Coherent manipulation of atomic wavefunctions in an optical lattice

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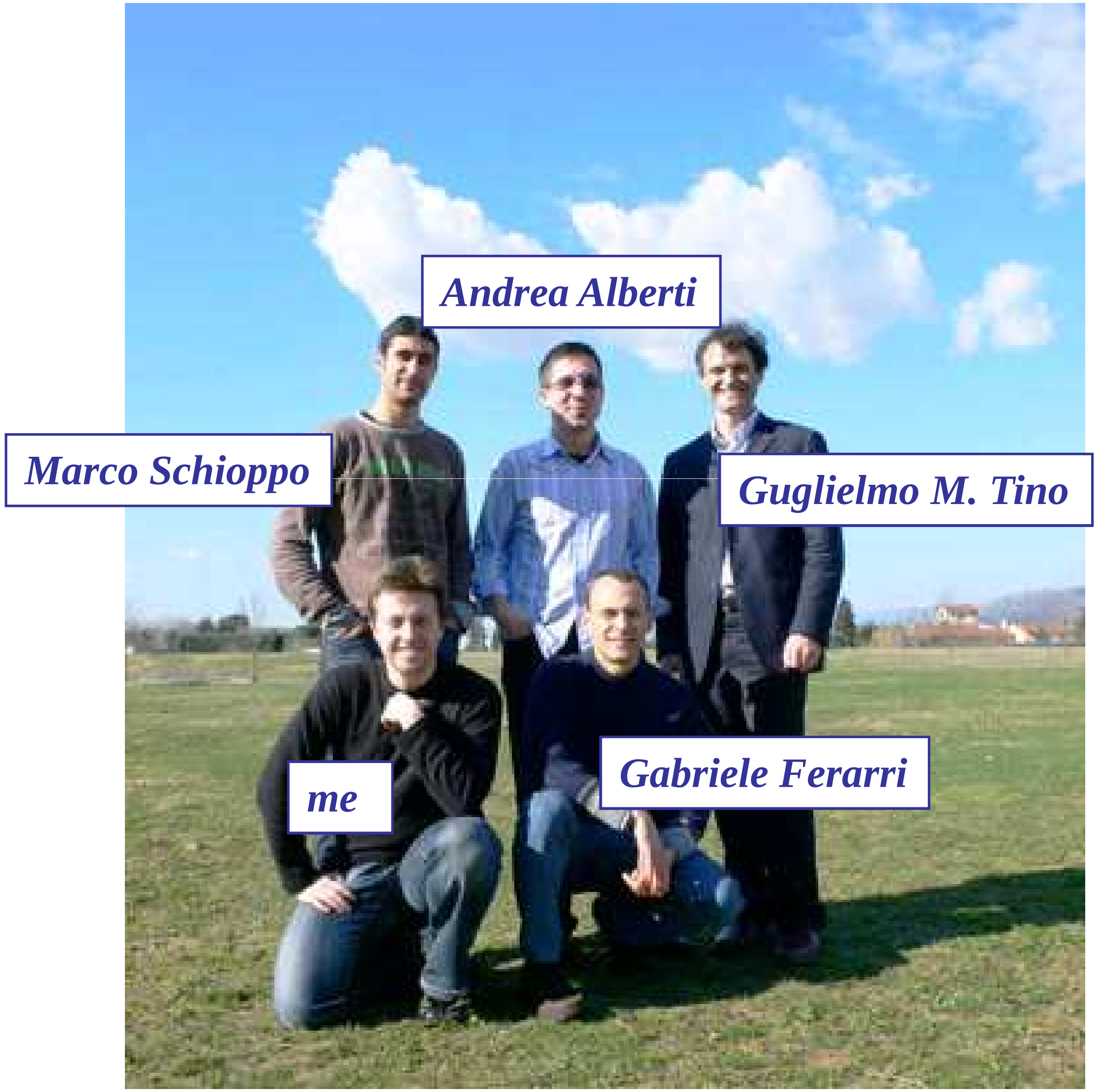
Group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me
Gabriele Ferarri

Outline

- *Sr^{88} and experimental setup*
- *Atoms in a tilted lattice potential*
- *Atoms in a modulated tilted lattice potential:*
  - *Resonant broadening of atomic wavefunctions*
  - *Breathing of atomic wavefunctions*
  - *Atoms climbing an optical lattice uphill*
- *Short-distance measurements*
- *Conclusion*

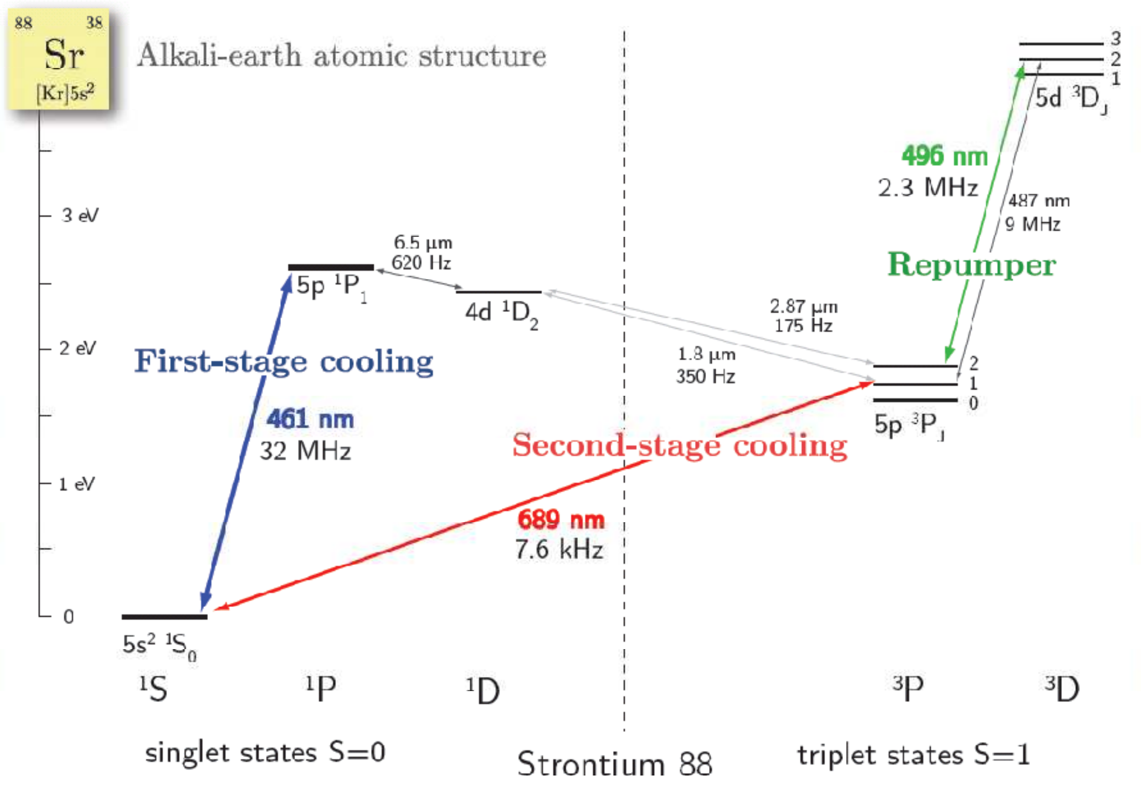
Sr^{88}

Strontium is an alkaline earth metal, its atomic number is 38

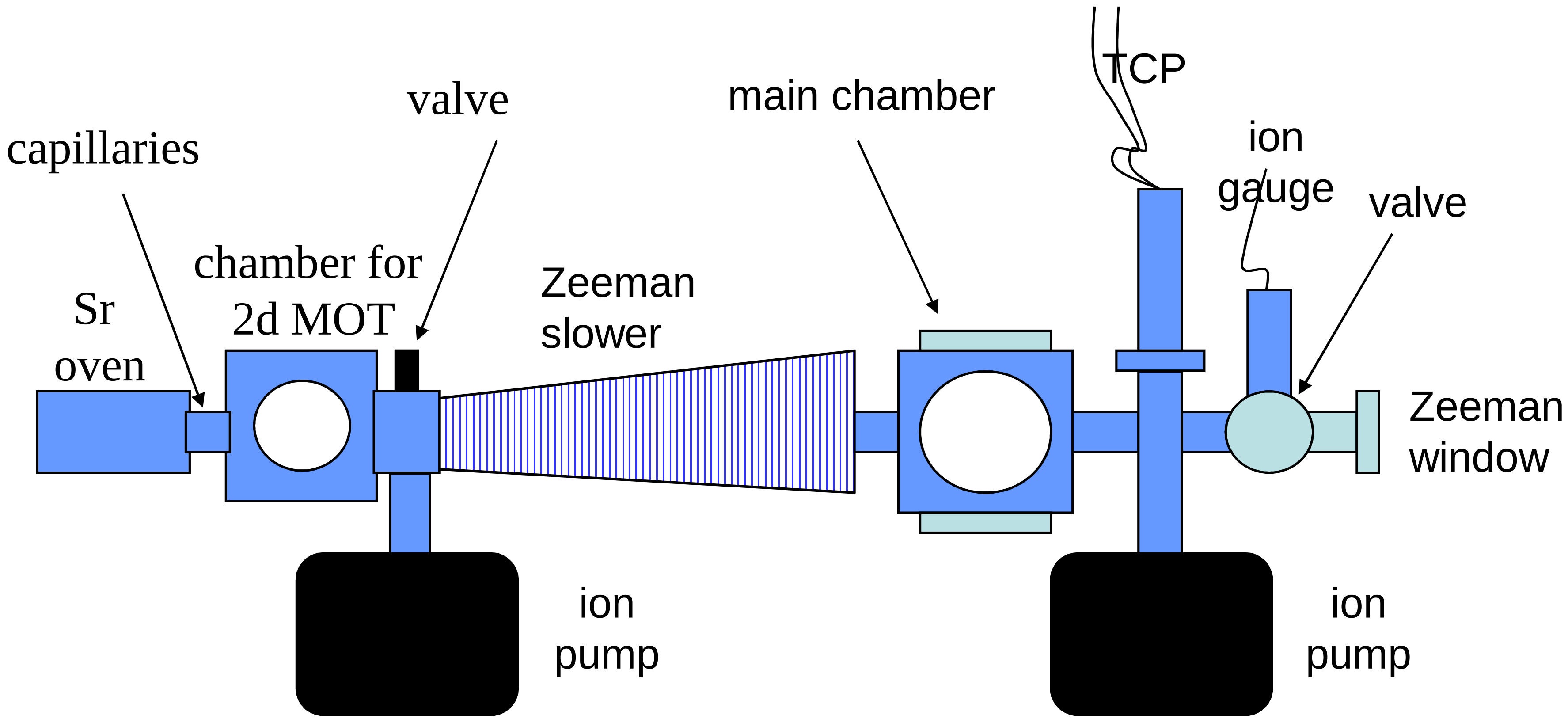
Sr isotope	Nucl. spin I	Abundance
88	0	82.6 %
87	9/2	7 %
86	0	9.8 %
84	0	0.56 %

a negligiable cross section

insensetive to a magnetic field



Experimental setup
vacuum

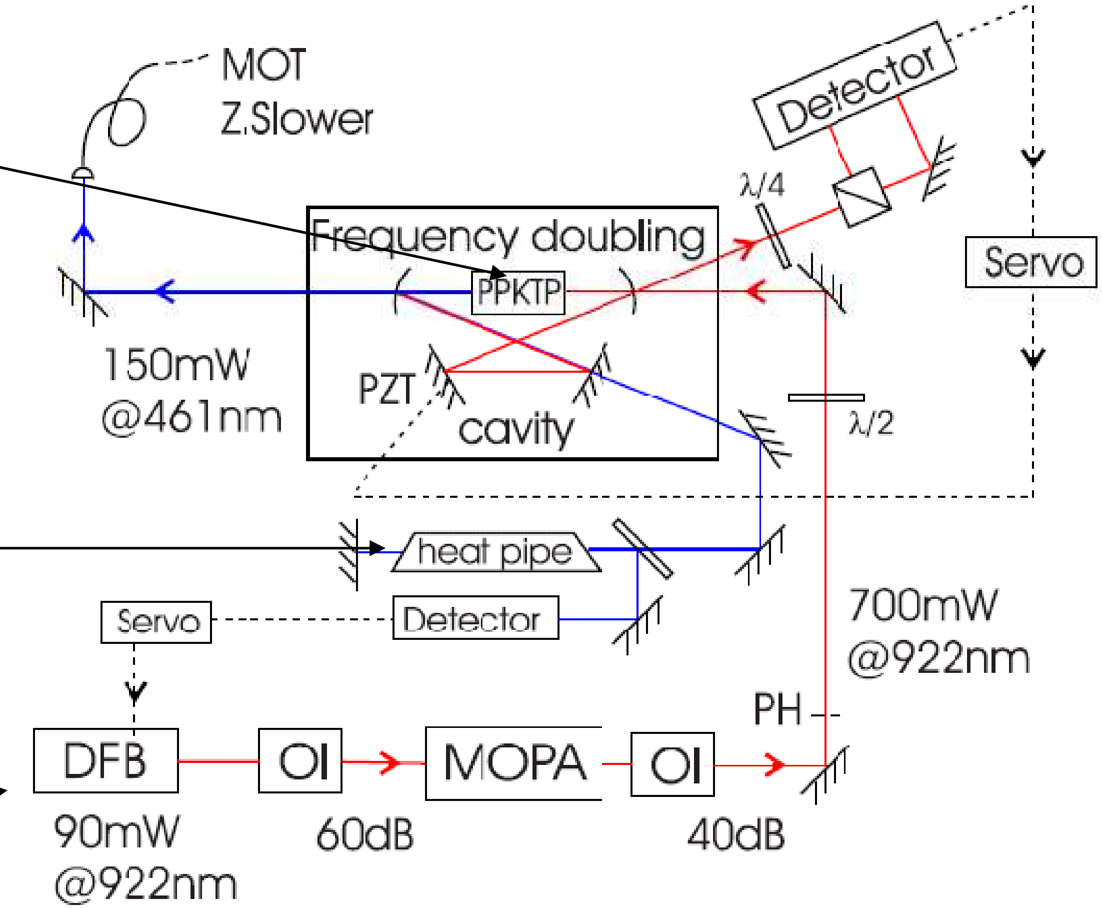


Experimental setup
laser park: blue source

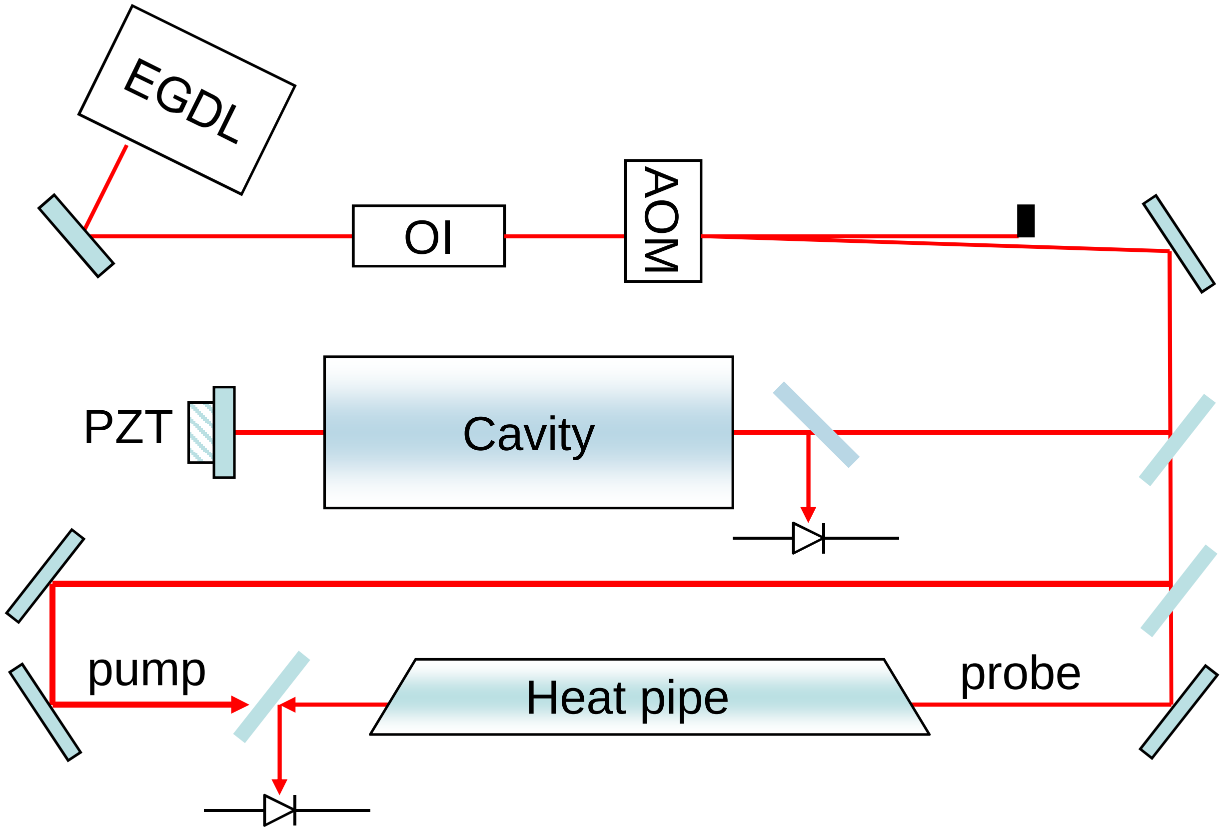
Frequency doubling crystal: $KTiOPO_4$

Heat pipe

Infrared source



Experimental setup
laser park: red source



All optical cooling and trapping of Sr

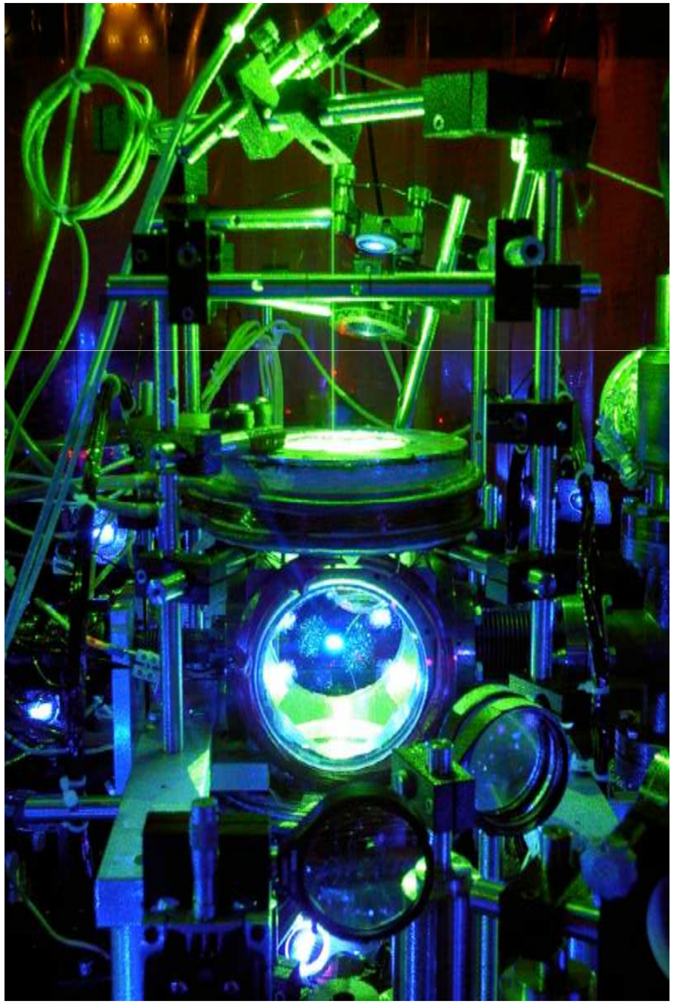
Sr oven: T ~ 500 °C, 10^{11} atoms/s

Zeeman slower: 5×10^{8} atoms/s

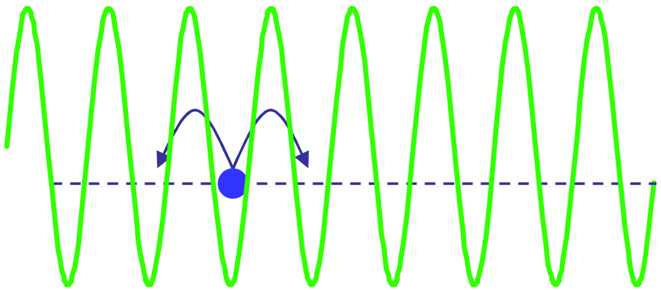
Blue MOT: λ =461 nm,
T ~ 1 mK, N ~ 5×10^{7}

Red MOT: λ =689 nm,
T ~ 1 μK, N ~ 4×10^{6}

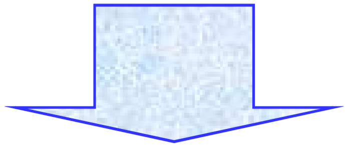
Optical lattice: λ =532 nm,
T ~ 1 μK, N ~ 2×10^{5}



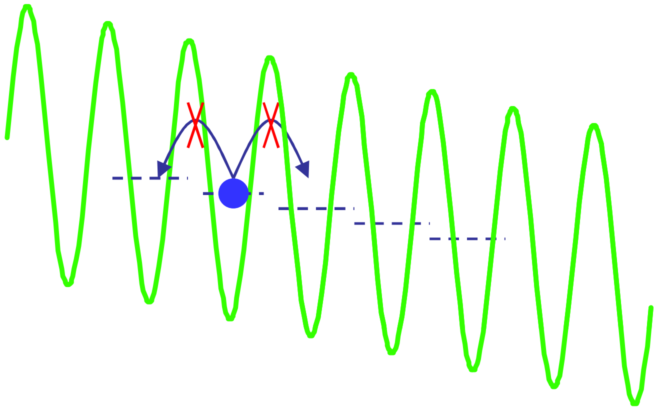
Atoms in a tilted lattice potential



Atomic states are
delocalized due to
the translation symmetry



atomic wavefunctions
will broad in time



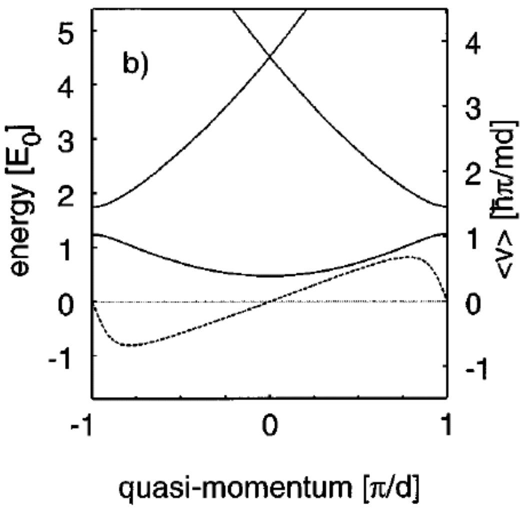
uniform force breaks
translation symmetry !!!

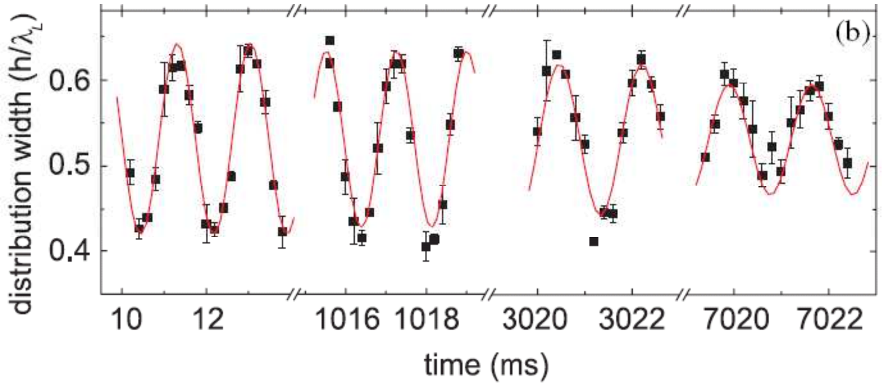
Atomic states became
localized
(Wannier-Stark state)

Bloch oscillations

The periodicity of the lattice (period *d*) leads to a band structure of the energy spectrum of the particle. Under the influence of a constant external force *F*, weak enough not to induce interband transitions, a given state evolves periodicly with a period T_B corresponding to the time required for the quasimomentum to scan a full Brillouin zone.

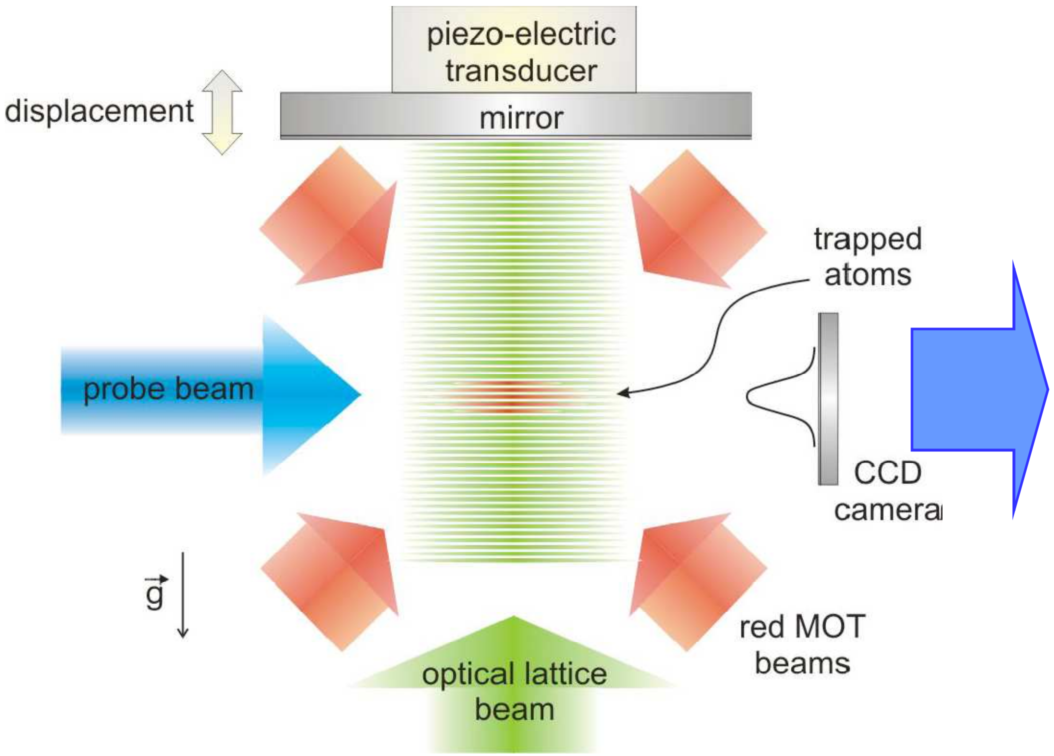
$$T_B = \frac{h}{Fd}$$

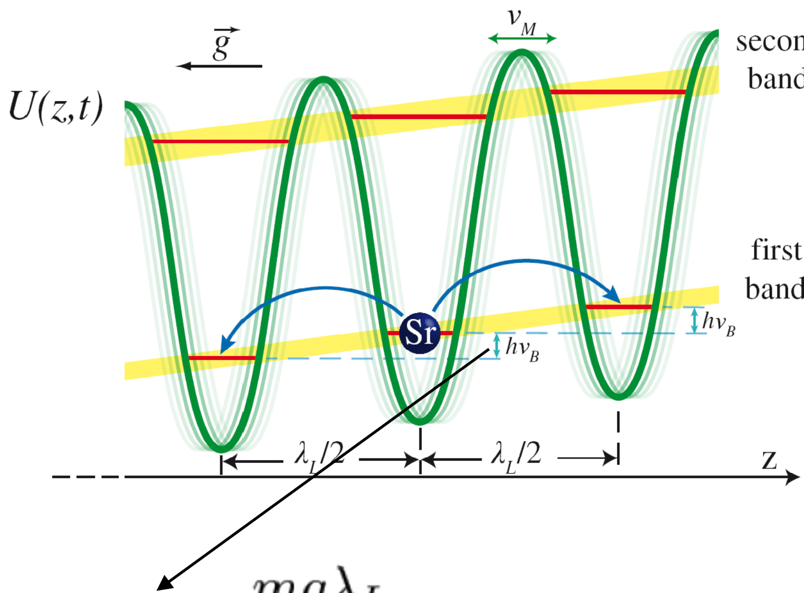




G. Ferrati et al.,
Long-Lived Bloch Oscillations with Bosonic Sr Atoms and Application to Gravity Measurement at the Micrometer Scale,
PRL **97**, 060402 (2006)

Driven lattice potential

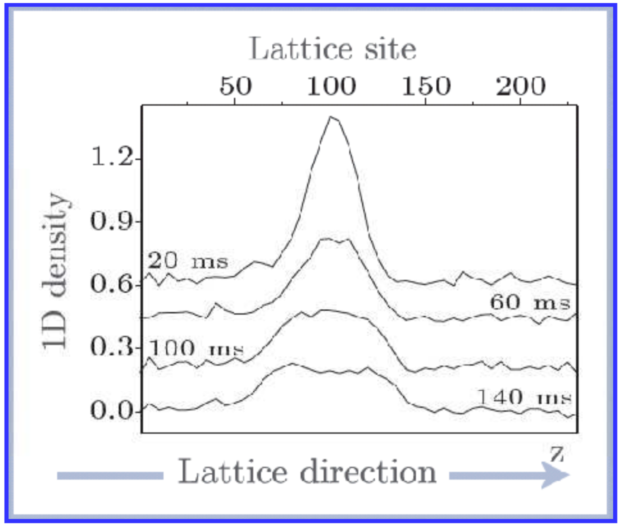


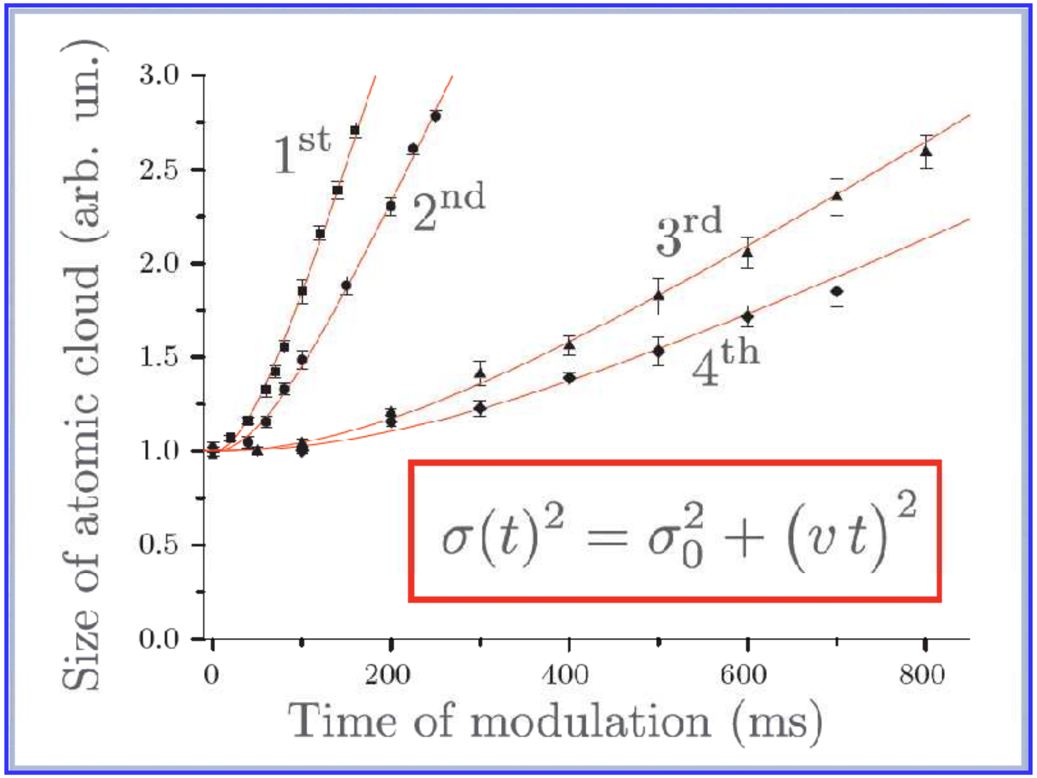


$$\nu_B = \frac{mg\lambda_L}{2h}$$

$$U(z,t) = mgz + \frac{U_0}{2}\cos\{2k_L[z - z_0\cos(2\pi\nu_M t)]\}$$

Resonant tunneling

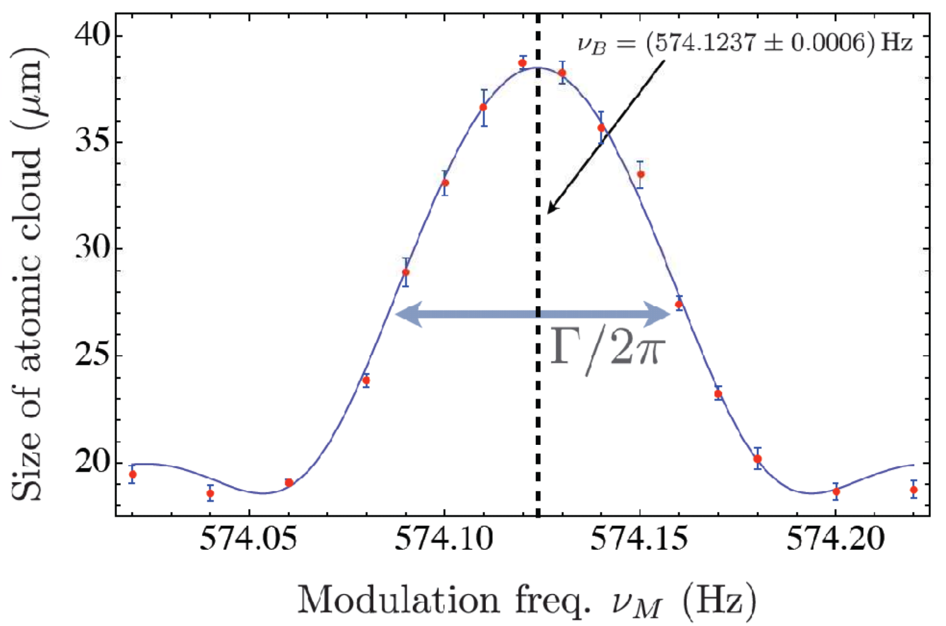




V. V. Ivanov *et al.*,
Coherent Delocalization of Atomic Wave Packets in Driven Lattice Potentials, PRL. **100**, 043602 (2008)

The atomic cloud broads linearly when $\omega_m = n \times \omega_B$

Resonance spectra



$$\sigma^2(t) = \sigma_0^2 + \left(\frac{Sin(\delta/\Gamma)}{\delta/\Gamma} v_o t \right)^2$$

Modulation time t=15 sec
ν_B = (574.1237±0.0006) Hz
Γ = (0.0223±0.0004) Hz

g = (9.805301±0.000026) m/s^2

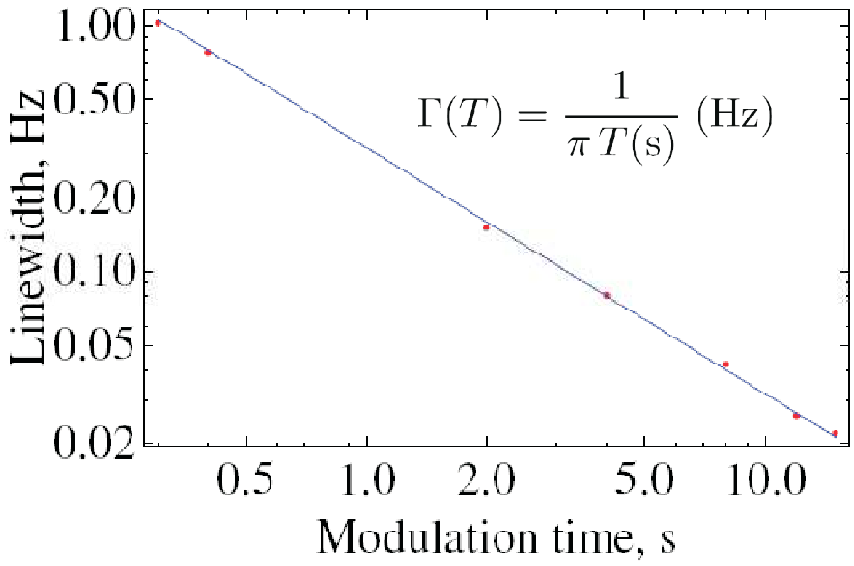
the measurements of Bloch frequency gives *g* with 1 ppm precision

The linewidth of the resonance

What defines the linewidth Γ ?

- natural linewidth of such transition is neglieble
- no decoherence process i.e. insensitive to a magnetic field neglieble atom-atom ineraction

the resonance linewidth should be Fourier limited



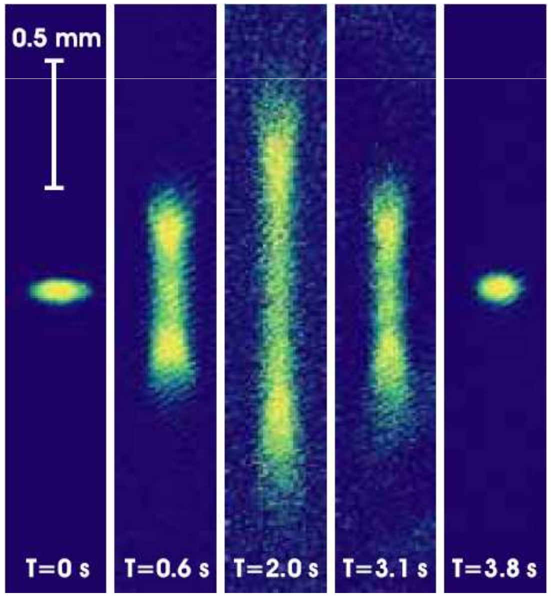
the resonance linewidth is purely Fourier limited up to 15 secodns of modulation

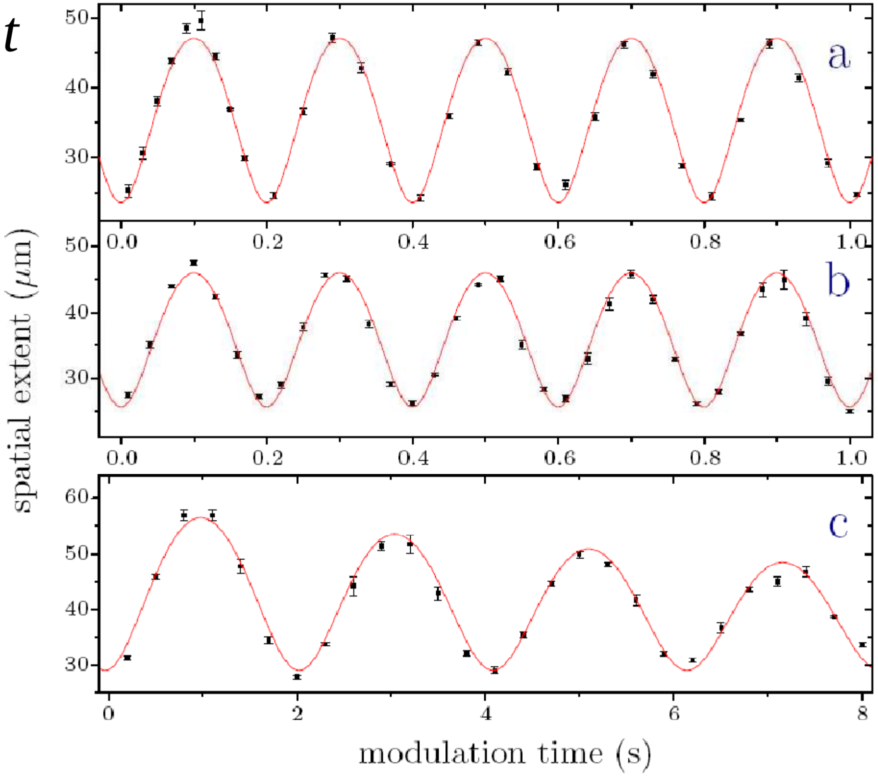
Breathing of atomic wavefunctions

What if $\omega_m \neq \omega_B$**?**

$$\frac{1}{\pi \times t}$$

$$\sigma^2(t) = \sigma_0^{\ 2} + \left(\frac{Sin(\delta / \Gamma)}{\delta / \Gamma} v_o t \right)^2$$





A. Alberti et al, *Engineering the quantum transport of atomic wavefunctions over macroscopic distances*, arXiv:0803.4069v [quant-ph]

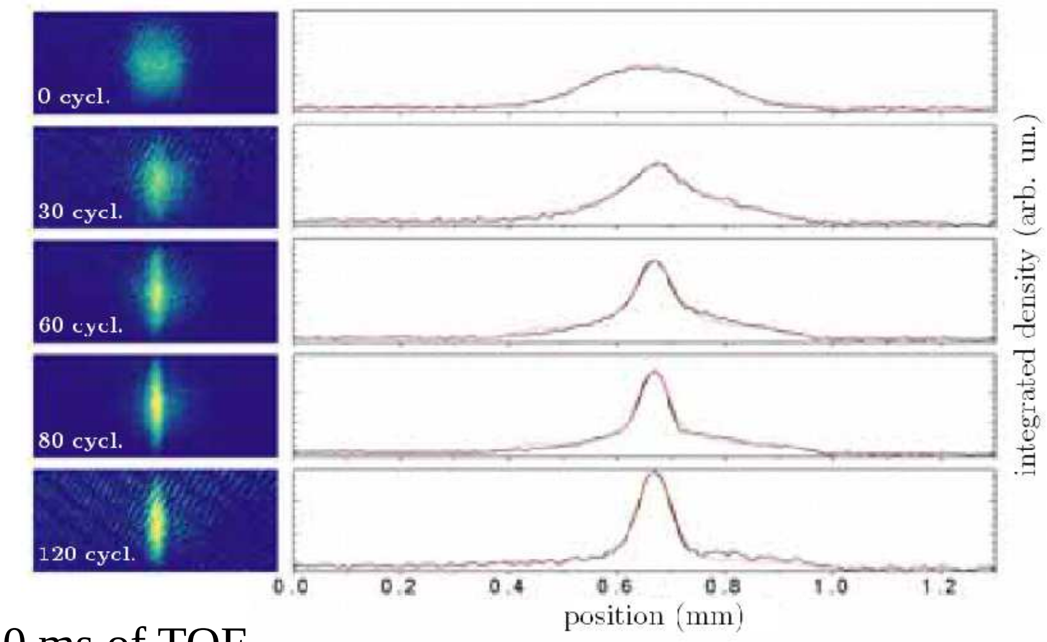
outstanding coherence time

τ>20 sec

A self-interference of the atomic wavefunctions

While in absence of driving the thermal sample expands following the usual gaussian profile, applying the driving we clearly observe the appearing of a non-Gaussian distribution

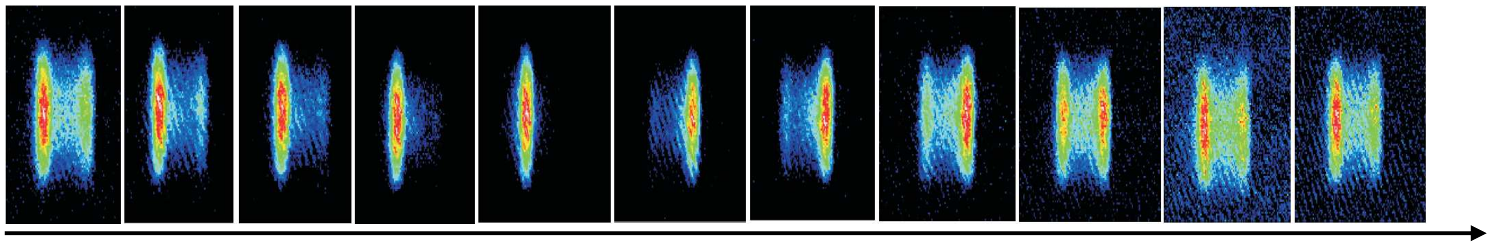
TOF signal 15 ms of expansion



Moreover stretching atomic wave-functions leads to an improvement of visibility of Bloch oscillations

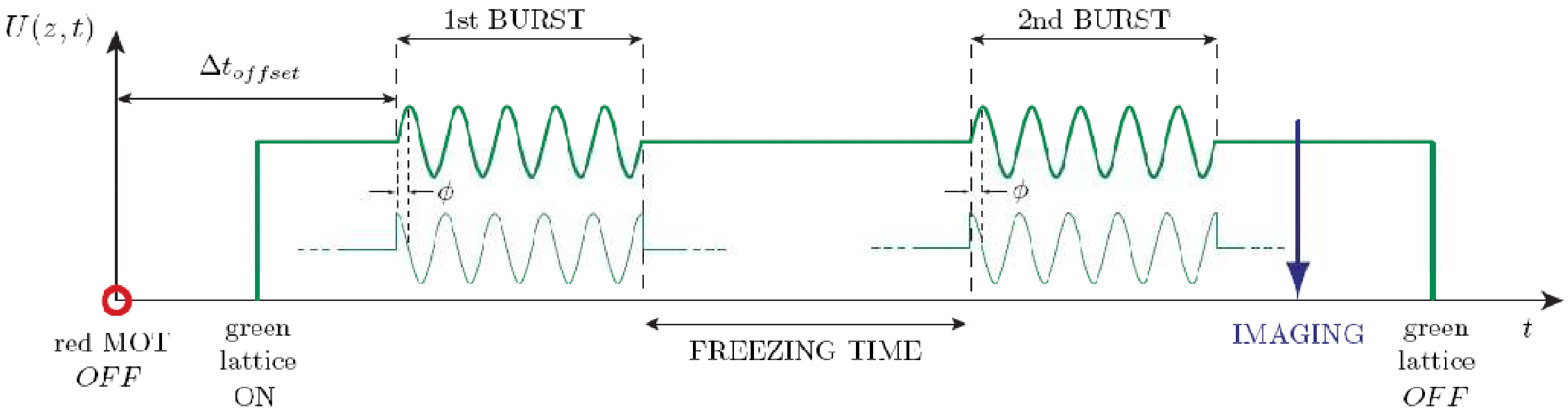
10 ms of TOF

T>Trec !

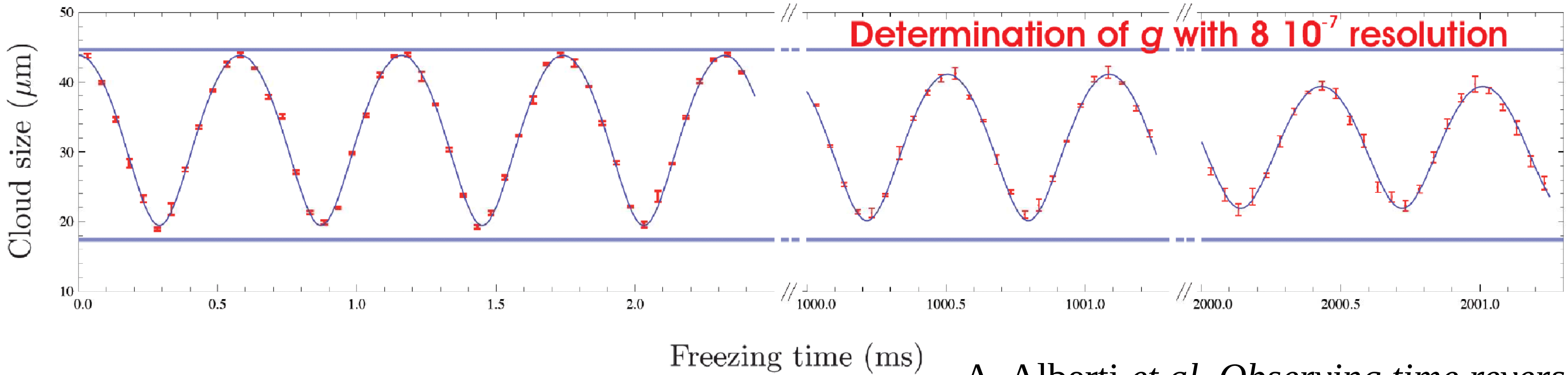


hold time in the modulated optical lattice t

A “time reversal” with thermal atomic cloud



An atomic wavefunction will either shrink either stretch further after the second pulse depending on a its phase, when second pulse is coming



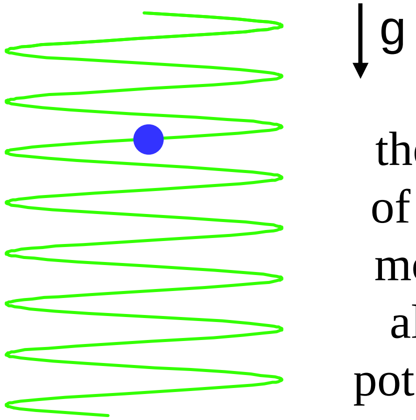
A. Alberti *et al*, *Observing time reversal in accelerated optical potential*, in preparation

Atoms climbing uphill

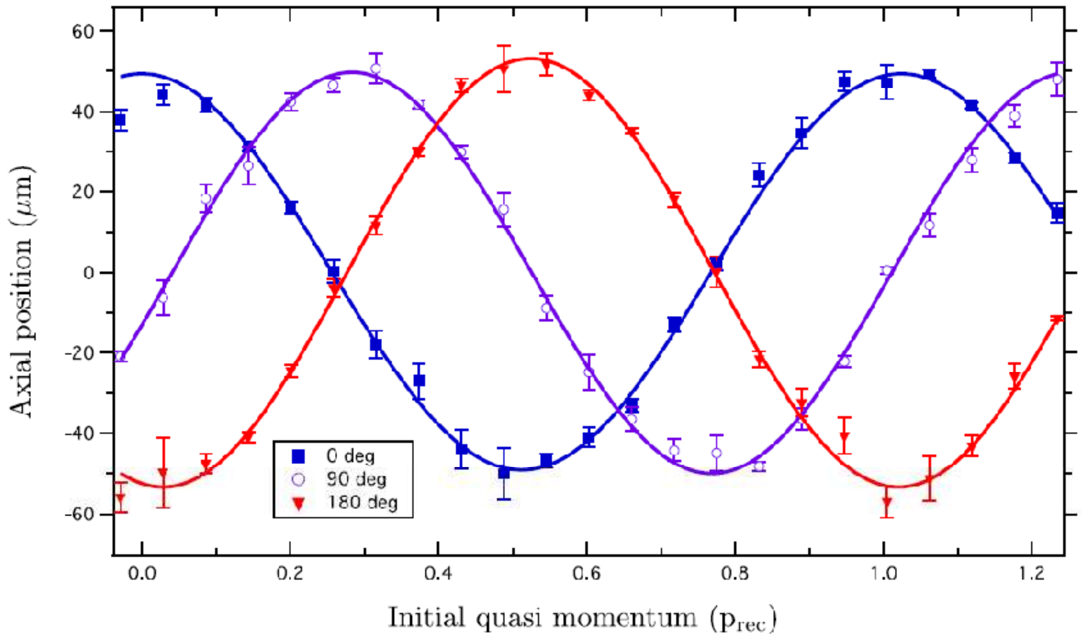
Can atoms move up or down due to a resonant tunneling ?

Yes

when the sample has a momentum dispersion of the order of the size of the Brillouin zone it becomes possible to move the center of mass of the sample along the lattice potential.

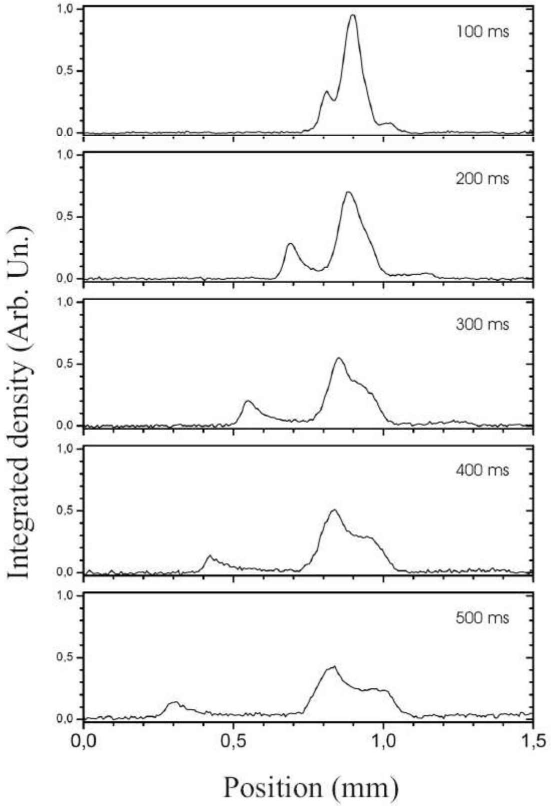


the center of mass of the sample will move up or down along the lattice potential depending on its phase, when the lattice is switch on

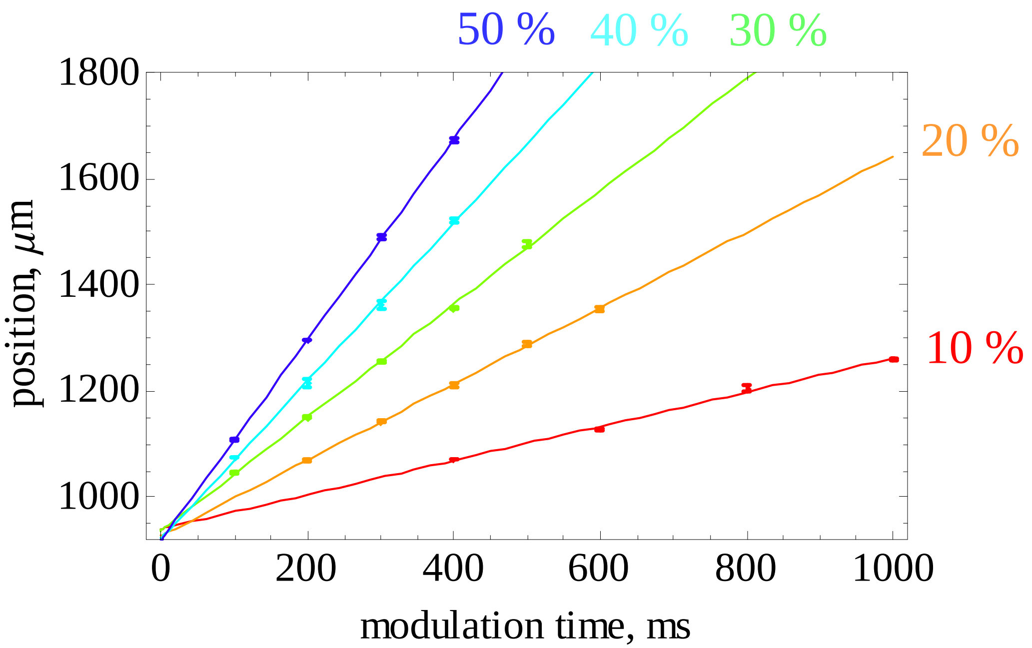


Atoms climbing uphill

the movement is more evident for atoms in 2nd band due to a higher tunneling rate



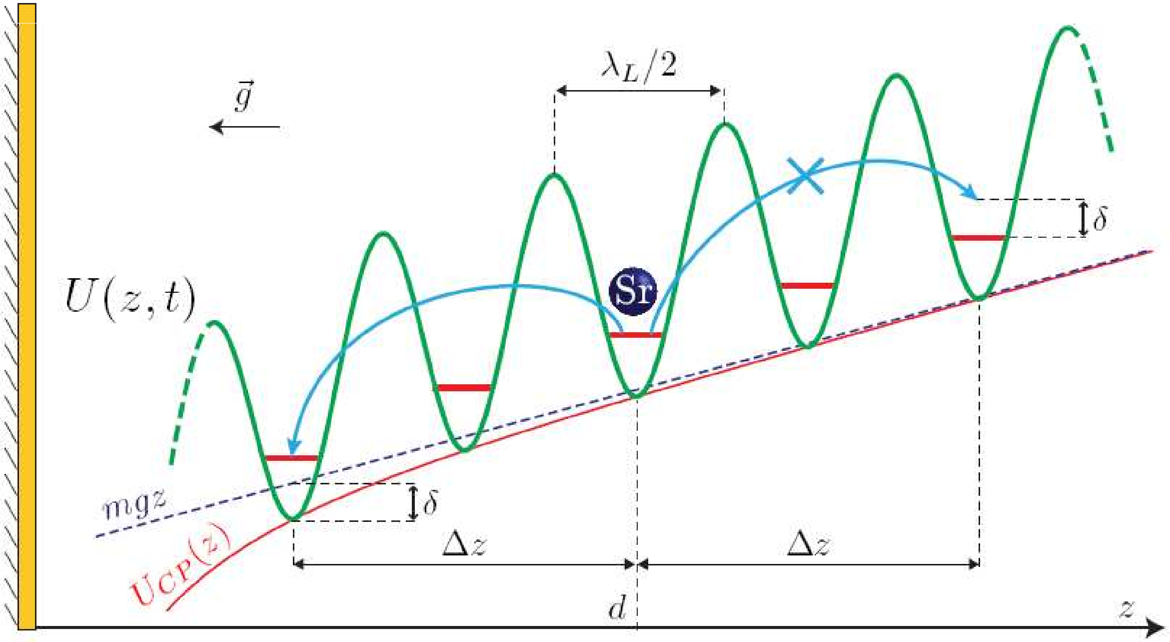
propagation of atoms in the 2nd band along the optical lattice, for different amplitudes of modulation in terms of trap depth



Probing potentials on short distances

The latest progress in laser cooling and, further in manipulation of cold atoms has provided a new probe for study potentials in vicinity of a surface. A typical micron size of a such probe has an intrinsic advantage compare to more conventional techniques.

We suggest to use the resonant tunneling.
A shift of the tunneling frequency would be a direct and accurate measurement of the surface potentials

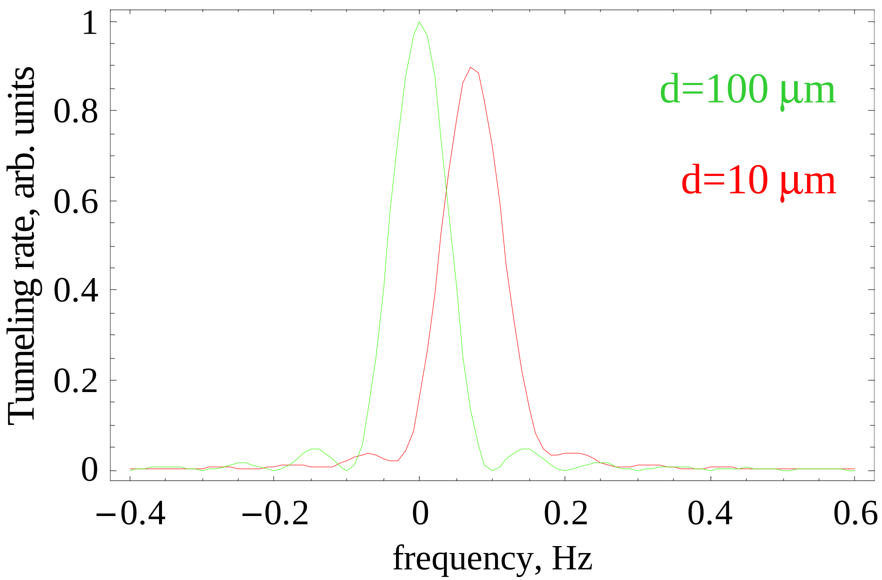


V. V. Ivanov *et al.*, *Resonant tunneling in an optical lattice as a probe of surface potentials*, in preparation

Probing potentials on short distances

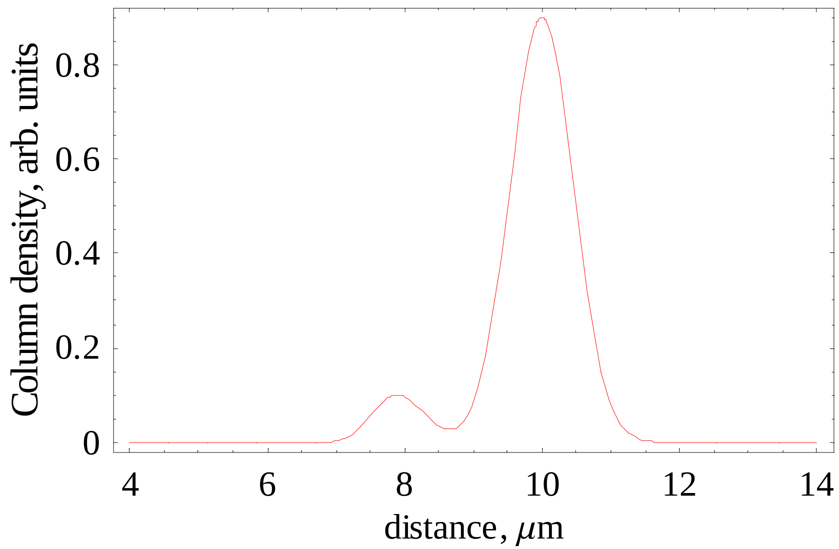
Near the surface we expect:

1. Shift of the resonant frequency due to the shift levels, because of Casimir forces
2. Broading of the tunneling profile due to the final width of the atomic cloud



expected abs. signal

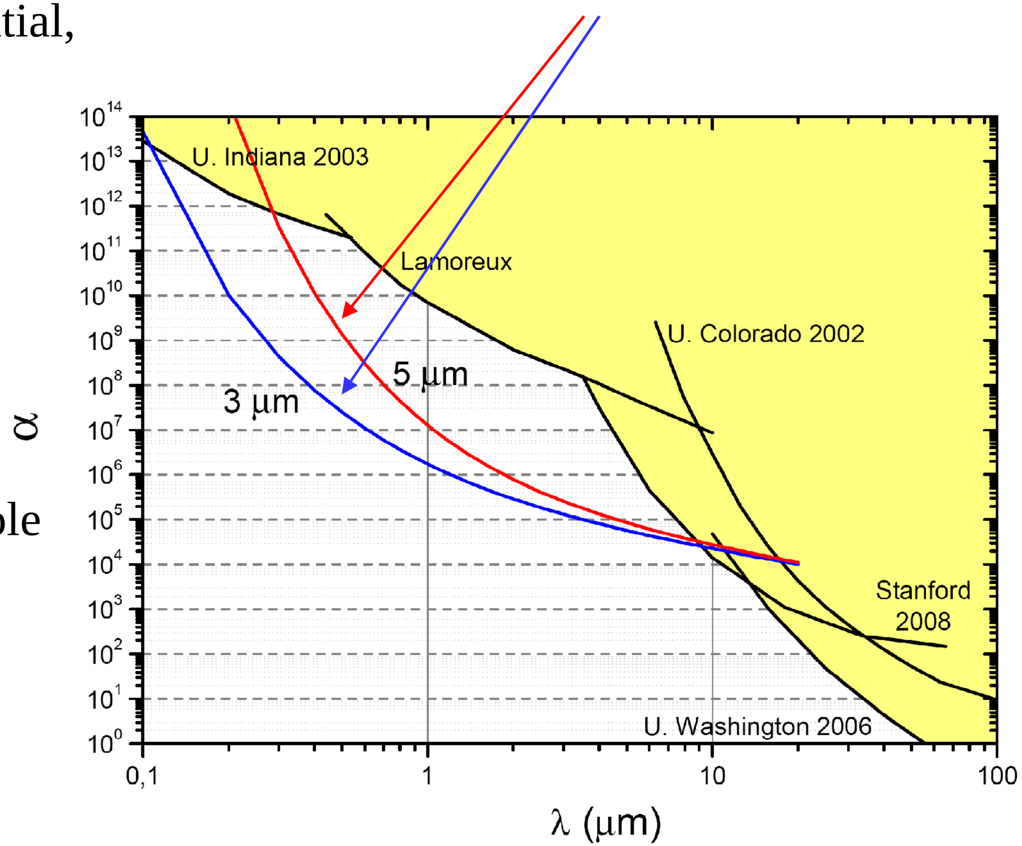
σ_{at}=1 μm



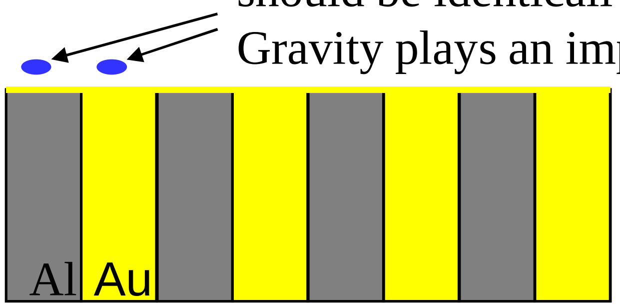
Experimental constrains on non Newtonian gravity

-theories going beyond the standard model predict deviations from the Newtonian gravity
-the correction to the Newtonian potential is generally described as a Yukawa type potential, but its intensity and range are not known,
-at short distances the deviations to the Newtonian potential are expected to be smaller than the Casimir forces

assuming sensetivity of 10^{-6} g

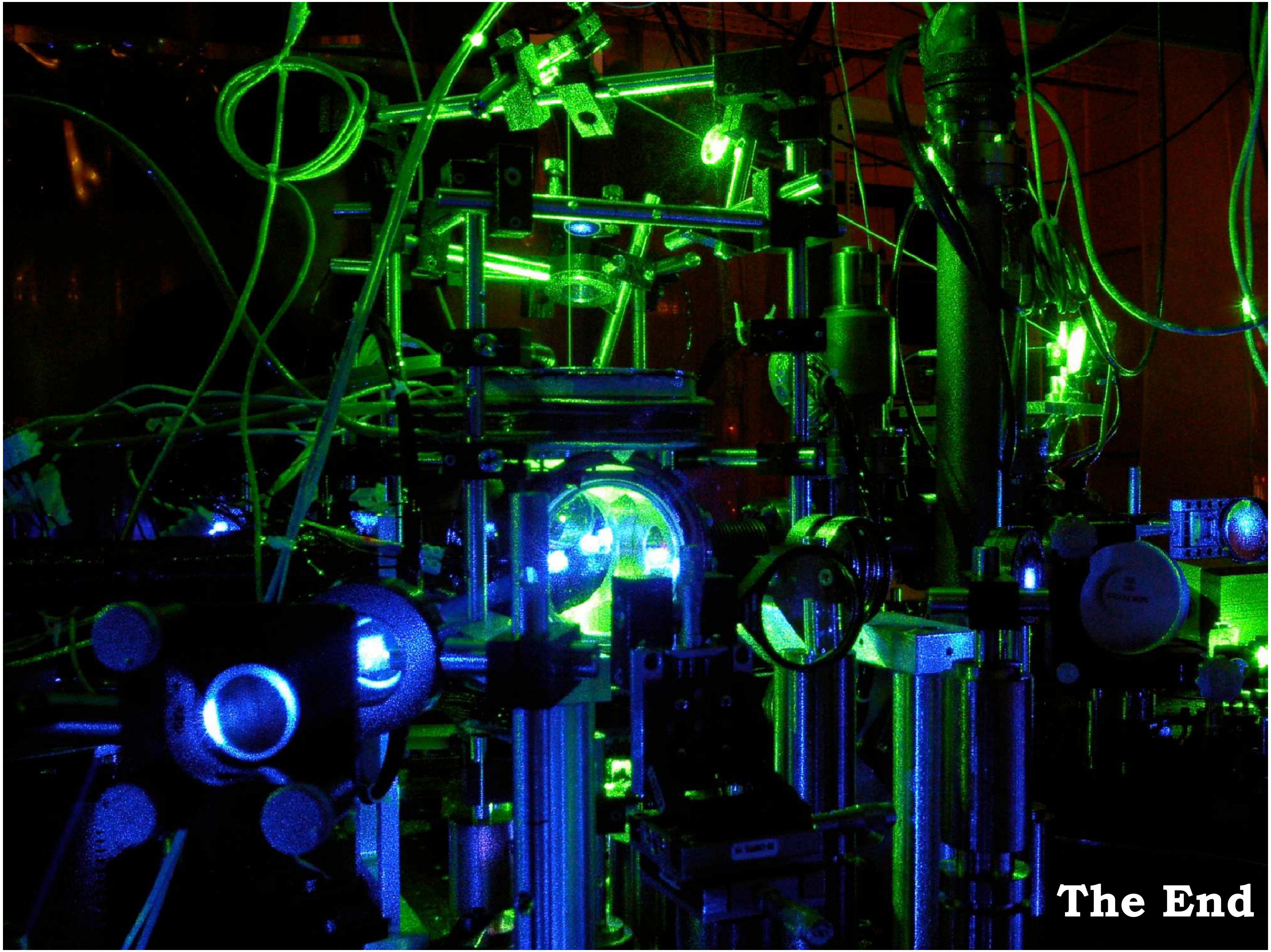


resonance spectrums should be identicall unless Gravity plays an important role



Conclusions

- *Sr^{88} is an ideal candidate for matter-wave interferometry*
- *direct and simple control of atomic wavefunctions*
- *can be used for precision measurements*


The End