ROSCOSMOS cosmonaut Oleg Novitskiy runs a session for the Plasma Kristall-4 experiment to investigate how low temperature gaseous mixtures lead to improved spacecraft designs. NASA ID: iss065e124411.

# Publication Highlights

## *Physical Science*

***The presence of gravity greatly influences our understanding of physics and the development of fundamental mathematical models that reflect how matter behaves. The ISS is the only laboratory where scientists can study long-term physical effects in the absence of gravity without the complications of gravity-related processes such as convection and sedimentation. This unique microgravity environment allows different physical properties to dominate systems, and scientists are harnessing these properties for a wide variety of investigations in the physical sciences.***

The ESA investigation Transparent Alloys – SEBA allows prolonged real-time observations of microscopic changes occurring during spaceflight to transparent metal mixtures.

When two liquid metals are mixed, parameters such as temperature, specific volume, and cooling velocity impact how the metallic blend solidifies. Either a single combined composition or two separate solids with bands and hexagonal arrangements can result, depending on the interaction and dynamics of such parameters. Nonequilibrium dynamical phenomena within the mix may explain the resulting pattern.

In this study published in *Scripta Materialia*, researchers for the first time present a real-time analysis of a two-solid microstructural formation in microgravity to describe the relative stability of the different patterns during directional solidification. Using optical imaging in microgravity, researchers observed the process of directional solidification of a metallic simulation mixture (SCN-DC). While this mixture is normally known only to create rod-like patterns during solidification, researchers discovered that at a slow growth rate, the metallic mixture forms both rods and bands separated by a sharp boundary. More specifically, the microstructural formations transitioned from band-like to rod-like patterns. The co-occurrence of bands and rods demonstrates a dynamic transition in an imbalanced system, given that the new configuration resulted from the variations of multiple physical parameters.

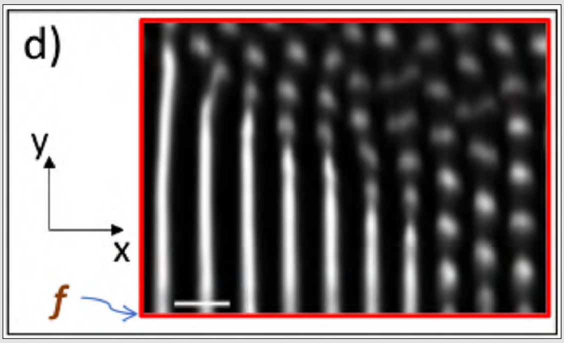


*Figure 16. Optical image of rod-like and band-like patterns coexisting during directional solidification of a metal mixture. Image adopted from Bottin-Rousseau, Scripta Materialia.*

Through this experiment, researchers showed how to produce a composite material with a self-organized architecture, thereby advancing the knowledge for conducting materials science research on particle self-assemblies and micropatterning.

*Bottin-Rousseau S, Witusiewicz VT, Hecht U, Fernandez JJ, Laveron-Simavilla A, et al. Coexistence of rod-like and lamellar eutectic growth patterns. Scripta Materialia. 2022 January 15; 207: 114314. DOI: 10.1016/j.scriptamat.2021.114314.*

The NASA investigation Cold Atom Lab uses microgravity to reach very cold temperatures that make atoms motionless. Immobilized atoms can be inspected for extended periods of time.

When atoms are cooled enough, they behave in a strange way not characterized by the

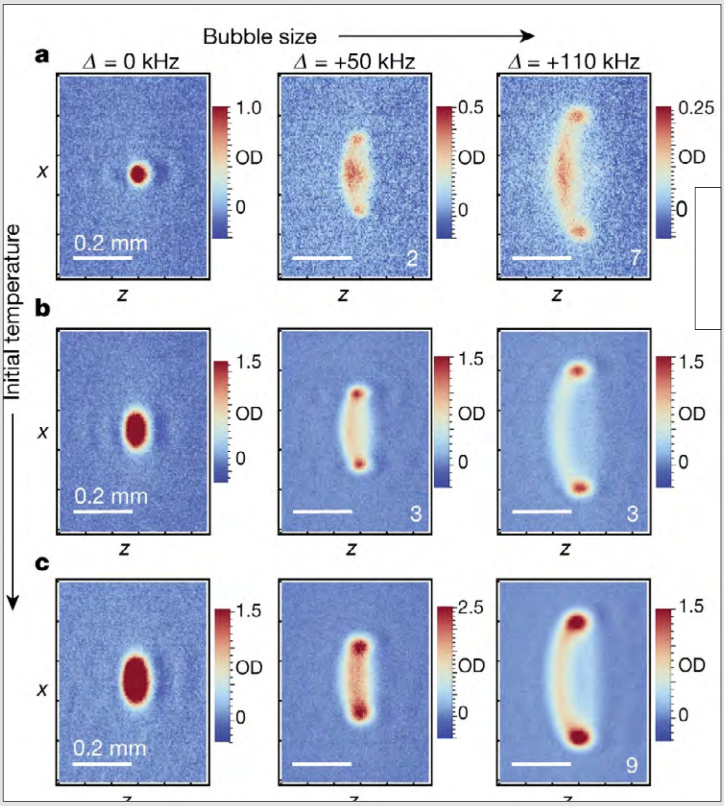


*Figure 17. Bubble growth of ultracold atoms. Image adopted from Carollo, Nature.*

four preexisting states of matter. When the temperature is extremely low, atoms slow down so much they almost stop moving and they stop behaving like individual atoms and more like a wave. When the atoms reach this state of slow, wavelike behavior, they are referred to as a Bose-Einstein Condensate—the fifth state of matter. In the Cold Atom Lab, researchers use multiple lasers and evaporative cooling to cool atoms down to temperatures of less than 100 picoKelvin, which is a billion times colder than the vacuum of space. Presently, researchers are looking to learn more about the shape and behavior of these atoms, as their behavior is still not well understood.

In a new study published in *Nature*, researchers used the Cold Atom Lab to observe the geometry and topology of resulting ellipsoids and produced some of the first geometric and thermodynamic measurements made with ultracold atoms in space. Results show that by varying the initial temperatures of atom samples, researchers created extremely thin, hollow spheres of different sizes and demonstrated that more cooling was associated with larger bubble size. Additionally, researchers characterized excitement within the atoms and produced imagery of the transition of shape. This result can only be achieved in microgravity because atoms on Earth pool downward and form a shape more like a contact lens than a bubble.

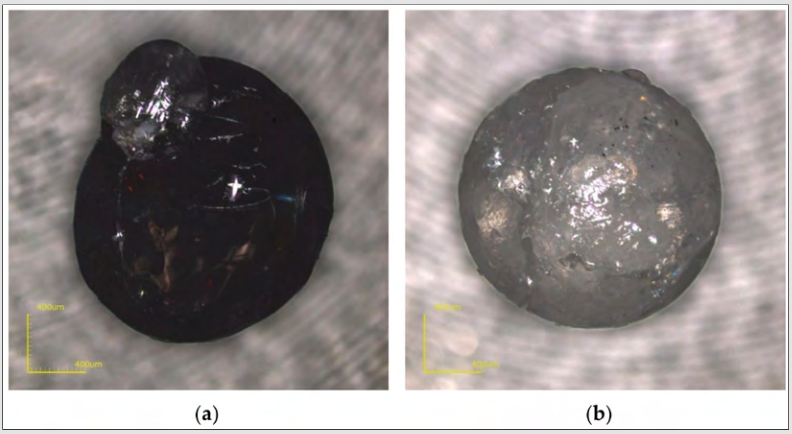
The observed ultracold bubble systems allow researchers to establish a model and theoretical framework for Bose Einstein Condensates. This result paves the way for work on understanding Bose Einstein Condensate thermodynamics and assists efforts to reach a condensed bubble state that allows for further discovery. These groundbreaking geometric results help advance fundamental quantum research by improving understanding of the shapes, dimensions, and interactions that exist in collections of ultracold atoms. Advancements of the Cold Atom Lab or similar future systems could help create new superconductors, improve quantum computing, and help us to better define how gravity interacts in our universe.

*Carollo RA, Aveline DC, Rhyno B, Vishveshwara S, Lannert C, et al. Observation of ultracold atomic bubbles in orbital microgravity. Nature. 2022 May 18; 1-6. DOI: 10.1038/s41586-022-04639-8.*

# Publication Highlights

## *Physical Science*

The JAXA facility Electrostatic Levitation Furnace (ELF) is a containerless laser heater that melts materials such as oxides, semiconductors, insulators, and mixed metals to study their behavior in high temperatures in microgravity. Because the samples do not touch the surface of a container during levitation, chemical reactions that would contaminate the sample do not occur in microgravity.



(a) (b)

*Figure 18. Lathanoid Yb2O3 sample before (a) and after (b) spaceflight. Note that Earth-based impurities are not present in microgravity. Image adopted from Ishikawa, Metals.*

The advancement of 3D printing technology calls for the development and use of different industrial materials. Lanthanoid sesquioxides are rare Earth metals used in oxide melting that have high melting temperatures, and their thermophysical properties are not yet well understood. To obtain density data for three different lanthanoids (Tm2O3, Yb2O3, and Lu2O3), a new study published in the journal *Metals* used high powered lasers to heat and melt spheres of the materials. The density and mass values recorded are among emerging data of less documented properties and provide a helpful benchmark for future testing and experimentation of materials with even higher melting temperatures.

In physical science, levitated samples can be produced by electrostatic and aerodynamic methods. On Earth, the collection of thermophysical data is challenged by methods such as container contamination and the requirement for a large electric field and gaseous environment. While the invention of electrostatic levitation methods has improved some ground testing, there are still certain elements that cannot be accurately assessed on Earth. On station, containerless melts allow the use of a smaller electric field.

Spherical samples of each material (Tm2O3, Yb2O3, and Lu2O3) were chemically treated to be reactive to radiation from the semiconductor laser. A collection of images from two different cameras were used to calculate the density. Slight mass losses were identified due to evaporation during the experiment, and densities were determined using the final masses weighed on the ground. However, the densities of Tm2O3, Yb2O3, and Lu2O3 were successfully measured by the ELF, and results showed good agreement with literature values. These results allow researchers to work towards measuring surface tension and viscosity and uncover thermophysical properties of materials that have even higher melting temperatures, such as zirconium dioxide (ZrO2) and hafnium oxide (HfO2).

*Ishikawa T, Koyama C, Oda H, Shimonishi R, Ito T, Paradis P. Densities of liquid Tm2O3, Yb2O3, and Lu2O3 measured by an electrostatic levitation furnace onboard the International Space Station. Metals. 2022 July; 12(7): 1126. DOI: 10.3390/met12071126.*

# Publication Highlights

## *Physical Science*

The NASA investigation Packed Bed Reactor Experiment-Water Recovery (PBRE-WR) investigation aboard the ISS studies the behavior of gases and liquids that flow simultaneously in open spaces (i.e., columns or beds). Different bed shapes and early introduction of gas-liquid mixing enhances interphase contact and promotes the formation of a homogeneous mixture.

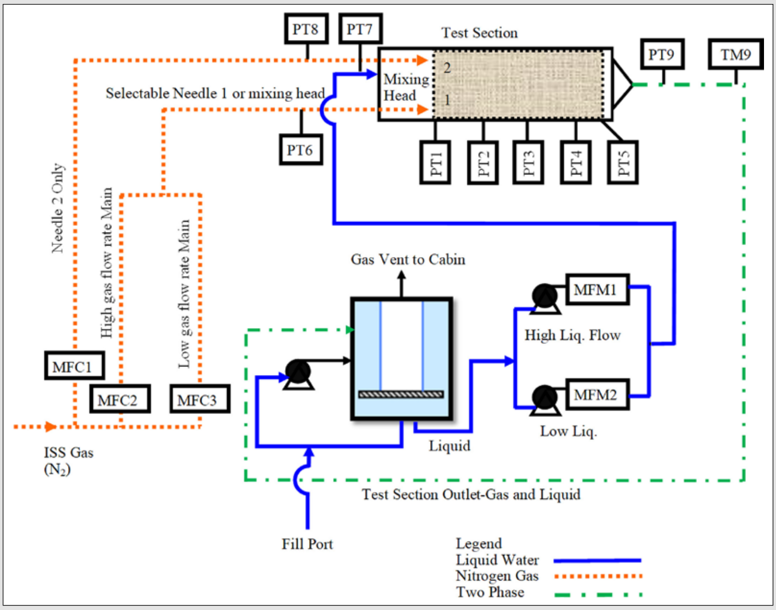


*Figure 19.* *Diagram of Packed Bed Reactor Experiment-2. Image adopted from Taghavi, American Institute of Chemical Engineers (AIChE).*

The first generation of the PBRE, designed to deliver controlled flows of gas and liquid in a loop system, generated small pressure oscillations during higher flow rates that were addressed by the second generation of the payload (PBRE-2). In a new report published in the journal *American Institute of Chemical Engineers (AIChE)*, researchers updated the PBRE-WR with perforations and a reduced bed packing size to eliminate external disturbances, minimize recirculation of gas and liquid, and increase overall pressure.

PBRE-2 uses the same glass material and random distribution of the packing beds, but each bed size was decreased from 3 mm to 2 mm to improve pressure readings during lower flow rates. After 400 gas-liquid flow rate combinations and their respective gas and liquid flushes, video observations, pressure traces, and pressure drop data, researchers identified four flow patterns (i.e., bubble flow, pulse flow, gas channeling, and large bubble pattern) that qualitatively characterize the behavior of two-phase gas and liquid flows in microgravity.

This testing successfully demonstrated that the new PBRE-2 system provides accurate results during higher gas and liquid flows. Enhanced understanding of hydrodynamics in microgravity leads to improved design and operation of two-phase gas-liquid flows, which is critical for chemical and biological systems involved in fuel cells, life-support, nutrient transport, heat pipes, materials processing, and pharmaceutical production.

*Taghavi M, Motil BJ, Nahra HK, Balakotaiah V. Gas–liquid flows through porous media in microgravity: Packed Bed Reactor Experiment-2. American Institute of Chemical Engineers (AIChE) Journal. 2022 April 19; DOI: 10.1002/aic.17727.*