Physical Sciences Research Presentation -

Committee on A Midterm Assessment of Implementation of the Decadal Survey on Life and Physical Sciences Research at NASA

2101 Constitution Avenue NW
Washington, DC

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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 and Condensation
- Capillary flow and Interfacial phenomena
- Cryogenic storage and handling

Materials Science

- Glasses and Ceramics
- Granular Materials
- Metals
- Polymers and Organics
- Semiconductors

Fundamental Physics

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

Complex Fluids

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

*Physical Sciences Research Mapped to Decadal Survey Identifiers**

Physical Sciences Research

Combustion Science

- Spacecraft fire safety (AP6, TSES8, TSES9)
- Droplets (AP7, AP8)
- Gaseous – premixed and non-premixed (AP7, AP8, AP9)
- Solid fuels (AP7, AP8)
- Supercritical reacting fluids (AP8)

Fundamental Physics

- Space optical/atomic clocks (FP2)
- Quantum test of equivalence principle (FP2)
- Cold atom physics (FP3)
- Critical point phenomena (FP4, AP5)
- Dusty plasmas (FP1)

Materials Science

- Metals (AP9)
- Semiconductors (AP9, AP10)
- Polymers (AP9)
- Glasses, ceramics (AP9, AP10)
- Granular materials (AP3, AP5, AP11)
- Composites (AP9, AP10, AP11)
- Organics (AP5, AP9)

Fluid Physics

- Adiabatic two-phase flow (AP1, TSES6)
- Boiling, condensation (AP1, TSES1)
- Capillary flow (AP1, AP2)
- Interfacial phenomena (AP1, AP2)
- Cryogenics (AP1, AP2, TSES2)

Biophysics

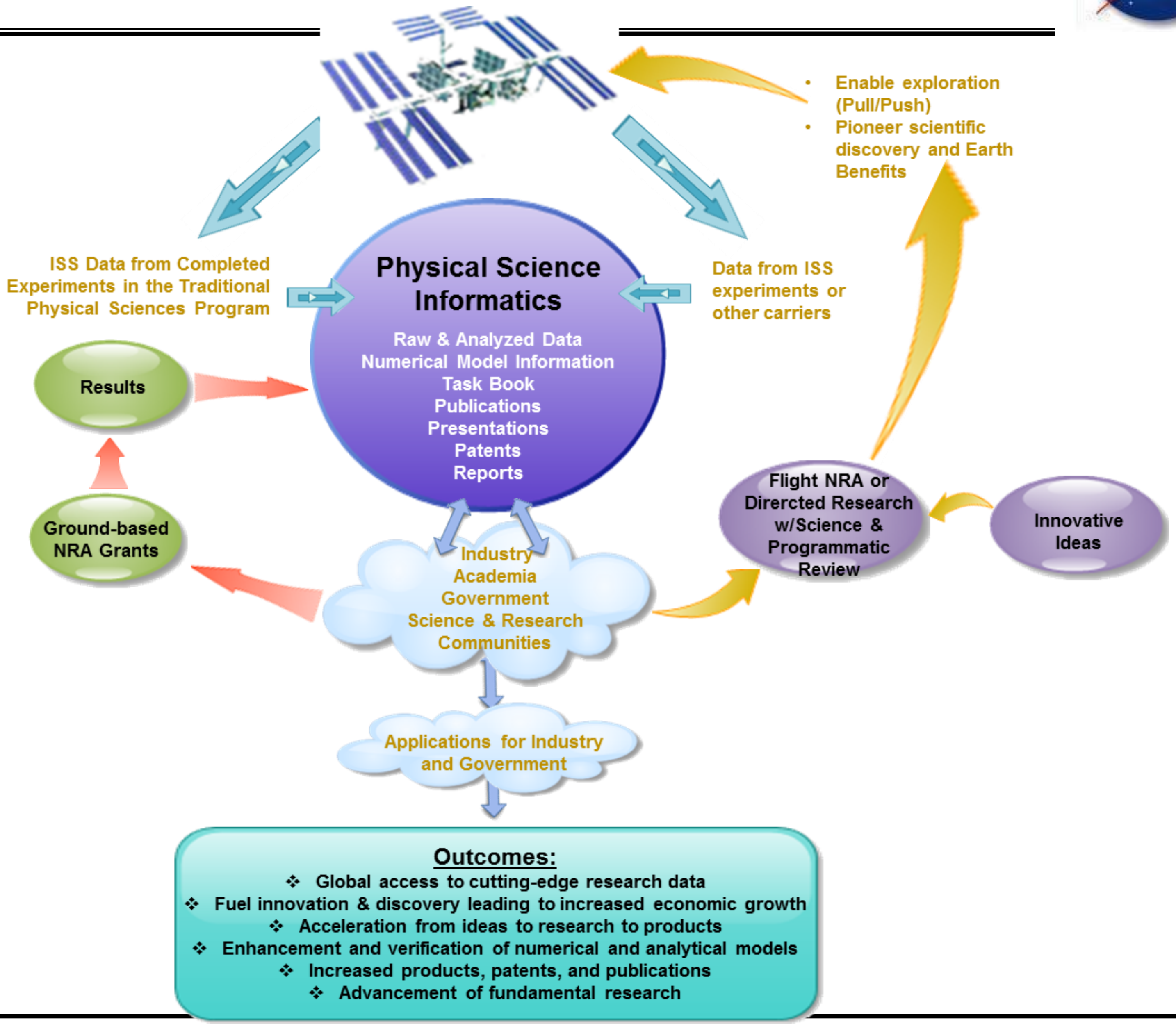
- Biomaterials (P1, P2)
- Biological macromolecules (AP5, AP9)
- Fluids for biology (P3, AP5)
- Biological physics (CC11)

Complex Fluids

- Colloids (FP1, AP5)
- Liquid crystals (FP1, AP5)
- Foams (FP1, AP5)
- Gels (FP1, AP5)
- Granular flows (AP3, AP5, AP11)

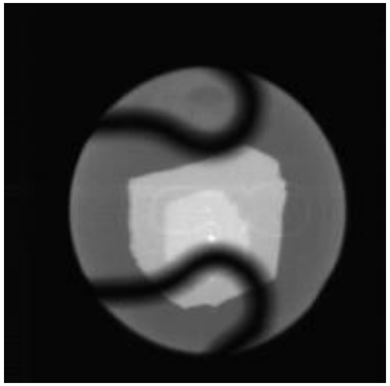
**Decadal survey recommendation identifier examples: AP7, TSES 6, and FP2*

Physical Sciences Research Program



Highlights and Research Findings

Electromagnetic Levitator



- FeCrNi austenitic steel casting alloy deeply undercooled with rapid solidification of primary ferrite and subsequent conversion to secondary austenite.
- This is a THERMOLAB-ISS sample, which is part of an ESA Topical Team with experiments on ESA's Electromagnetic Levitator (EML). The topical team consists of members from several countries, including Germany, Austria, US, Russia, and Japan, and receives input from an industrial advisory board.
- Batch 1 (of 6), which consists of 18 samples, is currently installed in the EML and sample processing is ongoing.
- Each of the 18 samples has experienced some processing and over 450 melt cycles have been completed

Coarsening of Solid-Liquid Mixtures, PI, Peter Voorhees

Professor Peter W. Voorhees of Northwestern University was elected into the 236th class of the American *Academy of Arts and Sciences*, one of the nation's oldest and most prestigious honorary societies. A total of 213 leaders in the sciences, social sciences, humanities, arts, business, and public affairs were elected into the academy in 2016.

Professor Voorhees is an experienced microgravity investigator and is currently the Principal Investigator for "CSLM-Coarsening of Dendritic Solid Liquid Mixture: The Low Volume Limit" which is completed testing and the final report is being written.

He has been a Principal Investigator on 4 experiment campaigns on ISS.

His proposal, "The Columnar to Equiaxed Transition and Dendrite Fragmentation," was selected for a MaterialsLab experiment.

CSLM 2

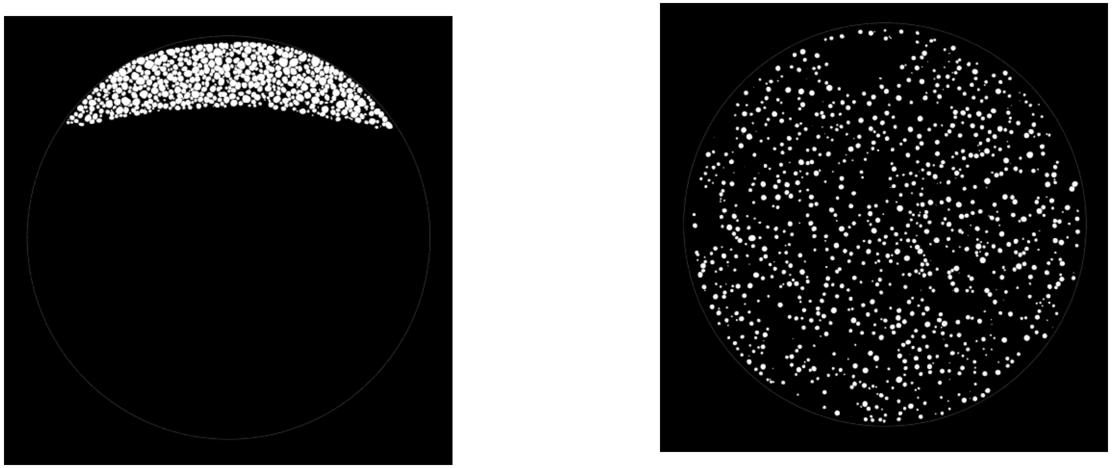


Figure 2. Lighter tin particles float on the solid-liquid mixture in normal earth gravity (left), while the low gravity environment of space (right) eliminates effects such as buoyancy, allowing for better understanding of particle growth and size distribution. (P. Voorhees).

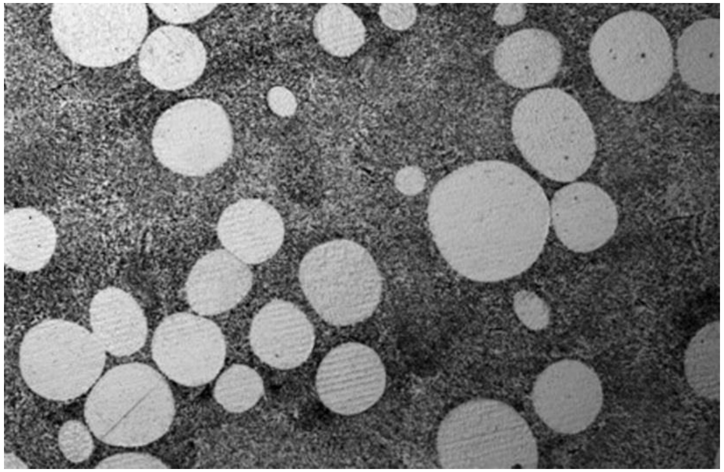
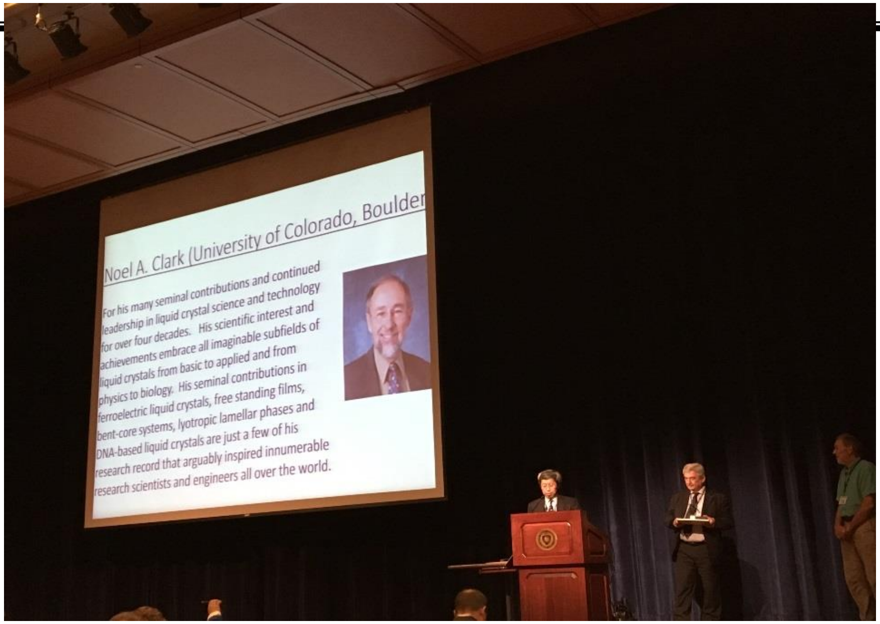


Figure 3. Micrograph of increment 7 sample showing visibility of particles.

OASIS PI, Noel Clark



On Aug, 4 , 2016, at the award ceremony of the International Liquid Crystal Conference at Kent State University, Professor Noel Clark was awarded this prestigious award for 2016, named as *Pierre Gilles de Gennes award.*

This award is given to a very much outstanding scientist in the research field. Here are the pics during the award given to him. The announcement was made by Hiroshi Yokoyama, the chair of the conference, and current elected president of International Liquid Crystal Society. The person presenting the medal to Noel is Claudio Zannoni (Past President) of Universita' di Bologna (retired).

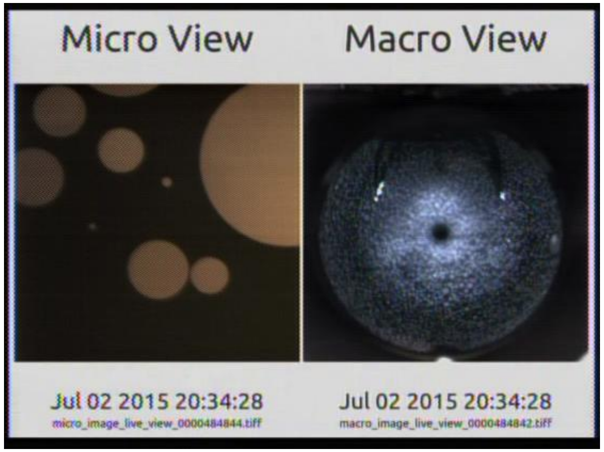
Observation and Analysis Smectic Islands in Space (OASIS)

Coarsening of islands (domains) of different layers on a very thin liquid crystal film bubble aboard the ISS in the OASIS experiment

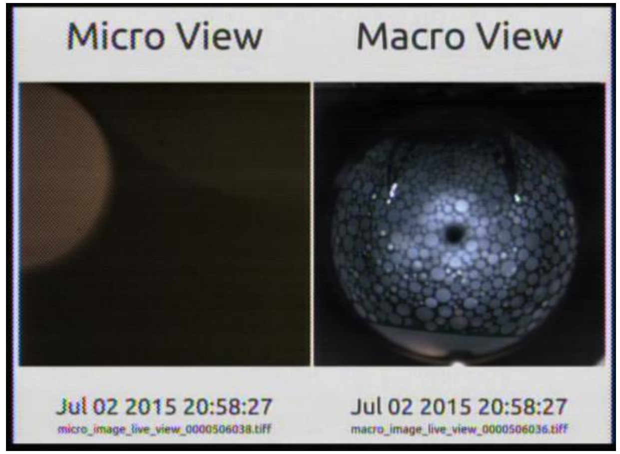
Microgravity studies of natural droplets on very thin liquid crystal films gave insight on hydrodynamics of droplets on very thin freely suspended liquid crystal films aboard the ISS in the OASIS experiment.

OASIS: Initial testing on ISS: Coarsening of islands on liquid crystal bubble

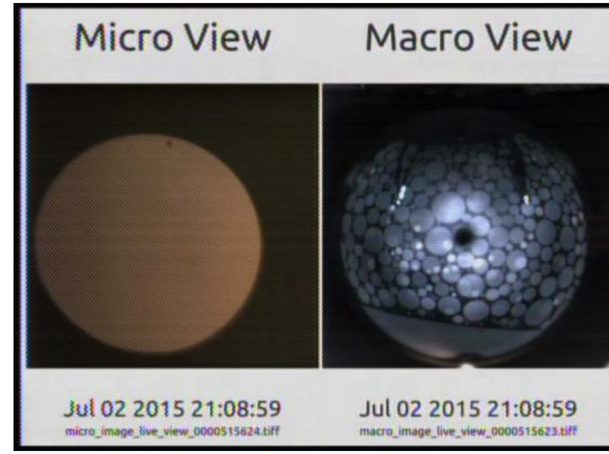
Coarsening of thin liquid crystal bubble: 138 min in microgravity. Cannot be observed in 1g.



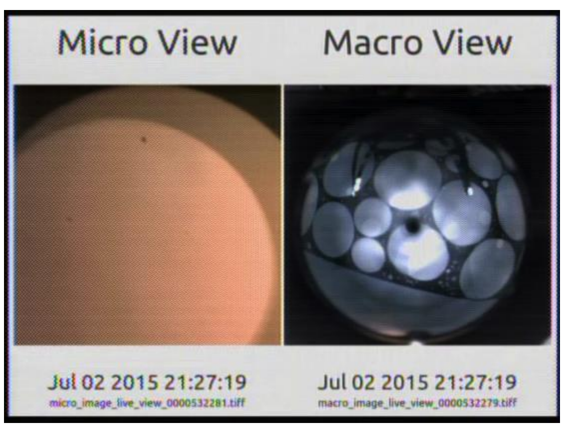
T≈ 0 min →



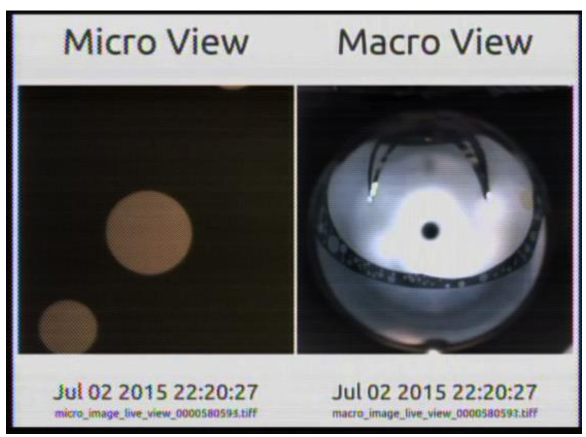
T= 14 min. →



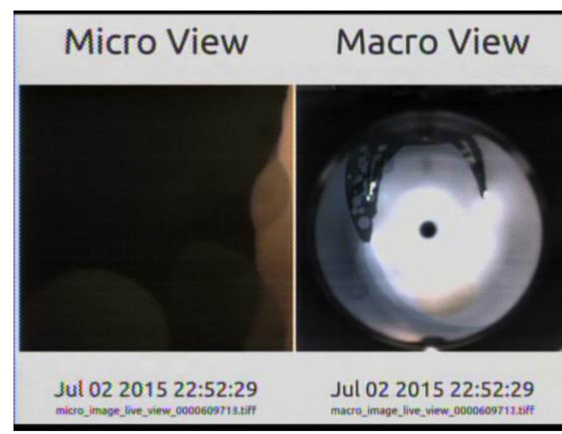
T= 34 min.



T= 53 min. →



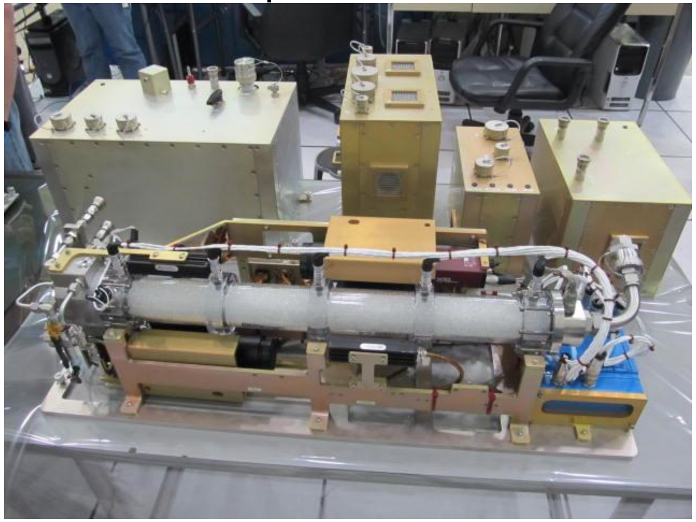
T= 106 min. →



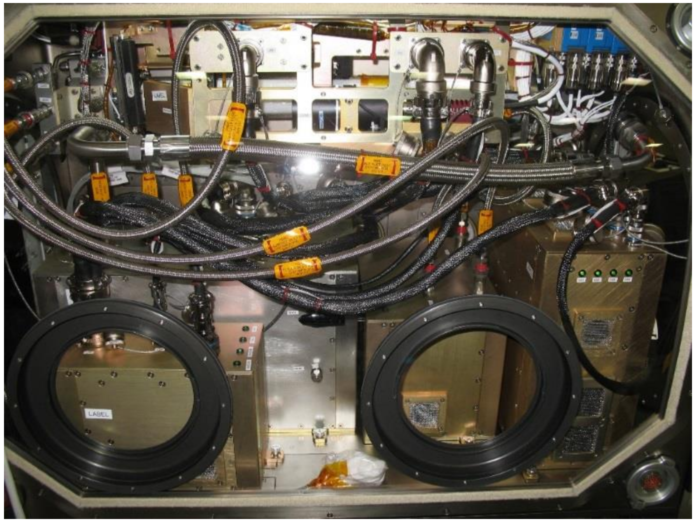
T= 138 min.

PBRE: ISS Post flight summary – wetting packing
PI: Brian Motil

- PBRE completed flight ops on the first (of two) test sections. The first test section is filled with glass beads (wetting packing), the second is filled with Teflon beads (non-wetting) – all other aspects are identical.
- Only pressure and flow data was down linked. High speed video was saved on hard drives that were returned in late August, but not available to the PI team yet.
- Pressure data indicates models predict transition from pulse to bubble flow within the range of flow rates used in aircraft experiments. However, at lower flow rates (not achievable in aircraft experiments), data indicates the presence of an unexpected flow regime (possible gas-continuous flow regime).
- Pressure drop models are still under review.



PBRE unit - packed bed column



PBRE in MSG

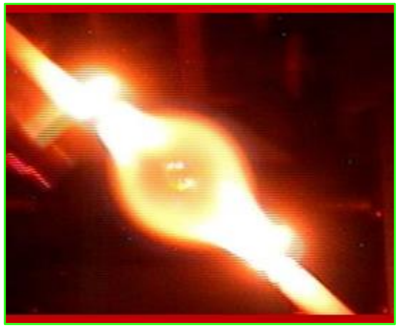
Completed Physical Sciences Experiments: 2011 to February 2017

Completed PS Experiments: 2011 to February 2017

Discipline	# of Completed Experiments
Combustion	16
Complex Fluids	12
Fluids	7
Fundamental Physics	3
Materials Science	11
Total	**49**

Combustion (Title, PI and Decadal Identifier)

1. SLICE, Structure and Liftoff in Combustion Experiment, Marshall Long & Mitchell Smooke, AP7 & AP8
2. BASS, Burning and Suppression of Solids, Paul Ferkul and Sandra Olson, AP6, AP7, TSES 8
3. BASS – 2, Burning and Suppression of Solids – 2, Sandra Olson, AP6, AP7, TSES 8
4. BASS – 2, Burning and Suppression of Solids – 2, Carlos Fernandez-Pello, AP6, AP7, TSES 8
5. BASS – 2, Burning and Suppression of Solids -2, James T'ien, AP6, AP7, AP8, TSES 8
6. BASS – 2, BASS – 2, Burning and Suppression of Solids -2, Subrata Bhattacharjee, AP6, AP7, AP8, TSES 8
7. BASS – 2, BASS – 2, Burning and Suppression of Solids -2, Fletcher Miller, AP6, AP7, TSES 8
8. FLEX, Flame Extinguishment, “Flame Radiation and Extinction,” Forman Williams, AP7 & AP8



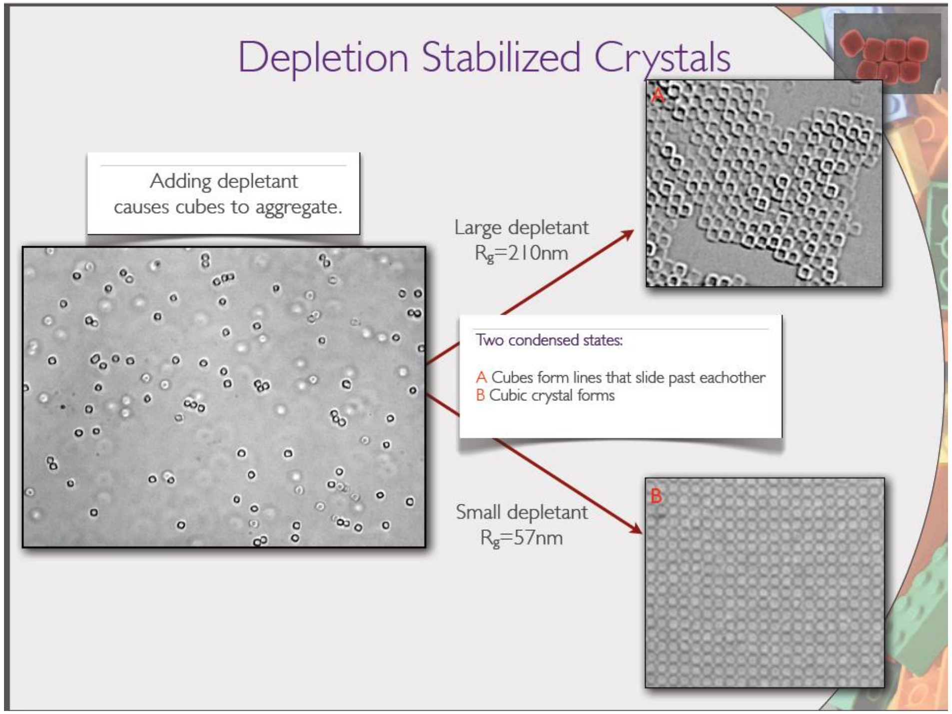
CIR/FLEX -Droplet Combustion ignition on ISS (Williams).

Combustion - Continued

1. FLEX -2, Flame Extinguishment – 2, Forman Williams & Fred Dryer, "Quiescent Droplet Experiments," AP7 & AP8
2. FLEX -2, Flame Extinguishment – 2, Tom Avedisian, "Surrogate Fuel Combustion," AP7 & AP8
3. FLEX -2, Flame Extinguishment – 2, Mun Choi & Fred Dryer, "Soot Volume Fraction," AP7 & AP8
4. FLEX -2, Flame Extinguishment – 2, Vedha Nayagam & Forman Williams, "Convective Flow Effects," AP7 & AP8
5. FLEX -2, Flame Extinguishment – 2, Daniel Dietrich, "Droplet Arrays," AP7 & AP8
6. FLEX ICE-GA, Flame Extinguishment Italian Combustion Experiment-Green Air, Patrizio Massoli & Raffaella Calabria, Inst. Motori Naples, AP7 & AP8
7. FLEX – 2J, Flame Extinguishment -2J, Hiroshi Nomura, Nihon Univ. & Masao Kikuchi, JAXA, AP7 & AP8
8. DECLIC - HTI, DEvice for the study of Critical Liquids and Crystallization - High Temperature Insert, Michael Hicks, FP4 & TSES 9

Complex Fluids

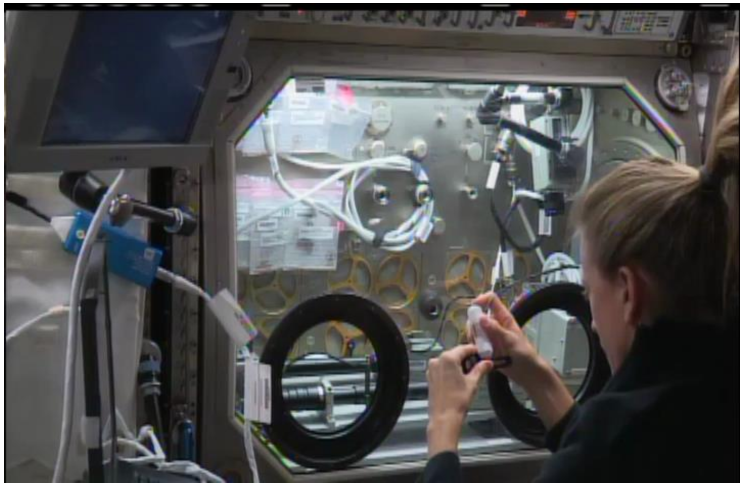
1. ACE - M1, Advanced Colloids Experiment, Matthew Lynch, AP-5 & FP-1
2. ACE – M2, Advanced Colloids Experiment, David Weitz, AP-5 & FP-1
3. ACE – M3, Advanced Colloids Experiment, Paul Chaikin, AP-5 & FP-1
4. ACE - H1, Advanced Colloids Experiment, Arjun Yodh, AP-5 & FP-1
5. ACE - H2, Advanced Colloids Experiment, Stuart Williams, AP-5 & FP-1
6. OASIS, Observation and Analysis of Smetic Islands in Space, Noel Clark, AP-5 & FP-1



Depletion of Stabilized Particles in micro-g. (Chaikin).

Complex Fluids (continued)

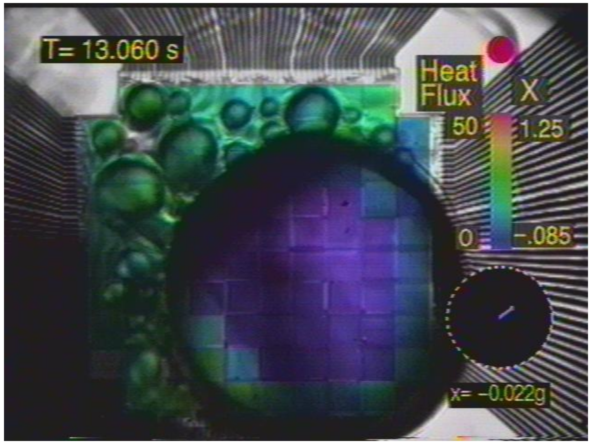
1. SHERE II, Shear History Rheology Experiment, Gareth McKinley, AP5
2. BCAT – 3-4, Binary Colloidal Alloy Test – 3-4, David Weitz, Paul Chaikin, AP-5 & FP-1
3. BCAT – 5, Binary Colloidal Alloy Test – 5, Matthew Lynch, David Weitz, Barbara Frisken, Paul Chaikin, Arjun Yodh, AP-5 & FP-1
4. BCAT – 6, Binary Colloidal Alloy Test – 6, Matthew Lynch, David Weitz, Paul Chaikin, Arjun Yodh, AP-5 & FP-1
5. InSPACE - 3, Investigating the Structure of Paramagnetic Aggregates from Colloidal Ellipsoids – 3, Eric Furst, AP-5 & FP-1
6. InSPACE – 3+, Investigating the Structure of Paramagnetic Aggregates from Colloidal Ellipsoids – 3+, Eric Furst, AP-5 & FP-1



Increment 36 Flight Engineer, Karen Nyberg, completes particle mixing in a vial sample using a large, magnetic stir bar during InSPACE-3+ operations on ISS on August 2, 2013. The InSPACE-3+ experiment is located in the MSG.

Fluid Physics

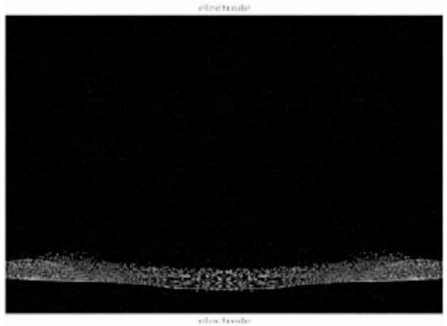
1. CCF – EU1, Capillary Channel Flow (propellant tanks), Michael Dryer, AP-2
2. CCF – EU2, Capillary Channel Flow, (water recovery), Mark Weislogel, AP-2
3. MABE – Microheater Array Boiling Experiment, Jungho Kim, AP-1, TSES-1
4. NPBX – Nucleate Pool Boiling Experiment, V.J. Dhir, AP-1, TSES-1
5. CVB – 2, Constrained Vapor Bubble-2, Pete Wayner and Joel Plawsky, AP-2 & TSES-1
6. CFE – 2, (11 vessel geometries), Capillary Flow Experiment-2, Mark Weislogel, AP-2
7. PBRE, Packed Bed Reactor Experiment – Brian Motil, AP-2 & TSES-6



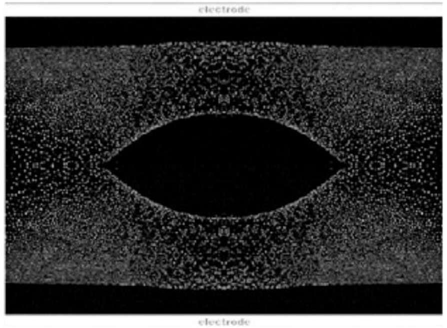
Pool Boiling with microheater array in Micro-g. (Kim)

Fundamental Physics – Mark Lee

1. PK -3+, Plasma Crystal (Dusty Plasma) 3+, John Goree, AP5
2. GRADFLEX, (Free Flyer), The GRAdient Driven FLuctuation Experiment, David Cannell, AP2
3. DECLIC – ALI, DEvice for the study of Critical Liquids and Crystallization, ALICE Like Insert, Inseob Hahn, FP4



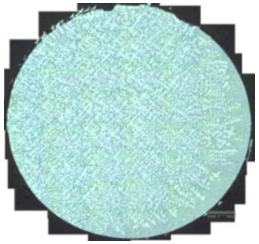
Dusty Plasma, 1g



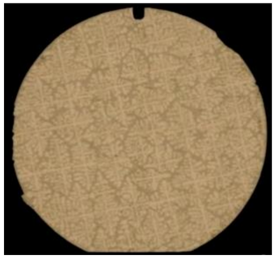
Dusty Plasma, Micro-g

Materials

1. SETA, Solidification Along a Eutectic Path in Ternary Alloys, Amber Genau, AP9
2. CSS, Comparison of Structure and Segregation in Alloys Directionally Solidified in Terrestrial and Microgravity Environments, David Poirier, AP9
3. MISCAST, Microstructure Formation in Castings of Technical Alloys under Diffusive and Magnetically-Controlled Convective Conditions, David Poirier, AP9
4. METCOMP, Metastable Solidification of Composites: Novel Peritectic Structures and In-situ Composites, Jon Dantzig, AP9
5. CETSOL, Columnar-Equiaxed Transition in Solidification Processing, Christoph Beckermann, AP9
6. DECLIC – DSI, DEvice for the study of Critical Liquids and Crystallization, Directional Solidification Insert, Rohit Trivedi, AP9
7. CSLM – 3, Coarsening of Solid Liquid Mixtures, Peter Voorhees, AP9



Al –Si (7wt% Si)
1-g (Poirier)



Al –Si (7wt% Si)
micro-g (Poirier)

Materials

1. CSLM – 4, Coarsening of Solid Liquid Mixtures, Peter Voorhees, AP9
2. EML – 1 PARSEC – Electromagnetic Levitator Batch 1 (1.1 & 1.2) – PARSEC: Peritectic Alloy Rapid Solidification with Electromagnetic Convection, Robert Hyers, Doug Matson, AP9
3. EML -1 ICOPROSOL – Electromagnetic Levitator Batch 1 (1.1 & 1.2) – ICOPROSOL: Thermophysical Properties and Solidification Behavior of Undercooled Ti-Zr-Ni Liquids Showing an Icosahedral Short-Range Order, Robert Hyers, Ken Kelton, AP9
4. EML -1 THERMOLAB – Electromagnetic Levitator Batch 1 (1.1 & 1.2) – THERMOLAB: Thermophysical Properties of Liquid Metallic Alloys - Modelling of Industrial Solidification Processes and Development of Advanced Product, Robert Hyers, Ken Kelton, Doug Matson, AP9

ESA’s Electromagnetic Levitator

Exploration – Journey to Mars

Human Exploration of Mars is Hard

20-30 tons
Ability to land large payloads needed

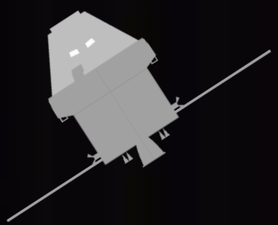
130 tons
Heavy-lift mass means **multiple** launches per mission

13.5 km/s Earth re-entry speed

800-1100 days away from Earth in micro gravity and high levels of radiation

Reliable in-space transportation:
Total continuous transportation power

Thin atmosphere and dusty conditions for surface operations.



44 minute max two-way communication delay
2-week blackout every 26 months when Earth and Mars are on opposite sides of the sun

20 tons of oxygen needed for ascent to orbit: In-Situ Resource Utilization (ISRU)

Mars is the Right Place for Human Exploration

- **Robotic exploration has provided a very sound basis for a human mission**
- **Mars weather Temperature: -86 C to 20 C**
  - Tolerable for typical spacecraft systems
  - Varies with location
- **Water available for propellant and use of ascent vehicle**
- **CO_2 in atmosphere for O_2 extraction**
- **Radiation measured and tolerable**
  - Even thin atmosphere provides some protection
  - Varies through day/night
- **Mars geology is right for the advantages of direct human interaction and sampling**
- **Mars can tell us a lot about Earth and the possibility of life in the solar system**

Demand Areas for the Journey to Mars

= Current HEOMD Activities
= Current STMD Activities

	Mission / Demand Areas	ISS	Cis-lunar Short Stay (e.g. ARM)	Cis-lunar Long Stay	Cis-Mars Robotic	Mars Orbit	Mars Surface
Working in Space and On Mars	In Situ Resource Utilization & Surface Power		Exploratory ISRU Regolith	Exploratory ISRU	Exploratory ISRU & Atmosphere	Exploratory ISRU	Operational ISRU & High Power
	Habitation & Mobility	Long Duration with Resupply	Initial Short Duration	Initial Long Duration		Resource Site Survey	Long Duration / Range
	Human/Robotic & Autonomous Ops	System Testing	Crew-tended	Earth Supervised	Earth Monitored	Autonomous Rendezvous & Dock	Earth Monitored
	Exploration EVA	System Testing	Limited Duration	Full Duration	Full Duration	Full Duration	Frequent EVA
Staying Healthy	Crew Health	Long Duration	Short Duration	Long Duration	Dust Toxicity	Long Duration	Long Duration
	Environmental Control & Life Support	Long Duration	Short Duration	Long Duration	Long Duration	Long Duration	Long Duration
	Radiation Safety	Increased Understanding	Forecasting	Forecasting Shelter	Forecasting Shelter	Forecasting Shelter	Forecasting & Surface Enhanced
Transportation	Ascent from Planetary Surfaces				Sub-Scale MAV	Sub-Scale MAV	Human Scale MAV
	Entry, Descent & Landing				Sub-Scale/Aero Capture	Sub-Scale/Aero Capture	Human Scale EDL
	In-space Power & Prop		Low power	Low Power	Medium Power	Medium Power	High Power
	Beyond LEO: SLS & Orion		Initial Capability	Initial Capability	Full Capability	Full Capability	Full Capability
	Commercial Cargo & Crew	Cargo/Crew	Opportunity	Opportunity	Opportunity	Opportunity	Opportunity
	Communication & Navigation	RF	RF & Initial Optical	Optical	Deep Space Optical	Deep Space Optical	Deep Space Optical
		EARTH RELIANT	PROVING GROUND			EARTH INDEPENDENT	

Relevant Exploration areas for SLPSRA – guide to strategic balancing within PS – some examples

- **Environmental Control and Life Support**
  - Air Revitalization
  - Water Recovery
  - Waste Management
  - Thermal Control
  - Spacecraft Fire Safety
- **In-Space Power**
  - Energy conversion systems
  - Energy transfer
- **In-Space Propulsion**
  - Liquid rocket propulsion systems
  - Cryogenic storage and transfer
- **Materials, Structures, Mechanical Systems, and Manufacturing**
  - In-space manufacturing
- **Crew Health**
  - Plants – water/nutrient management system
  - Biofilms
- **Planetary Surface**
  - Habitation and Mobility
  - In Situ Resource Utilization (ISRU)
  - Surface Power

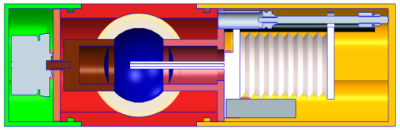
Overview, Status and Planning

Biophysics

Biophysics Program: MaterialsLab Reference Experiments

Macromolecules

Decadal Themes: FP1, AP9



Amyloid Fibril Formation

A. Hirsa, Rensselaer Polytechnic Institute

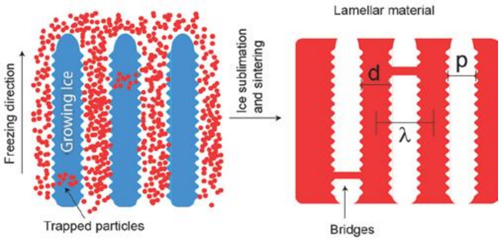
Quantify the effects of flow on fibrillization in the bulk and at interfaces (air/water), which can only be performed in the microgravity environment where deleterious effects from sample dimensions are mitigated.

Freeze Casting

Decadal Themes: AP5, AP9

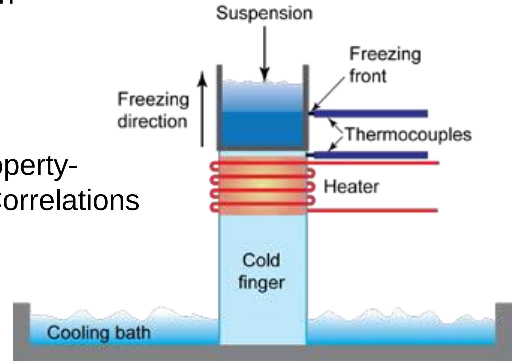
Microstructure Evolution in Freeze-Cast Materials

D. Dunand, Northwestern



Structure-Property-Processing Correlations

U. Wegst, Dartmouth

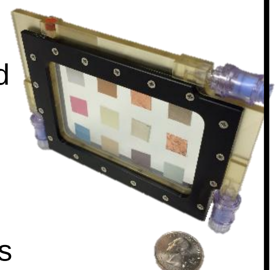


Conduct microgravity experiments on the formation of substrates, scaffolds, and surfaces relevant to biomaterials research, e.g. freeze casting.

Biofilms

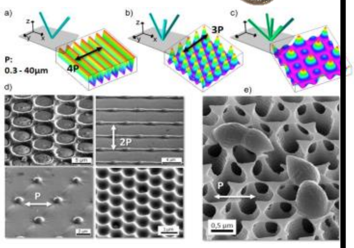
Decadal Themes: P1, P2

Polymicrobial biofilm growth and control during spaceflight



McLean, Texas State, San Marcos

Biofilm Formation, Growth, & Gene Expression on Different Materials and Environmental Conditions.



Zea, Colorado

Elucidate material/cell interactions in biofilm formations. Determine physical mechanisms of gravity-sensing in bacteria/fungi that leads to different formations of biofilms in microgravity

Biophysics Program: Protein Crystal Growth
Decadal Themes: AP5, AP9

Macromolecular Biophysics

- Protein Crystal Growth (DeLucas, Snell)
  - Empirically determine the beneficial effects of microgravity on the growth of large, high quality protein crystals
  - Determine the possible mechanistic means that give rise to the formation of large, high quality crystals
- Nucleation Precursors in Protein Crystallization (Vekilov)
  - Explore the effects of solution shear flow on the nucleation of protein crystals, which may enhanced or suppressed at different rates, including its complete absence, only possible in microgravity

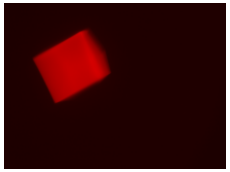
Macromolecular Biophysics, LMM-Growth Rate Dispersion as a Predictive Indicator for Biological Crystal Samples Where Quality can be Improved with Microgravity Growth

E. Snell, Hauptmann Woodard Med. Research Institute

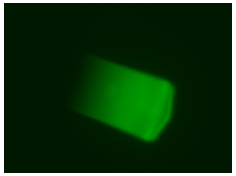
Structure of native protein in a new $P3_1$ spacegroup deposited as PDB id 3S0W

Macromolecular Biophysics, LMM- The Effect of Macromolecular Transport on Microgravity Protein Crystallization

L. DeLucas, University of AL at Birmingham



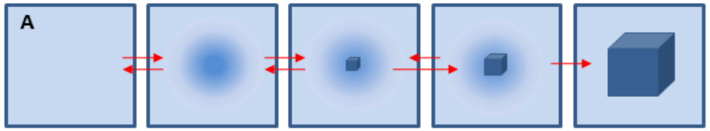
Left: Monomeric lysozyme crystal labeled with 594 D3 at 2.5%



Right: Monomeric lysozyme crystal labeled with 466 I4 at 2.5%

Macromolecular Biophysics, LMM, LMM- Solution Convection and the Nucleation Precursors in Protein Crystallization & ESA Protein Team

P. Vekilov, University of Houston



Proposed Two-Step Model for Nucleation: Dense Cluster Formation and Subsequent Nucleation

Combustion Science

Combustion Science - Status

- **Droplet Combustion:**

  Evaluate chemical kinetics of fuels in an idealized system

  Translate research to improve gas turbine and aircraft engine efficiency, control, and emissions.

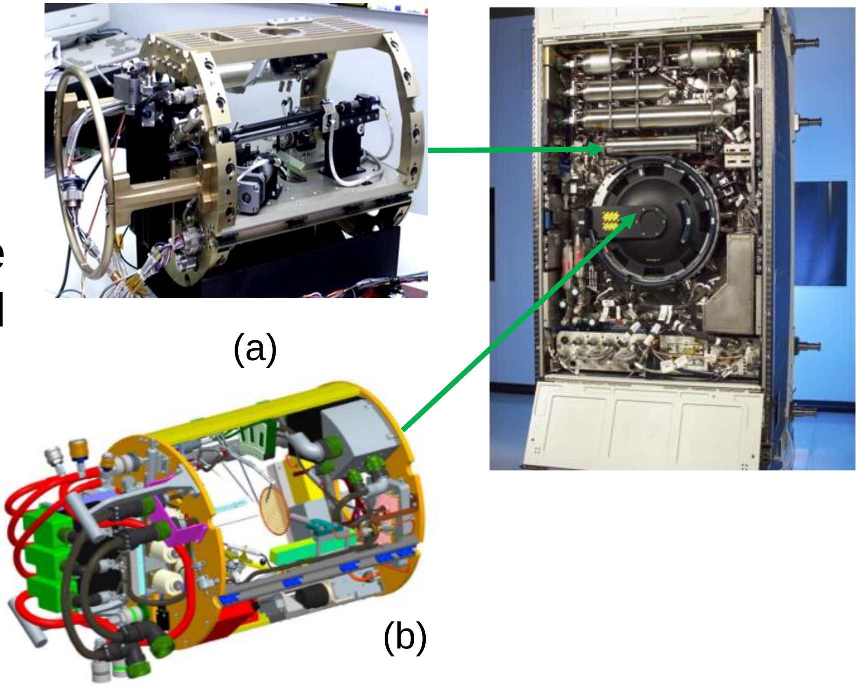
  Experiments: FLEX-2, FLEX-2J, Cool Flames Initiative

- **Gaseous Diffusion Flames:**

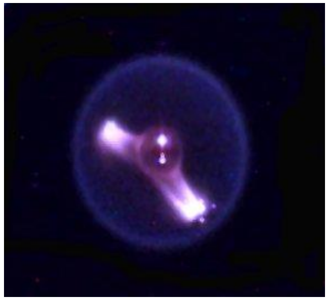
  Investigate soot processes, flame stability and extinction, flammability, and electric field effects

  Translate research to develop more energy-efficient energy systems for the future

  Experiments: ACME series (five investigations)



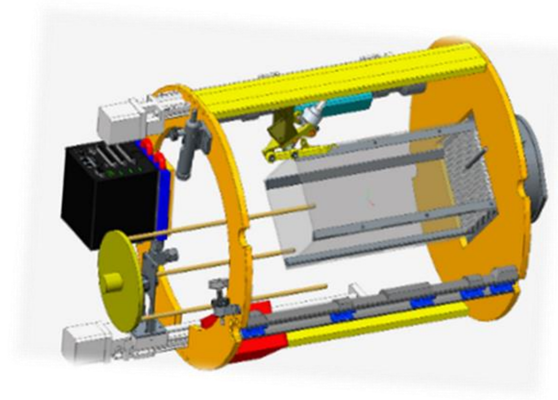
Combustion Integrated Rack (CIR) with inserts (a) for droplet combustion, and (b) for gaseous diffusion flames



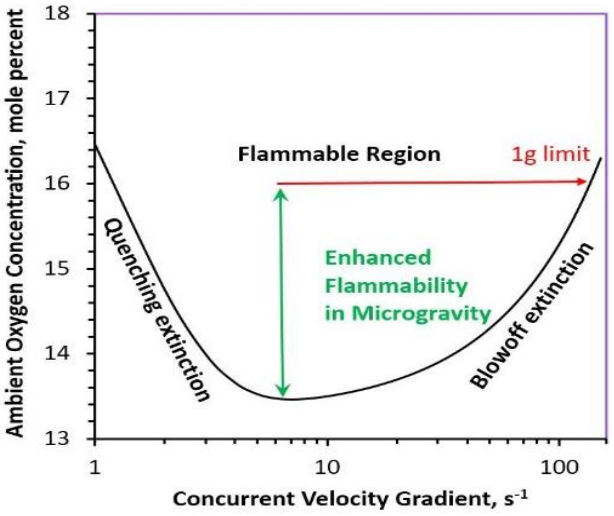
Spherical droplet flame on the ISS. Lack of buoyant acceleration in microgravity enables idealized flame configurations.

Combustion Science - Status

- **Fire Safety and Materials Flammability for Exploration:**
- Assess deficiencies in current flammability testing and understand fundamentals of solid fuels flammability
- Utilize findings to design an improved flammability test for materials selection and understanding of flame spread in spacecraft
- Experiments: BASS, SoFIE series, FLARE
- The Fire Safety projects above are synergistic and integral with the **AES** Division's - Large Scale Fire Safety Demonstration project, SAFFIRE



(a) SoFIE: Materials Flammability Insert for CIR



b) Enhanced microgravity flammability map from the ISS BASS-2 experiment

Evaluating Materials Flammability in Low-gravity and Martian gravity (using drop tower) compared to the NASA Standard Normal gravity Test.

S.L. Olson and P.V. Ferkul

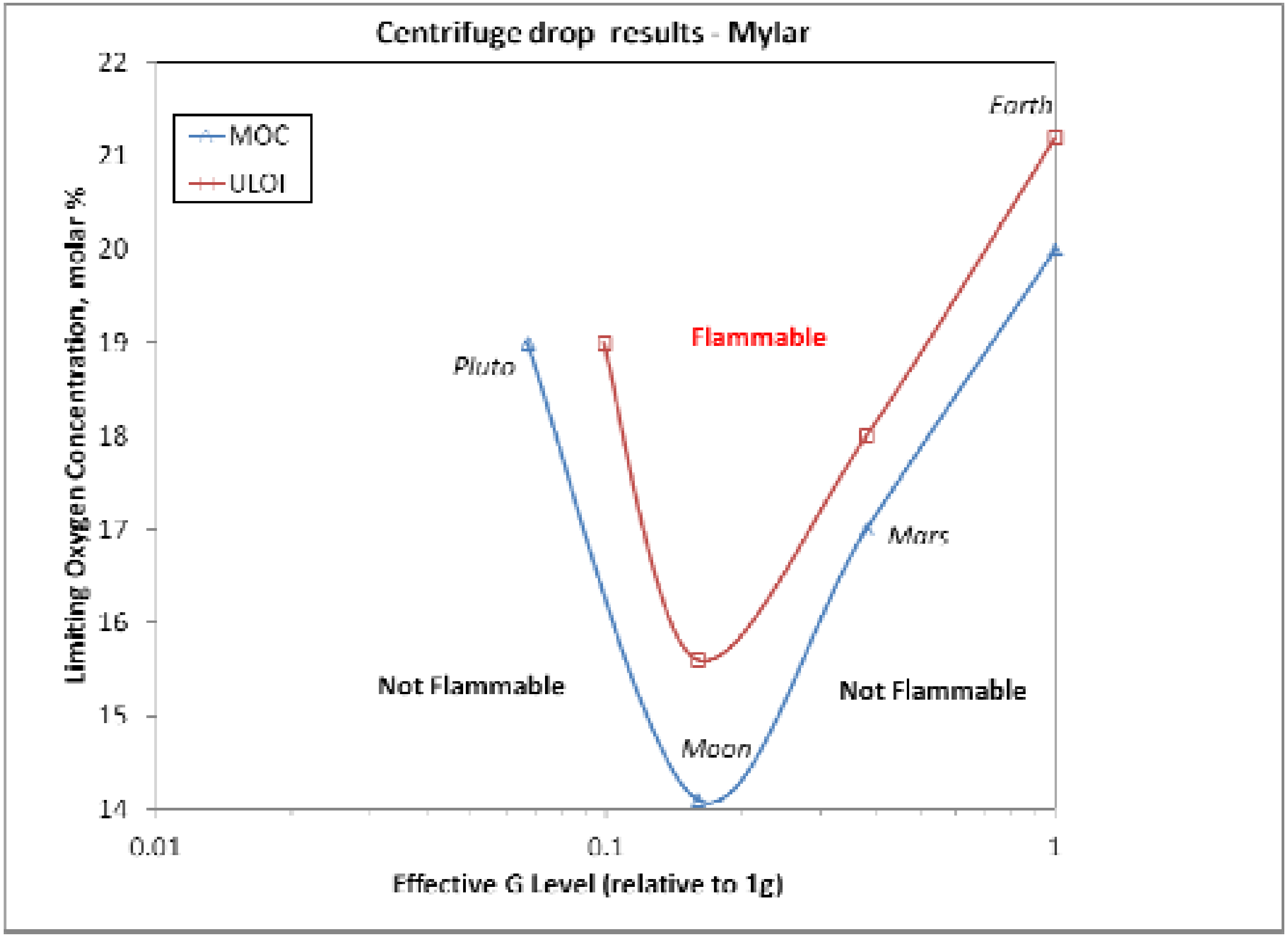
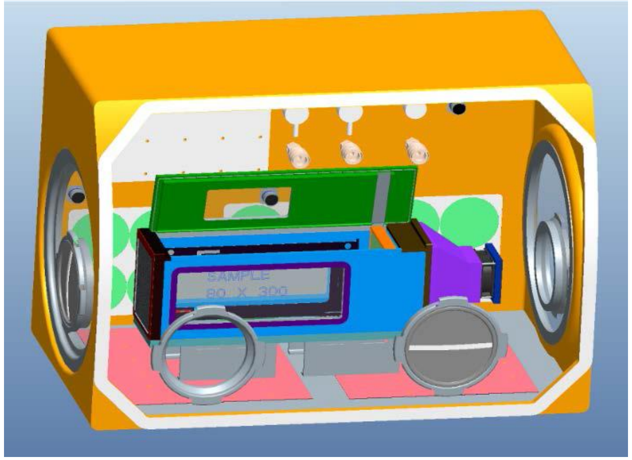


Figure 7. Limiting Oxygen Concentration as a function of g-level for Mylar. For a given oxygen concentration, there is range of g-levels which will permit the flame to be sustained.

CombustionLab - Planning

Microgravity Wind Tunnel experiment (MWT)

- CombustionLab NRA in Materials Flammability (MWT) – release TBD.
- For spacecraft fire safety experiments in a new Microgravity Wind Tunnel (MWT) to study:
  - Materials flammability for exploration in 1 atm
  - Match conditions of NASA 6001 test-1
  - Fundamental flammability processes
- SOFIE team determines requirements and initial test matrix
- Operations NRA – for new science investigations
- Collaborate with AES, STMD and Int. partners (JAXA, DLR and CASIS have expressed an interest)
- After Materials Flammability studies, MWT can designed to provide a platform for a broader NRA to include new experiments on cool flames and flame structure at low strain rates utilizing: Gas-jet diffusion flames and Fiber-supported droplet combustion



Conceptual Microgravity Wind Tunnel in Microgravity Science Glovebox

Gas-jet flame with co-flow

Exploration Atmospheres
(Bill Gerstenmaier's letter)

National Aeronautics and
Space Administration
Headquarters
Washington, DC 20546-0001

Reply to Attn of: Human Exploration and Operations Mission Directorate

TO: Distribution

FROM: Associate Administrator for Human Exploration and Operations

SUBJECT: Exploration Atmospheres

The Exploration Atmospheres Working Group (EAWG) Action Team recently briefed me on their recommendations for spacecraft internal atmospheric pressures and oxygen concentrations needed for future human exploration missions beyond low-Earth orbit. In addition to our current operational capabilities of 14.7 psia/21 percent oxygen and 10.2 psia/ 26.5 percent oxygen, I endorse their recommendation that those habitable elements associated with enabling high frequency EVA phases of a mission should be capable of operating at 8.2 psia total pressure and 34 percent oxygen to conduct EVAs, while meeting the Agency's health and safety requirements.

This memo serves to establish technical direction for adopting the 8.2 psia/34 percent oxygen as a capability for future missions involving high frequency EVA, with formal documentation of the requirement to follow. The current operational pressures will remain the standard for all other space systems. Until the formal documentation changes occur, I am requesting the responsible Human Exploration and Operations Mission Directorate programs to examine their technical content to ensure that it contains the appropriate near-term tasks to enable future implementation of this environment for flight use by 2022. The Human Research Program will perform the necessary human research studies and prebreathe protocol testing, the Advanced Exploration Systems Program will investigate materials flammability and develop life support and EVA systems, and the ISS Program will conduct flight experiments in support of understanding and technical concerns with this new requirement.

The EAWG had published a report in 2006 (republished in 2010, (http://ston.jsc.nasa.gov/collections/TRS/_techrep/TP-2010-216134.pdf) which details their work at that time. They have since had revisions and are in the process of preparing an update to that document. Should you need additional information, contact Don Henninger at JSC who chaired the EAWG. His contact information is donald.l.henninger@nasa.gov, (281) 483-5034.

William H. Gerstenmaier

Microgravity Materials Flammability
Exploration Reference Document - Planning

- Data, publications and overview information compiled from:
  - BASS, BASS-II, MWT,
  - SoFIE - GEL, SoFIE - MIST, SoFIE - NCV, SoFIE- RTDFS, SoFIE – SMμRF,
  - AES' SAFFIRE experiments 1- 6, and
  - JAXA's FLARE experiments.

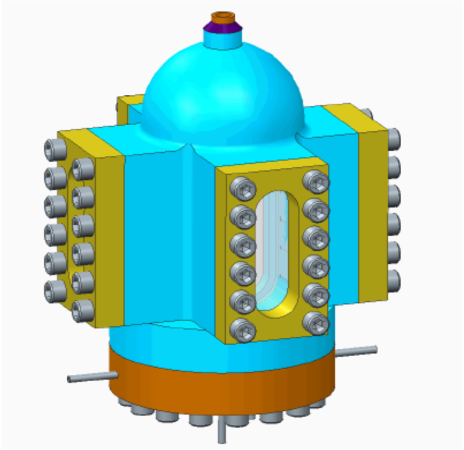
- Provides valuable microgravity combustion data in Spacecraft Fire Safety research for NASA's future Exploration Missions.

- Stored and accessible in PSI

CombustionLab - Planning

High Pressure and Supercritical Combustion Experiments

- Future CombustionLab NRA in High Pressure and Supercritical Combustion.
- Potential ISS-CIR or *Free Flyer* Experiment.
- Collaborate with engine manufacturers (GE, UTRC, Cummins) and CASIS for direct translation to advanced jet, diesel, and homogeneous charge compression ignition (HCCI) engine designs.
    - droplets and sprays
    - supercritical water oxidation and hydrothermal flames
    - high pressure-low temperature combustion i.e., cool flames at high pressure



Conceptual High Pressure Combustion Chamber with optical diagnostics access

Complex Fluids

Complex Fluids – Status

- **Colloids:**

  Conduct a series of 15 experiments to observe colloidal suspensions and processes for long time scales not available on Earth due to sedimentation and jamming.

  Experiments: ACE -Module (M), Heating (H), Temperature (T), and Electric Field (E)

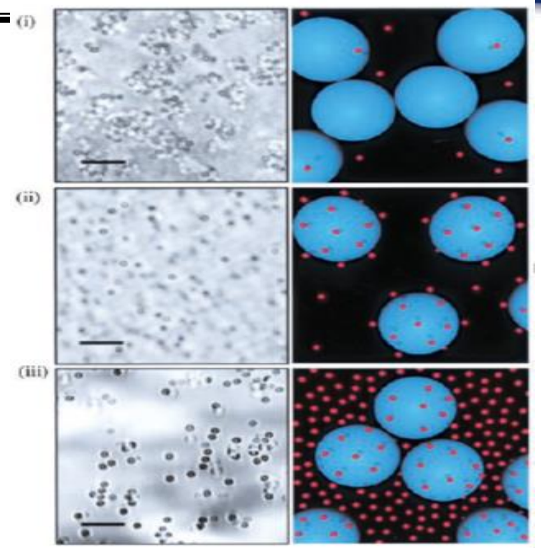
  - ACE M and H – series, ISS ops completed
  - ACE T – series, ISS operations in progress
  - ACE E - under development

- **Liquid Crystals:**

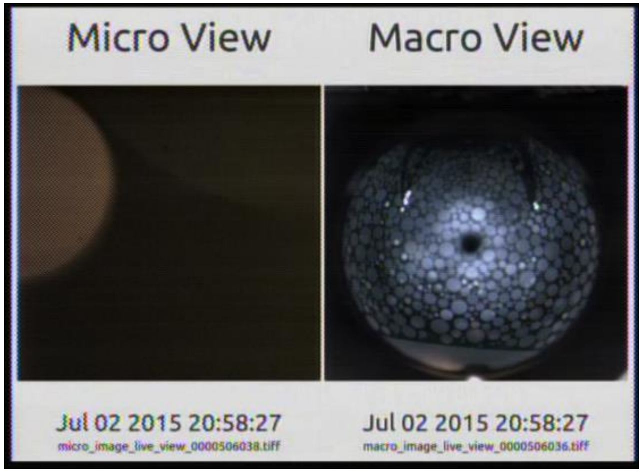
  Investigate the interfacial and hydrodynamic behavior of freely suspended liquid crystals (can only be done in 0-g environment). Advances critical aspects of generating well aligned electro-optic devices to enable scientists to improve the contrast, resolution and response time of liquid crystal display devices.

  Experiments:

  - OASIS - ISS ops complete, data analysis
  - MaterialsLab - Liquid Crystal Facility: Bulk and Bubble Reference Experiments – under development



Nanoparticle Haloing concentration effects (ACE H-2)



Liquid Crystal (LC) bubble with “islands” in 0-g from OASIS experiment operating on the ISS

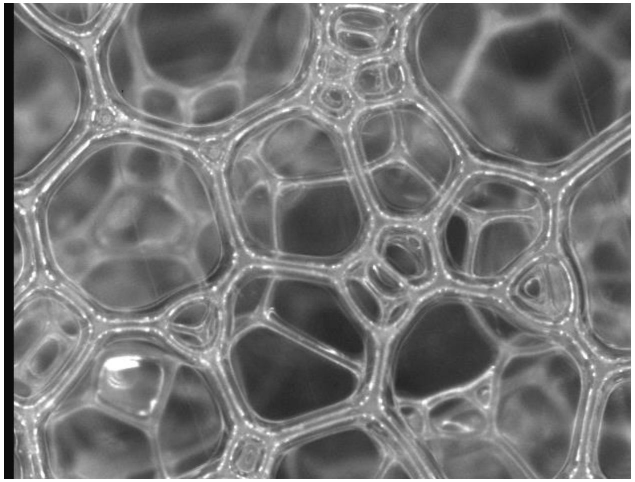
Complex Fluids - Status

- **Foams:**

  Study foam coarsening effects to develop materials (foams) with a more desirable rheology and better stability. 0-g facilitates mechanistic determination of foam destabilization by elimination of film draining around each cell structure.

  Advances technologies that use foams in manufacturing and processing. Experiments:

  - Foam Optics and Mechanics Expt, FOAM,
  - PArticle STAbilised Emulsions and Foams, PASTA (both ESA-led)



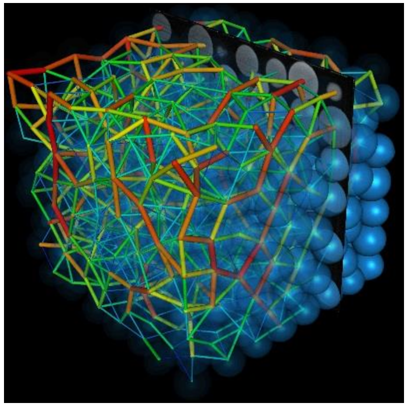
Foam structure without draining

- **Granular Flows:**

  Quantify the fundamental nature of jamming transition of granular materials in random close packing.

  Advances understanding of process that use granular flows. Experiment:

  - Compaction/Sound Transmission, COMPGRAN (ESA-led)



Reconstructed sample of particles, showing the boundaries of the particles (transparent blue), a single slice image (black and grey) and the contact forces between particles and the outer wall)

Fluid Physics

Fluid Physics - Status

- **Adiabatic Two-Phase Flows:**

  Develop fundamental tools to predict phase location and flow dynamics in low gravity two-phase systems (without heat transfer).

  Enables critical exploration technologies for water delivery/removal for biological systems; thermal control; life support; and space power.

  Experiments:
  - PBRE, Packed Bed Reactor Experiment, (ISS ops completed in Feb. 2017)
  - TPFSE, Two Phase Flow Separator (under development)

Temperature and Humidity Control for Advanced Plant Habitat

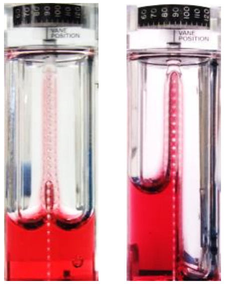
Hollow-fiber membranes for Biological Water Processors

The evolution of the “coffee cup” designed for partially wetting teas and coffees in microgravity

- **Capillary Flow And Interfacial Phenomena:**

  Investigate important capillary phenomena such as critical wetting, contact angle hysteresis, topological transitions, advancing and receding liquids on textured (real-world) surfaces.

  Experiments:
  - CFE-2, Capillary Flow Experiment-2, (ISS ops nearly completed & ISS data analysis phase).



Two different global equilibrium conditions for same geometry. Developing predictive models is critical to $86B commercial satellite industry.

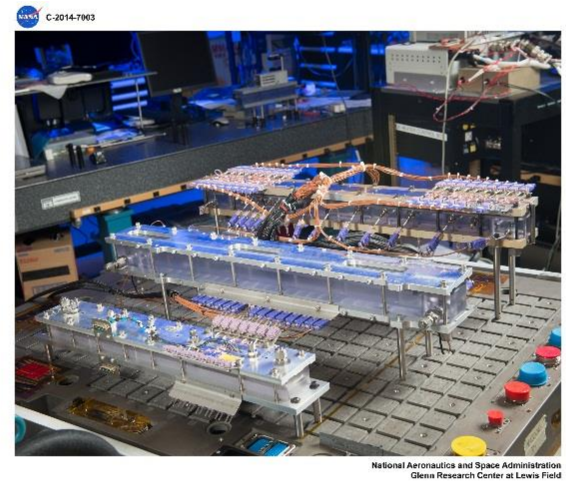
Fluid Physics - Status

- **Boiling and Condensation:**

  Develop reliable predictive capabilities for boiling and forced convective condensation in microgravity. Enables critical exploration technologies for thermal control and space power systems and cooling electronic systems. Will also lead to terrestrial applications to reduce energy use and CO2 emissions.

  Experiments in development:

  - Flow Boiling and Condensation Experiment, (FBCE)
  - Multiphase Flow and Heat Transfer, (MFHT) (ESA led)
  - ElectroHyDronamic Flow Experiment, (EHD)



Flow Boiling Condensation Experiment (FBCE) test module.

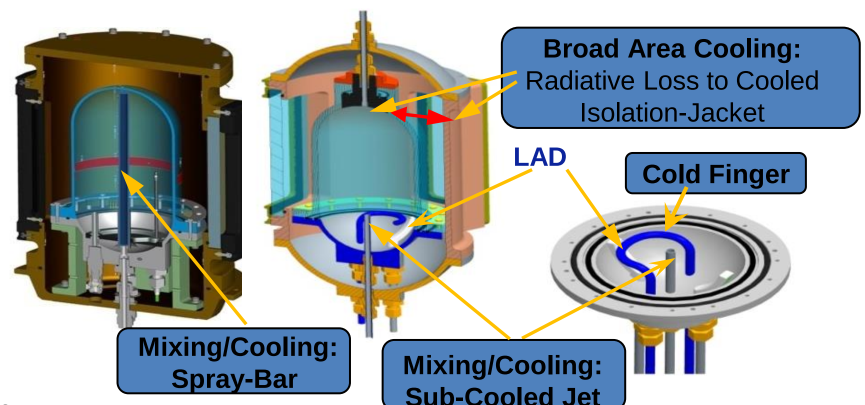
- **Cryogen Storage and Handling:**

  Conduct series of small scale simulant-fluid tests to de tools to enable long-term storage of cryogen propellar space.

  Enables critical exploration technology for cryogen propellant storage in space. Provides critical 0-g data STMD eCryo project.

  Experiments:

  - ZBOT collaboration with STMD, Ranked “Exploration Critical” for ISS manifesting
  - ZBOT - 2 and 3 (being evaluated)



Techniques to reduce “boil-off” of cryogen propellants

Zero Boil-Off Tank (ZBOT) Series

Principal Investigator: Dr. Mo Kassemi, CWRU

Co –Investigator: Dr. David Chato, NASA GRC

\Project Scientist: John McQuillen, NASA GRC

Project Manager: William Sheredy, NASA GRC

Engineering Team: ZIN Technologies, Inc


ZBOT Fluids Support Unit (FSU) & Engineering Model in MSG

ZBOT Experimental Series Description:

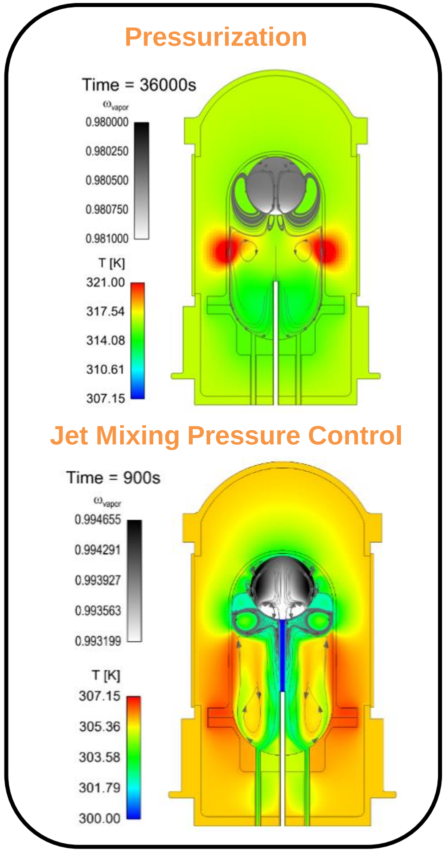
- Cryogenic propellant storage and transfer is an enabling technology in the critical path of all NASA's future long-duration missions
- ZBOT is a small-scale simulant-fluid science experiment and model development effort that investigates fundamental aspects of storage tank pressurization & pressure control in microgravity.
- A series of hierarchical science experiments will be carried focusing on three important Cryogenic Fluid management (CFM) issues in microgravity:
    - ZBOT-1: Studies tank pressurization and fluid mixing destratification (Launch Feb 2016)
    - ZBOT-2: Focuses on the effects of non-condensable gases on pressurization & pressure control
    - ZBOT-3: Quantifies droplet transport and phase change in microgravity for spray-bar droplet Active Cooling pressure control in Space

Synergetic Connection to STMD Evolvable Cryogenics (eCryo) Project:

- ZBOT Microgravity Data will be used to validate state-of-the-art two-phase CFD models for storage tank pressurization and pressure control under the "Development and Validation of Analysis Tools" task of eCryo Project.
- ZBOT Microgravity Data forms an important basis for an International Multi-Agency CFD tools Validation & Verification collaboration with the German (DLR) and Japanese (JAXA) Space Agencies.

Impact/Relevance to NASA's Evolvable Mars Exploration Campaign:

- Optimize development of zero boil-off pressure control - an OCT roadmap Mars mission-enabling technology.
- *Reduce propellant launch mass* (cost) and *decrease risks* for future space missions by aiding the development of dynamic pressure control schemes for long-term storage of cryogenic fluids.
- *Increase design reliability* by providing valuable microgravity archival data to the Cryogenic Fluids Management Community (CFM) at large and by benchmarking and improving CFD models/codes used by NASA and its future Prime Aerospace Contractors for (ground-tested-only) propellant tank designs.



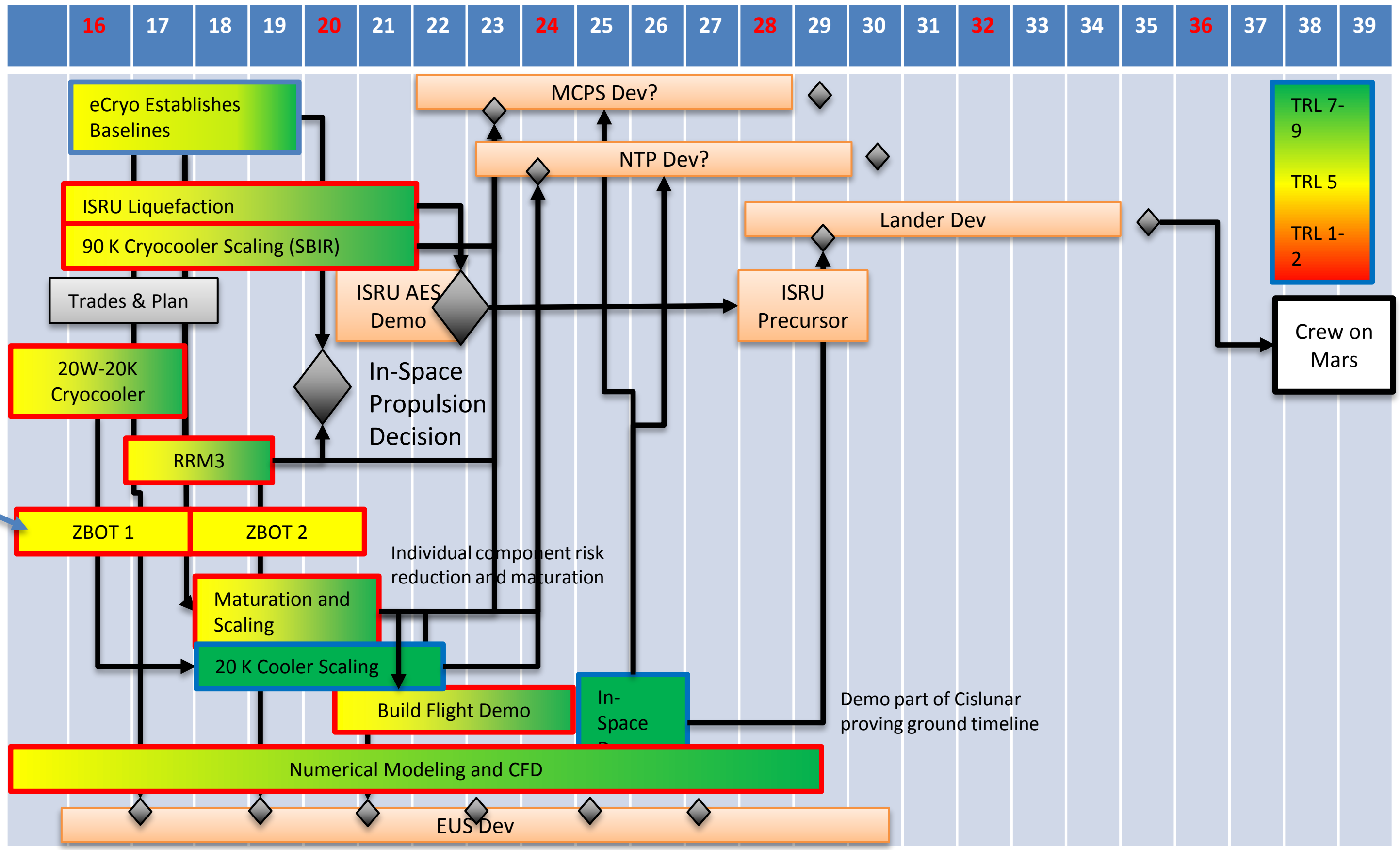
CFD Simulations

Fluid Physics - Planning

- Collaborate with STMD on future cryogenics experiments:
  - ZBOT- 2
  - ZBOT- 3
  - Large Scale Cryogenic Storage, Handling & Transfer expt.
    - Possible platforms include:
      - ISS experiment on external platform
      - Free Flyer experiment

Cryogen Tank

STMD - Notional Strategy for Cryogenic Fluid Management by Calendar



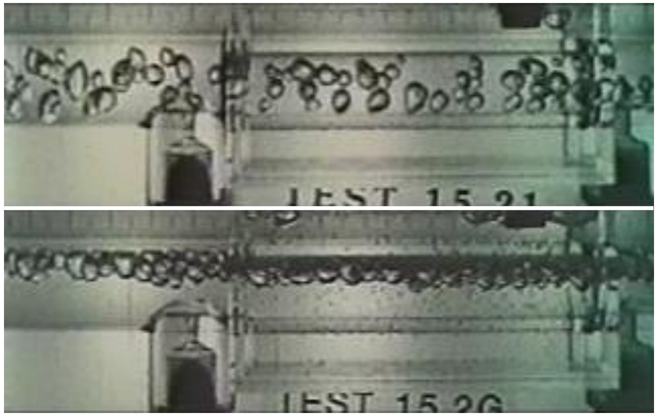
ZBOT included in STMD strategy

Wesley L. Johnson
Cryogenic Research Engineer
Cryogenic and Fluids Branch (LTF)
Glenn Research Center

Fluid Physics – Planning

- **Seek opportunities to collaborate with AES or STMD** shown below. Also provides candidate areas for future NRAs
- **Adiabatic Two-Phase Flow**
  - PBRE-AES – Two Phase Flow Pressure Drop in Packed Beds, Filters, Restrictions and Fittings for water recovery systems (in discussion w/AES)
  - TPFSE - Two Phase Flow Separator – alternate for rotary liquid-gas separator
- **Boiling, Evaporation and Condensation**
  - Heat Pipes (in discussion w/ STMD)
  - Urine Processor
  - Flow Boiling and Condensation (thermal management, nuclear electric propulsion)
- **Capillary Flow and Interfacial Phenomena**
  - Plant root zone water management system (in discussion w/ STMD)
- **Continue developing sufficient database** for future spacecraft designers, to <u>select the optimum thermal/fluid system in relevant environment</u> (partial or 0-g).

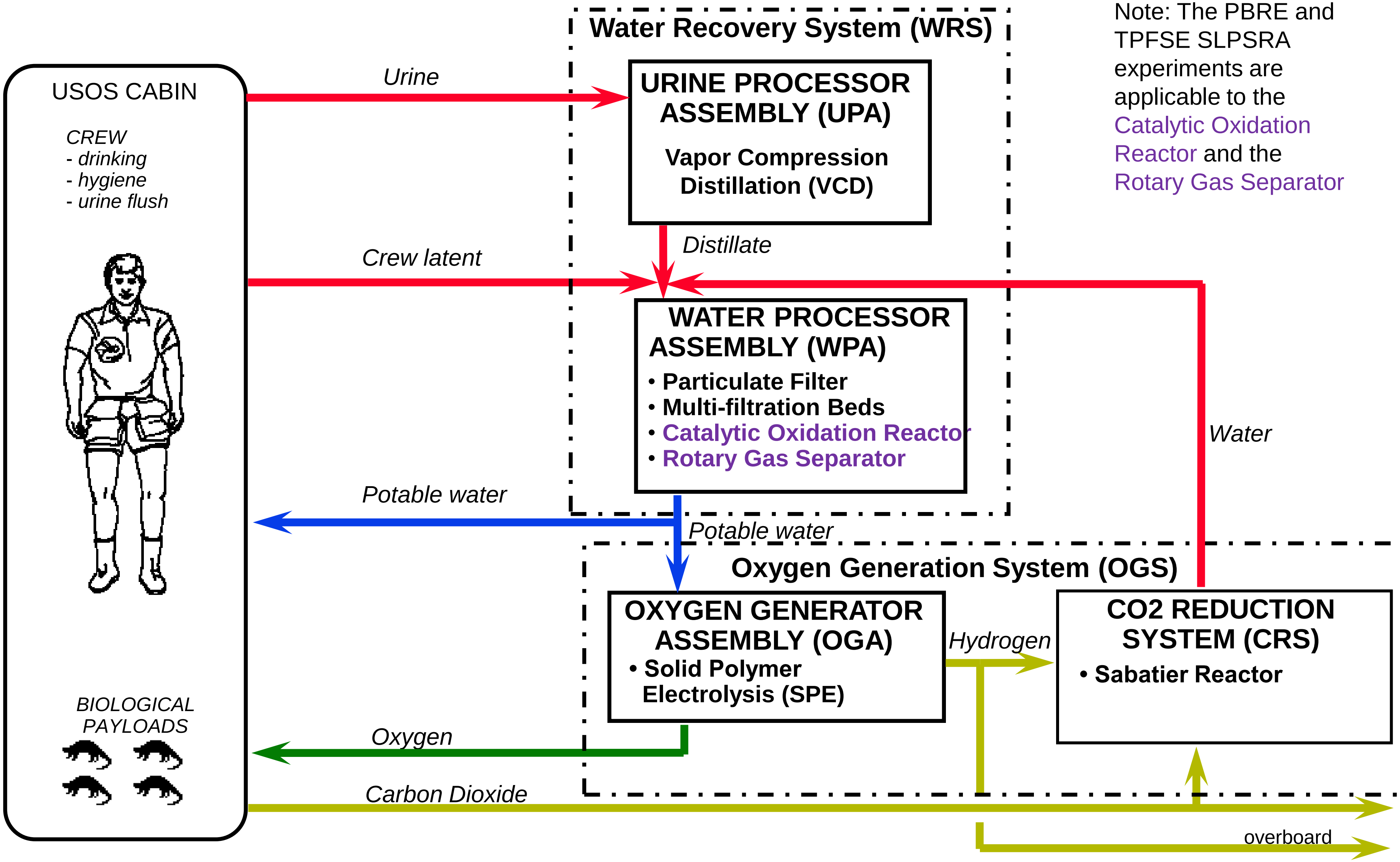
ISS Water Recovery System



Two phase flow in Micro-G (top) and 1-G (bottom)

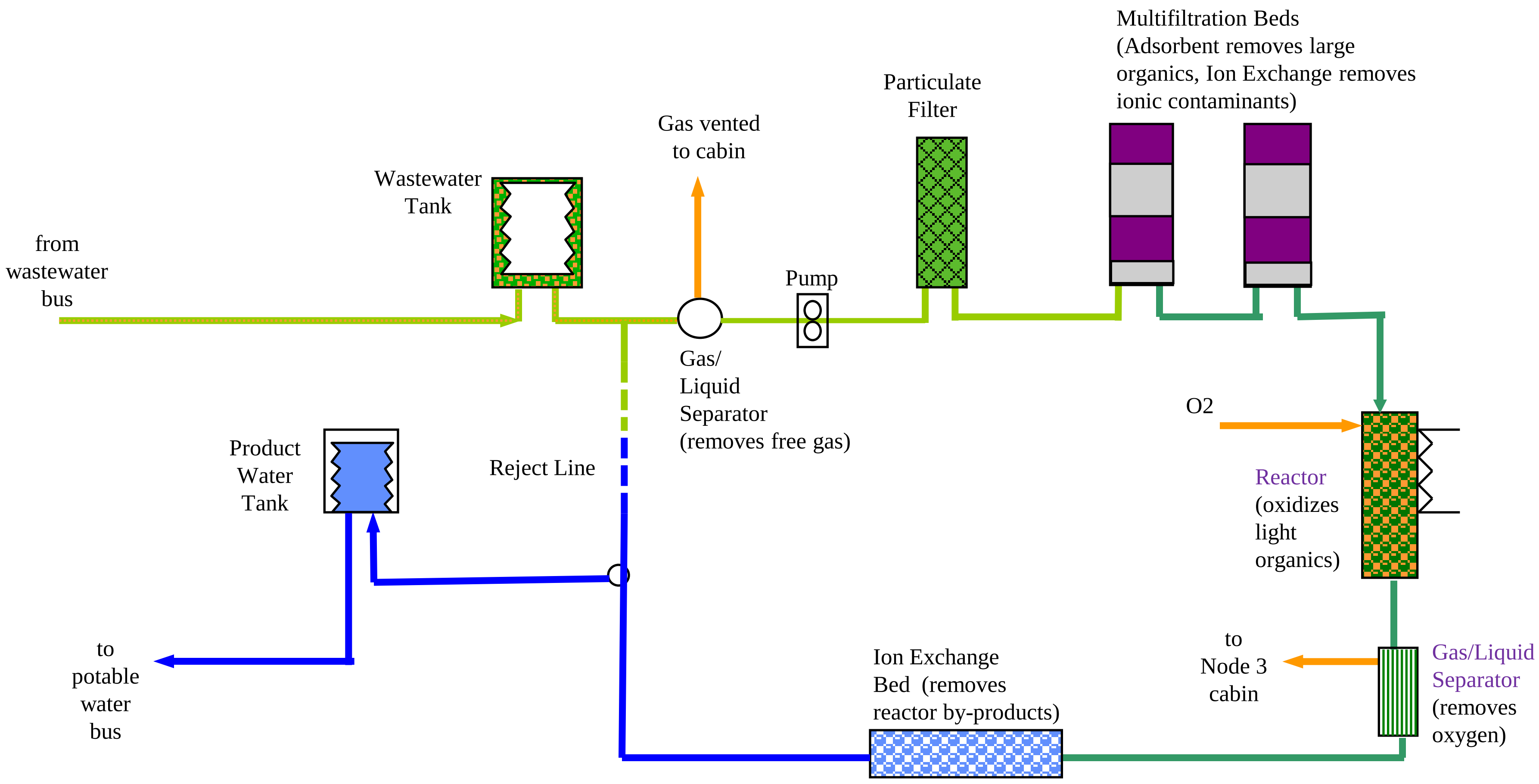
INTERNATIONAL SPACE STATION

ISS, Water Recovery System and Oxygen Generation System - Architecture Overview



Note: The PBRE and TPFSE SLPSRA experiments are applicable to the Catalytic Oxidation Reactor and the Rotary Gas Separator

Water Processor Simplified Schematic

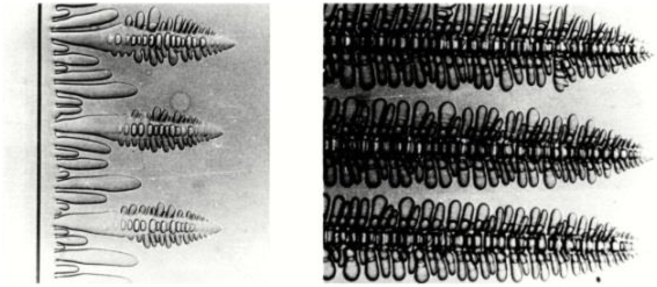


Materials Science

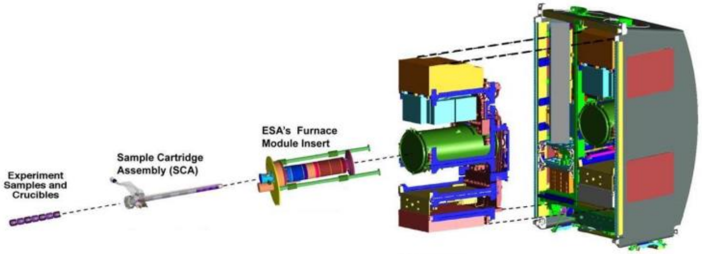
Materials Science - Status

Current Morphology Studies - Metals and Semiconductors

- Isothermal Processes– Utilize DECLIC, MSRR furnace inserts and MSG SUBSA device to study sintering and coarsening behavior.
  - Current Experiments CSLM, GEDS, FAMIS, DECLIC DSI
- Directional Solidification – Utilize the CNES DECLIC DSI, ESA MSRR furnace inserts and MSG devices to study growth patterns and morphological transitions involving columnar, branched and equiaxed growth in materials.
  - Current Experiments SETA, CETSOL, MICAST
- Crystal Formation – Utilize ESA MSRR inserts and MSG SUBSA to study impurity, dopant, and defect distributions in semiconductor single crystals
- Current Experiments:
  - ICEAGE, CdTe, SISSI
  - MaterialsLab - Solidificaton Microstructure, Cement, Brazing and Freeze Casting Reference Experiments



Above: Dendrite formation in a transparent, organic material



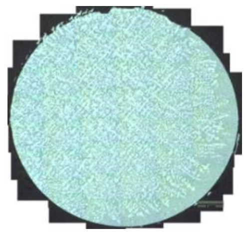
Above: Exploded view of the Microgravity Materials Science Research Rack (MSRR) showing ESA's Furnace Module Insert and Sample Cartridge Assembly.

Materials Science Program Overview: 11 Projects*
Metals and Alloys: Objective and Applications
Decadal Themes: AP9, TSES16

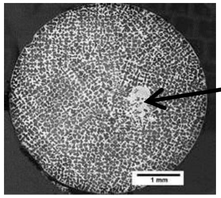
Objective:
1) Utilize the long term microgravity environment of the ISS to minimize gravity induced phenomena such as sedimentation and thermosolutal convection.
2) Conduct solidification experiments and liquid metal property measurements.
3) Evaluate the subsequent benchmark data and apply to Earth-based processes.

Applications:
- **Directional solidification of turbine blades**
- **Continuous casting**
- **Alloy development**
- **Mold design**
- **Predictive models**
- **Database of thermophysical properties**

Gravity induced solidification defects common to turbine blades

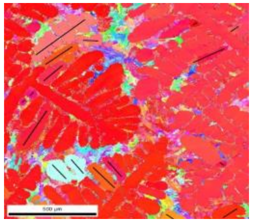


Dendrite clustering in an Al – 7wt.% Si alloy. The non-uniform structure compromise material properties



Directionally solidified lead-tin alloy showing a "freckle" casting defect. These are low-melting point and low strength areas.

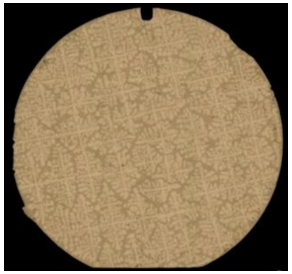
Microstructure of a turbine blade where the colors indicate dendrite orientations . These are grain boundaries, a source of weakness



Directionally solidified Al-Si alloy exhibiting mis-oriented dendrite arms. These are indicated by the black lines and are essentially in-situ defects.

Microgravity solidified Al-7% Si alloy shows a uniform dendritic network

Apply Microgravity
Gained Knowledge



Higher Temperature
Greater Efficiency
Longer Life

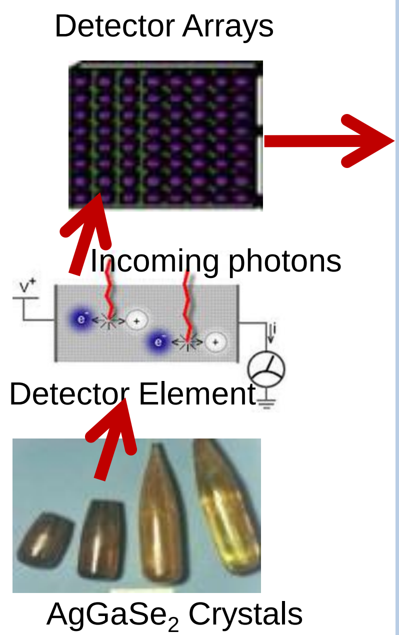
*Individual project details in backup

Materials Science Program Overview: More Than 5 Projects*
Semiconductors for Detectors and Sensors
Decadal Themes: AP9

Objective

Utilize the long duration microgravity environment on the ISS to better understand the growth processes and parameters required for the development of advanced semiconductor detectors and sensors.

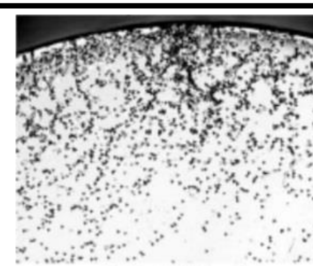
Apply knowledge to increase quality of crystals grown on Earth: higher production yield, increased transport mobility, fewer defects, increased dopant homogeneity.



Applications

- Electro-optical infrared (EOIR) systems
- Charged Couple Devices (CCD)'s
- MWIR and LWIR hyperspectral imagers
- Non-linear optics (NLO)
- Radio-frequency (RF) systems
- THz and radiation detection sensors
- High power transmitter/receiver modules
- Radiation hardened sensors for space systems
- Standoff multifunctional sensors
- Solar cells
- Cell phones

Right: Effect of wall contact on Ge crystals. One advantage of microgravity is that it enables crystal growth processes to be studied with little or no wall contact. Defect densities can be reduced by at least 2 orders of magnitude, improving carrier transport properties and detector sensitivity.



EPD ≈ $2 \cdot 10^4 cm^{-2}$

Wall contact

EPD ≈ $200 cm^{-2}$

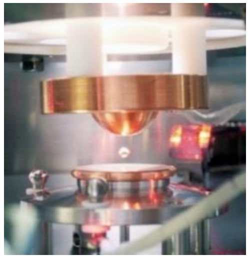
No wall contact

Materials Science - Status

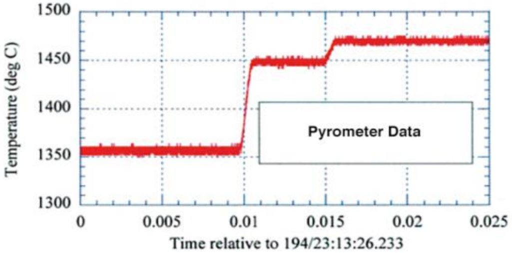
Thermophysical Property Measurements -

- Use microgravity environment to perform levitation experiments under conditions difficult or impossible to achieve on the ground
  - Low to near zero fluid flow in Electro-Magnetically levitated samples
  - Nearly ellipsoidal samples
  - Large Electro-Statically levitated samples,(low charge to weight)
- Make measurements of densities, specific heats, viscosities, and surface tension, and nucleation rates for liquid and undercooled metals, semiconductors, glasses, and ceramics.
- Utilize the ESA's Electro-Magnetic Levitator (EML) & JAXA's Electro-Static Levitation Furnace (ELF),
- Current experiments:
  - EML - PARSEC, Thermolab, ICOPROSOL,
  - ELF – MaterialsLab - Thermophysical Property Reference Experiment

Above: ESA Electromagnetic Levitator



Above: JAXA Electrostatic Levitation Furnace



Above: Pyrometry data of a double recalescence event.

Materials Science Program Overview: 8 Projects*
Levitation and Glass Formation Studies
Decadal Themes: AP9, AP11, TSES16

What is it?
Data (densities, specific heat, viscosity, etc.) from space studies on glass formation enabling the creation of advanced glasses.

What will it accomplish?
Insight needed to properly model glass forming industrial processes.

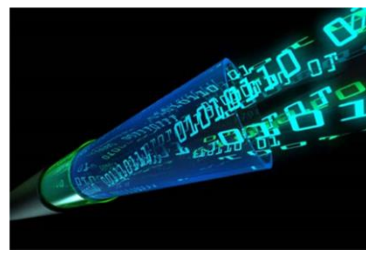
Why should NASA invest in it?
- Microgravity studies reduce convection and crystallization effects on the data collected.
-This R&D can extend range of glass formation leading to new products. Examples: photonic and structural glass materials and low cost bulk metallic glasses

What resources do you need?
-Uses: JAXA ESL, ESA EML, MSRR, LGF, SQF
-Uses: Astronaut time for sample exchange

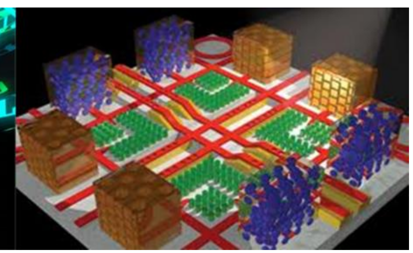
Project provides data for informatics-based process modeling, models which optimize ground-based industrial processes.

Examples: Many industrial processes, photonics (metal oxides), lasers, optical communications, imaging, holographic storage, adaptive optics, phase-conjugate mirrors, beamed energy, and semiconductors.

Optical fibers/device materials: Optical communications with higher bandwidth, faster transmission, reduced power and lower costs



Data transmission on an optical fiber



Optical device

Low-cost steel based BMG:
Faster cheaper fabrication of complex metal parts such as blow-molding of complex metal parts.
Current SOA BMG is Zr-based (~$32/kg).
Research on steel-based BMG could provide cheaper BMG materials (~$0.70/kg).

*Individual project details in backup

MaterialsLab Reference Experiments - Status

Reference Experiment	Lead Author from Selected Proposals	Proposal Title	Hardware	ISS Ops. Year	Collaboration
Brazing	Sekulic, UKentucky	Brazing of Aluminum Alloys IN Space	SUBSA	FY19	Belgium, Russia
Freeze-Casting	Dunand, Northwestern	Microstructure Evolution in Freeze-Cast Materials	PFMI	FY22	
	Wegst, Dartmouth	Structure-Property-Processing Correlations	PFMI	FY21	
Biofilms	McLean, Texas State - San Marcos	Polymicrobial biofilm growth and control during spaceflight	BioServe – BioCell / Microscope	FY20	SLPS-SB
	Zea, UC - Boulder	Biofilm Formation, Growth, and Gene Expression on Different Materials and Environmental Conditions	BioServe – BioCell / Microscope	FY19	SLPS-SB Germany
Liquid Crystals	Clark, UC - Boulder	Ferromagnetic Liquid Crystal Colloids in Microgravity	OASIS, LCF	FY22-23	Russia
	Rosenblatt, CWestern	Nanoparticles and Topological Defects in Thin Films	OASIS, LCF	FY23	Canada, France, Russia
	Yokoyama, Kent State	Monodisperse Liquid Crystal Domains	OASIS, LCF	FY23	Japan, Russia

MaterialsLab Reference Experiments - Status

Reference Experiment	Lead Author from Selected Proposals	Proposal Title	Hardware	ISS Ops. Year	Collaboration
Thermophysical Properties	Hyers, UMass - Amherst	Thermophysical Properties and Transport Phenomena	ELF	FY20	Germany, Japan, South Korea
	Matson, Tufts	Round Robin - Thermophysical Property Measurement	ELF, EML	FY20	Russia, Austria, Germany, Japan, South Korea, NIST
	Narayanan, UFlorida	A Novel Way To Measure Interfacial Tension	ELF	FY20	Japan
	Weber, Materials Dev.	Supercooled Molten Metal Oxides	ELF	FY20	Japan, Materials Development
	Ostrogorsky, Illinois Tech	Diffusion Coefficients of Dopants in Si and Ge Melts	SCA	FY21	Russia
Cement	Radlinska, Penn State	Microgravity Investigation of Cement Solidification	MSG	FY19	CASIS, Sauereisen Corp., BASF Corp., IPA Systems, NIST
Solidification Microstructure	Tewari, Cleveland State	Cellular/Dendritic Pattern Formation	SCA	FY22	
	Voorhees, Northwestern	Columnar to Equiaxed Transition, Dendrite Fragmentation	CSLM	FY20	

ISS MaterialsLab Phase 2, Sample Candidate List - Planning

Item	Topic	Proposed Experiment Concept	Workshop Chair
1	**Biophysics**	Biomaterials Facility - Containerless Bioreactor - Concentration Bioreactor - 12 plate bioreactor	Ulrike G.K. Wegst – Chair ; Dongbo Wang – Co-Chair; Jacinta C. Conrad – Co-Chair
2	**Biophysics**	3D Bioprinting	Ulrike G.K. Wegst – Chair ; Dongbo Wang – Co-Chair; Jacinta C. Conrad – Co-Chair
3	**Glasses and Ceramics**	Development of new optical, electrical, and high strength materials	Steve W. Martin - Chair; Richard Weber – Co-chair; Edwin Etheridge - Co-chair
4	**Glasses and Ceramics**	Diffusion Measurements	Steve W. Martin - Chair; Richard Weber -Co-chair; Edwin Etheridge – Co-chair
5	**Granular Materials**	Granular Materials Facility	David Frost - Chair; Mustafa Alsaleh – Co-chair
6	**Granular Materials**	A Study on Space Cements Processing	David Frost - Chair; Mustafa Alsaleh-Co-chair

Item	Topic	Proposed Experiment Concept	Workshop Chair
7	**Metals**	Soldering and Brazing and/or Welding Facility	Reza Abbaschian - Chair; Bob McCormick-Co-chair; Richard Ricker-Co-chair
8	**Metals**	Microstructural Development in DS Eutectic Alloys	Reza Abbaschian - Chair; Bob McCormick-Co-chair; Richard Ricker – Co-chair
9	**Polymers and Organics**	3D Printing of Polymers 3D Printing in Space	Bruce Chase - Chair; Mike Snyder - Co-chair; Eric Lin - Co-chair
10	**Polymers and Organics**	Improvement of uniformity during material synthesis in microgravity	Bruce Chase - Chair; Mike Snyder - Co-chair; Eric Lin - Co-chair
11	**Semiconductors**	High Temperature Furnace	N.B. Singh - Chair; Sudhir Trivedi - Co-chair
12	**Semiconductors**	Bulk Growth of Semiconductor Compounds for High Value Sensors and Detectors	N.B. Singh - Chair; Sudhir Trivedi - Co-chair

Physical Sciences Collaboration

- CASIS
- International Space Agencies
- Other NASA Divisions

CASIS – SLPSRA PS collaboration (with crew time savings)

Number	Experiment or hardware developed by SLPSRA	CASIS crew time (originally covered by SLPSRA), hours
1	**Light Microscopy Module: Biological Samples (**LMMBIO – 1)	10
2	**Light Microscopy Module: Biological Samples (**LMMBIO – 3)	10
3	**Advanced Colloids Experiment (**ACE – T6)	6
4	**Cement Reference Experiment**	5
5	**Light Microscopy Module** LMM upgrade – confocal and LMM camera	14
6	**Advanced Colloids Experiment** ACE – H2, installation only* (completed)	2
7	**Advanced Colloids Experiment** ACE – T1, installation only	2
8	**Advanced Colloids Experiment** ACE – 2R, installation only	2
9	**Advanced Colloids Experiment** ACE – T7, installation only	2
10	**Advanced Colloids Experiment** ACE – T9, installation only	2
	Total crew time savings for SLPSRA	**55**

CASIS – SLPSRA PS collaboration (Potential New)

Number	Experiment developed by SLPSRA	Commercial Partner	Launch year
1	Nucleation Precursors in Protein Crystallization (LMMBIO-2) - Vekilov		2018
2	Ring-Sheared Drop for the Study Amyloid Fibril Formation (RSD) - Hirsa	Cure Alzheimer's Fund and Cleveland Clinic	2019
3	MaterialsLab - Thermophysical Properties of Supercooled Molten Metal Oxides - Weber	Materials Development, Inc	2020
4	Two Phase Flow Separator – Chahine	DynaFlow Corp.	2020
5	MaterialsLab, Liquid Crystals - Monodisperse Liquid Crystal Domains -Yokoyama	MERK (Dr. Melanie Klasen-Memmer)	2022

NASA – ROSCOSMOS Agreement

NASA-Roscosmos Protocol
Utilization Sharing Plan on-board ISS
July 18, 2013

1. Roscosmos and NASA agree to work together to increase ISS utilization on-board ISS

2. Starting fall 2013, Roscosmos agrees to perform up to 5 hours per week average of USOS Utilization activities as agreed by NASA and TsNIIMASH for cooperative research approved by the Program Science Forum. The amount of hours can be increased with Program Manager concurrence.

3. Any video on NASA utilization activities being performed by Russian crew members will be sent to MCC-M at the same time the video is received by NASA.

4. Any data downlinked on NASA utilization activities being performed by Russian crew members will be sent to MCC-M within 24 hours of the data being received by NASA.

5. Any downlink video or data files from USOS science hardware under this agreement can be provided to Russian investigators with no constraints.

6. No compensation for crew time or utilization video/data files will result from this agreement.

For NASA:

Michael T. Suffredini 7/18/13

For Roscosmos:

Alexey B. Krasnov
18.07.13

NASA - Russian Collaboration in SLPSRA Physical Sciences, Feb. 2017

#	Experiment	Principal Investigator	Russian Investigators	Collaboration Status	ISS Ops
1	Observation and Analysis of Smectic Islands (OASIS)	Professor Noel Clark, University of Colorado	Professor Pavel Dolganov & Professor Vladimir Dolganov, Institute of Solid State Physics Professor Efim Kats, Landau Institute Theoretical Physics	Science Protocol & ISS PSF Protocol - signed, Experiment **COMPLETED**	July 2015- Jan. 2016, Mar 2016
2	Cool Flames Investigation - Open Science, (CFI-OS)	Lead: Professor F. Williams, Univ. of California, San Diego Also: Prof. Dryer, Princeton, Prof. Farouk, Univ. S. Carolina Dr. Nayagam, Case Western Dr Dietrich, NASA GRC	Dr. Sergey Frolov, N.N. Semenov Inst. Chemical Physics *Open Science Users – not funded,* Prof. Valentin Basevich, Dr. Andrei A. Belyaev, Dr. Sergey N. Medvedev, Dr. Igor Assovskii, Prof. Nickolay Smirnov, Moscow Lomonosov St Dr. V. Tyurenkova, Scientific Research Inst. System Analy. Inst. of Chemical Kinetics-Combustion, RAS Siberian Div. Dr. O. Korobeinichev, Dr. T. Bolshova, Dr. D.Knyazkov,	Science Protocol – signed ISS PSF Protocol - signed	Feb.- May 2017
3	Coflow Laminar Diffusion Flame (CLD Flame) – ACME	Professor Marshall Long, Yale University	Prof. Sergey Minaev, Far Eastern Federal University Dr. Valerii Babushok, Far Eastern Federal University Dr. Fedir Sirotkin, Far Eastern Federal University Dr. Evgenii Sereschenko, Russian Academy of Sciences	Science Protocol – draft ISS PSF Protocol - draft	2017-18
4	Electric-Field Effects on Laminar Diffusion Flames (E-FIELD Flames) -ACME	Professor Derek Dunn-Rankin, University of California - Irvine	Prof. Sergey Minaev, Far Eastern Federal University Dr. Fedir Sirotkin, Far Eastern Federal University Dr. Valerii Babushok, Far Eastern Federal University Dr. Roman Fursenko, Far Eastern Federal University	Science Protocol – draft ISS PSF Protocol - draft	2017-18
5	Structure and Response of Spherical Diffusion Flames (s-Flame) - ACME	Professor C. K. (Ed) Law, Princeton University	Dr. Vladimir Gubernov, P.N. Lebedev Physical Institute, RAS	Science Protocol - draft ISS PSF Protocol - draft	2018-19
6	Flame Design - ACME	Professor Richard Axelbaum, Washington University, St. Louis	Prof. Mikhail Yu. Sinev, N.N. Semenov Inst. Chem. Physics Prof. Sergey Frolov, N.N. Semenov Inst. of Chemical Phys Dr. Pavel Vlasov, N.N. Semenov Institute of Chemical Phys	Science Protocol & ISS PSF Protocol - draft	2018-19
7	Burning Rate Emulator (BRE) ACME	Prof. J Quintiere, University of Maryland	Dr. Alexander Snegirev, Saint-Petersburg State Polytechnic University	Science Protocol & ISS PSF Protocol - draft	2019 -20

NASA - Russian Collaboration in SLPSRA Physical Sciences, Feb. 2017, (Continued)

#	Experiment	Principal Investigator	Russian Investigators	Collaboration Status	ISS Ops
8	BRAzing of Aluminum Alloys IN Space	Professor Sekulic, University of Kentucky	Professor Mikhail Krivlev, Udmurt State University of Russia	Science collaboration established, in discussion	2019
9	Material Ignition and Suppression Test (MIST) - SOFIE	Professor Carlos Fernandez-Pello, University of California Berkeley	Professor Nickolay Smirnov, M.V. Lomonosov State University	Science Collaboration established, in discussion	2020-22
10	Growth and Extinction Limit of Solid Fuels (GEL) - SOFIE	Professor James S. T'ien, Case Western Reserve University	Professor Oleg Korobeinichev, Institute Chemical Kinetics & Combustion, Siberian Branch, RAS	Science Protocol -draft	2020-22
11	Diffusion Coefficients of Dopants in Si and Ge Melts	Professor Ostrogorsky, Illinois Tech	Professor G.N. Kozhemyakin and Dr. A.E. Voloshin A.A. Shubnikov Institute of Crystallography, Russian Academy of Sciences, Moscow, Russia	Science Collaboration established, In discussion	2021
12	Liquid Crystal Nanoplates, LCN, (LFC- Bulk)	Professor Cheng, Texas A&M	Prof. Vladimir Dolganov, Inst. of Solid State Physics Prof. Efim Kats, Landau Inst. Theoretical Phy	Science Protocol -draft	2022
13	Ferromagnetic Liquid Crystal Colloids in Microgravity, (LCF – Bulk and Bubble)	Professor Clark, University of Colorado – Boulder	Professor A.A. Levchenko, Professor Pavel Dolganov, Institute of Solid State Physics, Prof. Efim Kats, Landau Institute of Theoretical Physics, Russian Academy of Sciences, Moscow	Science Collaboration established, in discussion	2022-23
14	Nanoparticles and Topological Defects in Thin Films, (LCF –Bubble)	Professor Rosenblatt, Case Western Reserve	Prof. Leonid V. Mirantsev, Institute of the Problems of Mechanical Engineering, RAS, St. Petersburg; Dr. Elena Pikina, Oil and Gas Research Institute, RAS, Moscow, Russia	Science Collaboration established, in discussion	2022-23
15	Monodisperse Liquid Crystal Domains, (LCF – Bubble)	Professor Yokoyama, Kent State University	Professor Alexander Emelyanenko, Head of Liquid Crystal Laboratory, Lomonosov Moscow State University, Moscow, Russia	Science Protocol -draft	2022-23

Impact of Russian – NASA collaboration

- Russian- NASA agreement: Russian Scientists, selected by NASA PI or Co-Investigator on original NASA proposal, participate in ISS experiment. In exchange, Russian crew time is provided operate a portion of the experiment.

- Crew time provided by Cosmonauts –
  - OASIS – 21 hours (completed)
  - CFI in Increment 49/50 – 6 hours scheduled, February 2017
- Crew time provided by Russians – in negotiation
  - All five ACME experiments - 150 hours, (for five consecutive increments)

Challenge of Russian - NASA collaboration for 2017 and 2018.

- In March of 2017 the Russians are going to “two-crew” until the MLM laboratory launches. Currently the projected MLM launch is December 2017, so two-crew will continue through March 2018 based on Soyuz rotations.

- This challenge will exist for one year or more.

  – MLM: The Russian Multipurpose Laboratory Module

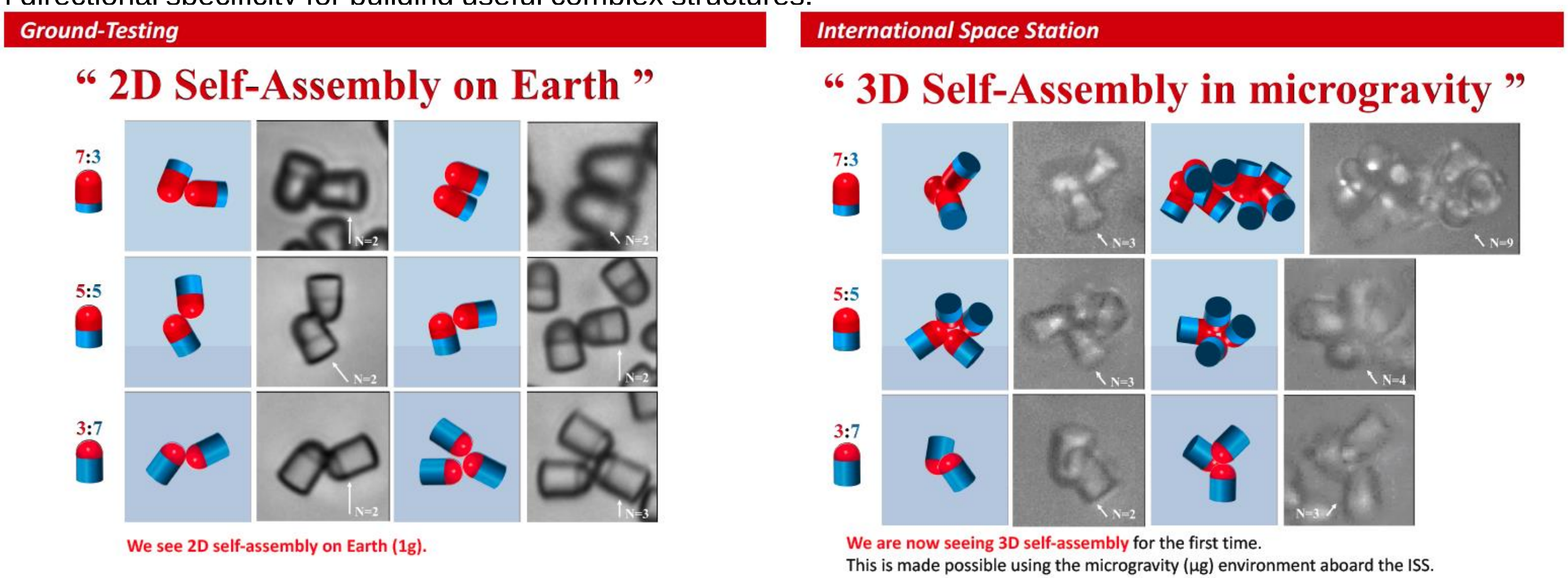
South Korea – NASA Collaboration,

Advanced Colloids Experiment – ACE T1

PI: Chang-Soo Lee, Chungnam University, S. Korea
Approach: FIR/LMM
Launch: SPX-9 and HTV-6, modules 1 and 2
ACE-T1 studies 3D self-assembly of complex (Janus, multi-sided) particles that are hydrophobic and hydrophilic (repel and attract water). Microgravity allows for the observation of 3D assembly of submicron particles that would sediment on Earth. The project studies colloidal engineering with an emphasis on self-assembly, which spontaneously forms precisely organized structures by thermodynamic equilibrium. This work has the promise of ultimately providing efficient and affordable manufacturing processes for functional devices and materials with novel or enhanced properties. The complex structures that result from self-assembly at the particle level are regulated by directional interactions. When assembling particles into larger 3D colloidal building blocks on Earth, gravity dominates, masking the electrostatic and van der Waals interactions that we need to better understand to control the creation of 3D structures. The microgravity environment can explore the effects of colloidal particle shape anisotropy. This has the promise of using particle shape-selective interactions with directional specificity for building useful complex structures.

Letter of Agreement

The National Aeronautics and Space Administration (NASA) and Chungnam National University (CNU) (hereinafter jointly referred to as the "Parties") have expressed a mutual interest in collaborating on the Advanced Colloids Experiment (ACE) to observe the behavior of colloidal systems using a microscope in the microgravity environment of the International Space Station (ISS).

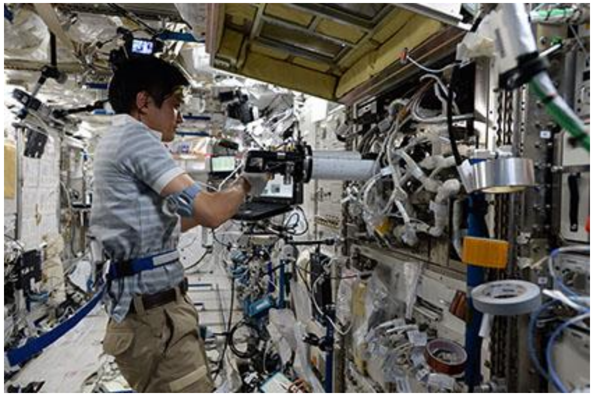


JAXA – NASA collaboration

Technical Understanding Document - NASA and JAXA collaborative investigations on ELF-US and BASS-J in formulation.

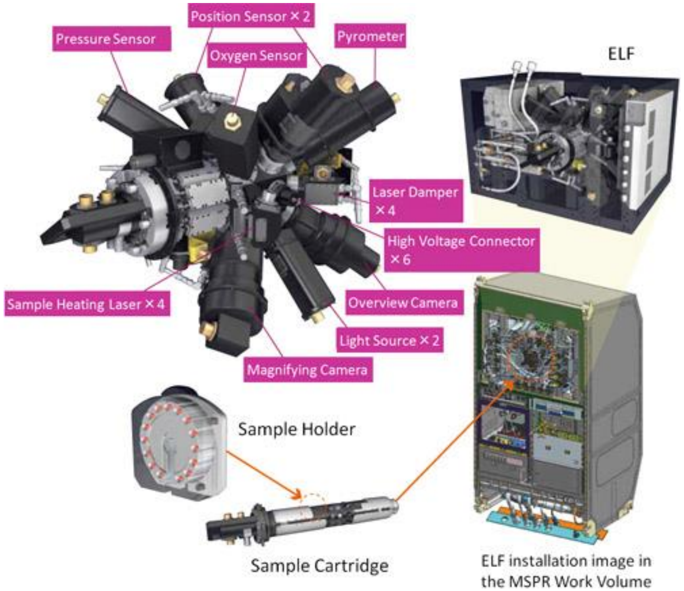
- NASA and JAXA have a mutual interest to share ISS flight hardware for materials science and combustion research to leverage their research programs and to maximize the efficient utilization of facilities. NASA has four investigator teams interested in using JAXA's Electrostatic Levitation Facility (ELF) and JAXA has an investigator who is interested in using NASA's Burning and Suppression of Solids (BASS) hardware.

ELF and BASS hardware



ELF on orbit

BASS operating in MSG on orbit



JAXA's Electrostatic Levitation Furnace (ELF)
Estimate: $60M

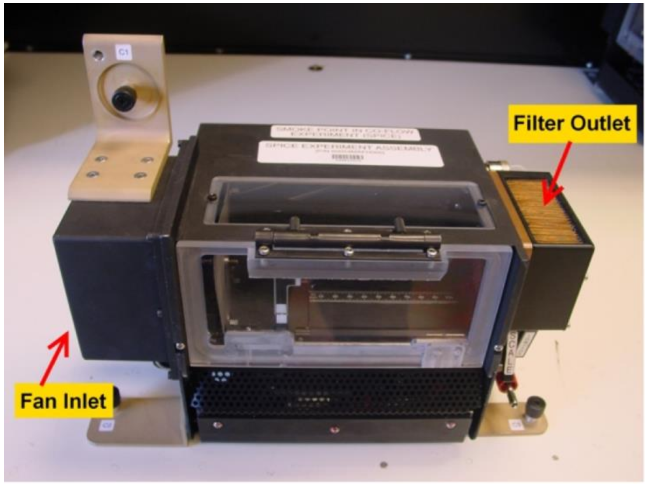


Figure 3. Fan Inlet/ Filter Outlet

NASA's BASS unit
Estimate: $3M (Life cycle cost est.)

ESA - NASA collaboration

- NASA- ESA Technical Understanding Document Operation of Facilities.
- ESA uses **International Topical Teams**. NASA funded scientists were competitively selected through NRA or ESA AO to participate on:
  - MSL, LGF and SQF, SCA - Sample Cartridge Assembly, Materials Science Experiments
  - Electromagnetic Levitator Series(EML): Materials Science experiments
  - Atomic Clock Ensemble in Space (ACES) (Fundamental Physics program, Mark Lee)

NASA – ESA TU Operation of Facilities

NASA-ESA Technical Understanding on Operation of Facilities
July 2013

NASA and ESA consider that the objectives in Annex 1 will be accomplished for the purpose of jointly implementing coordinated maintenance and operation of utilization facilities on ISS. These objectives will enable on-orbit collaborative use of the MSG, MSL, MSRR, EML, and ACES facilities. MSG, MSL, and MSRR have been used for ongoing science cooperation under the Early Utilization MOU. Annex 1 defines the technical responsibilities of NASA and ESA for each facility. Results from this coordination will be shared between the scientific teams under the experiment specific implementation processes.

This Technical Understanding (TU) documents NASA's and ESA's common position that their respective roles and responsibilities are equitably distributed for a common goal of enabling maximum utilization research. In the event that activities under this TU vary or do not proceed as expected, then NASA and ESA will consult with each other.

If expansion of these activities requires additional resources or the activities are beyond the scope of this TU which would require a legally binding agreement, NASA and ESA will consider pursuing such an agreement to include all of the appropriate legal terms and conditions.

7/17/13

Michael T. Suffredini Date
NASA

17/07/2013

Bernardo Patti Date
ESA

Leveraging ESA's facilities through collaboration

In exchange for crew time, NASA funded scientists participate in ESA experiments on the MSL/SCA, EML and ACES. ESA investment is shown below. (Note ACES developed by ESA and CNES. EML developed by ESA and DLR). Each facility required more than ten years to develop.

$60 M

MSL, LGF/SQF, SCA

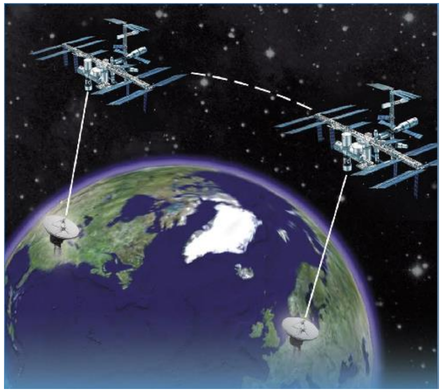
MATERIALS: Astronaut Frank DeWinne completing installation in the ***MSSR/MSL*** *prior to on-orbit commissioning October 2009. MSL developed by ESA.*

$70M

Electromagnetic Levitator Furnace

MATERIALS: Astronaut Alexander Gerst *completing installation of the ESA (with DLR)* ***EML****, October 2014 on ISS*

$150 -200 M

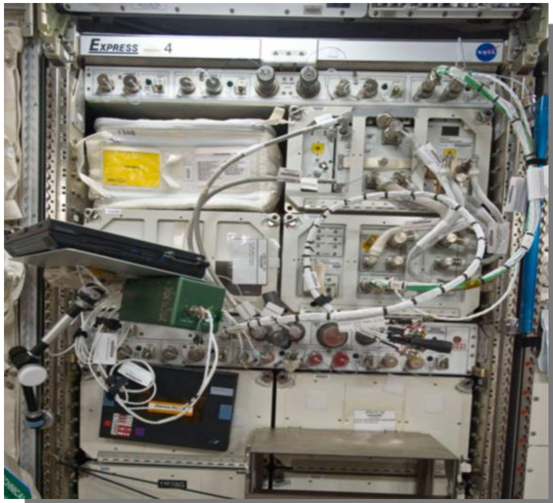


Atomic Clock Ensemble in Space. ESA to provide two microwave link stations: NIST and JPL. Launch: 2018

CNES – NASA Collaboration

- Letter of Agreement and Addendum – Bilateral collaboration for the use of DECLIC and DECLIC Reflight experiments. Experiments include critical point phenomena, transparent metal model solidification and super critical water mixture.
- CNES built the hardware, requiring nine years to develop, and also provides ground operations support. The CNES investment is shown below. NASA provided the launch and crew time. NASA funded scientists participate in the experiments:
  - High Temperature Insert, HTI & HTI-R
  - Directional Solidification Insert, DSI & DSI- R
  - Alice Like Insert, ALI & ALI-R

$30M



*MATERIALS, FLUIDS, and FUNDAMENTAL PHYSICS experiments: CNES-**DECLIC** in an EXPRESS Rack on ISS.*

DLR – NASA Collaboration

Letter of Agreement: Bilateral

The National Aeronautics and Space Administration (NASA) and the German Aerospace Center (DLR), hereinafter referred to as "the Parties," have discussed cooperative research activities in the field of fluid physics and applications aboard the International Space Station (ISS). These discussions have led to development of DLR's Capillary Channel Flow (CCF) Payload for use on ISS. It also involves the NASA provision of a launch to the ISS, on-orbit accommodation of the CCF Payload in the ISS-based Microgravity Science Glovebox (MSG), and provision of the necessary ISS resources to operate the main experiment (hereinafter referred to as the CCF Experiment) associated with CCF Payload.

Scott Kelly, installing CCF in the MSG on the ISS.

Capillary Channel Flow Experiment (CCF)

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

Objective:

•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.

Relevance/Impact

•The current design of spacecraft fuel tanks rely on additional reservoirs to prevent the ingestion of gas into the engines during firing. This research is required to update these current models, which do not adequately predict the maximum flow rate achievable through the capillary vanes eliminating the need to over design tanks.

Status:

- Original CCF experiment series completed.
- Over 5000 data points were collected.
- Hardware available for additional test runs by US and German investigator teams or others.

Planning

- *There is interest by the DLR investigator team to conduct additional tests on CCF.*

NASA - NIST MOU

to support NASA's "MaterialsLab" Materials Science Program

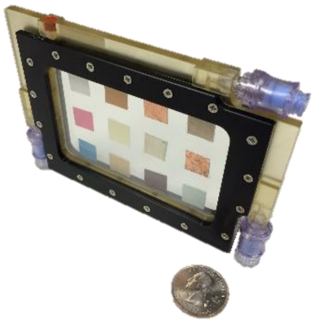
- NASA and NIST signed an MOU to work together on MaterialsLab in an joint effort to support the President's Materials Genome Initiative.
- *The purpose of this Memorandum of Understanding (hereinafter referred to as "MOU") is to establish a framework for cooperation between the National Aeronautics and Space Administration (hereinafter referred to as "NASA") and the National Institute of Standards and Technology (hereinafter referred to as "NIST") that enhances the impact of NASA's "MaterialsLab" microgravity materials science program and the impact of NIST's materials data and modeling activities including its leadership role in the Materials Genome Initiative (MGI).*
- NASA's MaterialsLab Research includes reference experiments in: Solidification Microstructure, Cement, Brazing, Thermophysical Property Measurements, Freeze Casting, Biomaterials and Liquid Crystals.
- NASA-NIST MOU signed March 2015 by Charles Bolden, NASA Administrator and Dr May, Director of NIST.

SLPSRA PS - SLPSRA SB Collaboration Established

Biofilms Reference Experiment

- Investigate the formation and architecture of a mixed bacterial biofilm, *Pseudomonas aeruginosa* plus *Escherichia coli*, on stainless steel
- Characterize biofilm growth of *Pseudomonas aeruginosa* (bacteria) *chrysogenum* (fungus) for mass, thickness, morphology, and associated gene expression when grown on different representative materials

ISS Incubator



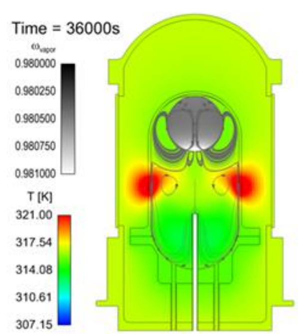
Sample Bio-cell

Bioserve microscope

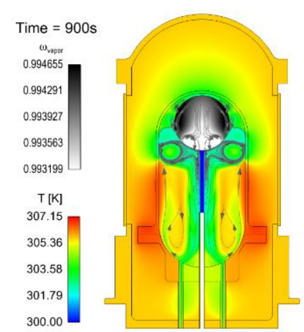
STMD - SLPSRA Collaboration - Established (Originally Push and now Pull)

- ZBOT
  - ZOT was originally a “Technology Push” that became a “Technology “Pull”
  - ZBOT-1: Studies tank pressurization and fluid mixing destratification in microgravity (Launch Feb 2016)
  - Synergetic Connection to STMD Evolvable Cryogenics (eCryo) Project:
  - ZBOT Microgravity Data will be used to validate state-of-the-art two-phase CFD models for storage tank pressurization and pressure control under the “Development and Validation of Analysis Tools” task of the STMD eCryo Project.
  - ZBOT Microgravity Data forms an important basis for an International Multi-Agency CFD tools Validation & Verification collaboration with the German (DLR) and Japanese (JAXA) Space Agencies.
  - Optimize development of zero boil-off pressure control - an OCT roadmap Mars mission-enabling technology.
  - Reduce propellant launch mass (cost) and decrease risks for future space missions by aiding the development of dynamic pressure control schemes for long-term storage of cryogenic fluids.

ZBOT 1: investigation



Pressurization



Jet Mixing Pressure Control

Possible New Collaboration with AES (Push and Pull)

1. **Pressure Drop in Two Phase Flow** Experiment. The objective is to test for differences between 1-G and micro-G pressure drop values across various filters and flow restrictors in a two phase flow system. Uses modified Packed Bed Reactor Experiment (PBRE) hardware on the ISS.

2. **Switchable Polarity Solvents** Experiment. The objective is to characterize interaction between the Switchable Polarity Solvent (SPS) and CO2(g) input by examining the interfacial phenomena via a variety of gas input methodology. Supports air revitalization and water recovery technologies by further development of a Carbon Dioxide and Water Recycling System. Uses a modified PBRE system on the ISS.

AES - **Pressure Drop in Two Phase Flow** using PBRE (Technology Pull)

Proposer name: Layne Carter
Theme: Water Recovery

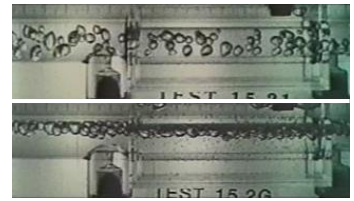
Objective: Evaluate Pressure Drop of Two Phase Flow in μ-Gravity

1) Test for differences between 1-G and μ-G bubble point values for filters with varied micron ratings. Bubble point is the pressure at which free gas in two-phase flow is forced through a filter.
2) Test for differences between 1-G and μ-G pressure drop values across various flow restrictors
3) Develop correlation for difference between bubble point and pressure drop behavior in experiments 1-G vs μ-G systems on the ISS.

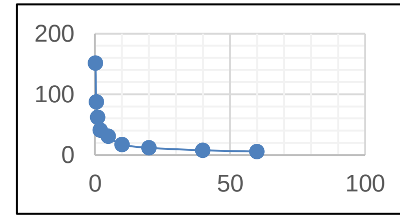
Impact/Applications:

- Anomalies on ISS indicate the bubble point and pressure drop across restrictions is higher in μ-G than 1-G. This test program will quantify the effect of μ-G on the bubble point and pressure drop across restrictions.
- This information will provide clarification on the unexpected accumulation of gas that has occurred on Water Recovery System (WRS) filters during ISS operations, and therefore provide better understanding of anomalous behavior and support further troubleshooting activities.
- Improves understanding of pressure drop in μ-G so future space exploration missions avoid further issues related to filters and restrictions in gas/liquid systems.

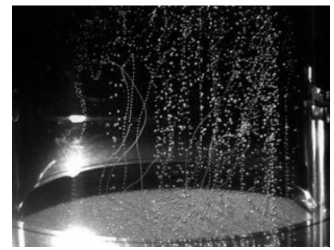
Facility: PBRE

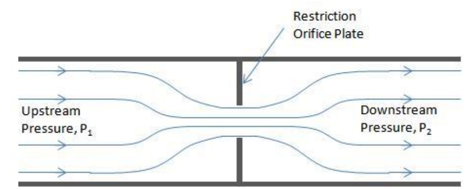


Two phase flow in Micro-G (top) and 1-G (bottom)



Plot of average bubble pt (mmHg) vs ilter micron rating



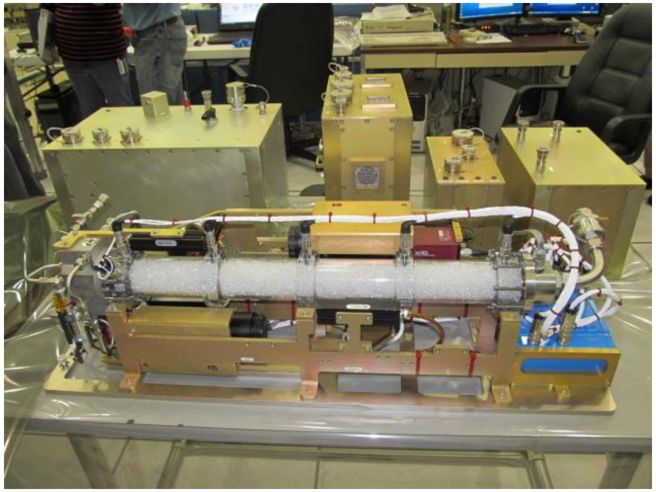


Above: Diagram of orifice flow ΔP
Left: Flow through filter after bubble point

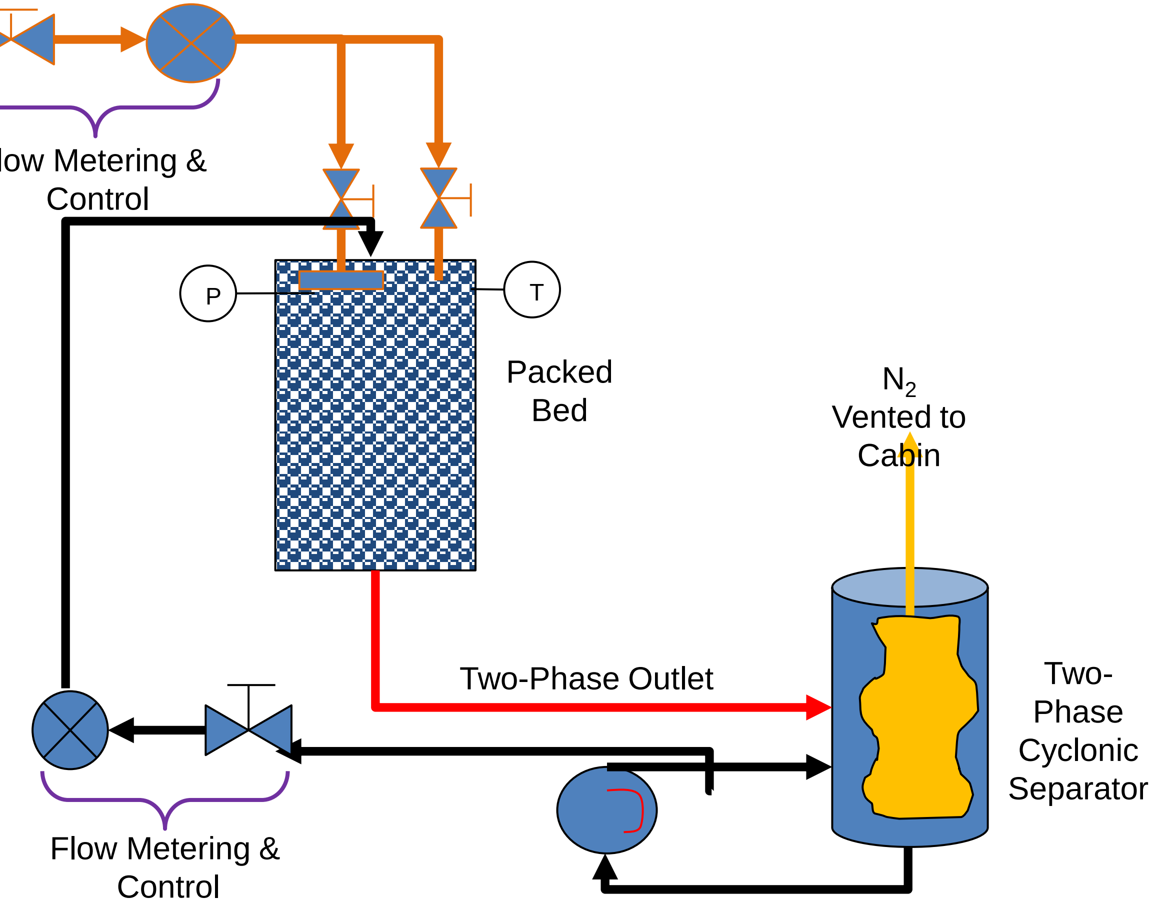
Microgravity Justification: In reduced gravity, there are no buoyancy driven flows; however density differences between the phases are manifested in terms of flow momentum effects. The gas phase is much smaller than that for the liquid phase; therefore, the gas can turn corners quicker than the liquid phase which is carried forward by its momentum. One consequence is a tendency for the gas phase to accumulate in regions of low pressure, such as the “vena contracta” for sudden contractions and in the corners downstream of expansions. As these gas bubbles grow, they will periodically shed large bubbles that accelerate the flow resulting in larger pressure drops and other flow instabilities.

Exploration Relevance: Space systems involving multiphase flows face significant design challenges because of the unique liquid/vapor configurations and phase distributions that occur in the absence of gravity. “Lessons learned” from the design and operation of the ISS Water Recovery Systems coupled with key insights is highly relevant to avoiding future issues

SLPSRA, Packed Bed Reactor Experiment
(Technology Push to AES)

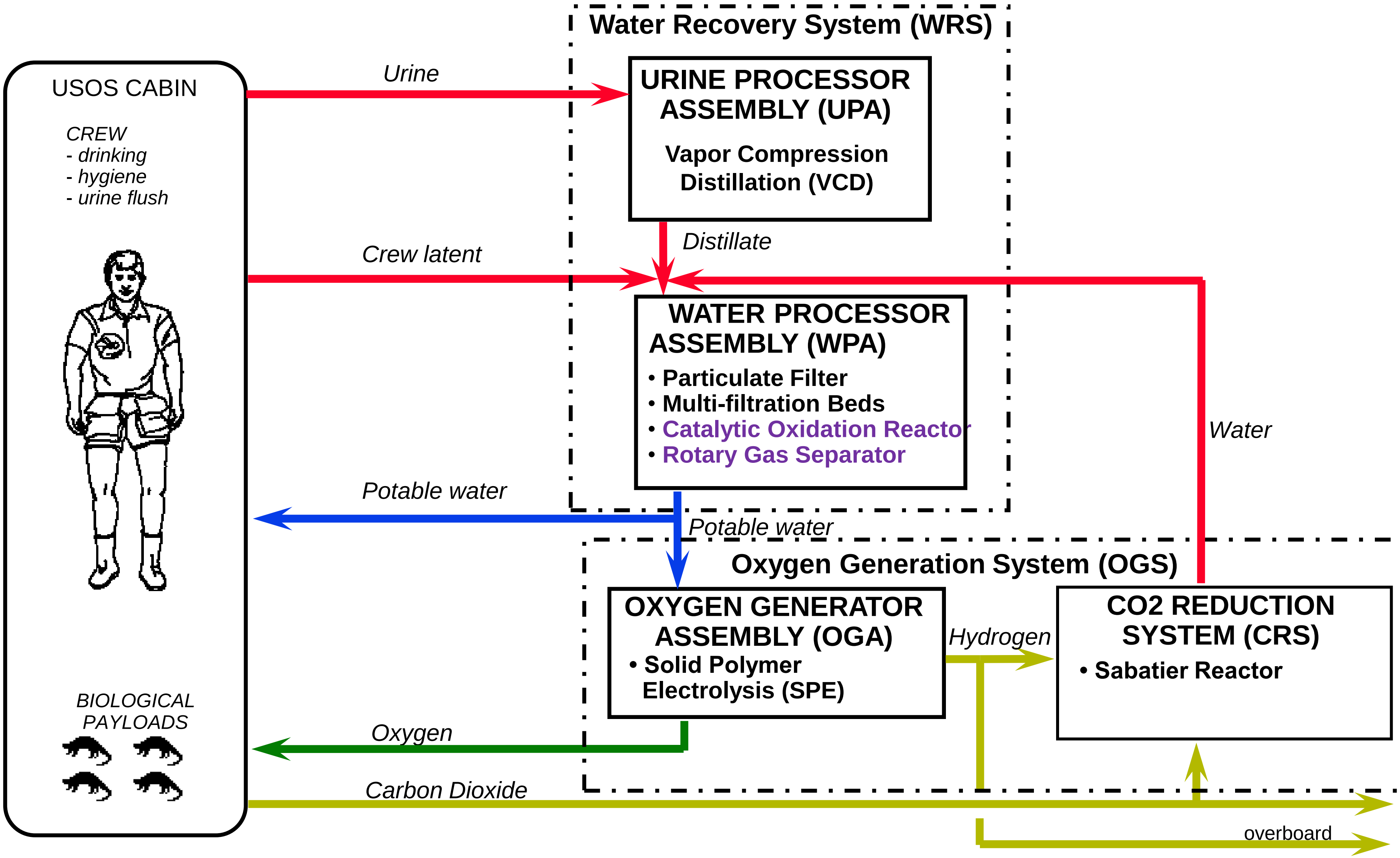


PBRE - packed bed column

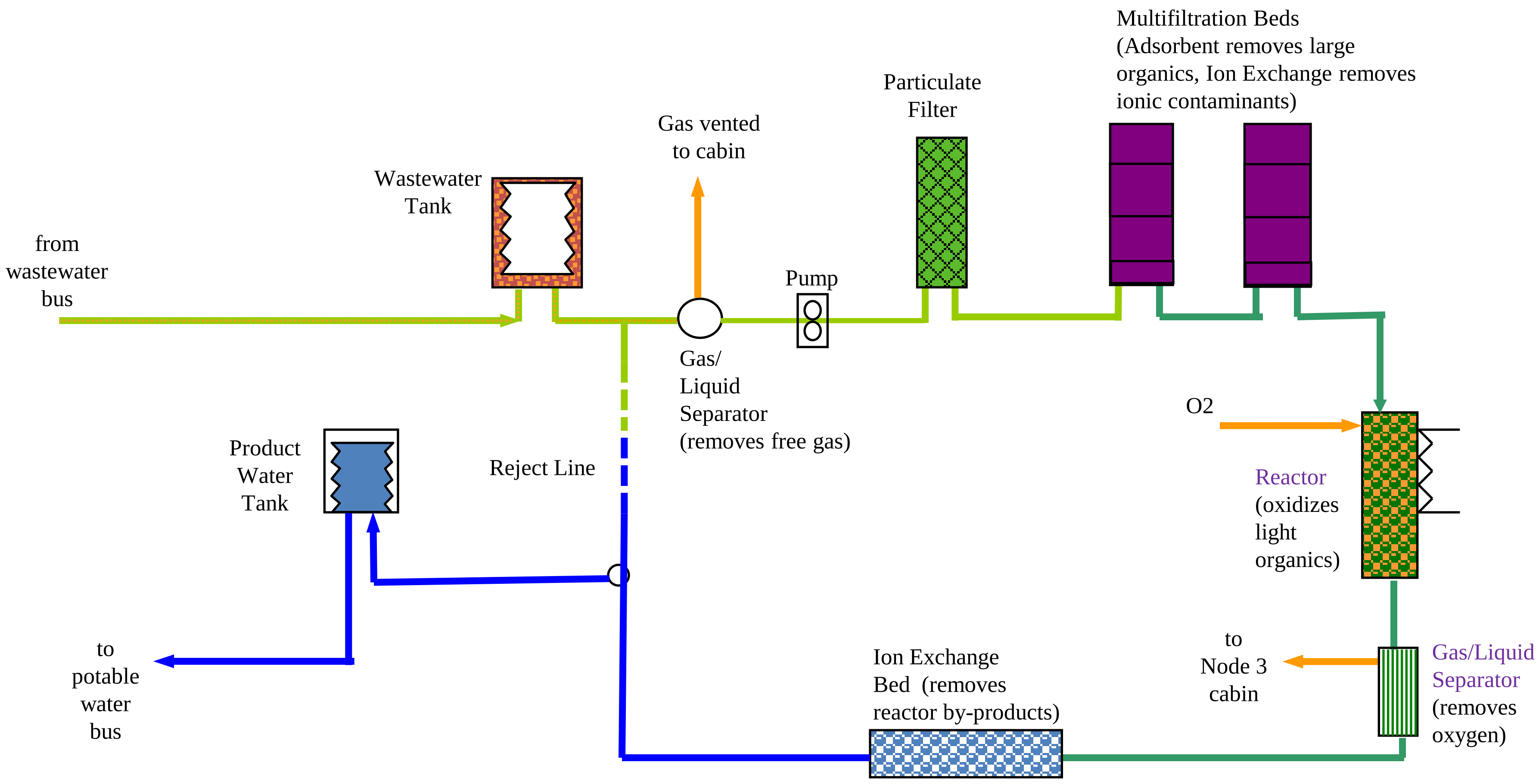


PBRE simplified schematic

ISS, Water Recovery System and Oxygen Generation System - Architecture Overview



Water Processor Simplified Schematic



Packed Bed Material for ISS WRS

Packed bed material for ISS WRS, Catalytic Oxidation Reactor (Alumina or Zirconium beads)

Potential new collaboration with STMD (Exploration Pull)

1. **Plant Root Zone Water Management System** Experiment using Aeroponics. The goal is to improve water and nutrient delivery and return from plant root zone in microgravity environment. To develop water management system using microgravity, passive, capillary driven flow. Develop approach could utilize drop towers, aircraft and ISS.
2. **Heat Pipe** ISS technology development experiment. This will aid in the development of future 1W to 10 KW power systems. This envisioned design uses a fission reactor with a Brayton or Sterling energy conversion systems. Two heat pipe loops are necessary: a 600 C sodium loop from the reactor to the power system and a 100 C high pressure water loop from the power system to the radiator.
3. **Trash to Gas - Drop Tower** Experiment. To further improve the technology development of converting trash to water and/or methane, using GRC's 5.2 second Microgravity Drop Tower. The research will evaluate four waste degradation techniques for observation of thermal characterization and trash conversion properties in a low g environment: steam-reforming, pyrolysis, gasification and plasma arc gasification application.

MaterialsLab - Reference Experiments

MaterialsLab Reference Experiments

Reference Experiment	Lead Author from Selected Proposals	Proposal Title	Hardware	ISS Ops. Year	Collaboration
Brazing	Sekulic, UKentucky	Brazing of Aluminum Alloys IN Space	SUBSA	FY19	Belgium, Russia
Freeze-Casting	Dunand, Northwestern	Microstructure Evolution in Freeze-Cast Materials	PFMI	FY22	
	Wegst, Dartmouth	Structure-Property-Processing Correlations	PFMI	FY21	
Biofilms	McLean, Texas State - San Marcos	Polymicrobial biofilm growth and control during spaceflight	BioServe – BioCell / Microscope	FY20	SLPS-SB
	Zea, UC - Boulder	Biofilm Formation, Growth, and Gene Expression on Different Materials and Environmental Conditions	BioServe – BioCell / Microscope	FY19	SLPS-SB Germany
Liquid Crystals	Clark, UC - Boulder	Ferromagnetic Liquid Crystal Colloids in Microgravity	OASIS, LCF	FY22-23	Russia
	Rosenblatt, CWestern	Nanoparticles and Topological Defects in Thin Films	OASIS, LCF	FY23	Canada, France, Russia
	Yokoyama, Kent State	Monodisperse Liquid Crystal Domains	OASIS, LCF	FY23	Japan, Russia

MaterialsLab Reference Experiments

Reference Experiment	Lead Author from Selected Proposals	Proposal Title	Hardware	ISS Ops. Year	Collaboration
Thermophysical Properties	Hyers, UMass - Amherst	Thermophysical Properties and Transport Phenomena	ELF	FY20	Germany, Japan, South Korea
	Matson, Tufts	Round Robin - Thermophysical Property Measurement	ELF, EML	FY20	Russia, Austria, Germany, Japan, South Korea, NIST
	Narayanan, UFlorida	A Novel Way To Measure Interfacial Tension	ELF	FY20	Japan
	Weber, Materials Dev.	Supercooled Molten Metal Oxides	ELF	FY20	Japan, Materials Development
	Ostrogorsky, Illinois Tech	Diffusion Coefficients of Dopants in Si and Ge Melts	SCA	FY21	Russia
Cement	Radlinska, Penn State	Microgravity Investigation of Cement Solidification	MSG	FY19	CASIS, Sauereisen Corp., BASF Corp., IPA Systems, NIST
Solidification Microstructure	Tewari, Cleveland State	Cellular/Dendritic Pattern Formation	SCA	FY22	
	Voorhees, Northwestern	Columnar to Equiaxed Transition, Dendrite Fragmentation	CSLM	FY20	

MaterialsLab Reference Experiment Cement

Decadal Themes: AP9, TSES16

Science Definition Team: Dr. Richard Grugel (NASA MSFC), Prof. Aleksandra Radlińska (Penn State), Mr. Dale Benz (NIST), Prof. Barry Scheez (Penn State), Dr. Jeffery Bullard (NIST), Dr. James Pawelczyk (Penn State), Ms. Annmarie Ward (Penn State), Sauereisen Corporation, BASF Corporation, IPA Systems, and CASIS (Jonathan Volk, Jennifer Lopez, and Kenneth Shields)

Objective:
1) Utilize the long term microgravity environment of the ISS to minimize gravity induced phenomena such as sedimentation and thermosolutal convection.
2) Ascertain and better understand complex crystal growth dynamics of cement.
3) Evaluate novel data and apply to Extraterrestrial and Earth-based processes.
4) Tabulate results in databases.

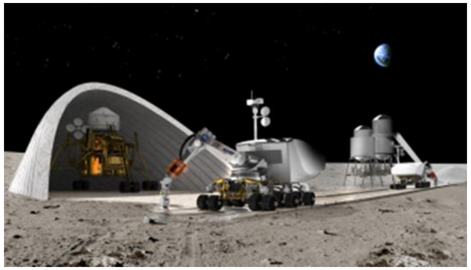
Applications:
- Terrestrial and extraterrestrial structures (Roads, Buildings, Dams)
- A better understanding of crystallite and pore formation, and morphology, will lead to improved properties.
- A small processing improvement can have huge production and application implications.

Benchmark Experiments Pertinent to In-situ Resource Utilization

Experiments conducted aboard the ISS will provide unique insight into the solidification behavior of cement in microgravity.

These investigations will provide benchmark data to support utilization of in-situ materials for Exploration missions in reduced gravity environments.

It is expected that the microgravity results will have application to Earth-based processing.



Exploration Missions will Rely on In-situ Materials for Construction

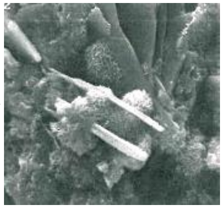
Microgravity Investigation leading to Terrestrial Applications

Conceptually Simple "Burst Seal"

Conduct simple experiments with complex samples aboard the ISS.

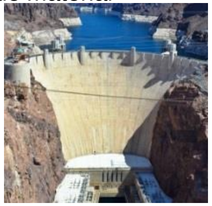
ISS Maintenance Workbench Area

Terrestrial sample evaluation



Portland Cement Paste

Concrete is the most widely used, greatest volume, man-made material



Hoover Dam

MaterialsLab Reference Experiment Brazing

Decadal Themes: AP9, TSES5

Science Definition Team: Dr. Richard Grugel (NASA MSFC), Prof. Dusan Sekulic (Univ. of Kentucky), Prof. Mikhail Krivlev (Udmurt State Univ. Russia), Dr. David Seveno (KU Leuven, Belgium), Dr. Sinisa Mesarovic (Washington State).

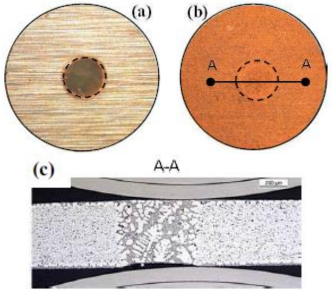
Objective:

Space experiments devoted to the problem of metallurgical brazing have been conducted by both NASA and Roscosmos starting with Skylab (1973-74) and Soyuz-6 (1969). Results of other Russian investigations (compiled by Paton 2003) and parabolic flights (Plester 1995, Langbun 1990) have also been reported. These studies provided proof-of-concept but offered no detailed analysis of the joining mechanism, particularly in the context of processing kinetics (enhanced wetting, spreading, capillarity) in a *microgravity* environment. The objective of this study is to quantify the brazing process through a series of experiments for NASA *microgravity* applications.

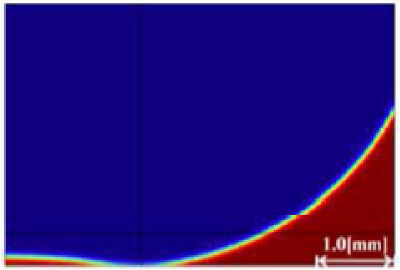
Applications:

Application would involve transferring the knowledge gained and adapting it to brazing in space for repair of pressure walls, and in situ construction. This will impact safety considerations and extraterrestrial infrastructure development.

Benchmark Experiments Pertinent to In Space Fabrication and Repair



Terrestrial hole-in-plate experiments. (
a) Before brazing, (b) After brazing, (c)
Sample cross-section: A-A



Simulation of the thin liquid film brea
kup in a T-joint configuration on a fl
at solid surface.

SUBSA furnace sample test ampoule is shown above. It is a quartz tube which contains aluminum discs, meant to simulate the brazing coupons, separated by alumina cloth. Also included in the quartz tube are 4 thermocouples.

MaterialsLab Solidification Microstructure Reference Experiment

Decadal Themes: AP9

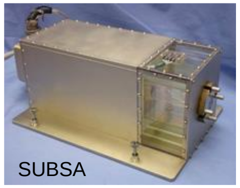
Science Definition Team: Dr. Richard Grugel (NASA MSFC), Prof. Peter Voorhees (Northwestern Univ.), Prof. Surendra Tewari (Cleveland State Univ.), Dr. Emine Gulsoy (Northwestern Univ.), Dr. Mohsen Eshraghi (California State Univ.- Los Angeles), Prof. Sergio Felicelli (Univ. of Akron).

Objective:
Lead-Tin and Lead-Antimony alloys will be used to understand the role thermosolutal convection plays in dendritic pattern formation and initiating secondary arm fragments (now effectively defects), factors that significantly influence mechanical properties. Only solidification experiments carried out in the ISS *microgravity* environment can provide such data..

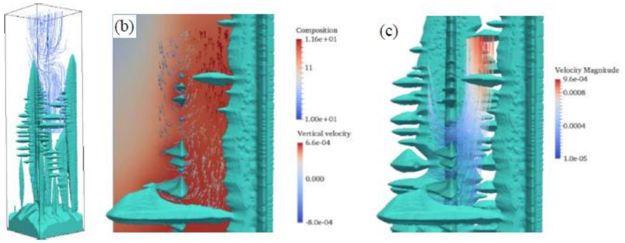
Applications:
The results are relevant to commercial casting practices. Understanding the role of convection on microstructural development can lead to novel mold designs which will improve material properties of components such as turbine blades and lighter, stronger, engine blocks. Directional solidification and knowledge of defect formation will provide significant MGI type modeling and new material development relevant data for MGI (NIST).

Benchmark Experiments Pertinent to Microstructural Development

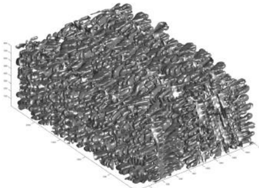
Development Approach:
The experiment will utilize an ampoule or sample processing unit that will be implemented in the SUBSA or CSLM furnace. Either furnace will be installed in the Microgravity Science Glovebox. Several samples will be included in a given ampoule allowing for experimental variables. The experiments will be complemented by a robust modeling effort.



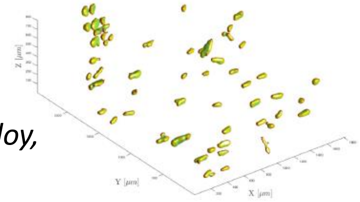
Utilizes Existing and Proven Hardware



Fluid flow and solute distribution about Pb-Sn dendrites growing under natural convection.



3D reconstruction of a Pb-Sn alloy, dendrite fragments revealed



State-of-the-Art Metallographic Analysis and Modeling.

MaterialsLab Thermophysical Properties Reference Experiment

Decadal Themes: AP9

Science Definition Team: Jan Rogers (NASA MSFC), Michael SanSoucie (NASA MSFC), Martin Volz (NASA MSFC), Ranga Narayanan (University of Florida, Gainsville), Satoshi Matsumoto (JAXA), Kevin Ward (University of Florida, Gainsville), Douglas Matson (Tufts University), Mikhail Krivilev (Udmurt State University), Vijay Kumar (Tufts University), Masahito Watanabe (Gakushuin University), Takehiko Ishikawa (JAXA), Hiroyuki Fukuyama (Tohoku University), Shumpei Ozawa (Chiba Institute of Technology), Geun Woo Lee (KRISS), Andreas Meyer (DLR), Hans Fecht (University of Ulm), Rainer Wunderlich (University of Ulm), G. Pottlacher (TU-Graz), Kenneth Kroenlein (NIST), Richard Weber (Materials Development, Inc.), Shinji Kohara (National Institute for Materials Science (Japan)), Jonghyun Lee (University of Massachusetts), Oliver Alderman (Materials Development, Inc.), Anthony Tamalonis (Materials Development, Inc.), Robert Hyers (University of Massachusetts), Joonho Lee (Korea University), Aleksandar Ostrogorsky (Illinois Institute of Technology), Prof. G.N. Kozhemyakin and Dr. A.E.Voloshin (Russian Academy Sciences)

Objective:

1) Utilize the microgravity environment of the ISS to minimize gravity-driven phenomena such as buoyancy-driven fluid flows and sedimentation.
2) Microgravity enables high-quality thermophysical property measurements.
3) Diffusion studies require quiescent melts (no bulk flow).

Applications:

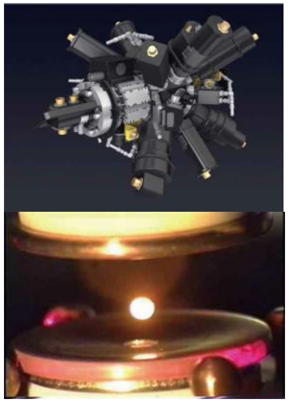
- Photonics (metal oxides)
- Lasers
- Optical communications
- Imaging
- Holographic storage
- Adaptive optics
- Semiconductors

Levitation Experiments on ELF

Experiments conducted aboard the ISS will provide accurate measurements of thermophysical properties of metals, glasses, metal oxides, and ceramics.

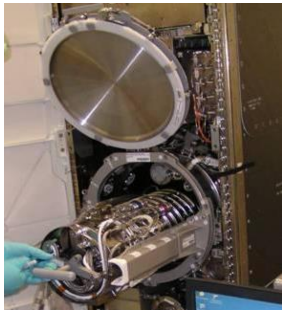
Experiments and objectives include a novel method to measure interfacial tension, a greater understanding the glass transition of metal oxides, baseline high-quality datasets, and a better understanding of photorefractivity.

It is expected that the microgravity results will have application to several industrial processes (semiconductors, oil recovery, welding, casting, etc.) and Earth-based glass processing.



Top: model of ELF hardware
Bottom: levitated sample in the ELF ground unit

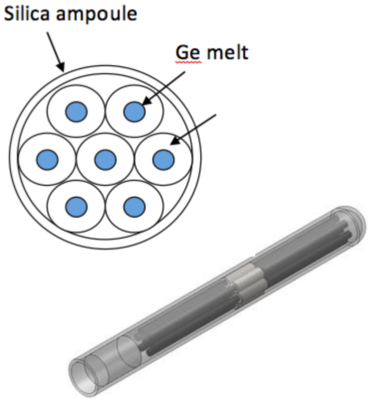
Diffusion Experiments in the LGF



Low Gradient Furnace (LGF)

Experiments conducted aboard the ISS will Investigate and measure the diffusion coefficients of several dopants in germanium.

Experiments are relevant to the semiconductor industry, which is a greater than $335B industry.



Bundle of capillary tubes in a SCA

Thermophysical Properties Ref. Experiment,

Decadal Themes: AP9

Title / Investigator / Facility	Measurement	Samples	Objectives	Impact	NIST Comments
A Novel Way to Measure Interfacial Tension Using the Electrostatic Levitation Furnace / Narayanan / ELF	Interfacial Tension	Zr, Au, Pt	A novel method to measure interfacial tension (IFT). Use of Faraday instability via electrostatic forcing to measure the IFT between a liquid and its surrounding atmosphere	Novel measurement technique useful for several materials and applicable to several industrial processes (semiconductors, oil recovery, welding, etc.)	On a purely "NIST" basis, this might have been the top ranked proposal. That is, this proposal focusses on how to measure a specific property better.
Round Robin - Thermophysical Property Measurement / Matson / ELF	Density, Surface Tension, Viscosity	Zr, TiZrNi, Steel, FeNi, Pt, Au, Zr w/ 3% O_2 in solution	Understand and control the sources of measurement error and to provide a baseline dataset for quantifying uncertainty in measurements (both space- and ground-based)	Baseline dataset (ensures the highest quality data). Proposed materials have industrial applications (casting, nuclear fuel rods, metallic glass)	Best proposal in terms of meeting MaterialsLab goals, objectives, and philosophy. The proposers seemed to have the best understanding of, and dedication to, the team science philosophy.
Microgravity Investigation of Thermophysical Properties of Supercooled Molten Metal Oxides / Weber / ELF	Density, Surface Tension, Viscosity	Al_2O_3, $Ca_{12}Al_{14}O_{33}$, $CaAl_2O_4$, $CaSiO_3$, $MgSiO_3$, $Al_6Si_2O_{13}$, $FeSiO_3$, $YbAlO_3$, $YbLa_2Al_5O_{12}$,	Accurate measurements of thermophysical property data for molten metal oxides. A greater understanding of the glass transition and of the requirements for optimizing and processing.	High value-added glass materials that are used in photonics, lasers, optical communications, and imaging applications	Highest potential impact to MGI goal of accelerating materials development and commercialization, i.e. expected relevance of the data obtained to the development of new materials that could then lead to new products and jobs.
Thermophysical Properties and Transport Phenomena Models and Experiments in Reduced Gravity / Hyers / ELF	Density, Surface Tension, Viscosity	$Bi_{12}SiO_{20}$, $Bi_{12}GeO_{20}$	Advance the understanding of photorefractivity. Measured properties will be used to model and test theories about the effect of processing on microstructure and material characteristics.	Potential to enable several new kinds of photonic devices, e.g. holographic storage, adaptive optics, phase-conjugate mirrors, beamed energy	Good, knowledgeable, team proposing good work. Has potential for great rewards if it hits. If were reviewing these proposals on an "NSF" basis, this would probably be the top ranked proposal.
Diffusion Coefficients of Dopants in Si and Ge Melts / Ostrogorsky / SCA	Diffusion Coefficients	Ge; Diffusing species: Ga, B, Sb, Si	Investigate and measure the diffusion coefficients of several dopants in Ge.	Differences in size and electronic structure of the selected dopants will influence properties an diffusion rates. Applications: transistors, detectors, photovoltaics.	This work addresses critical fundamental measurement science issues relevant to materials processing for a very important industry (i.e. semiconductor industry).

Biofilms Reference Experiment

Decadal Themes: P1, P2

Science Definition Team: Dr. Sridhar Gorti (NASA), Dr. Kevin Sato (ARC), Dr. Luis Zea (Colorado), Prof. Robert McLean (Texas State), Prof. Jennifer Barrila (Arizona State), Dr. Mark Ott (NASA), Prof. Cheryl Nickerson (Arizona State), Dr. David Klaus (Colorado), Dr. Simon Clemett (ERC), Ms. Mayra Nelman-Gonzalez (Wyle), Dr. Louis Stodieck (Colorado) , Dr. Ralf Moeller (DLR), Dr. Frank Muecklich (Saarland University)

Collaborations: SLPS-SB

Objective:

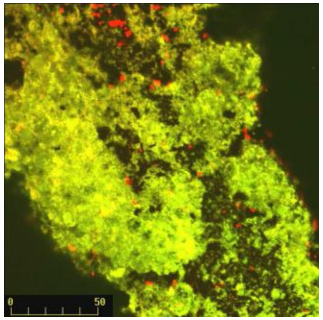
1) Utilize the long term microgravity environment of the ISS to study Biofilms in the absence of sedimentation and solution convection.
2) Ascertain and better understand complex growth dynamics of Biofilms of various bacterial or fungal compositions on varied substrates
3) Evaluate data and apply knowledge gained to development of new materials that inhibit biofilm formation and growth.

Applications:

1) Crewed spacecraft, water processing units, submarines, hospitals, medical devices, operating rooms, disinfecting potable water.
2) Bacterial species (e.g. human pathogens, and strains collected from ISS), growth media (e.g.simulate disinfected potable water, and urine), and substrata material relevant to crewed spacecraft,human spacecraft water processing units, and medical devices). applicable to safety and maintenance of crewed spacecraft, mitigation of biofilm-associated illnesses on the crew, and biofilm associated illnesses on Earth

Benchmark Experiments Pertinent to Identifying Biofilm Formation

1) Investigate the formation and architecture of a mixed bacterial biofilm, *Pseudomonas aeruginosa* plus *Escherichia coli*, on stainless steel. Conduct studies to determine the biofilm susceptibility to an antimicrobial agent, Silver. Examine the degradation of the stainless by the biofilm.
2) Characterize biofilm growth of *Pseudomonas aeruginosa* (bacteria) *chrysogenum* (fungus) for mass, thickness, morphology, and associated gene expression when grown on different representative materials used in ISS systems or surfaces. Elucidate the biological processes involved in the formation of the "column-and-canopy" type of biofilm morphology observed in space



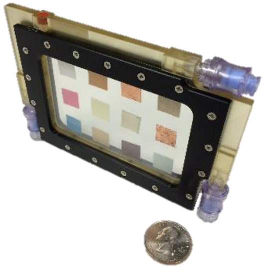
Biofilm: Exploration Missions will Rely on Developed Materials that Inhibit Biofilm Formations

Microgravity Investigation leading to Terrestrial Applications

Conduct simple experiments with complex samples aboard the ISS.

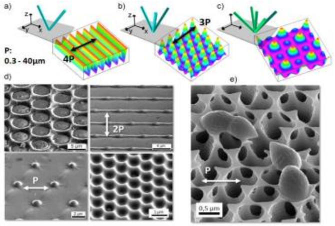
ISS Incubator for Bioserve

Terrestrial sample evaluation



Sample Bio-Cell

Potential applications: New materials and or methods for interaction and possibly eliminating and diminishing Biofilm formation



Patterned Surfaces

Freeze Casting Reference Experiment

Decadal Themes: AP5, AP9, TSES16

Science Definition Team: Dr. Sridhar Gorti (NASA MSFC), Prof. Ulrike Wegst (Dartmouth) , Prof. David Dunand (Northwestern), Prof. Peter Voorhees (Northwestern), Dr. Fridon Shubitidze (Dartmouth), Prof. Alain Karma (Northeastern), Prof. Rohit Trivedi (Iowa State)

Objective:
1) Utilize the long term microgravity environment of the ISS to minimize gravity induced phenomena such as sedimentation and thermosolutal convection.
2) Ascertain and better understand formation of complex low-weight, high-strength structures grown and sintered from directional solidification of solvent, in a solute slurry.
3) Develop computational methods for predicting obtained structures
4) Evaluate novel data and apply to Extraterrestrial and Earth-based processes.

Applications:

- Terrestrial and extraterrestrial structures (New Materials, Catalysts, Habitats, Structural Supports)
- A better understanding of pore formation, and morphology, will lead to improved properties.

Benchmark Experiments Pertinent to In-situ Resource Utilization

Experiments conducted aboard the ISS will provide unique insight into the directional solidification behavior of solvents in particulate slurries under microgravity condition.

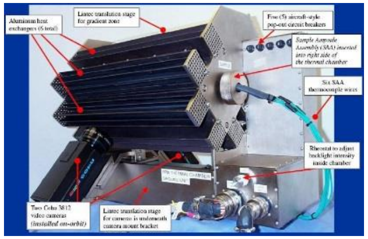
These investigations will provide benchmark data to support processing of low-weight, high-strength structures using in-situ materials for Exploration missions in reduced gravity environments.

It is expected that the microgravity results will have application to Earth-based processing.

Exploration Missions will Rely on Processing of In-situ Materials for Construction

Microgravity Investigation leading to Terrestrial Applications

Conduct simple experiments with complex samples aboard the ISS.



ISS PFMI

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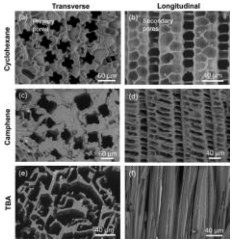
Terrestrial sample evaluation



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Potential applications: light-weight, high-strength structural materials

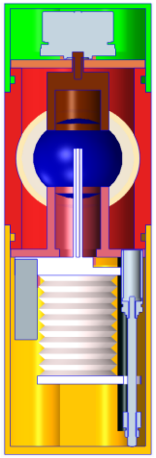
Aircraft
Bicycles
Automotive
Catalysts
Construction

Reference Experiment *Ring Sheared Drop* for the Study of Amyloid Fibril Formation

Decadal Themes: FP1, AP9

PI: Professor Amir Hirsa, Rensselaer Polytechnic Institute in Troy, New York
Co-I: Professor Prof. Juan Lopez, Arizona State University in Tempe, Arizona
International Co-I: Professor Iskander Akhatov, Skolkovo, Institute of Science and Technology in Skolkovo, Russia (*under consideration*)
PS: Dr. Sridhar Gorti, NASA MSFC
PM: Kevin DePew, NASA MSFC
Engineering Team: TBE

"Containerless" Fluid Chamber Design allows for the investigation of amyloid film formation under shear.



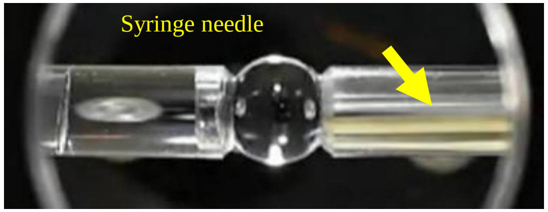
Ring Shear Drop Module:
delivers ~50ml fluid to be pinned between two rings, where one ring is fixed while the other rotates

Objectives:

- Investigate amyloid fibril formation nucleation and growth upon perturbing the native structure of a protein by hydrodynamic shear forces, using containerless bioprocessing facility and optical imaging techniques.

Relevance/Impact:

- Formation of amyloid fibrils is widely investigated due to its relevance in association with numerous neurodegenerative diseases, including Alzheimer's and Parkinson's disease. Amyloid fibril formation is a process by which destabilized or denatured protein molecules in solution self-assemble into nuclei and grow into fibrils that further aggregate into higher order structures. Decoupling the basic mechanisms that instigate protein denaturation and subsequent fibrillization is significant towards understanding degenerative disease. Elucidating the distinct roles of shear, convective transport, and interfaces requires the use of well-defined flow geometries and the ability to eliminate effects due to buoyancy, which can only be achieved under conditions of microgravity. The novel bioreactor to be developed for fibrillization studies will also have utility for other biological/non-biological systems.



Development Approach:

- Design experimental apparatus and procedures to constrain centimeter scale drops of dilute protein solution in water between two rings to study *fibrillization* under various shear and oscillation rates in the absence of solid walls, where containment is achieved by surface tension. Demonstration of ability to pin a fluid drop between two pinning rings has been achieved, in reduced scale, on a Zero-G parabolic flight.

Liquid Crystals Reference Experiments - applications

- Continue to develop an understanding of the complexity of structural properties of self assembled various liquid crystals to lead to the development of new pathways and new materials for better photonic crystals, defect free and fast interactive displays.
  - Inputs to database will be guided by FluidsLab Workshop recommendations and Science Definition Teams.
  - Database will be “open science” for the technical community. LCD industry is around $150B.
- Development of new types of multi layered liquid crystal materials leads to:
  - Manufacturing of Ultra High Definition (4K-2K), Holographic 3D very large liquid crystal display units.
  - High frequency electro-optics, tunable electro-optic filters.
  - High contrast/lower power consumption liquid crystal displays will enhance current manned space craft virtual control systems on board ISS or future space flight control systems.
- Proposed experiment topics from FluidsLab Workshop:
  - Molecular Dynamics of Liquid Crystals (MDLC),
  - Dynamical Behavior and Instability Phenomena (DBIP)

Flexible Transparent Liquid Crystal Display

Testing of SpaceX LCD controls

Liquid Crystal Reference Experiment

liquid crystal bulk and bubble film experiments

Ferromagnetic Liquid Crystal Colloids in Microgravity

Decadal Themes: FP1, AP5

Science Investigation Team: Professor Noel Clark, Prof. Joe Maclennan, Prof. Matt Glaser, Dr. Cheol Park, Dr. Min Shua (University of Colorado), Prof. A. Levchenko, Prof. P. Dolganov, Institute of Solid State Physics, Russian Academy of Sciences), Prof. Efim Kats((Landau Institute of Theoretical Physics, Russian Academy of Sciences)

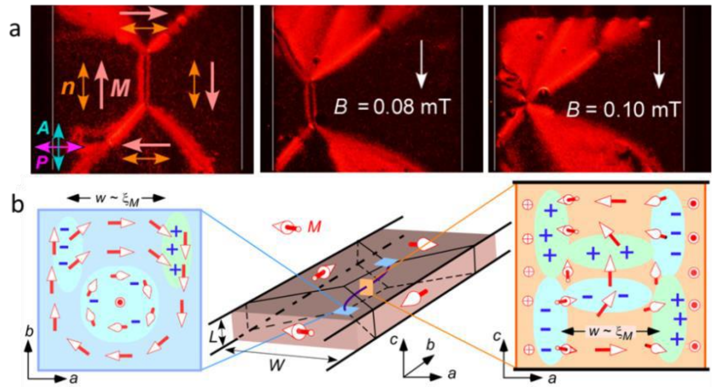
Russian Scientists: Prof. A.A. Levchenko, Professor Pavel Dolganov, Institute of Solid State Physics, Russian Academy of Sciences; Prof. Efim Kats (Landau Institute of Theoretical Physics, Russian Academy of Sciences, Moscow

Science Definition Team /Project Scientist: Padetha Tin (NASA Glenn USRA)

GRC Project Management: William Foster

Objective: To explore the dynamic behavior of ferromagnetic liquid crystals (LCs), a recently discovered colloidal suspensions of disk-shaped nanoparticles whose fluidity and permanent magnetization make ferromagnetic LCs ultrasensitive to applied magnetic fields, creating a host of possibilities for novel magnetic effects in situations where magnetic, interfacial, and soft elastic energies compete in the absence of gravity.

Relevance/Impact: Liquid crystal based composite materials for smart materials. Micro electronic devices of nano and microstructure fabrication for advanced opto electronics. Significantly impact the search for the new liquid crystal materials for high quality display electronics and opto electronics devices, fluorescence display devices, and therefore definitely impacts the over 150 billion dollar per year display electronics industry.



Closed flux loops formed in ferromagnetic nematic LCs sealed in a flat glass capillary. (a) Viewed between crossed polarizers under different magnetic fields. The directions of magnetization M and the nematic director n in each domain are shown. (b) Illustration of the topological defect structure in the flux loop shown in (a).

Development Approach:

- LiCRE I will use the modified OASIS MSG system.
- A dedicated bulk liquid crystal chamber and dedicated bubble film chamber will be designed for the experiments.
- Prof. Clark will use new types of disk shaped **ferro magnetic** liquid crystals

Liquid Crystal Reference Experiment

Bubble film experiment

Microgravity Studies of Nanoparticles and Topological Defects in Liquid Crystal Thin Films

Decadal Themes: FP1, AP5

Science Investigation Team: Professor Rosenblatt (Case Western Reserve University, Torsten Hegmann (Kent State University), Philip Taylor (Case Western Reserve University), Emmanuelle Lacaze (Université Pierre et Marie Curie, Paris), Robert Lemieux (University of Waterloo, Canada), Prof. Leonid V. Mirantsev , Dr. Elena Pikina (Russian Academy of Sciences)

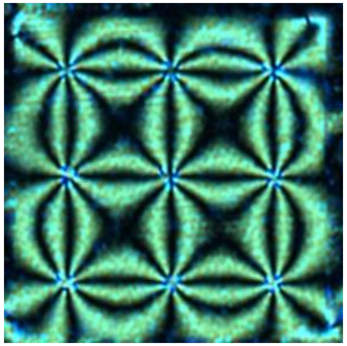
Russian Scientists: Prof. Leonid V. Mirantsev (Institute of the Problems of Mechanical Engineering, Academy of Sciences of Russia, St. Petersburg); Dr. Elena Pikina, Oil and Gas Research Institute, Russian Academy of Sciences, Moscow, Russia

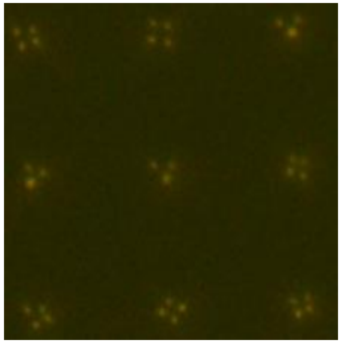
French Scientist: Professor Emmanuelle Lacaze (Institut des NanoSciences de Paris, France)

Canadian Scientist: Professor Robert Lameuse (Dean of Science, University of Waterloo, Canada)

Science Definition Team /Proj. Scientist: Padetha Tin (NASA Glenn USRA)

GRC Project Management: William Foster





Left image is a polarized photomicrograph liquid crystal defects pattern of "brushes" emanating from each defect core. Right image shows fluorescence from FCDs.

Objectives: Very thin liquid crystal film bubbles doped with Fluorescence Carbon Dots onboard ISS obviating the need for bounding substrates renders the study of spatial distribution and transport of the FCDs in and around topological defects in the smectic-C phase of the liquid crystal, especially close to the smectic-A phase transition temperature.

Relevance/Impact: Liquid crystal based composite materials for smart materials. Micro electronic devices of nano and microstructure fabrication for advanced opto electronics. Significantly impact the search for the new liquid crystal materials for high quality display electronics and opto electronics devices, fluorescence display devices, and therefore definitely impacts the over 150 billion dollar per year display electronics industry.

Development Approach:

- LiCRE I will use the modified OASIS Microgravity Science Glovebox system.
- A dedicated liquid crystal bubble film making unit will be designed.
- Prof. Rosenblatt will use new types of liquid crystals blended with **Fluorescence Carbon Nano Dots.**

Liquid Crystal Reference Experiments

Bubble film experiment

Structure and Dynamics of Monodisperse Liquid Crystal Domains created on Suspended Molecularly-Thin Smectic Films Using Sub-Femtoliter Inkjet Technology

Decadal Themes: FP1, AP5

Science Investigation Team: Professor Hiroshi Yokoyama (Director Liquid Crystal Institute, Kent State University), Yuka Tabe (Waseda University), Alexander Emelyanenko (Moscow State University), Padetha Tin (USRA/NASA Glenn)

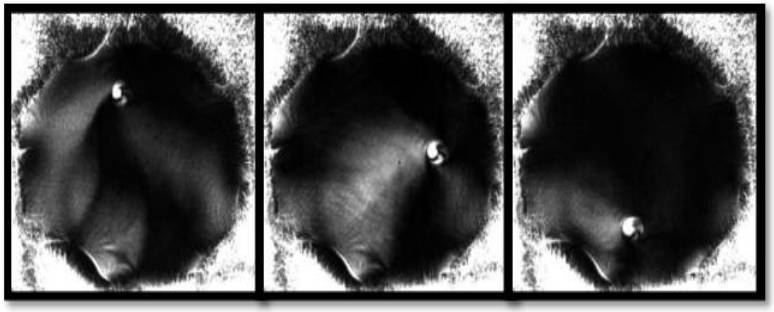
Russian Scientist: Professor Alexander Emelyanenko, Head of Liquid Crystal Laboratory, Lomonosov Moscow State University, Moscow, Russia

Japanese Scientist: Professor Yuka Tabe (Waseda University, Tokyo, Japan)

Commercial: Merck (Division of Liquid Crystal Materials Research)

Science Definition Team /Proj. Sci. Padetha Tin (NASA Glenn USRA)

GRC Project Management: William Foster



Snapshots of rotating island on a chiral smectic C free standing film subjected to a mass transport of alcohol across the free standing film. The snapshots are 3 sec apart from left to right, indicating the orientational rotation of the island and the rotational flow of the entire film

Objectives: Study the 2D self-organization of domains and nonequilibrium behaviors such as domain coalescence, Oswald ripening, Lehmann rotations and collective orientational excitations and 2D flow, domain-domain interactions of identical liquid crystal material of different host film and droplets or several different host and droplets leading to chemical-potential Marangoni studies, thermal dependent and field interaction studies with externally applied electric field and temperature gradients.

Relevance/Impact: Liquid crystal based composite materials for smart materials. Micro electronic devices of nano and microstructure fabrication for advanced opto electronics. Significantly impact the search for the new liquid crystal materials for high quality display electronics and opto electronics devices, fluorescence display devices, and therefore definitely impacts the over 150 billion dollar per year display electronics industry.

Development Approach:

- LiCRE will use the modified OASIS Microgravity Science Glovebox system.
- A dedicated liquid crystal bubble film making unit will be designed.
- Prof. Yokoyama will use **several types** of liquid crystals in the form **of near identical droplets** and islands on freely suspended thin films

ISS MaterialsLab Phase 2 - Example Candidate List Planning

Item	Topic	Proposed Experiment Concept	Workshop Chair
1	**Biophysics**	Biomaterials Facility - Containerless Bioreactor - Concentration Bioreactor - 12 plate bioreactor	Ulrike G.K. Wegst – Chair ; Dongbo Wang – Co-Chair; Jacinta C. Conrad – Co-Chair
2	**Biophysics**	3D Bioprinting	Ulrike G.K. Wegst – Chair ; Dongbo Wang – Co-Chair; Jacinta C. Conrad – Co-Chair
3	**Glasses and Ceramics**	Development of new optical, electrical, and high strength materials	Steve W. Martin - Chair; Richard Weber – Co-chair; Edwin Etheridge - Co-chair
4	**Glasses and Ceramics**	Diffusion Measurements	Steve W. Martin - Chair; Richard Weber -Co-chair; Edwin Etheridge – Co-chair
5	**Granular Materials**	Granular Materials Facility	David Frost - Chair; Mustafa Alsaleh – Co-chair
6	**Granular Materials**	A Study on Space Cements Processing	David Frost - Chair; Mustafa Alsaleh-Co-chair
7	**Metals**	Soldering and Brazing and/or Welding Facility	Reza Abbaschian - Chair; Bob McCormick-Co-chair; Richard Ricker-Co-chair
8	**Metals**	Microstructural Development in DS Eutectic Alloys	Reza Abbaschian - Chair; Bob McCormick-Co-chair; Richard Ricker – Co-chair
9	**Polymers and Organics**	3D Printing of Polymers 3D Printing in Space	Bruce Chase - Chair; Mike Snyder - Co-chair; Eric Lin - Co-chair
10	**Polymers and Organics**	Improvement of uniformity during material synthesis in microgravity	Bruce Chase - Chair; Mike Snyder - Co-chair; Eric Lin - Co-chair
11	**Semiconductors**	High Temperature Furnace	N.B. Singh - Chair; Sudhir Trivedi - Co-chair
12	**Semiconductors**	Bulk Growth of Semiconductor Compounds for High Value Sensors and Detectors	N.B. Singh - Chair; Sudhir Trivedi - Co-chair

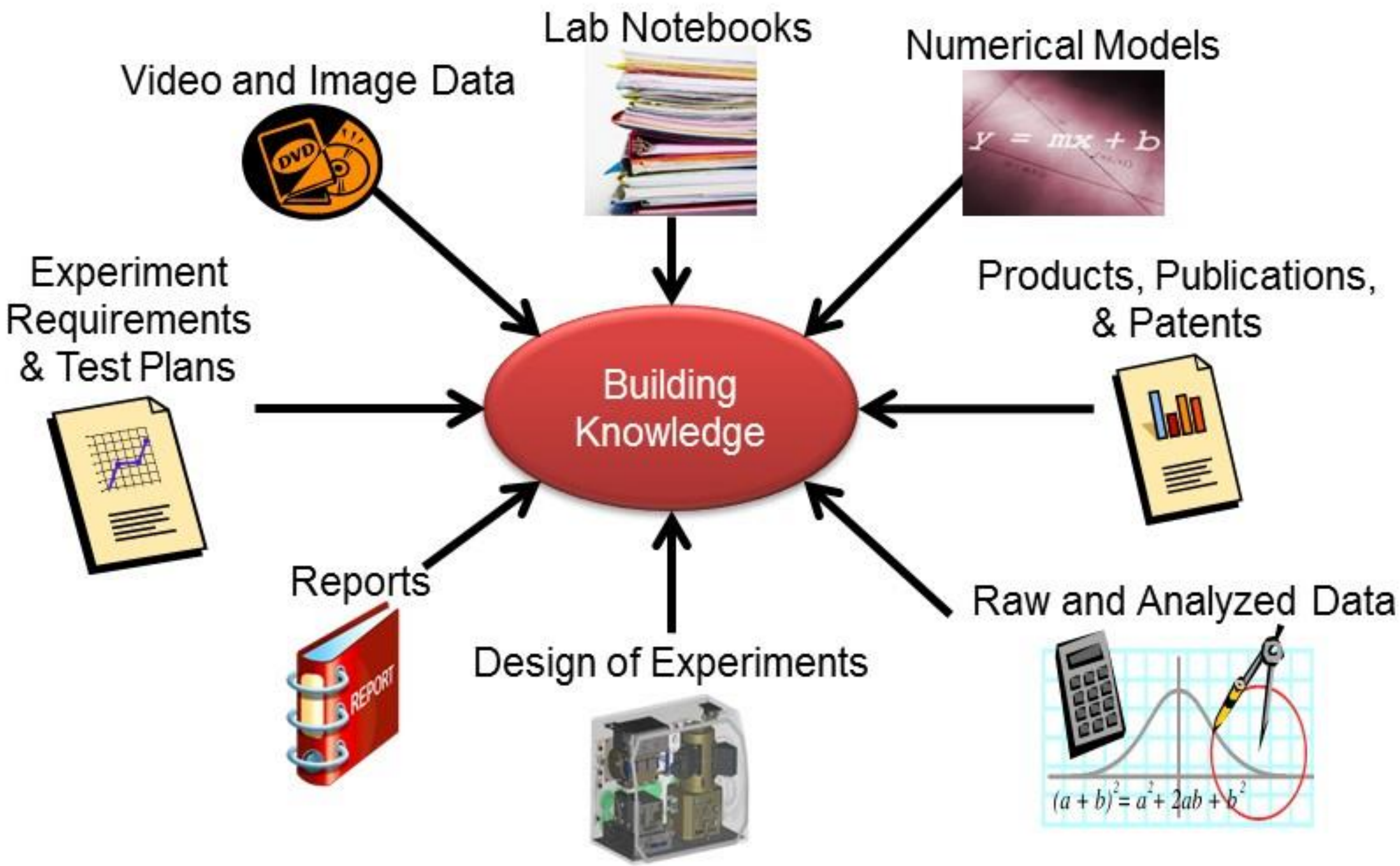
Physical Sciences Informatics

PSI - Physical Sciences Informatics System - **Motivation**

The NASA Physical Science Informatics (PSI) System is a repository for data and information acquired from microgravity physical science experiments performed on the International Space Station (ISS), Space Shuttle and Free Flyers, from various sponsors. The PSI system is accessible and open to the public as directed by the President's Open Data Policy. The website is: http://psi.nasa.gov/

"The resulting data from that envelope of experiments will then be used to create experimental informatics libraries that will support many more investigators and funded ISS-derived research. What that does is, it converts what would be normally a single [Principal Investigator] PI research opportunity into multiple PI research opportunities now and into the future". Marshall Porterfield, former Space Life and Physical Sciences Research and Applications Director.

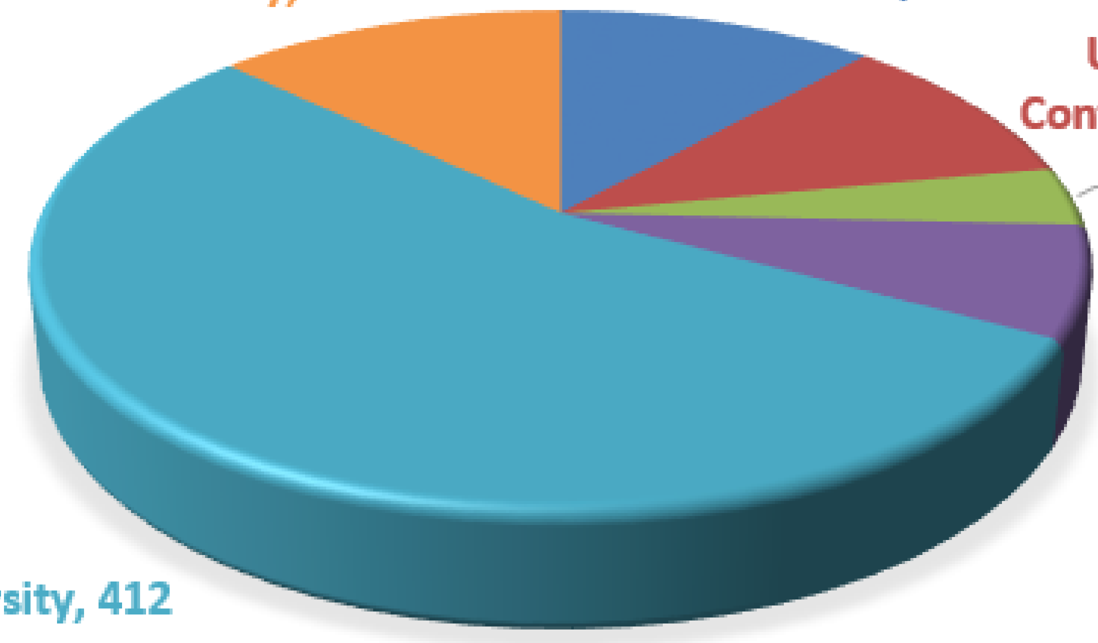
Elements of PSI – Turning Data into Knowledge



Physical Sciences Informatics – **History**

- The Physical Sciences Informatics System has been open to the public since November 2014.
- Over 750 Registered Users
- Over 39 experiments have been uploaded and are accessible to the public.
- Experiments include the following 5 Disciplines: Materials Science, Combustion, Fluid Physics, Fundamental Physics and Complex Fluids
- NRA Appendices A and B: 10 proposals were selected and funded for FY 2016 and 2017.

PSI User Demographic



Current total = 761

(as of February 7, 2017)

PSI Awarded Research from Appendices A and B

	PI Name	PI Organization	Proposal Title	Research Area	Investigation(s) Used	Grant Period
1	Sinisa Mesarovic	Washington State University	Computational Framework for Capillary Flows	Fluid Physics	CCF, CFE	2016-2017
2	Amir Riaz	University of Maryland, College Park	Gravity Scaling of Pool Boiling Heat Transfer: Numerical Simulations and Validation with MABE and NPBX	Fluid Physics	MABE, NPBX	2016-2017
3	Yongsherng Lian	University of Louisville	Development and Verification of a 3D Nucleate Pool Boiling Simulation Model Using PSI Data	Fluid Physics	NPBX	2016-2017
4	Yiguang Ju	Princeton University	Quantitative Studies of Cool Flame Transitions at Radiation/Stretch Extinction Using Counterflow Flames	Combustion Science	FLEX-1	2016-2017
5	Tanvir Farouk	University of South Carolina	Effect of external thermo-convective perturbation on cool flame dynamics: A multidimensional multi-physics CFD analysis	Combustion Science	FLEX-1	2016-2017

PSI Awarded Research – Appendices A and B (continued)

	PI Name	PI Organization	Proposal Title	Research Area	Investigation(s) Used	Grant Period
6	Sean Garrick	University of Minnesota	Utilization of the smoke aerosol measurement experiment data for advanced modeling and simulation of smoke generation in micro-gravity	Combustion Science	SAME	2016-2017
7	Lou Kondic	New Jersey Institute of Technology	Structure evolution during phase separation in colloids under microgravity	Complex Fluids	ACE-M1, BCAT-3, BCAT-4, BCAT-5, BCAT-6, PHaSE	2016-2017
8	Ebrahim Asadi	University of Memphis	Enhancement and Verification of Quantitative Phase-Field Crystal Modeling using NASA-PSI Coarsening in Solid- Liquid Mixtures Experiments Data	Materials Science	CSLM, CSLM-2, CSLM-2R, CSLM-3	2016-2017
9	Kegang Wang	Florida Institute of Technology	Testing Analytical and Numerical Models in Phase Coarsening using NASA Physical Sciences Informatics System	Materials Science	CSLM, CSLM-2, CSLM-2R, CSLM-3	2016-2017
10	Mohsen Eshraghi	California State University, Los Angeles	Pore-Mushy Zone Interaction during Directional Solidification of Alloys: Three Dimensional Simulation and Comparison with Experiments	Materials Science	PFMI	2016-2017

Physical Sciences Informatics - **Status**
2016 Physical Sciences Informatics NRA Appendix C

National Aeronautics and Space Administration
NASA Headquarters
Space Life and Physical Sciences Research and Applications Division
300 E ST SW
Washington, D.C. 20546-0001

Use of the NASA Physical Sciences Informatics System

NASA Research Announcement

NNH15ZTT001N NRA

APPENDIX C

Soliciting Proposals for Use of the NASA Physical Sciences Informatics System for Combustion Science, Complex Fluids, Fluid Physics, Fundamental Physics, and Materials Science

APPENDIX NUMBER: NNH15ZTT001N – 15PSI_C

Appendix Issued: September 15, 2016
Notices of Intent Due: October 31, 2016 (5:00 pm Eastern)
Proposals Due: December 15, 2016 (5:00 pm Eastern)

Catalog of Federal Domestic Assistance (CFDA) Number: 43.003

- Released: September 15, 2016
- Eligible experiments: 39
- Proposer WebEx: Oct. 5, 2016
- 31 NOIs received: Oct.30, 2016
- Proposals Due: December 15, 2016
- **March - April 2017: Panel Reviews**
- May 2017: Proposals selected
- Awards: October 2017

- Solicits ground-based research proposals from established researchers and graduate students.
- Proposals open to experimental and numerical studies.
- **Awards: $75,000 to $125,000/year for two years.**
- **Approximately 5 proposals will be selected** and funded for FY 2018 and 2019.

- The NRA is available at: http://tinyurl.com/NASA-15PSI-C
  For additional information on the PSI database, visit: http://psi.nasa.gov

Eligible Experiments for PSI NRA - Appendix C

#	Research Area	Investigation
1	Combustion Science	BASS (Burning and Suppression of Solids)
2	Combustion Science	DAFT (Dust and Aerosol Measurement Feasibility Test)
3	Combustion Science	DAFT-2 (Dust and Aerosol Measurement Feasibility Test–2)
4	Combustion Science	FLEX (Flame Extinguishment Experiment)
5	Combustion Science	SAME (Smoke Aerosol Measurement Experiment)
6	Combustion Science	SAME-R (Smoke Aerosol Measurement Experiment Reflight)
7	Combustion Science	SLICE (Structure and Liftoff in Combustion Experiment)
8	Combustion Science	SPICE (Smoke Point in Coflow Experiment)
9	Complex Fluids	ACE-M1 (Advanced Colloids Experiment–Microscopy – 1)
10	Complex Fluids	BCAT-3 (Binary Colloidal Alloy Test – 3)
11	Complex Fluids	BCAT-4 (Binary Colloidal Alloy Test – 4)
12	Complex Fluids	BCAT-5 (Binary Colloidal Alloy Test – 5)
13	Complex Fluids	BCAT-6 (Binary Colloidal Alloy Test – 6)
14	Complex Fluids	InSPACE-3 (Investigating the Structure of Paramagnetic Aggregates from Colloidal Ellipsoids–3)
15	Complex Fluids	InSPACE-3+ (Investigating the Structure of Paramagnetic Aggregates from Colloidal Ellipsoids–3+)
16	Complex Fluids	PCS (Physics of Colloids in Space)
17	Complex Fluids	PHaSE (Physics of Hard Spheres Experiment) STS-83, STS-94
18	Complex Fluids	SHERE (Shear History Extensional Rheology Experiment)
19	Complex Fluids	SHERE II (Shear History Extensional Rheology Experiment II)

#	Research Area	Investigation
20	Complex Fluids	SHERE-R (Shear History Extensional Rheology Experiment Reflight)
21	Fluid Physics	CCF (Capillary Channel Flow)
22	Fluid Physics	CFE (Capillary Flow Experiment)
23	Fluid Physics	CVB (Constrained Vapor Bubble)
24	Fluid Physics	CVB-2 (Constrained Vapor Bubble – 2)
25	Fluid Physics	MABE (Microheater Array Heater Boiling Experiment)
26	Fluid Physics	NPBX (Nucleate Pool Boiling Experiment)
27	Fundamental Physics	DECLIC-ALI (Device for the Study of Critical Liquids and Crystallization – Alice Like Insert)
28	Fundamental Physics	GRADFLEX (Gradient Driven Fluctuation Experiment), Free Flyer
29	Fundamental Physics	PKE-Nefedov & PK-3+ (Dusty Plasma)
30	Materials Science	CSLM (Coarsening in Solid-Liquid Mixtures)
31	Materials Science	CSLM-2 (Coarsening in Solid-Liquid Mixtures – 2)
32	Materials Science	CSLM-2R (Coarsening in Solid-Liquid Mixtures – 2 Reflight)
33	Materials Science	CSLM-3 (Coarsening in Solid-Liquid Mixtures – 3)
34	Materials Science	DECLIC-DSI (Device for the Study of Critical Liquids and Crystallization – Directional Solidification Insert)
35	Materials Science	IDGE (Isothermal Dendritic Growth Experiment), STS-62
36	Materials Science	ISSI (In-Space Soldering Investigation)
37	Materials Science	MICAST/CSS 6 & 7 (Comparison of Structure and Segregation in Alloys Directionally Solidified in Terrestrial and Microgravity Environments)
38	Materials Science	PFMI (Pore Formation and Mobility Investigation)
39	Materials Science	SUBSA (Solidification Using a Baffle in Sealed Ampoules)

Types of Investigations and Eligible Proposers for PSI NRA - Appendix C

This NRA solicits ground-based research proposals that present a compelling case on how the experimental data from the PSI system (http://psi.nasa.gov) will be used to promote the advancement of further research. Proposers must show a clear path from the scientific data obtained from the PSI system to the proposed investigation. In addition, the project must address an important problem in the proposed area of research and advance scientific knowledge or technology. Examples of proposed investigations that utilize PSI data include:

1. Enhancement and verification of numerical and analytical models;
2. Development or enhancement of data analysis or other informatics tools to increase science readiness;
3. A new ground-based experiment or data analysis to verify phenomena observed in the original investigation;
4. A new ground-based experiment or data analysis that expands upon the results from the original investigation;
5. A new ground-based experiment or data analysis that is not directly linked with the science objectives from the original investigation.

For **established researchers**, NASA is soliciting proposals that advance fundamental research in one of the physical sciences disciplines identified above that leads to future publications, patents or products.

For **graduate students** (students working towards an advanced degree), this NRA is soliciting proposals that advance fundamental research in one of the physical sciences disciplines identified above and also assist in the awarding of an advanced degree to the graduate student.

Physical Sciences Informatics – **Future plan**

- Approximately 14 -18 experiments will uploaded to PSI each year
- Experiments for the sixth discipline to be included - Biophysics
- In addition to SLPS-PS, microgravity physical science experiments will be added from AES, CASIS, DLR and CNES.
- Annual NRA solicitation
- Approximately 5 proposals to be selected each year.

Planned Experiments to be Uploaded to PSI from FY 2017- 2019

No.	Acronym	Title
1	MB1 - CASIS	Macromolecular Biophysics-1, The Effect of Macromolecular Transport on Microgravity Protein Crystallization
2	MB3 - CASIS	Macromolecular Biophysics-3, Growth Rate Dispersion as a Predictive Indicator for Biological Crystal Samples Where Quality Can be Improved with Microgravity Growth
3	SAFFIRE I - AES	Spacecraft Fire Experiment I
4	SAFFIRE II - AES	Spacecraft Fire Experiment II
5	SAFFIRE III - AES	Spacecraft Fire Experiment III
6	BASS-2	Burning and Suppression of Solids
7	CFI	Cool Flames Initiative
8	FLEX-2	Flame Extinguishment Experiment - 2
9	PSI grant	Effect of External Thermo-convective Perturbation on Cool Flame Dynamics: A Multidimensional Multi-physics CFD Analysis
10	PSI grant	Quantitative Studies of Cool Flame Transitions at Radiation/Stretch Extinction Using Counterflow Flames
11	PSI grant	Utilization of the Smoke Aerosol Measurement Experiment Data for Advanced Modeling and Simulation of Smoke Generation in Microgravity
12	SOFBALL	Structure of Flame Balls at Low Lewis Number
13	SSCE	Solid Surface Combustion Experiment
14	ACE-M1	Advanced Colloids Experiment - Microscopy 1
15	ACE-T6 -CASIS	Advanced Colloids Experiment - Temperature Control 6
16	ACE-H1	Advanced Colloids Experiment - Heated 1
17	ACE-H2	Advanced Colloids Experiment - Heated 2
18	ACE-M2	Advanced Colloids Experiment - Microscopy 2
19	ACE-M3	Advanced Colloids Experiment - Microscopye 3
20	ACE-T1	Advanced Colloids Experiment - Temperature Control 1
21	ACE-T8	Advanced Colloids Experiment - Temperature Control 8
22	ACE-T9	Advanced Colloids Experiment - Temperature Control 9
23	InSPACE	Investigationg the Structure of Paramagnetic Aggregates from Colloidal Ellipsoids
24	InSPACE-2	Investigationg the Structure of Paramagnetic Aggregates from Colloidal Ellipsoids - 2
25	OASIS	Observation and Analysis of Smectic Islands in Space
26	PSI grant	Structure Evolution During Phase Separation in Colloids Under Microgravity
27	CCF-EU1.1 -DLR	Capillary Channel Flow - EU1.1
28	CCF-EU2.1- DLR	Capillary Channel Flow - EU2.1
29	CCF-EU2.2 -DLR	Capillary Channel Flow - EU2.2
30	CFE-2	Capillary Flow Experiment - 2
31	CVB – CASIS	Constrained Vapor Bubble - CASIS
32	HTI-R - CNES	Device for the study of Critical Liquids and Crystallation - High Temperature Insert - Reflight
33	PBRE	Packed Bed Reactor Experiment
34	ZBOT	Zero Boil-Off Tank Experiment
35	PSI grant	Computational Framework for Capillary Flows
36	PSI grant	Development and Verification of a 3D Nucleate Pool Boiling Simulation Model
37	PSI grant	Gravity Scaling of Pool Boiling Heat Transfer: Numerical Simulations and Validation with MABE and NPBX
38	PBE	Pool Boiling Experiment, STS
39	STDCE	Surface Tension Driven Convection Experiment, STS
40	ALI-R -CNES	ALICE Like Insert - Reflight
41	CLYC – CASIS	Crystal Growth of Cs_2LiYCl_6:Ce in Microgravity
42	InI - CASIS	Detached Melt and Vapor Growth of InI in SUBSA Hardware
43	CSLM-4	Coarsening of Solid Liquid Mixtures - 4
44	DSI-R - CNES	Device for the study of Critical Liquids and Crystallation - Directional Dolidification Insert - Reflight
45	GEDS	Gravitational Effects on Distortion in Sintering
46	ICESAGE	Influence of Containment on the Growth of Silicon-Germanium
47	ICOPROSOL	Thermophysical Properties and Solidification Behavior of Undercooled Ti-Zr-Ni Liquids Showing an Icosahedral Short-Range Order
48	IDGE - STS 75	Isothermal Dendritic Growth Experiment - STS 75
49	IDGE - STS 87	Isothermal Dendritic Growth Experiment - STS 87
50	PARSEC	Peritectic Alloy Rapid Solidification with Electromagnetic Convection
51	THERMOLAB	Thermophysical Properties of Liquid Metallic Alloys - Modeling of Industrial Solidification Processes and Development of Advanced Products
52	TEMPUS	Tiegelfreies Elektromanetisches prozessieren Unter Schwerelosigkeit
53	ML - Cement	MaterialsLab – Cement Reference Expeiment
54	PSI grant	Enhancement and Verification of Quantitative Phase-Field Crystal Modeling using NASA-PSI Coarsening in Solid-Liquid Mixtures Experiments Data
55	PSI grant	Pore-Mushy Zone Interaction Druing Directional Solidification of Alloys: Three Dimensional Simulation and Comparison with Experiments
56	PSI grant	Testing Analytical and Numerical Models in Phase Coarsening Using NASA Physical Sciences Informatics System

Back -Up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youtube.com/NASA
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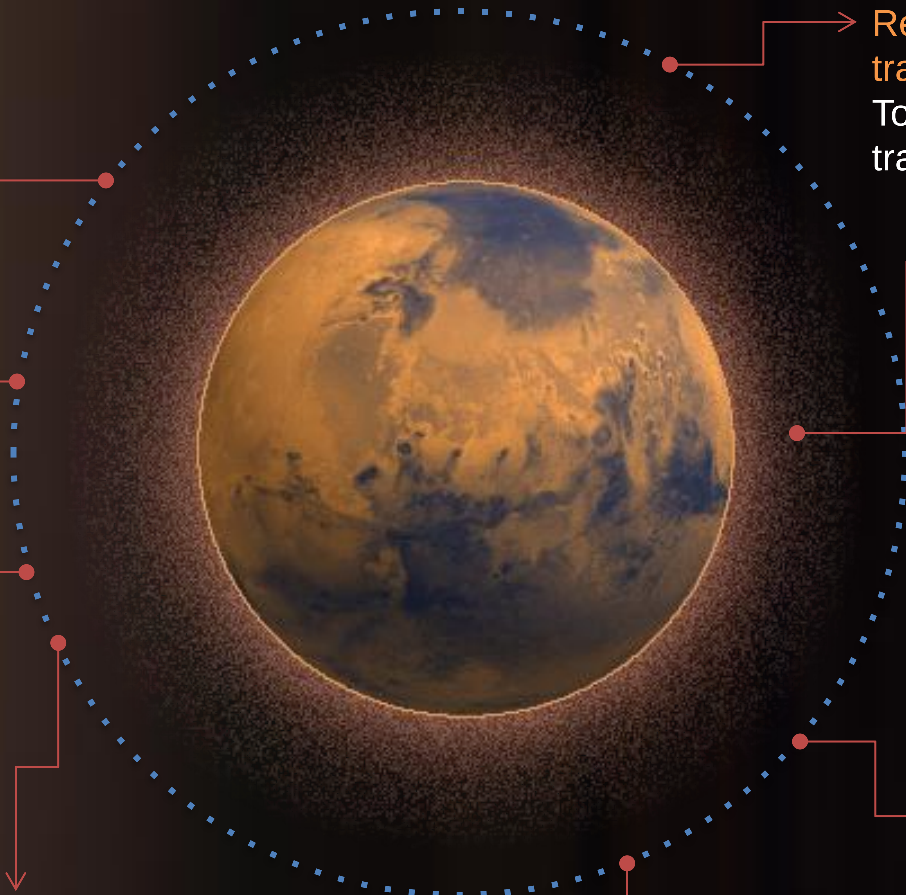
Human Exploration of Mars is Hard



20-30 tons
Ability to land large payloads needed

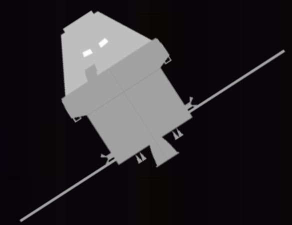
130 tons
Heavy-lift mass means **multiple** launches per mission

13.5 km/s Earth re-entry speed

800-1100 days away from Earth in micro gravity and high levels of radiation

Reliable in-space transportation:
Total continuous transportation power

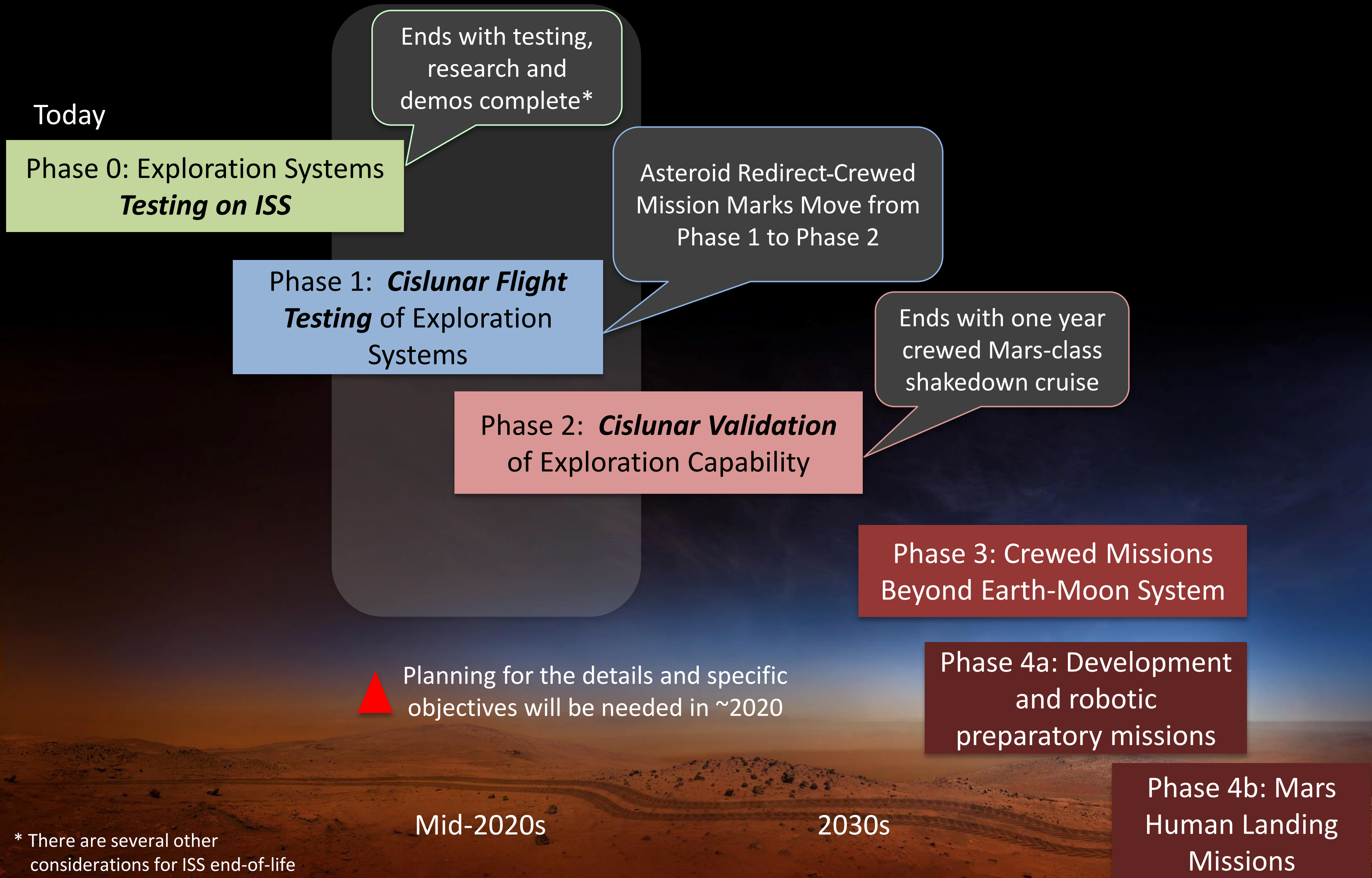
Thin atmosphere and dusty conditions for surface operations.



44 minute max two-way communication delay
2-week blackout every 26 months when Earth and Mars are on opposite sides of the sun

20 tons of oxygen needed for ascent to orbit: In-Situ Resource Utilization (ISRU)

Human Space Exploration Phases From ISS to the Surface of Mars



* There are several other considerations for ISS end-of-life

2015 OCT Technology Roadmaps - STMD

Demand Areas for the Journey to Mars

= Current HEOMD Activities
= Current STMD Activities

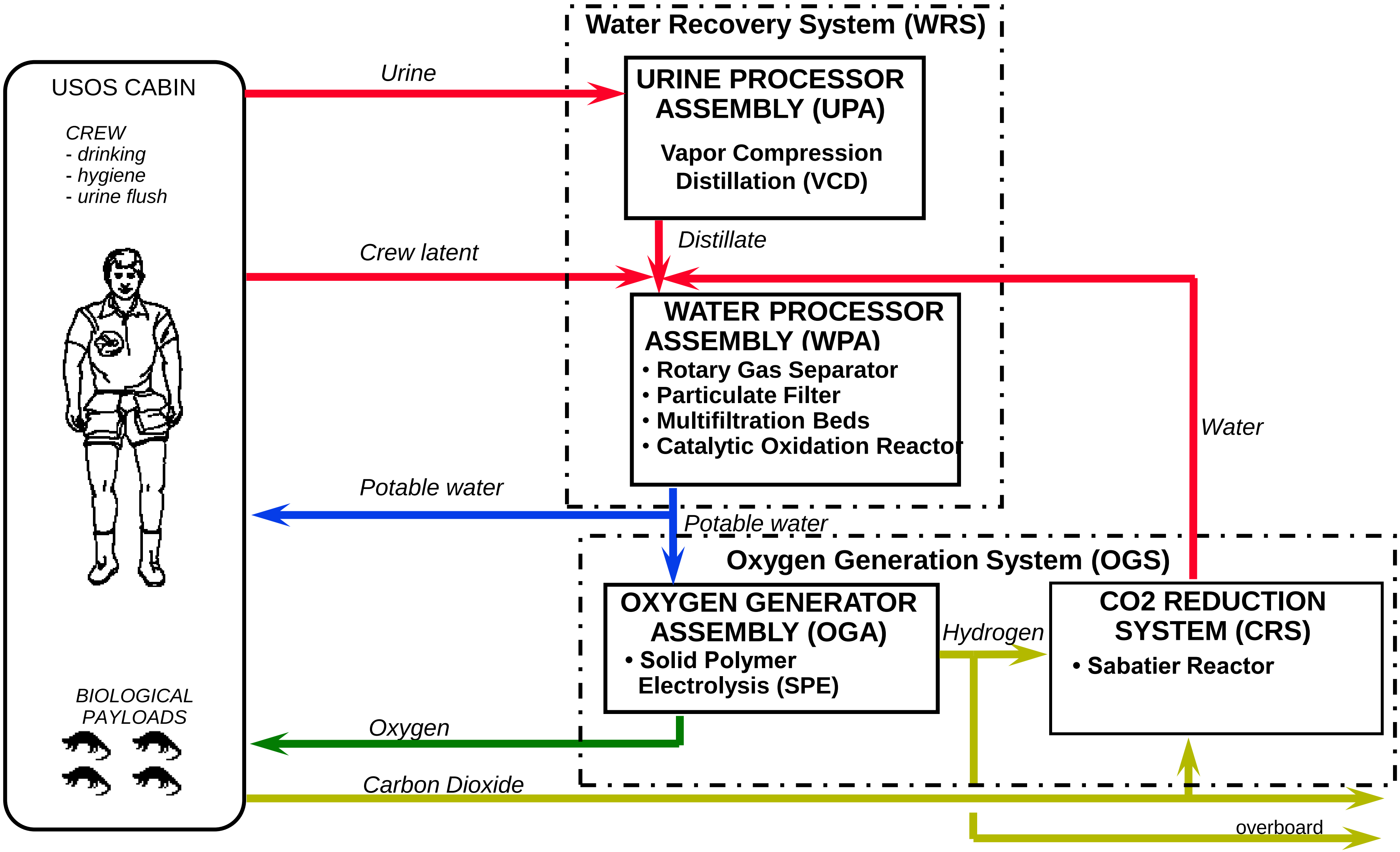
	Demand Areas \ Mission	ISS	Cis-lunar Short Stay (e.g. ARM)	Cis-lunar Long Stay	Cis-Mars Robotic	Mars Orbit	Mars Surface
Working in Space and On Mars	In Situ Resource Utilization & Surface Power		Exploratory ISRU Regolith	Exploratory ISRU	Exploratory ISRU & Atmosphere	Exploratory ISRU	Operational ISRU & High Power
	Habitation & Mobility	Long Duration with Resupply	Initial Short Duration	Initial Long Duration		Resource Site Survey	Long Duration / Range
	Human/Robotic & Autonomous Ops	System Testing	Crew-tended	Earth Supervised	Earth Monitored	Autonomous Rendezvous & Dock	Earth Monitored
	Exploration EVA	System Testing	Limited Duration	Full Duration	Full Duration	Full Duration	Frequent EVA
Staying Healthy	Crew Health	Long Duration	Short Duration	Long Duration	Dust Toxicity	Long Duration	Long Duration
	Environmental Control & Life Support	Long Duration	Short Duration	Long Duration	Long Duration	Long Duration	Long Duration
	Radiation Safety	Increased Understanding	Forecasting	Forecasting Shelter	Forecasting Shelter	Forecasting Shelter	Forecasting & Surface Enhanced
Transportation	Ascent from Planetary Surfaces				Sub-Scale MAV	Sub-Scale MAV	Human Scale MAV
	Entry, Descent & Landing				Sub-Scale/Aero Capture	Sub-Scale/Aero Capture	Human Scale EDL
	In-space Power & Prop		Low power	Low Power	Medium Power	Medium Power	High Power
	Beyond LEO: SLS & Orion		Initial Capability	Initial Capability	Full Capability	Full Capability	Full Capability
	Commercial Cargo & Crew	Cargo/Crew	Opportunity	Opportunity	Opportunity	Opportunity	Opportunity
	Communication & Navigation	RF	RF & Initial Optical	Optical	Deep Space Optical	Deep Space Optical	Deep Space Optical
		EARTH RELIANT	PROVING GROUND			EARTH INDEPENDENT	

Relevant Exploration areas for SLPSRA – guide to strategic balancing within PS – some examples

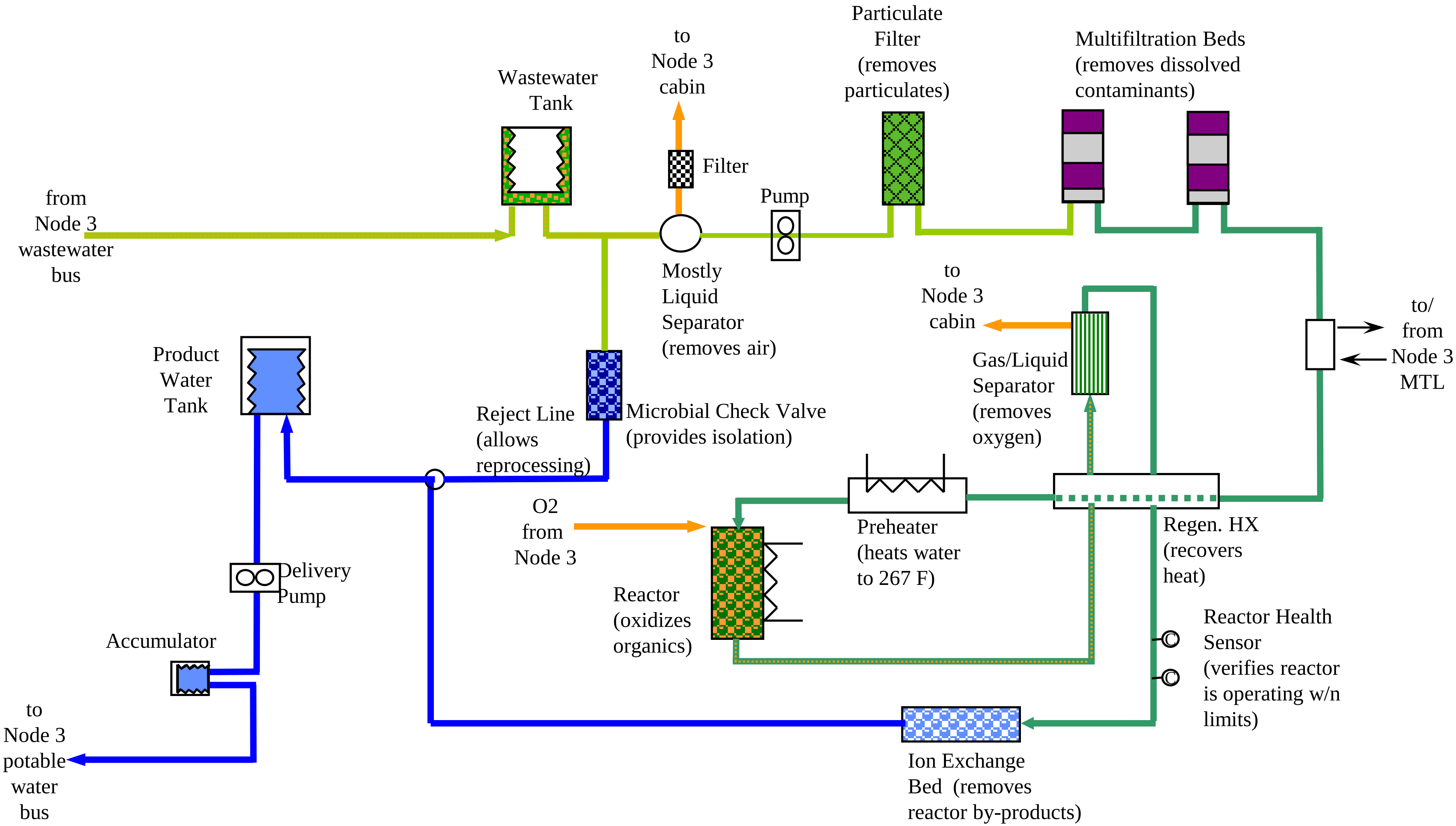
- **Environmental Control and Life Support**
  - Air Revitalization
  - Water Recovery
  - Waste Management
  - Thermal Control
  - Spacecraft Fire Safety
- **In-Space Power**
  - Energy conversion systems
  - Energy transfer
- **In-Space Propulsion**
  - Liquid rocket propulsion systems
  - Cryogenic storage and transfer
- **Materials, Structures, Mechanical Systems, and Manufacturing**
  - In-space manufacturing
- **Crew Health**
  - Plants – water/nutrient management system
  - Biofilms
- **Planetary Surface**
  - Habitation and Mobility
  - In Situ Resource Utilization (ISRU)
  - Surface Power

INTERNATIONAL SPACE STATION

WRS & OGS Architecture Overview

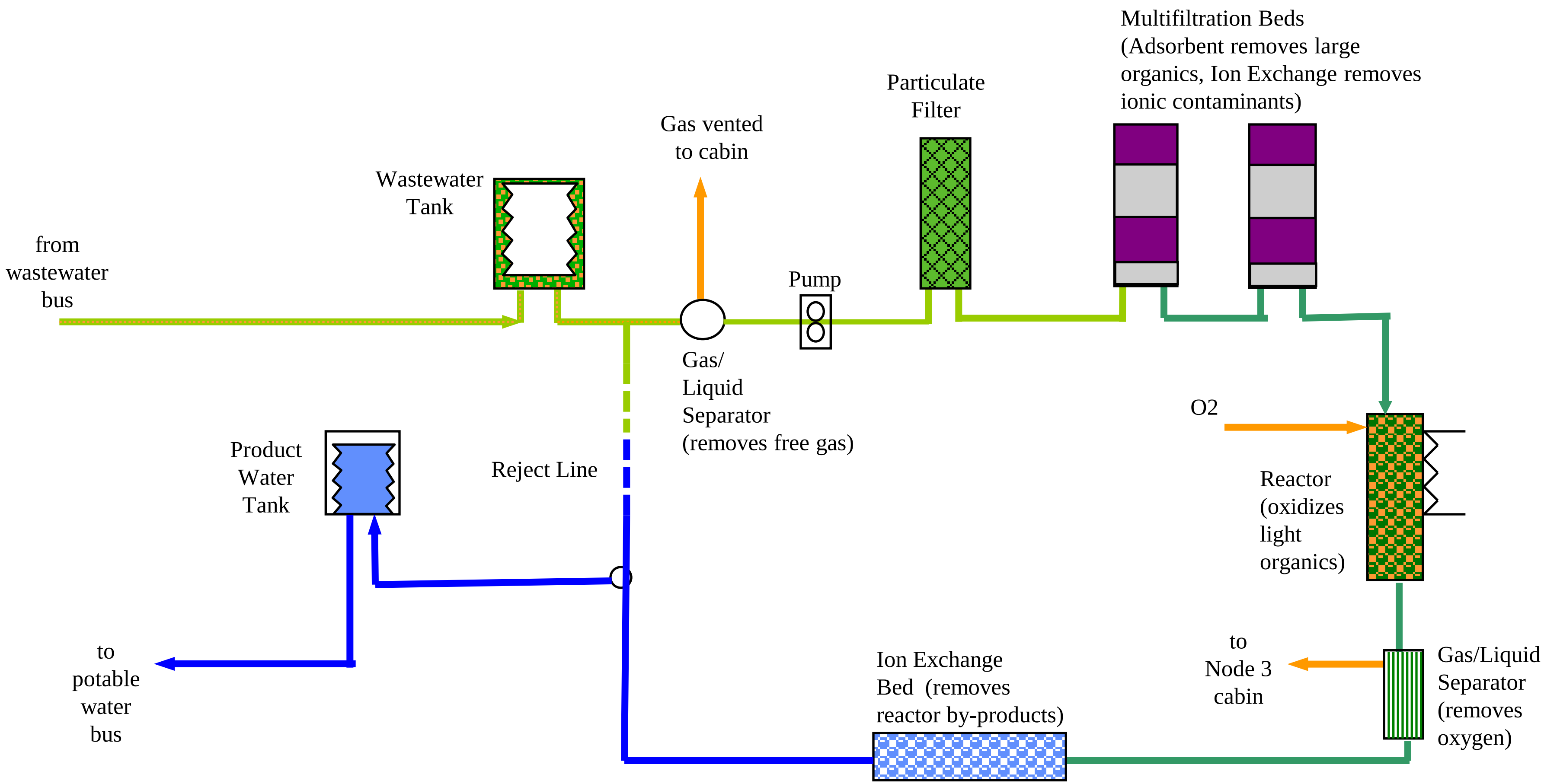


Water Processor Simplified Schematic

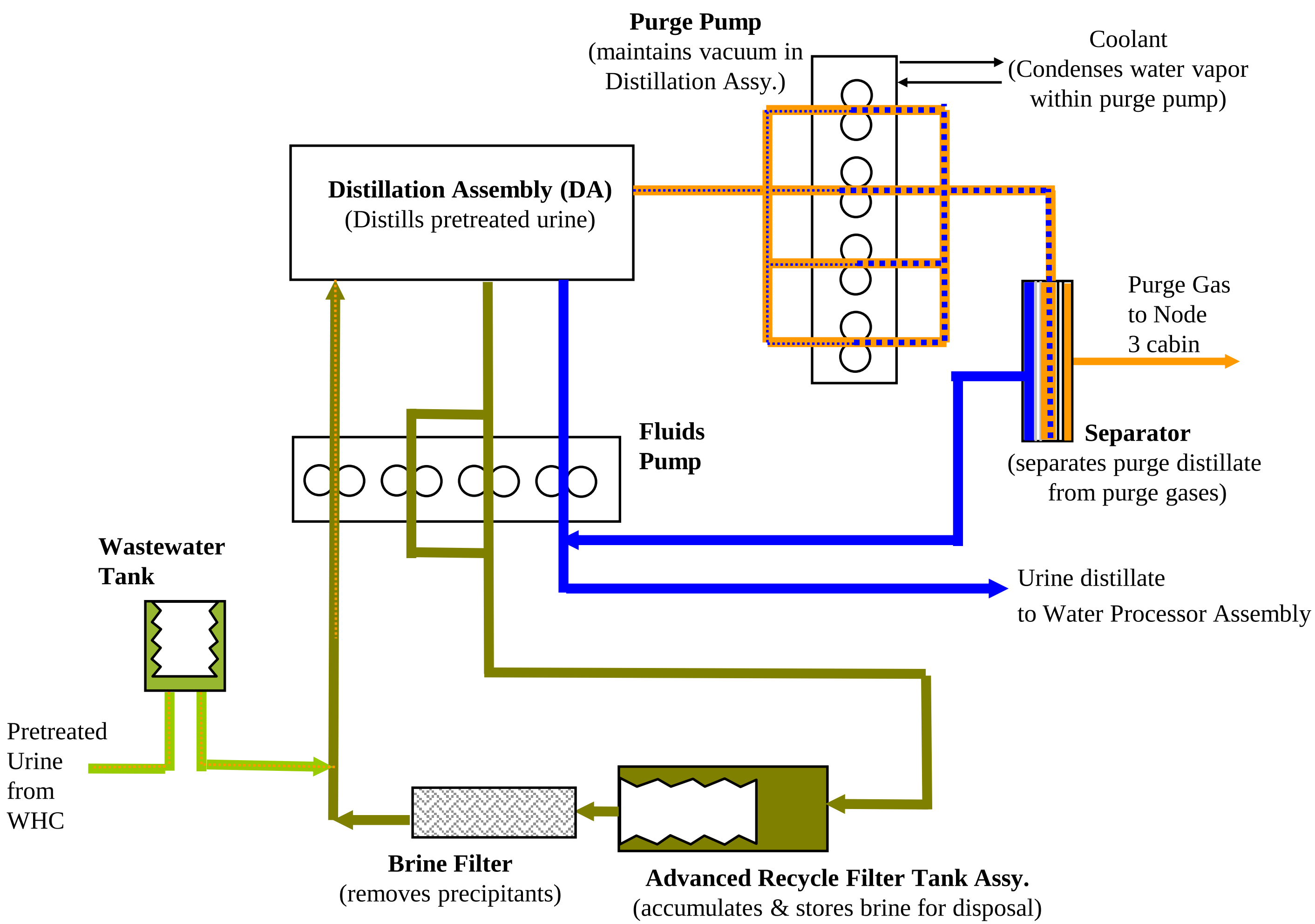


INTERNATIONAL SPACE STATION

Water Processor Simplified Schematic



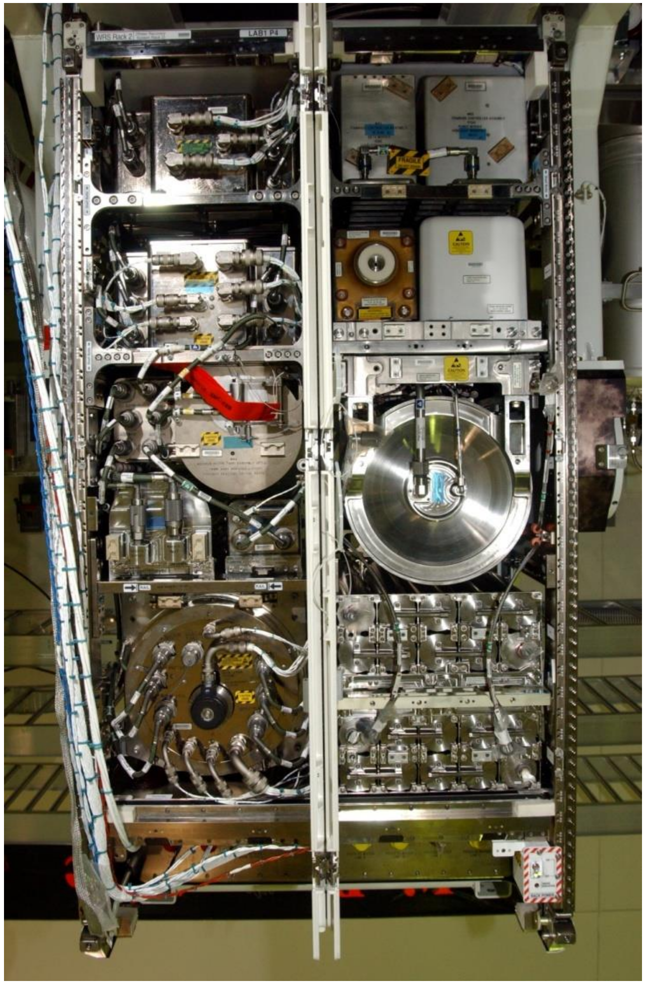
Urine Processor Assembly Simplified Schematic



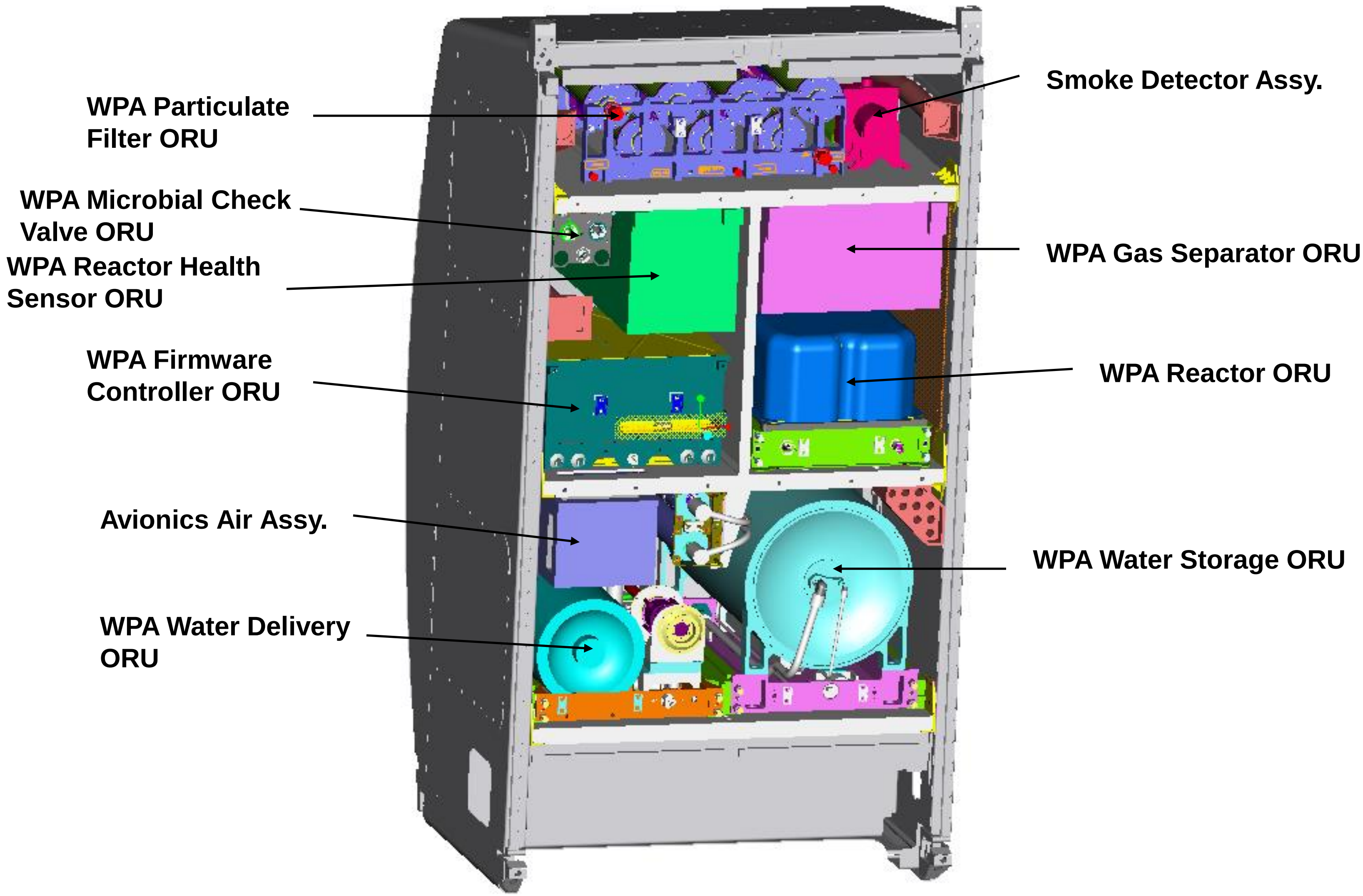
Water Recovery System (WRS)

Water Recovery System Rack #1

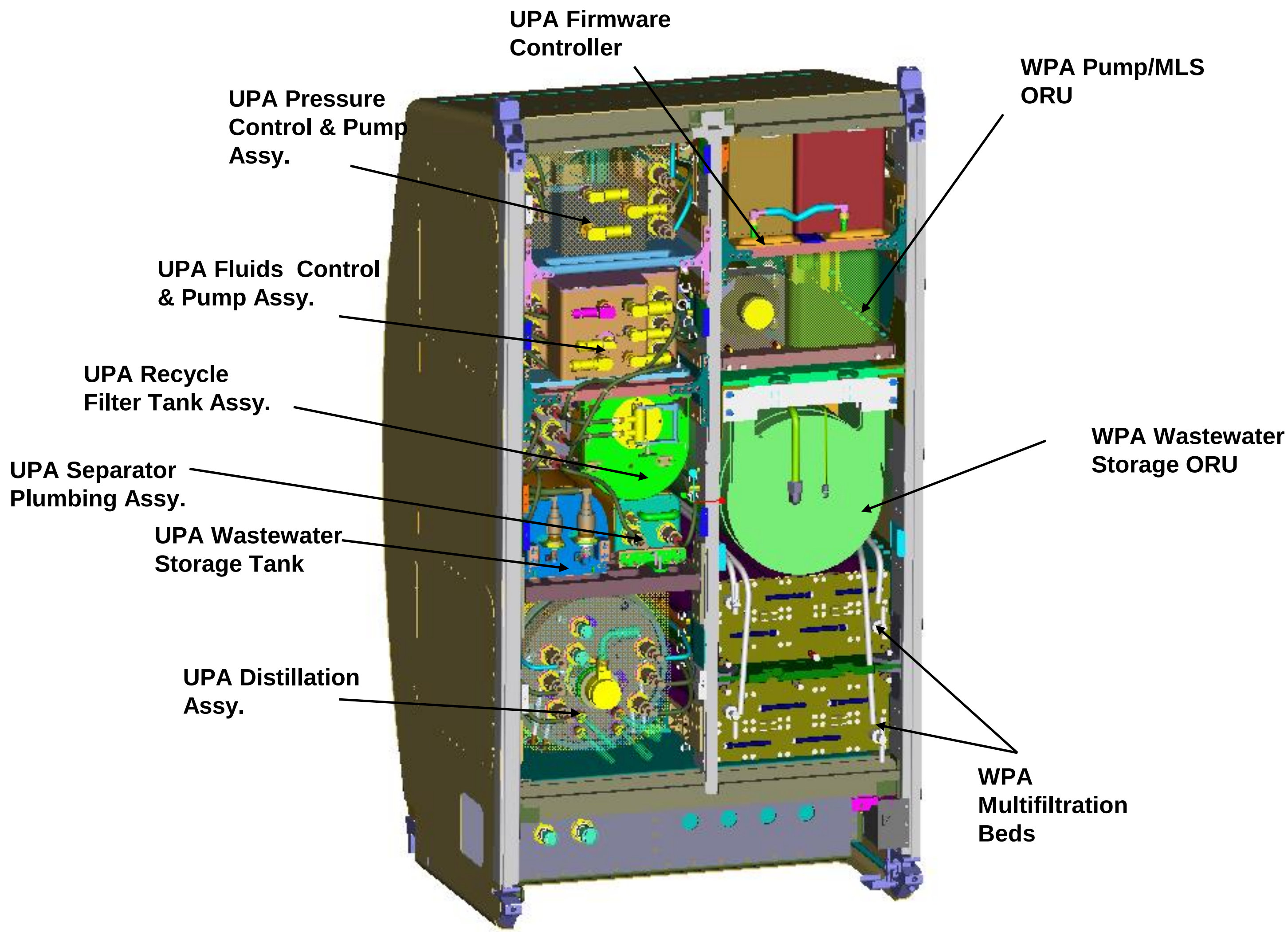
Water Recovery System Rack #2



Water Recovery System (WRS) Rack #1



WRS Rack #2



UPA Firmware Controller
WPA Pump/MLS ORU
UPA Pressure Control & Pump Assy.
UPA Fluids Control & Pump Assy.
UPA Recycle Filter Tank Assy.
UPA Separator Plumbing Assy.
UPA Wastewater Storage Tank
UPA Distillation Assy.
WPA Wastewater Storage ORU
WPA Multifiltration Beds

ISS Physical Sciences – Experiment Operations Timeline

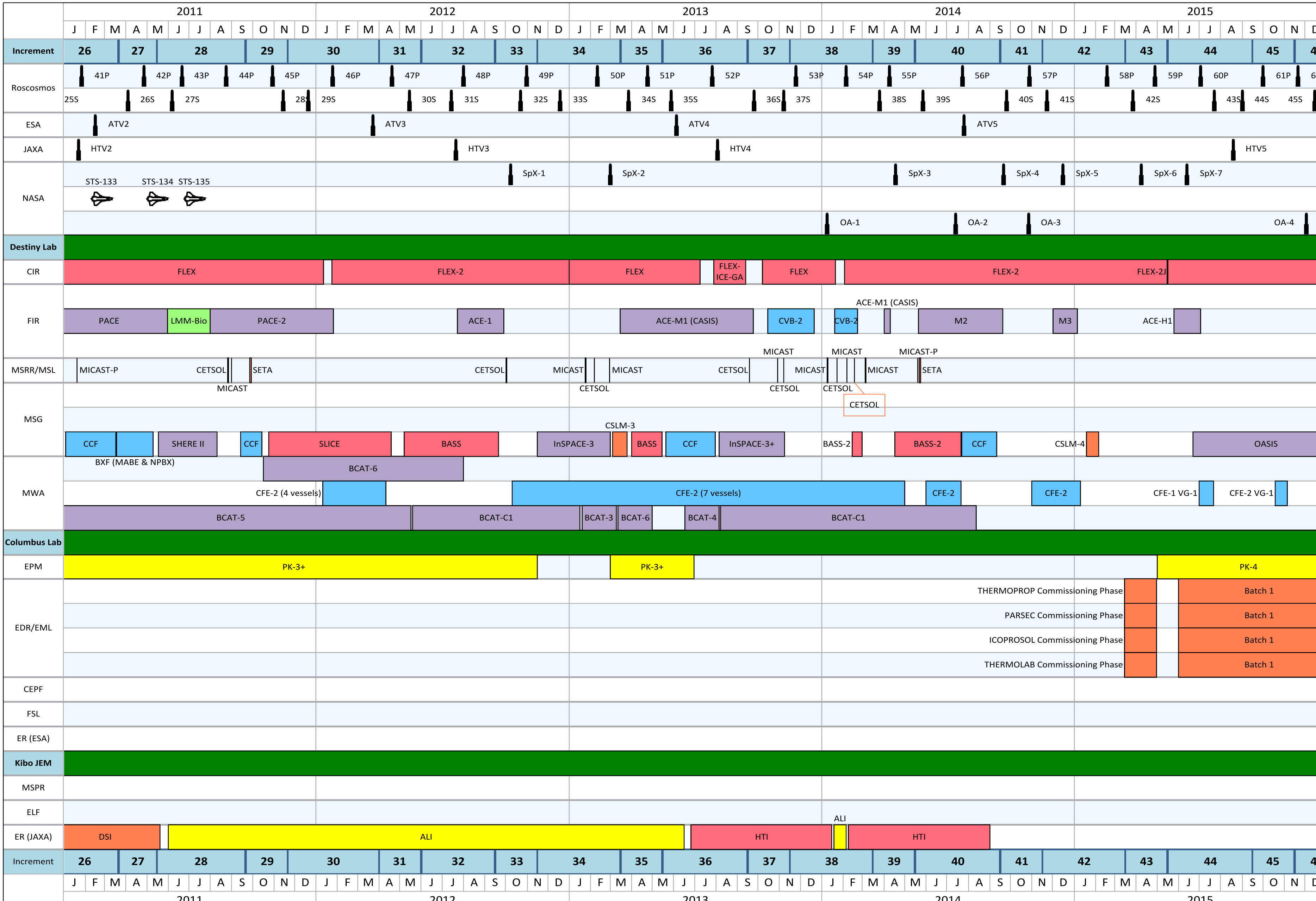
Legend

- Biophysics (MSFC/GRC)
- Combustion Science (GRC)
- Complex Fluids (GRC)
- Fluid Physics (GRC)
- Fundamental Physics (JPL)
- Materials Science (MSFC)
- Planned Experiment

ACE	Advanced Colloid Experiments	CCE	Chamber for Combustion Experiment	DAFT	Dust and Aerosol Measurement Feasibility Test	FOG	Formation of Gasrites	ISSI	In Space Soldering Investigation	OASIS	Observation and Analysis of Smectic Islands in Space	QTEST	Quantum Tests of the Equivalence Principle and Space-Time	SoFIE	Solid Fuel Ignition and Extinction
ACES	Atomic Clock Ensemble in Space	CCF	Capillary Channel Flow	DSI	Directional Solidification Insert	GCE	Group Combustion Experiment	LCN	Liquid Crystal Nanoplates	OS	Open Scienced	RSD	Ring Sheared Drop	SPADES	Spatiotemporal Evolution of Three-Dimensional Dendritic Array Structures
ACME	Advance Combustion via Microgravity Experiment	CET	Colummar to Equiaxed Transition	EHD	Electro Hydro Dynamic	GEDS	Gravitational Effects on Distortion in Sintering	MABE	Microheater Array Heater Boiling Experiment	PACE	Preliminary Advanced Colloids Experiment	SAME	Smoke Aerosol Measurement Experiment	SPICE	Smoke Point in Coflow Experiment
AI	Annular Injection	CETSOL	Columnar-to-Equiaxed Tranistion in Solidification Processing	ESTA	Eutectic Solidification in a Ternary Alloy	GTS	Growth of Ternary Semiconductors	MFHT	Multiphase Flow with Heat Transfer	PARSEC	Peritectic Alloy Rapid Solidification with Electromagnetic Convection	SCE	Solid Combustion Experiment	SUBSA	Solidification Using a Baffle in Sealed Ampoules
ALI	Alice Like Insert	CFE	Capillary Flow Experiment	FAMIS	Formulation of Amorphous Metals in Space	HTI-R	High Temperature Insert	MICAST	Microstructure Formation in Casting	PBRE	Packed Bed Reactor Experiment	SCWM	SuperCritical Water Mixture	TPFSE	Two-Phase Flow Separator Experiment
BASS	Burning and Suppression of Solids	CFI-OS	Cool Flames Investigation-Open Science	FBCE	Flow Boiling and Condensation Experiment	ICEAGE	Influence of Containment on the Growth of Silicon-Germanium	MICAST-P	Microstructure Formation in Casting-Poirier	PCS	Physics of Colloids in Space	SCWO	Supercritical Water Oxidation	μRSD	Microgravity Ring Shere Drop
BCAT	Binary Colloidal Alloy Test	CI	Conical Injection	FLARE	Flammability Limits At Reduced-g Experiment	ICE-GA	Italian Combustion Experiment for Green Air	MMB	Macromolecular Biophysics	PFE	Premixed Flames Experiment	SETA	Solidification along an Eutectic path in Ternary Alloys	VIPGRAN	Vibrational Phenomena in Granular Matter
BXF	Boiling Experiment Facility	CSLM	Coarsening in Solid-Liquid Mixtures	FLEX	Flame Extinguishment	IE	Interfacial Energy	MVCS	Morphological Variable Cross Section	PFMI	Pore Formation and Mobility Investigation	SHERE	Shear History Extensional Rheology Experiment	ZBOT	Zero Boil-Off Tank
CAL	Cold Atom Laboratory	CVB	Constrained Vapor Bubble	FOAM	Foam Optics and Mechanics	InSPACE	Investigating the Structures of Paramagnetic Aggregates from Colloidal Emulsions	NPBX	Nucleate Pool Boiling Experiment	PK	Plasma Crystal	SLICE	Structure and Liftoff In Combustion Experiment		

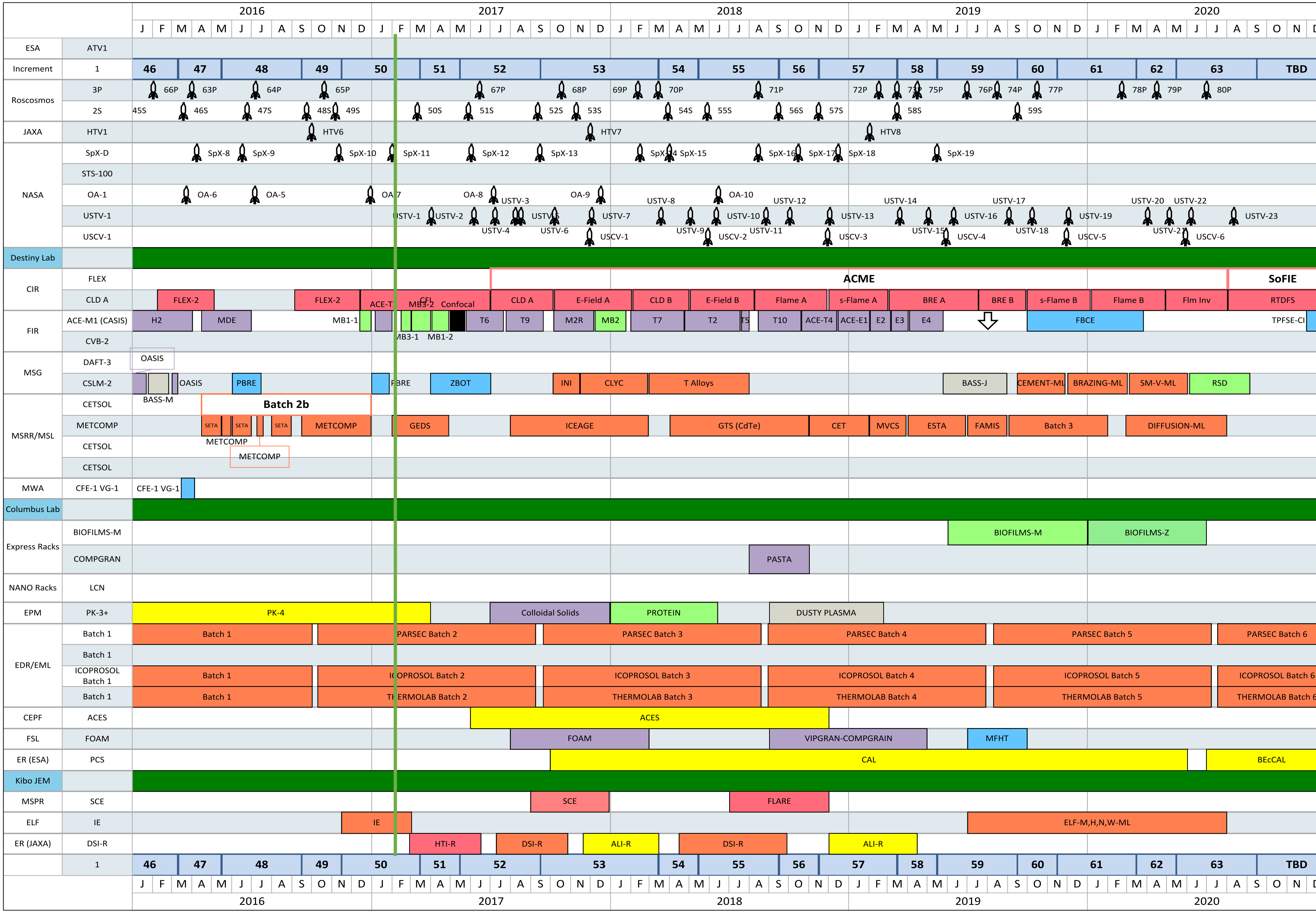
Snapshot Date: 5/3/2016

ISS Physical Sciences Traffic Model



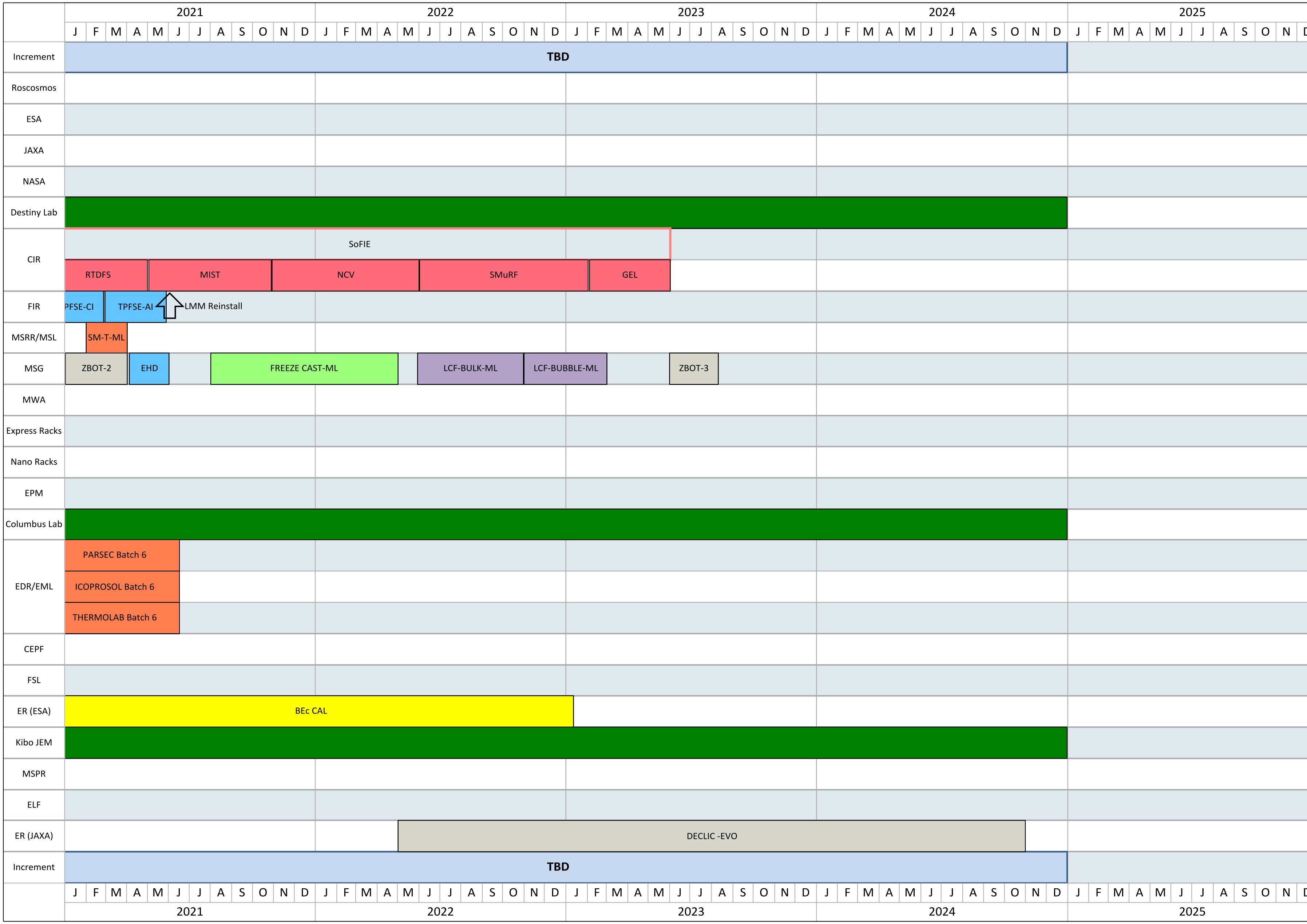
Snapshot Date: 2/1/2017

ISS Physical Sciences Traffic Model



Snapshot Date: 12/08/2016

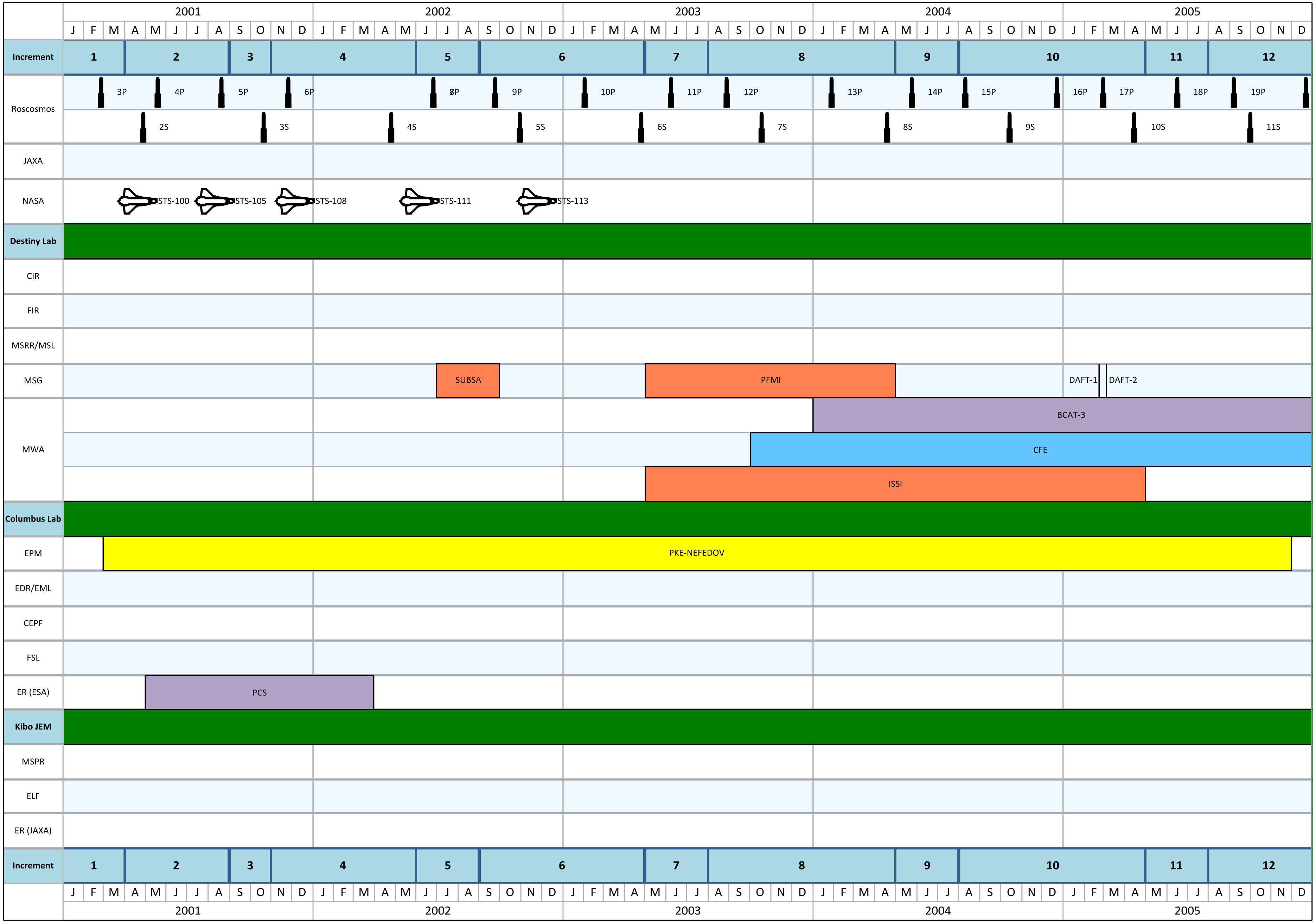
Physical Sciences Traffic Model
for Strategic Planning Purposes



ISS Physical Sciences - Historical Experiment Operations Timeline

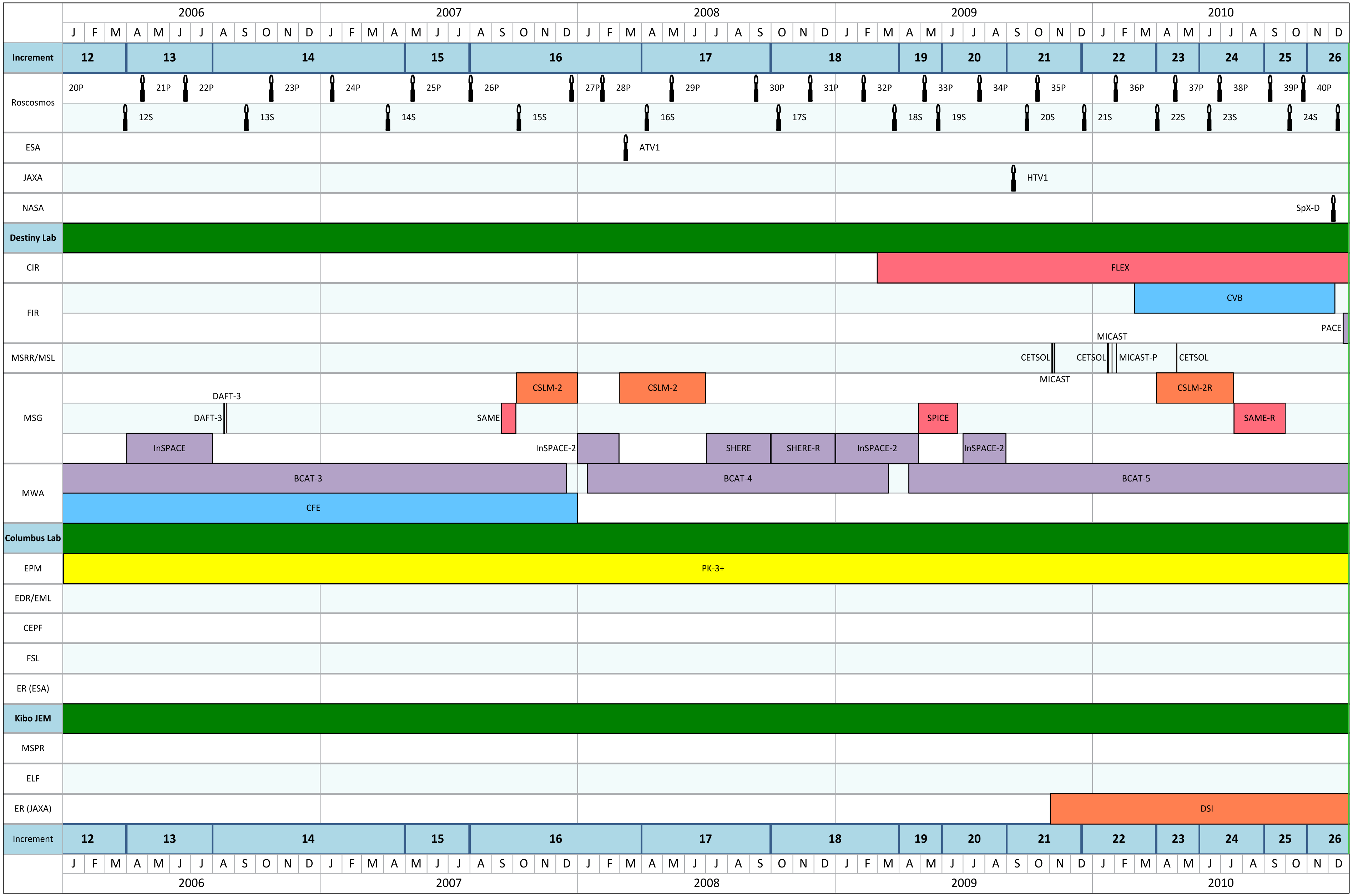
Snapshot Date: 5/3/2016

ISS Physical Sciences Traffic Model



Snapshot Date: 6/4/2015

ISS Physical Sciences Traffic Model



Materials and Biophysics Experiments

EML-NASA Research under ESA-Based Investigations
THERMOLAB and ICOPROSOL
Decadal Themes: AP9

Investigator: Dr. Kenneth Kelton, Washington University in St. Louis
PS: Michael SanSoucie, NASA MSFC
PM: Donnie McCaghren, NASA MSFC
Engineering Team: ESA

Objective:

- Determine the influence of liquid and solid short-range order on the nucleation barrier.
- Determination the composition dependence of nucleation rate and evaluate a new coupled flux model for nucleation.
- Correlate the nucleation kinetics with the local structure of the liquids.
- Correlate the local structure with containerless measurements of thermophysical properties.

Relevance/Impact:

- ISS Studies will provide thermophysical property data and test a new model for nucleation and growth, both needed for advanced computer-based modeling approaches to alloy development.
- Complimentary Beamline ESL studies will allow unprecedented measurements of high-temperature materials phase diagrams and structural properties of high temperature liquids.
- ICOPROSOL: The quasicrystals studied have unique structures holding promise for exciting new alloys, with potential applications as IR detectors, hydrogen batteries and hard, high temperature, corrosion resistant coatings.

Development Approach:

- THERMOLAB: Thermophysical properties, crystal nucleation rates and growth rates in quasi- and polyhedral- phase forming alloys will be measured in the undercooled state as a function of stirring.
- Sensitivity to impurities from containers will be avoided by the use of levitators – in ground-based studies with an electrostatic levitator and on ISS with an electromagnetic levitator.
- THERMOLAB: Many thermophysical properties, with the notable exception of specific heat, can be measured in a levitator on Earth, but with convective contamination. In particular the test of the coupled-flux nucleation model and the effect of diffusion on crystal growth rates in the liquid demand conditions ranging from quiescent to stirring conditions.

Instrumentation & Experiment Summary

- Utilizes the Materials Science Laboratory – Electromagnetic Levitator (MSL – EML)
- Ground-based support is provided by electrostatic levitation at Washington University
- Ground-based scattering studies of levitated liquids are made at the Advanced Photon Source (Argonne National Lab) and the Spallation Neutron Source (Oak Ridge National Lab)

Accomplishments

- Viscosity data for the Vit106 sample from the ISS experiments are consistent with the ground-based studies
- Disagreement of viscosity data between the ISS and ground-bases studies is most likely due to sample oxidation during the first few runs. This being one of the first few samples studied on the ISS, oxygen contamination came most likely from residual gas in the line.
- Time-Temperature-Transformation (TTT) data on Vit106 are incomplete. Further studies are planned for the future
- Recent Publications
  - "Connection of Fragility of Metallic Liquids with Cohesive Energy and High Temperature Structural Evolution," A. K. Gangopadhyay, C. E. Pueblo, M. L. Johnson, R. Dai, and K. F. Kelton, Submitted to Acta Materialia (September 2016).
  - "Kinetic and Structural Fragility – A Correlation between Structures and Dynamics in Metallic Liquids and Glasses," K. F. Kelton, Journal of Physics: Condensed Matter, in press.
  - "Measurements of the Temperature Dependent Total Hemispherical Emissivity Using an Electrostatic Levitation Facility," A. K. Gangopadhyay and K. F. Kelton, International Journal of Thermophysics, in press.
  - "Dramatically growing shear rigidity length scale in the supercooled glass former NiZr2," N. B. Weingartner, R. Soklaski, K. F. Kelton, Z. Nussinov, Physical Review B., 93, 214201 (2016).

EML-Electromagnetic Levitation Flight Support for Transient Observation of Nucleation Events

Decadal Themes: AP9

Investigator: Dr. Douglas Matson, Tufts University
PS: Michael SanSoucie, NASA MSFC
PM: Donnie McCaghren, NASA MSFC
Engineering Team: ESA

Objective:

- **Funding is for Dr. Matson's role as Team Member on the subprojects described below, associated with ESA-sponsored main projects as noted.**
- **Peritectic Alloy Rapid Solidification with Electromagnetic Convection (PARSEC).**
  - **This program investigates the effect of fluid flow on the solidification path of peritectic structural alloys.**
  - **Control of the solidification path would enable tailoring of the microstructure and properties of metal parts for applications including turbine blade directional solidification and magnetic material component motor fabrication.**
- **Thermophysical Properties of Liquid Metallic Alloys – Modeling of Industrial Solidification Processes and Development of Advanced Products (THERMOLAB – ISS).**
  - **Thermophysical properties of high temperature melts.**
  - **Research the influence of convection on the formation of different microstructure in a wide range of commercial alloys.**

Relevance/Impact:

- **Industrial welding, spray forming and casting operations for a class of soft magnetic materials, which have commercial and aerospace applications.**
- **In addition, this research addresses fundamental issues relating to rapid solidification behavior, metastable phase selection and analysis of the processes governing microstructural evolution.**

Development Approach:

- **Results from thermophysical property evaluation will be combined with the MHD convection definition.**
- **Recalescences studies from the undercooled melt will be done in the MSL-EML.**
- **These results will be compared results from ground-based EML and ESL.**

Instrumentation & Experiment Summary

- **Utilizes the Materials Science Laboratory – Electromagnetic Levitator (MSL – EML)**
- **Ground-based support at MSFC ESL lab**

Accomplishments

- **Electro-Magnetic Levitator Flight Ops**
  - **Batch 1.2 has been separated into three parts and the planned tests and their rough timeline are:**
    - **COMPLETED Batch#1.2a: ~100 cycles, Nov/Dec 2015**
      VIT106a, NiTa, FeCo
    - **COMPLETED Batch#1.2b: ~250 cycles, Mar-Jun 2016**
      FeCrNi, FeCo, FeCo, Cu75Co25, Cu89Co11, Zr, VIT106, LEK
    - **ONGOING Batch #1.2c: ~230 cycles, Oct-Nov 2016**
      MC2, CMSX-10, Zr, NdFeB, Ni60Al40, TiAlV
  - **Batch 2 Ground support program in progress**
- **Conducted ground-based non-levitation viscometry testing of steel alloy to baseline space results with Juergen Brillo of DLR**
- **Conducted ground-based EML density measurement using DLR EML with Juergen Brillo and Yuriy Plevachuk of Ivan Franko National University, Lviv, Ukraine.**
- **D.M. Matson, M. Watanabe, G. Pottlacher, G.W. Lee and H.-J. Fecht, "Thermophysical Property Measurement: A Call to Action", International Journal of Microgravity Science and Application, DOI 10.15011/ijmsa.33.330301, 33[3] (2016), pp. 330301 1-7.**
- **ESA Parabolic Flight on Batch 3 candidate alloys to demonstrate stability, coupling and processing parameter definition**
- **Presentation at ASGSR 2016, "Electromagnetic Levitation on the International Space Station"**

EML-Unified Support for THERMOLAB-ISS, ICOPROSOL, and PARSEC
Decadal Themes: AP9, TSES16

Investigator: Dr. Robert Hyers, University of Massachusetts
PS: Dr. Paul Craven, NASA MSFC
PM: Donnie McCaghren, NASA MSFC

Objective:

- **Provide magnetohydrodynamic (MHD) modeling support of macroconvection in various materials for three ESA sponsored projects:**
  - **Supports Peritectic Alloy Rapid Solidification with Electromagnetic Convection (PARSEC).**
  - **Supports Thermophysical Properties of Liquid Metallic Alloys – Modeling of Industrial Solidification Processes and Development of Advanced Products (THERMOLAB – ISS).**
  - **Supports Thermophysical properties and solidification behavior of undercooled Ti-Zr-Ni liquids showing an icosahedral short-range order (ICOPROSOL).**

Relevance/Impact:

PARSEC: Investigating the effect of fluid flow on the solidification path of certain alloys. Control of the solidification path would enable tailoring of the microstructure and properties of metal parts for specific applications.

THERMOLAB – ISS: Investigating the thermophysical properties of high-temperature materials. A better understanding of the physical properties will allow more efficient and more reliable production of metallic parts using these alloys.

ICOPROSOL: Investigating the nucleation and growth of quasicrystals, and the effect of atomic-scale order on the macroscopic properties of these alloys. This fundamental investigation may improve our ability to tailor the microstructure of metals for commercial applications.

Development Approach:

- **Thermophysical property measurements in MSFC ESL and on ISS.**
- **Quantitative magnetohydrodynamic (MHD) simulations enable the use of flow as an experimental variable to be controlled.**
- **Results from thermophysical property evaluation will be combined with the MHD convection models to quantify the flow in each flight sample at each phase of the experiment.**

Instrumentation & Experiment Summary

- **Utilizes the Materials Science Laboratory – Electromagnetic Levitator (MSL – EML)**

Accomplishments

- **Presentations**
  - **ASGSR 2016, "Thermophysical Properties of Zirconium-Oxygen alloys: Comparison of Flight and Ground Data"**
  - **Abstracts submitted to TMS 2017 (February 26-March 2, 2017) and ASGSR for 26-29 Oct. , 2016.**
- **Meetings attended**
  - **Participated in the Neutron Electrostatic Levitator Workshop, August 18-19, 2016 preparing for further collaborations related to MSL-EML, ELF, and MaterialsLab**
  - **Participated in ASGSR 2016 in October 2016**
- **Milestones for the flight experiment**
  - **Additional measurements of the influence of oxygen on thermophysical properties of zirconium using ESL at NASA MSFC Aug 1-5, 2016.**

Levitation Experiments on ISS
Applicable Decadal Themes: AP9, AP11, TSES16
Summary of Experiments

Investigator / Title / Facility	Measurement	Samples	Objectives	Impact	Topical Teams Supported
Hyers / Unified Support for THERMOLAB - ISS, ICOPROSOL, and PARSEC / EML	Density, Surface Tension, Viscosity	FeCo, FeCrNi, Vit106a*, Zr, Zr w/ 3% O_2 in solution	Provide magnetohydrodynamic (MHD) modeling support of macroconvection in various materials for three ESA sponsored projects: PARSEC, THERMOLAB-ISS, and ICOPROSOL.	A better understanding of the physical properties will allow more efficient and more reliable production of metallic parts using these alloys.	ESA: PARSEC, THERMOLAB-ISS, and ICOPROSOL, QUASI
Kelton / NASA Research under ESA-Based Investigations THERMOLAB and ICOPROSOL / EML	Density, Surface Tension, Viscosity	TiZrNi Vit106a*	TiZrNi: Research on quasicrystals to determine the influence of liquid and solid short-range order on the nucleation barrier. Vit106a: Research on bulk metallic glass (BMG) forming alloys	The quasicrystals studied have unique structures holding promise for exciting new alloys, with potential applications as IR detectors, and hydrogen batteries. BMGs have applications in sporting goods, gearboxes for missions to cryogenic planets, and hard, high temperature, corrosion resistant coatings.	ESA: ICOPROSOL, THERMOLAB-ISS, and QUASI
Matson / Electromagnetic Levitation Flight Support for Transient Observation of Nucleation Events / EML	Density, Surface Tension, Viscosity	FeCo, FeCrNi, nickel-based superalloys	Investigate the effect of fluid flow on the solidification path of peritectic structural alloys. Research the influence of convection on the formation of different microstructure in a wide range of commercial alloys. The THERMOLAB-ISS group receives input from an industrial advisory board to select materials for investigation.	Control of the solidification path would enable tailoring of the microstructure and properties of metal parts.	ESA: PARSEC and THERMOLAB-ISS
Hyers / Modeling and Simulation of Electrostatically Levitated Multiphase Liquid Drops / ELF	Density, Surface Tension, Viscosity	Steel and oxide melts (slag)	Provide magnetohydrodynamic (MHD) modeling support of macroconvection in various materials for fundamental research of steel processing using electrostatic levitation. Slag is the glass-like by-product leftover after a desired metal has been separated (i.e., smelted) from its raw ore. Slag is usually a mixture of metal oxides and silicon dioxide.	Investigating the effects of the interfacial phenomena between the molten steel and the oxide melts during processing from the viewpoint of the thermophysical properties. Understanding these phenomena will lead to more precise control of the processing of steels in foundaries.	JAXA: Interfacial Phenomena and Thermal Properties of High-Temperature Melts

***Vitreloy 106a (Vit106a): 58.5% Zr – 15.6% Cu – 12.8% Ni – 10.3% Al – 2.8% Nb**

Integrated Computational & Experimental Studies of Complex Dendritic Microstructure Development During Directional Solidification of Metallic Alloys (DECLIC & CETSOL)
Decadal Themes: AP9, AP10

Investigator: Dr. Alain Karma (Northeastern University)
ESA Primary Investigation Name: Columnar to Equiaxed Transition in Solidification Processing (CETSOL)
ESA Science Team Coordinator: Dr. Gerhard Zimmermann (ACCESS e.V., Aachen, Germany)
DECLIC DSI CNES Science Team Coordinator: Dr. Nathalie Bergeon (IM2NP, Marseille, France)
PS: Jonathan A. Lee, NASA MSFC
PM: Donnie McCaghren, NASA MSFC

Objectives:

Develop and utilize scale-bridging computational methods to model alloy solidification on: (i) a microstructure scale (100 µm to mm) with main focus on the dynamical selection of the primary cellular/dendritic array spacing,

(ii) a larger multigrain scale (several mm to cm) with main focus on the columnar-to-equiaxed transition.

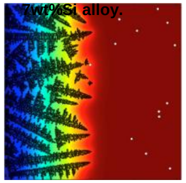
Relevance/Impact:

The mechanical properties of many industrial metallic alloys are determined by both the columnar and/or equiaxed grain structures and the dendritic microstructure inside each grain.

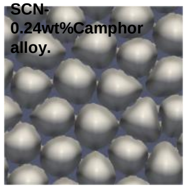
Development Approach:

- **Phase-field simulations will be used to model the dendritic spacing selection in directionally solidified Al-Si alloys and transparent succinonitrile (SCN)-based and Neopentylglycol (NPG)-based alloys.**
- **Dendrite Needle Network (DNN) simulations wil be used to model the columnar-equiaxed transition in Al-Si and both SCN- and NPG-based transparent alloys.**
- **Validation of model predictions is greatly simplified by the absence of buoyancy-driven convection.**

CETSOL: DNN simulation of columnar-equiaxed transition in an inoculated Al-7wt%Si alloy.



DECLIC/DSI: 3D phase-field simulation of cellular/dendritic array microstructure in directionally solidified transparent SCN-0.24wt%Camphor alloy.



Instrumentation & Experiment Summary:

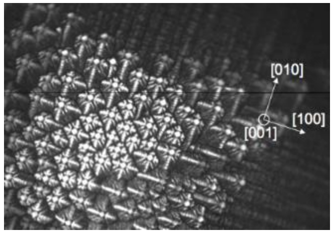
This project supports both the ESA CETSOL and Transparent Alloys and CNES DECLIC teams. The ESA team utilizes the Solidification with Quench Furnace, the Low Gradient Furnace, and the Microgravity Science Glovebox (MSG) Directional Solidification (DIRSOL) facility. The CNES team utilizes the DSI insert of the DECLIC facility. The PI is responsible for calculations only. No ISS resource requirements.

Accomplishments

- **Upgrading the computational model to include:**
  - **the effect of latent heat and**
  - **dendrite needle network.**
- **Conference paper presented in June 2016**
- **Publication in Acta Materialia in 2016**

Spatiotemporal Evolution of Three-Dimensional DENDRITIC Array Structures (SPADES)
Decadal Themes: AP9

PI: Rohit Trivedi / Iowa State
PS: Louise Strutzenberg
PM: Donnie McCaghren
Engineering Team: CNES



Coherent sidebranching observed in DSI with SCN-0.24 wt% camphor alloy

Objective: DSI-R support for DECLIC experiment

Relevance: **The sidebranch instability under investigation is crucial for dendritic growth and for determining the solute segregation pattern in the "mushy" zone that largely governs the properties of cast alloys. Development of rigorous dynamic models of microstructure formation provides insight enabling the development of advanced materials of commercial importance. The strength and other properties of an alloy are dependent on the microstructure.**

The experimental facilities at ISU needed to support the DECLIC/DSI effort include:

- **purification and characterization capabilities for SCN sample material**
- **thin sample directional solidification systems used for experimental matrix definition in advance of on-orbit ops, identifying growth parameters for flight sample composition that target the physics of interest (e.g. sidebranch structure formation)**
- **thin sample directional and isothermal annealing systems and ancillary equipment necessary for measurement of key material properties including partition coefficient, diffusion coefficient and anisotropy of interface energy**

The facility at ISU is the sole provider for all of these experimental capabilities.

Instrumentation & Experiment Summary

DECLIC-DSI accommodates solidification experiments at different velocities and thermal gradients using a transparent succinnonitrile/camphor material that can be observed by interferometric and video techniques. The DSI-R experiment SPADES focuses on the origin of sidebranches that occur when columnar solidification patterns transform from cellular to dendritic as a function of thermal gradient and solidification velocity and studies the potential for the formation of an intermediate multiplet pattern.

Accomplishments

- **DECLIC facility and DSI-R launched on Cygnus OA-5 10/17/16 and transferred to ISS on 10/27/16**
- **DECLIC facility was installed**
- **Check-out successfully completed on 11/28/16**
- **HTI-R science operations are underway**
- **DSI-R insertion and science operations are planned from 7/17 – 1/18.**

MSRR-Crystal Growth of Ternary Compound Semiconductors by Vapor Transport

Decadal Themes: FP1, AP9

PI: Dr. Ching-Hua Su, NASA MSFC
PS: Marvin W. Barnes, NASA MSFC
PM: Shawn Reagan, NASA MSFC

Objectives:

- To establish the relative contributions of gravity-driven fluid flows to the formation mechanism of (1) the non-uniform incorporation of point defects, such as dopant, impurity, and vacancy and (2) the extended defects, such as twinning, observed in the grown crystals as the results of buoyancy-driven convection and irregular fluid-flows.
- To evaluate the additional effects of gravity on the PVT growth processes by examining (1) the growth kinetics on various seed orientations (2) dopant distribution in the Cr doped ZnSe and (3) the compositional segregation and distribution in the ternary compounds grown by PVT.
- To assess self-induced strain effects developed during processing at elevated temperatures and retained on cooling caused by the weight of the crystals

Relevance/Impact:

- Crystal quality greatly influences the important electronic and optic properties in semiconductors.
- Studies in microgravity will be compared with three-dimensional numerical simulation including both mass transport and heat transfer to establish a fundamental understanding of the crystal growth process which will be used to optimize the crystal processing on Earth.

Development Approach:

- Perform crystal growth of ZnSe, Cr-doped ZnSe, and ZnSeTe by physical vapor transport process inside a fused silica ampoule.
- Characterize the structural, optical, and compositional properties of grown crystals by various techniques.

Instrumentation & Experiment Summary

- The experiments will be processed in the Low Gradient Furnace (LGF) in the Materials Science Research Rack (MSRR), International Space Station (ISS).
- The growth ampoules will be prepared at MSFC and loaded into the flight cartridge on ground.
- The growth furnace will be heated up to the prescribed temperature settings and allowed to reach steady state.
- The cartridge will be inserted fast (>1 mm/min), into the supersaturation position previously determined on the ground.
- The crystal starts growing on top of the seed by translating the furnace or sample cartridge and stops after six days.
- The thermal profile will be cooled down slowly to room temperature.

Accomplishments

Four papers have been published in refereed journals in 2016.

Example: "Thermoelectric properties of Tl-doped PbTeSe crystals grown by directional solidification", by Ching-Hua Su, was published on *Journal of Crystal growth*, 439, 80-86 (2016).

Dr. Su has been invited as a member of Editorial Advisory Board for the journal "*Recent Patents on Materials Science*" of Bentham Science publisher.

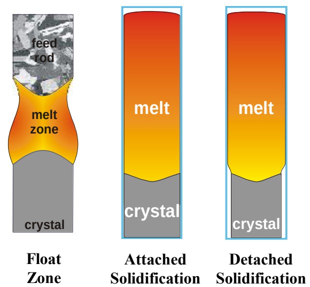
MSRR-Influence of Containment on the Growth of Silicon-Germanium (ICESAGE)

Decadal Themes: FP1, AP9

Investigator: Dr. Martin P. Volz, NASA MSFC
Co-I: Dr. Konstantin Mazuruk, University of Alabama in Huntsville
ESA Team Coordinator: Prof. Arne Cröll, University of Freiburg, Germany
PS: Marvin W. Barnes, NASA MSFC
PM: Shawn Reagan, NASA MSFC
Engineering Team: NASA MSFC

Objective:

The fundamental objective of the proposed research is to determine the influence of containment on the processing-induced defects and impurity incorporation in germanium-silicon (GeSi) crystals (silicon concentration in the solid up to 5 at%) for three different growth configurations in order to quantitatively assess the improvements of crystal quality possible by detached growth.

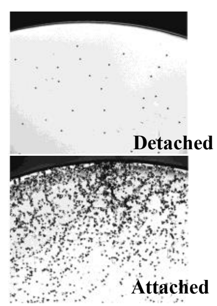


Relevance/Impact:

- **Defects in semiconductors propagate into the final electronic devices thereby reducing their performance**
- **Ideal is a breakthrough in understanding and control of detached terrestrial growth in many materials of technological and commercial interest.**

Development Approach:

- **Flight experiments utilizing the Bridgeman growth technique will be performed to study the crystallization of semiconductors in conditions which are ideally suited to providing detached growth of the crystal, i.e. the liquid-solid interface does not contact the ampoule wall.**
- **German team members will make use of free flyers (FOTON) and concentrate on experiments using the float zone crystal growth technique.**



Etch Pits

Instrumentation & Experiment Summary

A series of 10 sample cartridge assemblies (SCA)'s containing GeSi alloys will be processed in the Low Gradient Furnace (LGF) in the MSRR. The experiments will evaluate the effects of Si concentration, ampoule material (BN or SiO_2), and internal pressure across the melt on the occurrence of detachment in the grown crystals. The SCAs will be outfitted with thermocouples to provide near real-time temperature data to the science and engineering teams.

Accomplishments

Publication: "Dynamic stability of detached solidification", K. Mazuruk, M. P. Volz, Journal of Crystal Growth 444, 1-8, (2016)

**Recent studies: Ampoule configurations to establish positive, negative,
and zero pressure differentials across the melt meniscus have been
successfully
tested in the lab.**

MSRR-Fabrication of Amorphous Metals in Space (FAMIS)

Decadal Themes: AP9, AP10

Investigation Name: Fabrication of Amorphous Metals in Space (FAMIS)
PI: Dr. Douglas C. Hofmann (Jet Propulsion Laboratory)
Co-I: Dr. Andrew A. Shapiro (Jet Propulsion Laboratory)
Co-I: Prof. William L. Johnson (California Institute of Technology)
Co-I: Dr. Marios D. Demetriou (California Institute of Technology)
Co-I: Dr. Won-Kyu Rhim (California Institute of Technology)
Consultant: Prof. Konrad Samwer (University of Goettingen), Prof. Hans Fecht (Ulm University)
PS: Jonathan A. Lee, NASA MSFC
PM: Shawn Reagan, NASA MSFC
Engineering Team: NASA MSFC

Objective:

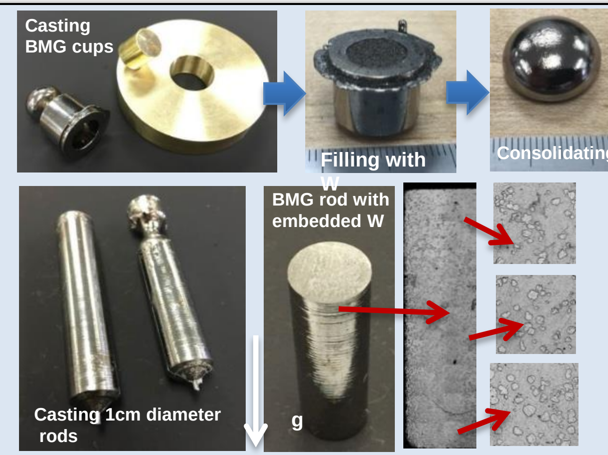
Develop W-reinforced BMG matrix composites with varying volume fraction and morphology of dense particles.

Relevance/Impact:

Metallic glasses have many desirable properties, especially their suitable for composites. Once unique subset of composites is penetrators, comprised of dense phased embedded in a BMG matrix. The dense phase increases the mass(for NASA missions which intend to study chemical composition of a body from an orbiting spacecraft) and the BMG adds a self-sharpening behavior which increases penetrating depth. However, due to the vast density difference between the two phases, processing these alloys into homogeneous and predictable microstructures in the presence of gravity is difficult.

Development Approach:

Produce a two phase BMG+W composite and try to process the alloy in the presence of gravity to demonstrate the negative effects of sedimentation. Develop a strategy to fabricate flight samples that allow the fabrication of microstructures that cannot be replicated on Earth.



The successful demonstration of using BMG cups followed by subsequent infiltration and casting to make near homogeneous W-reinforced composites

Instrumentation & Experiment Summary:

The Solidification and Quenching Furnace will be used to study sedimentation in a BMG composite with ~50% W powder to investigate the formation of composites with microstructures that cannot be attained on Earth.

Accomplishments

- **Developed casting technique for Vit 106**
- **Performed ground truth wear resistance testing**
- **Characterized ground samples**
- **Preparing for Science Concept Review, demonstrated the need for conducting microgravity research**

MSRR-Solidification Along an Eutectic Path in Ternary Alloys - SETA

Decadal Theme: AP9

U.S. Investigator: Dr. Amber Genau
Co-I: Dr. Ralph Napolitano, Iowa State University
PS: Dr. Peter Curreri, NASA MSFC
PM: Shawn Reagan, NASA MSFC
DLR Team Coordinator: Dr. Stephan Rex, ACCESS

Objectives and Contributions:

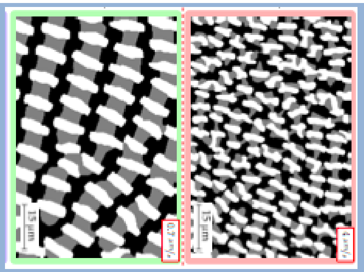
- Quantify three-phase ternary invariant eutectic solidification structures with respect to phase topology, periodicity, and relevant scaling lengths.
- Identify dominant growth modes, crystallographic orientation relationships and related transitions with respect to solidification velocity and thermal gradient.
- Measure effects of atomic-level sedimentation on volume fraction and morphology during ground-based experiments for comparison to flight results.
- Investigate the role of convective effects on off-eutectic compositions forced into fully coupled growth.
- Compare with relevant growth models and establish basis for new analytical descriptions.

Relevance/Impact:

- The specification of appropriate microstructural descriptors and quantification of natural and forced selection dynamics will provide the means necessary to prescribe and control composite microstructures in multi-component multiphase metallic systems.
- Other potential applications include multiphase growth in nonmetallic systems where aligned composite structures may give rise to specific physical properties or device functionality (e.g. special optical behavior).

Development Approach:

- The principal solidification technique will be gradient-zone directional growth, equipped with off-axis gradient bias and rotation capabilities. The principal measurements will include microstructural (SEM) and orientation (EBSD) imaging with computer-aided stereological measurements.
- Growth experiments are sensitive to thermal fluctuations, and gradient measurements will be made with an accuracy of 0.25 K/mm.
- Microstructural measurements will be made with spatial resolution of approximately 50 nm (will vary).



Ground based directional solidification structures, showing a transition in growth morphology associated with an increase in velocity. (Transverse cross-sections taken within 2 mm of the quenched growth front.) Space experiments will utilize Low Gradient Furnace MSRR insert.

Accomplishments

Working on the requirements for any US cartridges that would complement the SETA/ESA team studies. Batch 2b ESA samples have been processed on ISS.

<u>**Publications:**</u>

1. Sargin, R.E. Napolitano, and A.L. Genau, "The post-solidification effects in directionally solidified ternary eutectic Al-Cu-Ag alloys", February 2016, J. Phase Equilibria and Diffusion.

2. J. Hötzer, P. Steinmetz, M. Jainta, S. Schulz, B. Nestler, A. Dennstedt, A. Genau, M. Bauer, H. Köstler, U. Rüde, "Phase-field simulations of spiral growth during directional ternary eutectic solidification", March 2016, Acta Materialia.

MSRR-Multi-Scale Modeling and Experimentation on Liquid Phase Sintering in Gravity and Microgravity Environments
Decadal Themes: AP9

Investigation Name, PI: Randall M. German, San Diego State University; Co-I: Co-I Eugene A. Olevsky, San Diego State University.
PS: Biliyar N. Bhat, NASA MSFC
PM: Shawn Reagan, NASA MSFC
Engineering Team: development contractor – Teledyne Brown Engineering

Objective: **The proposed fundamental research is aimed at the achievement of two critical goals: (i) the in-depth analysis of the liquid phase sintering-induced pore-grain structure evolution by the de-convolution of the impact of gravity and (ii) exploring sintering under microgravity conditions as a promising technique for in-space fabrication and repair.**

Relevance/Impact: **The anticipated research outcomes will be relevant to current and future space exploration needs for habitat creation, extraterrestrial exploration, and vehicle *repair* activities during various NASA missions. Future NASA missions will require development of processes that permit fabrication and repair of critical components under reduced gravity conditions. This capability is needed to reduce resource requirements and the spare parts inventory while enhancing the probability of mission success.**

Development Approach:

The research project involves:

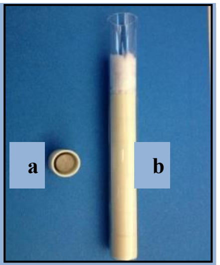
The development of the multi-scale computer code combining microscopic models (atomistic, Monte Carlo, or morphological energy minimization), mesoscale multiple grain models, such as Monte-Carlo-based simulations, and macroscopic finite-element-based continuum models of sintering. These will be combined to deliver verified predictions of macroscopic shape distortion during liquid phase sintering of heavy alloys.

Experimental verification of the developed multi-scale modeling framework in Earth and microgravity environments.

Integration into backward solutions to enable green body shaping in anticipation of the distortion to enable net-shaping to desired final sizes and shapes based on simulated evolution during sintering.

Instrumentation & Experiment Summary

Critical microgravity sintering experiments will be performed in the Low Gradient Furnace utilizing specially designed cartridges with multiple walled design. Experiment samples will be contained in alumina crucibles (a) stacked a quartz ampoule (b) which is evacuated and sealed (see figure on right) and then inserted into the cartridge. Parallel experimental runs will be conducted under identical conditions, except for the presence of gravity.



After the completion of the sintering experiments and the return of the ampoules or sample cartridges, the samples will be inspected, subjected to micro-tomography to image pores, and subjected to profile measurement (distortion), density (densification), and microscopy. Cross-sectioned profiles will be imaged, subjected to quantitative microscopy for grain size distribution, pore size distribution, porosity location, and other features such as contiguity and connectivity. These experimental results will be compared to model predictions in terms of grain size, pore size, the spatial location of each, while being linked to the model and macroscopic shape distortion.

Accomplishments

Randall M. German presented two papers in the Powder Metallurgy Conference held in Boston on June 6 and June 7, 2016, titled:

- **Variations in Microgravity Liquid Phase Sintering**
- **Microgravity Sintering Experiments with W-Ni-Cu-Mn Alloys**

MSRR-Directional Solidification Experiments on the International Space Station

Decadal Themes: AP9

Investigation Name: Microstructure Formation in Castings of Technical Alloys under Diffusive and Magnetically Controlled Convective Conditions (MICAST)
PI: Dr. David Poirier, University of Arizona
Co-I: Professor Surendra Tewari, Cleveland State University
PS: Dr. Richard Grugel, NASA MSFC
PM: Shawn Reagan, NASA MSFC
Engineering Team: Astrium

Objective:

Examine the effects of growth speed and speed-changes (step increase in growth speed and step decrease in growth speed) on the primary dendrite distribution and morphology during steady-state directional solidification of single crystal Aluminum – 7wt.% Silicon Alloys

Relevance/Impact:

The primary dendrite arm spacing and distribution during directional solidification (DS) of binary alloys on Earth is influenced by natural convection. This precludes obtaining steady-state growth morphology data need for quantitative comparison with theoretical models. Only directional solidification experiments carried out in the low gravity environment of space, which minimizes convection, can provide such data. Results from the investigation are technically relevant to directional solidification casting of, for example, turbine blades that are used in jet engines and land-based power generators. Examination of the microgravity processed samples will also shed light on detrimental defect formation.

Development Approach:

Al-7 wt% Si samples are directionally solidified to generate a steady-state array of dendrites after which the growth speed is changed with the intent of understanding the microstructure's morphological response. A growth-speed increase will generate additional primary dendrites and thus decrease primary spacing; conversely, a growth-speed decrease will eliminate dendrites thus increasing the spacing. We are comparing dendrite array morphologies of ISS samples grown in the absence of convection with those grown terrestrially. The first two, MICAST-6 (where the growth rate change was from 5μm/s to 50 μm/s) and MICAST-7 (rate change from 20 to 10 μm/s) have been processed, returned to Earth, and examined. The third, MICAST 12, (constant growth rate of 20 μm/s) has been processed aboard the ISS and has just been returned to Cleveland State University for initial examination

Instrumentation & Experiment Summary

Three experiments have been performed in the MSRR using the Solidification and Quench Furnace and, secondly the Low Gradient Furnace. These samples have been analyzed and data presented at relevant conferences. A number of Presentations have been made and Technical Papers published; sample evaluation is continuing.

Accomplishments

Publications

"Observation of Mis-Oriented Tertiary Dendrite Arms during Controlled Directional Solidification in Aluminum – 7 wt% Silicon Alloys," *Metallurgical and Materials Transactions A*: Volume 43, Issue 12 (2012), pp. 4724-4731.

"An Evaluation of Primary Trunk Diameters in Directionally Solidified Al-Si Alloys," Metall. Mater. Trans. A, 45A, 2014, pp. 4758-4761.

"Comparison of Directionally Solidified Samples Solidified Terrestrially and Aboard the International Space Station," Proceedings of 61st Annual Technical Conference of the Investment Casting Institute, Covington, KY, Oct. 5 – 8, 2014.

"Primary dendrite arm spacings in Al-7Si alloy directionally solidified on the International Space Station": Proceedings, Materials Science and Technology, Columbus, OH, 6 October 2015.

MSRR-Effect of Varying Cross-Section on Dendrite Morphology and Macrosegregation

Decadal Themes: AP9

Investigator: Dr. David Poirier, University of Arizona
Co-I: Dr. Surendra Tewari, Cleveland State University
Co-I: Dr. Nichlas Swinteck, University of Arizona
PS: Dr. Richard N. Grugel, NASA MSFC
PM: Donnie McCaghren, NASA MSFC
Engineering Team: NASA MSFC / Teledyne Brown Engineering

Objective:

Determine the effects of a cross-sectional change during directional solidification on dendrite array morphology, distribution, crystallographic orientation, and macro-segregation.

Relevance/Impact:

Single-crystal dendritic gas turbine blades containing complex internal cooling channels are cast via directional solidification, which progresses through many cross-sectional area changes. The convective flows associated with such cross-section changes can be responsible for casting-defects, which lead to component rejections. This study will elucidate the role of gravity in the formation of these defects and by including changes in cross-sectional area, expands and enhances the knowledge to be gained in professor Poirier's MICAST project (variation of translation/processing velocity). This investigation will also serve to enhance existing simulation models of directional solidification.

Development Approach:

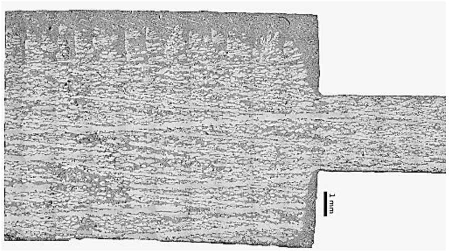
Al-7% Si, Pb-6%Sb, and Al-15%Cu alloy samples will be directionally solidified through approximately 4:1 cross-sectional area change at a constant growth speed and temperature gradient. Microstructural defects generated as a result of diameter changes during directional solidification will be examined from ground-processed samples. These samples will be grown over a range of velocity and temperature gradient conditions in order to identify the optimal processing conditions for the low gravity experiments planned to be conducted on the International Space Station.

Instrumentation & Experiment Summary

The experiments will be performed in MSRR, utilizing the Solidification and Quench Furnace. The proposed number of flight samples is 6, as is the number of subsequent Ground Truth samples.

Accomplishments

Ground-based work is continuing. Three technical papers have recently been published in the *Journal of Crystal Growth*.



Longitudinal microstructure of the experiments at the contraction in cross section. The primary aluminum dendrites are light gray, while the eutectic microconstituent is dark gray, Al-7Si solidified 10 $\mu m\ s^{-1}$

Ampoule development for flight samples has been initiated

MSRR Effect of Convection on the Columnar-to-Equiaxed Transition in Alloy Solidification and Transparent alloys

Decadal Themes: AP9

Investigator: Prof. Christoph Beckermann, Univ. Iowa
Project Scientist: Ellen Rabenberg, NASA-MSFC
Project Manager: Shawn Reagan, 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. Efforts include collaboration with the CETSOL team using the transparent alloys device. Visual data on the solidification front of an organic system is obtained during the experiments in order to validate models of solidification. The columnar to equiaxed transition is of particular interest to the CETSOL team. The CETSOL-1 transparent alloys experiments will be focused on the transition at constant thermal gradient. CETSOL-2 focuses on studies with the sample cooled by radiation and thermal diffusion.

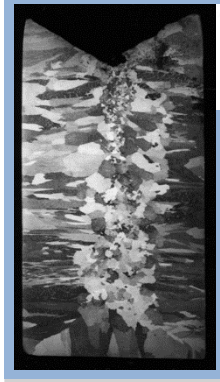
Relevance/Impact:

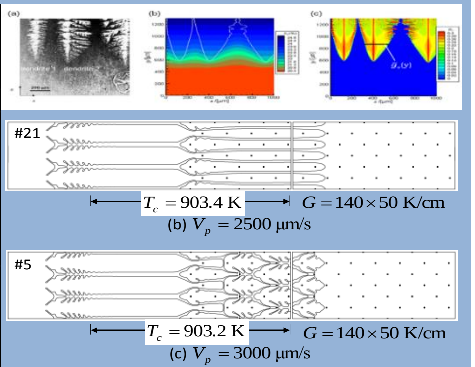
Grain structure is important for all metal castings and affects defect formation and properties. Gravity has a large effects on grain structure. NASA funding allows for meaningful continuation of ESA CETSOL experiments on ISS.

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) or SUBSA in the Microgravity Glovebox.***

Accomplishments

Samples being prepared to assess the feasibility of processing in the SUBSA furnace is being prepared.

Testing ongoing, incorporating slight changes are based on recent results from other similar testing.

Russian Furnace-Silicon on the ISS Investigation (SISSI)
Decadal Themes: AP9

U.S. Team Member: **Prof. Jeffrey Derby, University of Minnesota**
U.S. Team Member: **Dr. Martin Volz, NASA MSFC**
ESA Team Coordinator: **Prof. Thierry Duffar, France**
PS: **Dr Art Nunes, NASA MSFC**
PM: Donnie McCaghren, NASA MSFC

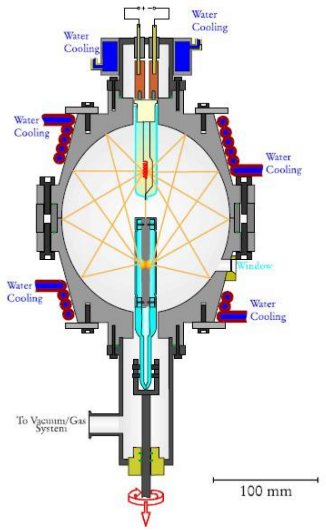
Objective:
- **The overall objective of this project is to carry out a sustainable research program on the utilization of microgravity conditions to solve fundamental material science problems in the field of crystallization of silicon for photovoltaic (PV) applications**
- **A specific objective of MSFC experiments is to utilize the 5 Tesla superconducting magnet to study the influence of convection on the incorporation and transport of oxygen, carbon and silicide particles in silicon used in solar cells.**
- **Rigorous, finite-element models are being developed at Minnesota for particle pushing and engulfment during crystal growth**

Relevance/Impact:
- **Solar cells based on crystalline silicon dominate the market with a market share of more than 95% today. Research in the area of crystallization of silicon crystals for photovoltaic applications is driven by the requirement of a continuous cost reduction of industrial production processes, which have to be optimized with respect to higher yield and better material. Understanding the dynamics of particle pushing and engulfment will enable improvements in process development.**

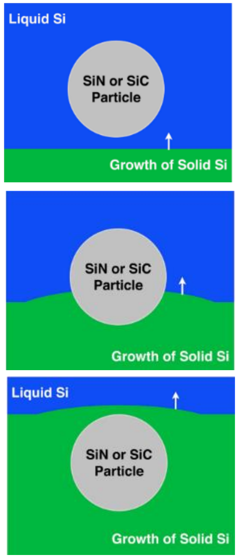
Development Approach:
- **The results of ground-based experiments are to be compared with microgravity experiments conducted on TEXUS sounding rockets, FOTON flights, and on the ISS**
- **Ground-based model development will be undertaken and validated with the phase-field approach. Extensive parametric studies will be conducted to understand the dominant physics and to compare to the microgravity experiments.**

Instrumentation & Experiment

Ground-based experiments and modelling are being conducted for comparison with TEXUS sounding rocket experiments and FOTON microgravity flights. ISS experiments in Russian furnace hardware are expected in 2017 or later.



Schematic drawing of the monoellipsoid furnace used to process Si samples by the float-zone technique



Engulfment of particles during silicon crystal growth

Detached Melt and Vapor Growth of InI in SUBSA Hardware

Decadal Themes: AP9

(CASIS funded)

Sponsor: CASIS & SLPSRA
PI: Prof. Aleksander Ostrogorsky, Illinois Institute of Technology
Co-I: Dr. Martin P. Volz, NASA, MSFC-SLPS funded
Co-I: Dr. Lodewijk van den Berg, STS Payload Specialist
Co-I: Prof. Arne Cröll, Freiburg University, Germany
Co-I: Dr. Alexei Churilov, Radiation Monitoring Devices, Inc.
PM: Donnie McCaghren, NASA, MSFC

Relevance/Impact:

- InI shows great promise as an advanced material for nuclear radiation detection at room temperature. Advantages over current materials include larger energy gap (less leakage current), non-toxic, non-hydroscopic, low melting point, and no compositional segregation during growth from the melt.
- InI can be used at elevated temperatures, increasing the number of potential industrial applications.

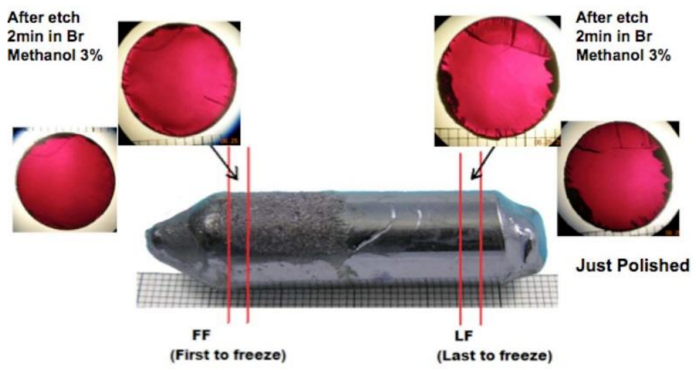
Development Approach:

- Extensive ground-based testing is to be conducted in the SUBSA ground unit. Ampoules will be utilized with the same outer dimensions as those used in previous SUBSA ISS experiments
- Microgravity crystal growth experiments will vary crucial growth parameters for both melt and vapor growth processes and the results will also be compared to ground-based experiments.

Instrumentation and Experiment Summary

The objective is to utilize the microgravity conditions on the ISS to study defect generation in InI crystals grown by both melt and vapor growth techniques. Specific goals include:

- Determine processing parameters to minimize defects
- Determine nature of defects
- Produce reference quality InI
- Compare detector



InI single crystal grown by the vertical Bridgman process and sections used for device fabrication

Crystal Growth of Cs_2LiYCl_6:Ce (CLYC) in Microgravity CASIS

Decadal Themes: AP9

(CASIS funded)

PI: Dr. Alexei Churilov, Radiation Monitoring Devices, Inc.
Co-I: Mr. Joshua Tower, Radiation Monitoring Devices, Inc.
Co-I: Dr. Martin Volz, NASA MSFC-SLPS funded
Co-I: Prof. Aleksander Ostrogorsky, Illinois Institute of Technology
PM: Donnie McCaghren, NASA, MSFC

Status and Objective:

- **Project selected by CASIS in 2014**
- **Objective is to utilize the microgravity conditions on the ISS to eliminate, reduce, or isolate the process parameters related to gravity towards the production of high quality crystals of Cs_2LiYCl_6:Ce (CLYC).**
- **MSFC role is participating in science development, ground-based testing with SUBSA furnace, ampoule development, characterization of ground and flight samples, and aligning the investigation within the scope of the MaterialsLab initiative.**

Relevance/Impact:

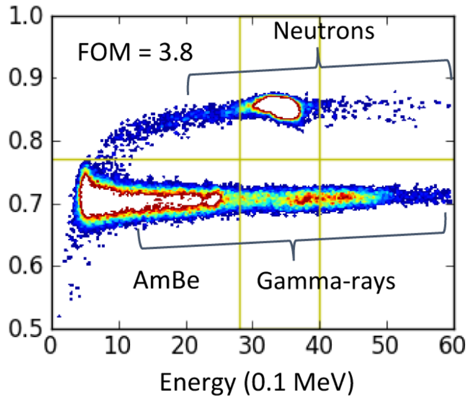
- **Cs_2LiYCl_6:Ce (CLYC) is a unique new scintillator crystal which has tremendous potential in nuclear and radiological detection applications. CLYC combines detection of gamma-rays and neutrons in a single sensor, while providing effective identification of each. This feature makes CLYC a very attractive detector in homeland security and nuclear non-proliferation applications, as well as in oil and gas exploration, particle and space physics, non-destructive testing, and scientific instruments.**

Development Approach:

- **Extensive ground-based testing is to be conducted in the SUBSA ground unit. Ampoules will be utilized with the same outer dimensions as those used in previous SUBSA ISS experiments**
- **Microgravity crystal growth experiments will vary crucial growth parameters and the results will also be compared to the ground-based experiments.**

Instrumentation & Experiment Summary

A series of crystal growth experiments of the scintillator crystal material Cs_2LiYCl_6:Ce will be conducted in the Solidification Using Baffles in Sealed Ampoules (SUBSA) furnace in the Microgravity Science Glovebox (MSG) on the ISS. The SUBSA furnace and associated hardware were previously used on the ISS and are now undergoing a refurbishment/recertification process.



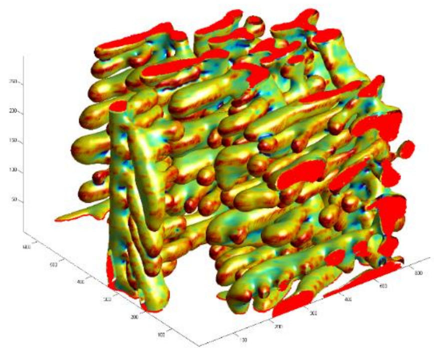
Power spectral density plot showing the separation between gamma rays and both thermal and fast neutrons for a 2" diameter CLYC crystal produced at Radiation Monitoring Devices. This characteristic enables detection of both gamma-rays and neutrons in a single sensor.

CSLM-Coarsening of Dendritic Solid Liquid Mixture: The Low Volume Limit

Decadal Themes: AP9

PI: Dr. Peter Voorhees, Northwestern University
PS: Dr. Walter Duvall
PM: Donnie McCaghren, NASA MSFC
Engineering Team: Zin

A dendritic two-phase mixture from the ISS experiments. The liquid is transparent. The solid-liquid interfaces are colored based on the mean interfacial curvature. Evident are the secondary dendrite arms and vertical primary dendrites. The experiment measures the evolution of these complex structures.



Objective: Understand the coarsening behavior of dendrites in two-phase solutions with a low volume fraction of solid

Relevance/Impact: The morphology of dendrites impacts material properties, but predicting and controlling the morphology of dendrites is difficult, particularly at low volumes where sedimentation and buoyancy driven fluids flows are significant. The effect of sedimentation and buoyancy driven convection on the pinching off of dendrites of particular interest.

Development Approach: Ground-based coarsening experiments and phase field calculations will be performed in support of flight experiments. Ground and flight samples will be processed at a varying volume fractions of solid phase and coarsening duration. Samples from the flight experiments will be sectioned and analyzed to determine the morphology of the dendrites and the manner in which it evolves in time. The evolution of the principal interfacial curvatures, topology, and surface area per unit volume over time will be determined. Due to the significant sedimentation of the solid dendrites observed on the ground, the experiments experiments can only be performed in space. Baseline ground-based experiments at higher volume fractions of solid will also be performed.

Instrumentation & Experiment Summary

The CSLM hardware will heat the samples above the eutectic temperature, thus allowing the dendrites to coarsen, and quench the samples to preserve the coarsened structures.

Accomplishments

- **Peter W. Voorhees elected into the 236th class of the American Academy of Arts and Sciences, one of the nation's oldest and most prestigious honorary societies. A total of 213 leaders in the sciences, social sciences, humanities, arts, business, and public affairs were elected into the academy in 2016**
- **Invited talk: "Quantifying Microstructure Evolution in 3D" presented at MRS Spring Meeting, March 29, 2016 in Phoenix, AZ**

LMM-The Effect of Macromolecular Transport on Microgravity Protein Crystallization

Decadal Themes: AP9

Investigator: Dr. Larry DeLucas (University of Alabama at Birmingham)
Co-PI: Prof. Christian Betzel (University of Hamburg)
Co-I: Dr. Dmitry V. Martyshkin (University of AL at Birmingham)
Prof. Karsten Dierks (University of Hamburg)
Prof. Annette Eckhardt (University of Hamburg)
Consultants: Dr. Sergey Mirov (University of AL at Birmingham)
Dr. William W. Wilson, Prof. Emeritus (MS State Univ.)
PS: Laurel J. Karr, NASA MSFC
PM: Donnie McCaghren, NASA MSFC
Engineering Team: NASA-GRC-Zin

Objective:

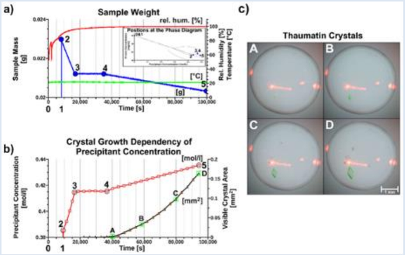
Validate the hypothesis that the improved quality of microgravity-grown biological crystals is the result of two macromolecular characteristics that exist in a buoyancy-free, diffusion-dominated solution: 1) Slower crystal growth rates, due to slower protein transport to the growing crystal surface and 2) Predilection of growing crystals to incorporate protein monomers versus higher protein aggregates due to differences in transport rates.

Relevance/Impact:

A structural understanding of biological macromolecules helps to discern their mechanisms; once that is understood, the mechanism can be aided or, more commonly, impeded through pharmaceutical design. Determining structure is dependent upon X-ray crystallography of well ordered crystals. Growth in microgravity sometimes improves the quality of crystals, and this experiment will help determine the reasons behind this improvement. Structure-based drug design relies on the knowledge of the three-dimensional structure of the biomolecular target/proteins

Development Approach:

Compare crystal growth rates and incorporation of protein aggregates of crystals grown on the ground versus those in microgravity. Compare the defect density and crystal quality via fluorescent-based atomic force microscopy and x-ray diffraction quality of crystals grown at different rates in a 1-g environment, using "Xtal Controller" to precisely control nucleation and growth rates of crystals.



Instrumentation & Experiment Summary:
The Light Microscopy Module will be used to visualize and measure crystal growth rates of protein and virus crystals grown in replicate within optically clear cells of a sample module. Using the planned confocal laser-scanning fluorescent microscope, the percentage incorporation of different molecular aggregates into the crystalline lattice of growing crystals will be measured.

Accomplishments

- SpaceX-10 flight scheduled for January 22, 2017, delayed
- Hardware filled with flight samples and frozen until flight

LMM-Growth Rate Dispersion as a Predictive Indicator for Biological Crystal Samples Where Quality can be Improved with Microgravity Growth
Decadal Themes: AP9

Investigator: Dr. Edward H. Snell, Hauptman Woodward Med. Research Institute
Co-I: Dr. Joseph Luft, Hauptman Woodward Med. Research Institute
PS: Dr. Laurel J. Karr, NASA MSFC
PM: Donnie McCaghren, NASA MSFC
Engineering Team: NASA GRC

Objective:

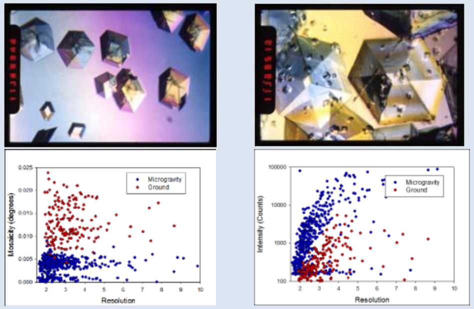
Validate the hypothesis that growth rate dispersion could be an indicator of crystals whose quality could be improved in microgravity. Growth rate dispersion is a phenomenon encountered in crystallization where seemingly identical crystals, produced from the same conditions, grow at different rates. It is contended that large growth rate dispersion on the ground is indicative of a sample that should be improved by microgravity growth.

Relevance/Impact:

A structural understanding of biological macromolecules helps to discern their mechanisms; once that is understood, the mechanism can be aided or, more commonly, impeded through pharmaceutical design. Determining structure is dependent upon X-ray crystallography of well ordered crystals. Growth in microgravity sometimes improves the quality of crystals, and this experiment will help in determining which crystals can be improved by microgravity growth. Structure-based drug design relies on the knowledge of the three-dimensional structure of the biomolecular target/proteins.

Development Approach:

Use molecular biology techniques to shift the growth rate dispersion properties of a single protein from low to high. Monitor growth rate dispersion of crystals grown on the ground and in microgravity to determine if there is a correlation between the physical qualities of the resulting crystals with those measurements.



Instrumentation & Experiment Summary:
The Light Microscopy Module will be used to visualize and measure growth rate dispersion of protein crystals grown in replicate within optically clear cells of a sample module.

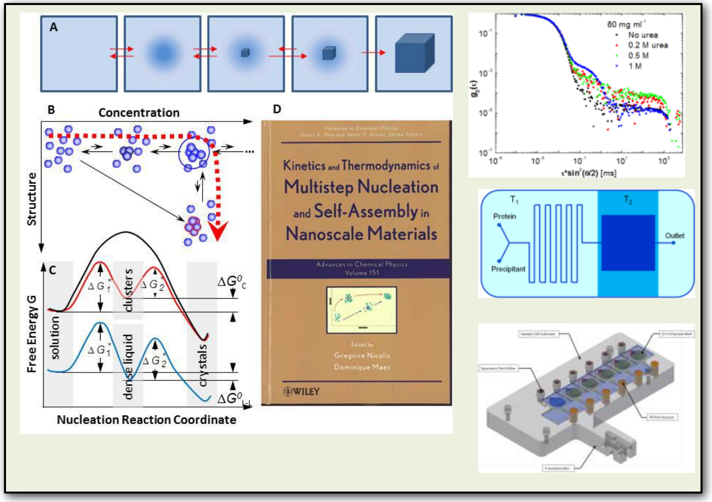
Accomplishments

- **SpaceX-10 flight scheduled for January 22, 2017, delayed**
- **Hardware filled with flight samples and frozen until flight**

LMM-Solution Convection and the Nucleation Precursors in Protein Crystallization & ESA Protein Team

Decadal Themes: AP9

Investigation *Name, PI: Prof. Peter Vekilov (Univ. Houston)*
Co-I: Dr. Jacinta Conrad (Univ. Houston)
Co-I/Co-PI: Dr. Dominique Maes (Brussels, Belgium)
Project Scientist: Dr. Sridhar Gorti (NASA-MSFC)
Project Manager: Donnie McCaghren (NASA-MSFC)
Engineering Team: LMM and ESA Hardware



Objective: To test if the absence of shear flow affects the concentration and properties of the nucleation precursors and establish the mechanisms of these effects. These efforts are synergistic: LMM provides the ability to observe nucleation with shear into the capillary which will complement the ongoing efforts with the ESA protein team.

Relevance/Impact: The existence of nucleation precursors and the correlation between their properties and the nucleation rate can be used to control protein crystal nucleation. Enhancement or suppression of nucleation can be used to achieve higher perfection of the grown crystals. Protein crystallization and improved crystal quality will aid in protein structure determinations and subsequently accelerate drug design.

Development Approach: Study the effects of solution flow on the cluster properties and nucleation. Test if the perfection of protein crystals can be improved by controlling nucleation via solution flow. In the absence of gravity driven convection and sedimentation effects on ISS, study the formation of clusters and nucleation processes at zero shear.

Acronyms

ACE	Advanced Colloids Experiment
ALI	Alice-Like Insert
BASS	Burning and Suppression of Solids
BCAT	Binary Colloidal Alloy Test
BXF	Boiling Experiment Facility
CCF	Capillary Channel Flow
CFE	Capillary Flow Experiment
CSLM	Coarsening of Solid-Liquid Mixtures
CSLM-2	Coarsening of Solid-Liquid Mixtures-2
CSLM-2R	Coarsening of Solid-Liquid Mixtures-2 Reflight
CVB	Constrained Vapor Bubble
DAFT	Dust and Aerosol Measurement Feasibility Test
DSI-DSIP	DEvice for the study of Critical LIquids and Crystallization - Directional Solidification Insert
DSI-R/SPADES	DEvice for the study of Critical LIquids and Crystallization - Directional Solidification Insert-Reflight
FLEX	Flame Extinguishment Experiment
FLEX-2	Flame Extinguishment Experiment-2
FLEX-2J	Flame Extinguishment Experiment-2 JAXA
GRADFLEX	Gradient Driven Fluctuation Experiment
HTI-R	High Temperature Insert-Reflight
InSPACE	Investigating the Structure of Paramagnetic Aggregates from Colloidal Emulsions
ISSI	In Space Soldering Investigation
LEO	Low Earth Orbit
MABE	Microheater Array Heater Boiling Experiment
MICAST/CSS	The Microstructure Formation in Casting of Technical Alloys under Diffusive and Magnetically Controlled Convective Conditions
MISSE	Materials International Space Station Experiment
NPBX	Nucleate Pool Boiling Experiment
PCS	Physics of Colloids in Space
PFMI	Toward Understanding Pore Formation and Mobility During Controlled Directional Solidification in a Microgravity Environment
PK-3	Dusty Plasma
PK-3+	Dusty Plasma
PSI	Physical Sciences Informatics
SAME	Smoke Aerosol Measurement Experiment
SAME-R	Smoke Aerosol Measurement Experiment - Reflight
SHERE	Shear History Extensional Rheology Experiment
SHERE II	Shear History Extensional Rheology Experiment II
SLICE	Structure and Liftoff in Combustion Experiment
SPICE	Smoke Point in Coflow Experiment
SUBSA	Solidification Using a Baffle in Sealed Ampoules

Physical Sciences ISS Facilities

ISS Facilities for Physical Sciences Research

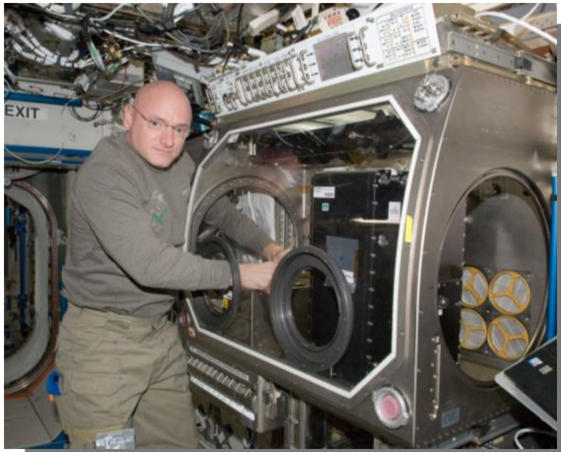
*COMBUSTION: Astronaut Mike Fincke completing install of the **CIR/**MDCA insert prior to CIR activation in January 2009.*

*FLUIDS, COMPLEX FLUIDS, BIOPHYSICS: Astronaut Paolo Nespoli operating the ACE experiment in the **FIR/**LMM*

*MATERIALS: Astronaut Frank DeWinne completing installation in the **MSSR/MSL** prior to on-orbit commissioning October 2009. MSL developed by ESA.*

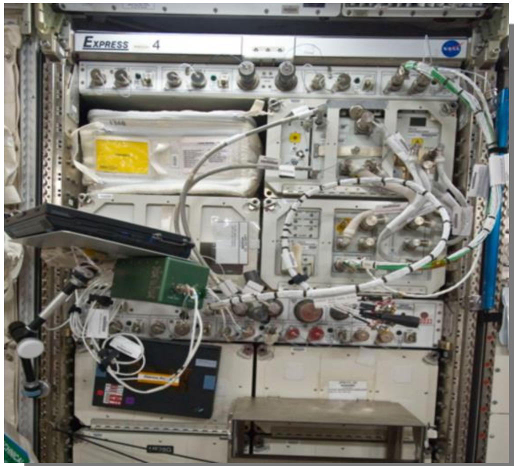
MATERIALS: Astronaut Alexander Gerst *completing installation of the ESA (with DLR)* ***EML****, October 2014 on ISS*

ISS Facilities for Physical Sciences Research



*COMBUSTION, FLUIDS, COMPLEX FLUIDS, MATERIALS, BIOPHYSICS: Increment 26 commander Scott Kelly installing CCF in the Microgravity Science Glovebox (**MSG**) on ISS*

*FLUIDS: Astronaut Cady Coleman operating the CFE experiment in Maintenance Work Area (**MWA**) on the ISS*

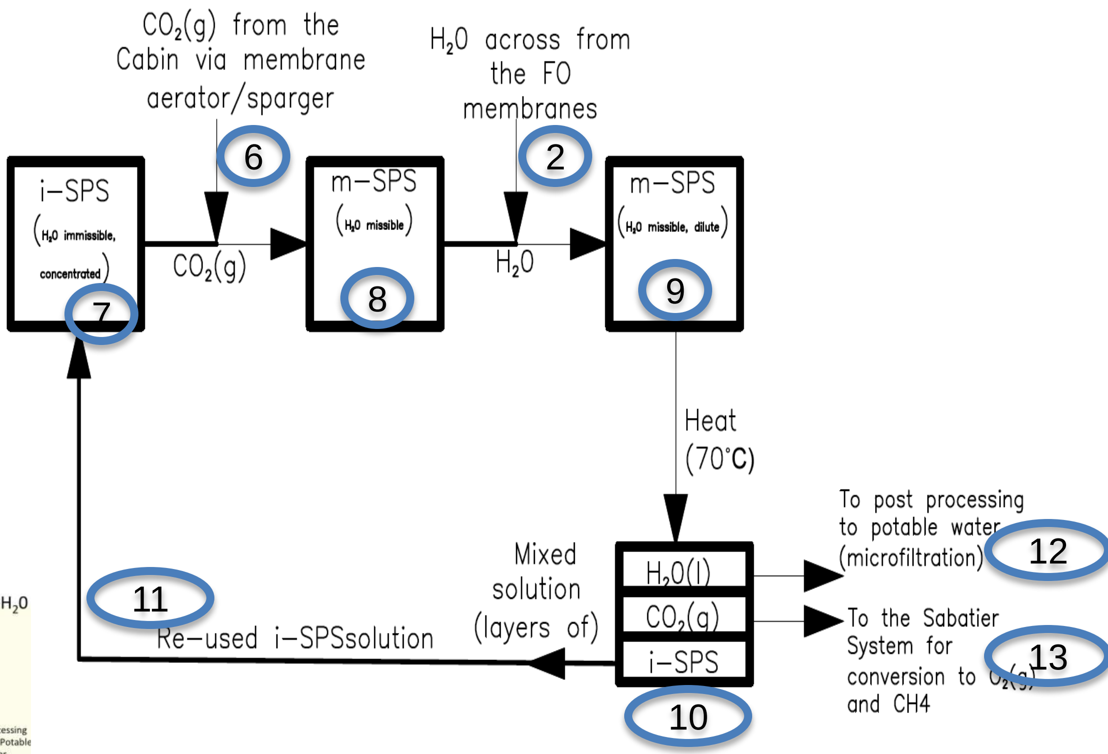


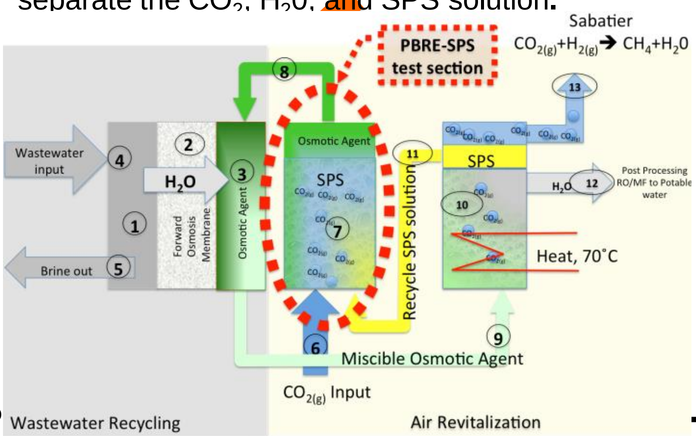
*MATERIALS, FLUIDS, and FUNDAMENTAL PHYSICS: CNES-**DECLIC** in an EXPRESS Rack on board ISS. To be launched after recent repair.*

AES - SBS Microgravity Experiment using PBRE (Technology Pull)

Objective:
To characterize the interaction between the Switchable Polarity Solvent (SPS) and $CO_{2(g)}$ input by examining the interfacial phenomena via a variety of gas input methodology.

- Test different $CO_{2(g)}$ introduction and removal methods to induce the SPS to switch between miscible and immiscible states.
- Examine the effect of bubble size, mixing patterns, and heat on SPS switching kinetics.
- Develop correlation based on various parameters in μ-G compared to 1-G.
- To effectively determine the best method to separate the CO_2, H_20, and SPS solution.





Oxygen Recovery

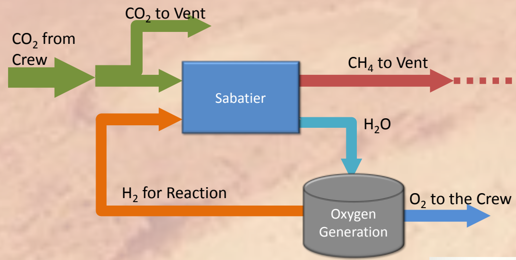
Oxygen Recovery and Recycling Development

NASA MSFC Environmental Control and Life Support Systems

ISS State-of-the-Art

~50% O_2 Recovery

Technology: Oxygen (O_2) is recovered from the carbon dioxide (CO_2) produced by the crew through a combination of the Sabatier reaction and water electrolysis.



Benefits:

- Reduces O_2/H_2O resupply requirements for long-duration missions
- Demonstrated on-orbit performance

UTAS Sabatier Reactor System Engineering Development Unit

Anticipated Challenges:

- Fines generation from pelletized catalyst
- Sintering of catalyst

Potential Solutions:

- Microlith™-based Sabatier reactor
  - Significantly reduced fines
  - Monolithic-type structure eliminated concern for sintering

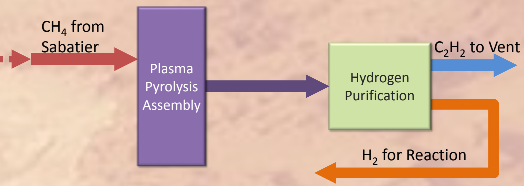
Precision Combustion, Inc. Microlith ™

Precision Combustion, Inc. Sabatier Reactor System

Building from ISS

75-90% O_2 Recovery

Technology: Methane (CH_4) produced by the Sabatier is partially reduced (pyrolyzed) to recover and recycle the hydrogen (H_2) needed for the Sabatier reaction. This is accomplished by using microwaves to generate a plasma for the reaction,



Benefits:

- Further reduces O_2/H_2O resupply requirements for long-duration missions
- Produces predominantly gaseous products

UMPQUA 3rd Generation Plasma Pyrolysis Assembly

Anticipated Challenges:

- Solid carbon generation
- Hydrogen purification from product gas stream

Potential Solutions:

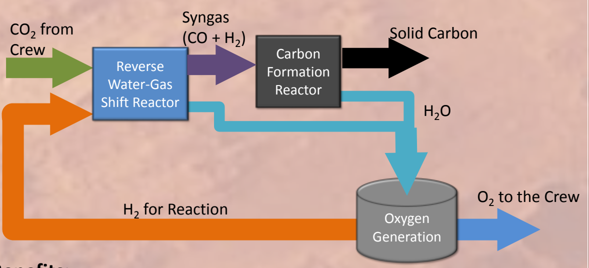
- Advanced carbon filtration or regenerable filtration
- Separation via Sorbents, Polymer Electrolyte Membranes, or Metal Hydrides

Questions may be directed to: Dr. Morgan Abney, NASA Marshall Space Flight Center (256)961-4758, morgan.b.abney@nasa.gov

Moving Beyond ISS

>90% O_2 Recovery

Technology: Oxygen is recovered from the CO_2 produced by the crew through a combination of the Bosch process and water electrolysis. The Bosch system has two steps: syngas production and carbon formation.



Benefits:

- Potentially eliminates the need for O_2/H_2O resupply for long-duration missions (except in emergencies)
- Produces solid carbon that can be repurposed

Anticipated Challenges:

- Solid carbon handling
- Catalyst regeneration or resupply

Reverse Water-Gas Shift Reactor

Potential Solutions:

- Advanced carbon filtration or regenerable filtration
- Novel carbon formation reactor design
- *In Situ* Resource Utilization for catalyst
- Novel catalysts

Zero Boiloff impact on Mars Mission

Attached please find excerpt from an AIAA paper by Stan Borowski et al that includes the analysis done by Stan wrt Zero Boil-Off mass saving for a Mars Mission. According to the numbers in this paper, the saving is substantial and its in the 25% range for both legs of the Trip. Mo Kassemi.

NASA Technical Memorandum 107071
AIAA–93–4170

Nuclear Thermal Rocket/Vehicle Design Options for Future NASA Missions to the Moon and Mars

Stanley K. Borowski and Robert R. Corban
Lewis Research Center
Cleveland, Ohio

Melissa L. McGuire
Analex Corporation
Brook Park, Ohio

Erik G. Beke
University of Dayton
Dayton, Ohio

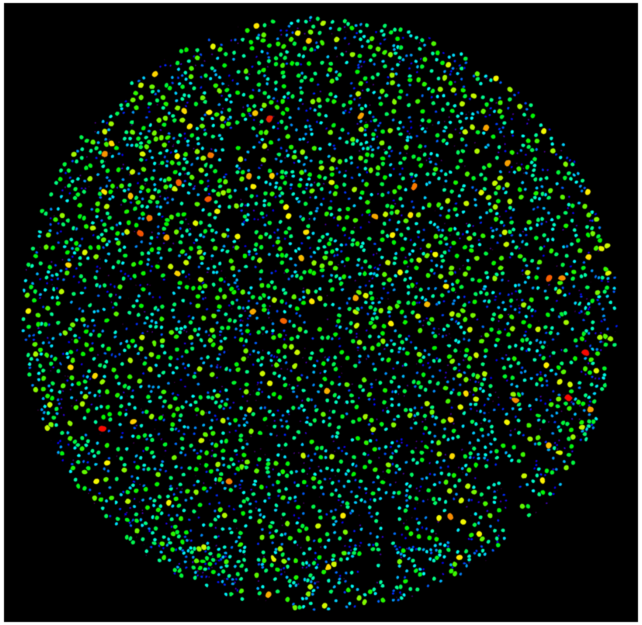
Prepared for the
Space Programs and Technologies Conference and Exhibit
sponsored by the American Institute of Aeronautics and Astronautics
Huntsville, Alabama, September 21–23, 1993

National Aeronautics and
Space Administration

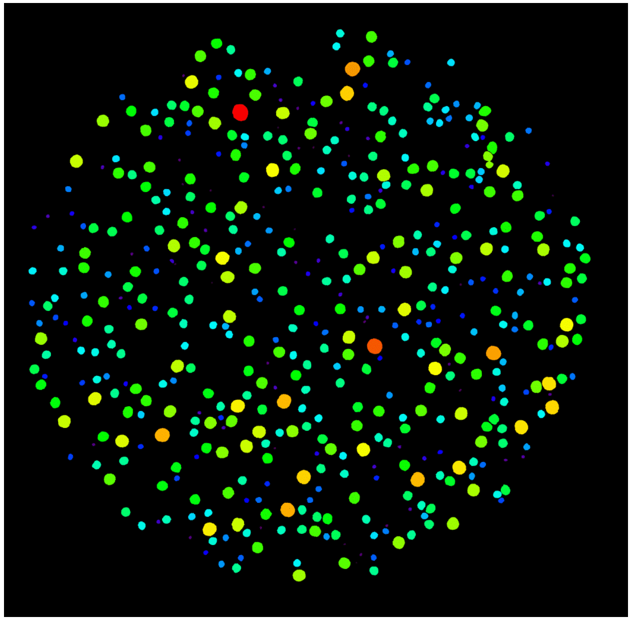
CSLM-3, ISS Results

Objective: to study the coarsening process using solid-liquid mixtures. Coarsening is a process by which large particles grow and small particles shrink.

An example of the coarsening process is provided by the results from the CSLM-3 Experiments conducted on ISS:



1.6 hours



48 hours

The colors denote the size of the particles, relative to the average. Using measurements such as these, it is possible to determine a particle size distribution and compare it to that predicted by theory. The comparison shows that the theoretical predictions are close to our measurements.