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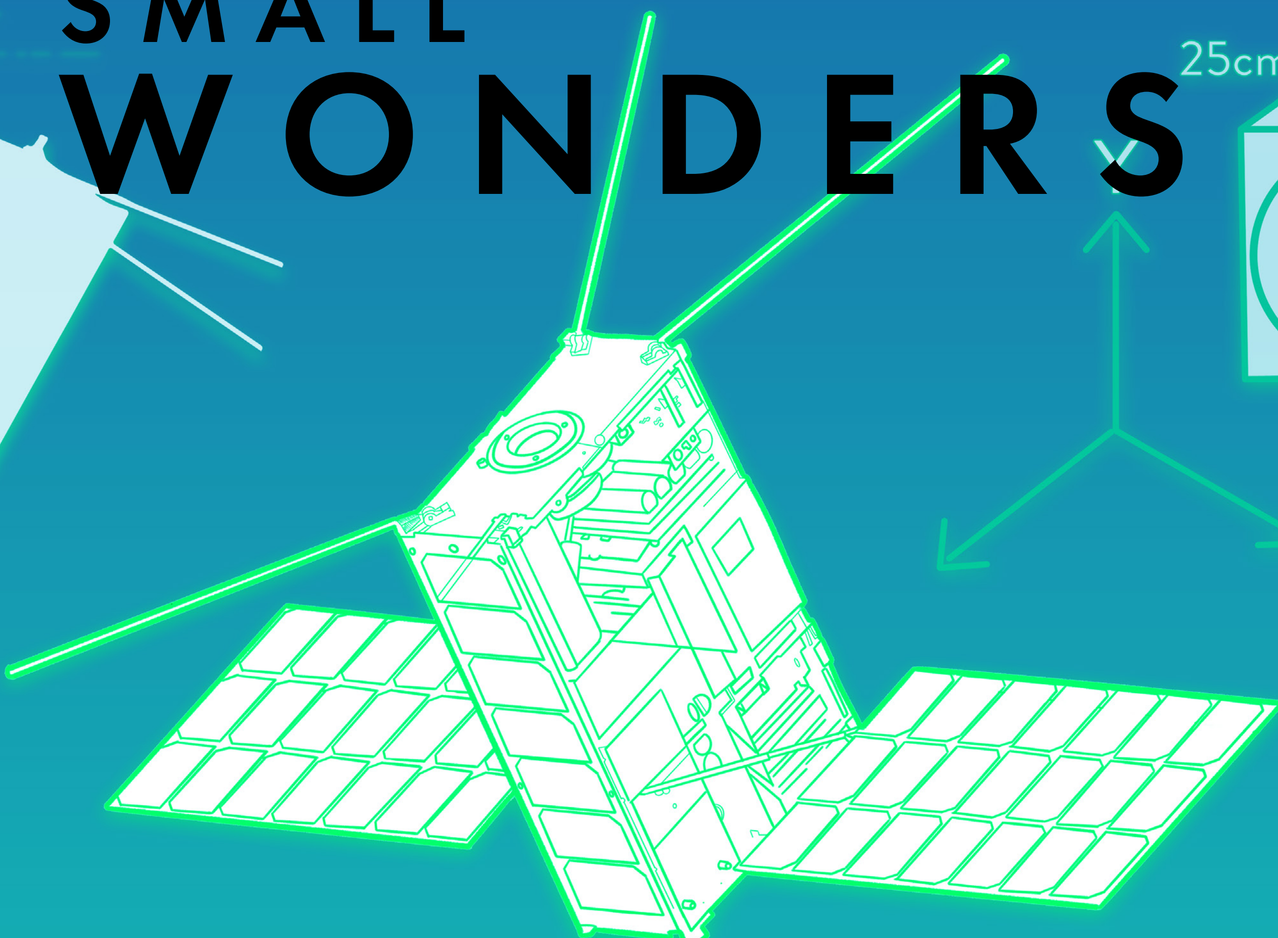

Shared Launches, Hardware Reliability, and SmallSat Tech at Goddard

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ABOUT THE COVER

These sketches symbolize the preliminary plans that NASA engineers create when visualizing SmallSat missions. Featured in the center is the Lunar IceCube CubeSat mission, which is led by Morehead State University in Morehead, Kentucky and also includes contributions from NASA's Goddard Space Flight Center in Greenbelt, Maryland; NASA's Jet Propulsion Laboratory in Pasadena, California; NASA's Katherine Johnson Independent Verification and Validation Center in Fairmont, West Virginia; and commercial partners. Lunar IceCube will fly thousands of miles to study water on the Moon. With NASA's Artemis program planning to land the first woman and next man on the Moon by 2024, Lunar IceCube is a precursor mission, scoping out key resources on the Moon that future astronauts will need.

Illustration by: NASA/Danielle Battle

OFFICE OF THE CHIEF

Like so many organizations around the world, NASA has spent the past few months adapting operations to carry work forward in a safe way. At the Strategic Partnerships Office, where interpersonal connection is a huge part of our mission, we've used all the virtual tools and resources we have to continue transferring Goddard's technologies to the private sector while fostering innovation within our science and engineering community.

Though the Small Satellite Conference is virtual this year, Goddard has committed to strong online participation. I know that webinars and instant messages aren't quite the same as meeting face-to-face, but if there's anything I've learned from this experience, it's that we are all connected, even when we're far apart.

Goddard's engineers have worked diligently over the past few years on five CubeSat missions that will fly to space in the near future. The missions feature bold science objectives and exciting new technologies that will expand the capabilities of the platform. From release mechanisms to thermal louvers, these patented technologies serve as a resource to companies interested in going to space.

Please turn the page for stories of Goddard innovation, including our commitment to SmallSat reliability and a full list of Goddard SmallSat technologies available for licensing. And remember, the Strategic Partnerships Office is only a video screen away.

Darryl Mitchell

Darryl R. Mitchell, Chief

Strategic Partnerships Office
NASA's Goddard Space Flight Center

SHARE THE RIDE

Rideshare makes access to space more affordable for SmallSat missions

A U.S. Air Force mission called STP-2, pictured here, carried more than 20 spacecraft into flight when it launched in 2019.

Photo Used with Permission from SpaceX, Inc.

Anyone who's caught a ride with a friend knows that rideshare has significant benefits. Instead of driving five separate cars to a party, multiple people can ride together in one car. It's convenient, cost-effective, and eliminates waste.

Though rideshare has existed for decades in the aerospace community, the expanding size of launch vehicles opened the door for new rideshare possibilities. In the 1990s, NASA, the United States Air Force, the United States Department of Defense, and other organizations began pursuing the advantages of rideshare. If a primary mission already paid for the launch vehicle, secondary payloads could be accommodated for a very low cost and save each mission valuable resources. Since then, the aerospace community has worked together in pursuit of better communication and collaboration, planning launches in a way that maximizes a launch vehicle's capacity.

Several recent rideshare launches have yielded amazing results. A private company, Spaceflight, Inc., set a rideshare record in 2018 with SSO-A, which toted 64 spacecraft for 35 customers into orbit. In 2019, the U.S. Air Force launched STP-2, a groundbreaking launch vehicle that carried 24 payloads and delivered them into three different orbits. Mission planners at NASA's Goddard Space Flight Center see this approach as the way of the future.

"The benefits of combining multiple spacecraft into one launch are huge," says Bob Caffrey, rideshare manager at Goddard. "The cost of going to space is so expensive, but when missions can save a chunk of the budget on launch costs, they can put that much more into their science objectives."

THE ORIGINS OF RIDESHARE

As with any NASA story, this one starts with acronyms. "ESPA" is an acronym within an acronym. The Evolved Expendable Launch Vehicle (EELV) program started in the 1990s, and the EELV Secondary Payload Adapter (ESPA) program was started to improve the accessibility and affordability of rideshare launches for U.S. spacecraft. Though the name of the EELV program changed, the ESPA acronym stuck.

ESPA rings attach to a launch vehicle and feature slots where secondary payloads can stow securely until deployment in space. Like a tool belt worn around the waist, an ESPA ring increases a launch vehicle's carrying capacity to accommodate SmallSats and CubeSats in addition to the larger primary payload.

Caffrey coordinates rideshare opportunities for Goddard, and over the past 20 years, he's seen a gradual change in the space community's view on rideshare.

"The issue is that we're seeing so much capacity on launch vehicles going wasted," Caffrey says. "I think we've hit an inflection point where we're seeing a shift from only dedicated launches to more rideshare launches. NASA is on the verge of seeing a dramatic reduction in our access to space costs, but we need to continue our collaborations with industry and the U.S. Air Force."

Partnerships have played a role in rideshare since the very beginning. CSA Engineering, a small business in 1998 and part of Moog Space and Defense since 2008, won funding through the Small Business Innovation Research (SBIR) program to design and build the original ESPA ring for the Air Force Research Laboratory Space Vehicles Directorate. Working with the U.S. Air Force Research Laboratory and the U.S. Department of Defense Space Test Program, CSA Engineering tested their ESPA ring design for the first time in 2002. Since then, government agencies and private industry alike have used rideshare to benefit their programs.

Caffrey credits the U.S. Air Force for leading the way in rideshare. The service branch funded early design work and created a rideshare user guide (RUG) that helped create standards for secondary spacecraft designs. Moog published an ESPA User's Guide in 2018. SpaceX followed suit with its RUG in 2019, and NASA is working on its own version of the RUG.

In order for rideshare to work, government, universities, and industry need to communicate about launch schedules, upcoming payloads, and ride configurations. With full participation and careful planning, millions of mission dollars a year can be saved through rideshare.

HITCHING A RIDE

Caffrey says a recent NASA mission called the Transiting Exoplanet Survey Satellite (TESS) provides a great example of a missed rideshare opportunity. When TESS launched in 2018 aboard a SpaceX Falcon 9 rocket, it flew all alone. TESS weighed about 400 kilograms, and the launch vehicle could have carried around 3,000 additional kilograms.

Landsat 9 is part of a series of satellites that have taken images of Earth since 1972.
Photo credit: NASA/Goddard Media Studios

By comparison, the U.S. Air Force mission called STP-2 carried 12 spacecraft and 12 CubeSats when it launched in 2019. STP-2 managed to deploy its payloads into three different orbits, making it more accommodating of missions that need specific orbits to accomplish their science or technology demonstration goals. Carrying a combination of spacecraft from U.S. Air Force, U.S. Department of Defense, NASA, the National Oceanic and Atmospheric Administration (NOAA), universities, and private companies, STP-2 represents a huge success story for rideshare.

Traditionally, each orbit would have required its own launch vehicle, costing approximately $60-$120 million apiece. It's easy to see how rideshare can lead to lower mission costs.

"This was a really good collaboration between NASA, the U.S. Air Force, and industry," Caffrey says. "The organizations that participated didn't have to pay for the entire launch vehicle – just a piece of it."

Caffrey says future NASA missions will more closely resemble the STP-2 launch rather than the TESS launch. Landsat 9, currently scheduled to launch in 2021, is a great example of future rideshare possibilities.

Much like the STP-2 mission, Landsat 9's launch vehicle will carry multiple payloads into different orbits. NASA, the U.S. Air Force, and Department of Defense teams are working on SmallSats that will catch a ride with Landsat 9.

"Some of the smaller missions flying with Landsat 9 would never get flown if it weren't for rideshare," Caffrey says. "You're saving money and enabling more science by sharing the launch vehicle."

MAKING THE SWITCH

In order to maximize the benefits of rideshare, members of the aerospace community need to communicate about launch schedules and mission requirements years in advance. At Goddard, Caffrey facilitates communication and works with Goddard principal investigators and systems engineers to find rides for their science missions and concept studies.

Some coordination involves the spacecraft themselves – SmallSat buses can be built specifically to fit into ESPA ring ports. Known as ESPA-class satellites, this level of standardization lowers spacecraft costs and minimizes any integration hardships. Early in mission timelines, Caffrey likes to sit down with principal investigators (PIs) and match payloads to upcoming launch opportunities. As PIs complete preliminary mission development steps, such as running their mission through Goddard's Mission Design Lab, Caffrey can help them figure out how to get their mission to space.

"It's great when you can say in your proposal that you've already identified multiple flight opportunities," Caffrey says.

As rideshare grows, NASA will further utilize tools such as the NASA Small Spacecraft Systems Virtual Institute (https://www.nasa.gov/smallsat-institute), an ongoing initiative for members of the SmallSat community to exchange information and pool resources. Though still in its initial phases, the website's Launch Portal lists upcoming NASA missions and possible rideshare adapters those launches will carry. If the timing and orbits match, missions can reach out to NASA and inquire about rideshare opportunities. The more mission planners coordinate, the more launch cost savings can be achieved.

"When an industry or a technology reaches an inflection point, things change," Caffrey says. "For example, huge changes happened when we shifted from mainframe computers to personal computers, or from landline phones to cell phones. Costs drop, efficiencies improve, markets shift, industry leaders change, and more. I'm excited to see how this inflection point will change the aerospace community."

In 2019, a SpaceX Falcon Heavy rocket launched the U.S. Air Force's STP-2 mission into orbit, including four NASA payloads.
Photo Used with Permission from SpaceX, Inc.

MEET THE MISSIONS

A cohort of CubeSat missions underway at Goddard

Building on a strong foundation of CubeSat development from the past decade, Goddard has five upcoming CubeSat missions that will tackle groundbreaking science objectives and demonstrate new technologies in space. The CubeSat platform has come into its own, making it an appealing and affordable option for Goddard's scientists and engineers. Spanning many Goddard scientific disciplines and areas of study, these five missions will continue to advance CubeSats as a versatile approach to spaceflight and validate new technologies for industry and university use.

BURSTCUBE

The BurstCube mission shows that small satellites can go after big objectives. The CubeSat will carry instruments designed to detect gravitational wave event counterparts called short gamma ray bursts. These cosmic signals coincide with gravitational wave events, which are ripples in space-time created by exceptionally violent and explosive events, such as black hole collisions.

BurstCube's 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.

The BurstCube mission will 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 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.

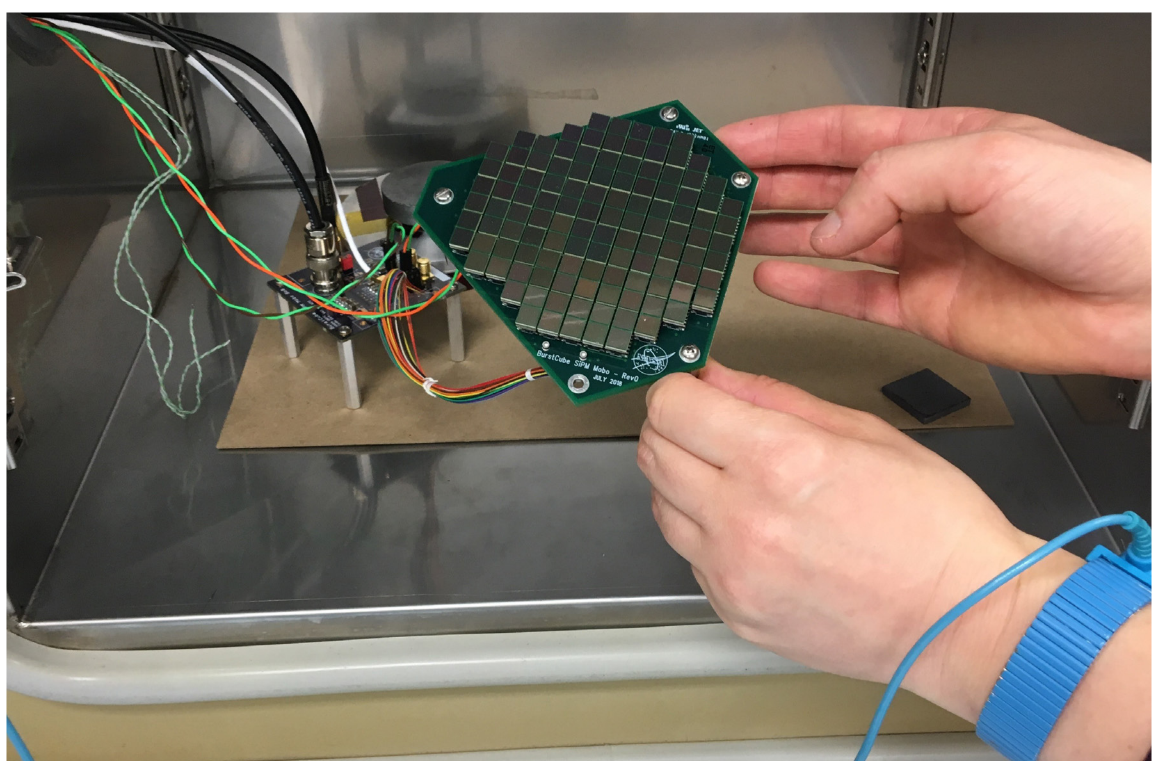


Photo Credit: NASA/Amy Klarup

BurstCube's silicon photomultiplier arrays will help the CubeSat supplement gravitational wave research.

As mission preparation carries forward, Principal Investigator Jeremy Perkins says they've made some adjustments to BurstCube's instrument based on results from a Naval Research Laboratory mission, which recently flew a similar silicon photomultiplier technology.

"It's really beneficial to gain this experience on small platforms, where you can take on more risk," Perkins says.

DIONE

Goddard flies satellites that study weather patterns on Earth as well as in space, and a CubeSat named Dione will turn its focus on the latter when it launches into low Earth orbit. Dione will be packed to the brim with information-gathering technologies, carrying one engineering experiment and four science instruments.

The CubeSat shares several instruments in common with another Goddard mission – just like petitSat, Dione will fly INMS and GRIDS. In addition to those two science instruments, Dione will also carry a flight-tested fluxgate magnetometer and the brand-new Dual Electrostatic Analyzer, which has not yet flown in space. Eftyhia Zesta is the principal investigator for the Dione mission.

Space weather typically comes from the Sun in the form of solar flares or coronal mass ejections, which send dollops of radiation into Earth's atmosphere and can cause trouble for satellites. With Dione's full ensemble of instruments, the team will study the effects of solar energy on Earth's magnetosphere and gather information to help predict space weather events.

In the future, NASA might fly an entire constellation of Dione-like spacecraft, working in tandem to take measurements from different locations in orbit. This is part of a larger movement at Goddard to pursue missions that feature small spacecraft flying in constellations. With CubeSats serving as testbeds for miniaturized technology, NASA can chase after heliophysics questions that still need answers.

GTOSAT

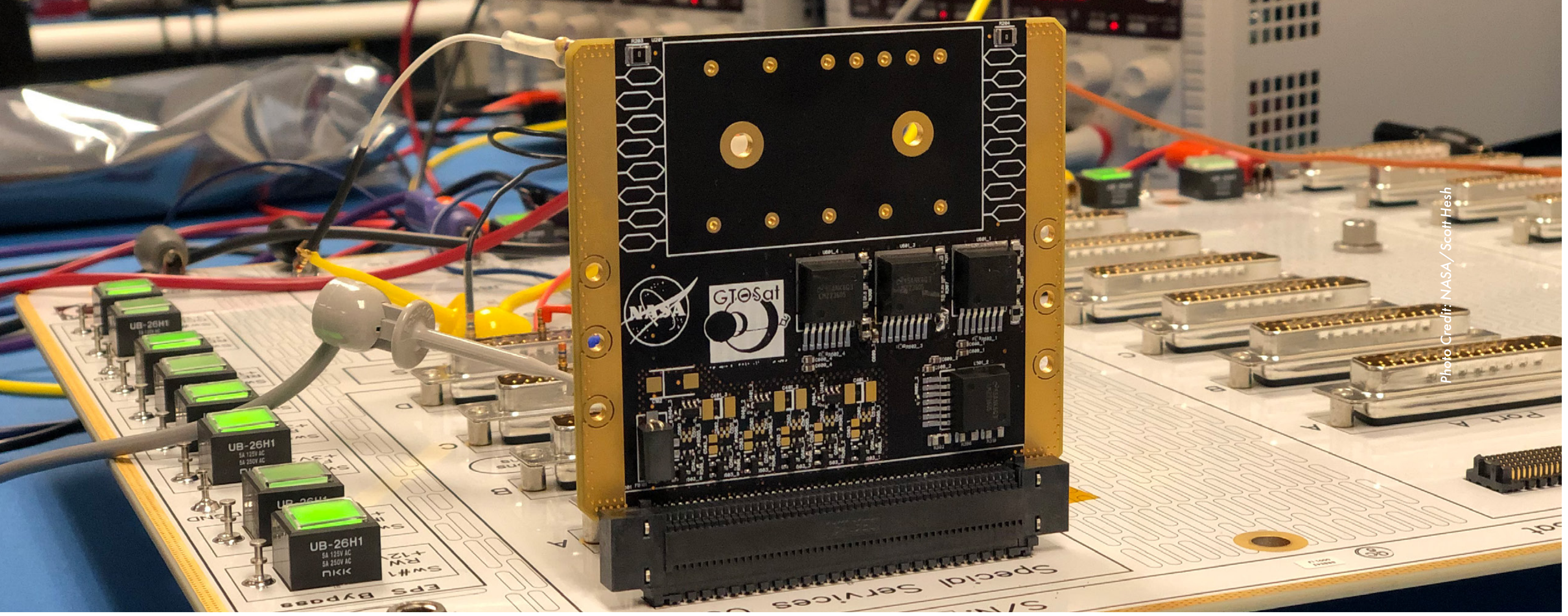
This hardy CubeSat is bound for a volatile environment where few CubeSats have dared to travel before – into the radiation-heavy Van Allen Belts, where charged particles endanger the function of a CubeSat's sensitive equipment. GTOSat (short for Geosynchronous Transfer Orbit Satellite) will need shielding and radiation-tolerant components to survive its mission into this harsh region around Earth.

"It's been a challenge designing for this intense radiation environment, 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.

Blum and her team are up for the challenge. The Van Allen Belts are 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.

The first instrument is an energy particle detector called the Relativistic Electron Magnetic Spectrometer (REMS). 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.

> "AS A PATHFINDER, ***GTOSAT WILL*** DEMONSTRATE ***HOW*** CUBESATS CAN BE USED ***BEYOND*** LEO."
>
> — Lauren Blum, GTOSat Principal Investigator



Goddard engineers test CubeSat components on a "flatsat," which serves as a testbed before the CubeSat mission is finished.

The second instrument, a 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 breaks the mold in another way – while most CubeSat missions fly in Low Earth Orbit (LEO) because of the greater availability of flight opportunities, 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, known as a geo-transfer orbit.

"As a pathfinder, GTOSat will demonstrate how CubeSats can be used beyond LEO," Blum says.

PETITSAT

Though diminutive in size, petitSat will tackle the challenging goal of studying Earth's ionosphere. Short for Plasma Enhancements in The Ionosphere-Thermosphere Satellite, petitSat carries two instruments – the Ion-Neutral Mass Spectrometer (INMS) and the Gridded Retarding Ion Drift Sensor (GRIDS).

The Goddard-developed INMS proved its space-worthiness on Dellingr, a CubeSat that launched in 2017. As part of the Dellingr mission, INMS successfully detected ions in the atmosphere. Engineers built another INMS for the petitSat mission, and this instrument will focus its efforts on studying irregularities in the density of Earth's ionosphere. The gaseous ionosphere is filled with electrically charged atoms and molecules, including pockets filled with unusual densities of electrons. Goddard scientists are interested in studying these irregularities because they can interfere with GPS and radar signals that NASA satellites use to communicate and send data back to Earth. When a radio wave hits an irregularity as it travels through the ionosphere, it can become distorted, impacting the quality of the transmission.

With the GRIDS instrument, provided by Utah State University and Virginia Tech, petitSat will be able to measure ion characteristics such as temperature, density, and drift. Together, INMS and GRIDS will provide a more complete picture of the ionosphere's plasma environment, helping scientists gain valuable information about the mechanisms at play.

"The petitSat mission builds off of Goddard's work with the Dellingr mission and is paving the way forward for other missions to examine Earth's upper atmosphere," says Jeff Klenzing, the mission's principal investigator. "The INMS and GRIDS instruments will also fly onboard the Dione mission."

SNOOPI

This Goddard CubeSat mission will test out a new technique to measure deep soil moisture, a metric that could prove useful for agriculture as well as flood and drought predictions. Instead of generating its own radio signal, the SNOOPI mission (Signals of Opportunity: P-band Investigation) will embrace a resourceful approach by leveraging a preexisting commercial radio signal. The "signal of opportunity" offers a powerful P-band frequency source, which can penetrate deeper into the ground than other frequencies in current use.

When the signal reflection returns to space, SNOOPI's tiny antennas will pick it up to produce maps that are related to moisture in the soil. Rajat Bindlish, a Goddard scientist with the mission, says that the P-band frequency directly measures the deeper parts of the soil column known as "the root zone."

"Current missions, like Soil Moisture Active Passive (SMAP), can only measure the surface soil moisture," Bindlish says. "Soil moisture in the deeper layers is estimated using land surface models."

With SNOOPI, Bindlish says, the team can make direct observations of root-zone soil moisture, which is important for agriculture and food security. Plant roots draw the water from deeper layers of the soil, and this information helps determine plant health and agricultural yield. It can also help forecast floods and drought.

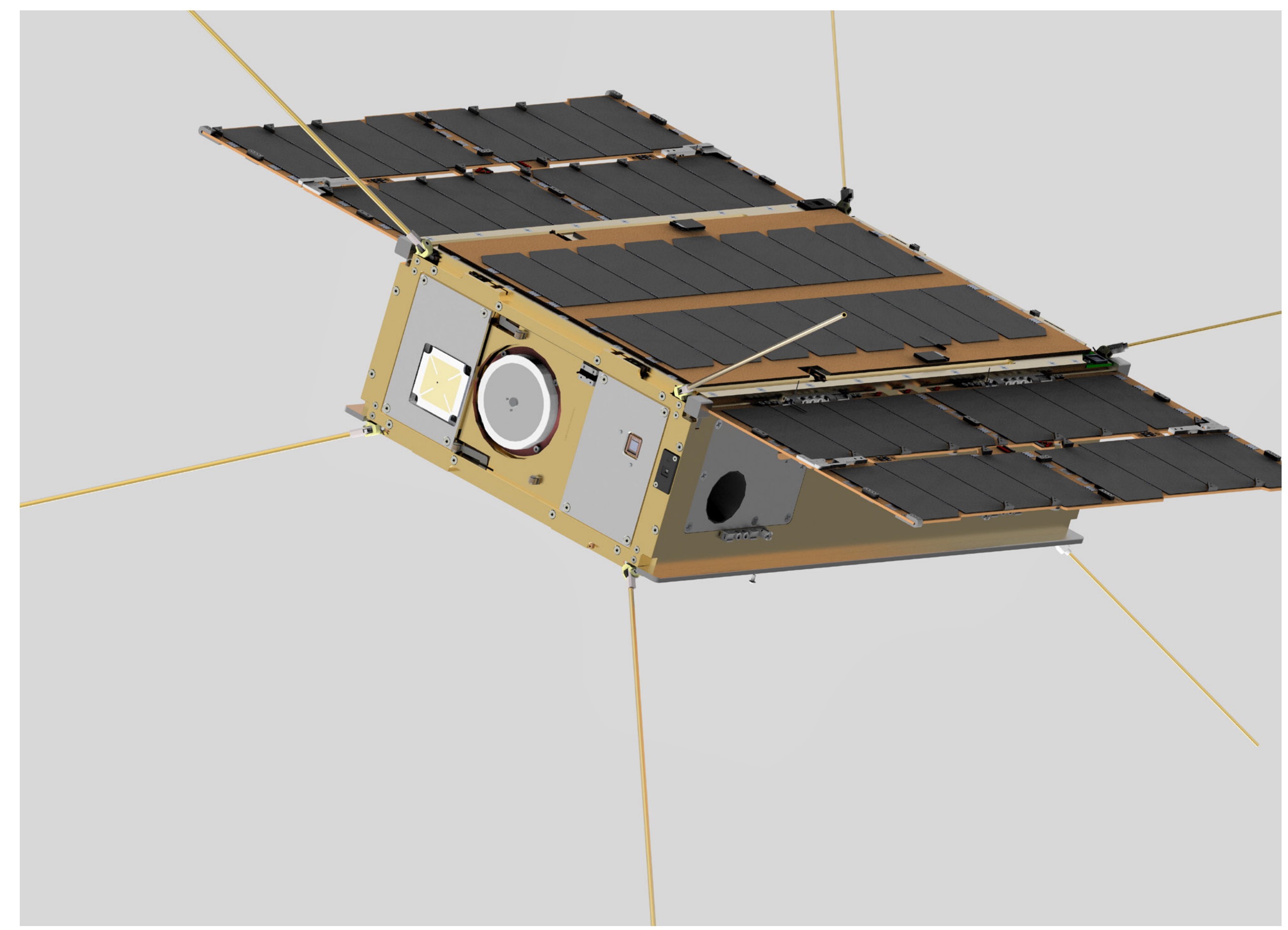
"Wet soil in the deeper layers will lead to larger floods because the rainfall will run off instead of getting absorbed in the soil," Bindlish adds.

Lead Instrument Engineer Manuel Vega says that the team has built engineering models for the major subsystems of the instrument, and testing is the next step.

Jeffrey Piepmeier, a Goddard engineer with the SNOOPI mission, says that CubeSats make it possible to do technology demonstrations such as this one by offering a relatively low-cost, accessible platform. As part of a cohort of Goddard CubeSat missions, SNOOPI benefits from the successes and advances of its teammates.

Of CubeSats, Piepmeier says, "The hardware may be smaller, but the science, instrument calibration, and performance are not."

The SNOOPI mission is led by Principal Investigator James Garrison of Purdue University.



This CAD model of the SNOOPI CubeSat shows the antennas that will pick up a preexisting commercial radio signal.

Photo Credit: NASA/Austin Tanner

ION CONTROL SYSTEM

Propulsion technology gives a boost to SmallSat missions

Some of NASA's biggest missions have used propulsion systems to explore the far reaches of the solar system. Propulsion systems help a spacecraft accelerate in the vacuum of space, and they can be used to maneuver in orbit or guide interplanetary trajectories. Being small in mass and minimalist in design, small satellites rarely have propulsion systems and rely on the power of gravity to keep them flying. This can lead to problems when a spacecraft drifts out of orbit.

There is another application for propulsion: attitude control systems, or ACS. Engineers at NASA's Goddard Space Flight Center have invented an actuator system designed specifically for CubeSats called the "Ion Control System." Built to be efficient and scalable, the patent-pending Ion Control System (ICS) opens up new possibilities for SmallSat missions.

"With CubeSats, a lot of times they don't have any propulsion system at all," says Steven West, a mechanical engineer at Goddard. "You have drag in low Earth orbit, and over time your CubeSat loses its orbit and burns up."

Though the idea of actuator systems for SmallSats has existed for decades, Goddard engineers began working on the ICS around four years ago. Goddard's SmallSat ambitions have grown, with plans for formation flying of SmallSat constellations, and technology development has kept pace to accommodate those plans.

"In order to keep control of your spacecraft, you need to have precision ACS actuators," West says. "It's really a key technology for these future small spacecraft missions."

IMPORTANT FEATURES

The CubeSat platform lends itself well to technology development and testing, and the ICS is no exception.

"One great thing about CubeSats is that they are relatively inexpensive to fly," says Bob Moss, a Goddard electrical engineer and lead for the ICS' Internal Research and Development proposal. "You can have a quick turnaround for another mission while making a few improvements."

When building a propulsion system for a SmallSat, Moss and his team considered which characteristics would lead to success in space. These include safety, scalability, and efficiency.

Larger missions often use propulsion systems that are pressurized and feature flammable or toxic materials. Since SmallSats typically share a launch vehicle with a larger, more expensive primary payload, it's important that secondary payloads don't result in damage to the larger mission. Pressurized SmallSat systems can result in explosions and damage a primary payload that flies on the same launch vehicle.

The ICS uses a nontoxic, inert metal as fuel and isn't pressurized, making it safer and reducing risk. In addition to being safe, the ICS is scalable, meaning it can be adapted to the size of a mission. The system uses commercial-off-the-shelf parts, and because of this, the ICS is inexpensive and integrates easily into a satellite bus.

Another key feature of the ICS is its efficiency. Because the system uses solid metal, it can carry more fuel in a compact fashion compared to gas or liquid fuel. Furthermore, the system's design decreases overhead power loss, which increases overall efficiency compared to other propulsion system designs.

"The testing we've done shows we've increased the system efficiency, meaning the power output divided by power input, from 7 percent to nearly 50 percent, which really sets it apart from what others have been doing and any prior testing that we've performed," says Dakotah Rusley, a Goddard electrical engineer.

APPLICATIONS

The ICS could be used to extend the life of SmallSat missions in orbit. Satellites slowly succumb to drag while in low Earth orbit, but with a propulsion system, engineers could correct the spacecraft's orbit and add months to the mission's lifespan.

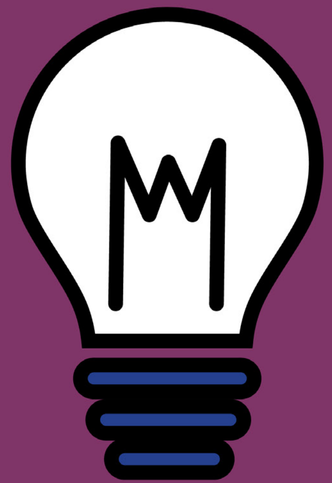
"The whole point of CubeSats is to enable real science on a small budget," Rusley says. "If we can enable more science and longer mission duration without increasing the budget, we're helping meet that goal."

"THE WHOLE ***POINT*** OF CUBESATS IS TO ***ENABLE*** REAL SCIENCE ***ON A SMALL BUDGET.*** IF WE CAN ENABLE MORE SCIENCE AND LONGER MISSION DURATION ***WITHOUT*** INCREASING THE BUDGET, WE'RE ***HELPING*** MEET THAT GOAL."

— DAKOTAH RUSLEY,
GODDARD ELECTRICAL ENGINEER

BENEFITS

- Easy to integrate with satellites
- Low cost
- Reduces contamination likelihood
- Enables easy customization



APPLICATIONS

- SmallSat propulsion
- CubeSat propulsion
- Formation flying technologies

The ICS also has applications in formation flying for SmallSat constellations. In 2015, Goddard flew a constellation of four large spacecraft called the Magnetospheric Multiscale Mission. Since then, Goddard has developed several SmallSat constellation concepts, all of which are still in early stages. An upcoming Goddard CubeSat mission called Signals of Opportunity: P-band Investigation (SNOOPI) could serve as a precursor to a follow-on constellation mission.

Technologies like the ICS enable these new types of missions by providing thrust that can keep the small spacecraft flying together while maintaining distance between them. As missions work through technology demonstrations on single CubeSat platforms, they pave the way for future constellations.

The ICS will fly on the petitSat mission, which is scheduled to launch in late 2021, as a secondary payload to the CubeSat's primary instruments. After six months of collecting science data, petitSat will turn on the ICS and gather data about its performance in space. Once the primary mission is complete, Moss and his team will use the ICS to adjust the spacecraft's attitude and measure the results.

LICENSING OPPORTUNITIES

The petitSat mission will increase the ICS' Technology Readiness Level even further, but interested companies are welcome to contact Goddard's Strategic Partnerships Office (SPO) about licensing this patent-pending technology. To learn more about the ICS, please read the Technology Opportunity Sheet (https://technology.nasa.gov/patent/GSC-TOPS-237) and contact SPO at techtransfer@gsfc.nasa.gov.

THE QUEST FOR RELIABILITY

SmallSat Reliability Initiative offers new resources for mission developers

The NASA-sponsored HaloSat CubeSat mission deployed from the International Space Station in 2018. Photo Credit: NASA

As the chief technologist for the Engineering and Technology Directorate at NASA's Goddard Space Flight Center, Michael Johnson keeps a close eye on the evolving landscape of SmallSat mission development. Small satellites, he says, are poised to accomplish incredible mission objectives that didn't seem possible just a few years ago.

"It's quite exciting that SmallSats are being used for deep space missions and going beyond low Earth orbit," Johnson says. "At Goddard, we're working to add more reliable capabilities to our SmallSat missions consistent with missions bound for deep space."

CubeSats surfaced more than 20 years ago as inexpensive and experimental platforms, meant to test new technologies and science concepts. These types of spacecraft typically take on a greater level of risk than traditional, more elaborate missions, which require extensive testing and thoroughly validated hardware. However, as SmallSat missions have blossomed in the past decade, Goddard engineers have come to view SmallSats as spacecraft that can adopt more challenging and complex objectives. This has resulted in an effort to boost the confidence of SmallSat missions as they grow to fill more central roles in NASA's plans.

For the last few years, Goddard has participated in a public-private collaboration called the Small Satellite Reliability Initiative. This all-volunteer endeavor seeks to improve the confidence that SmallSat-based missions will achieve their mission objectives.

This year, the initiative received funding from NASA Headquarters to compile a knowledge base that will incorporate best practices, lessons learned, design and development guidelines, and other resources acquired by the SmallSat community to date. In doing so, the initiative will help stakeholders, developers, and other interested groups improve their ability to achieve mission objectives with SmallSats.

"We're quite excited to deliver this product to the community," Johnson says.

An initial version of the SmallSat Mission Confidence Knowledge Base will launch during or shortly after the 2020 SmallSat Conference. Users can explore the online platform and provide feedback to continue improving the resource. The initiative is working closely with the Small Spacecraft Systems Virtual Institute, Johnson says.

This kind of resource-pooling effort is only possible through participation from organizations all across the SmallSat spectrum, from government agencies and private companies to nonprofits and universities. The intent, Johnson says, is to offer a broad assortment of knowledge targeting a diversity of mission developers and stakeholders.

"We're gathering up the best of what we know in order to leverage SmallSat activities from across the aerospace sector – this will allow the community to understand what's been done and what might be possible to achieve," Johnson adds.

There's immense value in working across organizations to accomplish mission objectives in a cost-effective manner, Johnson says. Though Goddard and the government sector can serve as an enabler and a catalyst, public-private collaborations such as the Small Satellite Reliability Initiative need participation from the private sector in order to thrive.

"There's so much value in working across sectors," Johnson says. "Knowledge is power, and when we can make knowledge available where it's needed and when it's needed, that helps everyone succeed."

"WE'RE GATHERING UP THE ***BEST*** OF WHAT WE KNOW IN ORDER TO LEVERAGE SMALLSAT ACTIVITIES FROM ACROSS THE AEROSPACE SECTOR – THIS WILL ***ALLOW*** THE COMMUNITY TO UNDERSTAND ***WHAT'S BEEN DONE*** AND ***WHAT MIGHT BE POSSIBLE TO ACHIEVE.***"

— Michael Johnson, Chief Technologist, Goddard Engineering and Technology Directorate

SOLAR SMALLSAT

Proposed SmallSat mission will test optical communication and heliophysics instrument

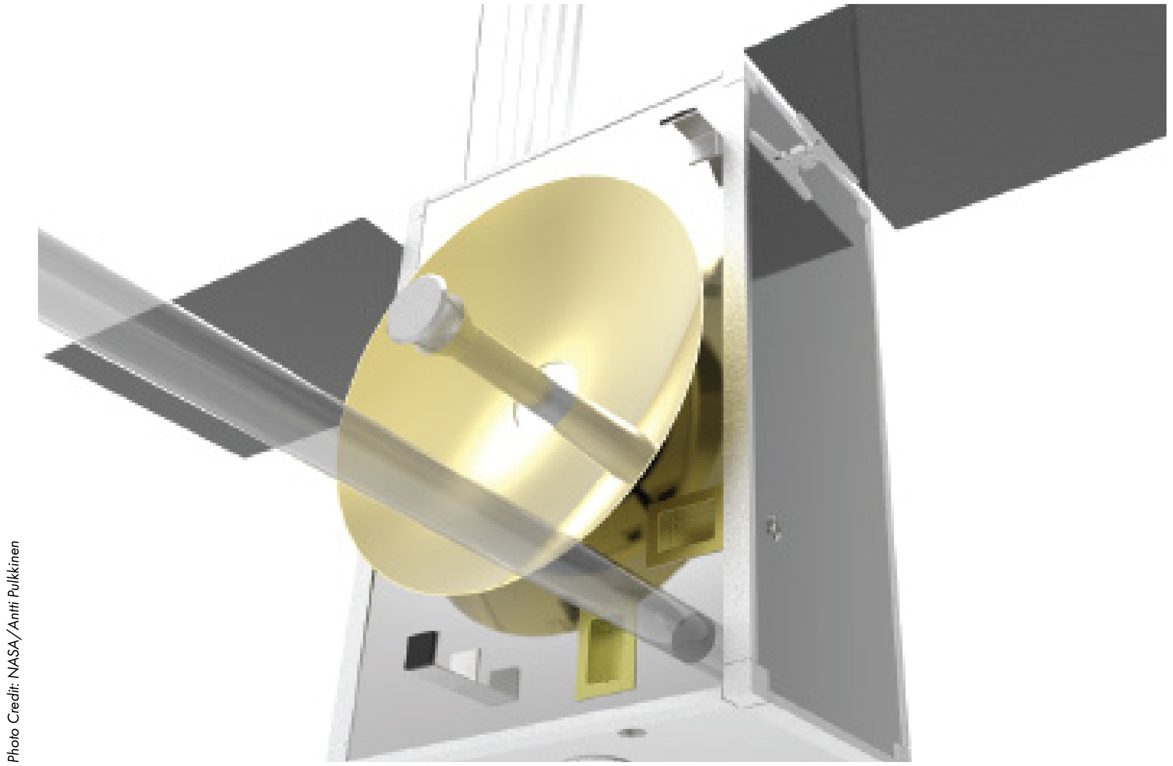


Photo Credit: NASA/Antti Pulkkinen

The proposed Science-Enabling Technologies for Heliophysics (SETH) mission will demonstrate a first-of-its-kind heliophysics instrument.

Optical communication, a first-of-its-kind heliophysics instrument, and creative rideshare approaches – from beginning to end, the proposed Science-Enabling Technologies for Heliophysics (SETH) mission is chock full of innovation.

"This is a SmallSat technology demonstration mission," explains Antti Pulkkinen, a Goddard scientist and principal investigator for SETH. "We're demonstrating high data rate optical communications on a SmallSat, and we're also demonstrating a new science instrument called HELENA."

In 2019, NASA funded SETH for a $400,000 mission concept study. If selected for further development, SETH will hitch a ride as a secondary payload with the Interstellar Mapping and Acceleration Probe (IMAP), a mission conducted by NASA, Johns Hopkins University's Applied Physics Lab (APL), and Princeton University.

SETH evolved from a larger mission concept called CATSCANS, which featured a constellation of SmallSats equipped with solar imaging instruments in deep space. While figuring out engineering logistics, Pulkkinen and his team determined that CATSCANS would generate enormous volumes of data. With some members of the constellation stationed far from Earth, standard communications systems wouldn't be able to handle the transmission of data from the spacecraft back to stations on the ground.

"This situation pushed us to look at new, innovative solutions for our communications system," Pulkkinen says.

Optical communication is a promising new technique for sending data back and forth through space using light instead of radio waves. Lasers can transmit data at higher rates and faster speeds than radio frequencies, which make them attractive alternatives to current communications methods.

The CATSCANS mission's solar imaging instruments would generate about 500 megabytes of data per day. Using standard X-band radio frequency systems, it would take six days for a spacecraft to send one day's worth of data back to Earth from about 46.5 million miles away. With an optical communications system, the downlink would only take 100 minutes.

NASA's Lunar Laser Communication Demonstration from 2013 to 2014 successfully tested optical communications technology, and the yet-to-be-launched Laser Communications Relay Demonstration (LCRD) will further prove the technique's value in space.

Though optical communication has a promising future, no one has yet developed or flown SmallSat optical communication systems in deep space, meaning that the technology hadn't advanced far enough to be used on the CATSCANS mission. Instead, Pulkkinen and his team decided to pursue a technology demonstration mission with a single SmallSat.

"LCRD is a geostationary mission, and the flight terminal weighs tens of kilograms," Pulkkinen says. "SETH's flight terminal will weigh around 3 kilograms, so it's a completely different engineering challenge."

If SETH can successfully demonstrate SmallSat optical communications in space, it will "open the floodgates" for working with large data volumes on SmallSat missions, Pulkkinen says. NASA could use SmallSats to take high-resolution images of the Moon's surface or conduct data-heavy astrophysics missions.

"Optical communication is science-enabling," Pulkkinen says. "Without it, we wouldn't be able to do missions like this."

The communications technology will support SETH's science instrument, called the HELio Energetic Neutral Atom (HELENA) detector. It's tailor-made to take direct measurements of solar energetic neutral atoms, a first for heliophysics instruments. In addition to making a splash in terms of fundamental science advancements, HELENA is also sensitive to solar X-rays and energetic charged particles, which pose dangers for human spaceflight. As NASA gears up for Moon and Mars missions, it's more important than ever to detect radiation threats. Instruments like HELENA could help protect space crews from harmful solar emissions.

If selected, SETH will take advantage of NASA's increasing rideshare opportunities by launching with the IMAP mission and other spacecraft on the same launch vehicle. Weighing around 180 pounds, the SETH spacecraft bus will fit onto an EELV Secondary Payload Adapter (ESPA) ring, which NASA and other organizations use to send multiple payloads together into space. ESPA rings can offer significant budgetary benefits, since launch costs are split between missions.

When the other ride share payloads deploy and the IMAP spacecraft separates from the upper stage of the launch vehicle, SETH will utilize upper stage disposal burn to achieve its intended course. This novel approach maximizes efficiency for the small spacecraft mission, allowing it to achieve a more desirable orbit than it would on its own.

"We're innovating not only in our spacecraft but also in how we get to our trajectory," Pulkkinen points out.

> OPTICAL COMMUNICATION IS ***SCIENCE-ENABLING***. WITHOUT IT, WE WOULDN'T BE ABLE TO DO ***MISSIONS*** LIKE THIS."
>
> — Antti Pulkkinen, SETH PI

Photo Credit: NASA/Bill Hrybyk

SOFTWARE FOR SMALLSATS

> FOR SMALLSAT MISSIONS THAT INVOLVE UNIVERSITY STUDENTS, WE WANT TO MAKE cFS ***EASIER*** FOR STUDENTS TO GET ***UP AND RUNNING***."
>
> — James Marshall, Goddard software engineer

GODDARD SOFTWARE FOR CUBESATS AND SMALLSATS

High-quality software sets the stage for mission success. Software engineers with NASA's Goddard Space Flight Center have spent years honing the specialized code that helps keep a spacecraft running smoothly. From simulating flight parameters to executing commands in space, software empowers CubeSat and SmallSat missions to capture new science data and demonstrate technologies in space.

Goddard has several open-source software packages that can help smaller missions get off the ground. The core Flight System (cFS) is a flight software framework with a layered architecture that builds on best practices from previous missions and works in tandem with mission-specific applications. The NASA Operational Simulator for Small Satellites (NOS^3) is a suite of tools that caters specifically to small satellite missions and helps shorten development timelines.

Flight-tested on recent CubeSat missions, these software offerings can save valuable time and ease budgets by preventing the need to start from scratch with software development. If your mission has software needs, please visit https://github.com/nasa/cFS to learn more.

NASA OPERATIONAL SIMULATOR FOR SMALL SATELLITES (NOS^3)

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," says Justin Morris, who helped develop NOS^3. "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 NASA's STF-1 CubeSat 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.

"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? NOS³ can help answer those kinds of questions."

As a NASA software, NOS³ 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 architecture adopted by many missions and used at seven NASA centers – adds yet another layer of efficiency to NOS³.

The software package can be downloaded directly from NASA's GitHub page at https://github.com/nasa/nos3.

core FLIGHT SYSTEM (cFS)

Flight software is the specialized code that runs onboard a spacecraft. With cFS, software developers at Goddard created a software package that included the core pieces of code that every mission needs, as well as the artifacts that accompanied it, featuring a "layered" approach that would allow for the addition of mission-specific code built on top of validated and existing code.

This structure includes an operating system abstraction layer that enables cFS to port from operating system to operating system with practically no modifications, a platform abstraction layer that makes it easy to port cFS to new flight computers, and the core Flight Executive layer that includes all of the common services NASA missions need to succeed.

This layered flight software framework also includes individualized mission applications, much like apps on a smartphone. cFS became fully open source in 2015, and many NASA missions have used cFS, including the CubeSat Dellingr and the larger Global Precipitation Measurement (GPM) mission.

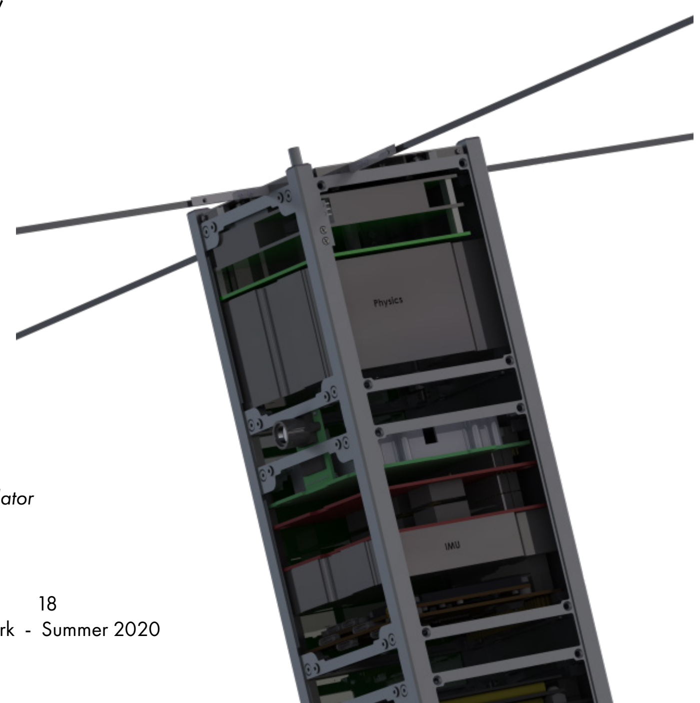
As the winner of NASA's 2020 Software of the Year award, cFS has a lot to offer the SmallSat community, and currently, Goddard software engineer James Marshall is working to increase cFS' accessibility by making it possible to write apps in Python. Previously, apps for cFS needed to be written in C or C++.

"Python is a popular computer language, especially in the university community," Marshall says. "For SmallSat missions that involve university students, we want to make cFS easier for students to get up and running."

Marshall says that cFS has a number of advantages that make it a natural fit for SmallSat and CubeSat missions. It has a robust flight heritage, and its open source nature makes it readily available.

"You can go to GitHub and download all the source code, which is perfect for a small university mission that doesn't have the budget to buy software," Marshall adds.

To view and download cFS, visit https://cfs.gsfc.nasa.gov.



The STF-1 mission demonstrated the use of the NASA Operational Simulator for Small Satellites (NOS³).

SMALLSAT TECHNOLOGY

NASA's Goddard Space Flight Center brings years of expertise in small satellite technology development and mission planning to the SmallSat community. Through NASA's Technology Transfer Program, members of the public can license patented technologies for their own use, saving valuable time and resources. Instead of starting from scratch, companies can incorporate Goddard technologies into their mission design, freeing up resources for other parts of the mission. Below, please find a list of featured technologies. To learn more about these licensing opportunities, or if you have questions about specific technology needs, please contact Goddard's Strategic Partnerships Office at techtransfer@gsfc.nasa.gov.

OPTICAL COMMUNICATION

OPTIMETRIC MEASUREMENTS OVER COHERENT FREE SPACE OPTICAL COMMUNICATION GSC-17781-1
Through utilizing coherent optical communication to combine optimetric measurements over an optical carrier, one can accurately measure Doppler and absolute ranging. This process works through a looping and synchronizing iteration, measuring frame, bit, and phase change values using a phase detector and clock data recovery apparatus. The technique improves free space optical communications.
Patent Number: 10,148,352

STEERING MIRROR ASSISTED LASER FINE POINTING GSC-17782-1
The system more finely points lasers so as to improve the precision of space optical communications and ranging. Through linking a laser beam mirror steering mechanism and associated closed loop control, any residual error in pointing to a desired target is reduced dramatically.
Patent Number: 10,228,465

ON-DEMAND, DYNAMIC RECONFIGURABLE BROADCAST TECHNOLOGY FOR SPACE LASER COMMUNICATION GSC-17922-1
The mirror system can address likely obstacles in space optical communications. Through using miniature adjustable mirrors and programmed phase delays to diffract a single communication beam, numerous diffracted beams can be sent to other satellites in various directions for communication and tracking.
Patent Pending

SPACECUBE

SPACECUBE V2.0 PROCESSOR CARD, ENGINEERING MODEL GSC-16673-1
SpaceCube is a cross-cutting, in-flight reconfigurable Field Programmable Gate Array (FPGA) based on-board hybrid science data processing system. The goal of the SpaceCube program is to provide 10 to 100 times improvements in on-board computing power while lowering relative power consumption and cost.
Patent Number: 9,705,320

SPACECUBE DEMONSTRATION PLATFORM GSC-15953-1
This fault-tolerant framework allows for recovery from radiation upsets. It is reconfigurable from the ground while in orbit. It can be used to produce fault tolerance technologies and serves as a generic data processing solution for space-based applications.
Patent Number: 8,484,509

SPACECUBE V2.0 FLIGHT PROCESSOR CARD GSC-16700-1
This flight processor card leverages six years of heritage SpaceCube designs while advancing the technology one more step. The processor architecture is designed to be better suited to handle radiation upsets than its predecessors, and it is built for a longer life cycle.
Patent Number: 9,549,467

SPACECUBE V2.0 MICRO GSC-16805-1
This technology is a subset of the SpaceCube v2.0 Engineering Model, Mini, and Engineering Test Unit designs. It is a Single Board Computer (SBC) intended for systems requiring low power and a very powerful data processor.
Patent Number: 9,851,763

SPACECUBE 2.0 FLIGHT CARD MECHANICAL SYSTEM GSC-17868-1
SpaceCube 2.0 is a family of high-performance reconfigurable systems designed for spaceflight applications requiring on-board processing. The SpaceCube 2.0 Flight Card Mechanical System is inherently adaptable and configurable for various configurations.
Patent Number: 10,681,837

SPACECUBE V2.0 PROCESSOR WITH DDR2 MEMORY UPGRADE GSC-17983-1
The improved version of the card assembly extends the life and design of the processor and provides even greater memory throughput to support the next generation of instruments.
Patent Number: 10,667,398

SPACECUBE V3.0 FLIGHT PROCESSOR CARD GSC-18136-1
SpaceCube v3.0 features the radiation-tolerant multi-core T2080 processor and the radiation-tolerant Kintex UltraScale FPGA. The SpaceCube v3.0 Flight Processor Card meets the industry standards in lightweight systems specifications.
Patent Pending

SPACECUBE V3.0 RADHARD MONITOR GSC-18417-1
The SpaceCube v3.0 RadHard Monitor is an FPGA IP that is responsible for providing monitoring to the SpaceCube v3.0 processor card for single-event upsets and other faults.
Patent Pending

SPACECUBE V3.0 MINI EVALUATION BOARD GSC-18418-1
The Evaluation Board is designed as a breakout and test platform for the SpaceCube v3.0 Mini. It breaks out several debug and communication interfaces, as well as a large amount of General Purpose I/O to common standard PCB connectors.
Patent Pending

SPACECUBE V3.0 FMC+ MEZZANINE TEST CARD GSC-18419-1
The Mezzanine Card is an FMC+ daughter card that enables testing and development of SpaceCube v3.0 and SpaceCube v3.0 Mini processor cards.
Patent Pending

SPACECUBE V3.0 MINI ASTM BOARD GSC-18420-1
The SpaceCube v3.0 Mini ASTM Board provides a way to connect the SpaceCube v3.0 Mini Processor Card to the Automated Safe-to-Mate Machine for electrical testing.
Patent Pending

SPACECUBE V3.0 AUTOMATED TEST SUITE GSC-18434-1
This technology provides automated testing of the functionality of the SpaceCube v3.0 hardware. Individual functional tests are collected into a test suite that are run automatically.
Patent Pending

SPACECUBE V3.0 FMC+ ASTM CARD GSC-18436-1
The FMC+ ASTM Card provides a way to perform tests on the SpaceCube v3.0 Processor Card.
Patent Pending

OTHER HARDWARE

WALLOPS FLIGHT FACILITY 6U ADVANCED CUBESAT EJECTOR (ACE) GSC-16795-1
The ejector system interfaces to the launch vehicle and functions to protect the primary payload from the nanosatellite, constrain the nanosatellite during launch, and perform a guided ejection afterwards.
Patent Number: 9,434,486

MINIATURE RELEASE MECHANISM OR DIMINUTIVE ASSEMBLY FOR NANOSATELLITE DEPLOYABLES (DANY) GSC-16900-1
NASA's DANY technology uses spring-loaded metal pins, a reliable burn-through mechanism, efficient bracketing, and a circuit board to reliably stow and release deployables on command. Using DANY, stowed deployables are securely fastened using the spring-loaded locking pins.
Patent Number: 9,546,008

RADIATION HARDENED 10BASE-T ETHERNET PHYSICAL INTERFACE GSC-16902-1
This Ethernet solution combines a custom circuit and a front-end field programmable gate array (FPGA) design to implement an Ethernet Physical Interface (PHY) in compliance with IEEE 802.3. The custom circuit uses available radiation-hardened parts and handles the electrical interface between standard differential Ethernet signals and the digital signal levels in the FPGA.
Patent Number: 9,680,527

CUBESAT FORM FACTOR THERMAL CONTROL LOUVERS GSC-17034-1
The thermal control louvers use passive thermal control to significantly improve the internal thermal stability of small spacecraft, creating a difference of several watts in dissipated heat between open and closed louvers. The modular design can be produced in large quantities and swapped into various sized plates to tailor the thermal control to each spacecraft's needs.
Patent Number: 9,862,507

CUBESAT COMPATIBLE HIGH RESOLUTION THERMAL INFRARED IMAGER GSC-17113-1
The thermal infrared imager has high quantum efficiency, broad spectral response, and ease of fabrication. It is small and compact, making it ideal for the CubeSat platform.
Patent Number: 10,306,155

DELLINGR 6U CUBESAT GSC-17152-1
The Dellingr CubeSat design is more reliable than previous CubeSat designs. It is cost effective and more robust in terms of volume and power than older designs.
Patent Number: 9,938,023

MICROSCALE ELECTRO HYDRODYNAMIC (EHD) MODULAR CARTRIDGE PUMP GSC-17220-1
This innovation incorporates a simplistic design that reduces the number of components required to make an assembly by up to 90 percent over previous iterations, ensuring a solid, reliable electrical connection to the electrodes that form the pumping sections. Its modular design allows for flexibility in incorporating the pump cartridge into various assemblies and applications.
Patent Number: 10,461,621

OCCULTER FOR CUBESAT CORONAGRAPH GSC-17246-1
This technology is designed to minimize noise from the coronagraph that can interfere with data collection and analysis. It has applications in solar research and photography where the goal is to image a dim object near a bright one.
Patent Number: 9,921,099

SMALLSAT ATTITUDE CONTROL AND ENERGY STORAGE GSC-17252-1
By replacing reaction wheel ensembles with reaction spheres, this technology reduces the overall size and net power consumption of conventional three-axis attitude control systems.
Patent Number: 10,053,242

GRAPHENE FIELD EFFECT TRANSISTORS FOR RADIATION DETECTION (GFET-RS) GSC-17279-1
Unlike conventional charge-sensing detectors, the GFET-RS utilizes the sensitive dependence of graphene conductance on local change of the electric field, which can be induced by interaction of radiation with the underlying absorber substrate. This technology provides low power consumption and high sensitivity radiation sensors for the commercial space industry and government agencies.
Patent Number: 9,508,885

MAGNETIC SHAPE MEMORY ACTUATOR GSC-17551-1
The push-pull type actuator utilizes a magnetic shape memory alloy. The actuator has nanometer precision and self-position sensing, enabling reliable actuation with applications ranging from precise optical instrument pointing to simple locking mechanisms.
Patent Number: 10,581,345

DEPLOYABLE BOOM FOR CUBESATS GSC-17579-1
The deployable boom for CubeSats is a rigid boom over 50 centimeters in length when deployed that houses a three-axis magnetometer. It is stowed on one side of the CubeSat with a double hinge system.
Patent Number: 10,717,548

NOVEL ANTENNA CONCEPT FOR CUBESAT PLATFORMS GSC-17864-1
By integrating the antenna into the structure of a CubeSat, the need for extruding antennas, packaging considerations, and a deployment mechanism are eliminated. The resulting antenna has reduced weight and volume, as well as increased dependability.
Patent Number: 10,361,472

ULTRA COMPACT STAR SCANNER GSC-17887-1
This innovative approach fuses the rapid advancements in miniaturized high-speed electronics with the ultra-compact freeform optical design from NASA efforts to create the next generation of stellar scanner instruments.
Patent Pending

A TWO-WAY MICROWAVE POWER DIVIDER USING MICROSTRIP TRANSMISSION LINES GSC-17888-1
The power divider has matched impedances via Klopfenstein tapered transmission lines to provide ultra-bandwidth functionality with low losses and a small physical footprint.
Patent Number: 10,370,127

SMALLSAT COMMON ELECTRONICS BOARD (SCEB) COMPLEMENT BOARD DESIGN: MEMORY CARD GSC-17902-1
The innovation is a miniaturized memory board that has up to 96 GB of NAND Flash memory along with either a radiation tolerant FPGA or a set of three commercial FPGAs. The memory board is designed to interface with the standard subsystems of Goddard's Modular SmallSat Architecture (GMSA).
Patent Pending

ACTIVE POINTING AND TRACKING DESIGN TO CORRECT YAW AND PITCH RANGE ERROR IN LASER SATELLITE-TO-SATELLITE TRACKING (SST) GSC-17923-1
By using a programmable phase mirror, a communication laser beam from the master satellite can be dynamically diffracted into multiple narrow beams, and each diffracted beam tracks a separate receiving satellite to broadcast information.
Patent Pending

MINIATURIZED ASTROMETRIC ALIGNMENT SENSOR GSC-17963-1
The technology advances satellite capabilities for astrophysical measurements, which are necessary for formation flying, relative navigation, and virtual telescope capabilities. The Miniaturized Astrometric Alignment Sensor makes it possible to measure a spacecraft's altitude and orientation with respect to known stellar objects.
Patent Number: 10,657,371

ION CONTROL SYSTEM GSC-17976-1
The electric propulsion system is suitable for small satellite attitude control, precision orbit control, constellation formation management, and extended low-thrust maneuvers.
Patent Pending

A BROADBAND, COMPACT LOW-POWER MICROWAVE RADIOMETER DOWN CONVERTER FOR SMALL SATELLITE APPLICATIONS GSC-18098-1
The system includes a fundamental local oscillator source composed of a broadband tunable frequency synthesizer as well as a crystal oscillator. The synthesizer employs a harmonic doubler to expand frequency coverage.
Patent Number: 10,659,094

SELF-REGULATING CURRENT CIRCUIT GSC-18108-1
This technology utilizes a switching regulator to provide high-efficiency power conversion. The Self-Regulating Current Circuit simplifies the deployment of a circuit as circuit resistance associated with wire and interfaces are negated due to the self-regulating circuit. The entire circuit can be miniaturized and can still provide relatively high constant current needed for nickel chrome based deployment devices.
Patent Number: 10,742,115

DEPLOYABLE SYSTEM FOR CUBESAT ELECTRIC FIELD INSTRUMENT (CEFI) GSC-18120-1
CEFI is a 3-axis electric field instrument with six rigid booms packaged into a less than 1.5U CubeSat volume.
Patent Pending

DIRECTION OF ARRIVAL ESTIMATION SIGNAL OF OPPORTUNITY RECEIVER GSC-18190-1
This transceiver technology for small satellite and CubeSat platforms enables maximization of antenna gain in a specific direction to receive desired signals and suppress signals from other directions.
Patent Pending

SILICON OXIDE COATED ALUMINIZED POLYIMIDE FILM RADIATOR COATING GSC-18217-1
This technology uses all the exposed surfaces on the six sides of a CubeSat as radiators. All the internal components are thermally coupled to the radiators. The technology lowers power demand and eliminates the need for voluminous heat regulation.
Patent Pending

SOFTWARE

THE CORE FLIGHT SYSTEM (CFS)
The cFS is a flight software framework with a layered architecture that builds on best practices from previous missions and works in tandem with mission-specific applications.

THE NASA OPERATIONAL SIMULATOR FOR SMALL SATELLITES (NOS³)
NOS³ is a suite of tools that caters specifically to small satellite missions and helps shorten development timelines.

Goddard's thermal control louvers use passive thermal control to significantly improve the internal thermal stability of small spacecraft.

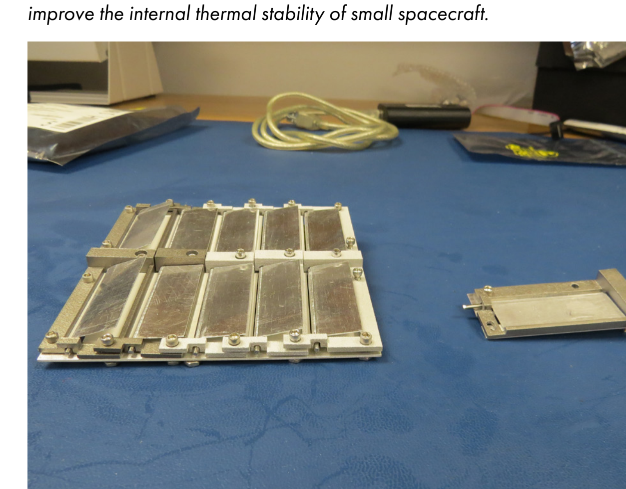


Photo Credit: NASA/Amy Klarup

EXHIBIT SCHEDULE

AUGUST 3RD

3:30 - 4:15PM MT — NASA'S CORE FLIGHT SYSTEM AND MULTI-MISSION NOS^3

ALAN CUDMORE IN GODDARD'S LIVE SMALLSAT SOFTWARE SERIES

NASA Goddard Space Flight Center's core Flight System, better known as cFS, is an open source flight software framework that is being used on an increasing number of missions across NASA, other space agencies, and the aerospace industry. The range of current and future cFS missions includes Artemis Gateway and the Orion crew capsule, spacesuits, Lunar orbiters and rovers, Earth orbiters, a Titan quadcopter, CubeSats, terrestrial drones and autonomous vehicles. Any embedded flight or ground system can use cFS and take advantage of the years of heritage and NASA experience built into cFS' flight-quality code base and an active open source community. This presentation will give a brief overview of the cFS project and open source community, followed by a more detailed look at the SmallSat oriented cFS distribution known as Multi-Mission NOS^3. The Multi-Mission NOS^3 cFS distribution is being used on five upcoming CubeSats at NASA Goddard Space Flight Center.

CLICK HERE TO JOIN

AUGUST 4TH

1:00 - 1:45PM MT — CUBESAT MISSION DEFINITION AND DESIGN LIVE DISCUSSION

LUIS SANTOS (MODERATOR), JOHN HUDECK, SEAN SEMPER, BEN CERVANTES, WILL MAST & JUAN RAYMOND IN GODDARD'S LIVE SMALLSAT SERIES

CubeSat developers at GSFC gather to answer questions and talk about their experience in the mission definition and design stages of a CubeSat development. Join the discussion by asking questions to our panel members.

CLICK HERE TO JOIN

2:00 - 2:45PM MT —OPENSATKIT — MAKING SPACE FOR CFS APPS

DAVE MCCOMAS IN GODDARD'S LIVE SMALLSAT SOFTWARE SERIES

OpenSatKit(OSK) provides a desktop environment for learning the core Flight System (cFS) Framework and apps, developing new apps and integrating apps into a functional system. OSK combines the following three open source projects: Ball Aerospace's COSMOS, NASA's cFS and 42 simulator. This presentation provides an overview of OSK's features and will demonstrate some of its functionality such as creating and running a 'hello world' app. For more information please go to https://github.com/OpenSatKit/OpenSatKit/wiki.

CLICK HERE TO JOIN

3:00 - 3:45PM MT — NASA OPERATIONAL SIMULATOR FOR SMALL SATELLITES — OVERVIEW AND NEW FUNCTIONALITY IN RELEASE 1.05.00

MATT GRUBB IN GODDARD'S LIVE SMALLSAT SOFTWARE SERIES

The NASA Operational Simulator for Small Satellites, commonly referred to as NOS^3, is an open-source, software only testbed for small satellites licensed under the NASA Open Source Agreement. It is a collection of Linux executables and libraries delivered in a ready-to-run virtual machine that can be customized for SmallSat missions. NOS^3 provides a development environment to write new FSW (using GSFC's cFS), generate hardware models, provide dynamics to those hardware models (using GSFC's 42), and a ground system to communicate with the virtual spacecraft. In Release 1.05.00, NOS^3 has added new functionality that will further assist missions in developing and testing their FSW, as well as adding the latest cFS 6.7 release.

CLICK HERE TO JOIN

4:00 - 4:45PM MT — GODDARD'S OFFICE OF STEM ENGAGEMENT (OSTEM) OFFICE HOURS

Do you have questions about internships or careers at Goddard? Visit Goddard's OSTEM team- ask questions and get answers real time!

CLICK HERE TO JOIN

AUGUST 5TH

10:30 - 10:45PM MT — NON-PROCUREMENT BUSINESS OPPORTUNITIES WITH NASA

JOE KROENER & ERIC MCGILL IN GODDARD'S LIVE SMALLSAT SERIES

Join us to discuss non-procurement business opportunities from NASA from Goddard's senior technology manager and the Agency partnerships office program director. Understand how NASA handles reimbursable and non-reimbursable partnerships, the goals of the Agency, and exciting collaboration opportunities for industry and academia. Also learn how Centers and the Agency are committed to streamlining processes in order to make doing business with NASA a smooth process.

CLICK HERE TO JOIN

11:00 - 11:45PM MT — MODULAR ARCHITECTURE FOR A RESILIENT EXTENSIBLE SMALLSAT

ROBIN RIPLEY IN GODDARD'S LIVE SMALLSAT SERIES

Goddard Space Flight Center developed a modular architecture for beyond-LEO SmallSat missions. This architecture allows the development of a system for harsh space environments while addressing affordability for small satellites. The modular and extensible nature of the architecture allows flexibility for components used (from commercial to highly customized hardware) and spacecraft size (from CubeSats to ESPA-class). This presentation will provide an overview of the architecture and some of the MARES-compatible components in development.

CLICK HERE TO JOIN

1:00 - 1:45PM MT — CUBESAT INTEGRATION, TESTING AND OPERATIONS LIVE DISCUSSION

LUIS SANTOS (MODERATOR), TOM JOHNSON, JOHN LUCAS, BRIAN ABRESCH, CHUCK CLAGETT AND JUAN RAYMOND IN GODDARD'S LIVE SMALLSAT SERIES

CubeSat developers at GSFC gather to answer questions and talk about their experience in the mission integration, testing and operations stages of a CubeSat development. Join the discussion by asking questions to our panel members.

CLICK HERE TO JOIN

2:00 - 2:45PM MT — GODDARD SMALLSAT OFFICE HOURS

Do you have questions about Goddard's SmallSat projects, missions, technology or capabilities? Now is the time to ask! Join this WebEx at any time during our Goddard SmallSat Office Hours to talk directly to members from the Goddard SmallSat team!

CLICK HERE TO JOIN

AUGUST 6TH

10:00 - 10:45PM MT — GODDARD'S OFFICE OF STEM ENGAGEMENT (OSTEM) OFFICE HOURS

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CLICK HERE TO JOIN

11:00 - 11:45PM MT — GODDARD SMALLSAT OFFICE HOURS

Do you have questions about Goddard's SmallSat projects, missions, technology or capabilities? Now is the time to ask! Join this WebEx at any time during our Goddard SmallSat Office Hours to talk directly to members from the Goddard SmallSat team!

CLICK HERE TO JOIN

Following more than a decade of engagement with the small satellite community, Goddard formed the Small Satellite Project Office in 2017.

Photo Credit: NASA/Small Satellite Project Office

THE SPARK

Goddard's The Spark shares stories about technology transfer at NASA and the innovative people who make it all possible. The magazine is published quarterly by the Strategic Partnerships Office at NASA's Goddard Space Flight Center.

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

Send suggestions to Amy Klarup, magazine editor: *amy.k.klarup@nasa.gov*.