



μQUANS

A new generation of high-performance operational quantum sensors

Atomes froids et applications embarquées

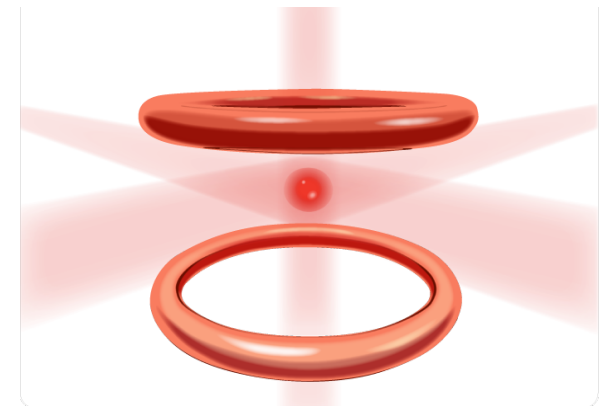
Bruno Desruelle, Muquans

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MUQUANS

- Our goal : launch on the market place a new generation of instruments based on laser-cooled atoms :
 - A high performance atomic clock
 - An absolute quantum gravimeter
 - Laser systems
- A strong technological partnership with our two academic partners:



Systèmes de Référence Temps-Espace





Our team and technical capacities

- Muquans : 20 employees (9 PhDs) who gather a deep expertise over a wide scope of competencies :
 - Quantum physics
 - Optics & laser
 - System engineering
 - Electronics & microwave
 - Opto-mechanics, ultra-high vacuum
 - Real-time software, data acquisition and signal processing
- A fully equipped laboratory : optics, electronics & microwave, vacuum

Absolute Quantum Gravimeter

Scientific background

- Cold Atom Gravimeter developed at LNE-SYRTE laboratory since 2003
- Participation to several international comparisons since 2009
- 20 peer-reviewed publications
- State-of-the-art performances :

$$1 \mu\text{Gal} = = 10^{-8} \text{ m.s}^{-2} \approx 10^{-9} \text{ g}$$

Accuracy	5.2 μGal
Record sensitivity	6 $\mu\text{Gal}/\text{VHz}$
Ultimate stability	0,2 μGal

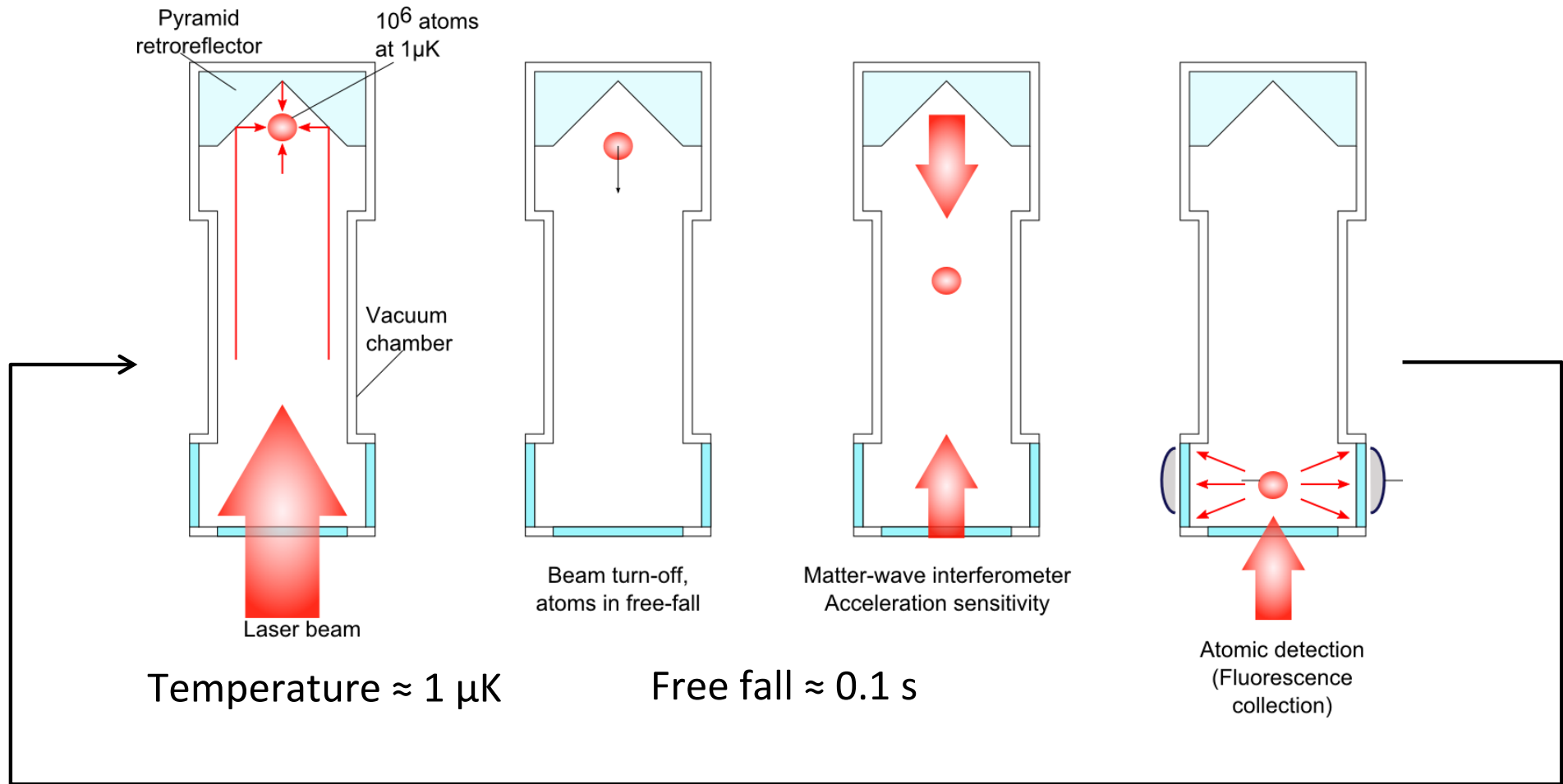




Key technological innovations

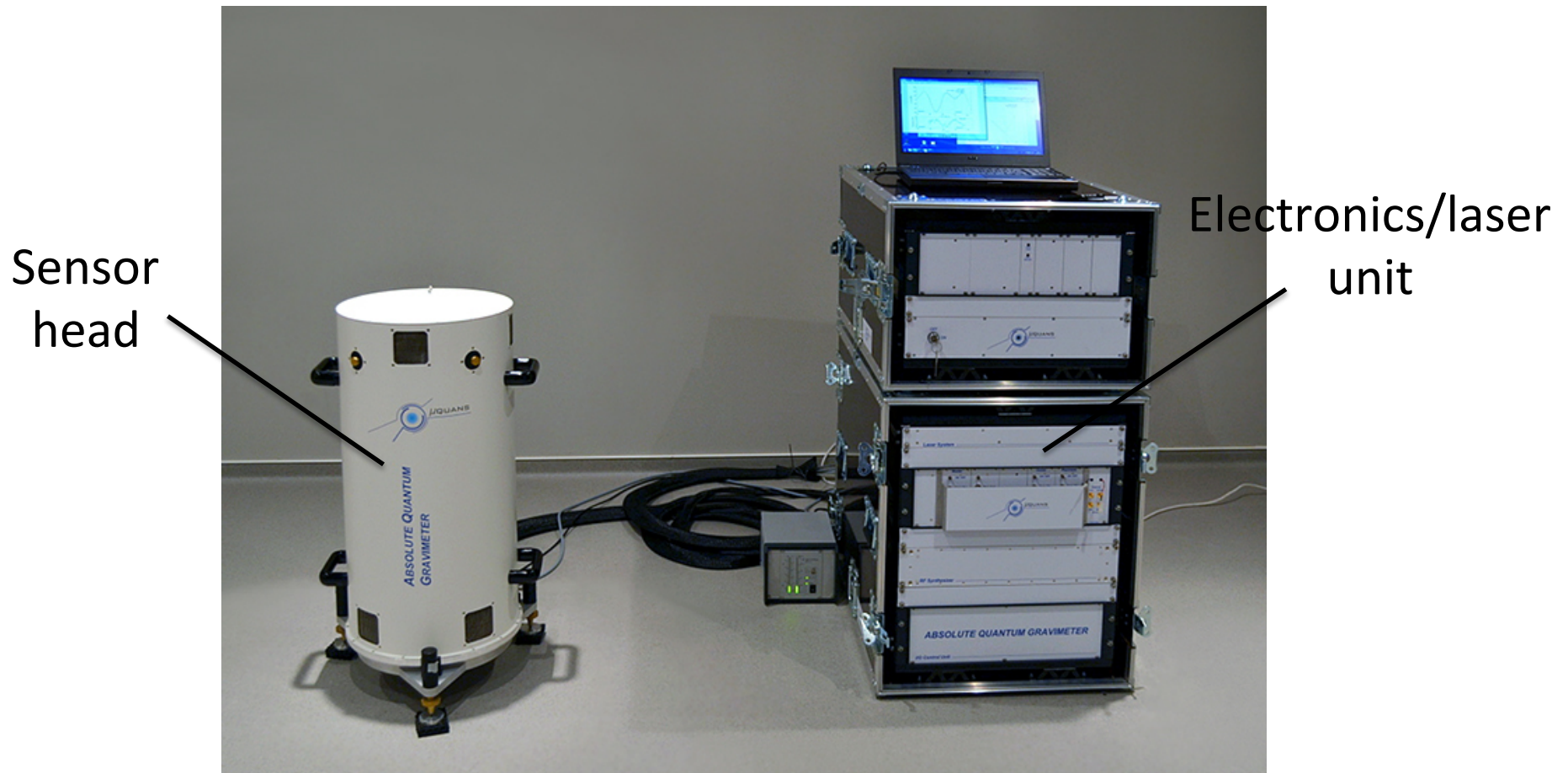
- **Hollow pyramid retroreflector**
 - *Single laser beam atom interferometer*
- **Telecom inspired laser system**
 - *Fibered, reliable and robust laser system*
- **Active compensation of ground vibration**
 - *Excellent immunity to vibration noise*

Principle of operation



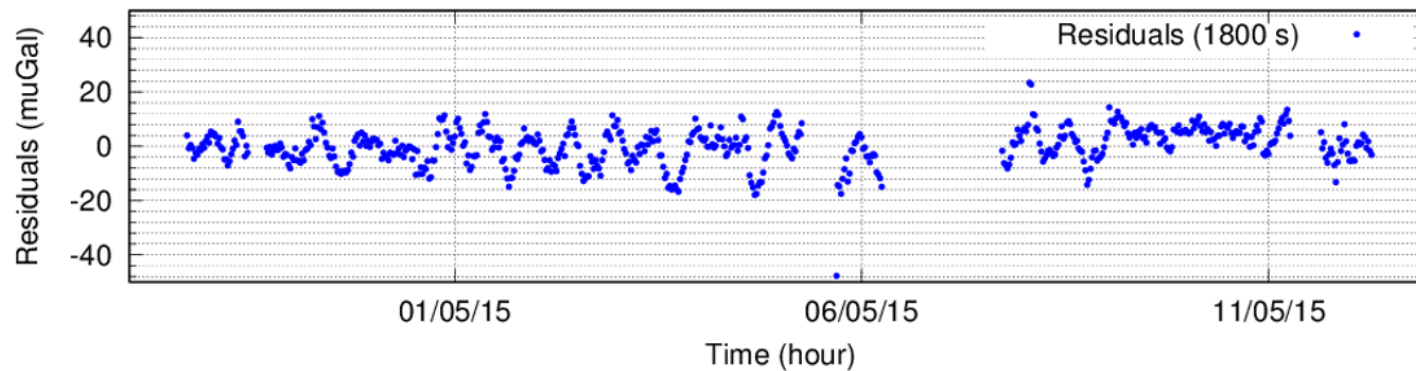
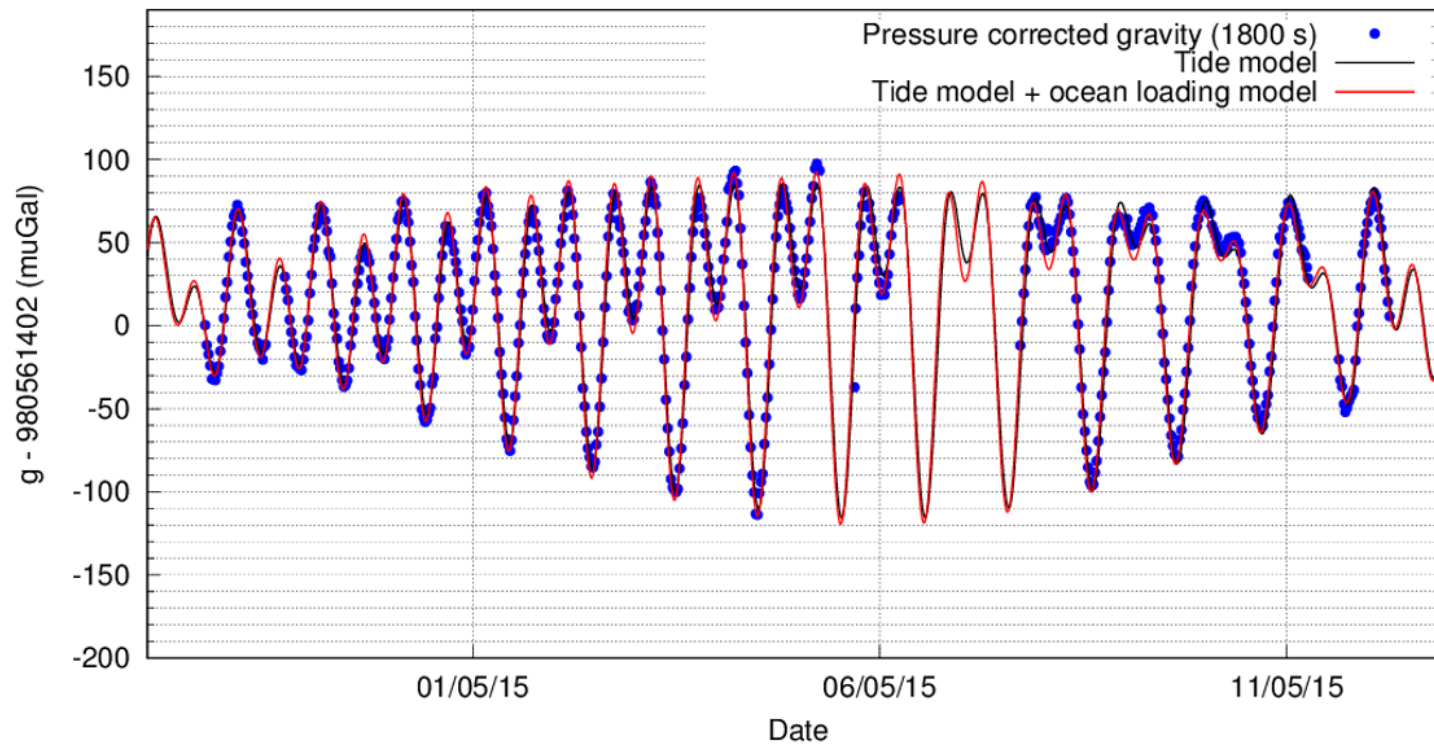
Measurement cycling frequency: a few Hz

Absolute Quantum Gravimeter



Completely automated operation

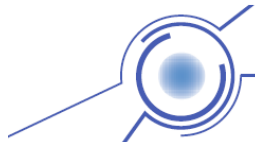
2 weeks gravity measurement



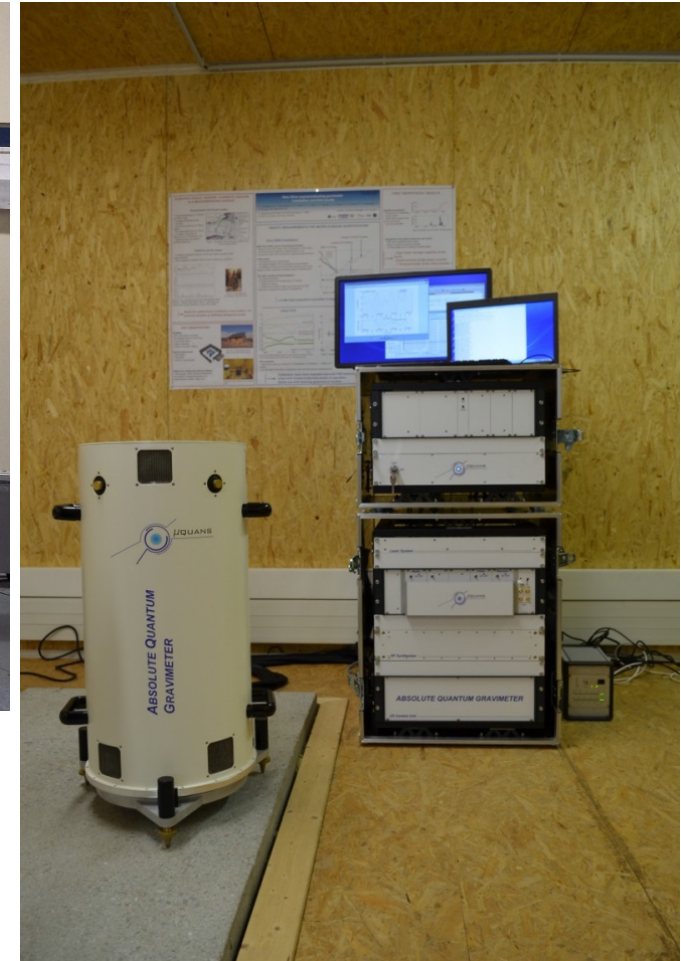


Summary of our characterizations

- Continuous measurements demonstrated over several days.
- 2 μGal in 20 min, Sensitivity = 50 $\mu\text{Gal}/\sqrt{\text{Hz}}$
- No measurable drift after 5 months
- Very good robustness w.r.t vibrations
- A small residual low-frequency noise, currently under investigation.



Transportability



The AQG has been moved around several times : set up time < 1 h

Credit : CNRS/RESIF (S. Bonvalot & N. Lemoigne), LNE-SYRTE (S. Merlet & F. Pereira)¹¹



Conclusion

- **The AQG is compliant with its original specifications :**

Sensitivity	50 $\mu\text{Gal}/\text{VHz}$
Long term stability	$\sim 1 \mu\text{Gal}$

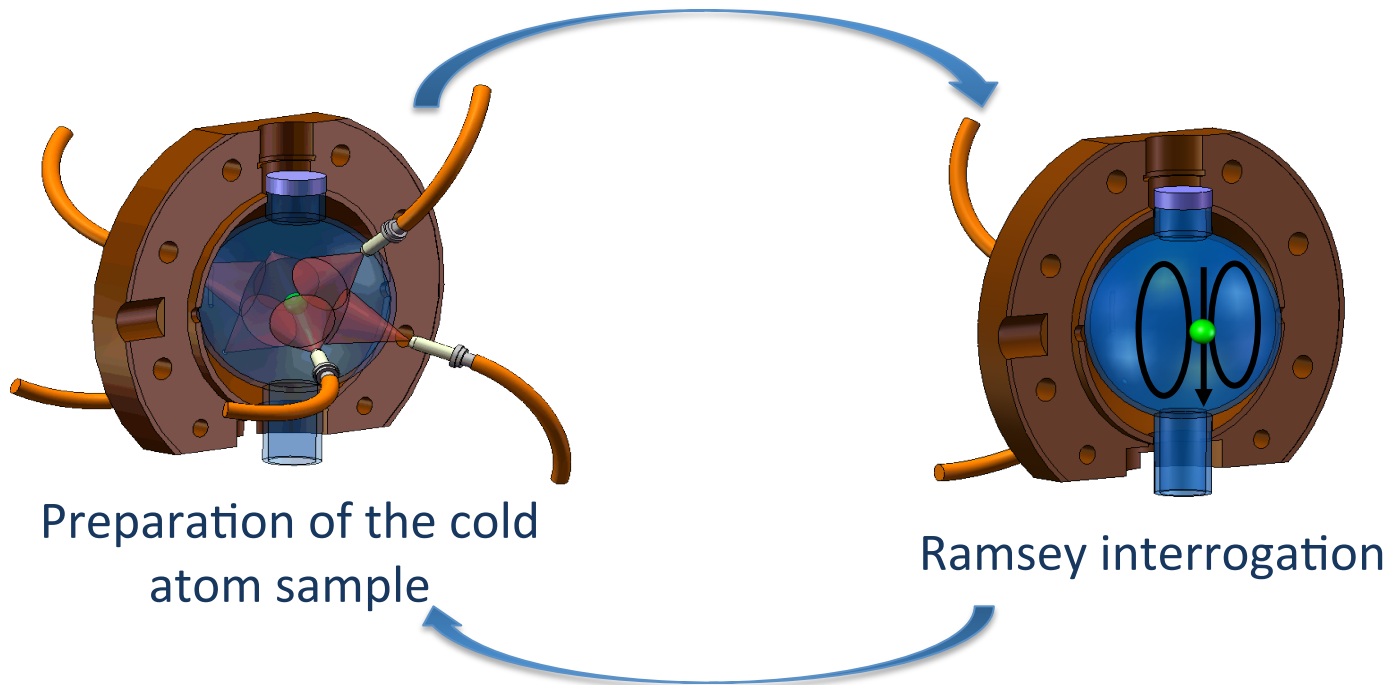
- Accuracy under investigation
- The sensor offers attractive features with respect to existing technologies :
 - Robustness against vibrations
 - Easy to use
 - Reduced maintenance
- **Commercially available !**

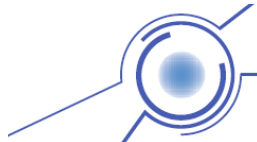
MuClock

Principle of operation

- Inspired by the HORACE concept developed at SYRTE :

Isotropic cooling + Ramsey interrogation in a microwave cavity





HORACE vs MuClock

- Several changes in clock architecture :
 - Rubidium atoms
 - Telecom laser system
 - Active stabilization of microwave cavity

=> Expect long term stability close to 1.10^{-15}



Muclock

The first commercial atomic clock
based on cold atoms

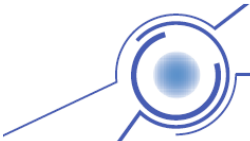


Performances:

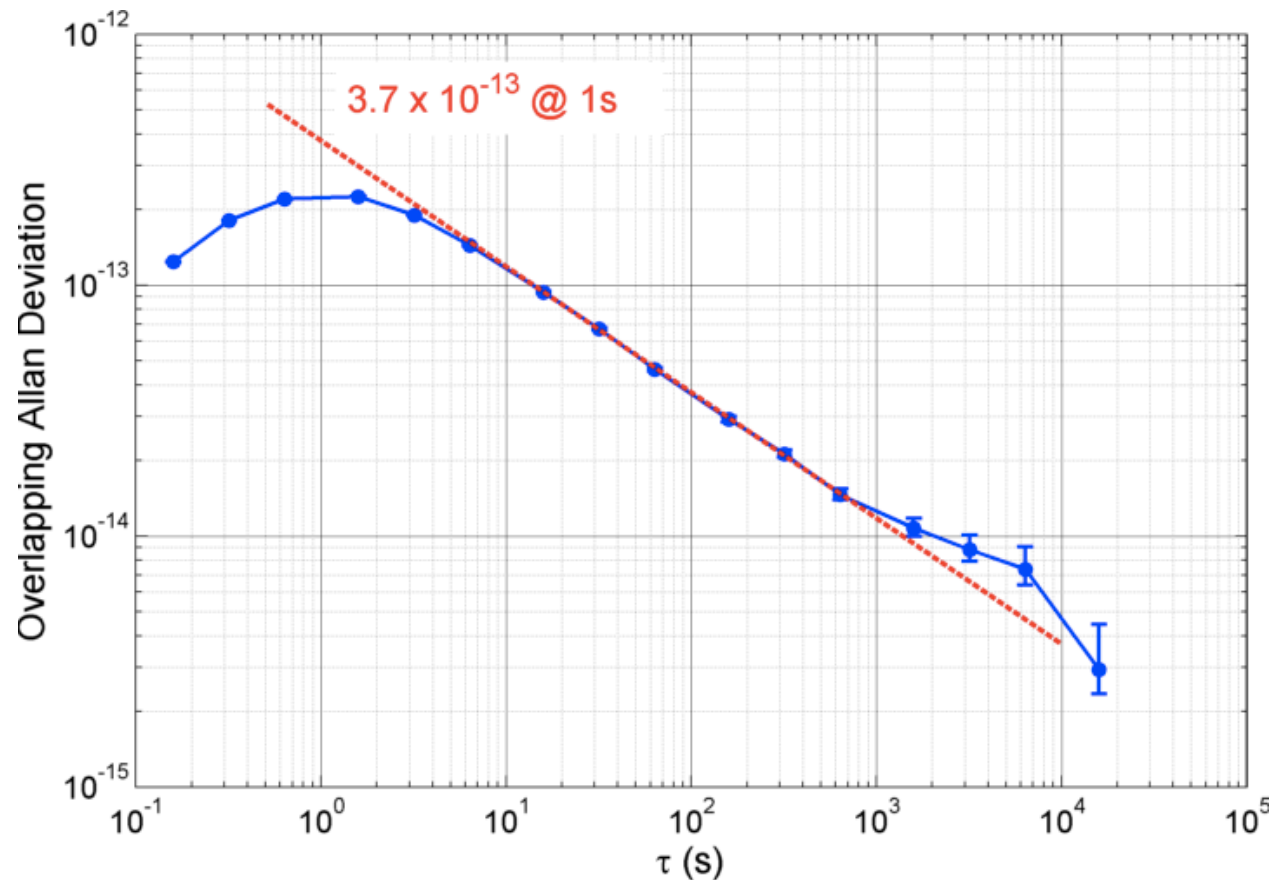
Stability @ 1 s	$< 3 \cdot 10^{-13}$
Long term stability	Obj : $1 \cdot 10^{-15}$
Accuracy	$< 5 \cdot 10^{-15}$

Physical characteristics:

Dimensions	120 x 50 x 50 cm ³
Weight	< 100 kg
Power consumption	200 W typ.
Lifetime	> 10 years



Allan deviation



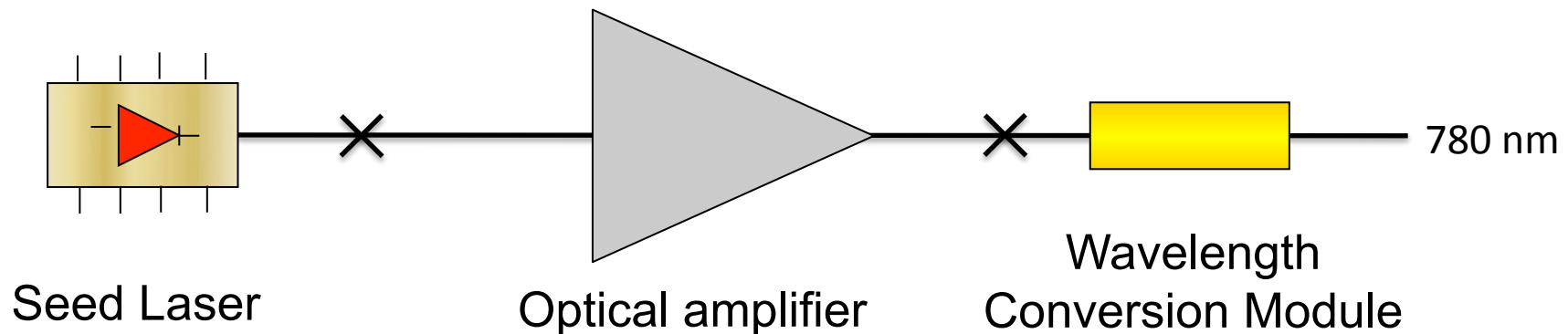
Short term stability close to spec
Long term stability under characterization

Laser technologies



General architecture

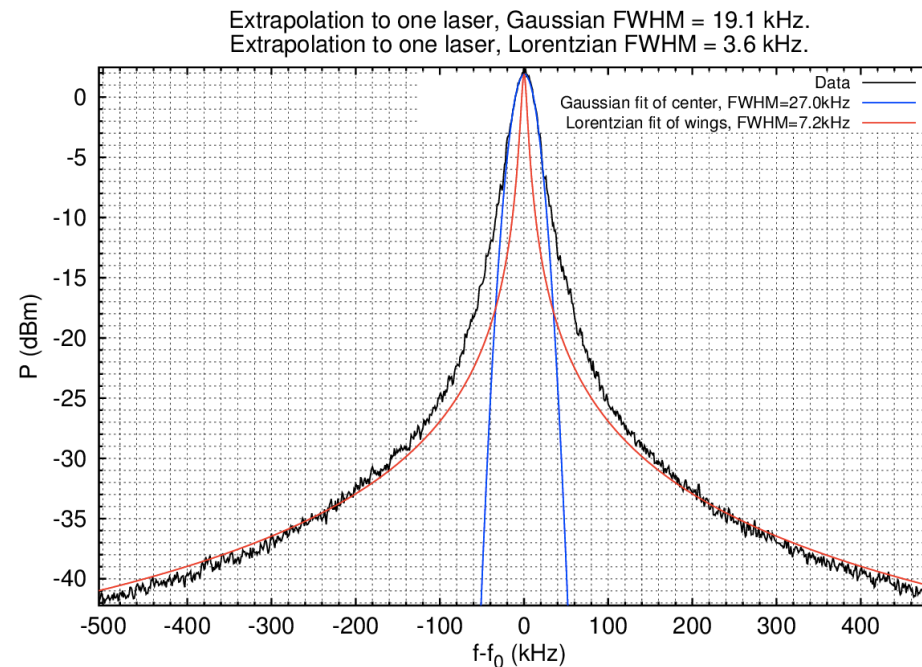
- Generation of 780 nm with frequency doubling of 1560 nm (telecom wavelengths). Tested with ICE and MINIATOM project



- Telecom components :
 - Extreme optical performances
 - completely fibered technology => no optical alignment
 - Robustness (Telcordia qualified)
 - Reliability

Unique spectral characteristics

- Careful optimization of laser electronics
- Careful selection of seed lasers



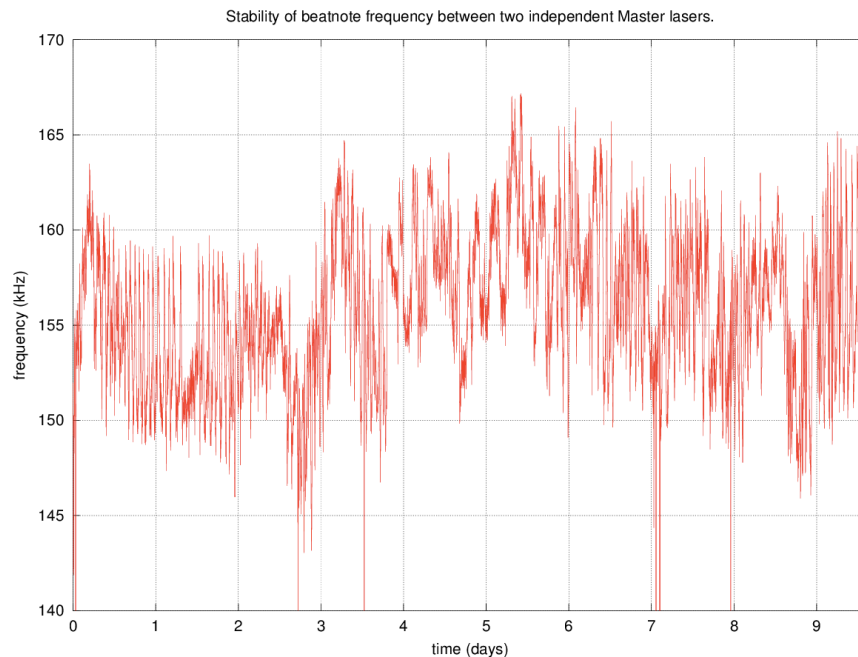
FWHM < 20 kHz



Frequency stability

Dedicated software & electronics for :

- Automatic frequency locking
- Long term frequency locking (2,5 months continuous locking demonstrated)



**Freq. fluctuations < 10 kHz rms
over 9 days**

Example of complete laser system



Input signals

Microwave synthesizer

Optical racks

Laser electronics

Power electronics

Power supply unit



Conclusion

- A lot of work done since the creation of the company :
 - AQG operational. First commercial unit delivered soon to the customer.
 - Detailed characterization of the MuClock expected soon. Second generation proto in fabrication
 - A complete portfolio of laser solutions dedicated to cold atom Physics, spectroscopy and quantum optics