Materials Design – Synthesis & Modelling

	Frankfurt am Main	Kaiserslautern	Mainz
Materials Design - Synthesis & Modelling	B1, B2, B4, B6, B13N	A7, A9, A12	A10, B5, B8
Cooperative Phenomena	A3, A8, B1, B2, B4, B6, B9, B11, B13N	A5, A7, A9, A12, B3	A10, B5, B8, B12
Excitations & Interactions	A3, A8, B1, B2, B4, B6, B9, B11, B13N	A5, A7, A9, A12, B3	A10, B5, B8, B12

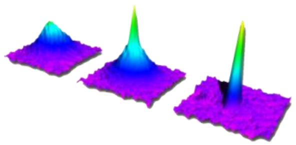
Engineering and controlling quantum matter

Model systems

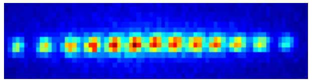
Theoretical ⇕ **modelling**

Real materials

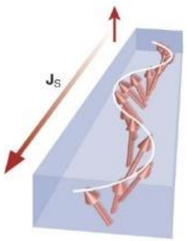
Ultracold quantum gases



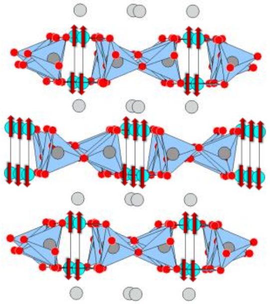
Trapped ions



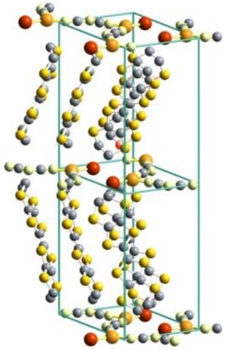
Magnons



Bulk quantum magnets

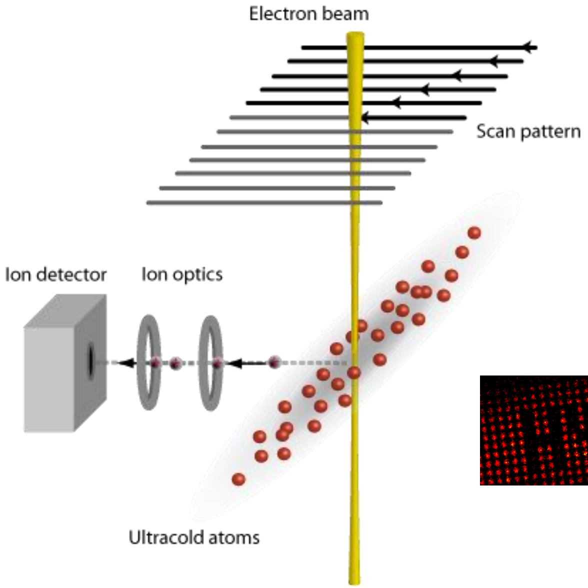


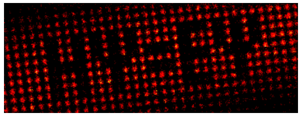
Charge-transfer salts



Microscopic control on the single particle level

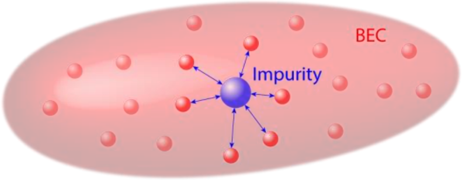
A9

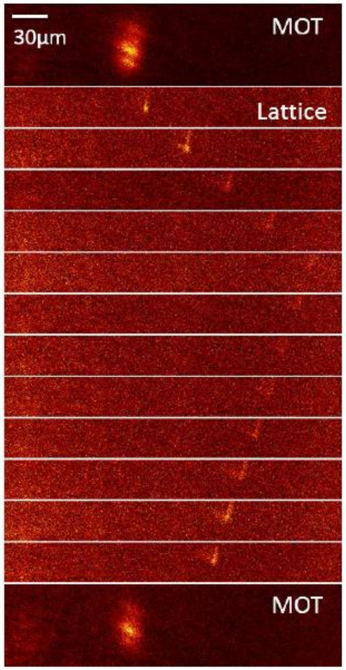




- high spatial and temporal resolution
- single atom sensitivity
- detection and manipulation

A12





- single cesium atoms in a rubidium BEC
- full control over internal states
- precision positioning

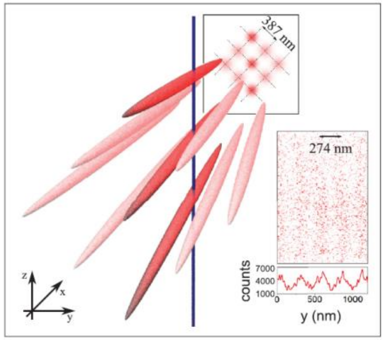
Flexible many-body systems

- set dimensionality of the problem

coupled 1D systems

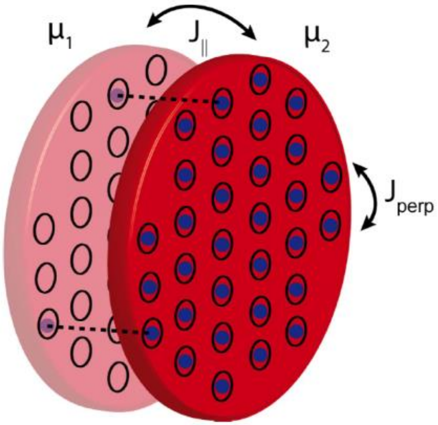
layered 2D systems

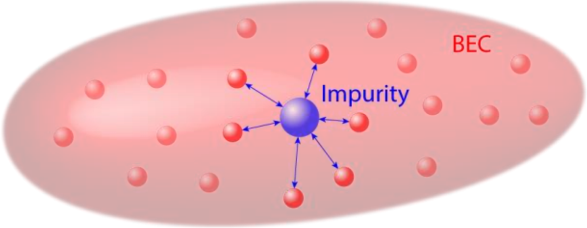
full 3D dynamics



PRL **113**, 215301 (2014)

A9 **B3**



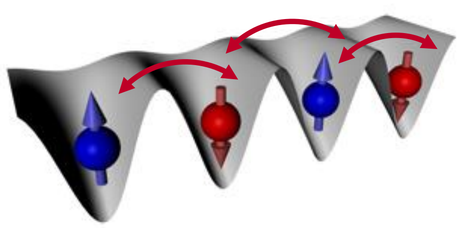


PRL **109**, 235301 (2012)

A12

Tunable interactions

- long-range interaction via Rydberg states

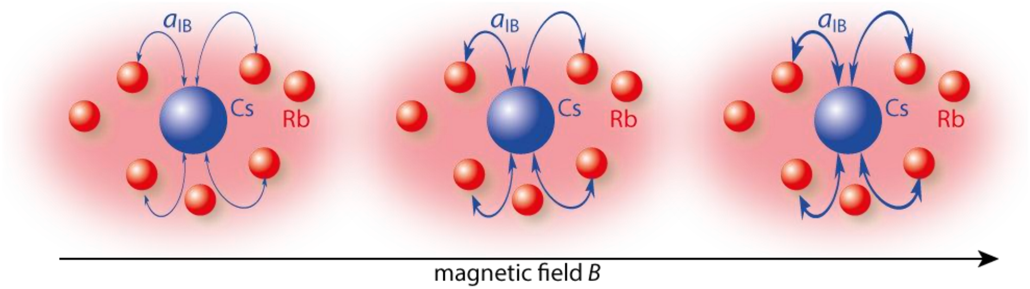


Nature Phys. **11**, 157 (2015)

A9 A5

- tune contact interaction via Feshbach resonance

A12

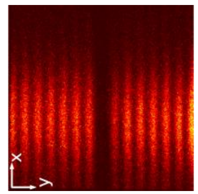


Ultracold Quantum Gases

Next:

- bosonic many-body dynamics and transport

A9

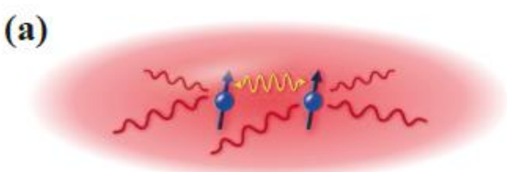


A3 projection operator technique

B3 QMC

- single and multi polaron physics

A12



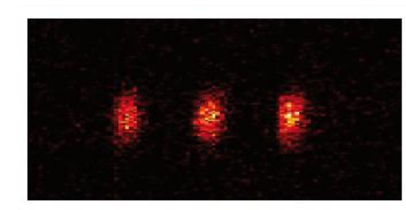
A3 real space DMFT

A5 time dependent DMRG

B3 study of fermionic spin chains

- long-range interactions in Rydberg lattice systems

A9



A3 real space DMFT

A5 TEBD

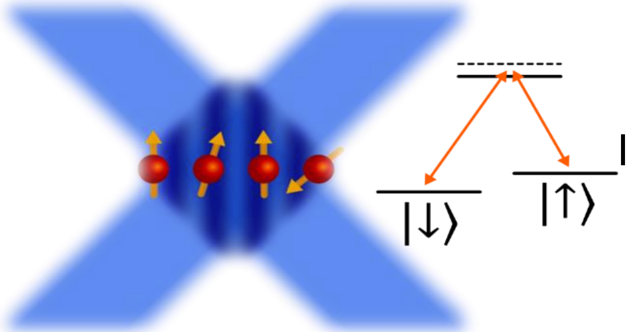
B1 B4 A10 related spin systems

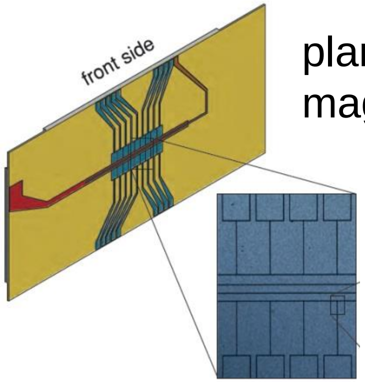
Trapped Ion Crystals

Control on the single particle level – entangled many-particle states

- Design of spin-spin interactions

A10

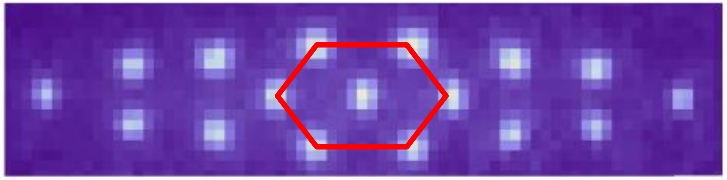




planar trap
magnetic force

PRL **107**, 207209 (2011)

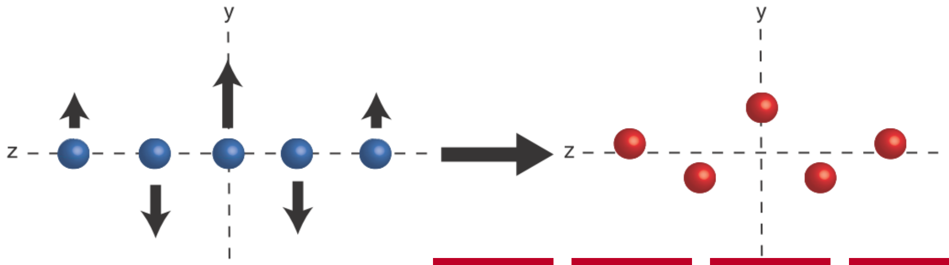
- From linear system to frustrated crystal



Triangular /
Kagome structures

PRL 109, 263003 (2012)

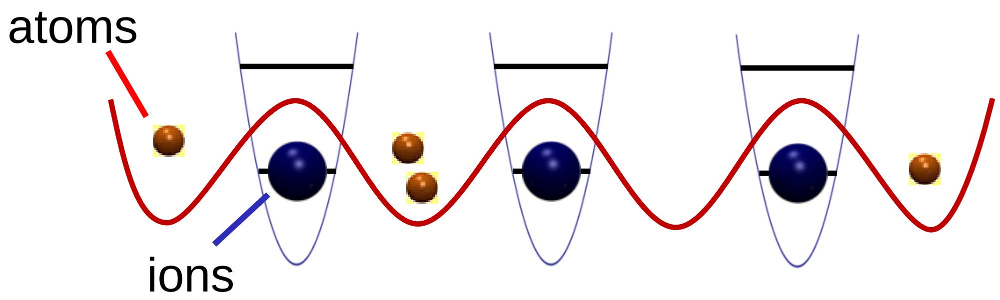
- Structural phase transitions
  spin-dependent quench



A3 B1 B2 B3 B4

Hybrid atom-ion quantum simulators

Emulating solid-state physics with a hybrid system of ultracold ions and atoms



$$\mathcal{H} = \sum_n \hbar\omega_n a_n^\dagger a_n + \sum_{\mathbf{k}} \epsilon_{\mathbf{k}} c_{\mathbf{k}}^\dagger c_{\mathbf{k}} + \sum_{\mathbf{k}\mathbf{k}'s} \lambda_{\mathbf{k}\mathbf{k}'s}(a_s^\dagger + a_s) c_{\mathbf{k}}^\dagger c_{\mathbf{k}'}$$

Phonons | Atoms | Atom-phonon coupling

Collaboration with Walter Hofstetter

- Phonons naturally included
- Fröhlich Hamilton
- Polarons
- Phonon-mediated interactions
- Peierls instability….

PRL **111,** 080501 (2013)

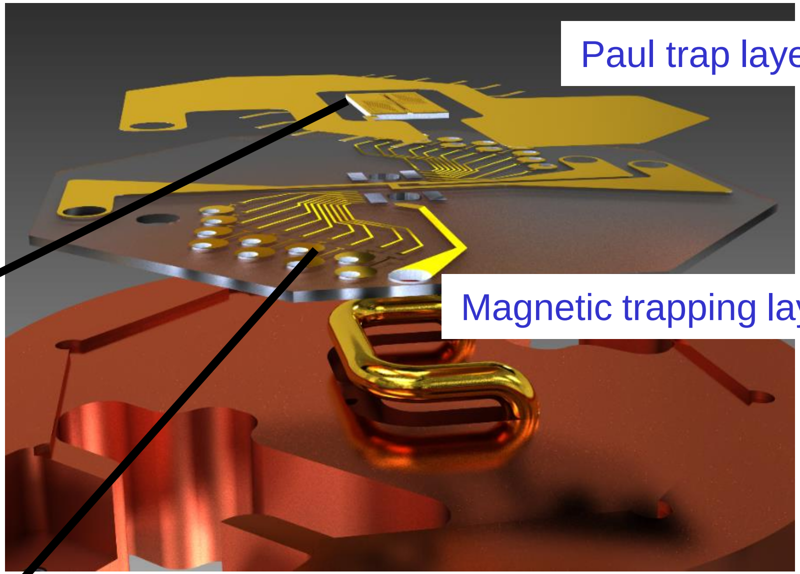
A3 **A5** **A9** **A10** **A12** **B1** **B2** **B3** **B13**

Planar hybrid atom and ion trap

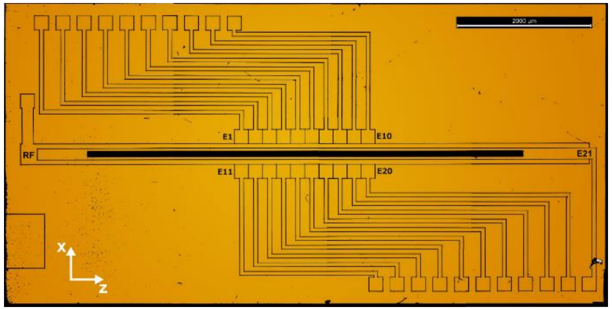
Hybrid microtrap

- Planar Paul trap holds Yb^+ crystal
- Magnetic trap for Rb BEC
- Tight confinement → 1D atom-ion system
- Integrated system → excellent stability
- Quantum operations in cold bath

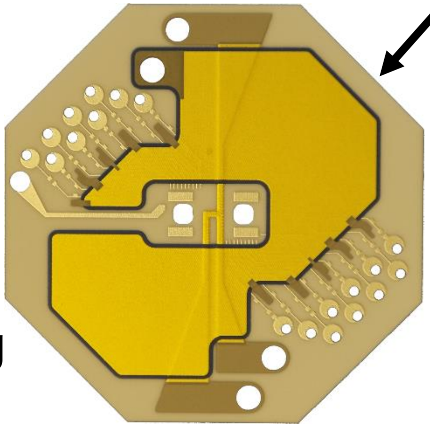
Explosion view of novel hybrid trap

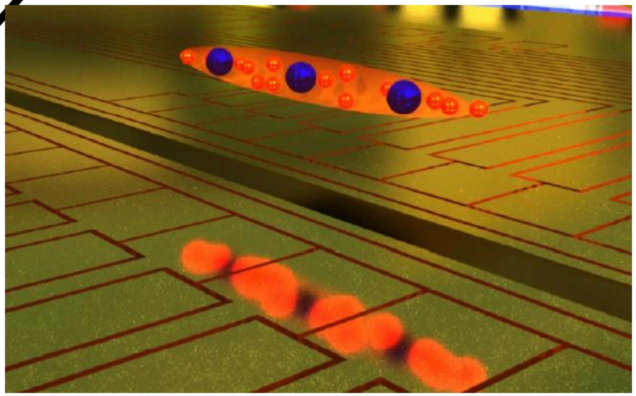


Planar ion trap
UC Berkeley
AG Häffner



Filter board and
electromagnets
for atom trapping





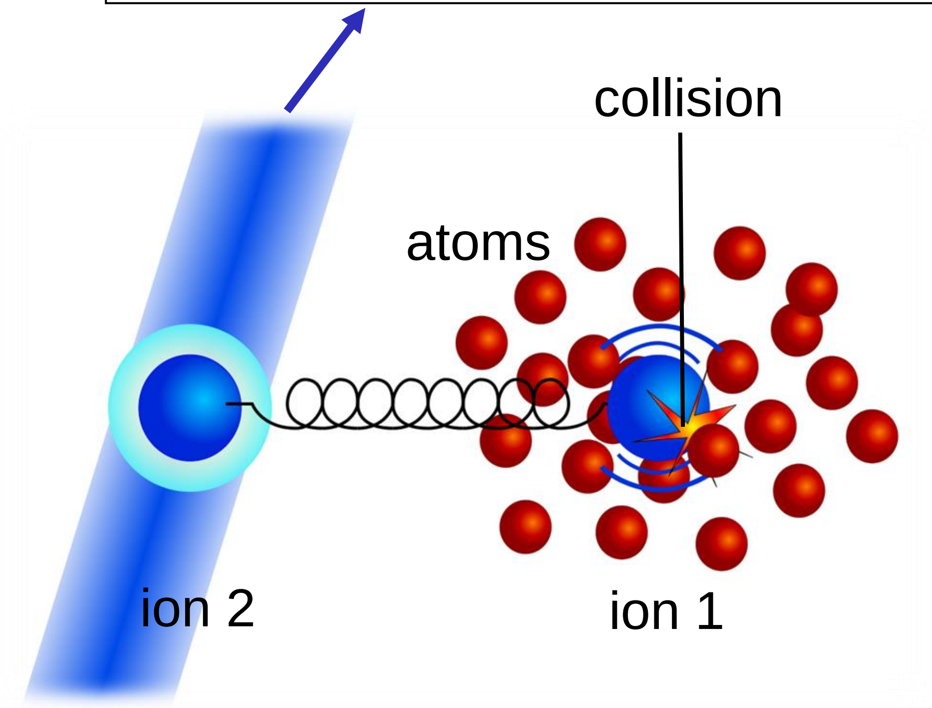
Three ion crystal in a BEC in the microtrap

Jannis Joger, *Diploma thesis* (2013).

Detecting atom-ion interactions

Trapped ions allow for accurate read out of motion

Raman laser @ 370nm for spin-motion coupling → Resolved regime
EIT → Continuous/real time regime



Quantum enhancement

→ Spin-motion entanglement in a two-ion string
→ Spin state detection by fluoresensce detection
→ Ion-atom collisions show up as decoherence

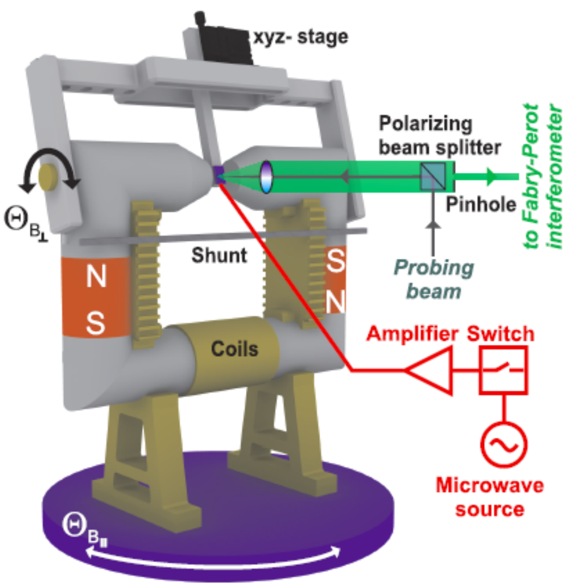
N. Ewald, *Master thesis, in prep.* (2015).

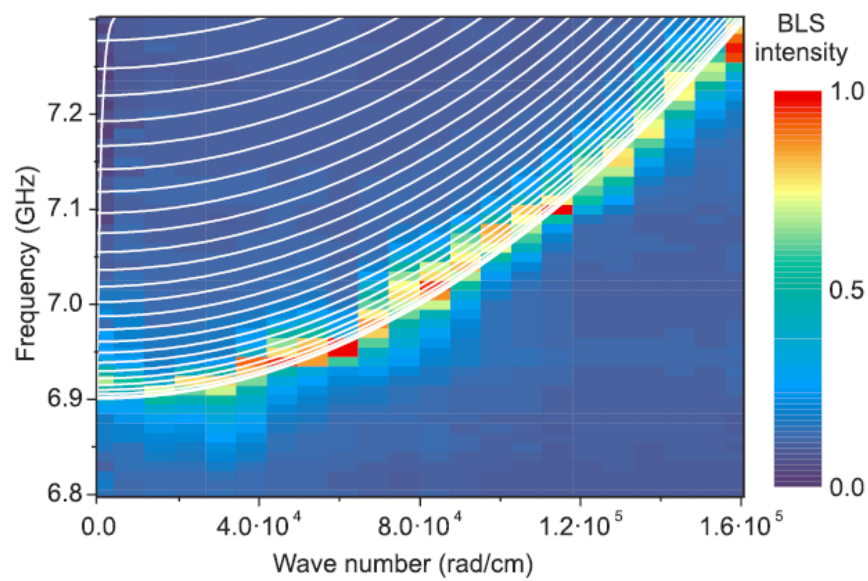
Hempel *et al., Nature Phot.* **7**, 630 (2013).
EPL **99**, 53001 (2012).

Magnons: interacting bosons on demand

A7 A8

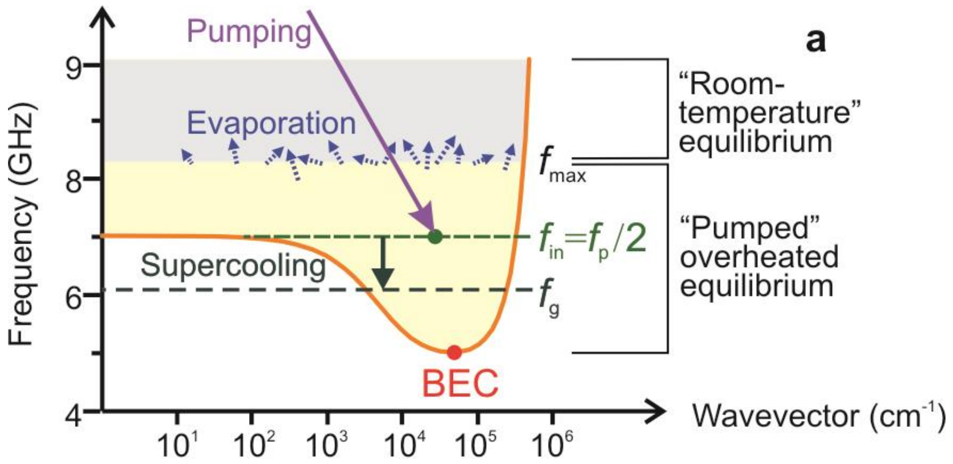
- magnons form a gas of interacting Bose-quasiparticles
- create magnons by parametric pumping
- detect magnons by Brillouin-light scattering





Dynamics of Bose-Einstein condensation

A7 A8

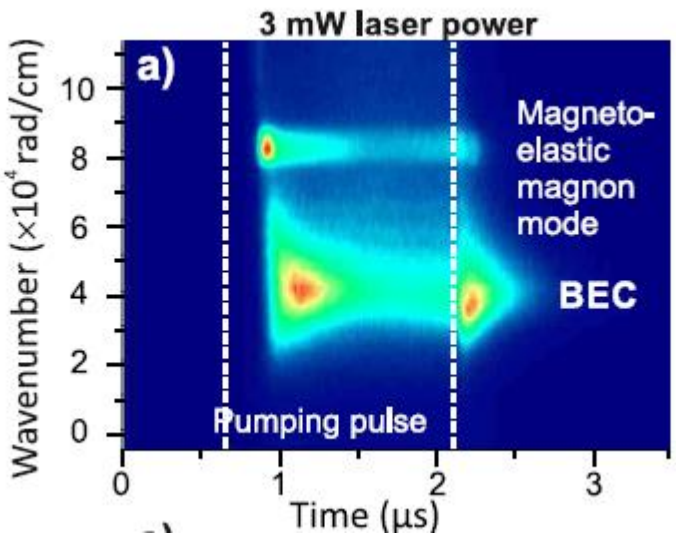


- non-equilibrium dynamics
- coherent interactions and phase transitions

Nat. Commun. **5**, 4452 (2014)

Next:

Magnon-phonon condensate



Theoretical Modelling

Next:

Pushing the limit of theoretical modelling

A3 Generalization of DMFT to non-equilibrium
Projection operator method for inhomogeneous systems

A5 Further extend DMRG to 2D systems

A8 Functional RG methods out of equllibrium

Bridge to real materials !

Materials Design – Synthesis & Modelling

	Frankfurt am Main	Kaiserslautern	Mainz
Materials Design - Synthesis & Modelling	B1, B2, B4, B6, B13N	A7, A9, A12	A10, B5, B8
Cooperative Phenomena	A3, A8, B1, B2, B4, B6, B9, B11, B13N	A5, A7, A9, A12, B3	A10, B5, B8, B12
Excitations & Interactions	A3, A8, B1, B2, B4, B6, B9, B11, B13N	A5, A7, A9, A12, B3	A10, B5, B8, B12