Fiscal Year:	FY 2021	**Task Last Updated:**	FY 03/10/2021
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)
Start Date:	04/01/2014	**End Date:**	09/27/2024
No. of Post Docs:	1	**No. of PhD Degrees:**	2
No. of PhD Candidates:	3	**No. of Master' Degrees:**	0
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	1
No. of Bachelor's Candidates:	2	**Monitoring Center:**	NASA JPL
Contact Monitor:	Callas, John	**Contact Phone:**	
Contact Email:	john.l.callas@jpl.nasa.gov		
Flight Program:	ISS		
Flight Assignment:	NOTE: End date changed to 9/27/2024 per U. Israelsson/JPL (Ed., 1/6/22) NOTE: Extended to 9/30/2022 per U. Israelsson/JPL (Ed., 3/9/21) NOTE: Extended to 10/28/2020 per PI (Ed., 2/28/2020) NOTE: Extended to 10/30/2019 per U. Israelsson/JPL (Ed., 12/14/17)		
Key Personnel Changes/Previous PI:	March 2018 report: Our Co-Principal Investigator (Co-PI) John Burke has left Air Force Research Laboratory (AFRL) to take a program management job at DARPA (Defense Advanced Research Projects Agency). Our points of contact at AFRL are now Brian Kasch and Gordon Lott.		
COI Name (Institution):			
Grant/Contract No.:	JPL 1502012		
Performance Goal No.:			
Performance Goal Text:			

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 (ISS). 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:	The CAL SM1 system ended operations in November 2019. As detailed in our previous reports, we were able to demonstrate adiabatic expansion in the SM1 system, with some limitations. During the current period we analyzed this data set and published the results. The key conclusion was that the adiabatic expansion method could be used to prepare a sample of cold atoms for atom interferometry experiments, but that the performance was limited by a background magnetic field that was considerably larger than expected. This prevented us from reaching some of our goals, such as setting a low-temperature record. From our data, we ere able to precisely characterize this background field. For future work, it will be important to prepare atoms in the non-magnetic m=0 spin state so that the effects of the background field can be eliminated. Some additional work remains to be done with the SM1 dataset. In our time of flight expansions, the Bose condensates can be observed to expand and twist under the influence of the background field. It should be possible to use this data to confirm our field model, but the calculations are challenging. We have initiated a theoretical collaboration with the group of Mark Edwards at Georgia Southern University, with whom we hope to develop tools for this type of analysis. These tools will be useful for many of the experiments to be performed on CAL and eventually Bose-Einstein Condensate/Cold Atom Laboratory (BECAL). The SM3 system was installed in December 2019 and the first Bose-Einstein condensates were quickly achieved in February 2020. The new system features a more complex atom chip geometry than SM1. This allows for atom interferometry experiments, but also makes sample preparation more complex. We have developed and implemented an adiabatic expansion sequence which positions atoms near the center of the atom interferometry beam. The confinement strength is reduced enough to avoid rapid expansion of the released atoms. The residual ‘sloshing’ motion of the atoms is small. The performance obtained so far, in terms of both confinement and sloshing, is not yet as good as we achieved in SM1. This can be improved with further work but we expect the initial results are sufficient for the atom interferometry experiments being performed. We have also carried out atom interferometry experiments using atoms prepared with a sequence developed by the Jet Propulsion Laboratory (JPL) team. (This preparation leads to larger release velocities than ours, but so far this is not a limitation.) As a demonstration of the atom interferometer capability, we have demonstrated a simple low-precision measurement of the atomic recoil velocity. We expect to publish the results in 2021. We also continue work on improving our ground-based trapped-atom Sagnac interferometer. Although the COVID shutdowns had some impact on our progress, we have rebuilt our condensate apparatus to use an atom chip which was developed by our collaborators at Air Force Research Laboratory (AFRL). We have achieved Bose-Einstein condensation in the new apparatus and, significantly, we have demonstrated that the atom trapping potential is at least an order of magnitude more stable than in our previous trap. We will take advantage of this stability to improve our rotation measurements.
Bibliography Type:	Description: (Last Updated: 07/01/2025)
Abstracts for Journals and Proceedings	Pollard A, Sackett C. "Cooling Rubidium 87 Atoms Using Adiabatic Expansion in Microgravity." Presented at 51st Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics, Portland, OR, June 1-5, 2020. Bulletin of the American Physical Society. 2020 Jun;65:4:abstract E01.00115. https://meetings.aps.org/Meeting/DAMOP20/Session/E01.115 , Jun-2020

Articles in Peer-reviewed Journals	Luo Z, Moan ER, Sackett CA. "Semiclassical phase analysis for a trapped-atom Sagnac interferometer." Atoms. 2021 Jun;9(2):21. Online March 27, 2021. https://doi.org/10.3390/atoms9020021 , Jun-2021
Articles in Peer-reviewed Journals	Moan ER, Horne RA, Arpornthip T, Luo Z, Fallon AJ, Berl SJ, Sackett CA. "Quantum rotation sensing with dual Sagnac interferometers in an atom-optical waveguide," Phys Rev Lett. 2020 Mar 27;124(12):120403. https://doi.org/10.1103/PhysRevLett.124.120403 , Mar-2020
Articles in Peer-reviewed Journals	Pollard AR, Moan ER, Sackett CA, Elliott ER, Thompson RJ. "Quasi-adiabatic external state preparation of ultracold atoms in microgravity." Microgravity Science & Technology. 2020 Dec;32:1175-84. https://doi.org/10.1007/s12217-020-09840-w , Oct-2020