Fiscal Year:	FY 2021	**Task Last Updated:**	FY 04/19/2021
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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PI Organization Type:	NASA CENTER	**Phone:**	303-725-1580
Organization Name:	NASA Jet Propulsion Laboratory		
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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:**	09/27/2024
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:**	
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Flight Program:	ISS		
Flight Assignment:	ISS NOTE: End date changed to 9/27/2024 per U. Israelsson/JPL (Ed., 10/20/21) NOTE: End date changed to 9/30/2023 per U. Israelsson/JPL (Ed., 4/16/21) NOTE: End date changed to 5/3/2021 per PI information (Ed., 5/6/19)		
Key Personnel Changes/Previous PI:			
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 (CAL). 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 strongly favors 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:	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 utilize the dual-species CALAI 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 this sixth and seventh year of performance, we have focused on maintaining operations throughout CAL's second year on the ISS and the development, launch, and commissioning of the new AI capable science module that enabled atom interferometry in the flight system in 2020. Notable achievements include 1) The first demonstration of atom interferometry in orbit, 2) Imaging of ultracold atoms in 3 dimensions in CAL, and 3) Adiabatic Rapid passage of >80% of Rb atoms to the magnetically insensitive state in space. Our ongoing work on this project will concentrate on working with the CAL Ground Test Bed (GTB), Engineering Testbed (EMTB), and CAL Flight Systems towards a) validating the flight hardware and b) proving all of the functionality of CAL for proof of principle and characterization studies to support our dual-species 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: 12/15/2022)
Articles in Peer-reviewed Journals	Aveline DC, Williams JR, Elliott ER, Dutenhoffer C, Kellogg JR, Kohel JR, Lay NE, Oudrhiri K, Shotwell RF, Yu N, Thompson RJ. "Observation of Bose–Einstein condensates in an Earth-orbiting research lab." Nature. 2020 Jun;582(7811):193-7. (Erratum in: Nature. 2020 Aug;584(7819):E1.) https://doi.org/10.1038/s41586-020-2346-1 ; PMID: 32528092 , Jun-2020
Journal/Magazine covers	Aveline DC, Williams JR, Elliott ER, Dutenhoffer C, Kellogg JR, Kohel JR, Lay NE, Oudrhiri K, Shotwell RF, Yu N, Thompson RJ. "Cover in the journal Nature for article, 'Observation of Bose–Einstein condensates in an Earth-orbiting research lab.' " Nature. 2020 Jun;582(7811):193-7. https://www.nature.com/nature/volumes/582/issues/7811 , Jun-2020