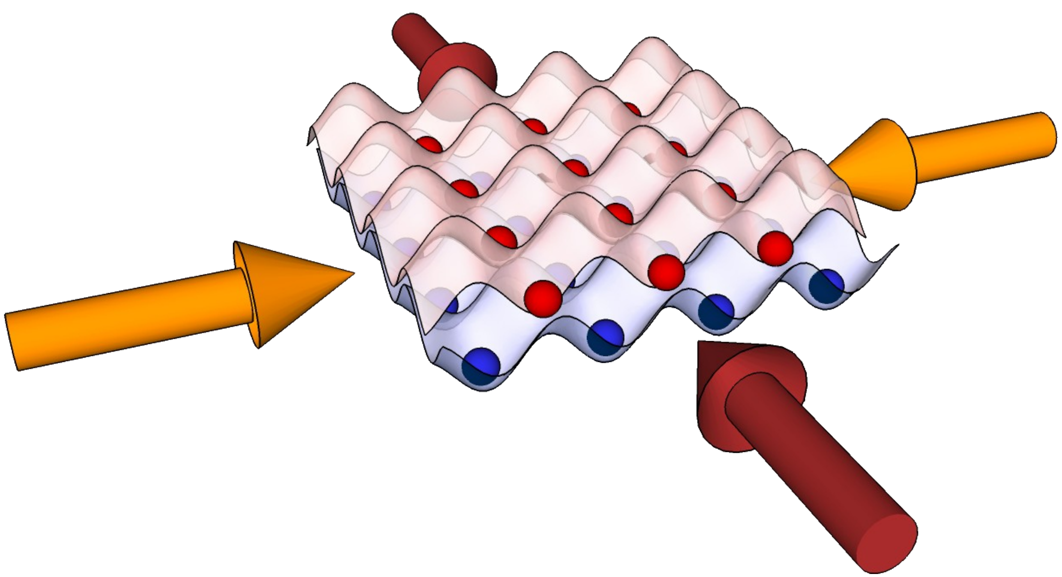
15/06/2012 – Alexandre DAREAU – Équipe Ytterbium

On the road to artificial gauge fields : Ytterbium cooling



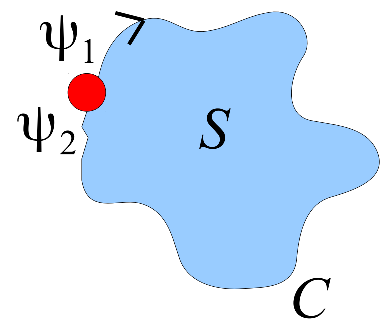
▶ Aharonov-Bohm effect :

Orbital magnetism for a charged particle

$$H = \frac{(\boldsymbol{P} - q\,\boldsymbol{A})^2}{2\mathrm{M}}$$

$$\boldsymbol{B} \neq 0 \Rightarrow \nabla \times \boldsymbol{A} \neq 0$$

Non-zero phase on a closed loop



$$\psi_2 = e^{i\alpha}\psi_1$$

Topological Berry phase : $\alpha = \frac{q}{\hbar}\oint_C \boldsymbol{A}\,dl = \frac{q}{\hbar}\iint_S \boldsymbol{B}\,ds$

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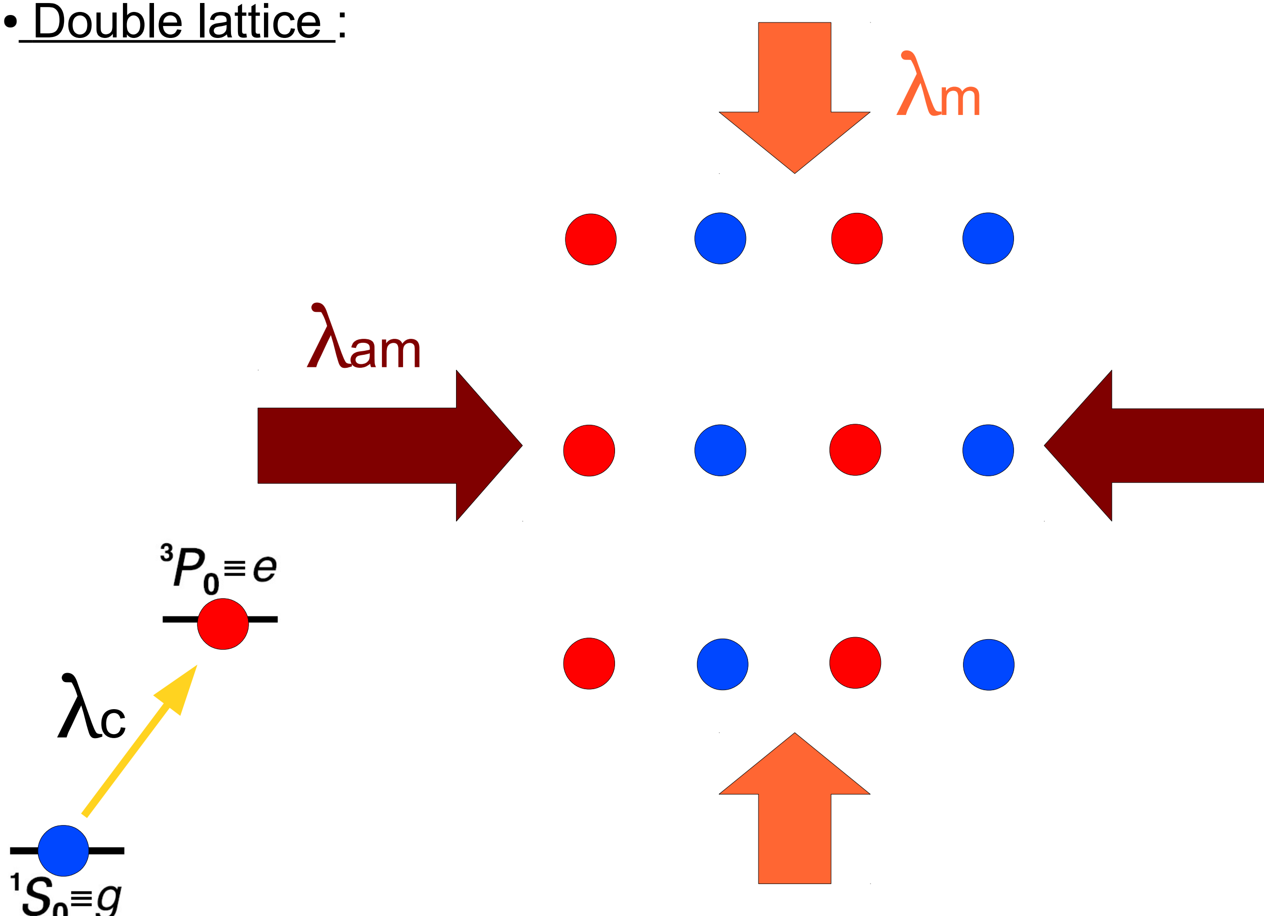
▶ Artificial gauge fields simulation :

- Double lattice :



F. Gerbier, J. Dalibard, New J. Phys. 12, 033007 (2010)

- Special wavelengths :

λ_m = "magic"

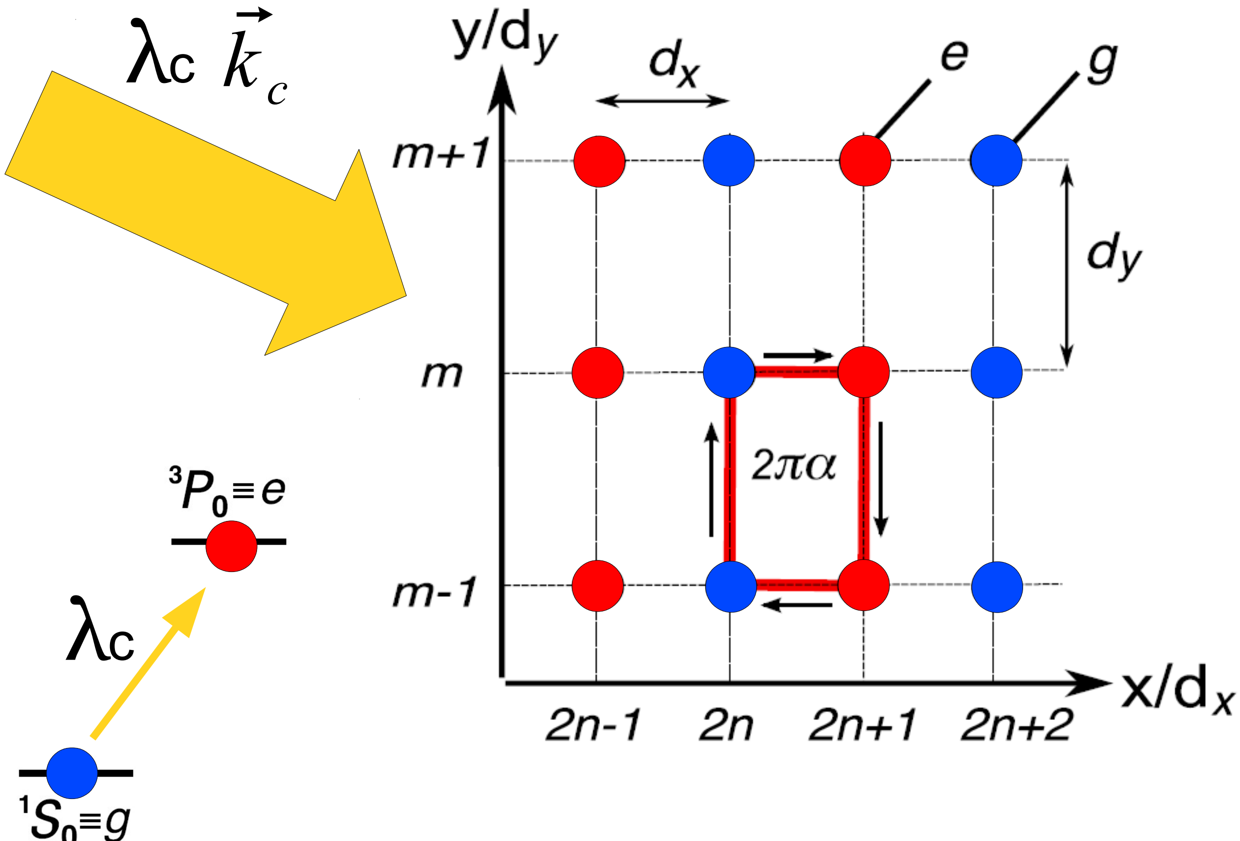
Same polarizability for *e* and *g*

λ_m = "anti -magic"

Opposite polarizability for *e* and *g*

▶ Artificial gauge fields simulation :

• Working diagram :



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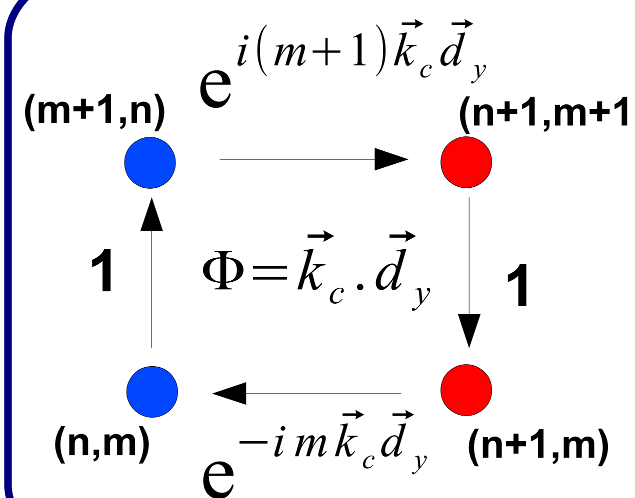
• X jumping induced by light :

$$|g\rangle \xrightarrow{\pi-pulse} -e^{i\Phi_m}|e\rangle$$

$$\Phi_m = m\,\vec{k}_c.\vec{d}_y$$



➡ Allows to simulate artificial magnetic fields using **neutral** particles.

NB : max flux $\Phi_{max}=k_c d_y=2\pi(\lambda_m/2\lambda_c) \longrightarrow \alpha_{max}=(\lambda_m/2\lambda_c)\approx 0{,}66$

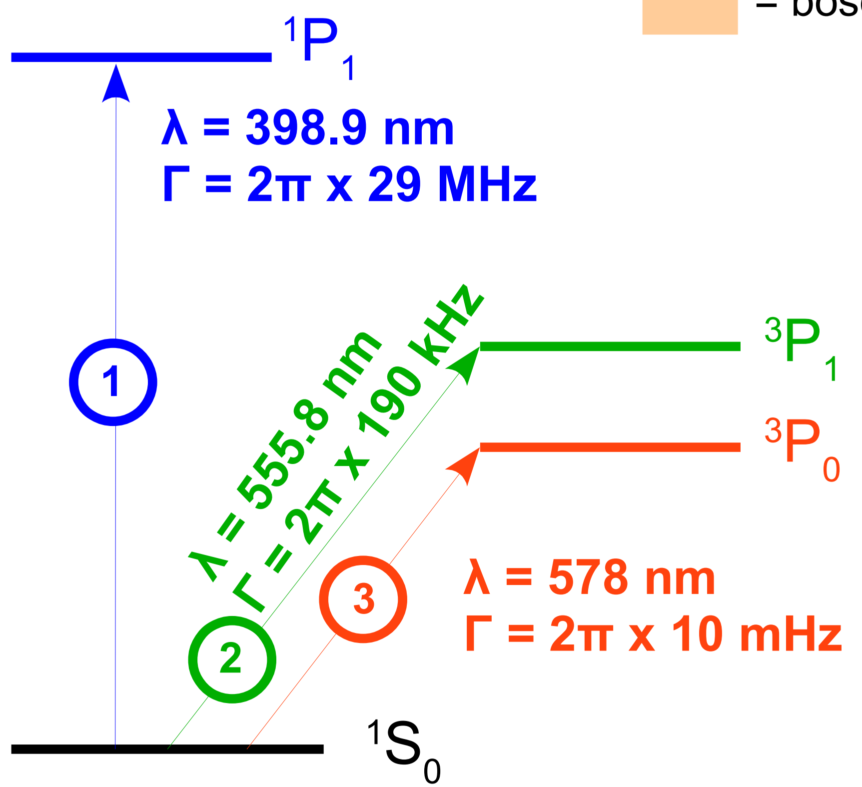
▶ Ytterbium : lanthanide (Z=70)

Isotope (N)	168	170	171	172	173	174	176
Abundance (%)	0,1	3	14	22	16	32	13
Nuclear spin	0	0	1/2	0	5/2	0	0

= fermion (171, 173)

= boson (168, 170, 172, 174, 176)

▶ Ytterbium atomic levels :



1 « Blue » transition : 399 nm

- Large Γ → efficient slowing
- T_D = 690 μK

→ **Zeeman ? MOT ?**

2 « Green » transition : 556 nm

- Small Γ → low Doppler temp.
- T_D = 4.4 μK

→ **Zeeman ? MOT ?**

3 « Clock » transition : 578 nm

- Metastable excited state
- lifetime ~ 16 s

→ **Coupling laser**

Yb MOT : T. Kuwamoto et al, PRA (1999), Yb BEC : Y. Takasu et al, PRL (2003)

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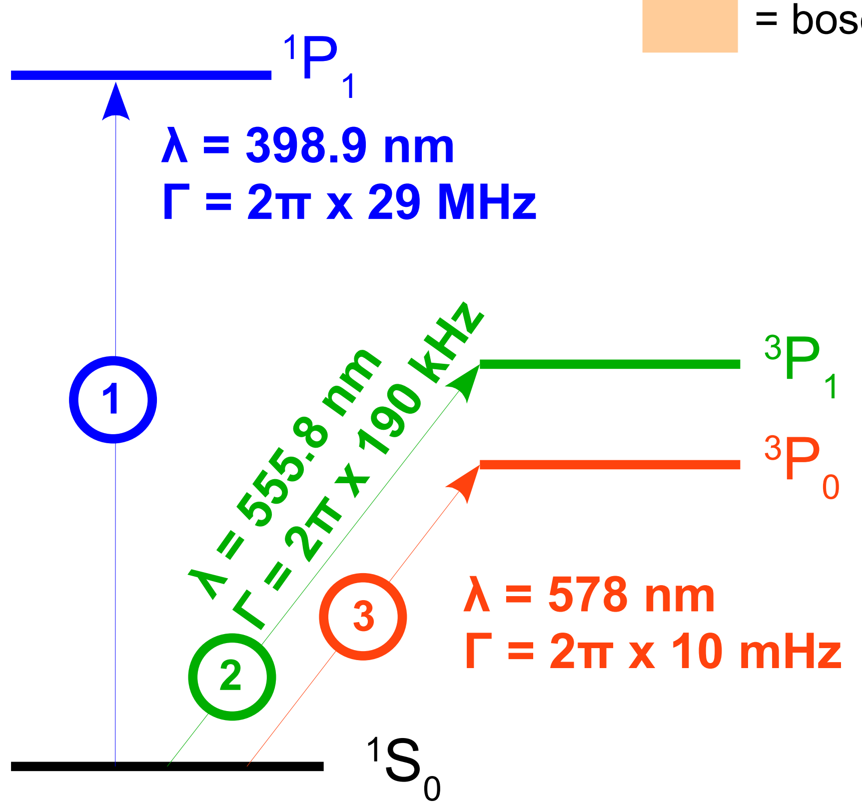

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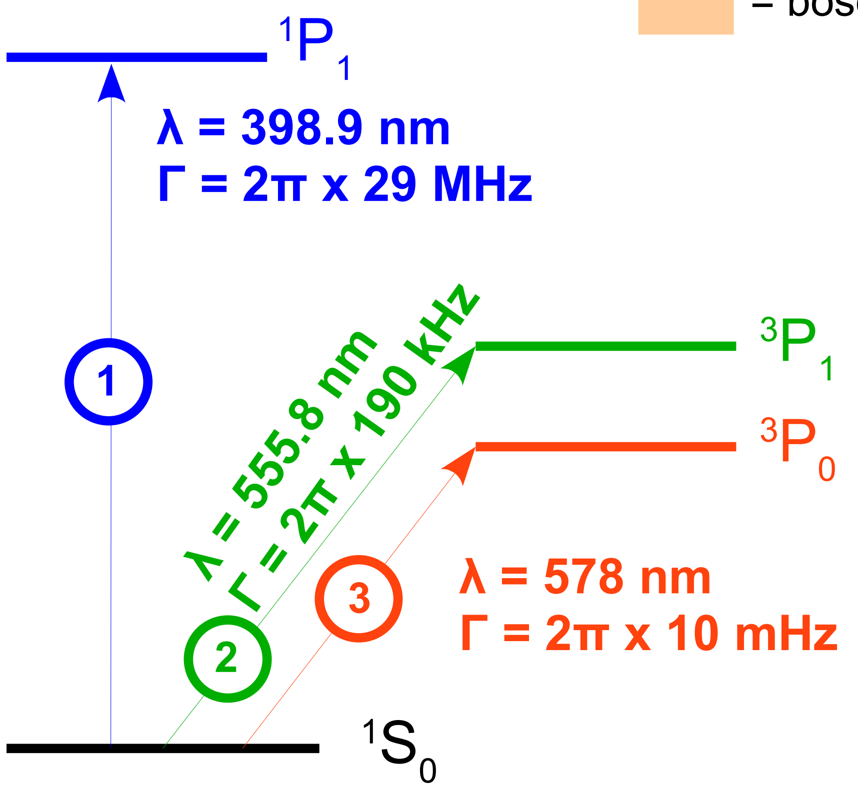

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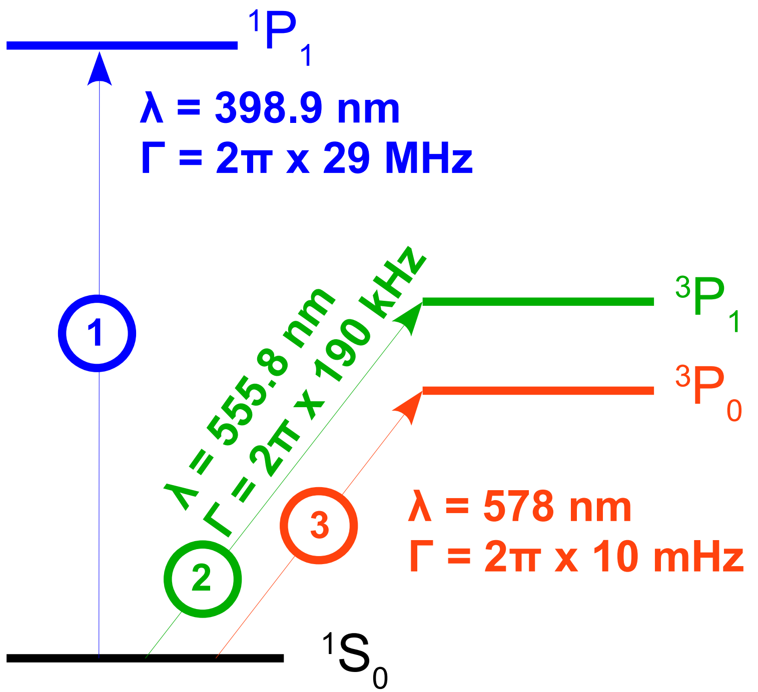
► Zeeman slower :

$F_{rad} \propto \Gamma$ ⟶ We take largest Γ ⟶ 1

► Magneto Optical Trap (MOT) :

Capture velocity $v_{capt} \propto \Gamma^{1/2}$

Doppler limit $T_D \propto \Gamma$



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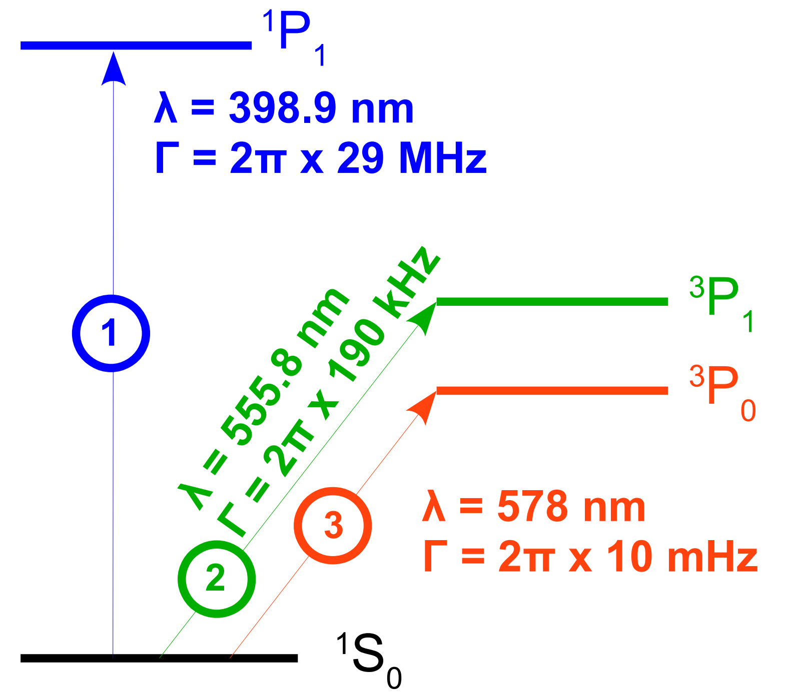

1 « Blue » transition : 399 nm

- Large Γ → high capture velocity (~ 40 m/s)
- T_D = 690 µK (no sub-Doppler for bosons)
- Decay from $^1P_1$ to metastable $^3P_0$ & $^3P_2$
- I_{sat} = 60 mW.cm^{-2} : hard to achieve high intensity @ 399nm

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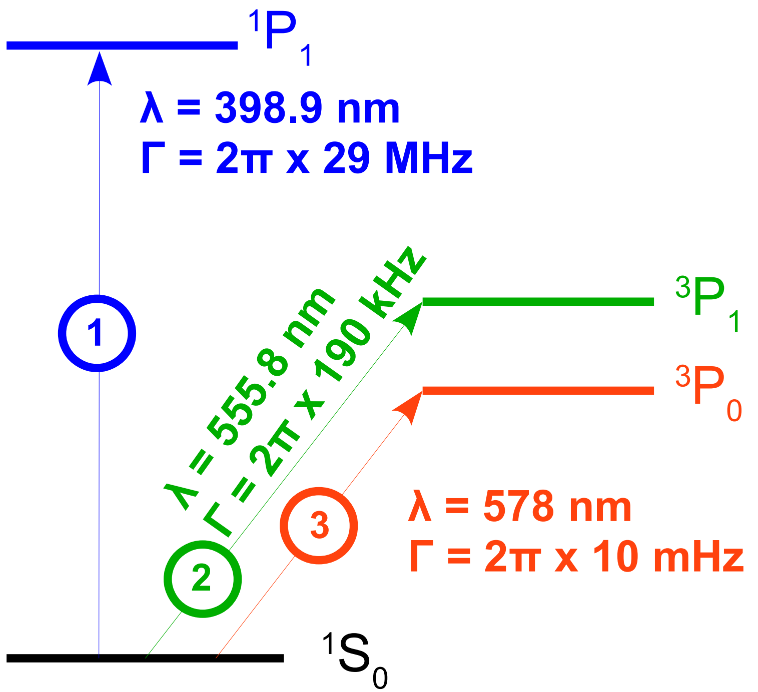

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2 « Green » transition : 556 nm

- small Γ → low capture velocity (~ 8 m/s)
- T_D = 4.4 µK
- Closed transition
- I_{sat} = 0.14 mW.cm^{-2}

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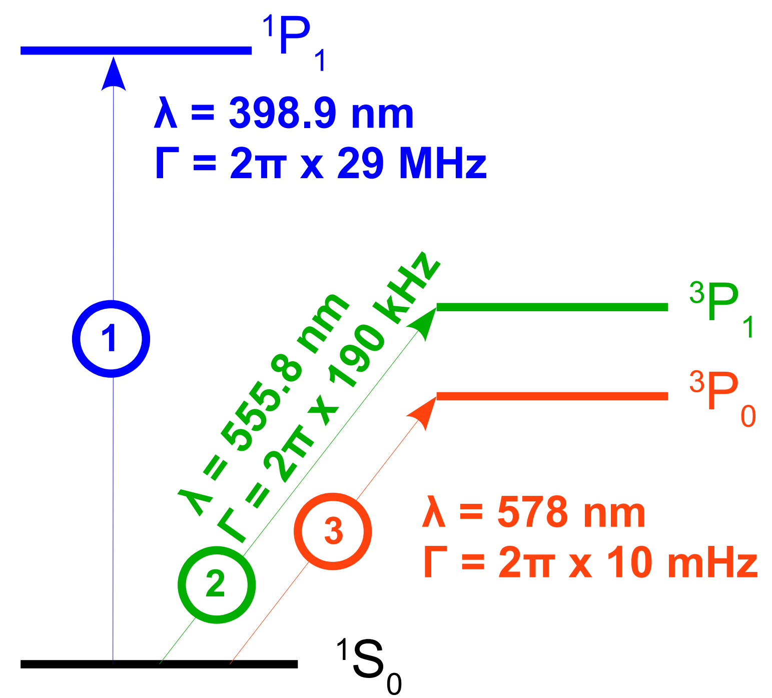
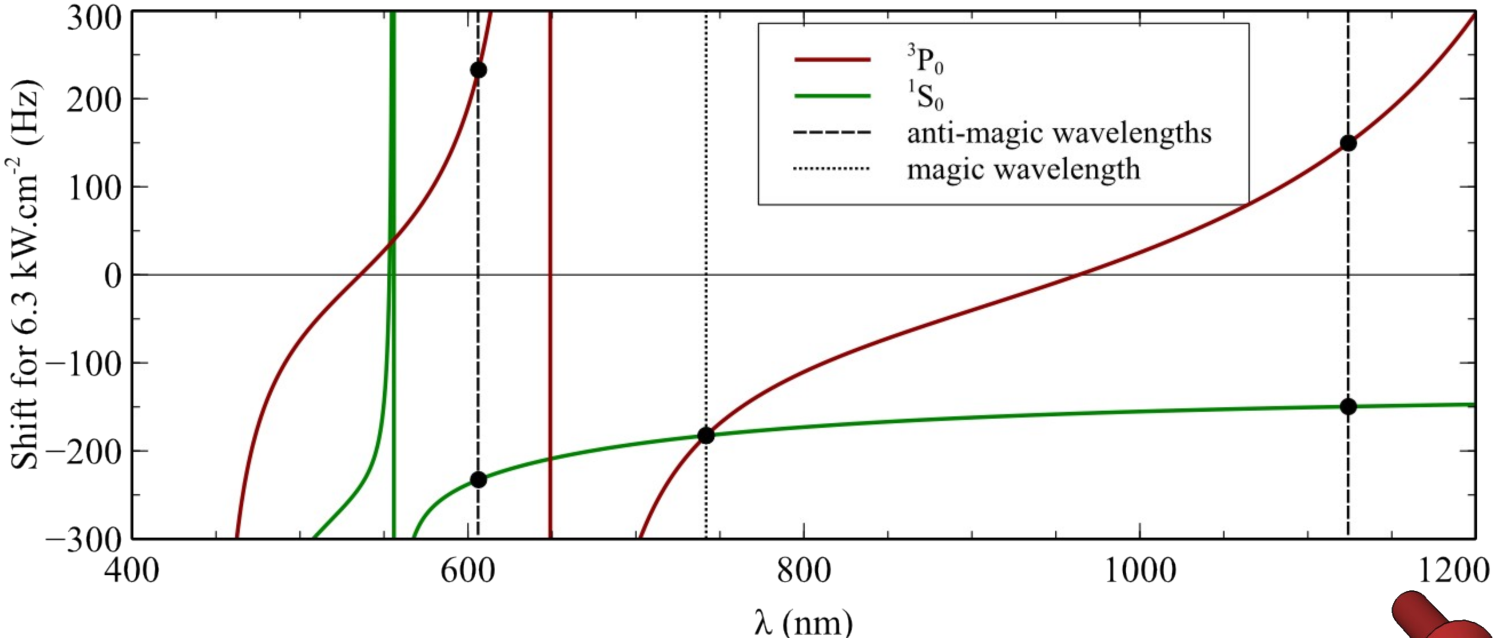
⟶ **MOT**

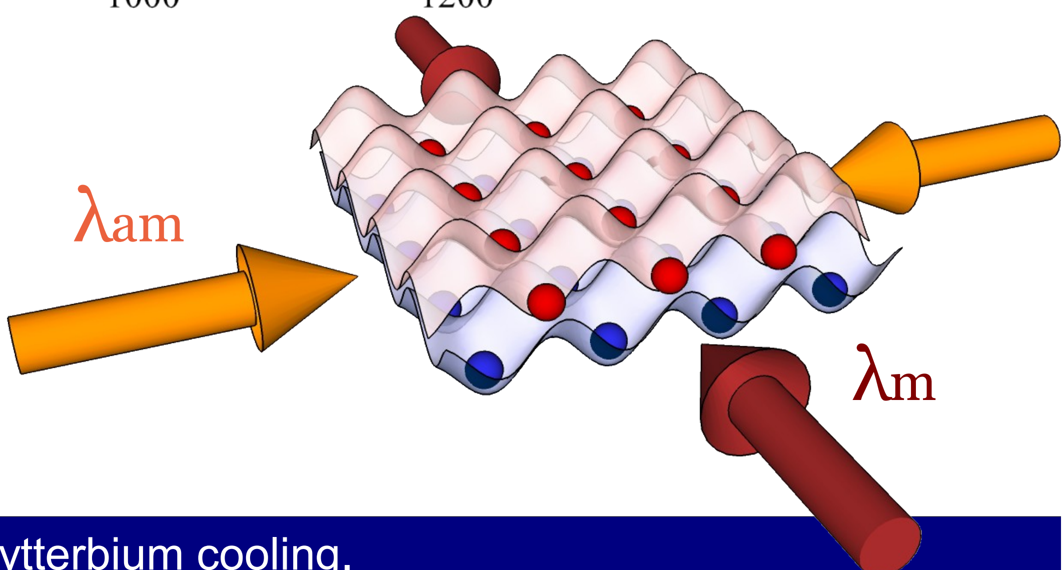


▶ Magic and anti-magic wavelengths :

Light shift for $^3P_0$ and $^1S_0$ as a function of wavelength for a 6,3kW.cm^{-2} laser intensity

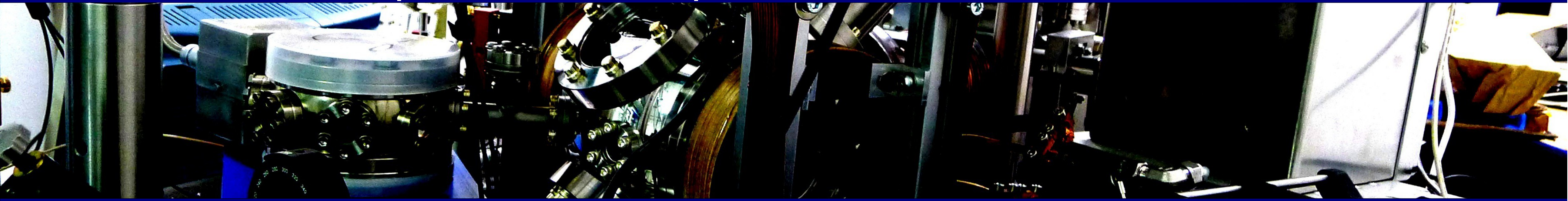


- "Magic" wavelength (λ_m) ≈ 760 nm
- "Anti-magic" wavelengths (λ_{am}) ≈ 620 nm or 1120 nm

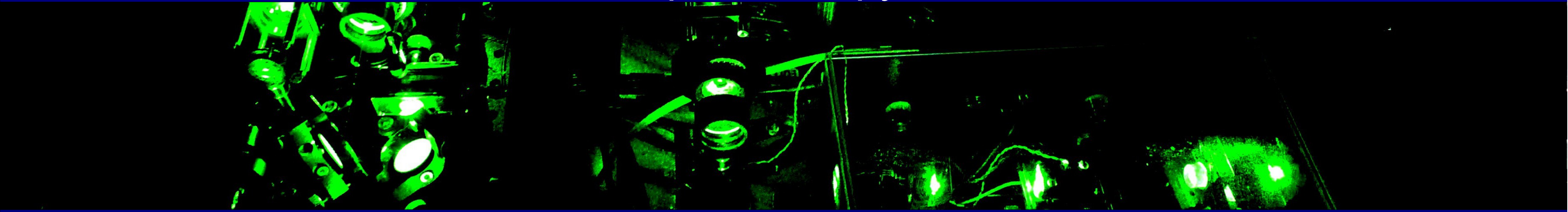


Outline of the talk :

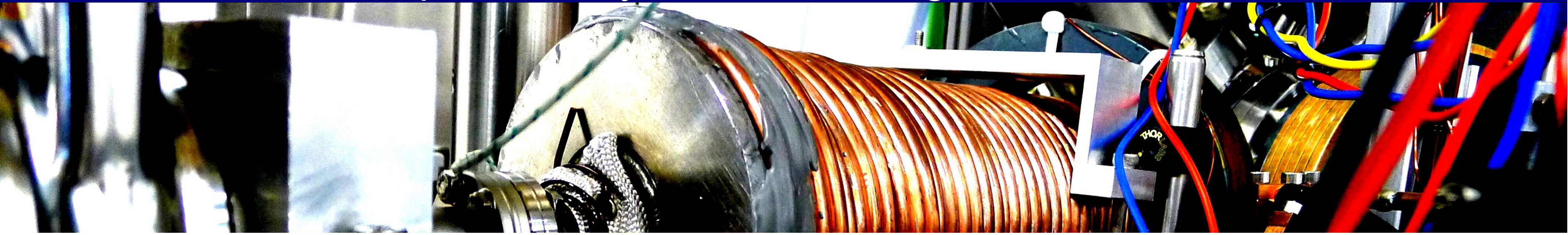
► Part 1 : Our experimental setup



► Part 2 : Lasers & Ytterbium spectroscopy



► Part 3 : First steps toward ytterbium cooling



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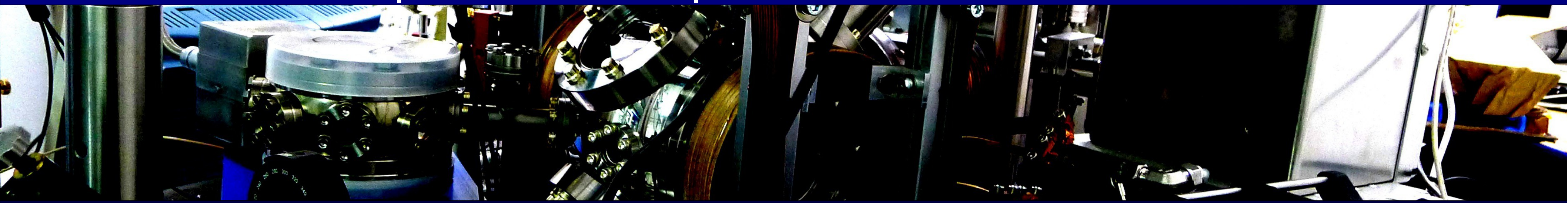

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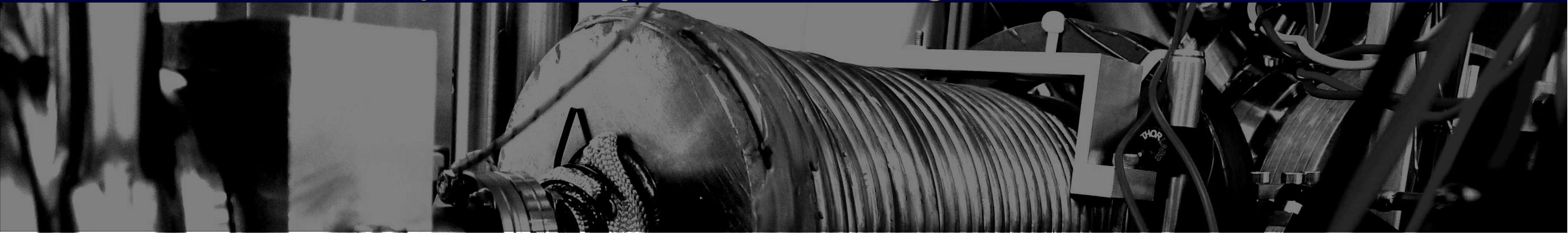
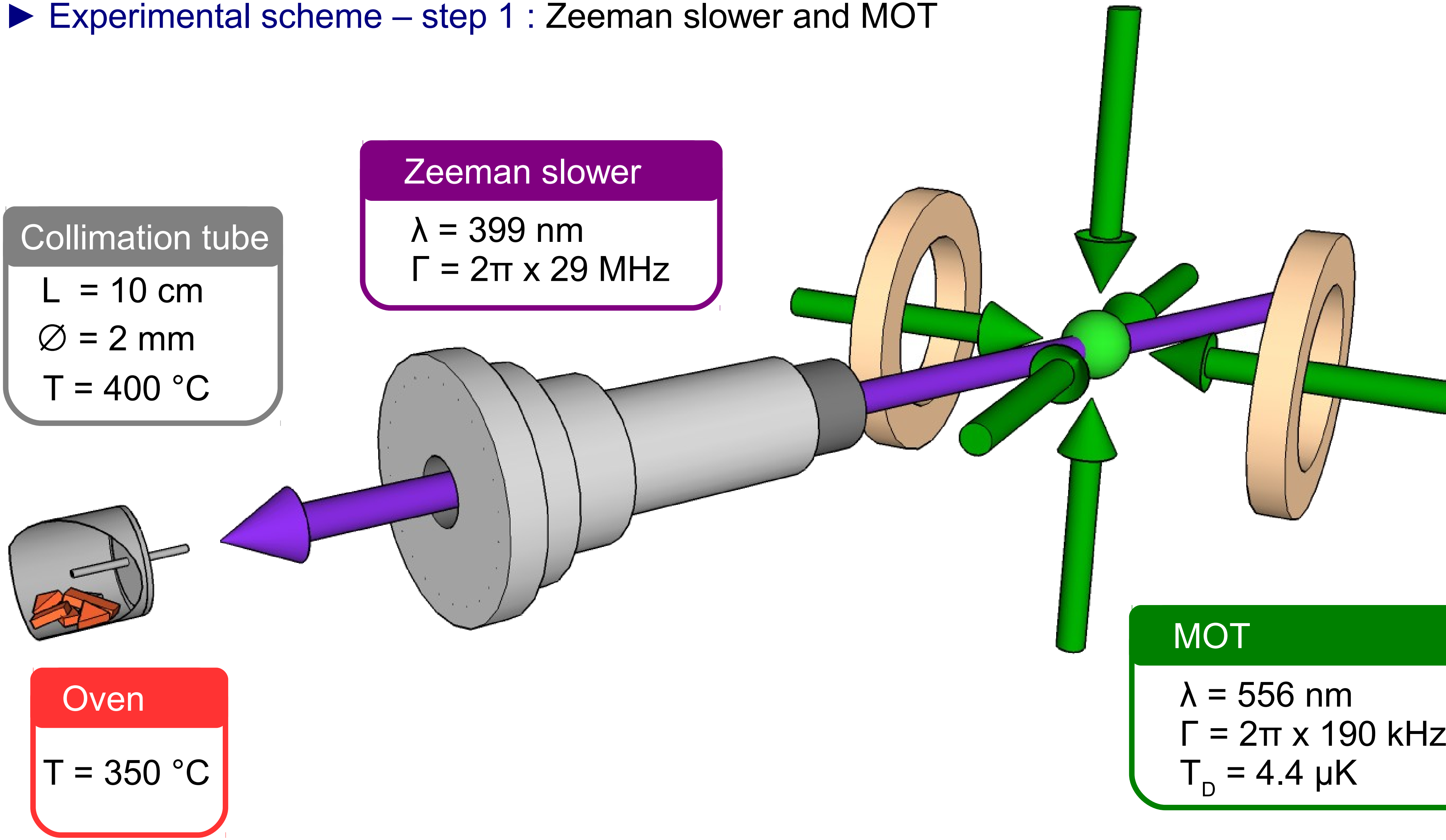


► Experimental scheme – step 1 : Zeeman slower and MOT



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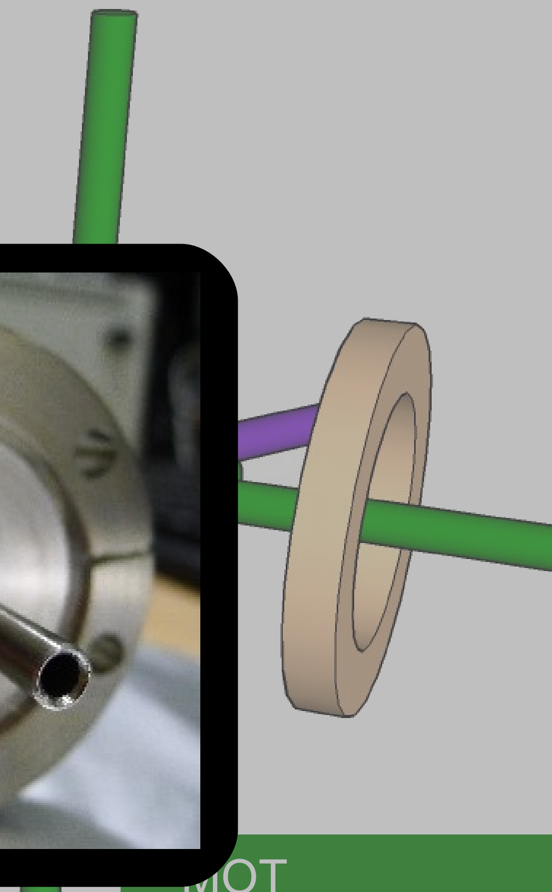


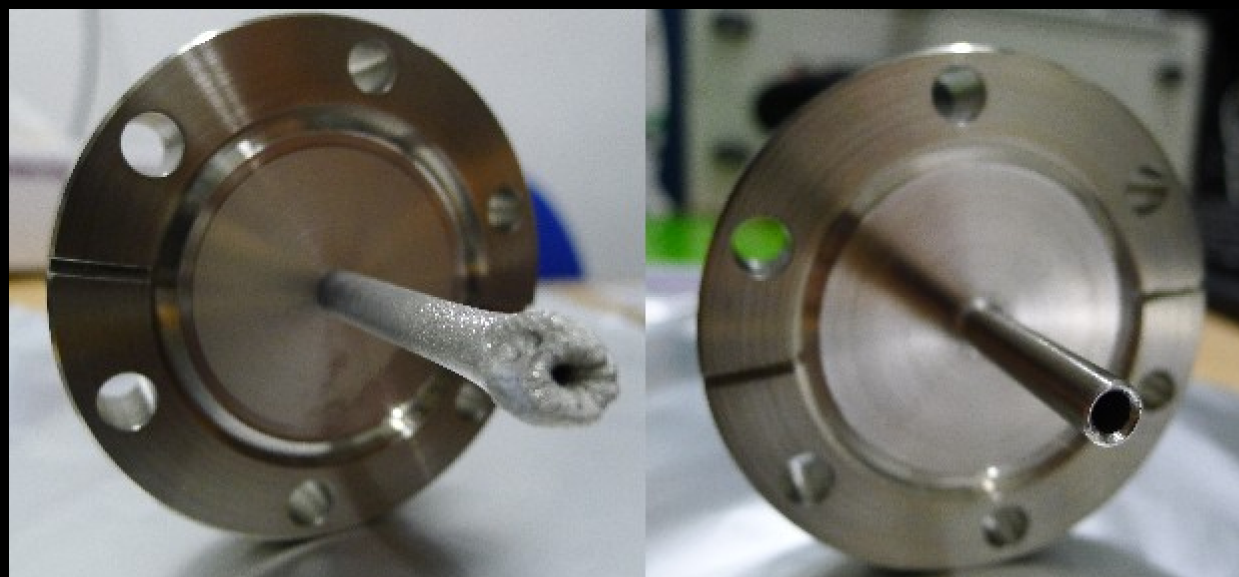
Zeeman slower

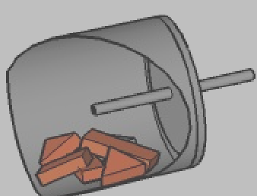
Collimation tube

L = 10 cm

∅ = 2 mm

T = 400 °C





Oven

T = 350 °C

MOT

λ = 556 nm

Γ = 2π x 190 kHz

T_D = 4.4 µK

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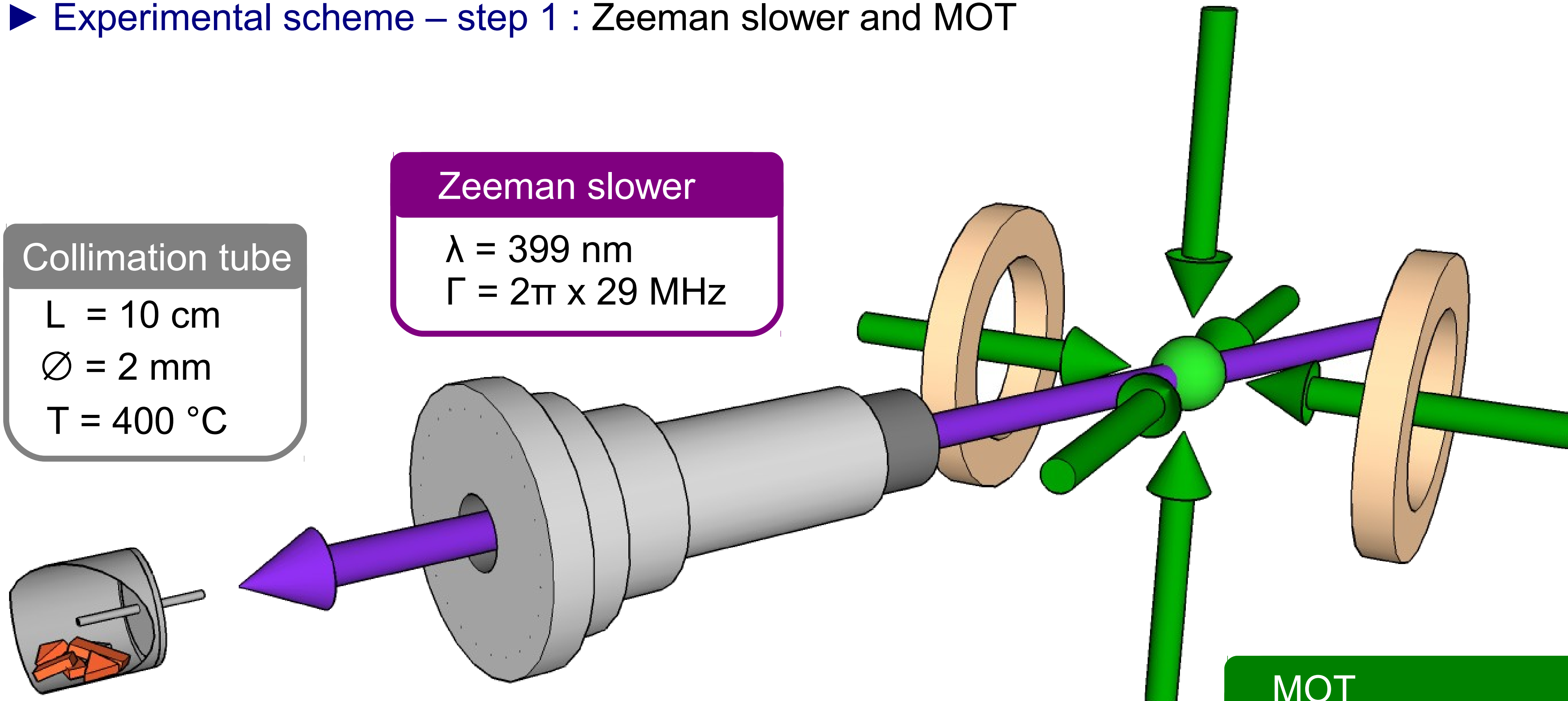

Zeeman slower

λ = 399 nm
$\Gamma = 2\pi$ x 29 MHz

Collimation tube

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Oven

T = 350 °C

MOT

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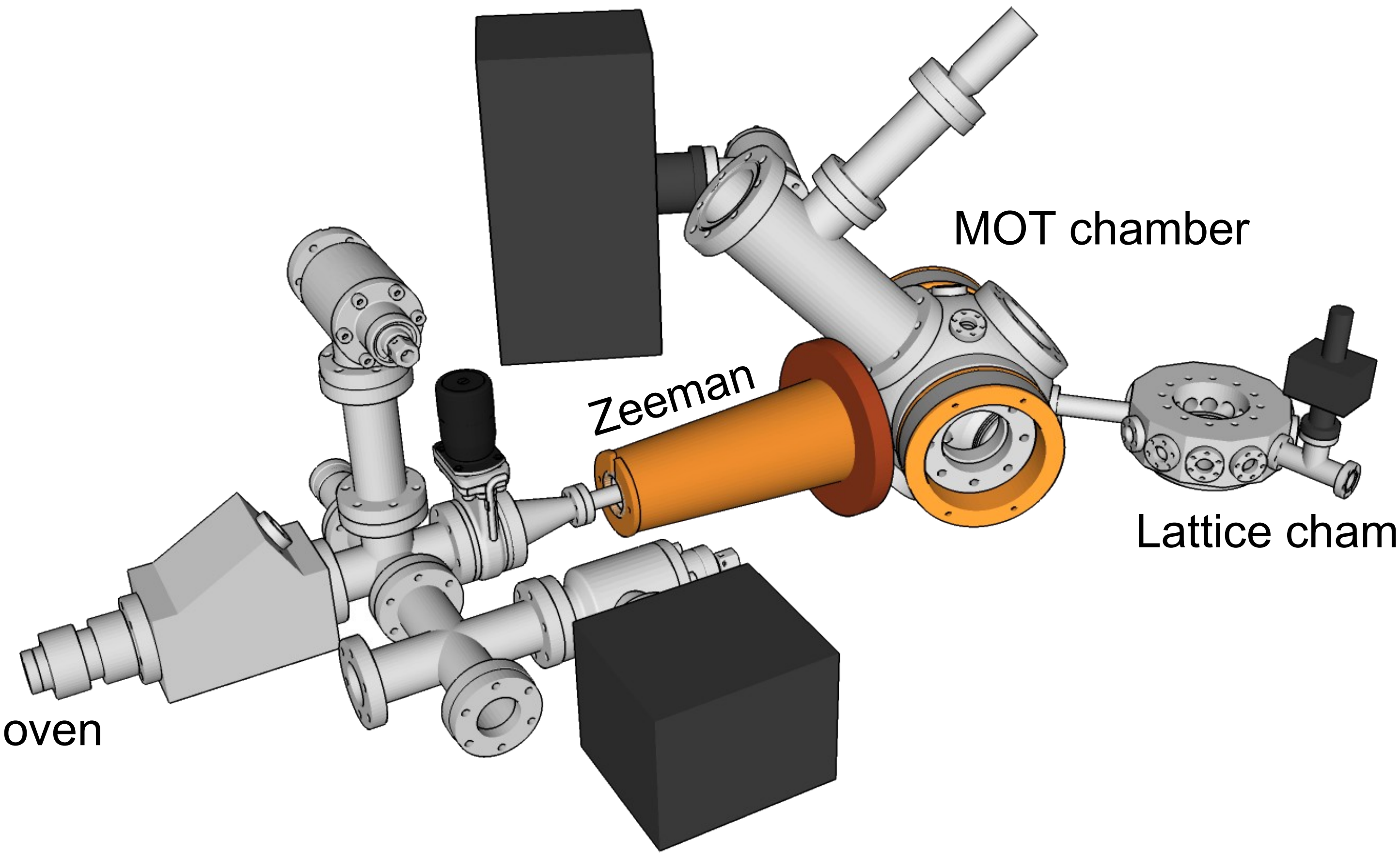
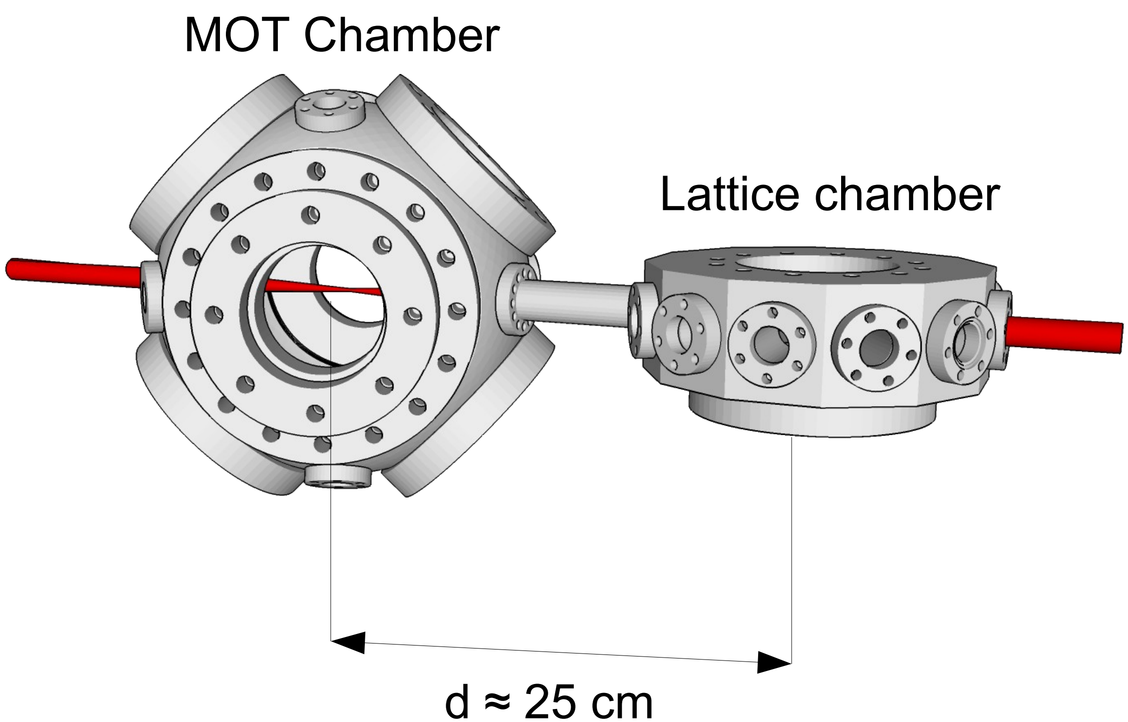
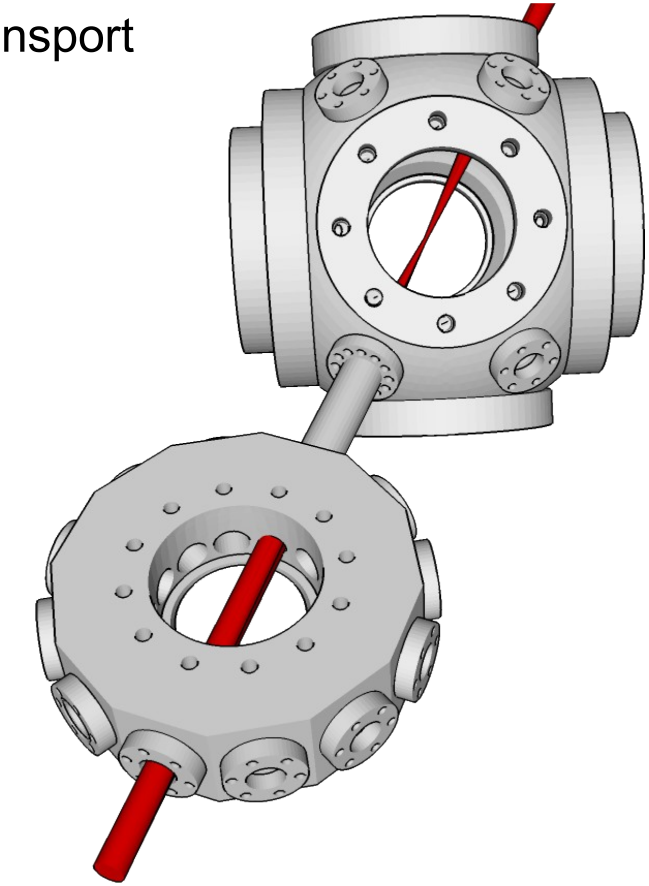
► Experimental setup : The vacuum system



▶ Experimental scheme – step 2 : Dipole trap and optical transport





Dipole trap

λ = 1070 nm
P = 50 W
waist = 80 µm

trap depth ~ 300 µK

NB: in Kyoto, T_{MOT} ~ 30 µK

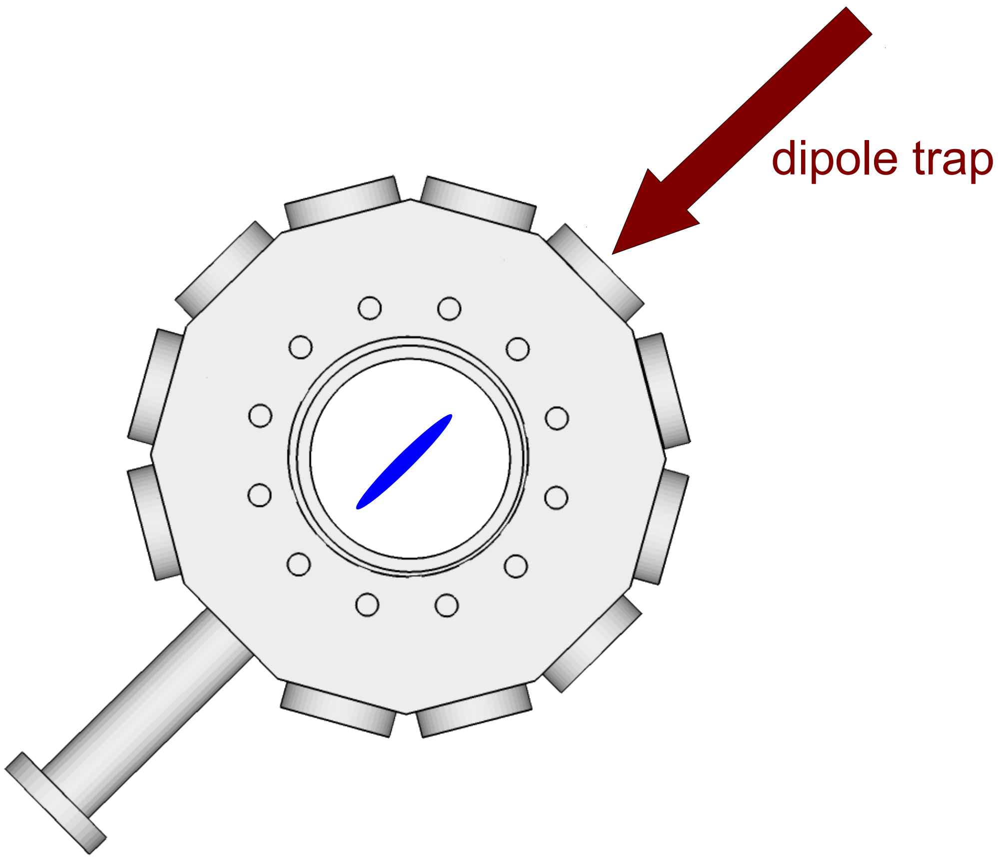
Transport

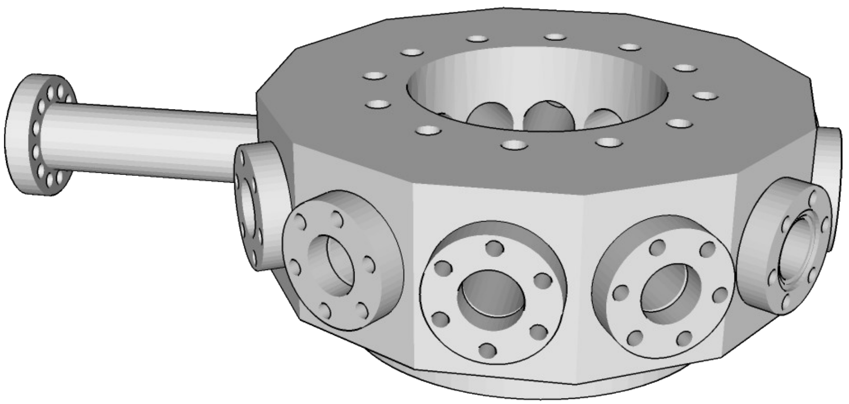
Optical transport to the lattice chamber by translating the dipole trap waist.

Lattice chamber

Better vacuum
Good optical access (vert. imaging)
12 sideports for lattices designing

► Experimental scheme – step 3 : Lattice





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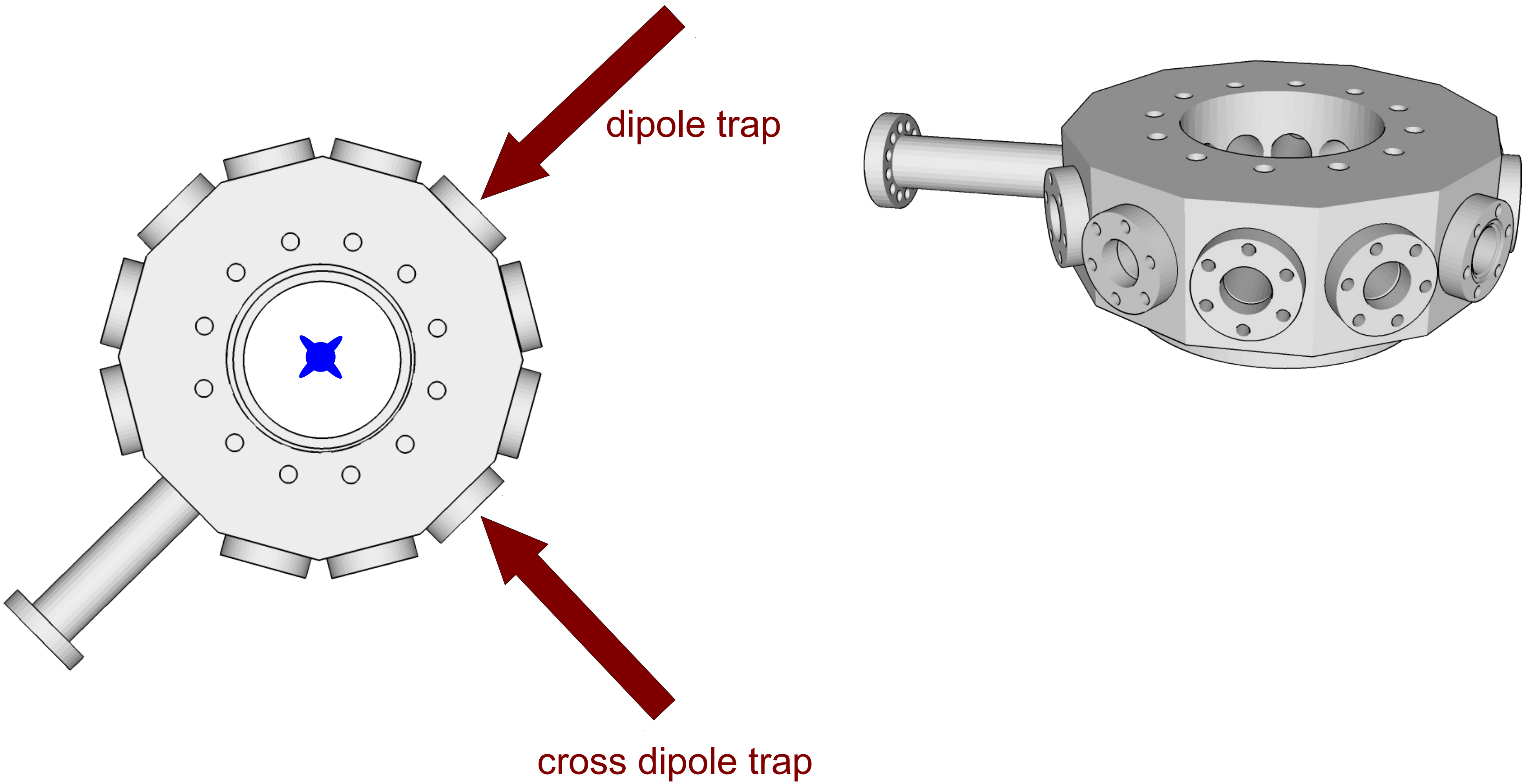

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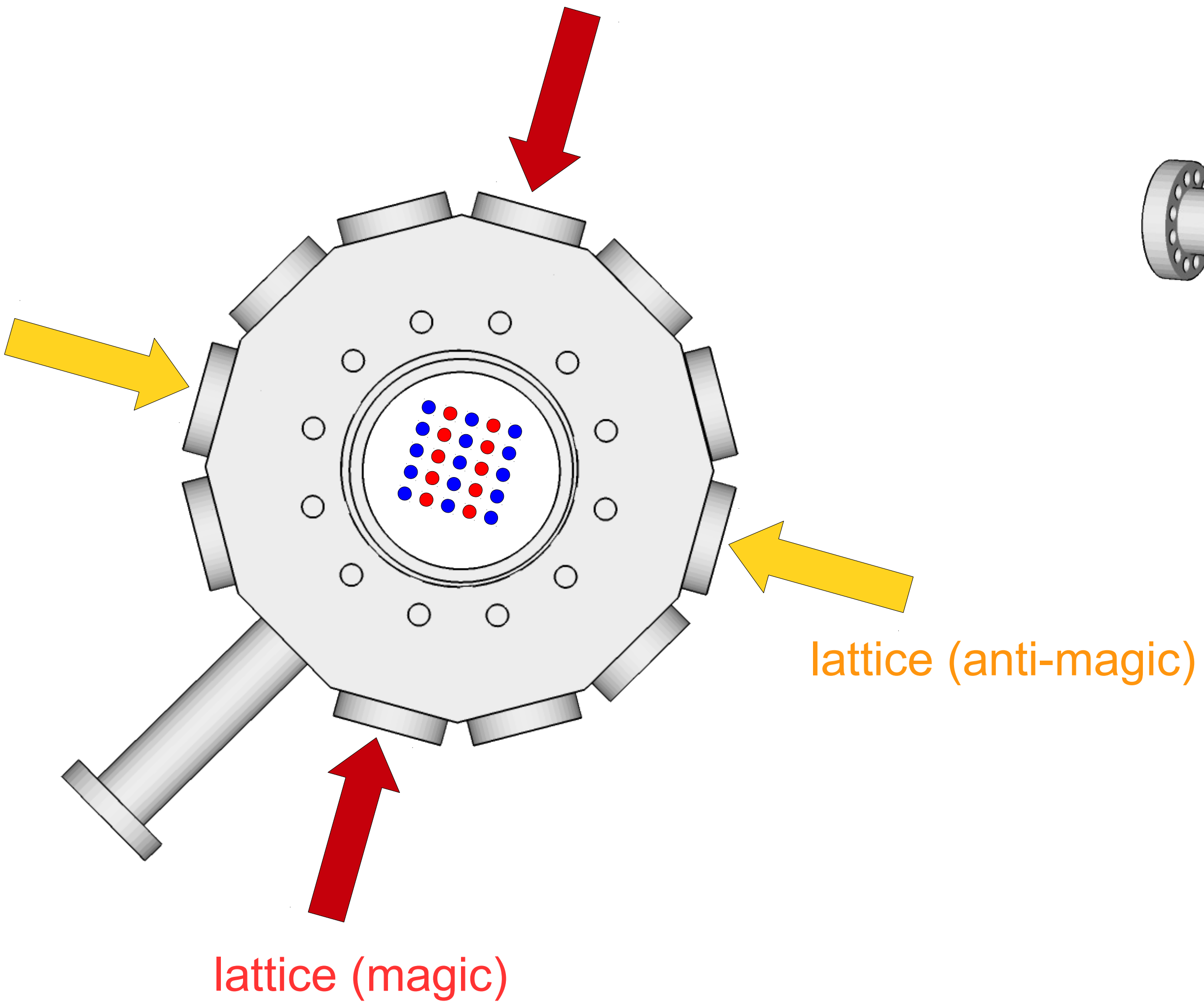

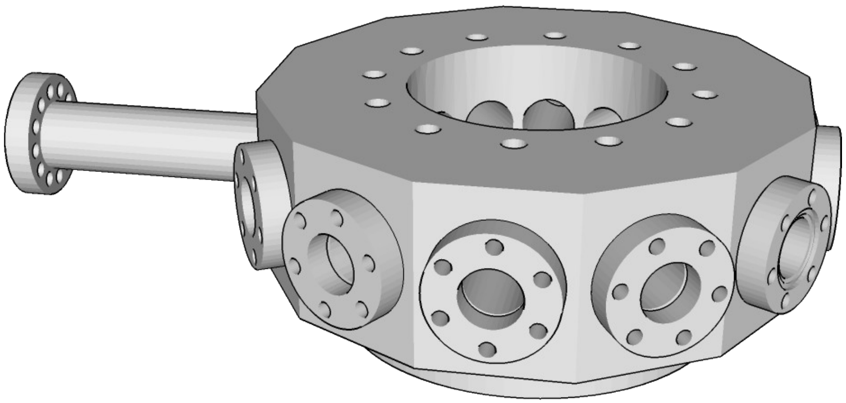

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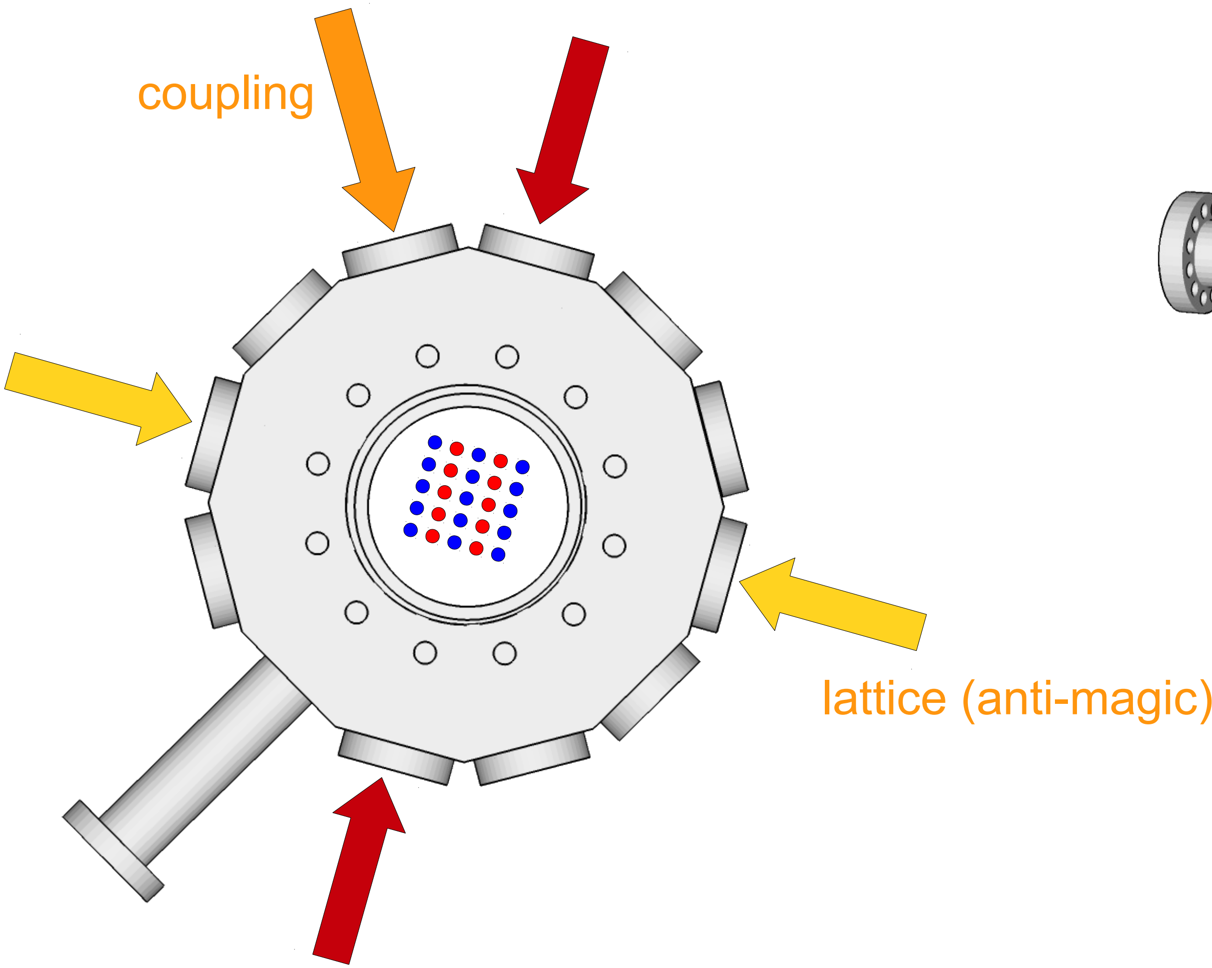

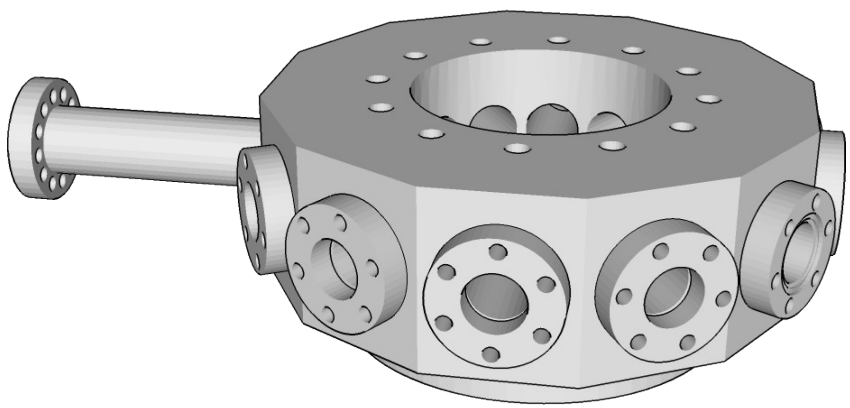

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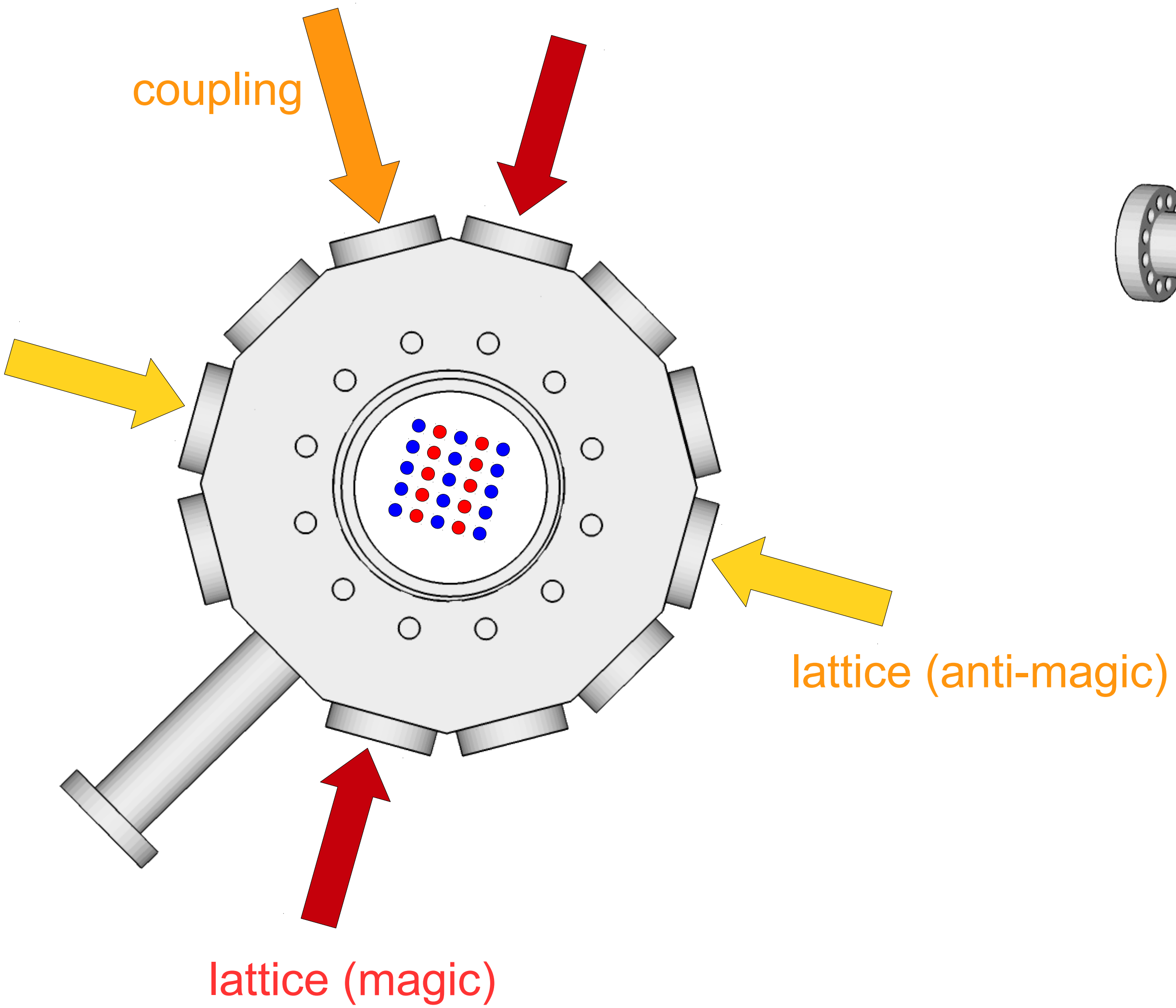

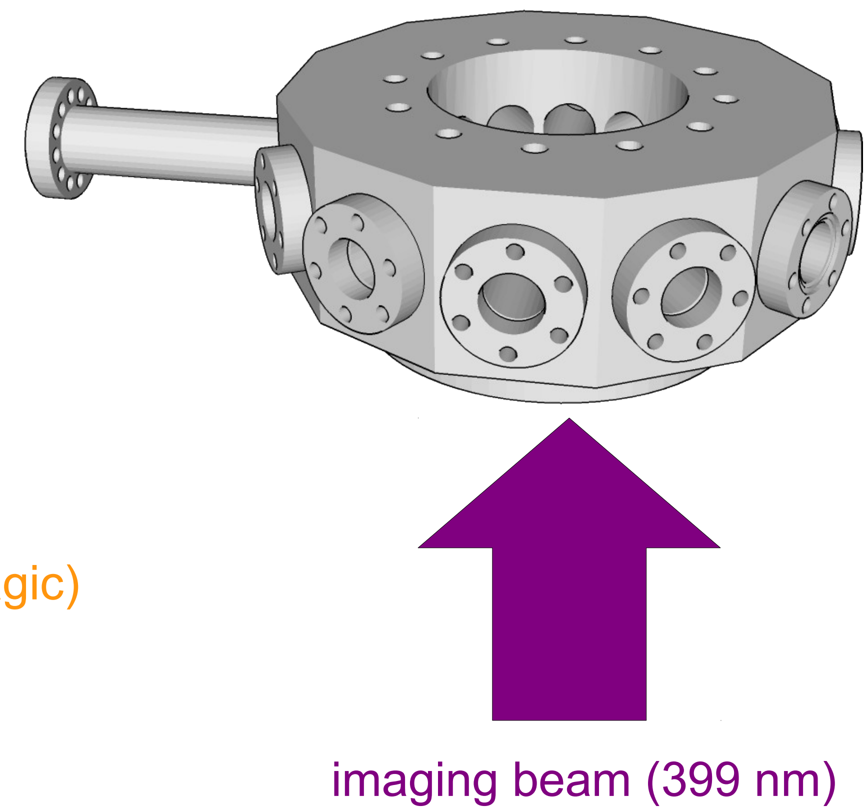

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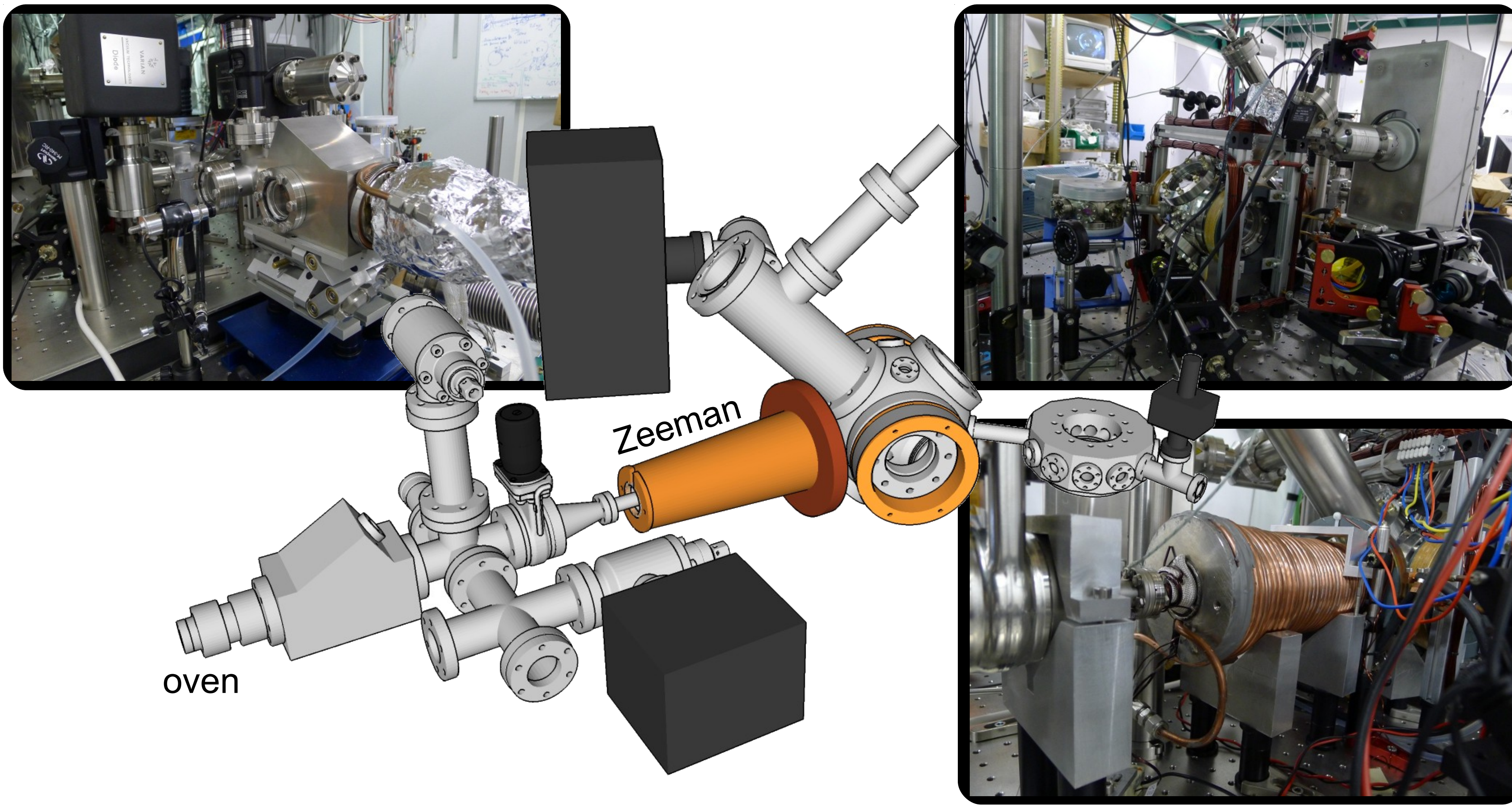

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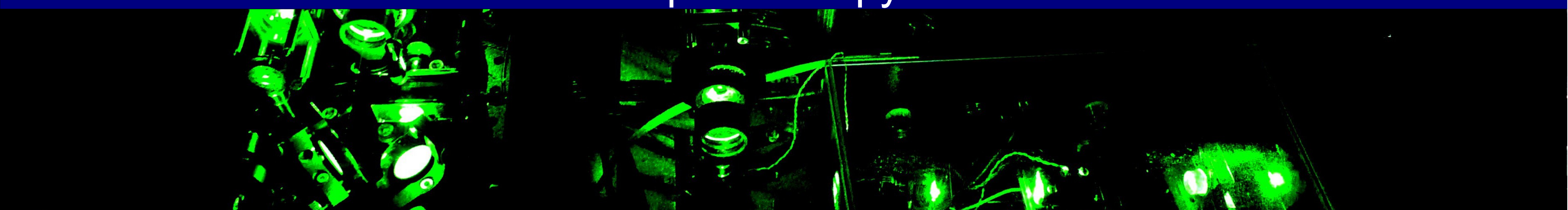

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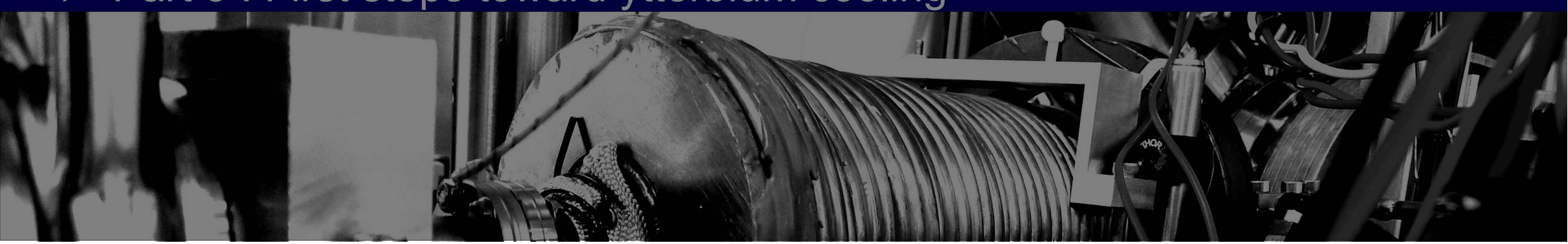


▶ Cooling lasers : frequency doubling (single pass)

1 « Blue » transition : 399 nm

- Large Γ → efficient slowing
- T_D = 690 μK

→ **Zeeman slower**

Toptica MOPA 500mW @ 798nm → non-linear crystal ppKTP → 399nm

$P_{blue} = \alpha P_{IR}^2$ α ~ 1.2 % W^{-1} NB : I_{sat} = 60 mw/cm²

2 « Green » transition : 556 nm

- Small width → low Doppler temp.
- T_D = 4.4 μK

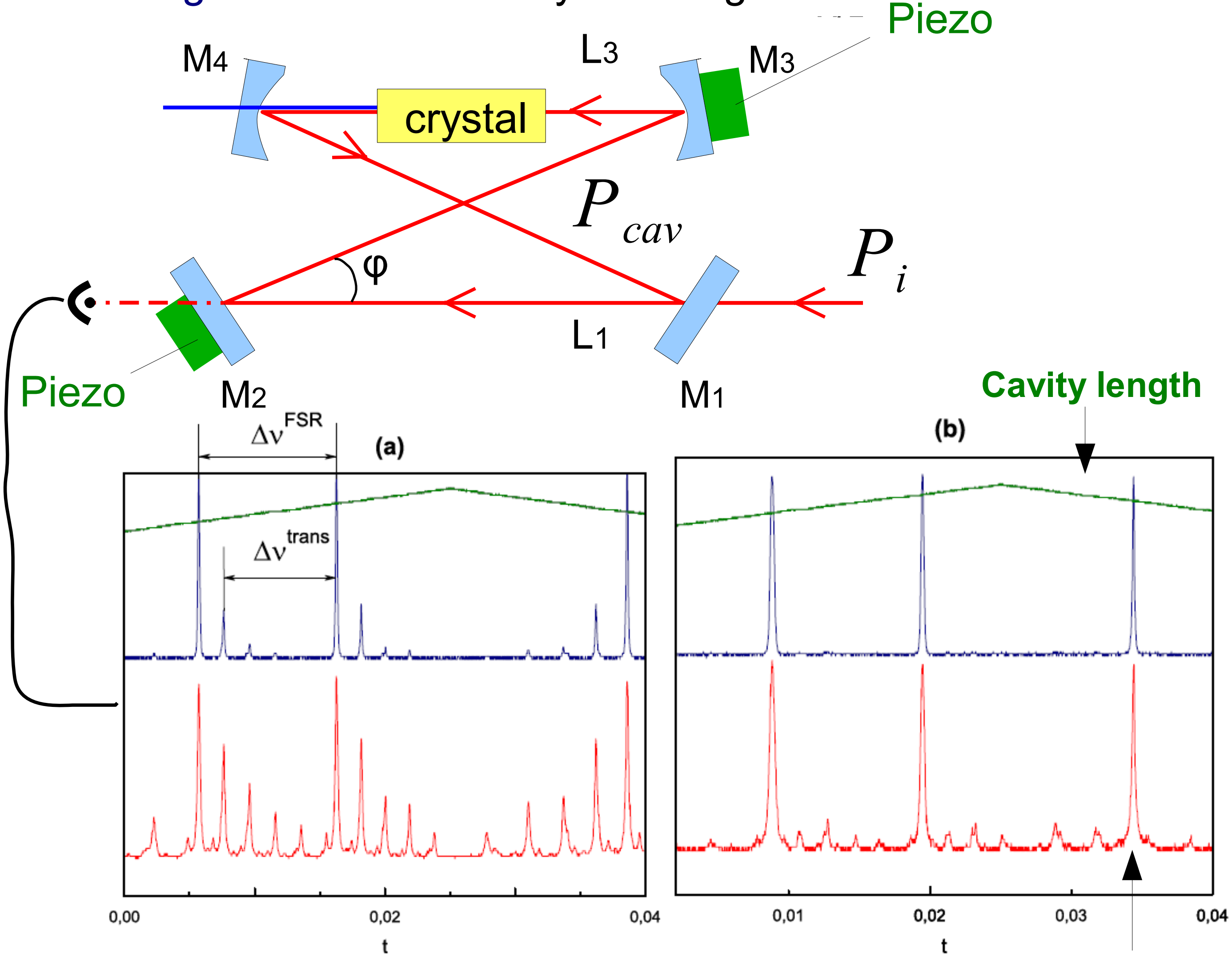
→ **MOT**

Menlo Orange one 2W @ 1112nm → non-linear crystal ppSLT → 556nm

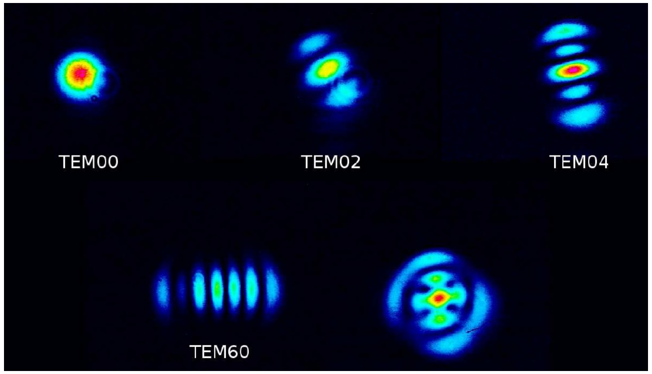
$P_{green} = \alpha P_{IR}^2$ α ~ 1 % W^{-1}

Only a few milliwatts in single pass ➡ use a cavity !

▶ Cooling lasers : Intra-cavity doubling



$$\frac{P_{cav}}{P_i} >> 1$$

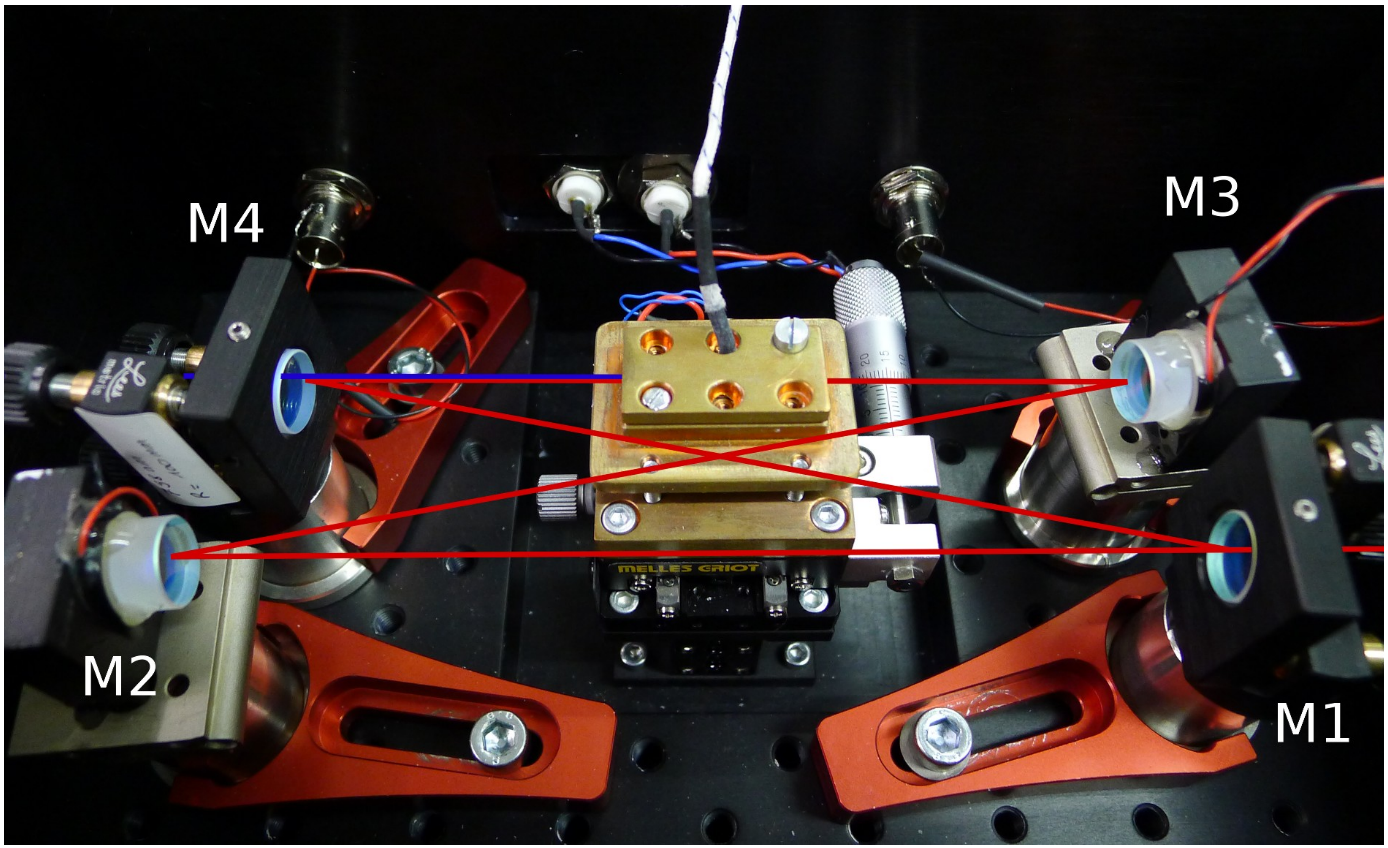


transverse modes

cavity resonance peaks

transmission peaks
Red = IR, Blue = 399nm

► Cooling lasers : Intra-cavity doubling



Green Cavity

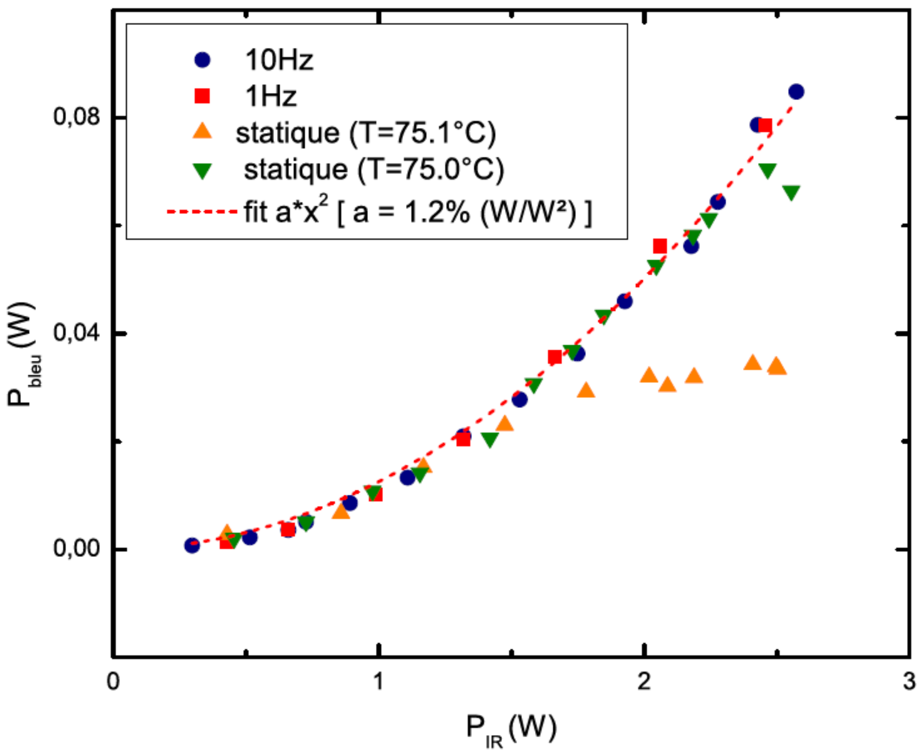
Finesse ~ 50
P (intra-cavity) ~ 10W
P green ~ 1 W

Blue Cavity

Finesse ~ 60
P (intra-cavity) ~ 4W
P blue ~ 150mW

► Cooling lasers : Blue laser thermal effects

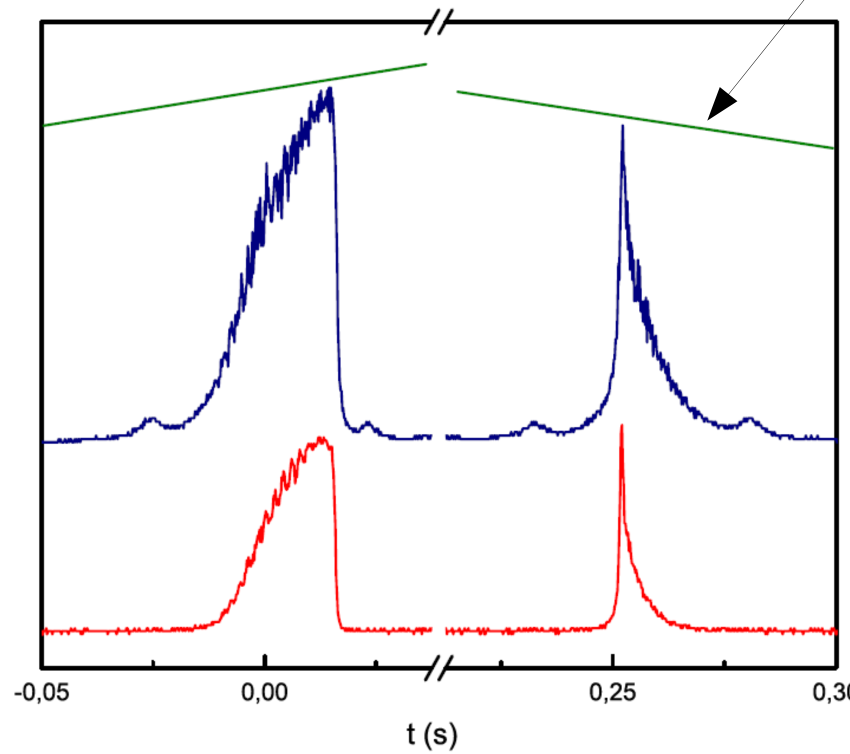
Thermal effects in continuous doubling regime



Intra-cavity doubling efficiency

Piezo tension (= – cavity length)

Extra noise and peaks distortion



Cavity resonance peaks

→ thermal effects with ppKTP crystals : Blue Induced Infra-Red Absorption (BLIIRA)
→ non-linear behaviour : bi-stability & hysteresis
→ messes the cavity locking → Move to a non-optimal doubling regime by increasing waist in the crystal

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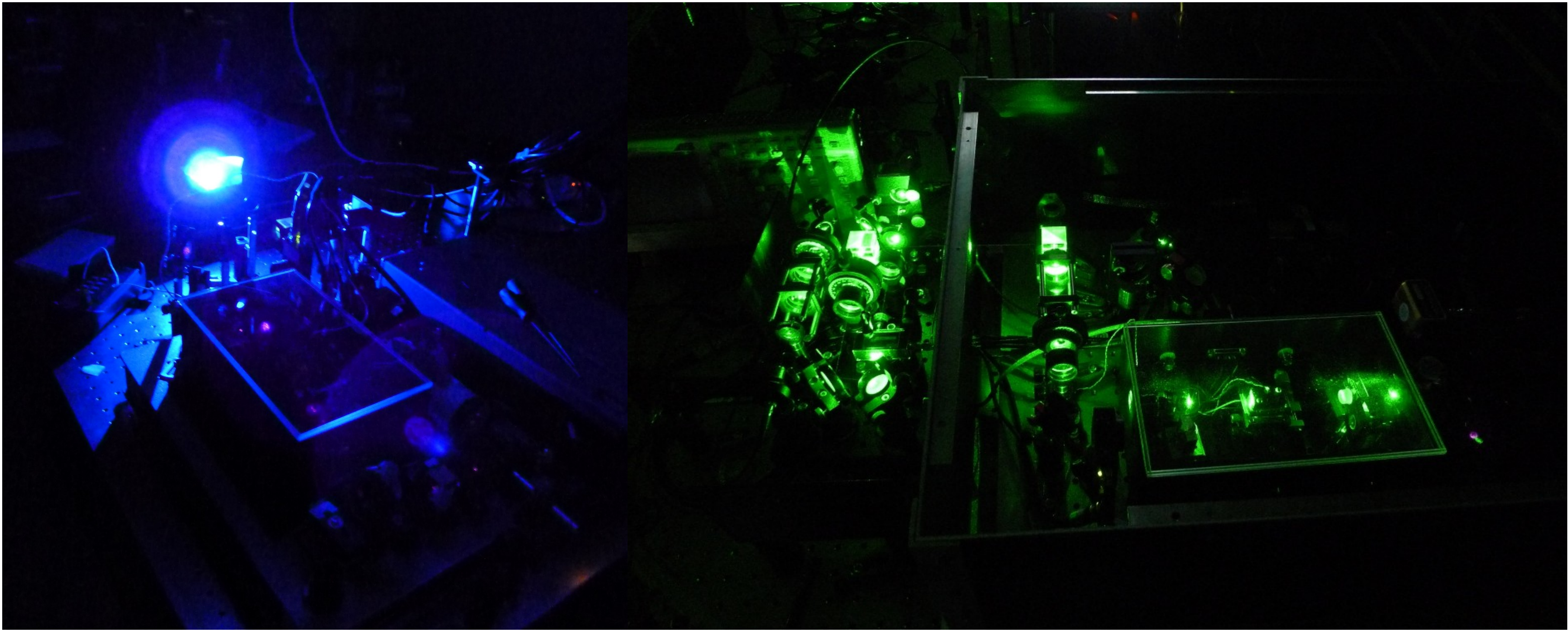
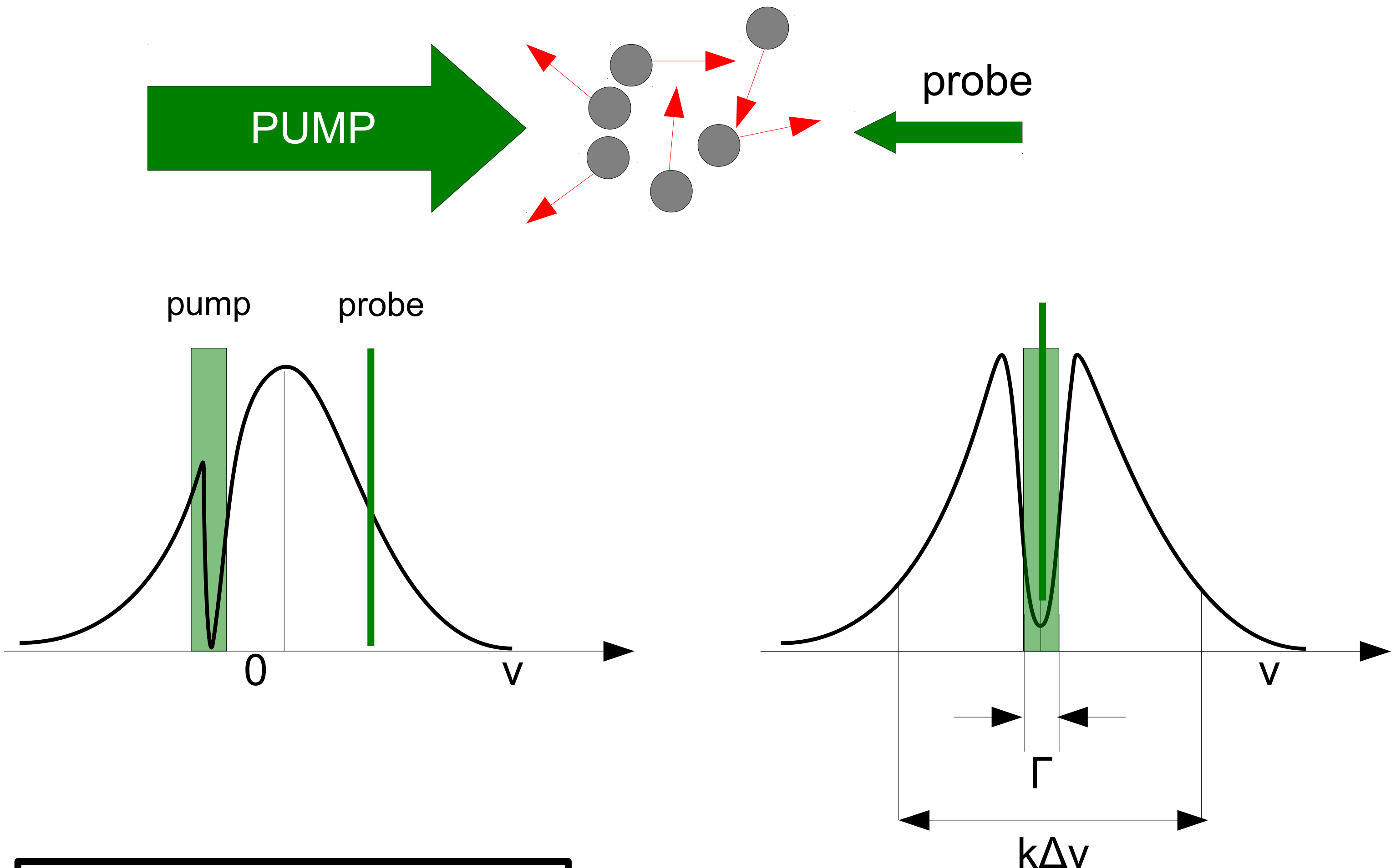
► Cooling lasers : Lasers at work !



▶ Spectroscopy : saturated absorption (Doppler-free spectroscopy)

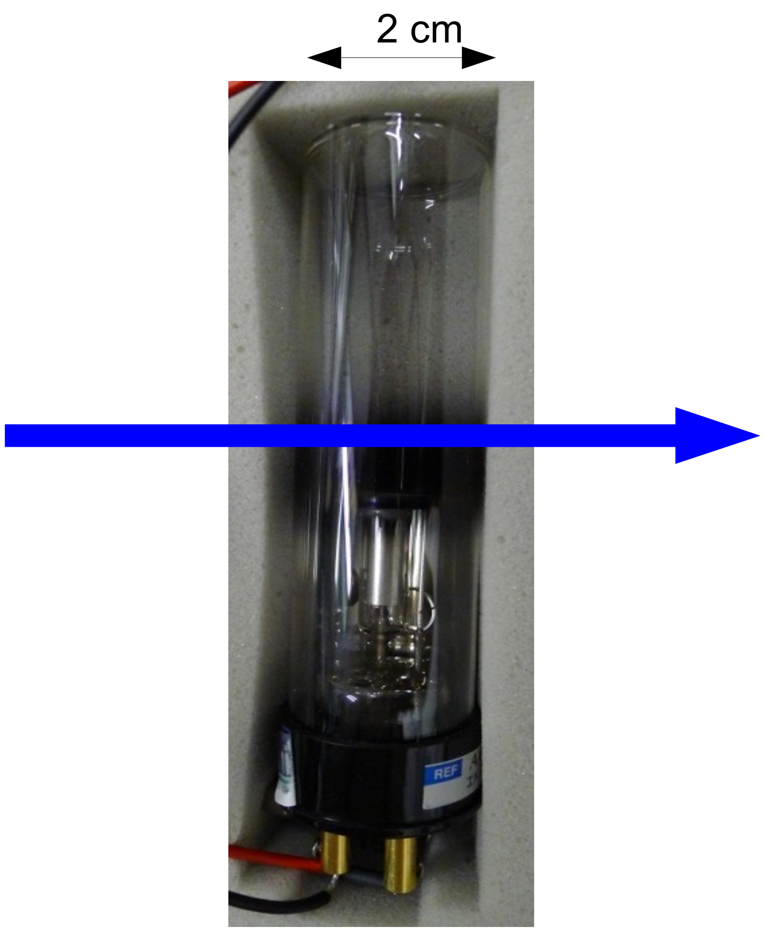


$$\text{Signal} \propto \frac{\Gamma}{(k\,\Delta\,v)} N_{atoms}$$

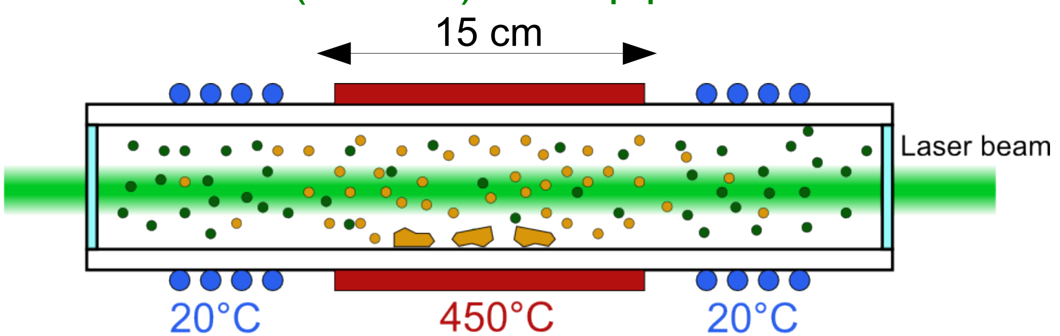
▶ Spectroscopy : Yb cells

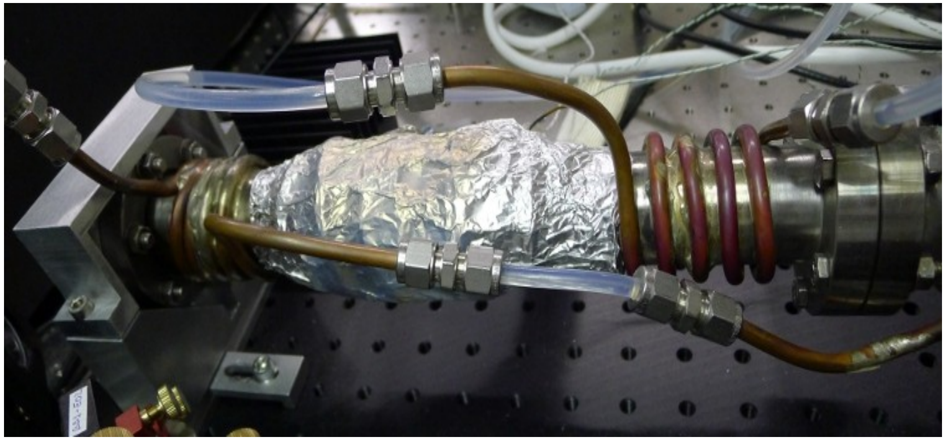
$$\text{Signal} \propto \frac{\Gamma}{(k\,\Delta v)} N_{atoms}$$

Blue laser (large Γ) : hollow cathode lamp

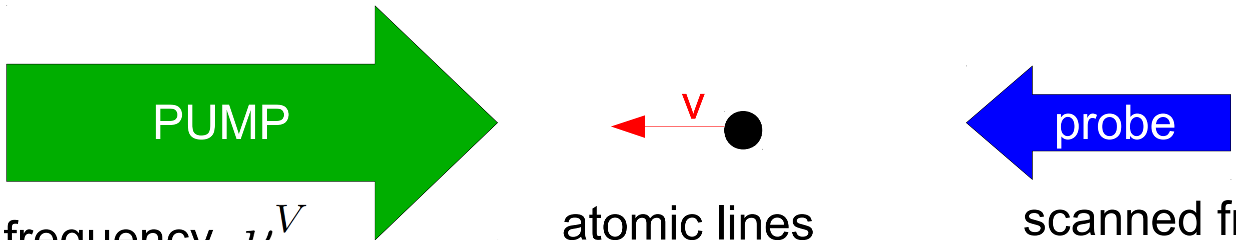


Green laser (small Γ) : heatpipe





▶ Spectroscopy : cross saturated absorption principle – one isotope



fixed frequency ν_p^V

atomic lines
blue $\rightarrow \nu_{\mathrm{at}}^V$
green $\rightarrow \nu_{\mathrm{at}}^B$

scanned frequency ν_s^B

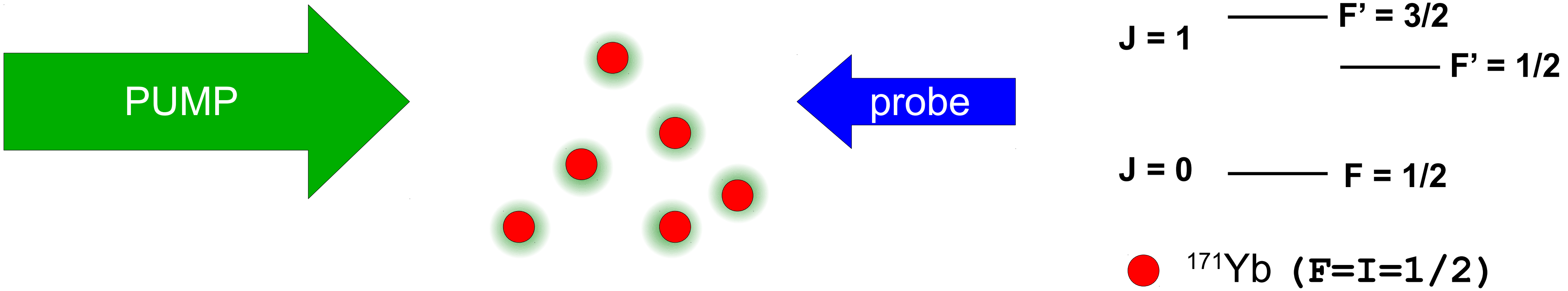
- Pump depletes a class of speed v such as : $\nu_p^V = \nu_{\mathrm{at}}^V - v/\lambda_V$
- Probe sees a dip in absorption for this class when $\nu_s^B = \nu_{\mathrm{at}}^B + v/\lambda_B$

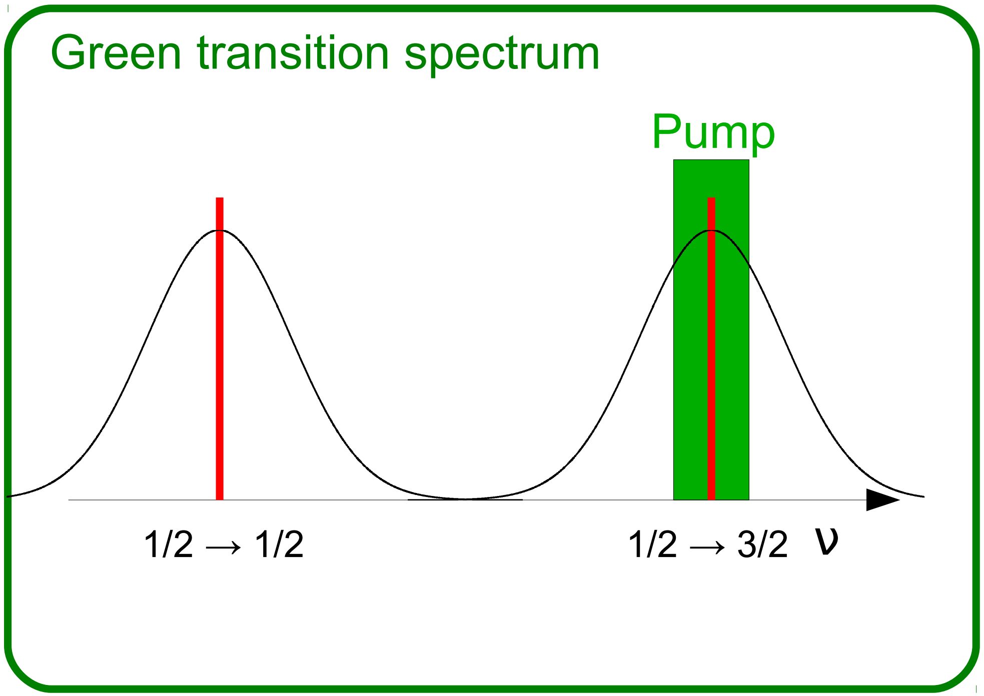
$$\longrightarrow \boxed{\nu_s^B = \nu_{\mathrm{at}}^B + \frac{\lambda_V}{\lambda_B}(\nu_{\mathrm{at}}^V - \nu_p^V)}$$

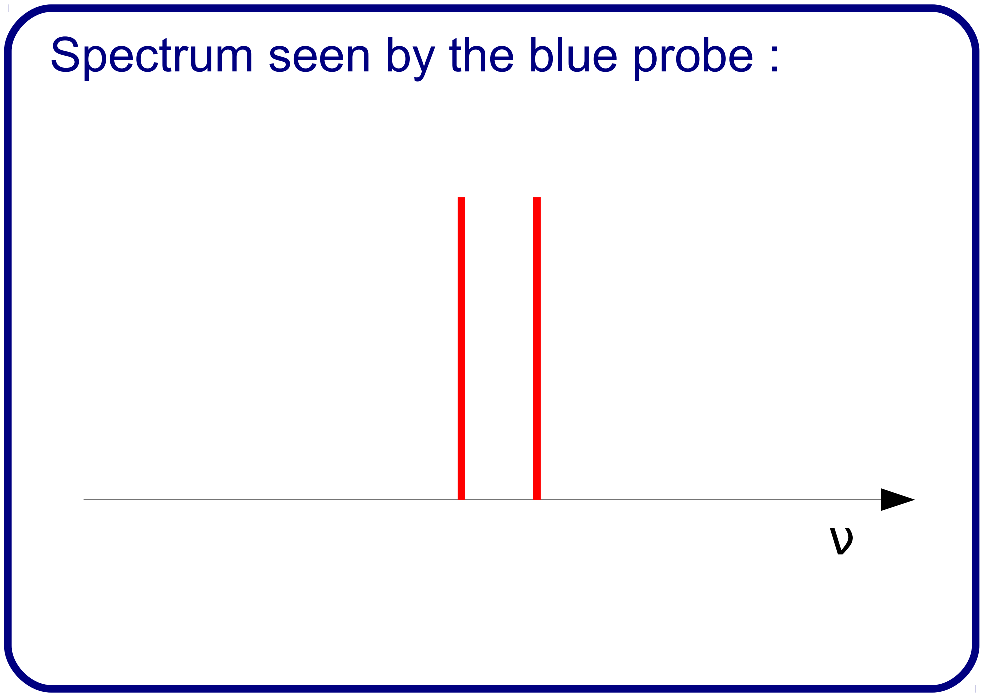
- If pump is within the Doppler profile of n_1 transitions ⟶ n_1 classes of speeds depleted
- If probe can scan over n_2 transitions ⟶ each class of speed shows n_2 lines

⟶ We see n_1 x n_2 lines (cross-over)

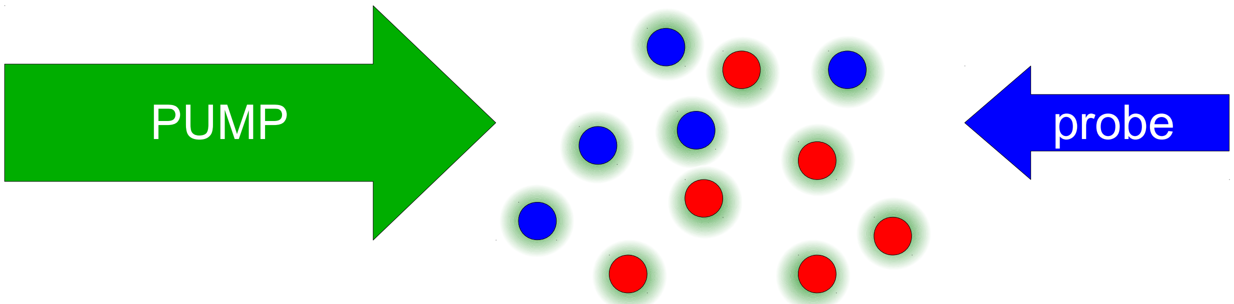
▶ Spectroscopy : cross saturated absorption principle – several isotopes

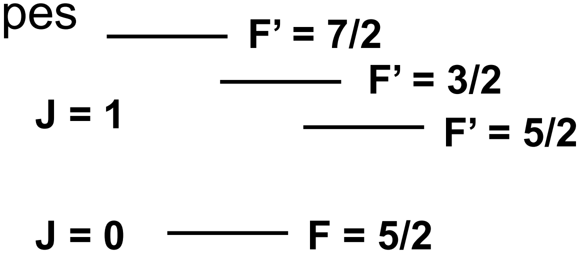






► Spectroscopy : cross saturated absorption principle – several isotopes

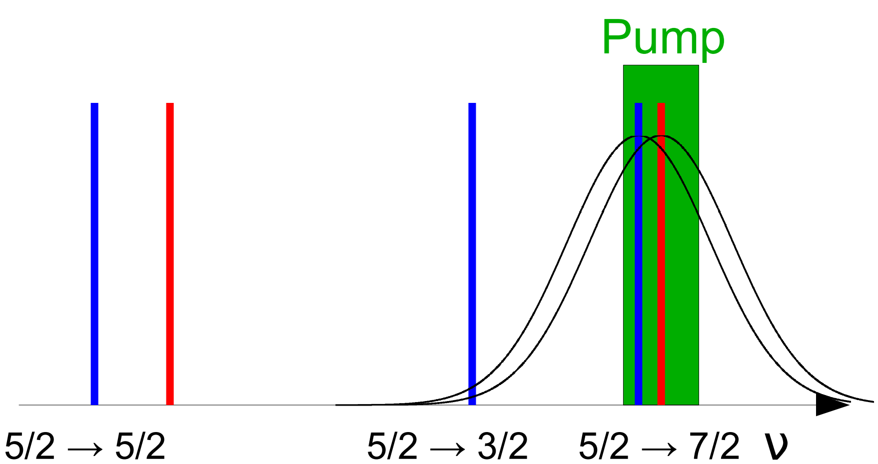




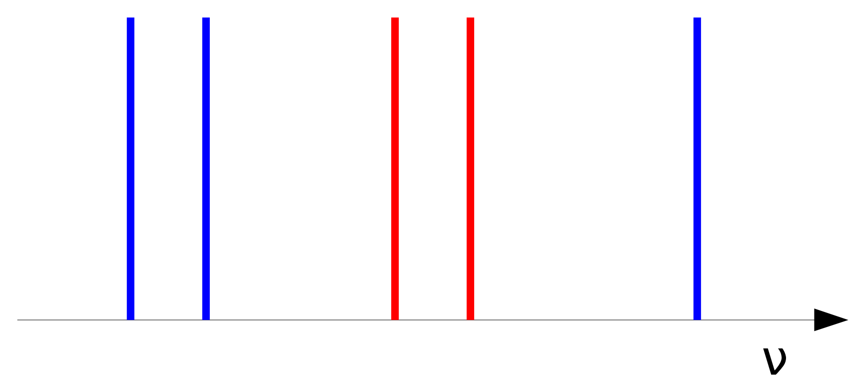
^{173}Yb (F=I=5/2)

^{171}Yb (F=I=1/2)

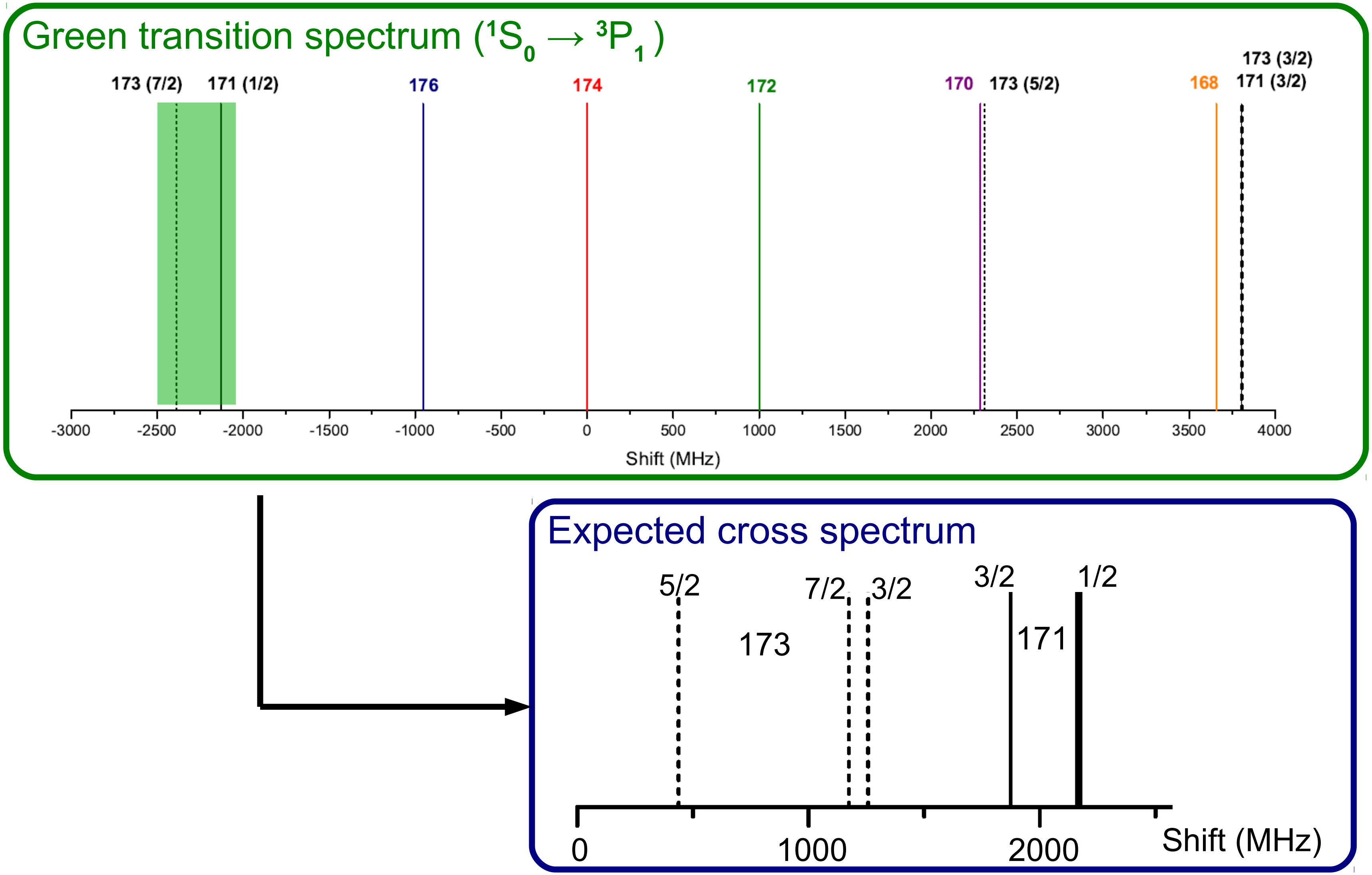
Green transition spectrum



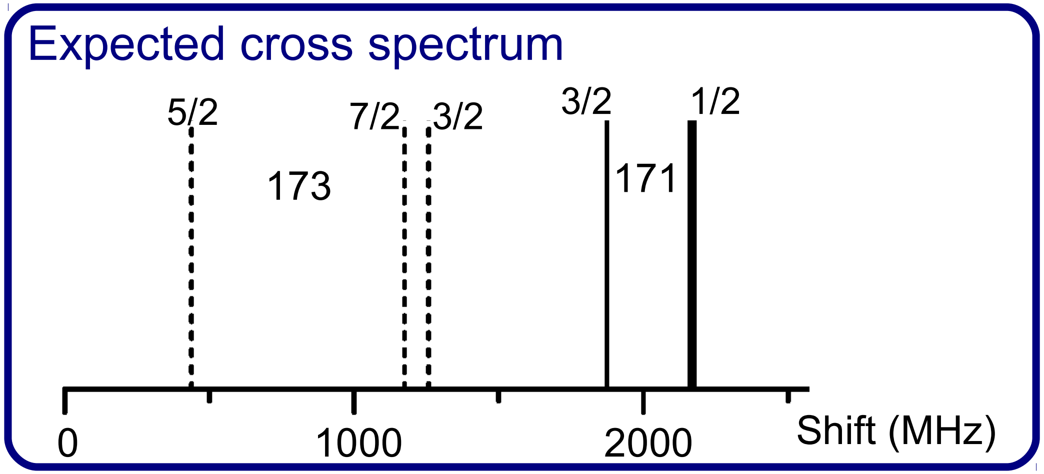
Spectrum seen by the blue probe :

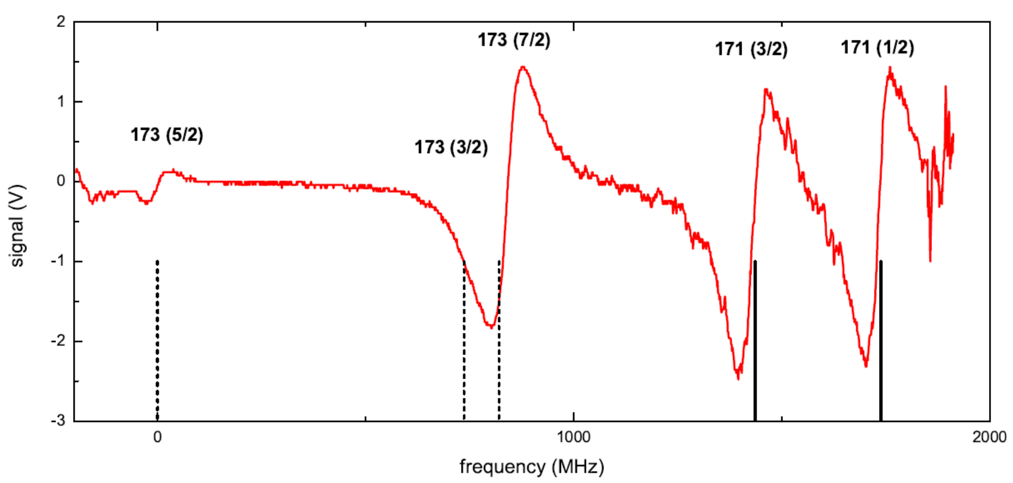


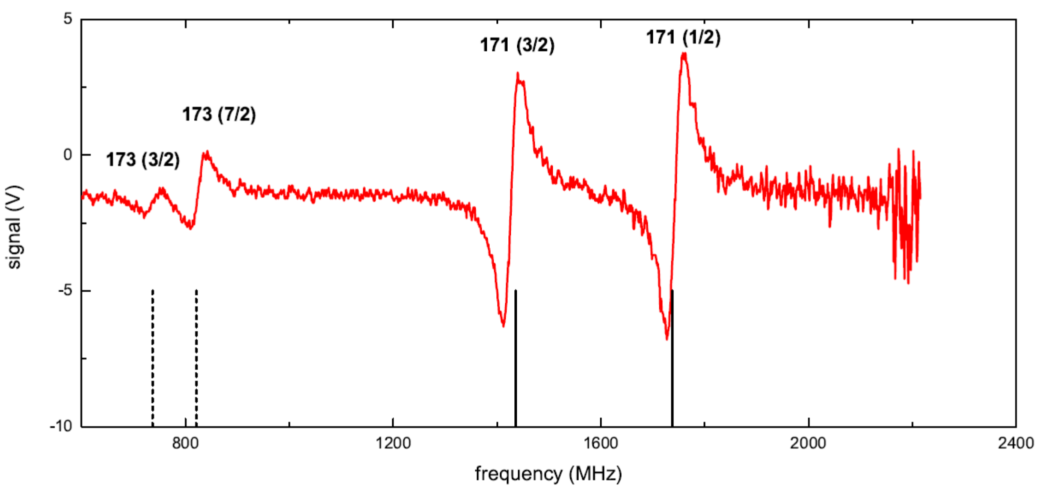
▶ Spectroscopy : cross saturated absorption experimental example



► Spectroscopy : cross saturated absorption experimental example





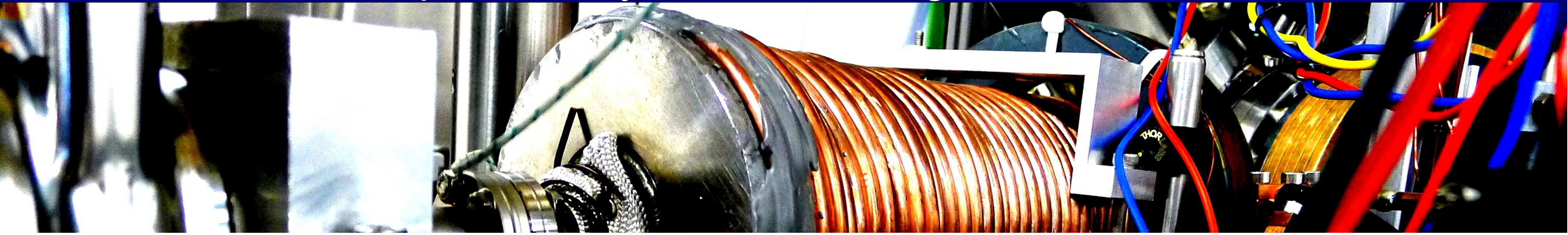


Outline of the talk :

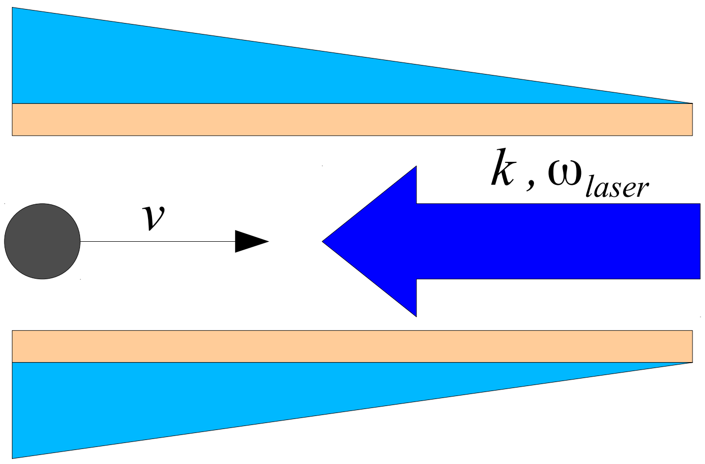
- ▶ Part 1 : Our experimental setup

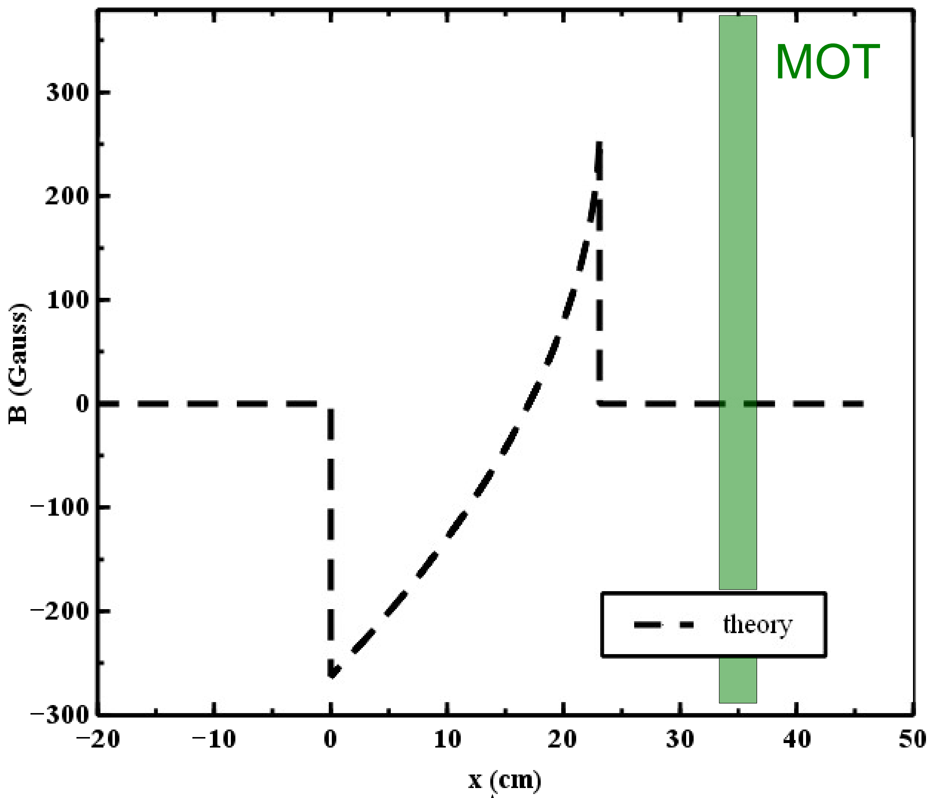
- ▶ Part 2 : Lasers & Ytterbium spectroscopy

- ▶ Part 3 : First steps toward ytterbium cooling



► Zeeman slower :





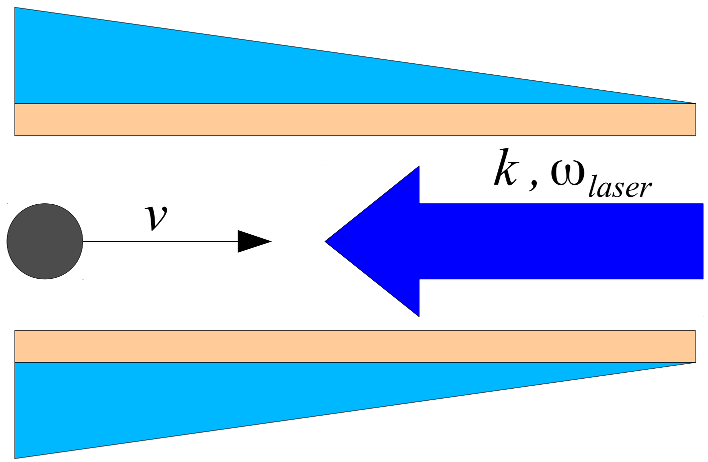
deceleration as constant force $\rightarrow v(x)$
+ ensure resonance condition :

$$\delta(x) = \omega_{laser} - \omega_{atomic} + kv(x) + \gamma B(x) = 0$$

$$\boxed{B(x) = B_1\left(1 - \sqrt{1 - \frac{x}{L}}\right) + B_0}$$

Gives laser detuning $\omega_{laser} - \omega_{atomic}$

► Zeeman slower :



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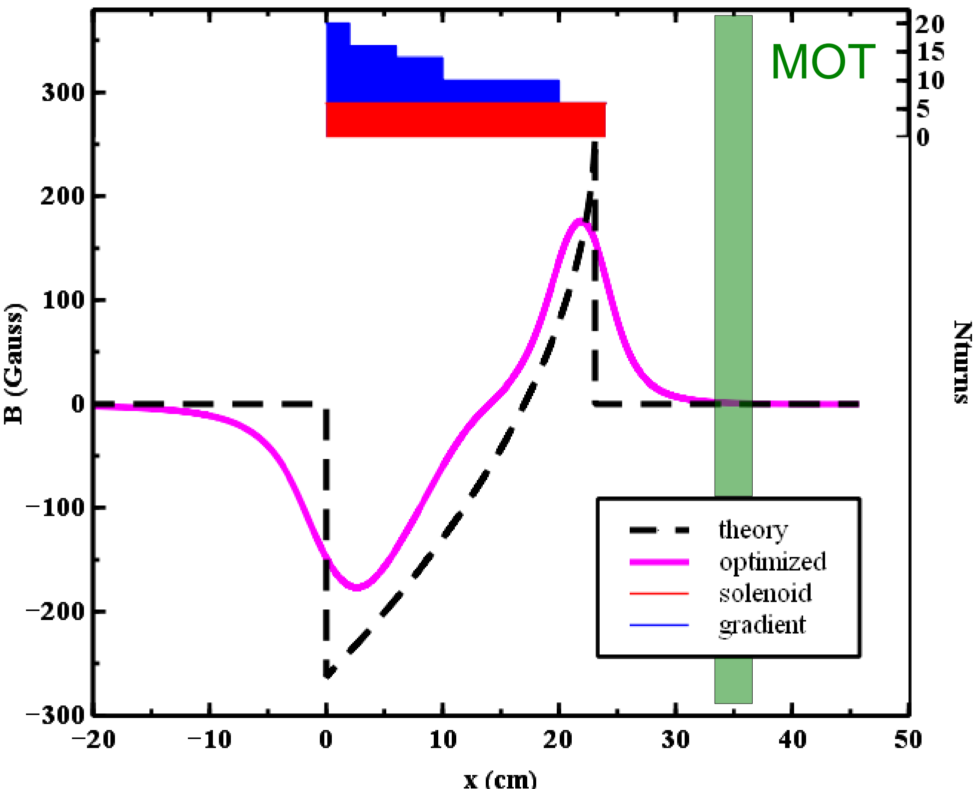
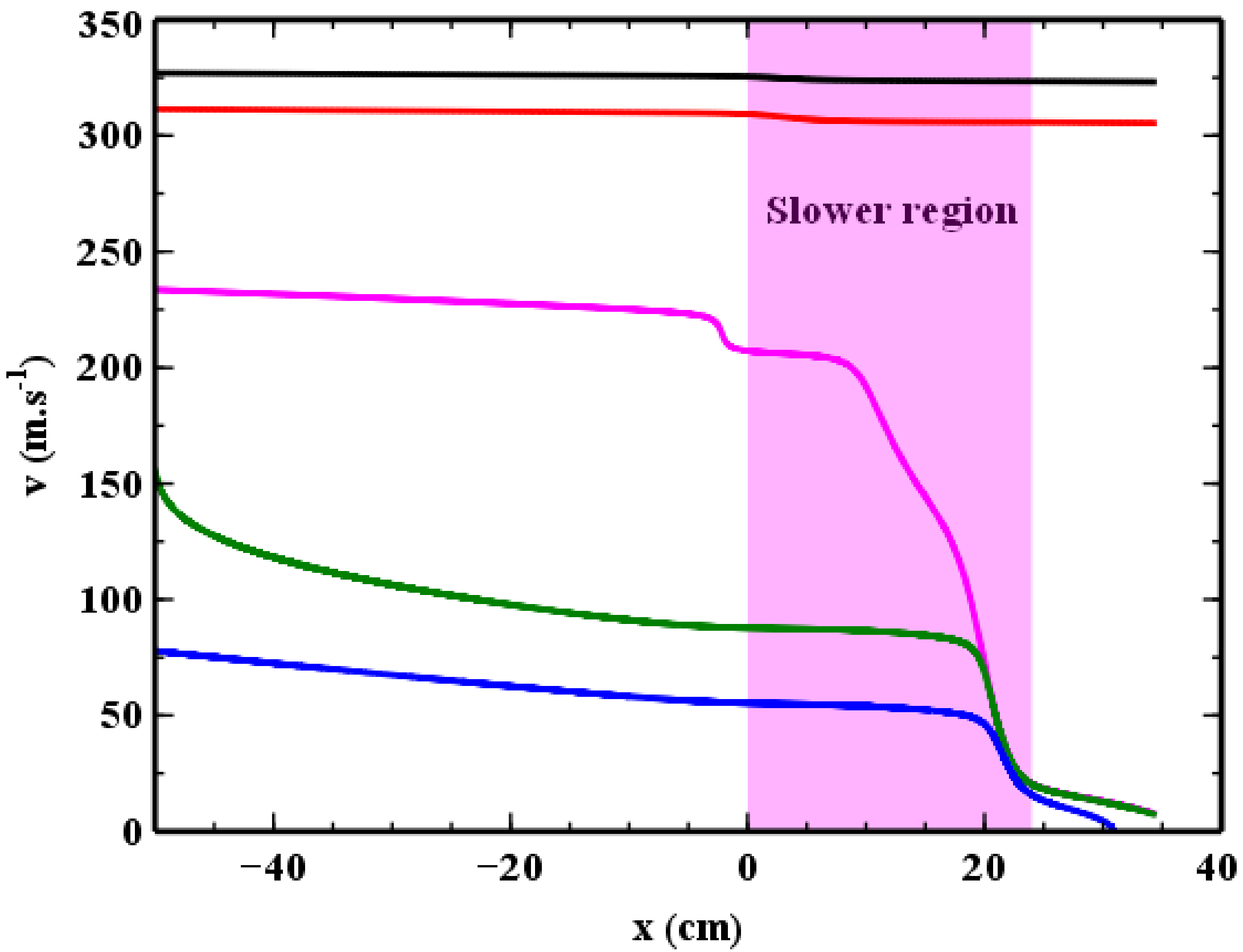


Gives laser detuning $\omega_{laser}-\omega_{atomic}$

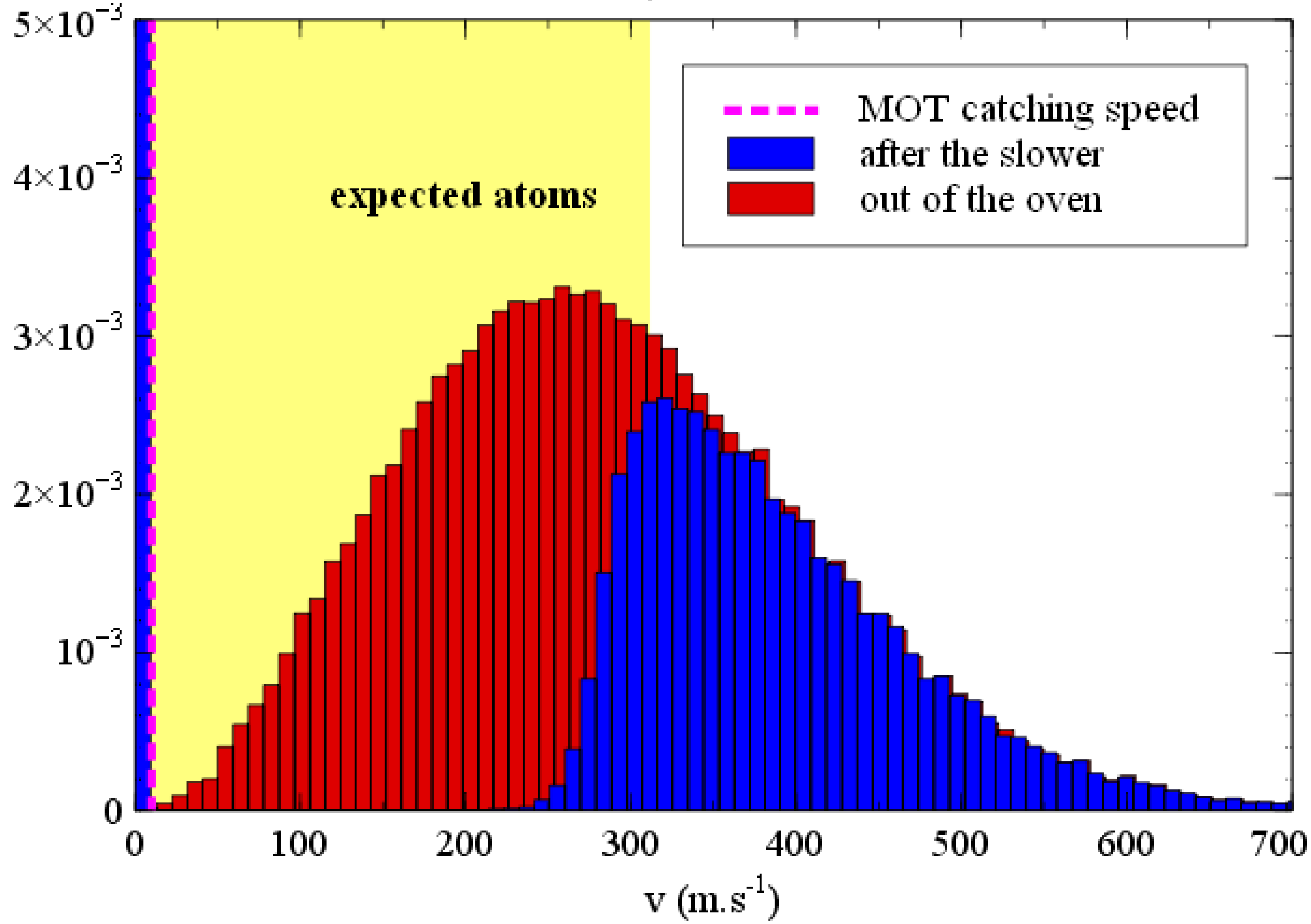
▶ Zeeman slower :

Simulated trajectories



► Zeeman slower :

Effect on speed distribution

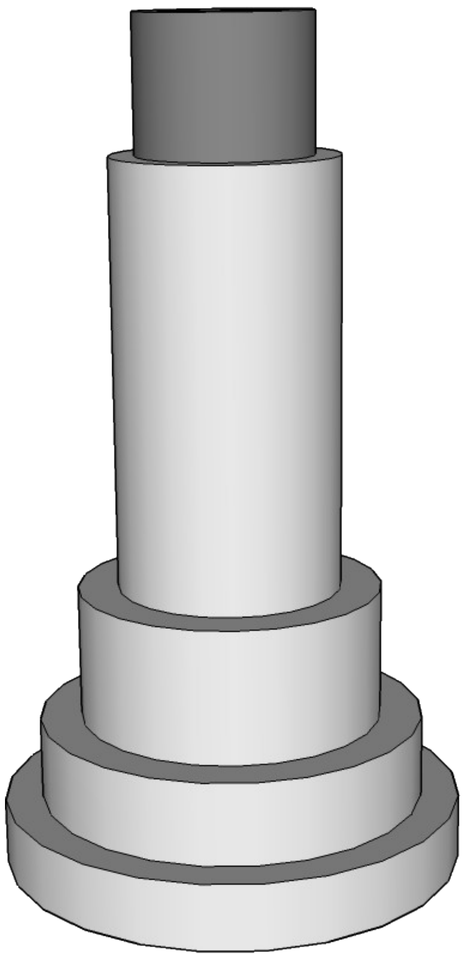


► Simulation results : – 16 % of the flux is captured
– 25 % of expected atoms are captured

NB : we consider that the MOT can catch atoms with v < 8m/s

NB' : we take transverse expansion of the beam into account (MOT expected capture radius ~ 2cm)

- Zeeman slower recipe :



$\equiv$

- ► Zeeman slower recipe :

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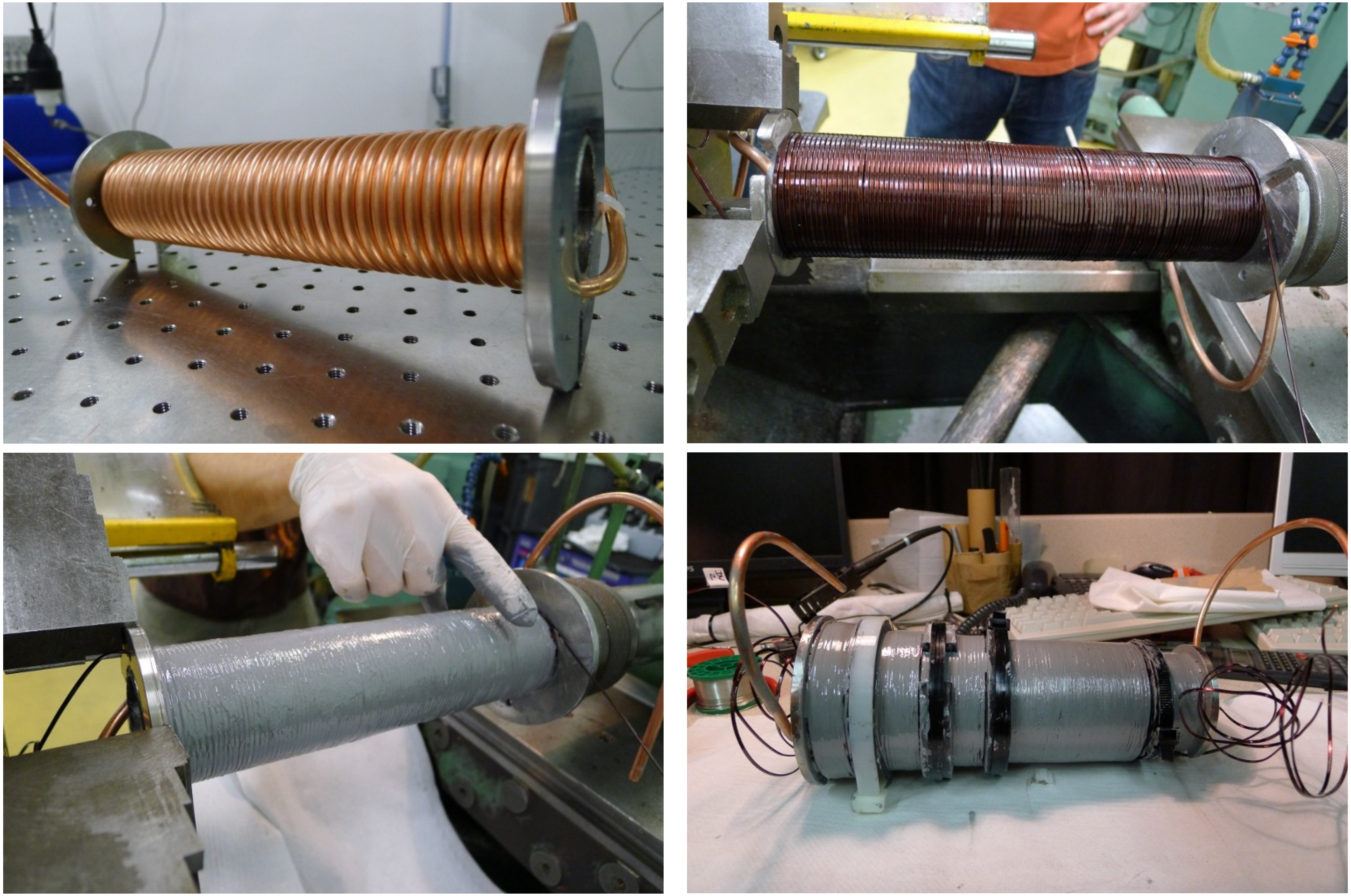
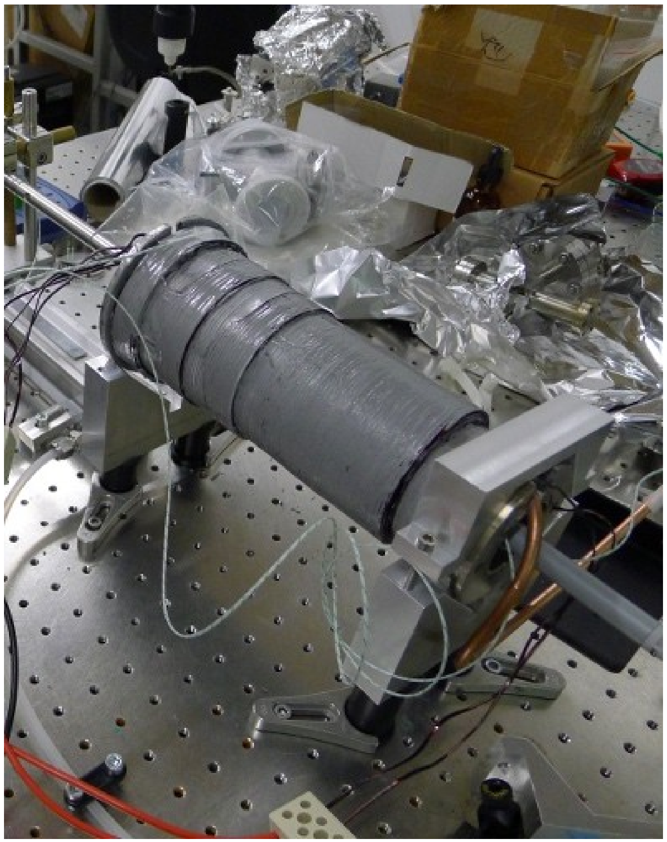
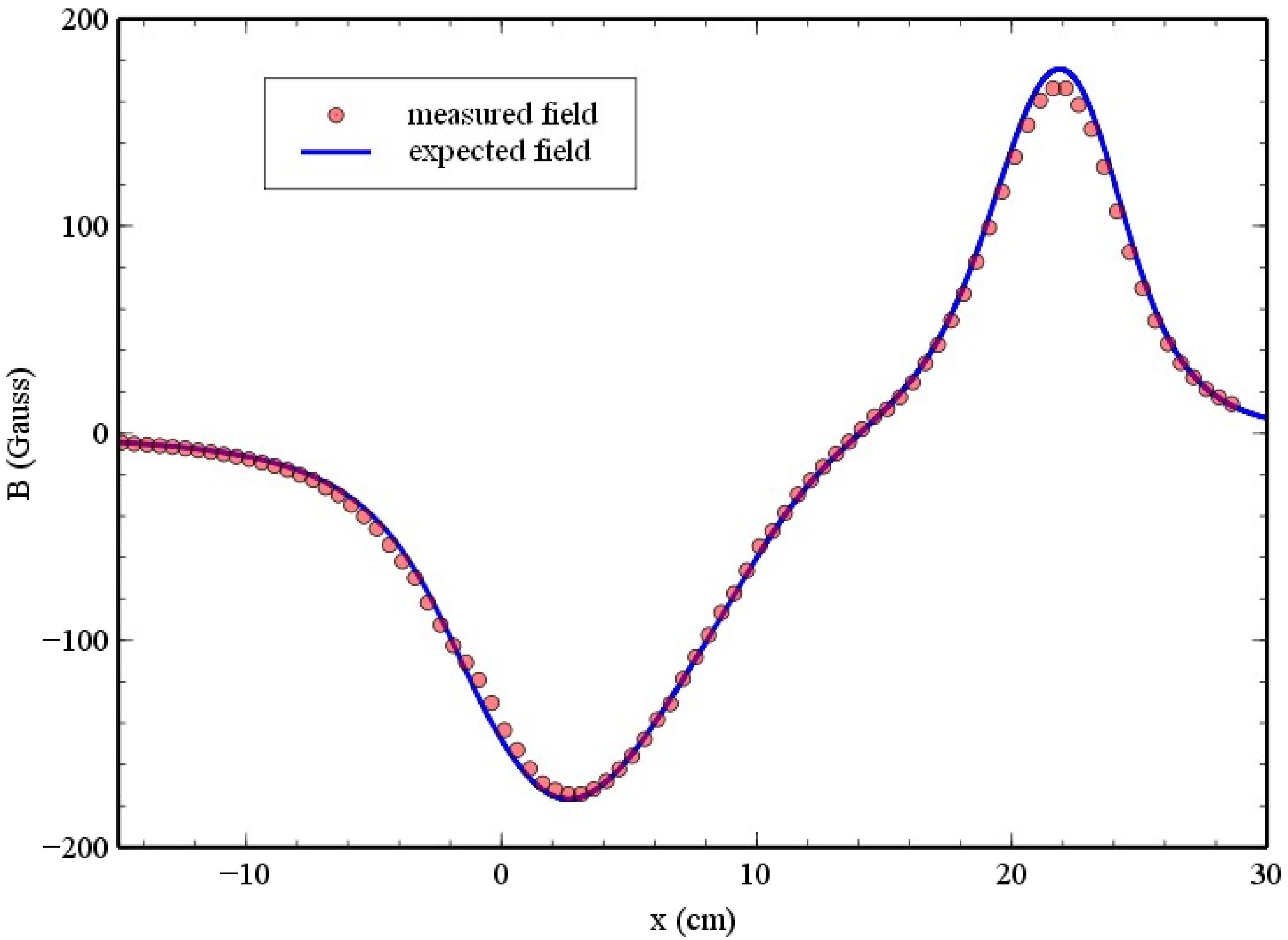
Laboratoire Kastler Brossel Physique quantique et applications

▶ Zeeman slower recipe :

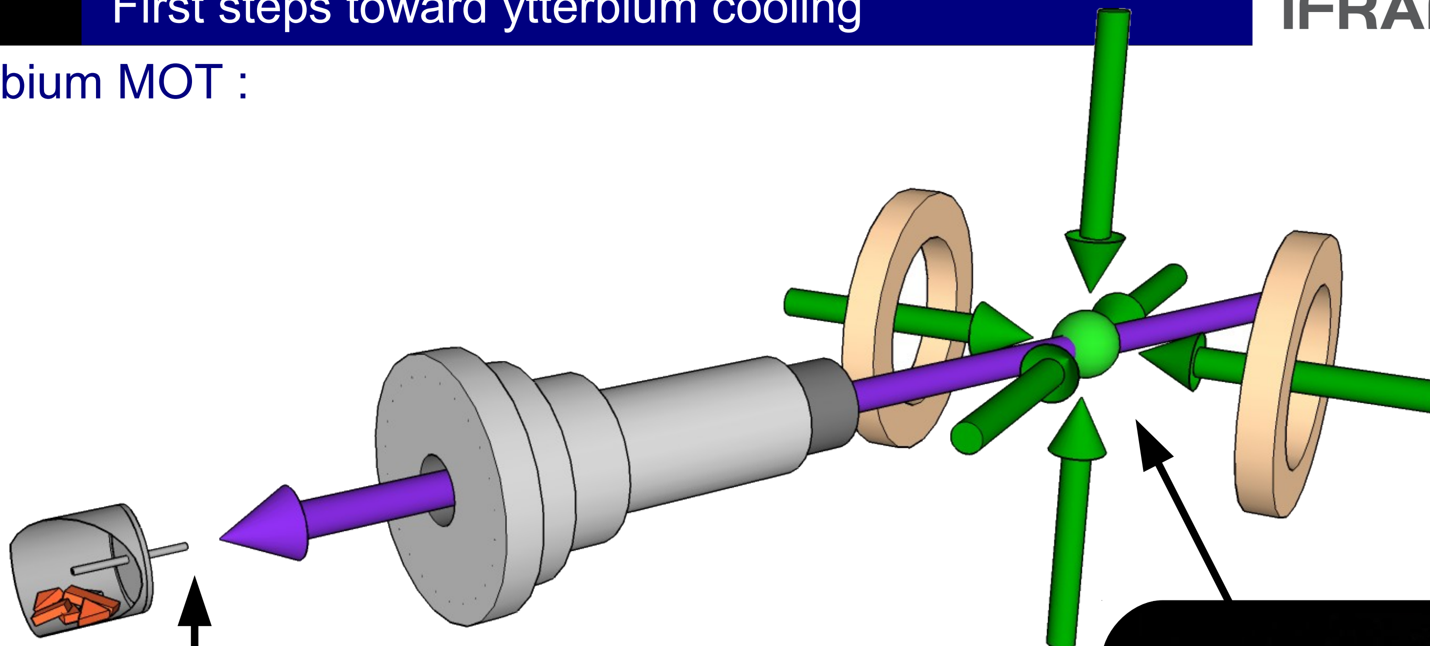


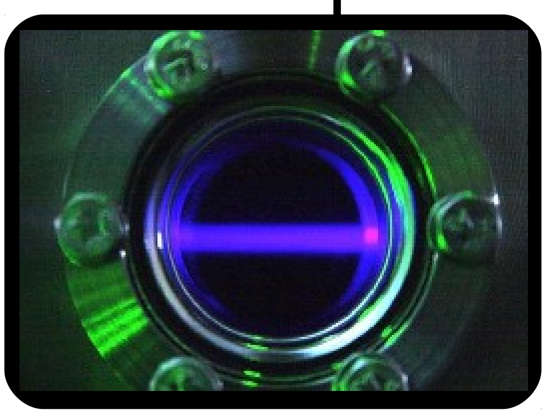
► Zeeman slower testing :





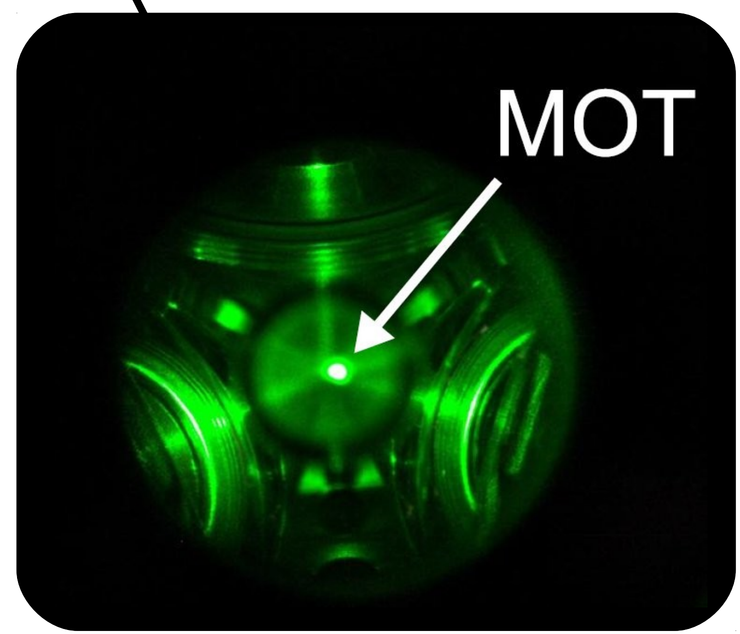
- An ytterbium MOT :





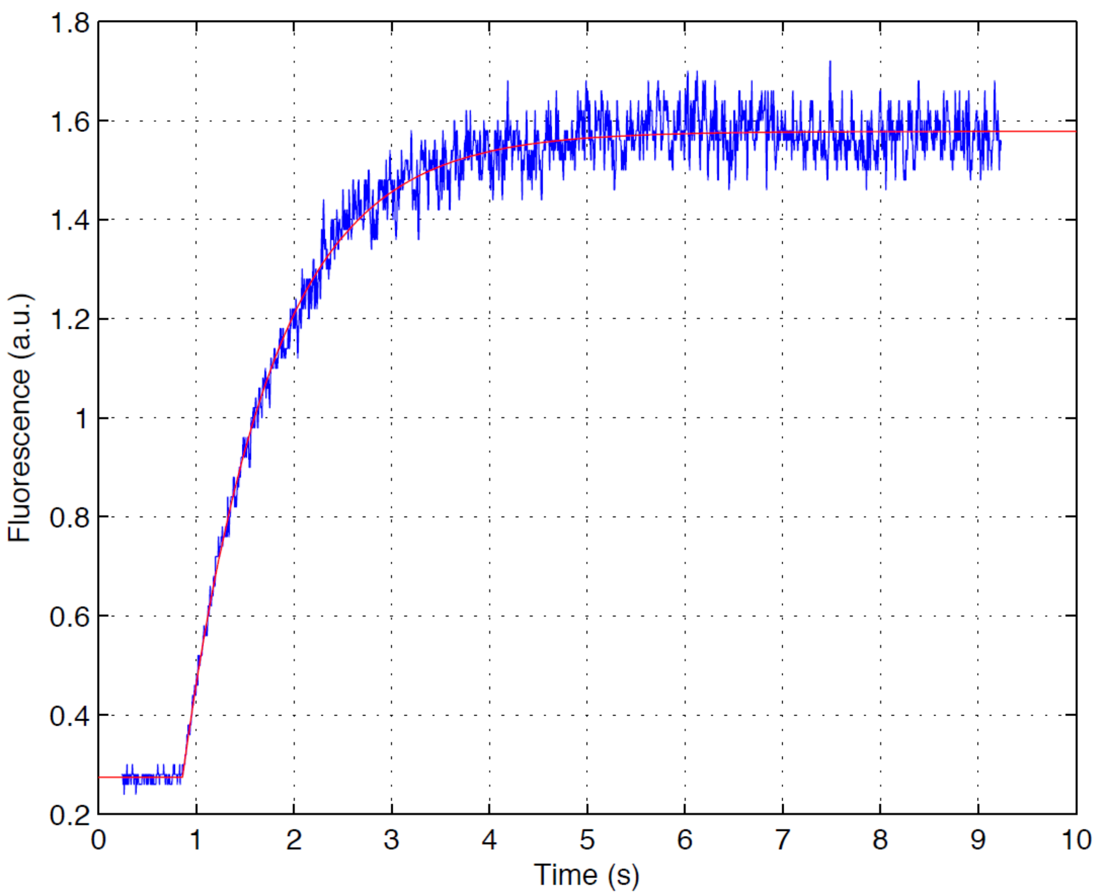
Atomic beam

Our first ^{174}Yb MOT !



▶ An ytterbium MOT :

MOT loading curve (fluorescence)



Simple loading model :

$$\frac{dN}{dt} = -\frac{N}{\tau} + R$$

Lifetime : τ

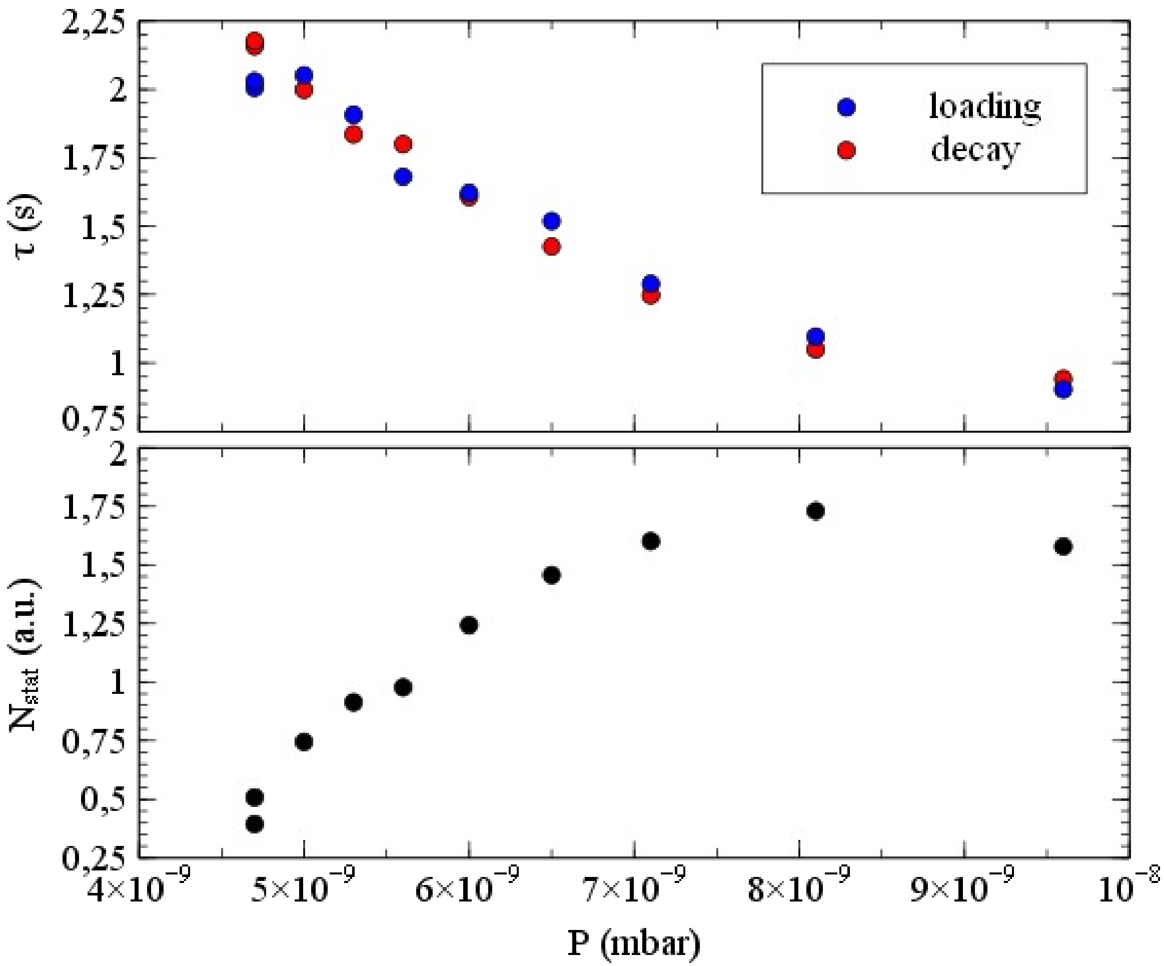
Stationary number : $N_{stat} = R\tau$

MOT properties

Atom number ~ 3 x 10^6
Life time ~ 1 s (vacuum limited)
Power / beam ~ 20 mW

► An ytterbium MOT :

Lifetime & number of atoms vs pressure



$$\frac{dN}{dt} = -\frac{N}{\tau} + R$$

Lifetime : τ

Stationary number : $N_{stat} = R\tau$

► Issues :

– vacuum improvement : **done !**

now working pressure ~ 8×10^{-10} mbars

new expected lifetime ~ 20 s

→ N_{stat} ~ 6×10^{7} atoms

– laser mode-hops kill MOT

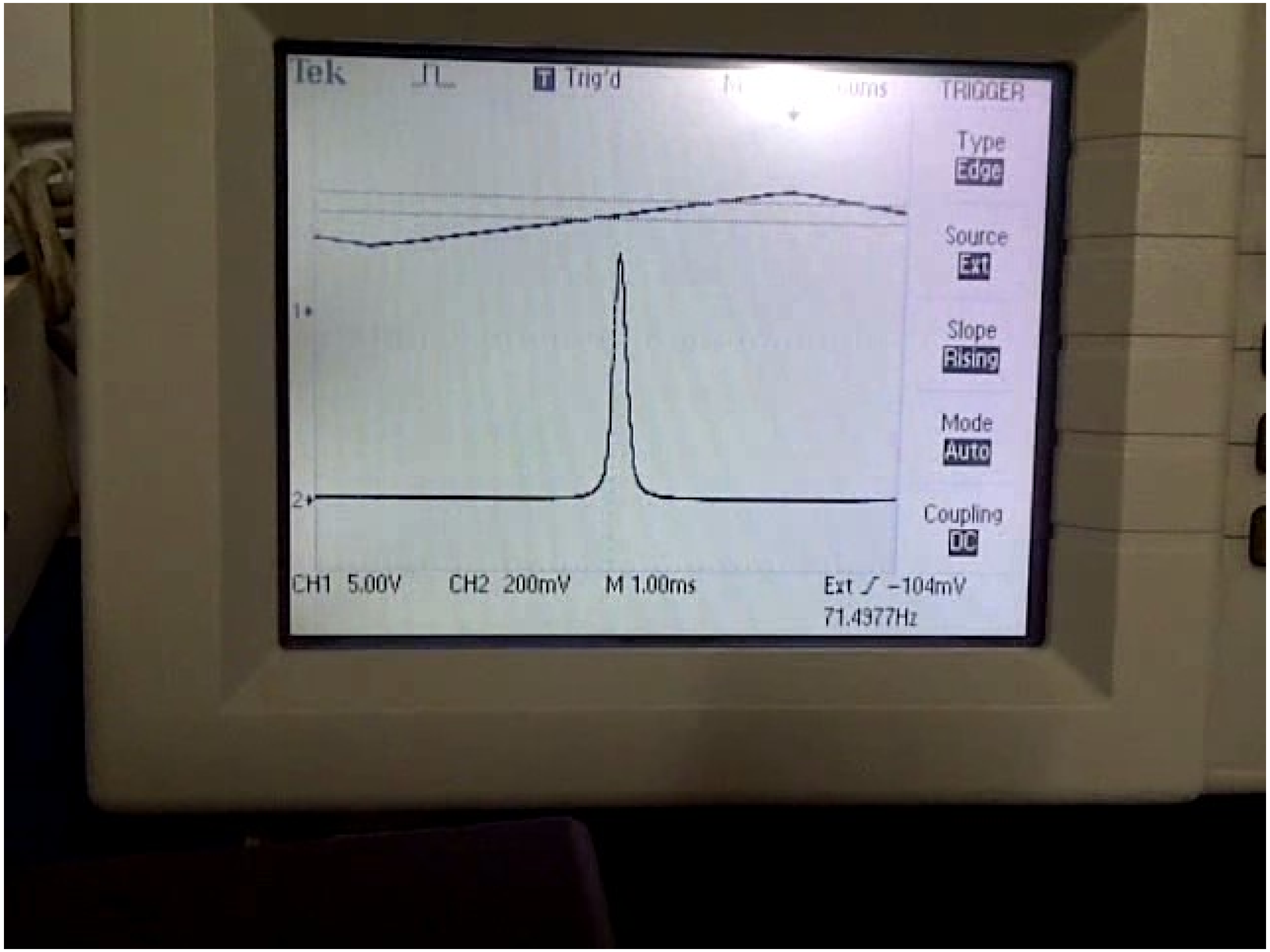
► To do :

– side-bands on MOT laser (↑ v_{capt})

– Zeeman & MOT parameters optimization

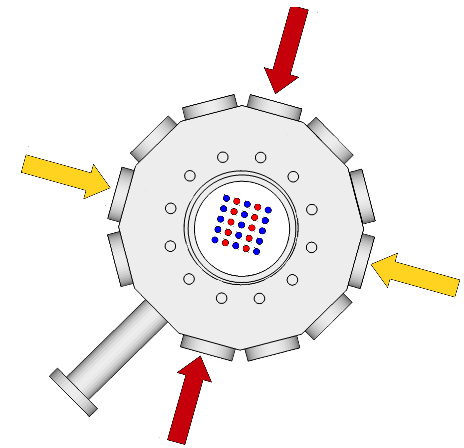
– temperature measurement.

▶ A jumpy laser :

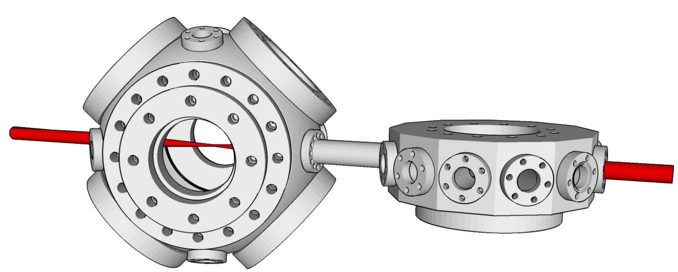


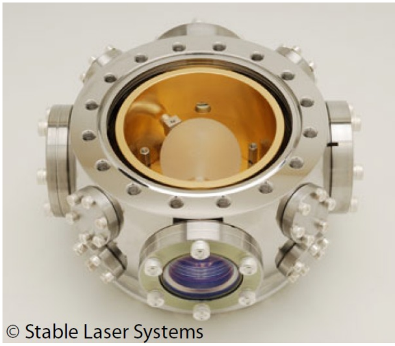
▶ What is next ?

- **Atomic beam** ✓
- **Zeeman slower** ✓
- **MOT** ✓
- **Dipole trap**
- **Transport**
- **Lattice**
- **Coupling laser**



– frequency summing
– locked to ultra-low expansion cavity





ULE cavity
Finesse : 3×10^5

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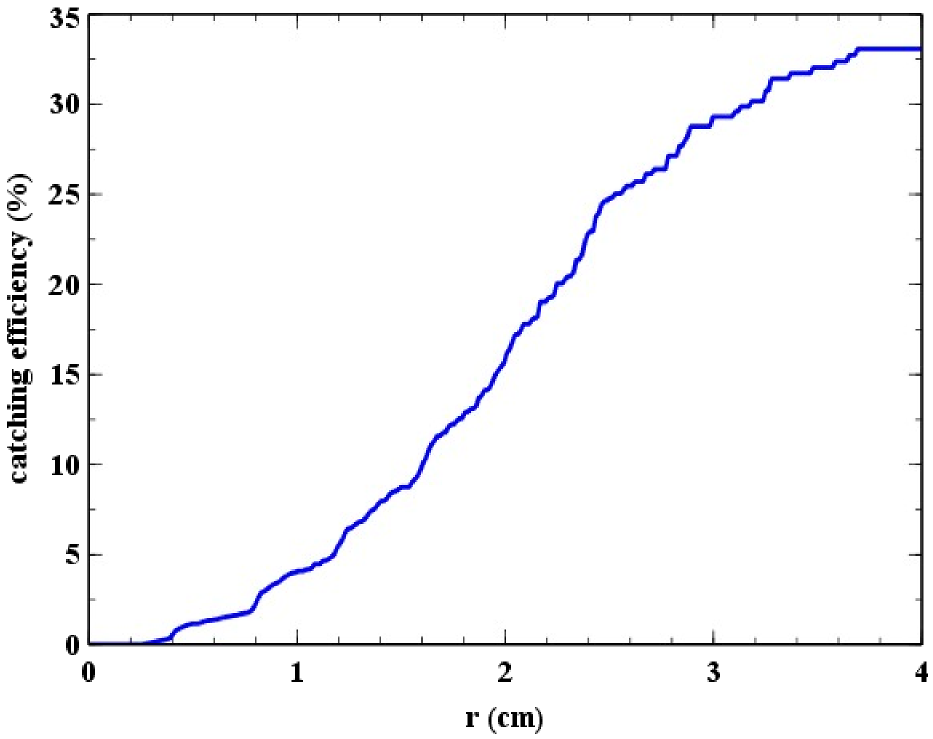
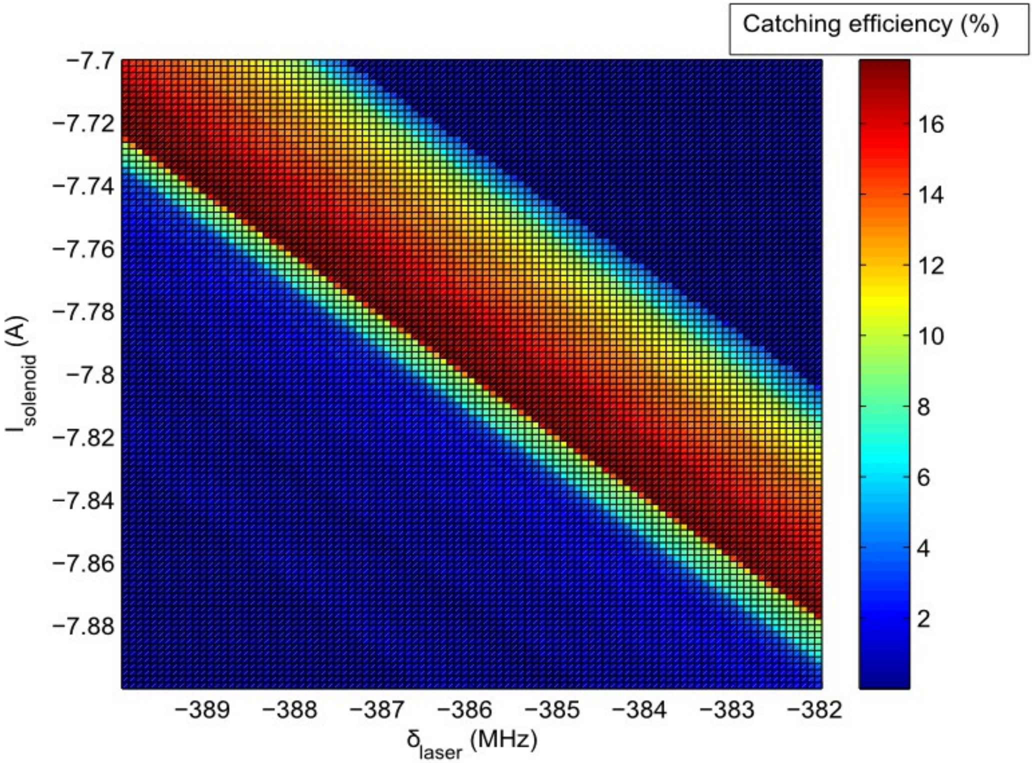
Thank you for your attention !

▶ Zeeman slower : extra plots

Transverse extension



Solenoid current vs laser detuning



► Zeeman slower testing :