# The Third International Conference on Few-body Physics in Cold Atomic Gases

## @Zhuhai, China 2019.6.6-6.10

Zhuhai Campus, Sun Yat-sen University, Zhuhai, China

# Contents

# I. About the Conference

Few-body physics has continuously played an important role in the development of the field of ultracold atoms. Few-body systems not only have their own fascinating quantum properties, but also have profound influence to the property of many-body systems. In recent years, there have been exciting experimental/theoretical achievements in exploring the few-body physics with cold atoms, including Rydberg atoms, quantum droplets, exotic cold molecules, and few-body interaction control, etc.

With these developments, we will organize an international conference on "Few-body Physics in Cold Atomic Gases" in Zhuhai, China on June 7-9, 2019. This is a third conference following the two ones held in 2013 and 2016 both in Beijing. The program of the conference will consist of about 20 presentations of most recent developments in this field and discuss future challenges and opportunities.

This conference is co-organized by Sun Yat-Sen University (Zhuhai Campus), the Institute of Physics (Chinese Academy of Sciences), the Institute for Advanced Study of Tsinghua University and Renmin University of China.

# II. Practical Information

**Registration**

Location：Zhuhai 2000 Year Hotel Reception Hall

Open Time: June 6th，15:00 - 20:00

June 7th to 9th，09:00 - 18:00

Registration Fee: 900 per participant

**Note:**

At registration, participants who need an official invoice for the registration fee should confirm the information of invoice, including title and tax number, and contact information.

*需要电子发票的参会人员，会务组将于会议结束后通过电子邮件发送至参会人员邮箱；

*需要纸质发票的参会人员，会务组将于会议结束后邮寄；如有问题，请通过电子邮件 fewbody2019@163.com 与会务组联系。

**Package Materials**

Each handed-out package includes a conference handbook, vouchers for lunch and dinner buffets.

**Venue**

The Millennium Hall, the 3rd floor, Zhuhai 2000 Year Hotel

**Dining**

Vouchers for Lunch and dinner buffets are included in the package for registered conference participants.

Location： The Western Food Cafe, the 1st floor, Zhuhai 2000 Year Hotel

Lunch Time：12:40 - 14:20，Dinner Time：l8:00 - 20:00

## Poster

Time： June 8th, 20:00 - 22:00.

Posting: Each poster white board has been numbered. Please put on posters at The Millennium Hall, the 3rd floor, Zhuhai 2000 Year Hotel according to numbers assigned in the poster list before 20:00, on June 8th.

Recycle of poster: Please recycle your poster before 22:00, on June 8th.

## Contact

Conference Email Address: fewbody2019@163.com

## Conference Organizing Committee

Zhenhua Yu (Sun Yat-sen University)
Xiaoling Cui (IOP, CAS)
Hui Zhai (IASTU)
Peng Zhang (Renmin University of China)

# III. Program Schedule

## June 6

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|---|---|
| **15:00** | *On-site Registration Open* |
| **18:00-20:00** | ***Dinner Buffet*** |

## June 7

| | | |
|---|---|---|
| **8:45 – 9:00** | | **Opening** |
| **Session I** | | |
| **Time** | **Speaker** | **Talk Title** |
| **9:00 – 9:50** | Rudi Grimm | Creating a new strongly interacting system in the lab: Resonant fermion mixture of Dy and K |
| **9:50 – 10:40** | Jing Zhang | Artificial gauge field of One-Dimensional Superradiance Lattices in Ultracold Atoms |
| **10:40 – 11:00** | | ***Tea break*** |
| **11:00 – 11:50** | Florian Schreck | Towards a continuous atom laser and ultracold RbSr: Steady-state Sr gas with unity phase-space density & Rb-Sr magnetic Feshbach resonances |
| **11:50 – 12:40** | Mingyang Guo | Dipolar quantum droplets of Dysprosium |
| **12:40 – 14:20** | | ***Lunch Buffet*** |
| **Session II** | | |
| **14:20 – 15:10** | Johannes Hecker Denschlag | Reaction kinetics of ultracold molecule-molecule collisions |
| **15:10 – 16:00** | Philip Gregory | Are ultracold molecular collisions sticky? |
| **16:00 – 16:20** | | ***Tea break*** |
| **16:20 – 17:10** | Kaden Hazzard | Ultracold molecule collisions: Quantum chaos, chemistry, and many-body physics |
| **17:10 – 18:00** | Bo Gao | Quantum-defect theories of interactions: recent progress and outlook |
| **18:00-20:00** | | ***Dinner Buffet*** |

# June 8

| **Session I** | | |
|---|---|---|
| **Time** | **Speaker** | **Talk Title** |
| **9:00 – 9:50** | F. Barry Dunning | Probing spatial correlations in cold strontium atomic gases using ultralong-range Rydberg molecules |
| **9:50 – 10:40** | Wenchao Xu | Strongly interacting photons |
| **10:40 – 11:00** | | ***Tea break*** |
| **11:00 – 11:50** | Sebastian Hofferberth | Free-space QED with Rydberg superatoms |
| **11:50 – 12:40** | Przemek Bienias | Self-bound clusters made out of light |
| **12:40 – 14:20** | | ***Lunch Buffet*** |
| **Session II** | | |
| **14:20 – 15:10** | Artem Volosniev | Two mobile impurities in a one-dimensional Bose gas: Ground state properties and quench dynamics |
| **15:10 – 16:00** | Shuhei M. Yoshida | Impurity-induced multibody resonances in a Bose gas |
| **16:00 – 16:20** | | ***Tea break*** |
| **16:20 – 17:10** | Ren Zhang | Wisdom from Few-body Physics for Simulation of Kondo Effect |
| **17:10 – 18:00** | Jesper Levinsen | Microscopic description of exciton-polaritons in microcavities |
| **18:00-20:00** | | ***Dinner Buffet*** |
| **20:00-22:00** | | **Poster Session** |

# June 9

| **Session I** | | |
|---|---|---|
| **Time** | **Speaker** | **Talk Title** |
| **9:00 – 9:50** | Doerte Blume | Density oscillations induced by individual ultracold two-body collisions |
| **9:50 – 10:40** | Christoph Eigen | Bose Gases Quenched to Unitarity |
| **10:40 – 11:00** | | ***Tea break*** |
| **11:00 – 11:50** | Yusuke Nishida | Zoo of quantum halos |
| **11:50 – 14:00** | | ***Lunch Buffet*** |
| **Session II** | | |
| **14:20 – 15:10** | Paul Julienne | Calculations of three body recombination and product distributions involving ultra cold atoms |
| **15:10 – 16:00** | Herwig. Ott | Rydberg molecules meet many-body physics |
| **16:00** | | Closing |
| **18:00-20:00** | | ***Dinner Buffet*** |

# Ⅳ. Abstracts of Invited Talks

## Creating a new strongly interacting system in the lab: Resonant fermion mixture of Dy and K

Rudi Grimm

*University of Innsbruck*

We have created a strongly interacting mixture of two different fermionic species, based on the combination of the isotopes 161Dy and 40K. The mixture is brought to deep degeneracy by evaporative cooling in an optical dipole trap [1]. Then the interspecies interaction is tuned to the unitarity limit by means of a broad Feshbach resonance, which we found near 218G. We observe long lifetimes (about 500ms) of the resonant mixture, demonstrating a dramatic Pauli suppression of losses. In first experiments on the resonant mixture, we observe several signatures of strong interactions, like strong deformations of the cloud, deep hydrodynamic behavior in the expansion, and strong drag effects between the two components.

Our new system represents the first Fermi-Fermi mixture ever realized in the lab that features mass imbalance and resonantly tunable interaction in combination with long-term stability. The unique mixture of 161Dy and 40K thus opens up a new world for few- and many-body physics with ultracold atoms.

[1] C. Ravensbergen, V. Corre, E. Soave, M. Kreyer, E. Kirilov, and R. Grimm, Phys. Rev. A 98, 063624 (2018).

# Artificial gauge field of One-Dimensional Superradiance Lattices in Ultracold Atoms

Jing Zhang

*Shanxi University*

There have been significant recent advances in realizing band structures with geometrical andtopological features in experiments on cold atomic gases. We experimentally realize one-dimensionally superradiance lattice (SL) with 87Rb Bose-Einstein condensate (BEC) based onelectromagnetically induced transparency (EIT). Based on one-dimensional SL in standing wave-coupled electromagnetically induced transparency, a far-detuned standing wave field isintroduced to synthesize a magnetic field. The relative spatial phase between the two standingwave coupling fields introduces a magnetic flux in the sawtooth loop transitions of the lattice.This flux determines the moving direction of excitations created in the SL and results innonsymmetric reactivities when the SL is probed in two opposite directions. Our workdemonstrates an in-situ technique to synthesize and detect topological matter in cold atoms.

References:[1] L. Chen, P. Wang, Z. Meng, L. Huang, H. Cai, D.-W. Wang, S.-Y. Zhu, J. Zhang “Experimentalobservation of one-dimensional superradiance lattices in ultracold atoms” Phys. Rev. Lett. 120,193601 (2018)

# Towards a continuous atom laser and ultracold RbSr: Steady-state Sr gas with unity phase-space density & Rb-Sr magnetic Feshbach resonances

Florian Schreck

*University of Amsterdam*

Ultracold atoms provide the best frequency references for clocks and are used as test masses in accelerometers. They are also a flexible platform to design well-controlled quantum many-body systems. We are exploiting the unique properties of strontium to advance these two research lines. Firstly we attempt to create a continuous atom laser, which would allow the steady-state operation of atomic clocks and accelerometers, thereby elimination a fundamental noise source present in pulsed measurement devices. Based on our 2017 work [1] we have created a steady-state Sr gas with unity phase-space density (PSD). Currently we are exploring Sisyphus cooling of Sr [2,3] and other improvements on our way to steady-state quantum degeneracy and a continuous atom laser. Secondly we work towards a quantum gas of RbSr ground-state molecules. These molecules have a large electric dipole moment and an unpaired electron, which is interesting for interaction control and many-body system design. In order to associate ultracold Rb and Sr atoms into RbSr molecules we intend to use unusual magnetic Feshbach resonances that we discovered in this system [4].

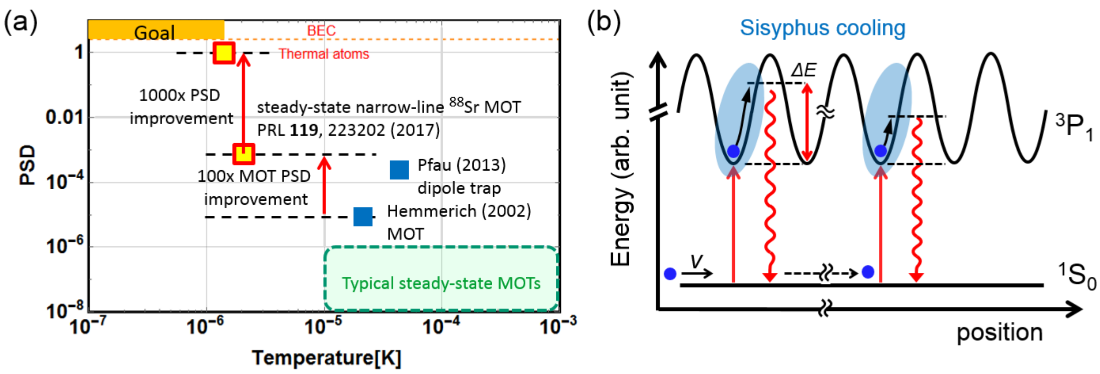


**Fig. 1** (a) Figures of merit of steady-state ultracold gas samples. (b) Principle of Sr Sisyphus cooling used in [3].

## References

[1] Shayne Bennetts, Chun-Chia Chen (陳俊嘉), Benjamin Pasquiou, and Florian Schreck, *Steady-State Magneto-Optical Trap*

*with 100-Fold Improved Phase-Space Density*, Phys. Rev. Lett. **119**, 223202 (2017).

[2] Alexandre Cooper, Jacob P. Covey, Ivaylo S. Madjarov, Sergey G. Porsev, Marianna S. Safronova, and Manuel Endres, *Alkaline-Earth Atoms in Optical Tweezers,* Phys. Rev. X 8, 041055 (2018).

[3] Chun-Chia Chen (陳俊嘉), Shayne Bennetts, Rodrigo González Escudero, Florian Schreck, Benjamin Pasquiou, *Sisyphus Optical Lattice Decelerator*, arXiv:1810.07157 (2018).

[4] Vincent Barbé, Alessio Ciamei, Benjamin Pasquiou, Lukas Reichsöllner, Florian Schreck, Piotr S. Żuchowski, and Jeremy M. Hutson, ***Observation of Feshbach resonances between alkali and closed-shell atoms*****, Nature Physics 14, 881 (2018).**

# Dipolar quantum droplets of Dysprosium

Mingyang Guo

*University of Stuttgart*

Ultracold dipolar quantum gases have great potential to realize novel quantum many-body phases arising from the long-range and anisotropic dipolar interaction. Competition between the dipolar interaction and contact interaction can manifest the effects of beyond-mean-field quantum fluctuation even in weakly interacting regime. In the experiment with Dysprosium, we observed a phase transition from a BEC to a self-bound droplet, which can survive even without external confinement. Like other liquids, these droplets demonstrate saturated density distribution and small compressibility. Recent experiments extend the critical number of the self-bound droplets for more than an order of magnitude, providing precise verification for existing theories. Besides a single self-bound droplet, self-organized droplets arrays are also created by tuning external trap geometry. Superfluidity in these arrays are being intensively investigated and a parameter region near the phase transition with coexistence of density modulation and phase coherence between the droplets was discovered recently, opening a possibility for realizing supersolid with ultracold atoms.

# Reaction kinetics of ultracold molecule-molecule collisions

Johannes Hecker Denschlag

*Universität Ulm*

Studying chemical reactions on a state-to-state level tests and improves our fundamental understanding of chemical processes. For such investigations it is convenient to make use of ultracold atomic and molecular reactants as they can be prepared in well defined internal and external quantum states. Here, we investigate a single-channel reaction of two Li2-Feshbach molecules where one of the molecules dissociates into two atoms 2AB ⇒ AB + A + B. The process is a prototype for a class of four-body collisions where two reactants produce three product particles. We measure the collisional dissociation rate constant of this process as a function of collision energy/temperature and scattering length. We confirm an Arrhenius-law dependence on the collision energy, an a4 power-law dependence on the scattering length a and determine a universal four body reaction constant.

# Direct observation of ultracold molecular reactions

Ming-Guang Hu

*Harvard University*

Ultracold atoms and molecules are ideal testbeds to study few-body physics. However, the few-body physics that describes breaking and forming of chemical bonds of molecules has only been crudely explored due to the lack of experimental data. Recent progress on ultracold molecules provides a new opportunity to explore chemical reactions at ultralow temperatures where reactions could proceed surprisingly efficient due to their quantum mechanical nature. We combine AMO techniques for ultracold reagent preparation and physical chemistry techniques for reaction product ionization detection to investigate a likely 4-center reaction, 2KRb -> K_2+Rb_2+KE (1.24 meV) below 1 micro-Kelvin. I will report our first direct observation of ultracold molecular reactions.

# Ultracold molecule collisions: Quantum chaos, chemistry, and many-body physics

Kaden Hazzard

*Rice University*

Experiments with ultracold molecules have revolutionized our ability to measure molecules' properties and engineer them into new forms of quantum matter. Understanding molecular collisions and reactions, and the influence of these on many-body matter, is crucial, but difficult. It remains impossible to calculate the relevant aspects of two-molecule collisions for even simple bi-alkali molecules.

I will describe schemes that will potentially allow experiments on ultracold molecules in tweezers and lattices to probe chemical collisions and reactions with an energy resolution as much as ten orders of magnitude (!) more precise than previously possible. Such measurements would be interesting not only for exploring an intrinsically new regime of chemistry and physics, but because they can answer important questions in quantum chaos and chemistry, as well as lead to new forms of quantum matter.

My group's research in this direction connects experimental procedures on ultracold molecules to questions in quantum chaos, chemistry, and many-body physics. I will discuss these efforts: (1) Developing connections between these areas. (2) Understanding the emergence of chaos using toy models of molecular collisions, and extracting the lessons they provide for realistic collisions. (3) Predicting many-body phases of matter incorporating these complicated collisions. We have found that these collisions can completely change the nature of many-body matter, causing it to differ even qualitatively from previous predictions. In the future, in order to understand molecular many-body physics, it is essential to incorporate the rich two-molecule collisional physics.

# Are ultracold molecular collisions sticky?

Philip Gregory

*Durham University*

Understanding and controlling collisions is crucial to the future of the burgeoning field of ultracold molecules. All experiments so far have observed fast loss of molecules from the trap, but the dominant mechanism for collisional loss is not well understood when there are no allowed 2-body loss processes. Here we present experiments with a gas of nonreactive ultracold RbCs molecules, prepared in their rovibrational and hyperfine ground state by association from a precooled mixture of atoms. We demonstrate precise control over the rotational and hyperfine quantum states of the molecule with microwaves [1], and through precision microwave spectrocopy examine the ac Stark effects caused by an off-resonant optical dipole trap [2,3]. We proceed to experimentally investigate collisional losses of nonreactive molecules, and compare our findings with the `sticky collision' hypothesis that pairs of molecules form long-lived collision complexes [4].

[1] P. D. Gregory et al., PRA 94, 041403(R) (2016).
[2] P. D. Gregory et al., PRA 96, 021402(R) (2017).
[3] J. A. Blackmore et al., QST 4, 014010 (2019).
[4] P. D. Gregory et al., arXiv:1904.00654v1 (2019).

# Probing spatial correlations in cold strontium atomic gases using ultralong-range Rydberg molecules

F. Barry Dunning

*Rice University*

Rydberg excitation in cold gases can lead to formation of ultralong-range Rydberg molecules in which scattering of the Rydberg electron leads to the binding of one, or more, neighboring ground-state atoms. For strontium 5sns 3S1 – 5s2 1S0 atom pairs, the dimer v=0 molecular wavefunction is strongly localized near the Rydberg-electron outer classical turning point. The likelihood of photoexciting such a molecule is therefore proportional to the probability for finding an atom pair with the required initial separation thus providing a valuable probe of particle correlations, i. e., of the pair correlation function g(2)(R). This is demonstrated by measurements of molecule formation using non-degenerate quantum gases of spin-polarized (fermionic) 87Sr and (bosonic) 84Sr under conditions where quantum statistics strongly influence the value of g(2)(R) As a reference, an unpolarized sample of 87Sr is used to approximate a gas of uncorrelated particles. The data show that the molecular formation rates mirror that expected based on the behavior of g(2)(R). The wavefunctions for the excited v=1 and v=2 vibrational states extend to smaller internuclear separations than the v=0 state and studies of their formation promise a means to explore spatial correlations at shorter ranges. The present work shows that measurements of molecular formation provide a novel means to study particle correlations at length scales of 20 – 500 nm that are inaccessible using alternate techniques. The approach is suitable for exploring a wide range of interesting phenomena including, for example, the pair correlation function in a gas with a large s-wave scattering length. Furthermore, studies of the creation of molecular trimers, tetramers,.. can be employed to obtain information on higher-order correlations.

Research undertaken in conjunction with T C Killian, J D Whalen, R Ding, S K Kanungo, S Yoshida, J Burgdorfer, R Schmidt, and H R Sadeghpour.

# Strongly interacting photons

Wenchao Xu

*Massachusetts Institute of Technology*

Manipulating individual photons is fascinating for building up all-optical quantum devices. In addition, it opens the possibility to realize novel quantum many-body states made with photons. Photons interact weakly in vacuum. However, via the combination of electromagnetically induced transparency and Rydberg atoms, strong mutual interactions between photons are realized. In this talk, I will present our group's work on the full control of the effective interactions of individual photons. These interactions range from attraction, characterized by the formation of bound states of photons, to repulsive interactions, which lead to the observation of emergent spatial structure.

# Free-space QED with Rydberg Superatoms

Sebastian Hofferberth

*University of Southern Denmark*

Photons, for all practical purposes, do not interact. Engineering reliable interactions between individual photons enables both practical applications and is of great fundamental interest. 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.

Here, we discuss our recent experiments coupling an optical medium smaller than a single Rydberg blockade volume to a few-photon probe field. Due to the large number of atoms in the blockaded volume and the efficient coupling to the probe light mode, we achieve coherent coupling between the probe field and the effective Rydberg "superatom" even if the probe pulse contains only a few photons. We observe the effective interaction between two and three photons, mediated by the single emitter, in the two- and three-body correlations imprinted onto the transmitted probe light. Our system enables us to study the dynamics of a single two-level system strongly coupled to a quantized propagating light field in free space and opens the way to controlled manipulation of few-photon pulses via Rydberg superatoms.

# Self-bound clusters made out of light

Przemek Bienias

*University of Maryland*

Recently, the combination of slow light polaritons with the strong interactions between Rydberg atoms has emerged as a promising system for inducing a strong interaction between photons. Potential applications range from the implementation of phase gate for photons, to single photon sources, as well as the generation of strongly correlated states of photons. I present our theoretical and experimental studies of strongly interacting photons. I show that these interacting photons can be used to prepare exotic and non-classical states of light. In the regime of attractive interactions, we identify multiple two-polariton bound states, calculate their dispersion, and study the resulting scattering resonances. For three-polaritons, we study the influence of the three-body force on the bound states. Finally, we propose a method of engineering novel molecular-like interactions between polaritons leading to self-bound clusters made out of light.

# Two mobile impurities in a one-dimensional Bose gas: Ground state properties and quench dynamics.

Artem Volosniev

*TU Darmstadt*

Impurity particles in an environment interact with one another via induced potentials, which make impurity-impurity correlations drastically different from those in free space. For instance, one can find materials in which electrons, even in spite of their fermionic nature and Coulomb repulsion, form a new bosonic bound state – bipolaron, the quasiparticle, which might play a role in the properties of high-Tc superconducting materials.

I study two impurities in a one-dimensional Bose gas. These impurities attract each other, because their energy is lowered when they share the same distortion of the Bose gas. Therefore, even if particles do not interact in free space they form a bound state when immersed in a Bose gas [any attractive interaction in one spatial dimension leads to a bound state, which, however, can be very shallow]. In this talk I discuss signatures of the induced impurity-impurity attraction in small trapped Bose gases. I focus on the ground state properties and quench dynamics.

# Impurity-induced multibody resonances in a Bose gas

Shuhei M. Yoshida

*NEC Corporation*

We consider the problem of an infinite-mass impurity that is coupled to $N$ non-interacting bosons. We show that a dynamical impurity-boson interaction, mediated by a closed-channel dimer, can induce an effective boson-boson repulsion, which strongly modifies the bound states consisting of the impurity and $N$ bosons. In particular, we demonstrate the existence of two “multibody” resonances, where all multibody bound states involving any $N$ emerge and disappear. The first multibody resonance corresponds to infinite impurity-boson scattering length, $a¥to +¥infty$, while the second corresponds to the critical scattering length $a_∗>0$ beyond which the trimer ($N=2$ bound state) ceases to exist. We show that the behavior at these “multibody resonances” is universal, since it occurs for any model with an effective three-body repulsion involving the impurity. We also discuss implications of these findings for the nature of the Bose polaron currently being studied in cold-atom experiments.

# Wisdom from Few-body Physics for Simulation of Kondo Effect

Ren Zhang

*Xi'an Jiaotong University*

Since the existence of intrinsic spin-exchange interaction, alkaline earth atoms have become the ideal platform to explore the Kondo physics in cold atom system. However, raising the Kondo temperature is still challenging. In this talk, I will show our proposal of using confinement induced resonance to enhance the spin-exchange interaction so as to raise the Kondo temperature to the regime achievable in the current experiment. In such a system, the clock state atoms are localized while the ground state atoms itinerate in a tube. The possible experimental signal will be addressed as well.

# Microscopic description of exciton-polaritons in microcavities

Jesper Levinsen

*Monash University*

We investigate the microscopic description of exciton-polaritons that involves electrons, holes and photons within a two-dimensional microcavity. We show that in order to recover the simplified exciton-photon model that is typically used to describe polaritons, one must correctly define the exciton-photon detuning and exciton-photon (Rabi) coupling in terms of the bare microscopic parameters [1]. For the case of unscreened Coulomb interactions, we find that the exciton-photon detuning is strongly shifted from its bare value in a manner akin to renormalization in quantum electrodynamics. Within the renormalized theory, we exactly solve the problem of a single exciton-polariton for the first time and obtain the full spectral response of the microcavity. In particular, we find that the electron-hole wave function of the polariton can be significantly modified by the very strong Rabi couplings achieved in current experiments. Our microscopic approach furthermore allows us to properly determine the effective interaction between identical polaritons, which goes beyond previous theoretical work, and which agrees well with recent experimental results [2]. Our findings are thus important for understanding and characterizing exciton-polariton systems across the whole range of polariton densities.

References:

[1] Jesper Levinsen, Guangyao Li, Meera M. Parish, arXiv:1902.07966

[2] E. Estrecho, T. Gao, N. Bobrovska, D. Comber-Todd, M. D. Fraser, M. Steger, K. West, L. N. Pfeiffer, J. Levinsen, M. M. Parish, T. C. H. Liew, M. Matuszewski, D. W. Snoke, A. G. Truscott, E. A. Ostrovskaya, arXiv:1809.00757

# Density oscillations induced by individual ultracold two-body collisions

Doerte Blume

*The University of Oklahoma*

Access to single particle momenta provides new means of studying the dynamics of few interacting particles. In a joint theoretical and experimental effort, we observe and analyze the effects of a finite number of ultracold two-body collisions on the relative and single-particle densities by quenching two ultracold atoms with initial narrow wave packet into a wide trap with inverted aspect ratio. The experimentally observed spatial oscillations of the relative density are reproduced by a parameter-free zero-range theory and interpreted in terms of cross-dimensional flux. We theoretically study the long time dynamics and find that the system does not approach its thermodynamic limit. The set-up can be viewed as an advanced particle-collider that allows one to watch the collision process itself.

# Bose Gases Quenched to Unitarity

Christoph Eigen

*University of Cambridge*

In ultracold atomic gases, Feshbach resonances allow access to the unitary regime, where the s-wave scattering length diverges and two-body interactions are as strong as theoretically allowed by the laws of quantum mechanics. Following more than a decade of exciting experiments on unitary Fermi gases, in particular those exploring the crossover between Bose-Einstein condensation and Bardeen-Cooper-Schrieffer superconductivity, unitary Bose gases have more recently emerged as an experimental frontier.

However, in Bose gases the strong interactions also lead to particle loss and heating, which establishes a complex interplay between the coherent and the dissipative dynamics, and makes the study of the unitary Bose gas an intrinsically non-equilibrium problem.

I will present some of our recent experiments trying to understand the dynamics and thermodynamics of Bose gases following a rapid quench into the unitary regime. Our momentum- and time-resolved measurements allow us to disentangle the coherent from the dissipative dynamics, observe that the gas attains a quasi-equilibrium state, and obtain the first quantitative results on this state. Our experiments also uncover a remarkable degree of universality in the post-quench behavior.

# Zoo of quantum halos

Yusuke Nishida

*Tokyo Institute of Technology*

Wave-particle duality in quantum mechanics allows for a halo bound state whose spatial extension far exceeds a range of the interaction potential. What is even more striking is that such quantum halos can be arbitrarily large on special occasions. The two examples known so far are the Efimov effect and the super Efimov effect, which predict that spatial extensions of higher excited states grow exponentially and double exponentially, respectively [1,2]. Here, we establish yet another new class of arbitrarily large quantum halos formed by spinless bosons with short-range interactions in two dimensions [3]. When the two-body interaction is absent but the three-body interaction is resonant, four bosons exhibit an infinite tower of bound states whose spatial extensions scale as $R_n\sim e^{(\pi n)^2/27}$ for a large $n$. The emergent scaling law is universal and is termed a semisuper Efimov effect, which together with the Efimov and super Efimov effects constitutes a trio of few-body universality classes allowing for arbitrarily large quantum halos. If time allows, universal bound states of one-dimensional bosons with two- and/or three-body attractions are also discussed [4,5].

[1] V. Efimov, "Energy levels arising from resonant two-body forces in a three-body system," Phys. Lett. B 33, 563-564 (1970).
[2] Y. Nishida, S. Moroz, and D. T. Son, "Super Efimov effect of resonantly interacting fermions in two dimensions," Phys. Rev. Lett. 110, 235301 (2013).
[3] Y. Nishida, "Semi-super Efimov effect of two-dimensional bosons at a three-body resonance," Phys. Rev. Lett. 118, 230601 (2017).
[4] Y. Sekino and Y. Nishida, "Quantum droplet of one-dimensional bosons with a three-body attraction," Phys. Rev. A 97, 011602 (2018).
[5] Y. Nishida, "Universal bound states of one-dimensional bosons with two- and three-body attractions," Phys. Rev. A 97, 061603 (2018).

# When interaction meets non-Hermitian: high-order exceptional point and enhanced pairing superfluidity

Xiaoling Cui

*Institute of Physics, Chinese Academy of Sciences*

When interaction meets non-Hermitian potential, it can often generate intriguing quantum phenomena that are distinct from or cannot be found in interacting Hermitian systems. Here I will introduce two of such phenomena that are uniquely induced by the interplay of interaction and non-Hermitian. One is to create arbitrarily high-order exceptional point with ultra-sensitive spectral response in the spinor condensate of ultracold bosons. The other is to enhance fermion pairing and superfluidity in a vast class of fermion systems with and without spin-orbit coupling. We have addressed these effects first from the few-body point of view, and then extended to many-body systems following the few to many crossover passage.

References:

Lei Pan, Shu Chen, Xiaoling Cui, Phys. Rev. A 99, 011601 (R) (2019); arXiv:1902.04769.

Lihong Zhou, Xiaoling Cui, iScience 14, 257 (2019).

# Calculations of three body recombination and product distributions involving ultra cold atoms

Paul Julienne

*Joint Quantum Institute, University of Maryland*

The three-body physics of ultracold atoms has proven to be a very rich area of theoretical and experimental studies. This talk describes numerical calculations of three-body recombination based on a "universal" van der Waals model of two- and three-body interactions [1]. The model uses pairwise additive long-range dispersion potentials cut off at short range to support a small number $1 \leq N \leq 6$ of s-wave bound states. It accurately represents multispin two-body Feshbach resonance interactions through a simple parameterization based on known resonance parameters. Results of applying the model for several quite different 3-body systems will be described. The model gives a qualitatively similar account to measured product distributions of dimer vibrational-rotational states for recombination of ultracold $^{87}$Rb atoms [2]. The model gives an accurate value for the measured three-body recombination coefficient of three unlike-spin $^{87}$Sr fermions held in optical lattice cells [3]. Finally, we develop a multispin model to compare to recent very precise experiments on the Efimov feature near the 33.5803(14) G Feshbach resonance of |1,-1> $^{39}$K atoms. Precise measurements [4] find the Efimov peak at a scattering length of $A_- = -14.08(17)\ r_{vdW}$, where $r_{vdW}$ is the van der Waals length. This is strikingly different from the expectation of $A_- = -9.7\ r_{vdW}$ based on the conventional view of "van der Waals universality" for cold atomic systems. While our model based on a single channel representation yields the conventional result, our multispin model accurately represents the 2-body Feshbach resonance with an $s_{res}$ strength parameter of 1.9 and predicts $A_- = -13.1\ r_{vdW}$, in substantially better agreement with experiment than a single channel model.

1. Yujun Wang and P. S. Julienne, “Universal van der Waals Physics for Three Ultracold Atoms,” Nat. Phys. 10, 768-773 (2014).

2. J. Wolf, M. Deiß, A. Krükow, E. Tiemann, B. P. Ruzic, Y. Wang, J. P. D'Incao, P. S. Julienne, J. Hecker Denschlag, “State-to- state chemistry at ultra-low temperature,” Science 358, 921-924 (2017).

3. A. Goban, R. B.. Hutson, G. E. Marti. S. L. Campbell, M. A. Perlin, P. S. Julienne, J. P. D'Incao, A. M. Rey, J. Ye, “Emergence of multi-body interactions in few-atom sites of a fermionic lattice clock,” Nature, 563, 369 (2018).

4. R. Chapurin, X. Xie, M. J. Van de Graaff, J. S. Popowski, J. P. D’Incao, P. S. Julienne, J. Ye, and E. A. Cornell, manuscript in preparation (2019).

# Rydberg molecules meet many-body physics

Herwig. Ott

*The Technical University of Kaiserslautern*

During the last two decades, ultracold quantum gases have become a valuable experimental platform for many-body physics, and a series of groundbreaking studies with bosonic and fermionic quantum gases has been carried out. At the same time, cooling and trapping of ultracold atoms has revolutionized the field of Rydberg physics. Today, both research directions are closely linked to each other and I will discuss how the two formerly disjunct areas of physics can benefit from each other. In particular, I will show that an atomic Mott insulator can serve as a platform to study driven-dissipative Rydberg gases in the antiblockade regime and that Rydberg molecules can be employed to tune the interaction in an ultracold quantum gas via an optical Feshbach resonance.

# Quantum-defect theories of interactions: recent progress and outlook

Bo Gao

*University of Toledo*

A systematic understanding of two-body interaction is a prerequisite for a systematic understanding of quantum few-body and quantum many-body systems. This is especially true for systems of atoms and molecules. In this talk, we hope to briefly review the motivations and the foundations of the quantum-defect theories (QDT) of interactions. We also intend to discuss our recent efforts in developing QDTs for multiscale potentials and QDTs for anisotropic potentials, such as those encountered in atom-molecule and molecule-molecule interactions. Through this discussion, we hope to affirm the possibility of QDT description for atomic and molecular interactions of all types. Such a prospect should provide both a motivation and ultimately tools for new classes of theories for chemical reactions, quantum few-body systems, and quantum many-body systems.

In collaboration with Ningyi Du.

# V. Poster List

| No. | Presenter | Affiliation | Title of the poster |
|---|---|---|---|
| 1 | Fang Qin | University of Science and Technology of China | Polaron in a p+ip Fermi topological superfluid |
| 2 | Jing-Bo Wang | University of Science and Technology of China | Chiral Majorana edge states in the vortex core of a p + i p Fermi superfluid |
| 3 | Liang, Zhaoxin | Zhejiang Normal University | Beliaev Damping of a Spin-Orbit-Coupled Bose-Einstein Condensate |
| 4 | Xiangyu Yin | Swinburne University of Technology | Cluster formation in two-component Fermi gases |
| 5 | Kui-Tian Xi | Zhejiang University | Fingering instabilities and pattern formation in a two-component dipolar Bose-Einstein condensate |
| 6 | Jian-Song Pan | Shanghai Jiao Tong University | Topological phases classied by spontaneously broken symmetries |
| 7 | Qing Ji | Renmin University of China | Connement-induced Resonance of Alkaline-earth-metal-like Atoms in Anisotropic Quasi-one-dimensional Traps |
| 8 | Kui-Tian Xi | Zhejiang University | Fingering instabilities and pattern formation in a two-component dipolar Bose-Einstein condensate |
| 9 | Wen Wen | Hohai university | Collective oscillation modes of a superfluid Bose-Fermi mixture |
| 10 | Mingyuan Sun | Tsinghua University | Many-body Effect of Efimov Physics in Bose-Fermi Mixtures |
| 11 | Qi Gu | School of Physics, Peking University | Bound-States Bands and Induced Resonance in Spin-1/2 Bose Gas with 1D SOC |
| 12 | Yuncheng Xiong | Peking University | Effects of Spin-orbit-coupling-induced Resonance in Ultracold Bosonic Systems |
| 13 | Pascal Naidon | RIKEN | Width and Shift of Feshbach resonances |
| 14 | Meng-Shan Wu | Wuhan Institute of Physics and Mathematics | Low-energy Ps scattering by H and He |
| 15 | Ningyi Du | University of Toledo, USA | Characteristics of atom-molecule elastic scattering |
| 16 | Fu-Quan Dou | Northwest Normal University | Fast quantum driving in two-level systems with interaction and nonlinear sweep |
| 17 | Caiyun Zhao | Wuhan Institute of Physics and Mathematics, CAS | Universal Three-Body Parameter of Heavy-Heavy-Light systems with negative intraspecies scattering length |

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| **18** | Jun-Yi Zhang | Wuhan Institute of Physics and Mathematics, CAS | possibility of formation of stable condensate of metastable positronium |
| **19** | Haiyuan Zou | Shanghai Jiao Tong University | Exactly solvable points and symmetry protected topological phases of quantum spins on a zig-zag lattice |
| **20** | Shuyu Zhou | Shanghai Institute of Optics and Fine Mechanics | Proposal for experimental investigation of Efimov physics in ultracold K-Rb mixtures in microgravity |
| **21** | Wenjie Liu | Sun Yat-sen Univerisity | Bloch oscillations of multi-magnon excitations in a Heisenberg XXZ chain |
| **22** | Min Zhunag | Sun Yat-sen Univerisity | Multiparameter estimation via an ensemble of spinor atoms |
| **23** | Bo Zhu | Sun Yat-sen Univerisity | Topological Floquet edge states in periodically curved waveguides |
| **24** | Shi Hu | Sun Yat-sen Univerisity | Dispersion suppressed topological thouless pumping |
| **25** | Ziheng Zhou | Sun Yat-sen Univerisity | Interaction effects on PT-symmetry breaking transition in atomic gases |
| **26** | Guangcun Liu | Sun Yat-sen Univerisity | Rabi spectroscopy in three dimensional optical lattice atomic clock |
| **27** | Xunda Jiang | Sun Yat-sen University | Universality of miscible-immiscible phase separation dynamics in two-component BoseEinstein condensates |
| **28** | Ling Lin | Sun Yat-sen University | Interaction induced topological pumping in shaking state-dependent optical lattices |