Workshop on

Hybrid Atomic Quantum Systems

28 – 30 September 2015

Schedule

Schedule

Monday 28/9

8:55 am	Opening
9:00 am	Michael Köhl *Hybrid quantum system of a trapped ion and a semiconductor quantum dot*
9:45 am	Coffee Break
10:15 am	Johannes Hecker Denschlag *A cold ion reacting with two ultracold neutral atoms*
11:00 am	Zbigniew Idziakszek *Ultracold atom-ion collisions in the presence of ion micromotion*
11:45 am	Lunch
1:30 pm	Melanie Schnell *Decelerating and trapping neutral, polar molecules – towards studying ultracold phenomena*
2:15 pm	Roland Wester *Cold collisions of trapped molecular anions*
3:00 pm	Coffee Break
3:30 pm	Oliver Dulieu *Formation of molecular ions by radiative association of cold trapped atoms and ions*
4:00 pm	Haggai Landa *Quasi-bound states in periodically driven scattering*
4:20 pm	Ziv Meir *Single collision between ground-state cooled ion and ultracold atoms*
4:40 pm	Armin Dehkharghani *Strongly interacting one-dimensional Bose systems and Bose polarons*
5:00 pm	Lab Tours
7:00 pm	Poster Session

Schedule

Tuesday 29/9

9:00 am	Tilman Pfau *A single charge in a Bose-Einstein condensate: from two to few to many-body physics*
9:45 am	Coffee Break
10:15 am	Svetlana Kotochigova *Motional and vibrational cooling of molecular ions with cold and highly-polarizable atoms*
11:00 am	Tobias Schätz *Trapping Ions Atoms and Molecules Optically*
11:45 am	Lunch
1:30 pm	Michael Drewsen *Rotational cooling of Coulomb-crystallized molecular ions by a helium buffer gas*
2:15 pm	Herwig Ott *Driven-dissipative Bose-Einstein condensates*
3:00 pm	Coffee Break
3:30 pm	Stefan Willitsch *Next-generation ion-atom hybrid trap for high-resolution cold-collision experiments*
4:00 pm	Johannes Schurer *Capture dynamics between ultracold atoms and an impurity ion*
4:20 pm	Philipp Wessels *Local ionization of ultracold gases induced by femtosecond laser pulses*
4:40 pm	Michal Tomza *Formation and control of molecular ions in ultracold ion-atom systems*
5:00 pm	Free Time
7:00 pm	Dinner

Schedule

Wednesday 30/9

9:00 am	Rene Gerritsma *Realizing a hybrid atom-ion trap for Li and* Yb^{+}
9:45 am	Coffee Break
10:15 am	Hossein Sadeghpour *Few-body dynamics of a Rydberg electron impurity in a quantum gas*
11:00 am	Paul Sebastian Julienne *Complex Collisions of Atoms and Molecules*
11:45 am	Lunch
1:30 pm	Walter Hofstetter *Bosonic lattice gases with long-range interactions and dissipation*
2:15 pm	Carlos Lobo *Optical Lattices with large scattering length*
3:00 pm	Departure

Posters

Posters

Sumanta Das	*Photonic phase gates via Rydberg blockade in optical cavities*
Anna Dawid	*Non-resonant laser field control of magnetically tunable Feshbach resonances in quantum ultracold atomic gases*
Henning Fürst Janis Joger	*A hybrid atom-ion trap for Li and* Yb^{+}
Andreas Geißler	*Condensation vs. Interaction: Competing Quantum Phases in Bosonic optical lattice systems at near resonant Rydberg dressing*
Rosario Gonzales-Ferez	*Ultralong-Range Rb-KRb Rydberg Molecules: Electronic Structure, Orientation and Alignment*
Jack Graneek Fabian Pokorny Simon Merz	*Motion manipulation of ammonia and 4-aminobenzo- nitrile with microwave fields*
Krzysztof Jachymski	*Emergence of chaos in the presence of densely overlapping Feshbach resonances*
Manoj Joshi	*Abstract*
Leon Karpa	*Advances in optical trapping of Barium ions*
Andrea Klumpp	*Reconfiguration dynamics of coupled zig-zag chains with trapped ions in a double well*
Maciej Kosicki	*Interaction in mixed ultracold trimers of rubidium and strontium*
Jochen Küpper	*Control of chemical reactivity through spatial separation of molecular conformations*
Alexander Lambrecht	*Ultracold collisions of an Ion in an optical dipole trap*
Tara Liebisch	*Ultracold chemistry of a single Rydberg atom in a BEC*
Vladimir Melezhik	*Atom-ion confinement-induced resonances*

Posters

Paula Ostmann	*Single particle dynamics in an ultracold Bose gas environment*
Tao Qin	*Theory of orbital order and weak ferromagnetism for the antiferromagnetic state of body-centered cubic A15-Cs3C60*
Bernhard Ruff	*Two-photon ionization of a Bose-Einstein condensate*
Burkhard Schmidt	*Supersymmetry and eigensurface topology of pendular states of diatomic molecules*
Julian Schmidt	*Advances in optical trapping of Barium ions*
Dandan Su	*Interacting bosons in an optical cavity*
Tomasz Wasak	*Theory for twin matter wave experiments*
Joschka Wolf	*Investigating reactive three-body collisions with* ^{87}Rb *atoms and a* $^{138}Ba^{+}$ *ion*
Tao Yin	*Polaronic effects in two-band quantum systems*
Mouffok Youcef	*Optical Properties of quaternary half-metal half Heusler alloys CoV1-xMnXSi*
Nikolaj Zinner	*Magnetism and dynamics in strongly interacting in strongly interacting one-dimensional systems*
Piotr Zuchowski	*Feshbach resonances in mixtures dimers of alkali-metal atoms with alkaline-earth and lanthanides: toward paramagnetic and polar molecules*

Abstracts of Lectures

(in chronological order)

Hybrid quantum system of a trapped ion and a semiconductor quantum dot

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Coupling individual quantum systems lies at the heart of building scalable quantum networks. Here, we report the first direct photonic coupling between a semiconductor quantum dot and a trapped ion and we demonstrate that single photons generated by a quantum dot controllably change the internal state of an Yb+ ion. We ameliorate the effect of the sixty-fold mismatch of the radiative linewidths with coherent photon generation and a high-finesse fiber-based optical cavity enhancing the coupling between the single photon and the ion. The transfer of information presented here via the classical correlations between the z projection of the quantum-dot spin and the internal state of the ion provides a promising step towards quantum state-transfer in a hybrid photonic network

References

[1] H. M. Meyer et al., Phys. Rev. Lett. 114, 123001 (2015).

A cold ion reacting with two ultracold neutral atoms

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We investigate reactions of a cold trapped ion (either Rb^+ or Ba^+) with ultracold Rb atoms (e.g. [1]). The particles collide in the dark such that they are all in the electronic ground state. We observe reactions either in terms of change of the ionic species or in terms of a release of energy. Already at moderate atomic densities of about 10^{12} cm^{-3} three-body processes strongly dominate the reactions at low collision energies. We have studied the scaling of the rate coefficients with collisional energy and compared the experimental results to classical trajectory calculations. Somewhat surprisingly, we find that the details of the micromotion-induced non-thermal energy distribution of the ion has important consequences on the observed scaling properties.

Furthermore, we have gained insights about the ionic molecular products after three-body recombination. Until recently, these molecular products have been elusive in several experimental groups. We show that this is due to fast secondary reactions and photo-dissociation.

References

[1] A. Härter, A. Krükow, A. Brunner, W. Schnitzler, S. Schmid, and J. Hecker Denschlag, Phys. Rev. Lett. 109, 123201 (2012).

Ultracold atom-ion collisions in the presence of ion micromotion

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Quantum defect method provides very convenient theoretical framework to describe ultracold atom-ion collisions in realistic systems, including effects of shape and Feshbach resonances [1]. In present experiments the ions are confined in radio-frequency traps, where they experience small-amplitude micromotion. Dynamics of a single ion immersed in ultracold reservoir of bosonic atoms either in condensed or non-condensed phase can be described using master equation formalism [2]. One can show that cold atomic gas modifies the stability diagram of the ion in RF trap creating the regions where the ion can be cooled or heated [2]

We develop a theoretical model for atom-ion collisions including the effects of ion micromotion. Our models is based on expansion of the wave function in the basis of time-dependent solutions for an ion in RF potential. For one-dimensional problem of a single ion immersed in ultracold gas of bosons we calculate the cooling rates, and compare them with predictions based on master-equation formalism. We discuss the limit when the Born approximation can be applied.

References

[1] Z. Idziaszek, A. Simoni, T. Calarco, P.S. Julienne, New J Phys. 13, 083005 (2011).
[2] M. Krych, Z. Idziaszek, Phys. Rev. A 91, 023430 (2015).

Decelerating and trapping neutral, polar molecules – towards studying ultracold phenomena

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The Hamburg Centre for Ultrafast Imaging (CUI), Hamburg

There has been rapid progress in the field of cold and ultracold molecular gases over the last decade, driven by a diverse range of applications in physics and chemistry. These include the study and exploitation of dipole-dipole interactions between cold polar molecules, which are long range, anisotropic, and tunable.

In low-temperature molecular gases it furthermore becomes possible to control chemical reactions using electric and magnetic fields and to study the role of quantum effects in determining chemical reactivity. For example, the electric dipole moment of cold polar molecules can serve as a handle to orient the molecules in space and allows us to explore the stereodynamics of chemical reactions. Cold molecules can also be useful for testing fundamental symmetries, for example by measuring the value of the electron's electric dipole moment, or searching for a time-variation of fundamental constants. For these applications, the sensitivity could be greatly enhanced by cooling the relevant molecules to low temperatures so that.

In the contribution, I will present direct approaches to produce cold molecules and schemes to keep them confined in molecule traps up to several seconds. Furthermore, potential pathways towards ultracold polar molecules and possible applications are discussed.

Cold collisions of trapped molecular anions

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Collisions at low temperature are strongly influenced by quantum mechanics: scattering cross sections show resonance structures and different internal quantum states may lead to qualitatively different collision properties. Cold ions in traps provide a well-suited environment to control and observe cold ion-atom collisions. In our group we employ cryogenic radiofrequency multipole traps. Our research focus lies on negatively charged molecular ions colliding with cryogenically cooled helium [1] or optically cooled rubidium atoms [2].

In this talk I will present our recent experimental and theoretical investigations of cold OH^- anions colliding with helium and hydrogen. Rotational state analysis [3] was employed to measure the inelastic scattering rate coefficient for the OH^- + He collision and compare them to quantum scattering calculations [4]. Three-body collisions of OH^- with hydrogen were investigated, and it could be shown that they form H^-H_2O complexes via an internal proton transfer [5]. Recently, we obtained evidence for direct rotational energy transfer in cold ion-molecule collisions.

References

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[2] J. Deiglmayr, A. Göritz, T. Best, M. Weidemüller, R. Wester, Phys. Rev. A **86**, 043438, (2012)

[3] R. Otto, A. von Zastrow, T. Best, R. Wester, Phys. Chem. Chem. Phys. **15**, 612 (2013)

[4] D. Hauser, S. Lee, F. Carelli, S. Spieler, O. Lakhmanskaya, E. S. Endres, S. S. Kumar, F. Gianturco, R. Wester, Nature Physics **11**, 467 (2015)

[5] D. Hauser, O. Lakhmanskaya, S. Lee, S. Roucka, R. Wester, New J. Phys **17**, 075013 (2015)

Formation of molecular ions by radiative association of cold trapped atoms and ions

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Radiative emission during cold collisions between trapped laser-cooled Rb atoms and alkaline-earth ions (Ca^+, Sr^+, Ba^+) and Yb^+, and between Li and Yb^+, are studied theoretically [1], using accurate effective-core-potential based quantum chemistry calculations of potential energy curves and transition dipole moments of the related molecular ions. Radiative association of molecular ions is predicted to occur for all systems with a cross section two to ten times larger than the radiative charge transfer one. Partial and total rate constants are also calculated and compared to available experiments. Narrow shape resonances are expected, which could be detectable at low temperature with an experimental resolution at the limit of the present standards. Vibrational distributions are also calculated, showing that the final molecular ions are not created in their ground state level.

References

[1] Humberto da Silva Jr, Maurice Raoult, Mireille Aymar and Olivier Dulieu, *New J. Phys.* **17** 045015 (2015)

Quasi-bound states in periodically driven scattering

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We present an approach for obtaining eigenfunctions of periodically driven time-dependent Hamiltonians. Assuming an approximate scale separation between two spatial regions where different potentials dominate, we derive an explicit expansion for scattering problems with mixed cylindrical and spherical symmetry, by matching wavefunctions of a periodic linear drive in the exterior region to solutions of an arbitrary interior potential expanded in spherical waves. Using this method we study quasi-bound states of a square-well potential in three dimensions subject to an axial driving force, in the nonperturbative regime [1]. We further employ our method to study the states of an atom quasi-bound to an ion that is periodically driven inside a Paul trap, by solving self-consistently the time-dependent wavefunctions of the atom together with the periodic force it exerts on the ion [2].

References

[1] H. Landa, arXiv: 1506.08779

[2] H. Landa and G. V. Shlyapnikov, *in preparation*

Single collision between ground-state cooled ion and ultracold atoms

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We experimentally study the dynamics of single, to few, elastic collisions between ultracold ^{87}Rb atoms and single $^{88}Sr^{+}$ ion. We prepare the atoms in a dipole trap and cool them below μK temperature before we overlap them with a single ion in its 3D motional ground-state (n<0.1). We trap the ion in a segmented linear RF Paul trap (RF=26.5MHz, Secular=1.3,0.85,0.58MHz) with excess micromotion compensated below 0.5mK in all three axes both in-phase and quadrature. Atom-ion collisions which interrupt the ion's micromotion phase heat the ion up [1,2]. We measure the temperature and the spin of the ion after single, to few, collisions using a narrow line-width (100Hz) laser resonant with an optical quadrupole transition. Alternatively, we measure the ion's steady-state temperature after hundreds of collisions using the Doppler re-cooling technique on a strong optical dipole transition. In our trap, a single collision increases the ion energy by roughly its uncompensated excess micromotion energy (~0.5mK) and also depolarizes its spin. The steady state temperature however (10's mK) is measured to be higher by more than an order of magnitude than any energy scale in our system. We plan to scan the ion trap parameters in order to get deeper understanding of the elastic collisions mechanism. Our goal is to study ultra-cold collisions beyond the semi-classical regime by looking only on the first few collisions.

References

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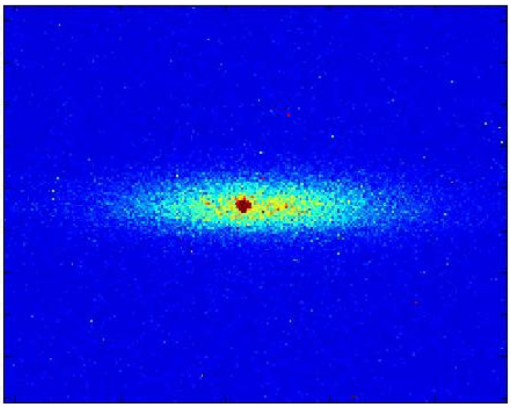

Figure: Single $^{88}Sr^{+}$ ion immersed in a cloud of ultracold ^{87}Rb atoms in a dipole trap.

Strongly Interacting One-Dimensional Bose Systems and Bose Polarons

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Strongly interacting one-dimensional quantum systems often behave in a manner that is distinctly different from their higher-dimensional counterparts. When a particle attempts to move in a one-dimensional environment it will unavoidably have to interact and 'push' other particles in order to execute a pattern of motion, irrespective of whether the particles are fermions or bosons. A present frontier in both theory and experiment are mixed systems of different species and/or particles with multiple internal degrees of freedom.

Here we consider trapped two-component bosons with short-range inter-species interactions much larger than their intra-species interactions and show that they have novel energetic and magnetic properties. In the strongly interacting regime, these systems have energies that are fractions of the basic harmonic oscillator trap quantum and have spatially separated ground states with manifestly ferromagnetic wave functions. Furthermore, we predict excited states that have perfect antiferromagnetic ordering. This holds for both balanced and imbalanced systems, and we show that it is a generic feature as one crosses from few- to many-body systems.

In addition we setup a new theoretical framework in one-dimension for describing and calculating the ground state energy for an impurity in a N-boson system. Our theory works for any number of N bosons as majority particles and also adaptive to any external confinement, arbitrary mass ratios and even small but non-zero intra-species interaction strength. The results for 1+8 polaron system show very well agreement with the numerically exact results and thus our theory can provide definite predictions for the experiments in cold atomic gases at zero temperatures.

A single charge in a Bose-Einstein condensate: from two to few to many-body physics

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Electrons attract polarizable atoms via a 1/r^4 potential. For slow electrons the scattering from that potential is purely s-wave and can be described by a Fermi pseudopotential. To study this interaction Rydberg electrons are well suited as they are slow and trapped by the charged nucleus. In the environment of a high pressure discharge Amaldi and Segre, already in 1934 observed a lineshift proportional to the scattering length [1].

At ultracold temperatures and Rydberg states with medium size principle quantum numbers *n*, one or two ground state atoms can be trapped in the meanfield potential created by the Rydberg electron, leading to so called ultra-long range Rydberg molecules [2].

At higher Rydberg states the spatial extent of the Rydberg electron orbit is increasing. For principal quantum numbers *n* in the range of 100-200 and typical BEC densities, up to several ten thousand ground state atoms are located inside one Rydberg atom, We excite a single Rydberg electron in the BEC, the orbital size of which becomes comparable to the size of the BEC. We study the coupling between the electron and phonons in the BEC [3].

We also observe inelastic processes caused by ground state atoms inside the Rydberg orbital. For high n (n>100) ground state atoms scatter many times elastically before an inelastic state change happens. These long lifetimes open perspectives for the imaging of the Rydberg electron's wave function by its impact onto the surrounding ultracold cloud [4].

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Motional and vibrational cooling of molecular ions with cold and highly-polarizable atoms.

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Recent experimental advances that have demonstrated sympathetic cooling of Coulomb-crystalized molecular ions with laser-cooled atomic ions [1, 2] have attracted a great deal of interest. This cooling method, however, only produces translationally cold molecular ions without achieving internal state relaxation. This is due to the state-indendent nature of the long-range Coulomb interaction between the molecular and atomic ions. References [3, 4] proposed and demonstrated a novel alternative cooling method that both cools external and internal molecular-ion degrees of freedom by collisions with ultracold neutral and highly-polarizable atoms.

In the present study we theoretically investigate the interactions between molecular ions and neutral atoms over a wide range of collision energies. At low energies quantum mechanical e_ects have a profound inuence on the molecular scattering from their long-range □1=r4 potential and play an important role in the description of the interplay between inelastic and elastic collisional processes. Elastic collisions cool the motion of molecular ions to mK temperatures, whereas inelastic collisions lower the internal rovibrational state of the molecular ion thereby leading to vibration- and rotation-less ions. In particular, we explore interactions of molecular ions with either highly-polarizable atoms or with helium atoms in order to gain insight into the motional and vibrational cooling of the ions. For our analyses we use a scattering model based on quantum defect theory (QDT) with the exible short-range boundary conditions. Unlike for the interaction between neutral particles, the atom-ion potential is much longer ranged and for temperatures as low as a few millikelvin multiple partial waves contribute to the rates. Moreover, the short-range parameters are found to have a strong partial-wave dependence leading to the dramatic change in the scattering mechanism going from nearly total reection for the s-wave dominated collisions to almost total inelastic quenching for higher temperatures.

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Nature 495, 490 (2013).

Trapping Ions Atoms and Molecules Optically

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Isolating ions and atoms from the environment is essential in experiments on a quantum level. For decades, this has been achieved by trapping ions with radiofrequency (rf) fields and neutral particles with optical fields. Our group demonstrated the trapping of ions by interaction with light [1,2]. We take these results as starting point for finally combining the advantages of optical trapping and ions [3]. In particular, ions provide individual addressability, high fidelities of operations and long-range Coulomb interaction, significantly larger compared to those of atoms and molecules.

We aim to demonstrate the improvement of our approach in the context of interaction and reaction at ultra-low temperatures as a showcase. Following the seminal work in the groups of Vuletic, Koehl and Denschlag in hybrid traps, we plan to embed optically trapped ions into quantum degenerate gases to reach lowest temperatures, circumventing the currently inevitable excess kinetic energy in hybrid traps, where ions are kept but also driven by rf-fields [4]. It might permit to enter the temperature regime where quantum effects are predicted to dominate, (i) in many-body physics, including the potential formation and dynamics of mesoscopic clusters of atoms [5] of a BEC, binding to the impurity ion, as well as (ii) the subsequent two-particle s-wave collisions, the ultimate limit in ultra-cold chemistry. We will report about our recent results [6] on optically trapping $^{138}Ba^{+}$ in a far-off-resonant dipole trap and ^{87}Rb atoms in a MOT in our laboratory.

References

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Rotational Cooling of Coulomb-Crystallized Molecular Ions by a Helium Buffer Gas

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In this talk, I will discuss recent experimental results on helium buffer-gas cooling of the rotational degrees of freedom of MgH^+ molecular ions, which are trapped and sympathetically crystallized in a linear radio-frequency quadrupole trap [1]. With helium collision rates of only ~10 s^{-1}, i.e. four to five orders of magnitude lower than in usual buffer gas cooling settings, we have cooled a single molecular ion to an unprecedented measured low rotational temperature of $7.5^{+0.9}_{-0.7}$K. In addition, by only varying the shape and/or the number of atomic and molecular ions in larger Coulomb crystals, we have tuned the effective rotational temperature from ~7 K up to ~60 K by changing the micromotion energy. The very low helium collision rate may potentially even allow for sympathetic sideband cooling of single molecular ions, and eventually make quantum-logic spectroscopy of buffer gas cooled molecular ions feasible. Furthermore, application of the presented cooling scheme to complex molecular ions should have the potential of single or few-state manipulations of individual molecules of biochemical interest. This latter perspective can hopefully be exploited to disentangle various processes happening in complex molecules, like light harvesting complexes.

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Driven-dissipative Bose-Einstein condensates

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Ultracold quantum gases are usually well isolated from the environment. This allows to study the ground state properties and the unitary dynamics of a many-body quantum system under almost ideal conditions. Introducing a controlled coupling to the environment “opens” the quantum system and non-unitary dynamics can be investigated. Such an approach provides new opportunities to study fundamental quantum effects in open systems and to engineer robust many-body quantum states.

In this talk I will present an experimental platform [1,2] that allows for the controlled engineering of dissipation in ultracold quantum gases by means of localized particle losses. This technique is exploited to study quantum Zeno dynamics [3] and non-equilibrium dynamics [4]. We were also able to realize non-equilibrium steady-states in a driven-dissipative Bose-Einstein condensate.

References

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Next-generation ion-atom hybrid trap for high-resolution cold-collision experiments

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The recent development of experiments for the combined trapping of cold ions and cold neutral atoms has paved the way for studying interactions between these species at extremely low energies [1]. Cold ion-atom hybrid systems were found to display a rich chemistry including charge exchange and the formation of molecular ions by radiative association [2]. An intriguing feature of cold collisions are scattering resonances which manifest themselves as marked modulations of the collision cross section at well-defined collision energies [3,4]. These resonances are a consequence of the quantum character of the collisions and reveal important information about the scattering dynamics, the underlying interaction potential and, in case of reactive collisions, the reaction mechanism. Although theory predicts them to be ubiquitous in reactive collisions between cold ions and atoms [3,4], the poor energy resolution of previous experiments has precluded their observation so far.

Here, we present a new type of hybrid trap which enables cold ion-atom collision experiments with a greatly improved energy resolution on the order of mK, accessing the regime in which resonances should be observable [3]. The experiment consists of strings of Coulomb-crystallized ions sandwiched in between two magneto-optical traps (MOT). Using radiation-pressure forces, cold atoms are shuttled back and forth between the MOTs during which they pass through the ion crystal with a well-defined, controllable energy. Here, we present a detailed characterization of the performance of the setup and first results on high-resolution collision experiments between cold Ca^+ ions and Rb atoms.

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Capture Dynamics between Ultracold Atoms and an Impurity Ion

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We consider an ultracold ensemble of trapped interacting bosonic atoms in which a single ion is created. We focus on effects induced by the atom-ion interaction and the impact of bound states onto the properties of the system. As a first step, we analyzed the influence of the atom-atom interaction and the atom number on the ground state properties [1]. Hereupon, we investigated the dynamics following a sudden creation of the ion in the atomic cloud [2]. The additional length scale originating from the atom-ion interaction becomes clearly apparent. These investigations serve as first building blocks for the understanding of hybrid atom-ion systems which exhibit intriguing phenomena as e.g. formation of molecular ions [3] and ion induced density bubbles [4]. Our study is carried out by means of the multilayer-multiconfiguration time-dependent Hartree method for bosons [5].

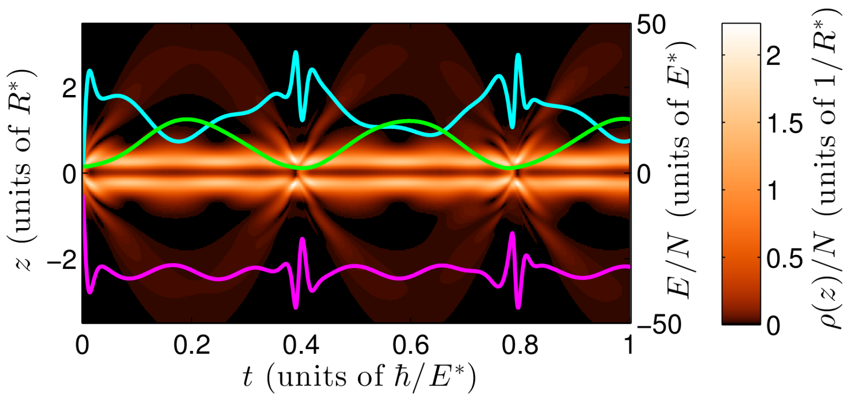

Fig. 1: Time evolution of the one-particle density ρ(z, t) and the components of the total energy per particle for a system with N = 2. The green, cyan, and magenta lines represent the trapping, kinetic, and ionic energy per particle, respectively. Two different oscillations stemming from the two energy scales can be observed.

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Local ionization of ultracold gases induced by femtosecond laser pulses

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The combination of ultracold atomic systems and ultrafast laser pulses promises insight into the coherence properties of macroscopic dissipative quantum targets and enables the preparation of hybrid quantum systems through local ionization of atoms in strong laser fields.

We report on the investigation of trapped ultracold ^{87}Rb atoms and Bose-Einstein condensates (BEC) exposed to femtosecond laser pulses of 512 nm wavelength and 290 fs duration. The intense light pulses ionize atoms within the focal region of the beam (7 µm waist) via two-photon absorption. The number of generated ions can be controlled by tuning the intensity or the wavelength of the laser pulses.

Remaining atoms are detected by resonant absorption imaging, either in situ or after time-of-flight. Atomic losses evident as a hole in the trapped cloud are evaluated and show a nonlinear increase with respect to the pulse energy corroborating the generation of ions in a multiphoton process. Additionally, first results on the relaxation dynamics of a thermal cloud and a condensate after exposure to a single pulse will be discussed as well as further perspectives on detection of the charged fragments.

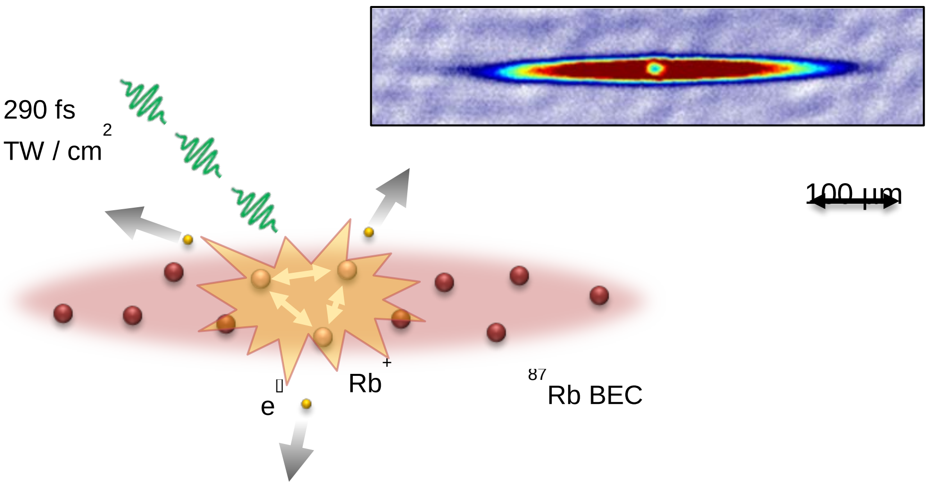

Figure 1: *^{87}Rb atoms in a BEC are ionized by femtosecond laser pulses in a two-photon process. The inset shows an absorption image with the remaining hole in the atomic cloud.*

Formation and control of molecular ions in ultracold ion-atom systems

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The electronic structure of the $(LiYb)^+$ molecular ion is investigated and subsequently employed in scattering calculations and photoassociation studies [1]. Feshbach resonances are shown to be measurable in the Li + Yb^+ system, despite the ion's micromotion in the Paul trap. Formation of molecular ions via spontaneous radiative association and laser-induced photoassociation are studied. Favorable conditions for sympathetic cooling of an Yb^+ ion by an ultracold gas of Li atoms are found and suggest excellent prospects for building a quantum simulator with ultracold Yb^+ ions and Li atoms [2].

The Feshbach resonances between the Ca^+, Sr^+, Ba^+, and Yb^+ ions immersed in an ultracold gas of the Cr atoms are proposed and analyzed as the first experientially feasible heteronuclear hybrid ion-atom system in which ion-atom interactions at ultralow temperatures can be controlled with magnetically tunable Feshbach resonances without charge transfer and radiative losses [3].

Finally, it is shown that molecular ions in weakly bound rovibrational states have a giant permanent electric dipole moment with a value up to 1000 Debye and a giant electric dipole polarizability. It is suggested how these electric properties can be controlled with magnetically tunable Feshbach resonances and how the molecular ion dynamics at ultralow temperatures can be controlled with a laser-induced Stark shift and measured in single-ion spectroscopy experiments [4].

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Realizing a hybrid atom-ion trap for Li and Yb^+

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Systems comprised of ultra-cold atoms interacting with trapped ions are interesting for studying cold chemistry, ultra-cold collisions and quantum many-body physics [1]. The time-dependent trapping field of the Paul trap can however cause heating in hybrid atom-ion systems, preventing reaching deep into the quantum regime. One way to mitigate this problem is to employ ion-atom combinations with a large mass ratio [2]. In my talk I will present the design and development of a hybrid Yb+/Li experiment. This combination has the highest convenient mass ratio - for species that still allow for straightforward laser cooling - of ~29. I also introduce a two-ion-atom detector we plan to implement in the experiment. Here, a pair of ions is used to detect atoms or atom-ion interactions by making use of non-classical states.

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Few-body dynamics of a Rydberg electron impurity in a quantum gas

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The non-equilibrium few-body dynamics in a BEC subject to a single Rydberg excitation/impurity is simulated. The absorption spectrum of the system with principal quantum number leading to formation of oligomeric molecular Rydberg states is investigated. The emergence of a shell structure in which ground state atoms arrange themselves in recombinatorial binding in different molecular potential wells is presented.

Complex Collisions of Atoms and Molecules

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Much success has been obtained in utilizing the resonantly tunable collisions of cold atoms to control the few- and many-body properties of atomic gases [1], with good prospects to control also molecular collisions [2]. As more complex cooled and trapped atomic, molecular, or ionic species become available for applications in more complex environments, it will be necessary to construct adequate theoretical models of their interactions. In this talk we will concentrate on understanding collisions in which there are dense sets of overlapping resonances, using simple models based on quantum defect theory [3,4]. Such models give qualitative ways to help understand the collisions of complex atoms like Dy, for which in some cases simple universal properties exist even in the midst of apparently chaotic spectra [5]. This talk will highlight some of the unsolved challenge confronting experiment and theory as to what extent complex atoms and molecules can be controlled in useful ways using external fields to tune their dense spectrum of near-threshold resonances.

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Bosonic Lattice Gases with Long-Range Interactions and Dissipation

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Recent experiments have shown that (quasi-)crystalline phases of Rydberg-dressed quantum many body systems in optical lattices (OL) are within reach [1]. While conventional neutral atomic OL gases lack strong long-range interactions, they arise naturally in Rydberg systems, due to the large polarisability of Rydberg atoms. In combination with the bosonic character of these systems, a wide range of quantum phases have been predicted. Among them are a devil's staircase of lattice-incommensurate density wave states as well as more exotic supersolid lattice order. High experimental tunability opens up a wide range of parameters to be studied. We study the ground state phase diagram at finite hopping amplitudes and in the vicinity of resonant Rydberg driving. Since different types of lattice-incommensurate order are to be expected, we apply a real-space extension of bosonic dynamical mean-field theory (RB-DMFT). This method allows a non-perturbative treatment of local quantum correlations and yields a rich phase diagram, illustrating the competition between interaction and condensation.
We furthermore investigate steady-state quantum transport in the dissipative-driven Bose-Hubbard model, which can be realized in coupled optical microcavities [2]. In our studies based on a Lindblad master equation combined with Gutzwiller mean-field theory, we observe a quantum Zeno effect and negative differential conductivity.

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Optical Lattices with large scattering length

Carlos Lobo

I will discuss a new proposal to go beyond the standard way of thinking of atoms in optical lattices by bringing in ideas from few-body physics. I will consider a setup where one atomic species is trapped in a lattice at full filling while another is untrapped (does not see the optical lattice) but has an s-wave contact interaction with the first one. If the interspecies scattering length a is positive and on the order of the lattice spacing d then the usual two- body bound (dimer) states overlap forming a polyatomic molecule extending over the entire lattice, which can also be viewed as a band solid for the untrapped species, where the trapped atoms play the role of ions. This setup requires large scattering lengths but minimises losses, does not need higher bands and adds new degrees of freedom which cannot easily be described in terms of lattice variables. As an example I show how to create an “electron”-phonon quantum simulator which exhibits renormalization of the phonon frequencies due to electron-ion interactions, Peierls instability, and where the effective phonon Hamiltonian can be mapped in some cases to a quantum transverse Ising model.

Abstracts of Posters

Photonic Phase Gates via Rydberg Blockade in Optical Cavities

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For realization of photonic quantum logic gates one requires strong non-linearity at the quantum level of a few to single photon [1]. A promising approach towards creating such nonlinearity is to utilize the excitation blockade in Rydberg EIT systems with optical depth much greater than unity [2,3]. It is, however, quite challenging to obtain this regime of optical depth in current experimental setting. We here propose a novel scheme to circumvent this challenge and achieve a high fidelity photonic phase gate by using Rydberg blockade in a Rydberg EIT ensemble trapped inside an optical cavity. Use of a cavity gives us two major advantages compared to ensembles in free space. (1) The cavity enhance the coupling of the incoming light to the atoms in the Rydberg ensemble, with controlled mode structure and high input-out efficiency [4]. (2) It effectively increases the non-linearity by increasing the optical depth with a factor proportional to the cavity finesses. We show that this allows the implementation of the gate by (i) encoding the qubit in a superposition of vacuum and single photon state of an input photon pulse or (ii) by encoding the qubit in two distinct modes. The phase flip operation between two photon pulses is attained by scattering the second one from a blockaded ensemble where the first was stored as a Rydberg excitation [5]. We also show how our gate can be used to improve quantum repeaters based on atomic ensembles. Thus our proposed gate can provide efficient photonic logic operations in future quantum networks.

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Non-resonant laser field control of magnetically tunable Feshbach resonances in quantum ultracold atomic gases

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Magnetically tunable Feshbach resonances represent the essential tool to control interaction between atoms in ultracold gases and serve as a gate into ultracold molecular world via magnetoassociation. There are systems, however, where Feshbach resonances occur with lower density or have parameters that are not useful in experiments. For example, magnetically tunable Feshbach resonances for polar paramagnetic ground-state diatomics are too narrow to allow for magnetoassociation [1].

It was recently shown that non-resonant light can be used to engineer the Feshbach resonances in their position and width in mixtures of open-shell and close-shell atoms (e.g. Rb+Yb) [2]. For non-resonant field intensities of the order of 109 W/cm2, it was found the width to be increased by 3 orders of magnitude, reaching a few Gauss. Here, we apply this non-resonant laser field control to other mixtures of open-shell and close-shell atoms being of experimental interest (Rb+Sr, Cs+Yb, Li+Yb) as well as to gases of alkali atoms (Li+Li, Rb+Rb). In the second case, we have found that the position of resonances can be noticeably controlled with non-resonant field intensity of the order of 107 W/cm2. We have also investigated the interplay between the laser wavelength and the intensity and have found that by decreasing the wavelength, the non-resonant field intensity lower by up to the order of magnitude has the same effect.

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A hybrid atom-ion trap for Li and Yb^+

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A setup for realising a hybrid system of ultra-cold atoms and ions is presented. This will allow studying the quantum dynamics of mixtures of fermionic atoms and ions. Recent theoretical analysis has shown that the time-dependent trapping field of the ions can cause heating in hybrid atom-ion systems. One way to mitigate this problem is to employ ion-atom combinations with a large mass ratio [1]. The highest convenient mass ratio - for species that still allow for straightforward laser cooling - is ~29, and is achieved by using the combination $^{174}Yb^+$ and ^{6}Li. Combining ion trapping technology with ultra-cold Li poses particular challenges that we address on this poster. We discuss a setup for measuring atom-ion interactions that involves an ancillary detection ion that is coupled to the probe ion by the Coulomb interaction.

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Condensation vs. Interaction: Competing Quantum Phases in Bosonic optical lattice systems at near resonant Rydberg dressing

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Recent experiments have shown that (quasi-)crystalline phases of Rydberg-dressed quantum many body systems in optical lattices (OL) are within reach [1]. While earlier neutral atomic OL gases lack strong long range interactions, they arise naturally in Rydberg systems, due to the large polarisability of Rydberg atoms. Combined with the bosonic character of the systems considered in our work, a wide range of quantum phases have been predicted. Among them are a devil's staircase of lattice incommensurate density wave phases [2] as well as the more exotic supersolid lattice order [3]. High experimental tunability opens up a wide range of parameters to be studied. Based on our previous analysis of the ”frozen” gas case, we studied the ground state phase diagram at finite hopping amplitudes and in the vicinity of resonant Rydberg driving. Since varying lattice incommensurate order is to be expected, we applied a real-space extension of bosonic dynamical mean-field theory (RB-DMFT). This method allows a non-perturbative treatment of local interactions and also takes lowest order nearest neighbour fluctuations into account. It therefore improves upon basic mean field theories such as obtained via the Gutzwiller approximation (GA), yielding a very rich phase diagram which illustrates the competition between interaction and condensation.

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Ultralong-Range Rb-KRb Rydberg Molecules: Electronic Structure, Orientation and Alignment

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We investigate the structure and features of an ultralong-range triatomic Rydberg molecule formed by a Rb Rydberg atom and a KRb diatomic molecule. In our numerical description, we perform a realistic treatment of the internal rotational motion of the diatomic molecule, and take into account the Rb(n, l ≥ 3) Rydberg degenerate manifold and the energetically closest neighboring levels with principal quantum numbers n′ > n and orbital quantum number l ≤ 2. We focus here on the adiabatic electronic potentials evolving from the Rb(n, l ≥ 3) and Rb(n = 26, l = 2) manifolds [1,2]. The directional properties of the KRb diatomic molecule within the Rb-KRb triatomic Rydberg molecule are also analyzed in detail [1,2].

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Motion manipulation of ammonia and 4-aminobenzonitrile with microwave fields

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Motion manipulation of large and complex molecules or molecules in their ground state requires methods that are compatible with high-field-seeking states. In inhomogeneous fields, molecules in high-field-seeking states experience a force towards the field maxima. However, true three-dimensional field maxima cannot be realized in free space with static fields alone. Therefore, motion manipulation of such quantum states requires the use of time-dependent fields. In a previous experiment using resonator-enhanced microwave fields, deceleration of a slow packet of ammonia molecules was achieved [1, 2]. In this case, the ammonia molecule can be considered an isolated two-level system to a good approximation.

In order to make this technique more generally applicable we are developing a modified experimental setup for larger and heavier molecules. 4-aminobenzonitrile (4-ABN) is an ideal candidate as it has a molecular mass of 118 u and possesses a large dipole moment, which is essential for a strong interaction with the microwave field. Due to its large density of states, 4-ABN cannot be treated as a two-level system. A numerical approach that utilises the dressed-state model has been developed to predict the ac-Stark shifts for the rotational energy levels of 4-ABN. Based on the calculated ac-Stark shifts, trajectory simulations allow for a detailed analysis of potential experimental setups for various microwave motion manipulation experiments with 4-ABN.

Here, we will present the results of the microwave motion manipulation experiments with ammonia as well as simulation results for 4-ABN and their impact on the new experimental setup.

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Emergence of chaos in the presence of densely overlapping Feshbach resonances

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Extremely dense sets of Feshbach resonances have been found, for instance, in highly magnetic lanthanide atoms. The statistics of the resonance spacings in erbium has recently been studied experimentally [1] and showed features characteristic for chaotic systems described by Random Matrix Theory. Here we study theoretically how the mutual interaction of overlapping resonances in a general situation can influence the resonance spacings. In our analysis we make use of a simple quantum-defect model, which provides analytical formula for the scattering length [2]. We find out that the statistical properties of resonance spacings may resemble chaotic behavior even if the assumptions of RMT are not fulfilled.

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A hybrid atom-ion trap for Li and Yb^+

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A setup for realising a hybrid system of ultra-cold atoms and ions is presented. This will allow studying the quantum dynamics of mixtures of fermionic atoms and ions. Recent theoretical analysis has shown that the time-dependent trapping field of the ions can cause heating in hybrid atom-ion systems. One way to mitigate this problem is to employ ion-atom combinations with a large mass ratio [1]. The highest convenient mass ratio - for species that still allow for straightforward laser cooling - is ~29, and is achieved by using the combination $^{174}Yb^+$ and ^{6}Li. Combining ion trapping technology with ultra-cold Li poses particular challenges that we address on this poster. We discuss a setup for measuring atom-ion interactions that involves an ancillary detection ion that is coupled to the probe ion by the Coulomb interaction.

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Manoj Joshi

In an ion trap, the trapping force pushes the atomic ions towards the trap centre and the Coulomb repulsion tries to keep them apart. In equilibrium state and at a low temperature, a periodic arrangement of atomic ions is realized which is known as ion Coulomb crystal. These crystals have remarkable properties and are suitable for Quantum simulations. In this poster I will present some preliminary results on ion Coulomb crystals and their feasibility to sideband cooling. Sideband cooling is a technique to reduce the motional quantum numbers of confined ions. Recently, we have cooled a single calcium ion confined in a Penning trap to its motional ground state and currently we are planning to extend it to more than one ion.

Advances in optical trapping of Barium ions

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Interaction of ions with optical potentials has been implemented in a number of groups, with promising applications in (quantum) simulations [1-4] and ion-atom interaction experiments [5,6]. In the latter case, the absence of rf-micromotion inside a purely optical and electrostatic potential should mitigate the intrinsic heating effect described by Cetina et al. [7]
In this poster, we present our most recent results for optical trapping of Barium ions. These include optical trapping of multiple ions, which is possible when the Paul trap axis coincides with the trapping laser's propagation axis. We also present an optical trap assisted method to controllably load samples of small numbers of ions, which is useful in the case of the large trapping volume in our Paul trap. We also discuss several methods to improve the lifetime of the ion in the optical trap. Finally, the design of our Paul trap with a large ion-electrode distance of 9mm and improved optical access allows for compensation of electric stray fields to better than 30mV/m with standard techniques, which could be improved using more sensitive methods, such as the one recently demonstrated in our group [6].

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Quench Dynamics of Two Coupled Ionic Zig-Zag Chains

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Ion traps are versatile tools for experiments in various fields, such as spectroscopy, quantum computing, molecular physics and biophysics [1]. Even though there is a large interest in the formation of various structures like ion crystals [2] or zigzag configurations [3,4] the underlying dynamics are often not well understood. Here we investigate the dynamics of trapped ions in a two-dimensional double well potential. The initial state of the ions in our setup is given by well-separated zig-zag configurations in both wells. After quenching the barrier between the wells various structures including the formation of lines and partial revivals to the initial zig-zag configuration can be observed to alternate with phases of irregular motion in the course of the time evolution.

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Interactions in mixed ultracold trimers of rubidium and strontium

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As there was recently growing interest in studies of ultracold, polar molecules with nonzero spin, such as RbSr or YbLi molecules we have started to explore the interactions in mixed trimers of strontium and rubidium in the lowest high-, and lowspin electronic states using single-, and multireference ab-initio approaches in the Born-Oppenheimer approximation.
RCCSD(T) method with effective core potentials was employed to compute potential energy surfaces in the high-spin case for the electronic triplet ground state of RbSr+Rb and the electronic doublet ground state of RbSr+Sr in A' irreducible representation of Cs symmetry point group. Studies of the minimum energy path with RCCSD(T) have shown a strong anisotropy of the interaction potential in both investigated trimers.
We have found that a strong anisotropic spin-exchange interaction is also very strongly angle-dependent in case of RbSr+Rb system.To explain that we performed MR CI calculations for low-spin singlet state and low-spin triplet state of Rb+Sr+Rb in A1 and B2 irreducible representation of C2v symmetry point group respectively. For the long-range part of interaction potential in RbSr+Rb and RbSr+Sr systems we have estimated the isotropic and anisotropic C6 coefficients. We have shown that interactions in described trimers primarily come from the dispersion effect.

Control of chemical reactivity through spatial separation of molecular conformations

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Many molecules have multiple conformations (rotational isomers), which can exhibit different reactivities, opening up perspectives to manipulate chemical reactions by selecting specific molecular conformations [1]. In a recent experiment we studied the reactive collisions between conformationally selected 3-aminophenol and a Coulomb crystal of laser-cooled Ca^+ ions. We found that the dynamics of the reactions of Ca^+ with cis- and trans-3-aminophenol are mainly controlled by conformer-specific differences in the long-range ion molecule interaction potential [2,3]. In a new experiment, we want to study short-range reactive effects in an ion-molecule reaction. We are investigating the polar cycloaddition reaction of conformationally selected 2,3-dihalobuta-1,3-diene with acetylene$^+$ or CO^+ ions. To analyze the products of this reaction, we developed a new ion trap that is coupled to a time of flight mass spectrometer. On the poster we present a summary of the Ca^+–aminophenol experiment, the new ion trap, and calculations and an outlook for the new experiment.

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Ultracold collisions of an Ion in an optical dipole trap

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Examining collisions of atoms and ions at extremely low velocities permits to gain information about the corresponding scattering potentials and therefore of quantum effects in chemical reactions. In the last years several experimental groups investigated cold collisions between atoms and ions, leading to better understanding of the atom-ion interaction in many different aspects[1-3]. Our approach to reach the regime of ultracold collisions is to precool a barium+ ion, trapped in a conventional Radio-Frequency (RF) trap, by Doppler cooling followed by sympathetic cooling via an ambient rubidium MOT. By spatially overlapping the ion and the atom ensemble within a bichromatic optical dipole trap we overcome the limitations set by heating due to the RF micromotion[4]. We present the apparatus in its recent stage, results of optical trapping of barium ions in a far-off-resonant dipole trap[5] and the first collision experiments of an Ba+ Ion in an optical dipole trap with an ambient Rb-MOT.

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Ultracold chemistry of a single Rydberg atom in a BEC

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A single Rydberg excitation in the high density and low temperature environment of a Bose-Einstein condensate (BEC) leads to a fascinating testbed of low-energy electron-neutral and ion-neutral scattering. For a Rydberg state with a principal quantum number of 100, there are thousands of ground-state atoms with which the Rydberg electron interacts. In a BEC the interparticle spacing is at approximately the same length scale as the Langevin impact parameter, making it possible to study the effect of ion-neutral collisions on time scales much faster than the Rydberg lifetime. We measure Rydberg collisions on μs timescales, which are faster than the timescale expected by Langevin physics, demonstrating an electron-assisted collision time. The collision of the Rydberg electron, Rydberg ion core, and neutral atom perturber leads to an n-dependent either exothermic reaction or production of Rb_2+. We compare our findings to simulations based on classical trajectory calculations for the motion of a neutral atom in the Butterfly electron-neutral potential energy curves and we find good agreement with the experiment. Understanding the physics of the collisional lifetimes of Rydbergs in dense media, allows one to tailor future systems as needed for studying Rydberg impurities in quantum gases either for quantum optics, quantum information, polaron physics, or electron-phonon coupling in a BEC.

Atom-Ion Confinement-Induced Resonances

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By using the computational technique for ultracold scattering in low-dimensions [1-3] we investigate confinement-induced resonances (CIRs) at the atom-ion scattering in the presence of an external tight transverse confinement. In the case of ``static ion" we have derived an analytic formula for the CIR position, which depends on the atom-ion scattering length in free-space, the width of the confining trap and the static dipolar polarisability of the atom. This result is in excellent agreement with our numerical calculation. Comparison of the atom-ion CIR and the well investigated atom-atom CIR [4,5] is performed. We also discuss an extension of the developed computational technique for more complicate case of ``moving ion" demanding inclusion of the coupling between the centre-of-mass and relative atom-ion motions.

Currently, several groups and laboratories are working on such hybrid atomic quantum systems (see, for example [6-8]) and our results are therefore so much in demand for the experiments.

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Motion manipulation of ammonia and 4-aminobenzonitrile with microwave fields

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Motion manipulation of large and complex molecules or molecules in their ground state requires methods that are compatible with high-field-seeking states. In inhomogeneous fields, molecules in high-field-seeking states experience a force towards the field maxima. However, true three-dimensional field maxima cannot be realized in free space with static fields alone. Therefore, motion manipulation of such quantum states requires the use of time-dependent fields. In a previous experiment using resonator-enhanced microwave fields, deceleration of a slow packet of ammonia molecules was achieved [1, 2]. In this case, the ammonia molecule can be considered an isolated two-level system to a good approximation.

In order to make this technique more generally applicable we are developing a modified experimental setup for larger and heavier molecules. 4-aminobenzonitrile (4-ABN) is an ideal candidate as it has a molecular mass of 118 u and possesses a large dipole moment, which is essential for a strong interaction with the microwave field. Due to its large density of states, 4-ABN cannot be treated as a two-level system. A numerical approach that utilises the dressed-state model has been developed to predict the ac-Stark shifts for the rotational energy levels of 4-ABN. Based on the calculated ac-Stark shifts, trajectory simulations allow for a detailed analysis of potential experimental setups for various microwave motion manipulation experiments with 4-ABN.

Here, we will present the results of the microwave motion manipulation experiments with ammonia as well as simulation results for 4-ABN and their impact on the new experimental setup.

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Single particle dynamics in an ultracold Bose gas environment

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We investigate the quantum dynamics of a single ion which is immersed into a Bose-Einstein condensate. The ultracold environment acts as a refrigerator, and thus, the influence on the motion of the ion is dissipative. Our focus lies on a detailed description of the environment and the particle-environment interaction. We aim to describe the effective dynamics of the damped particle dynamics using the full bath correlation function instead of a widely used phenomenological damping rate. In this way we gain a more thorough theoretical understanding of properties of quantum matter, such as superfluidity, when acting as an environment.

Rydberg excitation of trapped strontium ions

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Trapped Rydberg ions are a novel approach for quantum information processing [1,2]. This idea joins the advanced quantum control of trapped ions with the strong dipolar interaction between Rydberg atoms. For trapped ions this method promises to speed up entangling interactions [3] and to enable such operations in larger ion crystals [4].

Here, we report on the first trapped strontium Rydberg ions. A single ion was confined in a linear Paul trap and excited to Rydberg states from 26S to 33S using a two-photon excitation with 243nm and 308nm laser light. The transitions we observed are narrow (a few MHz linewidth) and the excitation can be performed repeatedly which indicates that the Rydberg ions are stable in the ion trap. In particular, for these Rydberg states the linewidth of the transition is currently mainly limited by Doppler shifts, which can be further reduced by technical improvements. Similar results have been recently reported on a single photon excitation of calcium ions [5].

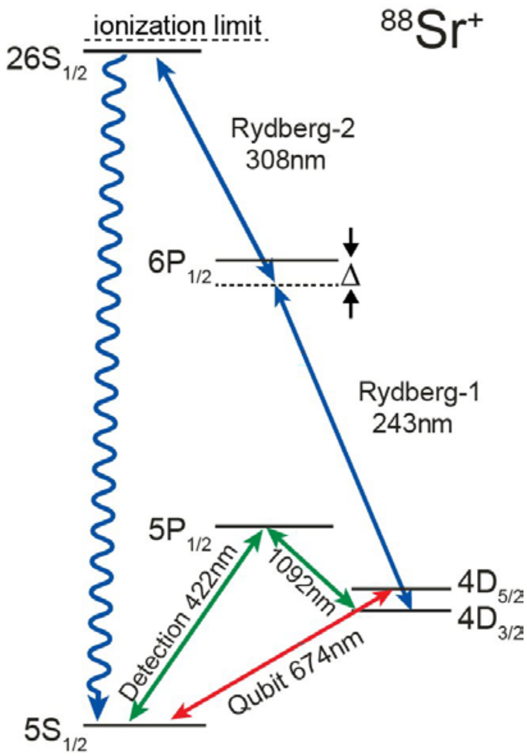

Fig. 1: *Level scheme for two-photon Rydberg excitation of strontium ions. Starting from a $4D_{3/2}$ state the 243nm and 308nm lasers lift the ion to the Rydberg state.*

The tunability of the 304-309nm laser should enable us to excite our strontium ions to even higher Rydberg levels. Such highly excited levels are required to achieve a strong interaction between neighboring Rydberg ions in the trap as will be required for quantum gates using the Rydberg interaction.

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Theory of orbital order and weak ferromagnetism for the antiferromagnetic state of body-centered cubic A15-Cs3C60

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The body-center cubic (bcc) A15-Cs3C60 showed superconductivity under pressure, with the parent state as antiferromagnetic insulator. It is reminiscent of the characteristics of the high Tc superconductors. Careful studies have been carried out to study the antiferromagnetic state of bcc A15-Cs3C60. The weak ferromagnetism at the low temperature is observed, and the antiferromagnetic order is identified through NMR spectrum. We developed a theory to understand the antiferromagnetic state. From the Anderson superexchange mechanism, we derived the effective Hamiltonian for the doped electrons in the (t1u)3 orbitals. By optimizing the energy, we compared the energy of different antiferromagnetic orders, and found the orbital order. We further considered the effect of the crystal field and determined the magnetic order with lower energy. Moreover, we gave an explanation to the weak ferromagnetism in the bcc A15-Cs3C60 based on the structure symmetry and Dzyaloshinskii-Moriya interaction, and predicted the possible spin direction.

Two-photon ionization of a Bose-Einstein condensate

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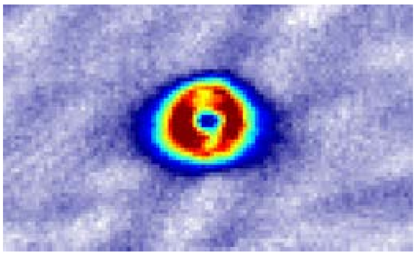
We report on the investigation of ^{87}Rb condensates interacting with femto-second laser pulses at 515nm wavelength. The light pulses ionize atoms of the condensate within the focus region (7µm waist) of the beam via two-photon ionization. The number of produced ions can be controlled by tuning the intensity and the wavelength of the femtosecond-laser or by changing the length of the pulse train. We work in a regime where several thousands of ions are created in the quantum gas.



Picture 2: Bose-Einstein condensate in an optical dipole trap after exposition to femtosecond-laser pulses.

The degenerate gas is prepared in a well-established scheme of cooling. Initially a magneto-optical trap (MOT) is loaded from the background vapor and pre-cooled with laser light. The cold atoms are then transferred to a magnetic trap (MT) where the Bose-Einstein condensation is driven by forced evaporative cooling.

After exposing the condensate to the laser pulses we detect the remaining atoms by resonant absorption imaging either in situ or after time of flight. This allows extracting the number of atoms and their temperature as well as studying the relaxation dynamics. First results on the relaxation of the condensate after interacting with one femtosecond laser pulse will be discussed.

Supersymmetry and eigensurface topology of pendular states of diatomic molecules

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Controlling the rotational degrees of freedom of molecules by external fields is of key importance for frontiers research areas such as molecular imaging or molecular reaction dynamics. For the case of pure first-order (orienting) or pure second-order (aligning) interaction, the corresponding pendular states of diatomic molecules can be expressed in terms of linear combinations of Mathieu functions (planar case) or spherical harmonics (spherical case) for which no closed-form expressions exist. However, the combined orienting and aligning interaction (arising, e. g., for permanent and induced electric dipole interactions of polar and polarizable molecules with collinear electric fields) leads to a conditionally exactly solvable Schrödinger equation. The analytic solutions can be found for specific loci in the plane spanned by the permanent and induced dipole interaction parameters, coinciding with the intersection of the eigenenergy surfaces and of other observables such as alignment and orientation cosines. We find that these loci can be traced analytically and that the number of single eigenstates as well as the number of their intersections can be characterized by a single integer index. For certain values of this index, distinctive for a particular ratio of the interaction parameters, we were able to find analytic expressions for eigenenergies and wavefunctions (as well as for expectation values such as orientation and alignment cosines) using the apparatus of supersymmetric quantum mechanics. In our ongoing work we apply these results to the time domain where we treat transient orientation and/or alignment of molecules induced by pulsed fields.

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Advances in optical trapping of Barium ions

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Confinement of ions assisted by optical potentials has been implemented in a number of groups, with promising applications in quantum simulations with ions [1-3] and ion-atom interaction experiments [4-6]. In the latter case, the absence of rf-micromotion inside a purely optical and electrostatic potential should mitigate the intrinsic heating effect described by *Cetina et al.* [7].

In this poster, we present our most recent results for optically trapping Barium ions without rf. These include trapping of multiple ions, which is possible when the Paul trap axis coincides with the trapping laser's *k*-vector. We present an optical trap assisted method to controllably load samples of small numbers of ions, which is useful in the case of the large trapping volume in our Paul trap. We also discuss several methods to improve the lifetime of the ion in the optical trap.

Finally, the design of our new Paul trap with a large ion-electrode distance of 6 mm and improved optical access allows for compensation of residual electric stray fields to better than 25 mV/m with standard techniques, which could be improved using more sensitive methods, such as the one recently demonstrated in our group [6].

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ınteracting bosons in an optical cavity

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We numerically simulate strongly correlated ultracold bosons coupled to a high-finesse optical cavity. Assuming that a weak classical optical lattice is added in the cavity direction, we describe this system by a generalized Bose-Hubbard model, which is solved by means of bosonic dynamical mean-field theory. For a single-mode cavity, pumped by a laser beam in the transverse direction, the complete phase diagram is established, which contains two novel self-organized quantum phases, lattice supersolid and checkerboard solid, in addition to conventional phases such as superfluid and Mott insulator[1]. At finite but low temperature, thermal fluctuations are found to enhance the buildup of these self-organized phases. We demonstrate that cavity-mediated long-range interactions can give rise to stable lattice supersolid and checkerboard solid phases even in the regime of strong s-wave scattering. In the presence of a harmonic trap, we discuss the coexistence of these self-organized phases, as relevant to experiments. Furthermore, we investigate a system of bosons coupled to two crossed cavity modes, whose axes' angle is 60 degree. We study self-organization phenomena in the resulting hexagonal lattice.

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Theory for twin matter waves experiments

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We develop the framework within Bogoliubov theory that describes the system in which atoms are scattered from a Bose-Einstein condensate into two separated regions. We find the full dynamics of the pair-production process, calculate the first and second order correlation functions, and show that the system is ideally number-squeezed. We calculate the maximum attainable interferometric precision to show how the entanglement between atoms from the two regions changes in time. We also provide a simple expression for the lower bound of the useful entanglement in the system in terms of the average number of scattered atoms and the number of modes they occupy. We apply our theory to the 'twin-beam' experiment [1]. The only numerical step of our semi-analytical description can be easily solved and does not require implementation of any stochastic methods.

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Investigating reactive three-body collisions with ^{87}Rb atoms and a $^{138}Ba^+$ ion

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Recent measurements in our lab with $^{138}Ba^+$ have shown that the three-body recombination is the main channel for ion loss in our system, even at moderate atomic densities of N= 10^{12} cm^3.

From the theoretical viewpoint ultracold three-body recombination is predicted to produce dominantly very weakly bound molecules - we however, observe ions of large energies after the ion was immersed in the cloud of ultra cold atoms.

Therefore we think that fast secondary processes like photodissociation play an important role.

I will report on the latest insights, that we have gained on these atom-atom-ion reactions.

Polaronic effects in two-band quantum systems

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In this work we study the formation and dynamics of polarons in a system with a few impurities in a lattice immersed in a Bose-Einstein condensate (BEC). Here we consider a two-band model for the impurity atoms, along with a Bogoliubov approximation for the BEC, with phonons coupled to impurities via both intra- and inter-band transitions. We decouple this Fröhlich-like term by an extended two-band
Lang-Firsov polaron transformation using a variational method. A Lindblad master equation is used to take into account residual incoherent coupling between polaron and bath. Under this polaronic treatment, the inter-band relaxation process leads to a description of impurity dynamics, which will renormalize Fermi's Golden Rule at different impurity-BEC coupling strength. For strong coupling, the polaron is tightly dressed in each band and can not hop between them, leading to an inter-band self-trapping effect.

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Optical Properties of quaternary half-metal half Heusler alloys CoV1-xMnXSi

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An ab initio calculations were performed using the full potential linearized augmented plane waves (FP-LAPW) within generalized gradient approximation (GGA) in framework of the density functional theory (DFT)) as implemented in wien2k code. In aims to predict the elastic, structural, electronic, magnetic and optical properties of CoV1-xMnXSi half Heusler alloys. The preliminary results of compounds exhibit half metallic ferromagnets behavior with polarization of 100% andmagnetic moments of 3μB which agree with Slater-Pauling rule. Elastic properties confirm the stability for wide range and the electronic properties like DOS, band structure, and optical properties were studied in detail, these properties make it good candidates for spintronics applications.

Keywords: DFT, half Heusler, half metallic, optical properties, spintronics.

Magnetism and dynamics in strongly interacting one-dimensional systems

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Strongly-interacting one-dimensional few-body systems provide a great playground for studying magnetic correlations. Using a combination of numerical [1] and analytical methods [2,3], we discuss how ferro- and antiferromagnetic few-body systems can be created and manipulated in trapped cold atomic systems. Of particular interest is the role of quantum statistics [4] and we consider multi-component bosonic and fermionic examples [5,6,7]. We will then discuss some examples of how strongly interacting particles can be used in quantum state transfer and more generally in spintronics [8,9]. Finally, we show some new examples of how time-dependent external confinement can be used to achieve generalized N-body exchange with near-perfect fidelity [10].

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Feshbach resonances in mixtures dimers of alkali-metal atoms with alkaline-earth and lanthanides: toward paramagnetic and polar molecules

Piotr Zuchowski

Feshbach resonances in mixtures of ultracold atoms have been intensively studied over past several years. Their applications include polar molecule formation or studies of many-body quantum phenomena, such as Efimov states. However, at present studies of mixtures are limited to alkali metals dimers only.

I will discuss possible mechanisms which lead to Feshbach resonances in systems other than alkali-metal dimers. These include alkali metal + ground state alkaline-earth atom mixtures, where very narrow and scarse Feshbach resonances can exist [1]. I will present also the study of Feshbach resonances in Er+Li system [2] in which there is tens of resonances for the fields below 1000 G including few broad resonances with the width larger than 10 G. We have checked the statistical distribution of these resonances and found that it is non-chaotic in contrast to Er2 or Dy2 systems [3]

The characteristics of resonances in both systems presented here can be useful in designing the experiments in which polar and paramagnetic molecules are formed.

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Directions

Center for Optical Quantum Technologies (ZOQ)

Luruper Chausee 149, 22761 Hamburg

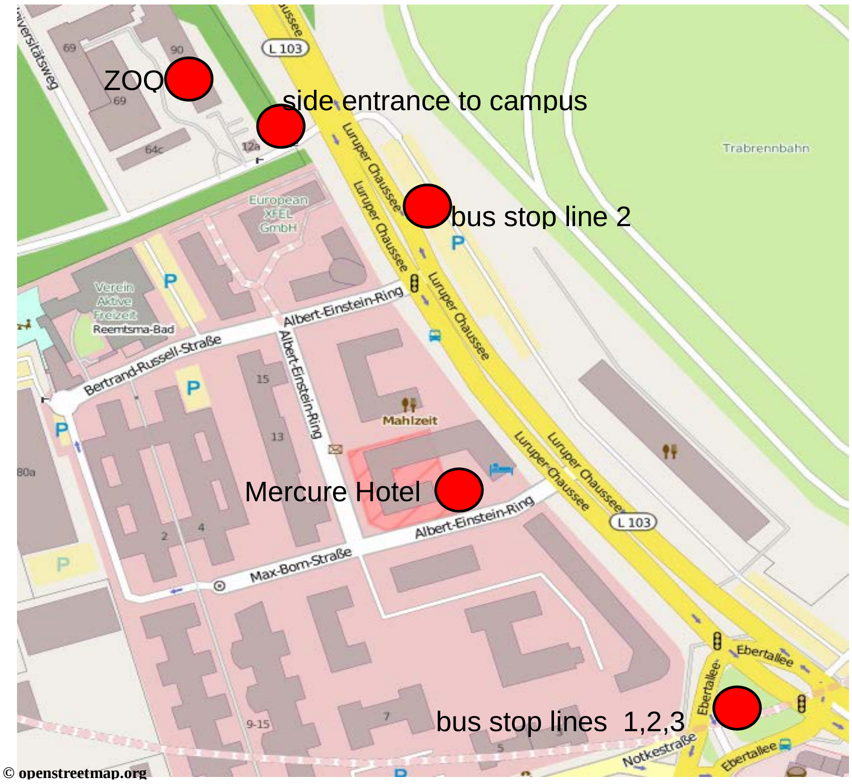
Building 90 on the DESY/University campus, directly on your right when entering the campus through the side entrance facing Luruper Chaussee (see map below).

Coming from the airport:

Public transport: Take the train S1 to *Othmarschen* (45 minutes), then bus 1 to *Trabrennbahn Bahrenfeld* (5 minutes). From here it is a short walk down Luruper Chaussee to the Mercure Hotel and the side entrance of the campus (see also map below).

Coming from Hamburg Altona train station:

Take the bus 2 to *Luruper Chausee/Desy* (15 minutes). The hotel and side entrance of the campus are on the opposite side of the street.



For more information on directions and the Hamburg public transport, please contact us or check www.hvv.de.

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