Determination of the effective saturation intensity $I_{\rm sat}$

To image the cloud of atoms by absorption, we shine a pulse of resonant light with an intensity I_0. After its propagation through the packet of atoms, the intensity of the imaging beam $I(x, y)$ obeys the following equation :

$$\frac{I_0}{I_{\rm sat}} - \frac{I}{I_{\rm sat}} + \ln\left(\frac{I_0}{I}\right) = DO_{\rm real} \equiv d(x, y) \tag{1}$$

where $d(x, y)$ is the real optical density. In the following, d denotes the maximum optical density $d = \max\{d(x, y)\}$. Experimentally, we measure an effective maximal optical density δ :

$$\ln\left(\frac{I_0}{I}\right) = DO_{\rm measured} \equiv \delta \tag{2}$$

We deduce from Eq. (1) the equation fulfilled by the parameters d, δ, I_0, and $I_{\rm sat}$:

$$1 - e^{-\delta} = \frac{I_{\rm sat}}{I_0}(d - \delta) \tag{3}$$

We now take a series of absorption images of the same cloud but with different durations ΔT for the pulse of light while keeping the product $\Delta T I_0$ constant. ΔT is varied from $\Delta T_{\rm min} = 250$ ns to $\Delta T_{\rm max} = 100$ μs, and the intensity from $I_{0\rm max} \simeq 23$ mW/cm^2 to $I_{0\rm min} \simeq 0.06$ mW/cm^2. The incident intensity of the beam I_0 is measured from the total power of the beam and the size of the beam at the level of the cloud : $I_0 = P/(2\pi\Delta x\Delta y)$ with $P = 13$ mW, $\Delta x =$ 0.24 cm and $\Delta_y = 0.37$ cm. From each image, we can plot the value of the function $g(\delta)$ as a function of the duration of the pulse ΔT :

$$g(\delta) = \frac{1 - e^{-\delta}}{d - \delta} = \frac{I_{\rm sat}}{I_0} = \frac{I_{\rm sat}}{I_{0\rm max}\Delta T_{\rm min}}\Delta T \tag{4}$$

Actually, d is obtained in the low incident intensity limit (i.e. for the "long pulses" : $\Delta T \geq 20$ μs $\Rightarrow$ $I_0 \leq 0.3$ mW/cm^2) for which $\delta \simeq d$. We stress that for this kind of experiment, d needs to be quite low ($d \leq 1$) in order to minimize the correction to optical density due to the finite linewidth of the imaging laser. In practice, we used $d \approx 0.7$ to perform those experiments.

The plot obtained from Eq. (4) gives a straight line with a slope $I_{\rm sat}/(I_{0\rm max}\Delta T_{\rm min})$, from which we deduce the effective intensity of saturation $I_{\rm sat}$. We use here only the points $\Delta T \leq 2$ μs $\Rightarrow I_0 \geq$ 3 mW/cm^2 for which $\delta < d$, the other points corresponding to longer pulses are used to determine d. These experiments have been done with various polarizations for the imaging beam[1]. The results are summarized in the following table :

Polar	I_0 [mW/cm^2]	$I_{\rm sat}$ [mW/cm^2]	Mean
π 150°	23.3	5.2 ± 0.2	5.4 ± 0.2
π 60°	23.3	5.5 ± 0.3	
σ^+	22.7	3.6 ± 0.1	3.55 ± 0.1
σ^-	23.3	3.5 ± 0.1	

(5)

For a given incident intensity, we can saturate more the atoms by using a circularly polarized light.

[1] "2005_11_10_!_ DATA_!_Polar_and_Int_at_Nbr_ph_fix.OPJ" for the row data, and 2005_11_10_!_ STAT_!_Polar_and_Int_at_Nbr_ph_fix.OPJ" for the result.