# NEWTONIAN NOISE CANCELLATION

Photo: Venkateswara


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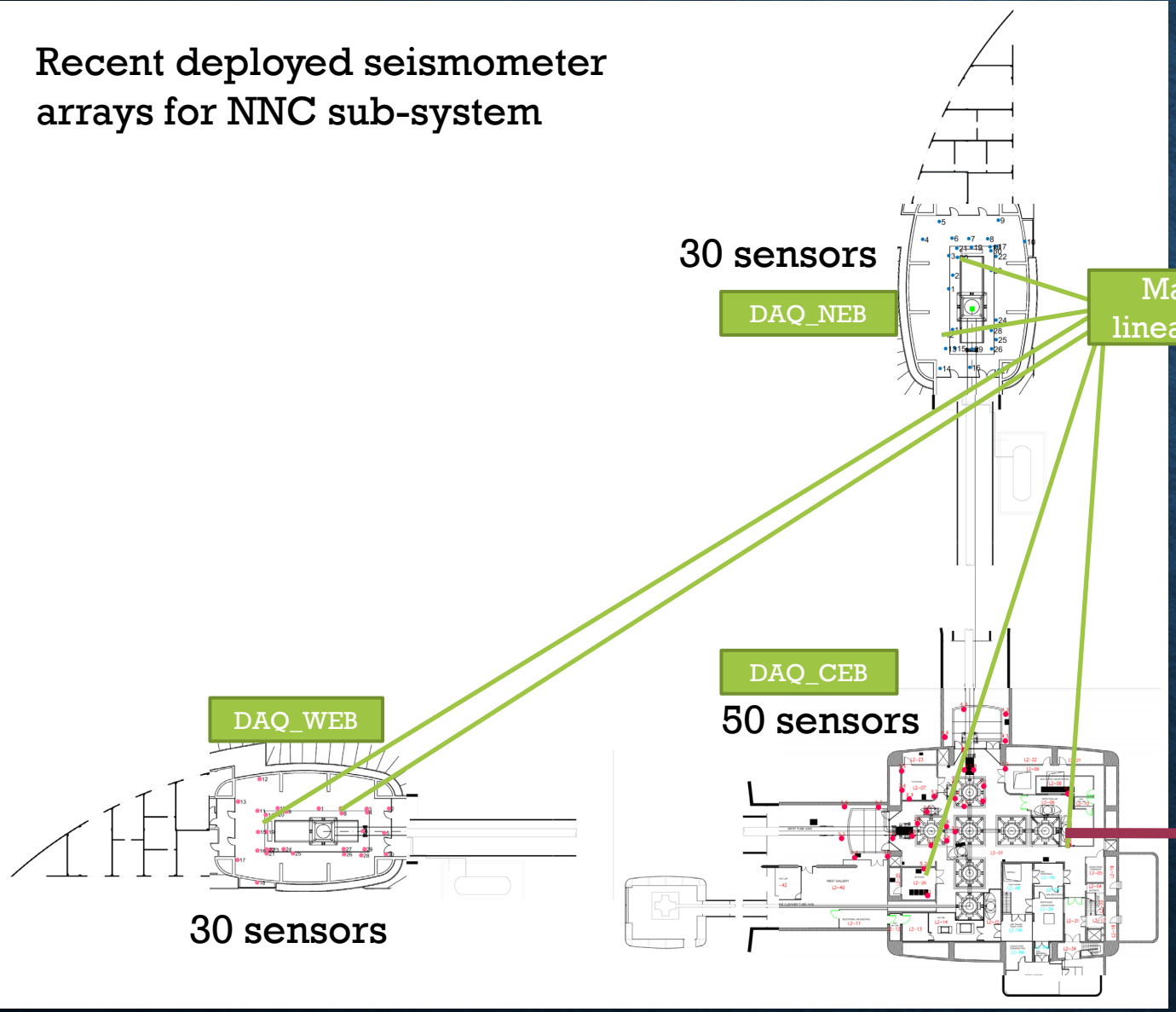
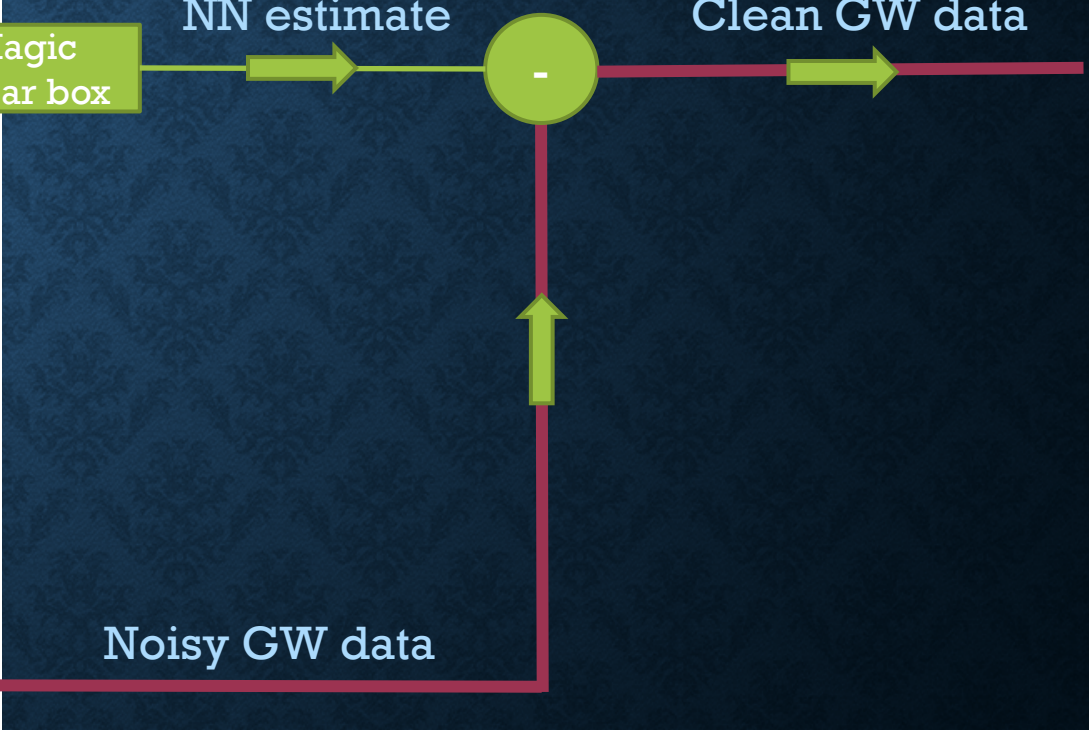
# NN CANCELLATION AT VIRGO

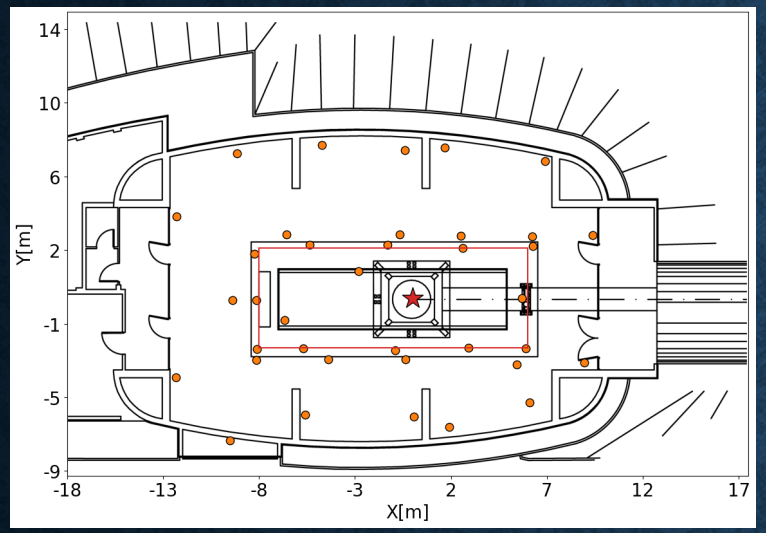
Recent deployed seismometer arrays for NNC sub-system



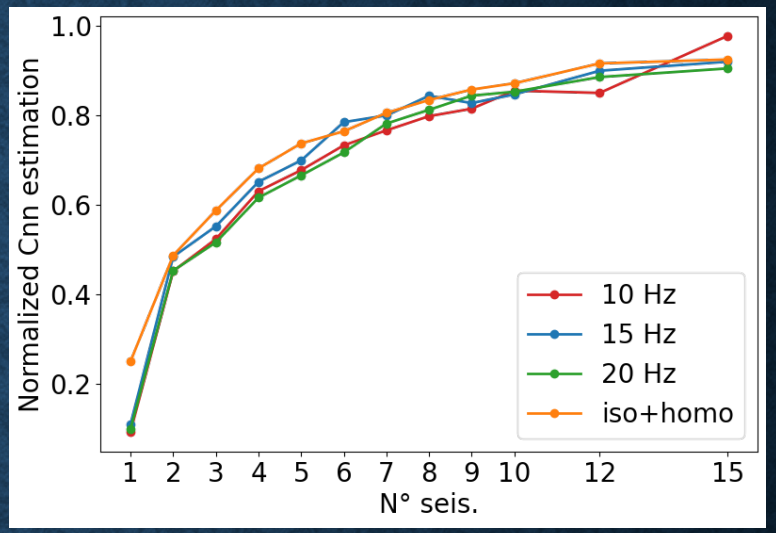



# ARRAY OPTIMIZATION

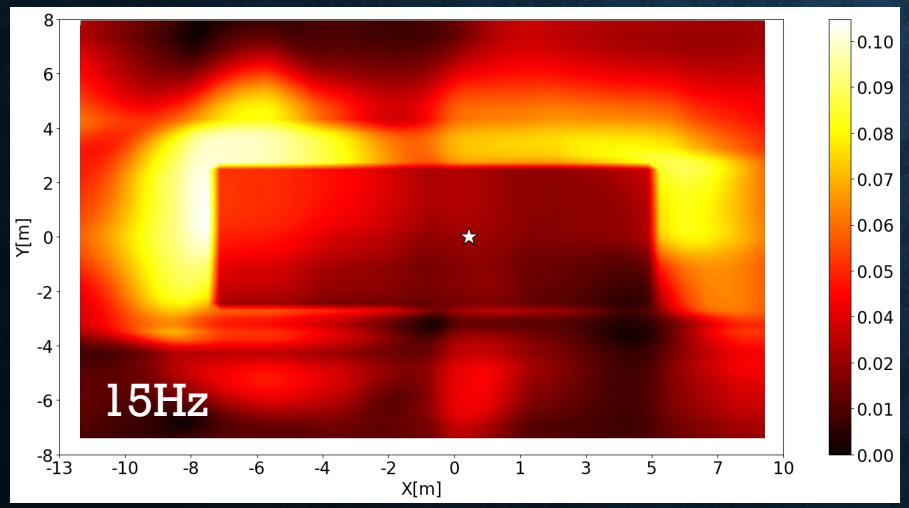
## (1) Site characterization




## (3) Performance prediction

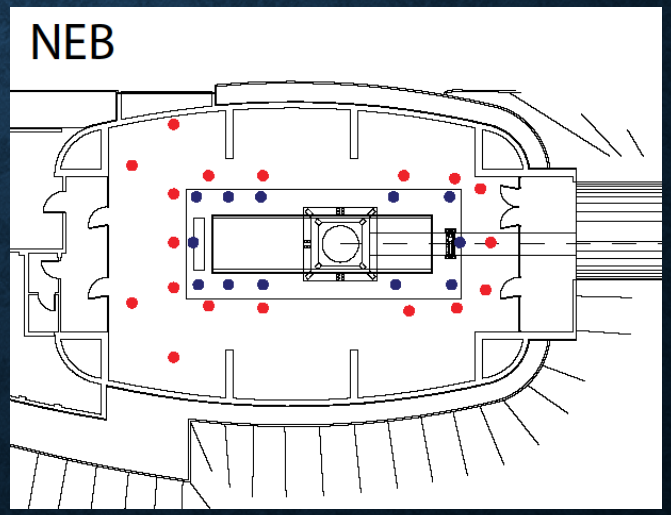



## (2) Optimal seismometer placement

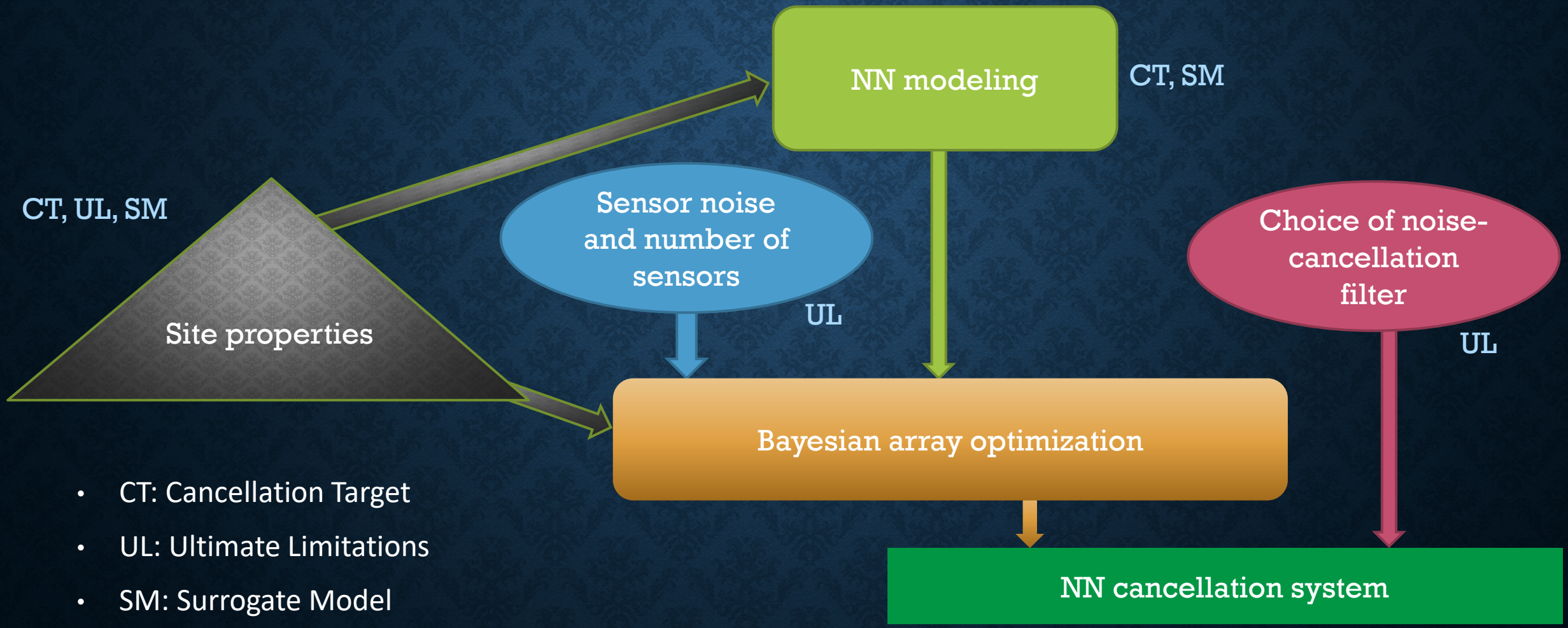



Badaracco et al (2020)

## (4) Final array configuration at Virgo



# DESIGN ELEMENTS OF A NN CANCELLATION SYSTEM




- CT: Cancellation Target
- UL: Ultimate Limitations
- SM: Surrogate Model

# FIR WIENER FILTER

Wiener filter
(FIR order M)

$$\begin{bmatrix} R_{yy}(0) & R_{yy}(1) & R_{yy}(2) & \cdots & R_{yy}(M) \\ R_{yy}(1) & R_{yy}(0) & R_{yy}(1) & \cdots & R_{yy}(M-1) \\ R_{yy}(2) & R_{yy}(1) & R_{yy}(0) & \cdots & R_{yy}(M-2) \\ \vdots & \vdots & \vdots & & \vdots \\ R_{yy}(M) & R_{yy}(M-1) & R_{yy}(M-2) & \cdots & R_{yy}(0) \end{bmatrix} \begin{bmatrix} h(0) \\ h(1) \\ h(2) \\ \vdots \\ h(M) \end{bmatrix} = \begin{bmatrix} R_{xy}(0) \\ R_{xy}(1) \\ R_{xy}(2) \\ \vdots \\ R_{xy}(M) \end{bmatrix}$$

Seismometer correlation matrix

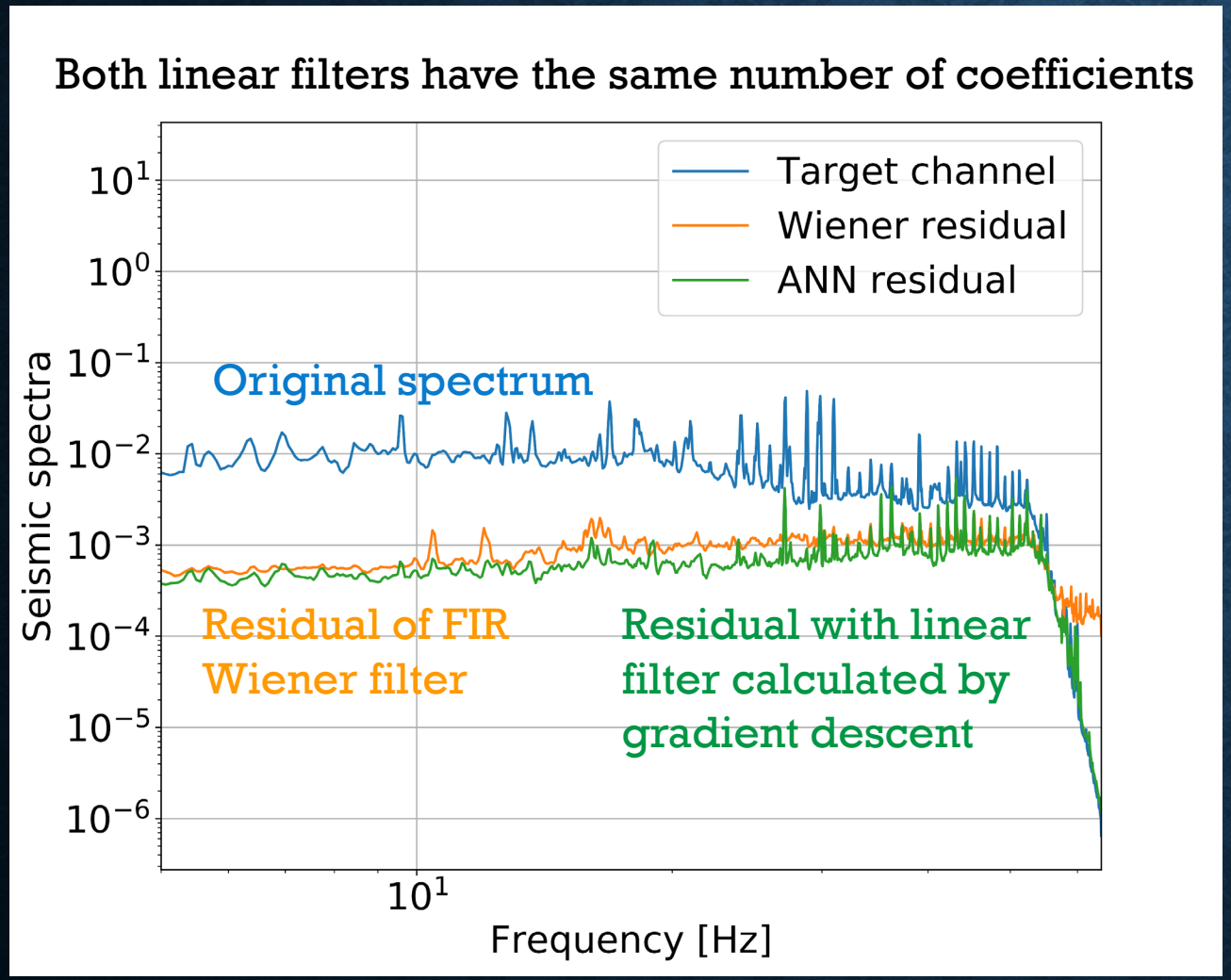
Correlations between seismometer and GW data

- Requires a huge number (millions) of correlation estimates.
- Leads to accumulation of high statistical errors in the estimate of the Wiener filter

**Novel filter designs:**

- Optimized linear-filter designs (gradient descent)
- Kalman filter
- Non-linear filter

# OPTIMAL LINEAR FILTERING

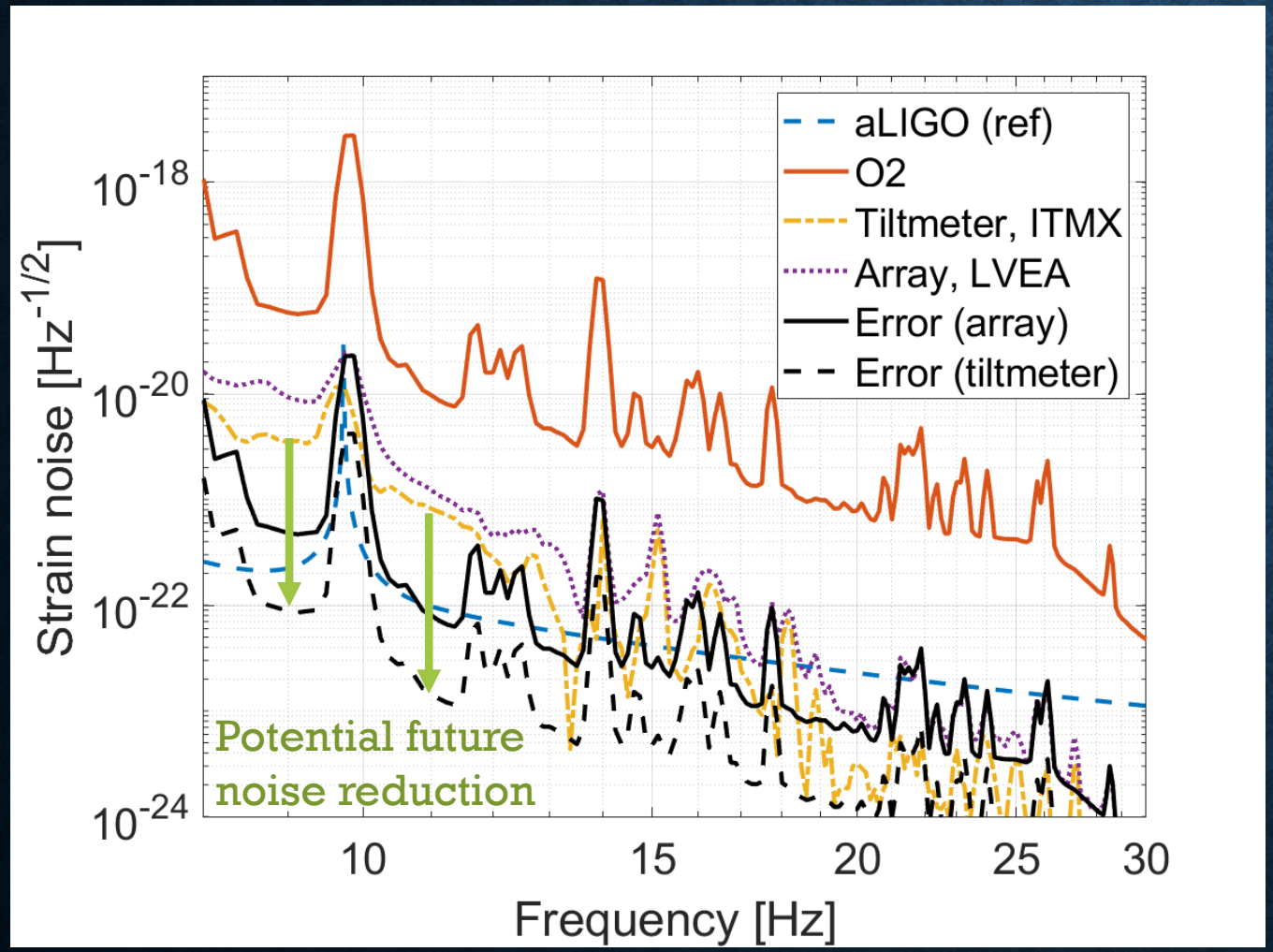



**Rumors**: Wiener filter is the optimal linear filter for the cancellation of stationary noise.

**Reality**: It depends on details. Statistical errors can limit cancellation performance. Filter optimization can be made less susceptible to statistical errors, e.g., using gradient descent.

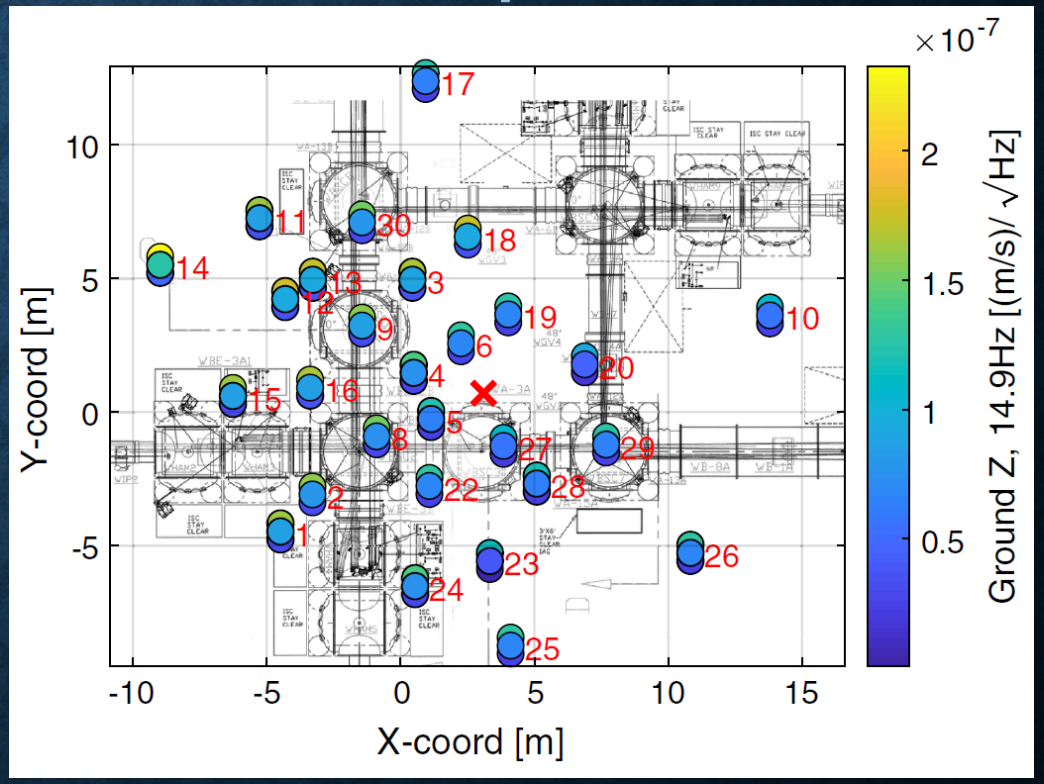
# THE LIGO HANFORD NN EXPERIMENT

Wiener filter to h(t) noise projection
(several months of data for correlation required)



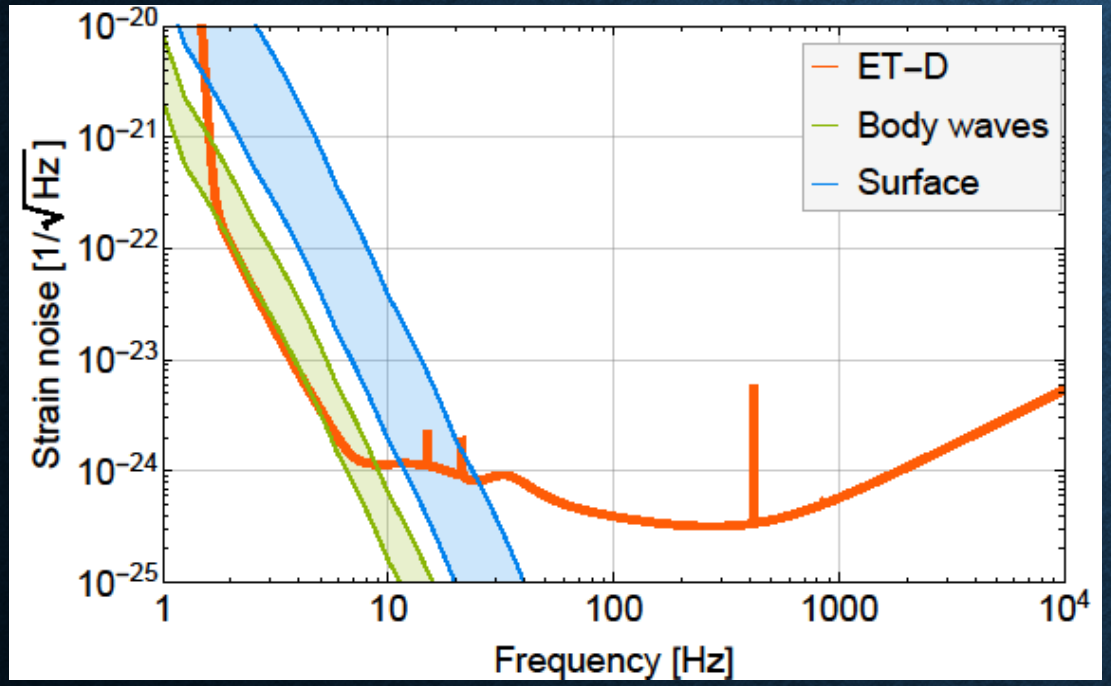

Harms et al (2020)

Hanford array in 2016/17

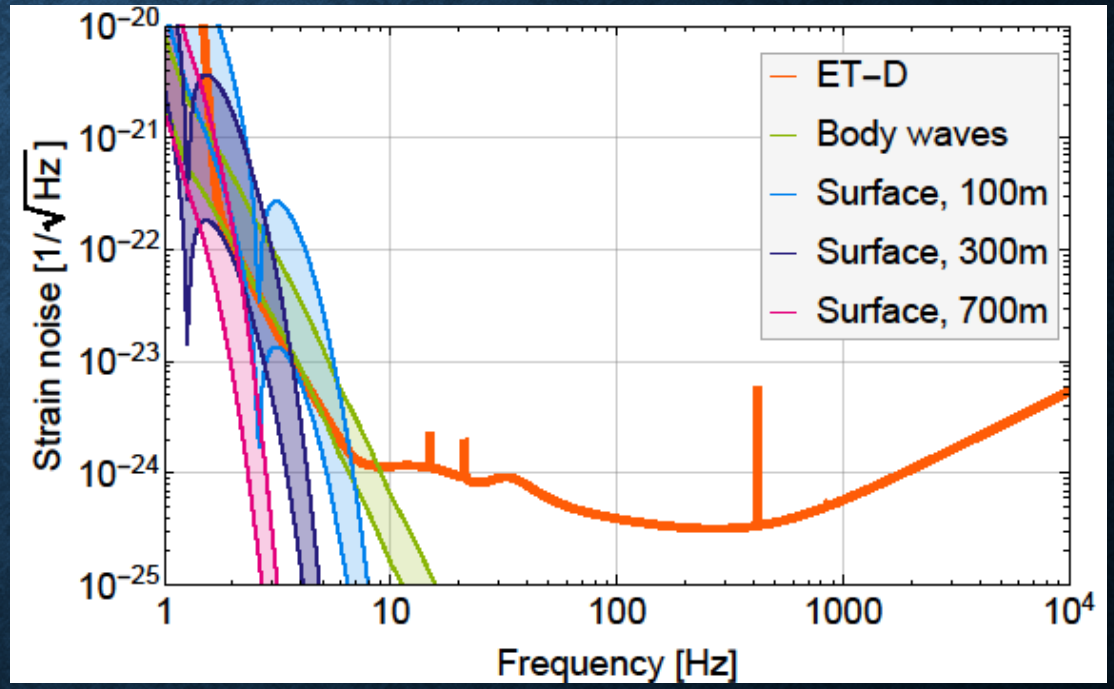


# ET NEWTONIAN-NOISE MODELS

Seismic NN
if ET where built at the surface



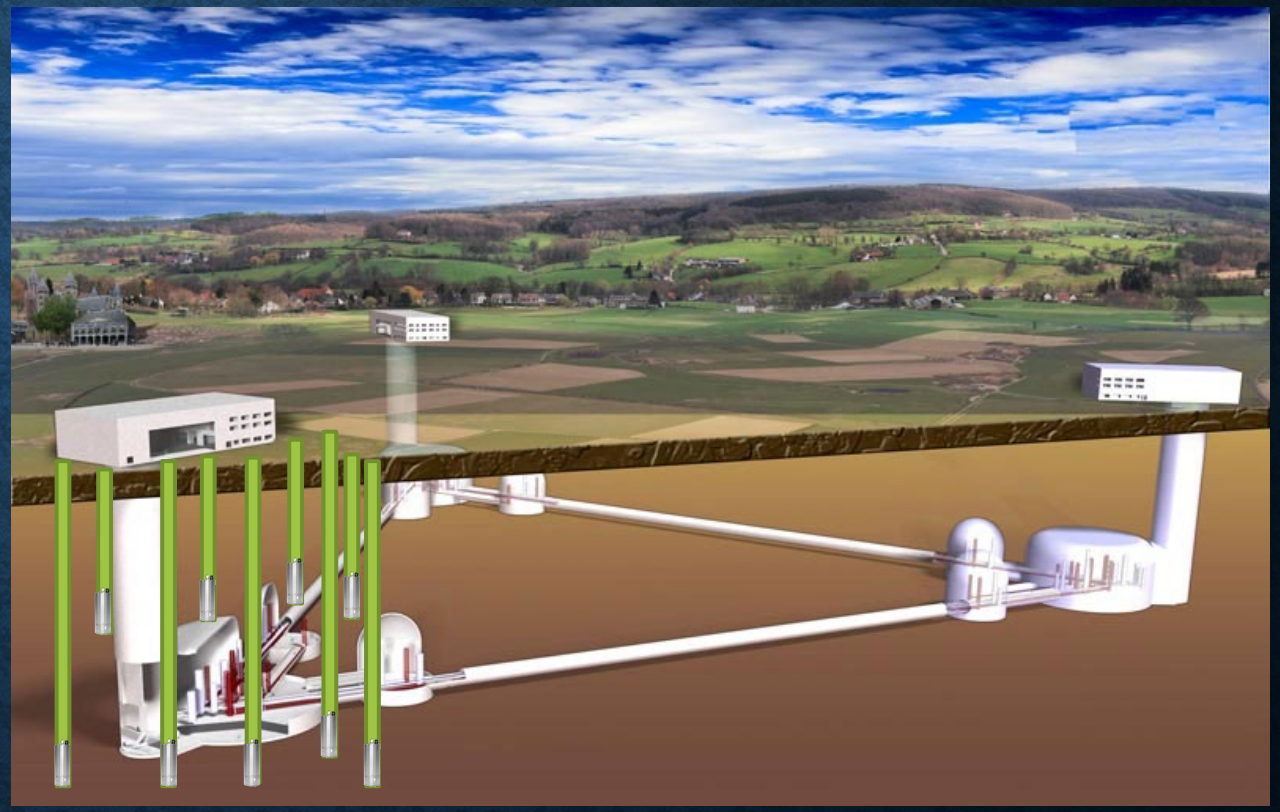

Seismic NN
underground




Badaracco/Harms (2019)

# ET NN CANCELLATION

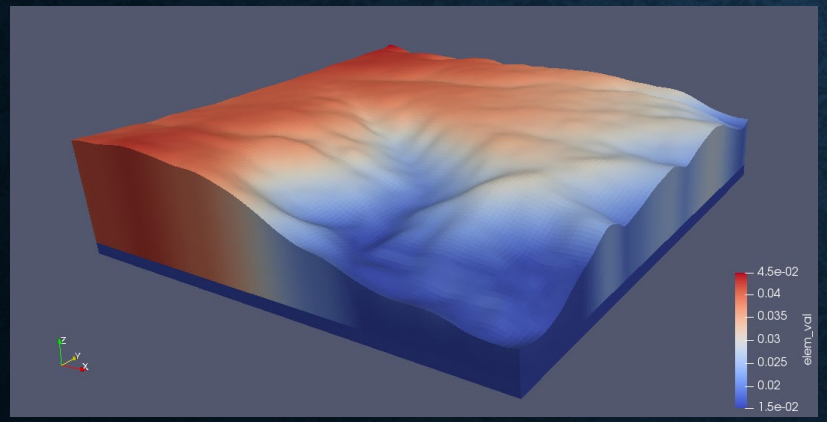
- Deploy borehole seismometers around the test masses (24 test masses in total of which 12 couple significantly to gravitational fluctuations).
- Horizontal boring and seismometer deployment, and deployment of several seismic sensors per borehole could greatly reduce cost of such a system.



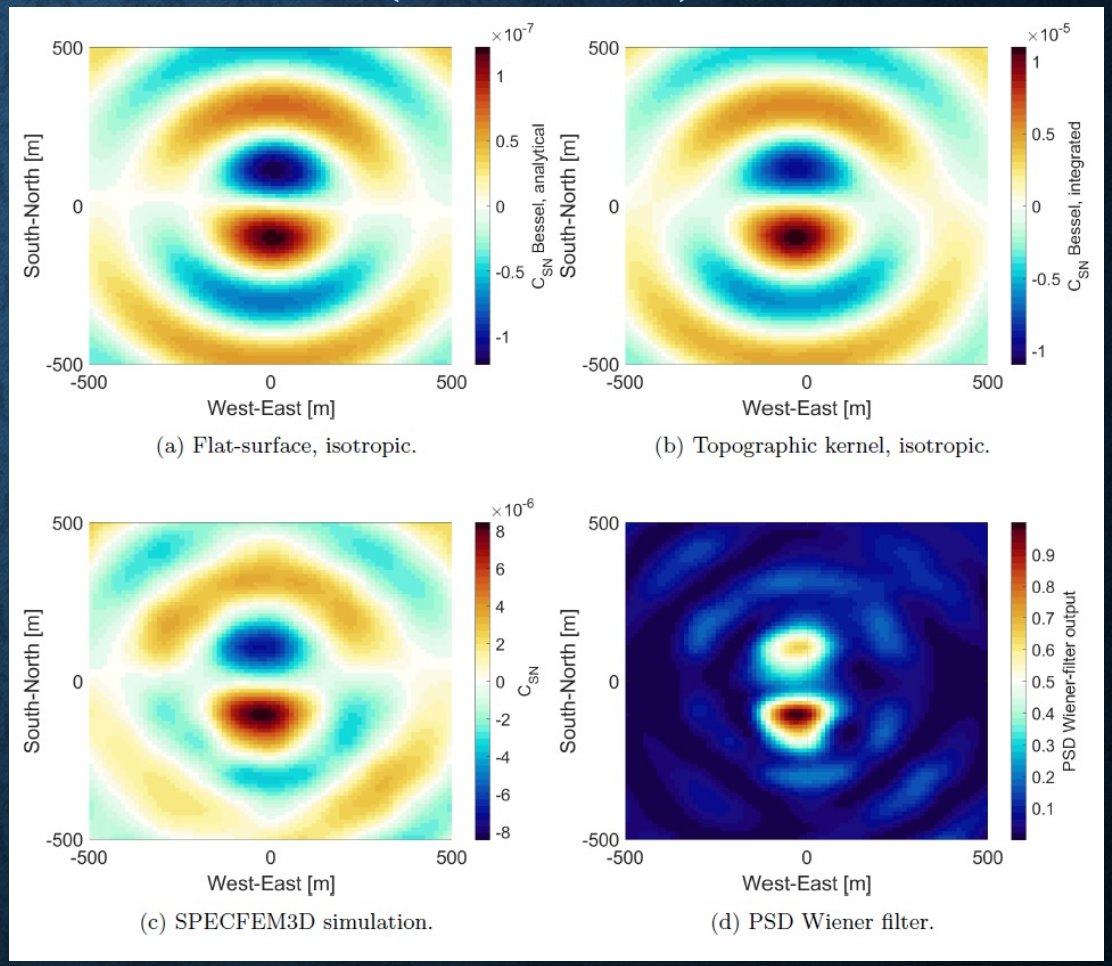
# NUMERICAL NN SIMULATIONS

## Two candidate sites


## A vertex location at Sardina candidate site



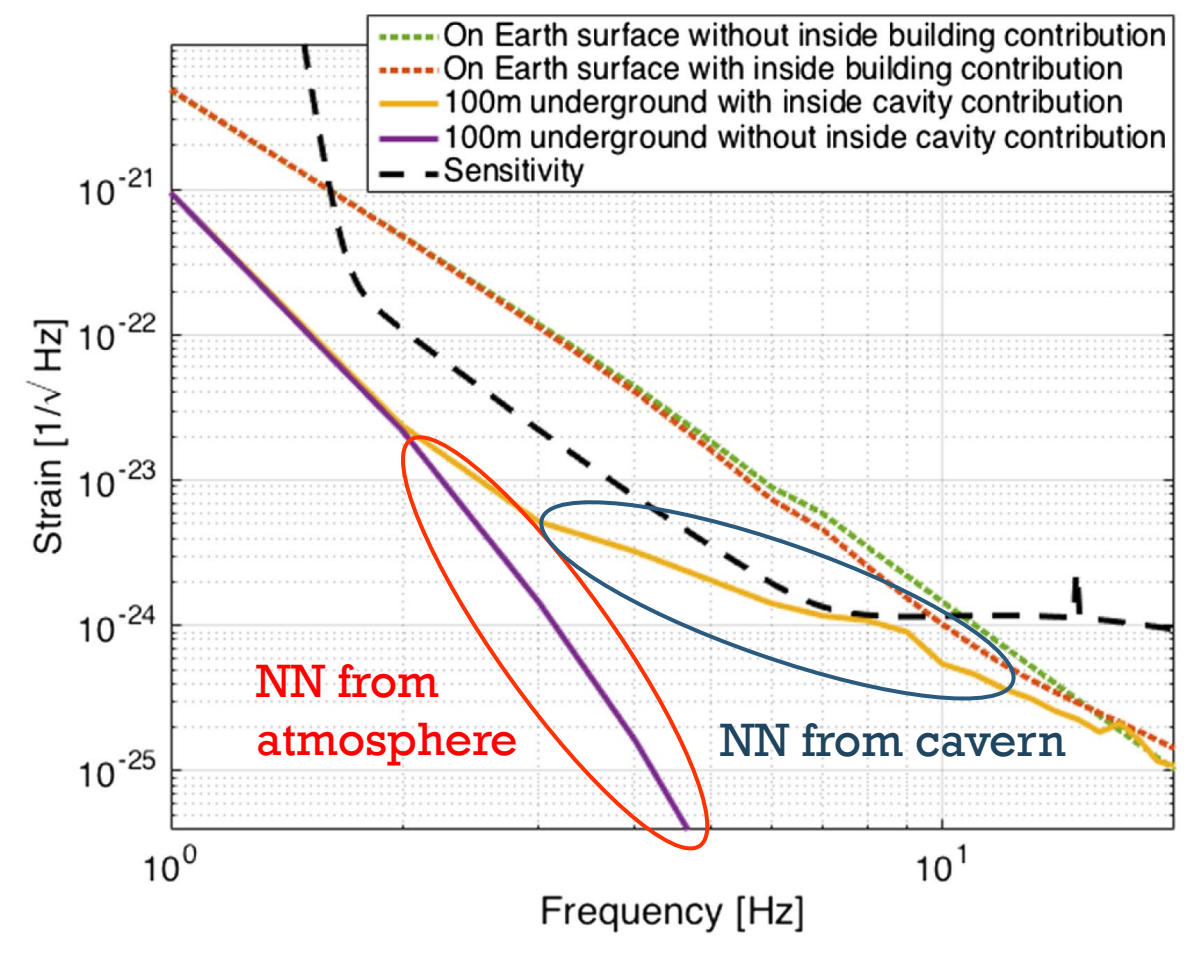

## Gravitoelastic correlations and Wiener filter (SPECFEM3D)




Andric/Harms (2020)

# EXTRA SLIDES

# ACOUSTIC NN



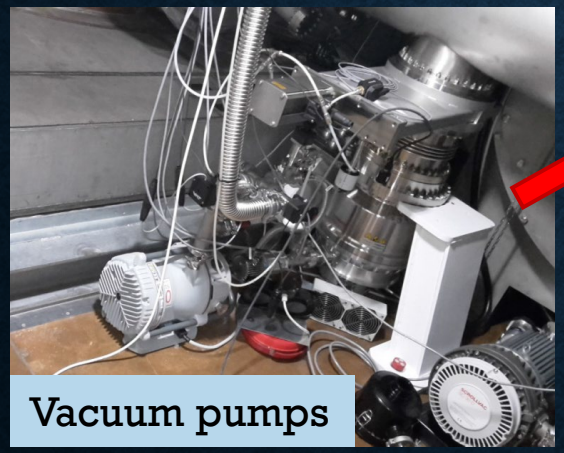

Fiorucci et al (2016)

- Already at 100m depth, if the site is sufficiently remote with low acoustic noise, ET is not limited by atm, acoustic NN anymore
- Acoustic NN originating from the caverns will likely require cancellation.

# INFRASTRUCTURE NOISE

## Excess NN to be avoided
(example: Virgo)

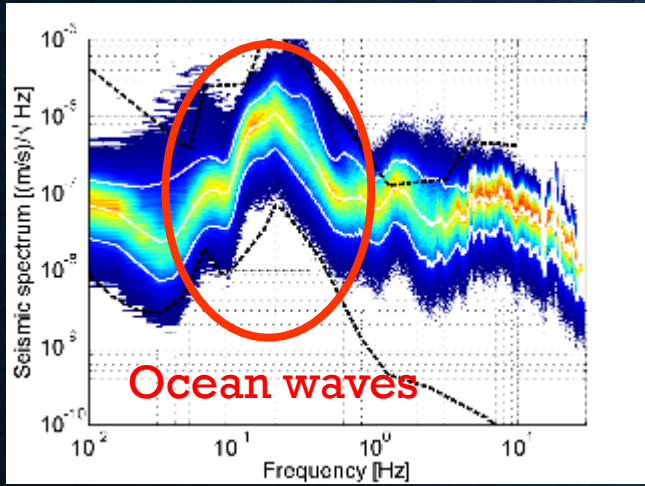




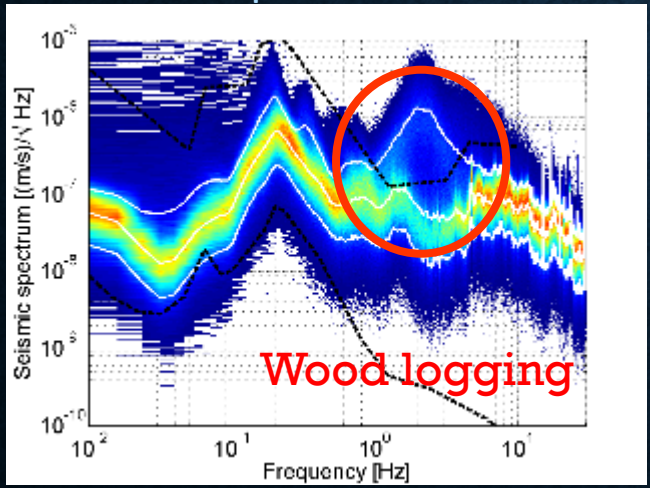

Credit: I Fiori

# SEISMIC FIELDS

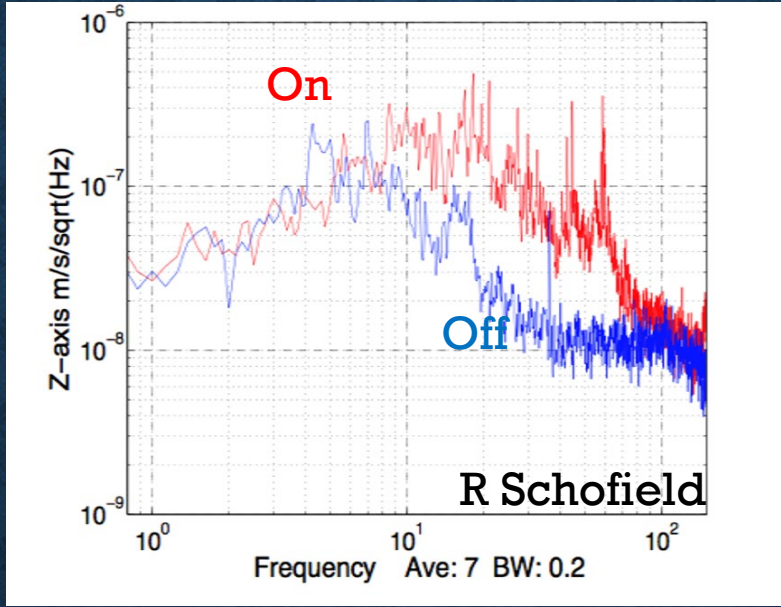
LIGO Livingston
March




September

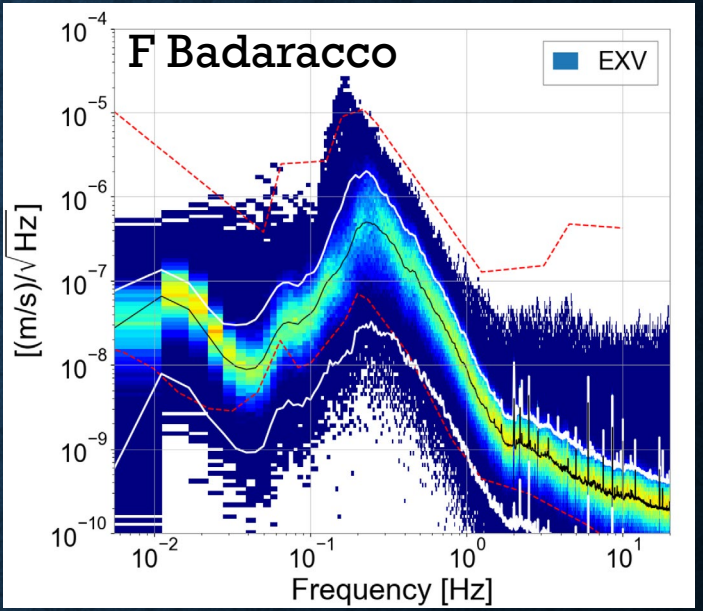



LIGO Hanford
Power outage




Local (mostly infrastructural) seismic sources produce dominant perturbations above a few Hz at LIGO/Virgo

KAGRA




KAGRA has managed to preserve an almost prestine environment below 20Hz (infrastructure produces excess noise above 20Hz)