Newtonian Noise Cancellation for Adv Virgo

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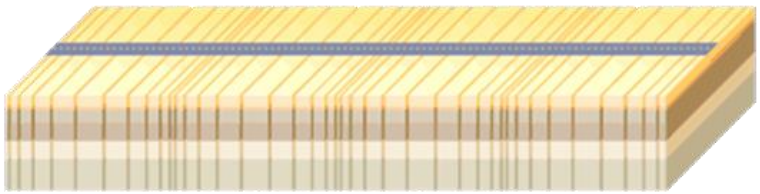
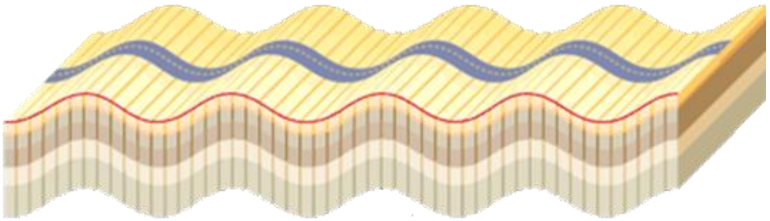
Contributing groups in Italy:
INFN Genova, INFN GSGC, INFN Napoli, INFN Pisa, INFN Roma 3
(with support from EGO)

Seismic NN

Density fluctuation inside medium



Surface/interface displacement



$$\frac{\xi(f)\, e^{-\frac{2\pi f h}{c_{\mathrm{hor}}}}}{f^2}$$

- Surface waves: Rayleigh, Love

  Body waves: compressional, shear
- Shear waves relevant when displacing surfaces/interfaces
- NN is non-stationary
- For Adv Virgo relevant between about 10Hz and 30Hz

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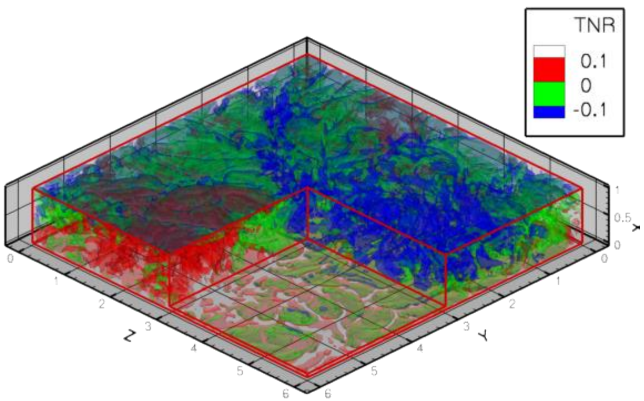
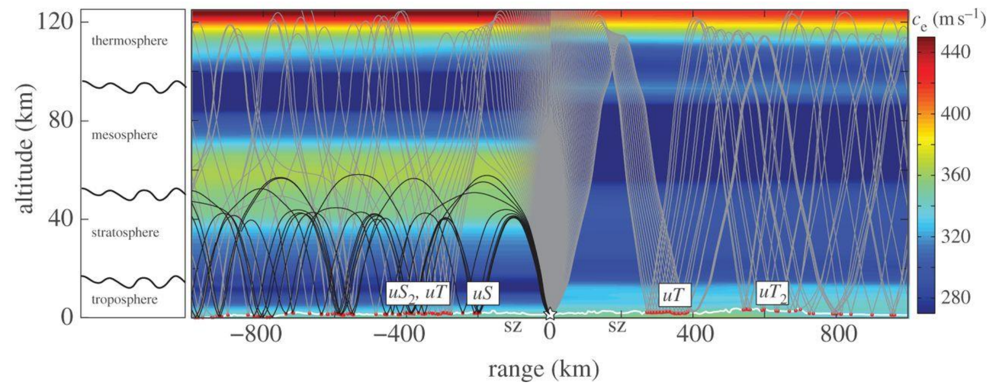
Atmospheric NN





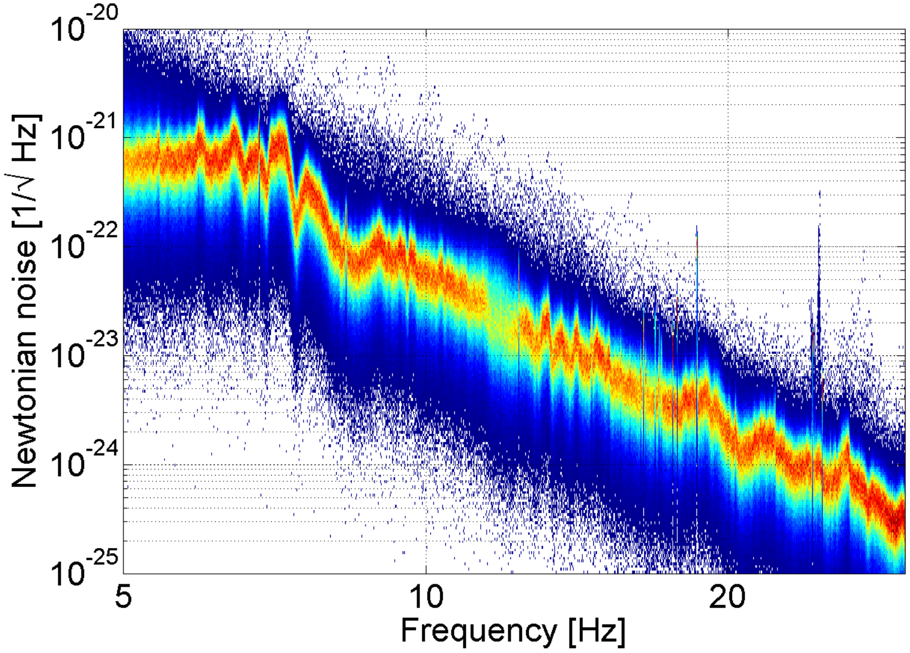
$$\frac{\delta \mathrm{T}(f)\, e^{-\frac{2\pi f r}{v}}}{f^{10/3}}$$

$$\frac{p(f)\, e^{-\frac{2\pi d f}{c_{\mathrm{hor}}}}}{f^{3}}$$

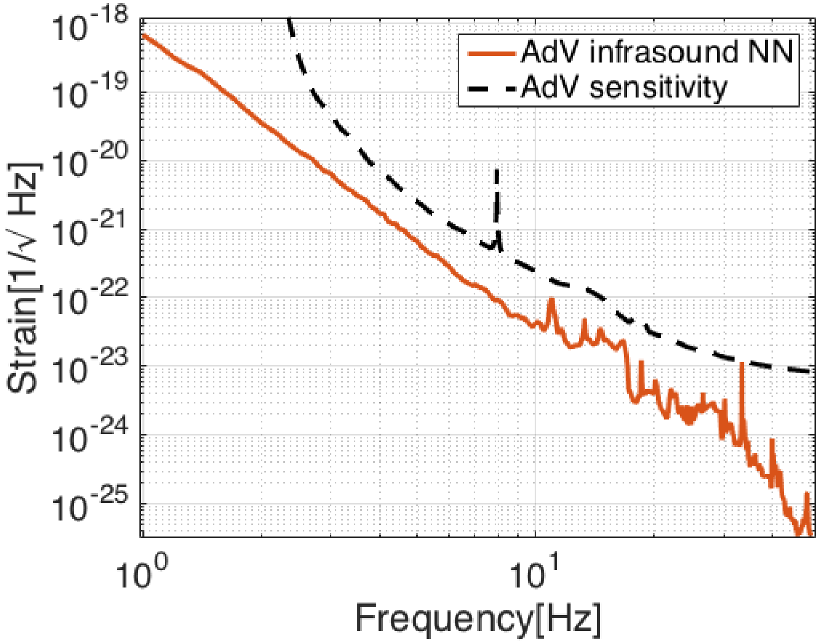
- Sound propagation inside atmosphere and laboratory buildings (only atmospheric perturbation relevant to Adv Virgo)
- Quasi-static temperature perturbations advected by wind
- Turbulence makes accurate modelling very challenging

AdV Newtonian-Noise Models

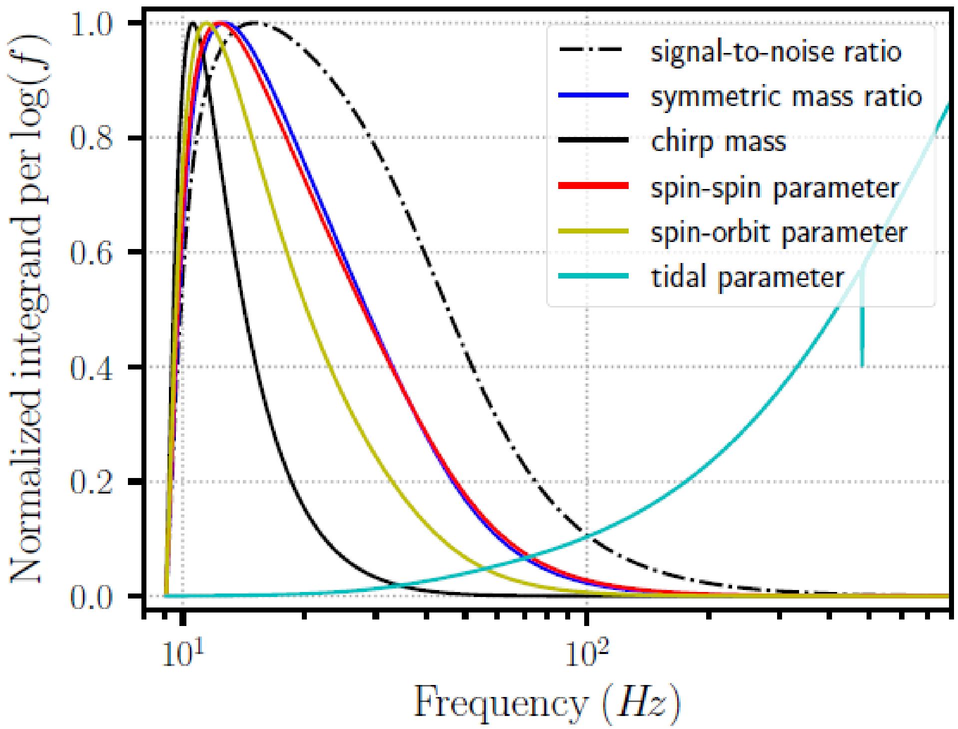
Rayleigh-wave model



Sound inside buildings



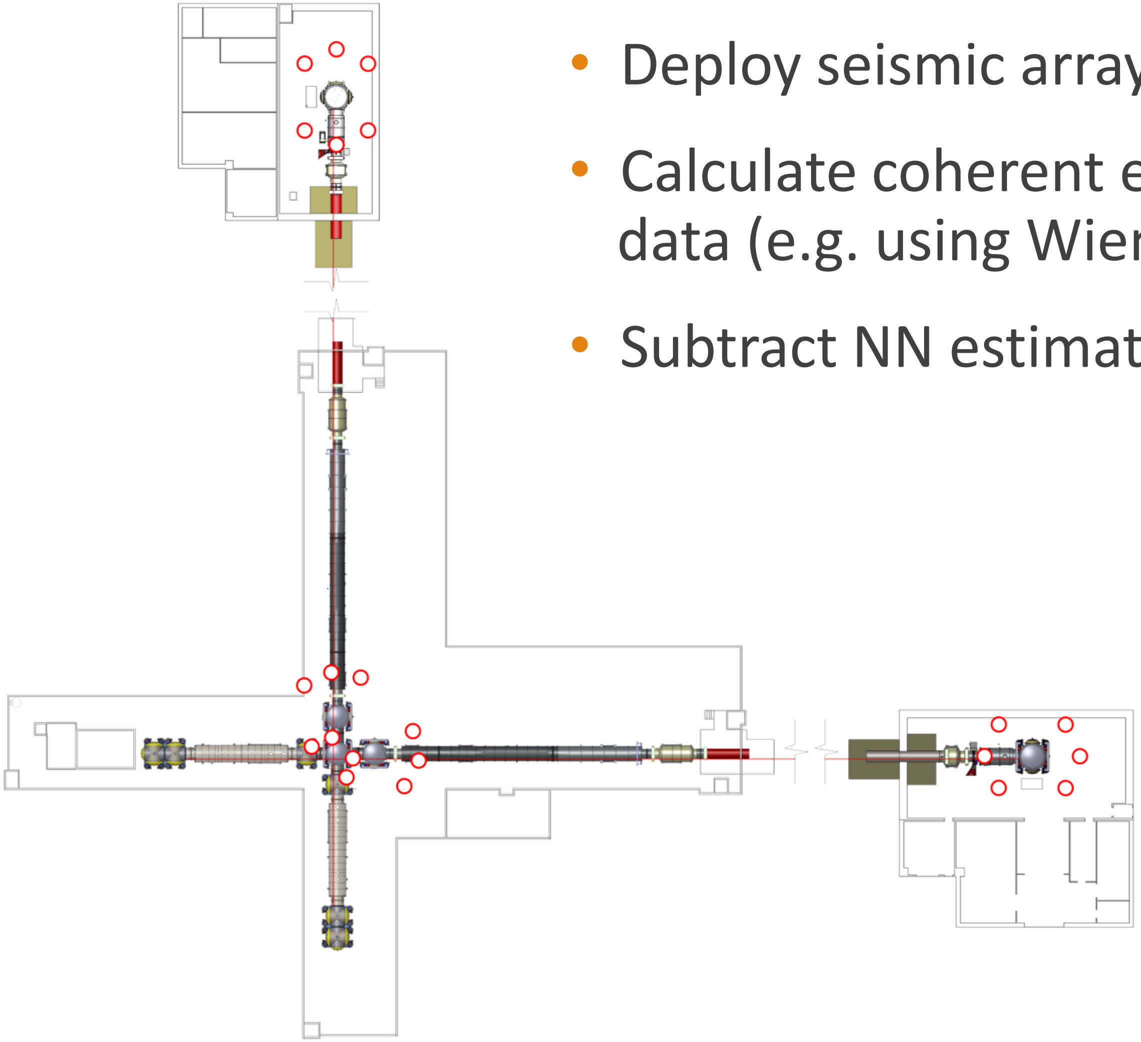
BNS: SNR and Parameter Estimation



Harry/Hinderer (2018)

Example: broadband Adv LIGO target sensitivity

NN Cancellation

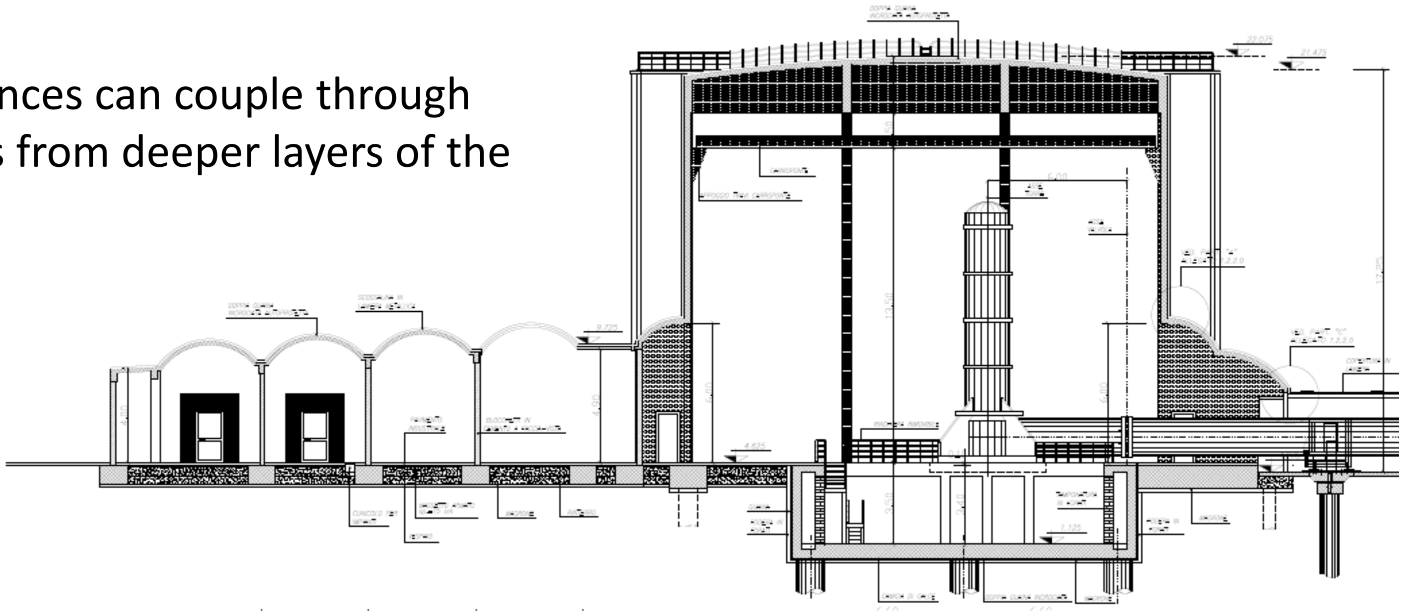


- Deploy seismic arrays around test masses
- Calculate coherent estimate of NN from seismic data (e.g. using Wiener filters)
- Subtract NN estimate from GW data

Virgo Infrastructure

Understanding NN in Virgo is a challenge:

- Rooms below surface under the test mass cause seismic scattering
- Division into soil, building concrete platform, and tower platform changes seismic correlations
- Seismic disturbances can couple through supporting poles from deeper layers of the ground

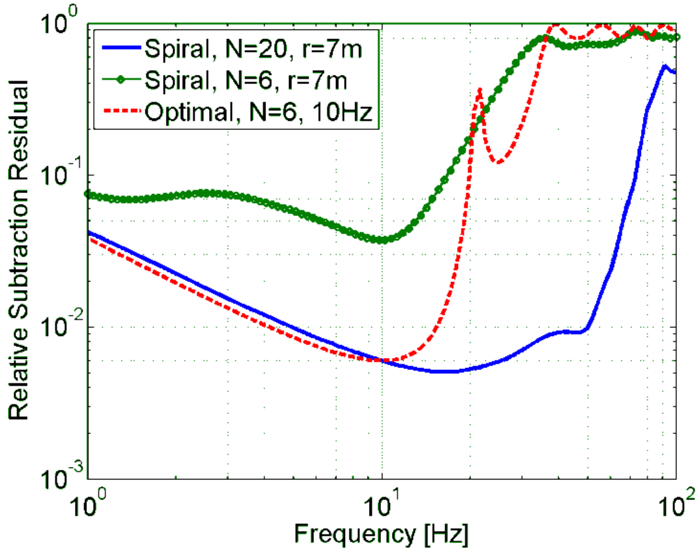


Importance of Array Optimization

Optimization can make the difference between insignificant cancellation and maximally possible cancellation.

Even if an array design was made with a high level of good intuition using some understanding of the seismic field, you can still expect that array optimization gives you another factor 2 and more in noise cancellation.

Rayleigh waves, c_R=250m/s



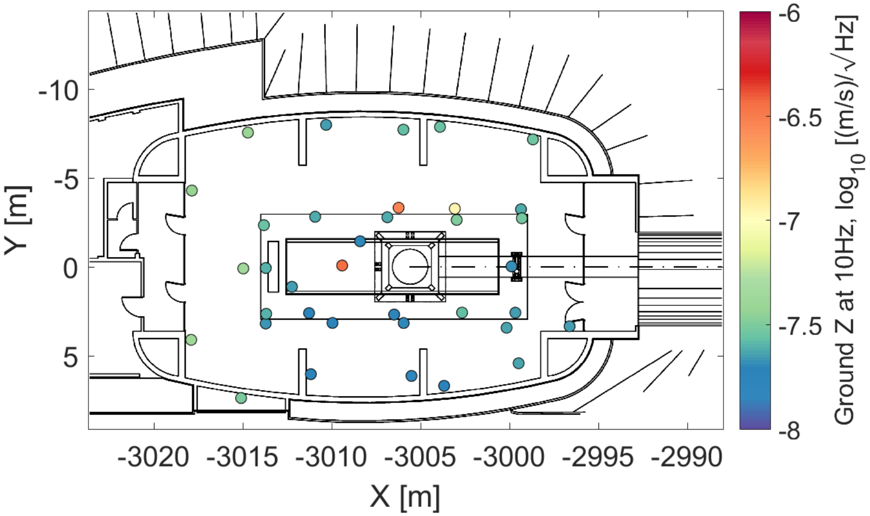
WEB Array Measurements

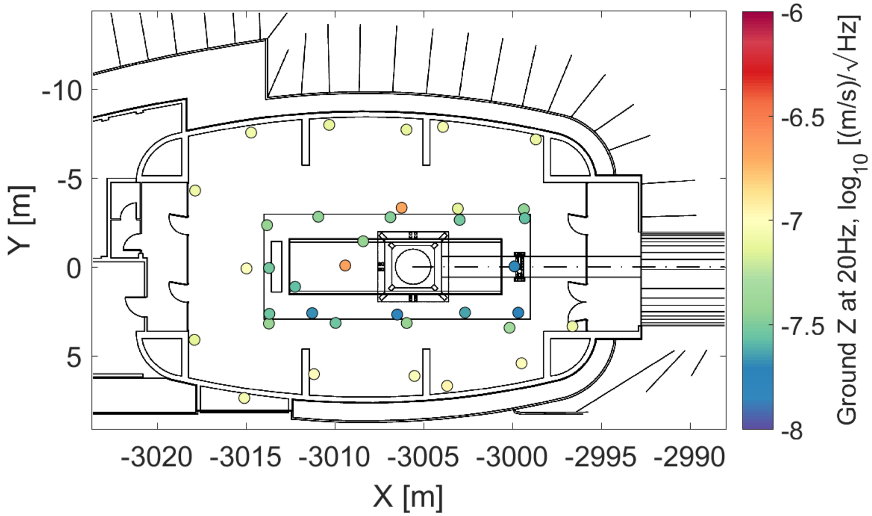
Two sensors across interface

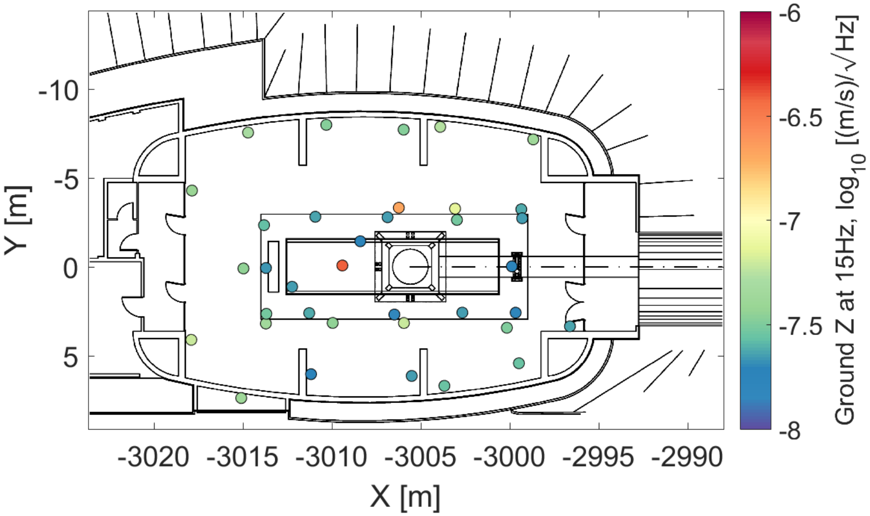
Central data unit

- Heavy mount plate fixed with double-sided tape to improve connection to ground
- Longer inter-sensor cabling to suppress coupling

WEB Seismic Spectra



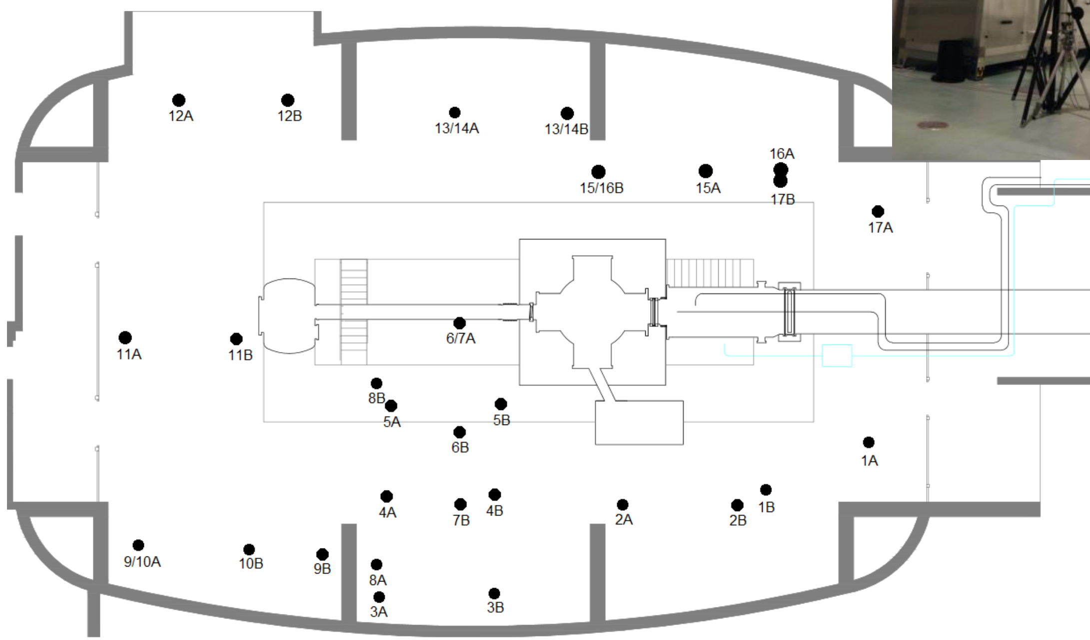




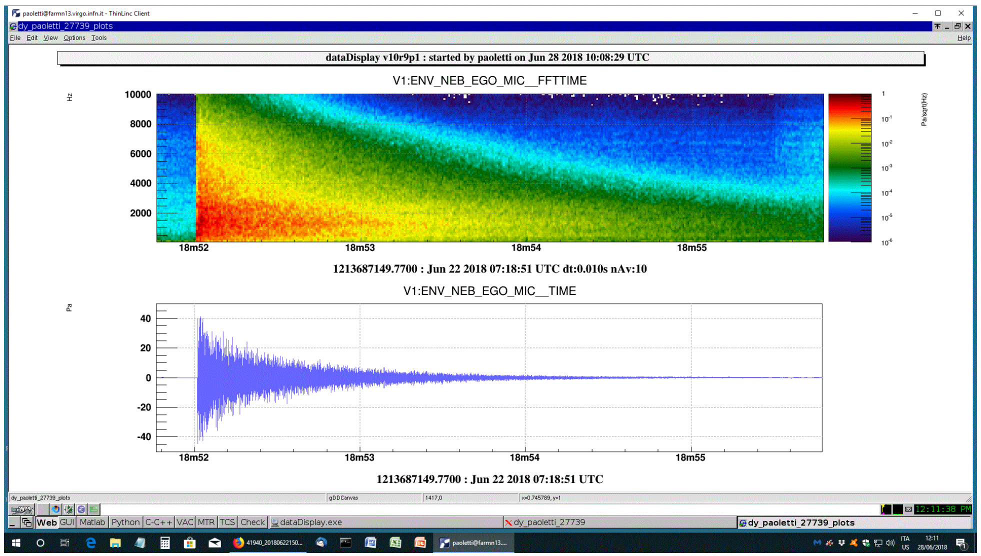
- Night-time data from Feb 1
- 10Hz: Minor discontinuities across platform interface; sources towards negative X
- 15Hz: Significantly stronger ground vibration near building walls; stronger discontinuities across interface
- 20Hz: Much stronger ground vibration near buildings walls; significant discontinuities across interface

Sound Measurements

Measurements of
- High-SNR transients
- Horizontal and vertical correlations of ambient field

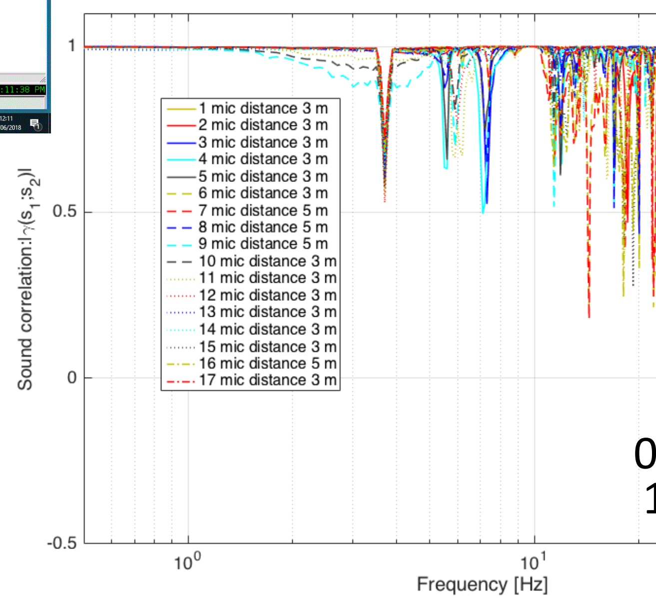


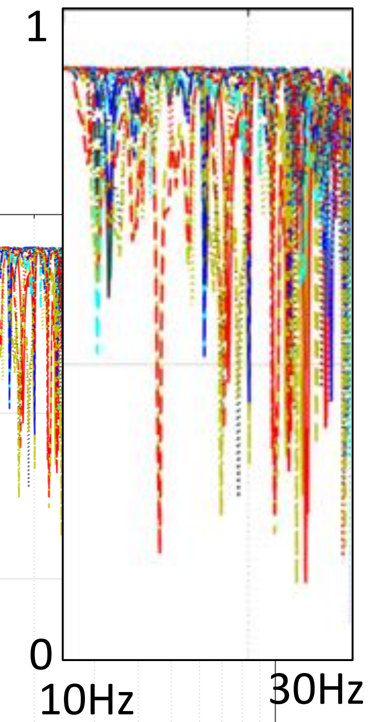
Reverberation Time and Correlations



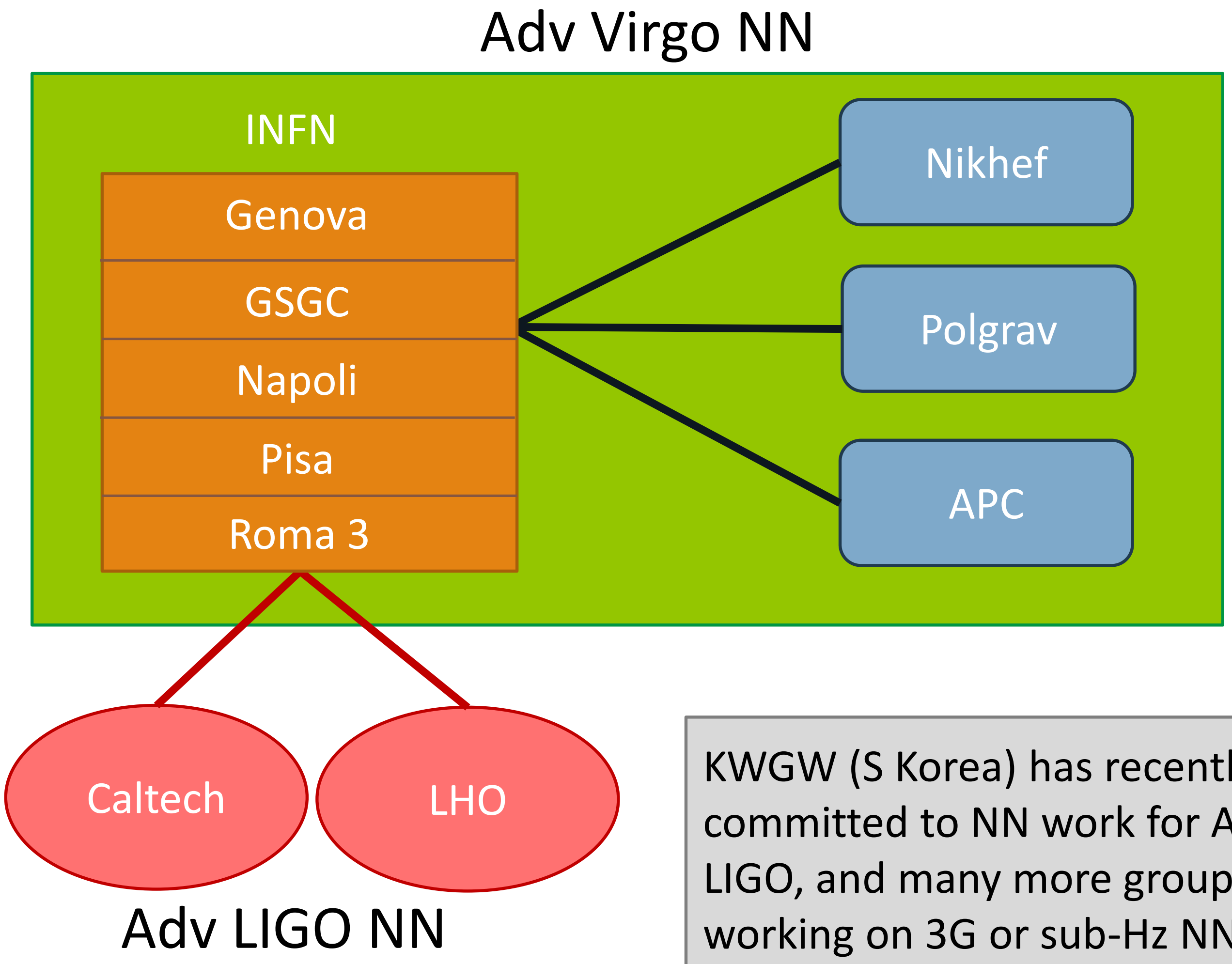
Reverberation time (T60) is about 4.5s in WEB.

Complex correlation field between 10Hz and 30Hz, which makes NN cancellation challenging





INFN and International Collaborators



KWGW (S Korea) has recently committed to NN work for Adv LIGO, and many more groups are working on 3G or sub-Hz NN.

INFN NN Expertise

- INFN has the **world leading experts** in NN modeling
- INFN has the **world leading experts** for the understanding and design of NN cancellation systems
- INFN has **top expertise** (through numerous past projects) in environmental sensing including underground and surface seismometer and microphone installations, and development of innovative seismic sensors
- INFN has **top expertise** in numerical simulations of environmental fields

INFN: Achievements 2017/2018

Seismic NN

- WEB array configuration and installation (with Polgrav, Nikhef)
- First analyses of WEB array data (spatial variation of seismic amplitudes, two-point spatial correlations)
- Validation of numerical simulations of seismic fields comparing ANSYS, Comsol and analytical solutions

Sound NN

- Improved model of sound NN considering contributions from inside and outside building (with APC)
- Minor modifications of NEB ventilation fan done to achieve some reduction of sound in NN band (with EGO)

Main Goals for 2019

Seismic NN

- Setting up seismometer array at NEB (with Polgrav, Nikhef) and, if possible, run in parallel with a locked Virgo interferometer
- Using array data (WEB and NEB) and numerical simulations to determine optimal array configurations for NN cancellations
- Plan seismic-array measurements for CEB (with Polgrav, Nikhef)
- Development of seismic tiltmeter for 10Hz to 30Hz

Sound NN

- Simulate sound field inside Virgo buildings to obtain more accurate NN model
- Assess the sound level that is required to avoid significant disturbances from sound NN
- Discuss strategies with EGO staff about how to further lower sound levels

2019 R&D for beyond O4

Seismic NN

- Development of adaptive filters also using machine-learning techniques
- Study feasibility of NN cancellation with noise-suppression goals of factor 10 and greater

Sound NN

- Plan microphone array measurements (with APC, Polgrav)
- Develop ideas for a sound NN cancellation system

Financial Requests, 2019

Genova	GSGC	Napoli	Pisa
Modeling of seismic fields inside Virgo buildings and associated NN **SW licenses: 6.5k€** **Maintenance local farm: 5k€**	Modeling of sound field inside Virgo buildings and associated NN **SW licenses: 3k€**	Tiltmeter development (optics, SLED, mechanics, feedthrough for fibers, amplifiers) **Total: 27.5k€**	Symbolic computations for NN modeling and subtraction **SW licenses: 0.5k€**