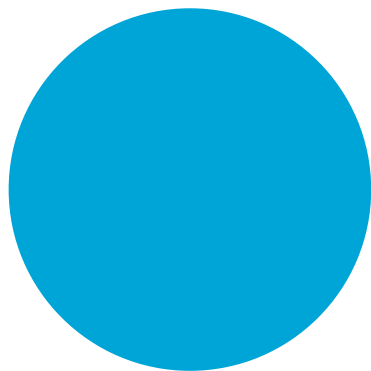


**iXblue**

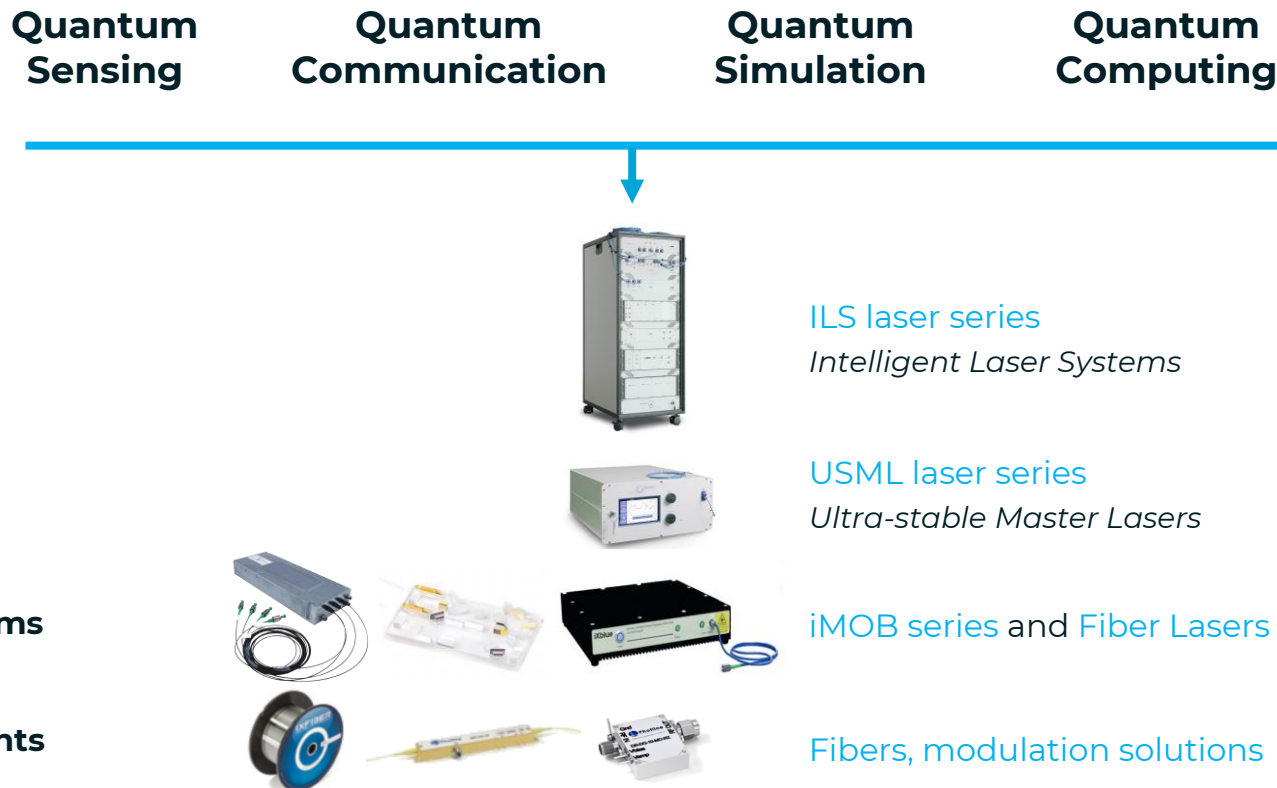


# Industrial Quantum Gravity Sensors

Vincent Ménoret – iXblue Quantum Sensors  
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# iXblue: a wide expertise in photonics for quantum technologies

From components to instruments



# iXblue Quantum Sensors

## Quantum sensors and laser systems

- Muquans created in 2011, Quantum Sensors division of iXblue since 2021
- Pioneer in the field of industrial quantum systems
- Industry-grade systems in operation all around the world



- **Cold atom gravity meters**
  - ( $\Delta g/g \approx 10^{-9}$ )



- **Cold atom atomic clock**
  - ( $\Delta f/f \approx 10^{-15}$ )



- **Optical frequency transfer**
  - ( $\Delta f/f \approx 10^{-20}$ )



- **Laser and subsystem solutions**
  - ( $\Delta \lambda/\lambda \approx 10^{-10}$ )



# Field measurements with the Absolute Quantum Gravimeter (AQG)

# The Absolute Quantum Gravimeter

## Quantum gravity measurements on the field

- 2 key choices

- Pyramid reflector (single beam)
- Frequency-doubled telecom laser

- Fully integrated

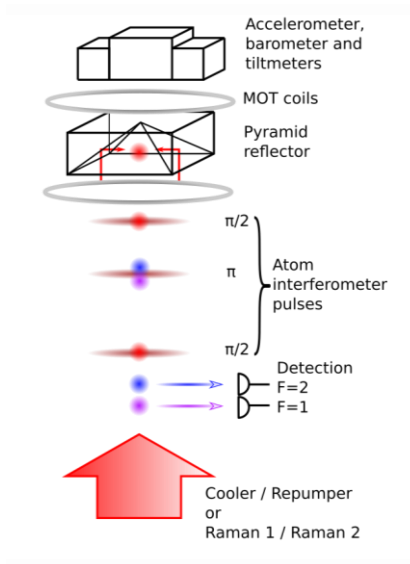
- Home-made electronics, software, etc
- Integrated monitoring and supervision
- Robust and compact design

- User-friendly

- Easy to install and operate
- Intuitive software
- Remote operation

- High-performance

- Continuous absolute gravity measurements
- Resolution  $1 \mu\text{Gal} = 10 \text{ nm}\cdot\text{s}^{-2}$  ( $\sim 10^{-9} g$ )



# Application to volcano monitoring

## NEWTON-g project

D. Carbone et al., Front. Earth Sci. 8:573396 (2020)

- AQG installed on Mt Etna in July 2020
  - 2800 m elevation
  - 2.7 km from summit craters
- Hard conditions
  - Volcanic tremor / eruptions
  - Temperature changes
  - Corrosive and dusty atmosphere
  - Difficult access (impossible in winter)
  - Unstable off-grid power supply
    - 6 months with no power in winter!
- Demonstration of the relevance of quantum technology
  - High-quality data (estimation magma dynamics)
  - Robust instrument



## Geophysical Research Letters<sup>\*</sup>

### RESEARCH LETTER

10.1029/2022GL097814

#### Key Points:

- We present the world's first time series acquired with an absolute quantum gravimeter in the summit crater zone of an active volcano
- Despite the unfavorable ambient

### Detecting Volcano-Related Underground Mass Changes With a Quantum Gravimeter

Laura Antoni-Micollier<sup>1</sup>, Daniele Carbone<sup>2</sup>, Vincent Ménoiret<sup>1</sup>, Jean Lautier-Gaud<sup>1</sup>, Thomas King<sup>2</sup>, Filippo Greco<sup>2</sup>, Alfio Messina<sup>2</sup>, Danilo Contrafatto<sup>2</sup>, and Bruno Desruelle<sup>1</sup>

<sup>1</sup>iXblue, Institut d'Optique d'Aquitaine, Talence, France, <sup>2</sup>Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania - Osservatorio Etna, Catania, Italy



# Quantum gravity sensing

## A mature technology

- Field-proven in various conditions
  - Volcano monitoring
  - Hydrology
  - Antarctica (geodesy)
  
- Advantages compared to classical solutions
  - Continuous absolute gravity measurements
  - High quality data
  - Easy to use



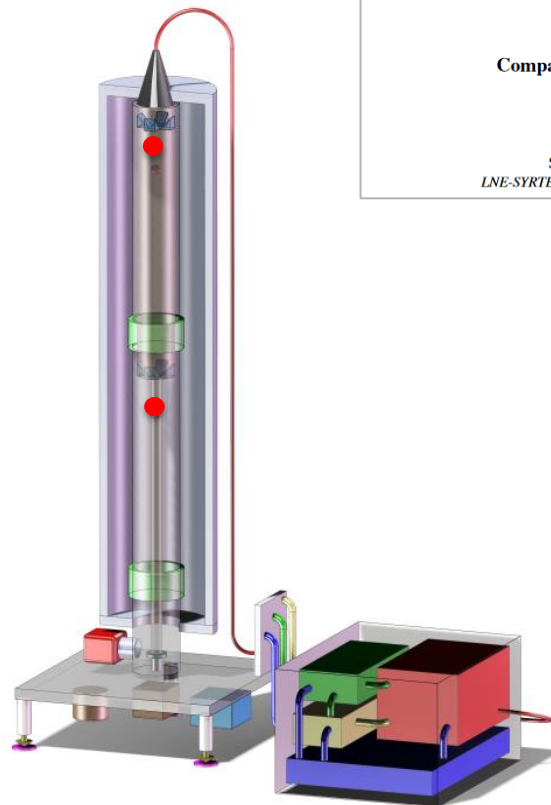
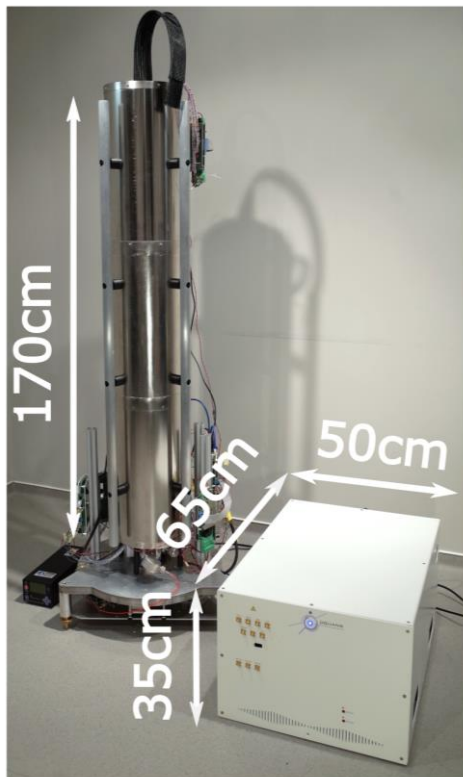




2

**Coming up next: Differential  
Quantum Gravimeter (DQG)**

# DQG: gravimeter + gradiometer in a single package



PHYSICAL REVIEW A **105**, 022801 (2022)

## Compact differential gravimeter at the quantum projection-noise limit

Camille Janvier<sup>1,2</sup>, Vincent Ménéret<sup>1,2</sup>, and Bruno Desruelle<sup>1,2</sup>  
*iXblue Quantum Sensors, F-33400 Talence, France*

Sébastien Merlet<sup>1,2</sup>, Arnaud Landragin<sup>1,2</sup>, and Franck Pereira dos Santos<sup>1,2</sup>  
*LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, F-75014 Paris, France*

Gravimeter

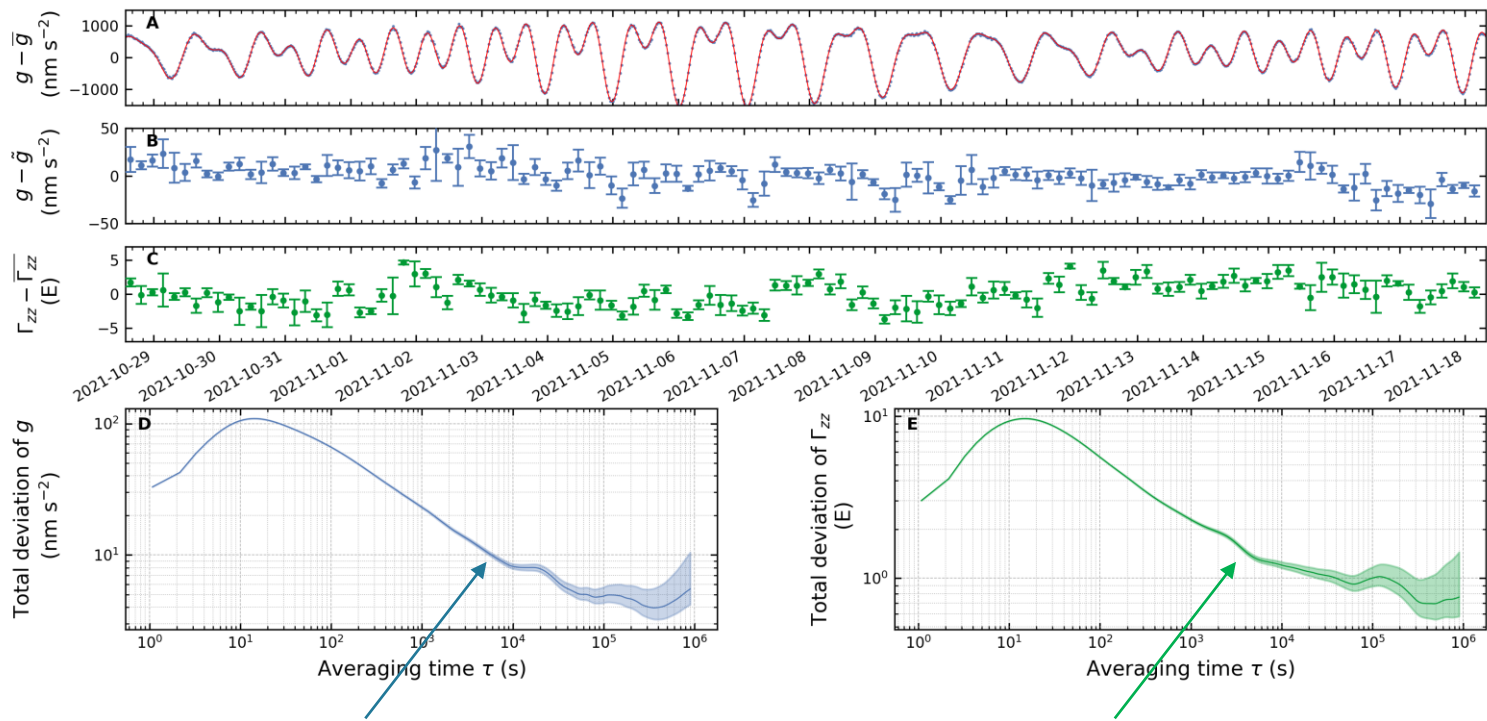
$$\bar{g} = \frac{g_1 + g_2}{2}$$

Gradiometer

$$\Gamma_{zz} = \frac{g_1 - g_2}{L}$$

Quantum Projection Noise limited

# Continuous measurements



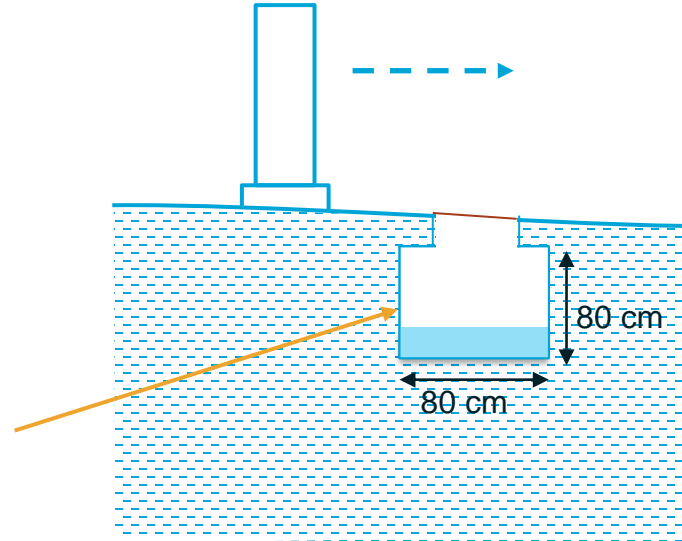
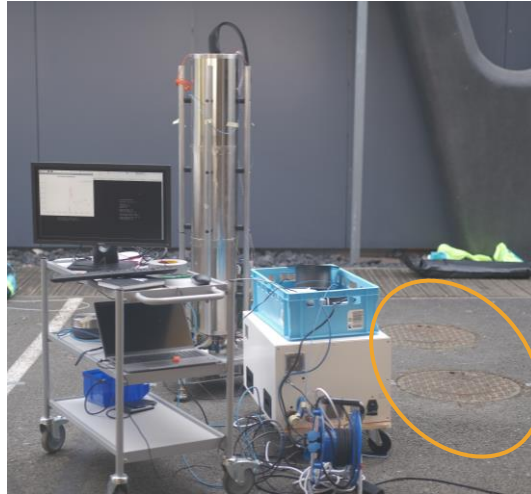
**Gravity:**  $1\mu\text{Gal}$  ( $10 \text{ nm}\cdot\text{s}^{-2}$ ) in 1 hour

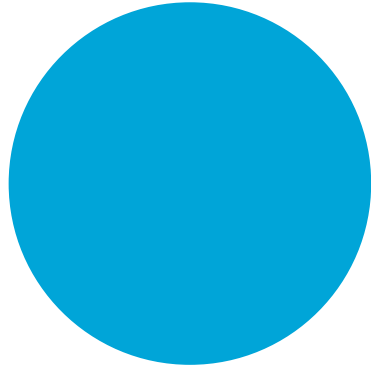
**Gravity gradient:**

- 2 E ( $2 \text{ nm}\cdot\text{s}^{-2}/\text{m}$ ) in 30 minutes
- Resolution  $\sim 0.1$  E ( $100 \text{ pm}\cdot\text{s}^{-2}/\text{m}$ )

# Gravity surveys

- Survey performed outdoors
- Detection of small cavities at shallow depths
- 15 – 20 minutes per point
- Clear gradient signature
  - Total amplitude ~ 50 E
  - Resolution ~ 5 E
- Applications
  - Civil engineering
  - Resource monitoring
  - Archeology
- A unique device : combined gravity and gradient measurements with state of the art performance: 1  $\mu\text{Gal}$  / 1 E





# Perspectives

# And now?

- Further integration and improvements of Absolute Quantum Gravimeter
- Field Differential Quantum Gravimeter
  - For autonomous gravity mapping
  - HE project about to start
- Onboard gravimetry
  - Project with ONERA for the French Oceanographic agency (SHOM)
- Next generation quantum sensors
  - iXatom joint lab
  - Multi-axes sensors
  - Hybrid classical/quantum sensors

**iXblue**