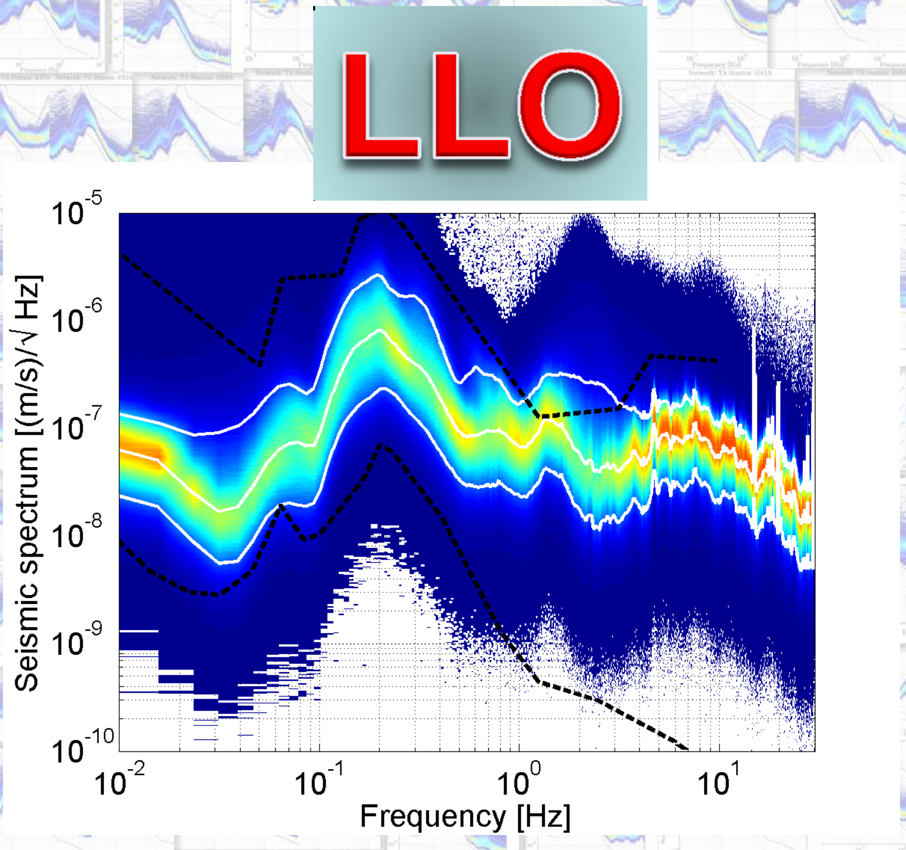
Newtonian Noise

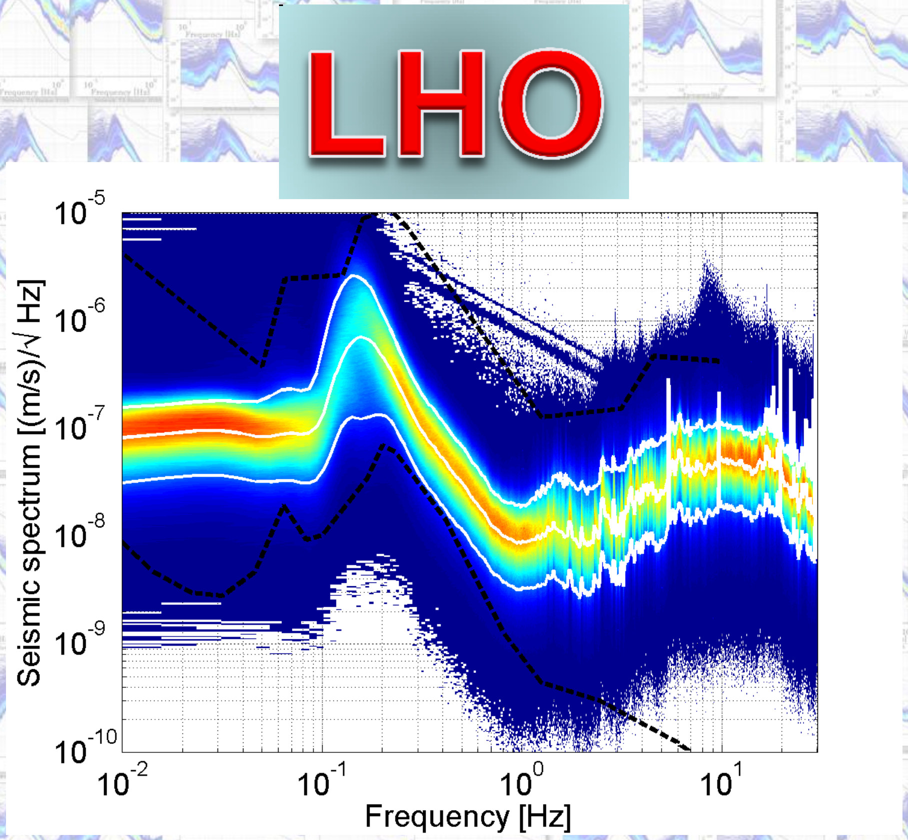
Surface and Underground

INFN, Sezione di Firenze

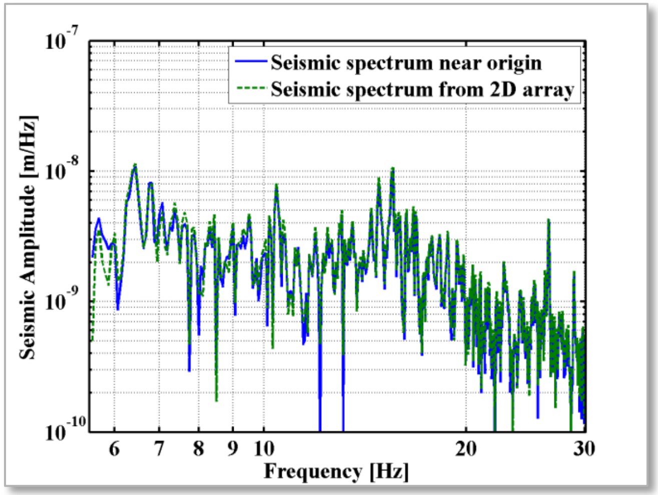
Jan Harms

Previously on NN: Seismic Histograms



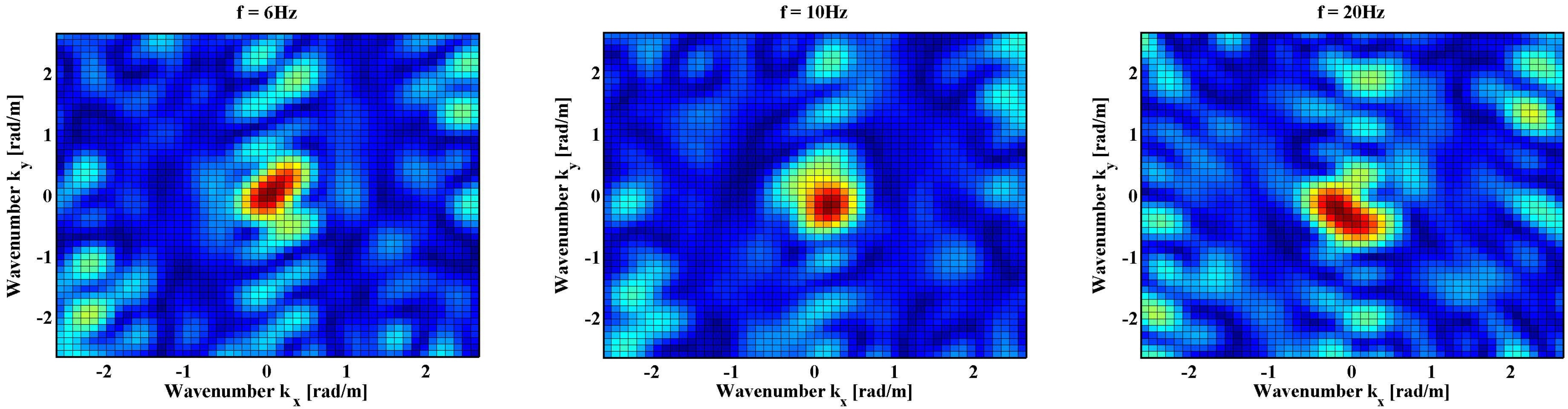


Plane-Wave Expansion



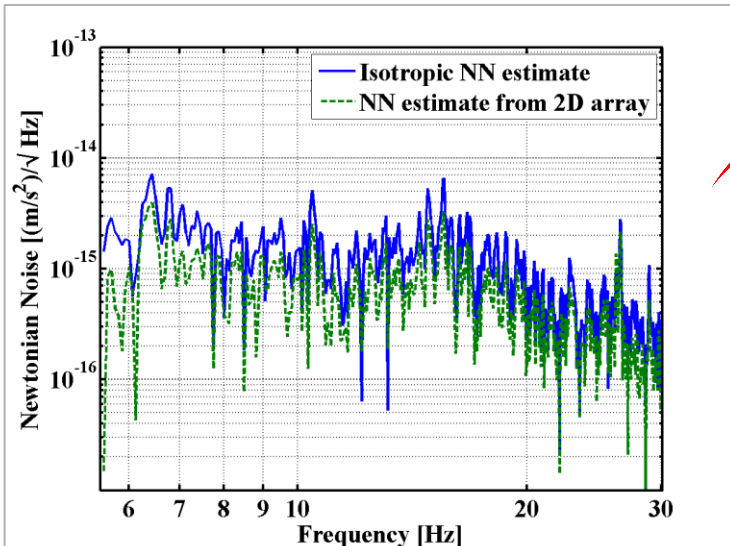
Curve 1: choose one seismometer near center of array

Curve 2: take all seismometers, calculate plane-wave expansion, integrate over all wave vectors, evaluate field at location picked for curve 1

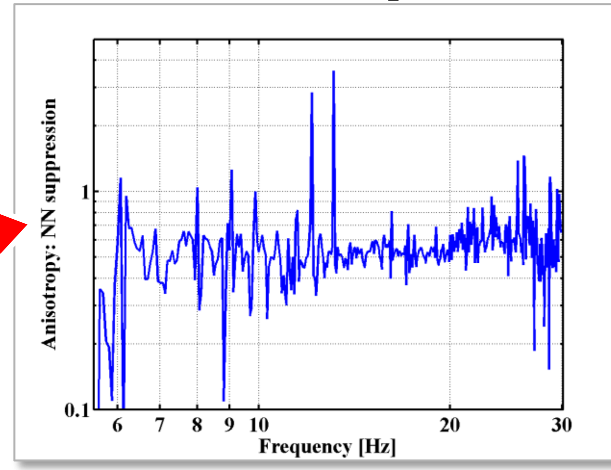


Newtonian Noise Spectra

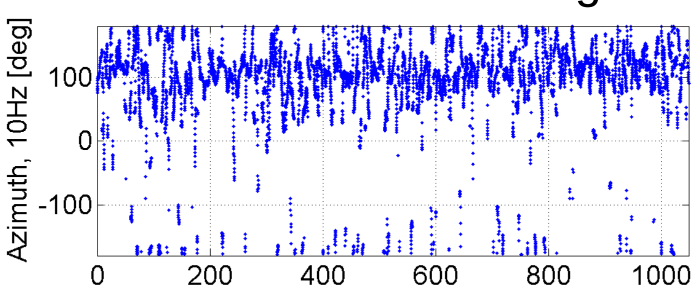
Comparison between single seismometer and array estimate



Ratio



Field at LHO/EY shows strong anisotropy



New estimate knows about:

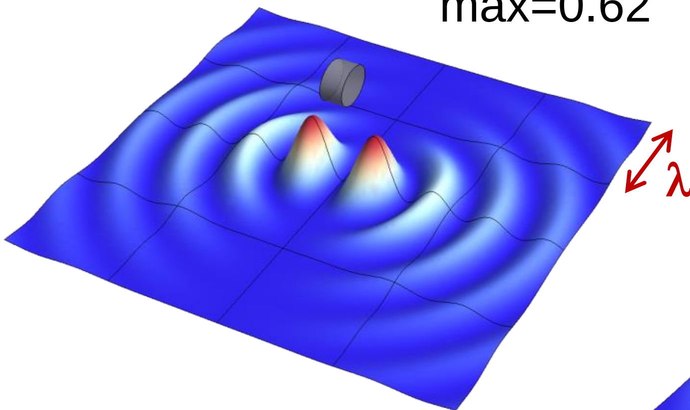
- Wave dispersion
- Scattering
- Anisotropy

New estimate does not know about:

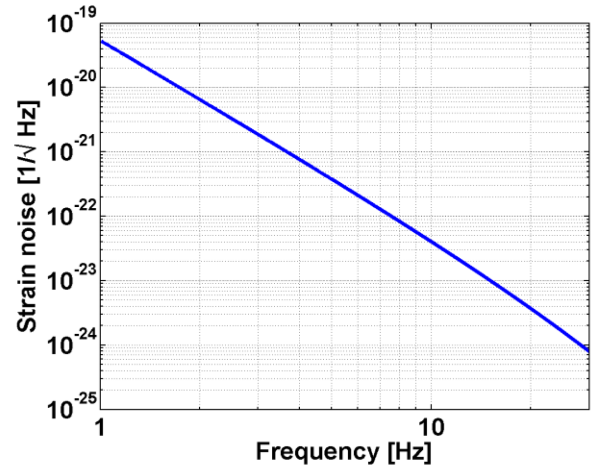
- Mode content (could be added using information about ground)

Rayleigh-Wave Subtraction

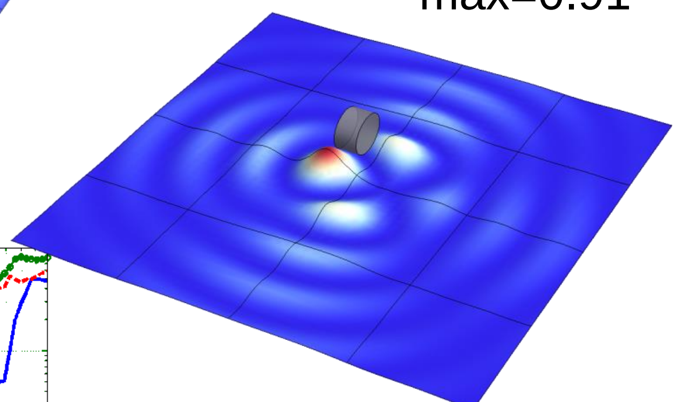
max=0.62



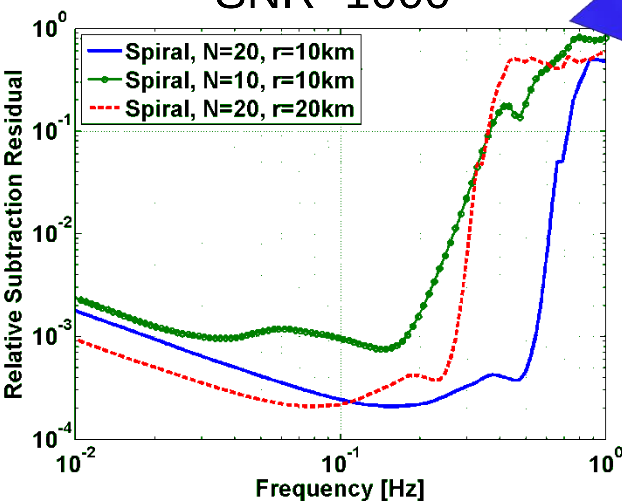
SNR=10



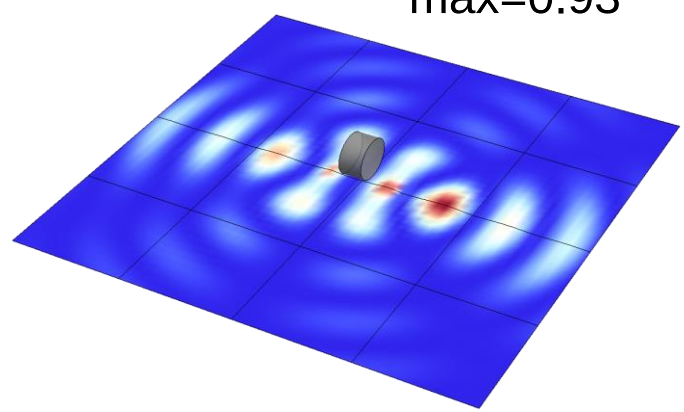
max=0.91

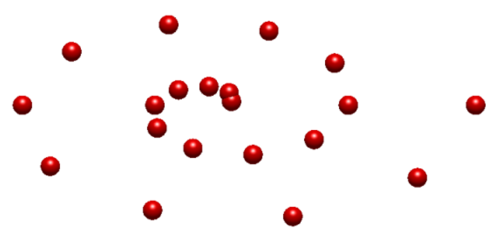


SNR=1000



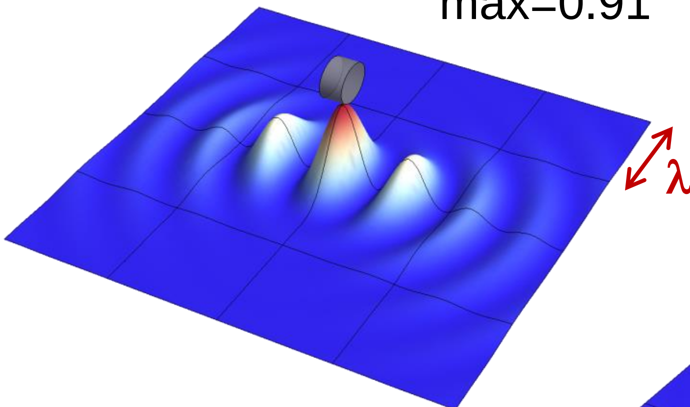
max=0.93



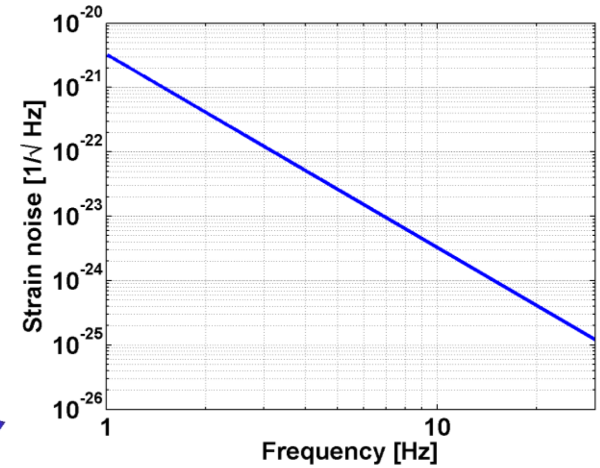


Compressional-Wave Subtraction

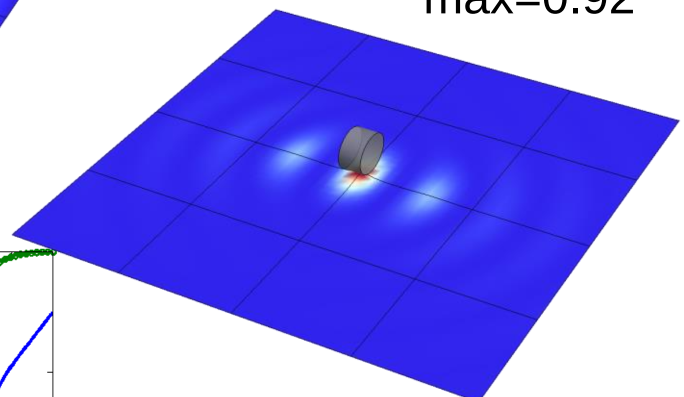
max=0.91



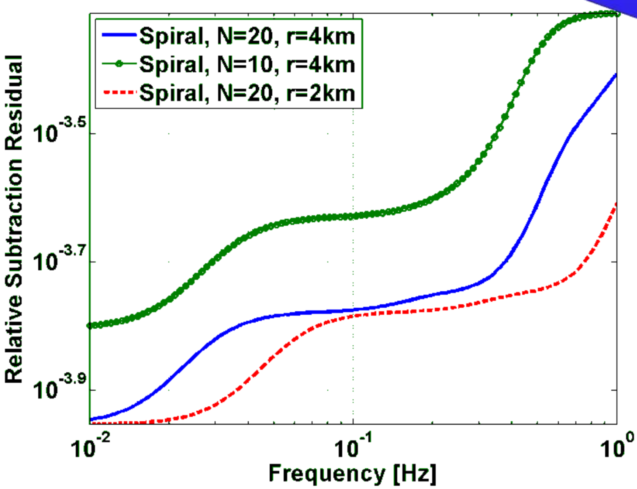
SNR=10



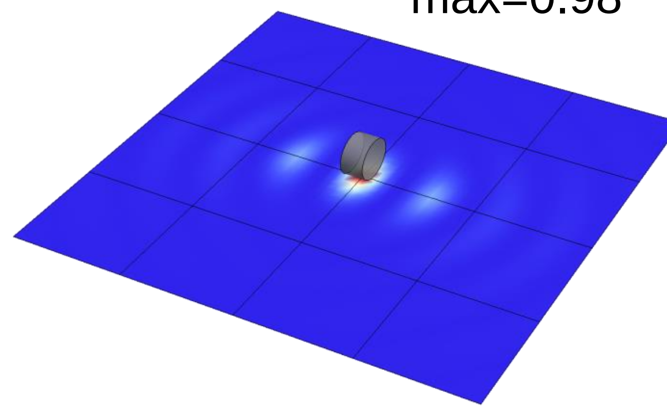
max=0.92

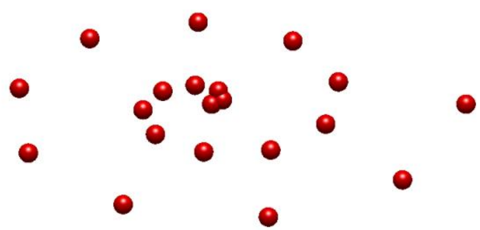


SNR=1000



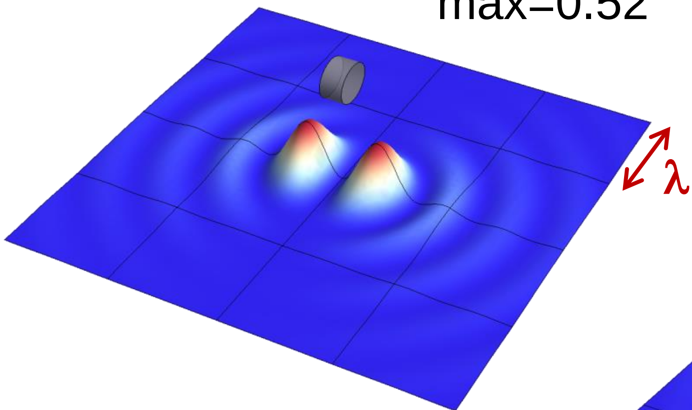
max=0.98



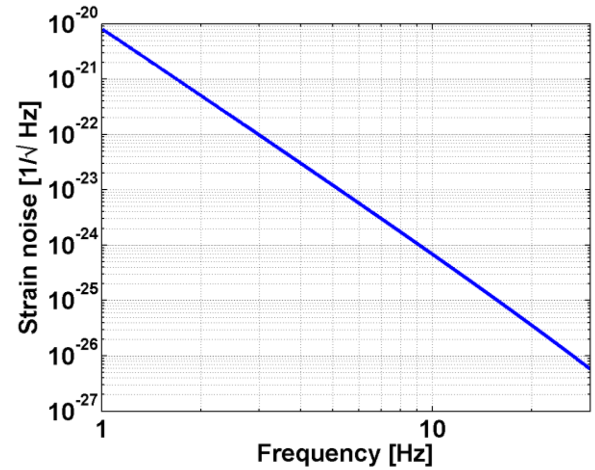


Infrasound Subtraction

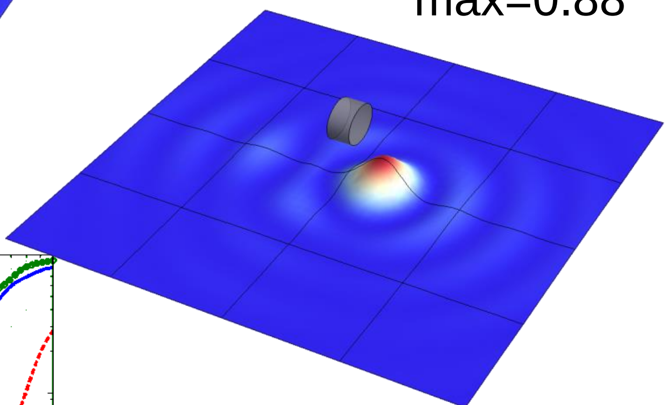
max=0.52



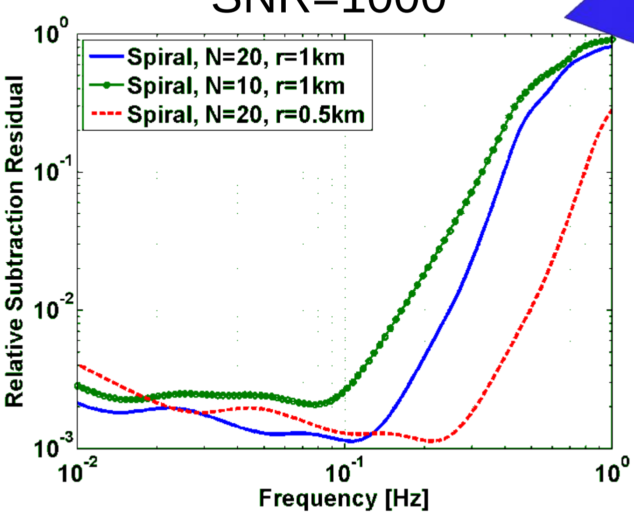
SNR=10



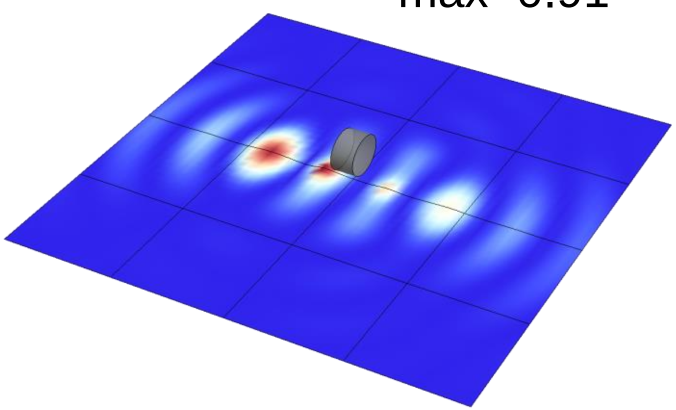
max=0.88

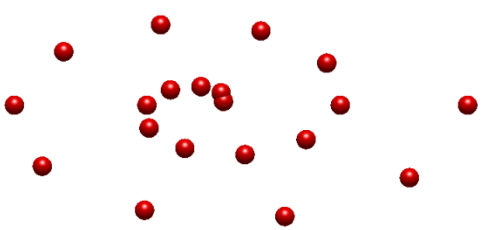


SNR=1000



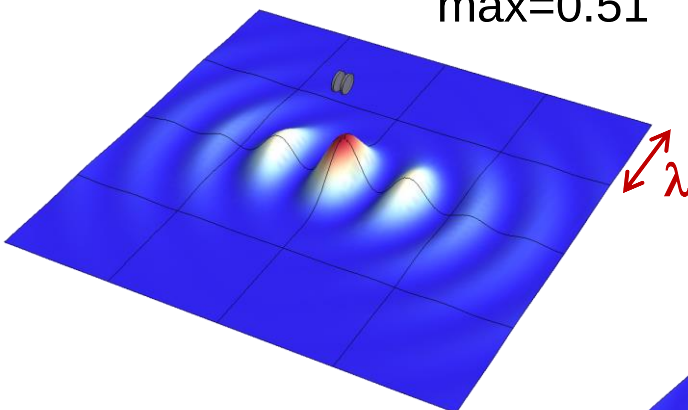
max=0.91



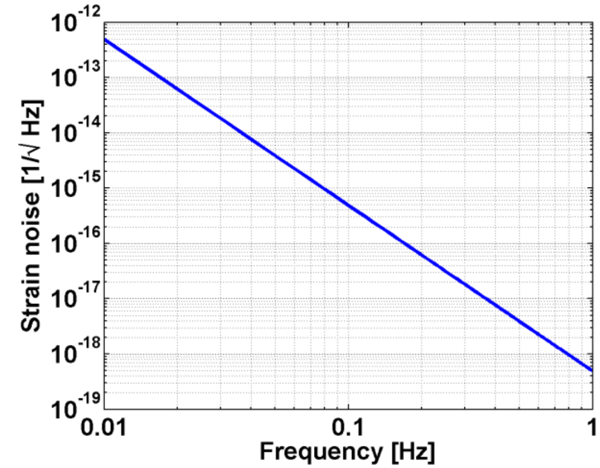


Infrasound Gradient Subtraction

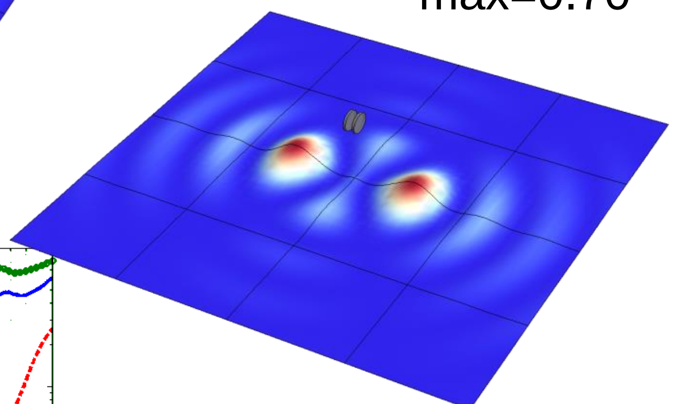
max=0.51



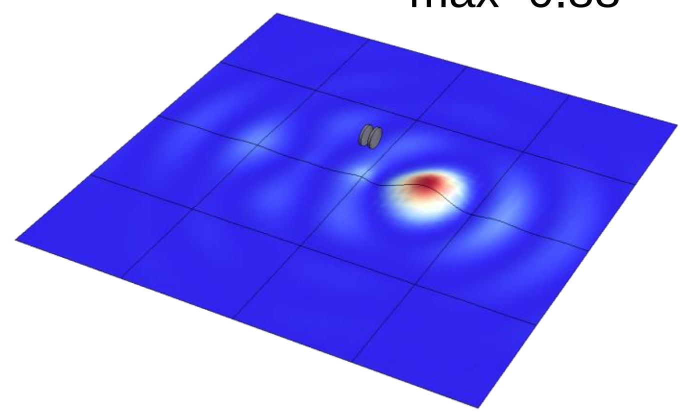
SNR=10



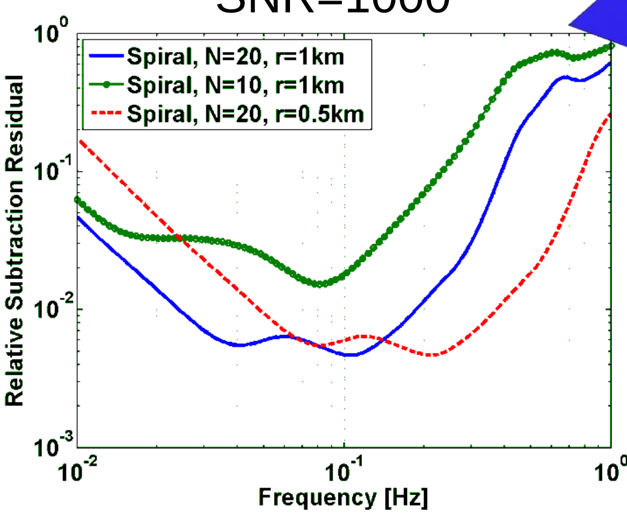
max=0.70

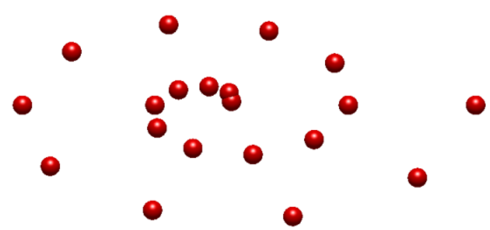


max=0.88



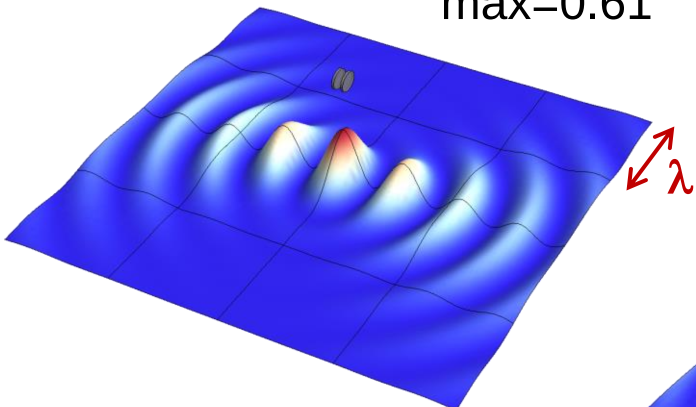
SNR=1000



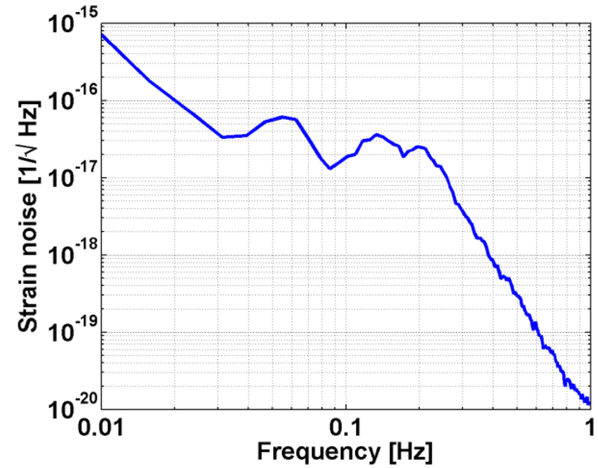


Rayleigh Gradient Subtraction

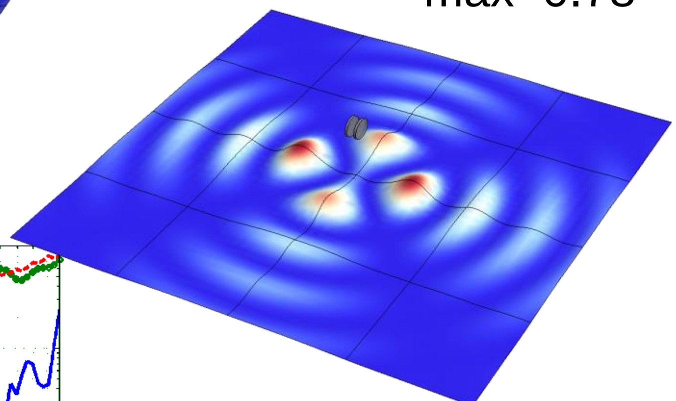
max=0.61



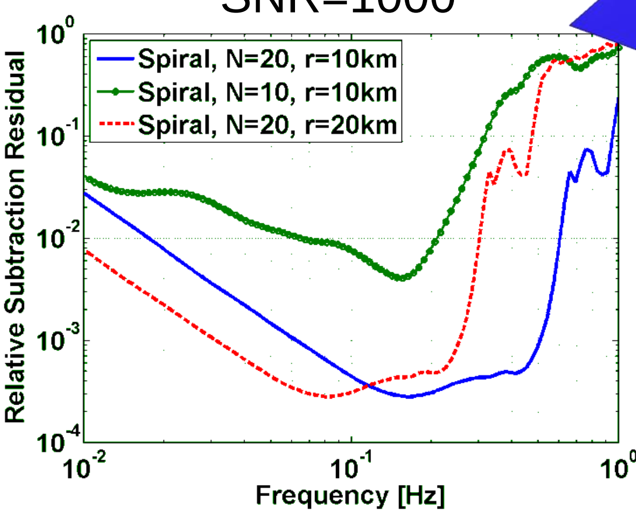
SNR=10



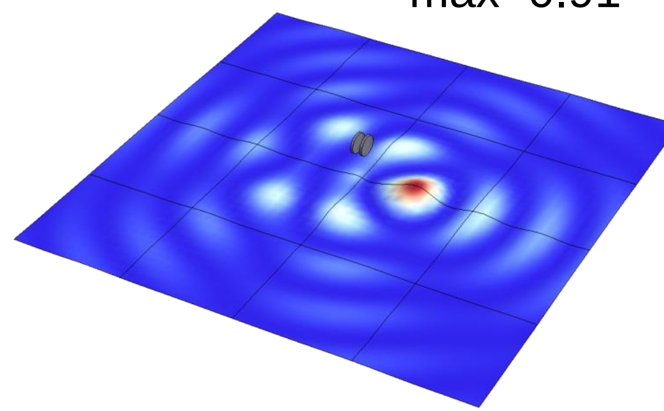
max=0.78

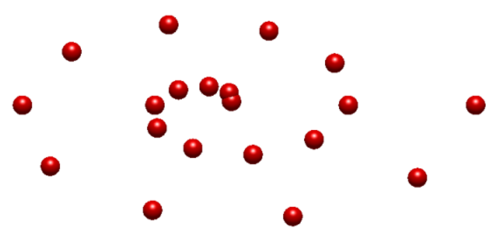


SNR=1000



max=0.91





Synopsis of NN Papers

Terrestrial gravitational noise on a gravitational wave antenna

PHYSICAL REVIEW D, VOLUME 30, 732 (**1984**)

Good: Starting point of all NN papers. Simple approach that gives almost accurate results for surface wave NN.
Not good: Today there are even simpler approaches that also give more accurate results. There is not just seismic surface NN.

Seismic gravity-gradient noise in interferometric gravitational-wave detectors

PHYSICAL REVIEW D, VOLUME 58, 122002 (**1998**)

Good: First paper to study NN from different types of seismic surface waves. Discussion of possible seasonal variations. NN means interesting physics. First statements on NN mitigation.
Not good: Far too complicated equations.

Synopsis of NN Papers

Relevance of Newtonian seismic noise for the VIRGO interferometer sensitivity

Class. Quantum Grav. 15, 3339 (**1998**)

Good: Careful study of interferometer response to NN that can be extended to low frequencies. Discussion of various seismic modes with focus on surface waves.
Not good: A lot of math and less physics.

Human gravity-gradient noise in interferometric gravitational-wave detectors

PHYSICAL REVIEW D, VOLUME 60, 082001 (**1999**)

Good: First paper to explore non-seismic NN. First paper to discuss non-stationary NN. A lot of physics.
Not good: ---

Synopsis of NN Papers

Off line subtraction of seismic Newtonian noise.

In: Recent Developments in General Relativity, Springer, Heidelberg (**2000**)

Good: First investigation of coherent NN subtraction using Wiener filters.
Not good: Does not discuss physical seismic/NN models or how to design sensor arrays.

Tumbleweeds and airborne gravitational noise sources for LIGO

Class. Quantum Grav. 25,125011 (**2008**)

Good: Best NN paper that I know. Plenty of interesting estimates. Will be the basis of many more studies.
Not good: Appeared on archive in 2000. Author could have done a little more in 8 years…

Synopsis of NN Papers

Simulation of underground gravity gradients from stochastic seismic fields

PHYSICAL REVIEW D 80, 122001 (**2009**)

Good: The paper that I look at most often because of useful equations. Presentation of all important equations for NN simulation, especially for surface waves.
Not good: Simulation results outdated and therefore no important results.

Newtonian-Noise Subtraction in 3rd Generation Underground Gravitational-Wave Detectors in Homogeneous Media

http://arxiv.org/abs/0910.2774v1 (**2009**)

Good: First paper to study NN underground, and NN subtraction of body-wave fields. Explains why underground NN subtraction will be relatively easy. Also studies subtraction of gravity transients and disturbances from local sources.
Not good: Should contain a prove that underground cavities don't scatter seismic waves significantly. Should include subtraction of surface waves.

Synopsis of NN Papers

Towards time domain finite element analysis of gravity gradient noise

J. Phys.: Conf. Ser. 228 012034 (**2010**)

Good: First paper that introduces seismic sources with the ability to accurately study gravity perturbations from transients.
Not good: Should have used physical source models and realistic estimates of energy radiated into the seismic field.

Improving the sensitivity of future GW observatories in the 1–10 Hz band: Newtonian and seismic noise

Gen Relativ Gravit 43:623–656 (**2011**)

Good: Summary of 2011 NN wisdom.
Not good: NN subtraction results based on worst-case seismic coherence model that was later adopted for ET preliminary design study, which created a lot of confusion.

Synopsis of NN Papers

Seismic topographic scattering in the context of GW detector site selection

Class. Quantum Grav. 29, 075004 (**2012**)

Good: Explains one of the many problems with low-f GW detectors near surface. First paper to discuss aspects of site selection with respect to NN.
Not good: Does not go beyond Born approximation of seismic scattering and therefore cannot predict amplitudes of scattered Rayleigh waves.

Newtonian noise and ambient ground motion for gravitational wave detectors

J. Phys.: Conf. Ser. 363 012004 (**2012**)

Good: Excellent characterization of sites in Europe as relevant to NN. Simulated NN reduction as function of detector depth and frequency.
Not good: Dynamical simulation does not use physical model of the seismic source.

Synopsis of NN Papers

Subtraction of Newtonian noise using optimized sensor arrays

PHYSICAL REVIEW D 86, 102001 (**2012**)

Good: NN subtraction tested on simulated data using FIR Wiener filters. Seismic surface field based on wavelets and includes local sources. Predicts NN subtraction performance. Contains many useful discussions on NN subtraction in general.
Not good: Should also simulate body waves. Should estimate reaction of ground to vibrations of vacuum tanks.

Newtonian Noise Limit in Atom Interferometers for Gravitational Wave Detection

http://lanl.arxiv.org/abs/1304.1702v1 (**2013**)

Good: First paper to present calculation of NN in atom interferometers. Provides formalism to calculate NN for arbitrary atom-interferometer configurations.
Not good: Based on old (Saulson style) seismic and NN models also neglecting the dominant atmospheric NN. Does not discuss NN subtraction.