Gravity gradient noise and site characterization for the Einstein Telescope

Mark Beker, Nikhef Amsterdam
on behalf of the ET design study team
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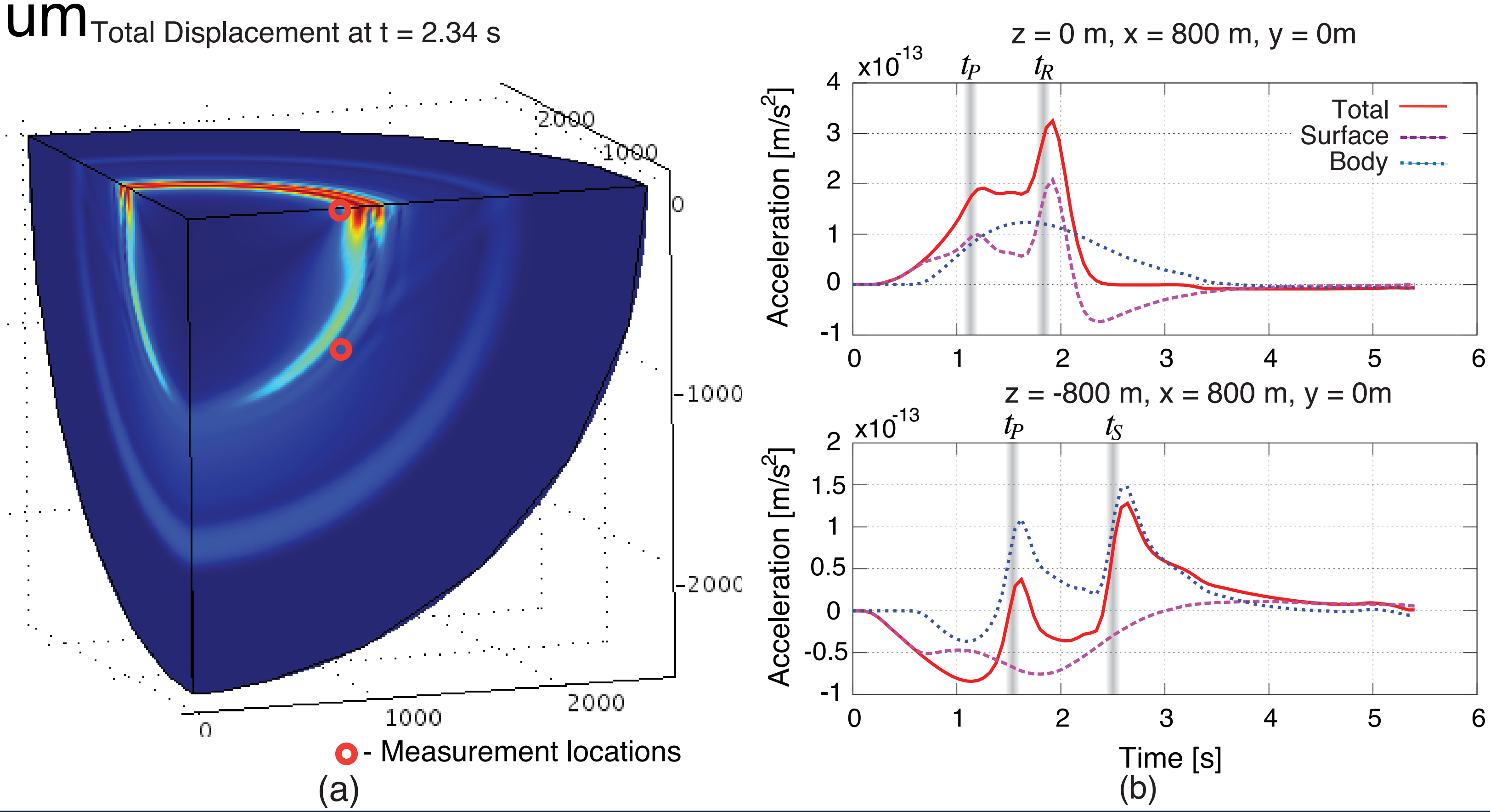
mbeker@nikhef.nl

Finite Element Analysis models were developed to better understand the GGN problem

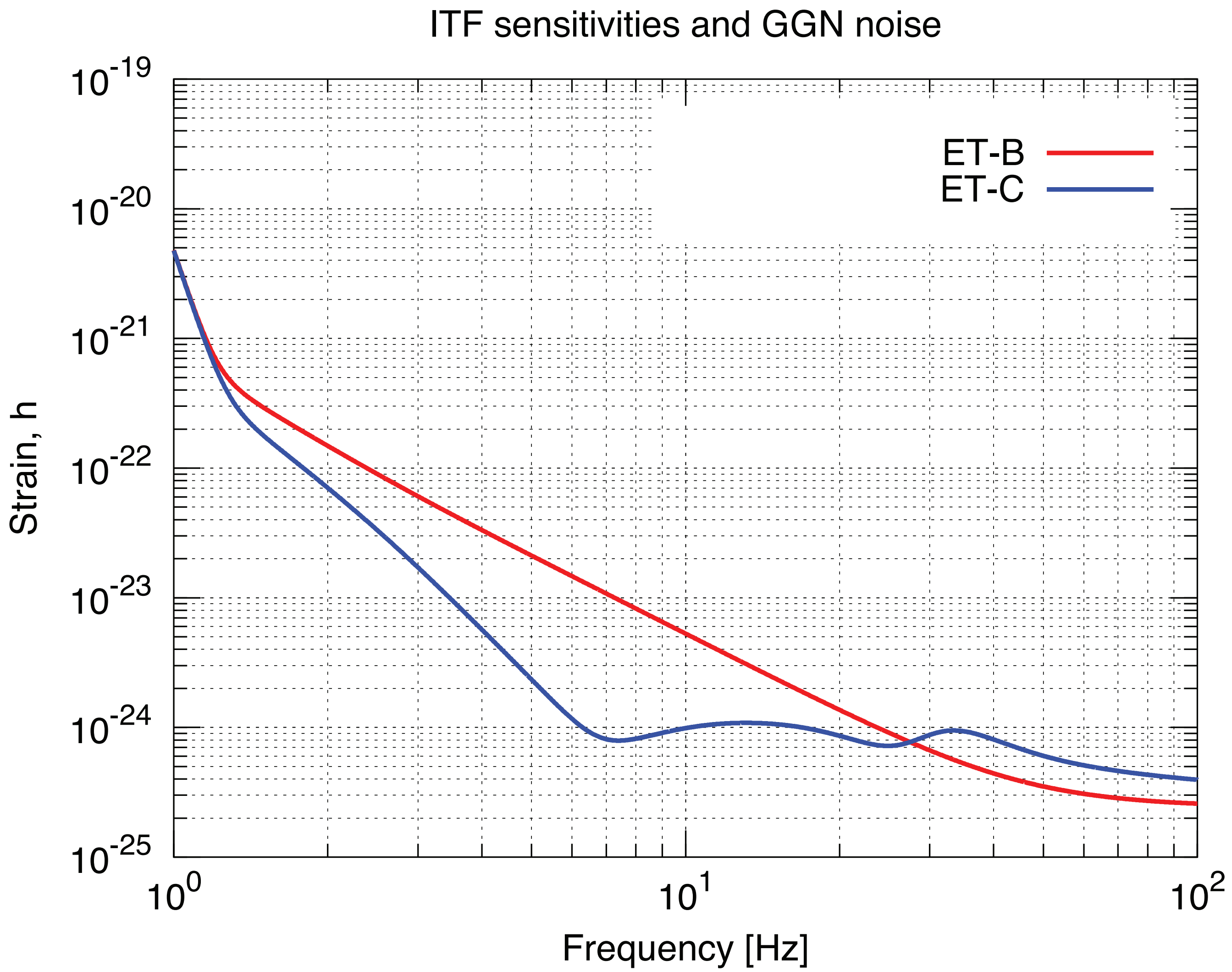
- FEA models have confirmed previous analytical results
- Gained a better understanding of GGN contributions
- Future work for FE analyses
  - In-homogenous / layered medium
  - Cavern geometries
  - Surface wave contributions
  - Testing subtraction schemes
- Improved analytical models developed (Giancarlo Cella, Jan Harms)

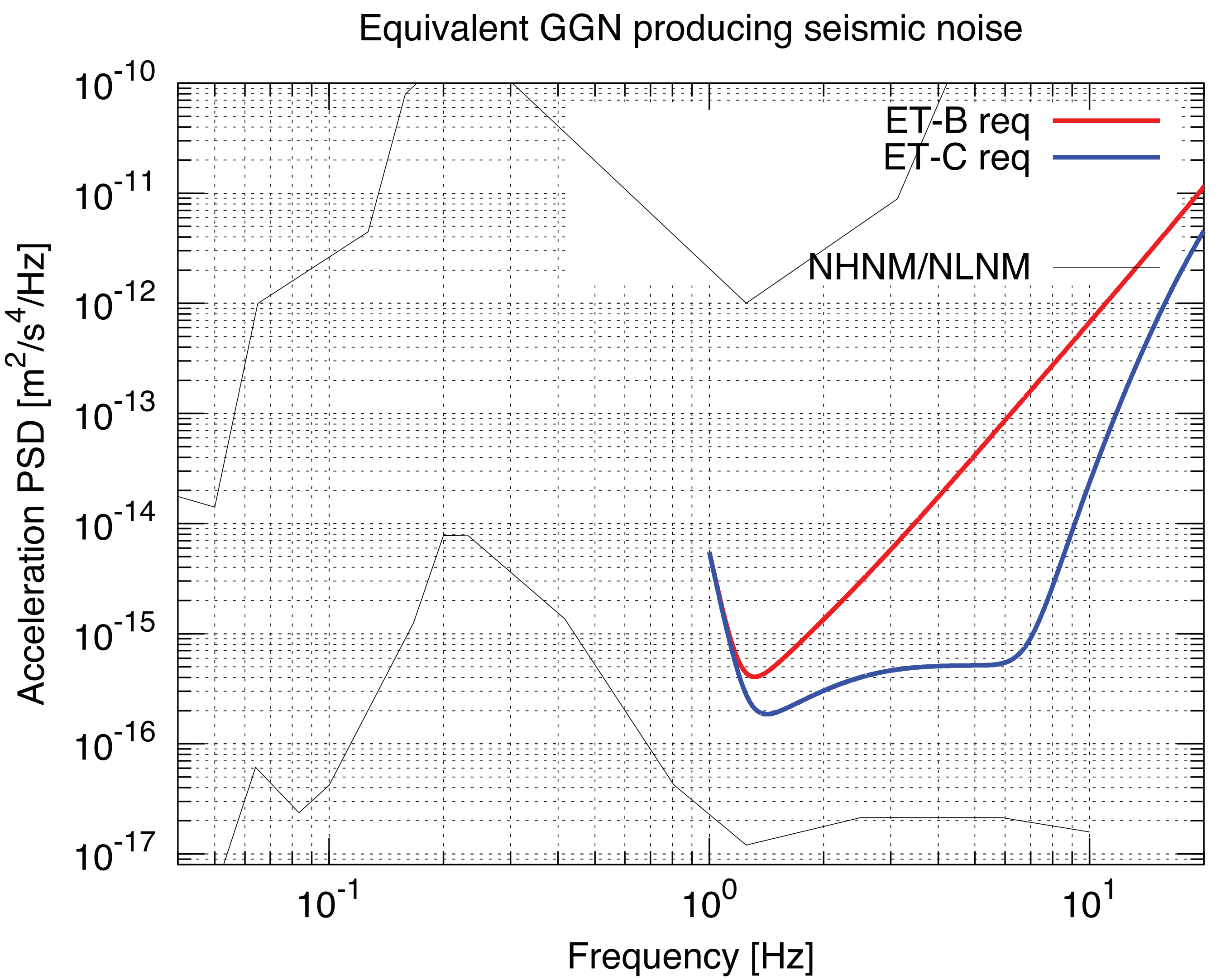
$$\mathbf{a}(\mathbf{y},t) = G\int_V \rho(\mathbf{r},t)\frac{\mathbf{r}'}{|\mathbf{r}'|^3}dV,$$

$$\mathbf{a}^{NN}(\mathbf{y},t) = \sum_i \xi_i(\mathbf{r},t)^T D\mathbf{a_i}(\mathbf{y},t_0),$$



ET sensitivity targets can be translated to an equivalent GGN producing seismic noise requirement





Assumptions: - Surface detector
- Isotropic body pressure waves
- Saulson Model

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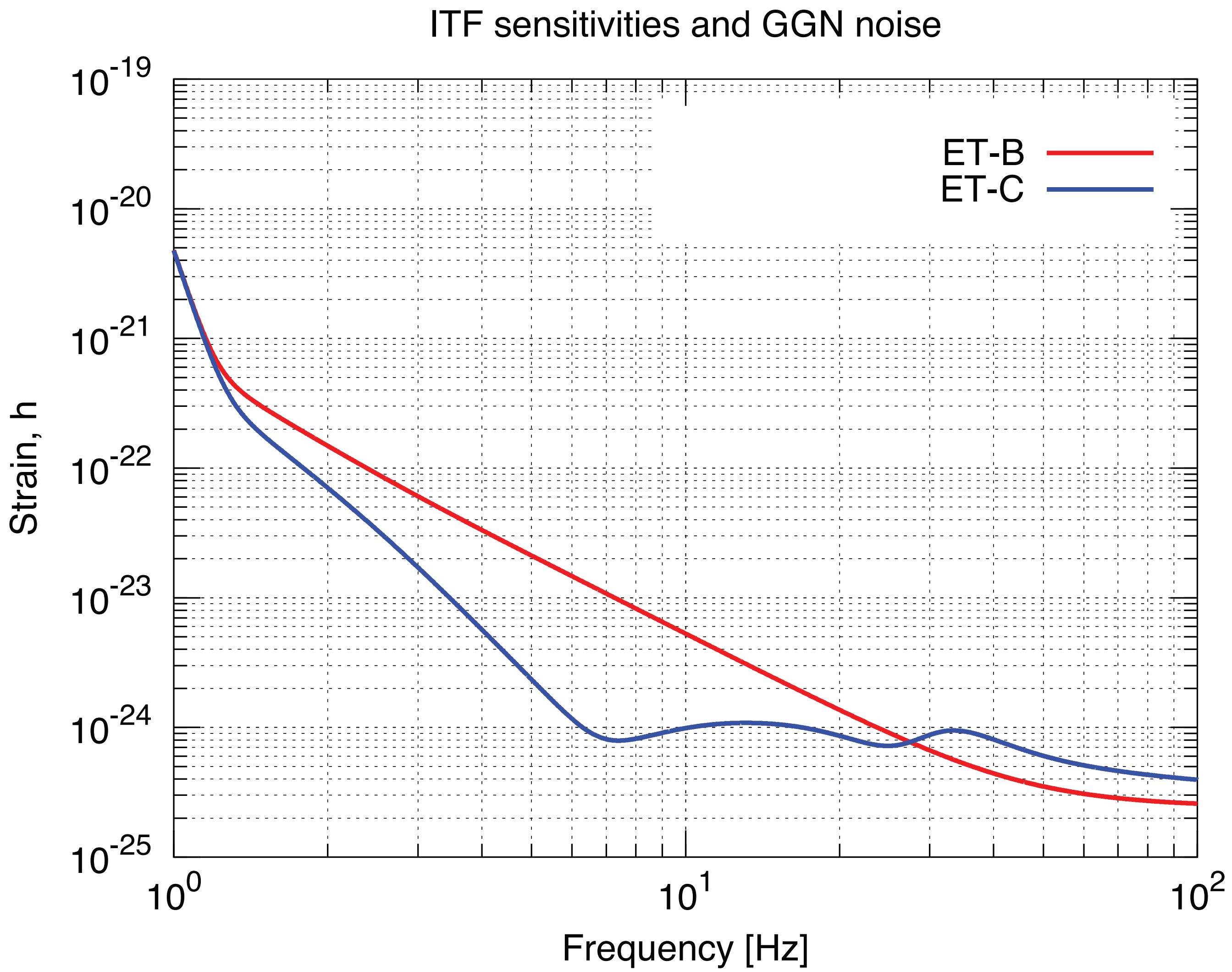
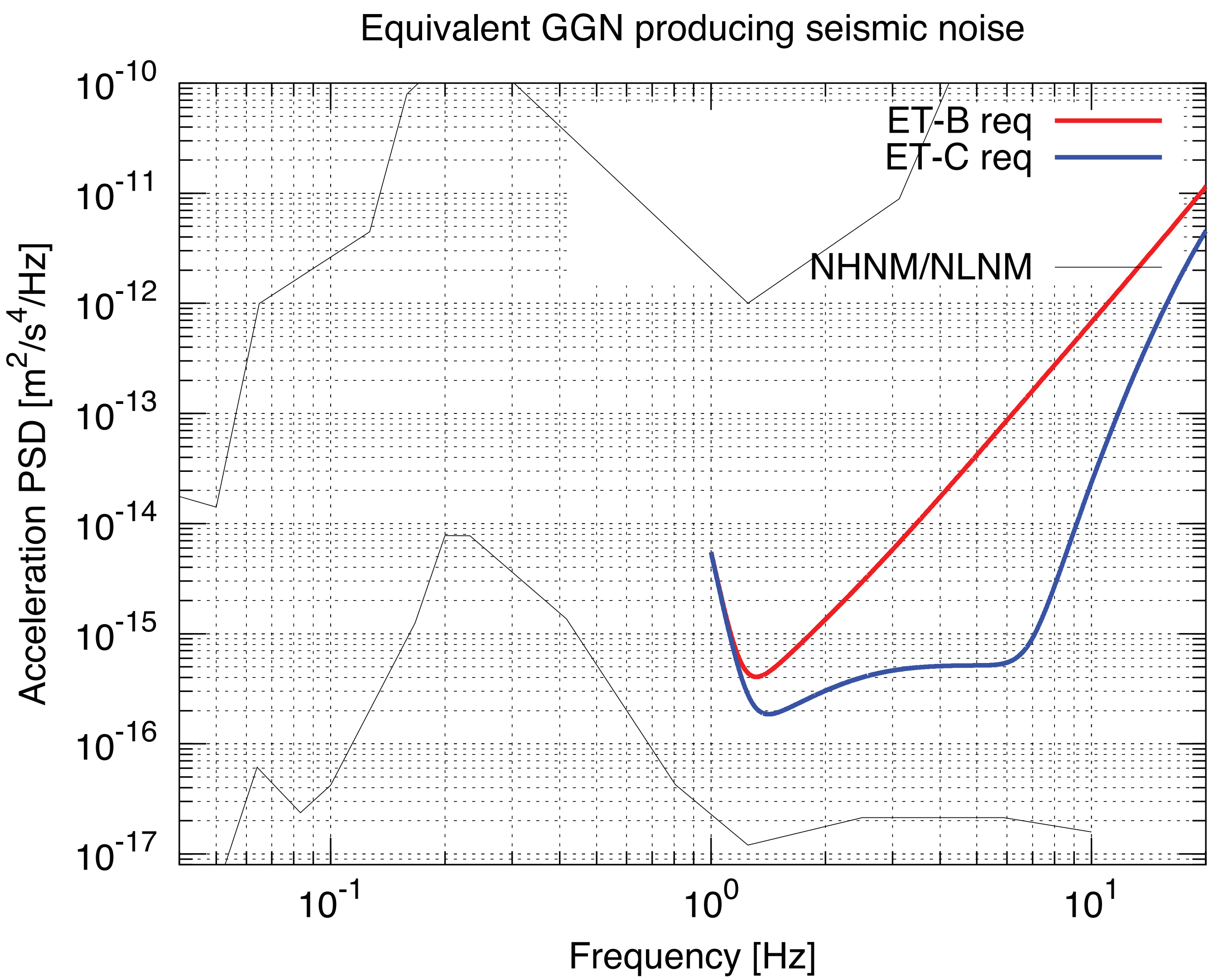


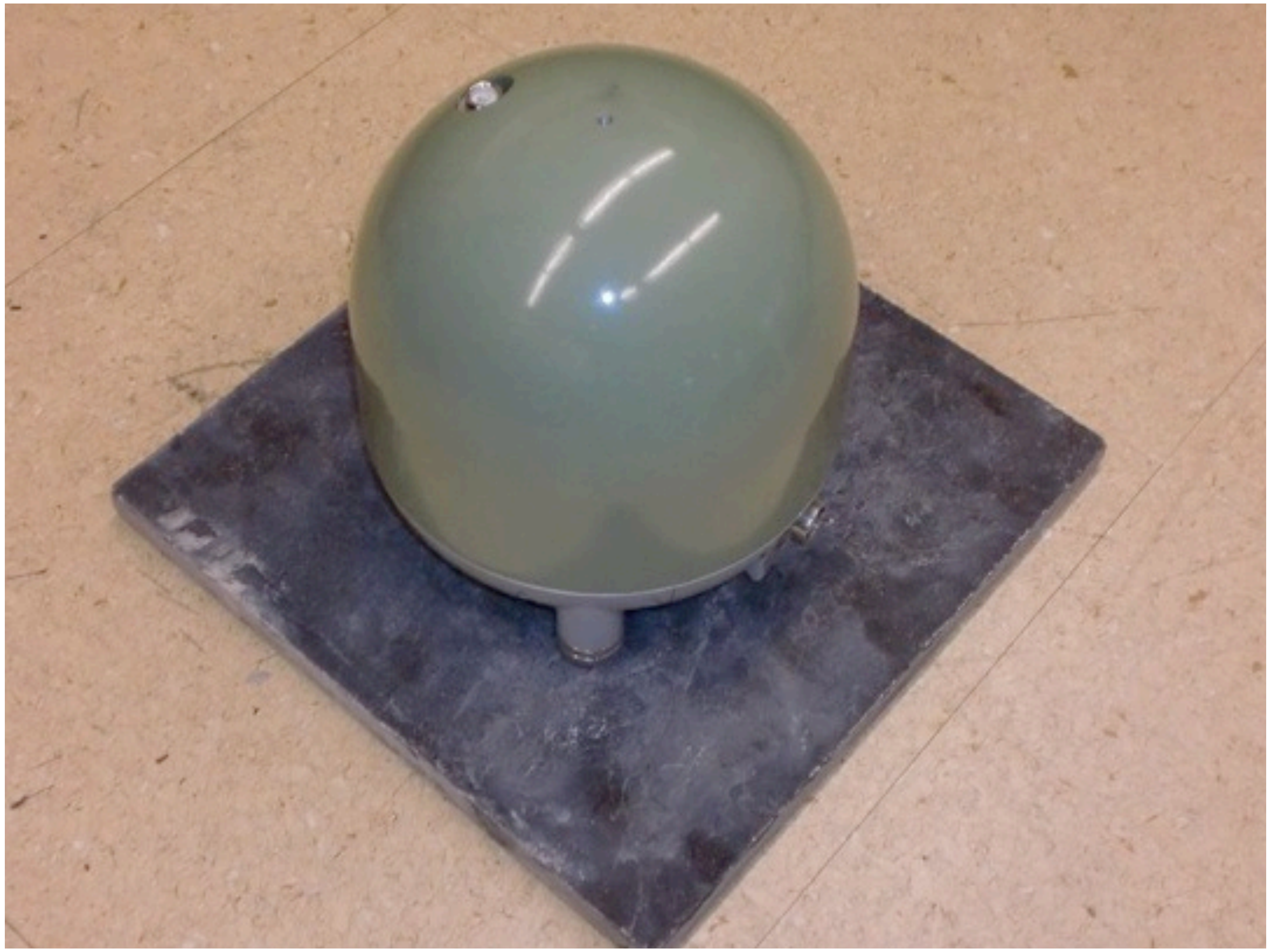


Assumptions:
- Surface detector
- Isotropic body pressure waves
- Saulson Model

Can a suitably seismically quiet location be found to satisfy this requirement?

Seismic measurements have been done throughout Europe to classify underground locations

- 2 Trillium 240 seismometers
  - Broadband mHz - 30 Hz
  - Hard-rock tile
  - Insulation cover
- Data acquisition systems
  - LabView readout through 18 bit DAQ card
  - Low noise amplifier



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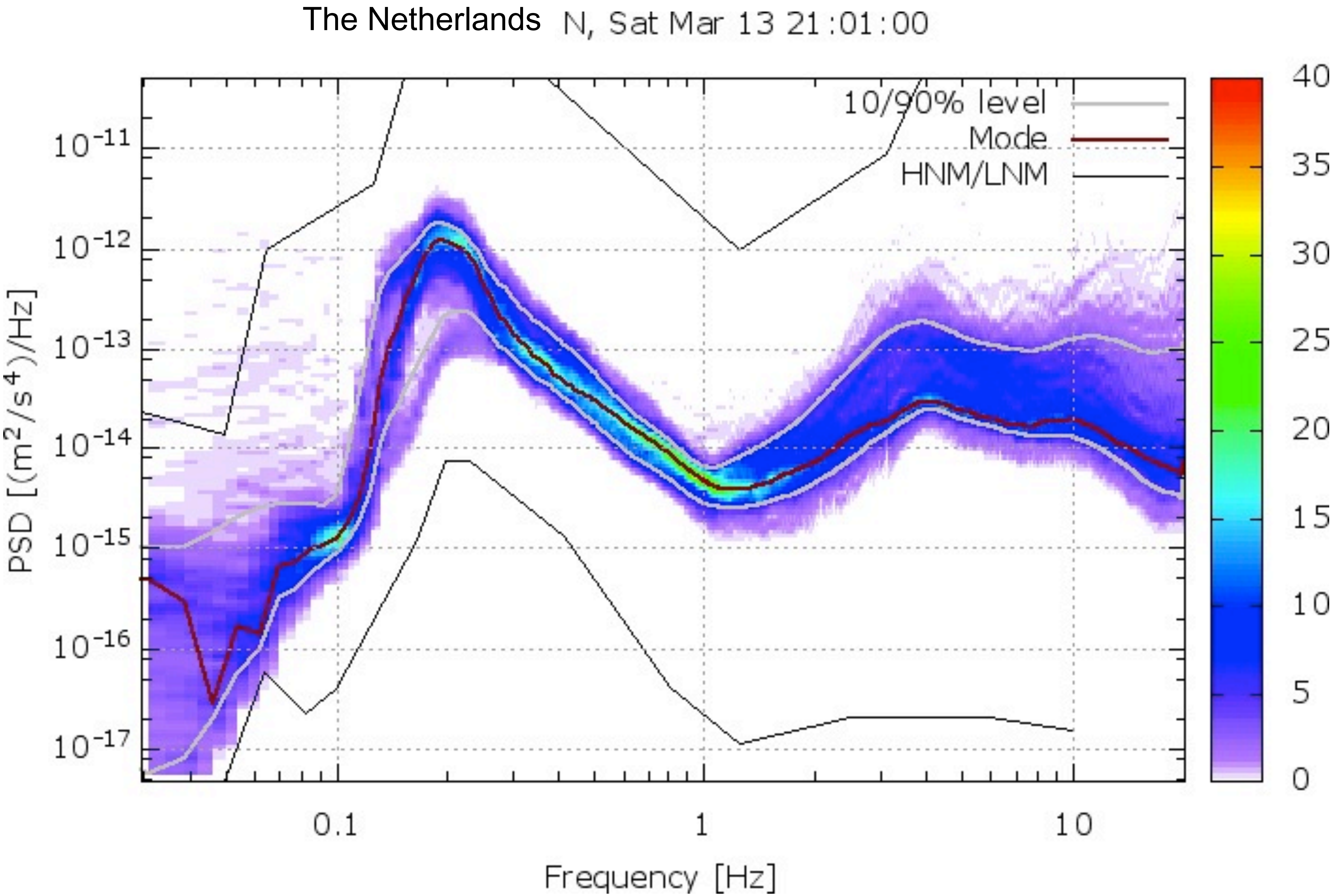
Characterization of sites is done using spectral variation plots of half hour averages

The Netherlands



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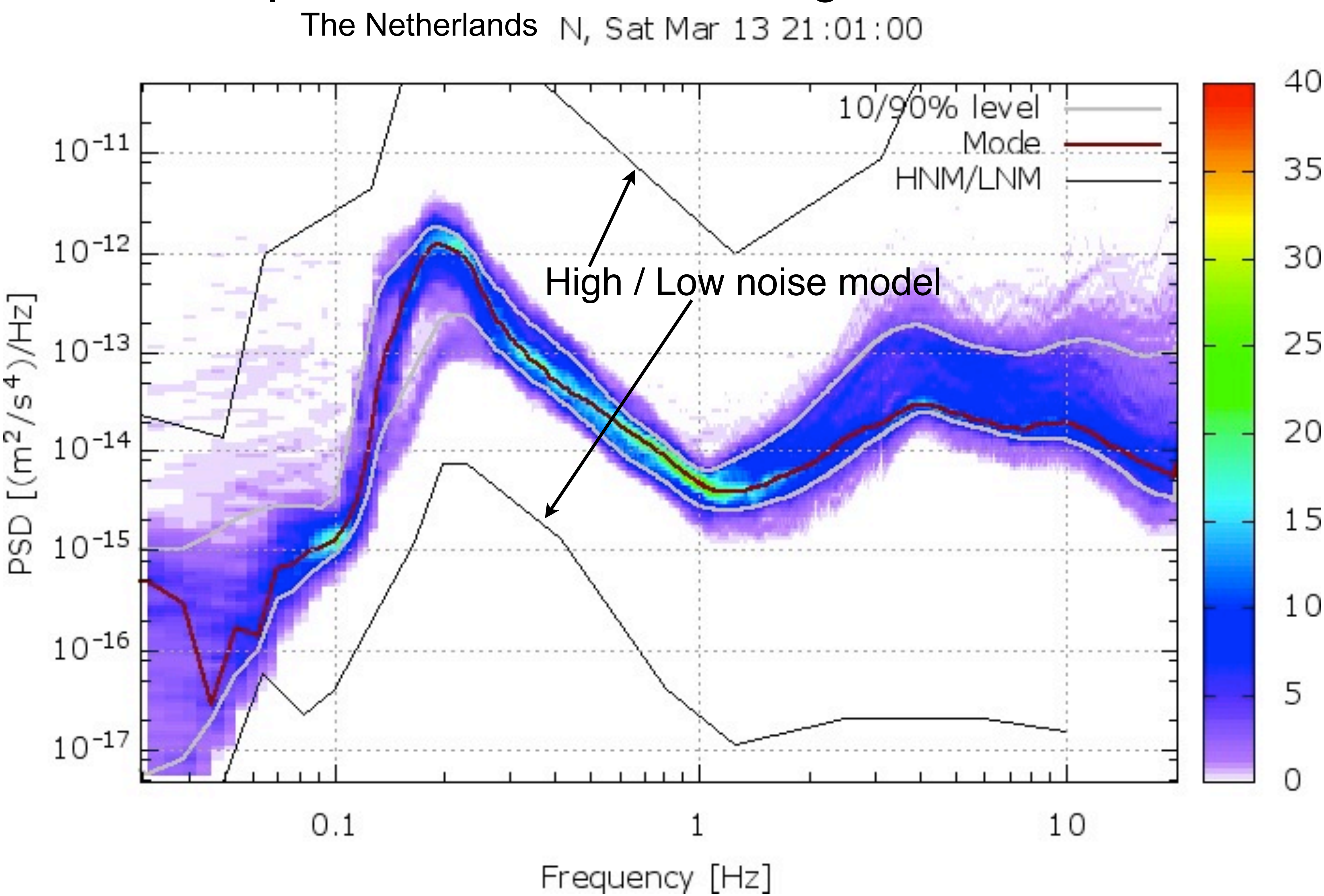

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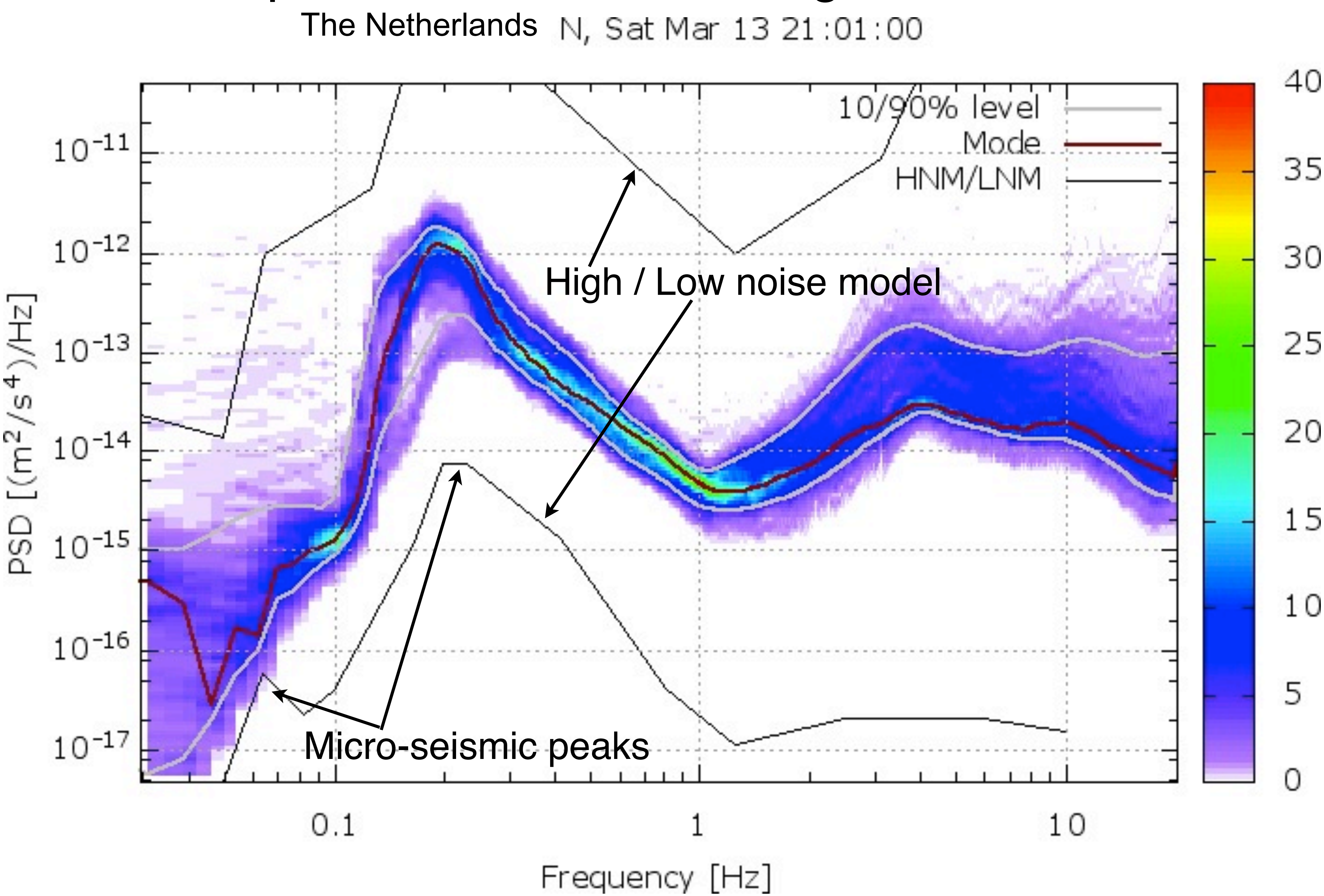
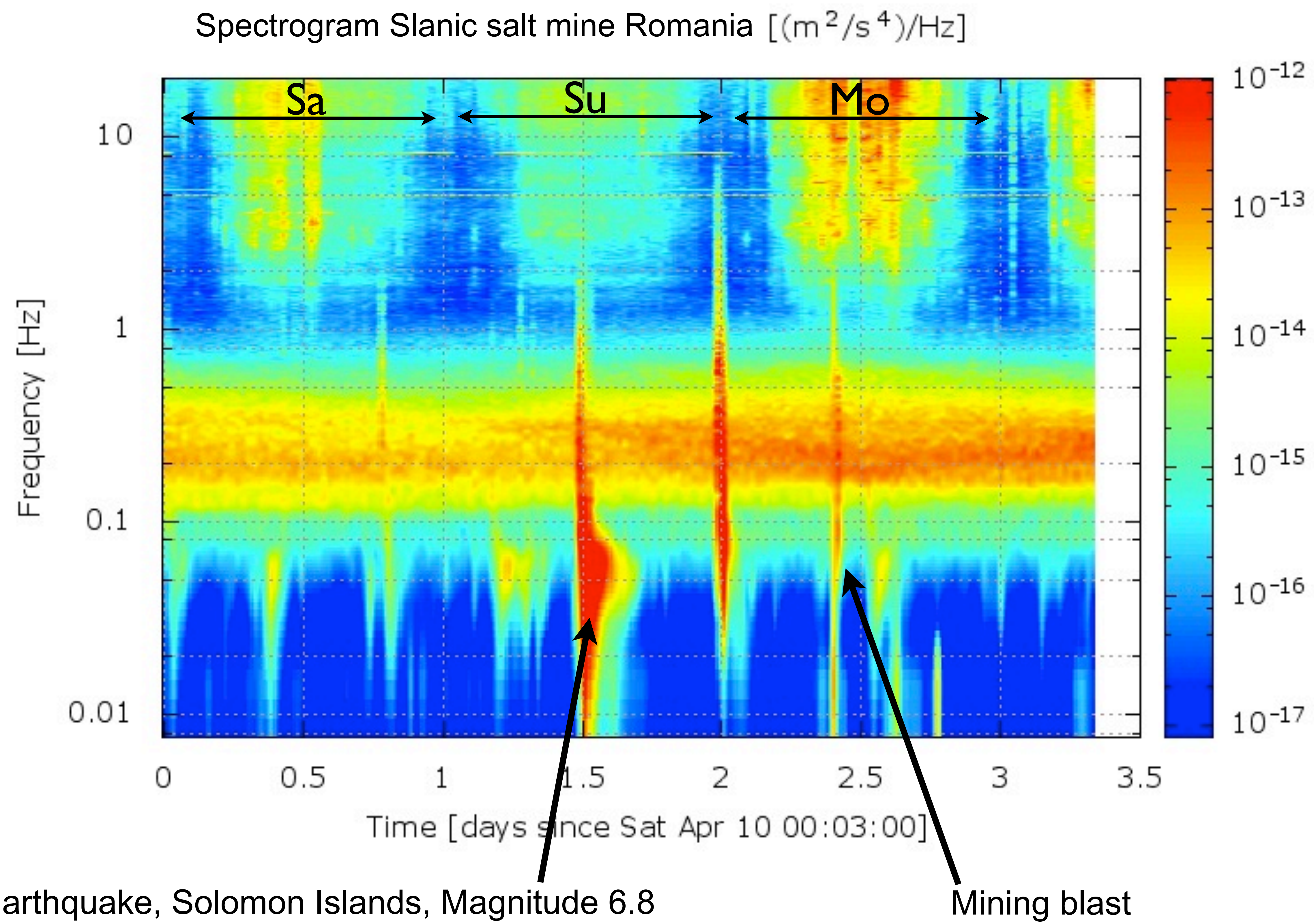
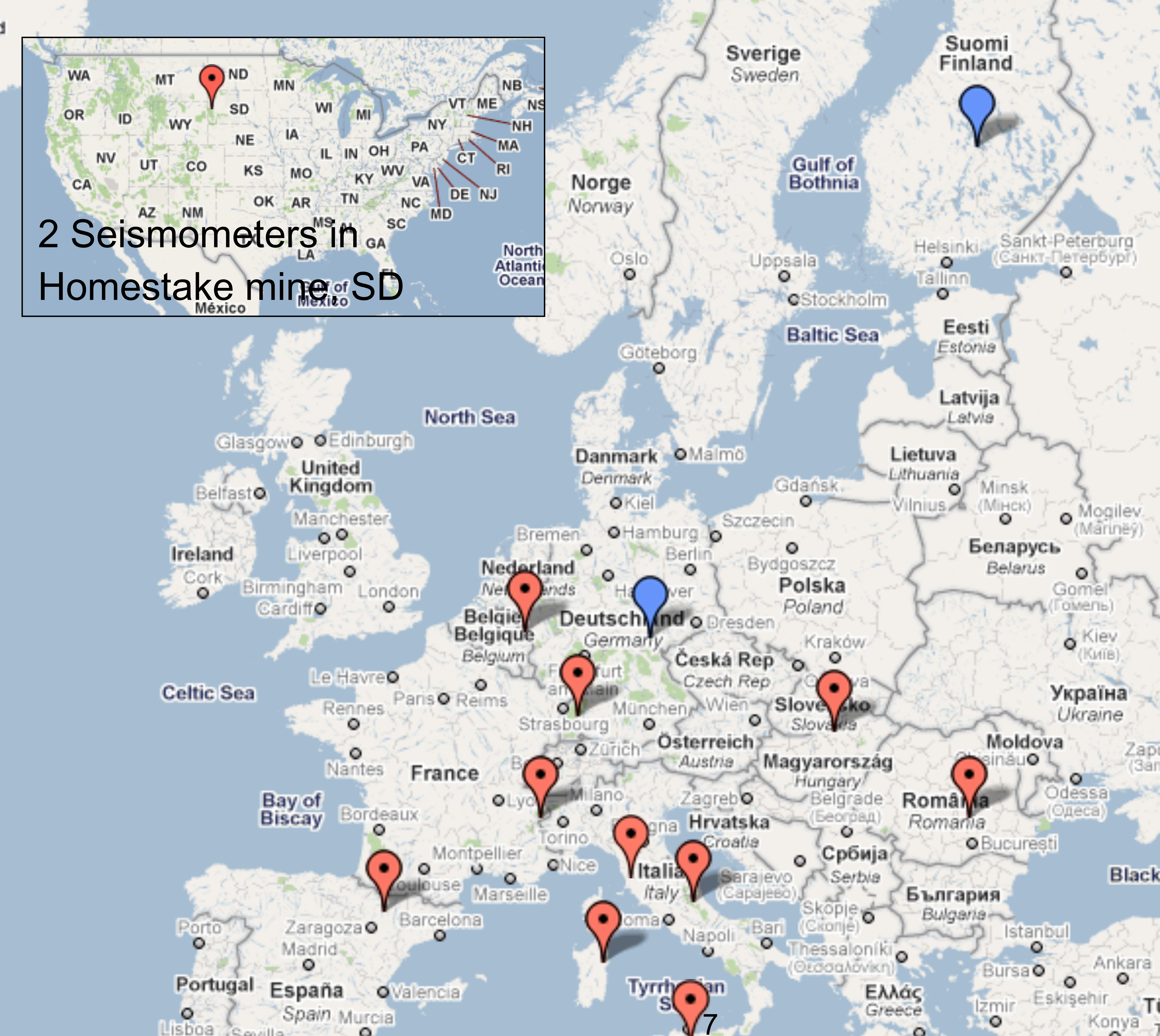


Seismic noise at 1 - 20 Hz is dominated by anthropogenic activity



Data collected from these sites

3rd party data obtained and analyzed from these sites



2 Seismometers in Homestake mine, SD

Data collected from these sites

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Thanks to:
Dr. Kazuaki Kuroda
Dr. Uchiyama Takashi
Dr. Osamu Miyakawa
Dr. Shinji Miyoki

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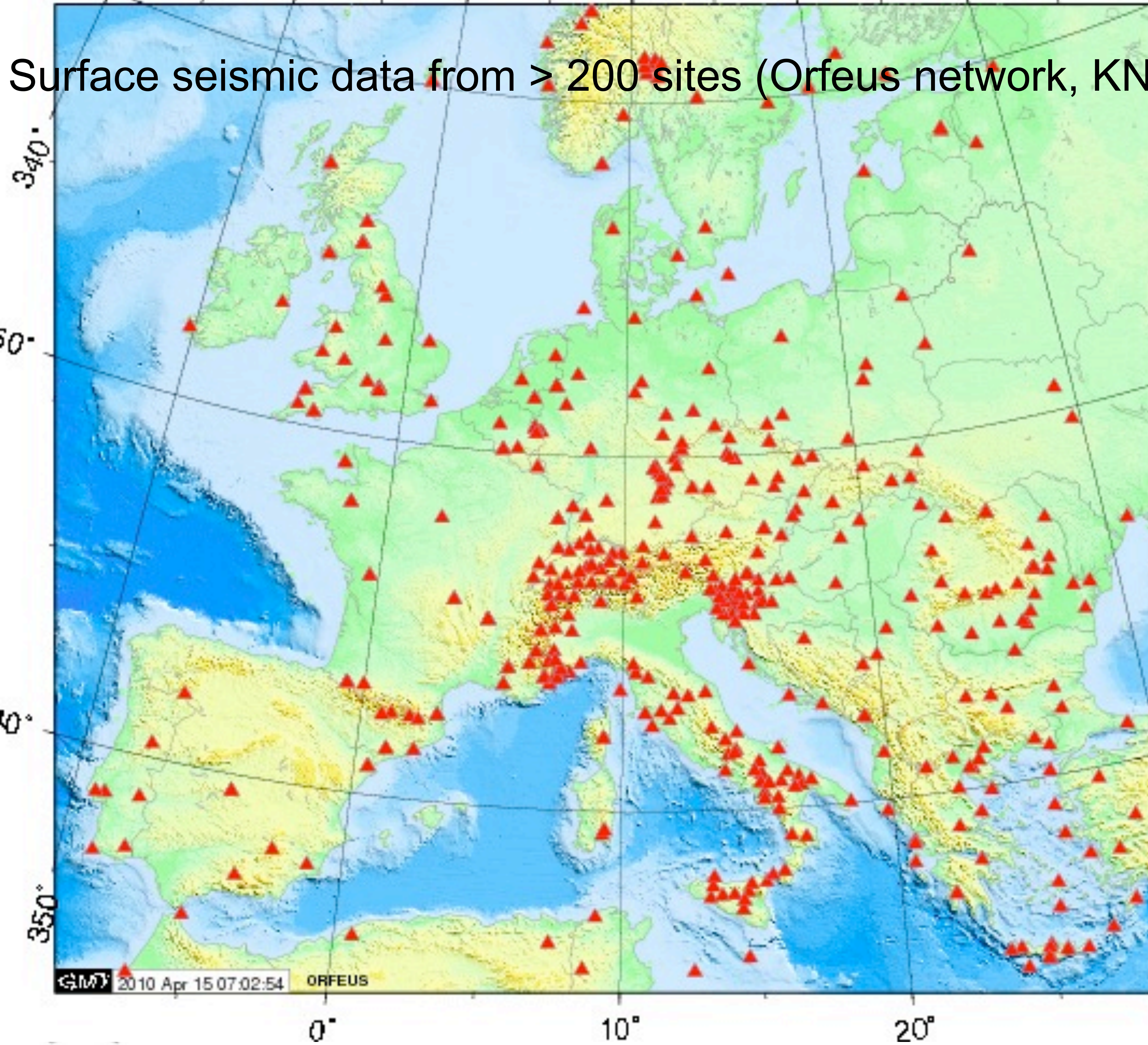
3rd party data obtained and analyzed from these sites

Surface seismic data from > 200 sites (Orfeus network, KNMI)



Data collected from these sites

3rd party data obtained and analyzed from these sites

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Results will be presented from all sites with a focus on three seismically interesting ones

- Sicily, Italy
- Heimansgroeve, The Netherlands
- Gyöngyösoroszi mine, Hungary
- Slanic Salt mine, Romania
- LSM, Frejus tunnel, France
- LSC, Canfranc, Spain
- Sos Enattos mine, Sardinia, Italy
- Gran Sasso, Italy
- Virgo site, Italy
- Black forest, Germany

- Moxa, Germany
- Konnevesi, Finland

- Kamioka, Japan
- Homestake mine, USA

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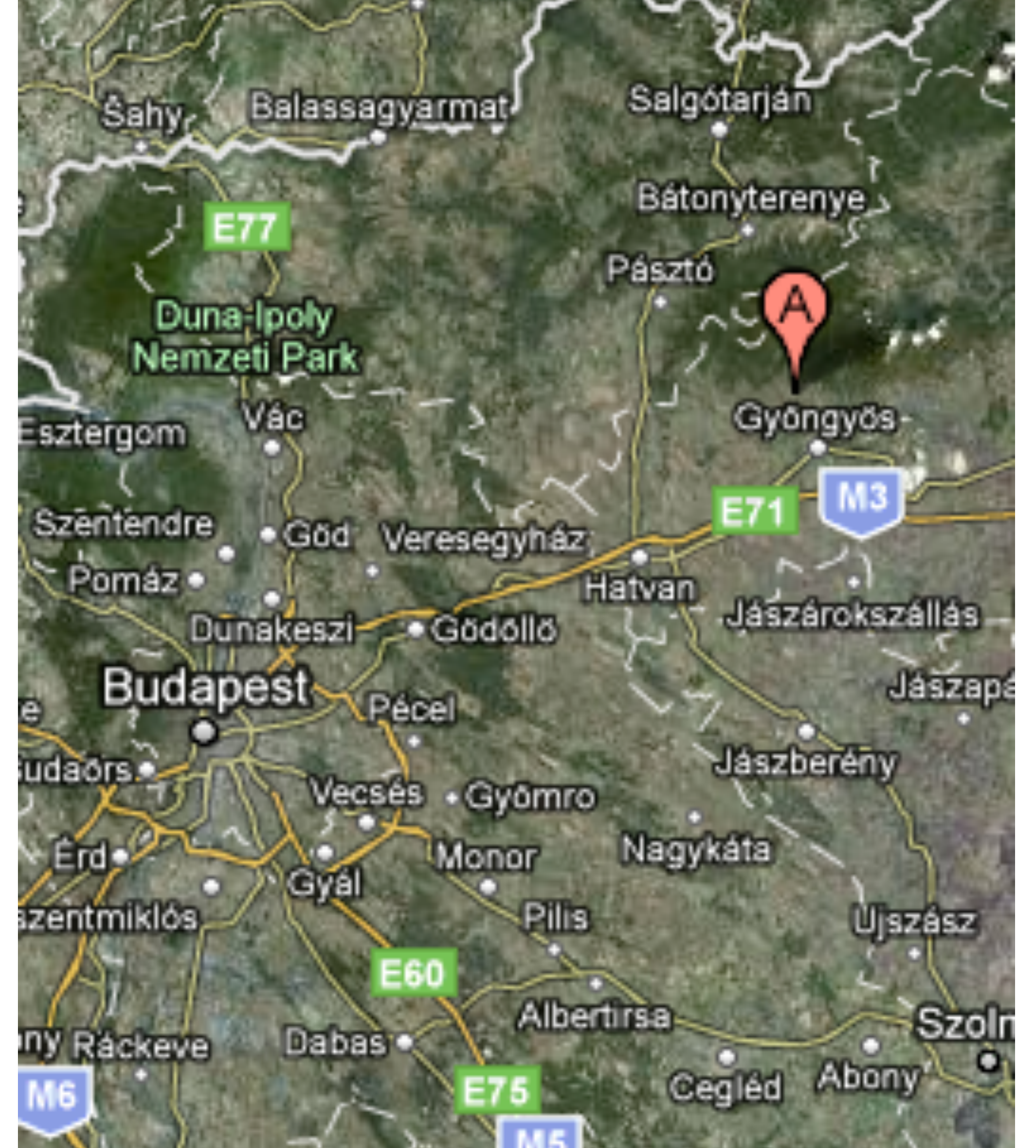
Gyöngyösoroszi mine - Hungary

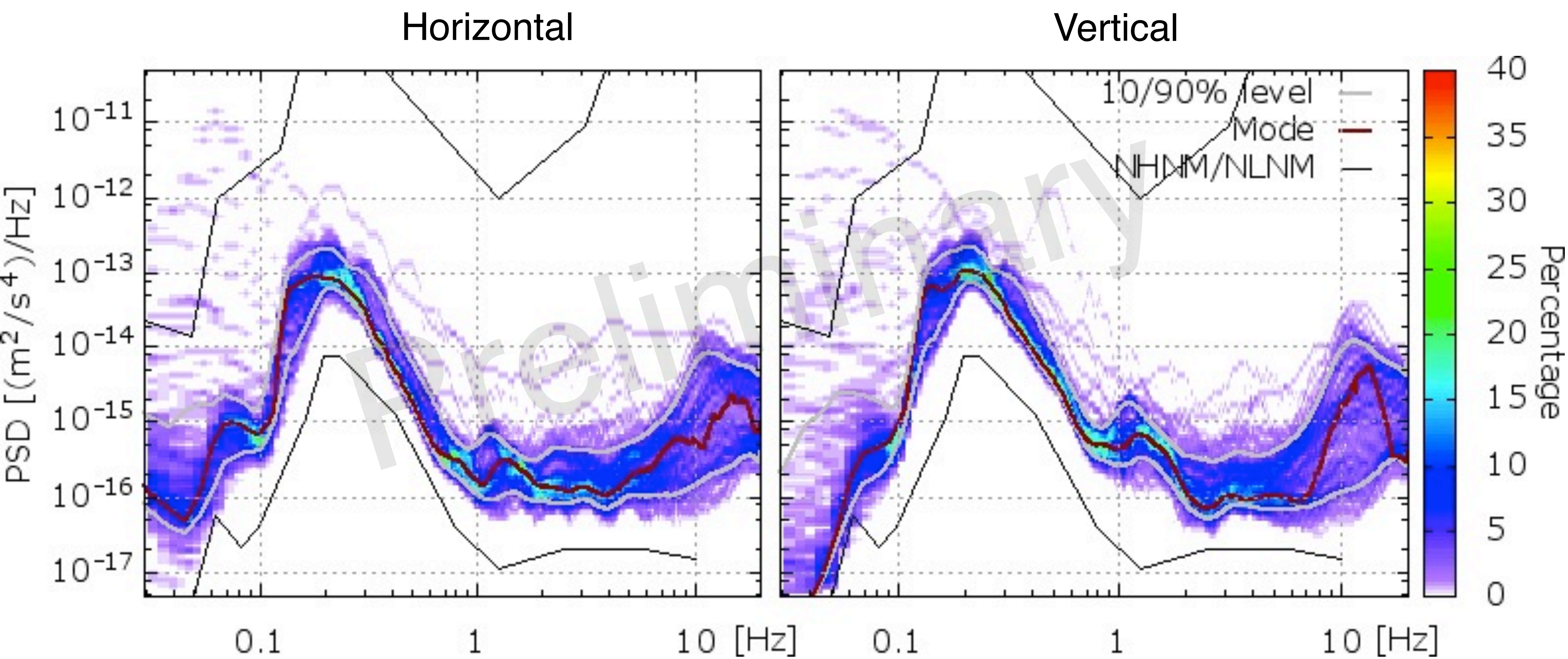
- Old lead-zinc mine currently being rehabilitated
- 80 km north east of Budapest
- Surrounding rock is Andezit and Andezit-tufa
- Underground depths ranging from 60 - 400 m at an altitude of 400 m
- Entrance by train through west entrance by lift at the eastern shaft



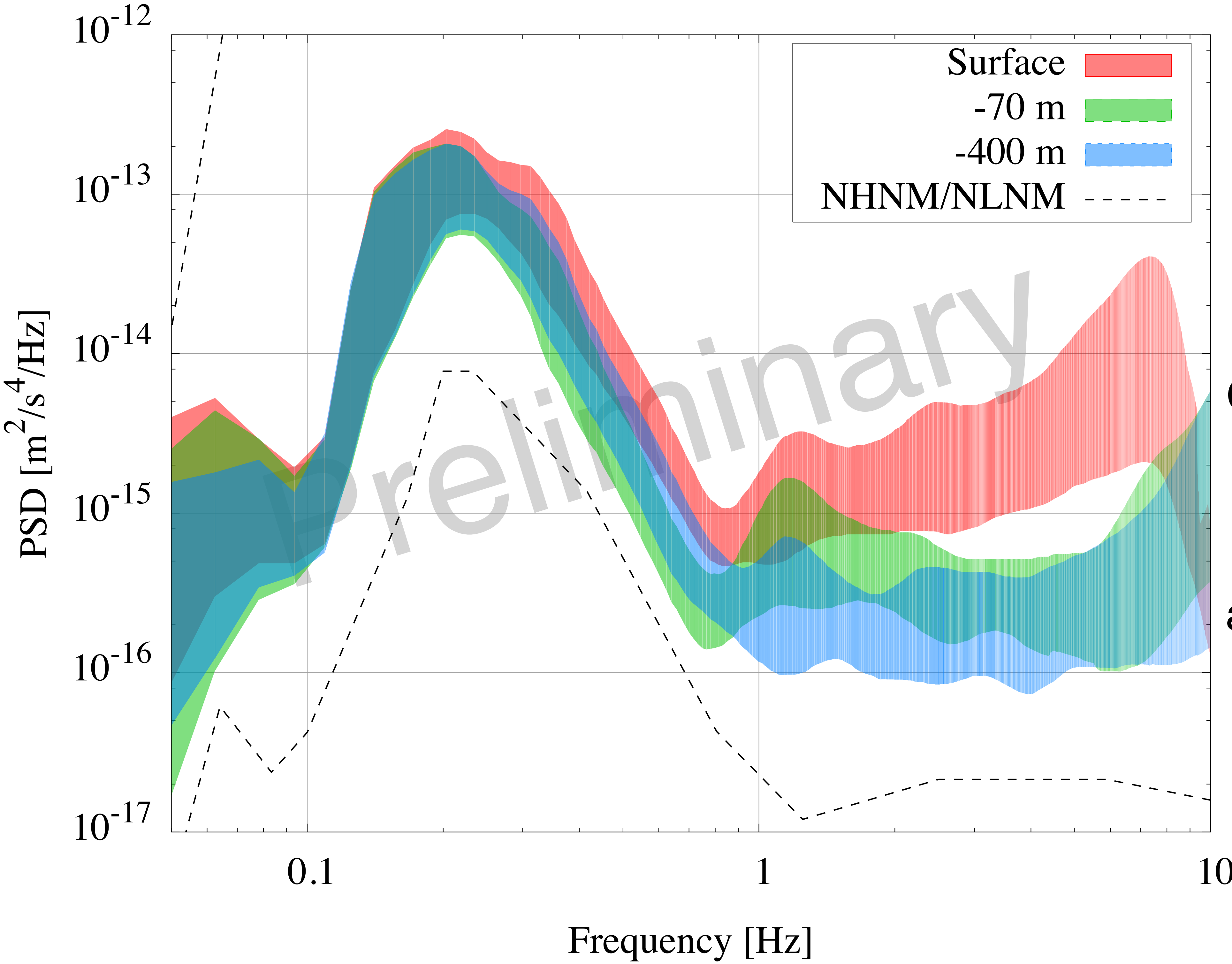
Two seismic stations installed in the mine
Measurements taken from 2-6 April

- Station “A”
  - Down secondary draft 3750 m from entrance
  - 400 m overhead rock
- Station “B”
  - 1450 m from entrance
  - 70 m overhead rock
  - close to ventilation system (~100 m)
- Seismometers placed on tile fixed by concrete to hard rock, then covered by acoustic insulation cover.
- Nearby permanent surface seismic station of the Hungarian Academy of Science

Results from the Hungary site showed it was a low seismic environment



A nearby surface seismic station provided a good indication of attenuation with depth

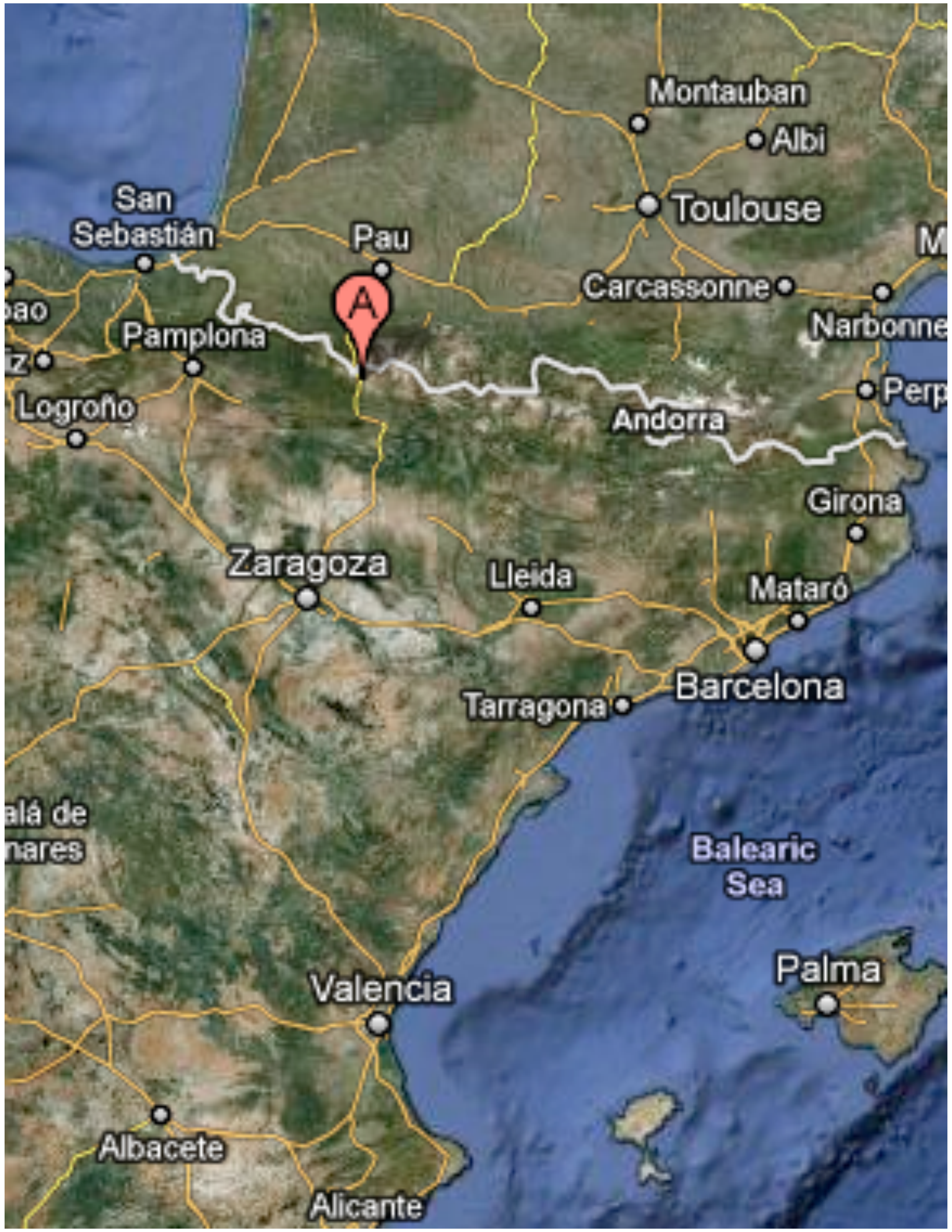


Order of magnitude in power

No (direct) atmospheric effects

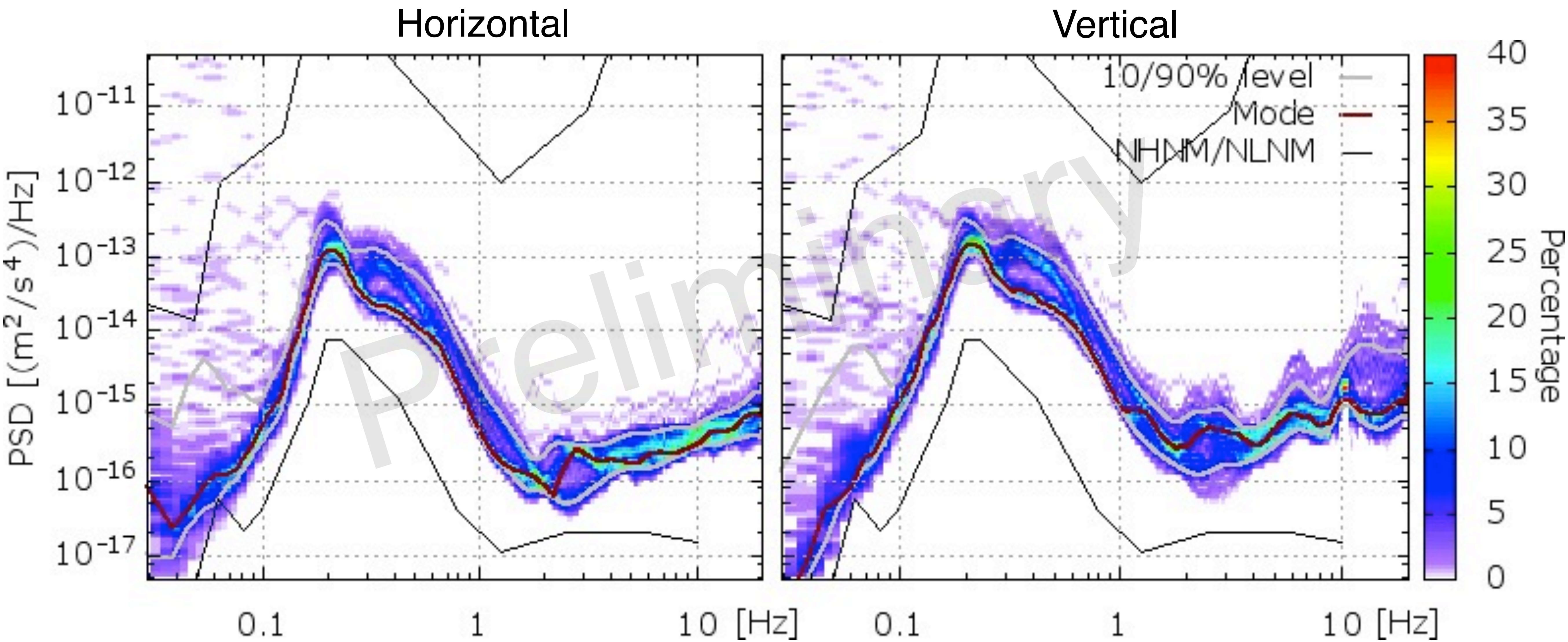
Laboratorio Subterráneo de Canfranc, Spain

- 8.5 km road tunnel in northern Pyrenees between France and Spain
- Access through parallel decommissioned railway tunnel
- Very low background experiments currently housed in lab (2500m water equivalent)
- Seismic measurements taken at 800m depth
- Very low population density



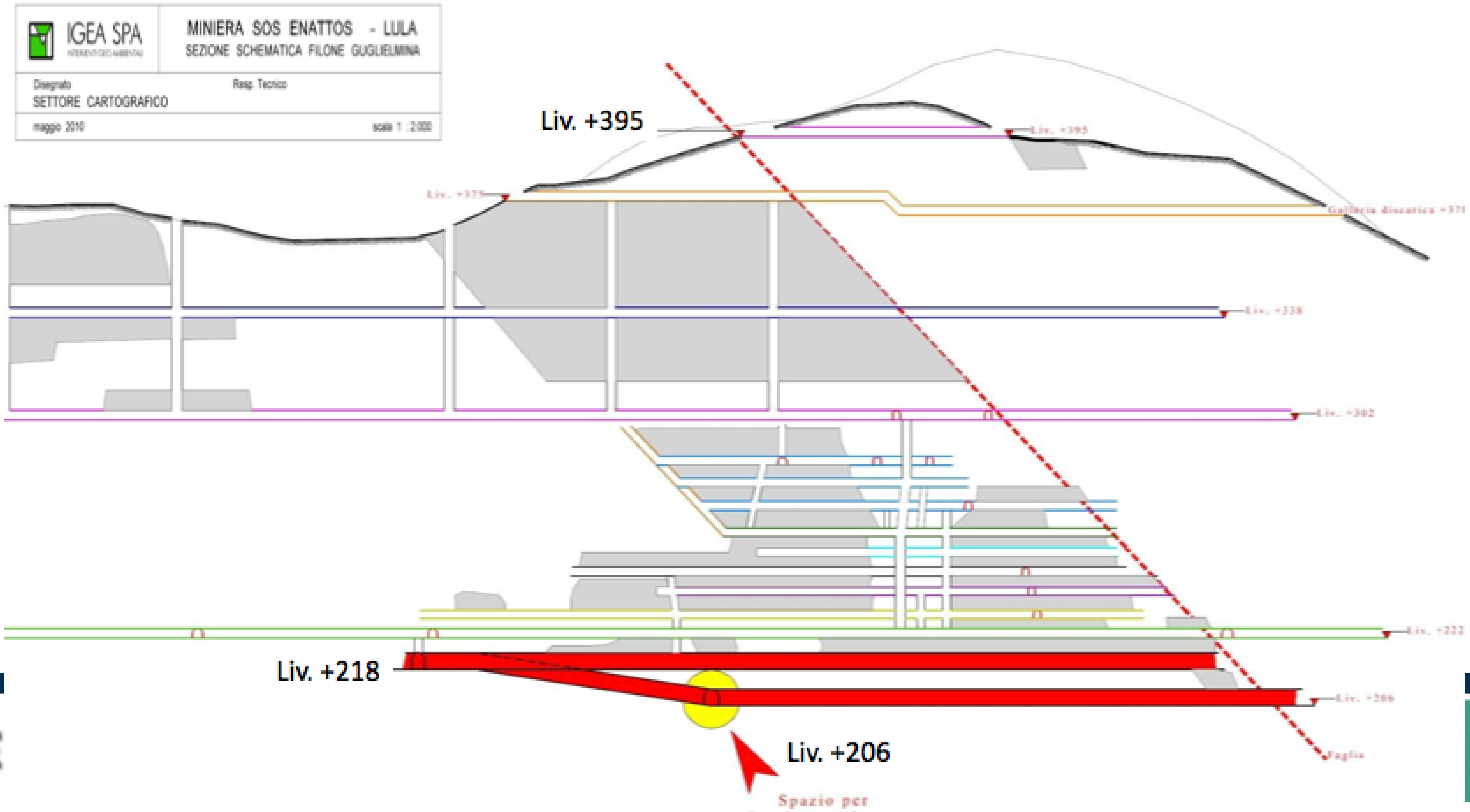
Laboratorio Subterráneo de Canfranc, Spain

The Canfranc site is a low seismic environment with a small spectral variation



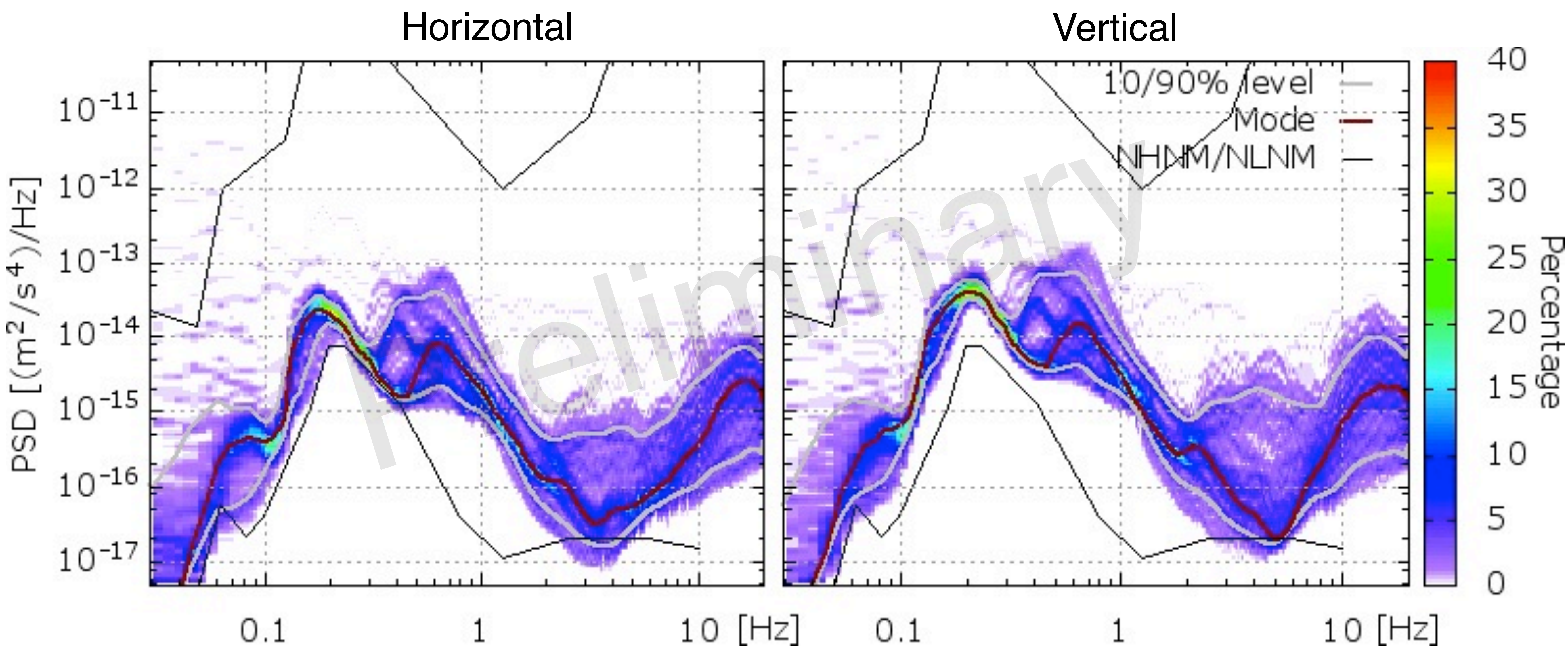
Sos Anattos Mine - Sardinia, Italy

- Former lead-zinc mine now converted to a tourist mine
- Near Lula, 50 km south of Olbia on north eastern side of the island
- Access via “cork screw” road tunnel
- Two seismometers installed at 190 m depth

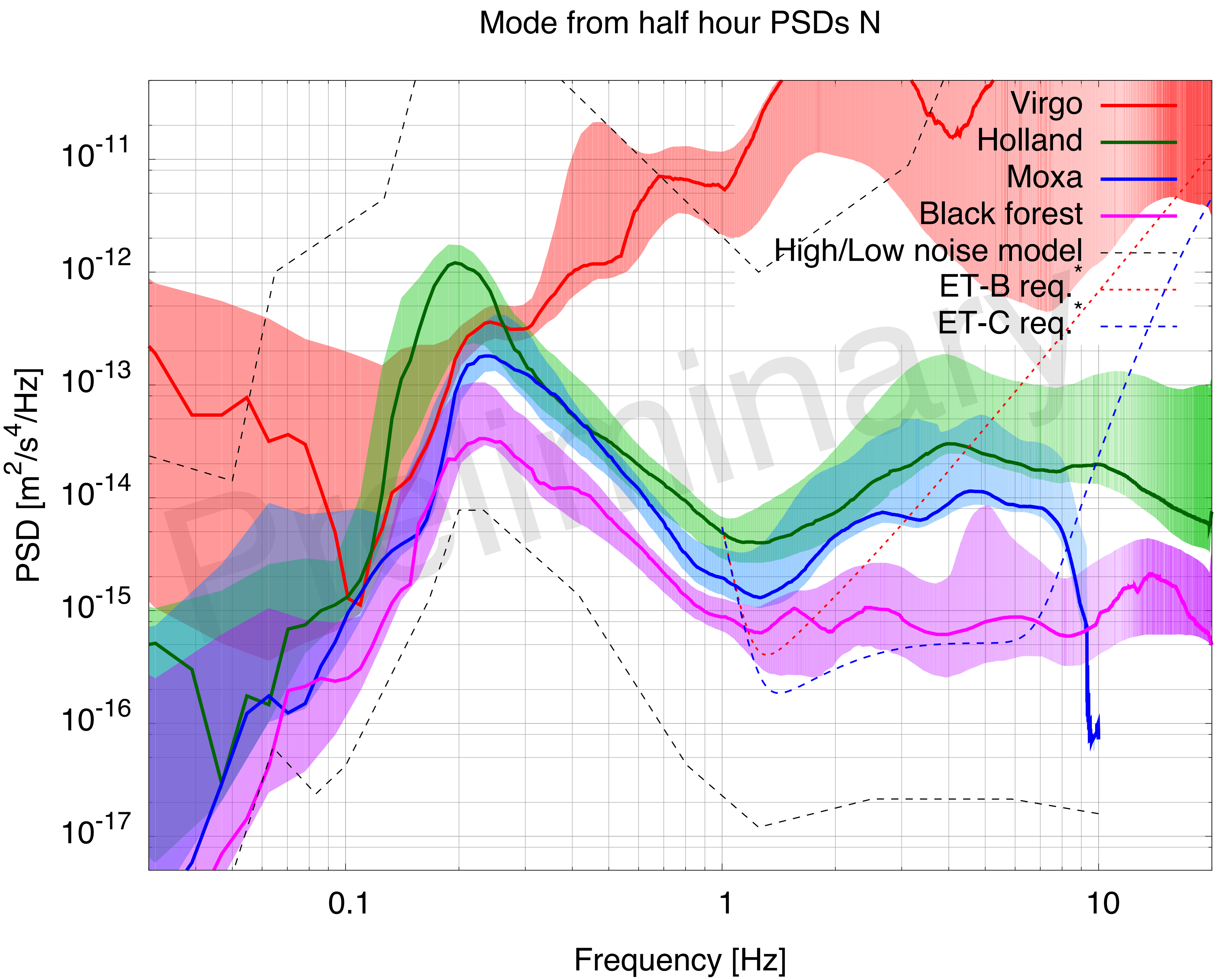


Sos Anattos Mine - Sardinia, Italy

The Sardinia site reached low quiet time spectra and had a "tertiary" microseismic peak



Shallow sites already showed orders of magnitude improvement on the existing GW detector site



Virgo, 0 m

Holland, 10 m

Moxa, 10 m

Black forest, 90 m

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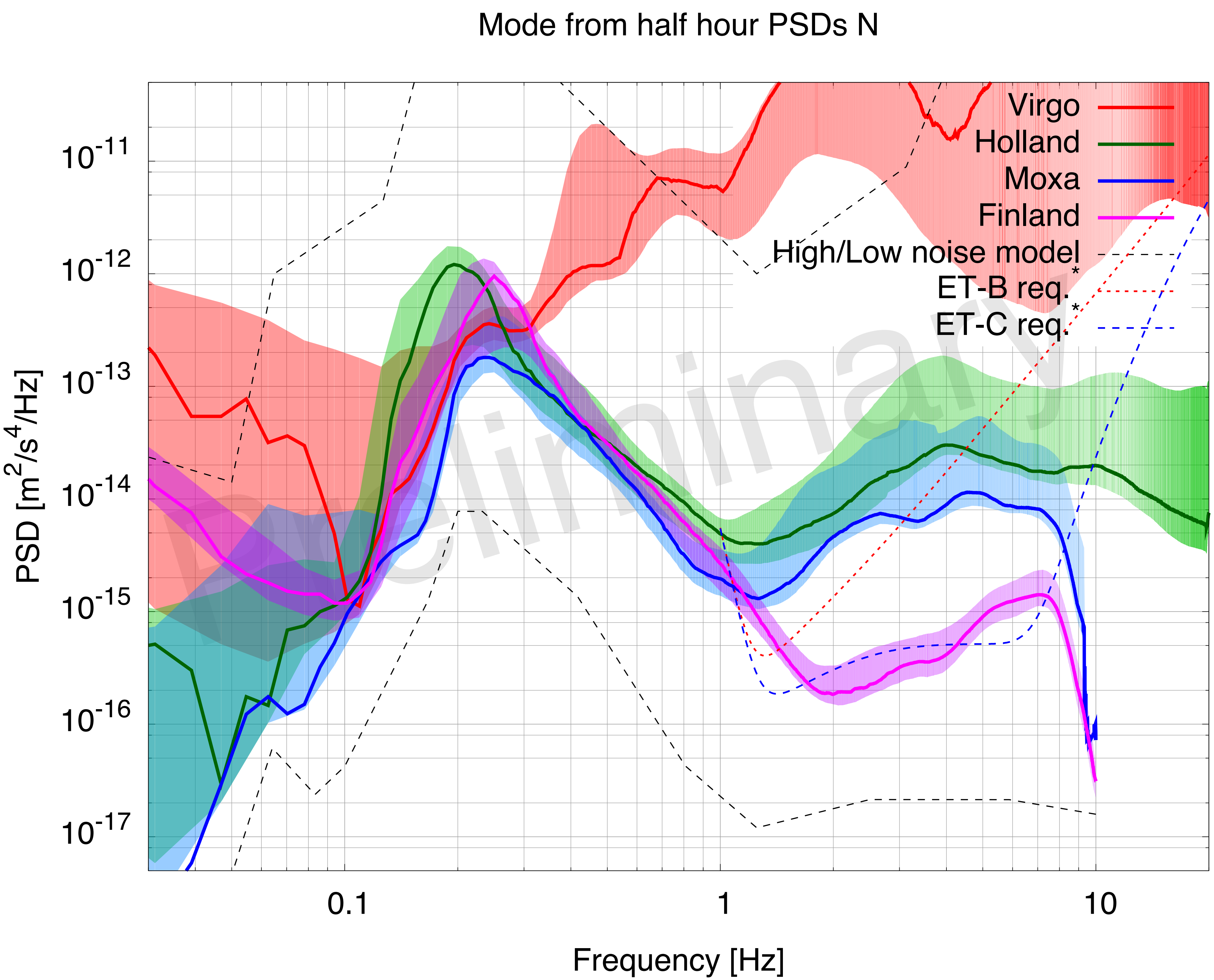


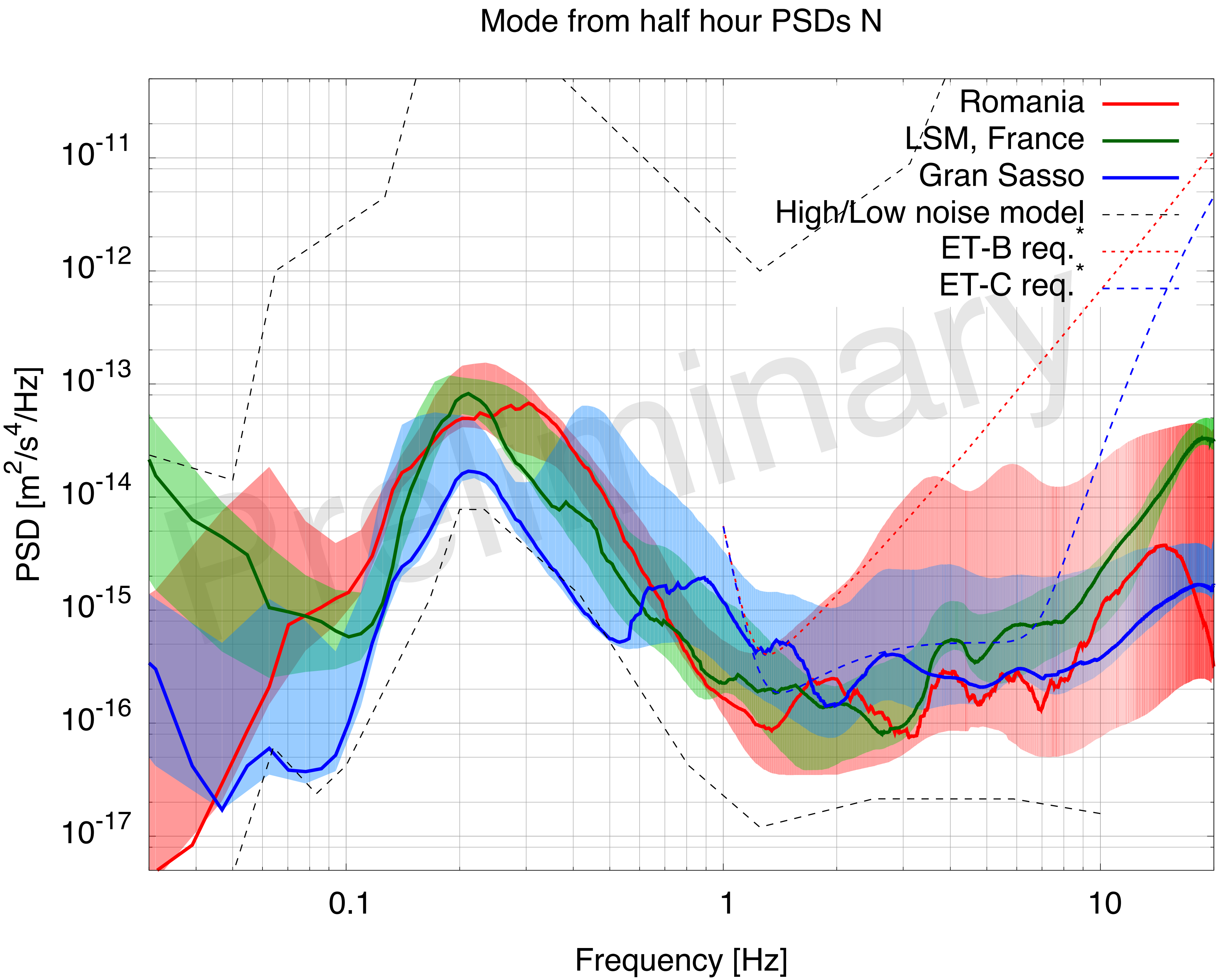
Virgo, 0 m

Holland, 10 m

Moxa, 10 m

Finland, 0 m

Deeper locations generally show lower seismic noise levels

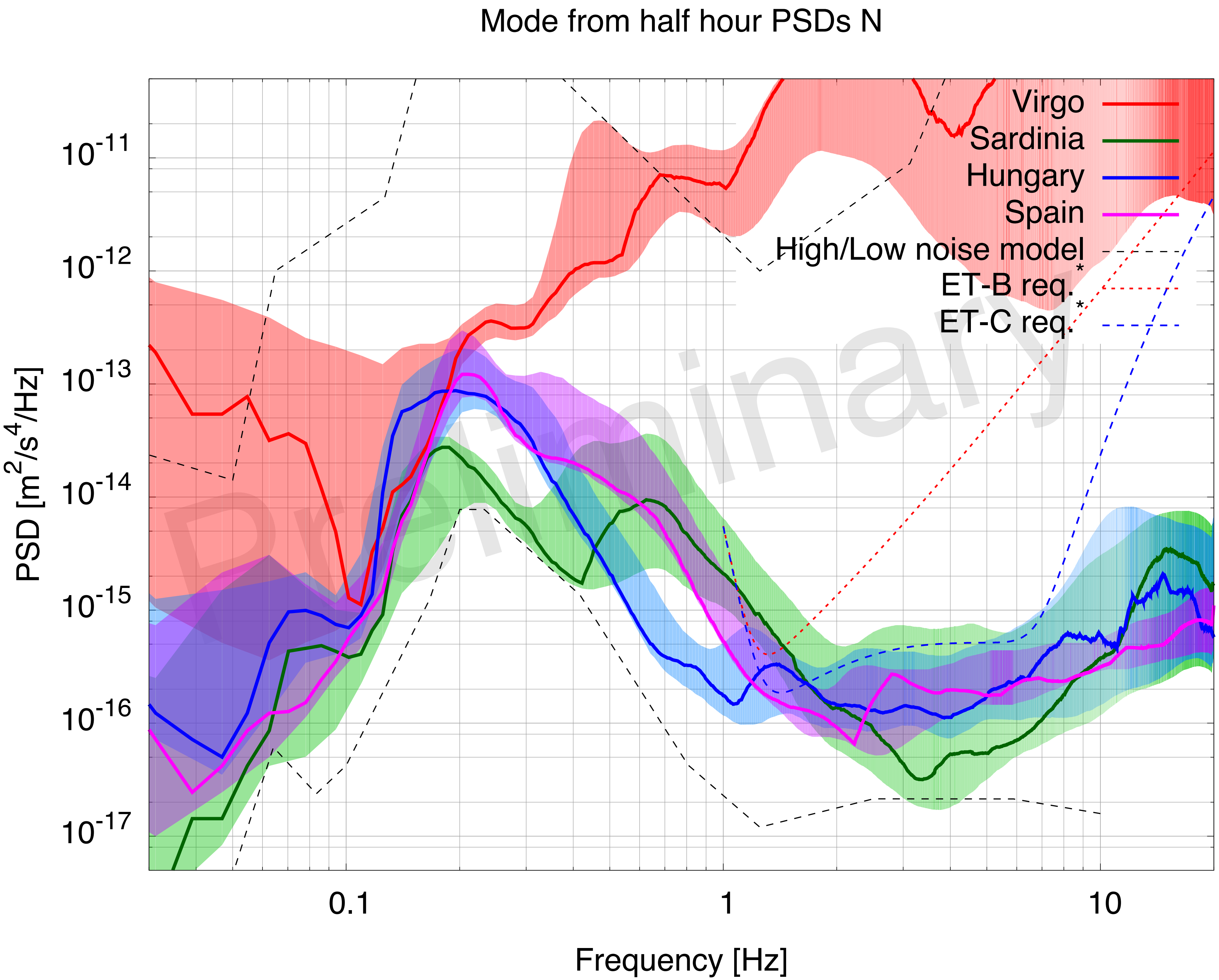


LSM, France, 1750 m

Gran Sasso, 1400 m

Romania, 190 m

Sites show considerable improvement on existing GW detector site



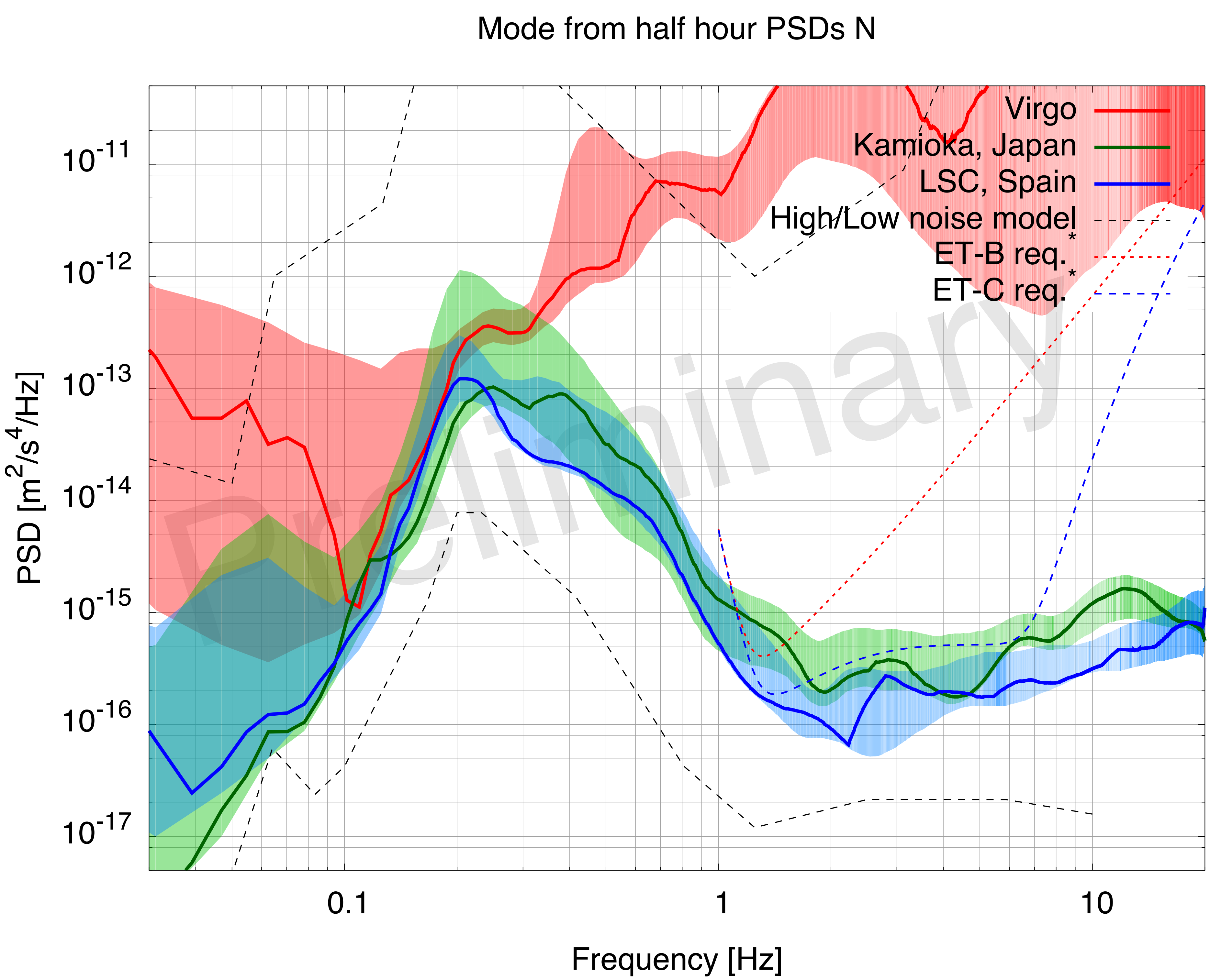
Virgo, 0 m

Sardinia, 185 m

Hungary, 400 m

LSC, Spain, 800 m

LCGT will profit from a seismically quiet environment



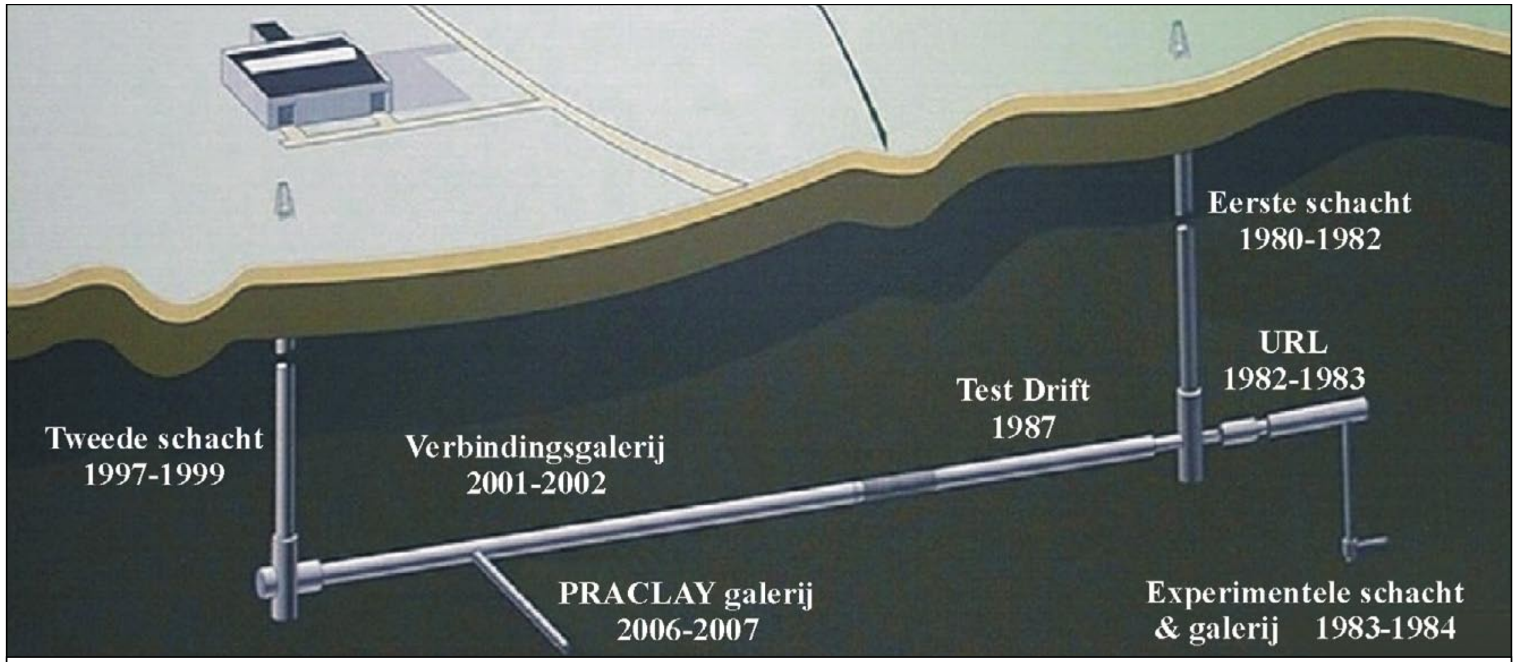
Virgo, 0 m

Kamioka, 1000 m

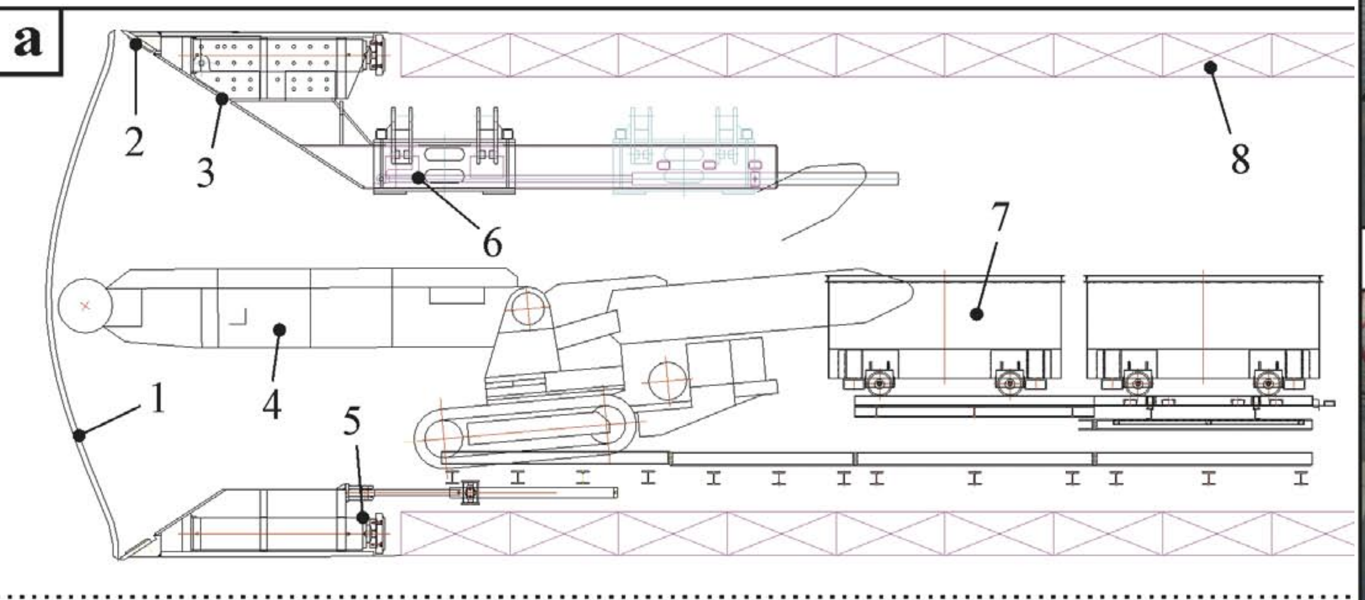
LSC, Spain, 800 m

Expect to visit a Belgium underground Nuclear waste storage research facility next month

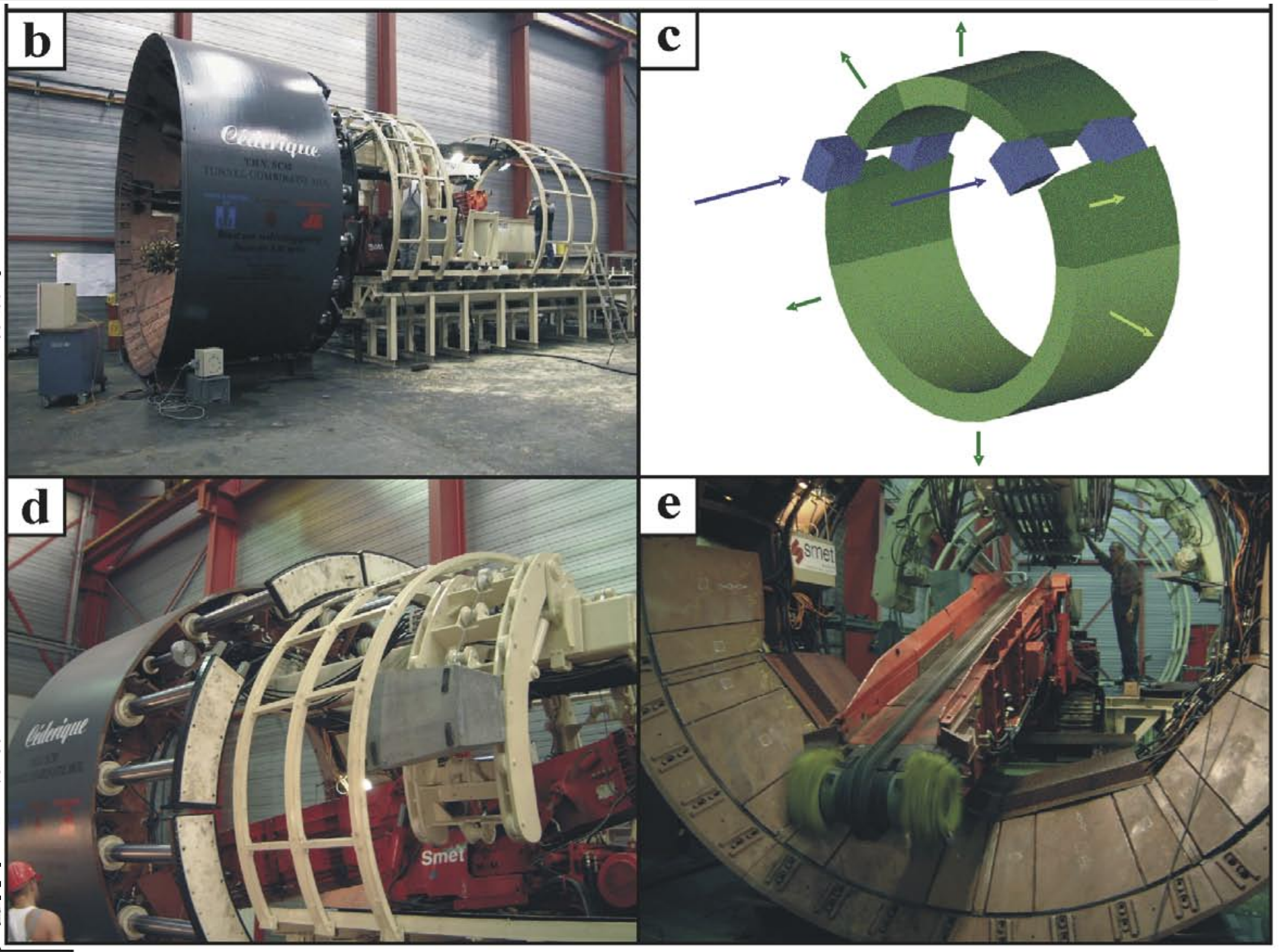
- HADES underground laboratory for nuclear waste storage
  - 223 m deep
  - In “Boomse” clay formation
  - Impenetrable by water
  - Well-known industrial drilling techniques used for excavation



↑ **Figuur 3** Constructiegeschiedenis van het ondergronds laboratorium HADES.



1: uitgravingsfront
2: snijschoen, de oversize is aanpasbaar van 0 tot 30 mm
3: schild
4: freeskop
5: hydraulische vijzel
6: bird-wing erector
7: wagon
8: bekleding: wedge-block syst

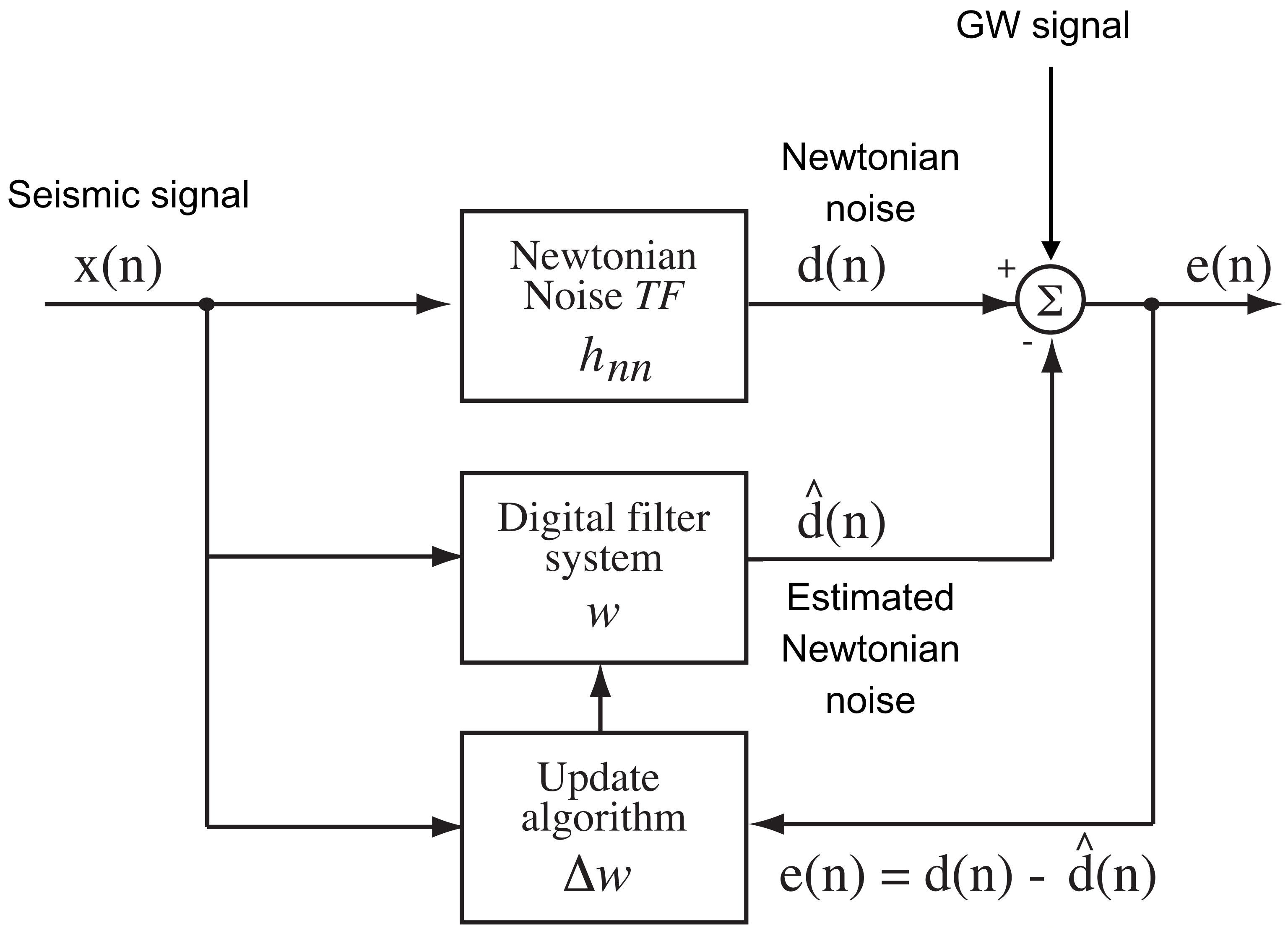


Next step is to ear-mark a few sites for long term investigation

- Criteria for candidate sites
  - Seismic and geological suitability
  - Commitment from local scientific and governing bodies
  - No other large scale infrastructure plans in the area
- Long term study for
  - Seismic noise, seasonal variation, rock stability
  - Geology / hydrology, suitability for large underground facilities
- Consider (self)generation of seismic noise in design phase

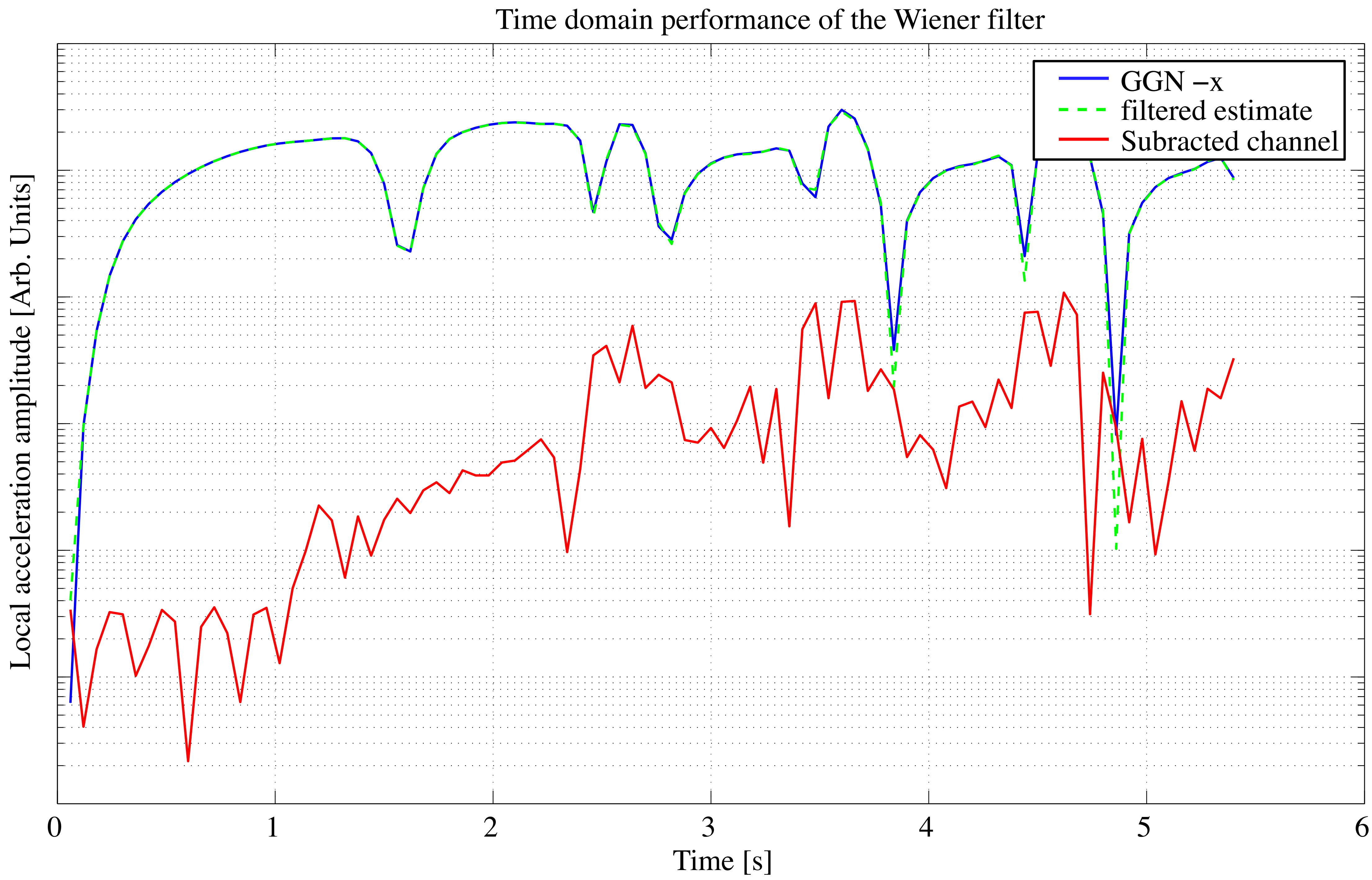
Seismic sensor array and filter algorithms can be used to predict and subtract GGN from local sources

- Use secondary sensors to measure the density perturbations around the detector.
- Create models that estimate the sensor to test mass impulse responses.
- Use adaptive filter techniques to estimate and reduce GGN



Better an enemy you know, then one that you don't.
- Sun Tzu

Results of simple filtering algorithm with FEA models show a GGN reduction of 1.5 orders of magnitude



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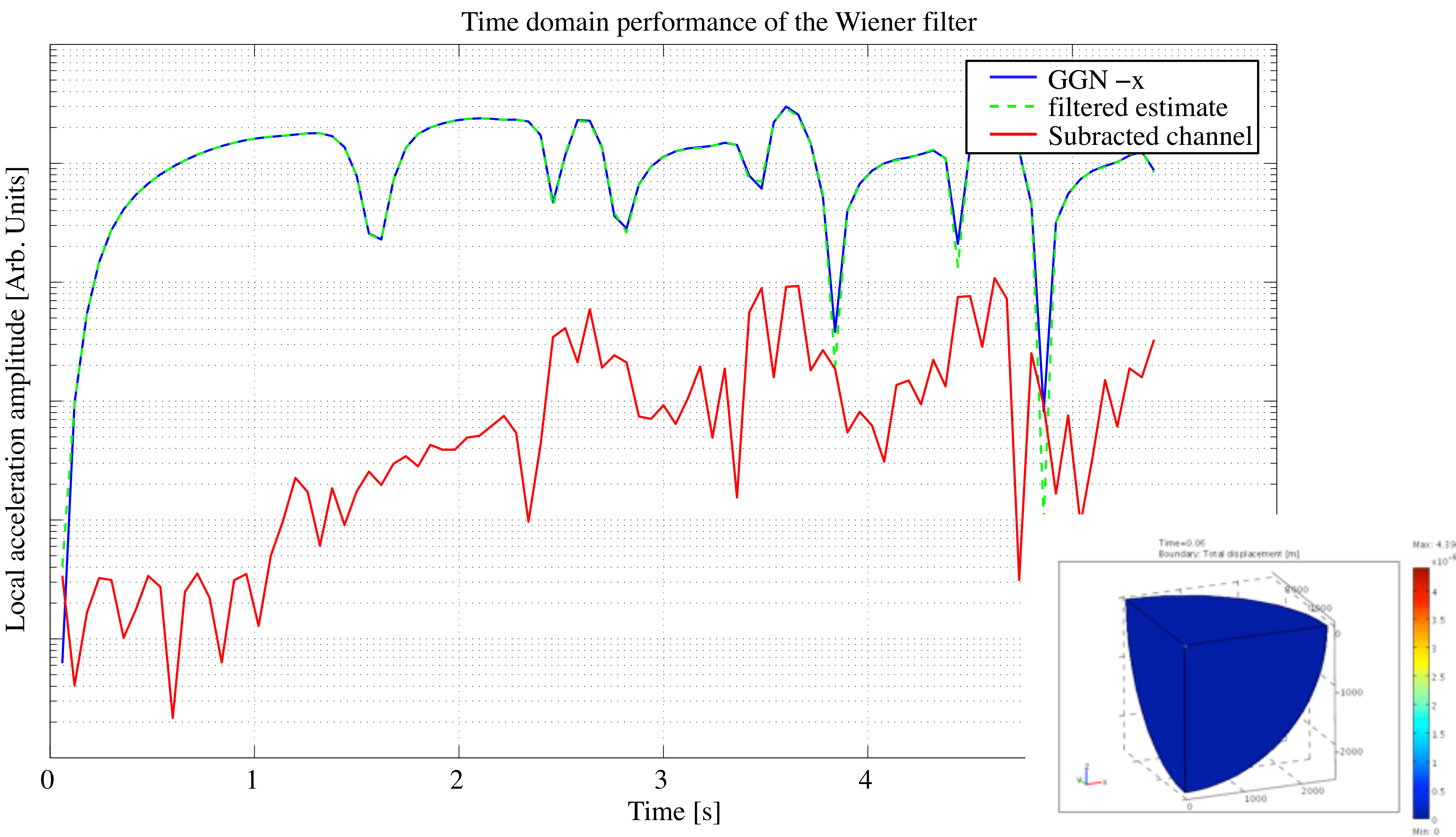
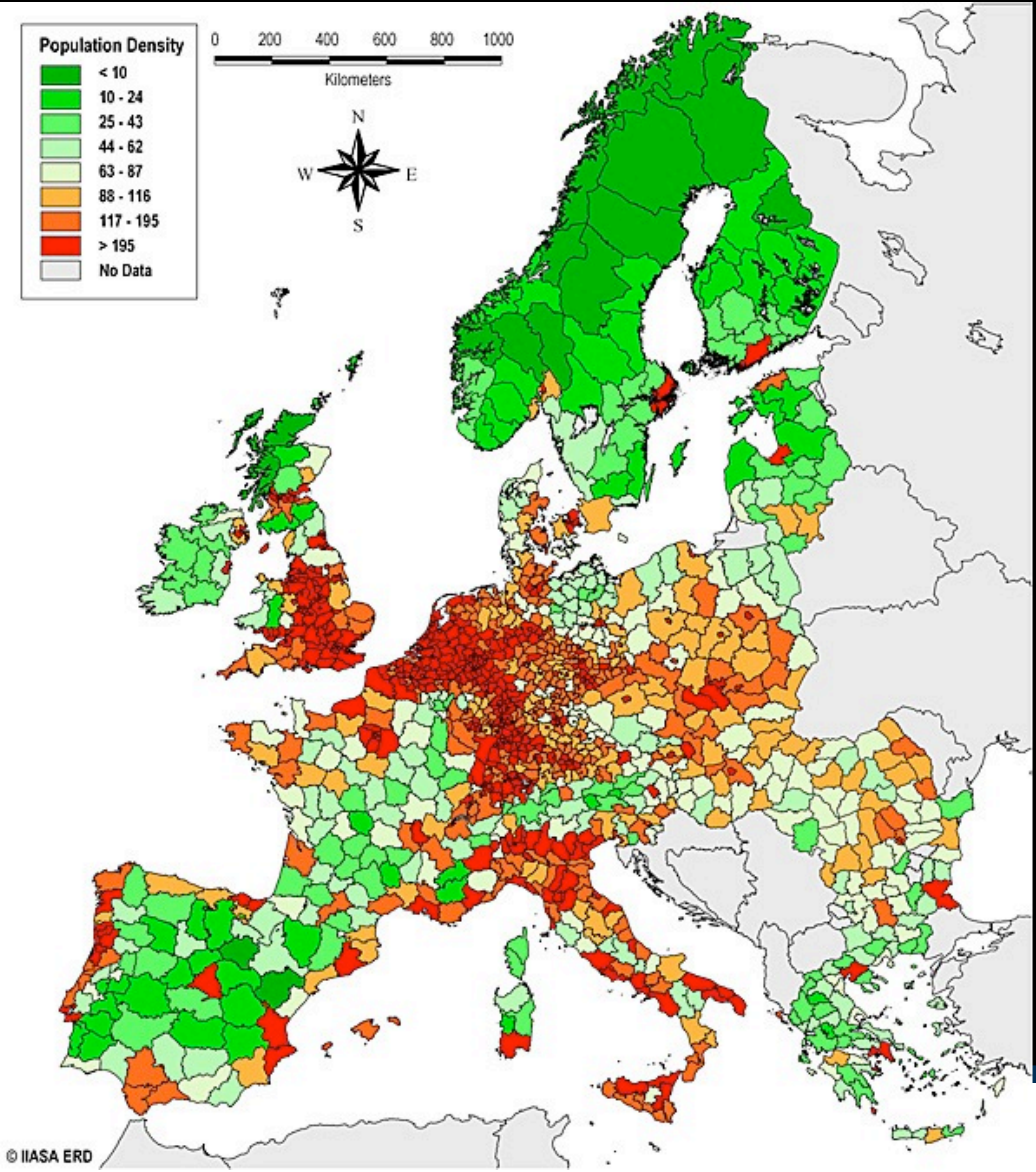


Conclusions

- Suitably seismically quiet locations for the Einstein telescope can be found in Europe
- Production of seismic noise due to our own activities (pumps,people) needs to be monitored and minimized
  - Seismic sensors and filtering schemes can be used for subtraction
- Next step: a long term study of a few sites in Europe
  - Seasonal variation / long term stability
  - Geo / Hydrological studies
  - Drive from local community is important



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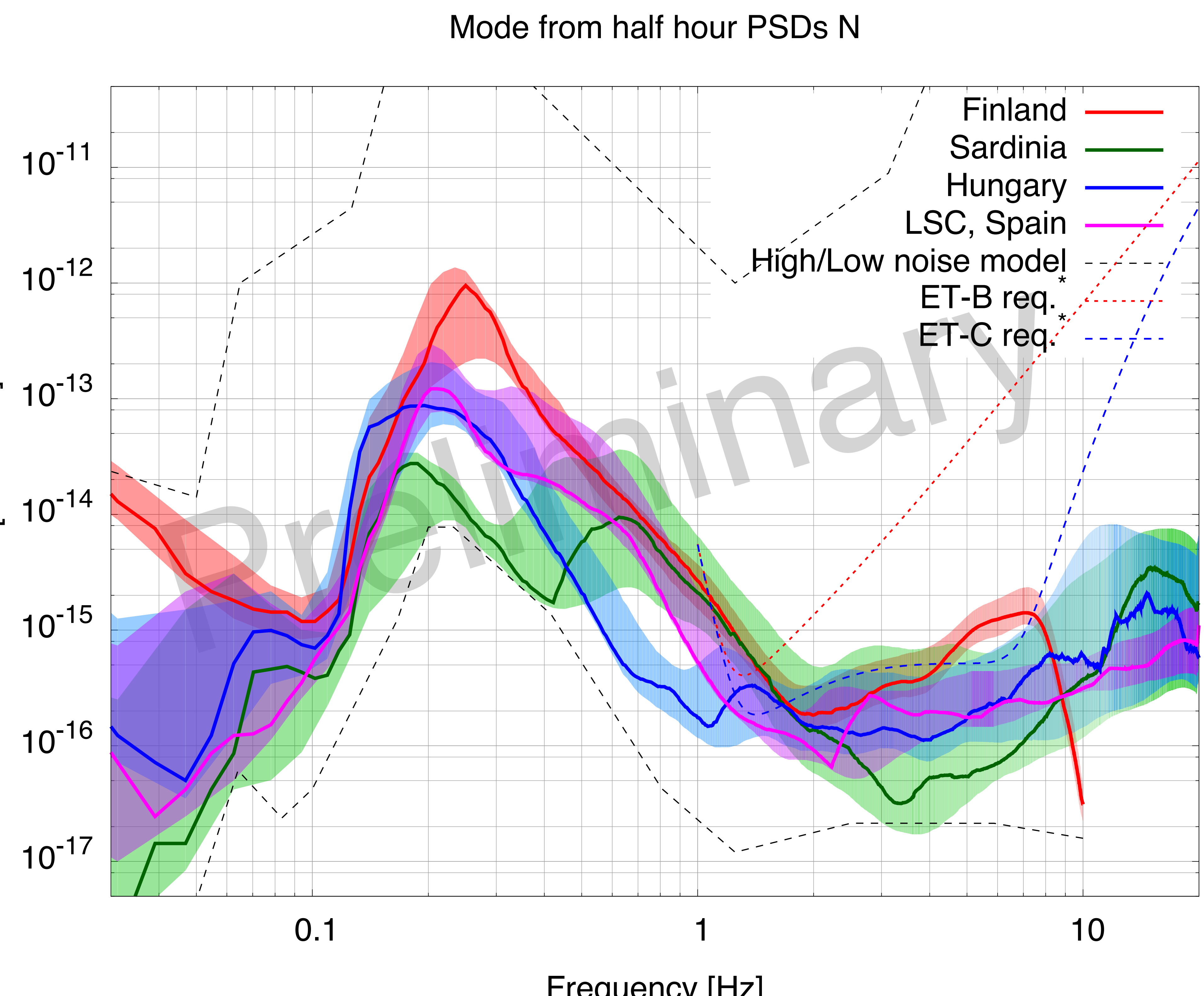
Summary of all locations



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Sardinia, 185 m

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LSC, Spain, 800 m