Large Scale Atom Interferometry with MIGA and ELGAR

B. Canuel, LP2N,IOGS/CNRS/Univ. Bordeaux
for the MIGA and ELGAR consortium

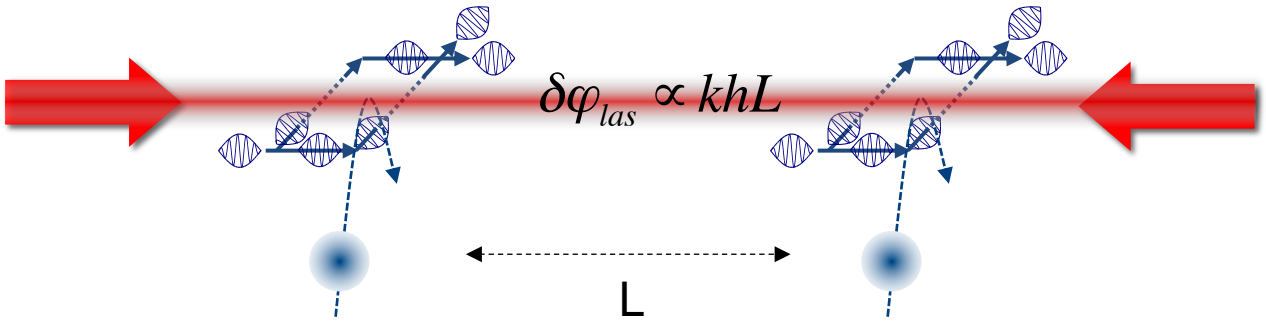
Outline

- Low frequency GW detectors with AI and GGN
- The MIGA antenna
  - Infrastructure/vacuum system/Atom source
- ELGAR initiative

Low frequency GW detectors with AI and GGN

GW detection with Atom gradiometry

Uses free falling atoms as “test masses” instead of mirrors

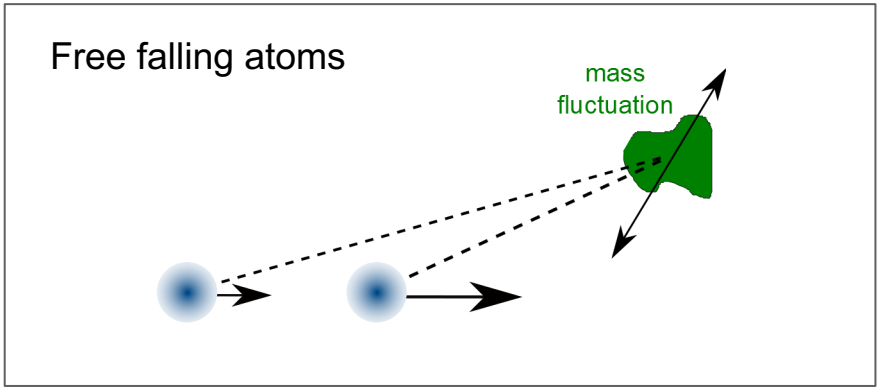


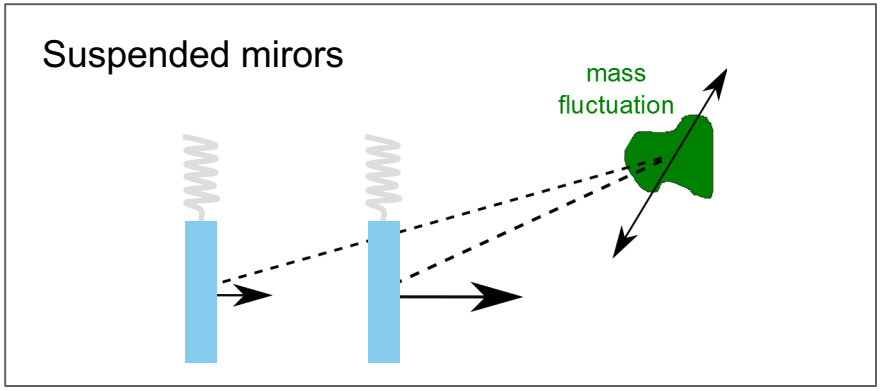
PHYSICAL REVIEW D **78,** 122002 (2008)

Atomic gravitational wave interferometric sensor

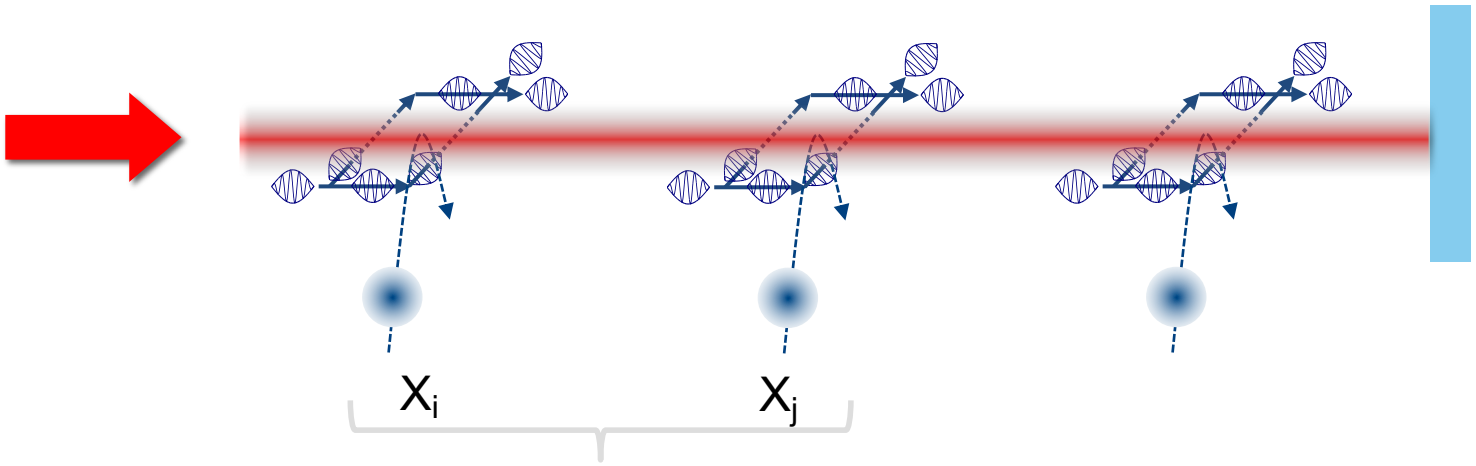
Savas Dimopoulos,[1,*] Peter W. Graham,[2,†] Jason M. Hogan,[1,‡] Mark A. Kasevich,[1,§] and Surjeet Rajendran[1,2,‖]
[1]*Department of Physics, Stanford University, Stanford, California 94305, USA*
[2]*SLAC, Stanford University, Menlo Park, California 94025, USA*
(Received 28 August 2008; published 19 December 2008)

Strong immunity to seismic noise
Sensitivity to Gravity Gradient Noise is the same





Networks of AI sensors for GGN reduction



$$\Delta\phi_{at}{}^{i}\text{-}\Delta\phi_{at}{}^{j}$$

- GW $\propto kh(X_i - X_j)$
- Gravity Gradient $\propto 2kT^2\left[a(X_i) - a(X_j)\right]$

Discrimination between GW effects and gravity gradients using the spatial resolution of the antenna

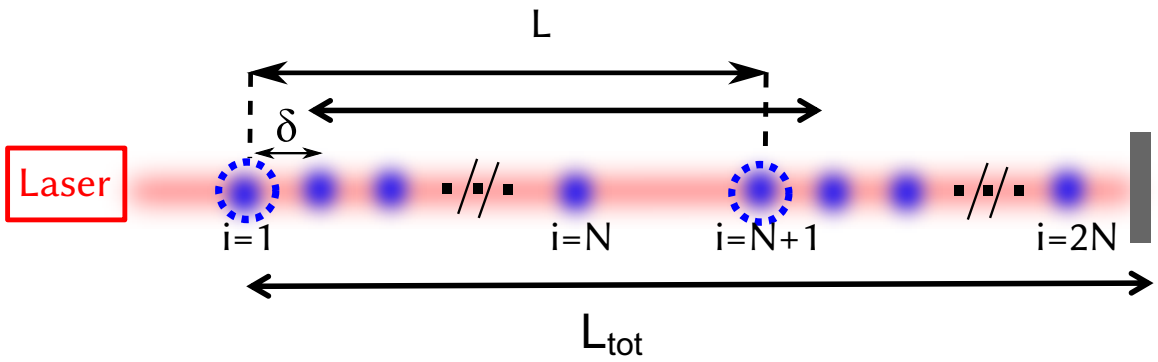
Phys. Rev. D **93**, 021101(R)

« MIGA » geometry: a prototype to:

- Test AI technology for GW detection
- Make advanced studies of GGN

GW detector geometry for GNN cancellation

Dense arrays of Atom Interferometers could be used as future GW detectors



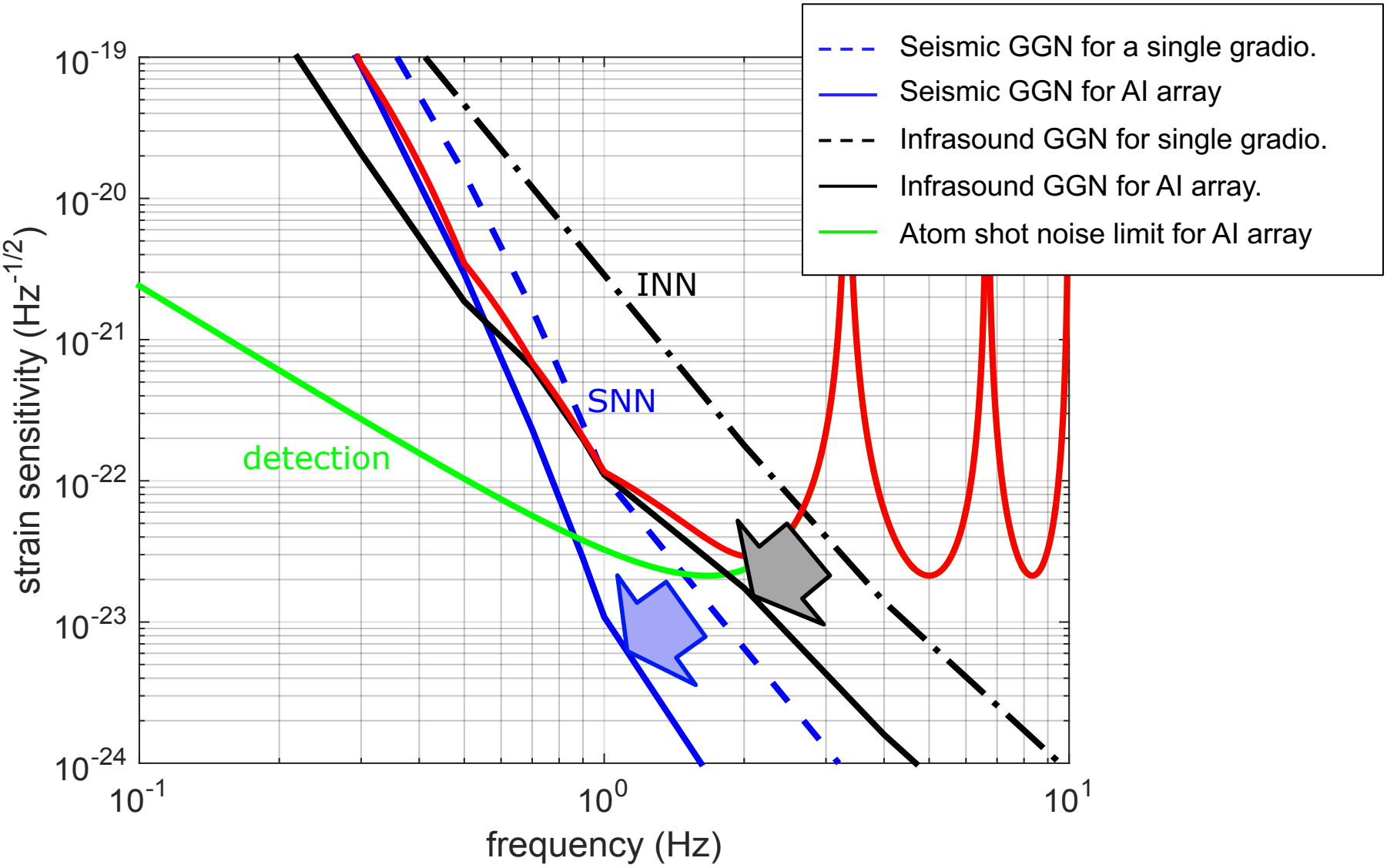
- L_{tot}=32 km
- N=80 gradiometers
- baseline L = 16.3 km

- Gravitational Wave signal can be extracted using a spatial averaging method
- N Correlated gradiometers enable to average the GGN over several realizations

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

- The geometry of the detector (δ,L) is chosen with respect to the spatial correlation properties of the GGN.

GGN reduction with an AI network



Reduction better than 10 at 1 Hz

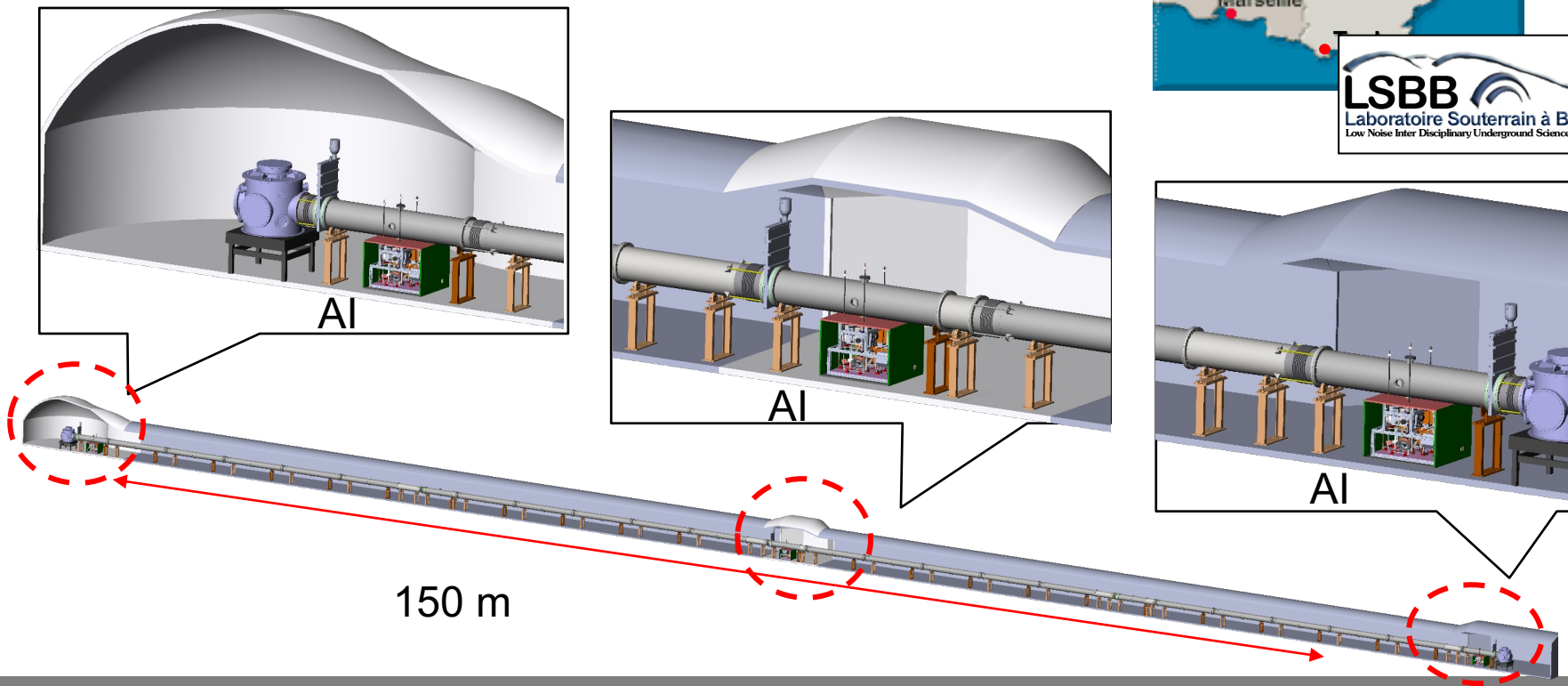
W. Chaibi, *et al.*, « *Low frequency Gravitational Wave detection with ground based Atom Interferometer arrays,* » Phys. Rev. D 93, 021101(R) (2016)

The MIGA antenna

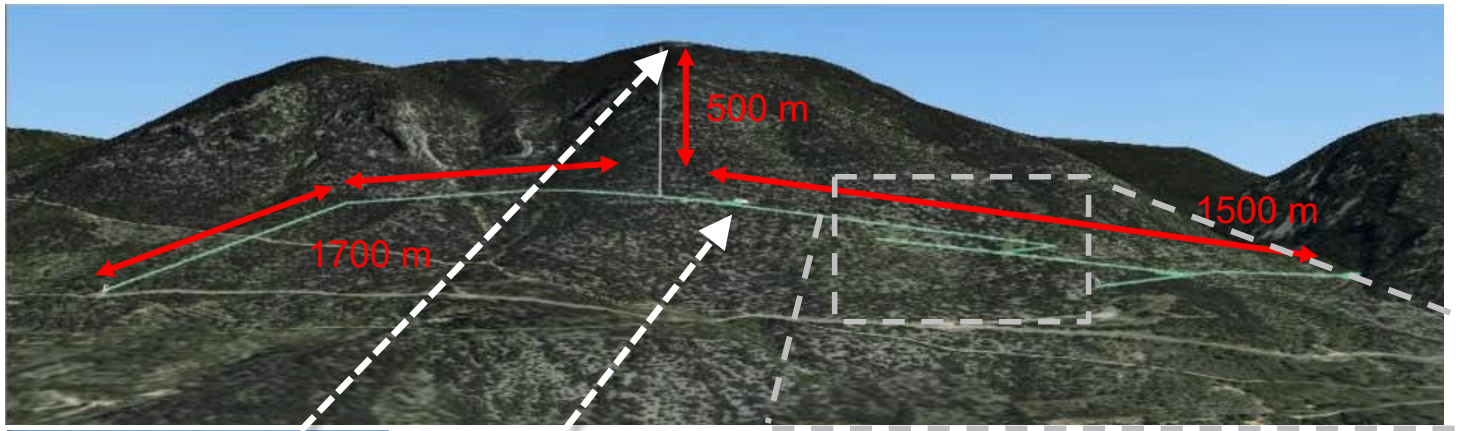
The MIGA antenna

- French research program carried out by 17 partners

- An array of Rb AI installed in a low noise underground lab.

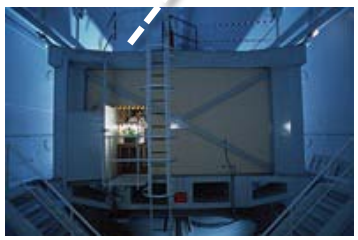


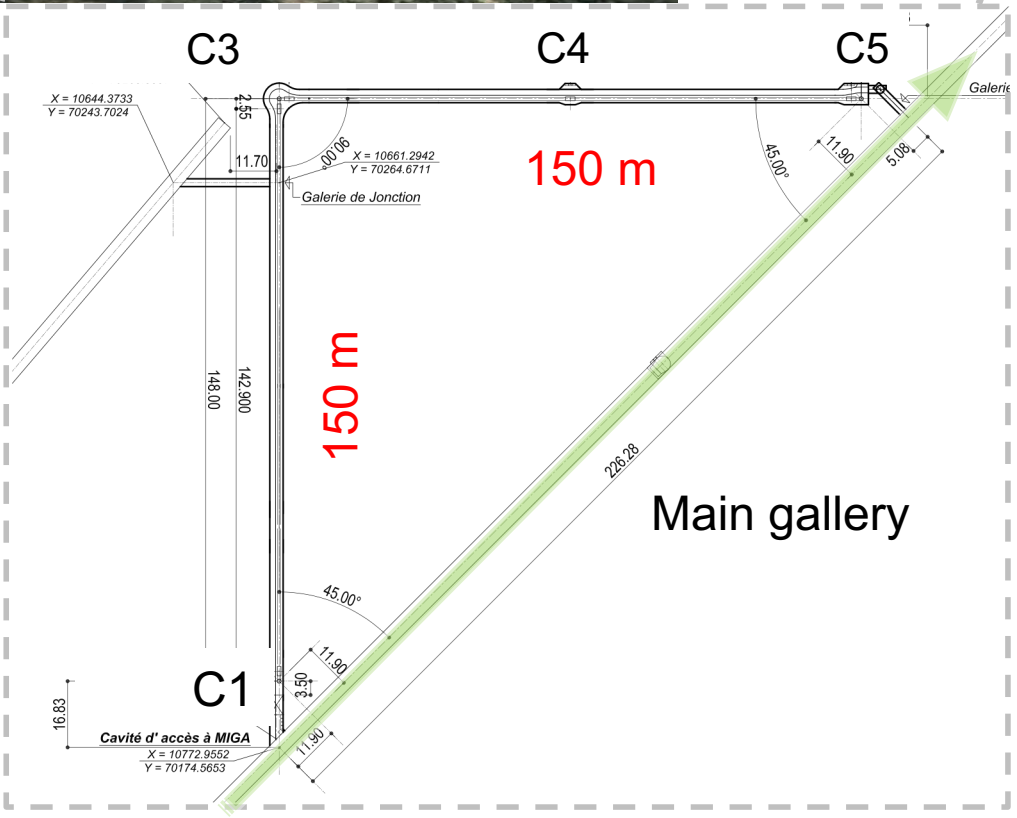
MIGA infrastructure



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

- A dismissed military facility
- Former command centre for nuclear force





- Two new perpendicular galleries of 150m dedicated to MIGA

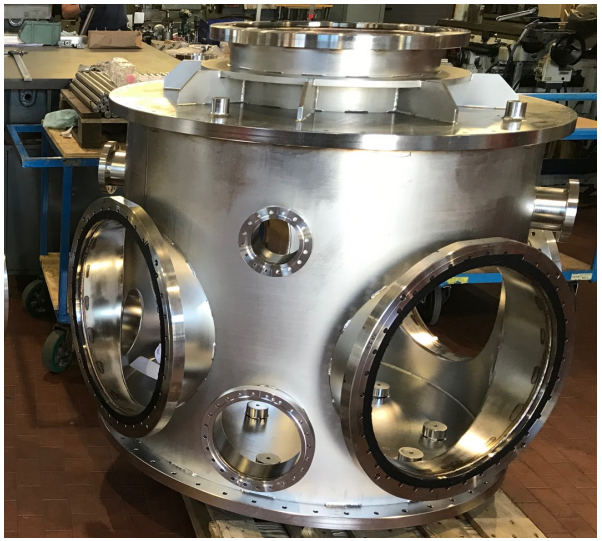
MIGA galleries at LSBB

Vacuum vessel

- Large aperture: 50 cm large, 150 m long, total volume of 30 m^3
- Must reach 10^{-9} mbar of residual pressure after Baking @200 °C with Pumping speed in normal operation 10000-20000 l/s
- Assembled and operated in rough conditions (humidity – cleanliness)

Most of the system composed by “standard” 6 m sections:

- SS304 with 5 mm thickness
- Uses “helicoflex“ flanges
- Every piece tested in factory to prove the ultimate pressure level (a few 10^{-10} mbar) before acceptance and shipping.

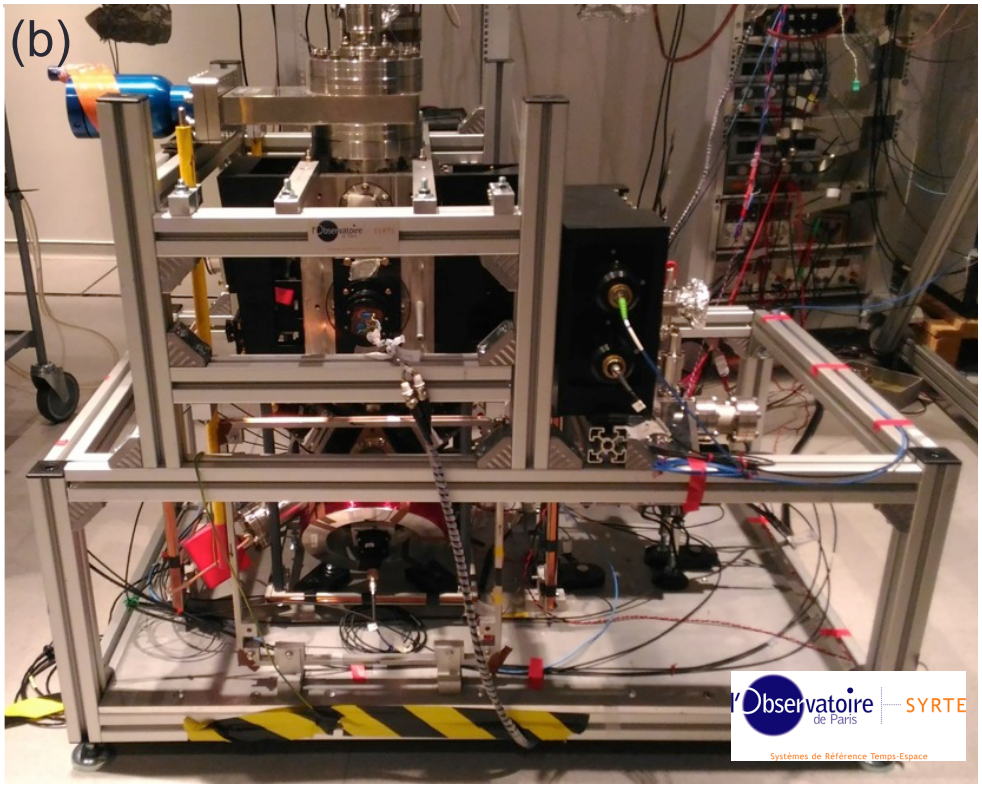


The atom sources

- Uses a combination of a 2D and 3D magneto-optic traps.
- Produce clouds of 5x10^8 atoms/s of Rb at T = $2.5\mu K$.

(a)

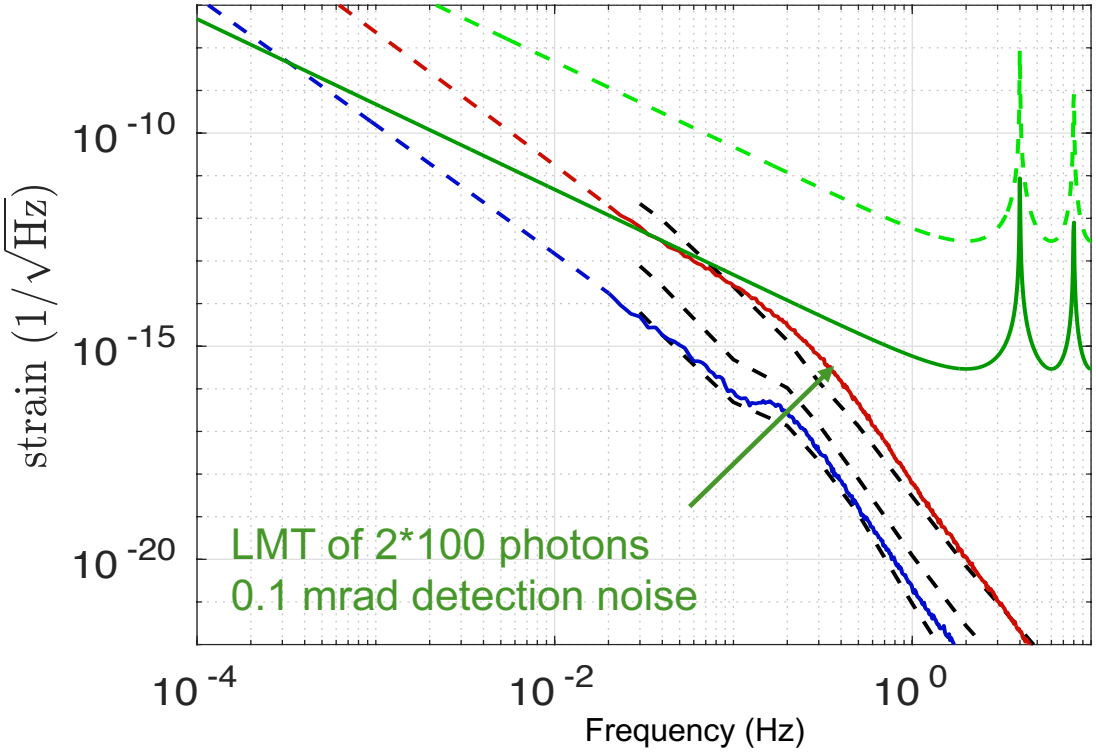
(b)



- Dedicated fiber laser system developed with Muquans to realize all functions for cooling/preparation/detection.
- Based on Telecom Technologies: robust, stable and remotely controllable to cope with rough conditions of LSBB
- 5/5 systems produced and characterized

MIGA Status and prospects

- All parts (vacuum, atom head&lasers) produced and tested.
- Vacuum system now being assembled. Following steps will be baking of the system and atom head connection.



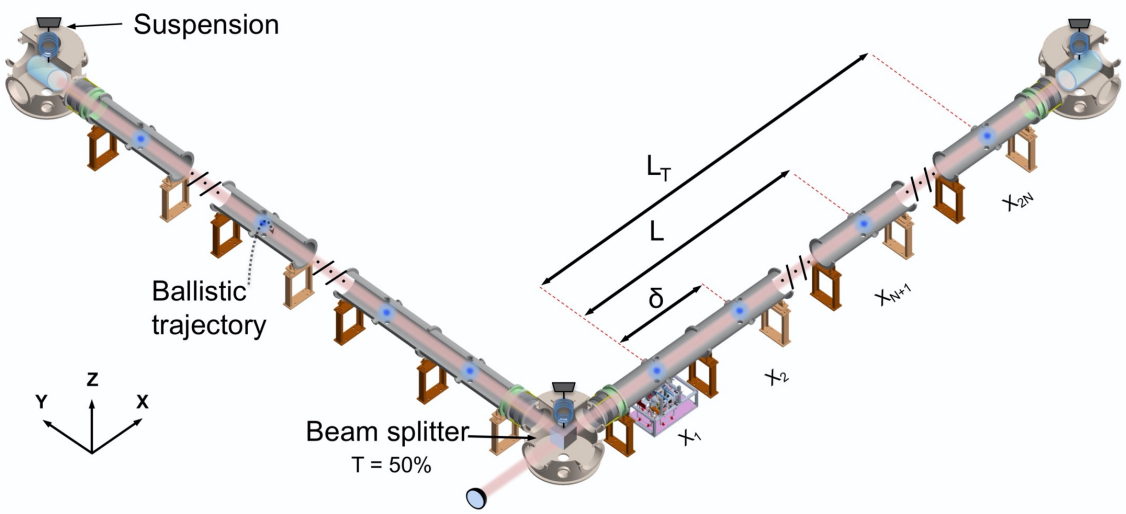
- Initial strain sensitivity 2.10^{-13} at 2 Hz.
- Study advanced measurement strategies & atom manipulation techniques
- Fill the sensitivity gap for GW detection
- Advanced studies of GGN

ELGAR

European Laboratory for Gravitation and Atom-interferometric Research

ELGAR - a European Laboratory for Gravitation and Atom-interferometric Research

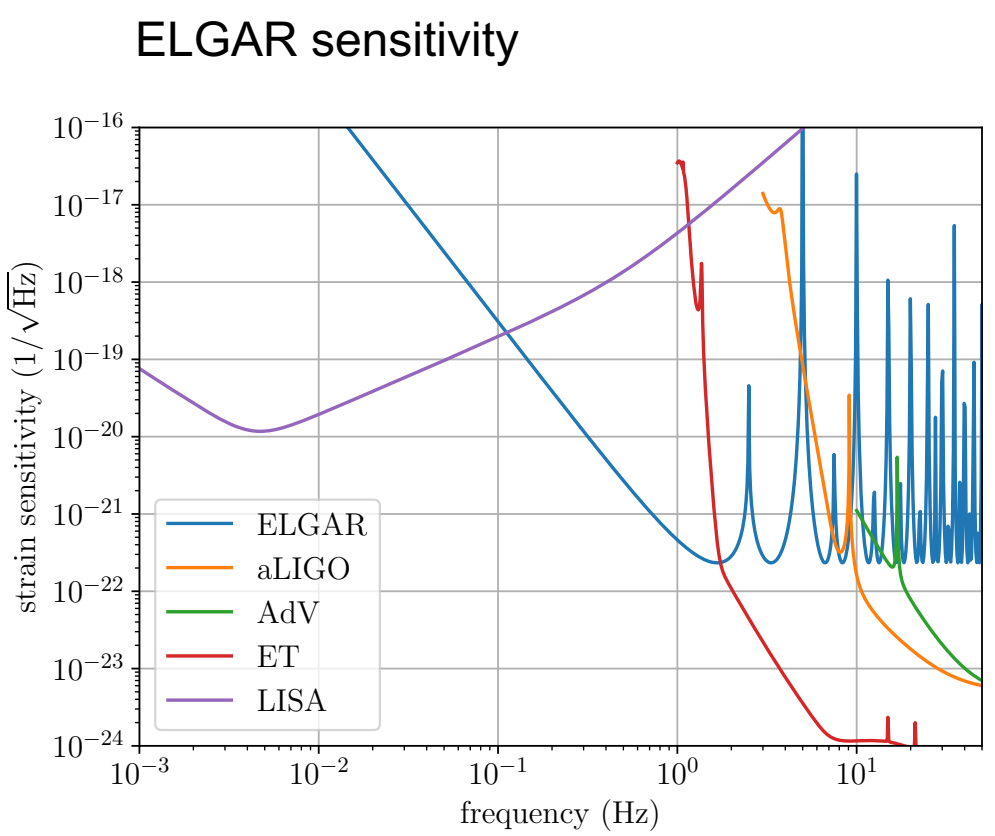
- Build an underground infrastructure based on large scale AI, to study space-time and gravitation with the primary goal of detecting **GWs in the infrasound band** (0.1 Hz-10 Hz).
- Opens multi-band GW astronomy: new sources, precision gravity/cosmology tests….
- ELGAR initiative is sustained since 2014 by a research group that now gathers about 60 scientists from more than 20 labs over 6 EU countries.
- Relies on large national initiatives for quantum technologies: MIGA (FR), VLBAI (GER), MAGIA (IT), UK National Quantum Technology Hub.

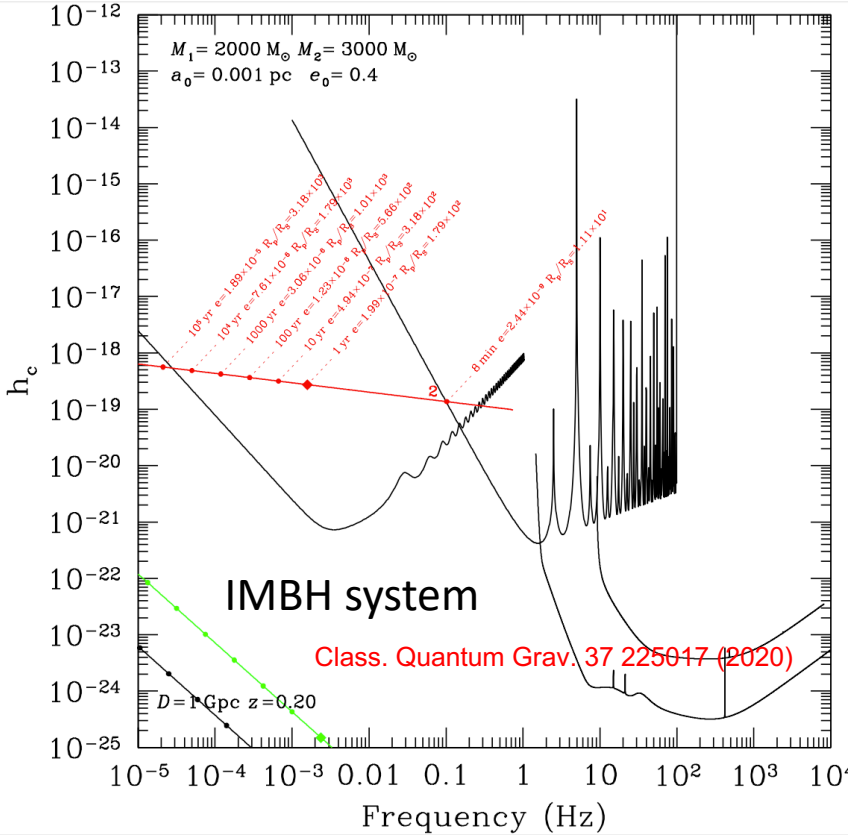


From Class. Quantum Grav. 37 225017 (2020)

Based on array of Atom gradiometers that reduces the contribution of Gravity Gradient Noise

Atomic source	
Species	^{87}Rb
Loading source	2D+ MOT
Equivalent atomic flux[a]	$1 \times 10^{12}\,\mathrm{s}^{-1}$
Ensemble type	ultracold source
Expansion velocity ($T_{\mathrm{eff}} \approx 100$ pK)	$100\,\mu\mathrm{m\,s}^{-1}$
Vertical launching velocity	$4\,\mathrm{m\,s}^{-1}$
Cloud size[b]	16 mm
Detector	
Single gradiometer	
Configuration	Double loop, four pulses
Interrogation time	$4T = 800$ ms
Atom optics	Sequential Bragg
Momentum transfer	$2n = 1000\ \hbar k$
Baseline	$L = 16.3$ km
Peak strain sensitivity (at 1.7 Hz)	$4.1 \times 10^{-21}\,\mathrm{Hz}^{-1/2}$
Full detector	
Number of gradiometers per arm	$N = 80$
Gradiometer separation	$\delta = 200$ m
Total baseline	$L_{\mathrm{eff}} = 32.1$ km
Peak strain sensitivity (at 1.7 Hz)	$3.3 \times 10^{-22}\,\mathrm{Hz}^{-1/2}$





- Proposed as ”design study” for H2020-INFRADEV-2017-1 & INFRADEV-01-2019-2020
- Preliminary design: Class. Quantum Grav. 37 225017 (2020)
- CNRS support through the creation of an « International research Network » starting in 2023.
- Future : subsystems design: ArXiv:2007.04014 [physics.atom-ph] (2020), gather EU support from an RI concept development or design study call

Conclusion

- MIGA: A pathfinder for large scale AI in a rich international context (AION, MAGIS, ZAIGA, VLBAI…).
- All the parts are ready and now being installed: Infrastructure works completed/Vacuum system, all Atoms heads produced/tested&/delivered.
- Ambition: fill the sensitivity gap for to build future observatories for the study of space-time and gravitation : ELGAR