Fiscal Year:	FY 2022	**Task Last Updated:**	FY 04/28/2022
PI Name:	Lundblad, Nathan Ph.D.		
Project Title:	Microgravity Dynamics of Bubble-Geometry Bose-Einstein Condensates		
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:	04240-6018	**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:	1	**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:**	0
No. of Bachelor's Candidates:	1	**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 3/31/2022 per B. Carpenter/NASA HQ (Ed., 1/4/2021) NOTE: New end date is 10/30/2020 per JPL (Ed., 5/21/19)		
Key Personnel Changes/Previous PI:	April 2022 report: Postdoctoral associate Joseph Murphree has been working since July 2020 and will finish June 2022. Recruitment has commenced for his successor		
COI Name (Institution):	Aveline, David Ph.D. (Jet Propulsion Laboratory) Lannert, Courtney Ph.D. (Smith College) Vishveshwara, Smitha Ph.D. (University of Illinois at Urbana-Champaign)		
Grant/Contract No.:	JPL 1502172		
Performance Goal No.:			
Performance Goal Text:			

Task Description:	Notions of geometry, topology, and dimensionality have directed the historical development of quantum-gas physics. With a toolbox of forces used to confine, guide, and excite Bose-Einstein condensates (BEC) or degenerate Fermi gases (DFG), physicists have used quantum gases to test fundamental ideas in quantum theory, statistical mechanics, and in recent years notions of strongly-correlated many-body physics from the condensed-matter world. We propose a specific program to explore a trapping geometry for quantum gases that is both tantalizing theoretically and prohibitively difficult to attain terrestrially: a quantum gas in a bubble geometry, i.e., a trap formed by a spherical or ellipsoidal shell structure, confining a 2D quantum gas to the surface of an experimentally-controlled topologically-connected “bubble.” The physics of a quantum gas confined to such a surface has not been explored terrestrially due to the limitations of gravitational sag; interesting work has certainly been done with gases confined to the lower regions of bubble potentials, but the fully symmetric situation has yet to be explored. The low-energy excitations of such a system are unexplored, and notions of vortex creation and behavior as well as Kosterlitz-Thouless physics are tantalizing aims as well. The solid-state modeling goals of the optical-lattice physics community are also fundamentally connected to the system, as the canonical Mott-insulator/superfluid transition features superfluid shells isolated between insulating regions. The central method to reach the sought-after bubble-geometry BEC or DFG is that of rf or microwave dressing of the bare trapping potentials provided by the Cold Atom Laboratory (CAL) “chip trap.” Radiofrequency dressing has been used conceptually through "rf-knife" evaporative cooling, but more recently through explicit construction of adiabatic potentials for interferometry, and shell-trap construction for both thermal and quantum gases. The proposed work is a window into a physical regime that is quite difficult to achieve terrestrially due to trap distortion; given the advantages of a microgravity environment, NASA CAL is uniquely positioned to realize the physics goals of this proposal.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	This work, while focused on the fundamental physics of ultracold atoms and not directly connected to human life, has a similar impact to life on Earth as that of all fundamental physics; it broadens our understanding of the physical world and helps us further cement our collective picture of quantum mechanics as "the way the world works." It explores the limits of how large Bose-Einstein condensates can be made, and to what extent the gravity-well of terrestrial labs render certain investigations difficult or impossible. The observations made aboard CAL through this project are a clear demonstration that physical insight can sometimes require microgravity facilities to be fully developed, and that spaceborne atomic physics experiments can be valuable contributions to our collective scientific efforts.
Task Progress:	The 2021-2022 period of this work was focused on continued data collection from the Cold Atom Laboratory (CAL) instrument, which had periodic data acquisition sessions in the new Phase 2 ("SM3") generation CAL apparatus. Lundblad and postdoctoral associate Joe Murphree were central drivers of this work in this period, together with our partner at Jet Propulsion Laboratory (JPL), David Aveline, who in addition to service as co-investigator was our primary liaison to experimental operations. Theory co-investigators Smitha Vishveshwara and student Brendan Rhyno provided regular insight and support, especially in regard to computational modeling of observed phenomena. Phase 2 ("SM3") of the CAL operation is ongoing, as in the previous year. With a new atom chip geometry, SM3 permits us to explore shells with aspect ratios closer to spherical, and also with reduced inhomogeneity due to a larger rf coil. We have recently focused mostly on a single trap/shell configuration (of several explored in the previous year) and have added data-taking from multiple spatial directions to our experimental repertoire, confirming that observed structures are indeed shell-like when viewed from multiple directions. Given initial proof-of-principle of Bragg-beam interferometry, we have continued developing model intuition for planned future experiments in that area. The goal of this exploration is to potentially provide thermometry information from a Bragg spectrum that would obviate the need for long time-of-flight expansion. In coming tests, we hope to use the multifrequency capability of CAL (microwave +rf, rf+rf) to gain clearer understanding of the bubble system. We initiated tests of the microwave version of the bubble-generating procedure (microwave ramps instead of rf ramps) with inconclusive but promising initial results. Continued theoretical development occurred within the shell collaboration, leading to published work from Rhyno, et al. focusing on thermodynamics in ultracold shells (https://). Lundblad also continued collaborative discussion with Dr. Barry Garraway of Sussex regarding the potential to use microwave fields aboard CAL to enhance bubble quality; a document regarding this technique titled "Optimised shell potential for microgravity Bose-Einstein condensates" is in final preparation. Many years of effort from students and postdocs culminated in final analysis related to (and writing of a) paper presenting our first results from the CAL experiment. "Observation of ultracold atomic bubbles in orbital microgravity" is in press in the journal Nature, and is also available on the arXiv preprint server (https:// Results of our research activities were presented at several conferences, including the 2021 American Physical Society (APS) Meeting of the Division of Atomic, Molecular, and Optical Physics (DAMOP). Additionally, Lundblad presented these results at the 2021 Marcel Grossman meetings.
Bibliography Type:	Description: (Last Updated: 02/04/2025)
Articles in Other Journals or Periodicals	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." arXiv preprint server. Posted August 12, 2021. https://doi.org/10.48550/arXiv.2108.05880 , Aug-2021
Articles in Peer-reviewed Journals	Frye K, Abend S, Bartosch W, Bawamia A, Becker D, Blume H, Braxmaier C, Chiow SW, Efremov MA, Ertmer W, Fierlinger P. "The Bose-Einstein condensate and Cold Atom Laboratory." EPJ Quantum Technol. 2021 Jan 4;8:1. https://doi.org/10.1140/epjqt/s40507-020-00090-8 , Jan-2021
Articles in Peer-reviewed Journals	Rhyno B, Lundblad N, Aveline DC, Lannert C, Vishveshwara S. "Thermodynamics in expanding shell-shaped Bose-Einstein condensates." Phys. Rev. A. 2021;104(6):063310. https://doi.org/10.1103/PhysRevA.104.063310 , Dec-2021