

# UPWARD

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## The New Gold Rush

3D PRINTING IN MICRO-G

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TOMATOSPHERE:  
ENTERING A NEW  
FRUITFUL PHASE

A NEW FACILITY FOR  
STUDYING QUANTUM  
PHENOMENA

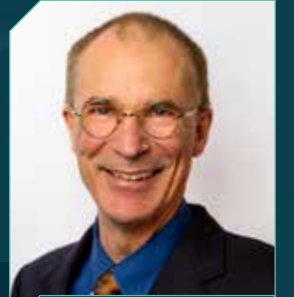
NASA AND CASIS IMPROVE  
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# THE VIEW FROM THE CUPOLA

BY RANDY GILES, CASIS



Randy Giles is the Chief Scientist of CASIS

Gravity is fascinating. So too is its absence. The International Space Station (ISS) U.S. National Laboratory is the world's most accessible platform where persistent microgravity is a science and engineering tool of extraordinary utility. In the near-zero-gravity environment of the ISS, investigators push frontiers in the life sciences—from the crystallization of proteins and other macromolecules, to the expansion of stem cell lines, to the study of human aging. And in microgravity, fluids don't flow and fuels don't burn as they do on Earth, revealing subtleties with real-world consequences in fluid and combustion engineering.

Gravity is not the only game in town. Looking ahead, the ISS will soon be home to CAL, the Cold Atom Lab developed by a research consortium led by the NASA Jet Propulsion Laboratory in Pasadena, California. With CAL, atoms will be cooled to within a few trillionths of a degree Celsius above absolute zero, making it the coldest place in the known universe for the study of exotic states of matter.

As you will learn in this issue of *Upward*, despite the numerous experiments conducted onboard the ISS National Lab, the space station does not house a hardware store stocked with spare parts and tools to deal with unexpected needs. It has something better—a 3D printer. 3D printing, also known as additive manufacturing, is embraced here on Earth by enthusiasts and engineers alike who convert stock material into forms of infinite variety for fun and profit. Likewise, the company Made in Space designed and built a 3D printer that is now operating on the space station as a research tool in additive manufacturing as well as a print-on-demand resource for station operations. A stand-out example of the latter was a ratcheting wrench printed for ISS Commander Barry Wilmore to service equipment onboard the ISS National Lab. For those who want to replicate their own, the print file of this wrench can be found at [nasa3d.arc.nasa.gov/detail/wrench-mis](http://nasa3d.arc.nasa.gov/detail/wrench-mis).

Beyond wrenches, in the future we can expect space vehicle components, replacement parts, and even biological tissues to be printed in space for a myriad of science, engineering, and commercial purposes. Indeed, humankind has made an extraordinary journey in the 2.5 million years since our ancestors first crafted cutting tools by flaking stone in a process of "subtractive" manufacturing. Who can guess how much farther we will go with additive manufacturing in space? Likely a very long way.

Not only is the ISS National Lab a platform for today's scientists and engineers to conduct groundbreaking research but it also serves as a source of education and inspiration for tomorrow's scientists and engineers. This issue will discuss Tomatosphere, a program in which K-12 students grow tomato plants from seeds flown on the ISS and returned to Earth. Tomatosphere, a perennial classroom favorite enjoyed by more than 3 million students in Canada and the United States since its inception in 2001, now counts among its alumni former 2<sup>nd</sup> grader and new astronaut candidate Loral O'Hara. By growing plants from "space" seeds and comparing them with plants of humble Earth origin, students learn about plant biology, genetics, nutrition, space science, and scientific methodology. Higher up the ladder of inquiry, students can also learn about "omics" (genomics, proteomics, metabolomics, etc.) that explain the roles and relationships of molecules in the living cell, their impact on the whole organism, and the influence of environmental factors on biological systems. It's said that from the acorn grows the mighty oak. We say that from the tomato seed grows our nation's future.

In addition to these feature articles, we encourage you to enjoy the spotlight articles that shed light on many gems of science and technology onboard the ISS National Lab—including CAL. We expect you'll find that fascination never grows old. ■

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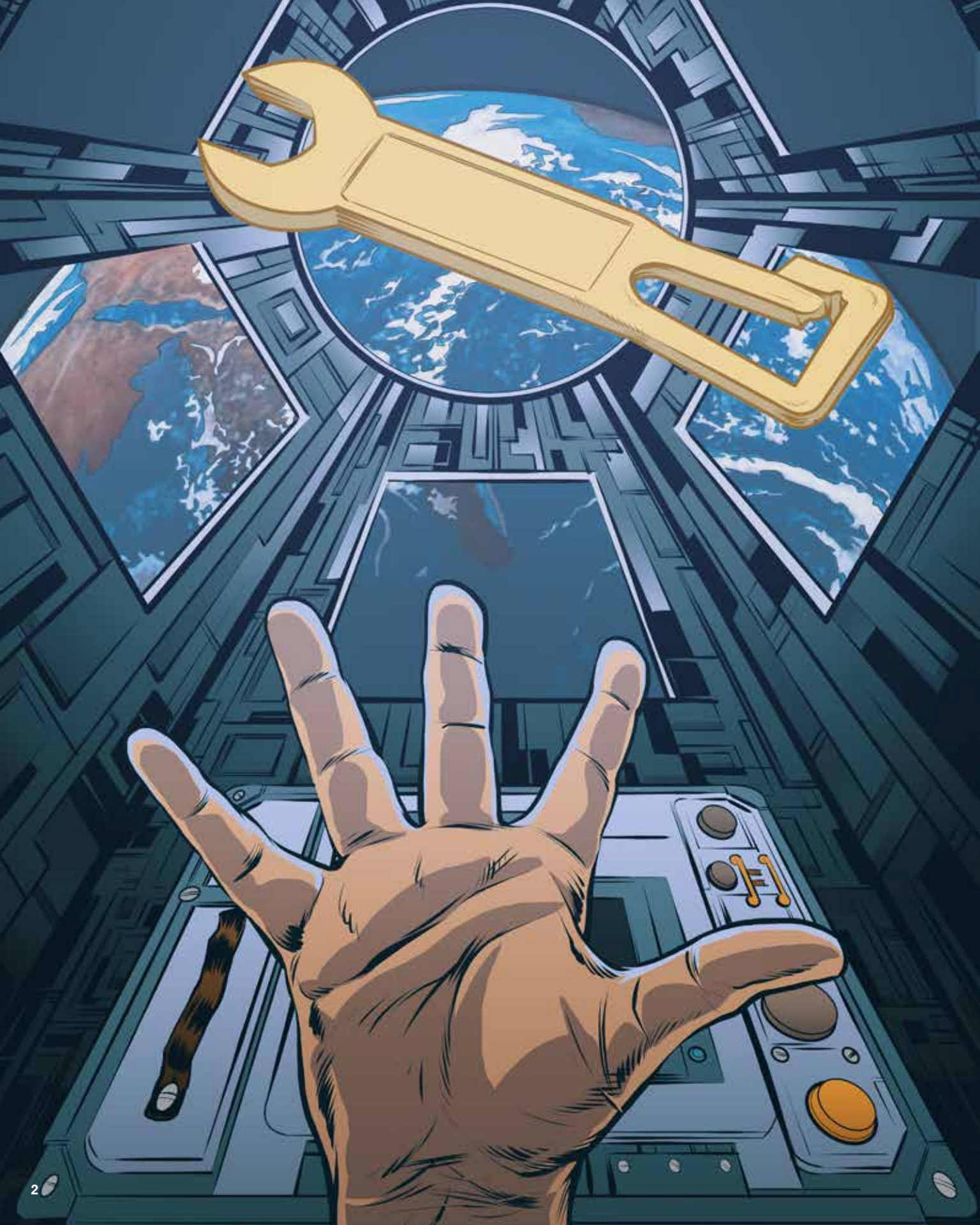
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# THE NEW GOLD RUSH: 3D PRINTING IN MICRO-G

BY ANNE WAINSCOTT-SARGENT

Until a year ago, commercially printing objects in space was the stuff of science fiction. Not anymore. At any given time onboard the ISS National Lab, a 3D printer receives data files from Earth that it transforms, layer by layer, using plastics, into fully functional tools and parts that ISS crew members can use.

This March marked one year since the Additive Manufacturing Facility (AMF) was launched as a permanent “machine shop” on the ISS, providing in-orbit fabrication services to customers from both the ISS National Lab and NASA.

The AMF, owned and operated by California-based Made In Space, has come a long way from its origins as a proof-of-concept payload launched to the ISS in 2014. That initial prototype proved that 3D printing in microgravity actually works and that there was commercial demand for parts Made In Space. Today, the AMF continues to produce objects on-demand not only for NASA but also for a multitude of commercial companies, fueling the growth of a new economy in low Earth orbit.



Made In Space





## SPACE-BASED MANUFACTURING

Ken Shields, director of operations at CASIS, sees several tangible and intangible benefits of being able to manufacture objects off the planet. “Theoretically, you could accelerate completion of end-to-end experimentation in orbit by exchanging out components in near real time as opposed to waiting for results and then sending up parts.”

Before the AMF, any spare parts for the ISS and materials or tools required for experiments on the ISS had to be transported from Earth on a launch vehicle and stowed away onboard until (or if) needed. With the AMF, an ISS crew member or user on the ground can custom design, print, and manufacture an object on demand on the ISS, with the ability to do multiple iterations.

“We can deploy much faster,” said Andrew Rush, Made In Space president and CEO.

As an example, Rush shared how quickly the team designed a ratchet for ISS Commander Barry Wilmore in 2014 using the prototype microgravity 3D printer. The ratchet was the first tool ever to be designed on the ground, emailed to space, and printed in orbit.

“We went from idea to part on station in a week. That is an order of magnitude faster than the traditional way of sending things to space,” Rush said.

The AMF builds upon that first prototype unit. The new commercial facility is larger, modular, and upgradable. From a capability standpoint, the AMF can both scan and verify the accuracy of the parts it prints with no user involvement.

While the AMF currently uses three types of thermoplastic polymers, it will support other feedstock as demand and applications grow. The plastics available now include: acrylonitrile butadiene styrene (ABS), the same material used to make LEGO® blocks; a high-density polyethylene (HDPE), such as the type found in home food containers; and an aerospace-grade polymer (polyetherimide polycarbonate or PEI-PC). Longer term, Rush and others could see these raw materials eventually recycled from other parts or recovered in situ from the moon or other planets.

Space-based manufacturing eliminates the need to design for the high shock and vibration of launch, which often results in products being over-designed, Rush said. “Making things in space allows us to actually optimize the design for the space environment rather than for the transportation system.”

## INDUSTRY INNOVATORS FLOCK TO THE AMF

*Medical, aerospace, and materials companies are showing the strongest interest in the AMF, Rush said. The medical industry wants to make human spaceflight safer by equipping physicians to print out surgical instruments and perform needed operations when human habitation on the moon or on other planets is realized.*

*In January, 3D4MD, a Toronto-based 3D printable medical solution provider, became the first company to use a 3D printer on the ISS to create medical supplies in space. The AMF printed a custom mallet finger splint using a laser hand scan saved from the fitting process for spacesuit gloves. The splint has immediate application, given how common hand injuries are for astronauts.*

*Aerospace companies are studying the design of space-optimized satellites that could be built and launched in orbit. They are also looking into how to make more digital tools for use on the ground and in space.*

*In the materials arena, Braskem, the largest thermoplastic resin producer in the Americas, is working with Made In Space to fabricate tools and spare parts in space using bio-based resin from sugarcane. Thermoplastic resins are raw, unshaped polymers that turn to liquid when heated and turn solid when cooled. The material can be continually remelted and remolded, allowing parts and scraps to be reprocessed. Thermoplastic resins tend to be recyclable, which adds to their value as a space material.*



## 3D PRINTING IN MICROGRAVITY

How does 3D printing in space work? Like an Earth-based 3D printer, the AMF uses an additive manufacturing method to print objects in layers of plastics, metals, and other feedstock materials. Made In Space relies on a 3D additive manufacturing technology called fused deposition modeling. Heating up the filament to a molten state, the material is precisely deposited through a trigger head in a back-and-forth pattern—layer by layer—until the part takes form.

“There are 3D printers that a lot of people might be familiar with that use this same technique,” said Rush. “To make it work in space, you need to eliminate gravity from the equation—everything from positioning of the head and the part, to how the material gets deposited, to making sure it sticks to itself, to managing the heat control.”

Moreover, the free-fall weightless environment of space results in the absence of convection, “so you need to make sure the hot parts stay hot and the cold parts stay cold without the benefit of natural convection,” Rush said.

## FROM THE EARLY VISION TO PRINTING SPACE-OPTIMIZED TOOLS

Made In Space has come a long way from the early days of proving its design. Initially the founders hoped to “buy a commercial off-the-shelf printer and tweak it until it could turn upside down and function as a space-capable printer,” said Rush.

The team spent many sleepless nights testing and retesting their design. They fine-tuned the printer during two weeks of parabolic flight testing, which was critical to proving the design.

The final system, designed to operate from the ground with no ISS crew member involvement, met NASA’s requirements for reliability, safety, and self-sustaining performance. The AMF can use a wide variety of materials as feedstock because it regulates temperature and humidity. Its own environmental control system also keeps the materials within appropriate levels of containment, a required safety regulation for ISS hardware and facilities. Interestingly, this containment feature has been incorporated into 3D printers on the ground.

Made In Space engineers on Earth control the AMF’s queue of print jobs, while internal cameras allow the company to monitor the printer’s operation and notify NASA when an object is printed and ready for retrieval by an ISS crew member.



Since the AMF began full operations this past summer, it has printed more than a dozen objects, including a space-optimized wrench designed by Lowe’s Home Improvement Stores for the ISS crew members to clip on their belts to more easily perform repairs. Made In Space has designed numerous other ISS tools, including a sensor adapter, hose adapters, and spacecraft parts.

Made In Space already has a six-month backlog of print orders. Besides NASA, AMF customers include private companies, private individuals, universities, K-12 schools, and other government agencies.

## AN UNCOMMON SPACE PARTNER

*On the surface, one of the more unconventional partners working with Made In Space is Lowe’s, the home improvement company. Look deeper though, and you realize that Lowe’s Innovation Labs uses technology, design, and the power of story to help customers and employees innovate and build the future. Lowe’s Innovation Labs is developing on-demand manufacturing technologies that will shape our future.*

*Kyle Nel, the Labs’ founder and executive director, regularly works with professional science-fiction writers to use short stories to jumpstart the creativity of Lowe’s leaders by helping them to better envision the future of hardware retailing.*

*“We are pursuing a narrative for how technologies, including additive manufacturing, make it possible to get exactly what you need, right when you need it,” Nel said.*

*Many of these futuristic concepts have found their way into Lowe’s stores to enhance the shopping experience of customers. They include everything from in-store robots to holograph-based virtual reality and 3D printing. Innovation Labs introduced an experimental 3D printer in one store to allow customers to “print” everyday hardware items. The strong response proved to Nel that Lowe’s needed a technology partner to take the 3D printing concept further. Made In Space fit the bill.*

*“They got what we were trying to do, and we got what they were trying to do—it was this beautiful synergy of space and Earth,” Nel said. “Working with uncommon partners like CASIS and Made In Space, we can do things together that we can’t do on our own.”*

*Lowe’s has helped design everything from 3D-printed ratchets to specialized wrenches for the ISS, as well as other products Nel could not discuss publicly. Nel believes that tools rugged enough to withstand the harsh environment of space and the demands of space operations would more than meet the future needs of a Lowe’s customer on Earth.*

*Nel and Made In Space visionaries also have devised a solution to a common byproduct of 3D printing: plastic waste. Their innovative prototype of a Plastic Recycler, while not yet deployed on the ISS, has the potential to efficiently turn plastic waste into filament that can be used to print new parts.*





(L to R) Kyle Nel, Executive Director of Lowe's Innovation Labs, and Jason Dunn, Chief Technology Officer of Made In Space, use a 3D printer on the ground.

Made In Space

## A LEO COMMERCIAL SPACE ECONOMY

Given the types of novel ideas already being generated, tested, and printed on the AMF with partners like Lowe's, CASIS's Shields believes the future is bright for the AMF on the ISS and that it will grow to become a critical component of building a sustainable commercial presence in low Earth orbit (LEO).

**“The queue of projects and potential customers that want to work with Made In Space indicate there is demand for this on the commercial side,” Shields said. “What they are doing is disruptive—it’s thinking outside the box. These are the kinds of companies that are going to lead the way in the LEO commercial market.”**

According to Shields, hundreds of millions of dollars have been invested to date by commercial players testing the waters for building a business in low Earth orbit, often using the ISS National Lab as their test bed. In the last year alone, approximately \$75 million has been invested in LEO projects and activities.

Made In Space is one of five companies now managing in-orbit commercial facilities on the ISS, a service provided by only a couple of companies just five years ago. By 2018, at least nine companies will be managing commercial facilities on the ISS, which together will total \$100 million in commercial investments in the LEO space sector. The AMF is a critical part of that future, said Shields.

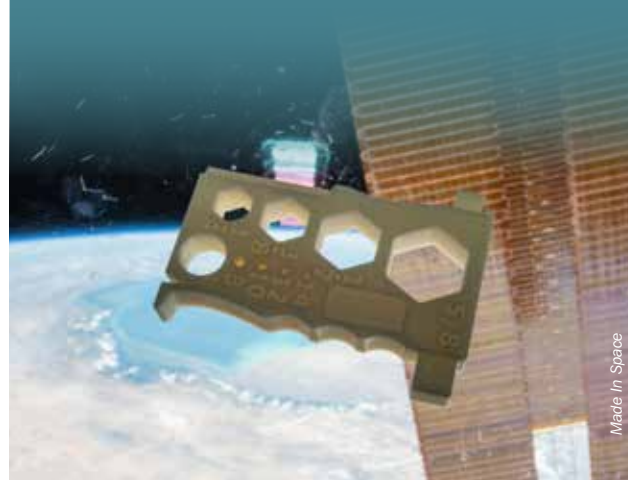
“The ability to manufacture things in space will be critical for us going beyond low Earth orbit to occupy other regions of space, be it other planets or other orbiting bodies,” Shields said. “The applications are endless as far as manufacturing parts and components to sustain oneself in the ultimate remote location.”

Looking at how far Made In Space has come—from idea to operational manufacturing service in the span of six years—Rush cannot hide his excitement. “I think that’s an incredible pace.”

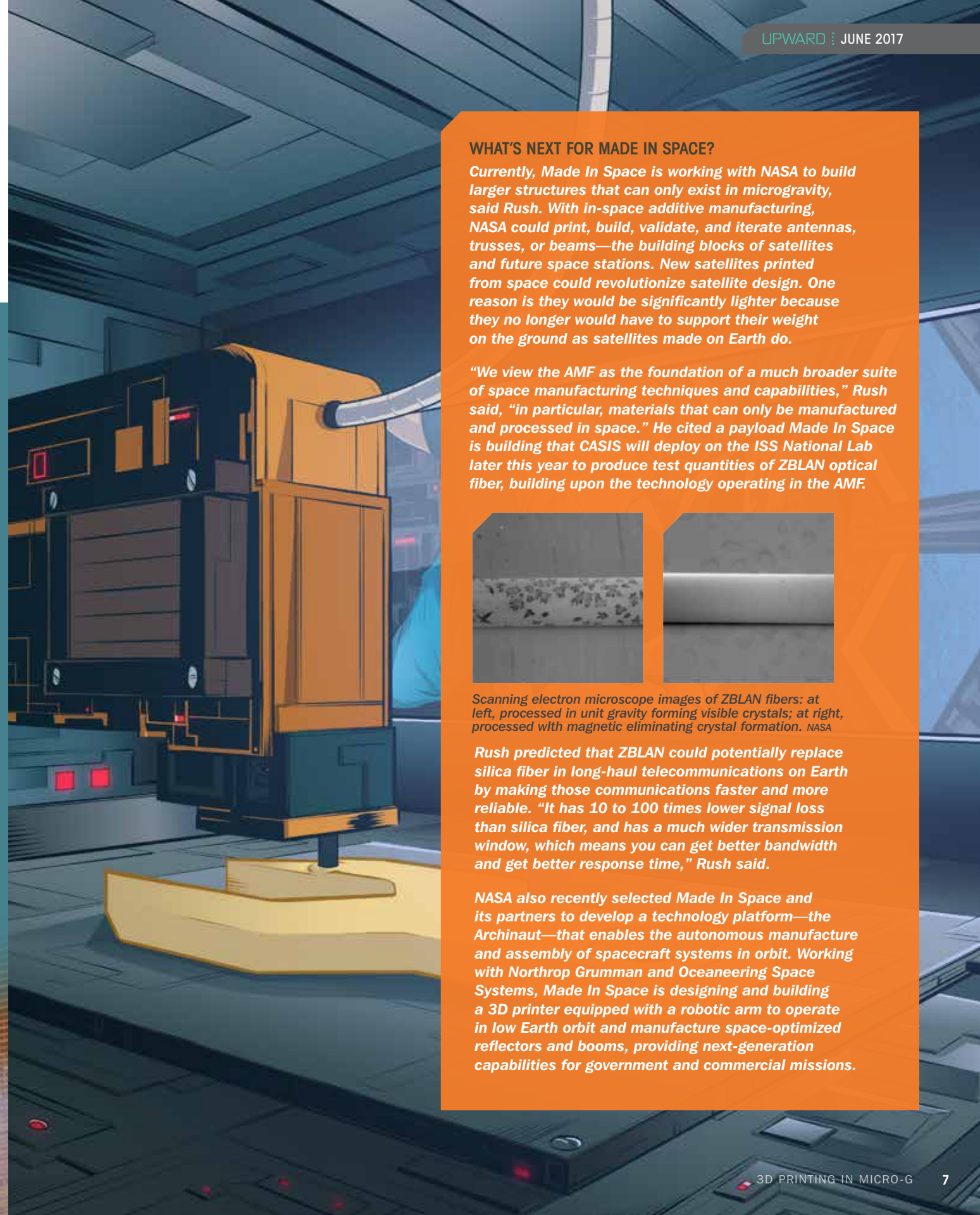
Rush and his colleagues have no intention of slowing down. “The design space is so broad, we are just seeing the very first applications of additive manufacturing,” he said. “I view the LEO economy, especially in-space manufacturing, as the next gold rush—we aim to expand utilization of space in as dramatic a way as possible through commercial activity on the AMF.” ■



*The Multipurpose Precision Maintenance Tool, pictured above, was the winning design of the 2014 Future Engineers Space Tool design competition, which gave students the opportunity to design a tool for ISS crew members to be 3D-printed on the AMF. The design was submitted by Alabama high school student Robert Hillan. The AMF can currently print solid objects up to 10 cm x 10 cm x 14 cm, which is slightly larger than a softball. To make larger objects, the AMF can print connection features into parts and have the larger object assembled in space. Made In Space officials say future AMF-printed objects will be significantly larger—the AMF will be able to print objects a foot or more in length on one side.*



Made In Space



## WHAT'S NEXT FOR MADE IN SPACE?

Currently, Made In Space is working with NASA to build larger structures that can only exist in microgravity, said Rush. With in-space additive manufacturing, NASA could print, build, validate, and iterate antennas, trusses, or beams—the building blocks of satellites and future space stations. New satellites printed from space could revolutionize satellite design. One reason is they would be significantly lighter because they no longer would have to support their weight on the ground as satellites made on Earth do.

“We view the AMF as the foundation of a much broader suite of space manufacturing techniques and capabilities,” Rush said, “in particular, materials that can only be manufactured and processed in space.” He cited a payload Made In Space is building that CASIS will deploy on the ISS National Lab later this year to produce test quantities of ZBLAN optical fiber, building upon the technology operating in the AMF.



Scanning electron microscope images of ZBLAN fibers: at left, processed in unit gravity forming visible crystals; at right, processed with magnetic eliminating crystal formation. NASA

Rush predicted that ZBLAN could potentially replace silica fiber in long-haul telecommunications on Earth by making those communications faster and more reliable. “It has 10 to 100 times lower signal loss than silica fiber, and has a much wider transmission window, which means you can get better bandwidth and get better response time,” Rush said.

NASA also recently selected Made In Space and its partners to develop a technology platform—the Archinaut—that enables the autonomous manufacture and assembly of spacecraft systems in orbit. Working with Northrop Grumman and Oceaneering Space Systems, Made In Space is designing and building a 3D printer equipped with a robotic arm to operate in low Earth orbit and manufacture space-optimized reflectors and booms, providing next-generation capabilities for government and commercial missions.



The Tomatosphere™ Education Program:

# ENTERING A FRUITFUL NEW PHASE

BY JULIA SABLE



**R**ight now, space tomatoes are growing in thousands of classrooms across North America. Through the award-winning Tomatosphere program, K-12 students cultivate and study seeds that were exposed to spaceflight conditions onboard the ISS National Lab. The program provides the space-flown seeds for free, along with educational resources that engage students in authentic experiments and extension activities.

A major strength of Tomatosphere is its hands-on, project-based design, said Karen Lindsey, a teacher at Lake Orienta Elementary School in Florida, who has participated in the Tomatosphere project since it began. “I love authentic learning, and the science content is



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directly tied into many of the standards I currently teach,” Lindsey said. “I also love how much the students collaborate while witnessing the growth of the seeds—I’ve been teaching for 35 years, and Tomatosphere is by far my favorite project!”

Like a healthy plant, the Tomatosphere program is growing in size and complexity as it matures. The program is now entering its second phase, using new instruments to add quantitative detail to students’ investigations.

## PLANTING THE SEEDS OF THE TOMATOSPHERE PROGRAM

Tomatosphere started as a Canadian Space Agency (CSA) project with the goal of getting Canada’s students excited about science, technology, engineering, and mathematics (STEM). In December 2000, Tomatosphere principal investigators Robert Thirsk, retired CSA astronaut, and Michael Dixon, professor at the University of Guelph, Ontario, sent their first batch of Heinz 9478 F1 hybrid tomato seeds into space. A bag of 200,000 seeds accompanied CSA astronaut Marc Garneau on the STS-97 mission of Space Shuttle Endeavor. The investigators worked with collaborators to create curricular support materials that were distributed to schools with the seeds. Over the last 16 years, the project has been

renewed several times under various co-investigators to fly more seeds and build more curricula.



Elementary students analyze plant growth.

Tomatosphere

As the program expanded in Canada, Tomatosphere caught the attention of teachers in the United States. Program leaders tried to accommodate the surge of requests from American classrooms, but the CSA struggled to manage large-scale distribution of seeds outside of Canada. To reach more schools, the program took the same approach as a plant reaching for more light—it grew new branches.

In 2016, Tomatosphere split into a Canada-based program operated by the nonprofit Let’s Talk Science and a U.S.-based program operated by the First the Seed Foundation, a STEM education initiative of the American Seed Trade Association. CASIS supports the Tomatosphere program by transporting seeds to and from the ISS National Lab and encouraging educators and students to participate in the program.



Tomatosphere

## A SPACE SUPERFOOD

*The first batches of Tomatosphere seeds rode on Space Shuttles Endeavor and Discovery. More recent batches have traveled to the ISS on reusable cargo vehicles. The latest batch launched to the ISS on the SpaceX CRS-11 resupply mission in June, when the Dragon capsule carried 1.2 million tomato seeds among its other payloads. The seeds will travel more than 12 million miles during their 30 days in space, circling the Earth 16 times a day. While in orbit, they are experiencing microgravity conditions and above-average radiation levels, but they will not be exposed to the vacuum of space; they remain in a storage area with Earth-like air pressure and temperature.*

*In March 2017, European Space Agency astronaut Thomas Pesquet discussed the Tomatosphere program in a CSA video. “We are already growing lettuce here on the Space Station,” said Pesquet, referring to the space-grown crop of red romaine lettuce that astronauts ate in August 2015. “But no salad is complete without tomatoes... Tomatoes can be a space superfood!”*



Tomatosphere is a good fit for the First the Seed Foundation, whose primary goal is “to give students an understanding about where their food comes from and get them excited about agriculture,” according to Ann Jorss, the foundation’s secretary and treasurer. To become smart consumers and stewards of natural resources, young people must practice asking fundamental questions about the foods and products they use every day.

**“Some kids don’t even know their hamburger comes from a cow!” said Sabrina DeVall, program manager of Tomatosphere in the U.S. “And that cow depends on plants: Without the seed that initiated the grain to feed that cow, you don’t have that burger. So much in our lives can be traced back to seeds.”**

Tomatosphere’s newly branched structure opens the program up to classrooms throughout America, as well as homeschool groups, afterschool programs, clubs, summer camps, Scout troops, and other groups of learners. As a result, Tomatosphere’s growth rate is accelerating. Compared with its first year, in which the program reached 2,700 classrooms, the Tomatosphere program has reached more than 20,000 classrooms

so far in 2017—more than 500,000 students—and plenty of seeds are still available. About one-third of this year’s participants are in the U.S., and that proportion is expected to rise.

**ENGAGING STUDENTS IN A REAL SPACE EXPERIMENT**

After registering on the First the Seed Foundation’s website, a participating classroom receives an envelope in the mail with two packets of 30–35 seeds each. One set of seeds was flown in space onboard the ISS and the other was not.

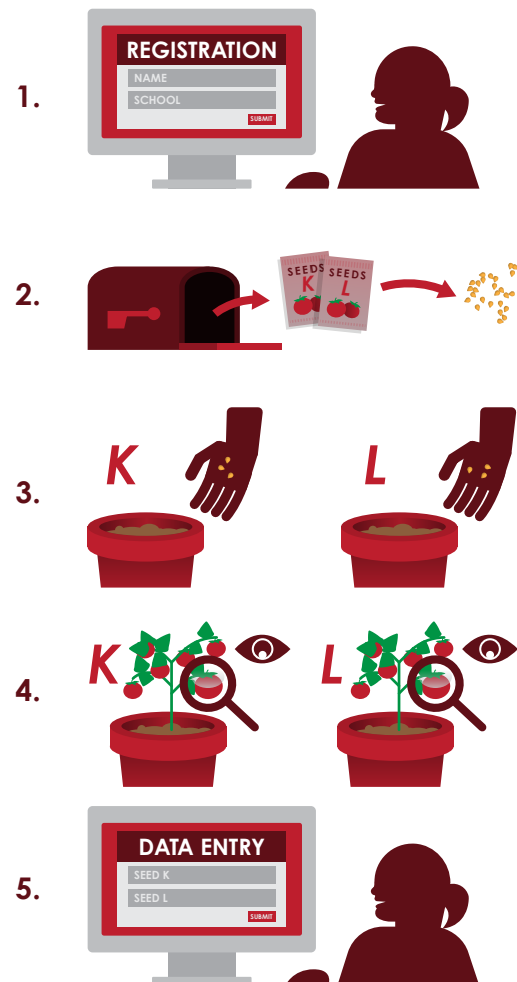
The seed packets are labeled only with letters such as K and L, not descriptive labels like “space” and “ground,” allowing students to learn the importance of a blind experiment for minimizing observational bias. If the students knew the identity of the space-flown seeds in advance, they might over-interpret their observations, expecting to see something special. Concealing the seeds’ origins also adds a fun sense of suspense. Students are not just conducting an experiment; they are solving a mystery.

The main experiment in the Tomatosphere program focuses on germination. Students follow a simple protocol to plant the seeds and track the seedlings that appear over the next few weeks. They can also observe the plants’ growth rates and physical characteristics and use these clues to hypothesize about which seeds flew onboard the ISS. The students find out which packet contained the space-flown seeds when the class reports its results to the Tomatosphere program through an online form. The germination data are then made available to scientists studying plants in space, so the students are contributing to real research.

The experiment and its accompanying resources provide natural entry points into lessons about plant biology, human health, and space exploration. The program also touches on the fundamentals of science. “It is a perfect project for teaching about the scientific method,” said Lindsey, who works with students in grades 3–5.



Tomatosphere



**BRANCHING INTO INTERDISCIPLINARY INSTRUCTION**

Teachers can also broaden the range of curricular connections to include social studies. After finishing the main germination experiment, many students continue caring for their Tomatosphere plants until they bear fruit. Instead of merely eating or cooking with their tomatoes, some students have sold their produce at local farmer’s markets and used the money to support school programs. The steps necessary for selling the tomatoes—calculating costs, anticipating demand, deciding how much to charge for the product—are real-world applications of important concepts in economics.

Another group of students had the idea of donating their produce to a local food pantry. With this simple act, DeVall noticed a remarkable increase in the students’ civic awareness and engagement.



**“I’m amazed how a project that starts with planting seeds can grow into lessons in economics and community service and cooking and all these other offshoots,” DeVall said.**

Julie Petcu, an enrichment teacher at St. Matthew School in Tennessee, challenges herself to keep the program fresh and fun year after year. For her 13th round of Tomatosphere experiments this fall, she plans to strengthen the link with her plant biology curriculum by having her students compare their tomato seedlings with other plant species. She also plans to intensify her emphasis on nutrition. Petcu is especially excited to incorporate more topics outside of STEM. “As I’ve matured as an educator, what I enjoy most is showing students how all of their educational disciplines are connected,” she said.

Petcu’s cross-disciplinary thinking aligns well with the Next Generation Science Standards (NGSS) that are currently being adopted by many districts across the nation. The NGSS were developed collaboratively in 2011–2013 by nongovernmental educational organizations including the American Association for the Advancement of Science, the National Science Teachers Association, and the National Academies of Science.

Like older science standards, the NGSS Framework recommends topics to cover at specific grade levels. Unlike the older standards, the NGSS provides continuity by grouping those topics into themes that span multiple grade levels. The themes, called Disciplinary Core Ideas, form one of three dimensions of science learning. The other two dimensions are Crosscutting Concepts and Science and Engineering Practices.

This three-dimensional approach is the game-changer that distinguishes the NGSS from other science standards. It pushes science education toward a more interdisciplinary model—for which Tomatosphere is well suited. Future phases of Tomatosphere are planned to more explicitly map the program’s curricula to the NGSS, providing teachers with a novel vehicle for reinforcing the standards.

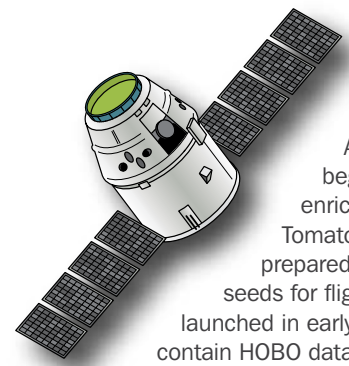


**A TOMATO ISN’T JUST A TOMATO**

*Inventive teachers are expanding Tomatosphere’s curricular connections beyond the typical STEM fields. This year, enrichment teacher Julie Petcu is adding a new twist by incorporating social studies. “A tomato isn’t just a tomato,” she said. “It’s got history, it’s got travel, it’s got culture. It’s got all these great stories!”*

*Native to South America, tomatoes followed a surprisingly convoluted route to North America. The word tomato derives from the Aztec word *tomatl*. In the 1500s, Spanish explorers encountered the tiny, tart ancestors of today’s tomatoes in parts of modern Peru and Ecuador. The Spanish brought the plants home, but parts of Europe were slow to embrace it as food. In England, the tomato plant was strictly ornamental for more than a century. People suspected the fruit was poisonous because the plant is in the nightshade family and its leaves and stems have an unpleasant odor. The tomato reached North America by way of the Caribbean in the 1700s.*





### TAKING THE TOMATOSPHERE PROGRAM TO NEW LEVELS

A new phase of Tomatosphere is just beginning and will provide an even more enriched learning experience for students. Tomatosphere seed distributor Stokes Seeds prepared bags of the usual Heinz 9478 F1 tomato seeds for flight to the ISS on SpaceX-11, which launched in early June. However, this time, the bags also contain HOB0 data loggers. These compact instruments, manufactured by Onset Computer Corporation, measure and record temperature, relative humidity, and pressure.

The data loggers will continuously monitor the seeds' environmental conditions for the entire three-month round trip—including transport to NASA's Kennedy Space Center, launch to the ISS on SpaceX-11, time spent onboard the ISS National Lab, reentry into Earth's atmosphere, and transport from the splashdown site back to Stokes Seeds. The sensors are fully automated and do not require any involvement from ISS crew members. Identical data loggers will monitor the control group of seeds on Earth over the same period.

Starting in spring of 2018, registered classrooms will have access to the data along with their packets of tomato seeds. The new challenge of analyzing quantitative data—likely the largest datasets the students have yet encountered—will support meaningful learning in math and computer science. New curricular support materials will help educators and students process, visualize, and interpret the data.

The data from this second phase of the program may also help explain why Tomatosphere's germination results vary so widely from year to year. Participants generally assume that the storage environment of the seeds on the ISS is similar to that of the control seeds on Earth, with microgravity being the only major exception. But it is possible that the space-flown seeds experience other deviations from Earth-like conditions during their journey. If the new Tomatosphere data reveal such differences, the results could have implications for other ISS experiments.

Following the exciting developments of this second phase, future phases of Tomatosphere seek to expand beyond the passive flight of seeds and into active research projects onboard the ISS National Lab. The Tomatosphere investigators envision germinating tomato seeds in the Vegetable Production System, also known as Veggie, on the ISS, freezing the seedlings for transport back to Earth, and performing postflight measurements of gene expression and protein production. Tomatosphere students at the high school level would then shift from making visual observations of plant growth to analyzing omics data from the postflight analysis.

**As Tomatosphere progresses through these exhilarating new phases, students and educators will find that its best qualities remain unchanged: it will still be hands-on, interdisciplinary, curriculum-based, and free! ■**

Learn more at [www.tomatosphere.org](http://www.tomatosphere.org)



Students examining seeds in germination pods.  
Tomatosphere



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## NASA Partners with CASIS to Improve Protein Crystal Growth in Space

BY SARA TEWKSBURY

While NASA is often associated with deep space exploration and reaching for the stars, NASA and CASIS also share a common vision of reaching upward to space to benefit life down on Earth. Both support the ISS as an unparalleled platform for innovation and research that enables discoveries that cannot be realized on the ground. Two recently co-sponsored projects highlight this common goal.

By coming together in partnership, CASIS and NASA's Space Life and Physical Sciences Research and Application Division (SLPSRA) recently joined forces to bring two projects to the ISS National Lab that otherwise may not have made it to orbit. Specifically, CASIS provided crew time that SLPSRA needed to conduct two fundamental-discovery protein crystal growth investigations sponsored by NASA.

Experiments that receive support from CASIS must benefit life on Earth, so the projects chosen for this co-sponsorship were carefully selected to fit the mission criteria of both NASA's SLPSRA and CASIS. The two investigations, which were launched to the ISS aboard the Falcon 9 spacecraft on SpaceX CRS-10 in February, are studying important aspects of protein crystal growth in space.



Both projects used the Light Microscopy Module onboard the ISS to observe the crystallization of proteins during spaceflight. NASA

One of the projects will test widely accepted theories of why protein crystals grown in space are often higher quality than those grown on Earth. Similarly, the other project seeks to understand why only certain proteins benefit from crystallization in microgravity. Higher-quality crystals allow researchers to better image and identify structural details of the proteins, which helps scientists better understand protein-drug interactions.

Thus, microgravity-based crystallization studies may help to inform and improve drug development.

By observing the fundamental physical dynamics of how crystals grow in space, the co-sponsored projects will look for indicators that predict which proteins might benefit most from space-based crystallization. CASIS is working toward development of a sustainable program for crystallizing macromolecules, including proteins, in microgravity. These co-sponsored projects aim to fine-tune the selection of proteins and environmental conditions to maximize efficiency of such research on the ISS—to the benefit of NASA, the ISS National Lab, and diverse user communities.

"This partnership demonstrates the ability of the ISS National Lab and NASA to work together with researchers to continually improve the quality and quantity of science returned to Earth," said Michael Roberts, CASIS deputy chief scientist. "The partnership will continue to optimize research capabilities in low Earth orbit and enable new collaborative projects." ■

SPOT LIGHT

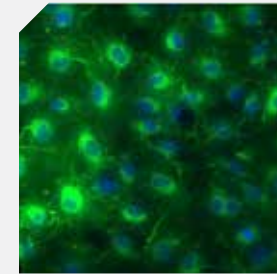
## Gators in Space – At Least Their Research

BY DEBBIE WELLS

Collaborative partnerships are key to enabling the growth of research, development, and commercialization opportunities on the ISS National Lab and setting the stage for a sustainable economy in low Earth orbit. Combining funding from multiple sources optimizes resources and enables space research projects that would not otherwise be possible. Recently, CASIS and the University of Florida Office of Research contributed \$250,000 in matching funds to enable the Joint UF/CASIS International Space Station Research Initiative. Through a mutual selection process, awards were made to three new-to-space UF investigators in December 2016, and the projects are scheduled to launch to the ISS National Lab in 2017/2018.



One of the awarded projects, led by principal investigator Mark Settles, aims to perform genomic analyses of algae grown onboard the ISS, with the long-term goal of domesticating and engineering algae for optimal production of biomass feedstocks. Based on work in terrestrial plants, microgravity may be perceived as an abiotic stress. Because abiotic stresses can signal the production of high-value compounds in algae, the investigators hope to explore whether spaceflight induces the synthesis of novel high-value compounds.



Microscopic image of human stem cells attached and growing on carrier beads. Josephine Allen, University of Florida

The second awarded project, led by principal investigator Josephine Allen, is motivated by astronaut data showing a link between spaceflight and risk of cardiovascular disease (CVD). Because dysfunctional vascular cells are an underlying contributing factor in CVD, it is important to study these cells under altered growth conditions. Allen hopes to better understand CVD on Earth by elucidating the mechanisms of vascular cell damage during spaceflight through transcriptomics. This project explores new lines of investigation into the molecular mechanisms of vascular cell damage that may in turn lead to novel treatment options.

The third awarded project, led by principal investigator Kirk Ziegler, will use the microgravity environment on the ISS to observe electrodeposition, a process by which an electric current is used to form thin metal features on conductive surfaces like electrodes. As consumer electronics become smaller and more densely packed, components such as heat exchangers and sensors

must also shrink in scale. Controlling the patterning of these components is critical at the micro-, macro-, and nanoscale to achieve the precise structures needed for component functionality. On Earth, measuring the forces involved in this process is challenging because of the confounding effects of gravity—but microgravity allows better visualization of the electrodeposition process. Success of this experiment would result in lower cost of production and increased performance of consumer electronics, enabling continued improvement in the overall performance of everyday devices.

Research through academic partnerships like the Joint UF/CASIS ISS Research Initiative combines resources of various institutions, creating the funding stream necessary for spaceflight endeavors. "The Joint UF/CASIS Research Initiative has been an exciting implementation partnership, and we look forward to the project results, which will build knowledge and future recognition for UF research programs," said Dr. Sobha Jaishankar, UF Office of Research. CASIS seeks other similar partnerships to leverage its funding, thereby expanding the usefulness of low Earth orbit and the ISS National Lab to new users. ■

SPOT LIGHT

## NASA's Cold Atom Laboratory: A New ISS Facility for Studying Quantum Phenomena

BY EMILY TOMLIN

What could be cooler than studying quantum gases in microgravity? It turns out, practically nothing! Scientists and engineers from the NASA Jet Propulsion Laboratory are using laser cooling technology to literally create the coldest place in the universe—and it will happen onboard the ISS.



NASA's Cold Atom Laboratory (CAL) Chip (Artist's Concept). NASA/JPL-Caltech

The Cold Atom Laboratory, or CAL, is a multi-user facility to study degenerate gases and other quantum phenomena in the ISS environment—the first space-based facility of its kind. Like the Alpha Magnetic Spectrometer (AMS) launched to the ISS in 2011 and discussed in the February 2017 issue of *Upward*, the CAL should help scientists unlock secrets about the physical universe, including gravity, dark matter, and dark energy, that are extremely difficult (or even impossible) to study on Earth. The CAL is currently expected to launch to the ISS within the coming year.

Within the CAL facility, which is coincidentally about the size of an ice box, lasers excite atoms which emit photons (and heat) and cool the contents of the CAL. A series of other steps, including a "knife" of radio waves that removes any leftover heated atoms, then further cools and condenses the matter into what scientists believe will be the coldest spot in the universe—just a billionth of a degree above absolute zero. Under these conditions, the atoms become a superfluid or a quantumly-condensed gas—or in physical terms, a collection of free, non-

interacting particles with pressure and other physical characteristics determined by quantum mechanical effect.

In this coldest of places, particles within the CAL will become a form of superfluid known as the Bose-Einstein condensate (BEC), a state of matter first observed by scientists in 1995. In this physical state, particles of matter behave more like waves than particles. Moreover, this extreme cold will allow the newly formed superfluids to be observable for as long as 10 seconds—a feat never before achieved, or perhaps even possible, on Earth. This may allow scientists to observe if the predicted behaviors of these superfluids actually occur—and perhaps even lend investigative technologies to larger concepts involving dark energy and the nature of gravity itself.

In addition to studying BECs, other experiments possible using the CAL may enable breakthroughs in General Relativistic investigations and other designer's quantum phenomena. This study of ultra-cold quantum gases in microgravity is also well aligned with U.S. goals for spaceflight research. A 2011 report from the U.S. National Research Council, "Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era," recommended that fundamental physics, and in particular the study of quantum gases and "the fundamental forces and symmetries of nature," should be a high priority area for R&D onboard the ISS.

While the CAL is not an ISS National Lab facility, it complements many of the ongoing efforts to make accessible the unique environment of space to advance scientific knowledge, enable fundamental discovery, and improve human understanding of the world, and the universe, around us. The first science teams to use CAL will include thought leaders in the physical sciences and three Nobel Prize winners—and the validation of this technology will serve as a pathfinder for future spaceflight initiatives to study exotic particles and other fundamental physical concepts that elude traditional ground experimentation. For more information, visit [coldatomlab.jpl.nasa.gov](http://coldatomlab.jpl.nasa.gov), and watch for additional updates once the facility is in orbit. ■

SPOT LIGHT



## The S.S. John Glenn Carries Science to Space

BY PATRICK O'NEILL

On April 18<sup>th</sup>, Orbital ATK's 7<sup>th</sup> ISS cargo resupply mission successfully launched from Cape Canaveral Air Force Station in Florida carrying more than 7,600 pounds of experiments and crew member supplies. Orbital ATK's Cygnus capsule, renamed the S.S. John Glenn in memory of the pioneering astronaut, was stocked with dozens of ISS National Lab sponsored investigations, all seeking to utilize the unique space environment to benefit life back on Earth. Payloads included physical sciences and genetics investigations, student experiments, Earth observation projects, and radiation studies—a few of which are highlighted below.

### Antibody Drug Conjugates (ADCs) in Microgravity

Startup company Oncolinx Pharmaceuticals, LLC is using the microgravity environment of the ISS to test the efficacy and metabolism of new cancer fighting drugs in 3D cell cultures. Azonafides are drugs that inhibit tumor growth. In combination with ADCs, therapeutics that target tumors through receptors on the surface of cancer cells, cancer therapies are more effective against cancer cells and less toxic to healthy cells. Oncolinx has been given exclusive access by the National Cancer Institute to investigate and commercialize Azonafide ADCs, along with funding for related ground studies. Compared with cell cultures in a dish on Earth, cell cultures in microgravity serve as better tumor models due to specific responses to the space environment. Improved models allow researchers to better test the performance of therapeutics, which could accelerate the timeline for bringing a drug to market. This investigation originated through a joint CASIS–Boeing "Technology in Space" prize associated with the MassChallenge Accelerator program (the largest-ever startup accelerator and the first to support high-impact, early-stage entrepreneurs without taking any equity).

### Crystal Growth of Cs<sub>2</sub>LiYCl<sub>6</sub>:CE Scintillators in Microgravity

Radiation Monitoring Devices, Inc. will use the ISS as a platform to conduct a series of experiments to grow scintillator crystals. Scintillators excite when exposed to certain types of radiation and can be used in detectors for safety monitoring or homeland security applications. The reduced fluid motion in microgravity could lead to the growth of scintillator crystals with higher purity and quality. This investigation leverages an updated facility onboard the ISS that acts as a furnace in microgravity, the Solidification Using a Baffle in Sealed Ampoules (SUBSA) hardware platform.

### Magnetic 3D Cell Culture for Biological Research in Microgravity

Nano3D Biosciences, Inc. will lay the foundation for flight experiments to explore the use of magnetic nanoparticles and magnetic fields to aid in the 3D culture of cells on the ISS. A growing demand exists for cell culture models that better capture the characteristics of living tissue. In microgravity, cell cultures naturally grow in three dimensions, resulting in models that better recapitulate cell growth in living organisms. This investigation seeks to incorporate magnetic cell culture technology into existing flight hardware and optimize platform operation to support continued 3D cell growth experiments on the ISS. As part of this ISS National Lab project, Nano3D Biosciences has also advanced its magnetic 3D bioprinting technology, which is currently commercially available, enabling researchers on the ground to mimic microgravity properties and discover new insights in drug development within biologically relevant cell culture systems on Earth.



Orbital ATK prepares for the 7<sup>th</sup> ISS cargo resupply mission. NASA

### Genes in Space-2

In this student investigation, high school student Julian Rubinfien seeks to determine whether DNA from telomeres (protective caps on the tips of chromosomes) can be amplified in space to create an assay capable of measuring telomere length during spaceflight. Understanding how the regulation of telomere length changes during spaceflight and the role that it may play in disease and aging is important for future space missions and for use of the spaceflight environment to model terrestrial disease states. This project resulted from the Genes in Space™ program, an annual competition in which students compete to send their DNA experiment to the ISS. The Genes in Space™ program is supported by a partnership between the Boeing Company, CASIS, miniPCR, Math for America, and New England Biolabs.

**Each of these space-based investigations will lead to discovery and innovation that advances an area of research and technology development of critical importance and direct relevance to humans on Earth. Were it not for the unique microgravity environment on the ISS National Lab, these experiments would not be possible. ■**

SPOTLIGHT



LIFE SCIENCES

## Microgravity Molecular Crystal Growth (MMCG) Program

The International Space Station (ISS) National Lab Microgravity Molecular Crystal Growth Program enables crystallographers to harness the conditions of low Earth orbit onboard the ISS to produce high-quality crystals suitable for their area of research and development.

Through a network of mentors and preferred partners, the MMCG program puts state-of-the-art hardware capabilities at your fingertips and reaps the benefits of experience through a community approach.



University of Alabama-Birmingham



Teledyne Brown Engineering



The Bionetics Corporation



University of Alabama-Birmingham



U.S. NATIONAL LABORATORY



POWERED THROUGH PARTNERSHIP



Explore the research capabilities of the ISS National Lab and learn more about our network of preferred partners that can support your space research.

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# News & Notes

FROM THE ISS NATIONAL LAB

## LAUNCHING TO THE ISS

*With the successful launch of the SpaceX-11 rocket in early June, the commercial resupply mission carried more than 40 payloads to the ISS National Lab. Key payloads include projects involving rodent research, heart stem cells, protein crystal growth, and a multi-user Earth observation platform. This mission also includes a project from household product company Procter & Gamble to study the behavior of microscopic particles in gels and creams.*

## DESTINATION IMAGINATION GLOBAL FINALS

*CASIS traveled to Knoxville, Tennessee in May for the Destination Imagination Global Finals Innovation Expo. The expo, which had an attendance of 17,000, is featured at CASIS education partner Destination Imagination's culminating event, Global Finals—a global science, technology, engineering, arts, and math challenge in which student participants showcase creative solutions to a variety of academic challenges. At the event, CASIS presented Space Station Explorers resources and held a workshop that took students on a simulated mission to the ISS. The CASIS booth also hosted education partners Zero Robotics (a student competition to design algorithms for robotic SPHERES satellites that operate inside the ISS) and NASA Johnson Space Center's STEM on Station.*

## DESTINATION STATION

*CASIS, the NASA ISS Program Science Office, and NASA Astronauts Anne McClain and Michael Barratt traveled to Seattle in May and Portland in June with the ISS Driven to Explore mobile exhibit as part of Destination Station outreach. The ISS team met with local companies to discuss access to space and the ISS National Lab as an innovation platform that can accelerate discovery in ways not possible on Earth.*

## BIO INTERNATIONAL

*In late June, CASIS participated in the BIO International Convention in San Diego, California, hosted by the Biotechnology Innovation Organization, which represents more than 1,100 biotechnology companies, academic institutions, state biotechnology centers, and related organizations in the U.S. and around the world. At the convention, scientist and NASA Astronaut Kate Rubins participated in a fireside chat with The Verge's Loren Grush to talk about Rubins' time in space, the types of research she conducted on the ISS National Lab, and future opportunities on the ISS for life science researchers. Additionally, CASIS met with a variety of biotechnology and pharmaceutical organizations and companies to discuss research possibilities available through the ISS National Lab.*

UPWARD

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