National Aeronautics and Space Administration

NASA

THE SPARK

TECH TRANSFER, PARTNERSHIPS, AND SBIR/STTR AT GODDARD

EARTH'S CHANGING CLIMATE *IS ON THIN ICE*

How Goddard Technologies Provide Climate Data to the World

VOLUME 20 | NUMBER 4 | FALL 2022

CONTENTS

ABOUT THE COVER

Polar bears already face shorter ice seasons - limiting prime hunting and breeding opportunities. The decline was even greater in the Barents Sea and the Arctic basin. Sea ice concentration during the summer months — an important measure because summertime is when some subpopulations are forced to fast on land — also declined in all regions, by 1 percent to 9 percent per decade.

Photo Credit: Mario Hoppmann / GSFC

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OFFICE OF THE CHIEF

When most people think of NASA Goddard, they think of rocket launchers and space missions – and with good reason. This past year alone, the James Webb Space Telescope started sending back incredible images of far-away galaxies and stars. NASA's Double Asteroid Redirection Test (DART) spacecraft successfully targeted and hit the binary asteroid system Didymos. And, with NASA preparing to return to the Moon and later travel on a manned mission to Mars, the Artemis 1 rocket lifted off from the Kennedy Space Center. These are all great achievements that garnered media attention and captured the public's imagination, and Goddard played a big role in all of those missions.

What is sometimes lost in all that excitement is all the great work that NASA is doing to contribute to our knowledge and understanding of what is happening right here on Earth. Most people probably don't know that NASA is a global leader in studying Earth's changing climate.

From space, sky, sea, and land, Goddard provides detailed climate data and research to the world, which helps us learn how the interconnected systems of our planet interact. Among the many relevant areas studied at Goddard are solar activity, sea level rise, the temperature of the atmosphere and ocean, the health of the ozone layer, air pollution, and changes in sea and land ice.

Three articles in this issue of The Spark examine several efforts made by Goddard engineers and scientists that could potentially provide valuable climate science data. Dr. Antti Pulkkinen, director of Goddard's Heliophysics Science Division, explains the exposed danger to our power gird, caused by Geomagnetically Induced Currents from solar storms. It also details how Goddard is working with utility companies to mitigate this important issue.

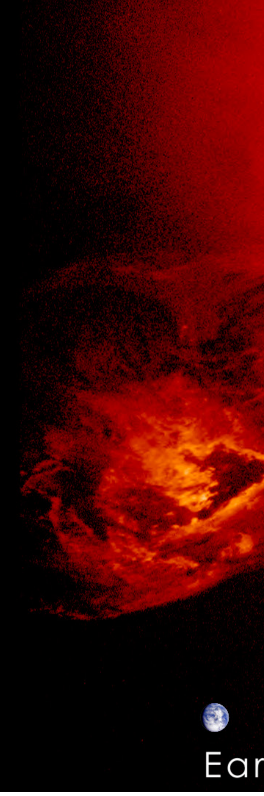
Two engineers with Goddard's Instrument Systems and Technology Division, Dr. Mark Stephen and Dr. Fabrizio Gambini, are now developing a new revolutionary microwave sounding instrument that will provide meteorologists with a higher optical resolution measurement of Earth's atmosphere. Finally, using NASA's ICESat-2 (Ice, Cloud, and land Elevation Satellite 2), a team of scientists from Goddard ventured on a two-week NASA mission to Greenland this summer, to validate measurements of sea ice thickness and help determine the rate of sea ice melting.

Supporting these new technologies and ushering them out into the world through licensing, partnerships, and commercialization is a key part of the Strategic Partnerships Office's role at Goddard. To achieve that goal, we seek new entrepreneurial partners in industry, including small business and start-up companies, to help us develop and implement key climate-related technologies for the 21st century and beyond.

Darryl R. Mitchell, Chief

Strategic Partnerships Office
NASA's Goddard Space Flight Center

GODDARD PROVIDES CRITICAL DATA TO THE POWER INDUSTRY TO MITIGATE MAJOR SPACE STORM BLACKOUTS



On Friday March 10, 1989, NASA scientists witnessed a powerful explosion on the Sun, which sent super-charged magnetic particles into space. Within minutes, the magnetic forces of the Sun unleashed what they described as a "billion-ton cloud of gas," equal to the amount of energy released if thousands of nuclear bombs exploded in unison. Traveling at an estimated rate of one million miles per hour, a vast storm cloud of solar plasma – gas of electrically charged particles - then rushed to Earth.

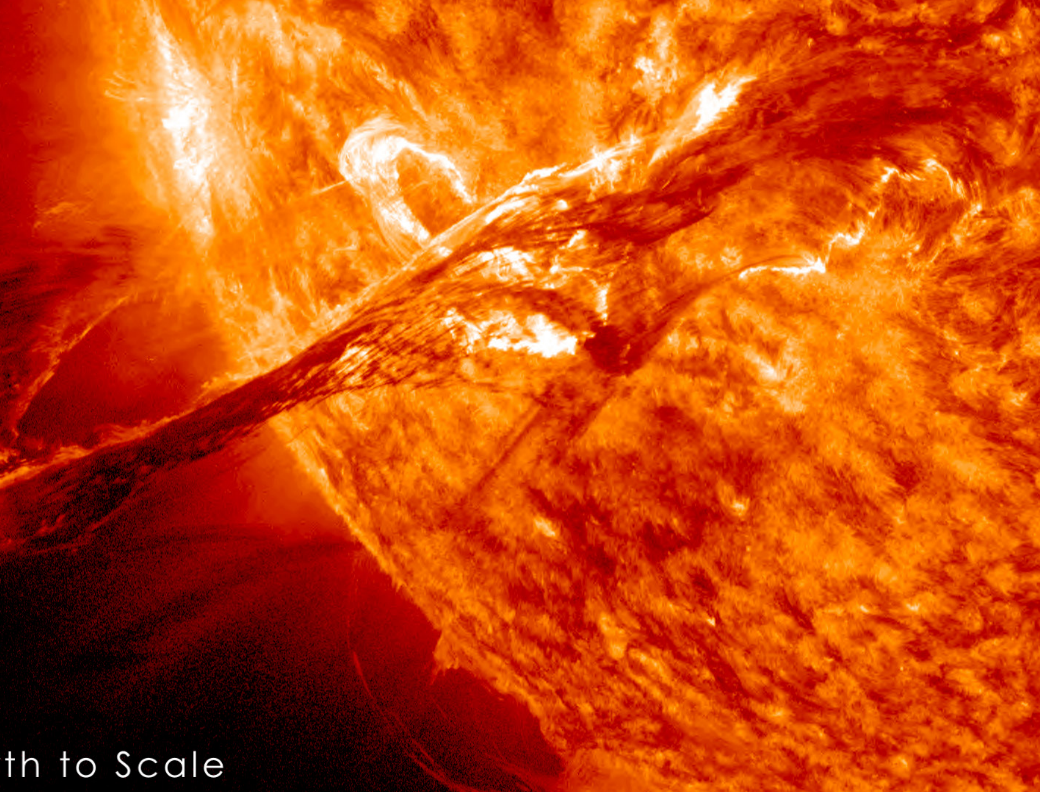
On March 12, the solar storm struck Earth's magnetic field, causing an incredibly powerful geomagnetic storm that produced electrical currents in the ground beneath much of North America. A day later, these currents found a weakness in the electrical power grid of Quebec, Canada. Due to Geomagnetically Induced Currents (GIC), it took less than two minutes for the entire power grid in the Canadian province of Quebec to completely lose power.

"Fundamentally, GIC are these extra electric currents that can flow into a technological system and damage things, such as power grids, oil and gas pipelines, communication cables and networks, and railway systems," explained Dr. Antti Pulkkinen, director of Goddard's Heliophysics Science Division. "These [electrical currents] are generated through an almost antenna-like behavior called inductive coupling [in which a magnetic field creates an electrical current that affects something else]. So, when you have a jolt to an electrical current system in such a very dynamic fashion, most power grids are not designed to handle the extra currents flowing through them, creating all sorts of problems for the operating system."

What followed in Quebec was a 12-hour blackout. Millions of people suddenly found themselves in dark office buildings and homes, or even stuck in stalled elevators. The blackout also closed schools and businesses, kept the Montreal Metro shut down during the morning rush hour, and closed Montreal's Dorval Airport.

But the blackout in Quebec was by no means an isolated, local event. Within minutes of the March 13 storm, over 200 power grid problems erupted across the continental United States as well. Some U.S. electrical utilities had their own cliffhanger problems to deal with. New York Power lost 150 megawatts the moment the Quebec power grid went down. The New England Power Pool lost 1,410 megawatts at about the same time. Fortunately, none of these caused a blackout in the U.S.

Since that nightmare event in 1989, NASA and the National Oceanic and Atmospheric Administration (NOAA) have been working to prevent anything like this from happening again, by helping energy providers prepare for space storms. To help the power trans-



Extreme solar flare, Photo Credit: NASA's Goddard Space Flight Center Scientific Visualization Studio

mission industry, Pulkkinen and his team at Goddard have spent considerable time and energy providing valuable research data to improve their understanding of the hazard itself.

"Thirty years ago, most U.S. utility companies had never heard of space or geomagnetic storms, they had no idea what the hell it was," said Pulkkinen. "Now, with the help of data and research provided by our Goddard office, they are better aware of this weird thing called a space weather storm that can be a problem and cause hazards."

Pulkkinen said there are two primary scenarios that impact power grids from a space storm. The first is a voltage collapse, where you can have a temporary blackout and the power grid goes off-line for a certain time period. In this case, power can be restored fairly rapid as the storm dissipates, and the grid survives severe damage.

"The second is sort of the end of the world scenario if you will, where one of these GICs are large enough to permanently damage high voltage transformers," says Pulkkinen. "This is a pretty scary scenario where it could potentially take years to restore those transformers and you could be looking at very extended blackouts across the nation. But what we are really concerned about right now is to better characterize what these extreme storms do to our infrastructure. That is the core of the work that we have been doing here at Goddard – partnering with our industry counterparts to really improve our understanding of how exposed we are to this problem."

Back in 2019, Pulkkinen along with Goddard engineers Todd Bonalsky, Troy Ames, and Carl Hostetter received a U.S. patent entitled a "Method of Using Power Grid as Large Antenna for Geophysical Imaging," for a technology and/or methodology for measuring and detecting the environmental conditions causing GIC. The way this Goddard-designed measuring system works is by repurposing high-voltage power transformer towers around the U.S. into a kind of large antenna capable of receiving geophysical and space physical remote sensing. This system could be used as a warning or alarm system, which can be triggered based on the amplitude of the GIC.

To test the system, Pulkkinen took this technology/methodology and partnered with American Electric Power, Dominion Virginia Power, and the Southern Company, to install scientific substations beneath their high-power transmission lines. The project represented the first time NASA used high-voltage power lines as a tool to map large-scale GIC caused by severe space storms.

"The project was a win-win for everyone involved," Pulkkinen said. "The project gave power companies the data about GICs, while offering scientists at NASA the opportunity to reverse engineer the data collected to learn more about what happens in the Earth's upper atmosphere when severe space weather is taking place. The response [from the utility companies] has been positive and, of course, people found it interesting to work with NASA to advance our scientific understanding of GIC."

Pulkkinen believes the data acquired from the project could help prevent future large-scale electrical blackouts and transformer damage caused by GIC. The

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data could also allow for better predictions for how space weather will affect power grids and how the problem can best be mitigated. After identifying the potential threat to existing power grids, Pulkkinen said the Federal Energy Regulatory Commission (FERC) – which regulates the transmission and wholesale sale of electricity in addition to licensing of non-federal hydro-power projects – require power companies to create operational plans to mitigate GIC.

"The GIC [topic] is now in a response phase with most U.S. utility companies," notes Pulkkinen. "To mitigate future solar storms, they are required by FERC to know what GIC is and why it's a hazard, so this issue should not come out of the blue. That comes through a regulatory framework. The point is: in the case of a significant space storm, [utility companies] need to have a plan in place to reduce its impact. So, when a utility company knows the hazards [of a solar storm] and creates a plan to mitigate it, the chance of major blackout will be significantly reduced. We did not have that level of preparedness in the past."

Dr. Antti Pulkkinen, director of Goddard's Heliophysics Science Division. Photo Credit: GSFC

Goddard engineers and scientists installing scientific substations beneath high-power transmission lines. Photo Credit: GSFC

Pulkkinen said many utility companies across the U.S. are presently in the assessment phase to determine what investments and/or operational procedures they need to make to reduce the vulnerability of their power grids in the face of space storms. However, Pulkkinen said Goddard's GIC stations are no longer taking measurements at the three utility industry partner locations and thus, the technology/methodology is presently in hibernation.

"There has been some background work on the engineering side [at Goddard] for the next generation of GIC stations to be more autonomous and independent, but we have not had an opportunity to install it at these three [partner] sites yet," noted Pulkkinen. "But I now believe industry is really well informed about these space storms, and with Goddard's help, they will have the tools and research data available to them to carry out these hazard assessments to find out exactly how exposed they are. That is absolutely transformational, and it gives me hope that when we have one of these extreme space storms occur in the future, we are going to be prepared. We here at Goddard have played a really central role in that."

Sun setting behind power lines. Photo Credit: Pixabay Image

Q&A

with Goddard Center Director

DENNIS ANDRUCYK


Photo Credit: NASA

> *"We have an awesome team, and I am proud to be a part of that team."*

On July 25, after 36 years of federal service, Goddard Center Director Dennis Andrucyk announced his retirement. Since 2004, Mr. Andrucyk has served in numerous senior executive leadership roles at NASA. He previously served as the deputy associate administrator for NASA's Science Mission Directorate, helping to oversee the planning, direction, and effective management of NASA programs focused on the scientific exploration of Earth, the Moon, Mars, and beyond.

Upon his announced retirement, NASA Administrator Bill Nelson had this to say about Mr. Andrucyk, "In my view, his crowning achievement at Goddard's helm has been overseeing the brilliant launch and awe-inspiring first images release of the James Webb Space Telescope, a mission that represents our vision at NASA to explore the secrets of the universe for the benefit of all. I'm grateful for his decades of public service and continued dedication to Goddard, NASA, and our nation."

Prior to joining the Science Mission Directorate, Mr. Andrucyk served as NASA's acting chief technologist and deputy associate administrator for its Space Technology Mission Directorate. He previously held many positions at Goddard, including director of its Applied Engineering and Technology Directorate, director of engineering, deputy director of engineering, chief of the Software Engineering Division, and chief of the Mission Engineering and Systems Analysis Division. He also served as Goddard's chief technologist and as associate chief of the Electrical Engineering Division. He was selected as a Goddard senior fellow in 2000.

Holder of a bachelor's degree in electrical engineering from the University of Maryland, Mr. Andrucyk has been a recipient several distinguished

NASA awards, including the NASA Outstanding Leadership Medal, NASA Exceptional Service Medal, Goddard Outstanding Leadership Honor Award, the Goddard Exceptional Achievement Award in Diversity and Equal Employment Opportunity, and also a two-time recipient of the Senior Executive Service Meritorious Presidential Rank Award.

Recently, The Spark magazine sat down with Mr. Andrucyk to talk about his career at NASA Goddard, and where he thinks the agency is headed in the future.

Q: You have had a long and distinguished career as at NASA Goddard, could you have imagined any other NASA project which could have better encapsulated your tenure and embodied the success of NASA Goddard missions, than the James Webb Space Telescope (JWST)?

A: I have been blessed with a little over 34 years of NASA service. I have worked on all kinds of projects, from SmallSats up through and including something as large as the James Webb Space Telescope. But I will tell you what, when you consider the magnitude of JWST and all the partners involved – all the U.S. government agencies, the European and Canadian Space Agencies, and all the NASA Centers – it was just a true testament to the team that helped pull JWST together. I can't think of another project that had the depth of experience coming from so many different places, on both the civil servant and contractor side. Yes, JWST was probably the most complex mission that I have worked on, and I think, ultimately will have the greatest impact on science.

Q: As somebody who has worked so long and so hard on the James Webb Space Telescope, what is your reaction to all these incredible images that we are seeing; are they better than expected, pretty much what you expected? Can words describe what we are getting from JWST?

A: I knew it was going to be great science and it's a follow up to the Hubble [Space Telescope]. Obviously, you are looking at a different segment of the electromagnetic spectrum, but the Hubble images had been just spectacular. Hubble is just the workhorse of science observatories, so I always imagined that JWST would exceed the capabilities of Hubble. But, when you are involved with it on a day-to-day basis for 25 years as I have, you sometimes lose sight of things. You get caught up in how the technology is going to work, how are we going to make the engineering work, how are we going to make sure our partners are under contract, and you forget about what the ultimate science is going to be. So, while I expected great things with JWST, the first images absolutely blew me away. When you look at that first star and you see galaxies that you could have never imagined with any kind of photobombing, it is spectacular. The images that we are getting far exceed anything that I would have expected.

Q: What have we learned thus far from those images?

A: We have not seen any peer-reviewed science coming out of it quite yet, but we are expecting it right around the corner. But I will tell you, one of the things that we did not imagine when we first built the James Webb Space Telescope, is just how much it has become a time machine, helping us look back to over two hundred million years after the big bang. In a universe that is 13.7 billion years old that is getting pretty close to seeing the origins of our universe, which is what JWST is all about. We are going to reap science dividends looking back in time. Another area of science that we hadn't planned on was the discovery of exoplanets. When we first conceived of JWST, we did not expect to do spectroscopy of the atmosphere for exoplanets. We are already doing spectroscopy of one exoplanet [WASP-39 b] that is revealing carbon dioxide. That is way cool. I think the proverbial sky is the limit on the science we are going to get from JWST.

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Q: So, when you think about it, the James Webb Science Telescope will help us to address one of the most fundamental questions in astronomy: are we alone? – which as you said, was not the original intent of the mission?

A: That is the beauty of many of our NASA missions. We have an original intent for what that mission is going to measure and quite often during that mission, we will find something new and unexpected. With JWST, it was the discovery of exoplanets, and we now have the ability to do spectroscopy and study the atmosphere of exoplanets to look for signs of life. But, now actually seeing it, it just gives me goose bumps. I don't know if we ever find people like Bipeds or humanoids like you see on Star Trek, but I will tell you what, looking for signs of life is just awesome. I can't wait to find out what the future holds.

Q: Besides the James Webb Space Telescope, which already is transforming our view of the universe, there are many other accomplishments during your tenure at Goddard. Some of those include: the Landsat 9 satellite launch, the OSIRIS-Rex mission, the Parker Solar Probe, the DAVINCI mission, the ongoing development of the Nancy Grace Roman Space Telescope, the first Minotaur IV rocket launch, as well as multiple International Space Station cargo resupply missions from Wallops. Is there anything in particular on that list of missions that stands out, or is the totality of those missions, which you believe represents your tenure at Goddard?

A: It is really the totality of it all. When you think about the magnitude of the responsibility of the Goddard Space Flight Center; we explore all four of our science areas from space. Earth Science is about protecting our own home planet. Heliophysics is understanding our Sun and its interaction with Earth. Planetary Science looks at all the other planets in our Solar System, and Astrophysics looks outside of our Solar System. Goddard has our fingerprints on each and every one of those science areas. Those missions that you just mentioned all demonstrate Goddard capabilities in each one of those areas. I am thrilled to have played a part in many, but not all, of these. You mentioned Landsat 9, which is playing a critical role in helping us to understand and manage global land resources. It is also giving us important data on Earth's climate. Since 1978, half of the polar ice cap has melted. We learned that from Landsat 9. We worked with the National Oceanic and Atmospheric Administration (NOAA) to build weather satellites and those spacecrafts give us imagery of hurricanes. And I will tell you what, the data from those satellites really helped identify the path of Hurricane Ian earlier this fall, and potentially saved lives in Florida. It's clear that many of our Goddard missions have made a tremendous impact in the areas of Earth Science, Heliophysics, Planetary Science and Astrophysics.

Q: During your tenure, would you agree that the Strategic Partnership Office (tech transfer) has taken on more importance and meaning at Goddard. If so, why is tech transfer important to the Goddard community?

A: Oh yes. What we do with tech transfer is an essential piece of what all government agencies should be about but Goddard in particular. If you consider our role in space exploration, it is the science. But we just don't do science for the sake of building an instrument in-house. But SPO in particular is doing a wonderful job of commercializing our technology and our technical capabilities. The question is: why do we do things in-house, and why do we have government sponsored technology development? One, is to make sure that the government takes on the non-recuring cost but also assumes the risk for building a capability that would otherwise be too expensive or risky for a commercial enterprise to take on. So, what the government does at Goddard in terms of developing a technology and commercializing it, is it actually makes U.S. aerospace corporations more competitive in a global marketplace. By commercializing our technologies, we are leveraging and managing the risk for the U.S. space industry, which is what the government can and should be doing. We develop unique things where there is a lot of risk involved, so making sure what we are doing is applicable to private enterprises is essential. Developing new technology and getting it commercialized is a key part of our role.

Q: Earlier, you mentioned all the partnerships NASA Goddard fostered to build and complete the James Webb Space Telescope

mission. Partnerships also plays a key role in what SPO does with tech transfer. Would you like to mention something about that?

A: Absolutely, partnerships go along with tech transfer. Take the NAFTU [Autonomous Flight Termination Unit] software developed at Wallops, which is a low-cost game-changing command and control system to ensure public safety during launch operations. With NAFTU, we are enabling the low-cost launch business in a big way. And, through the SPO office along with the patent council, I believe we have formed a partnership with nine corporations with that software, and I think about another 19 or 20 companies have expressed interest. So, we have seen a direct application of NASA developed capabilities in the commercial launch domain. With lower cost missions, this software is going to make access to space more affordable and commercial space a more realistic opportunity for many companies.

Q: What has been the most rewarding thing about serving as center director?

A: This is going to be a little more tactical than strategic, but it was only a couple of months [March 2020] after I started in this role as center director that this crazy thing called COVID hit. And I am just thrilled to say that not just myself, but the entire Goddard workforce worked through that. We are not completely out of the woods with COVID, but we are at the tail end of a pandemic and throughout that, we have been able to take action to keep our employees safe and keep our facilities accessible and safe.

Yes, COVID has impacted many of our missions, but we have been pretty much able to deliver on our commitments throughout the pandemic. I am so proud of the Goddard workforce and the people who have made these missions possible. We talked about JWST earlier. We were just getting through the final integration and test cycle when the pandemic hit [in February 2020] and that was an incredibly difficult time to keep the workforce going in a safe environment when we didn't know what safe was all about. You might recall in the beginning, we did not know if we were spreading COVID through airborne mechanisms or through touch on the surface, and son-of-gun, if we did not ultimately keep everybody safe in the end. I am very proud of the Goddard workforce and my small part in being able to make the JWST mission still happen during the pandemic.

Q: One of the things that you have championed here at Goddard is the development of a more diverse and inclusive workforce that encourages collaboration and partnership across NASA science. Talk about why you think that is an important achievement.

A: As I mentioned earlier, all of our missions are unique. We don't often build copies of things. So, in order to do something that is unique and that is very complex for the first time, it takes a lot of different opinions; it takes a lot of different voices in order to make that mission happen. Gathering ideas don't just come out of a book, you have to invent things along the way. Technical challenges require new ways of thinking and I believe a diverse environment in our workforce helps bring new ideas to the table. New concepts allow us to challenge each other to get the best out of what we need to do to make our missions happen. Since I have been center director, I see that play out on daily basis with our senior leadership team. About one third of our SES [senior executive service] personnel belong to an underrepresented minority group or are women. In the near future, we are moving up to 50 percent and growing. That diversity in key roles builds a tighter cohesion between flight projects, between engineering and science, and between S&A [supervision and administration] as we make our missions happen. The results speak for themselves with the very successful missions that we have already talked about.

Q: Prior to Goddard, your background is both as a government contractor and civil servant. How has that influenced and played a part as center director?

A: They both played a part but a little differently. Earlier in my career, I worked at the intel side of the DoD [Department of Defense] and quite often could not talk about what I did for a living. Being somebody who enjoys talking about what I do, it became a challenge. When I first walked up to the gates of the Goddard Space Flight Center in August of 1988, it was really an eyeopener. It was really exciting to

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see people walking around talking to each other and I thought, "I want to be a part of that." I was fortunate enough to get a job offer at NASA, and now, love being able to talk about what we do and the exciting missions that we have. To answer the other part of your question, I also enjoyed being a contractor and a contractor's motivation is sometimes different than a civil servant's motivation. On the government side at NASA, we are about exploring, about understanding science and making our missions happen. A contractor has that as a goal too, but their primary goal is to make sure that they can keep their business operational. So, there is a profit and loss piece to the contractor's equation that you don't have as much of on the government side. So, I learned a lot on the contractor side and understand what motivates a contractor, and that has helped make me a better civil servant. Along the way, I think I have been able to represent the interests of both, which has helped make Goddard a more successful agency.

Q: Earlier, we talked about tech transfer and partnerships, how has NASA Goddard missions influenced private industry?

A: I can give you a couple of examples. We've had some technology that has worked its way into private industry and that has really helped those companies. I mentioned one technology earlier, which is NASA's Autonomous Flight Termination Unit software. Using this software, it will hopefully enable Rocket Lab to launch their first mission in December of this year, and I am excited about that. Seeing Rocket Lab use that launch capability flying out of Wallops will be really cool. Another example is where [Code] 596 [Components and Hardware Systems Branch] developed a new concept for a reaction wheel and immediately commercialized it. As a result of a SBIR (Small Business Innovation Research) award, we are working with a small company called Ithaco [Space Systems Inc.] and they have developed that capability into a new business. We have influenced private industry by transferring technology to them. I see many of those kinds of examples elsewhere and it shows that NASA Goddard technology is getting out into industry and making industry more competitive.

Q: What do you think is your legacy here at NASA Goddard? How would you like to be remembered by the Goddard community?

A: When I walked in the door here at Goddard, I had three priorities. One was meeting our commitments. It wasn't satisfactory to just meet our scientific and engineering commitments, we had to deliver on scheduling and cost, which I believe we have done as much as we could in the COVID environment. On a lot of our missions, we are meeting or exceeding our commitments on schedule and cost, in addition to meeting our requirements in scientific and engineering capabilities.

My second priority is focusing on the future, by making Goddard more competitive in a proposal-driven environment and we have done a great job on that. Recently, NASA's Explorers Program selected the STAR-X mission [to receive $3 million for a nine-month X-ray and ultraviolet study], which could be used to investigate exploding stars, growing black holes, the formation of galaxy clusters in the universe, among other cosmic objects. The mission will be led by Goddard Principal Investigator Wil Zhang. And under [Goddard Chief Scientist] Jim Garvin's leadership, we are going to explore Venus with DAVINCI [Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging]. So, focusing on the future, Goddard succeeds in a competitive environment and is doing outstanding work.

The last priority is focusing on the people [at Goddard]. We want to build our workforce. We have a lot of shuffling of personnel as folks have retired or as people have taken more responsibility at NASA headquarters. We had people like Mark Clampin [Astrophysics Division Director in the Science Mission Directorate] and Dave Mitchell [NASA's Chief Program Management Officer] selected to work in director positions at headquarters. So, we've had people leave for awesome reasons, but we have been able to build a candidate pool to backfill all of those jobs. Allowing for career growth and providing a safe environment for our employees during a pandemic meets that final commitment of taking care of our people.

So, when I walk out the door of the Goddard Flight Space Center [on December 31], I know we have done a great job of meeting those priorities. I believe I can walk out of here thinking that I am very pleased of the work that I have done with the Goddard team. But it is just not about me, it is about the entire Goddard team.

Q: What do you think is the future of NASA Goddard missions? What does your crystal ball say?

A: Rather than looking into a crystal ball, let's talk about that light at the end of the tunnel. It is truly light at the end of the tunnel on the Goddard train. I am excited to say that Goddard did win another competition for HERMES [Heliophysics Environmental and Radiation Measurement Experiment Suite], which is putting space weather instruments on the Gateway, [NASA's lunar outpost where Artemis astronauts will live and work as they orbit the Moon]. There are other Goddard missions that are currently in works, such as the PACE [Plankton, Aerosol, Cloud, ocean Ecosystem] satellite, designed to understand ocean color, biogeochemistry, and ecology. That project is in its final integration and testing and going to be launched in the not-too-distant future. There is also the Roman Space Telescope [designed to study areas of dark energy, exoplanets and infrared astrophysics] being built at Building 5. DAVINCI, which is about a one-meter sphere that is going to drop down into the Venus atmosphere [to study the planet's atmosphere], and GDC [Geospace Dynamics Constellation] a mission concept to study the coupling between the magnetosphere and the ionosphere/thermosphere system. That is going to take us out to 2029. I know our engineers and scientists are up to the task and our future is very, very bright. As I retire, I am excited to stay on the sidelines and watch what is going to come out of this Goddard Space Fight Center. It is a good time to be here.

Q: Any final thoughts before you leave on December 31?

A: There is one thing that I would like to expand on when I was talking about our Goddard mission, and that is we succeed or fail as a team. During the pandemic, I am pleased to say, we still maintained a team focus on all of our Goddard missions. When folks come in through the gate every morning, —and it does not matter whether you are an engineer or a scientist, whether you are in mission or administrative support, whether you are government employee or a contractor—everyone here is about making the mission happen and about mission success. We have an awesome team of people at Goddard, and I am proud to be a part of that team. I am very grateful to NASA headquarters giving me the opportunity to do this job.

Photo Credit: NASA

Goddard Scientists Spent Summer Break Validating Sea Ice Thickness in Greenland

NASA Goddard scientist, from left, Nathan Kurtz, Rachel Tilling and Marco Bagnardi.
Photo Credit: Kate Ramsayer

ICE-Sat2 Captures Key Data On a Warming Planet

Most of us don't live in the polar regions of the planet, where we would come into contact with the frozen ocean, large ice sheets, or icebergs. Many of us have only seen those things in photographs, television, or in movies. But no matter where you live, these elements from the Earth's cryosphere have an impact on our climate.

Much of the cryosphere on Earth is located in either the Arctic or Antarctic regions of the planet. As temperatures begin to rise due to climate change, the ice in those places begins to melt and the planet as whole is affected by changes in the polar regions. Simply put, what happens in the cryosphere does not stay in the cryosphere.

As global warming causes more snow and ice to melt in the Arctic regions each summer, the ocean and land underneath the ice are exposed at the Earth's surface. When this occurs, the ocean and land absorb more incoming radiation from the Sun and then release more heat into the atmosphere. In a way, the ice melting causes more warming and so more ice melts.

This July, a team of Goddard scientists ventured on a two-week NASA mission to Greenland to validate measurements of sea ice thickness. Flying out of Thule Air Base in Greenland on a repurposed NASA Gulfstream V plane, the team used laser instruments and cameras onboard the plane along with NASA's ICESat-2 satellite to get a better understanding of the amount of sea ice melting during the summer months.

"[Climate Scientists] want to know what is happening with the sea ice thickness in the summer months because we know this is the time of the year when we are losing the biggest area of sea ice [to melting]," explained Dr. Rachel Tilling, assistant research scientist

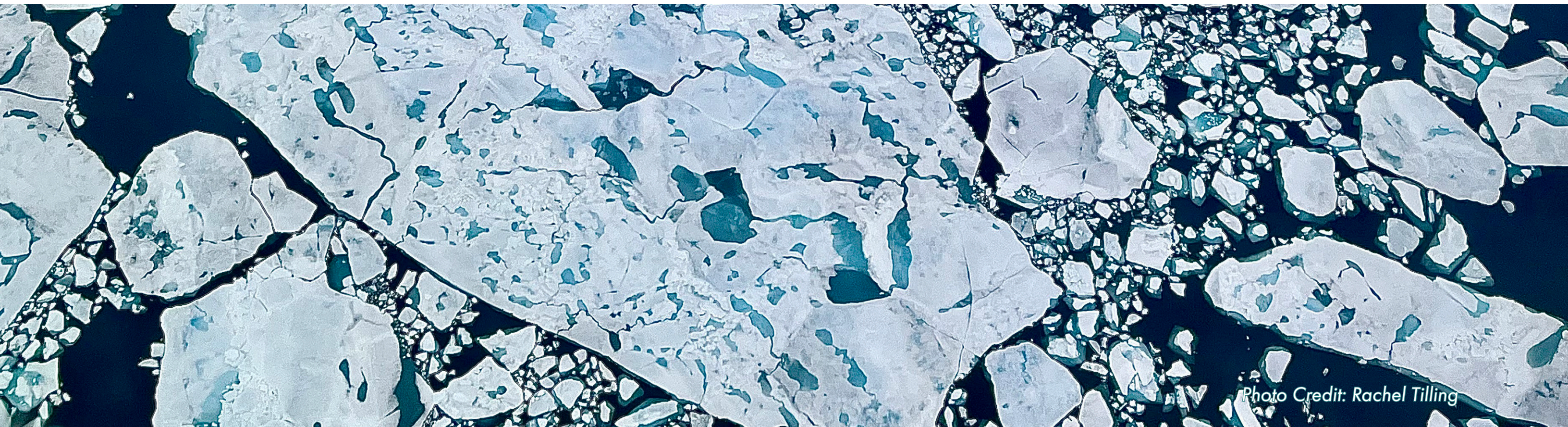

Photo Credit: Rachel Tilling

NASA Gulfstream V plane at Thule Air Base in Greenland. Photo Credit: Rachel Tilling

at Goddard's Cryospheric Sciences Laboratory and mission deputy. "With data we collected, if we can show that we are also losing [large amounts of] sea ice, that will be huge in terms of the climate impact that it might have. This is important data for the people that build their predictive climate models, which will give us a good idea of what is going to happen [with climate change] over the next few years, decades, or centuries even."

Built, tested, and managed by Goddard, ICESat-2 (Ice, Cloud, and land Elevation Satellite 2) is a NASA satellite primarily designed to measure the elevation of ice sheets and sea ice thickness within an inch or two. Launched on September 15, 2018, onboard a Delta II rocket, ICESat-2 carries a single instrument – an Advanced Topographic Laser Altimeter System (ATLAS), which captures the height of ice, along with vegetation, land surface, water, and clouds. ATLAS carries two onboard lasers, a primary laser and a backup. The fast-firing laser sends 10,000 pulses per second, which allows ATLAS to take measurements every 2.3 feet along the satellite's ground path. ICESat-2 was designed with enough fuel for seven years in orbit.

NASA Goddard's David Rabine monitors LVIS instrament.
Photo Credit: Kate Ramsayer

Onboard the Gulfstream V, the team used two other similar NASA laser instruments to measure the exact depth and height of the ice, snow, melt ponds, and ocean below. Because there were two onboard instruments, the plane flew at two different altitudes each flight – one about 33 thousand feet and the other at 1,600 feet. For many of these flights, ICESat-2 flew over the same path within a few hours, measuring the exact ice surface with its ATLAS laser instrumentation. The team then compared the three sets of data to better understand the sea ice is melting.

"To understand how the ice is melting, you first need to know exactly how much ice there is,'" said Tilling. "We've known for the last four decades that this area of Arctic sea ice has decreased rapidly. To actually

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understand how much of the ice is disappearing we needed to know what is going on underneath the surface, which is what ICESat-2 was able to give us."

Besides Tilling, other members of the Goddard team include Climate Scientist and team lead Dr. Nathan Kurtz, Research Professor Michelle Hofton, Senior Data Scientist Dr. Marco Bagnardi and Physical Scientist David Rabine. The summer campaign to Greenland was an extension of NASA's Operation IceBridge, whose mission is to monitor changes in polar ice. Operation IceBridge is the largest airborne survey of Earth's polar ice ever flown. This campaign to Greenland was particularly interested in measuring areas where snow covering the ice had melted and pooled into water, causing the ice to thin from the surface.

"There has never been any satellite before ICESat-2 that has been able to give us those direct measurements of summer sea ice," noted Tilling. "There have been other polar orbiting altimetry satellites that look at sea ice, but ICESat-2 is the first satellite that has given us that data and is able to get those sea ice thickness measurements accurately."

Tilling said another reason the team chose taking measurements in the summer months, which is the hardest time of year to operate in the Arctic region due to weather, is because that is the time of year when the least accurate measurements of sea ice have been taken in the past. The main weather problem the team incurred was cloud cover and fog. Large summer storm systems are the scourge of airborne campaigns around Greenland during the summer months as they can cover much of the region and disrupt air travel.

Lining up instruments and taking daily measurements onboard the aircraft was not an easy task. Due to the unpredictable summer storms and to properly calibrate the onboard laser instrumentation – where the pilot had to perform a lot of pitch and rolls with the aircraft – the team knew they were in for a daily stomach-turning roller coaster ride on the Gulfstream V.

"Once the ice starts to melt in the summer, you start to get a lot more water forming on the ice surface and then you start to get a lot more evaporation; it becomes much foggier, and cloudier than other times of the year," recalled Tilling. "Which means there are many days that you just can't safely fly over the sea ice, because the visibility is so bad, or the weather is too unpredictable to actually go and get these measurements. For safety, and for good data coverage, you needed cloud-free days."

While ICESat-2 orbits around much of the Arctic region, Tilling said the team chose Greenland to do their ice measurements because that is the best place to get different types of ice coverage needed for data collection. "We were in Greenland because of the access we would get to both young and old ice on the Arctic Ocean," she said, "With the data we collected from Greenland we could use that to improve [NASA's] data from the Arctic as a whole."

Since returning from Greenland in July, the team has been in process of compiling and analyzing the information and data that they have collected. Tilling said the goal of the mission was simply to make this data available to climate scientists through publicly available NASA data sets. Even though she said the team knew the mission was going to be "tricky" because of the uncertain weather, they really wanted a campaign to improve and upgrade NASA's summer ice measurements from ICESat-2.

"We know [from data collected] the Arctic is warming about three times faster than other parts of the planet," said Tilling. "We are seeing rapid change across the Arctic, but what we really have not had is a long-term series of measurements showing how the amount of sea ice is changing year-round. Hopefully, with ICESat-2 still going strong [in the years to come], we will start to look at long-term changes in sea ice and how it is being affected by climate changes."

NASA Goddard scientist, from left Nathan Kurtz, Michelle Hofton, Marco Bagnardi and Rachel Tilling, Photo Credit: NASA / Kate Ramsayer

Photo Credit: Rachel Tilling

GODDARD PROGRAM SUPPORTS SEED TECHNOLOGIES TO ADVANCE FUTURE SPACE MISSIONS


Chief Technologist Peter Hughes, Photo Credit: NASA

Goddard Chief Technologist Peter Hughes in NASA's Goddard Space Flight Center's Office of the Chief Technologist (OCT) takes a holistic view when identifying the technologies that are needed to advance NASA's most ambitious science and exploration goals. He, together with Deputy Chief Technologist Bhanu Sood, are charged with identifying the most promising areas for technology development in support of Goddard's lines of business (LOBs), including Earth Science, Heliophysics, Astrophysics, and Planetary Science. These LOBs are complemented by seven areas of expertise in science and engineering. Talented scientists and engineers in each of the LOBs make difficult strategic decisions about where to place critical resources, underpinning the success of the Office of the Chief Technologist at Goddard.

Hughes and Sood provide the strategic leadership to orchestrate those parallel processes in each LOB into a balanced integrated portfolio in response to top priorities in the current moment. This requires an intimate understanding of the details needed to recognize technological gaps that Goddard engineers and scientists may be uniquely positioned to fill. Effectively leading the charge for Goddard's LOBs also requires knowledge of the larger context and landscape at NASA and beyond. The goal is to identify the most promising potential industry partners to cultivate strategic relationships to enhance NASA missions without duplicating efforts.

> "Quantum technology is the most forward-reaching technology in our laps right now."

"Our primary role in OCT is to identify Goddard's technology priorities and new opportunities to develop them for missions and systems to enable their success and put us in a more competitive stance," Hughes says. "Core to the mission at Goddard are several lines of business—we have one of the largest collections of scientists and engineers conducting space and Earth science—and my job is to identify those technology areas and needs to run internal research and development. We need to understand the risks and technologies needed to make next-generation measurements and missions and encourage and stimulate innovation in the workforce. We

Deputy Chief Technologist Bhanu Sood, Photo Credit: NASA

come up with new ideas to address nascent technologies to support these mission opportunities and combine existing technologies in unique new ways to give us new capabilities. For that reason, we need to have a greater awareness of the broader technology landscape, nurturing partnerships with outside entities to combine technologies for the future."

OCT's primary responsibility is to manage Goddard's Internal Research and Development (IRAD) program along with NASA's Center Innovation Fund. The IRAD program provides essential "seed funding" to develop concepts, reduce technology risks, and advance human capital and technological capabilities. The goal always is to enable future missions and increase the odds of external technology and mission funding as needed to facilitate breakthrough scientific discovery driven by development of the most innovative technologies and tools. Hughes and Sood's keen awareness of the broader technological landscape allows for long-range planning and decision-making that makes it all possible. They also understand how all the various needs and opportunities align.

"Goddard's several lines of business in science and engineering play strongly into this work," Sood explains. "The IRAD program leverages these lines of business and identifies and aligns strategic priorities within each with the agency's broader priorities. We base our decisions to support particular IRADs on these alignments between agency priorities and those of the individual lines of business."

Each spring, OCT issues an integrated call for research proposals to address opportunities of interest that support some or all subsets of Goddard's LOBs. Evaluators then judge proposals on their technical merits and whether they directly support Goddard's strategic LOBs to enhance the center's competitive posture while using resources effectively and efficiently. Evaluators must also consider whether each proposal and technology have a realistic future and the extent and significance of progress likely to result from each investment.

"We provide funding for seed technologies that allow us to get our arms around new technology and development, so they can carry on and get follow-on funding leading to a mission or opportunity," Hughes says.

A good example of IRAD in action is NASA's DAVINCI mission, which will study the origins, evolution, and present state of Venus in unprecedented detail from the top of the clouds to the planetary surface. The mission aims to answer longstanding questions such as whether our neighboring planet was ever habitable. The groundbreaking mission was enabled by multiple IRADs over many years.

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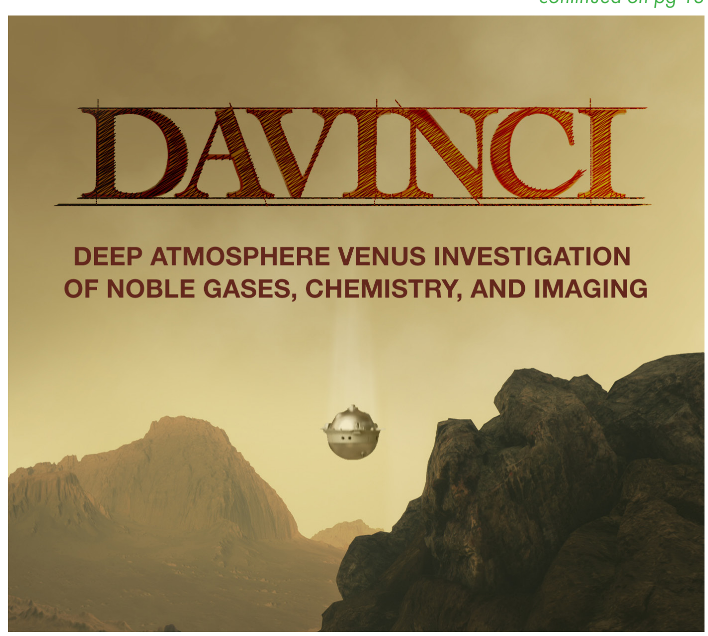

The DAVINCI deep atmosphere probe descends through the dense carbon dioxide atmosphere of Venus towards the Alpha Regio mountains. Photo Credit: GSFC

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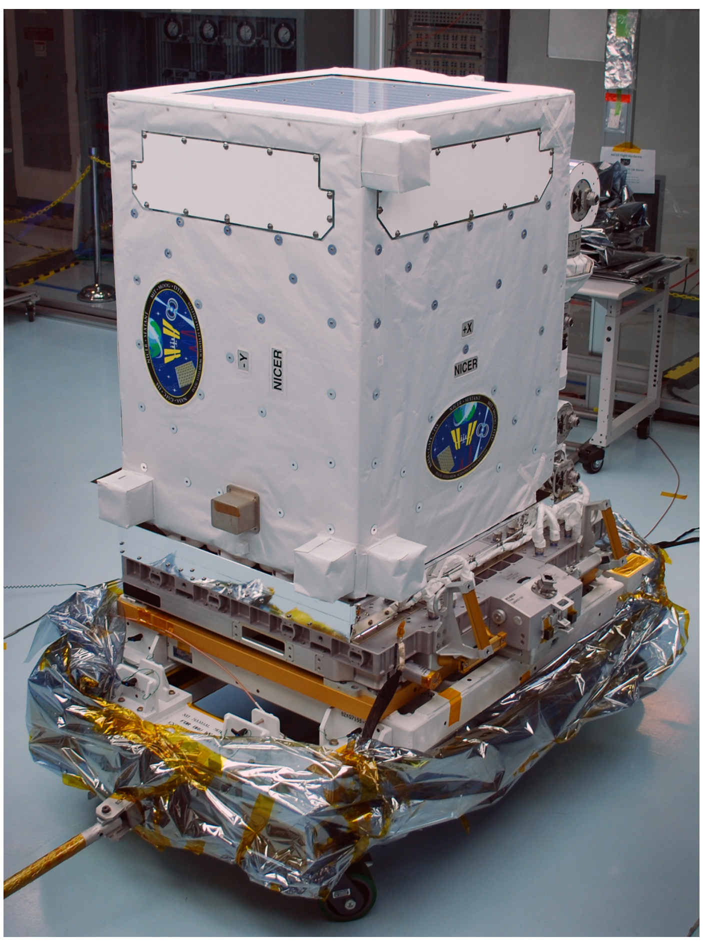
A natural byproduct of IRAD funding is New Technology Reports (NTRs), which are the lifeblood of Goddard's Strategic Partnerships Office (SPO), OCT's sister organization. Hughes estimates that IRAD-funded research and development generates dozens of NTRs each year. While the number that lead to patents and licenses is fewer, there are some notable examples. IRAD funding supported the development of SpaceCube Intelligent Multi-Purpose System for Enabling Remote Sensing, Communication, and Navigation (IMPS).

"SpaceCube is one example where we made investments 15 or 20 years ago for very small form computing in space," Hughes says. "We were approaching the CubeSat form before it was the rage and since then it has taken a lot of our missions by storm."

Other examples of patented and licensed technologies that began with the help of IRAD support include the Magnetospheric Multiscale (MMS) Navigator system and NASA's Neutron star Interior Composition Explorer (NICER). The MMS Navigator system has important implications for high-altitude GPS navigation. NICER provides high-precision measurements of neutron stars, which contain ultra-dense matter at the threshold of collapse into black holes. The Modulated X-Ray Source that enabled NICER and uses X-rays for deep space communication has since been adapted to advance medical X-ray imaging through a partnership with Massachusetts General Hospital. It is an example of the technology transfer that SPO facilitates to ensure that NASA innovations are making measurable impacts here on Earth.



The NICER payload, blanketed and waiting for launch.
Photo Credit: NASA/Goddard/ Keith Gendreau

What can we expect next? Hughes and Sood point to several different areas of focus today, including artificial intelligence and machine learning, 3D printed electronics and nanoscale offset printing, and integrated photonics. But if they had to pick just one area that is going to revolutionize future space missions and the broader technological landscape, they say it would have to be quantum technologies.

Quantum technologies rely on quantum mechanics, or the physical properties of subatomic particles, to make advances beyond what is possible with classical physics. They note that President Biden has signed two directives to advance national initiatives in quantum information science. An important aim is the development of quantum computers, which have potential to solve problems that even today's supercomputers cannot—or to solve them much faster. Advances in quantum information sciences are expected to drive innovation in many arenas, from energy to medicine, through fundamental advances in computation, networking, and sensing.

At Goddard, the primary focus area is quantum sensing, which promises more accurate and precise measurements of groundwater, hidden voids, and more. Funding from NASA's Small Business Innovation Research, Instrument Incubator, and the IRAD program has already led to the development of the first quantum sensor for mapping Earth's time-varying gravitational field. This is just the beginning of many more innovations to come, with implications that are difficult for even the most futuristic thinkers to imagine today.

"Quantum technology is the most forward-reaching technology in our laps right now," Hughes says. "It's a whole new mindset with implications for quantum communications and networks as well as quantum sensing. It's one of the key emerging and most disruptive technologies out there right now."

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Goddard Engineers Developing Revolutionary Technology to Better Measure the Earth's Atmosphere

Imagine getting a box of puzzle pieces but have no reference picture to show you what the completed puzzle is supposed to look like. That is the challenge climate scientists at Goddard's Earth Science Division mission directorate face today when looking at satellite information about Earth's atmosphere. Since 1978, NASA has launched dozens of satellites to measure the Earth's atmosphere at different altitudes to help us better understanding our planet's stratosphere but are still working to gain better clarity of what exactly that ever-changing picture looks like.

"The chemistry of Earth's atmosphere is remarkably stable, providing a relatively safe place for animals and plants to thrive," said Kevin Bowman, NASA's principal investigator for the Tropospheric Emission Spectrometer instrument on the Aura satellite, designed to study Earth's ozone layer, air quality and climate. "However, even small changes to the quality of the air that we breath can have profound impacts on our health. Understanding that stability, the ways it could be impacted by humans and how it interacts with the broader Earth system are key research tasks in atmospheric chemistry."

Bowman said understanding the composition of Earth's atmosphere is important for both air quality and climate change. Some of the gases that now enter the atmosphere from both human activity and natural processes are hazardous to our health. Among them are rising greenhouses gas concentration, which are causing Earth's climate to warm. Indeed, Bowman believes Earth's atmosphere is not something we can take for granted.

NASA Goddard scientists and engineers are constantly pursuing ways to enrich our knowledge of the Earth by improving measurements from satellites in space. Weather satellites presently take atmospheric measurements across a wide spectrum of frequencies, including ultra-violet, visible, infrared, and radio.
Microwave frequencies has also been used for many years to probe the Earth's atmosphere. A major strength of microwaves is that they pass through clouds much better than other frequencies do. This enables better measurement of water vapor and the temperature under all conditions.

As a result, microwave remote sensing has demonstrated tremendous value for use in weather prediction and climate science. However, a traditional drawback of using microwaves has been a limitation in the number of frequency channels that can be achieved. The greater frequency of channels, the better and more accurate the measurement. Where a microwave sensor might only have a couple dozen channels, a comparable infrared sensor frequency might have several thousand.

To break that technological bottleneck to enable thousands of microwave channels to take hyperspectral measurement Earth's atmosphere, there is ongoing research by a team of Goddard engineers and scientists. Hyperspectral microwave spectroscopy is a measurement that helps meteorologists dissect the Earth's planetary boundary layer (PBL), or the lowest part of the atmosphere, whose behavior is influenced by its contact with the planetary surface.

Dr. Mark Stephen and Dr. Fabrizio Gambini, two engineers with Goddard's Instrument Systems and Technology Division are now in development of a new sounding or measurement instrument, the Hyperspectral Microwave Photonic Instrument (HyMPI), that will provide a broader and higher resolution measurement of Earth's atmosphere. The HyMPI will perform atmospheric sounding or measurements of things such as Earth's pressure, temperature, wind speed, wind direction, liquid content, ozone concentration, pollution and other properties.

A key component that enables the HyMPI is its arrayed waveguide grating (AWG) technology, which is a wavelength or frequency system used in telecommunications to increase transmission capacity to optical networks. In this case, the AWG is being combined with photonic integrated circuits (PIC) – which is a microchip technology that transports, detects, and processes light – to develop an entirely new revolutionary AWG called serial arrayed waveguide grating (SAWG). This SAWG will produce high resolution measurements of not only Earth's atmosphere but potentially, of other planets. SAWG is a Goddard patent-pending technology, which when fully developed, will be available for licensure.

"You should think of this PIC technology as the same type of revolution [in technology] as when we transitioned from vacuum tubes to computer chips," said Stephen. "Photonic technology was developed for the telecommunications world. We are applying it in a different application. The SAWG technology we are developing [for the HyMPI] will allow satellites to take better hyperspectral microwave measurements of Earth's atmosphere."

The reason for stalled progress in hyperspectral microwave technology in the past rests in the numerous technological challenges associated with simultaneously processing an ultra-wide bandwidth at a hyperspectral resolution – needed for achieving multiple frequency channels – while maintaining a feasible instrument size, weight and power consumption, and cost. The SAWG, which uses a compact, narrowband, multi-channel optical filter, solves that technological problem and thus, significantly improves the vertical sounding resolution and accuracy of atmospheric water vapor and temperature measurements of Earth taken from satellites.

"To say that integrated photonics is a revolutionary technology is not an overstatement," said Gambini. "Our hyperspectral microwave photonic instrument is based on PICs from different platforms. This provides a sea change in [operating] capability because with the different PICs, we can minimize the power consumption of the system while achieving an unprecedented number of [microwave] channels."

The advantage of getting real-time PBL measurements of Earth's atmosphere from SAWG would provide

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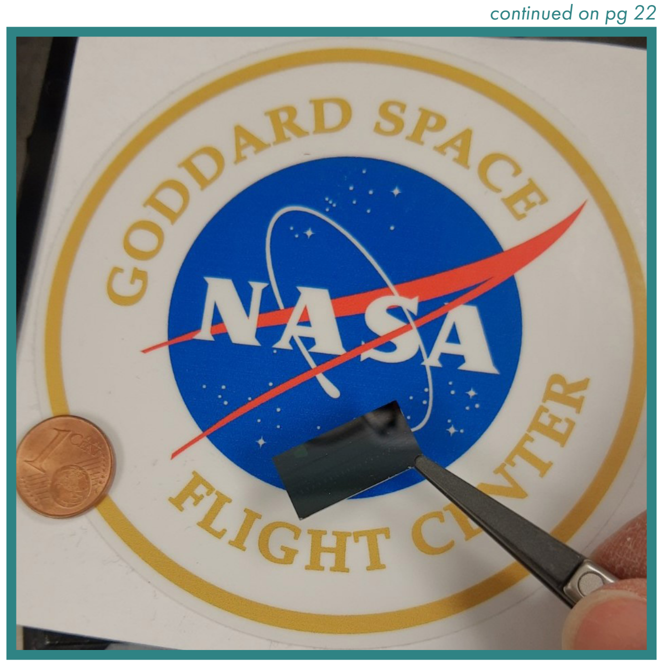

The SAWG is the size of a euro. Photo Credit: NASA / GSFC

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meteorologists with a more accurate picture of our planet's climate events. However, due to the volume of gases in the atmosphere above it, the PBL is the most difficult atmospheric measurement to obtain.

"The PBL is where we live and where we experience weather," explained Dr. Antonia Gambacorta, research physical scientist in the Climate and Radiation Laboratory at Goddard and has collaborated with Stephen and Gambini in the development of the SAWG. "It's been studied in great detail with lots of ground-based measurements, but there are large gaps, like over oceans and polar regions where we don't have as many ground-based instruments. Having the [SAWG] capability from space to probe and measure the boundary layer is important to study the connections between this layer and the rest of our atmosphere on a global basis. This remote sounding capability will help achieve a global perspective on the make-up and behavior of the boundary layer."

Development of the SAWG component has been matured from funding under Goddard's Radical Innovation Initiative Internal Research and Development Program, developed by Michael Johnson, chief technologist of the Goddard's Engineering and Technology Directorate. Presently in development, Stephen said SAWG is in technology readiness level (TRL) 3, where the concept has been formulated and they are targeting TRL 5 with packaged validation in the lab within two years.

To provide meaningful information and visualizations for scientists and meteorologists, Stephen said they are now working to dramatically reduce the size, weight, and power of the radio frequency signal processors in the SAWG by converting it to optical signals. These signals will be processed through the use of multiple PICs.

"We have computer models and a preliminary breadboard system assembled to show that optical processing on a PIC should work," said Stephen. "We believe, the SAWG could enable the first of its kind hyperspectral microwave photonic instrument, capable of measuring Earth's full microwave radiation spectrum."

(From Left to Right) Dr. Mark Stephen, Dr. Victor Torres, Dr. Antonia Gambacorta and Dr. Fabrizio Gambini, Photo Credit: NASA

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A Very Small Thing That Can Big Difference in Satellite At

An Upcoming Technology Demonstration will Test a New Propulsion Design

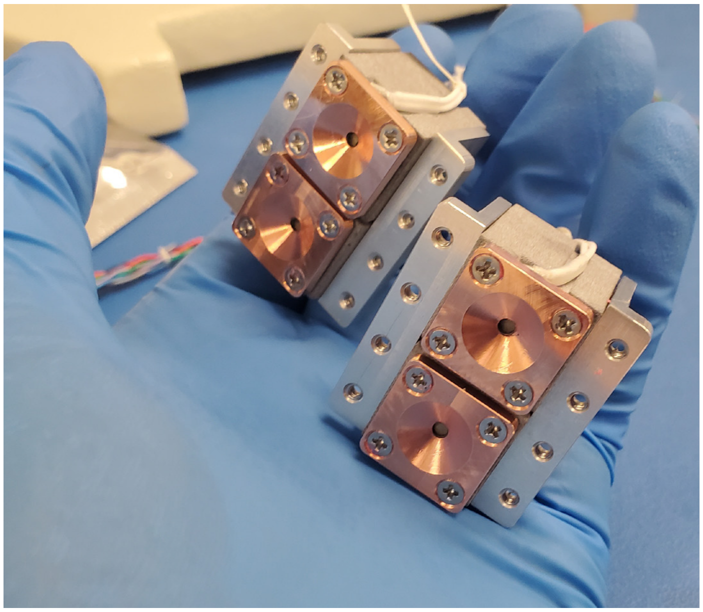
A SmallSat/CubeSat satellite orbiting the Earth or traveling through the Solar System sometimes encounter very small "forces." Some examples of these "forces" include solar pressure from sunlight or leaving the Earth's magnetic field. These small "forces" can pull the satellite just enough off course that they are unable to "point" and align in the proper direction to communicate back to the ground station on Earth or just properly maneuver in orbit.

For this reason, a SmallSat/CubeSat propulsion system must deliver very precise thrust in order to accurately control the position or attitude of these tiny satellites – otherwise referred to as "impulse bit." Reliability and high efficiency are of the utmost importance in these propulsion systems since there is normally no real opportunity to service them over their entire lifetime. Traditionally, these small "forces" are counteracted by utilizing onboard reaction wheels to rotate the spacecraft back to its intended attitude but eventually they will saturate.

Because of its low volume and mass, the ideal propulsion system for a SmallSat/CubeSat needs to balance reliability, scalability, simple low-pressure operation, safe propellent containment, and low cost in order to meet performance requirements. With NASA and private industry interested in utilizing SmallSats/CubeSats for cislunar, interplanetary and/or deep space missions in the near future, there is now a growing demand for an in-space propulsion system that enables these small satellites to better achieve attitude and orbit control.

"If you are going to the Moon or deep space; different places that don't have a strong magnetic field, you are going to need a good thruster system," said Luis Santos Soto, chief engineer of the Small Satellite Project Office at Goddard. "Selecting the most appropriate thruster product for a CubeSat can be a tricky challenge, but a critical step for any mission requiring in-space maneuverability and control."

A team of engineers at Goddard may have the answer that Santos Soto is looking for. Electrical engineers Robert Moss, and Dakotah Rusley, along with mechanical engineer Steven West, and Pathways intern and Purdue University Ph.D candidate Benjamin Nold have developed the Ion Control System (ICS). ICS consists of tiny electrical propulsion thrusters – measuring 1.5 x 1.5 x 2 centimeters – that can be placed on SmallSat/CubeSat and are designed for attitude and precision orbit control, constellation formation management, and extended low-thrust maneuvers in space. On an operational mission, ICS is controlled through the flight software on the spacecraft.



Tiny elecrtical propulsion thrusters, Photo Credit: NASA / GSFC

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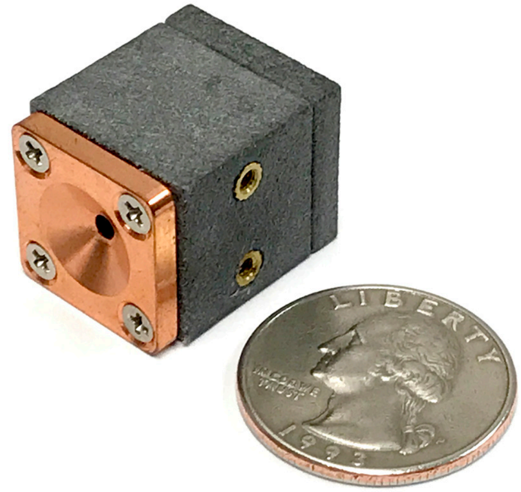

"The Ion Control System influences the spacecraft's attitude," explained Moss. "It is a low cost, high performance, easily configurable and scalable micro-propulsion system that can be implemented within the constraints of typical SmallSats/CubeSats. And what we have designed the ICS for, is as an actuator, which is a really super fine 'pointing' application." Presently, SmalSat/CubeSats use various mechanisms, such as reaction wheels, magnetic torquer bars and/or thrusters to properly maneuver, control and 'point' these small satellites in orbit. All of those products achieve their purpose, but in terms of its tiny size, power, customization, and capability, the design team believes the ICS is a better and more advanced technology. ICS is a patented Goddard technology available for licensure.

"The goal of ICS is to be able to use these very tiny thrusters to point [the satellite] very accurately," said Rusley. "Without getting overly technical, the way this product achieves this is with something called the 'impulse bit,' which is essentially the smallest unit of thrust that you can generate with a given system. So, for a really fine pointing application, like on a Small-

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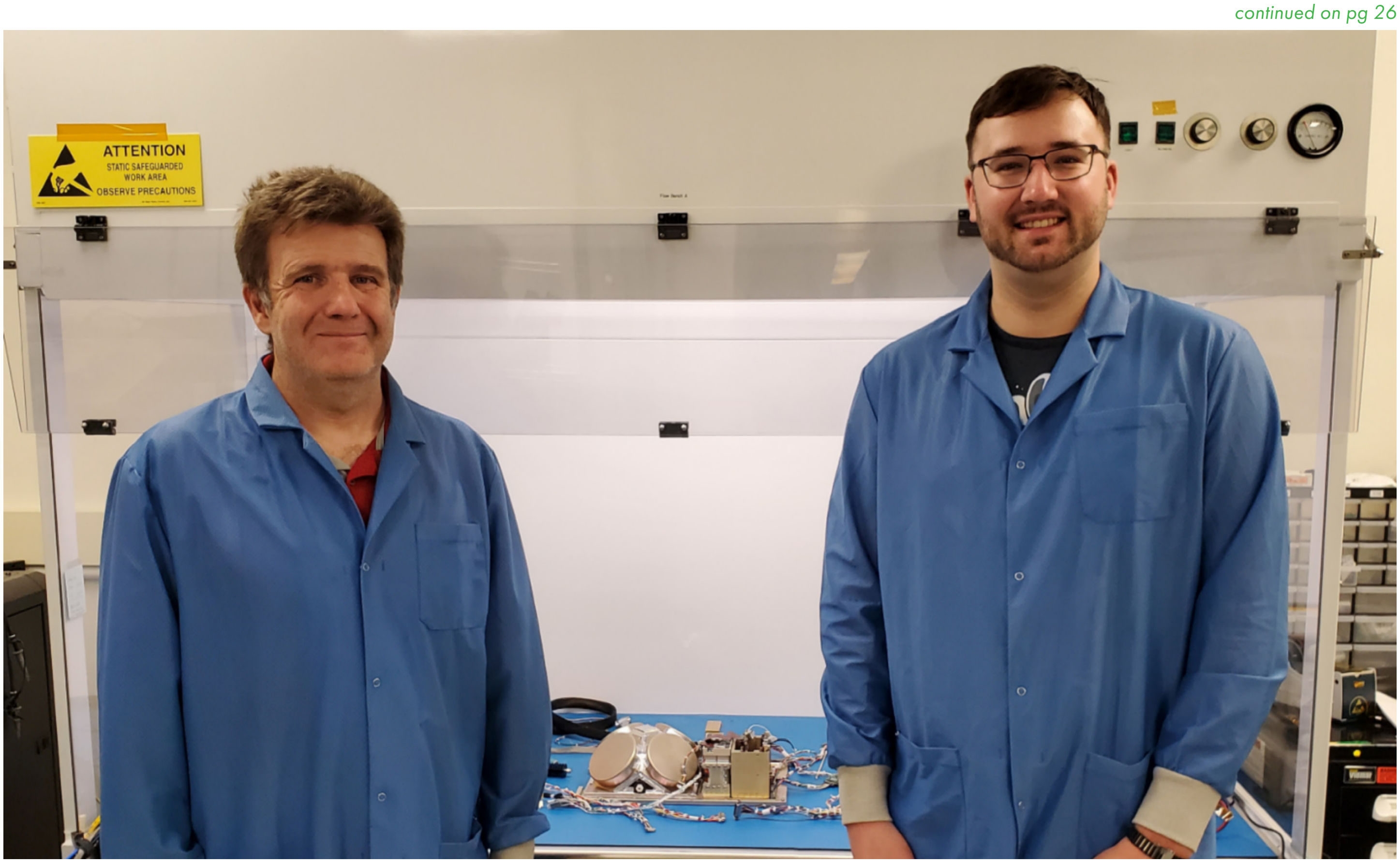
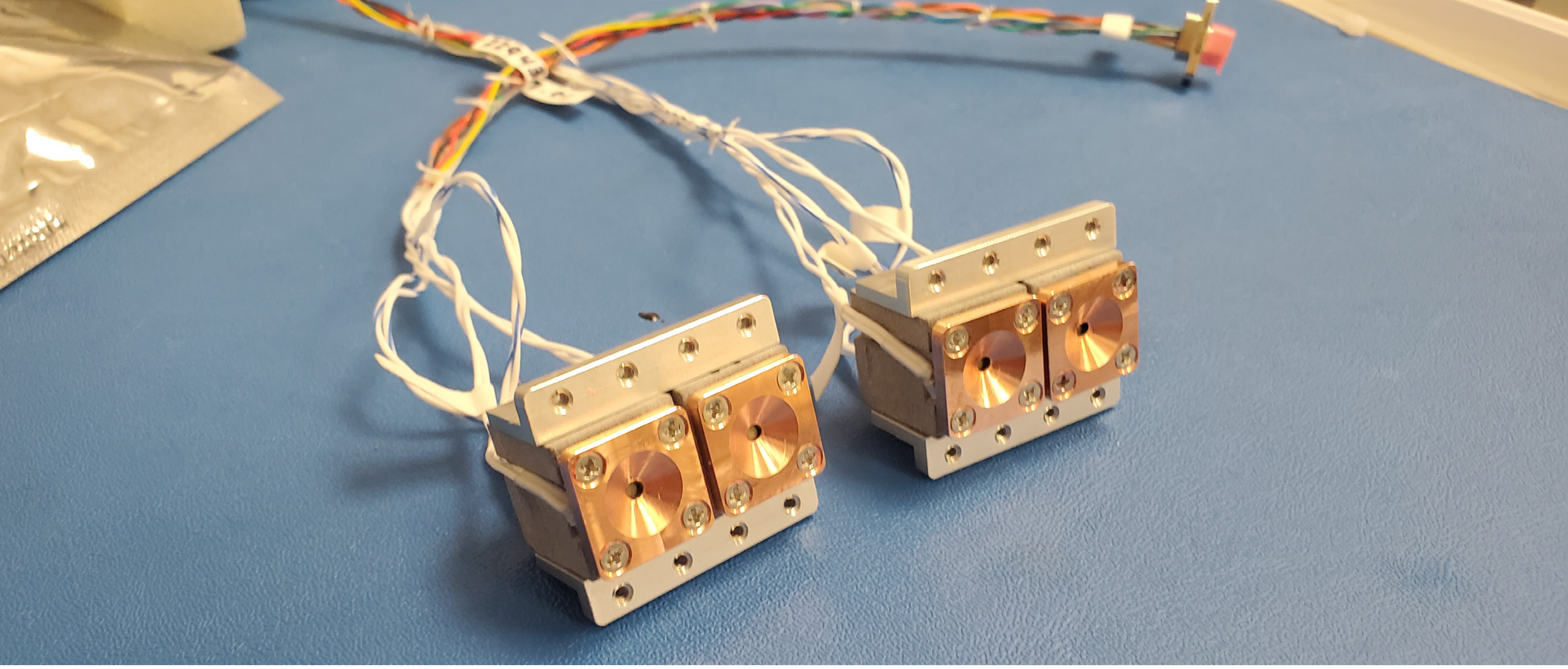


Bob Moss on the left, Dakotah Rusley on the right, Photo Credit: NASA / GSFC



Tiny elecrtical propulsion thrusters, Photo Credit: NASA / GSFC

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Sat/CubeSat, you want a very low 'impulse bit.' ICS is capable of finely controlling both the orientation and attitude of the spacecraft."

Moss and Rusley said the ICS can be the perfect thruster system used on the kinds of Distributed Systems Mission (DSM) projects that Goddard is currently focused on developing in the near future. A DSM is a mission that involves multiple spacecraft to achieve one or more common goals. Some DSM development includes constellations, formation flying missions, or fractionated missions. A key component and advantage of DSM is the idea that this is an open architecture where anyone can join and contribute to the network.

"There are a lot of NASA missions that are being conceived and proposed that involve formation flying," noted Rusley. "The ICS can be used to keep exact distances between the spacecraft. If for example, you want to be able to maintain control in the order of exactly 20 feet between two spacecraft, the ICS can manage that. With a larger thruster system, you might have to consistently overcorrect or under correct [the attitude] to stay in line. So, that is the niche that ICS is filling."

"Yes, because of the ICS scalability, it could potentially be used for DSM orbit maintenance – a string of pearls type of maintenance spacing of the CubeSat in formation flying," added Santos Soto. "So, if your spacecraft is getting too close, you could then you fire its ICS thrusters to try to keep it within a certain distance from the other spacecraft."

ICS was integrated into the petitSat mission, a Goddard CubeSat, as a technology demonstration. The satellite was launched from Kennedy Space Center on November 18 and rendezvoused with the International Space Station as cargo. Astronauts then ejected petitSat via Nanoracks CubeSat Deployer a week later. The petitSat mission is designed to help scientists understand how the ionosphere affects long distance radio communication, such as Global Positioning Systems or GPS and radio signals.

"Hopefully, a few days [after petitSat is ejected], we will get our first opportunity to communicate with the satellite and see how it is doing," said Moss. "We want to make sure that its stable and gets into its Sun pointing mode. Then after commissioning, we will hand the keys [of the satellite] over to the science team."

The Goddard team will then do roughly six months of its primary mission on petitSat, which is heliophysic science. After the science mission is completed, the ICS team will finally have an opportunity to do full test and demo of the ICS system while it is still in orbit.

"Once we get to this part of our tech demo part of the mission," said Moss, "we will turn the ICS on and it should start pulsing about once a second, and hopefully, we will get the spacecraft to start rotating. Based on how long it takes to start rotating, we can calculate how much thrust the ICS is producing. I am really excited about the upcoming tech demo, to really see if it is working and operating."

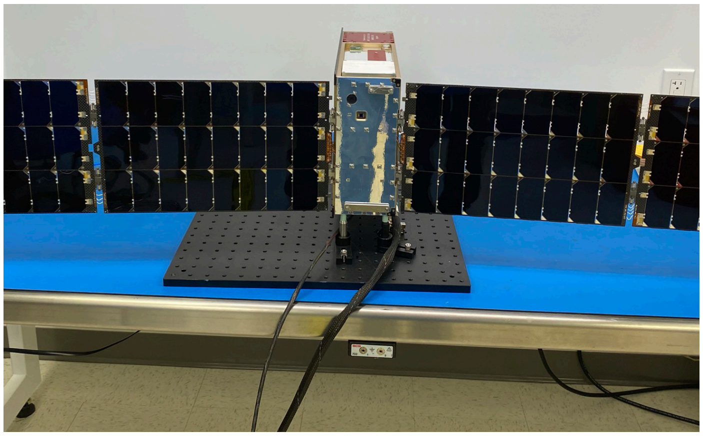
Depending on the mission, one of the other advantages of the ICS is that is scalable. You can put as many or as few of these tiny thrusters on a satellite. The thrusters are also cheap to manufacture.

"The cost of one of these little thruster assemblies is something along the line of $4 in material, not counting the engineering that goes into it," noted Rusley, of the ICS project, which started in 2017. "But if you think of the cold gas thruster [in a rocket engine] or something like that, those run into the tens of thousands of dollars to manufacture in a system. The ICS is an exciting piece of technology and I think that there is not much on the market that is like it, especially in this form factor."

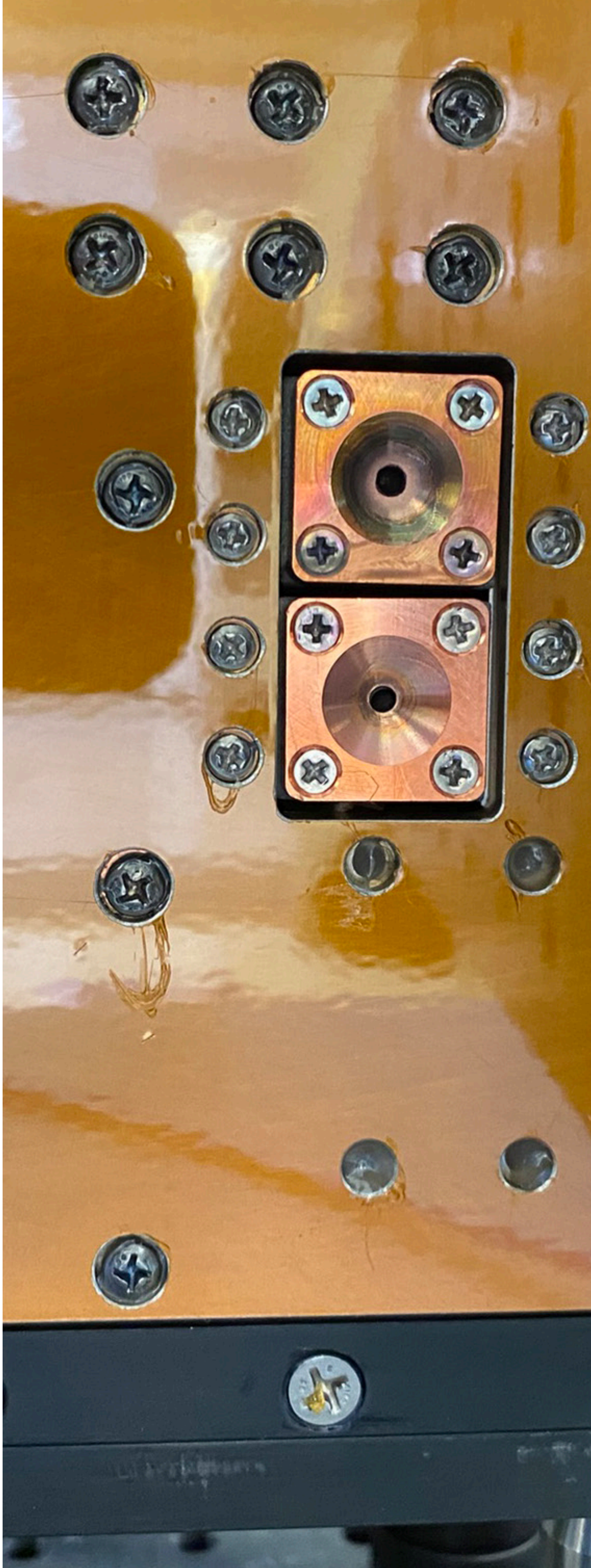
Designed using tungsten fuel for its high density, this increases the system efficiency and longevity of the ICS. Riding on a SmallSat/CubeSat like a hitchhiker, the ICS is inert in nature and can do no harm to the satellite or the mission.

"There is a lot of focus on [mission] safety, and on what can go wrong and cause harm to the primary mission," said Rusley. "The ICS is completely inert. There is no way this can explode or go into thermal overload. In short, the system presents no threat to the primary mission."

Over the past decade, driven by technology breakthroughs, industry commercialization, and private investment, there has been an explosion of activity in the SmallSat/CubeSat propulsion development world. The Goddard ICS team believe they have the developed the right kind of tiny technology to meet the industry's needs.



SmallSat with panels deployed, Photo Credit: NASA / GSFC



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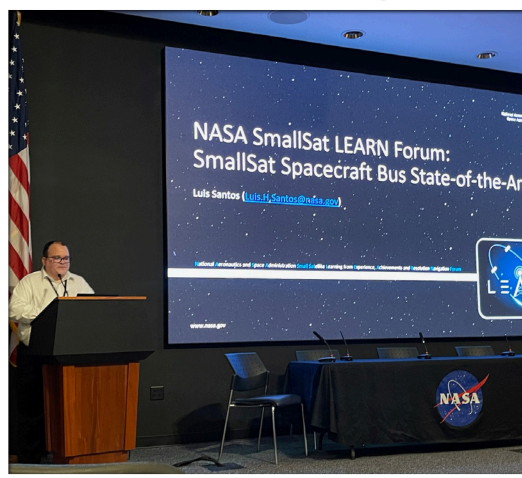

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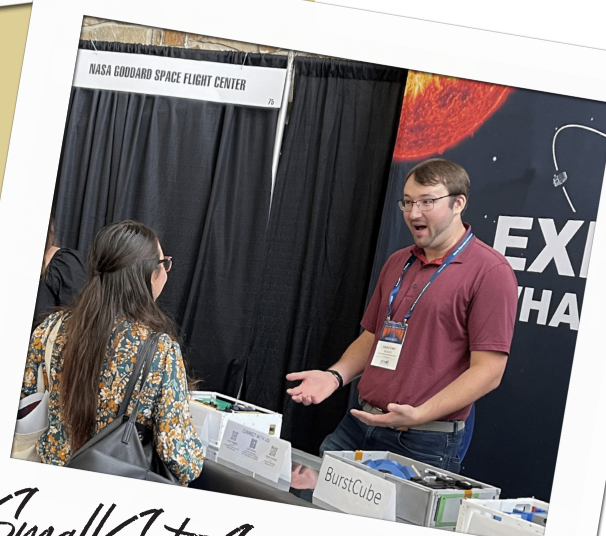

SmallSat Conference 2022

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