FOR 2247
From few to many-body physics with dipolar quantum gases

DFG FWF

5th International Workshop on

"Long-range interactions in the ultracold"

Hannover, June 25-28, 2018

Scientific organizers:

FOR 2247, A. Browaeys, F. Ferlaino, R. Löw, and S. Ospelkaus

Local Organization: S. Ospelkaus, E. Huenitzsch, and K. Pfennig

Leibniz Universität Hannover

IQ

General information on the workshop

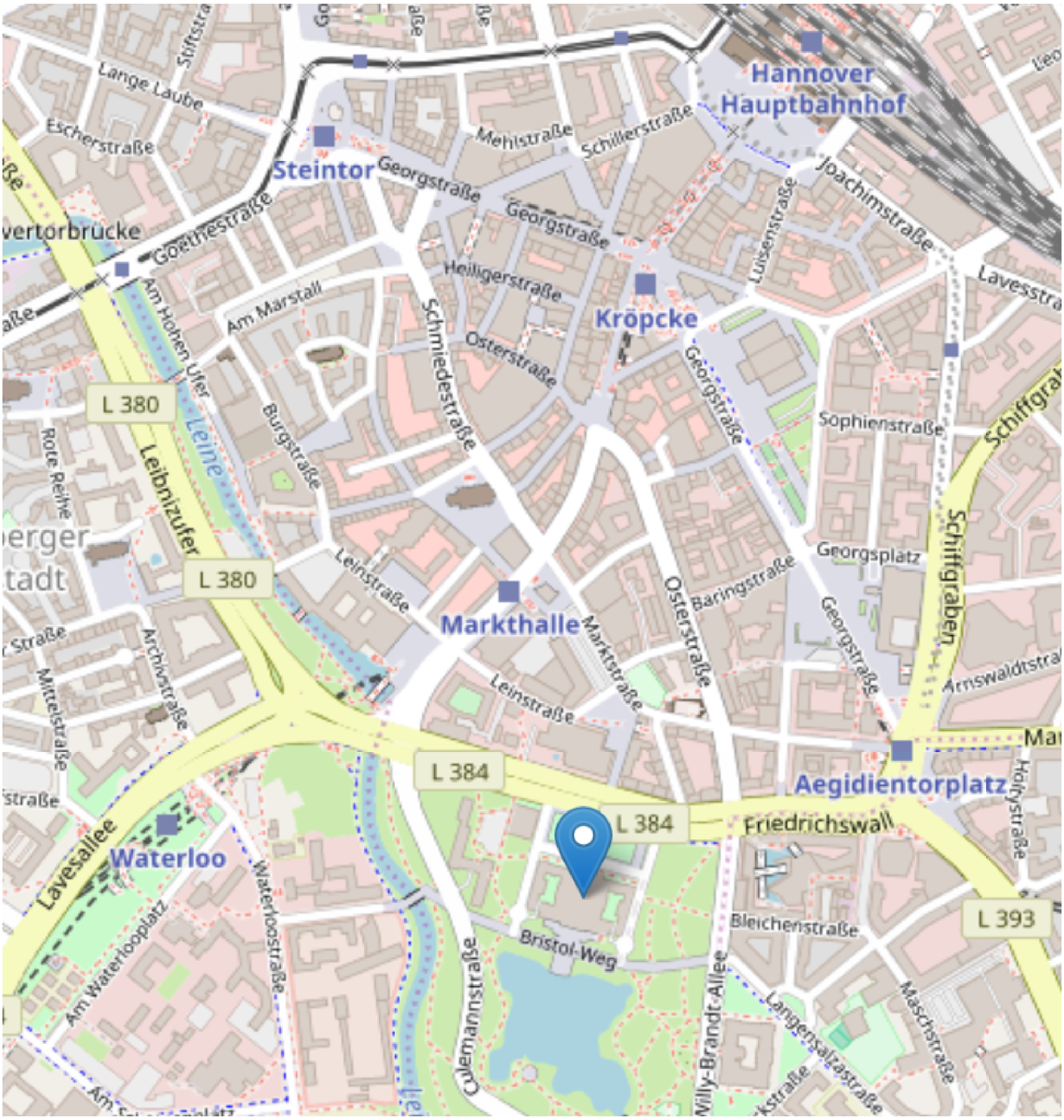
Following the now 4 year tradition of a workshop on "Long-range interactions in quantum systems" (2013, 2014, 2016, 2017), this year's 5th international workshop taking place in Hannover is organized by the DFG Research Unit "From few- to many-body physics with dipolar quantum gases" co-funded by the German Science Foundation DFG and the Austrian Science Fund FWF. This year the workshop will focus on dipolar interactions in few and many-body quantum systems enriched by a discussion of a wider range of long-range interactions.

Support/Funding

Venue

The conference takes place at

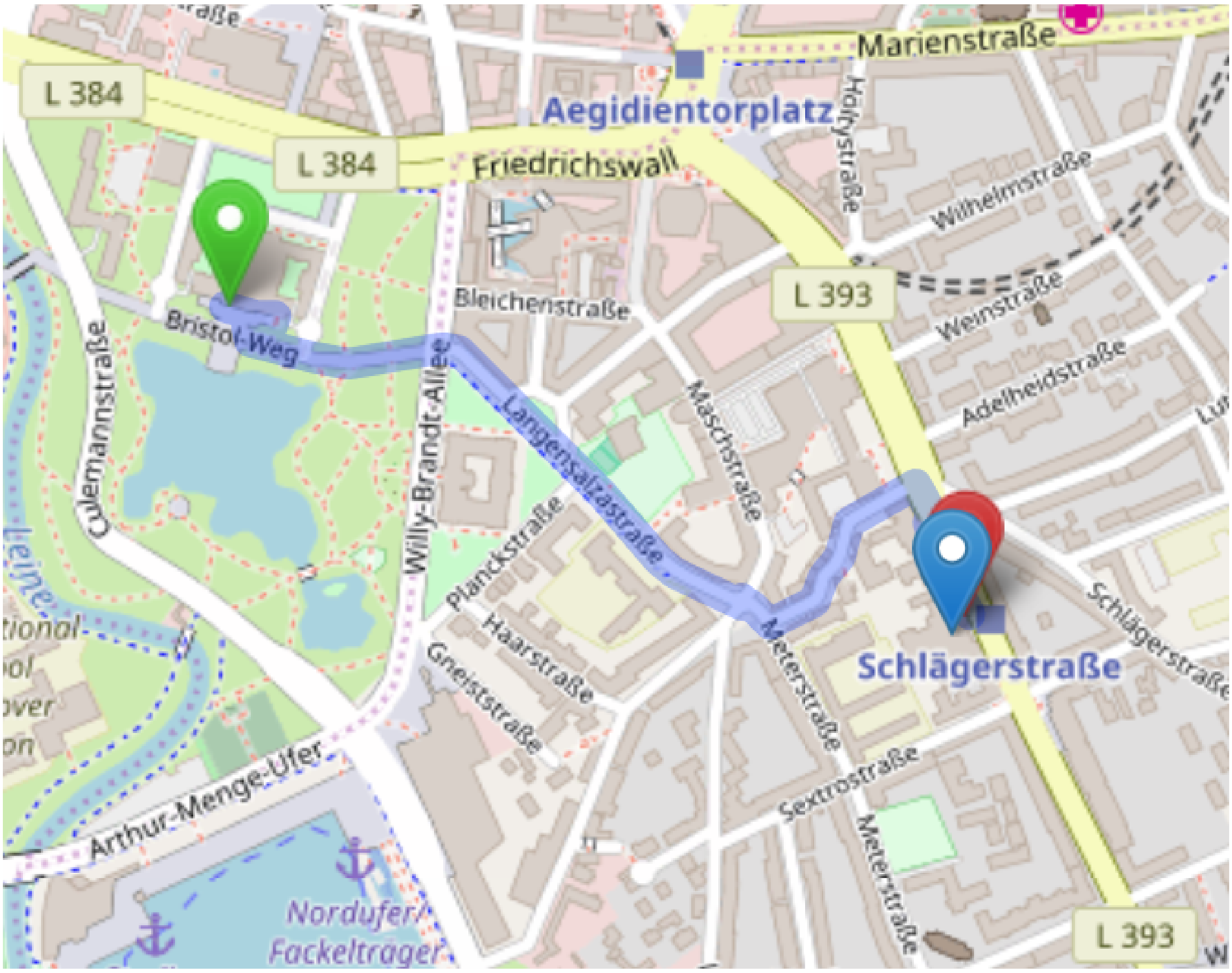
Neues Rathaus
Restaurant Gartensaal
Trammplatz 2
30159 Hannover



Accomodation

Most of the participants of the workshop stay at the **Hotel Dormero** in walking distance of the conference site.

Hotel Dormero
Hildesheimer Straße 34-38
30169 Hannover



Program

Monday, 25.06.2018		
17.00 – 21.00	**Registration / Get together**	

Tuesday, 26.06.2018		
08.45 – 09.00	**Welcome**	
09.00 – 09.30	Talk 1	**Ronen Rapaport** „Strong repulsive and attractive interactions in correlated quantum fluids of dipolar excitons and polaritons“
09.30 – 10.00	Talk 2	**Francois Dubin** „High-Tc Superfluidity with Trapped Two-Dimensional Dipolar Excitons“
10.00 – 10.30	Talk 3	**Guido Pupillo** „Exciton and charge transport via cavity-mediated long-range interactions“
10.30 – 11.00	**Coffee break**	
11.00 – 11.30	Talk 4	**Jonathan Simon** tba
11.30 – 12.00	Talk 5	**Hendrik Weimer** „Quantum many-body dynamics of driven-dissipative Rydberg gases“
12.00 – 12.30	Talk 6	**Ahmed Omran** „Quantum Many-Body Dynamics in Strongly Interacting Atom Arrays“
12.30 – 14.00	**Lunch**	
14.00 – 14.30	Talk 7	**Alessandro Zenesini** „Mixtures of ^{23}Na and ^{39}K: welcome to a new bosonic playground“
14.30 – 15.00	Talk 8	**Andreas Schindewolf** "Quantum Engineering of a Low-Entropy Sample of Molecules"
15.00 – 15.30	Talk 9	**Goulven Queméner** „Microwave shielding of ultracold dipolar molecules“
15.30 – 16.00	Talk 10	**Dajun Wang** „Dipolar collisions of ultracold NaRb molecules“
16.00 – 16.30	**Coffee break**	
16.30 – 19.00	**Postersession**	
19.00 – 21.00	**Dinner**	

Wednesday, 27.06.2018		
09.00 – 09.30	Talk 11	**Alexander Holleitner** „On the parabolicity of dipolar excition traps“
09.30 – 10.00	Talk 12	**Igor Lesanovsky** „Non-equilibrium absorbing state phase transitions in discrete-time quantum dynamics on Rydberg quantum simulators“
10.00 – 10.30	Talk 13	**Ofer Firstenberg** „Rydberg nonlinear optics with structural slow-light“
10.30 – 11.00	**Coffee break**	
11.00 – 11.30	Talk 14	**Tilman Pfau** „Experiments with dipolar Bose-Einstein condensates: quantum droplets, self-organization and superfluidity“
11.30 – 12.00	Talk 15	**Francesca Ferlaino** "Dipolar quantum gases of ultracold Erbium atoms: latest news from Innsbruck"
12.00 – 12.30	Talk 16	**Luis Santos** „Disordered models with power-law hopping“
12.30 – 14.00	**Lunch**	
14.00 – 14.30	Talk 17	**Christoph Gohle** „Ultra cold fermionic NaK molecules with 8 ms rotational coherence and dipolar Interaction“
14.30 – 15.00	Talk 18	**Matthias Weidemüller** „An ultracold mixture of ^{6}Li and ^{133}Cs atoms“
15.00 – 15.30	Talk 19	**Simon Cornish** „Coherent control of ultracold ground-state RbCs molecules in an optical trap“
15.30 – 16.00	Talk 20	**Martin Zwierlein** „Interactions in ultracold Bose-Fermi mixtures and ultracold molecules“
16.00 – 16.30	**Coffee break**	
16.30 – 17.00	Talk 21	**Piet O. Schmidt** „Quantum logic spectroscopy and metrology with trapped ions“
17.00 – 17.30	Talk 22	**Johnnes Hecker Denschlag** „Probing cold long-range collisions within an ion trap“
17.30 – 18.00	Talk 23	**Alexey Gorshkov** „Information propagation and entanglement gerneration with long-range interactions“
18.00 – 20.00	**Conference Dinner**	

Thursday, 28.06.2018		
09.00 – 09.30	Talk 24	**Hanspeter Büchler** „Emergent universal dynamics by dipolar exchange interaction for an atomic cloud coupled to an optical wave-guide“
09.30 – 10.00	Talk 25	**Andrea Morales** „Coupling two order parameters in a quantum gas“
10.00 – 10.30	Talk 26	**Carlos Sa de Melo** „Superfluid Phases of Dipolar Fermions in Optical Lattices“
10.30 – 11.00	**Coffee break**	
11.00 – 11.30	Talk 27	**Sylvain Nascimbene** „Quantum-enhanced sensing using non-classical spin states of a highly magnetic atom“
11.30 – 12.00	Talk 28	**Svetlana Kotochigova** „Orbital quantum magnetism of strongly interacting magnetic lanthanide atoms“
12.00 – 12.30	Talk 29	**Carsten Klempt** „EPR and spatial-mode entanglement in spinor Bose-Einstein condensates“
12.30	**Lunch**	

List of posters

Poster abstracts at the end of the booklet.

No.	Author	Title
1	Javier Arguello-Luengo	Analog simulation of quantum chemistry
2	Antun Balaz	Vortices in dipolar Bose-Einstein condensates
3	Luca Barbiero	Interaction Induced Topological Superconductivity in a Dipolar Spin Lattice
4	Thomas Bland	Quantum Ferrofluid Turbulence
5	Raul Bombin	Quantum dipolar Systems in 2D
6	Victoria Borish	Towards lattice spin models with Rydberg-dressed atoms
7	Fabian Böttchher	Dipolar quantum droplets and striped states
8	Patrick Cheinet	Few-body interactions in a cold Rydberg gas
9	Loriane Chomaz	Quantum spinor gases of dipolar fermions
10	Chiaolong Deng	Power-law localization in long-range hopping models with disorder
11	Kai Dieckmann	Ground state spectroscopy of ultracold dipolar ^{6}Li^{40}K molecules
12	Daniel Edler	Quantum Fluctuations in Quasi-One-Dimensional Dipolar Bose-Einstein Condensates and Bose-Bose mixtures
13	Amit J. Gangapuram	Quantum Zeno-based Detection and State Engineering of Ultracold Polar Molecules
14	Giergiel Krzysztof	Long range interactions in time lattices
15	Grecia Guijarro	Bilayer system of dipolar bosons: few-body bound states
16	Tobias Ilk	Dimensional Crossover for the Beyond-Mean-Field Corrections in the Confined Weakly Interacting Bose Gas
17	Philipp Itzhöfer	Rydberg physics and quantum-gas microscopy with multi-electron Er and Dy atoms
18	Luka Jibuti	Quantum Phase Transitions of Water Molecules
19	Tijs Karman	Microwave Shielding of Polar Molecules
20	Tijs Karman	Near-threshold bound states of the dipole-dipole interaction
21	Javad Kazemi	Long-Range Correlations in Driven-Dissipative Rydberg Gases
22	Nils Kjaergaard	Light scattering from dense and quantum degenerate atomic ensembles
23	Milan Krstajic	Towards an Erbium BEC in an Optical Box Potential
24	Jan Kumlin	Emergent universal dynamics for an atomic cloud coupled to a wave guide
25	Tim Langen	Towards Direct Laser Cooling of Barium Monofluoride
26	Steven Lepoutre	Spin exchange dynamics in chromium dipolar quantum gases
27	Philipp Lunt	Rydberg quantum optics in an ultracold atomic gas
28	Ferran Mazzanti	Droplet Formation in Dipolar Bose gases
29	Paolo Pedri	Spin mixing and protection of ferromagnetism in a spinor dipolar condensate
30	Axel Pelster	Ground state of an ultracold Fermi gas of tilted dipoles

31	Tom Peyrot	The collective Lamb Shift of a Nanoscale Atomic Vapour Layer within a Sapphire Cavity
32	Martin Robert-de-Saint-Vincent	Dissipative cooling of spin chains by a bath of dipolar particles
33	Jan-Niklas Schmidt	Anisotropic critical velocity of a dipolar superfluid
34	Frauke Seeßelberg	Rotational coherence of polar molecules in a magic trap
35	Luca Tanzi	Dysprosium dipolar condensate with broad Feshbach resonances
36	Arno Trautmann	Quantum degenerate mixtures of Erbium and Dysprosium atoms
37	Marcel Trümper	Laser cooling of Dysprosium
38	Kai Voges	Dual-species Bose Einstein condensation and Feshbach spectroscopy in a 23Na- 39K mixture
39	Sebastion Weber	Accurate Rydberg quantum simulations of spin-1/2 models
40	Marta Zamorano	Equation of State and Universality of a 2D Dipolar Gas
41	Klaudia Z. Kopczyk	Magnetically tunable Feshbach resonances in ultracold gases of europium atoms and mixtures of europium and alkali-metal atoms
42	Idziaszek Zbigniew	Trap-induced shape resonances in an ultracold few-body system of an atom and static impurities
43	Robert Zillich	Quantum phases of dipolar rotors on two-dimensional lattices

Abstracts of the talks

Talk 1

Strong repulsive and attractive interactions in correlated quantum fluids of dipolar excitons and polaritons

Ronen Rapaport

Weizmann Institute of Science, Herzl Street, Rehovot 7610001 Israel

Quantum fluids of matter with long range, anisotropic interactions display rich emergent collective phenomena. A prominent example is the dipole-dipole interaction, which has recently been addressed by a growing community, both from atomic physics as well as from condensed matter physics, with the latter being focused on dipolar quantum fluids of two-dimensional excitons, and very recently, on the introduction of interacting dipolar polaritons. These strongly interacting dipolar exciton and polariton systems offer opportunities to explore new collective phenomena which are currently inaccessible with atomic dipolar gases, and to demonstrate new types of quantum devices on the level of two-particle interaction.

In this talk I will start by presenting strong experimental evidence for the dynamical formation of a robust dark dense liquid phase of dipolar excitons in a bilayer system, and discuss how these observations are corroborated by a theory predicting a remarkable stabilization of a dense dark-spin exciton Bose-Einstein condensate, driven by particle correlations due to the strong dipolar interactions.

In the second part of the talk I will report on the first observation of a formation of an attractive polaron-like many-body correlated state of vertically coupled dipolar exciton fluids.

Finally, I will introduce recent experiments showing formation of flying electrically polarized dipolar-polaritons (dipolaritons) in optical waveguides, resulting in a very large, electrically tunable enhancement of the polariton-polariton interactions, a result promising for future implementations of a dipolar polariton blockade.

Talk 2

High-T_c Superfluidity with Trapped Two-Dimensional Dipolar Excitons

Suzanne Dang,[1] Romain Anakine,[1] Carme Gomez,[2] Aristide Lemaitre,[2]
S. Suffit,[2] K. West,[2] L. Pfeiffer,[2] M. Holzmann,[3] and Francois Dubin[1]

[1] *Sorbonne University, Paris, France*

[2] *University Paris-Saclay, Marcoussis, France*

[3] *University of Grenoble, France*

In the solid-state, bilayer GaAs quantum wells constitute a model platform to investigate the quantum phases accessible to dipolar gases. Indeed, such heterostructures allow to engineer dipolar excitons which result from the Coulomb attraction between spatially separated electrons and holes. In recent experiments we have reported signatures of quantum coherence and quantized vortices in the photoluminescence radiated by dipolar excitons confined in a two-dimensional trap[1]. Here we show that in this geometry the quantum regime is accessed through a transition obeying the Berezinskii-Kosterlitz-Thouless (BKT) mechanism. We show that the crossover occurs in a very unique way, due to strong dipolar interactions between excitons and to their underlying four-component spin-structure, thus reaching a critical temperature slightly above 1 Kelvin. In our experiments, the BKT transition is accessed by unveiling the excitons equation of state, at thermal equilibrium, together with its scale invariance. Using Monte-Carlo simulations we then quantify this behavior and localize the BKT crossover. The critical temperature and density are thus confirmed quantitatively by analyzing the excitons quantum spatial coherence and the spatial distribution of density fluctuations. The latter analysis allows us to reveal the expected defect-driven (topological) nature of the excitonic superfluid transition at two-dimensions [2].

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[1] R. Anankine et al. , Phys. Rev. Lett. **118**, 127402 (2017)

[2] S. Dang et al., submitted

Talk 3

Exciton and charge transport via cavity-mediated long-range interactions

Guido Pupillo[1]

[1] *University of Strasbourg, 67000 Strasbourg, France*

Strong light-matter interactions are playing an increasingly crucial role in the understanding and engineering of new states of matter with relevance to the fields of quantum optics, solid state physics and material science. Recent experiments with molecular semiconductors have shown that charge conductivity can be dramatically enhanced by coupling intra-molecular electronic transitions to the bosonic field of a cavity or of a plasmonic structure prepared in its vacuum state, even at room temperature [1]. In this talk, we discuss a proof-of-principle model for charge and exciton transport where light-matter hybridization enabled by long-range cavity mediated interactions provides an enhancement of conductivity in the steady-state. We discuss the roles of disorder and finite electronic band-width in the light-matter dressing and current enhancement. We demonstrate that under certain experimentally relevant conditions this enhancement can reach orders of magnitude [2, 3]. We conclude with a discussion of open questions in the field of vacuum-induced quantum materials.

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[1] E. Orgiu *et al.*, Nature Materials **14**, 1123 (2015)

[2] D. Hagenmüller, J. Schachenmayer, S. Schütz, C. Genes, and G. Pupillo, Phys. Rev. Lett. **119**, 223601 (2107)

[3] D. Hagenmüller, S. Schütz, J. Schachenmayer, C. Genes, and G. Pupillo, Phys. Rev. B **97**, 205303 (2018)

Talk 4

Tba

Jonathan Simon[1]

[1] *University of Chicago, IL 60637 USA*

Talk 5

Quantum many-body dynamics of driven-dissipative Rydberg gases

Hendrik Weimer[1, *]

[1] *Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover, Germany*

Ultracold Rydberg atoms provide an ideal testbed for study the interplay between strong coherent interactions and dissipative processes, a subject that has recently seen great attention following the discovery of dissipative state engineering for tailored many-body quantum states. However, in contrast to their fully coherent counterparts, our insights into dissipative many-body dynamics are still in its infancy. I will present the first steps towards a deeper understanding of driven-dissipative Rydberg gases based on a recently developed variational principle [1] as well as numerical simulations based on tensor network operators [2]. Specifically, I will investigate phase transitions of the steady state, including the presence of a multicritical point that is triggered by the dissipation within the system [3].

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[1] H. Weimer, Phys. Rev. Lett. **114**, 040402 (2015).

[2] A. Kshetrimayum, H. Weimer, and R. Orús, Nature Commun. **8**, 1291 (2017).

[3] V. R. Overbeck, M. F. Maghrebi, A. V. Gorshkov, and H. Weimer, Phys. Rev. A **95**, 042133 (2017).

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Talk 6

Quantum Many-Body Dynamics in Strongly Interacting Atom Arrays

Ahmed Omran,[1,*] Hannes Bernien,[1] Alexander Keesling,[1] Harry Levine,[1] Hannes Pichler,[1,2] Soonwon Choi,[1] Manuel Endres,[3] Markus Greiner,[1] Vladan Vuletić,[4] and Mikhail D. Lukin[1]

[1]*Department of Physics, Harvard University, Cambridge, MA 02138, USA*

[2]*ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA*

[3]*Division of Physics, Mathematics and Astronomy, California Institute of Technology, Pasadena, CA 91125, USA*

[4]*Department of Physics and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

The realization and control of large-scale quantum systems is an exciting frontier of modern physical science. Using a novel cold atom platform, we trap single neutral atoms in an array of optical tweezers, and use real-time feedback to prepare defect-free chains of tens of atoms in one dimension with a high fidelity and repetition rate [1]. Excitation of the atoms to Rydberg states enables strong and tunable van der Waals interactions over long distances, which allows for engineering an Ising-type Hamiltonian with non-trivial spatial correlations between Rydberg atoms.

I will talk about our experiments where we employ adiabatic transitions into crystalline states of Rydberg atoms to study the system properties close to a phase transition [2] and uncover universal scaling laws associated with different broken symmetries. Our platform allows for the simulation of quantum models that are classically intractable, the study of many-body dynamics out of equilibrium and generation of large-scale entanglement.

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[1] M. Endres *et al.*, Science **354**, 1024 (2016).

[2] H. Bernien *et al.*, Nature **551**, 579 (2017).

*Electronic address: `aomran@fas.harvard.edu`

Talk 7

Mixtures of ^{23}Na and ^{39}K: welcome to a new bosonic playground

A. Zenesini,[1,*] T. Schulze,[1] T. Hartmann,[1] K. Voges,[1] P. Gersema,[1] and S. Ospelkaus[1]

[1]*Institute for Quantum Optics, Leibniz University Hannover*

Mixtures of alkali atoms are multi-talented tools, which allow a wide variety of investigations, from mixture phenomena to molecules, from spectroscopy to chemistry. Sodium and potassium mixtures have recently attracted much interest due to the different isotope combinations and to the large dipole moment of the rovibrational electronic ground state molecules. The fermionic mixture has so far received major attention and Feshbach spectroscopy and molecular association have been successfully performed [1–3].

We focus our effort on the ^{23}Na^{39}K bosonic mixture, a still overlooked combination. We first demonstrate perform sympathetic cooling of potassium in a bath of sodium atoms both in magnetic and optical dipole trap down to dual species Bose-Einstein condensation [4]. Feshbach resonance spectroscopy in different spin mixtures reveals several resonances previously only theoretically predicted.

In this talk, I will present our results on ^{23}Na^{39}K collisional properties and the future directions including dipolar molecules and the investigation of beyond mean-field effects in degenerate mixtures [5].

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[1] Park et al, Phys. Rev. A 85, 051602(R) (2015)
[2] Zhu et al, Phys. Rev. A 96, 062705 (2017)
[3] Seesselberg et al, Phys. Rev. A 97, 013405 (2018)
[4] Schulze et al, Phys. Rev. A 97, 023623 (2018)
[5] Petrov, Phys. Rev. Lett. 115, 155302 (2015)

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Talk 8

Quantum Engineering of a Low-Entropy Sample of Molecules

Andreas Schindewolf
University of Innsbruck, Austria

Quantum many-body systems with long-range dipolar interaction are currently of immense interest in the theory and experiment community. Until recently, experimental realization with dipolar molecules was unfeasible due to high sample entropy. We present a novel method to prepare low-entropy samples of molecules as an ideal starting point for such experiments [1].

Starting from two spatially separated BECs, we form Rb-Cs precursor pairs by overlapping a Cs Mott insulator with superfluid Rb in an optical lattice. For this purpose, the Rb-Cs interaction is nulled at a Feshbach resonance's zero crossing. After the Rb atoms are localized by further enhancing the lattice depth, the paired atoms are associated to Feshbach molecules by means of the aforementioned Feshbach resonance. With this method we produce a low-entropy molecular sample with a filling fraction exceeding 30

Combining the method with a STIRAP technique to produce dipolar ground-state molecules, which we already realized with 90% efficiency [2], we will be able to address experiments in the context of dipolar many-body physics.

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[1] Phys. Rev. Lett. 118, 073201 (2017)
[2] Phys. Rev. Lett. 113, 205301 (2014)

Talk 9

Microwave shielding of ultracold dipolar molecules

Goulven Quéméner*

Laboratoire Aimé Cotton, CNRS, Université Paris-Sud,

ENS Paris-Saclay, Université Paris-Saclay, 91405 Orsay, France

Ultracold dipolar molecules are excellent candidates for engineering applications dealing with quantum technologies such as quantum simulation, quantum information, precision measurements and ultracold controlled chemistry [1, 2]. Therefore a lot of effort is devoted nowadays to produce ground state ultracold molecules in high densities [3] as well as to understand their properties [4]. One of a main goal is to create a quantum degenerate gas of dipolar molecules such as a Bose–Einstein condensate [5] or a degenerate Fermi gas [6]. This is for now a major missing step for ultracold molecules.

Unfortunatelly, when the molecules start to collide, whether they are chemically reactive [7] or not [8], a lot of molecules are lost in the process. Hoping for a long-lived quantum degenerate gas is then compromised unless to shield the molecules from collisional losses. This can be achieved by using a static electric field [9] but also by using microwaves [10].

I will show results for ultracold collisions of NaRb + NaRb in a microwave field and I will present how one can suppress the collisional losses of molecules as a function of the detuning, intensity and polarization of the field. This might be a necessary requirement for successful evaporative cooling to take place and for reaching quantum degeneracy.

I acknowledge the financial support of the FEW2MANY-SHIELD project (grant # ANR-17-CE30-0015) and the COPOMOL project (grant # ANR-13-IS04-0004-01) from Agence Nationale de la Recherche.

[1] L. D. Carr, D. DeMille, R. V. Krems and Jun Ye, New J. Phys. 11, 055049 (2009)

[2] J. L. Bohn, A. M. Rey, and J. Ye, Science 357, 1002 (2017)

[3] K.-K. Ni, S. Ospelkaus, M. H. G. de Miranda, A. Pe'er, B. Neyenhuis, J. J. Zirbel, S. Kotochigova, P. S. Julienne, D. S. Jin, J. Ye, Science 322, 231 (2008)

*Electronic address: goulven.quemener@u-psud.fr

[4] G. Quéméner and P. S. Julienne, Chem. Rev. 112, 4949 (2012)

[5] E. Cornell, C. Wieman, Rev. Mod. Phys.74, 875 (2002); W. Ketterle, Rev. Mod. Phys. 74, 1131 (2002)

[6] B. DeMarco, D. Jin, Science 285, 1703 (1999)

[7] S. Ospelkaus, K.-K Ni, D. Wang, M. H. G. de Miranda, B. Neyenhuis, G. Quéméner, P. S. Julienne, J. L. Bohn, D. S. Jin, J. Ye, Science 327, 853 (2010)

[8] X. Ye, M. Guo, M. L. González-Martínez, G. Quéméner, D. Wang, Sci. Adv. 4, aaq0083 (2018)

[9] M. L. González-Martínez, J. L. Bohn, G. Quéméner, Phys. Rev. A 96, 032718 (2017)

[10] A. Micheli, G. Pupillo, H. P. Büchler, P. Zoller, Phys. Rev. A 76, 043604 (2007)

Talk 10

Dipolar collisions of ultracold NaRb molecules

Dajun Wang

The Chinese University of Hong Kong, Hong Kong, China

In this talk, I will report our recent work on collisions of ultracold absolute ground-state $^{23}Na^{87}Rb$. Our studies are enabled by the capability of complete control on the internal states, including vibration, rotation, and hyperfine levels. Several results, including the inelastic collisions with different chemical reactivity and with and without the induced dipole-dipole interaction, will be discussed.

Talk 11

On the parabolicity of dipolar exciton traps

Alexander Holleitner
Walter Schottky Institut and Physics Department,
Technical University Munich, 85748 Garching, Germany

We present optical spectroscopy studies of dipolar exciton ensembles to explore the many-body phase diagram and transitions of such interacting bosonic particles. Photogenerated excitons coexisting with a 2D hole system are confined in very clean GaAs double quantum well structures and electrostatically trapped by local gate electrodes. We find, that the common approach of electrostatic trap geometries gives rise to an in-plane imbalance of charge carriers, which results in parabolic confinement potentials for the excitons. In photoluminescence spectra, we identify the emission of radiative recombination of both neutral indirect excitons and charged trions. We find that the charge imbalance in the excitonic ensemble strongly influences the radiative life times of both neutral and charged excitons, which cannot be explained by established theoretical models. Our findings shine new light on the ongoing efforts on the exploration of experimental signatures for "dark" and "gray" excitonic condensates.

We would like to thank S. Dietl, L. Sigl, L. Sponfeldner, G. Gardner, M. Manfra, and U. Wurstbauer for a very fruitful cooperation and the excellence cluster "Nanosystems Initiative Munich" NIM for financial support.

Talk 12

Non-equilibrium absorbing state phase transitions in discrete-time quantum dynamics on Rydberg quantum simulators

Igor Lesanovsky

The University of Nottingham, UK

I will present recent results on non-equilibrium processes taking place in discrete time on a two dimensional lattice system. This study is inspired by recent experimental progress in the realization of Rydberg lattice quantum simulators, which - in a rather natural way - permit the realization of conditional quantum gates underlying a discrete-time quantum evolution via quantum maps. I will consider a map which is constructed such that the reduced state at each time step is separable. In this case it can be shown that for long times the reduced state becomes stationary and displays a continuous phase transition in the density of excited spins. This phenomenon can be understood through a connection to the so-called Domany-Kinzel cellular automaton, which implements a classical non-equilibrium process that features a transition to an absorbing state. Near the transition density-density correlations become long-ranged, but interestingly the same is the case for quantum correlations despite the separability of the stationary state. Quantum correlations are quantified through the local quantum uncertainty and I show that in some cases they may be determined experimentally solely by measuring expectation values of classical observables.

Talk 13

Rydberg nonlinear optics with structural slow-light

Ohr Lahad[1] and Ofer Firstenberg[1,*]

[1]*Department of Physics of Complex Systems, Weizmann Institute of Science, Israel.*

Optical modulation of a finite medium can form an effective cavity that strengthens optical nonlinearities. We study the integration of these optically-induced cavities with a photonic quantum gate based on Rydberg blockade. We calculate the corresponding finesse and gate infidelity, establishing that the conventional limits imposed by the blockade optical depth are mitigated in long media [1]. The induced cavities delay the signal pulse via 'structural' slow light, as opposed to 'material' slow light conventionally used with Rydberg blockade. While the latter maintains the amplitude of the incoming signal, the former increases it in the medium.

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[1] O. Lahad and O. Firstenberg, Phys. Rev. Lett. **119**, 113601 (2017).

*Electronic address: `ofer.firstenberg@weizmann.ac.il`

Talk 14

Experiments with dipolar Bose-Einstein condensates: quantum droplets, self-organization and superfluidity

T. Pfau,[1] R. Wenzel,[1] F. Boettcher,[1] J.-N. Schmidt,[1] M. Eisenmann,[1]
M. Isoard,[1] S. Stringari,[2] T. Langen,[1] and I. Ferrier-Barbut[1]

[1] *5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany*

[2] *INO-CNR BEC Center and Dipartimento di Fisica, University of Trento, 38123 Povo, Italy*

We present a series of recent results in the study of dipolar dysprosium quantum gases.

Firstly, we study self-organized structure formation in these gases, which is similar to the Rosensweig instability in classical ferrofluids [1]. The corresponding phase-transition is characterized by the formation of self-bound droplets that are stabilized by beyond mean-field effects [2]. While the ground state of the system in 3D is a single droplet, we find theoretically that under strong anisotropic confinement the ground state becomes a striped state that consists of multiple droplets [3]. Experimentally we show that such self-organized stripes can indeed be generated, likely in a metastable excited state. We outline prospects to experimentally reach a phase coherent supersolid ground state.

Secondly, we report on the observation of the scissors mode of a single self-bound droplet [4]. The existence of this mode is due to the breaking of the rotational symmetry by the dipole-dipole interaction, which is fixed along an external homogeneous magnetic field. By modulating the orientation of this magnetic field, we excite the scissors mode and observe clear signatures of its non-linear coupling to other low frequency modes (see Figure 1).

Finally, we study the superfluid properties of a dipolar BEC [5, 6]. By moving an attractive laser beam through the condensate we observe an anisotropic critical velocity for the breakdown of dissipationless flow, which, in the spirit of the Landau criterion, can directly be connected to the anisotropy of the underlying dipolar excitation spectrum. Our observations are in excellent agreement with simulations based on the Gross-Pitaevskii equation and highlight the effect of dipolar interactions on macroscopic transport properties.

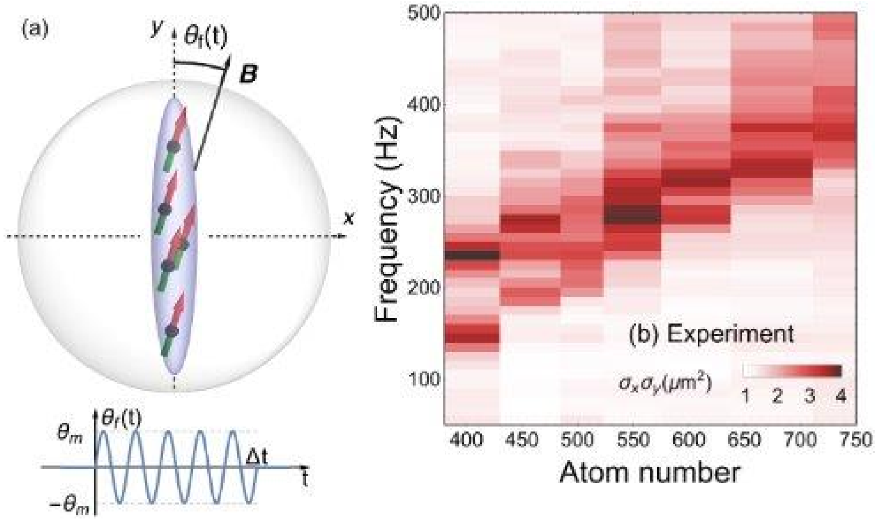

FIG. 1: (a) Experimental method to excite the scissors mode of a self-bound quantum droplet. The droplet is held in a cylindrically symmetric trap (around z) and the orientation of the field is modulated around its mean value along y for Δt at variable frequency. (b) Experimental response measured as a growth in the visible size of the droplet as a function of atom number and modulation frequency [4].

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Talk 15

Dipolar quantum gases of ultracold Erbium atoms: latest news from Innsbruck

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Discovered in liquid helium about 80 years ago, superfluidity is a counterintuitive phenomenon, in which quantum physics and particle-wave duality manifest at the macroscopic level. Since then, it has yielded many advances in understanding quantum matter, yet leaving mysterious some of its features. A hallmark of superfluidity is the existence of so-called "quasi-particles", i.e. elementary excitations dressed by interactions. Laudau predicted two type of quasi-particles. The first ones are the phonon modes, the well-known long-wavelength sound-wave quanta. The second ones, much more bizarre and intriguing, are massive quasi-particles named rotons. They have large momenta, and, contrarily to the common (quasi)particles for which the energy increases with the momentum, the roton dispersion relation exhibits a minimum at a finite momentum, called roton momentum. This unusual behavior expresses the tendency of the fluids to build up short-wavelength density modulation in space, precursor of a crystallization instability. In 2003, theoreticians suggested that a similar rotonic excitation might also occur in dipolar Bose-Einstein condensates because of the special properties of the long-rang and anisotropic dipole-dipole interaction. We here report on the first observation of roton quasiparticles in a dipolar gas of high magnetic Er atoms.

Talk 16

Disordered models with power-law hopping

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I will review some of our recent works on disordered models with power-law hops. I will start with a brief discussion on polar molecules pinned in an optical lattice. For imperfect lattice fillings, dipole-induced exchange of rotational states results in an effective disorder model for spin-like excitations, characterized by the presence of dominant multifractal states in three dimensional lattices [1]. I will then discuss one-dimensional systems with general power law hops, $1/r^a$, showing that algebraic localization occurs both for short-range ($a > 1$) and, more remarkably, for long-range ($a < 1$) hops [2]. Moreover, there is a surprising duality between the localization properties of long- and short-range models. In the final part I will comment about quasi-disordered, Aubry-André (AA), models with power-law hops [3]. Whereas in the standard AA model (infinite a) the whole eigenstate spectrum transitions from extended to localized at a critical quasi-disorder strength, at finite power a the spectrum may present a mobility edge. Moreover, a hierarchy of phases appears characterized by a transition of whole sections of the spectrum from extended to either localized (for $a > 1$) or multifractal (for $a < 1$). I will discuss in detail the corresponding phase diagram.

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Talk 17

Ultra cold fermionic NaK molecules with more than 10 ms rotational coherence and dipolar interaction

C. Gohle,[1] F. Seeßelberg,[1] R. Bause,[1] S. Eustice,[1]
M. Li,[2] S. Kotochigova,[2] I. Bloch,[3,1] and X.-Y. Luo[1]

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Since ultracold molecules are plagued by poorly understood two body losses, which limit their bulk life time, it can be useful to freeze molecular motion with a deep optical lattice potential. In this case, a many-body system with long range interaction needs to be realised with internal states. For molecules, one obvious choice for these internal states are superpositions of rotational energy eigenstates as these exhibit a large oscillating electric dipole moment, which mediates the long range interaction.

Simultaneously, due to their dipole moment, such states are also strongly affected by the external optical trapping potential of the lattice. Therefore, trapping fields need to be engineered such that the rotational polarisability (i.e. the dependence of the rotational frequency on the trapping light field intensity) becomes much smaller than the interaction energy between two molecules in the lattice. A rotational coherence time of 1.4 ms was demonstrated [1] by cancelling the rotational polarisability to first order by choosing an appropriate angle between the rotation axis and the trap field polarisation. The coherence time is limited by higher order terms in the stark shift due to a strong coupling of the rotation to the nuclear spins.

Following [2], we demonstrate how this coupling can be reduced by a few orders of magnitude by applying a small homogenous static electric field. In a 1D optical lattice we thereby demonstrate a rotational coherence time of up to 9.2 ms in a Ramsey experiment and reach over 10 ms coherence time by simple spin echo techniques. In addition, we demonstrate a clear density dependence of the observed coherence, indicating that the coherence time is in fact limited by dipolar interactions.

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Our findings pave the way towards observation of quantum phases of matter with strong long range interactions.

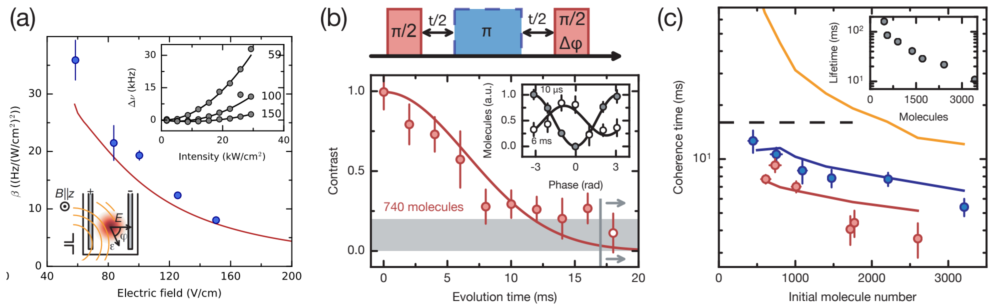

FIG. 1: Realising rotational coherence (a) dependence of the rotational hyperpolarisability on external DC field and rotational frequency as a function of light intensity from which the hyperpolarisability is extracted (inset). (b) Ramsey contrast of the rotational transition $J = 0 \rightarrow J = 1, m_J = 0$ as a function of hold time and example Ramsey fringes (inset). (c) Coherence time as a function of molecule number for Ramsey (red) and spin echo (blue) pulse sequences. Lines are MACE [3] simulation results. The inset shows 1/e lifetime of the mixture as a function of initial molecule number.

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Talk 18

An ultracold mixture of ^{6}Li and ^{133}Cs atoms

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We present our recent experimental investigations of few- and many-body physics with an ultracold mixture of fermionic ^{6}Li and bosonic ^{133}Cs atoms. By high-resolution Feshbach spectroscopy we precisely map out the two-body interaction at different magnetic fields. Due to the large mass ratio of our mixture we have observed successively three Efimov states near the s-wave Feshbach resonances and the role of intraspecies interaction in the heteronuclear Efimov scenario was investigated [1]. A triplet substructure is observed in the p-wave resonances instead of the well-know doublet ones [2]. The additional splitting is attributed to the spin-rotation interaction. Experimental efforts towards the study of many-body polaron physics and the creation of ground state polar ^{6}Li^{133}Cs molecules will be discussed.

* Work done in collaboration with B. Zhu, B. Tran, M. Gerken, E. Lippi, S. Häfner, M. Neiczer, and L. Klaus.

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Talk 19

Coherent control of ultracold ground-state $^{87}Rb^{133}Cs$ molecules in an optical trap

Simon L. Cornish,[1] Phil Gregory,[1] Jacob Blackmore,[1]
Rahul Sawant,[1] Jeremy M. Hutson,[1] and Jesus Aldegunde[2]
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The formation of ultracold heteronuclear molecules possessing long-range dipole-dipole interactions opens up many exciting areas of research spanning quantum computation, quantum simulation and fundamental studies of quantum matter. Long-lived, trapped samples of molecules with full quantum control of the molecular internal state are crucial to many of these applications. Here we demonstrate coherent microwave control of the rotational and hyperfine state of ultracold, chemically stable $^{87}Rb^{133}Cs$ molecules. We create up to 4000 molecules in the rovibrational and hyperfine ground state at a temperature of $\simeq 1.2\mu K$ and a peak density of $\simeq 10^{11}\,cm^{-3}$ using magnetoassociation on a Feshbach resonance [1] followed by optical transfer using stimulated Raman adiabatic passage [2]. We then use precision microwave spectroscopy of the rotational transition to probe the rich hyperfine structure of the molecule and exploit coherent Rabi oscillations to transfer the total population of molecules between hyperfine levels [3]. We subsequently investigate the AC Stark effect due to the trapping light in low-lying rotational levels and reveal a rich energy structure with many avoided crossings (see Fig.) between hyperfine states [4]. Understanding this structure allows us to trap the molecules in a range of internal states. We study the collisional lifetimes of the molecules in such traps for various rotational and hyperfine states, shedding light on the 'sticky collision' issue [5]. Finally, we describe our future plans for imaging and addressing of single molecules in ordered arrays as a basis for quantum simulation.

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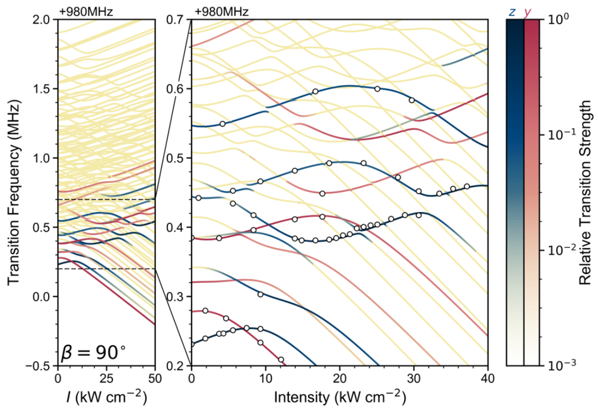

FIG. 1: AC Stark shift of the microwave transition between $N = 0, M_F = +5$ and $N = 1$ in ^{87}Rb^{133}Cs molecules [4].

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Talk 20

Interactions in ultracold Fermi-Bose mixtures and ultracold molecules

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Massachusetts Institute of Technology, USA

Talk 21

Quantum Logic Spectroscopy of a Single Molecular Ion

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Precision spectroscopy is a driving force for the development of our physical understanding. In particular laser cooling and manipulation has led to an advancement in precision spectroscopy. However, only few atomic and molecular species offer suitable transitions for laser cooling, limiting the variety of accessible species. This restriction can be overcome in trapped ion systems through quantum logic spectroscopy. Coherent laser manipulation, originally developed in the context of quantum information processing, allows to combine the special spectroscopic properties of one ion species (spectroscopy ion) with the excellent control over another species (logic or cooling ion) [1].

We experimentally demonstrate how the internal state of a single $^{24}MgH^{+}$ molecular ion can be detected through coupling to a $^{25}Mg^{+}$ atomic ion. Starting from the ground state of motion of a joint motional mode, a molecular state-selective optical dipole force changes the motional state only if the molecule is in a specific rovibrational state. The change of the motional state is efficiently detected on the atomic ion. This way, we observe black body radiation-driven quantum jumps between rotational states in the molecule. The detuning-dependence of the coupling strength of the optical dipole force allows us to perform spectroscopy on a specific electronic transition in the molecule [2]. This non-destructive detection technique represents a first step towards extending the exquisite control achieved over selected atomic species to much more complex species, such as molecular ions. Possible applications are model-independent probes for a possible variation of the electron-to-proton mass ratio [3], tests of parity violation using chiral molecules [4], or measurements of the electric dipole moment of the electron [5].

Residual off-resonant excitation followed by ro-vibrational diffusion in the molecular ion limits the efficiency of internal state detection. We show how excited motional Fock states enhance the detection sensitivity of such small forces beyond the classical limit and thus can in principle reduce the required interaction between the optical dipole force and the molecule. In contrast to schemes that rely on e.g. squeezing, Fock state metrology requires no phase coherence between

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the interaction creating the state and the signal to be measured. We demonstrate this phase independence by performing measurements of displacement and trapping frequency of a single ion with sensitivities below the classical limits in separate experiments, but using the same quantum state.

We acknowledge support from the DFG through CRC 1227 (DQ-*mat*), projects A06 and B05, and the state of Lower Saxony, Hannover, Germany.

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Talk 22

Probing cold long-range collisions within an ion trap

Johannes Hecker Denschlag[1]

[1] *University of Ulm, Germany*

We report on experiments where we study cold collisions between neutral Rb atoms and between Rb atoms with Rb ions. During the collision, a Rb atom of the collision pair is optically excited towards a Rydberg state with the main quantum number n between $n = 14$ and $n = 30$. We observe a variety of different resonances which are linked to atomic and diatomic Rydberg states, some of which are linked to butterfly states. When these Rydberg states decay via ionization, we trap the resulting ion in our trap and detect it with unit probability. The resonance spectra change markedly with the quantum number n. We present first interpretations of our experimental findings.

Talk 23

Information propagation and entanglement generation with long-range interactions

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[1] *Joint Quantum Institute and Joint Center for Quantum Information and Computer Science, NIST/University of Maryland, College Park, MD 20742, USA*

Atomic, molecular, and optical systems often exhibit long-range interactions, which decay with distance r as a power law $1/r^{\alpha}$. In this talk, we will derive bounds on how quickly information can propagate and entanglement can be generated in such quantum systems. We will also present protocols that attempt to saturate these bounds. Finally, we will touch on numerous applications of these bounds and protocols, ranging from bounding and enhancing the speed of quantum computers to illuminating the properties of quantum phases and phase transitions in and out of equilibrium.

Talk 24

Emergent universal dynamics by dipolar exchange interaction for an atomic cloud coupled to an optical wave-guide

Hanspeter Büchler[1]

[1] *University of Stuttgart, Germany*

We study the dynamics of a single collective excitation in a cold ensemble of atoms coupled to a one-dimensional wave-guide. The coupling between the atoms and the photonic modes provides a coherent and a dissipative dynamics for this collective excitation. While the dissipative part accounts for the collectively enhanced and directed emission of photons, we find a remarkable universal dynamics for increasing atom numbers exhibiting several revivals under the coherent part. While this phenomenon provides a limit on the intrinsic dephasing for such a collective excitation, a setup is presented, where this remarkable universal dynamics can be explored.

Talk 25

Coupling two order parameters in a quantum gas

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[2]*Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA*

Intertwined order is a controversially discussed concept in condensed matter physics. Though its microscopic origin is often unknow, it implies the simultaneous existence of independent order parameters and can allow materials to feature multiple properties. For example, ferroelectric and ferromagnetic orders can coexist in multiferroic materials leading to enhanced functionalities, or in high-temperature superconductors intertwining between charge- and spin-order can form superconducting states at high-transition temperatures.

I will report on our recent experimental realization of an intertwined ordered phase in a quantum gas. Our system is realized by a superfluid Bose-Einstein condensate (BEC) that can undergo self-organization phase transitions to the modes of two crossed optical cavities. The BEC is illuminated with a transverse pump laser beam whose detuning from atomic resonance can be changed to explore different regimes of interaction .

Far away from the atomic resonance of the D2 line of Rb87 we realize a supersolid phase of matter by symmetry enhancement of the composite order parameter to a U(1) symmetry [1]. Here we observe the simultaneous existence of a Higgs and Goldstone mode [2]. Approaching the atomic resonance this symmetry breaks down to a Z2xZ2, and we observe the emergence of a broad intertwined phase arising from the coupling of the individual order parameters. Intriguingly, we can induce coexistence of the orders even below the critical point of the individual ones. We explain our results with a microscopic Hamiltonian model which is also mapped to a mean-field free energy reproducing the phenomenology of the phases [3].

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Talk 26

Superfluid Phases of Dipolar Fermions in Optical Lattices

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I describe the emergence of superfluid phases of ultracold dipolar fermions in optical lattices for two-dimensional systems. Considering the many-body screening of dipolar interactions at intermediate and larger filling factors, I show that several superfluid phases with distinct pairing symmetries naturally arise in the singlet channel: local s-wave (sl), extended s-wave (se), d-wave (d) or time-reversal-symmetry breaking $(\mathrm{sl} + \mathrm{se} \pm i\mathrm{d})$-wave. I discuss the temperature versus filling factor phase diagram and show that d-wave pairing is favored near half-filling, that $(\mathrm{sl} + \mathrm{se})$-wave is favored near zero or full filling, and that time-reversal-breaking $(\mathrm{sl} + \mathrm{se} \pm i\mathrm{d})$-wave is favored in between. The inclusion of a harmonic trap reveals that a sequence of phases can coexist in the cloud depending on the filling factor at the center of the trap. Most notably in the spatial region where the $(\mathrm{sl} + \mathrm{se} \pm i\mathrm{d})$-wave superfluid occurs, spontaneous currents are generated, and may be detected using velocity sensitive Bragg spectroscopy.

Talk 27

Quantum-enhanced sensing using non-classical spin states of a highly magnetic atom

Thomas Chalopin,[1] Chayma Bouazza,[1] Alexandre Evrard,[1] Vasiliy Makhalov,[1] Davide Dreon,[1,*] Adam Barker,[2] Leonid A. Sidorenkov,[1,†] Jean Dalibard,[1] Raphael Lopes,[1] and Sylvain Nascimbene[1]

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Coherent superposition states of a mesoscopic quantum object play a major role in our understanding of the quantum to classical boundary, as well as in quantum-enhanced metrology and computing. However, their practical realization and manipulation remains challenging, requiring a high degree of control of the system and its coupling to the environment. In this talk, we present a recent experimental work performed with dysprosium atomic gases, where we manipulate the mesoscopic electronic spin $J = 8$ of individual atoms to create coherent superpositions between spin states of opposite orientation. We drive coherent spin states to quantum superpositions using non-linear light-spin interactions, observing a series of collapses and revivals of quantum coherence. These states feature highly non-classical behavior, with a sensitivity to magnetic fields enhanced by a factor 13.9(1.1) compared to coherent spin states – close to the Heisenberg limit $2J = 16$ – and an intrinsic fragility to environmental noise.

We also briefly discuss other recent experiments on the measurement of the dynamic electric polarizability of Dysprosium in the excited electronic state of the laser cooling transition at 626 nm. We show the existence of a magic light polarization for optical dipole traps at 1070 nm, around which Doppler cooling works efficiently for optically trapped gases [1].

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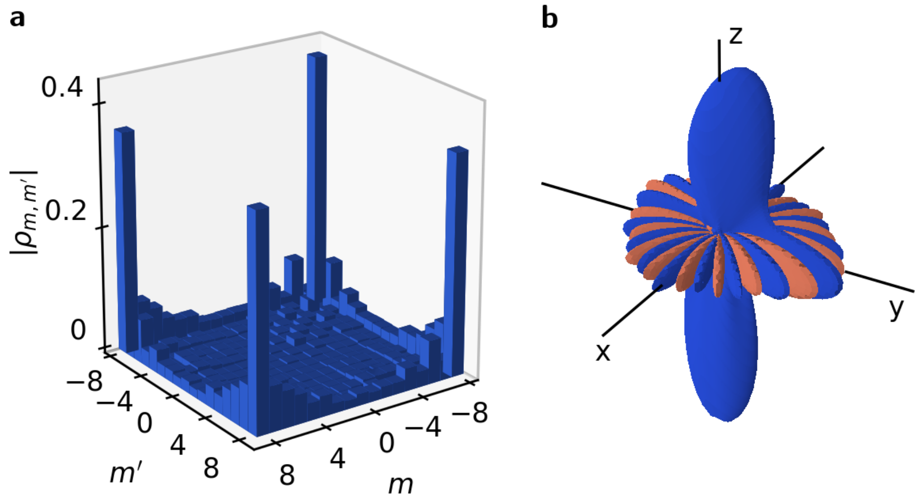

FIG. 1. Density matrix of the coherent superposition state reached in our experiment, as reconstructed from a tomography experiment (**a**: modulus of the density matrix coefficients. **b**: Angular Wigner function representation, with positive lobes along the north and south pole directions and interferences on the equator.

Talk 28

Orbital quantum magnetism of strongly interacting magnetic lanthanide atoms

Svetlana Kotochigova

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Magnetic moments of atoms and molecules originate from their electrons intrinsic spin as well as their orbital angular momentum. In solids the orbital component of the magnetic dipole moment revolutionized spintronics research and led to a novel branch of electronics, orbitronics. This orbital anisotropy is the crucial element in various scientific applications and magnetic technology. Inspired by the role of orbital anisotropy in magnetic solids and to deepen our knowledge of quantum magnetism, we study orbital anisotropy at the elementary level by capturing the behavior of strongly-interacting magnetic Erbium atoms in an optical lattice site. In particular, we simulate the time-dependent multi-channel spin-exchange dynamics of pairs of interacting Erbium atoms in sites of a deep three-dimensional optical lattice with negligible atomic tunneling between lattice sites. In our model atom pairs in different lattice sites are coupled by magnetic dipole-dipole interactions leading to dephasing of the intra-site spin oscillations. We also explore fractal dimensions of weakly-bound Dysprosium lanthanide molecules in an optical trap under the influennce of an external magnetic field. Our exact close-coupling simulations reveal a dynamic phase transition from partially localized states to totally delocalized states and universality in its distribution by increasing the magnetic field strength to only a hundred Gauss (or 10 mT). Finally, we prove the existence of nonergodic delocalized phase in the system and explained the violation of ergodicity by strong coupling between near-threshold molecular states and the nearby continuum.

Talk 29

EPR and spatial-mode entanglement in spinor Bose-Einstein condensates

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Spin changing collisions in alkaline Bose-Einstein condensates can be employed to generate highly entangled atomic quantum states. Here, we will report on the generation of two classes of entangled states. Firstly, we demonstrate the generation of two-mode squeezed vacuum states and record their characteristic quadrature correlations by atomic homodyning. We prove that the correlations fulfill Reid's criterion for continuous-variable Einstein-Podolsky-Rosen entanglement. The homodyne measurements allow for a full tomographic reconstruction, yielding a two-mode squeezed state with a 78% fidelity. The created state can be directly applied to atom interferometry, as is exemplified by an atomic clock measurement beyond the Standard Quantum Limit.

Secondly, we demonstrate entanglement between two spatially separated atomic modes. The entangled state is obtained by spatially splitting a Twin Fock state of indistinguishable atoms. The method opens a path to exploit the recent success in the creation of many-particle entanglement in ultracold atoms for the field of quantum information, where individually addressable subsystems are required. Finally, we will show how the measurement protocol can be extended to perform a Bell test of quantum nonlocality.

Abstracts of the posters

Poster 1

Simulation of Quantum Chemistry problems using cold atoms

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Quantum simulation offers the long-standing goal of using a quantum systems to face questions that are hard to understand classically. While full-fledged quantum computers may be built in the distant future, the next generations will be limited in size and by the presence of errors [1]. An alternative way to address quantum many-body problems is analog quantum simulation, where a highly controllable quantum system mimics the interactions of the Hamiltonian one wants to investigate. In fact, analog quantum simulators based on atoms in optical lattices [2] have already performed some simulations of condensed matter physics problems that are out of reach of classical computers [3, 4]. All those problems are based on local or short-range interactions, and are ideally suited for the existing simulators. Problems in quantum chemistry, in contrast, require long-range Coulomb interactions, and thus, it is harder to realize whether analog simulation can help in that field.

Here, we propose an experimental setup to solve quantum chemistry problems using cold atoms trapped in state-dependent optical lattices. In the same way that virtual photons mediate electronic interactions in nature, Coulomb interactions are induced by a spin excitation in a Mott insulator with the same spacing as the fermionic lattice. We discuss the main sources of systematic deviations rising from the discretization of the Hilbert space and illustrate this method solving the molecular potential for a molecule of Hydrogen. While the setup is discrete and finite, we show that precise results can be obtained for simple real molecules with moderate lattice sizes, and that it can be scaled. Apart from the standard advantages of analog simulation over quantum computing regarding the required degree of control, the present scheme does not rely on a judicious choice of molecular orbitals, but rather directly operates in real space [5].

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Poster 2

Vortices in dipolar Bose-Einstein condensates

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Effects of dipole-dipole interaction can significantly modify properties of Bose-Einstein condensates, as demonstrated in the recent experiment [1], where the Rosensweig instability was observed in a quantum ferrofluid of a strongly dipolar BEC, leading to a formation of atomic droplets. Here we extend previous theoretical description of such a system that takes into account only correction of the ground-state energy [2, 3], and develop a full Bogoliubov-Popov theory, which also accounts for the condensate depletion. Using this approach, we study the generation of vortices and their properties in strongly dipolar ^{164}Dy BEC, in particular the dependence of the critical velocity of a moving obstacle to shed vortex dipoles. We also use extensive numerical simulations to consider if quantum droplets [1] can emerge in fast rotating BECs.

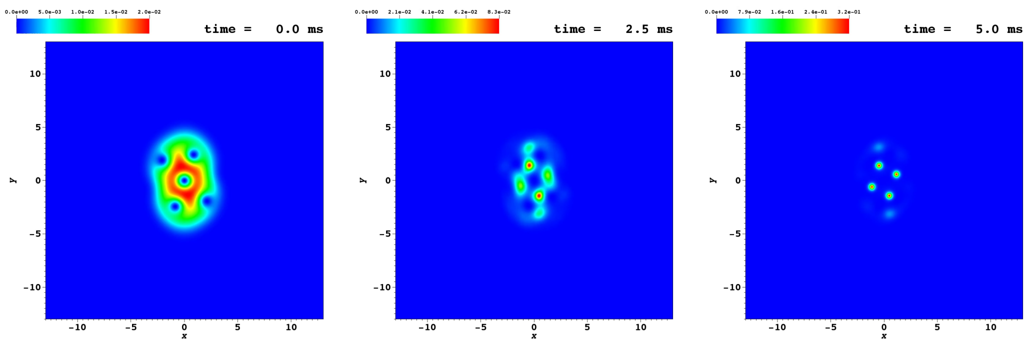

Fig. 1: Droplet formation in fast rotating dipolar BEC after a contact interaction quench.

[1] H. Kadau, et al., Nature **530**, 194 (2016).

[2] T. D. Lee, K. Huang, and C. N. Yang, Phys. Rev. **106**, 1135 (1957).

[3] A. R. P. Lima and A. Pelster, Phys. Rev. A **84**, 041604(R) (2011); Phys. Rev. A **86**, 063609 (2012).

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Poster 3

Interaction Induced Topological Superconductivity in a Dipolar Spin Lattice

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Poster 4

Quantum Ferrofluid Turbulence

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We study the elementary characteristics of turbulence in a quantum ferrofluid through the context of a dipolar Bose gas condensing from a highly non-equilibrium thermal state. Our simulations reveal that the dipolar interactions drive the emergence of polarized turbulence and density corrugations. The superfluid vortex lines and density fluctuations adopt a columnar or stratified configuration, depending on the sign of the dipolar interactions. When the interactions are dominantly dipolar, coherent vortex structures are formed, and quasi-classical quantum turbulence emerges through the quench. This system poses exciting prospects for realizing stratified quantum turbulence and new levels of generating and controlling turbulence using magnetic fields.

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Poster 5

2D Fermionic Dipoles at T = 0

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We analyse the ground state of a two-dimensional quantum system of fermionic dipoles in which all dipoles are polarized along the same direction in space. In our choice the dipole moments have X and Z spatial components. In this work,we use the diffusion Monte Carlo method that allows us to obtain ground state of the many body Schrödinger equation . We predict a phase transition from gas to solid at a critical density $nr_0^2 \sim 50$, which is five times lower than the one for the equivalent bosonic system. The existence of the stripe phase for hight polarization angles is also predicted and accurs at a lower density than in the bosonic case.

The aim of this work is to draw the phase diagram for the fermionic system: the inclusion of Fermi statistics makes the dipolar gas more respulsive, which is reflected in the appeareance of structure in the gas phase at lower densities than for the bosonic system (see figure 1). Whereas in the solid phase the inclusion of antisymetry do not give rise to a relevant change in the energy of the system. The net effect in the gas to solid transition is that the critical density gets dramatically reduce its value: especifically, for the isotropic case the transition occurs at $nr_0^2 = 50(10)$[3], compared to $nr_0^2 = 290(30)$[1] for the analogous bosonic system. Current work is on the determination of the borders of the stripe phase region of the phase diagram by studying both stability and structural properties.

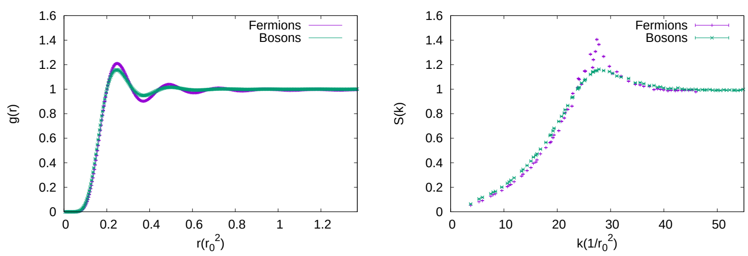

FIG. 1: Radial distribution function (up), and static structure factor (down) for the isotropic system at a density nr_0^2= 16 compared for the bosonic and the fermionic system.

[1] A. Macia, J. Boronat and F. Mazzanti, Phys. Rev. A **90**, 061601R (2014)

[2] R. Bombin, J. Boronat and F. Mazzanti, Phys. Rev. Lett. **119**, 250402 (2017)

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Poster 6

Towards lattice spin models with Rydberg-dressed atoms

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Rydberg-dressed atoms provide a versatile platform for engineering lattice spin models of interest for quantum simulation and quantum metrology. In our experiment, cesium atoms will be pinned in a blue-detuned two-dimensional optical lattice with a spacing dynamically variable over 1-5 µm. A 320 nm laser will off-resonantly couple ground-state atoms to nP Rydberg states with a single photon, enabling highly coherent and tunable interactions. The large interatomic spacings in our lattice and close optical access of our imaging system will facilitate single-spin-resolved imaging. We report progress on this apparatus, which will enable us to study frustrated magnetism, create states with metrological gain, and investigate quantum dynamics in lattices with tunable-range interactions.

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Poster 7

Dipolar quantum droplets and striped states

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The dipolar interaction allows for self-organized structure formation similar to the Rosensweig instability in classical ferrofluids. In our experiments with quantum gases of Dysprosium atoms, we observe a phase-transition between a gas and a liquid, characterized by the formation of self-bound droplets [1]. In contrast to theoretical mean field predictions the superfluid droplets did not collapse. We confirmed experimentally that this unexpected stability is due to beyond mean field quantum corrections of the Lee-Huang-Yang type. These droplets are 100 million times less dense than liquid helium droplets and open new perspectives as a truly isolated quantum system.

Under strong confinement in one dimension, we observe the formation of an array of stripes. We also study striped ground states theoretically and outline prospects to reach a phase coherent supersolid ground state [2].

In a further ongoing experiment we rotate the droplets by a spinning magnetic field and observe that they can be rotated faster than the transverse trapping frequency due to a surface tension counteracting the centrifugal force. We also observe the excitation of a scissors mode of the droplets [3].

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[1] M. Schmitt, M. Wenzel, F. Böttcher, I. Ferrier-Barbut, and T. Pfau, Nature **539**, 259 (2016)

[2] M. Wenzel, F. Böttcher, T. Langen, I. ferrier-Barbut, and T. Pfau, Phys. Rev. A **96**, 053630 (2017)

[3] I. Ferrier-Barbut, M. Wenzel, F. Böttcher, T. Langen, M. Isoard, S. Stringari, and T. Pfau, Phys. Rev. Lett. **120**, 160402 (2018)

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Poster 8

Few-body interactions in a cold Rydberg gas

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A gas of cold Rydberg atoms generally interacts through 2-body van der Waals interaction. When applying an electric field, it has long been observed that resonant dipole-dipole interactions can arise [1]. More recently we have demonstrated the possibility to find resonant processes involving 3 Rydberg atoms [2]. Although this experiment was performed with cesium atoms, we argued that similar 3-body interaction resonances should be observed in other atoms. It has now been observed by us in rubidium [3] with a small controlled number of atoms i = 2-5 as can be seen in figure 1.

This not only demonstrated the general nature of the process, but also the absence of signature of the three-body Förster resonances for exactly two interacting Rydberg atoms. As the observed three-body resonance appears at a different dc electric field with respect to the two-body resonance, it represents an effective three-body operator, which can be used to directly control the three-body interactions. This can be especially useful in quantum simulations and quantum information processing with neutral atoms in optical lattices.

This work was supported by the public Grant CYRAQS from Labex PALM (ANR-10-LABX-0039), the EU H2020 FET Proactive project RySQ (Grant No. 640378),the RFBR Grants No. 16-02-00383 and 17-02-00987, the Russian Science Foundation Grants No. 16-12-00028 (for laser excitation of Rydberg states) and 18-12-00313 (for theoretical analysis), the Siberian Branch of RAS and the Novosibirsk State University.

[1] K. A. Safinya *et al.*, Phys. Rev. Lett. **47**, 405 (1981).

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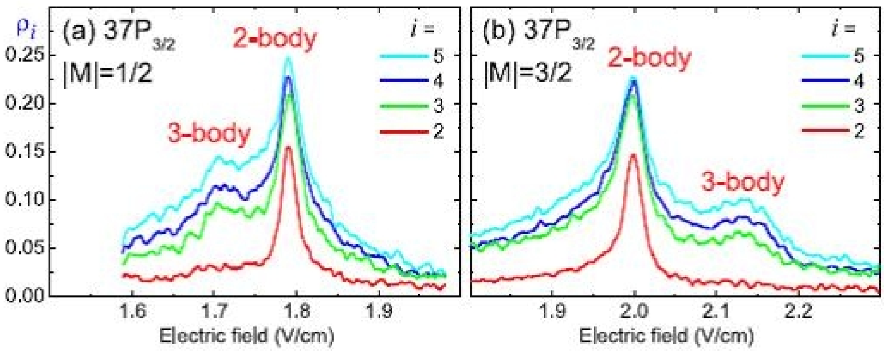

FIG. 1. Stark-tuned Förster resonance in Rb atoms observed for various numbers of atoms N=2-5: (a) atoms are in the initial state $37P_{3/2}(|M_J| = 1/2)$; (b) atoms are in the initial state $37P_{3/2}(|M_J| = 3/2)$. The main peaks are 2-body resonances, the additional peaks are 3-body resonances.

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[3] D. B. Tretyakov *et al.*, Phys. Rev. Lett. **119**, 173402 (2017).

Poster 9

Observation of the roton mode population in a dipolar quantum gas

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In my poster, I will present our experimental observation of the roton mode in a dipolar BEC of strongly magnetic erbium atoms. The roton mode denotes an elementary excitation of minimal energy at finite momentum, similar to the celebrated case of superfluid helium He-II, for which the roton mode was an essential key, brought by Lev landau in the early 1940's, to understand the mysterious behavior of the quantum fluid at that time [1]. It was then related by Richard Feynman to the strong correlations, resulting from the strong interactions occurring in the liquid. In contrast to He-II, the roton mode in a dipolar BEC does not require strong interactions, but arises from the long-range and anisotropic nature of the dipolar interactions, already at a mean-field level. First predicted in 2003 [2], it has remained elusive to observation. To investigate the roton mode in our experiment, we perform an interaction quench on an elongated BEC of 166Er atoms and observe the apparition of symmetric side peaks in the momentum distribution of the atomic cloud, when quenched below a threshold scattering length. We have probed the scaling of the momentum and the imaginary energy of the roton mode via a detailed study of the measured density distribution and a comparison with theory predictions from both an analytical model and extensive numerical simulations [3].

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[2] Santos, L., Shlyapnikov, G. V. & Lewenstein, M. Roton-maxon spectrum and stability of trapped dipolar Bose-Einstein condensates. *Phys. Rev. Lett.* **90**, 250403 (2003).

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Poster 10

Power-law localization in long-range hopping models with disorder

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The transport of excitations between pinned particles in many physical systems may be mapped to single-particle models with power-law hopping, $1/r^a$. For randomly spaced particles, these models present an effective peculiar disorder that leads to surprising localization properties. We show that in one-dimensional systems almost all eigenstates (except for a few states close to the ground state) are power-law localized for any value of $a > 0$. Moreover, we show that our model is an example of a new universality class of models with power-law hopping, characterized by a duality between systems with long-range hops ($a < 1$) and short-range hops ($a > 1$) in which the wave function amplitude falls off algebraically with the same power γ from the localization center.

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Poster 11

Ground state spectroscopy of ultracold dipolar ^{6}Li^{40}K molecules

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With the creation of dipolar molecules in their ro-vibrational ground state, a long-standing scientific goal has been achieved . In the ultracold quantum regime such molecules are a promising tool for the quantum simulation of a large class of many body effects and for quantum information processing , ultracold chemistry and mertrological applications. In our experiment, we use bosonic heteronuclear dimers of ^{6}Li and ^{40}K. Their deeply-bound ro-vibronic state possess a large permanent electric dipole moment of 3.6 Debye. This makes them a suitable candidate for investigating the plethora of effects originating from the long-range anisotropic dipole interaction.

Here we describe our two-photon spectroscopy scheme that recently enabled us to experimentally identify and address the diploar ground state of LiK. Our scheme differs from spectroscopic routes previously used for other alkali heteronuclear dimers, as only unperturbed molecular spin singlet states are involved and predominantly only one sole hyperfine state is addressed. As an important consequence this establishes an ideal three level system for the transfer by stimulated rapid adiabatic passage (STIRAP) to a single hyperfine component of the ground state.

We start from a sympathetically cooled, quantum-degenerate Fermi-Fermi mixture, and create weakly-bound ^{6}Li-^{40}K molecules via magnetic Feshbach association at 215.6 G in an optical dipole trap. We use the asymptotic bound state model (ABM) [1] to calculate the hyperfine composition of the Feshbach state and identify a spin singlet admixture of up to 52%. We then present data from our one-photon spectroscopic survey of the $B^1\Pi$ and $A^1\Sigma$ electronically excited states of the LiK* asymptote. A variety of new lines have been found and analyzed for the suitability as intermediate states for the transfer. In particular, we were able to address very deeply bound states of the $A^1\Sigma$ potential that offer a large overlap with the ground state at this inner turning point. Navigating a path written by the the available laser wavelengths, power and Franck-Condon overlap, we were first able to locate the $v = 3$ state by two-photon spectroscopy and Autler-Townes spectroscopy. Subsequently, the implementation of a new dye laser setup provided the necessary output power

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and wavelength tuning range for the discovery of the lower vibrational states $v = 2$ and $v = 1$ and eventually $v = 0$ (see Fig.1). We further present our efforts to coherently populate the ground state vie STIRAP, and to apply a static electric field to investigate the high ground state dipole moment of the ^{6}Li^{40}K mol

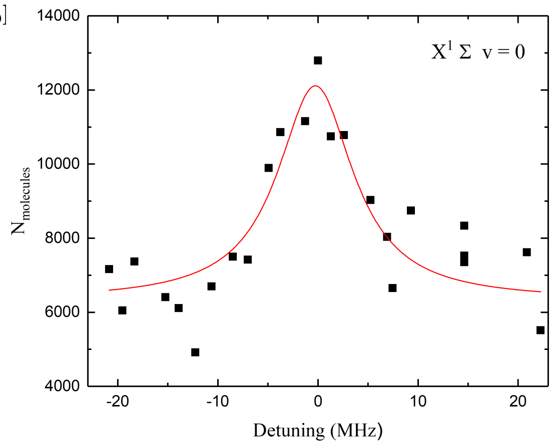

FIG. 1: Two-photon spectroscopy of the absolute electronic and ro-vibronic ground state $(X^1\Sigma, v = 0)$ of LiK.

[1] T. G. Tiecke, *et al.*, Phys. Rev. A, **82**, 042712 (2010).

Poster 12

Quantum Fluctuations in Quasi-One-Dimensional Dipolar Bose-Einstein Condensates and Bose-Bose mixtures

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Recent experiments have revealed that beyound-mean-field corrections are much more relevant in weakly-interacting dipolar condensates and mixtures of two different Bosons than in usual non-dipolar single-species systems. We show that in quasi-one-dimensional geometries quantum corrections in dipolar Condensates and Bose-Bose mixtures are strikingly different than in their three-dimensional cases. The energy correction of the condensates presents not only modified density dependencies, but it may even change from attractive to repulsive at a crtical density due to the surprising role played by the transversal directions. The anomalous quantum correctionss translates into a strongly modified physics for quantum-stabilized droplets.

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Poster 13

Quantum Zeno-based Detection and State Engineering of Ultracold Polar Molecules

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We present a toolbox for the controlled manipulation of ultracold polar molecules, consisting of detection of molecules, atom-molecule entanglement and engineering dissipative dynamics. Our setup is based on fast chemical reactions between molecules and atoms leading to a quantum zeno based collisional blockade in the system. We discuss the optimization of the relevant parameters as well as the consequences of residual imperfections.

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Poster 14

Long range interactions in time lattices

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Time crystals are many-body systems that, due to interactions between particles, are able to spontaneously self-organize their motion in a periodic way in time by analogy with the formation of crystalline structures in space in condensed matter physics.

In solid state physics properties of space crystals are often investigated with the help of external potentials that are spatially periodic and reflect various crystalline structures. Similar approach can be applied for time crystals because periodically driven systems constitute counterparts of spatially periodic systems but in the time domain. Wide class of condensed matter problems can be realized in the time domain if single-particle or many-body systems are resonantly driven. It opens up unexplored territory for investigation of condensed matter physics in time and for invention of novel "time devices" because time is our new ally. We propose [1] a way of creating time lattices similar to optical(space) lattices. In this new type of systems almost any long range interactions can be engineered in effective Hubbard or Bose-Hubbard types of Hamiltonians. This can be achieved by a proper periodic modulation of s-wave scattering length of atoms which are resonantly driven, for example, by a periodically oscillating atomic mirror .

[1] Giergiel, K., Miroszewski, A. & Sacha, K. 2018, Phys. Rev. Lett. , 120, 140401.

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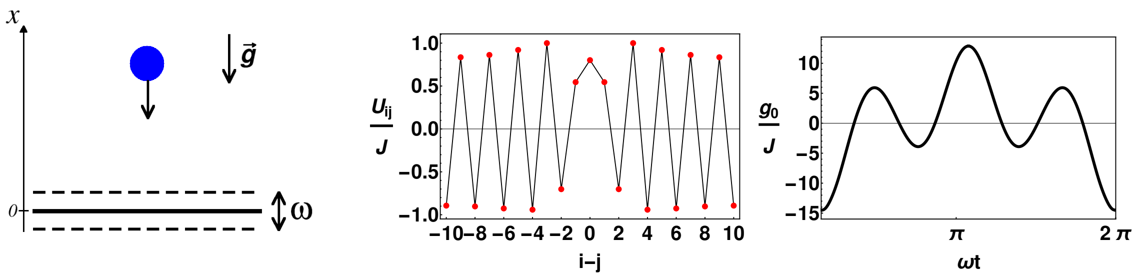

FIG. 1: Example of a system with exotic interactions: ultra-cold atoms bouncing on a harmonically oscillating mirror in a 1D model (left panel). The 20:1 resonance condition between mirror oscillations frequency and periodically moving atoms is fulfilled and the many-body system is described by the Bose-Hubbard Hamiltonian $\hat{H}_{\text{eff}} = -\frac{J}{2}\sum_{\langle i,j\rangle} \hat{a}_i^\dagger \hat{a}_j + \frac{1}{2}\sum_{i,j} U_{ij}\ \hat{a}_i^\dagger \hat{a}_j^\dagger \hat{a}_j \hat{a}_i$. In the middle panel we show the interaction coefficients U_{ij} corresponding to the periodically modulated scattering length $g_0(t)$ as presented in the right panel.

Poster 15

Bilayer system of dipolar bosons: few-body bound states

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Quantum Monte Carlo methods provide a powerful tool for predicting quantitatively the properties of many-body quantum system [1]. At the level of few-body physics, existence of bound-states (trimers, tetramers, etc.) for dipolar molecules in a bilayer is an open and controversial question. Anisotropy of the dipolar interaction (which can be attractive or repulsive) complicates the study but leads to rich physics [2]. The problem of two and three dipolar molecules can be solved analytically, the last one with more effort. However, as the number of dipoles is increased, the problem becomes essentially intractable using standard approaches. At this point Monte Carlo methods become highly competitive. We use Diffusion Monte Carlo method [3] to obtain the ground state energy and spatial distribution function of a bilayer system of dipolar bosons, where dipoles are oriented perpendicularly to the parallel planes. It is known that a dimer exists for *arbitrary* separation between layers [4]. For three and four dipoles, the bound state does not exist for small separation between the two layers. We find the critical value of the interlayer separation at which the trimer and tetramer appear. For the trimer, we have found that the dominant structure close to the critical separation is halo state, where two dipoles are close to each other while the third is far away. Five- and six-body bound states also exist (work in progress).

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Poster 16

Dimensional Crossover for the Beyond-Mean-Field Corrections in the Confined Weakly Interacting Bose Gas

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We investigate the beyond-mean-field corrections in a confined weakly interacting Bose gas at zero temperature. We start our study with a box with periodic boundary conditions. The transverse directions are tightly confined and we show that the system can exhibit three-dimensional as well as quasi-low-dimensional behavior. We are able to express the ground state energy for the 3D-2D and 3D-1D crossover in terms of well known functions. The correct inclusion of the beyond-mean-field terms naturally includes the confinement induced shift of the scattering length and we observe the occurrence of an effective three-body interaction due to quantum fluctuations. With this qualitative understanding in mind, we investigate the crossover in a harmonic trapping potential under the constraint, that the condensate remains in the lowest harmonic oscillator state as we are interested in the effect of the quantum fluctuations. This can be achieved by an additional attractive long-range potential. Then, we are able to give analytic expressions for the ground state energy in the quasi-low-dimensional regime and observe the analogue behavior as in periodic boundary conditions.

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Poster 17

Rydberg physics and quantum-gas microscopy with multi-electron Er and Dy atoms

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In recent years experiments with highly magnetic lanthanoid atoms have attracted great attention due to their rich interaction properties, allowing the study of few- and many-body effects arising from long-range and anisotropic dipole-dipole interactions. Here, we will present the future extensions to our new experimental apparatus for ultracold dipolar mixtures of erbium and dysprosium [1].

Unlike in alkali or alkaline earth metals, lanthanoides, with their complex electronic structure, offer the possibility to excite electrons not only from the 6s-shell but also from the open anisotropic 4f-shell to Rydberg states. Thus, s-, p-, d-, f- or h-Rydberg states can be excited via a simple two-photon excitation scheme. This allows for the investigation of Rydberg-Rydberg or Rydberg-ground state atom interactions for a larger set of parameters. A further noteworthy feature of lanthanoid Rydberg atoms is their optically active core. Since these species have several valence electrons, the core remains optically active even when one of those is excited to a Rydberg level. As a consequence, the Rydberg atom can be optically manipulated, cooled or even trapped.

Finally, novel concepts for quantum-gas microscopy in lanthanoides will be presented. Such schemes have been developed in collaboration with the Greiner group at Harvard University.

The latest results on our ultracold mixtures, including the production of double BECs, will be presented in a second poster "Quantum Degenerate Mixtures of Erbium and Dysprosium Atoms".

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Poster 18

Quantum Phase Transitions of Water Molecules

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We study a one-dimensional chain of identical dipolar particles embedded in the six-fold degenerate potential. The goal is to find the phase transitions and inspect the full phase diagram of the system as the dipolar interaction strength D is varied. The current research is motivated by the following experimental paper [1] about quantum behaviour of water molecules confined in nanocavities.

First we study a one-dimensional chain of dipolar particles interacting with each other through the dipole-dipole interaction. The phase diagram of the system is obtained within mean-field approximation. We find a disordered phase for $D < D_{crit}$, where all dipoles are oriented at random directions and an ordered phase for $D > D_{crit}$. For asymptotically large value of interaction strength, we observe that the dipolar particles are in a highly ordered phase, where all dipoles are oriented along the quantisation axis. Adding the six-fold degenerate potential does not change the global phase diagram of the system. Using perturbation theory we are able to calculate the new critical interaction strength $D^{'}_{crit} > D_{crit}$.

The ongoing research is on the two-dimensional system of dipolar particles imbeded in the six-fold degenerate potential and as an outlook we present results obtained for this system.

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Poster 19

Near-threshold bound states of the dipole-dipole interaction

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We study the two-body bound states of a model Hamiltonian[1] that describes the interaction between two field-oriented dipole moments. This model has been used extensively in many-body physics of ultracold polar molecules, but its few-body physics has been explored less fully. We characterize the pattern of bound states and their avoided crossings in the case of hard-wall short-range interactions. For more realistic Lennard-Jones short-range interactions, we consider parameters representative for magnetic atoms and polar molecules. For magnetic atoms, we find that the bound states are dominated by the Lennard-Jones potential, and the perturbative dipole-dipole interaction is suppressed by the special structure of van der Waals bound states. For polar molecules, we recover a dense manifold of dipole-dipole bound states that shows an induced-dipole or applied-field dependence that is similar to the patterns observed for hard-wall boundary conditions. This universal pattern of states may be observable spectroscopically for pairs of ultracold polar molecules.

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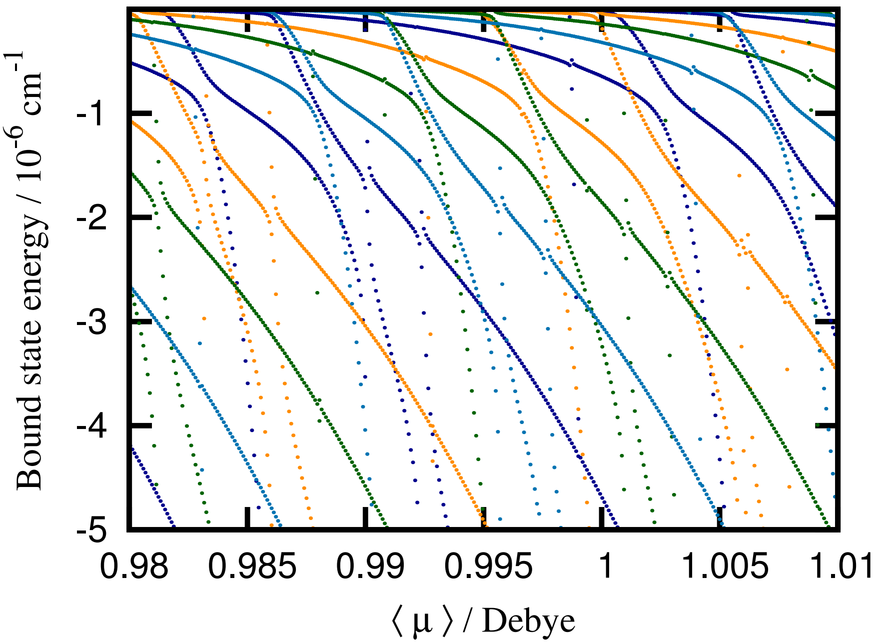

FIG. 1. Pattern of avoided-crossing bound states as a function of the field-induced dipole moment. The model parameters for the dipole-dipole and Lennard-Jones interaction are representative of polar molecules. Different colours correspond to results obtained for different well depths that sample a cycle of the s-wave scattering length.

Poster 20

Microwave Shielding of Polar Molecules

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We study microwave shielding of collisions of polar molecules, analogous to blue shielding for atoms. The goal is to engineer effective interaction potentials that are repulsive at long range, preventing short-range encounters of the molecules, thereby suppressing various loss mechanisms. In contrast to previous studies,[1, 2] we perform full coupled-channels scattering calculations to determine the efficiency of the shield, rather than drawing only qualitative conclusions from model adiabatic potentials. Furthermore, we also include molecular hyperfine structure. Hyperfine interactions lead to new loss channels, which are dominant in some realistic cases, and are suppressed by appropriate magnetic fields. We present numerical results for RbCs($^1\Sigma^+$) and CaF($^2\Sigma^+$) molecules. We find that for experimentally achievable static fields and microwave intensities, the probability of short-range encounters can be reduced by orders of magnitude without causing prohibitive microwave-induced losses.

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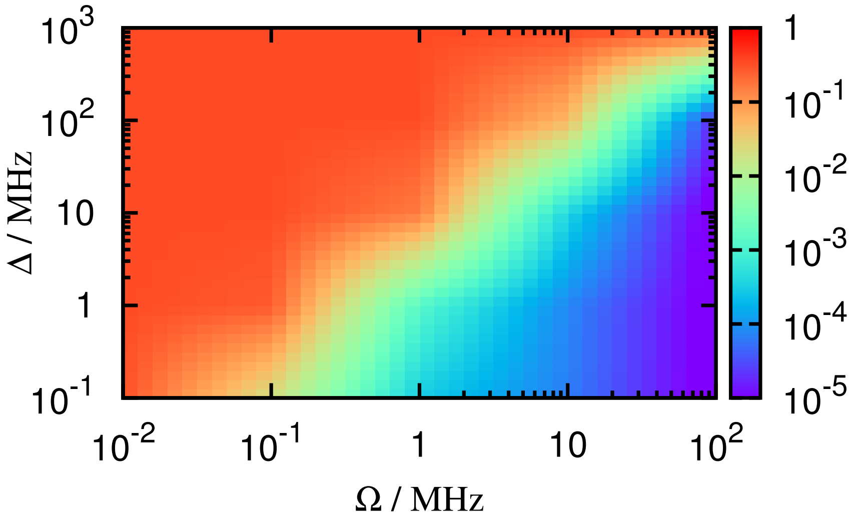

FIG. 1. Suppression of the probability of reaching short-range in a CaF-CaF collision, as a function of the microwave blue detuning, Δ, and the Rabi frequency, Ω.

Poster 21

Long-Range Correlations in Driven-Dissipative Rydberg Gases

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We perform a variational analysis of driven-dissipative Rydberg gases. As a first step, we extend the variational principle for dissipative many-body systems to long-range interaction and long-range correlation. We focus on dissipative Rydberg gases in the blockade regime and investigate the interplay between driving strength and dimensionality.

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Poster 22

Light scattering from dense and quantum degenerate atomic ensembles

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The scattering of light from dense atomic gases has received considerable recent interest [1]. At low density a medium is typically well described by a susceptibility formed by a simple product of atom number density and the atomic polarizability. For high atomic densities, however, dipole-dipole interactions may become considerable and affect the character of transmitted and scattered light [2].

In conjunction with dipolar interactions, the optical properties of a trapped, cooled gas may also be modified by the onset of quantum degeneracy. In the case of bosons, a change in the refractive index happens at the transition temperature [3] as was recently experimentally demonstrated [4]. For quantum degenerate fermions a suppression of light scattering has been predicted [5], but its direct observation has so far remained elusive [6].

Here we report on our experiments on light scattering from dense, trapped ultracold gases. We observe a marked difference in the scattering of light from a quantum degenerate gas of fermionic ^{40}K to that of a thermal gas of bosonic ^{87}Rb under similar conditions. In our experiments, probe light propagates along the axis of prolate atomic clouds and our observations involve complimentary measurements of light scattered in the sideways and forward directions.

Generally, for dense atomic samples - thermal or degenerate - the apparent extinction of light we observe in the forward direction (or more accurately in a small solid angle about the atomic and optical axis) deviates significantly from that predicted by naïvely accounting for diffusely scattered light as governed by the imaginary part of the medium susceptibility. We believe this effect is predominantly attributable to lensing of the Gaussian probe laser beam by the atomic sample [7]. We present measurements on dense but thermal gases of ^{40}K, where we can vary the temperature independently of atom number by sympathetically cooling the gas with ^{87}Rb.

Finally (and somewhat unrelated to the above), we will report on a demonstration of an optical

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antenna for 'radio-over fiber' based on Rydberg states of atoms [8].

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Poster 23

Towards an Erbium BEC in an Optical Box Potential

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This poster reports our progress towards producing a Bose-Einstein condensate (BEC) of dipolar erbium atoms in an optical box potential[1]. Our cooling protocol will closely follow existing methods [2]; a narrow line magneto-optical trap will be loaded using a Zeeman slowed atomic beam from an erbium oven. The atoms will then be optically trapped, and undergo optical transport to a separate glass cell for enhanced optical access. The atoms will then be confined to a quasi-2D box potential. The ability to tune the nature and the strength of the interactions, as well as the confining geometry, will allow us to probe many-body phenomena such as the appearance of a roton minimum in a quasi-2D dipolar gas [3] and supersolidity [4]. Furthermore, we also plan to investigate non-equilibrium many-body physics in quenched and driven quantum systems.

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Poster 24

Emergent universal dynamics for an atomic cloud coupled to a wave guide

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Motivated by recent experiments on strong coupling of a cloud of Rydberg atoms coupled to a propagating light field [1], we study the effect of interaction-induced dephasing in an atomic cloud of atoms coupled to an optical one-dimensional waveguide. The system's dynamics can then be described by dissipative terms characterising the collective emission of photons and coherent interaction due to the virtual exchange of photons. We show that the coherent exchange interaction gives rise to a universal dynamics with coherent oscillations and dephasing on a time scale that grows with the number of atoms in the cloud. Further, we discuss a possible experimental setup to decouple coherent and dissipative dynamics in order to observe the universal dynamics.

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Poster 25

Towards Direct Laser Cooling of Barium Monofluoride

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We present a new experimental setup for the laser cooling and trapping of barium monofluoride molecules. Laser cooling of molecules had long been considered impossible due to their complex vibrational and rotational level structure. However, beneficial Franck-Condon factors and selection rules allow for optical cycling in many molecular species [1–3], including barium monofluoride [4]. The molecules are generated through laser ablation in a 4K cryostat and precooled by collisions with a helium buffer gas. This results in a cold and intense beam that provides ideal starting conditions for transversal laser cooling, slowing and subsequent loading of a 3D magneto-optical trap. The resulting cold gas of heavy diatomic molecules will pave the way for a large number of novel and interdisciplinary applications ranging from few- and many-body physics to cold chemistry and tests of fundamental symmetries.

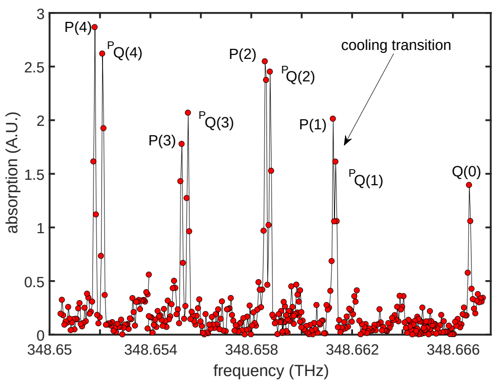

FIG. 1. Absorption spectroscopy of buffer-gas-cooled $^{138}B^{19}F$ molecules around the main cooling transition.

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Poster 26

Spin exchange dynamics in chromium dipolar quantum gases

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We study out-of-equilibrium spin dynamics of an ensemble of chromium atoms produced at the Magnetic Quantum Gases team of the Laboratoire de Physique des Lasers. This atomic species has a large $S = 3$ spin in its ground state, resulting in a magnetic dipole moment of $6\mu_B$ (μ_B is the Bohr magnetron) which induces significant dipole-dipole interactions between atoms.

We start with a quantum gas of ^{52}Cr in the $|S = 3, m_S = -3\rangle$ absolute ground state. We trigger the dynamics by rotating the spins of all atoms with respect to the magnetic field, using a resonant radio-frequency pulse. The evolution of the system is then characterized by monitoring the populations of the 7 spin components after Stern-Gerlarch separation. We tailor the initial spin tilting angle, the magnetic field properties (strength, direction and inhomogeneities), and the trapping scheme, for which we investigated the case of a Bose-Einstein condensate (BEC) in a harmonic trap, and the case of a 3D optical lattice with one atom per site. Comparison with numerical simulations provide an insight on the origin of the dynamics and the quantum state obtained during the evolution of the system.

In the superfluid case of a BEC, described in [1], the population dynamics is governed by the interplay between spin-dependent contact interactions, dipole-dipole interactions, and spin-orbit coupling provided by magnetic field gradients. It is well described by a mean field model, where each spin precesses around the field created by all other dipoles. The dynamics is induced by

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magnetic field gradients, either external or resulting from dipolar coupling, but once it has started it is mainly driven by strong spin-dependent contact interactions. We found that this driving results in the conservation of the initial ferromagnetic character of the condensate, and that this protection of ferromagnetism is a universal feature of spin mixing governed by contact interactions, provided they are large enough compared to the effect of the gradients.

In the case of a deep optical lattice, described in the Arxiv preprint [2], the atoms now solely interact via long range, anisotropic dipole-dipole interactions, realizing a spin-3 XXZ Heisenberg model for a unit filled array of 10^4 atoms. Mean field simulations fail to account for the observed dynamics, while it is well reproduced by a model adapted from the truncated Wigner approximation (Generalized Discrete Truncated Wigner Approximation [3], GDTWA). This indicates the emergence of quantum correlations between atoms. According to the GDTWA simulations, this isolated macroscopic system undergoes quantum thermalization, where wide scale entanglement between particules leads to thermal statistics for individual spin components.

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Poster 27

Rydberg quantum optics in an ultracold atomic gas

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Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons enables the realization of optical nonlinearities which can modify light on the level of individual photons [1, 2].

We present the investigation of higher-order photon correlations imprinted onto initially uncorrelated photons through an optical medium smaller than a single Rydberg blockade volume. We show that this single Rydberg superatom shows clear signatures in the connected part of the three-body correlation function. An idealized but exact solvable model of a two-level system coupled to a photonic mode allows for an interpretation of our experimental observations in terms of bound states and scattering states [3].

Additionally, we present the development of a new experiment designed to study the interactions between a large number of Rydberg polaritons simultaneously propagating through a medium with extremely high atomic density. It is proposed to achieve this aim by the use of Ytterbium, an alkaline-earth-like element, which possess, among others, an ultraviolet probe wavelength, a high optical depth per blockade volume and long coherence times.

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Poster 28

Quantum Monte Carlo description of dipolar droplets

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Recent experiments [1, 2] have reported on the formation of stable quantum droplets containing approximately from several hundreds to several thousands of ^{164}Dy atoms in the region of mean-field collapse. In these systems, beyond-mean-field effects become very important and dramatically limit the stability of the formed droplets through the compensation of attractive and repulsive forces, be means of a mechanism similar to the one described in [4].

From a theoretical point of view, these droplets have been analyzed in the framework of the extended Gross-Pitaevskii equation [3], which incorporates Lee-Huang-Yang corrections to the energy functional but still provides a mean-field picture of the system. In this work we use the Path Integral Ground State (PIGS) [5] method to describe the formation of droplets of dipolar bosons. Starting from a sensible model wave function of the many-body problem, stochastic propagation in imaginary time leads to an unbiased decryption of the exact ground state without further approximations. In this sense, the result is *exact* within statistical uncertainties. We analyze the critical number of atoms required to form a droplet as a function of the initial trapping aspect ratio, using a model two-body interaction that describes the known scattering properties of the Dy-Dy potential. Parameters such as the scattering length are fixed by solving the T-matrix problem corresponding to the combined two-body isotropic potential and the dipole-dipole force.

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Poster 29

Spin mixing and protection of ferromagnetism in a spinor dipolar condensate

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Our work focuses on the study of Bose-Einstein condensates with internal spin degrees of freedom, commonly known as spinor BECs. We study out-of-equilibrium physics of spin-3 chromium dipolar BECs following an excitation of the spin degree of freedom. We describe in particular spin dynamics which, we find, results from an interplay between contact and dipolar interactions. Here we focus on the theoretical studies in contact with the experiment at Villetaneuse [1].

Starting from a fully polarized spin 3 chromium dipolar BEC in state $m = -3$, we numerically investigate spin mixing dynamics after rotation of the collective spin by an angle θ compared to the magnetic filed. For $\theta \neq \pi/2$ dynamics is triggered by dipolar interactions [2]. On the contrary, for $\theta = \pi/2$ dipolar interaction does not drive any dynamics and magnetic filed gradient is necessary to trigger dynamics.

Just after rotation, all spins are aligned and the sample therefore has a ferromagnetic character. One striking observation derived from our simulations of the spinor Gross-Pitaevskii equation, which are in good agreement with experimental results, is a protection of a local ferromagnetic character of the gas while dynamics proceeds. Indeed, the local spin length remains close to its maximum, 3. Surprisingly the spinor remains locally ferromagnetic, despite the fact that spin dependent interactions energetically favor depolarization.

To understand this effect, we have solved the spinor Gross-Pitaevskii equation for a homogeneous BEC in presence of magnetic field gradients. We find that the initial ferromagnetic character of the BEC is protected by spin exchange contact interactions, which provide self-rephasing of the spinor components. Taking the phenomenological assumption that the spinor remains ferromagnetic, we developed a simple analytical model based on spinor hydrodynamic approach [3] to investigate the short time dynamics induced by a magnetic field gradient b.

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Poster 30

Ground state of an ultracold Fermi gas of tilted dipoles

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Many-body dipolar effects in Fermi gases are quite subtle as they energetically compete with the large kinetic energy at and below the Fermi surface (FS). Recently it was experimentally observed in a sample of erbium atoms that its FS is deformed from a sphere to an ellipsoid due to the presence of the anisotropic and long-range dipole-dipole interaction [1]. Moreover, it was suggested that, when the dipoles are rotated by means of an external field, the Fermi surface follows their rotation, thereby keeping the major axis of the momentum space ellipsoid parallel to the dipoles. Here we generalise a previous Hartree-Fock mean-field theory [2, 3] to systems confined in an elongated triaxial trap with an arbitrary orientation of the dipoles relative to the trap. With this we study for the first time the effects of the dipoles' arbitrary orientation on the ground-state properties of the system. Furthermore, taking into account the geometry of the system, we show how the ellipsoidal FS deformation can be reconstructed, assuming ballistic expansion, from the experimentally measurable real-space aspect ratio after a free expansion. We perform new and extensive measurements for various parameters to study the full angular dependence of the FS deformation and show that the FS does not simply follow rigidly the orientation of the dipoles, but depends additionally on the dipoles' orientation relative to the trap geometry, as well as on the trap anisotropy itself, see the illustration in Fig. 1. The presented direct comparison of the obtained analytical and numerical results with our experimental observations shows very good agreement. The developed theory is relevant for understanding and interpreting future experiments

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with ultracold fermionic dipolar quantum gases, where the investigated physics depends on the underlying structure of the FS.

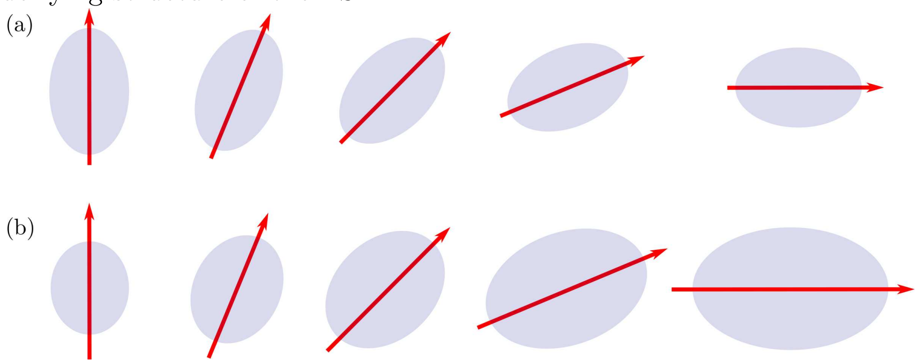

Fig. 1: Illustration of angular dependence of FS deformation in momentum space for system in anisotropic trap: (a) for weak DDI, when FS ellipsoid just rotates like a rigid object; (b) for strong DDI, when FS deformation strongly depends on dipoles' orientation.

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[3] V. Veljić, A. Balaž, and A. Pelster, Phys. Rev. A **95**, 053635 (2017).

Poster 31

The Collective Lamb Shift of a Nanoscale Atomic Vapour Layer within a Sapphire Cavity

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Collective effects in light scattering have gained a renewed interest recently with the recognition that they can bias the accuracy of atom-based sensors such as optical clocks by introducing unwanted energy level shifts. The resonant dipole-dipole interactions between atoms should lead to a collective frequency shift of the atomic lines. This shift, unfortunately named the cooperative or collective Lamb-shift (CLS) despite its classical nature, depends on the shape of the sample.

Here, I will present our recent measurements of the near-resonant transmission of light through a dense vapour of potassium confined in a slab cell with nanometer thickness in order to investigate the origin and validity of the collective Lamb-shift [1]. A complete model including the multiple reflections in the nano-cell accurately reproduces the observed strong asymmetry of the line shape and allows extraction of a density dependent shift of the atomic resonance.

Finally, I will present a new generation of glass nano-cells with super-polished surfaces. These cells are promising tools for revisiting long-range atom-surface interactions with thermal vapours.

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[1] T. Peyrot , The Collective Lamb Shift of a Nanoscale Atomic Vapour Layer within a Sapphire Cavity. https:/arxiv.org/abs/1801.01773Arxiv, arXiv:1801.01773 (2018).

Poster 32

Dissipative cooling of spin chains by a bath of dipolar particles

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The coupling of quantum systems to environments can lead to various consequences: typically it produces decoherence towards classical behaviors, but specific situations on the contrary produce quantum correlations [1, 2]. This is an exciting new paradigm, that opens the fascinating perspective of environment engineerin to protect or produce entangled states. In the context of quantum simulation of magnetism with cold atoms, this kind of dissipative approaches may contribute in preparing low energy many-body spin states of atoms in optical lattices. Recent such proposals involve the use of light as a bath, and spontaneous emission as the dissipative process [3, 4].

In the present work [5], we explore theoretically binary atomic mixtures, one species acting as spin chain, the other as bath. Namely, the spin chain is composed of spinful fermionic atoms in the Mott insulating regime, and it is coupled to a Bose Einstein condensate of a different species. The low-energy many-body states of the spin chain are driven by nearest-neighbor super-exchange interactions. Magnetic dipole interaction between fermions and bath lead to spin flips in the chain, associated with spontaneous phonon emission in the BEC. Thus, spin-thermalization can arise, due to the spin-orbit coupling conveyed by dipole-dipole interactions, an effect which is connected to the Einstein-de Haas effect. As we show here, spin-orbit coupling offers a possibility to directly cool the collective spin degrees of freedom in a spin-chain.

Starting from an uncorrelated thermal sample, we demonstrate in realistic settings, with spin chains of alkali atoms interacting with a BEC of a strongly dipolar species, that the dissipative cooling produces highly entangled low energy spin states of the chain in a timescale of a few seconds. In practice, the lowest energy singlet state driven by super-exchange interactions is efficiently produced. This dissipative approach is a promising alternative to cool spinful atoms in spin-independent lattices. It provides direct thermalization of the spin degrees of freedom, while traditional approaches are plagued by the inherently long timescale associated to the necessary spatial redistribution of spins under the effect of super-exchange interactions [6]. Furthermore,

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while the many-body ground state of the Heisenberg antiferromagnetic Hamiltonian has a singlet character at half-filling, in most experiments the collective spin is a conserved quantity which is typically not under control; thus, the possibility to couple to the total spin of the chain is essential to generically provide cooling down to the lowest energy states of spin chains.

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Poster 33

Anisotropic critical velocity of a dipolar superfluid

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One of the most remarkable properties of ultra cold atomic gases is the occurrence of superfluid states characterized by dissipationless irrotational flow. This dissipationless behaviour only appears below a certain "critical" flow velocity and is well-known for decades in liquid helium [1]. Similar to liquid helium superfluid phenomena like the critical velocity for vortex creation have also been observed in ultra-dilute superfluids of quantum-degenerate gases. In systems with non-negligible dipole interaction the superfluidity acquires the anisotropic character of the interaction resulting in the system's critical velocity depending highly on the flow direction [2].

Here we present transport measurements on a dipolar superfluid using a Bose-Einstein condensate of ^{162}Dy with strong magnetic dipole-dipole interactions. By moving an attractive laser beam through the condensate we observe an anisotropic critical velocity for the breakdown of dissipationless flow, which, in the spirit of the Landau criterion, can directly be connected to the anisotropy of the underlying dipolar excitation spectrum. In addition, the heating rate above this critical velocity reflects the same anisotropy. Our observations are in excellent agreement with simulations based on the Gross-Pitaevskii equation and highlight the effect of dipolar interactions on macroscopic transport properties, rendering anisotropic dissipation [3].

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Poster 34

Rotational coherence of polar molecules in a magic trap

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Quantum gases with dipolar interactions are a fascinating prospect for quantum simulation. Polar molecules have large electric dipole moments and long lifetimes, which makes them ideal candidates for realizing long range physics beyond nearest neighbor interactions.

The rotational degree of freedom of molecules can be used to encode spins. The ground and first excited rotational state however posses different parity. Therefore their polarizabilities at the optical frequencies employed for trapping can differ significantly. This leads to decoherence. Due to the anisotropy of the molecular polarizability, the polarization of the trapping field can be used to tune this differential light shift, even to a so-called magic condition, where it is zero. Then long coherence times between the two states can be achieved.

We experimentally explored the first excited rotational state manifold of ground state fermionic NaK [1] using microwave spectroscopy. We demonstrate how small static electric fields can be used to decouple nuclear spin and molecular rotation and thus to simplify the complex rotational state spectrum, enabling an even longer coherence time. Finally we study the rotational coherence of the molecules. We observe a density dependence of the coherence time, which we attribute to the movement of the molecules in the trap or the dipolar interaction between the molecules, as the $^{23}Na^{40}K$ rotational transition dipole moment amounts already to $2.72\ \mathrm{D}/\sqrt{3} = 1.57\ \mathrm{D}$.

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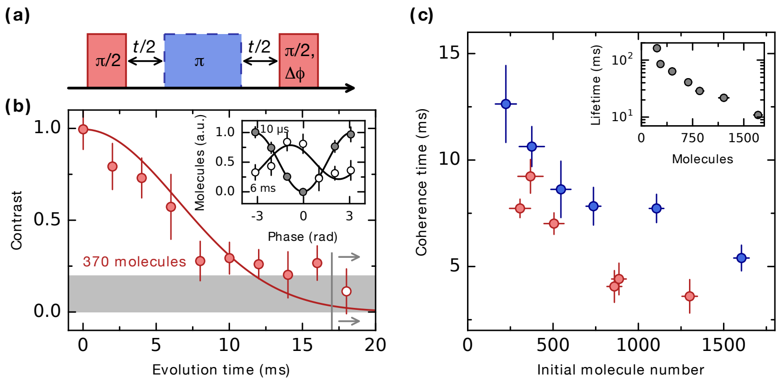

FIG. 1. (a) Microwave pulse sequences. Ramsey (only $\pi/2$-pulses) and Spin-Echo (all pulses) sequences are used to study the coherent evolution of molecules between the $|J, m_J\rangle = |0,0\rangle$ and $|1,0\rangle$ rotational states. To obtain a Ramsey or Spin-Echo fringe, the phase of the second $\pi/2$ pulse is scanned by $\Delta\phi$ compared to the first pulse for each evolution time t. b) Two exemplary Ramsey fringes are shown in the inset. Contrast of Ramsey fringes at different evolution times. The Ramsey coherence time t_2 is obtained by fitting a Gaussian evolution (red line). Error bars are calculated from the covariance matrix of the fit. c) Ramsey and Spin-Echo at various molecule numbers. Using Ramsey spectroscopy (red symbols) we obtain coherence times of up to 8 ms. A Spin-Echo sequence can remove residual single-particle effects due to eg. electric field gradients. Indeed we observe even larger Spin Echo coherence times t_2^* of up to 12.5 ms. However both t_2 and t_2^* dependent of the molecule number on the trap, that we vary by changing the hold time after Feshbach association. Both coherence times are shorter than the ground state molecule lifetime t_1 shown in the inset.

Poster 35

Dysprosium dipolar condensate with broad Feshbach resonances

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We report on the production of a Bose-Einstein condensate of ^{162}Dy atoms and on the characterization of its scattering properties. We employ an innovative technique based on a resonator-enhanced optical trap, allowing an efficient capture of the atoms from the magneto-optical trap. We use ultracold samples at temperatures just above condensation to investigate the spectrum of Feshbach resonances. Besides the chaotic distribution of narrow Feshbach resonances, typical of Lanthanides, we discover two rather isolated features at around 22 G and 27 G, with widths $\Delta \simeq 0.1$-1 G, comparable to the typical spacing between narrow resonances. A characterization using complementary measurements such as losses,thermalization, anisotropic expansion and molecular binding energy, points towards resonances of predominant s-wave character. Such resonances appear particularly appealing for a precise tuning of the contact interaction over a broad range, easing the investigation of quantum phenomena relying on the interplay between dipole and contact interactions.

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Poster 36

Quantum Degenerate Mixtures of Erbium and Dysprosium Atoms

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Highly magnetic atoms have proven to be successful and versatile model systems to investigate long-range dominated physics in both bulk as well as lattice systems. So far all experiments with dipolar gases have been using as atomic species either chromium, dysprosium, or erbium. Here, we demonstrate a dipolar mixture operation, which, for the first time, combines Er and Dy together. We efficiently produce double Bose-Einstein condensates, as well as a cold Bose-Fermi mixture.

The similar optical and physical properties of Er and Dy makes it convient to combine both species in one apparatus: For both elements, optical transitions with high scattering rates can be used for Zeeman slowing and imaging, while narrow transitions allow to cool the atoms in a MOT with very low Doppler temperature. This narrow-line MOT needs only five beams [1], leaving enough optical access to use the MOT chamber as a full science chamber. We present our next steps after capturing the atoms in the MOT, namely the loading of a far detuned optical dipole trap. Due to the similar mass and polarizability at 1064 nm, efficient evaporative cooling in a singe trap is possible, and efficient Bose-Einstein condensation of all abundant isotopes is achieved.

A major step toward future experiments is the achievement of double Bose-Einstein condensates: We are able to combine five different isotope mixtures to achieve double degeneracy. This requires a careful fine tuning of the magnetic fields due to the very dense Feshbach spectrum of either species as well as inter-species losses. We also present preliminary studies of the interspecies interaction between the two degenerate clouds.

In addition to the possibilities the main chamber of this setup offers, two additional chambers are under construction, dedicated to the study of Rydberg physics in ultracold lanthanoides as well as a quantum gas microscope, which are presented in a second poster "Rydberg physics and quantum-gas microscopy with multi-electron Er and Dy atoms" .

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Poster 37

Laser cooling of Dysprosium

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Ultra-cold dipolar quantum gases enable the study of many-body physics with long-range, inhomogeneous interaction effects due to the anisotropic character of the dipole-dipole interaction. These systems are expected to show novel exotic quantum phases and phase transitions which can be studied with dysprosium atoms. Dysprosium is a rare-earth element with one of the largest ground-state magnetic moments (10 Bohr magnetons) in the periodic table. Therefore, the dipole-dipole interaction is not a small perturbation but becomes comparable in strength to the s-wave scattering. This influences significantly the physical properties of the trapped atomic sample, such as its shape and stability.

This poster presents the current status of our experimental setup to generate dysprosium quantum gases. We present our results in laser cooling of dysprosium atoms and give an overview of our laser system and vacuum design.

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Poster 38

Feshbach spectroscopy and dual-species Bose-Einstein condensation of ^{23}Na - ^{39}K mixtures

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Ultracold polar ground state molecules are a powerful tool for the investigation of a wide range of physical phenomena as quantum chemical processes or exotic dipolar quantum phases. One way to prepare ultracold ground state molecules is based on a two-photon coherent Raman transfer starting from ultracold weakly-bound Feshbach molecules.

Here, we report on magnetic Feshbach resonance loss spectroscopy in all possible combinations of hyperfine sub-levels with an ultracold atomic mixture of ^{23}Na and ^{39}K. We use our results to refine potential energy curves for bosonic NaK molecules. Further, we identify and discuss the suitability of different magnetic field regions for the purposes of sympathetic cooling of ^{39}K in a bath of ^{23}Na atoms. We use our findings for the demonstration of dual-species degeneracy in the ^{23}Na ^{39}K mixture. The two condensates are created simultaneously by evaporation at a magnetic field of about 150 G, which provides sizable intra- and interspecies scattering rates needed for fast thermalization. Finally, we discuss the pathway for the production of Feshbach molecules as well as the two-photon Raman transfer to the rovibronic ground state.

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Poster 39

Accurate Rydberg quantum simulations of spin-1/2 models

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Using non-perturbative calculations of the interaction potentials between two Rydberg atoms taking into account both electric and magnetic fields, we can simulate a broad range of two-atom Rydberg systems. Benchmarks against varied experimental data show an excellent agreement between the simulations and experiments. We apply our simulation procedure to investigate under which experimental conditions spin-1/2 models can be accurately simulated using Rydberg atoms. More specifically, we determine experimental parameters for which a system of atoms that are laser driven to $nD_{3/2}$ Rydberg states and interacting via the van der Waals interaction can be mapped accurately to an Ising-like spin-1/2 model, despite the large number of Rydberg levels involved. Our investigations show the importance of a careful selection of experimental parameters in order not to break the Rydberg blockade mechanism which underlies the mapping. By selecting appropriate parameters, a good agreement is achieved between the measured time evolution and the numerically calculated dynamics of the Ising-like spin-1/2 model in systems with up to 49 atoms, i.e. in systems that are at the edge of numerical accessibility. This result opens exciting prospects for the realization of high-fidelity quantum simulators of spin Hamiltonians.

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Poster 40

Equation of State and Universality of a 2D Dipolar Gas

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For a gas at thermodynamic equilibrium, the equation of state relates quantitatively thermodynamic variables, e.g. the particle density n as a function of temperature T and the chemical potential μ at fixed volume.

For a dilute two-dimensional Bose gas with contact-like inter-particle interactions, the equation of state exhibits a particular scale invariance. For constant interaction strength, the phase-space density, $n\lambda_T^2$ where λ_T denotes the thermal de Broglie wavelength, becomes simply a function of the dimensionless parameter μ/k_BT. Furthermore, in the vicinity of the Berenzinskii-Kosterlitz-Thouless phase transition, such universal scaling between systems of different interaction strengths emerges when thermodynamic variables are renormalized by the strength of collisions.

Here we report experimental studies of 2D dipolar excitons trapped in a bilayer heterostructure and then reveal that the equation of state exhibits such universal scaling behavior, despite the dipolar character of repulsive interactions.

Poster 41

Magnetically tunable Feshbach resonances in ultracold gases of europium atoms and mixtures of europium and alkali-metal atoms

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We investigate magnetically tunable Feshbach resonances between ultracold europium atoms and between europium and alkali-metal atoms using multichannel quantum scattering calculations. For ultracold gases of europium atoms both homonuclear ^{153}Eu+^{153}Eu and heteronuclear ^{151}Eu+^{153}Eu systems are studied. Calculations for mixtures of europium and alkali-metal atoms are carried out for prototype systems of ^{153}Eu+^{87}Rb and ^{153}Eu+^{7}Li. We analyze the prospects for the control of scattering properties, observation of quantum chaotic behavior, and magnetoassociation into ultracold polar and paramagnetic molecules. We show that favorable resonances can be expected at experimentally feasible magnetic field strengths below 1000 G for all investigated atomic combinations. For Eu atoms, the dipolar interaction induces measurable resonances as a result of the competition between relatively weak short-range spin-exchange and strong long-range magnetic dipole-dipole interactions and a high density of resonances is expected at magnetic field strengths below 200 G without pronounced quantum chaos signatures. The present results may be useful for the realization and application of dipolar atomic and molecular quantum gases based on europium atoms in many-body physics.

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Poster 42

Trap-induced shape resonances in an ultracold few-body system of an atom and static impurities

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Hybrid systems of ultracold atoms and trapped ions or Rydberg atoms can be useful for quantum simulation purposes. By tuning the geometric arrangement of the impurities it is possible to mimic solid state and molecular systems. Here we study a single trapped atom interacting with a set of arbitrarily arranged static impurities and show that the problem admits an analytical solution [1]. An example of such a situation is displayed in Fig. 1, where a single atom moves in a harmonic trapping potential with two different impurities localized by separate traps. We analyze in detail the case of two impurities, finding multiple trap-induced resonances which can be used for entanglement generation. Our results serve as a building block for the studies of quantum dynamics of more complex systems.

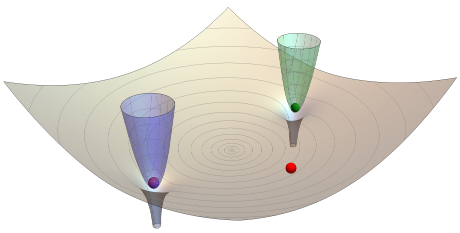

FIG. 1. An interaction potential experienced by a trapped atom (red sphere) in the presence of two localized impurities (purple and green spheres), which are localized by external trapping potentials (purple and green).

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Poster 43

Quantum phases of dipolar rotors on two-dimensional lattices

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The quantum phase transitions of dipoles confined to the vertices of two dimensional (2D) lattices of square and triangular geometry is studied using path integral ground state quantum Monte Carlo (PIGS) [1], generalized to include rotational degrees of freedom [2]. We analyze the phase diagram as a function of the strength of both the dipolar interaction and a transverse electric field. The study reveals the existence of a class of orientational phases of quantum dipolar rotors whose properties are determined by the ratios between the strength of the anisotropic dipole-dipole interaction, the strength of the applied transverse field, and the rotational constant. For the triangular lattice, the generic orientationally disordered phase found at zero and weak values of both dipolar interaction strength and applied field, shows a transition to a phase characterized by net polarization in the lattice plane as the strength of the dipole-dipole interaction is increased, independent of the strength of the applied transverse field, in addition to the expected transition to a transverse polarized phase as the electric field strength increases. The square lattice is also found to exhibit a transition from a disordered phase to an ordered phase as the dipole-dipole interaction strength is increased, as well as the expected transition to a transverse polarized phase as the electric field strength increases. In contrast to the situation with a triangular lattice, on square lattices the ordered phase at high dipole-dipole interaction strength possesses a striped ordering. The properties of these quantum dipolar rotor phases are dominated by the anisotropy of the interaction and provide useful models for developing quantum phases beyond the well-known paradigms of spin Hamiltonian models, realizing in particular a novel physical realization of a quantum rotor-like Hamiltonian that possesses an anisotropic long range interaction [3].

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