



Quantum gravity sensing for space geodesy



ESA Living Planet Symposium

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Company history

- 2011 - Muquans spins off 2 academic laboratories



French national metrology
lab for time and gravity



France' leading school for
optical engineering

- 35 employees (15 PhD) with deep expertise in
 - quantum physics, optics, lasers
 - electronics, microwave, opto-mechanics, ultra-high vacuum
 - real-time software, data acquisition and signal processing
- 2021 – Muquans merges with iXblue a globally acting company for
 - inertial navigation
 - photonics (functionised optical fibre, modulators, instrumentation, ...)
 - underwater imaging and positioning



Product lines

Absolute Quantum Gravimeter
($\Delta g/g \approx 10^{-9}$)



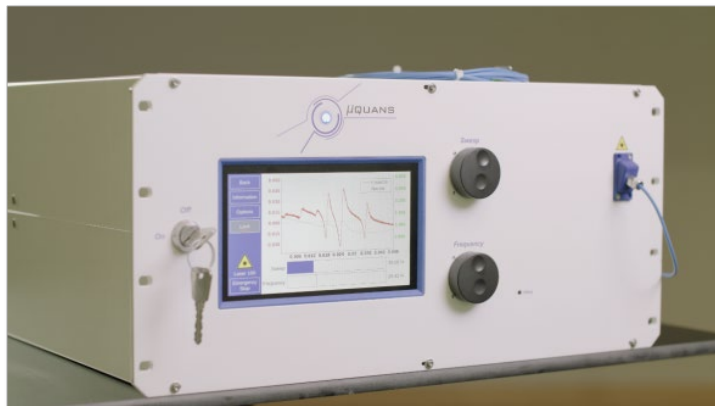
MuClock ($\Delta f/f \approx 10^{-15}$)



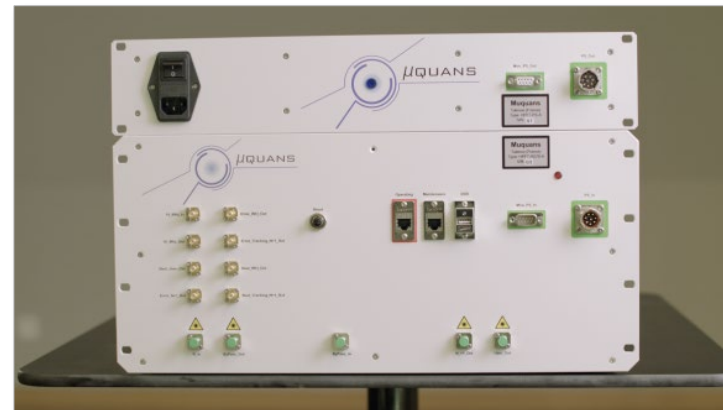
Differential Quantum Gravimeter
($\Delta g/g \approx 10^{-9}$ & $\approx 10^{-9} \text{ g / 1m}$)

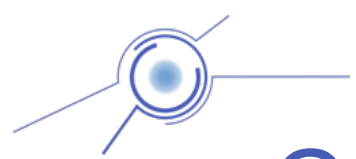


Laser systems for cold atom technology
($\Delta \lambda/\lambda \approx 10^{-10}$)



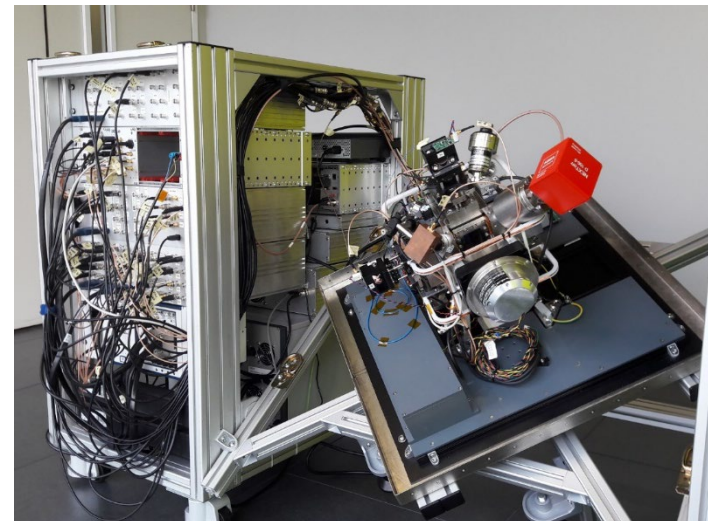
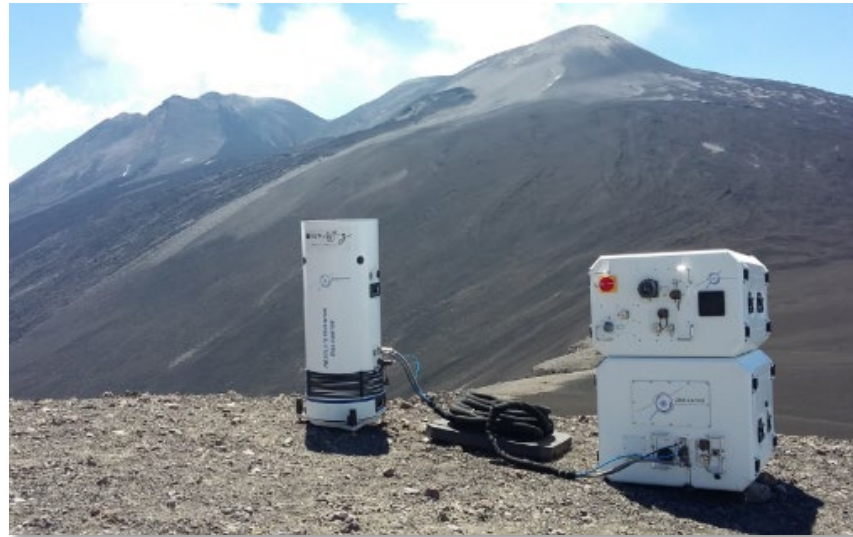
Frequency transfer over optical fiber
($\Delta f/f \approx 10^{-20}$)

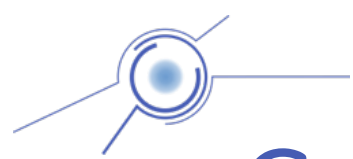




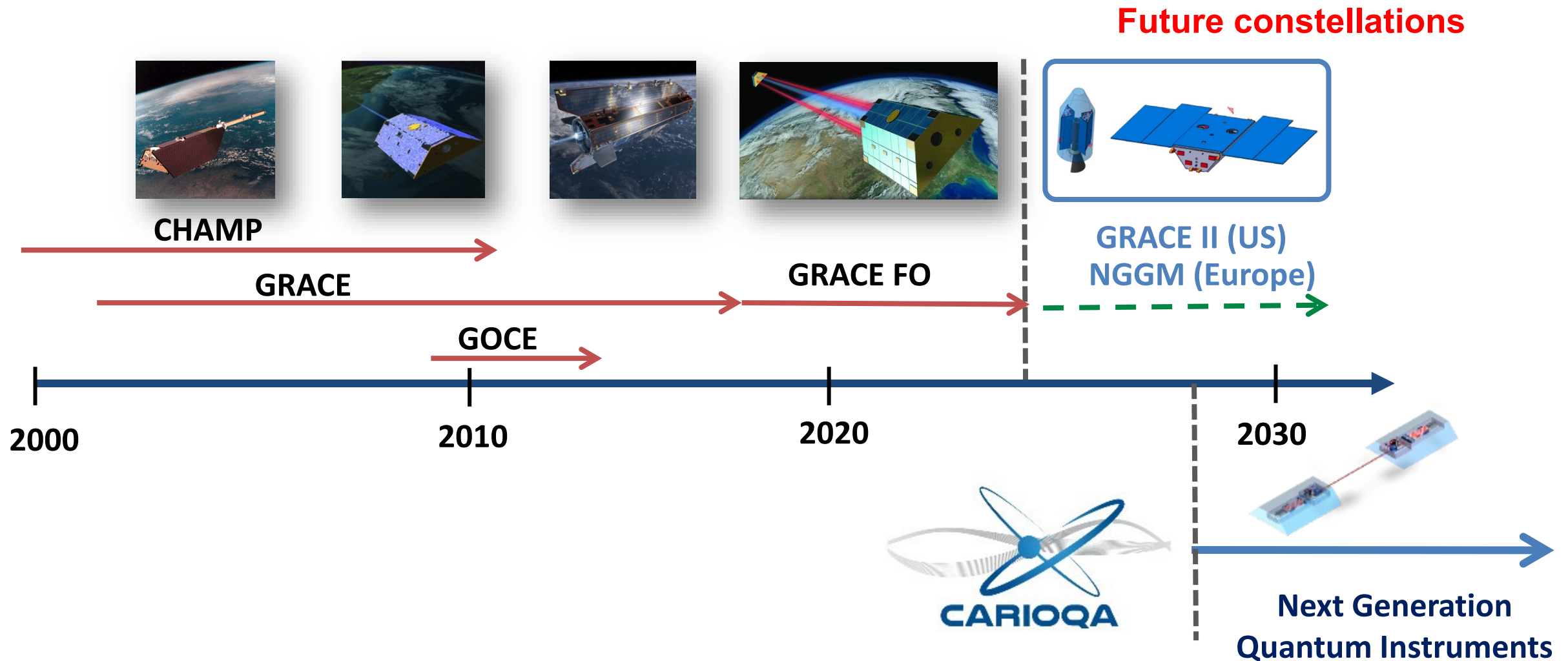
Quantum inertial sensors on Earth

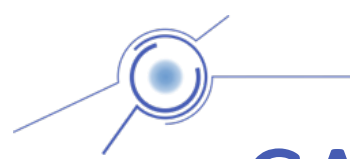
- Absolute Quantum Gravimeter > 10 units deployed for geophysics
- Shipborne Quantum Gravimeter : collaboration with ONERA
- Differential Quantum Gravimeter
- 3D accelerometer, strapdown configuration : on going research with LP2N



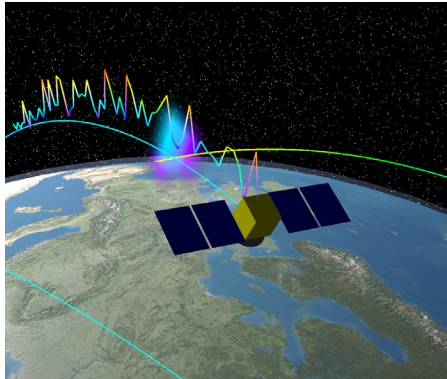


Gravity mapping from space (Courtesy T. Leveque, CNES)





CARIOQA Framework (Courtesy T. Leveque, CNES)



CARIOQA:

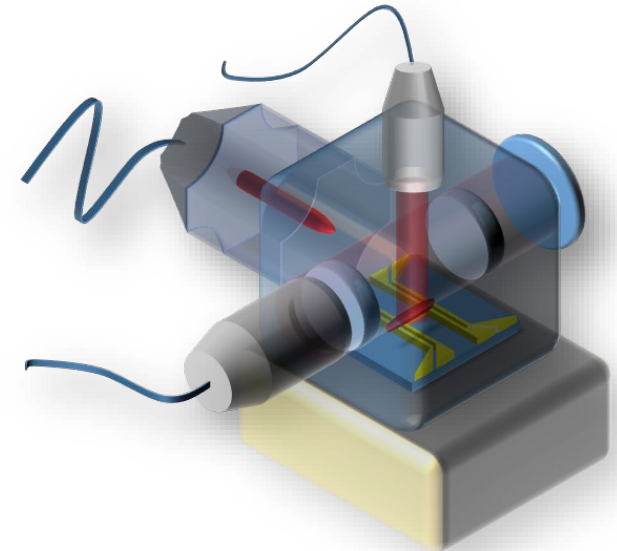
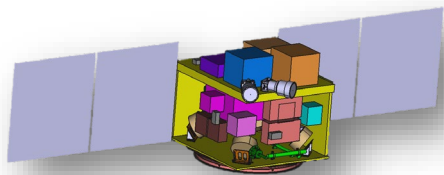
- **Cold Atom Rubidium Interferometer in Orbit for Quantum Accelerometry**
- Goal: demonstrate a Quantum Accelerometer on a satellite.
- **Scientific data feedback:** Earth gravity validation and Thermosphere modelling.

Instrument guidelines :

- **Atom accelerometer**
- **Sensitivity:** $< 10^{-9} \text{ m.s}^{-2}.\tau^{-1/2}$
- **Mass:** $< 100 \text{ kg}$
- **Consumption:** $< 100 \text{ W}$

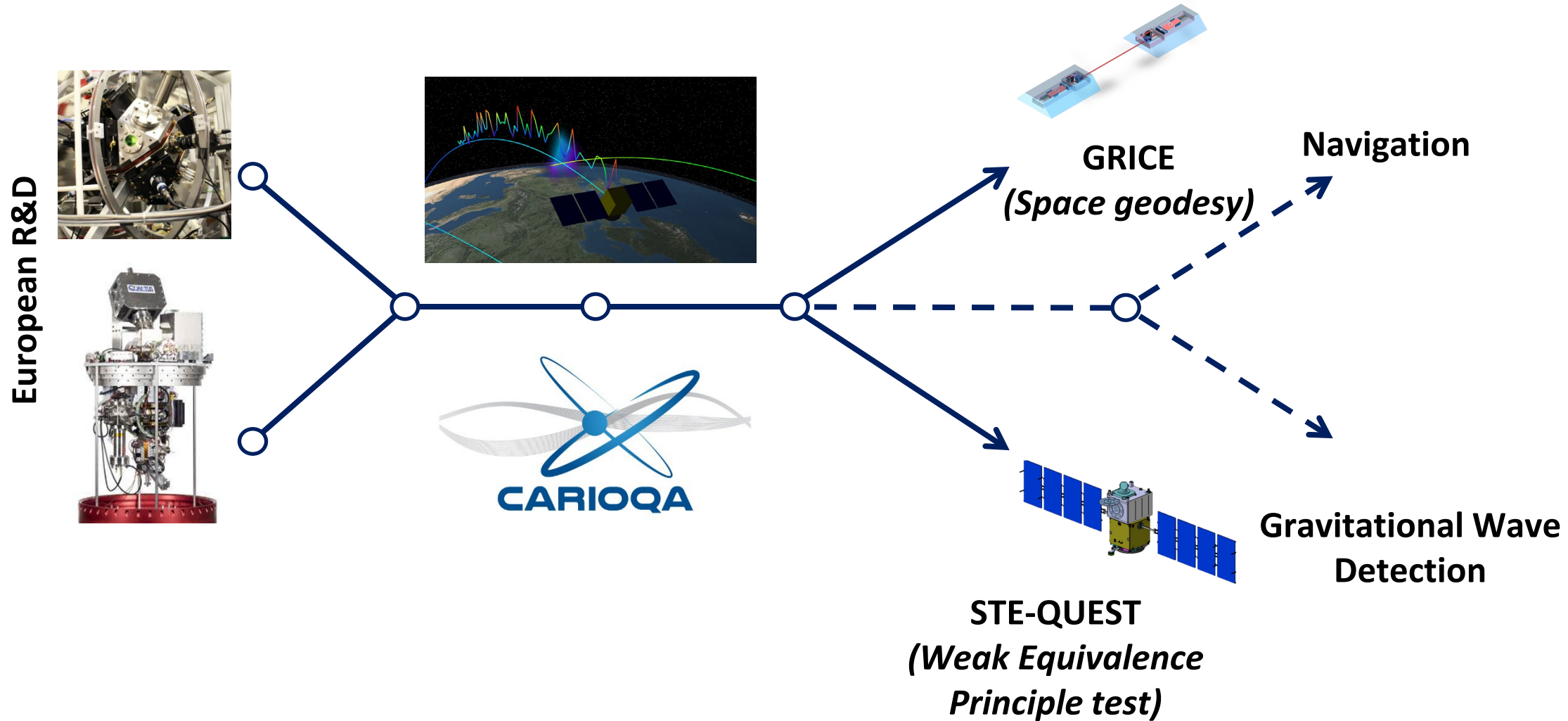
Mission :

- **Dedicated satellite platform**
- **Development:** $\sim 5 \text{ years}$
- **Mission lifetime:** $3 \text{ to } 5 \text{ years}$





CARIOQA : a quantum pathfinder mission





CARIOQA : iXblue laser system

iXblue



Engineering model Laser System (delivery : end of 2023)

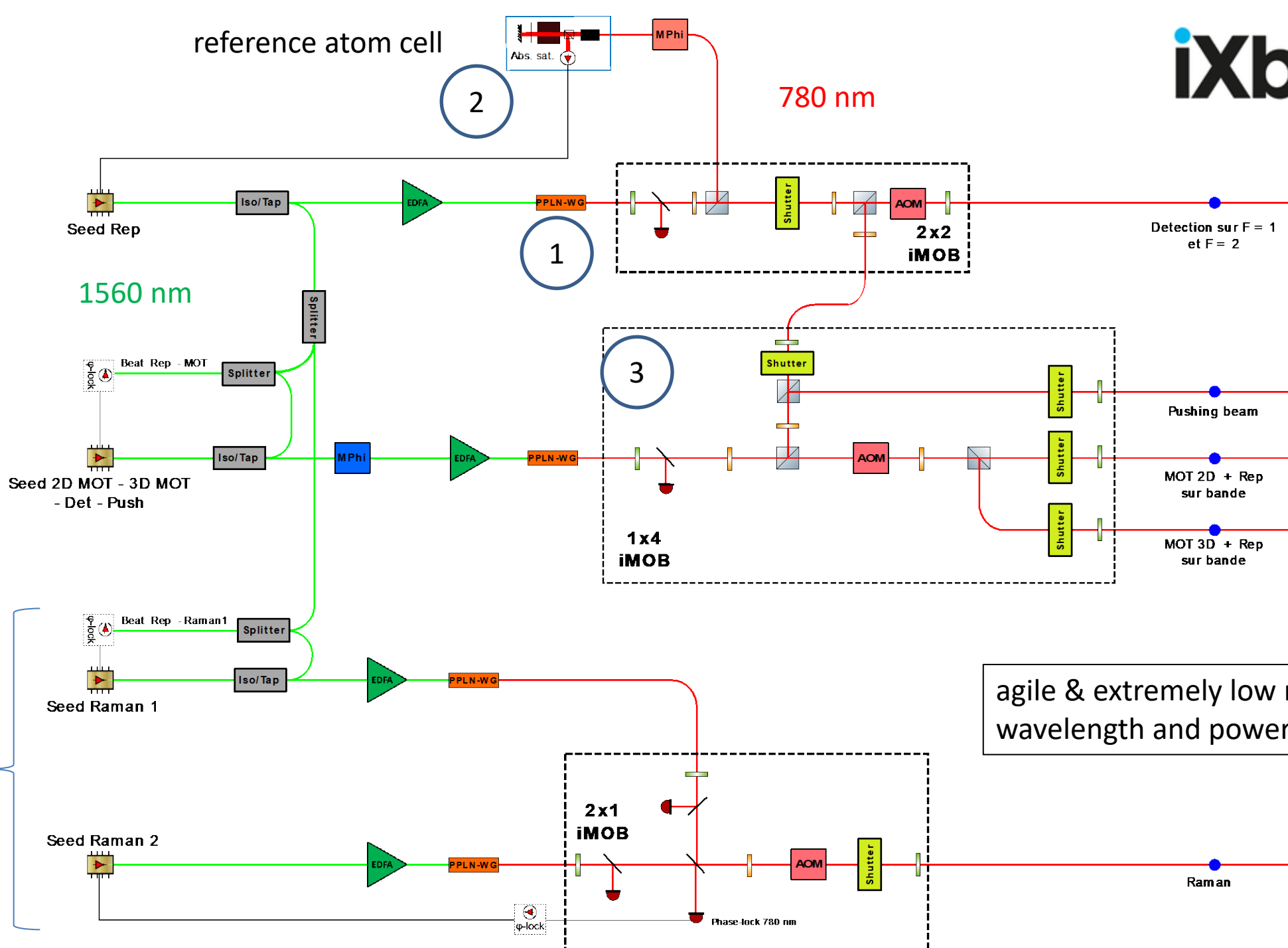
- Compact footprint :
 - Laser system : 35 x 30 x 30 cm³, < 30 kg
 - Control electronics : 30 x 30 x 30 cm³, < 15 kg
- Power consumption < 100 W
- Environmental testing (optics only) :
 - Vibrations (sinus and random)
 - Shocks
 - Temperature under vacuum
 - Radiation

reference atom cell

reference laser

atom
preparation

atom
interferometry





Optical subsystems

1 Frequency doubler : design iteration

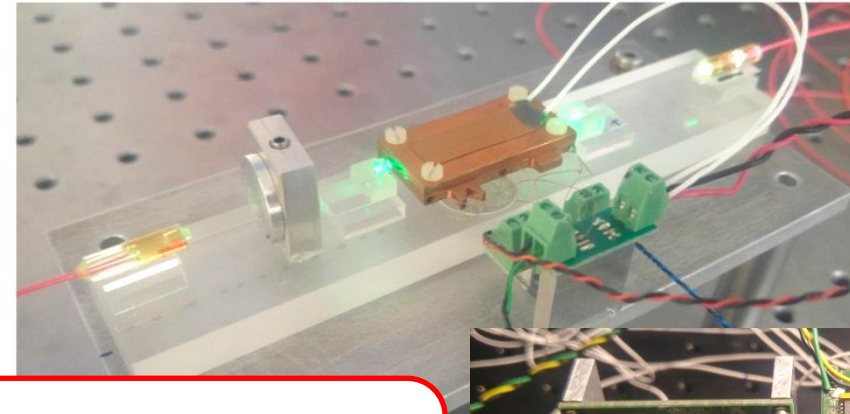
- More compact
- Improved behaviour against radiation
- Test of new crystals
- Hermetically sealed package

2 Saturated absorption cell

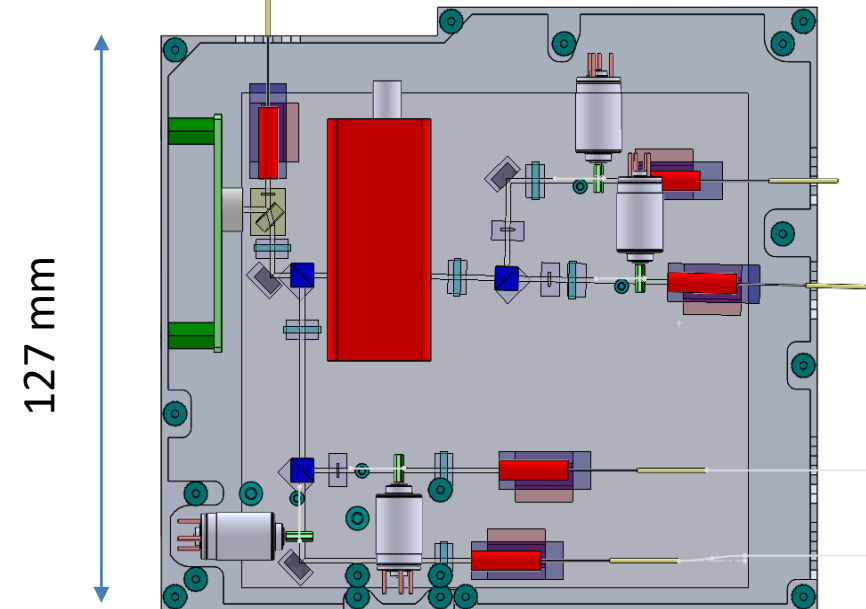
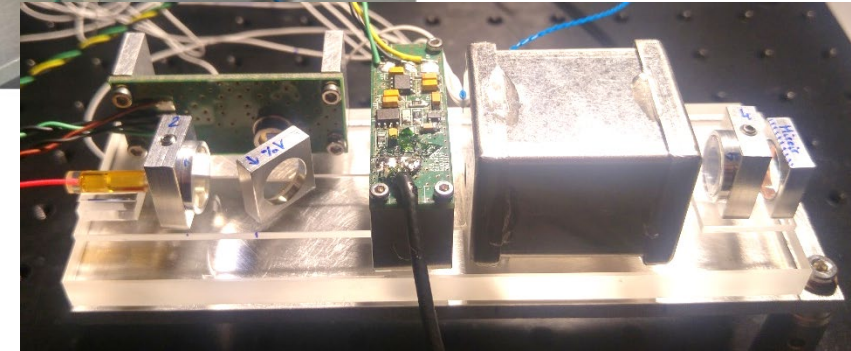
- New version with radiation hard fibre
- Qualification testing

3 Micro-optical bench :

- 1x4 splitting with AOM
- micro-optics assembly
- Improved compactness
- Improved thermal behavior
- Improved radiation hardness
- High reliability mechanical shutters



Environmental tests
successful





Conclusion

- Quantum gravity sensors for ground operation are commercially available
 - Several key advantages with respect to traditional techniques
 - Reliable high-performance instruments, suited for in-field operation
- Next generation instruments under commercial launch
 - Marine gravimeter
 - Differential quantum gravimeter
- Laser systems for space quantum sensors under development
 - CARIOQA EM to be delivered end of 2023

