A new Na-K aparatus to simulate quantum many-body phenomena

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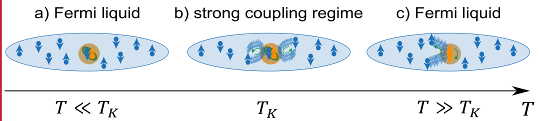
SynQS

Why Na-K mixtures

Kondo effect[1]

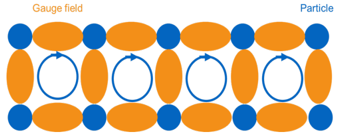
- Magnetic atoms (impurities) in a normal metal lead to a resistive minimum



- Fermi sea of ^{40}K is coupled to localized ^{23}Na spin impurity

Dynamical Gauge Fields[2]

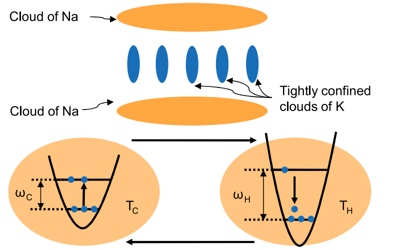
- Interaction between fundamental particles is described by gauge theories



- Fermionic species reside on lattice sites, bosonic species (gauge fields) on the links

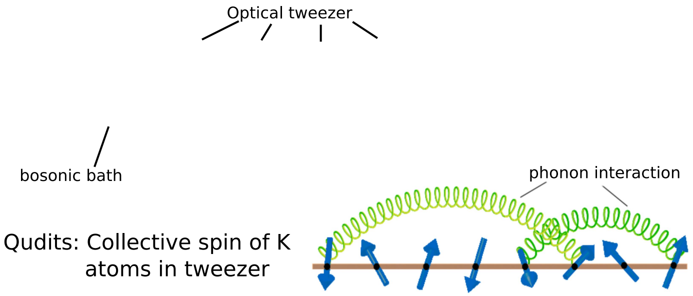
Quantum Refrigerator[3]

- Goal: Cool thermal cloud below degeneracy threshold



- Single K atoms transferred between two baths of Na atoms

Universal Quantum Computation[4]



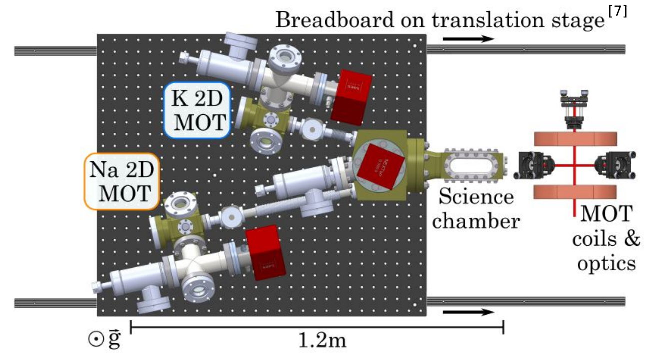
- Qudits: Collective spin of K atoms in tweezer
- Universal gate set: Qudit entanglement through phononic excitations (Na)

Why Na-K?

- Possibility to work with both ^{39}K and ^{40}K (bosonic and fermionic) in our design.
- Tuning knob of Feshbach resonances at magnetic fields of less then 300 G[5,6].
- Predicted to have fast spin changing collisions.

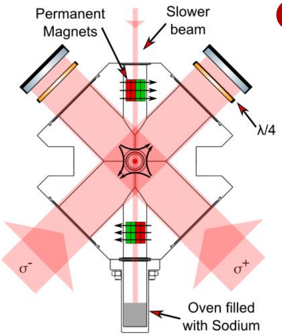
Towards ultracold mixtures

Mobile and modular vacuum system



- Modularity, to work on and optimize Na and K setups seperately.
- Vacuum system on a translation stage.
- Science chamber designed to give more optical access and facilitate higher numerical aperture

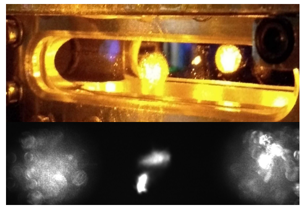
1 Seperated 2D magneto-optical traps



- Quadrupole magnetic field produced by four stacks of permanent magnets[8].
- Two red-detuned circularly polarized laser beams in retro-reflected configuration.

2 Dual species 3D magneto-optical trap

- Near-resonant push beam transports pre-cooled atoms into science chamber.
- Three laser beams in retro-reflected configuration and magnetic quadrupole field.
- Characterize cold atoms using flurescence imaging.

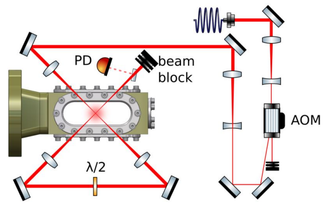


3 Na Crossed Optical Dipole Trap

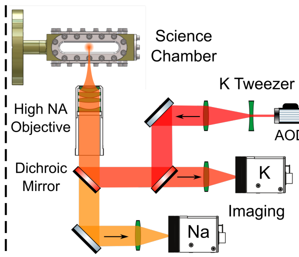
- Trapping potential:

$$V(r) \propto \frac{I(r)}{\Delta}$$

- IPG Fiber Laser: 100W at 1070nm.



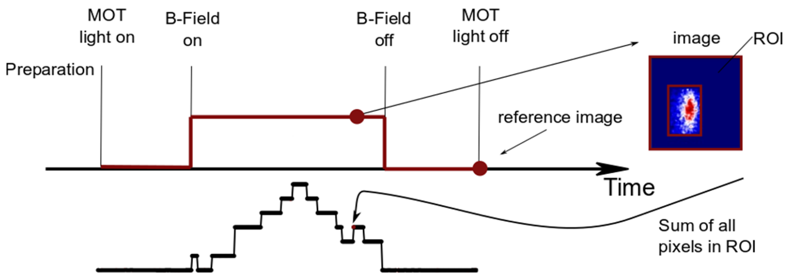
3 K Optical Tweezer



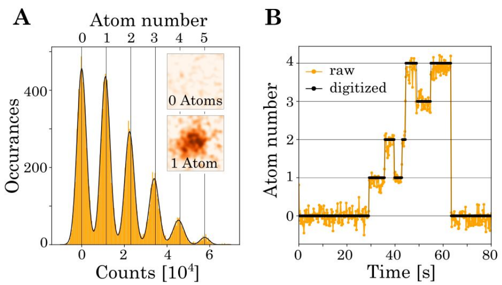
- TiSa Laser: 2W at 780nm.
- Focusing through imaging objective
- Mobile tweezer arrays generated by an AOD[9].

Towards Single Atom Resolution

Experimental Sequence

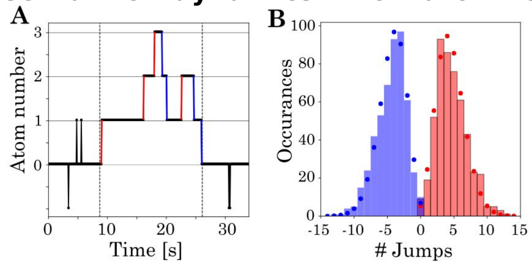


Single atom counting of Na



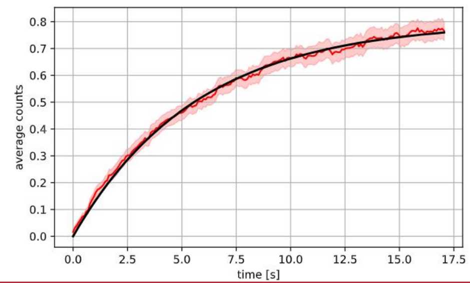
- Counting up to 10 Na atoms

Analyse Na MOT dynamics in low atom regime



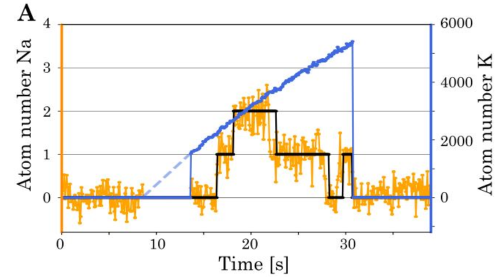
- Extract loss and load probabilities from direct counts of loss and load events $p_{load} = \frac{\#\text{ images with an atom load}}{\text{total number of images}}$ $p_{loss} = \frac{N_{loss}}{\sum_i N_i}$

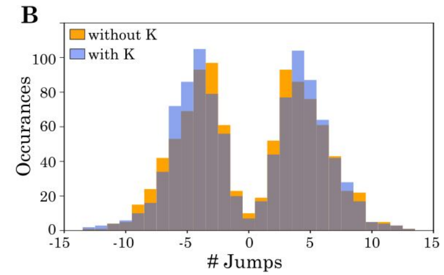
- Compare with model fit to the data $N(i) = \frac{p_{load}}{p_{loss}}(1 - \exp(p_{loss} i))$



Immersing Na into K

- Do we see an influence on Na if the K MOT is present?
- Immersing a few Na atoms into large K MOT





Related work [10]

Outlook

- Working on a new set of MOT coils to improve the single atom resolution by being able to work with higher magnetic field gradients
- The experiment control system should facilitate remote access to potentially run the machine 24 X 7.
- Techniques for active magnetic field stabilisation (based on NV centres in diamond) are also being developed for tight control over Feshbach fields.
- An innovative thermometric technique[11] will be used for non-demolition measurements.
- With the achievement of Na and K 3D MOT, we are actively working towards achieving the Na BEC in optical dipole trap and K tweezers.

References

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