Sub-Doppler laser cooling of Rb87 via gray molasses

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Quantum computation based on neutral atoms suffers from low gate fidelities mainly due to laser phase noise and finite atom temperature causing decoherence [1]. While phase noise can be significantly reduced by low-noise laser sources such as Titanium-Sapphire lasers or diode lasers filtered by higher-finesse cavities, temperature reduction requires advanced sub-doppler cooling techniques. Sideband cooling of atoms can be an effective approach to transfer an atom into a vibrational ground state, but a Lamb Dicke regime has to be realized beforehand.

A promising way to satisfy the condition of Lamb Dicke regime is a gray molasses laser cooling technique [2]. It is based on velocity dependent states that in case of correct optical field parameters decouples from two-frequency light when the velocity equals zero. Moreover, using other parameters but the same experimental setup one can obtain more then 90% loading of array, resulting in lower gates' operation times [3].

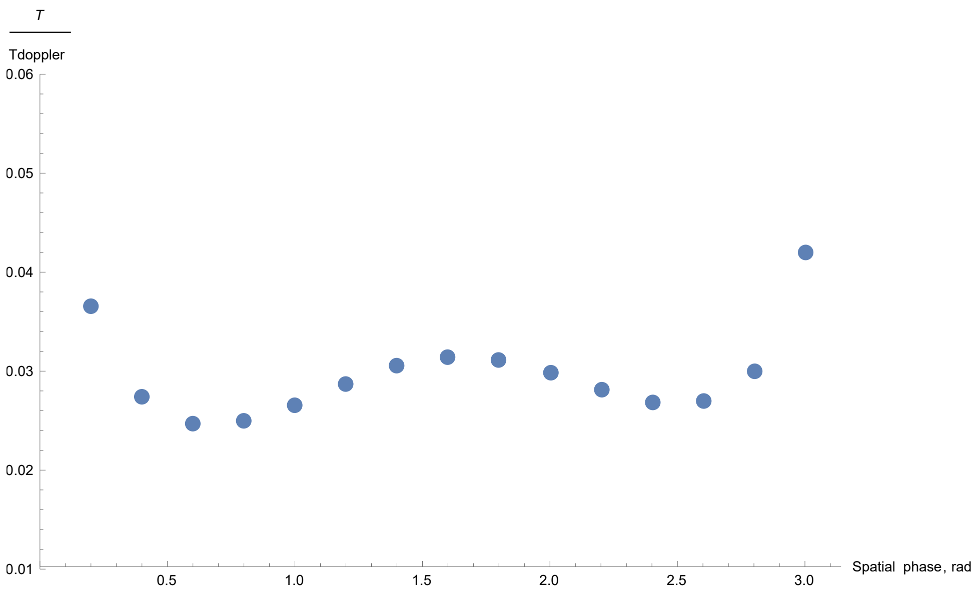

Figure 1: The dependence of atomic temperature on the spatial phase between optical gray molasses beams, ^{87}Rb; Rabi frequencies Ω_1= 10 MHz, Ω_2= 24 MHz; Detunings from resonance, D1 line, Δ_1= 200 MHz, Δ_2= 180 MHz

In order to find temperature observed in gray molasses regime one should solve OBE with density matrix, dependent on time and position. We use simple 3-level model of ^{87}Rb with only one spatial coordinate z. After an interaction time that is longer than the optical Δ^2/Ω, we can safely assume that the atomic density matrix depends no longer explicitly on time but only on position and velocity. We expand the density matrix in Fourier series:

$$\rho_{lj} = \sum_{n=-\infty}^{\infty} \rho_{lj}^{n} \exp(inkz)$$

This expansion allows to transform OBE into equations of type:

$$C_n \mathbf{x}_{n+2} + A_n \mathbf{x}_n + B_n \mathbf{x}_{n-2} = \gamma \delta_{n,0},$$

which can be solved using continued fractions method [4]. To derive the final temperature we expand denstity matrix elements in Bogolyubov series:

$$\rho_{ij}(z,p,t) = H^0_{ij}w(z,p,t) + H^1_{ij}\hbar k\frac{\partial}{\partial p}w(z,p,t) + \dots$$

and using the result obtained in [5], we express the temperature as:

$$\begin{aligned} D(z) =& \hbar^2 k^2 \left[\gamma H^0_{33} + \left(H^1_{13} + H^1_{31}\right) g_1 \sin(kz) \right. \\ & \left. + \left(H^1_{23} + H^1_{32}\right) g_2 \sin(kz+\varphi)\right]. \end{aligned}$$

$$T = \frac{\bar{D}}{k_B\beta},$$

where $\bar{D}$ is the momentum diffusion coefficient averaged over a wavelength, β is the friction coefficient, defined as the negative slope of the velocity-dependent force.

References

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