Studying the seismic Newtonian noise with an array of atom interferometers

S. Pelisson[1,2], B. Canuel[1,2], A. Bertoldi[1,2], S. Gaffet[1,3], R. Geiger[1,4], A. Landragin[1,4] G. Lefèvre[1,2], J. Harms[5,6], I. Riou[1,2], P. Bouyer[1,2]

[1] MIGA Consortium [2] LP2N, Université Bordeaux-IOGS-CNRS [3] GEOAZUR, UNSA, CNRS, IRD, OCA [4] LNE-SYRTE, Observatoire de Paris [5] INFN, Sezione di Firenze [6] Università degli studi 'Carlo Bo'

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LAPHIA Laser & Photonics in Aquitaine

université de BORDEAUX

INSTITUT d'OPTIQUE GRADUATE SCHOOL

Outline

1. Newtonian Noise Modelling
2. Seismic datas
3. Newtonian Noise on MIGA instrument
4. Rejection method
5. Results and perspectives

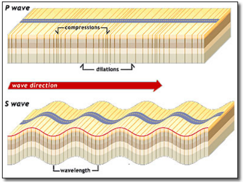
Newtonian Noise (NN) Modelling

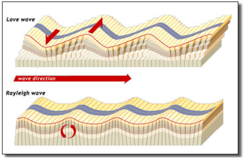
Atmospheric NN

- Quasi-static temperature perturbations
- Infrasound waves created by pressure fluctuations

Seismic NN

- Seismic spectra vary between different sites
- 2 wave-contributions:
  - Body-waves ⇒ P-,S-waves
  - Surface waves ⇒ Love waves, Rayleigh waves
- Dominant contribution at low frequencies (10 mHz - 1 Hz): **Rayleigh waves**





Rayleigh wave field

Gravity perturbation for a single test mass

- Field dominated by fundamental Rayleigh waves
- Underground cavity neglected
- Frequency-independent speed

$$\delta\phi(\vec{r}_0, t) = 2\pi G\rho_0 A e^{i(\vec{k}_\varrho\cdot\vec{\varrho}_0 - \omega t)} \left(\underbrace{-2e^{-hq_z^P}}_{eva.\ wave} + (1+\zeta(k_\varrho)) \underbrace{e^{-hk_\varrho}}_{surf.\ displ.} \right)$$

where

$$A = \frac{\xi_z(\vec{0}, 0)}{q_z^P - k_\varrho\zeta(k_\varrho)}$$

J. Harms, Living Rev. Gen. Rel. **18**, 3 (2015).

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Vertical displacement field

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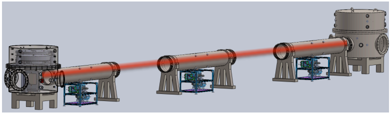
⇒ **Need for detailed informations on the local seismic field**

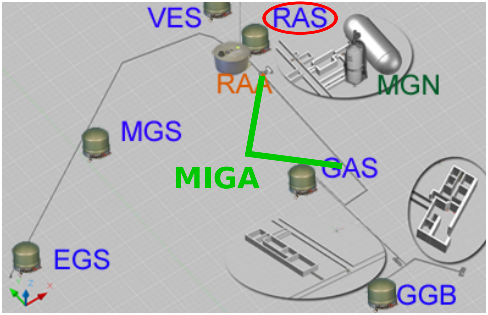
Onsite measurement

- Case study: MIGA instrument
- 2 arms of baseline $L = 300\,m$
- Underground detector at depth $h = 250\,m$



Canuel et al., Proc. SPIE **9900**, 990008-990008-12 (2016).

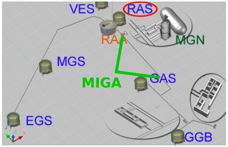
Site Map



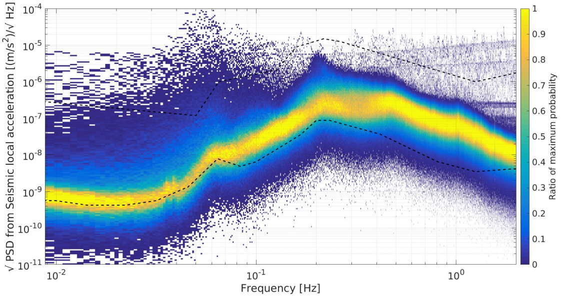
Onsite measurement

- Broad-band tri-axial seismometer
- STS-2 'Low Power' captor

Site Map



Seismic spectrum



Seismic NN

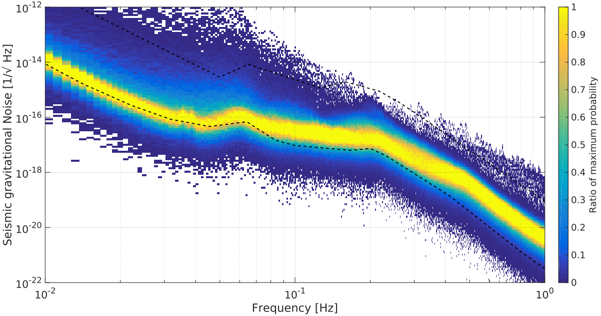
NN on a 300 m gradiometer

- Gravity acceleration perturbation on one single test mass

$$\delta\vec{a}(\vec{r}_0, t) = -\vec{\nabla}_0 \delta\phi$$

- Noise spectral density of differential acceleration along a baseline of length L

$$S(\delta\vec{a}(L\vec{e}_x) - \delta\vec{a}(\vec{0}); \omega)$$



Noise averaging

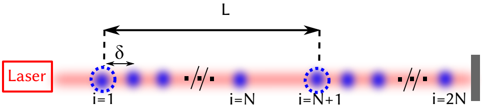
Mitigation of the NN

- Extracting the gravitational wave signal using averaging method

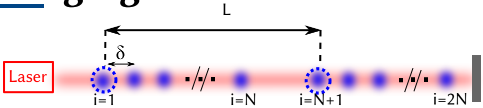
  ⇒ Averaging the the NN over several realizations

$$H_N(t) = \frac{1}{N}\sum_{i=1}^{N}\psi_i(t)$$

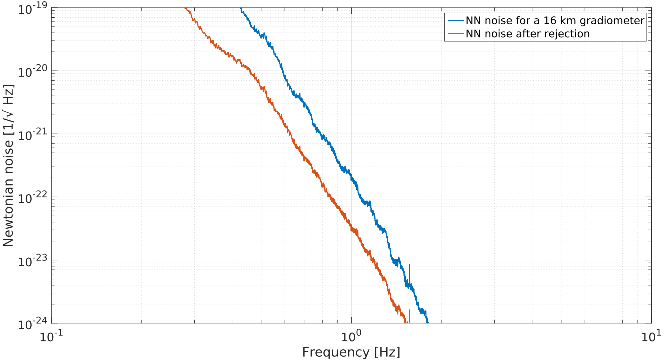
- $L_{tot} = 32\ km$; 80 gradiometers of baseline $L = 16\ km$
- Chaibi et al., PRD **93**, 021101(R) (2016).



Noise averaging



1 single gradiometer vs averaging over 80 gradiometers



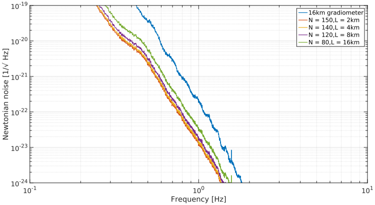
$\Rightarrow$ 1 order of magnitude rejected by averaging

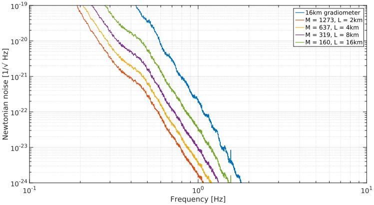
Improving the rejection ?

Changing the baseline

1. With the same sampling rate for the gravimeters along the arm
2. Changing the sampling rate ⇒ increasing the number of gravimeters
3. Baseline initially optimized for atmospheric noise rejection

Modifying the baseline L





Conclusions and Perspectives

Mitigation of Seismic Noise

- Real on-site datas
- Characterization of the seismic noise
- Statistical averaging
- Better rejection by increasing the sampling

Future work

- Mitigation with different sampling of the gravimeters
- Taking into account higher-order correlations
- Study of the atmospheric noise

Thank you for your attention !