Agenda

• PROGRAM THEMES
• ORGANIZATION CHARTS
• EXPERIMENT AND FACILITIES
• STRATEGIC OVERVIEW
• INTERNATIONAL COLLABORATION
• SUMMARY
• BACKUP
Physical Sciences Gravity Dependent Research Themes

**Combustion Science**
- Spacecraft fire safety
- Solids, liquids, droplets, gasses
- Supercritical reacting fluids
- Soot

**Fluid Physics**
- Two-phase flow
- Phase separation
- Boiling, condensation
- Capillary and interfacial phenomena

**Materials Science**
- Solidification
- Crystal growth
- Metals, alloys
- Electronic materials
- Glasses, ceramics
- Polymers

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

**Fundamental Physics**
- Atomic Clocks
- Low temperature physics
- Quantum measurement techniques
- Ultra-cold atom physics
- Dusty plasmas
Organizational Structure:
Human Exploration and Operations Mission Directorate

Public Affairs/Communications
Legislative Affairs
Int’l/Interagency Relations
General Counsel

Human Exploration and Operations Mission
Directorate
Associate Administrator
Deputy Associate Administrator
Deputy AA for Policy & Plans

Strategic Analysis
& Integration
Division
• Architecture studies & analysis
• Mission analysis
• Risk and requirements coordination

Mission Support
Services Office
• HR
• E & PO
• IT
• Mgt processes & internal controls

Resources
Management
Office

Space
Comm &
Navigation
Division

Launch
Services
Office

Space Shuttle
Exploration
Systems
Development
• SLS
• MPCV
• 21st Century
Ground Systems

Human
Spaceflight
Capabilities
• Core Capabilities
  • RPT
  • SFCO
  • MAF
  • MOD
  • EVA
  • CHS

ISS
• System O&M
• Crew & Cargo
Transportation Services

Commercial
Spaceflight
Development
• Commercial Crew
• COTS

Advanced
Exploration
Systems
• AES
• Robotic precursor measurements

Space Life &
Physical
Sciences
Research &
Applications
• HRP
• Fund. Space Bio
• Physical Sciences

ISS Nat’l Lab Mgt.
Physical Sciences Research Program Organization

Human Exploration and Operations Mission Directorate (HEOMD)

Space Life & Physical Sciences Research & Applications Division (SLPSRAD)

Human Research Program
Physical Sciences
Fundamental Space Biology

Glenn Research Center
Jet Propulsion Laboratory
Marshall Space Flight Center

Combustion Science
Complex Fluids
Fluid Physics
Fundamental Physics
Materials Science
Physical Sciences ISS
Experiments and Facilities
CIR designed to test fire prevention, detection and suppression of fires in space. Hardware was delivered on STS-126 (November 2008) to ISS and installed in the USLAB.

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

CIR provides a 100-liter chamber with eight optical windows with easily reconfigurable diagnostics, digital cameras and lighting with large data storage capability, gas distribution/cleanup, passive vibration isolation, and vacuum resources to support a wide range of gravity-dependent gaseous, liquid and solid combustion experiments.
Flame Extinguishment Experiment (FLEX/FLEX-2)

**Summary:** FLEX/FLEX-2 experiments are currently operating on ISS studying the combustion of single fuel droplets in microgravity. To date, 225/276 tests have been conducted (now starting FLEX-2). These tests involve different fuels, oxygen/diluent concentrations and ambient pressures. The results of this study have applications to spacecraft fire safety and fundamental combustion research.

**Description:** The FLEX experiments operate by ground command of the Multi-User Droplet Combustion Apparatus (MDCA) inside the Combustion Integrated Rack (CIR). The CIR allows for the accurate control of the ambient environment and provides the diagnostics, while the MDCA consists of the equipment necessary to dispense, deploy and ignite the free-floating liquid fuel droplet. For each test, the measured parameters are the droplet burning rate used for model validation and the radiative and diffusive extinction limits used for extinguisher design.

**Space Application:** The results of the FLEX experiments will help evaluate the efficacy with which inert gases extinguish flames in low-gravity for spacecraft applications. This will allow for further development of fire safety standards and detection/alarm systems for extraterrestrial spacecraft and habitats.

**Earth Application:** Flex will lead to improvements in energy efficiency (reduced carbon footprint) and reduced pollutant formation. Data collected will lead to better engine design, including those for alternative fuel sources (e.g., biofuels).

**Information:** [http://spaceflightsystems.grc.nasa.gov/Advanced/ISSResearch/Investigations/FLEX/](http://spaceflightsystems.grc.nasa.gov/Advanced/ISSResearch/Investigations/FLEX/)
MSRR designed to study a variety of materials including metals, ceramics, semiconductor crystals, and glasses for developing improved materials. MSRR was launched on STS-128 in August 2009 and is installed in the USLAB.

MSRR is a highly automated facility containing the Materials Science Laboratory (MSL) and 2 furnace inserts, provided by ESA, in which sample cartridges can be processed up to temperatures of 1400 °C. The experiments can be run by automatic command or via telemetry commands from the ground. The development of the research rack was a cooperative effort between NASA’s MSFC and ESA.
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
Fluids Integrated Rack - FIR

FIR designed to test and understand; critical technologies needed for advanced life support and future spacecraft thermal control, research in complex fluids (colloids) and life science experiments. Hardware was delivered on STS-128 (August 2009) to ISS and installed in the USLAB.

FIR provides the largest, contiguous volume for experimental hardware of any ISS facility, easily reconfigurable diagnostics, customizable software, active rack-level vibration isolation, and other subsystems that are required to support a wide range of gravity-dependent fluid physics and life science investigations.

Astronaut Bob Thirsk completing install of the FIR/LMM prior to FIR activation in December 2009.
Advanced Colloids Experiment (ACE)

**PIs:** Paul Chaikin (NYU, US), David Weitz (Harvard, US), Arjun Yodh (Penn, US); Matthew Lynch (P&G); Roberto Piazza (U. Milano, I); Luca Cipelletti (U. Montpellier, F); Peter Schall (U. Amsterdam, NL); and Chang-Soo Lee (S. Korea)

GRC Project Manager: MAH / Ronald Sicker
Project Scientist: USRA / William Meyer
NASA Customer: ESMO / Francis Chiaramonte
Key Contractor: ZIN Technologies

**Objective:**

- To observe the behavior of finely divided small particles that, are dispersed within a fluid. On Earth, due to gravity, colloidal particles settle to the bottom and for concentrated systems they are gravitationally jammed and not free to move about. For concentrated systems on Earth, this results in a glassy solid, which lacks the long range order characteristic of a crystal. For less concentrated systems on Earth the particles sediment out from the liquid. In the absence of gravity, the particles remain suspended in the liquid and are free to move about, they are driven by temperature. For concentrated systems, this results in the formation of crystalline structures, which have not been observed on Earth. For less concentrated systems, the particles tend to collect together and become larger, also behaving differently than when observed on Earth.

- When sedimentation and gravitational jamming are removed in a weightless environment, it becomes possible to observe how order arises out of disorder and to learn to control this process. Small colloidal particles can be used to model atomic systems and to engineer new systems. With a confocal microscope, temperature gradient cells, templates, and grids, we can observe this process in 3D and learn to control it.

### Project Life Cycle Schedule

<table>
<thead>
<tr>
<th>Milestones</th>
<th>SCR/MCR</th>
<th>RDR/SDR</th>
<th>PDR</th>
<th>CDR</th>
<th>VRR</th>
<th>Ph III FSR</th>
<th>FHA</th>
<th>Launch</th>
<th>Ops</th>
<th>Return</th>
<th>Final Report</th>
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<td>1/12</td>
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<td>5/12</td>
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<td>10/12</td>
<td>11/12</td>
<td>8/2013</td>
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**Image:** NASA astronaut T. J. Creamer performing Operations with CVB Module on the LMM.
Advanced Colloid Experiment - Status

- Facility – Fluids Integrated Rack, Light Microscopy Module
- Launch ACE-1A - about October 2012 (Space-X 3)
- ISS Operations planned for Winter 2012 – Spring 2013
- Hardware Approach: Produce separate sample modules using a common geometry for NASA sponsored and ISS Partner investigators.
- NASA Provides: Common sample module and ISS facility and procedures.
- PI Provides: Sample material that is compatible with the sample holder.
- Present capability is B/W imaging in Epi-illumination up to 100x or back-lighting with an LED
- Biological experiments using standard Opti-Cell sample holders.
Advanced Colloids

BCAT5 Sample 5 (6 to 13 Oct 2011): Preliminary Analysis
Similar to BCAT6 Samples 3-5

Processed Image Data
(cropped and contrast enhanced only)

2D Autocorrelation function

Astronaut Mike Fossum (ISS), Dr. Peter J. Lu & Prof. David Weitz (Harvard)
©2011 Peter J. Lu. All Rights Reserved. Unauthorized reproduction prohibited.
The Microgravity Science Glovebox (MSG) is designed to provide a sealed work environment and two levels of containment for hazardous materials processing on the ISS. The facility was delivered on UF-2 (June 2002) to ISS and installed in the US Lab. Fluid, combustion and materials science experiments have been conducted in the MSG.

MSG provides an enclosed isolated working environment of approximately 0.25 m$^3$ (9.2 ft$^3$) with distributed resources for the implementation and observation of investigations from many disciplines. Experiment resources include power, cooling, real-time data and video downlink, vacuum, venting, gaseous nitrogen, plus uplink of commands to the experiment.
Microheater Array Boiling Experiment (MABE) in Boiling eXperiment Facility (BXF)

**Summary:** The Microheater Array Boiling Experiment (MABE) has 96 individually controlled microheaters arranged in a 10x10 pattern to measure the local heat transfer and compare that with video data to assess the effect of vapor and liquid presence on boiling.

**Description:** Data about the power levels in the microheaters, and the conditions of the fluid are measured. A special camera will take high speed images (15x faster than standard video) and store the data on a hard drive aboard the ISS. Standard rate video will also be recorded.

**Space Application:** Boiling is used to generate vapor for turning turbines in some advanced concepts for space power generation, for temperature control aboard spacecraft, and for water purification. Uncontrolled boiling can cause problems for systems storing cryogenic rocket propellants such as liquid oxygen and hydrogen.

**Earth Application:** Boiling is used from everything cooking food, to purifying water, to generating steam for turning turbines in electrical generators, to cooling electronics.

**More information:**
http://spaceflightsystems.grc.nasa.gov/Advanced/ISSResearch/MSG/BXF/

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**MABE PI:** Prof. Jungho Kim, University of Maryland  
**PS:** John McQuillen & David Chao, NASA GRC  
**PM:** William A. Sheredy, NASA GRC

Subcooled nucleate boiling in \( \mu g \) viewed through the microheater array colorized with actual heat flux distribution, and from the side.
Microheater Array Boiling Experiment (MABE)
Two regimes with different slopes in Buoyancy Dominated Boiling (BDB), vs Surface tension Dominated Boiling (SDB)
- Can have a jump in heat flux at transition between regimes
- No unified power law dependence for gravity
- Transition between SDB and BDB given by \( \frac{L_{\text{heater}}}{L_{\text{capillary}}} = 2.1 \)
The Columbus External Payload Facility provides four powered external attachment sites for scientific payloads or facilities.

<table>
<thead>
<tr>
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<th>Columbus EPF</th>
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<tbody>
<tr>
<td>Mass capacity</td>
<td>230 kg (500 lb)</td>
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<tr>
<td>Volume</td>
<td>1 m³</td>
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<tr>
<td>Power</td>
<td>2.5 kW total to carrier (shared)</td>
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<td>Thermal</td>
<td>Passive</td>
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<td>Low-rate data</td>
<td>1 Mbps (MIL-STD-1553)</td>
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<tr>
<td>Medium-rate data</td>
<td>2 Mbps (shared)</td>
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<tr>
<td>Sites available per ELC</td>
<td>2 sites</td>
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<tr>
<td>Total ELC sites available</td>
<td>230 kg (500 lb)</td>
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NASA Participation in ESA’s Atomic Clock Ensemble in Space (ACES)

**ESA Project Scientist:** Luigi Cacciapuoti, ESTEC  
**U.S. PIs:** Dr. Nan Yu--JPL Team; Dr. Tom O’Brian—NIST Team

**Objectives:**
- Contribute to ACES objectives to validate the cold atom space clock to the $10^{-16}$ level; to perform time and frequency transfer to the Earth at the same stability level; and to test general and special relativity (gravitational red shift) to high precision
- Establish an ESA-NASA collaboration on Fundamental Physics in Space
- Validate and characterize the JPL trapped ion mercury clock technology and several NIST Atomic Clocks

**Relevance/Impact:**
- Improved knowledge about fundamental laws of nature
- Improved technology for space science (laser ranging, geodesy) and space exploration applications (autonomous navigation, formation flying)
- Improved technology for applications of societal, commercial, and national security importance (navigation, timekeeping, GPS, metrology).
- High educational and outreach value to validate importance of ISS research and inspire the next generation.

**Development Approach:**
- ACES flight hardware developed by ESA and CNES
- ESA will deliver a microwave link ground terminal to JPL and NIST to integrate into their frequency standards laboratory
- NIST and JPL scientists will compare the ACES clock stability aboard the ISS with their atomic clocks together with an ensemble of high performance standards using the microwave link and participate in data analyses.
- JPL - Ion mercury LITS-9, 10 and 11 atomic clocks
- NIST – Cs Fountain, Ion and Lattice clocks

- Launch is planned for 2015 followed by a 12-18 month operations phase.
<table>
<thead>
<tr>
<th>Theme</th>
<th>Experiments</th>
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</thead>
<tbody>
<tr>
<td>Droplet Combustion</td>
<td>FLEX ☢️ FLEX-2 ☢️ FLEX-ICE, ICE-2 ☢️ FLEX-2J ☢️ GCE</td>
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<tr>
<td>Gaseous Diffusion Flame</td>
<td>SPICE ☢️ SLICE ☢️ ACME</td>
</tr>
<tr>
<td>Solid Fuels &amp; Materials</td>
<td>BASS ☢️ FLAME</td>
</tr>
<tr>
<td>Super Critical Processes</td>
<td>HTI-WATER ☢️ SCWM ☢️ SCWO</td>
</tr>
<tr>
<td>Fire Safety</td>
<td>DAFT ☢️ DAFT-2 ☢️ SAME ☢️ SAME-R ☢️ SAME-3</td>
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</tbody>
</table>

Black: NASA Experiments
Blue: Non-NASA Experiments
Green: Possible New NASA Experiments
<table>
<thead>
<tr>
<th>Theme</th>
<th>Experiments</th>
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<tbody>
<tr>
<td>Colloids and Suspensions</td>
<td>PCS ➞ BCAT-3-6, BCAT-C1 ➞ PACE-1,2 ➞ ACE-1-3, COLIS</td>
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<td></td>
<td>InSPACE ➞ InSPACE-2 ➞ InSPACE-3</td>
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<td>Liquid Crystals</td>
<td>OASIS</td>
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<td>Foams</td>
<td>FOAM-C, PASTA-LIFT</td>
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<tr>
<td>Non-Newtonian</td>
<td>SHERE ➞ SHERE-R ➞ SHERE II</td>
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<tr>
<td>Granular Materials*</td>
<td>COMPGRTAN ➞ GRANULAR MEDIA</td>
</tr>
<tr>
<td>Dust Flows and Mitigation*</td>
<td>DUST MITIGATION</td>
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Black: NASA Experiments
Blue: Non-NASA Experiments
Green: Possible New NASA Experiments
* Identified Research Gap in Decadal Survey
# Fluid Physics

<table>
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<th>Theme</th>
<th>Experiments</th>
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<tbody>
<tr>
<td>Multiphase Flow with Heat Transfer</td>
<td>MABE, NPBX, RUBI, FBCE, MFHT</td>
</tr>
<tr>
<td>Life-Support Systems</td>
<td>PBRE, PBRE-2</td>
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<tr>
<td>Interfacial Flows and Phenomena</td>
<td>CFE, CFE-2</td>
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<td>Cryogenic Fluid Management</td>
<td>ZBOT, ZBOT-2, ZBOT-3</td>
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<tr>
<td>Thermal Management*</td>
<td>DOLFIN II</td>
</tr>
<tr>
<td>Space Nuclear Propulsion*</td>
<td>Liquid Metal Cooling and Thawing</td>
</tr>
</tbody>
</table>

**Legend:**
- **Black:** NASA Experiments
- **Blue:** Non-NASA Experiments
- **Green:** Possible New NASA Experiments
- * Identified Research Gap in Decadal Survey
## Fundamental Physics

<table>
<thead>
<tr>
<th>Theme</th>
<th>Experiments</th>
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<tbody>
<tr>
<td>Dusty Plasmas</td>
<td>PK-3 ➔ PK-3+ ➔ PK-4 ➔ DPPF, PlasmaLab</td>
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<tr>
<td>Fundamental Forces</td>
<td>ACES ➔ SOC</td>
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<td>QWEP</td>
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<td>Critical Phenomena</td>
<td>ALI</td>
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<tr>
<td>Quantum Gases*</td>
<td>Cold Atom Laboratory</td>
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</table>

Black: NASA Experiments  
Blue: Non-NASA Experiments  
Green: Possible New NASA Experiments  
* Identified Research Gap in Decadal Survey
## Materials Science

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<thead>
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<th>Theme</th>
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<tbody>
<tr>
<td><strong>Thermophysical Properties</strong> (EML)</td>
<td>PARSEC, ICOPROSOL, THERMOLAB, DIFFUSION MEASUREMENTS</td>
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<tr>
<td>Isothermal Processing</td>
<td>CSLM, CSLM-2, CSLM-R, CSLM-3, CSLM-4, GEDS, FAMIS</td>
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<tr>
<td>Directional Solidification (DECLIC)</td>
<td>DSI, SPADES</td>
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<td>Directional Solidification (MSRR)</td>
<td>CET SOL, FOG, METCOMP, SETA</td>
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<tr>
<td>Semi Conductor Crystal Growth (MSRR)</td>
<td>SISSI, MICAST, CGTS, RDGS</td>
</tr>
</tbody>
</table>

Black: NASA Experiments  
Blue: Non-NASA Experiments  
Green: Possible New NASA Experiments
Physical Sciences - near term NRA plan

• 2012 Complex Fluids NRA
  – 4-6 selections
  – 5 year grant
  – Facility: FIR/LMM.
  – New PIs will join ACE series with additional sample holders to be built.
  – International co-investigator collaboration welcomed

• 2012 JAXA KIBO AO
  – TBD selections: NASA Physical Science Interest: Combustion Science and Materials Science
    – 5 year grant
    – RYUTAI Rack – Fluid Physics Experiment Facility (FPEF), Solution Crystallization Observation Facility (SCOF), Protein Crystallization Research Facility (PCRF), Image Processing Unit (IPU)
    – KOBAIRO Rack – Gradient Heating Furnace (GHF),
    – SAIBO Rack – Cell Biology Experiment Facility (CBEF), Clean Bench (CB),
    – Multipurpose Small Payload Rack - Combustion Chamber

• 2013 Fundamental Physics (Quantum Gases) NRA
  – 4 -5 selections planned
  – 5 year grant
  – Facility: EXPRESS Rack
  – New PIs to Participate in Cold Atom Laboratory experiment
  – International co-investigator collaboration welcomed
## NASA’s International Cooperation in Physical Sciences on ISS

### Theme: Combustion Science

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Experiment</th>
<th>International Partners</th>
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<tr>
<td>FLAME</td>
<td>FLAmability of Materials Experiment</td>
<td>(\text{ESA} \quad \text{JAXA} \quad \text{CSA} \quad \text{ROS} \quad \text{COS} \quad \text{CNES} \quad \text{DLR} \quad \text{ASI} \quad \text{KARI} \quad \text{Other})</td>
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<td>BASS</td>
<td>Burning and Suppression of Solids</td>
<td>(\text{ESA} \quad \text{JAXA} \quad \text{CSA} \quad \text{ROS} \quad \text{COS} \quad \text{CNES} \quad \text{DLR} \quad \text{ASI} \quad \text{KARI} \quad \text{Other})</td>
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<td>SAME-3</td>
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<td>FLEX-ICE</td>
<td>Flame Extinguishment experiment–Italian Combustion Experiment</td>
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<td>Advanced Combustion via Microgravity Experiments</td>
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<td>SCWO</td>
<td>Super Critical Water Oxidation</td>
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<td>SCWM</td>
<td>Super Critical Salt Water Mixture Experiment</td>
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**Blue Print:** Experiment Acronyms in Blue are Sponsored by non-NASA Agency

*S:* Sponsor  
*P:* Participant
NASA’s International Cooperation in Physical Sciences on ISS

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### NASA’s International Cooperation in Physical Sciences on ISS

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Physical Sciences Program Summary

• Program consists of fundamental and applied science
• Physical Sciences Research Program has completed 30 experiments on the ISS since 2001.
• Approximately 53 flight investigations are in various stages of development and/or operations.
  – Approximately 26 experiments have been developed by NASA.
  – Approximately 27 International Collaborations with ESA, JAXA, CSA, RSA, CNES, DLR and South Korea are in effect. They are coordinated by the annual IMSPG, NRA’s, International Partner AO’s, etc.
• Research aligned with 2011 Life and Physical Sciences Decadal Survey recommendations
• Five on-orbit Facilities are utilized on the ISS: CIR, FIR, MSRR/MSL, DECLIC & MSG
• Complex Fluids (colloids) NRA to be released this year and is open to international collaboration.
Website for Physical Sciences Reduced Gravity Research:  
http://www.nasa.gov/directorates/heo/slpsra/index.html

For complete information on all International Space Station research please go to:  
http://www.nasa.gov/mission_pages/station/research/
BACKUP
Solicitations – history and future opportunities

• NRA/AO Status

  – Fluids 2008 (14 selections)
  – Combustion 2009 (6 selections)
  – ESA AO 2009 (8 selections)
  – Materials Science 2010 (7 selections)
  – Fundamental Physics (Atomic Clocks) 2011 (6 selections)
  – Complex Fluids NRA 2012
  – JAXA Kibo AO 2012
  – Fundamental Physics (Quantum Gases) 2013
Physical Sciences - Prior NRAs

- **2008 Fluid Physics NRA**
  - 14 selections made
  - Theme area - Multiphase Flow and Heat Transfer
    - Phase Separation
    - Flow Boiling and Condensation
    - Multiphase Flow Dynamics and Instabilities
  - Goal – select investigators for two-phase flow separator experiment (MSG) and flow boiling experiment (FIR) on ISS applicable to space power, thermal control and life support systems.

- **2009 Combustion Science NRA**
  - 6 selections made
  - Theme area – Flammability of Solid Materials common to human spaceflight
  - Goal - select investigators for future CIR experiment on ISS. An insert for material flammability experiments would be developed.

- **2010 Materials Science NRA**
  - 7 selections made
  - Theme areas – investigate microstructure or morphology in metals, alloys, electronic materials with potential commercial application
  - Goal - Experiments that are compatible with MSRR/MSL on ISS; specifically the Low Gradient Furnace (LGF) for semiconductor growth and metallurgical research or the Solidification and Quenching Furnace (SQF) for metallurgical research.
Physical Sciences – Prior NRAs (continued)

• 2011 Fundamental Physics NRA
  – Released July 2011
  – 6 selections
  – Theme areas
    ▪ Next generation clock technology
    ▪ Atom interferometer applications in space
  – Goal: Select U.S. investigators to join ESA’s existing science teams and participate in ESA flight experiments through mutually agreed upon contributions.

• 2009 ESA AO
  – 8 U.S. Scientists selected on ESA led international investigations.
  – Theme areas
    ▪ Material Science
    ▪ Fundamental Physics
    ▪ Fluid Physics
  – Goal: Select U.S. investigators to participate on ESA’s international science teams. Facilities to be utilized are EML, MSRR/MSL, PlasmaLab, Granular Matter Facility, etc.
NRA Plan for Physical Sciences

• 2012 Complex Fluids NRA
  – 4-6 selections
  – 5 year grant
  – Facility: FIR/LMM.
  – Purpose: New PIs will join the Advanced Colloids Experiment series.
  – Theme: Use the microscope to study colloidal processes such as crystalline structure, instabilities, glass transition, gelation, phase separation, etc. For concentrated systems, observe the formation of crystalline structures, which have not been observed on Earth. For less concentrated systems, the particles tend to collect together and become larger, vs settling to the bottom on Earth.

• 2012 JAXA KIBO AO - Collaboration
  – TBD selections
  – 5 year grant
  – JAXA Facilities: RYUTAI Rack – Fluid Physics Experiment Facility (FPEF), Solution Crystallization Observation Facility (SCOF), Protein Crystallization Research Facility (PCRF), Image Processing Unit
  – KOBAIRO Rack – Gradient Heating Furnace (GHF),
  – SAIBO Rack – Cell Biology Experiment Facility (CBEF), Clean Bench (CB),
  – Multipurpose Small Payload Rack - Combustion Chamber

• 2013 Fundamental Physics NRA
  – 4-5 selections
  – 5 year grant
  – Facility: EXPRESS Rack
  – Purpose: To participate in Cold Atom Laboratory experiment
  – Theme: Cold atom research at temperatures inaccessible on earth. Bose-Einstein studies to ~1 Pico-Kelvin in microgravity is possible vs 350 Pico-Kelvin achieved on earth. In microgravity it is possible to hold cold atoms in extremely weak traps, because the atoms need not be supported against gravity.
• 2014 Fluid Physics NRA
  – 6 selections
  – 5 year grant
  – Facility: FIR or MSG.
  – Theme: Multiphase Flow and Heat transfer in areas such as: Flow Boiling, Zero Boil Off for Cryogenic fluids, and Heat Pipes. May include on orbit experiments such as FBCE, MFHT

• 2015 Materials Science NRA
  – 6-10 selections
  – 5 year grant
  – Possible themes: Diffusion Measurements or Composite Materials
  – Facility: MSG.

• 2016 Combustion Science NRA
  – 4 selections
  – 5 year grant
  – Facility: CIR or MSG.
  – Possible themes: combustion studies in droplet, gaseous, solid fuels or premixed flames. May include on-orbit experiments: FLEX, SLICE or BASS
Experiments

- **Combustion Science**
  - Dust and Aerosol Measurement Feasibility Test (DAFT) [AP7]
  - Dust and Aerosol Measurement Feasibility Test-2 (DAFT-2) [AP7]
  - Smoke Aerosol Measurement Experiment (SAME) [AP7]
  - Smoke Aerosol Measurement Experiment Reflight (SAME-R) [AP7]
  - Smoke Point in Coflow Experiment (SPICE) [AP8]
  - Structure and Liftoff in Combustion Experiment (SLICE) [AP8]
  - Flame Extinguishment Experiment (FLEX) [AP8]

- **Complex Fluids**
  - Physics of Colloids in Space (PCS) [FP1]
  - Investigating the Structures of Paramagnetic Aggregates from Colloidal Emulsions (InSPACE) [AP5]
  - Investigating the Structures of Paramagnetic Aggregates from Colloidal Emulsions-2 (InSPACE-2) [AP5]
  - Shear History Extensional Rheology Experiment (SHERE) [AP5]
  - Shear History Extensional Rheology Experiment Reflight (SHERE-R) [AP5]
  - Shear History Extensional Rheology Experiment II (SHERE II) [AP5]
  - Binary Colloidal Alloy Test-3 (BCAT-3) [FP1]
  - Binary Colloidal Alloy Test- 4 (BCAT-4) [FP1]
COMPLETED ISS EXPERIMENTS, DEMONSTRATIONS, FACILITIES, AND INSERTS FROM THE PHYSICAL SCIENCES RESEARCH PROGRAM SINCE 2001*

• Fluid Physics
  – Capillary Flow Experiments (CFE) [AP2]
  – Constrained Vapor Bubble (CVB) [TSES1]
  – Microheater Array Heater Boiling Experiment (MABE) [AP1]
  – Nucleate Pool Boiling Experiment (NPBX) [AP1]
  – Capillary Channel Flow (CCF) [AP2]

• Fundamental Physics
  – Gradient Driven Fluctuation Experiment (GRADFLEX) [Free Flyer] [AP5]
  – Dusty Plasma (PK-3) [AP5]
  – Dusty Plasma (PK-3+) [AP5]

• Materials Science
  – Solidification Using a Baffle in Sealed Ampoules (SUBSA) [AP9]
  – Pore Formation and Mobility Investigation (PFMI) [AP9]
  – Coarsening in Solid-Liquid Mixtures (CSLM) [AP9]
  – Coarsening in Solid-Liquid Mixtures-2 (CSLM-2) [AP9]
  – Coarsening in Solid-Liquid Mixtures-2 Reflight (CSLM-2R) [AP9]
  – Comparison of Structure and Segregation in Alloys Directionally Solidified in Terrestrial and Microgravity Environments (MICAST/CSS) [AP9]
  – Directional Solidification Insert/Experiment (DSI) [AP9]
  – In-Space Soldering Investigation (ISSI) [AP10]
COMPLETED ISS EXPERIMENTS, DEMONSTRATIONS, FACILITIES, AND INSERTS FROM THE PHYSICAL SCIENCES RESEARCH PROGRAM SINCE 2001*

Demonstrations
• Preliminary Advanced Colloids Experiment (PACE)
• Preliminary Advanced Colloids Experiment-2 (PACE-2)
• Light Microscopy Module Biology Demonstration-1 (LMM/Bio-1)
• Light Microscopy Module Biology Demonstration-2 (LMM/Bio-2)

Inserts
• Multi-User Droplet Combustion Apparatus (MDCA)
• Light Microscopy Module (LMM)
• Materials Science Laboratory-Low Gradient Furnace (MSL-LGF) [ESA]
• Materials Science Laboratory-Solidification Quench Furnace (MSL-SQF) [ESA]

Facilities
• Combustion Integrated Rack (CIR)
• Fluids Integrated Rack (FIR)
• Materials Science Research Rack (MSRR)
• Microgravity Science Glovebox (MSG) [ESA]
• Dispositif pour l’Etude de la Croissance et des Liquide Critiques (DECLIC) [CNES]

* Experiments written in blue were built by non-NASA space agencies.
Summary - ESAS

• After ESAS, October 2005, the Physical Sciences Research Program
  – Five flight experiments in development and four in operations on the ISS.
  – Three facilities and two inserts were under development.
  – In parallel, ESA was developing two inserts
  – CNES was building one facility.

• Between October 2005 and May 2012, the Physical Sciences Research Program has conducted
  – 25 flight experiments on the ISS, of which 20 were developed by NASA, one
    Free Flyer experiment, two ISS Facilities, and two inserts.
  – One Facility was completed by the ISS program office, two inserts by ESA and
    one Facility by CNES.
  – Annual NRAs have been released from 2008 to 2011 in the disciplines of Fluid
    Physics, Combustion Science, Materials Science, and Fundamental Physics.
  – U.S. selections were made from the ESA 2009 AO.
Summary - Decadal Survey

• All of the Physical Sciences Research Program experiments fit within the Decadal Survey high priority recommendations selected by the Steering Committee.
  – There are currently 53 experiments under development.
    ▪ Twenty-six of these experiments are being developed by NASA
    ▪ Twenty-seven by other space agencies.
  – Two experiments (ZBOT, ZBOT-2) are coordinated with OCT’s cryogenic CPST tech demo and one life-support related experiment (PBRE) with ISS.
  – Current solicitation plan is to release a Complex Fluids NRA in 2012.
  – Fundamental Physics NRA may be released in 2013 to support the Cold Atom Laboratory.
  – Selections will be considered for the 2012 JAXA KIBO AO.

• There are five recommended areas of research that have little or no research being conducted:
  – AP3 - Dynamic granular Material Behavior to understand lunar and Martian soil mechanics,
  – AP4 - Dust Mitigation for human and robotic exploration of planetary bodies and
  – TSES14 - Space Nuclear propulsion systems including liquid metal cooling and thawing and system dynamics.
  – TSES1 – Active 2-phase flow questions relevant to thermal management.
  – FP3 – Quantum Gases
  – These areas could be funded through support by the ISS Program Office or through funding of 2015 initiative proposals to be considered as an overguide
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Description and Objectives:

- **Scientific Merit**: High quality research on the physics and applications of quantum gases. No current PIs in this highest Decadal priority area (FP3)
- **Technical Description**: multi-user ultra-cold atom facility
- **Physical Description**: Three EXPRESS rack lockers.
- **Objectives**: Cold atom research at temperatures inaccessible on earth. Bose-Einstein studies to ~1 Pico-Kelvin in microgravity is possible vs 350 Pico-Kelvin achieved on earth. In microgravity it is possible to hold cold atoms in extremely weak traps, because the atoms need not be supported against gravity.
- Demonstrate technology for next generation gyroscopes, accelerometers, and gravimeters in space.
- Implementation: In-house JPL build reliant on COTS hardware.

Approach:

- Upmass: 95 Kg
- Downmass: 0 Kg
- ISS Facility: EXPRESS rack accommodation in 3 lockers
- Initial study team includes Nobel Laureate
- **NRA used to select additional 4-5 investigators**
- Direct involvement of Graduate Students in research and EPO
- Includes 12 months ISS utilization
- Class D hardware classification; COTS for avionics and laser/optics
- JPL internal build for Coil and laser drivers
- Modular software approach allows easy bench testing

Collaborators/Roles:

Rob Thompson, JPL: Principal Investigator
William Phillips, NIST: Science team member (Nobel Laureate)
Dana Anderson, Colorado State: Atom chip
TBD, JPL: Project Manager

Justification:

- **ISS Justification**: Requires microgravity for long durations.
- **Value to Agency (Space Benefit)**
  - NASA has NO current activity in this highest priority Decadal survey research area.
  - Adds highest quality science to ISS research portfolio.
  - Pathfinder for future space based cold atom-based quantum sensors for space navigation. (Gyroscopes, accelerometers, and gravimeters)
- **Value to Public (Earth Benefit)**
  - Superb EPO potential through evoking Einstein and using Coldest spot in the Universe tag-line.
  - Train Graduate Students to be tomorrow's innovators.
  - Improved performance cold atom-based quantum sensors for smart navigation (military), scientific research, and resource prospecting (gradiometers).

**Point of Contact**: robert.j.thompson@jpl.nasa.gov

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**CAL EXPRESS rack implementation**

**Bose-Einstein Condensate**

**Upmass**: 95 Kg

**Downmass**: 0 Kg

**ISS Facility**: EXPRESS rack accommodation in 3 lockers

**Initial study team includes Nobel Laureate**

**NRA used to select additional 4-5 investigators**

**Direct involvement of Graduate Students in research and EPO**

**Includes 12 months ISS utilization**

**Class D hardware classification; COTS for avionics and laser/optics**

**JPL internal build for Coil and laser drivers**

**Modular software approach allows easy bench testing**
DECLIC is a multi-user facility to investigate low and high temperature critical fluids behavior, chemical reactivity in supercritical water, directional solidification of transparent alloys, and more generally transparent media under micro-gravity environment on board the International Space Station (ISS).

DECLIC is designed for remote science control, commonly called "Tele-science". Operation capabilities will offer scientists the possibility to remotely visualize and modify their selected experiment conditions in the ISS from User Home Base through CADMOS User Support and Operation Centre. Due to the interest of French and US scientific laboratories to co-operate in these fields of research, DECLIC has become a CNES-NASA co-operative project.
**Critical Phenomena study using CNES’ DECLIC ALI**

**U.S. PI:** Dr. Inseob Hahn, JPL  
**CNES Team:** Drs. Daniel Beysens and Yves Garrabos

**NASA Objectives and Contributions:**
- Study the temperature and density relaxation behavior near the critical point of a room temperature sample fluid (SF$_6$) in both single and two-phase region
- Measurement of thermal diffusivity, heat capacity, turbidity, density in two-phase
- Establish an ESA-NASA collaboration for further utilization of DECLIC for studies of critical phenomena and fluid physics

**Relevance/Impact:**
- Critical phenomena of fluids is used as a well-defined testbed to understand physical behavior that can be extrapolated to complex systems used in space applications
- Ultimately tests the Nobel prize winning theory which is used to predict behavior in varied complex systems.

**Development Approach:**
- DECLIC and ALI Hardware developed by CNES
- Hardware launched by NASA (April, 2010)
- Utilize interferometric capability of the instrument to perform the NASA investigation.
- Partner with CNES investigators on all ALI investigations.
CFE-2 Vane Gap Unit - Video
Capillary Channel Flow (CCF)

Summary: CCF was launched to the International Space Station on STS-131 (Flight 19A) on April 5, 2010. Installation in the Microgravity Science Glovebox and checkout of the CCF hardware occurred the week of December 27, 2010. The CCF experiment operations for Experiment Unit #1 (EU #1) commenced the first week of January 2011 and near 24/7 operations were performed though March 17, 2011. CCF was reinstalled on Sept. 13, 2011 and EU#2 was operated 24/7 from September 25 thru October 17, 2011.

Description: The CCF objective is to investigate the free surface shapes and performance limits, critical flow velocities, for open capillary channel flows in microgravity. The EU# 1 completed the test matrix for the parallel plate and groove geometries. The EU#2 completed the test matrix for the wedge geometry and include critical flow velocities and passive phase separation.

Space Application: To enable design of spacecraft tanks that can supply gas-free propellant to spacecraft thrusters, directly through capillary vanes, significantly reducing cost and weight, while improving reliability. Also has application to passive phase separation of liquid-gas flows in spacecraft life support systems.

Earth Application: CCF will verify model predications for a number of critical conditions where maximum flow rate occurs. This research is required to update the current models, which do not adequately predict the maximum flow rate through the capillary vanes.

More information: http://issresearchproject.grc.nasa.gov/MSG/CCF

PI: Prof. Michael Dreyer, ZARM
Co-I: Prof. Mark Weislogel, PSU
PS: Robert D. Green, GRC
PM: Robert Hawersaat, NASA GRC

Increment 29 commander, Mike Fossum, discussing CCF prior to re-installing with EU#2 in the Microgravity Science Glovebox on ISS on 9/13/2011

CCF science image of EU #1 test cell with groove channel

Free surface (liquid /gas interface

Flow direction
**Capillary Channel Flow Experiments on the ISS**

**ESA PI:** Prof. Michael Dreyer, ZARM  
**Co-I:** Prof. Mark Weislogel, Portland State University  
**PM:** Robert Hawersaat, NASA GRC  
**PS:** Robert Green, NASA GRC

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**Objectives**

- To enable design of spacecraft tanks that can supply gas-free propellant to spacecraft thrusters, directly through capillary vanes, significantly reducing cost and weight, while improving reliability.

- **Experiment #1 (EU#1)**
  - Determine critical flow-rates (choking) in the capillary-inertial regime as a function of channel length for true channel and half channel.
  - Probe the nature of critical behavior by introducing wave oscillation of variable amplitude and frequency for both channel configurations and variable lengths.

- **Experiment #2 (EU#2)**
  - Determine critical flow rates (choking) in the capillary-inertial, visco-capillary, and overlap regimes for wedge channels as a function of channel length.
  - Probe the nature of bubble transport, migration, and phase separation as a function of flow rate, channel length, bubble diameter and frequency.

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**Topics**

- Experimental studies of open capillary channel flow stability.
- Two experiment units with three different channel geometries.
- Steady, oscillating, unsteady, and two-phase flow conditions.
- Total of 50 days of effective experimental time aboard the ISS.
- Main ground station located at ZARM in Bremen, Germany.
- Interactive access to the ISS for controlling and data download.

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**Motivation: capillary channel flow in surface tension tanks**

Capillary channels with free liquid surfaces are widely used for propellant management in surface tension tanks. Vanes provide channels of various shapes to transport the liquid to the outlet. The free surfaces have to withstand the pressure difference and prevent gas ingestion; the stability is of significant importance for the spacecraft propulsion system.

**Experimentally investigated geometries of capillary channels**

Two experiment units (EU#1, EU#2) provide three different channel geometries, each with one or two free liquid surfaces. The plates are manufactured of glass for camera observation and surface image analysis; $a=5 \text{ mm}$, $b=25 \text{ mm}$, $H=30 \text{ mm}$, $\alpha=7.9^\circ$, variable length $l=0...48 \text{ mm}$.  

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- - - Kugeltank drop tower video - - -