A12 Controlled immersion of single neutral atomic impurities into a quantum gas of another species

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Overview Polarons

$$\hat{H} = \frac{\hat{p}^2}{2m_I} + \sum_{\mathbf{k}\neq 0} E_{\mathbf{k}} \hat{b}_{\mathbf{k}}^{\dagger} \hat{b}_{\mathbf{k}} + \sum_{\mathbf{k}\neq 0} \sqrt{\frac{\xi_{\mathbf{k}} N_0}{E_{\mathbf{k}}}} V_{IB}(\mathbf{k}) \hat{\rho}_I(\mathbf{k}) \left(\hat{b}_{\mathbf{k}} + \hat{b}_{-\mathbf{k}}^{\dagger} \right)$$
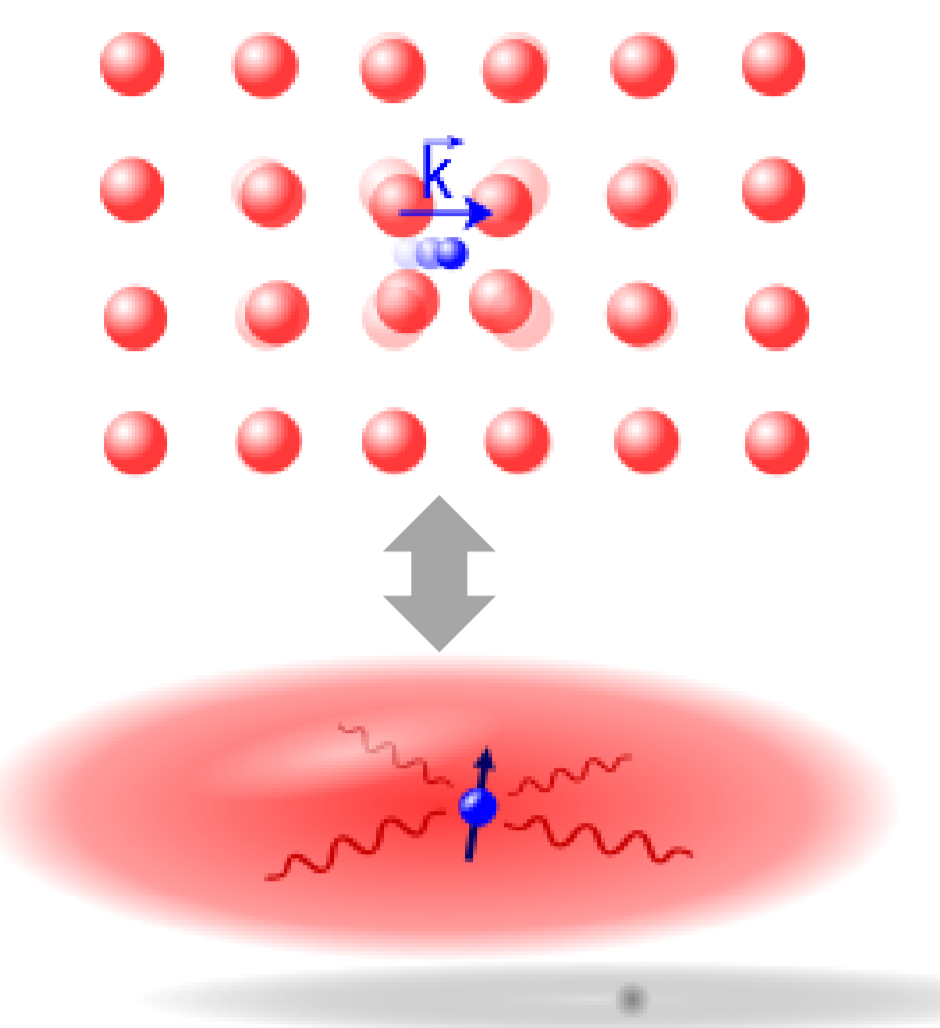
impurity kin. energy — Bogoliubov excitations — impurity - excitation interaction

$$\hat{H}_{polaron} = \frac{\hat{p}^2}{2m_I} + \sum_{\mathbf{k}\neq 0} \hbar\omega_{\mathbf{k}} \hat{b}_{\mathbf{k}}^{\dagger} \hat{b}_{\mathbf{k}} + \sum_{\mathbf{k}\neq 0} V_{\mathbf{k}} e^{i\mathbf{k}\cdot\hat{\mathbf{r}}} \left(\hat{b}_{\mathbf{k}} + \hat{b}_{-\mathbf{k}}^{\dagger} \right)$$

electronic kin. energy — phonons — electron - phonon interaction

Polaronic Coupling strength: $\alpha = \dfrac{a_{IB}^2}{a_{BB}\xi}$ → Same topic pursued with complementary methods in **A10**

Fröhlich Polaron
- Interaction of moving electron in polarizable medium is given by Fröhlich Hamiltonian[1]
- Polaron properties are given by interaction potential i.e. polaron coupling strength α
- Three cases: weak, intermeadiate and strong coupling regime

Bose Polaron [2]
- single impurity immersed in a quantum gas
- Role of phonons are taken by Bogoliubov excitations [3,4]
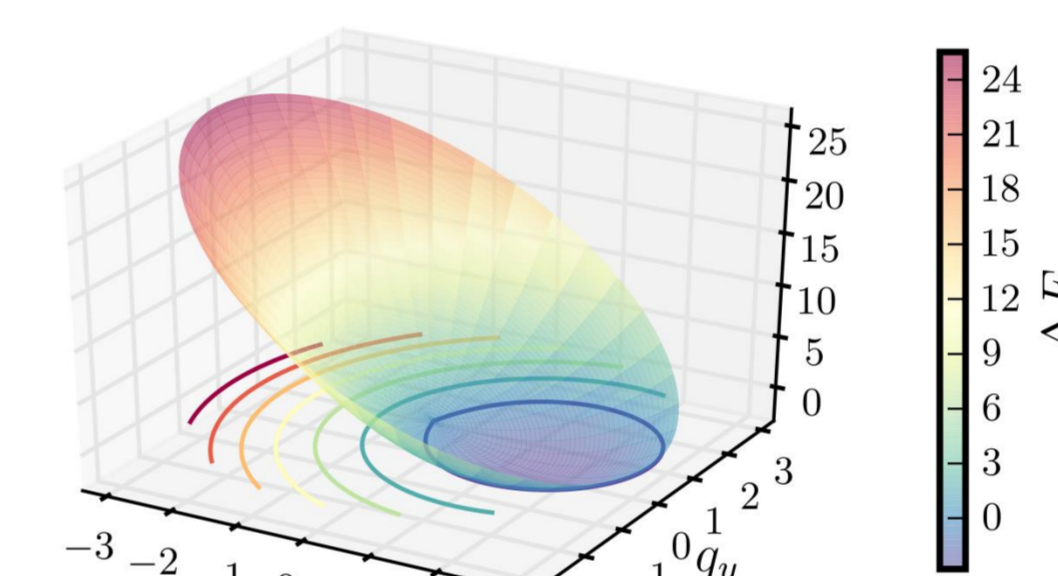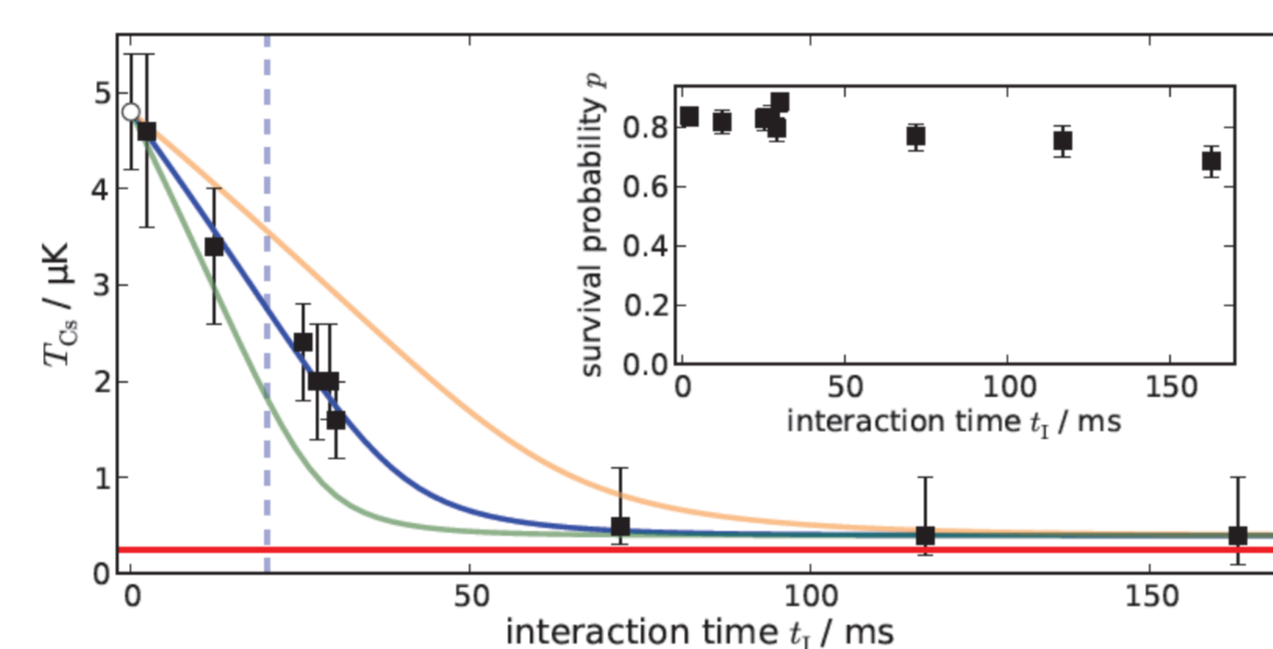- Hamilton structure is the same as in the Fröhlich-Hamilton

Thermalization of Rb and Cs
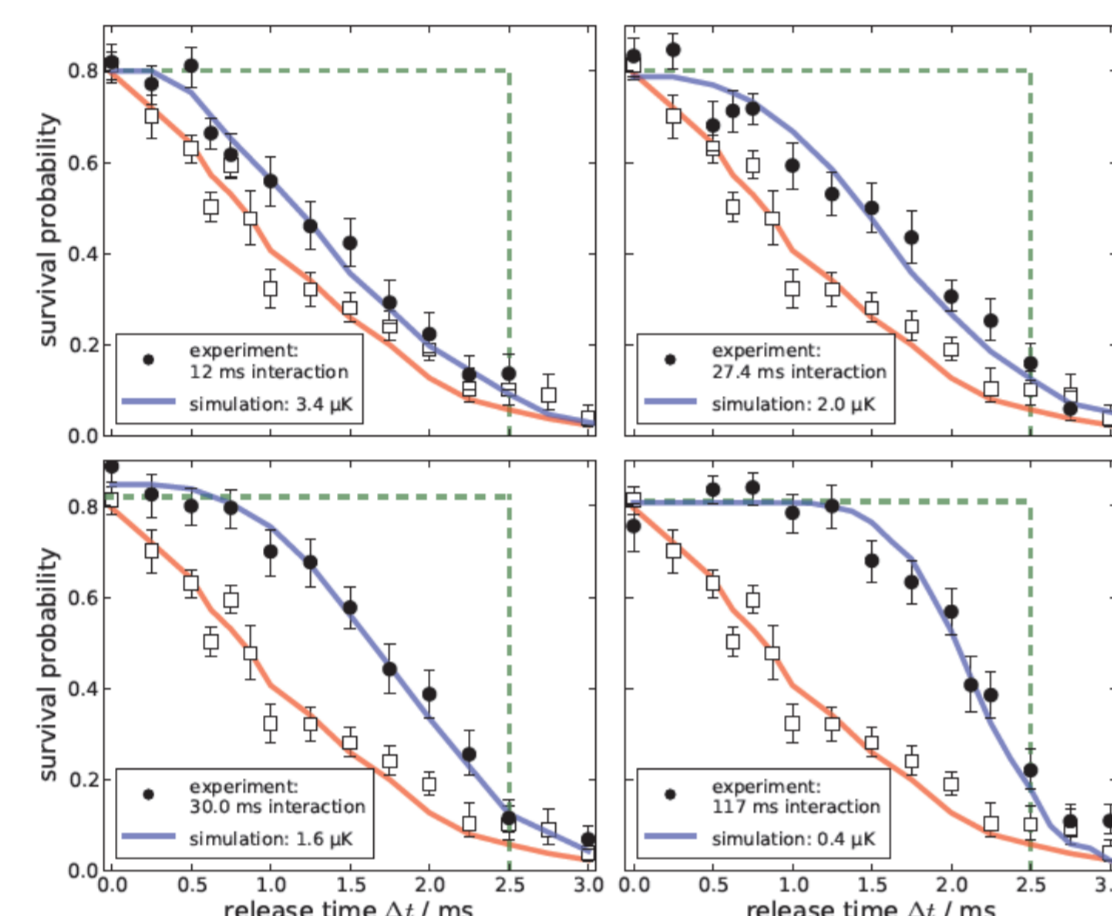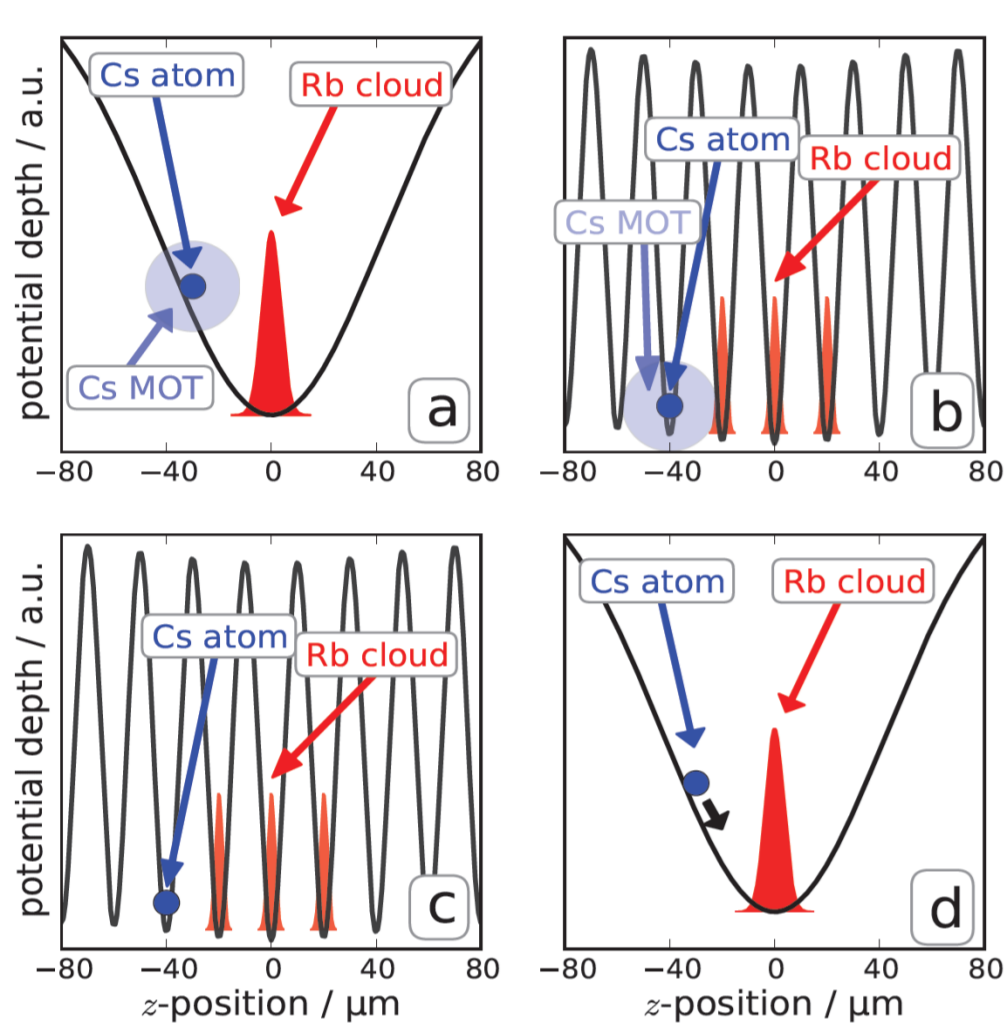
- after interaction atom is released from trap for time Δt and then recaptured
- compare survival probability with Monte Carlo Simulations to deduce T [5,6,7]
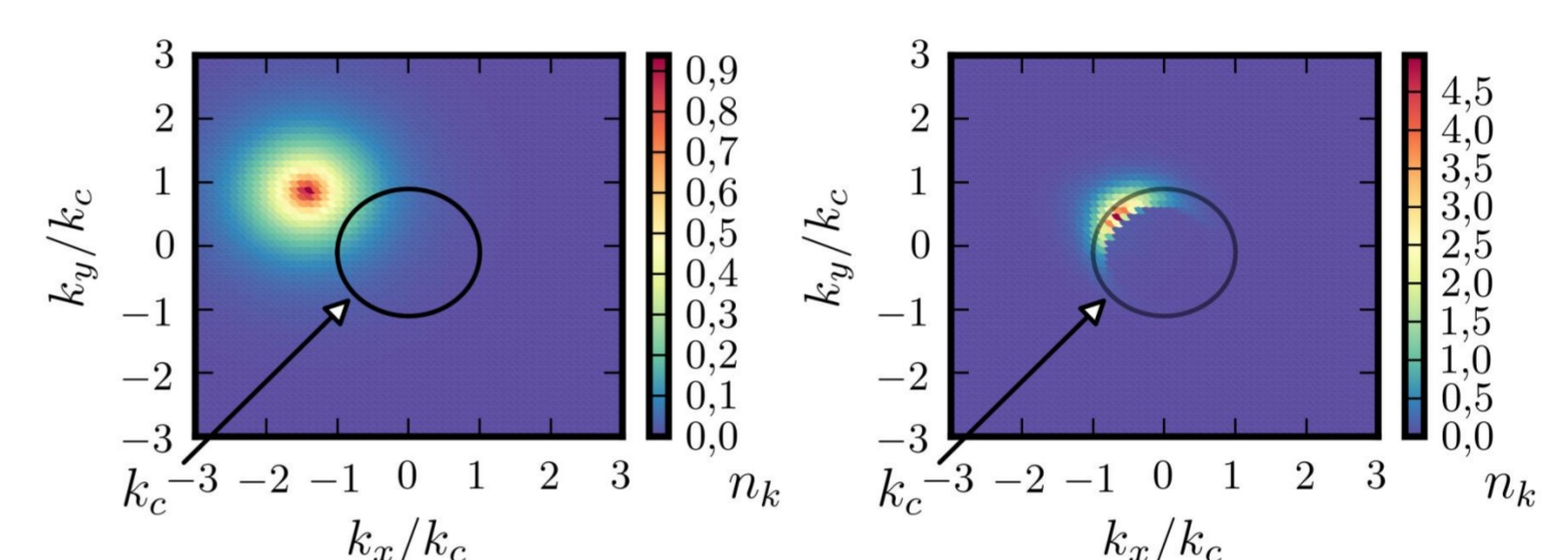
Simulation of the momentum distribution of atoms cooled by a T=0 quantum gas

- Extract Rb-Cs interaction strength from analytical model
- The analysis yields access to the energy distribution of the system in non-equilibrium situation

Atoms with momentum smaller $\vec{k}_c$ cannot be cooled further due to energy conservation

→ Collaboration with **A5**

New Topic: Polaron Dynamics

Observation of Polaron diffusion
- dynamics of impurities in a BEC trapped in an optical lattice
- dependence of the dynamics on the polaronic coupling strength
- deduce the effective mass by trap frequency measurements
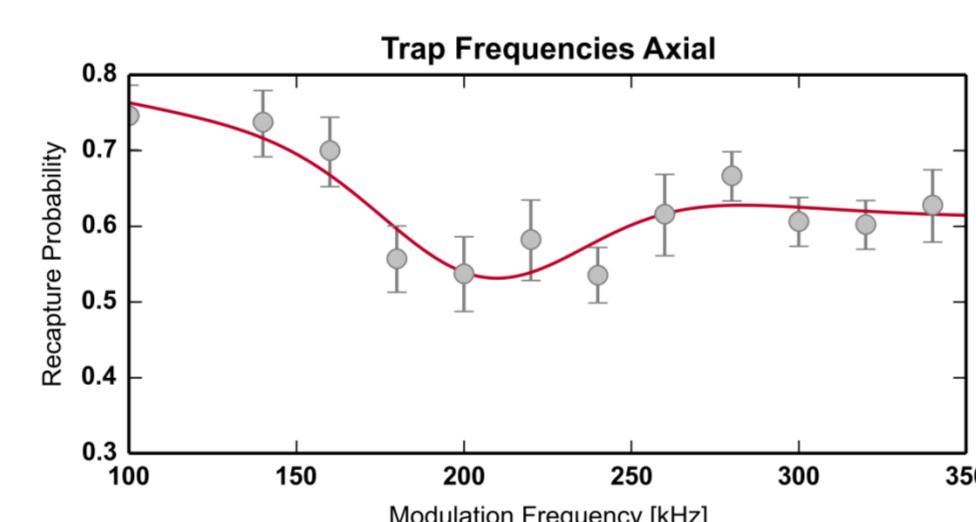
→ Collaboration with **A5**

Multi-polaron effects
- more than one impurity to measure polaron-polaron interaction
- effects of the effective mass and dynamics
- measure the position-position correlator
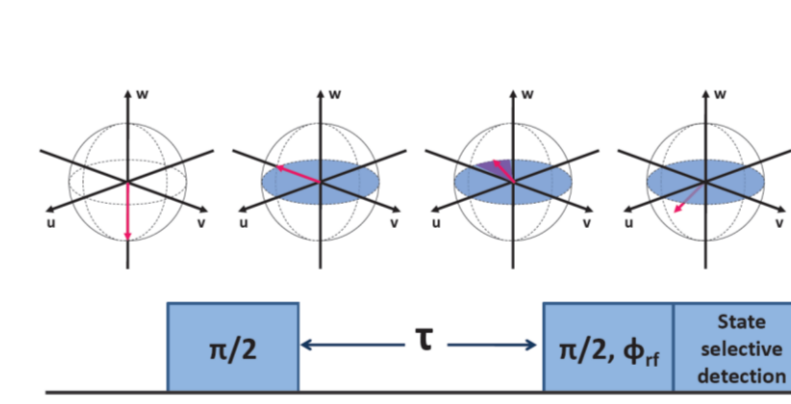
Observation of polaronic Bloch-oscillations
- induce Bloch oscillations in optical lattice by acceleration of the lattice, leading to a constant force
- Observe dynamics of impurity for different interaction strength
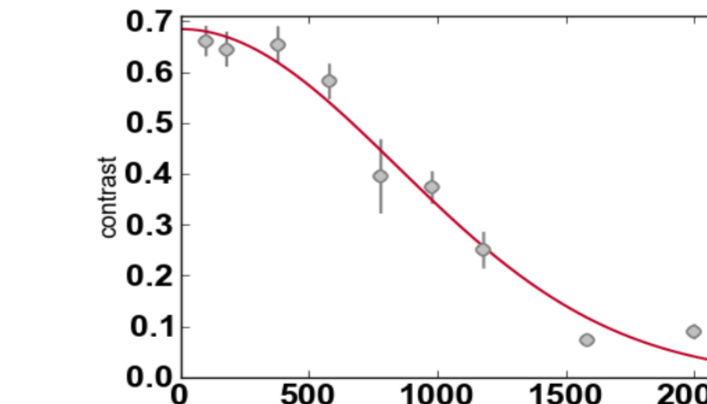- shaking the lattice may introduce photo-assisted tunneling
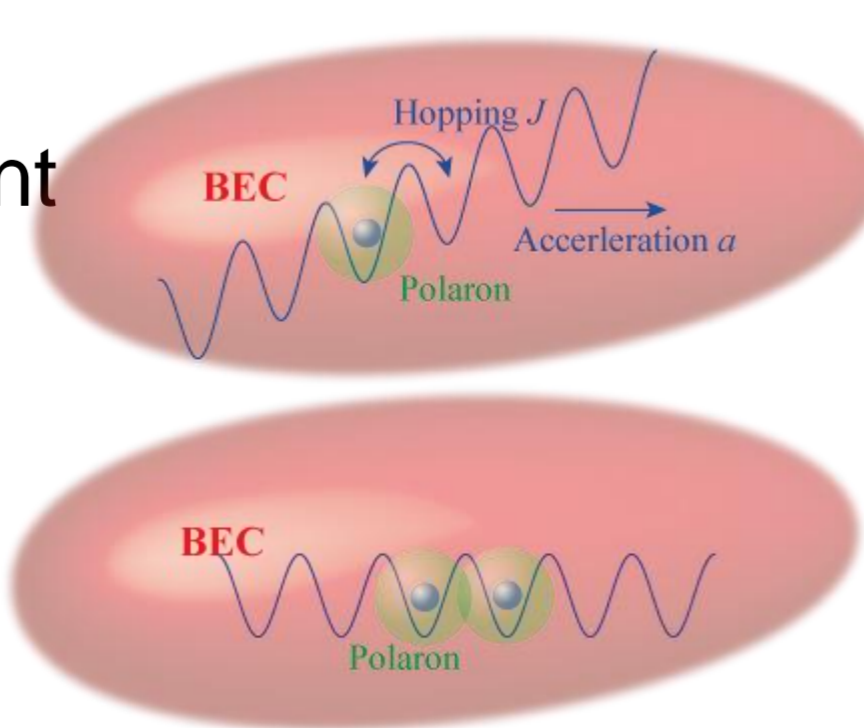
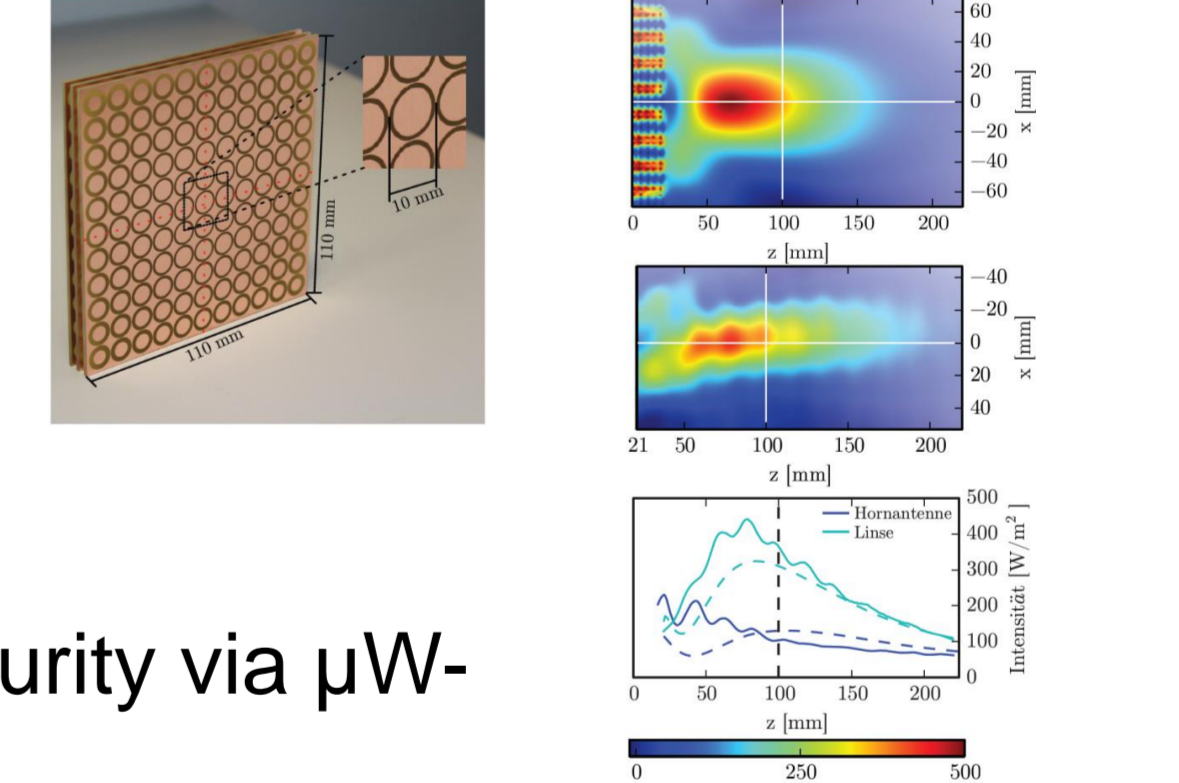→ Collaboration with **A3**

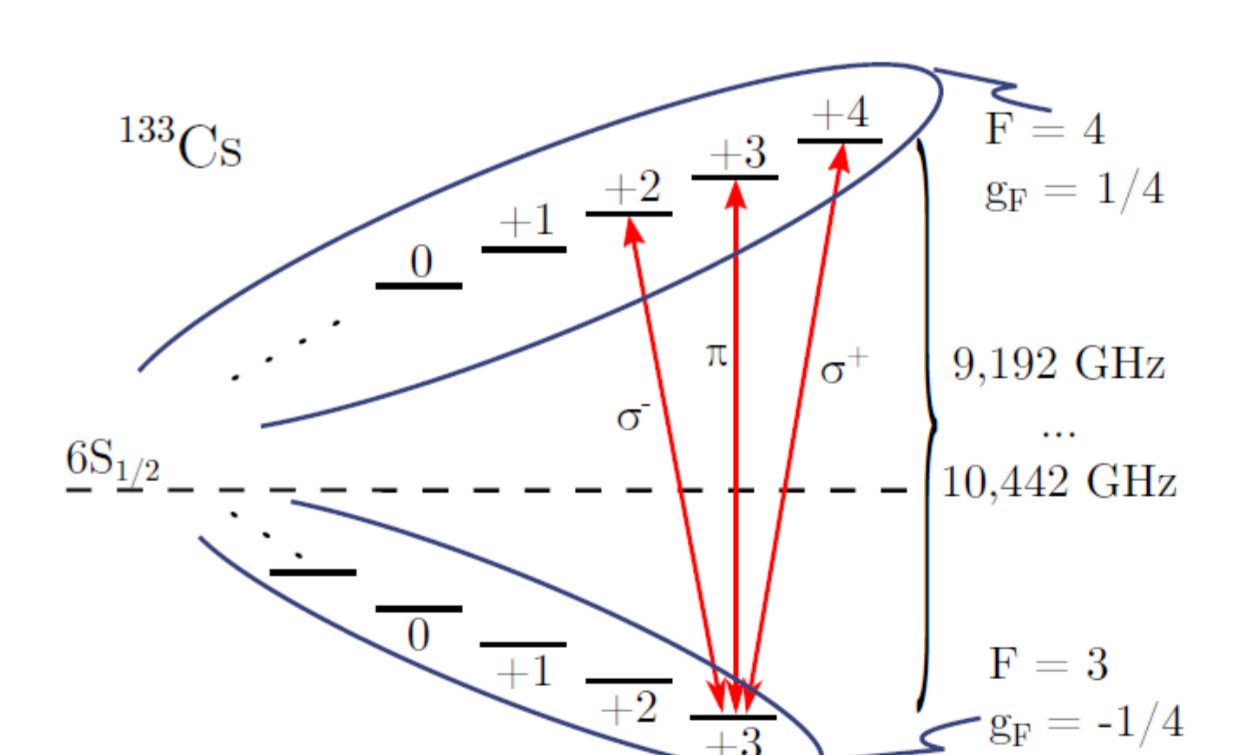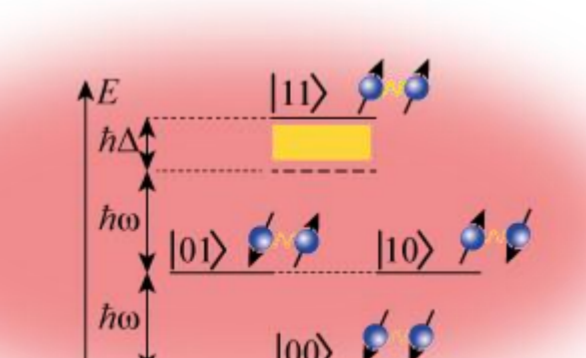## New Topic: Spinful Polarons

Ramsey Sequence — Coherence measurement — Metamaterial lens for µW
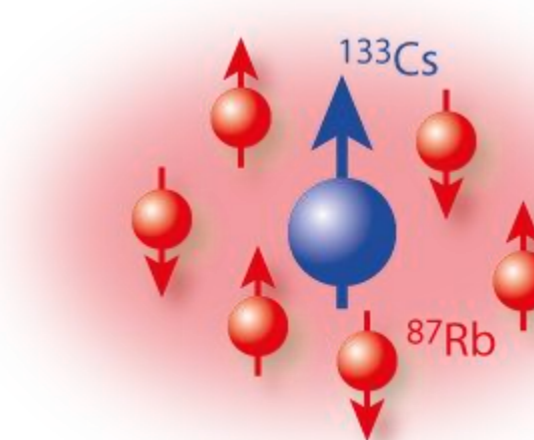
Characterization of impurity-bath interaction
- measuring the decay of coherence of the impurity via µW-Ramsey Spectroscopy

→ Same topic pursued with complementary methods in **A10**

Bath-induced correlations between impurities
- Spin-dynamics of two impurities prepared in coherent superposition
- quantum state tomography will reveal quantum correlations

→ Collaboration with **A3**

References

1. H. Fröhlich, Advances in Physics, 3, 325 (1954)
2. J. Tempere et. al., Phys. Rev. B. 80, 184504 (2009)
3. F. Grusdt, et. al, arXiv:1410.2203 (2014)
4. M. Bruderer, et al., Phys. Rev. A 76, 011605® (2007)
5. C. Tuchendler, et al., Phys. Rev. A 78, 033425 (2008)
6. N. Spethmann, et al., Appl. Phys. B 106, 513 (2012)
7. N. Spethmann, et al., Phys. Rev. Lett. 109, 235301 (2012)

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