Vision talk on site studies

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Einstein Telescope Meeting 2012
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December 4, 2012

Contents

Accomplishments of WG1

- Site studies
  - First and quick scan
    - **Seismic data**
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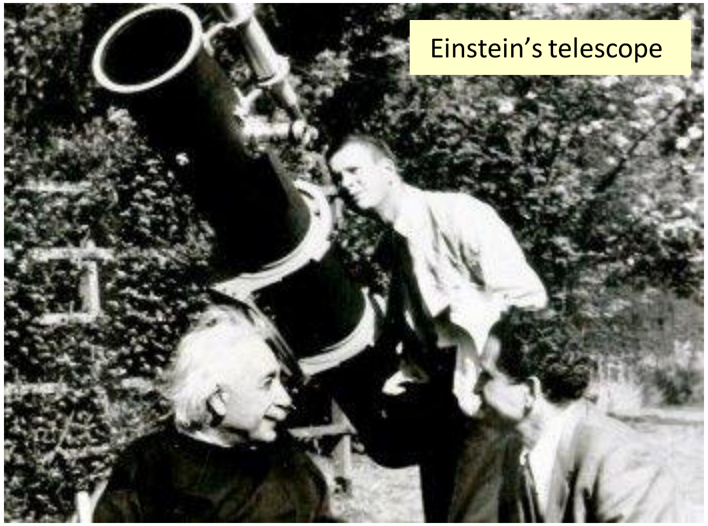
- GGN studies
  - GGN modeling, GGN subtraction techniques
    - **Sizable activity, approaching consensus**
- Infrastructure studies
  - Underground structures
    - **Tunnels, caverns, shafts**
    - **Construction techniques**
  - Surface structures
    - **Buildings, roads, etc.**
  - Vacuum system, cryogenics, safety systems
  - Costing

See contribution by David Rabeling



Future

Site studies

Accomplishments of WG1

- Site studies
  - First and quick scan
    - **Seismic data: extensive studies in Europe**

Mark Beker *et al.*

- Seismic studies
  - 15 sites in 11 countries
  - Typically 1 – 2 weeks of data
  - KNMI cross check
  - Worldwide effort
    - Europe
    - Kagra, Japan
    - Homestake, USA

Site studies

Accomplishments of WG1

- Site studies
  - First and quick scan
    - **Seismic data: also Japan and USA**
- Kagra
  - Seismic studies
  - Many more issues
  - Horizontal access site
- Homestake
  - Permanent sensor array
  - Vertical access site

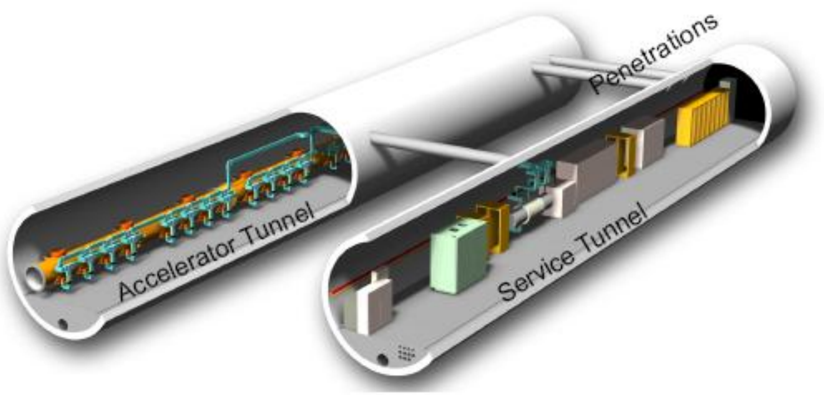
Site studies

Accomplishments of WG1

- Site studies
  - First and quick scan
    - **Seismic data: also Particle Physics - ILC**

- Seismic studies
  - Accelerator sites: Cern, *etc*.

International Linear Collider



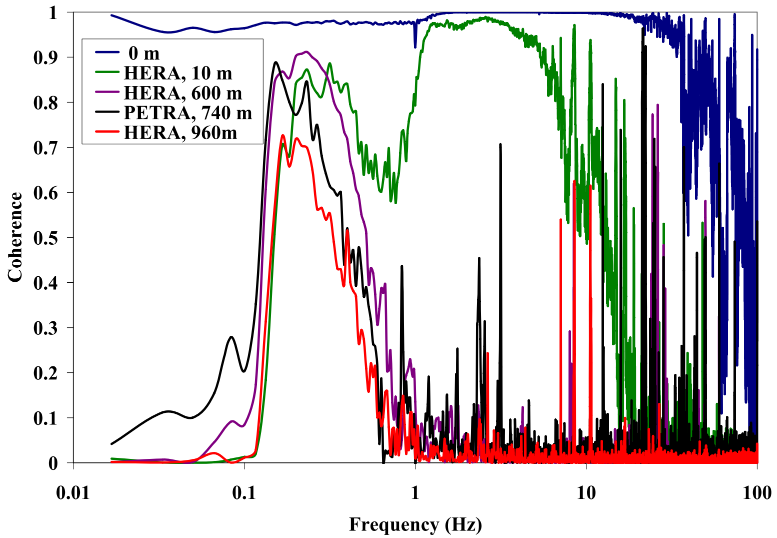


FIG. 6: (Color) Coherence spectra measured at different distances at DESY: 0 m, 10 m, 600 m, 740 m (diameter of PETRA ring) and 960 m in the HERA tunnel.

http://vibration.desy.de

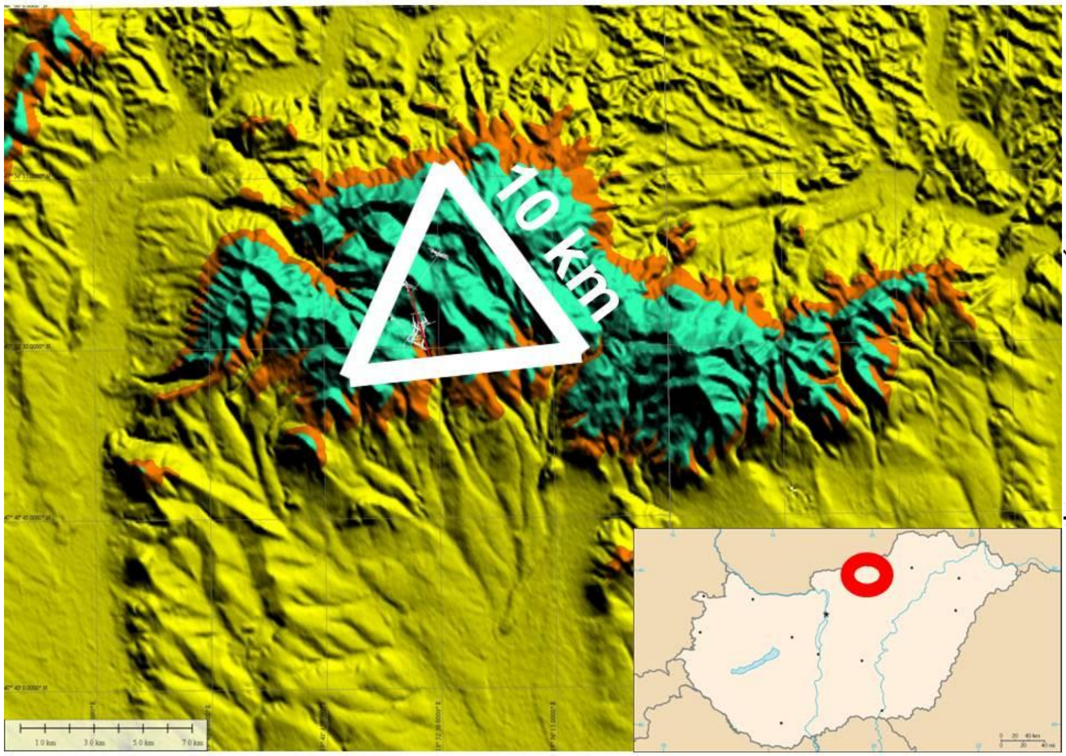
Sicily, Oct. 14, 2009: talk by Heiko Ehrlichmann (Desy)

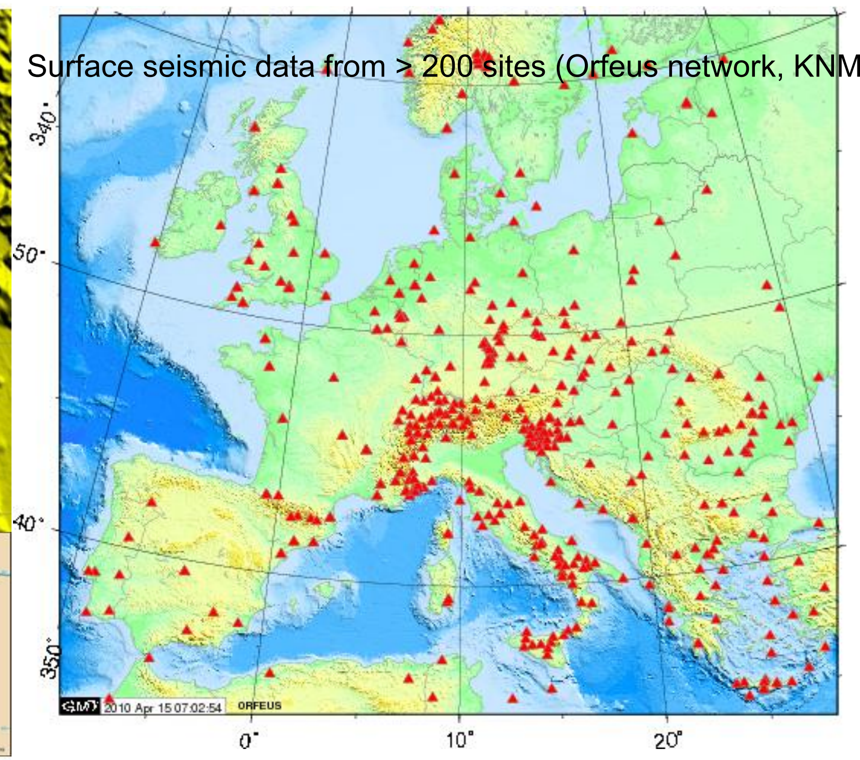
Site studies

Accomplishments of WG1

- Site studies
  - First and quick scan
    - **Seismic data**
    - **Geophysical issues**

- Geophysical community
  - Gran Sasso meeting: Feb. 9, 2009
  - KNMI collaboration
    - **Common data taking**
    - **Analysis procedures**
- IASPEI GA 2013
  - Goeteborg, Sweden
    - **With Prof. Plastino, proposed: Session on *"Gravitational, Nuclear and Solid Earth Physics for probing Earth's interior"***





Site studies

Accomplishments of WG1

- Site studies
  - First and quick scan
    - **Seismic data**
    - **Geophysical issues**
    - **Available infrastructure**
- Infrastructure
  - Horizontal access
  - Useful infrastructure

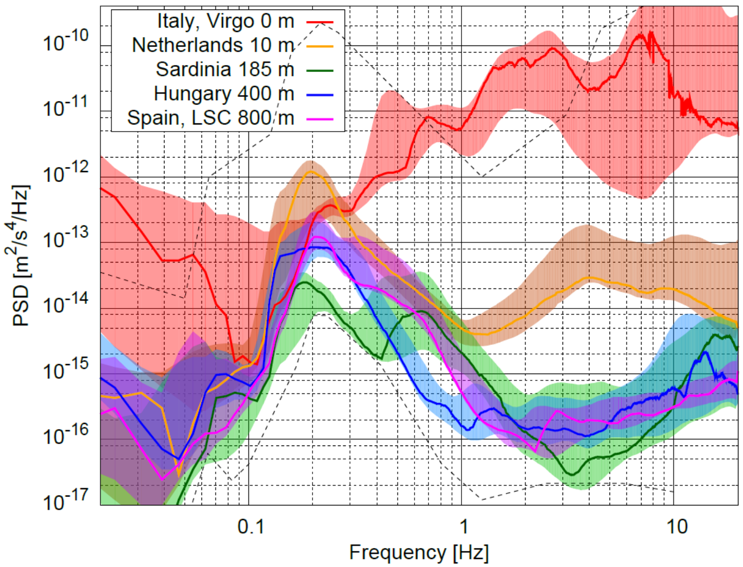
Site studies

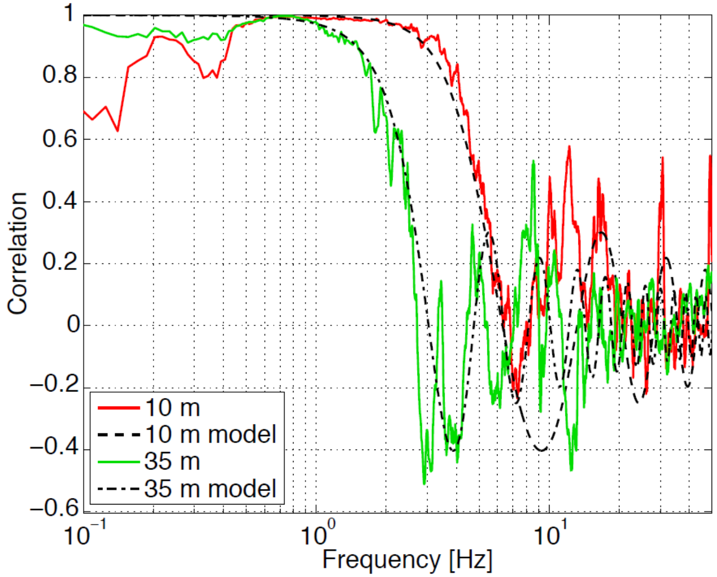
Accomplishments of WG1

- Site studies
  - First and quick scan
    - **Seismic data**
    - **Geophysical issues**
    - **Available infrastructure**
- Infrastructure
  - Vertical/horizontal access
  - Numurous issues

Vision: seismic data

- Seismic noise measurements
  - Power spectral densities
  - Correlations
    - Various sensor "grids"
- Long-term measurements
  - Over period of years
  - Few selected sites
  - Local teams

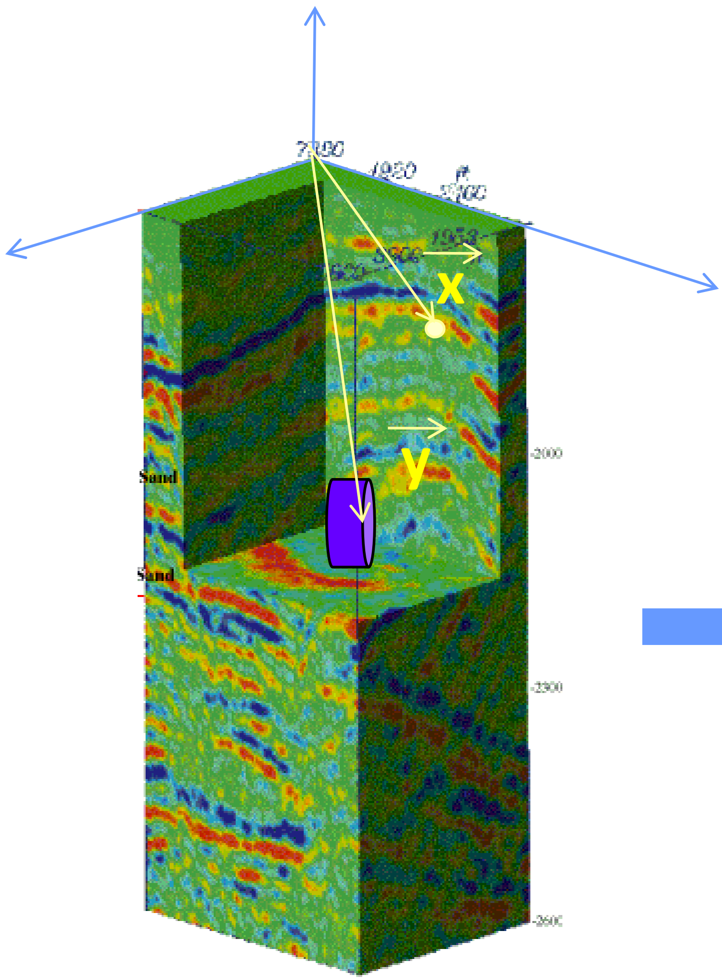




Gravity gradient studies

Accomplishments of WG1

- GGN studies
  - GGN modeling, GGN subtraction techniques
    - **Sizable activity, approaching consensus**



Acceleration of test mass

$$\mathbf{a}^{NN}(\mathbf{y},t) = G\int_V \rho(\mathbf{x},t)\,\mathbf{K}(\mathbf{x}-\mathbf{y})\,dV_x$$

$$\mathbf{K}(\mathbf{x}) = \frac{\mathbf{x}}{|\mathbf{x}|^3}$$

Mass density current

$$\mathbf{J}_m = \rho_0(\mathbf{x})\,\dot{\boldsymbol{\xi}}(\mathbf{x},t)$$

Static density of medium

Velocity of mass element

Mass conservation

$$\dot{\rho} + \nabla\cdot\mathbf{J}_m = 0$$

Frequency domain

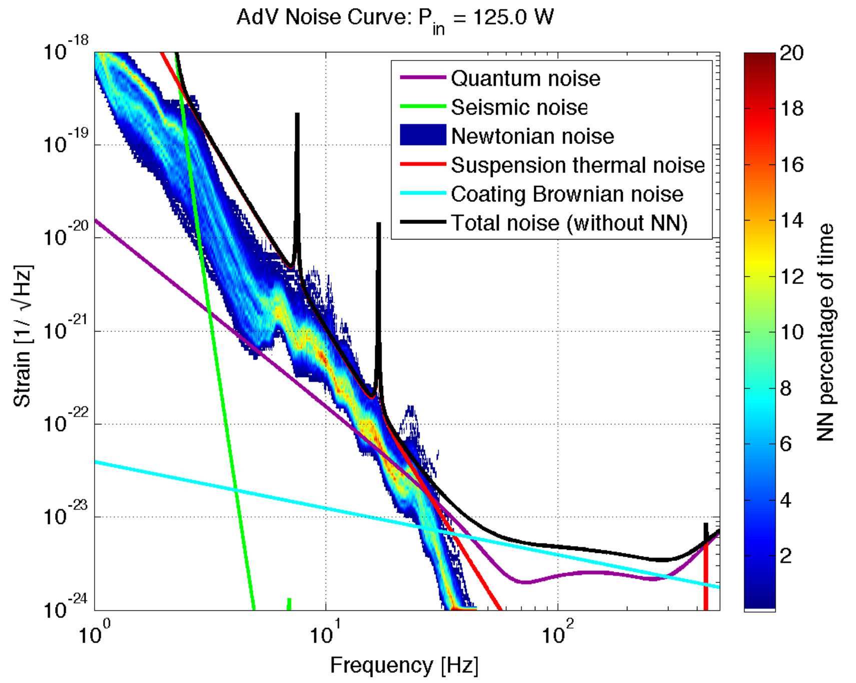
$$\mathbf{a}^{NN}(\mathbf{y},\omega) = -G\int_V \nabla\left[\rho_0(\mathbf{x})\,\boldsymbol{\xi}(\mathbf{x},\omega)\right]\mathbf{K}(\mathbf{x}-\mathbf{y})\,dV_x$$

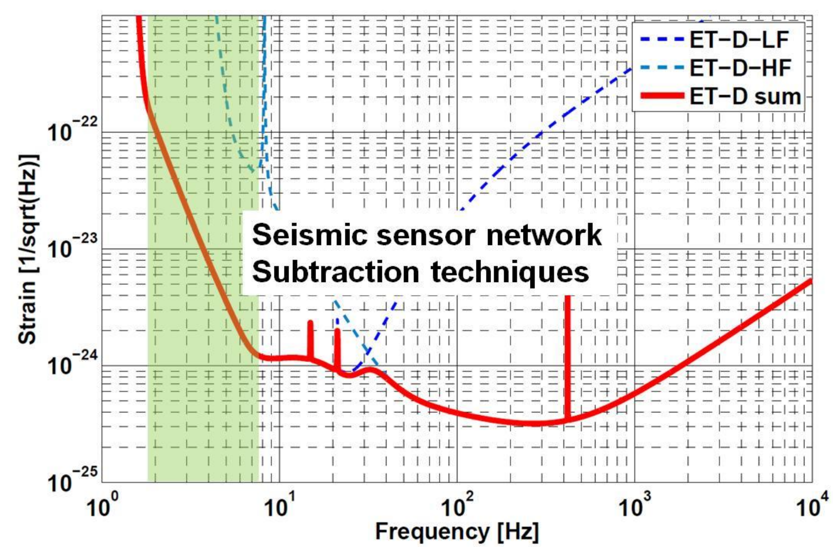
$\rho_0\nabla\boldsymbol{\xi}$ — Fluctuations of local density due to compressions

$\boldsymbol{\xi}\cdot\nabla\rho_0$ — Movement of density inhomogeneities (*e.g.* boundaries)

Gravity gradient noise: AdV and ET

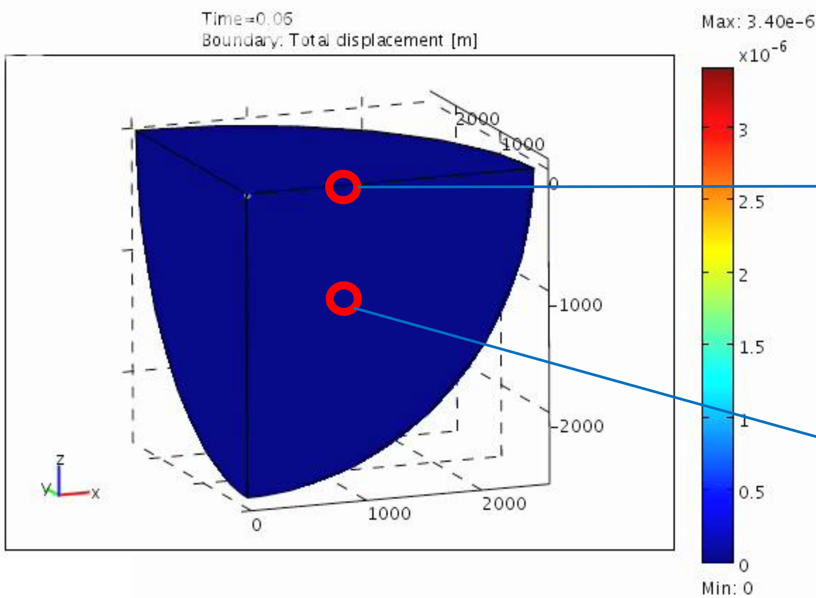
- Past GGN studies
  - Noise from seismic ground waves
    - Saulson, Phys. Rev. D30, 732 (1984)
    - Hughes and Thorne, gr-gc/9806018
    - Beccaria *et al*, CQG 15, 3339 (1998)
  - People walking near tests masses
    - Thorne and Winstein, gr-gc/9810016
- Noise source for Advanced detectors
  - Limits sensitivity at low frequency
    - LIGO-T070192-00R (2007)
    - Jan Harms *et al.*
    - Advanced Virgo (Mark Beker)
  - No shielding possible
    - Subtraction schemes under investigation

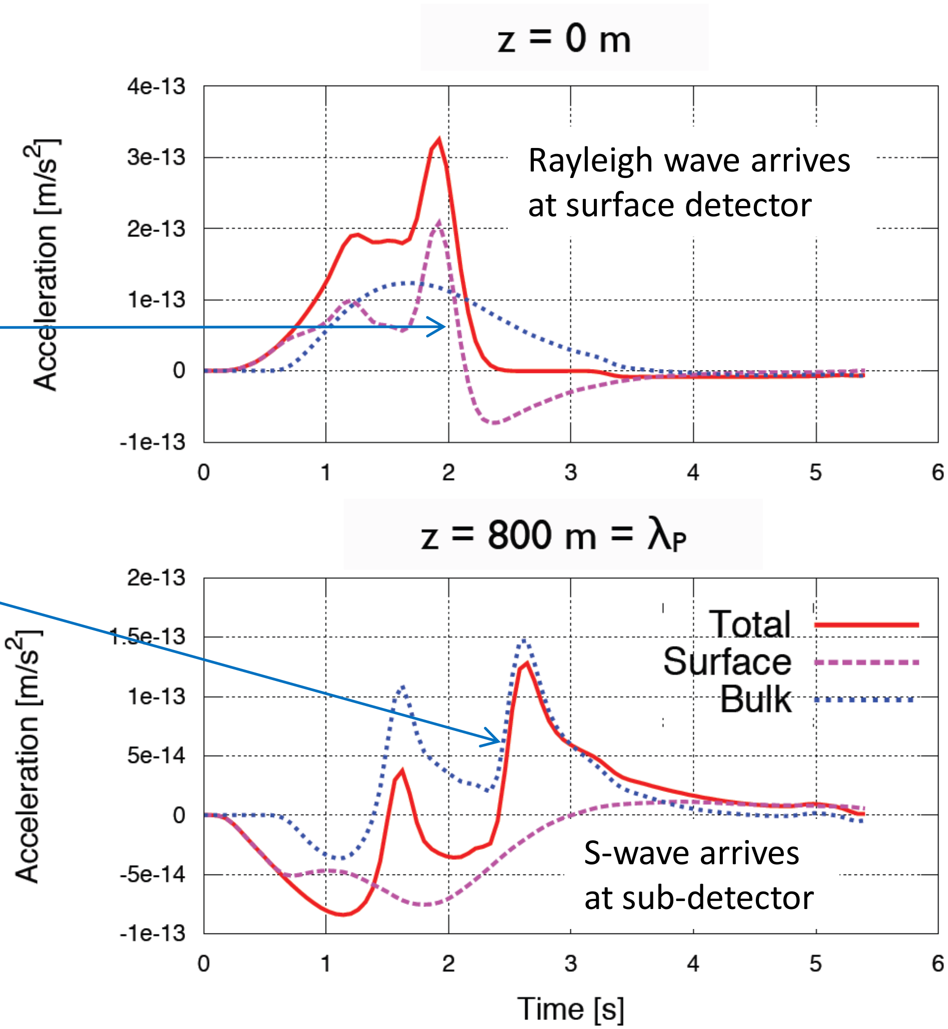


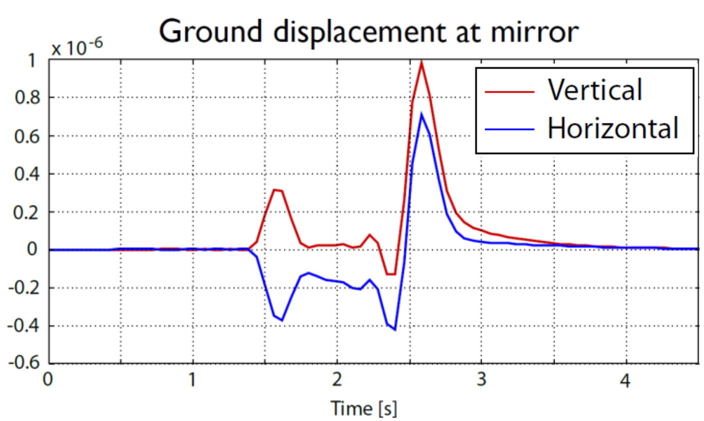


GGN modeling: impulse excitation

- Model cultural noise (FEA)





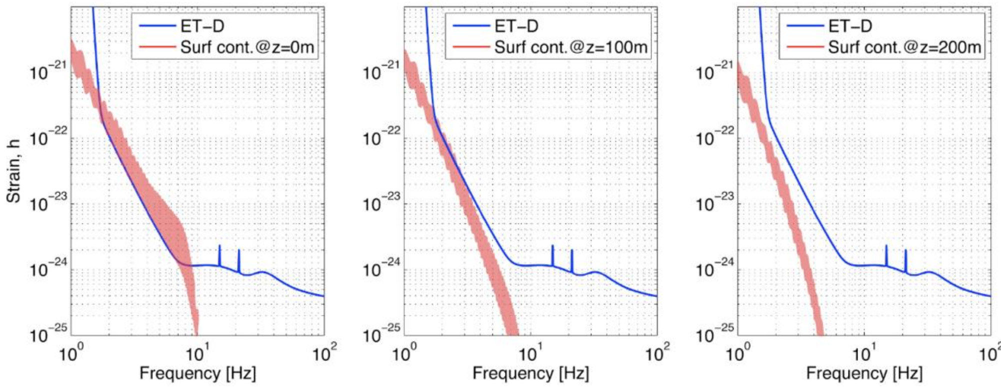


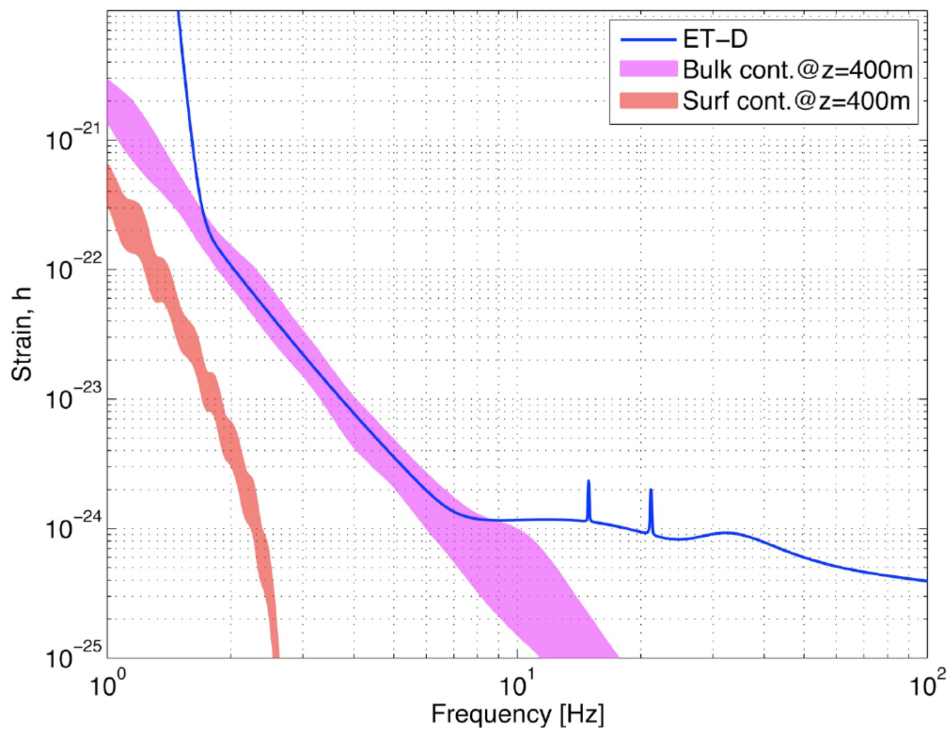
Reduction factor < 3, but Wiener filtering very effective for local "point" sources

ET modeling: Hungary site study

Accomplishments of WG1

- Site studies
  - First and quick scan
    - **Seismic data**
    - **Geophysical issues**
    - **Available infrastructure**
- GGN studies
  - GGN modeling "point" sources
    - **Employ filtering with a few sensors**
  - Stochastic sources
    - **Surface contributions**
      - Cella's model
      - Use measured seismic PSD
      - Predict attenuation with depth
    - **Bulk contributions**
      - Hughes and Thorne's model
      - Use measured seismic PSD
  - GGN prediction
    - **Few hundred meters depth is sufficient to suppress surface contribution**
      - Dominant contribution
      - Cultural noise
    - **Bulk contribution remains**
- GGN subtraction strategies





Newtonian noise subtraction

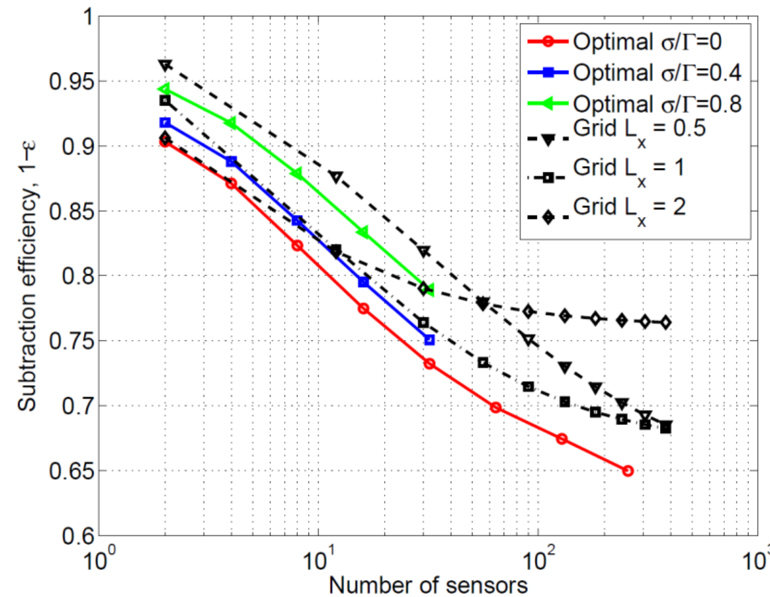
[G. Cella *et. al.*, Gen. Rel. Grav. (2010)]

- Seismic sensor (signal + noise) $X_I = s_I + \sigma_I$
- ITF output (GW signal + N. noise) $Y = H + N$
- Find $\alpha_I(\omega)$ to minimize "subtracted" signal $Y_s(\omega) = Y(\omega) + \int d\omega' \sum_I \alpha_I(\omega,\omega') X_I(\omega')$
- Optimal filters $\frac{\delta \langle Y_s(\omega)^* Y_s(\omega)\rangle}{\delta \alpha_I(\omega,\omega')} = 0$

Sensor noise appears in diagonal elements of cross-correlation matrix

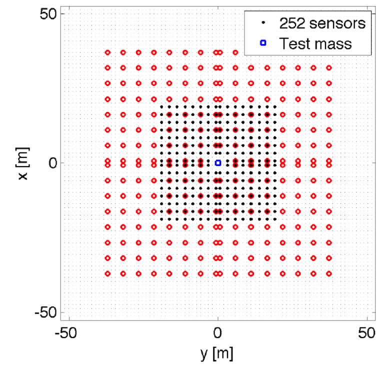
- Cella: simplified model $\alpha_I(\omega,\omega') = -\sum_K \int d\omega' \langle X_I(\omega)^* X_K(\omega')\rangle^{-1} \langle X_K(\omega')^* Y(\omega)\rangle$
  - Exponential cross correlation function between sensors $\langle \rho(\omega,\mathbf{x})^* \rho(\omega',\mathbf{x}')\rangle = 2\pi\Gamma(\omega)^2 \delta(\omega-\omega') e^{-\frac{|\mathbf{x}-\mathbf{x}'|}{\xi(\omega)}}$
- Subtraction efficiency
  - 1 = no subtraction
  - 0 = 100% subtraction

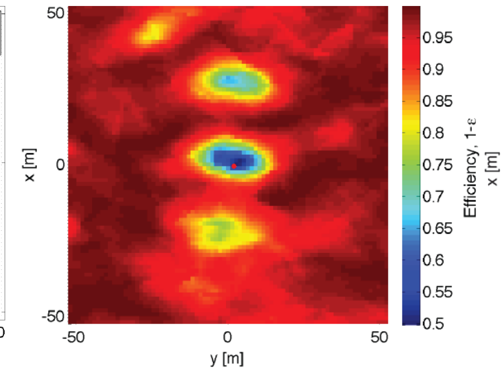
$$(1-\epsilon(\omega))^2 = 1 - \frac{C_{SN}^\dagger(\omega) C_{SS}(\omega)^{-1} C_{SN}(\omega)}{C_{NN}(\omega)}$$

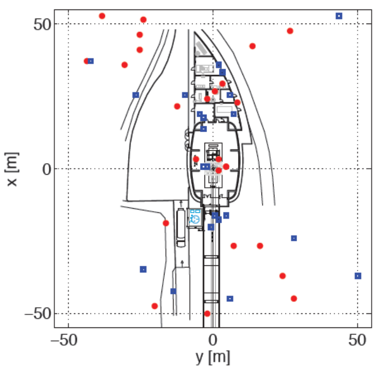


NN subtraction simulation

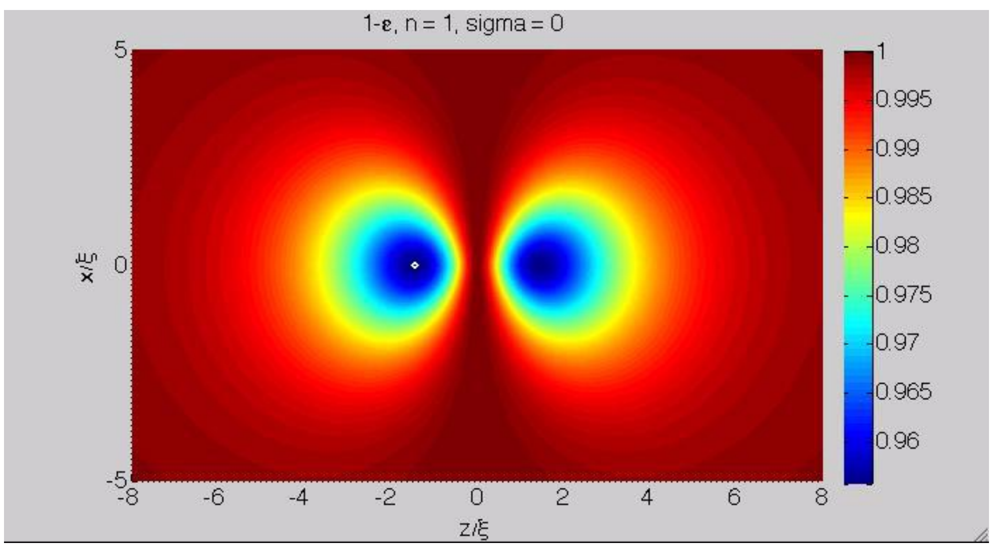
- Advanced Virgo
  - Seismic PSD data
  - Correlation data
- Seismic sensors
  - Sensitivity SNR = 25
- Sensor grid around test mass
  - Regular and optimized grids
- Sensor network
  - Large number of sensors

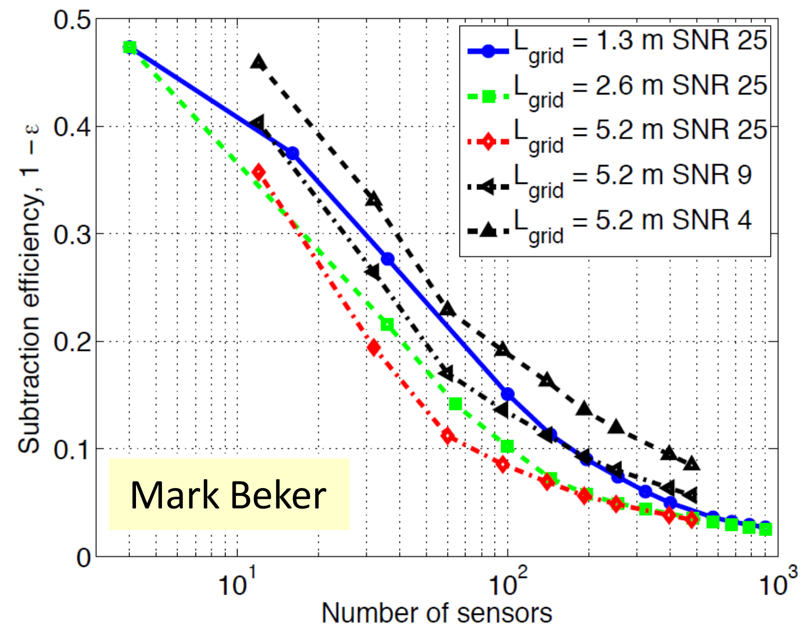






$$(1-\epsilon(\omega))^2 = \frac{\langle E(\omega)^* E(\omega)\rangle}{\langle Y(\omega)^* Y(\omega)\rangle} = 1 - \frac{C_{SNi}[C_{SS}(\omega) + C_{\Sigma\Sigma}(\omega)]^{-1}_{ij} C_{SNj}}{C_{NN}}$$





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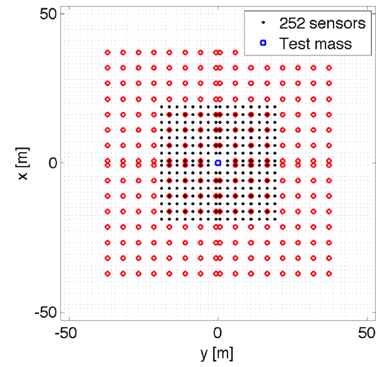

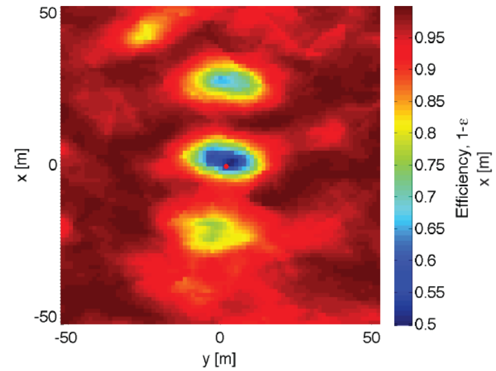

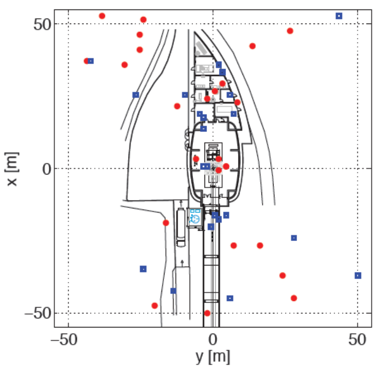

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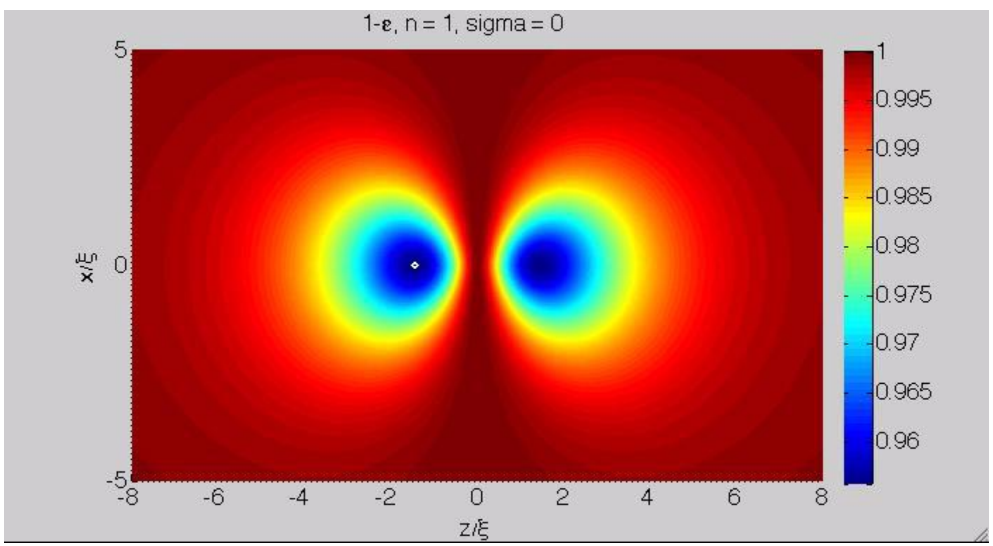
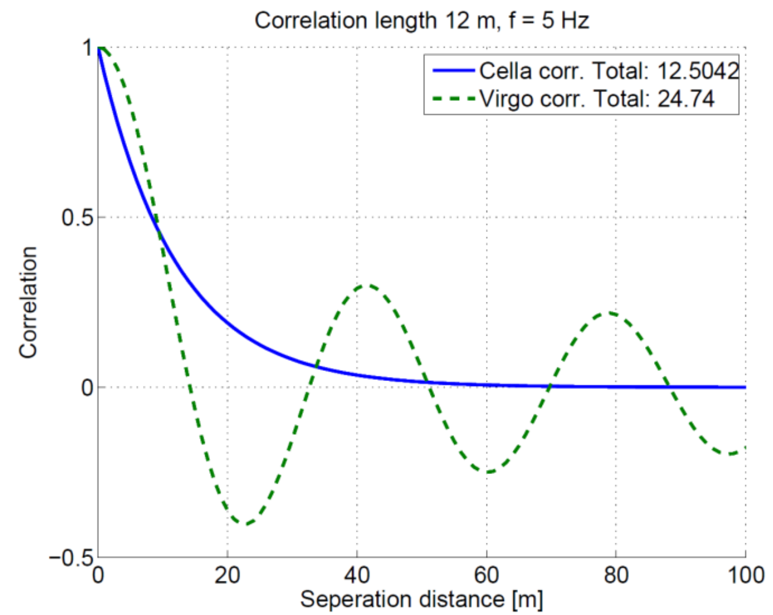
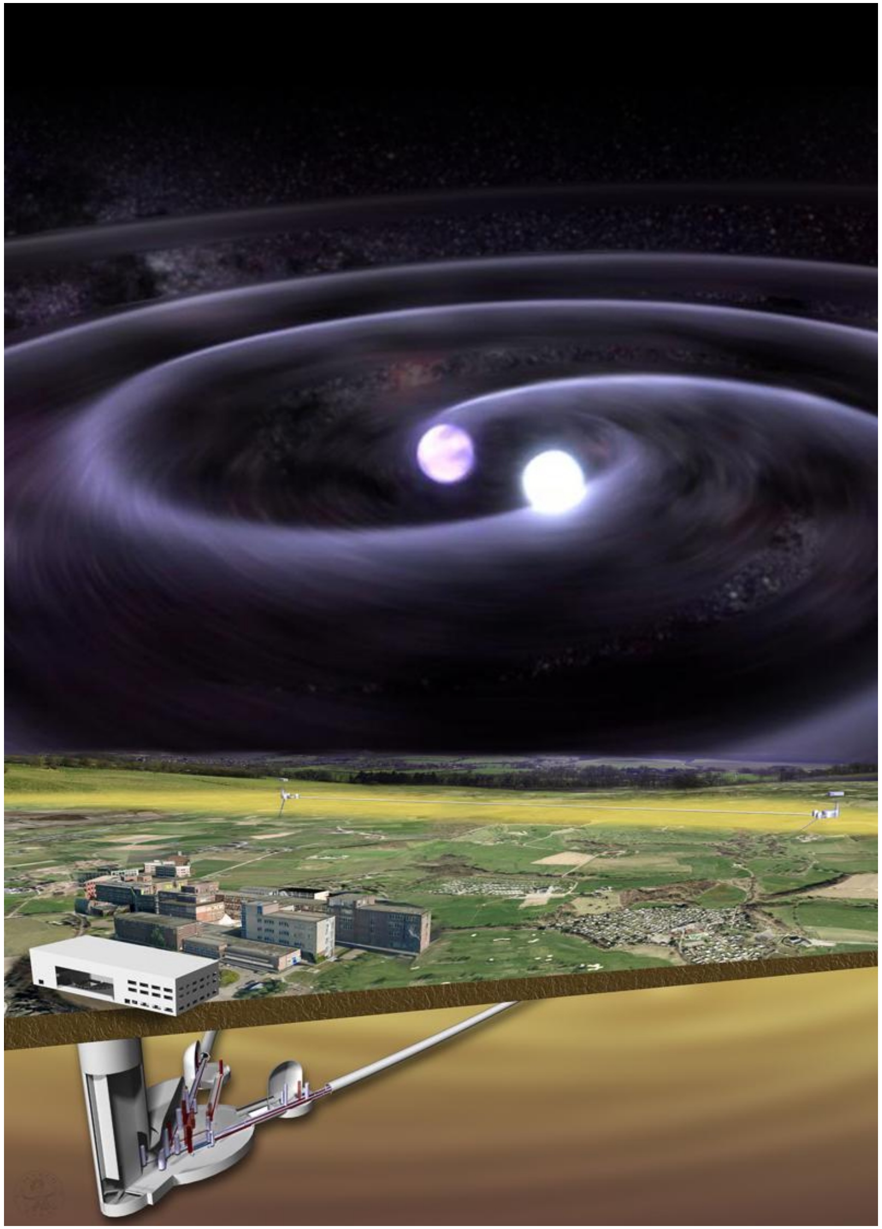
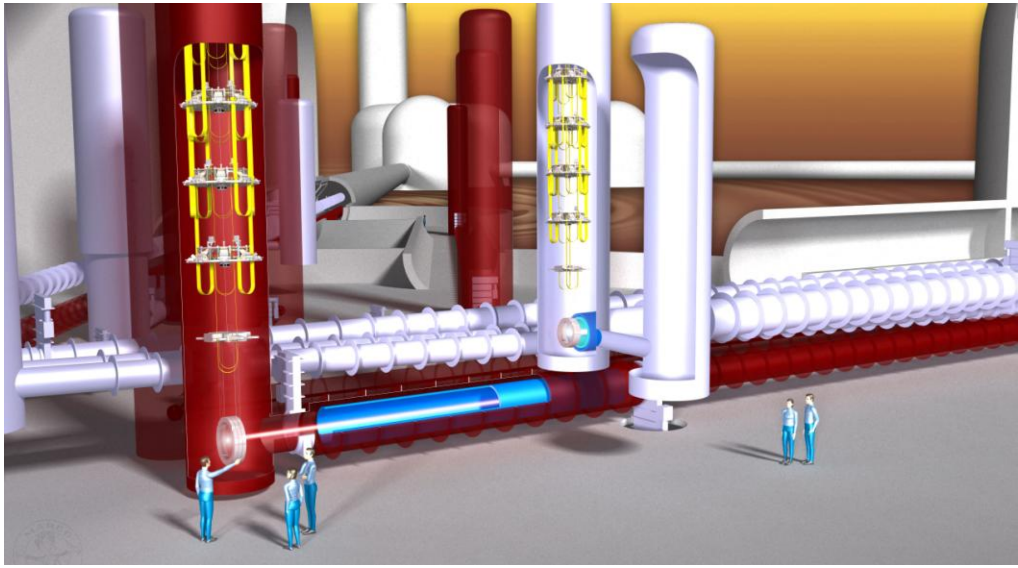
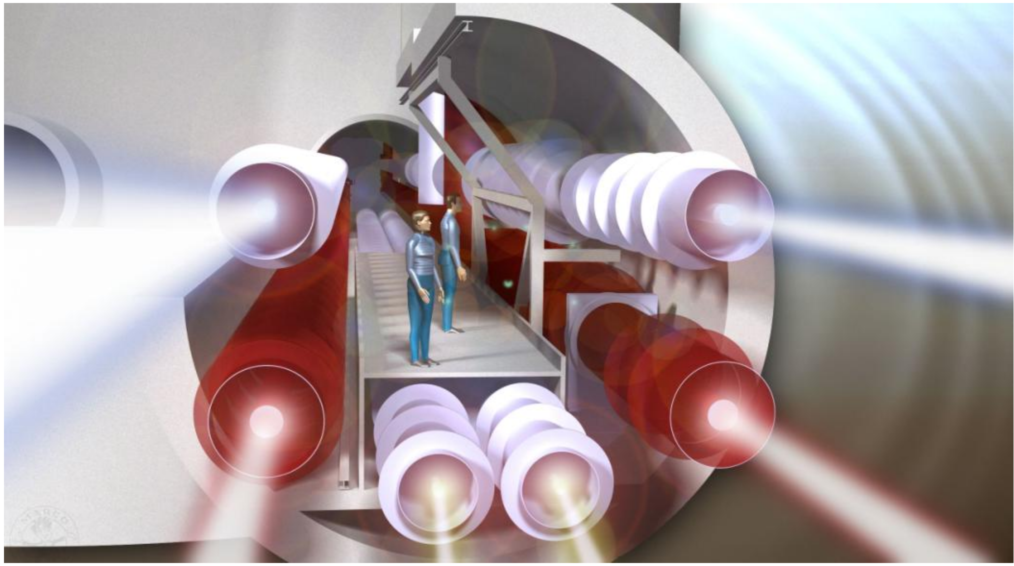




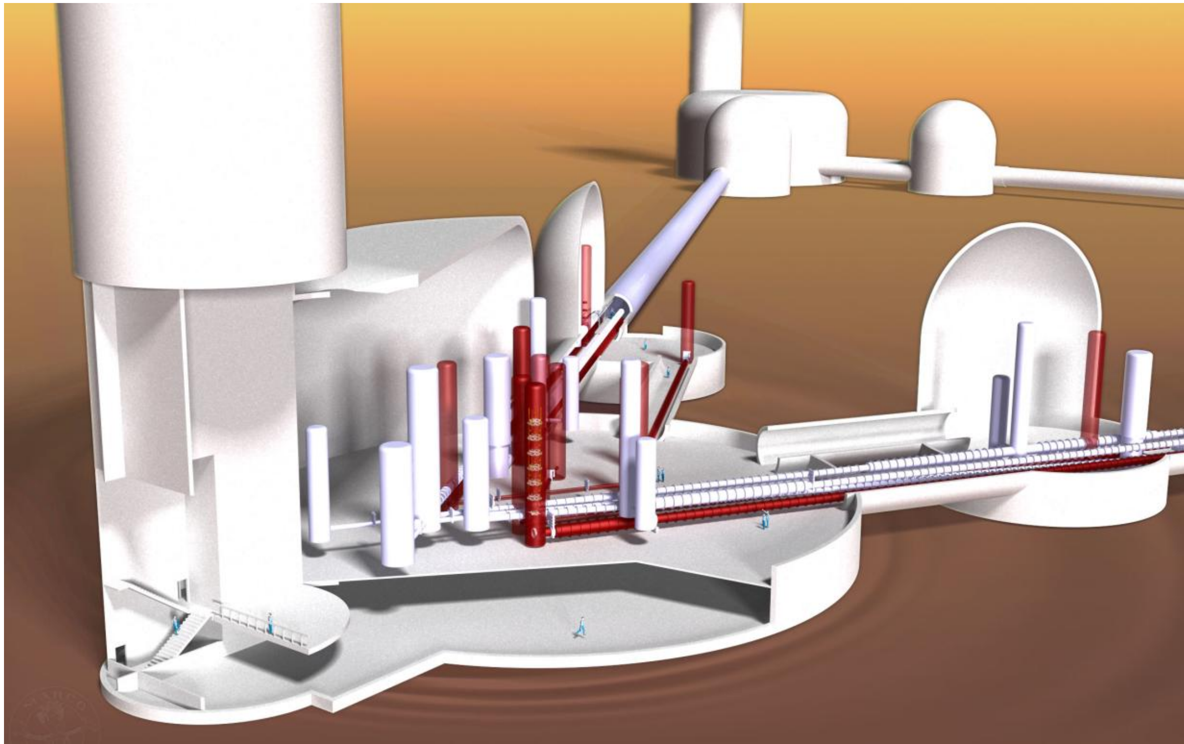
ET infrastructure

ET infrastructure

- Infrastructure: largest cost driver
  - Tunnels, caverns, buildings
  - Vacuum, cryogenics, safety systems
  - Collaborate with industry
    - COB (Amsterdam, October 9, 2008), STUVA
    - Big Science for Industry (Amsterdam, September 21, 2011)
    - Saes Getters Italy
    - Demaco Netherlands

- Experience
  - Kagra!
  - LIGO, Virgo, GEO
  - Underground labs
    - Gran Sasso, Canfranc,
    - Dusel, *etc.*
  - Mines
  - Particle physics
    - ILC, Cern, Desy, FLNL
  - Seismology
    - KNMI, Orfeus
  - Geology



Research and development

Proposed R&D program for Einstein Telescope

- Task 1: Studies at candidate sites
  - Collect long term seismic data in Europe
  - Information on attenuation, geology, coherence
  - Collaboration with local groups, geophysicists
  - Explore geophysical applications of Einstein Telescope
- Task 2: Sensor and network development
  - MEMS-based sensors
  - Opto-mechanical sensors
  - Network operation
- Task 3: Modeling of seismic and GGN noise
  - Analytical modeling of seismic and atmospheric systems
  - Validation of (FEA) modeling
  - Studies of subtraction problem
  - Regular workshops
- Coordination of activities
  - Transnational coordination of site studies and assessments: dedicated workshops
  - Database: administer and consolidate geophysical information
  - Consolidation of technical information: tunneling, vacuum, cryogenics, safety

Newtonian noise subtraction

- Seismic sensor (signal + noise) $$X_I = s_I + \sigma_I$$
- ITF output (GW signal + N. noise) $$Y = H + N$$
- Find $\alpha_I(\omega)$ to minimize "subtracted" signal

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- Simplified model $$\langle \rho(\omega,\mathbf{x})^* \rho(\omega',\mathbf{x}')\rangle = 2\pi\Gamma(\omega)^2\delta(\omega-\omega')e^{-\frac{|\mathbf{x}-\mathbf{x}'|}{\xi(\omega)}}$$
  - Exponential cross correlation function between sensors

$$\xi(\omega) : \text{Correlation length}$$

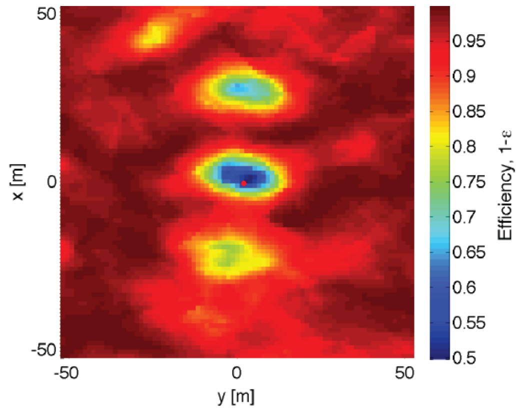
- Subtraction efficiency
  - 1 = no subtraction
  - 0 = 100% subtraction

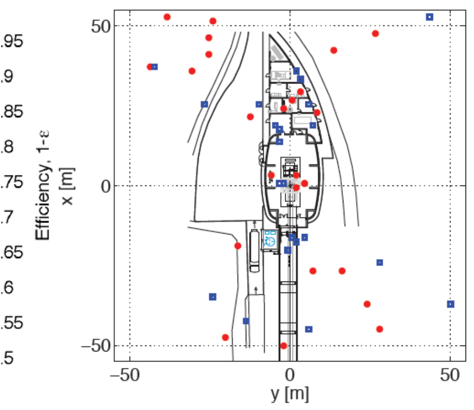
$$(1-\epsilon(\omega))^2 = 1 - \frac{C^\dagger_{SN}(\omega)C_{SS}(\omega)^{-1}C_{SN}(\omega)}{C_{NN}(\omega)}$$

[G. Cella, *et. al.*, Gen. Rel. Grav. (2010)]

NN subtraction simulation

- Advanced Virgo
  - Seismic PSD data
  - Correlation data
- Seismic sensors
  - Sensitivity SNR = 25
- Sensor grid around test mass
  - Regular and optimized grids
- Sensor network
  - Large number of sensors
  - Subtraction efficiency $1 - \varepsilon(\omega)$





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