Zeemanov upočasnjevalnik cezijevih atomov

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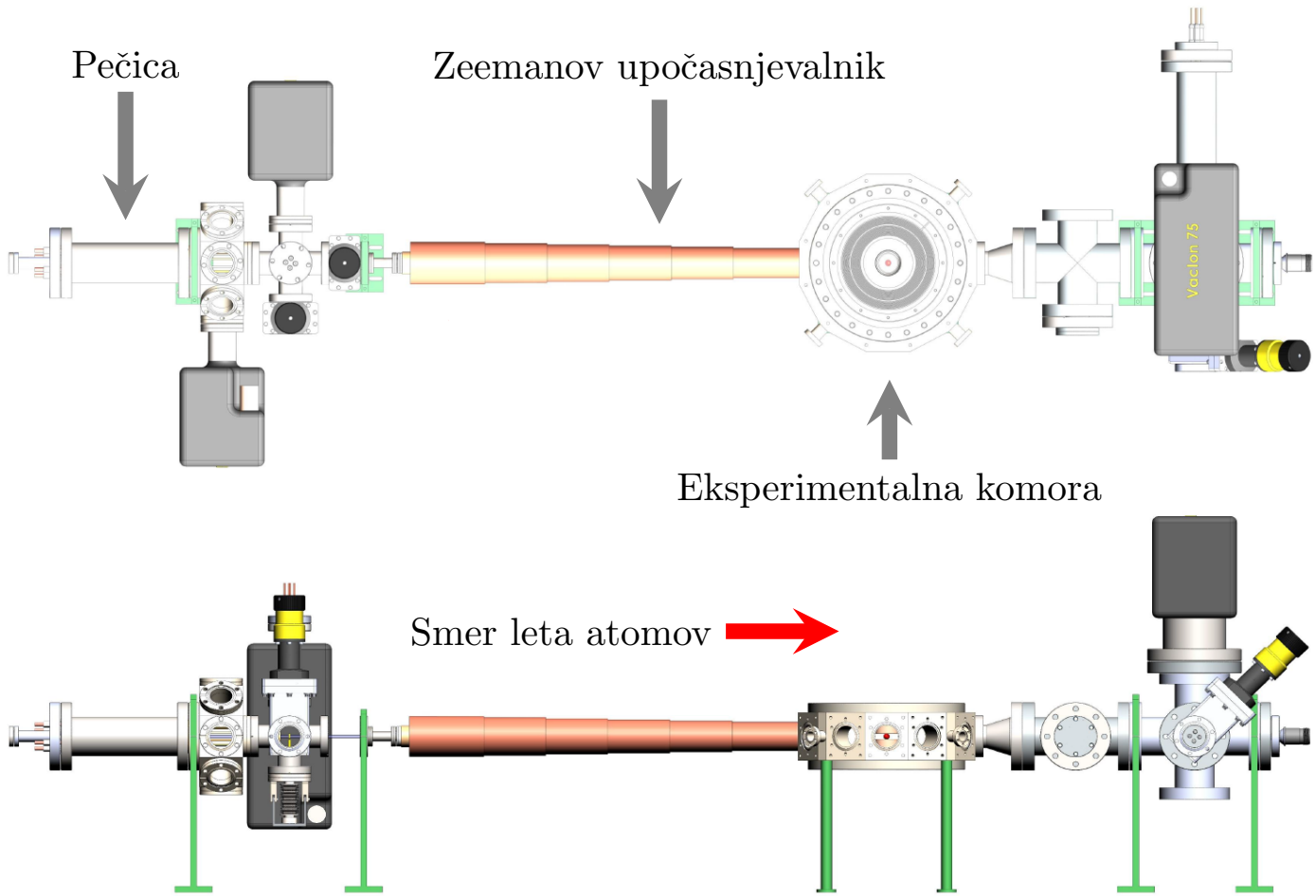
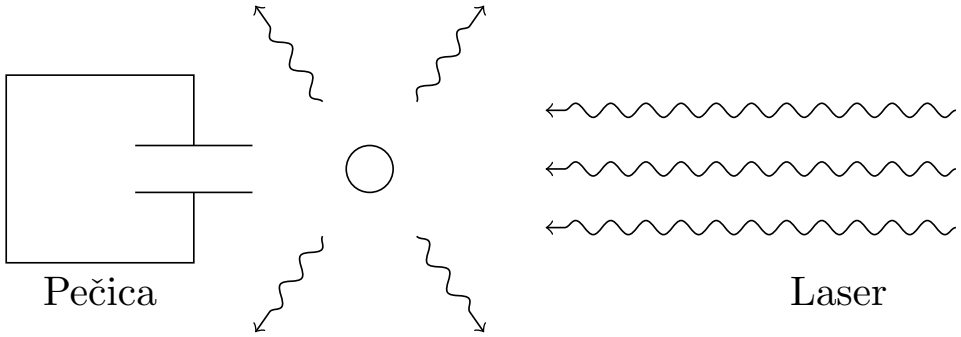
Eksperimentalni sistem



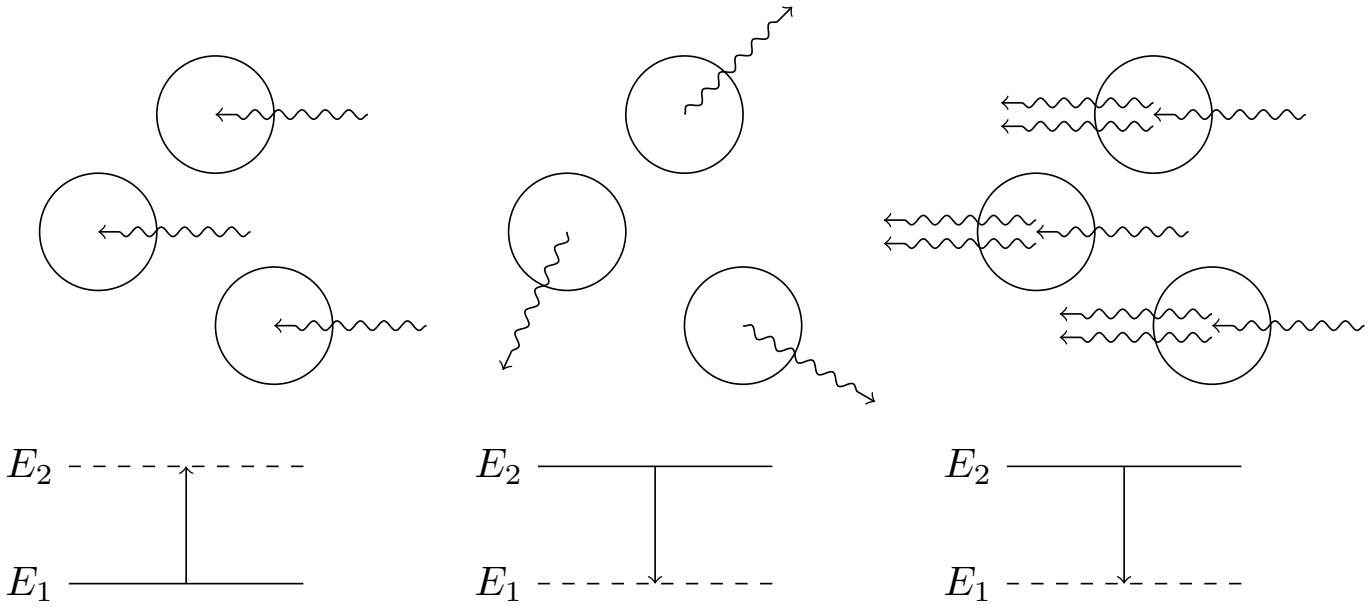
Zeemanov upočasnjevalnik

- Princip upočasnjevanja
- Interakcija atomov s svetlobo
- Dopplerjev pojav pri upočasnjevanju
- Zeemanov pojav pri upočasnjevanju
- Načrt upočasnjevalnika
- Hitrosti atomov v upočasnjevalniku
- Ovire pri upočasnjevanju

Princip upočasnjevanja



Gibalna količina fotona: $\hbar\mathbf{k}$



Interakcija atomov s svetlobo

$$\Psi_j(\mathbf{r},t) = \psi_j(\mathbf{r}) e^{-\mathrm{i}E_j t/\hbar}, \quad j \in \{1,2\}$$

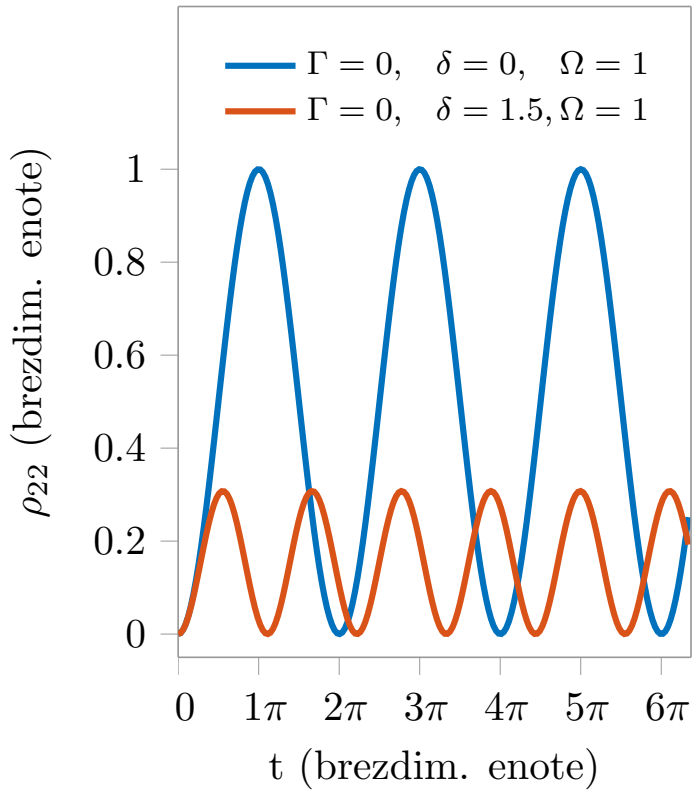
$$\Psi(\mathbf{r},t) = c_1(t)\Psi_1(\mathbf{r},t) + c_2(t)\Psi_2(\mathbf{r},t)$$

$$\mathrm{i}\hbar\frac{\partial\Psi}{\partial t} = \big(H_0 + e\mathbf{r}\cdot\mathbf{E}_0\cos(\omega t)\big)\Psi$$

$$|\Psi\rangle\langle\Psi| = \begin{pmatrix} c_1 \\ c_2 \end{pmatrix}\begin{pmatrix} c_1^* & c_2^* \end{pmatrix} = \begin{pmatrix} |c_1|^2 & c_1 c_2^* \\ c_1^* c_2 & |c_2|^2 \end{pmatrix} = \begin{pmatrix} \rho_{11} & \rho_{12} \\ \rho_{21} & \rho_{22} \end{pmatrix}$$

Interakcija atomov s svetlobo

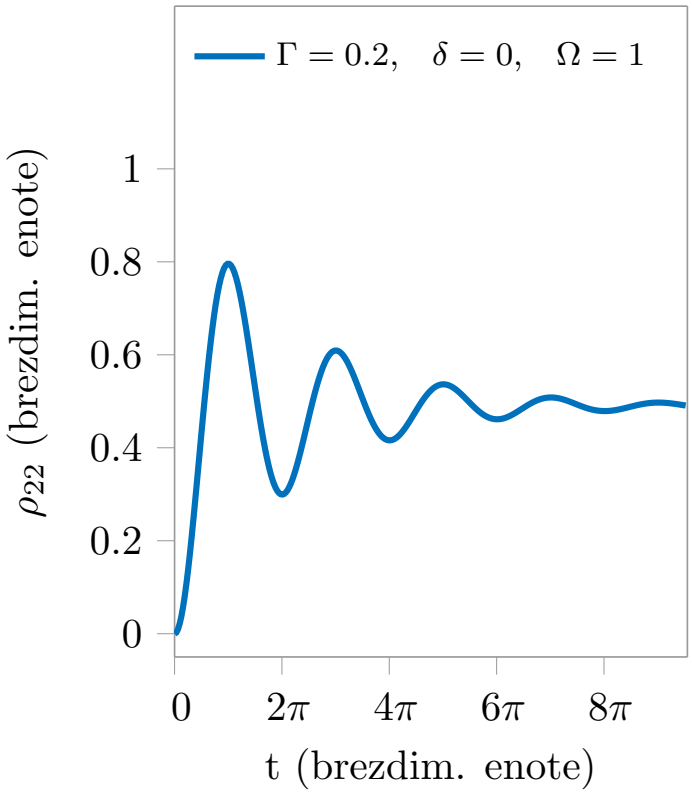
$$\frac{\mathrm{d}\rho_{11}}{\mathrm{d}t} = \frac{\mathrm{i}}{2}\left(\Omega^*\tilde{\rho}_{21} - \Omega\tilde{\rho}_{12}\right)$$
$$\frac{\mathrm{d}\rho_{22}}{\mathrm{d}t} = \frac{\mathrm{i}}{2}\left(\Omega\tilde{\rho}_{12} - \Omega^*\tilde{\rho}_{21}\right)$$
$$\frac{\mathrm{d}\tilde{\rho}_{12}}{\mathrm{d}t} = \frac{\mathrm{i}}{2}\Omega^*\left(\rho_{22} - \rho_{11}\right) - \mathrm{i}\delta\tilde{\rho}_{12}$$
$$\frac{\mathrm{d}\tilde{\rho}_{21}}{\mathrm{d}t} = \frac{\mathrm{i}}{2}\Omega\left(\rho_{11} - \rho_{22}\right) + \mathrm{i}\delta\tilde{\rho}_{21}$$



- Neuglašenost: $\delta = \omega - \omega_0$
- Transfomirani koherenci: $\tilde{\rho}_{12} = (\tilde{\rho}_{21})^* = \rho_{12}\exp(-\mathrm{i}\delta t)$
- Rabijeva frekvenca: $\Omega = \frac{e}{\hbar}\int \psi_1^*(r)\,\mathbf{r}\cdot\mathbf{E_0}\,\psi_2(r)\,\mathrm{d}^3r$

Interakcija atomov s svetlobo

$$\frac{\mathrm{d}\rho_{11}}{\mathrm{d}t} = \frac{\mathrm{i}}{2}\left(\Omega^*\tilde{\rho}_{21} - \Omega\tilde{\rho}_{12}\right) + \Gamma\rho_{22}$$
$$\frac{\mathrm{d}\rho_{22}}{\mathrm{d}t} = \frac{\mathrm{i}}{2}\left(\Omega\tilde{\rho}_{12} - \Omega^*\tilde{\rho}_{21}\right) - \Gamma\rho_{22}$$
$$\frac{\mathrm{d}\tilde{\rho}_{12}}{\mathrm{d}t} = \frac{\mathrm{i}}{2}\Omega^*\left(\rho_{22} - \rho_{11}\right) - \mathrm{i}\delta\tilde{\rho}_{12} - \frac{\Gamma}{2}\tilde{\rho}_{12}$$
$$\frac{\mathrm{d}\tilde{\rho}_{21}}{\mathrm{d}t} = \frac{\mathrm{i}}{2}\Omega\left(\rho_{11} - \rho_{22}\right) + \mathrm{i}\delta\tilde{\rho}_{21} - \frac{\Gamma}{2}\tilde{\rho}_{21}$$

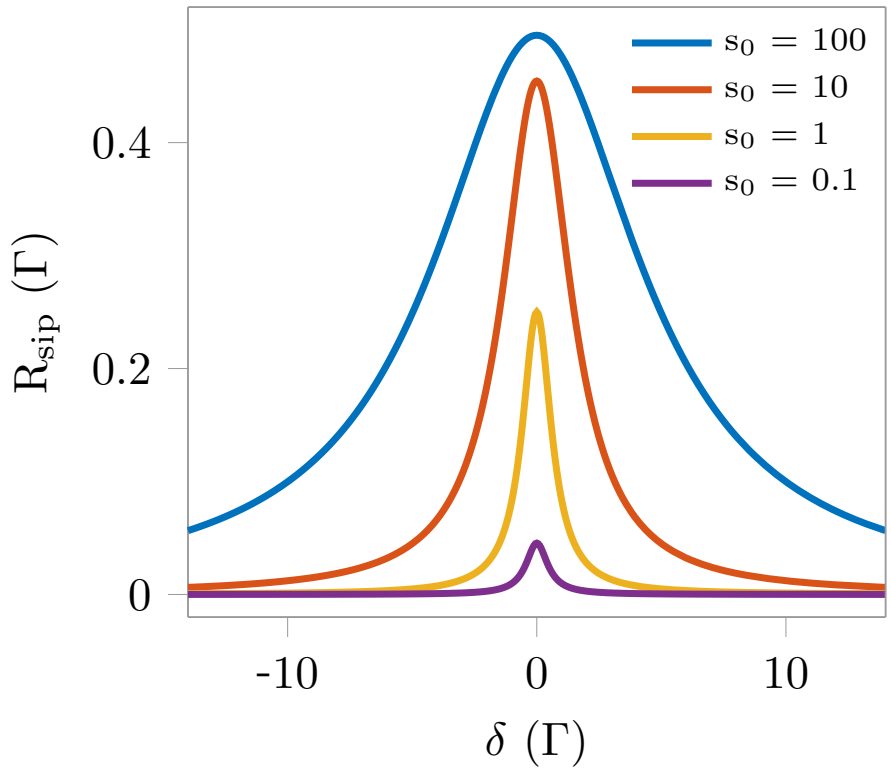


- Naravna širina: Γ
- Razpadni čas vzbujenega stanja: $\tau = \Gamma^{-1}$
- Ravnovesje ob času $t \gg \tau$

Interakcija atomov s svetlobo

Verjetnost za sipanje na časovno enoto:

$$R_{sip} = \Gamma\rho_{22} = \Gamma\frac{s_0/2}{1+s_0+(2\delta/\Gamma)^2}, \qquad s_0 = \frac{2\Omega^2}{\Gamma^2}$$



Dopplerjev pojav pri upočasnjevanju

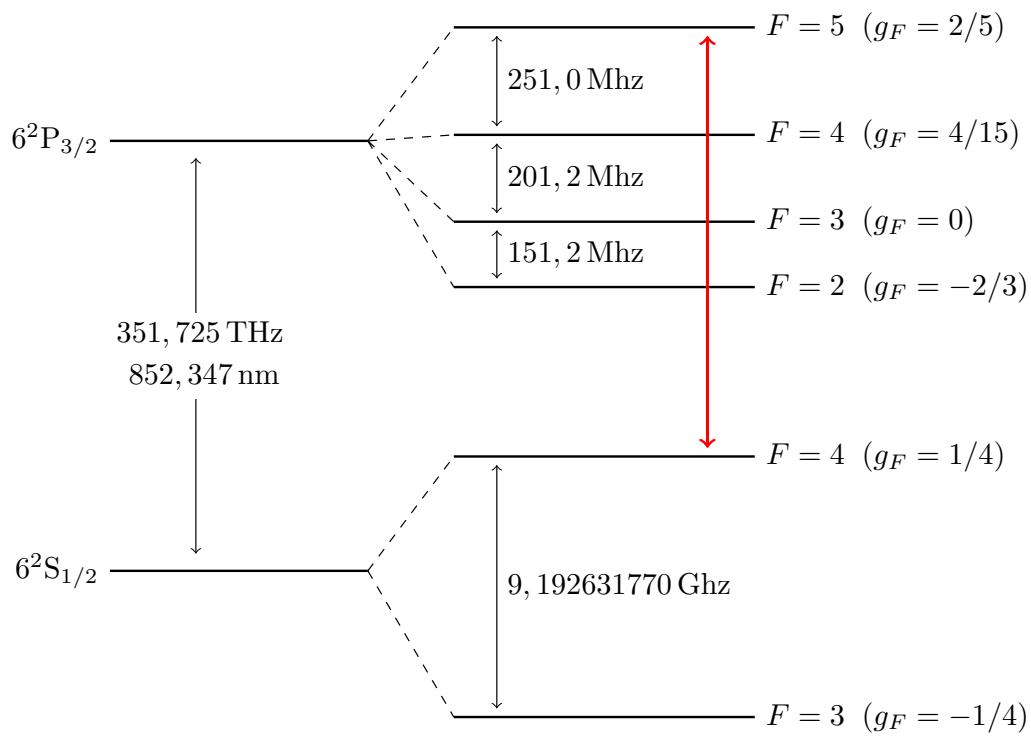
- Velikost sile: $F = \hbar k R_{sip}$
- Sila pada z naraščanjem neuglašenosti
- Dopplerjev pojav: $\omega' = \omega - \mathbf{k} \cdot \mathbf{v}$
- Dopplerjev premik $|k\Delta v| > \Gamma$ po upočasnitvi $\Delta v \approx 5\,\mathrm{m/s}$
- Pri upočasnjevanju se sila na atome manjša

Možne rešitve:

- Spreminjanje frekvence laserja med upočasnjevanjem
- Upočasnjevanje s svetlobo s širokim spektrom
- Zeemanov upočasnjevalnik

Zeemanov pojav pri upočasnjevanju

$$\omega_0'(z) = \omega_0 + g\frac{\mu_B B(z)}{\hbar}, \quad g = g_{F'}M_{F'} - g_F M_F$$



Načrt upočasnjevalnika

Minimalna dolžina:

$$F_{max} l_{min} = \frac{M v_0^2}{2}$$

Dosežena sila:

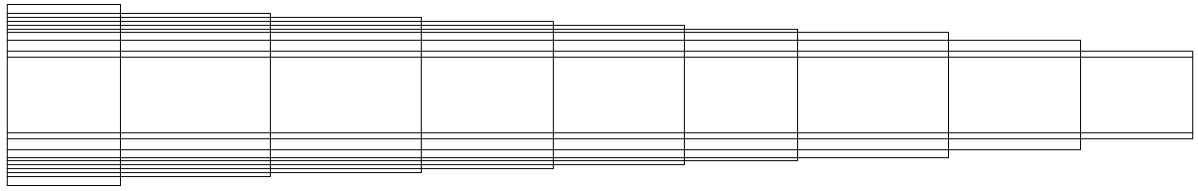
$$F = \eta F_{max}, \quad 0 < \eta < 1$$

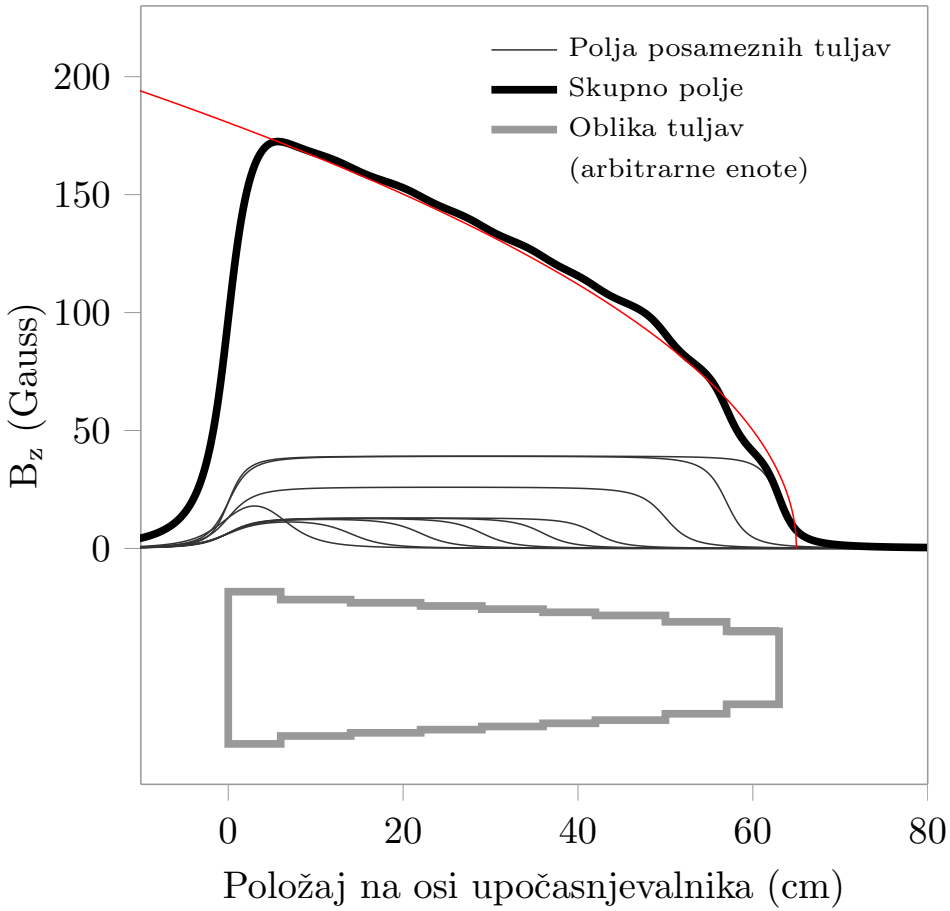
Polje upočasnjevalnika:

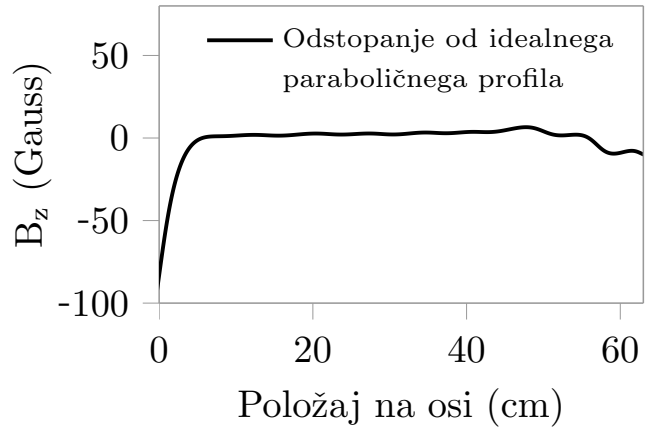
$$v_0^2 - v_z^2 = 2az$$

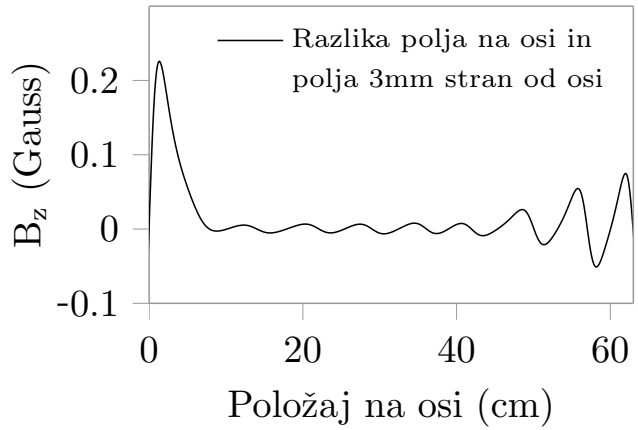
$$B(z) = \frac{\hbar k v_0}{g \mu_B} \sqrt{1 - \frac{z}{l_u}}, \quad l_u = \frac{l_{min}}{\eta}$$

Načrt upočasnjevalnika

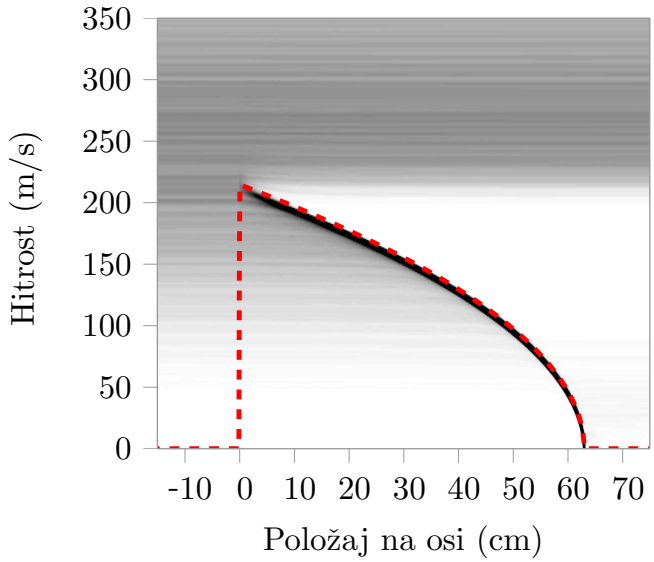


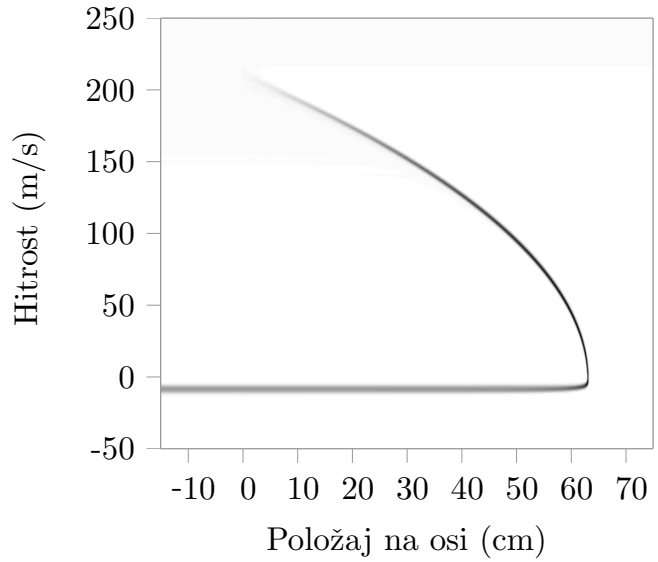


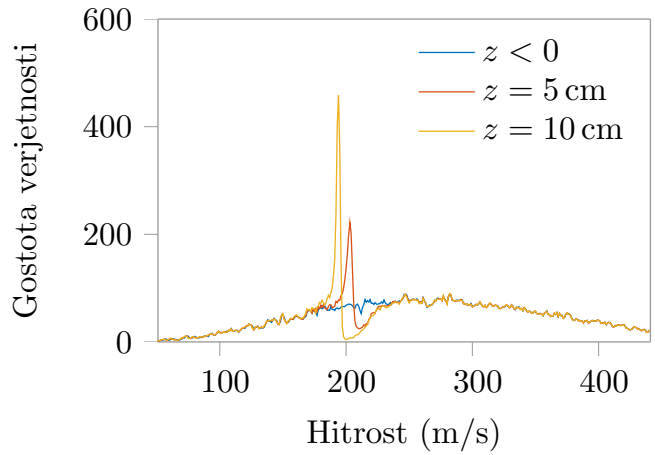


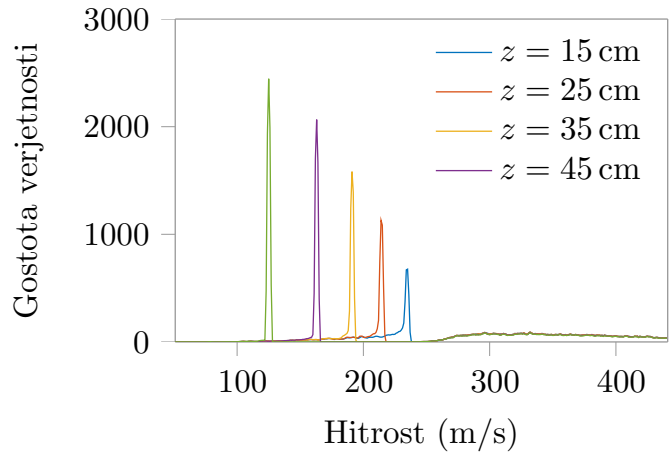


Hitrosti atomov v upočasnjevalniku

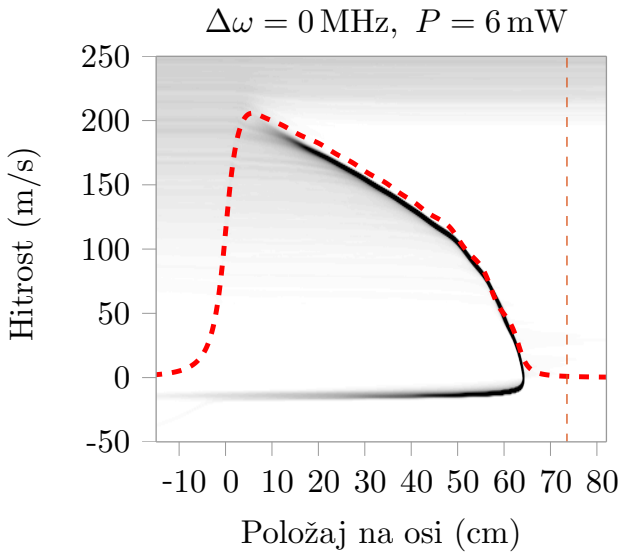


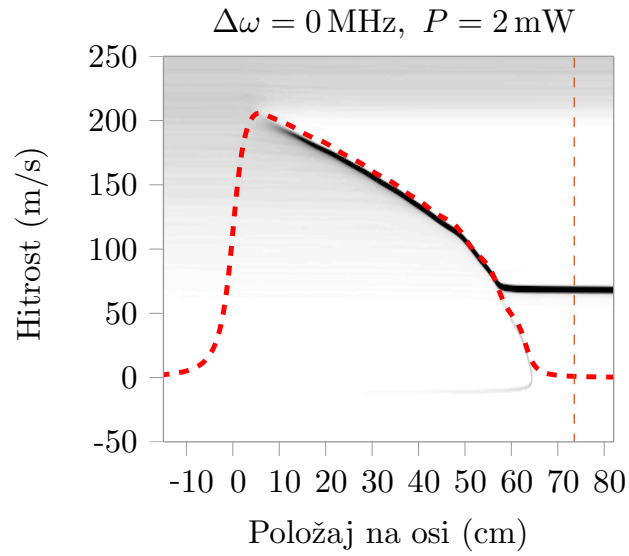


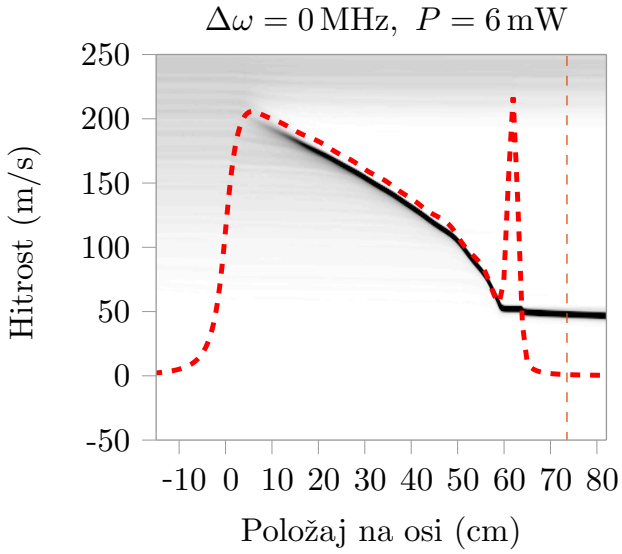


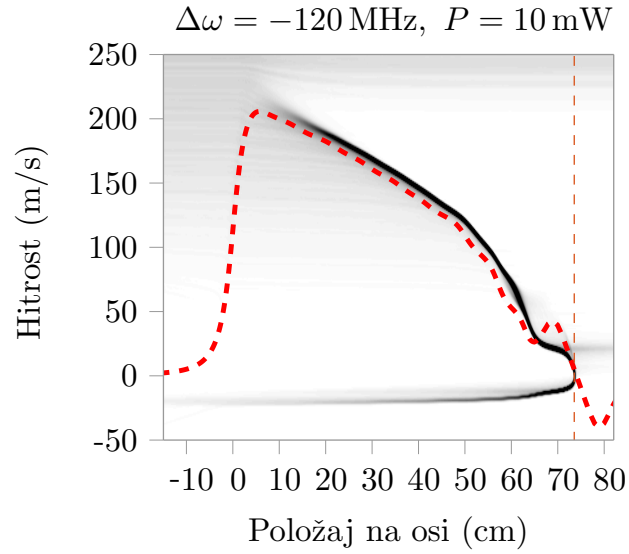


Ovire pri upočasnjevanju









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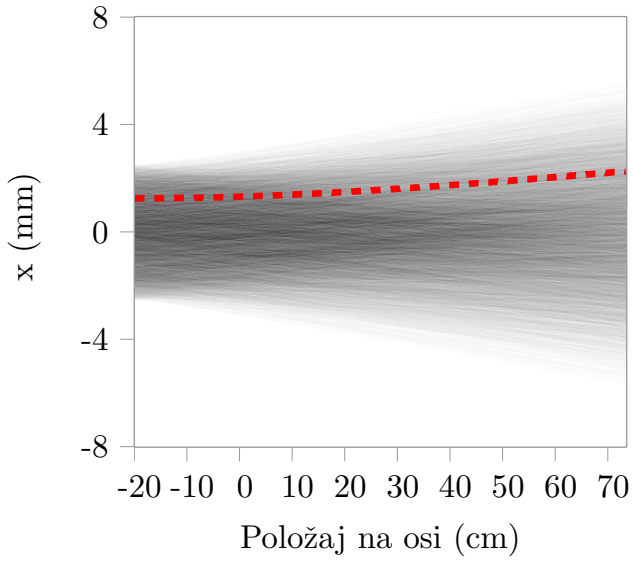
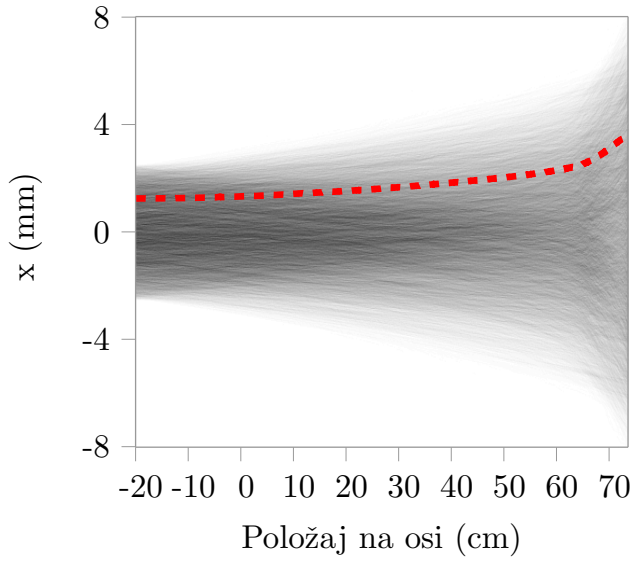
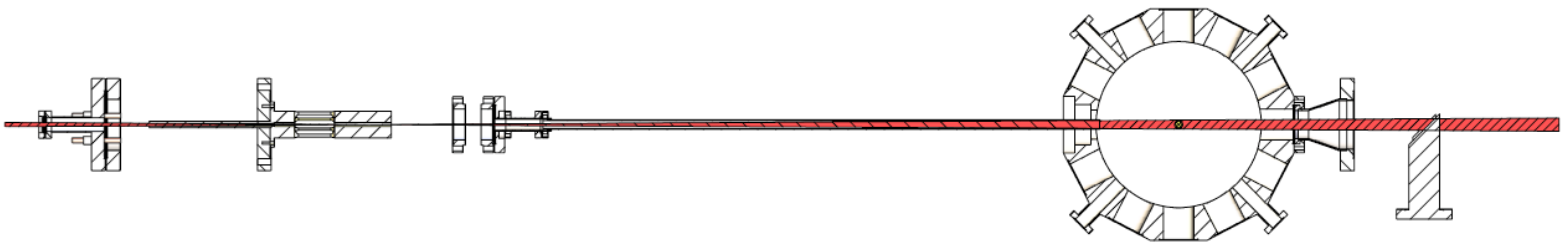
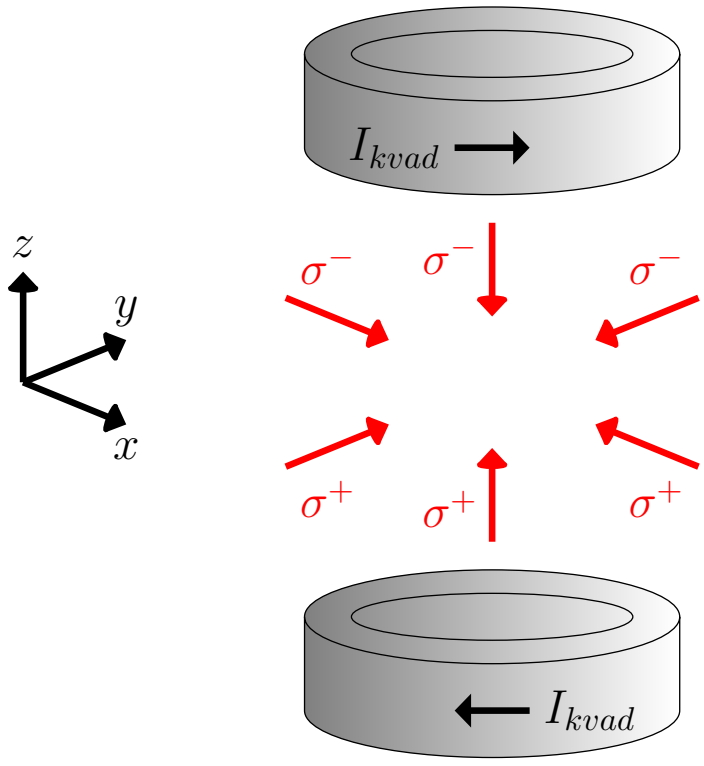
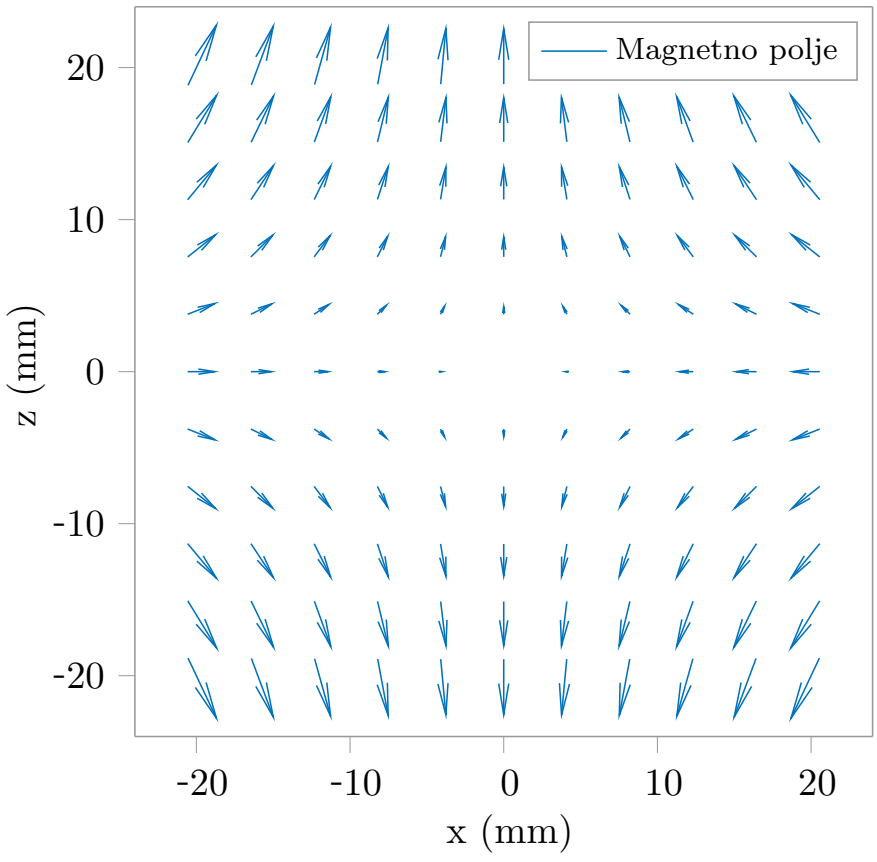






Magneto-optična past

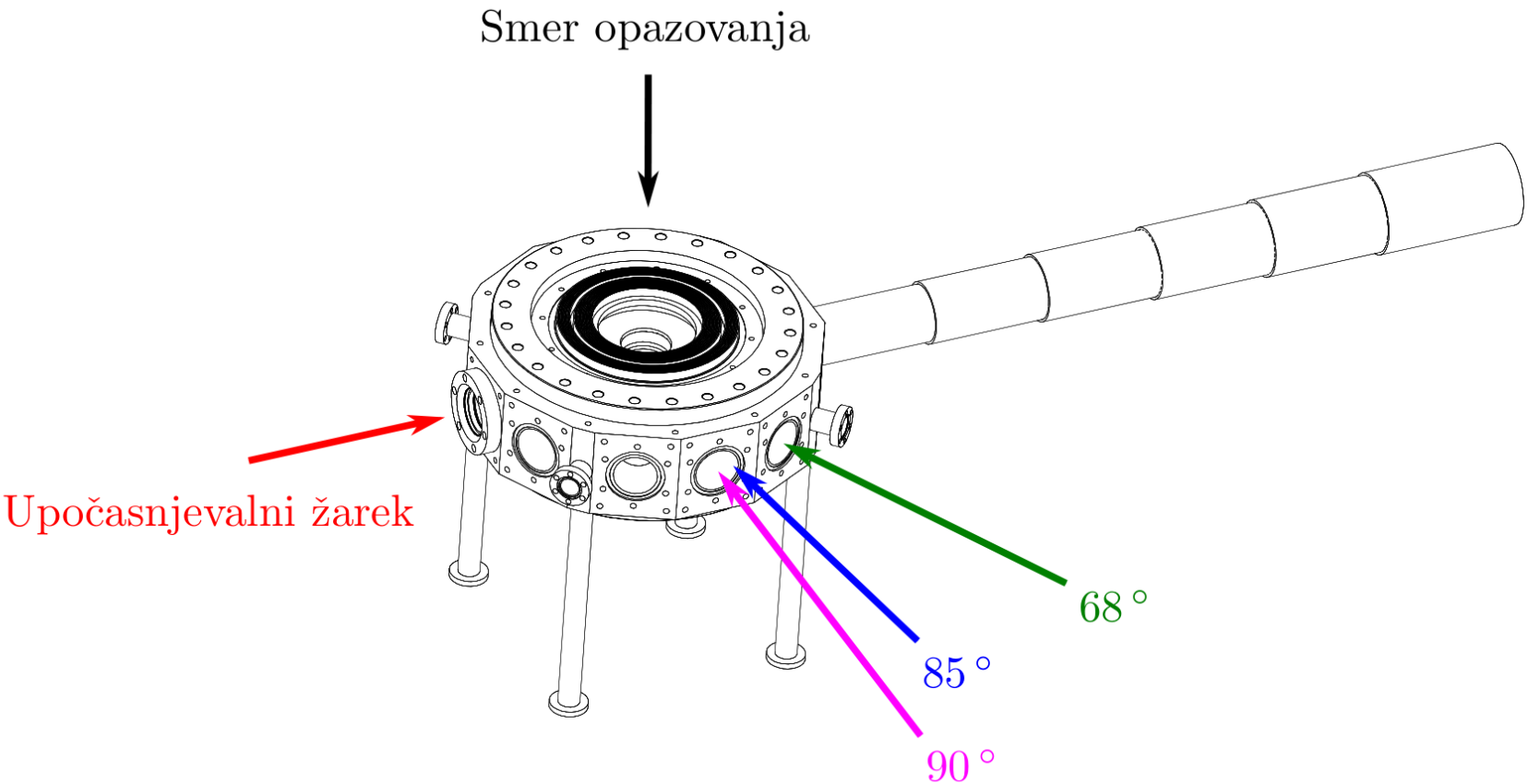




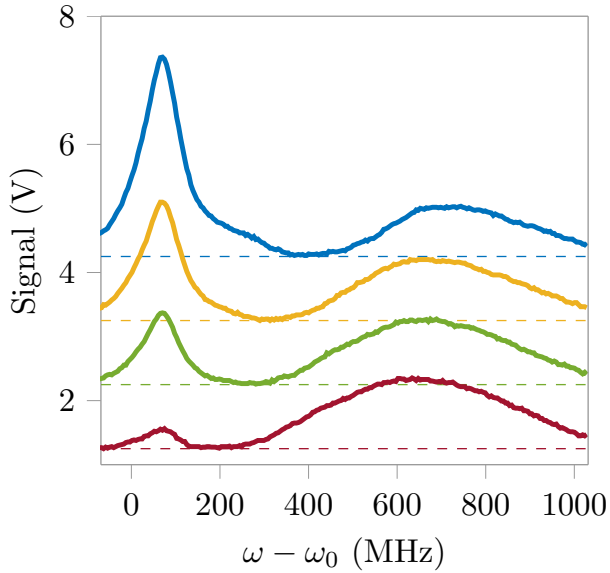
Sila je odvisna od hitrosti in položaja atoma:

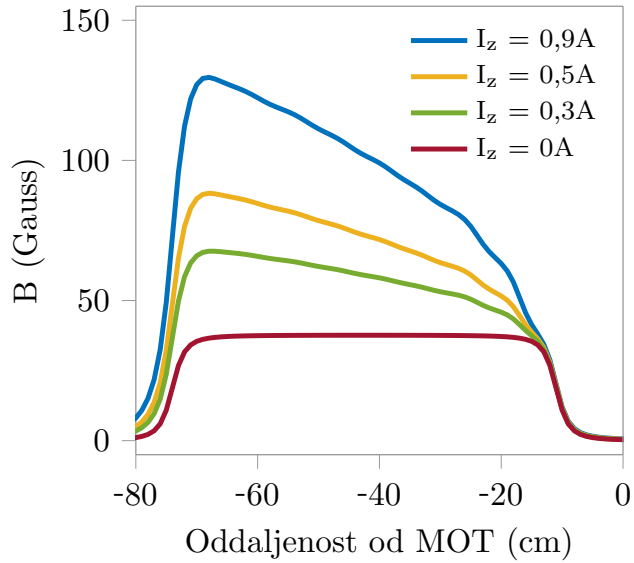
$$F_{MOT} = -\alpha v - \frac{\alpha\beta}{k} z$$

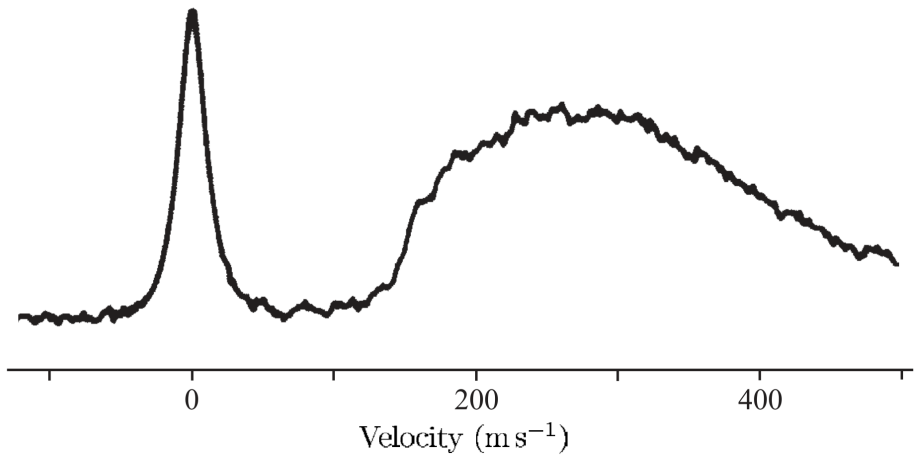
Meritve



Meritve





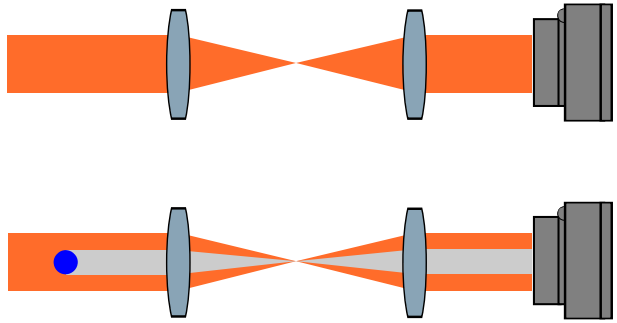


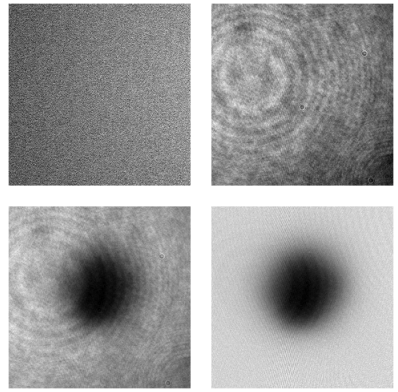
(Vir: C. J. Foot, Atomic Physics)

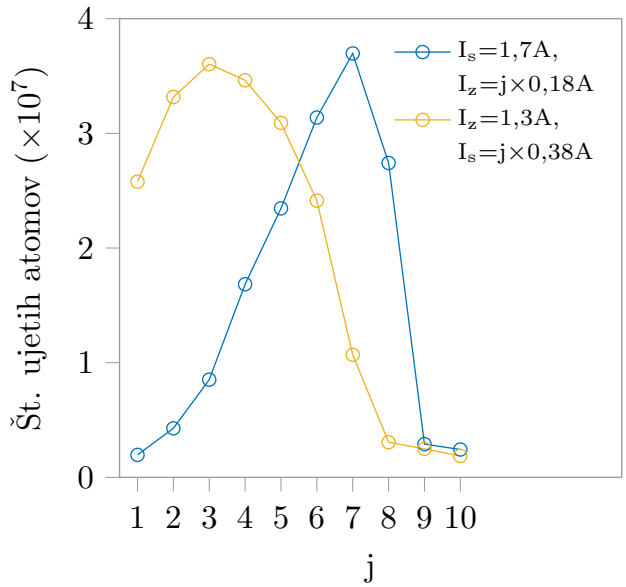
Absorpcijsko slikanje

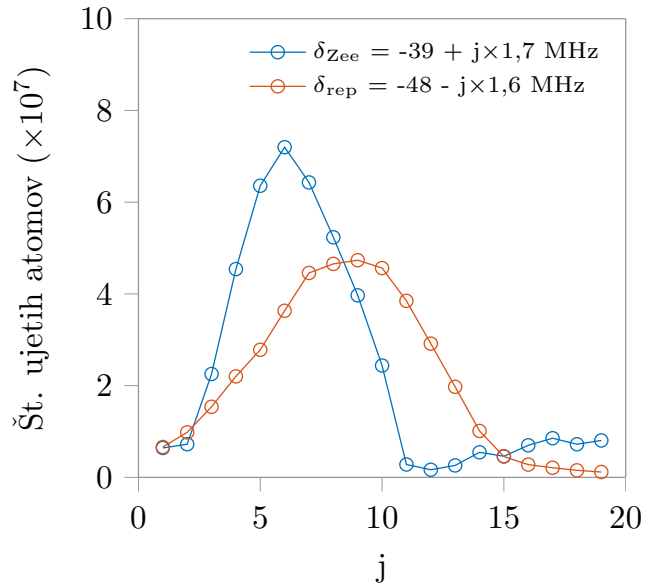
$$T(x,y) = \frac{I(x,y) - I_t(x,y)}{I_s(x,y) - I_t(x,y)}$$

$$T(x,y) = e^{-\sigma\mu(x,y)}$$









Brezdopplerska spektroskopija