Lasersko hlajenje cezijevih atomov

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Mentor: doc. dr. Rok Žitko
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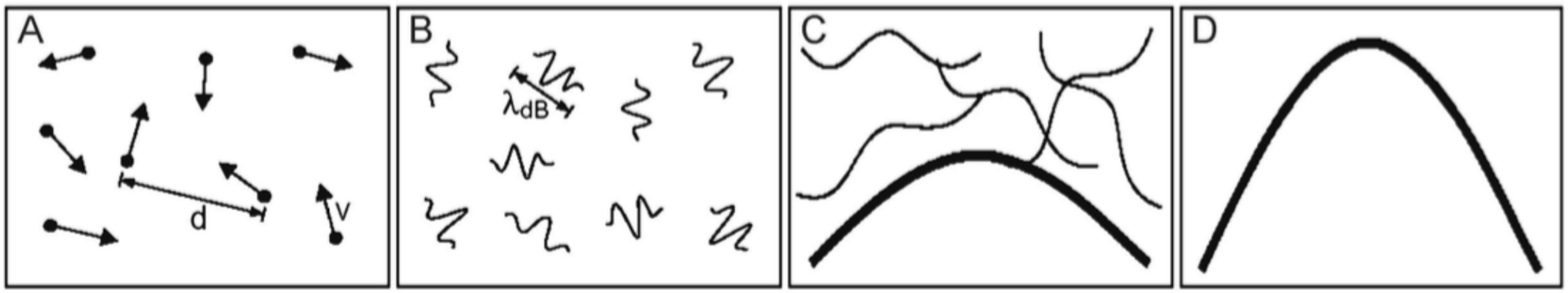
Ljubljana, 2016

Bose-Einsteinov kondenzat

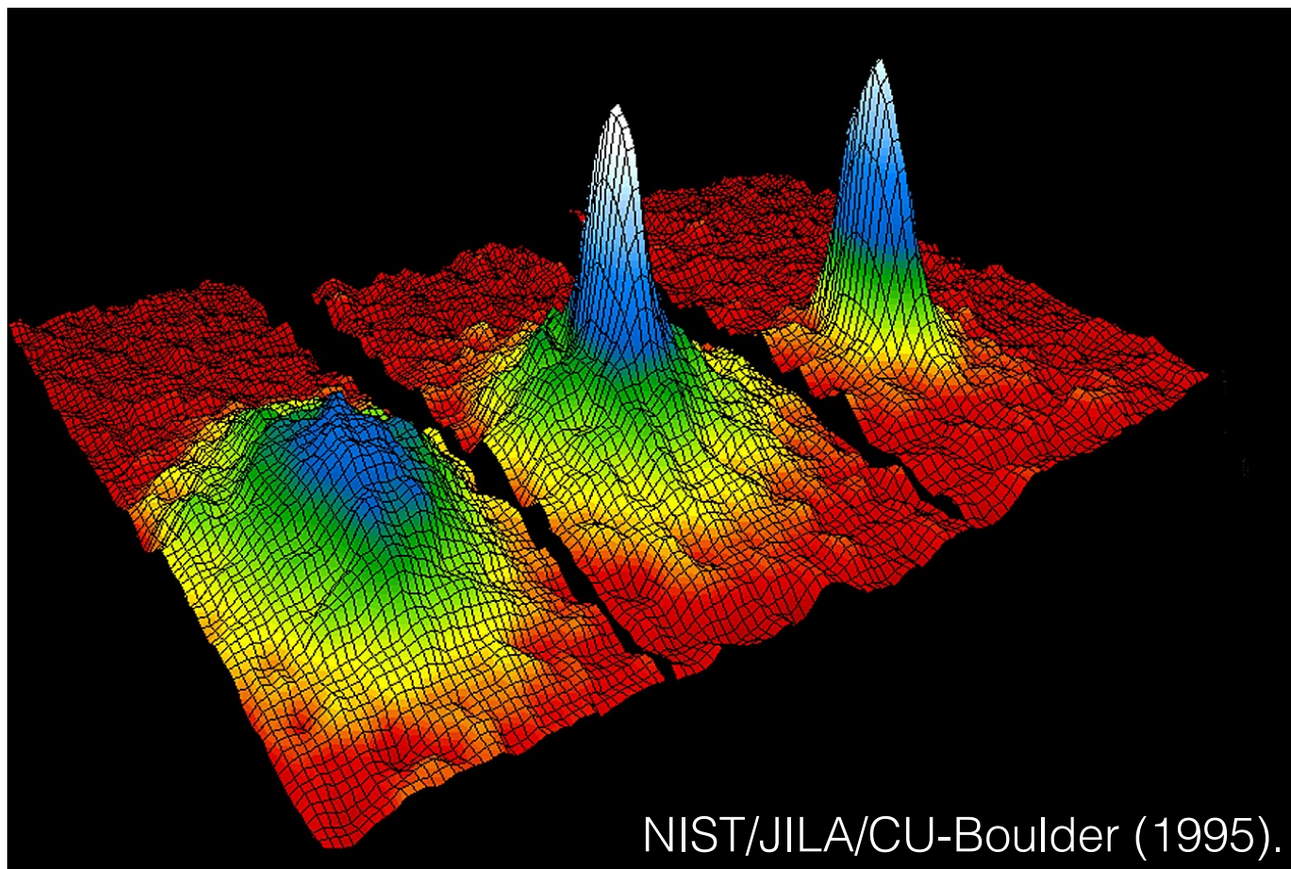


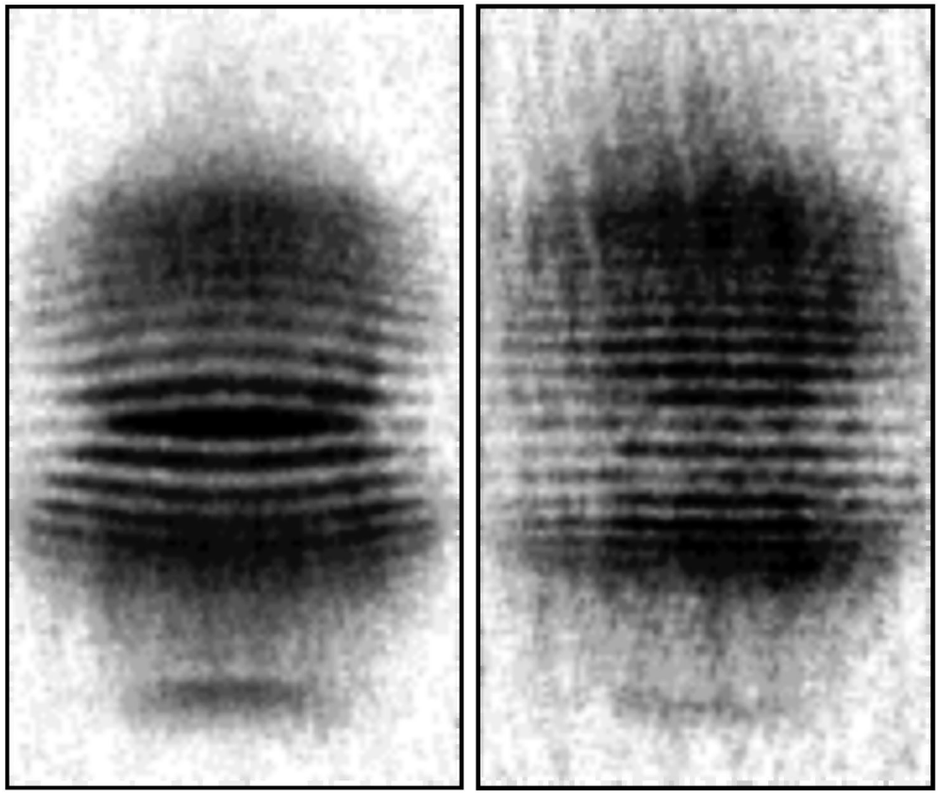
De Brogliejeva valovna dolžina:

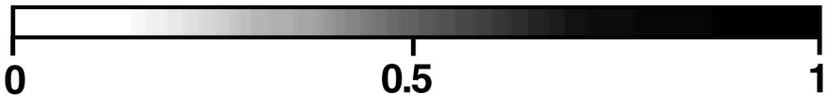
$$\lambda_{dB} = \frac{h}{\sqrt{2\pi m k_b T}}$$

Faznoprostorska gostota:

$$D = n\lambda_{dB}^3 \qquad D \approx 2{,}6$$

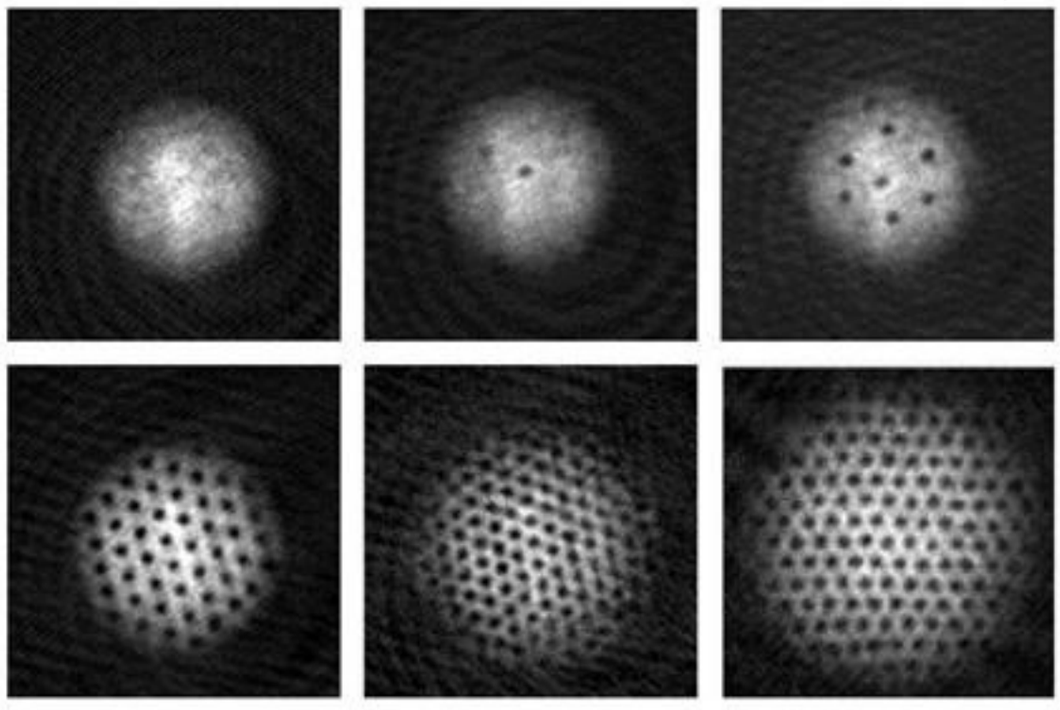

NIST/JILA/CU-Boulder (1995).



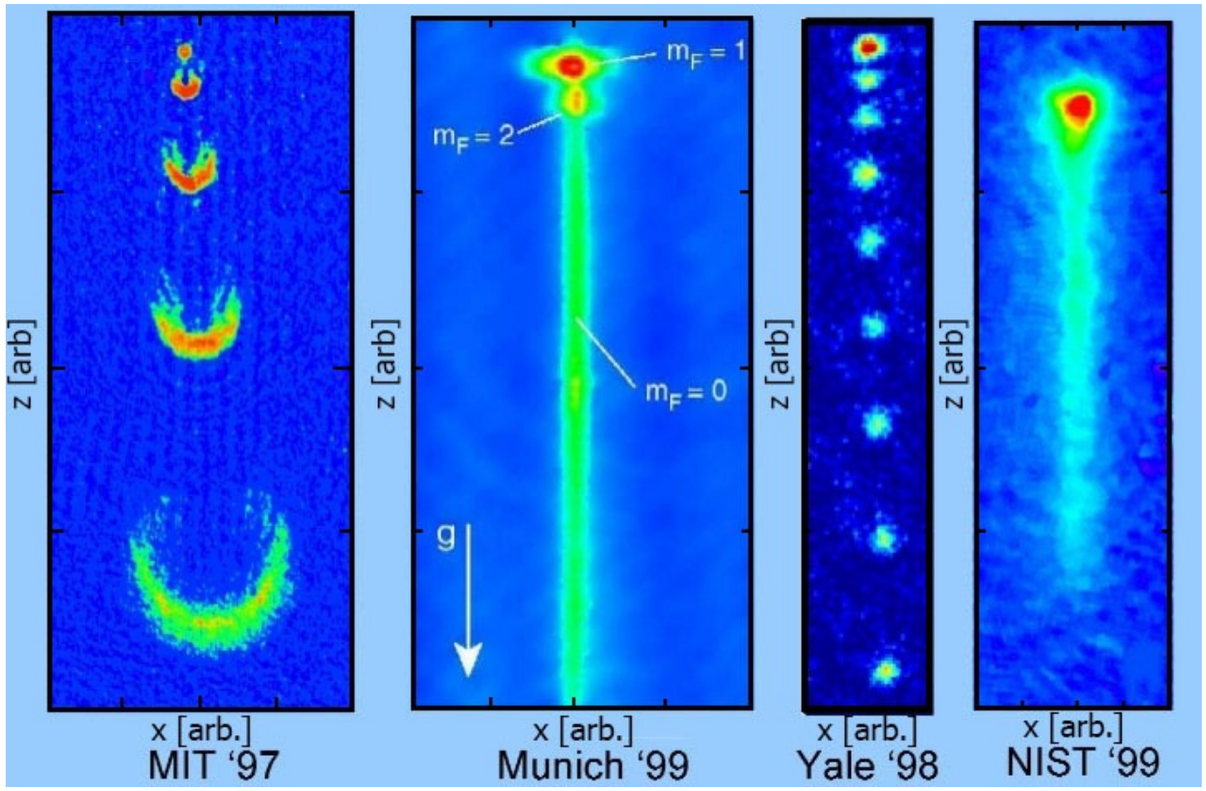


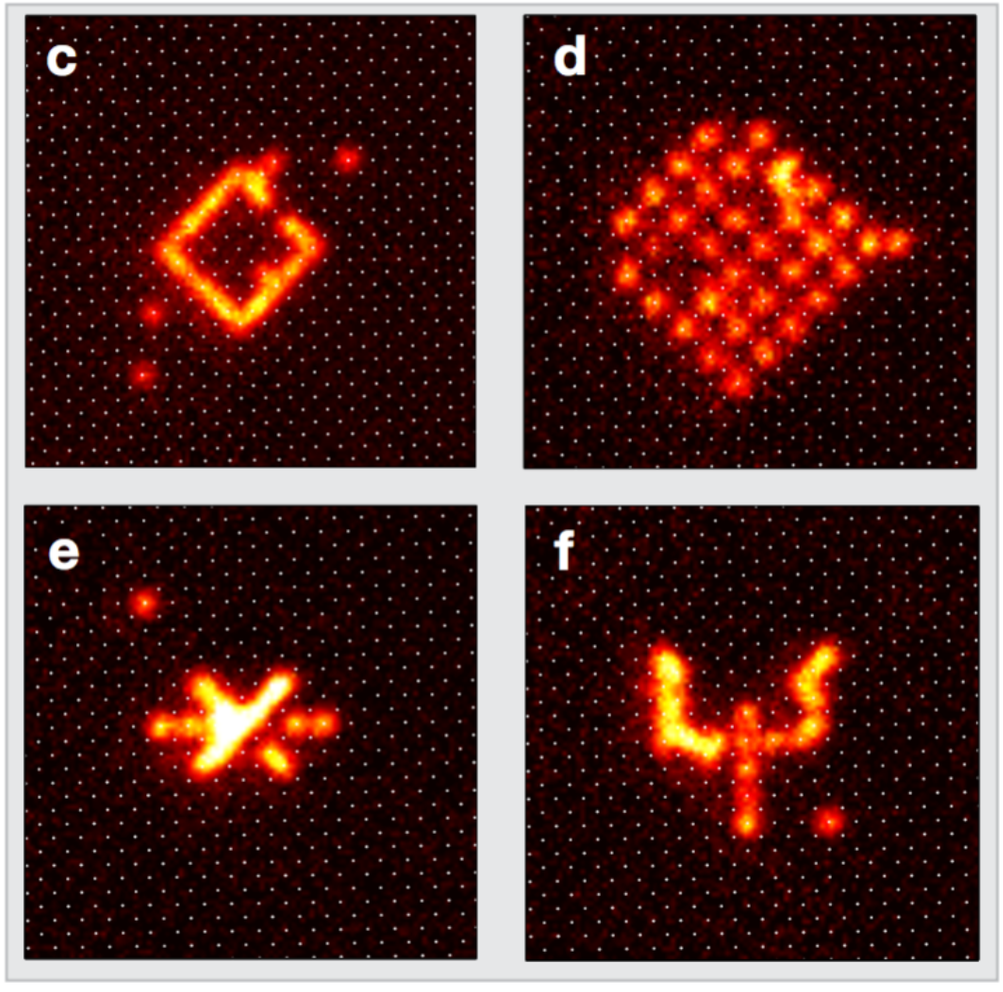
Absorpcija

M. R. Andrews *et al.*, Science **275**, 637 (1997).



P. Engels *et al.*, Phys. Rev. Lett. **90**, 170405 (2003).





C. Weitenberg *et al.*, Nature **471**, 319 (2011).

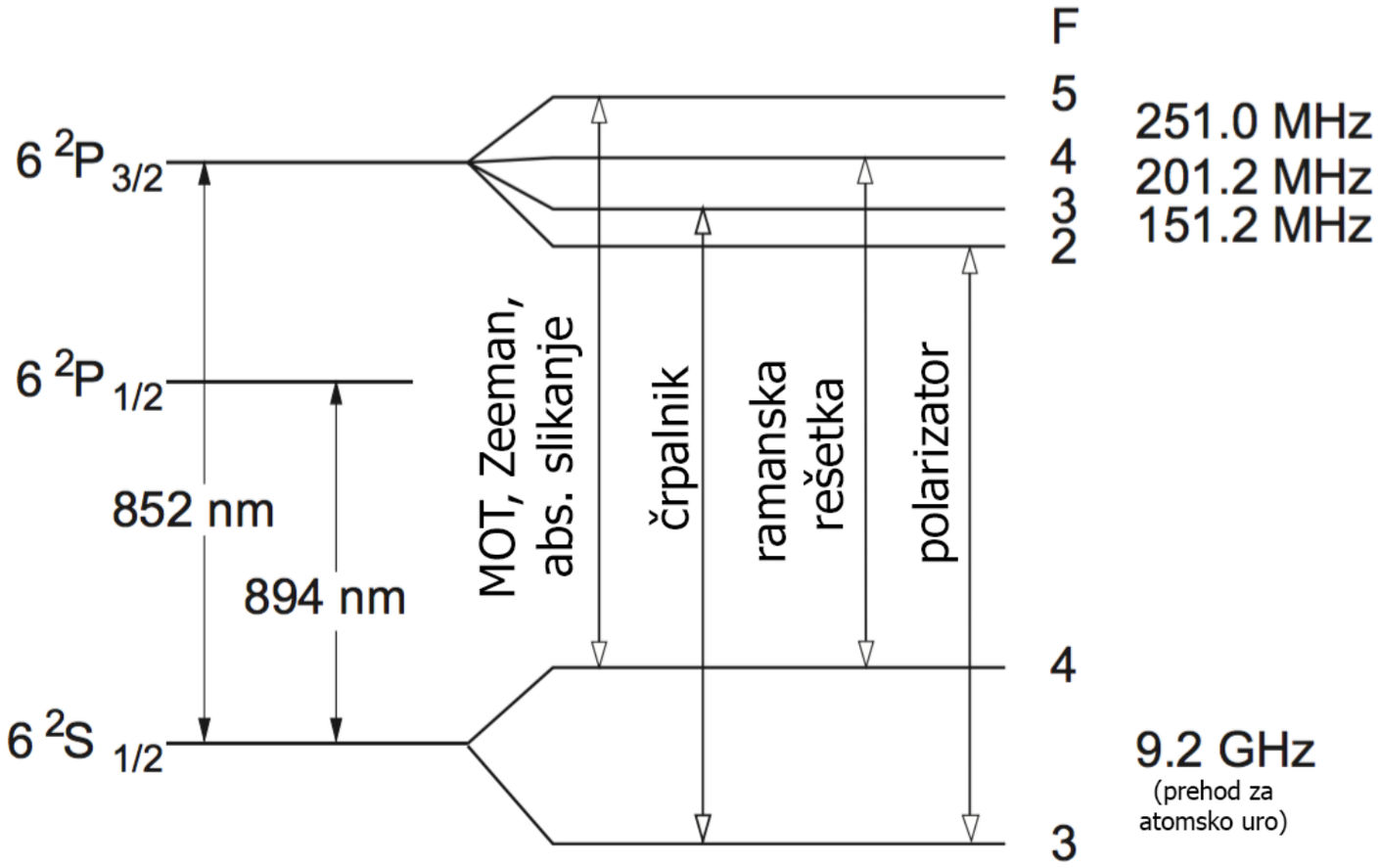
Cezijev atom

$^{133}\mathrm{Cs}$:

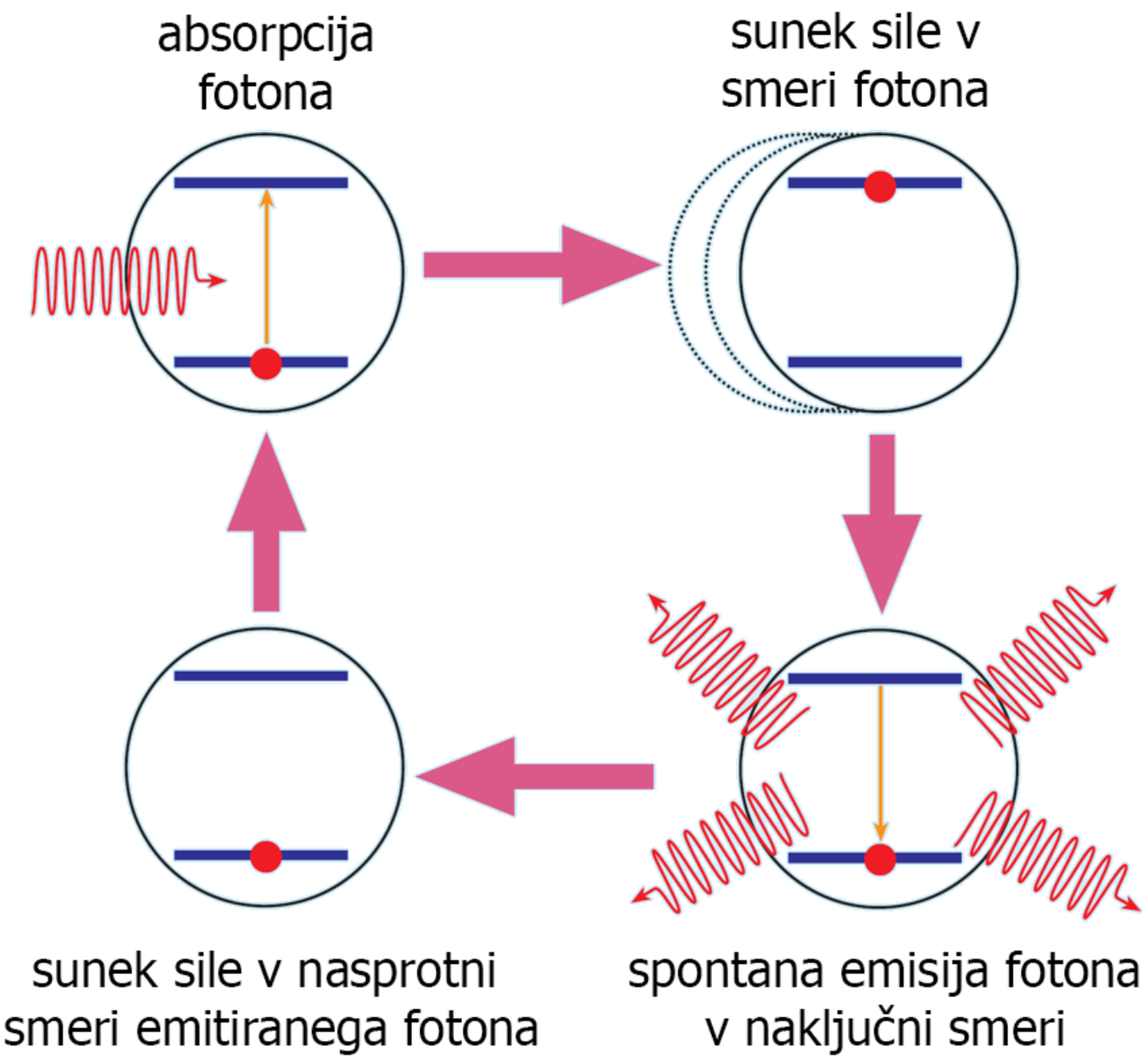
$$m = 2{,}21 \cdot 10^{-25}\ \mathrm{kg}$$

$$T_{tal} = 28\ ^{\circ}\mathrm{C}$$

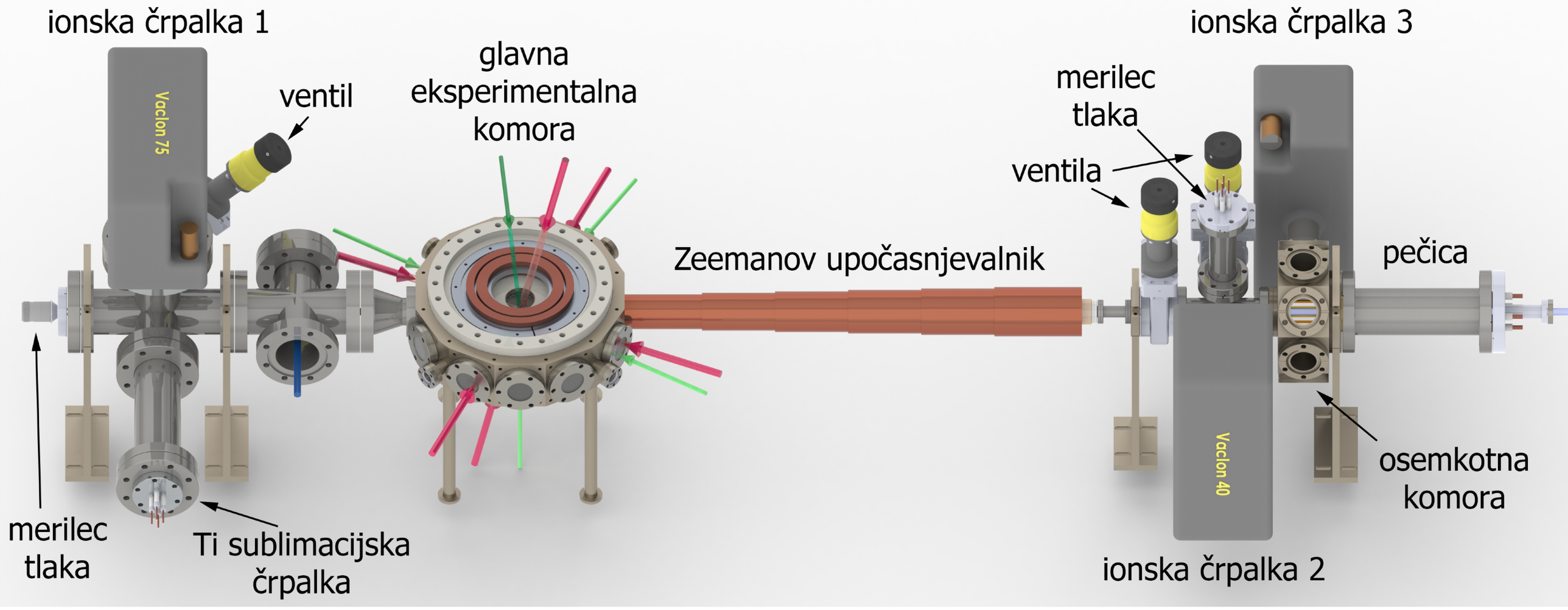
$$T_{rec} = 198\ \mathrm{nK}$$



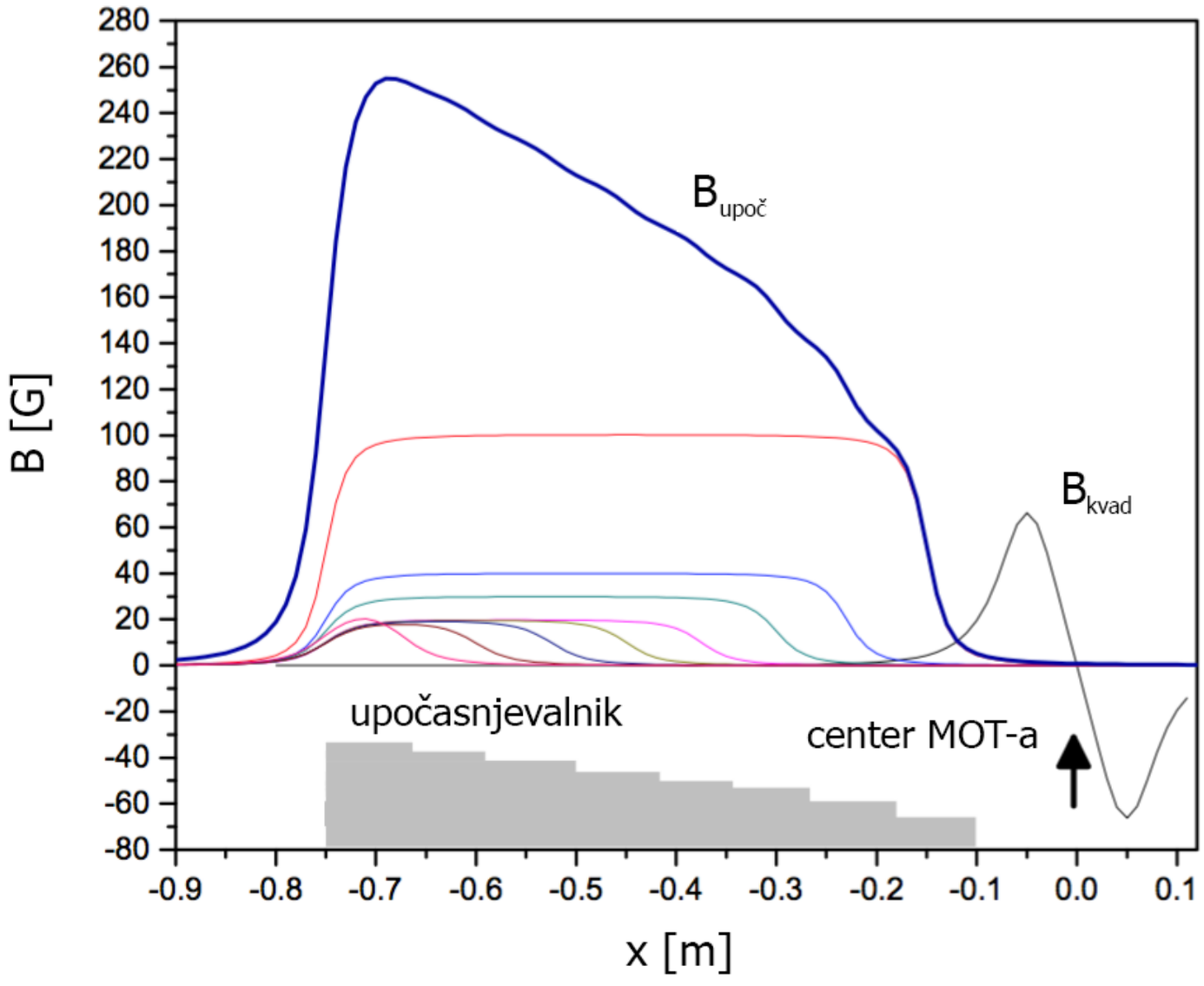
Lasersko hlajenje



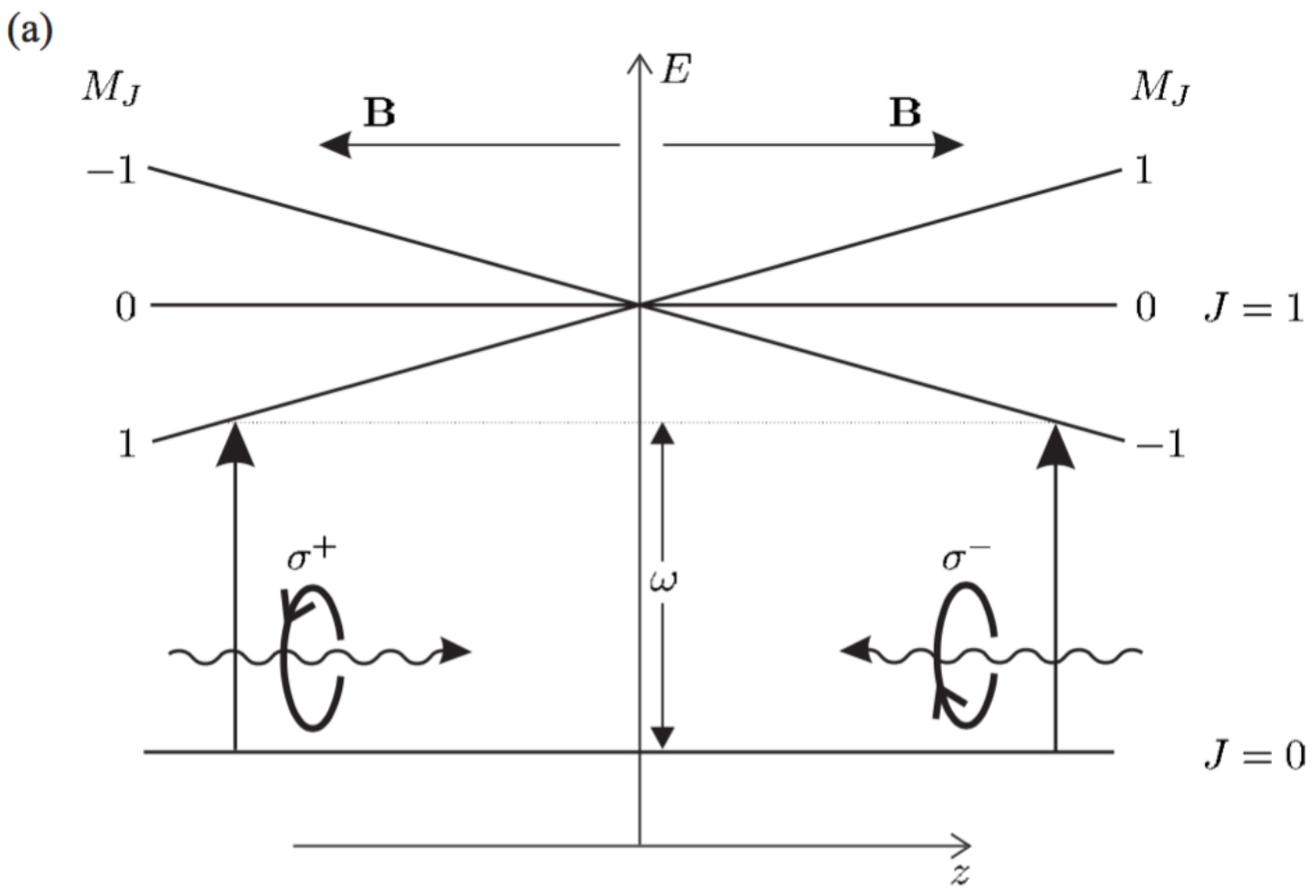
Lasersko hlajenje

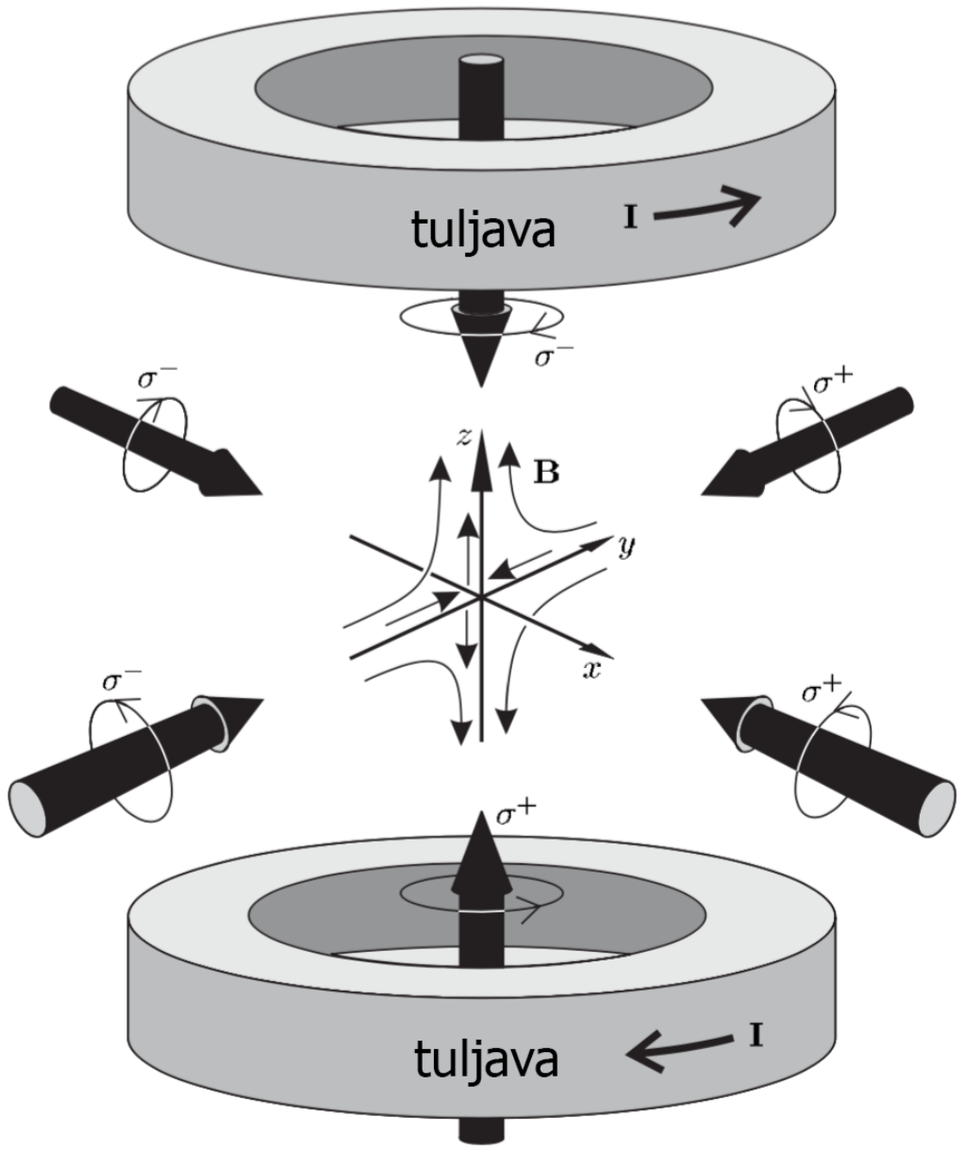


Zeemanov upočasnjevalnik

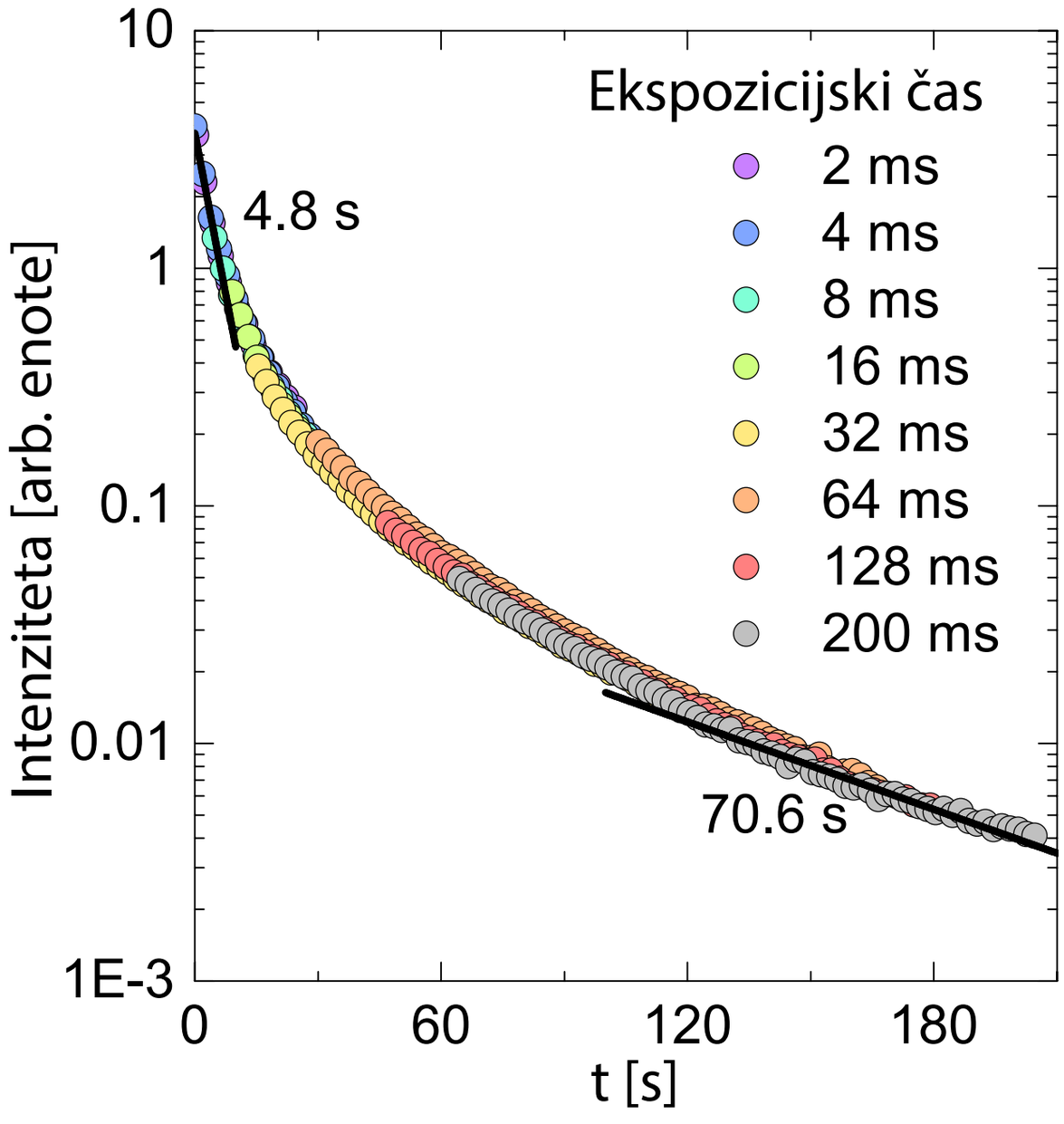


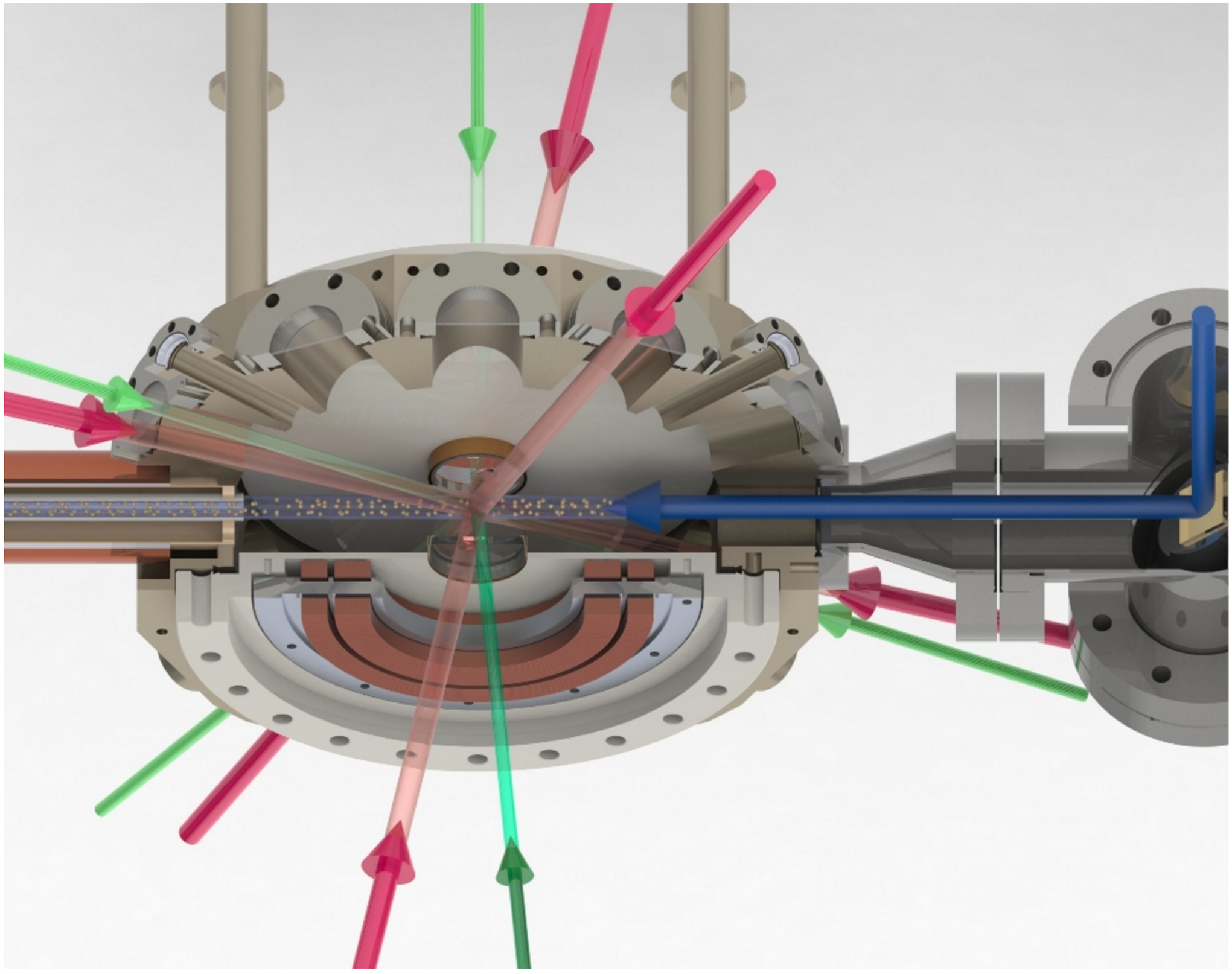
Magneto-optična past



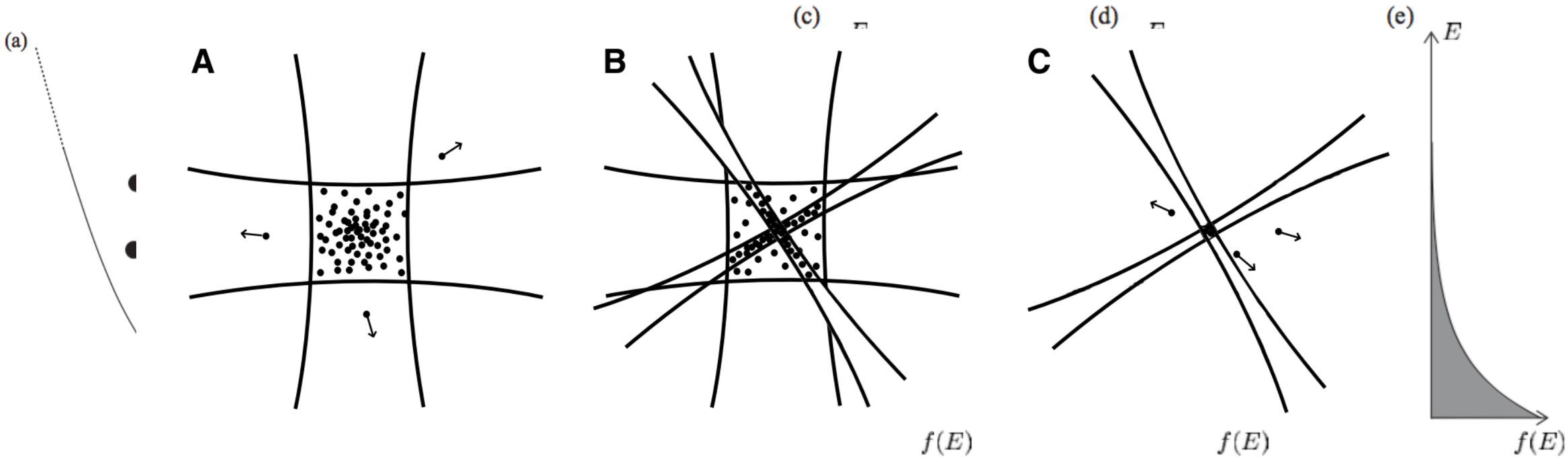


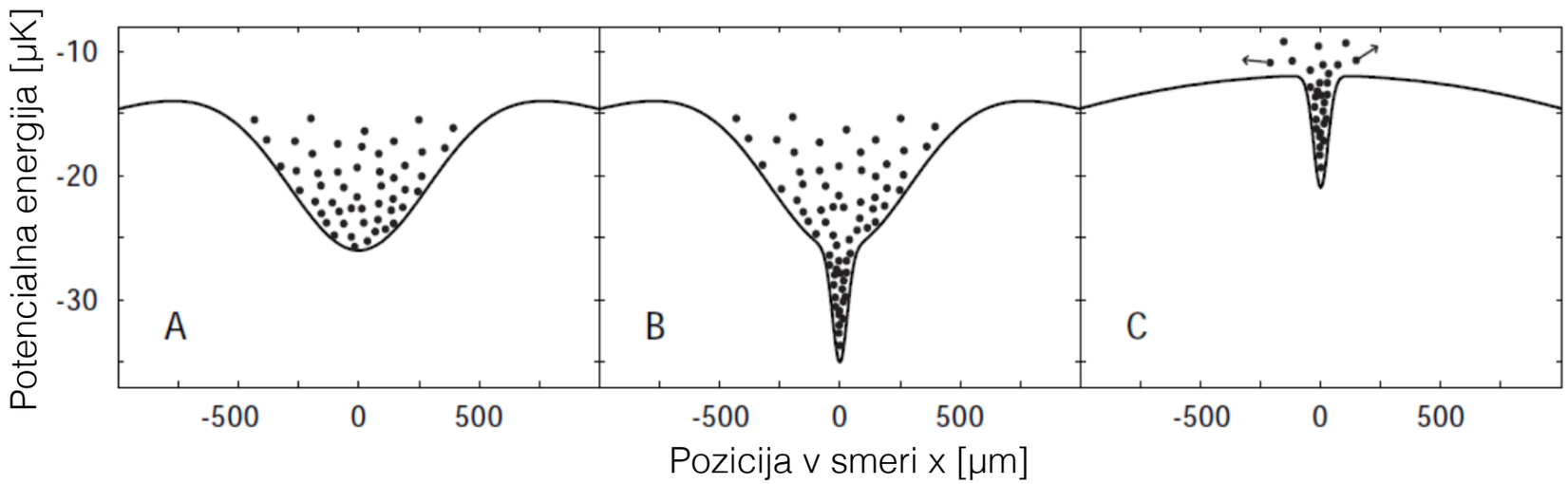
Magneto-optična past



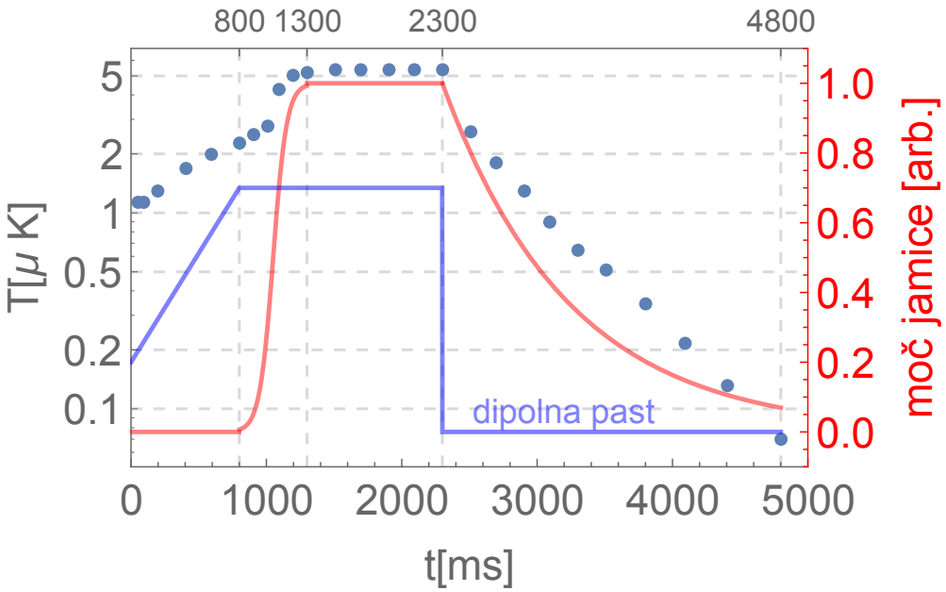


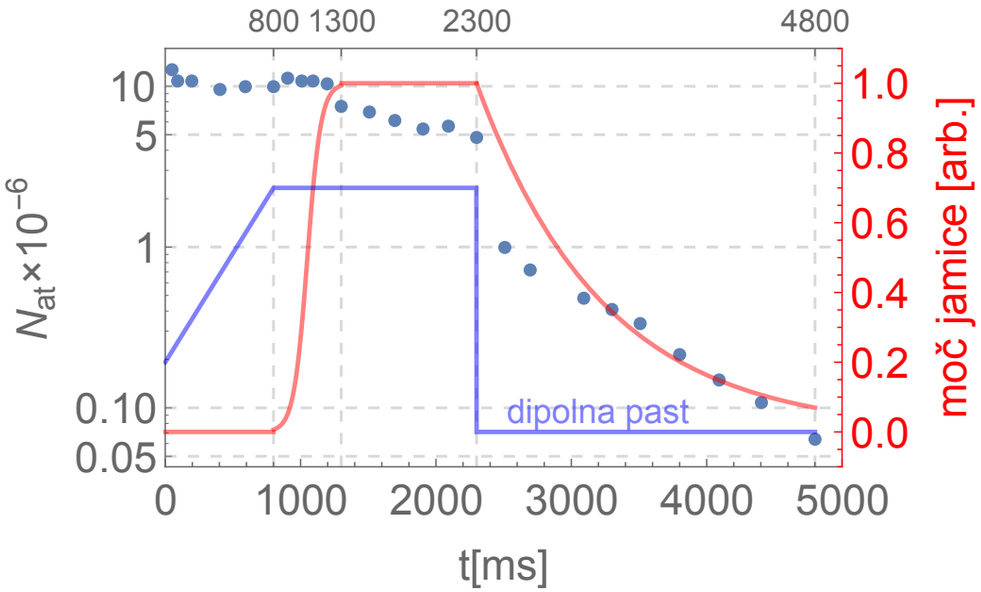
Evaporacijsko hlajenje

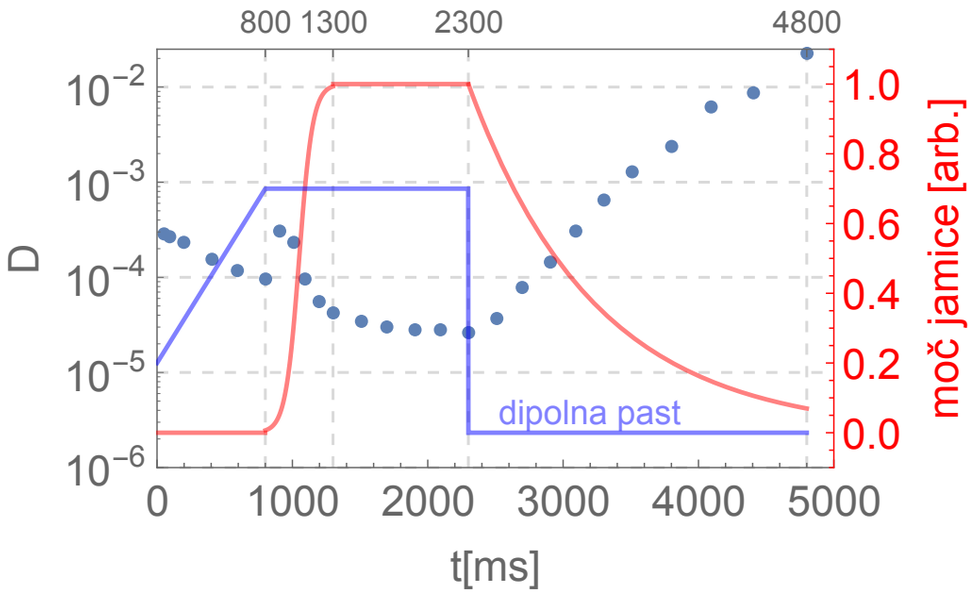


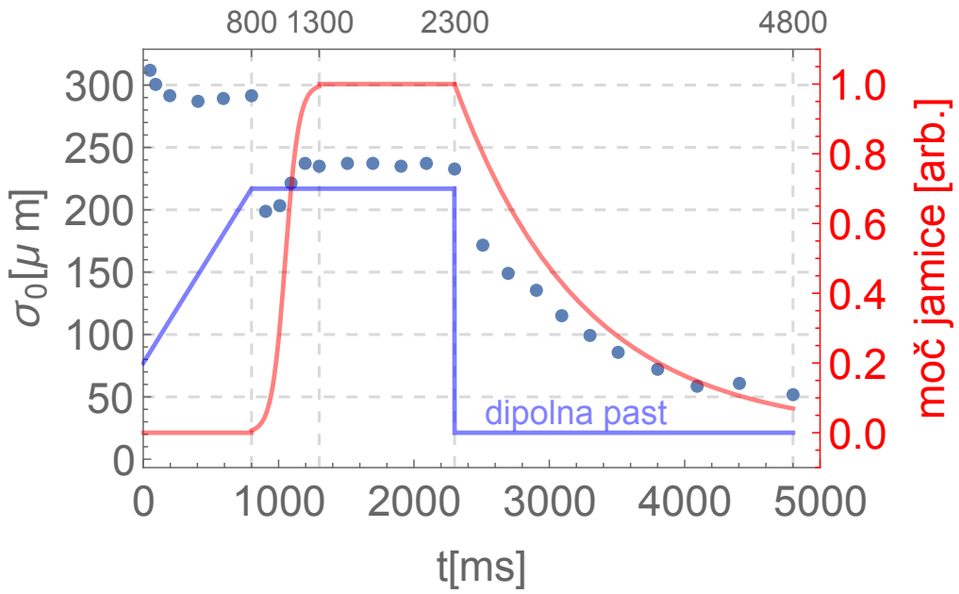


Weber *et al.*, Science **299**, 232 (2003).

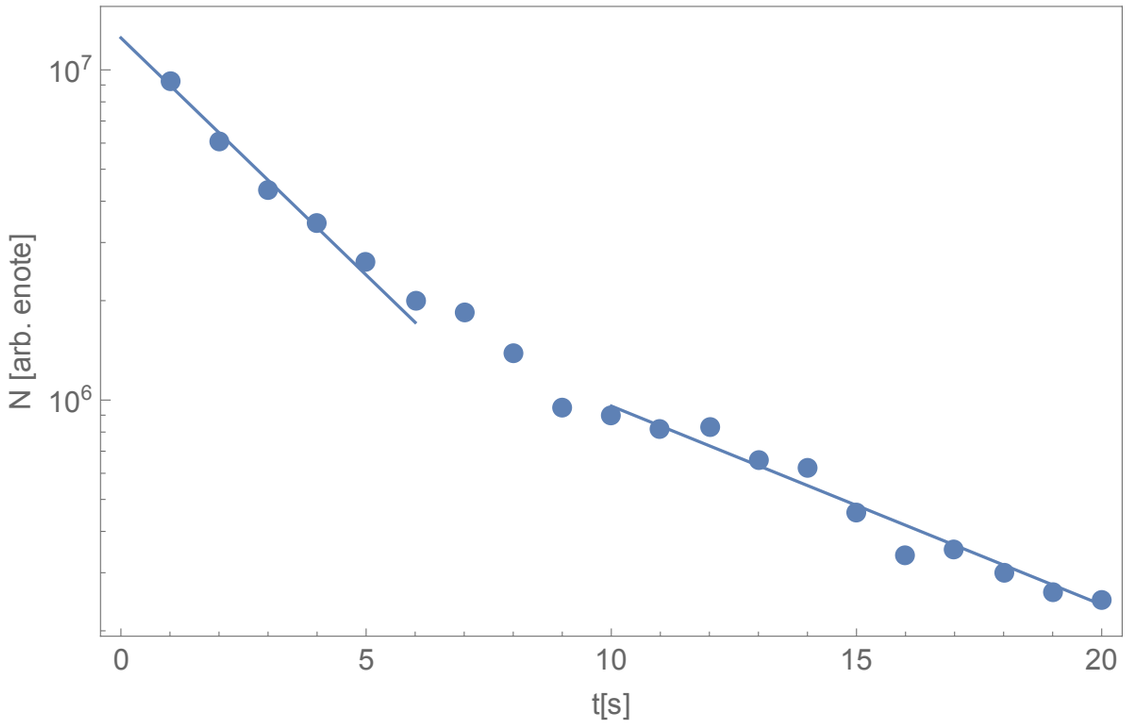

800 1300
2300
4800
T[μ K]
5
2
1
0.5
0.2
0.1
dipolna past
0
1000
2000
3000
4000
5000
t[ms]
1.0
0.8
0.6
0.4
0.2
0.0
moč jamice [arb.]

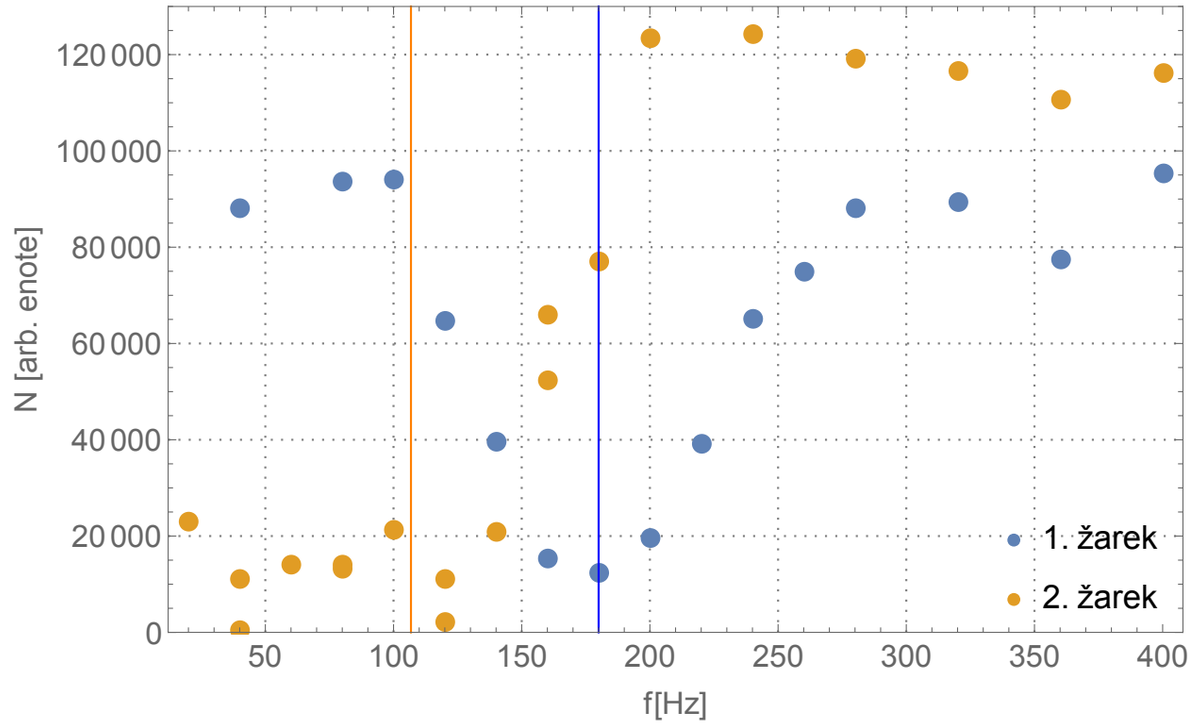

800 1300
2300
4800
$N_{at}\times10^{-6}$
10
5
1
0.10
0.05
dipolna past
0
1000
2000
3000
4000
5000
t[ms]
1.0
0.8
0.6
0.4
0.2
0.0
moč jamice [arb.]

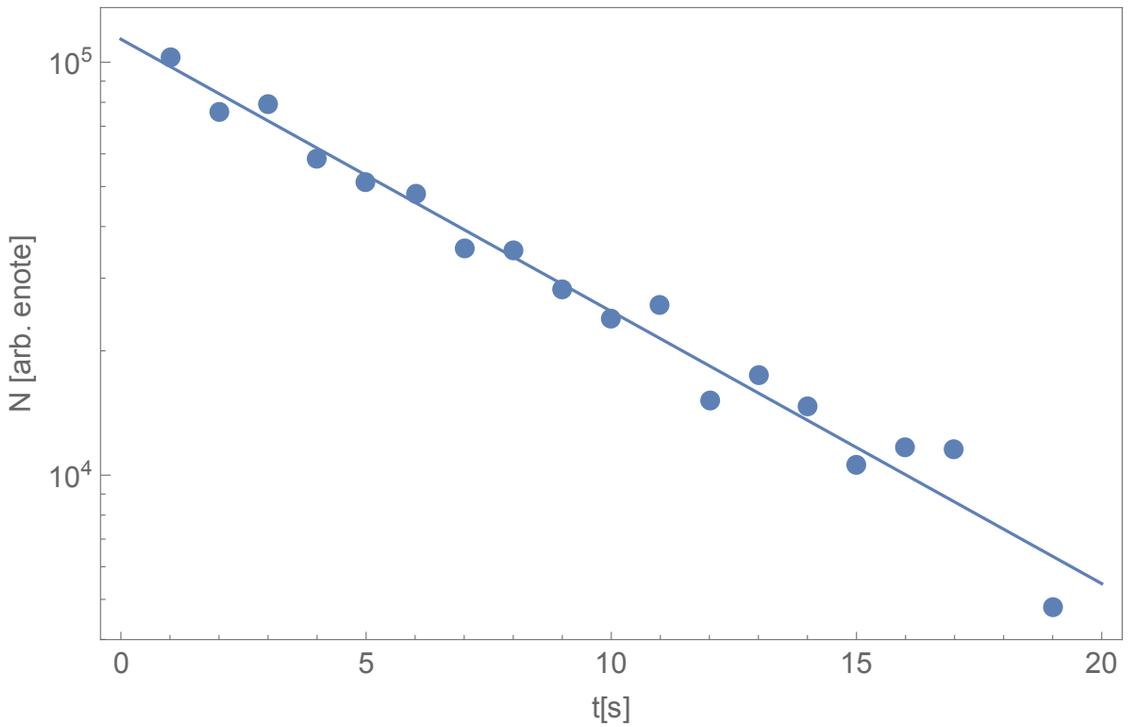

800 1300
2300
4800
D
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
dipolna past
0
1000
2000
3000
4000
5000
t[ms]
1.0
0.8
0.6
0.4
0.2
0.0
moč jamice [arb.]

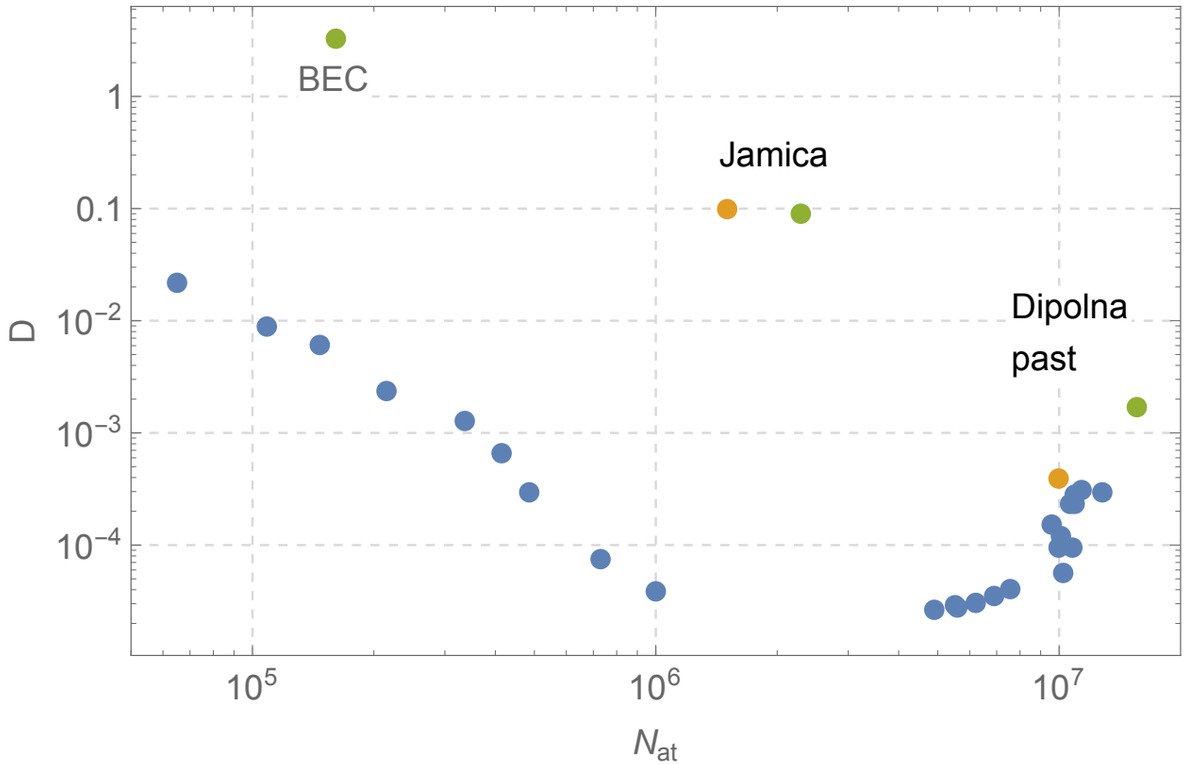

800 1300
2300
4800
$\sigma_0[\mu$ m]
300
250
200
150
100
50
0
dipolna past
0
1000
2000
3000
4000
5000
t[ms]
1.0
0.8
0.6
0.4
0.2
0.0
moč jamice [arb.]

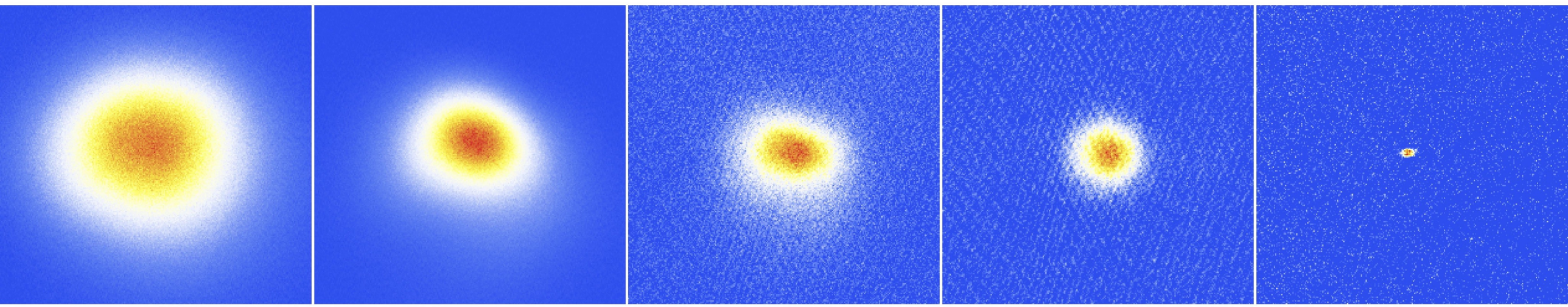
Izgube iz dipolne pasti in jamice











	Temperatura	Hitrost	Št. atomov	Fazno-prostorska gostota
Pečica	360 K	212 $\frac{\mathrm{m}}{\mathrm{s}}$	/	/
Zeemanov upočasnjevalnik	3 K	19 $\frac{\mathrm{m}}{\mathrm{s}}$	/	/
MOT	20 μK	5 $\frac{\mathrm{cm}}{\mathrm{s}}$	$3 \cdot 10^7$	$\approx 10^{-8}$
CMOT (optična melasa)	5 μK	2,5 $\frac{\mathrm{cm}}{\mathrm{s}}$	$1 \cdot 10^7$	$\approx 10^{-7}$
Degenerirano ramansko hlajenje	500 nK	7,9 $\frac{\mathrm{mm}}{\mathrm{s}}$	$2 \cdot 10^6$	$\approx 10^{-5}$
Dipolna past	1 μK	11 $\frac{\mathrm{mm}}{\mathrm{s}}$	$1 \cdot 10^6$	$\approx 10^{-4}$
Mala dipolna past (jamica)	3 μK	19 $\frac{\mathrm{mm}}{\mathrm{s}}$	$1 \cdot 10^5$	$\approx 10^{-4}$
Evaporacija	20 nK	1,6 $\frac{\mathrm{mm}}{\mathrm{s}}$	$1 \cdot 10^4$	$\approx 10^{-1}$

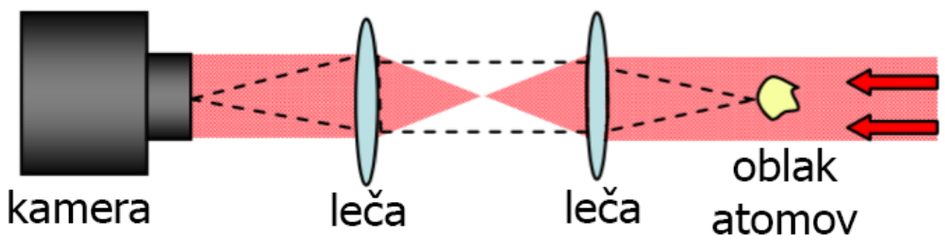
Skupina za hladne atome

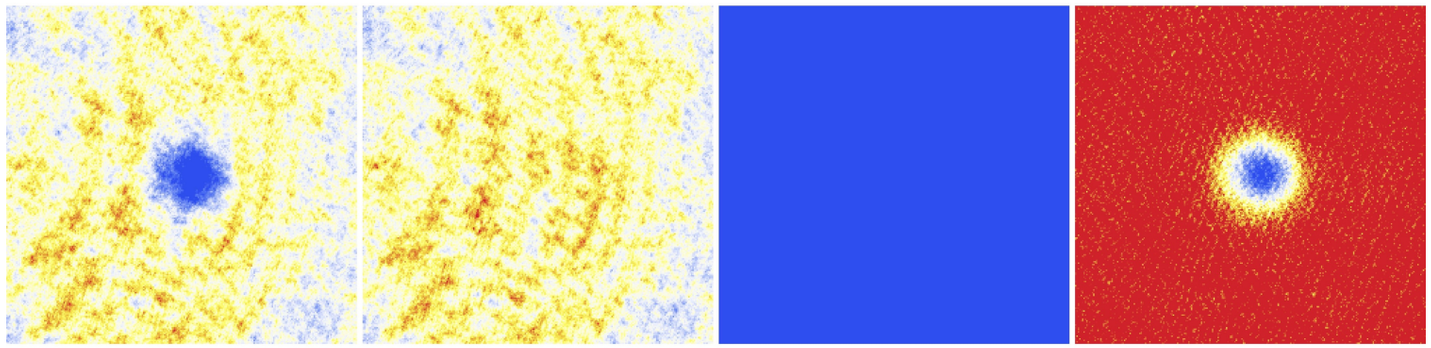
- Peter Jeglič
- Erik Zupanič
- Rok Žitko
- Jaka Pišljar
- Jure Brence
- Žiga Gosar
- Maj Škerjanc
- Rok Venturini

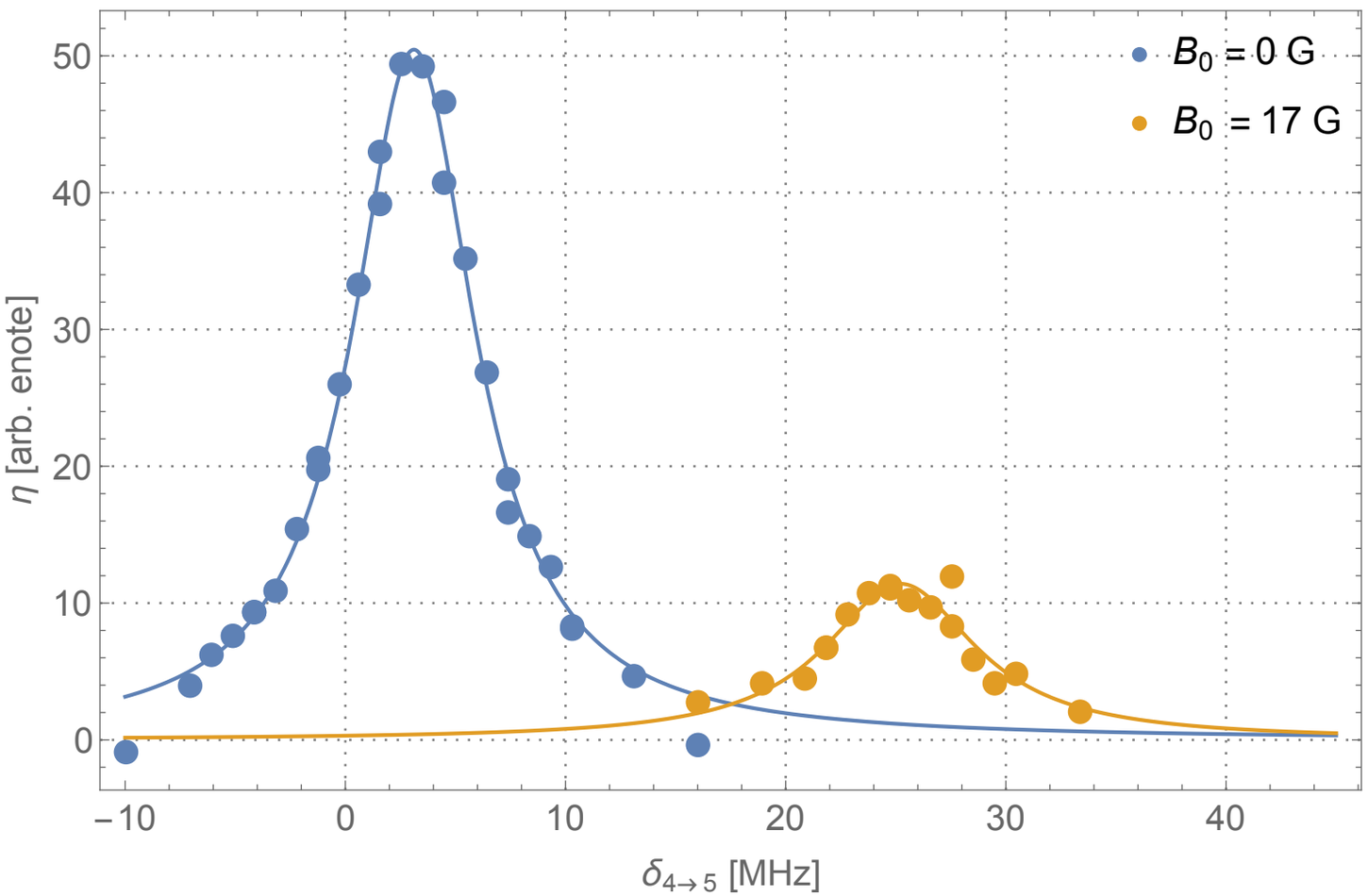
- Nekdanji študentje:
  - Nejc Janša
  - Pavel Kos
  - Nejc Rosenstein
  - Gregor Bensa

Hvala za pozornost

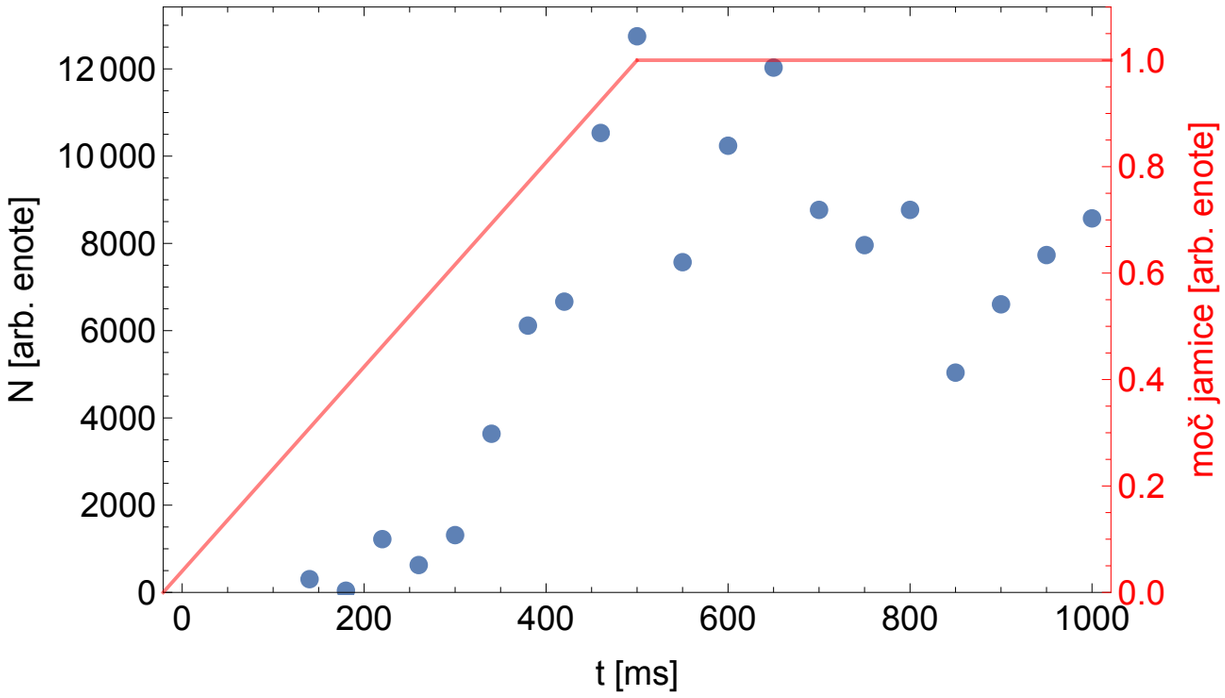
Slikanje

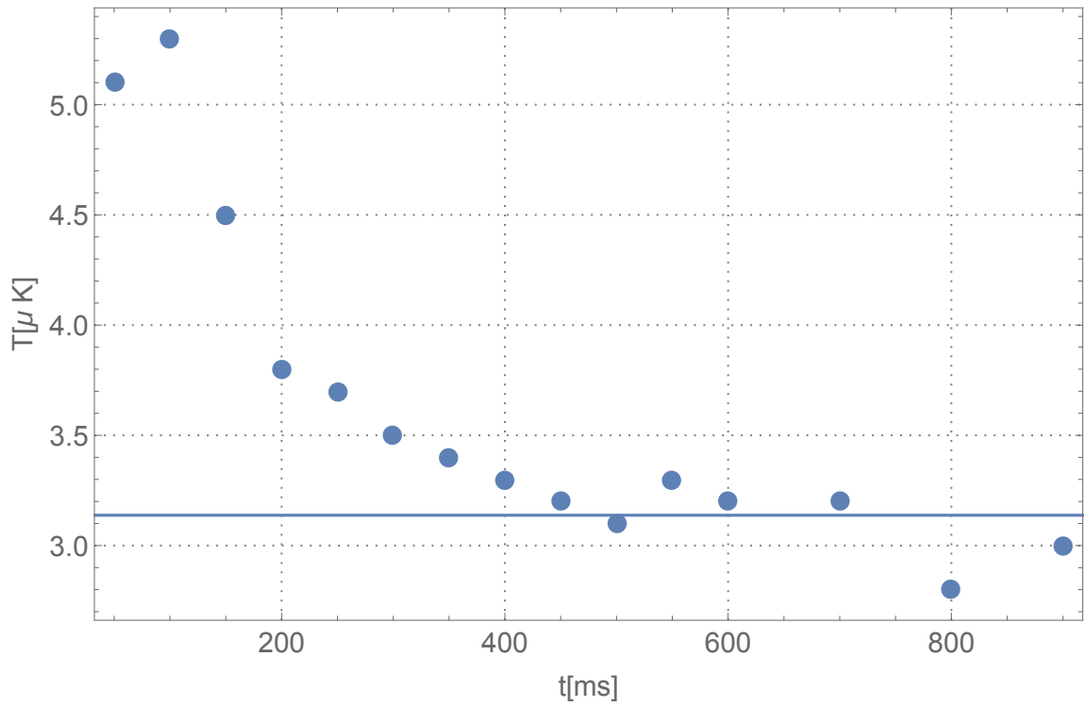

kamera
leča
leča
oblak
atomov



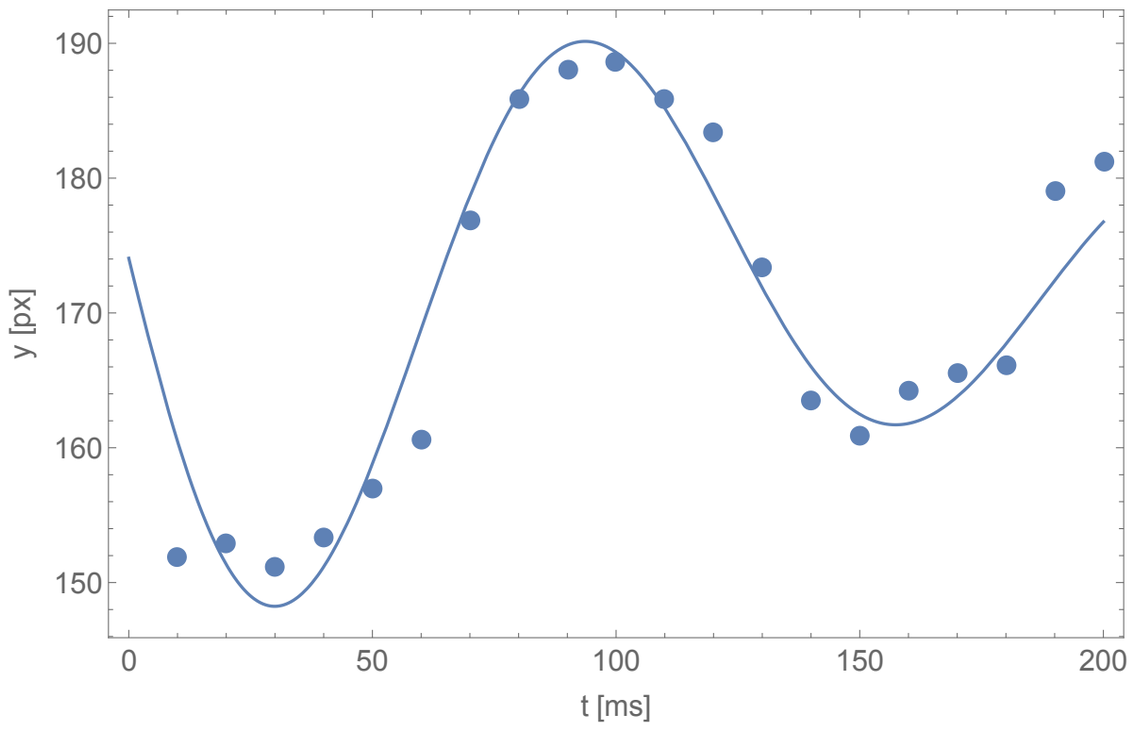

B_0 = 0 G
B_0 = 17 G
η [arb. enote]
$\delta_{4\to5}$ [MHz]
50
40
30
20
10
0
−10
0
10
20
30
40

Polnjenje in termalizacija jamice

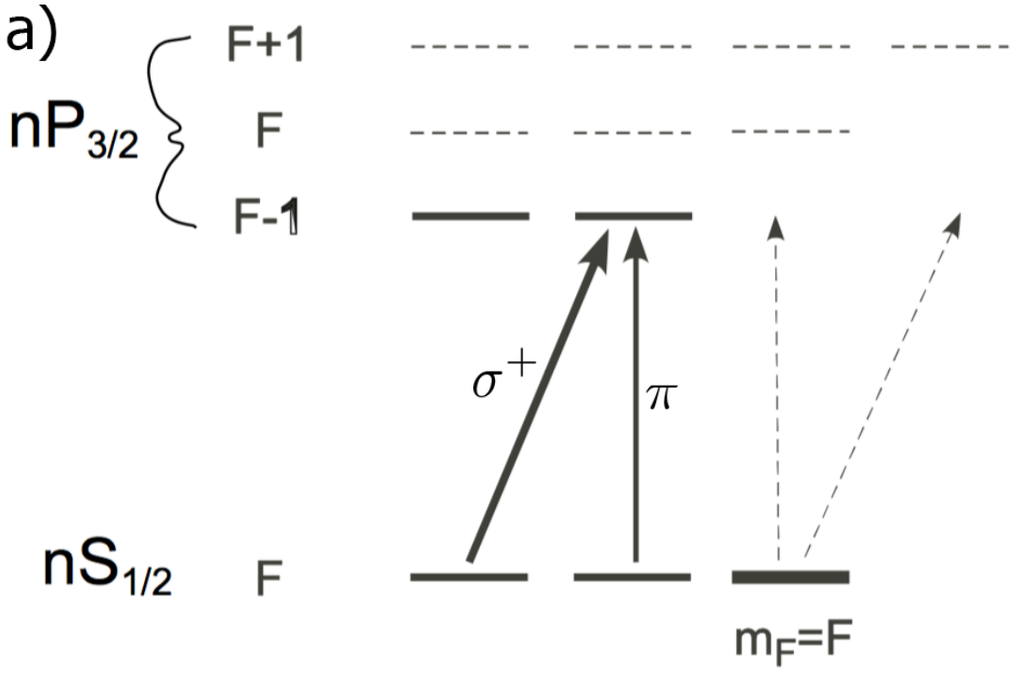


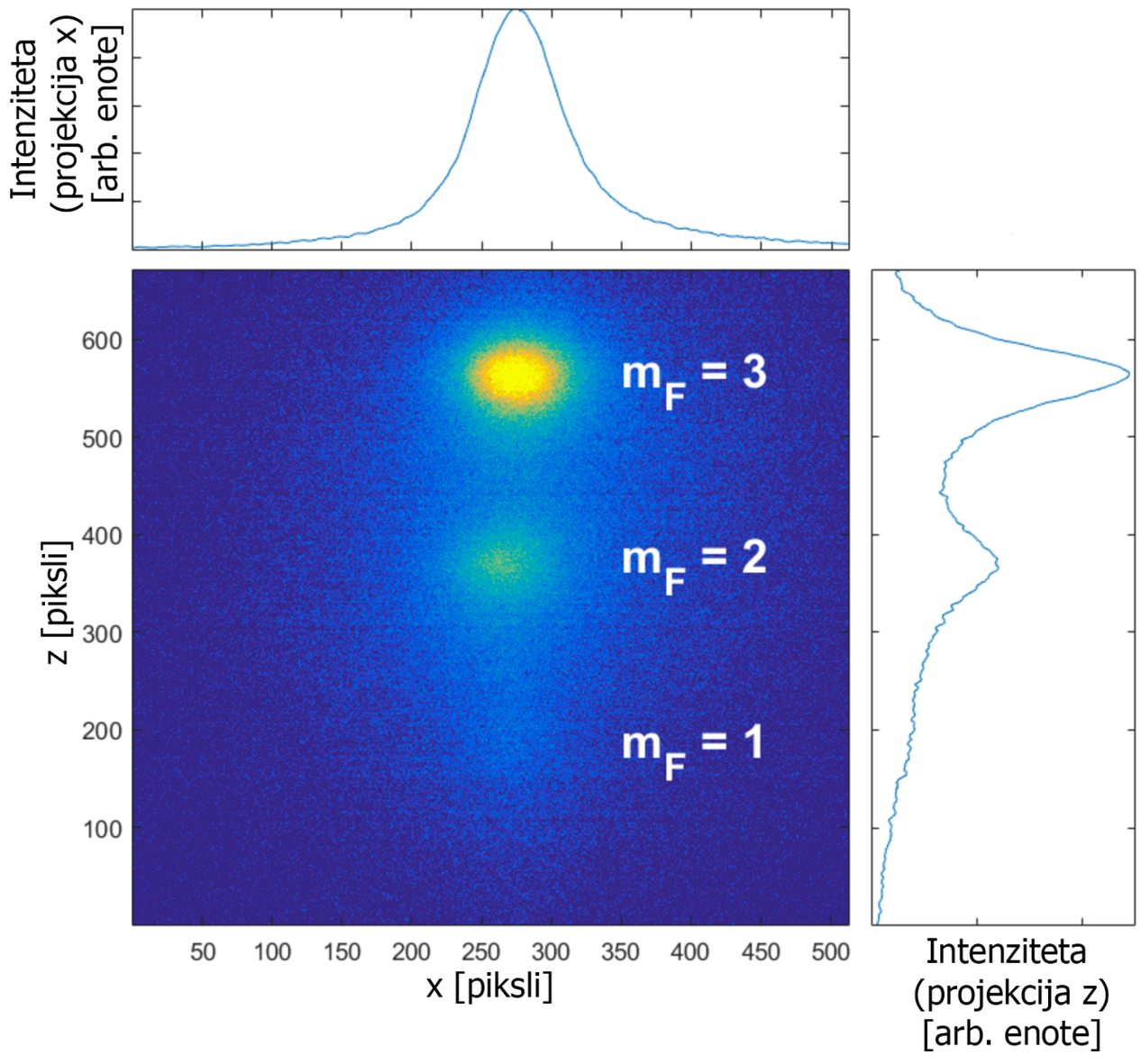


Oscilacije v dipolni pasti

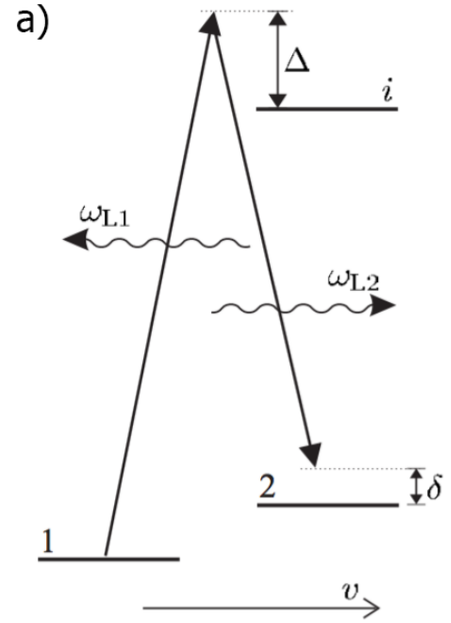


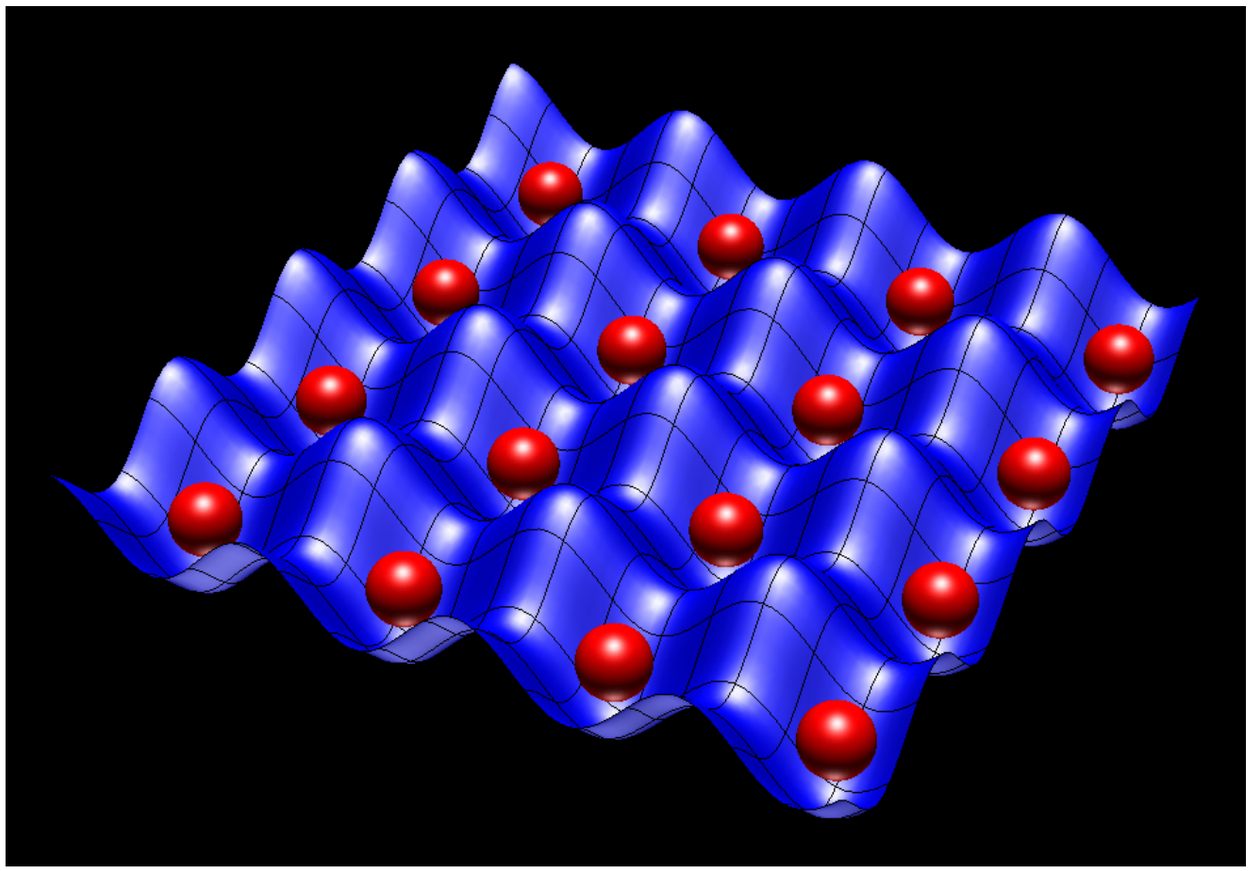
Polarizator

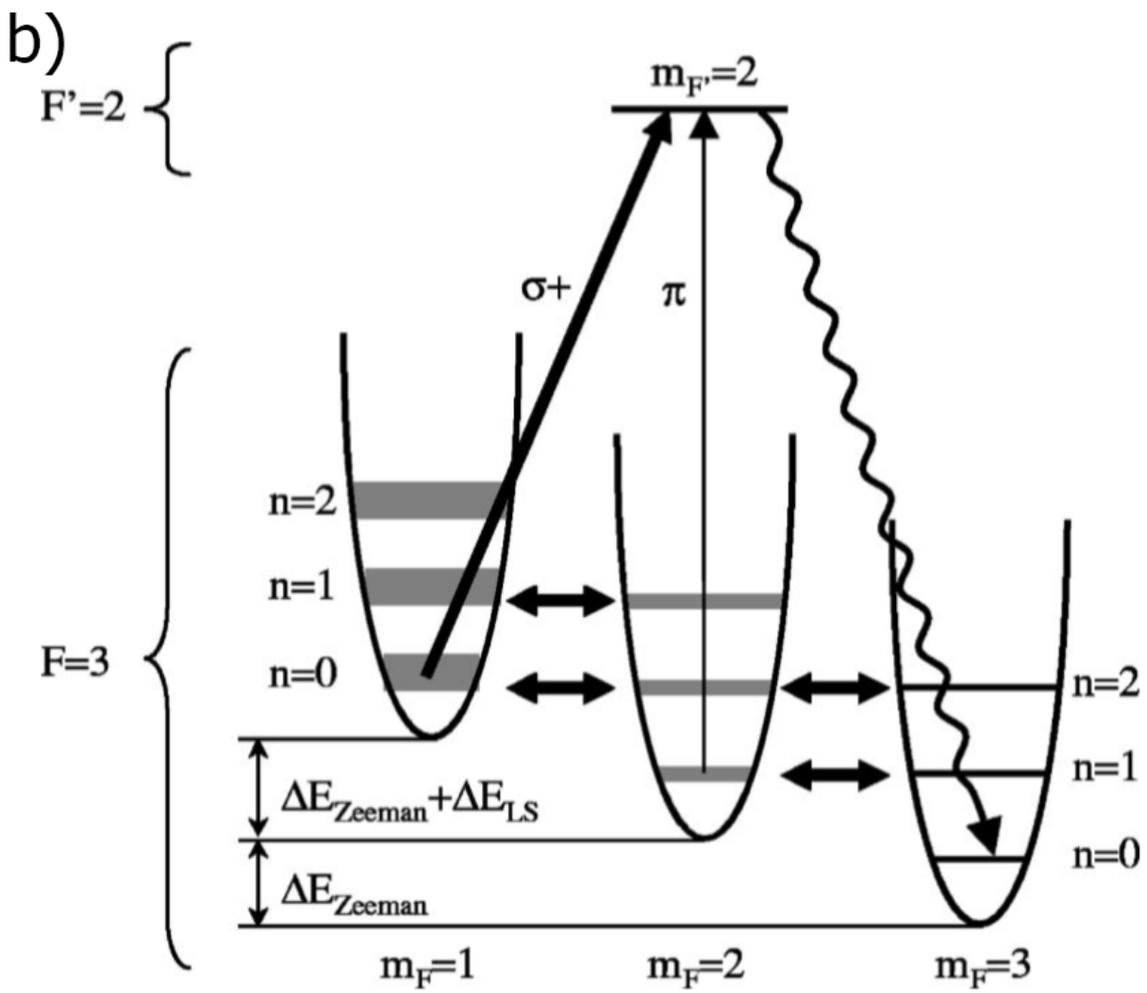




Degenerirano ramansko hlajenje

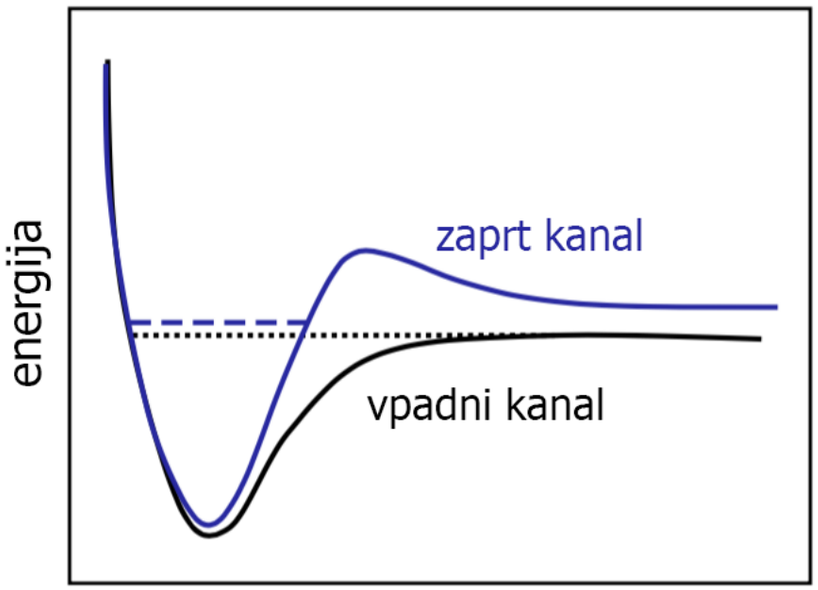


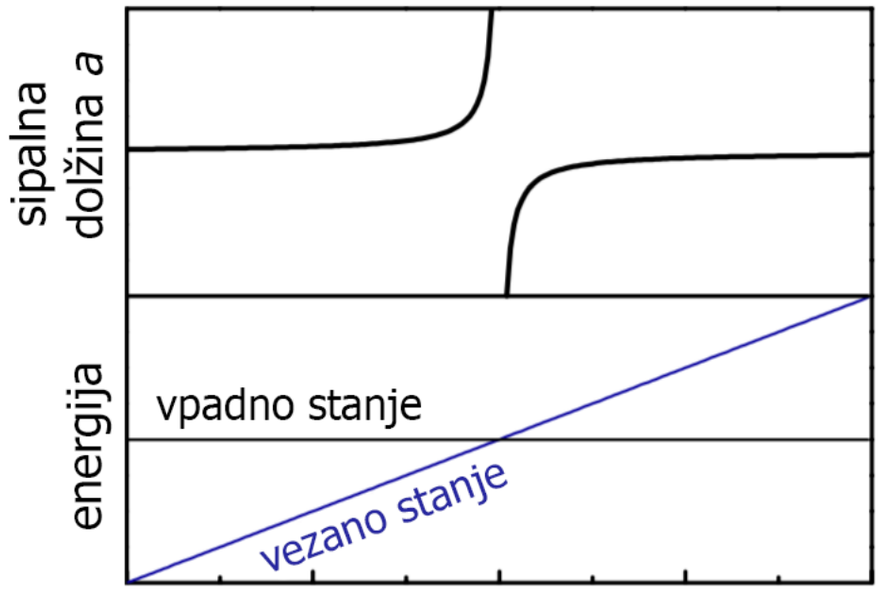


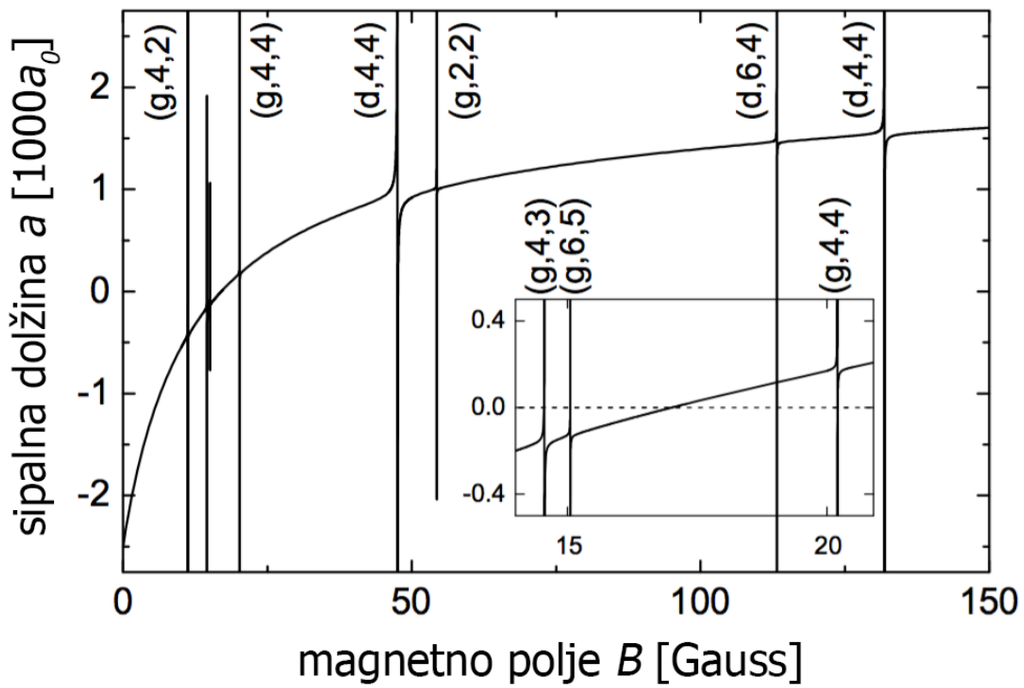


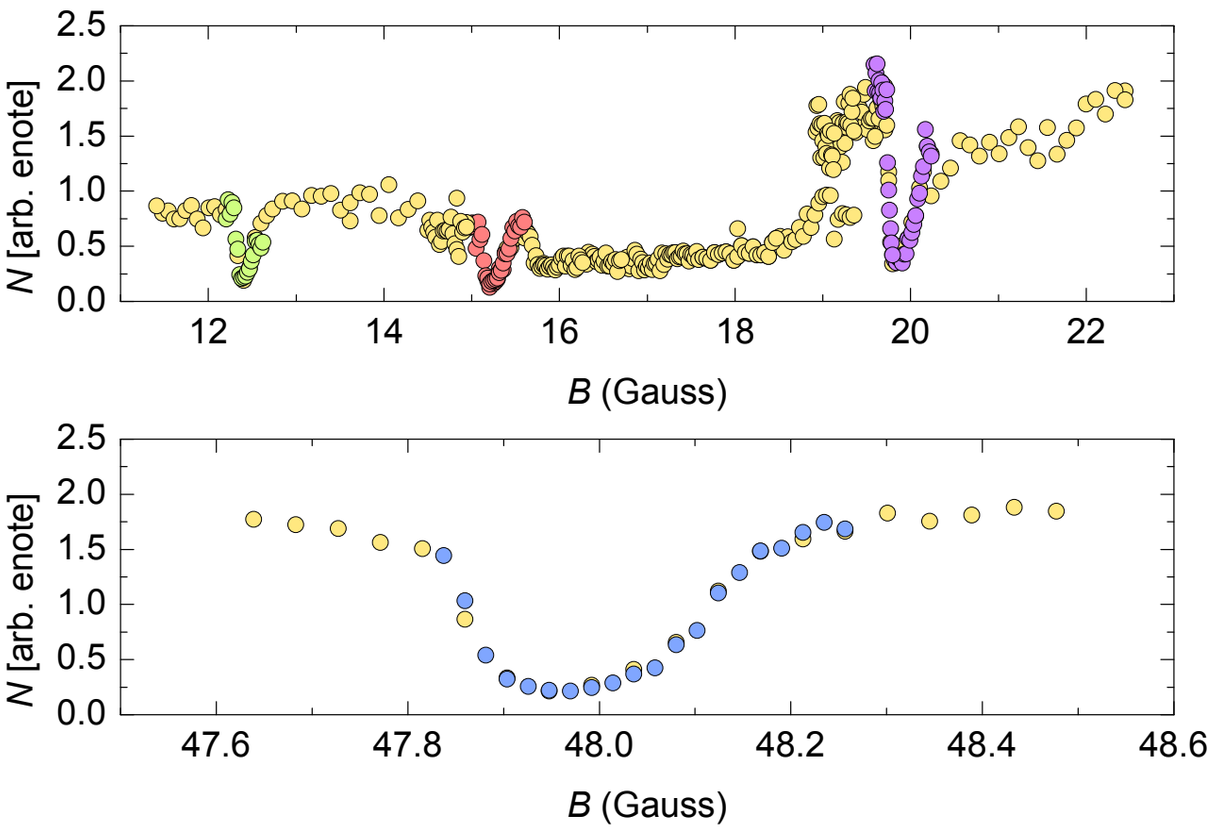
G. Di Domenico *et al.*, Phys. Rev. A **69**, 063403 (2004).

Tridelčne izgube







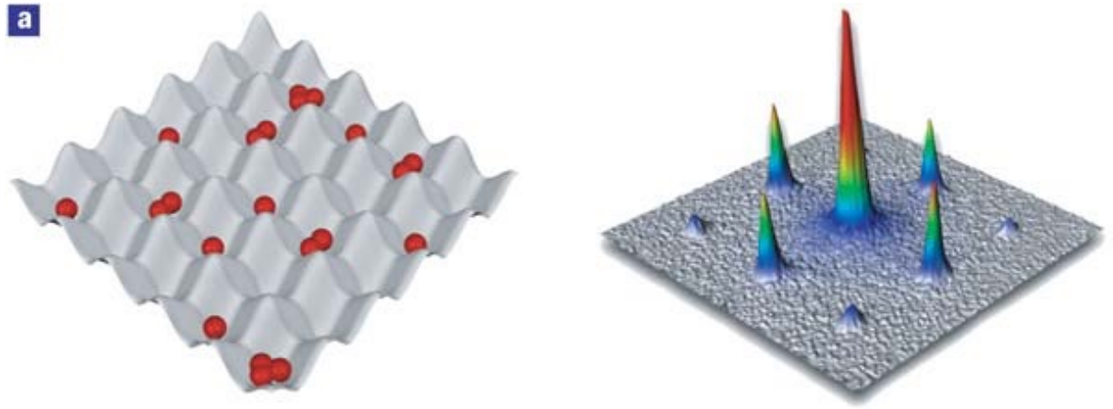


C. Chin *et al.*, Phys. Rev. A **70**, 032701 (2004).

Superfluid - Mottov izolator

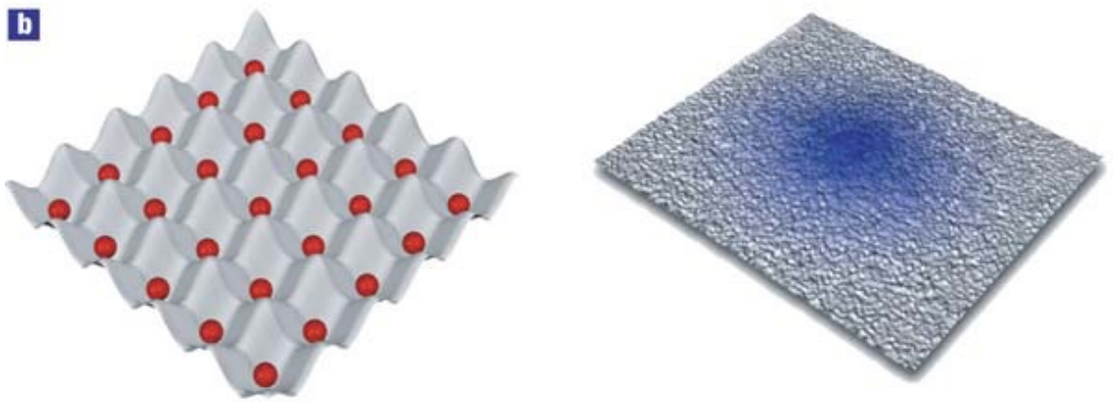
Bose-Hubbard: $$H = -t \sum_{\langle ij \rangle} \hat{a}_i^\dagger \hat{a}_j + \frac{U}{2} \sum_i \hat{n}_i(\hat{n}_i - 1)$$

$t/U \gg 1$



Superfluid

$t/U \ll 1$



Mott

I. Bloch, Nature Physics **1**, 23 (2005).

Enačbe

Sipalna sila: $$F_{sip} = \hbar k \frac{\Gamma}{2} \frac{I/I_{sat}}{1 + I/I_{sat} + 4\delta^2/\Gamma^2} \qquad I_{sat}(\omega) = \frac{\hbar\omega A_{21}}{2\sigma(\omega)}$$

Dipolna past: $$U_{dip}(\mathbf{r}) = -\frac{3\pi c^2 \Gamma}{2\omega_0^3} \left(\frac{1}{\omega_0 - \omega} + \frac{1}{\omega_0 + \omega} \right) I(\mathbf{r})$$

$$\Gamma_{sc}(\mathbf{r}) = \frac{3\pi c^2 \Gamma \omega^3}{2\hbar\omega_0^6} \left(\frac{1}{\omega_0 - \omega} + \frac{1}{\omega_0 + \omega} \right)^2 I(\mathbf{r})$$

Gaussov snop: $$I(\rho, z) = \frac{2P}{\pi w^2(z)} e^{-\frac{2\rho^2}{w^2(z)}}, \quad \text{kjer je } w(z) = w_0 \sqrt{1 + \left(\frac{z}{z_R} \right)^2}$$

Faznoprostorska gostota: $$D = n\lambda_{dB}^3 = \frac{N_{at}}{V} \left(\frac{h^2}{2\pi m_{Cs} k_b T} \right)^{3/2}$$

$$D = N \left(\frac{\hbar\bar{\omega}}{k_b T} \right)^3$$

Enačbe

Št. atomov (fluor): $N_{fluor} = \eta_q \frac{r_1^2}{4f_1^2} \frac{\Gamma}{2} t_{exp}$

Absorpcijsko slikanje: $T(x,y) = \frac{I_0(x,y) - I_D(x,y)}{I_B(x,y) - I_D(x,y)} = e^{-\sigma\eta(x,y)}$

$$N_{at} = \int \eta(x,y) dx dy = \sum_{x,y} l^2 \eta(x,y)$$

$$\eta(x,y) = \eta_0 e^{-x^2/w_x^2} e^{-y^2/w_y^2}$$

$$N_{fit} = \pi l^2 w_x w_y \eta_0$$

Enačbe

Magnetna levitacija:

$$U_g = m_{Cs} g z$$

$$U_{mag} = -\frac{3}{4}\mu_B B + \frac{15}{16}\frac{\mu_B^2}{\Delta E_0} B^2$$

$$\mu(B) = \left(\frac{3}{4} - \frac{15}{8}\frac{\mu_B}{\Delta E_0} B\right) \mu_B$$

$$U_{mag}(\rho) = -\frac{3}{4}\mu_B B_0 + \frac{1}{6}\frac{m_{Cs}^2 g^2 \rho^2}{\mu_B B_0}$$