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
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>
</tr>
</thead>
</table>
| **Prof. Paul Chaikin**  
[NASA Team: NYU]  
PI / Provide flight samples, science requirements, and data analysis | Professor of Physics, Department of Physics  
New York University, 607 Meyer Hall  
4 Washington Place at Broadway; New York, NY 10003  
Tel: 212-998-7694; Fax: 212-995-4016; chaikin@nyu.edu |
| **Dr. Andrew Hollingsworth**  
[NASA Team: NYU]  
Co-I / Provide flight samples, science requirements, and data analysis | Research Scientist, Department of Physics  
New York University  
4 Washington Place - Office 826; New York, NY 10003  
Tel: 212-998-8428; andrewdh@nyu.edu |
| **Prof. David Pine**  
[NASA Team: NYU]  
Co-I / Provide flight samples, science requirements, and data analysis | Professor of Physics, Department of Physics  
New York University, 601 Meyer Hall  
4 Washington Place at Broadway; New York, NY 10003  
Tel: 212-998-7744; Fax: 212-995-4016; Pine@nyu.edu |
| **Dr. Stefano Sacanna**  
[NASA Team: NYU]  
Co-I / Provide flight samples, science requirements, and data analysis | Research Scientist, Department of Physics  
New York University  
4 Washington Place - Office 826; New York, NY 10003  
Tel: 212-998-8480; S.Sacanna@nyu.edu |
| **Prof. Nadrian (Ned) Seeman**  
[NASA Team: NYU]  
Co-I / Provide flight samples, science requirements, and data analysis | Professor of Chemistry, Department of Chemistry  
New York University  
New York, NY 10003  
Tel: 212-998-8395; Ned.Seeman@nyu.edu |
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#### Science Team Members (continued):

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<tr>
<td><strong>Dr. Matthew Lynch</strong>&lt;br&gt;[NASA Team:  P &amp; G]&lt;br&gt;PI / Provide flight samples, science requirements, and data analysis</td>
<td>Principal Scientist, Colloid and Surfactant Laboratory&lt;br&gt;Procter &amp; Gamble Company&lt;br&gt;Beckett Ridge Technical Center 8256 Union Centre Boulevard, West Chester, OH  45069&lt;br&gt;Tel: (513) 634-9644; Fax: (513) 634-9944; <a href="mailto:lynch.ml@pg.com">lynch.ml@pg.com</a></td>
</tr>
<tr>
<td><strong>Thomas Kodger</strong>&lt;br&gt;[NASA Team:  P &amp; G and Harvard]&lt;br&gt;Co-I / Provide flight samples, science requirements, and data analysis</td>
<td>Research Scientist, Department of Physics&lt;br&gt;Harvard University, McKay 517&lt;br&gt;17 Oxford Street; Cambridge, MA 02138&lt;br&gt;Tel: 617-460-7659; <a href="mailto:tkodger@fas.harvard.edu">tkodger@fas.harvard.edu</a></td>
</tr>
<tr>
<td><strong>Prof. David Weitz</strong>&lt;br&gt;[NASA Team:  Harvard]&lt;br&gt;PI / Provide flight samples, science requirements, and data analysis</td>
<td>Mallinckrodt Professor of Physics and of Applied Physics, Department of Physics&lt;br&gt;Harvard University, Pierce 231&lt;br&gt;29 Concord Street; Cambridge, MA 02138&lt;br&gt;Tel: 617-496-2842; <a href="mailto:weitz@physics.harvard.edu">weitz@physics.harvard.edu</a></td>
</tr>
<tr>
<td><strong>Dr. Peter Lu</strong>&lt;br&gt;[NASA Team:  Harvard]&lt;br&gt;Co-I / Provide flight samples, science requirements, and data analysis</td>
<td>Research Scientist, Department of Physics&lt;br&gt;Harvard University, McKay 517&lt;br&gt;17 Oxford Street; Cambridge, MA 02138&lt;br&gt;Tel: 216-337-4981; <a href="mailto:plu@fas.harvard.edu">plu@fas.harvard.edu</a></td>
</tr>
<tr>
<td><strong>Prof. Arjun Yodh</strong>&lt;br&gt;[NASA Team:  U. Penn]&lt;br&gt;PI / Provide flight samples, science requirements, and data analysis</td>
<td>James M. Skinner Professor of Science&lt;br&gt;Director, Laboratory for Research on the Structure of Matter Department of Physics and Astronomy&lt;br&gt;University of Pennsylvania; Philadelphia, PA 19104-6396&lt;br&gt;Tel: 215-898-6354; Fax: 215-898-2010; <a href="mailto:yodh@physics.upenn.edu">yodh@physics.upenn.edu</a></td>
</tr>
<tr>
<td><strong>Dr. Peter Yunker</strong>&lt;br&gt;[NASA Team:  U. Penn]&lt;br&gt;Co-I / Provide flight samples, science requirements, and data analysis</td>
<td>Research Scientist, Department of Physics &amp; Astronomy&lt;br&gt;University of Pennsylvania&lt;br&gt;Philadelphia, PA 19104-6396&lt;br&gt;Tel: 832-545-8561; <a href="mailto:peter.yunker@gmail.com">peter.yunker@gmail.com</a></td>
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<td><strong>Prof. Roberto Piazza</strong>&lt;br&gt;[ESA Team: Milan and Montpellier]&lt;br&gt;Co-PI / Provide flight samples, science requirements, and data analysis</td>
<td>Professor of Condensed Matter Physics&lt;br&gt;Politecnico di Milano Dipartimento di Ingegneria Nucleare&lt;br&gt;Ponzio 34/3 - 20133 MILANO&lt;br&gt;Tel: +39-02-2399-6386; Fax: +39-02-2399-6309; <a href="mailto:roberto.piazza@polimi.it">roberto.piazza@polimi.it</a></td>
</tr>
<tr>
<td><strong>Dr. Stefano Buzzaccaro</strong>&lt;br&gt;[ESA Team: Milan and Montpellier]&lt;br&gt;Co-PI / Provide flight samples, science requirements, and data analysis</td>
<td>Professor, Dipartimento di Chimica, Materiali e Ingegneria Chimica&lt;br&gt;Politecnico di Milano - Sede Ponzio&lt;br&gt;Edificio Ce.S.N.E.F. - Soft Condensed Matter Lab&lt;br&gt;via Ponzio 34/3, 20133 MILANO (Italy)&lt;br&gt;Tel: +39-0223996361/6337; Fax +39-0223996309; <a href="mailto:stefano.buzzaccaro@mail.polimi.it">stefano.buzzaccaro@mail.polimi.it</a></td>
</tr>
<tr>
<td><strong>Prof. Luca Cipelletti</strong>&lt;br&gt;[ESA Team: Milan and Montpellier]&lt;br&gt;Co-PI / Provide flight samples, science requirements, and data analysis</td>
<td>Professor, Laboratoire des Colloïdes&lt;br&gt;Verres et Nanomatériaux (UMR CNRS-UM2 5587),&lt;br&gt;CC26, Université Montpellier 2, 34095 Montpellier Cedex 5, France&lt;br&gt;Tel: +33 4 67 1 435 88; <a href="mailto:luca.cipelletti@univ-montp2.fr">luca.cipelletti@univ-montp2.fr</a></td>
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<tr>
<td><strong>Prof. Peter Schall</strong></td>
<td>Professor of Physics, <em>Van der Waals-Zeeman Institute</em></td>
</tr>
<tr>
<td>[ESA Team: UvA and Milan]</td>
<td>Universiteit van Amsterdam, Science Park 904, C2 Room 228</td>
</tr>
<tr>
<td>Co-PI / Provide flight samples,</td>
<td>1098 XH Amsterdam, The Netherlands</td>
</tr>
<tr>
<td>science requirements, and data</td>
<td>Tel: +31-20-525-6314; Fax: +31-20-525-5788; <a href="mailto:ps@peterschall.de">ps@peterschall.de</a></td>
</tr>
<tr>
<td>analysis</td>
<td></td>
</tr>
<tr>
<td><strong>Dr. Marco A. C. Potenza</strong></td>
<td>Research Scientist, Dipartimento di Fisica</td>
</tr>
<tr>
<td>[ESA Team: UvA and Milan]</td>
<td>Università di Milano and INFM,</td>
</tr>
<tr>
<td>Co-PI / Provide flight samples,</td>
<td>Via Celoria, 16, Milano I-20133, Italy</td>
</tr>
<tr>
<td>science requirements, and data</td>
<td>Tel: +39-02-503 17209 - v. Celoria, 16; Fax: +39-02-503-17712; <a href="mailto:marco.potenza@unimi.it">marco.potenza@unimi.it</a></td>
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<td><strong>Dr. Sandra Veen</strong></td>
<td>Research Scientist, <em>Van der Waals-Zeeman Institute</em></td>
</tr>
<tr>
<td>[ESA Team: UvA and Milan]</td>
<td>Universiteit van Amsterdam, Science Park 904, C4 Room 226</td>
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<td>Co-PI / Provide flight samples,</td>
<td>1098 XH Amsterdam, The Netherlands</td>
</tr>
<tr>
<td>science requirements, and data</td>
<td>Tel: +31-20-525-5966; Fax: +31-20-525-5788; <a href="mailto:sj.veen@uva.nl">sj.veen@uva.nl</a></td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td><strong>Prof. Gerard Wegdam</strong></td>
<td>Professor of Physics, <em>Van der Waals-Zeeman Institute</em></td>
</tr>
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<td>[ESA Team: UvA and Milan]</td>
<td>Universiteit van Amsterdam, Science Park 904, C4 Room 239</td>
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<td>Co-PI / Provide flight samples,</td>
<td>1098 XH Amsterdam, The Netherlands</td>
</tr>
<tr>
<td>science requirements, and data</td>
<td>Tel: +31-20-525-6313; Fax: +31-20-525-5788; <a href="mailto:g.h.wegdam@uva.nl">g.h.wegdam@uva.nl</a></td>
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<tr>
<td><strong>Prof. Chang-Soo Lee</strong></td>
<td>Professor of Chemical Eng., Department of Chemical Engineering</td>
</tr>
<tr>
<td>[S. Korean Team: CNU]</td>
<td>School of Engineering, 1-258</td>
</tr>
<tr>
<td>PI / Provide flight samples,</td>
<td>Chungnam National University</td>
</tr>
<tr>
<td>science requirements, and data</td>
<td>Daejeon, Korea</td>
</tr>
<tr>
<td>analysis</td>
<td>Tel: 82-42-821-5896; <a href="mailto:rhadum@cnu.ac.kr">rhadum@cnu.ac.kr</a></td>
</tr>
</tbody>
</table>
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

Cubes

Ellipsoids

DNA mediated seeds

Pacmen

Tetra clusters
Expected results and how the expected results will advance the field

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

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)

P&G spent 2 plus years with LANL and UCSB with high-powered computers to model this behavior ... no luck!

Dr. Matt Lynch
Principal Scientist
Corporate Research Division
Procter & Gamble Company
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 and understand what happens 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).
ACE-M-1

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
FITC, 63X oil

Flight LMM 9/17/13 - S4 FITC.00001_00490
Flight LMM 9/17/13 - S4 TxR.00001_00990

TxR, 63X oil
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.
U. Penn investigation goals and objectives (2/2)

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)
“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 μ-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
CNU investigation goals and objectives

**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

“Sedimentation”

Ground state

Low probability of assembly in the ground state

Microgravity

“Self-assembly”
ACE-1A Workhorse wells filled with cylindrical Janus particles
Test filling Professor Lee’s samples (CNU – S. Korea)

Successful fill with repeatable volume fraction close to target of (2 - 4%) and clean.

E111122-5.2ndFill: $\phi = 4\% \pm 1\%$

- 127,000 particles in 100 \mu L water
- Swirl-draw bottom
- No bubbles
- Sample well not sealed (practice fill)

E111122-6: $\phi = 4\% \pm 1\%$

- 127,000 particles in 100 \mu L water
- Swirl-draw bottom
- No bubbles
- Sample well not sealed (practice fill)
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.”

Zhengdong Cheng
Texas Engineering Experiment Station
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.”

Boris Khusid
New Jersey Institute of Technology (NJIT)
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.”

Ali Mohraz
University of California – Irvine (UCI)
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.
• 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
Human Research Program and Space Biology
Space Life and Physical Sciences Research Division
NASA Headquarters - Room 7L85
300 E Street SW
Washington, D.C. 20546-0001

Phone: 202-358-2211
FAX: 202-358-3091
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:

Dr. Francis Chiaramonte  
NASA Headquarters 2M14  
Washington DC  20546-00001  
Email: Francis.P.Chiaramonte@NASA.Gov  
Tel.: (202) 358-0693