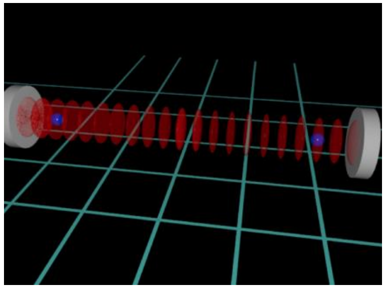

The MIGA project

Matter-wave laser **I**nterferometric **G**ravitation **A**ntenna

Precision gravity measurements with atom interferometry

Remi Geiger (SYRTE, Observatoire de Paris), on behalf of the MIGA collaboration

GPHYS Workshop - Institut d'Astrophysique de Paris, 06/07/2015

Outline

1. Overview of the MIGA project
2. Atom interferometry and GW detection
3. MIGA main subsystems (brief)
4. Status and perspectives

Overview of the MIGA project

- **Equipex project :** 10 years (2013 – 2023), 9 M€, 13 research institutes, 2 companies
- **Goal : precision gravity measurements with Atom Interferometry (AI)**
- Design and realization of an instrument targeting 2 applications:

1. « Applied » gravity: monitoring of underground mass distributions

   → Applications: geophysics, hydrology

2. Fundamental physics

   → Test setup for applications of AI to gravitational wave (GW) detection

   → Other tests of gravitational physics (UFF, Lorentz invariance).

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2. Fundamental physics

   Today's talk

   → Test setup for applications of AI to gravitational wave (GW) detection

   → Other tests of gravitational physics (UFF, Lorentz invariance).

***References (MIGA subsystems and geophysics applications)**:*

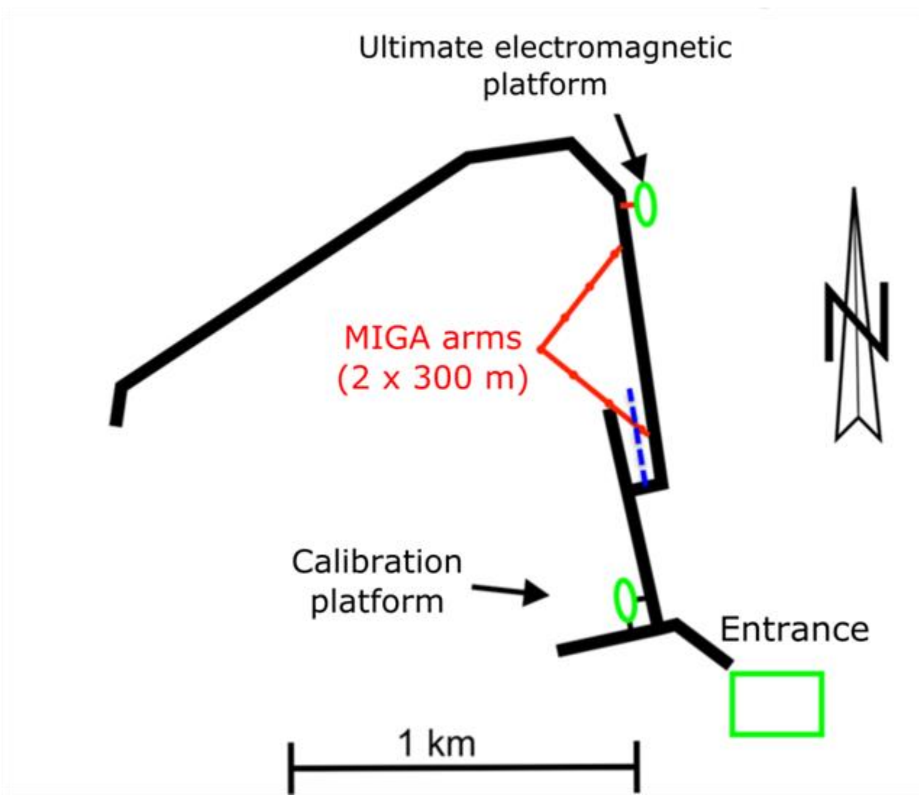
- *B. Canuel et al, E3S Web of Conferences **4**, 01004 (2014)*
- *R. Geiger et al, Proceedings of the 50th Rencontres de Moriond, arXiv:1505.07137 (2015)*

Overview of the MIGA project

LSBB
Laboratoire Souterrain à Bas Bruit
Low Noise Inter Disciplinary Underground Science & Technology

Implementation site

- Low noise underground laboratoy
- Site of (hydro)-geological interest



Principle of the MIGA instrument (in brief)

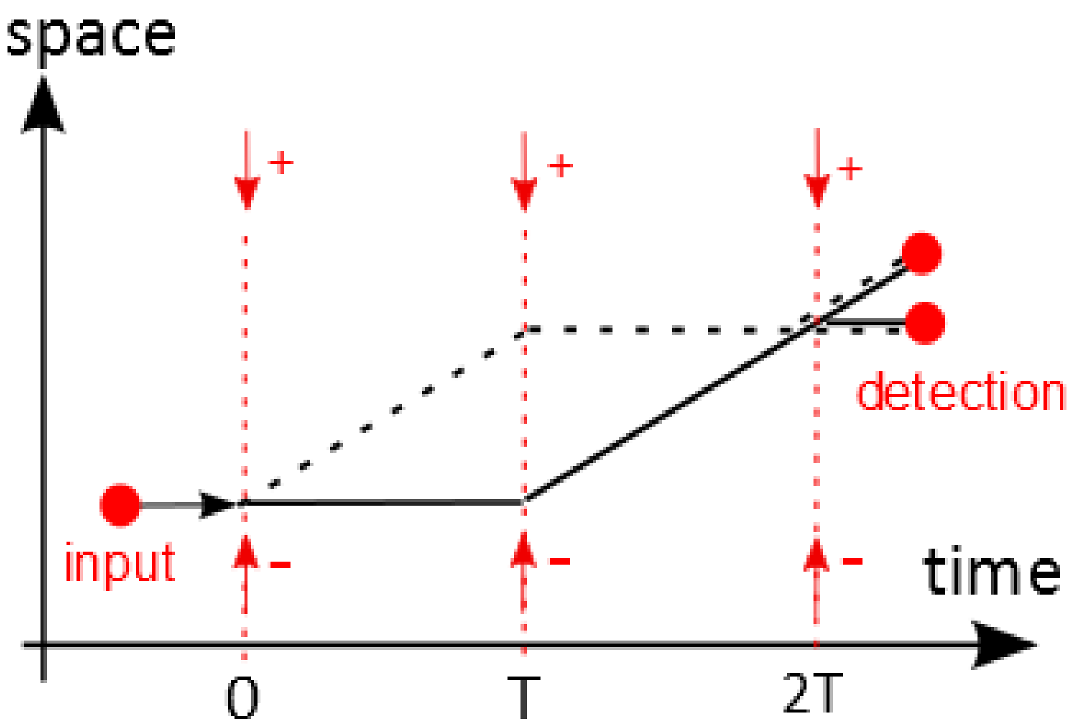
More details : FOMO 2014 summer school, lecture notes

https://sites.google.com/site/researchgeiger/home/teaching

Principle of atom interferometry

→ Probe the local phase of a laser beam using free falling atoms

→ Mach-Zehnder like interferometer using counter-propagating lasers



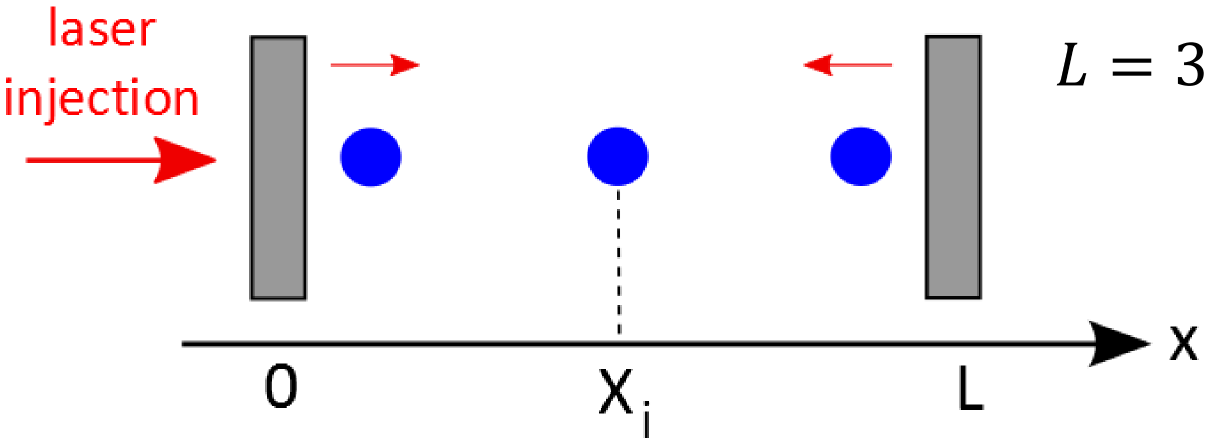
AI output: $P \propto \cos \Delta\Phi$

$$\Delta\phi = 2kT^2 a$$

$$2k = \frac{4\pi}{\lambda} = \frac{4\pi\nu_0}{c}$$

Local accelaration of the laser/atom

Principle & orders of magnitude



$L = 300\ m$ cavity

Rb87 atoms:

$\lambda = 780\ nm$

Interferometer phase shift at position x : $\Delta\phi(x) = 2kT^2 a(x)$

Interrogation time $2T \approx 0.5\ s$; Phase sensitivity = 1/SNR ~ 1 mrad/shot

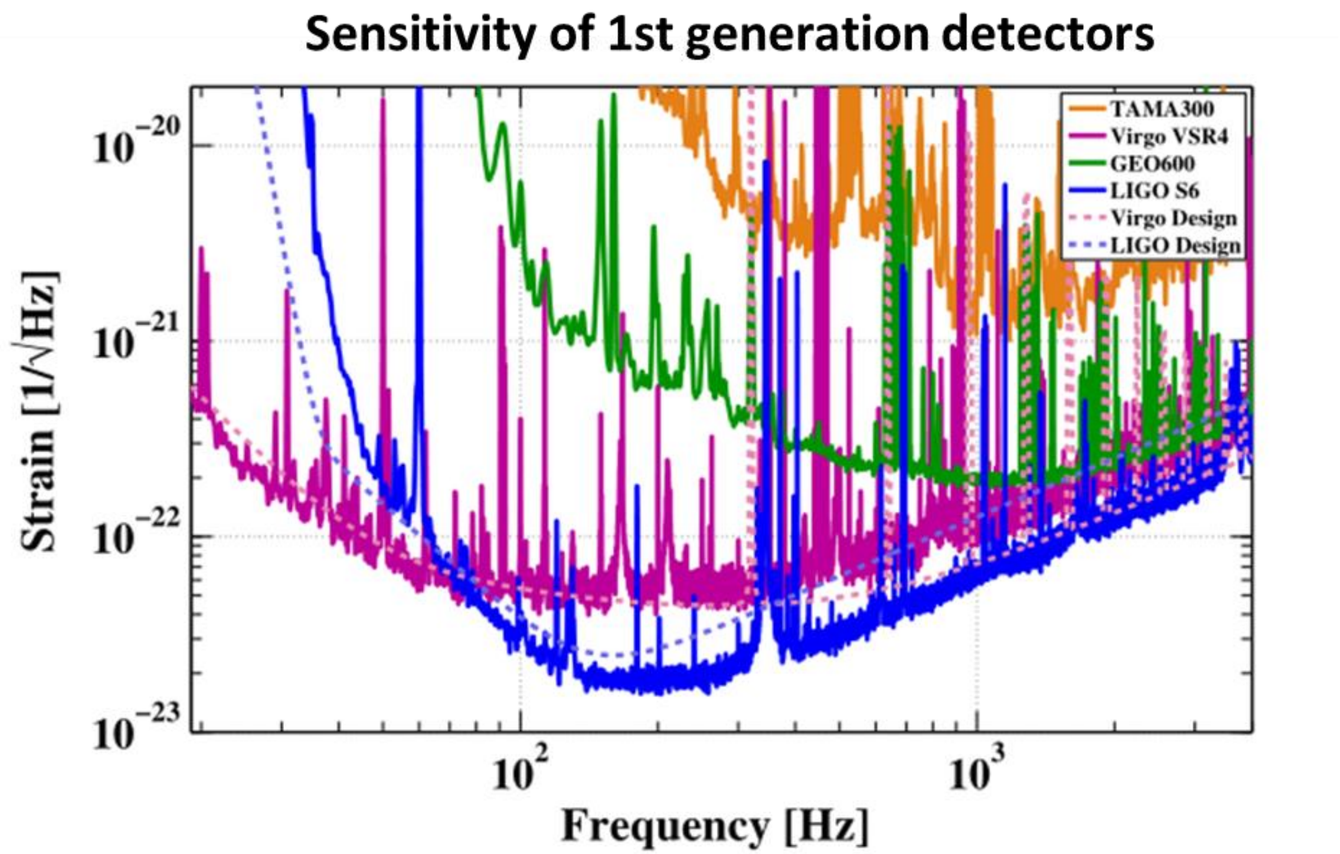
Acceleration sensitivity $\sim 10^{-10}\ m.s^{-2}/\sqrt{Hz}$

Gravity gradient sensitivity $\sim 10^{-13}\ s^{-2}/\sqrt{Hz}$ → 1 ton at 100 m

GW detection with AI ?

Optical Fabry-Perot Michelson GW detectors

demonstrated outstanding performances !

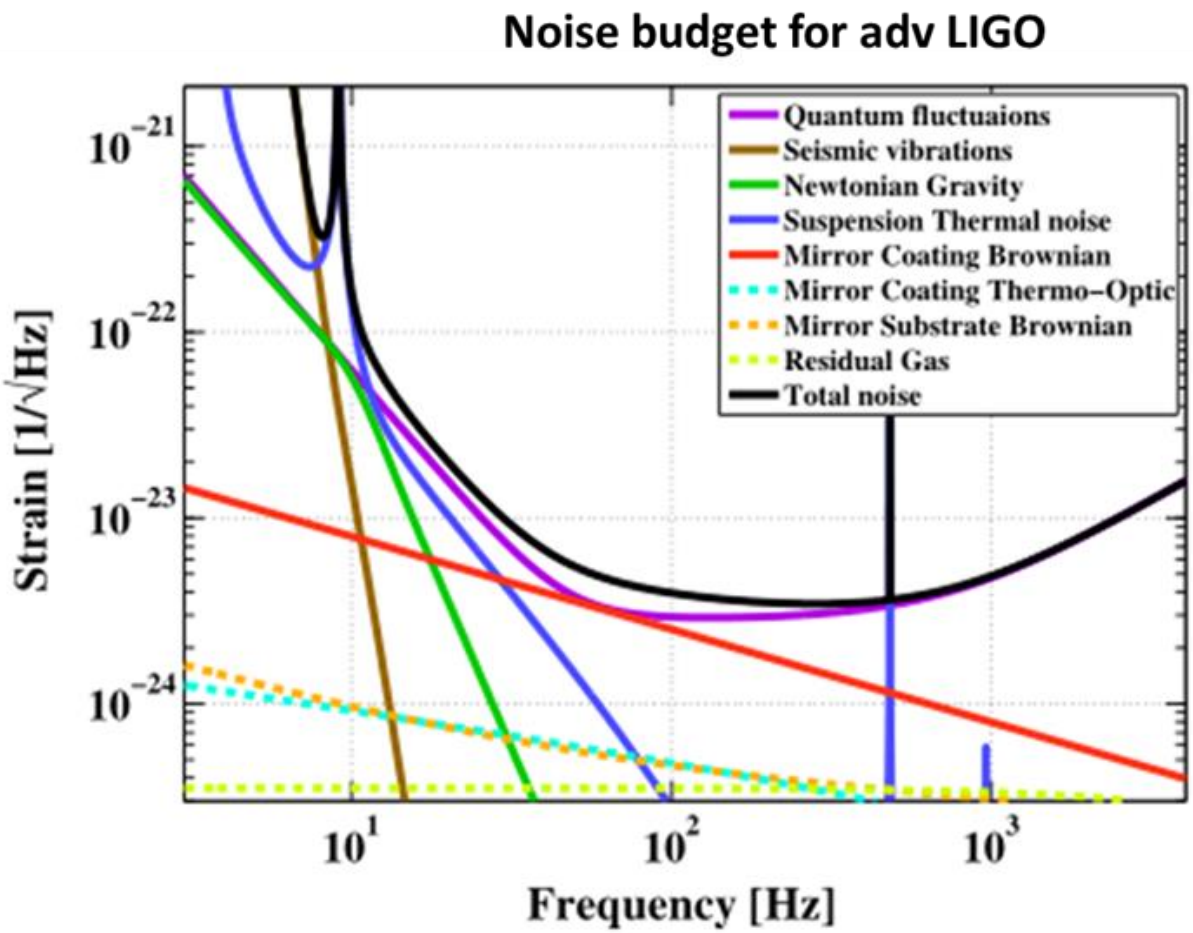


*From Adhikari, Rev. Mod. Physics **86**, 121 (2014)*

GW detection with AI ?

And next generation detectors will be even better….

But they will still have limitations at low (< 10 Hz) frequency.



*From Adhikari, Rev. Mod. Physics **86**, 121 (2014)*

GW detection with AI ?

Motivation:

- At low frequencies (<10 Hz), optical GW detectors are limited by **motion noise**
- Residual seismic noise (design of suspension system)
- Thermal noise in the suspensions
- Thermodynamical noise in the mirror, etc.

Why not using perfectly free falling test masses to measure the laser phase?

→ Atom interferometry

The advantages of these atomic techniques are many: the clouds have a very high immunity to radiation pressure noise, very low thermal noise, and no suspension noise. The common launch for the atomic clouds makes the influence of seismic noise nearly zero. However, the Newtonian noise is a problem for the atom interferometers just as it is for laser interferometers. A spaced-based detector, Atomic Gravitational wave Interferometric Sensor (AGIS), has also been proposed to circumvent these terrestrial limits (Hogan *et al.*, 2011).

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Newtonian Noise

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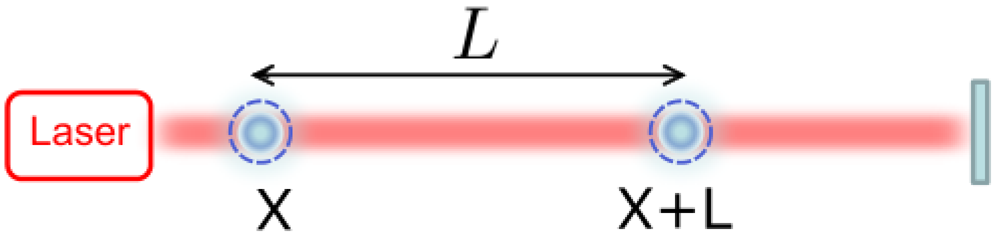
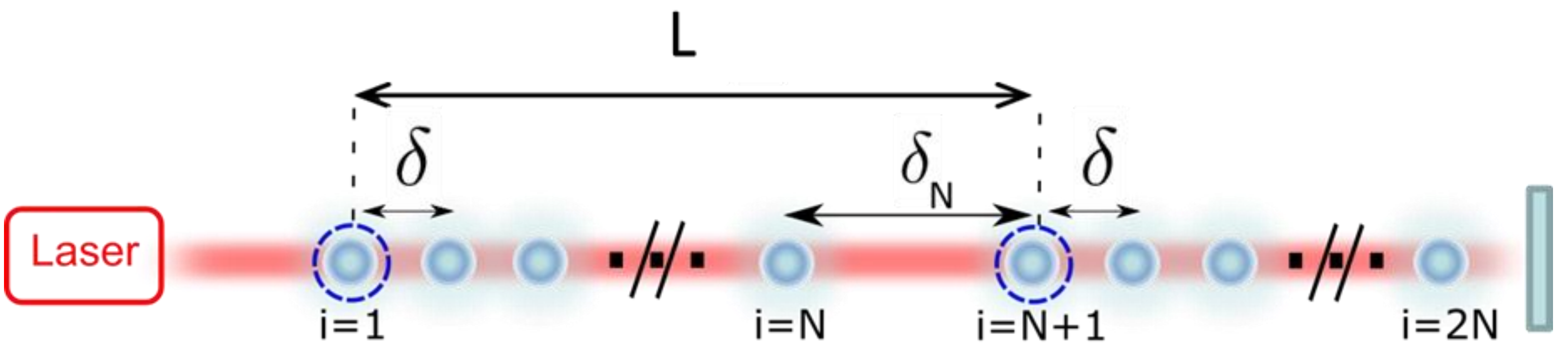


$$\psi(X,t) = 2nk\left[\frac{L\ddot{h}(t)}{2} + a_x(X+L,t) - a_x(X,t)\right] \otimes s_\alpha(t)$$

Impossible to distinguish a fluctuating gravity gradient from the GW signal with 2 test masses.

Beating Newtonian Noise with AI arrays



Idea : repeat the gradiometer experiment to obtain several realizations of the NN

The NN characteristic length (few km at most) is << GW wavelength

→ average the NN to zero.

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

W. Chaibi, R. Geiger, B. Canuel, A. Bertoldi, A. Landragin, P. Bouyer, *submitted for publication*

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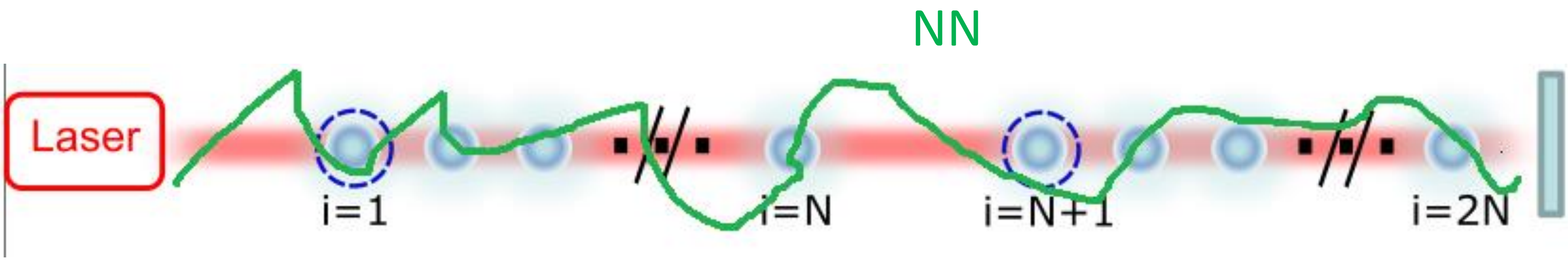

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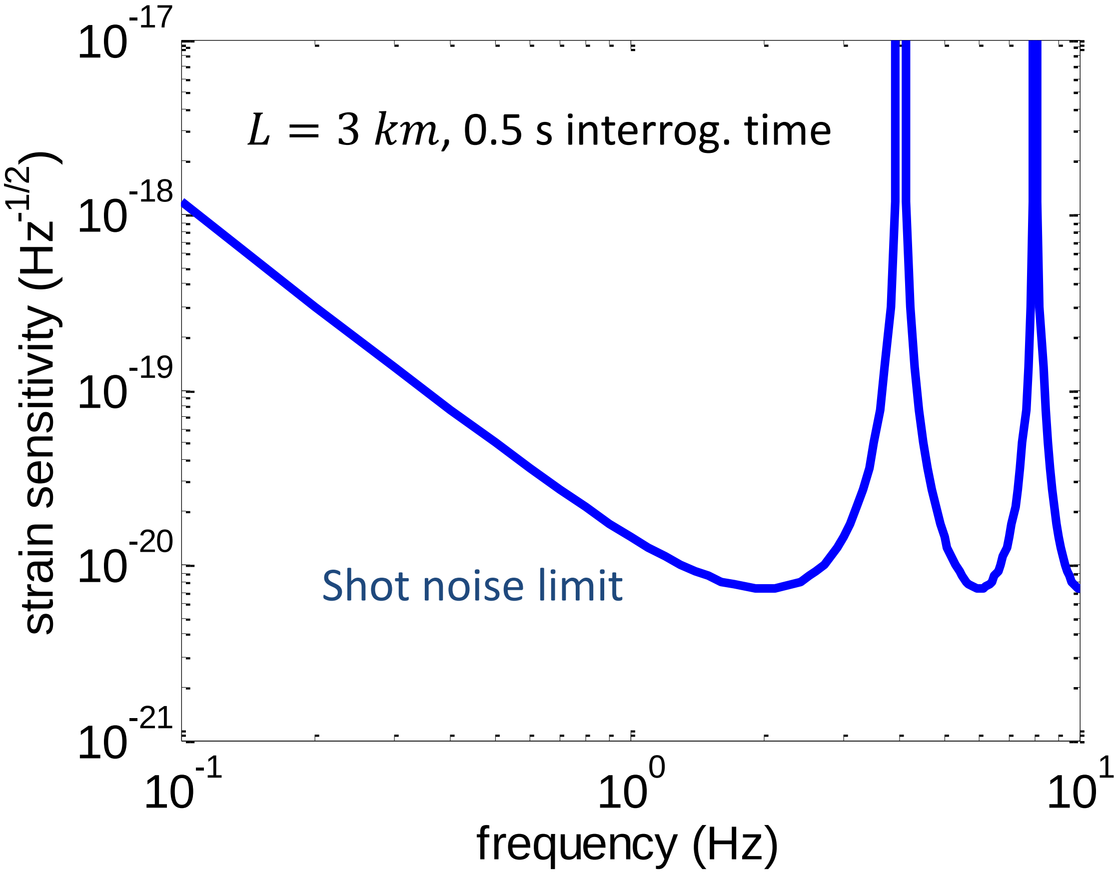
Shot noise limited AI GW detector

$$h \sim \frac{\delta\phi}{nkL}$$

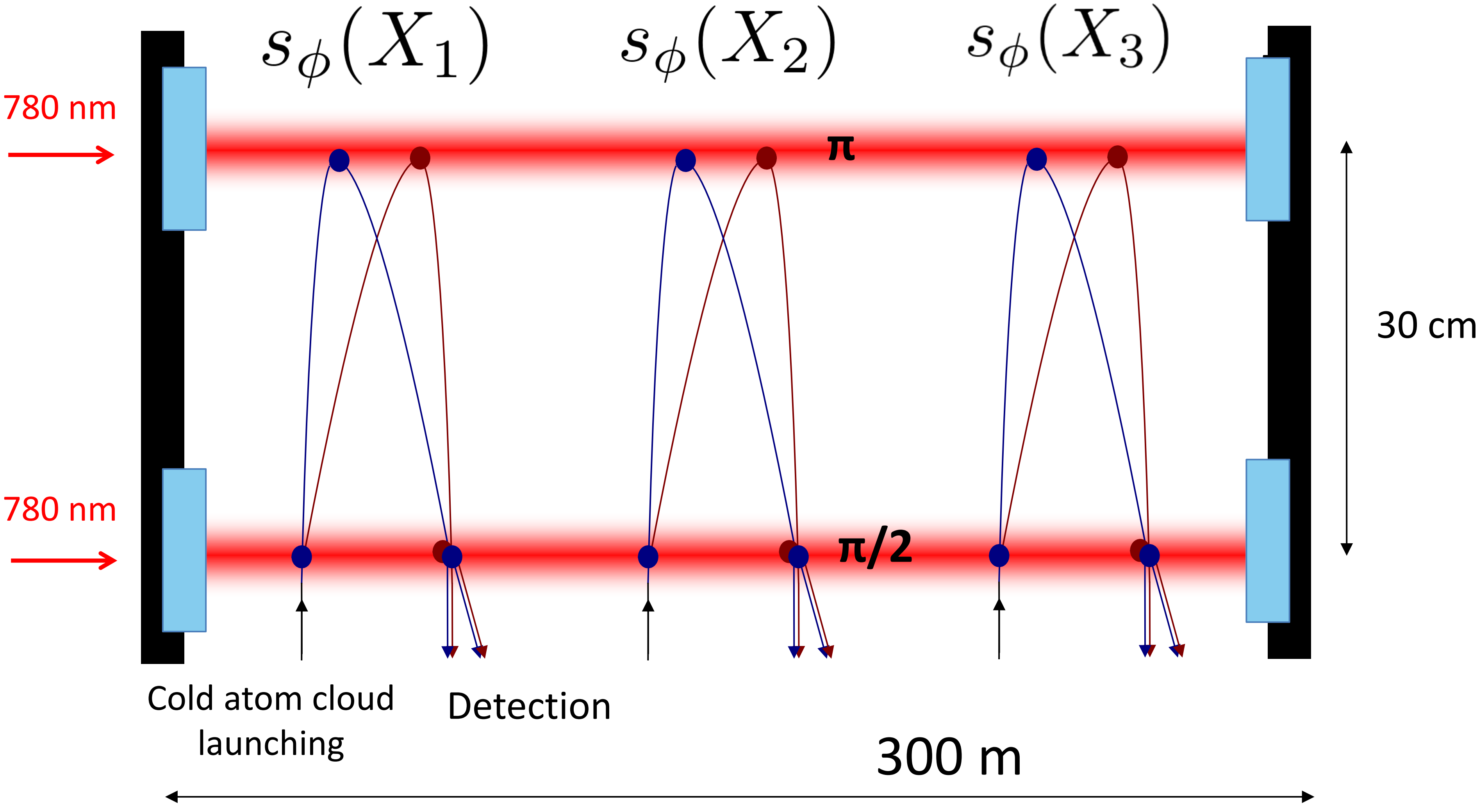
- $\delta\phi = 1\ \mu rad/\sqrt{Hz}$ (10^{10} atoms/second, 20 dB squeezing)
- $n = 1000$ Large Momentum Transfer beam splitters)



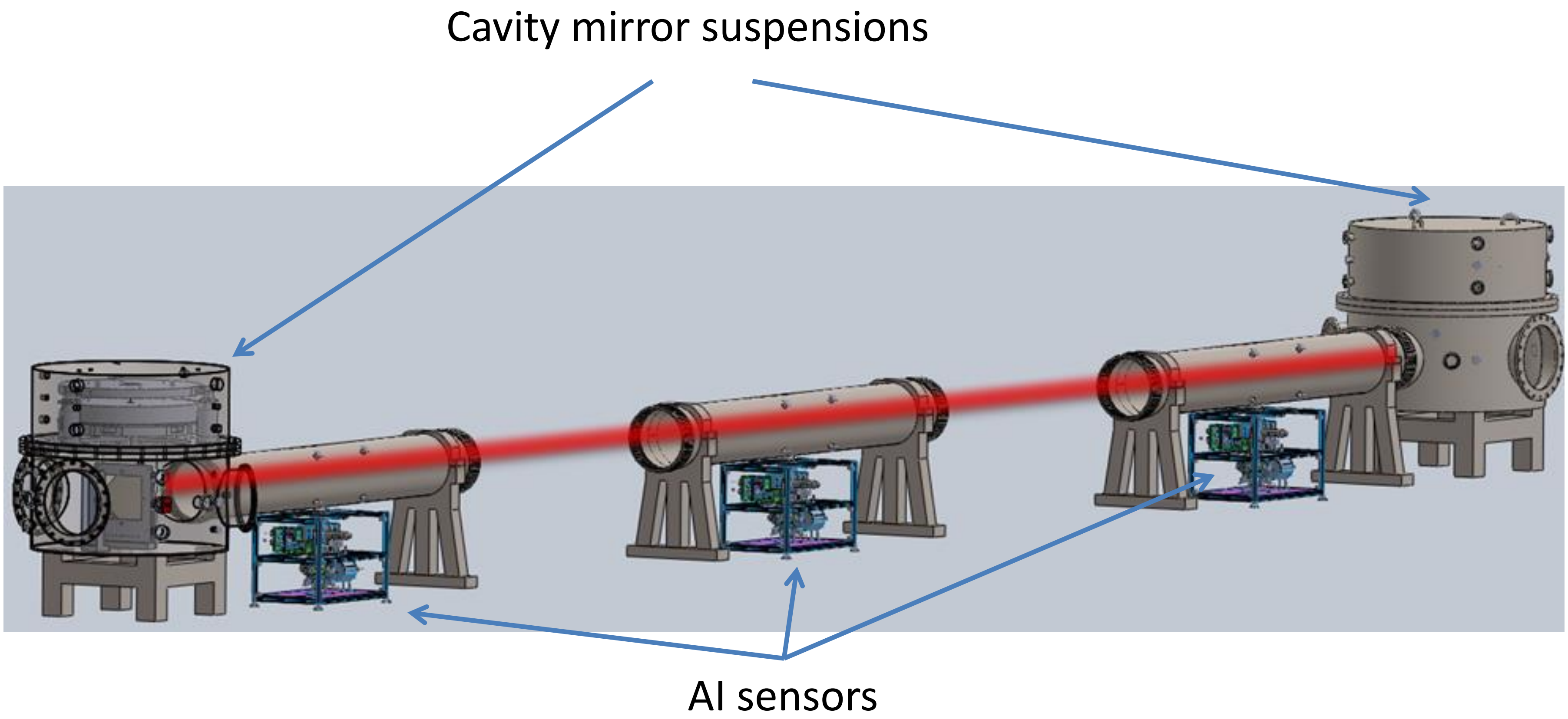
A (very) challenging project

for atom optics !

MIGA geometry



MIGA main subsystems



MIGA main subsytems

- SYRTE (Paris) : cold atom source and detection system, AI expertise
- LP2N (Talence): cavity design, vacuum system
- ARTEMIS (Nice): cavity mirror suspensions, GW detection expertise
- µQuans (Talence): laser systems
- LSBB (Rustrel): tunnels & site management, geophysics expertise

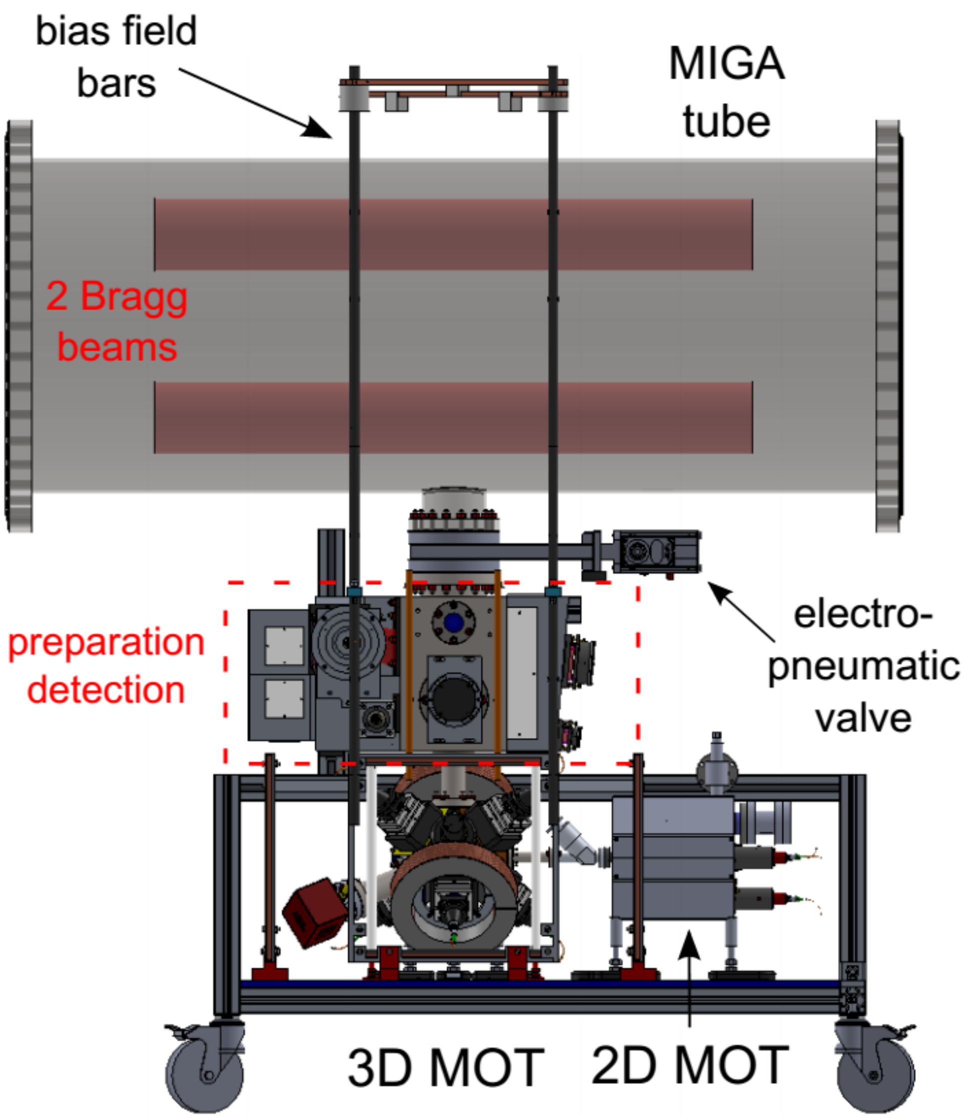
LP2N Laboratoire Photonique, Numérique et Nanosciences

ARTEMIS

µQUANS

LSBB Laboratoire Souterrain à Bas Bruit
Low Noise Inter Disciplinary Underground Science & Technology

Cold atom source



10^8 atoms at 2 µK

launched at 4 m/s

Design by Louis Amand

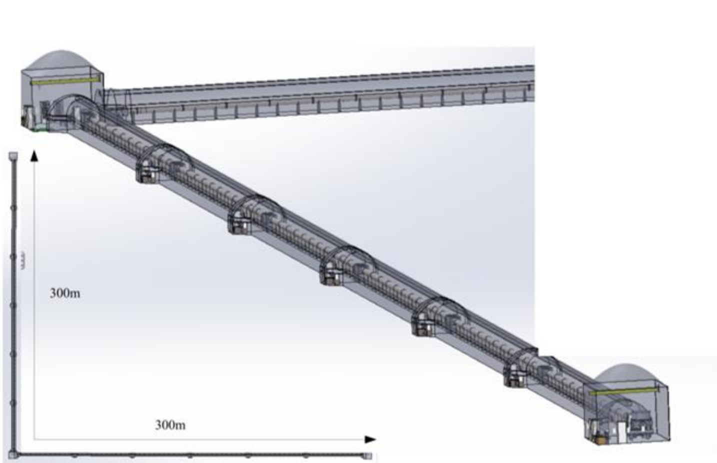
Similar to that of the

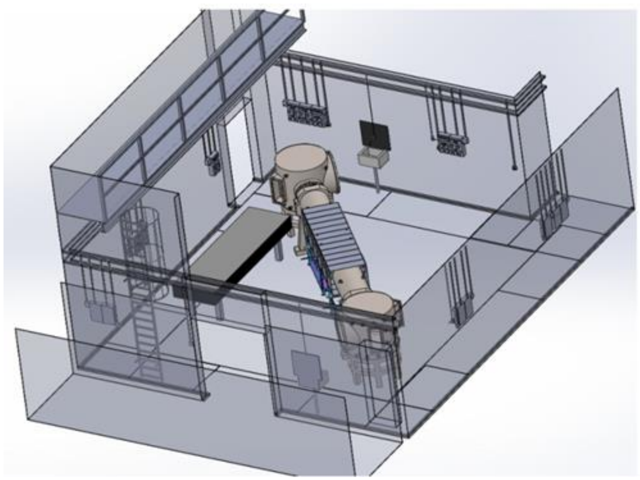
cold atom fountains and

to the SYRTE gyroscope.

MIGA : status and perspectives

- First cold atom source delivered by SYRTE to LP2N (June 2015)
- 6 m AI gradiometer in the optical cavity under design
- Development of high sensitivity AI techniques at SYRTE
- Beginning of the digging of the MIGA galleries at LSBB (Jan. 2016)
- MIGA installation at LSBB in 2018
- MIGA commissioning and data runs: 2018-2023.





Conclusion

- MIGA : an instrument to study applied and fundamental gravity
- Applications in **geophysics**, e.g. monitoring of subsurface mass transfers
- **Test setup for GW detectors with AI**.

→ Ideas: use free falling atoms instead of suspended mirrors + network of AIs to resolve the Newtonian Noise

→ gain at low frequency (< 10 Hz)

- Many **challenges in cold atom physics** to reach $\sim 10^{-20}/\sqrt{Hz}$ strain sensitivity levels around 1 Hz
- Important European effort → towards a EU research infrastructure ?

The MIGA team (a part of it)

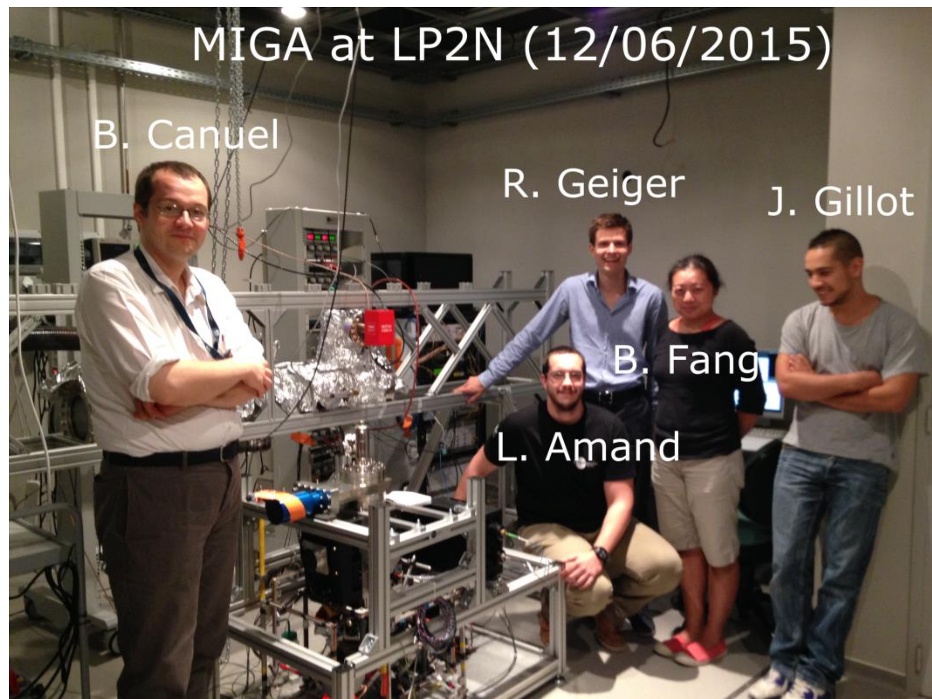
LP2N: I. Riou

P. Bouyer

ARTEMIS:
W. Chaibi

SYRTE
D. Holleville

A. Landragin



Thank you for your attention