Universität Heidelberg

Engineering a 3-component Fermi gas with ultracold atoms

Martin Ries
Physikalisches Institut
Universität Heidelberg

EMMI Workshop Hirschegg, 30.08.2012

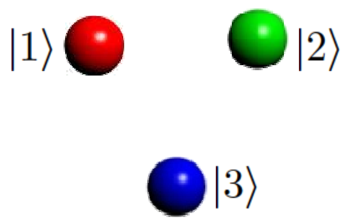
Outline

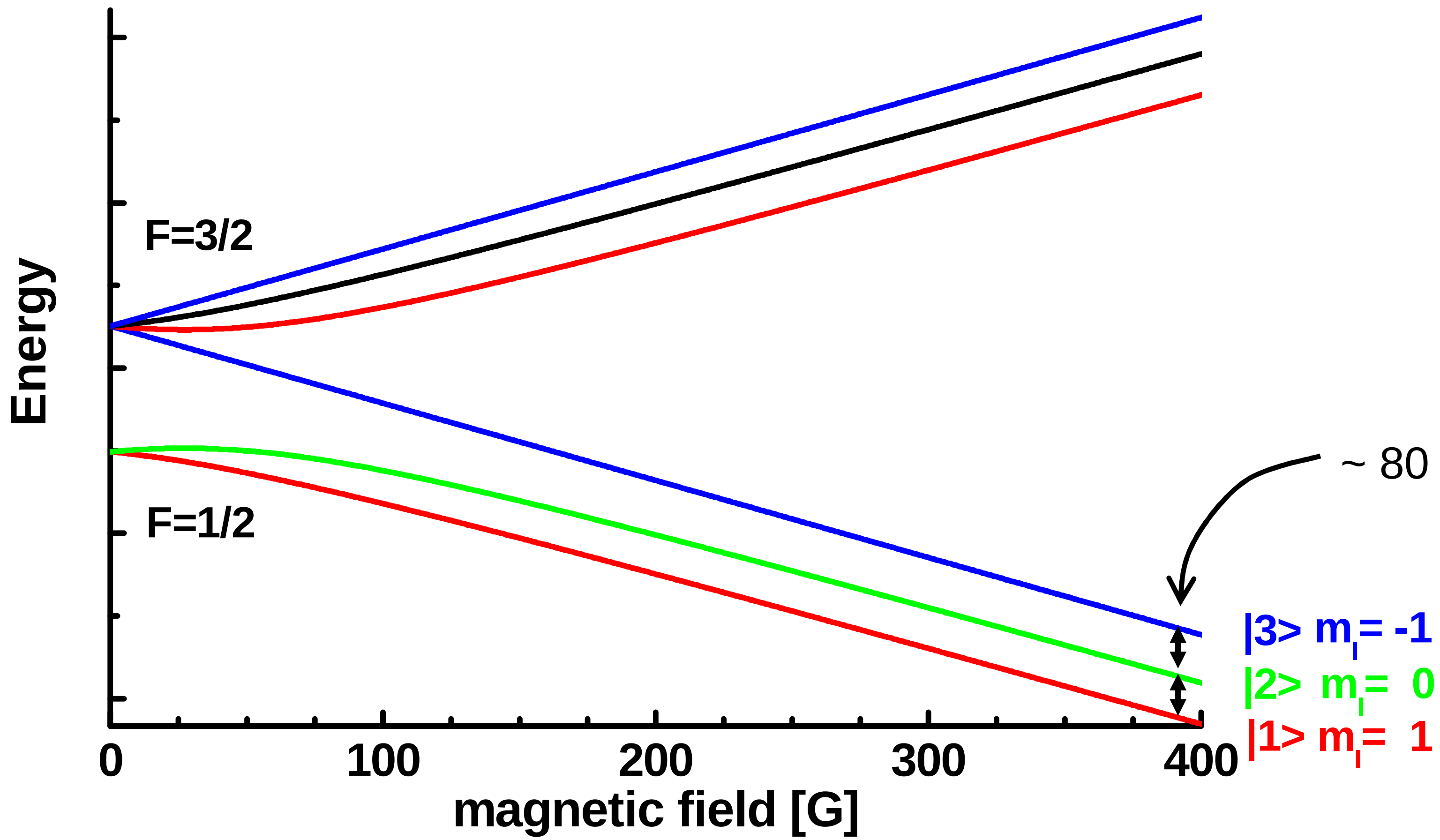
Engineering a 3-component Fermi gas with ultracold atoms

- How can it be realized?
- How does it compare to QCD?
- How far are we?

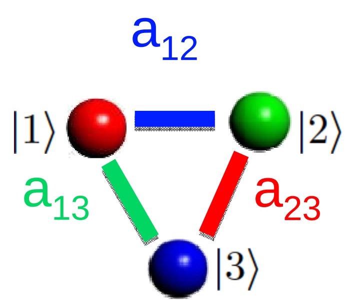
Our Fermions: the ^{6}Li system

Use lowest 3 hyperfine states of ultracold ^{6}Li





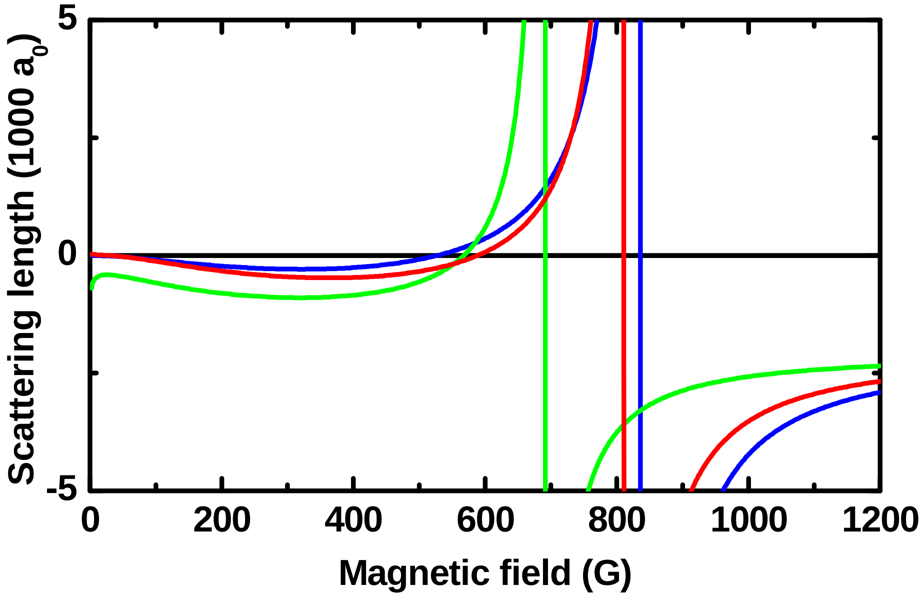
The ^{6}Li system (2): Interactions



- Ultracold gases: contact interaction,
  s-wave scattering

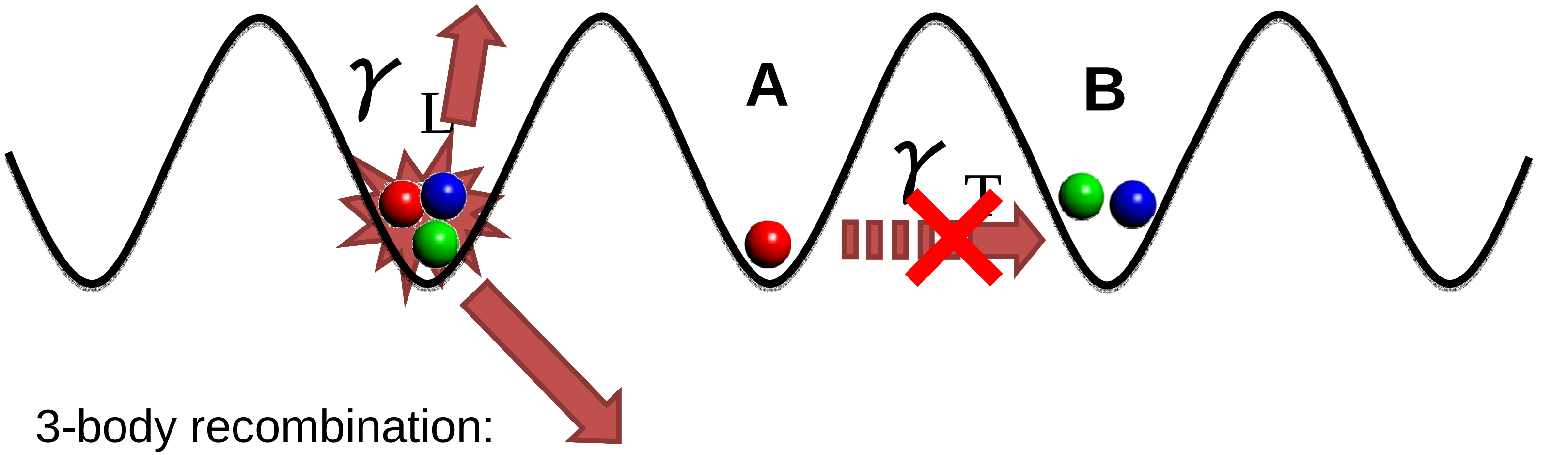
- Scattering length a

- Tunable via Feshbach resonance



Resonances overlap
=> Can tune all a_{ij} into strongly interacting limit at the same time!

The challenge: 3-body recombination

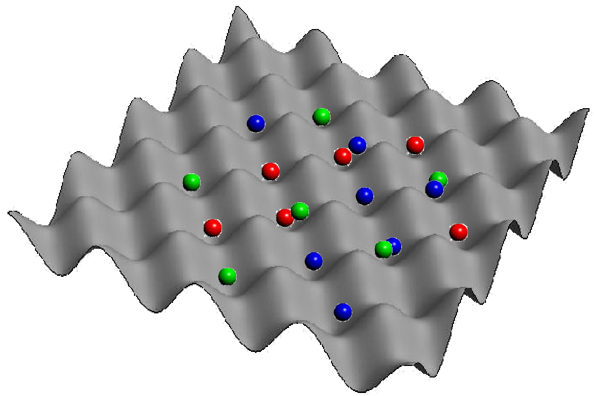


3-body recombination:
Dimer and free atom
are lost from trap

Quantum Zeno loss blocking

⇒ Sample is unstable!

⇒ Solution: put Fermi gas into an optical lattice!
2D for optimum diagnostics



T. Ottenstein *et al.*, PRL **101**, 203202 (2008)

A. Kantian *et al.* PRL **103**, 240401 (2009)

3-component Fermi Hubbard Hamiltonian

$$H_{FH} = -\sum_{\langle i,j\rangle,\sigma} J_\sigma (c^\dagger_{i,\sigma} c_{j,\sigma} + H.c.) + \sum_{i,(\sigma_1,\sigma_2)} U_{\sigma_1\sigma_2} n_{i,\sigma_1} n_{i,\sigma_2}$$

Tunneling

$\langle i, j\rangle$: neighboring sites

σ : spin state

Onsite interaction

i : lattice site

(σ_1, σ_2) : all spin state combinations

A. Kantian *et al.* PRL **103**, 240401 (2009)

Introduce Loss Blocking

UNIVERSITÄT HEIDELBERG

- Idea: project H_{FH} onto subspace where 3 spin states per site are forbidden

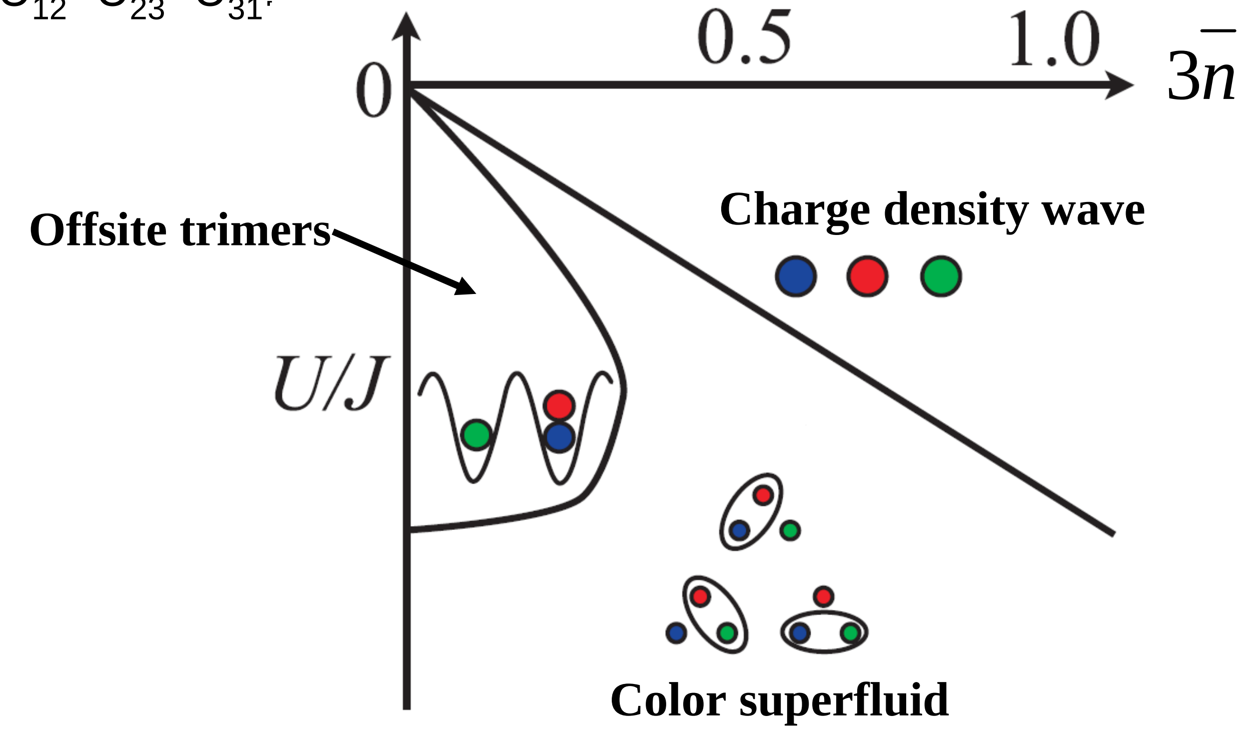
$$H_{LB} = P H_{FH} P$$

$$P = \prod_i P_i = \prod_i (1 - n_{i,1} n_{i,2} n_{i,3})$$

A. Kantian *et al.* PRL **103**, 240401 (2009)

Phase diagram

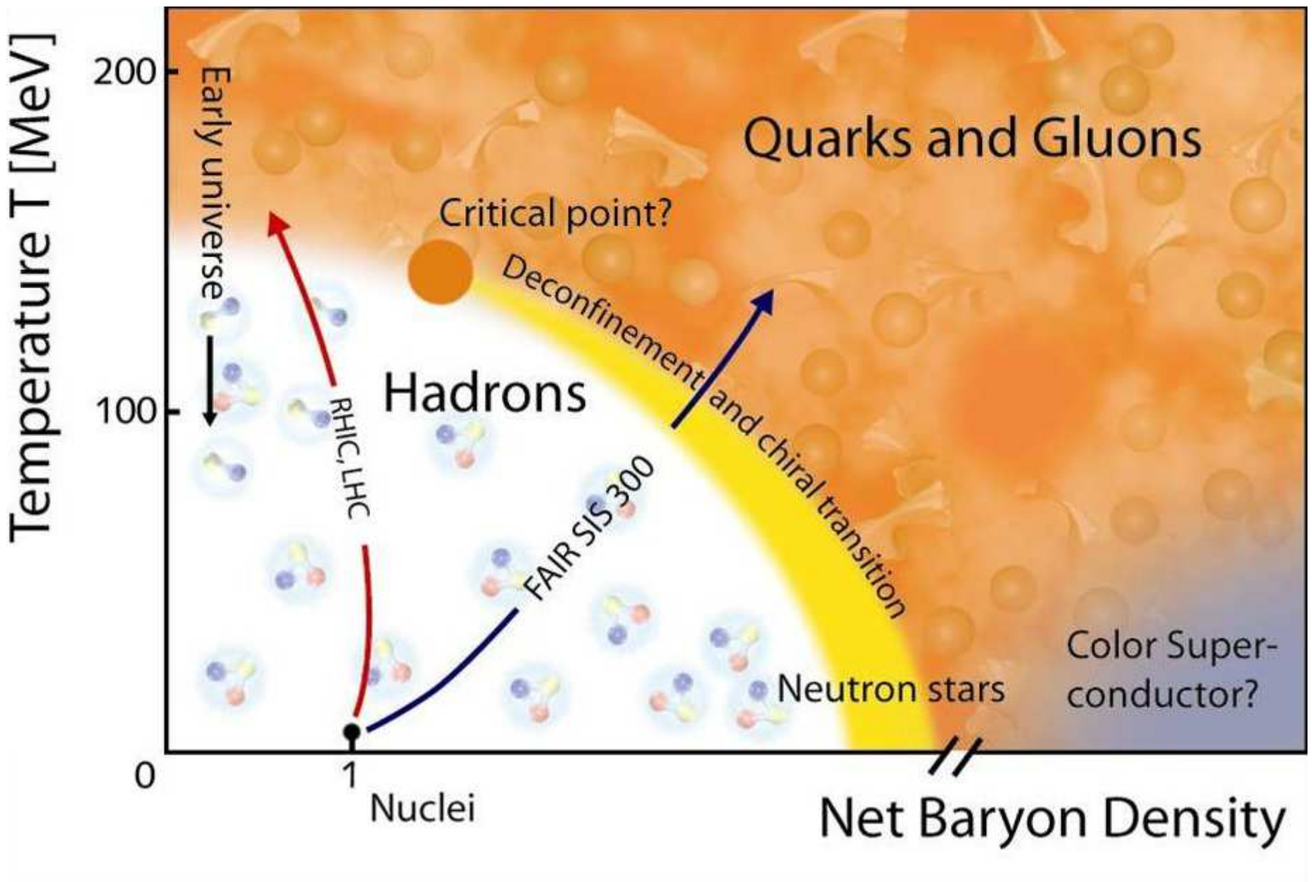
- 1D, $U_{12}=U_{23}=U_{31}$:



- 2D, $U_{\sigma\sigma}$ for ^{6}Li: Qualitatively similar

A. Kantian *et al.* PRL **103**, 240401 (2009)
A. Privitera *et al.* PRA **84**, 021601 (2011)

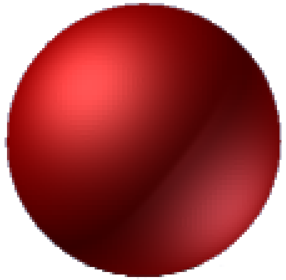
QCD phase diagram



www.gsi.de

Experimental Approach

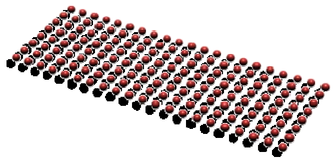
1. Magneto-optical trap (MOT), laser cooling



2. 3D dipole trap, evaporative cooling

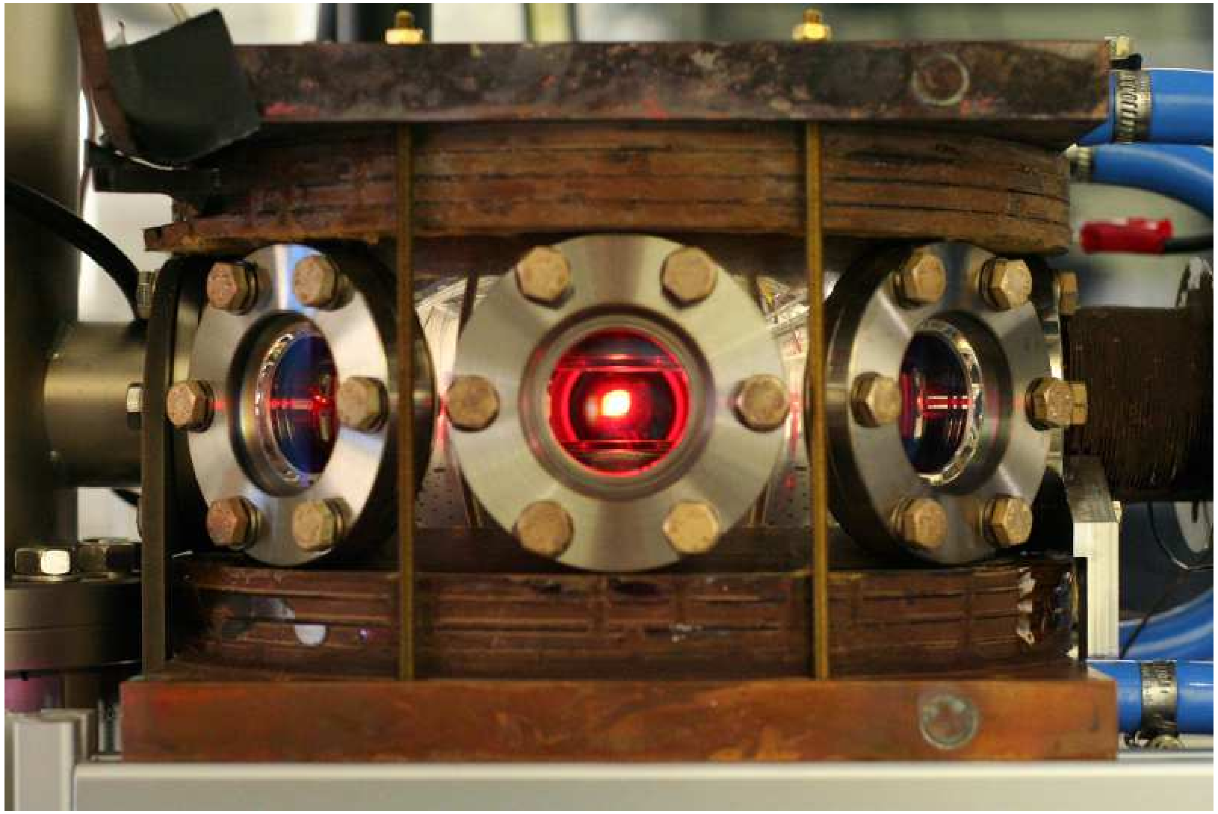
3. 2D potential

4. 2D optical lattice



1st stage: MOT

UNIVERSITÄT HEIDELBERG



- Loading rate:

  ~ 5 · 10^8 atoms/s

- Vacuum lifetime:

  ~ 23 min

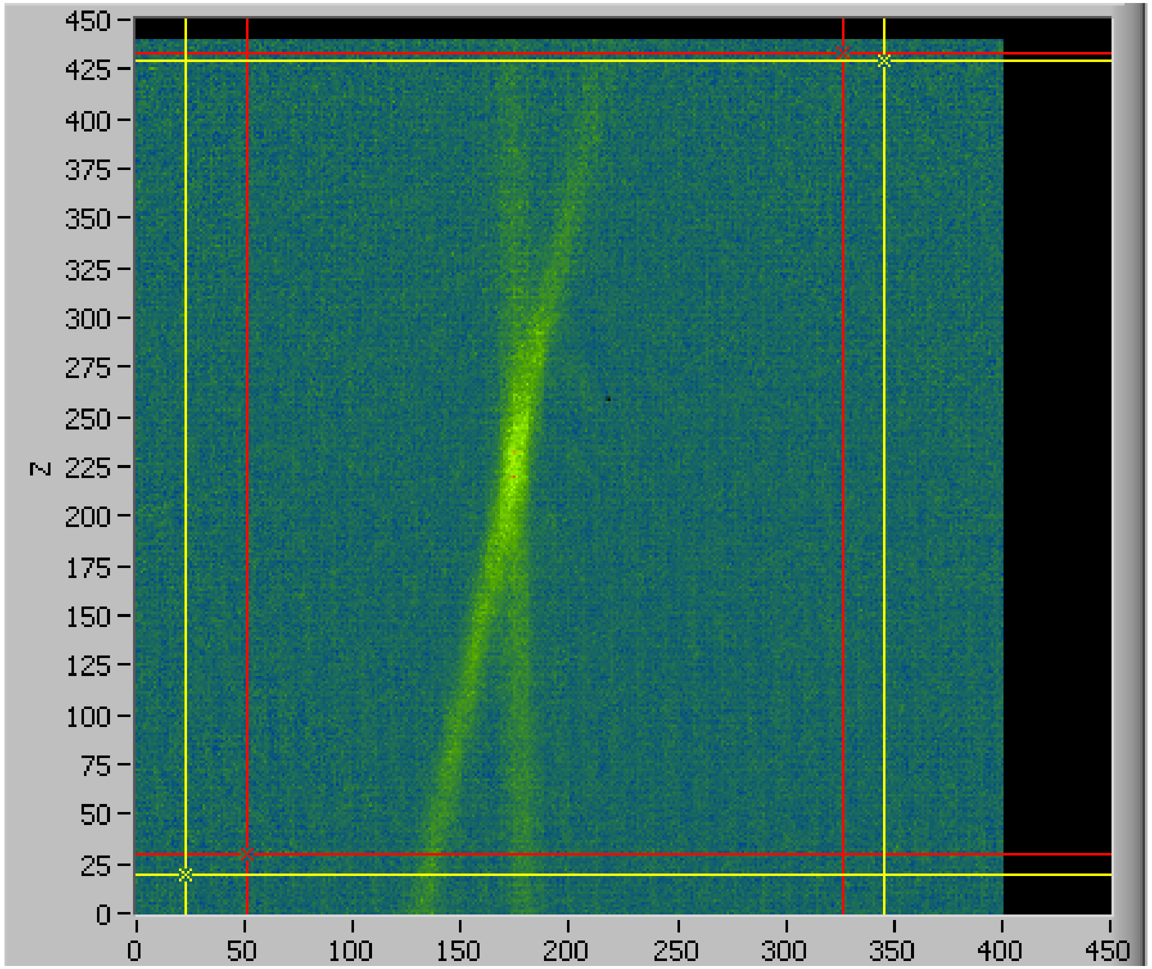
  (p ≈ 10^{-12} mbar)

- Temperature limit:

  T_D ≈ 140 µK

2nd stage: 3D dipole trap

- **200 W @ 1064 nm**
- Elliptical beams
- Forced Evaporation by lowering trap depth:
  T ≈ 100 nK
  T/T_F ≈ 0,3



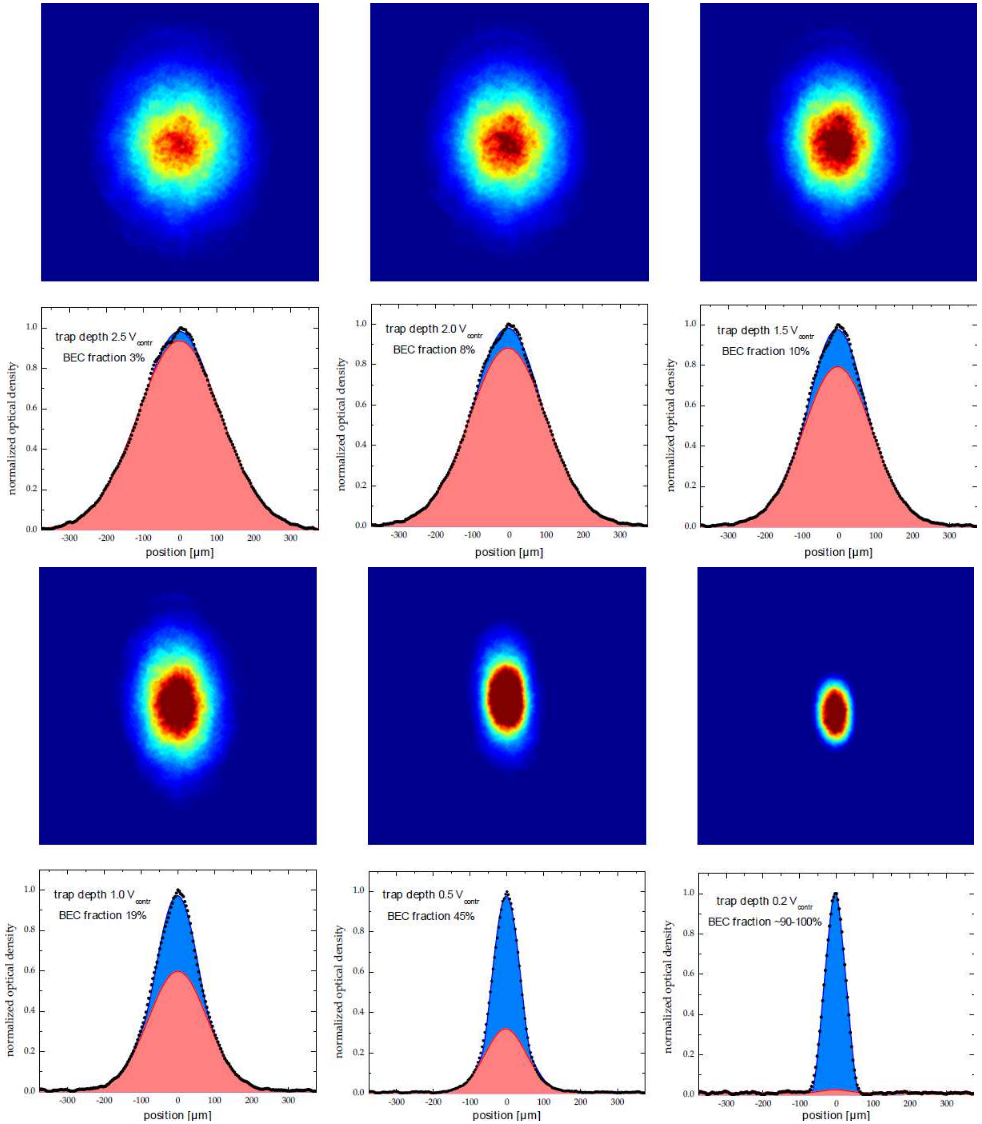
BEC of molecules in 3D trap

UNIVERSITÄT
HEIDELBERG

- Evaporation:

  Li_2 molecules form BEC

- Starting point for experiments!

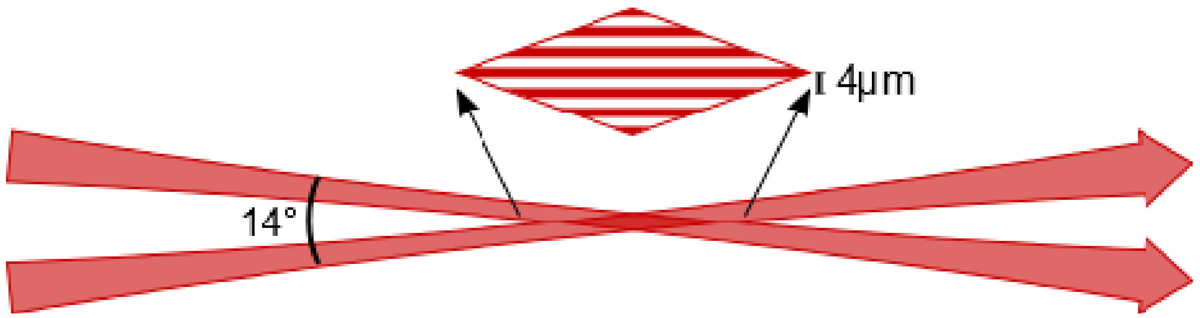


3rd stage: 2D confinement

- Interfere 2 beams under an angle
- Interference fringes: pancake shaped dipole potentials

  diameter ≈ 1,2 mm

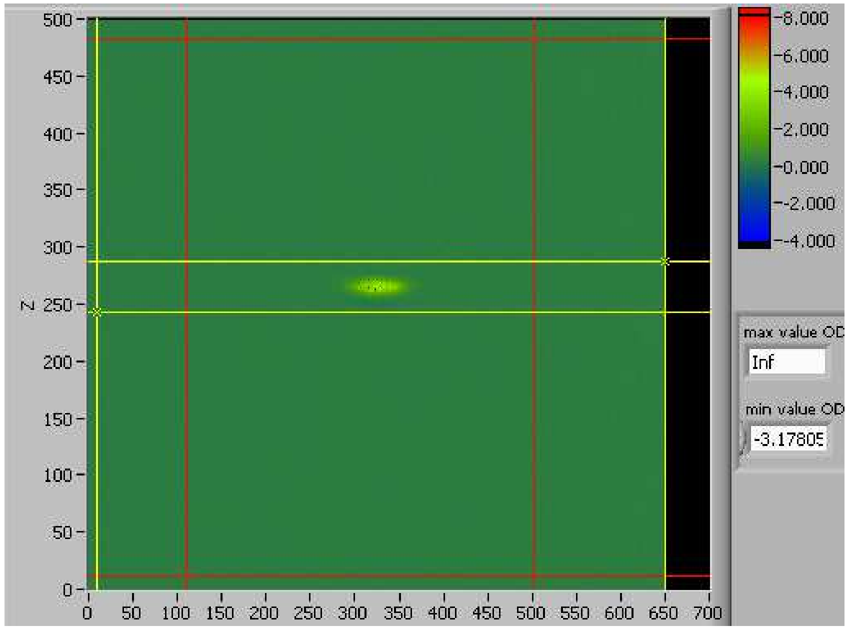
  spacing ≈ 4 µm



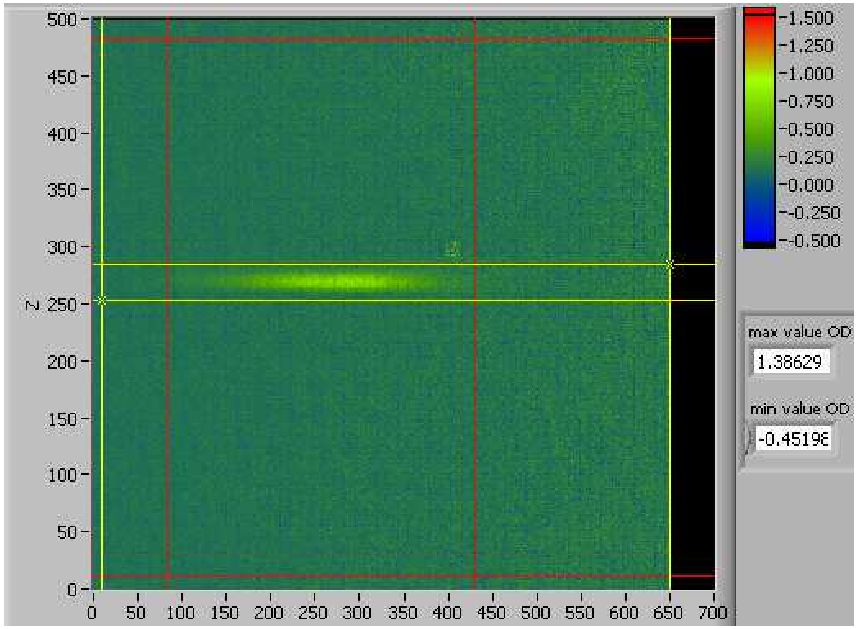
UNIVERSITÄT HEIDELBERG

First atoms in 2D trap

- Transfer BEC from 3D dipole trap into 2D confinement
- Only horizontal expansion
  => sign for 2D trap, but single pancakes cannot be resolved



3D trap



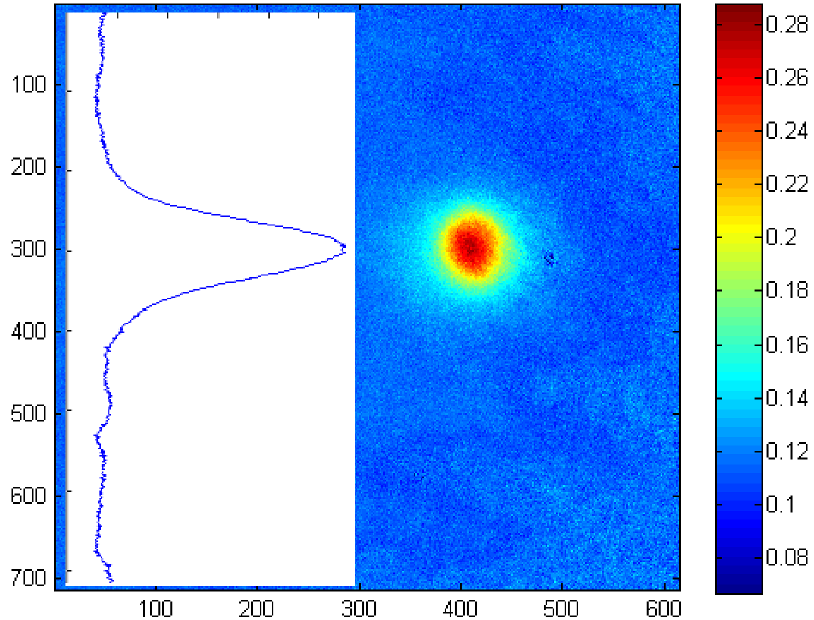
2D pancakes

Kapitza-Dirac scattering on 2D trap

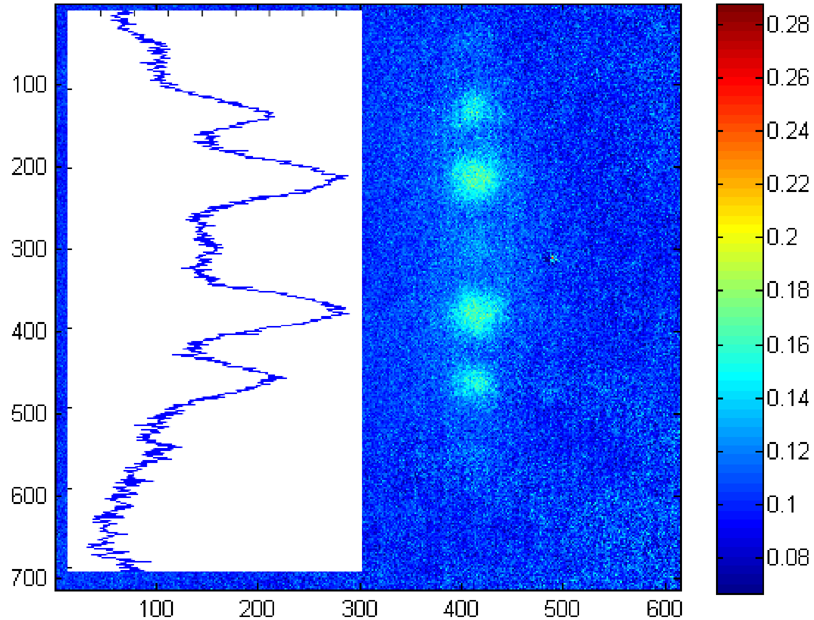
UNIVERSITÄT
HEIDELBERG

- Release BEC slowly from 3D dipole trap, let molecules fly

- Quick (~100µs) pulse with 2D trap
  => Molecules are diffracted on light potential
  different diffraction orders can be observed

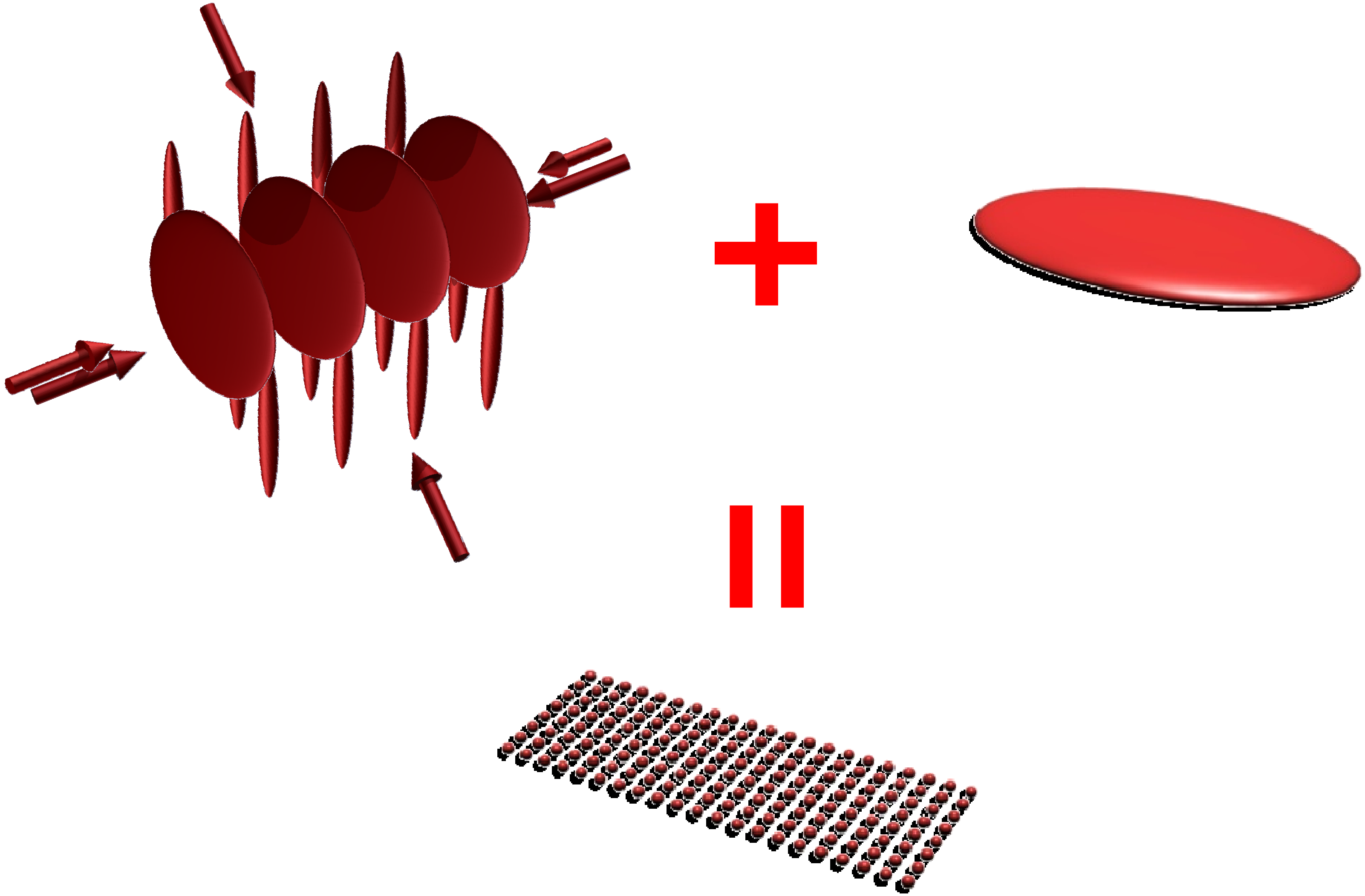


without pulse



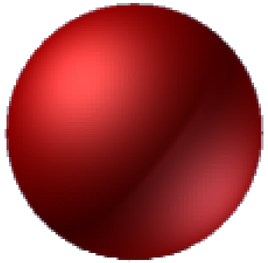
with pulse

4th stage: optical lattice



Experimental approach

1. Magneto-optical trap (MOT)

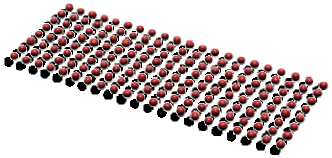


2. Ultracold Fermi gas in 3D potential

3. 2D potential

( )

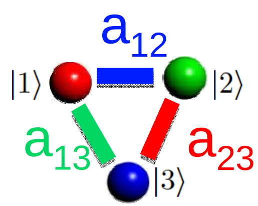
4. 2D optical lattice



in progress

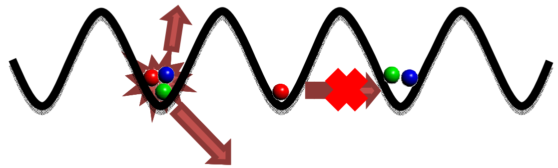
Conclusion

- Three component Fermi gas: Realization with ultracold atoms possible

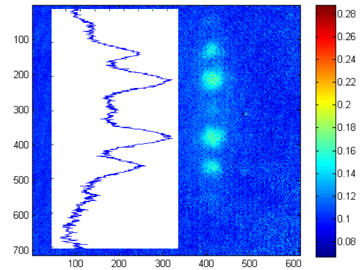


- Challenge: 3-body losses

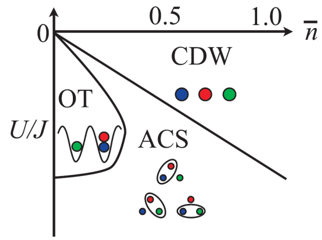
  $\Rightarrow$ lattice potential

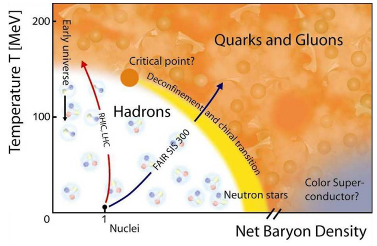


- Apparatus almost ready to provide first results!



- What can we learn for QCD?





The team

€€€:

erc

EMMI

MAX-PLANCK-GESELLSCHAFT

GRADUIERTENAKADEMIE
Fördern junger Wissenschaft!
www.graduiertenakademie.uni-heidelberg.de