Fiscal Year:	FY 2024	**Task Last Updated:**	FY 02/28/2024
PI Name:	Cornell, Eric Ph.D.		
Project Title:	Zero-G Studies of Few-Body and Many-Body Physics		
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:	80309-0440	**Congressional District:**	2
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:	1	**No. of Master' Degrees:**	0
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	1
No. of Bachelor's Candidates:	3	**Monitoring Center:**	NASA JPL
Contact Monitor:	Callas, John	**Contact Phone:**	
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Flight Program:	ISS		
Flight Assignment:	NOTE: End date changed to 9/27/2024 per U. Israelsson/JPL (Ed., 10/20/21) NOTE: End date changed to 8/31/2021 per U. Israelsson/JPL (Ed., 5/12/2020) NOTE: End date changed to 4/30/2020 per PI (Ed., 5/1/19)		
Key Personnel Changes/Previous PI:			
COI Name (Institution):	Engels, Peter Ph.D. (Washington State University, Pullman) Mossman, Maren Elizabeth Ph.D. (University of San Diego)		
Grant/Contract No.:	JPL 1502690		
Performance Goal No.:			
Performance Goal Text:			

Task Description:	Future advances in both technology and fundamental science will hinge on a better understanding of the weird effects of quantum mechanics on collections of electrons, atoms, molecules, and so on. In some cases, experiments probing this so-called “quantum few-body and many-body physics” can be more readily accomplished in the weightless environment found in an orbiting laboratory. We propose a staged series of experiments, including (1) “first science” experiment, to be performed in the Cold Atom Laboratory (CAL) flying in the International Space Station (ISS) first-generation, to answer a question in few-body quantum physics that can’t be performed in a ground-based laboratory: how universal are the weakly bound clusters of three atoms known as Efimov trimers? In a weightless environment, experiments can be performed at very low densities and temperatures, the perfect conditions for these exotic but fragile quantum states to form. (2) Bose gases with “infinite” interactions. As interactions between atoms become stronger, there is a crossover between gas-phase and liquid behavior. In ultra-cold atoms, the crossover is between a quantum liquid and a quantum gas. (3) Highly rotating quantum gases. Many of the most exotic and unexplored predicted states of matter occur in the presence of very strong magnetic fields, for electrons, or high rates of rotation, for neutral particles. We will explore Quantum Hall physics in highly rotating Bose and Fermi gases. Experiments (2) and (3) will benefit significantly from the longer expansion times and weaker traps possible in weightlessness. Preliminary versions of both experiments will be done in a ground-based laboratory in order to establish the foundation for future flight-based experiments.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	Physics is the discipline that provides understanding of biology and chemistry at the most microscopic level, and the area within physics most relevant to chemistry and biology is “few-body physics.” It is an often neglected portion of physics, because it is so difficult to do! An important way to make progress is to simplify, simplify, simplify: to come up with model systems in which we can make progress that can later be applied to human-centric disciplines like biology, and develop exotic and useful new materials. A promising way to simplify is to study matter at lower temperature, and lower densities. The Cold-Atom Lab (CAL) flying in the International Space Station (ISS) is where we will reach the lowest possible temperatures, and low densities, to do our studies of simple, yet intricate (think “snowflakes”) clusters of three or four atoms. We have been doing prefatory experiments and calculations here on Earth. Not at as low temperature, but still cold enough to help us learn things we will need to know to do the space experiments. While CAL is now in flight, we have been participating in the effort to remotely tune it up for maximum performance and are progressing with few-body experiments using CAL.
Task Progress:	A key event in this reporting period has been the launch of a new science module, SM3B, in August 2023. In preparation for the launch of the new science module, our team actively worked together with the scientists and engineers at NASA's Jet Propulsion Laboratory (JPL) to assemble a comprehensive list of pre-commissioning tests. The purpose of these tests was to ensure the satisfactory performance of the new module for our proposed experiments with potassium, and to generate important benchmark data against which the module’s performance could be compared after installation. In parallel to this, our team focused on adapting our experimental procedures to the new capabilities of SM3B to ensure rapid progress after its installation. Microgravity offers an increased set of technical possibilities for how ultracold atoms can be manipulated. Accordingly, our team has performed extensive numerical studies to exploit new ways of preparing the atoms in the internal states needed for the proposed few-body experiments. Such state preparation steps need to be carefully designed so that unwanted heating of the ultracold sample is avoided. To easily implement new procedures, we have also developed a Python-based table builder to better automate the task of writing programs with which the NASA Cold Atom Lab (CAL) apparatus can be controlled. After the installation of SM3B on the International Space Station (ISS), an anomaly was detected during the commissioning phase when surprisingly short lifetimes of the atomic clouds were measured. An intense sequence of studies conducted by the JPL team concluded that the root cause was an issue with CAL’s ultrahigh vacuum. Fixing this problem requires the exchange of SM3B for an already built and tested science module, SM1. SM1 has successfully been used in ground-based studies at JPL since the original launch of CAL SM2 in 2018; however, this module has a slightly different magnetic field configuration than SM3B (due to the layout of the current-carrying tracks on the atom chip). We are therefore currently in the process of adapting our magnetic field models and experimental procedures to be able to quickly start potassium experiments after the installation of SM1 to the ISS. In another line of work, we have provided input to NASA for the development of an updated version of the Physical Sciences Informatics (PSI) database. PSI is the central hub for accessing the experimental images taken with CAL. While our team has developed an efficient code for handling data downloads and locally organizing our data, it was clear that PSI had a number of shortcomings. In 2023, NASA decided to undertake an overhaul of the PSI database, leading to PSI 2.0. To support this development, we worked together with the NASA/JPL team to assemble a list of suggested improvements that will enhance the user experience of PSI 2.0. Now that these changes and upgrades are installed, we are retooling our local data handling software to provide us with the most efficient data evaluation. This is done using a custom software suite programmed in Python. Theoretical research conducted by our group has been spearheaded by Jose D’Incao. This research focused on comparing the behavior of potassium-39, as used in CAL, with lithium-7, a species that is used in Earth-based studies. This comparison led to important insights, pointing at directions in which our theoretical models can be further improved to interpret forthcoming results from CAL. Such improvements have been and will continue to be one of our major tasks for our theory work during the next grant period. During this grant period, a number of undergraduate and graduate students have worked on this project. At Washington State University, graduate student, Colby Schimelfenig, has worked with co-Principal Investigators (co-PIs) Engels and Mossman to analyze data from PSI and to continue to model the experimental system. At University of San Diego, Mossman engages with a number of undergraduate researchers to plan experiments and learn how to perform experiments remotely. One of these students, Kathryn Anawalt (now at Boeing), developed a new Python-based programming tool to make building programs for CAL experiments more familiar for the PIs across the collaborations. In doing this, she worked closely with Mossman and Jason Williams (JPL) to make sure limitations of the apparatus were incorporated to reduce mistakes in the writing of experimental control sequences. During Summer 2023, Kathryn visited JPL, taking a tour of the facilities and measuring the magnetic field strength for the “fast Feshbach coils” at the ground testbed. These tests verified that the magnetic field strength of the coils matched our models, an important benchmark for our studies.

	A microgravity environment offers fascinating new perspectives for the investigation of intricate quantum mechanical few-body physics. The study of new phases of matter as well as applications to interferometric measurements are two examples for highly promising paths forward with direct relevance for topics suggested by the recent Decadal Survey. Within the frame of CAL, our team, as well as the team of Jason Williams and Ethan Elliott (JPL), are working in these directions. We are actively collaborating with Drs. Williams and Elliott to further promote few-body physics in microgravity through various channels. We have submitted white papers providing input for the recent Decadal Survey, have presented talks at a joint US-German workshop on future cooperation, and have presented a combined talk of our teams at the FunPAG Virtual Science Workshop in January 2024 to formulate input to NASA's Fundamental Physics Program. We have additionally made efforts to discuss the importance of few-body physics to the younger generation and to the general public. At the launch of SM3B from the NASA Wallops Flight Facility, co-PI Mossman took part in an outreach effort to bring CAL science to the public in an interview conducted by NASA Public Relations (PR) alongside JPL's Jason Williams. In November 2023, Mossman presented a colloquium talk at California State University, Long Beach dedicated to performing ultracold atom experiments in microgravity, with a focus on few-body physics. This talk engaged primarily undergraduate and masters-level physics students. Our team will continue to closely work together with the scientists and engineers at JPL to advance few-body research in microgravity and to promote CAL and microgravity research to the scientific community and general public.
Bibliography Type:	Description: (Last Updated: 02/29/2024)
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