National Aeronautics and Space Administration

NASA Microgravity Materials Science* Overview

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Human Exploration and Operations Mission Directorate
NASA

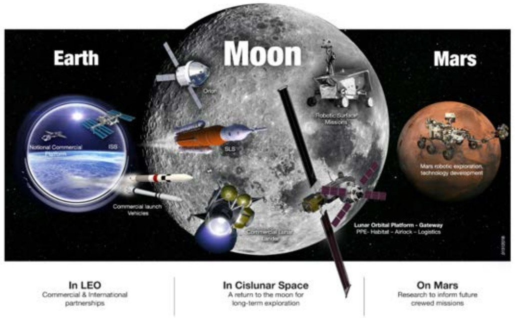
SLPSRA Vision, Mission and Goals

Vision

We lead the space life and physical sciences research community to enable space exploration and benefit life on Earth

Mission

1. Enable exploration (EE)
2. Pioneer scientific discovery (PSD)

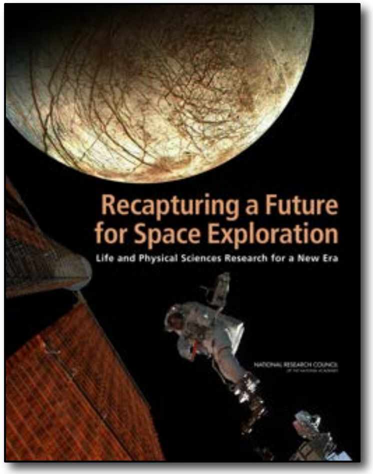


Goals

1. EE in response to pull
2. EE by providing push
3. PSD by refining use of all platforms
4. PSD by helping others utilize space
5. Maintain key capabilities

Implementation Principles

1. Ensure Scientific Integrity
2. Maximize Open Science
3. Cultivate Partnerships
4. Use Stepping Stones
5. Be an Early Adopter
6. Share Methods and Results



Space Life and Physical Sciences Research and Applications Division Organizational Structure

Level 1

Director: Craig Kundrot
Deputy Director: Diane Malarik
Chief Scientist: Brad Carpenter
Life Scientist: Ruth Siboni
Admin Assistant: Erin Welshans (c)
Partnerships: Doug Gruendel (c)
Partnerships: Lisa Carnell (d)
Partnership Consultant: Michael Marge (c)

Technical Writer: Courtney Sexton (c)
BAH Team Lead: Michelle Wadkins (c)
Schedule and Risk Lead: Laura Krepel (c)
Schedule & Risk Mgmt: Matt Cunningham (c)
Documentation Team Lead: Katie Wampler (c)
SharePoint Development Lead: Joseph Burg
SharePoint SME: Claude Elton (c)
SharePoint SME: Mario Ortega (c)

Level 2

Space Biology
Program Manager: Nicki Rayl
Program Scientist: David Tomko

Physical Sciences:
Program Manager: Diane Malarik*
Program Scientist: Fran Chiaramonte
Program Scientist: Brad Carpenter

Level 3

KSC
Bryan Onate
Howard Levine

ARC
Elizabeth Taylor
Kevin Sato

JPL
Ulf Israelsson
Nan Yu

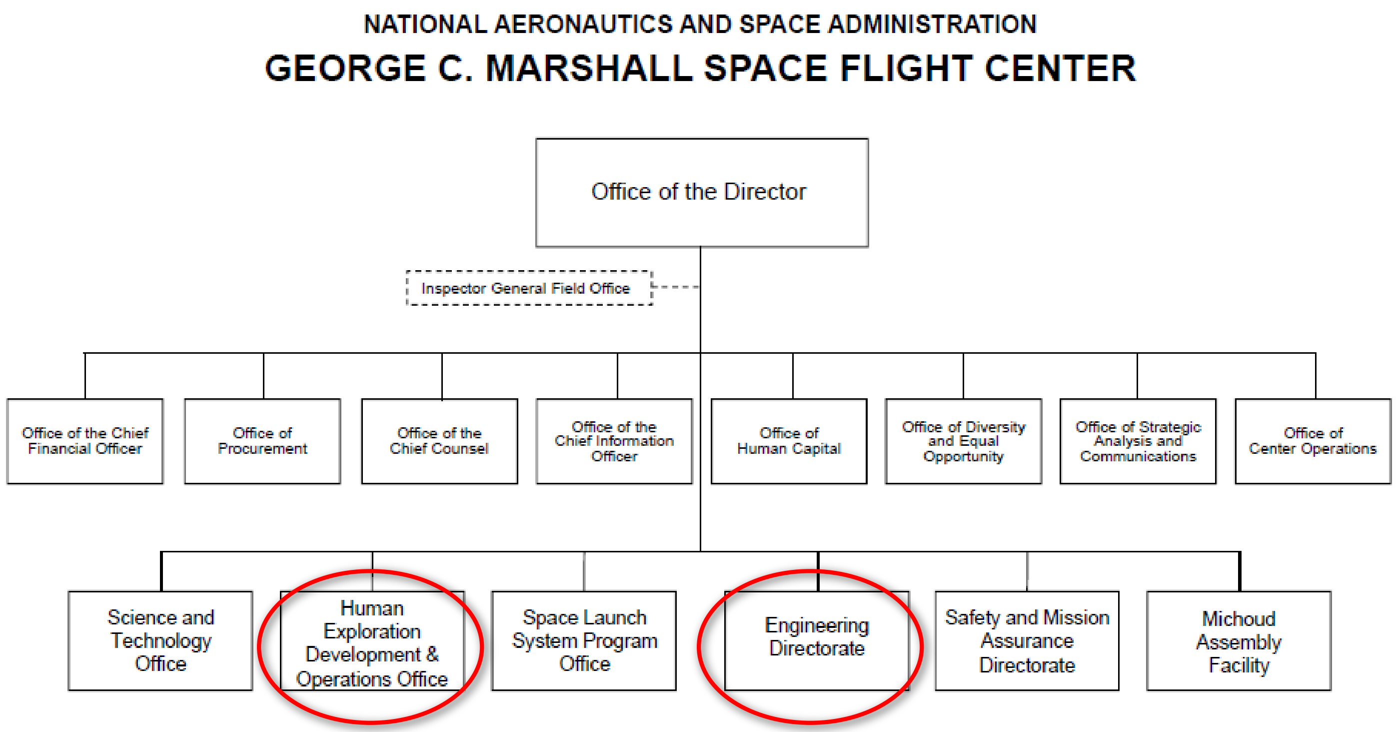
MSFC
Shawn Reagan
Mike SanSoucie*
Louise Strutzenberg*

GRC
Kelly Bailey
David Urban

L4 = Project Managers and Project Scientists

*Acting

MSFC Organizational Structure



Physical Sciences Research Program – Research Areas

Combustion Science

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

Biophysics

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

Fluid Physics

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

Materials Science

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

Fundamental Physics

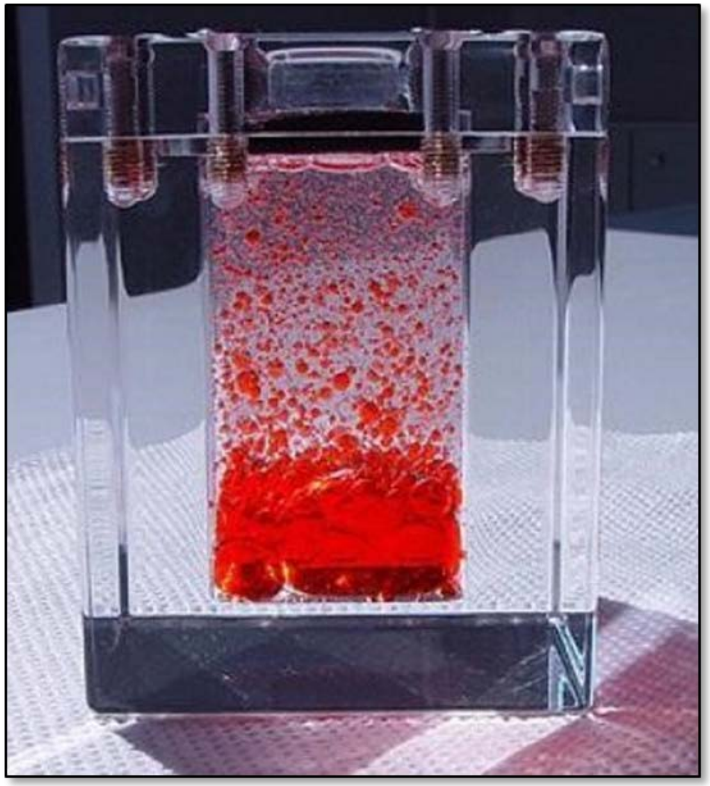
- Space Optical/Atomic Clocks
- Quantum test of Equivalence Principle
- Cold atom physics
- Critical point phenomena
- Dusty plasmas

Complex Fluids

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

Why Microgravity?

On Earth more dense materials (or liquids) settle.

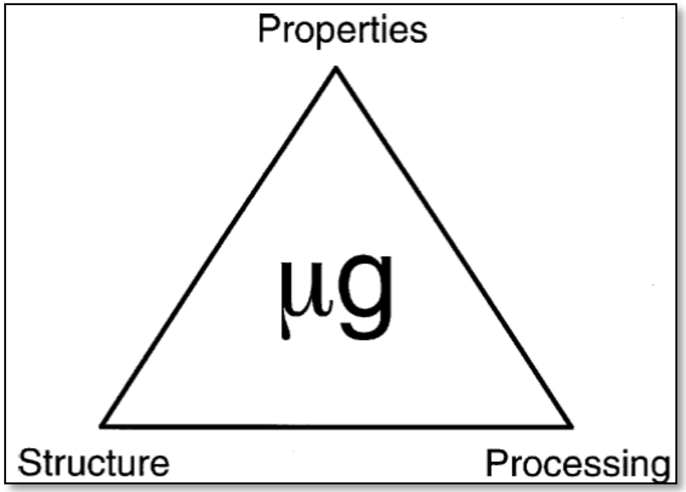


A container with an oil and water mixture of different densities on Earth. Photo credit: ESA.

In space things are different.

An Astronaut floating through the ISS.

Why Microgravity for Materials Science?



Establishing quantitative and predictive relationships between the way a material is produced (processing), its structure (how the atoms are arranged), and its properties is fundamental to the study of materials.

Materials processing often involves fluid phases which are subject to the effects of buoyancy and sedimentation in the Earth-based lab.

Microgravity studies provide Materials Scientists a unique platform to study the structure/processing/properties without the strong effects of Earth's gravity and provide insights that cannot be accessed in Earth-based lab.

Why is Microgravity Materials Science & Biophysics research important to Earth?

Microgravity-related research has the potential for near-term breakthroughs in biopharmaceuticals and materials science.

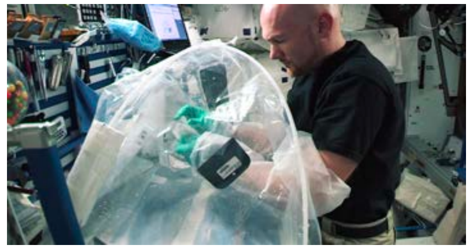
The International Space Station enables this research by providing a microgravity environment that greatly reduces buoyancy-driven convection and sedimentation in fluids

Applications of microgravity materials science and biophysics research include:

- Better turbine blades for aerospace engines
- Higher quality steel
- New materials for medical lasers
- Improved semiconductor devices
- New pharmaceuticals
- Data from reduced gravity can provide insight to improve model of materials behavior and properties for Earth-based use

Example of a Microgravity Materials Science Experiment

- **Microgravity Investigation of Cement Solidification (MICS)**
  - PI: Dr. Aleksandra Radlińska, Penn State



Penn State Ph.D. Grad Student Juliana Neves with box containing MICS samples returned from the ISS

- **The International Space Station (ISS) provides a long-duration spaceflight environment for conducting microgravity experiments**
- **The microgravity environment greatly reduces buoyancy-driven convection, pressure head and sedimentation in fluids.**

Recent example: Preliminary Flight results
MICS Flight Operations: Last half of 2019

Principal Investigator: *Prof. Aleksandra Radlinska (Penn State University)*

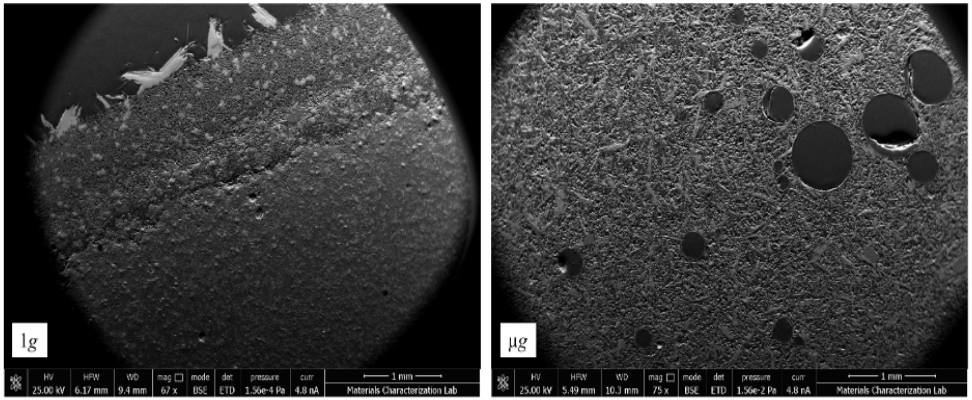
Team/Partnering/Collaboration: NIST, Sauereisen Corporation, BASF Corporation, IPA Systems, and CASIS

Objective:

- This is a benchmark experimental study of cement hydration in reduced gravity, applicable to: NASA extraterrestrial infrastructure development utilizing in-situ materials and advancing our knowledge of Earth-based processing.

Experimental Approach:

- Ground based work was performed at MSFC and Penn State under direction of Dr. Radlinska
- Burst-Seal bags were used to mix the reactants and initiate the reaction in the MWA
- Samples are being evaluated via diagnostic techniques including SEM and TEM as well as micro-hardness testing to determine optimum processing parameters for microgravity experiments
- Dependent variables: Microstructure and micro-hardness.
- Independent variables: Mixing procedures and composition. (First sample set has same mixing procedure. Second sample set has the reaction quenched at 3 pre-determined times.)
- Samples: Many different sample compositions including various binders and aggregates are being studied. Some experiments used isopropanol to quench the reaction.



Polished surface of C_3S pastes hydrated at 1*g* (left) and µ*g* (right). The 1*g* sample shows a porosity gradient and the cross-section of large portlandite crystals at the surface as a result of buoyancy. The µ*g* sample shows the presence of large air bubbles and uniform porosity.

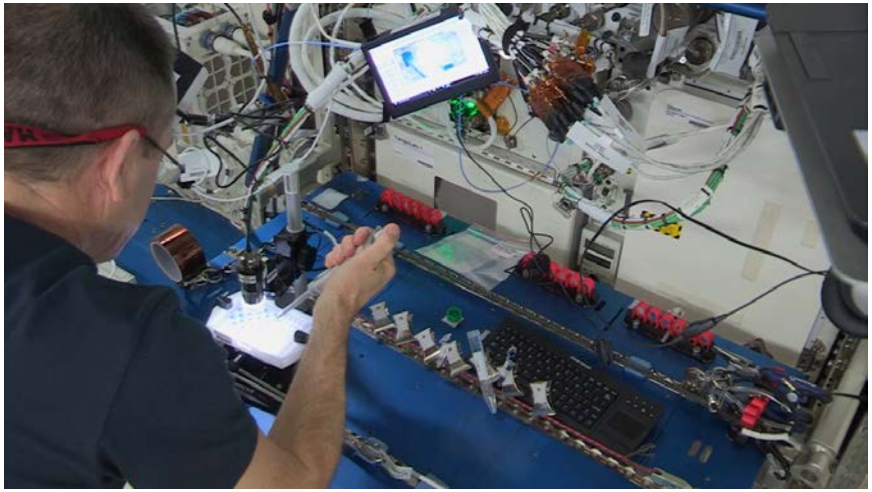
- **Relevance/Impact:**
  - This investigation is foundational for understanding cement hydration on extraterrestrial bodies.
  - This investigation sheds considerable light on crystal hydration kinetics, phase formations, pore distribution, and material properties.
  - Understanding and controlling the crystal growth kinetics and morphology could significantly increase cement strength.

Microgravity Materials Science Community

- **More than 40 current Grants and activities**
- **International Partners including:**

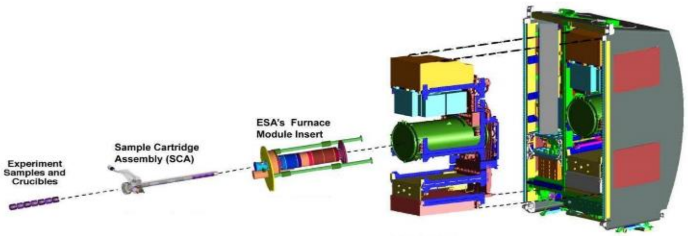
- **International collaborators including:**
  - Austria
  - Belgium
  - Canada
  - Germany
  - Japan
  - Russia
  - South Korea

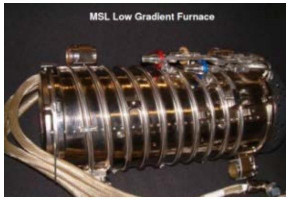
Group photo during an ISS-EML International Working Group (IWG) meeting in Cologne, Germany



An Astronaut performing protein crystal growth experiments on the ISS.

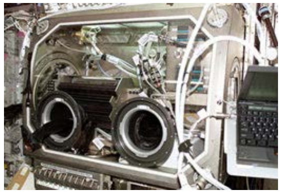
MSFC ISS Physical Sciences Research Content



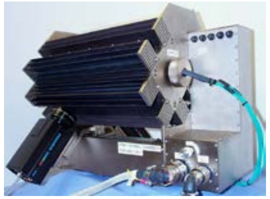


MSL/LGF Sample Cartridge Assembly (SCA)

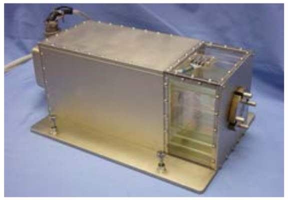
Exploded view of the Microgravity Materials Science Research Rack (MSRR) showing ESA's Furnace Module Insert and Sample Cartridge Assembly, Two Furnace Inserts (LGF and SQF) at right.



Microgravity Science Glovebox (MSG)



Pore Formation and Mobility (PFMI)



Solidification Using a Baffle in Sealed Ampoules (SUBSA)

Expedite the Processing of Experiments to Space Station (EXPRESS)

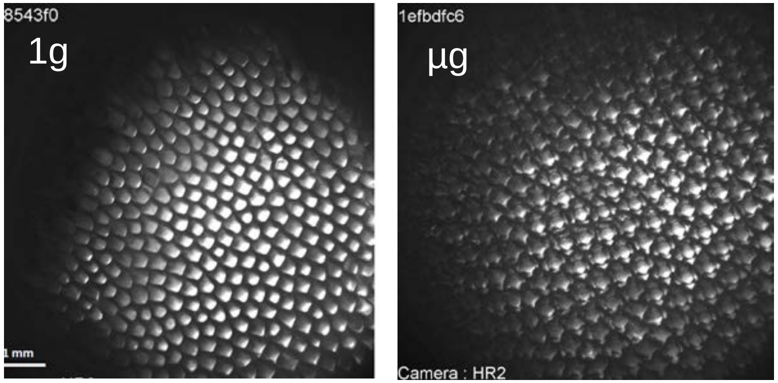
Observation and Analysis of Smectic Islands In Space (OASIS)

Light Microscopy Module (LMM)

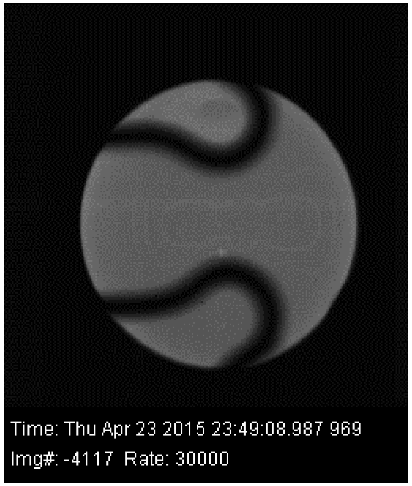
JAXA Electrostatic Levitation Furnace

Materials Science Research

- **A large variety of Materials Science research is either recently completed, ongoing or planned on ISS**
  - Solidification Microstructures
    - Isothermal Processes
      - CSLM, GEDS, FAMIS
    - Directional Solidification and Freeze Casting
      - SETA, CETSOL, MICAST, DECLIC DSI, FC1, FC2, SM1, SM2
  - Crystal and Formation and Growth
    - GTCS, Chemical Gardens
  - Infrastructure Materials and Processes in Microgravity
    - MICS (cement), BRAINS (brazing), ISSI (soldering)
  - Thermophysical Properties research
    - ESA Electromagnetic levitation (ISS-EML)
    - JAXA Electrostatic Levitation Furnace (ELF)
    - Low to near zero fluid flow in levitated samples in microgravity
    - Measurements of density, specific heat, surface tension, and viscosity
      - On metals, semiconductors, oxides, and glasses
    - Current ISS-EML experiments: ELFSTONE, ICOPROSOL, PARSEC, THERMOLAB, QUASI
    - Current ELF experiment: Modeling and Simulation of Electrostatically Levitated Multiphase Liquid Drops
      - Goal: measure the interfacial tension between molten iron and slag. The results of the project could help with more efficient production of higher quality steel
    - 6 Planned ELF experiments: Thermophysical Properties and Solidification



Succinonitrile (SCN) – 0.5 wt% camphor
Axial view of dendritic array from DECLIC-DSIR
(growth direction towards camera)



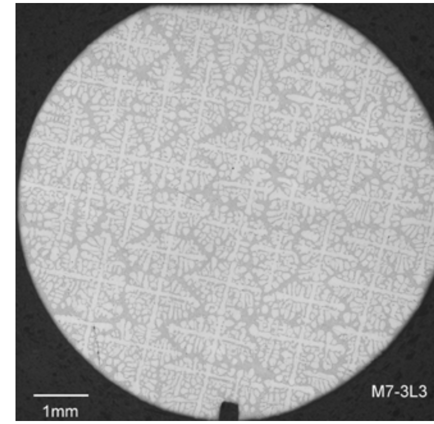
FeCrNi austenitic steel casting alloy deeply undercooled with rapid solidification of primary ferrite and subsequent conversion to secondary austenite.

Benefits From Research

- **Our materials research programs studies materials with these applications:**
  - Semiconductors
  - Welding
  - Casting
  - Alloy development
  - Glass processing

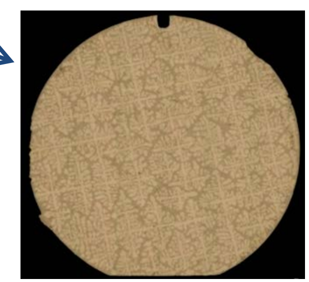
- **Our PCG research efforts are focused on understanding**
  - The physics of improved protein crystal quality in microgravity
  - Establishing protocols for setting up and optimizing crystallization experiments on ISS.
  - High quality crystals can be used to help develop new pharmaceuticals.

Bulk metallic glasses (BMG's) are being researched on ISS. BMG's doesn't get brittle in extreme cold. NASA is researching this material to make gears for rovers to be used in extreme cold.



An aluminum-7wt% silicon sample directionally solidified on the ISS. The applications of this science are solidification castings that are used in gas turbine "jet" engines.

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



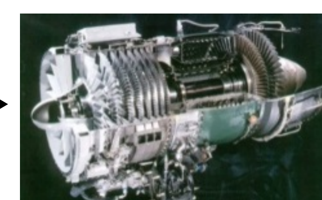
Apply Microgravity

Gained Knowledge

Higher Temperature

Greater Efficiency

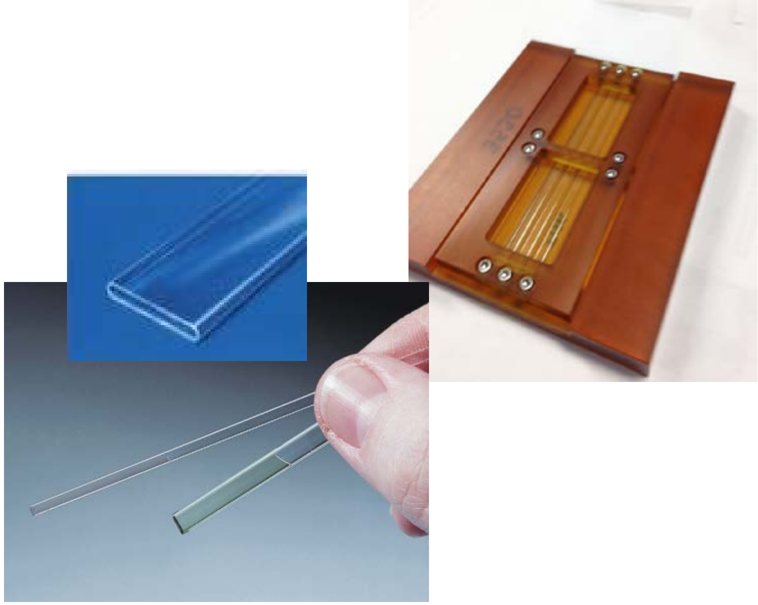
Longer Life



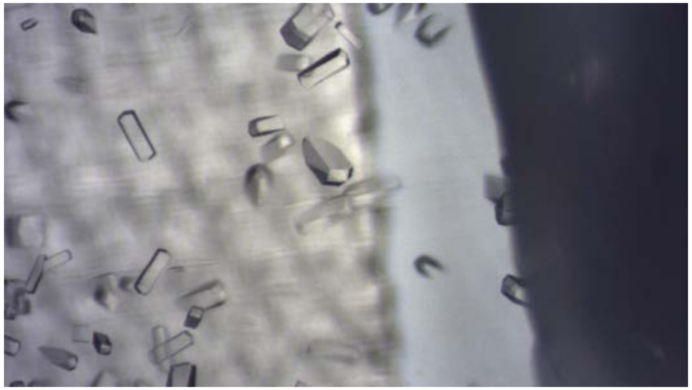
Biophysics Research

- An example of biophysics research is protein crystal growth (PCG).

- Microgravity missions have shown that crystals of some proteins (and other complex biological molecules such as viruses) grown on orbit are larger and have fewer defects than those grown on Earth.



PCG hardware used in space.



Lysozyme crystals grown on ISS during ops in July 2018/ Returned on SpaceX-15.

- The improved data from the space-grown crystals significantly enhance scientists' understanding of the protein's structure and this information can be used to support structure-based drug design.
- Additional projects in Biophysics include studies of Biofilms

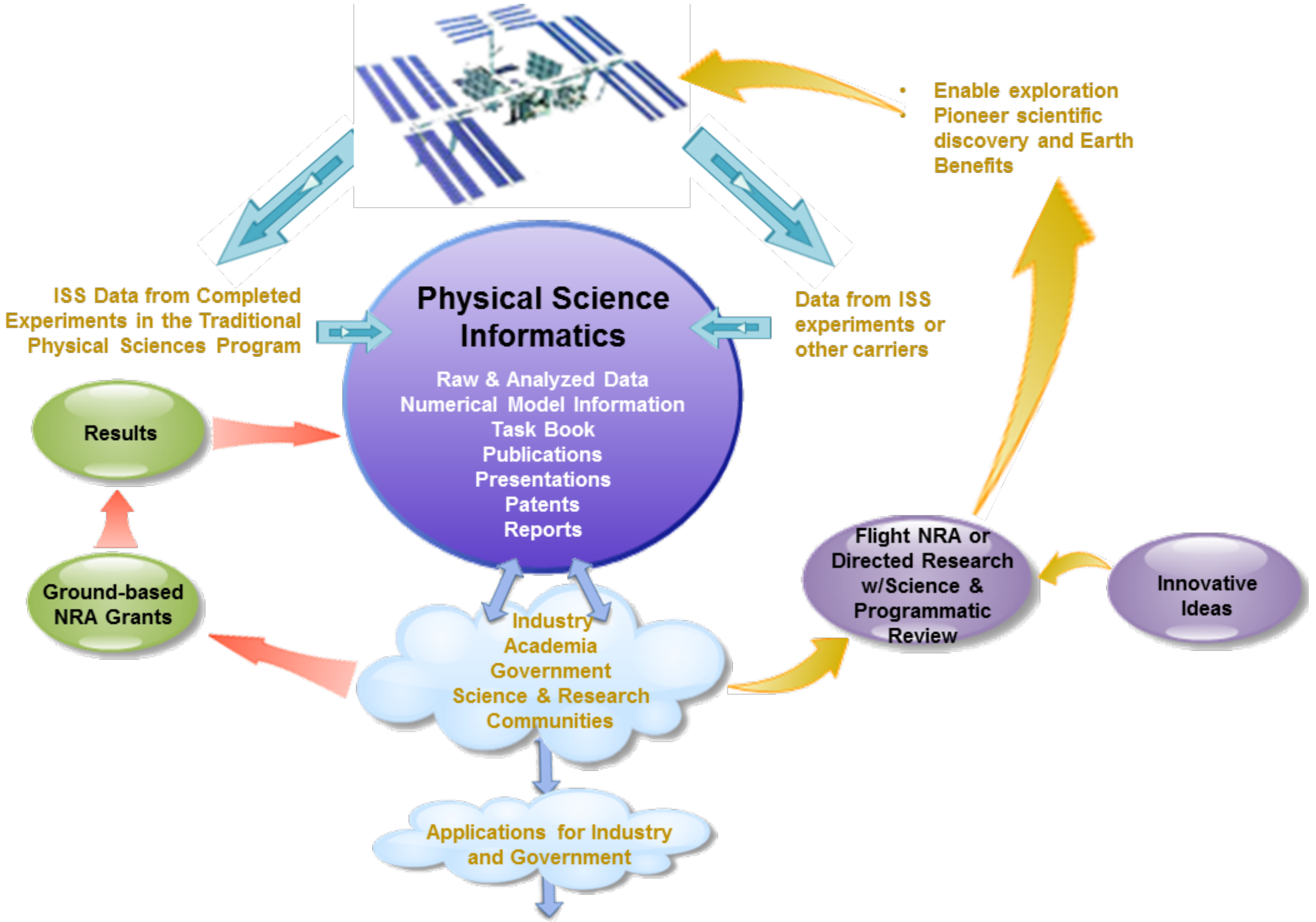
Future NRA and Workshops

- **Potential future NRA topics and research priorities to flow from workshops which engage the exploration pull community:**

- **Materials Science:** Joint workshop with CASIS at ISS R&D conference, July 29&30, 2019 in Atlanta, GA
- Potential topics include:
  - Advanced manufacturing for in-space fabrication and repairs
  - Joining of materials
  - Metallic alloys for high-temperature and cryogenic applications
  - Lunar habitat and infrastructure materials
  - Functional materials for space and terrestrial uses
  - Techniques for thermophysical measurements and microstructure assessment

- **Biophysics**: Biofilms workshop, joint with Space Biology and ECLSS, at the Center for Biofilm Engineering annual conference, to address biofouling issues in ECLSS Water Processing Assembly. Participants in planning include Kevin Sato (ARC/SB), Sid Gorti (MSFC/Biophysics) and Layne Carter (MSFC/ECLSS)
- July 16-19, 2019 in Bozeman, MT

Physical Sciences Research Program – Research Concept to Data



Outcomes:

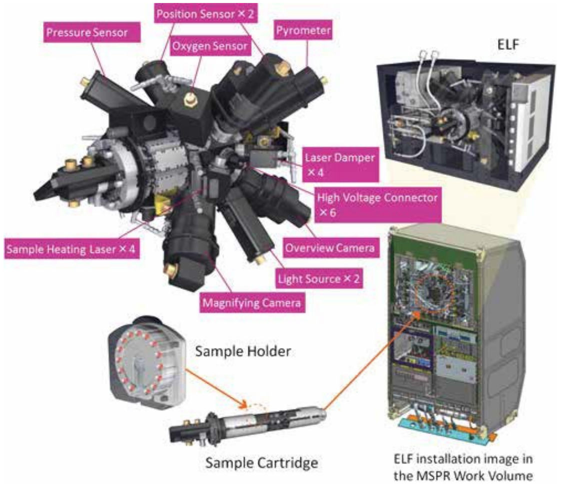
- Global access to cutting-edge research data
- Fuel innovation & discovery leading to increased economic growth
- Acceleration from ideas to research to products
- Enhancement and verification of numerical and analytical models
- Increased products, patents, and publications
- Advancement of fundamental research

PSI website: http://psi.nasa.gov/index.html

Summary

- **Ongoing and near-term operations on ISS including:**
  - ESA ISS-EML
  - JAXA ELF
  - MSRR
  - Glovebox
  - SUBSA
  - PCG & Biofilms

- **Acknowledgment: NASA Space Life and Physical Sciences Research and Applications (SLPSRA)**



Electrostatic Levitation Furnace (ELF)

Materials Science Research Rack (MSRR) ground unit.