Studying fluctuations of the local gravity field 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], and P. Bouyer[1,2]

[1]MIGA Consortium
[2]LP2N, Laboratoire Photonique, Numérique et Nanoscience, Université Bordeaux-IOGS-CNRS : UMR 5298, rue F. Mitterand, F-33400 Talence, France
[3]GEOAZUR, UNSA, CNRS, IRD, OCA, 250 rue Albert Einstein, 06560 Valbonne, France
[4]LNE-SYRTE, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Université, UPMC Univ. Paris 06, LNE, 61 av. de l'Observatoire, 75014 Paris, France
[5]INFN, Sezione di Firenze, I-50019 Sesto Fiorentino, Italy
[6]Università degli studi 'Carlo Bo', I61029 Urbino, Italy

Abstract

The progresses of atom interferometry allows to create new design for detecting weak fluctuations of the gravity field. Applications of these design extend from precision gravimetry to gravitational waves detection. Here we propose a new detection strategy for **gravitational waves (GW)** detection below few Hertz based on a correlated array of **atom interferometers (AI)** ([1,2,3]). This array could also provide a new way to characterize terrestrial fluctuations of gravity field so we propose to look at these fluctuations both as a noise to be reduced for GW detection and as a subject of interest for geophysical studies. The studies are made with real data made on an underground laboratory, LSBB located in Rustrel in the south of France.

I - Detecting gravitational waves with cold atoms

- Atoms ⇔ matter-waves
- Lasers are used to manipulate these matter-waves
- Sensitivity $\Delta\phi$ depends on the potential difference cumulated along the two paths

Atom gradiometer

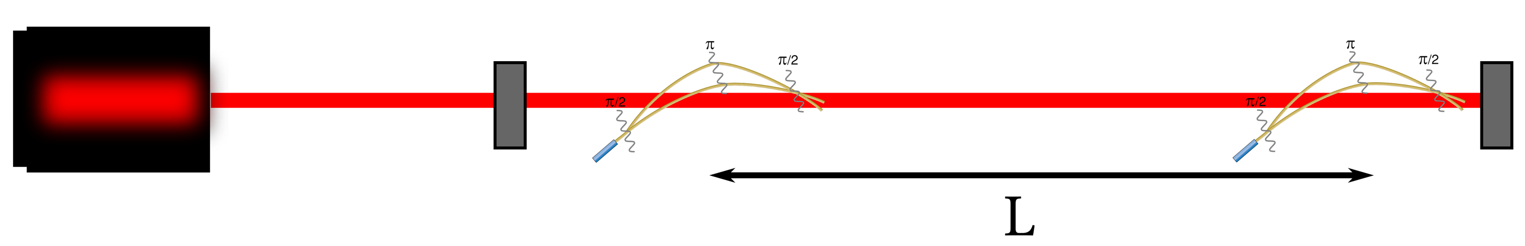

Fig.1: Atomic gradiometer made of 2 AI (yellow lines) in a laser cavity separated by a distance L.

Gradiometer sensitivity[4]

$$\Delta\phi(X,t) = \epsilon(X,t) - \epsilon(X+L,t) + 2nk\left[\left(\frac{L\ddot{h}(t)}{2} + a_x(X+L,t) - a_x(X,t)\right)\right] \otimes s_\alpha(t)$$

II - Local gravity fluctuations

Each gravimeter measures the local gravity fluctuations. These fluctuations could be of two different origins:

- Gravitational wave signal
- Terrestrial signal

The terrestrial signal is separable in two distinct parts:

The atmospheric part

Coming from the infrasound waves propagating in the atmosphere around the detector due to pressure fluctuations.

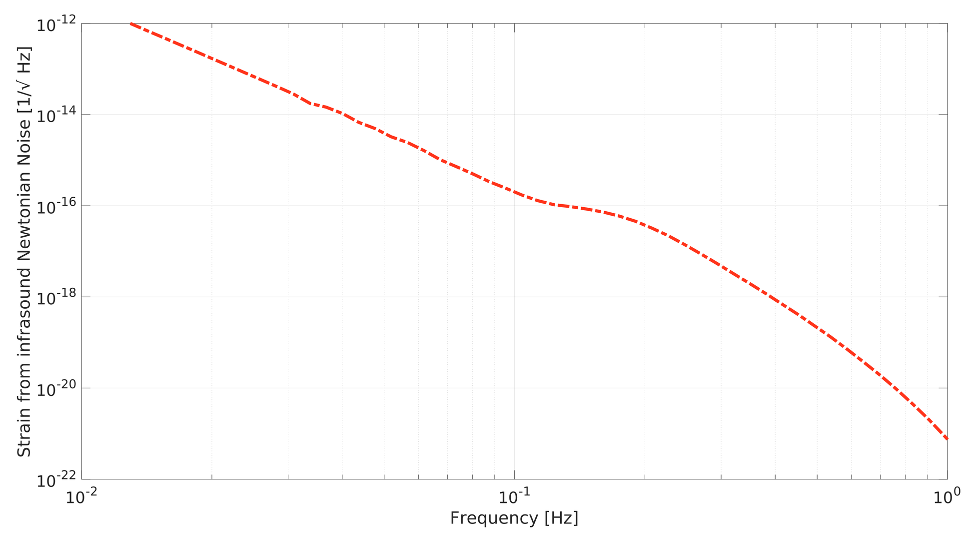

Fig.2: Strain noise from atmospheric pressure fluctuation on a gradiometer of $L = 300$ m

The seismic part

Originating from the seismic field around the detector.

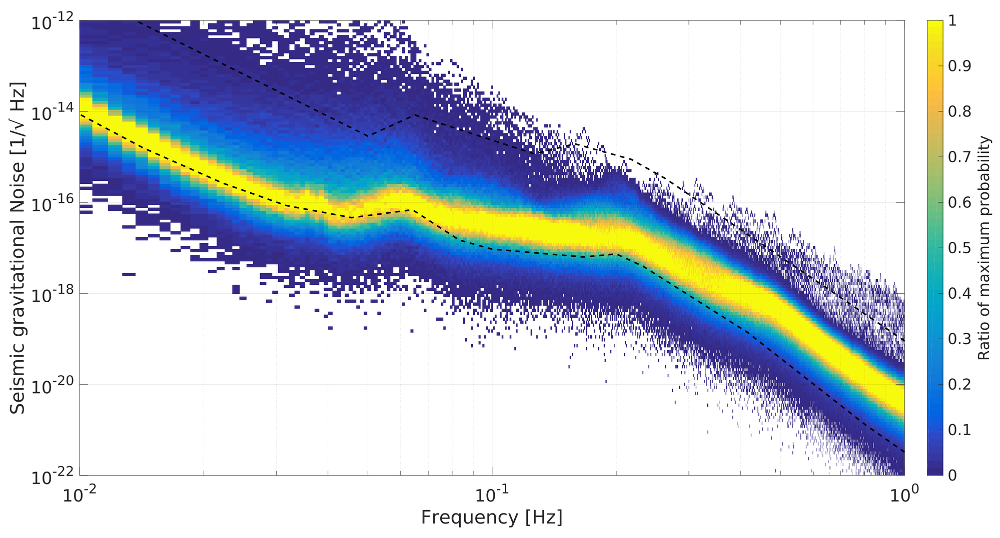

Fig.3: Strain noise from seismic field on a gradiometer of $L = 300$ m

The two curves above are obtained from measurement taken from [6] for atmospheric part and from seismic data collected on Rustrel (France) where a project exists to install that kind of atomic gradiometer.

III - Newtonian noise rejection strategies

The terrestrial fluctuations of gravity field is a source of noise for GW detection known as **Newtonian noise (NN)**. NN is therefore considered as a fundamental limit for any ground based GW detectors at the sub-Hz level. The use of an array of AI allows to realize position resolved measurement of gravity fluctuations unlike optical GW detectors as VIRGO/LIGO. This possibility allows to imagine some strategies to reject the NN. One of these strategie recently proposed [7] consist to averaging the NN over several realizations of the measurement using the scheme presented below.

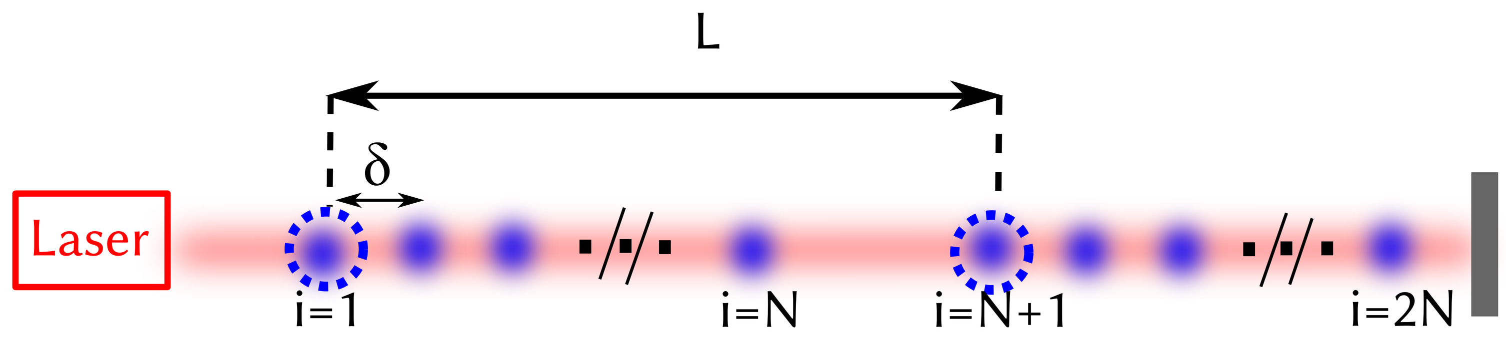

Fig.4: Array of atomic gradiometer similar to the one displayed on Fig.1.

To investigate the efficiency of the rejection, we worked out the NN on site of LSBB using the measurement of the seismic spectrum presented on figure below.

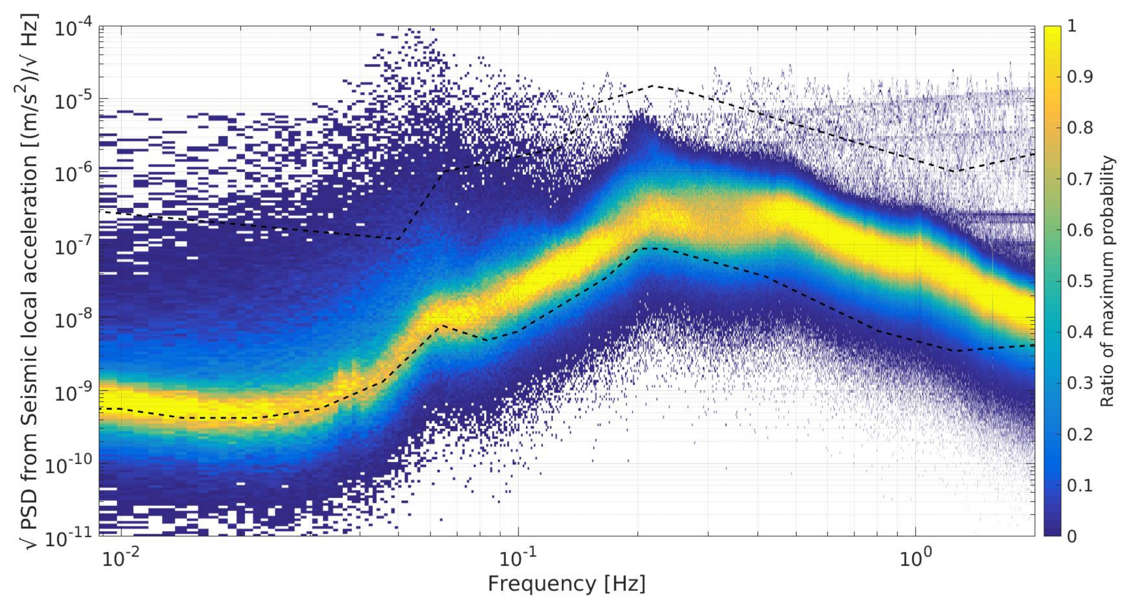

Fig.5: Seismic spectrum measured at LSBB responsible of the NN displayed on Fig.3 and Fig.5.

The NN is presented here for one single gradiometer of $L = 16$ km (upper curve) and for an array of AI (lower curve).

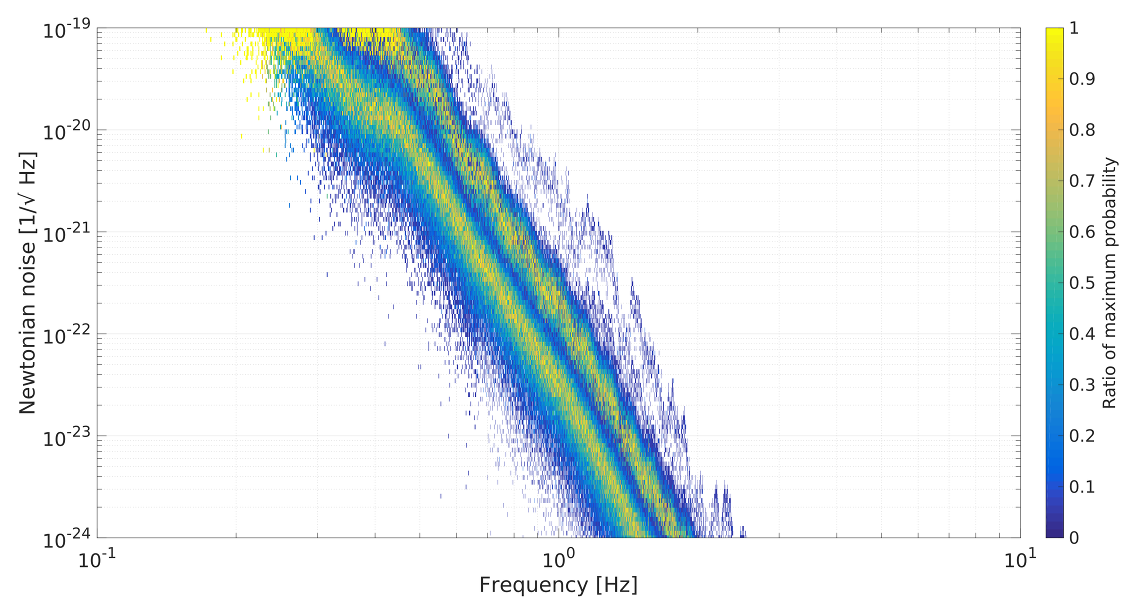

Fig.6: NN for a single gradiometer of length 16 km (upper curve) compared with an array of AI (lower curve).

This method allows to lower the NN by one order of magnitude. Some other strategies might lead to higher rejection. We currently work on the improvement of these strategies by taking into account higher correlations between each AI.

IV - Perspectives

- Atom interferometry can be a powerful tool to detect tiny fluctuations of the gravity field ⇒ access to spatial signature of gravitational effects.
- We explore the possibility to map the Earth gravity field with an array of atomic gravimeters.
- Study of new method to understand and reject NN in GW detectors ⇒ go beyond the configuration studied here.

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