Levitation Experiments on ISS: Science and Applications

National Aeronautics and
Space Administration

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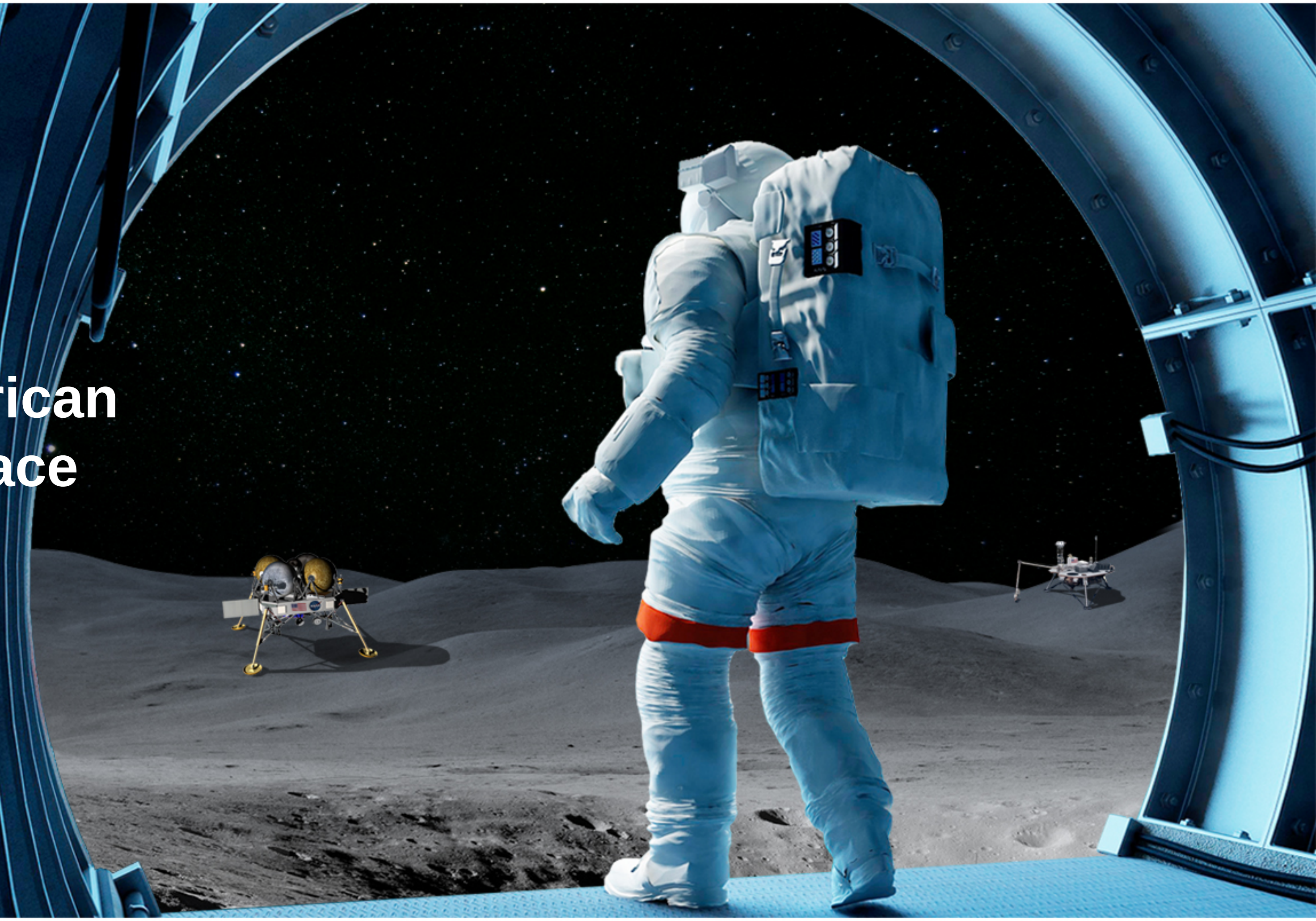

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NASA Marshall Space Flight Center, Huntsville, AL

Robert Hyers, University of Massachusetts

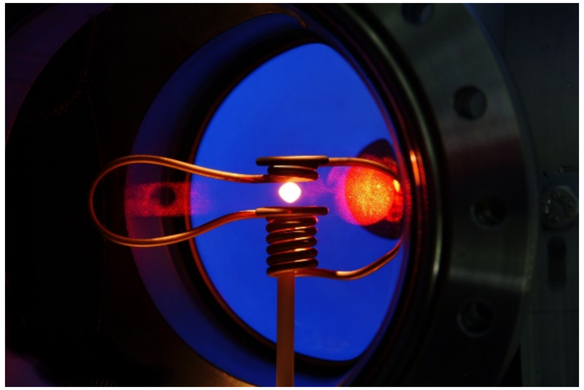
Kenneth Kelton, Washington University in St. Louis

Douglas Matson, Tufts University

Ranga Narayanan, University of Florida

Richard Weber, Materials Development, Inc.

Levitation Facilities on ISS



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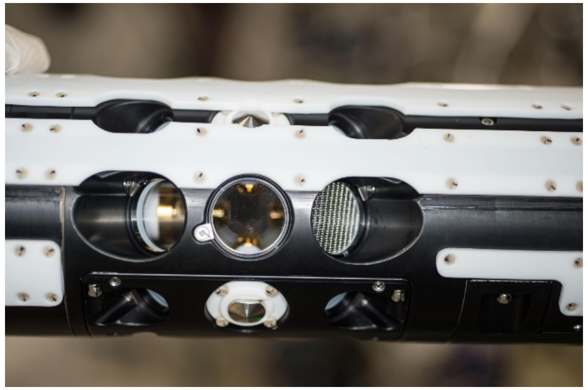
A sample being heated in ESA's Electromagnetic Levitator. Photo Credit: ESA/DLR



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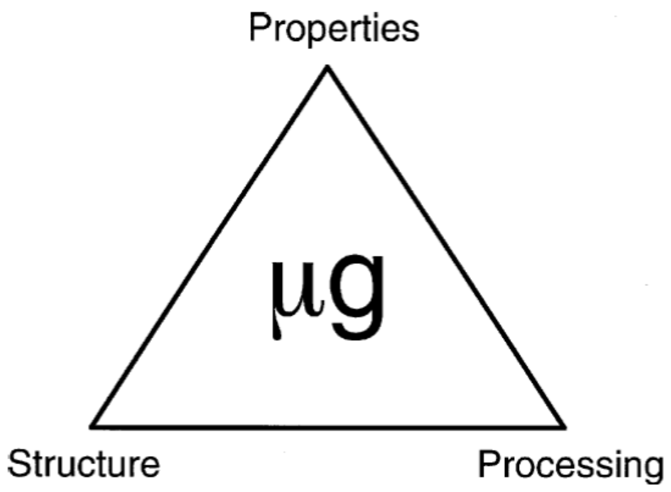
The Electrostatic Levitation Furnace (ELF) sample cartridge. Photo Credit: NASA

- **There are 2 levitations facilities currently in use on ISS**
  - ESA's International Space Station Electromagnetic Levitator (ISS-EML)
    - Has been in operation since 2015.
    - US investigators are on several of the European research projects.
    - The experiments are split into Batches of 18 samples each.
      - Batch 1 is complete and scheduled to return this year
      - Batch 2 is on ISS and experiments are ongoing
      - Batch 3 is being prepared for operation
      - Batch 4 is in planning discussions
  - JAXA's Electrostatic Levitation Furnace (ELF)
    - Launched to the ISS in 2015 and has initiated operations.
    - The ELF sample holder contains 15 samples.
    - In 2016 NASA selected four proposals to the MaterialsLab NASA Research Announcement (NRA) for experiments on the ELF.

Why Levitation in Microgravity

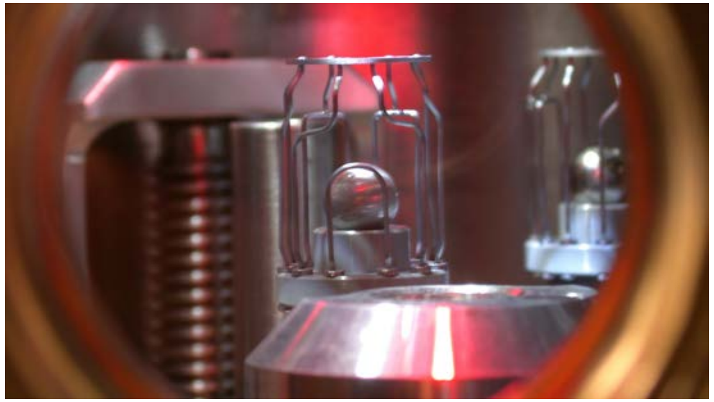
- **The International Space Station (ISS) provides a long-duration spaceflight environment for conducting microgravity experiments.**
- **The microgravity environment greatly reduces buoyancy-driven convection, pressure head and sedimentation in fluids.**
- **Many thermophysical properties can be measured in a levitator on Earth, but with convective contamination.**
  - This contamination plays a significant role in the formation of the intermediate phases.
  - In particular nucleation and viscosity measurements demand quiescent conditions.



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

ISS-EML Investigators

- **Robert Hyers (University of Massachusetts)**
  - Member of research projects: THERMOLAB, ICOPROSOL, and PARSEC
  - Objectives:
    - Provide magnetohydrodynamic (MHD) modeling support of macroconvection in various materials for PARSEC, THERMOLAB–ISS, and ICOPROSOL
- **Kenneth Kelton (Washington University in St. Louis)**
  - Member of research projects: THERMOLAB, ICOPROSOL, and QUASI
  - Objectives
    - Determine the influence of liquid and solid short-range order on the nucleation barrier.
    - Correlate the nucleation kinetics with the local structure of the liquids.
- **Douglas Matson (Tufts University)**
  - Member of research projects: PARSEC, THERMOLAB, and ELFSTONE
  - Objectives:
    - Investigate the effect of fluid flow on the solidification path of peritectic structural alloys.
    - Research the influence of convection on the formation of different microstructure in a wide range of commercial alloys.



An EML sample ready to be processed. Photo credit: DLR.

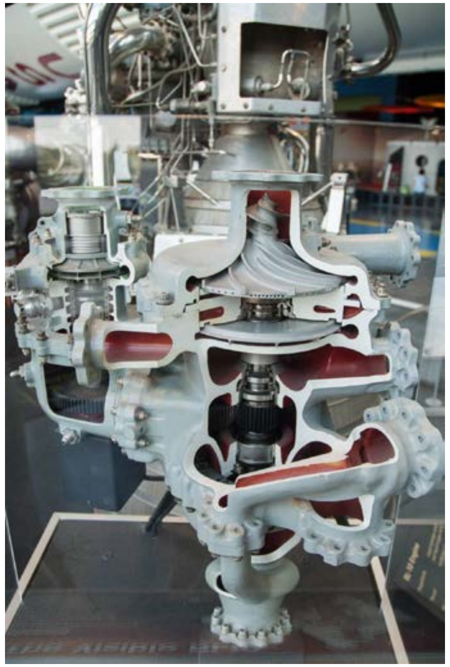
- **ISS-EML Research Teams with US involvement**
  - ELFSTONE: Electromagnetic Levitation Flight Support for Transient Observation of Nucleation Events
  - PARSEC: Peritectic Alloy Rapid Solidification with Electromagnetic Convection
  - THERMOLAB – ISS: Thermophysical Properties of Liquid Metallic Alloys – Modeling of Industrial Solidification Processes and Development of Advanced Products
  - ICOPROSOL: Thermophysical properties and solidification behavior of undercooled Ti-Zr-Ni liquids showing an icosahedral short-range order
  - QUASI: Quasi-Crystalline Undercooled Alloys for Space Investigation

Research on ISS-EML

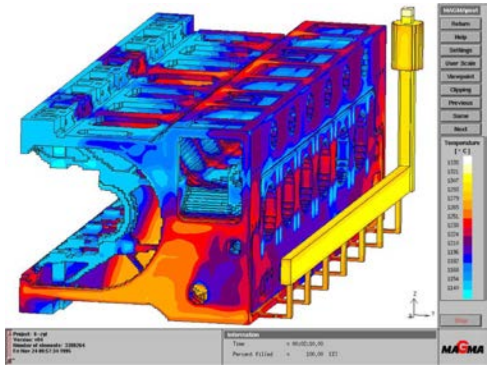
- **High quality thermophysical properties of high-temperature materials are critical to develop accurate models of**
  - Casting
  - Welding
  - Metal additive manufacturing

- **Thermophysical properties could lead to more efficient and more reliable production of metallic parts for**
  - Space Exploration
  - Commercial applications
  - Industrial applications

- **In many cases, the accuracy of available property data is the limiting factor in the predictive capabilities of the models.**



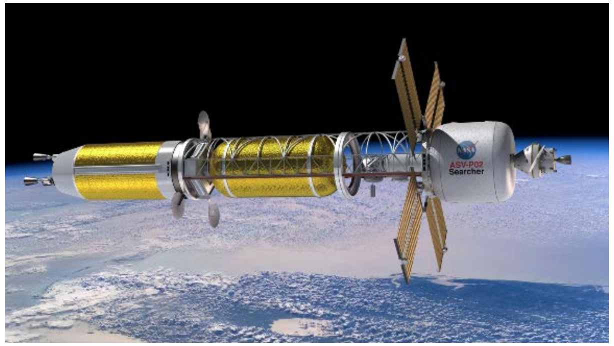
The RL 10 turbopump. Photo credit: NASA.



A model of a casting process.

Application: High Temperature Materials for Nuclear Thermal Propulsion

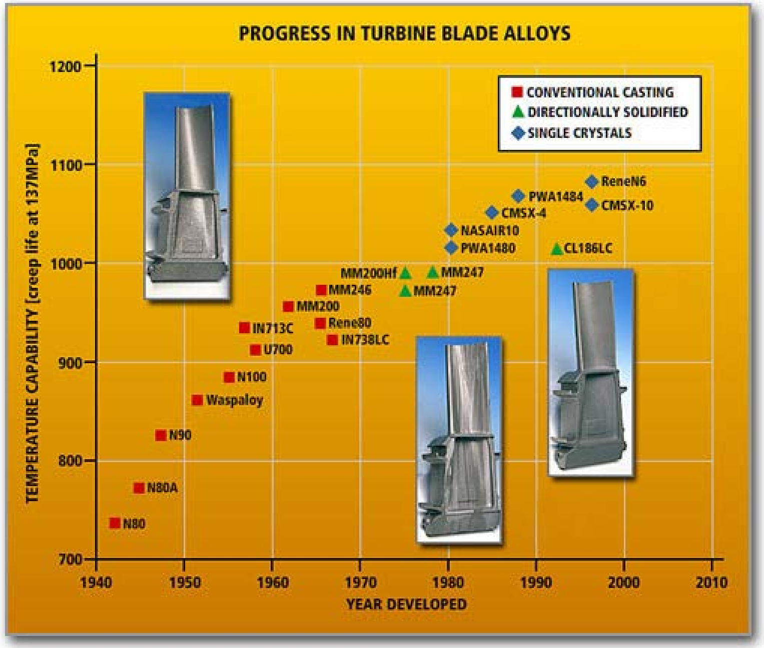
Fuel rods for nuclear propulsion.
Photo Credit: NASA



Concept of nuclear-thermal crew transport
for Mars mission. (NASA Illustration)

- **The US investigators and their teams are collaborating with ESA's THERMOLAB project**
  - One part of THERMOLAB is measuring thermophysical properties and solidification behavior of zirconium alloys used in nuclear reactors
  - Alloys provided by Areva
    - a French manufacturer of nuclear power plants.
  - Synergistic design goals with NASA NTP
  - Measurements will improve manufacturing of reactor components
    - leading to higher performance and higher reliability
  - The results of this study will be used to improve safety, reliability, and cost of nuclear power in space and on Earth

Application: Turbine Blades



Evolution of nickel-based superalloys. CMSX-10 data is currently being evaluated following successful testing during ISS-EML Batch 1.
Photo Credit: NASA

- **THERMOLAB has tested 3 Ni-based superalloys (CMSX-10, MC2, and LEK-94) in ISS-EML Batch 1.**
  - Superalloys are key materials for turbopumps in chemical rockets.
  - Superalloys are also the key component in jet engines; better superalloys allow more efficient airliners and military aircraft.
  - Measurements will improve manufacturing of superalloy components, leading to higher performance and higher reliability.
- **The US Investigators collaborate with ESA's THEMOLAB project on measuring thermophysical properties of metals and alloys.**
  - These properties are critical to accurate models of casting, welding, and metal addtive manufacturing.
- **Better models improve the quality, reliability, and cost of manufactured parts.**

ELF Investigators

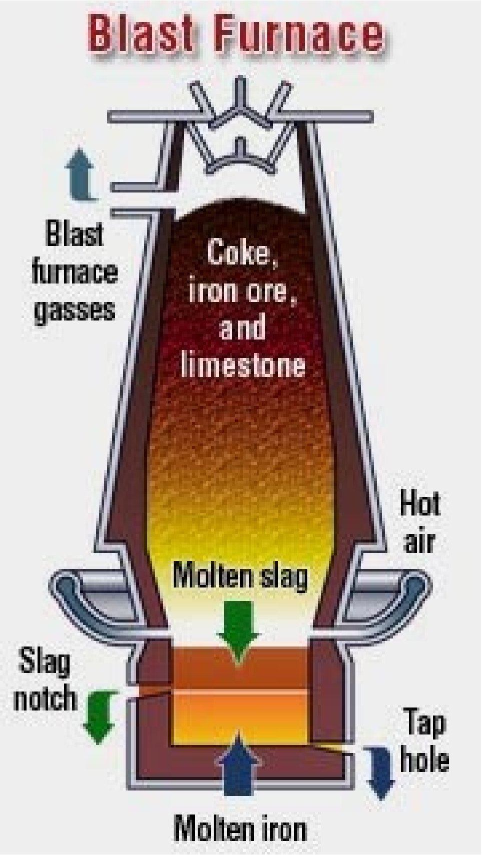
- **Robert Hyers (University of Massachusetts)**
  - Modeling and Simulation of Electrostatically Levitated Multiphase Liquid Drops
    - Dr. Hyers is a Co-Investigator on a Japanese research team.
    - Experiments for this project on ELF began in 2018.
  - Thermophysical Properties and Transport Phenomena Models and Experiments in Reduced Gravity
- **Douglas Matson (Tufts University)**
  - Round Robin - Thermophysical Property Measurement
- **Ranga Narayanan (University of Florida)**
  - A Novel Way to Measure Interfacial Tension Using the Electrostatic Levitation Furnace
- **Richard Weber (Materials Development, Inc.)**
  - Microgravity Investigation of Thermophysical Properties of Supercooled Molten Metal Oxides

Levitated sample in the ELF ground unit. Photo Credit: JAXA.

Model of ELF hardware.
Photo Credit: JAXA.

Application: Steel Industry

- **Dr. Hyers is collaborating with Japan to investigate the effects of the interfacial phenomena between the molten steel and the oxide melts during processing from the viewpoint of the thermophysical properties.**
  - During steel making processes, such as continuous casting, the impurity in the cast steel is influenced by the interplay between the molten steel and molten slags.
  - Understanding the interfacial phenomena is necessary in order to produce higher purity steels.
  - The results of the project are expected to be utilized for more efficient production of higher quality steel
  - The samples of interest are Iron/Welding Flux (Cao-SiO2-TiO2-FeO) and Iron/Slag (CaO-SiO2-Al2O3)



Schematic of a blast furnace, showing slag layer on top of molten iron.
Photo Credit: National Slag Association.

Exploration Relevance – MaterialsLab ELF Investigations

Metal Oxides

- The work seeks to make accurate measurements of equilibrium and supercooled melt density, viscosity and surface tension.
- Properties are an essential element of models that correlate properties and structure to advance development of applied materials and support fundamental understanding of glass formation and nucleation.
- The materials of interest are precursors to high value-added glass materials that are used in
  - Lasers
  - Optical communications
  - Imaging
  - Photonic devices

Round Robin

- The proposed work seeks to understand and control the sources of measurement error and to provide a baseline dataset for quantifying uncertainty in measurements (both space- and ground-based).
- The proposed materials have industrial applications
  - Casting
  - Nuclear fuel rods
  - Metallic glasses

Non-Linear Optical Materials

- Advance the fundamental understanding of the origins of photorefractivity in certain photorefractive crystals and the manufacturing processes needed to apply this understanding to new devices on Earth.
- Potential to enable several new kinds of photonic devices ranging from
  - Holographic storage (which would compete with flash memory, CD/DVD/BluRay, and hard disks)
  - Adaptive optics
  - Phase-conjugate mirrors (which can passively correct images of space from Earth)

Interfacial Tension

- Novel measurement technique useful for several materials and applicable to several industrial processes including:
  - Semiconductor crystal growth
    - Improved modeling of Czochralski and Bridgman process of single crystal encapsulated growth such as GaAs and GaSe
  - Additive manufacturing
    - Precise surface tension measurements allows prevention of droplet formation during selective laser melting process and is key to predictive controlled processing.
  - In-Space Welding
    - Tension forces dominate in space -- Capillary-driven flows influence structure and stability of welds

Conclusions

- **Materials Science research utilizing levitation is a significant portion of SLPSRA's funded efforts.**
  - Levitation research takes advantage of the unique microgravity environment available on ISS
- **This research has applications to NASA exploration needs as well as for ground-based industry.**
- **Applications include:**
  - Better turbine blades for aerospace engines
  - Higher quality steel
  - New materials for optical devices, lasers, and photonics
  - Improved semiconductor devices
  - Nuclear Thermal Propulsion (NTP)
- **Levitation research on ISS is ongoing**
  - Additional research is planned
  - SLPSRA is planning a joint Materials Science Workshop with CASIS at the ISS R&D conference in Atlanta, July 29 – August 1, 2019. Workshop details TBD.
    - Anticipate developing a new NASA Research Announcement (NRA)
- **Acknowledgment: NASA Space Life and Physical Sciences Research and Applications (SLPSRA)**