Fiscal Year:	FY 2016	**Task Last Updated:**	FY 02/16/2016
PI Name:	Sackett, Charles Ph.D.		
Project Title:	Development of Atom Interferometry Experiments for the International Space Station's Cold Atom Laboratory		
Division Name:	Physical Sciences		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:	FUNDAMENTAL PHYSICS--Fundamental physics		
Joint Agency Name:		**TechPort:**	No
Human Research Program Elements:	None		
Human Research Program Risks:	None		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
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Zip Code:	22904-1000	**Congressional District:**	5
Comments:	Other names: CA Sackett; Cass Sackett.		
Project Type:	Flight,Ground	**Solicitation / Funding Source:**	2013 Fundamental Physics NNH13ZTT002N (Cold Atom Laboratory--CAL)
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No. of PhD Candidates:	4	**No. of Master' Degrees:**	0
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:	1	**Monitoring Center:**	NASA JPL
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Flight Program:	ISS		
Flight Assignment:			
Key Personnel Changes/Previous PI:			
COI Name (Institution):	Burke, John Ph.D. (Air Force Research Laboratory)		
Grant/Contract No.:	JPL 1502012		
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Task Description:	The ultimate objective of this proposal is to develop an ultra-high sensitivity atom interferometer capable of operating in and benefiting from a microgravity environment. The interferometer would be specifically suited for measurements of rotations, but it would be broadly applicable to a variety of precision measurements. Ground and flight based efforts are proceeding in three broad areas. First, we are performing ground studies and developing a flight mission for the Cold Atom Laboratory (CAL) to study atomic techniques for inertial sensing in microgravity. Ground efforts include development of new rotation-sensing techniques and implementation of an optically suspended atom source for gravimetry. Flight efforts involve implementation and characterization of atom interferometry techniques using the CAL apparatus on the International Space Station. Second, we are investigating methods to produce an ultra-low temperature atom source in free space using the CAL		

apparatus. The apparatus produces atoms confined in a magnetic trap, but inertial measurements require free atoms. We will investigate releasing the atoms by gradually turning off the trapping fields, allowing the atoms to adiabatically expand and cool off. This can produce a relatively dense and very low-velocity sample that is ideal for atom interferometry methods.

Third, we will continue ground-based studies to develop novel precision measurement techniques for use with atom interferometry, such as tune-out spectroscopy. Techniques like this are useful for advancing scientific knowledge and would be good candidates for future flight studies.

Rationale for HRP Directed Research:

Research Impact/Earth Benefits:

The development of precision inertial sensing techniques is useful for Earth-based as well as space-based navigation. Besides using direct sensing for inertial navigation, rotation sensing can also be useful for north-finding while gravity sensing can be used to tabulate local gravity variations and form a type of three-dimensional map for navigating.
These techniques also have many applications in geophysics. Gravity sensing can be used for oil and mineral exploration, while rotation sensing can detect dynamics in the Earth's core. Gravity sensing also has defense applications such as locating underground tunnels and potential screening cargo for high-density contraband or weapons.

Other precision measurement applications have less direct impact, but advance scientific knowledge. For instance, precision tune-out spectroscopy measurements of atomic matrix elements can be used to improve the interpretation of atomic parity violation experiments. These in turn impact our understanding of the standard model of particle physics and thus the nature of our universe. Direct benefits of such understanding can be hard to trace, but in general the continued advance of technological applications builds on advances in our fundamental knowledge.

Task Progress:

Progress in this reporting period can be separated into three tasks: planning for flight operations on the Cold Atom Laboratory (CAL), development of new atom-based inertial sensing methods, and development of new precision measurement techniques based on atom interferometry.
For flight planning, we have developed and analyzed three related experiments. The first is adiabatic cooling and release, in which Bose-condensed atoms are released from a magnetic trap into free space by slowly reducing the magnetic field amplitude. When the trap field is suitably low, the atoms are transferred to a magnetically insensitive state to avoid degradation of subsequent measurements from environmental fields. When performed correctly, this method can produce extremely cold atoms, with temperatures on the order of 100 picoKelvin (pK). This corresponds to extremely low atomic velocities, which prevents the atom sample from expanding or drifting out of the interaction region in subsequent experiments. Adiabatic expansion also provides the minimum possible size expansion for a given amount of cooling, so the final sample is relatively compact.

Successful implementation of adiabatic expansion requires careful control of the magnetic fields. We have imported the CAL field design into a numerical simulation tool and developed a set of control trajectories for the fields. The expansion method is limited by uncontrolled environmental fields and gradients. We developed an expansion to an estimated temperature of 200 pK which is robust against the expected level of stray fields. We plan to continue investigating the field geometry to determine if further cooling is possible.

We have also developed experiments to implement atom interferometry using a Bose-Einstein condensate that has been released from the trap. A set of experiments will be used to optimize parameters and test the performance of atom interferometry. A culminating experiment will be a measurement of the atomic recoil frequency using a contrast interferometer.

We also developed a method to implement simultaneous interferometers using both rubidium and potassium atoms. This requires careful control of the laser beams used to manipulate the atoms to ensure that both species respond correctly. Using this technique we can measure the ratio of the atomic recoil frequencies, which could ultimately provide improved knowledge of the mass ratio of the species.

Finally we have proposed and developed an alternative inertial measurement technique in which the atomic sample is used as a "proof mass" reference for rotation sensing. A set of three atom clouds can be prepared in a line that is aligned to the controlling laser beam. After a delay time the atom clouds can be imaged, and any rotation of the system will appear as a deviation in the apparent orientation of the line. This method is readily sensitive enough to detect the orbital motion of the International Space Station.

These experiments have been presented for our Science Concept Review, and were approved by the advisory board for CAL.

On the ground, we are also developing the "proof mass" rotation sensing technique. This is more challenging since it is not possible to observe the atoms for a long time without supporting them against gravity. However, we have implemented a magnetic trap with excellent cylindrical symmetry such that atoms can be set to oscillating along one axis, and over time the Coriolis force causes the axis to precess. We have observed sensitivity at the level of 1 mrad/s, and expect to be able to reach Earth rate sensitivity with further optimization.

Also on the ground, we have developed a high-precision method for tune-out spectroscopy. This is the determination of a light frequency for which an atom has zero response. Using light at this frequency can be useful for some applications like dual species atom trapping. It also allows a precise characterization of the quantum state of the electrons in an atom. Our technique is based on atom interferometry and is about one hundred times more precise than previous methods. The resulting improvements in our understanding of electrons in atoms will be useful for many applications. A notable example is interpreting parity violation experiments in atoms, where the quantum state is needed in order to relate the measured parity violation in the atom to the fundamental properties of the electron-nucleon interaction. Understanding these properties better will improve our understanding of fundamental particle physics.

These types of experiments would benefit greatly from a microgravity environment, since that would allow long interaction times without needing to support the atoms against gravity. The magnetic fields we use to support the atoms introduce a number of perturbations that must be controlled for and limit our precision.

Articles have been submitted to the following peer-reviewed journals:

	Fallon AG, Sackett CA. "Obtaining atomic matrix elements from vector tune-out wavelengths using atom interferometry." Atoms, in press, expected publication July 2016. Oh E, Horne RA, Sackett CA. "Fast phase stabilization of a low frequency beat note for atom interferometry." Rev Sci Instrum, in press, expected publication July 2016.
Bibliography Type:	Description: (Last Updated: 07/01/2025)
Abstracts for Journals and Proceedings	Horne R, Sackett C. "Magnetic Waveguide for Atom Interferometry and Inertial Navigation Applications." Presented at the 45th Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics, Madison, Wisconsin, June 2–6, 2014. Bulletin of the American Physical Society. 2014;59(8):Abstract ID: BAPS.2014.DAMOP.D1.70. http://meetings.aps.org/link/BAPS.2014.DAMOP.D1.70 , Jun-2014
Abstracts for Journals and Proceedings	Sackett C. "Atom Interferometry using Bose-Einstein condensates on Earth and in Space." 81st Annual Meeting of the APS Southeastern Section, Columbia, SC, November 12-15, 2014. Bulletin of the American Physical Society. 2014;59(18):Abstract ID: BAPS.2014.SES.DB.1. https://meetings.aps.org/link/BAPS.2014.SES.DB.1 , Nov-2014
Abstracts for Journals and Proceedings	Sackett CA, Arpornthip T, Fallon A, Burke JHT. "Atom Interferometry Aboard the ISS." Presented at the 30th Annual Meeting of the American Society for Gravitational and Space Research, Pasadena, California, October 22-26, 2014. 30th Annual Meeting of the American Society for Gravitational and Space Research, Pasadena, California, October 22-26, 2014. https://www.asgsr.org/index.php/presentation-abstracts-10-25-2014 ; accessed 2/16/2016. , Oct-2014
Articles in Peer-reviewed Journals	Leonard RH, Fallon AJ, Sackett CA, Safronova MS. "High-precision measurements of the 87Rb D-line tuneout wavelength." Phys Rev A. 2015 Nov; 92(5):052501. http://dx.doi.org/10.1103/PhysRevA.92.052501 , Nov-2015
Papers from Meeting Proceedings	Sackett C, Leonard RH, Fallon A. "Atom interferometry using Bose-Einstein condensates on Earth and in space." Presented at SPIE Photonics West (OPTO): Slow Light, Fast Light, and Opto-Atomic Precision Metrology VIII, San Francisco, California, February 7-12, 2015. Proceedings of SPIE. Vol. 9378, Slow Light, Fast Light, and Opto-Atomic Precision Metrology VIII:93781Y, 2015. http://dx.doi.org/10.1117/12.2086847 , Mar-2015
Papers from Meeting Proceedings	Burke JH. "Magnetically guided cold atom gyroscopes and their photonic requirements." Presented at SPIE Photonics West (OPTO): Slow Light, Fast Light, and Opto-Atomic Precision Metrology VIII, San Francisco, California, February 7-12, 2015. Proceedings of SPIE. Volume 9378, Slow Light, Fast Light, and Opto-Atomic Precision Metrology VIII:93781Z, 2015. http://dx.doi.org/10.1117/12.2087490 , Mar-2015