APPLICATION CHECKLIST
Presidential Faculty/Student Collaboration and Publication Grant

Deadline February 26th

Please print and complete this checklist and attach it as the cover page of your grant application. For more information about Presidential Faculty/Student Collaboration and Publication grants, please see http://gustavus.edu/facdev/GrantOpportunities/PresidentialGrant.php.

Faculty information

Name:___Jessie Petricka________________ Dept:____Physics____________________

Email: ___jpetrick@gustavus.edu_________ Rank:_____Assistant Professor_______

Student Information

Name:___Daniel McDougall_______________ Year:_____Junior____________________

Email: ____dmcdouga@gustavus.edu________ Major:_____Physics + Math___________

Checklist

Project Details

x Brief description of the proposed project including its collaborative nature

XClear statement of anticipated outcomes

xLikely placement for publication or performances

x Anticipated research completion date

Participant Details

x Names and brief biographies of all participants

x Explanation of how this project fits into the career of the faculty

x Explanation of how this project fits into the educational trajectory of the student (include year of graduation; student eligibility is limited to full-time returning students)

X Presidential Budget Proposal Form attached as last page of application

X Nine (9) copies of completed application (including this checklist) to be submitted to the John S. Kendall Center for Engaged Learning (SSC 119)

If successful, my proposal can be used as an example to assist future faculty applications. This decision will not in any way influence the evaluation of my application.

Yes / No (please circle one)

Presidential Faculty/Student Collaboration Grant
BUDGET INFORMATION

Faculty Stipend ($300 per week, up to $2,400)

Student Summer Stipend ($400 per week, up to $3,200)

Student Summer Campus Housing ($XXX per week, up to 8 weeks)

ITEM		**AMOUNT**
Equipment (e.g., transcription machine, camera, cassette recorder; but not to include computer hardware)		$0
1:	Cost:	
2:	Cost:	
3:	Cost:	
Materials (e.g., books, printing, software, lab supplies)		$0
1:	Cost:	
2:	Cost:	
3:	Cost:	
Travel Costs (cannot include conference travel; see http://[illegible]/finance/travel.htm for allowable travel expenses)		$0
Airfare:		
Mileage: Number of miles_____ @ $0.55/mile		
Lodging:		
Meals:		
Stipends & Housing		$5950
Faculty Stipend	$300 per week, up to $2,400	$2400
Student Summer Stipend	$400 per week, up to $3,200	$3200
Student Summer Campus Housing	$43.75 per week, up to 8 weeks, $350	$350
TOTAL EXPENSES		$5950
AMOUNT REQUESTED		$5950

Have you applied for, or received funding from, another source to help support this project? **No**

Funding Source:

Amount:

Please explain how the Presidential will be used in addition to the other funding.

Production and Trapping of Molecular Ions *via* Laser Ablation

Jessie Petricka
Daniel McDougall

Brief description of the proposed project and collaboration:

This request is for funds to support the research of PI Jessie Petricka and Gustavus student Daniel McDougall in the summer of 2010. The overall goal of this study involves the construction, testing and use of the first stages of an ultracold molecular ion trapping laboratory at Gustavus. Over the course of this investigation the PI and student will work closely together to conduct all stages of the research.

Daniel McDougall was a student in my Experimental Modern Physics course in the fall of 2009. During this course, Daniel was an eager learner. He showed an ability to grasp the fundamentals of an experiment, and was quick to employ his knowledge to the task at hand. In addition, he would seek answers to questions that went beyond the scope of the immediate laboratory material. Further, he showed interest in the many nuanced technical points that were shielded from students to smooth completion of the lab. This shows his inquisitive nature and experimental maturity, core requirements for an experimental physicist. His expressed interest in graduate school, along with his firm commitment to the project, will make him a keen student with which to build an ultracold molecule trapping lab. This process will not only build on his experiences from my lab course but will introduce Daniel to the many new experimental physics techniques, new physical subjects and current literature. This in turn will allow him to confirm his desire for graduate school, and better prepare him for that environment, post-Gustavus.

Project description:

The field of atomic physics has seen an explosion of interest, activity and results in the last 15 years due to the AMO (atomic, molecular, and optical) community's ability to control both the internal and external degrees of freedom of matter. Such control has allowed for the creation of ultra-cold and ultra-pure quantum samples with which to do experiments. By far the bulk of the results have been with a few specific neutral atoms, where the internal structures of those atoms allow for specific cooling and trapping techniques[1]. Yet the achievements of the ultracold atom field with this small set are remarkable. From basic quantum science with Bose-Einstein Condensation and degenerate Fermion gases[2,3], to fundamental precision measurements of constants and spectroscopy[4], even practical atomic sensors and ultra-precise atomic clocks[5], ultracold atoms have revolutionized the field of AMO. Unfortunately, these techniques fail for more complex atoms and for molecular samples, samples whose complexity would lead to vast increases in scientific understanding and practical utility.

General molecular experiments follow the same basic routine as atomic experiments, sample production, followed by manipulation and then detection. As alluded to, the first step, production is the enabler that allows a host of other study. Much of the current focus is on producing ultracold neutral molecules, as neutral molecules can be brought into close proximity to one another, achieving a density where quantum effects are important and bring the atoms to where short range forces will cause the molecules to interact. Even though the field is rapidly making progress toward this goal, the growing number of competing techniques is neither general nor able to produce the high density and cold temperatures that applications and scientific study require[6].

The study of molecular ions, on the other hand, has seen less attention for a couple of reasons. One is because a clear production method (as for neutrals) is yet to be found. Another is that ions interact via the long range Coulomb force. Coulombic repulsion pushes ions apart, reducing the density of the sample and dwarfing any short range interactions. Their study, though, is interesting for several reasons. The trapping of ions is a well established and straightforward field, working generally for any charged object[1]. While certain applications and studies with ultracold molecules would not work with ions, several of the most interesting remain, including the study of cold chemistry[7], ultra-precise measurement of molecular transitions, and implementation of a scalable quantum computer[8].

The production and trapping of molecular ions is an immediate goal of this research, and a stepping stone towards the production of ultracold molecular ion samples. Simply put, we will accomplish this goal through the coupling of laser ablation to a linear Paul trap. Laser ablation is the process whereby a high-powered pulsed laser beam is focused onto a suitable precursor containing the molecule of interest. The high energy of the beam is deposited on the surface, critically heating it to the point of ejecting material. Many forms of the target, with both ions and neutrals, are ejected into a plume that is ejected from the surface. In this way, almost any desired species can be created, given the choice of suitable precursor[9].

Once the ions are produced from ablation, the next step of the process is trapping. The simplest and strongest way to interact with charged particles is through electric fields. Fields created by even modest voltages (tens of volts) over reasonable distances (few to ten millimeters) can cause motion in charged particles that overwhelms the particles thermal motion. The optimal field geometry would be a field extremum (e.g. a minimum to attract positively charged ions) to create a potential well to trap the ion. But Earnshaw's theorem states that a field extremum cannot occur in free space, only at a charged surface[1]. This is easy to see since the divergence of the electric field in free space is zero. What can be created, however, is a time averaged extremum through the use of an AC field. One such realization of this is the linear Paul trap. A Paul trap consists of four parallel cylindrical conducting rods arranged in a square pattern. Rods on opposite corners are electrically connected to an oscillating voltage, with adjacent corners of opposite sign. The net effect of this field on a charged particle is a time averaged potential that has a minimum along the axis of symmetry parallel to the rods. Simple endcaps with positive voltage provide axial confinement to trap the ions in all three dimensions.

Upon trapping, ions can be cooled a number of different ways. Laser cooling, the staple of neutral atom research, can cool simple ions but again fails for molecules due to their internal structure. The simplest method for cooling those with complex structure is collisional cooling, whereby laser or cryogenic cooling is used to cool an auxiliary gas refrigerant (simple ion[10] or noble buffer gas[9] respectively) which is brought into thermal contact with the molecular ions. To date the choice of refrigerant has been successful in cooling either only the external degrees of freedom (motion) or, to a very limited extent, both. It is clear that further research in the methods for producing ultracold ions, if successful, would be a boon to further scientific research. What is limiting progress is experience with molecule ion / refrigerant reactions and interactions. We plan to study these for a variety of molecular ions and refrigerants. By measuring the reactions such as recombination rates, and interactions such as cooling efficiency[10], we believe that suitable choices can be found that allow cooling both external and internal degrees of freedom to the ultra cold regime.

References:

1. Foot, C. *Atomic Physics*. (Oxford University Press: Oxford, 2005).
2. O'Hara, K.M., Hemmer, S.L., Gehm, M.E., Granade, S.R. & Thomas, J.E. Observation of a Strongly Interacting Degenerate Fermi Gas of Atoms. *Science* 1079107 (2002).doi:10.1126/science.1079107
3. Anderson, M.H., Ensher, J.R., Matthews, M.R., Wieman, C.E. & Cornell, E.A. Observation of Bose-Einstein Condensation in a Dilute Atomic Vapor. *Science* **269**, 198-201 (1995).
4. DeMille, D. et al. Enhanced Sensitivity to Variation of m_ ${$e$}$/m_ ${$p$}$ in Molecular Spectra. *Physical review letters* **100**, 43202 (2008).
5. Rosenband, T. et al. Frequency Ratio of Al+ and Hg+ Single-Ion Optical Clocks; Metrology at the 17th Decimal Place. *Science* **319**, 1808-1812 (2008).
6. Carr, L.D., DeMille, D., Krems, R.V. & Ye, J. Cold and ultracold molecules: science, technology and applications. *New Journal of Physics* **11**, 055049 (2009).
7. Hudson, E.R. et al. Production of cold formaldehyde molecules for study and control of chemical reaction dynamics with hydroxyl radicals. *Phys. Rev. A* **73**, 063404 (2006).
8. DeMille, D. Quantum Computation with Trapped Polar Molecules. *Phys. Rev. Lett.* **88**, 067901 (2002).
9. Petricka, J. A New Cold Molecule Source: The Buffer Gas Cooled Molecular Beam. (2007).
10. Hudson, E.R. Method for producing ultracold molecular ions. *Phys. Rev. A* **79**, 032716 (2009).

Anticipated outcome and research goals:

Implementation goals for this research:

- We will design and purchase a modular, multipurpose, ultra-high vacuum chamber for experiments.
- We will set up and characterize a pulsed Nd:Yag laser system for laser ablation.
- We will design and construct a RF electrostatic trap for the confinement of the molecular ions.

In addition to design and construction, the following system tests will be performed to validate performance goals of the apparatus:

- Ablation yield will be measured for optimization of various optical configurations.
- Trap confinement and lifetimes will be measured to establish preferred geometries and overall vacuum levels.

The results of this research will be directly relevant to the submission of several grants in the fall of 2010 for the funding of future work. Development of experimental techniques will apply to the future

- Develop a charge recombination experiment protocol.
- Develop a cryogenic buffer gas cooling plan.
- Create and present a project poster.

Anticipated research completion date:

Complete major purchases by the end of spring term.
Establish a functioning ion trap by the end of summer 2010.

Participant details

Jessie Petricka

I received my undergraduate education at Carleton College (2001). As a senior thesis, I studied the theory of atomic Rubidium Bose-Einstein-Condensation. I then went to graduate school at Yale University. During my first two years there (2001-2002), I worked on an experiment to sensitively measure the gravitational field. This experiment was based on a cold atom fountain. Launching the atoms in a parabolic trajectory changes their phase, as they interact with gravity. An interferrometetric phase measurement provides a very precise way to quantify gravity's effects on the atom. This experiment introduced me to atomic laser systems, vacuum systems, and many other atomic techniques for the cooling and trapping of neutral atoms.

My thesis work (2003-2006) focused on building an apparatus for the production of cold molecules. During the course of this work, I designed and built the machine from its inception. The resulting device was the first of its kind to use laser ablation and buffer gas cooling for making an intense and cold molecule beam. Today, this technique is used by several molecular research groups worldwide both as a precursor for further cooling and as a beam source for scientific experiments.

My realization of this work required me to become proficient in optical, cryogenic, electronic, and mechanical design and operation. This has given me a body of AMO laboratory experience that is directly applicable to other experiments. In addition to this experience, I developed several computational and theoretical methods related to this project. For instance, I modeled the buffer gas cooling process using Monte Carlo integration methods, and compared the results to my tested apparatus efficiencies in an effort to maximize production. In addition, I developed a theory for trapping neutral molecules using a microwave cavity.

After defending my thesis, I performed postdoctoral research at Duke University (2007-2008). While there, I explored the properties of ultracold neutral fermions. These properties have analogues to other areas of physics such as superconductors, neutron stars, and black holes. Some of the experiments that I took data on were in the areas of quantum viscosity, universal behavior, and spin dynamics.

How this project fits into the career of Jessie Petricka

I am beginning an independent research program in the area of ultracold molecular physics. This area is a growing subfield of atomic physics, which itself has seen spectacular results in the last ten years. Ultracold molecules and atoms has been my specialty since I began graduate study. At Gustavus, I believe that I can bring my expertise to bear in doing fundamental research to further this field.

I plan to educate and train Gustavus undergraduates in this program, when given the necessary funding. Their experiences in the lab will introduce them to modern atomic physics laboratory techniques. These methods include optics/lasers, photo and electrical sensors, computer programming, apparatus design and construction, ultra-high vacuum, and circuit/electrical design. The process of this education will also introduce both the student and myself to new atomic physics literature and ideas.

During the course of this research novel methods and experiment results will be presented as a basis for future funding from internal sources such as GAC and external sources such as the NSF. As the apparatus complexity advances this research will become viable as a scientific apparatus. The result of scientific experiments will be presented to peer-reviewed publication. I am actively collaborating with Dr. Eric R. Hudson (UCLA) who has a similar program and goals. We actively share ideas and techniques and discuss appropriate experiments to undertake at each location. We envision the GAC cold molecule lab to be a setup that is accessible to undergraduates, yet provides positive input and direction to the overall goal of producing ultracold molecules. As an example, measurement of recombination rates with several different species would elucidate the relationship between molecular ionization potential and cooling potential.

In addition to the research laboratory setting, I plan to leverage any possible avenues of this research into the undergraduate laboratory classroom here at GAC. For example, I would like to include more experiences in our curriculum that show the effects of quantum mechanics to students. Two examples of a lab experiment that show quantum mechanical effects are the demonstration of Bell's inequality and the Hanbury-Brown-Twiss effect. Both of these experiments utilize AMO methods in their demonstration, and could be done with equipment and knowledge gained from the cold molecule work.

Daniel McDougall

I was born and raised in Northfield, Minnesota, where I began my interest in physics in an advanced placement physics course in high school. At Gustavus Adolphus College, I decided to strive for undergraduate degrees in both physics and mathematics, and I plan to graduate in May of 2011. While physics has always been my main focus, the extra mathematical insight has helped immensely in understanding the material. Through my education at Gustavus, I have learned that I enjoy the theoretical as well as the practical aspects of experimental physics. After graduation, I am excited to attend graduate school to further explore my devotion to physics.

How this project fits into the educational trajectory of Daniel McDougall.

As I continue my undergraduate studies at Gustavus, this project will provide me with valuable laboratory experience. Working on a long-term project will be exceedingly more beneficial than the lab work I have already done, as I will be able to get more involved and become more proficient in the experimental aspect of physics. I hope to learn new abilities and techniques that will be useful toward becoming a better experimentalist, which will ultimately assist me in my education at graduate school.