Annual Progress Summary, July 2011

To: technicalreports@afosr.af.mil

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: 08/01/2010 to 07/31/2011

Annual accomplishments (200 words max):

Production, Cooling, and Detection.

Polar molecules can now be produced in a 3D optical lattice, and we have seen indirect evidence of ultracold LiNa. Various types of molecules were cooled in analog-controlled voltage Stark deceleration, and in (cryogenic) beams down to 40 m/s. We laser cooled SrF, both in transverse and longitudinal directions and demonstrated novel STIRAP/FOPA schemes. We have been calculating superradiance-assisted vibrational cooling, and finally the first narrowband spectroscopic evidence of ultracold RbCs was produced.

Structure and Chemistry.

Cold collisions between different species were observed, measured, and their cross sections calculated. We demonstrated that bimolecular chemical reactions can be suppressed by two orders of magnitude in a 2D optical lattice trap. More detailed theoretical studies of thermochemical and long-range stabilizing interactions between ultracold KRb molecules will now be extended to other species and we proposed schemes to control the Stark shift of rotational states using lasers and electric fields.

Quantum Information/Simulation.

We proposed the use of Rydberg-mediated polar molecule interactions, methods to produce cluster states using dipolar interactions, and compared the use of polar molecules and ions for single photon nonlinearities. In addition, our many-body quantum simulations based on dipolar interactions and molecular Feshbach resonances included exotic spin textures in magnetic superfluids, exotic paired states and Majorana fermions, Shiba states in fermionic superfluids, magnetism, and few-body bound states.

In addition, we studied realistic quantum information processing schemes with molecular ions and anisotropic effects in opical lattices.

Molecular Ions.

With the demonstration of superconducting ion traps on an integrated chip we performed detailed calculations for interfacing polar molecules with circuit QED systems. We modelled photodissociation of molecular ions, particularly $BaCl^+$.

Archival publications (published) during reporting period:

[1] J.F. Barry, E.S. Shuman, and D. DeMille. A bright, slow cryogenic molecular beam source for free radicals. *Phys. Chem. Chem. Phys*, in press, 2011.

[2] M. A. Bellos, D. Rahmlow, R. Carollo, J. Banerjee, O. Dulieu, A. Gerdes, E. E. Eyler, P. L. Gould, and W. C. Stwalley. Ultracold metastable rb_2 molecules in their v"=0 level by blue-detuned photoassociation. *Phys. Chem. Chem. Phys.*, in press, 2011.

[3] Jason N. Byrd, John A. Montgomery Jr., and Robin Côté. Structure and thermochemistry of K_2Rb, KRb_2, and K_2Rb_2. *Phys. Rev. A*, 82:010502(R), 2010.

[4] K. Chen, S. J. Schowalter, S. Kotochigova, A. Petrov, W. G. Rellergert, S. T. Sullivan, and E. R. Hudson. Molecular-ion trap-depletion spectroscopy of $BaCl^+$. *Phys. Rev. A*, 83:030501(R), 2011.

[5] R. W. Cherng and E. Demler. Neutral skyrmion configurations in the low-energy effective theory of spinor-condensate ferromagnets. *Phys. Rev. A*, 83:053614, 2011.

[6] R. W. Cherng and E. Demler. Symmetry analysis of crystalline spin textures in dipolar spinor condensates. *Phys. Rev. A*, 83:053613, 2011.

[7] Caleb Christensen. Ultracold molecules from ultracold atoms: Interactions in sodium and lithium gas. *Ph.D. Thesis, MIT*, 2011.

[8] M. H. G. de Miranda, A. Choatia, B. Neyenhuis, D. Wang, G. Qumner, S. Ospelkaus, J. L. Bohn, J. Ye, and D. S. Jin. Controlling the quantum stereodynamics of ultracold bimolecular reactions. *Nature Physics*, 7:502, 2011.

[9] Alexey V. Gorshkov, Salvatore R. Manmana, Gang Chen, Eugene Demler, Mikhail D. Lukin, and Ana Maria Rey. Quantum magnetism with polar alkali dimers. *Phys. Rev. A*, in press, 2011.

[10] Alexey V. Gorshkov, Salvatore R. Manmana, Gang Chen, Jun Ye, Eugene Demler, Mikhail D. Lukin, and Ana Maria Rey. Tunable superfluidity and quantum magnetism with ultracold polar molecules. *Phys. Rev. Lett.*, in press, 2011.

[11] Z. Idziasek, G. Quemener, J. L. Bohn, and P. S. Julienne. A simple model of ultracold polar molecule collisions. *Phys. Rev. A*, 82:020702(R), 2010.

[12] Liang Jiang, Takuya Kitagawa, Jason Alicea, A. R. Akhmerov, David Pekker, Gil Refael, J. Ignacio Cirac, Eugene Demler, Mikhail D. Lukin, and Peter Zoller. Majorana fermions in equilibrium and driven cold atom quantum wires. *Phys.Rev.Lett.*, 106:220402, 2011.

[13] D. S. Jin and J. Ye. Polar molecules in the quantum regime. *Physics Today*, 64:27, 2011. invited review.

[14] J.-T. Kim, Y. Lee, B. Kim, D. Wang, W.C. Stwalley, P. L. Gould, and E. E. Eyler. Spectroscopic analysis of the coupled $1^1\Pi$, $2^3\Sigma^+(\Omega = 0^-, 1)$, and $b^3\Pi(\Omega = 0^{+/-}, 1, 2)$ states of the KRb molecule using both ultracold molecule and molecular beam experiments. *Phys. Chem. Chem. Phys.*, in press, 2011.

[15] S. Kotochigova. Dispersion interactions and reactive collisions of ultracold polar molecules. *New J. Phys.*, 12:073041, 2010.

[16] S. Kotochigova and D. DeMille. Electric-field-dependent dynamic polarizability and state-insensitive conditions for optical trapping of diatomic polar molecules. *Phys. Rev. A*, 82:063421, 2010.

[17] Elena Kuznetsova, Robin Côté, and Susanne Yelin. Coherent laser manipulation of ultracold molecules. To appear as chapter in"Laser Pulses / Book 3 (ISBN 978-953-308-56-9", Publisher: InTech, 2011.

[18] Elena Kuznetsova, Seth T. Rittenhouse, Hossein R. Sadeghpour, and Susanne F. Yelin. Rydberg atom mediated polar molecule interactions: a tool for molecular-state conditional quantum gates and individual addressability. *Phys. Chem. Chem. Phys.*, in press, 2011.

[19] L. Lamata, D. R. Leibrandt, I. L. Chuang, J. I. Cirac, M. D. Lukin, V. Vuletic, and S. F. Yelin. Ion crystal transducer for strong coupling between single ions and single photons. *Phys. Rev. Lett.*, 107:030501, 2011.

[20] Hsin-I Lu, Julia Rasmussen, Matthew J. Wright, Dave Patterson, and John M. Doyle. Cold and slow molecular beam. *Phys. Chem. Chem. Phys.*, in press, 2011.

[21] L. P. Parazzoli, N. J. Fitch, P. S. Zuchowski, J. M. Hutson, and H. J. Lewandowski. Large effects of electric fields on atom-molecule collisions at millikelvin temperatures. *Phys. Rev. Lett.*, 106:193201, 2011.

[22] G. Quemener and J. L. Bohn. Dynamics of ultracold molecules in confined geometry and electric field. *Phys. Rev. A*, 83:012705, 2011.

[23] B. C. Sawyer, B. K. Stuhl, M. Yeo, T. V. Tscherbul, M. T. Hummon, Y. Xia, J. Klos, D. Patterson, J. M. Doyle, and J. Ye. Cold heteromolecular dipolar collisions. *Phys. Chem. Chem. Phys.*, in press, 2011.

[24] D. I. Schuster, Lev S. Bishop, I. L. Chuang, D. DeMille, and R. J. Schoelkopf. Cavity QED in a molecular ion trap. *Phys. Rev. A*, 83:012311, 2011.

[25] E. S. Shuman, J. F. Barry, and D. DeMille. Laser cooling of a diatomic molecule. *Nature*, 467:820, 2010.

[26] Eric Vernier, David Pekker, Martin W. Zwierlein, and Eugene Demler. Bound states of a localized magnetic impurity in a superfluid of paired ultracold fermions. *Phys. Rev. A*, 83:033619, 2011.

[27] Shannon X. Wang, Yufei Ge, Jaroslaw Labaziewicz, Eric Dauler, Karl Berggren, and Isaac L. Chuang. Superconducting microfabricated ion traps. *Appl. Phys. Lett.*, 97(244102), 2010.

[28] B. Wunsch, N. T. Zinner, I. B. Mekhov, S.-J. Huang, D.-W. Wang, and E. Demler. Few-body bound states in dipolar gases and their detection. *Phys. Rev. Lett.*, in press, 2011.

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