National Aeronautics and Space Administration

Biological and Physical Sciences

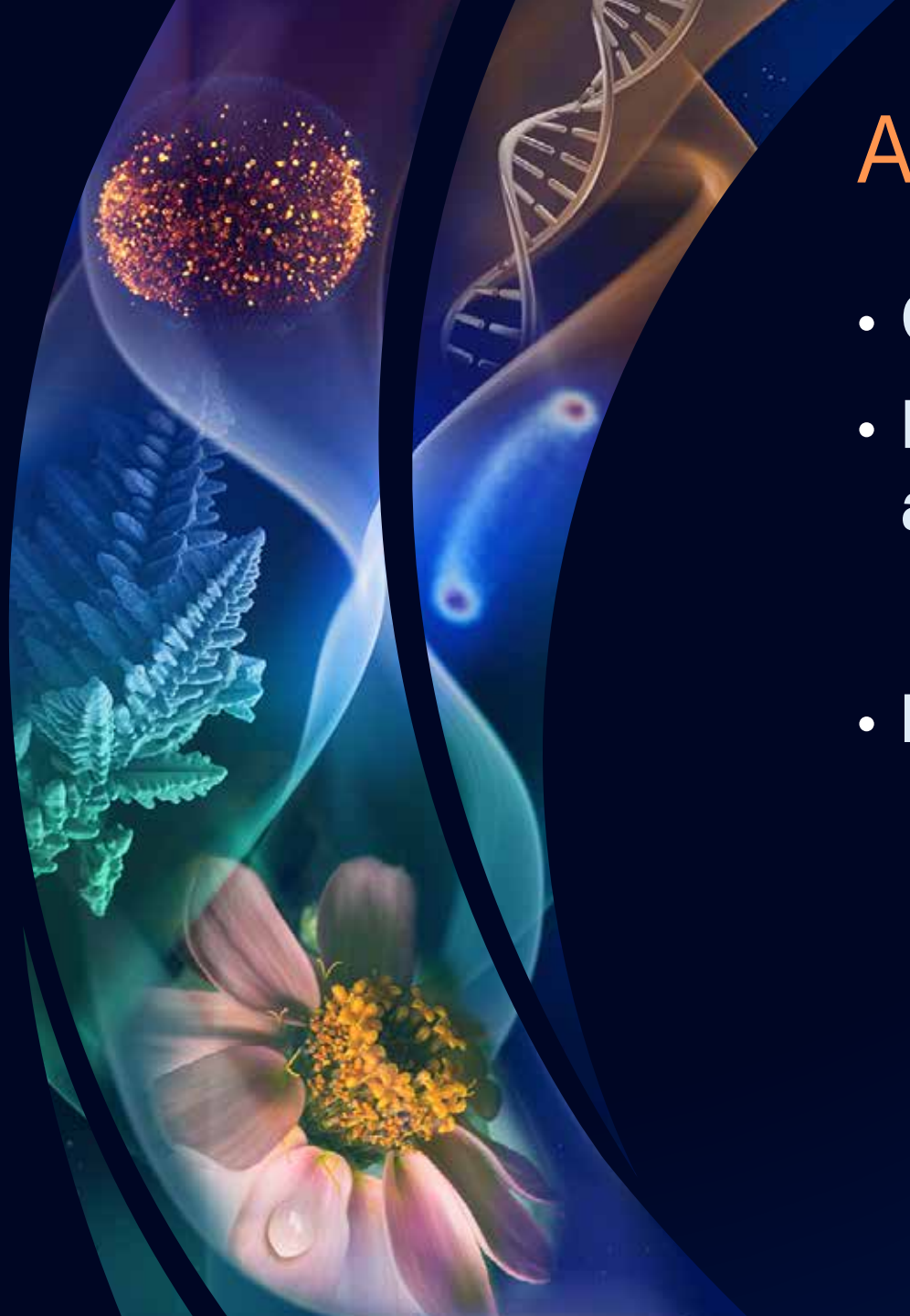
Committee on Biological and Physical Sciences Meeting

Physical Sciences Overview

Oct. 14, 2021

Francis Chiaramonte
Program Scientist for Physical Sciences

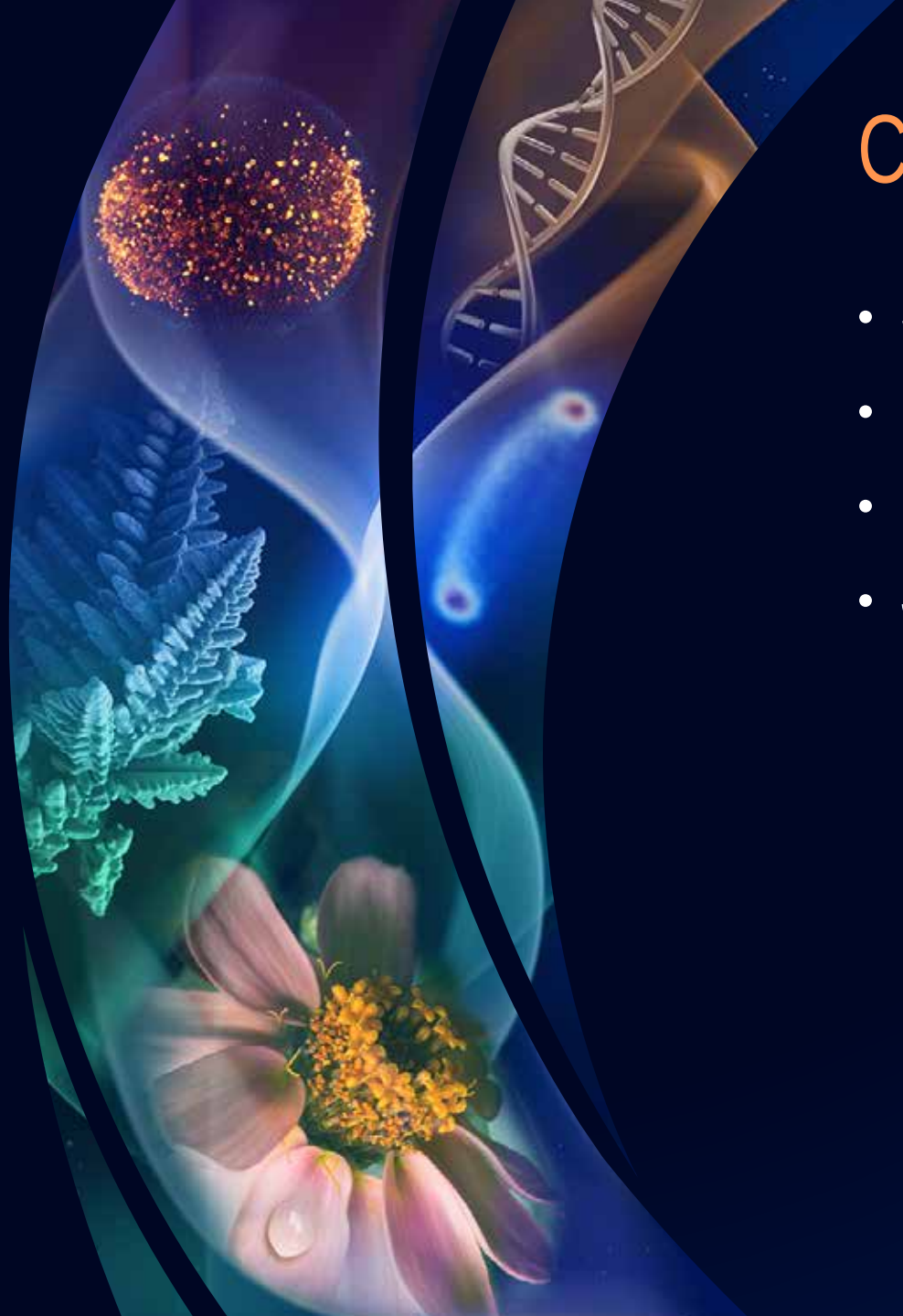




Agenda

- **Overview of current program**
- **Notable changes & transformative science areas**

- **Back-up**
  - Detailed Program Overview
  - Collaborations
  - Highlights

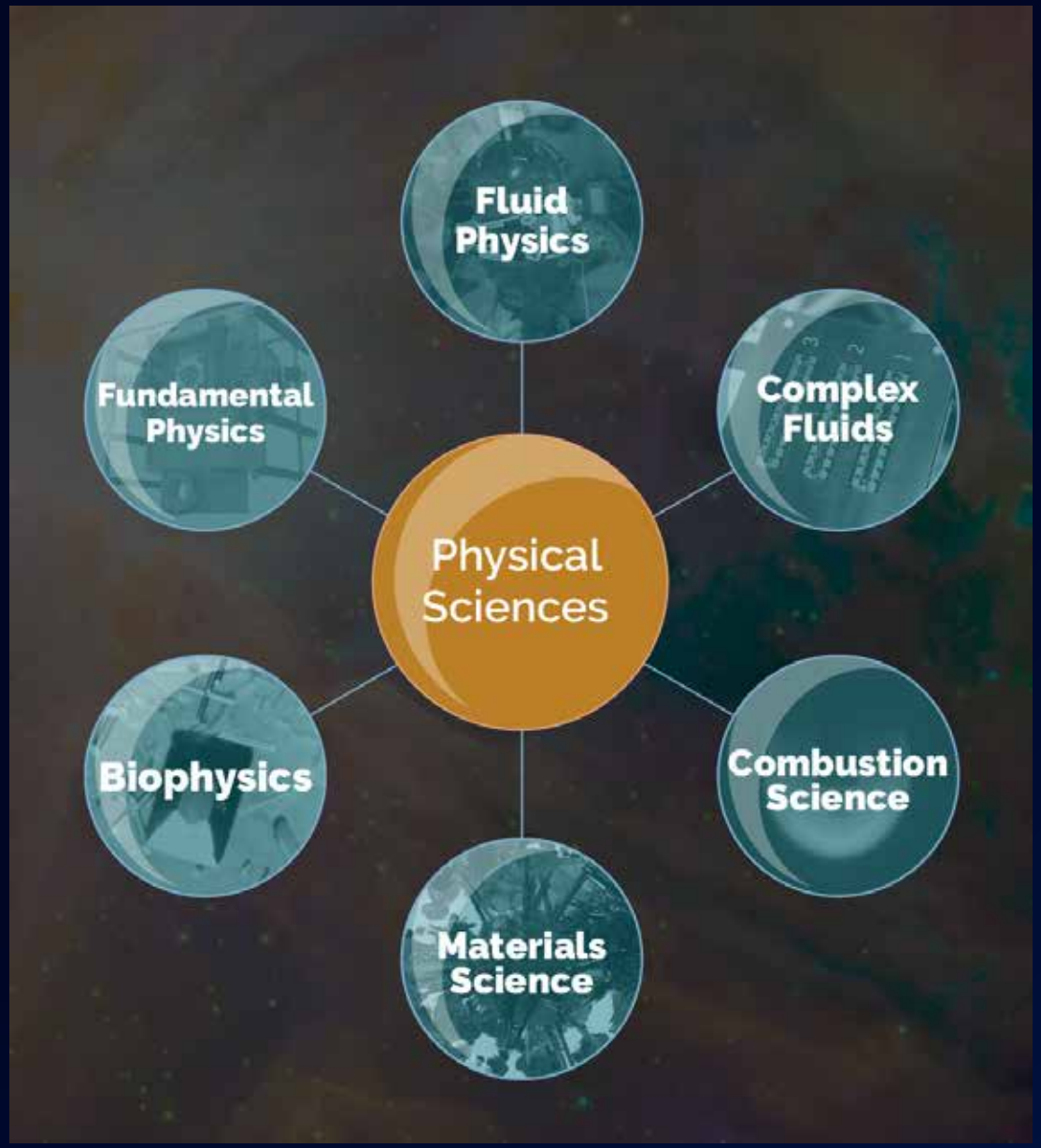


Contributors

- **Suman Sinha Ray – Complex Fluids/Soft Matter**
- **Dan Dietrich – Combustion Science**
- **Mike Sansoucie – Materials Science and Biophysics**
- **John Mcquillen – Fluid Physics**

Overview of Current Program

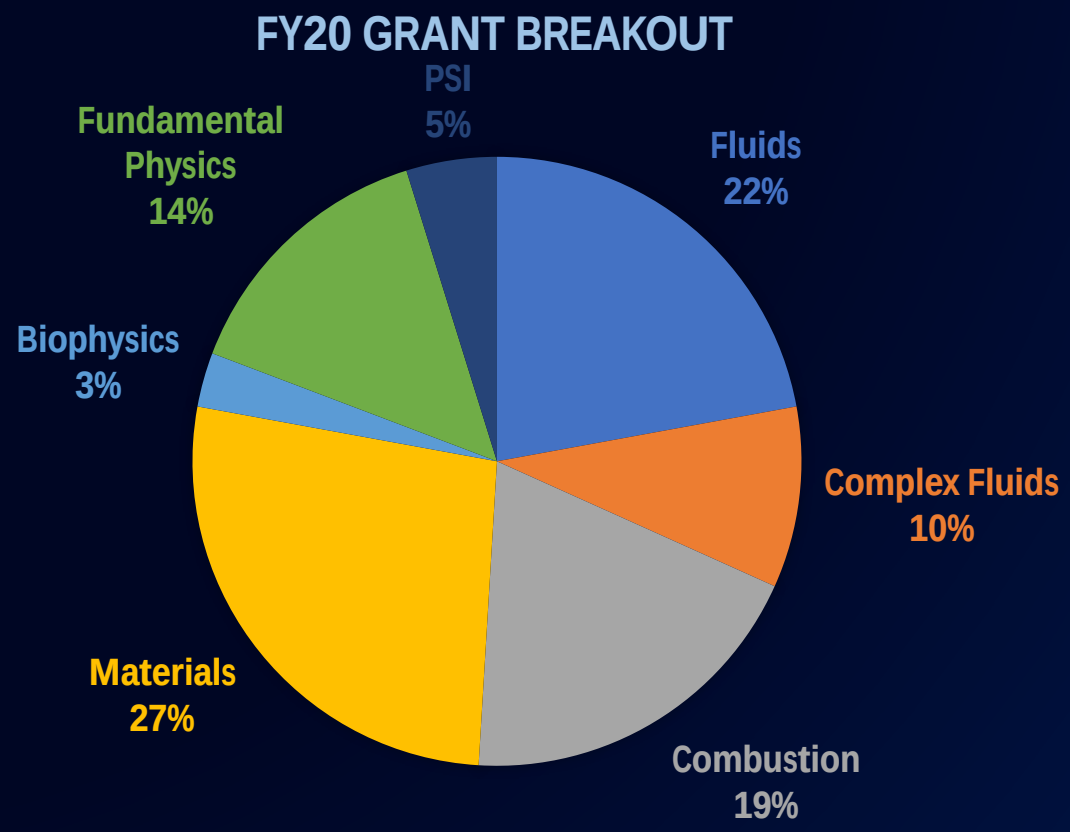




Objectives

- Investigate **fundamental laws** of physics and **physical processes** using the space environment
- Identify the underlying **processes** and develop models for physical systems in space
- Develop **technologies** to enable spaceflight research
- Promote **open science** through Physical Science Informatics
- Transfer the knowledge and technology of space-based research to **benefit life on Earth**

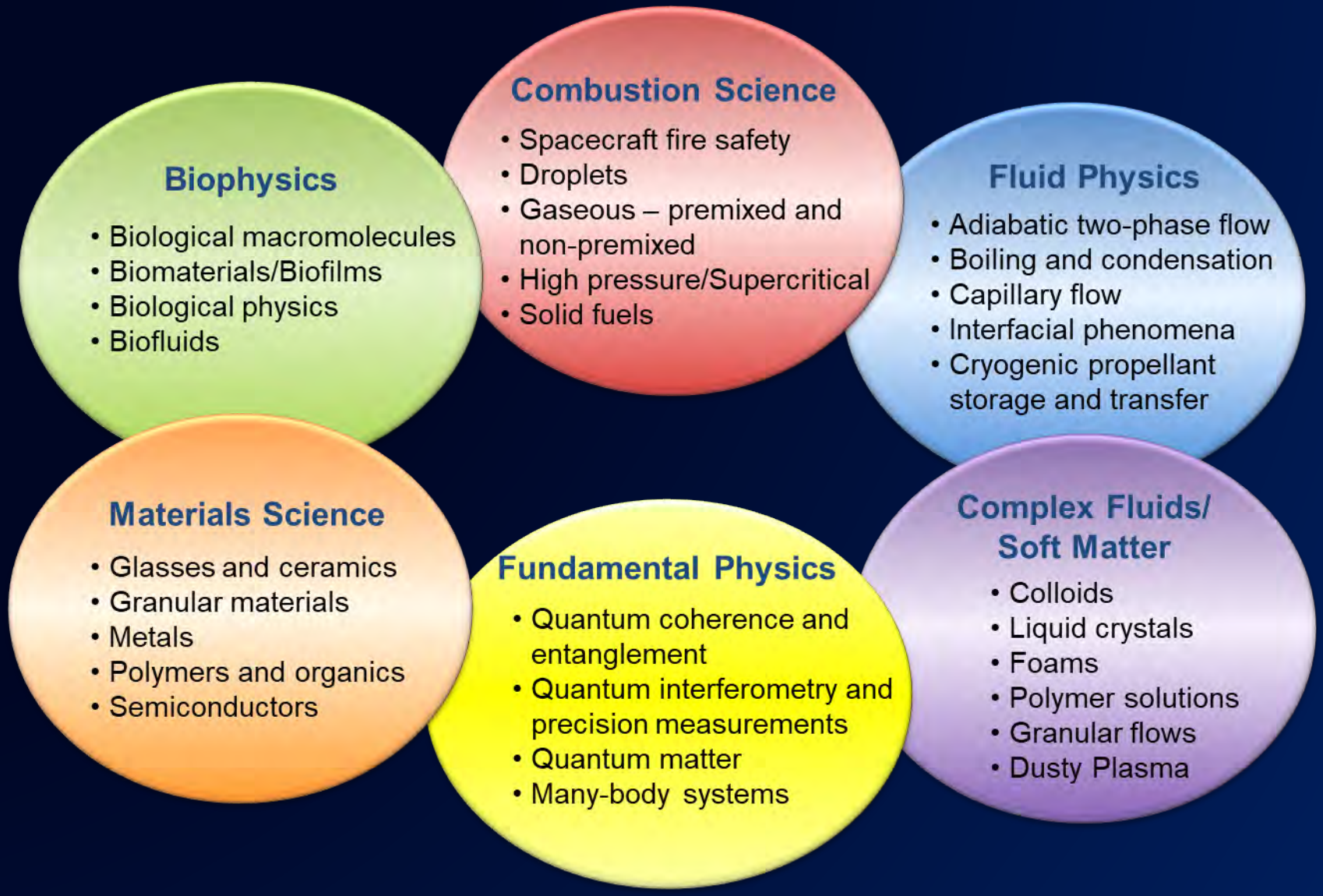
Physical Sciences Content



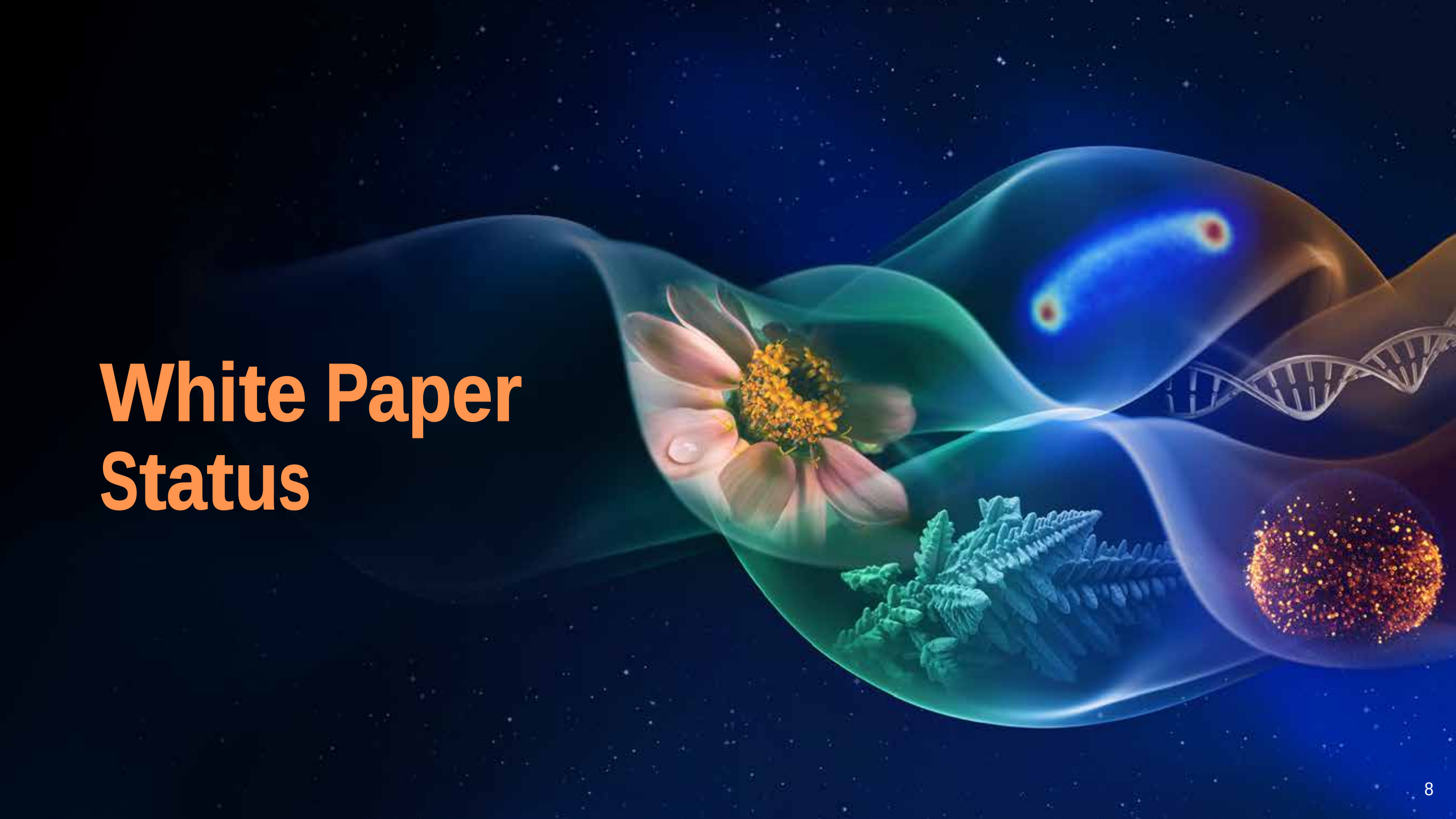
Total PS FY20 Grants	104
Flight	64
Ground	40

Number Directed vs Competed	
Directed	10
Competed	94

Physical Sciences Program Overview



White Paper Status



White Paper Count – completed or in progress

RESEARCH AREA	Current total
Combustion	11
Fluids	8
Complex Fluids/Soft Matter	13
Materials	11
Biophysics	2

Notable Changes & Transformative Science Areas



Complex Fluids/Soft Matter

Notable changes in NASA-funded research:

Advanced Colloids Experiment (ACE) T6
(Matt Lynch, P&G)

- Studied fundamental physics associated with gel coarsening to improve the shelf-life stability of products in collaboration with P&G.
- Used confocal microscopy in microgravity (LMM) to study the 3-D behavior of microscopic particles in gels and creams
- Resulted in *new* aerosol spray product line to reduce wrinkles, and freshen clothes while traveling (4 patents)

Advanced Colloids Experiment (ACE) T11
(Borris Khusid & Paul Chaikin)

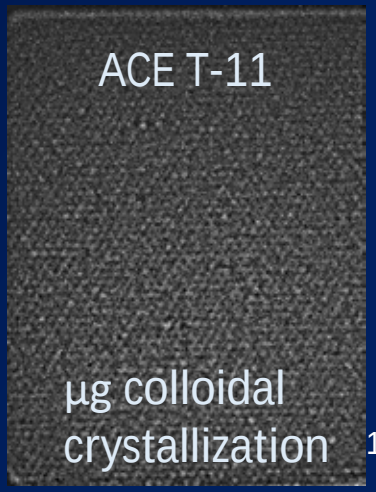
- Studied the feasibility of producing FCC crystalline structure utilizing micron-sized large particle predicted theoretically at volume fraction >0.54.
- Microgravity allowed the team to create macroscopically large crystalline FCC structure using micron sized particles, which is impossible on earth due to sedimentation.
- Opened up the possibility of developing optical computers.

OASIS (Liquid Crystals)
(Noel Clark)

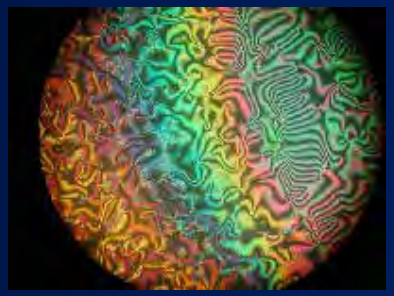
- Performed the first ever experiment with liquid crystal in microgravity condition using ferro electric liquid crystals of various chemical structures.
- Developed fundamental understanding of interfacial phenomena in liquid crystal film that results in "*island*" defect (Ostwald Ripening), film rupture (Rayleigh-Taylor instability), thermal migration of defect.
- Answered fundamental questions in liquid crystals with potential to help industry.

Notable changes in the field:

1. Soft matter research became more interdisciplinary across physics, chemistry, biology and engineering (e.g., colloidal system activated by biological agents, etc.)
2. Introduction of machine learning in augmenting fundamental understanding and theoretical modeling
3. Emergence of newer field that capitalizes on microgravity research (e.g., metamaterials, soft robotics, etc.)
4. Characterization capability improved significantly (e.g., microscopy, spectroscopy, etc.)



Complex Fluids/Soft Matter



Transformative science areas:

Pursuits of fundamental science:

Opportunity to study active, **non-equilibrium** matter, devices, phenomena and materials, with equilibrium systems for comparison. Apply external forces and power through fields: electromagnetic, pressure, shear and stress, temperature and light fields that we program and control in space and time. These fields drive the systems far from equilibrium and also to probe their physical and chemical properties. On Earth gravitational sedimentation confines most active systems to 2D with numerous artifacts due to floors and boundaries. Microgravity literally adds another dimension to the problem making available 3D motion, 3D processing, 3D fundamental science, 3D protocols and 3D active materials and devices. Microgravity allows us to study fundamentals of via reduced impact of sedimentation, buoyancy.

NASA exploration:

Self-reliant sustainable/circular ecosystem

- Additive manufacturing to create custom structures on demand utilizing the resources in hand

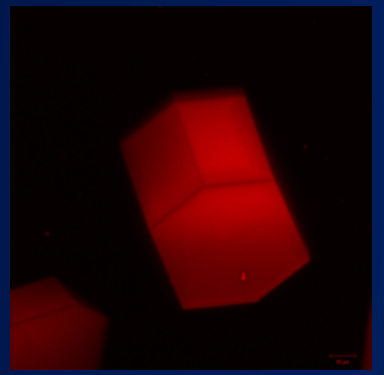
In space habitat development (e.g., metamaterials to gain improved functionality, rheological understanding for processability, etc.)
Soft robotics to perform multitude of tasks during long duration space flight and deep space habitat formation with minimal robotic arms:

- Soft robotics allow us to handle odd-shaped object and varied "grip strength" to handle objects with a wide range of toughness/ tenderness
- The robotic arm can be designed to reach intricate places without loss of performance

Terrestrial Application:

Soft robotics for automation from critical (e.g., surgery) to large scale industrial system.
Tech. from in space habitat development can help in developing improved insulation materials for building and net zero emission system

Biophysics



Notable changes in NASA-funded research:

Collaborations between ARC and MSFC on investigations of biofilm formation and inhibition mechanisms were initiated.

- Experiments conducted aboard the ISS will provide unique insight into the mechanisms of attachment, growth and subsequent proliferation of biofilms in the absence of convection, critically important for continued presence in space- both on ISS and long duration missions.

BPS research contributes to the understanding of terrestrial factors that limit the quality of protein crystals grown in the lab.

- BPS research also investigates the practical use of the ISS microgravity environment for producing higher-quality crystals of important proteins that are difficult to crystallize in terrestrial labs.
- Over 50 protein structures have been solved or significantly improved with microgravity-grown crystals.
    - One example is human serum albumin, which is most abundant protein in human blood, a carrier of many compounds including hormones, fatty acids, and numerous drugs.

Notable changes in the field:

- Improvements in the intensity of available x-ray sources for crystal analysis have reduced the size of the crystal required (often a limiting factor before).
    - This means that even a small, high-quality crystal can be utilized for structure determination.
- Cryo-electron microscopy and the successes of AlphaFold reduce the need for x-ray crystallography.

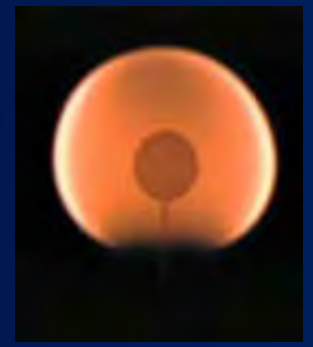
Biophysics



Transformative science areas:

- **Advance scientific knowledge**
  - Protein Crystal Growth in microgravity provides the ability to isolate and control environmental factors (such as gravity-driven convection) that contribute to the nucleation and growth rate.
    - Ultimately, understanding the contribution of each environmental factor allows for better control of the process and improvements in the quality of crystals.
- **Meet the needs of human and robotic exploration missions**
  - Studies on the effects of the space environment on bacterial or fungal biofilms will help with mitigation strategies of biodegradation or biocorrosion of materials and biofouling of fluid systems.
    - Advance fundamental knowledge for developing materials that are resistant to or inhibit biofilm formation and growth.
    - Reduce the dependency on chemical agents, which are potential health and ECLSSS hazards in closed spacecraft environments.
- **Benefit life on Earth**
  - Biofilms are major contaminants in hospitals, medical devices for patient care and treatment, and in homes.
    - Spinoffs from ISS biofilm mitigation strategies should have direct translation to medical and domestic use.
  - Structural biology is key to understanding how biological systems work, including how proteins and nucleic acids interact with one another and with other small molecules.
  - Microgravity investigations of amyloid fibril formation may be directly applicable to understanding their formation within tissues or cells, which may lead to understanding the prevalence or onset of Alzheimer's and Parkinson's diseases.
    - This research will also inform corporations that manufacture biopharmaceuticals.

Combustion



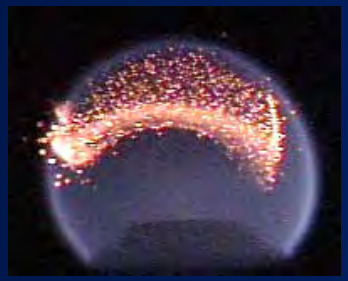
Notable changes in NASA-funded research:

- Cool-flame supported droplet combustion – major discovery in combustion science leading to significant new research. Remains an active area of research
  - Over 500 citations of BPS cool flame research since 2012, over 200 of the first two publications
  - Related new discoveries of warm flames, hot-flame re-ignition, dual flames, etc.
  - Impetus for Cool Flames Investigation with Gases (CFI-G) discovery of burner-supported spherical cool flames funded by NSF/CASIS
- Classical/textbook 'benchmark' ACME series of experiments completed in the CIR
  - Benchmark data of burning and extinction of ‘textbook’ flames in microgravity (CLD, S-Flame, Flame Design)
  - Novel experiments with gaseous fuels show steady-state burning of polymeric materials can occur in cabin atmospheres of future crewed spacecraft (BRE)
  - Experiments involving innovative flame control concepts (E-Field Flames) with potential future applications to burners that maximize efficiency and minimize emissions
  - Publications of ACME data now appearing in literature

Notable changes in the field:

- *High Pressure Transcritical (HPTC) Research* – Active and emerging area with immense practical implications. Both fundamental and applied research with applications (gas turbine, diesel engines, advanced HCCI, RCCI engines and waste incineration) driving the need for more fundamental information
- *Low-Temperature, Cool Flames Research* – Active and emerging area with applications beyond traditional combustion (low carbon fuels, material synthesis). BPS-funded research a pioneer in this area
- *Turbulent Combustion* - ‘Holy Grail’ of combustion research with immense practical implications (all terrestrial combustion systems from engines to wildfires)
- *Wildfire Research* – Microgravity provides the opportunity to investigate aspects of wildfire growth and spread in a well controlled, buoyancy free, flow field. Simplified approach will gain more insight to advance the development of theory and models.
- *Spacecraft Fire Safety* – Limited to NASA applications, but essential as NASA moves beyond LEO

Combustion



Transformative science areas:

Pioneering scientific discovery - Most Important Needs

- **High Pressure Transcritical Combustion (HPTC)** – Active and emerging area of research driven by practical (e.g., engine design) needs. Very little fundamental information available and microgravity testing (buoyant-free) has a high likelihood of transformative discoveries. In terrestrial studies advances hampered by the disappearance of the liquid/gas interface and the buoyant force that scales with P^2
  - Physical Properties, Phase Transition and Chemical Kinetics
  - Low temperature chemical kinetics
  - High temperature chemical kinetics
- **Low Temperature Chemical Kinetics** – Active and emerging area of research with implications beyond traditional combustion. Continue BPS-funded pioneering research in this area. Advanced engine design and new engine concepts (HCCI, RCCI) and future fuels (biofuels, electrofuels) require predictive understanding of low temperature chemical kinetics that does not exist.
- **Turbulent Combustion** – The 'holy grail' of combustion research with extreme relevance for virtually all combustion applications (e.g., engines, furnaces, etc.). Microgravity studies can play a small, but important role (e.g., transitional flames, sub-model development) in a large and important, multidisciplinary field.

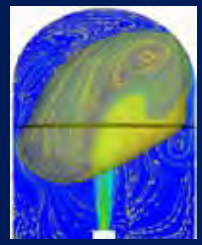
Enabling space exploration - Spacecraft Fire Safety (SFS) – Research is needed to enable long-duration, manned exploration missions beyond LEO

- Material flammability
  - Partial gravity
  - High oxygen, low pressure
- Fire Modeling, Fire Detection, Fire Suppression, Ignition

Benefitting life on Earth – Combustion the dominant source of energy worldwide and will likely remain so for the foreseeable future. Even as developing countries transition to e-fuels, combustion will dominate civil and military air transport, rail and marine applications. Chemical energy storage from renewables (electrofuels) and subsequent combustion an emerging energy concept.

Fluid Physics





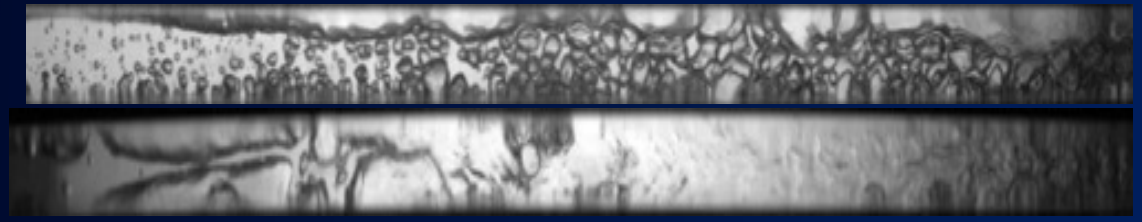
Notable changes in NASA-funded research:

- **Zero Boil Off Tank** experiment (ZBOT-1) Science Experiment was performed successfully abroad the ISS and partially filled the knowledge gap by providing the much-needed high fidelity microgravity data for tank pressurization and pressure control CFD model validation. The models are intended for scale-up design for microgravity applications.
- **Electrohydroynamics** Experiment - Electrically Driven Liquid Film Flow Boiling. Goal - fundamentally understand the effects of microgravity on the interaction of electric and flow fields in the presence of liquid/vapor phase change. Status: One patent and two provisional patents. Yagoobi, et al
  - 1) "Gravity Independent Liquid Cooling for Electronics", 2) "Two-Phase Heat Transport Device Using Electrohydrodynamic Conduction Pumping" 3) "Electrohydrodynamic Drying of Moist Porous Materials," for DEP assisted drying
- **Packed Bed Reactor Experiment**
  - Validated semi-empirical pressure drop model for relevant low flow rates and
  - Direct observation of gas accumulating in the bed over time. Gas creates a region no longer useable for a reaction and the pressure drop increases (performance drops off). Not observed in normal gravity. Updated semi-empirical numerical models to be used for future exploration water recovery system performance. Hardware is now being utilized by the ECLSS water reclamation effort.
- **Flow Boiling and Condensation Experiment**
  - For two phase thermal management systems, specifically boiling and condensation, knowledge of reduced gravity behavior evolved. By using ground and aircraft reduced gravity data, empirical correlations were improved, then theoretical correlations, followed by theoretical models and ultimately computational models. Basically, empirical correlations are being replaced with first principles.

Notable changes in the field:

- Ever increasing reliance of the two-phase and cryogenic fluid management science and engineering communities and aerospace industries on state-of-the-art CFD models validated by experiments to predict the behavior and performance of propellant storage tanks and other two-phase flow operations and technologies in microgravity.
- Emphasis on amassing world databases for fluid physics.
- Emphasis on developing accurate, experimentally validated, Computational Fluid Dynamics models for two-phase fluid flow and heat transfer.

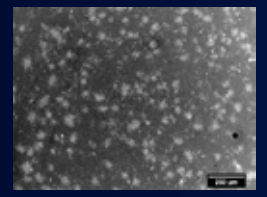
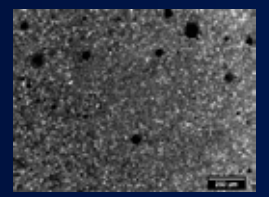
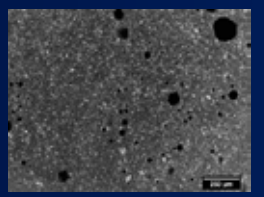
Fluid Physics



Transformative science areas:

- **Pioneering scientific discovery and Enabling space exploration:**
- One of the most important directions of research that is partly addressed by the ZBOT series of experiments is development of innovative and transformative *pressure control* strategies that allows for efficient, reliable and lossless storage and transfer of **cryogenic propellants**. Understanding the phase change and transport of volatile fluids in microgravity is essential for preserve propellants on orbit and allowing refueling operation is Space to carry out and sustain long-duration human planetary exploration missions to Moon, Mars and beyond.
- The need for scientific understanding and discoveries of liquid/vapor phase change phenomena in the absence of gravity will remain valuable in providing the foundation for development of next generation of light weight **thermal management systems:**
    - Nuclear fission Rankine power cycle for future space missions (Moon, Mars) and deep space missions.
    - Vapor Compression heat pump for planetary bases (Moon, Mars)
    - Thermal Control Systems and advanced Life Support Systems for spacecraft
    - Cryogenic systems, such as nuclear thermal propulsion, fuel depots, tank chill-down.
- Thermal Management systems also includes **cooling of electronics,** computers, etc. in space. This is true, for example, for satellites and NASA's near and long term missions. As an example, the next generation of data centers will be built in space as well. Cooling of various components of these data centers will require novel technologies. These novel technologies will be based on multi-physics phenomena, such as the EHD driven cooling devices. Thus, it is valuable for NASA to support basic and applied research in Fluid Physics/Thermal Management areas.

Materials Science

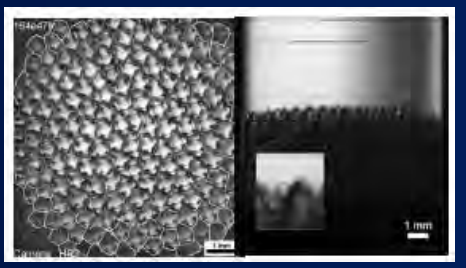
Notable changes in NASA-funded research:

- Experiments with Portland cement in reduced gravity were completed, which will help with NASA's exploration missions.
  - The Microgravity Investigation of Cement Solidification (MICS) experiment showed that as the gravity level decreased the amount of trapped air and porosity in the samples increased.
    - This will result in less strength when compared with Earth cements.
    - Follow-up research will be done via MISSE and through a PSI grant.
- Sintering in space was completed for the first time (W particles in Ni, Cu, Mn matrix).
  - Early results from research on liquid phase sintering indicate that sintering results in less densification in microgravity.
    - Pore sizes were larger and the pore/grain distribution was also larger in the microgravity samples.
      - This is expected to impact the mechanical properties of sintered parts in reduced gravity.
- US-led research on the JAXA ELF was funded and the experiments have begun.
  - Includes a variety of research, from novel measurement techniques to studies of metal oxides for potential optics applications to photorefractive materials.
    - Uncertainty in thermophysical properties data, e.g., density, surface tension, and viscosity, is often 15% or greater.
      - Measurements of thermophysical properties in microgravity can drastically reduce the uncertainties in the data.
        - This allows more accurate flow modeling, which enhances materials and processes development.

Notable changes in the field:

- Integrated Computational Materials Engineering (ICME) & Machine Learning (ML)
  - Bringing together computation, experiment, and data (both experimental and computational) to develop materials more rapidly than by Edisonian approaches.
  - Computational methods can be used to predict and evaluate effects of potential alloying elements and process modifications towards strengthening an alloy.
  - As mentioned above, microgravity enables the gathering of high precision data
    - This improves the accuracy of models for manufacturing processes, such as additive manufacturing and welding processes.

Materials Science



Transformative science areas:

How can the program advance scientific knowledge?

- Utilize the reduced gravity environment to inhibit masking phenomena such as buoyancy driven convection and sedimentation, and perform experiments targeted to address gaps in fundamental understanding of the underlying physics of materials science.
  - Coupling key benchmark experiments with rapidly evolving multiscale modeling techniques provides significant insights into underlying physics of microstructure formation and evolution during solidification processes (e.g. columnar equiaxed transition (CET), grain boundary migration, dynamics of secondary side-branch formation, and the transformation behavior of metastable phases).
  - Understanding of underlying physics operative during solidification as the departure from equilibrium increases is a broadly acknowledged gap in knowledge that has potential to be transformative from a fundamental perspective as well as seeding important advances across a wide range of materials systems and processes.
    - For example, additive manufacturing techniques such as Selective Laser Melting (SLM), Direct Energy Deposition (DED), Bound Metal Deposition, as well as high-speed processing techniques in glass forming systems.

How can the program meet the needs of human and robotic exploration missions?

- Support of NASA Lunar infrastructure fabrication efforts by studying porosity, microstructure, and properties of relevant materials in reduced gravity.
- Microstructure, solidification, and thermophysical properties experiments could help optimize materials and processes required to create infrastructure on demand on the Moon.
  - The fundamental physics of relevant materials and processes in reduced gravity will enable successful construction of Lunar infrastructure such as habits, landing pads, roads, and structural ceramic materials.

How can the program benefit life on Earth?

- BPS investigates the thermophysical properties of high-temperature materials, such as nickel-based superalloys used in aerospace turbines, and the formation of grain morphology during solidification.
  - A better understanding of the thermophysical properties and how the structure of a metal forms will allow for more efficient and more reliable production of metallic parts.

Conclusion






- **Complex Fluids/Soft Matter** - Investigate active, non-equilibrium matter, devices, phenomena and materials. To provide activity and dynamics we need to apply forces and power through different fields, electromagnetic, pressure, shear and stress, temperature and light fields that we program and control in space and time. These fields provide a way to both drive the systems far from equilibrium but also to probe their physical and chemical properties.
- **Biophysics** - Research on the ISS will help improve understanding biofilm-resistant materials by limiting use of chemical agents in removal of biofilm formations on enhanced substrates to address crew survivability and improvements in the health care applications.
- **Combustion Science** – For Spacecraft Fire Safety research is needed to enable long-duration, manned exploration missions beyond LEO. In High Pressure Transcritical Combustion active and emerging area of research driven by practical (e.g., engine design) needs. Very little fundamental information available and microgravity testing (buoyant-free) has a high likelihood of transformative discoveries.
- **Fluid Physics** - Development of innovative and transformative *pressure control* strategies that allows for efficient, reliable and lossless storage and transfer of cryogenic propellants. The need for scientific understanding of liquid/vapor phase change phenomena in the absence of gravity will remain essential will provide the foundation for development of next generation of light weight, thermal management space systems.
- **Materials Science** - Support Lunar Surface Construction using 3D printing techniques using regolith 'processing' materials methodologies (cementitious, micro-wave sintering, etc.). Focus research in a reduced gravity environment on studying porosity, microstructure and materials properties. Also, investigate thermophysical properties of high-temperature materials, such as nickel-based superalloys used in aerospace turbines, and the formation of grain morphology during solidification.

Physical Sciences - Lunar Surface Science Workshop

The NASA Biological and Physical Sciences Division completed a workshop on fundamental and applied research on the Moon in physical sciences on **August 18–19, 2021**. This workshop brought together the scientific community, commercial companies, and NASA Divisions and Programs with the goals of discussing investigations on reduced gravity and lunar environmental effects in physical sciences research for sustained lunar human habitation and in preparation for human exploration to Mars and to inform and inspire the science community to contribute white papers for the Biological and Physical Sciences Decadal Survey. Lunar Surface Science Workshop (usra.edu)

This workshop will focus on the following umbrella topics:

- Lunar dust and its properties, behavior, and mitigation
- Life support and thermal management
- Materials flammability and habitat fire safety
- Extraction of water-ice from regolith research, including separation, purification, electrolysis, and liquefaction
- Lunar environment and its effects on materials
- Lunar research in extraction, processing, and handling
- Lunar research for advanced manufacturing
- Fundamental physics research on the lunar surface



Products from the Workshop:

- Workshop Report from the community input and findings from the breakout sessions – in progress
- Inspiring the community to produce and submit whitepapers for the Decadal Survey

Deep Dive



Questions for CBPSS

	Question
1	How to engage the research community more than we currently do? (Ground programs, science definition teams, workshops, etc?)
2	How to deliver experiments to flight faster?
3	How to establish more collaborations (International, Commercial, OGAs, etc)?

Thank You!



Back - Up



Program Needs, Questions and Concerns



Program Needs

1. Build a robust research program with regular solicitations to support ground and flight investigations in fundamental research and applied research for exploration and terrestrial applications. Develop a strong a research community that will support and strengthen the BPS program with innovative and new ideas for growth.
2. Need stronger representation in NASA's Exploration focused Directorates to identify BPS applied research opportunities.
3. Need to increase collaboration with: International Partners, other space agencies, other NASA Divisions, other Federal agencies and commercial entities to leverage opportunities
4. Expand use of other experiment platforms (suborbital, commercial LEO, CLPS) to conduct experiments.

Program Issues and Concerns

1. Experiments take about 7 years for flight PI science to be developed and completed on the ISS.
2. Flight PI grants should be increased. Project cost overruns limit new solicitations.
3. Lessons learned from prior flight experiments need to be taught to new project teams. Many projects are being cancelled. Successful methods should be passed down.
4. Develop broad ground-based program.

Collaborations

Collaborations



- JAXA
  - FLARE - Thin film material flammability
  - Group Combustion Experiment-2, GCE-2: 2-D array droplet combustion.
  - Electrostatic Levitator Furnace (ELF) Experiments, ELF 1 -6 – Thermophysical Property measurements of metals and medal oxides.



- ROSCOSMOS
  - SoFIE Materials Flammability – Two investigations
  - Brazing experiment (BRAINS)



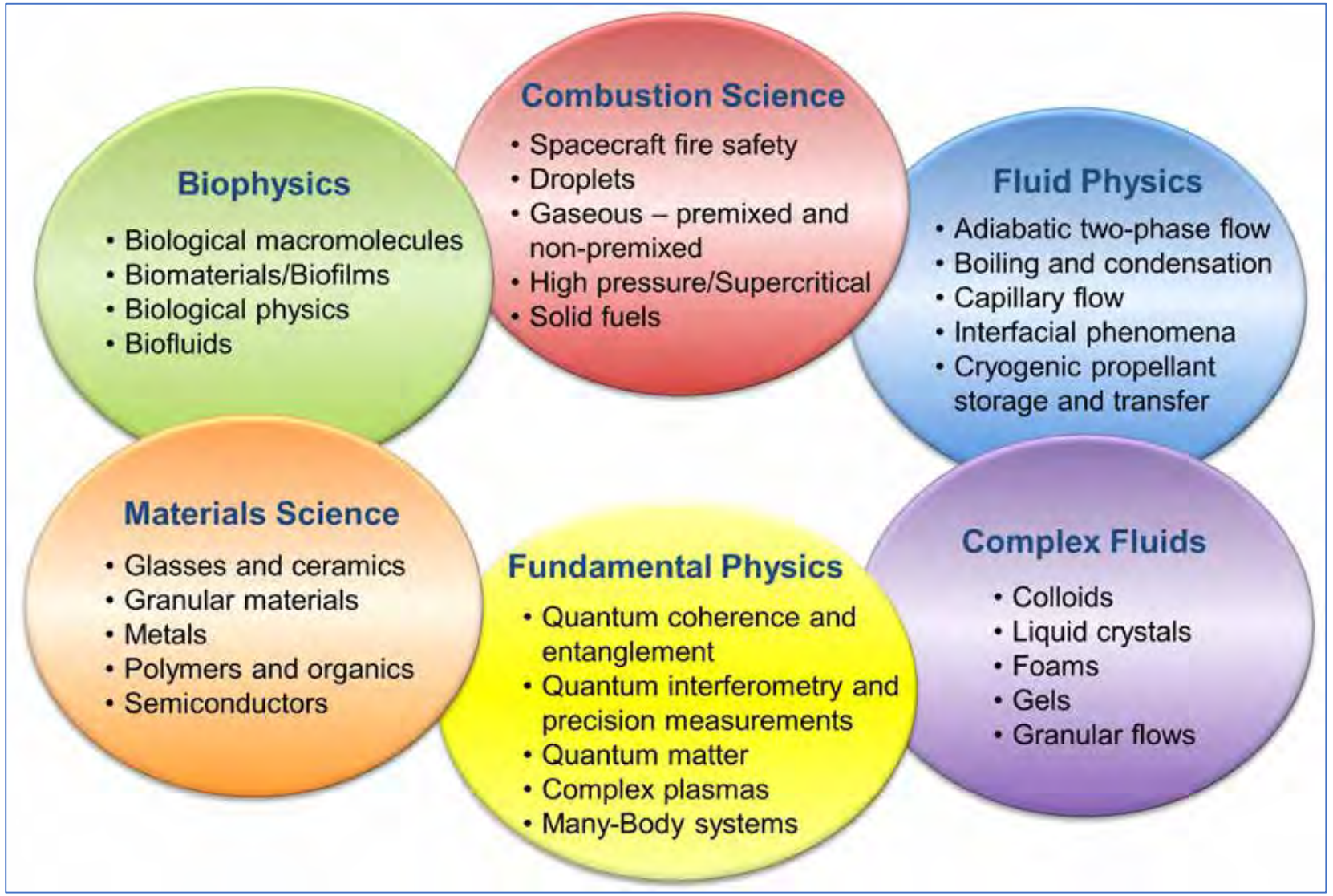
- ESA
  - Saffire Combustion experiments
  - An agreement for future thermophysical properties experiments on ISS-EML. Batches 1 - 4.
  - FY21-2 – NASA and ESA investigators conduct tests in ESA's *Foam Optics and Mechanics (FOAM) Experiment* in the Soft Matter Dynamics (SMD) insert in ESA's Fluid Science Lab.

Collaborations

- DLR
  - Zero Boiloff Tank Experiment – Filling and Transfer, ZBOT-FT .
  - Use of FLUMIAS microscope
- CNES
  - DECLIC – ALI 1 & 2, DSI 1 -2, HTI –2, SCWO and Aerosol series of experiments
- ISSNL
  - ISSNL and NSF selected two research teams to conduct experiments on BPS's FBCE.
  - Advanced Colloids Experiments in NASA Fluids Integrated Rack.
  - ISSNL to use the RSD hardware developed by NASA –BPS. Data to be shared.
- AFRL
  - Oscillating heat pipes, X37-B data (AFRL) and numerical simulation (NASA).
- NASA STMD
  - Zero Boiloff Tank experiment series (ZBOT - 1, NC, DP and FT)
  - Moon to Mars Planetary Automated Construction Technologies (MMPACT)
- NASA - AES
  - Packed Bed Reactor Experiment – Water Recovery systems

Detailed Program Overview

Physical Sciences Research Program



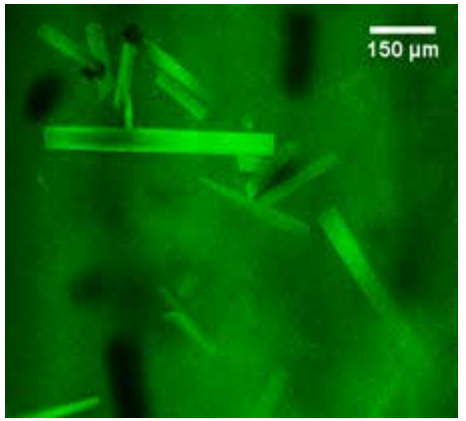
Biophysics

Protein Crystal Growth

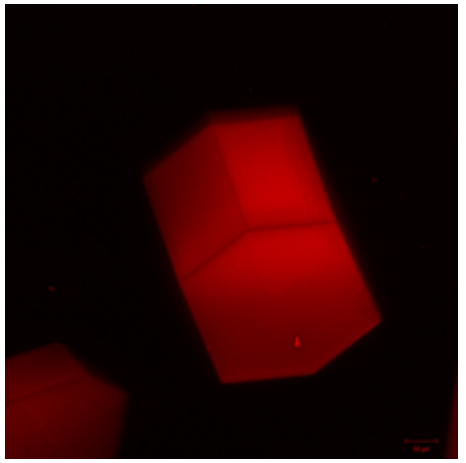
The Light Microscopy Module (LMM) is a modified commercial, highly flexible, state-of-the-art light imaging microscope facility that provides researchers with powerful diagnostic hardware and software onboard the International Space Station (ISS).

The PIs that have used LMM for protein crystal research include:

- Lawrence DeLucas, Aerospace Corp.
  - Objective: Validate the hypothesis that the improved quality of microgravity-grown biological crystals is the result of macromolecular characteristics that exist in a buoyancy-free, diffusion-dominated solution.
- Edward Snell, Hauptman Woodward Med. Research Institute
  - Objective: Validate the hypothesis that growth rate dispersion can be an indicator of crystals whose quality could be improved in microgravity.
- Peter Vekilov, University of Houston
  - Objective: Investigate if the absence of shear flow affects the concentration and properties of nucleation precursors and establish the mechanisms of these effects.



ISS-grown crystals of fluorescently-labeled pfGST (DeLucas).



ISS-grown crystals of fluorescently-labeled lysozyme (DeLucas).

Protein Crystal Growth

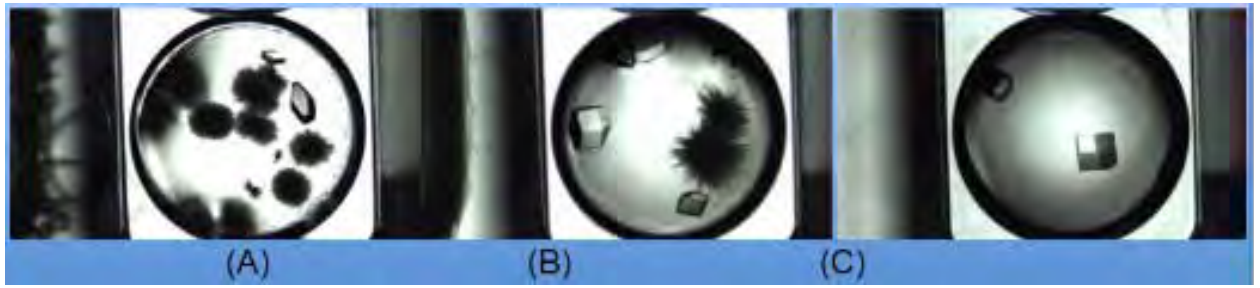
The Real-Time Protein Crystal Growth - 2 (RTPCG-2) project is designed to allow protein crystallization experiments on the International Space Station (ISS) that more closely mimic terrestrial methods, with on-orbit screening and optimization of crystallization conditions in an iterative process.

The RTPCG-2 Science Definition Team (SDT) consists of the following members:

- Dr. Daniel Carter, New Century Pharma
- Dr. Timothy Mueser, University of Toledo
- Dr. Stephen Quirk, Kimberly-Clark Corp

RTPCG-2 will develop procedures for ISS crew members to:

- Set up crystallization experiments on ISS using stock solutions just as they are set up in terrestrial laboratories
- Capture optical images of the crystallization experiment to be shared with terrestrial investigators.



Flight results show improvement in lysozyme crystal size/quality with iterative crystallization (RTPCG-1). Conditions were modified on-orbit from (A) 1.6 M NaCl to (B) 1.2 M NaCl to (C) 0.8 M NaCl by the crew, with feedback from the PI.

Biophysics

In the ring-sheared drop (RSD) hardware on ISS, a liquid drop is constrained by two contact rings, where the rings differentially rotate. This differential rotation generates a flow in the bulk primarily through surface shear viscosity.

- PI: Amir Hirsa, Rensselaer Polytechnic Institute; Co-I: Juan Lopez, Arizona State University
  - Objective: Examine the formation and flow of amyloids in the absence of surface tension and other complications created by the solid walls of a container. Results could contribute to better understanding of Alzheimer's disease as well as to development of advanced materials.
- PI: Juan Lopez; Co-I: Amir Hirsa
  - Dr. Lopez is working with the ISSNL on a follow-on RSD experiment.
  - The goal of the project is to understand and control protein aggregation at free surfaces, especially when the concentration of protein is high. Protein aggregation at free surfaces is an Achilles' heel in pharmaceutical manufacturing that degrades product quality and process yield.
  - The new droplet deployment system develop and launched. Protein solution samples to be tested.

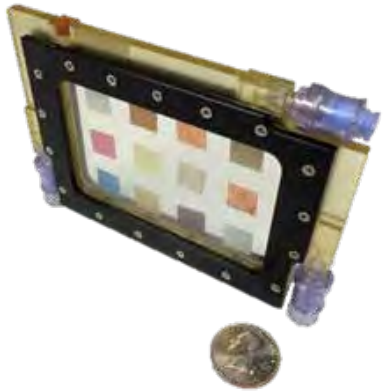




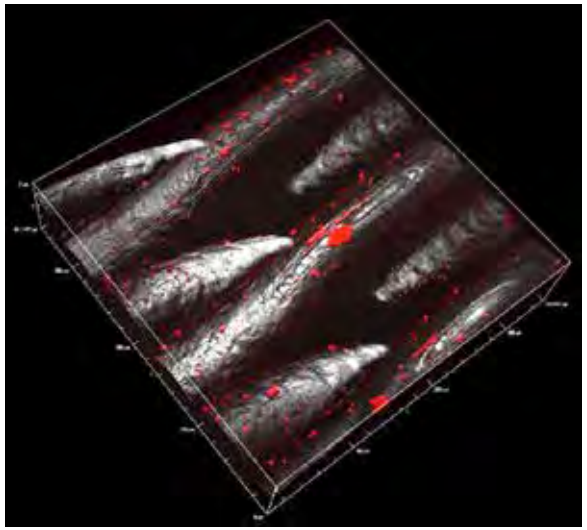


Left: Christina Koch Operating RSD Flight Hardware on ISS
Upper Right: RSD Test Cell Lower Right: Pinned Drop on ISS

Biofilms



BioCell used in biofilm experiments on the ISS



Bacterial contamination of a steel wire mesh.

The goal of these experiments is to support space exploration by developing knowledge of biofilm formation and inhibition mechanisms.

- The experiments use BioCells, which are placed in a Plate Habitat (PHAB) for incubation.
- Sample analysis will be completed on ground using confocal microscopy, RNA-sequencing, and/or scanning electron microscopy.

There are currently 2 PIs with Biofilms experiments on the ISS:

- Luis Zea, University of Colorado, Boulder
  - Objective: Characterize biofilm mass, thickness, morphology and the associated gene expression using different spaceflight-relevant microbial species and substrata materials, to help determine the physical mechanisms of material/micro-organisms interaction in biofilms.
- Robert McLean, Texas State University
  - Objective: Develop knowledge of biofilm formation and inhibition mechanisms with respect to varying material/microorganism interactions

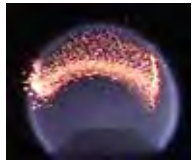
Top Publications - Biophysics

- Wenchuan Ma, James F. Lutsko, Jeffrey D. Rimer, and Peter G. Vekilov, “Antagonistic cooperativity between crystal growth modifiers,” Nature, 577, 497-501 (2020).
- Monika Warzecha, Lakshmanji Verma, Blair F. Johnston, Jeremy C. Palmer, Alastair J. Florence, and Peter G. Vekilov, "Olanzapine crystal symmetry originates in preformed centrosymmetric solute dimers," Nature Chemistry, vol. 12, pages 914–920 (2020).
- Luis Zea, Robert J.C. McLean, Tony A. Rook, Geoffrey Angle, D. Layne Carter, Angela Delegard, Adrian Denvir, Robin Gerlach, Sridhar Gorti, Doug McIlwaine, Mononita Nur, Brent M. Peyton, Philip S. Stewart, Paul Sturman, Yo Ann Velez Justiniano, “Potential biofilm control strategies for extended spaceflight missions,” Biofilm, 2, (2020) 100026.
- Patrick M. McMackin, Shannon R. Griffin, Frank P. Riley, Shreyash Gulati, Nicholas E. Debono, Aditya Raghunandan, Juan M. Lopez, and Amir H. Hirsa, "Simulated microgravity in the ring-sheared drop," npj Microgravity, Vol. 6, No. 2, 03 January 2020.
- Alexander McPherson and Lawrence James DeLucas, "Microgravity protein crystallization," npj Microgravity, Vol. 1, 3 September 2015.
- Martirosyan A, DeLucas LJ, Schmidt C, Perbandt M, McCombs D, Cox M, Radka C, Betzel C. "Effect of macromolecular mass transport in microgravity protein crystallization." Gravitational and Space Research. 2019;7:33-44. Published online: 10 Sep 2019. https://doi.org/10.2478/gsr-2019-0005 , Sep-2019
- Bruno AE, Charbonneau P, Newman J, Snell EH, So DR, Vanhoucke V, Watkins CJ, Williams S, Wilson J. "Classification of crystallization outcomes using deep convolutional neural networks." PLoS One. 2018 Jun 20;13(6):e0198883. eCollection 2018. https://doi.org/10.1371/journal.pone.0198883 ; PubMed PMID: 29924841; PubMed Central PMCID: PMC6010233 , Jun-2018
- Niessen KA, Xu M, George DK, Chen MC, Ferré-D'Amaré AR, Snell EH, Cody V, Pace J, Schmidt M, Markelz AG. "Protein and RNA dynamical fingerprinting." Nat Commun. 2019 Mar 4;10(1):1026. https://doi.org/10.1038/s41467-019-08926-3 ; PubMed PMID: 30833555; PubMed Central PMCID: PMC6399446 , Mar-2019

Combustion Science

Fundamental Combustion - Gaseous Fuels

Advanced Combustion via Microgravity Experiments (ACME)



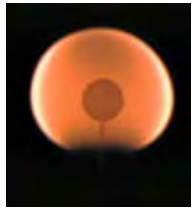
Burning Rate Emulator (BRE)
Quintiere & Sunderland: UMd
A fire safety experiment using gaseous fuels to study solid fuel flammability



Electric-Field Effects on Laminar Diffusion Flames(E-FIELD Flames)
Dunn-Rankin: UCI
An experiment using electric fields to control flames



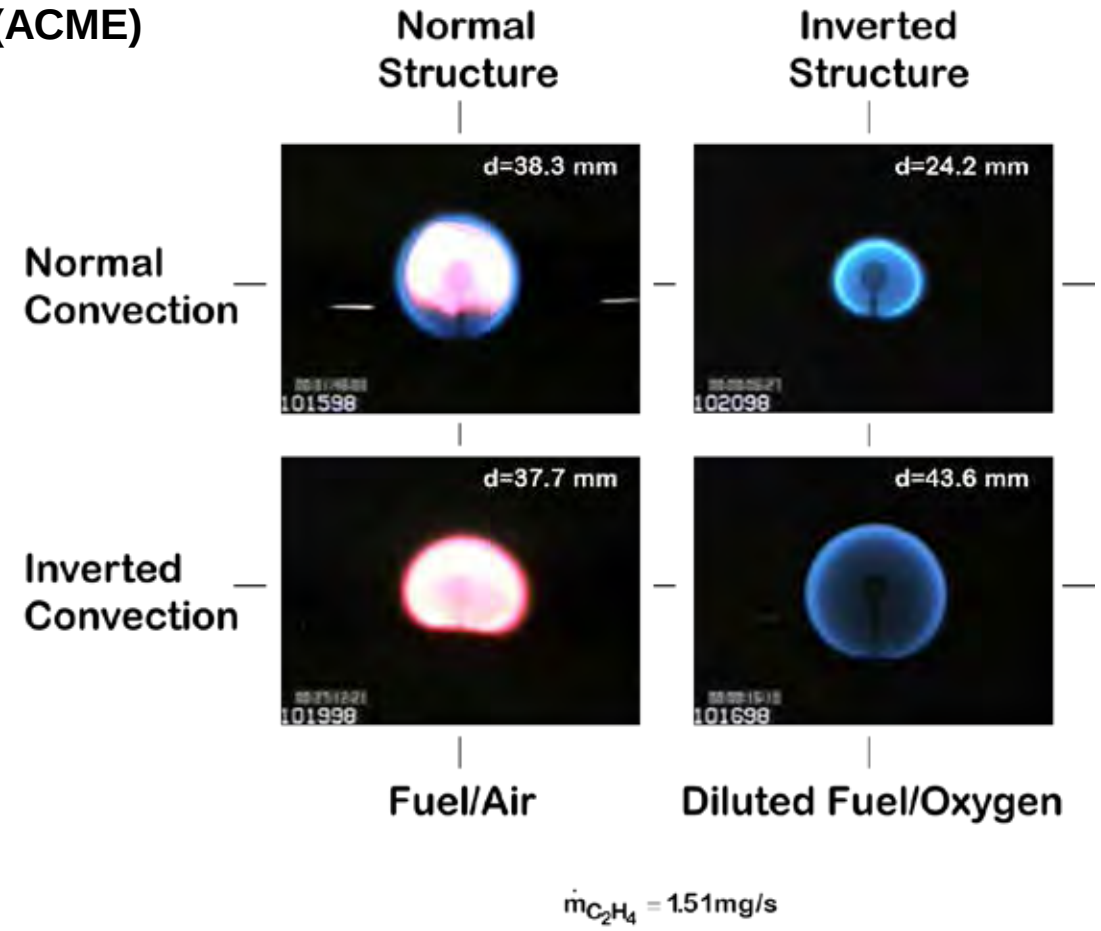
Flame Design
Axelbaum: WUStL et al.
Experiments examining soot inception and transport and flame structure



Structure and Response of Spherical Diffusion Flames (s-Flame)
Law: Princeton
An investigation studying soot formation/destruction mechanisms and combustion chemistry



Coflow Laminar Diffusion Flame (CLD Flame)
Smooke and Long: Yale
Detailed experiments on the structure and stability of gas-jet diffusion flames

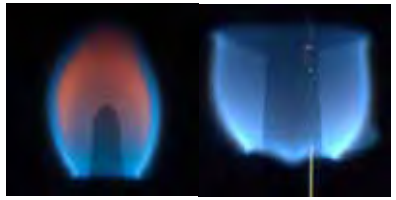


Flame Design: Axelbaum WUStL et al.
Soot inception and transport through control of the flame structure
To guide lower polluting combustors and to facilitate carbon sequestration

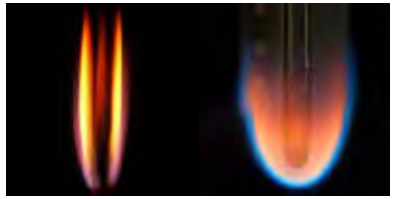
42

Spacecraft Fire Safety - Solid Fuels

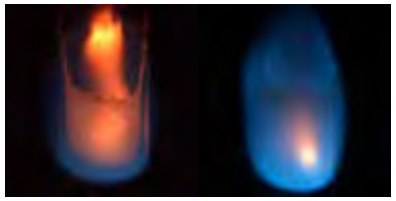
Solid Fuel Ignition and Extinction (SoFIE)



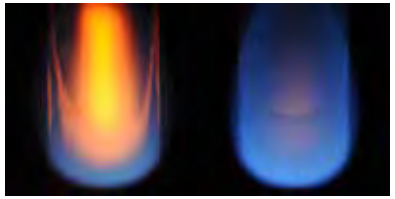
Material Ignition and Suppression Test (MIST)
Fernandez-Pello: UC Berkeley
Fundamental experiments of solid material ignition from an external heat source



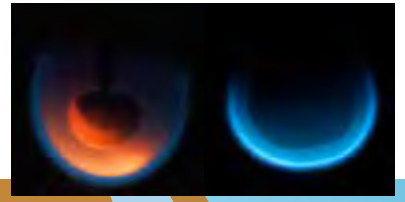
Spacecraft Materials Microgravity Research on Flammability (SMµRF)
Olson: NASA GRC
Flame spread experiments studying the flammability limits of solid fuels



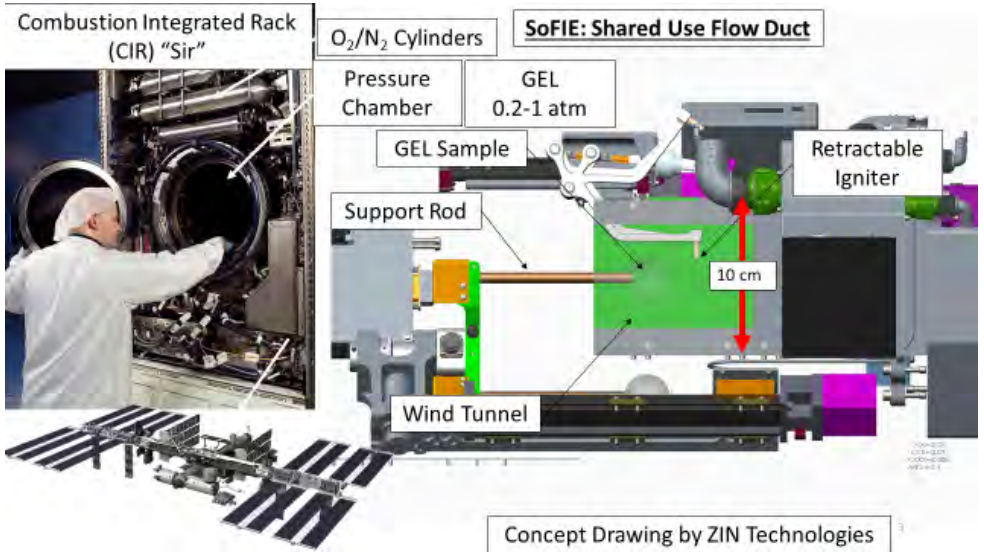
Narrow Channel Apparatus (NCA)
Miller: San Diego State University
Flame spread experiments focused on thick polymeric materials



Residence Time Driven Flame Spread (RTDFS)
Bhattacharjee: San Diego State University
Opposed-flow flame spread over thin acrylic sheets to examine fuel thickness effects



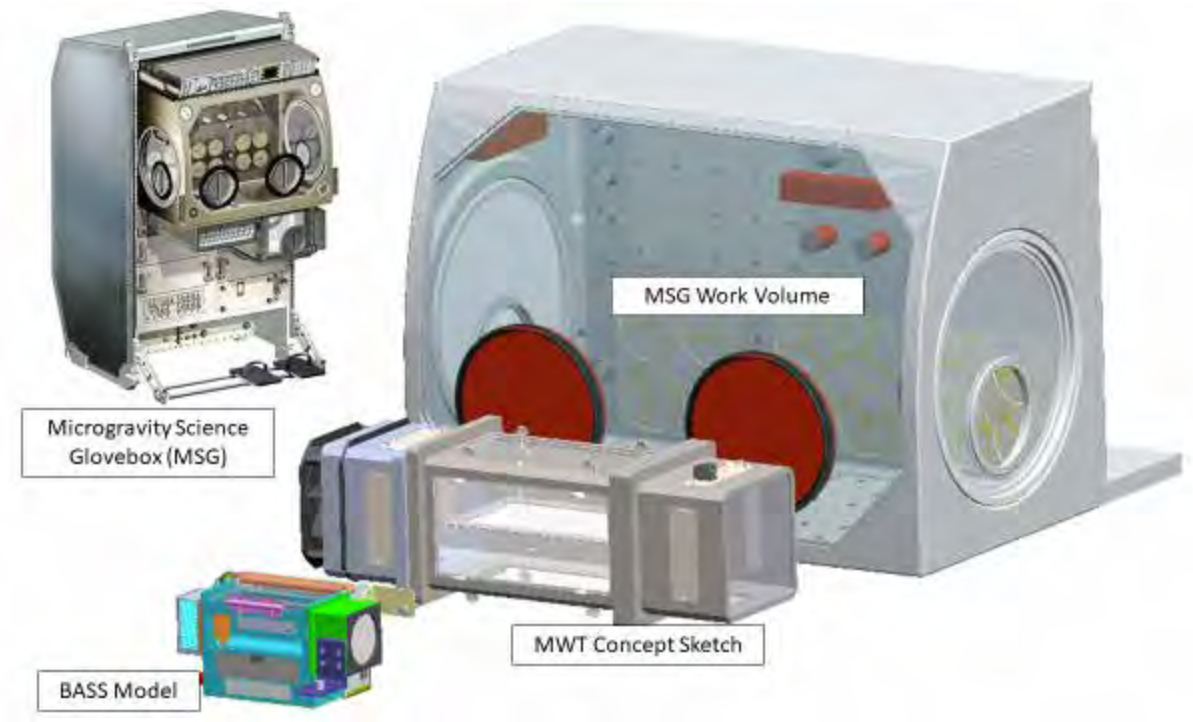
Growth and Extinction Limit (GEL)
T'ien: Case Western Reserve University
Investigating effect of gravity, flow, O_2, pressure, and fuel preheating on the combustion of polymeric spheres



Future Concept ISS Facility

Microgravity Wind Tunnel (MWT)

- MWT is a ‘facility within a facility’ that will eventually support multiple investigations in combustion science and spacecraft fire safety
- Will feature an instrumented wind tunnel with experiment-specific modules that can be swapped out quickly and easily by the crew
  - Solid fuel module (first to be developed) will allow large (NASA Test 6001 sized) solid material samples
  - Future modules to support liquid and/or gaseous fuel experiments



Supercritical Water Mixture and Oxidation (SCWM and SCWO)

High Temperature Insert HTI/HTI-R1/ HTI-R2

Pure SCW — 2011

Behavior of Pure Water Near the Critical Point
Yves Garrabos, ICMCB, Bordeaux, PI
Carole Lecoutre, ICMCB
Michael Hicks, GRC
Uday Hegde, CWRU

DECLIC

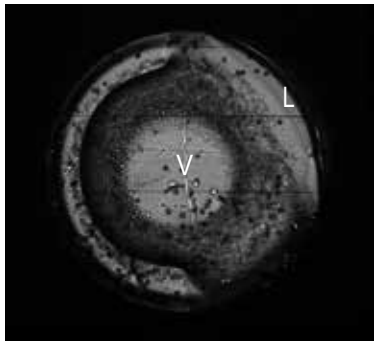
SCW / salt solution — 2017

Behavior of a Salt-Water Mixture Near the Critical Point-1 (SCWM-1)
Michael Hicks, GRC, PI
Uday Hegde, CWRU
Yves Garrabos, Carole Lecoutre, Sam Marre, ICMCB, Bordeaux



HTI/HTI-R insert (DECLIC)

DECLIC Hardware developed by:
CNES, Toulouse
Cecile Fiachetti, PM
Christophe Delaroche, PM



Dissolution of the Liquid (L)-Vapor (V) interface near the critical point (SCWM-1)

SCW / TBD (salt-2 / CO2) — 2021

Behavior of a Salt-Water Mixture Near the Critical Point-2 (SCWM-2)
Michael Hicks, GRC, PI
Uday Hegde, CWRU
Yves Garrabos, Carole Lecoutre, Sam Marre, ICMCB, Bordeaux

DECLIC-Evo

SCWO-D Insert

SCWO — ca 2024

Supercritical Water Oxidation (SCWO) Processes Including Phase Transitions, Transcritical Fluid Dynamics and Hydrothermal Flames



10 mm

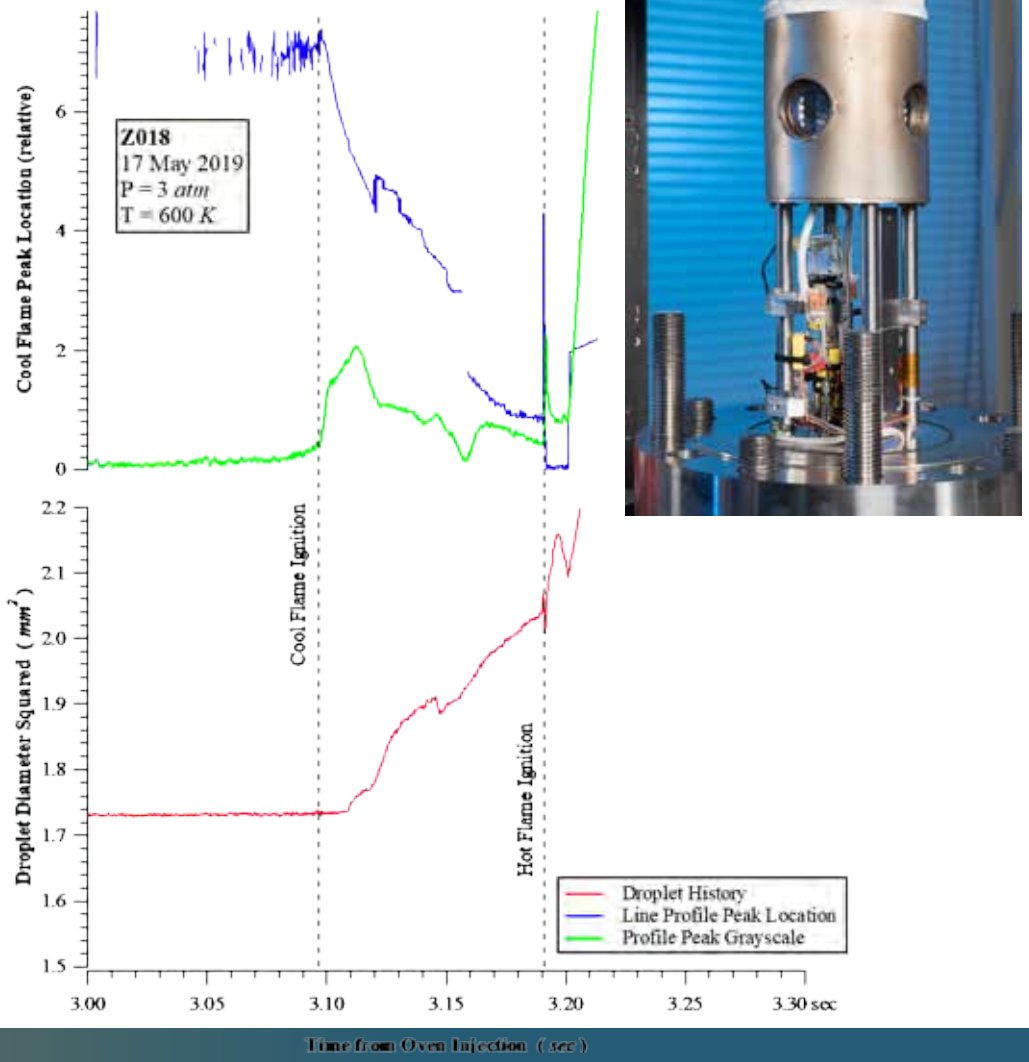


Ethanol-Water Hydrothermal Flames-GRC SCWO Lab

Future Combustion Research

High Pressure Transcritical Combustion (HPTC)

- Highest priority research area from 2014 peer-review of combustion program
- Leverage the discovery of cool-flame supported droplet combustion
- High pressure facility built and operational in GRC Zero-Gravity facility
- On-going experiments involving droplet ignition
- Access to high quality microgravity environment offers significant potential to improve understanding of high pressure combustion
- Science Definition Team to provide peer input for future activities in process





Top Publications – Combustion

- Williams, F.A., and V. Nayagam. "Quasi-steady combustion of normal-alkane droplets supported by cool-flame chemistry near diffusive extinction." Combustion Theory and Modelling 23(4) (2019): 748 – 770
- Nayagam, V., D.L. Dietrich, M.C. Hicks, and F.A. Williams. "Radiative extinction of large n-alkane droplets in oxygen-inert mixtures in microgravity." Combustion and Flame, 194 (2018): 107 - 114
- Ju, Y., C.B. Reuter, O.R. Yehia, T.I. Farouk and S.H. Won. "Dynamics of Cool Flames." Progress in Energy and Combustion Science, 75 (2019): 100787
- Alam, F.E., A.C. Aghdam, F.L. Dryer, and T.I. Farouk. "Oscillatory cool flame combustion behavior of submillimeter sized n-alkane droplet under near limit conditions." Proceedings of the Combustion Institute, 37(3) (2019):3383 – 3391.
- Farouk, T. I., D. Dietrich, and F.L. Dryer. "Three stage cool flame droplet burning behavior of n-alkane droplets at elevated pressure conditions: Hot, warm and cool flame." Proceedings of the Combustion Institute, 37(3) (2019):3353 – 3361.
- Hossain, S., I.S. Wichman, F.J. Miller, and S.L. Olson. "Opposed flow flame spread over thermally thick solid fuels: buoyant flow suppression, stretch rate theory, and the regressive burning regime." Combustion and Flame 219 (2020): 57-69
- Marcum, J. W., P. Rachow, P. V. Ferkul, and S. L. Olson. "Low pressure flame blowoff of the stagnation region of cast PMMA cylinders in axial mixed convective flow." Combustion and Flame 216 (2020): 385-397.
- Bhattacharjee, S., and L. Carmignani. "Radiation-kinetics interactions: A comparison of opposed-flow flame spread in a low-velocity microgravity and low-pressure downward environments." Proceedings of the Combustion Institute (2020) to appear.
- Endo, M., J.S. Tien, P.V. Ferkul, S.L. Olson, and M.C. Johnston. "Flame growth around a spherical solid fuel in low speed forced flow in microgravity." Fire Technology 56(1) (2020): 5-32.

Complex Fluids

Complex Fluids: Colloids

Advanced Colloids Experiments – Temperature Controlled (ACE-T)

Objectives: Obtain phase diagrams as a function of temperature, particle concentration, and geometry.

ACE-T4, PI: Arjun Yodh, University of Pennsylvania

- Focus: Effect of polydispersity – how to inhibit glasses from crystallizing in microgravity – one example, time release (glassy) coatings on medicines. Monodisperse glasses crystallize in space and behave quite differently.

ACE-T7, PI: Paul Chaikin, New York University

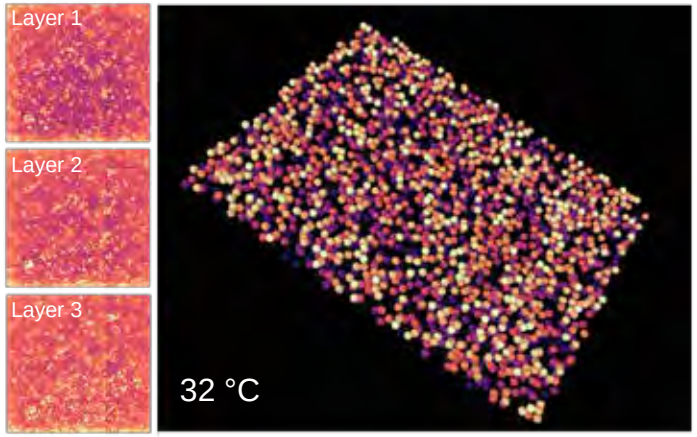
- Focus: Determine Phase Diagram for Cubes. These supercube crystals grow much larger in space. Relevant for advanced optical materials.

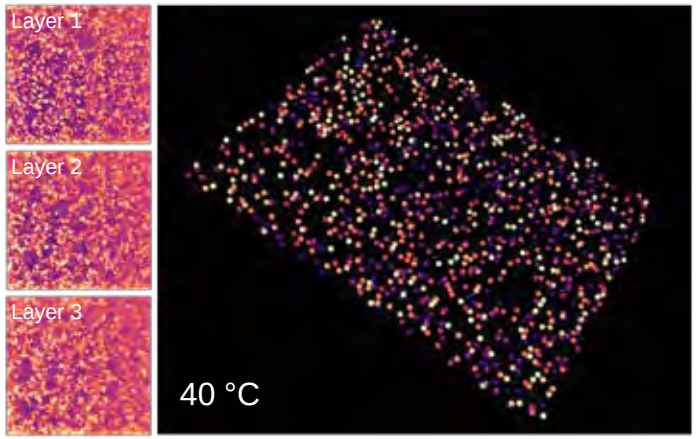
ACE-T11, PI: Boris Khusid, New Jersey Institute of Technology

- Focus: Determine Phase Diagram for Spheres. Monodisperse glasses crystallize in microgravity – observe the disorder to order transition.

ACE-TR-1, PI: Boris Khusid, New Jersey Institute of Technology, Paul Chaikin and Andrew Hollingsworth New York University

- Focus: Determine Phase Diagram for Ellipsoids. Elliptical particles seen to self-align in microgravity where we can also study the formation of defects. Particles the size of the wavelength of light may be used to control light.





ACE-T4 This work will provide information about the microstructure of gels, and about how gels evolve and break in response to internal stresses that are different from stresses that arise on earth due to gravity. These insights, enabled by microgravity, could be useful for the design of tougher and more durable gels.

Complex Fluids: Colloids

Advanced Colloids Experiments – Temperature Controlled (ACE-T)

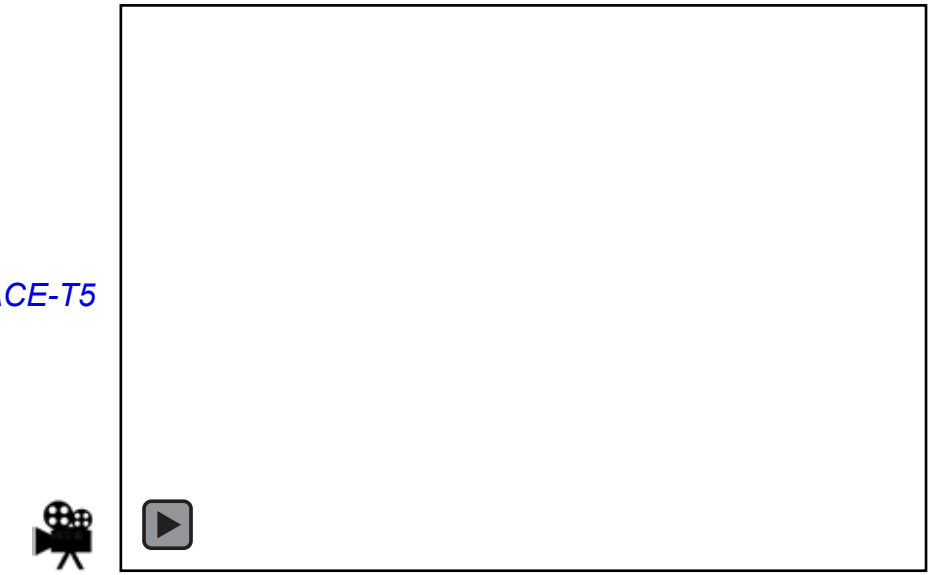
ACE-T5, PI: Ali Mohraz, University of California, Irvine
- Objective: Quantify the theory behind bigels useful for creating large surface area electrodes and creating coatings that ensure the human body does not reject implanted tissues and devices.

ACE-T6, PI: Matthew Lynch, Proctor and Gamble
- Objective: Examine shelf life stabilizers as a function of stabilizer polydispersity. Can study coarsening of real-world colloidal gels without collapse in microgravity.

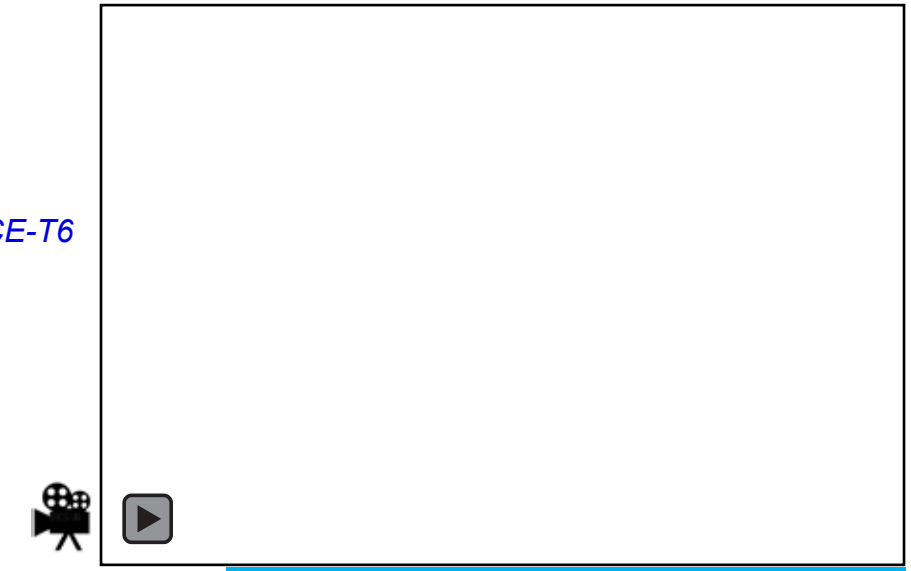
ACE-T9, PI: David Marr, Colorado School of Mines
- Objective: Assembling colloidal structures from micron-sized particles using magnetic fields.

ACE-T12, PI: Stuart Williams, University of Louisville
- Objective: Study Nano-particle Haloing which may enable the development of more efficient solar collectors by providing more charge carriers.

ACE-T5



ACE-T6



A 3D image of a product stabilizer where microgravity enabled us to see (with sedimentation removed) that some particles sizes were more effective than others.

Complex Fluids: Liquid Crystal Facility

Noel Clark, University of Colorado at Boulder

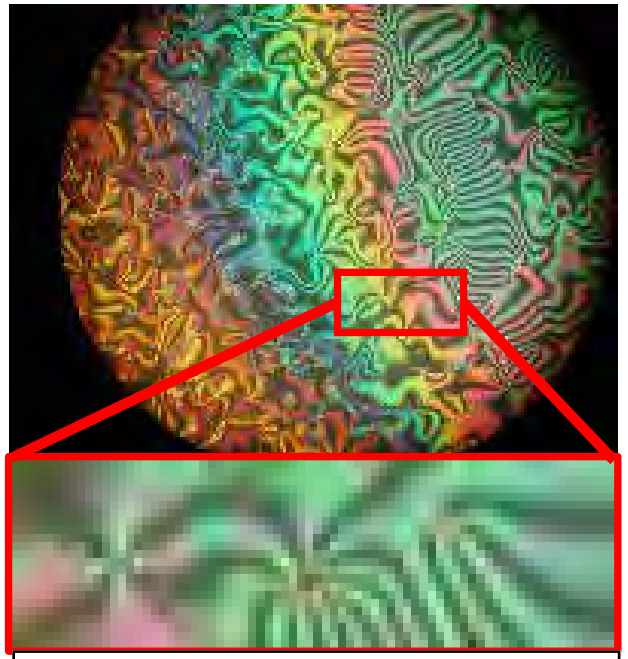
- Objective: Study of interactions and dynamics of ferro magnetic inclusions in freely suspended liquid crystal films

Charles Rosenblatt, Case Western Reserve

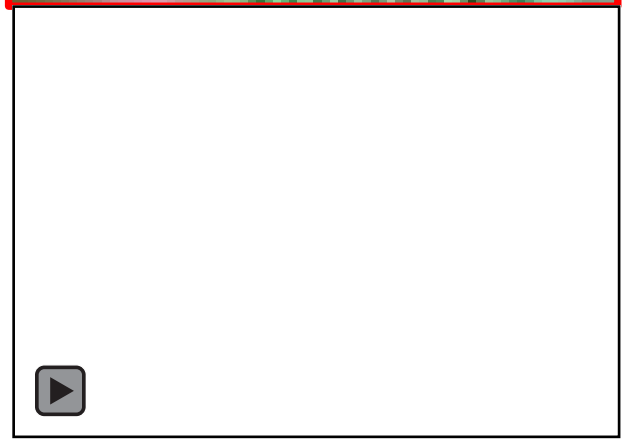
- Objective: Examine thin, smectic-C films, their 2D topological defects, and nanoparticle inclusions in a microgravity environment

Hiroshi Yokoyama, Kent State University

- Objective: Study structural evolution of islands on liquid crystal films: Ostwald Ripening, island-island Interactions, and Lehmann Rotation.



Topological Defects and Liquid Crystals



Ferromagnetic droplet in the rotating magnetic field as a function of amplitude and frequency

Foam Optics And Mechanics (FOAM)

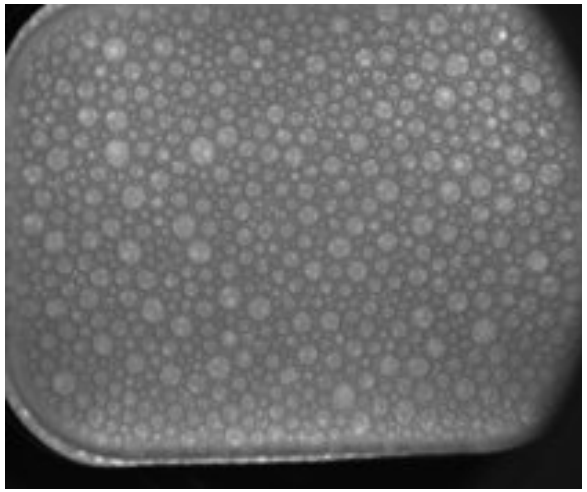
Team Coordinator : Professor Dominique Langevin (University of Paris, France)
US PI: Douglas Durian, Physics Department, University of Pennsylvania
Team: D. Weaire (Ireland); Nicolas Vandewalle, Hérvé Caps, Giles Delon (Belgium); Ko Okamura (Japan); Andrei Sonin (Russia)

Objectives:

- To exploit microgravity conditions to quantify and elucidate the unusual elastic character of foam structure and dynamics.
- To observe how the foam melts into a simple viscous liquid as a function of both increasing liquid content and shear strain rate.
- The flight research generates valuable fundamental guidance for the development of foam materials with more desirable rheology and better stability.



FOAM C Hardware, ISS Image



FOAM C Image from ISS

Top Publications – Complex Fluids

- Susser, Adam; Sata Harkai, Samo Kralj, and Charles Rosenblatt. "Transition from escaped to decomposed nematic defects, and vice versa." Royal Society of Chemistry: Soft Matter Journal.
- Sherman, Zachary M., and James W. Swan. "Spontaneous Electrokinetic Magnus Effect." Physical Review Letters 124, no. 20 (2020): 208002.
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- T. Yang, B. Sprinkle, Y. Guo, J. Qian, D. Hua, A. Donev, D.W.M. Marr, and N. Wu, “Reconfigurable Microbots Folded from Simple Colloidal Chains”, Proceedings of the National Academy of Sciences of the USA, 2020, DOI:10.1073/pnas.2007255117.

Fluid Physics

Adiabatic Two-Phase Flow

Packed Bed Reactor Experiment (PBRE-1), PI: Brian Motil, NASA GRC

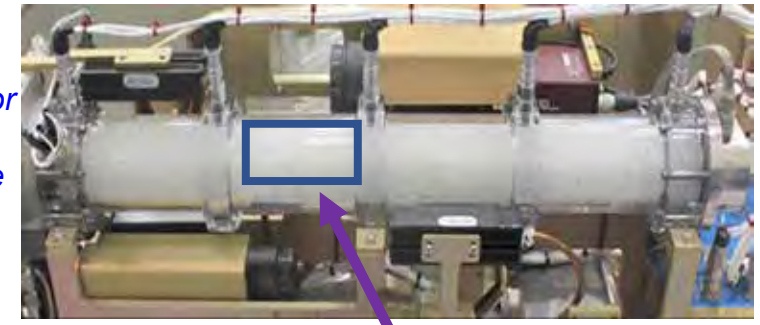
- Objective: Investigate the impact of packing diameter on the role and effects of gravity on hydrodynamics of gas-liquid flow through porous media.

Packed Bed Reactor Experiment (PBRE-2), PI: Brian Motil, NASA GRC

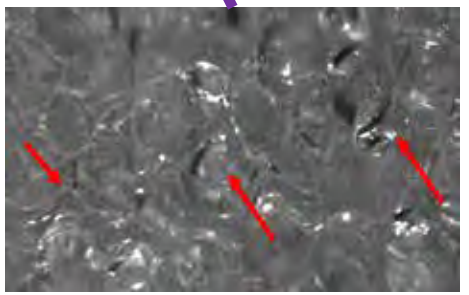
- Objective: Extended investigation on the impact of packing diameter on the role and effects of gravity on hydrodynamics of gas-liquid flow through porous media.

PBRE-Water Recovery, PI: Layne Carter, NASA MSFC

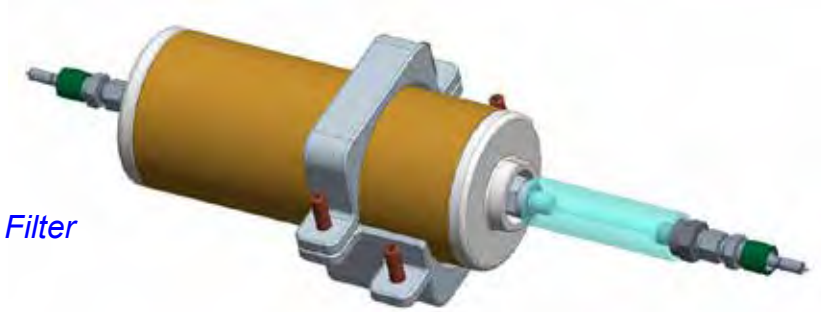
- Objective: Develop/validate scaling laws and design tools for future water recovery systems in μ-g and partial-g environments, including start up and transient operations.
- Objective: Identify strategies to recover from undesired trapped gas bubbles in system components such as the following:
  - PBRE-WR-1: Pressure drop across catalytic packed bed.
  - PBRE-WR-BPF: Bubble point measurements with filter
  - PBRE-WR-BPBF: Bubble point measurement with brine filter
  - PBRE-WR-FH: Flex hose
  - PBRE-WR-CV: Check valves
  - PBRE-WR-O: Orifices



Packed Bed Reactor Experiment Test Section and Cradle



Trapped bubbles inside the packed bed affect the pressure drop and distribution and flushing the column before each run with gas or liquid seems to impact the effective porosity in the bed

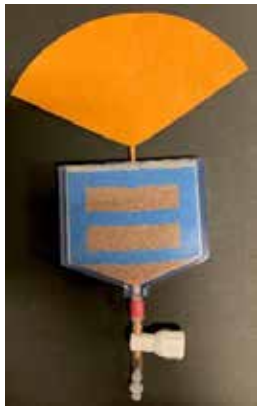


CAD Model of Urine Transfer Filter Test Article

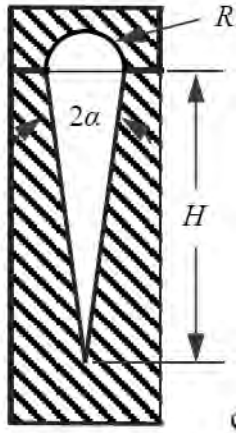
Capillary Flow

Plant Water Management (PWM), PI: Mark Weislogel, Portland State University

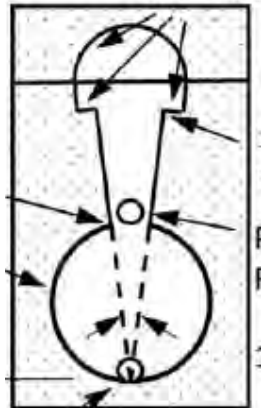
- Objective: Evaluate options for adequate hydration and aeration techniques for soil media and other farming strategies including but not limited to: Aeroponics, Hydroponics, and Soil-based media
- Soil (PWM-S): Establish a “capillary gradient” using material wettability to provide controlled to establish the ability to compare typical
- Hydroponics (PWM-H): Demonstrate the ability to utilize system geometry to provide positive water control for plant hydration.
- Root Accommodation Channel (PWM-HRAC): Provide accommodations for root growth as plant matures in a hydroponic channel.
- Parallel Channel (PWM-PHRAC): Examine system stability for growing multiple plants at different growth stages and water uptake rates.



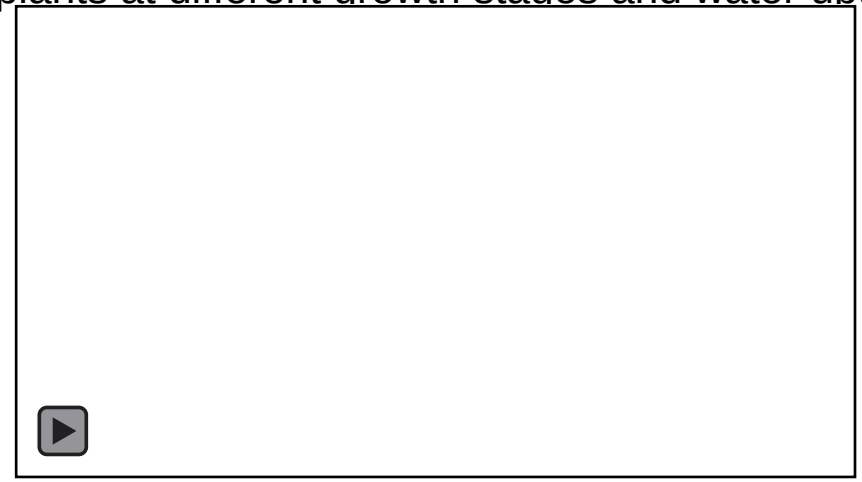
PWM –S test cell



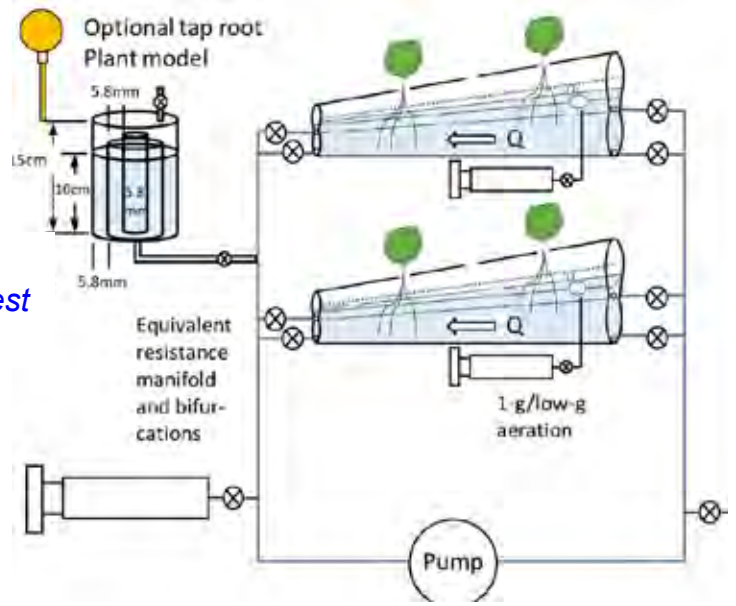
PWM –H Cross-Section



PWM –HRAC Cross-Section



Portland State Drop Test of PWM-H with plant simulate



PWM – PHRAC Test Setup

Fluid Physics: Cryogenic Fluid Management

Zero Boil Off Tank Experiment -1 (ZBOT - 1): PI: Mo Kassemi, Case Western Reserve University

- Objective: Investigate the effect of heat transfer on tank pressurization in microgravity and observe impact of mixing on destratification.

Zero Boil Off Tank Experiment – Non-Condensables (ZBOT - NC): PI: Mo Kassemi, Case Western Reserve University

- Objective: Investigate the effect of noncondensable gasses on microgravity vapor transport in the ullage during pressurization.

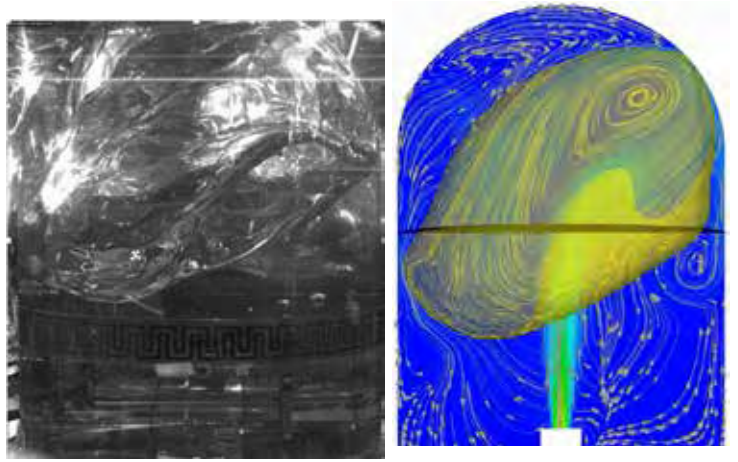
Zero Boil Off Tank Experiment - Droplet Phase Change (ZBOT- DP): PI: Mo Kassemi, Case Western Reserve University

- Objective: Examine an array of different active cooling strategies, and establish a microgravity foundation for comparison and optimization future storage pressure control design.

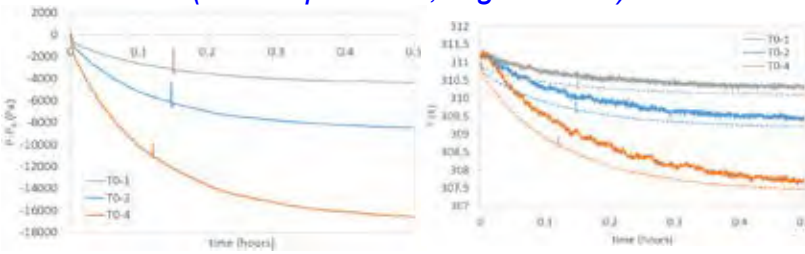
Zero Boil Off Tank Experiment - Filling and Transfer (ZBOT - FT): PI's: Michael Dryer, University of Bremen, University of Bremen and Mo Kassemi, Case Western Reserve University.

- Objective: understand the effect of microgravity on two-phase phase change and flow on tank filling of a volatile fluid.

In Space Cryogenic Refueling Research - Transfer Line – Investigate chill down and associated boiling heat transfer to Support Cryogenic Propellant Tank Transfer Research. Two NRA proposals selected.



Ullage Shape during jet mixing
(left –experiment, Right model)



Impact of jet mixing on
(left -saturation pressure, right- temperature)

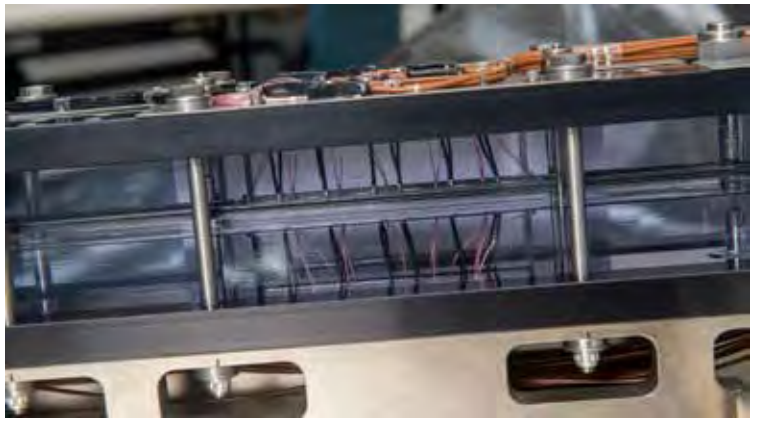


Cryogenic Fuel Depot Concept

Fluid Physics: Thermal Management

Rankine Power Cycle and Cryogenic Line Chill-down

- Flow Boiling and Condensation Experiment (FBCE), PI. Issam Mudawar, Purdue University
  - Objective: Develop experimentally validated, mechanistic model for microgravity annular condensation and dimensionless criteria to predict minimum flow velocity required to ensure both gravity independent annular condensation.
- **2021 NSF/CASIS Transport Phenomena sollicitation** - two proposals selected



Heated Section of Flow Boiling Test module

μG Flow Boiling Test on aircraft

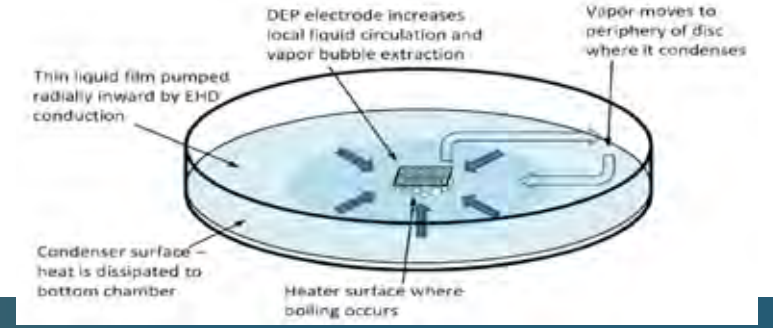


μG Condensation Test on aircraft



Electronic Cooling

- Electrohydrodynamics Experiment (EHD), PI: Jamal Yagoobi, Worcester Polytechnic Institute
  - Objective: Characterize the effects of gravity on the interaction of electric and flow fields in the presence of phase change specifically pertaining to EHD generated two-phase flow and liquid film boiling and di-electro-phoretically (DEP) extracting bubbles from heating surface.
- **EPSCoR grant**, Impacts of Gravity on Dropwise Condensation Enhanced Heat Pipes PI: Chen Li, College of Charleston
  - Objective: Investigate Dropwise Condensation in drop tower.



EHD experiment Concept

Top Publications – Fluid Physics

- Qiu, Yue, Deepak Garg, Liwei Zhou, Chirag R. Kharangate, Sung-Min Kim, and Issam Mudawar. "An artificial neural network model to predict mini/micro-channels saturated flow boiling heat transfer coefficient based on universal consolidated data." International Journal of Heat and Mass Transfer 149 (2020): 119211.
- Lee, Jeongmin, Lucas E. O'Neill, and Issam Mudawar. "3-D computational investigation and experimental validation of effect of shear-lift on two-phase flow and heat transfer characteristics of highly subcooled flow boiling in vertical upflow." International Journal of Heat and Mass Transfer 150 (2020): 119291.
- Motil, Brian J., Enrique Ramé, Paul Salgi, Mahsa Taghavi, and Vemuri Balakotaiah. "Gas–Liquid Flows Through Porous Media in Microgravity: The International Space Station Packed Bed Reactor Experiment." AIChE Journal: e17031.
- T.T.T Nguyen, A. Kundan, J. Yu, P.C. Wayner Jr., J.L. Plawsky, D.F. Chao, R.J. Sicker, "Rip Currents: A Spontaneous Heat Transfer Enhancement Mechanism in a Wickless Heat Pipe," IJHMT 149 119170 (2020).
- Bhattacharya, S., Roy, I., Tice, A., Chapman, C., Udangawa, R., Chakrapani, V., Plawsky, J. L., and Linhardt, R.J, "One Step Solution for High Conductivity and High Charge Storage Capacity of Electrospun Fibers," ACS Appl. Mater. Interfaces 2020, 12, 19369−19376.
- Kassemi M, Hylton S, Kartuzova O (2020) "1G and Microgravity Sel-Pressurization; Experiments and CFD Model Validations across Ra and Bo Regimes." Int. J. Microgravity Sci. Applications, Vol 37, (1) pp. 370103: 1-6.

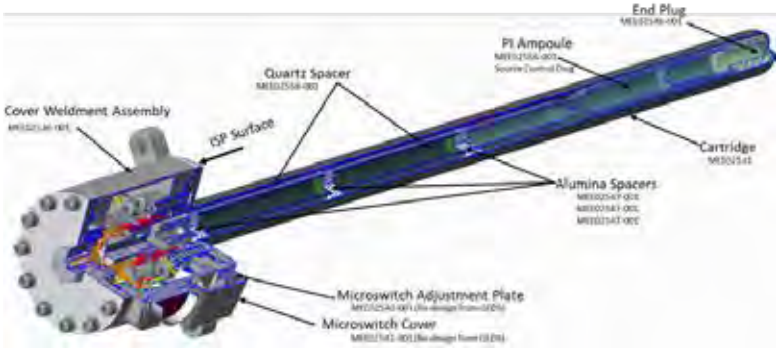
Materials Science

Solidification – High Temperature

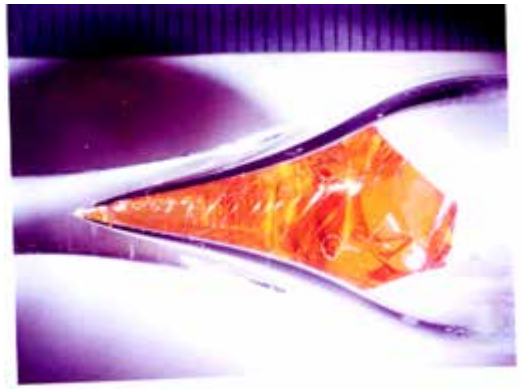
Materials Science Research Rack (MSRR) Materials Science Laboratory (MSL) Low Gradient Furnace (LGF)

Sample Cartridge Assemblies (SCA) for the PIs to perform their science

- Rand German, San Diego State
  - Objective: Understand the underlying scientific principles to predict density, size, shape, and properties for liquid phase sintered bodies over a broad range of compositions.
- Ching-Hua Su, NASA MSFC
  - Objective: Evaluate the effects of gravity on Physical Vapor Transport (PVT) container-less growth processes of semiconductors. Microgravity PVT-grown semiconductors could provide improved crystalline quality and electro-optical properties.
- Doug Hofmann, NASA JPL
  - Objective: Develop tungsten-reinforced bulk metallic glass (BMG) matrix composites and demonstrate wear resistance as compared to samples made on the ground.
- Alexsander Ostrogorsky, Illinois Institute of Technology
  - Objective: Measure diffusion coefficients of dopants in germanium. An accurate understanding of the diffusivities of impurities in Si and Ge is of high technical value for industry.

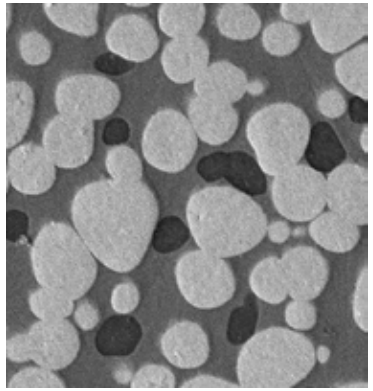


Design of SCA for Dr. Su.

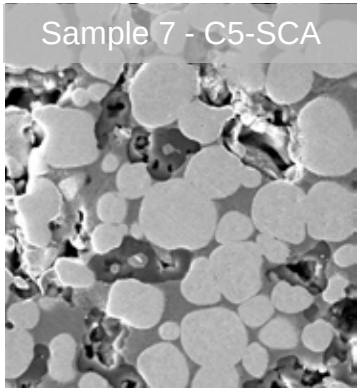


Horizontally grown ZnSe crystal grown horizontally on ground in support of Dr. Su's experiment. The (110) facets aligned parallel to the gravitational direction.

GEDS



Ground experiment:
Pores and grains are round



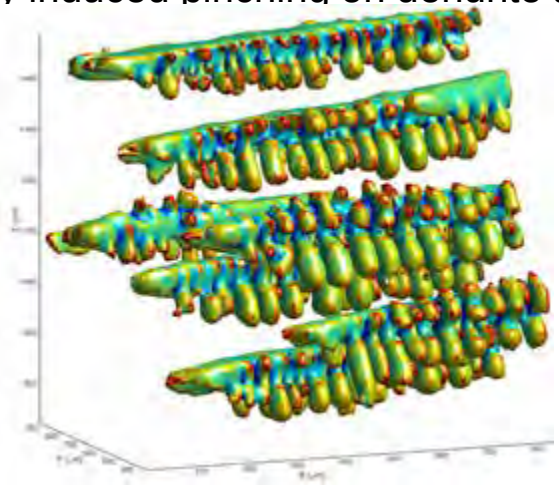
Microgravity Experiment:
Less densification and different pore/grain distribution

- The Gravitational Effects on Distortion in Sintering (GEDS) experiment focuses on understanding the underlying scientific principles to predict density, size, shape, and properties for liquid phase sintered bodies over a broad range of compositions.
  - The final GEDS sample was processed on Wednesday, June 24th, 2020, on the International Space Station.
- The GEDS experiment completed heat cycles at over 1200°C to induce liquid phase sintering densification of high-density tungsten alloys
  - Early results indicate less densification in microgravity, even with liquid formation to assist sintering.
- The pathway for microstructure-density-distortion is clearly different in microgravity from that on Earth.
- All experiments were completed without leaks or other failures. One sample cartridge assembly (SCA) was returned to the PI, **Dr. Rand German**, on 2/5/2020.
  - The rest of the SCAs are expected to return on SpX-21 (December 2020) and Spx-22 (Summer 2021).

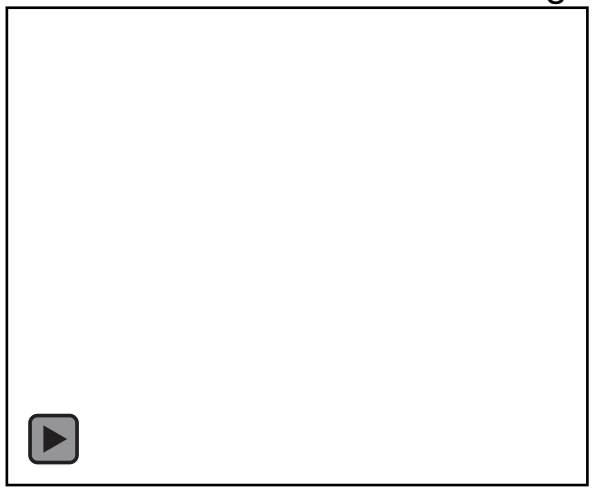
Solidification – Mid Temperature

The Solidification Using a Baffle in Sealed Ampoules (SUBSA) hardware is a furnace that can heat samples up to 850°C for a variety of materials science experiments, and there are currently 3 NASA-funded Investigators with upcoming SUBSA experiments:

- Dusan Sekulic, University of Kentucky
  - Objective: Better understand processing kinetics (enhanced wetting, spreading, capillarity) of brazing in low-g environments.
- Christoph Beckermann, University of Iowa
  - Objective: Improve the understanding of the columnar-to-equiaxed transition (CET) during solidification of metal alloys.
- Peter Voorhees, Northwestern University
  - Objective: Given the importance of dendrite fragmentation on the presence and location of a CET, examine the roles of melting and capillarity induced pinching on dendrite arm fragmentation, retraction and coalescence during cooling.



Pb-Sn alloys processed on the ISS



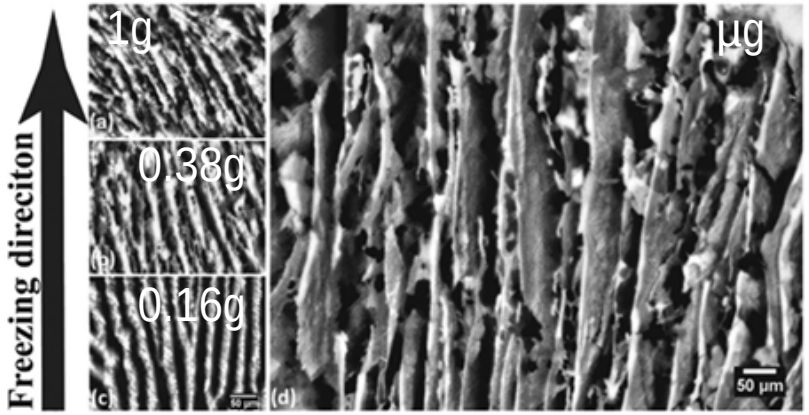
Capillary induced fragmentation

Solidification – Low Temperature

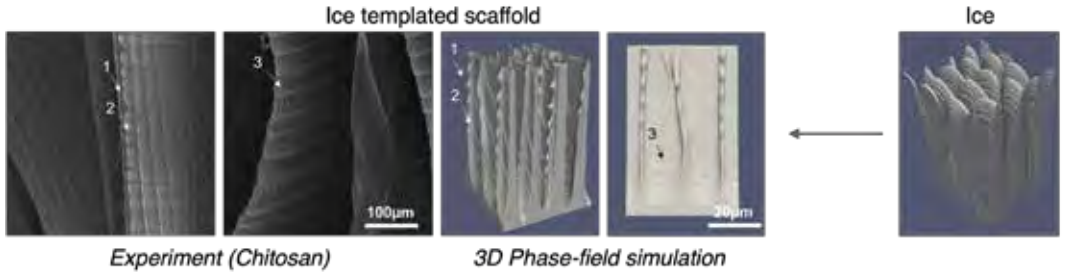
The Pore Formation and Mobility Investigation (PFMI) hardware will melt samples of a transparent modeling material, e.g. succinonitrile and succinonitrile water mixtures. There are currently 2 Investigators with upcoming PFMI experiments:

- David Dunand, Northwestern University
  - Objective: Improve understanding of solidification behavior of freeze cast materials, which will allow for the development of improved processing techniques.
  - Potential applications include high strength, low weight materials.

- Ulrike Wegst, Northeastern University
  - Objective: Investigate the underlying physics of forming complex scaffolds using the freeze casting methodology.
  - Potential applications include lightweight structural materials as well as scaffolds for peripheral nerve repair.



Dunand: Longitudinal cross-sections of sintered TiO_2 samples sintered from 20 wt% TiO_2 aqueous suspensions directionally solidified under (a) terrestrial, (b) Martian, (c) lunar, and (d) microgravity conditions.



Wegst: Features of freeze-cast templated structures captured by both experiment and 3D phase-field simulation. The salient features include the formation of **lamellae** (1), **undulated ridges** (2) and **wrinkled cell walls** (3).

Ji et al. (2019) MRS Fall Meeting 2019, 1-6 December, Boston, MA, USA

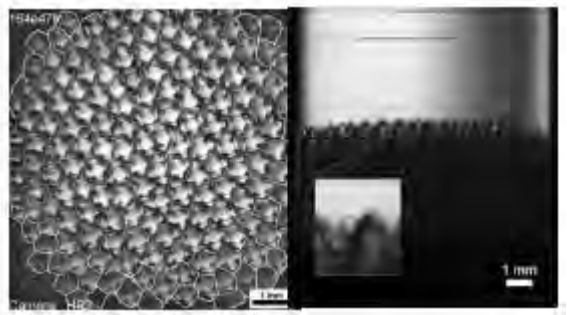
Solidification – Transparent Alloys

Device for the study of Critical Liquids and Crystallization – Directional Solidification Insert (DECLIC-DSI) is a facility that can be used to study directional solidification of transparent alloys, such as succinonitrile (SCN).

These alloys solidify the same way metals do and form the same microstructures in the process.

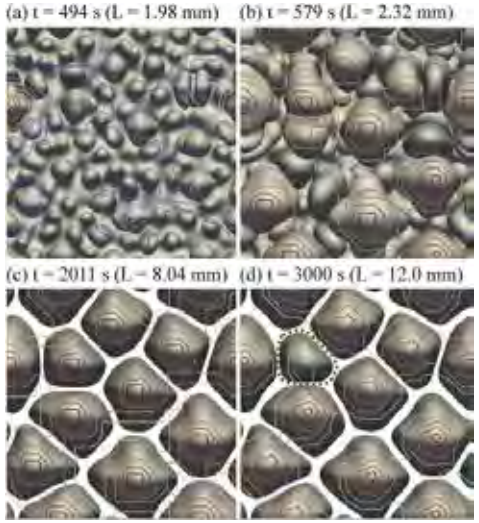
Dr. Rohit Trivedi, Iowa State University

- Objective: Examine the origin and growth of dendrite side-branches during directional solidification. Improved understanding of microstructure formation provides insight into enabling the development of advanced materials of commercial importance.



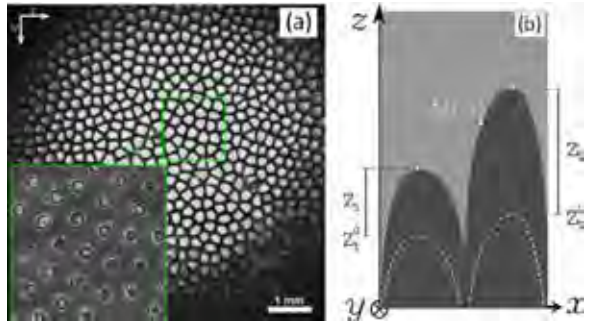
Axial and transverse views of dendritic interface in DECLIC-DSIR on ISS.

Mota, Ji, Lyons, Strutzenberg, Trivedi, Karma & Bergeon, IAC-19-A2.6.2 (October 2019).



Phase field model of interface shape and thermal field for v=4 µs in DECLIC-DSI composition.

Song, et. Al., Acta Mat, 150 (2018)



Axial view of interface with corresponding view of interferometric construction.

Pereda, et. al., Phys Rev E, 102.3, 32804.

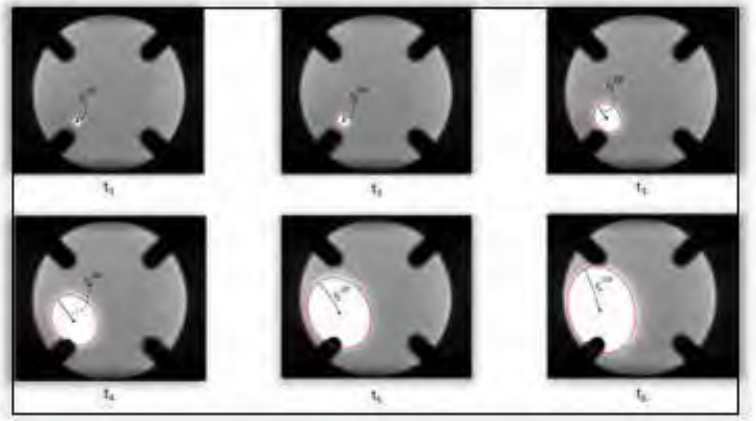
Thermophysical Properties

International Space Station Electromagnetic Levitator (ISS-EML)

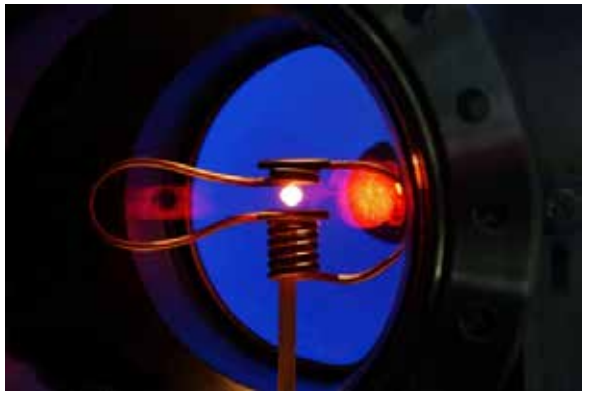
- A multi-user facility for the melting and solidification of conductive metals, alloys, or semiconductors in ultra-high vacuum, or in high-purity gaseous atmospheres.
- The heating and positioning of the sample are accomplished using electromagnetic fields generated by a coil system.
- Installed in the European space laboratory Columbus.

There are currently 3 US PIs with experiments on the ISS-EML

- Robert Hyers, University of Massachusetts
    - Objective: Investigate the thermophysical properties of high-temperature materials used for modeling of material production processes, e.g. additive manufacturing, welding, and casting.
- Kenneth Kelton, Washington University in St. Louise
    - Objective: Correlate the nucleation kinetics with the local structure of a liquid alloy by measuring its thermophysical properties. Applications include bulk metallic glass materials.
- Douglas Matson, Tufts University
    - Objective: Investigate the effect of fluid flow on the solidification path of aerospace alloys, and to measure the thermophysical properties of high-temperature materials. Applications include turbine blades, industrial welding, automobile components.



Growth velocity analysis of a ZrNi ISS-EML sample. Liquid is gray, solid is white.



Sample levitated in an EML at DLR.

Thermophysical Properties



Sample levitated in ELF on ISS during Dr. Matson's ops.



ELF Sample cartridge.

JAXA Electrostatic Levitation Furnace (ELF)

- Materials science facility for thermophysical properties (e.g. density, surface tension, and viscosity) measurement of molten metals, alloys, glasses, and oxides.
- Samples are levitated with an electrostatic field and heated with 4 970nm 40W lasers.
- ELF is installed in the MSPR-2 (Multi-purpose Small Payload Rack #2) in Japanese Experimental Module "KIBO" in the ISS.

There are 4 US investigators with experiment on the JAXA ELF:

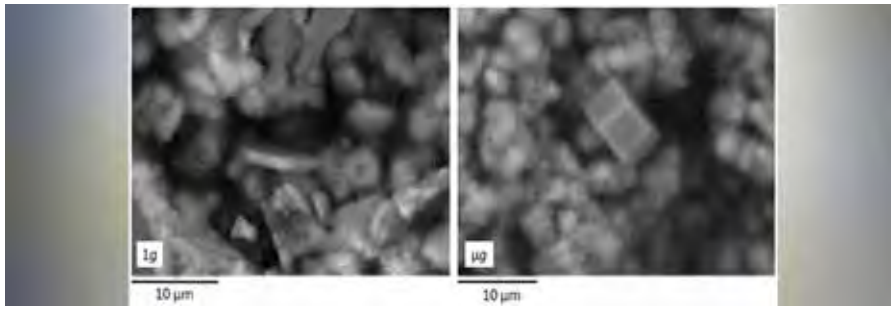
- Robert Hyers, University of Massachusetts
  - Objective: Advance the understanding of photo-refractivity, which has applications in holographic storage, adaptive optics, and phase-conjugate mirrors, using $Bi_{12}SiO_{20}$ and $Bi_{12}GeO_{20}$.
- Douglas Matson, Tufts University
  - Objective: Understand and control the sources of measurement error and to provide a baseline dataset for quantifying uncertainty in measurements (both space- and ground-based).
- Ranga Narayanan, University of Florida
  - Objective: Investigate a novel method to determine the interfacial tension, which is a property that impacts industrial processes such as semiconductor crystal growth and additive manufacturing.
- Richard Weber, Materials Development, Inc
  - Objective: Develop new understanding of the behavior of oxide liquid, glass and ceramic materials in extreme conditions and non-equilibrium conditions. Applications include photonics, lasers, and piezo electrics.

Microgravity Investigation of Cement Solidification (MICS)

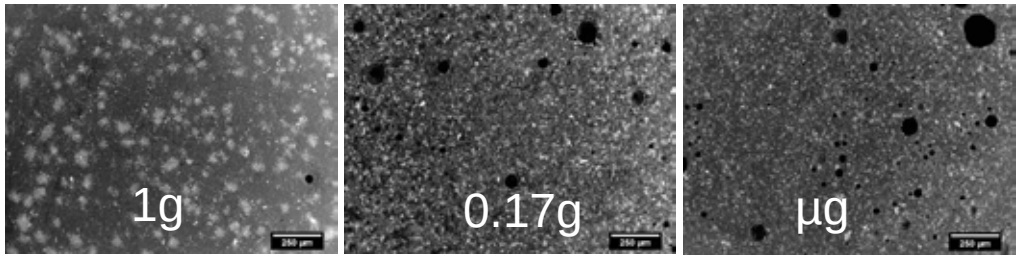
- The MICS experiment used burst pouch samples (shown below).
- Astronauts mixed the Portland cement and water while on orbit by bursting the seal between pouches.
- The TechShot Multi-use Variable-gravity Platform (MVP) was also used to simulate Lunar and Martian gravity.
- Aleksandra Radlińska, Penn State University
  - Objective: Investigate and understand the complex hydration reactions, solidification, and microstructure formation in cement paste subjected to a reduced environment.



MICS burst pouch



Microstructure of solidified cement on Earth and in microgravity (ISS). Crystals tend to grow larger and more uniform in reduced gravity.



As the gravity level decreases, the amount of trapped air and porosity in the samples increases. Microgravity conducted on ISS. Lunar gravity on ISS using centrifuge, MVP.

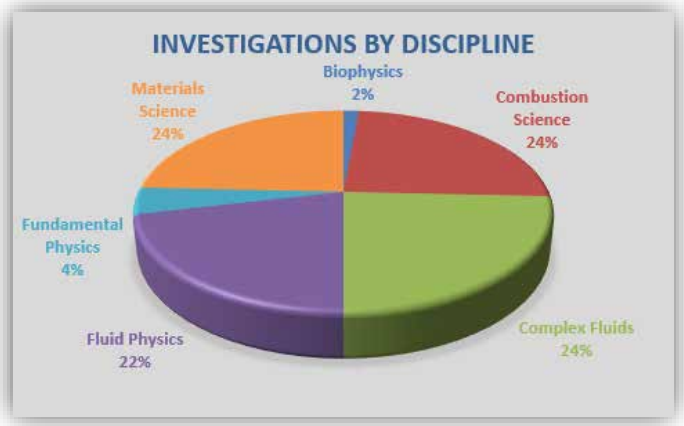
Top Publications - Materials

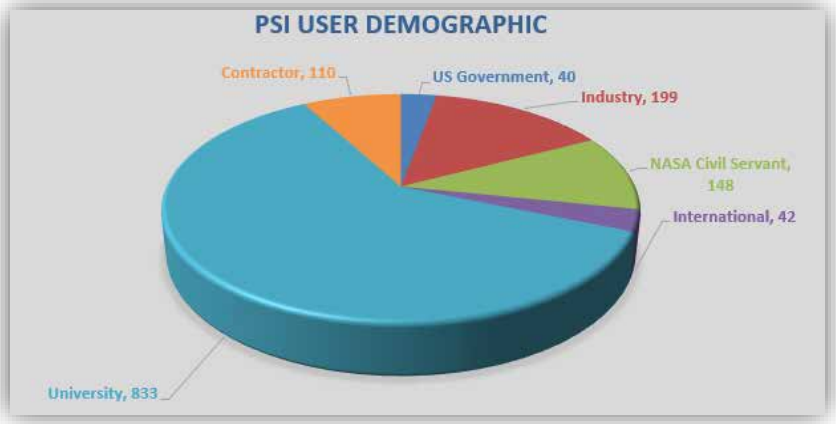
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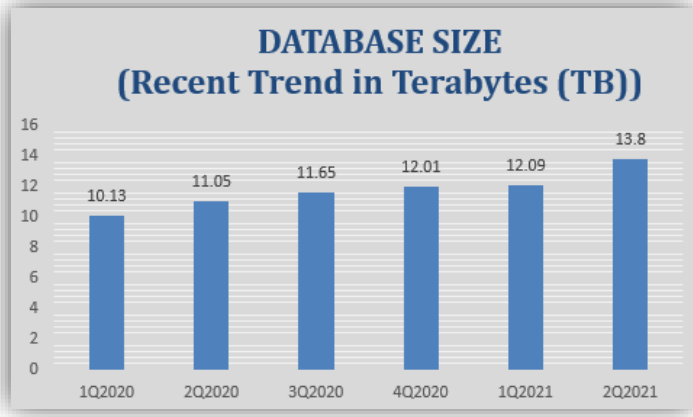
Physical Sciences Informatics System (PSI)

PSI Statistics June – **added 10 Users in May**

72 Investigations | **1,372** Users (+10) | **140** Proposals | **36** Awarded PIs

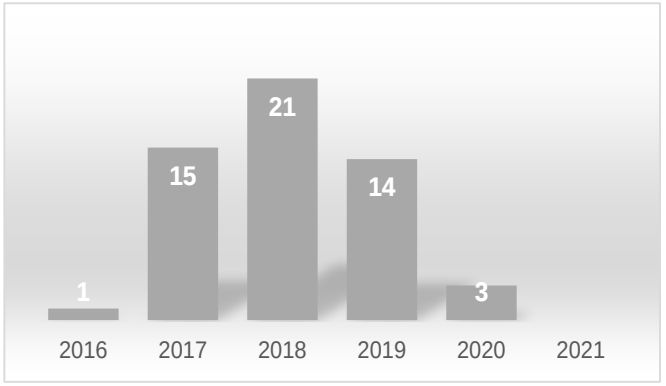


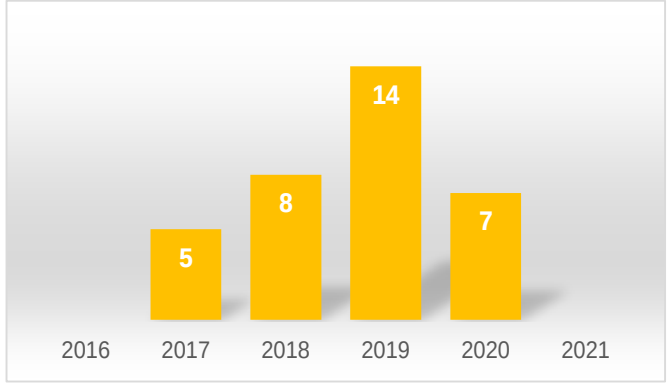


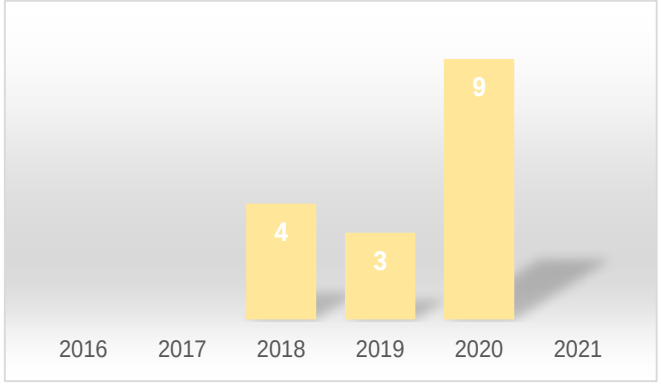


PSI Metrics June – **6 peer rev papers, 2 Awards, 1 MS**

54 Presentations/Abstracts | **40** Journal Articles (+6) | **16** Other Pubs







Physical Science Informatics (PSI) 2021

ROSES - 2021 PSI Program Element

- **To be released: September 15, 2021**
- Eligible flight and ground investigations: 78
- **Proposals Due: January 10, 2022**
- Selections (target): June 2022

- Solicits ground-based research proposals. (Annually)
- Solicits proposals from the following six research areas: Biophysics, Combustion Science, Complex Fluids, Fluid Physics, Fundamental Physics, and Materials Science.
- Ground-based research proposals that present a compelling case on how the data from the PSI system will be used to promote the advancement of further research using data analysis, or numerical and analytical models, or new ground-based experiments.
- **Awards: $100,000/year for two years.**
- **Approximately 5 proposals will be selected**.

- The program element will be available in NSPIRES as part of ROSES-2021.
- For additional information on the PSI database, visit: https://nasa.gov/PSI