Laser cooling of atoms using a frequency comb

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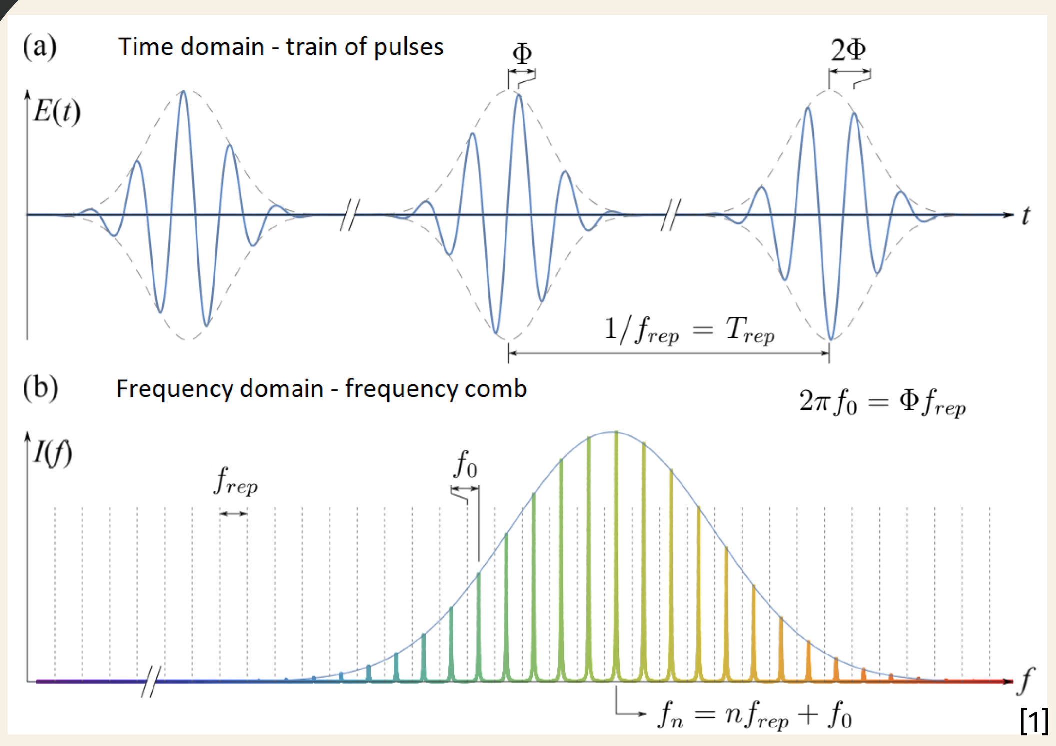
Motivation

Despite the great development and advancement of the laser technology, there are no continuous wave (cw) laser sources in UV spectrum. Therefore, laser cooling is still limited to a small portion of atoms. The solution presents itself in the form of a frequency comb (FC) since it has high peak power needed for an efficient frequency conversion via nonlinear effects.

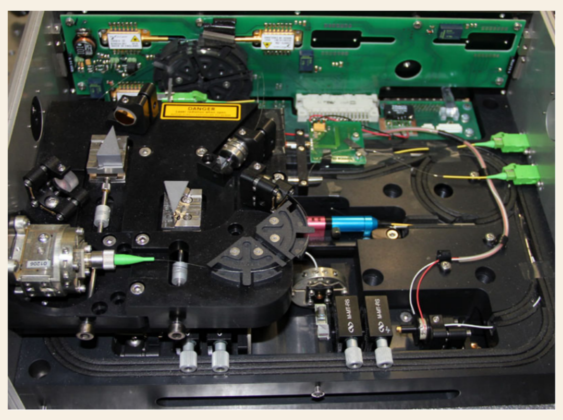
Main idea of this experiment lies in the thesis that a FC can be considered as a series of phase-coherent cw lasers and one tooth is analogous with a cw laser.

FC is also proposed as a laser source for the cooling of atoms and molecules with complex level structure and multiple atomic species.

Frequency comb

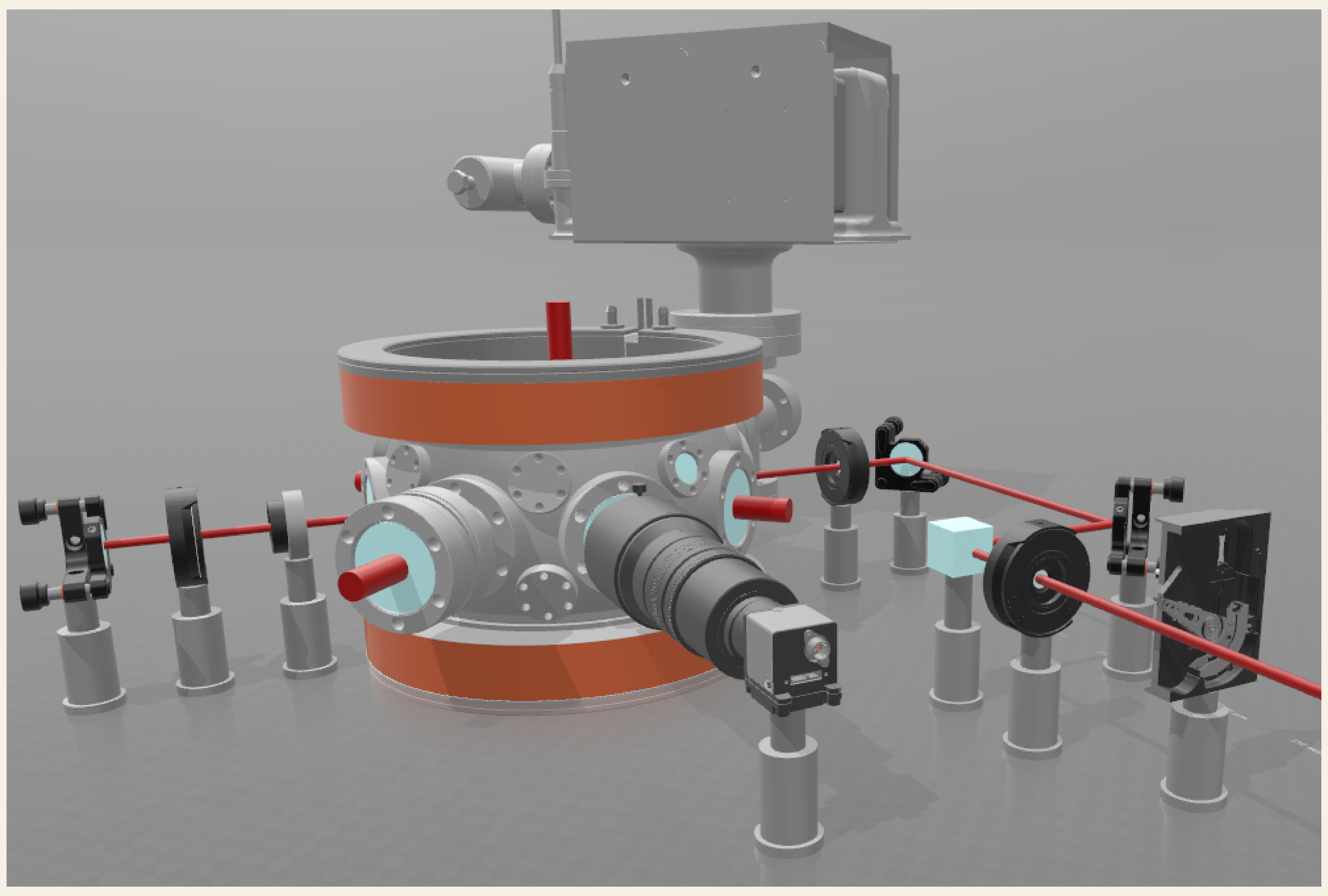


A train of pulses in the mode-locked laser creates frequency comb in frequency domain, an equidistant series of spectral components .



In this experiment we use Erbium doped fiber laser, with central wavelength at 1560 nm and a second harmonic generation unit to generate FC centered at 780 nm.

Experimental setup

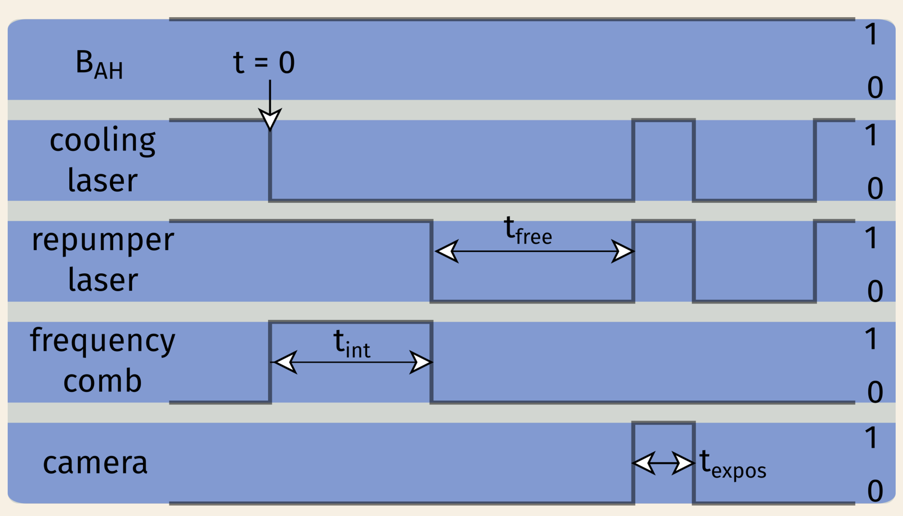


^{87}Rb MOT is generated from the vapour in the standard 6-beam configuration. In a figure above, MOT beams are presented with thick red beams and gradient coils are presented with orange cylinders around the vacuum chamber. Frequency comb interacts with a precooled atomic cloud in counter-propagating 1D geometry (first beam comes from the right side and is retroreflected).

Number of atoms in precooled cloud is around 10^7, with an initial temperature around 250 μK.

Intensity of the FC tooth which interacts with atoms is up to $5 \cdot 10^{-3}$ mW/cm².

Polarization of the FC beams are σ^+ and σ^-.

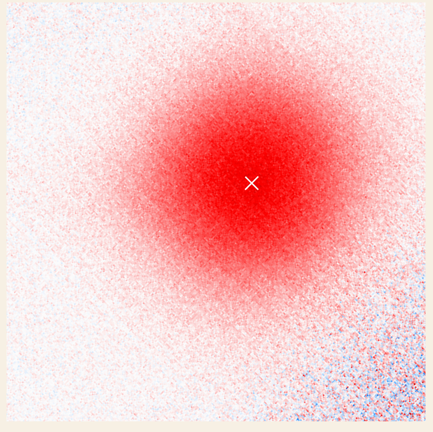


Results

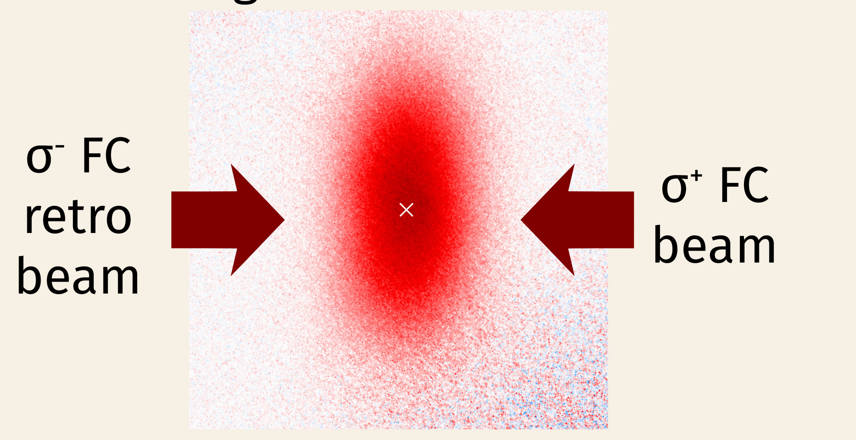
To compare experimental results with the theory, we evaluated Fokker-Planck equation for a two level atom system and suitable parameters for ^{87}Rb atom. For the specific temperature dependence we matched variable parameters in the theory with ones in the experiment.

$$-\frac{1}{m}\frac{\partial}{\partial v}\big(F(v)\rho(v,t)\big)+\frac{1}{m^2}\frac{\partial^2}{\partial v^2}\big(D(v)\rho(v,t)\big)=\frac{\partial}{\partial t}\big(\rho(v,t)\big)$$

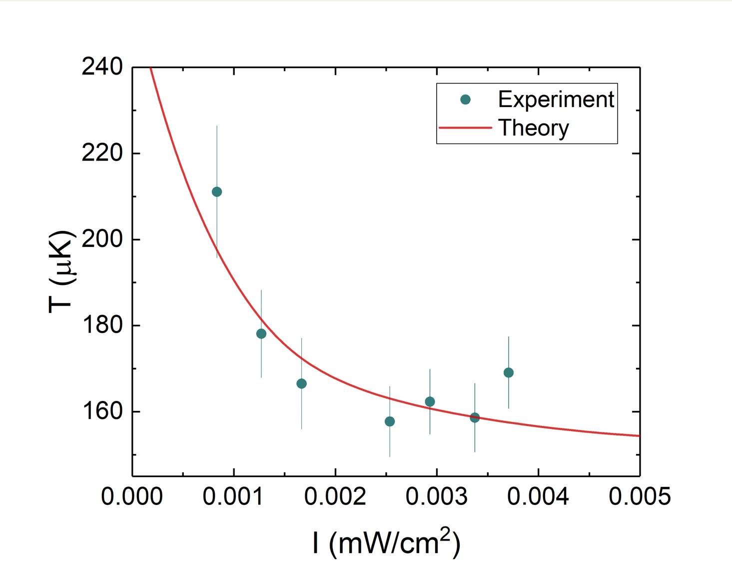
After exposure of a precooled cloud with a counter-propagating FC laser, there is noticable squeezing of the cloud in a dimension parallel to the propagation direction of the incoming laser beams.



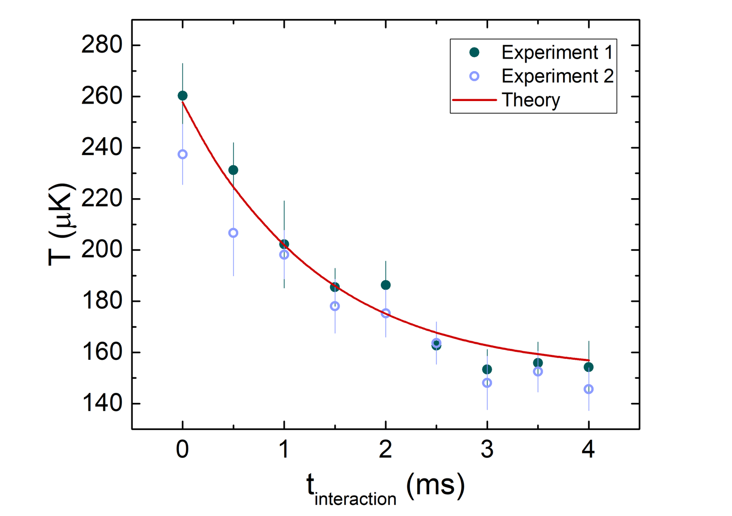
Initial cloud - before interaction with FC.



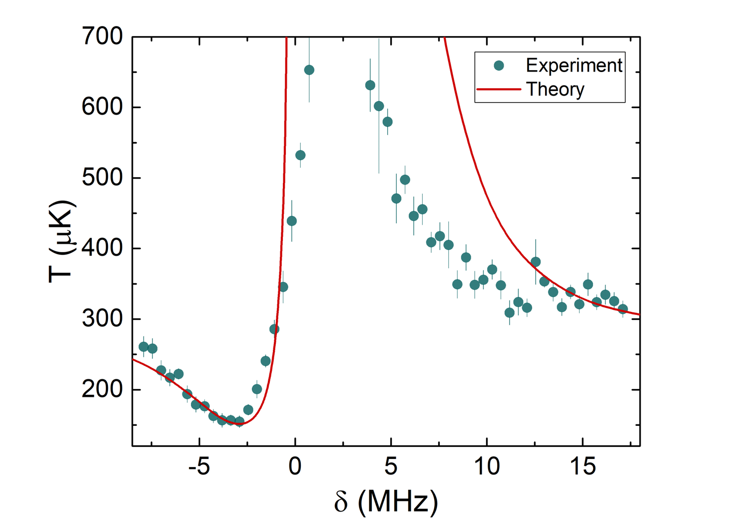
Cloud after 3.5 ms of interaction with counter-propagating FC laser beams.



Temperature dependence on the intensity of the one tooth of the FC is measured for constant interaction time with FC (t_{int} = 3 ms). Detuning of the FC beams is -2/3 Γ from the cooling resonance.



Interaction time when the cloud reaches the steady state after interaction with the FC is at 3 ms. There are two different measurements, with two different beam sizes (but the same intensity, I=$2 \cdot 10^{-3}$ mW/cm²), with detuning- 2/3 Γ.



Temperature dependence on the detuning of the FC beams is consistent with the Doppler theory. In the region with negative detunings there is characteristic Doppler cooling profile. In this set of measurements interaction time is constant (t_{int} = 3 ms), as well as intensity of the FC beams (I = $2 \cdot 10^{-3}$ mW/cm²).

Conclusion

We have performed a measurement of the Doppler cooling with a frequency comb. We compared experimental data with the theory evaluated using the Fokker-Planck equation. All measured dependencies fit very well to the theory. This set of measurements confirms our thesis that we can cool atoms with a FC and that one tooth of a FC is analogous with a cw laser.

Future perspectives

Recently, we started to build an optical cavity which will be coupled with the FC to examine frequency comb cavity cooling.

We're going to build a new frequency comb laser source with higher intensity per comb tooth. It will be simultaneously used as a cooling and repumping laser to generate cold atomic cloud. Finally, along by careful designing of a characteristic frequency comb frequencies, we're going to simultaneously cool two atomic species, ^{85}Rb and ^{87}Rb.

[1] Adopted from: Jones, D. J.; Diddams, S. A.; Ranka, J. K.; Stentz, A.; Windeler, R. S.; Hall, J. L.; Cundiff, S. T. Carrier-Envelope Phase Control of Femtosecond Mode-Locked Lasers and Direct Optical Frequency Synthesis. Science Vol. 288, 5466(2000), pages. 635-639