A new Na-K apparatus for simulating quantum many-body phenomena

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

KIRCHHOFF-INSTITUT FÜR PHYSIK

SynQS

Jan Kilinc, Lilo Höcker, Rohit Prasad Bhatt, Fred Jendrzejewski

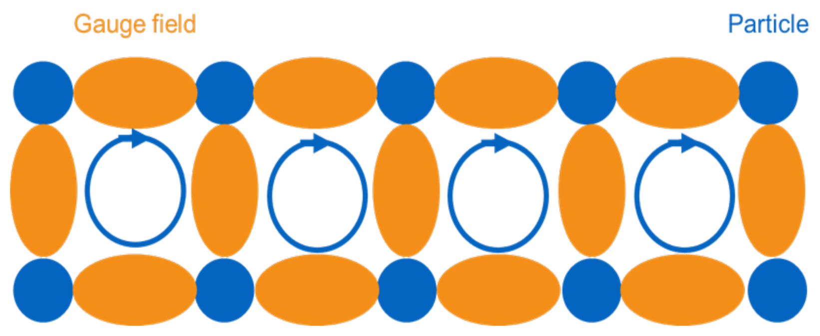
Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

jan.kilinc@kip.uni-heidelberg.de

Why quantum mixtures?

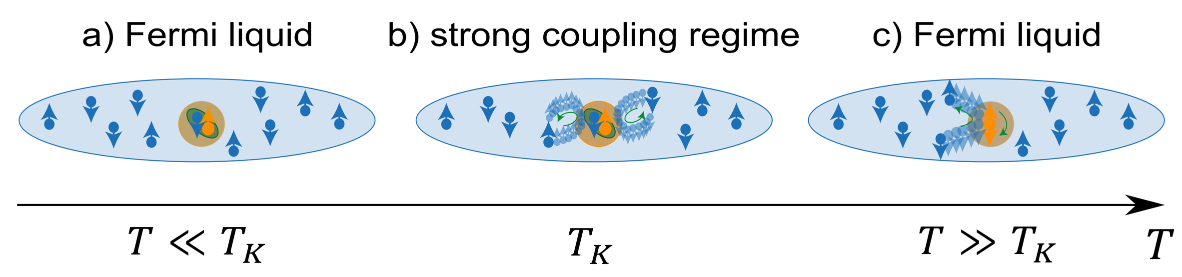
Dynamical Gauge Fields[1]

- Interaction between fundamental particles is described by gauge theories
- Implementation: Fermionic species reside on lattice sites, bosonic species (gauge field) on the links



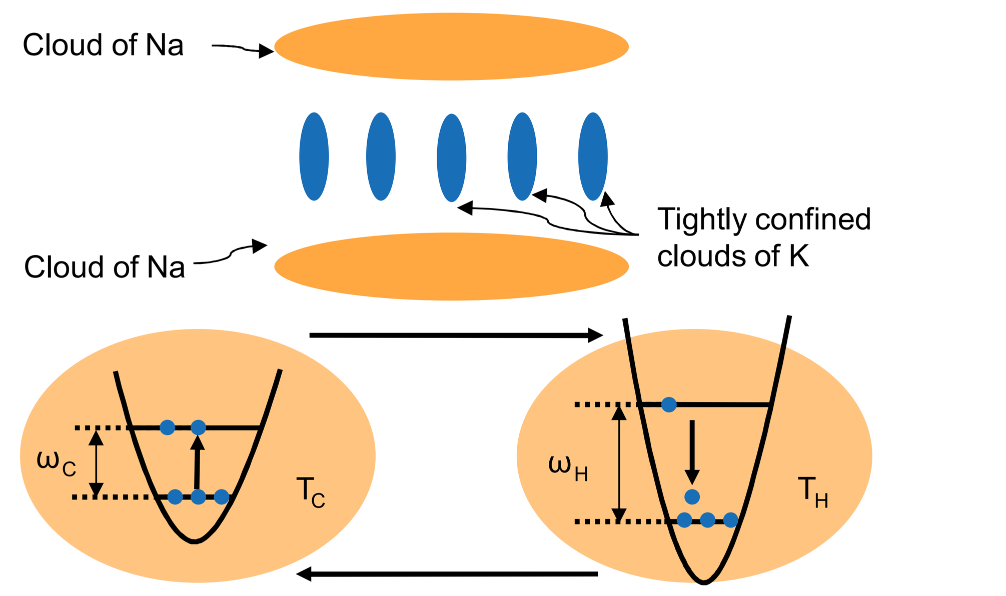
Kondo effect[2]

- Spin-dependent interactions between a localized magnetic impurity and a Fermi sea.
- At characteristic temperature scale resonant scattering occurs between the fermions and the impurity.
- Implementation: ^{23}Na spin impurity embedded in Fermi sea of ^{40}K.



Quantum Refrigerator[3]

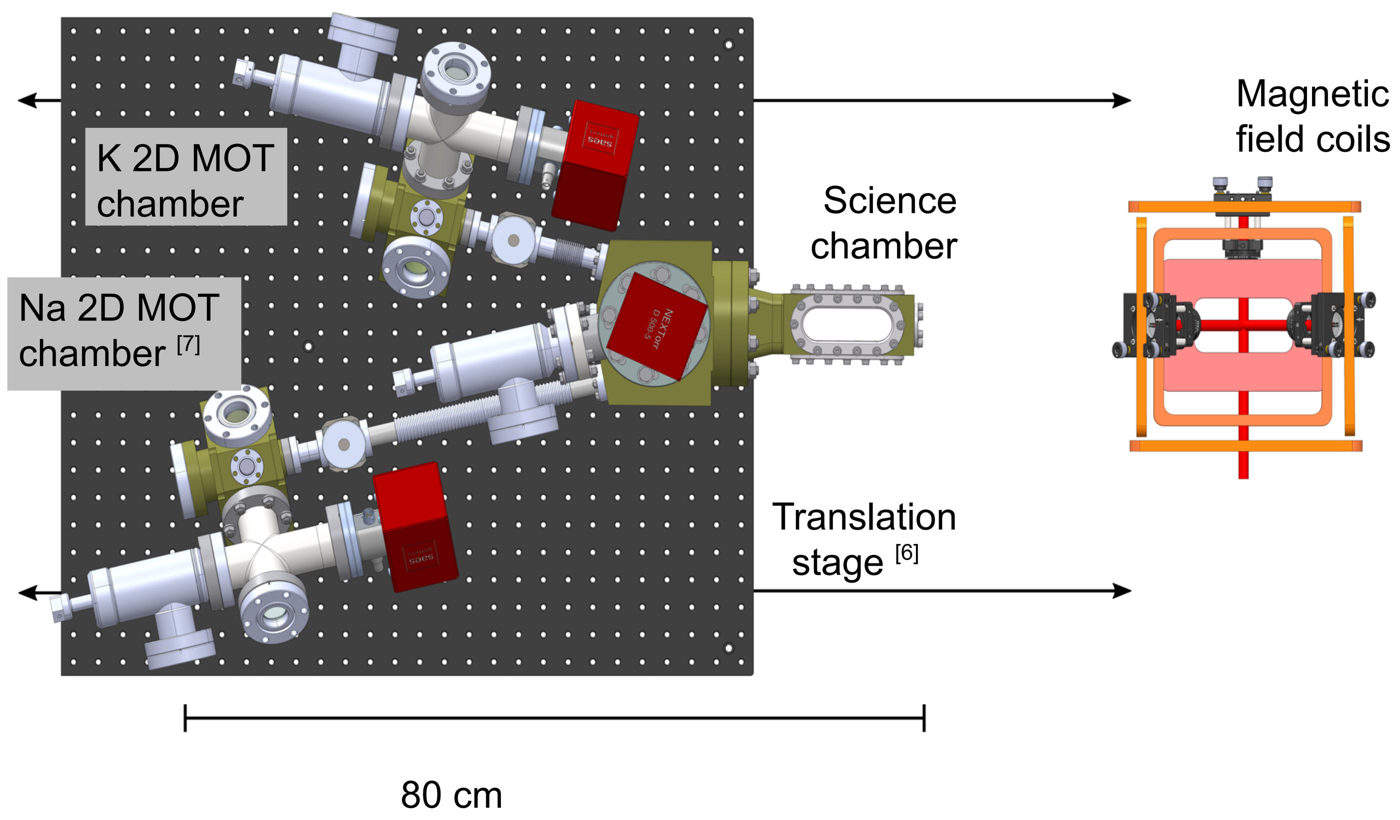
- Goal: Cool thermal cloud below degeneracy threshold
- Implementation: Single K atoms (working medium) transferred between two (hot and cold) baths of Na Atoms



Why Na-K?

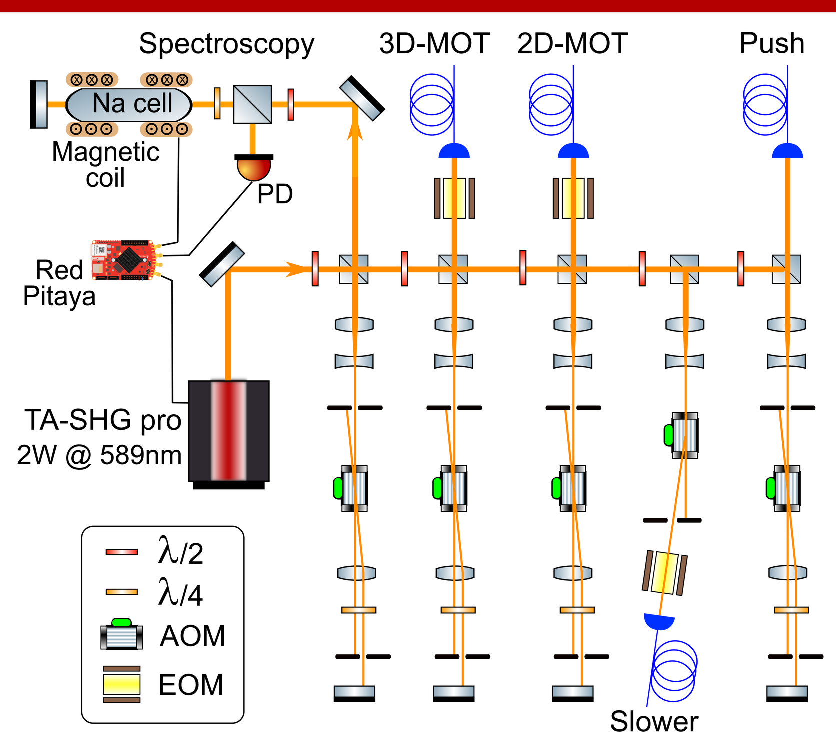
- Possibility to work with both K-39 and K-40 (Bosonic and Fermionic) in our design.
- Tuning knob of Feshbach resonances at moderate magnetic fields of less than 300 G[4,5].
- Predicted to have fast Spin Changing Collisions.

Mobile and modular vacuum system

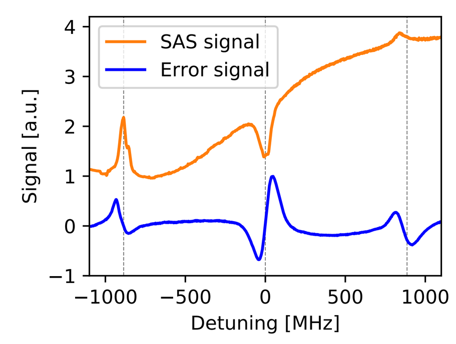


- Modularity, to work on and optimize Na and K setups separately.
- Vacuum system on a translation stage.
- Science chamber designed to give more optical access and facilitate higher numerical aperture.

Na laser system

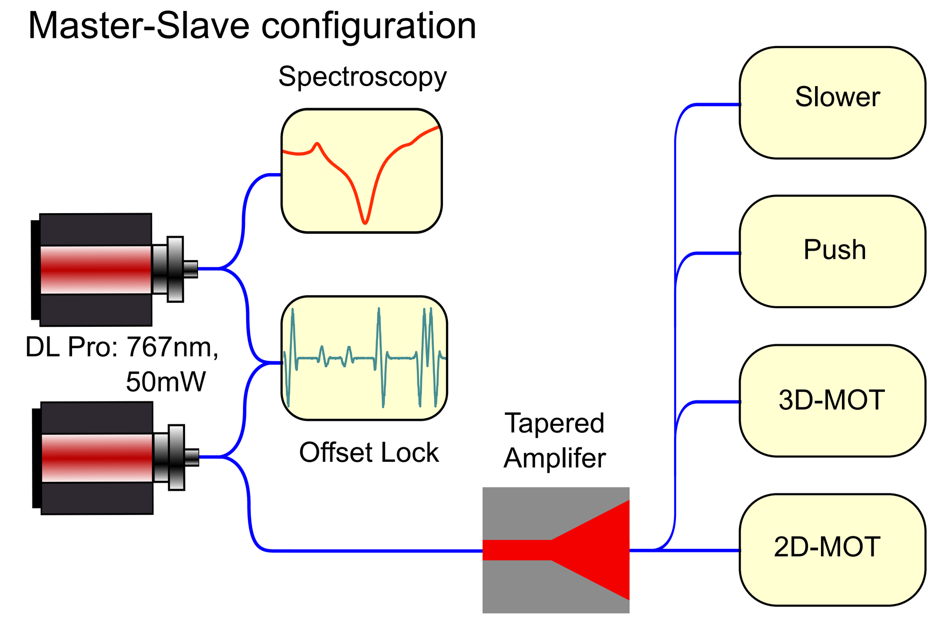


- Laser locking using Zeeman modulation

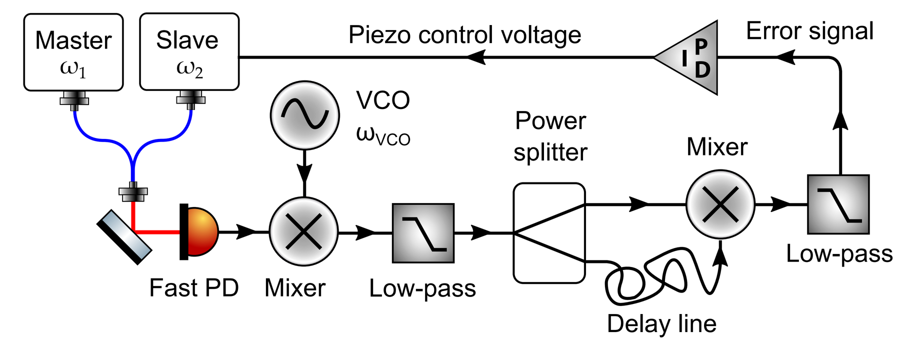


K laser system

- Master-Slave configuration



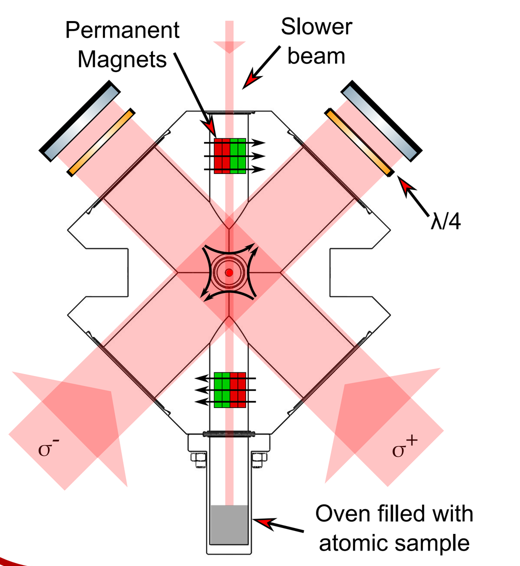
- Offset Lock for switching ^{39}K ⟷ ^{40}K



Experimental steps

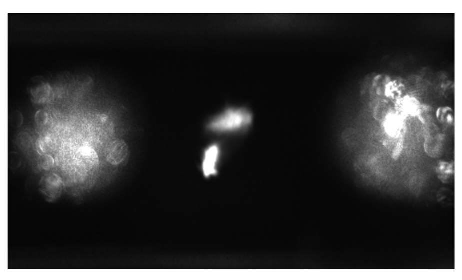
1 Seperated 2D magneto-optical traps

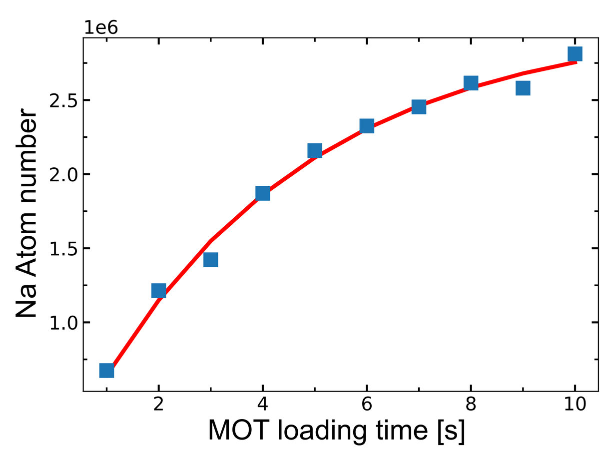
- Quadrupole magnetic field produced by four stacks of permanent magnets.
- Two red-detuned circularly polarized laser beams in retro-reflected configuration.

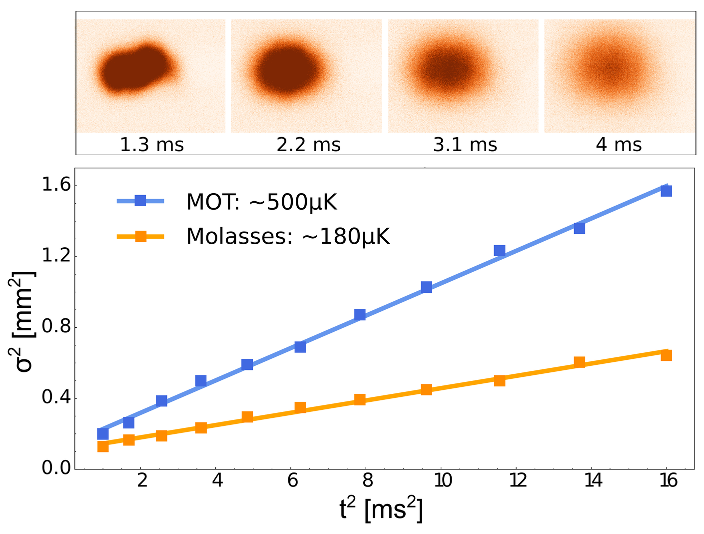


2 Dual-species 3D magneto-optical trap

- 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 fluorescence imaging with sCMOS Zyla 5.5.

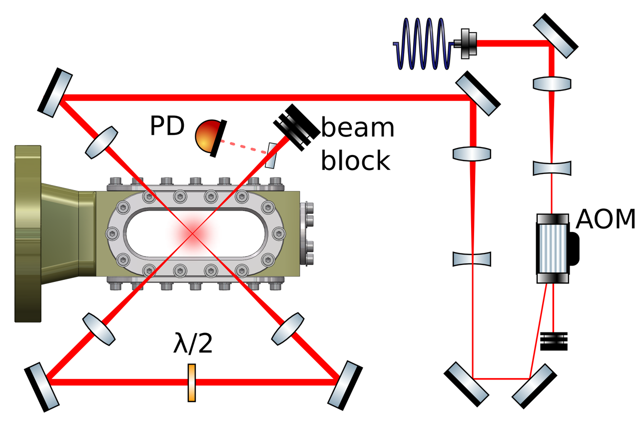




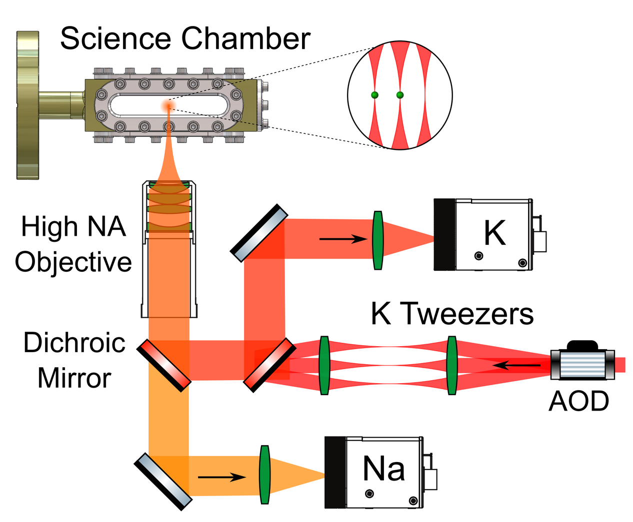


3 Na Crossed Optical Dipole Trap

- Trapping potential: $V(r) \propto \frac{I(r)}{\Delta}$
- IPG Fiber Laser: 100W at 1070nm.
- Focused beam waist: 50μm ➡ Trap depth: ~2mK.
- Goal: Condensation through evaporative cooling.



3 K Optical Tweezers



- TiSa Laser: 2W at 780nm.
- Focusing through Imaging Objective
- Mobile tweezer arrrays generated by an AOD[8].
- Goal: Defect-free tweezer array of sympathetically cooled K-atoms.

Outlook

- 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.
- We are also implementing an optimized high resolution imaging scheme with single-atom resolution.
- An innovative thermometric technique[9] will be used for non-demolition measurements.
- Techniques for active magnetic field stabilisation (based on NV centres in diamond) are also being developed for tight control over Feshbach fields.
- The experiment control system should facilitate remote access to potentially run the machine 24 X 7.

References

1. Alexander Mil, Torsten V. Zache, Apoorva Hegde, Andy Xia, R. K. P. Bhatt, Markus K. Oberthaler, Philipp Hauke, Jurgen Berges, and Fred Jendrzejewski. "A scalable realization of local U(1) gauge invariance in cold atomic mixtures." Science 367 (2020): 1128 - 1130.
2. Johannes Bauer, Christophe Salomon, and Eugene Demler Phys. Rev. Lett. 111, 215304.
3. Wolfgang Niedenzu and Igor Mazets and Gershon Kurizki and Fred Jendrzejewski. Quantum (3) 155 (2019).
4. Torben A. Schulze, Torsten Hartmann, Kai K. Voges, Matthias W. Gempel, Eberhard Tiemann, Alessandro Zenesini, and Silke Ospelkaus Phys. Rev. A 97, 023623.
5. Cheng-Hsun Wu, Jee Woo Park, Peyman Ahmadi, Sebastian Will, and Martin W. Zwierlein. Phys. Rev. Lett. 109, 085301.
6. Design inspired from the group of Manuel Endres, California Institute of Technology.
7. G. Lamporesi, S. Donadello, S. Serafini, and G. Ferrari. Review of Scientific Instruments 84, 063102 (2013).
8. Alexandre Cooper, Jacob P. Covey, Ivaylo S. Madjarov, Sergey G. Porsev, Marianna S. Safronova, Manuel Endres, PhysRevX .8.041055.
9. Mohammad Mehboudi, Aniello Lampo, Christos Charalambous, Luis A. Correa, Miguel Ángel García-March, and Maciej Lewenstein Phys. Rev. Lett. 122, 030403.

isoQuant SFB1225

Emmy Noether-Programm DFG