UNIVERSITÀ DI SIENA
1240

Characteristics of unconventional ^{87}Rb magneto-optical traps (MOT)

Low Energy Seminar - Matteo Da Valle

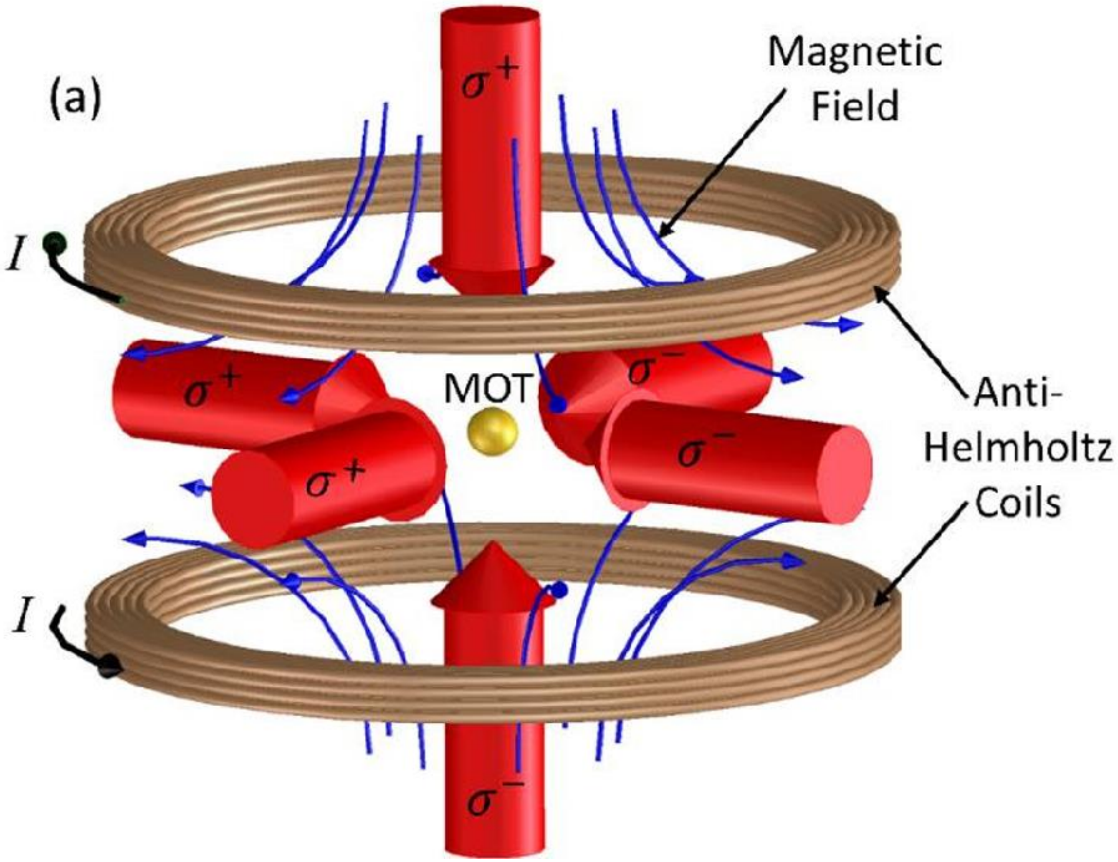
Magneto-Optical Traps

Why MOT:

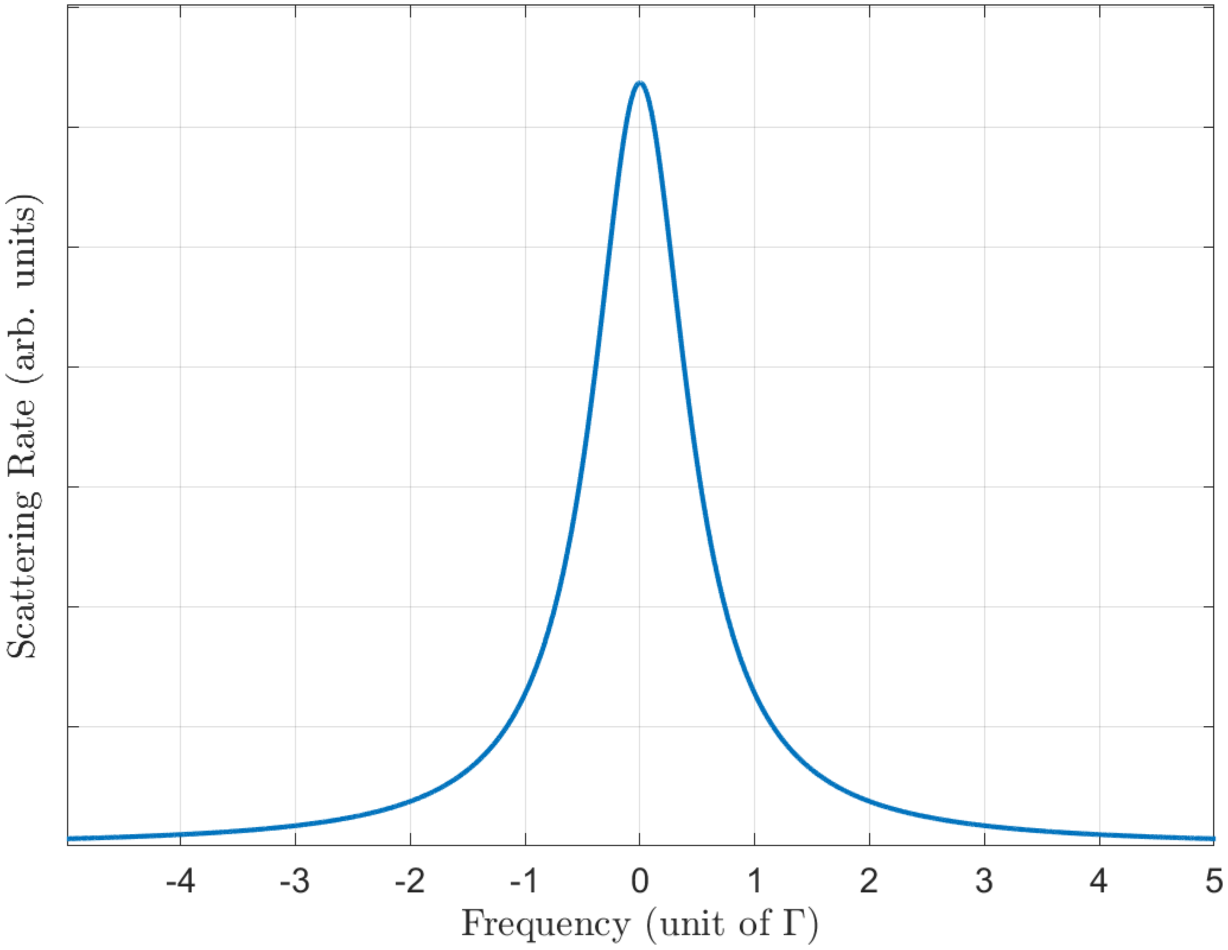
- Low Temperature ($\mu K \div mK$)
- Spatial Confinement (cloud dimension $\sim mm$)

MOT Layout:

- 3 pairs of counterpropagating LASER beams
- Quadrupole Magnetic Field ($B = 0$ in the center)



Doppler Cooling



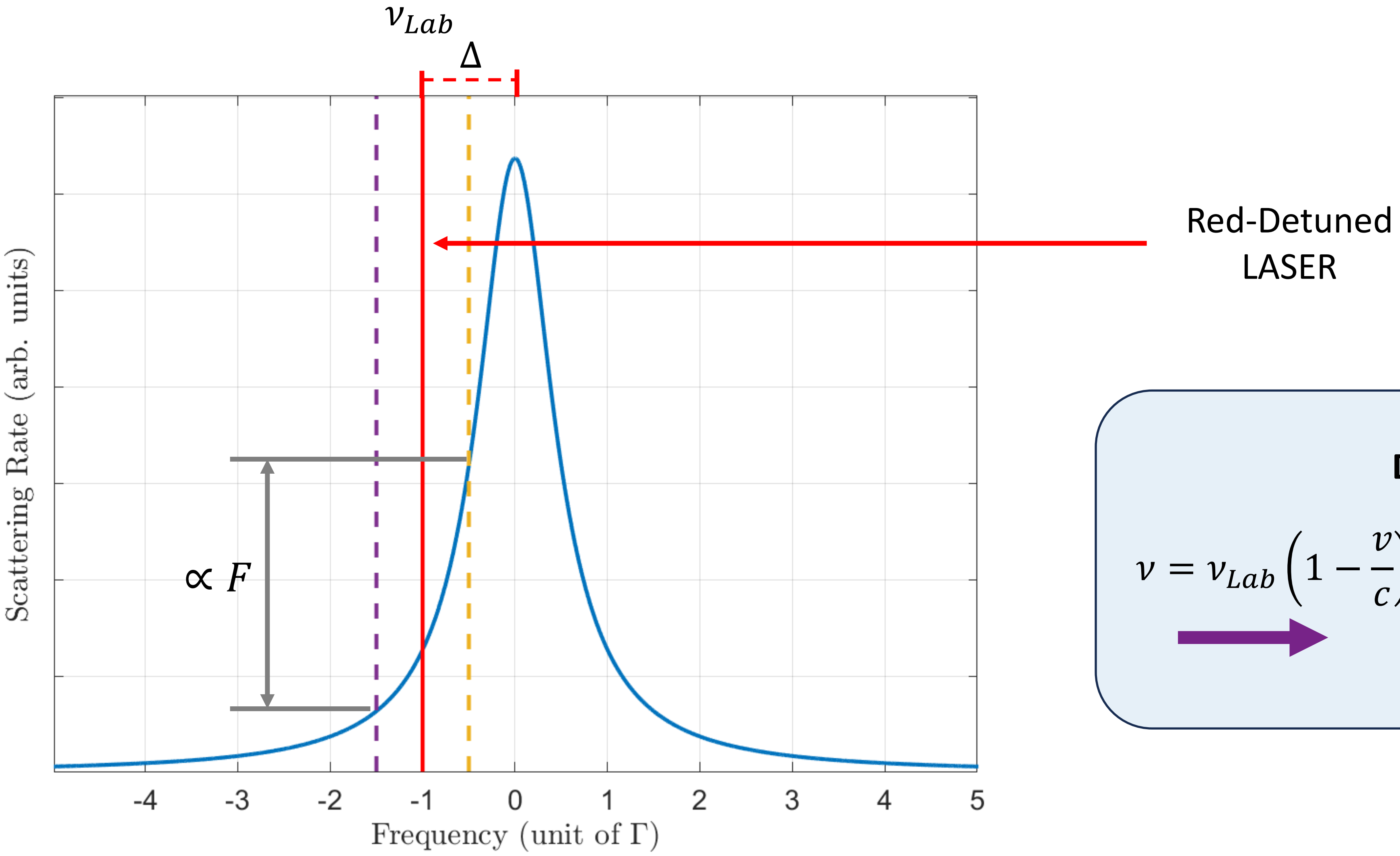
Electric dipole transition

$$L(\nu) \propto \frac{1}{(\nu - \nu_0)^2 + (\Gamma/2)^2}$$

$\nu_0 = resonant\ frequency$

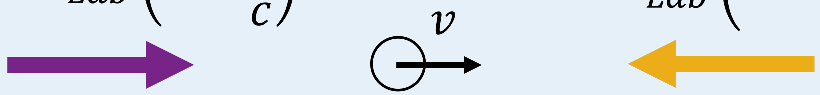
$\Gamma = FWHM$

Doppler Cooling

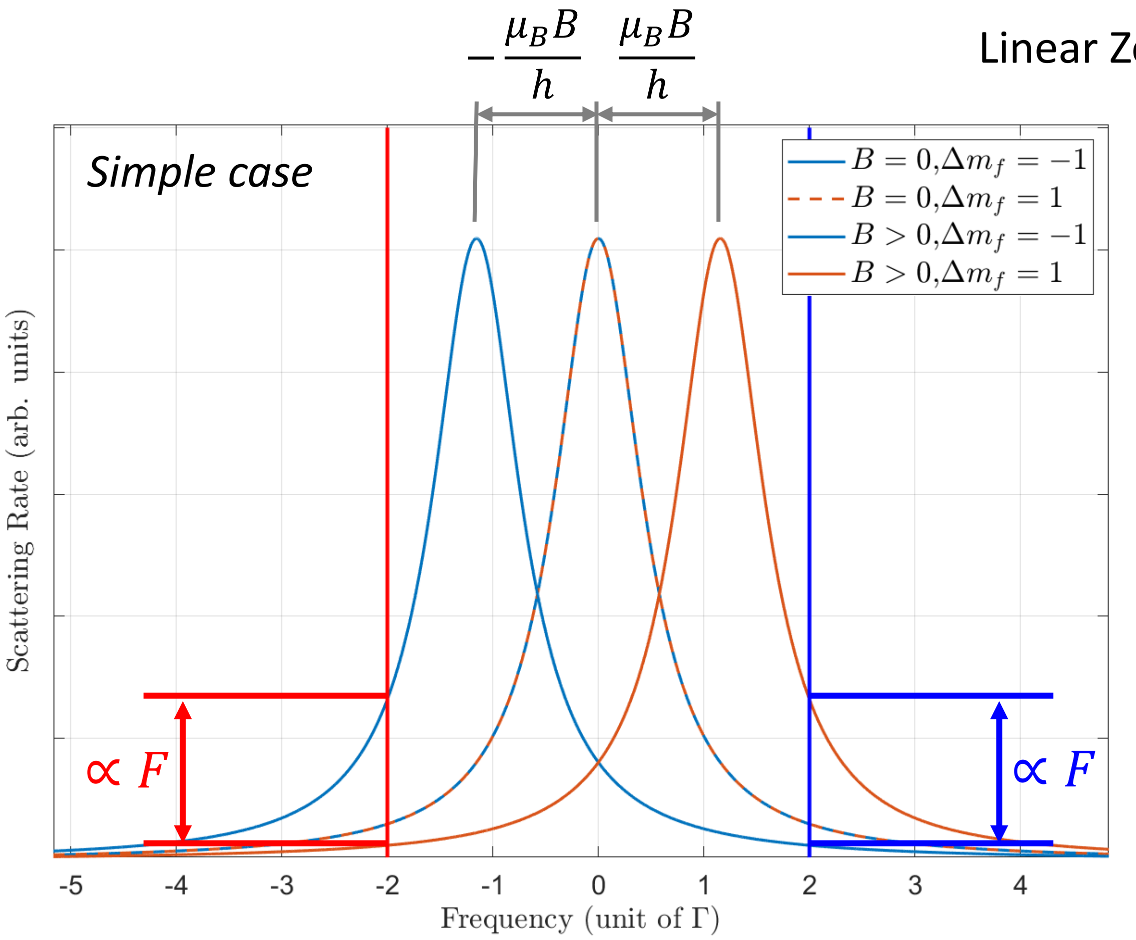


Doppler effect

$\nu = \nu_{Lab}\left(1 - \frac{v}{c}\right)$ $\qquad$ $\nu = \nu_{Lab}\left(1 + \frac{v}{c}\right)$



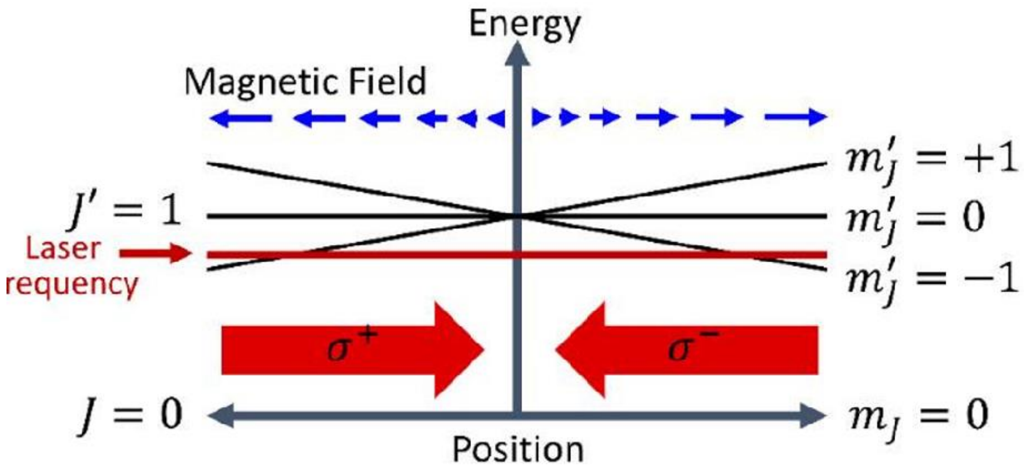
Magnetic Confinement



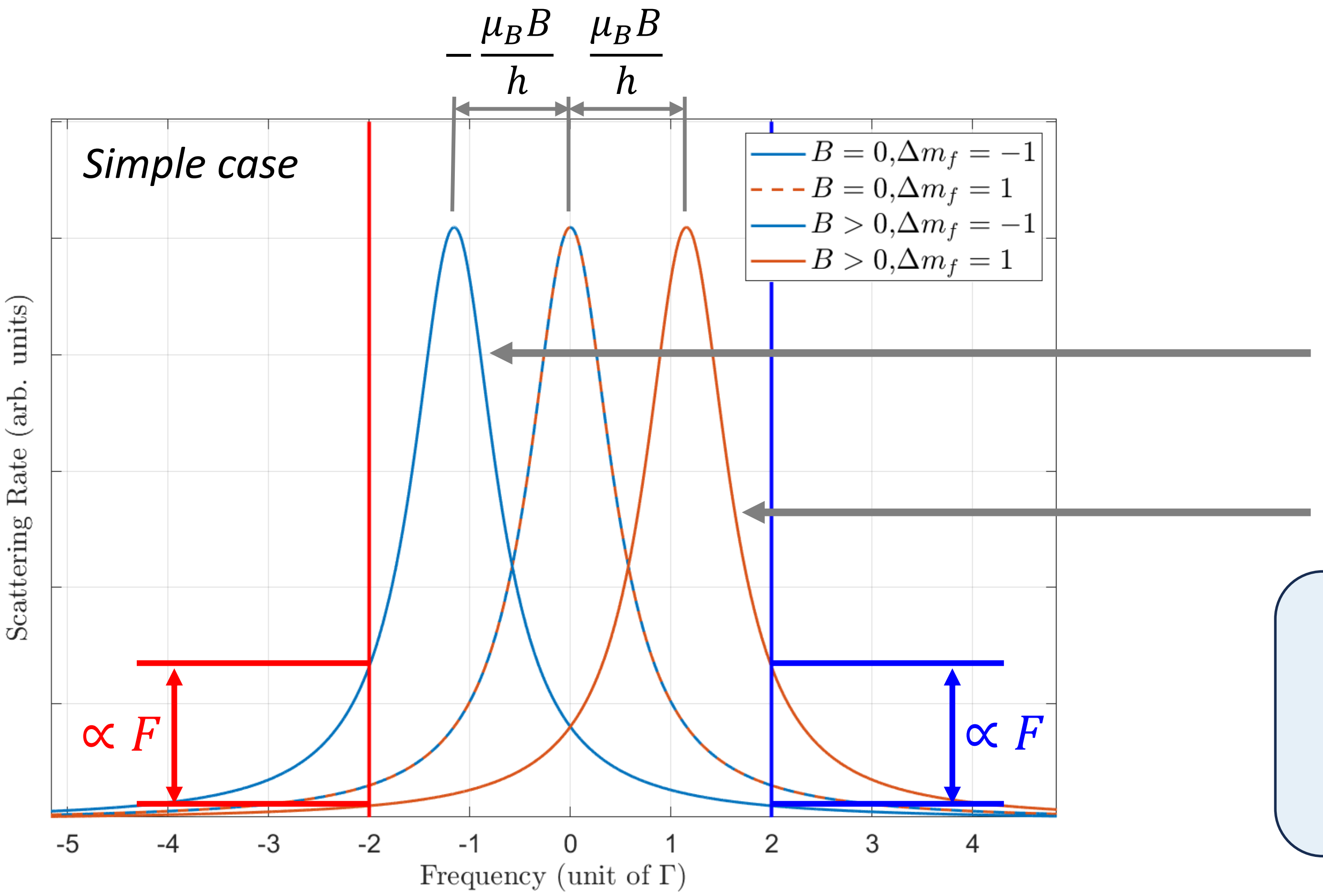
Linear Zeeman Effect $\quad \Delta\nu_{l,u} = [m_l(g_u - g_l) + g_u \Delta m]\frac{\mu_B B}{h}$

Simple case

$$\Delta\nu_{l,u} \propto \Delta m \frac{\mu_B B}{h}$$

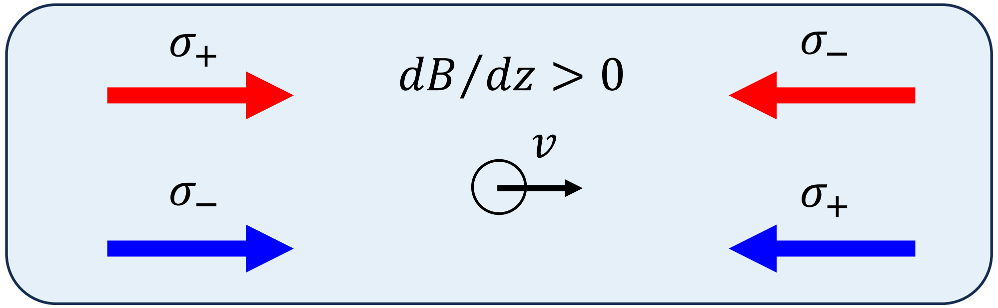


Magnetic Confinement



Left-handed circular polarized light σ_-

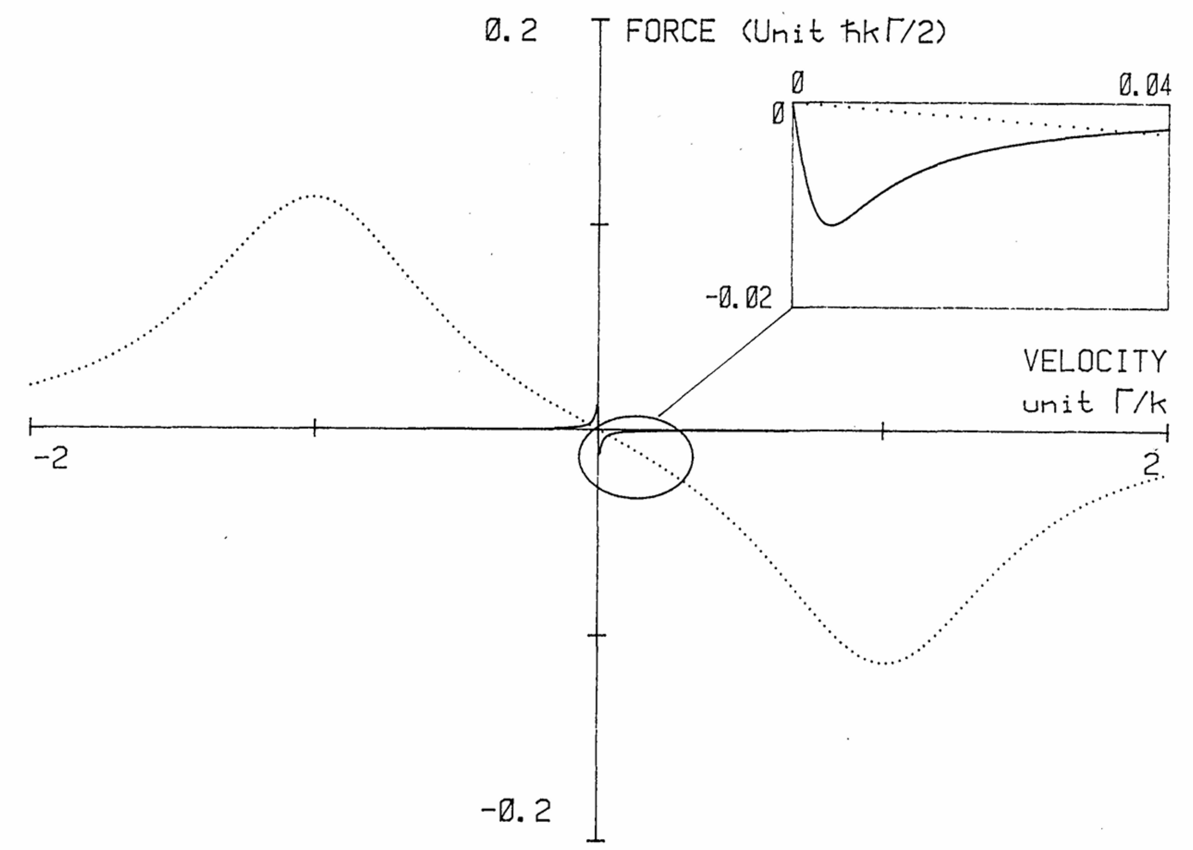
Right-handed circular polarized light σ_+



Sub-Doppler cooling

$T_{Doppler} = h\Gamma/2k_b \ (145\ \mu K\ for\ Rb\ D2) > T_{observed}$

Sub-Doppler cooling mechanisms

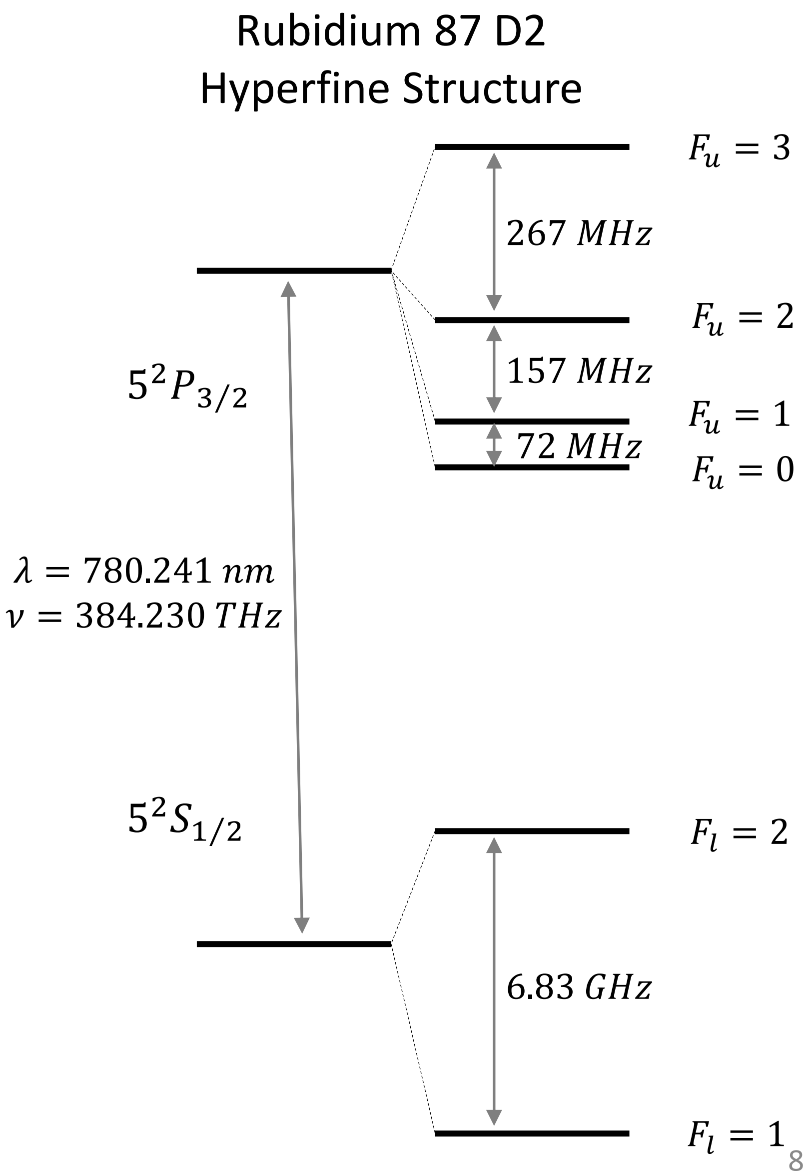


Example of Sub-Doppler cooling forces (—) vs Doppler cooling forces (···)

Type-I vs Type-II MOTs

Dipole Interaction: $F_u - F_l = \begin{cases} +1 \\ 0 \\ -1 \end{cases}$

- $+1$ → Type I MOT
- $0, -1$ → Type II MOT

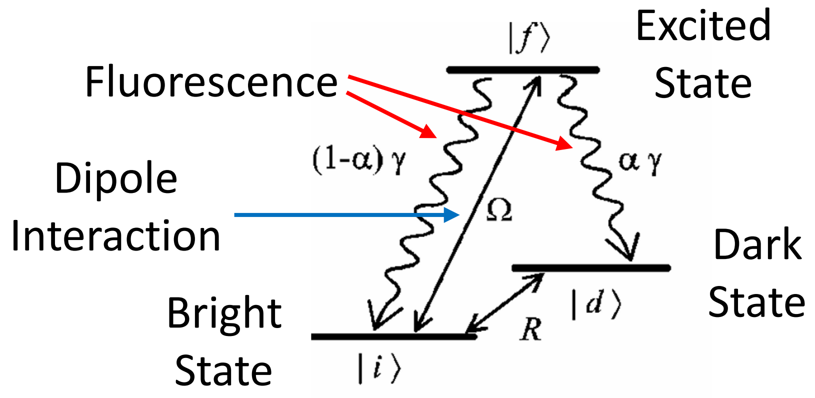


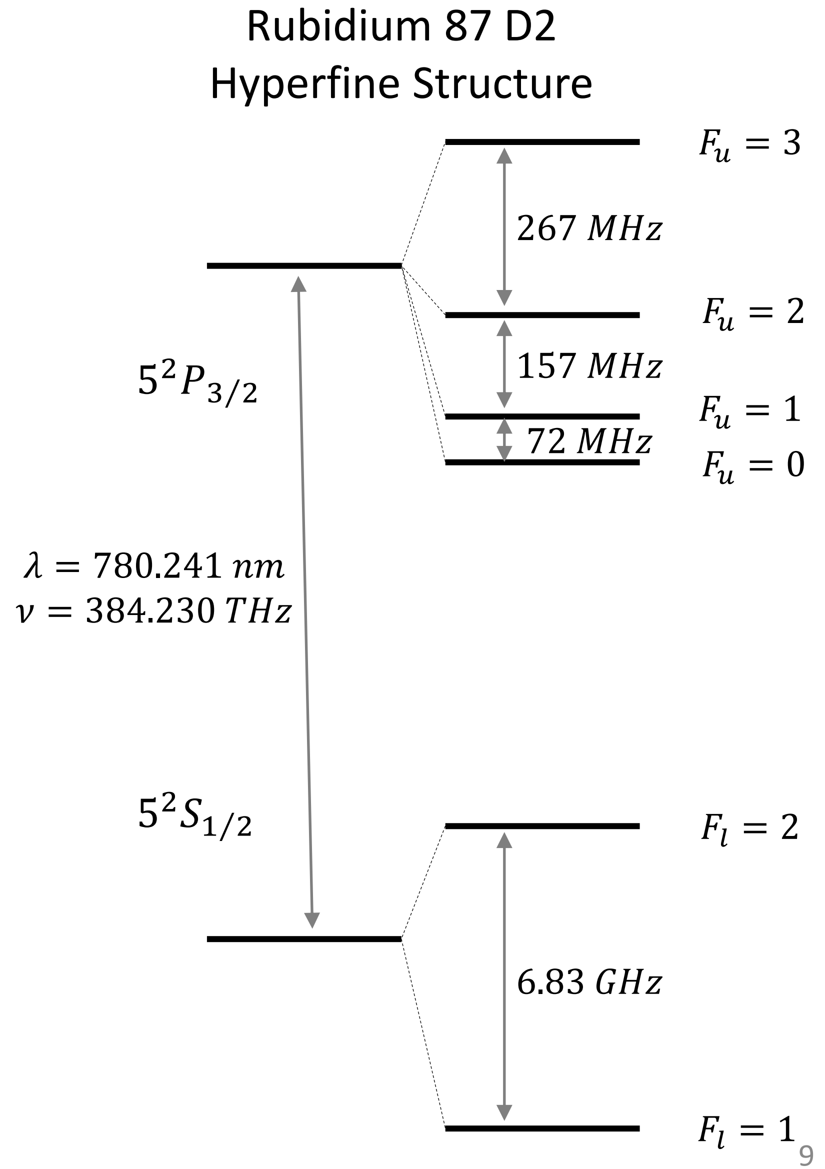
Type-I vs Type-II MOTs

Dipole Interaction: $F_u - F_l = \begin{cases} +1 \\ 0 \\ -1 \end{cases}$

- $+1$ → Type I MOT
- $0, -1$ → Type II MOT → Dark State Problem

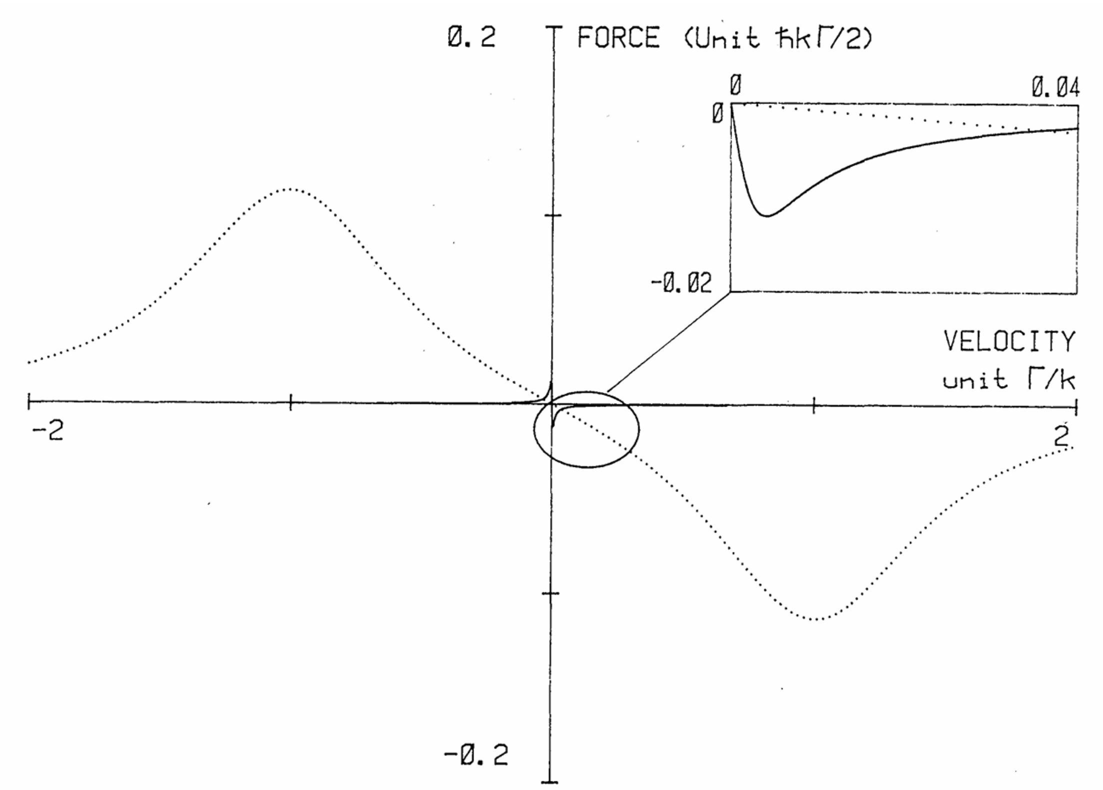
Dark State Problem



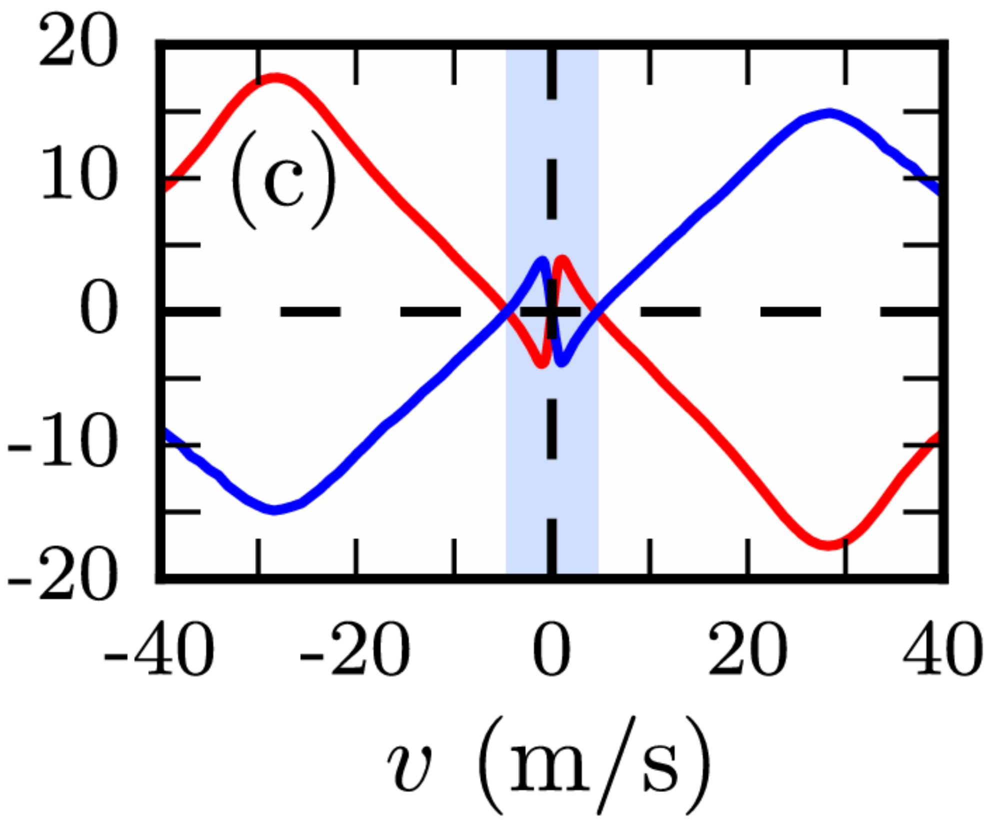


Sub-Doppler Cooling – Type-II MOT

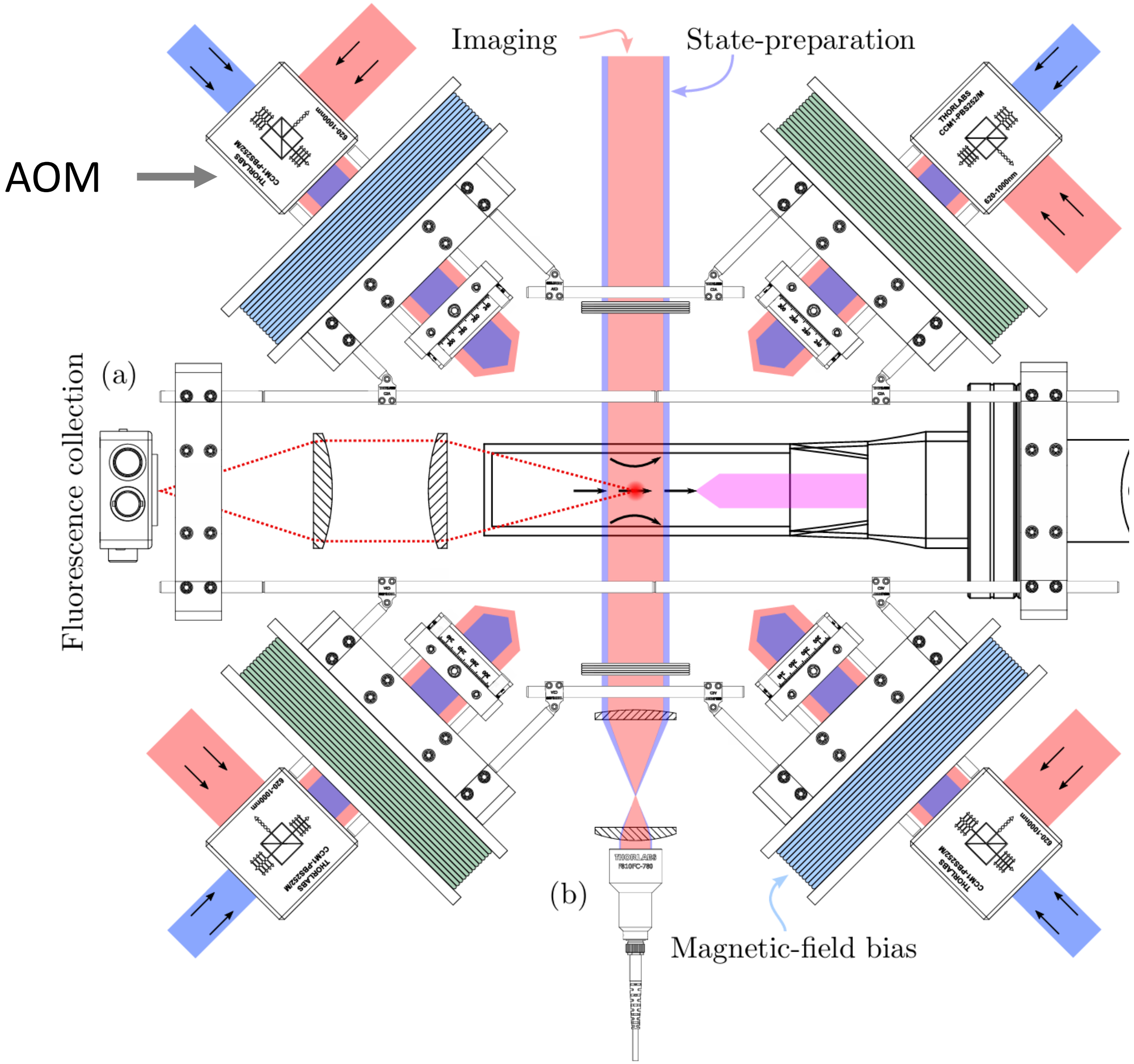
Type I MOT

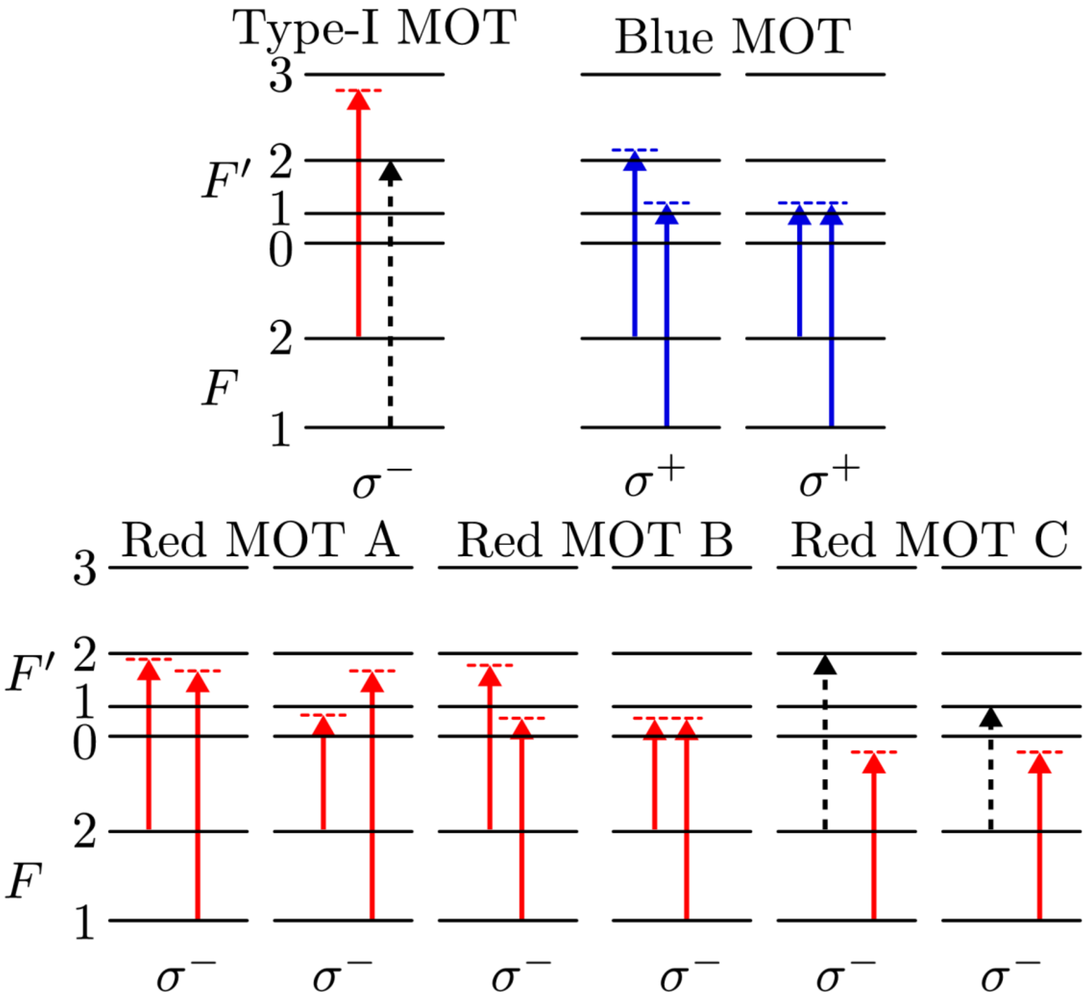


Type II MOT



Experimental Setup

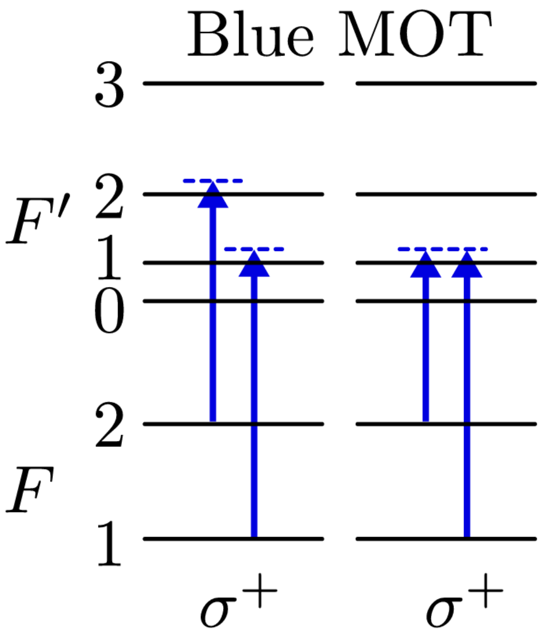




Blue MOT: Capture velocity

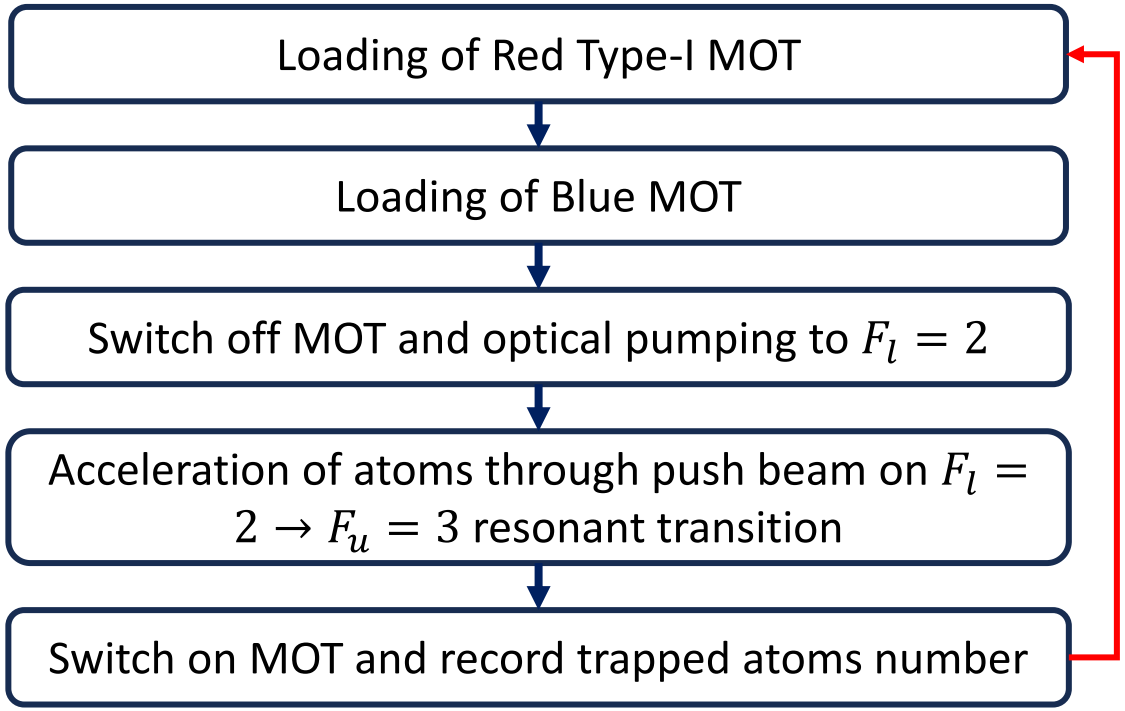
1. Loading of Red Type-I MOT
2. Loading of Blue MOT
3. Switch off MOT and optical pumping to $F_l = 2$
4. Acceleration of atoms through push beam on $F_l = 2 \rightarrow F_u = 3$ resonant transition
5. Switch on MOT and record trapped atoms number

(then back to step 1)

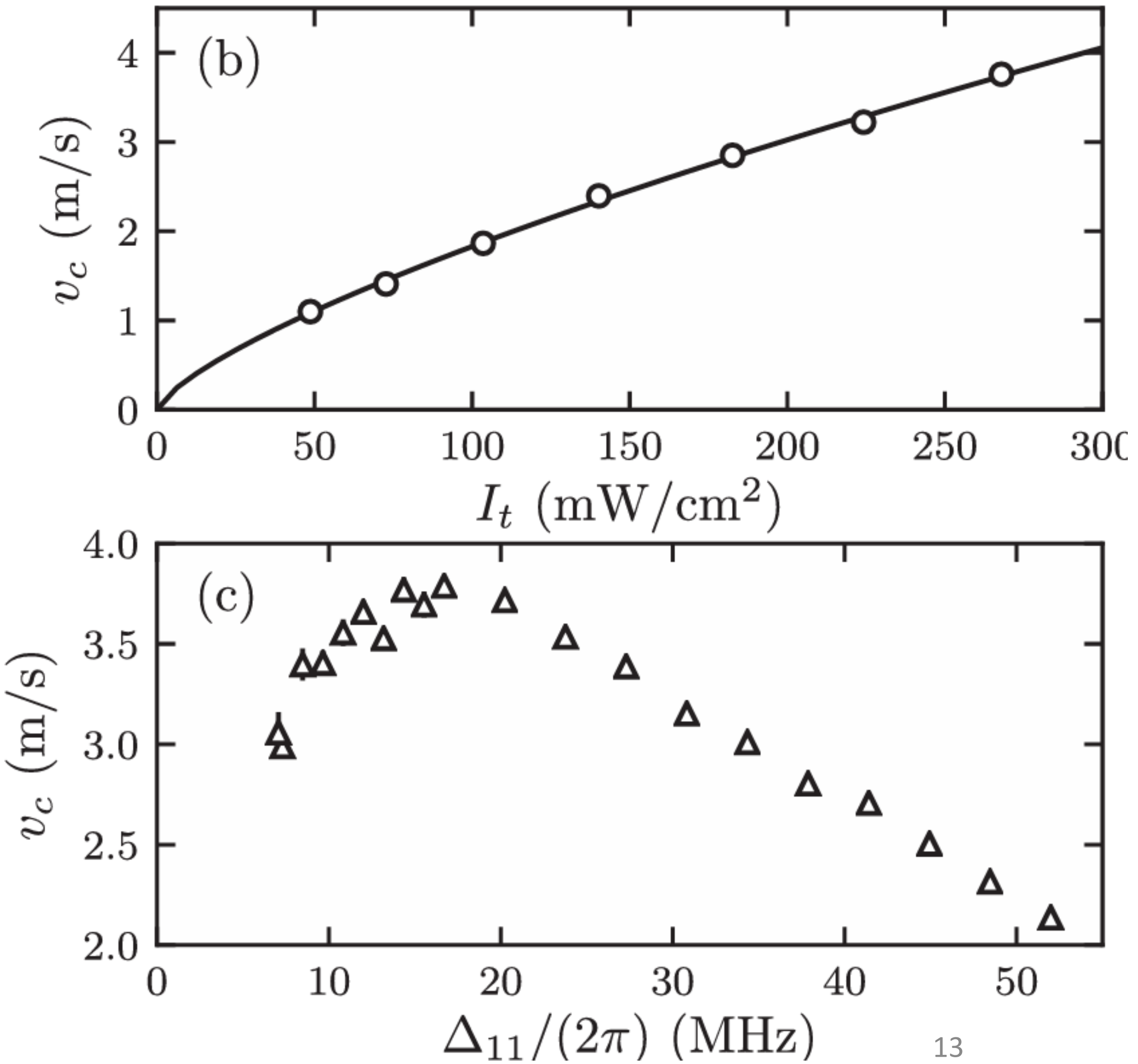


$$N_{Recap}(v_0) = N_0(F=1) + \frac{N_0(F=2)}{\sqrt{\pi}\sigma(v_0)} \int_{-v_c}^{v_c} \mathrm{e}^{-\frac{(v-v_0)^2}{2\sigma(v_0)^2}} dv$$

Blue MOT: Capture velocity



$$N_{Recap}(v_0) = N_0(F=1) + \frac{N_0(F=2)}{\sqrt{\pi}\sigma(v_0)} \int_{-v_c}^{v_c} e^{-\frac{(v-v_0)^2}{2\sigma(v_0)^2}} dv$$



Blue MOT: Trapping Efficiency

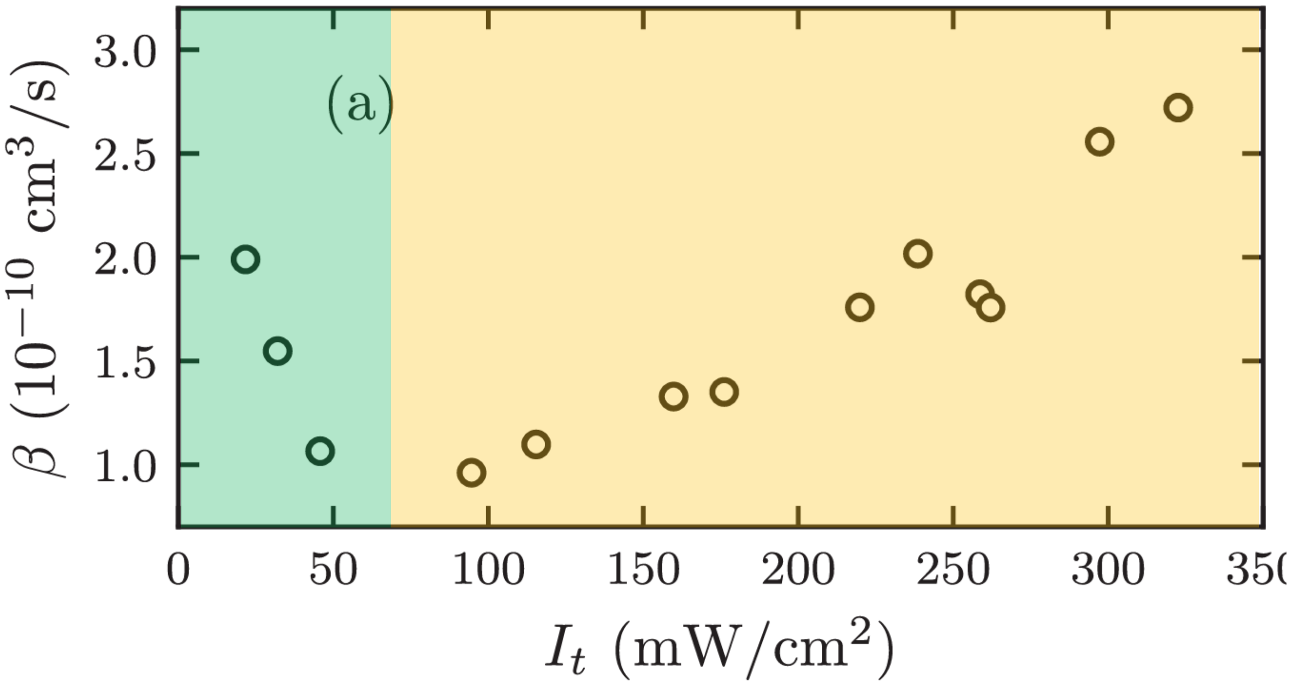
Phenomenological model $$\frac{dN}{dt} = -\gamma N - \beta \int n(\vec{r})^2 d^3r$$

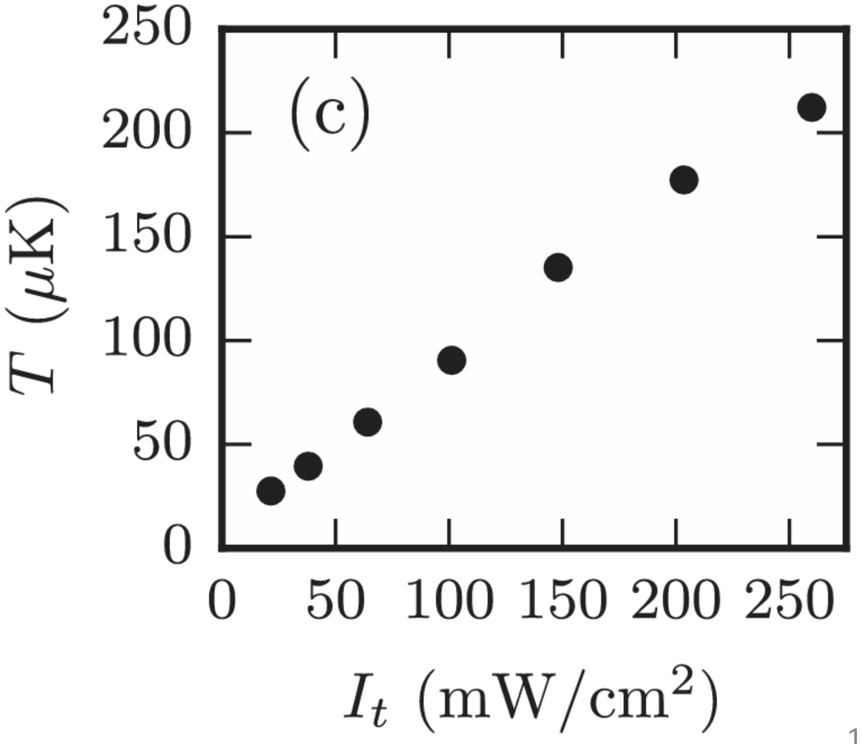
$\gamma N =$ loss rate due to collisions with untrapped atoms

$\beta \int n(\vec{r})^2 d^3r =$ loss rate due to trapped atoms interaction

Blue MOT: Trapping Efficiency

Phenomenological model $$\frac{dN}{dt} = -\gamma N - \beta \int n(\vec{r})^2 d^3r$$

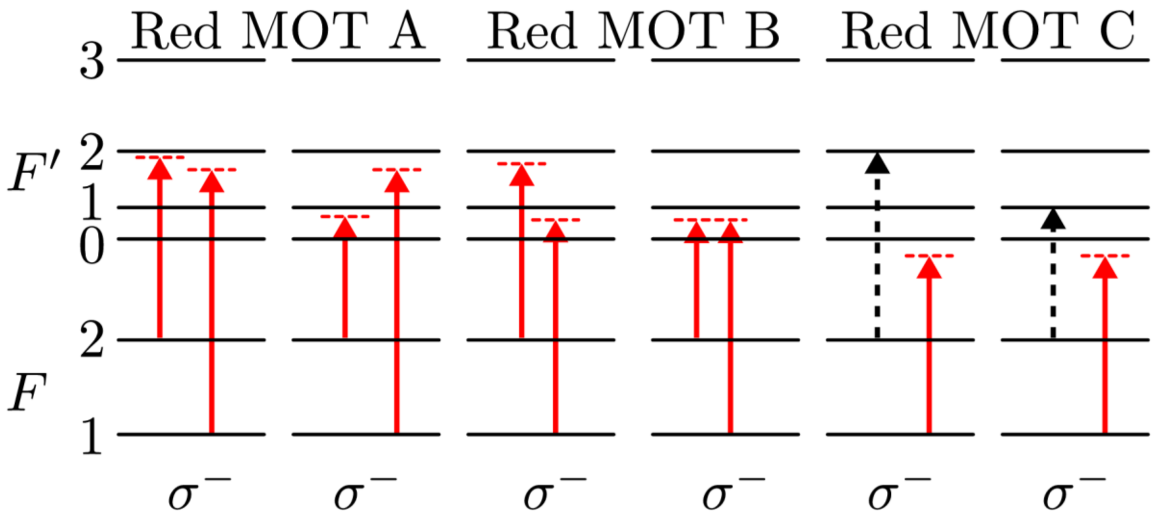


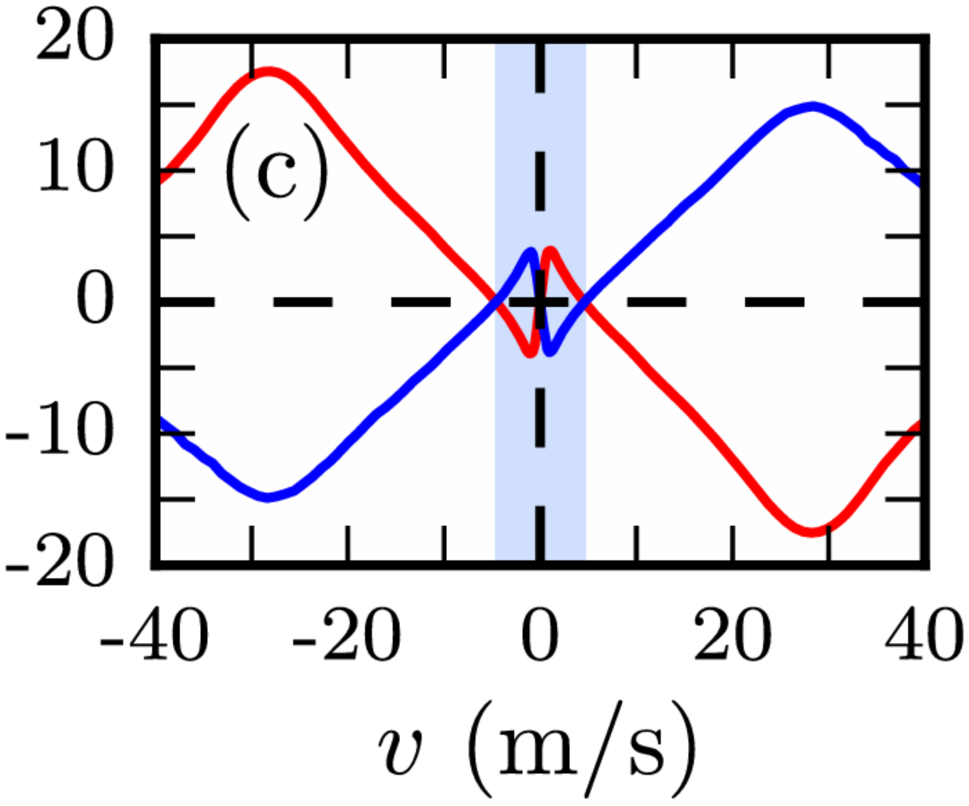


Type II Red MOT

Main results:

1. High Temperatures ($> 10mK$)
2. Poor confinement
3. Good lifetimes τ_{max}



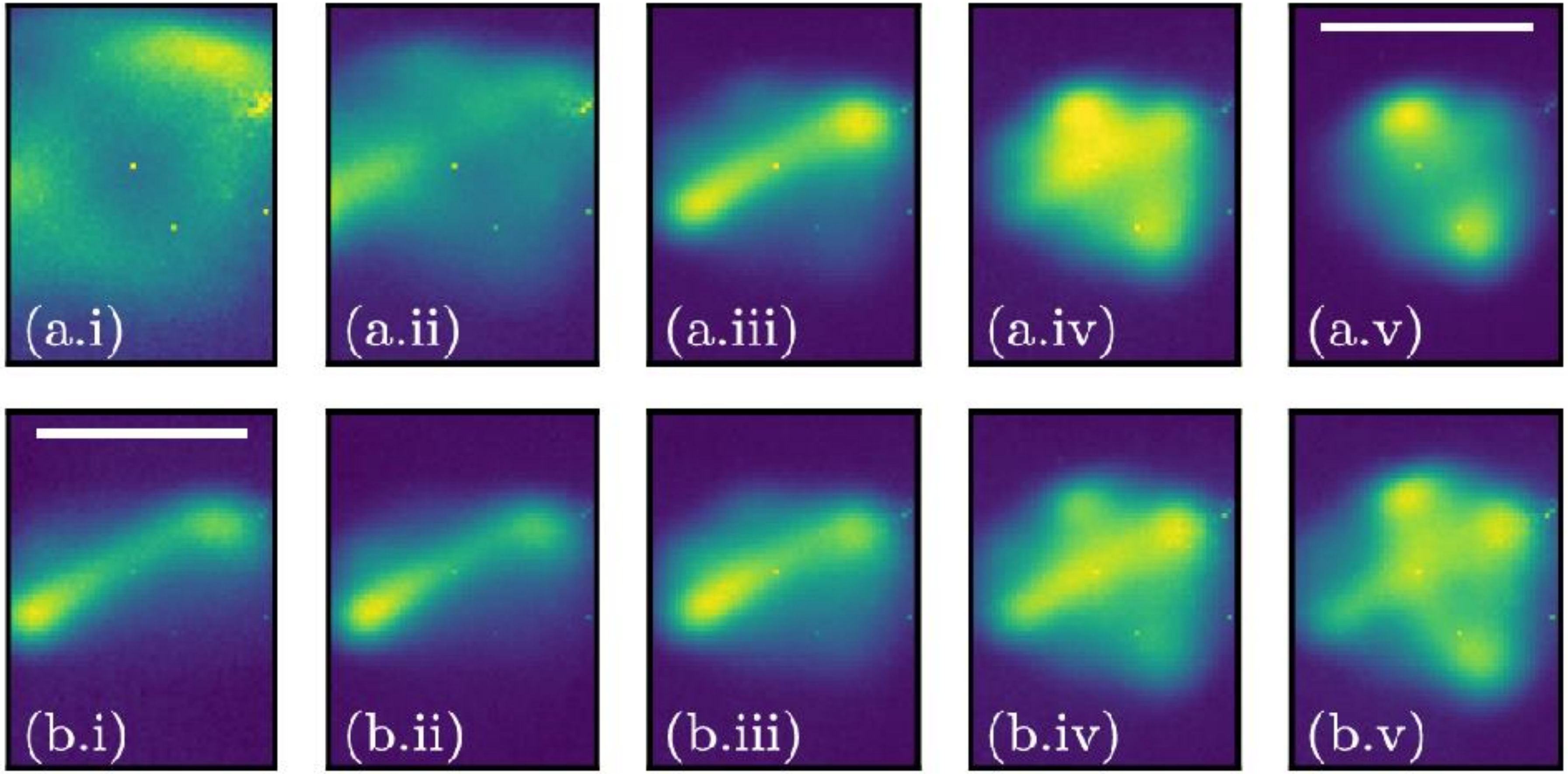


Type II Red MOT – Red MOT B Shape

B' →

$I_t = 103\ mW/cm^2$

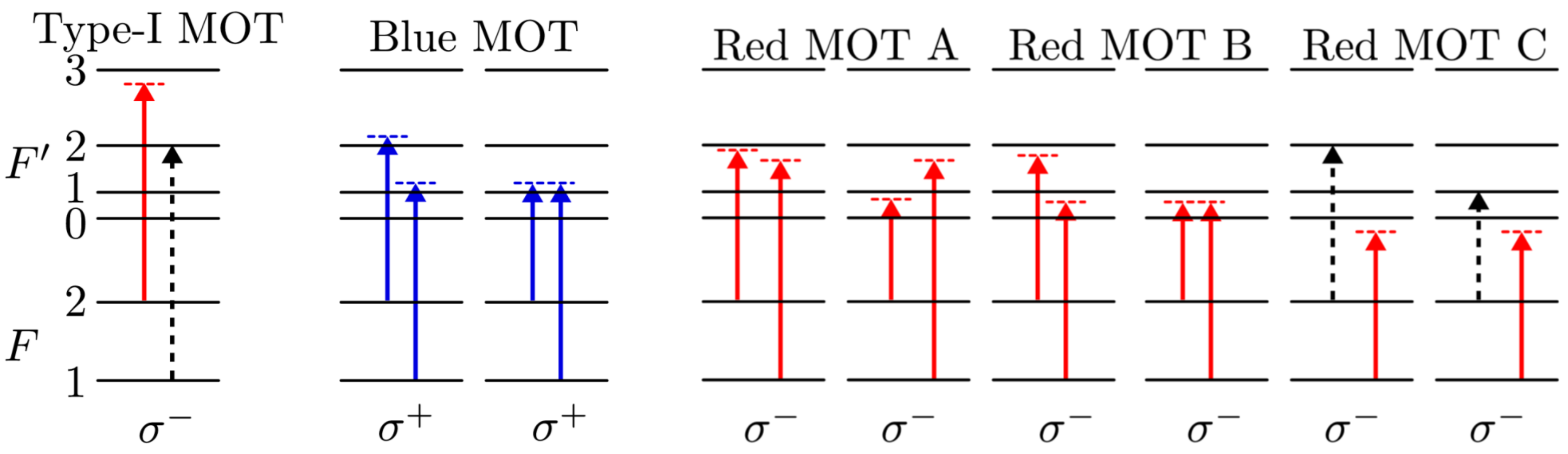
$B' = 53\ G/cm$



→ I_t

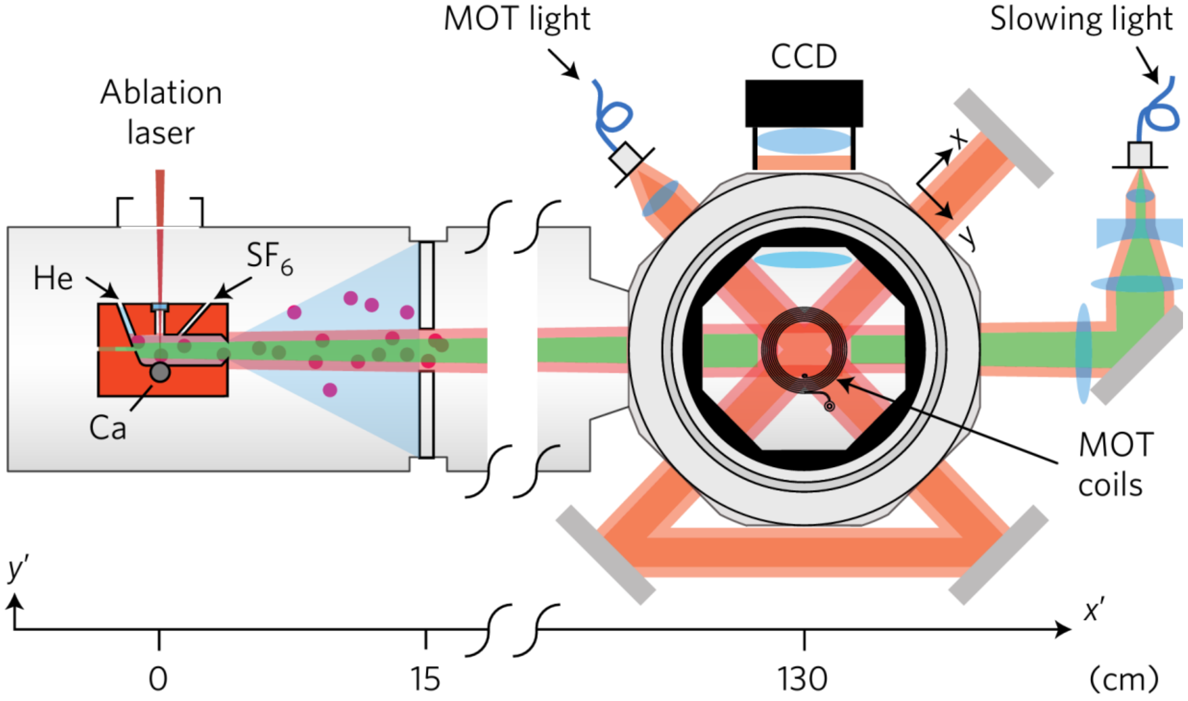
Conclusions

MOT	Appearance	$T(mK)$	$\tau_{max}(s)$	$Size\ (mm)$
Type-I MOT	Gaussian			
Blue MOT	Gaussian	$0.02 - 0.2$	13	0.5
Red MOT A	Gaussian	$10 - 25$	14	1
Red MOT B	Ring-Like	> 25	9	5
Red MOT C	Diffuse	> 25	4	5



Conclusions

- Empirical characterization of Type-II MOT
- Validation of semiclassical analysis made on ^{87}Rb
- Starting point for laser cooling and MOT on molecules, which is more feasible for Type-II MOT w.r.t. Type-I MOT (e.g. CaF, Yb)



Bibliography

- K. N. Jarvis, B. E. Sauer, and M. R. Tarbutt, “Characteristics of unconventional Rb magneto-optical traps”, Phys. Rev. A 98, 043432 (2018).
- K. N. Jarvis, J. A. Devlin, T. E. Wall, B. E. Sauer, and M.R. Tarbutt, “Blue-Detuned Magneto-Optical Trap”, Phys. Rev. Lett. 120, 083201 (2018).
- J A Devlin and M R Tarbutt, “Three-dimensional Doppler, polarization-gradient, and magneto-optical forces for atoms and molecules with dark states”, New J. Phys. 18 123017 (2016).
- J. J. McClelland, A. V. Steele, B. Knuffman, K. A. Twedt, A. Schwarzkopf, and T. M. Wilson, “Bright focused ion beam sources based on laser-cooled atoms”.
- J. Dalibard, C. Cohen-Tannoudji, “Laser cooling below the Doppler limit by polarization gradients: simple theoretical models” (1989)
- S. Truppe, H. J. Williams, M. Hambach, L. Caldwell, N. J. Fitch, E. A. Hinds, B. E. Sauer and M.R.Tarbutt, “Molecules cooled below the Doppler limit”