Fiscal Year:	FY 2022	**Task Last Updated:**	FY 12/09/2022
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:**	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:	No changes to key personnel		
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, concentrate on the physics of pairwise interactions and low-energy s-wave Feshbach molecules in ultracold quantum gases as a means to overcome uncontrolled Atom Interferometer (AI) shifts associated with the differential center of mass of two atomic species influenced by gravity gradients and rotations. Our efforts aim to utilize the dual-species Cold Atom Laboratory (CAL) AI for proof-of-principle demonstrations of long atom-photon coherence times in space, phase-readout techniques, and characterizations of the rotational noise on the International Space Station (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 to test some of the most fundamental questions of modern physics. In this year of performance, we have focused on maintaining operations throughout CAL's fourth year on the ISS and the commissioning of an upgraded frequency reference capable of sympathetic cooling of potassium in flight. Notable achievements include: 1) The first demonstration of dual-species Bose Einstein condensates in space 2) Achieved simultaneous dual-species atom interferometry in orbit. Our ongoing work over the next year will concentrate on preparing rubidium-87 and potassium-41 dual-species ultracold gases for our planned flight projects. Due to the technical innovations required in our project and the sensitivity to numerous experimental/environmental parameters, access to the CAL testbeds (Ground Test Bed/GTB and Engineering Testbed/EMTB), has and will be enabling to mature our studies and to optimize our utilization of CAL. We will further prepare for the upcoming installation, commissioning, and continuation of science using a new Science Module (SM3B) to be installed in CAL in 2023.
Bibliography Type:	Description: (Last Updated: 05/30/2024)
Articles in Peer-reviewed Journals	Schkolnik V, Budker D, Fartmann O, Flambaum V, Hollberg L, Kalaydzhyan T, Kolkowitz S, Krutzik M, Ludlow A, Newbury N, Pyrlik C, Sinclair L, Stadnik Y, Tietje I, Ye J, Williams J. "Optical atomic clock aboard an Earth-orbiting space station (OACESS): Enhancing searches for physics beyond the standard model in space." Quantum Sci. Technol. 2022 Nov 18;8:014003. http://dx.doi.org/10.1088/2058-9565/ac9f2b , Nov-2022
Articles in Peer-reviewed Journals	Waiblinger K, Williams JR, D'Incao JP. "Quenched magneto-association of ultracold feshbach molecules." Phys. Rev. A, 2021 Sep 8;104:033310. http://dx.doi.org/10.1103/PhysRevA.104.033310 , Sep-2021
Articles in Peer-reviewed Journals	D'Incao JP, Williams JR, Gaaloul N, Efremov MA, Nimmrichter S, Schrinski E, Elliott B, Ketterle W. "Perspectives and opportunities: A molecular toolkit for fundamental physics and matter wave interferometry in microgravity." Quantum Sci. Technol. 2022 Nov 17;8:014004. http://dx.doi.org/10.1088/2058-9565/aca04a , Nov-2022
Articles in Peer-reviewed Journals	Carollo RA, Aveline DC, Rhyno B, Vishveshwara S, Lannert C, Murphree JD, Elliott ER, Williams JR, Thompson RJ, Lundblad N. "Observation of ultracold atomic bubbles in orbital microgravity." Nature. 2022 May 18;606:281-86. http://dx.doi.org/10.1038/s41586-022-04639-8 , May-2022