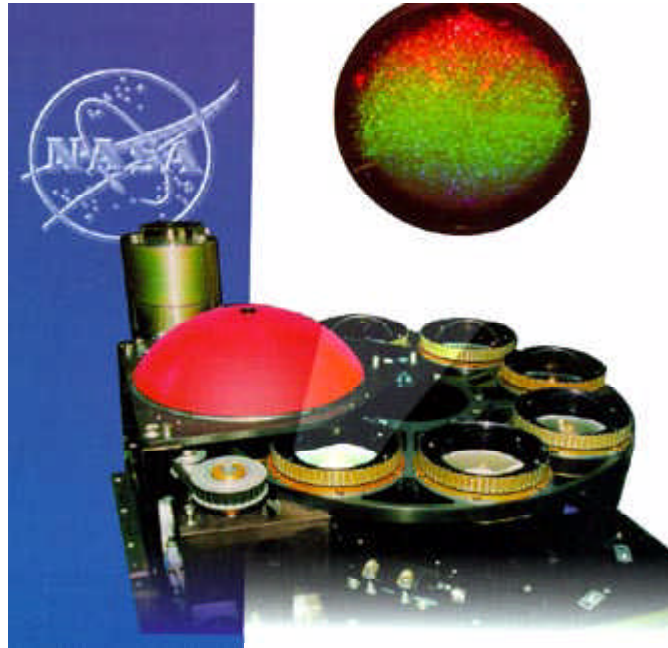


# Physics of Hard Spheres Experiment: Significant and Quantitative Findings Made



*PHaSE hardware: an interior view of the test section without walls.*

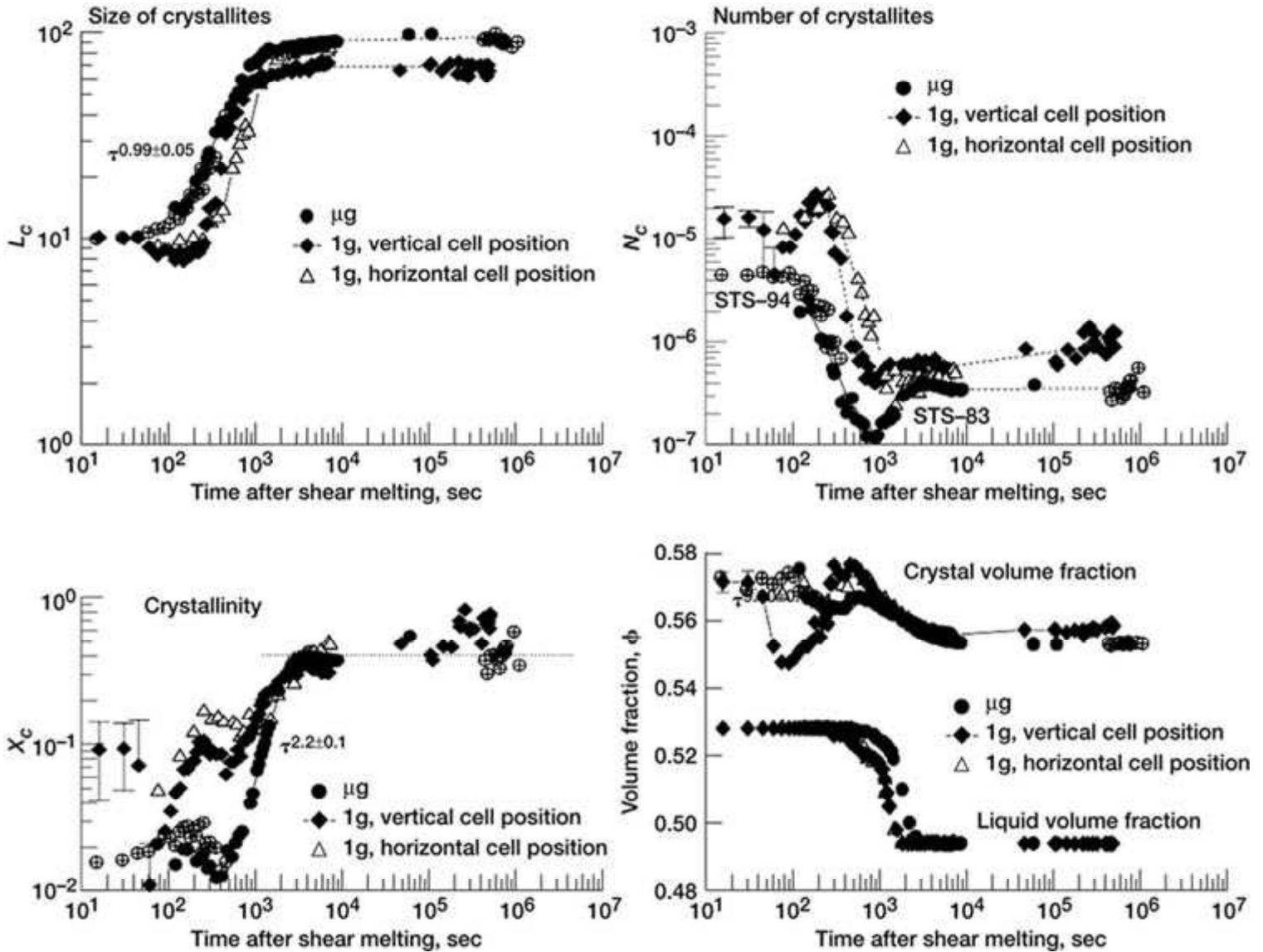
Direct examination of atomic interactions is difficult. One powerful approach to visualizing atomic interactions is to study near-index-matched colloidal dispersions of microscopic plastic spheres, which can be probed by visible light. Such spheres interact through hydrodynamic and Brownian forces, but they feel no direct force before an infinite repulsion at contact. Through the microgravity flight of the Physics of Hard Spheres Experiment (PHaSE), researchers have sought a more complete understanding of the entropically driven disorder-order transition in hard-sphere colloidal dispersions. The experiment was conceived by Professors Paul M. Chaikin and William B. Russel of Princeton University. Microgravity was required because, on Earth, index-matched colloidal dispersions often cannot be density matched, resulting in significant settling over the crystallization period. This settling makes them a poor model of the equilibrium atomic system, where the effect of gravity is truly negligible.

For this purpose, a customized light-scattering instrument was designed, built, and flown by the NASA Glenn Research Center at Lewis Field on the space shuttle (shuttle missions STS-83 and STS-94). This instrument performed both static and dynamic light scattering, with sample oscillation for determining rheological properties. Scattered light from a 532-nm laser was recorded either by a 10-bit charge-coupled discharge (CCD) camera from a concentric screen covering angles of  $0^\circ$  to  $60^\circ$  or by sensitive avalanche photodiode

detectors, which convert the photons into binary data from which two correlators compute autocorrelation functions. The sample cell was driven by a direct-current servomotor to allow sinusoidal oscillation for the measurement of rheological properties.

Significant microgravity research findings include the observation of beautiful dendritic crystals, the crystallization of a "glassy phase" sample in microgravity that did not crystallize for over 1 year in 1g (Earth's gravity), and the emergence of face-centered-cubic (FCC) crystals late in the coarsening process (as small crystallites lost particles to the slow ripening of large crystallites).

Significant quantitative findings from the microgravity experiments have been developed describing complex interactions among crystallites during the growth process, as concentration fields overlap in the surrounding disordered phase. Time-resolved Bragg scattering under microgravity captures one effect of these interactions quite conclusively for the sample at a volume fraction of 0.528. From the earliest time until the sample is almost fully crystalline, the size and overall crystallinity grow monotonically, but the number of crystallites per unit volume (number density) falls. Apparently nucleation is slower than the loss of crystallites because of the transfer of particles from small to large crystals. Thus, coarsening occurs simultaneously with growth, rather than following the completion of nucleation and growth as is generally assumed. In the same sample, an interesting signature appears in the apparent number density of crystallites and the volume fraction within the crystallites shortly before full crystallinity is reached. A brief upturn in both indicates the creation of more domains of the size of the average crystallite simultaneous with the compression of the crystallites. Only the emergence of dendritic arms offers a reasonable explanation. The arms would be "seen" by the light scattering as separate domains whose smaller radii of curvature would compress the interior phase.



Crystallization kinetics of sample 3; volume fraction, 0.528 (where  $t$ , time;  $L_c$ , average crystallite size (in particle diameters),  $X_c$ , crystalline fraction, and  $N_c$ , number density).

In fiscal year 1999, numerous papers, a doctoral dissertation, and the PHaSE final report were produced. Although this flight project has been completed, plans are in place for a follow-on colloid experiment by Chaikin and Russel that employs a light microscope within Glenn's Fluids and Combustion Facility on the International Space Station.

PHaSE is providing us with a deeper understanding of the nature of phase transitions. The knowledge derived has added to the understanding of condensed matter. In addition, the burgeoning study of the dynamics of colloidal self-assembly may lead to the development of a range of photonic materials that control the desirable properties of light. Thus, applications of ordered colloidal structures include not only ultrastructure ceramics, but also photonic crystals and photothermal nanosecond light-switching devices. Industries

dealing with semiconductors, electro-optics, ceramics, and composites stand to benefit from such advancements.

**Find out more about this research <http://exploration.grc.nasa.gov/phase/>.**

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