National Aeronautics and Space Administration

tech transfer

# SmallSat Ascension

## Small Satellites on the Rise at Goddard

Inside: Goddard SmallSat Technologies

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# From the Chief

The SmallSat revolution is in full swing, and it's exciting to watch it happen in real time. Tiny satellites smaller than a microwave oven have only grown in popularity and functionality since they emerged as educational tools 20 years ago. At Goddard, we're pushing the platform to accomplish bigger and bolder science objectives as we reap the awards that these versatile spacecraft have to offer.

Technology development and innovation drive these accomplishments. The challenges that SmallSats bring – from limited power availability to tight budgets – force our engineers to travel down unexplored avenues in search of solutions. The technologies that arise from this process benefit NASA, but they also can benefit industry through technology transfer and commercialization.

Turn the page to find stories of collaboration and creativity. Learn more about Goddard's upcoming CubeSat missions, including petitSat, BurstCube, and GTOSat, scheduled to launch in the next few years. Take a look at the patented technologies invented at Goddard and available for licensing – you might find something that matches your interests.

Finally, get to know the people who develop and work with NASA technology every day. The Strategic Partnerships Office is your conduit to the Goddard community, and we hope you get in touch with us.

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About the cover: NASA's Goddard Space Flight Center has a host of cube satellite missions past and present. Known as CubeSats, these small satellites are filling spacecraft niches and spurring innovative technology development. Missions featured in the left-hand diamond, starting at the top and going clockwise: IceCube, Dellingr, STF-1, and CeREs. Missions featured in the right-hand diamond, starting at the top and going clockwise: GTOSat, BurstCube, petitSat, and HaloSat.

# Noteworthy News

Noteable updates from Goddard's Technology Transfer Office

### Goddard Technology Wins NASA Government Invention of the Year

The NASA Inventions and Contributions Board has selected “Miniaturized High-Speed Modulated X-Ray Source” (MXS), invented by Keith Gendreau, Zaven Arzoumanian, Steven Kenyon, and Nick Salvatore Spartana, as the 2019 NASA Government Invention of the Year. MXS played a role in NASA's Neutron star Interior Composition Explorer (NICER)/Station Explorer for X-ray Timing and Navigation Technology (SEXTANT) mission, an external attached payload on the International Space Station (ISS) that launched in 2017. As an X-ray source, MXS was used to calibrate the payload's X-ray detectors on the ground, providing both an energy reference and, uniquely, a timing reference. The device is smaller than prior state-of-the-art X-ray sources and can be manufactured at a low cost. Beyond deep space communication and astrophysics, MXS has applications in medical imaging and non-destructive testing.

Another Goddard technology received Honorable Mention for 2019 NASA Government Invention of the Year: “System and Method for Providing a Climate Data Analytic Services Application Programming Interface,” which is a component of MERRA Analytic Services. Invented by John Schnase, Daniel Duffy, and Glenn Tamkin, MERRA Analytic Services is the first NASA system to enable near real-time use of petabyte scale climate data sets. The system integrates high-performance and cloud computing capabilities with cluster storage, MapReduce analytics and a climate data services application program interface to move the work of generating commonly-used data analysis products to the server side. Doing so reduces the time and cost of creating these products by a factor of 1,000. MERRA Analytic Services addresses the biggest impediment to wider use of NASA satellite data and climate model outputs by offloading the burden from the end-user. This results in a transformational capacity to deliver climate analytics as a service.

### NASA’s *Spinoff* Publication Available Online

Printed regularly since 1976, NASA’s *Spinoff* publication tells the stories of NASA technologies that “spinoff” to become commercial products. The 2019 edition features profiles of technologies from each NASA center, including Goddard. This year’s collection includes the story of California-based company AOSense, Inc., which is working with Goddard through Small Business Innovation Research (SBIR) contracts to develop small, portable optical atomic clocks. A second feature describes another company connected to Goddard through an SBIR contract. The company, called Adcole Maryland Aerospace, designed a small star tracker suitable for SmallSat platforms. To read each article, please visit https://spinoff.nasa.gov/Spinoff2019/pdf/Spinoff2019.pdf.

Above: NASA's Government Invention of the year produces X-rays.
Below: *Spinoff* magazine describes successful technology transfer stories from NASA.




# SmallSat Ascension

Small satellites are having a moment. According to market research firm Northern Sky Research, the SmallSat market will yield $37 billion by 2027. A June 2019 podcast by The New Economist claims that “business opportunities for small satellite technology are infinite.”

At NASA’s Goddard Space Flight Center, scientists devise new and innovative uses for SmallSats each year, constantly raising the bar for SmallSat accomplishments. Goddard engineers and technicians are hard at work developing the platform to reach ever higher levels of advancement. The year 2018 marked the launch of two Goddard cube satellites (CubeSats, for short) – HaloSat in May, followed by STF-1 in December.

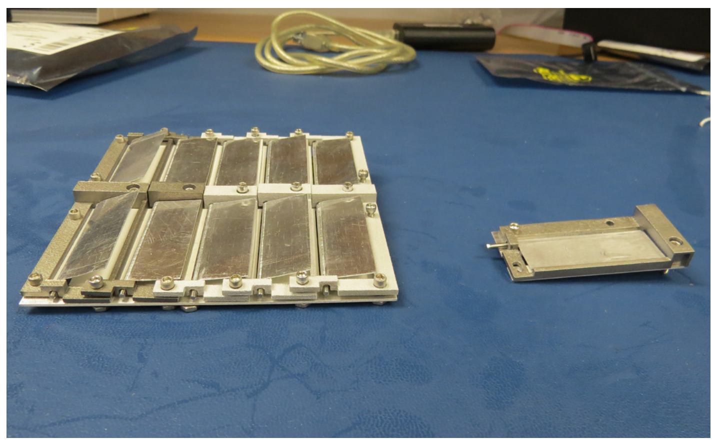
Both spacecraft broke new ground in their own ways. HaloSat is NASA’s first astrophysics-focused CubeSat, and STF-1 is testing an open source software called NASA Operational Simulator for Small Satellites, or NOS$^3$.

With more CubeSat missions in the works, Goddard harbors a wealth of technologies, capabilities, and expertise that can benefit the SmallSat community. Reach out to Goddard’s Technology Transfer Office today to take advantage of these opportunities, and learn more about Goddard’s SmallSat savvy by turning the page.

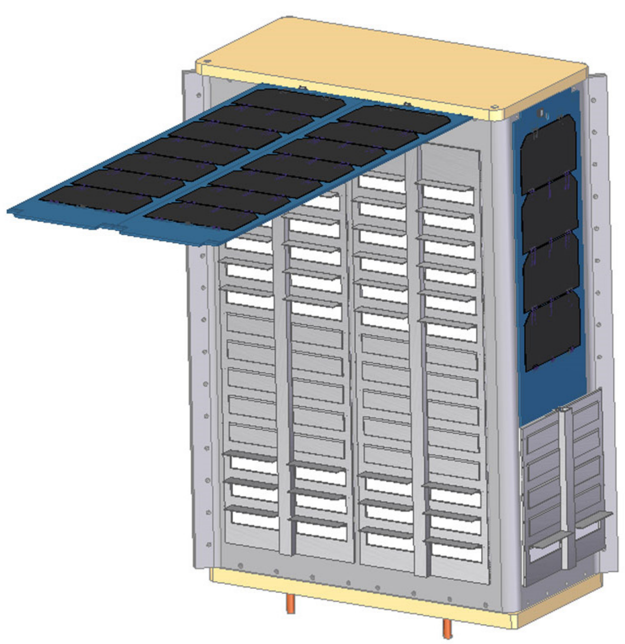
HaloSat is pictured above being deployed from the International Space Station.

# Technology Spotlight: Thermal Louvers

## Thermal louvers use passive cooling for temperature stability



Above: Thermal louvers have bimetallic springs that coil and uncoil with changes in temperature.
Below: This illustration shows CubeSat Form Factor Thermal Control Louvers on a 6U CubeSat.



Human space travel relies heavily on thermal control – without it, temperatures on board the International Space Station could get as hot as 250 degrees Fahrenheit or as cold as negative 250 degrees Fahrenheit. While these conditions pose dangers to astronauts, they also can cause malfunctions in equipment and instruments on unmanned missions.

CubeSats are no exception. Although they started out as learning tools for college students 20 years ago, CubeSat missions now feature advanced science experiments and technology demonstrations. With this shift in purpose, CubeSat developers have needed to adapt the platform.

Allison Evans, a mechanical engineer at NASA's Goddard Space Flight Center, created a miniaturized passive cooling technology designed specifically to address this problem in small satellites.

"A lot of instruments require thermal stability," Evans explains. "Some of them are sensitive to thermal changes if they've been calibrated at a certain temperature."

Other subsystems that generate large volumes of power include propulsion technologies and high-powered radios, both of which can increase the heat production of a small satellite.

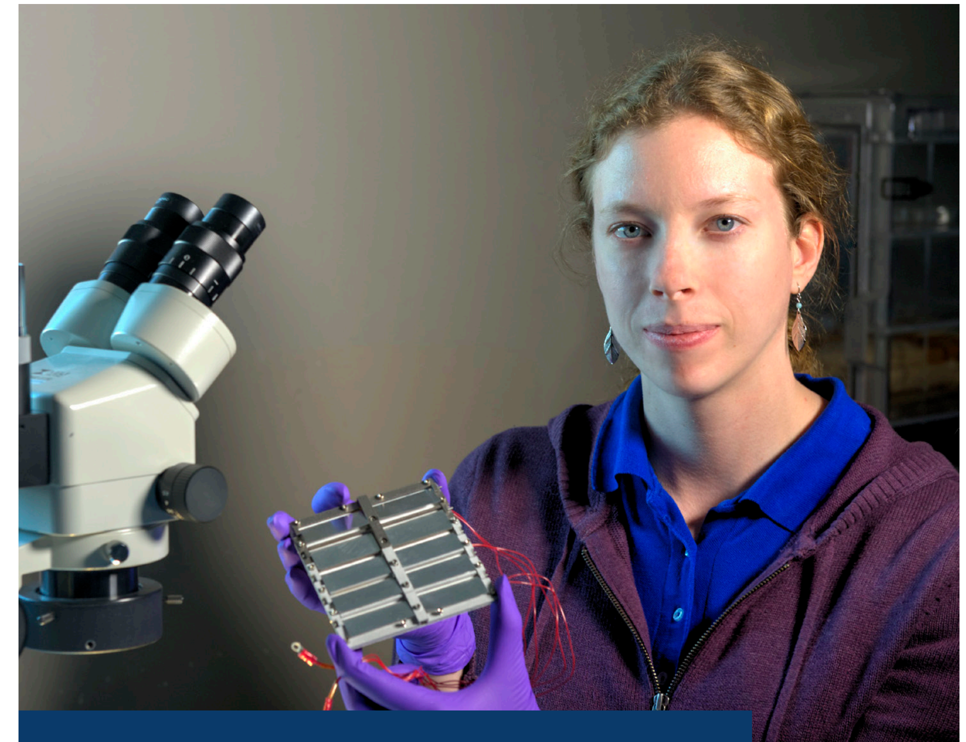
Since CubeSats are small and limited in power, they can't afford to lose huge amounts of energy on thermal control systems, requiring a solution that consumes little to no energy. When Evans started working at Goddard, she looked for technologies that use passive cooling to achieve thermal stability. In her search, she learned about larger missions that had used thermal louvers, devices consisting of blades that open and shut in response to temperature fluctuations.

"Thermal louvers seemed to work great, but they were way too big for a CubeSat mission," Evans says.

Evans received Goddard Internal Research and Development funding to miniaturize the technology, and her design for "CubeSat Form Factor Thermal Control Louvers" was patented in 2018.

The thermal louvers rely on bimetallic springs that coil and uncoil with changes in temperature. When heat increases inside the spacecraft, the springs uncoil. This moves rods





Allison Evans created a miniaturized passive cooling technology to address thermal stability in small satellites.

**Due to the modular nature of the technology, the thermal louvers can be adjusted based on the size of a CubeSat mission.**

attached to flaps, causing them to open. The open flaps cool the spacecraft by allowing the heat to dissipate. The flaps close when the temperature lowers and the bimetallic springs coil up again, conserving heat.

Dellingr, a Goddard CubeSat currently in orbit, is carrying thermal louvers as part of a technology demonstration. Though the mission isn't using the louvers directly to control temperature, Dellingr is providing an important platform for testing the technology.

"We've shown that the flap can open and close in space conditions," Evans explains. "Over the span of the entire mission, we'll be recording data to confirm it's operating as designed."

Due to the modular nature of the technology, the thermal louvers can be adjusted based on the size of a CubeSat mission. The louvers can accommodate a 1U size CubeSat or larger, easily scaling to the requirements of the mission.

"The only part you need to custom manufacture is the back plate," Evans says. "For the other parts you can order 50 at a time and they'll all fit together."

Evans will have a poster at the 33rd Annual Small Satellite Conference in Logan, Utah on August 3-8.

For more information on licensing this technology, please visit **https://technology.nasa.gov** and search the NASA Patent Portfolio for "louvers."

Alternatively, contact Goddard Technology Manager Eric McGill, **eric.s.mcgill@nasa.gov**.

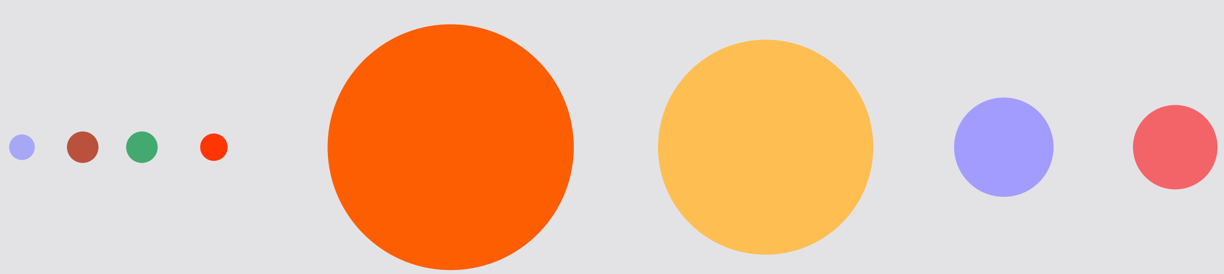
# The Future of SmallSats

"GOVERNMENT LABS CONTINUE TO PRODUCE STATE-OF-THE-ART TECHNOLOGIES"

"INDUSTRY IS WILLING TO THINK WAY OUTSIDE THE BOX AND TAKE RISKS"

"I SEE BOTH SIDES CONTINUING TO EVOLVE AND WORK TOGETHER"

## SMALLSAT EXPLORATION FROM



## OUR SOLAR SYSTEM TO DEEP SPACE



# Government, industry, and academic perspectives on small satellites

McGill cites the IceCube mission as a SmallSat success at Goddard.
Image Credit: NASA

For such a tiny platform, small satellites have made a big splash by challenging the way NASA has traditionally proposed Earth science missions. Large, billion-dollar spacecraft are giving way to faster, more flexible approaches as developers explore the possibilities that SmallSats and CubeSats can bring.

“Right now in Earth science, we’re pushing multiple mission concepts that are all SmallSats or constellations of SmallSats,” says Matthew McGill, Chief Technologist for the Earth Science Division at NASA’s Goddard Space Flight Center. “That’s a pretty big change from where we started several years ago, when we didn’t have any SmallSats or constellation concepts.”

This rapid shift is playing out within Goddard’s Earth science community, but it’s also taken root in industry and academia. With lower costs, faster timelines, and more accessible paths to launch, SmallSats are opening the door to a wider demographic of user groups.

According to McGill, who is also Goddard’s Deputy Director of the Earth Sciences Division, Goddard will need to break from tradition to adapt to this new playing field. While larger missions presumably will always exist, SmallSats can open up new ways to explore space and spur the development of innovative technology. Tech Transfer spoke with diverse sectors of the SmallSat community to explore the dynamics of this rapidly shifting industry.

## Generational Shifts

In addition to his leadership roles in the Earth Sciences Division at Goddard, McGill also works as a researcher in lidar remote sensing of the atmosphere, with an emphasis on clouds and aerosols. McGill points out that his perspective pertains specifically to Earth science at Goddard, which faces different challenges than the other divisions.

“The landscape at Goddard is evolving,” McGill says. “Meanwhile, industry is up and running with SmallSats and CubeSats for passive remote sensing. They have the venture capital, and they’re moving forward in pursuit of new applications.”

Companies have more flexibility than government agencies like NASA, McGill says. The funding structures in government move at a slower pace than that of industry, which can interfere with NASA’s ability to complete projects at a rapid clip. As companies join the SmallSat revolution, they can maneuver in ways that NASA cannot.

"THE LANDSCAPE AT GODDARD IS EVOLVING."

- MATTHEW MCGILL

When it comes to funding, this ability to be flexible can help industry in significant ways. NASA’s Earth Science Technology Office (ESTO) funds technologies through a competitive selection process, supporting “numerous Earth and space science missions as well as commercial applications.”

Industry's flexibility helps it to pursue breakthrough technologies, which ESTO seeks to fund, McGill says. "Industry is willing to think way outside the box and take risks," he adds. "Goddard is more risk-averse, and we tend to default to the safer position, taking a more incremental approach."

At the same time, McGill says, Goddard's Earth Sciences Division is undergoing a generational shift. Older modes of thought – building enormous and expensive missions with operational lifetimes that span decades – are giving way to newer ideas, which include more affordable, shorter-term projects that can be more easily replaced.

"The SmallSat phenomenon is driven largely by budgets," McGill explains. "The pure science world would always encourage you to go bigger and push the envelope, but we're in a world of smaller budgets. The message flowing from the top is very clear: innovate smaller."

With this shift in mindset, younger engineers and scientists have responded to the call.

"In Earth science, we have some new hires who talk about SmallSats and how to achieve objectives with them," McGill says. "They want to adapt to the changes and approach new ways of partnering with industry, academia, or other agencies to enable new science capabilities. I see that as the future."

## Advancing Technology

Robert Rea, a former civil servant and Air Force research and development officer who is now a consultant with Virginia-based Axcel Innovation, circulates a weekly newsletter highlighting the latest news articles about unmanned aircraft systems (UAS) and small satellites. Rea says he's always amazed to see the diversity of uses for UAS and SmallSats, as well as their ability to work together.

"The range of applications continues to surprise me every day," Rea adds. "They range from counting penguins and peering under jungle canopies to managing inventories and exploring caves."

Startup companies have used CubeSats to capture images of Earth, which can then be sold to customers. For example, Planet Labs in California has customers in precision agriculture, consumer mapping, government, insurance, finance, and energy infrastructure, according to its website.

As the private sector grows, the role of the government has shifted around spaceflight, Rea says.

With the emergence of more space-related companies, "the private sector has advanced technology and provides rockets, which NASA uses to launch their satellites," Rea explains. "This has allowed NASA to retain a role at the federal level in developing advanced research projects that the private sector still cannot afford to pursue."

An instrument developed for the HARP CubeSat mission will be adapted for the larger PACE mission. Image Credit: NASA





As a result, federal agencies like NASA can push the frontiers of technology instead of spending time and resources on basic equipment and materials, Rea adds. As more small satellite vendors enter the market, NASA can focus on the truly innovative portions of missions.

This interplay of government and industry, Rea says, should be considered a positive for innovation. Though dynamics have changed since NASA's early years in the 1960s, government labs continue to produce state-of-the-art technologies.

"In areas where the private sector has reached their financial limit – that's where the government needs to step in and push back the frontiers of new technologies," Rea says.

## SmallSats Spark Creativity

Small satellites are especially adept at spurring innovation, says Vanderlei Martins, a physics professor at the University of Maryland, Baltimore County. In 2017, Martins wrote an article for online publication The Conversation entitled, "SmallSat Revolution: Tiny Satellites Poised to Make Big Contributions to Essential Science."

"At the time I wrote that article, I wanted to point out that SmallSats were going from engineering demonstrations to small spacecraft that can do real, meaningful science," Martins explains. "And that's clearly what is happening now – a revolution."

Martins says that SmallSats and CubeSats provide certain constraints, which have forced scientists and engineers to approach spaceflight from different angles than before.

"One of the big advantages of SmallSats is the room for creativity," Martins adds. "All of these limitations open up chances to invent new ways of solving problems."

Martins is the principal investigator for the Hyper-Angular Rainbow Polarimeter (HARP) mission, a CubeSat scheduled to launch in October 2019. The HARP spacecraft will take highly accurate measurements of aerosol and cloud properties. The 3U CubeSat, with its small size and relatively inexpensive cost, allowed Martins and his team to take more risks and test out new ideas.

For example, Martins used a commercial-off-the-shelf sensor that cost less but typically wouldn't be used for larger missions, which require scientifically proven sensors that can cost up to 1,000 times more.

With some modifications to the commercial sensor, Martins says the instrument "performed amazingly well. Now, for a bigger mission, we could consider that sensor."

As SmallSats open the door to greater diversity in spacecraft development, with universities and students being able to work on missions, Martins says he expects SmallSats to continue growing in popularity.

"Space agencies have a very particular way of doing things and a set of rules which are followed," Martins adds. "It's a process that produces very good outcomes and it's highly reliable, but you become stuck in that structure, and it can be hard to do innovative things in many different directions. With small satellites, you get more people involved at universities, and you get students who are not driven by all those rules. New concepts are born from that."

However, Martins states, larger missions and the government will always have a role in scientific exploration and engineering. Small satellites, he says, can supplement or complement larger missions by multiplying the number of measurements a mission can make or by providing measurements from different angles.

"I see both sides continuing to evolve and work together," he concludes.


Developers work on IceCube at Goddard. Image Credit: NASA

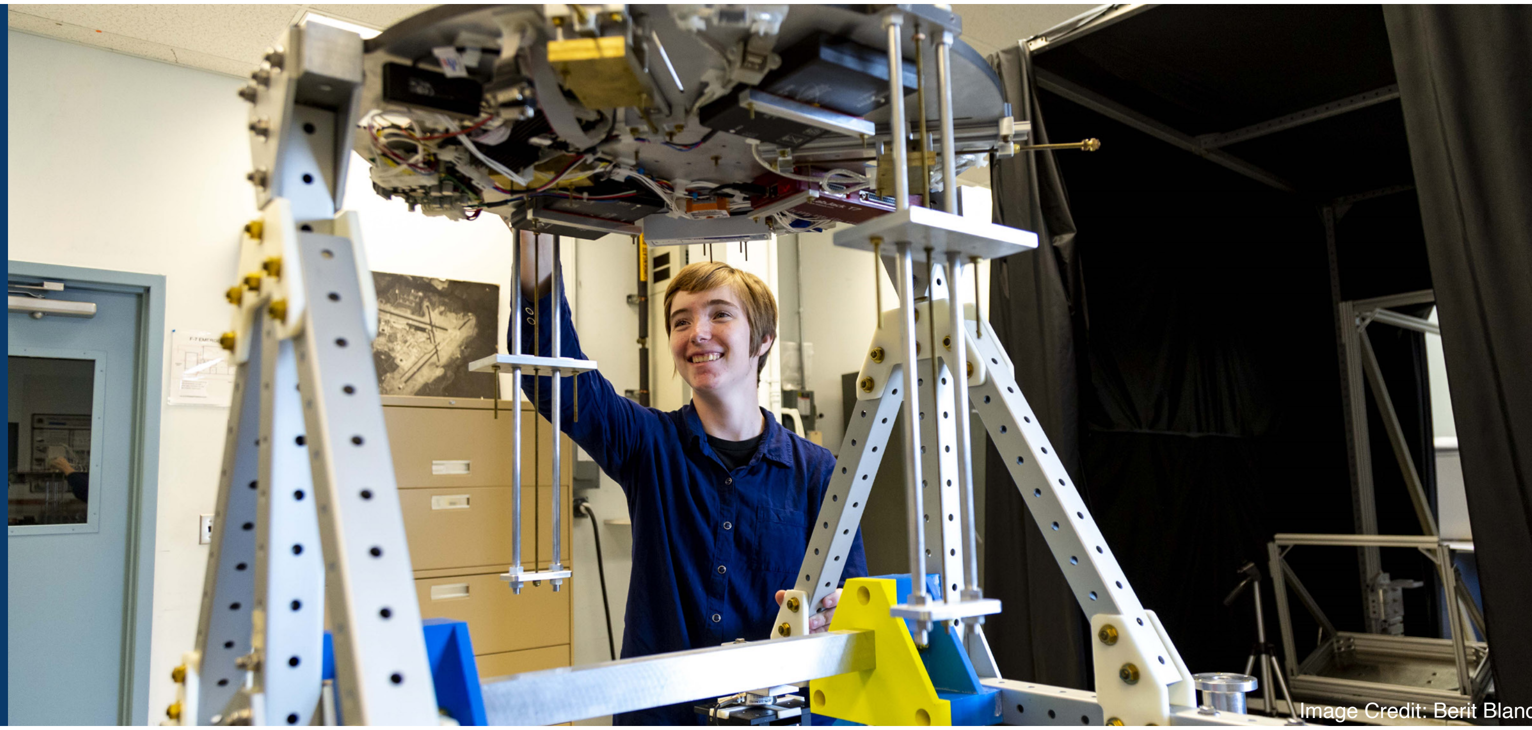


Image Credit: Berit Bland

# Summer Interns gain hands-on experience with SmallSat tech at Wallops

Kimberly Whaley (left) and Nathan Spicer-Davis (right) spent the summer of 2018 working at NASA's Wallops Flight Facility as interns for John Hudeck, deputy program manager of the Small Satellite Project Office. Hudeck says that CubeSats provide unique opportunities for undergraduate and graduate students to gain hands-on experience with spaceflight technology. The relatively short time-frame of CubeSat missions make them ideal educational tools in addition to their scientific capabilities.

Whaley and Spicer-Davis worked in the Small Satellite Test Laboratory, where they gained experience with equipment that will be used to validate small satellite components. They also made progress updating a release mechanism for small satellites, an adaptation of a smaller technology called the Diminutive Assembly for Nanosatellite deploYables (DANY). Known as Double DANY, the technology needed adjustments made after its redesign, and the students studied the technology as part of their summer project.

*Tech Transfer* magazine caught up with Whaley and Spicer-Davis to learn more about their internships and how they plan to use the skills they developed during their time at NASA.

**Where are you attending university, and what is your major?**

**KW**: I'm a student at North Dakota State University. I originally started as just a mechanical engineering major, but since then I have added electrical engineering as a double major. I'm also planning on getting my MS in mechanical engineering through the school's accelerated master's program.

**NSD**: I am currently attending University of Maryland pursuing a double degree in mechanical engineering and math.

**What is your year in school?**

**KW**: By the end of this semester, I will have finished my second year. I'm planning on going for six years in total.

**NSD**: I am currently a freshman and will be a sophomore in the fall 2019 semester.

**What was your project for your summer internship?**

**KW**: My official title was "Small Satellite Test Engineer." The name is slightly misleading; I didn't test satellites, but I did test the equipment that would test the satellites. Some of the main projects I worked on were testing an Attitude Control Subsystem Testbed, figuring out data processing for a Torque Measurement Table, and refurbishing a model of the small satellite IceCube.

**NSD**: Over the summer, another intern and I worked on testing the viability of using an air bearing to test small satellite attitude control systems. To do this we tested the theoretical methodology to find where problems arise and create solutions to get around them. The goal was to have an operational test table that would be able to test small satellites as small as 1U CubeSats. Also, a secondary project I had was testing and making design changes to a solar panel release mechanism for 6U cube satellites.

**What did you learn from working with SmallSat technology?**

**KW**: I learned a lot of things, like how attitude systems work or how satellites are designed. However, I think the biggest thing I learned was how to think like an engineer. Before this internship, all my jobs were food-service based, which are fast paced and don't require a lot of thought. This internship (and John Hudeck especially) taught me how to slow down, think about what I'm doing, and consider all of the factors in order to find the best solutions to problems. I was still learning that lesson up until the end of the summer, so maybe I didn't get to apply it at Wallops so much, but it has definitely changed the way I approach things like research back at my school.

**NSD**: While working with SmallSat technology, I learned about how attitude control systems and reaction wheels work. I also learned more about the engineering process when running through testing and making design changes to the air bearing system. On a higher level, I also learned more about how projects are created and ran through NASA and how NASA works with contractors and other research institutes.

**How do you plan to use these skills in your future career?**

**KW**: Learning how to think like an engineer is obviously going to be useful for any engineering work I do in the future.

**NSD**: The skills I learned will be useful in a future career as I'll have experience applying the engineering process in an actual work environment. Even though what I was doing had a very specific goal and process, I can apply what I did more generally to any engineering job. The skill of problem solving is a hard one to master and requires a large amount of experience to be quick and efficient at it. This experience let me test my skills as an engineer so I could find where I needed to improve.

**What did you enjoy most about working on SmallSat projects?**

**KW**: That last one is a hard one, as I loved just about everything in my internship. I think my favorite thing wasn't the work itself, but the people. Everyone I met at Wallops seemed to be really passionate about what they were doing, and many even had time to answer questions about their work, despite me being just an intern. I hope I can find a culture like that after I graduate.

**NSD**: The thing I enjoyed most about working on the SmallSat project was being able to apply all the math and physics I had learned in order to predict and correct for things observed when testing the air bearing system. There were many things that were unexpected when we started testing that were solved by taking measurements and applying physics. I also enjoyed working with the experienced people that were part of the project that were always willing to offer their expertise.

*This interview has been edited lightly for length and clarity.*

# Internships at Goddard

NASA internships, fellowships, and scholarships leverage NASA's unique missions and programs to enhance and increase the capability, diversity and size of the nation's future STEM (science, technology, engineering and math) workforce. Goddard offers hundreds of internship opportunities each year across four campuses located at:

**Goddard Space Flight Center**

Greenbelt, MD

**Wallops Flight Facility**

Wallops Island, VA

**Goddard Institute for Space Studies**


New York, NY

**Katherine Johnson Independent Verification and Validation Facility**


Fairmont, WV

## Internship Requirements

Basic eligibility requirements include U.S. citizenship, 3.0 or higher GPA, at least 16 years of age at the time of application, and a current student status of accepted or enrolled in an accredited U.S. college or university.

Interested students should submit an application through **https://intern.nasa.gov** and should indicate availability for spring, summer, and fall.

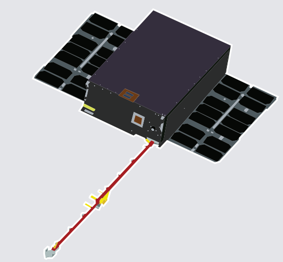
For additional information, please contact: **GSFC-Education@mail.nasa.gov**

**400**

**Goddard Interns for Summer 2019**



# Going Strong



## Radiation-hardening capabilities will help GTOSat survive in the Van Allen Belts

GTOSat will venture where few CubeSats have dared to travel before – into a radiation-heavy, harsh environment full of charged particles that endanger the sensitive equipment onboard. Scientists at Goddard's Space Flight Center plan to launch GTOSat (short for Geosynchronous Transfer Orbit Satellite) in the early 2020s, and in the meantime, they're working hard to equip the CubeSat with the shielding and radiation-hardened components it will need to survive.

"It's been a challenge to make it radiation hardened, because a lot of CubeSat components and subsystems currently on the market are not radiation tolerant," says Lauren Blum, a Goddard scientist and principal investigator for the GTOSat mission.

GTOSat will study the Van Allen Belts, donut-shaped areas in Earth's magnetosphere that contain highly energetic particles capable of causing significant damage to satellites. Blum says GTOSat will use two instruments to study these important regions.

"One of our main goals is to better predict what Earth's radiation belts will do in response to solar or geomagnetic activity," Blum adds. "The radiation belt content and location can change dramatically due to coronal mass ejections or other solar drivers. Energetic particles within the radiation belts can be damaging to astronauts and electric spacecraft, so it's pretty crucial to characterize and ultimately predict their variations."

In order to fulfill this mission, Goddard engineers will need to build GTOSat with much hardier materials than CubeSats typically require. The two main threats involve single-event upsets – when an energetic particle interferes with the function of an electronic device – and the total amount of radiation accumulated over time.

Most CubeSat missions fly in Low Earth Orbit (LEO) because of the greater availability of flight opportunities and a more benign spaceflight environment. For GTOSat, however, a more challenging orbit is required. To study the Van Allen belts, GTOSat will take a radically different orbit from LEO, swinging close to Earth and then flying far into the midst of the belts in an elliptical pattern. Both the radiation and the unusual orbit present unique challenges to the mission.

"With the increasing interest in using CubeSats for planetary science as well, there does seem to be more availability of radiation tolerant components, and that has helped us," Blum says. Because CubeSats will need to travel farther to reach planets beyond Earth, they will need to survive longer and be built with hardier parts.

GTOSat consists of two scientific instruments – an energy particle detector called the Relativistic Electron Magnetic Spectrometer (REMS) and a flux gate magnetometer. REMS is based on an instrument onboard the Van Allen Probes, a NASA mission launched in 2012 to study the Van Allen belts. Using a magnet to bend energetic electrons onto a plane of detectors, REMS will measure the energy spectrum of electrons in the outer belt.

The flux gate magnetometer will measure Earth's magnetic field, giving a reference point to let the GTOSat team know where electrons are coming from relative to the field.

GTOSat will employ a shielding technology from NASA's Langley Research Center to help protect it from radiation. Because CubeSat missions move at a relatively rapid pace, the team will have the opportunity to see GTOSat come to fruition in only a few years.

"That's one of the beautiful things about CubeSats – the fast turnaround makes it challenging, but it's a good way to keep up with the fast-paced advancements in this industry and take advantage of them," Blum says.

# Lines of Communication

## Goddard CubeSat missions plan to leverage the Near Earth Network

SeaHawk, the first CubeSat to connect to NASA's Near Earth Network, captured this image on the California coast.

In spring of 2019, a little satellite called SeaHawk flew above the verdant waters of Monterey Bay and took an image of the California coastline. The next day, SeaHawk passed over the NASA Near Earth Network (NEN) receiving station on Wallops Island, Virginia. As the satellite flew by, its radio broadcasted data to antennas at Wallops, which successfully captured the image files and transferred them to NASA's Goddard Space Flight Center. The result: a beautiful picture of California's blue ocean waters, bright green vegetation, and puffy white clouds.

SeaHawk is the first CubeSat to connect to NASA's Near Earth Network, a collection of ground-based tracking stations that relay data from spacecraft to mission operations centers all over the world. CubeSats have become increasingly appealing platforms for technology demonstrations and science experiments. Historically, though, they haven't connected to the communications networks used by larger missions.

As CubeSats adopt higher quality flight radios, Near Earth Network managers are preparing to support upcoming NASA CubeSat missions. By connecting to the Near Earth Network — which is managed, operated, and maintained by Goddard — CubeSats will be able to tap into a vast network of tracking stations to transmit science data quickly and securely.

Traditionally, CubeSats have used radios that operate in the Ultra High Frequency (UHF) band, according to Scott Schaire, Near Earth Network (NEN) Wallops Manager and NEN CubeSat Strategy Lead. While small and inexpensive, these UHF radios have a few downsides. First, they're restricted to a relatively low data rate, meaning they transmit data slowly back down to Earth. Additionally, UHF-band radios are susceptible to interference – anything from local police radios to pizza delivery trucks can compromise the signal.

"Since UHF is not allocated as a primary frequency for NASA missions, there's not much you can do about it," Schaire explains. "Can you imagine launching a CubeSat and not being able to talk to it because someone is delivering pizza?"

To avoid this problem, larger missions use radios that operate in other frequencies, such as the Ka-, S- and X-bands, which are compatible with the Near Earth Network. These frequencies are allocated for NASA missions, so interference doesn't threaten the mission.

However, CubeSat budgets tend to run slim, and flight radios for these bands can set back a CubeSat mission by tens of thousands of dollars. With recent developments, though, "these types of radios are starting to become available at low cost and higher maturity," Schaire says.

SeaHawk, which utilized a French X-band radio, scored a big success when it successfully transmitted data to Goddard via the Near Earth Network. Schaire expects it will be the first of many CubeSat missions to take advantage of this resource. In fact, the Near Earth Network is testing communication modulations that promise to triple the data rate for CubeSats and larger NASA missions, as well.

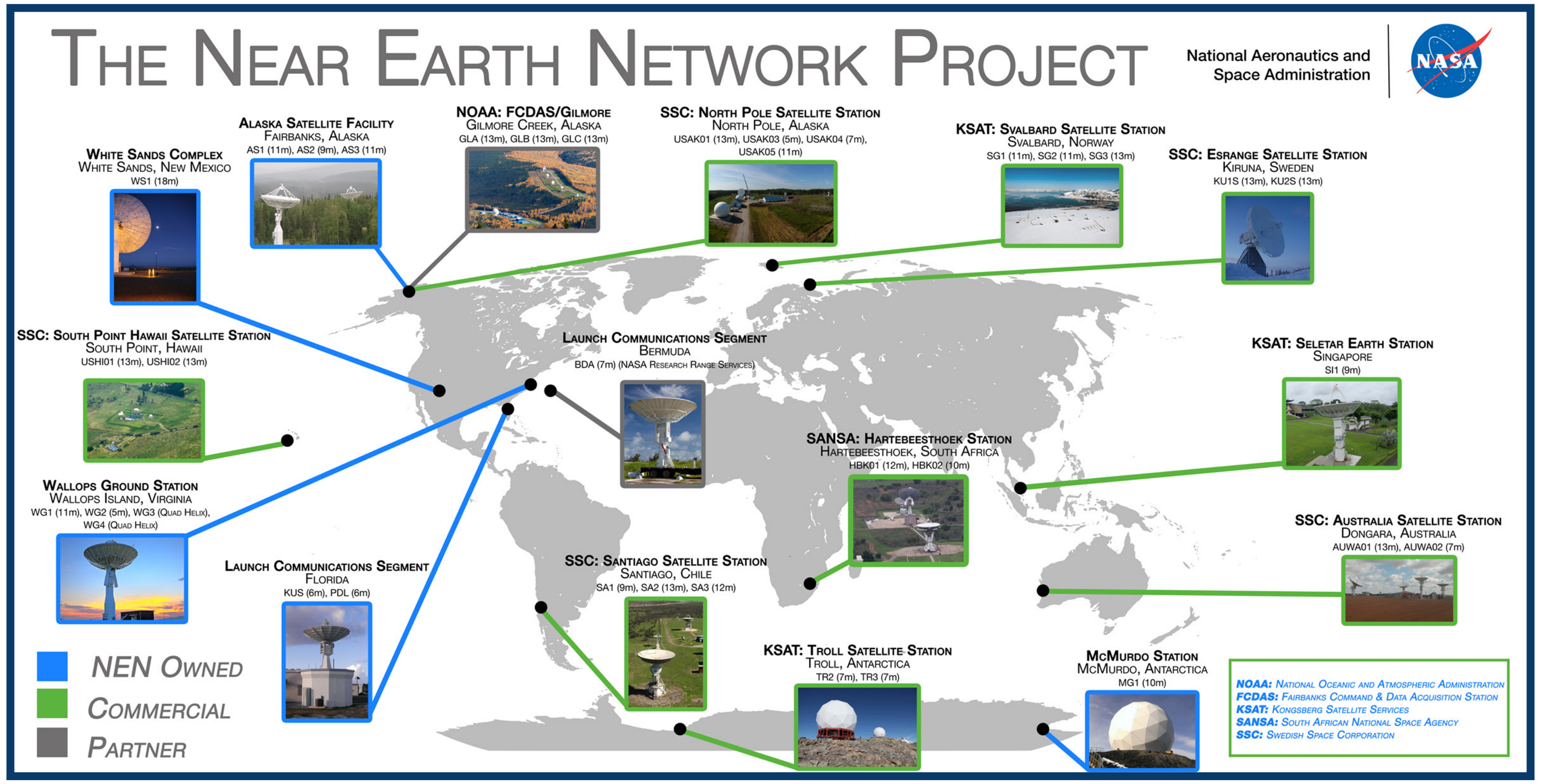
"CubeSats are wonderful testing grounds for all these technologies," Schaire says.

Of Goddard's upcoming CubeSat missions, petitSat, GTOSat, and BurstCube likely will be supported by the Near Earth Network. Going forward, Schaire and his team will continue identifying Near Earth Network compatible radios and antennas while supporting CubeSat missions in their transition to these systems.

Scott Schaire is the Near Earth Network (NEN) Wallops Manager and NEN CubeSat strategy lead.

"It's a very exciting time for CubeSats," Schaire adds.

The Near Earth Network is part of NASA's Space Communications and Navigation (SCaN) program. The SeaHawk mission is led by the University of North Carolina Wilmington, with John M. Morrison as principle investigator. For more on the petitSat, GTOSat, and BurstCube missions, please see the CubeSat Mission Guide at the back of the magazine.



# Bursting onto the Scene

## Goddard's BurstCube mission features silicon photomultiplier technology and fast communication

CubeSats are making space more accessible, says Georgia de Nolfo, a scientist at NASA's Goddard Space Flight Center. Earlier in her career, before the CubeSat revolution hit full throttle, she worked on high altitude balloon flights, which required her to spend several months in remote regions of the world to collect science data with suborbital balloons.

De Nolfo says the fast-paced, creative nature of CubeSats reminds her of high altitude balloon missions. She enjoyed the fast pace and challenge of balloon missions, when problems needed solving in real time. "You're testing things as you go, and if something breaks, you have to go to the local hardware store," she adds. "Sometimes you have to drive several hours to get to a store. It's a very exciting environment."

Currently, de Nolfo and Goddard scientist Jeremy Perkins are working on a CubeSat called BurstCube, which will use compact, low-power silicon photomultiplier arrays coupled with scintillating crystals to measure bursts of light associated with colliding neutron stars.

CubeSats are transforming the way NASA does science, de Nolfo says, adding that "these missions really get you to start thinking outside the box."

BurstCube's instrument will look for short gamma ray bursts, which are electromagnetic counterparts to gravitational waves. LIGO's famous observations of gravitational waves bolstered the scientific community's motivation to continue learning more about these phenomena.

Jeremy Perkins (left) and Georgia de Nolfo (right) pose with BurstCube technology that will be used to detect and localize gamma-ray bursts for gravitational-wave science.

"The amazing thing is that you can examine the properties of space-time with a CubeSat," de Nolfo says. "The subject matter is just as exciting as it gets."

### Talking to TDRS

The instrument consists of four scintillator crystals paired with silicon photomultiplier arrays. Photons from traveling gamma rays are absorbed in the scintillator crystal because of its molecular structure. When a photon bumps into a molecule inside the crystal, an electron gets kicked into a higher energy state. When this electron drops back down into a low energy state, it creates a flash of light that the silicon photomultipliers can measure.



"If a short gamma ray burst goes off and it's picked up by the BurstCube detectors, we will see a rate increase in the number of photons we detect from a specific location in the sky," explains Perkins, who is the principle investigator for the mission. "Automated software onboard BurstCube will be able to find the location in the sky where the burst came from."

The BurstCube mission plans to feature a new capability for CubeSats – connecting to NASA's Tracking and Data Relay Satellites (TDRS), which quickly relay data for a variety of NASA missions. Most CubeSat missions aren't equipped with radios capable of connecting to NASA's advanced communications networks, but with CubeSats like BurstCube, that paradigm is changing.

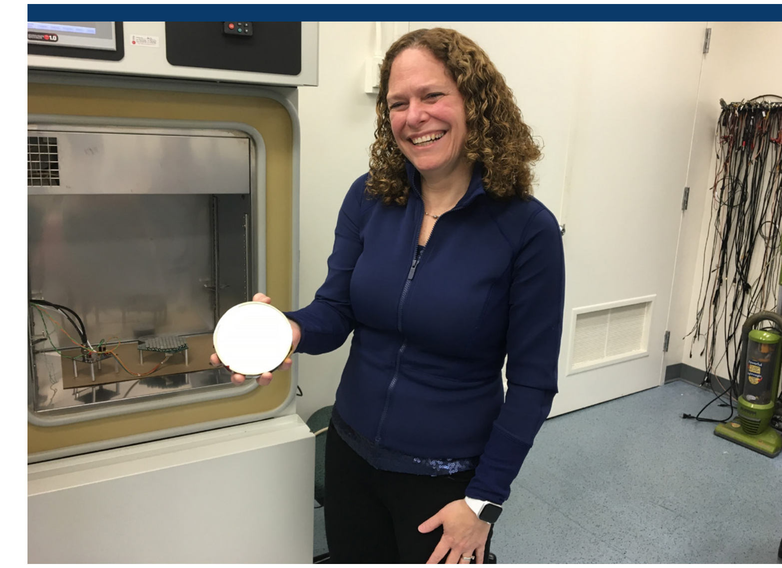
"For the science we're doing, it's vitally important to get the information out to the scientific community as rapidly as possible, and with larger missions, we've traditionally done that through TDRS," Perkins says. "With CubeSats, the main challenge is that most radios used on the big missions are the same size or bigger than our whole spacecraft."

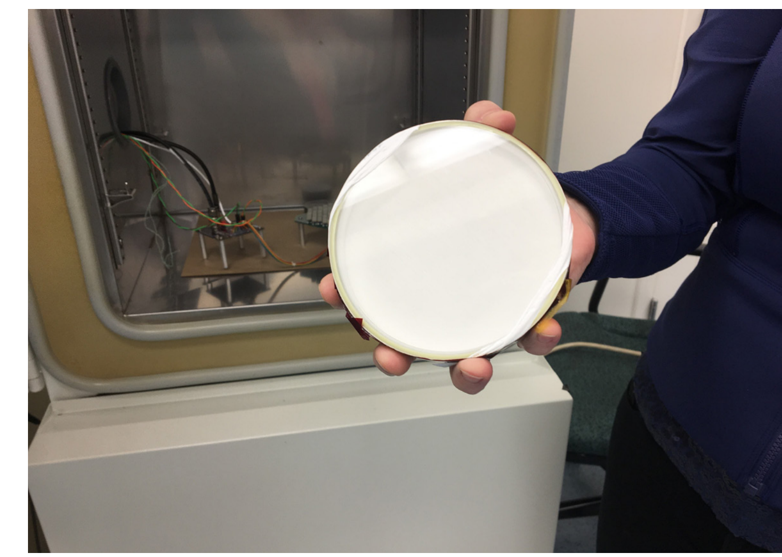
With power and size constraints, CubeSats pose an unusual communications challenge. Despite this obstacle, Perkins and the BurstCube team have found a commercial radio worthy of the task. Further validation is needed, but the solution holds promise.

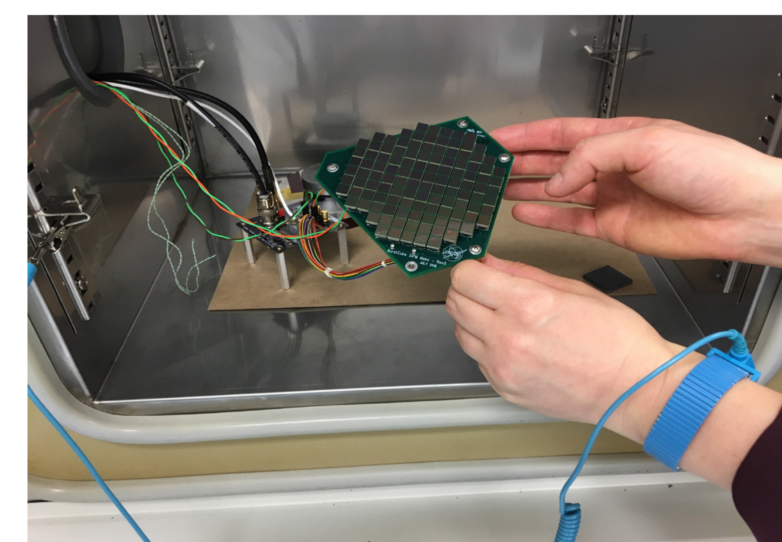
Perkins says that Goddard is an ideal place to find CubeSat communications solutions because many components of the mission, including TDRS, are managed at the center.

"For the science we're doing, it's vitally important to get the information out to the scientific community as rapidly as possible."

- Jeremy Perkins







Georgia de Nolfo displays scintillating crystal and Burstcube's silicon photomultiplier arrays at a Goddard lab. Image Credit: NASA.

### Commercial Applications

BurstCube's primary technology – the silicon photomultiplier – has applications outside of astrophysics, particularly in the industries of medical imaging and defense.

In the medical field, silicon photomultipliers can be used in Positron Emission Tomography (PET) imaging, which leverages scintillation crystals coupled with photomultipliers to produce cross-sectional images of the human body. Traditionally, this has been achieved with photomultiplier tubes, but silicon photomultipliers have a number of advantages over the older technology.

With a more compact size, better stability, and low power requirements, silicon photomultipliers are well-suited for space, but also fit into niches for industries on Earth. Outside of medicine, silicon photomultipliers can be used to pinpoint the location of nuclear materials, an application relevant to defense.

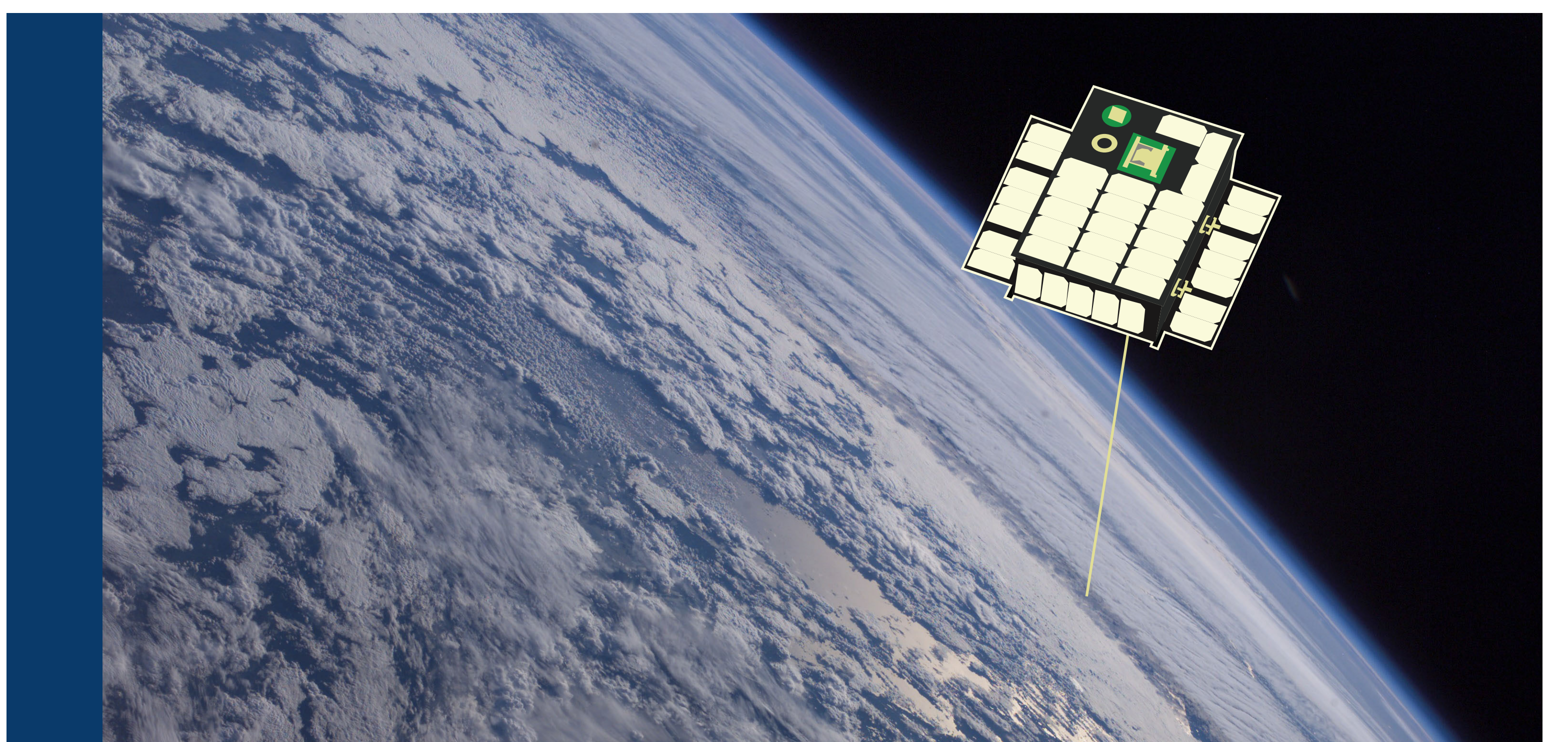
### CubeSat Advantages

For Goddard, the silicon photomultiplier arrays will enable the BurstCube mission to supplement gravitational wave research on a relatively small, inexpensive platform. Not only will BurstCube be able to detect gamma ray bursts, but it will also provide information about where in the sky the gamma ray burst came from. With access to TDRS, BurstCube can relay that information quickly to the ground.

"Once that information gets to the Gamma-ray Burst Coordinates Network, which is run here at Goddard, the whole community gets access," Perkins says. "Depending on the situation, you can have space telescopes like Swift look at it, or ground-based telescopes can make observations."

Currently, BurstCube is scheduled to launch in the early 2020s.

"It's amazing to me that we'll be looking at the electromagnetic counterpart of a gravitational wave with a CubeSat," de Nolfo adds. "How incredible is that?"





# Small but Mighty

## Goddard SmallSat technology transferred to a small business in Utah

Thermal Management Technologies' Gecko Release Mechanism is based on a Goddard technology for small satellites.

After two years, a small but mighty piece of NASA SmallSat technology has transferred successfully to industry, thanks to a connection made at the 2017 Small Satellite Conference in Logan, Utah.

Thermal Management Technologies (TMT), a company based in North Logan, Utah, licensed the Diminutive Assembly for Nanosatellite deploYables (DANY) in 2018, and this year, TMT completed its first sale.

"Our business is very focused on the small satellite industry, which is one of the reasons we liked this particular release mechanism that we licensed," says Scott Schick, director of engineering at TMT. "This device fits in well with the other thermal control and structural technologies that we sell."

> **"With this device, we're better positioning ourselves to support engineers and missions that fit into the small satellite market."**
>
> - Scott Schick

DANY – created by Goddard inventors Luis Santos, Scott Hesh, and John Hudeck – provides a reliable mechanism to secure deployable elements of a small satellite, safely stowing them until receiving a signal to burn through a plastic restraining link and release them for use in space. Deployable elements on a small satellite can include solar arrays, sun shades, radiators, or antennas. The entire assembly is about the size of a credit card, making it ideal for small satellites that have significant space restraints.

TMT used DANY as the core of its "Gecko Release Mechanism," named after the device's gecko-like size and ability to grip tightly onto a spacecraft.

Over the past year, Schick and his team have worked to modify NASA's original design to enable the production of multiple units. After several months of adjustments, TMT now has a marketable product ready for sale.

Schick says that when it comes to working with NASA technologies, "it's important to do your homework and make sure you understand what it takes to turn the technology into a product. With this device, we're better positioning ourselves to support engineers and missions that fit into the small satellite market."

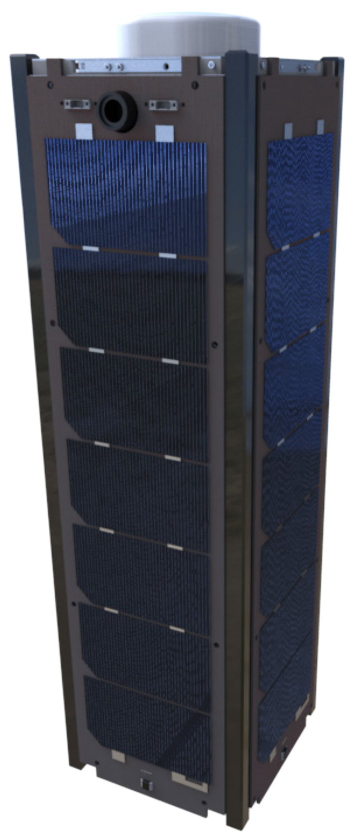
Technology managers with the Goddard Technology Transfer Office are always available to answer questions or help move projects forward. For more information, please email techtransfer@gsfc.nasa.gov or call 301-286-5810.

# To the Power of Three

## NASA Operational Simulator for Small Satellites (NOS$^3$) is a game changer for SmallSat missions

A small satellite celebrated across the state of West Virginia made it to space at the tail-end of 2018. It's a moment that Justin Morris, project manager for Simulation to Flight 1 (STF-1), remembers clearly.

"There aren't words to explain how exciting it was to see the launch go off without a hitch," Morris says.



STF-1 is West Virginia's first spacecraft, created through a collaboration between NASA's Katherine Johnson Independent Verification and Validation Facility and West Virginia University (WVU), among other collaborators. The 3U CubeSat is flying four science experiments from WVU, but its key objective is to demonstrate the use of a new SmallSat software program called NASA Operational Simulator for Small Satellites (NOS$^3$).

So far, STF-1 has carried out its mission with great success, much to the excitement of the team.

With NOS$^3$ demonstrating its worth throughout the mission life cycle of STF-1, the software will support future Goddard CubeSat missions, including GTOSat, petitSat, and BurstCube. The Goddard SmallSat community has praised the software's effectiveness in reducing programmatic and technical risk, which boosts the likelihood of mission success.

Morris and his fellow software developers designed NOS$^3$ specifically to serve small satellite missions, which have specific requirements that differ from larger missions. This customized ability has made NOS$^3$ a valuable asset at Goddard, but also outside of NASA, with users including the National Science Foundation Center for Space, High Performance, and Resilient Computing, the Air Force Institute of Technology, and the MIT Lincoln Laboratory.

"NOS$^3$ is essentially your spacecraft running on your laptop," says Matthew Grubb, lead engineer of the STF-1 mission.

**Efficient and customizable**

NOS$^3$ brings several compelling advantages to SmallSat missions. It lessens cost, reduces risk, and allows missions to focus on accomplishing science objectives.

CubeSat missions tend to move at a fast pace, meaning that progress will advance more quickly if multiple stages of the mission can happen in parallel. NOS$^3$ is able to emulate flight hardware, allowing a software-only test environment early in the mission's development and testing phases. Developers don't have to wait for physical hardware to be in place and can perform coding, instrument integration, and software testing while hardware is being acquired.

"NOS$^3$ builds testing into your development process," Morris states. "I like comparing it to working out – sometimes the hardest part of getting up to go for a run is just getting started. Having NOS$^3$ is like sleeping with your running shoes on – it provides a convenient environment to hit the ground running."

NOS$^3$ is also customizable. Though it was developed for the STF-1 mission, NOS$^3$ can adapt to other SmallSat missions, and the software package includes information on how to add simulators for hardware that is specific to a particular SmallSat.

Since the simulations require no hardware at all, developers can run tests and play out scenarios that would otherwise be impossible to accomplish on the hardware itself. For STF-1, the team could run programs that simulated hardware failures to see what would happen to the entire system in the event of a malfunction.

Matthew Grubb Works on the STF-1 spacecraft.

"You can run scenarios from any location and on any subsystem," Morris says. "For example, if the antenna doesn't deploy, will the software still meet your requirements? NOS$^3$ can help answer those kinds of questions."

**"We like to say that small satellites open the door to space. NOS$^3$ is helping bring people to that door."**

-Matthew Grubb

As a NASA software, NOS$^3$ integrates seamlessly with Goddard's core Flight System (cFS) and other software programs designed for spacecraft systems, including Goddard-developed 42. This compatibility with cFS – a software adopted by many missions and used at seven NASA centers – adds yet another layer of efficiency to NOS$^3$.

**Open source software**

The team behind NOS$^3$ has made the software package open source, meaning anyone can download the code and use it on their own project. By making NOS$^3$ free and accessible, Morris and his team seek to support other members of the SmallSat community.

"It's only been open source for a year, but we get contacted about this software two or three times a month," Morris says. "Because it's open source, we're starting to build a community around NOS$^3$."

NOS$^3$ is available as one among hundreds of software packages compiled in the online NASA Software Catalog. Those interested in downloading NOS$^3$ can visit https://invention.nasa.gov and search for "NASA Operational Simulator for Small Satellites." The software package can be downloaded directly from NASA's GitHub page at https://github.com/nasa/nos3.

"We like to say that small satellites open the door to space," Grubb adds. "NOS$^3$ is helping bring people to that door."

# Technology Manager Q&A:

*Tech Transfer* magazine catches up with Technology Manager Eric McGill

> “
> **In many cases, companies would be reinventing the wheel to develop their own technology when it would expedite their time to market if they licensed the technology from us.”**
>
> - Eric McGill

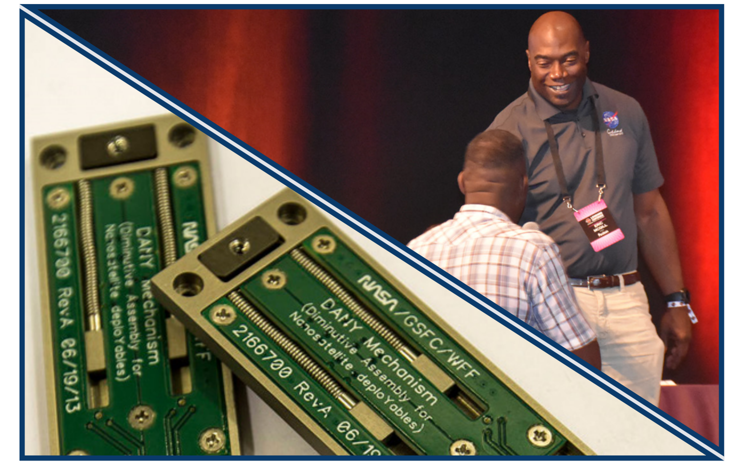
At the 2017 Small Satellite Conference in Logan, Utah, a company called Thermal Management Technologies (TMT) dropped by Goddard’s booth to check out a NASA technology called the Diminutive Assembly for Nanosatellite deploYables, or DANY for short. This meeting eventually led to a license agreement between Goddard and TMT, which now sells the technology under the name “Gecko Release Mechanism,” for its gecko-like size and ability to grip tightly onto a spacecraft.

“In the case of TMT, we saw them on the floor and realized their products were in the same technology area as some of ours,” says Eric McGill, a technology manager with Goddard’s Tech Transfer Office. In his role at Goddard, McGill works to forge technology connections between NASA and industry. When it comes to SmallSat and CubeSat technology, Goddard and industry have a lot to offer each other.

“Licenses help us because now we can procure that technology,” McGill points out. “We’re helping a commercial space business and the economy by association, and in return, they help us on the supply side.”








Eric McGill was the technology manager responsible for the licensing agreement between Goddard and Thermal Management Technologies.

> “
> **As we continue to deploy more CubeSats, we will build and establish heritage around an increasing number of components.”**
>
> - Eric McGill

Tech Transfer magazine met with McGill in his office to learn more about Goddard’s technology portfolio and how the center engages with the SmallSat industry.

**Why does Goddard’s Technology Transfer Office attend the SmallSat Conference every year?**

There’s a center-wide initiative at Goddard to legitimize the science that can be done with CubeSats. Years ago, CubeSats were thought to offer only student-grade science, and you couldn’t get a lot of NASA-grade scientific data out of CubeSats.

Now, with the miniaturization of scientific instruments and demonstrations by students and other groups that CubeSats can host various payloads, they have caught up to larger missions. You can do NASA-grade science on CubeSats, and over the past couple of years, many of our CubeSat missions have focused on proving that you can get really good space-related data from CubeSats.

The Tech Transfer Office at Goddard wants to communicate our desire to partner with industry to commercialize our technologies. We’re looking to make our unique facilities and capabilities available to the CubeSat community to help raise awareness and enable access to our technologies and resources. We believe that Goddard’s involvement and experience with scientific instrumentation allows us to provide resources that are not found elsewhere in the CubeSat community.

It’s part of our mission to make technologies that we use available to the commercial space industry, as well as other industries. Ultimately, we believe there is a direct path for the use of our CubeSat-related technologies for commercial CubeSats.

**What technology needs do SmallSat and CubeSat developers have?**

Part of our mission is simply to raise awareness. Once they are aware, we are here to partner and transfer technologies. We do secondary research to figure out what industry needs, but we don’t know exactly what companies want until you talk to them. That’s one big reason we attend these conferences — we gain the opportunity to meet companies, and they tell us what they’re looking for.

**Where do Goddard’s interests and those of the SmallSat community overlap?**

Goddard has a research and development legacy that industry could find valuable in terms of CubeSat and SmallSat subsystems. In many cases, companies would be reinventing the wheel to develop their own technology when it would expedite their time to market if they licensed the technology from us.

When CubeSat companies are building out systems, if they check to see if any NASA technologies could shorten their product development cycles, then we have done our job. An investor putting $50 million into a fleet of CubeSats would be wise to choose components with flight heritage. Missions can be delayed by implementing a part with no flight heritage. In order to reduce risk in that area, you implement something with heritage, and in some cases, we have that technology available. As we continue to deploy more CubeSats, we will build and establish heritage around an increasing number of components.

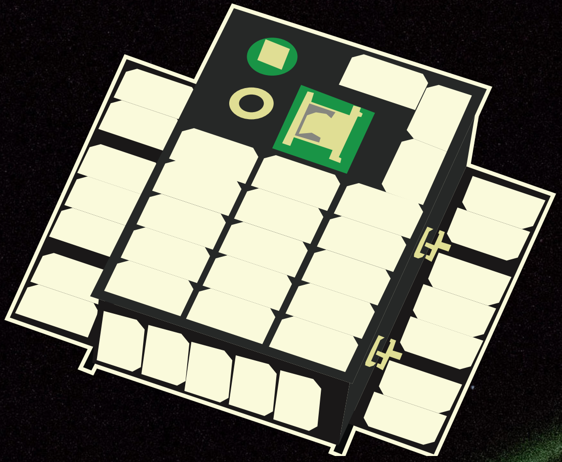
NASA’s research and development focus is broad. Most companies are operating in a narrow space, so chances are good that over time, we will have a collection of subcomponents with established flight heritages that industry would be wise to leverage.

**What do you want businesses to know about working with Goddard?**

The overall message I want to share is that doing business with us has never been easier. We’re working very hard to be industry friendly, to enable commercialization. It’s part of our mission to transfer technologies to industry for the benefit of the economy, and we’re here to help.

To learn more about the Strategic Partnerships Office, please visit https://partnerships.gsfc.nasa.gov.
To connect with a technology manager, please email techtransfer@gsfc.nasa.gov.

# CubeSat Mission Guide



## BurstCube

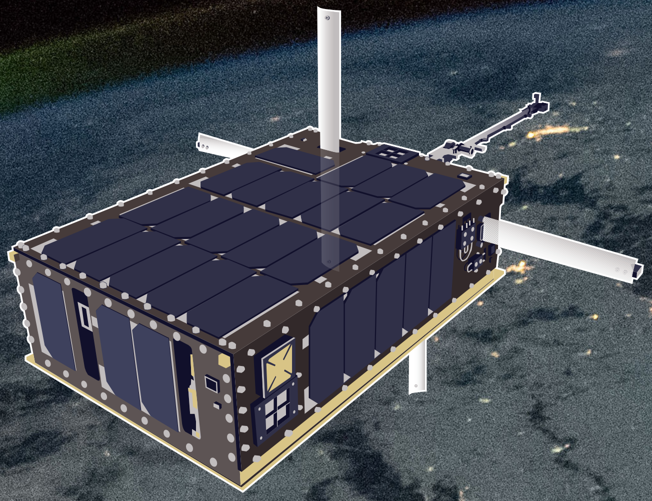
A 6U CubeSat searching for difficult-to-observe electromagnetic events called gamma ray bursts (GRBs), focusing specifically on short GRBs, which are counterparts of gravitational wave sources

Projected launch date: Early 2020s

New features: Will likely connect to NASA's Tracking and Data Relay Satellite (TDRS) configuration

Goddard technologies:

- 6U Dellingr bus
- Four cesium iodide scintillators
- Low-power silicon photomultipliers
- Custom electronics



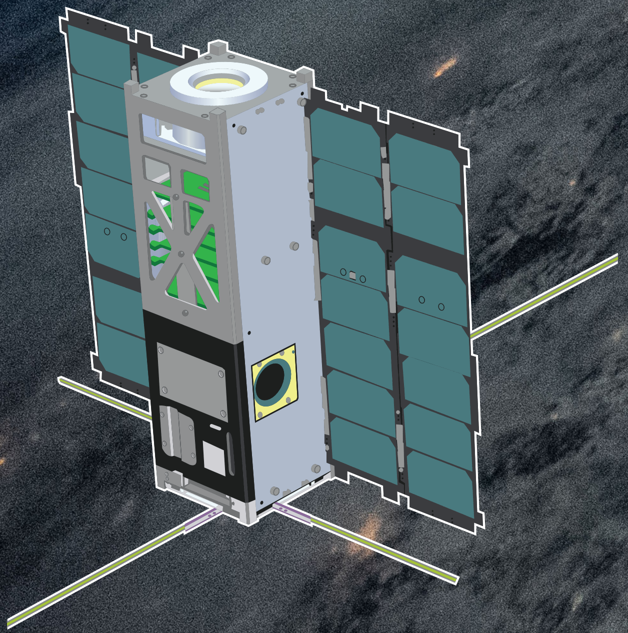
## Dellingr

A 6U CubeSat offering a reliable, robust and cost-effective design

Launch date: 2017

New features: Designed to increase resiliency and capability while containing costs

Goddard technologies:
- DANY
- Thermal louvers (tech demo)
- 6U Dellingr bus
- Deployable boom



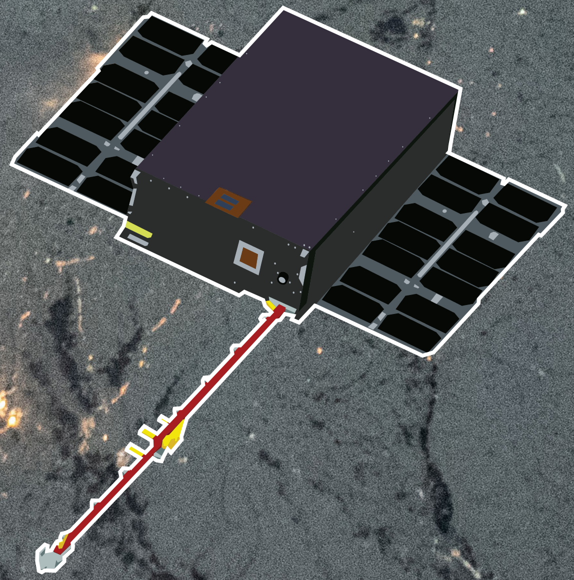
## CeREs

A 3U CubeSat examining radiation belt electron energization and loss processes

Launch date: 2018

Goddard technologies:

- Miniaturized Electron and Proton Telescope (MERiT)
- CubeSat Form Factor Thermal Control Louvers



## GTOSat

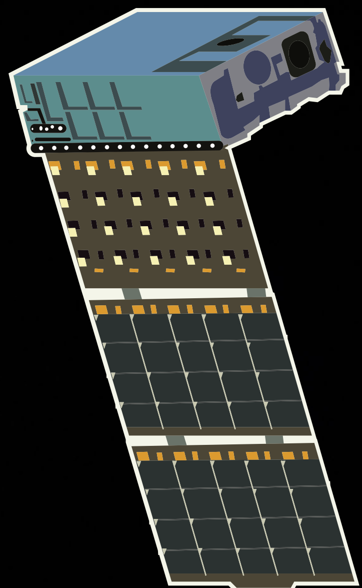
A 6U CubeSat to advance our quantitative understanding of acceleration and loss of relativistic electrons in the Earth's outer radiation belt

Projected launch date: Early 2020s

New features: Will incorporate radiation-hardened components to survive the harsh environment of the Van Allen belts

Goddard technologies: Dellingr-X bus

# Big Science Done Small



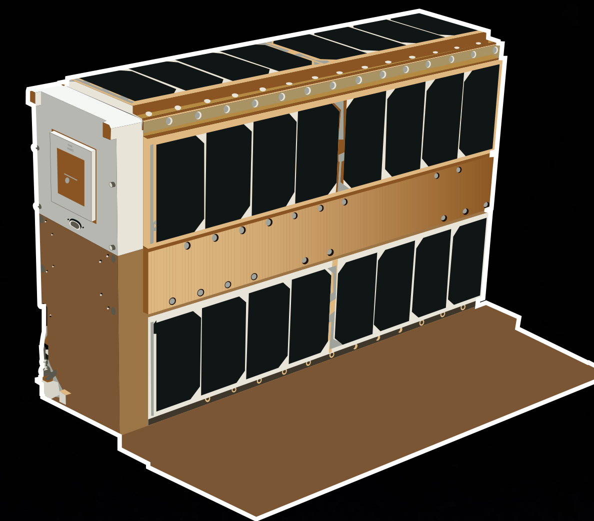
## HaloSat

A 6U CubeSat measuring X-ray emitting gas in the halo surrounding the Milky Way galaxy in search of missing matter

Launch date: 2018

New features: One of NASA's first CubeSats to conduct astrophysics research

Collaborators: University of Iowa, Blue Canyon Technologies, Johns Hopkins University



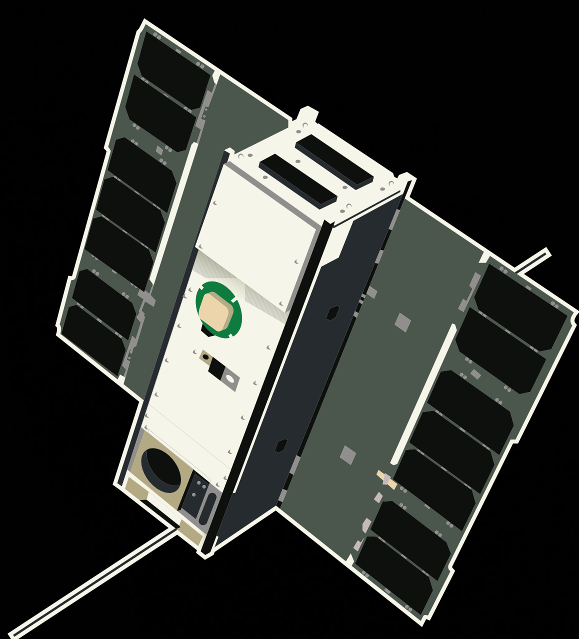
## petitSat

A 6U CubeSat examining density irregularities in Earth's ionosphere

Projected launch date: Early 2020s

New features:

Goddard technologies:
- Dellingr-X bus
- Mini ion and neutral mass spectrometer



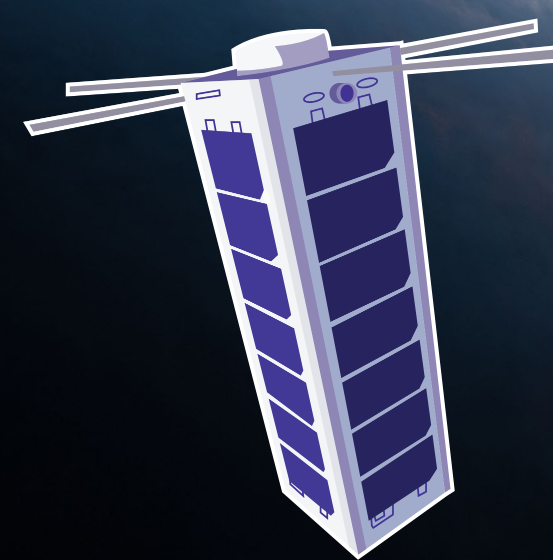
## IceCube

A 3U CubeSat demonstrating the use of an 883 Gigahertz radiometer in space

Launch date: 2017

New features: Capable of producing a global ice cloud map in the 883 Gigahertz band

Collaborators: Virginia Diodes, Inc.



## STF-1

A 3U CubeSat demonstrating NASA simulation technologies and carrying three science experiments

Launch date: 2018

New features: First CubeSat to use NASA Operational Simulator for Small Satellites ($NOS^3$)

Collaborators: West Virginia University, West Virginia Space Grant Consortium

Goddard technologies: $NOS^3$

# Technology Transfer Outreach and Engagement

**Goddard Sciences and Exploration Directorate Poster Party**
February 26, 2019

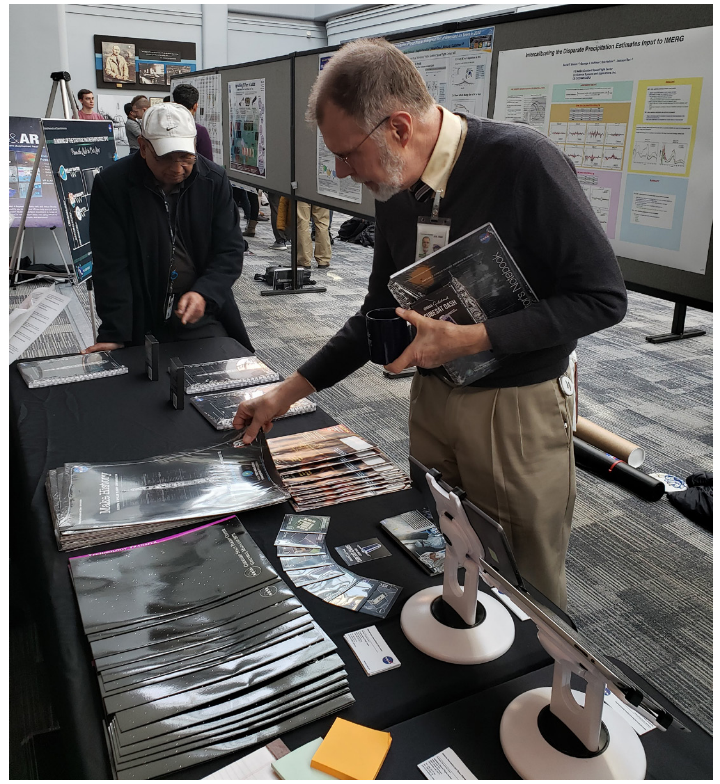
The Goddard Technology Transfer Office (TTO) participated in the 12th Annual Sciences and Exploration Directorate Poster Party, bringing an exhibit on technology transfer and speaking to innovators about submitting new technology reports. The event gave innovators an opportunity to showcase their scientific work from the past year through displaying scientific posters. Goddard technology managers connected directly with innovators by talking to them about their posters and encouraging them to submit new technology reports related to their work.

**Goddard Memorial Symposium**
March 19-21, 2019

Representatives with Goddard TTO attended the 57th Annual Goddard Memorial Symposium in Silver Spring, Maryland. The symposium is sponsored by the American Astronautical Society, and it brings together professionals across a range of sectors, from government officials and legislators to representatives of private industry and academia. Speakers included John Mather, a Goddard astrophysicist and Nobel Laureate.

**Maryland Technology Economic Development Corporation Visit**
March 21, 2019

Goddard TTO invited eight guests from the Maryland Technology Economic Development Corporation (TEDCO) to visit Goddard labs and learn more about opportunities for technology transfer. Each region of Maryland was



A Goddard employee visits the Strategic Partnerships Office booth at the Science and Exploration Directorate Poster Party.

represented by the TEDCO attendees, who are responsible for economic development in their respective regions. The visit included an overview presentation given by a senior technology manager that focused on Goddard’s mission and unique capabilities, as well as technology transfer, partnerships, and SBIR/STTR programs. The representatives also toured Goddard labs and facilities that could benefit their portfolio of technology companies and startup organizations.

**SPIE Defense and Commercial Sensing Conference**
April 18, 2019

A representative with Goddard TTO spoke at the International Society for Optics and Photonics (SPIE) Defense and Commercial Sensing Conference in Baltimore, Maryland. The representative talked to an audience of about 30 people, sharing information about Goddard TTO and presenting a review of sensor technology development at Goddard pertaining to Earth science. The review included several specific Goddard technologies available for licensing.


Goddard Technology Manager Kerry Leonard poses with a winning team at the Conrad Challenge, hosted at NASA's Kennedy Space Center. Image Credit: NASA.

**Conrad Challenge**
April 23-26, 2019

Goddard TTO participated in the 2019 Conrad Challenge at NASA’s Kennedy Space Center. The challenge brought together hundreds of student teams from around the world to solve real-world problems using science- and technology-based solutions. Goddard TTO and the Conrad Foundation worked through a Space Act Agreement to support young entrepreneurs in applying NASA technologies to their product ideas. Two of the winning teams used NASA technologies for their business pitches. Goddard TTO also judged submissions, mentored participants in further developing their pitches using NASA technology, and brought an exhibit displaying information on various technology transfer opportunities. Additionally, Goddard TTO gave a presentation on technology transfer to an audience of about 200 people, including students and representatives from industry and academia.

**FLC National Meeting**
April 23-25, 2019

A representative with Goddard TTO participated in the 2019 Federal Labs Consortium National Meeting in Orlando, Florida on April 23-25. The meeting connected technology transfer professionals from across the country and hosted educational sessions on licensing, commercialization, litigation strategy, and more.

**FLC Eastern Shore Industry Day**
May 7, 2019

Goddard TTO participated in the Federal Labs Consortium Eastern Shore Industry Day in Salisbury, Maryland. The event brought together students and local entrepreneurs interested in learning more about technology transfer opportunities with federal labs.

**Advancing Innovation Training**
May 8, 2019

Goddard TTO traveled to Wallops Flight Facility in Wallops Island, Virginia, to give a technology transfer training called “Advancing Innovation” The training featured information on Goddard TTO, walking participants through the process of technology transfer, from new technology reporting to licensing and commercialization. The training also included an interactive case study at the end of the presentation.

**America’s Air and Space Expo**
May 10, 2019

Two representatives with Goddard TTO participated in the “Joint Base Andrews Air Show: America’s Air and Space Expo” at Andrews Air Force Base in Camp Springs, Maryland. The representatives handed out Spinoff brochures and information about Goddard TTO, displaying NASA Home and City on iPads so that attendees could view and interact with the website.

# Featured SmallSat Technologies and Patents

**A Broad-Band, Compact, Low-Power Microwave Radiometer Down-Converter for Small Satellite Applications**

Patent Pending

**A Miniaturized Astrometric Alignment Sensor for Distributed & Non-Distributed GN&C Systems**

Patent Pending

**Airborne Power Supply Unit (APSU) - Buck Converter Deck**

Patent Pending

**Deployable Boom for CubeSats**

Patent Pending

**Graphene Field Effect Transistors for Radiation Detection**

Patent Number: 9,508,885

**Ion Control System**

Patent Pending

**Ka Band Earth Coverage Antenna for NASA's Ka-Band Communication for Earth Observing Missions**

Patent Pending

**Magnetic Shape Memory Alloy Actuator for Instrument Applications**

Patent Pending

**Micro scale Electro Hydrodynamic (EHD) Modular Cartridge Pump**

Patent Pending

**New Lenslet Array Based Integral Field Spectrograph Design for High Detector Pixel Efficiency**

Patent Number: 10,236,166

**Novel Antenna Concept for CubeSat Platforms**

Patent Number: 10,361,472

**On-Demand, Dynamic Reconfigurable Broadcast Technology for Space Laser Communication**

Patent Pending

**Optimetric Measurements over Coherent Free Space Optical Communication**

Patent Pending

**Photovoltaic Lithium Ion Battery**

Patent Pending

**Reaction Spheres for Multi-Axis Attitude Control and Energy Storage on Small Satellites**

Patent Number: 10,053,242

**Self-Regulating Current Circuit (SRC2) for Satellite Deployment Devices**

Patent Pending

**SmallSat Common Electronics Board (SCEB) Complement Board Design: Memory Card**

Patent Pending

**Spherical Occulter Coronagraph CubeSat (SpOC Cube)**

Patent Number: 9,921,099

**Steering Mirror Assisted Laser Fine Pointing**

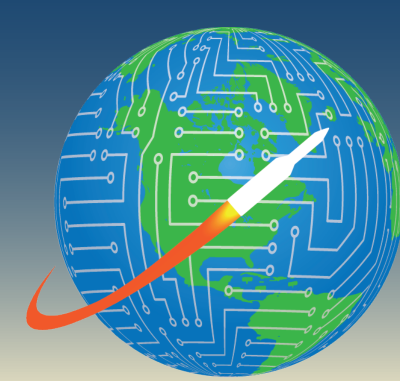
Patent Number: 10,228,465

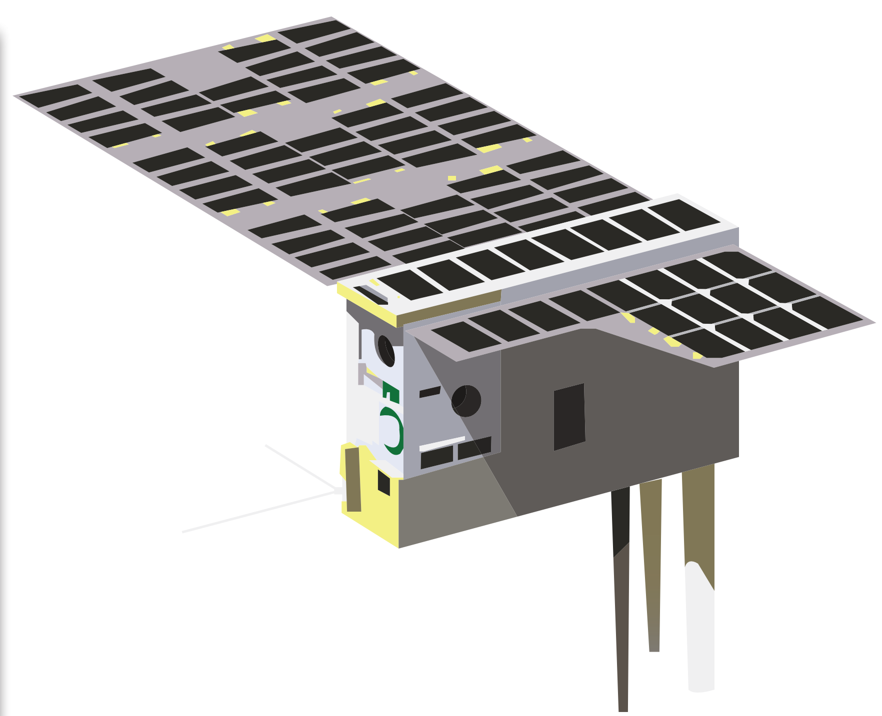
**Ultra-Compact Star Scanner**

Patent Pending

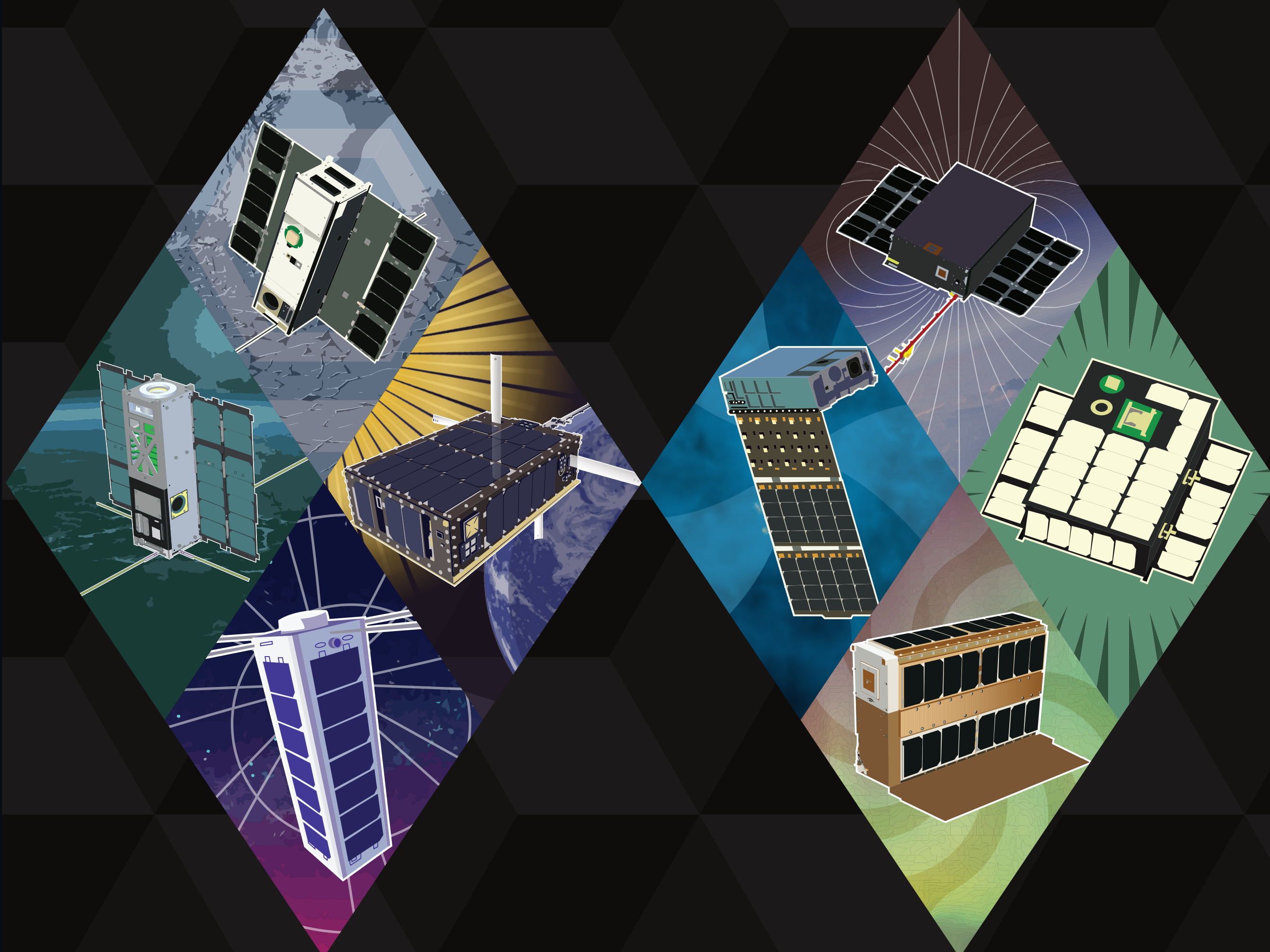
For more information about Goddard technologies, please visit

***technology.nasa.gov***





NASA CubeSat CubeRRT features the patent pending Broad-Band, Compact, Low-Power Microwave Radiometer Down-Converter for Small Satellite Applications. Image Credit: NASA



## NASA Goddard *Tech Transfer News*

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Also available online at: *https://partnerships.gsfc.nasa.gov*

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