Fiscal Year:	FY 2021	**Task Last Updated:**	FY 09/22/2021
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:	5	**No. of PhD Degrees:**	1
No. of PhD Candidates:	3	**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:	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.
Task Progress:	The reporting period has been marked by significant hardware changes to the CAL apparatus. These include the commissioning of the new science module SM3 which launched in December 2019, a change of the current paths on the chip that became necessary after a powersupply failure, and the installation of the replacement for a microwave module that will soon make cold potassium available for experimentation with CAL. During all those changes, our team has diligently analyzed the implications for our planned experiments and has worked together with the CAL team at the Jet Propulsion Laboratory (JPL) to ensure the success of the operations. In preparation for our upcoming experiments with potassium, we have performed calibrations and tested state preparation procedures using 87Rb. We anticipate that these procedures can quickly be adapted to potassium when potassium becomes available. In order to efficiently handle the increased amount of data made available to our group, we have also developed an extensive new software suite. The software automatically handles the deep file structure of the compressed files downloaded from the Physical Sciences Informatics (PSI) database and can automatically unpack and categorize the data. An extensive set of scripts has been implemented to perform the data analysis. Together with a short set of test routines that we have established for the CAL apparatus, the enhanced software also provides a quick and efficient way of testing the normal functioning of the apparatus in a specific setting that is most relevant for our experiments. Our experimental studies with the CAL apparatus have been accompanied by ground based studies conducted at both JILA and Washington State University (WSU). While JILA has continued its line of research into Efimov physics which provides highly relevant benchmark data for the planned CAL experiments, the WSU team has focused on studies into laser cooling and sympathetic cooling of potassium that provide insights into possible optimizations of the CAL procedures generating ultracold potassium clouds. JILA ground-based experiments have also expanded the focus to include a study of "implosions," an effect where an ultra-cold atoms folds in upon itself after the interactions between the atoms are suddenly tuned to be attractive. Our team has been in active discussions with the JPL team about the current CAL operation, about future extensions, and about the mitigation of anomalies that occurred with the instrument. Both graduate students and postdocs have been involved in this work in the frame of our collaboration. Furthermore, one of our team members, Maren Mossman, has contributed to the mentoring of a JPL "pre-doc," working on code for the calculation of magnetic fields that was shared from our collaboration. Maren has also been interviewed and quoted in a Nature News article discussing CAL, and has been featured in a NASA JPL video for Women's Equality Day in 2020. The research at JILA has resulted in an article published in Physical Review Letters, which is one of the highest ranked journals in this field of research. During this reporting period, the theoretical component of our collaboration has focused on the implementation of several improvements that made the few-body numerical codes developed at JILA substantially accurate and efficient. These improvements have now been applied for various atomic species allowing for a more complete description of few-body processes with an emphasis on the importance of the spin structure in precisely determining the properties of Efimov states near Feshbach resonances. Other theoretical achievements include the development of numerical codes that determine elastic and inelastic atom-atom scattering properties for 39K and 87Rb atoms in an arbitrary spin state. These are necessary to determine the efficiency of the various experimental procedures to be further implemented at CAL and have been used frequently in our collaboration.
Bibliography Type:	Description: (Last Updated: 02/29/2024)
Articles in Peer-reviewed Journals	Xie X, Van de Graaff MJ, Chapurin R, Frye MD, Hutson JM, D'Incao JP, Julienne PS, Ye J, Cornell EA. "Observation of Efimov Universality across a nonuniversal Feshbach resonance in K-39." Phys Rev Lett. 2020 Dec;125(24):243401. https://doi.org/10.1103/PhysRevLett.125.243401 ; PMID: 33412063 , Dec-2020
Articles in Peer-reviewed Journals	Mark MJ, Flannigan S, Meinert F, Jag-Lauber K, D'Incao JP, Daley AJ, Naegerl H-C. "Interplay between coherent and dissipative dynamics of bosonic doublons in an optical lattice." Phys Rev Res. 2020 Oct-Dec;2(4):043050. https://doi.org/10.1103/PhysRevResearch.2.043050 , Oct-2020

Significant Media Coverage	Gibney E. "Universe’s coolest lab creates bizarre quantum matter in space. Nature News article interviewed and quoted M. Mossman and discussed research efforts of the Ultracold Few-Body Physics Team." Nature News article published June 11, 2020. https://doi.org/10.1038/d41586-020-01773-z , Jun-2020
Significant Media Coverage	Mossman M. " 'Cold Atom Lab,' NASA JPL video for Women’s Equality Day in 2020 featured M. Mossman speaking about the Cold Atom Lab." NASA JPL video for Women’s Equality Day, released August 26, 2020., Aug-2020