UPWARD

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CASIS™

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THE VIEW FROM THE CUPOLA

BY JEFFREY MANBER, CEO, NANORACKS

Jeffrey Manber is the Chief Executive Officer of NanoRacks

NanoRacks is proud to be featured in this issue of *Upward*, which explores the International Space Station (ISS) as a launch platform. Whether on station or above, we and other innovators are helping fuel the CubeSat revolution by offering rideshare alternatives and faster launch timetables. Thanks to new business models for launching rockets and to computing advances that have fueled smallsat development, the barriers to enter space have lowered, giving more people affordable access to space.

In December, NanoRacks had 14 satellites launch above the altitude of the ISS using an ISS Commercial Resupply Vehicle. We became the first company to launch above station in November 2016, and these latest missions validate our vision to repurpose in-space vehicles while demonstrating the capacity of the space station program.

Moreover, we are entering an exciting era in space defined by a new philosophy: Not everything we use in space must be made on Earth.

As part of NASA's Next Space Technologies for Exploration Partnerships (NextSTEP) Phase II program, NanoRacks recently concluded the Ixion Initiative study, a five-month commercial habitat feasibility analysis showing that we can repurpose the second-stage of an Atlas V in space—even unmanned—using robot technology already used on Mars today.

With our partner MDA, a Maxar Technologies company (formerly MacDonald, Dettwiler and Associates, Ltd.), we demonstrated four different habitat configurations, from very simple to much more complex with showers and toilets, using the upper stage of a rocket. This is tremendously exciting; with minimal launch and repurposing costs, we have shown the technical feasibility of a low Earth orbit deep space gateway.

With advances in artificial intelligence, robotics, software, and electronics, the materials and hardware used in space will increasingly be repurposed there, whether they're satellites, second stages of launch vehicles, or discarded hardware.

Targeting the 2024 timeframe, we can integrate two or three second stages to build a commercial platform capable of performing in-space manufacturing, conducting astronaut training, or serving as a testbed for deep space missions. We envision the ISS playing a critical role, with space station crew helping to re-outfit a new commercial module after it docks unmanned at the space station.

The NextSTEP feasibility study is one of many milestones NanoRacks is celebrating. Our progress building the world's first commercial airlock in space received an infusion of funding led by Space Angels, the leading source for capital for early-stage space ventures. As manufacturing ramps up, Space Angels' investment is key for maintaining the schedule and NanoRacks' increased level of quality assurance. We thank Space Angels for leading our bridge round—they have emerged as a much-needed international coalition of sophisticated investors focused on commercial space. We are on schedule to launch the airlock in late 2019 and anticipate signing our first commercial contracts shortly thereafter. We are also exploring a second, or Series B, funding round with Space Angels this year.

All these activities build on our vision of the future—an ecosystem where launches are plentiful, the in-space destination is king, and commercial habitats and space stations populate our solar system with customers from every sector of our society. We are thankful to NASA, the Center for the Advancement of Science in Space (CASIS), and the American taxpayer for their commitment to low Earth orbit. We are actively looking for ways to leverage that commitment to deliver more value to people on Earth, and collaboration is critical. I continue to be inspired by the maturing public-private partnerships evident every day as we journey closer to the prize: a self-sustaining and vibrant new space economy. ■

JUMPSTARTING
THE CUBESAT REVOLUTION
with Reliable Launch from the ISS

BY ANNE WAINSCOTT-SARGENT, *Contributing Author*

Does your small satellite need a ride to space? It is getting a lot easier thanks to NASA and commercial partners, who are establishing the ISS as a reliable launchpad for smallsats that perform a dizzying array of research, communications, and Earth-observation missions.

To date, more than 190 CubeSats (smallsats traditionally measuring 10 cm x 10 cm x 11 cm) have launched from the ISS into low Earth orbit (LEO). The majority of these have been deployed by NanoRacks, a commercial service provider that supports customers using the ISS U.S. National Laboratory as a platform for both smallsat launch and R&D on the interior and exterior of the ISS.

Technological advances fueling smallsat developments and new business models for launching rockets have lowered the barriers to entry to space, giving more people affordable access.

"Small satellites are helping democratize the use of space," said NanoRacks CEO Jeff Manber.

SIZE MATTERS

CubeSats are cheaper and lighter, so getting them into orbit is easier and less risky. And as the size and cost of increasingly capable electronics shrinks, smallsats are becoming just as capable as their larger predecessors for certain applications. They also do not require the cost of a dedicated launch vehicle needed by larger satellites.

Jenny Barna, director of launch at Spire Global, a satellite-powered data company, noted that the certainty and timing of launches is a barrier in the smallsat industry. Spire currently has 58 smallsats in orbit, more than a quarter of which were launched from the ISS or visiting vehicles through NanoRacks, and they plan to continue growing the size of their constellation in 2018. Barna recalled how there was a global shortage of rideshare opportunities in 2015 and 2016, especially for commercial satellites.

"We had raised sufficient funding by the summer of 2014 and were expected to have the initial constellation up by the end of 2015, but all launches were extremely delayed, leaving new businesses like ours struggling to move forward," Barna said. "Access through NanoRacks and the space station helped us get part of the way there and showed our investors and potential customers that our technology worked."

ACCESS TO LEO DRIVING NEW INNOVATIONS

By making deployment accessible to so many people, the ISS has helped create a new space industry, sparked commercial innovation, and enabled new research and scientific discoveries. Remote sensing data from smallsats is used in the oil and gas, mining, fishing, and other industries, and for atmospheric science and humanitarian applications such as disaster response and search-and-rescue missions. For example, Spire's satellites monitor weather and marine and air traffic. Moreover, telecommunication capabilities within satellites may enable technologies and services such as global Wi-Fi and advanced GPS.

Spire satellite deployment NASA

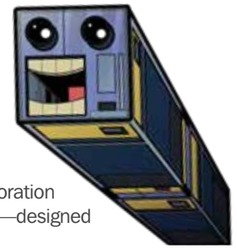
MORE ABOUT SPIRE

Spire tracks ships globally to monitor for illegal or underreported fishing and has a contract with the National Oceanic and Atmospheric Administration (NOAA) to provide temperature, pressure, and humidity readings for improved weather forecasts. Spire will also soon expand its tracking capabilities to the skies, helping airlines meet a new International Civil Aviation Organization mandate requiring certain international flights to report aircraft position every 15 minutes.

Spire's Nick Allain, director of brand development, said future capabilities enabled by smallsats will be "customer-driven—where you can take our data set and combine or fuse it with something else and come out with something really powerful." Allain said companies can already take pictures on demand anywhere on the planet. Using the vessel-tracking technology already available, they will be able to identify a vessel suspected of illegal fishing and tell a satellite with one of these advanced cameras onboard to take a picture at the coordinates of the ship. "In this case, you can catch people in the act rather than having to prove it circumstantially," he said.

The ISS National Lab's ability to accelerate R&D and technology demonstrations in this sector by serving as a reliable launchpad is a powerful catalyst for innovation. "We've reached this wonderful moment where space is playing a role helping us here on Earth," said Manber.

Dozens of ISS National Lab payloads over the last few years have signaled rapid growth in interest and innovation from the smallsat community. In 2016, NanoRacks completed the first-ever smallsat launch to reach an altitude higher than that of the ISS and repeated this feat in 2017. In 2017 they also launched the QB50 payload, a constellation of 28 CubeSats—developed through a European Union Commission collaboration with academic and research institutes from 23 countries—designed to study the upper reaches of the Earth's atmosphere.



"The ISS has become critical as a platform for research in microgravity and in the low Earth orbit space environment, as a proving ground for human space exploration, and now as a launch platform for small satellites," said Benjamin Malphrus, director of Morehead State's Space Science Center, which has also launched multiple NanoRacks-supported ISS National Lab payloads in recent years.

For example, the Cosmic X-Ray Background Nanosatellite launched in 2017 is a CubeSat designed and built by Morehead State that has the potential to give astrophysicists the most precise measurements ever made of the cosmic background X-ray radiation that occupies space between galaxies—putting together an accurate picture of the evolution of the early universe, which has implications for fundamental physics and beyond.

A pair of CubeSats being deployed from the NanoRacks CubeSat Deployer on the ISS

NanoRacks/NASA

Similarly, the Dependable Multiprocessor experiment (DM-7) launched in 2016 validated the design of a new payload processor for use in smallsats and other spacecraft. DM-7 is a miniature parallel processor that harnesses the processing power of commercial off-the-shelf technology to benefit science and may ultimately allow companies to do more processing on spacecraft and reduce requirements for raw data transmission to the ground. Moreover, with middleware from Honeywell, the DM-7 processor costs between $20,000 and $30,000, compared with current processors today that are in the $250,000 range.

Various related payloads addressing the need for advanced technologies within spacecraft include ISS National Lab projects from Hewlett Packard Enterprise, Business Integra Technology Solutions, Yosemite Space, and others, including a project from NovaWurks in 2017 pioneering a concept to assemble larger satellites from small independent components separately delivered to the ISS and then assembled in orbit by the astronaut crew.

A NASA mock-up of the NanoRacks Airlock Module successfully passed astronaut extravehicular activity training testing at Johnson Space Center's Neutral Buoyancy Lab in Houston, Texas.

NanoRacks

INCREASING CAPACITY AND FREQUENCY

Manber notes that the number of ISS users interested in smallsat deployment continues to grow and includes new space firms like Spire, research universities like Morehead State, and government agencies like the U.S. Department of Defense. This is consistent with trends above and below LEO, as small satellites for observing conditions on Earth are the fastest-growing segment of the $260.5 billion global satellite industry, according to an annual report issued by the Satellite Industry Association. Additionally, SpaceWorks' 2017 market assessment expects microsatellite launches to grow 10 percent annually over the next six years.

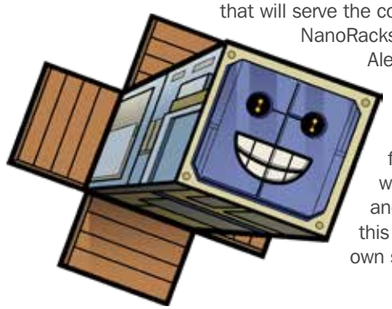
Recognizing the need for a greater capacity of CubeSat launches from the ISS and the capability to launch larger payloads, NanoRacks plans to deploy the first commercially owned airlock on the ISS in 2019. Currently, the Japan Aerospace Exploration Agency (JAXA) operates the only airlock on station for transferring payloads from the interior to the exterior of the ISS. The airlock is relatively small and opens only ten times a year, with five of those openings allocated to JAXA.

The new commercial NanoRacks Airlock Module will have five times more capacity than the JAXA-operated airlock and will accommodate larger satellites (up to 150 kilograms). It also will be able to deploy multiple smallsats at once, something not possible with the current airlock. Once the new airlock is installed, ISS crew members will be able to assemble payloads in orbit using parts sent to the ISS in cargo transfer bags.

NASA has already indicated that they have many uses for the new airlock, according to Manber. "NASA has hardware that is getting old on the outside of the space station that they can't bring in, and this way they can," Manber said. "We are also talking to other companies that are seeing great ways to use the airlock even as a staging point for commercial lunar missions."

THE FUTURE OF SMALLSATS IN LEO

In addition to serving current customer needs, the NanoRacks commercial airlock's modular design (the "Gateway to Space") sets the stage for the design of future satellite deployment platforms that will serve the commercial sector in a post-ISS era. NanoRacks is partnering with Boeing and Thales Alenia Space on manufacturing key parts of their airlock module. The outside of the airlock also offers access to power and Wi-Fi communications for externally mounted payloads, which is of interest to commercial and government customers. "For us, this is a stepping stone to having our own space station," Manber said.



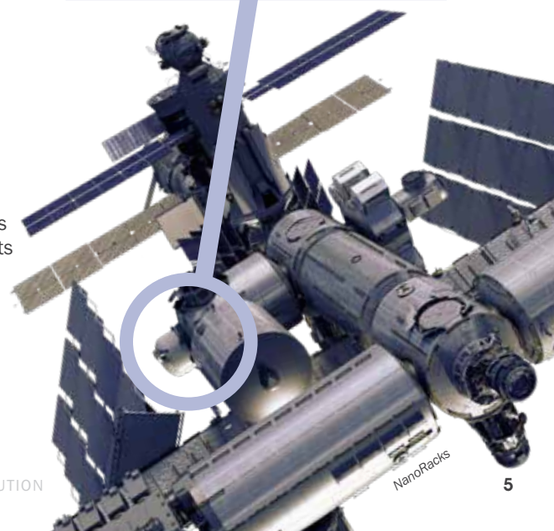
Manber predicts that the industry will continue to move toward slightly larger and more capable smallsats, with commercial customers, universities, and governments leveraging the lower cost and rapid development cycle from design to deployment that they offer compared to large monolithic spacecraft. "I think it will go beyond LEO, and we are going to begin to see smallsats used in deep space and on planetary missions," he said.

The ability of companies like NanoRacks and their advanced technologies to meet future demand for launch platform capabilities is critical. International partners have expressed strong interest in extending LEO platform operations beyond the current ISS funding end date of 2024. The most viable path forward for government or private sector parties is a next-generation, newly constructed space station. Even as questions about what comes after the ISS continue to be debated, one thing is clear: Smallsats are here to stay. ■

NanoRacks

WHAT IS AN AIRLOCK?

An airlock consists of a small chamber with two airtight doors in series that do not open simultaneously. It permits people and objects to pass between a pressure vessel and its surroundings while minimizing pressure change and atmosphere loss in the vessel.



NanoRacks

RESHAPING DRUG DELIVERY

MILLIONS OF CRYSTALS AT A TIME

BY AMELIA WILLIAMSON SMITH, *Staff Writer*

Many cancer therapies, such as Merck & Co.'s immunotherapy drug Keytruda®, are dilute solutions of large molecules called monoclonal antibodies in a saline solution that must be given intravenously (IV) through a slow infusion over the course of several hours in a doctor's office or hospital. However, if pharmaceutical companies like Merck discover a way to formulate these drugs as highly concentrated crystalline suspensions, the medicine may one day be given as a simple injection under the skin during a quick visit to a doctor's office.

A team of Merck researchers is utilizing the unique microgravity environment of the ISS National Lab as a first step in trying to achieve just this.

"The drug might provide tremendous benefit, but the route of administration isn't necessarily ideal," said Matthew Truppo, executive director and head of Chemical Biotechnologies and Global Structural Sciences at Merck. "If we could simplify the administration, it would be better for the patient and practitioner, and it would make the entire process a little easier to handle."

Merck's investigation, led by Principal Investigator Paul Reichert, associate principal scientist at Merck, launched on SpaceX CRS-10 in February 2017. The experiment sought to grow millions of highly ordered, uniform crystalline particles of the therapeutic monoclonal antibody Keytruda®. The team's research has applications aimed not only at improving drug formulation and delivery but also at improving the drug purification process. Additionally, results from this investigation could lead to improved drug stability and storage.

> *"Conducting experiments on the ISS National Lab gives us the opportunity to test unique preparations and make primary discoveries that we can then apply to drug development on the ground and onward to manufacturing," Reichert said. "It's a long process, but what we find in this investigation could be very important not only for the drug Keytruda® but also for therapeutic monoclonal antibodies in general."*

CONDUCTING A DIFFERENT KIND OF PROTEIN CRYSTAL GROWTH EXPERIMENT

Many protein crystallization experiments on the ISS seek to grow large, high-quality crystals (or crystal complexes of proteins bound to small molecules) for structural analysis aimed at structure-based drug design. However, Merck's investigation is quite different. Instead, Reichert and his team were aiming to grow a crystalline suspension of millions of tiny uniform crystals.

Monoclonal antibodies are not very soluble, which is why it is difficult to get highly concentrated formulations of drugs like Keytruda®. If it were possible to produce high-quality crystalline suspensions of therapeutic monoclonal antibodies, it would enable pharmaceutical companies such as Merck to change the formulation of these drugs from an IV to an injection, which would greatly improve patients' quality of life. If such drugs could be given as a quick injection at a doctor's visit, it would save time and reduce costs.

This investigation followed from experiments in the space shuttle era, in which Merck researchers crystallized another biologic drug, alpha interferon, and instead of getting a single large crystal, they got a crystalline suspension of small crystals that were very uniform in size. "We're applying what we learned from the space shuttle era to a new type of biologics, monoclonal antibodies," Reichert said.

Monoclonal antibodies make up the majority of therapeutic biologic drugs. However, many monoclonal antibodies are difficult to crystallize on Earth, which is why Merck turned to the ISS National Lab for crystallization. Minimizing gravity significantly reduces physical forces that are dominant on the ground, contributing to the production of more ordered, high-quality crystals that often provide higher-resolution structures.

WHAT IS KEYTRUDA®?

Keytruda® (pembrolizumab) is an immunotherapy drug approved by the U.S. Food and Drug Administration to treat melanoma, non-small cell lung cancer, head and neck cancer, Hodgkin lymphoma, bladder cancer, and tumors with MSI-H or dMMR.

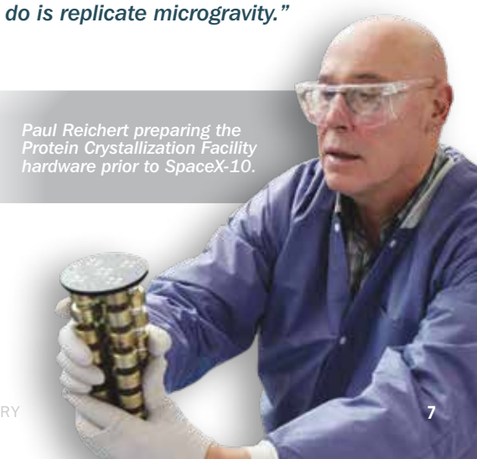
The drug helps the body's own immune system detect and destroy cancer cells.

Some cancer cells have a high expression of a protein called PD-1 (programmed death receptor-1), which prevents the immune system's T-cells from detecting the cancer cells. Keytruda® binds to PD-1 on the cancer cells so the T-cells can recognize the cancer cells as mutants and orchestrate the immune system to fight and destroy them.

WHAT ARE BIOLOGIC DRUGS?

Biologic drugs are unlike normal drugs in that they are not manufactured through a chemical process in a lab. Instead, biologics are a class of drugs made from large complex molecules derived from living organisms, such as microorganisms or human or animal cells.

> *"The ISS represents a truly unique laboratory platform where you can access conditions that you just can't access here on Earth," Truppo said. "There are many things you can replicate on Earth that are conditions you might find in space, but what you can't do is replicate microgravity."*



Paul Reichert preparing the Protein Crystallization Facility hardware prior to SpaceX-10.

USING MICROGRAVITY TO GROW HIGH-QUALITY CRYSTALS

To grow high-quality crystals, Reichert and his team took advantage of the decreased fluid motion in microgravity and improved conditions for the formation of ordered crystal lattices. These benefits of space-based crystallization are due to several physical forces being reduced in microgravity.

"When you're trying to get very high quality and very uniform crystals, it's important to have a really slow and orderly process by which those molecules come together to form a crystal," Truppo said. "The more you minimize movement within the solution and rely solely on the ability of the molecules to one by one come together and build the crystal lattice, the more likely you'll get a highly ordered, pure crystal."

By crystallizing therapeutic monoclonal antibodies on the ISS National Lab, Merck researchers hope to learn more about the key variables affecting crystal growth that could then be applied to pharmaceutical applications of interest back on Earth.

"To be able to take away a fundamental force for an extended period of time and see how that affects processes we are used to running on Earth could potentially lead to incredible insights into the fundamentals of how those processes work," Truppo said. "And then we can start thinking about how to exploit that information back on the ground and change the way we do things."

IMPROVING DRUG STORAGE AND PURIFICATION

The production of high-quality crystalline suspensions of monoclonal antibodies could allow for improvements in drug formulation (changing from an IV formulation to an injection), and it could also lead to improvements in drug storage and purification.

"Currently, most monoclonal antibody preparations have a limited shelf life and must be stored under refrigerated conditions in large, cumbersome bags," Reichert said. "It would be advantageous to develop a concentrated drug substance that is stable at room temperature that could be moved to formulation sites around the world in small containers."

ISS crew member Thomas Pesquet removing the Protein Crystallization Facility hardware from the incubator on the ISS.
NASA

Merck

HOW DO REDUCED PHYSICAL FORCES IMPROVE CRYSTALLIZATION?

In microgravity, several physical forces are minimized, which improves the conditions for ordered crystal growth.

⊕ ***Sedimentation:*** *On the ground, as crystals grow in a vial, gravity causes crystals to fall to the bottom and sediment. However, in microgravity, the crystals remain suspended in the solution. This results in less turbulence around the crystal as it is growing, which leads to higher-ordered crystals.*

⊕ ***Convection:*** *On Earth, temperature differences in a poorly mixed solution lead to a density difference, which gravity drives into two currents (the warmer lower-density fluid moves up, and the cooler higher-density fluid moves down). In microgravity, however, temperature differences do not lead to convection currents, resulting in less bulk fluid movement around the crystals and the growth of more uniform crystals. Additionally, the absence of convection currents results in a more uniform temperature gradient that can benefit crystal growth because precise temperature control is needed.*

⊕ ***Rate of molecular diffusion:*** *Microgravity reduces the rate at which molecules move in a solution. This allows the molecules to enter the crystal lattice more slowly and in a more organized, orderly way.*

Merck is currently trying to demonstrate that crystalline suspensions of monoclonal antibodies are stable in long-term storage at room temperature, which would be a tremendous advantage. It would eliminate the need for and costs of refrigerated transportation and would enable distribution of the drug in areas of the world that lack refrigeration. Additionally, lowering the costs of production and transport could ultimately lead to lower costs for patients.

Merck is also hoping to improve the purification process involved in manufacturing therapeutic monoclonal antibodies. Currently, monoclonal antibodies are produced using cell culture fermentation, followed by multiple steps to purify and isolate the active ingredient from the fermentation broth using a technique called chromatography. This purification process is effective, but it is also very time consuming and expensive. Merck is trying to see whether crystallization could be used to purify monoclonal antibodies directly from the fermentation broth, thus significantly reducing or eliminating the need for extensive chromatography and, in turn, lowering production costs.

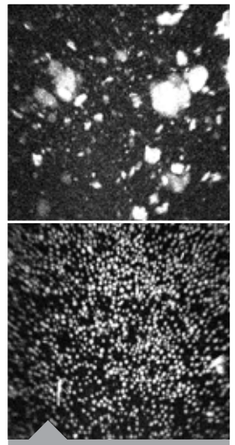
In their SpaceX-10 investigation, Reichert and his team sent to the ISS samples of the monoclonal antibody at different steps in the purification process, including some that were very crude extracts from the fermentation broth. The researchers wanted to see whether crystals would form out of the crude broth and what level of purity could be achieved.

"The question is—can we directly crystallize out of the fermentation broth?" Truppo said. "Can we produce crystals that potentially match the quality and purity of our entire production process, in which we do multiple chromatography steps until we get to a very pure antibody?"

ANALYZING SAMPLES AND APPLYING RESULTS

Reichert and his team are now in the process of analyzing their samples. The team first performed microscopic analyses to determine the particle size distribution of the flight samples versus ground samples in a blind study. Reichert said preliminary results are successful, and the differences between the ground and spaceflight samples are clear.

"The samples crystallized in microgravity contain highly ordered, uniform crystalline suspensions similar to the crystalline suspensions of alpha interferon from our previous space shuttle experiments," Reichert said. "This is exciting because it demonstrates the results are reproducible under these conditions."



UV imaging of a ground control sample (top) and spaceflight sample (bottom) from Merck's investigation, clearly showing the much more uniform size and distribution of crystals grown in microgravity.
Merck

The team is also using a battery of biophysical characterization methods to analyze the samples. If the space-grown crystals meet the desired property parameters, researchers can apply that information to experiments back on the ground. "It would give us a lead that tells us we should invest the extra time and resources to identify alternate process conditions on Earth that could be used to recreate the crystals we observed in space," Truppo said.

The team's findings could help researchers better understand the crystallization process of not only Keytruda® but also therapeutic monoclonal antibodies in general. Such knowledge could lead to important advances in monoclonal antibody drugs that could one day translate into significant improvements in quality of life for patients with cancer and autoimmune disorders.

WHAT HARDWARE WAS USED IN THE EXPERIMENT?

There are many hardware options for protein crystallization that support various methods of crystal growth. Merck researchers used two types of hardware in their investigation.

⊕ ***Protein Crystal Growth (PCG) Box:*** *The PCG box can hold five six-packs of samples. This hardware enables a process called vapor diffusion, which is usually used to grow crystals for structural analysis. The PCG box is easy for ISS crew members to operate—they simply use a wrench hooked on the side of the hand-held box to turn a valve that exposes the protein samples to solvent.*

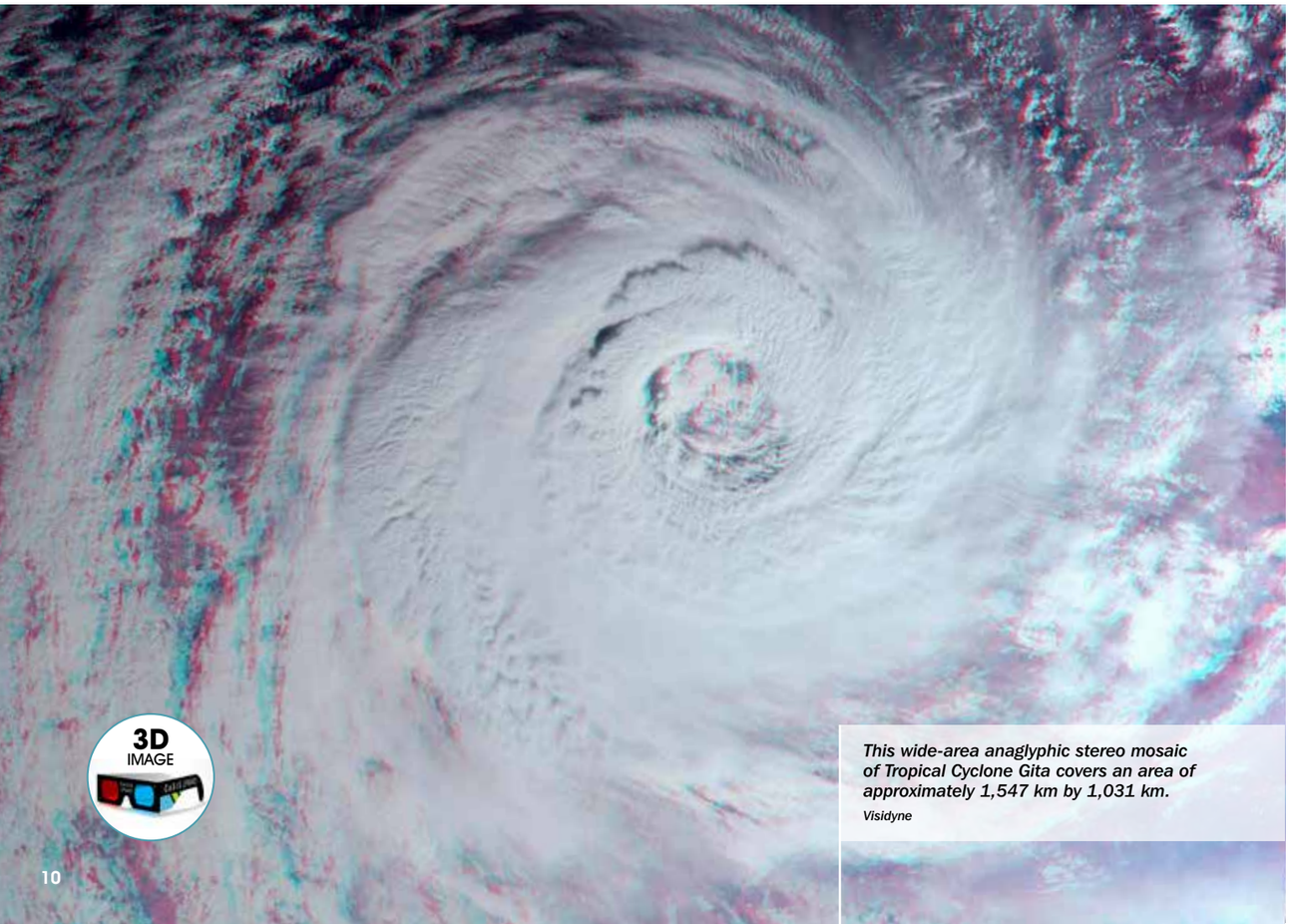
⊕ ***Protein Crystallization Facility:*** *This hardware consists of a module that holds up to five stacks of seven 1-mL bottles. The module can be kept at a very precise temperature, and researchers can vary the conditions within the module. To operate the hardware, ISS crew members place the module into an incubator and ramp up the temperature to induce crystallization.*

"This experiment really has boundless potential applications," Truppo said. "And I can't think of any better example of boundless research than conducting experiments in space onboard the ISS National Lab." ■

TROPICAL CYCLONE IN SIGHT

TRACKING HURRICANES & TYPHOONS **FROM SPACE**

BY JESSICA SCARFUTO, *Contributing Author*



3D IMAGE

This wide-area anaglyphic stereo mosaic of Tropical Cyclone Gita covers an area of approximately 1,547 km by 1,031 km.

Visidyne

Tropical cyclones, also known as hurricanes and typhoons, are the most destructive natural forces on Earth—causing an estimated 10,000 deaths and $26 billion in property damage worldwide each year. In recent decades, scientists have become much better at predicting where these storms might hit and how powerful they will be. However, as seen with Hurricane Katrina and many others, initial predictions can be off, leading to terrible consequences for the affected communities.

Improved measurements and predictions of tropical cyclone intensity and trajectory would help communities better prepare for such storms. Providing such measurements is the aim of an ISS National Lab project by Visidyne, Inc. called Cyclone Intensity Measurements from the ISS (CyMISS).

The CyMISS project is using the unique vantage point of low Earth orbit to measure the most intense area outside a tropical cyclone's eye, called the eyewall. Towering eyewall clouds are the strongest indicators of storm intensity and trajectory, and higher-accuracy measurements of the altitudes of these clouds could lead to better predictions of a storm's path and strength, said A.T. Stair, president of Visidyne and co-investigator for CyMISS

"Our objective is to obtain high-resolution measurements of several tropical cyclones that are Category 3 and higher," said Stair. "And we now have a very good collection of almost a dozen of them."

Building on the success of the CyMISS project, Visidyne has started a new commercial company called Trans World Analytics, Inc. (TWAI). The company will first use high-altitude, solar-powered vehicles, followed by microsatellites, to characterize tropical cyclone eyewall clouds and measure storm intensities, with the goal of achieving lifesaving advancements in global knowledge about these devastating storms.

HURRICANE TRACKING TODAY

The United States currently tracks tropical cyclones using a combination of satellite imagery, Doppler radar, and hurricane hunter aircraft. Weather monitoring satellites, which have been in use since the 1960s, are helpful in tracking storm development over the ocean and predicting surface tracks using sequences of images. Meteorologists use Doppler radar to detect rain, forecast the strength and location of rain bands, measure wind speed and direction, and predict rainfall totals. Although these technologies are helpful in collecting information about storms, the most accurate tropical cyclone information is gathered using reconnaissance aircraft called hurricane hunters.

Hurricane hunter reconnaissance aircraft

NOAA/United States Air Force

Hurricane hunter aircraft are operated by the U.S. Air Force out of Biloxi, Mississippi, and by the National Oceanic and Atmospheric Administration (NOAA) out of Tampa, Florida. These operations rely on flying specialized aircraft directly into tropical cyclones at low altitudes (between 500 and 10,000 ft) to gather critical information about the storms, such as their central pressure, eye location, wind speeds, and overall size. This method results in accurate forecasting, but it is also extremely expensive and potentially dangerous. Six hurricane hunter aircraft and their crews (a total of 53 lives) were lost between 1945, when flights began, and 1974.

Given the hefty price tag, no other country in the world sends hurricane hunters into tropical cyclones. Instead, nearby countries use forecasts based on U.S. hurricane hunter data, while more distant nations rely on warnings issued by the Joint Typhoon Warning Center in Pearl Harbor, Hawaii, which uses a technique called the Dvorak method. Developed in the 1970s, this method uses photographs from weather satellites to analyze the overall cloud pattern of a tropical cyclone and make predictions based on that pattern.

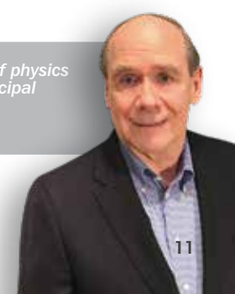
However, the Dvorak method is somewhat rudimentary, according to Paul C. Joss, professor of physics emeritus at the Massachusetts Institute of Technology (MIT) and principal investigator of CyMISS. The method's predictions are based on the assumption that storms with the same cloud patterns will have the same intensity and have no underpinnings in atmospheric physics.

"The Dvorak method is subject to very large errors," Joss said, "yet that's the best that most of the world can depend on."

Visidyne's commercial spin-off, TWAI, will focus on closing this gap. Joss said the primary goal is to increase coverage and forecast accuracy of tropical cyclone intensities and surface tracks for countries like India, Australia, Japan, and the Philippines, which do not have hurricane tracking systems like the one used in the U.S.

Paul C. Joss, professor of physics emeritus at MIT and principal investigator of CyMISS

Visidyne



IMAGES FROM THE ISS

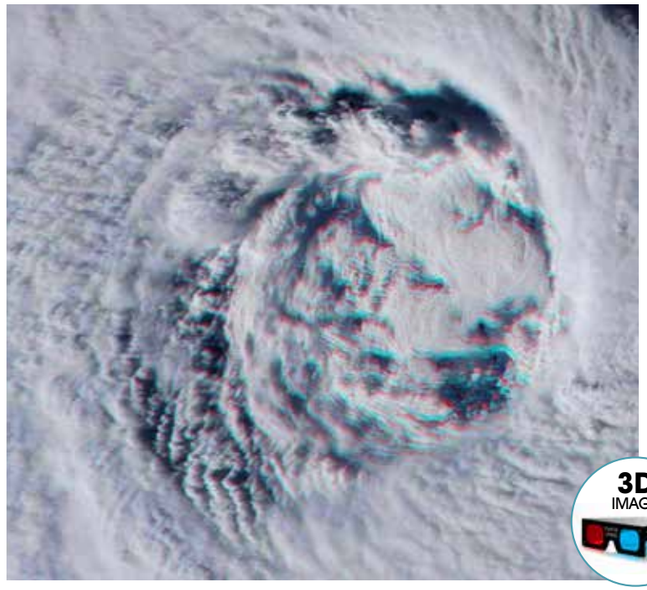
NASA

The origins of the CyMISS project trace back to the early 1990s as a joint effort between Russia and the U.S., to measure tropical cyclone intensities. Unfortunately, this project was discontinued in 2004 amidst a sharp decrease in cooperative projects with Russia. Visidyne began seeking alternative sources of funding, and after securing a grant from CASIS in 2013, began to study tropical cyclones using high-resolution photos taken by fixed cameras onboard the ISS.

The ISS National Lab provides a unique platform for monitoring tropical cyclones because its orbit covers virtually all the regions where tropical cyclones are found. This comprehensive coverage from low Earth orbit enables accurate storm measurements from the Pacific Rim and Australia to the Arabian Peninsula and east Africa, where U.S. hurricane hunters do not fly.

Visidyne can determine the relative altitude of eyewall clouds by applying a photographic technique known as parallax to sequences of high-resolution images taken from the ISS. Using this technique, two photographs of the same object are taken at slightly different angles and pieced together to measure depth. This allows CyMISS researchers to create three-dimensional images, which they can use to accurately measure the altitudes above sea level of the storm's cloud features.

CyMISS researchers use these and other data to measure the intensity of a tropical cyclone using a complex method that analyzes eyewall cloud altitudes and temperatures in the context of independently available sea-surface temperature data. By applying the laws of thermodynamics, researchers use this information to derive a formula that measures the storm's central sea-level pressure with higher accuracy than other remote-sensing techniques.



3D IMAGE

This anaglyphic stereo mosaic provides a close-up view of the large eye of Tropical Cyclone Gita and covers an area of approximately 300 km by 200 km.

Visidyne

HOW ARE CyMISS IMAGES TAKEN?

For the CyMISS project, ISS imagery for storm analysis is taken using a camera mounted in the Cupola (a Nikon D4S camera, and more recently a D5, fitted with a 50-mm fixed-length lens using automatic exposures). Visidyne communicates with ISS crew members via NASA's Johnson Space Center and notifies them of upcoming flyovers of tropical cyclones, the predicted times of overflights, and whether the ISS will pass to the left or right of the storm. Images are then taken at an interval of one per second during the flyover. Once the flyover is complete, the images are sent to NASA and Visidyne via real-time data downlink for analysis.

Central sea-level pressure is the most critical component in determining a tropical cyclone's strength, and accurate measurement of this quantity allows scientists to determine the peak sustained winds in a well-developed tropical cyclone to within 10 mph. Real-time updates of the central pressure of a tropical cyclone are also key to forecasting its future intensity changes and surface track. This technique is expected to be most accurate and reliable for the most powerful and dangerous storms, with intensities of Category 3 or higher.

ON THE HORIZON

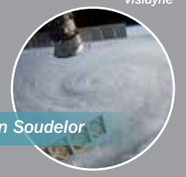
TWAI aims to build on the success of the CyMISS project and further develop techniques for accurately monitoring and predicting the intensities and tracks of tropical cyclones on a global scale. The goals are to use remote sensing methods that will provide cost-effective worldwide coverage of tropical cyclone intensities with accuracies comparable to those attained with hurricane hunter aircraft for the U.S. and adjacent countries and to supplement the data gathered by hurricane hunters for improved forecasting of storms that impact the U.S. To do this, TWAI hopes to deploy a small constellation of microsatellites in low Earth orbit.

Color mosaic of Hurricane Irma created using a long sequence of images acquired from the ISS on September 10, 2017, just as the eye of the storm was hitting the Florida Keys.

Visidyne

Hurricane Harvey

Visidyne



Typhoon Soudelor

WHAT IS A TROPICAL CYCLONE AND WHEN IS IT CALLED A HURRICANE OR TYPHOON?

A tropical cyclone is a large-scale low-pressure system at least 1,000 km across that 1) develops over tropical or sub-tropical waters; 2) does not develop as the result of a weather front, a boundary between two air masses with different temperatures; 3) has very strong and organized convection, or thunderstorm activity; and 4) has a powerful surface wind circulation around a well-defined center, called the eye.

Tropical cyclones with sustained surface winds of 39 mph or higher are called tropical storms, whereas those with maximum sustained winds lower than 39 mph are tropical depressions. Tropical cyclones with winds reaching at least 74 mph are called different terms depending on their location. Storms in the central and northeastern Pacific Ocean, Atlantic Ocean, Caribbean Sea, and Gulf of Mexico are colloquially called hurricanes; storms in the northwestern Pacific Ocean are called typhoons; and storms in the southwestern Pacific and Indian Oceans are called tropical cyclones.

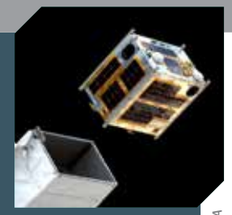
The implications of such an approach are exciting, given that most regions of the world cannot afford the use of hurricane hunter aircraft. However, given the high cost of deploying a constellation of microsatellites, TWAI first intends to use high-altitude vehicles called Solar Falcons™ to optimize the data acquisition techniques developed by CyMISS onboard the ISS and to use these techniques for improving tropical cyclone measurements and forecasts worldwide.

Designed to fly at 65,000 ft, the Solar Falcons™ resemble unmanned airships but are much lighter and more durable. They are solar powered, capable of reaching speeds up to around 80 mph, and can remain in flight for weeks at a time, following tropical cyclones throughout the storms' lifetimes. In addition to measuring cloud altitudes within a tropical cyclone's eyewall, the Solar Falcons™ will also be able to track the storms at night and measure cloud temperatures using infrared cameras—two limitations researchers were not able to address through CyMISS.

Once operational, the Solar Falcons™ could provide an unprecedented range of coverage, needing just five ground sites to obtain nearly global coverage of tropical cyclones: two for North America and three to cover the Western Pacific rim, Australia, and the Indian Ocean. "It's a way of getting started at a much lower price point," said Joss.

Although the Solar Falcons™ will not be able to provide continuous worldwide coverage of all tropical cyclones like microsatellites, this intermediate step will enable better measurements of storm intensity and improved predictions of landfall location and storm strength at the time of landfall. A Solar Falcon™ will also be able to hover in place over the landfall site, allowing scientists to better determine the nature and extent of damage following a storm. If all goes as planned, TWAI hopes to launch its first Solar Falcon™ by the end of 2019.

WHY MICROSATELLITES?



European Space Agency/NASA

Although deploying microsatellites is expensive, TWAI believes the satellites will become cost-effective over time. The expected lifetime of such satellites is at least 10 to 20 years, during which time the satellites would continually collect data. Moreover, the microsatellites would be able to measure a storm's intensity about once every 90 minutes. Hurricane hunter aircraft, by comparison, cost tens of millions of dollars per year to operate and are generally sent into a storm no more than about once every six hours.

"The CyMISS project is an important first step toward closing the gap in accurate and reliable global forecasting of tropical cyclones," Joss said. "Higher-accuracy predictions could potentially save countless lives and help to significantly reduce the property damage resulting from these devastating storms." ■

Demand for Small Satellites Launches Commercial Innovation

BY ANNE WAINSCOTT-SARGENT, *Contributing Author*

CubeSats, small cube-shaped satellites composed of units that measure 10 cm on each side and weigh less than 1.4 kg, are a cost-effective way to conduct research in space. CubeSats may be launched as secondary payloads, also known as rideshares, on an orbital launch vehicle or deployed directly into low Earth orbit (LEO) from the ISS. To date, close to 200 CubeSats have been launched from the ISS, most of these using a deployer built and operated by commercial services provider NanoRacks (see *Jumpstarting the CubeSat Revolution with Reliable Launch from the ISS* on page 2). As demand for nanosatellites (1–10 kg) grows and new applications emerge, NanoRacks and others are finding new pathways to meet increasing market demand.

In 2019, NanoRacks plans to begin operation of the first commercially owned airlock on the ISS—a module used to transfer payloads between the interior and exterior of the space station. The current airlock NanoRacks uses for CubeSat deployment is operated by the Japan Aerospace Exploration Agency and only opens a few times a year. The new commercial airlock will increase capabilities and opportunities for CubeSat launch from the ISS.

In addition to the NanoRacks facilities, two other companies plan to offer small satellite launch services in LEO from the ISS or from commercial cargo carriers visiting the ISS. Both LaMont Aerospace in Houston and Seattle-based company bSpace will launch small satellites from visiting vehicles or new platforms attached to the exterior of the ISS. For launch from the ISS, the station's robotic arm will transfer payloads from the visiting vehicle into one of the ExPRESS Logistics Carriers (an unpressurized payload platform attached to the ISS), where the satellites can be launched on demand independent of airlock cycles.

Craig Walton, a veteran of NASA's Johnson Space Center and now president and CEO of LaMont Aerospace, said his company aims to address the issue of satellite customers waiting too long for rideshares. A key difference in his company's business model is that it can support the launch of larger microsatellites (100–400 kg), as well as standard CubeSats (1–100 kg).

Computer-aided design image of the RM3S Deployer, designed with the purpose of deploying nanosatellites and microsatellites from the ISS
LaMont Aerospace

LaMont has also partnered with industry players to integrate propulsion systems into these nanosatellites and larger microsatellites, giving customers the ability to boost their satellites into higher orbits for longer operational life. "Now instead of your satellite dying in 12 months, you can boost it to realize a five- to seven-year lifecycle," Walton explained.

David Burcham, bSpace co-founder and CEO, said his company is scheduled to have the first deployment of its ARQ modular launch system in 2020. The size of a motorcycle, ARQ will be able to rapidly deploy up to 200 small satellites per flight. Burcham emphasized that by not depending on either airlock cycles or crew time, bSpace will be able to offer customers minimal in-orbit wait times and hopes to support satellites with propulsion systems.

"Once we are flying, our goal is to partner with companies on station to extend their reach to customers," Burcham said. "The future of the ISS and coming commercial stations is privatization, and we hope to be at the forefront." ■

SPOT LIGHT

CASIS in the Classroom

BY JULIA SABLE, *Staff Writer*

During ISS Expeditions 53–56, NASA is dedicating a higher-than-usual proportion of crew member time to educational activities. Former teachers are even a part of the ISS crew during what NASA has termed the "Year of Education on Station." Teacher-astronauts like Joe Acaba and Ricky Arnold (who arrived at the ISS this month) are not only recording videos and talking with students through live downlinks but also devoting substantial time to education-related science experiments.

Students record measurements of tomato plants grown from space-flown seeds as part of the Tomatosphere program
Tomatosphere

NASA Astronaut Joe Acaba reads from a children's book as part of the Story Time From Space program
NASA

The increased availability of crew members for educational activities is a boon for the Space Station Explorers Consortium, a growing community of CASIS partner organizations. For example, Amateur Radio on the International Space Station, which connects ISS crew members with children all over the world, is maintaining an impressive schedule of two or more amateur radio contacts per week—all operated by volunteers. Moreover, perennial programs such as Tomatosphere, Sally Ride EarthKAM, Zero Robotics, and Genes in Space are enjoying continued popularity, registering many new participants on top of the regulars that participate year after year.

This summer, the Student Spaceflight Experiments Program, which is celebrating its ninth year of partnership with NanoRacks, will launch 34 new student-designed experiments to the ISS on SpaceX CRS-15. For younger students, established program Story Time From Space is adding a new component called Science Time From Space, in which new crew member videos and activity guides will feature science, technology, engineering, and math curriculum related to concepts in the children's books traditionally read by crew members from the Cupola.

Moreover, new Space Station Explorers programs are also benefitting from the increased crew member availability, using innovative approaches to make students' engagement with the ISS more direct, authentic, and affordable. In Magnitude.io's ExoLab program, for example, a crew member activates a plant investigation in an ExoLab flight unit on the ISS, and middle school students run parallel experiments in their lower-cost classroom ExoLabs. Another program, Quest for Space, has developed flight and classroom versions of an automated, multipurpose experiment platform. Students program and test experiments in their classroom units and then upload their code to the flight unit onboard the ISS, which runs the programs and returns the resulting data. Both the ExoLab and Quest for Space programs are launching new hardware on SpaceX CRS-14 that will enable long-term operation with room to scale up as participation grows.

These are just a few of the new and innovative ways CASIS is bringing the ISS to educators and students—not only in classrooms but also in afterschool programs, museums, libraries, and other learning environments.

Learn more about Space Station Explorers programs at ***www.spacestationexplorers.org/educational-programs.*** ■

SPOT LIGHT

Capturing Imagination Through Design

BY AMY ELKAVICH, *Staff Writer*

Ever since NASA Astronaut Gordon Cooper developed the first U.S. manned mission patch for the Gemini 5 flight in 1965, patches have been used to highlight spaceflight missions. At first glance, a patch is simply a bit of colored thread woven together, but the patch also holds special meaning—it is a powerful symbol that conveys the spirit and excitement of a mission and the importance of mission objectives to human endeavors in space. Furthermore, patch design provides a unique opportunity to develop nontraditional partnerships that advance the visibility of ISS National Lab achievements and inspire the next generation to learn more about space-based research.

Each year, CASIS selects a creative and nontraditional partner to design an Advancing Research Knowledge (ARK) patch aimed at inspiring passion for ISS National Lab research. To design recent ARK patches, CASIS collaborated with creative minds from two entities that have already made rich contributions toward inspiring audiences—Marvel, known for their popular comic book characters and superhero movies, and Lucasfilm, known for the iconic Star Wars™ franchise. Comics and science fiction films often embrace scientific themes, making them a logical source for patch design inspiration.

In 2016, CASIS worked with Marvel and Marvel Custom Solutions Group to design an ARK patch featuring the well-known Rocket and Groot characters from the comic series and major motion picture, "Guardians of the Galaxy." The established Marvel brand helped CASIS engage public awareness of ISS research by designing a visually appealing patch that was revealed to the public at Comic-Con 2016 in San Diego. In addition to being featured on the patch, Marvel's Rocket and Groot were recently incorporated into a recent Marvel Entertainment–CASIS Guardians of the Galaxy Space Station Challenge, in which students proposed experiments that could be conducted onboard the ISS.

The challenge was designed to promote student interest in a broad range of research areas. Rocket, with his proclivity for engineering and innovation, welcomed materials sciences, engineering, and enabling technology development experiments on "Team Rocket." Experiment submissions related to fundamental biological and regenerative science concepts went to "Team Groot," with Groot representing plant biology and genetics. The two characters were instrumental in inspiring students to participate in the challenge, which received a tremendous response. Two winning student experiments will become official ISS National Lab investigations and launch to the ISS later this year.

Like the collaboration with Marvel, CASIS worked with Lucasfilm in 2017 to design an ARK patch featuring some of the most recognizable Star Wars droids: BB-8, K-2SO, and Chopper. The patch itself is in the shape of the famed Millennium Falcon spaceship, and the image on the patch includes both the ISS and the Death Star: two highly recognizable space stations—one real and one imagined—working together to disseminate the advantages of ISS research.

The Star Wars patch garnered substantial public and media attention, but the collaboration extended beyond the patch alone. Lucasfilm subsequently created a 10-episode web series on the science featured in the Star Wars universe, including an episode on spaceships featuring the ISS and highlighting research and facilities on station. The partnership with Lucasfilm provided a unique opportunity to unite the creative power and enthusiastic audience of the Star Wars franchise with the innovative research taking place on the ISS.

Characters and storylines in science fiction films and comics demonstrate the importance of heroism and teamwork in achieving lofty goals that often revolve around protecting life or the safety of a civilization. Similarly, the ISS National Lab and CASIS are intent on conducting research that benefits humanity, and to do so, it is crucial to inform the next generation of space explorers of the science and educational opportunities on the ISS.

Another year, another patch, and another visionary collaboration are on the horizon. The soon-to-be-released 2018 ARK mission patch will continue the tradition of attracting space explorers of all ages to the extraordinary science taking place on the ISS—stay tuned!

The 2017 CASIS ARK mission patch, produced in partnership with Lucasfilm
Lucasfilm

SPOT LIGHT

News & Notes FROM THE ISS NATIONAL LAB

CASIS ANNUAL REPORT

In January, CASIS released its 2017 Annual Report in both online and print formats. The report summarizes key achievements of the ISS National Lab community and highlights successes in maximizing utilization and science return, enabling commercial service expansion, continuing growth in new customer engagement and private sector utilization, and maturing powerful partnerships. The report also features links to in-depth information on research projects in the pipeline, current metrics, and an interactive map of the ISS National Lab Network. To explore the 2017 CASIS Annual Report, go to ar2017.iss-casis.org.

CASIS PUBLIC BOARD MEETING

The CASIS board of directors and executive management held a public board meeting in League City, Texas, in January to present the 2017 CASIS Annual Report, review progress toward providing access and opportunity onboard the ISS National Lab, and outline the organization's future goals. In conjunction with the meeting, CASIS hosted an ISS National Lab Implementation Partner and Commercial Service Providers Workshop for all companies currently conducting business on the ISS. For more information about the public board meeting, go to www.iss-casis.org/publicboardmeeting.

LAUNCHING TO THE ISS

Two recent launches—Orbital ATK CRS-8 in November and SpaceX CRS-13 in December—carried a variety of payloads to the ISS National Lab aimed at benefiting life on Earth. Key payloads included plant science research, technology demonstrations, life science studies, and student projects. These launches culminated a successful year in which more than 100 ISS National Lab-sponsored experiments were launched to the space station. Looking ahead, SpaceX-14 is anticipated to launch to the ISS no earlier than April 2, carrying 20 payloads ranging from the life and physical sciences to Earth observation, remote sensing, and education projects.

DESTINATION STATION

CASIS and the NASA Program Science Office traveled to Atlanta, Georgia, earlier this month and will head to Salt Lake City, Utah, in May as part of Destination Station outreach. Destination Station events provide an opportunity for the ISS team to meet with local companies to showcase research possible on the ISS National Lab and discuss how the innovative platform can accelerate discovery in ways not possible on the ground.

EDUCATION WORKSHOP

In February, CASIS hosted the 2018 Space Station Explorers Partner Workshop with 50 CASIS science, technology, engineering, and mathematics education partners. The annual workshop provides an opportunity to discuss strategies for building new education partnerships, developing cutting-edge learning activities, and supporting large-scale implementation of education programs.