Fiscal Year:	FY 2020	**Task Last Updated:**	FY 03/03/2020
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:**	10/28/2020
No. of Post Docs:	0	**No. of PhD Degrees:**	0
No. of PhD Candidates:	3	**No. of Master' Degrees:**	0
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:	2	**Monitoring Center:**	NASA JPL
Contact Monitor:	Callas, John	**Contact Phone:**	
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Flight Program:	ISS		
Flight Assignment:	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:	We are pleased to report progress on the project, for both ground-based and flight-based efforts. In the flight effort, we took data through 2019 and demonstrated adiabatic cooling. As mentioned in the previous report, we observed unexpected heating and loss of the atoms during the cooling process. The effect seemed intermittent, making it difficult to study systematically. We ultimately found an experimental procedure that usually provided enough atoms to continue cooling, but we were not able to conclusively explain the source of the losses. We were able to successfully expand atoms into a trap with a mean frequency of about 3 Hz, corresponding to a temperature of about 1 nK. While this remains above our ultimate goal of 0.1 nK, it is an important milestone because it corresponds to residual velocities low enough to enable atom interferometry. We were unable to reach lower temperatures because the apparatus featured a background magnetic field gradient that was somewhat larger than expected. We measured the field gradient to be about 50 mG/cm, compared to a specification of 10 mG/cm. This field distorts the trap and causes the atoms to be lost when the trap is too weak. We were able to release the atoms from the 3 Hz trap and observe their subsequent behavior. Because of the large background gradient, the atoms were accelerated relatively quickly, but they could be observed for about 0.5 s. To avoid this acceleration, we hope to transfer the atoms the $m = 0$ Zeeman state where they do not interact with the magnetic field. This has been previously demonstrated in the CAL apparatus. At the end of 2019, the apparatus stopped functioning well, but at the same time the new SM2 module was launched as replacement unit. SM2 has now been installed and is operating well. It offers the capability to perform atom interferometry, which will be the focus of the next year’s operation. In our ground efforts, we have successfully implemented an atom interferometer gyroscope with Earth-rate sensitivity. A Bose-Einstein condensate is produced in our specially-designed magnetic trap. Off-resonant lasers are used to coherently split the condensate into wave packets, which are then driven into circular trajectories orbiting the trap with a diameter of about 0.5 mm. When the packets are subsequently recombined they exhibit interference, and the phase of the interference is related to the rotation rate of the experimental platform. We observe interference signals with a visibility of about 60%. We have verified the rotation sensitivity by slightly rotating the optical table holding the apparatus, and the measured interference shift agrees with expectations. This work has been written up and submitted to Physical Review Letters. We have also carried out a theoretical study of the interferometer performance and limitations. This turns out to depend sensitively on the anharmonicity of the trapping potential. We developed a method to experimentally characterize the anharmonicity and were able to determine the anharmonic terms with an accuracy of 10% to 30%. A major effort over the past year has been upgrading the apparatus to improve its stability and speed of operation. This will enable more careful studies of its performance and extension to higher sensitivities. The new trap features additional shimming coils to allow adjustment of the anharmonicity. The new apparatus is nearly complete. We have collaborated with our partners at Air Force Research Laboratory (AFRL) to produce a unique atom chip that the trap will use.
Bibliography Type:	Description: (Last Updated: 06/25/2025)