Towards quantum simulation with Rydberg states of erbium atoms

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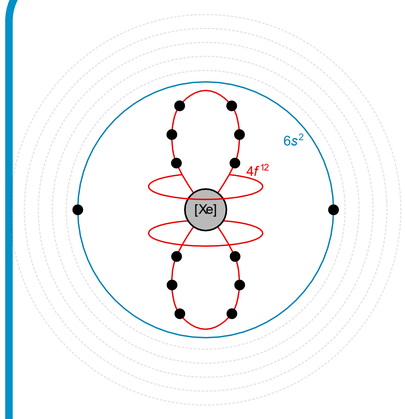
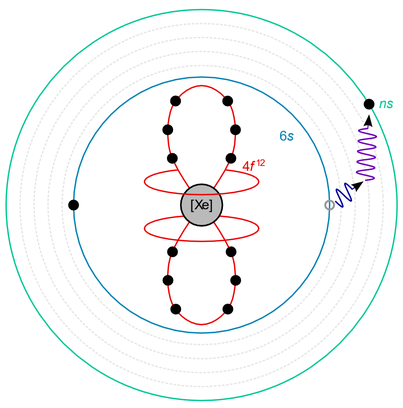
Why erbium?



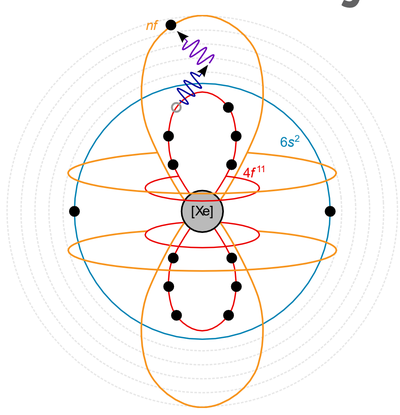
$|g\rangle := [\mathrm{Xe}]4f^{12}6s^2$

Erbium ground state



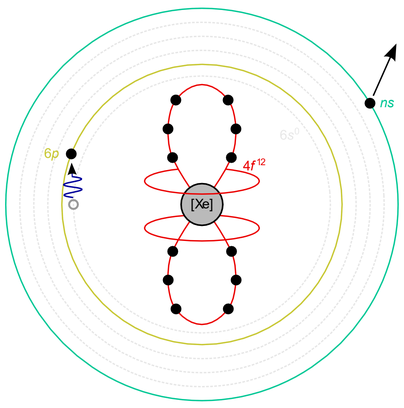
$|\mathrm{Ryd_s}\rangle = [\mathrm{Xe}]4f^{12}6sns/nd$

Rydberg excitation of $6s\ e^-$



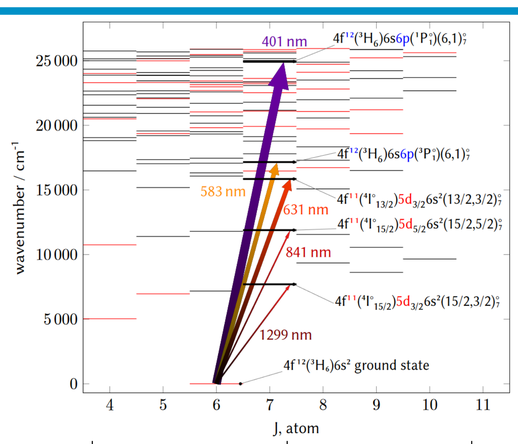
$|\mathrm{Ryd}_f\rangle = [\mathrm{Xe}]4f^{11}6s^2np/nf/nh$

Rydberg excitation of $4f\ e^-$



$|\mathrm{Er}^+\rangle = [\mathrm{Xe}]4f^{12}6p$

Isolated core excitations



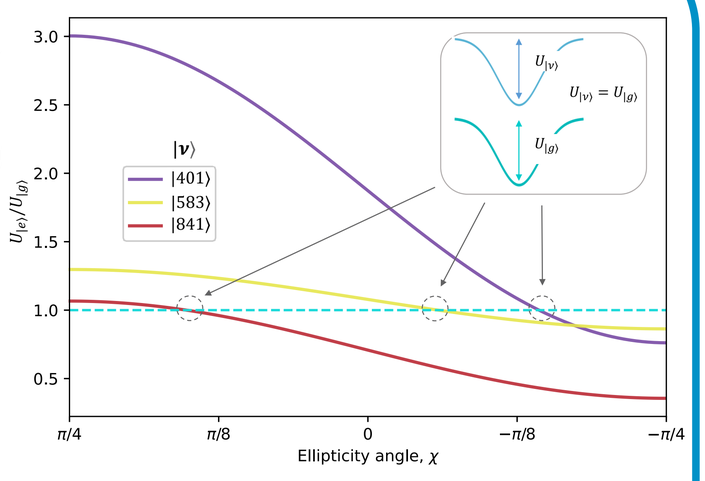
	$\lvert 401\rangle$	$\lvert 583\rangle$	$\lvert 841\rangle$	$\lvert 1299\rangle$
$\Gamma/2\pi$	28 MHz	190 kHz	8 kHz	1 Hz
	Cooling, fast imaging.	MOT, non-destructive imaging.	Sub-Doppler cooling.	State preparation.

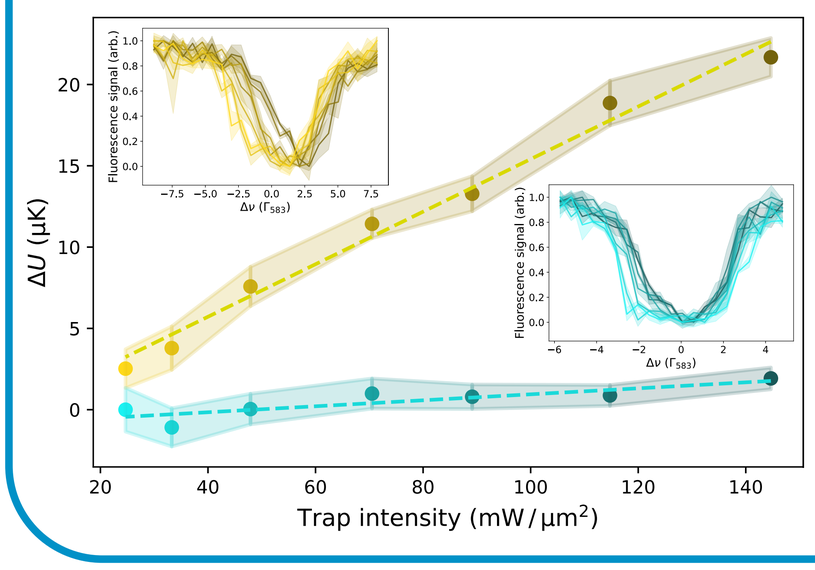
Magic trapping conditions

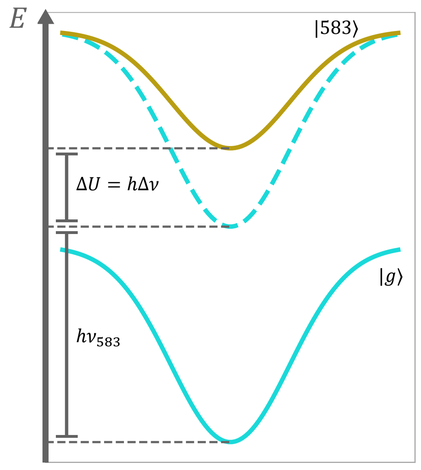
- Magic trapping, $U_{|\nu\rangle}/U_{|g\rangle} = 1$, predicted in 486 nm trap.
- Tuneable with control of trapping light polarisation ellipticity, χ:

$$\Delta U(\mathbf{r}) = U_{|\nu\rangle} - U_{|g\rangle} = -\frac{\Delta\alpha(\nu,\chi)}{2\epsilon_0 c} I(\mathbf{r}).$$

- Observe magic condition with 583 nm light in 488 nm trap:

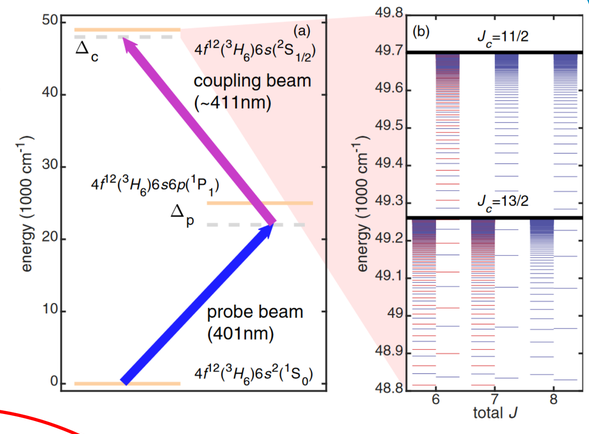


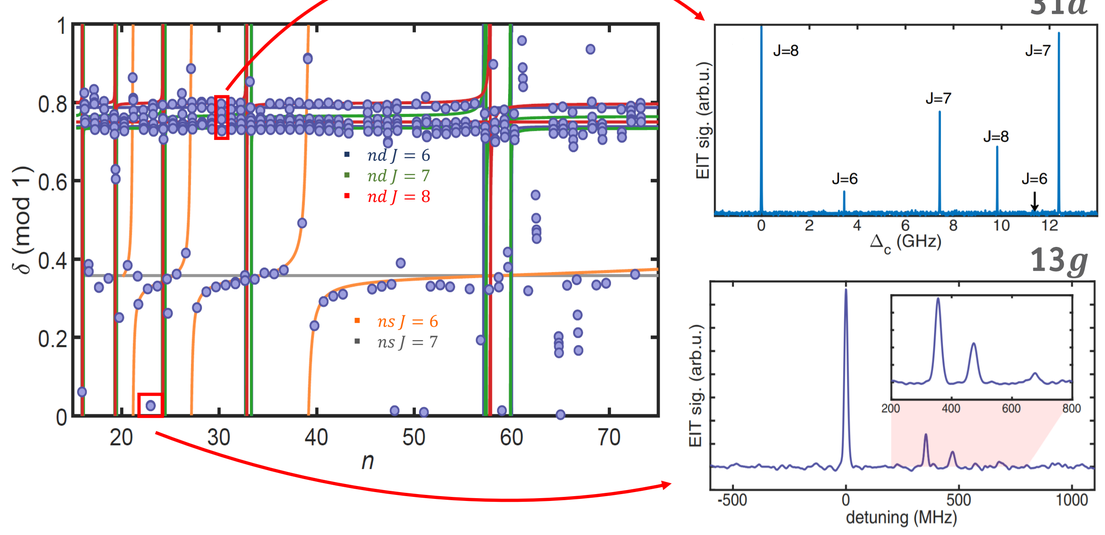




Rydberg states [1]

- Identified ~ 550 different states (up to $n = 140$) using EIT on hot atomic beam.
- Two main series with core angular momentum $J_c \in \{11/2, 13/2\}$.
- Energies, $E = E_{\mathrm{ion},J_c} - \underbrace{\frac{R_\mu}{(n-\delta_{J_c})^2}}_{\nu_{J_c}}$.
- Observed two-photon excitation to Rydberg g state ($\Delta l = 4$).

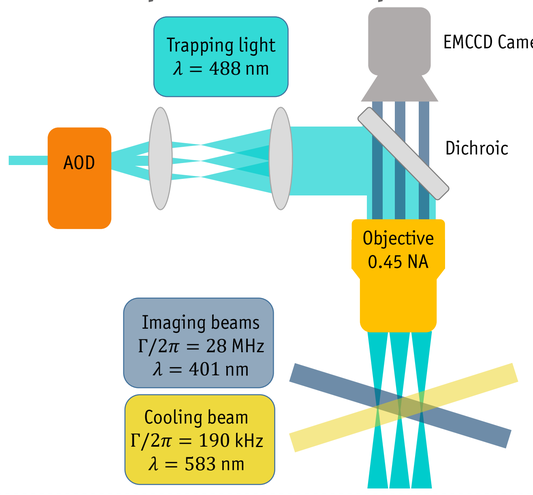




- Confirmed results by loss spectroscopy on atoms in MOT.

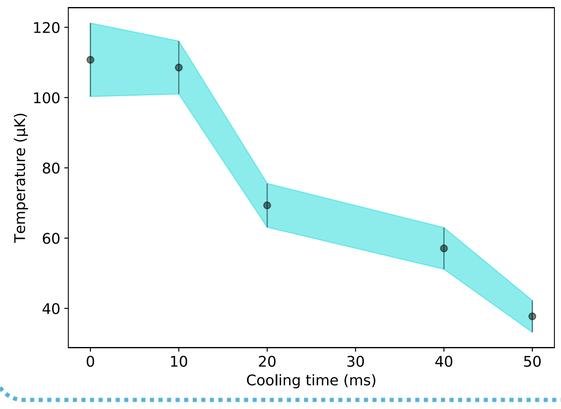
Erbium in tweezers

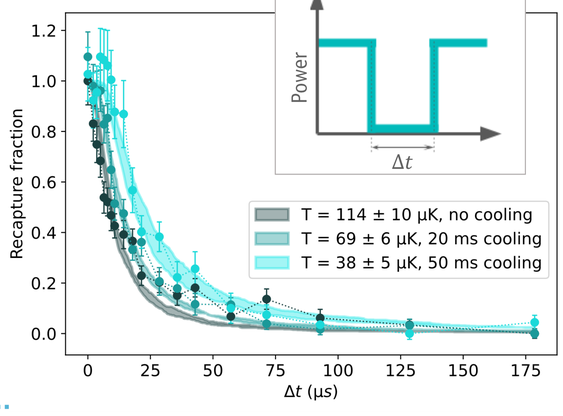
Experimental setup



Cooling with 583 nm light

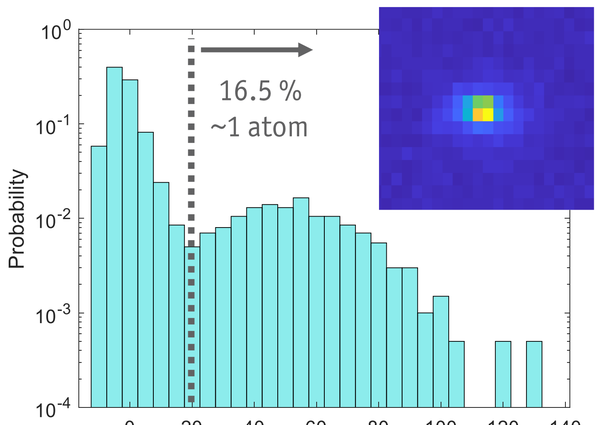
- Cool atoms with single $\Gamma/2\pi = 190$ kHz beam.





Imaging

- Can detect single atoms imaging with $\Gamma/2\pi = 28$ MHz line for 60 μs.



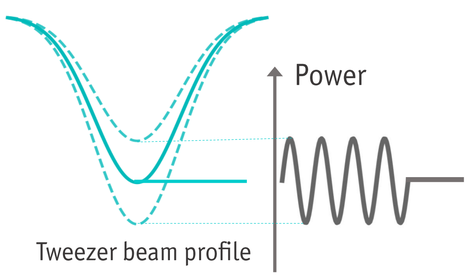
Histogram after 100 ms of 583 nm light

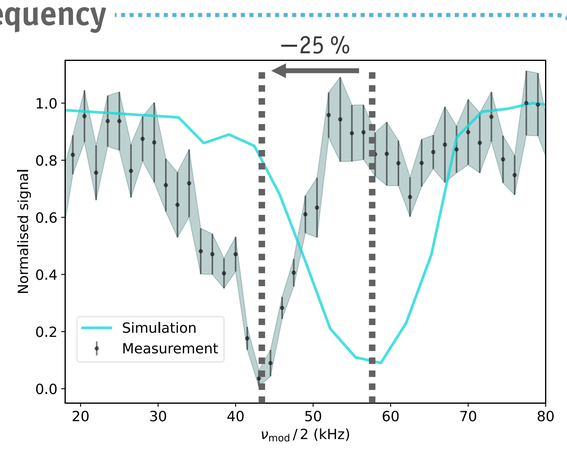
- Plan to image whilst cooling using $\Gamma/2\pi = 190$ kHz (583 nm) transition.

Averaged 583 nm fluorescence image

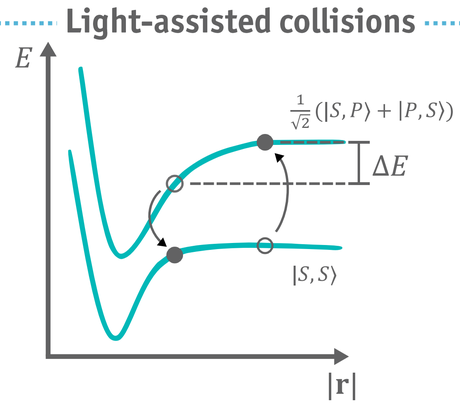
Trap frequency

- Measure radial trap frequency using parametric heating.





Light-assisted collisions



- Two-body loss to single atoms.

References

[1] A. Trautmann, M. J. Mark, P. Ilzhöfer, H. Edri, A. El Arrach, J. G. Maloberti, C. H. Greene, F. Robicheaux and F. Ferlaino, Phys. Rev. Research **3**, 033165 (2021).

M. A. Norcia and F. Ferlaino, Nature Physics **17**, 1349-1357 (2021).

ÖAW Österreichische Akademie der Wissenschaften

FWF Der Wissenschaftsfonds.

Dipolar Quantum Gases

erc

FNSNF Swiss National Science Foundation