Fiscal Year:	FY 2016	**Task Last Updated:**	FY 02/01/2016
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		
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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
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Flight Program:	ISS		
Flight Assignment:			
Key Personnel Changes/Previous PI:			
COI Name (Institution):	D'Incao, Jose Ph.D. (University of Colorado)		
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, recently 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 second year of this project, we finalized the science concepts, requirements, and feasibility studies for both the originally proposed flight project, studying Feshbach molecules as a tool to enhance high-precision AI-based experiments in space, as well as for the flight experiments to use the CAL dual-species AI to further mature the technology of high-precision AI for enabling future space-based fundamental physics missions. For each proposed study, the approach, science management and data analysis plans, generalized experimental sequences, science requirements, and all other relevant experimental considerations were compiled into a Science Requirements Document that was submitted for review in October, 2015. At the same time, our group presented and conditionally passed the Science Concept Review to the CAL Science Review Board, allowing the project to continue in its flight status. As part of the Feshbach molecule filtering study we 1) Developed the specific sets of experimental sequences required to associate and dissociate the heteronuclear molecules with minimal heating and loss. 2) Characterized the expected efficiency for removing unpaired atoms while minimally perturbing the Feshbach molecules. 3) Developed the dual-species imaging routine, error budgets, and analyses for optimally measuring the differential density distributions for the dissociated clouds and estimated the total averaging time required to achieve differential center-of-mass accuracy on the nanometer scale. 4) Identified the ground tests required to sufficiently characterize the atomic and molecular loss rates, heating rates, and all potential ground tests to optimally utilize the experimental time with the CAL apparatus on the ISS, and 5) Identified potential shortfalls and mitigations for this study. For the dual-species AI studies, our tasks over the year included: 1) Calculated the expected contrast and systematic shifts based on the Bragg-beam design. 2) Developed the experimental sequences for demonstrating extended atom-photon coherence in a 3-pulse AI in free fall. 3) Developed the experimental sequences for observing rotational phase-fringes on the ISS. 4) Quantified the expected SNR and optimum sensitivity for the dual-species AI, leading to the required interrogation times and expected precision of each measurement. 5) Identified the possible AI-based ground tests to optimally utilize the experimental time with the CAL apparatus on the ISS, and 6) Identified potential shortfalls, mitigations, and applications of the CAL AI, including the feasibility of using the CAL AI during the anticipated down time as a high-precision sensor for local accelerations and rotations. Recent work on this project has concentrated on assisting the CAL Ground Test Bed (GTB) and Science teams in maturing the GTB to a) validate the flight hardware and b) provide all of the functionality of CAL in a ground-based lab system 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 will be enabling to mature our studies and to optimize our utilization of CAL. This work will progress through the remaining two months of this second-year effort.
Bibliography Type:	Description: (Last Updated: 12/15/2022)
Abstracts for Journals and Proceedings	Williams J, D'Incao J, Chiow S-W, Yu N. "Atom Interferometry with Ultracold Quantum Gases in a Microgravity Environment." Presented at the 6th International Symposium on Physical Sciences in Space and the 10th International Conference on Two-Phase Systems for Space and Ground Applications, Kyoto, Japan, September 14-18, 2015. 6th International Symposium on Physical Sciences in Space and the 10th International Conference on Two-Phase Systems for Space and Ground Applications, Kyoto, Japan, September 14-18, 2015. , Sep-2015
Abstracts for Journals and Proceedings	Williams J, D'Incao J, Chiow S-W, Yu N. "Atom Interferometry with Ultracold Quantum Gases in a Microgravity Environment." Presented at 46th Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics, Columbus, OH, June 8-12, 2015. 46th Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics, Columbus, OH, June 8-12, 2015. Abstract #C2.004. http://adsabs.harvard.edu/abs/2015APS..DMP.C2004W , Jun-2015
Abstracts for Journals and Proceedings	Williams J, Chiow S-W, Kellogg J, Kohel J, Yu N. "Atom Interferometer Technologies in Space for Gravity Mapping and Gravity Science." Presented at the 46th Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics, Columbus, OH, June 8-12, 2015. 46th Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics, Columbus, OH, June 8-12, 2015. Abstract ##K1.064. http://adsabs.harvard.edu/abs/2015APS..DMP.K1064W , Jun-2015
Abstracts for Journals and Proceedings	D'Incao JP, Williams JR. "Fundamental Interactions for Atom Interferometry with Ultracold Quantum Gases in a Microgravity Environment." Presented at 46th Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics, Columbus, OH, June 8-12, 2015. 46th Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics, Columbus, OH, June 8-12, 2015. Abstract #D1.036. http://adsabs.harvard.edu/abs/2015APS..DMP.D1036D , Jun-2015