Group Meeting:

Short Brief Introduction: Shortcut to adiabaticity to decompress BEC

Zhenfu Zhang

May 11 2011

arXiv:0910.0709 [pdf, ps, other]

Fast optimal frictionless atom cooling in harmonic traps

Xi Chen, A. Ruschhaupt, S. Schmidt, A. del Campo, D. Guery-Odelin, J. G. Muga

Journal-ref: Phys. Rev. Lett. 104, 063002 (2010)

Subjects: **Quantum Physics (quant-ph)**

Theory

arXiv:0910.2992 [pdf, ps, other]

Frictionless dynamics of Bose-Einstein condensates under fast trap variations

J. G. Muga, Xi Chen, A. Ruschhaupt, D. Guery-Odelin

Received 16 October 2009, in final form 4 November 2009
Published 4 December 2009

Journal-ref: J. Phys. B 42, 241001 (2009)

Subjects: **Quantum Physics (quant-ph)**; Quantum Gases (cond-mat.quant-gas)

arXiv:1009.5868 [pdf, ps, other]

Shortcut to adiabaticity for an interacting Bose-Einstein condensate

Jean-François Schaff, Xiao-Li Song, Pablo Capuzzi, Patrizia Vignolo, Guillaume Labeyrie

Comments: 5 pages, 4 figures

Subjects: **Quantum Gases (cond-mat.quant-gas)**

Experiment

Outline:

1. Theoretical part:

(1) shortcut idea

(2) decompress trajectory for BEC

2. Experimental part:

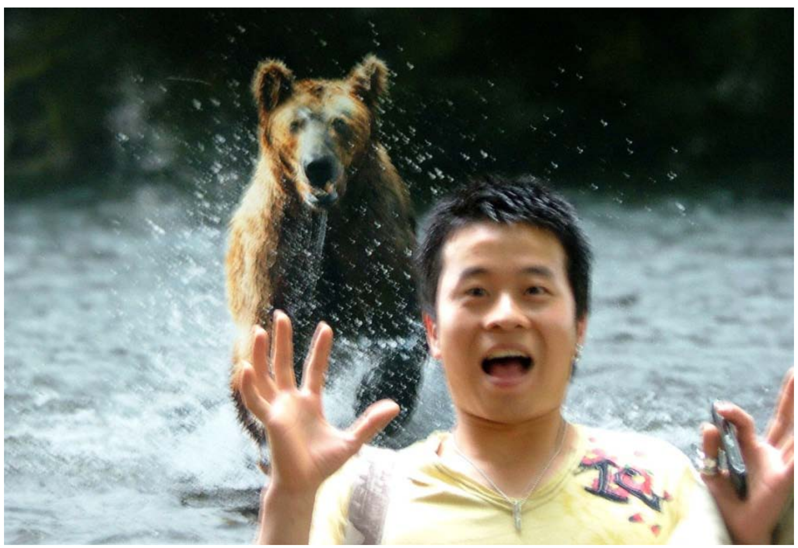
(1) procedures

(2) results & phenomena

Adiabatic process:

A physical system remains in its instantaneous eigensates and eigenvalues if a given perturbation is acting physical system on it slowly.

Property: SLOW !

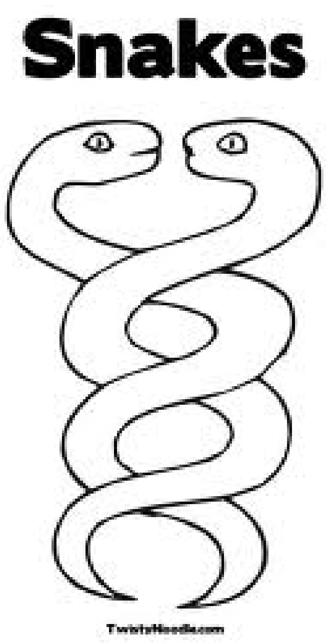


Need “Shortcut”!

Shortcut to adiabaticity idea

Objective:
get the same result to the adiabaticity !

Find an invariant operator that commute with system Hamiltonian at t=0 and t_f !



Engineer a frequency trajectory connecting the equilibrium states (only need) in the final and initial points.

J. Math. Phys. 10, 1458 (1969)
PRL, 104, 063002 (2010)

Lewis-Riesenfeld invariants

System Hamiltonian $H(t)$ $$i\hbar\frac{\partial}{\partial t}|\Psi(t)\rangle = H(t)|\Psi(t)\rangle$$

Construct invariant $I(t)$ satisfies $$i\hbar\frac{\partial I(t)}{\partial t} - [H(t), I(t)] = 0$$

$$|\Psi(t)\rangle = \sum_n c_n|\psi_n(t)\rangle$$ c_n are time-independent amplitudes,

$$|\psi_n(t)\rangle = e^{i\alpha_n(t)}|\phi_n(t)\rangle$$ $I(t)|\phi_n(t)\rangle = \lambda_n|\phi_n(t)\rangle$, λ_n constant

$H(0)$ → $H(t_f)$ populations in the initial and final instantaneous bases are the same, but admitting transitions at intermediate times.

$$[I(0), H(0)] = 0$$
$$[I(t_f), H(t_f)] = 0$$

the eigenstates of I(t) equal the solutions of H(t) at t=0, t_f. Guarantee a state transfer without final excitations.

J. Math. Phys. 10, 1458 (1969)
PRL, 104, 063002 (2010)

decompress trajectory for BEC

1D cigar shaped trap

$$\mathrm{i}\hbar\frac{\partial\psi}{\partial t} = \left[-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2} + \frac{1}{2}m\omega(t)^2x^2 + g|\psi|^2\right]\psi,$$

Ansatz: $\psi(x,t) = \mathrm{e}^{-\beta(t)}\,\mathrm{e}^{-\alpha(t)x^2}\phi(x,t).$

Scaling: $\rho = x/b \quad \Phi(\rho,t) = \phi(x,t)$

$$\mathrm{i}\hbar\frac{\partial\Phi}{\partial t} = -\frac{\hbar^2}{2m}\frac{1}{b^2}\frac{\partial^2\Phi}{\partial\rho^2} + \left[\frac{1}{2}m\omega(t)^2 + \mathrm{i}\hbar\dot{\alpha} - \frac{2\hbar^2}{m}\alpha^2\right]b^2\rho^2\Phi$$
$$+ \left[g\,\mathrm{e}^{-(\alpha+\alpha^*)x^2}\,\mathrm{e}^{-(\beta+\beta^*)}|\Phi|^2\right]\Phi + \left[\mathrm{i}\hbar\dot{\beta} + \frac{\hbar^2\alpha}{m}\right]\Phi$$
$$+ \left[2\frac{\hbar\alpha}{m} + \mathrm{i}\frac{\dot{b}}{b}\right]\hbar\rho\frac{\partial\Phi}{\partial\rho}, \qquad (3)$$

JPB, 42, 241001 (2009)

After several algebra steps ....

$$i\hbar\frac{\partial\Psi}{\partial\tau} = -\frac{\hbar^2}{2m}\frac{\partial^2\Psi}{\partial\rho^2} + \frac{m\omega_0^2}{2}\rho^2\Psi + gb|\Psi|^2\Psi.$$

One case: In TF limit:

Boundary conditions

$$\omega_0 = \omega(0)$$
$$\omega_f = \omega(t_f)$$

$$b(0) = 1, \quad \dot{b}(0) = 0, \quad \ddot{b}(0) = 0$$
$$b(t_f) = (\omega_0/\omega_f)^{2/3} \quad \dot{b}(t_f) = 0 \quad \ddot{b}(t_f) = 0$$

Using scaling relations

$$\ddot{b} + \omega(t)^2 b = \frac{\omega_0^2}{b^2}, \qquad \tau(t) = \int_0^t \frac{dt'}{b},$$

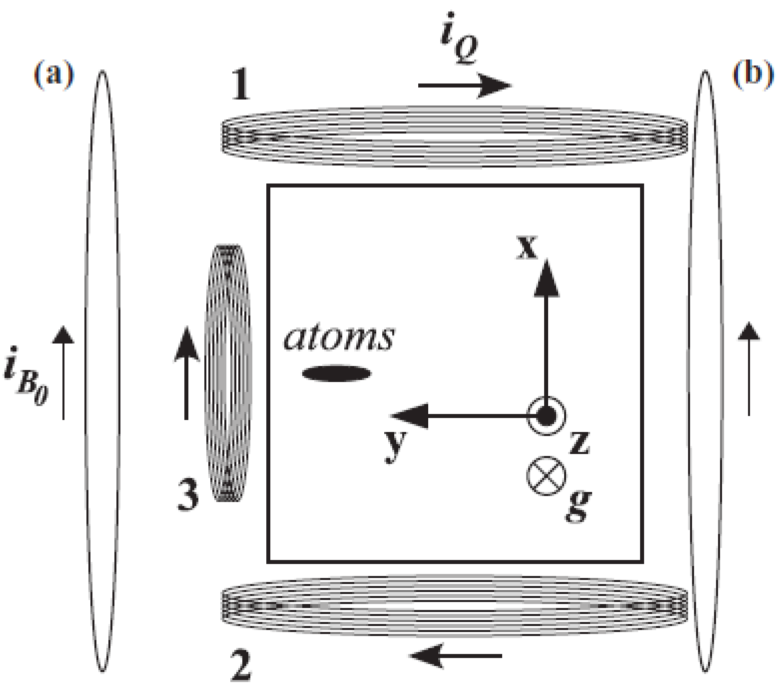
$\omega(t)^2$ Can be calculated

→ this is decompression trajectory

JPB, 42, 241001 (2009)

Experimental Setup and Model:

3D GPE



QUIC TRAP

$$i\hbar\frac{\partial}{\partial t}\psi(\mathbf{r},t)=\left[-\frac{\hbar^2}{2m}\nabla^2+U(\mathbf{r},t)+\tilde{U}N|\psi(\mathbf{r},t)|^2\right]\psi(\mathbf{r},t)$$

$$U(\mathbf{r},t)=\frac{1}{2}m\,\omega_\perp(t)^2(x^2+z^2)+\frac{1}{2}m\,\omega_\parallel^2(t)y^2+mgz,$$

$$\psi(\mathbf{r},t)=(b_\perp^2 b_\parallel)^{-1/2}\chi(\boldsymbol{\rho},\tau(t))\exp[i\phi(\mathbf{r},t)]$$

$$\rho_x=x/b_\perp,\ \rho_y=y/b_\parallel,\ \rho_z=z/b_\perp+ga/\omega_{0\perp}^2$$

$$\tau(t)=\int_0^t \mathrm{d}t'/[b_\perp^2(t')b_\parallel(t')]$$

EPL, 93, 23001 (2011)

Following theoretical paper, get 16 independent boundary conditions.

Simplify the process ----→ remain axial size of BEC constant, shortcut work only along radial direction

Decompression trajectory

$$\ddot{b}_\perp(t) + b_\perp(t)\omega_\perp^2(t) = \omega_{0\perp}^2 / b_\perp(t)^3, \tag{4}$$

$$\omega_\parallel(t) = \omega_{0\parallel} / b_\perp(t), \tag{5}$$

$$b_\perp(t)^4 \ddot{a}(t) + 2b_\perp(t)^3 \dot{b}_\perp(t)\dot{a}(t) + \omega_{0\perp}^2 a(t) - \omega_{0\perp}^2 b_\perp(t)^3 = 0, \tag{6}$$

EPL, 93, 23001 (2011)

Decompression trajectory simulation

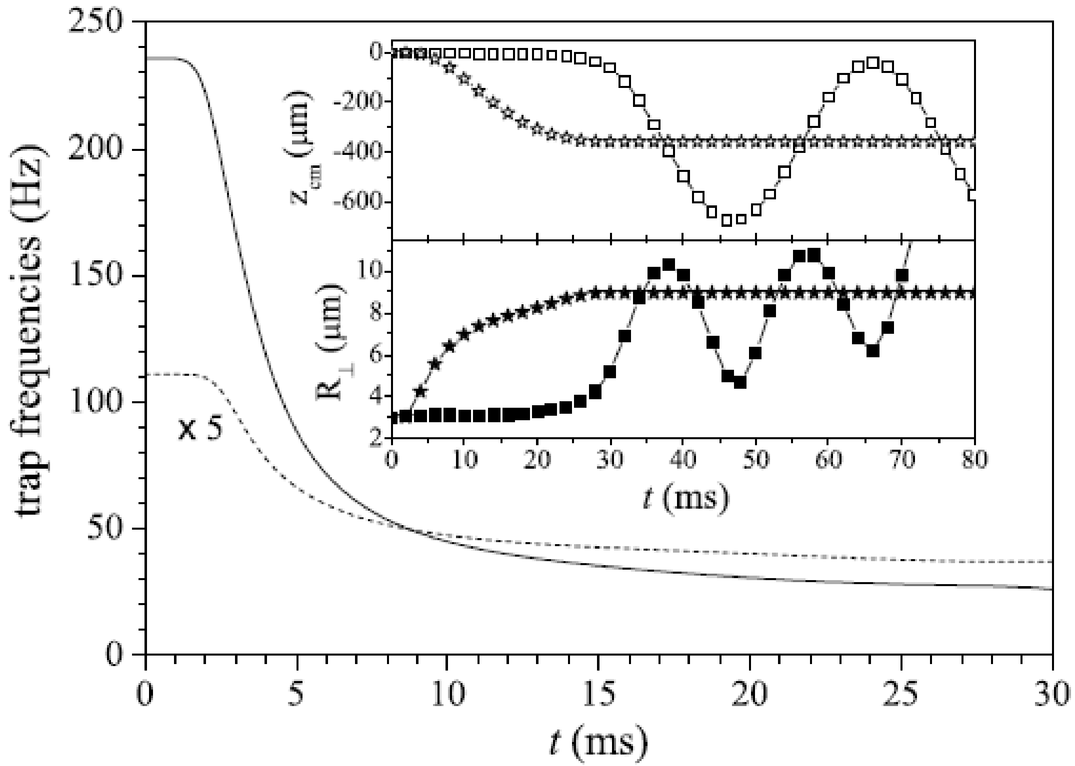


Fig. 2: Shortcut BEC decompression in 30 ms. We plot the shortcut trajectories $\omega_\perp(t)/2\pi$ (solid line) and $\omega_\parallel(t)/2\pi$ ($\times 5$, dashed line). The insert compares the subsequent evolution of the BEC's center of mass (open symbols) and radial size (solid symbols) for the shortcut (stars) and linear (squares) decompressions (GPE simulation).

EPL, 93, 23001 (2011)

Center of mass position

Shortcut (star)

Linear decompression (square)

Radial size

Shortcut
reach equilibrium soon!

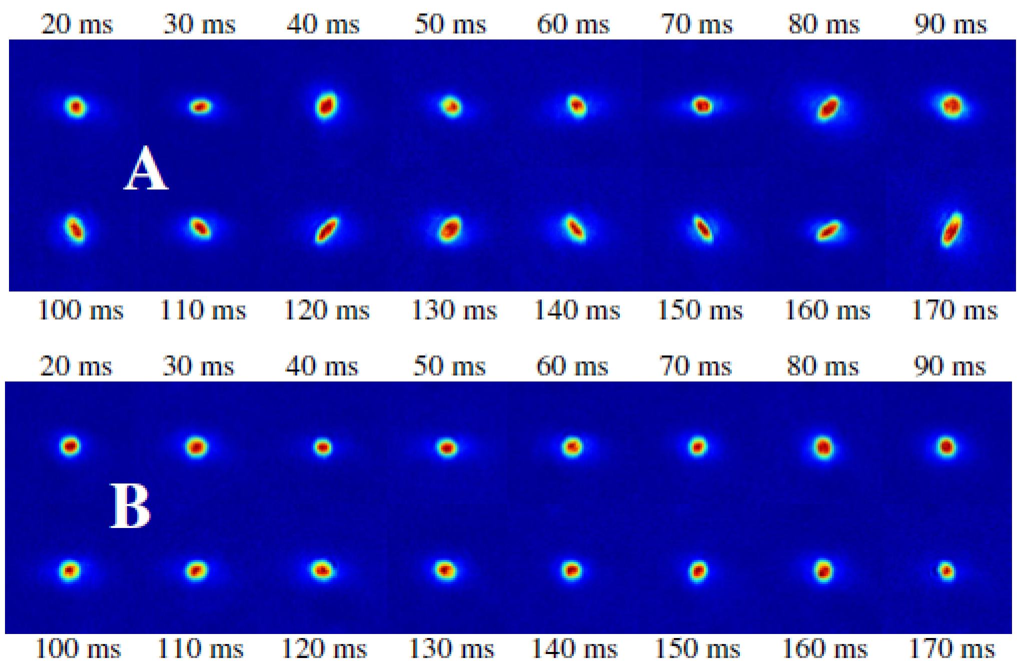
dipole oscillation $\omega_{f\perp}$

breathing oscillation $2\omega_{f\perp}$

results & phenomena

Holding time in QUIC

Linear



shortcut

1. Deformation
2. Angular motion (scissors mode)
   $\delta n = Cxy$

1. Deformation suppressed
2. Stationary

Fig. 1: (Color online) Linear *vs.* shortcut BEC decompression. We compare the time evolution of the BEC after two different decompression schemes: (A) a 30-ms-long linear ramp and (B) the shortcut trajectory (see text). The center-of-mass motion has been subtracted from these time-of-flight images for clarity.

EPL, 93, 23001 (2011)

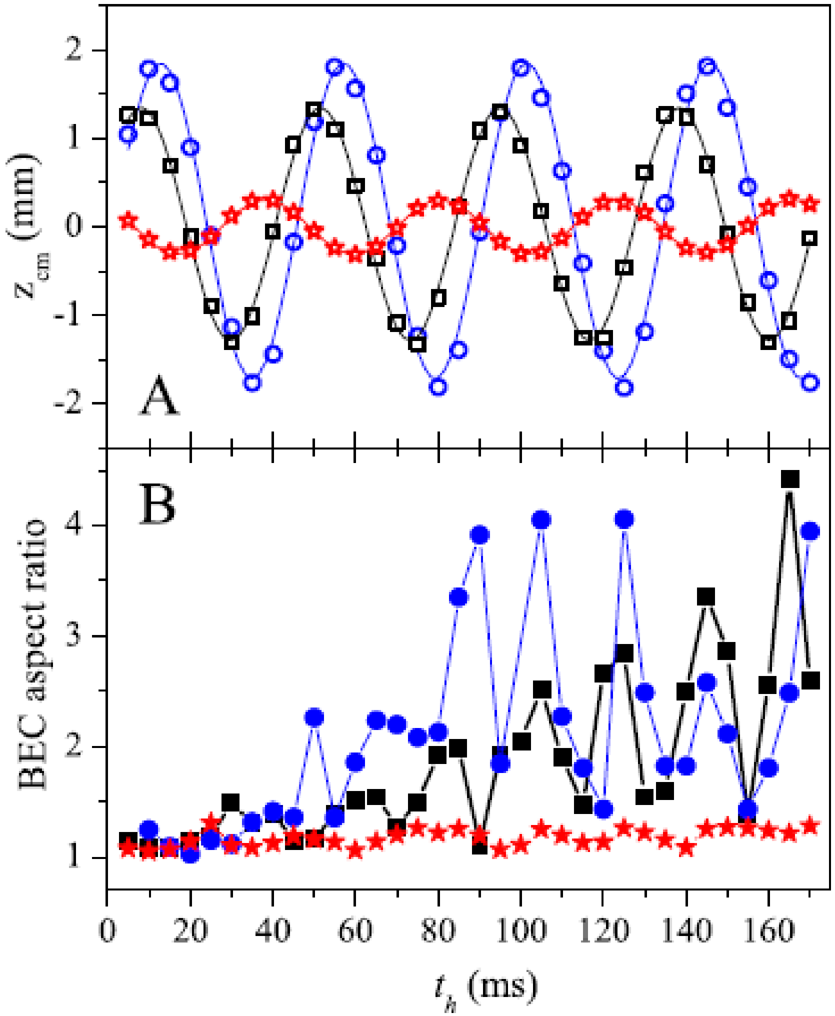


Fig. 3: (Color online) Decompression-induced excitations. We report the temporal evolution of (A) the center-of-mass position and (B) the aspect ratio of the BEC after three different decompression schemes: an abrupt decompression (open circles); a 30 ms linear ramp (squares); the 30 ms shortcut trajectory (stars). All measurement are performed after a 28-ms-long time of flight.

Shortcut (imperfections exist)

abrupt

linear

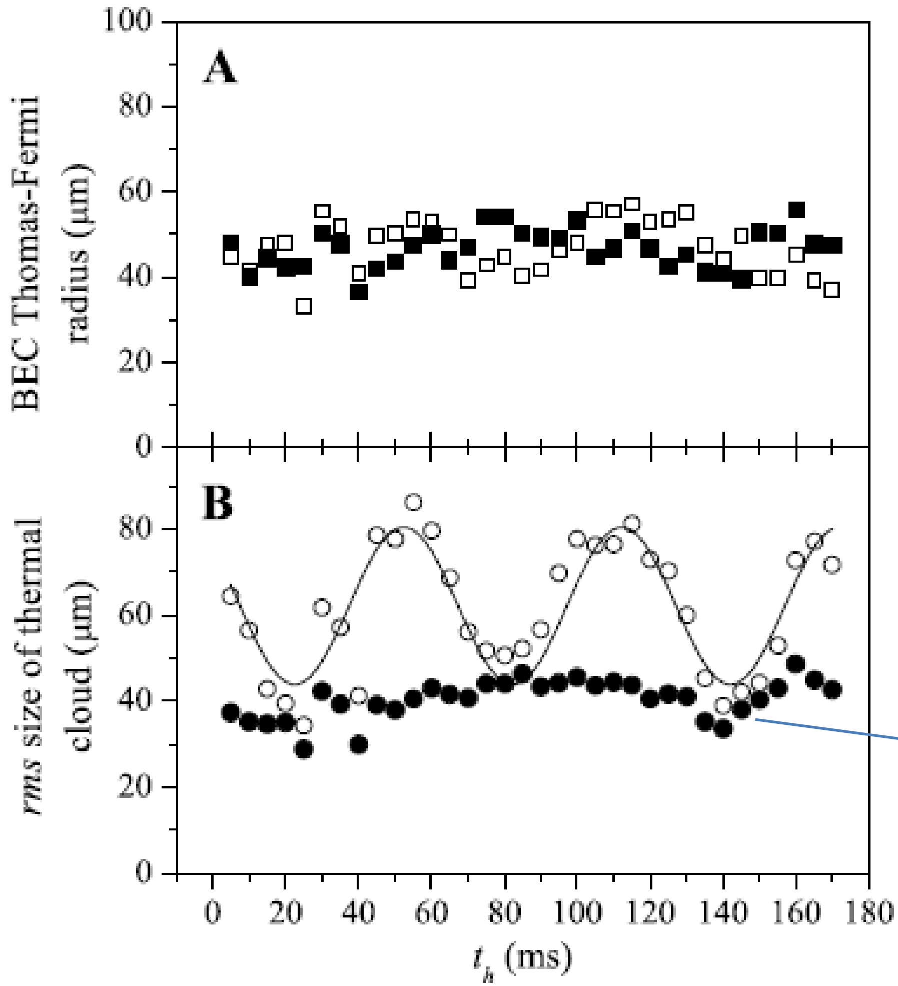
Shortcut reduce the dipole excitation by a factor of 6 and 4.3 compared with abrupt and linear schemes

Shortcut reduce breathing excitations by a factor of 12 and 10.

EPL, 93, 23001 (2011)

TF radius

Thermal cloud



Only shortcut at radial direction! ----→ behavior independent of BEC

Remain stationary

Initial 130nk (after evap)

Final 22nk

Fig. 4: BEC *vs.* thermal cloud decompression. We plot the sizes of the BEC (A) and thermal component (B) *vs.* t_h for the shortcut trajectory. The filled and empty symbols correspond to the radial (vertical) and axial directions, respectively.

EPL, 93, 23001 (2011)

Experiment imperfections:

1. Mismatch the theoretical and experimental frequency trajectory

2. Trap Anharmonicity

3. limited spatial resolution and noise

4. more…

EPL, 93, 23001 (2011)

Summary:

Shortcut idea is introduced.

Use shortcut to adiabaticity frequency trajectory to cool down atoms in a much time (30ms) from 130nk to 22nk.

This technique reduce the excitations.

Thank you !