Newtonian Noise

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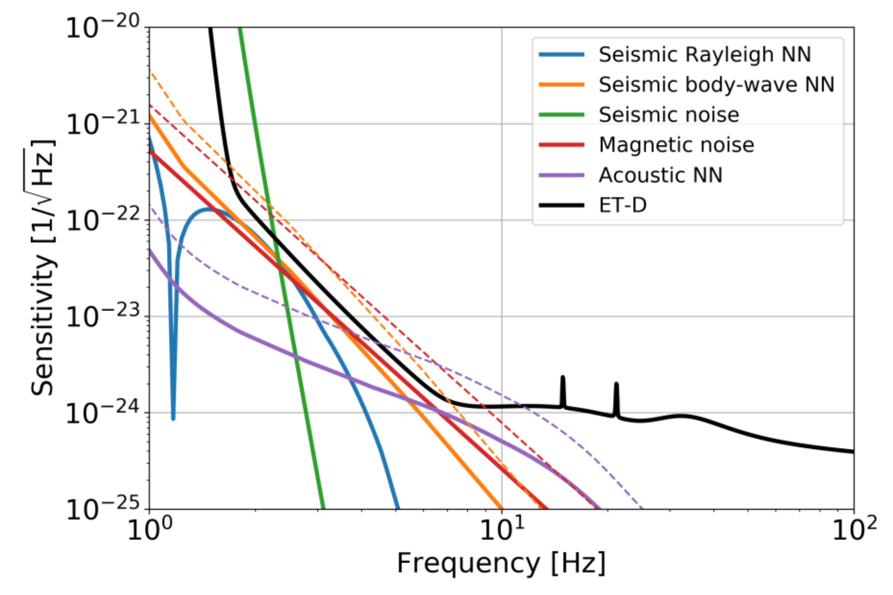
Characteristics of Newtonian noise

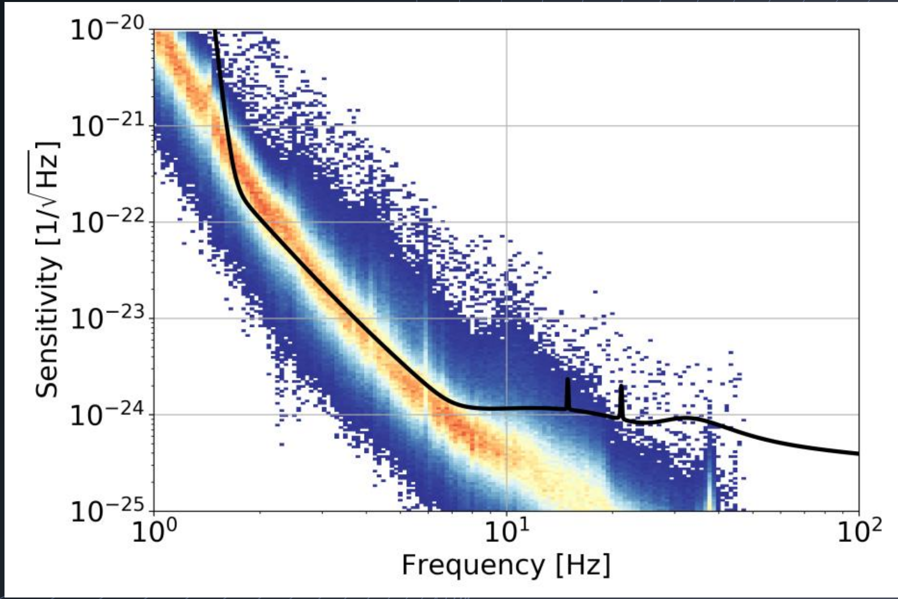
- Produced by gravitational coupling between environment and suspended test masses
- Avoiding Newtonian noise is the main justification to build ET underground
- The focus of current investigations lies on Newtonian noise from seismic fields
- Contributions from underground and surface seismic displacement can both be relevant
- It is possible that a mitigation method of Newtonian noise would improve the sensitivity of ET

Newtonian-noise models

Environmental noise budget

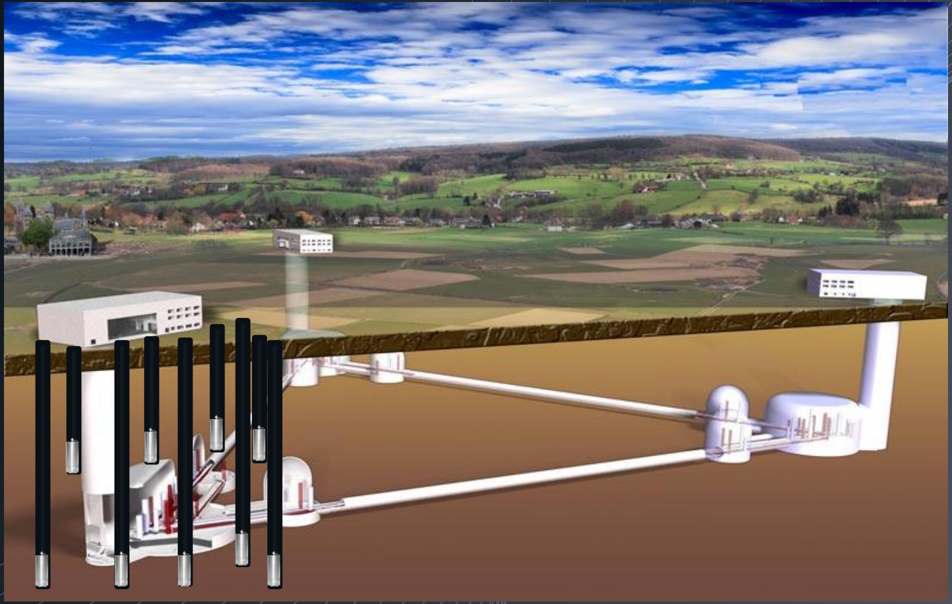


Model as spectral histogram of seismic Newtonian noise



Mitigation by noise cancellation

- Deploy borehole seismometers around the test masses
- Pass seismic data through a filter whose output is subtracted from ET GW data
- Example: A Wiener filter can be estimated from correlations observed between seismometers and ET GW data
- Novel filter designs might help to overcome performance limitations of a Wiener filter



Limitations of noise cancellation

- Information content in seismic data, which depends on array configuration and type of seismic sensor (seismometer, tiltmeter, strainmeter,…)
- Sensitivity limits of the seismic sensors
- Limitations from filter design, e.g., a Wiener filter is optimal for stationary fields, and it must be estimated from a very large number of correlation measurements (of order 100.000.000), which leads to significant statistical errors

Example: FIR Wiener filter

Wiener filter
(FIR order M)

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

Autocorrelation matrix of seisometer

Correlations between seismometer and ET GW data

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

Novel filter designs:

- Optimized Wiener-filter designs (dimensional reduction by SVD)
- Kalman filter
- Non-linear filter

Path towards NN cancellation in ET

GSSI

- Site characterization (already before site selection, but with much increased intensity after site selection)
- Development of numerical methods to close the gap between analytic models and data
- Exploration of new optimization techniques for the calculation of array configurations
- Modern filter designs also based on machine learning
- Development of innovative borehole deployment schemes (e.g., robotic installations in horizontal boreholes, several sensors per borehole)
- Development of seismic sensors that allow full wave-polarization reconstruction

What's in for science?

GW instrument scientists and geophysicists are often looking at similar problems (not all part of Newtonian-noise science):

- Ground tilt produced by atmospheric pressure fields and wind relevant to interferometer control
- Origin and nature of oceanic microseisms relevant to interferometer control
- Earthquake-early warning (being implemented for GW detectors, but also being developed for seismologists based on gravitational observations)
- Modeling of the planetary boundary layer for atmospheric NN predictions
- Faithful monitoring of atmospheric pressure fluctuations (solving the wind-noise problem) for acoustic NN cancellation
- LIDAR atmospheric tomography of temperature and humidity fields for atmospheric NN cancellation