Fiscal Year:	FY 2018	**Task Last Updated:**	FY 07/08/2018
PI Name:	Williams, Jason Ph.D.		
Project Title:	Fundamental Interactions for Atom Interferometry with Ultracold Quantum Gases in a Microgravity Environment		
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		
PI Email:	Jason.R.Williams.Dr@jpl.nasa.gov	**Fax:**	FY
PI Organization Type:	NASA CENTER	**Phone:**	303-725-1580
Organization Name:	NASA Jet Propulsion Laboratory		
PI Address 1:	Quantum Sciences & Technology Group		
PI Address 2:	4800 Oak Grove Dr 298-103B		
PI Web Page:			
City:	Pasadena	**State:**	CA
Zip Code:	91109-8001	**Congressional District:**	27
Comments:			
Project Type:	Flight	**Solicitation / Funding Source:**	2013 Fundamental Physics NNH13ZTT002N (Cold Atom Laboratory--CAL)
Start Date:	04/01/2014	**End Date:**	05/03/2019
No. of Post Docs:	0	**No. of PhD Degrees:**	0
No. of PhD Candidates:	0	**No. of Master' Degrees:**	0
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:	0	**Monitoring Center:**	NASA JPL
Contact Monitor:	Callas, John	**Contact Phone:**	
Contact Email:	john.l.callas@jpl.nasa.gov		
Flight Program:	ISS		
Flight Assignment:	ISS		
Key Personnel Changes/Previous PI:	February 2017 report: Dr. Ethan Elliott, Jet Propulsion Laboratory, is a world expert in the development of leading edge quantum gas facilities for ground and space-based fundamental physics experiments. Notably, he continues to play a leading role in the development, integrating, and testing of numerous subsystems of NASA's multiuser Cold Atom Lab facility. Dr. Elliott joins the project as a Co-Investigator to provide expertise to essentially all aspects of the project. His specific efforts will include leading the planned ground testbed studies, cooperating in the experimental sequence development, and analysis and dissemination of the results to the scientific community.		
COI Name (Institution):	D'Incao, Jose Ph.D. (University of Colorado) Elliott, Ethan Ph.D. (Jet Propulsion Lab)		
Grant/Contract No.:	Internal Project		
Performance Goal No.:			
Performance Goal Text:			

Task Description:	Precision atom interferometers (AI) in space promise exciting technical capabilities with diverse applications of interest to NASA. These quantum sensors are particularly relevant for fundamental physics research, with proposals including unprecedented tests of the validity of the weak equivalence principle, precision measurements of the fine structure and gravitational constants, and detection of gravity waves and dark matter/dark energy. Our studies will utilize the capabilities of NASA's multi-user Cold Atom Laboratory (CAL), in the microgravity environment onboard the International Space Station (ISS), to study mitigation schemes for the leading-order systematics expected to limit future high-precision measurements of fundamental physics with AIs in microgravity. The flight experiments, supported by theoretical investigations and ground studies at our facilities at Jet Propulsion Laboratory (JPL), will concentrate on the physics of pairwise interactions and molecular dynamics in ultracold quantum gases as a means to overcome uncontrolled AI shifts associated with the gravity gradient and few-particle collisions. We will further utilize the dual-species AI for proof-of-principle tests of systematic mitigations and phase-readout techniques for use in the next-generation of precision metrology experiments based on AIs in microgravity. Our proposed studies require the effective position invariance, long free fall times, and extremely low temperature samples uniquely available with the CAL apparatus. It is anticipated that our studies can lead to the unprecedented level of control and accuracy necessary for AIs to explore some of the most fundamental physical concepts in nature.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	Our studies are designed to achieve technological advances in precision metrology that can only be realized in the microgravity environment of the Cold Atom Laboratory. We utilize the tools of ultracold atomic and molecular physics (namely Feshbach resonances) for exquisite control of the differential center-of-mass distributions of the dual-species quantum gases and on methods to use the fundamentals of few-body interactions to maintain coherence in atomic ensembles for enhanced precision sensor capabilities. Subsequent proof-of-principle studies with the dual-species atom interferometer on CAL will further advance the state of the art for precision interferometry with ultracold matter waves. The impact of such research to the field of metrology can be seen through its potential to increase precision for atom-interferometry and also the possibility of engineering highly efficient system-specific devices based on the fundamental nature of few-body interactions. The microgravity environment of the CAL facility will strongly favor such explorations and allow for the possibility of uncovering novel effects and quantum phases of matter, a major goal in ultracold quantum gases and other disciplines of fundamental physics. These studies can benefit life on Earth by providing both fundamental understanding of nature in previously inaccessible environments and energy regimes, and by enhancing the tools available for scientific exploration at the highest precision.
Task Progress:	Precision atom interferometers (AI) in space promise exciting technical capabilities with diverse applications of interest to NASA. These quantum sensors are particularly relevant for fundamental physics research, with proposals including unprecedented tests of the validity of the weak equivalence principle, precision measurements of the fine structure and gravitational constants, and detection of gravity waves and dark matter/dark energy. Our studies will utilize NASA's Cold Atom Laboratory (CAL), in the microgravity environment onboard the International Space Station, to study the leading-order systematics expected to limit future high-precision measurements of Einstein's weak equivalence principle with dual atomic-species AIs in microgravity. The flight experiments, supported by theoretical investigations and measurements using the ground test bed facilities at JPL, will concentrate on the physics of pairwise interactions and low-energy s-wave Feshbach molecules in ultracold quantum gases as a means to overcome uncontrolled AI shifts associated with the differential center of mass of two atomic species influenced by gravity gradients and rotations. We will further utilize the dual-species AI, expected to be integrated into CAL, for proof-of-principle demonstrations of unprecedented atom-photon coherence times, phase-readout techniques, and characterizations of the rotational noise on the ISS for use in the next-generation of precision metrology experiments based on AIs in microgravity. Our proposed experiments require the effective position invariance, long free fall times, and extremely low temperature samples uniquely available with the CAL apparatus. It is anticipated that these studies can lead to the unprecedented level of control and accuracy necessary for future space missions, based on precision AIs, to test some of the most fundamental questions of modern physics. In the fourth year of the project, we have finished our theoretical studies relevant for molecular delta-kick cooling, a possible cooling technique that can allow us to obtain much colder molecular samples for our interferometry studies as well as enable optimized collimation for two, initially co-trapped, atomic species. The differential ballistic expansion for two species is a limitation for achieving ultra-low temperatures for these dual-species gas studies in microgravity. In applying delta-kick cooling for molecules we found that the molecular internal degree of freedom can generate torques during the cooling process depending on the strength and duration of the delta-kick pulse. Such effects, although interesting from the fundamental point of view, are detrimental to our precision interferometry studies. Our analysis, therefore, focuses in determining the parameter regime in which such effects can be mitigated. We have developed a novel theoretical approach that accounts for the effects of the center-of-mass and relative motion of the molecules and additional studies are currently been performed in order to determine the final cooling efficiency. We are currently on the stage of developing other numerical tools to extract all the information necessary for qualitatively describing the delta-kick cooling technique for heteronuclear molecules in the microgravity environment. We have also pursued during this year preliminary theoretical studies relevant for molecular association using magnetic field ramps. This represents an alternative method to the one we have previously proposed (within this program) using RF fields. We ultimately want to determine which of the methods for association and dissociation is more efficient in the microgravity environment. In order to qualitatively explore this problem, we developed a theoretical model in which a few atoms are subjected to an artificial trapping potential whose trap frequency is adjusted to reproduce the average interatomic distance in the ultracold gas. This model has been successfully used to analyze previous experiments in molecular formation and we will extend such an approach to include various quantitative aspects related to the few-body physics in the problem. In particular, processes that can lead to molecular losses during the magnetic field ramp and the possible formation of Efimov states. At this point, our studies were focused on a system with only two atoms. As a running test, this has all the ingredients relevant for our future experiments with dual species atomic gases (87Rb and 41K), a study to be performed in the next step of our program. Although the theoretical studies are nearly complete, experimental efforts have been hampered during this year due to required efforts by key group members to build and test the CAL flight system. These efforts lead to the successful launch of CAL to the ISS on May 21, 2018. Therefore, during the fourth year, our ongoing work on this project has concentrated on working with the CAL Ground Test Bed (GTB) and CAL flight systems towards a) validating the flight

	hardware and b) providing all of the functionality of CAL for proof of principle and characterization studies to support the flight science projects. Due to the technical innovations required in our project and the sensitivity to numerous experimental/environmental parameters, access to the GTB has and will be enabling to mature our studies and to optimize our utilization of CAL.
Bibliography Type:	Description: (Last Updated: 05/30/2024)
Abstracts for Journals and Proceedings	D'Incao J, Williams J. "Theoretical studies of association and dissociation of Feshbach molecules in a microgravity environment." Presented at the 48th Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics (DAMOP), Sacramento, CA, June 5-9, 2017. Bulletin of the American Physical Society. 2017;62(8):abstract Q1.00085. http://meetings.aps.org/link/BAPS.2017.DAMOP.Q1.85 , Jun-2017
Abstracts for Journals and Proceedings	Williams J, D'Incao J. "Opportunities for Maturing Precision Metrology with Ultracold Gas Studies Aboard the ISS." Presented at the 48th Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics (DAMOP), Sacramento, CA, June 5-9, 2017. Bulletin of the American Physical Society. 2017;62(8):abstract P9.00007. http://meetings.aps.org/link/BAPS.2017.DAMOP.P9.7 , Jun-2017
Abstracts for Journals and Proceedings	Williams J, D'Incao J. "Maturing Space-Based Precision Metrology with Quantum Gas Studies Aboard the ISS." Presented at the 2017 NASA Fundamental Physics Workshop, Santa Barbara, CA, May 31-June 2, 2017. 2017 NASA Fundamental Physics Workshop, Santa Barbara, CA, May 31-June 2, 2017. , May-2017
Abstracts for Journals and Proceedings	D'Incao J, Williams J. "Theoretical studies of association and dissociation of Feshbach molecules in a microgravity environment." Presented at the 2017 NASA Fundamental Physics Workshop, Santa Barbara, CA, May 31-June 2, 2017. 2017 NASA Fundamental Physics Workshop, Santa Barbara, CA, May 31-June 2, 2017. , May-2017
Abstracts for Journals and Proceedings	Williams J. "The Cold Atom Laboratory (CAL): A facility for ultracold atom experiments aboard the ISS." Presented at the 2017 Sacramento State Physics Colloquium Series, Sacramento, CA, November 9, 2017. 2017 Sacramento State Physics Colloquium Series, Sacramento, CA, November 9, 2017. https://www.csus.edu/physics/events/colloquiaarchive.html#spring17 , Nov-2017