Interferometric Laser Cooling of Atomic Rubidium

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We report the 1D cooling of ^{85}Rb atoms using a velocity-dependent optical force based upon Ramsey matter-wave interferometry. Using stimulated Raman transitions between ground hyperfine states, 12 cycles of the interferometer sequence cool a freely moving atom cloud from 21 to 3 μK. This pulsed analog of continuous-wave Doppler cooling is effective at temperatures down to the recoil limit; with augmentation pulses to increase the interferometer area, it should cool more quickly than conventional methods and be more suitable for species that lack a closed radiative transition.

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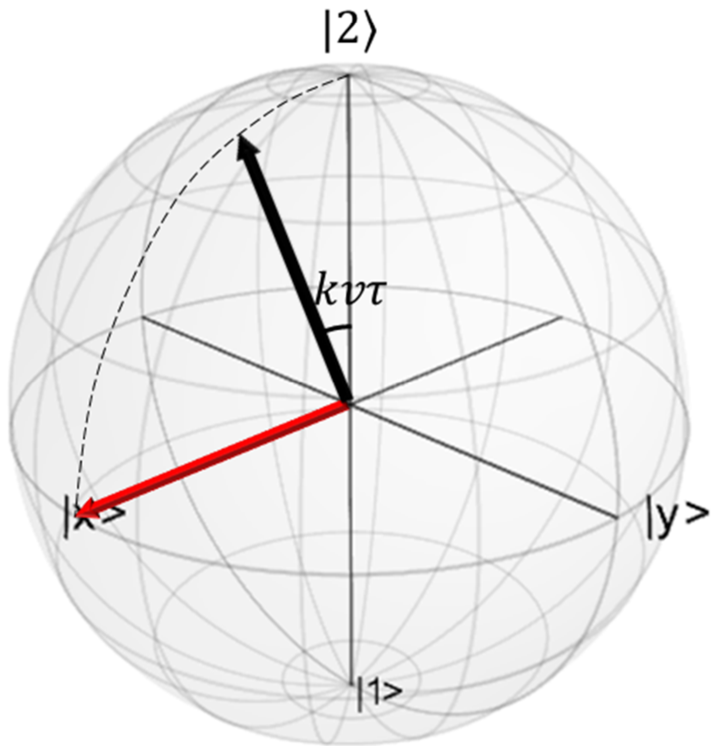
Publication list

- 'Algorithmic cooling' in a momentum state quantum computer , Phys Rev Lett 91 037904 (2003)
- Coherent amplification in laser cooling and trapping , Phys Rev A 73 033409 (2006)
- Atom cooling using the dipole force of a single retroreflected laser beam, Phys Rev A 80 013836 (2009)
- Opto-mechanical cooling with generalized interferometers , Phys Rev Lett 105 013602 (2010)
- Mirror-mediated cooling: a paradigm for particle cooling via the retarded dipole force, Annual Review of Cold Atoms & Molecules 1, 353-378 (2013)

Contents

- Principle of the cooling skim
- Experimental implementation
- Limitations and advantages

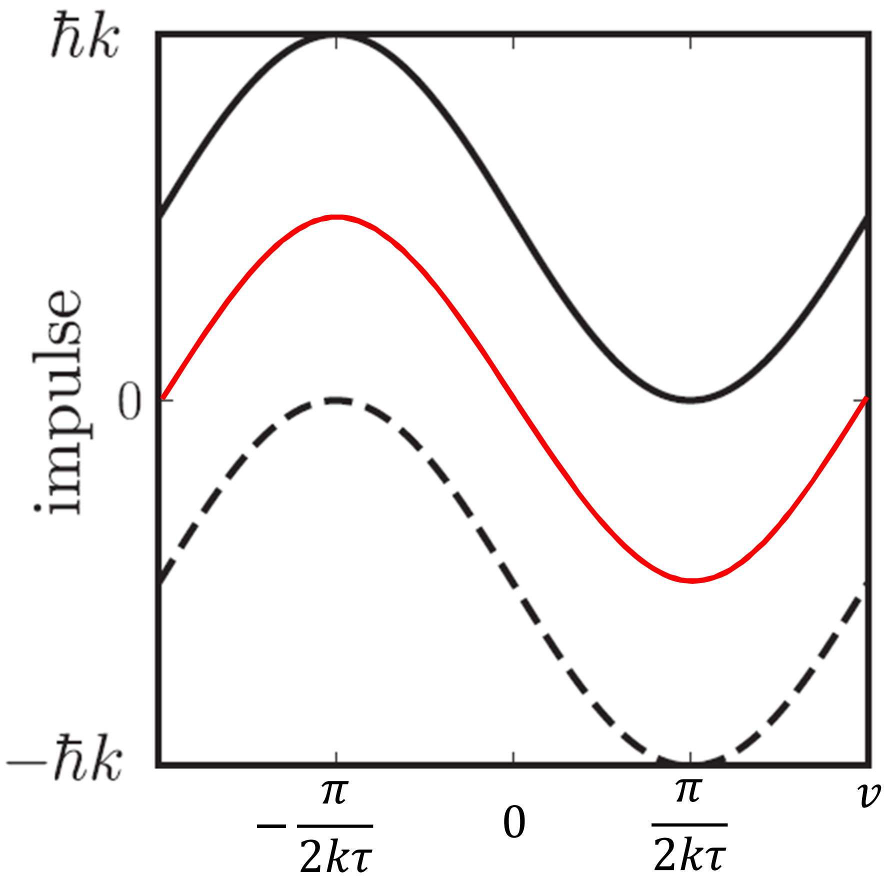
Toy model



$$|c_2|^2 \simeq \frac{(1 + \cos(kv\tau - \phi_{rel}))}{2}$$

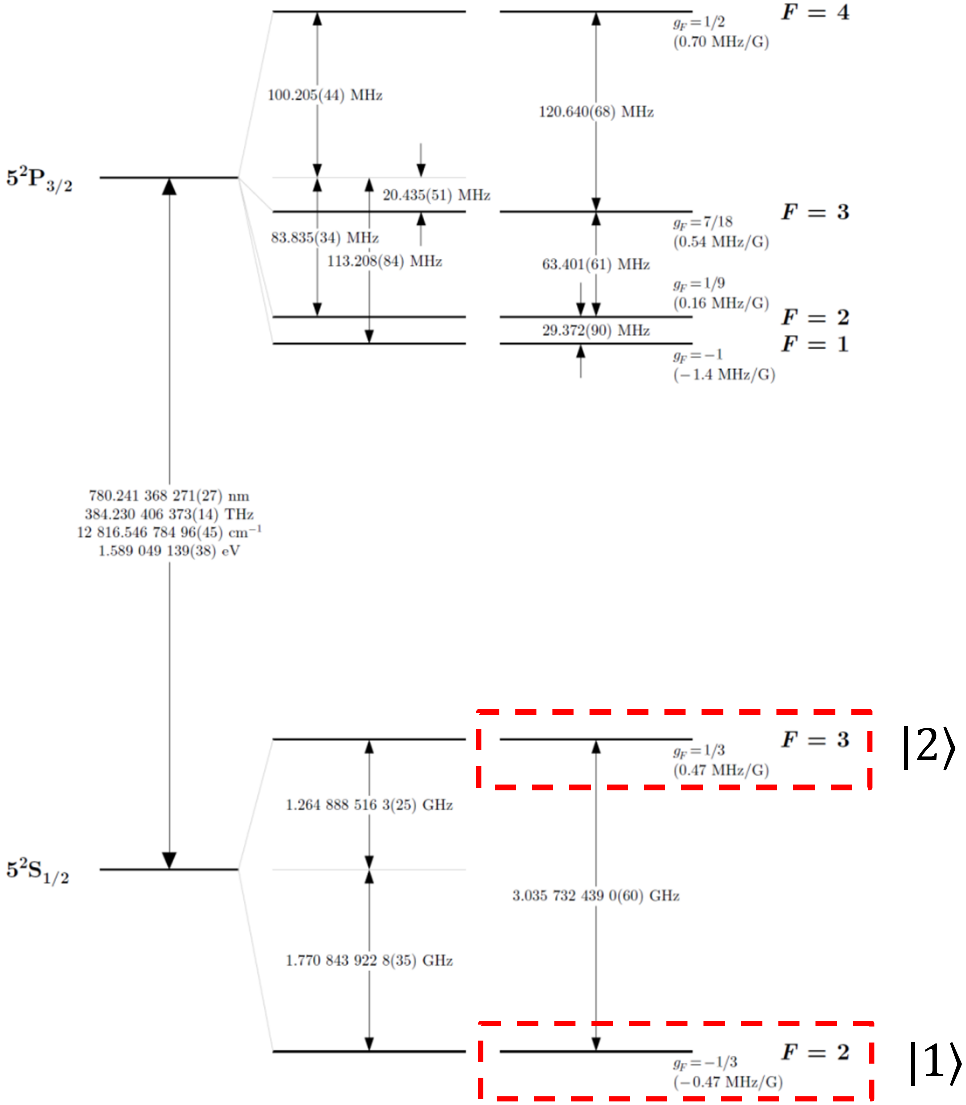
$$\vec{\Omega} = \Omega_R \hat{x} - \delta \hat{z}$$

Mean impulse



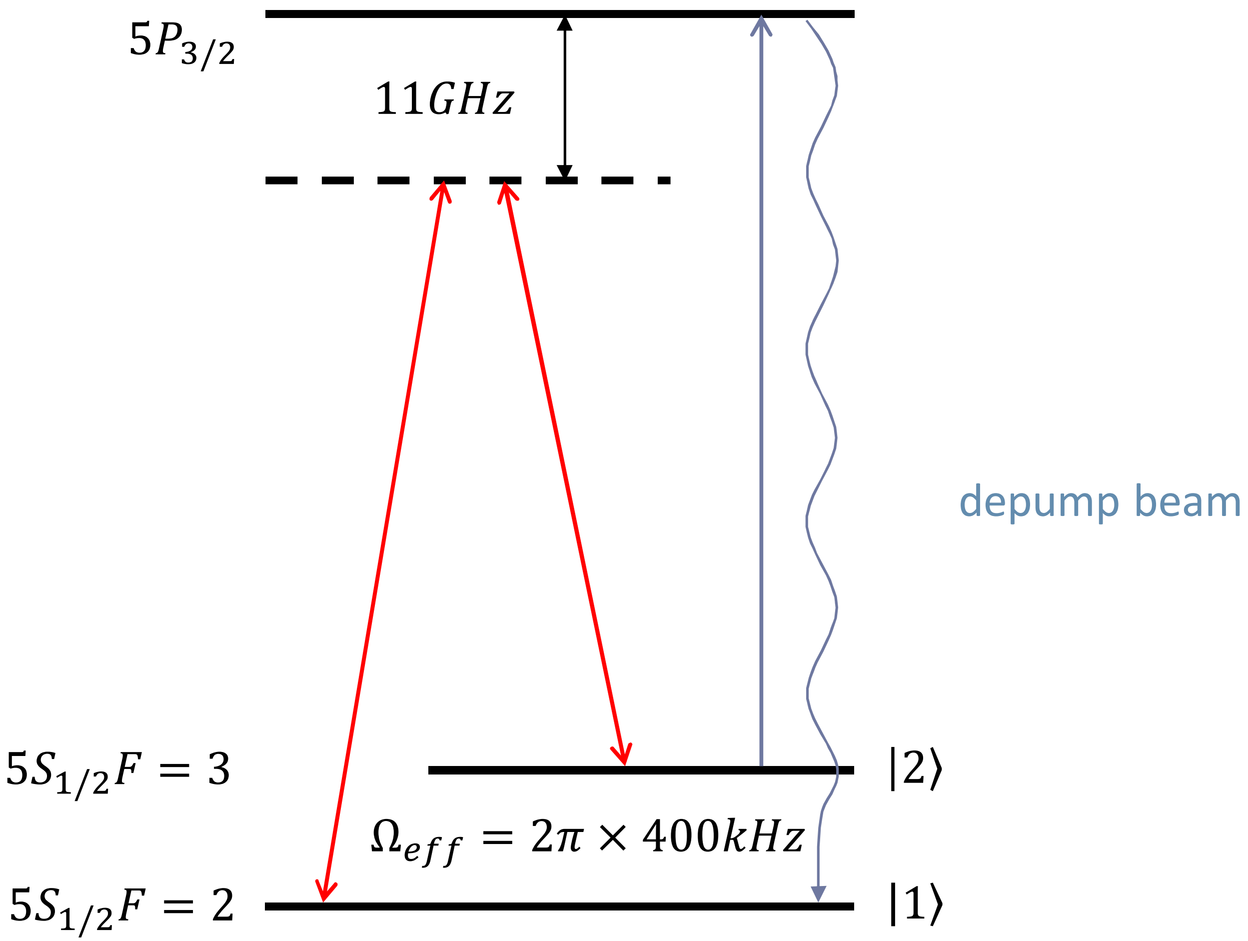
$$|c_2|^2 \simeq \frac{(1+\cos(kv\tau - \phi_{rel}))}{2}$$

^{85}Rb

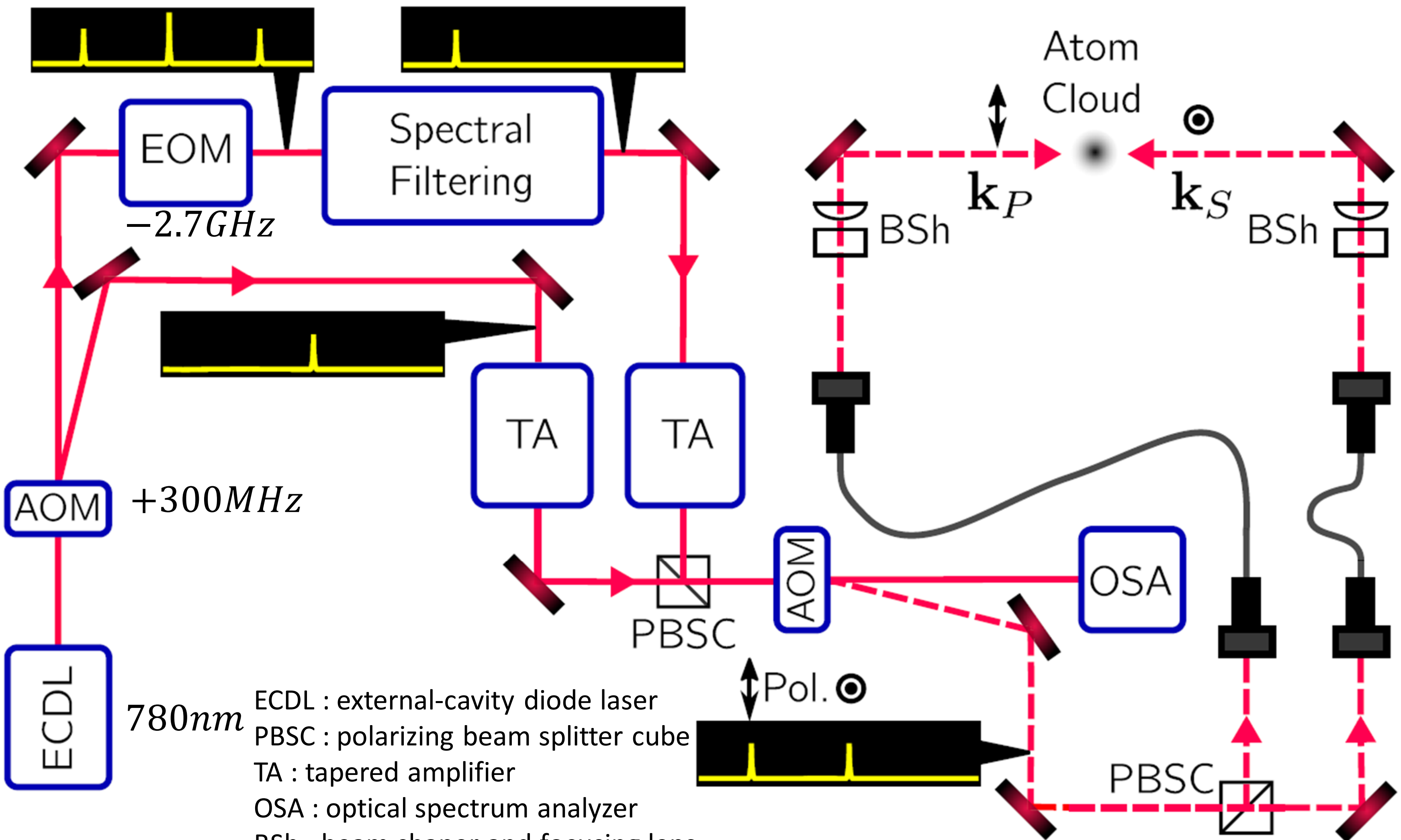


$5^2P_{3/2}$
$5^2S_{1/2}$
100.205(44) MHz
120.640(68) MHz
20.435(51) MHz
83.835(34) MHz
113.208(84) MHz
63.401(61) MHz
29.372(90) MHz
$g_F = 1/2$
(0.70 MHz/G)
$F = 4$
$g_F = 7/18$
(0.54 MHz/G)
$F = 3$
$g_F = 1/9$
(0.16 MHz/G)
$F = 2$
$F = 1$
$g_F = -1$
(−1.4 MHz/G)
780.241 368 271(27) nm
384.230 406 373(14) THz
12 816.546 784 96(45) cm^{-1}
1.589 049 139(38) eV
1.264 888 516 3(25) GHz
1.770 843 922 8(35) GHz
3.035 732 439 0(60) GHz
$g_F = 1/3$
(0.47 MHz/G)
$F = 3$
$|2\rangle$
$g_F = -1/3$
(−0.47 MHz/G)
$F = 2$
$|1\rangle$

^{85}Rb


$5P_{3/2}$
$11GHz$
depump beam
$5S_{1/2}F = 3$
$|2\rangle$
$\Omega_{eff} = 2\pi \times 400kHz$
$5S_{1/2}F = 2$
$|1\rangle$

Raman pulse generation

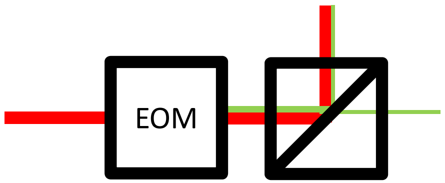


ECDL : external-cavity diode laser
PBSC : polarizing beam splitter cube
TA : tapered amplifier
OSA : optical spectrum analyzer
BSh : beam shaper and focusing lens

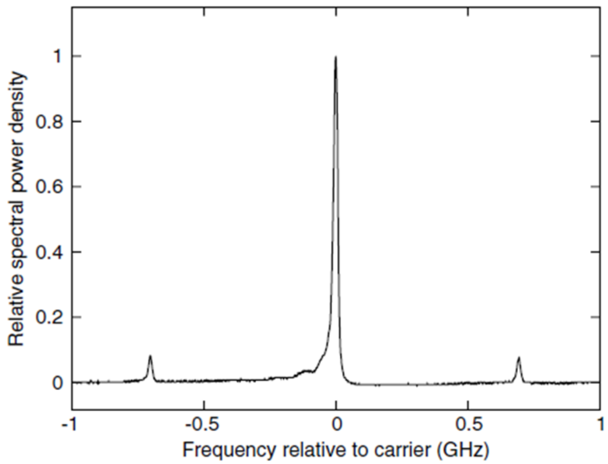
Spectral filtering - carrier wave removal

$$E = \begin{pmatrix} e^{i\omega_0 t} cos\theta \\ e^{i\omega_0 t} sin\theta \end{pmatrix} \xrightarrow{\text{EOM}} E = \begin{pmatrix} e^{i(\omega_0 t + m cos\Omega t)} cos\theta \\ e^{i\omega_0 t} sin\theta \end{pmatrix}$$

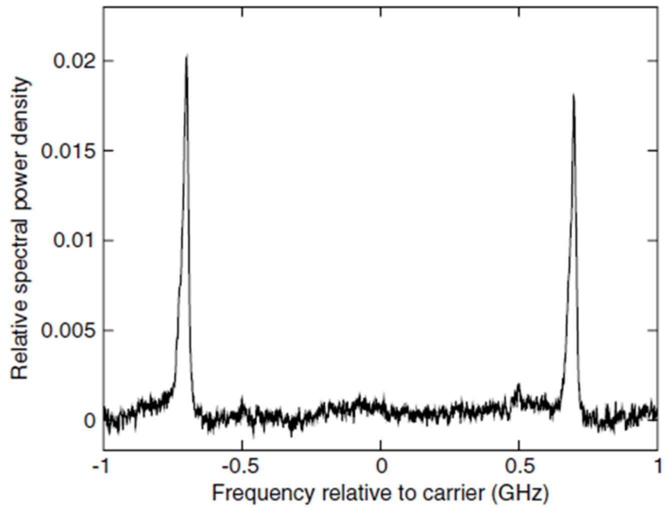
$$= \begin{pmatrix} J_0(m) cos\theta \\ sin\theta \end{pmatrix} e^{i\omega_0 t} + \begin{pmatrix} cos\theta \\ 0 \end{pmatrix} e^{i\omega_0 t} \sum_{n \neq 0} i^n J_n(m) e^{in\Omega t}$$



carrier wave and sidebands have different polarization

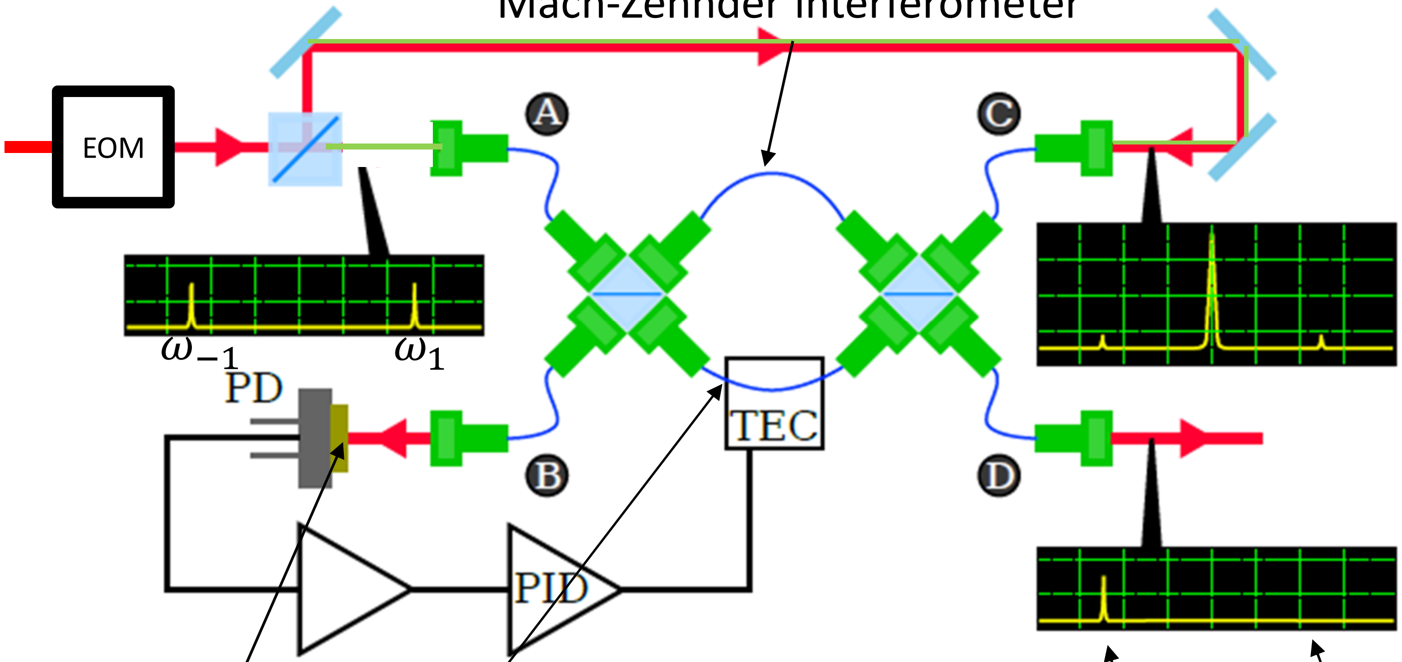


PBS
(transmission axis
orthogonal to
polarization
of the carrier)



Spectral filtering – unwanted sideband removal

Mach-Zehnder interferometer



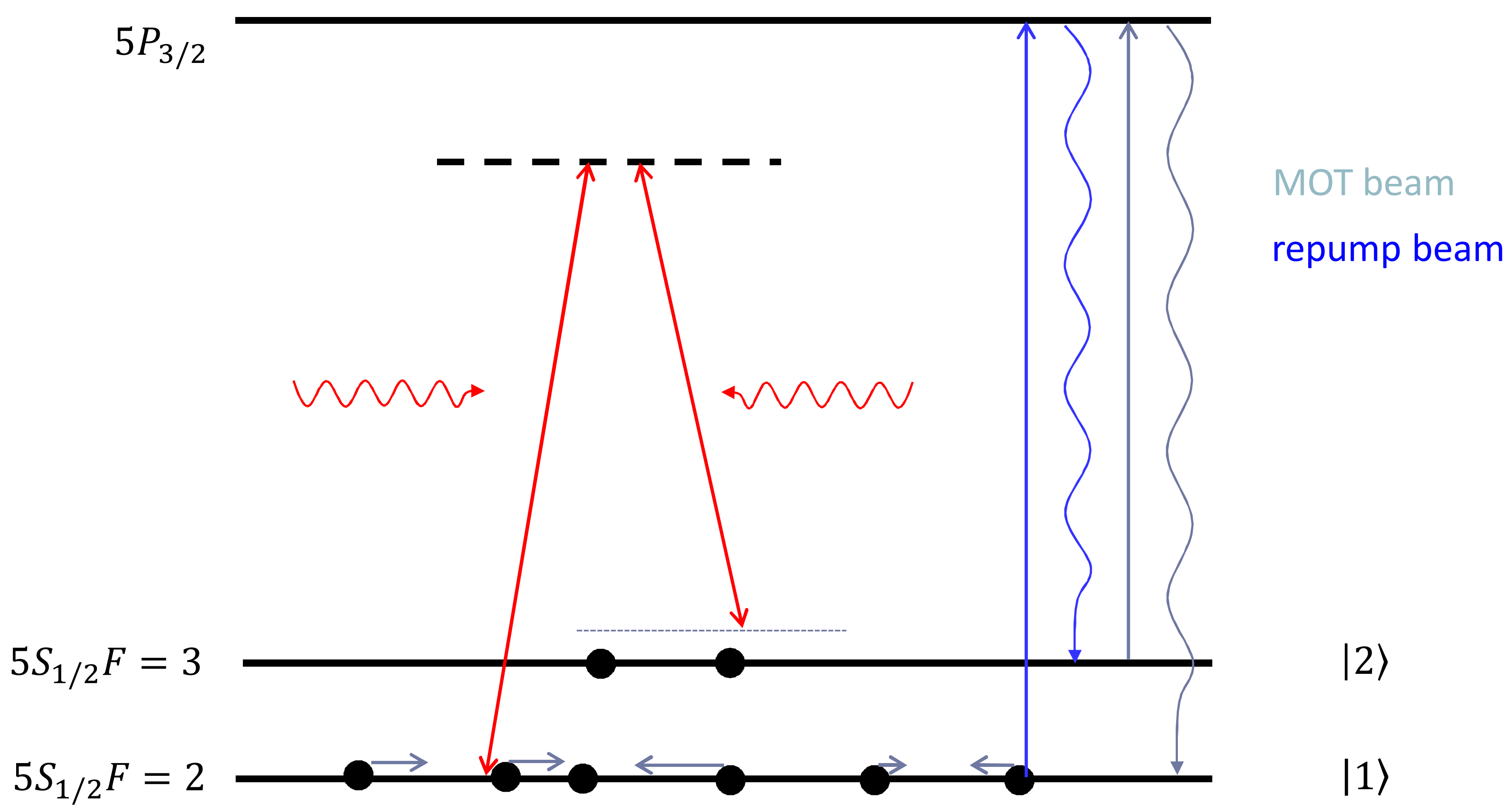
refractive index depends on the temperature

destructive interference

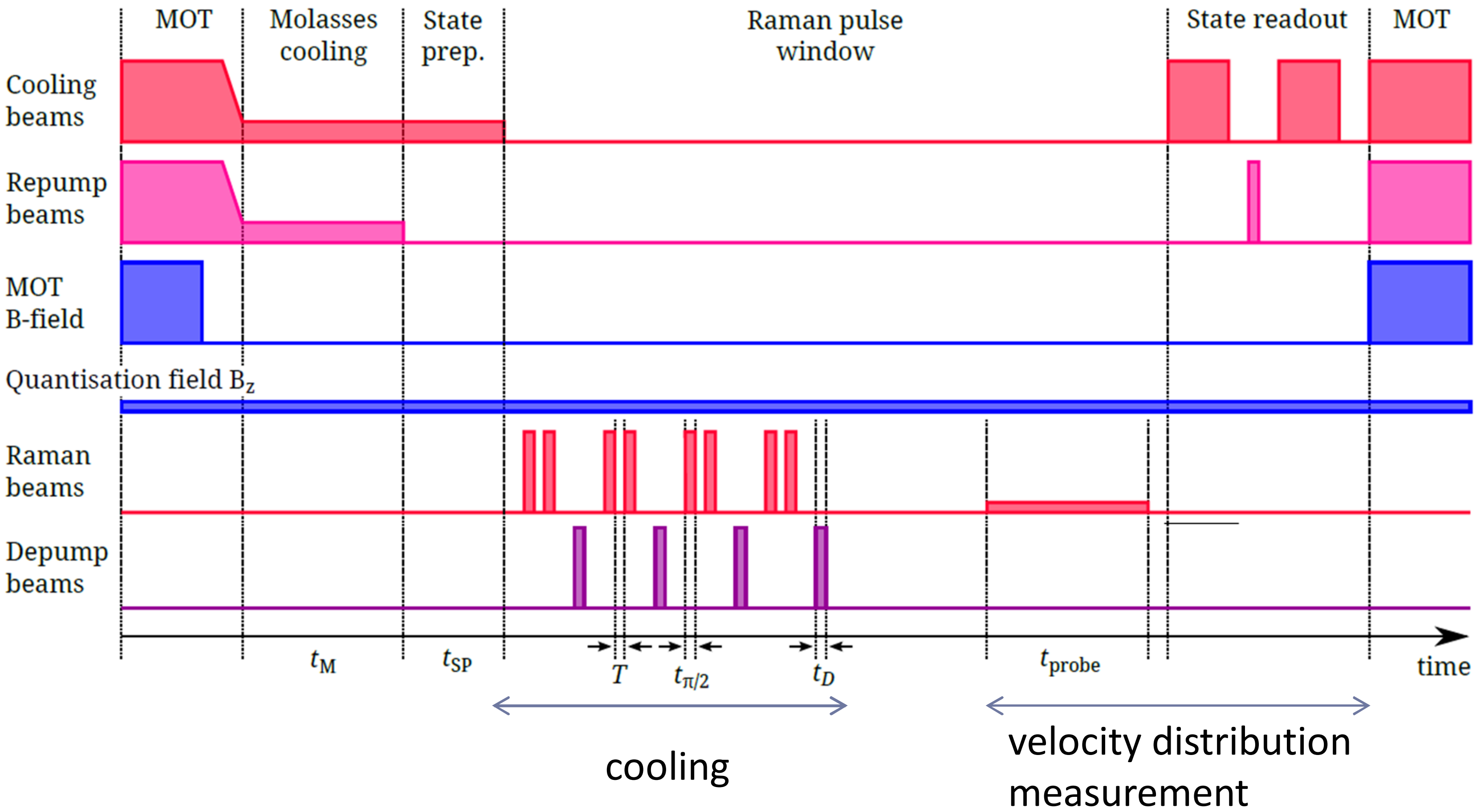
constructive interference

maximized when
phase difference of two path : $\delta(\omega_{-1}) = 0, \delta(\omega_1) = \pi$

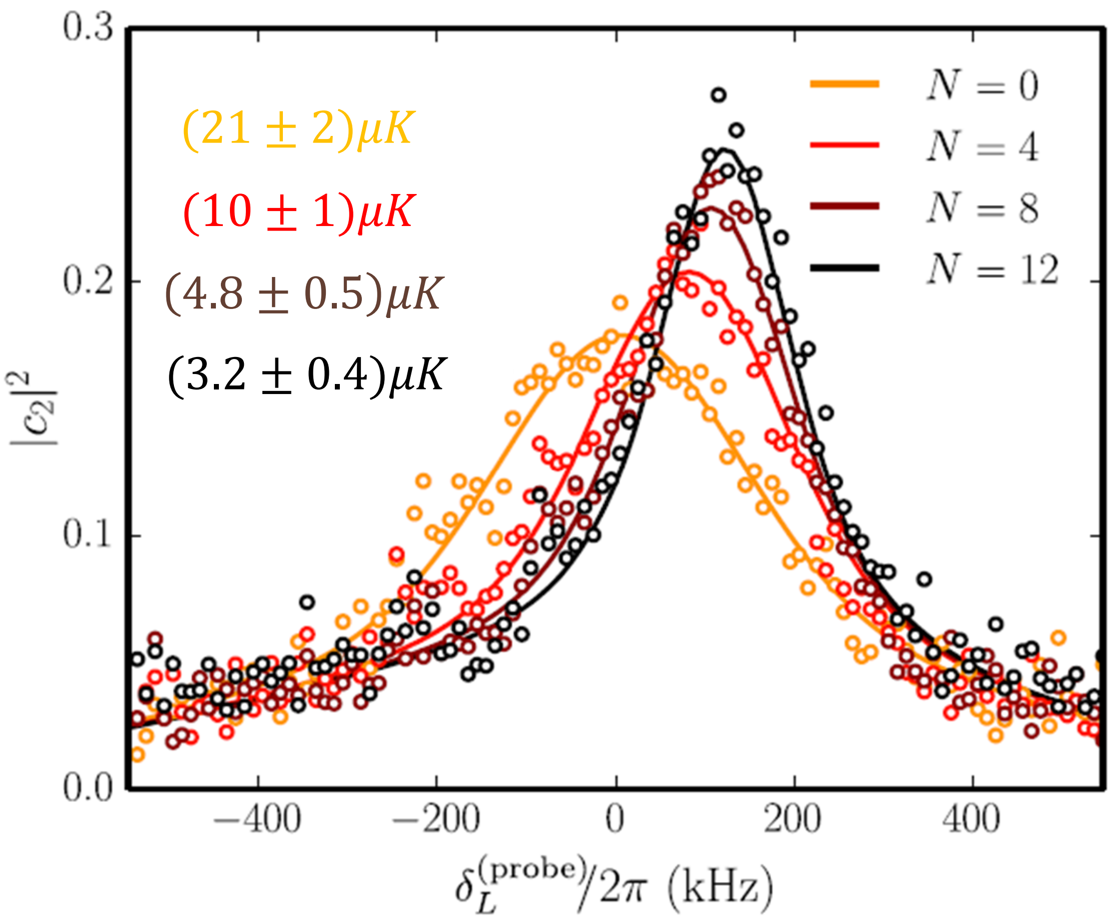
Raman velocimetry



Timing diagram of experiment

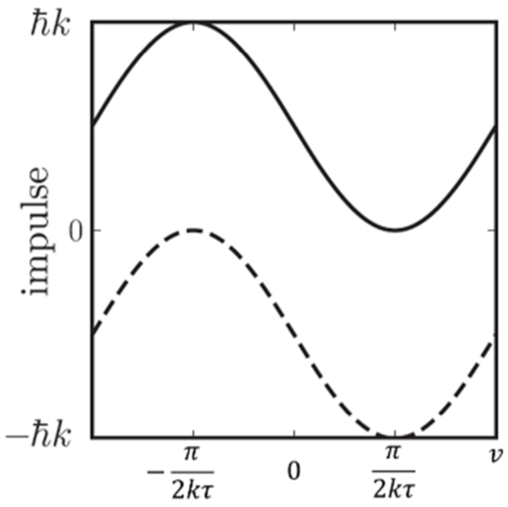


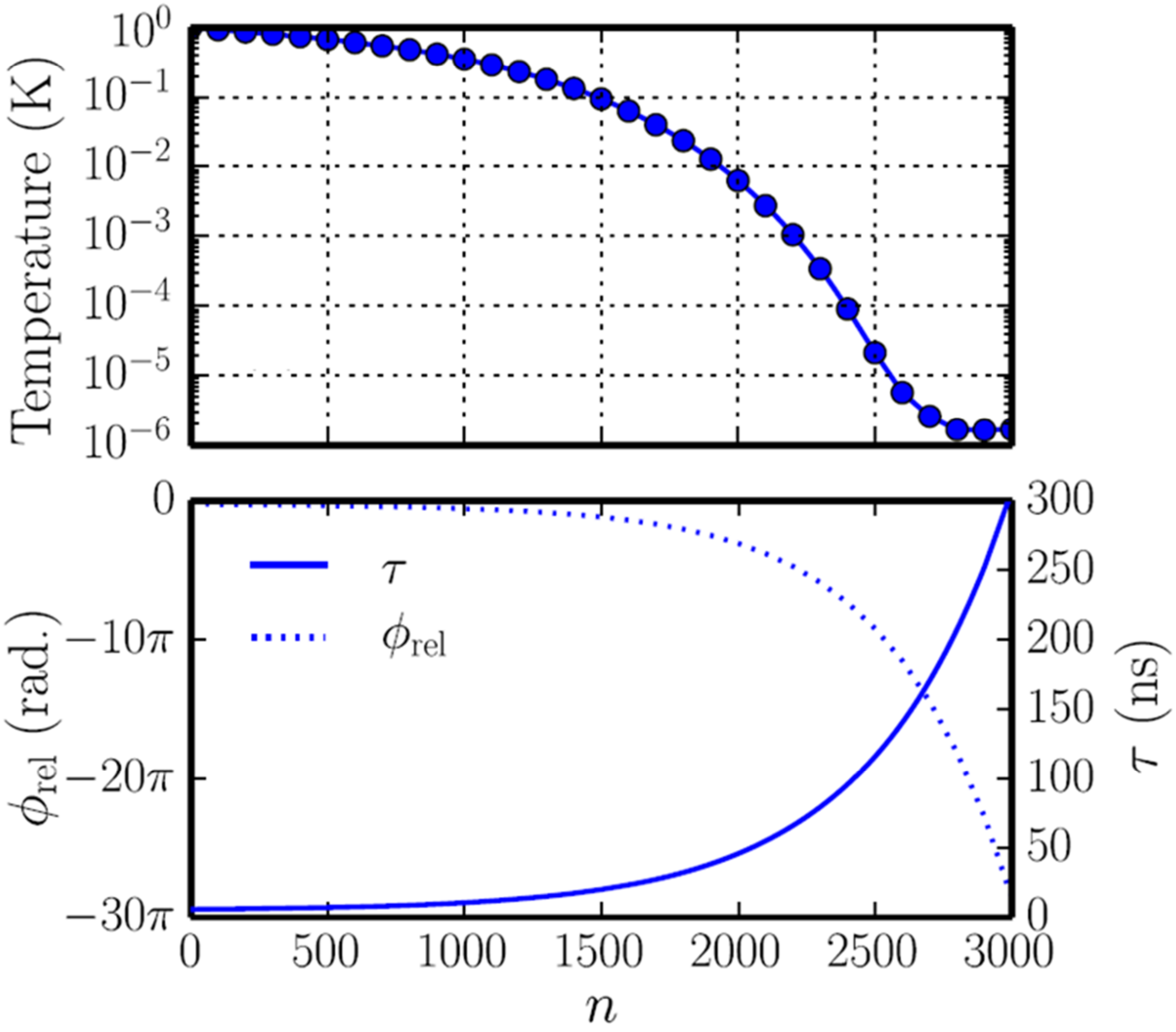
Result



$(21 \pm 2)\mu K$
$(10 \pm 1)\mu K$
$(4.8 \pm 0.5)\mu K$
$(3.2 \pm 0.4)\mu K$
$N = 0$
$N = 4$
$N = 8$
$N = 12$
$|c_2|^2$
0.0
0.1
0.2
0.3
−400
−200
0
200
400
$\delta_L^{(\mathrm{probe})}/2\pi$ (kHz)

Limitation





lowest temp limit $\sim 1\mu K$

capture range $\sim \pi/k\tau$

Advantage

EUROPHYSICS LETTERS 1 February 2000

Europhys. Lett., **49** (3), pp. 302–308 (2000)

Frequency-independent laser cooling based on interferometry

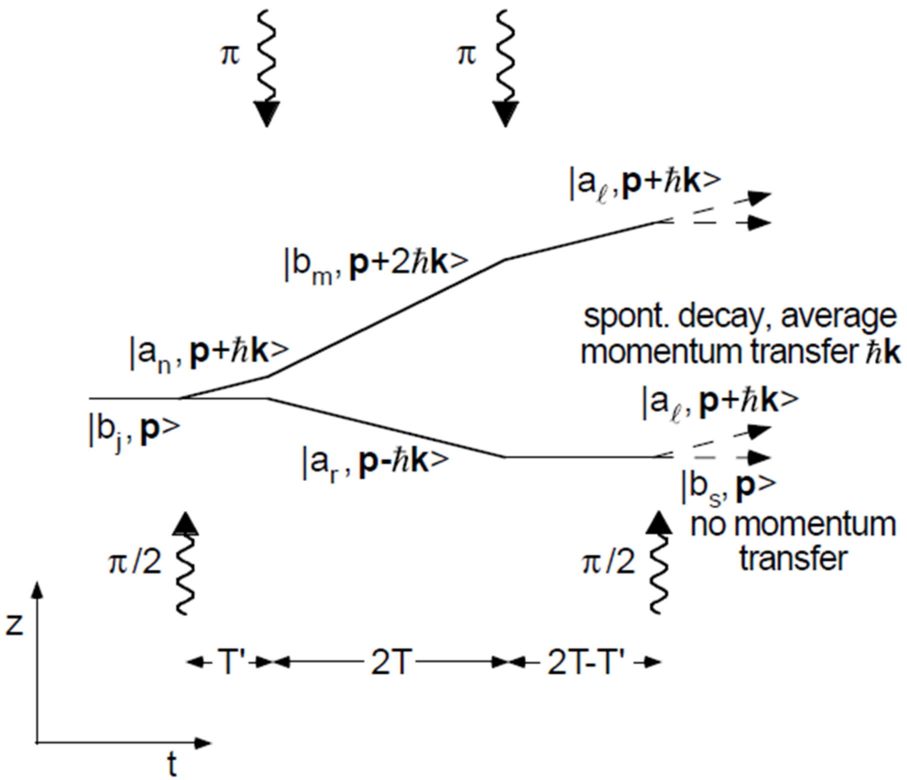
M. Weitz and T. W. Hänsch

Max-Planck-Institut für Quantenoptik - 85748 Garching, Germany

(received 30 September 1999; accepted in final form 28 November 1999)

PACS. 32.80.Pj – Optical cooling of atoms; trapping.
PACS. 33.80.Ps – Optical cooling of molecules; trapping.
PACS. 03.75.-b – Matter waves.

Advantage



$$a_{\boldsymbol{p}+\hbar\boldsymbol{k}} \propto \frac{1}{2}\left(1+e^{-i\varphi(p_z)}\right)$$

$$\varphi(p_z) = ((p_z k/m)+\omega_r)8T$$

Cooling atoms with microwave

It is impossible to cool atoms with microwave analog to magneto optical trap. Because fast spontaneous emission is a crucial part of MOT for initializing atoms and removing entropy of the atoms.

There is a paper about cooling an artificial atom with microwave.

Principle of their method is the same as optical cooling of trapped ion.

Valenzuela, S.O. *et al*. Microwave-induced cooling of a superconducting qubit. Science **314**, 1589-1592 (2006)