Newtonian Noise

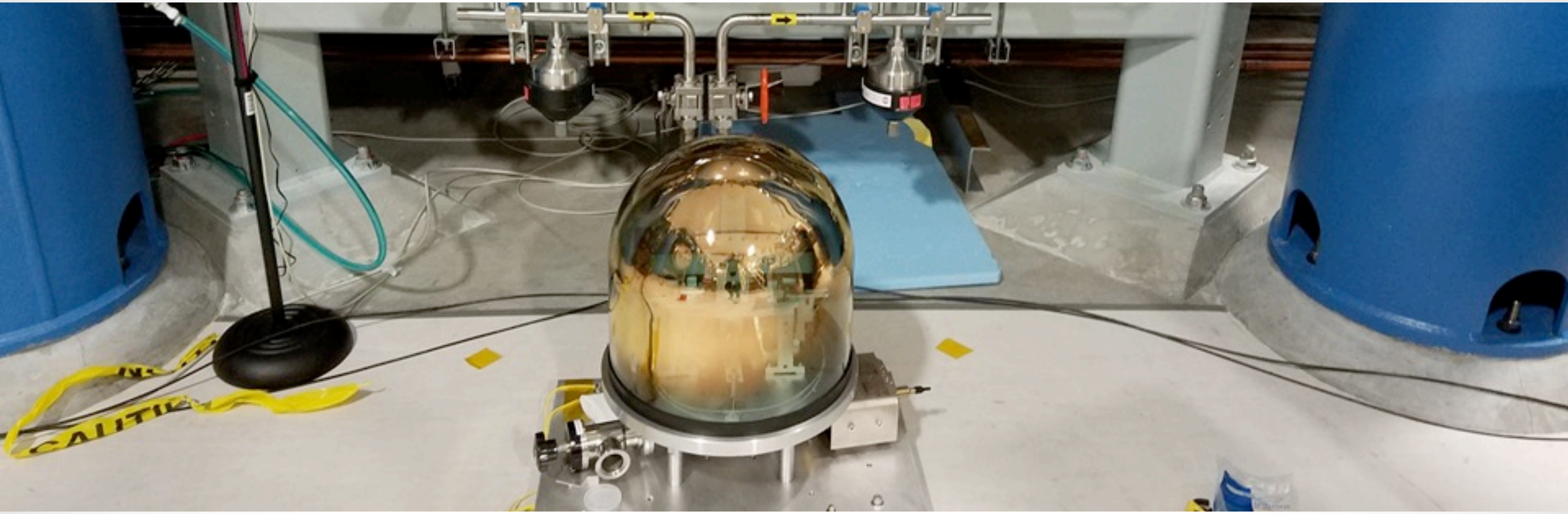
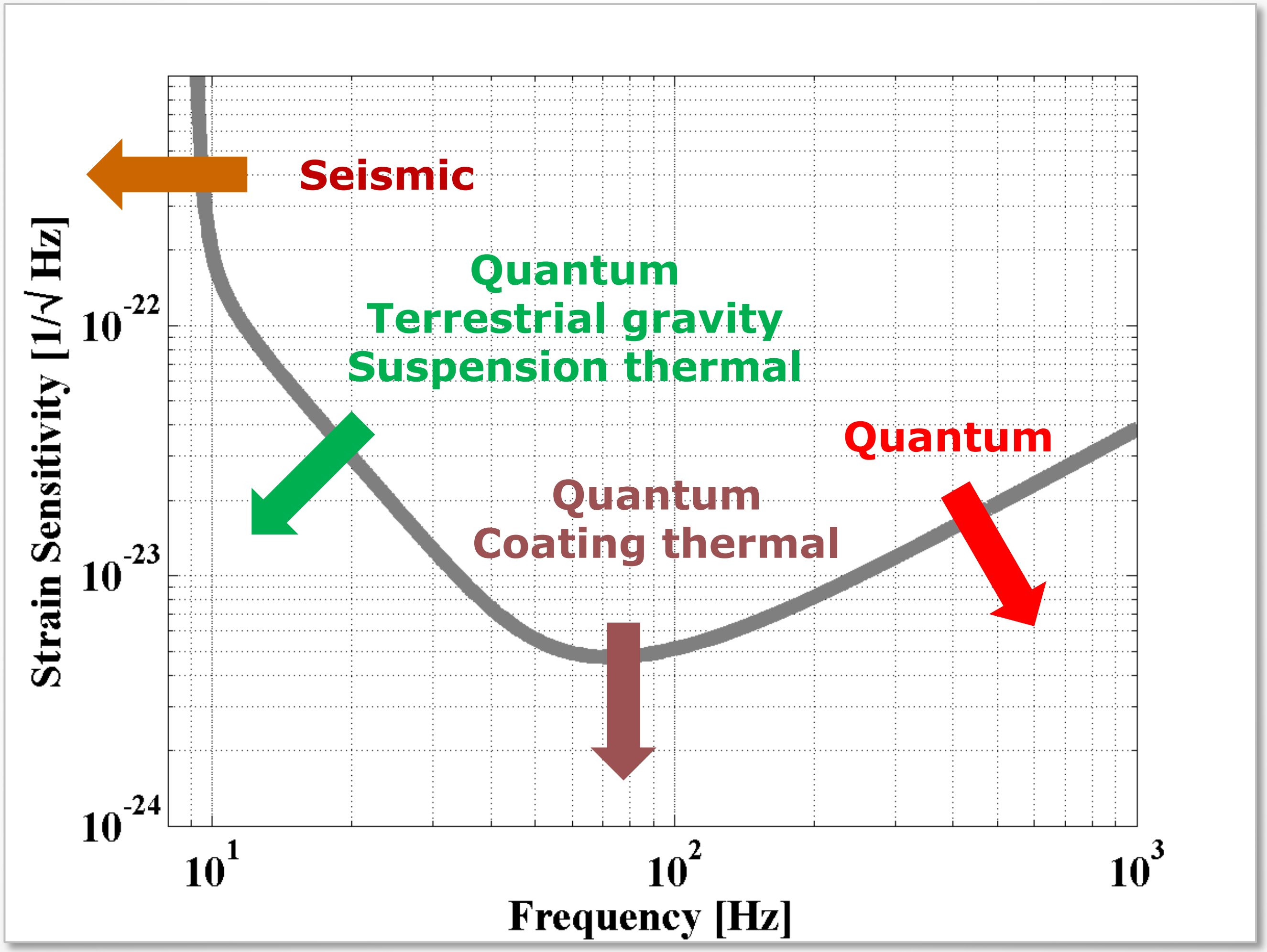


Photo: Venkateswara

Jan Harms
Gran Sasso Science Institute (GSSI)
INFN LNGS

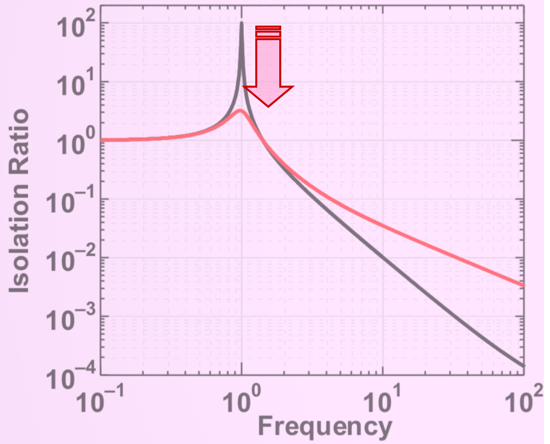
Main Noise Sources



Principles of Seismic Isolation

Damping

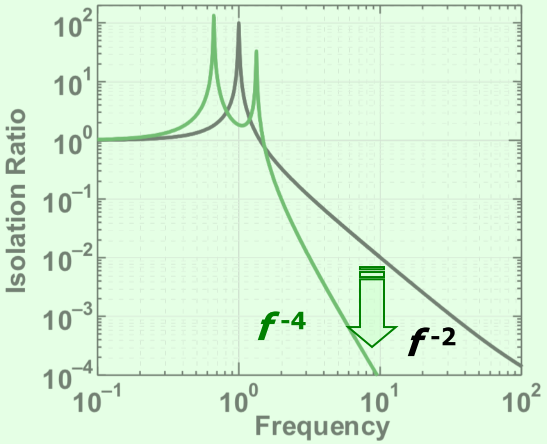
Lower peak height



Less isolation

Cascaded

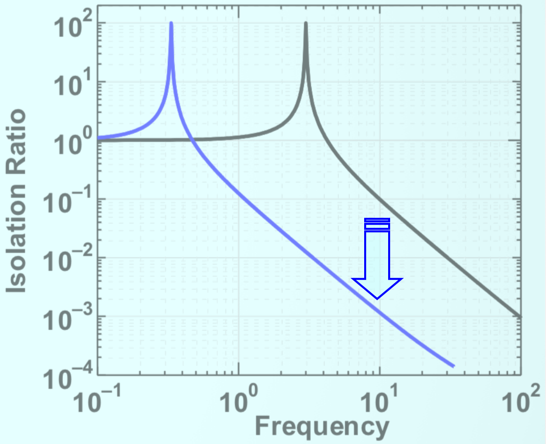
Steeper isolation curve



More peaks

Larger structure

Lower resonance frequency

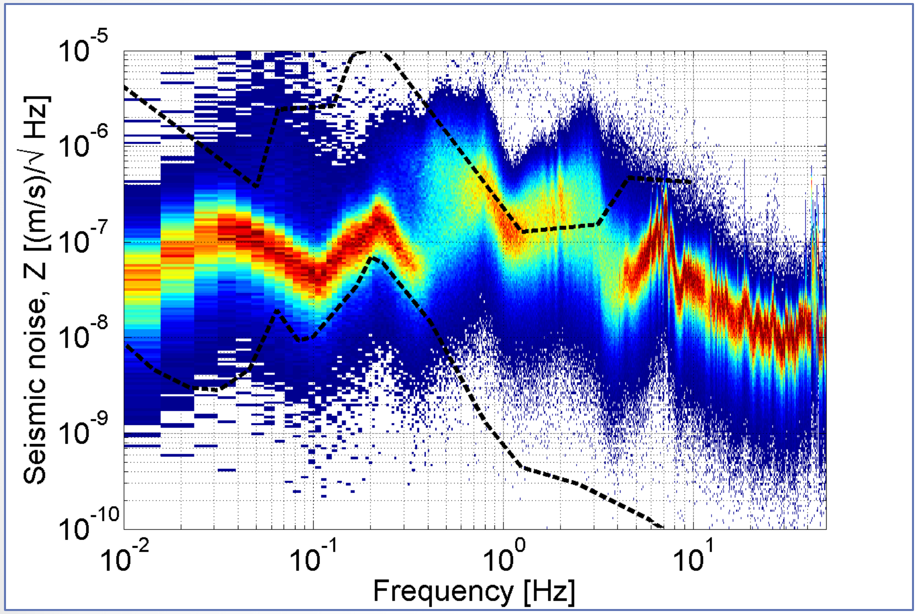


Difficult to realize

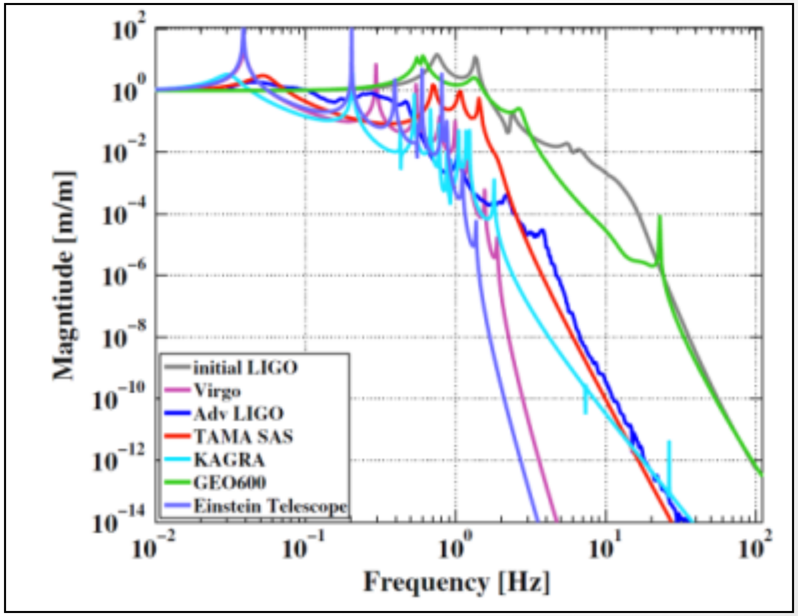
In pratice: use combination of these methods

Seismic Noise

Ground motion at the Virgo site

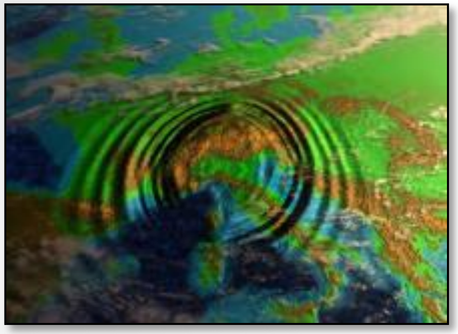


Modelled seismic isolation performance



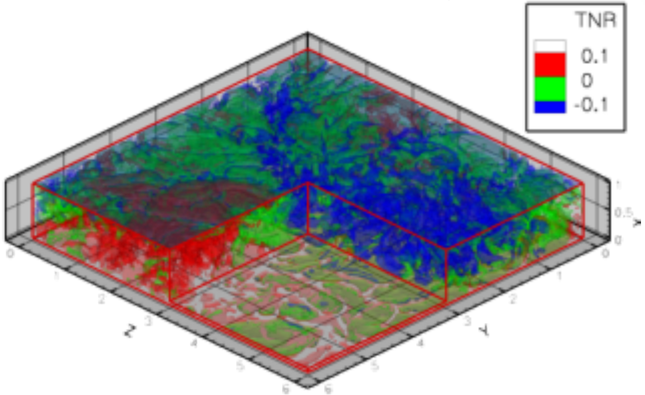
Newtonian Gravitational Noise

Seismic noise



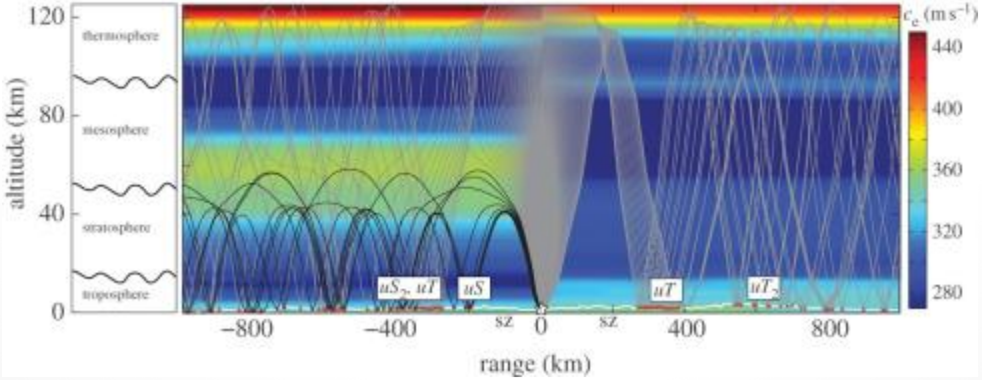
$$\frac{\xi(f)\, e^{-\frac{2\pi f h}{c_{\rm hor}}}}{f^2}$$

Advected temperature fluctuations



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

Infrasound



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

Modelled Sources

Gravity models developed so far are summarized in:

"Terrestrial Gravity Fluctuations"

Effects:

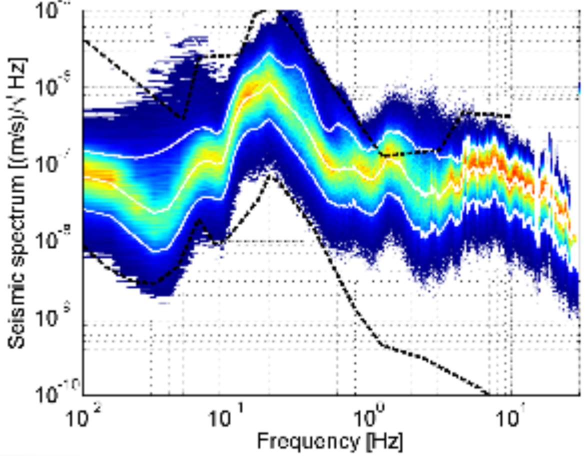
- Reflection of seismic waves from surface (flat or rough)
- Scattering of seismic waves from cavities
- Reflection of infrasound waves from surface (flat or rough)

Sources:

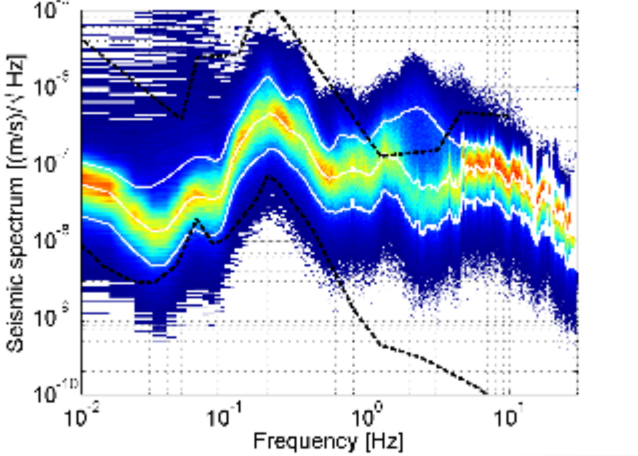
- Seismic fields (surface, body)
- Seismic point sources (force, double couple)
- Lighthill process (turbulent sound generation)
- Advected field of temperature perturbations
- Infrasound field
- Oscillations, translations, rotations of arbitrary bodies
- Shock waves

Site Characterization
Seismic Spectra: LLO

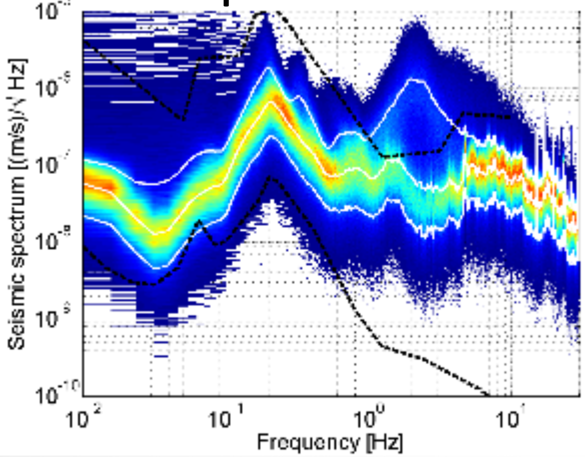
March



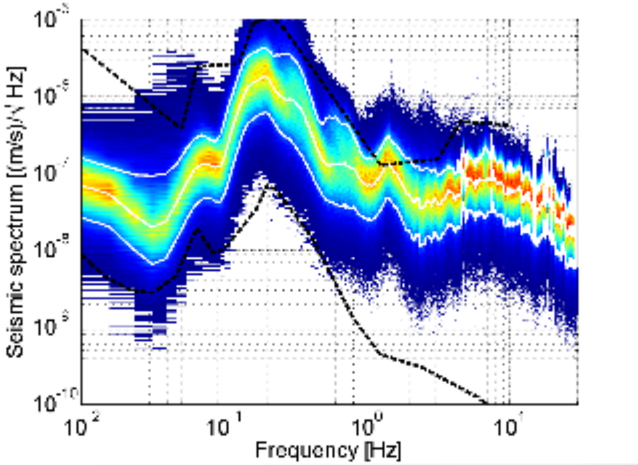
June



September

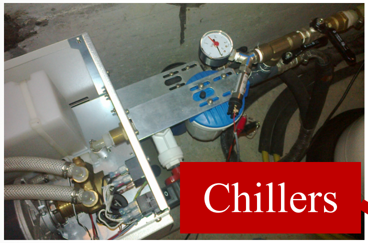


December



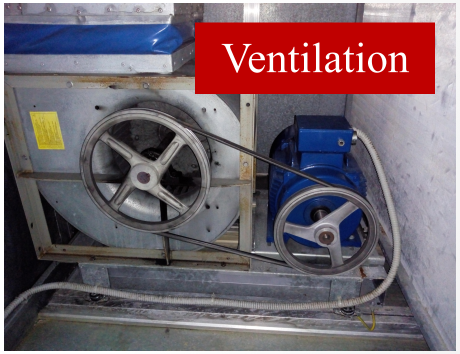
Infrastructure Noise

Excess NN to be avoided
(example: Virgo)



Chillers

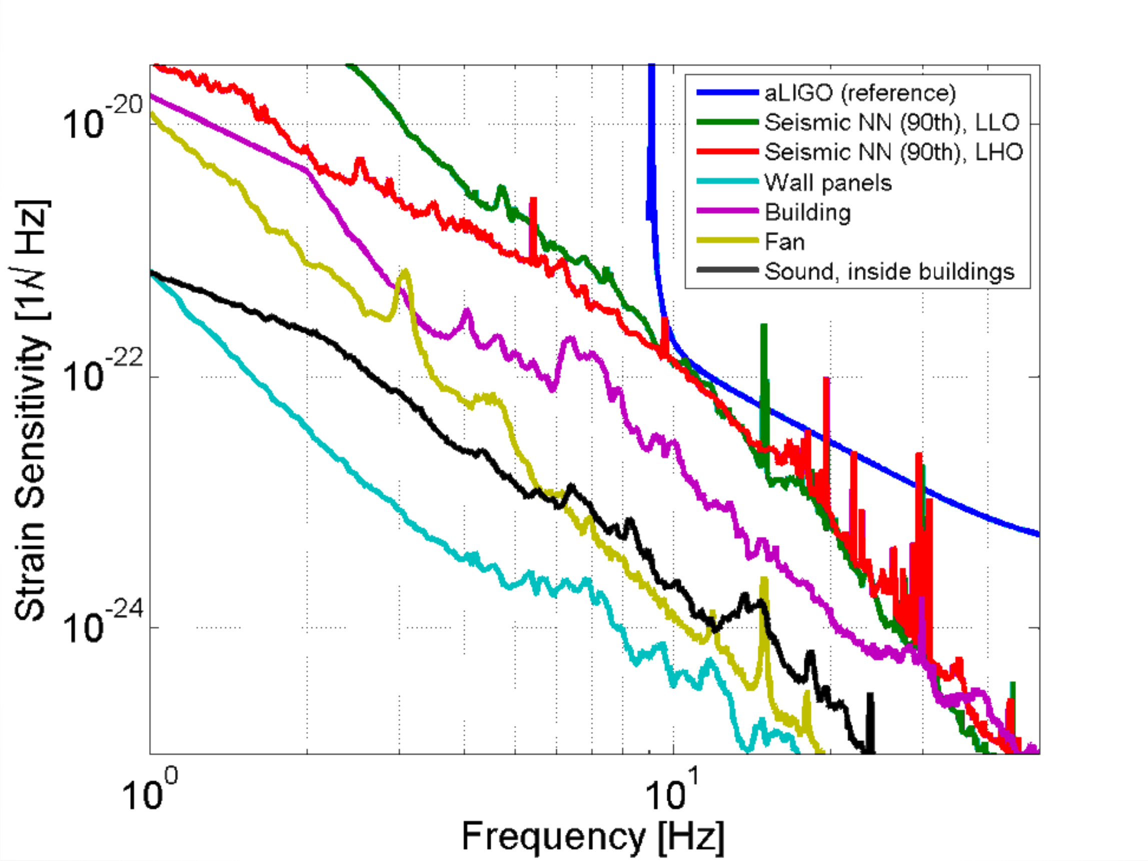
Credit: I Fiori



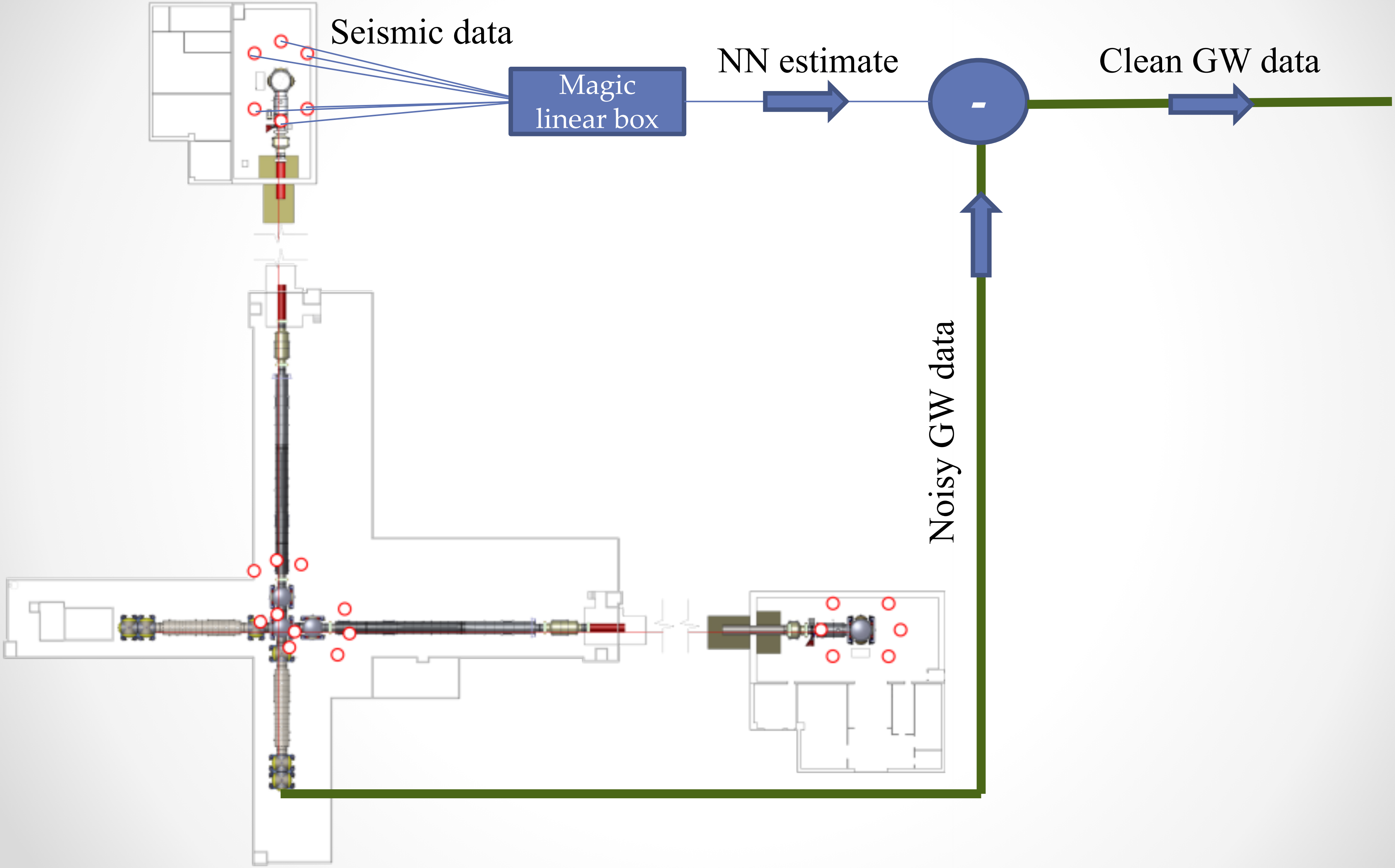
Ventilation

Vacuum pumps

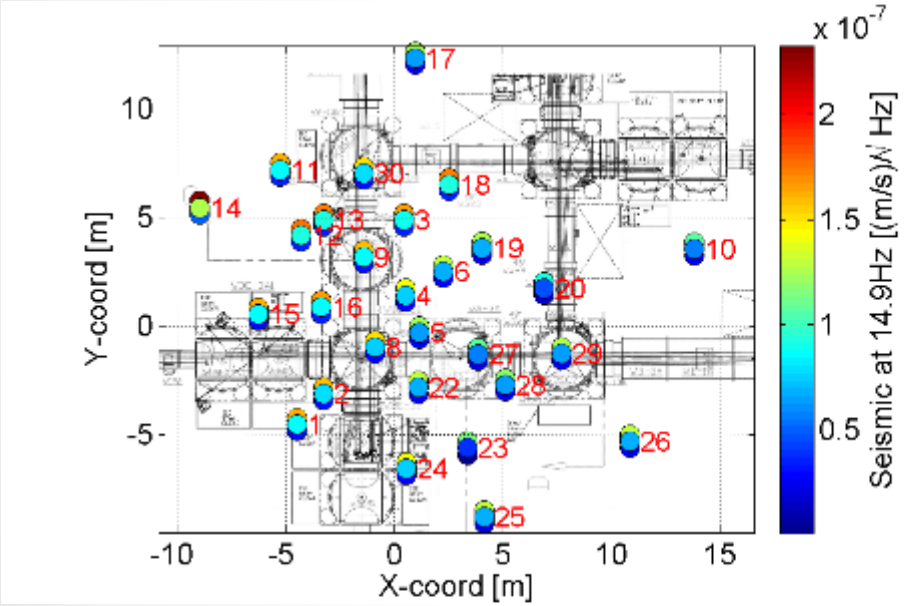
Terrestrial Gravity Noise in LIGO

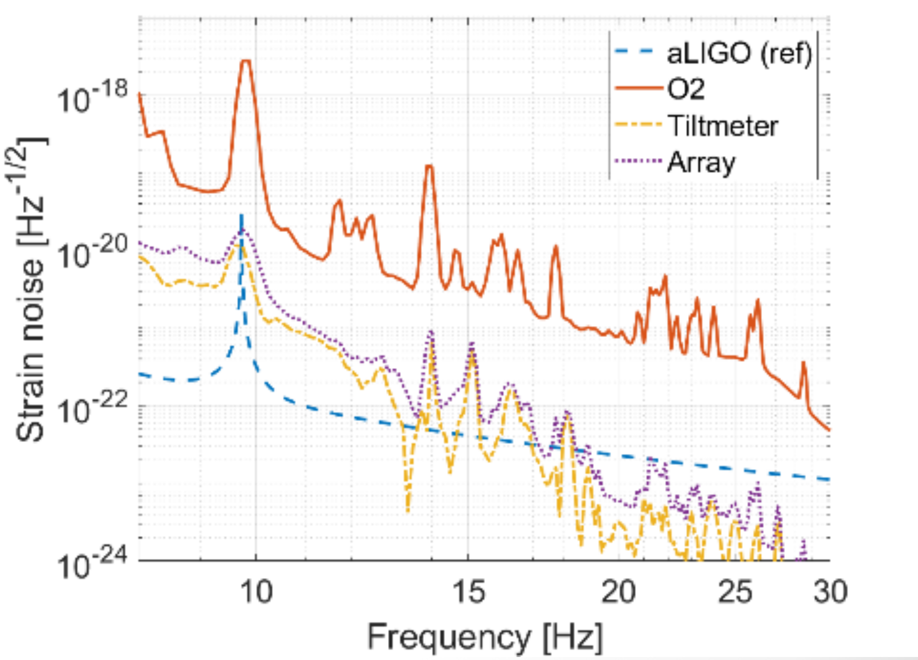


Noise Cancellation

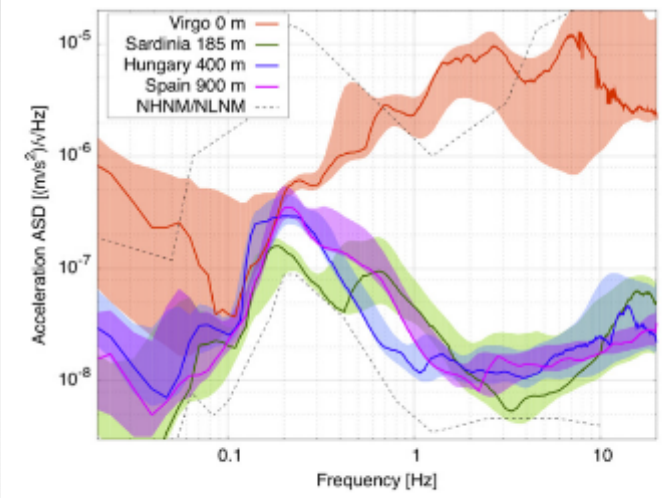


Wiener Filtering at LIGO

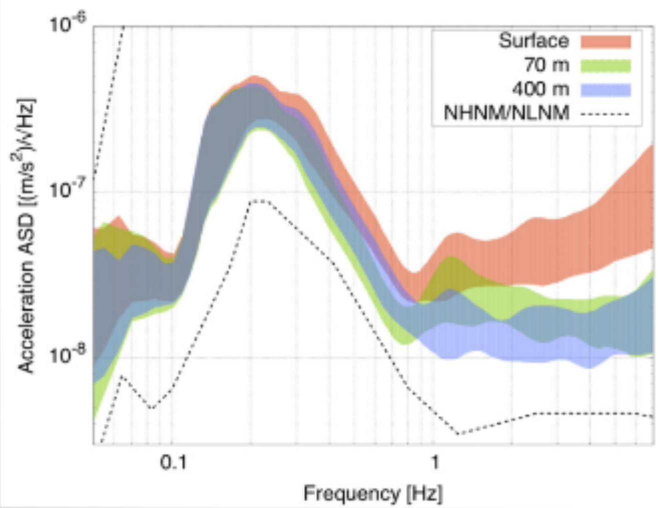




Seismic Spectra



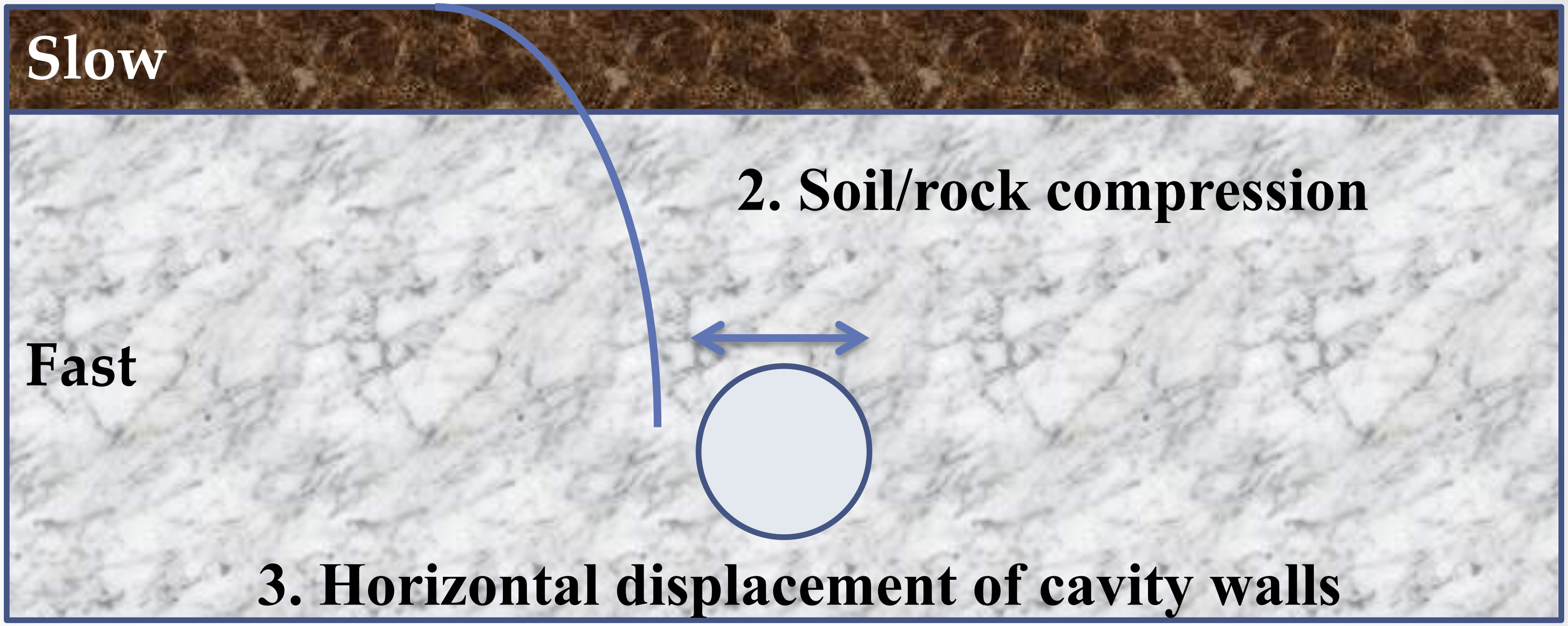
Underground seismic noise orders of magnitude weaker. Note: Virgo seismic noise is mostly infrastructural.



Beker et al, 2015

Observation at the same site: Seismic noise above 1Hz significantly reduced (suppression with depth is site dependent).

Rayleigh NN



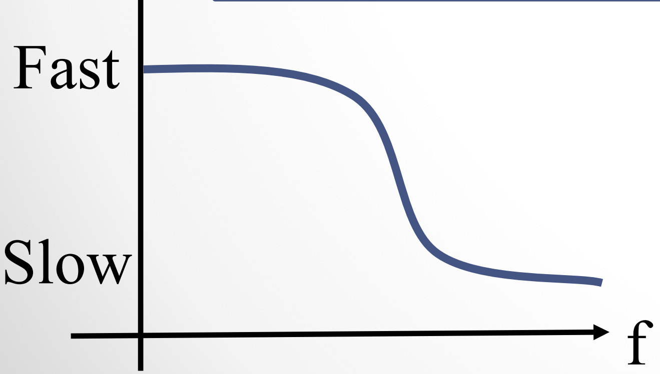
1. Vertical surface displacement

Slow

2. Soil/rock compression

Fast

3. Horizontal displacement of cavity walls



A Rayleigh NN model requires:

1) Spectrum of vertical surface displacement
2) Dispersion curve
3) Density estimates for near surface soil and rock around the cavern

Length Scales

1) Depth

2) Reduced wavelengths

   a) $1/k$ (reduced Rayleigh wavelength)
   b) $(1/k^2 - 1/k_P^2)^{1/2}$ (inh. vertical compressional wavelength)
   c) $(1/k^2 - 1/k_S^2)^{1/2}$ (inh. vertical shear wavelength)

$$\exp(-\kappa \cdot d)$$

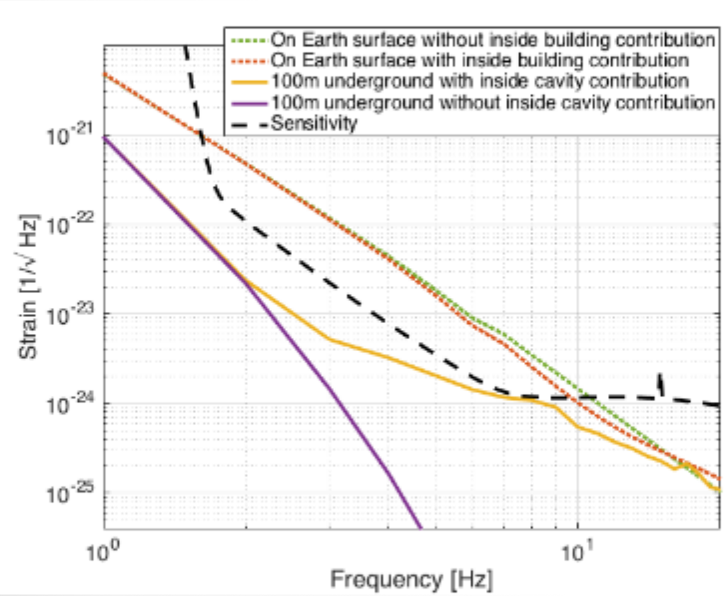
Gravity Noise Reduction Underground

Two examples

Gravity noise from sound waves

$$\delta\phi(\vec{r}_0,t) = 4\pi\frac{G\rho_0}{\gamma\, p_0}\mathrm{e}^{\mathrm{i}(\omega t-\vec{k}_\varrho\cdot\vec{\varrho}_0)}\boxed{\mathrm{e}^{-k_\varrho|z_0|}}\frac{\delta p(\omega)}{k^2}$$

Exponential suppression

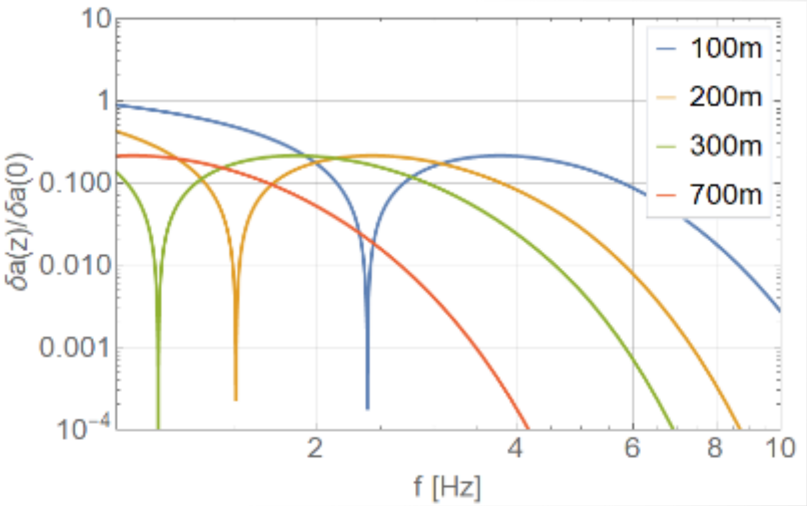


Gravity noise from Rayleigh waves

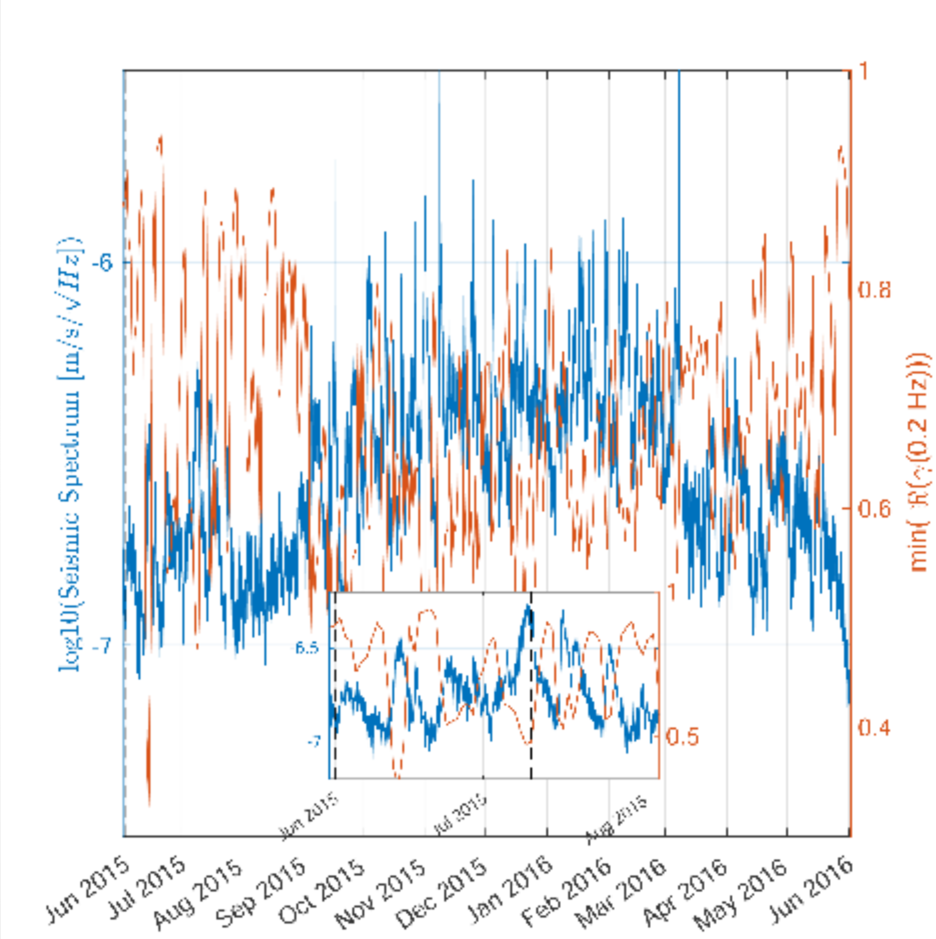
$$\delta\phi_{\mathrm{surf}}(\vec{r}_0,t)+\delta\phi_{\mathrm{bulk}}(\vec{r}_0,t) =$$
$$2\pi G\rho_0 A\mathrm{e}^{\mathrm{i}(\vec{k}_\varrho\cdot\vec{\varrho}_0-\omega t)}\left(\boxed{-2\mathrm{e}^{-hq_z^{\mathrm{P}}}}+(1+\zeta(k_\varrho))\boxed{\mathrm{e}^{-hk_\varrho}}\right)$$

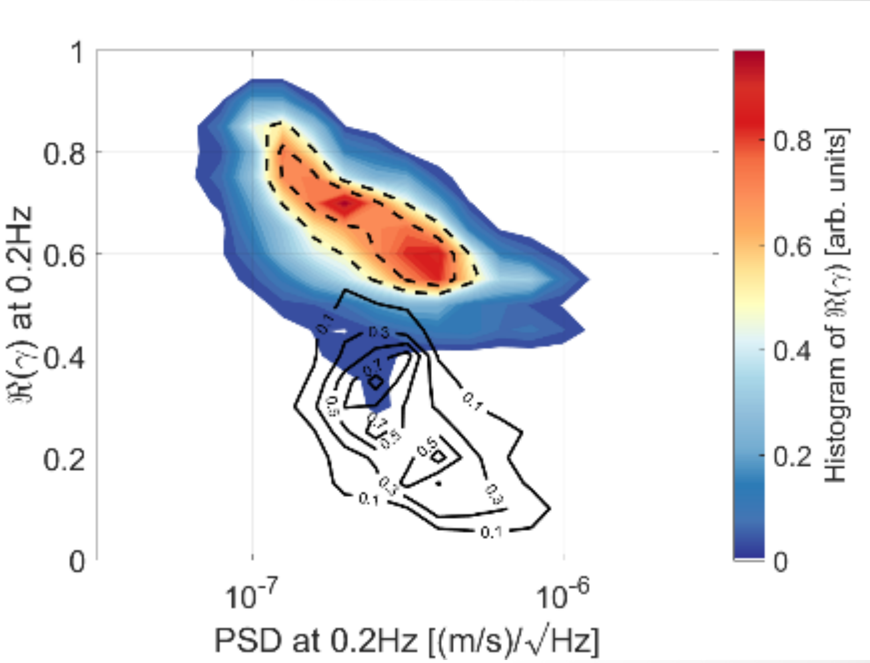
Evanescent wave

Surface displacement



Oceanic Microseisms

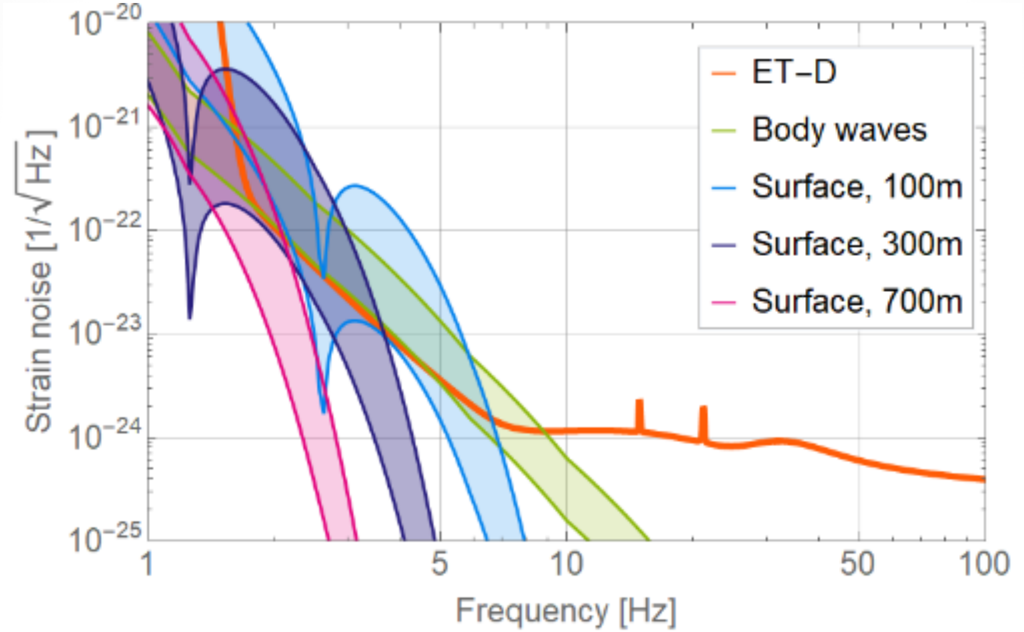




Suggested explanation:

1) When oceanic microseisms are strong, then the sources are relatively close and Rayleigh waves dominate
2) If microseisms are near the low-noise model, then many distant sources contribute and body waves dominate

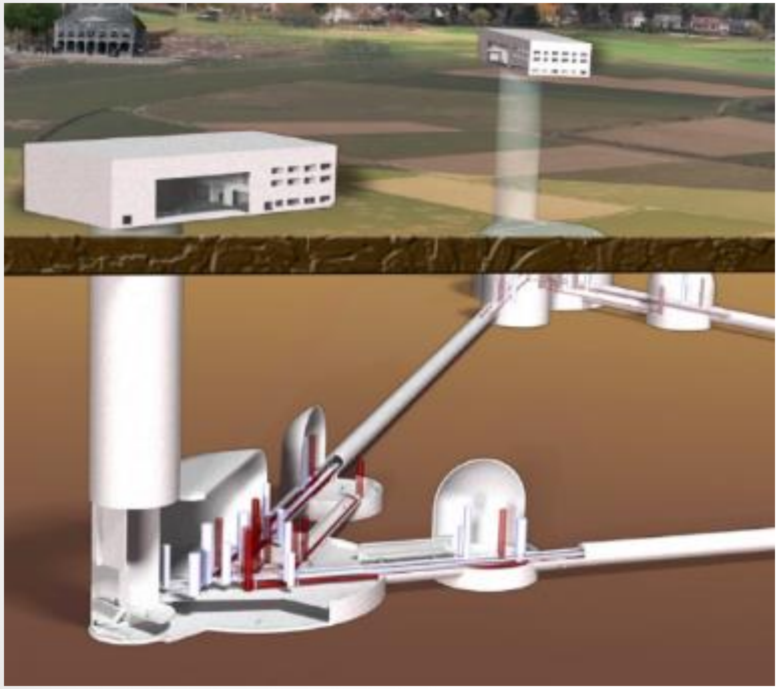
Seismic NN



Rayleigh dispersion model:
1.8km/s @ 1Hz, 750m/s @ 5Hz,
450m/s @ 10Hz

Seismic models:
Body wave: 3x – 12x LNM
Surface: 50x – 1000x LNM

Underground Sources



Under investigation:

- How much does detector infrastructure elevate underground seismic noise?
- Do air currents from ventilation produce significant gravity noise?
- How far from test masses do we need to keep water accumulation?

Water NN

Full dimension:

1) Capilary / gravity waves
2) Transportation
3) Compression / sound

Localized perturbation:

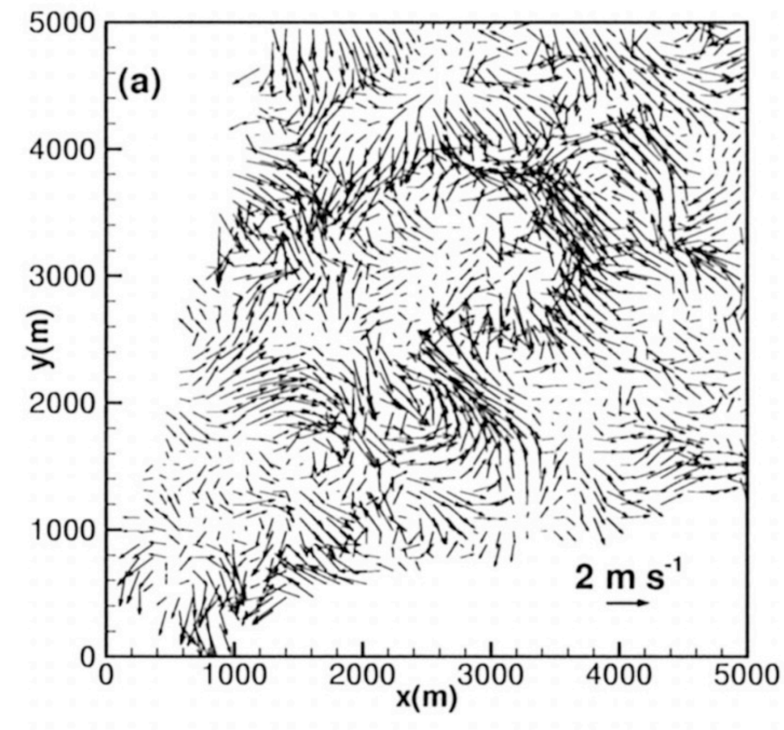
4) Vortices / turbulence
5) Channel-floor to water-surface interaction
6) Flow around obstacles

Water flow and waves are both too slow for (1) – (3) to matter (exponential cut-off at very low frequencies), even if the water flows closely to the test mass.

Perturbation produced by vortices and other structures included in (4) – (6) in the NN band are supported by small water volumes and associated NN is very likely insignificant, but one should look at this more carefully.

Atmospheric Tomography

Volumetric Doppler scans with LIDAR



Chai et al, 2004

Current LIDAR systems are able to monitor, among others, wind speeds, and temperature or humidity fields.

In principle, technology is ready to cancel atmospheric NN from advection.

LIDAR is not sensitive enough yet (by some orders of magnitude) to sense pressure fluctuations.