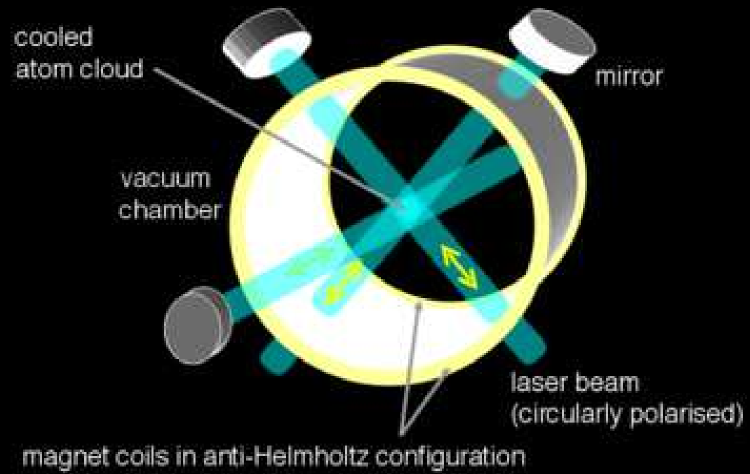

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High resolution imaging of ultracold potassium atoms for quantum simulation

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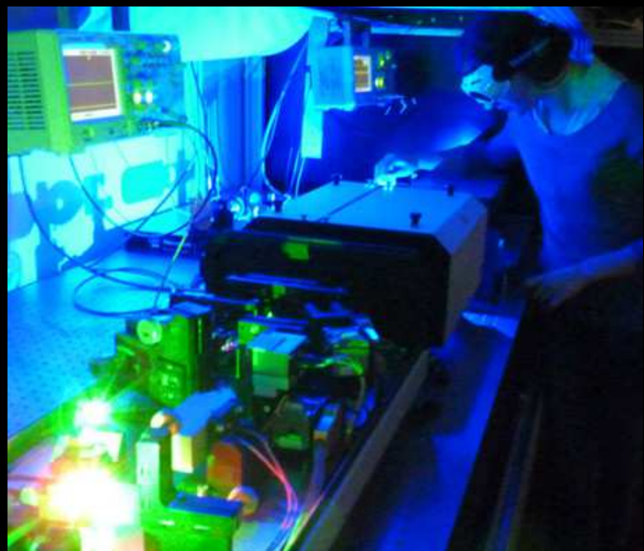
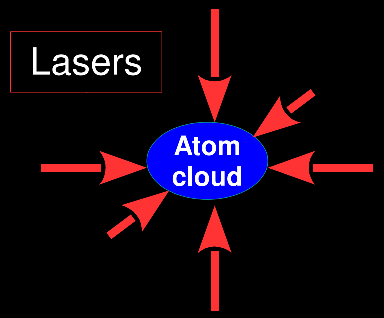


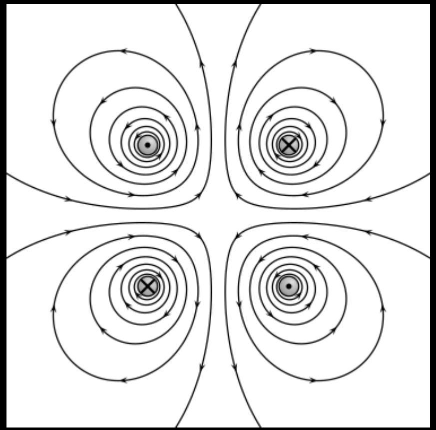
Exotic Quantum Matter group

Magneto-optical trap (MOT)

1 – (sub)Doppler cooling ~15µK



2 – Quadrupolar magnetic field
↔ magnetic trapping

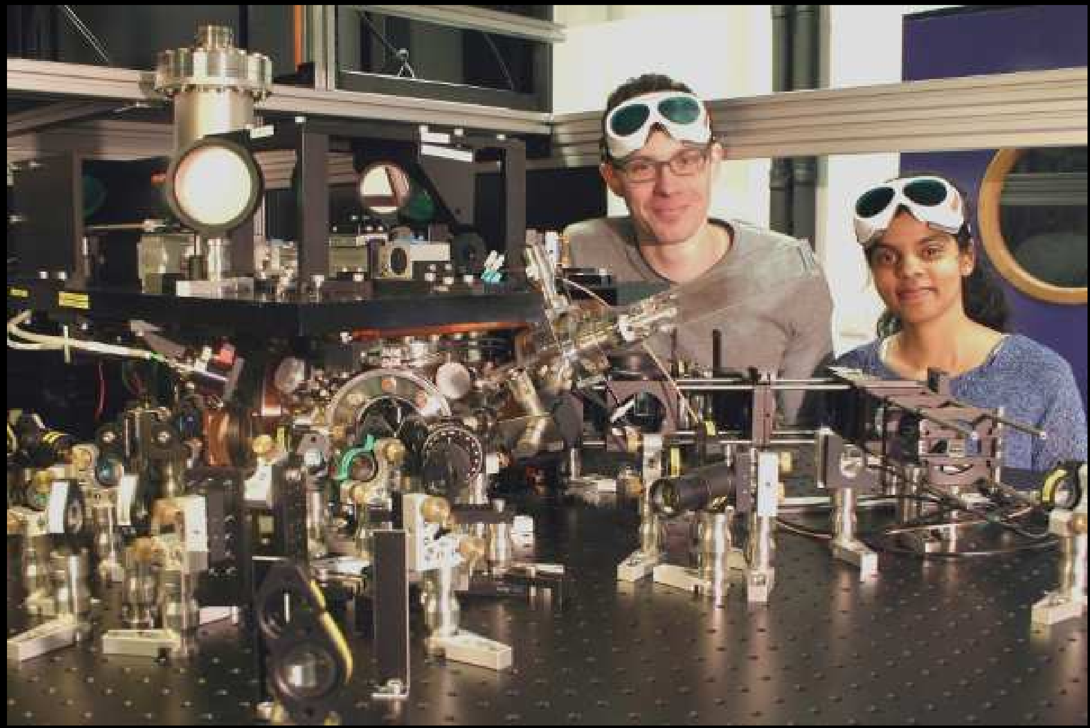


→ Use for neutral atoms
(no Coulomb interaction)
→ Potassium :
- ^{39}K= boson and ^{40}K= fermion
- 1 valence electron ↔ H

Rydberg states

- R ~$n^2 a_0$
- High dipolar momemtum

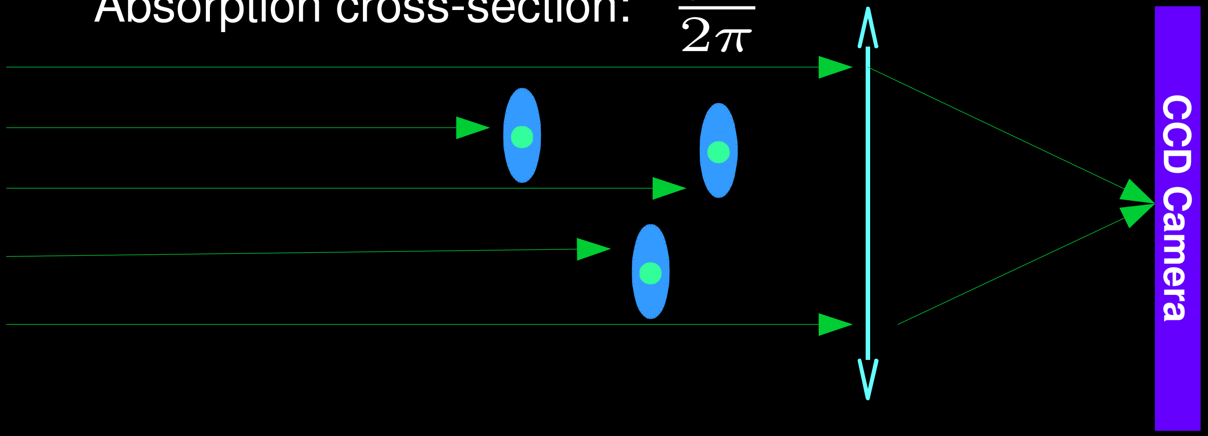
↔ strong VdW interactions
→ Quantum simulation
(magnetism, quantum dynamics)

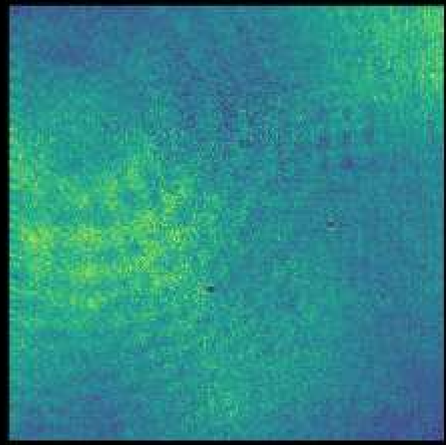


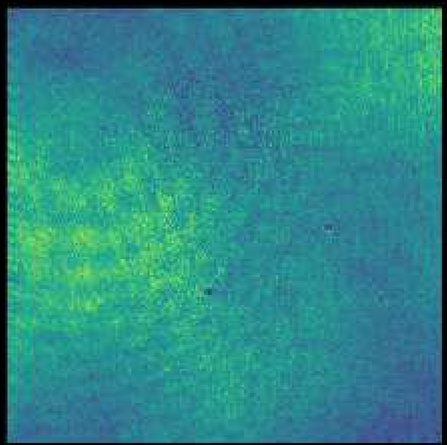
Absorption imaging

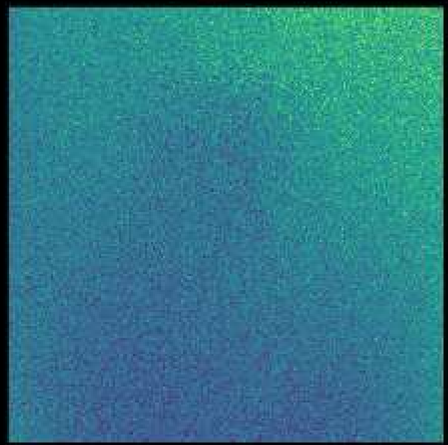
Basic idea: Illuminate the atoms with resonant laser light and measure the shadow

Absorption cross-section: $\frac{3\lambda^2}{2\pi}$





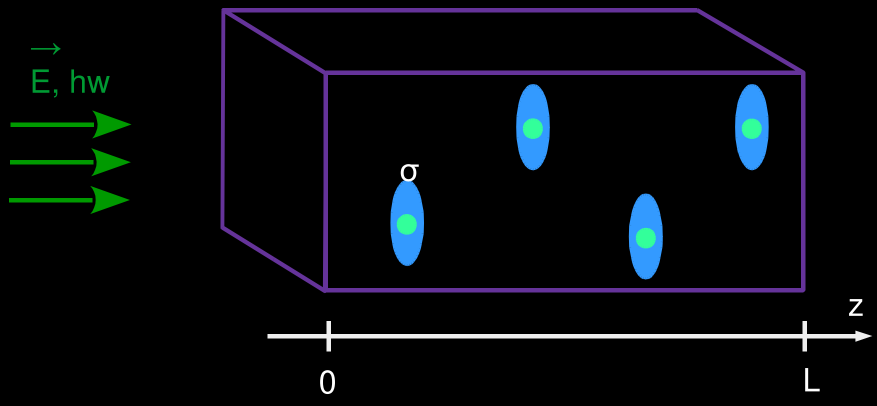




→ How much information can we extract from such images? i.e., particle number, fluctuations

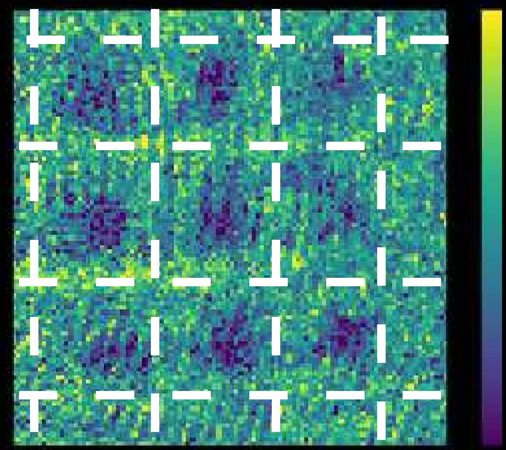
Theoretical model

Task 1: Calibrate the atom number contained in an array of 9 microtraps



$$n_{1D} = \frac{N}{L}$$

$$n_{2D} = \frac{N}{A}$$



Experiment :

$$OD = \alpha\, n_{1D}\, L$$

$$\frac{I(z=L)}{I(z=0)} = \frac{A-B}{D-B}$$

Loi de Beer-Lambert :

$$dI = -\alpha\, n_{1D}\, I dz$$

$$\frac{I_L}{I_0} = e^{-\sigma n_{2D}}.$$

$$N = \frac{-A}{\sigma} \sum_{i,j} \ln\left(\frac{A-B}{D-B}\right)$$

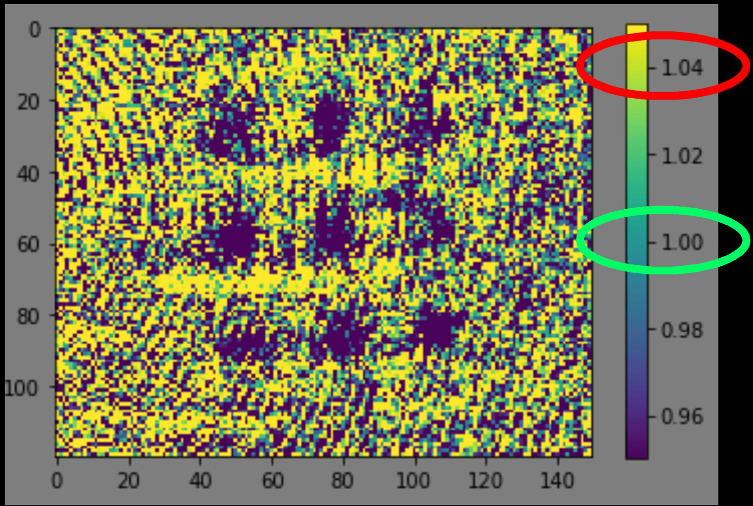
→ N~ 100 particles

→ Errors ? Inaccuracies ?

→ Depends a lot on the background

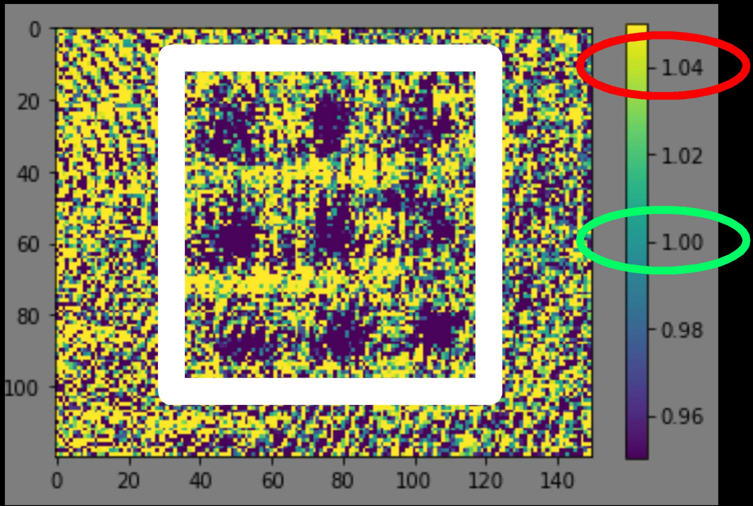
Offset

Ideal case : $\dfrac{A-B}{D-B} \sim 1$



Offset

Ideal case : $\frac{A-B}{D-B} \sim 1$



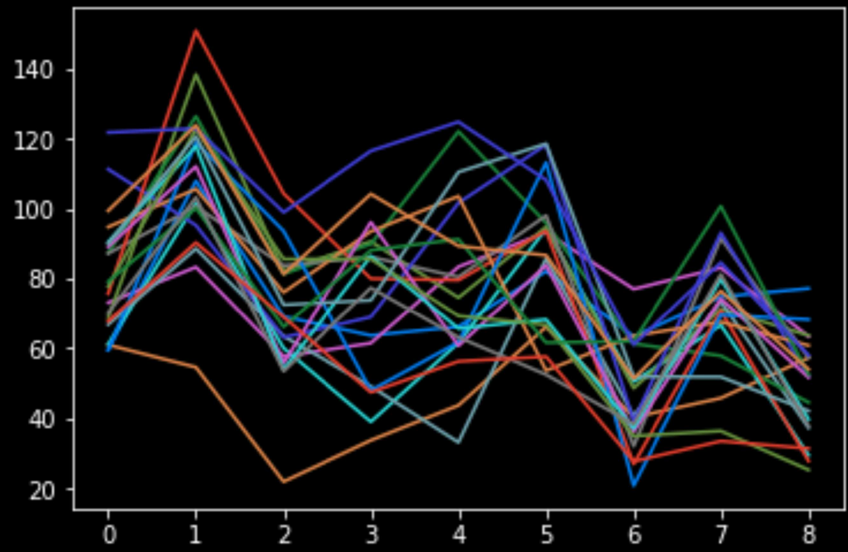
around sites → avoid fluctuations

$$\left.\begin{aligned}\bar{A} &= \sum_{ij} A_{ij}\, mask_{ij} \\ \bar{D} &= \sum_{ij} D_{ij}\, mask_{ij}\end{aligned}\right\} \frac{\bar{A}}{\bar{B}} = offset = 1{,}02$$

$$A \rightarrow \frac{A}{offset} \equiv D$$

→ Mask :

$$\begin{pmatrix} 0..........00000000000.........0 \\ 0..........011111111110..........0 \\ 0..........0110......0110..........0 \\ 0..........0110......0110..........0 \\ 0..........011111111110..........0 \\ 0..........00000000000..........0 \end{pmatrix}$$



Correlations

Task 2: Analyze the atom number fluctuations. Are they Poisson distributed var(N)~N ?

Correlations between sites → $N_{ij}^{\exp} = N_{ij}^{true} + N_{ij}^{corr}$

$$If\ N_{ij}^{true} \sim Poisson \rightarrow Var(N_{ij}^{true}) = \langle N_{ij}^{true} \rangle_j$$

<u>Covariance matrix</u>

$$Cov(N_{ij}^{\exp}, N_{kj}^{\exp}) = \langle N_{ij}^{\exp} N_{kj}^{\exp} \rangle_j - \langle N_{ij}^{\exp} \rangle_j \langle N_{kj}^{\exp} \rangle_j$$

Où : $\langle X_{ij} \rangle_j = \frac{1}{21} \sum_{j=1}^{21} X_{ij} \equiv \bar{X}_i$

$$Cov(N_{ij}^{\exp}, N_{kj}^{\exp}) = Cov(N_{ij}^{true}, N_{kj}^{true}) + \langle (N_j^{corr})^2 \rangle$$

$$i \neq k \rightarrow Cov(N_{ij}^{\exp}, N_{kj}^{\exp}) = \overline{(N_j^{corr})^2}$$

$$i = k \rightarrow Cov(N_{ij}^{\exp}, N_{ij}^{\exp}) = Var(N_{ij}^{true}) + \overline{(N_j^{corr})^2}$$

Correlations

$$\begin{pmatrix} Var(N_{11})+(N_{11}^{corr})^2 & (N_{12}^{corr})^2 & (N_{13}^{corr})^2 & (N_{14}^{corr})^2 \\ (N_{21}^{corr})^2 & Var(N_{22})+(N_{22}^{corr})^2 & (N_{23}^{corr})^2 & (N_{24}^{corr})^2 \\ (N_{31}^{corr})^2 & (N_{32}^{corr})^2 & Var(N_{33})+(N_{33}^{corr})^2 & (N_{34}^{corr})^2 \\ (N_{41}^{corr})^2 & (N_{42}^{corr})^2 & (N_{43}^{corr})^2 & Var(N_{44})+(N_{44}^{corr})^2 \end{pmatrix}$$

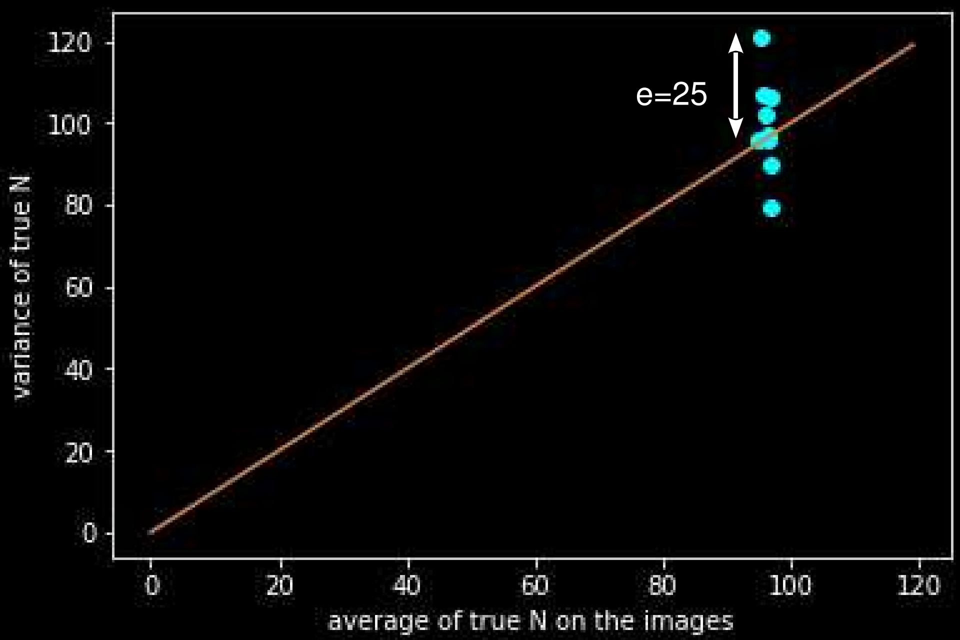
$$\langle (N_i^{corr})^2 \rangle = \frac{1}{8} \sum_{k \neq i=1}^{9} (N_{ik}^{corr})^2$$

$$\begin{pmatrix} Var(N_{11}) & 0 & 0 & 0 \\ 0 & Var(N_{22}) & 0 & 0 \\ 0 & 0 & Var(N_{33}) & 0 \\ 0 & 0 & 0 & Var(N_{44}) \end{pmatrix}$$

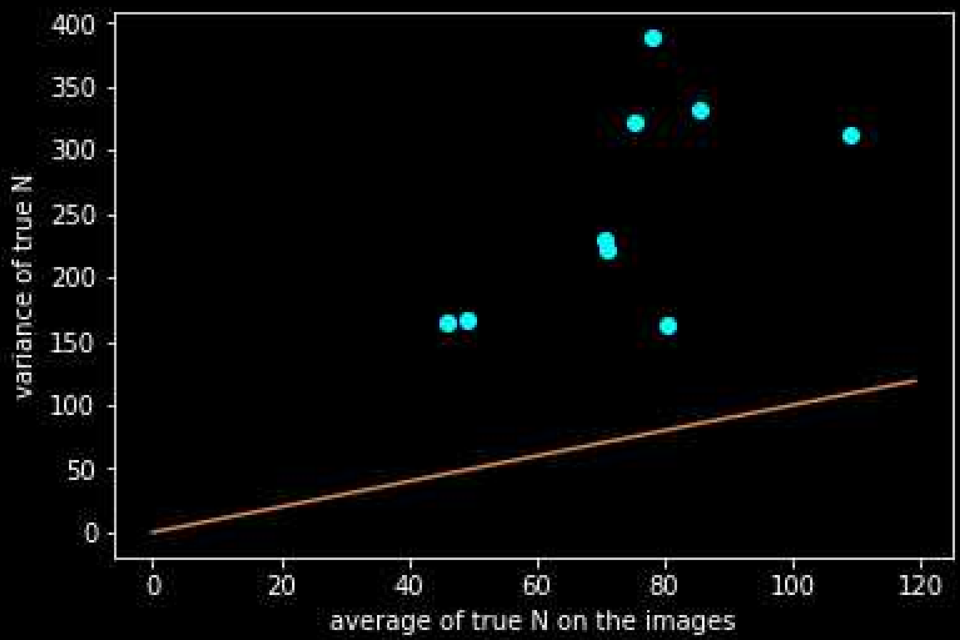
Correlations

$$Var(N_{ij}^{true}) = f(\bar{N}_j)$$

Theoretical variables following a Poisson distribution



For experimental data



Conclusion → fluctuations of errors > fluctuation particle number

Conclusion

With just one image :

- Determine the number of particles in the cavity
- Determine the influence of fluctuations
- Correction of correlation and environmental errors

Next :

- Machine / measurement errors
- Improve precision of the analysis (manually → mathematically)