TACC – Trapped Atom Clock on a Chip

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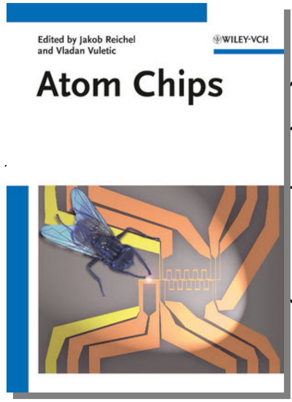
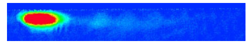
Physique quantique et applications

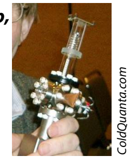
l'Observatoire de Paris — SYRTE

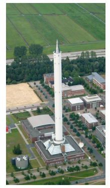


Complex manipulation



Compact setup, fast BEC

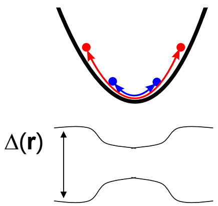


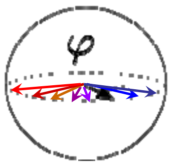


Drop tower proven!
Quantus collaboration

Integrated metrology devices?

Trap shifts: Dephasing

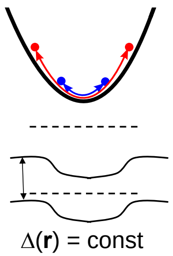


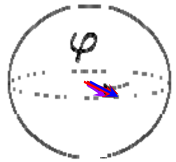


potential and interactions shift the energy levels

ensemble of atoms will dephase (inhomogeneous broadening)

Solution: "Magic" fields



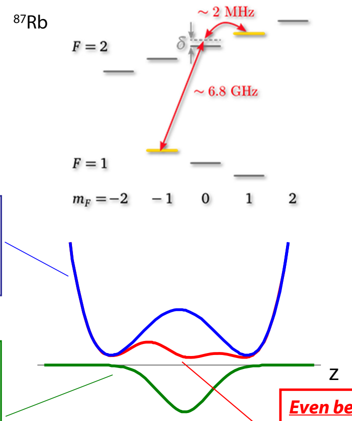


There can be a shift, but it is constant in space.

An ensemble of atoms stays in phase.
Coherence is preserved.

Key idea in optical lattice clocks!

"Magic" fields for Rb



Zeeman shift

$U^{(1)}_{Zeeman} = g_F m_F \mu_B |B|$

identical to 1st order

Collisional shift

$a_{11} = 100.44\, a_0$
$a_{22} = 95.47\, a_0$
$a_{12} = 98.09\, a_0$

Scattering lengths identical to 5%

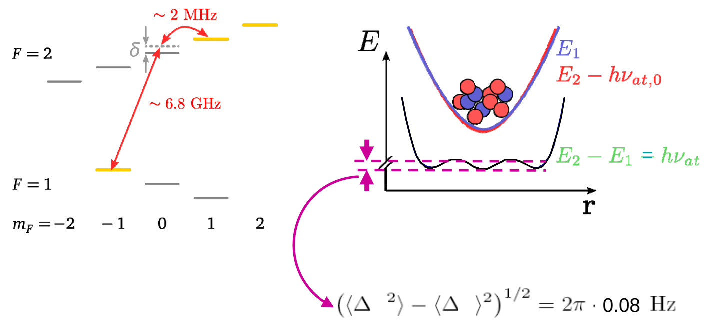
Even better: *the two 2nd order shifts can be tuned to compensate each other.*

Lewandowski et al., PRL **88**, 070403 (2002); Treutlein et al., PRL **92**, 203005 (2004).

Dephasing time: Prediction for TACC

^{87}Rb

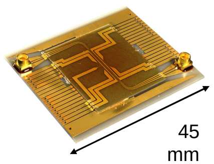
quasi-identical magnetic trap

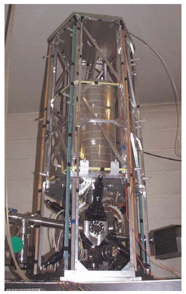


$(\langle\Delta\ ^2\rangle - \langle\Delta\ \rangle^2)^{1/2} = 2\pi \cdot 0.08$ Hz

→ **Predicted dephasing time** $\tau_{coh} = 2.8$ s

Can we reach a relevant range for compact clocks?



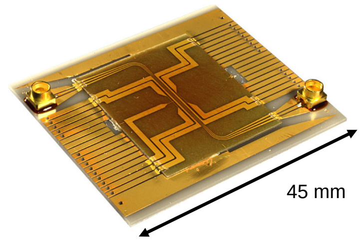


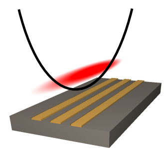
***Stability:** ~ 10^{-12} $s^{-1/2}$*

***Target stability:** ~ 10^{-13} $s^{-1/2}$ range*

***Stability:** ~ 10^{-14} $s^{-1/2}$*

TACC: Trapped-Atom Clock on a Chip





- Coplanar waveguide for microwave excitation
- Incorporate atomic clock know-how and techniques:
  - Two-layer magnetic shielding
  - Stable, low-noise current sources
  - Interrogation: homebuilt frequency chain with low phase noise, locked on H maser
  - + lots of SYRTE know-how

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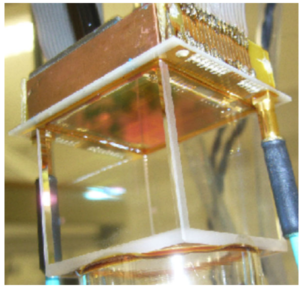

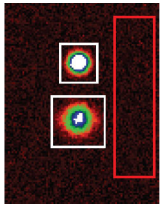

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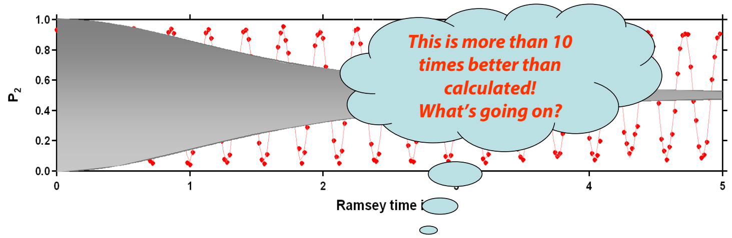
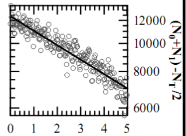
Ramsey measurement

C. Deutsch et al PRL **105**, 020401 (2010)



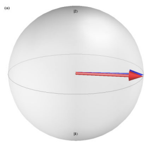
Contrast decay time T_{coh} = 58 ±12 s

- Magnetic trap, $\{\omega_x, \omega_y, \omega_z\}/2\pi = \{32(1), 97.5(2.5), 121(1)\}$ Hz
- Evaporative cooling to 175nK (30nK above T_c)
- 25000 atoms
- Ramsey spectroscopy.
  Vary Ramsey time (but keep trapping time constant).

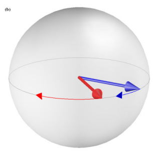


Spin self-rephasing

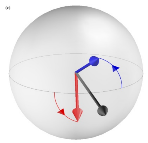
A quantum effect caused by particle statistics



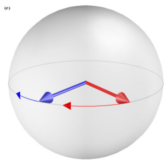
just after p/2 pulse



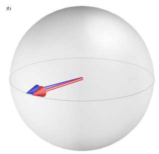
Free evolution: Hot atoms have stronger detuning, rotate faster than cold atoms.



ISRE rotates spins around their sum



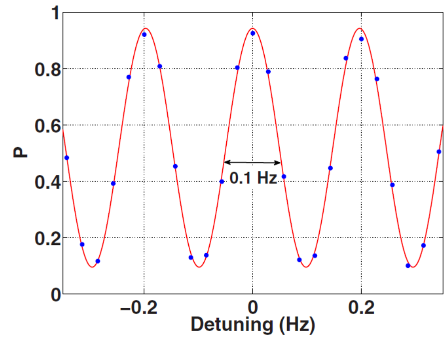
After half a spin rotation, hot atoms are "behind" cold atoms and catch up => **synchronisation**



Atoms stay synchronised because opening angle is small.

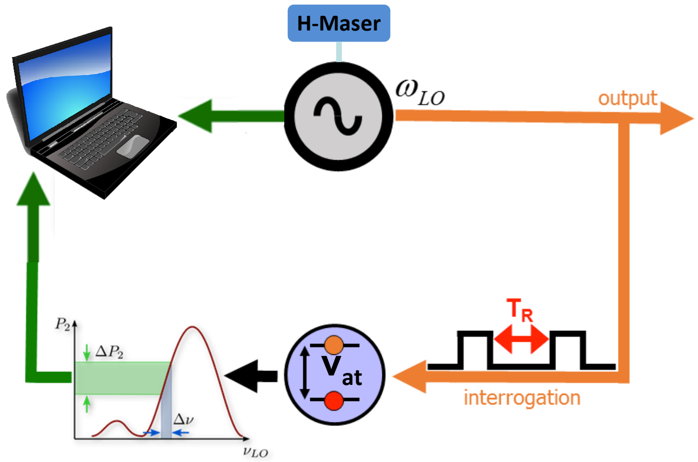
C. Deutsch et al PRL **105**, 020401 (2010)

TACC Ramsey fringe

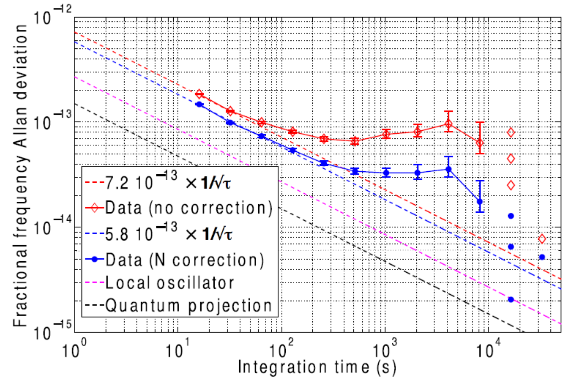


- ***Ramsey time: T_R=5s***
- ***Fourier-limited linewidth***
- ***85% contrast***

Clock stability measurement

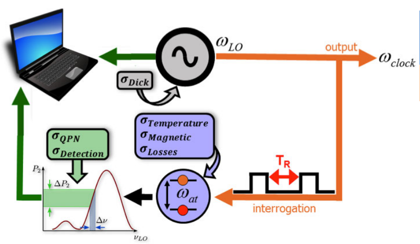


Allan variance



Stability: 5.8 10-13 $s^{-1/2}$

Stability budget

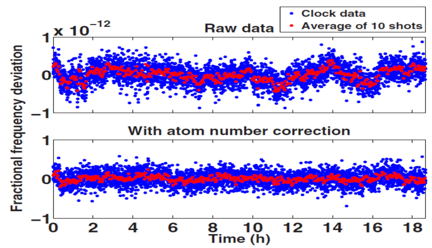


Relative frequency stability (10^{-13})	at 1 shot	at 1 sec
Measured	1.5	5.8
Temperature	1.0	3.9
Magnetic field	0.7	2.6
Local Oscillator	0.7	2.7
Quantum projection	0.4	1.5
N correction	0.3	1.3
Atom loss	0.3	1.1
Detection	0.3	1.1
Total estimate	1.5	6.0

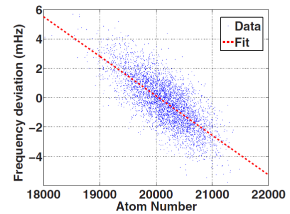
Stability of a trapped-atom clock on a chip, R.Szmuk, V. Dugrain, W. Maineult, J. Reichel and P. Rosenbusch, PRA **92**, 012106 (2015).

Clock frequency: Compensating the atom number dependence

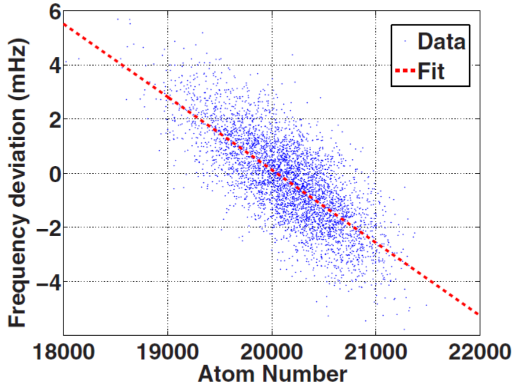
Relative frequency deviation over 18h



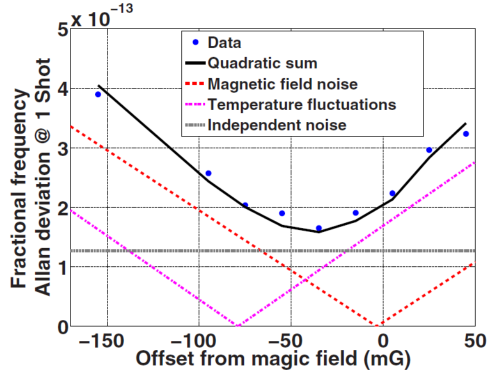
Reproducible dependence on N_{at}



Atom number – clock frequency correlation



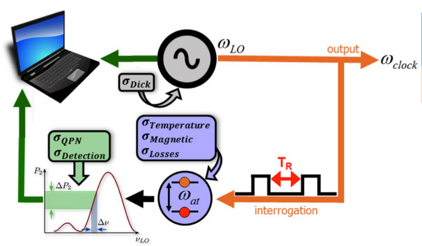
Magnetic field dependence



Magnetic field stability: 16 μG shot-to-shot

Temperature stability: 0.5 nK shot-to-shot

Stability budget



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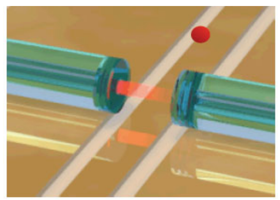
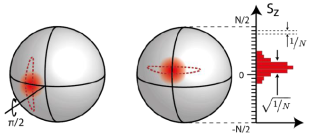
Perspectives

- **Some "easy" improvements:**
  - Reduce dead time (MOT loading)
  - Improve current source stability
- **eeTACC: Use quantum technologies**
  - Spin squeezing
  - Non-destructive detection



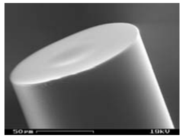
Perspectives: Cavity-enhanced chip clock

- Cavity squeezing now works well: **>20dB**
- But has **never been tested at a metrologically relevant level**:
  Proof-of-principle clock:
  10^{-9} relative stability (Vuletic group).
  ICOLS, Kasevich group: 10^{-11} !
- **We have TACC: 5.8 10^{-13} $s^{-1/2}$!**



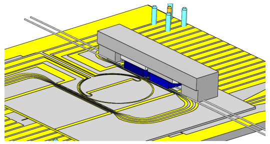
TACC 2.0 Design

Cavity:



- Length: L ~ 1 mm
- Mode waist: w_0 ~ 8 µm
- Finesse: F ~ 10000

Atom chip:



Ω wire for magnetic transport

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