Cold atoms near surfaces

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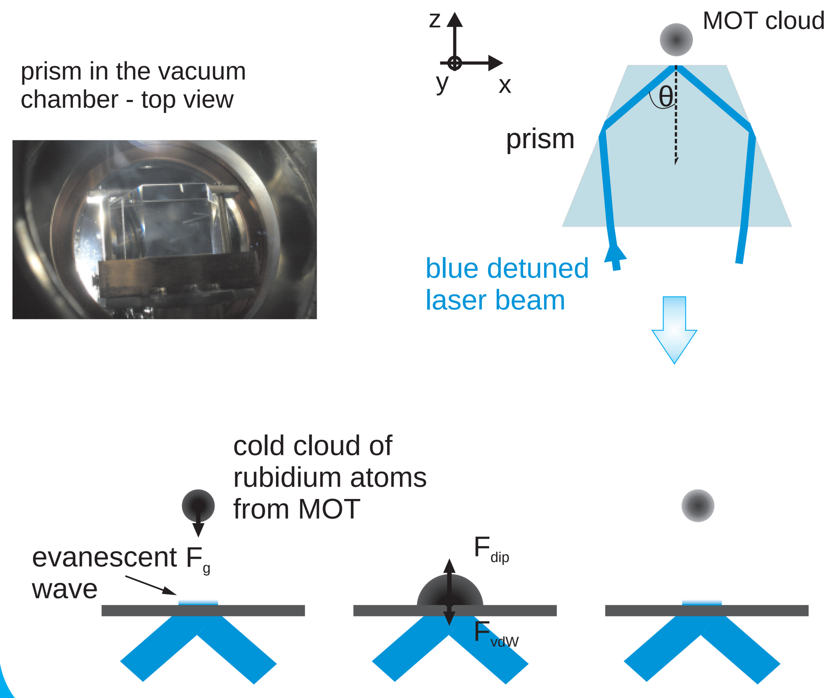
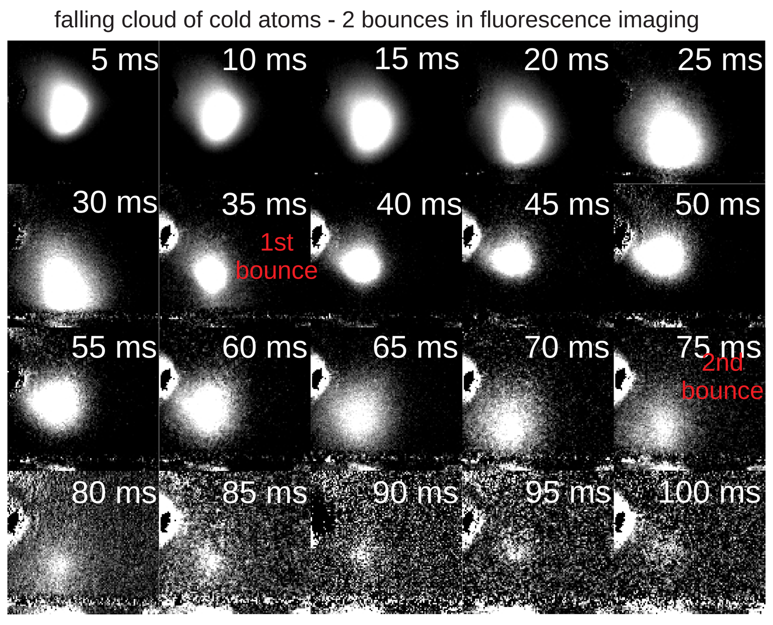
ABSTRACT

Evanescent wave could be used to control and detect atoms in surface systems. In such situations its detuning is very close to resonance. It is thus important to investigate changes in internal and external degrees of freedom caused by such evanescent wave.
In our optical dipole mirror for rubidium atoms [1, 2] we investigated main aspects of radiation pressure exerted by evanescent wave (both far-, blue-detuned and close to resonance) on bouncing atoms. Some further applications, like measurements of changes in populations of Zeeman sublevels during the bounce, the radiation pressure exerted by circularly polarized evanescent wave [3], measurements with prism coated with thin gold film etc., are briefly presented.

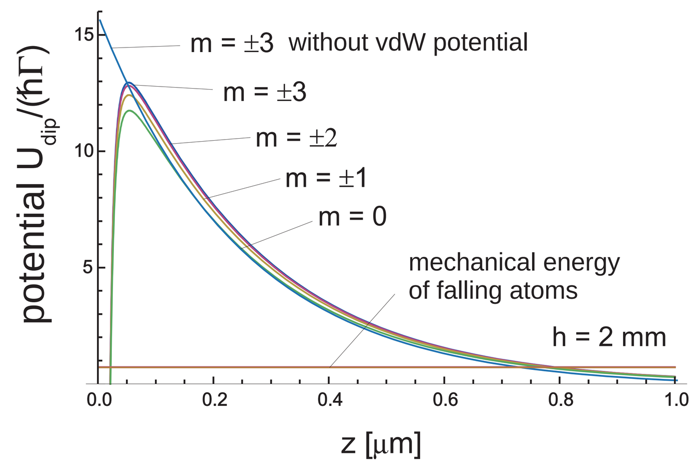
PRINCIPLE OF THE OPTICAL DIPOLE MIRROR





POTENTIALS OF A DIPOLE MIRROR

$$U(z) = U_{dip}(z) + U_g(z) + U_{vdW}(z)$$
$$= U_0 e^{-\frac{2z}{d}} + mgz - \frac{q}{z^3}$$



RADIATION PRESSURE

SOME THEORY

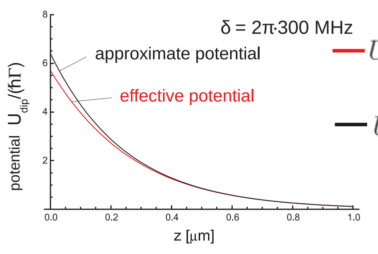
propagating component of the wave vector of EW along the surface → recoil momentum of the atom

$$k_x = k_0 n \sin\theta \qquad p_{rec} = \hbar k_x$$

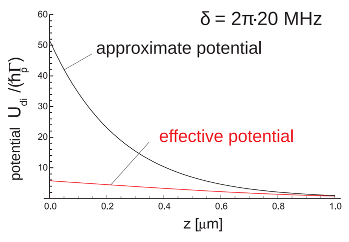
number of scattered photons
$$p_{sp} = \int_{-\infty}^{\infty} \Gamma_{sp}[z(t)]dt$$
(along classical trajectory of an atom)

for two level atom
$$\Gamma_{sp}[z(t)] = \frac{\Gamma}{2}\frac{\frac{I[z(t)]}{I_S}}{1+\left(\frac{2\delta}{\Gamma}\right)^2+\frac{I[z(t)]}{I_S}}$$

effective and approximate dipole potential (for two level atom)



$$U_{dip}(z) = \frac{\hbar\delta}{2}\ln\left(1+\frac{\Omega_1^2(z)}{2\delta^2}\right)$$
$$U_{dip}(z) = \frac{1}{4}\frac{\hbar}{\delta}\Omega_1^2(z)$$



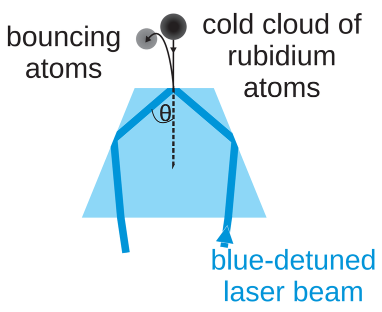
far detuning $\frac{\Omega_1^2}{2\delta^2} \ll 1$

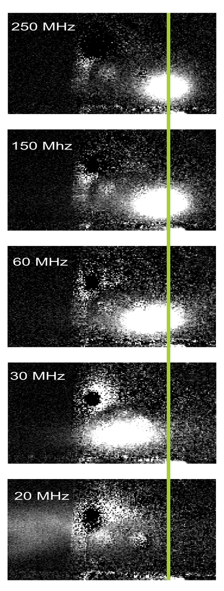
$$\Gamma_{sp} \approx \frac{1}{2}s\Gamma \approx \frac{\Omega_1^2\Gamma}{4\delta^2} = \frac{\Gamma^3}{8\delta^2}\frac{I(z)}{I_s}$$
$$\frac{m}{2}\left(\frac{dz}{dt}\right)^2 + U_{dip}(z) = E_\perp$$
$$p_{sp} = \frac{md}{\hbar}\frac{\Gamma}{\delta}v_\perp \quad (*)$$

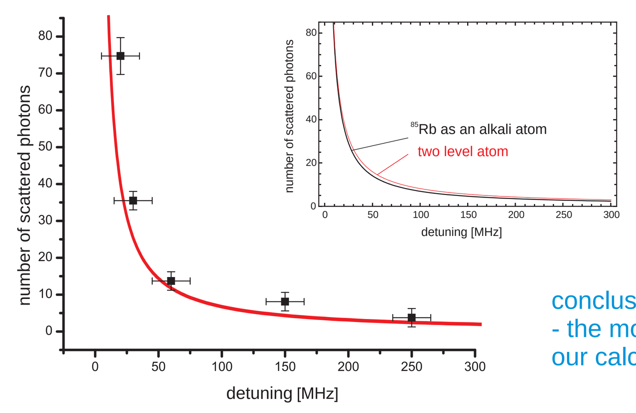
small detuning $\frac{\Omega_1^2}{2\delta^2} \gg 1$

$$\vec{F}_{dip}(\vec{r}) = -\frac{\hbar\delta}{2}\vec{\nabla}\left[\ln\left(1+\frac{\Omega_1^2}{2\delta^2}\right)\right]$$
$$m\ddot{z} = mg + F_{dip}(z)$$
$$p_{sp} = \int_{-\infty}^{\infty}\Gamma_{sp}[z(t)]dt$$
$z(t)$ numerical integration

ONE FAR-DETUNED EVANESCENT WAVE

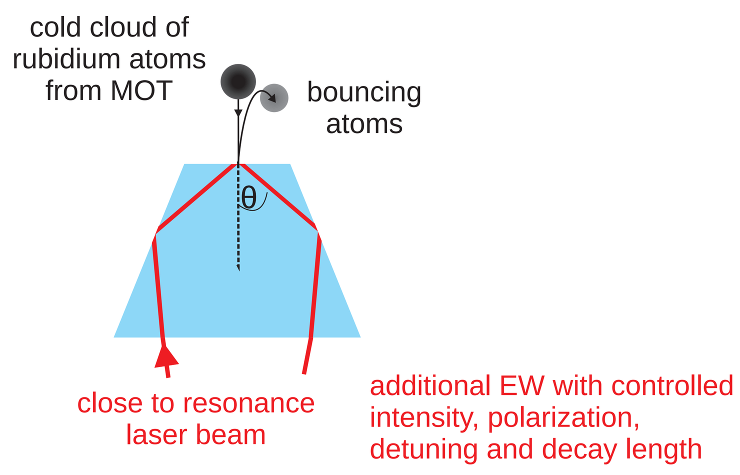


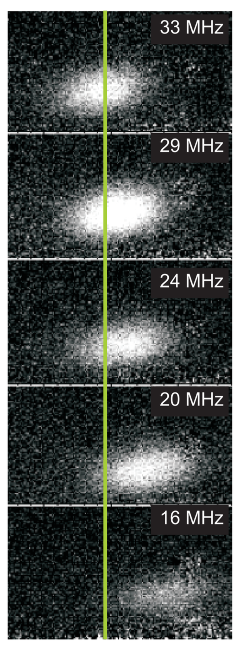




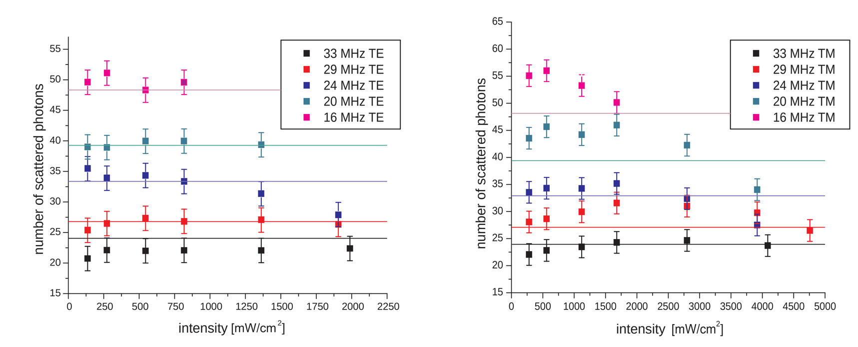
conclusions:
- the model of two-level atom is sufficient in our calculations

ONE CLOSE TO RESONANCE EVANESCENT WAVE

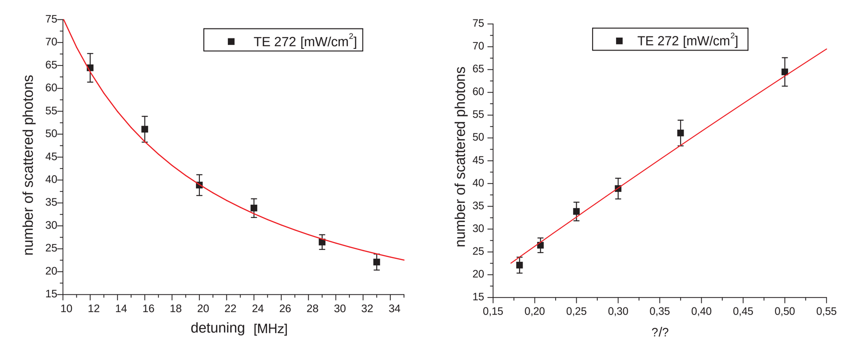




number of scattered photons versus evanescent wave intensity dependance (experimental and theoretical; for TE and TM polarization)

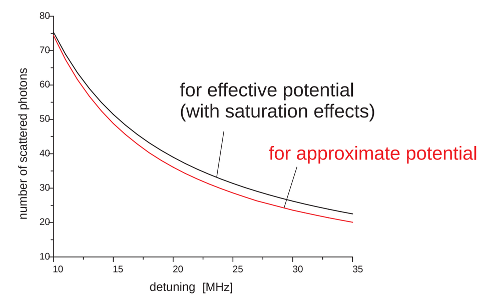


radiation pressure in an evanescent wave - number of scattered photons versus detuning (or reversed detuning) for one selected intensity and polarization state (TE)

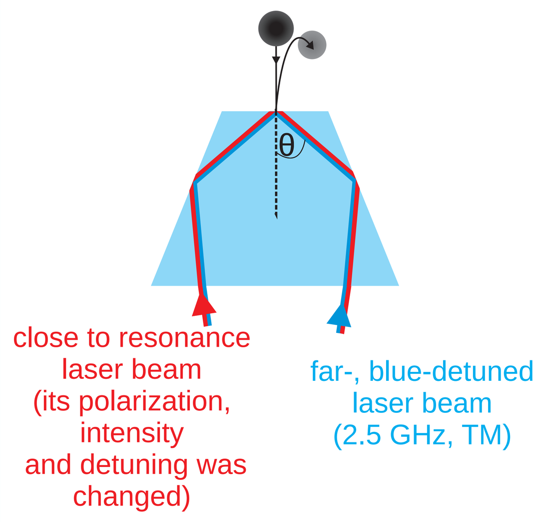


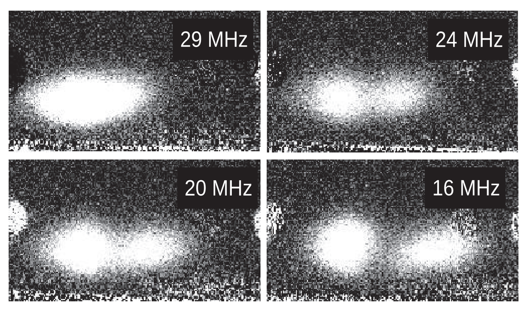
conclusions:
- no observed dependance between intensity and number of scattered photons in close-to-resonance evanescent wave
- equation (*) can be also used near resonance (as shown below)

theoretical calculations of number of scattered photons p_{sp} versus evanescent wave detuning (for approximate and effective potential)

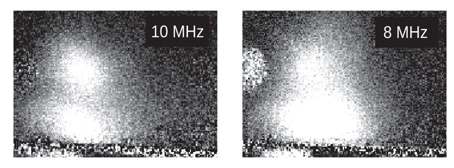


TWO EVANESCENT WAVES



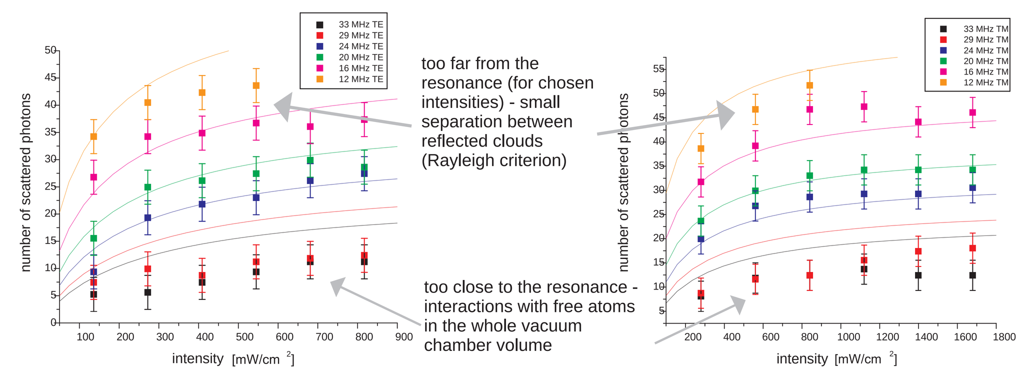


"snowman effect" - too close to the resonance (from the blue side):

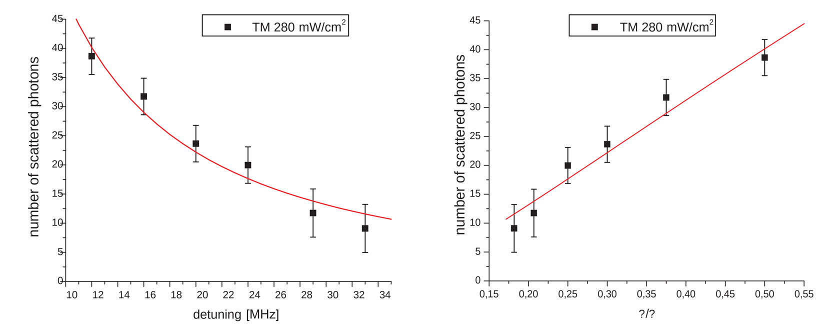


calculations:
- added potentials of both evanescent waves;
- trajectory of an atom calculated for this combined potential;
- in number of scattered photons calculations only the close-to-resonance evanescent wave was taken into account
- nonlinear dependance of number of scattered photons on intensity is expected

number of scattered photons versus evanescent wave intensity dependance (experimental and theoretical; for TE and TM polarization)



radiation pressure in a potential of two evanescent waves - number of scattered photons versus detuning (or reversed detuning) for one selected intensity and polarization state (TM)

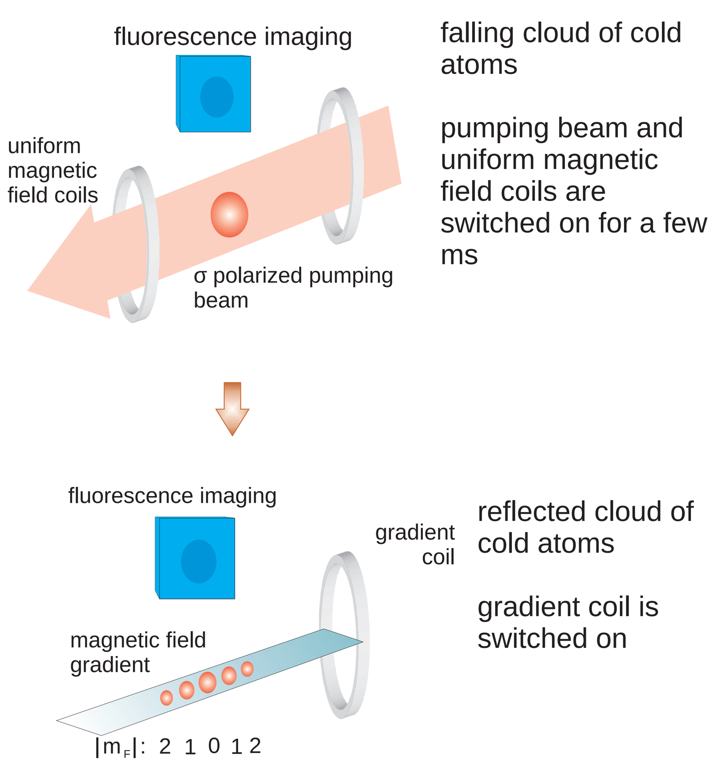


conclusions:
- very good agreement between theoretical calculations nad experimental values
- our method of calculating number of scattered photons treating the interactions of atoms with both potentials separately seems to be correct

OUTLOOK

STERN-GERLACH EFFECT OF MAGNETIC SUBLEVELS

test of decoherence with and without metallic layer



falling cloud of cold atoms

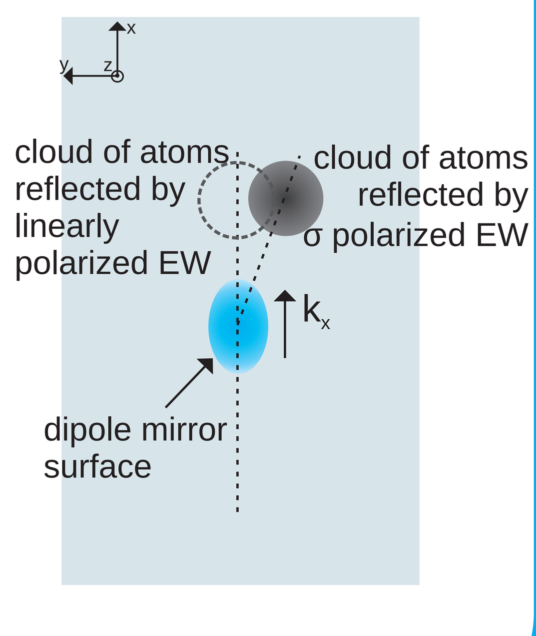
pumping beam and uniform magnetic field coils are switched on for a few ms

reflected cloud of cold atoms

gradient coil is switched on

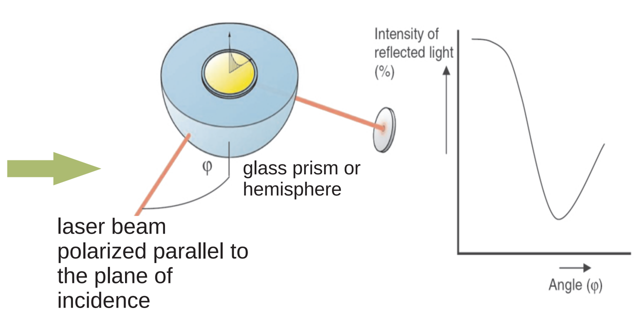
σ POLARIZED EVANESCENT WAVE

it is expected [3] that for circularly polarized evanescent wave the radiation pressure force experienced by the atoms is not colinear with the evanescent wave's propagation vector



OPTICAL DIPOLE MIRROR WITH METALLIC LAYER

thin gold layer on the prism surface
↓
surface plasmon polaritons
↓
enhancement of the intensity of EW
↓
observation of radiation pressure



cooperation with Syddansk Universitet (Odense and Sonderborg, Denmark)

OTHER

1. **effective potential of the close to resonance EW**
- information about the effective dipole potential based on the measurement of the threshold value of U_{dip} + U_{vdW} potentials (reversing the idea presented in [7])

2. ***quantum reflection***
- reflection of atoms with energy greater than the potential barrier or reflection by attracting potential
- observations in modified, more complicated potential [5]

3. ***Casimir-Polder potential***
- QED corrections to the van der Waals potential (retardation effects)
- precise mesurement of number of atoms reflected by optical dipole mirror for various intensities and detunings of EW (shape of the potential)

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