Fiscal Year:	FY 2023	**Task Last Updated:**	FY 06/02/2023
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:	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:**	0
No. of Bachelor's Candidates:	2	**Monitoring Center:**	NASA JPL
Contact Monitor:	Callas, John	**Contact Phone:**	
Contact Email:	john.l.callas@jpl.nasa.gov		
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:	May 2023 report: Postdoctoral associate Joseph Murphree departed June 2022 (ColdQuanta, Madison WI). Recruitment has continued for his successor. Also, Courtney Lannert, Ph.D. has retired and is no longer with the project (Ed., 6/20/23).		
COI Name (Institution):	Aveline, David Ph.D. (Jet Propulsion Laboratory) 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 2022-2023 period of this work was focused on continued data collection from the NASA Cold Atom Laboratory (CAL) instrument, which had periodic data acquisition sessions in the ongoing Phase 2 ("SM3") generation CAL apparatus. Lundblad was central driver 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 the anticipated arrival of "SM3B" upgrades, we have been aiming to wind down physics studies of the current experimental configuration – a shell with aspect ratio closer to spherical and reduced inhomogeneity – by performing a detailed investigation of the shell-trapped gas near the BEC transition. In particular, all previous work showed thermal (non-BEC) gas in the bubble structures, and we have aimed data-taking sessions to elucidate this loss of coherence. We have also focused on diagnosing and eliminating residual micro-motion in these traps.
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" was published in the journal Nature (https://).

A review article of interest in bubble physics was published: "Perspective on quantum bubbles in microgravity." Quantum Sci Technology 8, 024003 (2023). https:// .

Results of our research activities were presented at several conferences and international workshops, including the 2022 American Physical Society (APS) Meeting of the Division of Atomic, Molecular, and Optical Physics (DAMOP), Sao Paolo Workshop on Low Dimensional Quantum Gases (March 2023), Heraeus 777 (Ultracold Matter and Applications, December 2022), and FINESS 2022 (Finite Temperature Non-equilibrium Superfluid Systems Conference - May 2022).

[Ed. Note: See Bibliography for complete citations.]

Bibliography Type: Description: (Last Updated: 06/20/2023)

Abstracts for Journals and Proceedings

Lundblad N. "Ultracold bubbles in space: Atomic physics aboard the International Space Station." FINESS 2022 (Finite Temperature Non-equilibrium Superfluid Systems Conference), St. Martin, Germany, May 2-6, 2022.
Abstracts. FINESS 2022 (Finite Temperature Non-equilibrium Superfluid Systems Conference), St. Martin, Germany, May 2-6, 2022. , May-2023

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Lundblad, N. "Studying ultracold bubbles in orbital microgravity with the NASA Cold Atom Laboratory." Workshop on Low Dimensional Quantum Gases, Sao Paulo, Brazil, March 19-22, 2023.
Abstracts. Workshop on Low Dimensional Quantum Gases, Sao Paulo, Brazil, March 19-22, 2023. , Mar-2023

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Lundblad N. "Studying ultracold bubbles in orbital microgravity with the NASA Cold Atom Laboratory." WE-Heraeus-Seminar, Bad Honnef, Germany, December 12-16, 2022.
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