Fiscal Year:	FY 2021	**Task Last Updated:**	FY 08/04/2021
PI Name:	Khusid, Boris Ph.D.		
Project Title:	Advanced Colloids Experiment-Temperature and Gradient Control (ACET11)		
Division Name:	Physical Sciences		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:	COMPLEX FLUIDS/SOFT MATTER--Complex Fluids		
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:	07102-1982	**Congressional District:**	10
Comments:			
Project Type:	Flight	**Solicitation / Funding Source:**	2013 Complex Fluids & Macromolecular Biophysics NNH13ZTT001N
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No. of Master's Candidates:		**No. of Bachelor's Degrees:**	
No. of Bachelor's Candidates:	1	**Monitoring Center:**	NASA GRC
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Flight Program:	ISS		
Flight Assignment:	ISS--Space X-19 NOTE: End date changed to 8/31/2022 per NSSC information (Ed., 12/10/21)		
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Task Description:	NOTE 1/21/2020: Continuation of "Kinetics of Electric Field-Driven Phase Transitions in Polarized Colloids," grant NNX13AQ53G, with same Principal Investigator Dr. Boris Khusid. Motivation: The widespread use of colloidal processes for scalable manufacturing of structured materials emphasizes a critical need for improving fundamental understanding of the role of external fields in directing non-equilibrium phenomena in suspensions. The challenge is due to kinetic limitations because the particles can be trapped into metastable configurations for a long time due to the lower mobility of multi-particle structures compared to that of individual particles. Microgravity offers a unique opportunity to study these phenomena by removing masking gravity effects, such as particle sedimentation, convection, and jamming. The proposed research addresses both fundamental and technological questions in the science of colloids aimed at understanding the equilibrium and metastable crystalline, liquid, and glassy structures and the use of these materials in additive manufacturing. Objectives: Conduct tests in the International Space Station (ISS) Advanced Colloids Experiment (ACE) facility to elucidate the mechanisms of non-equilibrium phenomena underlying the assembly of colloidal particles assisted by temperature field gradients and suggest novel routes for processing functional materials. Methodology: A novel approach will be used to study mechanisms for formation of metastable and glassy phases in suspensions in the ISS and for comparison on Earth. A single sample will be exposed to a temperature gradient to cover the interesting range of particle densities. As the particle density is directly measured by microscopy, a priori knowledge of the gradient profile is not required. Experiments will involve setting up a temperature gradient to observe the resulting structures and then locally mix a region of known density to watch it glassify or crystallize. Quantitative data on the suspension rheology will come from microrheology measurements through tracking particle thermal motion. Deliverables: Understanding of non-equilibrium phenomena in colloids driven by temperature gradients and experimental database for the control and manipulation of colloidal structures in space and terrestrial applications.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	Research Overview • Why is the research needed? New functional materials are, in principle, created using micron-sized particles suspended in fluid (called colloids) that self-organize into crystalline structures or amorphous glass phases by means of entropic forces or under the control of non-equilibrium drive as supplied, for example, by temperature gradients. The ACE-T11 experiments utilize confocal microscopy for time- and space-resolved, 3D imaging of spherical colloidal particles, whose phases can be controlled by adding depletants and/or adjusting spatial temperature changes around a particular location and applying temperature gradients. The smaller particles allow the tuning of the interactions between the colloids, and in this way control the structure, density and composition of the colloidal dispersion. • What will be accomplished? In ACE-T11, the phase behavior of micron-sized colloidal particles is studied by varying the particle number density. Under certain conditions, the particles self-organize into crystalline, or dense amorphous glass phases set by the particle number density. Increasing the particle number density enables a study of the crystallization and/or glass formation over a controlled range of particle densities. Three-dimensional structures that are impossible to create or reform on Earth due to gravitational sedimentation (high density contrast between particles and fluid) can be observed and controlled in microgravity. • What will be the impact of the research? Ultimately, the ability to design functional structures – based on micron-scale building blocks – with a variety of well-controlled three-dimensional bonding symmetries, amorphous structures and different rheologies will allow new devices for chemical energy production and storage, photonics and communication, and a new set of slurries and pastes useful for additive manufacturing. Such materials might include photonic crystals with programmed distributions of defects. Optical technology utilizing such materials may offer intriguing solutions to unavoidable heat generation and bandwidth limitations facing the computer industry. Insights will also be gained as to the formation of amorphous glass phases as distinct from the crystalline phases, a question raised by previous microgravity experiments, as yet unresolved, where glass phases found on Earth readily crystallized in micro-g. The beginning of this process is understanding the basic interactions between micro- and nanoscale particles, and how to control the colloidal structure using external sources such as temperature gradients and light. • Space Applications: Eventually, future space exploration may use self-assembly and self-replication to make materials and devices that can repair themselves. Self-assembly and evolutionarily-optimized functional units are key to long-duration space voyages. Even more immediate is the requirement of replacement parts and specialized repair facilities for space missions. 3D printing and additive manufacturing will be necessary for future space missions. The development of particle slurries and pastes with the appropriate rheological properties that work in both micro-g and conventional gravity will be needed. One objective of this experiment is to develop such materials. • Earth Applications: This investigation involves several fundamental and practical aspects of soft matter science with potential applications on Earth. Self-assembly processes are crucial to making functional materials and devices from small particles. Improved design and assembly of structures fabricated in microgravity may have use in a variety of fields from medicine to electronics on Earth. Ultimately, the ability to design and build functional structures based on colloids will allow new devices for chemical energy, communication, and photonics, including photonic materials to control and manipulate light. The rapidly growing fields of 3D printing and additive manufacturing rely on the assembly and sintering of particle aggregates and the preparation of high-density slurries and pastes of different colloidal materials and with different rheological and mechanical properties is a main goal of these studies.
Task Progress:	The study was conducted within the scope of the originally-proposed research plan. The New Jersey Institute of Technology (NJIT) and New York University (NYU) researchers worked in closed collaboration with researchers from the NASA Glenn Research Center and ZIN Technologies to carry out experiments on colloidal crystallization of hard-sphere suspensions in the ACE Light Microscopy Module (LMM) on the ISS. Experiments demonstrated that colloidal particles became orderly arranged creating the face centered cubic (FCC) lattice structure as predicted by most recent computer simulations. This outcome provided the first confirmation of computer simulations of liquid crystallization of hard spheres.

Bibliography Type:	Description: (Last Updated: 02/06/2025)
Abstracts for Journals and Proceedings	Lei Q, Khusid B, Kondic L, Hollingsworth AD, Chaikin PM, Meyer WV, Reich AJ. "Colloidal crystallization under microgravity." To be presented at the 37th Annual Meeting of the American Society for Gravitational and Space Research, Baltimore, MD, November 3-6, 2021. 37th Annual Meeting of the American Society for Gravitational and Space Research, Baltimore, MD, November 3-6, 2021. Abstract ID: 202172. , Nov-2021
Abstracts for Journals and Proceedings	Lei Q, Khusid B, Kondic L, Hollingsworth AD, Chaikin PM, Meyer WV, Reich AJ. "Phase transitions in colloids under microgravity." Presented at the American Physical Society March Meeting 2021, Virtual, March 15-19, 2021. Bulletin of the American Physical Society. 2021;Abstract: B07.00004. https://meetings.aps.org/Meeting/MAR21/Session/B07.4 , Mar-2021
Papers from Meeting Proceedings	Lei Q, Khusid B, Kondic L, Hollingsworth AD, Chaikin PM, Meyer WV, Reich AJ. "Building colloidal crystals under microgravity." Paper presented at the 10th Annual International Space Station Research and Development Conference, Virtual, August 3-5, 2021. Meeting paper ID: 130. 10th Annual International Space Station Research and Development Conference, Virtual, August 3-5, 2021. , Aug-2021