NATIONAL ACADEMIES *Sciences Engineering Medicine*

Sunsetting and Emerging Research Approaches: Panel on FOUNDATIONS

Committee on Biological and Physical Sciences in Space

4:15 PM September 17, 2025

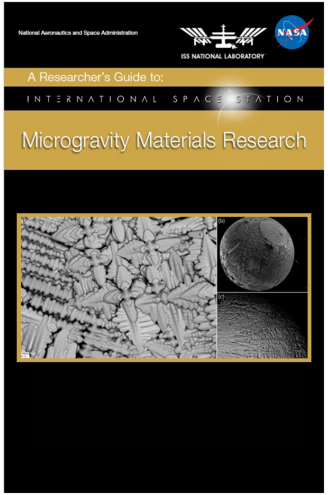
Professor Douglas M. Matson, Mechanical Engineering, Tufts University

Disclaimer: These slides are a personal assessment of issues through the lens of an observer who has participated in LEO Materials Science μg testing for four decades and the views expressed do not necessarily reflect those of Committee or the Academies.

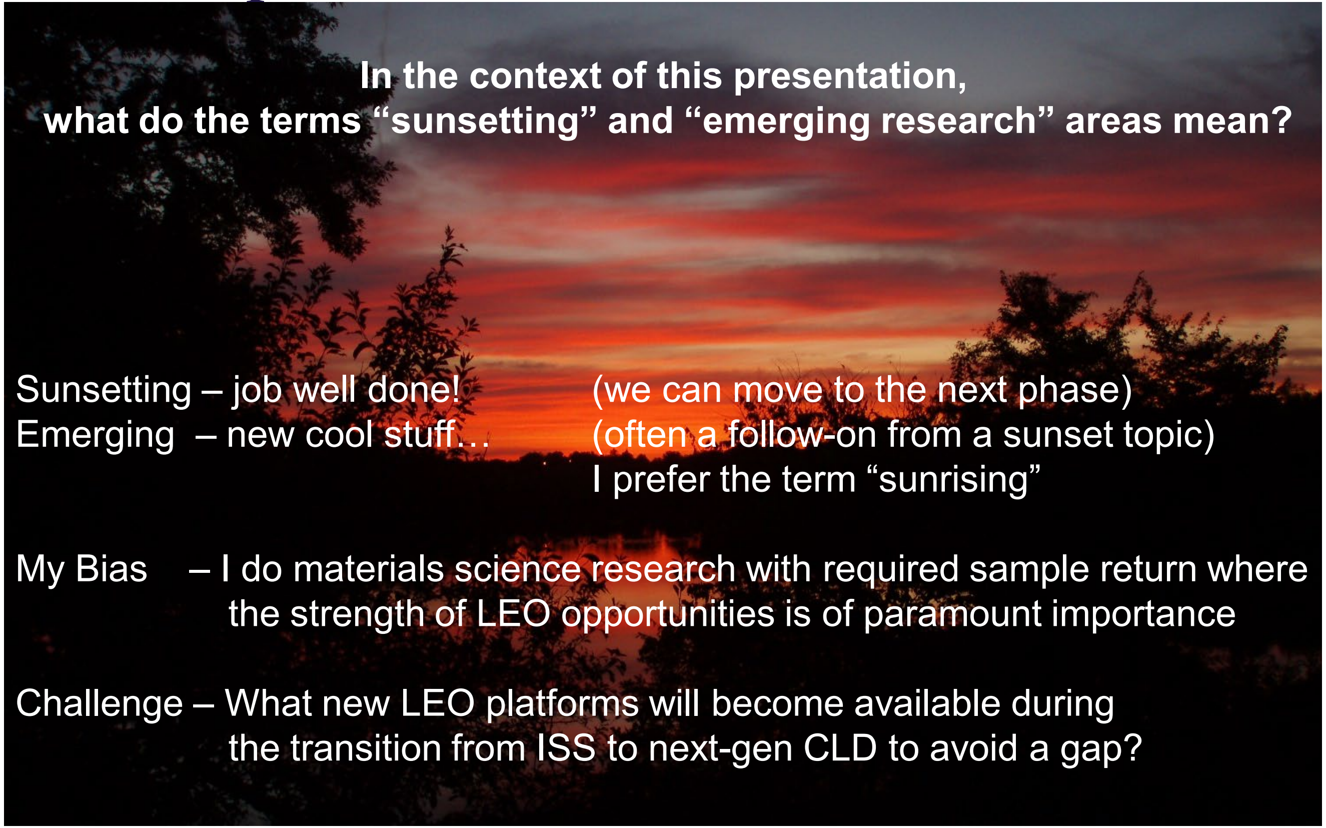
Presentation Overview

Key Focus of the Session:
What research areas in NASA BPS decadal roadmap FOUNDATIONS' goals are in periods of transition and could benefit from the ongoing evolution of research platforms, and the U.S.'s space exploration programs?

- My take on what do we mean by sunsetting and emerging approaches
- Observations from my career
  - "sunsetting"
  - "sunrising" (emerging)
- International partner viewpoint
- Examples of emerging approaches
- Conclusions



The transition process



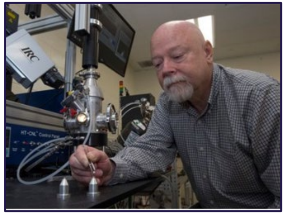
Observations on the impact of ***Sunsetting***

My career spans experiments on the shuttle Columbia, through technology development on the NASA Vomit-Comet and ESA Zero-G, to ISS testing with the JAXA ELF and the ESA/DLR ISS-EML.
Over the years the investigations matured over time and sunsetting was an integral part of this process.

Columbia TEMPUS — Study of the fundamentals of rapid solidification targeting use of microgravity to access metastable phases at deep undercooling in simple alloy systems.

Study the kinetics of nucleation/growth during solidification of elemental and binary alloys.

ISS-EML — Study microstructural evolution and identification of solidification pathways in ternary alloys.



Study phase selection and transformation kinetics with focus on ferrous alloy systems.

JAXA-ELF — Study influence of convection which requires a knowledge of properties to model flow

Measure thermophysical properties in simple analog systems

Compare to commercial alloy properties (Stainless Steel / Inconel)

[uncertainty quantification]

Validate flow predictions anchoring model performance with test results

Develop a transformation model and validate across a variety of systems

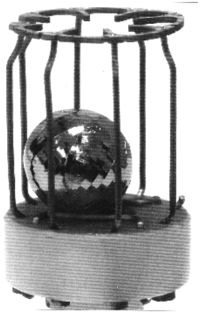
ICME synthesis to predict properties and allow risk mitigation and process optimization concentrating on exploration applications

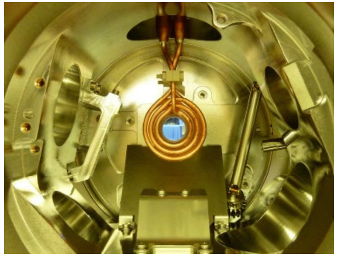
Observations on the impact of ***Sunrising***

Previous *sunsetting* evaluations involved building off success to identify **new emerging research areas**. The more you learn, the better your ability to prioritize the next steps while avoiding knowledge gaps.

Take-away from lessons learned – before going to space, test it on ground, validate facility performance in short-term microgravity using parabolic flight, then go to space. For success, you need a **robust** ground-based development program.

Research focus has **organically shifted** over time from fundamental to applied science driven by the current exploration timeline. Many high-value projects successfully focus across this spectrum.





The one unifying positive theme apparent from the evolution of rapid solidification studies is that **international partnerships and collaboration were enabling factors** in the success of past NASA programs leading to development of defensible priorities for future exploration investigations.

How are international partners viewing the transition process?

Partners spent a LOT of money developing world-class *μg* platforms
US has done well to be able to **negotiate use** of these resources
Continued use of collaborative facilitates enables

- cost effective utilization (no facility development costs/US support cheap)
- multi-investigator leveraging of resources and science focus
  (akin to bio approach with multiple studies on a single organism)
- international cross-fertilization of ideas to keep US current/competitive

Both JAXA and ESA seem to indicate that the *sunsetting/emerging* labels are **not aligned with their vision** of how to approach the transition period.

JAXA Utilization Prospects toward Post-ISS

September 17, 2025

Space Environment Utilization Center
Japan Aerospace Exploration Agency

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Continuous use of Kibo utilization platforms in Post-ISS

- JAXA has been promoting development and use of **"Kibo utilization platform (PF)" as prioritized utilization area** that can contribute to R&D and promising outcome.
- In physical sciences discipline, **materials research platform using the Electrostatic Levitation Furnace (ELF)** is one of the Kibo PFs. Also, **combustion research platform using the Solid Combustion Experiment Module (SCEM)** is identified as a candidate of new PF.
- Since Kibo Utilization PFs have unique capabilities and advantages as a research and utilization environment, **continuous outcome will be expected even in Post-ISS LEO utilization.**
- **JAXA is studying to use the same or similar environment in Post-ISS as Kibo Utilization PFs.**

Health and Longevity - Rodent missions
Small satellite deployment
Drug design - Protein crystallization missions
Exposed facility port utilization
Innovative Materials - Electrostatic Levitation Furnace
New platform candidates

Prioritized by: A certain number of demands / users; Unique Capability on ISS; Scheduled, Frequent Opportunities; Standardized Process

"Bottom-up", fundamental research

Present — 2030 — Post-ISS

Kibo Utilization Platform

Preparation for Post-ISS
- ✓ Advancing facility
- ✓ Expand commercial use

- ■ Continuous use of Kibo's environment to produce LEO utilization outcomes
- ■ Public utilization (science, national R&D)
- ■ Flexible implementation of companies' idea and businesses

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JAXA's ISS/Kibo utilization strategy toward Post-ISS

Future visions of JAXA's LEO utilization in 2030s (Post-ISS phase):

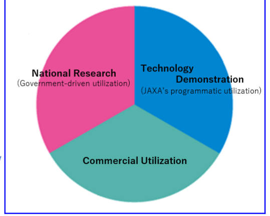
Space environment utilization in LEO is established as a part of human social and economic activities after Kibo utilization

1:1:1 Portfolio of these 3 areas is aimed

Three Activity Areas to realize the visions:

1. **JAXA's programmatic utilization (Technology Demonstration)**
   - Acquire human space flight technologies
   - Accumulate data for human space exploration
   - Demonstrate new technologies
2. **Government-driven utilization (National Reseach)**
   - Solve social issues in research
   - Enhance the value of related research results
3. **Commercial utilization**
   - Promote open innovation with commercial use
   - Provide independent and constant services to the end users.

Portfolio of three utilization areas [Toward Post-ISS]



Present — 2030 — After the retirement of the ISS

Establish "Kibo" as an R&D testbed | Transition phase (~2030) | LEO utilization service is provided by the private sector

3

ELF and SCEM are primary experimental apparatus for JAXA's physical science research.

MSPR Work Volume (WV) compatible payloads on the ISS

ELF consists of a main system installed in the Work Volume (WV) in the MSPR2 (Multi Purpose Small Payload Rack) and gas bottles installed in the Small Experiment Area (SEA).

20 sample holders filled with samples are attached to sample cartridges, which are inserted into the main system of the ELF to perform experiments with commanding from ground operators.

Multi-purpose Small Payload Rack (MSPR) on the ISS

SCEM is composed of elements including combustion vessel, experiment insert, camera units and power and communications control unit.

These elements must be assembled in the Work Volume (WV) in MSPR2, a space dedicated to experimental devices loading to be ready for experiments.

The oxygen for combustion experiments is supplied from the gas bottle installed in a Small Experiment Area (SEA).

The oxygen is led through the gas supply tube provided between WV and SEA.

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Slide content courtesy of Dr. Masao Kikuchi
Mission Manager, JAXA

Summary on JAXA's Prospects

- JAXA continues the utilization of the LEO microgravity environment into the Post-ISS era, aligned with "Kibo Utilization Strategy*".
- Installation of the experimental apparatus for the current Kibo platforms, including ELF and SCEM for physical sciences area, on future LEO destinations is foreseen.
- Experiments on future LEO destinations at a scale comparable to those performed on the ISS/Kibo are aimed.
- Balanced portfolio among academic research (scientific utilization), commercial utilization, and JAXA program utilization is aimed to realize.

* https://humans-in-space.jaxa.jp/kibouser/library/item/scheme_4summaryEn.pdf

ESA's future directions for materials science in space: some considerations

Wim Sillekens

For Doug Matson, Tufts University; September 8, 2025

→ THE EUROPEAN SPACE AGENCY

Materials science in space: Way forward

ESA's Exploration Science Programme

- Our programme is currently going from SciSpacE (Science in the Space Environment) to Exploration Science, following the extension of ISS/LEO with Moon and Mars research activities
- Two streams of science (under overall coordination of the Chief Exploration Scientist)
  - Exploration-focussed topics (local resources, environments and effects, crew health and performance, habitation): driven by programmatic needs ("top-down") and with a close link with technology de-risking
  - Exploration-enabled topics: driven by scientific needs ("bottom-up"), excellence based and arranged through highly competitive AOs
- Materials science is traditionally rooted in the latter as microgravity research, but new activities will develop in the former (e.g., in-situ resource utilisation, in-space manufacturing)

Materials science in space: Way forward

Science consultation

- ESA has solicited advice from the scientific community in the form of so-called Facility Definition Teams (FDTs), to outline the concepts/capabilities of post-ISS research (LEO) facilities
- The FDT Materials Science proposes the following (with the associated key topics from the white paper in brackets)[1)]
  - Containerless processing facility, to address gravity-related scientific issues on thermophysical properties and structural evolution (topic A: thermophysical properties; topic B: structural evolution), based on heritage from ISS EML
  - Directional solidification facility, to address gravity-related scientific issues on structural evolution (topic B: structural evolution), based on heritage from ISS MSL, TA and XRF
  - Additive manufacturing facility, to address gravity-related scientific issues on in-space manufacturing (topic C: space exploration)

1) Akamatsu S., et al.; *ESA SciSpacE White Papers: #06 Materials Science*; European Space Agency, Directorate of Human Spaceflight and Robotic Exploration Programmes (2022) – https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Research/The_SciSpacE_White_Papers

Materials science in space: Way forward

Some (personal) reflections

- The transition from the ISS to post-ISS (CLD) research in LEO will require a transition to smaller, less complicated experiment facilities to align with the utilities and capabilities offered by these CLD platforms; this will present a challenge in a context of increasing requirements on for instance experiment diagnostics
- During the transition period, there will be an increased need for ground-based and suborbital platforms for scientific purposes as well as for post-ISS payload development (technology demonstration)
- In the ESA approach of exploration-focussed and exploration-enabled research strands, a categorisation in terms of sunsetting and emerging science seems not to be useful

Slide content courtesy of Dr. Wim Sillekens, Materials Science Coordinator, ESA

My interpretations

JAXA has significant investment in platforms showing significant and novel results and will continue to support innovation based on their successes (property measurement and combustion). The key challenge is the transition from the ISS to new CLDs. Emphasis is on maintaining a **balanced portfolio** post-ISS.

- Technology demonstrations
- National research priorities
- Commercial utilization

ESA also has significant investment in successful facilities (containerless processing, directional solidification, and additive manufacturing). The **transition from *Science in the Space Environment* to *Exploration Sciences*** has two key prongs (exploration-focused and exploration-enabled). Two key additional challenges then arise.

- First is the evolution to smaller, less complicated facilities (and an associated investment) that align with the capabilities of the CLD opportunities.
- Second is the need to provide a robust ground-based program to ensure continuity during the ISS/CLD transition and to conduct appropriate technology development testing to ensure continued future success.

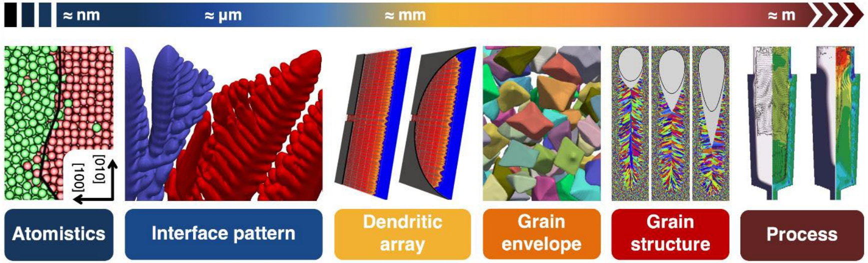
Common themes

- International partners have invested heavily and worked hard to develop highly effective test platforms
- Both foresee a need to nurture international partnerships and keep collaborations strong
- Each remains committed to their existing long-range agency plan for space exploration
- Neither agency wants to see next-gen hardware accept reduced functionality

Examples of Emerging Technologies: ICME

Foundations theme: recycling and sustainability

Integrated Computational Materials Engineering is an approach to design materials and products by integrating computational models **across multiple scales** to link processing, structure, properties, and performance to enable development of exploration centered materials processing technologies.



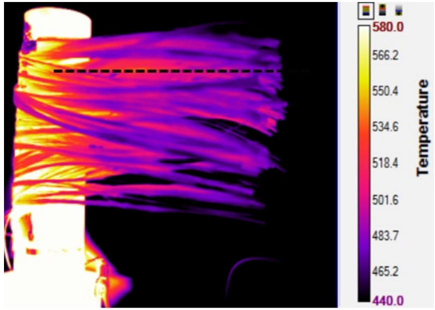
Hoyt, Asta, Karma: Mater. Sci. Eng. R 41, 121 (2003) | Tourret et al.: Acta Mater. 122, 220 (2017) | Tourret et al.: JOM 67, 1776 (2015) | Souhar et al.: Comp Mater Sci 112, 304 (2016) | Chen, Gandin, Guillemot: Acta Mater. 115, 448 (2016) | Combeau et al: Metall. Mater. Trans. B 40, 289 (2009)

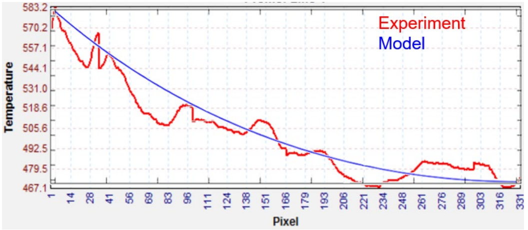
In the context of the exploration mission, uncertainty quantification supports safety and risk mitigation.

Examples of Emerging Technologies: Heat dissipation

Foundations theme: thermal management

Carbon Fiber Performance

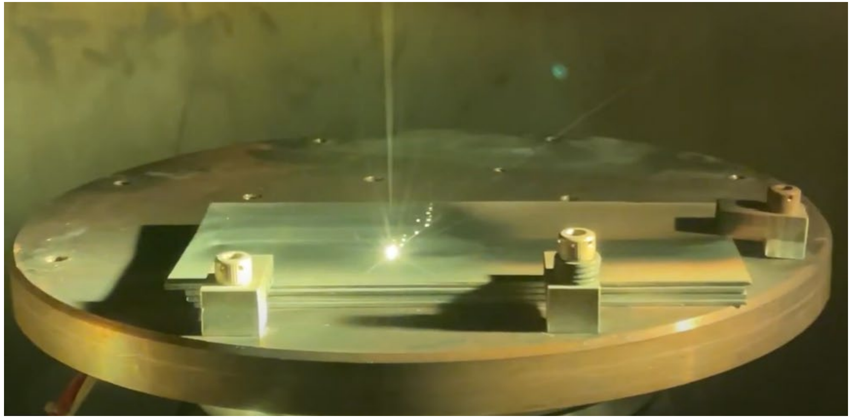




Radiators for Nuclear-Electric Propulsion represent ~ 40% of a spacecraft's mass.

Examples of Emerging Technologies: In-Space Manufacturing

Foundations theme: recycling and sustainability



https://www.nasa.gov/centers-and-facilities/marshall/nasa-to-transform-in-space-manufacturing-with-laser-beam-welding-collaboration/

Conclusions

Sunsetting and sunrising are not new concepts but they **focus the perspective** on innovation in the NASA research portfolio and **articulate** how individual elements relate and answer the decadal KSQs while avoiding knowledge gaps. Partners don't seem to see the need for sunsetting/emerging exercise as this is already an integral part of their evolution of science focus. To me, this formalization actually <u>does</u> help stakeholders reposition the new vision of NASA's science exploration mission and I don't see any significant conflict between US/partner perspectives. **Sunset/Emerging is a communication tool**.

Need to leverage/nurture international partnerships and keep collaborations strong

- Partnerships are cost-effective and promote efficient use of scant resources
- Collaborations ensure that cross-fertilization of ideas thrives between agencies
- Retain commitment to aggressively support international partner facility migration from ISS to CLD
- Avoid technology gaps and duplication of effort

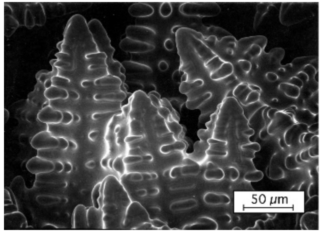
My personal observations are:

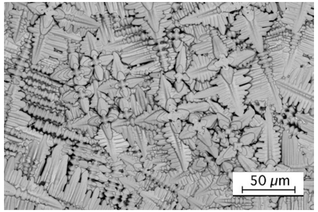
- US will concentrate on mission-critical and applied exploration approaches
- International partners will maintain a significant concentration of fundamental science which can only be done in space with an emphasis on promoting benefit-to-society on earth or agency-specific goals
- Partners are not sold on the semantics of the new US approach but are willing to work with NASA to maximize good science return; the combination of the above two approaches is stronger than either alone.

The strength of collaborative approach is that the NASA/JAXA/ESA team can still **addresses science issues across the applied/fundamental spectrum**.

The key is to have <u>active participation</u> between partners while still **allowing each to concentrate on agency specific priorities.**

Acknowledgements





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Thanks to the **NASA engineering** staff at MSFC since my days in rocket technology development and through flight support testing using facilities at M&P and ground support and technology development activities using the Electrostatic Levitation (MSFC-ESL) facility.

Special thanks to my **colleagues** at JAXA, ESA and DLR for their unwavering peer support during preparation, testing and post-flight analysis of microgravity levitation experiments.

And most of all, to my **research group members** who drove the evolution of microgravity solidification science through their passion for learning and for their dedication to investigating how to enable future space exploration.