Measuring densities of cold atomic clouds smaller than the resolution limit.

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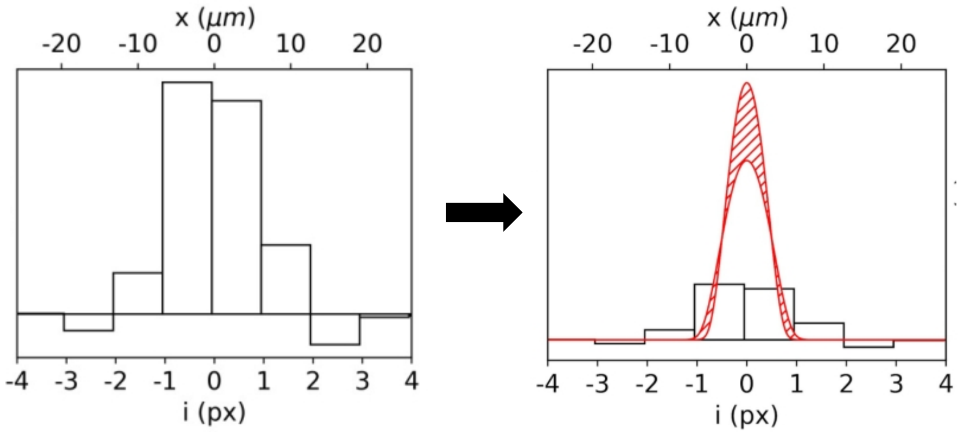

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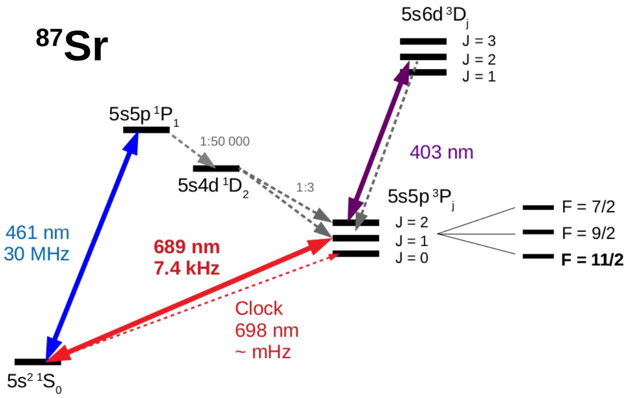
Université Sorbonne Paris Nord

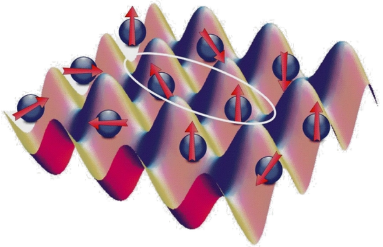
Experimental setup to study quantum magnetism on optical lattices

LPL Laboratoire de physique des lasers



ULTRA COLD ^{87}Sr IN OPTICAL LATTICES STUDYING QUANTUM MAGNETISM BEYOND SPIN ½

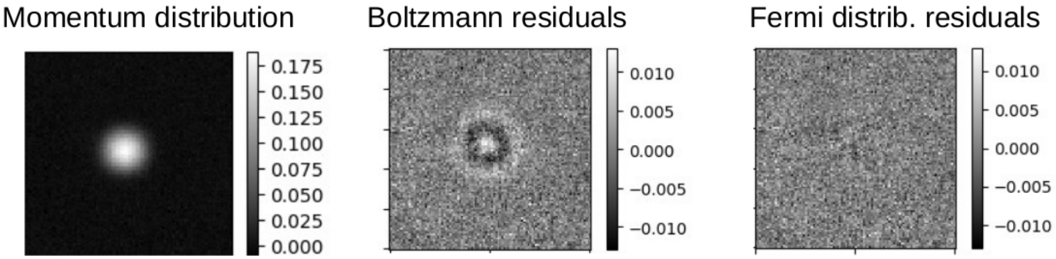
Magnetism with Nuclear Spins



$$H_{Heis} = -J \sum_{<i,j>} \vec{S}_i . \vec{S}_j$$

Fermi gas with 10 spin states 10^4 atoms at T/T_F ~ 0.2

($T \approx 30$ nK, $T_F \approx 150$ nK)



P. Bataille and al. **Phys. Rev. A 102, 013317 (2020)**

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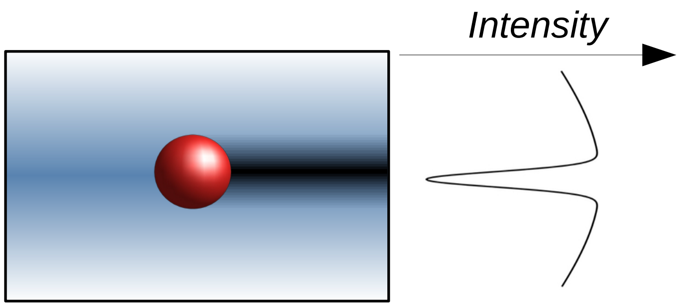
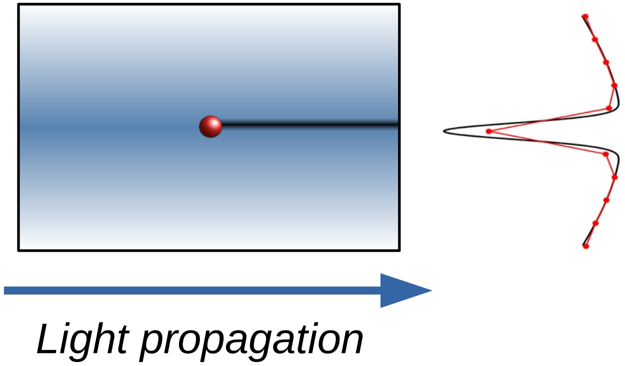
Absorption imaging of objects smaller than the resolution limit



Beer Lambert Law

$$\frac{dI(x,y,z)}{I(x,y,z)} = -n(x,y,z)\sigma_0 dz$$



Resolution limited

Diffraction, abberations, pixelation

Collected light over an area (pixel) matched to the resolution

$$P(i,j) = \iint_{D_{i,j}} I(x,y)dxdy$$

$$\log\left(\frac{P(i,j)}{P_0(i,j)}\right) \neq \frac{1}{a^2}\iint_{D_{i,j}} \log\left(\frac{I(x,y)}{I_0(x,y)}\right) dxdy$$

Log of averaged transmission ≠ **Averaged density of atoms**

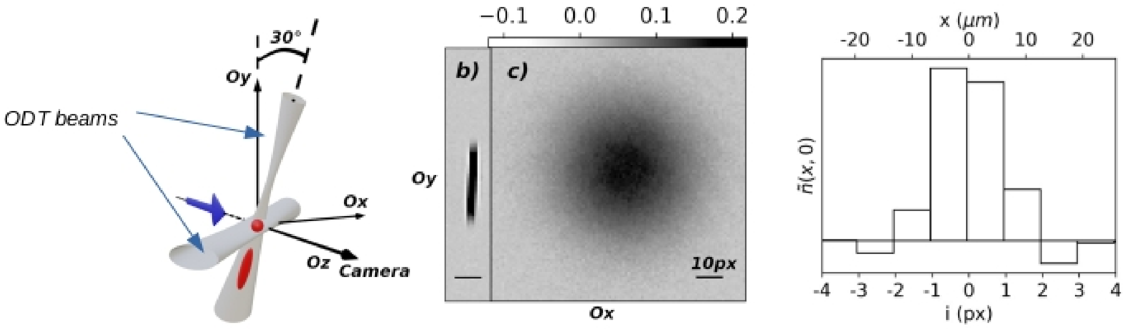
$= - \tilde{n}(x,y)\sigma_0$

Error not only on peak density measurement but also on atom number count.

Phys. Rev. A 104, 033309

Analysis for objects smaller than the resolution limit

Our setup:



Distorsion of measured atomic density on unresolved (d) dimension along the short axis (b).

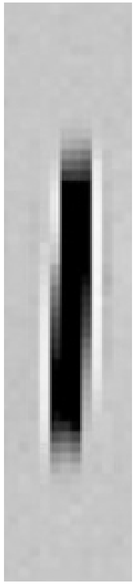
Core principle:

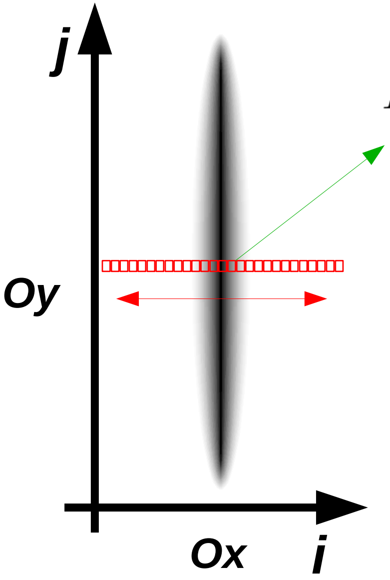
The number of scattered photons per atom depends on the optical thickness, *i.e.* size, of an atomic cloud.

→ *Shadowing Effect*

[Phys. Rev. A 104, 033309]

Analysis of the scattered photons





local ratio of missing photons R_{ph} per pixel (i,j)

$$R_{ph}(i,j) = \frac{P_0(i,j) - P(i,j)}{P_0(i,j)}$$

Summation over pixel line for longitudinal profile

$$R_{ph}(j) = \sum_i R_{ph}(i,j)$$

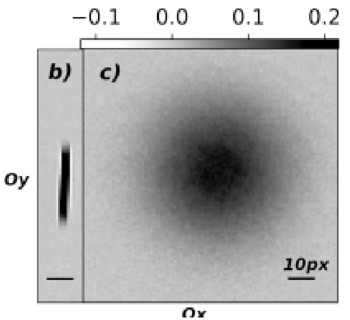
Gauss ansatz : defines the transverse size σ_x to be measured

$$n(x,y) = e^{-\frac{x^2}{2\sigma_x^2}}\tilde{n}(0,y)$$

Express the local density with respect to the absorbed photons. Depends on the parameter σ_x only

$$R_{ph}(j) = \frac{\sigma_x}{a}F(\sigma_0 \tilde{n}(0,aj))$$

$$N_{at} = \frac{\sqrt{2\pi}a\sigma_x}{\sigma_0}\sum_j F^{-1}\left(\frac{a}{\sigma_x}R_{ph}(j)\right)$$

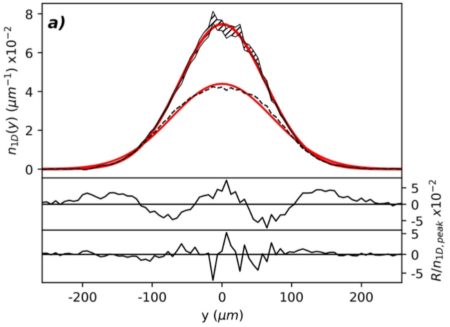


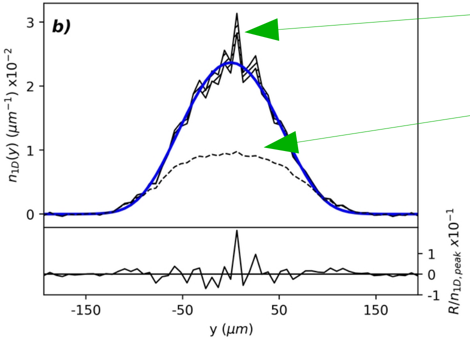
Phys. Rev. A 104, 033309

Verification

Longitudinal distorted profile (resolved dimension)

$$R_{ph}(j) = \frac{\sigma_x}{a} F\big(\sigma_0 \tilde{n}(0, aj)\big)$$

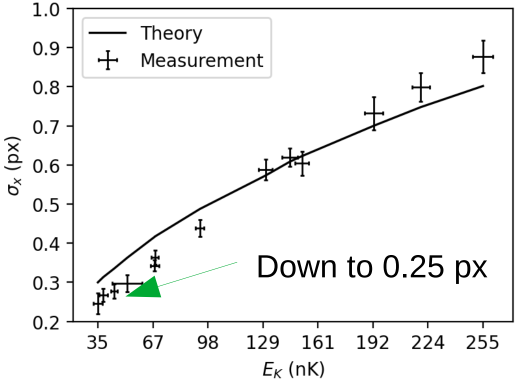




Our method

Standard analysis

Transverse unresolved dimension



Thermal gas :

Boltzman distribution
Curve fitting of the recovered cloud shape.
Residuals show distorted shape initially.
Only noise after recover.

Fermi gas :

Degenerate Fermi gas at 0.2 T_F.

Expected distribution with **no free parameter**.
Residuals show that the recovered profile match the expected profile.

Prediction with independent measurement of the **temperature** and **confinement frequencies**

$$\frac{1}{2} m\omega^2 \sigma_{x_{th}}^2 = E_K$$

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