Fiscal Year:	FY 2015	**Task Last Updated:**	FY 12/20/2015
PI Name:	Bigelow, Nicholas Ph.D.		
Project Title:	Consortium for Ultracold Atoms in Space		
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:	14627-0171	**Congressional District:**	25
Comments:			
Project Type:	Flight	**Solicitation / Funding Source:**	2013 Fundamental Physics NNH13ZTT002N (Cold Atom Laboratory--CAL)
Start Date:	04/01/2014	**End Date:**	04/30/2019
No. of Post Docs:	3	**No. of PhD Degrees:**	0
No. of PhD Candidates:	5	**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:**	
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Flight Program:	ISS		
Flight Assignment:	NOTE: Extended to 4/30/2019 per U. Israelsson/JPL (Ed., 12/14/17)		
Key Personnel Changes/Previous PI:			
COI Name (Institution):	Pritchard, David Ph.D. (Massachusetts Institute of Technology) Stamper-Kurn, Dan Ph.D. (University of California, Berkeley) Vuletic, Vladan Ph.D. (Massachusetts Institute of Technology) Kasevich, Mark Ph.D. (Stanford University) Ketterle, Wolfgang Ph.D. (Massachusetts Institute of Technology) Lukin, Mikhail Ph.D. (Harvard) Mueller, Holger Ph.D. (University of California, Berkeley) Phillips, William Ph.D. (University of Maryland) Ye, Jun Ph.D. (University of Colorado)		
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Performance Goal No.:			
Performance Goal Text:			

Task Description:	Consortium for Ultracold Atoms in Space (CUAS) We represent a research consortium of senior people, all pioneers in Bose-Einstein condensation, atom optics, atom interferometry, and related areas, with experience with NASA's program on fundamental research in microgravity. The Consortium's work is described in the context of four Tasks. Task 1: Advanced Clocks in Space and Time Transfer Task 2: Maturing and Advancing Atom Interferometer Technology for Space Task 3: Precision Atom Interferometric Measurement in Space Task 4: Strategies for the Frontier of Ultracold Atoms in Space. The Consortium is: N. P. Bigelow, M. Kasevick, W. Ketterle, M. Lukin, H. Müller, W. D. Phillips, D. Pritchard, D. Stamper-Kurn, V. Vuletic, and J. Ye. We have established a cooperation with German Scientists: C. Braxmaier, W. Ertmer, C. Lämmerzahl, A. Peters, E. M. Rasel, and W. P. Schleich. In forming this Consortium, we have several aims: (1) to, in one consolidated move, provide NASA with a community of talented and respected researchers who are committed to developing well thought out, highly impactful precision, quantum gas and atomic physics space experiments; (2) to support several first-class experimental efforts with significant potential to impact NASA interests and specifically to impact future flight experiments or indeed to become flight definition experiments; and (3) to provide intellectually compelling strategies that will impact future generations of flight experiments, aboard the International Space Station (ISS) and beyond. This consortium will provide NASA with a far larger return than could be expected from a series of individual projects. In part this is because of the natural synergies among the interests and expertise of the Consortium members. In part this is because the membership is meeting regularly in person and via teleconference in order to create and refine ideas beyond the work described at the formation of the consortium, challenging each other to advance only the most excellent projects to NASA. The interests and expertise of the Consortium represent two of the four Thrusts identified in a recent National Research Council (NRC) report and the current NASA Research Announcement: (1) Precision Measurement of Fundamental Forces and Symmetries and (2) Quantum Gasses. In the present proposal we choose to focus on two specific areas: ultra-performance clocks and clock networks and atom interferometers (including those using degenerate quantum gasses). We have developed a cooperation plan with leading German expert scientists involved with DLR sponsored work in Bremen who are collaborators on this proposal. Berkeley and Stanford lead Tasks 2 and 3. MIT, U.C./JILA, and Harvard lead Task 1. U. Md., Rochester, and MIT lead Task 4. Members of the Consortium can and often will contribute to all four tasks with priorities being set by the lead institutions.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	Significant progress has been made on atomic interferometry and atomic clocks in terrestrial experiments. The work has long-term impact for fundamental science, navigation technologies, and global clock synchronization. Clocks are vital to navigation, communication, and security. Atom interferometry: Demonstrate 50 pK kinetic temperatures and 30 photon recoil, 50% contrast, 1.1 s interrogation time atom interferometry (18 cm wavepacket separation). First demonstration of a cavity-based atom interferometer. The cavity provides power enhancement, spatial filtering, and a precise beam geometry, enabling new techniques such as low power beamsplitters (<100μW), large momentum transfer beamsplitters with modest power, or new self-aligned interferometer geometries. A manuscript has been accepted by Physical Review Letters and will be featured in an upcoming viewpoint article by Alex Cronin in Physics Today. We have applied this novel technology to set limits on fifth forces that are undetectable in previous experiment by a "screening" mechanism which suppresses the forces in the vicinity of massive objects. Such theories have been studied in the context of dark matter and dark energy. Using atoms as test particles avoids triggering the screening and allows us to rule out a broad range of theories that could explain the observed cosmic acceleration. This work has been submitted for publication. Clock Networks Tested a novel quantum, cooperative protocol for operating a network of geographically remote optical atomic clocks. Theoretically showed that such a network can be operated near the fundamental precision limit set by quantum theory. Furthermore, the internal structure of the network, combined with quantum communication techniques, guarantees security both from internal and external threats. Realization of such a global quantum network of clocks will allow construction of a real-time single international time scale (world clock) with unprecedented stability and accuracy. We have initiated proof-of-concept experiments aimed at exploring key elements of such a network. We have recently finished evaluation of our Sr II clock's total accuracy, and we have now reached 2.1 x 10^-18, an improvement of a factor of three over the previous world record. We have started designing an optical cavity for collective measurement of Sr atoms in a cavity QED setting, in preparation for spin squeezing and connection between two clocks.

	A goal is to demonstrate an entangled network of clocks. We have taken two steps towards this goal. (1) In our work towards an optical transition clock with Yb atoms that operates below the standard quantum limit, we have finished the assembly of an optical resonator operating in the strong coupling regime (peak cooperativity of 40), and are ready to install the system inside the vacuum chamber. (2) We have achieve a magneto-optical trap for Yb both on the wide singlet transition, and on the narrow triplet transition that yields much lower atomic temperatures. The remote entanglement between clocks will be achieved by communication via photonic quantum bits. We have shown that a single photon can create a strongly entangled state of a large atomic ensemble containing 3000 Rb atoms. We demonstrate that the atomic state upon detection of a single photon is characterized by a negative Wigner function, which represents the first observation of a negative Wigner function for a system containing more than a few atoms. Moreover, we also verify an entanglement depth (minimum number of mutually entangled atoms) comprising 90% of the ensemble.
Task Progress:	This report covers the first six months of the work of the Consortium for Ultra Cold Atoms in Space. Consortium for Ultracold Atoms in Space (CUAS) The Consortium's work is described in the context of four Tasks. Task 1: Advanced Clocks in Space and Time Transfer Task 2: Maturing and Advancing Atom Interferometer Technology for Space Task 3: Precision Atom Interferometric Measurement in Space Task 4: Strategies for the Frontier of Ultracold Atoms in Space. The Consortium is: N. P. Bigelow, M. Kasevick, W. Ketterle, M. Lukin, H. Müller, W. D. Phillips, D. Pritchard, D. Stamper-Kurn, V. Vuletic, and J. Ye. We have established a cooperation with German Scientists: C. Braxmaier, W. Ertmer, C. Lämmerzahl, A. Peters, E. M. Rasel, and W. P. Schleich. We have made significant progress in the development of technologies for space based atom interferometer. Specifically, this includes preparation of some of the coldest atomic vapor samples ever realized on Earth (even colder samples will be created in Space in the future). We have developed new and novel strategies for using atom interferometers in Space to set limits on dark matter and energy, addressing some of the most important open questions in Physics, questions that relate to the fundamental nature of space and time. We are making significant progress on atomic clock technology and global synchronization. Terrestrial and Space based atomic clocks are vital to next generation GPS, navigation and ultra high speed, secure communication networks. Several publications were in preparation as of January 1, 2015.
Bibliography Type:	Description: (Last Updated: 07/03/2025)