Newtonian Noise and its Cancellation in Third Generation Detectors

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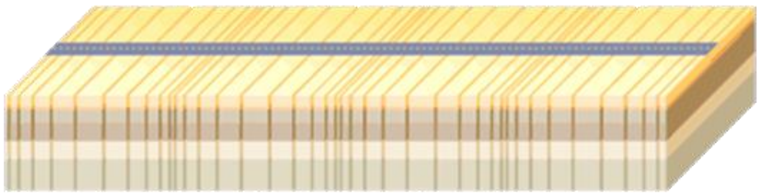
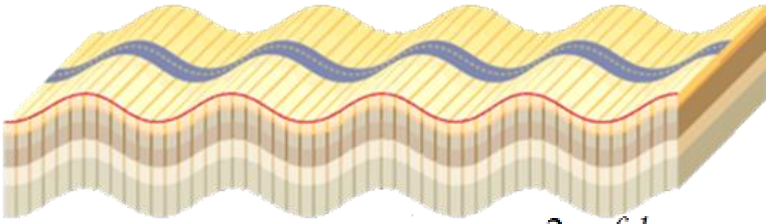
Seismic NN

Density fluctuation inside medium



Surface/interface displacement

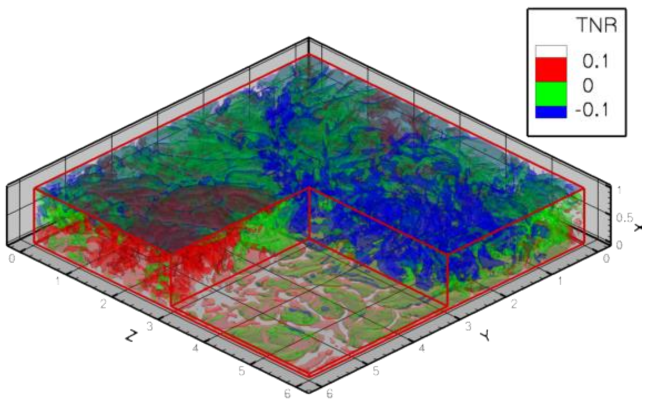


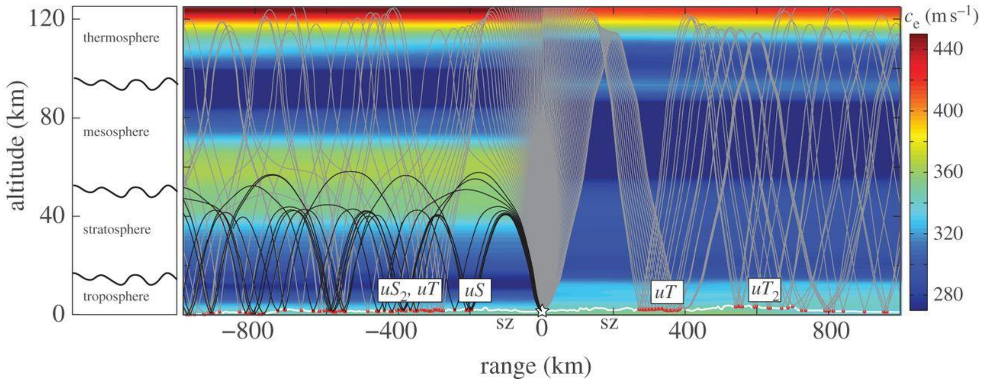
$$\frac{\xi(f)\, e^{-\frac{2\pi f h}{c_{\mathrm{hor}}}}}{f^2}$$

- Surface waves: Rayleigh, Love

  Body waves: compressional, shear
- Shear waves relevant when displacing surfaces/interfaces
- NN is non-stationary
- In the foreseeable future relevant only below 30Hz

Atmospheric NN





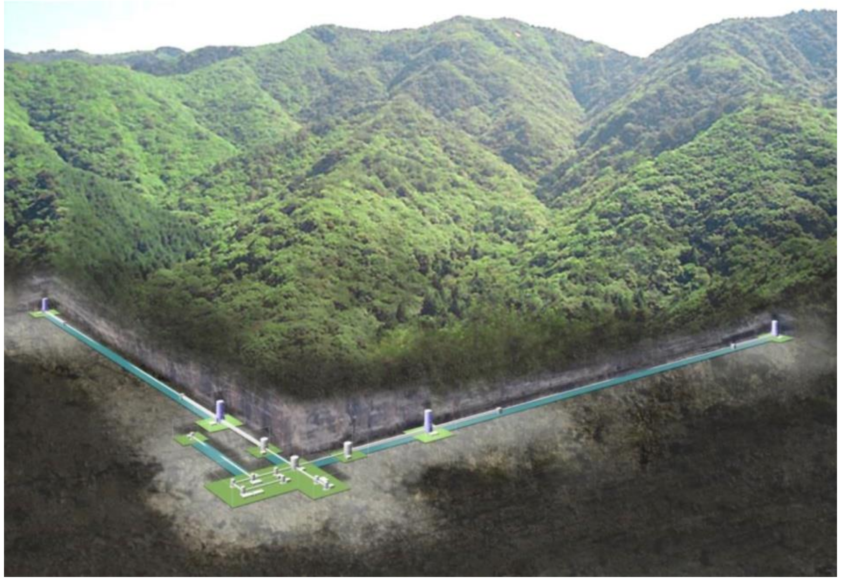
$$\frac{\delta T(f)\, e^{-\frac{2\pi f r}{v}}}{f^{10/3}}$$

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

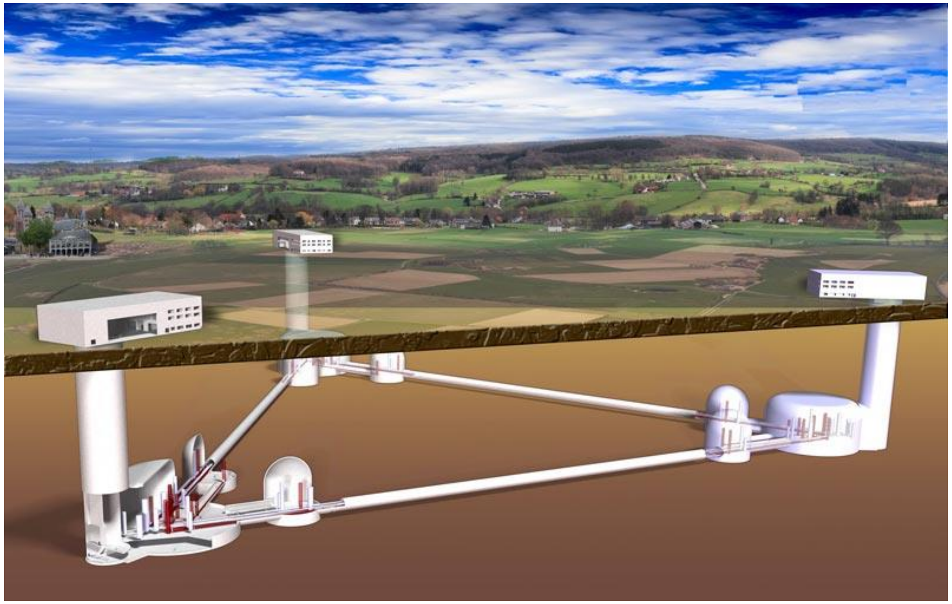
- Quasi-static temperature perturbations advected by wind
- Sound propagation inside atmosphere and laboratory buildings
- Turbulence makes accurate modelling very challenging

Underground Sites

KAGRA



Future: Einstein Telescope

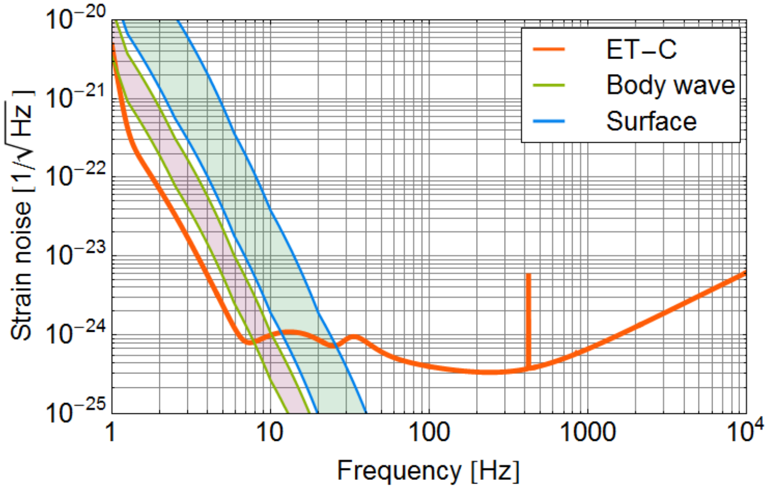


Reduction of seismic noise and associated gravity noise

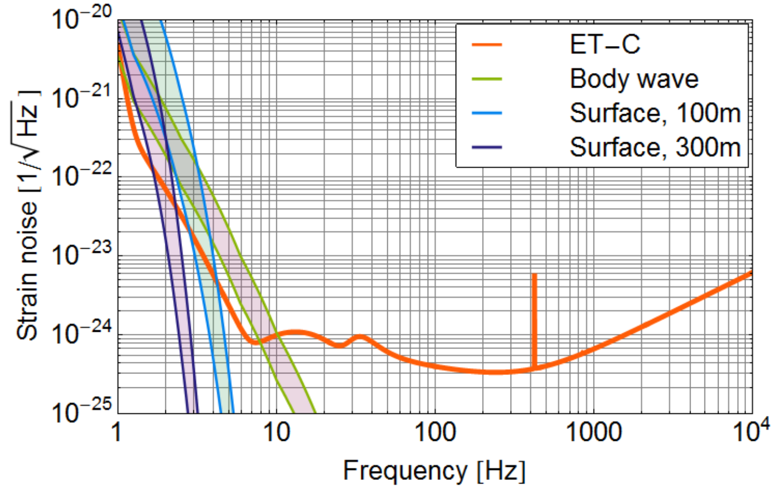
Reduction of atmospheric gravity noise

Seismic NN

Seismic NN in a surface detector



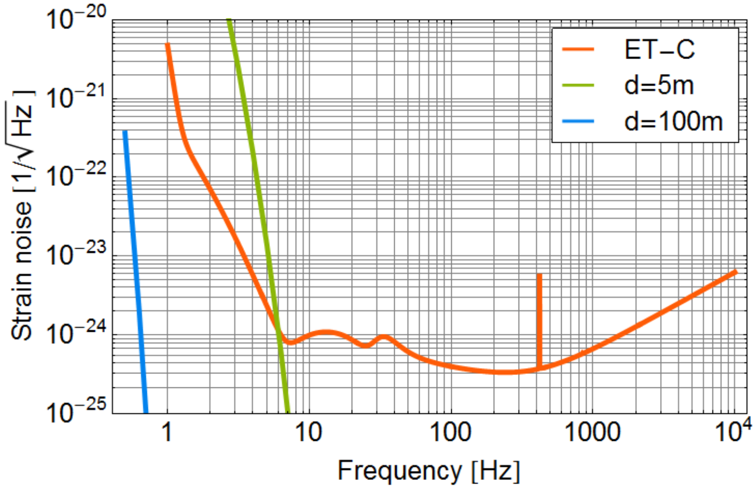
Seismic NN in an underground detector



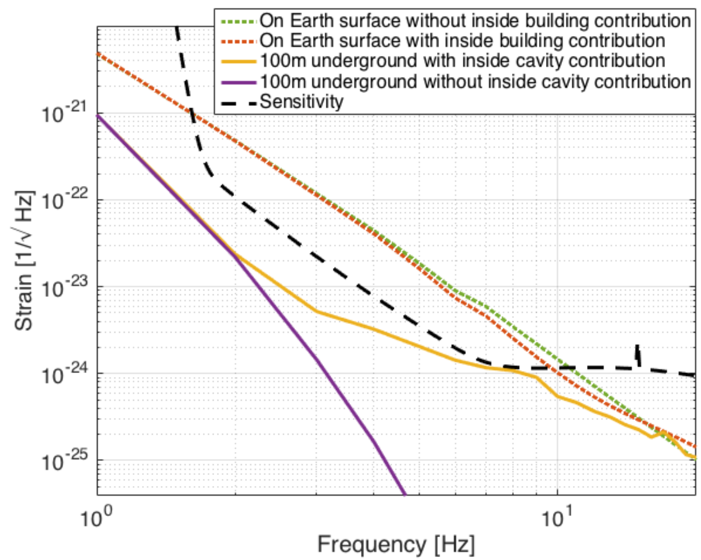
- Seismic models: Body wave: 3x – 12x LNM, Surface: 50x – 1000x LNM
- Rayleigh dispersion model: 1.5km/s @ 1Hz ® 300m/s @ 10Hz
- Includes contributions from cavity-wall displacement
- Homogeneous half space (except for Rayleigh dispersion)

Atmospheric NN

Temperature NN
Uniform air flow, v=20m/s



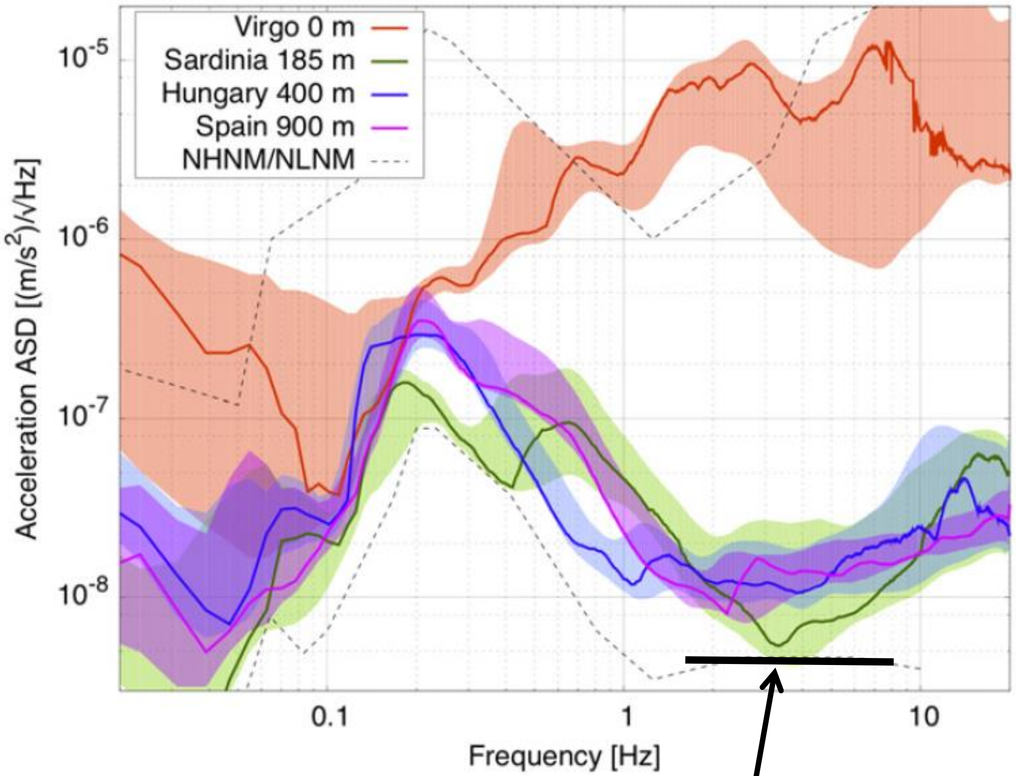
Infrasound NN



- Atmospheric NN limits sensitivity of ET-type detectors if built at the surface
- Going underground very efficiently suppresses atmospheric NN
- Atmospheric NN will be extremely challenging to cancel

Underground Seismic Spectra

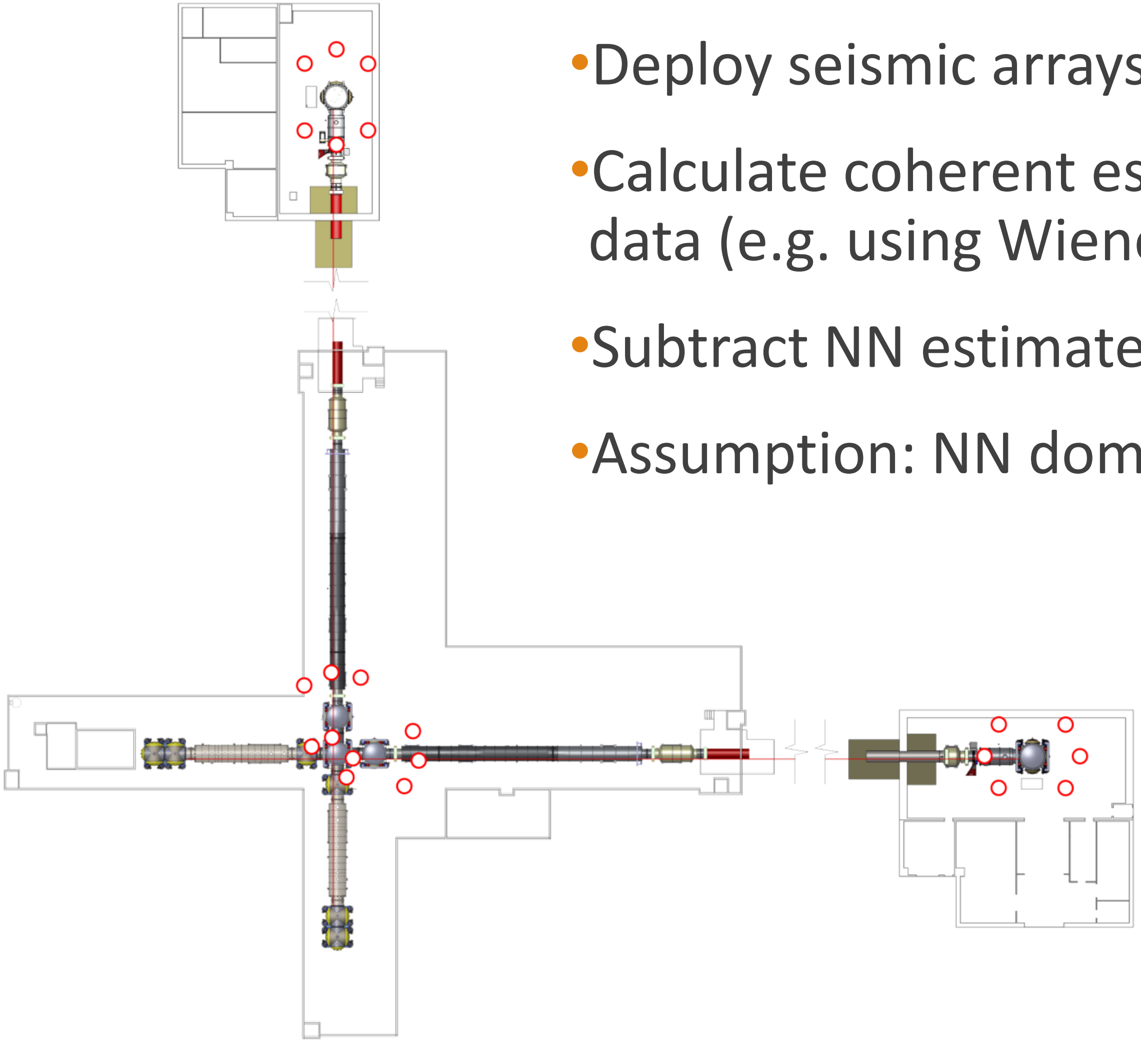
Beker et al, 2012



Requirement ET

(conservative: underground displacement dominated by compressional waves)

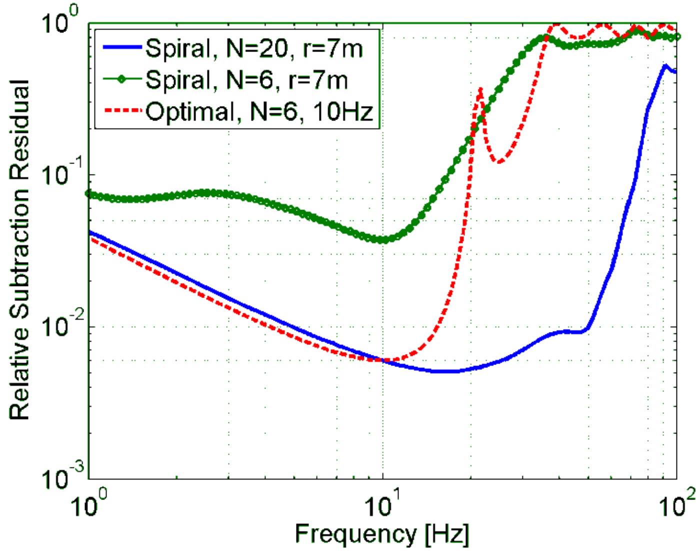
NN Cancellation



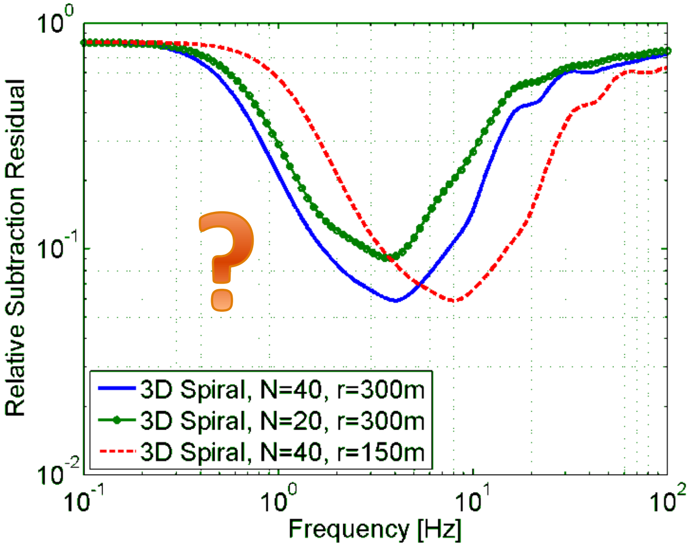
- Deploy seismic arrays around test masses
- Calculate coherent estimate of NN from seismic data (e.g. using Wiener filters)
- Subtract NN estimate from GW data
- Assumption: NN dominated by Rayleigh waves

Importance of Array Optimization

Rayleigh waves, c_R=250m/s

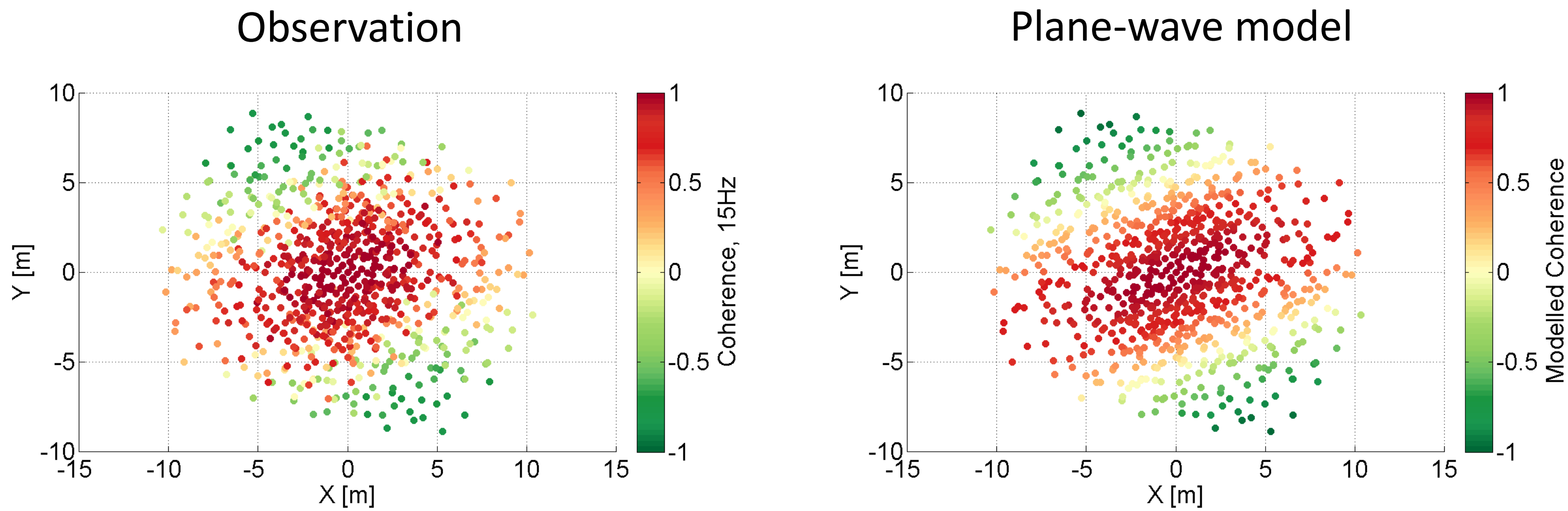


Body waves (1/3 P, 2/3 S), c_P=5km/s



- Optimization can make a big difference in performance
- Shear waves are a huge challenge for underground NN cancellation
- We haven't tried optimization of underground arrays yet
- We need to consider alternative sensors (tiltmeters, strainmeters, gravity gradiometers)

LIGO Hanford Measurements (2012)



- Anisotropic, plane-wave model gives qualitatively good match with observation
- Mismatch is not minor. It demonstrates inhomogeneity of the seismic field, due to local seismic sources

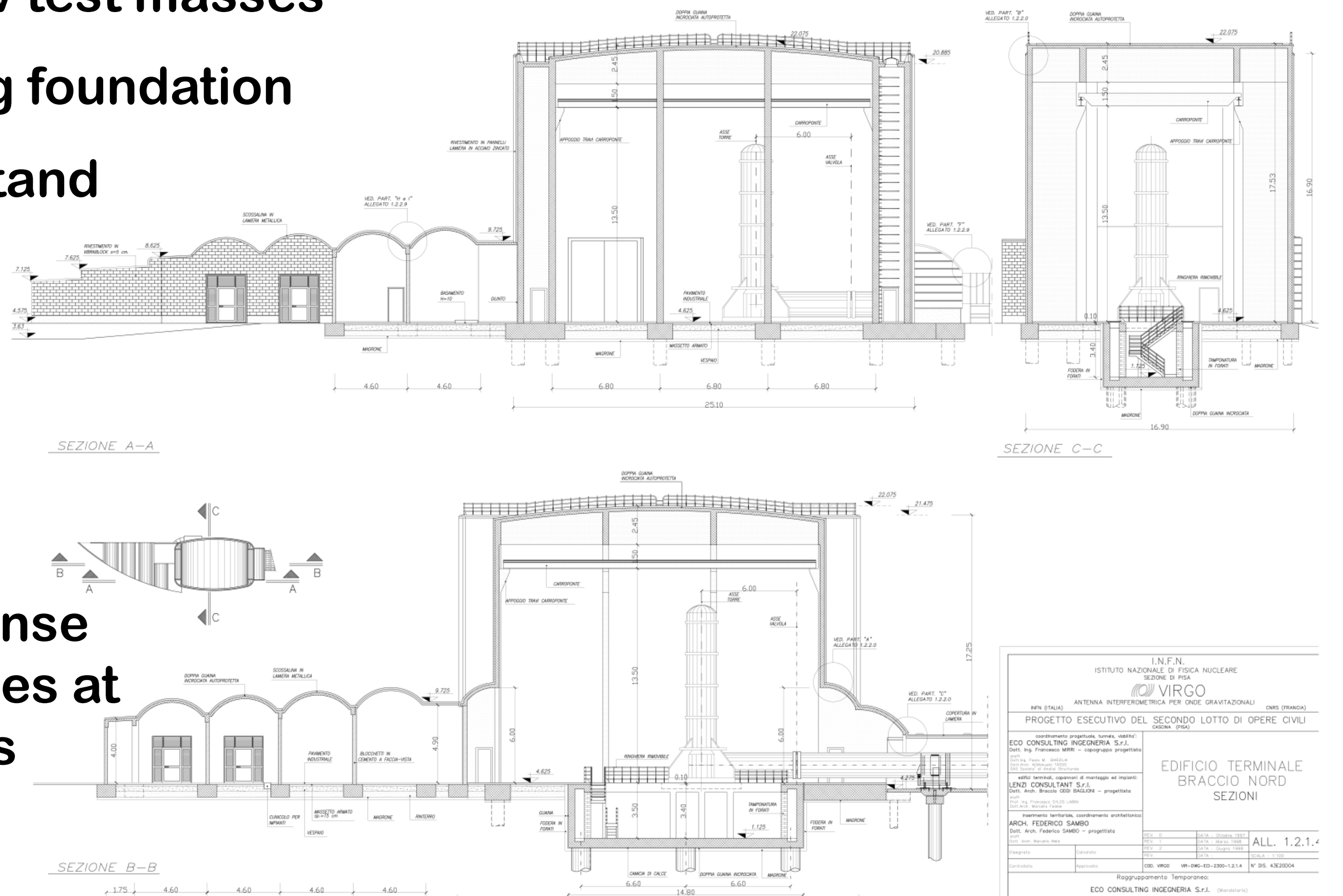
Virgo Infrastructure

Modelling NN for Virgo is not simple

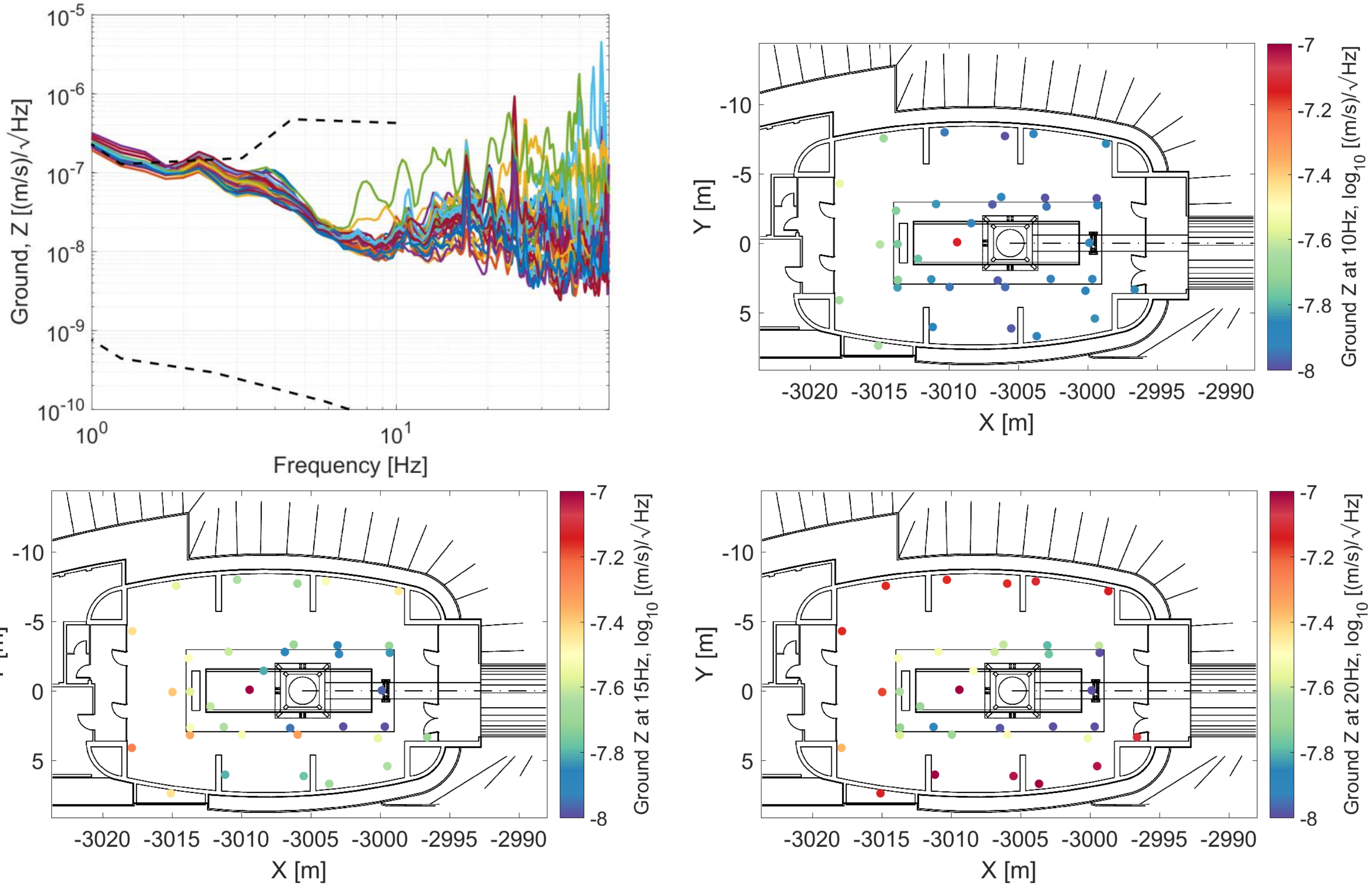
- **Lab space below test masses**
- **Poles supporting foundation**

We need to understand

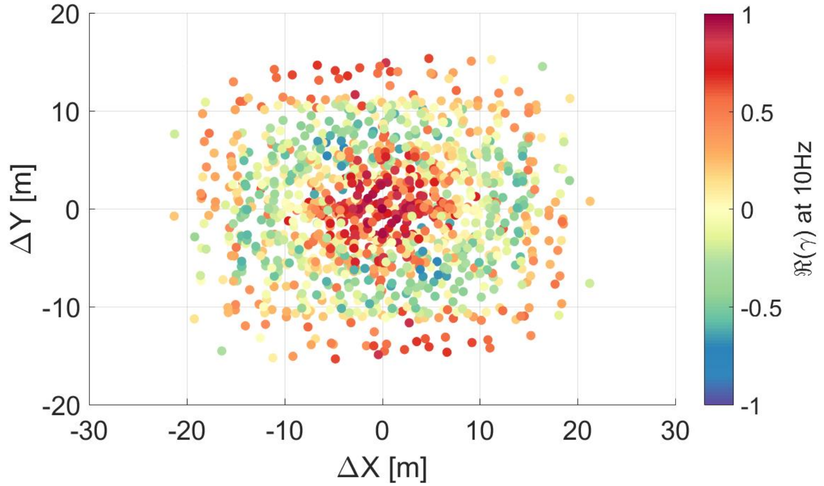
- **Seismic correlation**
- **Seismometer placement**
- **Structural response to seismic sources at various locations**



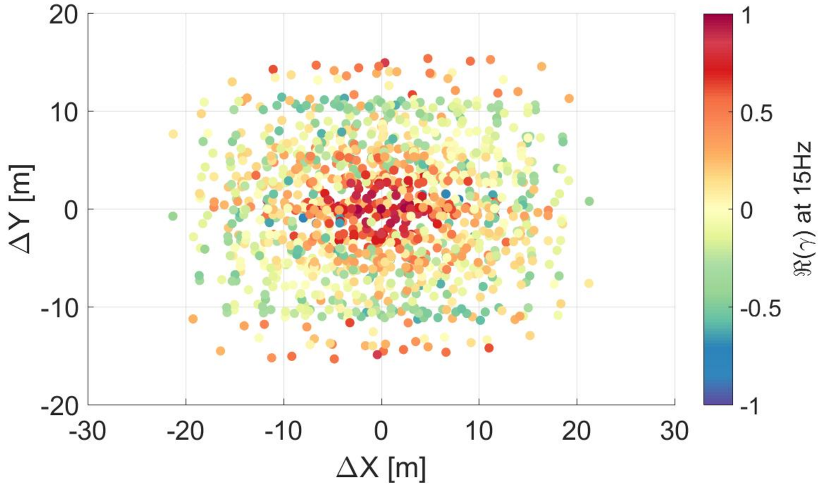
Seismic Noise at Virgo

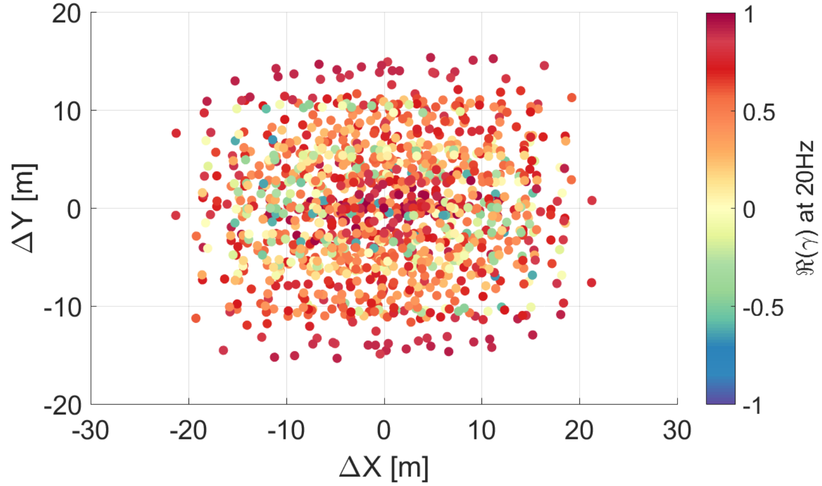


Correlation Measurements at Virgo



- Insignificant imprint of infrastructure symmetries on seismic field at 10Hz
- Correlations higher for sensor separations along arm direction at 15Hz
- Results at 20Hz not understood





Gravity Noise R&D

Present

- Virgo/LIGO site characterization and development of cancellation systems
- Composition of seismic field including body-waves, Rayleigh waves (Homestake underground/surface array)

Near future

- Alternative sensors (seismic strainmeters, tiltmeters)
- Hydrodynamical simulations for *atmospheric NN*
- *NN cancellation* for underground sites

Distant future

- Atmospheric tomography (LIDAR)
- Use gravity gradiometers for NN cancellation
- Distributed seismic sensing with optical fibers