μQUANS

Horloges à atomes froids industrielles

Assemblée Générale 2017 de FIRST-TF

Institut d'Optique d'Aquitaine, Talence

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June 9, 2017

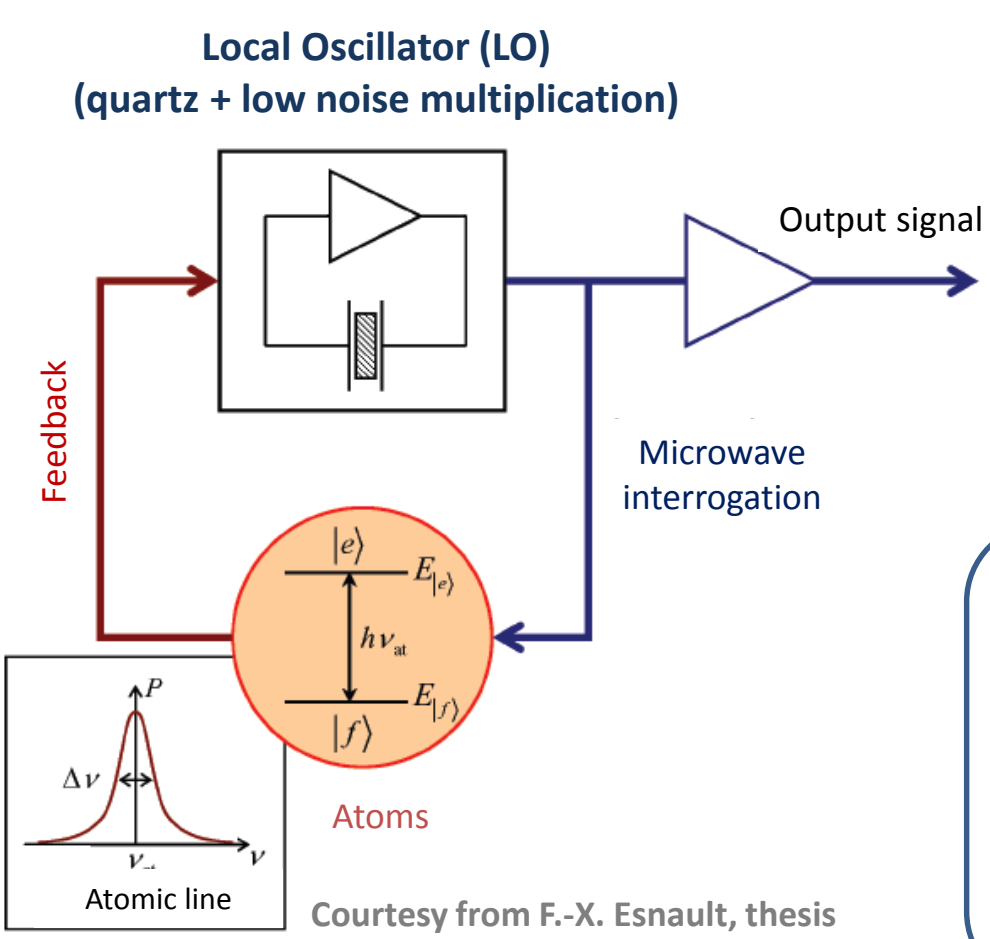
Muquans

- Created in 2011
- Located at Institut d'Optique d'Aquitaine
  - Strong support from local & national public authorities
  - A unique scientific and technical environment
- 23 employees (10 PhDs)
- **Main products:**
  - **Absolute Quantum Gravimeter: AQG**
  - **High Performance Cold Atom Clock: MuClock**
  - **High Stability Fiber links: Refimeve**
  - **Custom Scientific Lasers**

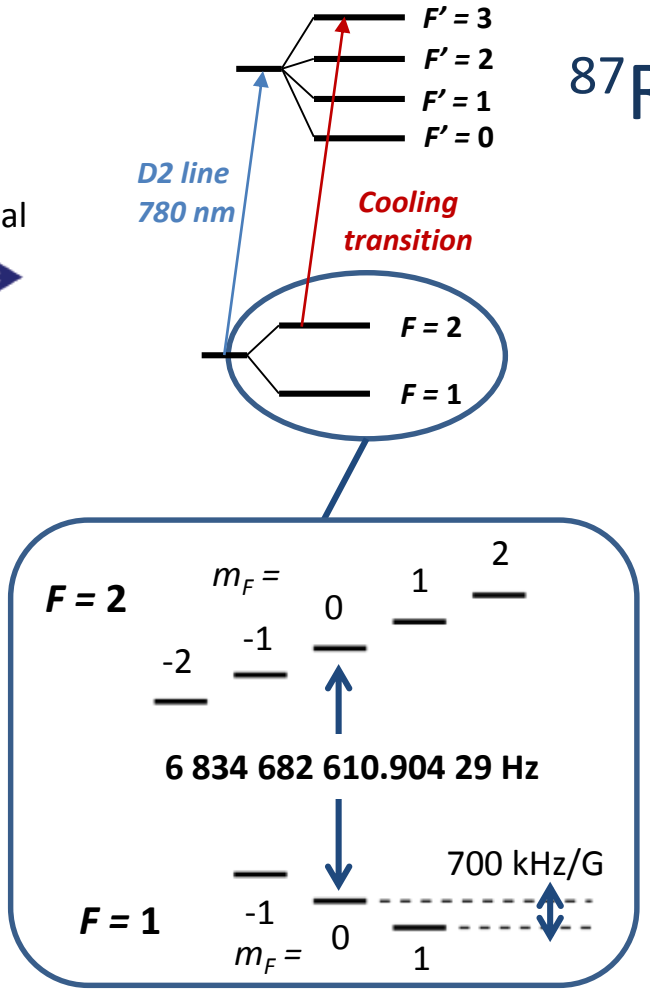
Outline

1. **Working Principles**
2. Recent Results
    1. MuClock 00
    2. Comparison Rubiclock/MuClock 00
3. Muclock Target Specifications

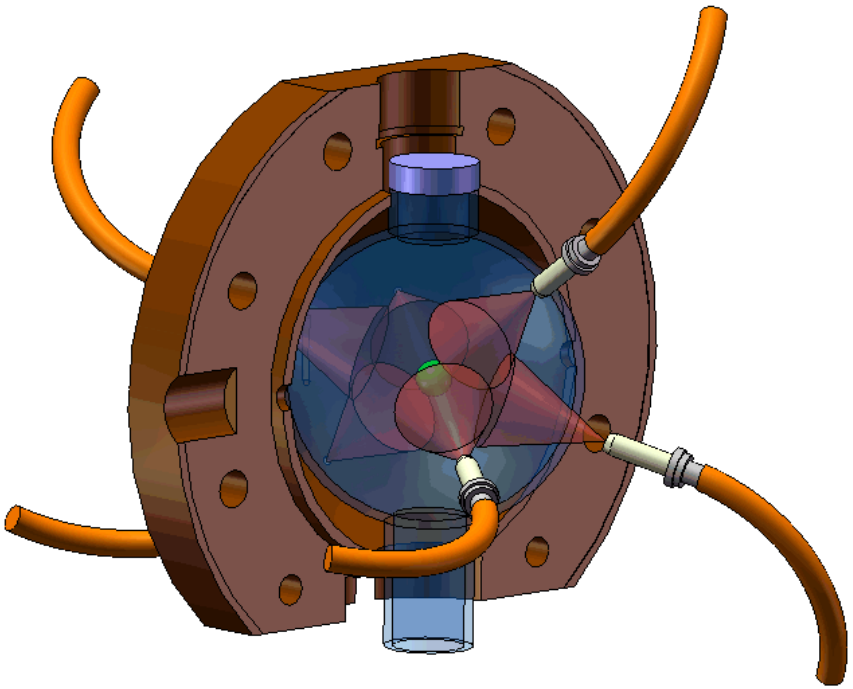
Working Principles



Courtesy from F.-X. Esnault, thesis

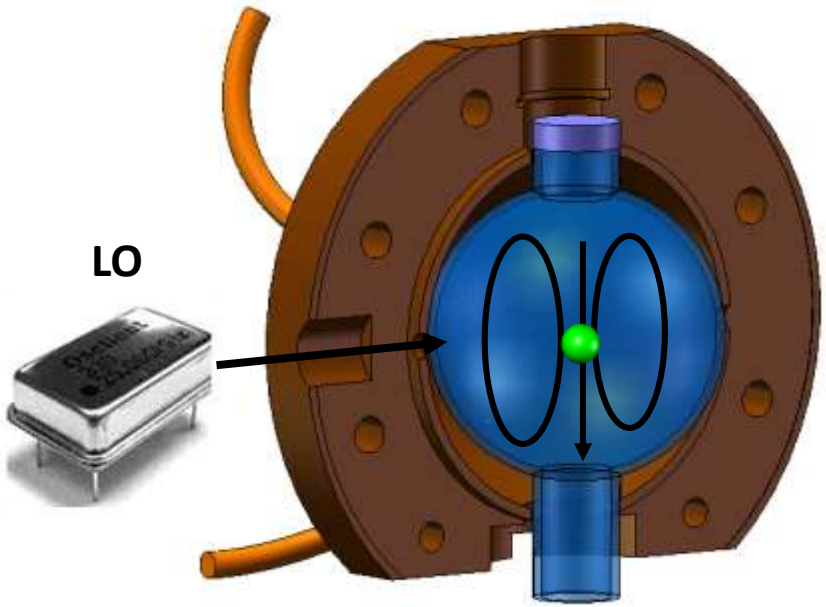


Working Principles



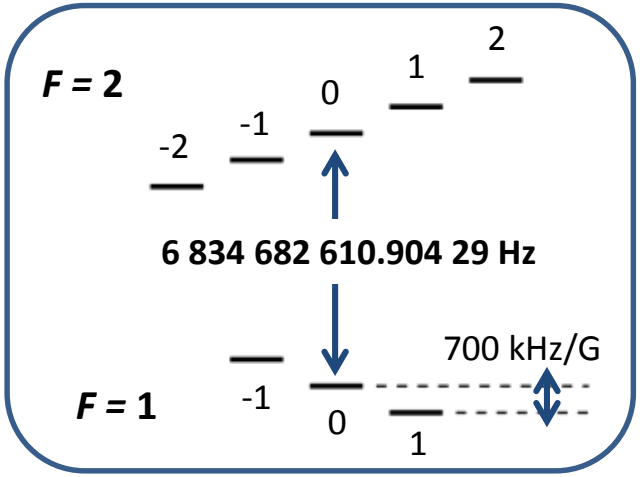
Step 1: isotropic light cooling.
$N_{\mathrm{at}} \sim 10^7$ in detection column.

Working Principles

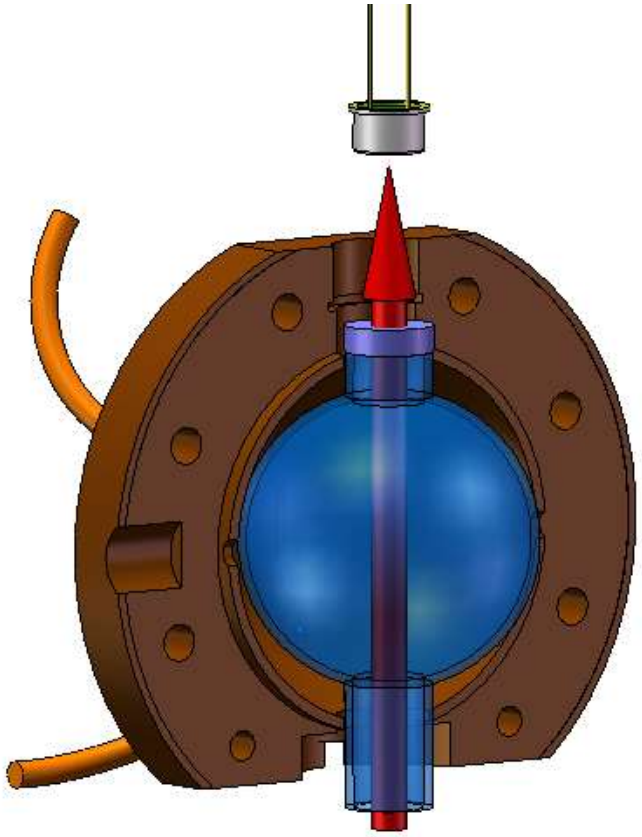


Step 1: isotropic light cooling. $N_{\mathrm{at}} \sim 10^7$ in detection column.

Step 2: microwave interrogation while the atoms are free falling in the cavity. $T_{\mathrm{R}} \sim 40$ ms.



Working Principles



Step 1: isotropic light cooling. $N_{\mathrm{at}} \sim 10^7$ in detection column.

Step 2: microwave interrogation while the atoms are free falling in the cavity. $T_{\mathrm{R}} \sim 40$ ms.

Step 3: detection of the absorption on the cooling transition. Only one state (F = 2) is detected.

- **Compact design**
- **Recaptured atoms**
- **High repetition rate (10 Hz)**

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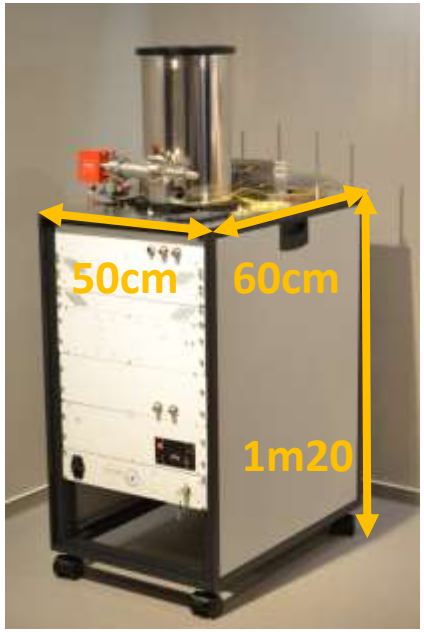
Recent Results

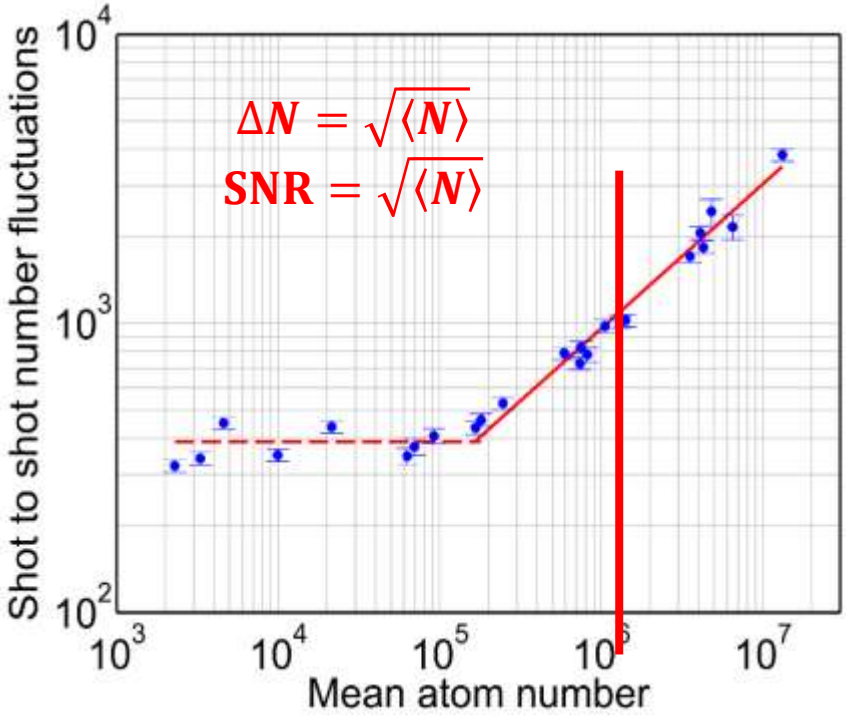
- MuClock:
  - Similar principle as Rubiclock – full re-design
  - Fully assembled – Fully automated
  - Dedicated for continuous long-term operation



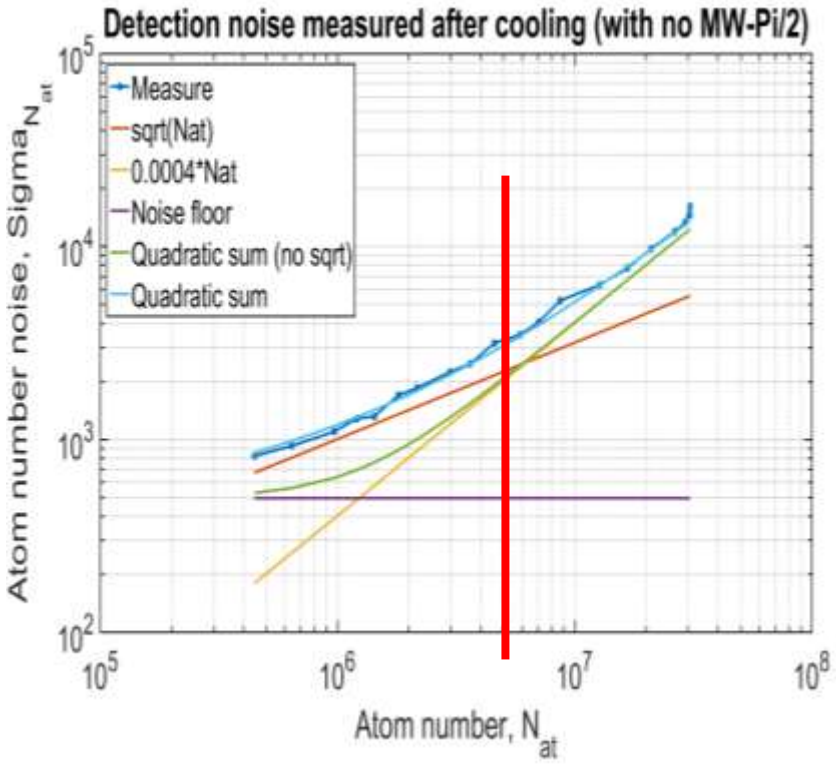
Recent Results

- MuClock 00:
  - Almost shot-noise limited detection

Rubiclock

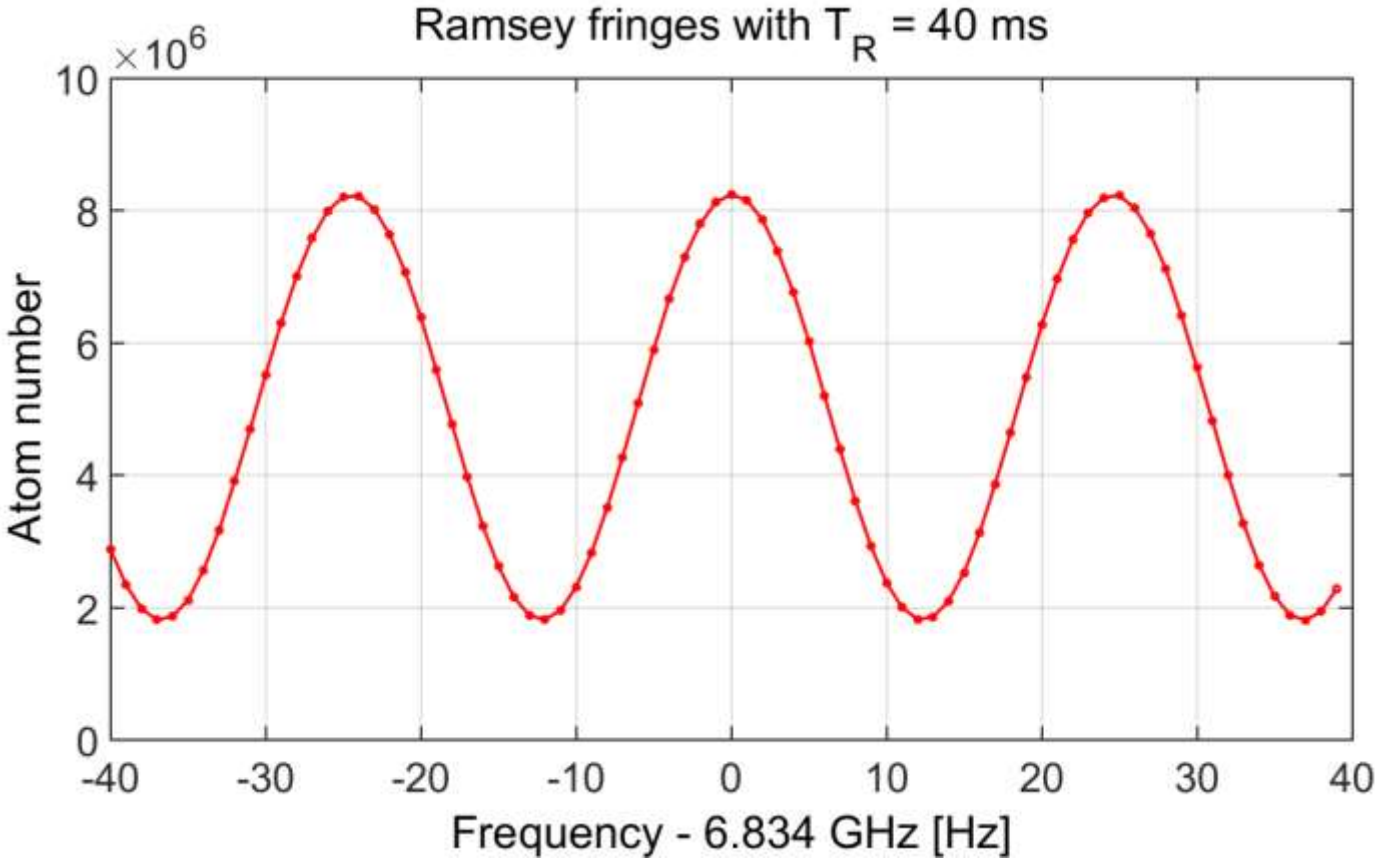


MuClock 00



Recent Results

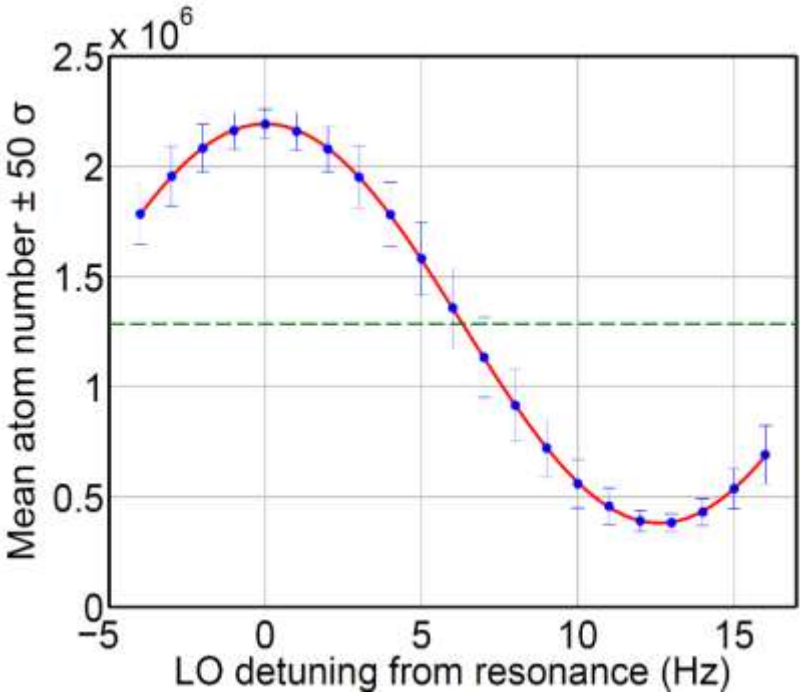
- MuClock 00:
  - Lock on Ramsey fringes: C = 64%

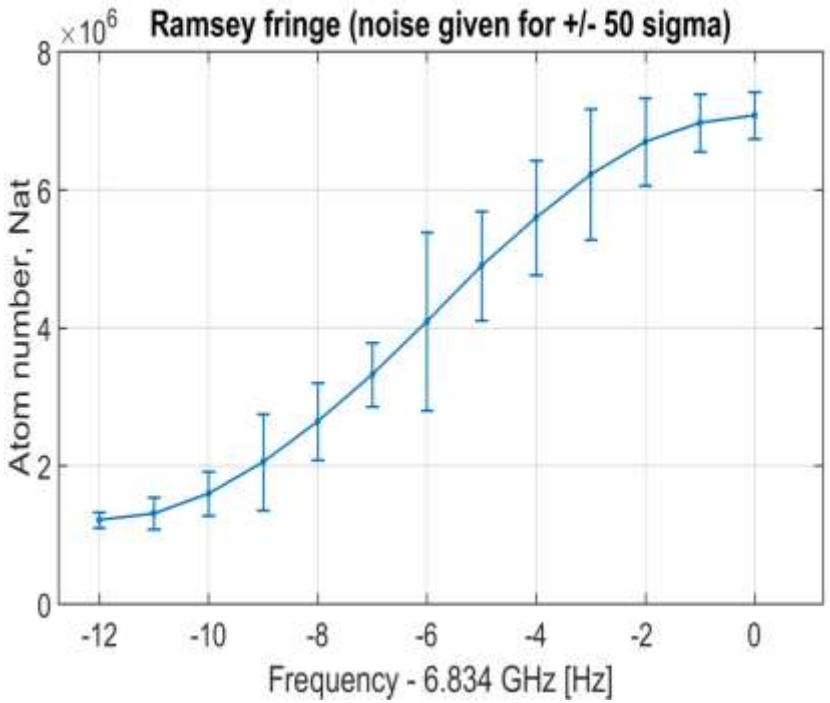


Recent Results

- Comparison Rubiclock/MuClock 00:
  - Central fringe noise

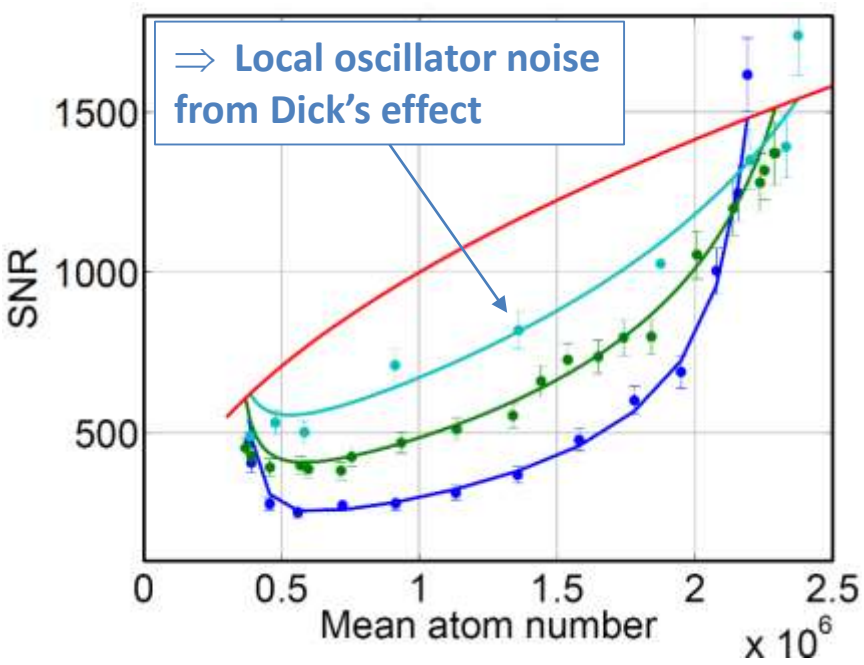
T_R = 40 ms - FWHM = 12.5 Hz

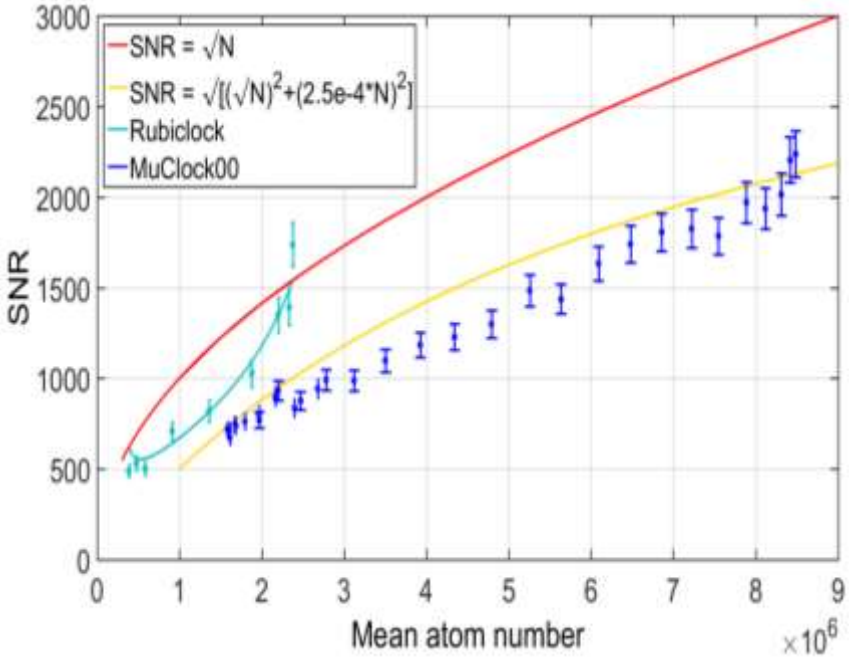




Recent Results

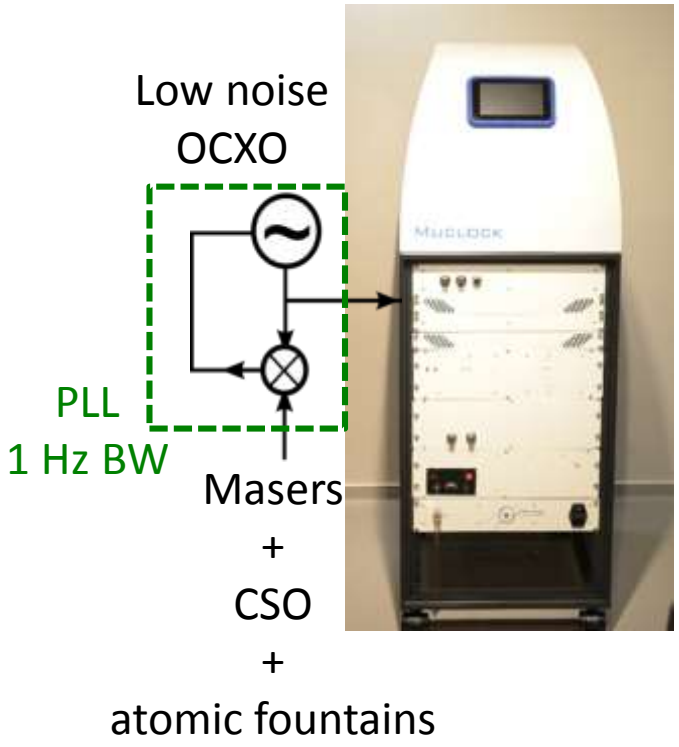
- Comparison Rubiclock/MuClock 00:
  - Dick effect limited measurement





Recent Results

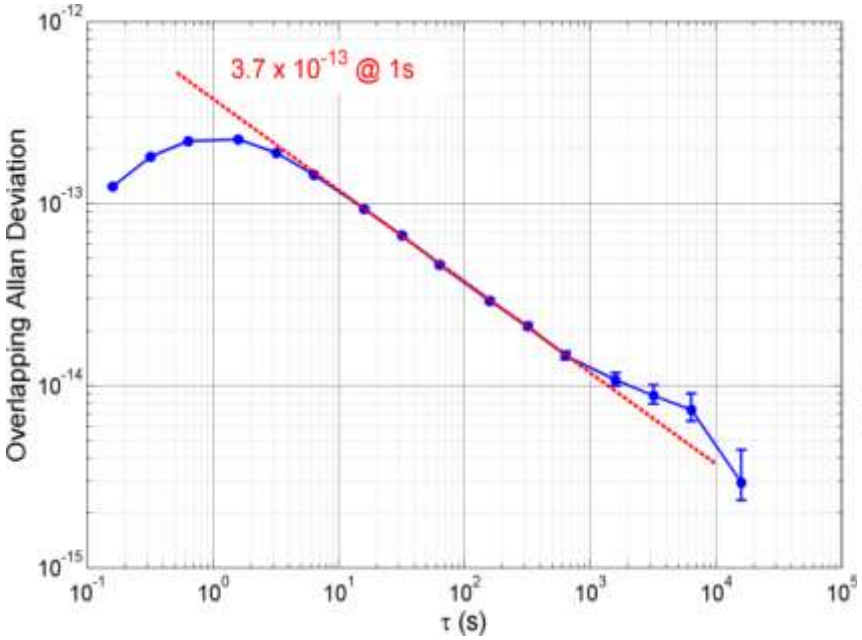
- Comparison Rubiclock/MuClock 00:
  - Short-term stability at SYRTE



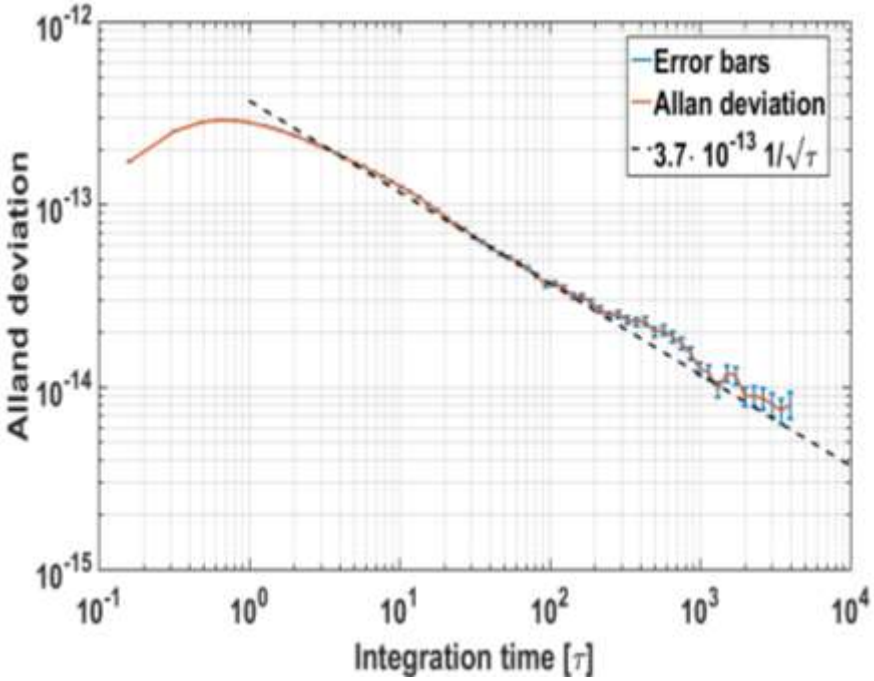
Recent Results

- Comparison Rubiclock/MuClock 00:
  - Short-term stability at SYRTE

SNR = 800 at mid-fringe



SNR = 800 at mid-fringe
(could be 1500, as measured at Muquans)

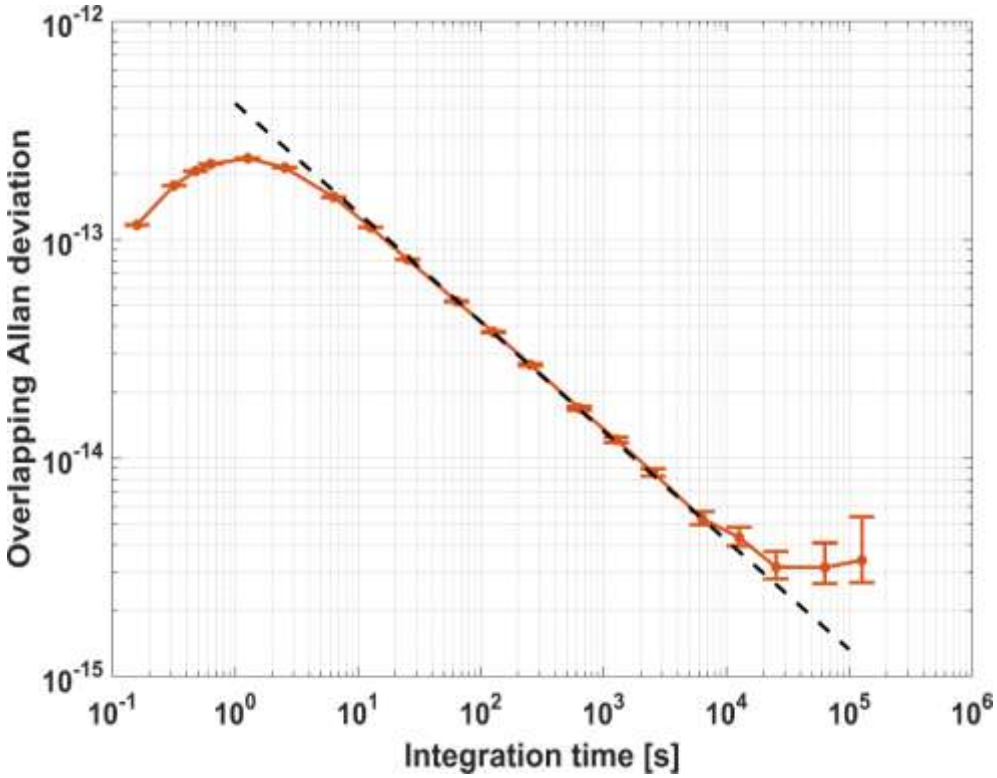


First measurement: less than a month at SYRTE

Recent Results

- Study on Rubiclock/MuClock00:
  - Long-term stability at SYRTE
  - Under evaluation:
    - Magnetic field stability
    - Cavity pulling
    - Cavity's phase gradients

Rubiclock



Recent Results

- Summary:

Rubiclock	MuClock 00
Less atoms: ⇒ Detection limited by QPN	More atoms: ⇒ Better SNR ⇒ More sensitive to technical noise
Short-term stability: Maximum performances reached	Short-term stability: ⇒ Comparable to Rubiclock ⇒ Upgrades on Dick effect expected (in progress) ⇒ Possible upgrades on technical noise (mid-term)
Long-term stability/accuracy: ⇒ Still under evaluation	Long-term stability/accuracy: ⇒ Compared to Rubiclock

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Muclock Target Specifications

- Stability:

Averaging time (s)	Relative ADEV
1	< 3.0E-13
10	< 9.5E-14
100	< 3.0E-14
1000	**< 9.5E-15**
10000	**< 3.0E-15**
86400 (1 day)	**< 1.0E-15**

< 0.1 ns in a day

- Accuracy and other specs:

Accuracy	**better than 5.0E-15**
Long term behavior	**flicker floor < 1.0E-15**
Lifetime	10 years
Volume	155x55x80 cm^3
Mass	135 kg
Power consumption	< 250 W

Conclusion

- We have developed a high performance atomic clock based on laser cooled atoms

- Short term stability in the low 10^{-13}: **work in progress**
- Long term stability in the low 10^{-15}: **work in progress**
- Accuracy in the 10^{-15}: **work in progress**

- Industrial approach for all the components

  => high reliability, ease of use

Acknowledgments

l'Observatoire de Paris — SYRTE

Systèmes de Référence Temps-Espace

Great Collaboration with SYRTE

- R. Szmuk
- D. Holleville
- A. Landragin
- N. Dimarcq
- Many more people at SYRTE…

cnes

CENTRE NATIONAL D'ÉTUDES SPATIALES

Support by CNES

- F.-X. Esnault
- J. Delporte

esa

Support by ESA

- P. Waller

bpifrance

μQUANS

Great team at Muquans!

Thank you for your attention

Rubiclock

- RubiClock (operated by J.-F. Schaff and R. Szmuk):
  - Research project in collaboration between SYRTE and Muquans
  - Demonstration of principle – 0g-flights