National Aeronautics and Space Administration

NASA

EXPLORE SCIENCE

Physical Sciences Program
CBPSS - National Academies
Fall Meeting

Oct. 28, 2020

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Biological and Physical Sciences Division



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Harri Vanhala, NRESS Sr. Scientist

Preethi Manoharan, NRESS Sr. Scientist

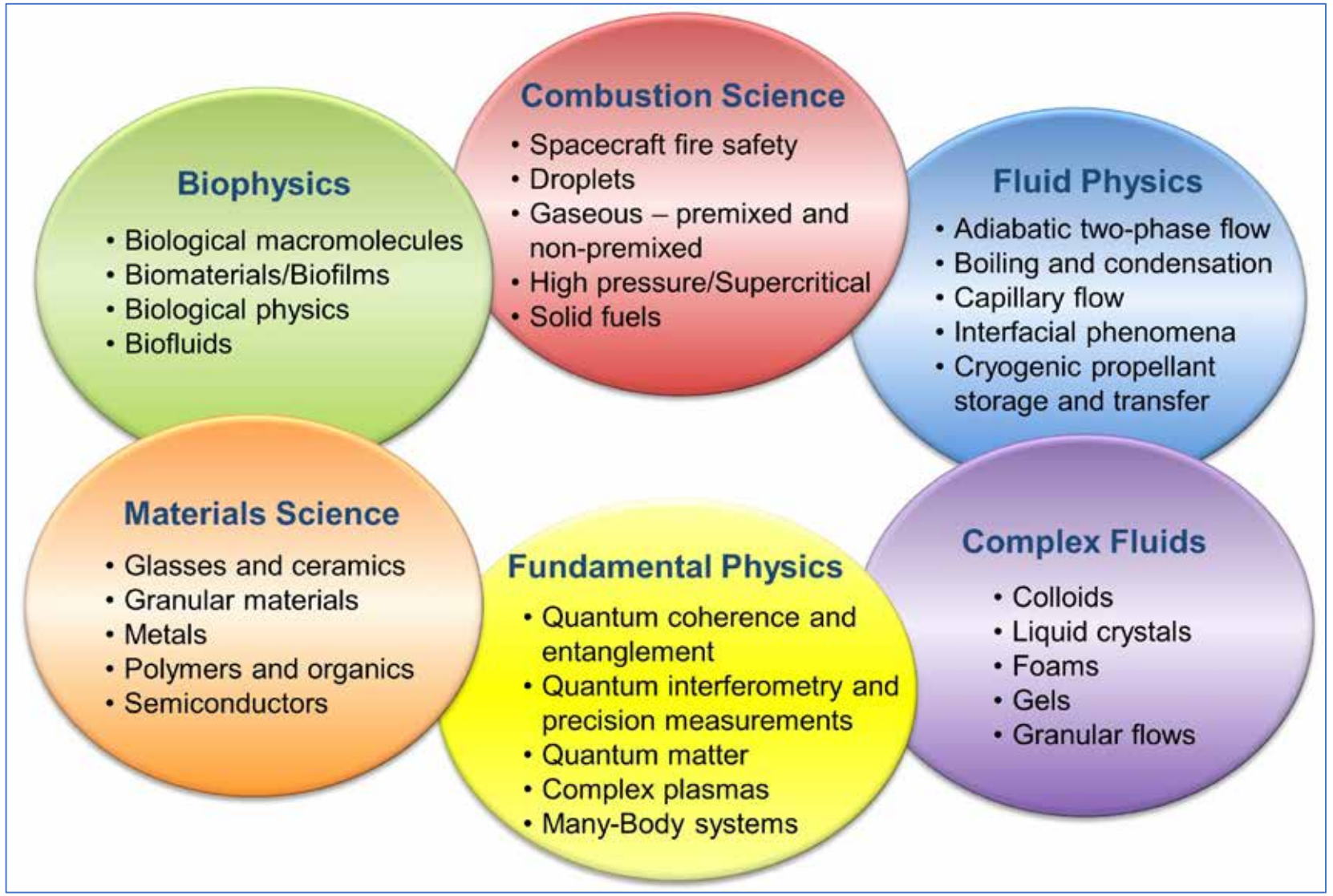
Agenda

Physical Sciences Program

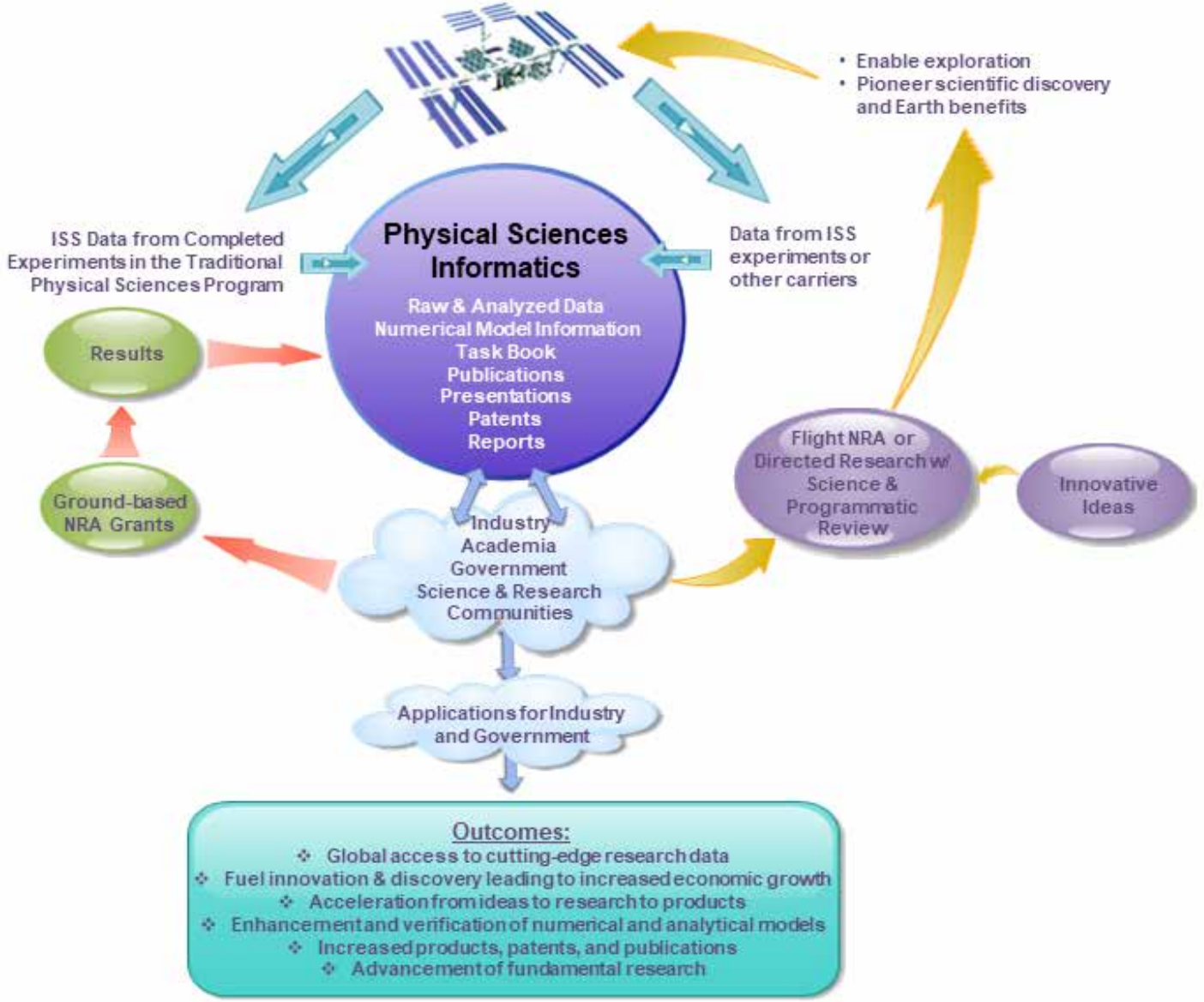
- Overview
- Changes and evolution in context of SMD
- Status, Planning, Research Accomplishments
- Program Trends and Potential Science Directions as part of SMD
- Trends, Forecasting Science Directions in the Community
- Challenges of Interest for the Decadal Survey
- Discussion and Q&A

Overview

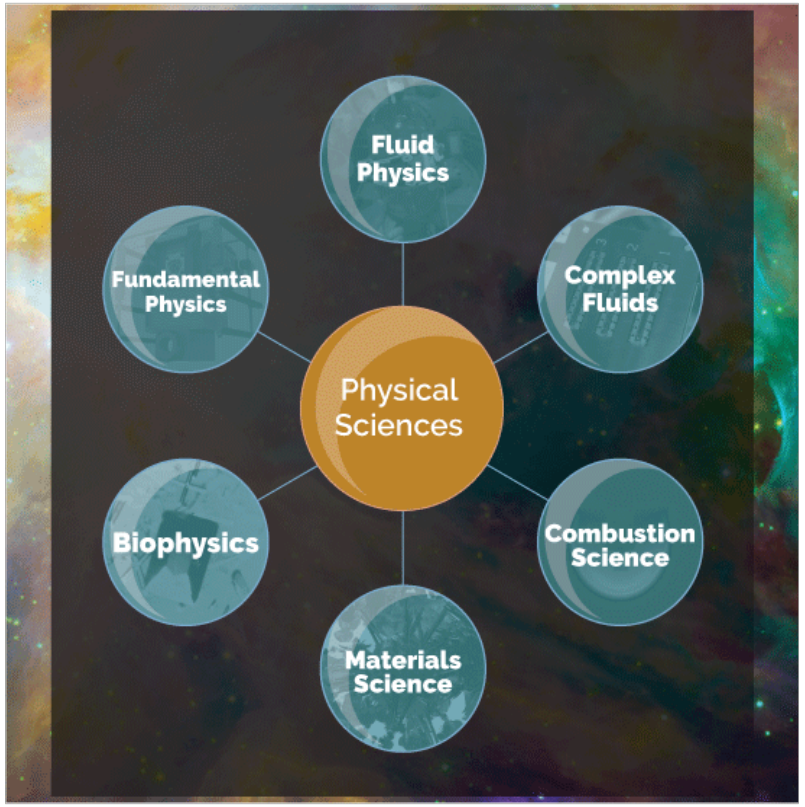
Physical Sciences Research Program

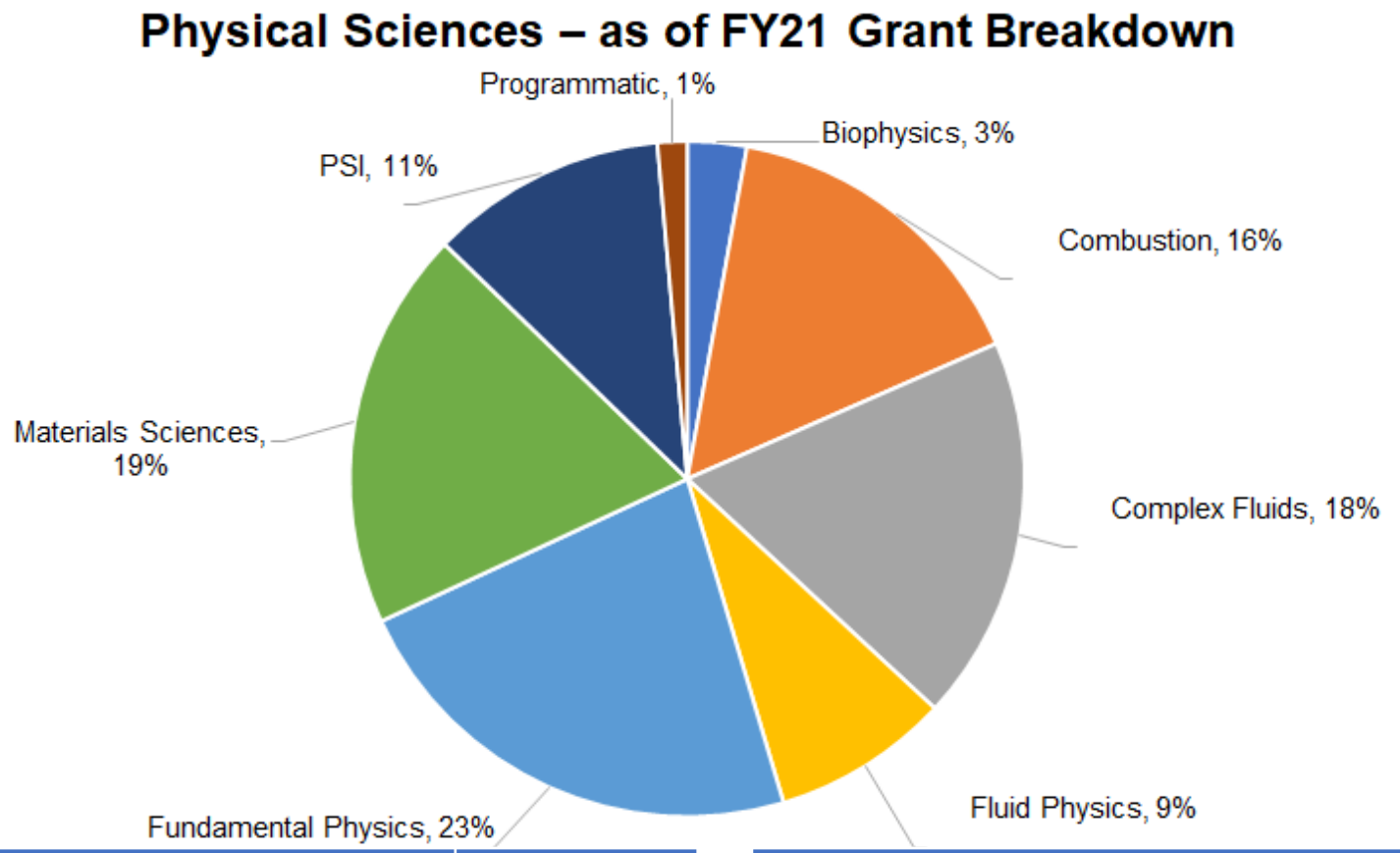


Physical Sciences Research Program - Access for Investigators



BPS Structure – Physical Sciences

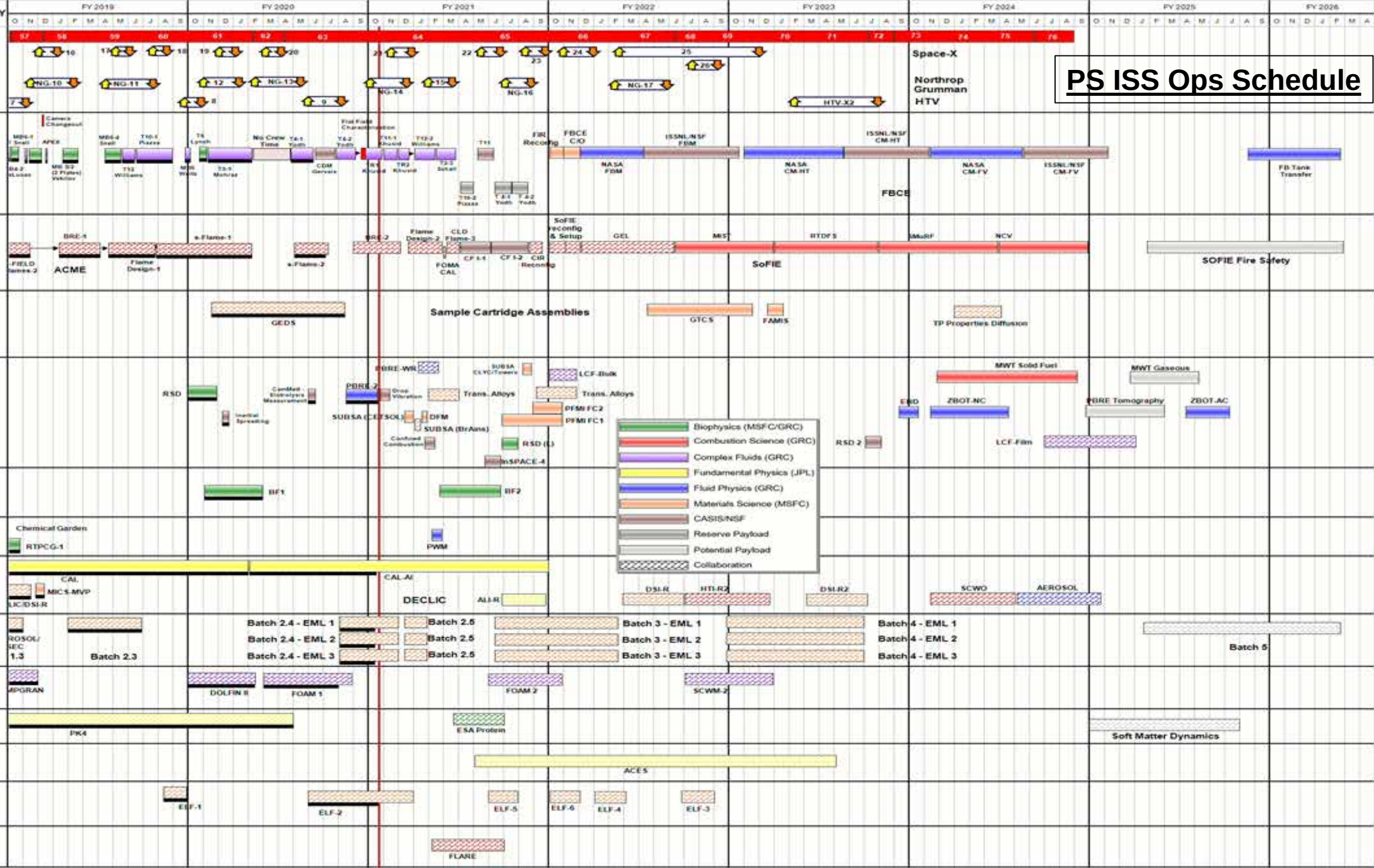




Total PS FY21 Grants	141
Flight	117
Ground	24

Number Directed vs Competed	
Directed	10
Competed	131

PS ISS Ops Schedule



Changes and evolution in context of SMD

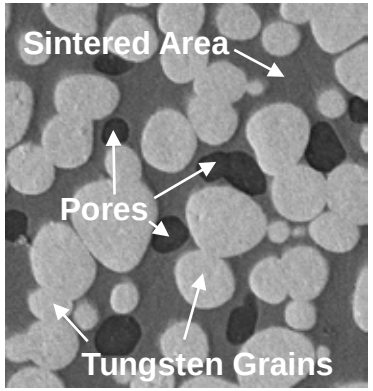
The BPS program have moved into SMD intact, so no changes.

Status, Planning, Research Accomplishments

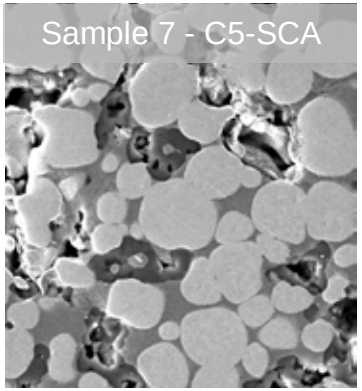


Highlights

Gravitational Effects on Distortion in Sintering (GEDS)



Ground experiment:
Pores and grains are round



Microgravity Experiment:
Less densification and different pore/grain distribution

- The 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.
  - Liquid phase consists of 50% nickel, 20% tungsten, 15% copper, and 15% manganese.
  - Early results indicate less densification in microgravity, even with liquid formation to assist sintering.
  - Pore sizes are larger and more polygonal in shape
- 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).

Thermophysical Properties



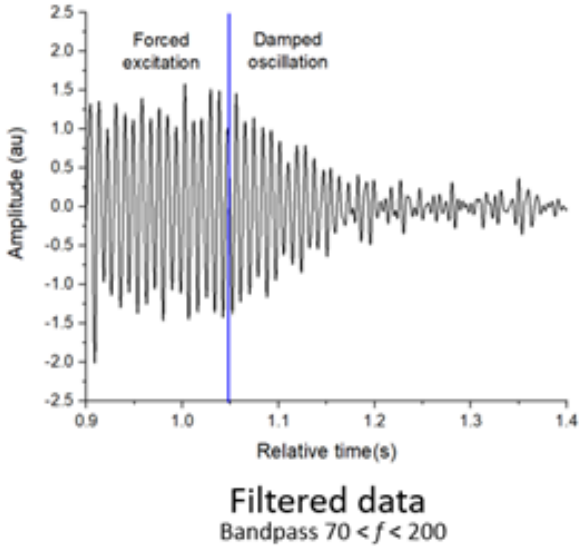
Au sample levitated in ELF on ISS.

US-led experiments have begun on the Japan Aerospace Exploration Agency (JAXA) Electrostatic Levitation Furnace (ELF).

- First US Principal Investigator: Dr. Douglas Matson, Tufts University
- Objective: Understand and control the sources of measurement error of thermophysical properties (e.g. density and viscosity) and to provide a baseline dataset for quantifying uncertainty in measurements (both space- and ground-based).

Dr. Matson plans to complete his science goals by conducting the following:

- Baseline ELF thermophysical property measurement experiments
  - Comparing those results to experiments on the ISS-Electromagnetic Levitator (ISS-EML) and ground-based measurements taken at the NASA MSFC electrostatic levitation (ESL) laboratory and other levitators throughout the world.
- Computer modeling will evaluate theories used to predict the influence of gravity on property measurement experiments.
- A variety of materials are being investigated
  - Including, elements (Au, Pt, Zr), alloys (FeCrNi, Inconel 625, CMSX-4+), and bulk metallic glass (CuZrAl). Many of which have aerospace applications
- Preliminary results on Gold have been promising.
  - Measured surface tension of Au in air at 1344 K, and the results compared favorably to previously published Earth-based data.



Filtered oscillation data from Au sample for viscosity measurement.



Bulk Metallic Glasses (BMG's) have many interesting properties, for example they do not get brittle in extreme cold.

Biofilms

Space Biofilms – Bacterial Preliminary Observations

PI: Luis Zea, University of Colorado, Boulder

Key Results to Date

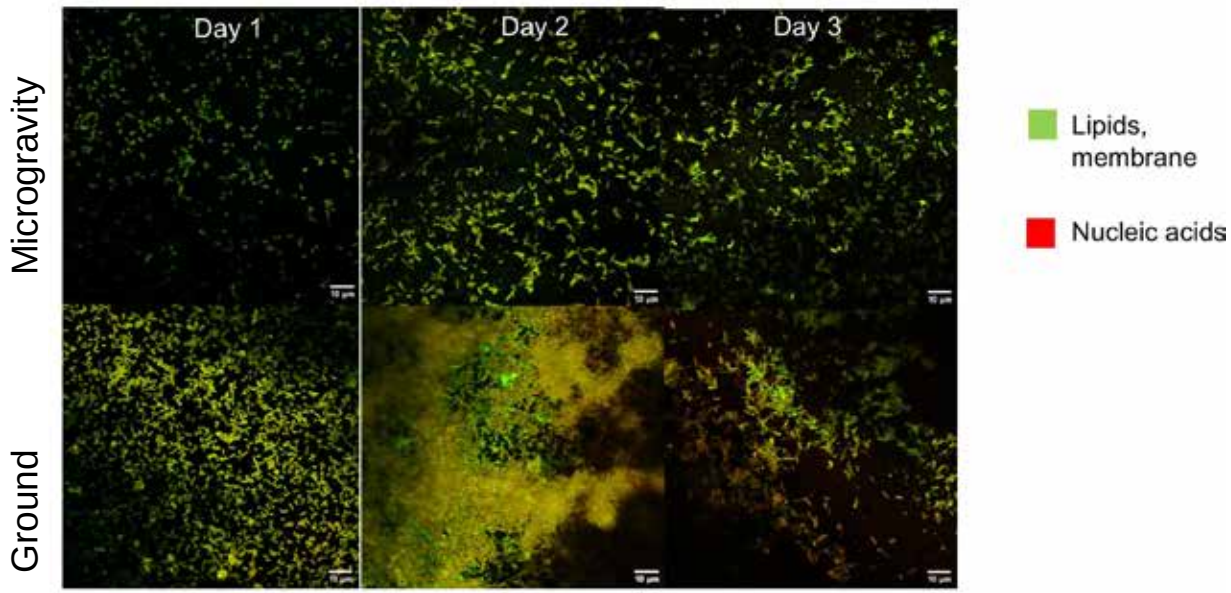
- Analysis is ongoing, but the preliminary observations are very exciting.
  - Reduced gravity sample is much more turbid (or “cloudy”) than the control sample.
  - Biofilms formed in microgravity had lower mass and lower thickness than their Earth controls.

Impact/Application

- Developed biofilm-resistant materials can be a tremendous cost advantage by limiting use of chemical agents in removal of biofilm formations on enhanced substrates.
- Materials that inhibit/prevent biofilm formations for the health care industry.



Two equivalent samples of Pseudomonas aeruginosa cultured in rich medium at 37C for three days over a stainless steel 316 coupon.
Left: Spaceflight sample.
Right: Matching Earth control sample.



Morphology results of biofilm growth on 316SS.

Packed Bed Reactor Experiment

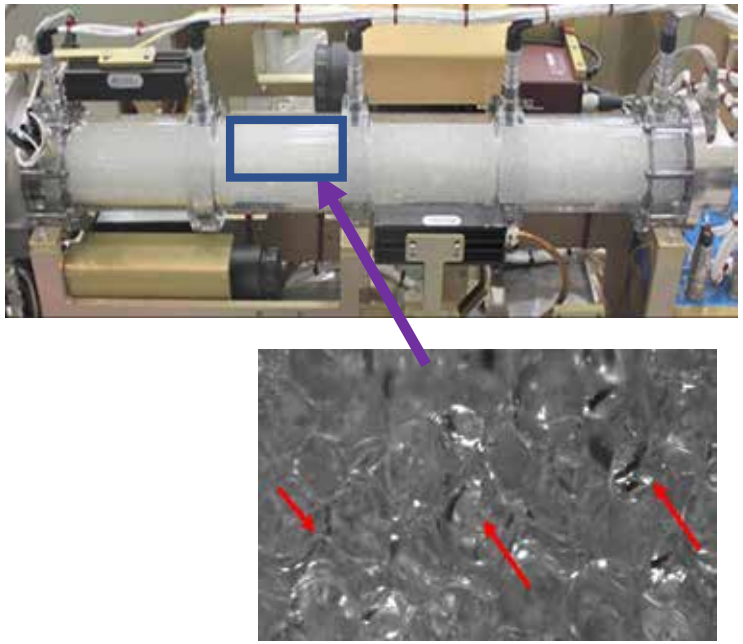
PI: Brian Motil, NASA GRC

Experiment Completes Testing aboard the ISS

- Experiment operated smoothly and 1090 test points were executed.
- Several tests had longer data collection times in order to ensure steady flows were achieved.
- Trapped bubbles affect the effective porosity in the bed which impacted the pressure drop.

Results Published from Earlier Testing

- For “slow” flows, the pressure drop depends on the packing wettability since the surface tension force dominates for the glass beads (wetting) while the viscous or frictional forces dominated for Teflon beads (non-wetting).
- For faster flows, it was determined that hysteresis effects are greatly diminished in microgravity and pressure drop is nearly independent of wettability of the packing material.
- 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, https://aiche.onlinelibrary.wiley.com/doi/abs/10.1002/aic.17031



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

$$f_{TP} = \frac{-\Delta P}{Z}\frac{d_p}{\rho_L U_{LS}^2}\frac{\varepsilon^3}{1-\varepsilon} = \frac{1-\varepsilon}{Re_{LS}}\left[180 + 0.8\left(\frac{Re_{GS}}{1-\varepsilon}\right)^{\frac{1}{2}}\underbrace{\left(\frac{Su_L(1-\varepsilon)}{Re_{LS}}\right)^{\frac{2}{3}}}_{\text{Dynamic phase interaction term}}\right] + 1.8$$

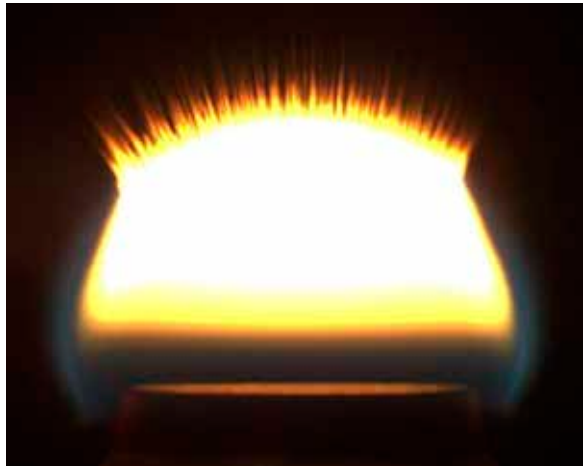
Motil, B. J., Balakotaiah, V., and Kamotani, Y., AIChE J., vol 49, no. 3, pp. 557-565 (2003).

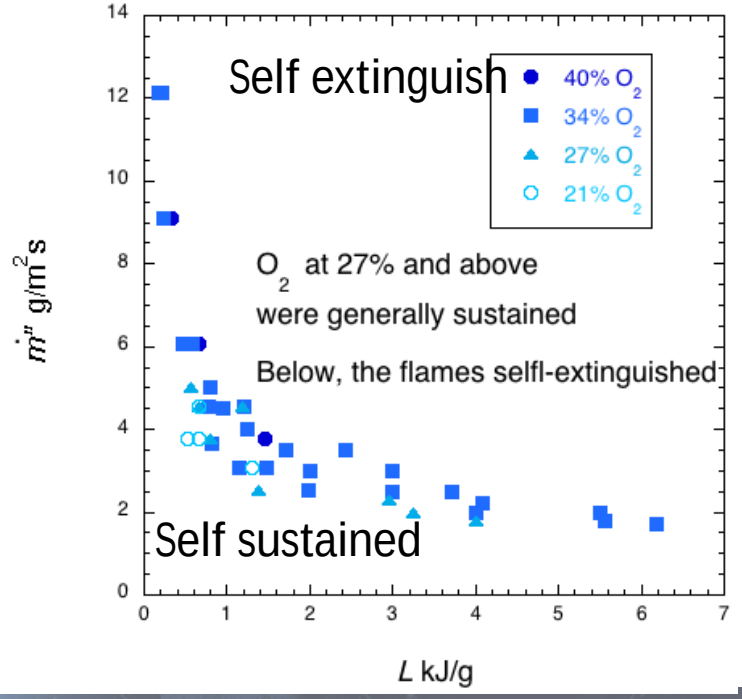
Semi-empirical model for pressure drop prediction

ACME Burning Rate Emulator (BRE)

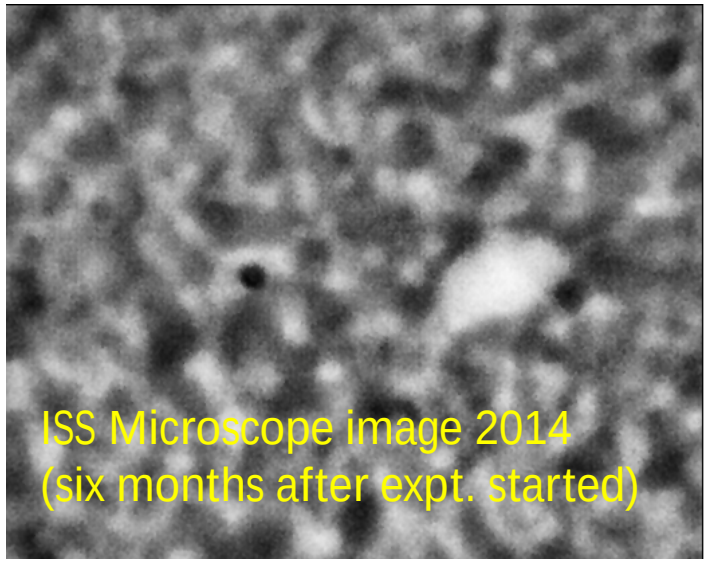
Steady-state flames of solids and liquids can exist for atmospheres of enriched oxygen expected in future crewed spacecraft (2020)

- The possibility of steady-state flames (for solid materials) in quiescent (diffusion), microgravity is an on-going debate in the combustion community.
- ISS tests have yielded tremendous insight into how solids and liquids can burn in long-duration microgravity. The BRE burner emulates real polymeric fuels using gases and matching the heat of gasification, heat of combustion, surface temperature, and smoke point.
- The ISS tests also shed light on why most flames will extinguish in air.
- Immense implications for spacecraft fire safety.
- 2 papers submitted for publication

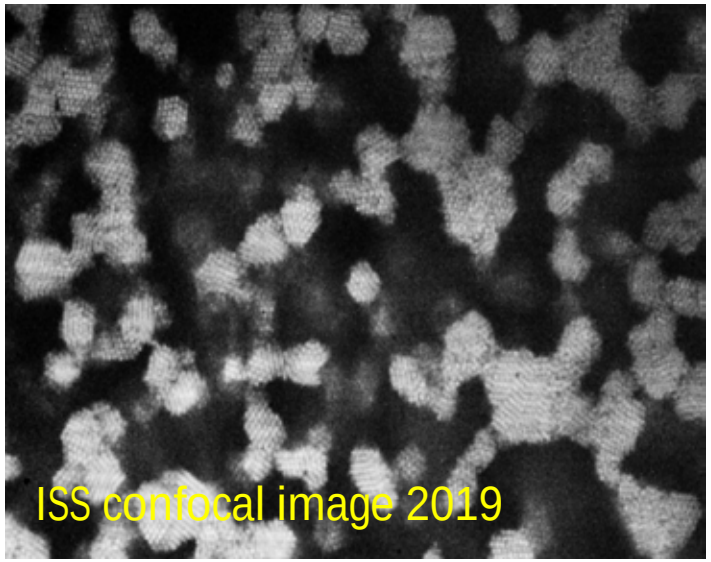




Advanced Colloids Experiment with a Microscope-M2R (ACE-M2R)



several years later in micro-gravity





David Weitz
Harvard University



Peter Lu
Harvard University

Seeing the microscopic (particle level) evolution of a colloidal-polymer system in microgravity. Same image in 2014, left and 2019, right.

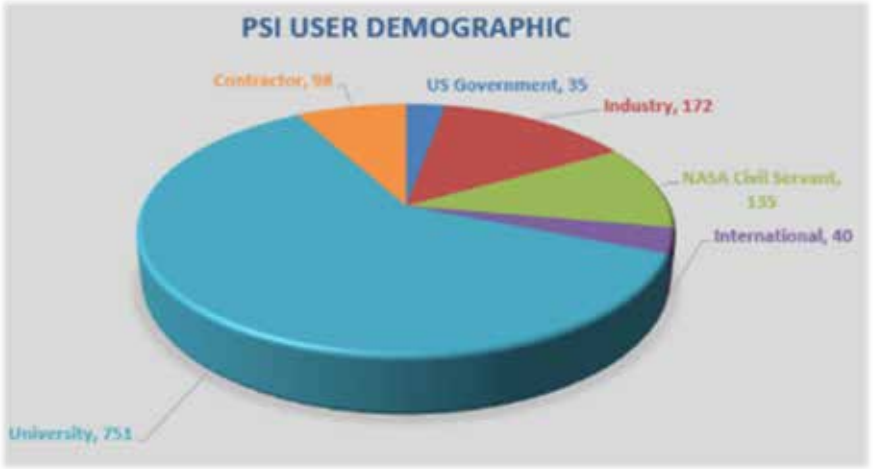
The ACE–M2R samples equilibrated on the ISS for several years, which provides a unique environment without sedimentation, which fundamentally precludes making these observations over similar timescales on earth. As a direct consequence of the launching of the confocal attachment to Light Microscopy Module (LMM), a microgravity microscope, in 2017, ACE–M2R was able to collect a completely new, large and spectacular set of 3D confocal microscopy data on a colloid-polymer sample that has been kinetically-arrested in microgravity; again, this is impossible on earth. We may be seeing behavior which is fundamentally new, not just to space, but to physics in general; our observations are a direct consequence long-term sample evolution in microgravity onboard ISS, enabling experiments which last far longer than can be conducted on earth.

All of the particles appear to form neat rows, in perfect order; we think that they have crystallized. Moreover, they do not seem to be all part of the same crystal, but a bunch of microcrystals, so that it's unlikely that they were formed as a result of external influences like the glass walls of the sample chamber. These observations shed light on the question that we and many others have raised on the nature of gels: are they fundamentally arrested internally, like a glass, or is the underlying stable structure a crystal? That we seem to find crystals if we wait long enough when sedimentation is removed suggests that their thermodynamically-stable structure is crystalline, providing strong evidence for some positions within longstanding debates within condensed-matter physics community. Furthermore, these results could have practical applications in the development of better stabilizers for a number of household products, personal care products, and medicine. For example soaps, fabric softeners, and other multi-components systems that would separate on Earth can use colloidal-polymer (col-pol) stabilizers based on depletion attraction to significantly extend their shelf life, and these results can help guide the models used to design the stabilizer.

Physical Science Informatics (PSI)Metrics

1,231 Users | **140** Proposals | **41** Awarded PIs



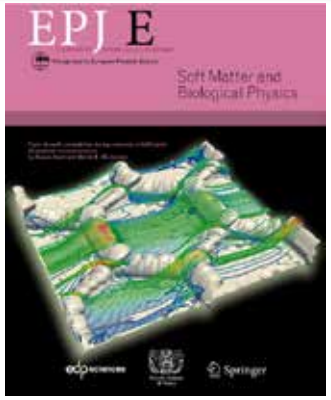




From 22 research grants awarded

Since 2017

* 4 new NRA generated ground investigations
* 32 Articles in Peer Reviewed Journals, 3 in other journals - ***137+ citations***
* 53 Papers or Abstracts for Proceedings



- **2018 Journal of Materials Science Cahn Prize Best Pape**r – K Ankit, M Glicksman “Measuring solid–liquid interfacial energy fields: diffusion-limited patterns.”
- **Feb 2020 cover of The European Physical Journal E** for 'Growth competition during columnar solidification of seaweed microstructures.’, Ankit K, Glicksman, M



Status

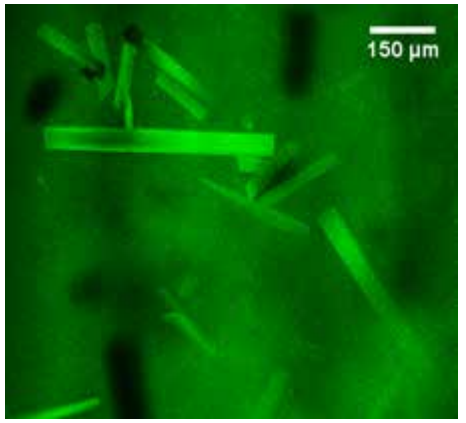
Biophysics

Protein Crystal Growth

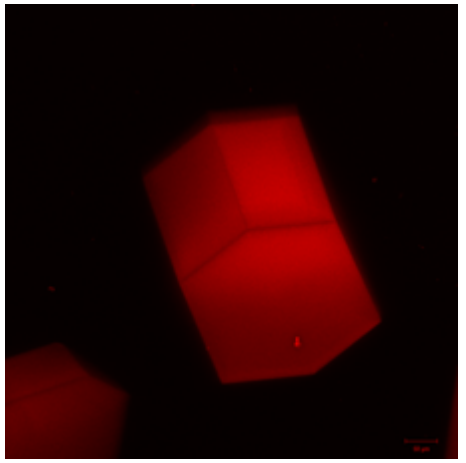
The Light Microscopy Module (LMM) is a modified commercial, highly flexible, state-of-the-art light imaging microscope facility that provides researchers with powerful diagnostic hardware and software onboard the International Space Station (ISS).

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.

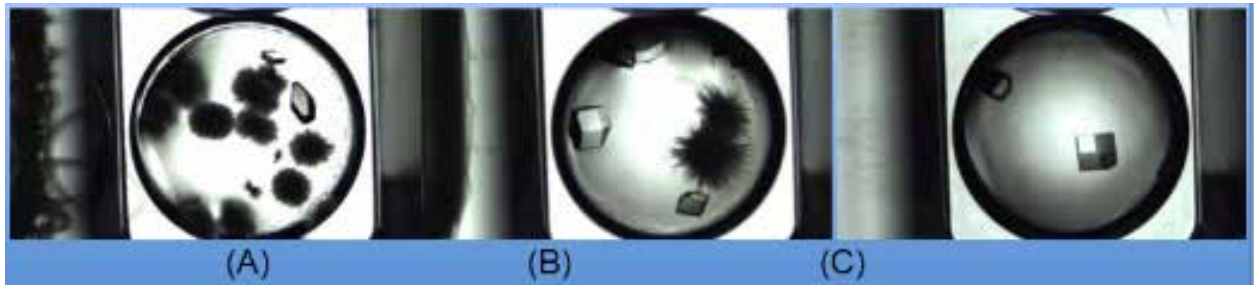
The RTPCG-2 Science Definition Team (SDT) consists of the following members:

- 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.

The hardware and samples are scheduled to launch in February 2021.



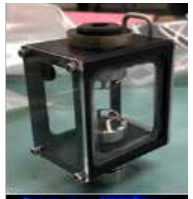
Flight results show improvement in lysozyme crystal size/quality with iterative crystallization (RTPCG-1). Conditions were modified on-orbit from (A) 1.6 M NaCl to (B) 1.2 M NaCl to (C) 0.8 M NaCl by the crew, with feedback from the PI.

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, Rennselaer 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 hardware and samples are scheduled to launch in February 2021.

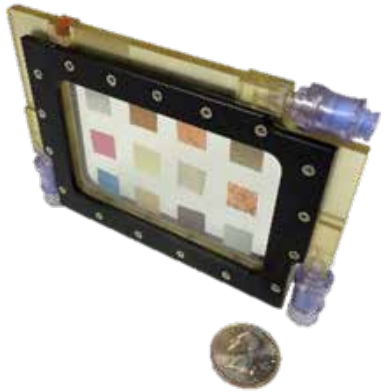




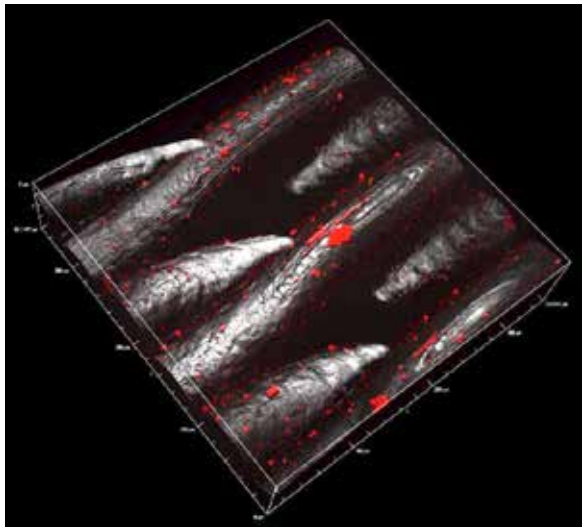


Left: Christina Koch Operating RSD Flight Hardware on ISS
Upper Right: RSD Test Cell Lower Right: Pinned Drop on ISS

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

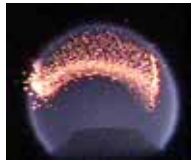
Top Publications - Biophysics

- 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

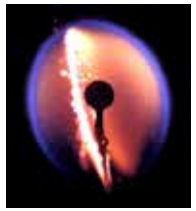
Advanced Combustion via Microgravity Experiments (ACME)



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



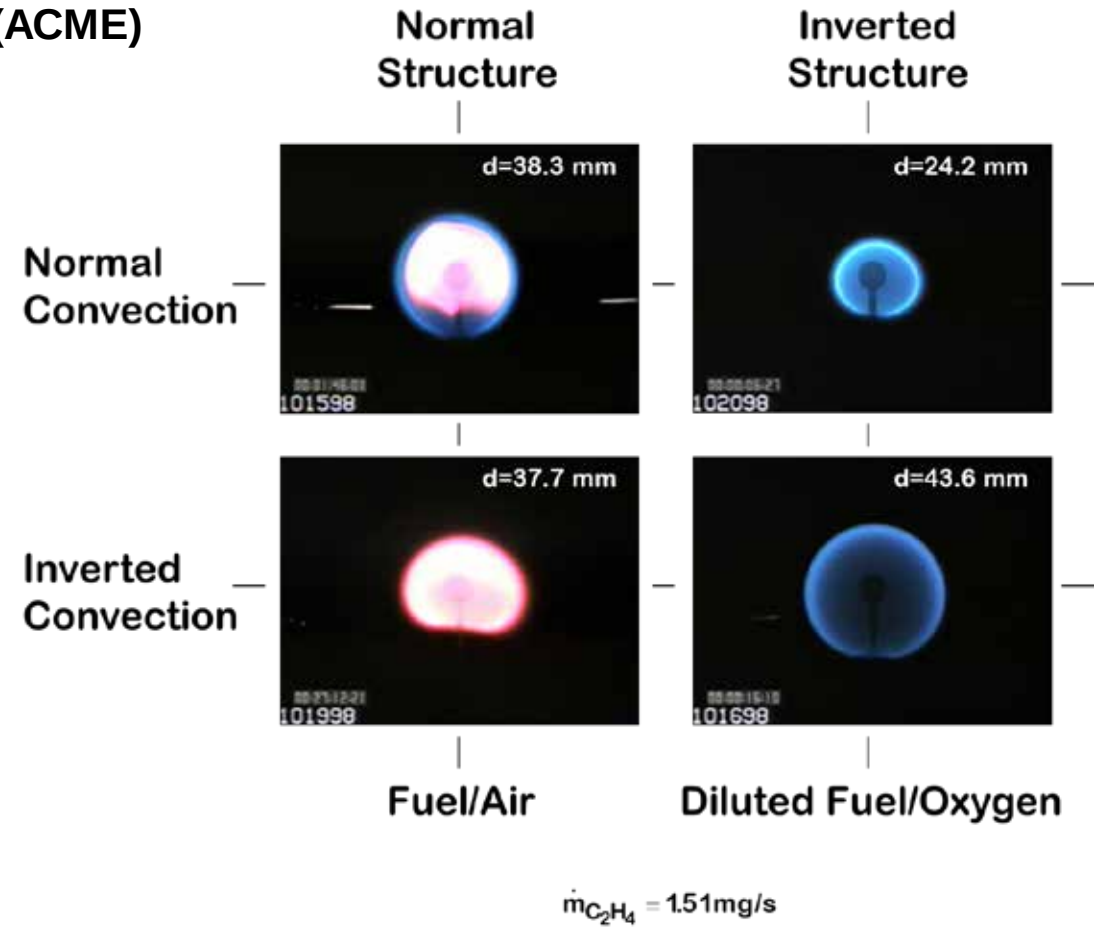
Flame Design
Axelbaum: WUStL et al.
Experiments examining soot inception and transport and flame structure



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

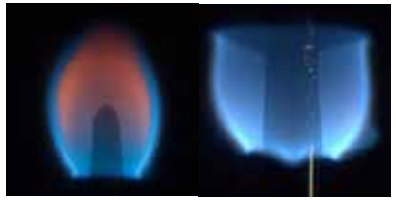


Flame Design: Axelbaum WUStL et al.
Soot inception and transport through control of the flame structure
To guide lower polluting combustors and to facilitate carbon sequestration

28

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



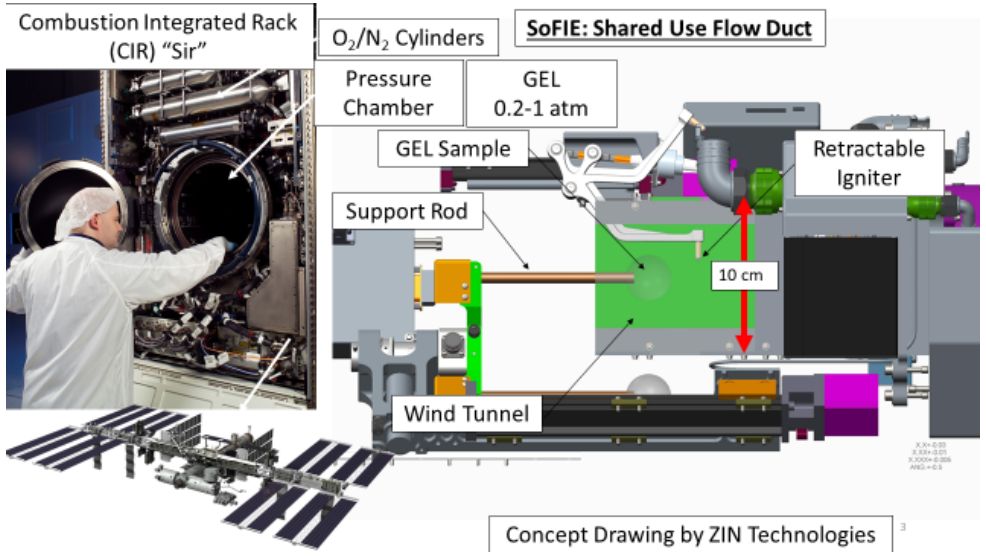
Narrow Channel Apparatus (NCA)
Miller: San Diego State University
Flame spread experiments focused on thick polymeric materials



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



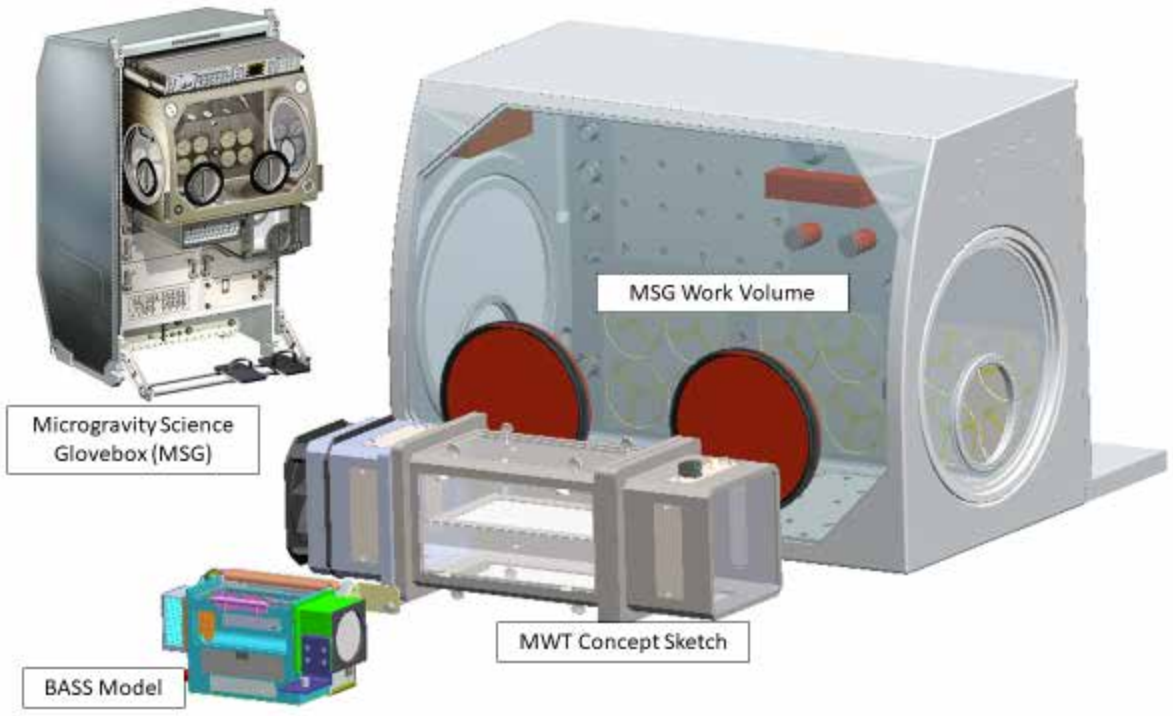
Growth and Extinction Limit (GEL)
T'ien: Case Western Reserve University
Investigating effect of gravity, flow, O_2, pressure, and fuel preheating on the combustion of polymeric spheres



Future 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

DECLIC

SCW / salt solution — 2017

SCW / TBD (salt-2 / CO2) — 2021

DECLIC-Evo

SCWO — ca 2024

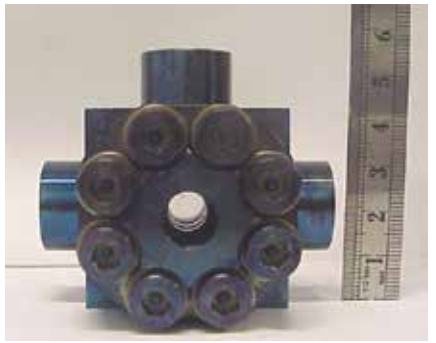
SCWO-D Insert

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

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

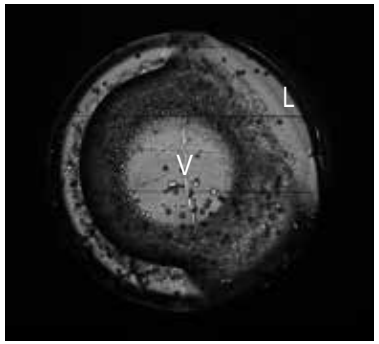
Behavior of a Salt-Water Mixture Near the Critical Point-2 (SCWM-2)
Michael Hicks, GRC, PI
Uday Hegde, CWRU
Yves Garrabos, Carole Lecoutre, Sam Marre, ICMCB, Bordeaux

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

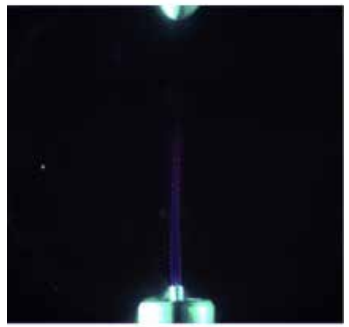


HTI/HTI-R insert (DECLIC)

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)



10 mm

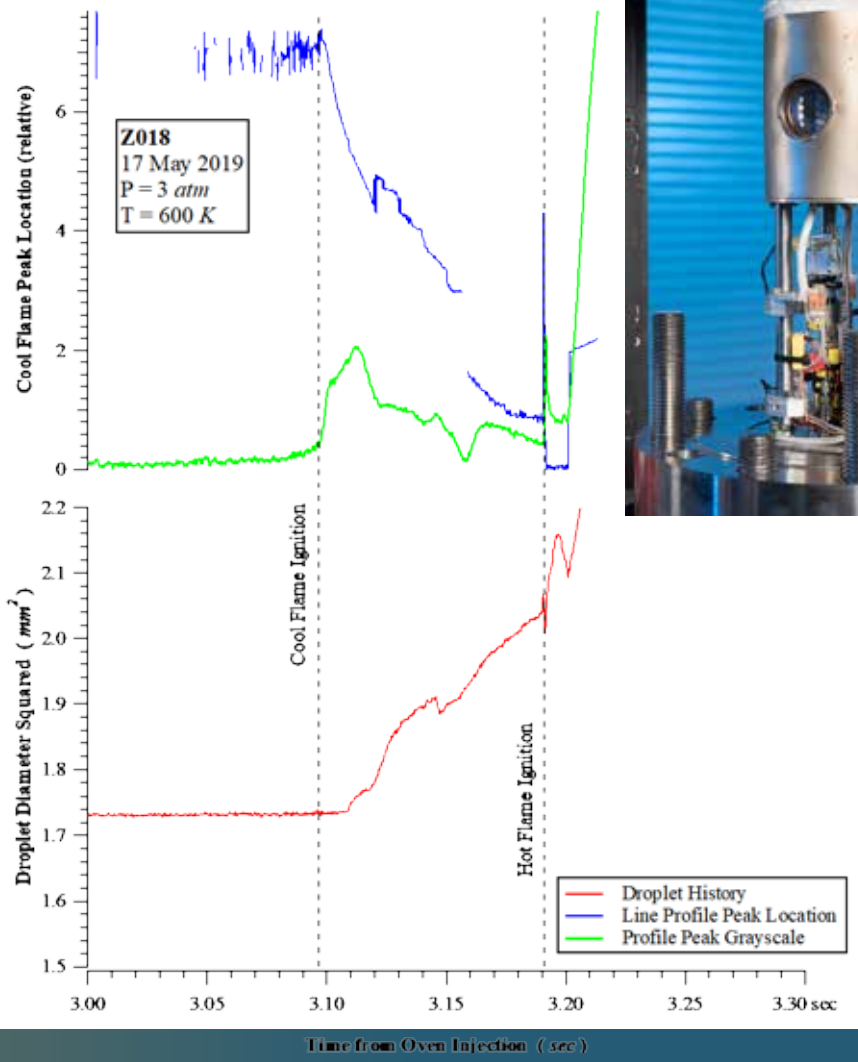


Ethanol-Water Hydrothermal Flames-GRC SCWO Lab

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

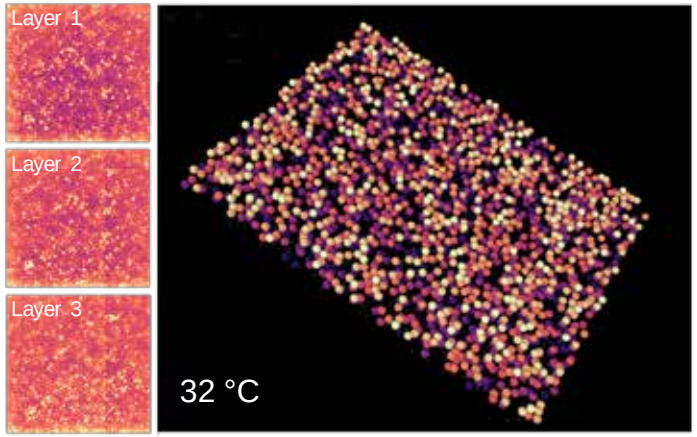
- Focus: Determine Phase Diagram for Cubes. These supercube crystals grow much larger in space. Relevant for advanced optical materials.

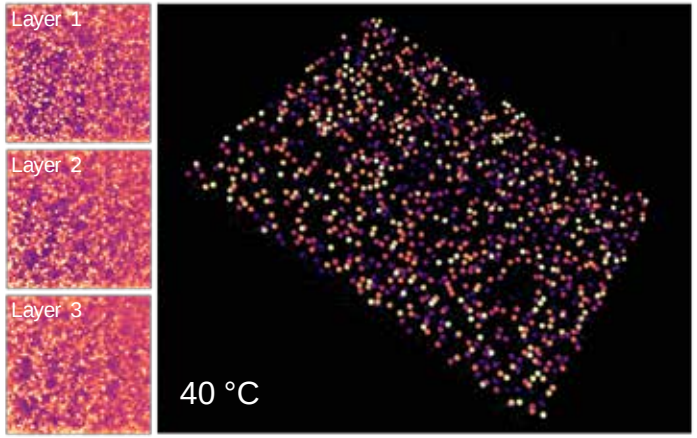
ACE-T11, PI: Boris Khusid, New Jersey Institute of Technology

- 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)

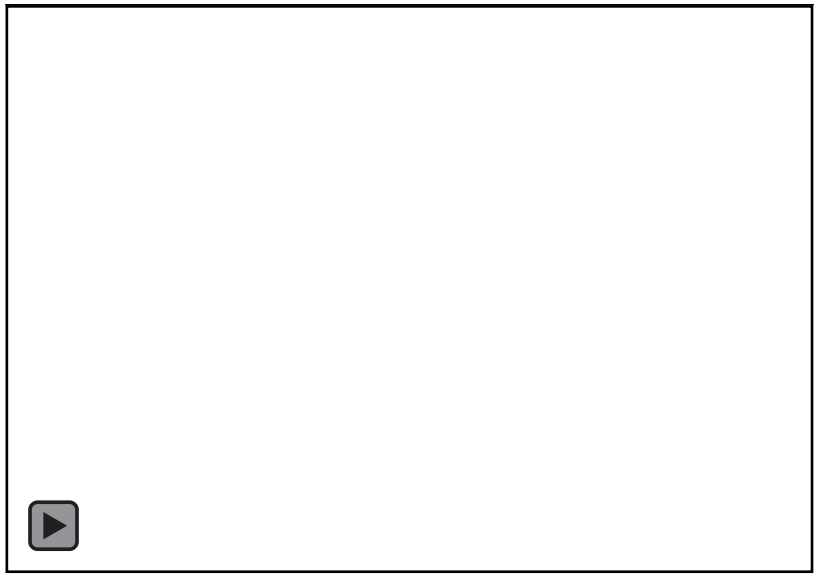
ACE-T5, PI: Ali Mohraz, University of California, Irvine
- Objective: Quantify the theory behind bigels useful for creating large surface area electrodes and creating coatings that ensure the human body does not reject implanted tissues and devices.

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

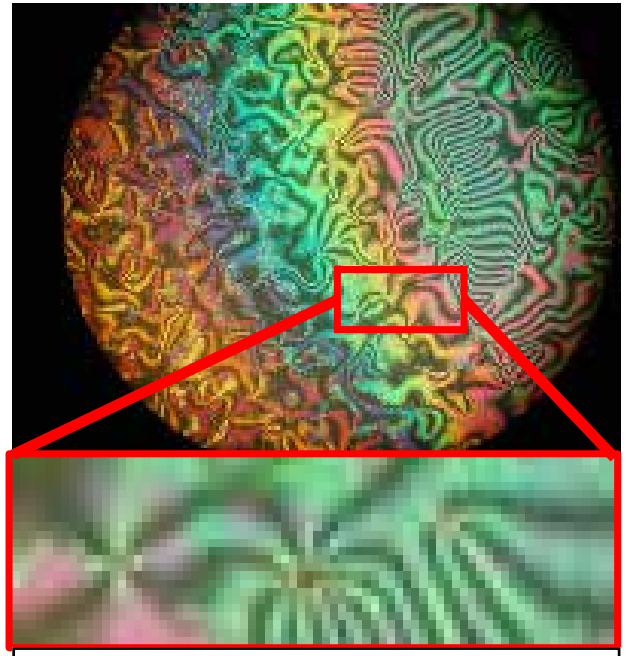
- Objective: Study of interactions and dynamics of ferro magnetic inclusions in freely suspended liquid crystal films

Charles Rosenblatt, Case Western Reserve

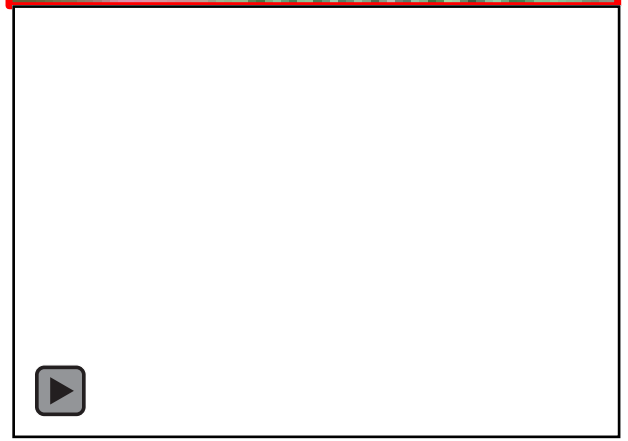
- Objective: Examine thin, smectic-C films, their 2D topological defects, and nanoparticle inclusions in a microgravity environment

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



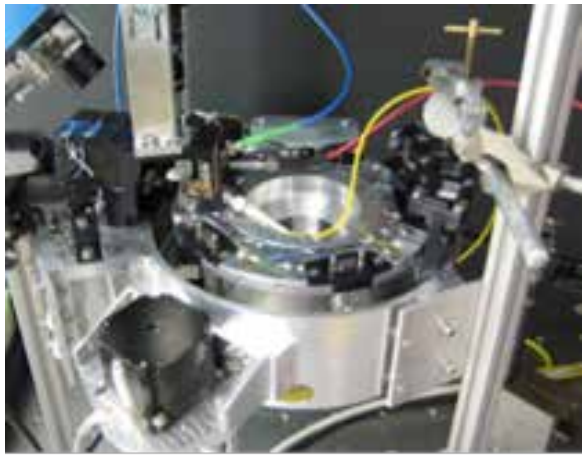
Ferromagnetic droplet in the rotating magnetic field as a function of amplitude and frequency

Foam Optics And Mechanics (FOAM)

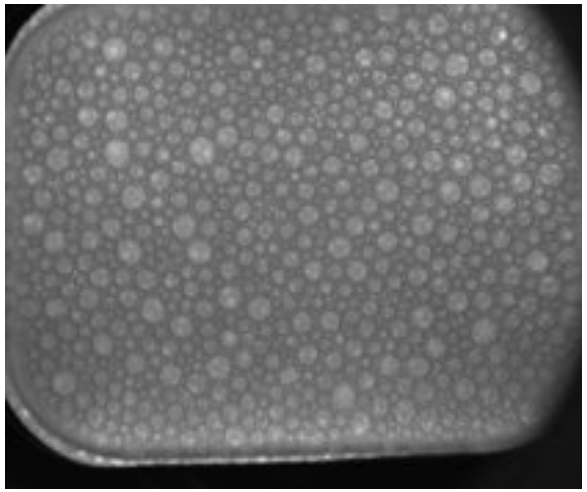
Team Coordinator : Professor Dominique Langevin (University of Paris, France)
US PI: Douglas Durian, Physics Department, University of Pennsylvania
Team: D. Weaire (Ireland); Nicolas Vandewalle, Hérvé Caps, Giles Delon (Belgium); Ko Okamura (Japan); Andrei Sonin (Russia)

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.
- Andrew J. Ferris,a Sajedeh Afghah,b Robin L. B. Selinger, Jonathan V. Selinger b and Charles Rosenblatt "Electric field-induced crossover from 3D to 2D topological defects in a nematic liquid crystal: experimental verification" Royal Society of Chemistry: Soft Matter Journal.
- Hollingsworth, Andrew, Paul Chaikin, Lou Kondic, Alton Reich, and Boris Khusid. "Model hard ellipsoids: the practical matter of producing them." Bulletin of the American Physical Society 65 (2020).
- Zagzag, Yvonne, M. Francesca Soddu, Andrew D. Hollingsworth, and David G. Grier. "Holographic molecular binding assays." Scientific Reports 10, no. 1 (2020): 1-7.
- Middleton, Christine, Mark D. Hannel, Andrew D. Hollingsworth, David J. Pine, and David G. Grier. "Optimizing the synthesis of monodisperse colloidal spheres using holographic particle characterization." Langmuir 35, no. 20 (2019): 6602-6609.
- M. Kaganyuk and A. Mohraz, "Shear-Induced Deformation and Interfacial Jamming of Solid-stabilized Droplets", Soft Matter 16, 4431 (2020).
- M. Kaganyuk and A. Mohraz, “Impact of Particle Size on Droplet Coalescence in Solid-Stabilized High Internal Phase Emulsions.” Langmuir, 35, 12807 (2019) [Featured on the Cover].
- Wilken, Sam, Rodrigo E. Guerra, David J. Pine, and Paul M. Chaikin. "Hyperuniform Structures Formed by Shearing Colloidal Suspensions." arXiv preprint arXiv: 2002.04499 (2020).
- Zagzag, Yvonne, M. Francesca Soddu, Andrew D. Hollingsworth, and David G. Grier. "Holographic Molecular Binding Assays," Scientific Reports 10, no. 1 (2020): 1-7.
- Chen, Wei, and Hiroshi Yokoyama. "Rapid thickness mapping of free-standing smectic films using colour information of reflected light." Liquid Crystals (2020): 1-16.
- Snyder, Kaitlynn, Rushna Quddus, Andrew D. Hollingsworth, Kent Kirshenbaum, and David G. Grier. "Holographic Immunoassays: Direct Detection of Antibodies Binding to Colloidal Spheres." Soft Matter (2020). https://doi.org/10.1039/D0SM01351J.
- Invited for publication in special issue “Applications of Additive Manufacturing in Pharmaceutics” https://www.mdpi.com/journal/pharmaceutics and will be submitted in Oct 2020. Elele E, Shen Y, Boppana R, Afolabi A, Bilgili EA, Khusid B, Electro-hydrodynamic drop-on-demand printing of aqueous suspensions of drug nanoparticles.
- 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.

Complex Fluids – Nov 2021

The goal is to investigate the fundamental problems that involve molecular and particle dynamics, self assembly, and chemical reactions that result from alignment among constituents so that the final outcome can be influenced. This will include the investigation of “far from equilibrium” phenomenon, complexity and cooperativity and to imagine life-like materials and machines of technological importance.

Discussions with international partners are in progress to share hardware, such as ESA’s Soft Matter Dynamics unit, DLR’s FLUMIAS microscope, NASA’s Liquid Crystal Facility, and KERMit.

Sample topic areas include:

- Colloidal Suspensions
- Foams
- Emulsions
- Granular Materials
- Liquid Crystals

Approximately 3 Selections

Fluid Physics

Adiabatic Two-Phase Flow

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

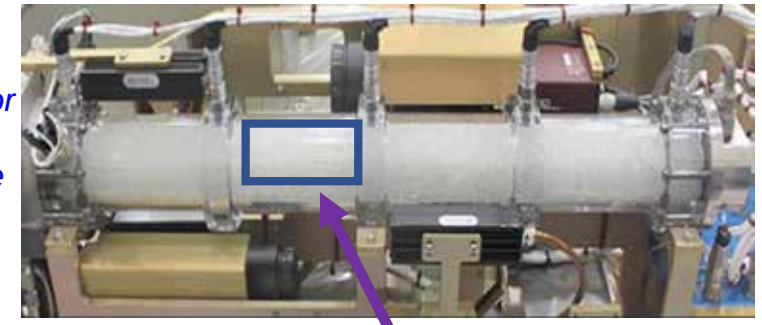
- Objective: Investigate the impact of packing diameter on the role and effects of gravity on hydrodynamics of gas-liquid flow through porous media.

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

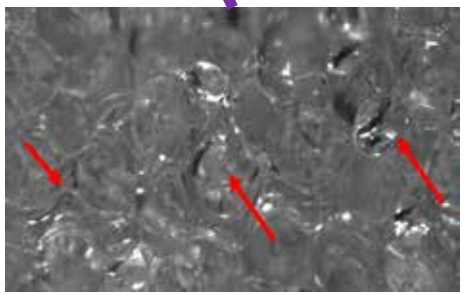
- Objective: Extended investigation on the impact of packing diameter on the role and effects of gravity on hydrodynamics of gas-liquid flow through porous media.

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

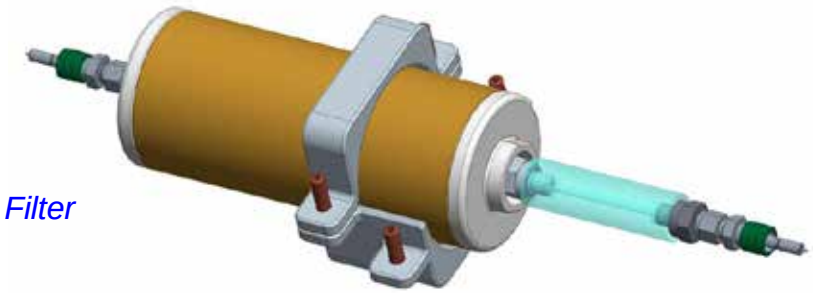
- Objective: Develop/validate scaling laws and design tools for future water recovery systems in μ-g and partial-g environments, including start up and transient operations.
- Objective: Identify strategies to recover from undesired trapped gas bubbles in system components such as the following:
  - 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

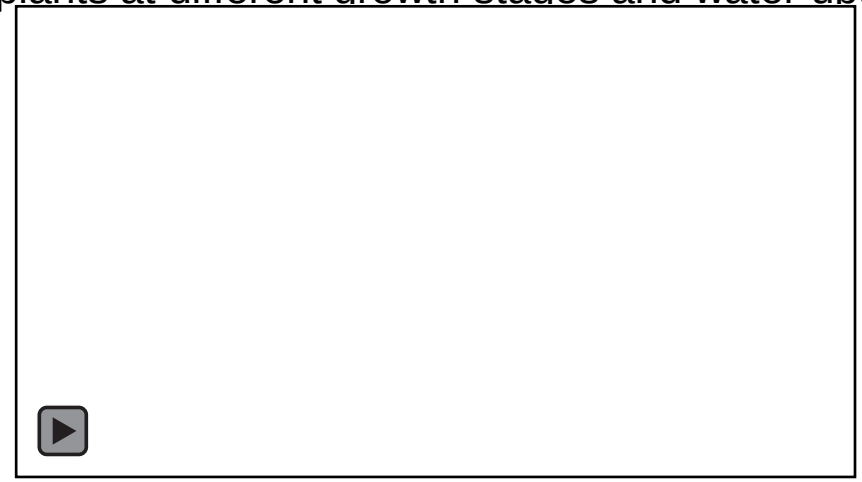


CAD Model of Urine Transfer Filter Test Article

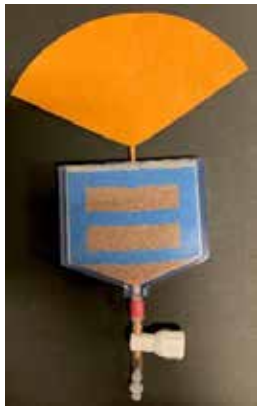
Capillary Flow

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

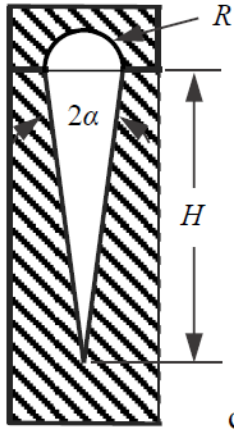
- Objective: Evaluate options for adequate hydration and aeration techniques for soil media and other farming strategies including but not limited to: Aeroponics, Hydroponics, and Soil-based media
- Soil (PWM-S): Establish a “capillary gradient” using material wettability to provide controlled to establish 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.



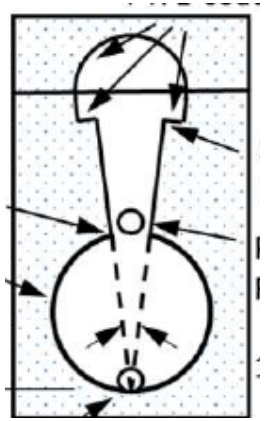
Portland State Drop Test of PWM-H with plant simulate



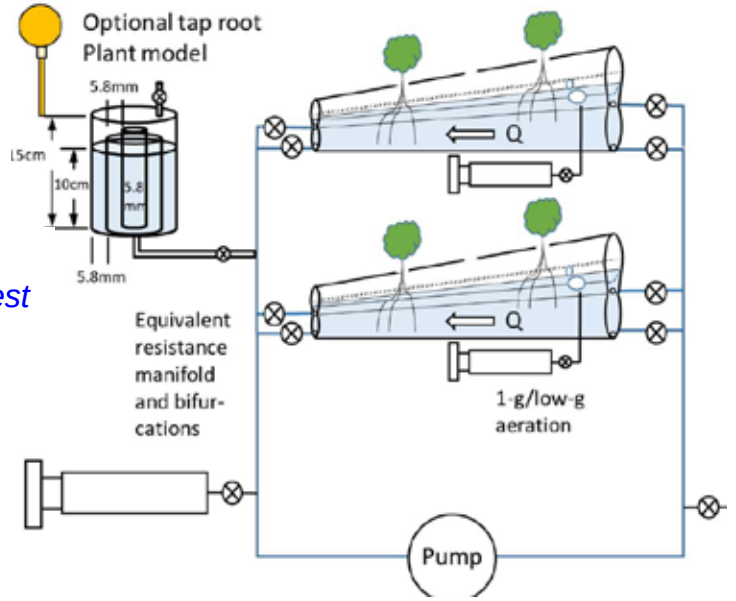
PWM –S test cell



PWM –H Cross-Section



PWM –HRAC Cross-Section



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 NonCondensibles (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 Active Cooling (ZBOT-AC): 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.

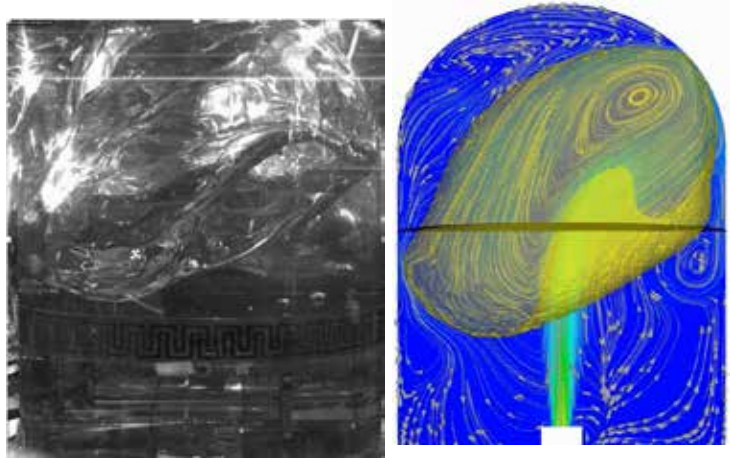
Zero Boil Off Tank Experiment Filling and Transfer (ZBOT-FT): PI's: Michael Dryer, University of Bremen, University of Bremen and Mo Kassemi, Case Western Reserve University.

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

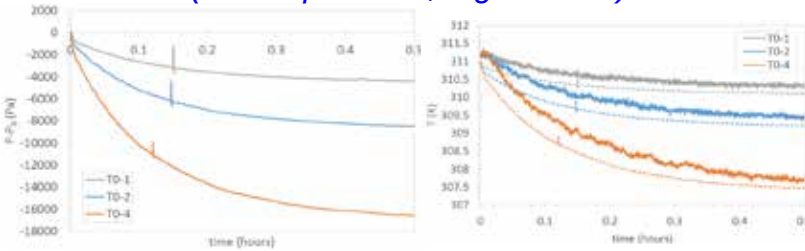
ISS Cryogenic External Experiment (ICEE): PI's: Jason Hartwig, NASA and Mo Kassemi, Case Western Reserve University

- Objective: Investigate and understand the effect of microgravity on evaporation, condensation, boiling phenomena and the associated two-phase flow transport regimes that impact tank and line chill-down and tank to tank transfer operations of cryogenic

NRA Flow Boiling - to Support Cryogenic Propellant Tank Transfer Research



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 Chilldown

- 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 solicitation**

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.

Heated Section of Flow Boiling Test module



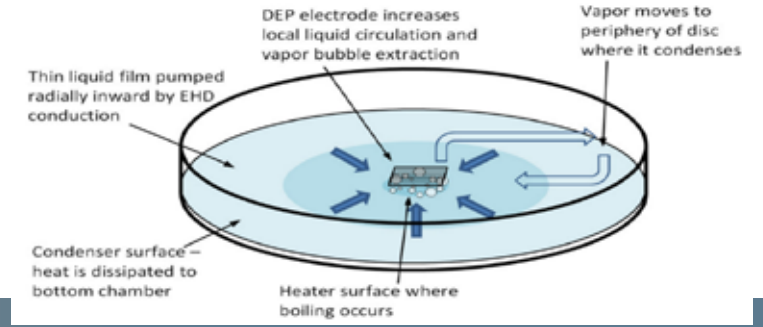
µG Flow Boiling Test on aircraft



µG Condensation Test on aircraft



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.

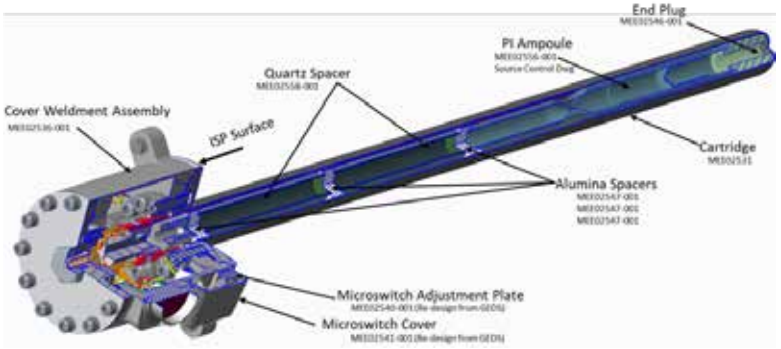
Materials Science

Solidification – High Temperature

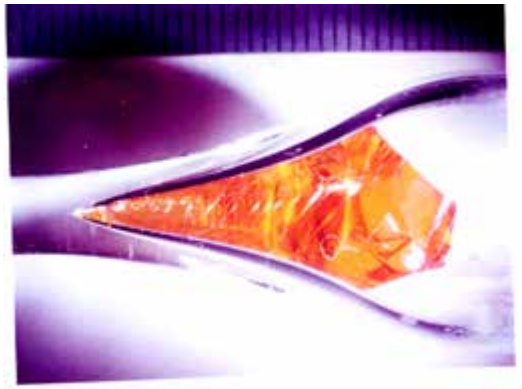
Materials Science Research Rack (MSRR) Materials Science Laboratory (MSL) Low Gradient Furnace (LGF)

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) containerless 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.

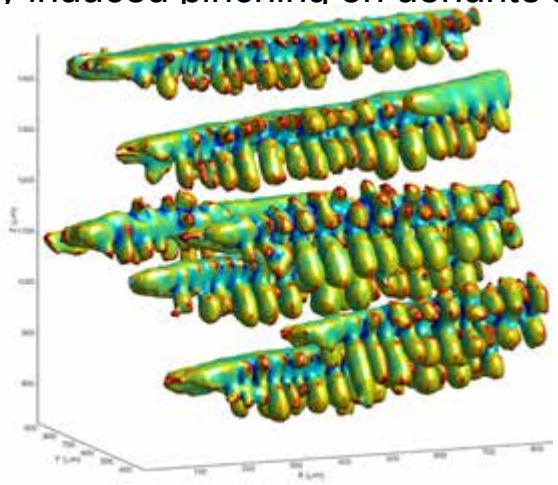


Horizontally grown ZnSe crystal grown horizontally on ground in support of Dr. Su's experiment. The (110) facets aligned parallel to the gravitational direction.

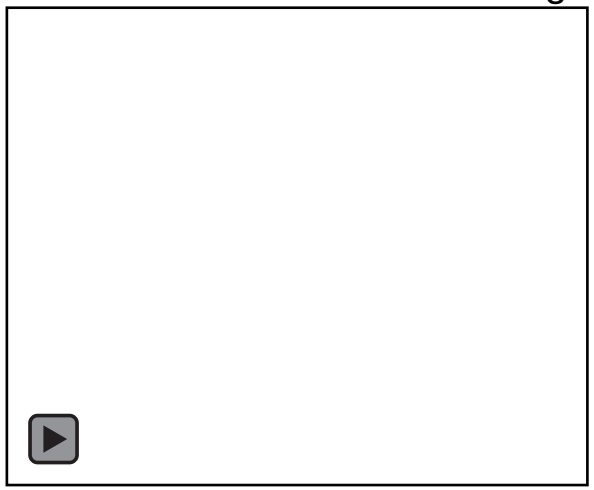
Solidification – Mid Temperature

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



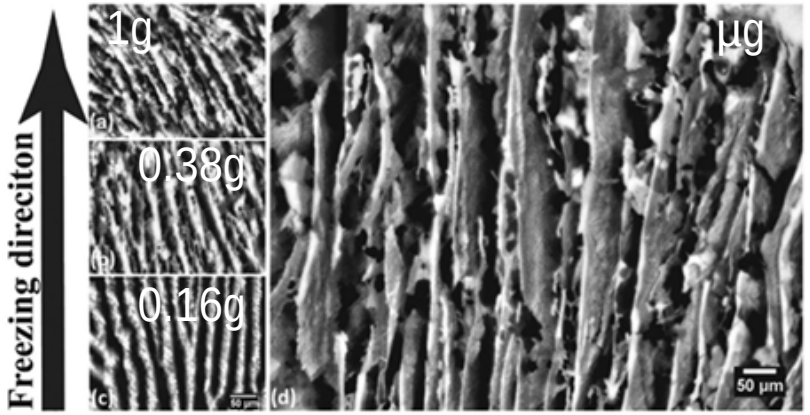
Capillary induced fragmentation

Solidification – Low Temperature

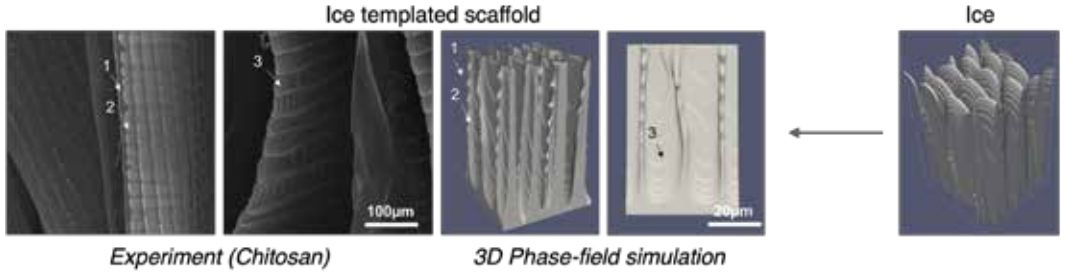
The Pore Formation and Mobility Investigation (PFMI) hardware will melt samples of a transparent modeling material, e.g. succinonitrile and succinonitrile water mixtures. There are currently 2 Investigators with upcoming PFMI experiments:

- 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

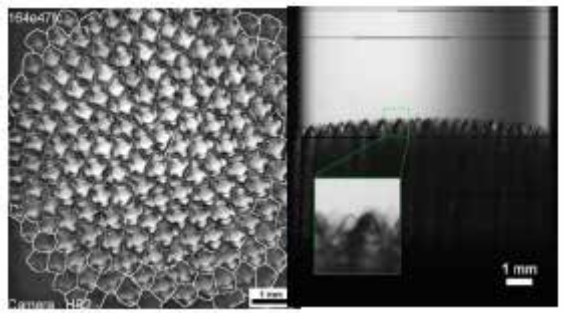
Solidification – Transparent Alloys

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.

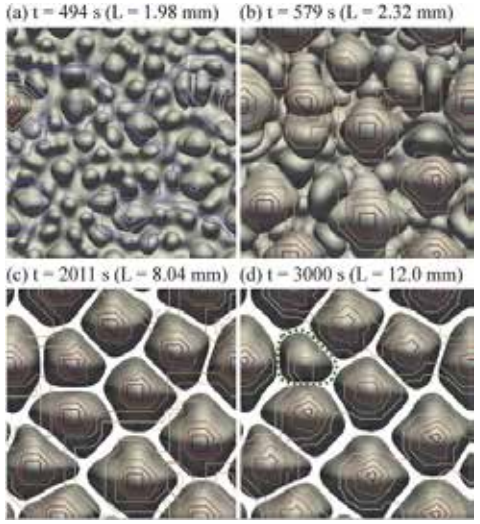
Dr. Rohit Trivedi, Iowa State University

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



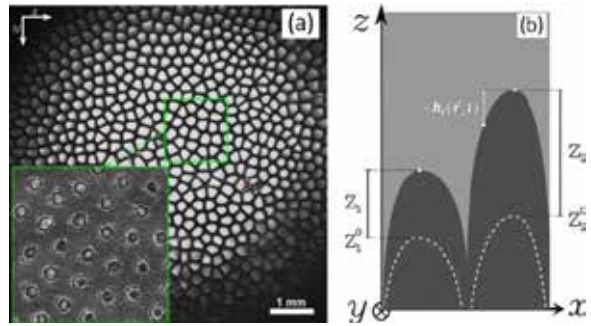
Axial and transverse views of dendritic interface in DECLIC-DSIR on ISS.

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.

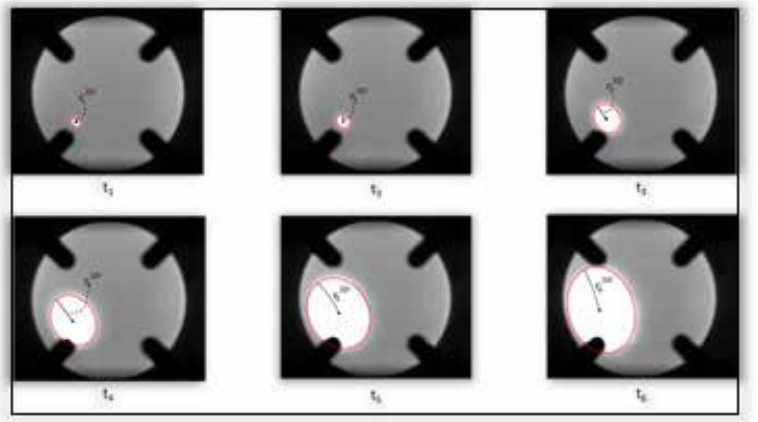
Thermophysical Properties

International Space Station Electromagnetic Levitator (ISS-EML)

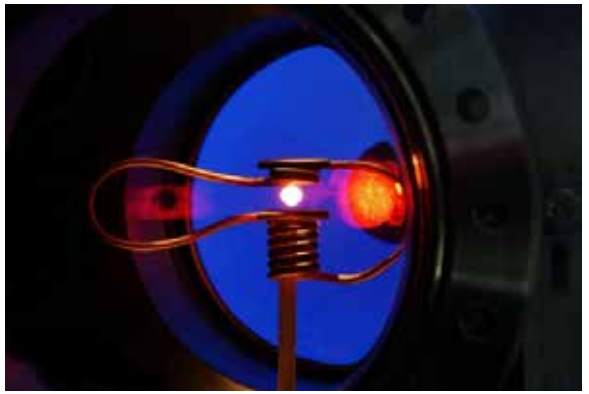
- A multi-user facility for the melting and solidification of conductive metals, alloys, or semiconductors in ultra-high vacuum, or in high-purity gaseous atmospheres.
- The heating and positioning of the sample are accomplished using electromagnetic fields generated by a coil system.
- Installed in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

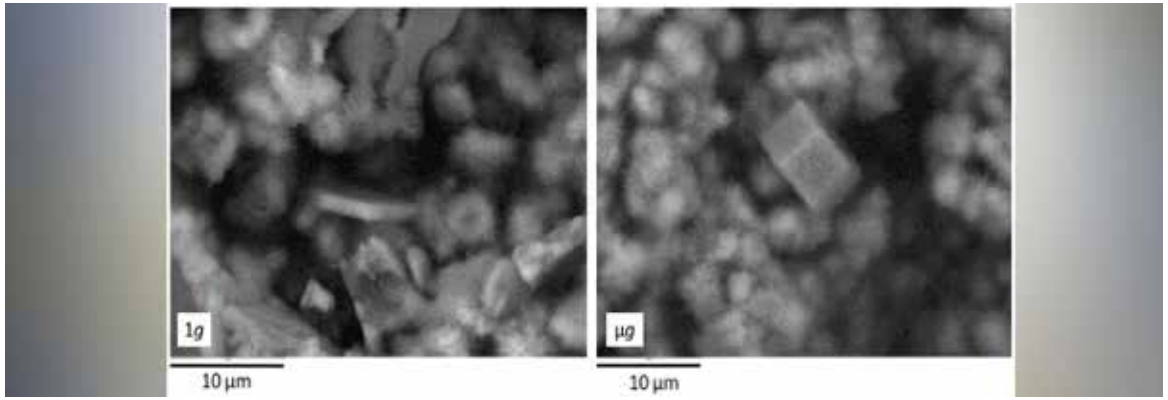
- Robert Hyers, University of Massachusetts
  - Objective: Advance the understanding of photorefractivity, which has applications in holographic storage, adaptive optics, and phase-conjugate mirrors, using $Bi_{12}SiO_{20}$ and $Bi_{12}GeO_{20}$.
- Douglas Matson, Tufts University
  - Objective: Understand 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 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. Crystals tend to grow larger and more uniform in reduced gravity.

Top Publications - Materials

- F.L. Mota, N. Bergeon, A. Karma, R. Trivedi, and J.M. Debierre, “Oscillatory-nonoscillatory transitions for inclined cellular patterns in three-dimensional directional solidification,” Physical Review E 102.3 (2020): 032803.
- Xiao Xiao, Jonghyun Lee, Robert W. Hyers, and Douglas M. Matson, "Numerical representations for flow velocity and shear rate inside electromagnetically levitated droplets in microgravity," npj Microgravity, Vol. 5, No. 7, 25 March 2019.
- J.M. Gentile, D.D. Stauffer, D.C. Hofmann, J.R. Trelewicz, “Shear localization and its dependence on microstructural length scales in metallic glass composites,” Materialia, 9, 100598, (2020)
- D. C. Van Hoesen, A. K. Gangopadhyay, G. Lohöfer, M. E. Sellers, C. E. Pueblo, S. Koch, P. K. Galenko, and K. F. Kelton, “Resistivity Saturation in Metallic Liquids Above a Dynamical Crossover Temperature Observed in Measurements Aboard the International Space Station,” Physical Review Letters, 123, 226601, 26 November 2019.
- M. Mohr, R.K. Wunderlich, D.C. Hofmann, H.-J. Fecht, “Thermophysical properties of liquid Zr52.5Cu17.9Ni14.6Al10Ti5—prospects for bulk metallic glass manufacturing in space,” Microgravity, 5, 24 (2019).
- Torabi Rad M, Beckermann C, "A truncated-Scheil-type model for columnar solidification of binary alloys in the presence of melt convection," Materialia, 2019 Sep, 7:100364.
- Glicksman, M. and Ankit, K., "Thermodynamic behaviour of solid-liquid grain boundary grooves." Philosophical Magazine, 14 Mar 2020.
- Etesami SA, Laradji M, and Asadi E, "Reliability of molecular dynamics interatomic potentials for modeling of titanium in additive manufacturing processes," Computational Materials Science, 2020 Nov, 184:109883.
- Shutov IV, Kamaeva LV, Krivilyov MD, Yu C-N, Mesarovic SM, and Sekulic DP, "Effect of processing parameters on microstructure in brazing of Al-Si alloys," Journal of Crystal Growth, 2020 Jan 15, 530:125287.
- Neves J, Collins P, Wilkerson R, Grugel R, Radlinska A, "Microgravity effect on microstructural development of tri calcium silicate (C3S) paste," Frontiers in Materials, 2019 April.

Collaborations

Collaborations – upcoming or in-discussion







- JAXA
  - FLARE Thin film material flammability
  - Group Combustion Experiment-2, GCE-2: 2-D array droplet combustion.
- ROSCOSMOS
  - SoFIE Materials Flammability – Two investigations
  - Brazing experiment (BRAINS)
- ESA
  - Saffire experiments
  - An agreement for future thermophysical properties experiments on ISS-EML Batch 5 is in work.
  - FY20 & FY21 Testing of Foam Optics and Mechanics (FOAM) Experiment in Soft Matter Dynamics (SMD) insert in ESA Fluid Science Lab.
  - Discussions of sharing Soft Matter Dynamics (SMD) hardware with ESA for future investigations in foams, colloidal suspensions, emulsions and granular materials.

Collaborations – upcoming or in-discussion

- DLR
  - Discussion of Sounding Rocket Expt. transfer of volatile fluids with modeling activity.
  - Discussions on cement experiment, MASON
  - Use of FLUMIAS microscope
- CNES
  - DECLIC – ALI, DSI, SCWO and Aerosol series of experiments
- ISSNL
  - Advanced Colloids Experiments in NASA Fluids Integrated Rack.
  - ISSNL and NSF planning to release research announcement for use of FBCE.
  - NASA and ISSNL are discussing collaborations for research of additive manufacturing materials and processes.
  - ISSNL to share the RSD developed by NASA
- NASA STMD
  - Advanced high heat flux electrohydrodynamic flow
  - Additive manufacturing In Space
- AFRL
  - Oscillating heat pipes

Physical Science Collaborations

Agency	Expts	Disciplines	Experiment Acronyms	Notes
Roscosmos	15	Complex Fluids, Combustion, Materials Science	OASIS* CFI, ACME-E-Field, BRE, S-Flame, Flame Design, CLD Flames; SoFIE-Gel, SoFIE-MIST; BRAINS, Diffusion, LCF-Bulk 1,2, LCF-Film 1,2,3	Russian Crew time for Russian investigator access to NASA SLPS experiment
ESA ASI	25	Complex Fluids, Fluid Physics, Fundamental Physics, Materials Combustion	EML: Batch 1-M,K,H, Batch 2-M,K,H, Batch 3-M,K,H, Batch 4-M,K,H; MSRR/MSL: Cetsol, Micast; FOAM, Dolfin, Compgran, PK-4, ACE-T2, ACE-T10, Trans.Alloys, Protein, ACES,SMD (plan) FLEX-ICE-GA	Access to ESA hardware in exchange for NASA crew time and upmass
JAXA	5	Materials Science, Combustion	ELF-US- 1, 2, 3, 4, 5, 6; Flare, FLEX-2J, GCE-US	JAXA furnace & combustion hardware; NASA launch services, cold stowage, etc
CNES	7	Combustion, Fluids, Fund. Physics	HTI-R, ALI-R, DSI-R, HTI-R2, DSI-R2, SCWO and AEROSOL	CNES hardware, NASA upmass, crew time
DLR	3	Fundamental Physics, Fluid Physics	CCF, BECCAL, ZBOT-FT (ground program)	DLR hardware, NASA upmass, crew time
South Korea	2	Complex Fluids	ACE - T1, ACE-T1-3	NASA hardware, S. Korea - Co-I,
Thailand	2	Complex Fluids	LCF – Film 1, 2	NASA hardware, Thailand - Co-Is
ISS National Lab (CASIS)	11	Biophysics, Complex Fluids, Materials Science	ACE-H2, ACE-T1, ACE-2R, ACE-T7, ACE-T6, MICS, LMM Bio-1, LMM Bio-3, RTPCG-1, RTPCG-2, FBCE-reuse	NASA hardware & PIs, ISSNL crew time; MICS and FBCE reuse- ISSNL investigators
NIST	4	Fundamental Physics, Materials	ACES, MICS, MICS-MVP, ELF-US-1	NIST Co-Is (on proposals)
NSF	1	Fundamental Physics	PK-4, FBCE-reuse	NSF funds & selects PIs, SLPS - hardware
Multi Agencies	1	Combustion	Transcritical Combustion (ground program)	SLPS drop tower rig, guest PIs, discussion
NASA - STMD	3	Fluid Physics	ZBOT, ZBOT-NC, ZBOT-AC, ZBOT-FT: *ISS CFM External Experiment*	SLPS Hardware, STMD numerical support *STMD-Hardware, SPLS- Co-I & ISS support*
NASA - AES	6	Fluid Physics, Combustion	PBRE-WR 1 - 6, SCWO	SLPS- core hardware; AES- PI, test articles

Completed experiments shown in blue print

Solicitations

Solicitation Summary

Recent Selections

Open Solicitations

- Fluid Physics – September 2020
- Physical Science Informatics Appendix G – September 2020

Future Solicitations

- Physical Science Informatics – September 2021
- Materials Science – October 2021
- Fluid Physics – October 2021
- Complex Fluids – November 2021
- Combustion Science-Fire Safety – November 2021
- Fundamental Physics – May 2022
- Research Opportunities for US Scientists – European Space Agency AO for the Electromagnetic Levitator, thermophysical properties of materials, 2022
- High Pressure Transcritical Combustion - 2023

Recent Selections in Physical Sciences

Physical Science Informatics (PSI) NRA Appendix F Selections

PI Name	PI Organization	Proposal Title	Research Area
Amir Riaz	University of Maryland	Pool Boiling Heat Transfer Mechanisms in Low Gravity: Numerical Experiments of MABE and NPBX Data	Fluid Physics
Sunghwan Jung	Cornell University	Enhanced particle tracking in STDC data and its industrial application of Marangoni convection	Fluids Physics
Travis Walker	South Dakota School of Mines & Technology	Investigation of Aspherical Magnetic Particles in Low-Gravity Environments	Complex Fluids
Robert Hyers	University of Massachusetts	Non-contact measurement of thermal conductivity of undercooled and reactive liquid metals	Materials Science
Adrienne Dove	University of Central Florida	Processing and analysis of the Strata-1 dataset to explore granular mechanics of a realistic system in a long-duration low-gravity environment	Materials Science

Open Solicitations

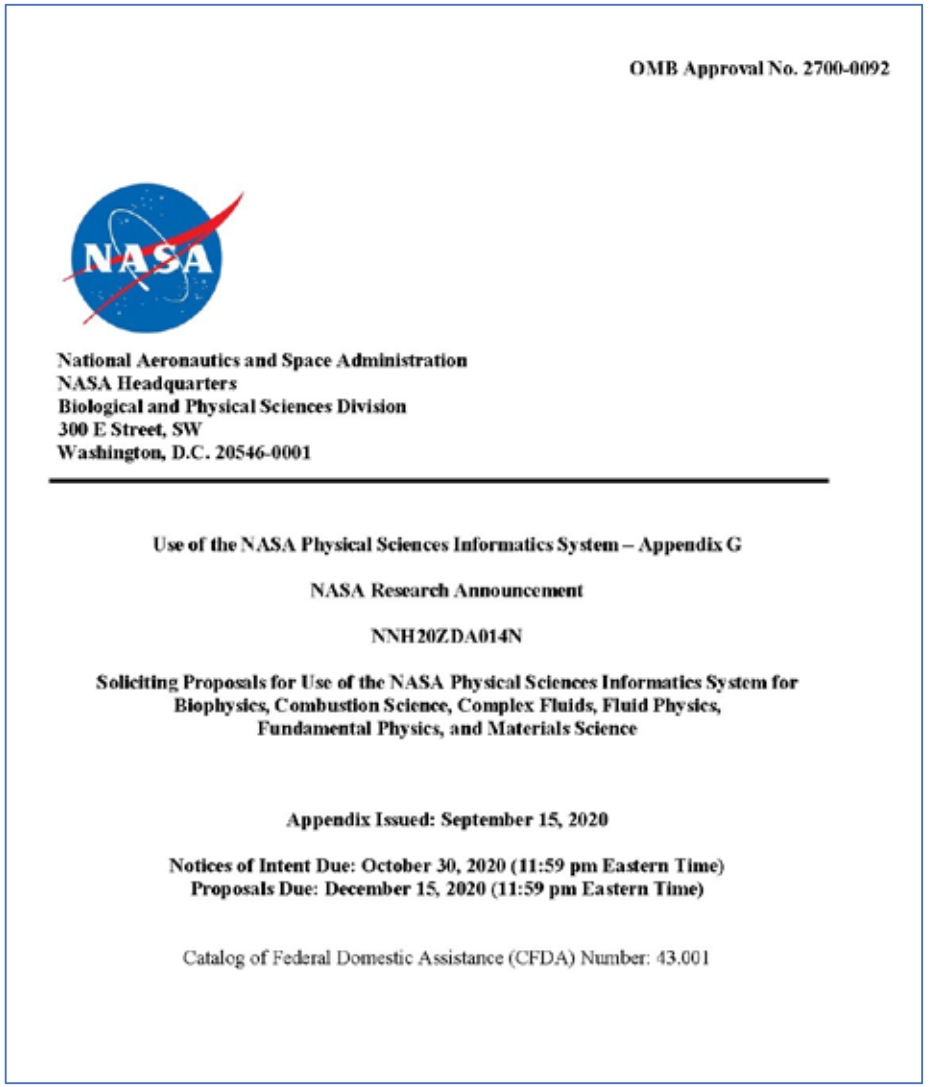
Physical Science Informatics (PSI) NRA

PSI Appendix G

- Released: September 15, 2020
- Eligible flight and ground investigations: 70
- **Proposals Due: December 15, 2020**
- Selections (target): June 2021

- 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 NRA is available at: https://go.nasa.gov/3hwnN6i
- For additional information on the PSI database, visit: http://psi.nasa.gov



OMB Approval No. 2700-0092

National Aeronautics and Space Administration
NASA Headquarters
Biological and Physical Sciences Division
300 E Street, SW
Washington, D.C. 20546-0001

Use of the NASA Physical Sciences Informatics System – Appendix G

NASA Research Announcement

NNH20ZDA014N

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

Appendix Issued: September 15, 2020

Notices of Intent Due: October 30, 2020 (11:59 pm Eastern Time)
Proposals Due: December 15, 2020 (11:59 pm Eastern Time)

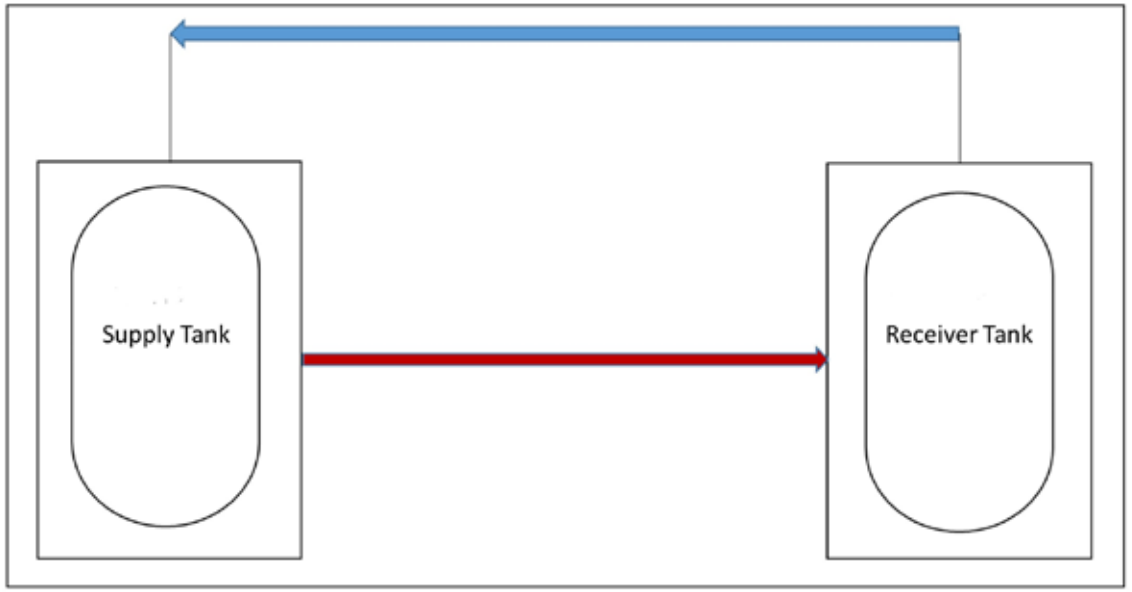
Catalog of Federal Domestic Assistance (CFDA) Number: 43.001

Research Opportunities in Physical Science Appendix A - Fluid Physics

- Released: September 1, 2020
- **Proposals Due: December 1, 2020**
  - Required Step 1 proposals: October 1, 2020
  - Invited Step-2 Proposals: December 1, 2020
- Solicits proposals for fluid physics experiments to be conducted on the ISS.
- **Awards:$247,500 per year for a total maximum award amount up to approximately $1,237,500 for a 5 year period.**

- The NRA is available at: http://tinyurl.com/NRA-NNH20ZDA012N-AppendixA

- NASA is seeking proposals to determine the best use of the new flow boiling module for the FBCE using simulant fluid, in support of in-space cryogenic propellant tank transfer research.
- Once currently planned test runs for FBCE are completed, NASA intends to replace the original flow boiling module with a new boiling module that has a geometry that more resembles the propellant tank transfer process.
- All proposal concepts must fit within FBCE hardware capabilities that are currently designed.



Future Solicitations

Physical Science Informatics 2021

- Release: September 15, 2021
- Eligible flight and ground investigations: >72
- **Proposals Due: December 15, 2021**
- Selections (target): June 2022
- **Awards: $100,000/year for two years.**
- **Approximately 5 proposals will be selected**.
- The solicitation will be available in NSPIRES as part of ROSES 2021.

- 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.
- For additional information on the PSI database, visit: http://psi.nasa.gov

- Note: PSI solicitation released annually

Materials Science – Oct 2021

- Additive Manufacturing
  - Materials Science experiments in ISS to enhance STMD-funded In-Space Manufacturing (ISM)
- Advanced Materials for Lunar Sustainability
  - Develop materials production and repair processes necessary to sustain extended-duration lunar surface operations
- Approximately 3 Selections

ESA AO, thermophysical properties of materials – mid 2022

- Thermophysical Properties
  - ESA AO Solicitation using the Electromagnetic Levitator. US scientists encouraged to participate on proposals.
  - Approximately 3 US investigators for ESA AO

Fluid Physics –Oct 2021

- **Oscillating heat pipes** - Numerical modeling in collaboration with AFRL (X37B microgravity testing and data), JPL (modeling lead), and GSFC (OHP lab testing).

- **Water Recovery** – Numerical modeling proposals from ISS PBRE – WR data. ISS water recovery devices such as filters, packing material, and valves will be tested on the ISS using the packed bed reactor device to gain an understanding of the fluid gas behavior in microgravity the AES division.

- **Water Recovery, Packed Bed Reactor Experiment (PBRE) with Tomography -** ISS experiment with the PBRE using diagnostic for 3D rendering of bubbles inside the packing material using tomography.

Approximately 3 Selections

Complex Fluids – Nov 2021

The goal is to investigate the fundamental problems that involve molecular and particle dynamics, self assembly, and chemical reactions that result from alignment among constituents so that the final outcome can be influenced. This will include the investigation of “far from equilibrium” phenomenon, complexity and cooperativity and to imagine life-like materials and machines of technological importance.

Discussions with international partners are in progress to share hardware, such as ESA’s Soft Matter Dynamics unit, DLR’s FLUMIAS microscope, NASA’s Liquid Crystal Facility, and KERMit.

Sample topic areas include:

- Colloidal Suspensions
- Foams
- Emulsions
- Granular Materials
- Liquid Crystals

Approximately 3 Selections

Combustion Science: Fire Safety Nov 2021

AES SoFIE - AES Flammability Fire Safety Tests - Directed Research. POC: Gary Ruff.

BPS SoFIE-2 - BPS Solicitation planned for release in FY 2022 and funded in FY 2023. The research call will emphasize applied flammability research for crewed vehicles at various exploration atmospheres. International collaboration on NRA is encouraged.

The Artemis Human Landing System and the Mars Exploration Command Module are both now planning on 26.5% pO2 at 10.2 psi. Lunar surface habitats are currently planing for 100% pO2 at 8.4 psi.

BPS MWT - BPS Solicitation planned for release in FY 2022 and funded in FY 2023. The NRA will emphasize applied flammability research for space exploration. Tests at 1 atm, although oxygen levels my be 21% or lower. The data will be used to compare with the 1-g, NASA 6001 - test 1 flammability results of spacecraft materials. International collaboration on NRA is encouraged.

AES/BPS Saffire VII - VIII: Planned. Requirements definition in progress. International Science Team. Managed by AES Program. POC: Gary Ruff.

Approximately 4 - 6 Selections

High Pressure Transcritical Combustion - 2023

- Highest priority from 2014 Microgravity Combustion Science Workshop
- GRC 0-g facility developed to support testing
  - Currently operational
- SDT kick-off Oct 2020 to seek peer input into research priorities and goals
- SDT effort will lead into NRA to solicit new investigators

Program Trends and Potential Science Directions as part of SMD

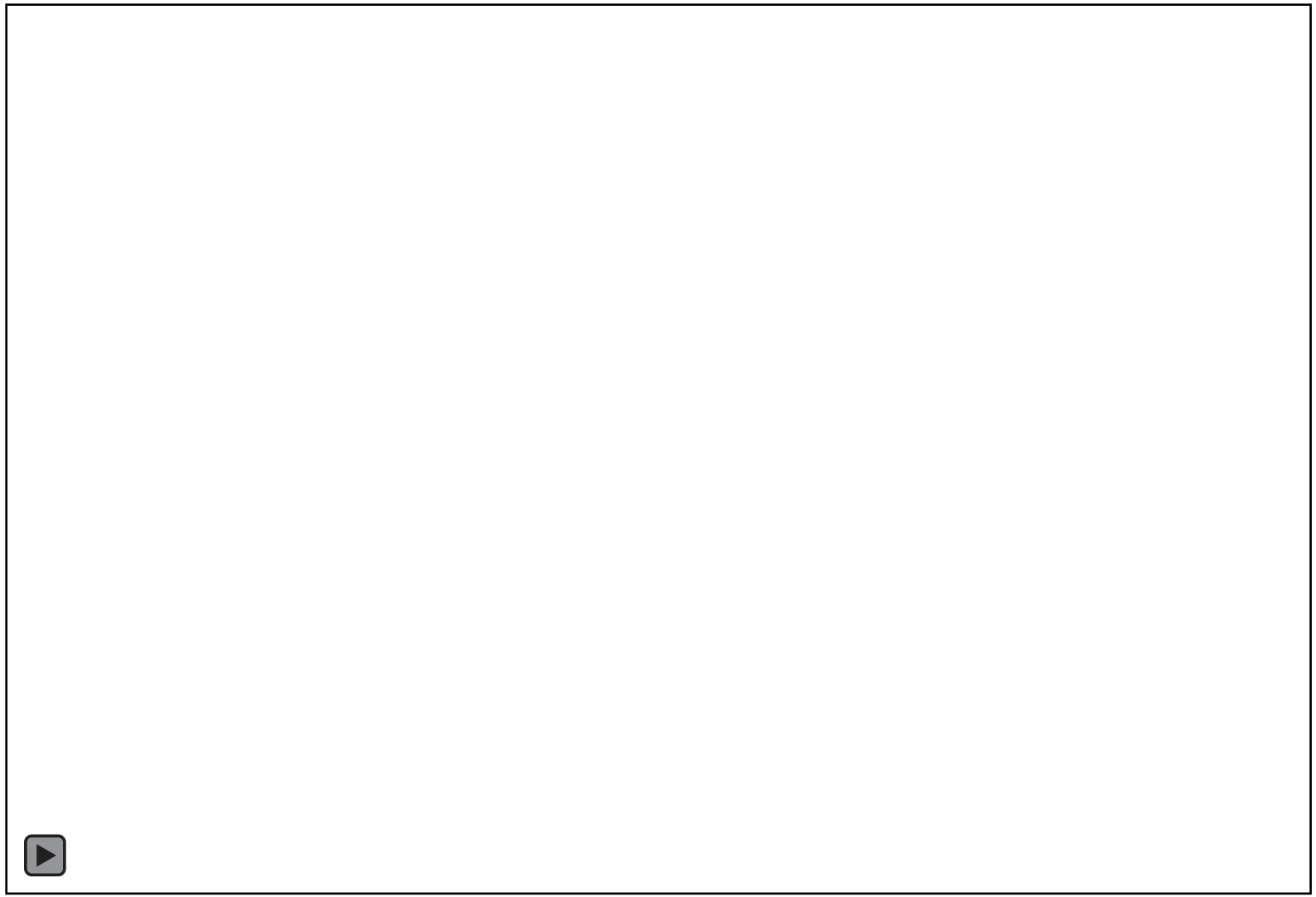
As we begin activities for the next Decadal Survey we will continue our pursuit of discovery based fundamental research, research supporting NASA's exploration goals and terrestrial applications, and with the focus of achieving transformative science.

Transformative research involves ideas, discoveries, or tools that radically change our understanding of an important scientific or engineering concept or educational practice or leads to the creation of a new paradigm or field of science, engineering, or education. Such research challenges the current understanding or provides pathways to new frontiers.

(National Science Foundation)

Unexpected Observations of Cool-Flame Burning during FLEX Experiments

- Studying ignition, burning and hot-flame extinction of hydrocarbon droplets (FLEX)
- For alkane fuels, following radiative extinction of hot-flame the droplet seemed to continue to burn
- Initial speculation that droplet burning supported by a low-temperature (cool) flame
  - Thought to be impossible. Cool flames precede hot flames, not the other way around
- Significant scaling, data analysis, theoretical and numerical modeling proved cool-flame burning



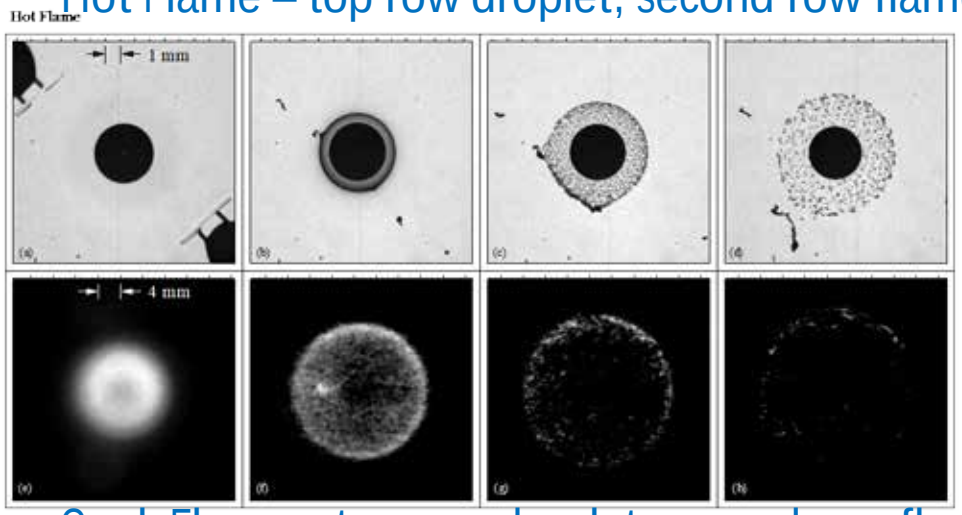
FLEX-35 Heptane Air

Discovery of Quasi-Steady Cool Flames

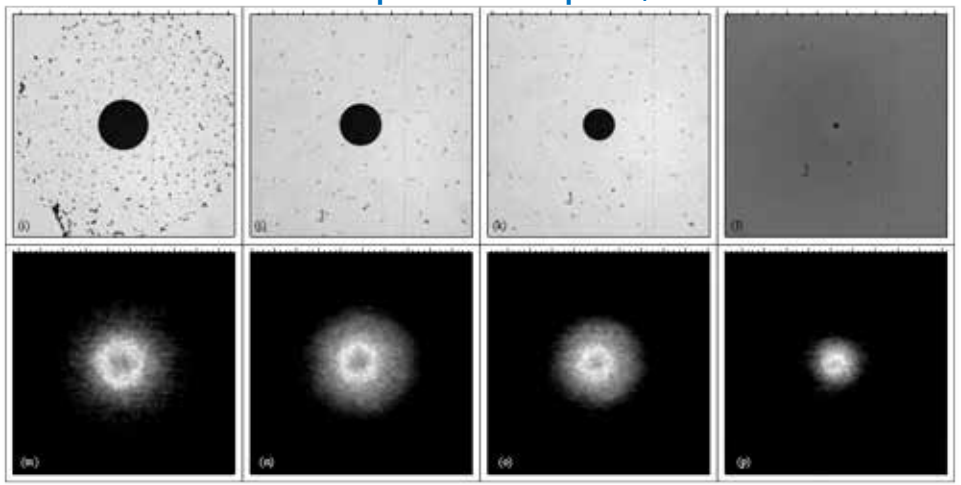
ISS droplet experiments showed unexpected (and thought to be impossible) cool-flame supported droplet combustion
Relevance: Improved understanding of low temperature chemical kinetics important in future internal combustion engines

- Over 200 citations between the first two (below) and approximately 500 citations of PI/Co-I publications of ISS cool flame results
- Discovery led to further discoveries of academic and practical importance
  - Spontaneous hot-flame re-ignition
  - Dual flame
  - Warm flames (intermediate temperature chemical kinetics)

Hot Flame – top row droplet, second row flame



Cool Flame – top row droplet, second row flame



Landmark papers

Nayagam, V., Dietrich, D. L., Ferkul, P. V., Hicks, M. C., and Williams, F. A. (2012). *"Can cool flames support quasi-steady droplet burning"*, Combustion and Flame, 159: 3583 – 3588.

Farouk, T. I. and Dryer, F. L. (2013). *"Isolated n-heptane droplet combustion in microgravity: "Cool Flames" - two-stage combustion"*, Combustion and Flame, 161: 565 – 581.

Trends, Forecasting Science Directions in the Community

2019 Biofilms Workshop

- This Workshop was held in conjunction with the 2019 Montana Biofilm Science and Technology Meeting
- **Topics of discussion** during the Workshop included:
  - Understanding impact of microbiomes in closed environments on NASA's missions
  - Investigations of the role of microbes in the biofilm formation and biofouling of life support system(s)
  - Development of mitigation strategies to reduce failure of life support systems.
  - Understanding biofilm formations within the confines of the material environment aboard the International Space Station
- **Knowledge gaps** identified during this workshop include:
  - What are the chemical changes, potential corrosion risk, equipment- and site-specific microbial changes along with potential for biofouling of key valves and equipment during dormancy?
  - What materials are more and less prone to biofilm formation under microgravity conditions?
  - How can a reduced gravity environment be used to develop the materials or surface treatments resistant to biofilm formation and growth.
  - Are there changes in bacterial or fungal biofilms due to space environments that may translate to modification of their virulence, resistance to mitigation strategies, or promoting biodegradation of materials?

2014 Combustion Workshop

- Panels in 5 sub-disciplines including spacecraft fire safety
- Representatives from academia, industry and government research labs
- Identify and prioritize experiment concepts, research foci and identify new facilities

Fundamental Combustion

1. **High Pressure/Supercritical (S)**
   - **Overwhelmingly viewed as highest priority**
   - Low temperature/cool flames also very high priority
2. Droplets/Sprays (**D**)
   - **High pressure/supercritical**
   - Low temperature/cool flame
3. Gaseous, non-premixed flames (**G**)
   - Low temperature/cool flame research
   - Low stretch diffusion flames a high priority
   - **High pressure combustion**
4. Premixed Flames
   - Not viewed as a high priority
5. Heterogeneous Combustion
   - Not viewed as a high priority

- *2020 High Pressure Transcritical SDT to update prioritization*

Spacecraft Fire Safety

- 2014 Combustion Workshop (**F**)
  - Material flammability
  - Large-scale fire
- **Research priorities also determined by AES/customers**
- Flammability research closely linked to fundamental combustion work
- AES funding other aspects of fire safety research
- AES funding Safire to examine large-scale fire behavior

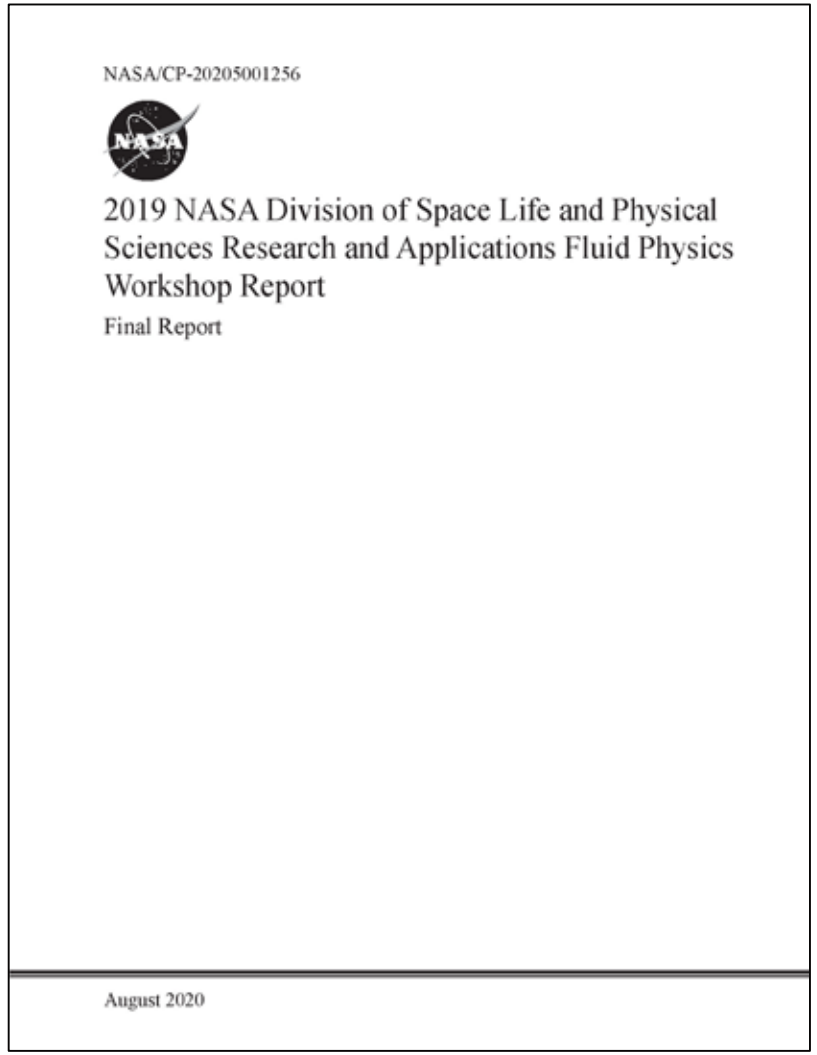
- *2021 Spacecraft Fire Safety TIM with key stakeholders*

2019 Materials Science for the ISS Workshop

- The Workshop report and presentations can be found here:
  - https://www.issnationallab.org/workshops/2019-materials-in-space/
- Workshop, Breakout sessions - key results:
  - **Functional Materials**
    - Overarching themes included additive manufacturing, materials reuse, high-value materials, and thermophysical property data
      - Additive manufacturing in microgravity could enable the production of novel functional or high-performance materials that are difficult to produce on Earth.
      - Research in microgravity could elucidate fundamental physics and the role of gravity versus other factors in various additive manufacturing processes in order to facilitate better technology development for both terrestrial and space applications.
  - **Materials Characterization, Microstructure, and Process Modeling**
    - The overarching themes of the discussions on process modeling were largely centered on developing an understanding of the processing-microstructure-property-performance relationships of materials developed on, and for use on, the ISS.
    - The overarching themes of the discussions on materials characterization and microstructure included additive manufacturing in space, material solidification processes in microgravity, on-orbit microstructure and testing capabilities, and data-driven manufacturing approaches.
  - **Lunar Infrastructure and Surface Operations**
    - This breakout session identified several overarching themes, with the highest priorities for ISS research being advanced manufacturing and advanced materials development.
      - Studies in microgravity would provide valuable information about how materials adhere and bond without a gravity force.
      - Synthesizing new materials in reduced gravity using lunar resources could produce materials with properties that are significantly different from those prepared on Earth.

2019 Fluids Physics Workshop

- 185 Registrants from NASA, Academia, ESA, Commercial, ISS-NL, NSF, AFRL
- **Boiling and Condensation**
  - Increase Critical Heat Flux
  - Examine surface characteristics especially for condensation
  - Improve Modeling
  - System stability
- **Heat Pipes**
  - Explore Interfacial and intermolecular phenomena.
  - Improve modeling, simulation and performance prediction.
  - Evaluate devices and systems.
- **Water Recovery**
  - Advance understanding of multi-phase adiabatic and non-adiabatic fluid physics.
  - Develop advanced diagnostic techniques with full field measurements .
- https://ntrs.nasa.gov/api/citations/20205001256/downloads/CP-20205001256.pdf?attachment=true


NASA/CP-20205001256

2019 NASA Division of Space Life and Physical Sciences Research and Applications Fluid Physics Workshop Report

Final Report

August 2020

2020 Grand Challenges in Soft Matter Workshop

- Co-sponsored by APS Division of Soft Condensed Matter Physics (DSOFT)
- Final report being issued: Final Draft Received Oct. 2020.
- Grand Challenges include
  - **Machines Made out of Machines** - develop understanding of complex dynamics and cooperativity.
  - **Scalable Self-sustaining Ecosystems** – develop understanding fundamental dynamical organizational principles.
  - **Active materials and metamaterials** – develop the understanding of interplay between designed microscopic structure and activity and the macroscopic optical, magnetic and mechanical properties.
  - **Intelligent processing and machine learning** – utilize not only in analyzing experiments and simulations but in designing and running experiments, recognizing, categorizing and discovering new phenomena and even formulating theories.

Challenges of Interest for the Decadal Survey

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

Keystone Capability: High Temperature Furnace

A high temperature furnace with float zone capability enables non-contact processing and the processing of high melt-point materials.

Non-contact processing:

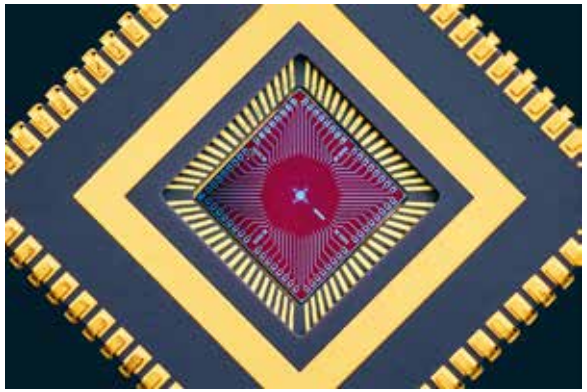
- Eliminates any reaction between the melt and container walls, greatly decreasing the incorporation of impurities and defects.
- Enables the study of the effects of microgravity on materials processes (i.e., defect generation, solutocapillary convection, and mass transport) without the deleterious interaction of the melt with the crucible wall.

Temperatures up to 1500°C: Enables processing of industrially relevant and important materials such as; silicon (most ubiquitous semiconductor in electronics and photovoltaics), cobalt and nickel-based superalloys for aerospace applications, semiconductors for x-ray and gamma-ray astronomy. Enables studies of exploration-relevant materials found in Earth's mantle or found on the Moon, Mars, asteroids, etc. (e.g., manganese orthosilicates and olivines).

Applications:

- Photovoltaic cells (e.g., silicon) for power generation
- Advanced semiconductors for electronics
- Remote sensing scientific instruments and sensors (e.g., CdZnTe as gamma-ray detector)







HPTC - Physical and Chemical Behaviors Near the Thermodynamic Singularity

Concept: Study binary molecular systems consisting of two hydrocarbon species in a buffer gas at high pressure and temperature conditions to explore the thermo-physical properties and chemical kinetics of multi-molecular systems near the thermodynamic singularity

Motivation: The physical and chemical properties of multicomponent fluids near the thermodynamic singularity (critical point) are poorly understood – both qualitatively and quantitatively. Terrestrial laboratory-scale experiments are contaminated by the effects of gravity and buoyancy. This lack of predictive knowledge makes the rational development of the next generation of engines and other reacting systems applications (i.e. materials synthesis, nano-materials) nearly impossible.

Experiment: Unlike the thermodynamic critical point for pure systems, binary and ternary systems exhibit a 'fuzzy' near-critical region. The preliminary concept is a freely-deployed droplet with the ability to vary component species and the ambient pressure and temperature. Possible diagnostics include imaging, PLIF, and Raman techniques.

Partnership/Collaboration: AFOSR



Droplet Ignition, T = 570 K, P = 25 atm
Impossible in 1-g as droplet falls off fiber

Fundamental Combustion

Concept: Utilize microgravity facilities to provide insights into basic combustion phenomena that will enable the design of the next generation of combustion systems, such as Gas turbine engines, Diesel engines etc. Research areas include:

- High pressure transcritical phenomena
  - Objective: Microgravity testing to achieve transformative insights into transcritical phenomena (transport properties, chemical kinetics, etc.)
- Chemical kinetics
  - Objective: Obtain benchmark data on flame ignition and extinction to validate and improve detailed chemical kinetic mechanisms
- Weak, low stretch flames
  - Objective: Use microgravity facilities to achieve weak, low stretch flames not possible in terrestrial facilities
- Turbulent Combustion
  - Objective: Testing in microgravity to study turbulent flames without buoyancy-induced instabilities present in terrestrial lab studies

Spacecraft Fire Safety

Concept: Terrestrial fires are dominated by buoyancy-induced flows not present in spacecraft fires. Spacecraft fire safety standards for material flammability, detector design, suppression and post-fire clean-up must be based on the unique hazards of the partial- and microgravity of spacecraft. Research areas include:

- Material flammability

  Objective: Measure changes in material flammability as a function of gravity level, oxygen and pressure (relevant spacecraft atmospheres)

- Fire behavior

  Objective: Determine the influence of gravity on fire ignition and growth and toxic product generation to assess risk to the crew

- Fire detection

  Objective: Study flame microgravity fire 'signatures' to optimize detector design

- Fire suppression

  Objective: Evaluate and optimize suppression technologies for spacecraft fire extinguishers

Micro-Manipulation of Molecules in Microgravity

Concept: Utilize the Soft Matter Dynamics module and the ensemble measurement capability to quantify behavior of colloidal solutions, emulsions and gels, in larger volumes and more concentrated solutions when subjected to a variety of stimulation such as temperature, agitation, etc.

Motivation: Chemical reactions of large complex molecules are the result of splitting and combining the molecular bonds between atoms. Targeting specific bonds to cleave as well as positioning and properly orienting reactant molecules to combine into the desired products will increase the yields while reducing the amounts of required reactants and waste products.

Experiment: Build up of a SMD simulator and Interfaces to accommodate in a NASA rack. Modification of the SMD to incorporate both electric field and magnetic field capabilities. Design and construction of a sample preparation and reactant storage capability.

Soft Matter Grand Challenge: Machines Made out of Machines

Concept: Develop machines able to self-assemble, self-repair, self-replicate, microcompartmentalize, specialize, operate as distributed engines, compute, and learn. Aside from the clear utility of intelligent machines they also demand an understanding of complex dynamics, non-equilibrium assembly and cooperativity that we sorely lack. These machines would have the potential to impact technologies from smart fabrics to soft robotics. (The biological analogue are cells which can form organisms which can self-assemble, self-replicate, disassemble, and reform as other organisms. To create prototypes we first want to use materials with different densities requiring microgravity for assembly.)

Motivation: Imagine an interacting network of active elements each with its own power source and which is connected to its neighbors chemically or physically. What we know from network theory and from preliminary experiments is that interesting phenomena occur as soon as the network nodes are nonlinear. We envision as elements micron scale machines which assemble into larger scale metamachines. The elements can dissemble to replicate and reform different metamachines.

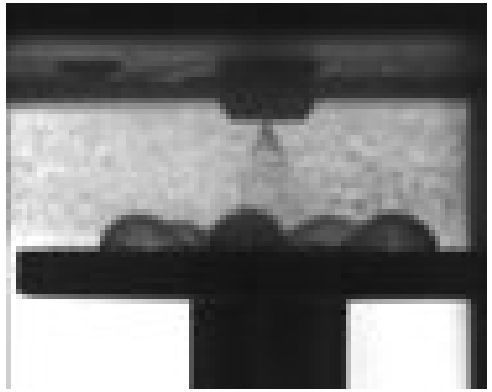
Soft Matter Grand Challenge: Machines Made out of Machines - Continued

Ops concept: Ability to actively manipulate samples while observing them through oculars or video display in real time. Ability to apply a variety of fields, (voltage, frequency, temperature, etc.) with a trained researcher. Due to the sophisticated nature of the lab environment required , the samples will need to be prepared on the ground. However, the sample volumes are very small allowing thousands of samples to be flown at one time. Each sample can exhibit a large range of behaviors when an external field is applied leading to a large number of scientific experiments.

Flight hardware and facilities: ESA's Soft Matter Dynamics hardware, microscope such as NASA's LMM, KERMIT or DLR's FLUMIAS. Microscope oculars needed for hands- on operation. Microscope diagnostics for particle manipulation such as laser tweezers, magnetic, electric and temperature field gradient capability and confocal microscopy. Also required is the ability for sample shearing and mixing. Also needed is for microscope is multicolor illumination to distinguish different types of particles that have been tagged with color dyes simultaneously. NASA's Liquid Crystal Facility with magnetic field capability. High speed data acquisition.

Partnerships/Collaboration: ESA, DLR, CNES, ASI and the ISSNL are in discussion

Dribbling the Droplets



Concept: Liquid Droplet, film and Jet Impact, spreading and flow studies onto superhydrophobic surfaces.

Motivation: Superhydrophobic surfaces would form a protective gaseous barrier that can be used to prevent the formation of biofilms, serve as a heat transfer insulator, and precisely position minute amounts of liquid for the advancement of chemistry.

Hands on ISS Science: There is a long history of capillary experiments that have been conducted manually by the astronauts for the Capillary Flow Experiments, Interface Configuration Experiments, Capillary Structures for Exploration Life Support either as planned experiments or "Saturday Morning Science." Without significant complication, automation limits the droplet fluid volume, velocity, angle of droplet impact. In addition, first-hand observation has been beneficial to identify penomena and behavior that the visalization system may miss.

Experiment: Buildup of fluid containment glovebox optimized for visulization including illumination (using both uniform white light and laser light sheets) standart rate and highspeed video from at least two-othogonally located positions with time synchronization.

Materials Science processes in space



Materials Science: Utilize microgravity facilities to provide insights into materials science phenomena that will enable space exploration in extreme environments, such as on the Lunar or Martian surface, the surface or subsurface of an icy moon, or in orbit around the Moon.

Research areas include:

- Advanced Manufacturing
  - Objective: Progress advanced manufacturing in Space (and on Earth) by improving our understanding of the underlying physics of the relevant processes, including **additive manufacturing, welding, and freeze casting**.
- Advanced Materials for Lunar Sustainability
  - Objective: Utilize microgravity research to understand the effects of reduced gravity on manufacturing, infrastructure construction (e.g. habitats, landing pads, roads, and berms), repair processes (e.g. welding and brazing), in-situ resource utilization (e.g. extraction of metals from regolith), and advanced materials development (e.g. synthesizing materials from in-situ resources) necessary to sustain extended duration surface operations.
    - Advanced cement studies building on prior ISS research.
    - Studies of synthesizing new materials in reduced gravity using Lunar resources.
    - Resource processing, including extraction of metals and oxygen from regolith.

To investigate the above research areas, the experiments will investigate the following:

- How do we predict porosity and material consolidation and understand the differences in thermal profiles in reduced gravity?
- How does the reduction of buoyancy driven convection and sedimentation impact manufacturing processes?

Discussion and Q&A

Backup

Fundamental Combustion - Liquid Fuels

Flame Extinguishment Experiment (FLEX)
UC San Diego, Princeton, Cornell, UC Davis, U South Carolina
Testing examined flammability limits of pure liquid fuels

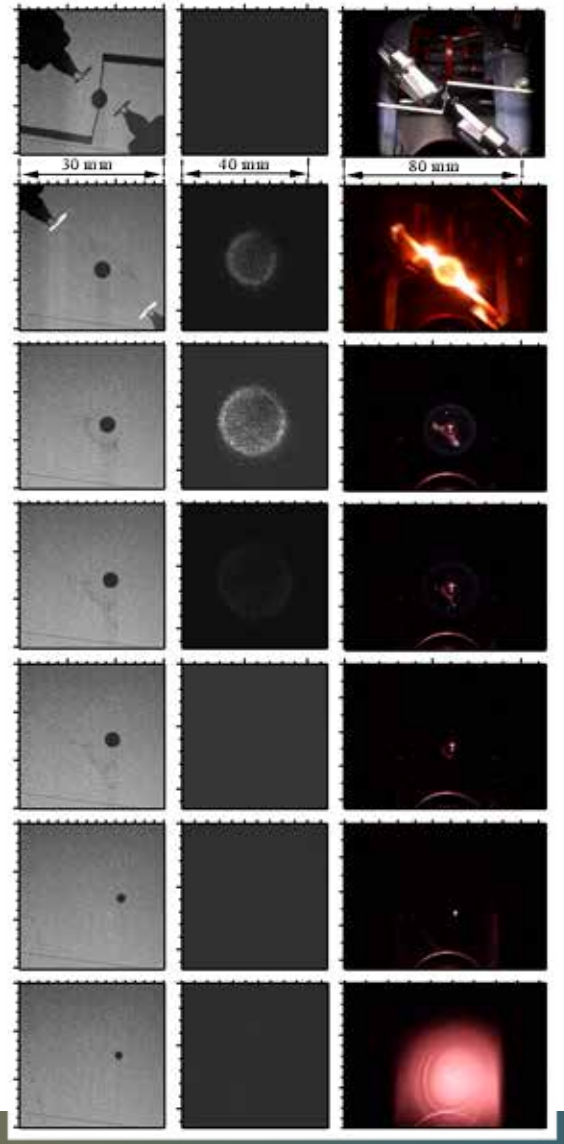
FLEX Italian Combustion Experiment for Green Air (FLEX-ICE-GA)
Collaboration with ASI/Istituto Motori
Extended testing to combustion of biologically-derived fuels

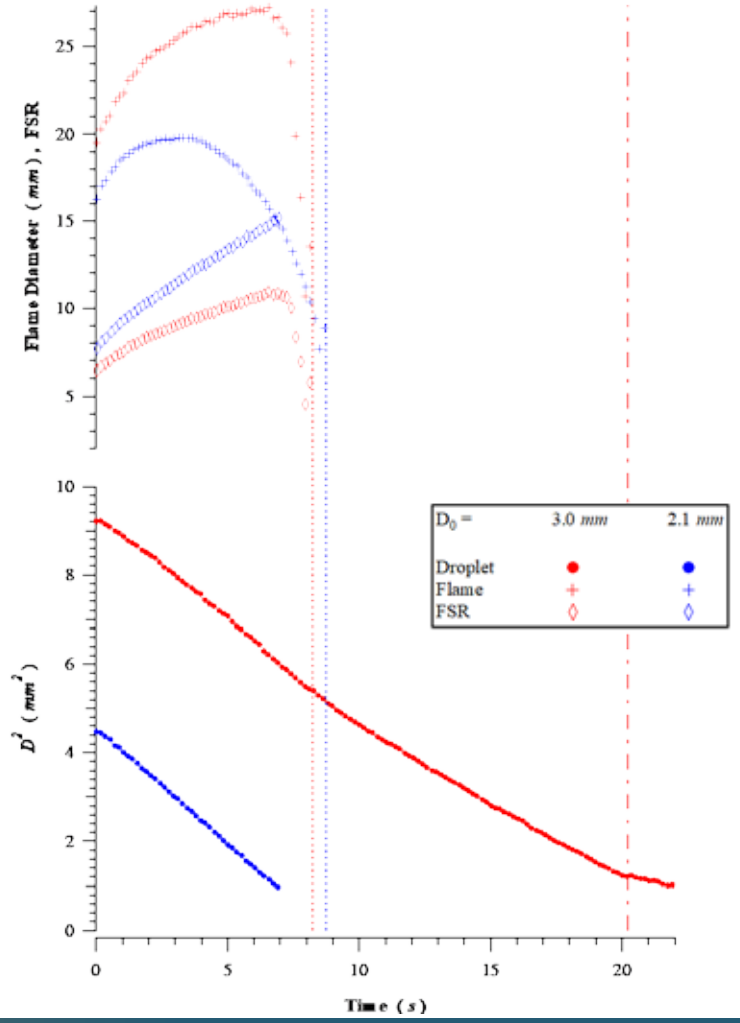
Flame Extinguishment Experiment - 2
UC San Diego, Princeton, Cornell, UC Davis, U South Carolina
Examined mixtures of pure fuels, liquid-phase transport, droplet interactions

FLEX-2J
Collaboration with JAXA, Nihon U., Yamaguchi U.
Studied flame spread over linear droplet arrays

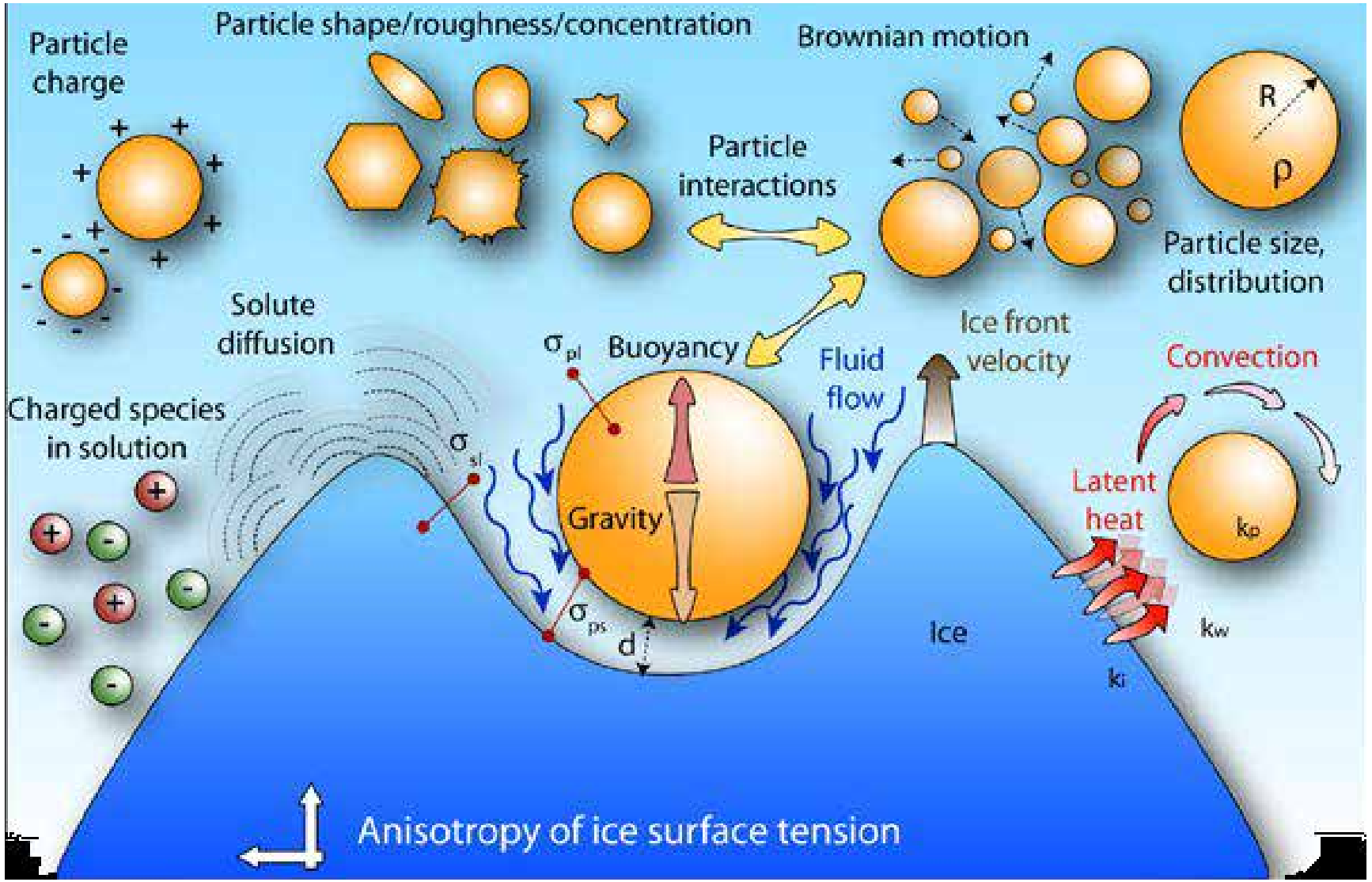
Cool Flame Investigation (CFI)
UC San Diego, U South Carolina
Further examination of quasi-steady cool flame burning after discovery during the FLEX experiments

Group Combustion Experiment (GCE)
Collaboration with JAXA, Nihon U., Yamaguchi U.
A JAXA led effort with NASA that examined flame spread through 2-D droplet clouds





Freeze Casting



Fundamentals of freeze casting.

PSI NRA Proposal Data by Research Area

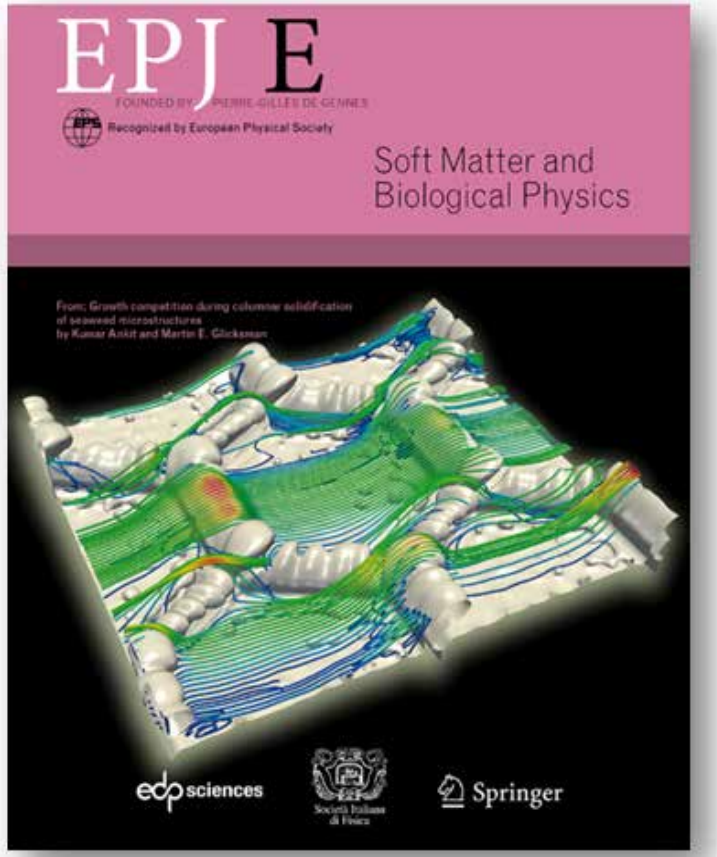
Appendix	Awarded proposals by research area				
	Combustion Science	Complex Fluids	Fluid Physics	Fundamental Physics	Materials Science
Appendix A	1	-	1	-	-
Appendix B	2	1	2	-	3
Appendix C	2	1	2	-	1
Appendix D	1	1	2	-	1
Appendix E	1	1	1	-	2
Appendix F	-	1	2	-	2
Total	**7**	**5**	**10**	**-**	**9**

Of the 31 awarded proposals, 4 were submitted by graduate students and 27 were submitted by established researchers.

PSI Science Highlight

Abstract

The mechanisms by which interfacial instabilities instigate the growth of solidification patterns is a topic of longstanding interest. In columnar solidification of metallic melts, where the solid-liquid interfacial energy is anisotropic, evolving dendritic patterns compete depending on their relative misorientation. By contrast, organic “plastic crystals”, such as alloys based on succinonitrile, where the anisotropy in their solid-liquid interfacial energy is extremely weak, solidify forming seaweed patterns that typically exhibit little, if any, growth competition. We explore in this study mechanisms by which columnar solidification microstructures of binary alloys with low crystalline anisotropy compete. We adopt toward this end a validated Navier-Stokes multiphase-field approach to characterize the influence of grain misorientation, seed morphology, and melt advection on the growth competition. Simulated seaweed patterns indicate profound influences of all three factors, although characteristic solidification morphologies are observed to evolve depending on the melt flow intensity.



Feb 2020 cover of The European Physical Journal E for “Growth competition during columnar solidification of seaweed microstructures”, K Ankit, M Glicksman