Senseurs quantiques intégrés : une utilisation opérationnelle des atomes froids

Journée F2S
Bruno Desruelle, Muquans
11 janvier 2018
Outline

• General presentation of Muquans

• Review of our measurement solutions:
  – Absolute Quantum Gravimeter
  – MuClock

• Laser and optical technologies
Our company

Muquans successfully exploits high-precision measurements based on quantum manipulation of laser-cooled atoms
Company overview

• Company created in 2011.
• Strong scientific background

• 25 employees (12 PhD), gathering a deep scientific & technological expertise:
  – Quantum physics, Optics & laser
  – Electronics & microwave, Opto-mechanics, ultra-high vacuum
  – Real-time software, data acquisition and signal processing
Our product line

<table>
<thead>
<tr>
<th>Cold atom gravity meter ($\Delta g/g \approx 10^{-9}$)</th>
<th>Atomic clock ($\Delta f/f \approx 10^{-15}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.jpg" alt="Cold atom gravity meter" /></td>
<td><img src="image2.jpg" alt="Atomic clock" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Laser systems for atom cooling and precision spectroscopy ($\Delta \lambda/\lambda \approx 10^{-10}$)</th>
<th>Frequency transfer over optical fibers ($\Delta f/f \approx 10^{-20}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3.jpg" alt="Laser systems for atom cooling and precision spectroscopy" /></td>
<td><img src="image4.jpg" alt="Frequency transfer over optical fibers" /></td>
</tr>
</tbody>
</table>
Absolute Quantum Gravimeter
General architecture

• Laser cooled Rb atoms in free fall + matter wave interferometry with light pulses

• Huge benefit from research activities conducted at SYRTE

• Key technological innovations:
  – Hollow pyramid retroreflector (patented)
    → 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
Measurement sequence

1. Laser beam
2. 10^6 atoms at 1μK
3. Beam turn-off, atoms in free-fall
4. Matter-wave interferometer
   Acceleration sensitivity
5. Atomic detection
   (Fluorescence collection)
Our first generation instrument

Control unit
95 cm, 90 kg

Sensor head
80 cm, 25 kg

Completely automated operation
1 month gravity measurement

- One month continuous gravity measurements
- \( \sigma_g(3600 \text{ s}) < 2 \mu\text{Gal} \)
Markets and applications

Monitoring of the Earth:
- Volcanology
- Seismology

Sustainable management of underground resources:
- Geothermics & Hydrology
  - Oil & gas
  - Mining industry

Subsurface imaging:
- Civil Engineering
- Void, tunnel and cavity detection
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)
MuClock
Muclock

A commercial atomic clock with improved long term stability and accuracy w.r.t state of the art

Performances:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability @ 1 s</td>
<td>&lt; 3.10^{-13}</td>
</tr>
<tr>
<td>Long term stability</td>
<td>Obj : 1.10^{-15}</td>
</tr>
<tr>
<td>Accuracy</td>
<td>&lt; 5.10^{-15}</td>
</tr>
</tbody>
</table>

Physical characteristics:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>120 x 50 x 50 cm^3</td>
</tr>
<tr>
<td>Weight</td>
<td>&lt; 100 kg</td>
</tr>
<tr>
<td>Power consumption</td>
<td>200 W typ.</td>
</tr>
<tr>
<td>Lifetime</td>
<td>&gt; 10 years</td>
</tr>
</tbody>
</table>
Principle of operation

10 Hz repetition frequency
Long term stability

Lab temperature fluctuations $\approx 5^\circ\text{C}$ pk-pk
Laser technologies
General architecture

- Generation of 780 nm with frequency doubling of 1560 nm (telecom wavelengths).

- **Telecom components:**
  - Extreme optical performances
  - Completely fibered technology => no optical alignment
  - Robustness (Telcordia qualified)
  - Reliability
Laser characteristics

- Power > 250 mW
- Spectral width < 40 kHz
- Freq. fluctuations < 50 kHz
- Sweeping rate > 500 MHz/ms
- PLL between Raman frequencies
- PER > 20 dB
- Frequency locking maintained over several months
- Completely fibered
- Ultra-compact (19'', 1U, 50 cm depth)
Our portfolio

• Laser sources:
  – 1 W output power
  – Free-running or fixed frequency
  – User friendly interface

• Intelligent laser systems
  – Multiple output fibers
  – Integrated frequency and power control
Fibered optical benches

- Fibered inputs & outputs
- Based on micro-optics technology. Qualified for telecom operation.
- Adjustable splitting ratios
- Several configurations: 1x2, 2x2, 1x3, 2x3...
  + AOM
  + Shutters
Conclusion

The beginning of a new era:
- First generation gravimeters commercially available.
- Second generation instruments under development.
- Optimization of our Muclock under way. Close to specifications.
- Solutions available for high performance transfer of optical frequencies.
- A complete portfolio of laser solutions dedicated to cold atom Physics, spectroscopy and quantum optics.