Advanced Colloids Experiment (ACE)

Science Overview

(ASGSR Meeting – Orlando, FL)

Friday, November 8, 2013
Crystal Room, 4:40 – 5:00 pm

Bill Meyer - presenting
(a.k.a. – William V. Meyer, Ph.D.)
BCAT and ACE NASA Project Scientist
USRA at NASA-GRC
Email: William.V.Meyer@NASA.Gov,
Tel.: (216) 433-5011
BCAT-5 Slow Growth Sample Module in a window of the International Space Station (ISS)

A 3-minute movie on BCAT-5 science follows:
Why Microscopy?

Fundamental science and colloidal engineering can be pursued and understood directly at both the macroscopic level and the microscopic level - the particle level. For example: BCAT vs. ACE.

We call the bridge between the macroscopic and microscopic theory – or understanding in theory.
Advanced Colloids Experiment (ACE)
Enabling Soft-Condensed Matter Microgravity Research
Fundamental Science and Engineering Research at the Particle Level

Advanced Colloids Experiment (ACE)
Light Microscopy Module (LMM) and the Advanced Colloids Experiment (ACE)

Fluid Integrated Rack (FIR) and Light Microscopy Module launched Aug 2009. Assembly and checkout complete January 2011. Then used for the CVB experiment.

LMM is being built-up in phases and used for colloids and biology research.
Previous ACE-1 Science Team Members (1/4)

Science Team Members:

<table>
<thead>
<tr>
<th>Key Personnel [Affiliation] / Role</th>
<th>Contact Information (Contacts listed in alphabetical order)</th>
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The investigation goals and objectives for 7 ACE science teams follow:
New York University (NYU)
ACE-1 science team

Ned Seeman
Andy Hollingsworth
Paul Chaikin
Stefano Sacanna
Dave Pine

Center for Soft Matter Research – New York University (NYU)
NYU investigation goals and objectives (1/2)

In General:
• Fundamental studies of Order, Frustration: the role of shape on structure.
• Technologies for complex processes: self-assembly, motility, toward self-replication.

In Detail:
• Ellipsoids, Cubes, DNA functionalized particles, Lock and Key particles, 2-3-4 particle clusters.
• Order-disorder phase diagrams.
• Exotic Phases - Cubatic, Rotator, Quasicrystal, Soft rotation mode glass, Colloidal polymer w & w/o branching.
• Self-assembly - Crystals designed from specific DNA mediated interactions, Assembly of dissimilar particles with Lock & Key, Swimmers as active mixers and superdepletants, Self-replication of sequenced colloidal seeds.
NYU investigation goals and objectives (2/2)

particles with shape and specific attractions
Expected results and how the expected results will advance the field

We want specificity, control and reversibility in interactions

Specific Interactions with DNA

Developing the understanding and know-how needed to get “billions” of particles to self-replicate and self-assemble in a controlled fashion.
Procter & Gamble (P&G)
ACE science team

Dr. Matt Lynch
Corporate Research Division
Procter & Gamble Company

Tom Kodger
Applied Physics
Harvard University
P&G investigation goals and objectives

Colloidal gels define the microstructure of materials, including consumer products. This often determines the product shelf life.

Polydisperse (real-world) systems are complicated and not well understood. To control these systems, an understanding of the evolution (coarsening) of microstructure is required.
Earth benefits/spin-off applications

For Procter & Gamble (P&G):

• Product shelf-life extended
• Product quality enhanced
• Production cost lowered (stabilizers are expensive)
• Transportation cost reduced (by concentrating essence)

Why this work with colloids is important: we have

• Weakly-attractive systems - phase separation
• Strongly-attractive systems - gelation or crystallization
• Frontiers of soft-squishy colloids (soft - very cool)
Advanced Colloids Experiment (ACE)-M1

Science Objective
(Decadal Survey Area Complex Fluids, FP1 and AP 5):
To remove gravitational jamming and sedimentation and then use a microscope to observe at the particle level:
• colloidal engineering (the effects of polydispersity),
• to control phase separation to improve product shelf-life and quality.

Application:
ACE-M-1 – Launch SPX-2:
• Extending product shelf-life is a multi-billion $ concern for P&G. (Lynch, P&G Principal Scientist works with NASA through a Space Act Agreement)
• Colloidal gels define the microstructure of materials, including consumer products. This often determines the product shelf life.
• Polydisperse (real-world) systems are complicated and not well-understood. To control these systems, an understanding of the evolution (coarsening) of microstructure is required.

Above: Dr. Matthew Lynch (P&G Principal Scientist), and ACE-M1 NASA Principal Investigator (PI), along with Chris Lant (ZIN-Technologies optics engineer), ground-testing the ACE-M1 hardware and software, while also testing a next generation confocal microscope for possible use in microgravity aboard the International Space Station (ISS).
Advanced Colloids Experiment-M-1 (ACE-M1)

PI: Dr. Matthew Lynch - The Procter and Gamble Company (P&G)
Co-I: Tom Kodger - Harvard

The present experiment on ISS is returning pleasant surprises. Two sizes of stabilizer particles with a size difference of 20% are behaving quite differently in microgravity. The larger particles are building scaffolding (they are product stabilizers) and the 20% smaller particles are swarming about. This is visible in 37MB movie, which is provided on jump drive to keep this document from swelling. On Earth, in normal gravity, this behavior is not evident.

Above: Single frame from short movie showing different behavior visible in microgravity for two sizes of P&G product stabilizer. Each of the two sizes has been fluorescently dyed a different color (false-colored blue and green by Co-I, who made the particles, and who is color-blind for other colors.)
10X/0.3 mosaic of S5 at 75 μm depth 5 h after mix, FITC filter, Flight GMT/274
Flight LMM 9/17/13 - S4 FITC.00001_00490

FITC, 63X oil
Flight LMM 9/17/13 - S4 TxB.00001_00990
Harvard ACE science team

David Weitz

Peter Lu
Harvard investigation goals and objectives (1/2)

- **Crystal nucleation**
  Nucleation rates orders of magnitude different from simulation
  Proper kinetics require no sedimentation

- **Binary crystallization**
  Cannot buoyancy-match two types of spheres in the same solvent

- **New material crystals**
  Photonic band-gap crystals require high refractive index (high density)

- **Phase separation beyond BCAT**
  Morphological characterization of interfaces

- **Gels in μg** (picture on next page)
New science: gels in μg

Gelation is driven by liquid-gas phase separation
Systems buoyancy-matched only at short times
Long time behavior cannot be tested on earth
Delayed collapse, aging, long-term evolution
University of Pennsylvania (U. Penn)
ACE science team

Arjun Yodh
Matthew Lohr
Matthew Gratale
U. Penn investigation goals and objectives (1/2)

- Assembly of Anisotropic Particles
- Disorder-induced Crystal-Glass Transitions
- Jamming Phenomenology

- Without temperature-sensitivity (ACE-M), use index-matched (core-shell/soft) particles at various volume fractions to map basic effects (dynamical and structural).
- With temperature-sensitivity (ACE-H), use index-matched core-shell PS/PMMA-NIPA particles to much more fully map basic effects.
Swellable Particles are Swell

- Melting in 3D, 2D, Thin Films, & quasi-1D (cylinders) (Science, 2005; PRE, 2008; PRL, 2010; PRE, 2010)
- Freezing Criteria in 2D (JCP, 2010)
- Colloidal Antiferromagnets (Nature, 2008)
- Aging in Glasses (PRL, 2009)
- Crystal-Glass Transition (PRL, 2010)
- Jamming: Shadow Systems, Phonon Density of States (PRL, 2010)
Earth benefits/spin-off applications

“The coffee ring effect is very common in everyday experience,” Yunker said. “To avoid it, scientists have gone to great lengths designing paints and inks that produce an even coating upon evaporation. We found that the effect can be eliminated simply by changing the shape of the particle.”

Peter J. Yunker, Tim Still, Matthew A. Lohr, and A. G. Yodh,

Milan / Montpellier ACE science team

Roberto Piazza

Stefano Buzzaccaro

Luca Cipelletti
Milan / Montpillier investigation goals and objectives

Birth, structure and evolution of depletion gels in $\mu$-gravity

A samples
15-32°C stable
32°-35°C gel

B samples
15°-30°C stable
30-35° gel

Black dots
(ISS experiment)

ACE – T range

Image
University of Amsterdam (UvA) and Milan ACE science team

Dr. Sandra Veen (Amsterdam)  
Dr. Marco Potenza (Milan)

Prof. Gerard Wegdam (Amsterdam)  
Prof. Peter Schall (Amsterdam)
UvA / Milan investigation goals and objectives

Study Critical Casimir effect
Use temperature control
→ Attraction on/off
→ Follow structure formation
→ “Reaction kinetics“

Vary Temperature → Vary attraction strength

Vary Rate of change → Equilibrium vs. out-of-equilibrium

Reverse Temperature → Repeat Experiment

Image in real + reciprocal space
Chungnam National University (CNU) ACE science team

Prof. Chang-Soo Lee
Department of Chemical Engineering, Chungnam National University (CNU), South Korea

Group members involved in this project
• Chang-Hyung Choi
• Jae-Min Jung
• So-Young Han
Microscopic self-assembly

1. Combination of force
2. Shape
3. Topology

Particle assembly

New Functional Materials

Novel building block
“atoms” & “molecules” of tomorrow’s materials

Ref.: Science, 306, 2004
Nature materials, 10, 2011
Microscopic self-assembly

Plan 1

Anisotropic building blocks
(Janus amphiphilie)

Hydrophobic domain
Hydrophilic domain

Programmed assembly for dimers

"Self-assembly"

Ground state

Microgravity

Low probability of assembly in the ground state
ACE-1A Workhorse wells filled with cylindrical Janus particles
Test filling Professor Lee’s samples (CNU – S. Korea)

E111122-5.2ndFill: \( \varnothing = 4\% \pm 1\% \)
Fill Notes
- 127,000 particles in 100 \( \mu \)L water
- Swirl-draw bottom
- No bubbles
- Sample well not sealed (practice fill)

E111122-6: \( \varnothing = 4\% \pm 1\% \)
Fill Notes
- 127,000 particles in 100 \( \mu \)L water
- Swirl-draw bottom
- No bubbles
- Sample well not sealed (practice fill)

Successful fill with repeatable volume fraction close to target of (2 - 4\%) and clean.
Lock-and-key two-sided (Janus) particles self-assemble in 3D in microgravity

Depicted in the adjacent composite image (on the left) are Janus particles (one of the CNU experiments), which forms unique 3-d structures in microgravity. On Earth, their configurations are confined by gravity to form 2-d structures (when the particle concentration is not so high that they stack). Janus particles are named after the Roman god with two faces. For these Janus particles, one-half of their surface is composed of hydrophilic groups and the other half of hydrophobic groups. This lays the foundation for Future ISS work that will use smaller particles to study the kinetics driving self-assembly (in the absence of sedimentation).

Prof. Chang-Soo Lee, International Space Station (ISS) data taken with ACE – August 17, 2012
Liquid Crystals of Nanoplates

Investigate the crystallization and self-assembly of disk-shaped particle suspensions, especially the ones that are highly anisotropic in shape, in microgravity and comparing the results with that in gravity.

“Discotics are very interesting systems that offer a rich spectrum of applications once the properties are well understood. A rich set of liquid crystal structures can be obtained through self-assembly of colloidal disks. Claims to be able to make disks of controlled size and aspect ratios. An excellent materials-oriented proposal.”
Kinetics of electric field-driven phase transitions in polarized colloids

Develop and conduct experiments to elucidate the fundamental microscopic mechanisms and create new strategies and predictive tools to control electrically driven processes in a suspension of interacting colloidal particles.

“This proposal takes full advantage of understanding electric-field induced colloidal assembly in a microgravity environment. The large international team is excellent, with expertise in experiment, theory, and simulation.”
Fabrication, Crystallization, and Folding of Complex Colloidal Molecules under the Influence of Applied External Fields

Fabricate colloidal molecules of prescribed composition and architecture (on ground); Determine the role of applied electric field in the assembly of achiral and chiral building blocks (on ground and at ISS); Co-assemble, by self- and directed-methods, colloidal chains and tetrameters to produce open double networks with non-linear mechanical properties (on ground and at ISS).

“An extremely creative proposal to study the self-assembly of macromolecules using colloids as molecular analogs. The investigators use anisotropic building blocks and anisotropic fields to generate structures with complex symmetries …”

David Marr
Colorado School of Mines
Understanding the Morphology and Stability of Bijels Using Microgravity

Gain a better fundamental understanding of the relationship between the microstructure, rheology, stability, and processability of bijels [bicontinuous interfacially jammed emulsion gels] through synergistic ground-based and microgravity experiments and theoretical calculations.

“Understanding the underlying mechanism for the formation of bijels could lead to a robust synthesis platform for bulk micro-structured hybrid materials. Bijel systems using particle stabilization are quite novel; it is very probable that experiments in microgravity along with ground-based experiments will lead to materials with very significant applications.”
The Effect of Macromolecular Transport on Microgravity Protein Crystallization

Compare incorporation of protein aggregates into growing protein crystals on ISS and on earth; Measure crystal growth rates in 1g versus μg for different size aggregates of proteins; compare the defect density and crystal quality via fluorescent-based atomic force microscopy and x-ray diffraction quality of crystals grown at different rates in a 1g environment.

“A highly specialized international team proposes to investigate systematically the impact of microgravity on the quality and size of protein crystals. Several characterization methods are considered. The proposal has several innovative aspects … .”
Amyloid fibril formation in microgravity: Distinguishing interfacial and flow effects

Investigate the influences of flow and fluid interfaces on the amyloid formation process. The study of protein amyloid fibrils formation also provides a model for studying biomolecular transport phenomena. Furthermore, the experiments can be performed aboard the ISS with essentially no container [using a ring sheared drop flow apparatus.] “… could have a high impact on the understanding of neurodegenerative diseases such as Alzheimer’s and Parkinson’s. Expertise in both theory and experiments as well as strong preliminary data suggest the proposed work will be successful. …”
Growth Rate Dispersion as a Predictive Indicator for Biological Crystal Samples Where Quality Can be Improved with Microgravity Growth

Test the hypothesis that the presence of growth rate dispersion in macromolecular crystals grown on the ground is an indicator of crystals that can be improved when grown in microgravity.

“Aims to perform a systematic investigation of the effect of growth rate dispersion on crystal quality, with the goal of predicting which proteins may benefit from microgravity crystallization. …”
Solution convection and the nucleation precursors in protein crystallization

Explore the effects of a hitherto unstudied factor for the nucleation of protein crystals: solution shear flow: Test if shear flow affects the concentration and properties of the nucleation precursors and establish the mechanisms of these effects; Test if shear flow assists nucleation inside the dense liquid clusters; Test if the perfection of protein crystals can be improved by controlling nucleation via solution flow.

“Address nucleation and the role of solution flow on the process of nucleation, a key problem in protein crystallization. …”
CARA/Petri Plant use of the LMM to see the expression of fluorescent tags.

Anna-Lisa Paul and Rob Ferl
U. of Florida

Fluorescent image of Arabidopsis (stem) taken during LMM ground-testing for CARA/Petri Plant demonstration planned for the SpaceX-3 mission.
• Space Biology NRA (2014, 2015, 2016 …)  
  Research Opportunities in Space Biology.
• The ILSRA is untitled as of yet…. But it’s the solicitation that falls under: International Space Life Science Working Group (ISLSWG)-- Space Life Sciences. We anticipate this to be out in 2014.

David L. Tomko, Ph.D., Program Executive  
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Space Life and Physical Sciences Research Division  
NASA Headquarters - Room 7L85  
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Several teams of international partners are planning experiments using the Light Microscopy Module (LMM) for colloids research on the International Space Station (ISS).

For more information regarding these international collaborations with NASA, please contact:

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