Annual Progress Summary, July 2013

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Subject: Annual Progress Statement to Dr. Tatjana Curcic

Contract/Grant Title: (MURI 09) Production, Manipulation, and Applications of Ultracold Polar Molecules

Contract/Grant #: FA9550-09-1-0588

Reporting Period: 08/01/2012 to 07/31/2013

Annual accomplishments:

Production, Cooling, and Detection.

We can now cool exotic atoms and molecules from slow beams and directly load them into a magneto-optical trap (MOT). Most notably, we demonstrated direct loading of a slow CaF beam into a magnetic trap. We demonstrated a 2D MOT for YO, aiming towards 3D and we keep decreasing temperatures using evaporative cooling of OH. We also constructed a 3D MOT for SrF and are investigating loading laser-slowed molecules into this MOT. Transverse confinement of alaser-slowed molecular beam can improve trap loading efficiency and we characterized a photo-association pathway to direct production of rovibronic ground state RbCs toward creating large samples of trapped ground state molecules. A new buffer gas source of CH allows unprecedented densities and we Stark decelerated these beams to capture 5% to allow to study the important $CH + CH \rightarrow C_2H + H$ reaction. New direct spectroscopic methods and improved amplifiers are being implemented to improve those experiments. Analysis and demonstration of KRb in external fields increase coherence times by an order of magnitude, and a number of improvements allows optimization of the formation of KRb and Rb₂. We finished the simulation of superradiant decay found that typical experimental settings involving vibrational transitions will show superradiant effects.

Structure and Chemistry.

We have computed long-range coefficients for all combinations of bi-alkali molecules with a small external static electric fiel. We explored KRb+KRb, and identified longrange barriers due to quadrupolar interactions even with attractive dipolar interactions where tetramers might be possible. We have analyzed cold-collision properties of OH in crossed electric and magnetic fields and have identified a novel set of quantum numbers to describe this case. We found that ultracold collisions of alkali dimers may result in a novel "sticking" for milliseconds, with implications for trap stability etc. We also find that Li +Li and Li +Na collisions are well-described by a universal quantum Langevin model with unit probability of loss at short range, leaving rates dependent only on the long-range interaction.

Quantum Information/Simulation.

We have realized a spin lattice model using dipolar exchange interactions in a threedimensional optical lattice, have investigated quantum phases of quadrupolar particles, such as some homonuclear molecules and are now investigating quasi-1D and 2D manybody effects of particles with resonances due to in-plane dipole moments. We simulated the realization of topological states using polar molecules on a lattice, studied the effect of dipole-dipole collisions on the transport properties in 2D and the similarity between dipolar fermions and a 2D electron gas in the vicinity of the Wigner crystal transition, propose polar molecules as a test bed for understanding strongly correlated phases of electronic systems.

Molecular Ions.

A general method for rotational microwave spectroscopy and control of polar molecular ions via direct microwave addressing is considered, making use of spatially varying AC Stark shifts.

Archival publications (published) during reporting period:

- M. Babadi and E. Demler. Collective excitations of quasi-two-dimensional trapped dipolar fermions: transition from collisionless to hydrodynamic regime. *Phys. Rev. A*, 86:063638, 2012.
- [2] M. Babadi, B. Skinner, M. M. Fogler, and E. Demler. Universal behavior of repulsive two-dimensional fermions in the vicinity of the quantum freezing point. *Europhys. Lett.*, 103:16002, 2013.
- [3] J. Banerjee, D. Rahmlow, R. Carollo, M. Bellos, E. E. Eyler, P. L. Gould, and W. C. Stwalley. Spectroscopy and applications of the $3^3\sigma^+$ electronic state of ${}^{39}k^{85}rb$. (J. Chem. Phys, submitted).
- [4] J. Banerjee, D. Rahmlow, R. Carollo, M. Bellos, E. E. Eyler, P. L. Gould, and W. C. Stwalley. Direct photoassociative formation of ultracold krb molecules in the lowest vibrational levels of the ground state. *Phys. Rev. A*, 86:053428, 2012.
- [5] J. Banerjee, D. Rahmlow, R. Carollo, M. Bellos, E. E. Eyler, P. L. Gould, and W.C. Stwalley. Spectroscopy of the double minimum 3 ${}^{3}\pi_{\omega}$ electronic state of ${}^{39}k^{85}$ rb. J. Chem. Phys., 138:164302, 2013.
- [6] M.A. Bellos, R. Carollo, J. Banerjee, M. Ascoli, A.-R. Allouche, E. E. Eyler, P. L. Gould, and W. C. Stwalley. Upper bound to the ionization energy of ⁸⁵rb₂. *Phys. Rev.* A, 87:012508, 2013.
- [7] M.A. Bellos, R. Carollo, J. Banerjee, E. E. Eyler, P. L. Gould, and W. C. Stwalley. Excitation of ultracold molecules to trilobite-like rydberg states. (in press), 2013.
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- [10] John L. Bohn and Goulven Quéméner. Dipolar radicals in crossed electric and magnetic fields. *Molecular Physics*, 111:00268976.2013.783721, 2013.
- [11] Jason N. Byrd and Robin Côté. Formation of ultracold tetramers by photoassociation of bi-alkali dimers. in preparation (to be submitted to PRL), 2013.
- [12] R. Carollo, M.A. Bellos, D. Rahmlow, J. Banerjee, E. E. Eyler, P. L. Gould, and W. C. Stwalley. Observation and analysis of resonant coupling between near-degenerate levels of the $2^1\sigma_a^+$ and $1^1\pi_q$ states of ultracold ⁸⁵rb₂. *Phys. Rev. A*, 87:022505, 2013.
- [13] D. DeMille, J. F. Barry, E. R. Edwards, E. B. Norrgard, and M. H. Steinecker. On the transverse confinement of radiatively slowed molecular beams. *Molecular Physics*, 111:1, 2013.
- [14] M. I. Fabrikant, N.J. Fitch, N. Farrow, Tian Li, Jonathan Weinstein, and H.J. Lewandowski. Traveling-wave deceleration of ch buffer-gas beams. (submitted), 2013.
- [15] N.J. Fitch, D.A. Esteves, M.I. Fabrikant, T.C. Briles, Y. Shyur, L.P. Parazzoli, and H.J. Lewandowski. State purity of decelerated molecular beams. *Journal of Molecular Spectroscopy*, 278:1, 2012.
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- [17] Jr. Jason N. Byrd, H. John A. Montgomery, and Robin Côté. Controllable binding of polar molecules and metastability of one-dimensional gases with attractive dipole forces. *Phys. Rev. Lett.*, 109:083003, 2012.
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- [19] D. S. Jin and J. Ye. Introduction to ultracold molecules: New frontiers in quantum and chemical physics. *Chemical Reviews*, 112:4801, 2012.
- [20] J.T. Kim, Y. Lee, B. Kimand D. Wang, P. L. Gould, E. E. Eyler, and W.C. Stwalley. Spectroscopic investigation of the a and $3 \, {}^{1}\sigma_{+}$ states of ${}^{39}k^{85}rb$. J. Chem. Phys., 137:244301, 2012.
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Changes in research objectives, if any: None

Change in AFOSR program manager, if any: None

Extensions granted or milestones slipped, if any: None

Include any new discoveries, inventions, or patent disclosures during this reporting period (if none, report none): None