# ICAP29 Satellite Meeting on Ultracold Molecules

June 22-24, 2026, Hong Kong, China

Venue: Room LT2, G/F, Yasumoto International Academic Park (YIA), The Chinese University of Hong Kong, Shatin, Hong Kong, China

## PROGRAM

| Time \ Date | June 22 (Mon) | June 23 (Tue) | June 24 (Wed) |
|---|---|---|---|
| | Registration (08:30 – 09:20) | | |
| 09:00 – 09:30 | Welcome remarks (09:20 – 09:30) | **Luis Santos** | **Simon Cornish** |
| 09:30 – 10:00 | **John Bohn** | **Xiaoling Cui** | **Li Du** |
| 10:00 – 10:30 | **Yangqian Yan** | **Peng Zhang** | **Connor Holland** |
| 10:30 – 11:00 | *Coffee break* | | |
| 11:00 – 11:30 | **Thomas Pohl** | **Hanns-Christoph Nägerl** | **Jee Woo Park** |
| 11:30 – 12:00 | **Tao Shi** | **Kai Dieckmann** | **Jun Rui** |
| 12:00 – 13:30 | *Lunch* | | |
| 13:30 – 14:00 | **Tijs Karman** | **Xinyu Luo** | |
| 14:00 – 14:30 | **Bo Yan** | **Pengjun Wang** | Lab tour (Science Centre North Block and Sir Run Run Science Building) |
| 14:30 – 15:00 | **Tim Langen** | **Junyu Lin** | |
| 15:00 – 15:30 | *Coffee break* | Poster session *(& coffee break)* | |
| 15:30 – 16:00 | **Stefan Truppe** | | |
| 16:00 – 16:30 | **Michał Tomza** | | |
| 16:30 – 18:00 | | | |
| 18:00 | *Conference Dinner* | | |

| June 22 (Monday) | |
|---|---|
| 08:30 – 09:20 | Registration |
| 09:20 – 09:30 | Welcome remarks |
| **Session 1** Chair: Dajun Wang (CUHK) | |
| 09:30 – 10:00 | *Collisional aspects of a fermionic KRb gas*<br>**John Bohn** (JILA, University of Colorado Boulder) |
| 10:00 – 10:30 | *Two-body chemical reactions in ultracold Fermi gases: From contact thermodynamics to non-equilibrium kinetics*<br>**Yangqian Yan** (The Chinese University of Hong Kong) |
| 10:30 – 11:00 | *Photo-taking and coffee break* |
| 11:00 – 11:30 | *Quantum phases of strongly interacting dipolar molecules*<br>**Thomas Pohl** (Vienna University of Technology) |
| 11:30 – 12:00 | *Many-body quantum phases in micro-wave shielded polar molecules*<br>**Tao Shi** (Institute of Theoretical Physics, Chinese Academy of Sciences) |
| 12:00 – 13:30 | *Lunch (Sandwiches)* |
| **Session 2** Chair: Yangqian Yan (CUHK) | |
| 13:30 – 14:00 | *Low-entropy arrays of microwave-shielded molecules*<br>**Tijs Karman** (Radboud University) |
| 14:00 – 14:30 | *Deep laser cooling and optical trapping of BaF molecules*<br>**Bo Yan** (Zhejiang University) |
| 14:30 – 15:00 | *Laser cooling of complex molecules*<br>**Tim Langen** (TU Wien) |
| 15:00 – 15:30 | *Coffee break* |
| 15:30 – 16:00 | *Towards a BEC of a stable molecule*<br>**Stefan Truppe** (Imperial College London) |
| 16:00 – 16:30 | *Ultracold strongly dipolar alkali-metal--silver molecules*<br>**Michał Tomza** (University of Warsaw) |
| 18:00 | *Conference dinner (4/F, Serenade Chinese Restaurant, Tsim Sha Tsui)* |

| June 23 (Tuesday) | |
|---|---|
| **Session 3** Chair: Tao Shi (ITP, CAS) | |
| 09:00 – 09:30 | *Dipolar ladder gases: from floating phases to anyon condensates*<br>**Luis Santos** (Institute of Theoretical Physics, Leibniz University of Hannover) |
| 09:30 – 10:00 | *From universal bound state to single-molecule array in microwave-shielded ultracold molecules*<br>**Xiaoling Cui** (Institute of Physics, Chinese Academy of Sciences) |
| 10:00 – 10:30 | *Complex lifetime of ultracold molecules*<br>**Peng Zhang** (Renmin University of China) |
| 10:30 – 11:00 | *Coffee break* |
| 11:00 – 11:30 | *To be announced*<br>**Hanns-Christoph Nägerl** (University of Innsbruck) |
| 11:30 – 12:00 | *Rotational spectroscopy and magic wavelengths for ultracold LiK molecules*<br>**Kai Dieckmann** (National University of Singapore) |
| 12:00 – 13:30 | *Lunch (Chung Chi College Staff Restaurant, CUHK)* |
| **Session 4** Chair: Jiazhong Hu (Quantum Science Center of GBA) | |
| 13:30 – 14:00 | *Controlling and understanding Fermi gases of polar molecules*<br>**Xinyu Luo** (Max-Planck-Institute of Quantum Optics and Hainan University) |
| 14:00 – 14:30 | *Tetratomic states of microwave dressed and associated ultracold $^{23}Na^{40}K$ molecules*<br>**Pengjun Wang** (Shanxi University) |
| 14:30 – 15:00 | *Evaporative cooling of polar molecules to Fermi degeneracy in 3D and 2D confinements*<br>**Junyu Lin** (JILA) |
| 15:00 – 18:00 | Poster session *(& coffee break)* |

| June 24 (Wednesday) | |
|---|---|
| **Session 5** Chair: Zhendong Zhang (HKU) | |
| 09:00 – 09:30 | *Interfacing individual ultracold polar molecules and Rydberg atoms in optical tweezers*<br>**Simon Cornish** (Durham University) |
| 09:30 – 10:00 | *Assembling, entangling, and probing NaCs molecule arrays*<br>**Li Du** (Harvard University) |
| 10:00 – 10:30 | *Quantum many-body physics with molecular tweezer arrays*<br>**Connor Holland** (Princeton University) |
| 10:30 – 11:00 | *Coffee break* |
| 11:00 – 11:30 | *A versatile platform for ultracold NaK molecules*<br>**Jee Woo Park** (Pohang University of Science and Technology) |
| 11:30 – 12:00 | *Progresses towards quantum gas microscope of polar NaRb molecules*<br>**Jun Rui** (Hefei National Laboratory, University of Science and Technology of China) |
| 12:00 – 13:30 | *Lunch (The Harmony, LG2/F, Lee Woo Sing College, CUHK)* |
| 14:00 – 18:00 | Lab tour (Science Centre North Block and Sir Run Run Science Building) |

## POSTER PRESENTATIONS

| No. | Name | Affiliation | Title |
|---|---|---|---|
| 1 | **Archie Baldock** | Durham University | Near-deterministic loading of optical tweezer arrays via repulsive barricade potentials |
| 2 | **Leonard Paul Bleiziffer** | Institute of Theoretical Physics, Chinese Academy of Sciences | Training neural nets as quantum many-body ground states |
| 3 | **Dylan Brown** | Imperial College London | Slowing of AlF molecules using a low cost, robust deep ultraviolet laser system |
| 4 | **Rory Carabok** | Imperial College London | Towards 10^6 CaF molecules in a MOT: Simulated beam-line optimisation and a new 1K cryogenic source |
| 5 | **Matteo Ciardi** | TU Wien | Metastable droplet arrays of ultracold dipolar molecules |
| 6 | **Clement Debavelaere** | Imperial College | Radiation pressure slowing of YbF |
| 7 | **Christine Frank** | Max Planck Institute of Quantum Optics | Controlled symmetry breaking of the Fermi surface in ultracold polar molecules |
| 8 | **Xin-Yuan Gao** | The Chinese University of Hong Kong | In-situ observation of magnetostriction crossover in a strongly dipolar two-dimensional Bose gas |
| 9 | **Daniel Hoare** | Imperial College London | Development of a hybrid optical tweezer array of ultracold CaF molecules and Rb Rydberg atoms for quantum simulation and computation |
| 10 | **Jongheum Jung** | Princeton University | Evaporative cooling of bosonic molecules shielded by a static electric field |
| 11 | **Tsz Chun Lau** | The Chinese University of Hong Kong | Non-Abelian dynamics in strongly interacting spinor Bose gases |
| 12 | **Kai Yuen Lee** | The Chinese University of Hong Kong | Emergent elliptic flow of few Fermions: Explicitly Correlated Gaussian study for the dynamics of strongly interacting few-body systems |
| 13 | **Grace Li** | Harvard University | 2D laser-cooling of an asymmetric top molecule |
| 14 | **Jiaming Li** | Sun Yat-sen University | Orbital and spin control of p-Wave dipolar interactions in ultracold Li-6 |
| 15 | **Simeng Li** | Imperial College London | Towards eEDM measurements using ultracold trapped YbF molecules in an optical lattice |
| 16 | **Dongkyu Lim** | Korea University | Investigation of the hyperfine structure and optical cycling scheme of 25MgF molecules via LIF spectroscopy |
| 17 | **Shaokun Liu** | Sun Yat-sen University | Orbital-resolved three-body recombination across a p-Wave Feshbach resonance in ultracold $^{6}$Li |
| 18 | **Holly Middleton-Spencer** | University of Birmingham | Observations of half-quantum vortices and symmetry breaking in molecular Bose-Einstein condensates |

## POSTER PRESENTATIONS

| No. | **Name** | Affiliation | Title |
|---|---|---|---|
| 19 | **Shuai Peng** | Sun Yat-sen University | Dissipation as a projective probe of quantum correlations in a unitary Fermi gas |
| 20 | **Zhaopeng Shi** | The Chinese University of Hong Kong | Bose-Einstein condensate of ultracold NaRb molecules with tunable dipolar interactions |
| 21 | **Kai Voges** | Leibniz University Hannover | Developing a hybrid tweezer array of molecules and atoms for quantum technology applications |
| 22 | **Fritz von Gierke** | Leibniz University Hannover | Electric-field control of atom-molecule Feshbach resonances |
| 23 | **Gaoren Wang** | Dalian University of Technology | Tuning ultracold collisions of molecules in non-adjacent rotational states by the electric field |
| 24 | **Haitian Wang** | Institute of Physics, Chinese Academy of Sciences | Interaction-induced dimension reduction and Bose-Fermi duality for bound states in microwave-shielded ultracold molecules |
| 25 | **Yu Wang** | Wuhan University | Supersolidity of attractive three-color fermions on a square optical lattice |
| 26 | **Chun Kit Wong** | Institute for Quantum Optics and Quantum Information | Light-induced losses and Pauli suppression of inelastic collision of Feshbach molecules of 161Dy40K |
| 27 | **Xiaorong Yu** | Hefei National Laboratory | Towards a quantum gas microscope of NaRb polar molecules |
| 28 | **Bingcheng Zeng** | Vrije Universiteit Amsterdam | Laser cooling and trapping of helium dimers |
| 29 | **Zixuan Zeng** | Zhejiang University | Sub-Doppler cooling and optical trapping of BaF molecules |
| 30 | **Anwei Zhu** | Max-Planck-Institute of Quantum Optics | Towards ultracold fermionic 6Li87Rb polar molecules |
| 31 | **Connor Holland** | Princeton University | Many-body spin physics and molecular collisions in CaF tweezer arrays |

# ABSTRACTS OF INVITED TALKS

Abstracts are arranged alphabetically by speaker name.

### *Collisional aspects of a fermionic KRb gas*

**John Bohn**, JILA, University of Colorado Boulder

We consider collisions of ultracold fermionic molecules in the context of the JILA KRb experiment. Specifically we focus on two areas. The first concerns mapping the ground and rotationally excited state molecules into a pseudo-spin-1/2 system. Collisions can induce entanglement among the molecules, manifested by single-molecule decoherence. We find that that molecular loss, enhanced by particle exchange symmetry, can lead to a suppression of collective spin decoherence, a mechanism we refer to as "loss-induced quantum autoselection." Coupled with electric-field shielding, this eMect can lead to fully-coherent spin-mixing dynamics. In a second endeavor, we consider evaporative cooling of the molecules to quantum degeneracy, in both 3D and quasi-2D geometries, and including Pauli blocking. We show this cooling to be eMicient, leading to the promise of degenerate molecule Fermi gases in this system.

This work was supported by the JILA Physics Frontier Center

### *Interfacing individual ultracold polar molecules and Rydberg atoms in optical tweezers*

**Simon L. Cornish**, Department of Physics, Durham University

We report our experimental progress towards a hybrid quantum network comprised of individually trapped polar molecules interfaced with Rydberg atoms. We produce single RbCs molecules in optical tweezers which allows for single-site control and imaging [1]. Alongside the molecules, excess Rb (or Cs) atoms are prepared in the motional ground state and excited to Rydberg states with a two-photon excitation scheme. For an atom-molecule separation of 310(40) nm, we first demonstrate blockade of the transition to the Rydberg state due to the charge-dipole interaction with the molecule in the rotational ground state [2]. We then demonstrate resonant dipole-dipole interactions between individual atoms and molecules by tuning the energy difference between a pair of Rydberg levels to match the spacing of a rotational transition in the molecule. This enhanced interaction allows for observation of blockade at micron-scale separations and provides a route to non-destructive readout of the state of the molecule and Rydberg-mediated entanglement of a pair of molecules.

[1] D.K. Ruttley *et al*., "Enhanced Quantum Control of Individual Molecules Using Optical Tweezer Arrays", PRX Quantum **5**, 020333 (2024).
[2] A. Guttridge, D.K. Ruttley *et al*., "Observation of Rydberg blockade due to the charge-dipole interaction between an atom and a polar molecule", Phys. Rev. Lett. **131**, 013401 (2023).

### *From universal bound state to single-molecule array in microwave-shielded ultracold molecules*

**Xiaoling Cui**, Institute of Physics, Chinese Academy of Sciences

We exactly study polyatomic clusters of ultracold molecules dressed by an elliptic microwave field. It is shown that hexatomic bound state is much more favored than tetratomic one, with binding energy exceeding twice of the latter for a wide range of microwave couplings. These bound states can be accurately predicted by effective one-dimensional (1D) models that incorporate angular quantum fluctuations, despite the physical system is in 3D free space. Such a dimension reduction is purely due to the anisotropy of long-range interactions, in contrast to the conventional case due to external confinement. The hard-core feature of 1D models ensures Bose-Fermi duality of these bound states, i.e., they share identical spectrum and real-space density in bosonic and fermionic systems. Extending to large ensemble of molecules, our results suggest the formation of a self-bound single-molecule array as ground state for both bosonic and fermionic systems.

References:
Tingting Shi, Haitian Wang, XC, Phys. Rev. Lett. 136, 043402 (2026).
Haitian Wang, Tingting Shi, XC, 2511.09856.

### *Rotational spectroscopy and magic wavelengths for ultracold LiK molecules*

**Kai Dieckmann**, National University of Singapore

We report our progress in achieving long coherence times for LiK molecules and the determination for magic wavelength conditions in optical potentials. Our study begins with rotational spectroscopy of the J=1 hyperfine structure at 215.5 G. Through precise measurement and analysis of transition frequencies to excited rotational states, we extract the hyperfine interaction constants. A specific stretched state transition is further investigated by high resolution spectroscopy. In a 1070 nm optical dipole trap, the coherence time is limited to the microsecond scale. To extend the coherence time, we perform frequency-dependent polarizability calculations for both the ground state and the first rotationally excited state of 6Li40K. Spin-orbit coupling between the A1S and b3Pi potentials helps locating the transition from ground state molecules to the |b3Pi,v=0,J=1⟩ state at 314.2305 THz. We experimentally calibrate the differential polarizability near this transition and identify several magic wavelengths where the differential light shift across the trap is negligible and long-rotational coherence times are to be expected. Magic points happen at detunings of −8.8 GHz (for 90° laser polarization) and +6.5 GHz (for 0° laser polarization) relative to the nearest transition. At the +6.5 GHz magic point, the differential polarizability changes by only 70 mHz/(W/cm^2) as laser intensity varies from 0 to 7 kW/cm^2. At this detuning the spontaneous scattering rate in an optical light field is expected to be approximately 30mHz. We discuss the use for future measurements of the rotational coherence on optical lattice potentials.

### *Assembling, entangling, and probing NaCs molecule arrays*

**Li Du**, Harvard University

Ultracold polar molecules offer an exciting platform for quantum science due to their strong, tunable long-range dipolar interactions and rich internal structure. When assembled into molecule arrays with full quantum control, they can enable the exploration of highly coherent, low-entropy many-body systems in previously inaccessible regimes.

In the Ni group at Harvard, we have been developing a bottom-up approach to assemble, control, and read out ultracold NaCs molecules in optical tweezer arrays starting from individual atoms. In this talk, I will present how ground-state molecules are synthesized in the motional ground state of optical tweezers, and how long-lived rotational coherence is achieved by engineering the tweezer polarization, enabling controlled entanglement between molecules and the realization of an iSWAP gate.

I will also discuss recent progress toward non-destructive readout of molecular rotational states using Rydberg atoms, as well as new approaches for scaling to large, defect-free arrays of molecules leveraging electric-field dipolar shielding, paving the way for ultracold molecule arrays to become a scalable quantum simulation platform.

### *Quantum many-body physics with molecular tweezer arrays*

**Connor Holland**, Princeton University

Molecular tweezer arrays are an exciting new platform for quantum science, combining the rich internal structure of molecules with the microscopic detection and control available in tweezer arrays. In this talk, I will present the first explorations of quantum many-body physics in molecular tweezer arrays. First, I will report observations of coherent many-body dynamics in 1/r^3 XXZ/XYZ spin chains, realized in CaF tweezer arrays under Floquet driving. These dynamics include quantum walks of single magnons, appearance of magnon bound states, and coherent creation/annihilation of spins. Next, I will present work on creating many-body entangled states of molecules that provide quantum metrological advantage. Specifically, using 1/r^3 XXZ models, we have created - for the first time - spin-squeezed states of molecules that exceed the Standard Quantum Limit. I will also discuss how the observed spatial correlations of XXZ-squeezed states vary with XXZ anisotropy, and how these correlations act as witnesses for many-body entanglement and EPR steering. Lastly, if time permits, I will briefly discuss our recent work to scale up array sizes to 10s of particles. Importantly, these larger arrays open the door to exploring spin physics in 2D geometries, where phenomena such as thermalization and spin-squeezing are qualitatively different than in 1D.

### *Low-entropy arrays of microwave-shielded molecules*

**Tijs Karman**, Radboud University

We propose to deterministically load single molecules into optical tweezer arrays or lattices from either thermal or degenerate gases, with a high probability of occupying the tweezer's motional ground state. Strong repulsion between microwave-shielded molecules prevents multiparticle occupancy. Our proposal represents a robust scheme for deterministic single molecule preparation directly in the motional ground state with expected fidelities exceeding 99% for small trap volumes and highly polar species. This method can be scaled to thousands of traps limited by the reservoir molecule number, opening the door to large, low-entropy polar molecule arrays for quantum computation, quantum simulation, and precision measurement.

### *Laser cooling of complex molecules*

**T. Langen**, Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien

Molecules are emerging as powerful platforms for precision measurement science, offering unique sensitivity for high-resolution spectroscopy and tests of fundamental symmetries. These experiments can probe energy scales and interactions that complement searches at high-energy collider facilities, opening new avenues for discovering physics beyond the Standard Model in previously unexplored regimes.

Achieving the required level of control over molecules demands precise manipulation of both internal quantum states and external motion, as well as long coherence times. Laser cooling provides a versatile route to meet these requirements [1].

While well-established techniques enable control over molecular vibrational and rotational degrees of freedom, extending laser cooling to heavy species remains challenging. In particular, complex hyperfine structures arising from multiple nuclear spins significantly complicate the realization of efficient optical cycling. Yet it is precisely these heavy, complex molecules that are especially promising candidates for searches for nuclear parity and time-reversal violation.

In this talk, I will introduce novel laser-cooling strategies designed to address these challenges [2,3]. I will present experimental implementations of these techniques and their application to several isotopologues of barium monofluoride (BaF) [4], and discuss their scalability and prospects for cooling other molecular species – including radioactive ones - relevant to precision tests of fundamental symmetries [5,6]. Finally,

I will outline a new experiment based on laser-cooled BaF molecules aimed at probing nuclear-spin-dependent parity violation and the weak interaction.

[1] T. Langen, *et al.*, Nature Phys. **20**, 702 (2024)
[2] M. Rockenhäuser, *et al.*, Phys. Rev. Res. **6**, 043161 (2024)
[3] F. Kogel*, T. Garg*, *et al.,* New J. Phys. **27**, 055001 (2025)
[4] F. Kogel*, T. Garg*, *et al.,* New J. Phys. **27**, 013001 (2025)
[5] F. Kogel, *et al.,* Phys. Rev. Res. **7**, L022041 (2025)
[6] F. Kogel, *et al.,* arxiv:2510.16203 (2025)

### *Evaporative cooling of polar molecules to Fermi degeneracy in 3D and 2D confinements*

**Junyu Lin**, JILA

Production of low-entropy samples of ultracold dipolar molecules would enable observations of novel phases and dynamics predicted by spin-motion models [1-3], such as the generalized t-J model. Here, we report evaporative cooling of ultracold KRb molecules confined in either 3D or 2D trap geometries into deep Fermi degeneracy. Efficient evaporation is initiated by providing a favorable ratio of elastic to inelastic dipolar collisions, enabled by resonant electric field shielding [4] for 3D samples or by purely repulsive dipolar interactions [5] for quasi-2D samples. Further evaporation into deep degeneracy is limited by Pauli blocking which suppresses the ratio of elastic to inelastic collisions. This work explores the influence of dimensional confinement on the interplay of the density of states of degenerate fermions and dipolar scattering, setting the stage for future studies of novel many-body dynamics with deeply degenerate polar molecules.

[1] J. Li, et al, Nature 614, 70–74 (2023)
[2] A. N. Carroll, et al., Science 388, 381-386 (2025)
[3] C. Miller, et al., Nature 633, 332–337 (2024)
[4] J. Li, et al, Nat. Phys. 17, 1144–1148 (2021)
[5] G. Valtolina, et al., Nature 588, 239–243 (2020)

### *Controlling and understanding Fermi gases of polar molecules*

**Xin-Yu Luo**, Max-Planck-Institute of Quantum Optics, Hainan University

Ultracold polar molecules are emerging as a powerful platform for quantum simulation, quantum computing, and cold chemistry. In this talk, I will first review the challenges and status of cooling a Fermi gas of polar molecules in order to realize and explore exotic quantum phases such as p-wave superfluids and Bose-Einstein condensates of dipolar tetramers. Then I will show our observation of controlled symmetry breaking of the Fermi surface of sodium-potassium molecules with double microwave shielding, representing a direct quantum many-body signature of dipolar interactions in molecular Fermi gases. In the end, I will show our progress of developing a compact dual-species setup for producing a Fermi gas of lithium-rubidium molecules, a promising system for realizing exotic dipolar quantum phases at low temperatures.

### *A versatile platform for ultracold NaK molecules*

**Jee Woo Park**, POSTECH

Ultracold polar molecules are a promising platform for quantum simulation and quantum information science because they combine strong, long-range dipolar interactions with precise internal-state control. In this talk, I will present our recent progress toward a versatile ultracold NaK platform that can access both bosonic and fermionic isotopic combinations. We have realized a broadly interaction-tunable Bose-Bose mixture of Na-$^{41}$K and have successfully created Na$^{41}$K Feshbach molecules. In the same apparatus, we have also produced a degenerate Bose-Fermi mixture of Na-$^{40}$K, alongside the formation of Na$^{40}$K Feshbach molecules. I will discuss ongoing efforts in excited-state spectroscopy for two-photon transfer to the rovibrational ground state, and our longer-term goal of extending this platform to a quantum gas microscope for both bosonic and fermionic NaK molecules.

### *Quantum phases of strongly interacting dipolar molecules*

**Thomas Pohl**, Institute for Theoretical Physics, Vienna University of Technology

Recent experimental breakthroughs in preparing and stabilizing ultracold ensembles of heteronuclear molecules have opened up exciting new avenues for investigating the many-body physics of strongly dipolar quantum matter. In particular, the high degree to which the long-range interaction between molecules can be controlled and shaped with precisely tuned microwave fields [1] offers unique possibilities for exploring exotic phases of dipolar matter and can yield conditions that challenge traditional descriptions of quantum gases.

Here, we discuss these prospects from different angles. On the one hand, we employ large-scale path-integral quantum Monte Carlo simulations to study the phase diagram of microwave-dressed molecules, covering regimes from weak to strong interactions and from small to large particle numbers. The peculiar shape of micro-wave induced interactions is shown to stabilize self-bound quantum droplet states and drive transitions to two-dimensional superfluid phases or superfluid membranes, floating in free space with a thickness of a single molecule – and which can eventually undergo a transition to a crystalline monolayer that remains self-bound without external confinement [2]. We explore the required symmetries of microwave-engineered interactions for the emergence or absence of such molecular crystal phases and discuss corresponding implications for recent and future experiments.

Quantum fluctuations play a key role for the many exotic states found in dipolar condensates. Yet, a consistent theoretical description of quantum fluctuations and their stabilizing role in dipolar quantum gases has remained lacking. We discuss the major conceptual challenges in developing such a theory and present corresponding solutions that address this long-standing problem. The presented framework permits to go beyond the popularly employed local-density approximation to the Lee-Huang-Yang (LHY) energy-correction and, thereby, enables a self-consistent determination of the equation of state. For the first time, this yields the phase diagram of dipolar Bose-Einstein condensates and resolves deviations between current LHY-predictions and observations.

Future directions and open questions on the rich physics of dipolar quantum matter from weak to strong interactions will also be discussed.

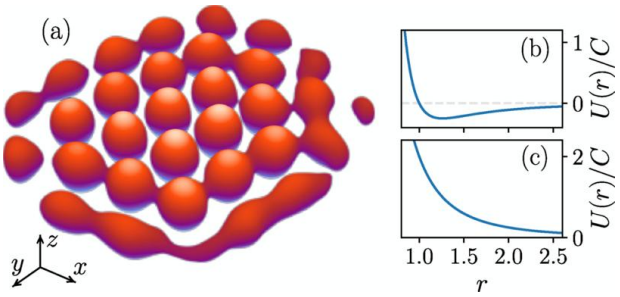


Figure 1: (a) Illustration of a self-bound monolayer crystal, with a single molecule in each lattice site. Shown is the isosurface at a fixed particle density obtained from quantum Monte Carlo. Panels (b), (c): microwave-induced potential as a function of the intermolecular distance r , in (b) the *x*-*y* plane and (c) along the *z*-axis.

[1] A. Schindewolf, *et al*., Strongly dipolar molecular Bose-Einstein condensates: From few- to many-body physics, arXiv:2512.14511 (accepted in Rev. Mod. Phys.).

[2] M. Ciardi, K.-R. Pedersen, T. Langen, and T. Pohl , Self-Bound Superfluid Membranes and Monolayer Crystals of Ultracold Polar Molecules, Phys. Rev. Lett. **135**, 153401 (2025).

### *Progresses towards quantum gas microscope of polar NaRb molecules*

**Jun Rui**, Hefei National Laboratory, University of Science and Technology of China

Ultracold polar molecules open a new door to explore long-range many-body physics beyond the scope of exiting quantum simulation platforms. After enormous efforts of the community on the quantum control of polar molecules during the last two decades, we are now witnessing rapid progresses towards the exploration of quantum many-body phenomena enabled by either DC or AC electric field shielded collisions. In this talk, I will introduce the design and progresses of a new NaRb quantum gas microscope apparatus under construction at USTC. Several severe technical challenges have been encountered and solved. In the end, I will present an outlook of the new experimental probabilities provided by this new apparatus.

### *Dipolar ladder gases: from floating phases to anyon condensates*

**Luis Santos**, Institute of Theoretical Physics, Leibniz University of Hannover

Experiments on dipolar quantum systems, and very especially on polar molecules, are opening interesting possibilities for the quantum simulation of spin models. In particular, dipoles in optical ladders (made with optical lattices or tweezer arrays) offer a particular simple platform for the study of the intriguing ground-state physics and dynamics resulting from the interplay of frustration and long-range interactions. I will first discuss the realization of a peculiar topological floating phases of dipolar bosons in tilted square ladders [1]. I will then move to triangular ladders, where managing the dipolar orientation and strength of the external electric field, allows for the quantum simulation of a very rich landscape of quantum phases of interest for quantum magnetism, including chiral phases, non-chiral two-component magnon Luttinger liquids, and quadrupolar nematic phases [2].

In the last part, I will discuss how dipolar bosons in triangular ladders may realize an intriguing state, the so-called anyon condensate [3]. I will comment on what is meant here with anyons, and discuss how properly-tuned dipoles can be employed to realize this peculiar state [4].

[1] H. Korbmacher, G. A. Domínguez-Castro, M. Łącki, J. Zakrzewski, and L. Santos, Phys. Rev. A **112**, L011301 (2025).
[2] A. Dasgupta, M. Łącki, H. Korbmacher, G. A. Dominguez-Castro, J. Zakrzewski, and Luis Santos, PRA **113**, L031301 (2026)
[3] C. D. Batista, and R. D. Somma, Phys. Rev. Lett. **109**, 227203 (2012).
[4] A. Dasgupta and L. Santos, on-going.

### *Many-body quantum phases in micro-wave shielded polar molecules*

**Tao Shi**, Institute of Theoretical Physics, Chinese Academy of Sciences

We show that the effective interaction potential between microwave-shielded polar molecules consists of an anisotropic van der Waals-like shielding core and a modified dipolar interaction. This effective potential is validated by comparing its scattering cross-sections with those calculated using intermolecular potential involving all interaction channels. It is shown that a scattering resonance can be induced under microwave fields and a field-link tetramer bound state emerges. With the effective potential, we further study the Bardeen-Cooper-Schrieffer pairing, Bose-Einstein condensations, and supersolid phases in microwave-shielded molecular gas. We show the fermionic superfluid critical temperature drastically enhanced near the resonance, a formation of self-bound bosonic droplets with reduced condensate fraction resembling a magnified Helium 4, and a formation of supersolidity controlled by the microwave elliptical angle.

### *Ultracold strongly dipolar alkali-metal–silver molecules*

**Michał Tomza**, Faculty of Physics, University of Warsaw

Ultracold polar molecules are an exceptional platform for exploring fundamental questions in quantum physics and chemistry. Their rich internal structure and long-range dipolar interactions enable applications ranging from controlled chemical reactions and precision spectroscopy for tests of fundamental physics to quantum simulation of strongly correlated many-body systems and quantum information processing. Strong, long-range, and anisotropic dipolar interactions play a central role in these applications, making the permanent electric dipole moment, $d$, a key figure of merit for ultracold molecules.

Among ground-state alkali-metal diatomic molecules [1], LiCs has the largest dipole moment of 5.5(2) D, but its relatively large rotational constant is disadvantageous. Recently, it was predicted that ground-state alkali-metal–silver molecules, such as KAg, RbAg, and CsAg, should have nearly a factor of two large dipole moments of 8.5 D, 9.0 D, and 9.5 D [2].

Here, we present a relativistic *ab initio* investigation of the ground and excited electronic states of highly polar alkali-metal-silver molecules (LiAg, NaAg, KAg, RbAg, CsAg, FrAg) [3]. Potential energy curves (PECs) are computed for all states dissociating to the lowest $^2S_{1/2} + {}^2S_{1/2}$ and first excited $^2S_{1/2} + {}^2P_{1/2}$ and $^2S_{1/2} + {}^2P_{3/2}$ asymptotes using the Fock-space coupled-cluster method with single and double excitations (FSCCSD). Scalar and spin–orbit relativistic effects are included using small-core energy-consistent pseudopotentials and a two-component relativistic Hamiltonian, resulting in PECs in the Hund's case (c) representation.

We predict large permanent electric dipole moments for the ground $X^1\Sigma^+$ states and determine spin-spin coupling constants for the $a^3\Sigma^+$ states. Franck–Condon factors between ground and excited electronic states are evaluated, revealing favorable optical pathways for molecular stabilization via the $A^1\Sigma^+$ states and for imaging or laser cooling via the $b^3\Pi$ states. In addition, we predict the presence of low-lying heavy Rydberg states. Our results provide essential guidance for the optical formation, detection, and control of strongly polar alkali-metal–silver molecules, highlighting their potential for applications in quantum many-body physics and quantum information science.

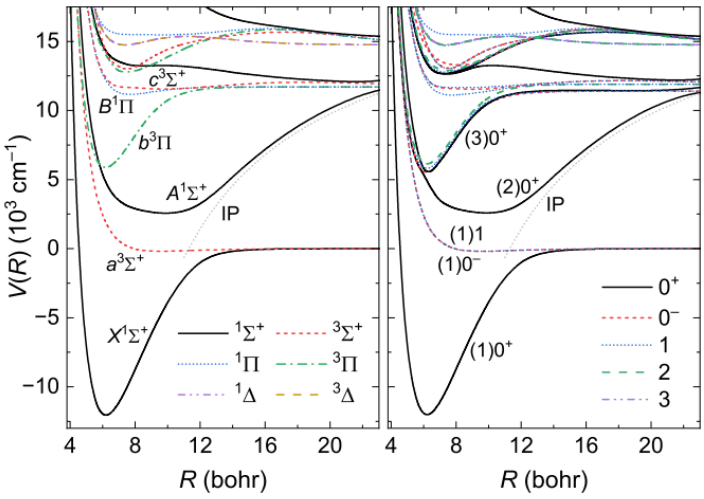


Figure 1: Potential energy curves of the ground and excited electronic states of the CsAg molecule [3].

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[2] M. Śmialkowski, M. Tomza, *Highly polar molecules consisting of a copper or silver atom interacting with an alkali-metal or alkaline-earth-metal atom*, Phys. Rev. A **103**, 022802 (2021)

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### *Towards a BEC of a stable molecule*

**Stefan Truppe**, Centre for Cold Matter, Blackett Laboratory, Imperial College London

We report recent progress toward producing a Bose–Einstein condensate of stable, deeply bound, and polar AlF molecules. AlF combines several favourable properties for reaching ultracold temperatures: its deep chemical bond makes molecule–molecule reactions endothermic, and long-lived collisional complexes are strongly suppressed, suggesting that direct evaporative cooling may be feasible without additional shielding. AlF also has an alkalineearth-like electronic structure with a strong cycling transition in the deep ultraviolet. Using this transition, we have trapped and cooled AlF in a magneto-optical trap. We present progress toward increasing the phase-space density by implementing grey molasses cooling and by developing a Zeeman slower aimed at improving trap loading and accumulation. In addition, weak spin-forbidden transitions provide access to narrow-line cooling and accumulation in conservative traps, with potential applications in precision measurements.

### *Tetratomic states of microwave dressed and associated ultracold $^{23}Na^{40}K$ Molecules*

**Pengjun Wang**, Shanxi University

In this talk, I will present the microwave spectroscopy of tetratomic molecules from microwave-dressed fermionic $^{23}Na^{40}K$ molecules. When the two lowest rotational states of the molecules are dressed by a microwave field, weakly bound tetramer states emerge in the entrance channel with free dark excited states and a dressed state. The spectroscopy of these weakly bound tetramers is probed by another microwave field that drives transitions from the populated dressed states. By precisely discriminating the complex hyperfine structure of the dark excited level from the dressed-state spectroscopy, the binding energy of the tetratomic molecules is measured and characterized. Our work contributes to the understanding of complex few-body physics within a system of microwave-dressed molecules and may open an avenue toward the creation and control of ultracold polyatomic molecules.

References:

1. Ziiang Li, Zhengyu Gu, Pengjun Wang, Jing Zhang, Efficientproduction of ultracold polar molecules 23Na40K in their absolute ground state via intermediate state of the coupled complex B1Π|ν = 4〉 ~ c3Σ+ |ν = 25〉 , Sci. China Phys. Mech. Astron. 66, 293011 (2023).
2. Zhengyu Gu, Xuansheng Zhou, Wei Chen, Wei Han, Fulin Deng, Tao Shi, Pengjun Wang, Jing Zhang, Tetratomic states of microwave dressed and associated ultracold 23Na40K molecules, arXiv:2509.23634.

### *Deep laser cooling and optical trapping of BaF molecules*

**Bo Yan**, Zhejiang University

BaF molecules are compelling systems for precision measurements, particularly in the search for the electric dipole moment (EDM) of the electron. Their relatively high mass and electronic structure make them especially sensitive to symmetryviolating interactions, and cooling them to ultracold temperatures can dramatically improve the statistical and systematic precision of such measurements. In this work, we present a comprehensive study on deep laser cooling of BaF. We demonstrate that the capture velocity and cooling efficiency are significantly enhanced by employing a conveyor-belt, blue-detuned magneto-optical trap (MOT). This approach enables the production of a cold molecular sample with a notably high phase-space density. We further improve this density by applying gray molasses cooling, which provides additional subDoppler cooling. Building on these advances, we successfully load the cold BaF molecules into an optical dipole trap, where we investigate further cooling mechanisms and the potential for evaporative cooling toward quantum degeneracy. Our results mark an important step toward the realization of ultracold, trapped BaF molecules for next-generation EDM searches and quantum science applications.

### *Two-body chemical reactions in ultracold Fermi gases: From contact thermodynamics to non-equilibrium kinetics*

**Yangqian Yan**, The Chinese University of Hong Kong

Two-body chemical reactions are a key observable in ultracold molecular gas experiments. Starting from a non-Hermitian effective field theory consistent with the Lindblad master equation, we apply two complementary descriptions of reactive p-wave molecular Fermi gases. First, a generalized contact-loss relation connects the two-body loss rate in any partial-wave channel to a single thermodynamic contact. For a p-wave Fermi gas, this relation gives closed-form loss rates from the classical regime to deep quantum degeneracy and predicts a finite zero-temperature loss rate set by the Fermi energy. Second, an inelastic quantum Boltzmann equation reveals a fractional N-body decay law with a temperature-dependent exponent: $N = 7/3$ at high temperature and $N = 44/21$ at zero temperature, rather than the naive value $N = 2$. Momentum-selective p-wave loss self-thermalizes the gas at high temperature but drives it genuinely out of equilibrium in the degenerate regime. For trapped gases, a fast-flowing approximation reduces the six-dimensional phase-space dynamics to a single hyperradial coordinate. Together, these two frameworks reproduce recent molecular loss experimental data without fitting parameters.

### *Complex lifetime of ultracold molecules*

**Peng Zhang**, School of Physics, Renmin University of China

In ultracold molecule gases, complexes can be formed during two-body collisions. The lifetime of these complexes has been measured in various experiments via the detection of two-body losses. For many types of ultracold molecules, the observed complex lifetime is much longer than those predicted by the standard theory of chemistry. We propose an explanation of this phenomenon. Specifically, by a calculation of Virial expansion, we show that in the low-temperature cases, the complex lifetime may become temperature-dependent and increases with the decreasing of temperature. That is essentially due to the quantum coherence between two-molecule scattering state and the “complex state” (quasi-bound state), which is not completely broken by the thermal fluctuation.

If time is enough, in this talk I will also introduce another result, which is about the micro-wave shielding ultracold molecules. The shielding can not only modify the effective two-molecule interaction but also induce effective three-body and four-body interactions. The properties of these effective interactions are investigated.