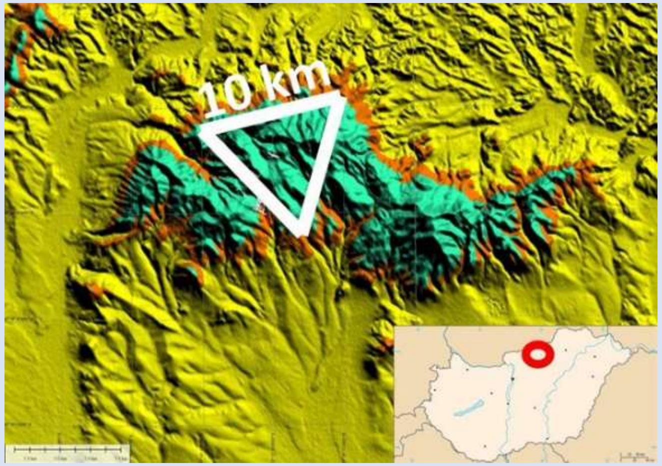
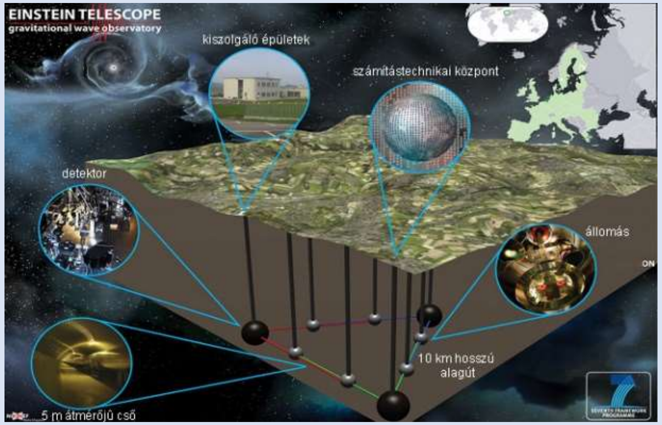
Abstract

- Mátra Gravitational and Geophysical Laboratory (MGGL)
- Newtonian Noise (NN)
- Infrasound Monitoring System (ISM)
- Data collection
- Data processing
- Bowman’s median noise model
- NN from infrasound at Einstein Telescope
- Results
- Developing new methods in data evaluation
- Further plans

Mátra Gravitational and Geophysical Laboratory

- MGGL Laboratory was founded in 2015 by Wigner RCP
- Site: Gyöngyösoroszi mine, Nitrokémia Zrt, 88 below the ground
- Aim: investigate the noise background at a candidate site for Einstein Telescope + other geophysical investigations [1][2][3]
- Measurements:
  - seismic
  - infrasound
  - electromagnetic
  - cosmic muon
- Partner Institutes:
  - Wigner RCP
  - Univ. of Miskolc (HU)
  - MTA Atomki (HU)
  - MTA RCAES GGI (HU)
  - Univ. of Warsaw





http://einsteinteleszkop.hu

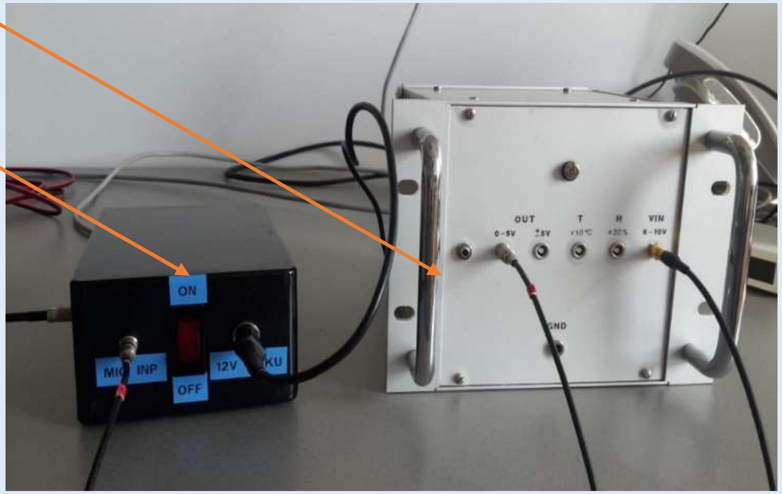
Newtonian noise (NN)

- Produced by terrestrial gravity fluctuations (seismic, atmospheric, water …)
- Contributes to the instrumental noise of gravitational-wave detectors
- Can not be shielded from the mirrors of the detectors
- Building GW detectors 100-200 m under the ground helps to mitigate NN
- Careful site selection: seismically quiet site, homogenous rock, small fluctuations of air pressure, etc. [4]
- Noise cancellation using Wiener filters exploits correlation between reference data streams(seismometers, microphones) and a target data stream (interferometer) to provide a coherent estimate of certain noise contributions to the target sensor [5]. (Assuming data from all data streams are described by stationary, random processes.)

Infrasound Monitoring System

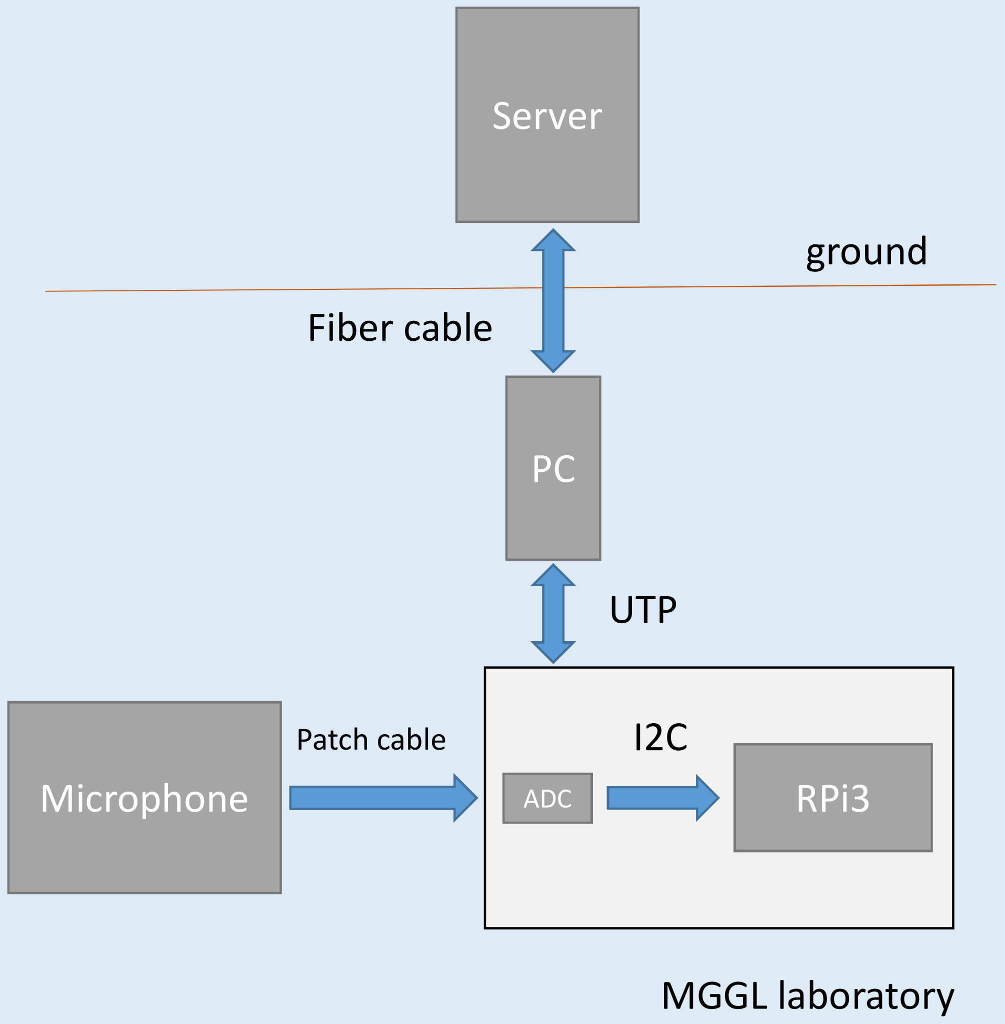
- Developed by MTA ATOMKI (Debrecen, Hungary)
- ISM = data acquisition system + microphone
- Microphone:
  - Small size (13 x 13 x 15 cm)
  - Small weight
  - Robust hardware

Sensitivity (mV/Pa)	200
Frequency range (Hz)	0.01-10
Pressure range (Pa)	-12.5-12.5
Input voltage (V)	6-10
Output voltage (V)	0-5



Data collection

- Raspberry Pi 3 Model B
- Adafuit ADS1115 analog-digital converter
- Timesamples
    - NTP or RTC optionally
- microSD card
    - Stores Raspbian operating system
    - Permanently stores measurement data
    - 32 Gb (industrial version)
- Software for data collection written in c++
- Data is sent to a server abobve the ground



Data processing

1. Divide measurement data into segments of same length

2. Subtract the mean of segment data from each value of the segment, then apply a Nuttal-window on the signal:

$$\tilde{p}[n] = w[n](p[n] - \langle p \rangle) \qquad w[n] : \text{Nuttal window}$$

3. Fast Fourier transform the windowed signal: $$P_k = \sum_{n=0}^{N-1} \tilde{p}[n] \cdot e^{-\frac{2\pi i}{N}kn}$$

4. Compute the one-sided Power Spectral Density (PSD) of the segment:

$$PSD_k^{(p)} = \frac{2}{f_s \cdot N \cdot W} |P_k|^2$$

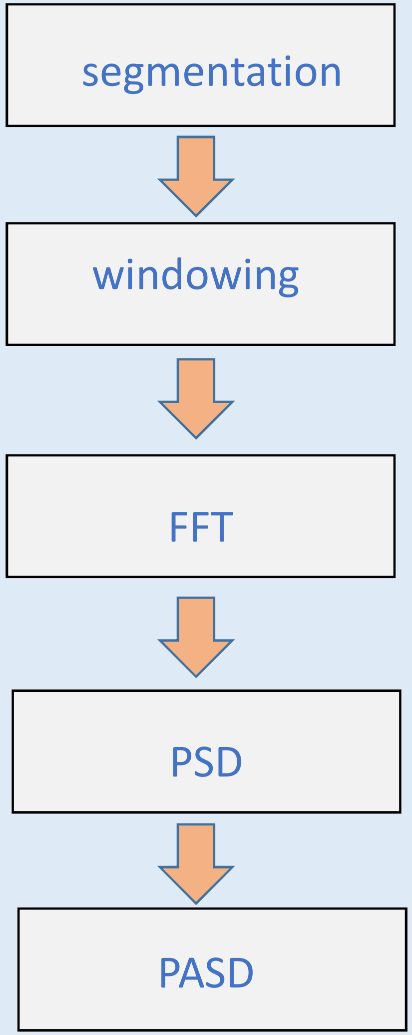
N: number of samples in the segment;

k : Fourier number corresponding to freq. $f = k\frac{f_s}{N}$;

f_s : sampling frequency; P_k : value of Fourier-spectrum corresponding to k

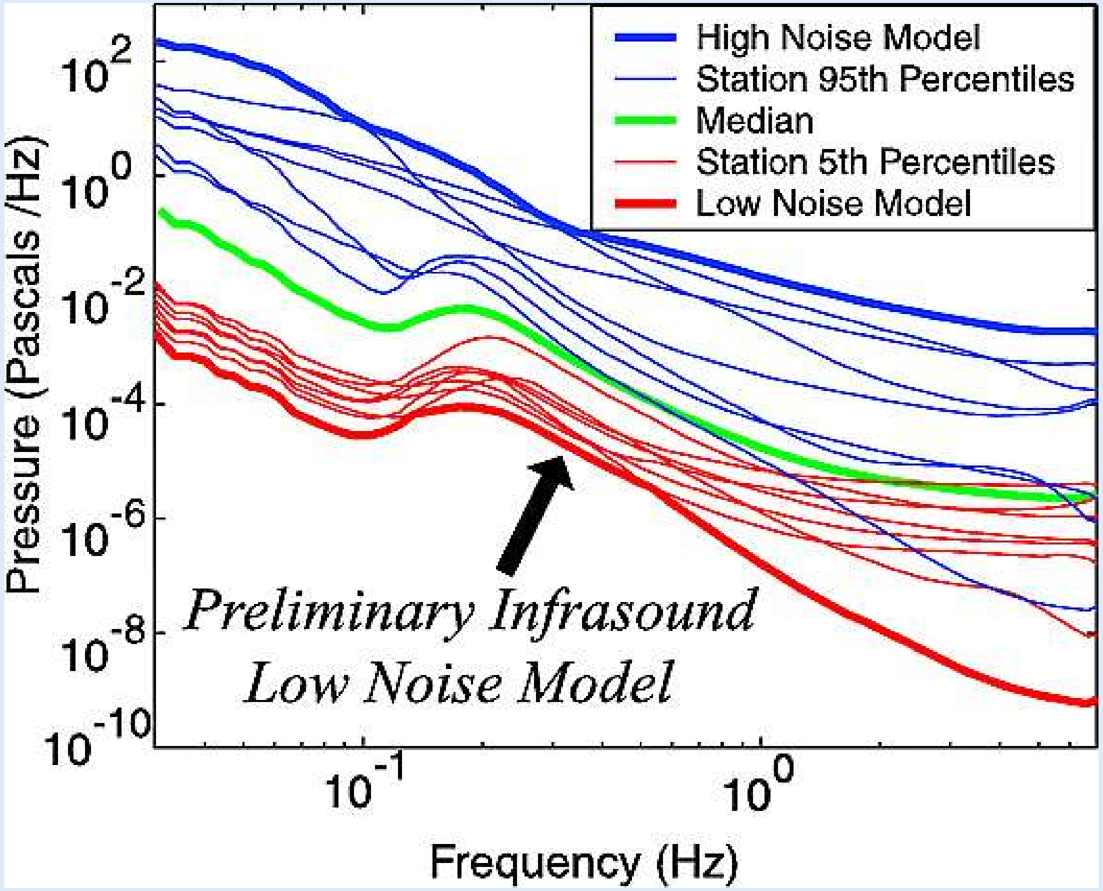
$W = \frac{1}{N}\sum_n^N w[n]^2$ normalizing constant

5. Get Pressure Amplitude Spectral Density from PSD: $$PASD_k^{(p)} = \sqrt{PSD_k^{(p)}}$$



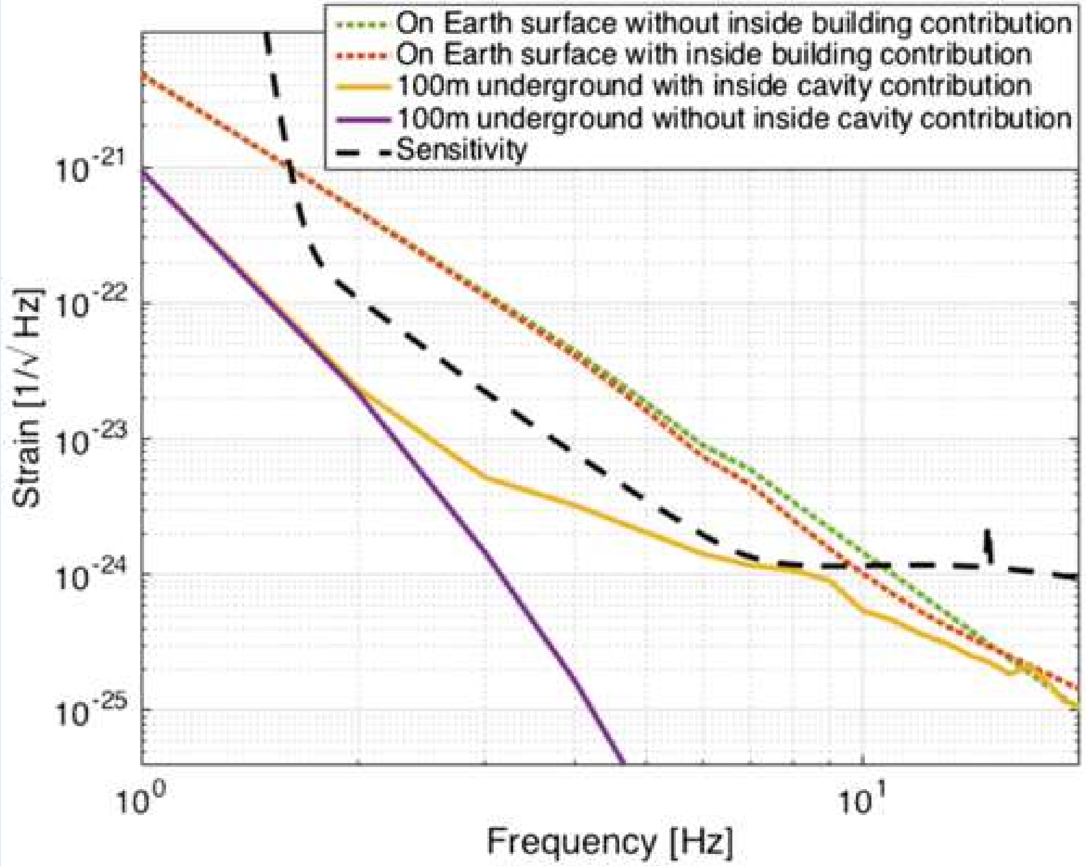
Bowman’s median noise model

- The ambient infrasound noise environment is characterized for 21 globally distributed infrasound arrays in the frequency band of 0.03 to 7 Hz.[6]
- Power Spectral Density (PSD) is measured for one site of each array for 21 intervals at each of four times of day from January 2003 through January 2004.



NN from infrasound at Einstein Telescope

- Difficult to mitigate NN of infrasound-origin under the ground:
  - Resonances determined by the geometry of the cavities
  - Machines: electricity generators, pumps, cryocoolers, air conditioning
- Recently a method was presented in [7] to estimate the infrasound originated NN. They used Bowman's median noise curve during modelling NN.
- If our representative noise curves of MGGL do not exceed the Bowman median curve, we could expect that the infrasound NN noise at Mátra would be lower than the estimated infrasound NN for ET



Results of infrasound measurements at MGGL

- PASD noise curve exceeds Bowman-median [3]
- Miners work in three shifts, different type of noise can occur anytime
- More sophisticated data analysis is needed to find different sources of noise, and find the most silent time inetrvals

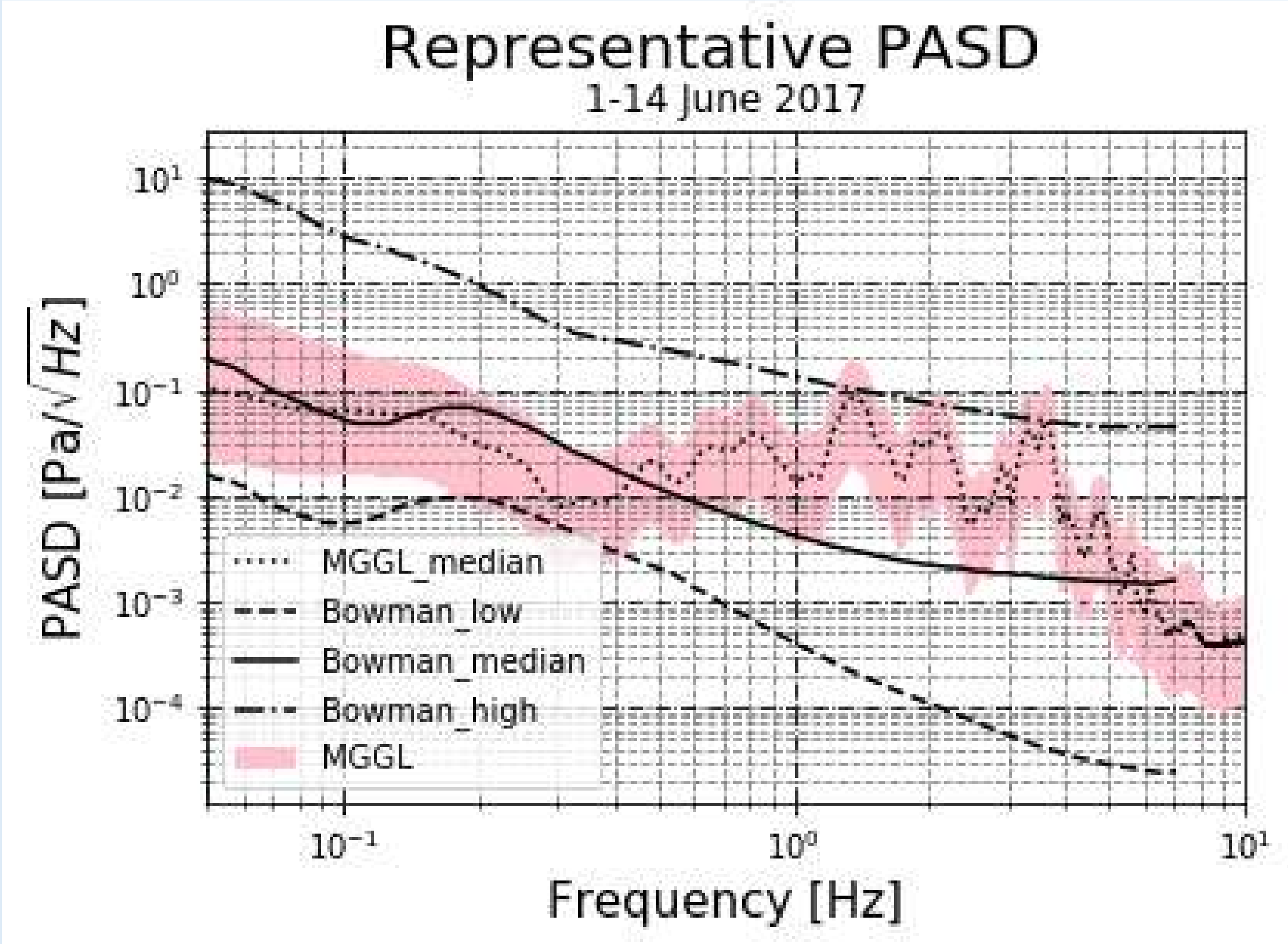
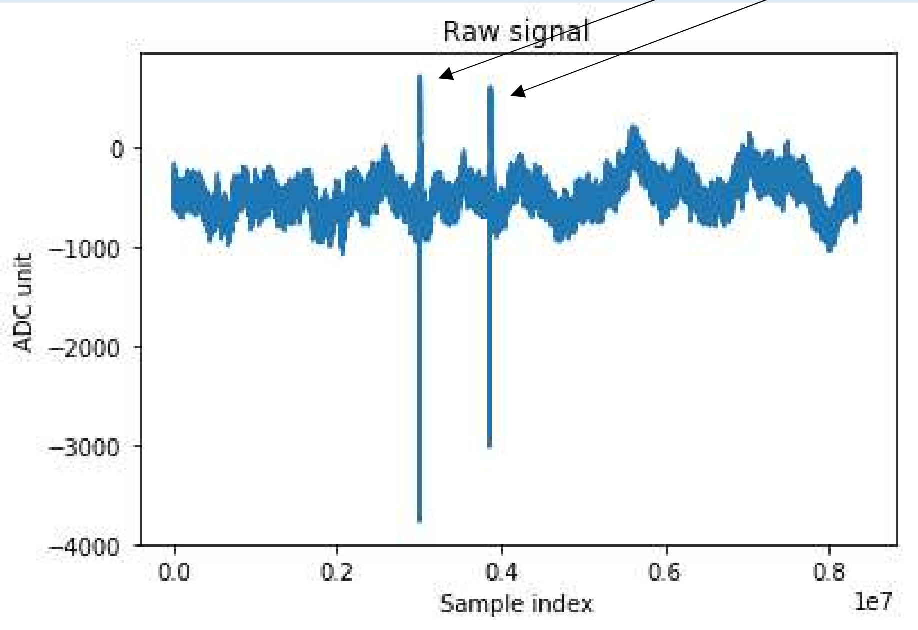
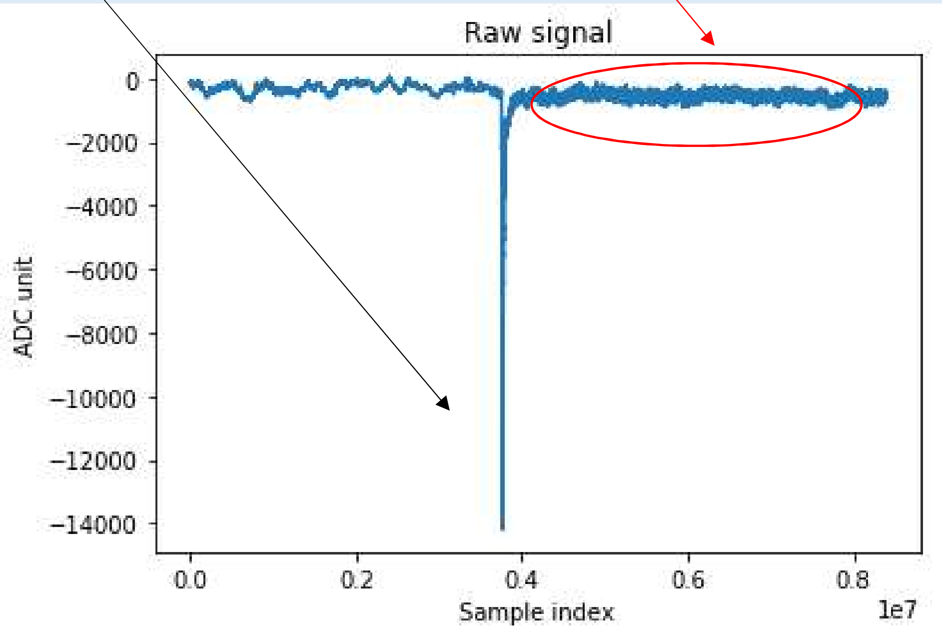


Illustration of the problem

Different types of noise: short duration with excess power or continuous





Discrete Haar-transform

Recursive method, the length of „s” is halved in each step

$s_i^{(0)}$: Original signal, where $i = 1, 2, \ldots N$

$$s_i^{(n+1)} = \frac{1}{\sqrt{2}}\left(s_{2i-1}^{(n)} + s_{2i}^{(n)}\right)$$ Similar to moving average; informs us of the trend of the signal in different scales

$$d_i^{(n+1)} = \frac{1}{\sqrt{2}}\left(s_{2i-1}^{(n)} - s_{2i}^{(n)}\right)$$ Similar to moving difference; informs us of the fluctuations of the signal in different scales

$$s^{(0)} = (1, 2, 5, 0, 8, 7, 1, 9)$$

$$d^{(1)} = \left(\frac{-1}{\sqrt{2}}, \frac{5}{\sqrt{2}}, \frac{1}{\sqrt{2}}, \frac{-8}{\sqrt{2}}\right)$$

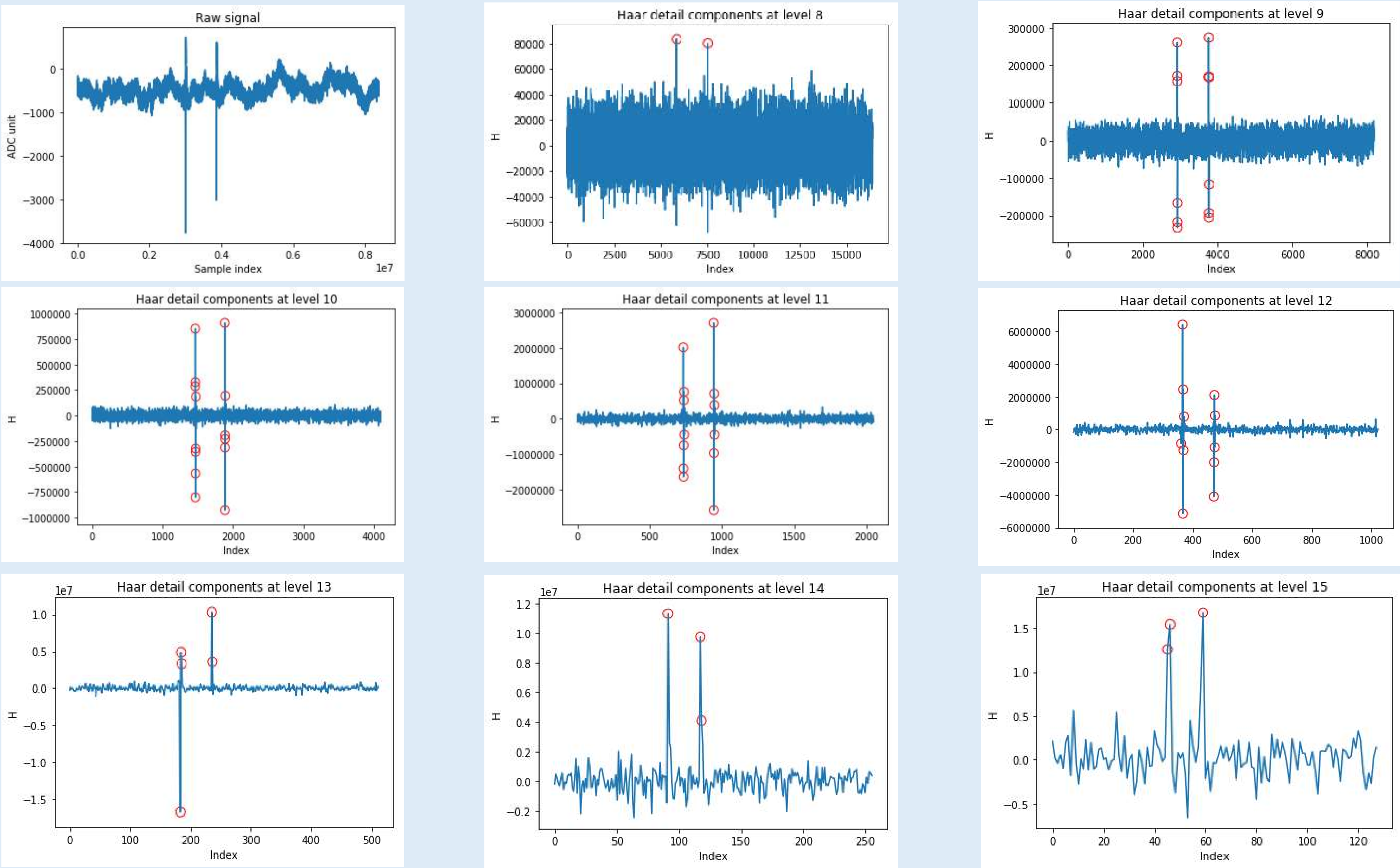
$$s^{(1)} = \left(\frac{3}{\sqrt{2}}, \frac{5}{\sqrt{2}}, \frac{15}{\sqrt{2}}, \frac{10}{\sqrt{2}}\right)$$

$$d^{(2)} = \left(\frac{-6}{2}, \frac{9}{2}\right)$$

$$s^{2} = \left(\frac{8}{2}, \frac{25}{2}\right)$$

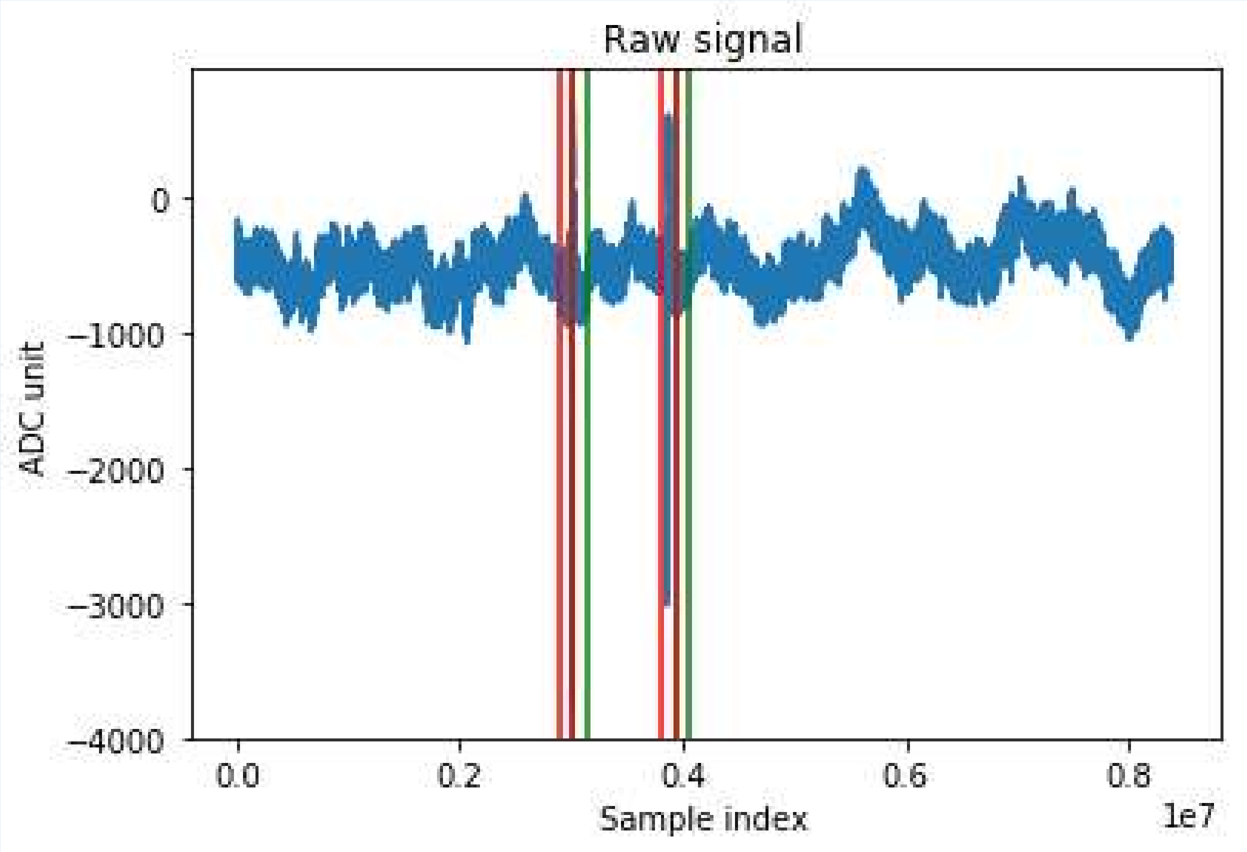
Method to find noisy data segments

- We are interested in the relevant changes in the fluctuations
- Supposition: fluctuations of different levels are mainly from a given univariate sample, with some outliers
- Search for outliers in the detail component vectors (d) at each step of the recursive process
- Use median absolute deviation (MAD), which is a robust measure of the variability (v) of a univariate sample
- Consider $d_i^{(n+1)}$ as an outlier, if $\left|d_i^{(n+1)}\right| > \mathrm{c} * v^{(n+1)}$, where c is an arbitrary constant, and $v^{(n+1)}$ is the variability
- Find segments of the original signals which are overlap by outliers of given scales



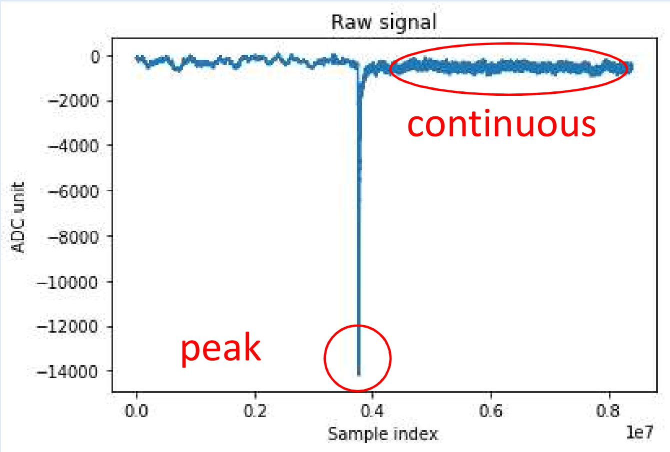
Raw signal
ADC unit
Sample index
1e7
Haar detail components at level 8
Haar detail components at level 9
Haar detail components at level 10
Haar detail components at level 11
Haar detail components at level 12
Haar detail components at level 13
Haar detail components at level 14
Haar detail components at level 15
H
Index

Result

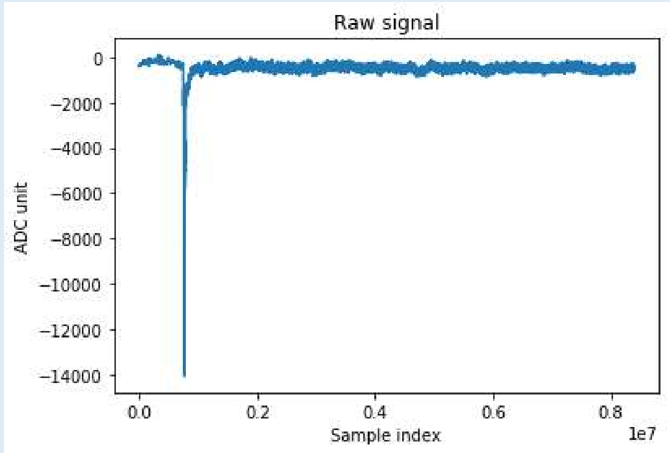


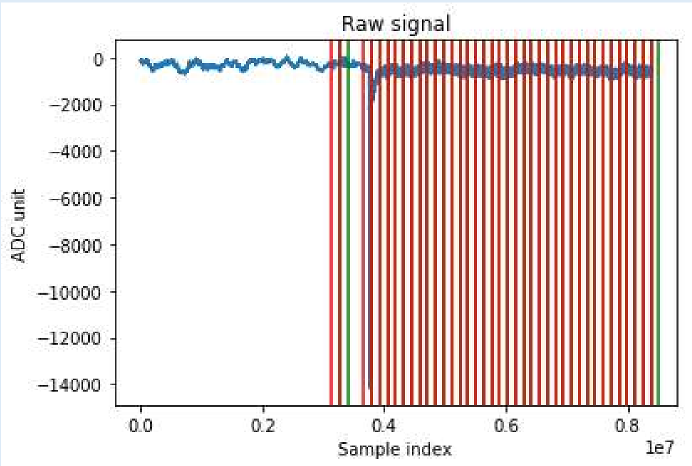
Raw signal
ADC unit
0
−1000
−2000
−3000
−4000
0.0
0.2
0.4
0.6
0.8
Sample index
1e7

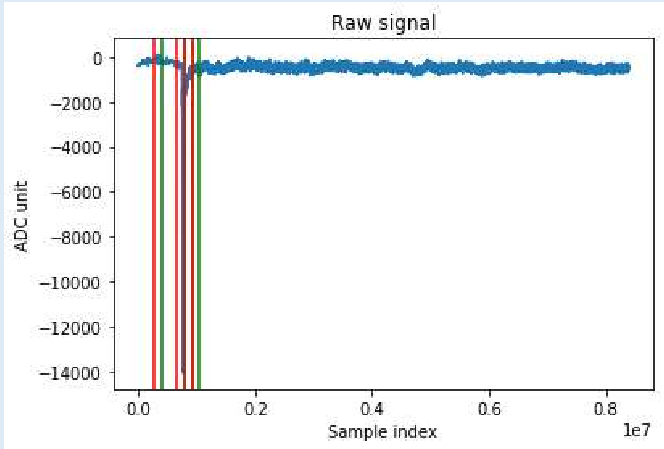
Mixed noise



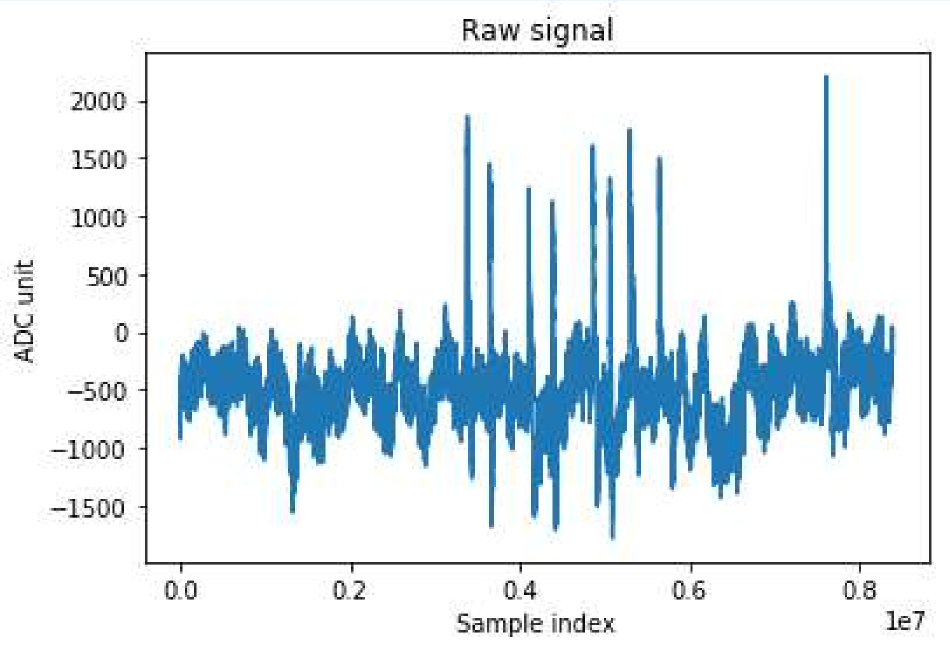
Shift the signal

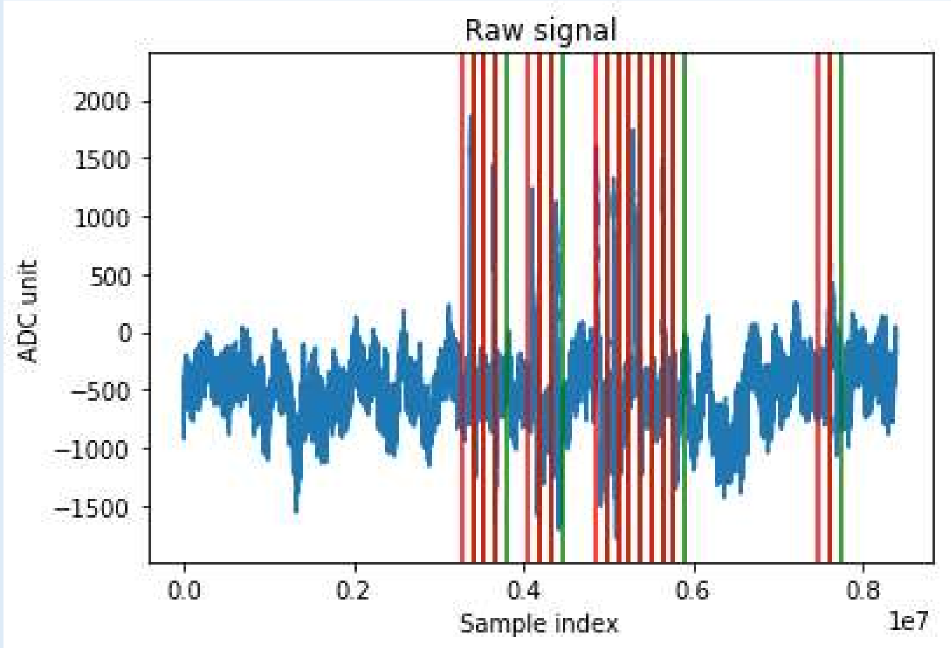






Excessive peak is found in both csases, continous noise only in the first case. This can help to detect when the nature of continous noise changes.


Raw signal
ADC unit
Sample index
1e7


Raw signal
ADC unit
Sample index
1e7

Further plans

- Separating segments with peak-type noise from continuous-type noise segments
- Identifying sources of different types of noise
  - Controlled „noise creating” in the mine in the near future
- Categorizing segments according the type of continuous noise they include
- Computing representative PASD of segments most similar to natural background infrasound noise

References

[1] Barnaföldi et al. (2016) A Mátrai Gravitációs és Geofizikai Laboratórium első mérései és mérési programja. Magyar Geofizika, 57/4, 152-169

[2] Barnaföldi et al. (2017) First report of long term measurements of the MGGL laboratory in the Mátra mountain range. Class. Quantum Grav., V34, 114001 (22pp), (arXiv:1610.07630)

[3] P Ván et al. (2018) Long term measurements from the Mátra Gravitational and Geophysical Laboratory (arXiv:1811.05198)

[4] ET Science Team (2011): Einstein gravitational wave telescope, conceptual design study Technical Report ET-0106C-10 (www.et-gw.eu/etdsdocument)

[5] Towards a first design of a Newtonian-noise cancellation system for Advanced LIGO. Class.Quant.Grav. 33 (2016) no.24, 244001 (arXiv:1606.01716)

[6] J. R. Bowman, G. E. Baker, and M. Bahavar. Ambient infrasound noise. Geophysical Research Letters, 32(9).

[7] D Fiorucci et al. (2018). Impact of infrasound atmospheric noise on gravity detectors used for astrophysical and geophysical applications. Physical Review D, 97(6), 062003.