SEISMIC GLITCHNESS AND NEWTONIAN NOISE AT THE CANDIDATE SITES

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with the contribution of many other people involved in these activities…

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Outline

- Introduction
- Newtonian Noise
- Newtonian Noise Glitchness
- Results of the analysis
- Conclusions

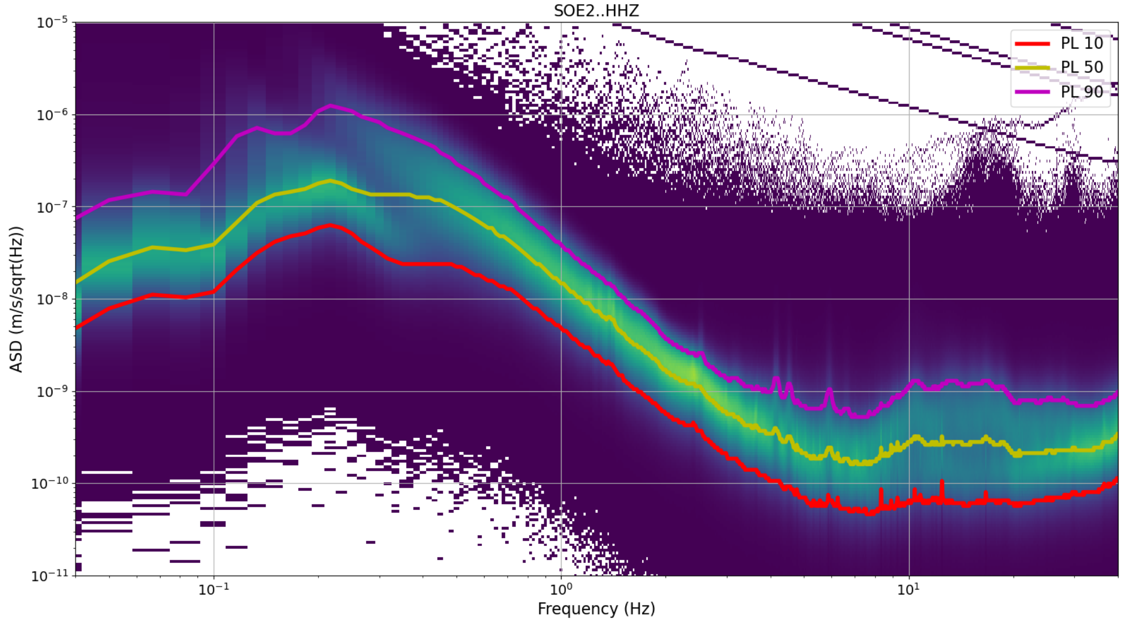
Introduction

- We focused on the effect of Newtonian Noise on the low frequency band (2-10 Hz) for the GW sources whose expected signal is limited in that band, for example coalescence of Intermediate Mass Black Holes;
- The Newtonian Noise is expected to be one of the dominant noise source in this frequency band;
- An excess of Newtonian Noise, even for a short time interval, could even completely hide such kind of signals;
- The aim of this work is to provide a lower limit for the detectability of short duration signals in the low frequency band, like IMBH;

Newtonian Noise

Motivation

- Newtonian Noise have a large variability, depending on the site, season, weather and other local conditions;
- The variability can be easily recognized by directly analyzing the seismic noise



Seismometer at Sos Enattos
Placed in cavern at -111 m
Data from:
21/12/2021
to
20/12/2022

- Variability of about one order of magnitude in the 1-10 Hz band

ET EINSTEIN TELESCOPE

Newtonian Noise

Simple Model

- The NN can be estimated from the measured seismic noise using a simplified model:
- $\tilde{h}_{NN} = \frac{4\pi}{3} G \rho_0 \frac{2\sqrt{2}}{L} \frac{1}{(2\pi f)^2} \tilde{x}$

F. Amann *et al. 2020 Rev Sci Instrum.* **91** 094504

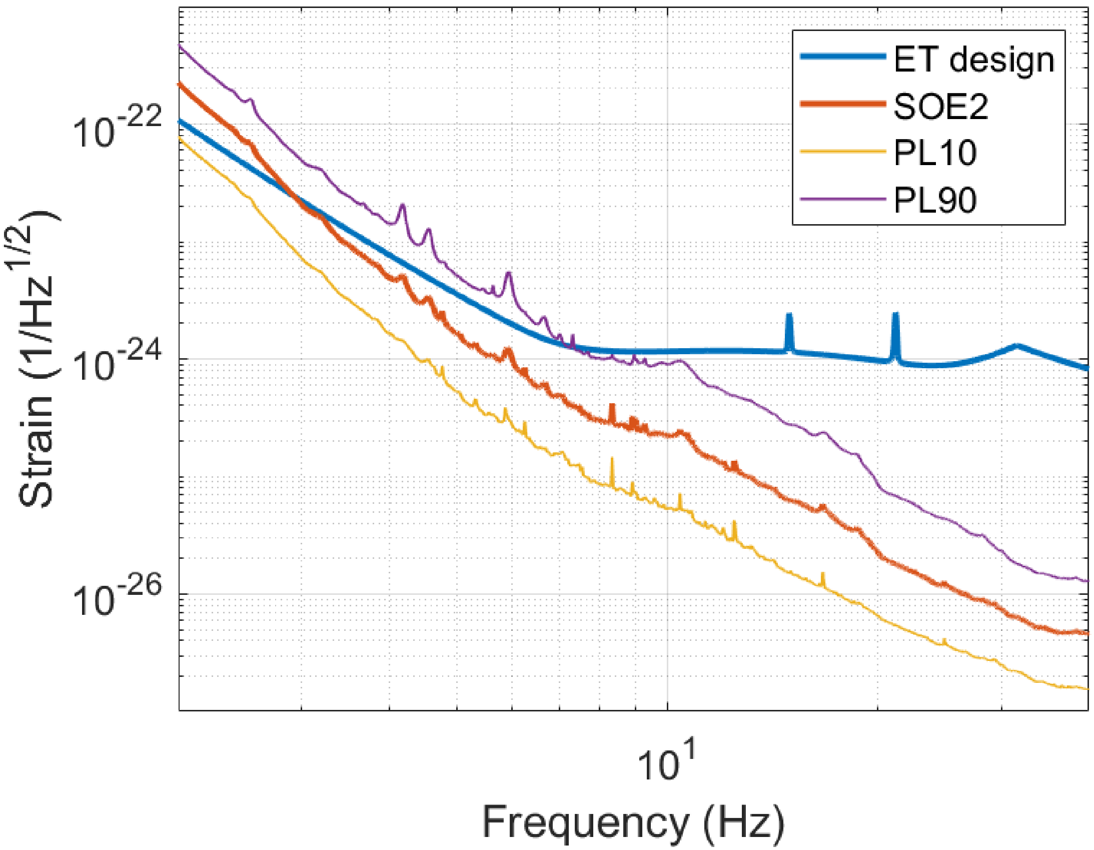
- Assuming:
  - Contribution only from body waves;
  - 1/3 of contribution to seismic noise coming from compressional waves;
  - Spherical or cubic cave;
  - Uncorrelated NN on the ITF Test Masses;
- Other mechanism can increase the NN level;
- Anyway, this expression provides for a credible lower limit;

J. Harms et al.,
Eur. Phys. J. Plus (2022) 137:687

Newtonian Noise

Simple Model

- Example: Projection of the NN with the measurements collected at Sos Enattos, at level 2 (111 m underground): median and 10, 90 percentiles;



Newtonian Noise Glitchness

Noise to Target Ratio

- Anyway, a simple projection does not consider the non-stationarity of NN (Glitchness) on the detectability of short duration GW signals.
- To this aim a more effective indicator is the so-called Noise to Target Ratio (NTR):

- $NTR = \sqrt{\frac{1}{\Delta f}\int_{f_1}^{f_2} df\ \frac{\tilde{h}_{NN}\tilde{h}_{NN}}{S_n}}$

A. Allocca et al.,
Eur. Phys. J. Plus (2021) 136:511

- S_n is the PSD of the ET target sensitivity;
- $\Delta f = f_2 - f_1$ is the selected bandwidth;

Newtonian Noise Glitchness

Noise to Target Ratio

- A value of NTR larger than one implies that, in the selected dataset, the contribution of the NN is limiting the ET sensitivity;

- If the bandwidth of the GW signal is larger than f_2 one can recover the signal since the NN is not significant for high frequency (f_2=10 Hz);

- Otherwise, the GW signal is fully lost;

- In order to quantify the impact of the NN glitchness, it is necessary to fix a time scale for the typical signal duration;

Newtonian Noise Glitchness

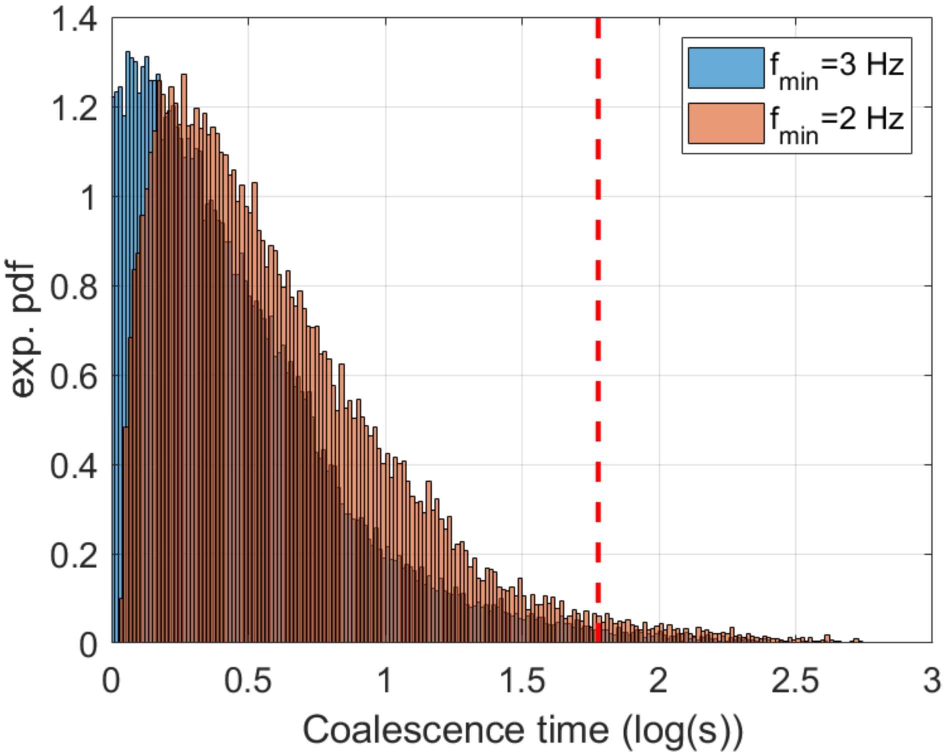
Time Window Definition

- To choose the right time window for the NTR we set a reference mass *m* of the binary BH system from the relation:
- $\frac{m}{M_\odot} = 2.2\ kHz\ \frac{1}{f_{ISCO}}$
- with $f_{ISCO} = \frac{f_2}{2}$
- than, by randomly selecting the masses m_1 and m_2 according to the condition:
- $f_1 < 4.4\ kHz \frac{M_\odot}{m_1+m_2} < f_2$
- we obtain the coalescence time:
- $\tau = 2.2\ s \left(\frac{1.21\ M_\odot}{M_c}\right)^{\frac{5}{3}} \left(\frac{100\ Hz}{f_1}\right)^{\frac{8}{3}}$

Newtonian Noise Glitchness

Time Window Definition

- This procedure was applied in two different cases:
  - f_1=2 Hz, f_2=10 Hz
  - f_1=3 Hz, f_2=10 Hz



- In both cases, by setting **Δt=60 s** more than 97% of the resulting coalescing time is included

Results of the Analysis

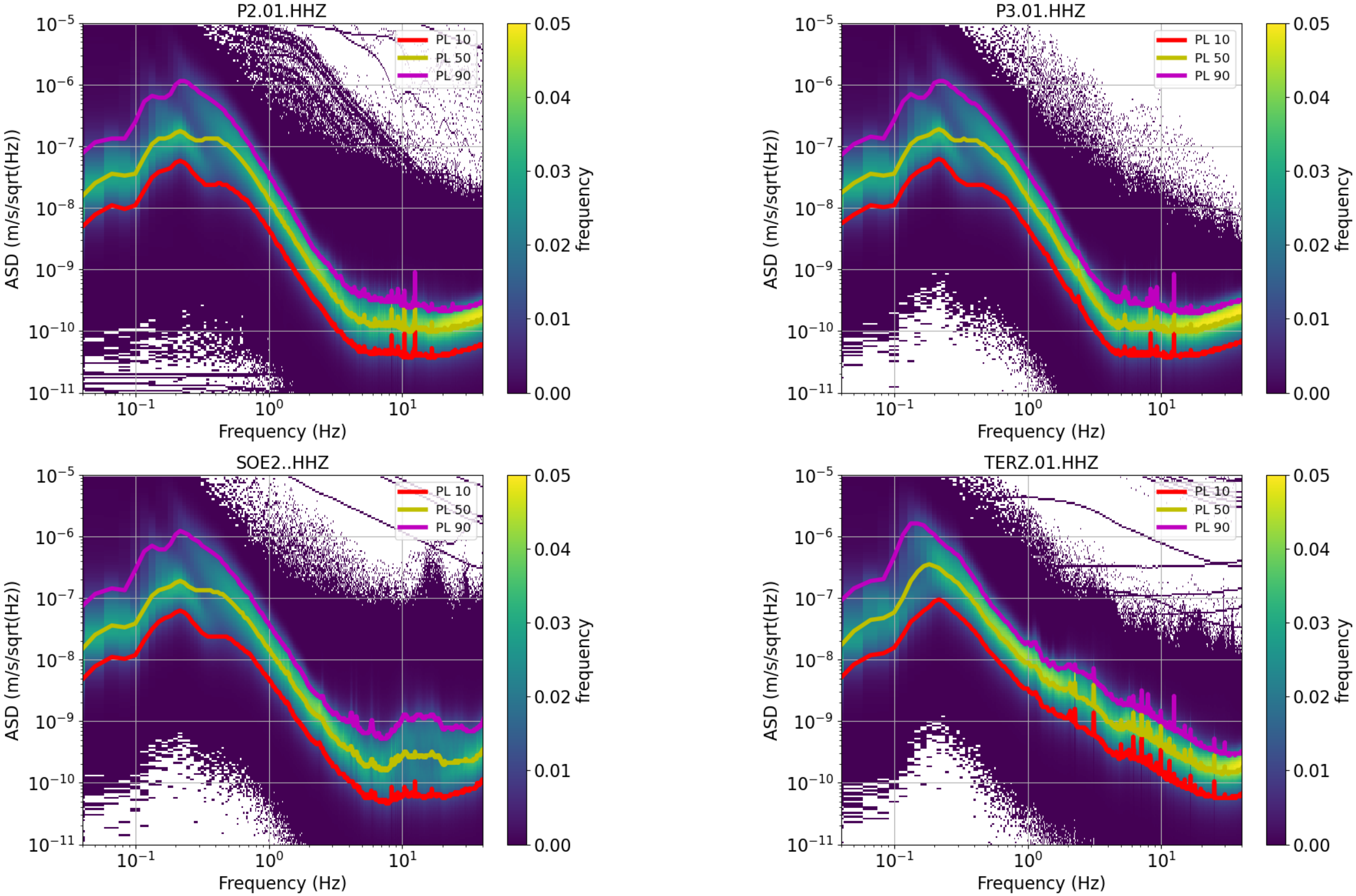
Location and time interval

- Once selected the time window, the NTR can be computed over a long-time interval by properly processing the seismic data collected in that interval;
- In particular, this procedure was applied to seismic data collected in:
  - Terziet (Euregio Meuse-Rhine):
    - NL.TERZ.01.HHZ: seismometer at -250 m;
  - Sos Enattos (Sardinia):
    - ET.P2.01.HHZ seismometers at -250 m;
    - ET.P3.01.HHZ seismometers at -250 m;
    - ET.SOE2..HHZ: seismometer at -111 m;
- Time interval: 21/12/2021 – 20/12/2022

Results of the Analysis

Seismic Noise

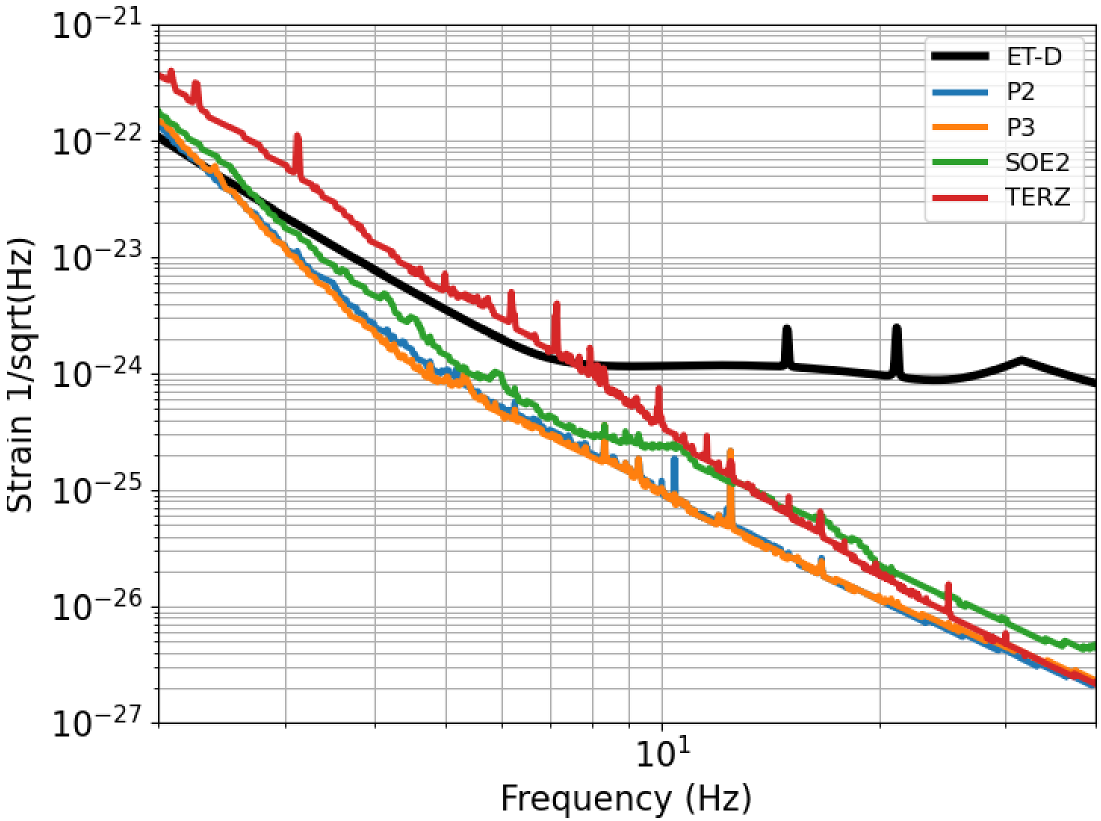
- Variability of seismic noise in the selected locations



Results of the Analysis

Newtonian Noise

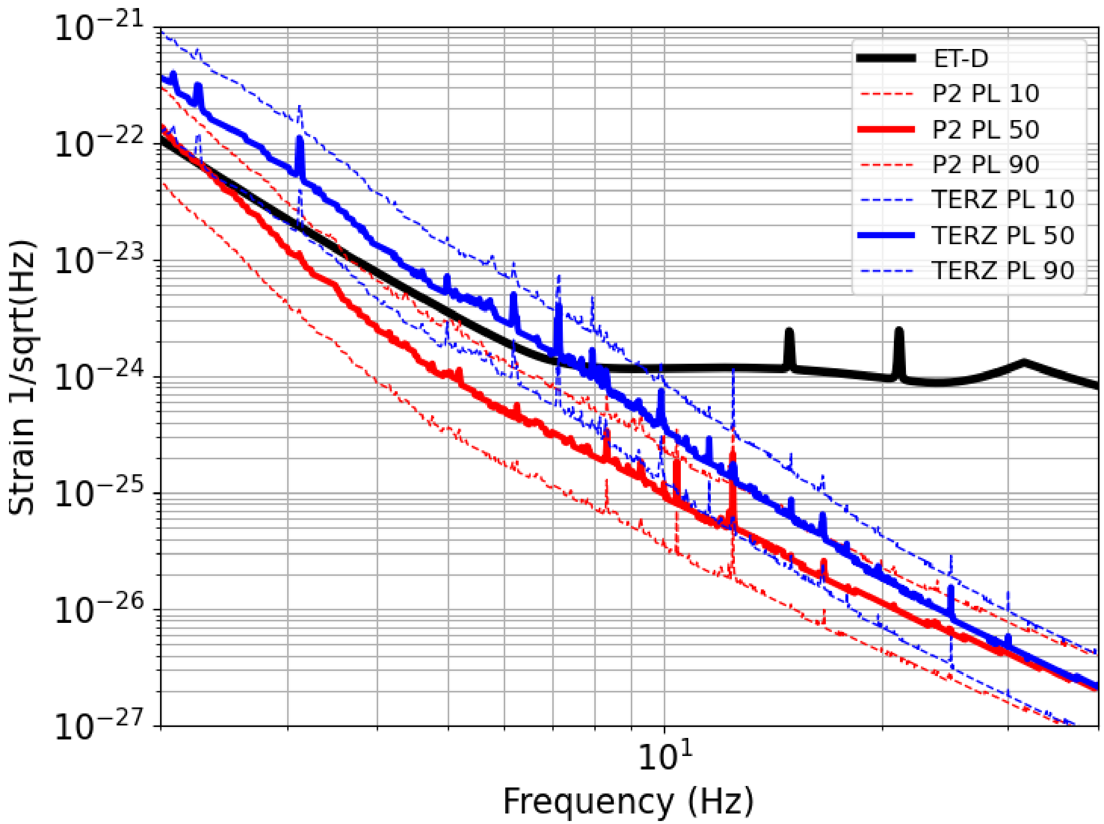
- A rough comparison can be done by directly estimating the NN from the median spectra



Results of the Analysis

Newtonian Noise

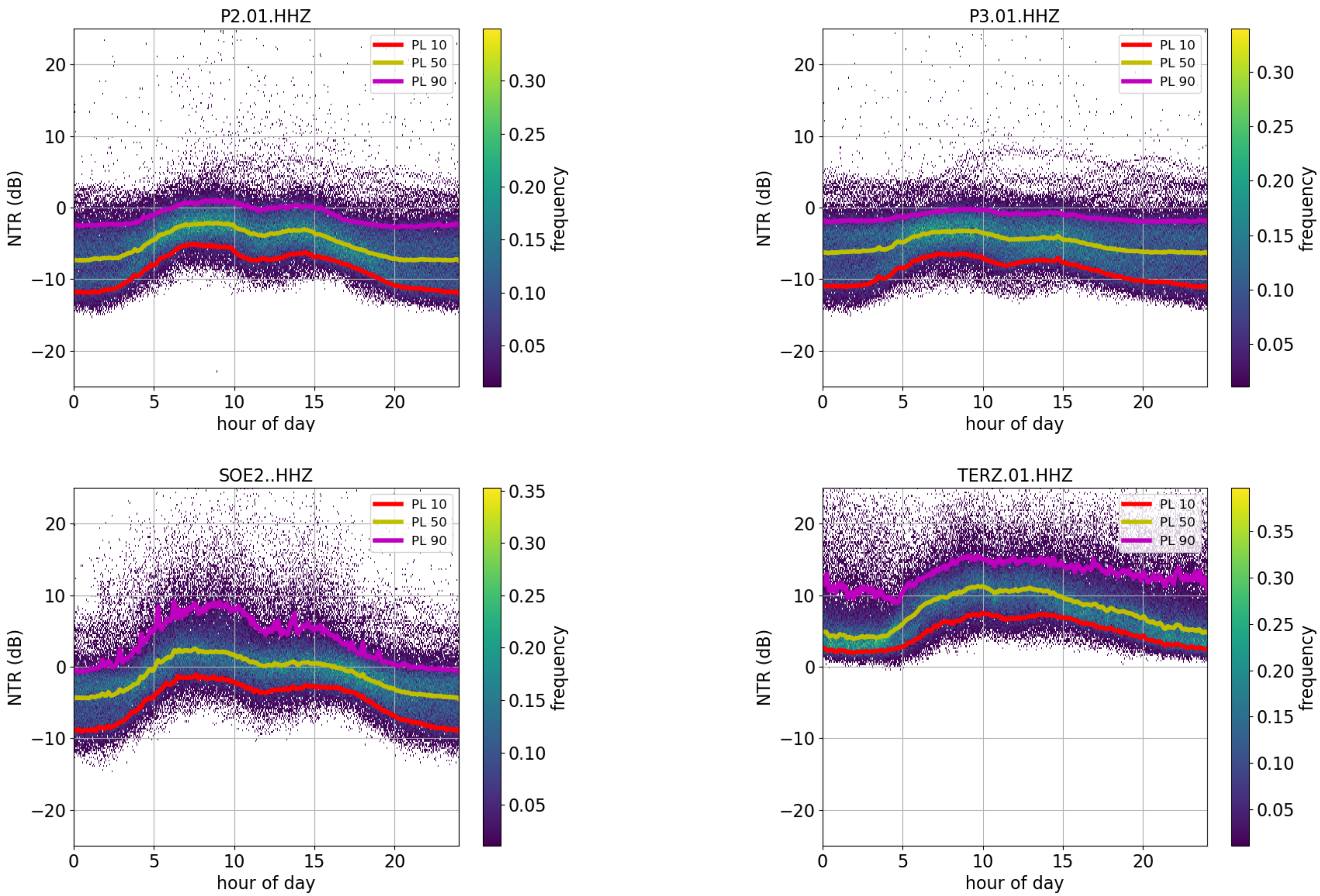
- Better information from the percentiles (only two sites for clarity)



Results of the Analysis

NTR 2-10 Hz

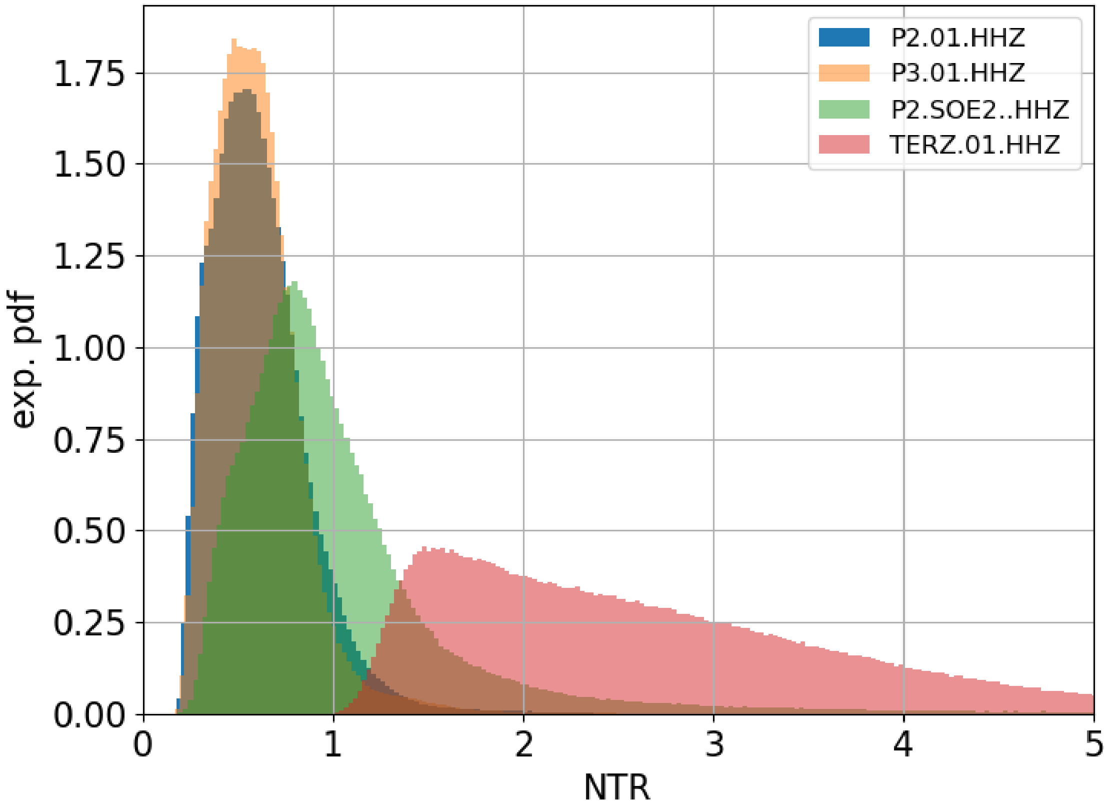
- Distributions along the day



Results of the Analysis

Full NTR Comparison

- Comparison of the full distributions for each site



P2: P(NTR>1)=6.5%
P3: P(NTR>1)=4.7%
SOE2: P(NTR>1)=38.6%
TERZ: P(NTR>5)=8.9%

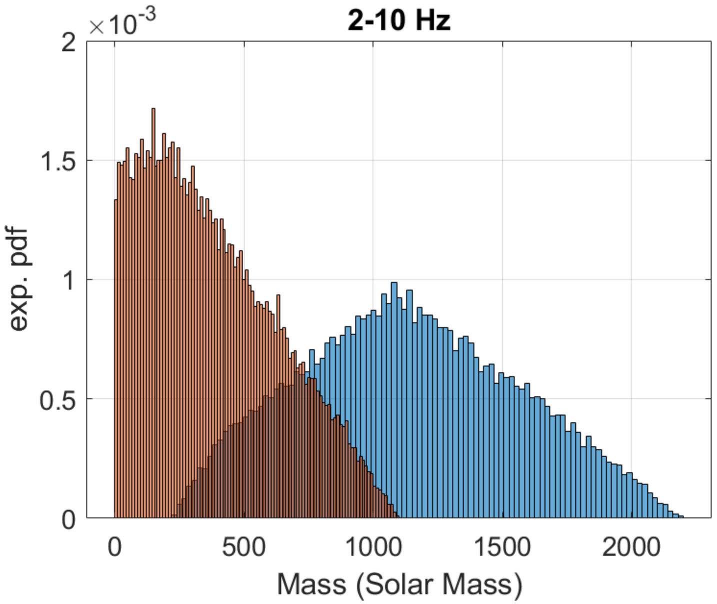
Conclusions

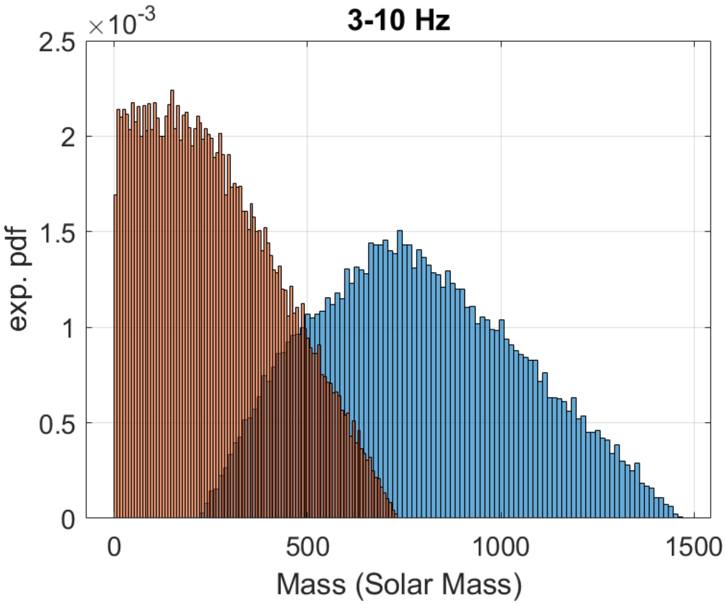
- Clear indication that, at least for Sardinia, NN could be a limited issue for sources whose spectrum is limited in the 2-10 Hz frequency band;
- Otherwise, a NN cancellation of a factor 5 is needed to recover to final ET sensitivity for more than 90% of time;
- A change in the detector geometry and length (L shape, 15 km long) should reduce the effect of NN.

Spare Slides

IMBH Mass Distribution

- Mass of the IMBH binary systems resulting from the simulation used to set the time window

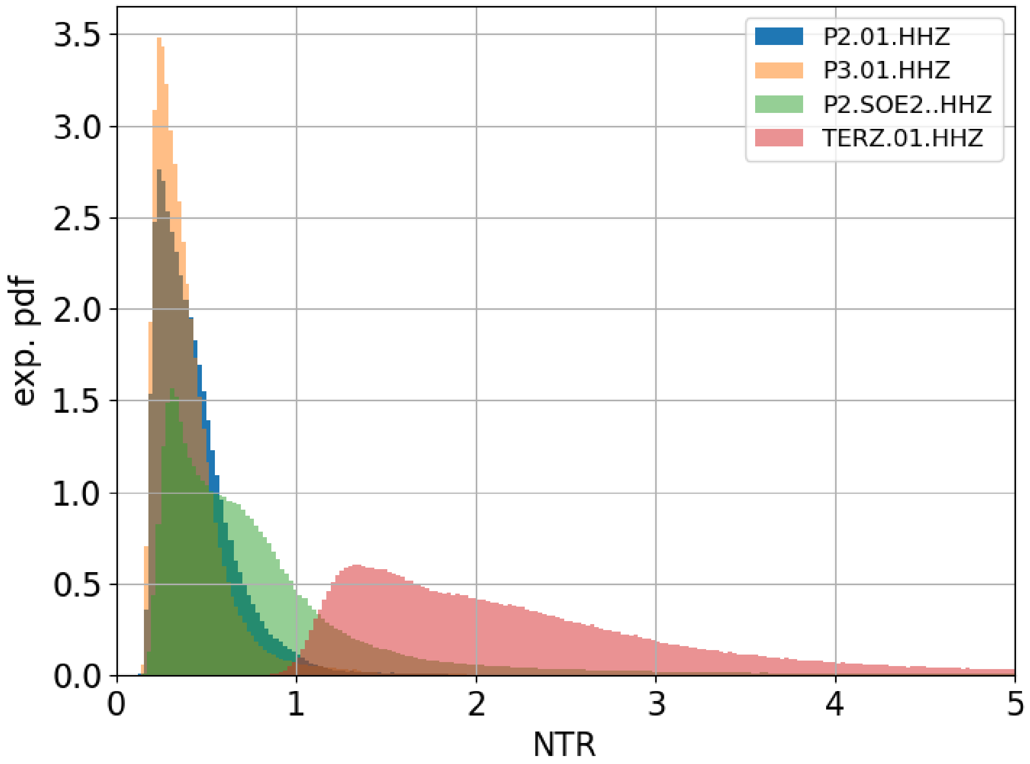




Spare Slides

NTR Comparison (3-10 Hz)

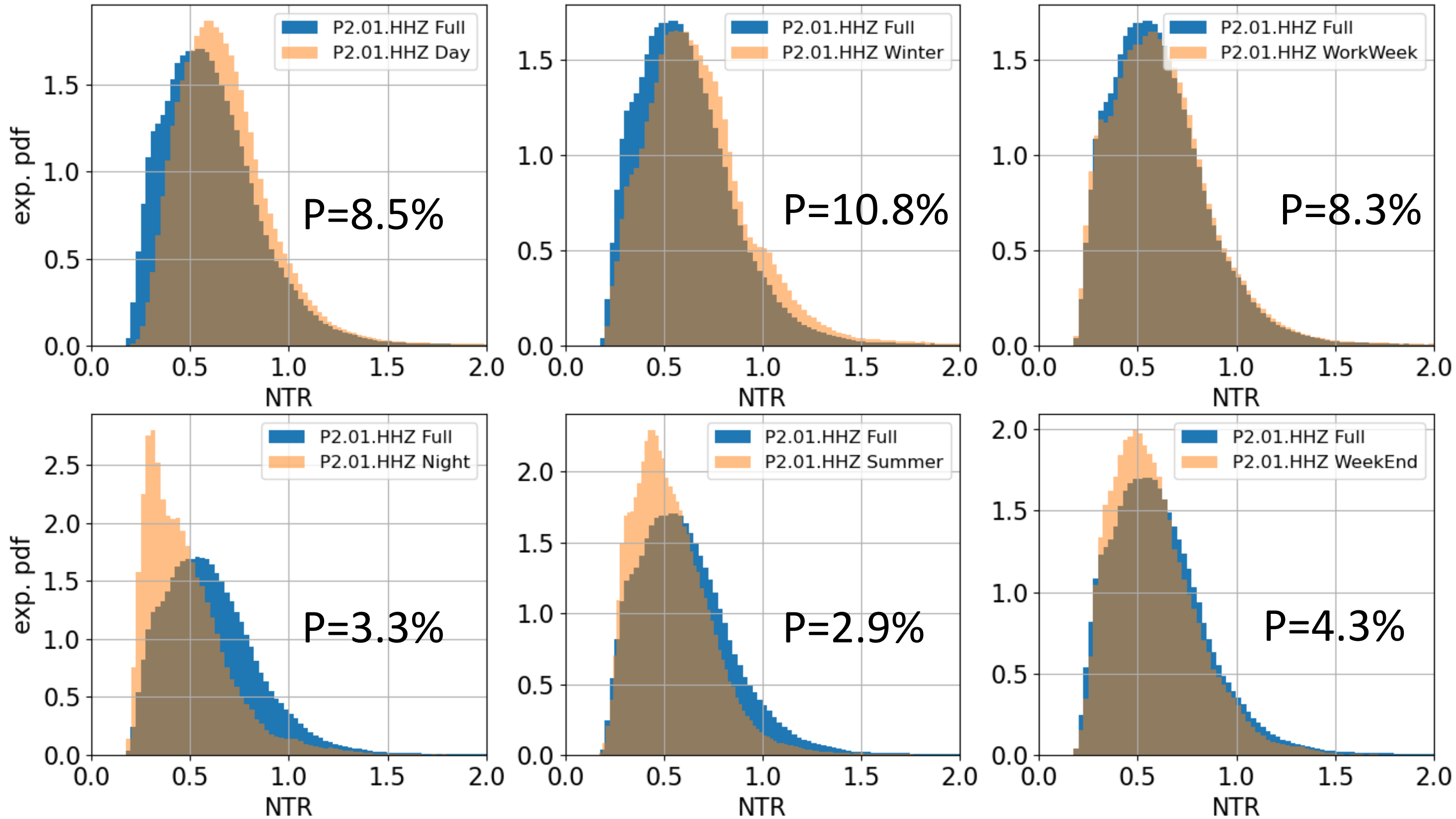
- Comparison of the full distributions for each site



Spare Slides

P2 - NTR 2-10 Hz

- Detailed distributions for each site:
  - P(NTR>1)=6.5%



Spare Slides

TERZ - NTR 2-10 Hz

- Detailed distributions for each site:
  - P(NTR>5)=8.9%