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

Combustion Science

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

Biophysics

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

Fluid Physics

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

Materials Science

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

Fundamental Physics

- Space Optical/Atomic Clocks
- Quantum test of Equivalence Principle
- Cold atom physics
- Critical point phenomena
- Dusty plasmas

Complex Fluids

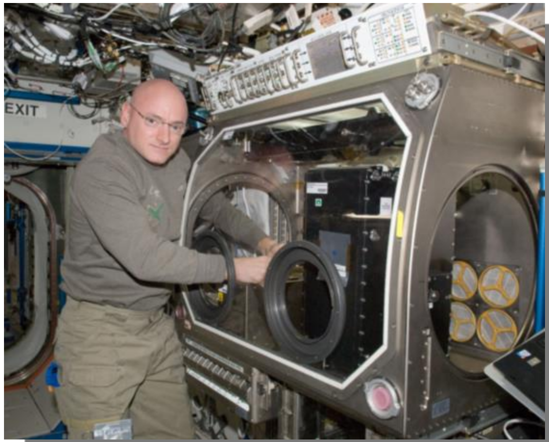
- Colloids
- Liquid crystals
- Foams
- Gels
- Granular flows

ISS Facilities for Physical Sciences Research

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

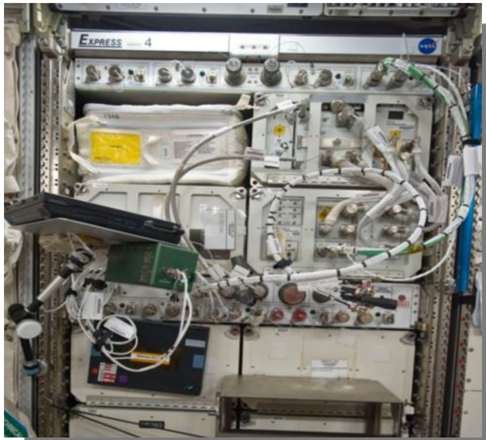
Astronaut Frank DeWinne completing installation in the MSRR prior to on-orbit commissioning October 2009

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



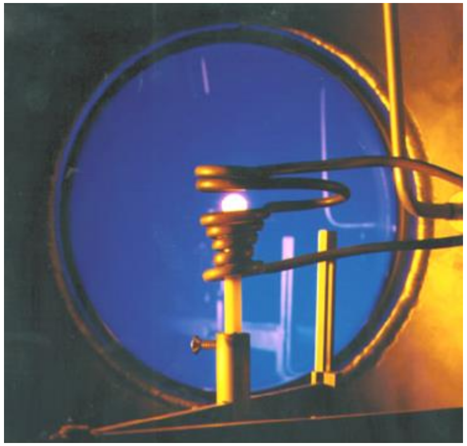
Increment 26 commander Scott Kelly installing CCF in the Microgravity Science Glovebox on ISS

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

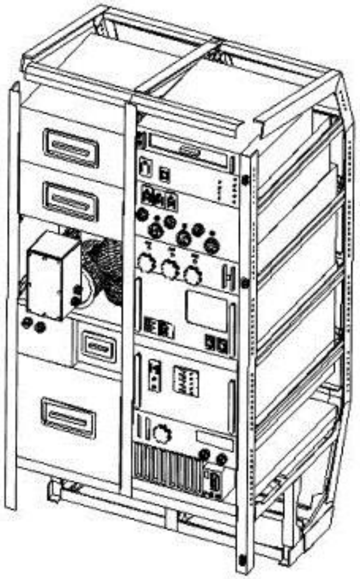


DECLIC installed in an EXPRESS Rack on board ISS

New ISS Facility: Material Science Laboratory Electromagnetic Levitator (MSL-EML)



Coil system for both positioning and heating



- 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 Collaboration

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

Physical Sciences Program Content

NASA's International Cooperation in Physical Sciences on ISS

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

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

Theme	Acronym	Experiment	International Partners							
			ESA	JAXA	CSA	ROS COS MOS	CNES	DLR	ASI	KARI
Combustion Science	SOFIE (5 teams)	Solid FLAmabiity of Materials Experiment								
	BASS-2 (5 teams)	Burning and Suppression of Solids								
	FLEX-2 (5 teams)	Flame Extinguishment Experiment–2								
	FLEX-2J	Flame Extinguishment experiment– with JAXA		P						
	SCE	Solid Combustion Expt. - 2012 JAXA AO, Fujita, Olsen..(2015, MSPR)		S						
	GCE	Group Combustion Experiment - 2D droplet array		S						
	FLEX-ICE	Flame Extinguishment experiment–Italian Combustion Experiment							P	
	ISFSS	Int'l Standard of Fire Safety in Space – 2012 JAXA AO, Fujita,Olsen,etal (2016,MSPR)		S						
	ACME (5 teams)	Advanced Combustion via Microgravity Experiments (Gaseous)								
	SCWO (planned)	Super Critical Water Oxidation	P				P			
	SCWM	Super Critical Salt Water Mixture Experiment					S			

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			ESA	JAXA	CSA	ROS COS MOS	CNES	DLR	ASI	KARI
Complex Fluids	ACE (9 teams)	Advanced Colloids Experiment	P	P						P
	COLLOID	Colloidal Solids Experiment	S							
	PASTA-LIFT	PArticle STAbilized Emulsions and Foams–Liquid Film Tensiometer	S							
	Soft Matter Dynamics (formerly FOAM-C)	Foam Optics and Mechanics–Coarsening	S							
	BCAT-C1	Binary Colloidal Alloy Test-Canada 1			S					
	LCN	Liquid Crystal Nanoplates	P			P				
	InSPACE-3+	Investigating the Structure of Paramagnetic Aggregates From Colloidal Emulsions-3+								
	OASIS	Observation and Analysis of Smectic Islands in Space				P		P		
	VIPGRAN (COMPGRAN)	Compaction and Sound Transmission in Dense Granular Media	S							

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			ESA	JAXA	CSA	ROS COS MOS	CNES	DLR	ASI	KARI
Fluid Physics	FBCE	Flow Boiling and Condensation Experiment								
	RUBI	Reference mUltiscale Boiling Investigation	S							
	MFHT	Multiphase Flow with Heat Transfer using Thermal Platform	S							
	ZBOT	Zero Boiloff Tank Experiment								
	ZBOT-2	Zero Boiloff Tank Experiment - 2								
	ZBOT-3	Zero Boiloff Tank Experiment - 3								
	CCF	Capillary Channel Flow						S		
	CFE-2	Capillary Flow Experiment–2								
	DOLFIN II	Dynamics of Liquid Film/ Complex Wall Interaction	S							
	CVB-2	Constrained Vapor Bubble–2								
	EHD	Electro-HydroDynamic flow								
	PBRE	Packed Bed Reactor Experiment								
	TPFSE (2 teams)	Two Phase Flow Separator Experiment								
	JEREMI	JAXA Marangoni Flow Experiment (Narayanan, Kamotani)		S						
	VIPIL-Faraday (Planned)	ESA Vibration in Liquids experiment, planning stages (Narayanan)	S							

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			ESA	JAXA	CSA	ROS COS MOS	CNES	DLR	ASI	KARI
Fundamental Physics	ACES (5 teams)	Atomic Clock Ensemble in Space	S							
	SOC (planned)	Space Optical Clock	S							
	CAL (5 teams)	Cold Atom Laboratory								
	CAL -2	Cold Atom Laboratory - 2								
	QTEST (planned)	Quantum Weak Equivalence Principle	P							
	PK-4	Plasma Kristall–4	S							
	PLASMALAB (planned)	Kinetic studies of strongly coupled systems: Interdisciplinary Research with Complex Plasmas	S							
	ALI-R	Alice Like Insert - reflight					S			

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Theme	Acronym	Experiment	International Partners							
			ESA	JAXA	CSA	ROS COS MOS	CNES	DLR	ASI	KARI
Materials Science	CSLM-4	Coarsening of Dendritic Solid-Liquid Mixtures-4								
	DSI-R/SPADES	Spatiotemporal Evolution of Three-Dimensional Dendritic Array Structures					S			
	MICAST	Microstructure Formation in Castings	S							
	CETSOL	Columnar to Equiaxed Transition in Solidification Processing	S							
	SETA	Solidification along an Eutectic path in Ternary Alloys	S							
	METCOMP	Metastable solidification of Composites	S							
	SISSI	Silicon ISS Investigation	S							
	CET	Columnar to Equiaxed Transition								
	ICEAGE	Influence of Containment on the Growth of Silicon Germanium								
	CGTS (CdTe)	Crystal Growth of Ternary Compound Semiconductors								
	IE-ELF	Interfacial Energy- Electrostatic Levitator Furnace – 2012 JAXA AO, Watanabe, Heyers, et al. (2017, ELF)		S						
	GEDS	Gravitational Effects in Distortion in Sintering								
	FAMIS	Formation of Amorphous Metallics In Space								
	FOG	Formation of Gasarities								
	THERMOLAB	Thermophysical Properties of Liquid Metallic Alloys	S							
	ICOPROSOL	Thermophysical properties and solidification behavior of undercooled Ti-Zr-Ni liquids showing in icosahedral short-range order	S							
	PARSEC	Peritectic Alloy Rapid Solidification with Electromagnetic Convection	S							

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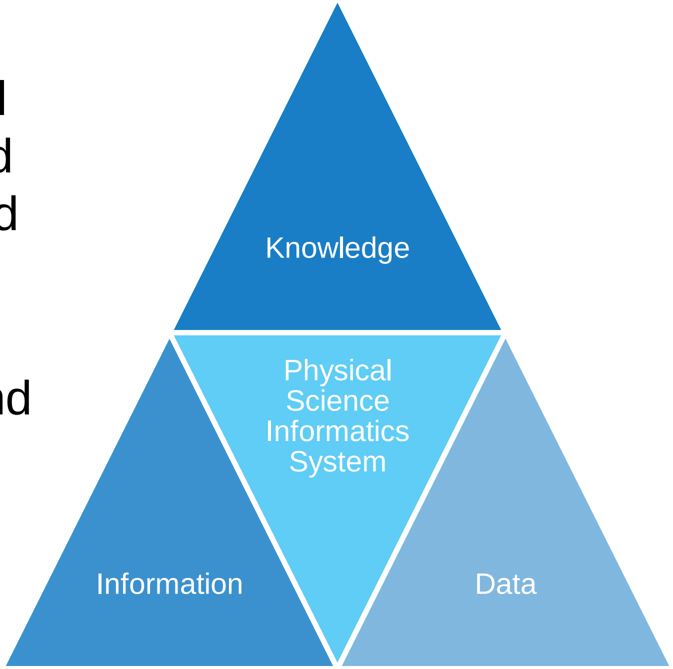
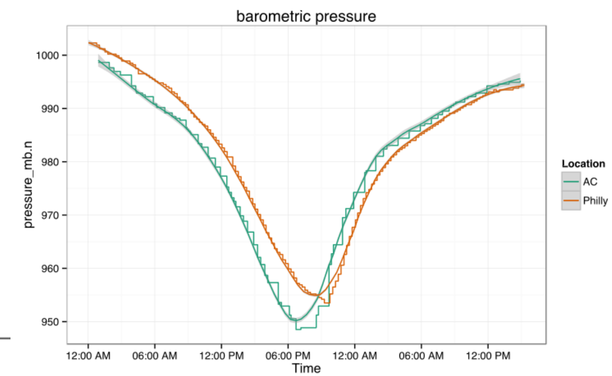
Objective

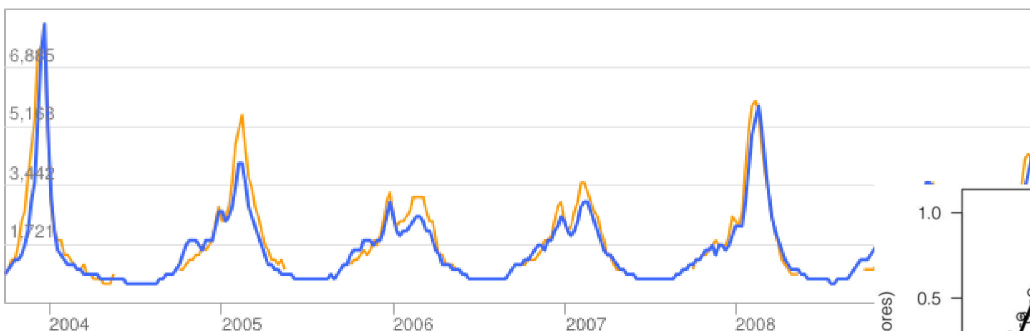
- Physical Science Informatics system implements Office of Science and Technology Policy (OSTP) memorandum, Feb. 22, 2013 entitled “Increasing Access to the Results of Federally Funded Scientific Research” by enabling multiple researchers simultaneous, **open-science,** access to synergistically build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

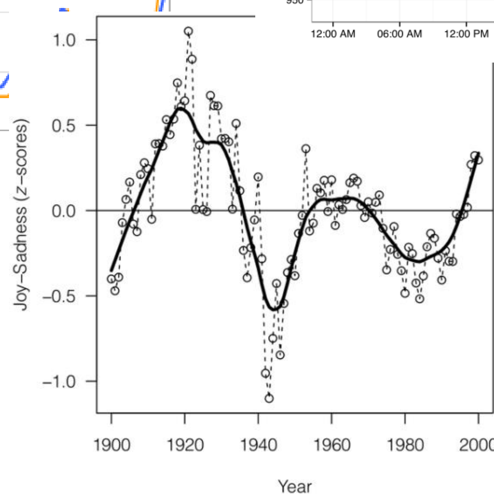


Open Science Examples

- 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:



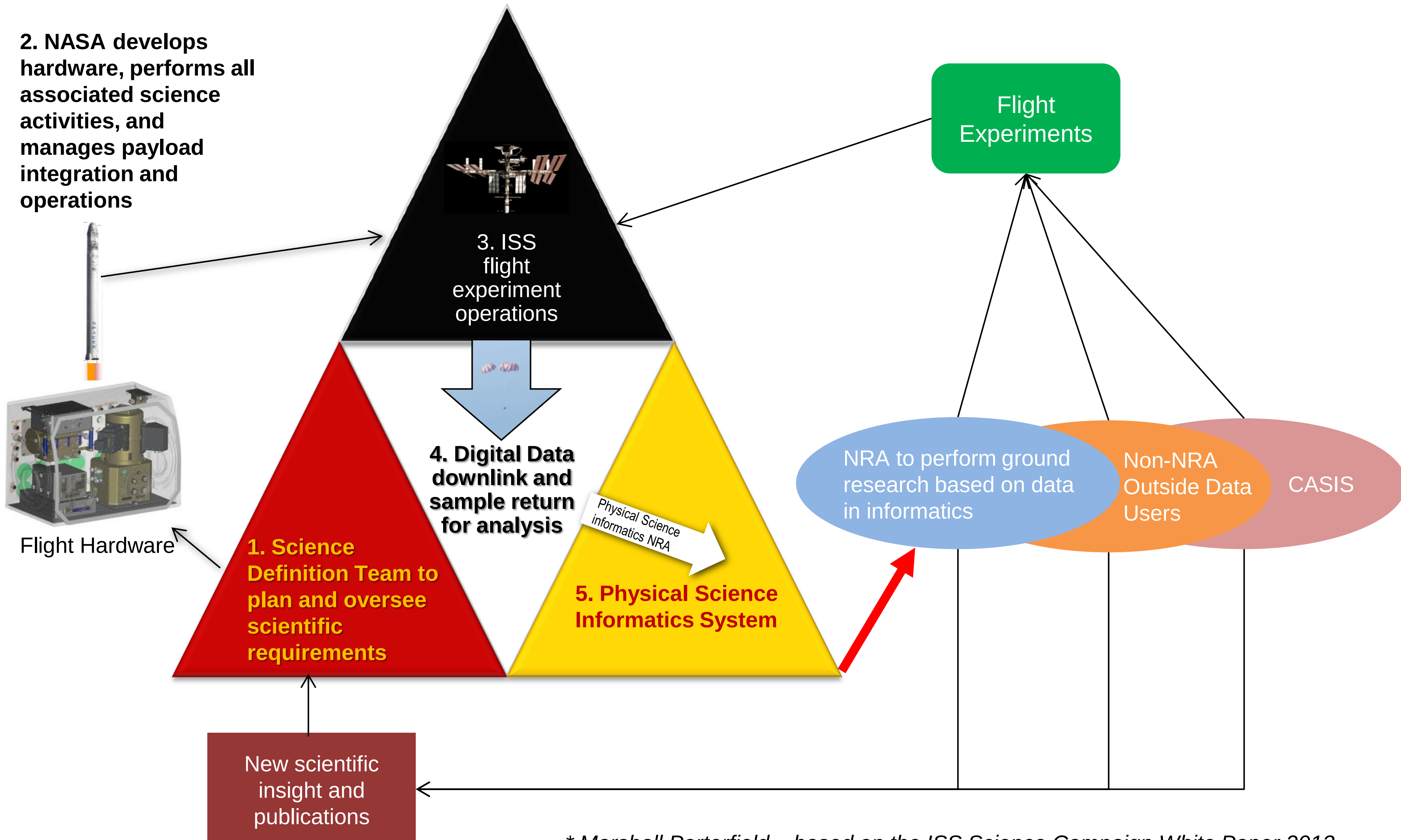




- Tracking Hurricane Sandy: Barometric pressure data from local weather stations, available on-line, accurately track the storm’s path.

- 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.

DATA DISSEMINATION
Physical Sciences Informatics System*



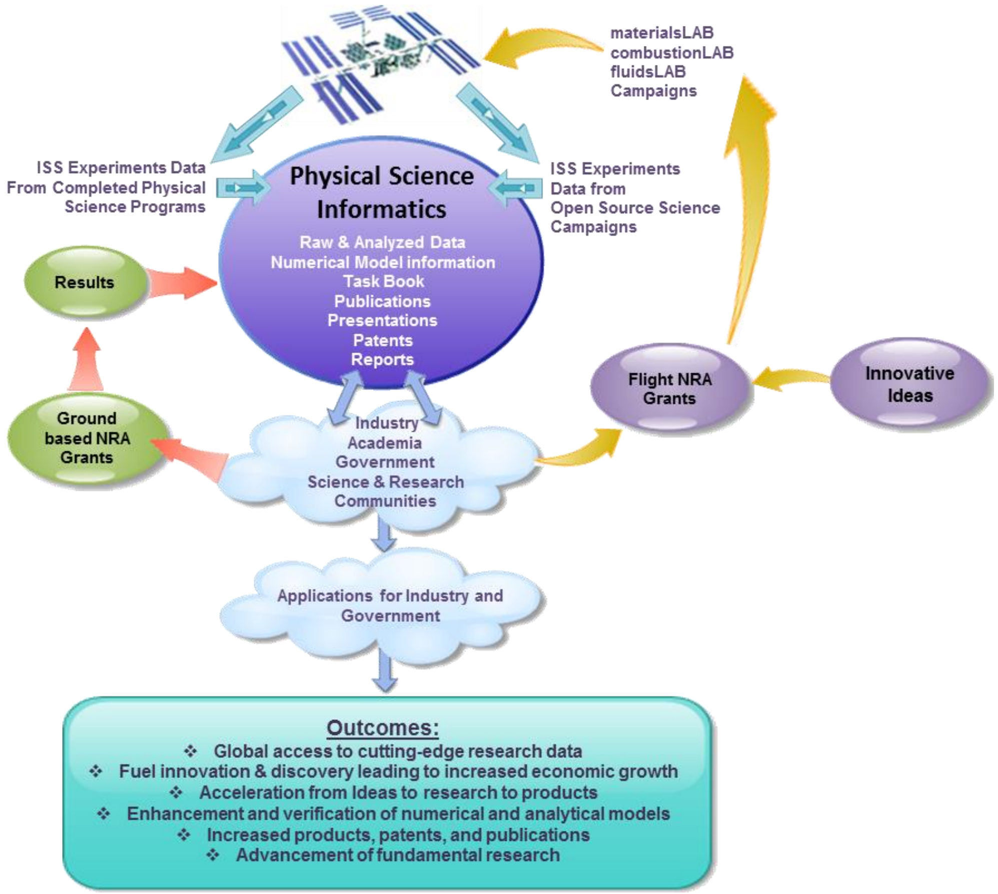
* *Marshall Porterfield – based on the ISS Science Campaign White Paper 2013*

- Open Science Concept

MaterialsLab - Vision

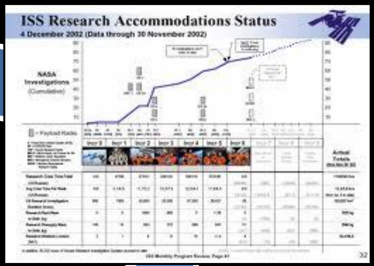
From Microgravity Science to Open Science Informatics

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

Engineering-Driven Science

Partners:
Industry
Academic institutions
DOD
Other Government agencies
International partners
NASA
CASIS

Physical Sciences – MaterialsLab Open Source Science Campaign

- 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
- Registration: http://icpi.nasaprs.com/NASAmaterialsLABWorkshop2014

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

Rank	Experiment Topic/ Concept Title	Objective	Scientific/ Technical Merit	Microgravity Justification	Terrestrial Applications	Benefits to NASA	Significance / Impact	Research Partners (If Known)	Facilities (New or Existing)	Remarks
#1 High Priority	Understanding the microstructure and morphological development of dendritic array growth	To gather benchmark data for quantifying fundamental aspects (MGI)	Correlate process parameters with microstructure development	Isolate/ Eliminate thermosolutal convection and enable structure formation and minimize defects	Foundry/ forming processes (e.g. Turbine Blades, Vanes, Aero Structures	Successful utilization of ISS facility and objectives	To improve industrial applications and predictive models	Aerospace Automotive Biomedical, Forming, Academia	MSRR-LGF, MSRR-SQF, JAXA-GHF, JAXA-ELF, ESA-EML, MSG-CSML, MSG-PFMI, MSG-SUBSA	RFI ref:04;09;13;15;22;48;39

Summary Table for Metals (continued)

#2 High Priority	Thermo-physical 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/concentration convection	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;33;34;55;56;

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

NASA CombustionLab Workshop - Six Disciplines

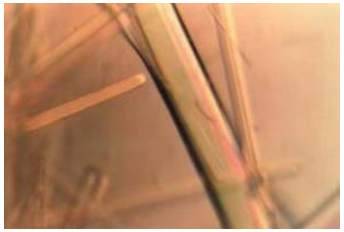
- **Fire Safety**
- **Droplets, Sprays and Aerosols**
- **Premixed Flames**
- **Non-premixed Flames**
- **Heterogeneous Reaction Processes**
- **High Pressure and Supercritical Reacting Systems**

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**

Representative Experiments

Macromolecular Biophysics (MMB-MB-1-3)



Crystallized structure of a nucleosome core particle that was grown aboard the Mir space station. (NASA)

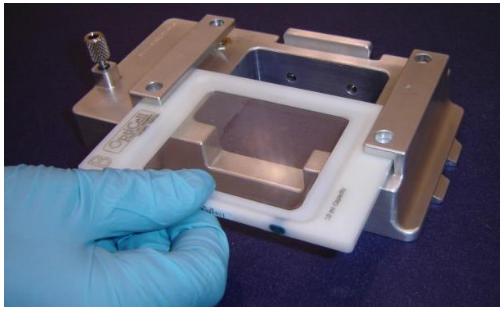
Macromolecular Biophysics (MMB-MB 1-3)

Principal Investigator: Larry DeLucas, UAB; Edward Snell, HWI; Peter Vekilov, UH

Project Scientist: Laurel Karr, MSFC, Patton Downey, MSFC, Sid Gorti, MSFC

Project Manager: Ronald Sicker, NASA GRC

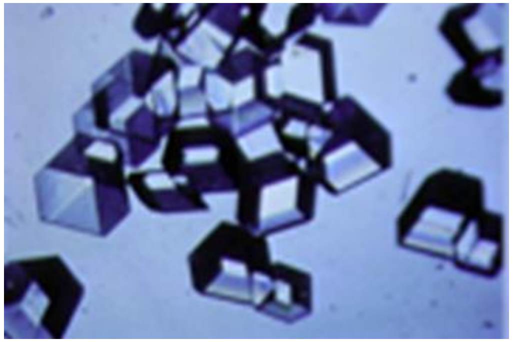
Engineering Team: ZIN Technologies, Inc.



Existing LMM/ACE sample holder

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.



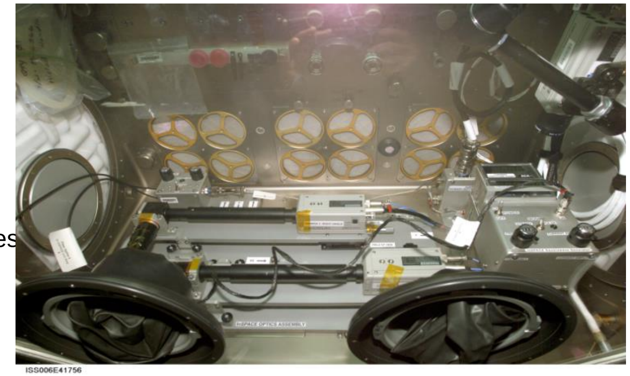
Insulin Crystals grown in space (DeLucas)

Investigating the Structures of Paramagnetic Aggregates from Colloidal Emulsions-3+, (InSPACE-3+)

WBS: 904211.04.02.30.06

Glenn Research Center

PI: Professor Eric Furst, University of Delaware
PS: Dr. Robert Green, NASA GRC
DPS: Lauren Sharp, NASA GRC
PM: Nang Pham, NASA GRC
Engineering Team: ZIN Technologies



InSPACE in MSG

Vial Assembly

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 Helmholz 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.

ISS Resource Requirements

Accommodation (carrier)	Microgravity Science Glovebox
Upmass (kg) (w/o packing factor)	0.00 (samples and experimental hardware are stowed on ISS)
Volume (m^3) (w/o packing factor)	0.00 (samples and experimental hardware are stowed on ISS)
Power (kw) (peak)	0.030
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

Milestones	RDR	PDR	CDR	Ph III FSR	SAR	FHA	Launch	Ops	Return	Final Report
InSPACE-3+	NA	NA	5/2009	12/2010	2/2011	3/2011	5/2011	Dec 2013-Feb 2014	2nd QTR CY2014	Return + 1yr

InSPACE-3

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

Glenn Research Center

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.

(Left) BASS-II flow duct held by Astronauts Alex Gerst and Reid Wiseman; (Right) BASS-II team at the GRC Telescience Center.

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 GN_2 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 up-mass/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)

ISS Resource Requirements

Accommodation (carrier)	MSG
Upmass (kg) (samples, igniters, camera cards)	5 kg
Volume (m^3)	0.05 m^3
Power (kW) (peak)	50 W
Crew Time (hrs)	100 hrs
Autonomous Ops (hrs)	0 hrs
Launch/Increment (remaining launches/increments)	Orb-1, Inc. 39-40

Project Life Cycle Schedule

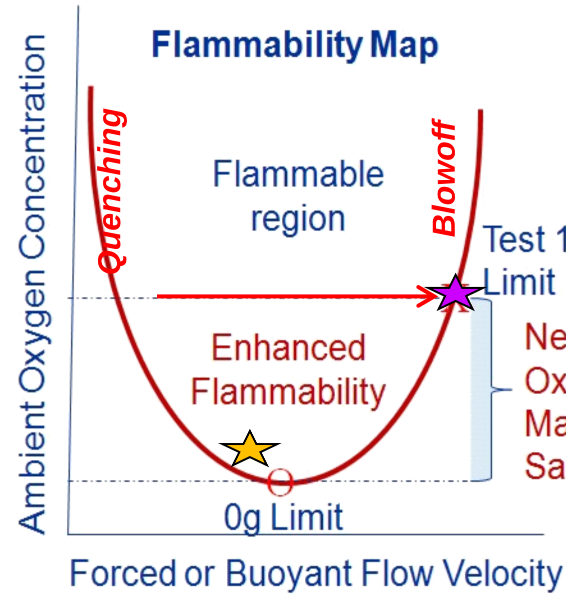
Milestones5	**Launch**	**Ops Start**	**Ops End**	**Final Report**
Actual/ Baseline	Jan 2014	Feb 2014	Aug 2014	Aug 2015

Revision Date: 8/21/2014

Materials flammability screening in 1g (NASA Test 1) is not conservative

Astronaut Rick Mastracchio running BASS-II in the MSG

- 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).



1g – limiting O_2 – 16%, just before blowoff

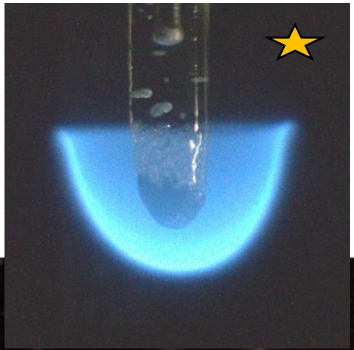
Blowoff in **0g**: dim flame strengthens but then blows off when flow is increased (1-20 cm/s).

16% O2 FLOW

Acrylic rods: Negative Oxygen Margin of Safety = 2.4% O2

Astronauts Alex Gerst and Reid Wiseman holding the BASS flow duct

0g ~ limiting O_2 – 13.6%



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

Glenn Research Center

Objectives:

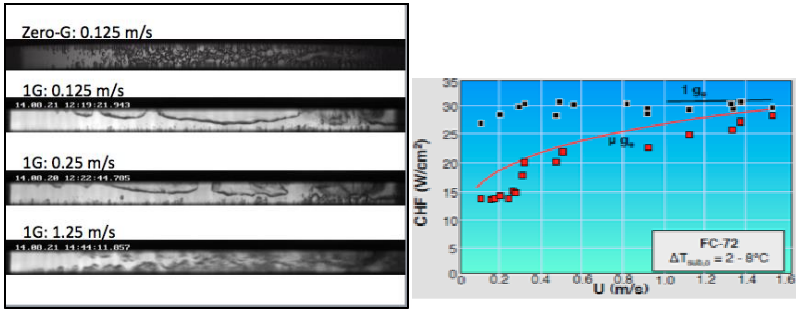
- Develop experimentally validated, gravity independent, mechanistic model for microgravity annular flow condensation and microgravity flow boiling critical heat flux (CHF).

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.



Critical Heat Flux (CHF) data and model predictions for microgravity and Earth gravity for flow boiling.

ISS Resource Requirements

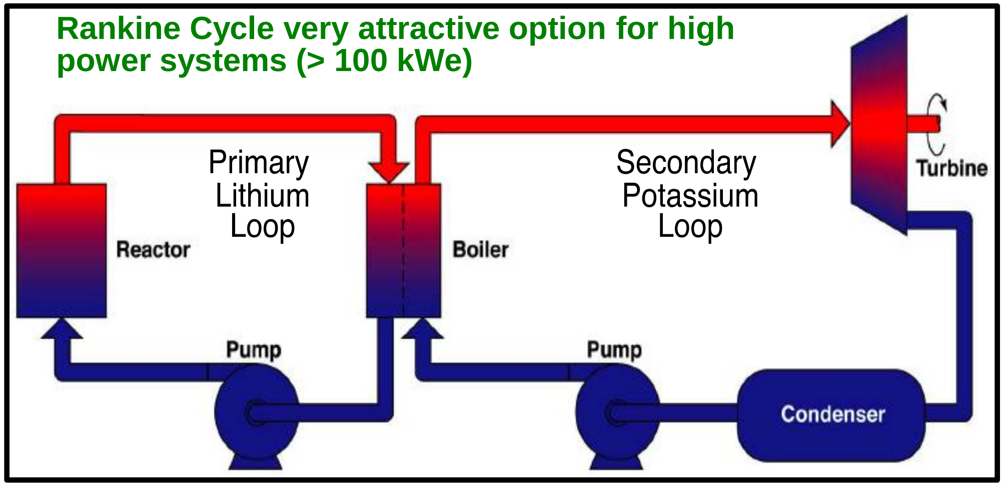
Accommodation (carrier)	Fluid Integrated Rack (FIR)
Upmass (kg) (w/o packing factor)	225 kg (estimated)
Volume (m^3) (w/o packing factor)	0.3 m^3 (estimated)
Power (kw) (peak)	2500W (estimated)
Crew Time (hrs) (installation/operations)	TBD
Autonomous Operation	6 months
Launch/Increment	12/2017

Project Life Cycle Schedule

Milestones	SCR	IDR	RDR	PDR	CDR	Ph III Safety	FHA	Launch	Ops complete	Final Report
FBCE	11/11	12/12	2/2014	3/2015	6/2016	8/2017	9/2017	12/2017	6/2018	12/2019

Flow Boiling and Condensation Experiment (FBCE)

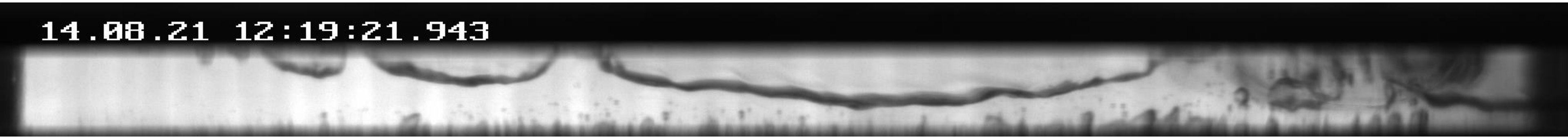
- Thermal management systems responsible for controlling temperature and humidity using Thermal Control System (TCS) consisting of Heat Acquisition, Heat Transport and Heat Rejection hardware.
- Refrigerator/freezer components provide cooling for science experiments and food storage.
- Advanced water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



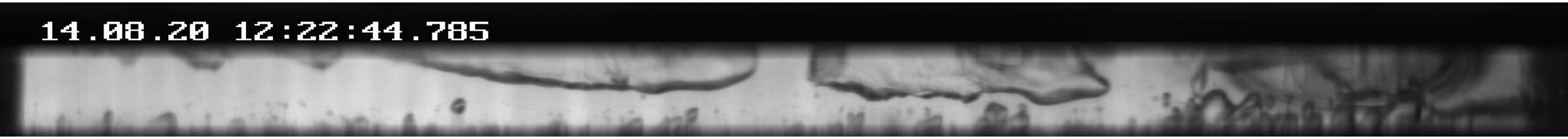
FBCE Flow Boiling Module Videos

Zero-G: 0.125 m/s

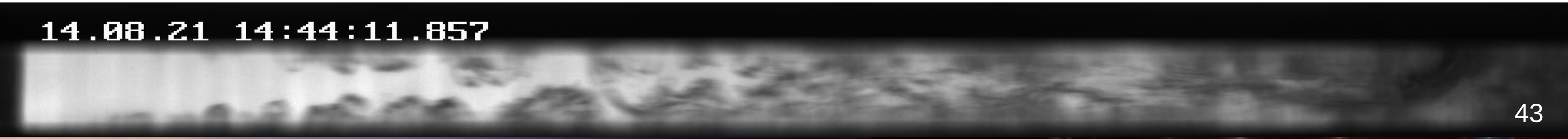
1G: 0.125 m/s



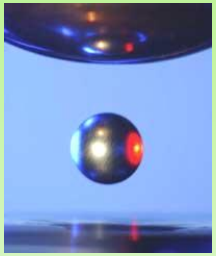
1G: 0.25 m/s

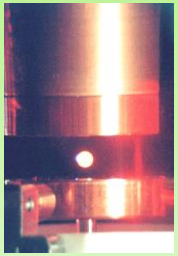


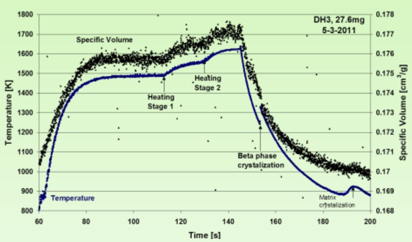
1G: 1.25 m/s

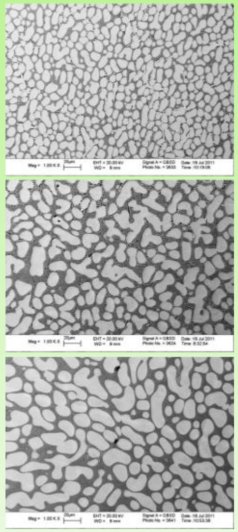


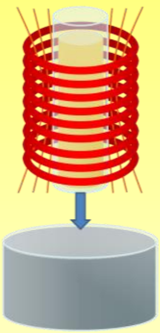
Study of Mushy-Zone Development in Dendritic Microstructures with Glass-Forming Eutectic Matrices

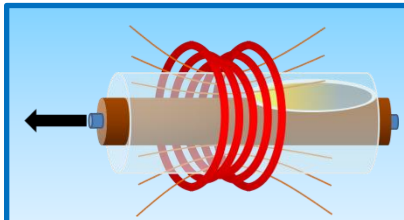


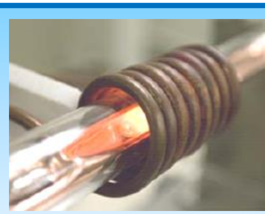


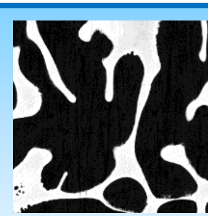












Technical Goals and Objectives

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 POC dch@jpl.nasa.gov Phone: (818) 731-6500	JPL/Caltech
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)

U.S. CSS PI: Prof. David Poirier, The University of Arizona
ESA MICAST Team Coordinator: Dr. L. Ratke, Inst. of Materials Physics in Space, DLR, Germany
ESA CETSOL Team Coordinator: Charles-André Gandin, ARMINES-ENSMP-CEMEF, Sophia Antipolis, France

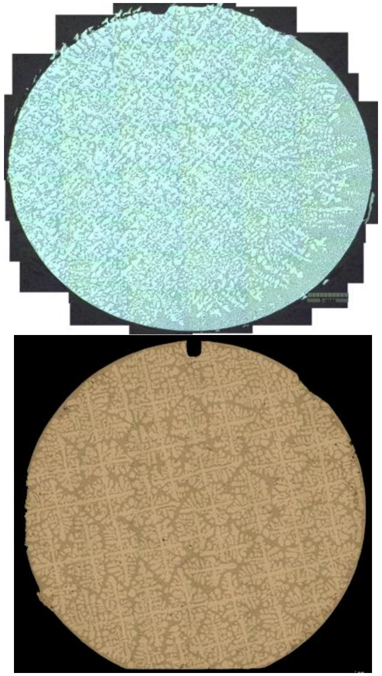
Summary:
The CSS Experiment is performed in the Materials Science Research Rack. The purpose is to determine microstructural development and provide insight regarding defect generation in directionally solidified dendritic alloys. The first US sample was processed aboard the ISS in the Low Gradient Furnace 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.

More information: ASM Handbook, Volume 15, Casting, p 445; Fluid Sciences and Materials Science in Space, Springer-Verlag, 1987, p. 477.



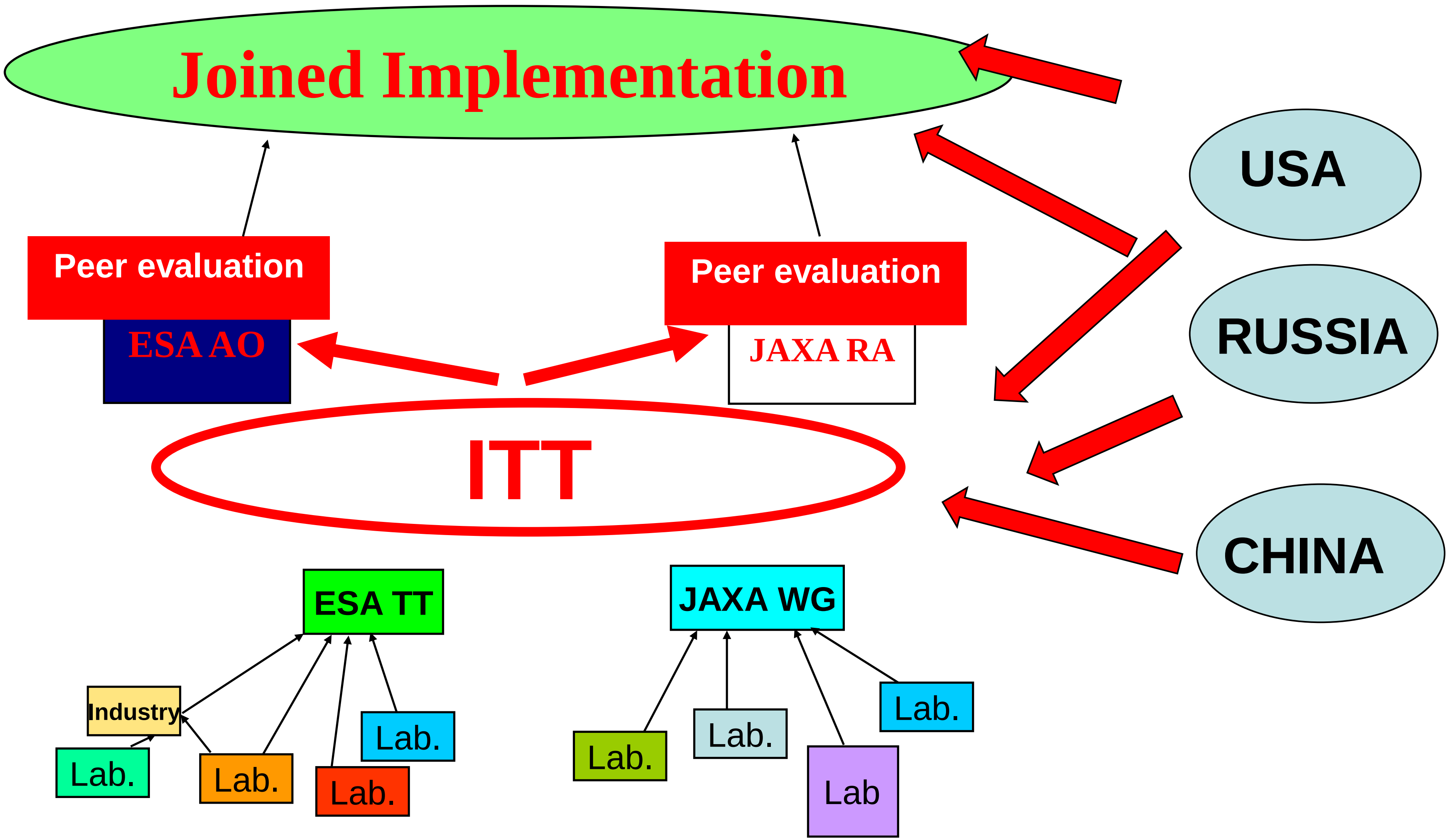
Top: The Al – 7wt.% Si sample solidified on Earth exhibits dendrite clustering due to gravity induced convection. Bottom: The sample grown in the quiescent microgravity environment of space exhibits a uniformly spaced dendritic network.

http://www.nasa.gov/exploration/multimedia/highlights

- BACK - UP

Topical Team Approach

INTERNATIONAL COOPERATION



Link to Space Technology

Exploration Driven

MAPPING

Physical Sciences Research to Space Technology Roadmaps

- 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*

Experiment Acronyms

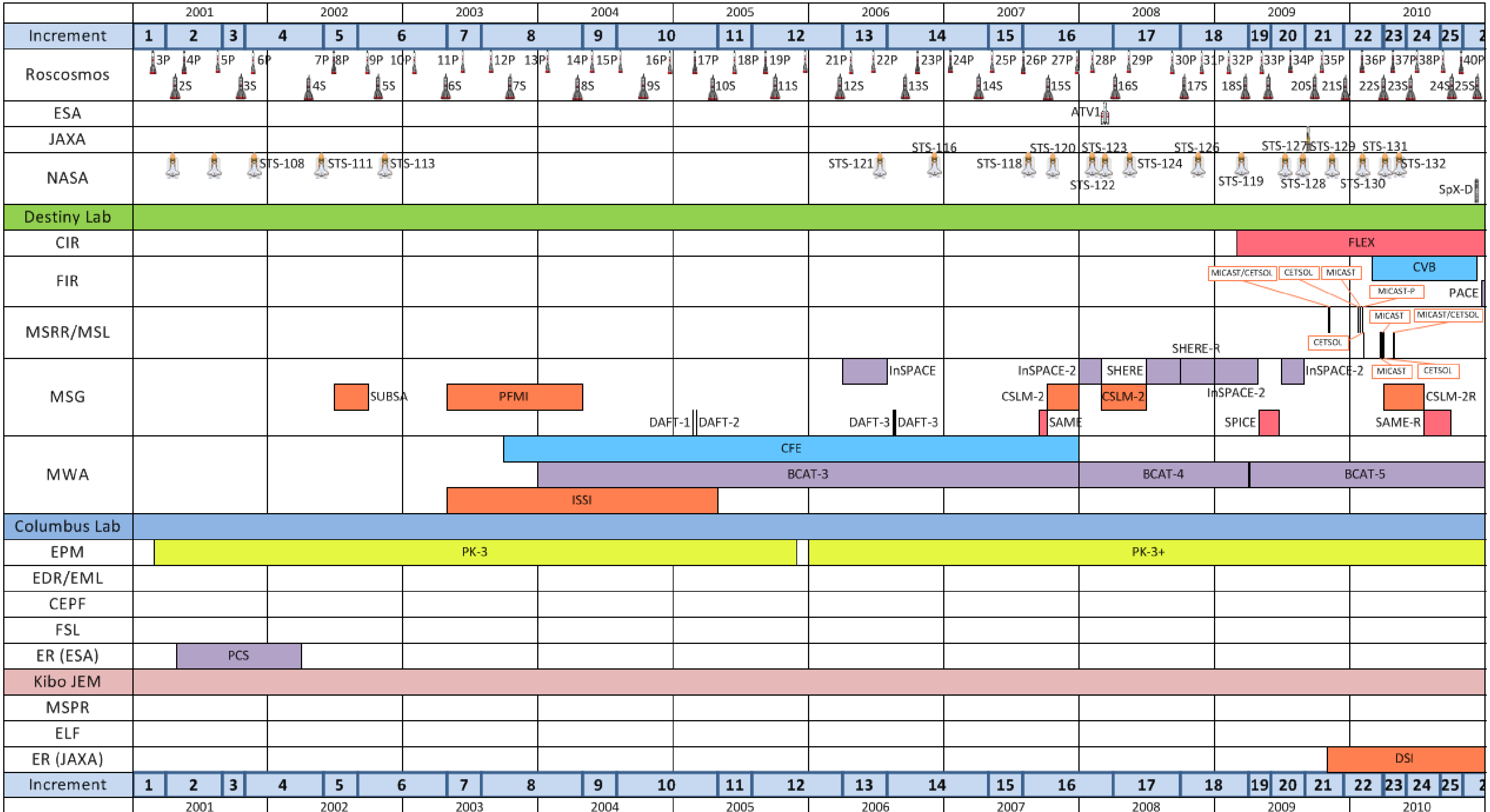
ACES	Atomic Clock Ensemble in Space
BASS	Burning and Suppression of Solids
CFE	Capillary Flow Experiment
CCF	Capillary Channel Flow
CVB	Constrained Vapor Bubble
EHD	ElectroHydroDynamic flow experiment
HPE-L	Heat Pipe Experiment - Loop
FAMIS	Formulation of Amorphous Metals in Space
FBCE	Flow Boiling and Condensation Experiment

MsFHT	Multiphase Flow And Heat Transfer Experiment
MVCS	Morphological study in Variable Cross Section
MWT-FS	Microgravity Wind Tunnel - Fire Safety
PBRE	Packed Bed Reactor Experiment
PBRE-A	Packed Bed Reactor Experiment - Applied
PBRR	Packed Bed Reaction Rate Experiment
SoFIE	Solid Fuel Ignition and Extinction
TPFSE	Two Phase Flow Separator Experiment
ZBOT	Zero Boil-off Tank Experiment

ISS Operations Schedule

Snapshot Date: 9/2/2014

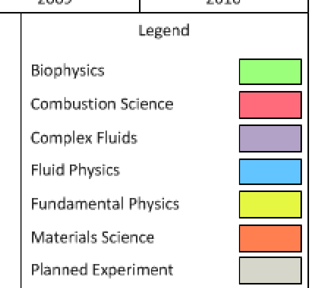
ISS Physical Sciences Traffic Model



ATV	Automated Transfer Vehicle
BCAT	Binary Colloidal Alloy Test
CEPF	Columbus External Payload Facility
CETSOL	Columnar-to-Equiaxed Tranistion in Solidification Processing
CFE	Capillary Flow Experiment
CIR	Combustion Integrated Rack
CSLM	Coarsening in Solid-Liquid Mixtures
CVB	Constrained Vapor Bubble
DAFT	Dust and Aerosol Measurement Feasibility
DSI	Directional Solidification Insert
EDR	European Drawer Rack
ELF	Electrostatic Levitator Furnace
EML	Electro-Magnetic Levitator
EPM	European Physiology Module
ER	Expedite the Processing of Experiments to Space Station Rack
ESA	European Space Agency

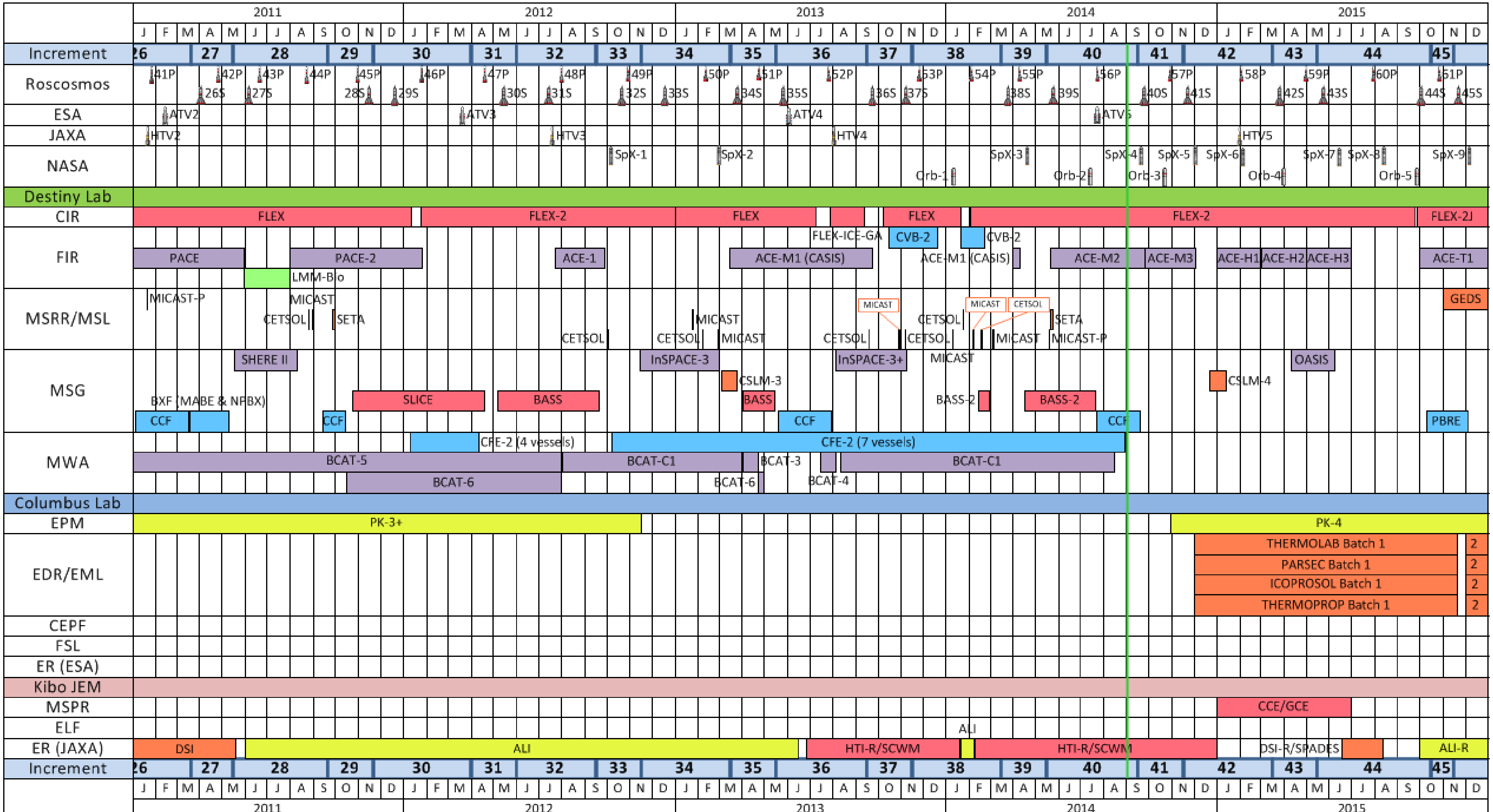
FIR	Fluids Integrated Rack
FLEX	Flame Extinguishment
FSL	Fluid Science Laboratory
HTV	H-II Transfer Vehicle
InSPACE	Investigating the Structures of Paramagnetic Aggregates from Colloidal
ISSI	In Space Soldering Investigation
JAXA	Japan Aerospace Exploration Agency
JEM	Japanese Experiment Module
MICAST	Microstructure Formation in Casting
MICAST-P	Microstructure Formation in Casting-Poirier
MSG	Microgravity Science Glovebox
MSL	Materials Science Laboratory
MSPR	Multi-Purpose Small Payload Rack
MSRR	Materials Science Research Rack
MWA	Maintenance Work Area
NASA	National Aeronautics and Space

PACE	Preliminary Advanced Colloids Experiment
PCS	Physics of Colloids in Space
PFMI	Pore Formation and Mobility Investigation
PK	Plasma Crystal
Roscosmos	Russian Federal Space Agency
SAME	Smoke Aerosol Measurement Experiment
SHERE	Shear History Extensional Rheology
SPICE	Smoke Point in Coflow Experiment
SpX	SpaceX
STS	Space Transportation System
SUBSA	Solidification Using a Baffle in Sealed



Snapshot Date: 9/2/2014

ISS Physical Sciences Traffic Model



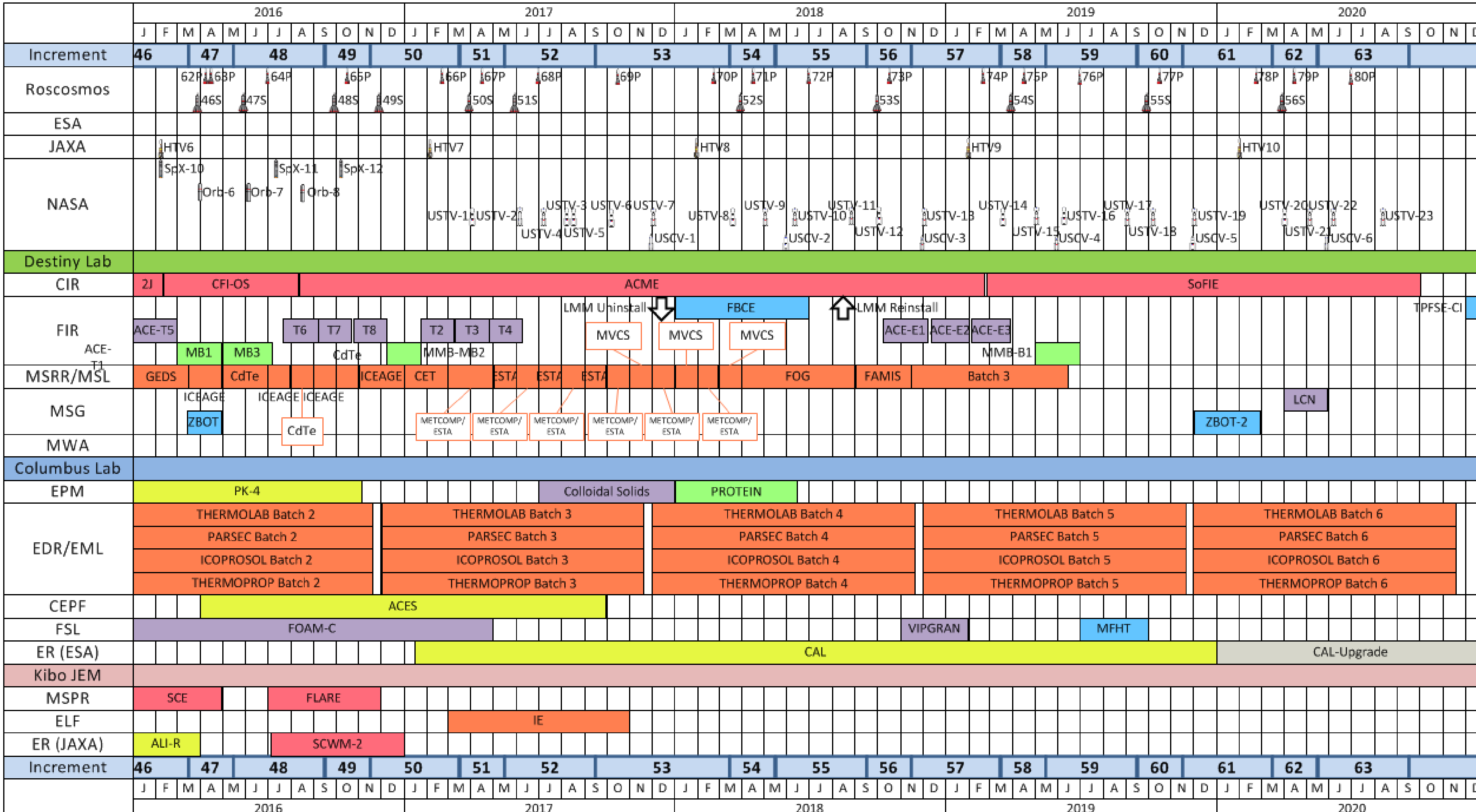
ACE	Advanced Colloid Experiments	ELF	Electrostatic Levitator Furnace	LMM	Light Microscopy Module	SCWM	SuperCritical Water Mixture
ALI	Alice Like Insert	EML	Electro-Magnetic Levitator	MABE	Microheater Array Heater Boiling	SETA	Solidification along an Eutectic path in Ternary Alloys
ATV	Automated Transfer Vehicle	EPM	European Physiology Module	MICAST	Microstructure Formation in Casting		
BASS	Burning and Suppression of Solids	ER	Expedite the Processing of Experiments to Space Station Rack	MICAST-P	Microstructure Formation in Casting-Poirier	SHERE	Shear History Extensional Rheology
BCAT	Binary Colloidal Alloy Test					SLICE	Structure and Liftoff In Combustion
BXF	Boiling Experiment Facility	ESA	European Space Agency	MSG	Microgravity Science Glovebox	SPADES	Spatiotemporal Evolution of Three-Dimensional Dendritic Array Structures
CASIS	Center for the Advancement of Science in	FIR	Fluids Integrated Rack	MSL	Materials Science Laboratory		
CCE	Chamber for Combustion Experiment	FLEX	Flame Extinguishment	MSPR	Multi-Purpose Small Payload Rack	SpX	SpaceX
CCF	Capillary Channel Flow	FSL	Fluid Science Laboratory	MSRR	Materials Science Research Rack	ZBOT	Zero Boil-Off Tank
CEPF	Columbus External Payload Facility	GCE	Group Combustion Experiment	MWA	Maintenance Work Area		
CETSOL	Columnar-to-Equiaxed Tranistion in Solidification Processing	GEDS	Gravitational Effects on Distortion in	NASA	National Aeronautics and Space		
		HTI-R	High Temperature Insert	NPBX	Nucleate Pool Boiling Experiment		
CFE	Capillary Flow Experiment	HTV	H-II Transfer Vehicle	OASIS	Observation and Analysis of Smectic Islands in Space		
CIR	Combustion Integrated Rack	ICE-GA	Italian Combustion Experiment for Green				
CSLM	Coarsening in Solid-Liquid Mixtures	InSPACE	Investigating the Structures of Paramagnetic Aggregates from Colloidal	Orb	Orbital		
CVB	Constrained Vapor Bubble			PACE	Preliminary Advanced Colloids Experiment		
DSI	Directional Solidification Insert	JAXA	Japan Aerospace Exploration Agency	PK	Plasma Crystal		
EDR	European Drawer Rack	JEM	Japanese Experiment Module	Roscosmos	Russian Federal Space Agency		

Legend

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

Snapshot Date: 9/2/2014

ISS Physical Sciences Traffic Model

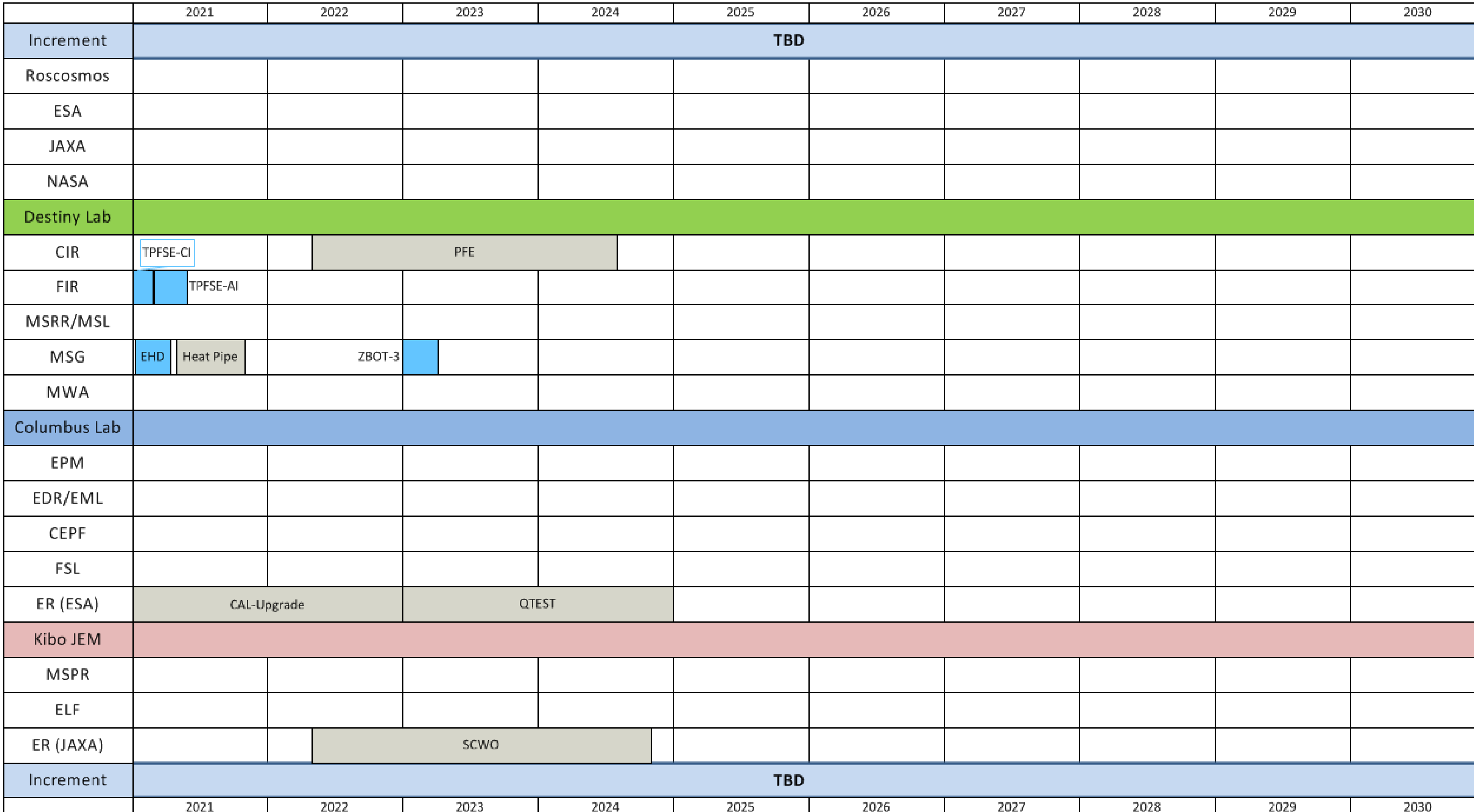


ACE	Advanced Colloid Experiments
ACES	Atomic Clock Ensemble in Space
ACME	Advance Combustion via Microgravity Experiment
ALI	Alice Like Insert
CAL	Cold Atom Laboratory
CdTe	Cadmium Telluride
CEPF	Columbus External Payload Facility
CET	Columnar to Equiaxed Transition
CETSOL	Columnar-to-Equiaxed Transition in Solidification Processing
CFI-OS	Cool Flames Investigation-Open Source
CIR	Combustion Integrated Rack
EDR	European Drawer Rack
ELF	Electrostatic Levitator Furnace
EML	Electro-Magnetic Levitator
EPM	European Physiology Module
ER	Expedite the Processing of Experiments to Space Station Rack
ESA	European Space Agency
ESTA	Eutectic Solidification in a Ternary Alloy
FAMIS	Formulation of Amorphous Metals in Space
FBCE	Flow Boiling and Condensation Experiment
FIR	Fluids Integrated Rack
FLARE	Flammability Limits At Reduced-g
FOAM	Foam Optics and Mechanics
FOG	Formation of Garites
FSL	Fluid Science Laboratory
HTV	H-II Transfer Vehicle
ICEAGE	Influence of Containment on the Growth of Silicon-Germanium
IE	Interfacial Energy
JAXA	Japan Aerospace Exploration Agency
JEM	Japanese Experiment Module
LCN	Liquid Crystal Nanoplates
LMM	Light Microscopy Module
MFHT	Multiphase Flow with Heat Transfer
MICAST	Microstructure Formation in Casting
MMB	Macromolecular Biophysics
MSG	Microgravity Science Glovebox
MSL	Materials Science Laboratory
MSPR	Multi-Purpose Small Payload Rack
MSRR	Materials Science Research Rack
MVCS	Morphological Variable Cross Section
MWA	Maintenance Work Area
NASA	National Aeronautics and Space
Orb	Orbital
PBRE	Packed Bed Reactor Experiment
Roscosmos	Russian Federal Space Agency
SCE	Solid Combustion Experiment
SCWM	SuperCritical Water Mixture
SETA	Solidification along an Eutectic path in Ternary Alloys
SoFIE	Solid Fuel Ignition and Extinction
SpX	SpaceX
TPFSE	Two-Phase Flow Separator Experiment
USCV	United States Crew Vehicle
USTV	United States Transfer Vehicle
VIPGRAN	Vibrational Phenomena in Granular Matter
ZBOT	Zero Boil-Off Tank

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

Snapshot Date: 9/1/2014

ISS Physical Sciences Traffic Model

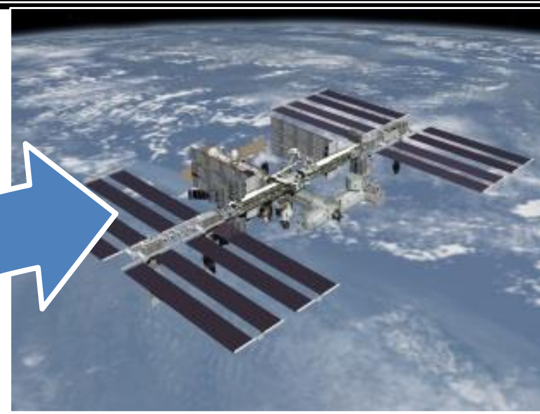


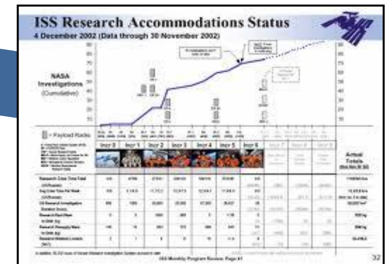
AI	Annular Injection
CAL	Cold Atom Laboratory
CEPF	Columbus External Payload Facility
CI	Conical Injection
CIR	Combustion Integrated Rack
EDR	European Drawer Rack
EHD	Electro Hydro Dynamic
ELF	Electrostatic Levitator Furnace
EML	Electro-Magnetic Levitator
EPM	European Physiology Module
ER	Expedite the Processing of Experiments to Space Station Rack
ESA	European Space Agency
FIR	Fluids Integrated Rack
FSL	Fluid Science Laboratory
JAXA	Japan Aerospace Exploration Agency
JEM	Japanese Experiment Module
MSG	Microgravity Science Glovebox
MSL	Materials Science Laboratory
MSPR	Multi-Purpose Small Payload Rack
MSRR	Materials Science Research Rack
MWA	Maintenance Work Area
NASA	National Aeronautics and Space
PFE	Premixed Flames Experiment
QTEST	Quantum Tests of the Equivalence Principle and Space-Time
Roscosmos	Russian Federal Space Agency
SCWO	Supercritical Water Oxidation
TPFSE	Two-Phase Flow Separator Experiment
ZBOT	Zero Boil-Off Tank

Legend

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

"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 Recomendaton 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

NASA MaterialsLab Workshop - initial assessment of collaboration potential*

- 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)

* Experiment and/or samples are on-orbit and operating (or operations planned) in CY2013

- **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

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 –

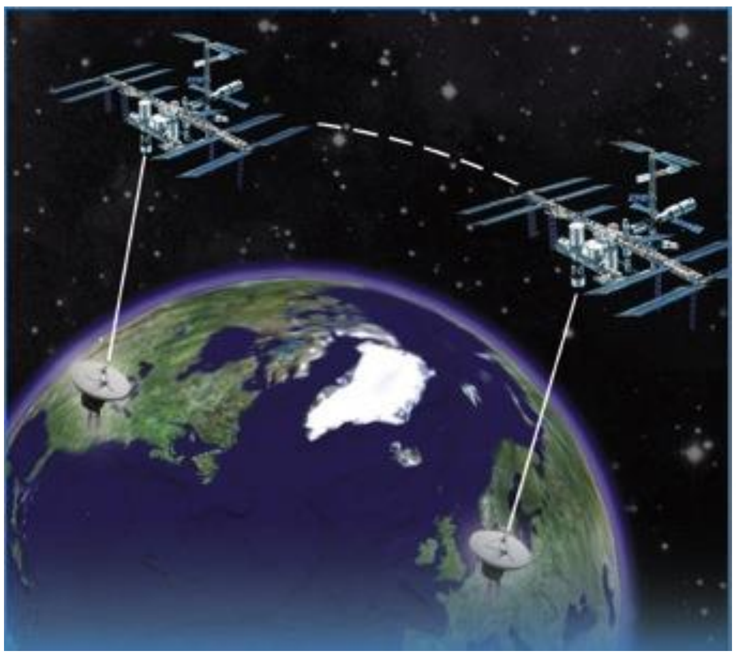
Additional Slides

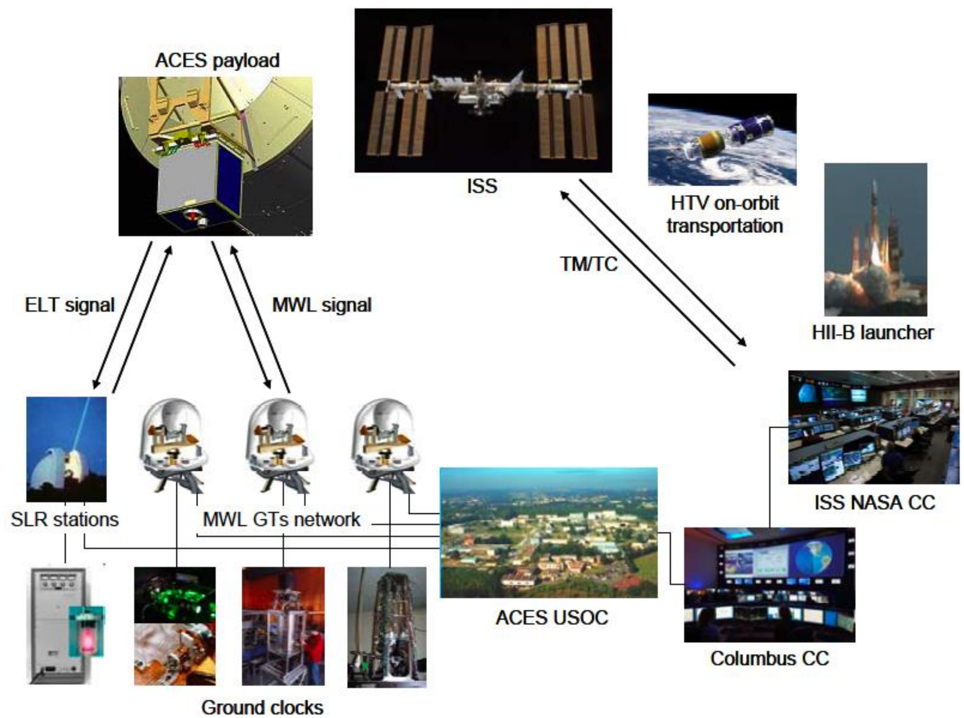
US Collaboration in the ESA ACES Mission

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

Science Objectives:

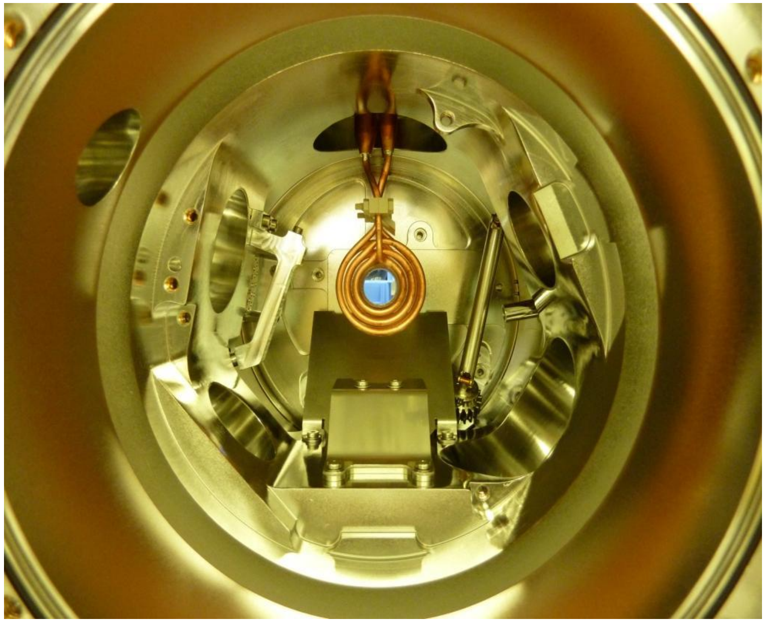
- Demonstrate validate a new generation of atomic clocks in space (10^{-16} stability and accuracy level)
- Demonstrate the capability to compare ground clocks on a world-wide basis (stability better than 10^{-16})
- Test fundamental laws of physics to high accuracy (gravitational Red-shift, drift of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

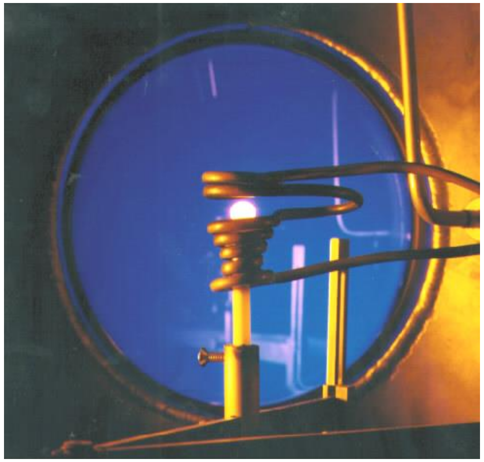




New ISS Facility: ESA's ElectroMagnetic Levitator

No container = freely floating, no reaction nor contamination





Coil system for both positioning and heating

- 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)*

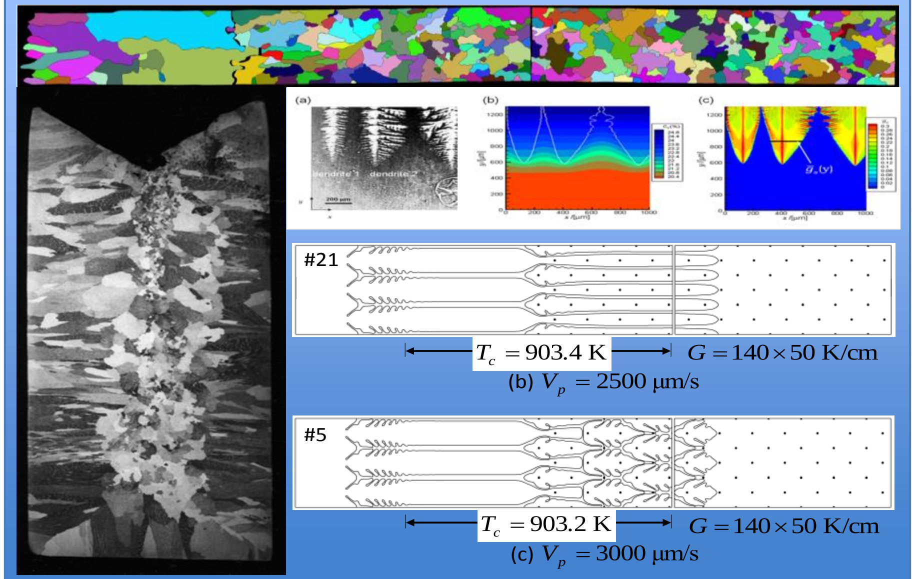
Project Scientist: *Ellen Rabenberg (NASA-MSFC)*
Project Manager: *Dr. James P. Downey (NASA-MSFC)*
Engineering Team: *TBD*

Objective: *To study columnar-to-equiaxed grain structure transition and effect of convection in alloys by using directional solidification with and with out 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:



Instrumentation & Experiment Summary:
- *Ground based work: Will be performed at MSFC under direction of Dr. Beckermann*
- *Flight experiments: On International Space Station (2020).*
- *ISS requirements: Low-gradient furnace (LGF) on Materials Science Research Rack (MSRR).*

ISS Resource Requirements

Accommodation (carrier)	
Upmass (kg) (w/o packing factor)	5kg each
Volume (m^3) (w/o packing factor)	690 x 185 x 185mm each
Power (kw) (peak)	2.54 kW (for 0.5 hrs), total power max 1.82 kW
Crew Time (hrs)	1.5 hrs
Autonomous Ops (hrs)	
Launch/Increment	SpaceX-12 launch/ Inc 50

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