NASA Physical Sciences Overview
Presentation to:
Committee on Biological and Physical Sciences in Space
The National Academies Keck Center
500 Fifth Street, NW, Washington, DC
Conference Room 208
October 7-8, 2014

Francis Chiaramonte,
Program Executive for Physical Sciences
SLPS Gravity-Dependent Physical Sciences Research

**Biophysics**
- Biological macromolecules
- Biomaterials
- Biological physics
- Fluids for Biology

**Materials Science**
- Metals
- Semiconductors
- Polymers
- Glasses, Ceramics
- Granular Materials
- Composites
- Organics

**Combustion Science**
- Spacecraft fire safety
- Droplets
- Gaseous – Premixed and Non-Premixed
- Solid Fuels
- Supercritical reacting fluids

**Fluid Physics**
- Adiabatic two-phase flow
- Boiling, Condensation
- Capillary Flow
- Interfacial phenomena
- Cryogenics

**Complex Fluids**
- Colloids
- Liquid crystals
- Foams
- Gels
- Granular flows

**Fundamental Physics**
- Space Optical/Atomic Clocks
- Quantum test of Equivalence Principle
- Cold atom physics
- Critical point phenomena
- Dusty plasmas
ISS Facilities for Physical Sciences Research

Astronaut Mike Fincke completing install of the CIR/MDCA insert prior to CIR activation in January 2009.

Astronaut Frank DeWinne completing installation in the MSRR prior to on-orbit commissioning October 2009.

Astronaut Paolo Nespoli operating the ACE experiment in the FIR/LMM.

Increment 26 commander Scott Kelly installing CCF in the Microgravity Science Glovebox on ISS.

Astronaut Cady Coleman operating the CFE experiment in Maintenance Work Area on the ISS.

DECLIC installed in an EXPRESS Rack on board ISS.
New ISS Facility: Material Science Laboratory
Electromagnetic Levitator (MSL-EML)

• The MSL-EML is the result of cooperation between ESA and DLR; is on the ISS being installed in the ESA Columbus laboratory. MSL-EML is a multi-user facility for the melting and solidification of conductive metals, alloys, or semiconductors, in ultra-high vacuum, or in high-purity gaseous atmospheres. This is especially important for reactive materials, whose properties can be very sensitive to contamination. The heating and positioning of the sample are accomplished using electromagnetic fields generated by a coil system. Melting and solidification can both take place without containers, thanks to the 0 g environment.

• The facility will contain an Experiment Unit (EU) that can accept different Experiment Inserts (EI). The Experiment Carrier will provide all necessary services to the EU.
NRA’s
Physical Sciences: how the program was rebuilt since 2005 (ESAS) – NRA history

- 2008 Fluid Physics (Two Phase Flow and Heat Transfer)
  - 5 flight and 9 ground selections
- 2009 Combustion Science (Materials Flammability)
  - 6 flight selections
- 2009 ESA AO (Materials Science)
  - 3 flight selections
- 2010 Materials Science (Directional solidification in MSL)
  - 7 flight selections
- 2011 Fundamental Physics (Atomic Clock with ESA)
  - 6 flight selections
- 2012 Complex Fluids and Biophysics (LMM -Colloids and Macromolecular)
  - 8 flight selections
- 2012 JAXA AO (Materials (ESL) and Combustion)
  - 2 flight selections
- 2013 Fundamental Physics (CAL)
  - 5 flight and 2 ground selections
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Physical Sciences – Traditional NRA’s

- 2016 Fundamental Physics NRA (CAL -2)
  - selections TBD
Physical Sciences – Open Science NRA’s

- 2015 Complex Fluids or Fluid Physics
  - 3 selections
- 2016 Materials Science
  - 5 selections
- 2016 Fluids Physics or Combustion Science
  - 3 selections
- 2018 Fluid Physics or Combustion Science
  - 3 selections

- Ground Based - Accessing Physical Sciences Informatics System
  - Semi-Annual NRA will solicit ground based physical science research to address high priority recommendations of Decadal Survey, and maximize ISS use. Small grant awards about 50 -75k.
  - All six Theme areas: Biophysics, Combustion Science, Complex Fluids, Fluid Physics, Fundamental Physics and Materials Science
  - NRA’s to start in 2015 depending on funding availability
International Cooperation: NASA Physical Sciences Research

• Multilateral Engagement: International Microgravity Strategic Planning Group (IMSPG)
  – Coordinate the development and use of ISS research among microgravity research programs in areas of common interest to maximize the productivity of microgravity research internationally.
  – Meets once a year on the margins of the annual meeting of the American Society for Gravitational and Space-Research
  – Members: ASI, CNES, CSA, ESA, DLR, JAXA, NASA and Roscosmos
  – Priority Areas for International Coordination Include:
    • All disciplines within Physical Sciences
    • Sharing facilities, experiment-specific hardware, data, etc.
Benefits of International Cooperation on ISS Research

- The ISS laboratory has reached a mature configuration including many unique research facilities provided by each International Partner.
- To maximize the utilization of these facilities, the partners are pursuing cooperative arrangements where partners perform investigations in each other’s facilities and utilize each others on-orbit (and ground) resources.
- Benefits:
  - Allows access to more researchers from more countries
  - Fosters cooperative research objectives between partners
  - Allows complementary research to be performed in multiple facilities
  - Facilitates wide distribution of research data
  - Avoids duplication of facilities/capabilities in the severely limited volume of the ISS
  - Reduces crew training and operations planning by re-using existing facilities/capabilities
  - Reduces overall cost of research
  - Maximizes the return on investment for each facility
International Cooperation:
NASA Physical Sciences Research

• Bilateral Engagement: NASA works directly with other space agencies or research institutions - especially the ISS partner agencies (examples):
  – ESA: Collaborative research in the ESA Material Science Laboratory (MSL) furnaces using ESA-developed cartridges and supporting development of NASA cartridges, Electro Magnetic Levitation (EML) facility and Microwave Ground link stations for the Atomic Clock Ensemble in Space Experiment. (common and unilateral objectives)
  – ASI: Collaboration to study Biofuels using the NASA Combustion Integrated Rack
  – CNES: Joint use of a CNES DECLIC hardware for joint investigations in fluid physics and/or solidification of transparent materials.
  – JAXA: Cooperation on the combustion of fuel droplets using NASA’s Combustion Integrated Rack (CIR) and JAXA’s Group Combustion Experiment Module (GCEM) hardware to perform experiments (common and unilateral objectives).
  – Russia: OASIS – Scientists’ protocol and ISS Program protocol – study the unique behavior of liquid crystals in microgravity using the NASA Microgravity Sciences Glovebox
## NASA’s International Cooperation in Physical Sciences on ISS

<table>
<thead>
<tr>
<th>Theme</th>
<th>Acronym</th>
<th>Experiment</th>
<th>International Partners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biophysics</td>
<td>PROTEIN</td>
<td>Protein Nucleation and Growth Kinetics Experiment (Vekilov)</td>
<td>ESA</td>
</tr>
<tr>
<td></td>
<td>Nano Step-2</td>
<td>Solution Crystallization Observation Facility, (SCOF), Suzuki, (V)</td>
<td>JAXA, CSA, ROS, COS, MOS, CNES, DLR, ASI, KARI</td>
</tr>
<tr>
<td></td>
<td>MMB-MB1</td>
<td>Effect of Macromolecular Transport on Protein Crystallization (D)</td>
<td></td>
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<tr>
<td></td>
<td>MMB-MB2</td>
<td>Solution Convection and Nucleation Precursors in Protein Crystallization (V)</td>
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<tr>
<td></td>
<td>MMB-MB3</td>
<td>Growth Rate Dispersion of Biological Crystal Samples (S)</td>
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<td></td>
<td>RSD</td>
<td>Ring Sheared Drop - Amyloid Fibril Formation in Microgravity (Hirsa)</td>
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</tbody>
</table>

**Blue Print:** Experiment Acronyms in Blue are Sponsored by non-NASA Agency

| S: Sponsor | P: Participant |
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<tbody>
<tr>
<td>Combustion Science</td>
<td>SOFIE</td>
<td>Solid FLAmability of Materials Experiment</td>
<td>JAXA</td>
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<tr>
<td></td>
<td>BASS-2</td>
<td>Burning and Suppression of Solids</td>
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<td></td>
<td>FLEX-2</td>
<td>Flame Extinguishment Experiment–2</td>
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<td></td>
<td>FLEX-2J</td>
<td>Flame Extinguishment experiment– with JAXA</td>
<td>P</td>
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<tr>
<td></td>
<td>SCE</td>
<td>Solid Combustion Expt. - 2012 JAXA AO, Fujita, Olsen..(2015, MSPR)</td>
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<tr>
<td></td>
<td>GCE</td>
<td>Group Combustion Experiment - 2D droplet array</td>
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<td></td>
<td>FLEX-ICE</td>
<td>Flame Extinguishment experiment–Italian Combustion Experiment</td>
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<tr>
<td></td>
<td>ACME</td>
<td>Advanced Combustion via Microgravity Experiments (Gaseous)</td>
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<tr>
<td></td>
<td>SCWO</td>
<td>Super Critical Water Oxidation</td>
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<td></td>
<td>SCWM</td>
<td>Super Critical Salt Water Mixture Experiment</td>
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<tbody>
<tr>
<td>Complex Fluids</td>
<td>ACE (9 teams)</td>
<td>Advanced Colloids Experiment</td>
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<td></td>
<td>COLLOID</td>
<td>Colloidal Solids Experiment</td>
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<td>PASTA-LIFT</td>
<td>PArticle STAbilized Emulsions and Foams–Liquid Film Tensiometer</td>
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<td></td>
<td>Soft Matter Dynamics (formerly FOAM-C)</td>
<td>Foam Optics and Mechanics–Coarsening</td>
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<td>BCAT-C1</td>
<td>Binary Colloidal Alloy Test–Canada 1</td>
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<td></td>
<td>LCN</td>
<td>Liquid Crystal Nanoplates</td>
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<tr>
<td></td>
<td>InSPACE-3+</td>
<td>Investigating the Structure of Paramagnetic Aggregates From Colloidal Emulsions-3+</td>
<td>P</td>
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<td></td>
<td>OASIS</td>
<td>Observation and Analysis of Smectic Islands in Space</td>
<td>P</td>
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<tr>
<td></td>
<td>VIPGRAN (COMPGRAN)</td>
<td>Compaction and Sound Transmission in Dense Granular Media</td>
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<td>ESA</td>
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<tr>
<td>Fluid Physics</td>
<td>FBCE</td>
<td>Flow Boiling and Condensation Experiment</td>
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<td>RUBI</td>
<td>Reference mUltiscale Boiling Investigation</td>
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<td></td>
<td>MFHT</td>
<td>Multiphase Flow with Heat Transfer using Thermal Platform</td>
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<td>ZBOT</td>
<td>Zero Boiloff Tank Experiment</td>
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<td>ZBOT-2</td>
<td>Zero Boiloff Tank Experiment - 2</td>
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<td>ZBOT-3</td>
<td>Zero Boiloff Tank Experiment - 3</td>
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<td>CCF</td>
<td>Capillary Channel Flow</td>
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<td>CFE-2</td>
<td>Capillary Flow Experiment–2</td>
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<td>DOLFIN II</td>
<td>Dynamics of Liquid Film/ Complex Wall Interaction</td>
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<td>CVB-2</td>
<td>Constrained Vapor Bubble–2</td>
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<td></td>
<td>EHD</td>
<td>Electro-HydroDynamic flow</td>
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<td>PBRE</td>
<td>Packed Bed Reactor Experiment</td>
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<td>TPFSE (2 teams)</td>
<td>Two Phase Flow Separator Experiment</td>
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<td>JEREMI</td>
<td>JAXA Marangoni Flow Experiment (Narayanan, Kamotani)</td>
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<td></td>
<td>VIPIL-Faraday (Planned)</td>
<td>ESA Vibration in Liquids experiment, planning stages (Narayanan)</td>
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### NASAs’s International Cooperation in Physical Sciences on ISS

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<td></td>
<td>ESA</td>
</tr>
<tr>
<td><strong>Fundamental Physics</strong></td>
<td><strong>ACES</strong> (5 teams)</td>
<td>Atomic Clock Ensemble in Space</td>
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<td></td>
<td><strong>SOC</strong> (planned)</td>
<td>Space Optical Clock</td>
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<td></td>
<td><strong>CAL</strong> (5 teams)</td>
<td>Cold Atom Laboratory</td>
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<td><strong>CAL -2</strong></td>
<td>Cold Atom Laboratory - 2</td>
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<td></td>
<td><strong>QTEST</strong> (planned)</td>
<td>Quantum Weak Equivalence Principle</td>
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<td><strong>PK-4</strong></td>
<td>Plasma Kristall–4</td>
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<td><strong>PLASMALAB</strong> (planned)</td>
<td>Kinetic studies of strongly coupled systems: Interdisciplinary Research with Complex Plasmas</td>
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<td></td>
<td><strong>ALI-R</strong></td>
<td>Alice Like Insert - reflight</td>
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<tr>
<td>Materials Science</td>
<td>CSLM-4</td>
<td>Coarsening of Dendritic Solid-Liquid Mixtures-4</td>
<td>ESA</td>
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<td>DSI-R/SPADES</td>
<td>Spatiotemporal Evolution of Three-Dimensional Dendritic Array Structures</td>
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<td>MICAST</td>
<td>Microstructure Formation in Castings</td>
<td>ESA</td>
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<td></td>
<td>CET</td>
<td>Columnar to Equiaxed Transition in Solidification Processing</td>
<td>ESA</td>
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<td></td>
<td>SETA</td>
<td>Solidification along an Eutectic path in Ternary Alloys</td>
<td>ESA</td>
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<td></td>
<td>METCOMP</td>
<td>Metastable solidification of Composites</td>
<td>ESA</td>
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<td>SISSI</td>
<td>Silicon ISS Investigation</td>
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<td></td>
<td>CET</td>
<td>Columnar to Equiaxed Transition</td>
<td>ESA</td>
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<tr>
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<td>ICEAGE</td>
<td>Influence of Containment on the Growth of Silicon Germanium</td>
<td>ESA</td>
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<td>CGTS (CdTe)</td>
<td>Crystal Growth of Ternary Compound Semiconductors</td>
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<td></td>
<td>GEDS</td>
<td>Gravitational Effects in Distortion in Sintering</td>
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<tr>
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<td>FAMIS</td>
<td>Formation of Amorphous Metallics In Space</td>
<td>ESA</td>
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<tr>
<td></td>
<td>FOG</td>
<td>Formation of Gasarities</td>
<td>ESA</td>
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<tr>
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<td>THERMOLAB</td>
<td>Thermophysical Properties of Liquid Metallic Alloys</td>
<td>ESA</td>
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<tr>
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<td>ICOPROSOL</td>
<td>Thermophysical properties and solidification behavior of undercooled Ti-Zr-Ni liquids showing in icosahedral short-range order</td>
<td>ESA</td>
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<tr>
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<td>PARSEC</td>
<td>Peritectic Alloy Rapid Solidification with Electromagnetic Convection</td>
<td>ESA</td>
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Objective

- Physical Science Informatics system implements Office of Science and Technology Policy (OSTP) memorandum, Feb. 22, 2013 entitled “Increasing Access to the Results of Federally Funded Scientific Research” by enabling multiple researchers simultaneous, open-science, access to synergistically build upon ISS data.

- Maximize the value of this important data by mass disseminating past, current, and future ISS physical science data to the broad science, engineering, and STEM community including industry, academia, and government.

- Accelerate from ideas to state-of-the-art of physical sciences research and to products, publications, and patents.
Open Science Examples

• Data science: A new emerging field with the goal of “extracting meaning from data and creating data products”. [definition courtesy of Wikipedia.]
• Has emerged as a new field to glean knowledge and new understanding from the large volume and diversity of data being published or available and accessible on the internet.
• Examples:

• Tracking Hurricane Sandy: Barometric pressure data from local weather stations, available on-line, accurately track the storm’s path.

• Human behavior researchers using Google n-gram database (data from Project Gutenberg) found evidence for distinct historical periods of positive and negative moods in 20th century books.
1. Science Definition Team to plan and oversee scientific requirements

2. NASA develops hardware, performs all associated science activities, and manages payload integration and operations

3. ISS flight experiment operations

4. Digital Data downlink and sample return for analysis

5. Physical Science Informatics System

Flight Experiments

NRA to perform ground research based on data in informatics

Non-NRA Outside Data Users

CASIS

New scientific insight and publications

• Open Science Concept
Fully utilize ISS as national laboratory to conduct microgravity materials science and disseminate data into open source informatics, to accelerate revelation of materials science mysteries, develop engineering need-driven higher-performing materials for NASA and the nation, and enhance STEM education.

- Access to global science/engineering community
- Simultaneous rapid multiplicative investigations
- Break-through scientific advance of real value
- World-wide STEM education opportunity
- Low cost and high-throughput research
- Use of existing facilities as much as possible
- Minimum Astronaut intervention and time
- Visible, applicable, and high return on investment
- Industry-driven engineering fulfillment
- Potential of discovering higher-performing material
“MaterialsLab”
A New Generation of Materials Science Experiments onboard ISS

**Purpose:** Engineers & scientists identify most promising engineering-driven ISS materials science experiments

**Goal:** Seek needed higher-performing materials by understanding materials behavior in microgravity

**Open Science and Informatics:** Inspire new areas of research, enhance discovery and multiply innovation

**Partners:**
- Industry
- Academic institutions
- DOD
- Other Government agencies
- International partners
- NASA
- CASIS
NASA will host the **MaterialsLab Workshop, April 15-16, 2014**, in the Washington, D.C., area (Hilton Crystal City Hotel, Arlington, Va).

**Purpose:** The workshop participants will advise NASA on future research directions for the microgravity materials science program. Facilitating the future research directions, is a new *Physical Science (PS) Informatics System* that will provide global access to all past, present and future ISS PS experimental data. This will promote an open science approach to scientific data analysis and become a gateway to hundreds of new ISS-based scientific investigations that will define the next generation of ISS experiments. The subsequent multiplication of investigators with data access will greatly enhance discovery and innovation.

**Theme areas:** metals, semiconductors, polymers, biomaterials, nano-materials, glasses, ceramics, granular materials, organics and composites.

- Participants: Academia, Industry and Government Agencies
- Websites for the materialsLAB Workshop:
  - Request for Information:  [http://tinyurl.com/mrhxt9g](http://tinyurl.com/mrhxt9g)
NASA MaterialsLab Workshop - Six Disciplines

- **Biomaterials**
  Chairs: Ulrike Wegst (Dartmouth College), Dongbo Wang (NIST); NASA facilitator: Sridhar Gorti

- **Glasses and Ceramics**
  Chairs: Steve Martin (Iowa State University), Edwin Ethridge (Southern Research Association), Richard Weber (Materials Development); NASA facilitator: Jan Rogers

- **Granular Materials**
  Chairs: David Frost (Georgia Institute of Technology), Mustafa Alsaleh (Caterpillar); NASA facilitator: Patton Downey

- **Metals**
  Chairs: Reza Abbaschian (University of California, Riverside), Bob McCormick (Power Systems Manufacturing), Richard Ricker (NIST); NASA facilitators: Peter Curreri, Richard Grugel

- **Polymers and Organics**
  Chairs: Bruce Chase (University of Delaware/DuPont), Eric Lin (NIST), Mike Snyder (Made in Space); NASA facilitator: Bilyar Bhat

- **Semiconductors**
  Chairs: N. B. Singh (University of Maryland, Baltimore County), Sudhir Trivedi (Brimrose); NASA facilitator: Martin Volz

(Composites and Nanomaterials topics discussed within appropriate sessions)
# Summary Table for Metals

<table>
<thead>
<tr>
<th>Rank</th>
<th>Experiment Topic/Concept Title</th>
<th>Objective</th>
<th>Scientific/Technical Merit</th>
<th>Microgravity Justification</th>
<th>Terrestrial Applications</th>
<th>Benefits to NASA</th>
<th>Significance/Impact</th>
<th>Research Partners (If Known)</th>
<th>Facilities (New or Existing)</th>
<th>Remarks</th>
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</thead>
<tbody>
<tr>
<td>#1 High Priority</td>
<td>Understand the microstructure and morphological development of dendritic array growth</td>
<td>To gather benchmark data for quantifying fundamental aspects (MGI)</td>
<td>Correlate process parameters with microstructure development</td>
<td>Isolate/eliminate thermosolutal convection and enable structure formation and minimize defects</td>
<td>Foundry/forming processes (e.g. Turbine Blades, Vanes, Aero Structures)</td>
<td>Successful utilization of ISS facility and objectives</td>
<td>To improve industrial applications and predictive models</td>
<td>Aerospace Automotive Biomedical, Forming, Academia</td>
<td>MSRR-LGF, MSRR-SQF, JAXA-GHF, JAXA-ELF, ESA-EML, MSG-CSML, MSG-PFMI, MSG-SUBSA</td>
<td>RFI ref:04;09;13;15;22;48;39</td>
</tr>
</tbody>
</table>
#2 High Priority  | Thermophysical properties  | Provide baseline experimental data as part of MGI  | Improve precision of key parameters to advance ability to develop predictive process modeling  | Improved sample handling, reduced contamination, and reduced thermal/convection process  | Development of process, performance and theoretical models  | Better understanding of extraterrestrial processes and influence of gravity in manned spacecraft and physical/biological systems  | Improved industrial application and predictive models, development of universal scaling models  | Aerospace, Automotive, casting and forming industry, semiconductors, ceramics (MGI), Academia  | MSFC-ESL, JAXA-ELF, ESA-EML, MSRR-LGF, MSRR-SQF, JAXA-GHF; EXPRESS Rack could be used for new hardware  | RFI ref: 08;23;3 3;34;55; 56;  

Summary Table for Metals (continued)
MaterialsLab Go Forward Plan

• Final Report

• Prioritize Science Themes/Recommendation

• Stand up project

• Develop collaborations

• Develop NRAs

• Select Science Definition Teams

• Develop Flight hardware

• Collect ISS data

• Enter into PS Informatics System
- Fire Safety
- Droplets, Sprays and Aerosols
- Premixed Flames
- Non-premixed Flames
- Heterogeneous Reaction Processes
- High Pressure and Supercritical Reacting Systems
NASA FluidsLab Workshop - Five Disciplines

- Adiabatic Two-Phase Flows
- Boiling and Condensation
- Capillary Flow and Interfacial Phenomena
- Cryogen Storage and Handling
- Complex Fluids – Liquid Crystals
Macromolecular Biophysics (MMB-MB-1-3)

Description: Conduct manual Macromolecular Biophysics (MMB), Protein Crystal Growth (PCG) experiments with PI specific frozen samples operated in the FIR/LMM. PI will provide frozen MMB samples that will be thawed and observed in LMM.

- A protein crystal is a specific protein repeated over and over a hundred thousand times or more in a perfect lattice.
- These proteins control aspects of human health and understanding them is an important beginning step in developing and improving treatments for diseases.
- The space station provides a unique environment where we can improve the quality of protein crystals. While we can grow high-resolution crystals both in space and on the ground, those grown in space are often more perfectly formed.
**Objectives:**

- Visually study the gelation transition in magneto-rheological (MR) fluids under steady and pulsed magnetic fields.
- InSPACE-3 studies the effect of particle shape on the kinetics of aggregation and structures formed by DC and pulsed magnetic fields in suspensions of super paramagnetic particles.

**Justification:**

- Additional, or extra science runs are needed to further investigate a parameter space of lower magnetic field strengths and pulsed frequency to better understand the hindered coalescence of the InSPACE-3 fluid samples, compared to InSPACE-2 results.

**Relevance/Impact:**

- Directly aligns with high priorities from the NRC Decadal survey on Biological and Physical Sciences.
  - FP1: Research on complex fluids. Study the structures and forces important to the properties of the materials in microgravity.
  - AP5: Understand complex fluid physics in microgravity including fluid behavior of granular materials, colloids, etc.
- Microgravity data of the structure and dynamics of aggregate formation under magnetic fields will provide a fundamental assessment of the micro-rheology of magneto-rheological (MR) fluids. The results will have MR applications for limb and dextrous motion in robotic components and human-robotic interfaces for EVA suits. Earth applications include improved active damping systems for bridges (to counter act wind gusts) and buildings.
- This work will also provide fundamental understanding in the directed self-assembly of colloids using magnetic fields and has potential application in development of new functional materials at the nano-scale level.

**Development Approach:**

- InSPACE-3 will utilize the InSPACE-1 experiment hardware presently on ISS, and InSPACE-2 Helmholtz coil assembly and light guide tool.
- An improved vial assembly design was used to allow orthogonal views of the resulting aggregate structures.
- InSPACE-3 hardware will consist of 3 vial assemblies, each with different ellipsoid-shaped particles MR fluid and 3 backup vial assemblies.

**Accommodation (carrier)**

<table>
<thead>
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<th>Microgravity Science Glovebox</th>
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**Upmass (kg)**

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**Volume (m³)**

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**Power (kw)**

<table>
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<th>(peak)</th>
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<tr>
<td>0.030</td>
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</table>

**Crew Time (hrs)**

| 53.5 |

**Autonomous Ops (hrs)**

| 2-3 hours of unattended operations per test run |

**Launch/Increment**

| STS 134 Endeavour (Flight ULF-6). |

**Project Life Cycle Schedule**

<table>
<thead>
<tr>
<th>Milestones</th>
<th>RDR</th>
<th>PDR</th>
<th>CDR</th>
<th>Ph III FSR</th>
<th>SAR</th>
<th>FHA</th>
<th>Launch</th>
<th>Ops</th>
<th>Return</th>
<th>Final Report</th>
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</thead>
</table>
InSpace-3: request for additional experiments

James W. Swan and Eric M. Furst (PI)
University of Delaware

InSpace-3 is studying the assembly of paramagnetic colloidal ellipsoids in pulsed magnetic fields. The study parameters included ellipsoid aspect ratios of 2:1, 3:1 and 4:1 and spanned field strengths ranging from 500-1500 A/m and pulse frequencies from 0.66 to 20 Hz. We found that the colloidal ellipsoids possess some amount of remnant magnetization so that in the absence of applied field particles form disordered aggregates. The strength of this aggregation appeared weaker for particles with higher aspect ratio, probably due to the reduced ability for particles to coordinate their orientation in the absence of the applied field. This weaker aggregation is apparent in the structures of the suspensions immediately after the astronaut has dispersed the particles but before the field has been turned on (see figure 1).

Figure 1: From left to right are initial suspension configurations for 2:1, 3:1 and 4:1 aspect ratio particles respectively.

The best initial dispersion was achieved with particles having a 4:1 aspect ratio. We observed that these particles exhibit highly dynamic behavior in the pulsed fields. At low field strengths and frequencies, the particles form columns that move throughout the sample and coalesce to reduce the magnetic interaction energy. At high field strengths and frequencies, the particles jam in an initial aggregated configuration and show little coalescence during the course of the experiment. Still at our lowest field strength, 500 A/m, and frequency, 0.66 Hz, the coalescence observed is not as considerable as observed during the InSpace-2 experiments. A wider range of parameters is necessary to assess the kinetics of the self-assembly process.

While the range of pulse frequency available to the microgravity science glove box is limited, the field strength may be adjusted more flexibly. We propose additional experiments at field strengths of 200 A/m and 800 A/m. The characteristic interaction energy between paramagnetic ellipsoids scales with the field strength squared so that these additional experiments provide two orders of magnitude variation in the strength of interaction. This is necessary to best allow for the
Burning and Suppression of Solids – II (BASS-II)
WBS: 904211.04.02.20.09

Objectives:
- Study the ignition, flame growth, flame spread, and extinction limits for solid fuels burning in low velocity forced convective flows in microgravity.
- Begin to bridge the gap between the normal gravity NASA-STD-6001 Test #1 method, ground-based microgravity tests, and actual material flammability in microgravity.
- Provide SoFIE PIs with preliminary data to refine Science Requirements.
- Practical, realistic (thicker) fuels in typical geometries will be examined, including slabs, cylinders, and spherical sections.
- The primary variables include:
  - Forced flow velocity (speed and direction)
  - Ambient oxygen concentration (via working volume GN₂ vitiation)
  - Sample geometry (rods, spherical section, slabs, films, and fabric sheets)

Relevance/Impact:
- Spacecraft fires are a significant risk factor for human exploration.
- Understanding material flammability and suppression in actual spacecraft environments relative to 1g materials screening is needed to mitigate this risk.
- Decadal Survey: Required by 2020: “NASA should develop and implement new testing standards to qualify materials for flight. Research is necessary in materials qualification for ignition, flame spread, and generation of toxic and/or corrosive gases in relevant atmospheres and reduced gravity levels.” “Improved methods for screening materials in terms of flammability in space environments will enable safer space missions. Present tests, performed in normal gravity, are not adequate for reduced gravity scenarios.”
- Ground-based drop tower testing provides some data, but long-duration microgravity data is needed to study flammability limits for all but the thinnest films.

Development Approach:
- Utilize existing on-orbit SPICE/SLICE hardware, multi-user, re-usable apparatus, minimizing upmass/volume, costs.
- Rapid-turnaround flight of new samples, igniters, and more camera cards.
- Utilize crew time and ground support for real time ‘lab partner’ operations.
- Utilize on-orbit resources (GN₂, sensors)

PI Team: Sandra L. Olson, NASA GRC
Subrata Bhattacharjee, San Diego State Univ.
Fletcher J. Miller, San Diego State Univ.
A. Carlos Fernandez-Pello, UC Berkeley
James S. T’ien, Case Western Reserve Univ.

PS: Paul Ferkul, USRA
PM: Bob Hawarsaat, NASA GRC
Engineering Team: ZIN Technologies, Inc.

ISS Resource Requirements

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<thead>
<tr>
<th>Accommodation (carrier)</th>
<th>MSG</th>
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<tr>
<td>Upmass (kg) (samples, igniters, camera cards)</td>
<td>5 kg</td>
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<tr>
<td>Volume (m³)</td>
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<tr>
<td>Power (kW) (peak)</td>
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<tr>
<td>Crew Time (hrs)</td>
<td>100 hrs</td>
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<tr>
<td>Autonomous Ops (hrs)</td>
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<tr>
<td>Launch/Increment (remaining launches/increments)</td>
<td>Orb-1, Inc. 39-40</td>
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Project Life Cycle Schedule

<table>
<thead>
<tr>
<th>Milestones</th>
<th>Launch</th>
<th>Ops Start</th>
<th>Ops End</th>
<th>Final Report</th>
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Revision Date: 8/21/2014
Materials flammability screening in 1g (NASA Test 1) is not conservative.

- Materials fire screening tests are done in 1g, but materials are more flammable in 0g.
- In the normal gravity screening tests, flames extinguish by blowoff, where the buoyant flow is too fast for the chemical reactions to occur in the hot flame zone.
- In reduced gravity (0g, Lunar g, Martian g), the flow is slower (reduced-g buoyancy or spacecraft ventilation flows of 5-20 cm/s) and a flame can be sustained at lower $O_2$ where the slower reactions have enough residence time in the hot zone.
- We need to measure the Negative Oxygen Margin of Safety to de-rate materials.
- Very few materials have been rated even in 1g at 34% $O_2$, 8.2 psia (exploration atmosphere).

Blowoff in 0g: dim flame strengthens but then blows off when flow is increased (1-20 cm/s).
Flow Boiling and Condensation Experiment (FBCE)

PI: Prof. Issam Mudawar, Purdue University
Co-I: Dr. Mohammad M Hasan, NASA GRC
PS: Dr. David F. Chao, NASA GRC
PM: Nancy R Hall, NASA GRC
Engineering Team: GRC Engineering

Objectives:
- Develop experimentally validated, gravity independent, mechanistic model for microgravity annular flow condensation and microgravity flow boiling critical heat flux (CHF).

Relevance/Impact:
- Key thermal systems and power generating units must be designed to reduce the size, weight and enhance reliability.
- Two-phase thermal systems utilizing flow boiling and condensation can yield significant enhancement in thermal performance.
- Relevant to a wide range of systems:
  - advanced two-phase thermal control system for life support and habitation
  - Rankine cycle, power generation (solar dynamic, nuclear), regenerative fuel cells
  - in space long term storage and transfer of cryogenic propellant

Development Approach:
- To be developed inhouse by GRC Engineering.
- Develop an integrated flow boiling/condensation experiment to serve as a primary platform for obtaining two-phase flow and heat transfer data in microgravity with dielectric fluid, normal-perfluorohexane.
- Engineering models will be used for flight hardware development and flight hardware unit will also be developed.

ISS Resource Requirements

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<tr>
<th>Accommodation (carrier)</th>
<th>Fluid Integrated Rack (FIR)</th>
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<td>Upmass (kg)</td>
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<td>Volume (m³)</td>
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<td>(w/o packing factor)</td>
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<td>Power (kw)</td>
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<td>(peak)</td>
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<td>Crew Time (hrs)</td>
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<td>(installation/operations)</td>
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<td>Autonomous Operation</td>
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Project Life Cycle Schedule

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<tr>
<th>Milestones</th>
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<th>Ph III Safety</th>
<th>FHA</th>
<th>Launch</th>
<th>Ops complete</th>
<th>Final Report</th>
</tr>
</thead>
</table>

Critical Heat Flux (CHF) data and model predictions for microgravity and Earth gravity for flow boiling.
Flow Boiling and Condensation Experiment (FBCE)

- Thermal management systems responsible for controlling temperature and humidity using Thermal Control System (TCS) consisting of Heat Acquisition, Heat Transport and Heat Rejection hardware.
- Refrigerator/freezer components provide cooling for science experiments and food storage.
- Advanced water recovery systems transfer crew and system wastewater into potable water for crew and system reuse.

Rankine Cycle very attractive option for high power systems (> 100 kWe)
FBCE Flow Boiling Module Videos

Zero-G: 0.125 m/s

1G: 0.125 m/s

1G: 0.25 m/s

1G: 1.25 m/s
Study of Mushy-Zone Development in Dendritic Microstructures with Glass-Forming Eutectic Matrices

Technical Goals and Objectives

Task Objective: To study how dendrites growth and coarsen in Bulk Metallic Glass Matrix Composites
How? Directional solidification, moving melt zone, mushy-zone processing, electrostatic levitation
Flight Objective: Study dendrite morphology in the mushy zone in the absence of gravity driven convection and sedimentation effects

Value to NASA and Others

- Glassy composites are being investigated by NASA, DOD and industry for a wide range of products (shielding, gears, cell phones, panels, etc.)
- Future commercialization of alloys requires knowledge of viscosity and dendrite morphology
- NASA funding and three spaceflights lead to the development of the bulk metallic glass industry and the current program is the most ambitious yet

Investigator | Location
--- | ---
PI – Dr. Douglas C. Hofmann | JPL/Caltech
POC | dch@jpl.nasa.gov
Phone: (818) 731-6500
Co-I – Prof. William L. Johnson | Caltech
Co-I – Dr. Andrew A. Shapiro | JPL/Caltech
Co-I – Dr. Won-Kyu Rhim | Caltech
Co-I – Dr. Marios Demetriou | Caltech

Resources and Schedule

| Award | $450k/year for three years of ground based work |
| What? | Study Dendrites in Glass Forming Liquids |
| Flight Date | 2016 |
| Where? | Ground based work completed at NASA Jet Propulsion Laboratory and Caltech. Flight experiments on International Space Station |
| ISS Requirements | Solidification and Quenching Furnace on Materials Science Research Rack |
Comparison of Structure and Segregation in Alloys Directionally Solidified in Terrestrial and Microgravity Environments (CSS)

Summary:
The CSS Experiment is performed in the Materials Science Research Rack. The purpose is to determine microstructural development and provide insight regarding defect generation in directionally solidified dendritic alloys. The first US sample was processed aboard the ISS in the Low Gradient Furnace on the MSRR/MSL in February 2010; the second sample was processed in January 2011, this time in the Solidification with Quench Furnace module. Both samples have been returned and are currently being evaluated.

Description:
Dendritic alloys are characterized by an internal, forest-like, network of metallic branches. The alignment and distribution of these branches directly influences a solidified materials tensile strength, toughness, electrical conductivity, thermal conductivity, and other properties. The presence of Earth’s gravity induces buoyancy and convective effects during solidification which disrupt the developing structure and compromises material properties. Solidification experiments in microgravity are strictly diffusion controlled, which promotes a uniform microstructure and leads to improved material properties. Knowledge gained from the microstructure will be incorporated into numerical models which will improve our understanding of Earth-based processes. The work involves a team of scientists from the US and Europe.

Space Application: Improved alloys result in aerospace products, such as turbine blades, with lower weight and or greater strength.
Earth Application: Stronger alloys with improved creep resistance.

http://www.nasa.gov/exploration/multimedia/highlights
• BACK - UP
Topical Team Approach
INTERNATIONAL COOPERATION

Joined Implementation

Peer evaluation

ESA AO

Peer evaluation

JAXA RA

ITT

USA

RUSSIA

CHINA

Industry

Lab.

Lab.

Lab.

Lab.

Lab.

Lab.

Lab.

Lab.

Lab.
Link to Space Technology

Exploration Driven
• TA02: In-Space Propulsion Systems*
  – Propellant Storage, Transfer & Gauging Liquid
    • Zero Boiloff: ZBOT > ZBOT-2 > ZBOT-3,
    • Fluid Management: CFE > CFE-2, CCF
• TA03: Space Power & Energy Storage
  – Power Generation: FBCE
• TA05: Communication and Navigation: ACES
• TA06: Human Health, Life Support and Habitation Systems
  – Environmental Control and Life Support Systems and Habitation Systems
    • Air Revitalization, and Water Recovery & Management: PBRE > PBRE-A** > PBRR**
      – Liquid-Gas Phase Separation: CFE-2, TFPSE
    • Waste Management: SCWM > SCWM-2 > SCWO**
  – Environmental Monitoring, Safety and Emergency Response
    • Fire Prevention, Detection and Suppression
      – Materials Flammability: BASS-2 > SoFIE > MWT-FS** (NASA STD 6001 Test 1)
• TA12: Materials, Structures, Mechanical Systems and Manufacturing: FAMIS, MVCS
• TA14: Thermal Management Systems
  – Heat Pipes: CVB > CVB-2 > CVB-3** > HPE-L**
  – Two-Phase Pumped Loop Systems: FBCE, MFHT, EHD

* from OCT Space Technology Roadmaps, 2014 (blue), ** proposed experiment
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>ACES</td>
<td>Atomic Clock Ensemble in Space</td>
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<tr>
<td>BASS</td>
<td>Burning and Suppression of Solids</td>
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<tr>
<td>CFE</td>
<td>Capillary Flow Experiment</td>
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<tr>
<td>CCF</td>
<td>Capillary Channel Flow</td>
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<td>CVB</td>
<td>Constrained Vapor Bubble</td>
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<td>EHD</td>
<td>ElectroHydroDynamic flow experiment</td>
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<td>HPE-L</td>
<td>Heat Pipe Experiment - Loop</td>
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<td>FAMIS</td>
<td>Formulation of Amorphous Metals in Space</td>
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<td>FBCE</td>
<td>Flow Boiling and Condensation Experiment</td>
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<td>MsFHT</td>
<td>Multiphase Flow And Heat Transfer Experiment</td>
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<td>MVCS</td>
<td>Morphological study in Variable Cross Section</td>
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<td>MVCS</td>
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# ISS Physical Sciences Traffic Model

## Increment Table

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## Destin Lab

- **CIR**: FLEX, FLEX-2, FLEX, FLEX-2, FLEX-2
- **FIR**: PAC1, PAC-2, PAC-1, ACE-1, ACE-M1(CAS5), ACE-M2, ACE-M3, ACE-H1, ACE-H2, ACE-H3, ACE-T1
- **MSRR/MSL**: MCAST-P, CETOL, SETA, SHERII, SHERI
- **MSG**: SLICE, BASS, CCF, CCF, CCF, GLM-1, OASIS
- **MWA**: BCAT-5, BCAT-6, BCAT-C1, BCAT-C2, BCAT-4

## Columbus Lab

- **EPM**: THERMOLAB Batch 1
- **EDR/EML**: PARSEC Batch 1
- **CEPF**: ICP/PROTOCOL Batch 1
- **ER (ESA)**: THERMOPROP Batch 1

## Kibo JEM

- **MSG**: CCE/GCE
- **EFL**: ALI-R

## Legend

- Electrophysiology
- Combustion Science
- Complex Fluids
- Fluid Physics
- Fundamental Physics
- Materials Science
- Planned Experiment
# ISS Physical Sciences Traffic Model

## Columbus Lab
- **EPM**
  - PK-4
  - Colloidal Solids
  - PROTEIN
- **EDR/EML**
  - THERMOLAB Batch 2
  - THERMOLAB Batch 3
  - THERMOLAB Batch 4
- **CEPF**
  - ACES
- **ER (ESA)**
  - CAL
- **RiboJEM**
- **ER (JAXA)**
- **MSG**
  - LMMP-MP2
  - ICEAGE
- **MWA**
  - ZBOT-2

## Destiny Lab
- **CIR**
  - CI-OS
- **FIR**
  - ACES-T5
- **MSRR/MSL**
  - GDRS
  - ICEAGE
- **ACME**
  - FLARE

## Legend
- Biophysics
- Combustion Science
- Complex Fluids
- Fluid Physics
- Fundamental Physics
- Materials Science
- Planned Experiment
# ISS Physical Sciences Traffic Model

## Increment

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### Destiny Lab

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### Kibo JEM

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### Legend

- Biophysics
- Combustion Science
- Complex Fluids
- Fluid Physics
- Fundamental Physics
- Materials Science
- Planned Experiment

### Acknowledgments

- Name
- Name
- Name
- Name
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- Name
“MaterialsLab”
A New Generation of Materials Science Experiments

Purpose: Engineers & scientists identify most promising engineering-driven ISS materials science experiments

Goal: Seek needed higher-performing materials by understanding materials behavior in microgravity

Open Science and Informatics: Inspire new areas of research, enhance discovery and multiply innovation

Engineering-Driven Science

Partners:
Industry
Academic institutions
DOD
Other Government agencies
International partners
NASA
CASIS
NASA MaterialsLab Workshop - Six Disciplines

- Biomaterials
- Glasses and Ceramics
- Granular Materials
- Metals
- Polymers and Organics
- Semiconductors
MaterialsLab Schedule

- MaterialsLab
  - Workshop held April 15-16, 2014
  - Final report completed July 25, 2014
  - Recommendation planned for mid November 2014 (except Biomaterials)
  - Biomaterials Special Session, Dec. 3, 2014 at MRS Conference
  - Biomaterials Recommendation in 2015
FluidsLab & CombustionLab Schedule

- FluidsLab
  - Special Sessions held for Complex Fluids on June 30, 2014 and Fluid Physics on Sept. 29, 2014
  - Workshop to be held Oct. 24-25, 2014 (ASGSR Conf.)
  - Report and Recommendation in 2015
- CombustionLab
  - Workshop to be held Oct. 24-25, 2014 (ASGSR Conf.)
  - Report and Recommendation in 2015
- Biomaterials
  NIH, NIST, RPI, Dartmouth College
- Glasses and Ceramics
  Southern Research Association, Materials Development, Tuffs, Iowa State University
- Granular Materials
  Caterpillar, Georgia Institute of Technology
- Metals
  Power Systems Manufacturing, GE, United Technologies, University of California, NIST
- Polymers and Organics
  DuPont, NIST, Made in Space, Ford, University of Delaware,
- Semiconductors
  Brimrose Corp., University of Maryland, DOD

* CASIS, ESA, JAXA and CNES expressed an interest participating in some topical areas.
Experiment List - Past, Present and Future
31 Completed ISS Physical Science Investigations (2001 - June 1, 2013)

- **Combustion Science (MSG)**
  - Dust and Aerosol Measurement Feasibility Test (DAFT)
  - Dust and Aerosol Measurement Feasibility Test-2 (DAFT-2)
  - Smoke Aerosol Measurement Experiment (SAME)
  - Smoke Aerosol Measurement Experiment Reflight (SAME-R)
  - Smoke Point in Coflow Experiment (SPICE)
  - Structure and Liftoff in Combustion Experiment (SLICE)
  - Burning and Suppression of Solids (BASS)

- **Complex Fluids (FIR, MSG, MWA)**
  - Physics of Colloids in Space (PCS)
  - Investigating the Structures of Paramagnetic Aggregates from Colloidal Emulsions (InSPACE)
  - Investigating the Structures of Paramagnetic Aggregates from Colloidal Emulsions-2 (InSPACE-2)
  - Investigating the Structure of Paramagnetic Aggregates from Colloidal Ellipsoids–3 (InSPACE-3)
  - Shear History Extensional Rheology Experiment (SHERE)
  - Shear History Extensional Rheology Experiment Reflight (SHERE-R)
  - Shear History Extensional Rheology Experiment II (SHERE II)
  - Binary Colloidal Alloy Test-5 (BCAT-5)

- **Fluid Physics (FIR, MWA)**
  - Capillary Flow Experiments (CFE)
  - Constrained Vapor Bubble (CVB)
  - Microheater Array Heater Boiling Experiment (MABE)
  - Nucleate Pool Boiling Experiment (NPBX)

- **Fundamental Physics (EPM)**
  - Gradient Driven Fluctuation Experiment (GRADFLEX) [Free Flyer]
  - Dusty Plasma (PK-3)
  - Dusty Plasma (PK-3+)

- **Materials Science (MSRR/MSL, MSG)**
  - Solidification Using a Baffle in Sealed Ampoules (SUBSA)
  - Pore Formation and Mobility Investigation (PFMI)
  - Coarsening in Solid-Liquid Mixtures (CSLM)
  - Coarsening in Solid-Liquid Mixtures-2 (CSLM-2)
  - Coarsening in Solid-Liquid Mixtures-2 Reflight (CSLM-2R)
  - Coarsening in Solid Liquid Mixtures-3 (CSLM-3)
  - Comparison of Structure and Segregation in Alloys Directionally Solidified in Terrestrial and Microgravity Environments (MICAST/CSS)
  - DECLIC, Directional Solidification Experiment (DSI)
  - In-Space Soldering Investigation (ISSI)
14 Current (or recently completed)* ISS Physical Science Investigations

- **Combustion Science (CIR)**
  - Flame Extinguishment Experiment (FLEX) [partial]
  - Flame Extinguishment Experiment–2 (FLEX-2) [partial]

- **Complex Fluids (FIR, MSG, MWA)**
  - Binary Colloidal Alloy Test-3 (BCAT-3) [partial]
  - Binary Colloidal Alloy Test-4 (BCAT-4) [partial]
  - Binary Colloidal Alloy Test-6 (BCAT-6) [partial]
  - Investigating the Structure of Paramagnetic Aggregates from Colloidal Ellipsoids–3+ (InSPACE-3+)
  - Advanced Colloids Experiment-M1 (ACE-M1)

- **Fluid Physics (EXPRESS, FIR, MSG, MWA)**
  - Capillary Flow Experiment-2 (CFE-2)
  - Capillary Channel Flow (CCF)
  - Constrained Vapor Bubble-2 (CVB-2)
  - DEvice for the study of Critical LiQuids and Crystallization - High Temperature Insert-Reflight (DECLIC HTI-R or SCWM/HTI-R)

- **Fundamental Physics (EXPRESS)**
  - DEvice for the study of Critical LiQuids and Crystallization - Alice Like Insert (DECLIC-ALI)

- **Materials Science (EXPRESS, MSRR/MSL)**
  - DEvice for the study of Critical LiQuids and Crystallization - Directional Solidification Insert-Reflight (DECLIC DSI-R)
  - Comparison of Structure and Segregation in Alloys Directionally Solidified in Terrestrial and Microgravity Environments (MICAST/CSS) batch 2A set 2

* Experiment and/or samples are on-orbit and operating (or operations planned) in CY2013
60+ awarded (FY14-20) ISS Physical Science Investigations

**Biophysics (FIR, EPM)**
- Macromolecular Biophysics – M1 (MMB-M1)
- Macromolecular Biophysics – M2 (MMB-M2)
- Macromolecular Biophysics – M3 (MMB-M3)
- Macromolecular Biophysics – C1 (MMB-C1)
- Macromolecular Biophysics – C2 (MMB-C2)
- Macromolecular Biophysics – C3 (MMB-C3)
- PROTEIN (PROTEIN)

**Combustion Science (CIR, MSG, MSPR, EXPRESS)**
- Advanced Combustion via Microgravity Exp (ACME)
- Burning and Suppression of Solids (BASS-2)
- Chamber for Combustion Experiment/Group Combustion Experiment (CCE/GCE)
- FLame Extinguishment eXperiment-2JAXA (FLEX-2J)
- FLame Extinguishment eXperiment ICE GA (FLEX ICE GA)
- Smoke Aerosol Measurement Experiment (SAME-3)
- Supercritical Water Mixture (SCWM-2)
- Solid Fuel Ignition and Extinction (SoFIE)

**Complex Fluids (FIR, EPM, FSL, MSG)**
- Advanced Colloids Experiments – C1 (ACE-C1)
- Advanced Colloids Experiments – C2 (ACE-C2)
- Advanced Colloids Experiments – C3-4 (ACE-C3-4)
- Advanced Colloids Experiments – C4 (ACE-C5)
- Advanced Colloids Experiments – C6 (ACE-C6)
- Advanced Colloids Experiments – C7 (ACE-C7)
- Advanced Colloids Experiments – E (ACE-E)
- Advanced Colloids Experiments – H1 (ACE-H1)
- Advanced Colloids Experiments – H2 (ACE-H2)
- Advanced Colloids Experiments – H3 (ACE-H3)
- Advanced Colloids Experiments – M2 (ACE-M2)
- Advanced Colloids Experiments – M3 (ACE-M3)
- Advanced Colloids Experiments – M4 (ACE-M4)
- Advanced Colloids Experiments – M5 (ACE-M5)
- Advanced Colloids Experiments – M6 (ACE-M6)
- Advanced Colloids Experiments – M7 (ACE-M7)
- Advanced Colloids Experiments – M8 (ACE-M8)
- Advanced Colloids Experiments – T1 (ACE-T1)
- Advanced Colloids Experiments – T2 (ACE-T2)
- COLLOID (COLLOID)
- Foam Optics and Mechanics Experiment – C (FOAM-C)
- Observation and Analysis of Smectic with Electromagnetic Convection (OASIS)
60+ awarded (FY14-20) ISS Physical Science Investigations cont.

- **Fluid Physics (FIR, MSG)**
  - ElectroHydroDynamic Flow (EHD)
  - Flow Boiling and Condensation Experiment (FBCE)
  - Multiphase Flow with Heat Transfer (MFHT)
  - Multiphase Flow with Heat Transfer – 2 (MFHT-2)
  - Packed Bed Reactor Experiment (PBRE)
  - Two-Phase Flow Separator Experiment – Annular Injection (TPFSE-AI)
  - Two-Phase Flow Separator Experiment – Conical Injection (TPFSE-CI)
  - Zero Boil-Off Tank (ZBOT)
  - Zero Boil-Off Tank – 2 (ZBOT-2)
  - Zero Boiloff Tank – 3 (ZBOT-3)

- **Fundamental Physics (CEPF, EPM, EXPRESS)**
  - Atomic Clock Ensemble in Space (ACES)
  - Alice Like Insert – R (ALI-R)
  - Cold Atom Laboratory (CAL)
  - Plasma Crystal – 4 (PK-4)

- **Material Science (EDR-EML, MSG, MSRR/MSL)**
  - Cadmium Telluride (CdTe)
  - Columnar-to-Equiaxed Transition in Solidification (CETSOL)
  - Coarsening in Solid-Liquid Mixtures – 4 (CSLM-4)
  - DEvice for the study of Critical LIquids and Crystallization, Directional Solidification Experiments – 2R (DECLIC DSI-2R)
  - Formulation of Amorphous Metals in Space (FAMIS)
  - Formation of Gasrites (FOG)
  - Gravitational Effects on Distortion in Sintering (GEDS)
  - Influence of Containment on the growth of Silicon-GErmanium (ICESAGE)
  - ICOPROSOL – electromagnetic levitator expt.
  - Peritectic Alloy Rapid Solidification with Electromagnetic Convection (PARSEC)
  - Solidification along an Eutectic path in Ternary Alloys (SETA)
  - THERMOLAB –
  - THERMOPROP –
Additional Slides
US Collaboration in the ESA ACES Mission

Atomic Clock Ensemble in Space (ACES) – an ESA ISS Experiment (2016 Launch)

Science Objectives:
• Demonstrate validate a new generation of atomic clocks in space (10^{-16} stability and accuracy level)
• Demonstrate the capability to compare ground clocks on a world-wide basis (stability better than 10^{-16})
• Test fundamental laws of physics to high accuracy (gravitational Red-shift, drift of fine structure constant, and anisotropy of light.)
New ISS Facility: ESA’s ElectroMagnetic Levitator

No container = freely floating, no reaction nor contamination

- Sample heating possible up to 2000degC
- Pyrometer (resolution 0.1K >600degC, 100Hz)
- 2 cameras (axial, radial high speed) (high speed up to 190kHz)
- Vacuum and inert gas (Ar, He or mixture)
- Trigger needle and chill cooling capability

Sample container for 18 samples – crew activity only for container exchange
Effect of Convection on the Columnar-to-Equiaxed Transition in Alloy Solidification (CET)*

Investigation Name, PI: Prof. Christoph Beckermann (Univ. Iowa)

Project Scientist: Ellen Rabenberg (NASA-MSFC)
Project Manager: Dr. James P. Downey (NASA-MSFC)
Engineering Team: TBD

Objective: To study columnar-to-equiaxed grain structure transition and effect of convection in alloys by using directional solidification with and without grain refiner, multi-scale and phase-field computer simulations.

Relevance/Impact: Grain structure is important for all metal castings and affects defect formation and properties. Gravity has a large effects on grain structure. NASA funding allows for meaningful continuation of ESA CETSOL experiments on ISS.

Development Approach: Study grain structure transition and dendrite fragmentation in the absence of gravity driven convection and sedimentation effects.

Instrumentation & Experiment Summary:

- Ground based work: Will be performed at MSFC under direction of Dr. Beckermann
- ISS requirements: Low-gradient furnace (LGF) on Materials Science Research Rack (MSRR).

* Prof. Beckermann participating in ESA’s MSL-SETA experiments

ISS Resource Requirements

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<td><strong>Volume (m³)</strong></td>
<td>690 x 185 x 185mm each</td>
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<td>(w/o packing factor)</td>
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<td><strong>Power (kw)</strong></td>
<td>2.54 kW (for 0.5 hrs), total power max 1.82 kW</td>
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