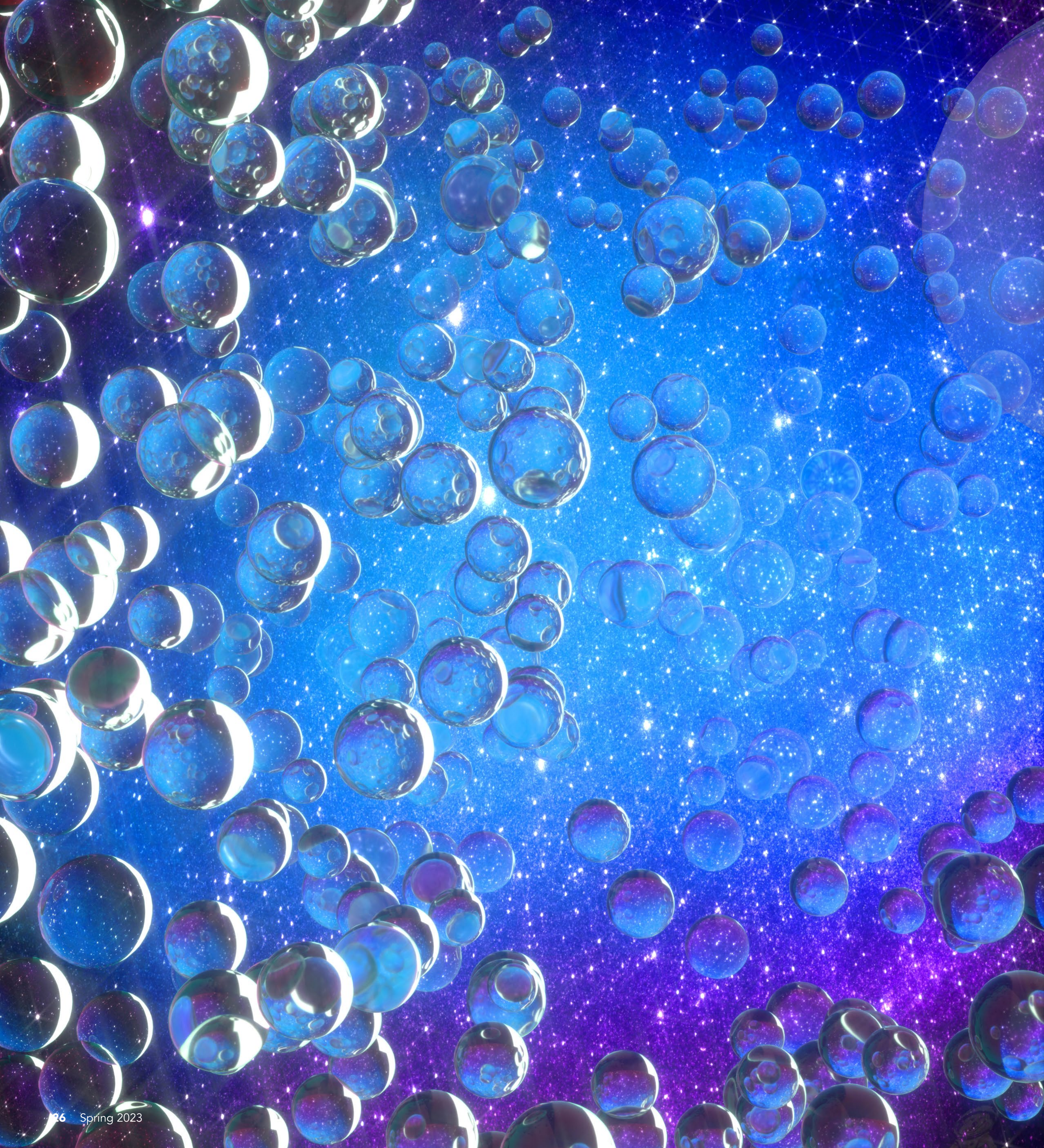

A LIGHT ON MOVING BUBBLES ...IN SPACE

Automated experiments allow three UCSB professors to study bubble dynamics in multiphase liquids aboard the International Space Station

Multiphase flows contain one material in more than one phase, such as when bubbles (gas) occur in liquid. The dynamics of such bubbles play an important role in many applications, and the ability to control them would enable increased efficiency in such processes as liquid purification, water harvesting, and heating and cooling, both on Earth and in space.

Understanding the fundamentals of bubble dynamics is difficult on Earth, because gravity and other related phenomena, such as friction, pressure, buoyancy, and natural convection, affect their behavior, making it hard to isolate a single cause of a particular phenomenon. Things are more clear in space. That is why, last November, UC Santa Barbara professors **Yangying Zhu**, **Paolo Luzzatto-Fegiz** (both in Mechanical Engineering), and **Javier Read de Alaniz** (Chemistry) sent a cargo of experiments to the International Space Station (ISS).

"The question we wanted to answer," Zhu says, "was, can we manipulate fluid movement — for example, bubbles in liquid or liquid droplets on a surface — in space? And can we program a bubble to move in a certain direction and at a certain velocity? Doing these experiments in microgravity allowed us to have a better fundamental understanding of the physics involved."

Space-based applications include, for instance, boiling for thermal management, which is easy on Earth. "Buoyancy causes vapor bubbles to leave a hot surface, and the surface produces more bubbles for continuous heat transfer," Zhu explains. "In space, bubbles are stuck on the surface, dramatically hindering heat transfer."

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Some researchers have used an electrostatic charge to try to manipulate bubbles in space, but the high voltage the system requires makes it prone to degradation. Others have used ultrasound, but that method is overly complex. "Our method is much easier," Zhu says. "We use light, which is programmable and can be reconfigured in real time, to manipulate droplets and bubbles."

The approach is based on two different light-sensitive molecules that Read de Alaniz developed in his lab. "Exploring the behavior of light-responsive molecules on the ISS provides a unique opportunity to investigate both stability and photo-reactivity in zero gravity, which will inspire new molecular designs," he says. The molecules were dissolved in a solvent, sealed in vials, and sent to space in eleven cuvettes, each containing a different combination of molecule and solvent designed to produce bubbles of different sizes. During the experiment, LED lights in a linear array adjacent to the vials were illuminated in sequence, lighting only one side of the bubble or droplet at a time. That caused the molecules to undergo a reversible, almost instantaneous conformational change, such that a long-chain molecule might become a ring but with its chemistry unchanged.

This series of cuvettes containing light-sensitive molecules dissolved in various solvents (giving the liquids their different colors) were sent to space. There, LED lights were shined on one side of each solution, causing a conformational change in the synthesized molecules and leading to a change in surface tension, which, in turn, led each bubble to move.

"The light-induced shape change of the molecule is really important, because it can modify the surface tension at the interface with the droplets or a bubble, producing higher tension on one side and lower tension on the other," Zhu says. "That causes the fluid to flow from the low-tension side to the high-tension side, inside and outside the bubble or droplet. It's like having two vortices, which can cause the droplet to move in a kind of swimming motion."

In another experiment, the bottom surface of a boiling chamber that Zhu built was heated to create a vapor bubble. (She designed and tested the various experimental components before sending them to the ISS.) The team anticipated that, when the bubble encountered the light beam, the same forces would be generated, causing it to "swim" away from the heated surface.

As is common for space experiments — where scientists cannot make adjustments after launch — Zhu describes the project as a "partial success," explaining that they were unable to observe what they expected to see in the boiling chamber. It is possible, she notes, that between the time when the experiments were sent and were run on the ISS, the surfactant in that part of the experiment may have degraded. Nevertheless, the overall experiments successfully showed that bubbles can be moved by light, and that the flow responds quickly even to relatively low light intensities. The experiments were captured on video, which Luzzatto-Fegiz, an expert on surfactant transport, is using now to develop a mathematical model. "We are getting to find out what the possibilities are with this approach," he says. "That's very exciting."