Fiscal Year:	FY 2021	**Task Last Updated:**	FY 02/01/2022
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Project Title:	Direct Detection of Dark Energy on Einstein Elevator (D3E3)		
Division Name:	Physical Sciences		
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Program/Discipline--Element/Subdiscipline:			
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:	91109	**Congressional District:**	27
Comments:			
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No. of PhD Candidates:		**No. of Master' Degrees:**	
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No. of Bachelor's Candidates:		**Monitoring Center:**	NASA JPL
Contact Monitor:	Israelsson, Ulf	**Contact Phone:**	
Contact Email:	ulf.e.israelsson@jpl.nasa.gov		
Flight Program:			
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Technical Background
Dark energy is the greatest mystery in fundamental physics to date. 70% of the Universe energy content is in the form of dark energy, which is responsible for the observed accelerated expansion. While little is known about the nature of dark energy, it is conjectured to be a new scalar field that weakly interacts with normal matter. To be consistent with the current solar system observations, however, such interactions should be environment dependent and screened locally. Possible scalar fields with screening mechanisms are described in the forms such as chameleon, symmetron, and galileon models. Recently, cold atom experiments using atom interferometers in a ground laboratory have contributed significantly to the constraints of chameleon and symmetron models, thanks to the “thin-shell” effect of these two models.

Chameleon and symmetron models emerged from the cosmology community, where the above-mentioned screening mechanism is realized, in the framework of the scalar field theory. By incorporating these models in the master equations of atomic sensors, which utilize quantum mechanical properties of individual atoms for force measurements, theory predicts that there must be extra forces merely due to the presence of dark energy fields, and that these forces are orders of magnitude weaker than gravity. We propose to operate atomic sensors near a structured mass as the source of dark energy force in microgravity. Microgravity allows extended interrogation time and thus enhanced sensitivity in a small and well-characterized package, and the structured source mass is designed to suppress the gravity effect while maintaining the dark energy signal. These innovative approaches enable sensitivity beyond those achieved in laboratory experiments.

Programmatic Background

As one of our key international partners, collaborative research with the German Aerospace Center (DLR) into direct detection of dark energy in a DLR facility is an excellent programmatic rationale to further build our relationship with DLR, exchange technical knowledge with DLR, and develop and demonstrate critical atom interferometry technology, in the pursuit of this proposed directed research activity.

As a result of the 2011 NRA (NASA Research Announcement), NASA selected Holger Muller (Berkeley) and Nan Yu to participate in the European Space Agency (ESA) Quantum Weak Equivalence Principle (QWEP) study from 2012 to 2017. As part of that study, they realized they could use the QWEP atom interferometer approach to search for the chameleon dark energy candidate.

Muller and his students designed an apparatus and performed a dark energy experiment. In addition to the NASA support, this activity was also supported by National Science Foundation (NSF) and Defense Advanced Research Projects Agency (DARPA). They published their results in Science in 2015.

Task Description:

In a 2018 Phys Rev D paper extending the previous work, Sheng-wey Chiow and Nan Yu noted that, “For pointlike particles such as atoms, the depth of screening is larger than the size of the particle, such that the screening mechanism is ineffective and the chameleon force is fully expressed on the atomic test particles. Extra force measurements using atom interferometry are thus much more sensitive than bulk mass based measurements, and indeed have placed the most stringent constraints on the parameters characterizing chameleon field.” They further wrote that, “In this paper, we present a measurement concept of direct detection of chameleon forces using atom interferometers in microgravity, with a sensitivity sufficient to detect any predicted chameleon force or rule out the theory completely.”

While the only precision measurements with atom interferometers to date have only been demonstrated in ground laboratories, there have been significant efforts recently to bring the technology to a microgravity environment and space, including drop towers, sounding rocket experiments, and the Cold Atom Laboratory. However, none of these experiments will demonstrate precision measurements beyond the state of the art on the ground. Even Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) will not have true precision measurement capabilities per its baseline plan approved at the Preliminary Design Review. On the other hand, the University of Hannover Einstein Elevator (EE) microgravity facility, with high dropping repetition rate of 300 per day, offers the possibility for accumulating enough data through averaging for precision measurements. With the commissioning of EE and the availability of the German DLR MAIUS-I (Matter-Wave Interferometry in Microgravity) BEC (Bose-Einstein condensate) machine, an opportunity arises for conducting the first precision measurements in a microgravity environment. Given the JPL Planning, Programming, Budgeting, and Execution (PPBE) line to develop atom interferometry (AI) for the Einstein Elevator, NASA can fund developing and verifying a microgravity instrument that could either detect chameleon dark energy particles or rule such a theory out completely. Given the status of modern physics, this is a highly significant effort.

Implementation

We propose to use this opportunity to collaborate with DLR for direct detection of dark energy measurements. The atomic sensor will be implemented in an ultra-high vacuum chamber capable of generating ultra-cold atoms. We plan on leveraging the existing hardware of MAIUS-I, a compact cold atom instrument that was used in a DLR sounding rocket experiment. Professor Ernst Rasel and his team at Hannover University will repurpose MAIUS-I and modify the vacuum chamber for dark energy measurements. We will work with DLR to conduct the experiment in the Einstein Elevator (EE) at Hannover, where 4-s of microgravity time will be available every 5 min. The free-fall time and the repetition rate will provide sufficient sensitivity for pushing the boundaries of dark energy models.

Summary

The proposed D3E3 will improve the state-of-the-art constraints on scalar field theories by several orders of magnitude by performing cold atom experiments in the microgravity environment available in the Einstein Elevator. The improved sensitivity will close the gap in the parameter space of chameleon for dark energy density at currently observed level, decisively testing the validity of the chameleon model.

References:

Hamilton P, Jaffe M, Haslinger P, Simmons Q, Müller H, Khoury J. ASTROPHYSICS. Atom-interferometry constraints on dark energy. Science. 2015 Aug 21;349(6250):849-51. https://

Chiow S, Yu N. "Multiloop atom interferometer measurements of chameleon dark energy in microgravity." Physical Review D. 2018 Feb;97(4):044043. https://

Highly Constrained Research
The goal of this research is to verify whether or not Atom Interferometry (AI) can detect or rule out the chameleon theory of dark energy It is constrained by the following:

Based on the previous work the Jet Propulsion Laboratory (JPL) has already initiated a collaboration with University of Hannover scientists, Prof. Ernst Rasel and Prof. Wolfgang Ertmer, to perform this research in the Einstein Elevator. They will be able to re-purpose MAIUS (Matter-Wave Interferometry in Microgravity) rocket hardware for use in the elevator, as long as approval is given to move forward on this in the short term. They have submitted a proposal to refurbish the MAIUS laser system for this collaboration to the German Aerospace Center (DLR), and are anticipating a

Rationale for HRP Directed Research:	positive answer. If we are unable to take advantage of the availability of the MAIUS hardware for this purpose now, we may lose the opportunity for this research altogether. It is expected that to perform a similar experiment on the International Space Station (ISS) would cost at least as much as the Cold Atom Laboratory (CAL) development, depending on the ultimate requirements chosen for the flight project. Insufficient Time for Solicitation JPL does not have the funding or the opportunity to solicit research from the community in this area. The next NASA Research Announcement (NRA) is years away, and it is specifically targeted for performing research using the as-yet-built DLR funded Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) follow-on ISS experiment to CAL. The opportunity from the availabilities of Einstein Elevator (EE) and MAIUS-I is opportunistic and unanticipated. The Einstein Elevator is currently in the commissioning phase, and is expected to be fully operational in two years. At the same time, the repurpose of MAIUS-I for EE is already planned. It is anticipated that atom interferometer experiments will have priority for the first few years.
Research Impact/Earth Benefits:	
Task Progress:	New project for FY2021.
Bibliography Type:	Description: (Last Updated:)