UPWARD®

MAGAZINE OF THE ISS NATIONAL LAB | ISSNATIONALLAB.ORG/UPWARD | MARCH 2026

MANUFACTURING ARTIFICIAL RETINAS IN SPACE

ON PAGE 4

VOLUME 9 ISSUE 1

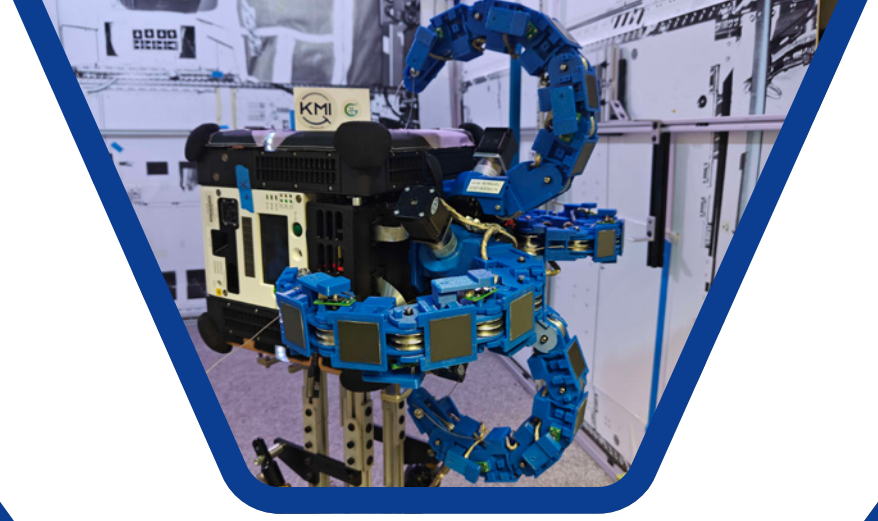
10TH ANNIVERSARY EDITION

VIEW FROM THE CUPOLA
CADY COLEMAN

ADDRESSING THE PROBLEM OF SPACE DEBRIS

GROWING USEFUL BACTERIA IN SPACE

ISS NATIONAL LABORATORY®
CENTER FOR THE ADVANCEMENT OF SCIENCE IN SPACE®



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Letter From the Editor

Amelia Williamson Smith

Ten years ago, I sat at my computer brainstorming how best to share the amazing science enabled by the ISS National Lab. It was then that *Upward* was born.

We chose the magazine's name for many reasons. We look upward to the ISS—our nation's only orbiting laboratory—to solve some of humanity's greatest challenges and to create things not possible on the ground. We endeavor upward in our pursuit of advancing science and technology in space to improve life on Earth. And we raise our aspirations upward beyond the ISS to a future where commercial space stations operate in a robust low Earth orbit (LEO) economy.

I hope you enjoy this 10th anniversary edition, in which we highlight how the idea of manufacturing products in space for use on Earth is no longer confined to science fiction. Studies enabled by the ISS National Lab over the past decade have shown that not only is this vision possible—it's right around the corner.

As we look ahead to this exciting future, we also take a moment to look back on the road that brought us here. The ISS has served as an invaluable testbed for in-orbit production. It's a place where companies can validate systems and facilities, refine and optimize production processes, and uncover ways to scale their manufacturing on future LEO platforms. It remains a critical step toward the next industrial revolution—in space.

I am so proud of how far *Upward* has come over the last 10 years and all the stories we've shared that showcase the value of conducting research and technology development in space. I am thankful for our amazing team that helped bring the idea of the magazine to life. And I am grateful to you, our readers, for joining us on this incredible journey of discovery. We hope you continue to follow along as we forever strive upward.

Amelia Williamson Smith

Upward Managing Editor

CELEBRATING 10 YEARS OF UPWARD®

VIEW FROM THE CUPOLA

By Cady Coleman | Retired NASA Astronaut

Cady Coleman (Colonel (Ret) USAF), is a former NASA astronaut, a scientist, and the author of the book "Sharing Space." She flew on two space shuttle missions and spent almost six months living and working on the ISS.

In 2010, the day after my 50th birthday, I got the best present imaginable. I climbed aboard a Russian Soyuz rocket with my two crewmates and launched to the International Space Station (ISS). As a scientist-astronaut, it was the fulfillment of a long-held dream to live for almost six months on the ISS, where every day I worked with scientists on the ground to conduct unique experiments not possible on Earth.

As we celebrate a quarter century of continuous human presence on the ISS, I'm inspired to reflect on how we got here and the enormous impact our scientific and engineering research in space has made. I'm honored to contribute to this 10th anniversary issue of the ISS National Lab's *Upward* magazine, a marvelous place to learn about those stories of discovery.

On my first space shuttle flight, our goal was to help ensure we were designing the ISS to operate successfully as a space laboratory. Routine operations on the space station today were big questions back then. How will scientists on the ground interface with astronauts? How and when will the scientists receive their data? What kind of equipment is needed to conduct state-of-the-art research in many disciplines? However, my biggest question at the end of our 16-day mission—the longest shuttle mission at that time—was: "Why are we coming home? We have so much work to do up here!"

Our scientific journey in space has greatly evolved since then. The orbiting laboratory has been the site of amazing discoveries, with each experiment and each set of results building on the ones that came before. In many realms, from combustion to biology, ISS science has deepened our understanding of fundamental processes, giving us the building blocks to produce new materials, design new drugs and medical devices, and expand options for growing food, even in inhospitable environments.

As astronauts, we serve as the scientists' partners in space, always aware that our efforts are part of a broader mission of discovery. It is a privilege to be part of a family that includes not only our astronaut crewmates but the engineers and scientists who design the experiments we conduct. The family also includes the people who tell the stories of those discoveries, which is so important to sustaining the work we do and inspiring others to join our efforts. As you read the three features in this issue highlighting remarkable innovations from ISS National Lab-sponsored research, imagine all the people and work that led us here.

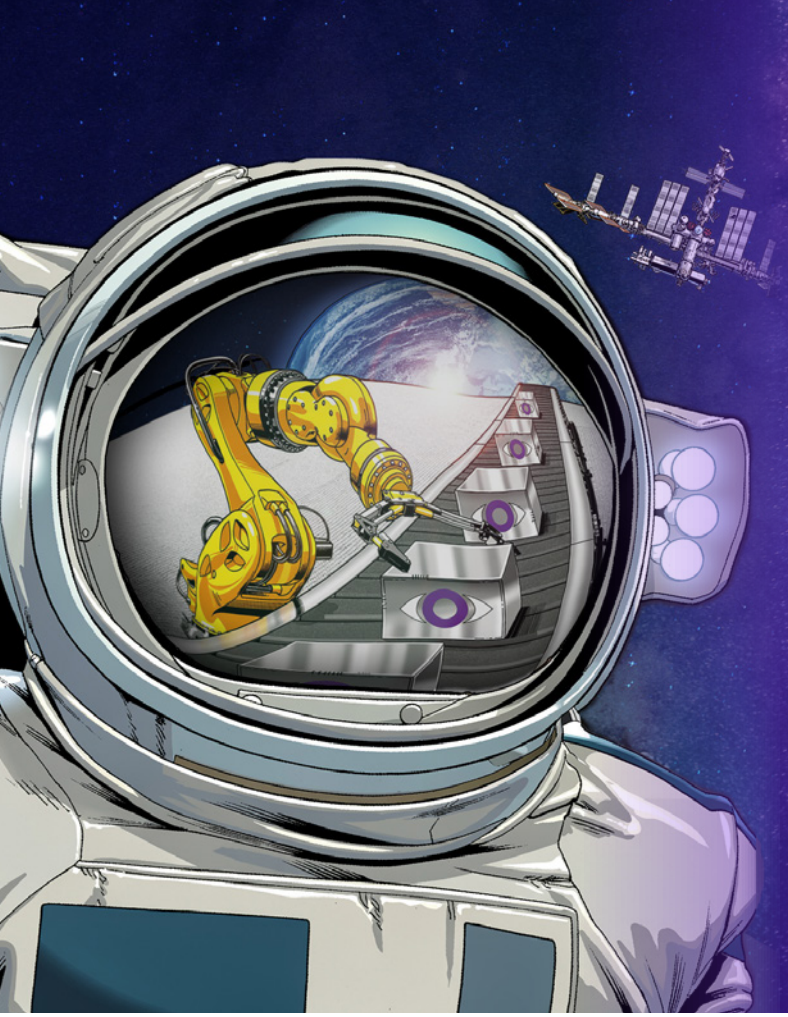
This issue's cover story showcases LambdaVision's research on manufacturing artificial retinas for those blinded by retinitis pigmentosa and age-related macular degeneration. In collaboration with the ISS National Lab, NASA, and Space Tango, LambdaVision has successfully produced several high-quality artificial retinas on the ISS. Microgravity

facilitates the production of these highly uniform, 200-layer protein-based thin films without the sedimentation issues that limit manufacturing on Earth. Now the startup is working to refine processes and lay the groundwork for scalable in-space production and future clinical trials.

As the second astronaut ever to capture a free-flying object from the ISS using the CANADARM2 robotic arm, I was intrigued by this issue's feature on Kall Morris Inc. (KMI). The startup is advancing technology that could help with space debris removal, a difficult and growing challenge. KMI leveraged the ISS National Lab to successfully test its REACCH (Responsive Engaging Arms for Captive Care and Handling) system. REACCH unfurls its tentacle-like arms to capture free-floating objects, gripping them with technology that mimics the way a gecko's feet enable it to walk up walls. After further refinement, REACCH will progress to capturing space objects in low Earth orbit (LEO).

Given my early materials work as a polymer chemist, I'm particularly excited about the feature on the U.S. Naval Research Laboratory's investigation into microbes that produce melanin, a natural pigment. Among other fascinating properties, melanin is known to protect cells against radiation and oxidative stress and can also bind to environmental toxins, properties that matter both to astronauts in space and those of us here on the ground. Studying melanized microbes in microgravity could generate valuable insights into how these organisms produce protective compounds, informing the development of advanced biomaterials and potentially new therapeutics.

As an astronaut, there is no greater satisfaction than being part of an experiment that leads to a leap forward in our understanding. Looking back at the full scope of what has been accomplished on the ISS and the thousands of people responsible for its success, I know that satisfaction is shared widely. Our cumulative experience operating an international scientific outpost in space has built invaluable capabilities, infrastructure, and collaborative models—both scientific and international—that will be pivotal as we continue to explore in LEO and beyond. This milestone and the legacy of our space station aren't endpoints; they are bridges to an exciting future.



Manufacturing Artificial Retinas in Space to Restore Sight on Earth

By Amelia Williamson Smith,
Managing Editor

Imagine an environment with saltwater four to five times saltier than the ocean. There are places on Earth where the water pools in shallow ponds with little oxygen, and the harsh sun beats down with brutally intense UV radiation. What's more, the salty water amplifies the light, making it all the more punishing. There's no way an organism could survive in that extreme environment, right?

Wrong. *Halobacterium salinarum* is a microscopic, single-celled organism that not only survives in these hypersaline ponds—it thrives.

This purple-tinted extremophile lives at the edge of what's biologically possible for life on Earth. It can do this because of a light-activated protein called bacteriorhodopsin that turns light into chemical energy without oxygen or carbon through a proton-pumping process.

Scientists at LambdaVision are harnessing this unique mechanism to restore sight in those blinded by macular degeneration. The startup developed an artificial retina using hundreds of layers of bacteriorhodopsin.

To produce the artificial retinas, the protein is deposited onto a scaffold using a precise layer-by-layer assembly method. Small, oval-shaped artificial retinas are punched out of the thin film. But gravity-driven forces on Earth cause inconsistencies in the film's layers that can make parts of it unusable.

To address this problem, LambdaVision decided to take bacteriorhodopsin from its extreme environment on Earth to another extreme environment: space. In microgravity, the team can produce artificial retinas with layers that are much more uniform. For this reason, the startup has set its sights on in-orbit manufacturing.

What is proton pumping?

When bacteriorhodopsin absorbs light, the protein changes shape and pushes protons out of the cell. Once there are more protons outside than inside, it creates a gradient that causes the protons to flow back in. When this happens, *H. salinarum* makes ATP—the molecule it uses for energy.

LambdaVision leveraged this proton-pumping mechanism in its artificial retinas. When light hits the artificial retina, the bacteriorhodopsin creates a proton gradient, and the charged particles stimulate retinal neurons connected to the optic nerve, restoring vision.

Space-based factories manufacturing products for Earth may sound like science fiction, but research leveraging the International Space Station (ISS) National Laboratory is demonstrating that it could soon become a reality. Over the past 10 years, LambdaVision has conducted nine ISS investigations to develop and optimize a system to produce artificial retinas in orbit.

"Every launch, every opportunity to advance our artificial retinas on the ISS has been incredible for gaining a greater understanding of what's possible in low Earth orbit," said Jordan Greco, chief scientific officer at LambdaVision. "And to be at the forefront of in-space production as one of the first to potentially have a product manufactured in microgravity is really exciting."

Replacing Rods and Cones

The retina is a light-sensitive tissue in the back of the eye that converts light into signals the brain interprets as images. Photoreceptor cells called rods and cones contain light-activated proteins—much like bacteriorhodopsin—that turn the light into electrical signals. These signals are transmitted through a neural network to the optic nerve, which leads to the brain's visual cortex. If a person's photoreceptor cells become damaged, the system cannot function, leading to vision loss.

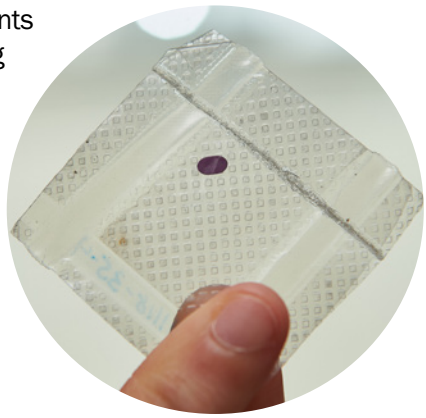
Age-related macular degeneration (AMD), a condition affecting nearly 20 million Americans over the age of 40, causes photoreceptor cells to break down. In these patients, central vision is lost, often rendering the faces of loved ones unrecognizable and making daily tasks like reading and driving nearly impossible.

LambdaVision CSO Jordan Greco, CEO Nicole Wagner, and Lead Engineer Daniel Sylva working in the company's lab in Woodbridge, Connecticut.

LambdaVision

A rare genetic disorder called retinitis pigmentosa also damages photoreceptor cells, but affects sight in the opposite way. Vision starts to fade from the outer edges inward, leading to tunnel vision and eventual blindness. This condition occurs in roughly one in 4,000 people, and vision loss can begin as early as age 10.

LambdaVision's goal is to one day provide a solution for patients with these devastating disorders that currently have no cure. The company's artificial retina, composed of multiple layers of bacteriorhodopsin, can be implanted in the eye to replace lost photoreceptor cells, Greco explained.



LambdaVision's protein-based artificial retina, the small purple dot, is about the size of a paper hole punch.

Peter Morenus/UConn Photo

"Our film aims to essentially function as an artificial photoreceptor cell layer that can absorb light and generate a signal that stimulates the retina's remaining neural circuitry, leading to functional vision for patients," he said. "It is designed to be placed in the back of the eye with a surgery that retinal surgeons are already familiar with."

In their lab on Earth, LambdaVision scientists developed a process to manufacture artificial retinas using automated dipping machines. The base layer is a scaffold that is dipped into a series of beakers, which alternate between bacteriorhodopsin, a polycation binder, and wash solutions.

But the solutions are subject to the effects of gravity, and just as sugar settles at the bottom of a teacup, sedimentation occurs in the beakers. Buoyancy-driven convection also creates turbulent flows that can cause uneven coating. These factors can lead to inconsistent layering.

"It's not such a big deal when you're dipping it 10 or 20 times, but when you do this 50 to 200 times, any imperfection at an earlier layer is going to be compounded," explained Nicole Wagner, LambdaVision CEO. "What that means for our current artificial retina is that in our terrestrially manufactured process, we have a tremendous amount of waste."

The team must carefully select the most uniform sections of the films and discard the rest. Not only is the process wasteful, it also limits scalability. By taking the process to a microgravity environment, sedimentation, buoyancy, and inconsistencies are significantly reduced.

"In space, we have very even coating and a much more uniform thin film, so it takes the guesswork out of finding the areas of the greatest homogeneity, and it's a lot less waste," Wagner said.

Microgravity Manufacturing

LambdaVision's artificial retinas could benefit greatly from microgravity, but to manufacture them in space, the company had to develop a whole new coating process.

"We needed to change the design entirely to support that environment," Greco said. "But also from a quality standpoint, we always knew we needed to transition to a closed-loop fluidic chamber approach because it's more appropriate for the regulations around manufacturing."

To do this, the startup worked with ISS National Lab Commercial Service Provider Space Tango. Together, they designed a small system that fits into Space Tango's CubeLab hardware.

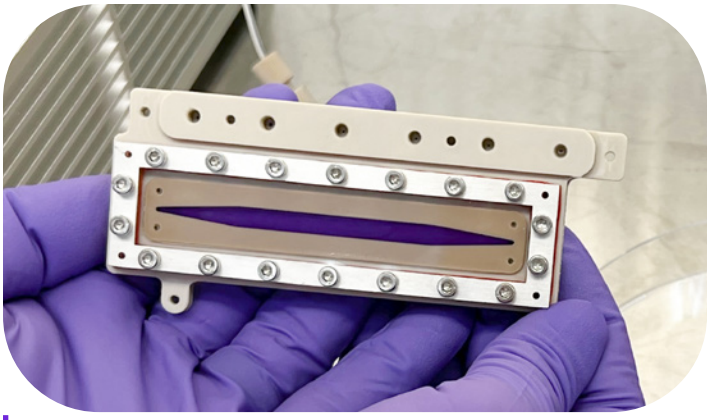
"It's amazing that we get to help LambdaVision and similar companies at this early stage of research and development," said Space Tango mechanical engineer Chess Necessary. "Hopefully, one day it will lead to actually manufacturing these products in space and sending them back to Earth."

The system contains solution-filled bags and a chamber with a scaffold. The solutions are pumped into the chamber in an alternating fashion. As each solution flows over the scaffold, it forms a uniform thin layer. This process is repeated to build the artificial retina layer by layer.

Once the CubeLab-based system is installed on the ISS, it is completely automated, requiring little to no astronaut intervention. "We're completely autonomous, which gives us a lot of flexibility in terms of the kind of platforms we can move to in the future," Wagner said. "We're also a low-mass payload, so we can create many artificial retinas using a very small footprint, which is valuable."

Deintegration of a CubeLab containing LambdaVision's artificial retinas produced in microgravity.

Space Tango



The thin film development chamber for in-space production of LambdaVision's artificial retinas.

Space Tango

However, the system isn't just a black box in space. Cameras and flow sensors monitor each layer as it forms.

"If something doesn't go quite right in the protocol, the system stops and sends us a message, and we can take actions to correct it from the ground," said Zach Jacobs, director of software engineering at Space Tango.

With each ISS investigation, the team continues to hone and optimize the production process. Every time the system flies, an exact replica remains at NASA's Kennedy Space Center to run in parallel as a ground-based control. When the system returns from the ISS, the thin films in both systems are removed at the same time so the only variable is gravity. LambdaVision can then run analyses on both sets to determine microgravity's effects.

The ability to utilize the ISS as a testbed has been critical, Jacobs said. "If you're going to manufacture at scale, you have to be able to flesh out your production process by going to space multiple times and iterating to figure out what works in microgravity and what doesn't."

Upward and Onward

Over the course of nine flights, some sponsored by the ISS National Lab and some by NASA, LambdaVision has made exceptional progress. The startup has produced four 50-layer films and six 200-layer films with a precision that is difficult to achieve on the ground. Analysis revealed that the space-produced films had better homogeneity, optical performance, and biocompatibility than those manufactured on Earth. The artificial retinas made in space were also more stable and reproducible, and the production process used less raw material.

Additionally, ISS testing allowed LambdaVision and Space Tango to validate the fluidics in their production system and improve automation, fault detection, uptime, and imaging capabilities. LambdaVision has also made significant strides toward establishing good manufacturing practices, standardizing procedures, and developing environmental monitoring and contamination mitigation protocols.

The startup's next ISS investigation is scheduled to launch later this year. The mission will focus on increasing the number of films produced to further explore production parameters. The team will continue advancing the hardware and analytical methods for improved quality.

"Through our flight projects on the ISS, we've taken a lot of the risk out of demonstrating the value of manufacturing in space," Wagner said. "We're now thinking about how we scale in orbit and what's next as we transition from the ISS to other platforms in the future."

LambdaVision recently reserved space on the Starlab commercial space station, currently in development, to continue space-based production of its artificial retinas after ISS retirement.

LambdaVision's ISS research has also allowed the startup to attract additional funding. So far, the company has leveraged capital and support from NASA and the ISS National Lab to raise around $23 million to further develop its technology. Wagner hopes to begin preclinical trials in late 2027 or early 2028 and then progress to the FDA review process.

The advances that LambdaVision and Space Tango have made also extend beyond the production of artificial retinas. "We are pioneering solutions in space that will pave the way for many future industries," Wagner said.

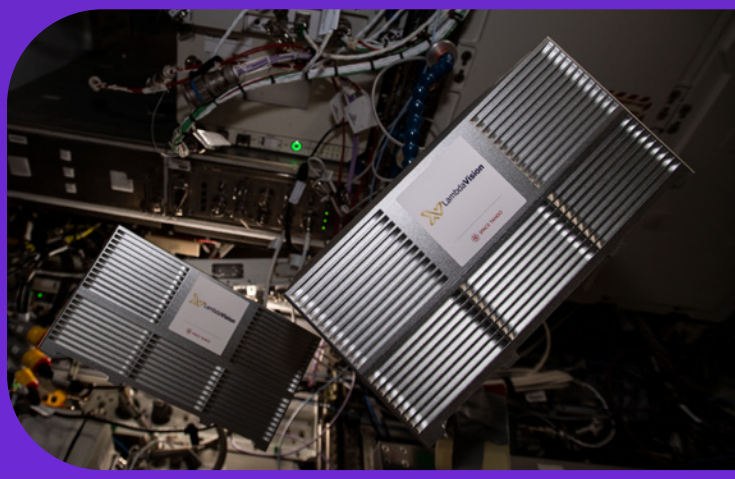
At the end of the day, though, Greco says it's really about helping people. "We're excited about what the next couple of years will bring as we advance our production methods, perform further experiments in microgravity, and collect more data on the efficacy of our artificial retina. But to be able to someday help restore vision in a person experiencing blindness—that would be an amazing outcome."

LambdaVision CSO Jordan Greco pipetting bacteriorhodopsin, the light-activated protein used in the company's artificial retinas.

LambdaVision

LambdaVision CEO Nicole Wagner purifying the protein bacteriorhodopsin for the production of artificial retinas.

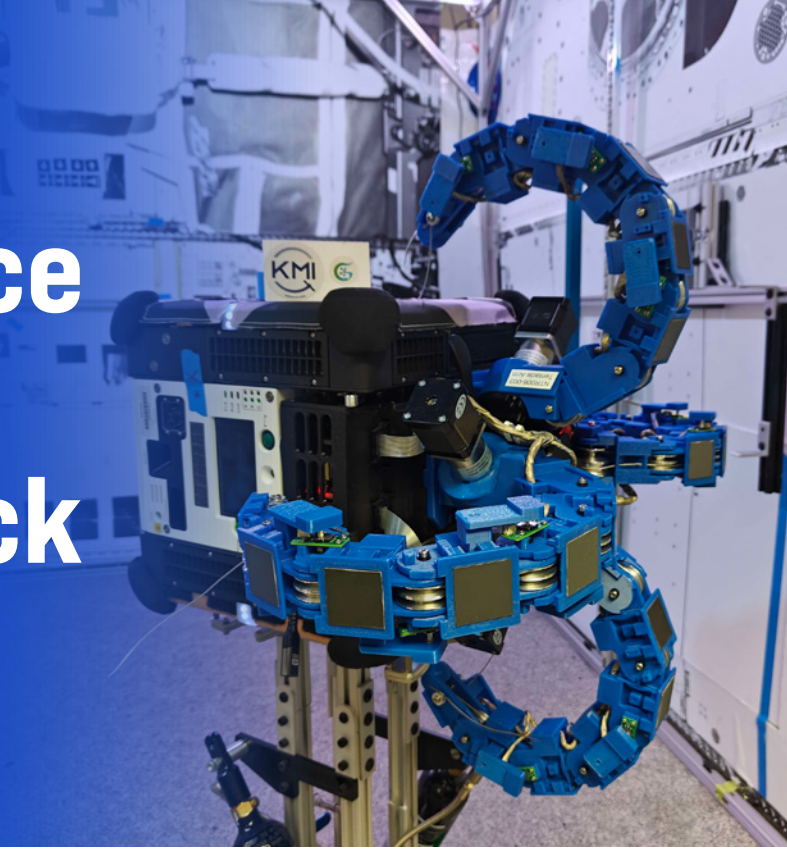
LambdaVision



LambdaVision's artificial retina production system in a CubeLab on the ISS.

NASA

Addressing the Problem of Space Debris With an Orbital Tow Truck



By Amelia Williamson Smith,
Managing Editor

It's mesmerizing to watch its arms unfurl gracefully like an octopus's tentacles. Micro-patterned pads on each arm allow it to adhere to surfaces, much like a gecko's feet stick to a windowpane. And most amazing of all, it could be the key to keeping Earth's orbit safe.

What is it? The REACCH capture system from startup Kall Morris Inc (KMI).

The REACCH (Responsive Engaging Arms for Captive Care and Handling) system can dock with an unprepared space object, latch on, and safely steer it to a new position or deorbit it, functioning as an orbital tow truck. This capability is especially important for addressing space debris, the millions of human-made objects in Earth's orbit that are no longer useful. The debris could be nonfunctional satellites, parts from launched rockets, or pieces from old spacecraft—all moving at speeds up to 10 times faster than a bullet.

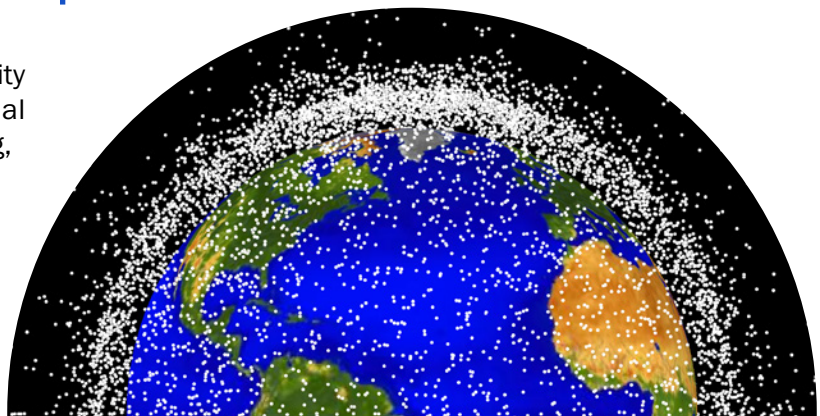
Space debris is a growing problem that could lead to a paralyzing gridlock. The more debris in orbit, the higher the likelihood that pieces of debris collide, leading to a lot more debris and an even higher likelihood of collisions. It could have a runaway effect that would clutter Earth's orbit so much that it would become impassable.

The impact would be significant. Not only would humanity be unable to operate spacecraft like the International Space Station (ISS), but satellites for weather forecasting, communications, GPS, and national security would be destroyed. In such a scenario, it could take years, or even decades, to clear. Addressing this issue now is critical, and KMI is up for the challenge.

"We looked at it as young professionals and thought: if this problem isn't solved, we won't have careers in aerospace because the whole industry will just disappear. Something has to be done," explained Adam Kall, KMI co-founder and chief strategy officer.

The REACCH system could provide a solution by removing debris from the path of operational satellites or maneuvering satellites out of the way to avoid collisions that create more debris. But to advance the system, the company needed a way to test it in space. Kall and his team created physics simulations to model how the system would work without gravity, but couldn't trust simulations alone. They needed results from a real-life microgravity demo.

> ***LEO, the region of space within 2,000 km of the Earth's surface, is the most concentrated area for orbital debris.***
>
> *NASA ODPO*



Launching a small satellite was an option, but it would be costly and allow only one test run. To really validate the system, they needed a space-based platform where they could do multiple runs, and the perfect test bed was orbiting overhead, available through the ISS National Laboratory®.

"I discovered the ISS when I was eight years old. I looked up at the sky and saw this bright dot flying over," Kall recalls. "I never dreamed I would have an experiment on it."

Clearing Space and Adding Value

KMI was founded in 2019 with a vision to clear space of the clutter. In addition to tackling the space debris problem, KMI's REACCH system would also extend the life of satellites, providing substantial value for satellite operators.

"Most of the time, a satellite's mission is not over because some clock runs out," Kall explained. "The mission is over because a computer no longer works, a radio no longer receives a signal, or some other mission-critical problem occurs."

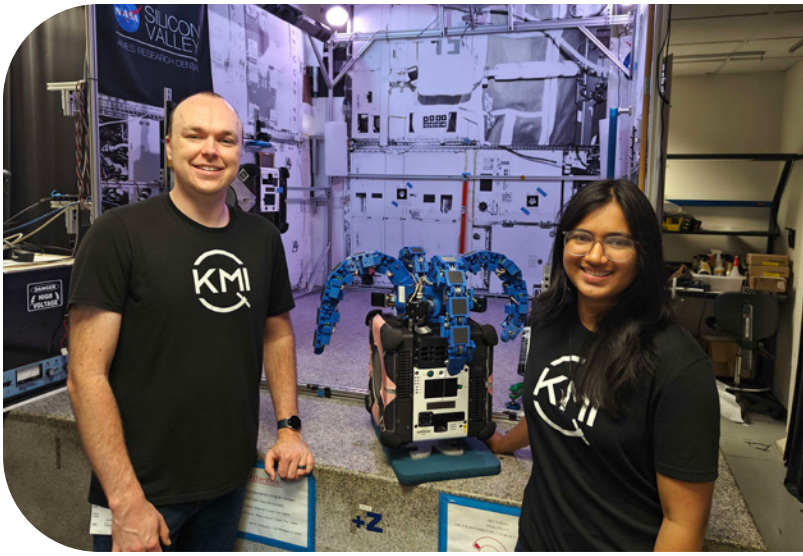
But before a critical problem happens, the satellite must be deorbited. This means operators must determine when the risk of failure is high enough to call it quits, often prematurely ending the satellite's life. But what if they didn't have to worry about that? What if they could keep satellites going longer?

What's that in the background?

REACCH started out as a University of Southern California (USC) experiment funded by the Defense Advanced Research Projects Agency (DARPA). But in 2020, the COVID-19 pandemic hit, and the experiment stalled out. Dave Barnhart, who was leading the project, was left with a prototype of the system on his shelf collecting dust.

Right about that same time, KMI was starting to design its own space debris capture system and envisioned it having tentacle-like arms that could latch onto unprepared objects. They were trying to learn all they could about designing technology for space and signed up for a webinar that Barnhart was hosting.

As they watched the webinar, they couldn't help but focus their attention on what was in the background. There, on the shelf behind Barnhart, they spotted exactly what they had been envisioning. "Thank goodness he didn't have a virtual background on," Kall said, still astounded by the serendipity. Through an agreement with USC, KMI was able to pick up where the project left off, making design changes to improve the technology.



KMI engineers Sam Cassidy and Preksha Madhva at NASA's Ames Research Center for REACCH preflight testing.

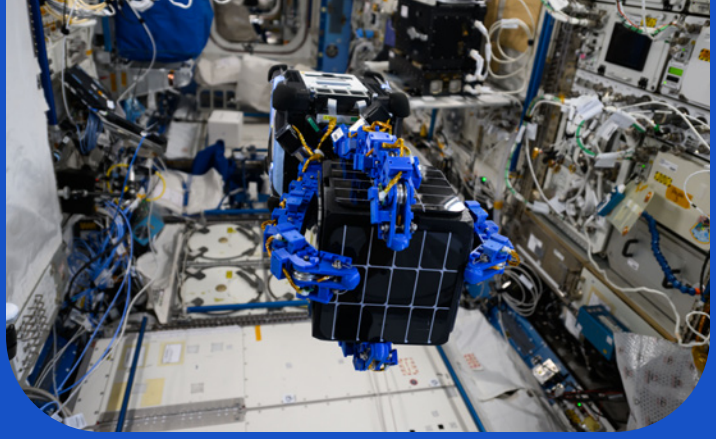
KMI

When a satellite finally loses its last drop of productivity, that's when REACCH could come in, Kall said. "By providing de-orbiting services, we are allowing satellite operators to gain more from each satellite they launch, we're limiting the number of launches that need to occur because satellites will last longer, and we're increasing revenue for everyone involved, all while keeping space safe."

So how does REACCH capture debris? The system consists of a small hub with eight articulated metal arms that mechanically unfurl around an object, conforming to its surface. As soon as the first arm segments near the hub detect pressure, the motion cascades down the arms like falling dominoes.

KMI team members preparing to conduct EMI (electromagnetic interference) testing at NASA's Johnson Space Center (left to right: Tom Ziegler, Zachery Champion, Corinne Moore, and Austin Morris).

KMI



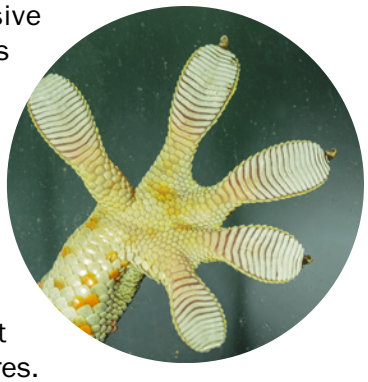
The REACCH system approaching and capturing a target object on the ISS.
NASA

"The complex mechanical engineering within the arms allows us to deploy them not as a bear hug, where the tips of the arm trace the outer path of the object, but instead as a kind of unrolling pattern very similar to what octopi do," Kall said. "It doesn't matter the geometry of what you're grabbing, the arms will follow the surface."

The arms also have a micro-patterned dry adhesive, a class of materials that imitate how gecko feet stick to things, explained Tom Ziegler, an electrical engineer at KMI. It may be surprising, but when two materials touch, most of their surface area is not making contact. Even for extremely smooth surfaces, the points where the surfaces actually touch are very minimal.

"When you zoom in at the atomic scale, it's likened to jamming one mountain range on top of another," Ziegler explained. "You'll get a couple points of localized contact where individual atoms happen to be really close to each other, but for the most part, there's a comparatively large gulf of space between them, even for precisely machined surfaces."

So how can geckos grip a wall without falling? Their feet contain a bunch of tiny, flexible fibers that more closely conform to surfaces. This increases the amount of surface area making contact, allowing for a stronger hold.



The micro-patterned adhesive on REACCH's arms contains tiny wedges that mimic the flexible fibers on geckos' feet. The adhesive is directional, gripping the surface when pressed and slid one way and releasing when moved the opposite way. No residue is left behind, so REACCH won't damage objects that it captures. The system's gecko-like grip is especially useful for capturing satellites or tumbling pieces of debris.

Importantly, REACCH doesn't have to wrap around an object and hold it—it just has to attach to the object and push it. This means it can relocate things much larger than itself. And with REACCH, objects do not need a docking adapter installed, allowing the system to capture almost anything.

It was beautiful engineering, Kall said, but the question was: how well would it work in space and on what types of objects?

Preparing for Anything

Space surfaces can vary a lot. They may be rough and jagged or smooth and slick. They might be hard and solid, or they may have some give. They could be multilayer insulation, smooth acrylic, crumpled aluminum, or covered in solar panels. Because you never know what you'll encounter in orbit, REACCH must be prepared for any scenario.

A Second Trip to Station

KMI will soon conduct a second investigation through the ISS National Lab—this time outside of the space station. The company aims to test its micro-patterned adhesive and the material's mechanisms in the harsh space environment to confirm that it retains its adhesion capabilities and grip strength over time. To do this, a sample of the adhesion material will be installed in the MISSE Flight Facility on the exterior of the ISS, where it will remain for several months before returning to Earth for analysis.

This upcoming project was selected through the ISS National Lab's Orbital Edge Accelerator program, which aims to connect innovative startups and global investment partners and integrate them into the growing space economy.

The KMI team wanted to run tests using many types of targets, but space on the ISS and launch vehicles is limited. So, they came up with a creative solution: a 28-centimeter cube with six sets of faceplates, each made of a different material that could be attached with Velcro and swapped.

"We wanted to study what the interaction looked like with different materials and how that changes the way we would approach an object we're capturing with that type of surface," said Austin Morris, KMI co-founder and chief technology officer.

For the spaceflight experiment, the team sent up a scaled-down version of REACHH with four arms instead of the full eight. Once REACCH arrived on station, it was attached to Astrobee, a small free-flying robot, as a stand-in for KMI's future carrier spacecraft. Because the ISS is a crewed laboratory, instead of getting just one test run, the team got 172.

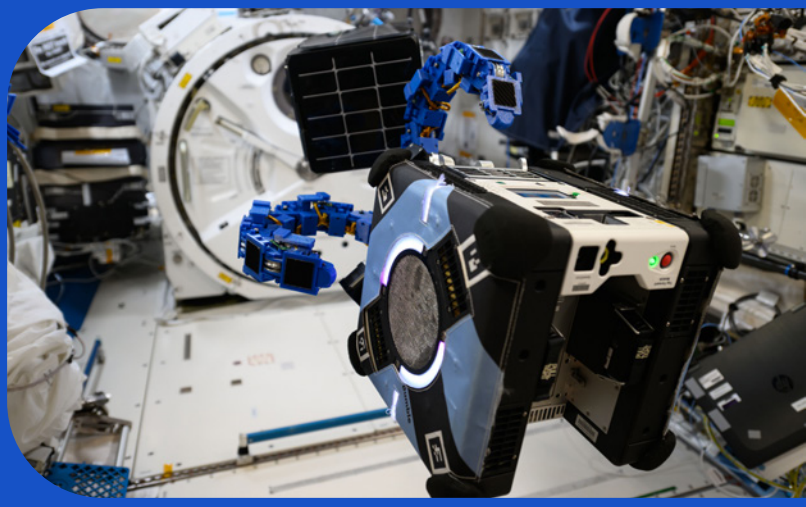
"On the ISS, we got multiple repetitions, the astronauts giving us ideas, making adjustments, changing materials," Kall explained. "That would have been 172 CubeSat launches, and we got it all done in 200 days through a single launch to the space station. It's hard to express the value because without it, we wouldn't have been able to do this."

In addition to swapping out materials, the crew tested several different scenarios: a stationary target, a tumbling target, and an approaching target. They also varied the approach angle and speed. While the astronauts ran tests on the ISS, KMI's engineers watched from the ground in near real time, allowing them to see results and quickly adjust the experiment as needed. All in all, there were six test sessions over five months.

While REACCH was on station, the KMI team kept an ISS tracker app on their phones. Every time the space station passed overhead, they would go outside—even in the middle of the day when the ISS wasn't visible. "We'd still go out because we knew our experiment and the astronauts running it were up there, and it was just this amazing moment," Kall recalls.

From Demo to Debris Capture

The team anxiously watched the experiments, waiting for data confirming that REACCH was successful. After the first few captures, the relief was palpable. KMI could confidently say that REACCH worked well in most scenarios. However, even more important were the failures.



The REACCH system, attached to a free-flying Astrobee robot, maneuvers through the ISS to capture a test object.

NASA

The KMI technical team set up to conduct REACCH testing on the ISS from their Michigan office (left to right: Tom Ziegler, Sam Cassidy, Preksha Madhva, Zachery Champion, Rose Schopfer, Adam Kall, Austin Morris).

KMI

REACCH's arms successfully capture and grip a target object during testing on the ISS.

NASA

"It performed very well in the majority of cases, which was outstanding for us to see, but more valuable are the ones where it didn't perform well because that highlights for us the areas we can further improve," Morris said.

The team found that material type did affect REACCH's capture performance. Surfaces with more texture or a little bit of give worked better than hard, slick surfaces, which REACCH had more difficulty securely grasping.

Using these results, KMI has been working on prototyping to improve REACCH's design. The team now has the data to confirm their simulation models match the real performance observed on the ISS. This means they can use the simulation to validate larger-scale plans and be confident they will work without any further spaceflight testing, which is immensely valuable, Morris said.

"If the ISS National Lab didn't exist, we would not have been able to do our experiment," Kall emphasized. "We would have had to launch our technology and hope that it worked, and we wouldn't have gained nearly as much valuable insight."

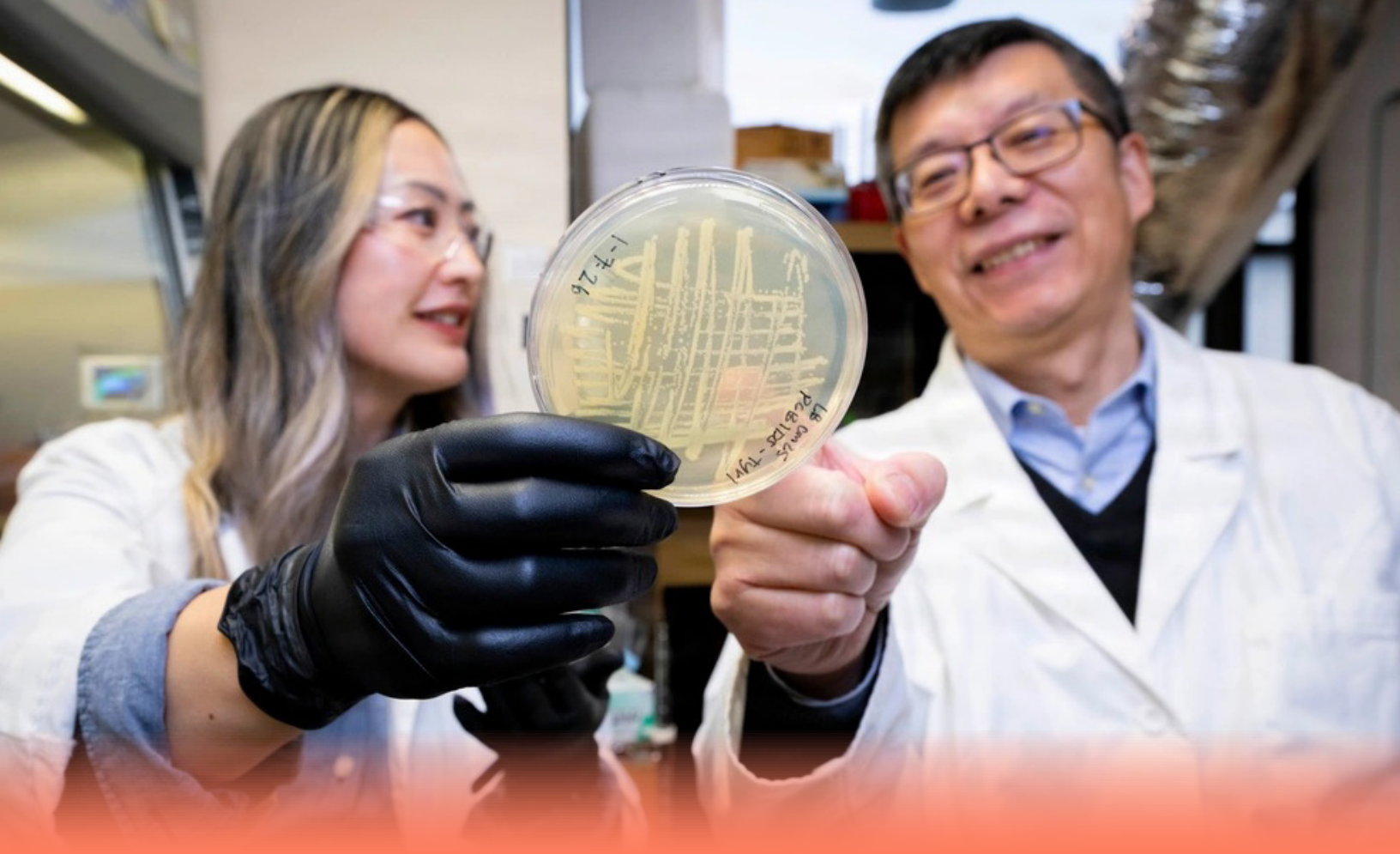
Once the team has fully refined the design and confirmed that REACCH will work for all materials and scenarios, it will be ready to go back to space. This time, though, will be the real deal: a mission to deorbit existing objects from space.

The team sees endless possibilities for REACCH. It could be used for spacecraft end-of-life services or to relocate satellites. It could also be used to shuttle spacecraft to and from a refueling hub or distribute supplies for an in-space manufacturing plant.

In the future, Kall hopes his son will have the chance to go outside on a dark night and see not just one bright dot but many space stations flying overhead. "The ISS is a beautiful laboratory and starting point for expansion into space," he said. "As the ISS reaches the end of its life, it's because we're ready to take that next step and grow into multiple space stations and endeavors."

But to achieve this future, one thing is clear: we need to declutter space, Ziegler said. "The ability to move stuff around needs to be figured out to unlock some of the exciting next steps in the orbital economy."

NASA astronaut Suni Williams, who supported most of KMI's testing on the ISS, poses with the REACCH system.
NASA



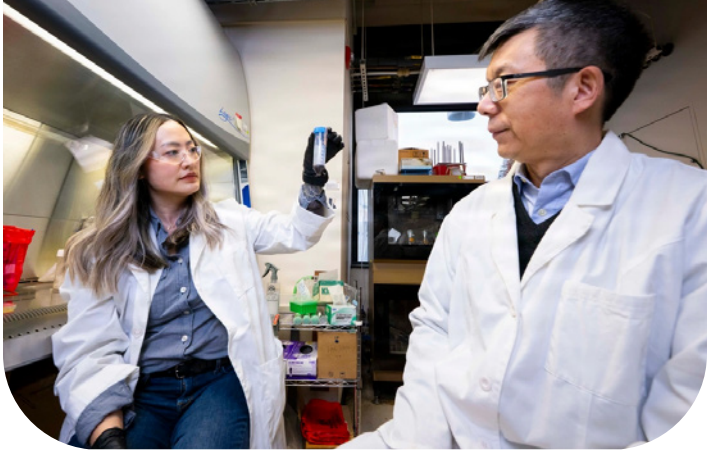
Why Growing Useful Bacteria in Space is Harder Than It Looks

By Stephenie Livingston, *Senior Staff Writer*

Place a living thing in a hostile environment and its usual biological cycles unravel, giving way to survival and change. A desert plant curls inward to save water. A deep-sea fish gains the ability to glow. In the ruins of Chornobyl, site of the 1986 nuclear disaster, blackened fungi creep across reactor walls, absorbing radiation that should kill them. And in space, microbes—among the smallest organisms ever sent beyond Earth—redirect their energy, dialing down routine cellular work and ramping up intricate survival responses to withstand microgravity.

Those extremes, whether radiation-soaked ruins or the weightless conditions of space, form the backdrop of biologist Zheng Wang's research. At the U.S. Naval Research Laboratory (NRL), he explores how life responds when pushed to its limits and whether the intricate stress responses that sustain organisms can also power new applications.

For years, scientists have imagined using microbes as tiny factories beyond Earth that grow food, medicines, and materials on demand for astronauts traveling far from home. One material has been especially intriguing: melanin, the pigment best known for coloring human skin, hair, and eyes. Beyond its role in appearance, melanin can also absorb



Tiffany Hennessa (left), U.S. Naval Research Laboratory (NRL) research biologist, and Zheng Wang, NRL research biologist, analyze a microbial sample in Washington, D.C.

U.S. Navy photo by Sarah Peterson

ionizing radiation, dissipate energy, neutralize reactive chemicals, and remain stable across extreme temperatures. In microbes, melanin functions as a protective barrier against environmental stress, with antioxidant activity, environmental remediation capacity, and thermal regulatory properties—features that may help organisms survive in space.

That protective power is what drew Wang's team to melanin as a candidate for space biomanufacturing. To produce it efficiently, the researchers turned to *Escherichia coli*, a widely used bacterium that is easy to reprogram.

Because *E. coli* does not make melanin on its own, Wang and his NRL team engineered it to convert a common amino acid into the dark pigment, which can absorb radiation and sustain microbial growth. "Our long-term goal is to make materials where they're needed, in space," he says, "rather than transporting everything from Earth."

But when those melanin-producing microbes reached the International Space Station (ISS), microgravity began interfering. The investigation, part of the Melanized Microbes for Multiple Uses in Space Project (MELSP) sponsored by the ISS National Laboratory®, launched in November 2023 to see whether engineered microbes could reliably produce protective materials in space. Wang and his team discussed their findings in a 2025 study published in *npj Microgravity*. They found that while the bacteria could still synthesize melanin in space, microgravity interfered with how cells absorbed nutrients, handled stress, and allocated metabolic resources, reducing output.

"The biggest takeaway is that if we want to manufacture materials using microbes in space, we have to solve the issue of how nutrients get into cells," said Wang, principal investigator of MELSP and a research biologist at NRL's Center for Bio/Molecular Science and Engineering. "Without that, the cells become stressed and stop functioning in the way we expect."

A Reality Check for Space Factories

Radiation is one of the most persistent hazards of long-duration spaceflight. By manufacturing melanin in space, microbes could one day help protect astronauts or equipment and reduce the need to launch heavy shielding from Earth. On the ground, producing melanin is relatively straightforward. Scientists use *E. coli* bacteria engineered to convert the amino acid tyrosine into melanin pigment. In flasks and fermenters on Earth, the bacteria darken predictably, turning petri dishes dark brown. But the space samples looked odd.

"In space, it looked more like coffee with milk," says Wang.

At first, the latte-like appearance of the samples made the team suspect a genetic failure. Perhaps the engineered bacteria weren't turning on the right genes in space. But further analyses showed the genetic machinery was still working, including tyrosinase, the enzyme that drives melanin production in the engineered *E. coli*.

"So the problem wasn't the enzyme," says Wang, "It was everything happening around the cells."

Chemical measurements pointed to the culprit. Large amounts of the melanin precursor, tyrosine, lingered unused in the growth medium after spaceflight. The cells couldn't move the material inside. "Without gravity," Wang explained, "nutrient transport just didn't work the same way."

On Earth, gravity helps fluids mix and circulate, constantly bringing nutrients into contact with cells. In microgravity, that sort of churning disappears. Cells that evolved under gravity's steady pull suddenly must function in a world without it. Under those stressful conditions, the bacteria "shifted their energy toward protecting themselves instead of making melanin," Wang said. Technically, they still could produce melanin, but they didn't have the energy.

To isolate the effects of microgravity on *E. coli*, the team collaborated with microbiologist Cheryl Nickerson and her laboratory at Arizona

Microbial samples for the experiment sit on display in Washington, D.C.

U.S. Navy photo by Sarah Peterson

State University to recreate aspects of the space-based microgravity environment on Earth using a Rotating Wall Vessel (RWV) bioreactor. This NASA-developed system cultures cells under low-fluid-shear conditions that mimic microgravity.

When Nickerson and her team ran experiments in the RWV using the same *E. coli* strain used on the ISS, they observed the same pattern. The bacteria produced less melanin, showed disrupted metabolism, and had lower cell survival.

She emphasized that "as with any model, the RWV is not perfect and does not completely reproduce the full extent of environmental factors associated with spaceflight."

That limitation, she added, is why "it is necessary to fly biological spaceflight experiments for a more complete understanding."

The takeaway, Wang says, is that engineering microbes for space will require more than genetic tweaks. Future efforts may need to focus on designing growth environments, such as bioreactors that actively move nutrients, manage stress, and compensate for the absence of gravity so bacteria can focus on production rather than just fighting for their lives.

Why Fungi May Fare Better

Alongside bacteria, the team also sent fungi to the space station. Fungi tend to survive where other organisms falter. They are more complex than bacteria, sturdier than many animal cells, and unusually comfortable in environments that would wipe out most life. If space biology is a stress test, fungi are the organisms you send when you want to see what still works after everything else breaks.

The team's fungal samples are still being analyzed, but the initial results are striking. All of the samples survived spaceflight, and, unlike the engineered bacteria, the fungi continued to produce a steady amount of melanin.

That durability is what draws researchers like Tiffany Hennessa, a research biologist in NRL's Laboratory for Molecular Interfaces and co-principal investigator of MELSP, to fungi in the first place. "Fungi are incredibly tough," she said. "Even after extreme freezing or drying, they're able to recover and grow."

What interests Hennessa most, though, is how fungi change when survival becomes the only priority. Under stress in space, cells sometimes activate biochemical pathways they rarely use on Earth. In doing so, they can produce molecules that never appear under gentler conditions.

Some of the fungal strains sent to the space station were deliberately impaired. A few were engineered to be unable to repair DNA damage. Others were stripped of melanin's usual protections. If those organisms persist anyway, Hennessa wants to know what compensates for it. Not exactly what keeps them alive, but what new chemistry that pressure forces them to invent.

"We're interested in whether space pushes organisms to produce molecules beyond melanin," she said. "We want to know whether the same stress responses that keep them alive can be redirected toward producing something useful to humanity."

Lessons From Hostile Worlds

Long before Wang sent microbes to the space station, he was thinking about places where life is not supposed to survive. One of them was Chornobyl.

In the years after the nuclear accident, scientists surveying the ruins found something unexpected. Communities of bacteria and fungi were thriving in radiation levels harmful to most life. Many of them shared a strange trait. They were dark, saturated with melanin. The same pigment that gives human skin its color appeared to act more like armor than sunscreen in an extreme situation. Even stranger, some organisms seemed to benefit from radiation exposure, with melanin playing a role that researchers have cautiously likened to a radiation-assisted form of metabolism.

Microbial growth spreads across the damp interior of an abandoned building in the Chornobyl exclusion zone.

Wendelin Jacober

That observation stayed with Wang. If melanin-producing microbes could survive in one of the most irradiated environments on Earth, he wondered what else they might endure, and what the pigment itself might be capable of doing.

The question followed him to another extreme: the icy skies above Antarctica. Wang's team sent fungal samples aloft on a high-altitude balloon, into thin air where ultraviolet radiation is so intense it can disintegrate DNA and kill unprotected microbes outright. They are currently analyzing data from this investigation to understand the roles of melanin and DNA repair in such a harsh environment.

By the time Wang turned his attention to space, the pattern was clear. But space would test Earth's biology against something a bit different. Microgravity does not burn or poison cells. It is a unique stressor that reprograms cellular and molecular mechanisms in unexpected ways, allowing cells to survive under spaceflight conditions.

The lesson, Wang says, is that space is a novel environment and does not always test biology in obvious ways. It exposes which survival strategies are fundamental on Earth and which may only work under its gravity. What the microbes onboard the space station ultimately demonstrated is that biological usefulness depends on context. Traits that serve organisms well under Earth's gravity do not always translate to microgravity, where cells recalibrate internal pathways to meet unfamiliar demands.

That may be the most useful result of all. The experiment served as a reminder that the cellular adaptations that prevail in space are often very different from what performs best for the same organism on Earth. For anyone envisioning biology as infrastructure beyond the planet, Wang says, that distinction matters. And if Earth grows more extreme, the organisms that already survive—or even thrive—under extremes are worth studying. They reveal how life keeps going when conditions turn hostile.

FORGING THE PATH

By Francisco Córdova, ISS National Lab COO

Francisco Córdova serves as Chief Operating Officer for the ISS National Laboratory®, the world's premier space-based research facility, where he leads a team that is shaping the future of research in space and is working with commercial partners to establish a robust and sustainable low Earth orbit economy.

Continuity in Low Earth Orbit: The Foundation of a Thriving Space Economy

Let's go back 15 years. It's 2011. The International Space Station (ISS) has just been completed. SpaceX is in its infancy, testing rockets with more ambition than certainty. Launch costs are extraordinarily high, satellites are expensive, and access to space is limited to a handful of government-led missions. The space shuttle has just been retired, and with it, a sense of routine human activity in orbit disappears.

At that moment, the low Earth orbit (LEO) research ecosystem is effectively near zero.

For decades, activity in space had been driven almost entirely by government priorities (primarily NASA), with a focus on exploration and the technologies required to sustain human life beyond Earth. Research was conducted *for space*, not *for Earth*. The ISS, while remarkable, risked becoming a symbol of achievement rather than a platform for continuous innovation.

Then something changed. We changed the paradigm.

We stopped treating the ISS as a rare, inaccessible asset and began to see it for what it could truly be: a national laboratory. A place not just for astronauts and government experiments, but for researchers, startups, and industries seeking answers to problems that cannot be solved on Earth alone.

We opened access. We equipped the space station with cutting-edge facilities. We enabled companies to send payloads, develop technologies, and build capabilities in microgravity. And most importantly, we shifted the *purpose* of research in orbit.

Instead of focusing solely on how to live in space, we began asking: how can space improve life on Earth? That shift has been transformative.

Today, more than 60% of the research conducted on the ISS is focused on delivering tangible benefits back to Earth. Researchers are leveraging the unique space environment to advance pharmaceuticals, materials science, biotechnology, and manufacturing processes in ways not possible on the ground.

But the evolution didn't stop there. We took it a step further, recognizing that scientific discovery alone is not enough. For a sustainable LEO economy, research must be paired with commercial viability. Companies must not only innovate in space but also survive and scale on Earth.

This has led to a critical insight: The companies that have most successfully leveraged microgravity are those built on strong terrestrial business models.

Space can accelerate discovery, but Earth remains the primary market. Companies that understand this (those that design solutions with clear commercial pathways) are far more likely to thrive in orbit and beyond.

And this is where continuity becomes essential. The progress we've made over the past decade did not happen overnight. It required sustained investment, consistent access, reliable launch capabilities, and a stable platform for research and development. The ISS has provided that continuity. It has allowed ideas to mature, companies to iterate, and an ecosystem to take root. To date, the ISS National Lab has

flown nearly 1,000 research payloads, becoming the single most prolific space research entity in the world.

But continuity is not just about infrastructure, it is about demand. As we approach the transition from the ISS to commercial LEO destinations (CLDs), we face a critical inflection point. It is not enough to build the next generation of platforms; we must ensure there is a robust, sustained pipeline of research and development ready to utilize them from day one.

CLDs should not come online and then scramble to find customers. They must launch into an environment where demand is already strong, where companies are already investing, and where research programs are already in motion. That continuity of demand is what will enable a seamless transition from a government-led model to a commercially driven ecosystem.

Maintaining that demand requires intentional action. We must continue to fund and support space-based R&D. We must keep the pipeline full, ensuring that startups, academic institutions, and industry players are actively developing experiments, technologies, and products destined for orbit.

And we must be pragmatic about how we bridge the gap. Because a gap in demand is just as dangerous as a gap in capability.

Engaging other existing platforms will play a critical role in this transition. Commercial "free flyers" can absorb some of the near-term demand, provide additional access points, and help ensure that momentum is not lost as the ISS eventually sunsets and CLDs come online.

Without sustained utilization, the business case for CLDs weakens. Investors hesitate. Operators struggle. And the fragile ecosystem we have spent more than a decade building risks contraction at precisely the moment it should be expanding.

Innovation does not thrive in uncertainty. Markets do not grow without stability. And ecosystems do not survive without continuity, of both capability and demand.

Low Earth orbit is no longer just a destination for exploration; it is an emerging economic domain. To fully realize its potential, we must treat it as such: with long-term vision, sustained commitment, and uninterrupted access.

Because the lessons of the past 15 years are clear: When you provide continuity in space, innovation follows. When you sustain demand, markets emerge. And when both are aligned, impact—both in orbit and on Earth—is inevitable.

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UPWARD

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