Fiscal Year:	FY 2024	**Task Last Updated:**	FY 10/02/2023
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Project Title:	Thermal Fluctuations of Colloidal Gels		
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Program/Discipline--Element/Subdiscipline:	COMPLEX FLUIDS/SOFT MATTER--Complex Fluids		
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Space Biology Special Category:	None		
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Comments:			
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Task Description:	We propose to study colloidal gels using the data from the Advanced Colloids Experiment-Microscopy-1 (ACE-M-1) experiments. Colloidal gels are formed from sticky micron-sized solid particles in a liquid, where over time the particles stick together and form random clumps that eventually bridge across the entire sample chamber in tangled networks. The ACE-M-1 data set consists of a large number of optical microscopy movies of colloidal gels. In microgravity, these gels are long-lived, rather than collapsing under their own weight as happens in ground-based experiments. Our group has expertise in analyzing microscope images, using particle tracking, particle image velocimetry, and differential dynamic microscopy. The movies reveal the gels have visible thermal fluctuations that likely reveal information about their rheological properties, local elasticity, etc. There is also some clear sense of length scales: some gels have thick aggregated regions, while others have more tenuous gel strands and free particles. We can connect structure and dynamics. We propose to analyze these movies to pull out this information, and to perform complementary ground-based experiments to validate the observations. For example, the Physical Sciences Informatics (PSI) movies are all 2D cuts through 3D samples, and we will use ground-based confocal microscopy to cross-check the samples with some 3D data sets; to confirm inferences about 3D structure from the 2D images. A particular appealing feature of the ACE-M-1 experiments is that they studied polydispersity (gels made of mixtures of two distinct particle types) and polydisperse systems are a long-time interest of the Principal Investigator (PI). We will use our ground-based experiments to study gels with higher polydispersity, which should in turn suggest new microgravity investigations in the future. This PSI investigation will be done by the Weeks lab at Emory University; there will not be any other collaborators.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	Colloids are suspensions of small solid particles suspended in a liquid. Examples include paint, ink, pastes, and blood. "Small" means the particle diameters range from ~10 nm to ~10 microns. Thermal motion is relevant: Brownian motion allows particles to diffuse. Often precautions are taken to prevent the solid particles from sticking together. If particles have attractive interactions, they can stick together in free-floating aggregates, or large tendrils that can span across the system. The latter is a colloidal gel. Colloidal gels are used in applications such as water purification, skin creams, and also show up in some food products such as jellies and jams. In food, colloidal gels modify the texture and shelf-life stability of the food. Our NASA-funded study of colloidal gels should improve our understanding of long-term stability of colloidal gels, as well as how they initially form.
Task Progress:	RESULTS FOR MICROGRAVITY DATA: The Advanced Colloids Experiment-Microscopy-1 (ACE-M-1) data set has 9 distinct experiments on 8 different samples, where the different samples are made with different levels of attractive interaction – that is, different levels of particle stickiness. Undergraduate student Swagata Datta studied the ACE-M-1 data in 2022 working with the Principal Investigator (PI) Eric Weeks. We have determined that of the 9 experiments, 4 are suitable quality to be fully analyzed. These experiments have 50-60 hours of data each. Fortunately, these four experiments include the one with the highest attractive interaction, and also the one with the lowest attractive interaction, thus spanning the entire range. The samples are composed of equal amounts of small (1.8 micron diameter) and large (2.2 micron diameter) particles. In general, these two particles species behave similarly, although results below will show behaviors of both to highlight any differences. We have learned several interesting facts about the data. First, the colloidal gel samples show aging: the dynamics slow down as a function of time. Mean square displacement curves taken from different time points in the sample show that particles diffuse slower than normal diffusion: the curves rise with lag time dt showing that particles diffuse slightly, but as dt^(0.3) rather than dt^(1.0). The dynamics are noticeably slower as the sample ages from 2 hours to 56 hours since preparation. For the non-gel sample, the mean square displacement curves taken at different time points are essentially the same, and the curves rise as dt^(1.0), indicating the particles diffuse normally rather than being stuck together. There are also structural differences between the colloidal gel samples and the non-gel sample. We can measure structural differences with the pair correlation function g(r), which measures the likelihood of finding particles a certain distance from each other. Samples with stronger attractions have higher peaks. Moreover, the peak height grows slowly over the course of the experiment for the gel samples. This relates to the slowing of the dynamics: both changes (slower dynamics, stronger peak height) indicate that particles are becoming more stuck together. This means the gel is stronger; for example, macroscopically, the sample would have a higher viscosity, or higher elastic modulus, or both. NEW GROUND-BASED EXPERIMENTS: This past year we have additionally done ground-based experiments on colloidal gels. This work is being done by graduate student Waad Paliwal, lab technician Ben Lonial, and PI Eric Weeks. Ben earned his undergraduate degree in physics (with honors) in May 2023. He is now taking a gap year, continuing work in the Weeks Lab, and focusing on the NASA project. In 2021-22, Waad made mixtures of colloids, solvent, and “depletant.” A depletant is a polymer added to the liquid which causes particles to stick together. By controlling how much depletant is added, we control how sticky the particles are. Waad and Eric then took confocal microscopy movies of these colloidal gels. Subsequently, Ben learned these techniques from Waad and Eric. In this past year (2023), Waad has investigated what can be seen in three-dimensional images of the gels (imaged using confocal microscopy) as compared to two-dimensional images. This is to help us calibrate the ACE-M-1 data, which are only 2D images. The question she (Waad) is studying in particular is to understand how 2D observations are related to 3D reality. For example, suppose initially we see in a 2D gel image that each particle is stuck to two other particles on average. Waad finds that in the 3D data, this generally means that a particle has six neighboring particles on average; that is, the measurements differ by roughly a factor of three. Unfortunately, we’re finding that this calibration factor (three) varies quite a bit from experiment to experiment, ranging from two to four. We have not found any obvious sign as to what the calibration factor will be from looking at 2D images. Thus, we cannot be certain what the calibration factor should be for the ACE-M-1 data. Additionally, Ben Lonial has begun making colloidal gels with particles with extreme size polydispersity. Our goal is to understand how the mixture of particle sizes changes the gel structure. While the ACE-M-1 data uses two different particle sizes, they are fairly similar in size (1.8 micron and 2.2 micron diameter), so we do not expect the gel structure to vary a huge amount due to these sizes. On the other hand, with the larger range of sizes in Ben’s new samples, we should be able to see differences. For example, the larger particles should have significantly larger numbers of

	neighboring particles that stick to them. We will determine how the number of attached neighbors scales with the particle size.
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