CNRS
Centre National de la Recherche Scientifique

INFN
Istituto Nazionale di Fisica Nucleare

Reference Seismic Data for Virgo

VIR-0390A-15

Irene Fiori
European Gravitational Observatory

22 September 2015

Abstract

We provide reference spectra of seismic noise of the Virgo site. These are computed using datasets collected with 3-axis seismometers over different time perionds lasting from 1 week to 1 year. Datasets have been collected at variuos locations either at Virgo experimental buildings floor or outdoor at the EGO site. For each data sample we computed statistical percentile curves. We illustrate some simple comparisons among different dataset and with similar seismic spectra of Ligo LLO. All Virgo percentile spectra described in this note have been collected in one *Matlab* formatted file which is available in VirgoTDS together with this document.

VIRGO A joint CNRS-INFN Project
Via E. Amaldi, I-56021 S. Stefano a Macerata - Cascina (Pisa)
Secretariat: Telephone (39) 050 752 521 * FAX (39) 050 752 550 * Email: ego@ego-gw.it

Editions

First: 10 October 2014

Revisions: 22 September 2015

Attached documents

File: VIR-0390A-15.mat (Matlab data file)

File: VIR-0390A-15.m (Matlab script file reproducing Figure 3)

Abstract

This note provides reference spectra of seismic vibration noise of the Virgo site. Spectra are computed using datasets recorded by 3-axis seismometers over different time periods lasting from 1 week to 1 year. Datasets have been collected at variuos locations either indoors at Virgo experimental buildings floor or outdoors around the EGO site. For each data sample we computed statistical percentile curves. We illustrate a few comparisons among our dataset and with similar seismic spectra of Ligo LLO. All Virgo percentile spectra described in this note have been collected in one Matlab formatted file which is available in Virgo TDS together with this document.

Contents

1. **Introduction .... pg. 3**
2. **Datasets .... pg. 3**
3. **Data processing .... pg. 4**
4. **Description of attached file Virgo_SeismicData.mat .... pg. 5**
5. **Some plots .... pg. 7**
6. **References .... pg. 15**

1. Introduction

This report provides seismic vibration spectra of the site of the Virgo gravitational wave detector. Data were taken over different time periods ranging from 1 week to 1 year length, between years 2004 and 2013. Data include records from both tri-axial seismometers mounted on the basement slab of Virgo experimental buildings and tri-axial seismometers settled on soil at some external locations near the Virgo central building and the arm tunnels. These data have been processed to provide a statistical description of seismic noise at the site. Percentile level spectra are produced. The X-th percentile spectra tells that there is a X-% probability of finding a seismic amplitude less of the given value. In particular X=1,5,10,25,50,75,90,99 percentile thresholds are used. These spectra have been used as input for Advanced Virgo simulations in particular for stray light noise simulations and noise projections.
In the following we describe the datasets (Sec.2) and the data processing (Sec.3). We collected this data in one *Matlab* formatted file whose structure we describe in Sec. 4. We compare our seismic spectra with those of LIGO LLO [1] (Sec.5).

2. Datasets

Station n.	Name	Location	Sensor / Digitizer	Bandwidth (*)	Time	Length	Notes
1	CEB-1	Central building floor L2, near BS	Guralp 40T-30s / Virgo DAQ	100mHz to 25Hz	Jan 01 2011 to Jan 7 2012	1 year	
2	CEB-2	Central building floor L2, near BS	Guralp 40T-30s/ Virgo DAQ	100mHz to 100 Hz	Jun 04 2011 to Sep 03 2011	3 months	VSR4, only science mode segments
3	MCB	Mode Cleaner building floor L1, tower pit	Episensor FBA-EST /Virgo DAQ	300mHz to 25Hz	Jan 05 to Jun 08 2013	6 months	ADC noise limiting below 500mHz
4	NEB	Nord End building floor L1, tower pit	Episensor FBA-EST /Virgo DAQ	300mHz to 25Hz	Jan 05 2013 to Jun 08 2014	1 year	ADC noise limiting below 500mHz
5	WEB	West end building floor L1, tower pit	Episensor FBA-EST /Virgo DAQ	300mHz to 25Hz	Jan 05 2013 to Jun 08 2014	1 year	ADC noise limiting below 500mHz
6	V1	Central building floor L2, near BS	Lennartz 3D-5s /REFTEK	100mHz to 25Hz	19 to 25 Feb 2004	5 days	indoor
7	V2	External ground close to N tunnel at 150m from CEB	Lennartz 3D-5s /REFTEK	100mHz to 25Hz	19 to 25 Feb 2004	5 days	outdoor
8	V3	External ground at 100m from CEB SE corner	Lennartz 3D-5s /REFTEK	100mHz to 25Hz	19 to 25 Feb 2004	5 days	outdoor
9	V4	External ground close to W tunnel at 200m from CEB	Lennartz 3D-5s /REFTEK	100mHz to 25Hz	19 to 25 Feb 2004	5 days	outdoor
10	V5	External ground close to W tunnel at 750m from CEB	Lennartz 3D-5s /REFTEK	100mHz to 25Hz	25 Feb to Mar 09 2004	12 days	outdoor
11	INGV1	External ground SW of CEB	Lennartz 3D-5s /REFTEK	100mHz to 62.5 Hz	12 to 17 Nov 2009	5 days	outdoor
12	INGV2	External ground SW of CEB	Lennartz 3D-5s /REFTEK	100mHz to 62.5 Hz	12 to 17 Nov 2009	5 days	outdoor
13	INGV3	External ground SW of CEB	Lennartz 3D-5s /REFTEK	100mHz to 62.5	12 to 17 Nov 2009	5 days	outdoor

Table 1. The datasets. (*) Effective useful bandwidth accounting for sensor unitary response, sensor noise, and sampling frequency.

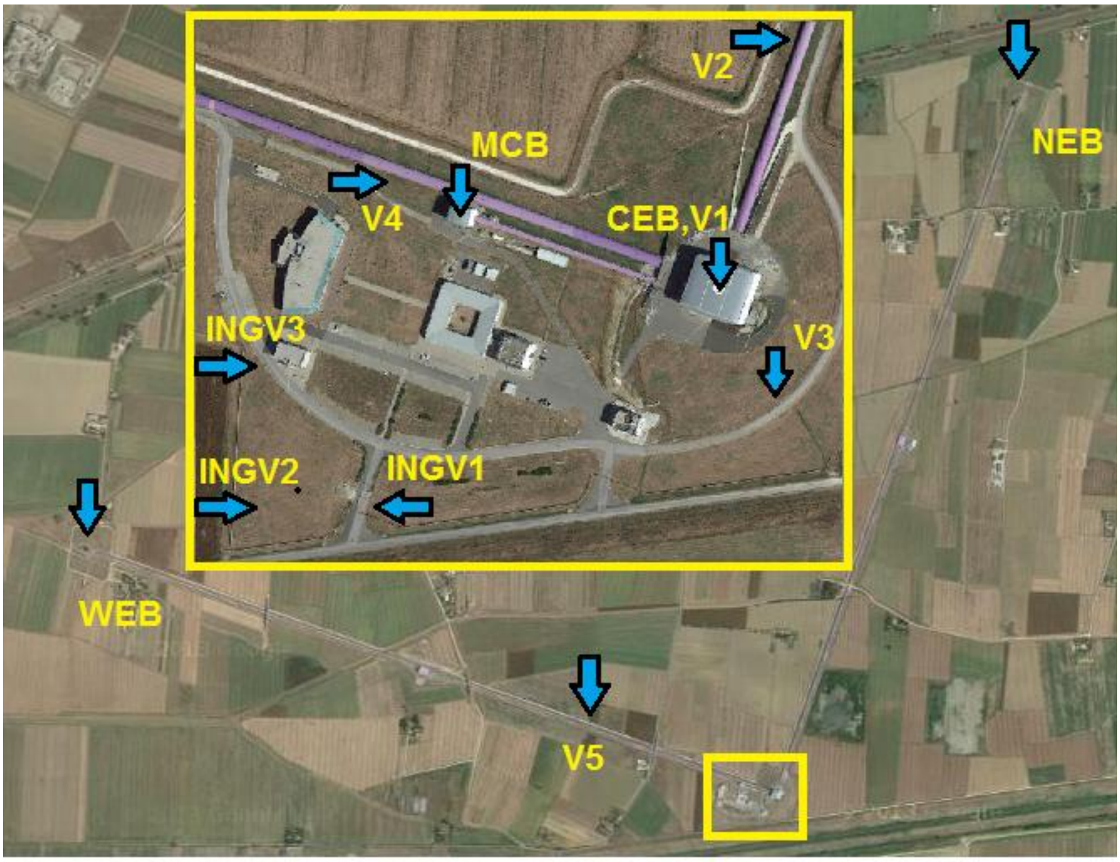

Figure 1. Sensors location map.

3. Data processing

- Data are read in 1800s long segments. Segments are contiguous assuring a full coverage of the analyzed period. An high-pass filter (3rd order Butterworth f_cut 30mHz) is applied to Episensor channels (MCB, NEB, WEB datasets) to rmove large thermal drifts. CEB-2 dataset is downsampled from 1kHz to 200Hz using Matlab decimate function. The Matlab Welch's method is used to produce the amplitude spectral density (ASD) averaged spectrum for each segment. A time window of 128s is used with no overlap, corresponding to 14 averages and frequency bin spacing of 0.008Hz.

- Each ASDs set is visually inspected to identify and remove those spectra that correspond to sensor "off" or saturated signal, or any anomalous condition in general. Figure 2 shows for example the selection case for V1 dataset. Just for the CEB-2 dataset, corresponding to CEB seismometer during VSR4 Virgo Science Run, an extra selection is applied based on the ITF science mode flag and only the good ASD during science mode periods have been kept.These periods correspond to no extra seismic noise from people or machineries in the experimental buildings.

- ASD are calibrated in units of m/sqrt(Hz). The calibration factor used depends on the se nsor: for the Guralp 40T sensor: (0.00125 ms-1/V) / ($2\pi f$), for Episensors (0.245 ms-2/V) / $(2\pi f)^2$, for Lennartz sensors: (0.0025 ms-1/V) × (1.59 E-6 V/counts) / ($2\pi f$).

- For each frequency bin the data of all ASD are histogrammed and used to compute the ASD value which is not exceeded for a given X fraction of time, which is called percentile level. Percentile Levels (PL) are computed for percent time fractions X = 1, 5, 10, 25, 50, 75, 90, 95 and 99.

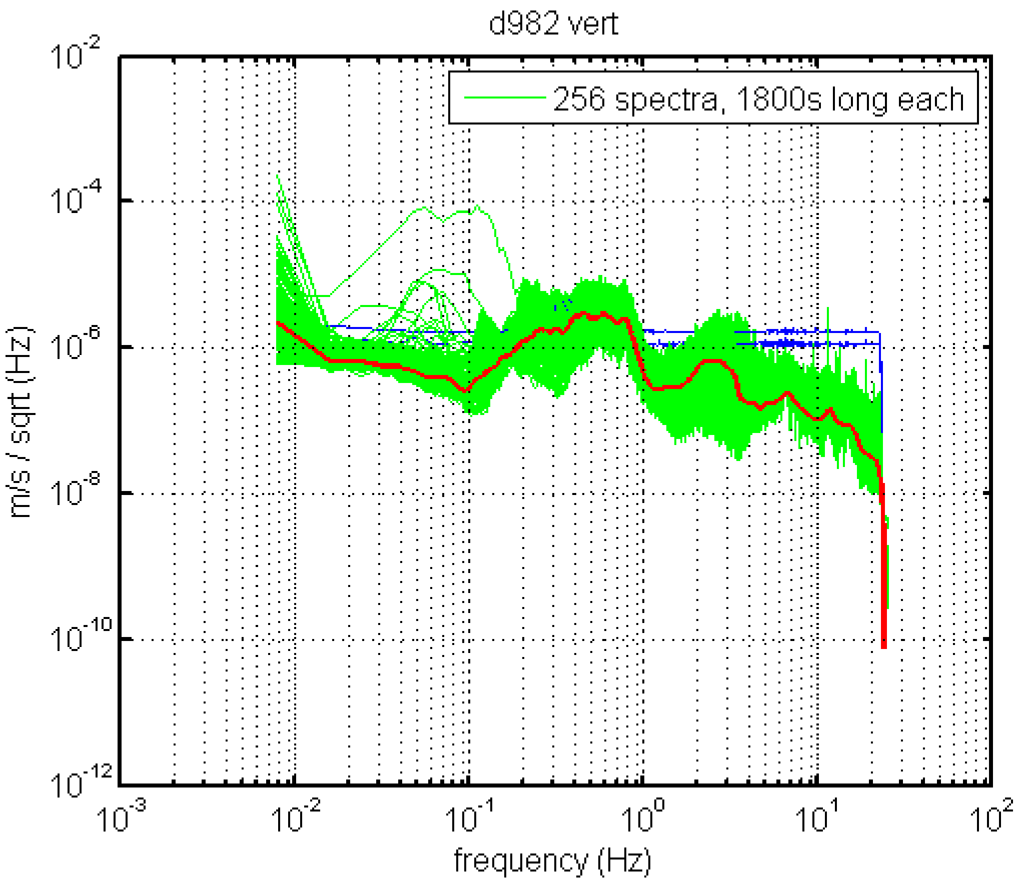

Figure 2. Calibrated ASDs of the V1 dataset: green=accepted ASD, blue=discharged ASD. Red line is the mean value of accepted ASDs.

4. Description of attached file Virgo_SeismicData.mat

Percentile levels are stored into a Matlab .mat formatted file named Virgo_SeismicData.mat, which can be found in the Virgo TDS as auxiliary file attached to this document. The file contains one structure type variable *VirgoSeismicPL* whose fields are described in the Table below.

Field	description
VirgoSeismicPL.description	Description of the dataset, total length and number of segments
VirgoSeismicPL.sensor.description	Station name, Sensor type, Sensor location, Sensor orientation
VirgoSeismicPL.sensor.name	Channel name
VirgoSeismicPL.sensor.Latitude	Latitude of sensor location
VirgoSeismicPL.sensor.Longitude	Longitude of sensor location
VirgoSeismicPL.f	Frequency vector for each PL spectrum
VirgoSeismicPL.spectra	PL spectra (one for each thr value)
VirgoSeismicPL.spectraSmoothed	PL spectra (one for each thr value) smoothed
VirgoSeismicPL.units	m/sqrt(Hz)
VirgoSeismicPL.thr	Percentile fractions (1,5,10,25,50,75,90,95,99)
VirgoSeismicPL.initialTime.gps	dataset initial time, GPS
VirgoSeismicPL.initialTime.str	dataset initial time, dd-mmm-yyyy hh:mm:ss
VirgoSeismicPL.finalTime	dataset final time, GPS
VirgoSeismicPL.finalTime	dataset final time, dd-mmm-yyyy hh:mm:ss
VirgoSeismicPL.examinedTimeFraction	Total time fraction covered after removing bad segments

There are 39 sensors in the file, making 13 triplets corresponding to the 13 seismic stations in Table 1 (same order). Each triplet contains axis EW, NS and VERTICAL for the same sensor (always in this order).

So, for example to access the 90-th percentile of Virgo CEB floor seism along N-arm during VSR4 science:

```
>> freq=VirgoSeismPL(5).f(:,7);

>> data= VirgoSeismPL(5).spectra(:,7);
```

A simple matlab script, which reproduces Figure 3, is also attached to this document in TDS.

.

5. Some plots

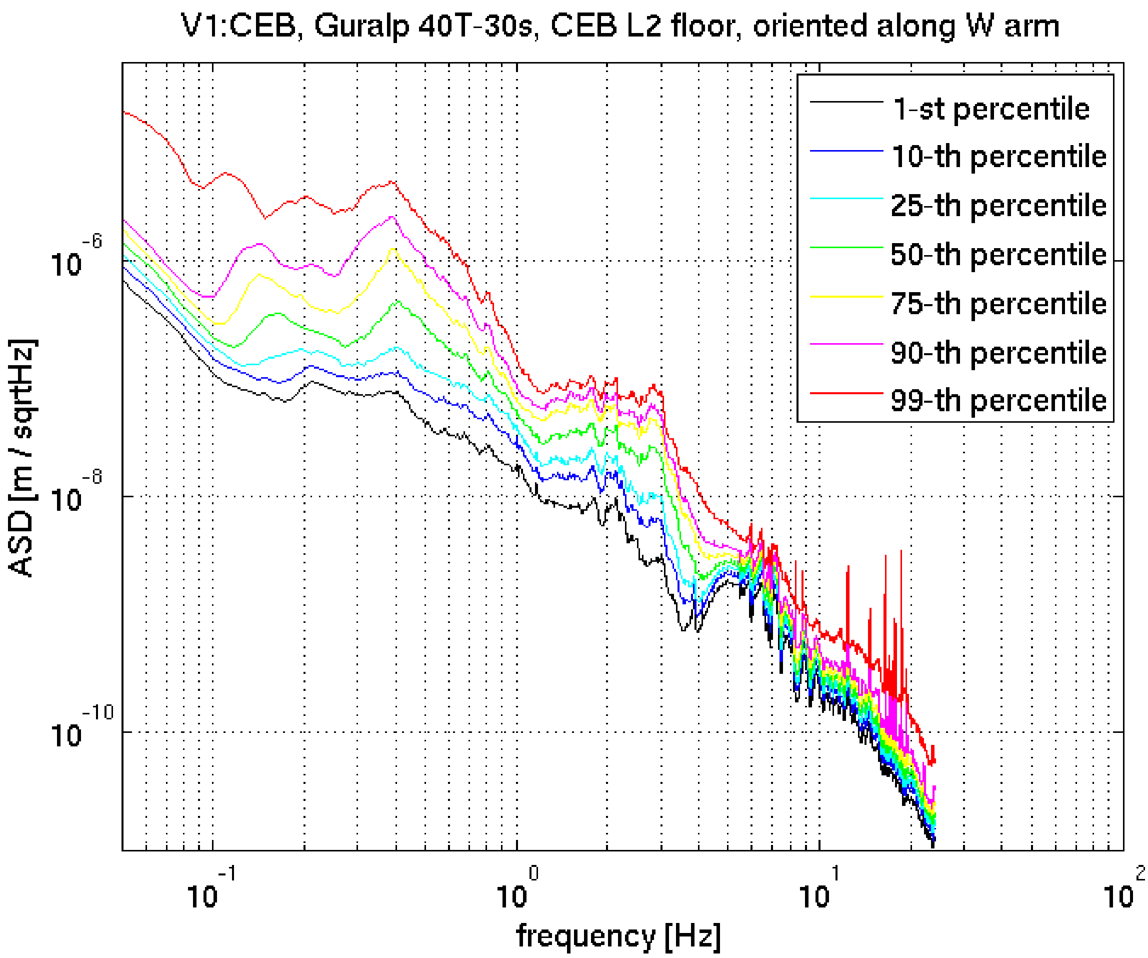

Figure 3. Virgo CEB seismic percentile spectra, along W arm direction, based on 1 year long statistics.

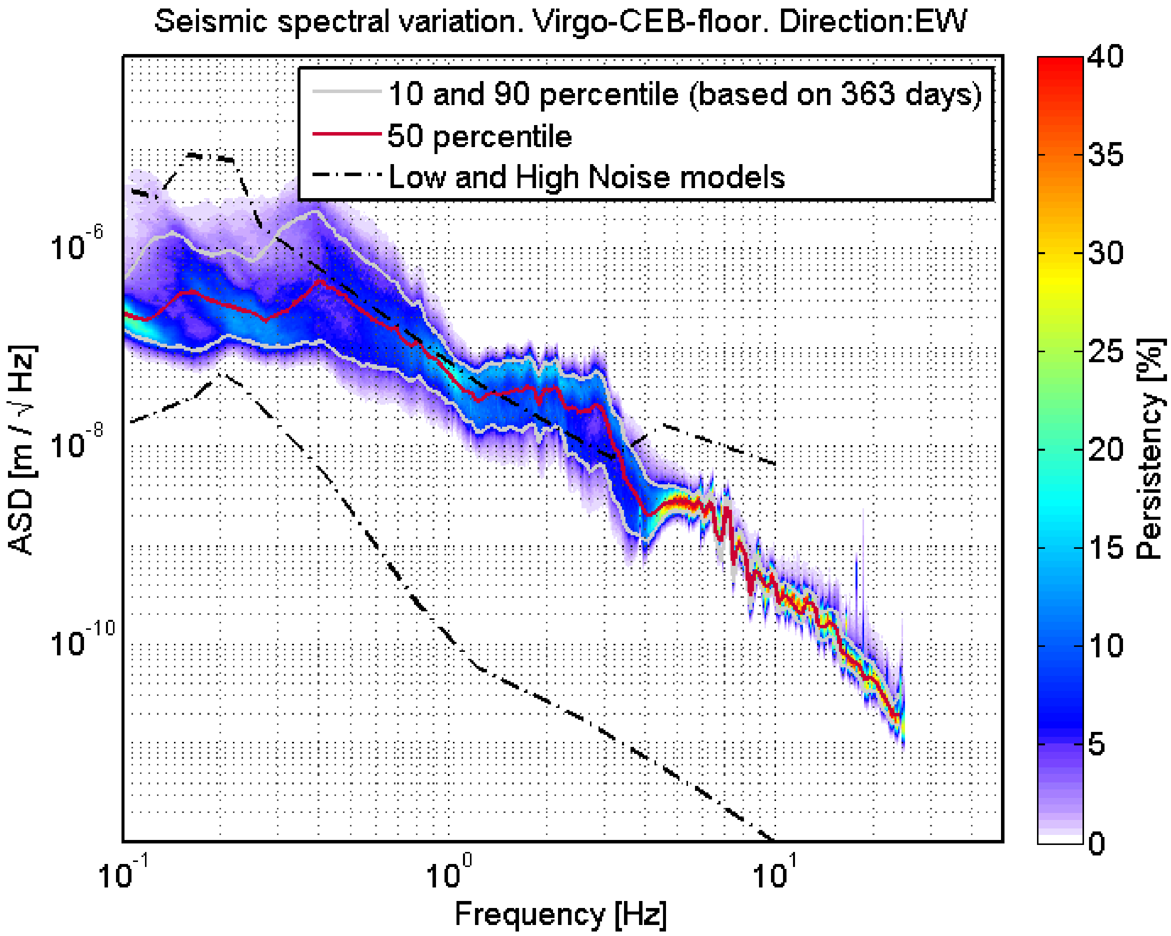

Figure 4. Virgo CEB seismic persistency plot, along W arm based on 1 year statistics. Here the full ASD set of CEB-1 is used, the color scale measures the occupancy of X-Y bins. The 10-th, 50-th and 90-th smoothed PL spectra are overlaid, as well as Peterson's Low and High Noise models [*J.Peterson, Observations and modeling of seismic background noise, Open-File Report 93-322, 1993*].

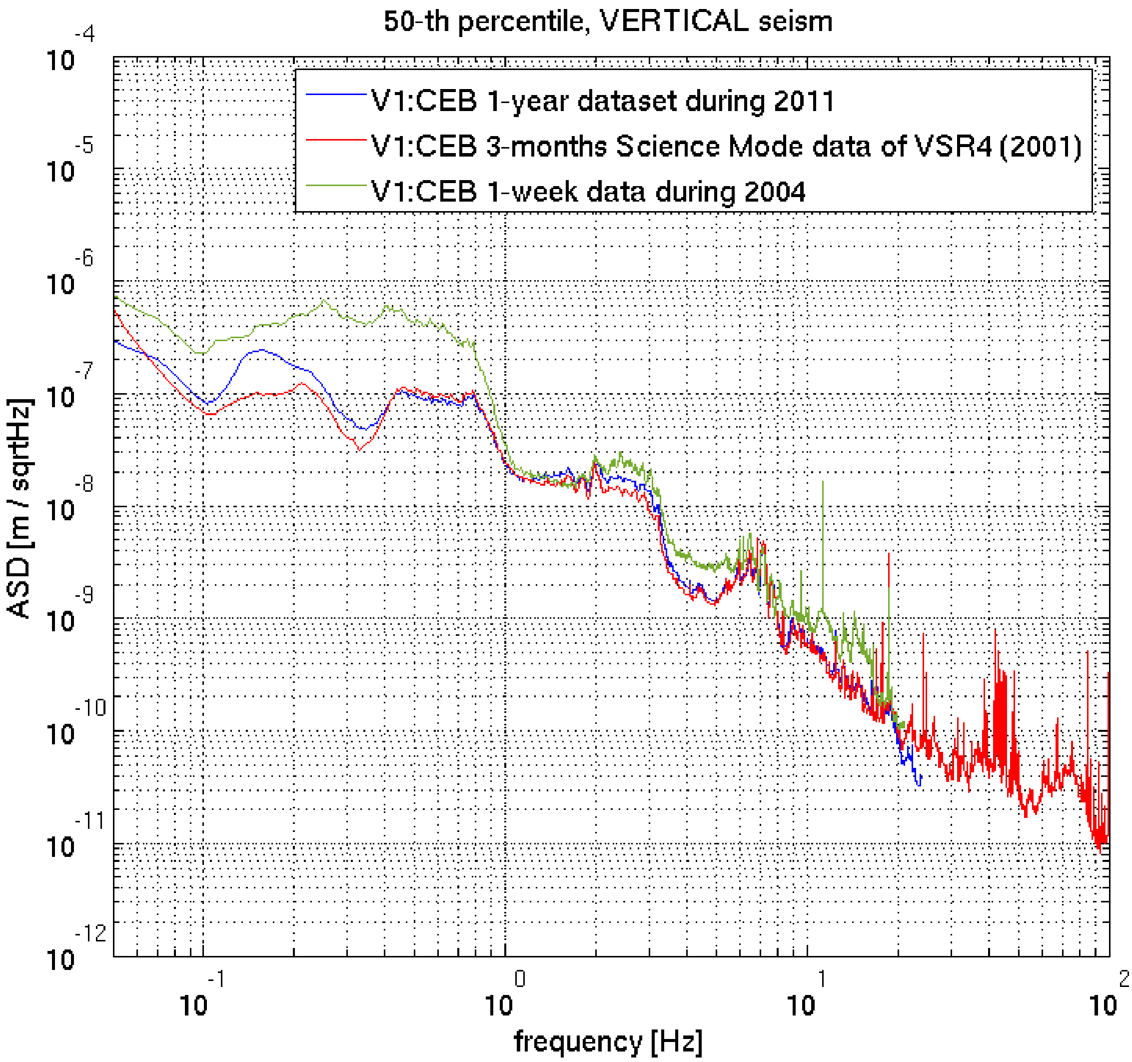

Figure 4. Virgo CEB 50th seismic percentile along VERT direction, comparing 1year, VSR4 and 1-week datasets. Values below 1Hz are more accurately estimated in longer datasets, values above 1Hz are reasonably accurate also in short datasets.

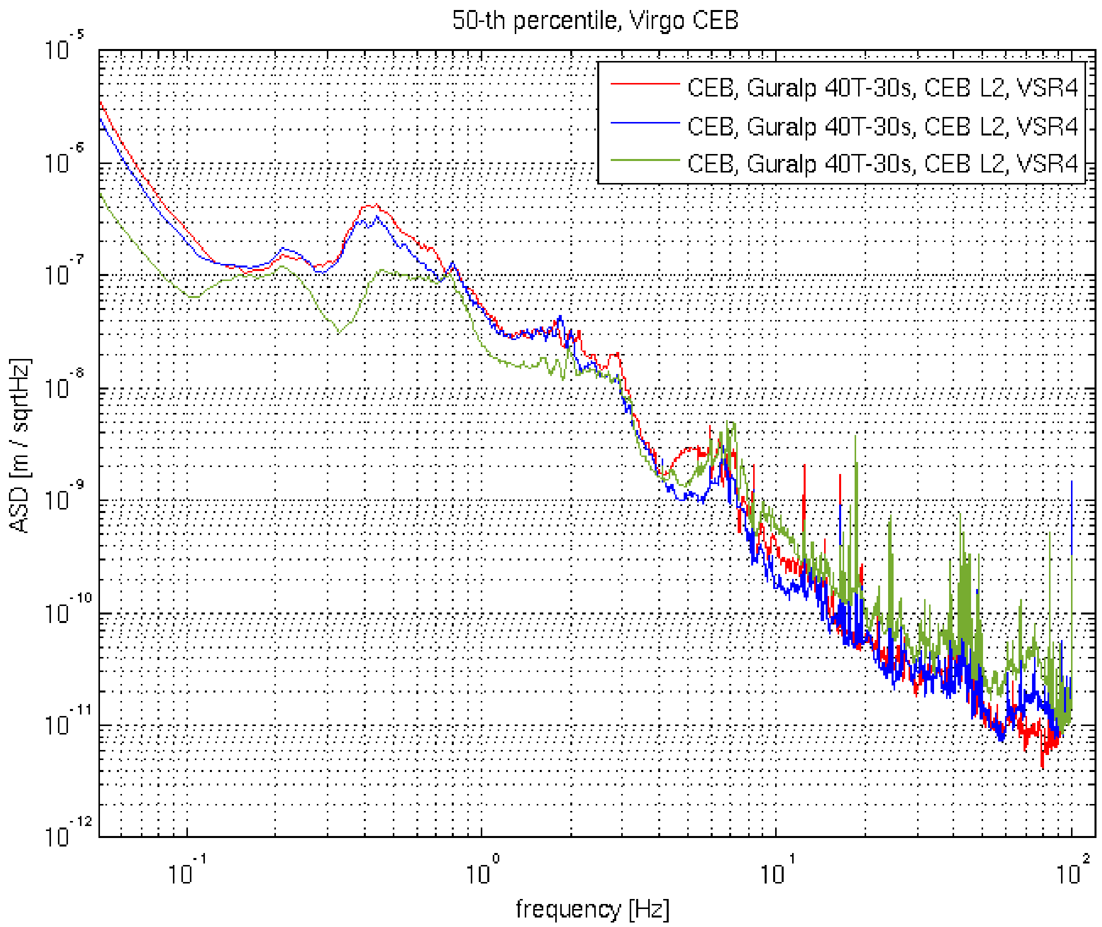

Figure 5. Virgo CEB 50-th seismic percentiles along all three directions.

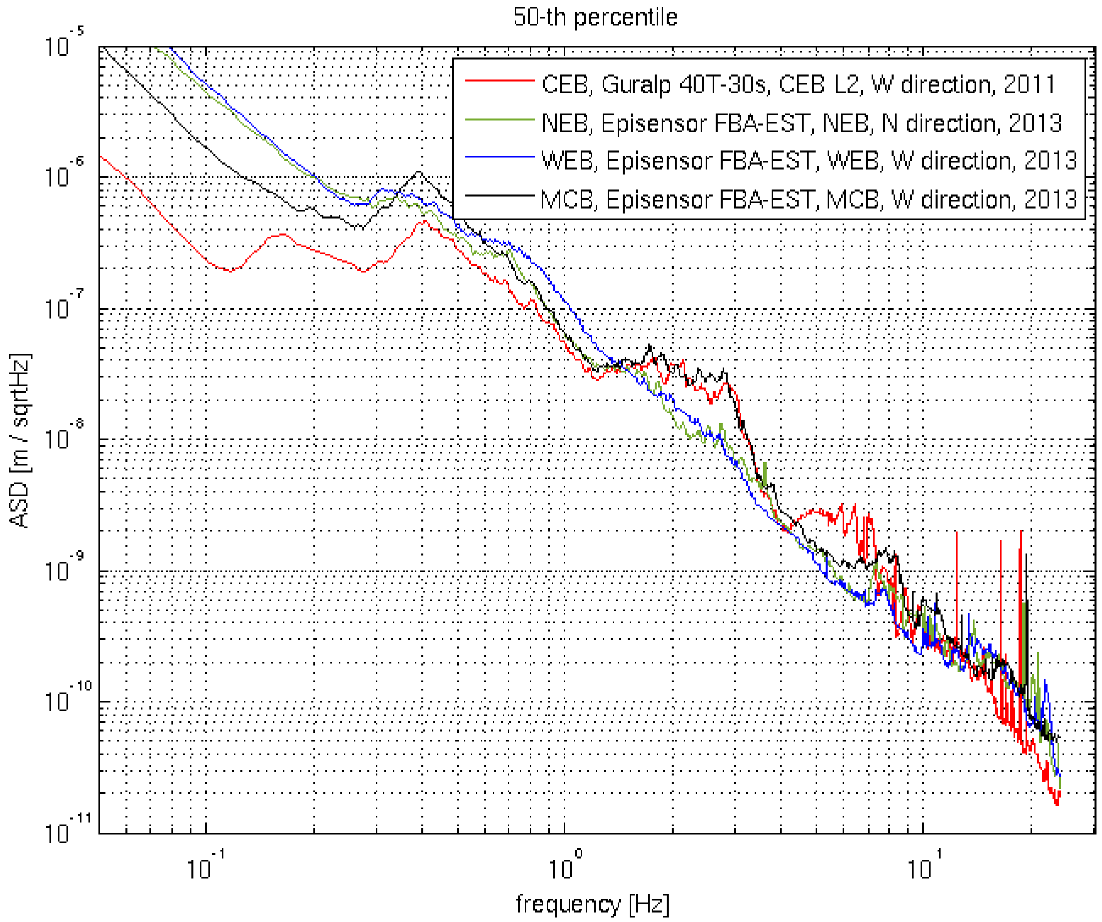

Figure 6. Virgo 50-th seismic percentile spectra (horizontal) in all 4 experimental buildings. End and MC buildings spectra are spoiled by ADC noise below 0.3Hz.

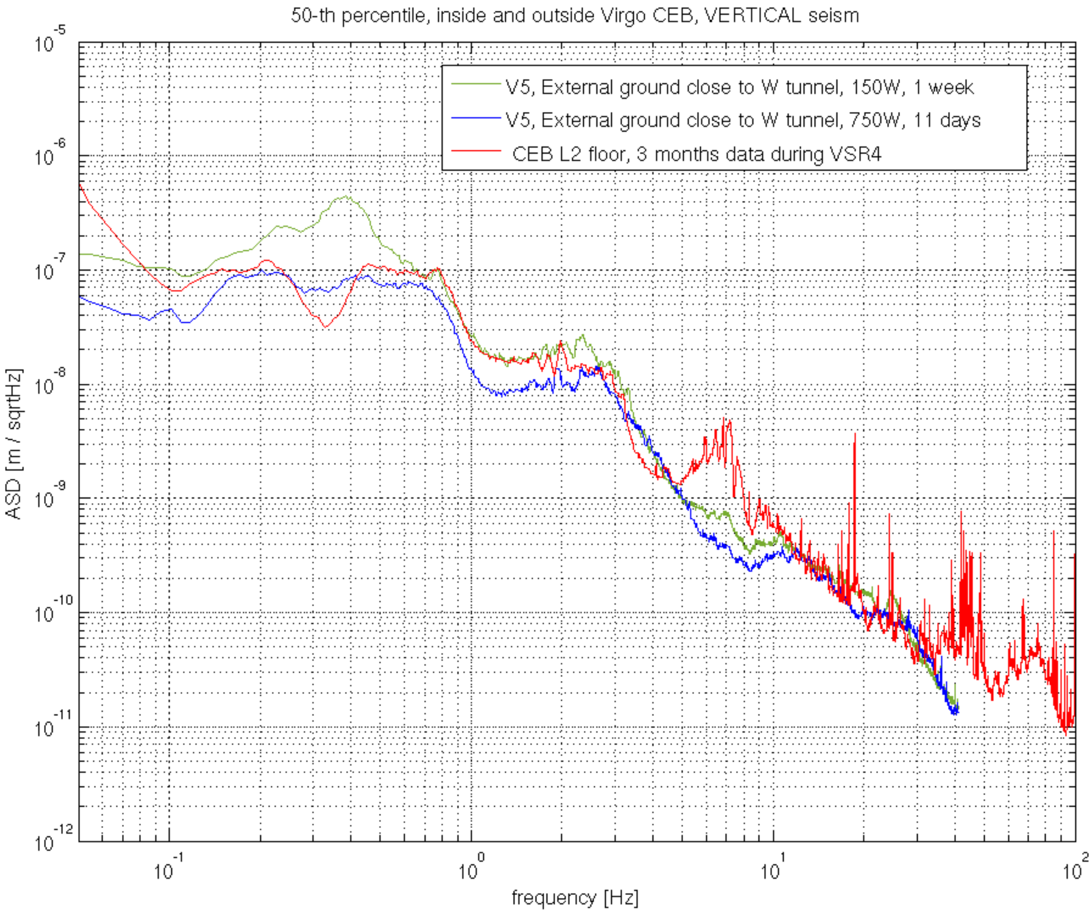

Figure 7. Vertical 50-th seismic percentile spectra inside CEB and on external ground.

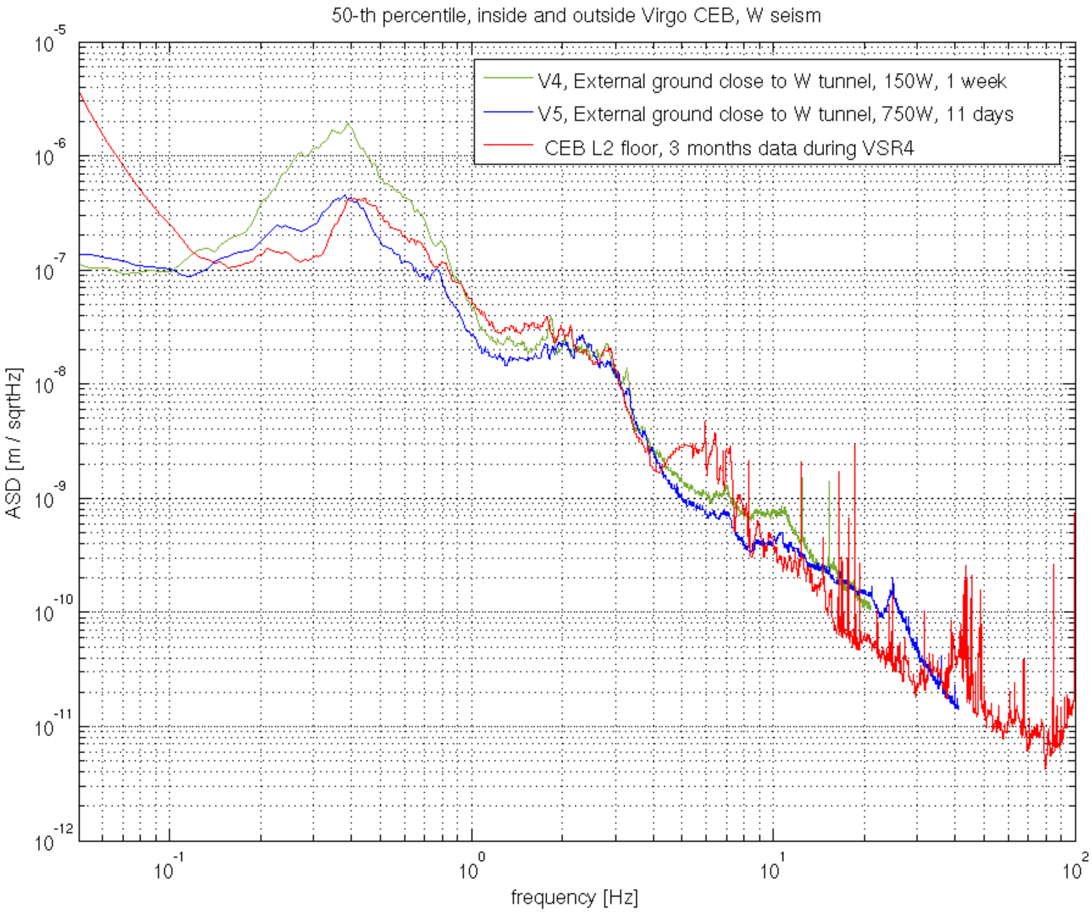

Figure 8. Horizontal 50-th seismic percentile spectra inside CEB and on external ground.

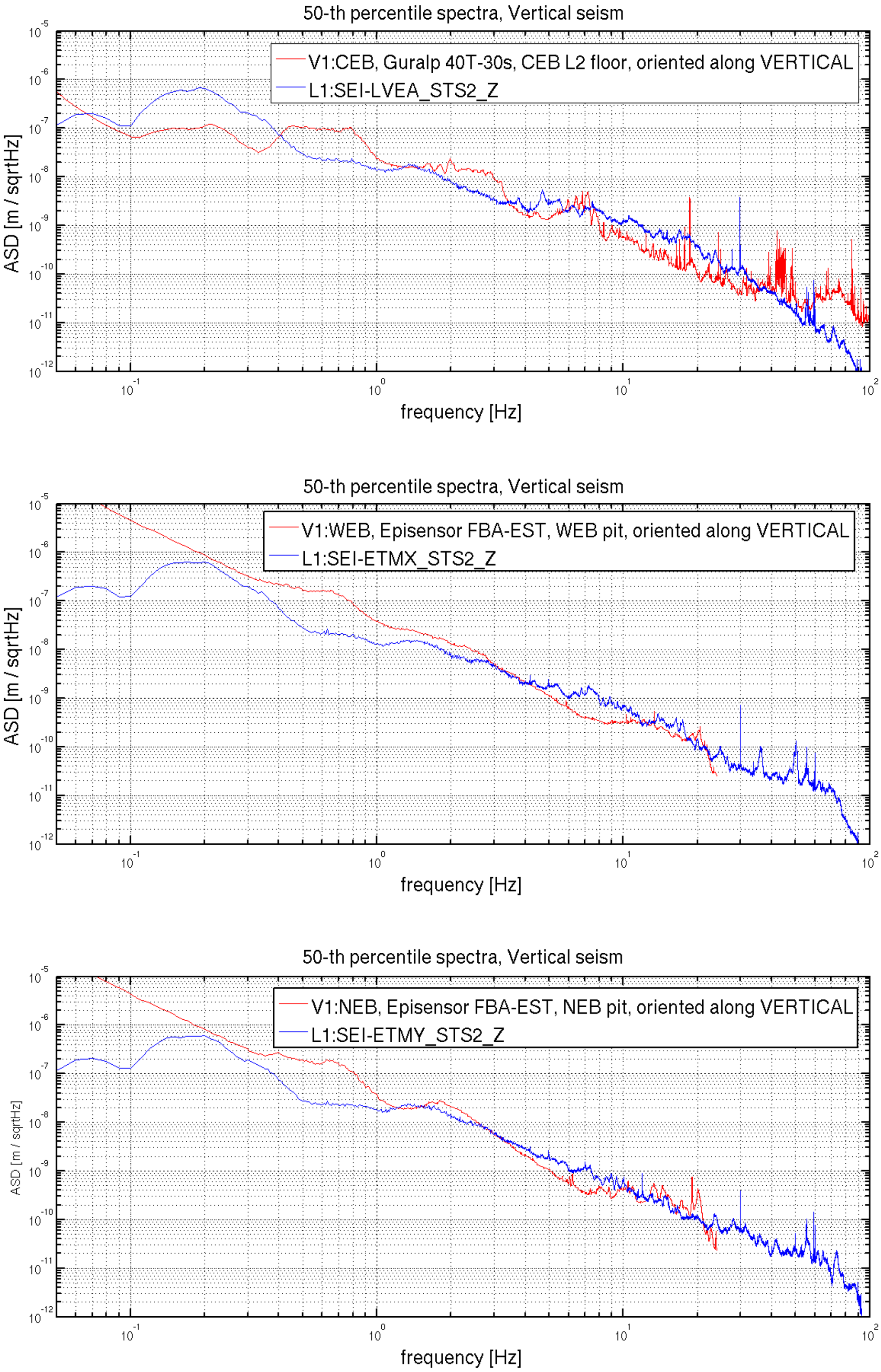

Figure 9. Vertical 50-th seismic percentile spectra at Virgo CEB and Ligo LLO Vertex stations (top), at Virgo NEB and LLO End-Y stations (middle), at Virgo WEB and LLO End-X stations.

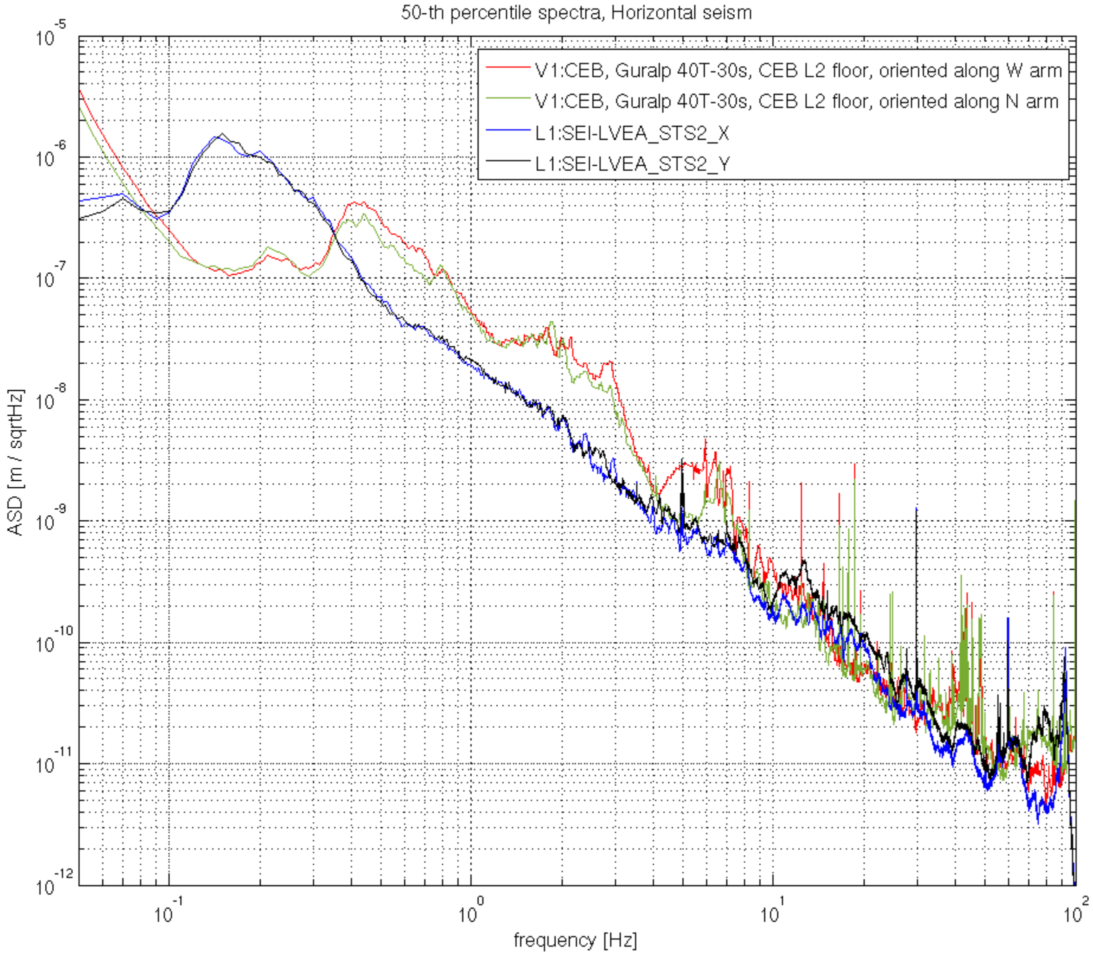

Figure 10. Horizontal 50-th seismic percentile spectra at Virgo CEB and Ligo LLO Vertex station.

References

[1] P.Fritschel, S.Waldman, "Reference Seismic Data for LLO" LIGO-T0900312-v1.