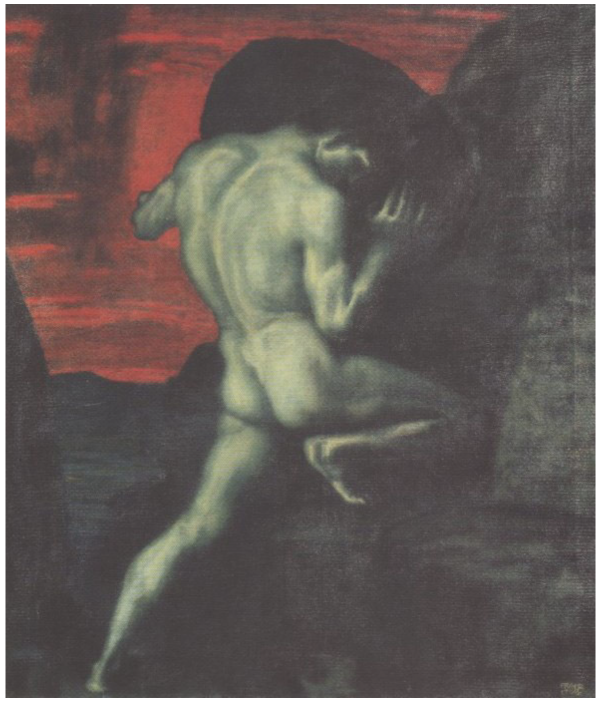
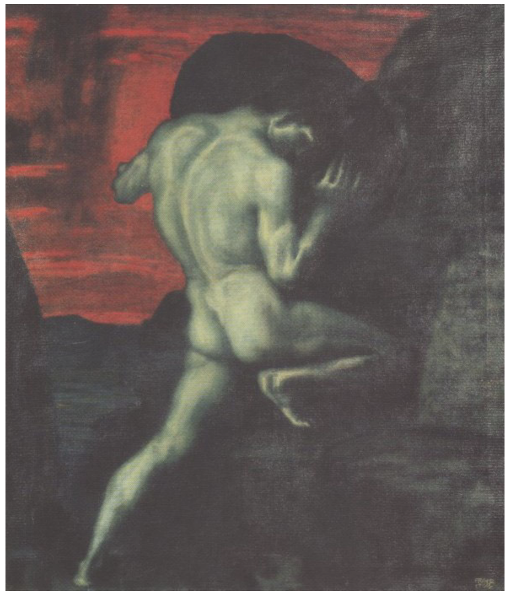
Sub-Doppler cooling of ^{40}K in three-dimensional gray optical molasses

Diogo Rio Fernandes

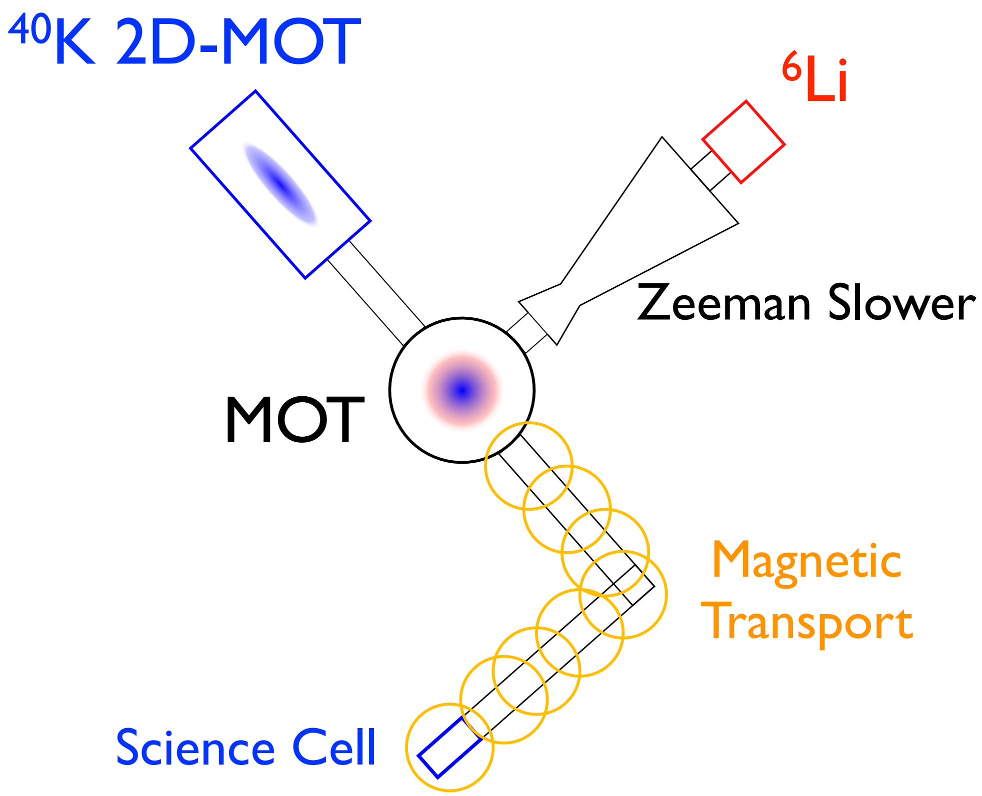


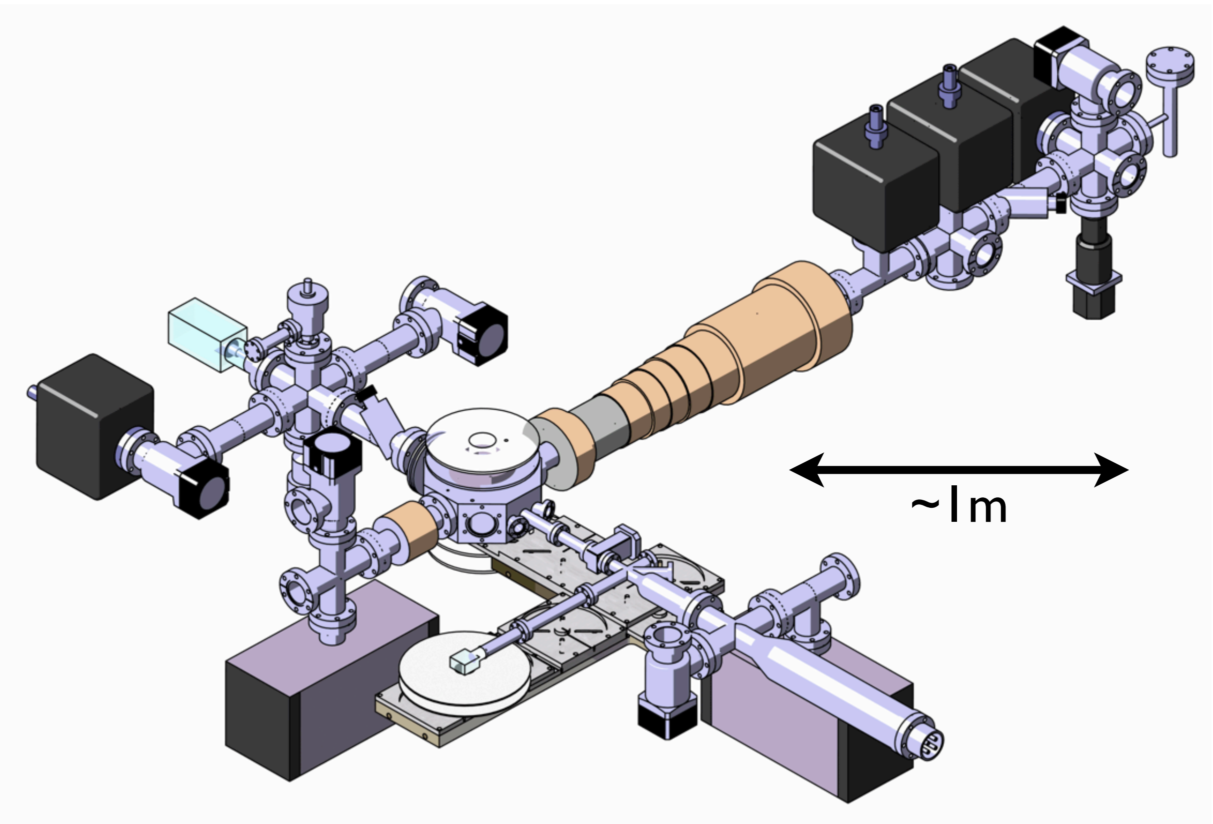
Outline

- Experimental apparatus
- Motivation for sub-Doppler cooling
- Gray molasses in a nutshell
- Discussion of experimental results
- Final remarks



Experimental Apparatus



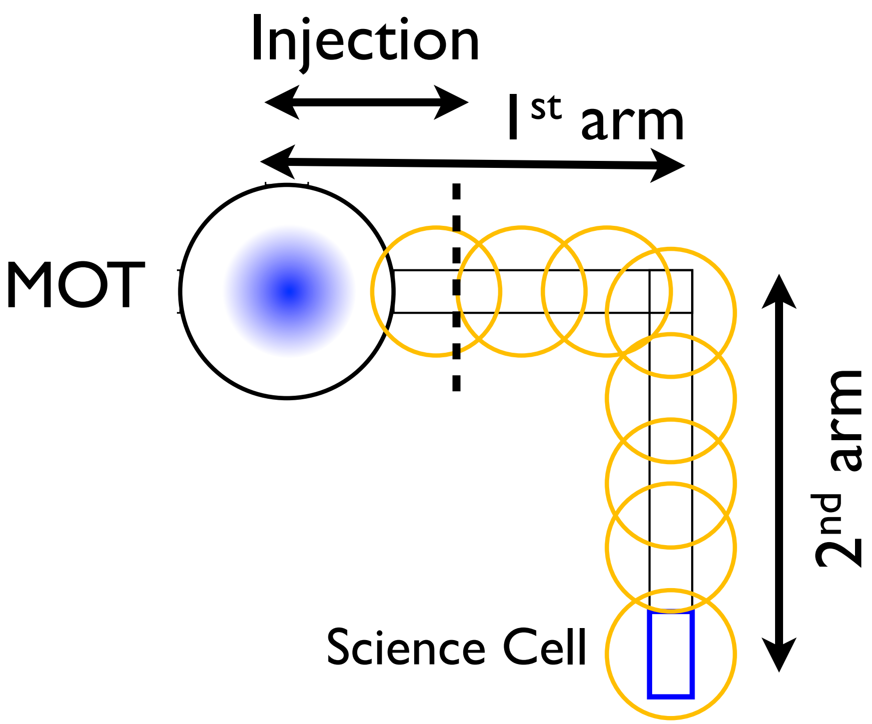


Typical flux for ^{6}Li and ^{40}K: ~10^9 at/s
Best number of atoms achieved in MOT: ~8×10^9 at for each species

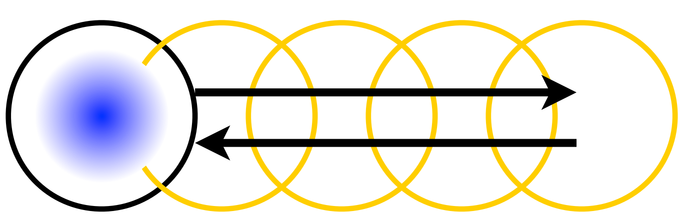
Ridinger, A. *et al.* EPJ D **242**, 223–242 (2011)

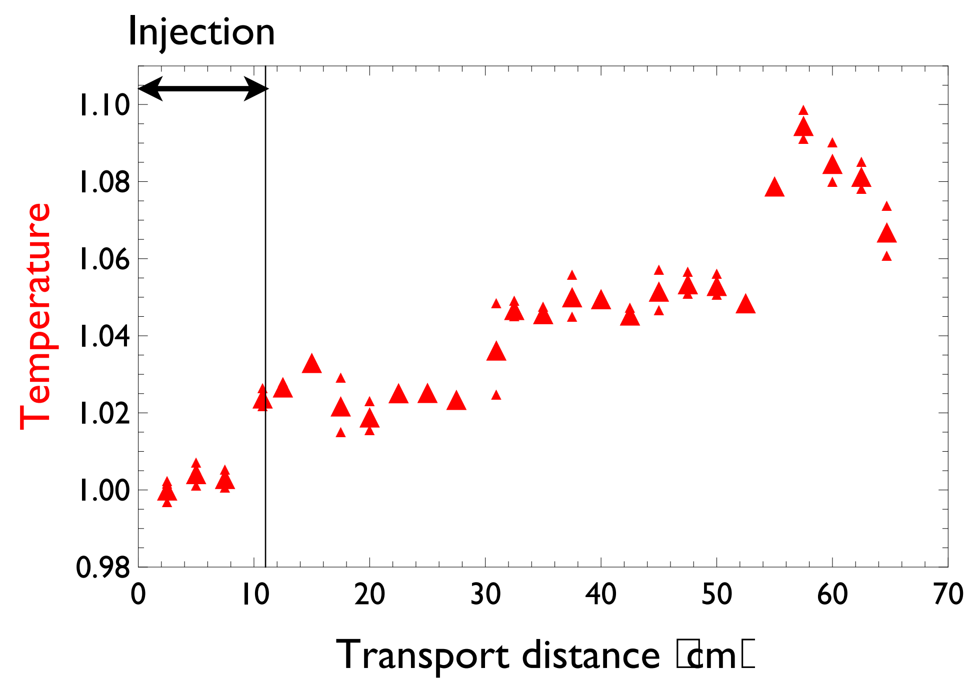
Experimental Apparatus

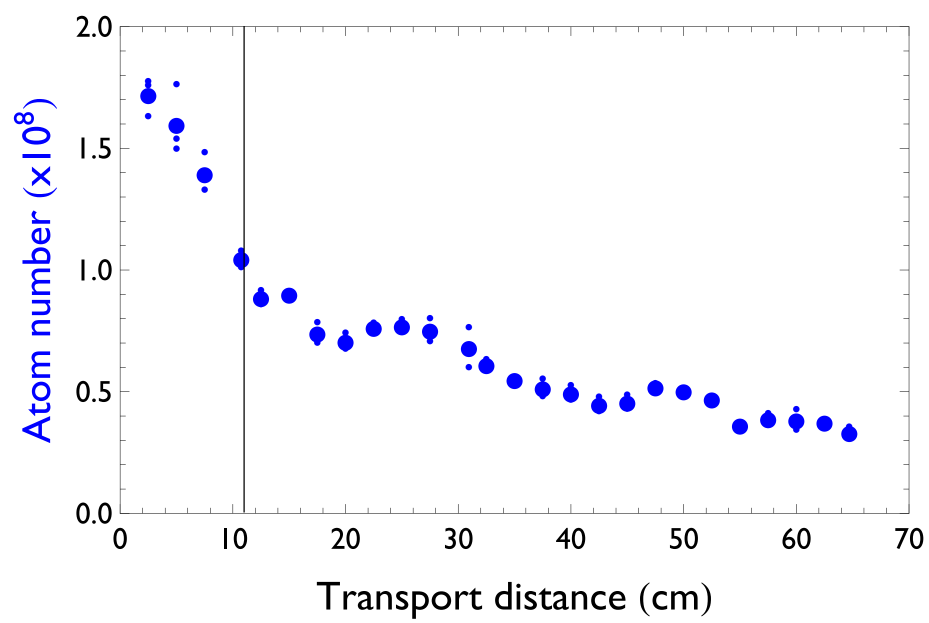
Magnetic Transport of ^{40}K



$$T_0 = 300\,\mu\mathrm{K}$$
$$b' = 140\,\mathrm{G}\cdot\mathrm{cm}$$







Heating ~10/2=5%

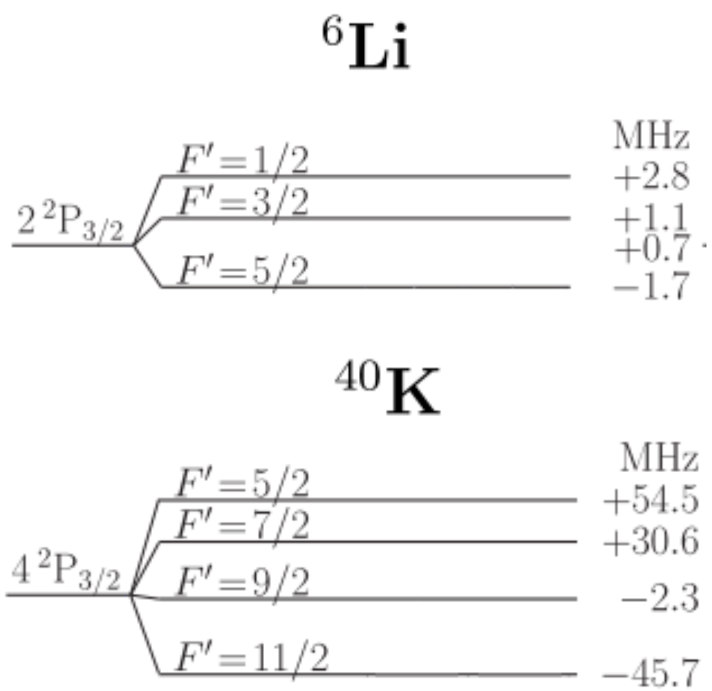
	Δt (s)	τ (s)
Injection	0.62	3
To Elbow	0.85	30
2^{nd} arm	2.5	30
Total	4	

Efficiency ≳40%

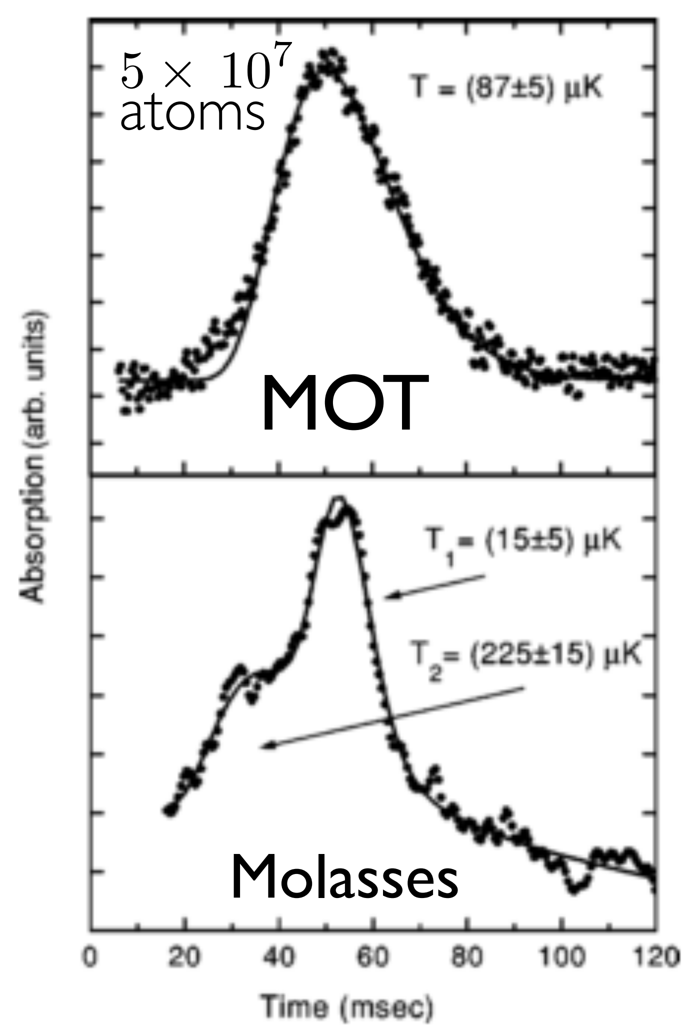
Runaway evaporation not yet observed in the Science cell

Improving the initial conditions

Sub-Doppler cooling



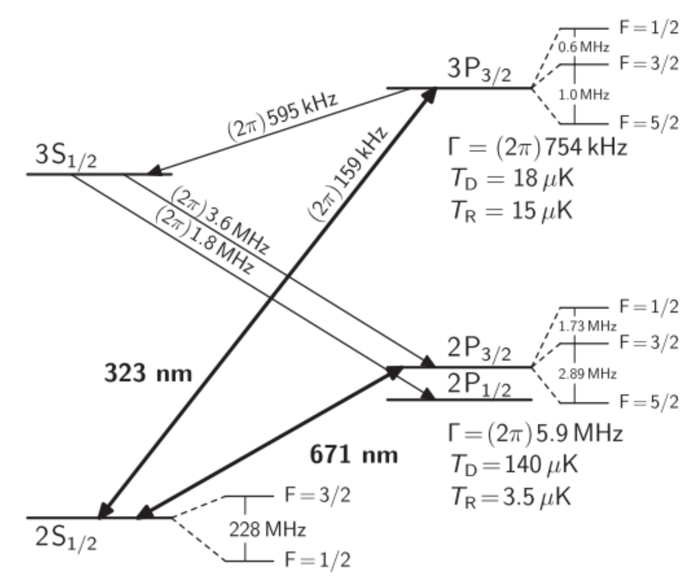
^{40}K



Modugno, G. *et al.* PRA **60**, R3373 (1999)

Narrow transition MOT

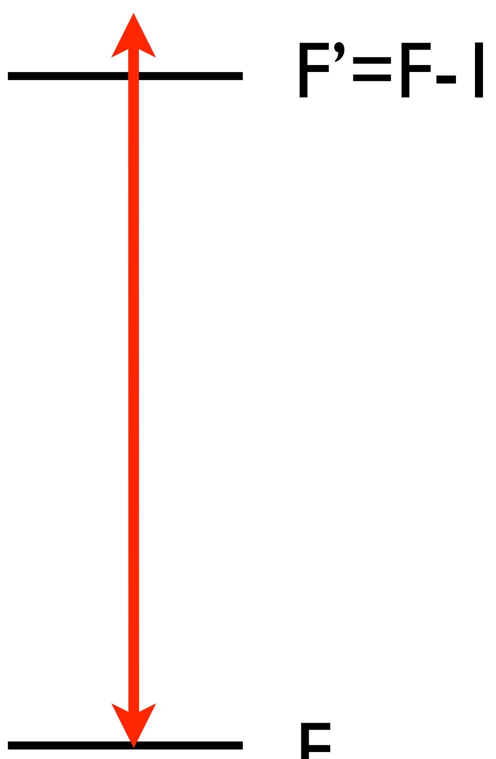
	λ (nm)	T_D (µK)
^{6}Li	323	18
^{40}K	405	24

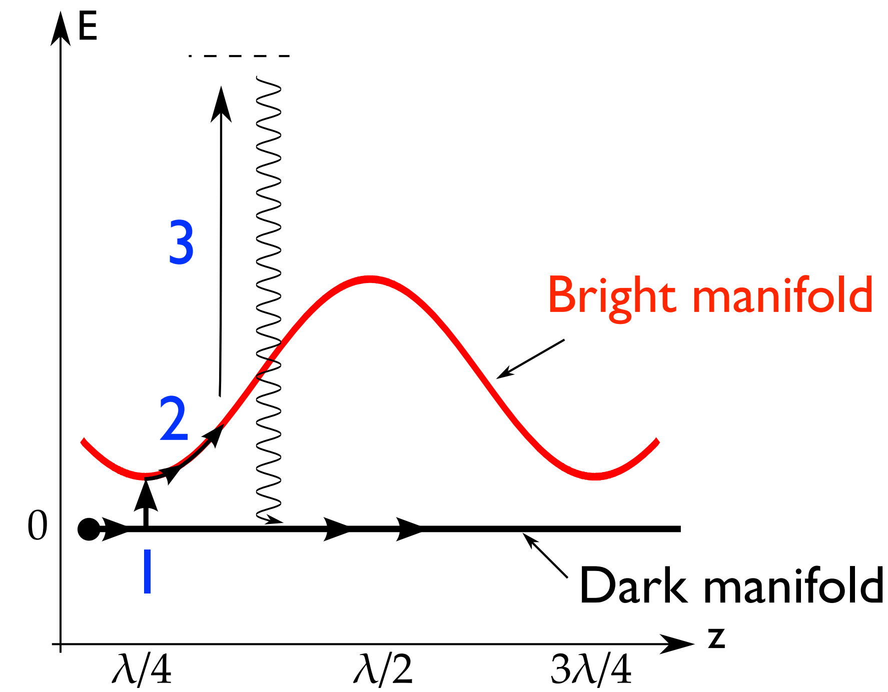


^{6}Li: Duarte, P. et al. PRA **84**, 061406 (2011)
^{40}K: McKay, D. et al. PRA **84**, 063420 (2011)

Gray molasses:
a simple picture

Cooling transition F→F’=F-1
involves 2 dark states



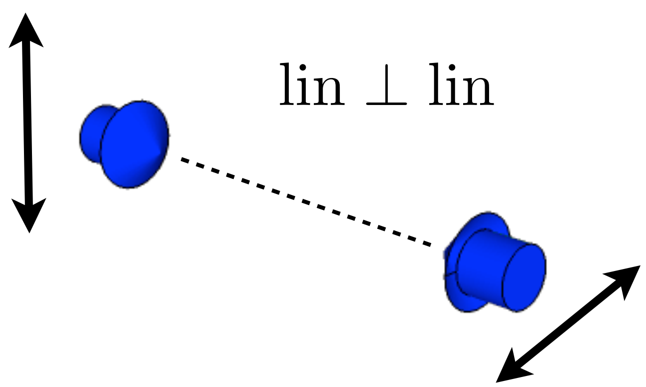


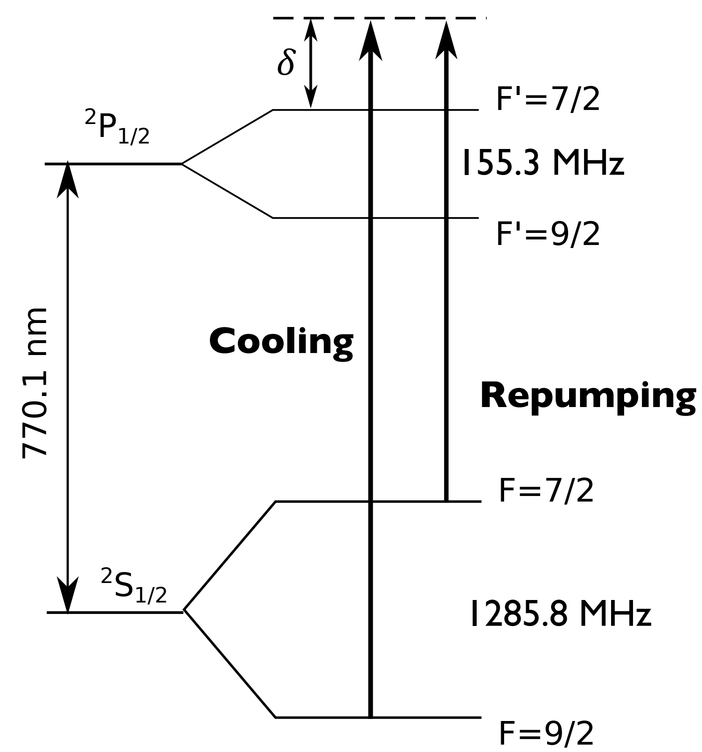
Sisyphus-type cooling in gray molasses:

1. (Motional) coupling to the bright manifold in the “valley”
2. Loss of kinetic energy by climbing the potential hill
3. Optical pumping back to the dark manifold

Ol'shani M. and Minogin V. Opt. Commun. **89**, 393 (1992)
Grynberg, G. and Courtois, J.-Y. EPL **27**, 41 (1994)
Cohen-Tannoudji, C. - Collège de France

Numerical solving of the OBE



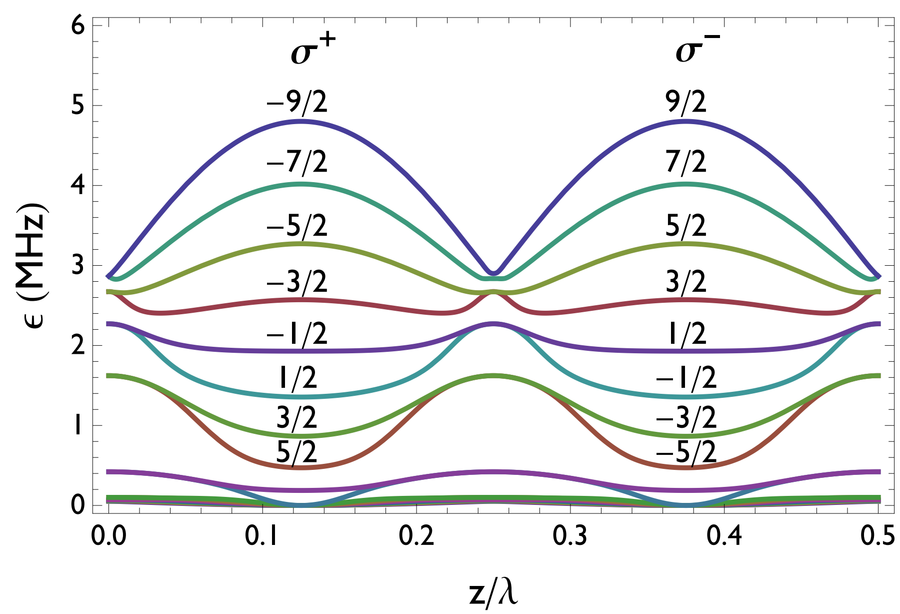


$$I_{\rm cool} = 20 I_{\rm sat}$$

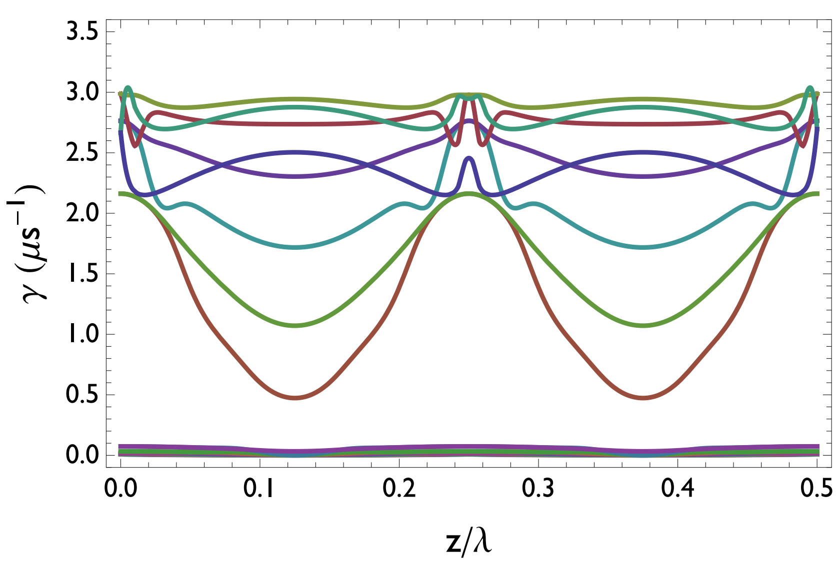
$$I_{\rm repump} = I_{\rm cool}/8$$

$$\delta = 3\Gamma$$

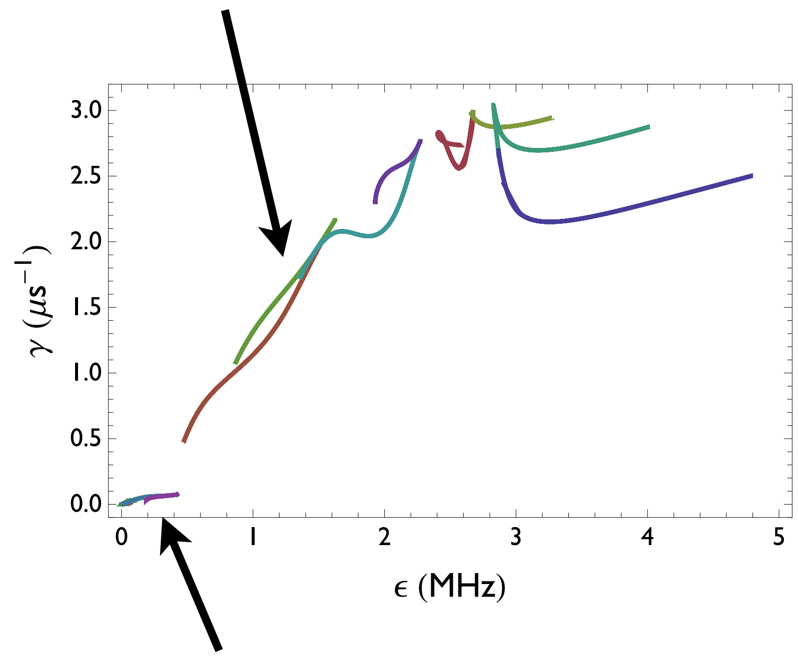
Light shift



Optical pumping rate



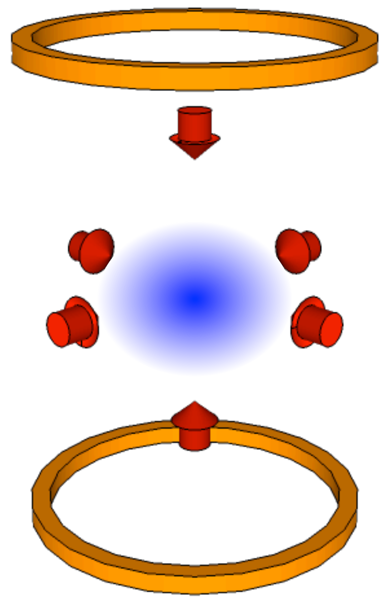
Positive correlation



Dark manifold

Courtesy of Saijun Wu

Experimental Sequence



MOT

$$I_{\mathrm{cool}} = 13 I_{\mathrm{sat}} \qquad N_0 = 5 - 7 \times 10^8$$

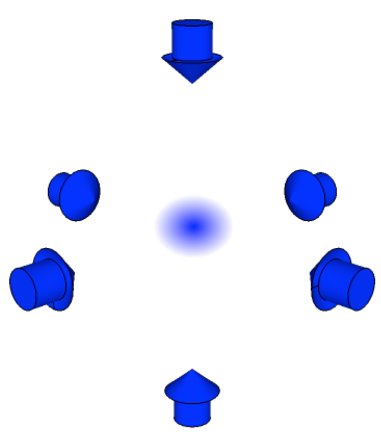
$$I_{\mathrm{repump}} = I_{\mathrm{cool}}/20 \qquad T \approx 200\,\mu\mathrm{K}$$

$$b' = 9\,\mathrm{G}\cdot\mathrm{cm}^{-1} \qquad I_{\mathrm{sat}} = 1.75\,\mathrm{mW/cm^2}$$

C-MOT

$$b' = 9 \xrightarrow{5\,\mathrm{ms}} 60\,\mathrm{G}\cdot\mathrm{cm}^{-1} \qquad T \sim 1\text{–}4\,\mathrm{mK}$$

$$\sigma_{\mathrm{rms}} = 1.4\,\mathrm{mm}$$



D_1 Molasses

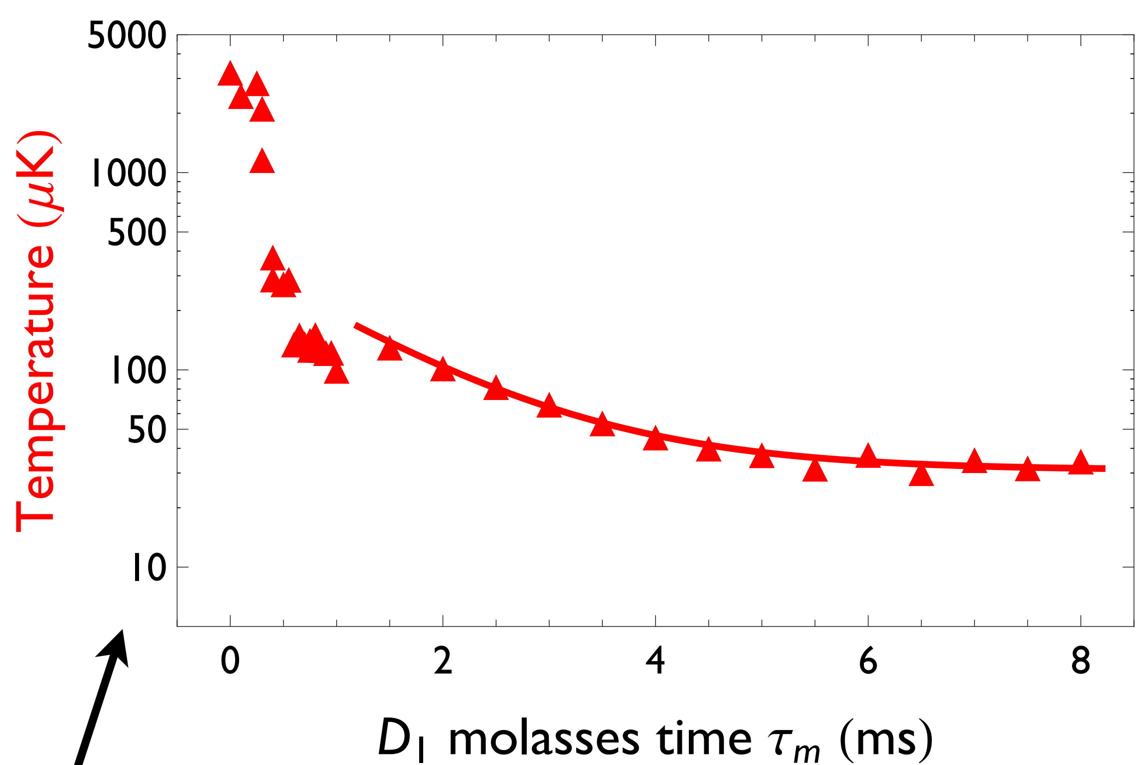
$$I_{\mathrm{cool}} = 14 I_{\mathrm{sat}}$$

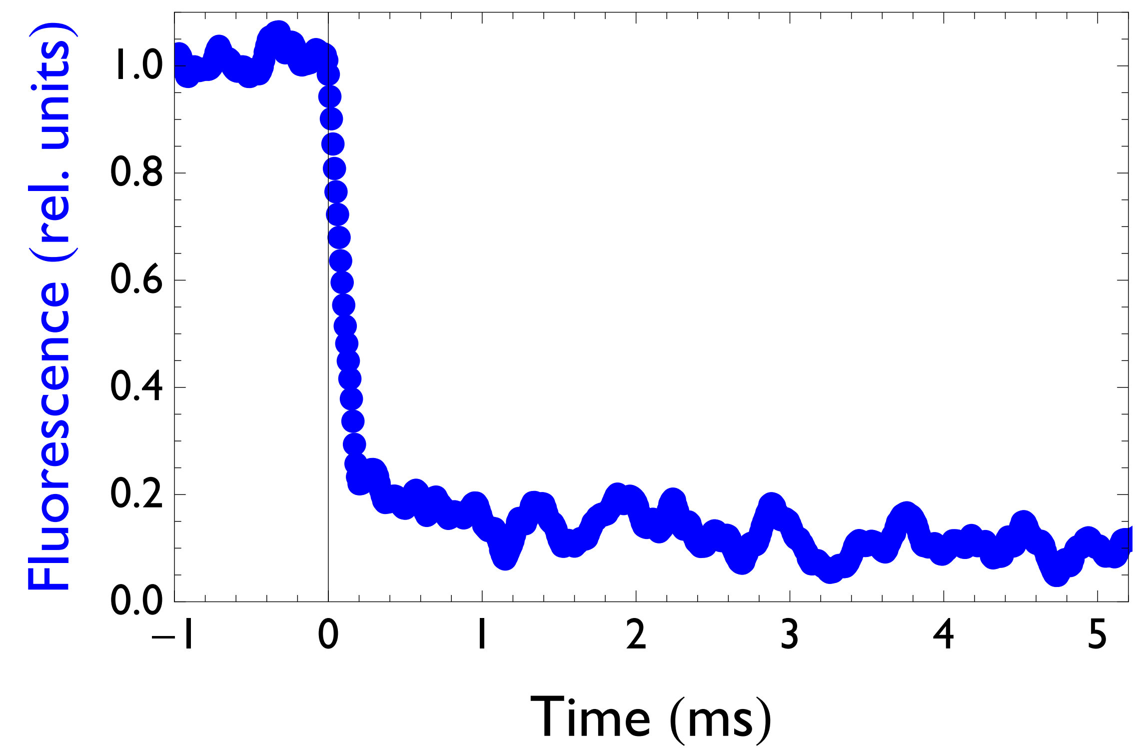
$$I_{\mathrm{repump}} = I_{\mathrm{cool}}/8$$

$$\vec{B} = 0$$

3D gray molasses in Cesium: Boiron, D. *et al.* (Y.C. & C.S.) PRA **53**, R3734 (1996)

Fast cooling dynamics





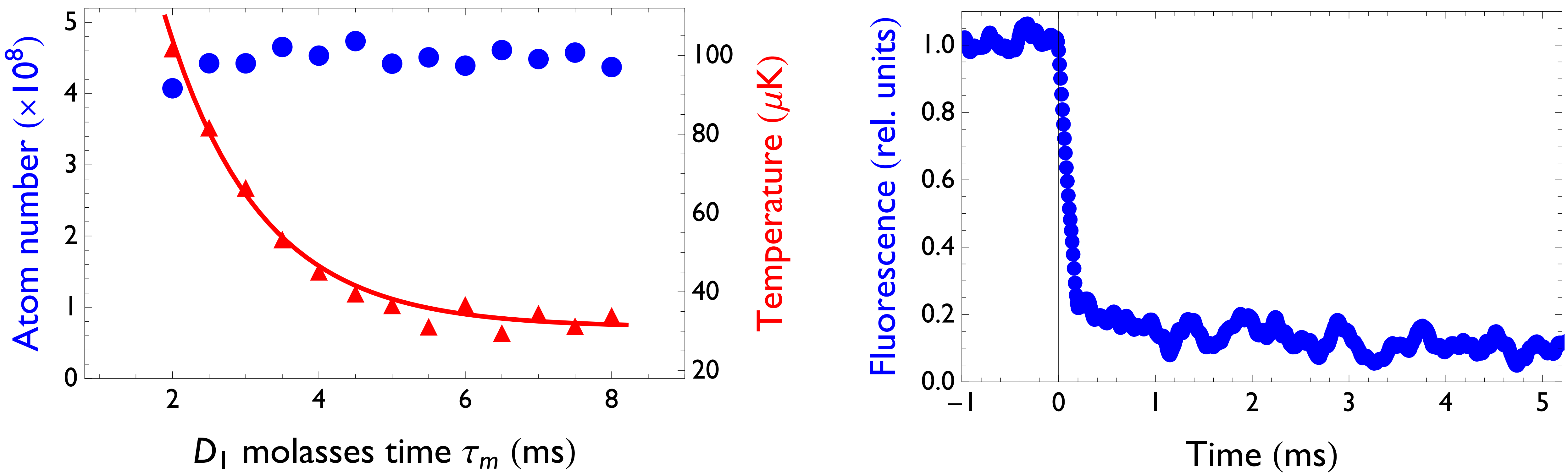
Log scale!

Two dynamics

Fast cooling: 4mK to ~100μK in <1ms

Slow cooling: 100uK to 30uK in 6ms

Fast cooling dynamics



Two dynamics → Fast cooling: 4mK to ~100μK in <1ms

Two dynamics → Slow cooling: 100uK to 30uK in 6ms

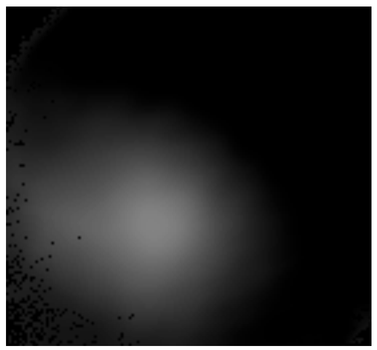
Capture efficiency in molasses = 100%

Plateau of low fluorescence ⇒ atoms trapped in dark states

Temperature determination

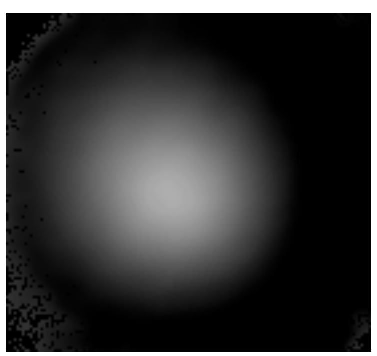
TOF=3.5ms

no molasses

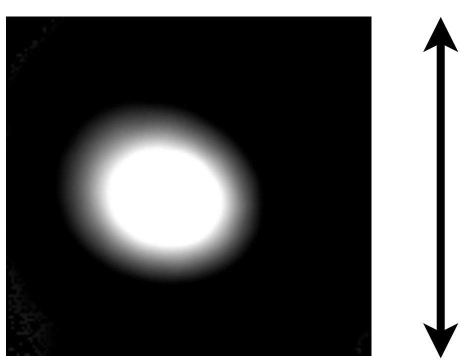


TOF=17ms

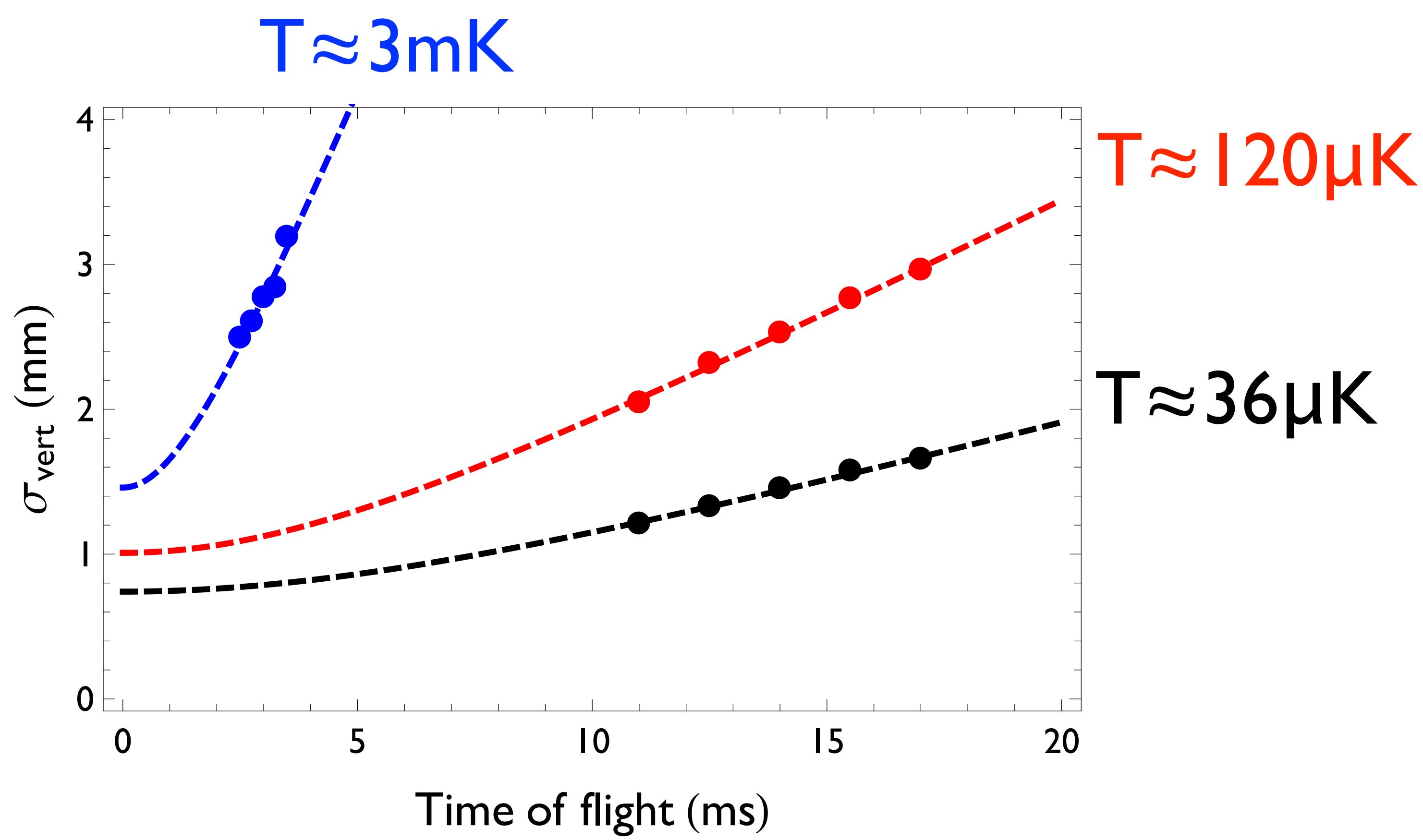
τ_M = 1.5 ms



τ_M = 6.0 ms



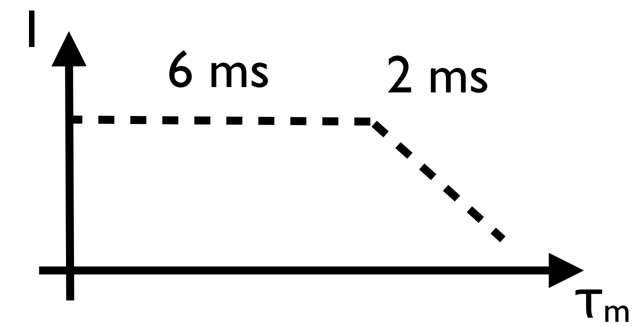
≈1.5 cm



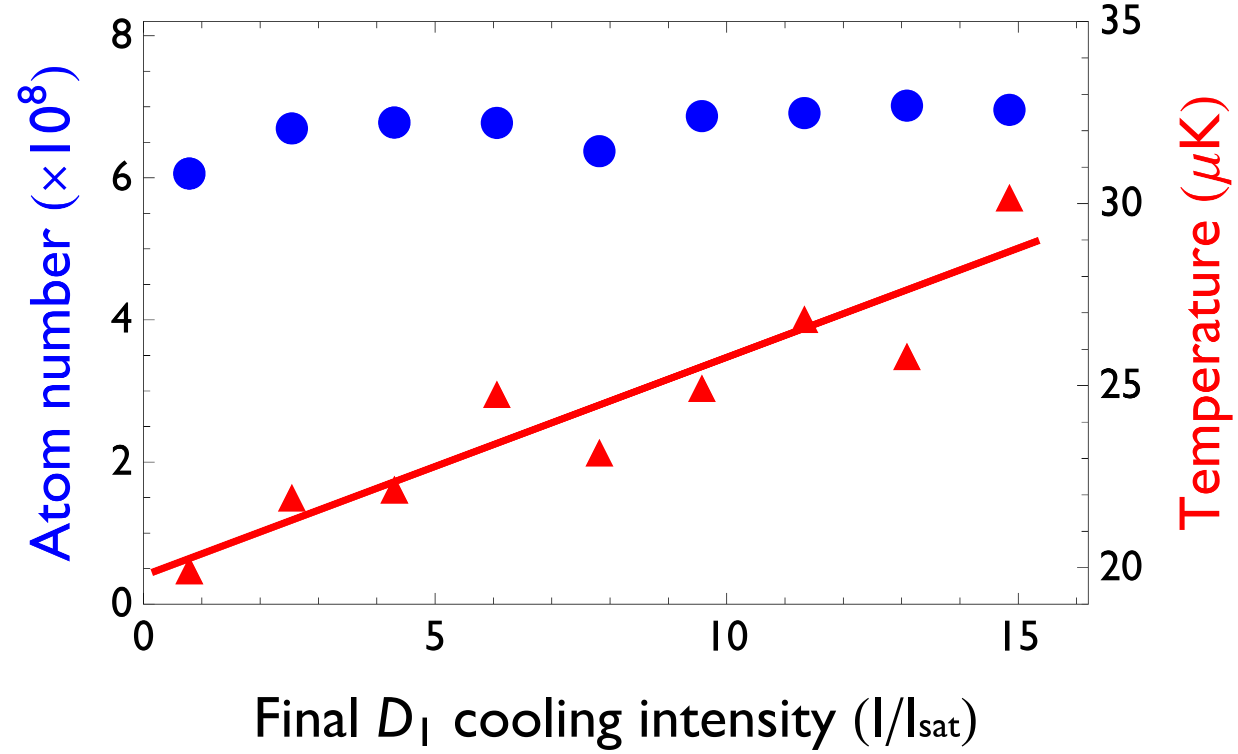
Light intensity dependence

Varying light intensity

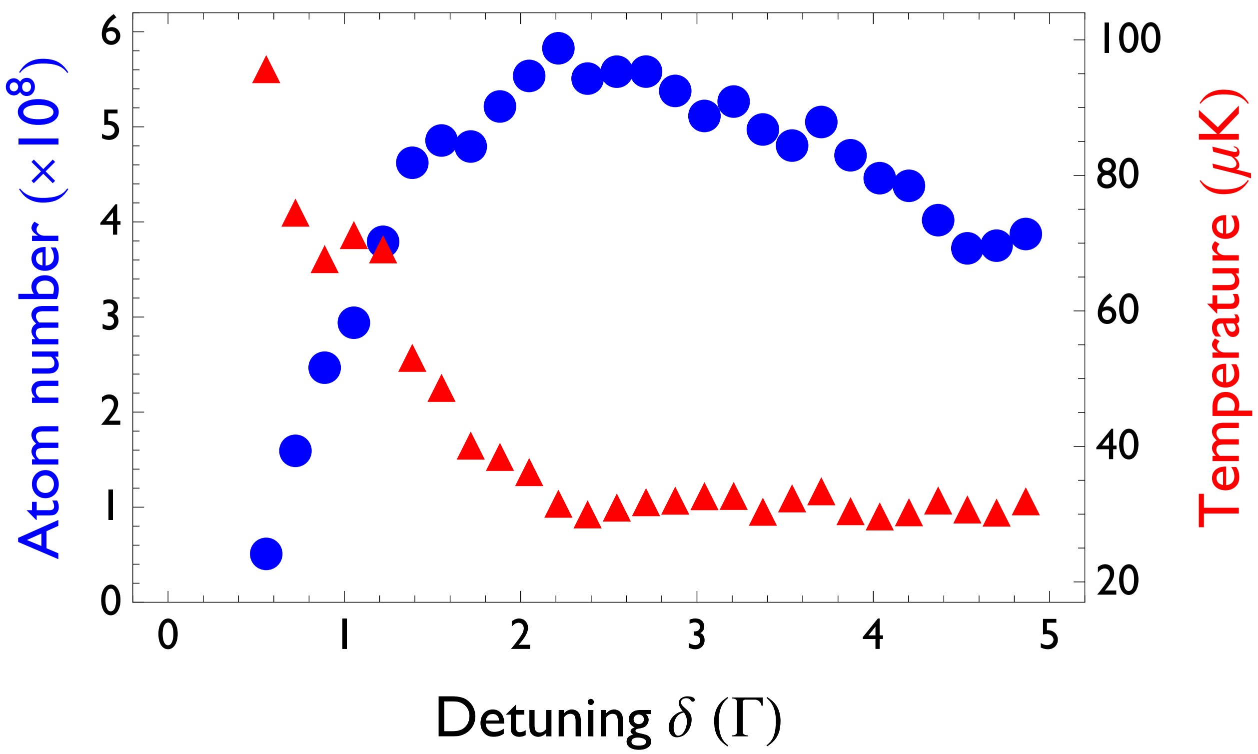
100% capture efficiency



Two-step sequence



Optimal parameters

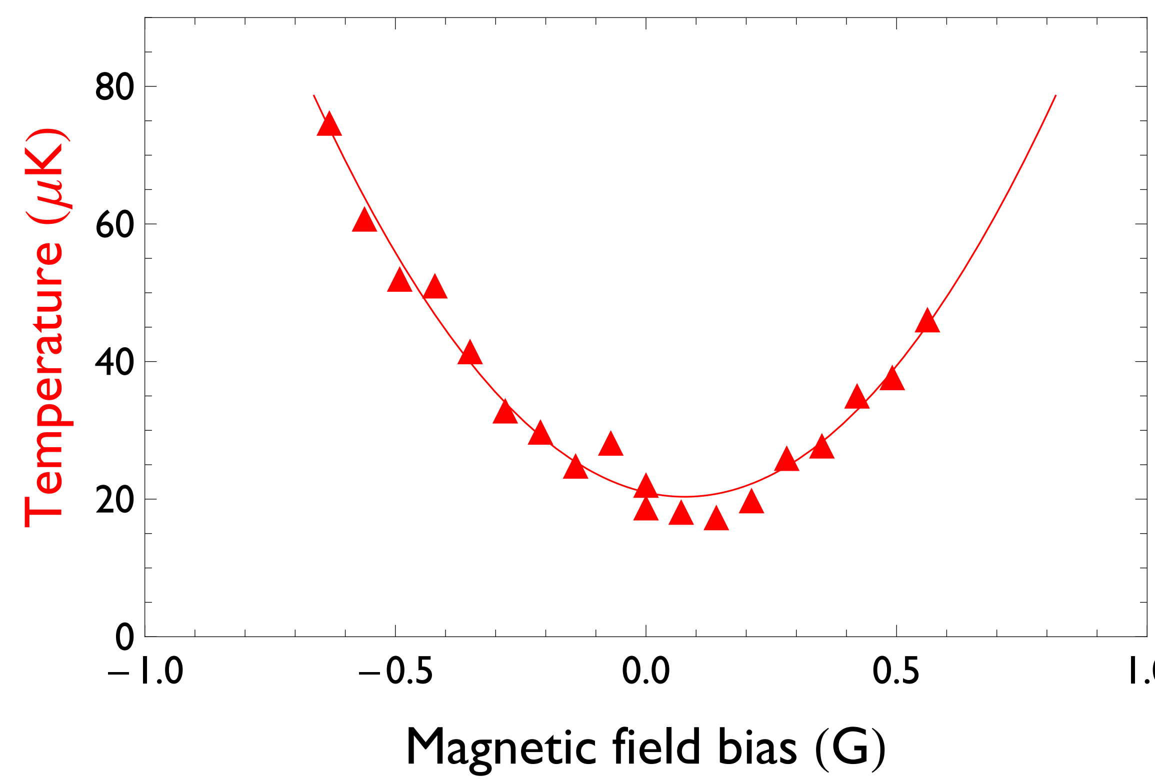


	duration (ms)	$I_{\text{cool}}(I_{\text{sat}})$
capture phase	6	14
cooling phase	2	$14 \to 1$

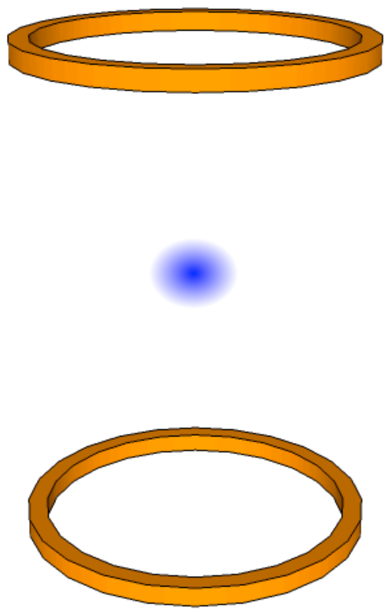
$$\delta_{\text{cool}} = \delta_{\text{repump}} = +2.3\Gamma$$
$$I_{\text{repump}} = I_{\text{cool}}/8$$
$$T_{\text{final}} \approx 20\,\mu\text{K}$$

Temperature limit of this scheme?

- ambient magnetic field bias compensated
- no atomic density dependence observed
- what is the limiting factor?
- role of the off-resonant excitation?



Loading into a Quadrupole Trap



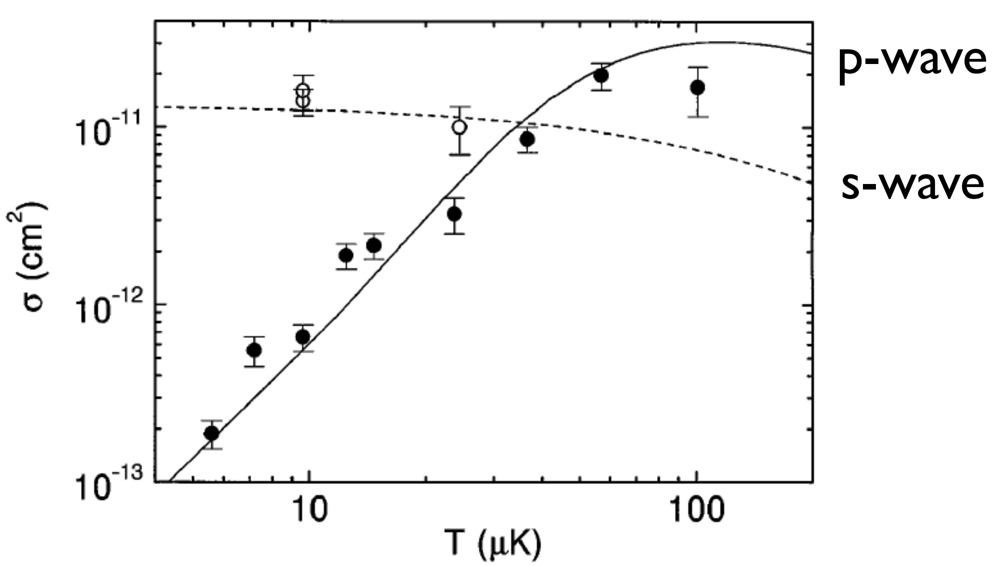
$$b' = 76\,\mathrm{G}\cdot\mathrm{cm}^{-1}$$
$$N = 2.5 \times 10^{8}$$
$$T = 80\,\mu\mathrm{K}$$

$$\mathrm{PSD} \approx 2 \times 10^{-5}$$

	D_2 molasses [1]	Blue MOT [2]
N	$\sim 10^{7}$	1.5×10^{8}
T(μK)	15	45
$n_0\,(\mathrm{cm}^{-3})$	$\sim 10^{10}$	1.2×10^{10}
PSD $(\times 10^{-5})$	0.4	0.04

[1] Modugno, G. *et al.* PRA **60**, R3373 (1999)

[2] McKay, D. et al., PRA **84**, 063420 (2011)



DeMarco, B. *et al.* PRL **82**, 4208 (1999)

→

Good starting point
for evaporation

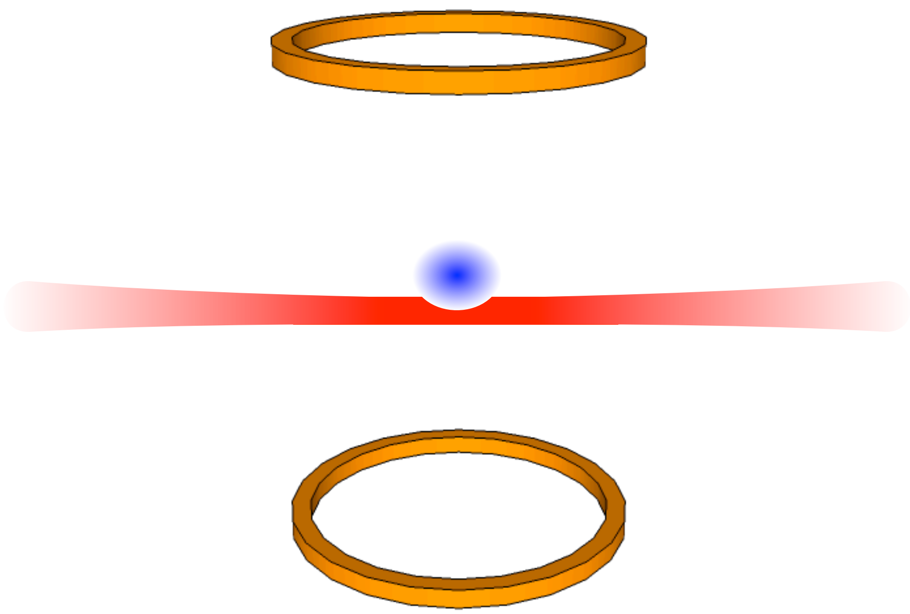
$$\gamma_{\mathrm{coll}} \approx 23\,\mathrm{s}^{-1}$$

Future Steps

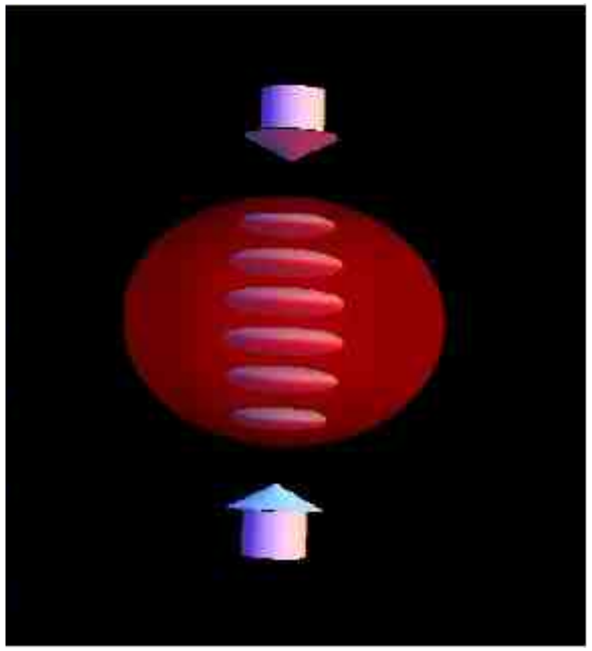
- Test the improvement on transport efficiency to the science cell

- Evaporation in a hybrid trap

- Loading into a 1D optical lattice
- Study of a system with mixed dimensions



Lin, Y.-J. *et al.* PRA **79**, 063631 (2009)



Nishida, Y. and Tan, S. PRL **101**, 170401 (2008)
Nishida, Y. PRA **82**, 011605(R) (2010)

D_1 molasses for Lithium isotopes
(preliminary results)

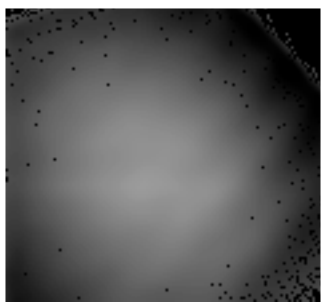
^{6}Li

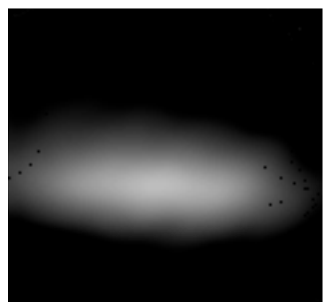
^{7}Li

Vertical lin⊥lin 1D gray molasses

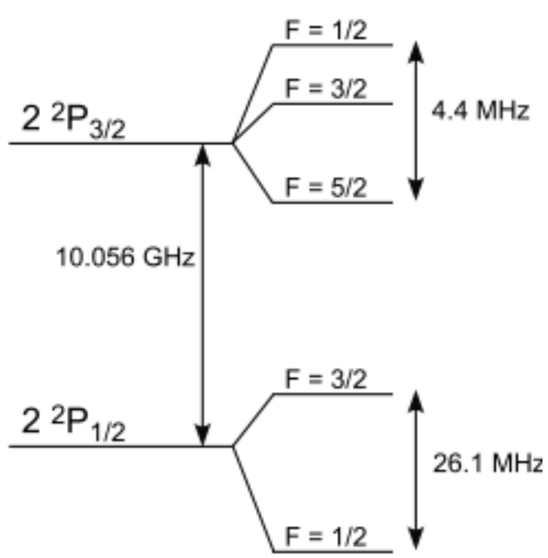
no molasses | with molasses

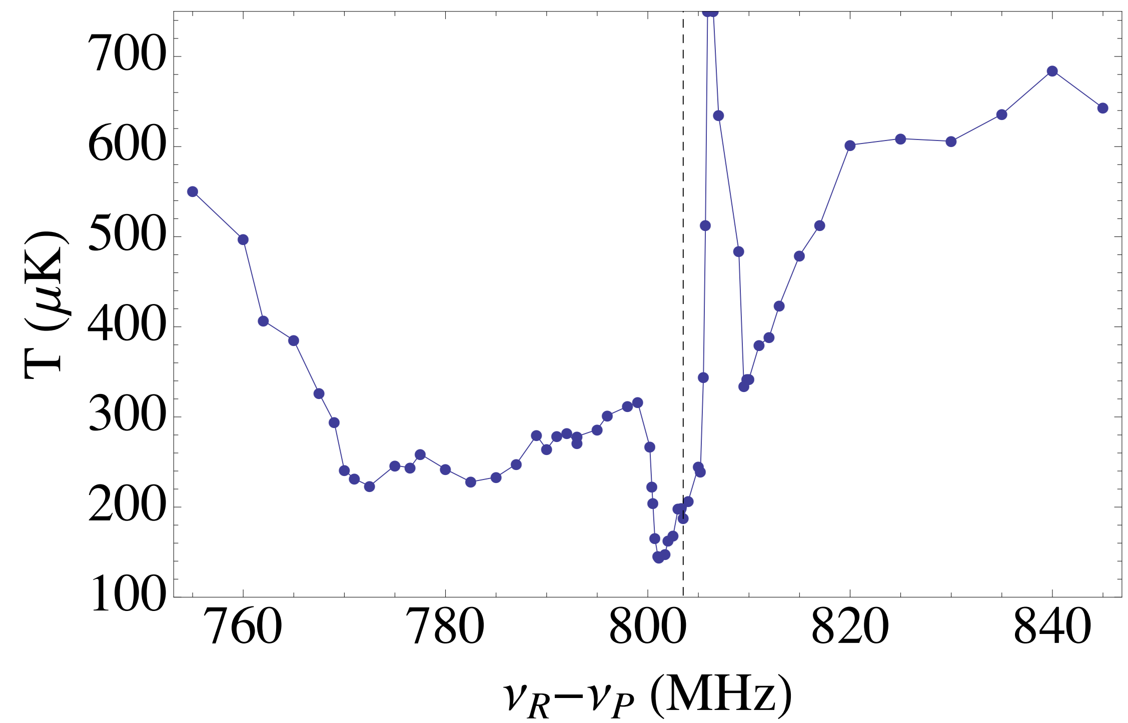
TOF = 2 ms

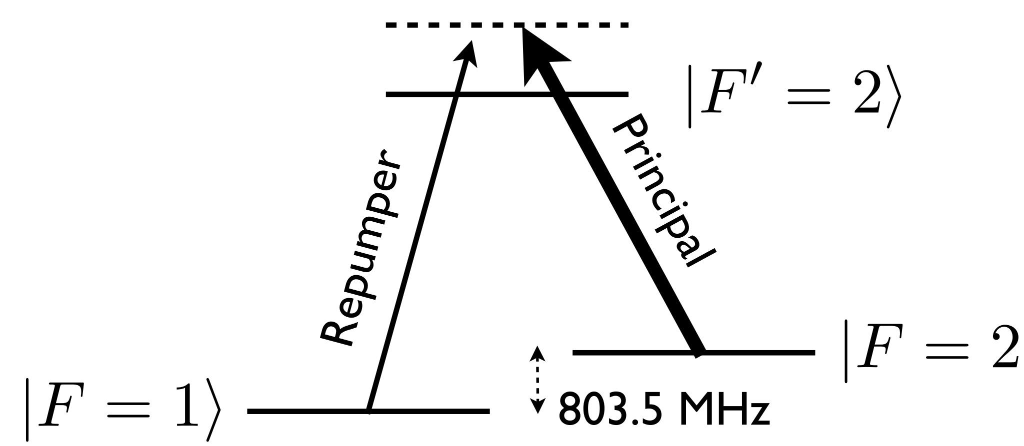




T_{vert} = 1 mK | T_{vert} = 60 μK



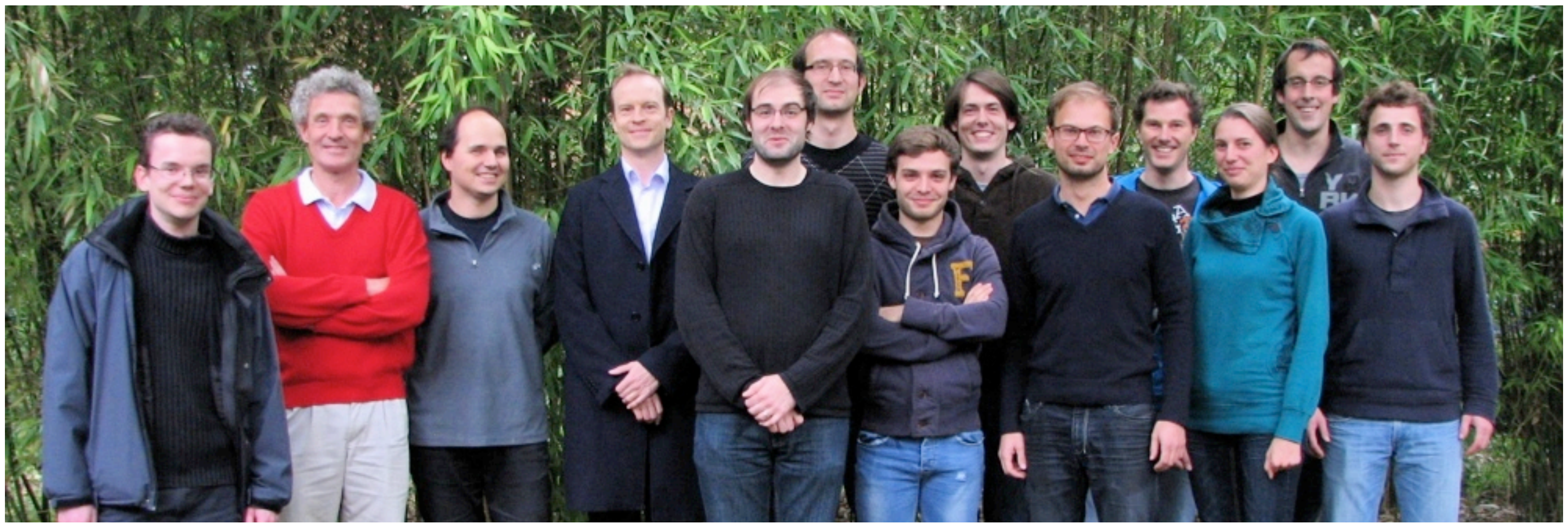




Thanks to Ulrich E. and Andrea B. for powerful laser source

Fermix-Termodynamix team

Christophe S. Norman K. Franz S.



Frédéric C. DRF

Saijun W.

Daniel S.

Lev K.

Thanks for listening

arXiv:1210.1310 [cond-mat.quant-gas]

ECOLE NORMALE SUPERIEURE
UPMC PARIS UNIVERSITAS
cnrs
erc European Research Council
IFRAF Institut Francilien de Recherche sur les Atomes Froids
FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA