ALL OPTICAL QUANTUM BUBBLE TRAP IN MICROGRAVITY

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in Aquitaine

INSTITUT d'OPTIQUE GRADUATE SCHOOL

Quantum gases in Microgravity

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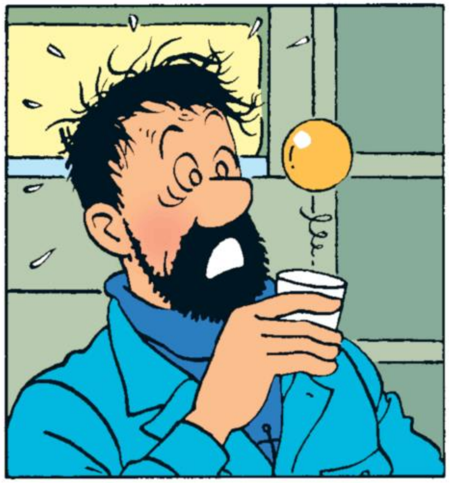
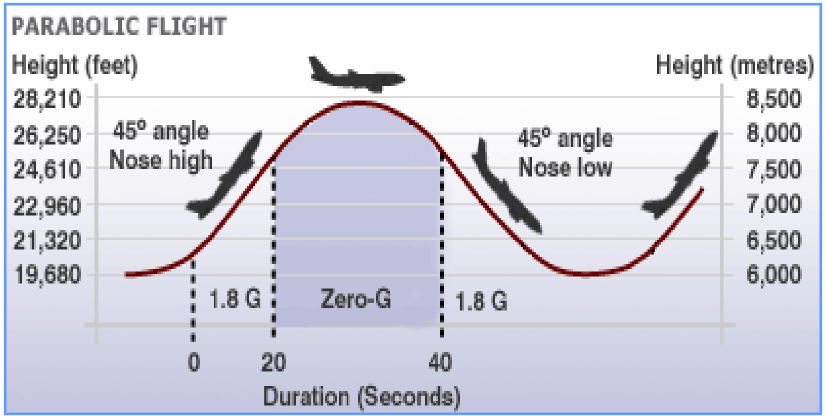
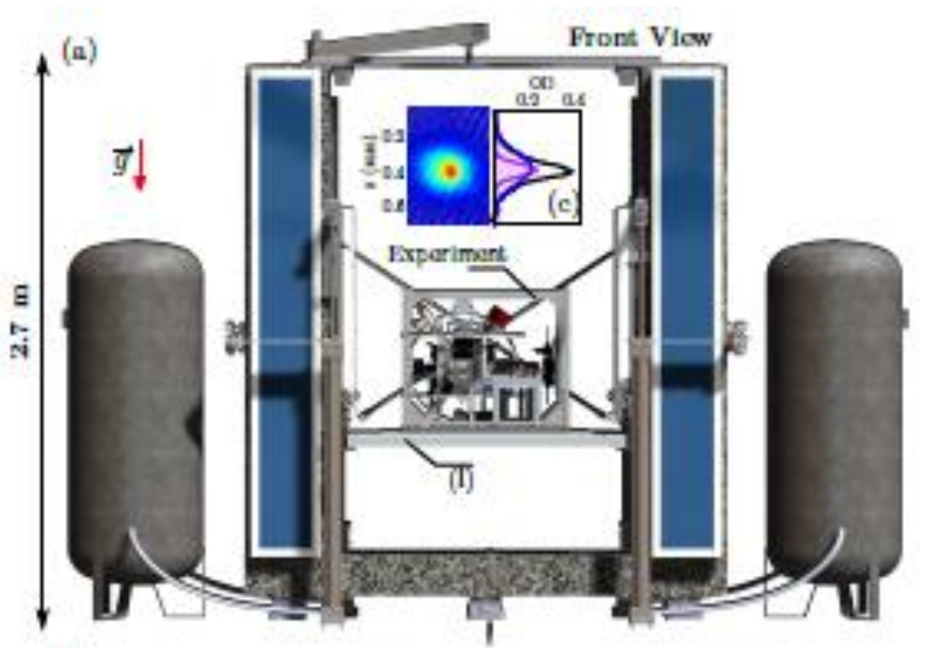


Quantum counter part of the whisky bubble:
2D system with a new topology

Our strengths:

- BEC in microgravity
- All optical methods

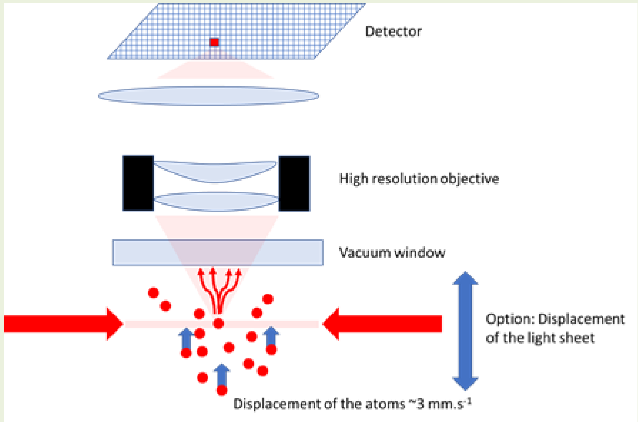




WHY A LASER?

Advantages of all optical method:

- Feshbach resonances → interactions
- ≈ spin-independent trap
- Optical access

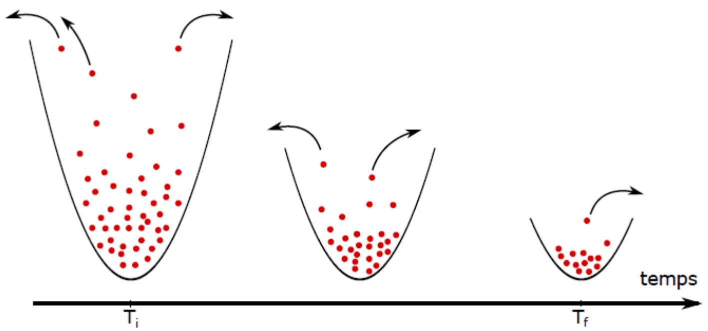


- Light engineering → atom transport, spherical potential…

Space: The atoms doesn't fall +magnetic trap=atom chip

All optical Bose Einstein Condensate

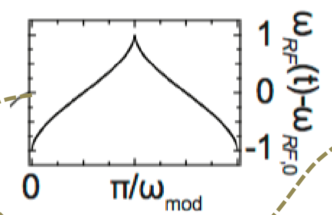
- **Evaporative** cooling

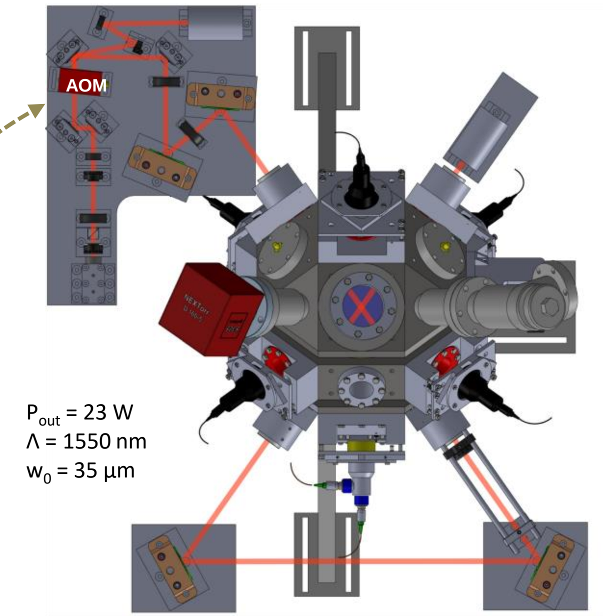


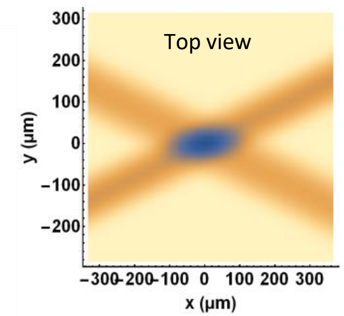
- **Dipole** force:

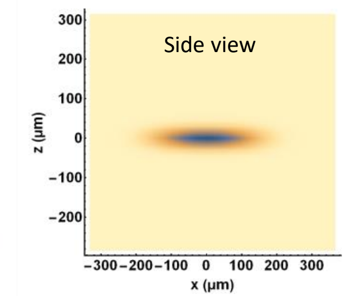
$$\widetilde{U}(x) = \frac{1}{T_{mod}} \int_0^{T_{mod}} U(x - \xi(t))dt$$

$$U(r) = \frac{\hbar\Omega(r)^2}{4\delta} = \frac{\hbar\Gamma^2}{8\delta}\frac{I(r)}{I_s}$$









- Compact Optical Dipole Trap for onboard applications/Fibered telecom laser 22W CW

- **Time Averaged Potential**

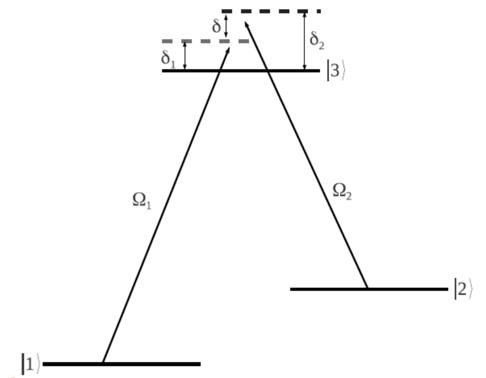
R. Roy et al, PhysRevA 93.043403

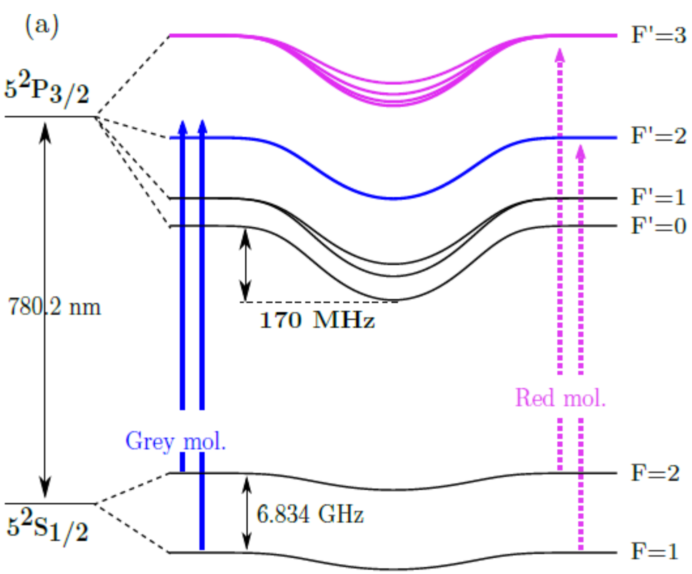
ALL OPTICAL BOSE EINSTEIN CONDENSATE

COLD ATOM RESERVOIR

- Grey Molasses and Velocity Coherent Population Trapping (VCPT)
- Λ-enhanced scheme (Raman condition δ=0, phase locked beams)
  - Long-lived Dark states
  - Lower diffusion rate
  - 5 times faster than red detuned molasses

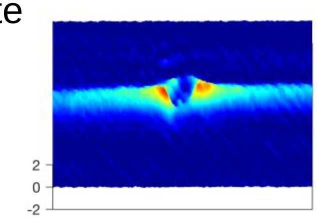
$$|NC\rangle = (\Omega_2|1\rangle - \Omega_1|2\rangle) \, / \, (\Omega_1^2 + \Omega_2^2)$$





EFFICIENT LOADING EFFICIENCY

- The 'trapped' atoms are transparent to the cooling beam thanks to the light shift of the excited state



- The trap is spatially modulated to increase the capture volume

FAST COOLING

- The trap is compressed adiabatically, and the evaporative cooling is achieved in about 1s

BEC with 100 000 atoms (Tc=140 nK)

MICROGRAVITY AT « HOME »

- ZERO-G simulator (including partial gravity)
- 500 ms of microgravity
- 1 shot every 13.5 s
- 125 hours of microgravity per year
- Payload mass: 250 kg
- Payload size: 1 m^3

Symetrie (Nîmes, France)

ALL OPTICAL BEC IN MICROGRAVITY

- The evaporative cooling is achieved during the phase of hypergravity
- 10000 condensed atoms (Tc~150 nK)
- Minimal temperature of 35 nK by adiabatic decompression of the trap

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All-Optical Bose-Einstein Condensates in Microgravity

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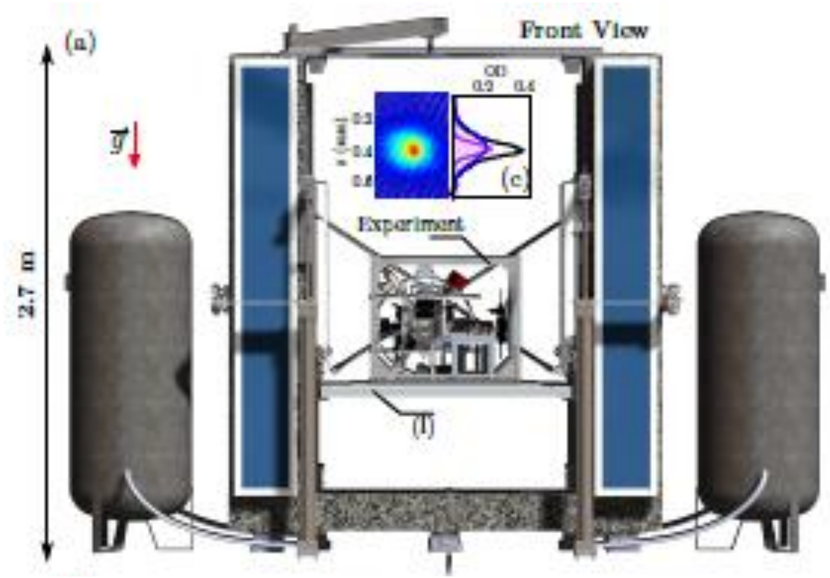
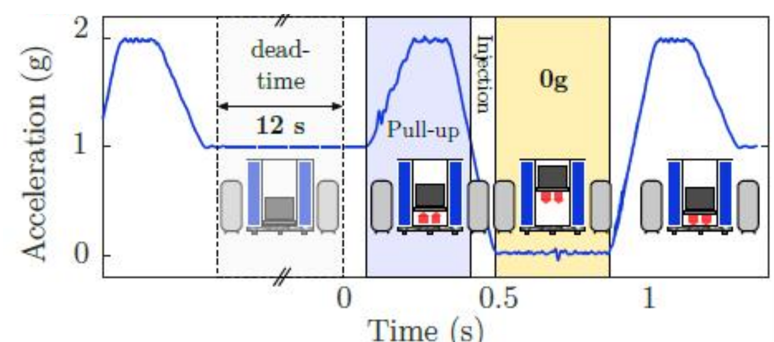
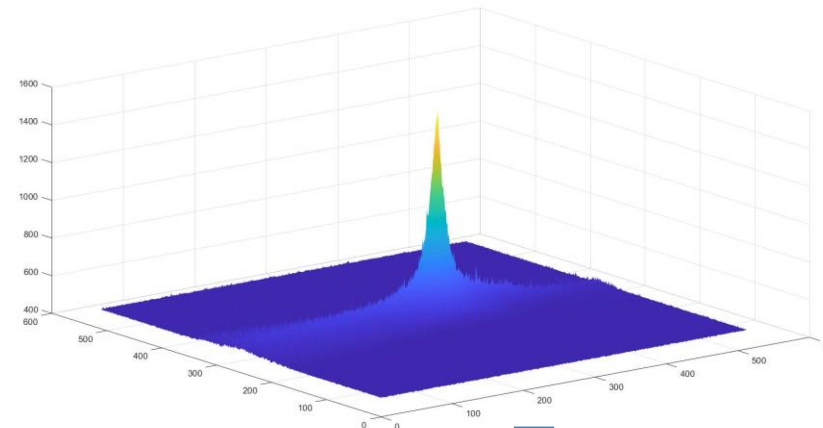


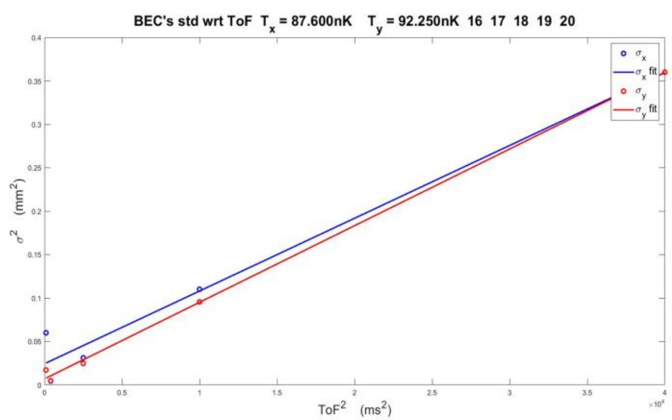
240 BECs per hour
200 000 BECs per year
Effective microgravity time per year: 125 hours



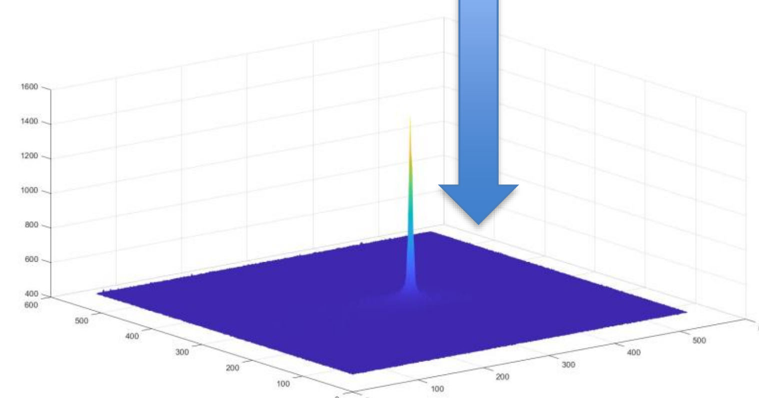
ALL OPTICAL BEC ONBOARD THE ZERO-G PLANE



Spatial expansion of ultra-cold gas during 100 ms



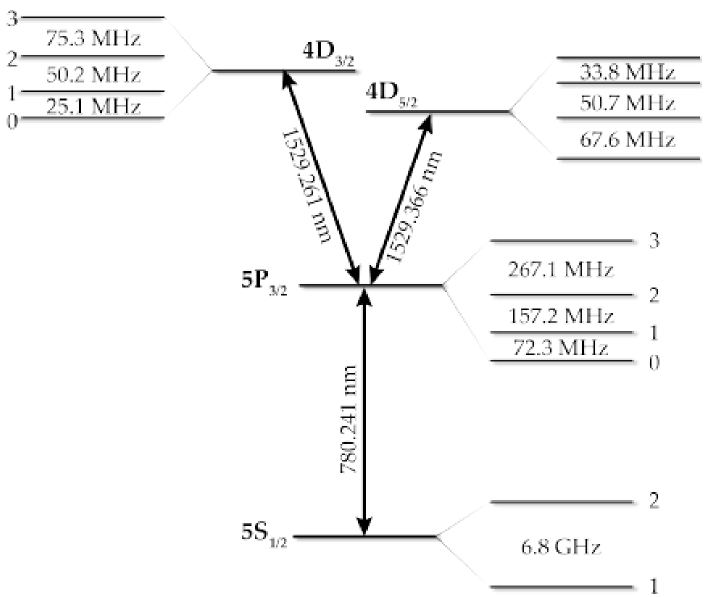
Evaporative Cooling
In a dipole trap

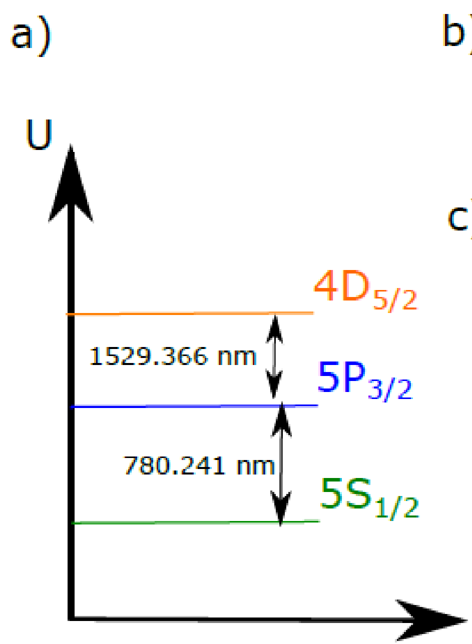


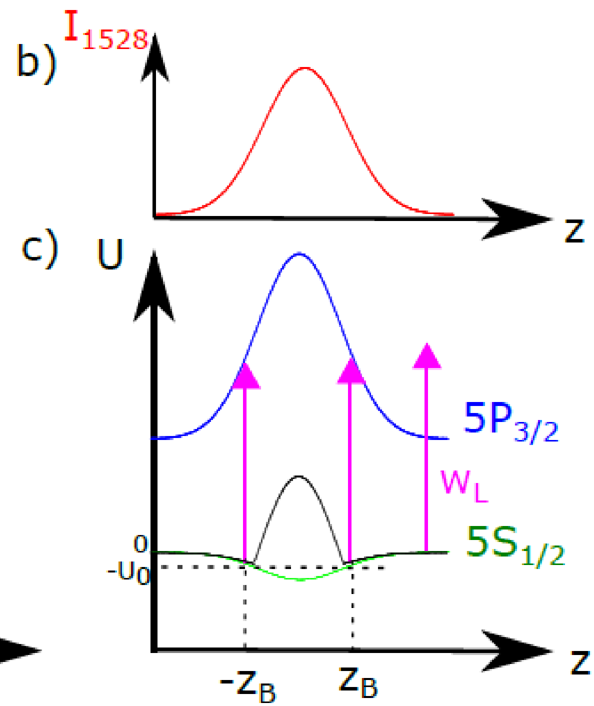
PRINCIPLE OF THE ALL-OPTICAL BUBBLE

Double dressed states

- Telecom wavelength → lighshift of the excited states (**blue detuned**)
- 780 nm light







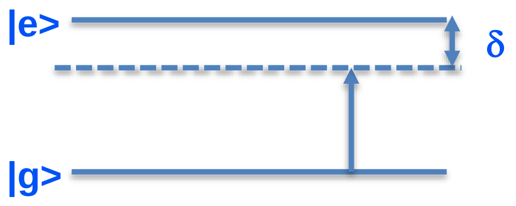
Dressed State picture

- Physical model from [Dalibard1985]

- The dressed states |1> and |2> are a superposition of |g> and |e>.

$$|1,n;\boldsymbol{r}\rangle = exp[i\varphi(\boldsymbol{r})/2]\cos\theta(\boldsymbol{r})\,|e,n\rangle + exp[-i\varphi(\boldsymbol{r})/2]\sin\theta(\boldsymbol{r})\,|g,n+1\rangle$$

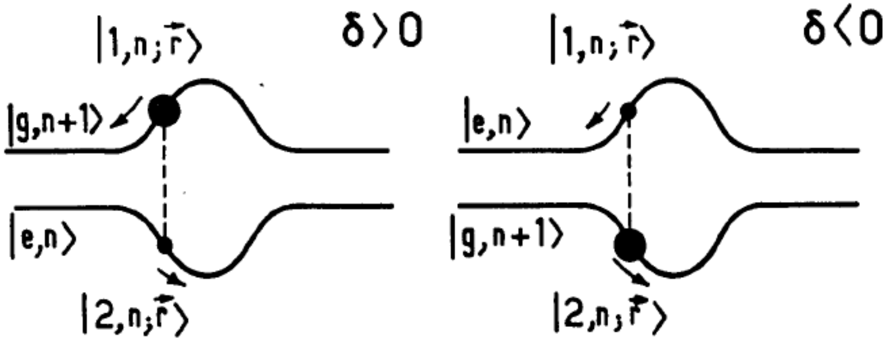
$$|2,n;\boldsymbol{r}\rangle = -exp[i\varphi(\boldsymbol{r})]\sin\theta(\boldsymbol{r})\,|e,n\rangle + exp[i\varphi(\boldsymbol{r})]\cos\theta(\boldsymbol{r})\,|g,n+1\rangle$$



$$\cos 2\theta(\boldsymbol{r}) = -\delta/\Omega(\boldsymbol{r}) \qquad \sin 2\theta(\boldsymbol{r}) = \omega_1(\boldsymbol{r})/\Omega(\boldsymbol{r})$$

- The dipole force (first term) depends on the population ratio in |1> et |2>. For instance it can explain the sign of the force related to the detuning (δ>0 or δ<0):

$$F_{dip} = \frac{\hbar\nabla\Omega}{2}(\rho_{22}-\rho_{11}) - \hbar\nabla\theta(\rho_{12}+\rho_{21})$$



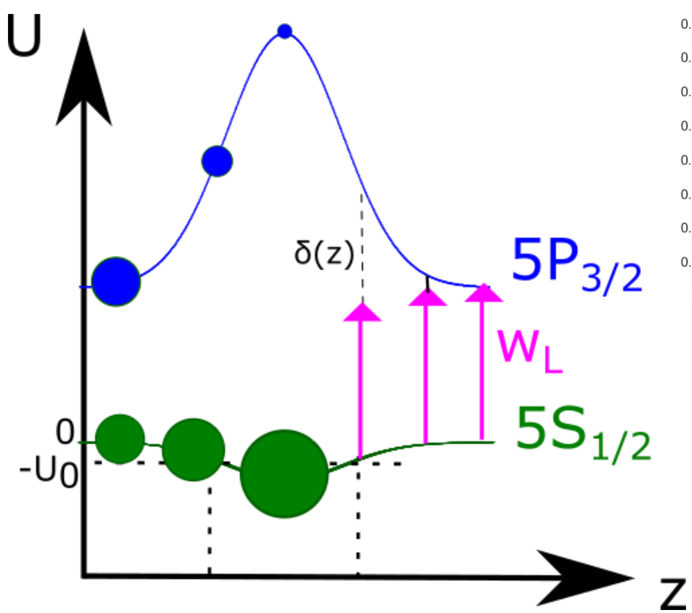
[Dalibard1985] J. Dalibard and C. Cohen-Tannoudji. Dressed-atom approach to atomic motion in laser light : the dipole force revisited. J. Opt. Soc. Am. B, 2(11) :1707-1720 (1985).

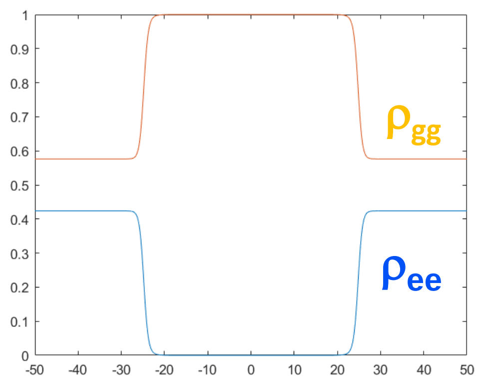
DOUBLE DRESSED STATE

- Idea from Aufrons [Bellouvet2018]: double dressed states

$$U(z) = \int_{\infty}^{z} dz' \left\langle \frac{d\hat{p}_A(z')}{dt} \right\rangle = -\int_{\infty}^{z} dz' \left[\rho_{ee}(z') \frac{dU_{5P}}{dz'} + \rho_{gg}(z') \frac{dU_{5S}}{dz'} \right]$$

- 780 nm light implies a mixing of the population in state 5P and 5S, which modifies the dipole force produced by the telecom laser.





$$\rho_{ee}^{st}(z) = \frac{\Omega_R^2}{\Gamma(z)^2 + 4\delta(z)^2 + 2\Omega_R^2}$$

Spatial dependent detuning 5S -> 5P

Lifetime 5P

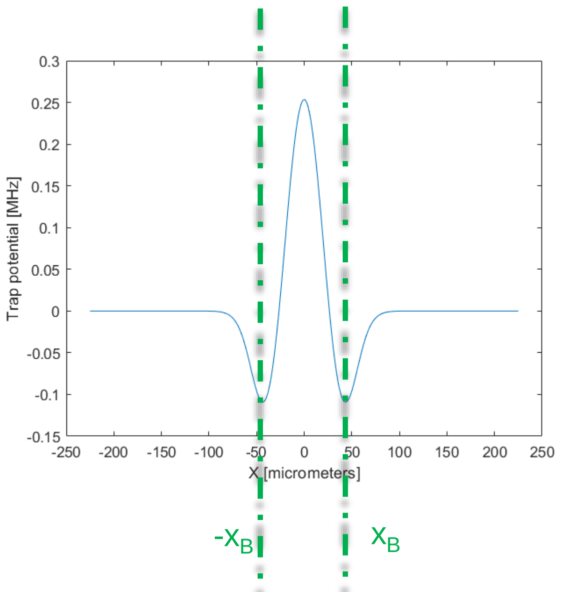
780 nm

[Bellouvet2018] M. Bellouvet, C. Busquet, J. Zhang, P. Lalanne, P. Bouyer, and S. Bernon. Doubly dressed states for near-field trapping and subwavelength lattice structuring. Phys. Rev. A, 98 :023429 (2018).

Parameters of the Trap

- Trap frequency ω : fit of the trap potential
- Trap depth U_0
- Bubble Radius R_{bub}
- Diffusion rate τ_D $\qquad \tau_d = \frac{1}{\Gamma \rho_{ee}(x_B)}$
- Escaping rate τ_S

$$p_{eff} = \sqrt{\frac{2}{5}}\hbar\frac{\omega_{780}}{c} \qquad \tau_S = \frac{2mU_0}{p_{eff}^2 \Gamma \rho_{ee}(x_B)}$$



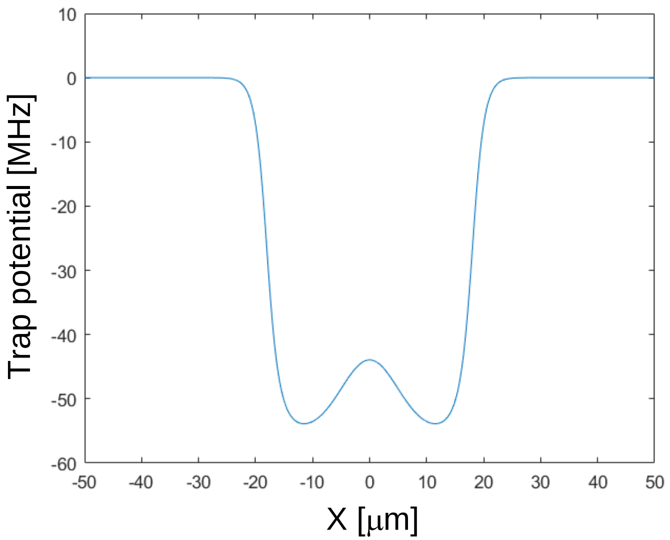
SUMMARY

- Waist laser telecom: 10 μm
- λ_1=1529 nm, P_1= 0.925 W,
- 780 nm laser: $\lambda_{780}+0$ MHz
- Ω_R=100 MHz

$\omega=2\pi*6351$ Hz
$U_0/h= 2\pi*(-53.9)$ MHz
R_{bub}= 11.5 μm
τ_D= 97 μs
τ_s= 3.5 s

Control of the parameters:

$\lambda_1 \rightarrow \omega, R_b, \tau_D$
$P_{1529} \rightarrow \omega, R_b$
waist $\rightarrow \omega, R_b$
$\delta_{780} \rightarrow \omega, U_0$
$\Omega_R^{780} \rightarrow \omega, U_0, R_b$



$\lambda_1 \rightarrow$ Funny zone between the two transitions at 1529 nm

Play with λ_1 To increase τ_D (τ_D~74 ms for λ_1=1529.26099 nm tradeoff with Trap frequency, or required more laser power)

The trap is decompressed when we decrease the radius Rb (with Larger waist for instance or playing with Ω_R) $\rightarrow$ the telecom power can be increased to increase both at the same time

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