National Aeronautics and Space Administration

# NASA BPS Foundations Program Update, Foundations Goal Update

**Brad Carpenter, Program Scientist**

**8 October 2024**

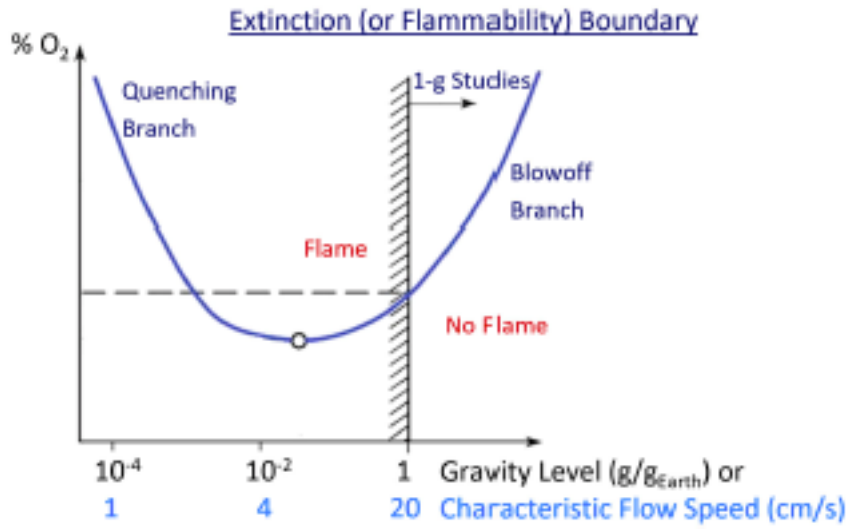
BPS

**B**iological & **P**hysical **S**ciences

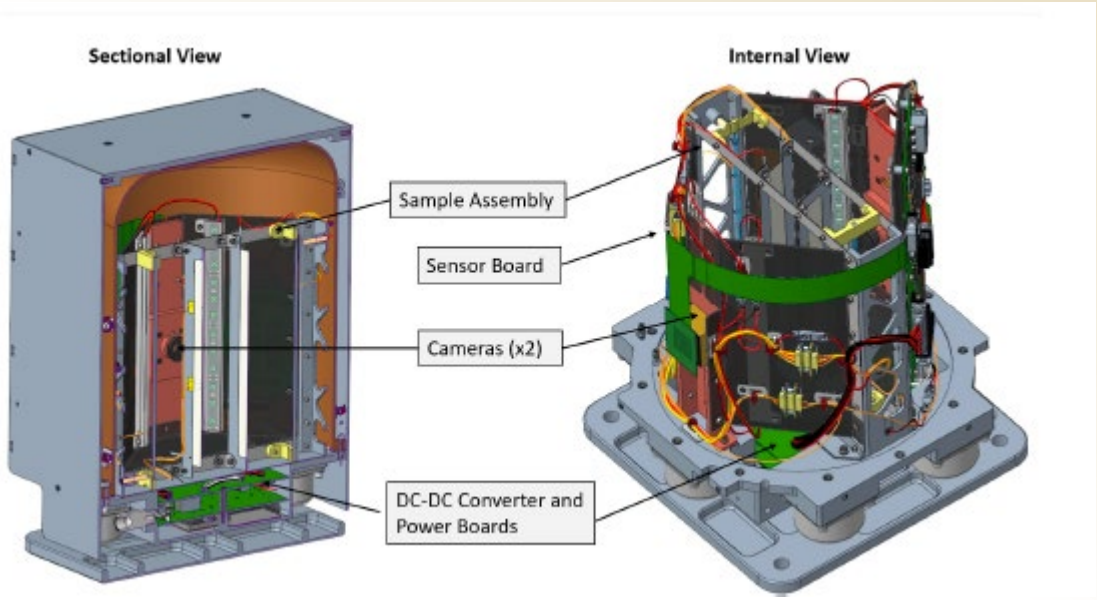
# Program Update

# Science Highlights: Foundations

## Flammability of Materials on the Moon – FM2 on the Artemis uncrewed demonstration




Flammability limit vs flow/gravity level

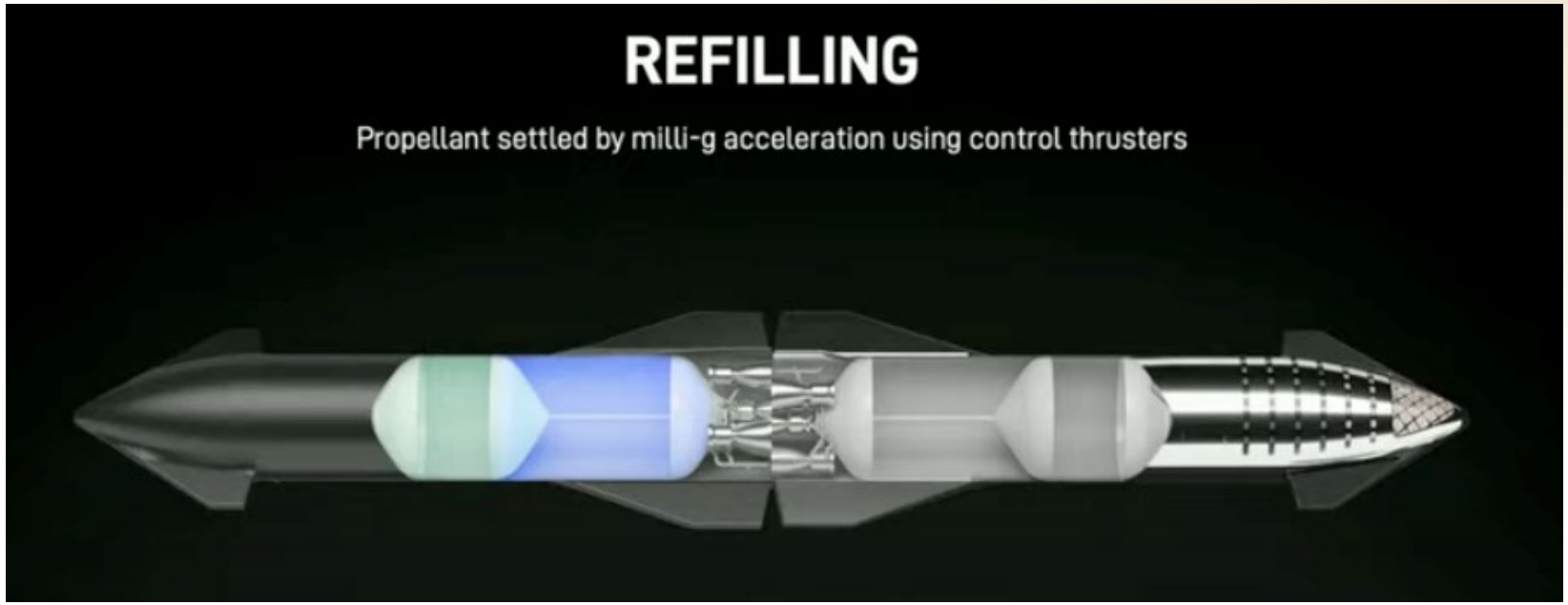



FM2 experiment concept

Convection carries oxygen into a flame, but also carries heat away. The result is that materials can be more flammable in reduced gravity, when buoyant convection is weak, than at Earth gravity. Data is needed to understand flammability at elevated oxygen levels in lunar gravity. The FM2 project is the first effort to obtain data relevant to operations at elevated oxygen levels and reduced gravity.

# Science Highlights: Foundations

## Flow Boiling and Convection Experiment – Transfer Line

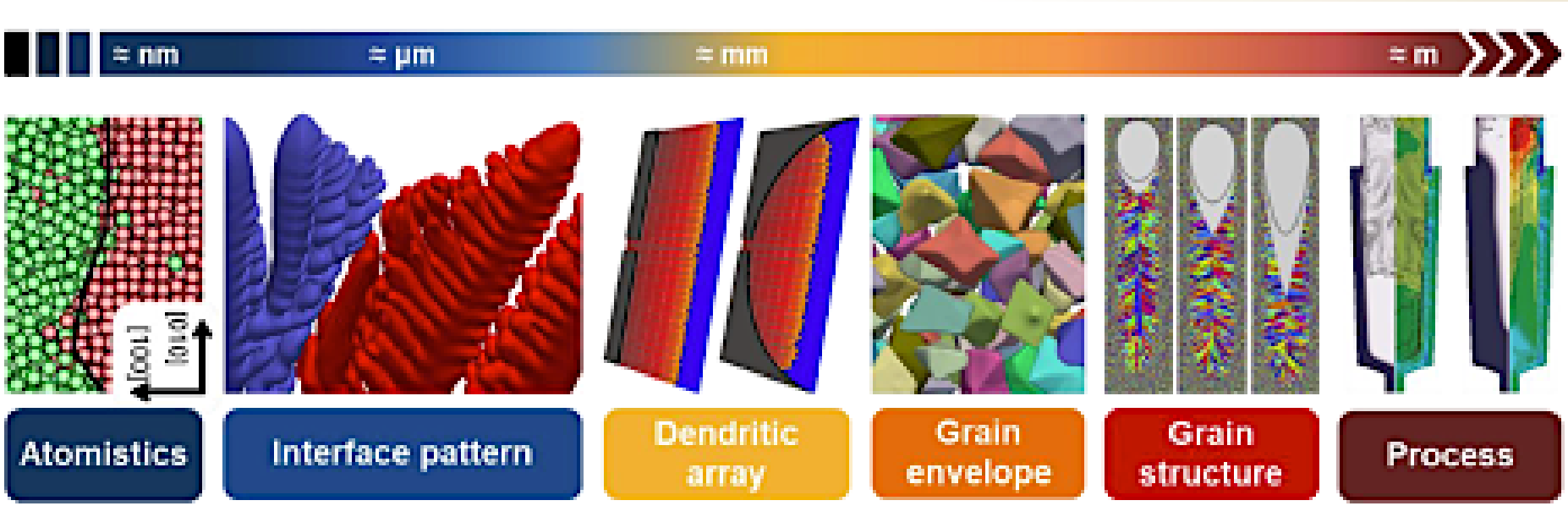



From: https://www.youtube.com/watch?v=Oee66sAXGtc

Transfer of cryogenic fuels between vehicles is a critical capability for exploration missions. The density difference between liquid and gaseous fuels is O(1000-100), so vaporization during line chilling can result in large pressure spikes

# **Science Highlights:** Foundations

Integrated Computational Materials Engineering – final report from the science team




Solidification processes at different length scales

# **Solicitations:** Foundations

**Physical Sciences 2024 Research Opportunities in Space and Earth Science (ROSES) Call**

- Includes all Physical Sciences Disciplines - with some focus applied
- Release planned for later this month
- Proposals due early 2025
- Awards begin fiscal 2026

We’re Back!

# **Publications:** Foundations

**Combustion**


- Bhattacharjee, S., Casabier, N, The Importance of Solid Phase Longitudinal Conduction in Flame Spread over Cylindrical and Flat Fuels: A Comparative Scale Analysis, Fire Safety Journal, https://doi.org/10.1016/j.firesaf.2023.104001
- Johnston, Michael C., S. T. James, Sheng-Yen Hsu, Ching-Wei Wu, Sandra L. Olson, and Paul V. Ferkul. "Quenching extinction of solid sphere diffusion flames induced by a sudden removal of gravity." Fire Safety Journal (2024): 10413 https://doi.org/10.1016/j.firesaf.2024.104137
- Matson, Amanda, Michael C. Hicks, Uday G. Hegde, and Peter V. Gordon. "An elementary model for an advancing autoignition front in laminar reactive co-flow jets injected into supercritical water." The Journal of Supercritical Fluids (2024): 106210. https://doi.org/10.1016/j.supflu.2024.106210
- Michael C. Johnston, James S. T'ien, Sheng-Yen Hsu, Ching-Wei Wu, Sandra L. Olson, Paul V. Ferkul. Quenching extinction of solid sphere diffusion flames induced by a sudden removal of gravity. Fire Safety Journal https://doi.org/10.1016/j.firesaf.2024.104137
- Sharma, A., Li, Y., Liao, YT.T. et al. Effects of Confinement on Opposed-Flow Flame Spread over Cellulose and Polymeric Solids in Microgravity. Microgravity Sci. Technol. 36, 20 (2024). https://doi.org/10.1007/s12217-024-10106-y
- Li, Chengyao, S. James, Paul V. Ferkul, Sandra L. Olson, and Michael C. Johnston. "Extinction of solid diffusion flame in microgravity: Details of quenching and blowoff processes." Proceedings of the Combustion Institute 40, no. 1-4 (2024): 105373. https://doi.org/10.1016/j.proci.2024.105373
- Chengyao Li, James S. T'ien, Paul V. Ferkul, Sandra L. Olson, Michael C. Johnston. Extinction of solid diffusion flame: details of quenching and blowoff processes. Proceedings of the Combustion Institute, 2024. https://doi.org/10.1016/j.proci.2024.105373

# **Publications:** Foundations

**Soft Matter**


- Lei, Qian, Boris Khusid, Lou Kondic, Paul M. Chaikin, Andrew D. Hollingsworth, Alton J. Reich, Richard B. Rodgers, and William V. Meyer. "Large, defect-free FCC colloidal crystals under microgravity." arXiv preprint arXiv:2404.07291 (2024). https://doi.org/10.48550/arXiv.2404.07291
- Treerathat Chomchok, Pemika Hirankittiwong, Apichart Pattanaporkratana, Bussayamas Phettong, Natthawat Hongkanchanakul, Pongthep Prajongtat, Tyler R. Hatch, Dharmendra Pratap Singh, and Nattaporn Chattham, "Rotation of liquid crystal microdroplets in the intensity minima of an optical vortex beam," Opt. Express 32, 24372-24383 (2024) https://doi.org/10.1364/OE.523355
- Kim, Jongmin, Reya Ganguly, Jaesung Kim, Ronald J. Sicker, Francis P. Chiaramonte, William V. Meyer, Catherine A. Frey et al. "Formation of three-dimensional (3D) Self-Assembled Clusters of Anisotropic Janus Particles in Microgravity." Gravitational and Space Research 12, no. 1: 115-129 https://doi.org/10.2478/gsr-2024-0008.
- Dillavou, Sam, Jesse M. Hanlan, Anthony T. Chieco, Hongyi Xiao, Sage Fulco, Kevin T. Turner, and Douglas J. Durian. "Bellybutton: accessible and customizable deep-learning image segmentation." Scientific Reports 14, no. 1 (2024): 14281. https://doi.org/10.1038/s41598-024-63906-y
- Chase, Dylan, and Michael Cromer. "Roles of chain stretch and concentration gradients in capillary thinning of polymer solutions." Fluid Dynamics Research 56, no. 1 (2024): 015505. https://doi.org/10.1088/1873-7005/ad255d
- Krucker-Velasquez, Emily, Martin Z. Bazant, Alfredo Alexander-Katz, and James W. Swan. "Rugged potential of mean force and underscreening of polarizable colloids in concentrated electrolytes." arXiv preprint arXiv:2404.01512 (2024). https://doi.org/10.48550/arXiv.2404.01512

# **Publications:** Foundations

**Fluid Physics**


- Narayanan, Jayachandran K., Chirag R. Kharangate, Sonya Hylton, Mohammad Kassemi, Jason W. Hartwig, and Jeffrey R. Mackey. "Three-Dimensional CFD Simulations in the Film Boiling Regime During Liquid Nitrogen Chilldown Process." In AIAA SciTech Conference 2024. 2024. https://doi.org/10.2514/6.2024-0354
- Berthier, Jean, Ashleigh B. Theberge, and Erwin Berthier. Open-channel microfluidics: Fundamentals and applications. IOP Publishing, 2024. https://doi.org/10.1088/978-0-7503-5507-0
- O'Connor, Nathaniel, Michal Talmor, and Jamal Yagoobi. "Upstream Electrohydrodynamic Conduction Pumping for Flow Distribution Control of Parallel Microchannel Evaporators." ASME Journal of Heat and Mass Transfer 146, no. 4 (2024). https://doi.org/10.1115/1.4064442
- Ignatius, I. B., B. Dinesh, G. F. Dietze, and R. Narayanan. "Influence of parametric forcing on Marangoni instability." Journal of Fluid Mechanics 981 (2024): A8. https://doi.org/10.1017/jfm.2024.58
- Mudawar, Issam, Steven J. Darges, and V. S. Devahdhanush. "Prediction technique for flow boiling heat transfer and critical heat flux in both microgravity and Earth gravity via artificial neural networks (ANNs)." International Journal of Heat and Mass Transfer 220 (2024): 124998. https://doi.org/10.1016/j.ijheatmasstransfer.2023.124998
- Plawsky, Joel. "Constrained Vapor Bubble Experiment (CVB) in the Light Microscopy Module (LMM)." Gravitational and Space Research 12, no. 1 (2024): 60-63. https://doi.org/10.2478/gsr-2024-0004
- Nagrani, Pranay P., Amy M. Marconnet, and Ivan C. Christov. "Hydrodynamics of bubble flow through a porous medium with applications to packed bed reactors." AIChE Journal 70, no. 4 (2024): e18343. https://doi.org/10.1002/aic.18343

# **Publications:** Foundations

**Fluid Physics, ii**


- Narayanan, Jayachandran K., Jason W. Hartwig, Jeffrey R. Mackey, Mohammad Kassemi, and Chirag R. Kharangate. "Experimental investigations on the flow boiling and heat transfer characteristics during chilldown process in a closed loop chilldown test section." International Journal of Heat and Mass Transfer 232 (2024): 125915. https://doi.org/10.1016/j.ijheatmasstransfer.2024.125915
- Mudawar, Issam, Steven J. Darges, V. S. Devahdhanush, Mohammad M. Hasan, Henry K. Nahra, R. Balasubramaniam, and Jeffrey R. Mackey. "Two-phase flow instabilities during microgravity flow boiling onboard the International Space Station." International Journal of Heat and Mass Transfer 234 (2024): 126102. https://doi.org/10.1016/j.ijheatmasstransfer.2024.126102
- Afzal, Arshad, Seunghyun Lee, Sung-Min Kim, and Issam Mudawar. "Gaussian process regression to predict dryout incipience quality of saturated flow boiling in mini/micro-channels." Applied Thermal Engineering (2024): 124137. https://doi.org/10.1016/j.applthermaleng.2024.124137
- Noh, Hyeonseok, Seunghyun Lee, Sung-Min Kim, and Issam Mudawar. "Utilization of XGBoost algorithm to predict dryout incipience quality for saturated flow boiling in mini/micro-channels." International Journal of Heat and Mass Transfer 231 (2024): 125827. https://doi.org/10.1016/j.ijheatmasstransfer.2024.125827
- Mudawar, Issam, Steven J. Darges, and V. S. Devahdhanush. "Critical heat flux for flow boiling with saturated two-phase inlet in microgravity onboard the International Space Station." International Journal of Heat and Mass Transfer 233 (2024): 126017. https://doi.org/10.1016/j.ijheatmasstransfer.2024.126017

# Publications: Foundations

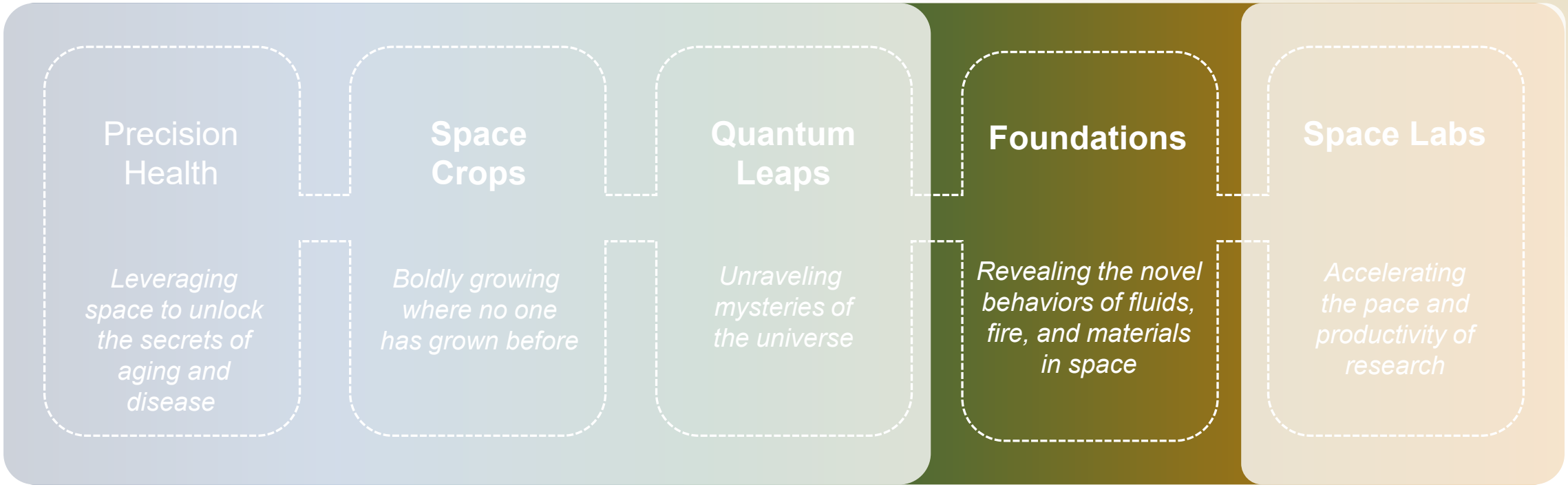
## Physical Sciences Informatics


1. **Sharma A, Koch DL**. "Rotation of a fiber in simple shear flow of a dilute polymer solution." ArXiv preprint server. Posted October 1, 2023. https://arxiv.org/abs/2310.00792 , Oct-2023
2. **Nagrani PP, Marconnet AM, Christov IC** "Bubble entrapment and displacement through packed-bed reactors." 76th Annual Meeting of the APS Division of Fluid Dynamics, Washington, DC, November 19-21, 2023.
3. **Cromer M, Vasquez PA**. "Macro-micro coupled simulations of dilute viscoelastic fluids." Preprints.org. Posted October 6, 2023. doi: 10.20944/preprints202310.0298.v1 , Oct-2023
4. **Vasquez PA, Walker B, Bloom K, Kolbin D, Caughman N, Freeman R, Lysy M, Hult C, Newhall KA, Papanikolas M, Edelmaier C**. "The power of weak, transient interactions across biology: A paradigm of emergent behavior." Physica D: Nonlinear Phenomena. 2023 Nov 15;454:133866. https://doi.org/10.1016/j.physd.2023.133866 , Nov-2024
5. **Youssoufi S, Lentnera A, Riaz A, Balaras E.** "A study of subcooled pool boiling using direct numerical simulations." 4th International Conference on Fluid Flow and Thermal Science (ICFFTS 2023), Lisbon, Portugal, December 7-9, 2023. Abstracts. 4th International Conference on Fluid Flow and Thermal Science (ICFFTS 2023), Lisbon, Portugal, December 7-9, 2023. , Dec-2023
6. **Bellur K, Medici EF, Hermanson J, Choi CK, Allen JS**. "Modeling liquid–vapor phase change experiments: Cryogenic hydrogen and methane." Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2023 Oct 20;675:131932. Online ahead of print. https://doi.org/10.1016/j.colsurfa.2023.131932 , Oct-2023
7. **Kumar M.** "Structure and properties of the terrestrial vs. microgravity solders under extreme conditions of elevated and cryo temperatures." 39th Annual Meeting of the American Society for Gravitational and Space Research, Washington, DC, November 13-18, 2023. Abstracts. 39th Annual Meeting of the American Society for Gravitational and Space Research, Washington, DC, November 13-18, 2023. , Nov-2023
8. **Saseendran, V., Yamamoto, N., Collins, P.J**. et al. Unlocking the potential: analyzing 3D microstructure of small-scale cement samples from space using deep learning. npj Microgravity 10, 11 (2024). https://doi.org/10.1038/s41526-024-00349-9
9. **Deu Morel R**. "Simulating microgravity E-FIELD flames using a mechanism including chemiluminescence species." M.S. Thesis for Engineering Internship from ISAE-ENSMA, University of California, Irvine, 2023. , Dec-2023
10. **Dru L.** "Electric field flames 1g experiment validation for PeleLMeX simulation using microgravity conditions." M.S. Thesis for Engineering Internship from ISAE-ENSMA, University of California, Irvine, 2023. , Dec-2023
11. **Esquivias Rodriguez B, Chien Y-C**. "A comparison between water addition and CO2 addition to a diffusion jet flame." Combustion Science and Technology. International Colloquium on the Dynamics of Explosions and Reactive Systems (ICDERS) Special Issue, under review as of March 2024. , Mar-2024
12. **Vasquez PA, Walker B, Bloom K, Kolbin D, Caughman N, Freeman R, Lysy M, Hult C, Newhall KA, Papanikolas M, Edelmaier C**. "The power of weak, transient interactions across biology: A paradigm of emergent behavior." Physica D: Nonlinear Phenomena. 2023 Nov 15;454:133866. https://doi.org/10.1016/j.physd.2023.133866 , Nov-2024
13. **Dove A, Nicola A, Schang K, Cassidy D.** "Granular mechanics behaviors observed in multiple variable-gravity experiments relevant to planetary surfaces." AGU 23 (Annual Meeting of the American Geophysical Union), San Francisco, CA, December 11-15, 2023.Abstracts. AGU 23, Annual Meeting of the American Geophysical Union, San Francisco, CA, December 11-15, 2023. Abstract: EP23B-03. https://agu.confex.com/agu/fm23/meetingapp.cgi/Paper/1446963 , Dec-2023

# Roadmap Update

# Thriving in Space

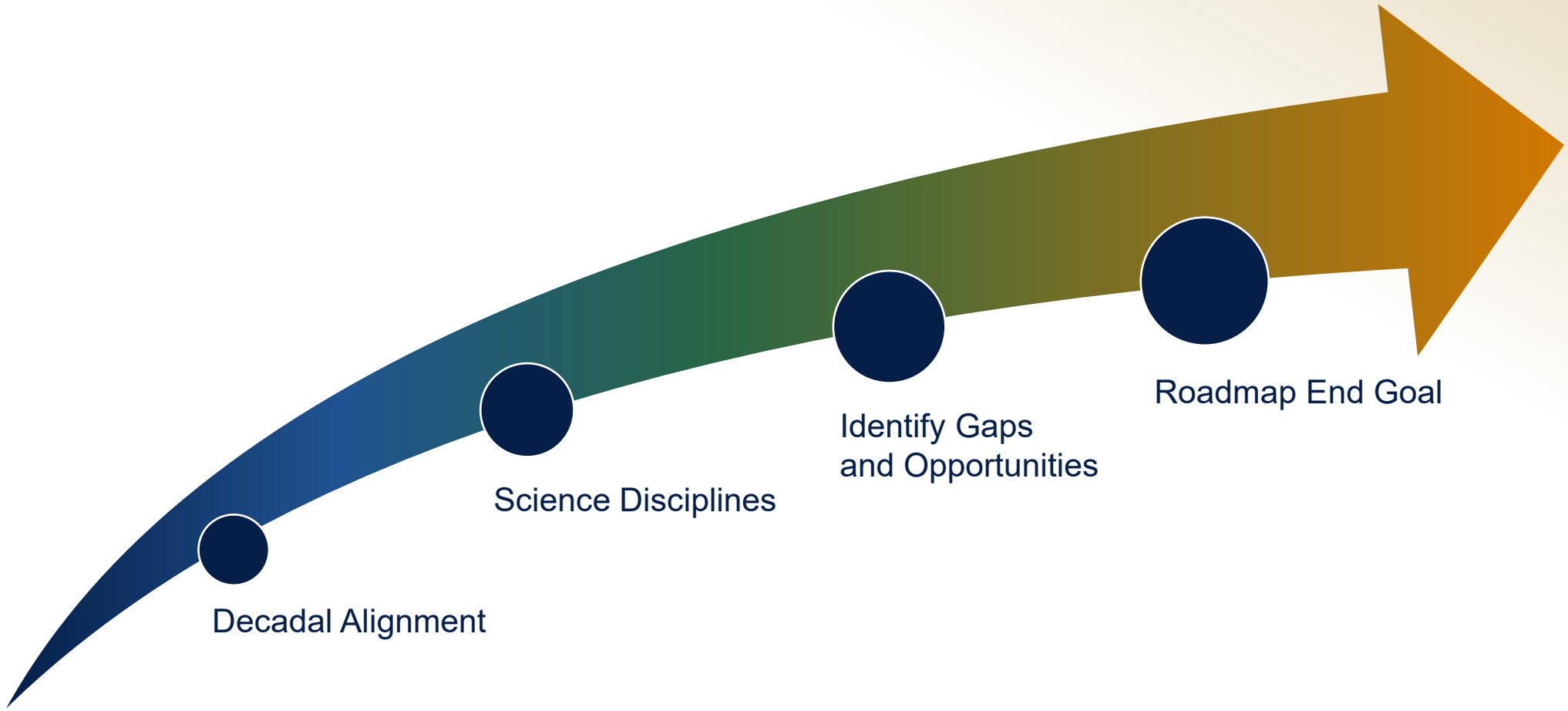
Revolutionary research in extraordinary places.



# Foundations

- Goal: to investigate fundamental physical systems and processes to lay the foundation for space exploration and to benefit life on earth.

# **Goal Overview:** Foundations



# **Decadal Alignment:** Foundations

## Living and Traveling in Space

- Principles for processing and use of local materials
- Chemical and physical properties that govern fluid behavior in space

## Phenomena Hidden by Gravity or Terrestrial Limitations

- Principles that organize the structure and functionality of materials
- Laws that govern the behavior of systems far from equilibrium

# **Decadal Alignment:** Foundations

**Research Campaign:** Build a foundation for increasingly circular ecosystems in space, á la Manufacturing Materials and Processes for Sustainability in Space (MATRICES)


Twenty-first century acronym technology

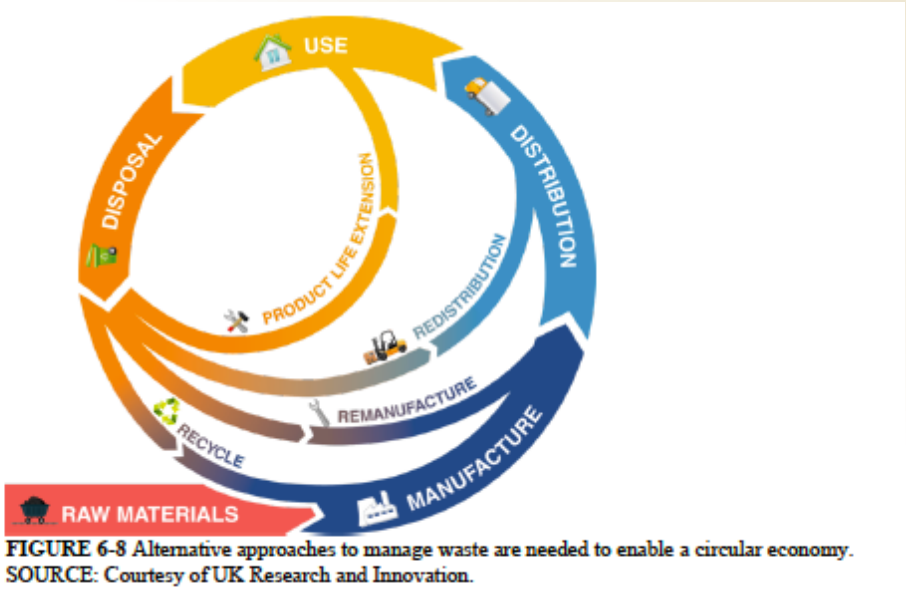



FIGURE 6-8 Alternative approaches to manage waste are needed to enable a circular economy.
SOURCE: Courtesy of UK Research and Innovation.

Circular economies can reduce waste and improve efficiencies

# **Science Goal:** Foundations

## Themes:

- Cryo Fluids & Thermal Management
- Fire Safety
- Recycling and Sustainability
- Manufacturing & Processing in Space

## Disciplines:

- Open Science
- Condensed Matter Physics
- Synthetic Biology
- Combustion
- Materials Science
- Cryogenic Fluids
- Fluid and Thermal Science

## Space-Relevant Stressors:

- Altered Gravity
- Space Radiation
- Lunar and Martian Regolith
- Altered Magnetic Field
- Altered Atmospheric Pressure
- Altered Partial Pressure of Gases

# **Identify Gaps & Opportunities:** Foundations

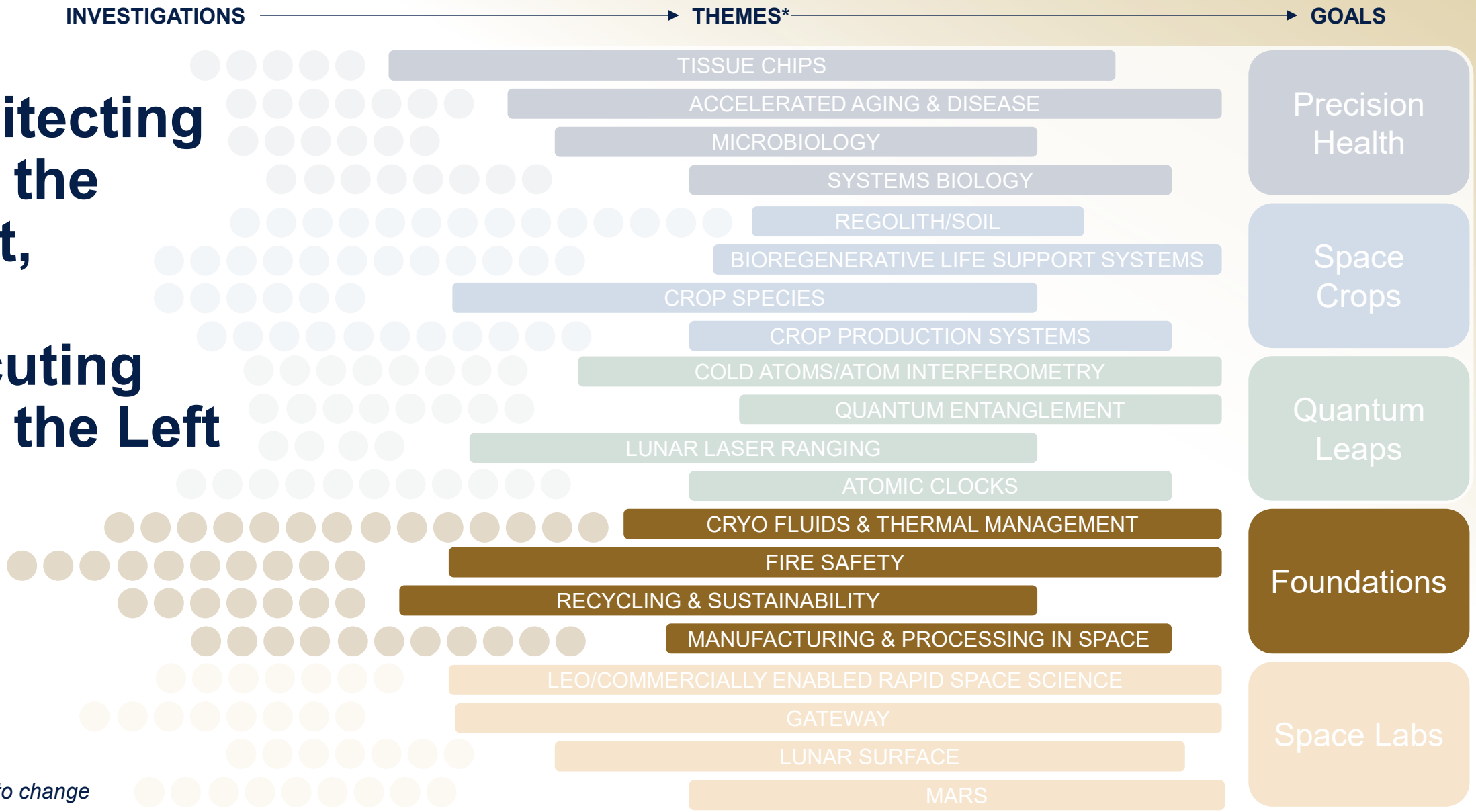
- Enabling Exploration Science
  - Fire safety solutions (safe materials, fire detection, extinguishment)
  - Cryogenic fuel thermal fluid system behavior prediction
  - Engineering foundation for translating Earth-developed processes to space
  - Materials for an evolution to increasing independence from Earth-supplied logistics
- Scientific Discovery
  - Finding new uses and capabilities for space platforms, especially the upcoming generation
  - Driving science forward in areas like functional and active matter, energy, and conservation
- Building Partnerships and Foundations
  - Keeping NASA at the center of an international scientific effort in space research
  - Maintaining a healthy research community in core disciplines vital for NASA’s future

# **Roadmap End Goals:** Foundations

- **Provide fundamental knowledge:**
  - to improve performance of exploration systems.
  - to inform design strategies for future spacecrafts and habitats.
  - to inform in-situ resource utilization processes for the Moon.
  - to create a sustainable exploration ecosystem in LEO, on the Moon, and on Mars.

# Architecting from the Right,

# Executing from the Left




**Draft – subject to change*