National Aeronautics and Space Administration

Cutting edge
Goddard's Emerging Technologies

A Pint-Size Foreshadowing of Things to Come

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Lunar IceCube Wins Slot on Exploration Mission-1

Scientists Herald Age of Deep-Space Exploration with CubeSats

Morehead State University Professor Benjamin Malphrus, who is leading the Lunar IceCube mission, stands in front of the university's 21-meter ground station antenna that will be handling the mission's communications needs.

Lunar IceCube has won a coveted slot as one of 12 diminutive secondary payloads to deploy during the first planned flight in 2018 of NASA's next-generation Space Launch System (SLS) and the second for its Orion Multi-Purpose Crew Vehicle — an event that scientists say will signal a paradigm shift in interplanetary science.

Morehead State University in Kentucky is leading the six-unit (6U) CubeSat mission, with significant involvement from Goddard scientists and engineers and the Massachusetts-based Busek Company. It will be among the "first batch" of small, fully operational satellites to deploy and gather scientific information in deep space, said Pam Clark, the mission's science principal investigator at Goddard. Although CubeSats are evolving rapidly, scientists so far have confined their use to investigations in low-Earth orbit.

Under the university-led partnership, Morehead State's Space Science Center will build the 6U satellite bus and provide communications and tracking support via its 21-meter ground station antenna. Busek will provide the state-of-the-art electric propulsion system and Goddard will construct IceCube's only miniaturized instrument, the Broadband InfraRed Compact High Resolution Explorer Spectrometer (BIRCHES).

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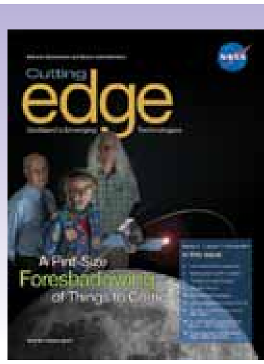
About the Cover



Goddard's Dave Folta, Pam Clark, and Dennis Reuter are helping develop the Lunar IceCube, one of Goddard's first deep-space CubeSat missions. Morehead State University in Kentucky is managing the mission, which will prospect for water in ice, liquid, and vapor forms from a highly inclined elliptical lunar orbit.

Photo Credit: Bill Hrybyk/NASA

The instrument will prospect for water in ice, liquid, and vapor forms from a highly inclined elliptical lunar orbit. Goddard also will model a low-thrust trajectory taking the pint-size satellite to lunar orbit with very little propellant.

"Goddard scientists and engineers have deep experience in areas that are critical to interplanetary exploration," said mission Principal Investigator Benjamin Malphrus, explaining why the university teamed with Goddard. "The significant expertise at Goddard, combined with Morehead State's experience in smallsats and Busek's in innovative electric-propulsion systems, create a strong team."

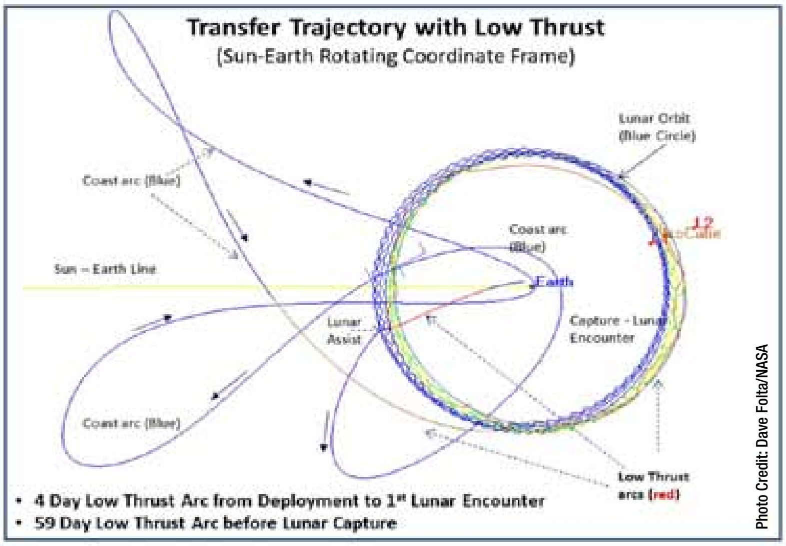


Photo Credit: Dave Folta/NASA

Getting to the moon will require that the Lunar IceCube take a circuitous route that uses the gravity of the sun, Earth, and moon.

The spacecraft will be one of 12 payloads installed inside the upper stage of NASA's newest rocket — the SLS, a 38-story launch vehicle designed to ferry humans and gear to the moon and beyond. Once the rocket reaches a certain position on its way to the moon during the Exploration Mission-1 (EM-1) flight, ground controllers will release the payloads, which will follow their own trajectories to their final destinations in and around the moon.

So far, NASA has selected three other payloads: the Jet Propulsion Laboratory's Lunar Flashlight, which will complement IceCube; the NASA Ames Research Center's BioSentinel, which will study radiation-induced DNA damage of live organisms in lunar space; and the NASA Marshall Space Flight Center's Near Earth Asteroid, which will fly by and characterize one near-Earth object that is relevant to human exploration.

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BREAKING NEWS:

Goddard Wins Another Exploration Mission-1 CubeSat Mission; Joins Lunar IceCube

At press-time, *CuttingEdge* learned that another CubeSat mission involving significant contributions from Goddard scientists has won a berth on NASA's Exploration Mission-1 (EM-1) in 2018. The pint-size spacecraft will be one of the first to venture into interplanetary space.

NASA chose the CubeSat Mission to Study Solar Particles over the Earth's Poles Enhancement (CuSPP+) to study the sources and acceleration mechanisms of solar and interplanetary particles near Earth's orbit. Led by the San Antonio, Texas-based Southwest Research Institute (SwRI), the six-unit (6U) CubeSat will fly three miniaturized instruments, including the Goddard-developed Miniaturized Electron and Proton Telescope (MERiT).

MERiT is a modification of a similar sensor that is now being built for the Compact Radiation Belt Explorer (CeREs) mission, a three-unit (3U) CubeSat mission slated to fly in 2016 (*CuttingEdge*, Spring 2014, Page 8). Goddard also had been working with SwRI on another 3U CubeSat, called CuSPP (*CuttingEdge*, Summer 2014, Page 7).

"For the EM-1 opportunity, we just proposed an increment to CuSPP to make it interplanetary, thus CuSPP+," said Goddard Lead Co-Investigator Eric Christian, who is working with co-investigators Shri Kanekal and Nikolaos Paschalidis on the instrument.

CuSPP+ joins the Lunar IceCube (see related story, page 2) as one of 12 payloads to deploy during EM-1, the first test flight of NASA's Space Launch System, a 38-story launch vehicle. While Lunar IceCube will gather data from a highly elliptical lunar orbit, CuSPP+ will study charged-particle dynamics in interplanetary space. ❖

The Busek Company is developing Lunar IceCube's low-thrust electric propulsion system, the RF Ion BIT-3 thruster.

Competitions are ongoing to fill the other EM-1 slots. As of press-time, NASA had announced the selection of a heliophysics-related mission also involving significant contributions from Goddard scientists (see page 3).

A Pathfinder for Deep-Space Exploration

"Lunar IceCube is a key pathfinder experiment for future small-scale planetary missions," said Goddard scientist Avi Mandell, who is assisting his colleague, Dennis Reuter, in the development of BIRCHES. "I believe the future looks bright for science on CubeSats due to their fantastic versatility. That's why it was so important to be one of the teams to participate in this first launch of deep-space CubeSats. Once we understand how to design these platforms, the possibilities are endless as to what we can do with them."

Since their development more than a decade ago by Morehead State University Professor Bob Twiggs, then a professor at Stanford University, and Jordi Puig-Suari, an engineer at California Polytechnic State University, CubeSats have evolved principally from tools of instruction to full-fledged scientific platforms, which, given their relatively low cost and ease of integration, have become increasingly more appealing to professional scientists.

In recent years, NASA and other government agencies have invested more R&D resources into advancing new miniaturization technologies that will support more robust scientific investigations from these platforms. "A lot of people are interested in answering scientific questions with these small devices," explained Bob MacDowall, a Goddard scientist who is serving as a member of IceCube's science team. "I'm betting that we already have about 100 deep-space CubeSat concepts floating around," Clark added. "This is where things are headed."

Challenges and Innovative Technology

IceCube will prospect for lunar volatiles and water during its six months in lunar orbit. While JPL's Lunar Flashlight will locate ice deposits in the moon's permanently shadowed craters, IceCube's BIRCHES will investigate the distribution of water and other volatiles as a function of time of day, latitude, and regolith age and composition. Its study is not confined to the shadowed areas.

Although other missions, such as the Lunar Prospector, Clementine, Chandrayaan-1, and Lunar Reconnaissance Orbiter, discovered various signatures of water and hydroxide, their instruments weren't optimized for fully or systematically characterizing the elements in the infrared wavelength bands ideal for detecting water, MacDowall said. The high-resolution BIRCHES, on the other hand, was specifically designed to distinguish forms of water — ice, vapor, and liquid, he said.

Lunar IceCube, in short, could ultimately help

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scientists understand the role of external sources, internal sources, and micrometeorite bombardment in the formation, trapping, and release of water on the moon.

Although the instrument traces its heritage to instruments flying on NASA's Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) and New Horizons missions, the team said miniaturization challenges remain.

Goddard scientists Avi Mandell and Dennis Reuter are developing the BIRCHES instrument for the new Lunar IceCube mission.

For instance, BIRCHES will carry a 1,000,000-pixel detector that will sense infrared signals emanating from the lunar surface. To record those signals, instrument developers will have to design a read-out channel linking each pixel to an amplifier that then bolsters the signal. "All of that is a pretty chunky piece of hardware," not particularly conducive to fitting inside a satellite bus no larger than a large cereal box, Mandell said.

The team also needs to assure that sensitive electronics are protected against radiation — a significant concern in deep space. "I have no doubt that these challenges are solvable," Clark said.

Getting There

But before the Lunar IceCube can begin its science operations, it will have to get to the moon first — another challenge given the miniscule real estate set aside for propellant. Busek's RF Ion BIT-3 thruster, along with a carefully designed trajectory modeled by Goddard's state-of-the-art trajectory-design software, will get IceCube to its destination in about three months, said Dave Folta, the Goddard orbital engineer who has developed advanced tools for modeling lunar orbits for spacecraft equipped with both chemical and low-thrust propulsion systems (see related story, page 8).

"It doesn't matter the size of the spacecraft, I still have to do the same functions when designing a trajectory," Folta said. "It doesn't matter how much this guy weighs, either. They want me to get this to the moon."

The journey will begin after deployment. Ground controllers will fire Busek's miniaturized electric thrusters — the world's only propulsion system powered with an iodine propellant — driving the spacecraft along a path that uses the gravity of the sun, Earth and moon, looping around Earth a couple times and then to its destination. Because the thrusters operate electrically using small amounts of propellant, an orbital path that takes advantage of gravitational acceleration from the Earth and moon is vital, he added.

"While low-thrust systems minimize fuel, they can't accommodate a rapid change in the orbit's velocity, making EM-1's outbound path impossible for us," Folta said, explaining the mission's circuitous route. "Our propulsion system will allow us to naturally capture a lunar orbit. The force of our low-thrust system is analogous to an ant pushing on the spacecraft over many days. It's an efficiency thing. That's the whole point of this low-thrust trajectory."

Although much work remains, team members say that for now they want to savor NASA's selection of their mission. "The real breakthrough stuff in CubeSat technology will now happen," Clark said. "That's what I love about CubeSats. They will help us revolutionize the way we do deep-space science and I'm absolutely delighted that Goddard will play a role." ❖

CONTACTS

Pamela.E.Clark@nasa.gov or 301.286.7457
David.C.Folta@nasa.gov or 301.286.6082
Robert.J.MacDowall@nasa.gov or 301.286.2608
Avi.Mandell@nasa.gov or 301.286.6293

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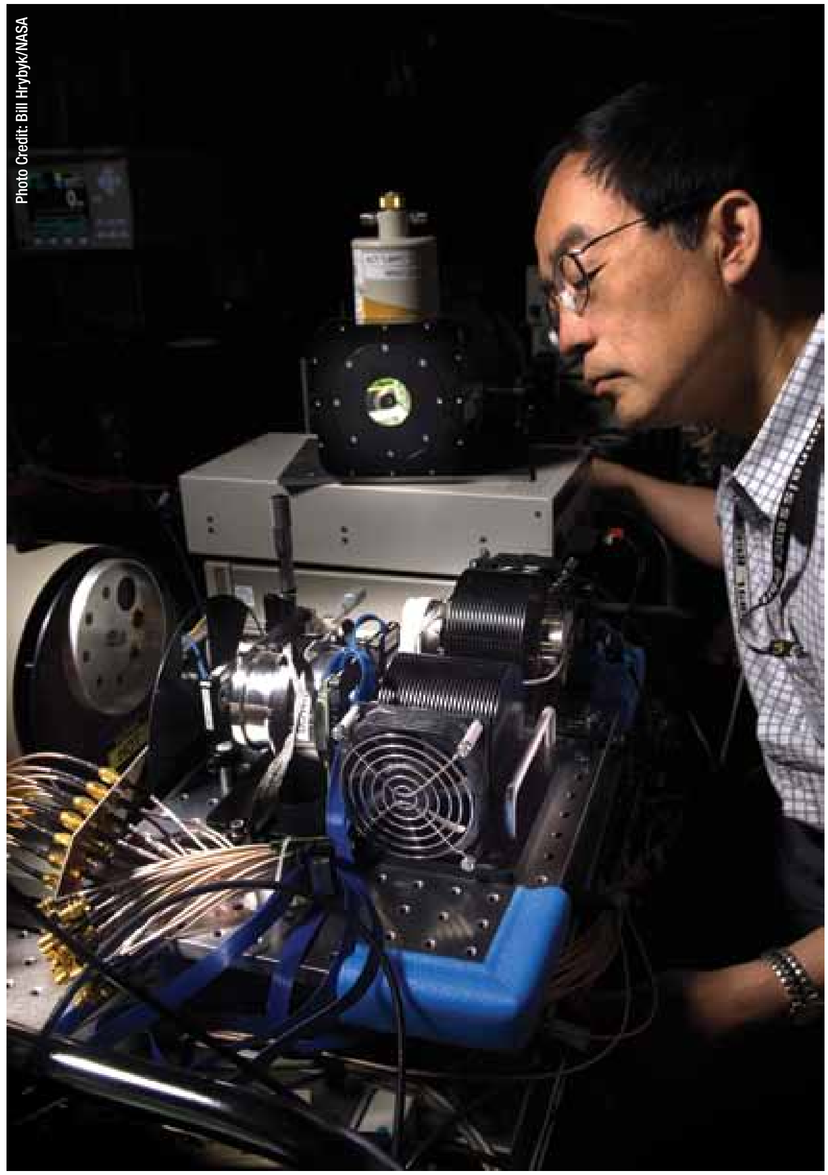
The Dawn of a New Detector

Goddard Collaborates with DRS Technologies to Create Mid-Infrared Detector

Goddard scientist Xiaoli Sun and his industry partner have created the world's first photon-counting detector sensitive to the mid-infrared wavelength bands — a spectral sweet spot for a number of remote-sensing applications, including the detection of greenhouse gases on Earth, Mars, and other planetary bodies, as well as ice and frost on comets, asteroids, and the moon.

"We have developed a new type of mid-infrared detector," said Sun, who worked with the Dallas, Texas-based DRS Technologies to advance the detector, which has since garnered additional funding support from the Department of Defense. "This is a true success story," Sun said, adding that NASA had been looking for this type of detector for years. "It's a happy story because new detector development is difficult, requiring years of hard work, continued funding, and some luck."

The new detector, made of a special alloy called Mercury-Cadmium-Telluride (HgCdTe) used principally in infrared detectors, is well suited for lidar. This remote-sensing technique involves shining a laser light on a target and then analyzing the reflected light or signal to learn more about the physical properties of the illuminated object.



Goddard scientist Xiaoli Sun worked with his contractor partner to create the world's first photon-counting mid-infrared detector.

What's unique about this detector, which is about the size of a sesame seed, is its ability to process the returning infrared signal at a single-photon level. "People have tried to produce single photon detectors in this wavelength band for a long time. Existing detectors can only detect signals containing hundreds of photons per pulse. It is the combination of the HgCdTe material and a near-noiseless avalanche photo-electron multiplication process that made this possible," Sun said. As a result of this advance, the new detectors enjoy unparalleled sensitivity.

Achieving this level of sensitivity wasn't an easy feat. Detecting photons one-by-one with near-perfect reliability is dauntingly difficult, especially at mid-infrared wavelengths, Sun added. In fact, it took DRS Technologies nearly eight years to manufacture a 16-pixel photon-counting detector array. "It's difficult manufacturing these things," Sun said. "DRS is the only company in the world that can routinely make them."

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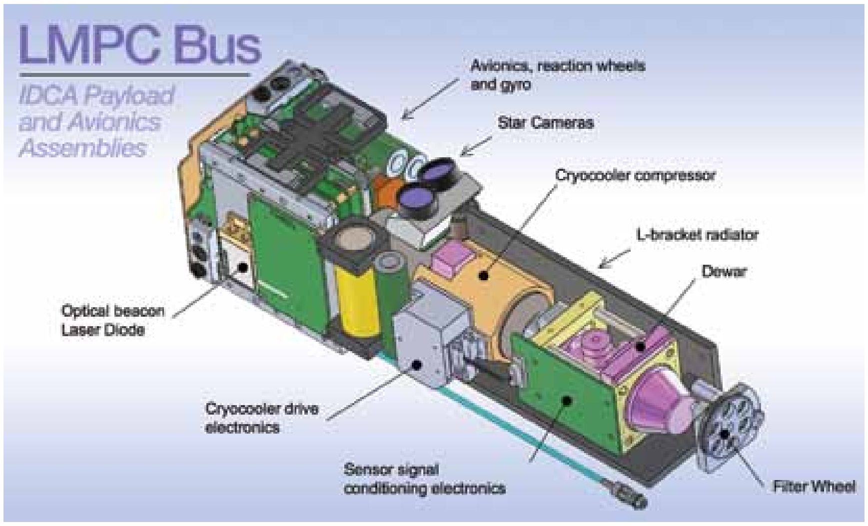
First Out of the Gate

The detectors already have customers. Goddard scientist Jim Abshire has installed the detector into his CO2 Sounder Lidar. This instrument carries a pair of tunable laser transmitters and a two-wavelength laser-absorption spectrometer that measures both carbon dioxide and oxygen (*CuttingEdge*, Fall 2011, Page 4). His colleague, Harris Riris, is now developing a similar instrument to measure methane using the same technique (*CuttingEdge*, Winter 2015, Page 7).



This artist's rendition shows the design of NASA's CubeSat Demonstration of a Photon-Counting Infrared Detector, which will carry a new mid-infrared detector championed by co-creator Xiaoli Sun.

Both instruments — strong candidates for NASA's proposed Active Sensing of CO2 Emissions over Nights, Days, and Seasons mission — operate by bouncing a laser light, which is tuned to a narrow band in the infrared, off Earth's surface. Like all atmospheric gases, carbon dioxide, oxygen, and methane absorb the infrared light as it travels back to the instrument. The more gas along the light's path, the deeper the absorption lines as measured by the detectors.

"We always wanted to have more sensitive detectors because we can then use lower-power lasers, which, in turn, reduce the size, power, and cost of the instrument," Sun explained, adding that a researcher at NASA's Langley Research Center also has acquired the detector for a lidar instrument he's developing for carbon-dioxide measurements. In addition, Abshire is now investigating the detectors' use for measuring the global climate on Mars.

Laser-Altimeter CubeSat Demonstration

The detector also holds great promise for laser altimetry, and more particularly, NASA's proposed Lidar Surface Topography (LIST) mission, which would measure land surface topography for hazards and water runoff, also by bouncing laser light off the Earth's surface and analyzing the time-of-flight, amplitude, and polarization of the returned signal.

Next year, Sun and his team are expected to find out just how well the detector array performs a LIST-type measurement when it flies as the principal payload on NASA's CubeSat Demonstration of a Photon-Counting Infrared Detector, a three-unit CubeSat now being built by the California-based Aerospace Corp.

Funded by NASA's In-Space Validation of Earth Science Technologies program, Aerospace Corp. is adapting a small cryogenic cooler previously used on a Black Brandt rocket to hold the 16-element detector. As part of this year-long technology demonstration, the team will try firing laser light from a ground station to the low-Earth orbiting CubeSat to determine the detectors' performance and ability to withstand the harsh radiation found in space.

Infusion Success: Other Beneficiaries

In addition to benefiting Earth and planetary remote sensing, for which Sun and DRS Technologies originally began the development effort, the new detector could be used in free-space laser communications, information science and data-encryption, medical imaging, DNA sequencing, astrophysics, and materials science, just to name a few applications.

Working with DRS Technologies, the Defense Advanced Research Projects Agency is now investing in a larger array for a flash lidar — a research effort that Sun hopes to leverage as he further advances the technology for civilian-space use.

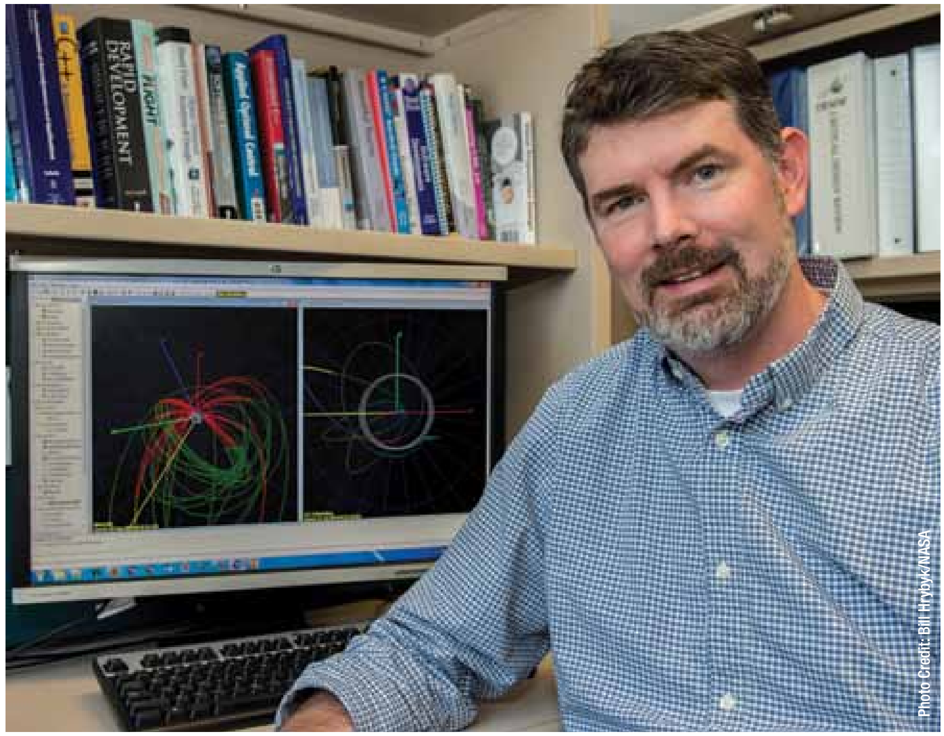
"The future of these detectors is big," said Irene Bibyk, an associate with NASA's Earth Science Technology Office, one of several technology-development programs that helped advance the HgCdTe detectors. "They're evolutionary. They're disruptive. They have so many applications. Everything about this technology development was exemplary. That's why I call Xiaoli Goddard's 'rising sun.'" ❖

CONTACT

Xiaoli.Sun-1@nasa.gov or 301.614.6732

The GMAT Wizards

Software Developers Nominated for Prestigious NASA Award



Goddard engineer Steven Hughes and his team created the world's only enterprise, open-source space-mission design capability used for a variety of missions, including the Lunar iceCube.

Sending a rocket or other spacecraft beyond low-Earth orbit requires some mathematical wizardry, especially when calculating the amount of fuel needed to propel a heavy vehicle beyond Earth's gravitational clutch and the best route the spacecraft should follow to reach its destination.

This formerly time-consuming and mentally taxing exercise is now much easier, thanks in large part to the Goddard-developed General Mission Analysis Tool (GMAT). This modeling program allows mission-control specialists to rapidly plot a course for all types of spacecraft.

One-of-a-Kind Tool

Since its development, the world's only enterprise, open-source space-mission design tool has earned plenty of accolades from its government and industry users, but for those who developed the feature-rich system, nothing compares to the recognition they received recently when Goddard selected GMAT as its nominee for NASA's prestigious "Software of the Year" award. The team will learn shortly whether NASA has chosen GMAT over other NASA nominations.

"We're delighted with the recognition. Our team has put a lot of hard work into GMAT and it's great to see it helping so many NASA and industry efforts," said GMAT Project Manager Steven Hughes, recalling the events leading up to the nomination.

He and his team began working on the software tool more than a decade ago shortly after NASA had begun phasing out a mission-calculation tool called "Swing By." The team, which includes five engineers, five developers, one tester, and a number of industry and university collaborators, collected requirements and spent two years designing an open-source program customizable to meet the agency's needs.

"The original plan for GMAT was to be an engineering design tool, but due to its success, we decided to qualify the software for operational support," he added.

> *"The entire idea behind GMAT was to develop a tool that was highly customizable, openly available, autonomous, and fast. I think we succeeded and that's rewarding."*
>
> *— Steven Hughes, Goddard engineer*

Extensive testing helped ensure all components worked properly before the team released a flight-qualified version of the GMAT system in 2013, the same year NASA launched the Mars Atmosphere and Volatile Evolution mission, whose team used GMAT in preparation for flight, Hughes said. Even now, some 12,000 tests are run each night to find glitches before they become bigger problems.

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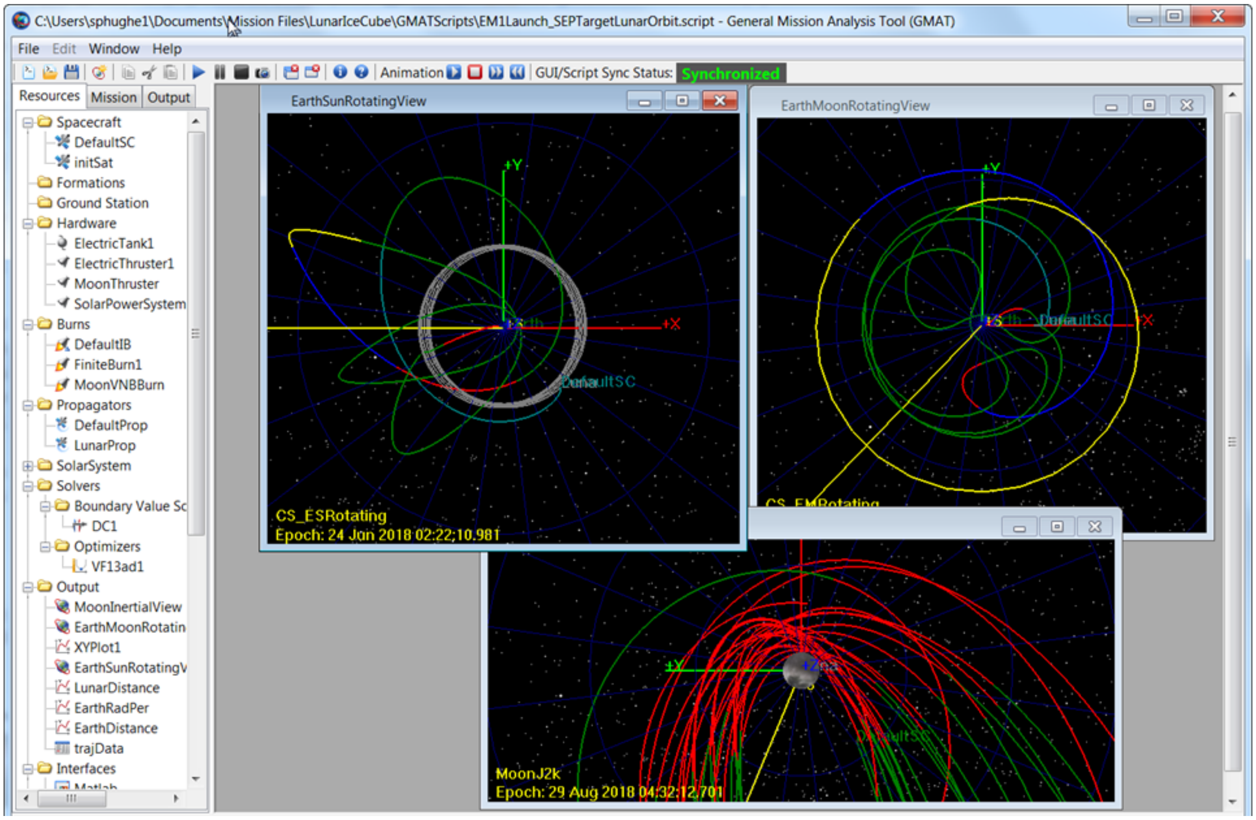

This image shows the GMAT-created trajectory for the Lunar IceCube mission. Photo Credit: Dave Folta/NASA

"We have models of spacecraft, fuel tanks, thrusters; we have models of the solar system and how it affects the motion of spacecraft," Hughes said. "We have things that are called solvers that let you say, 'My mission needs to be in an orbit that has these basic requirements, it needs to come within this distance of the moon but it can't come any closer than this.' It has a lightweight, built-in programming language so you can customize your solution to meet unique mission needs."

High-Profile Missions Supported

Having supported several high-profile missions, including the Lunar Reconnaissance Orbiter and the Magnetospheric Multiscale mission, GMAT now is on tap for use on NASA's Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) in 2016 and the Transiting Exoplanet Survey Satellite (TESS) in 2017. "The TESS mission is using GMAT as the primary tool," Hughes says. "And OSIRIS-REx plans to use it for launch-window analysis. A lot of Goddard missions have used GMAT in some way."

Also on the team's docket is calculating a course for Lunar IceCube, a recently selected deep-space CubeSat mission. It will require a complicated trajectory to insert it in a highly elliptical lunar orbit with comparatively little fuel (see related story, page 2). "These are unstable orbits and it doesn't take much to change the trajectory," Hughes said.

Goddard-managed missions aren't GMAT's only beneficiaries, however.

Because GMAT is open source, universities, other government agencies, and private industry have used the tool for everything from orbit propagation and simulations to maneuver interception and collision avoidance — applications well beyond those anticipated by the design team. So far, the application and its source code have been downloaded more than 49,000 times for all releases.

"The entire idea behind GMAT was to develop a tool that was highly customizable, openly available, autonomous, and fast," Hughes said. "I think we succeeded and that's rewarding." ❖

CONTACT

Steven.P.Hughes@nasa.gov or 301.286.0145

Dennis Andrucyk Reflects on NASA's Technology Future

Space technology isn't new to Dennis Andrucyk, who prior to his selection as deputy associate administrator of NASA's Space Technology Mission Directorate (STMD) in April, served as the director of Goddard's Applied Engineering and Technology Directorate (AETD), among other technology-related positions. In his new STMD role, Andrucyk manages the directorate's day-to-day operations and helps plot the strategic direction of the agency's space-technology program. In this one-on-one interview with *CuttingEdge,* Andrucyk shares his thoughts across a wide range of topics.


Photo Credit: Joel Kowsky/NASA

Dennis Andrucyk, who prior to his selection as deputy associate administrator of NASA's Space Technology Mission Directorate in April, served as the director of Goddard's Applied Engineering and Technology Directorate.

You've held a number of highly visible positions during your NASA career. What do you hope to accomplish as the deputy associate administrator for the agency's Space Technology Mission Directorate?

I've been incredibly fortunate in my NASA career. I've had the opportunity to lead several of Goddard's engineering divisions before becoming the director of engineering. Along the way, I've also served as the Goddard chief technologist. Moving to NASA Headquarters gives me a chance to apply my engineering and technology experiences to develop future technologies we will need to do great science and work beyond low-Earth orbit.

Is NASA on the right track from a technological point of view?

Yes. Establishing STMD as a stand-alone organization, with the sole charter of developing technology for science and human exploration, ensures that the agency's technological needs are satisfied. In addition, STMD has developed a broad set of programs that addresses the full lifecycle of technology development.

One of the greatest hurdles a technology must overcome is mitigating the risk it introduces into a flight mission. The STMD technology portfolio addresses not only early technology R&D, but also supports flying and testing those systems in the environments where they will be used. This allows us to meet our technical, schedule, and cost commitments.

What do you think are the greatest challenges? Which trends do you see emerging that would affect R&D at NASA? Which technologies are absolutely necessary for NASA to meet its future missions and goals?

Fortunately, we understand the general path forward. NASA has established its vision for human exploration beyond low-Earth orbit. The decadal surveys are helping guide scientific and technology investments. NASA's Office of the Chief Technologist has coordinated with the mission directorates and NASA's centers to develop technology roadmaps for the future. That said, the greatest challenge is probably the same one that affects all government programs: funding. Nevertheless, I think STMD is doing amazing work with the funding levels we have received.

Do you foresee a change in direction?

At the higher levels, we know what technologies we can invest in, and, if we had enough funding, what we should be investing in. Unfortunately, in a constrained budget environment, we need to formalize a strategy for what we actually will be investing in. To that end, STMD has initiated the development of a Strategic Implementation Plan that will document how we will address that need. In creating this plan, we will look across our portfolio to be sure we are getting the greatest return possible for our technology investment.

How do you see Goddard's technology development fitting into the STMD activities?

Goddard is actively engaged in the Laser Communications Relay Demonstration (LCRD) and Wallops is a major contributor in the Low-Density

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Supersonic Decelerator. Goddard's personnel allocation is oversubscribed, with excellent ongoing programs. Perhaps one of the reasons I've mentioned LCRD is that Steve Jurczyk and I recently toured the LCRD labs, talked to project personnel, and came away energized. Goddard is a key player in achieving STMD goals and there is no reason to believe that will change in the future.

What advice could you give Goddard technologists?

Goddard has a very robust and effective new business organization and process. Technologists should coordinate through the center's lines of business (LOBs), with the center chief technologist, and the AETD chief technologist to better understand what technology needs are being pursued and what opportunities for funding are on the horizon. It's also great to establish a connection with key center scientists (either directly or through the LOB management teams) to get their perspective and to see if the technologists can provide direct support to the scientists' pursuits. ❖

LISA Pathfinder Set to Launch This Fall

Goddard Participating in International Effort to Test Gravitational-Wave Detection Technique

A mission aimed at demonstrating technologies essential for detecting gravitational waves in space is set to launch this fall.

LISA Pathfinder, a European-led mission scheduled to launch aboard a Vega rocket from Kourou, French Guiana, in October, will carry the European LISA Technology Package (LTP) and the NASA-provided Disturbance Reduction System (ST7-DRS), both designed to demonstrate a technique called drag-free control, a key element in the proposed Laser Interferometer Space Antenna (LISA) that has been under development in the U.S. and Europe for several decades.

Once launched, the spacecraft will use its propulsion module to travel to the first Earth-sun Lagrange point (L1), located about 621,000 miles (1.5 million kilometers) from the Earth in the direction of the sun.

"The LISA Pathfinder is the opening shot" in the long-running and continuing effort to ultimately fly a mission dedicated to detecting gravitational waves, said Tuck Stebbins, a Goddard scientist who was instrumental in the development of the LISA mission. "This demonstration is important."

Einstein's Prediction

First postulated by Albert Einstein nearly a century ago in his theory of general relativity, gravitational waves happen when massive objects, such as supermassive black holes, spiral together and merge in the universe. The resulting collision creates waves in the fabric of space-time, radiating out in all directions, much like a stone thrown into a pond. Although scientists have found clues suggesting their existence and have created models showing what they might look like (*Tech Trends*, Spring 2006, Page 2), no one has ever directly measured these powerful forces of nature.

If detected, their discovery would revolutionize the field of astrophysics and open new venues for studying galaxy formation and evolution, black-hole growth, the end states of stars, cosmology, and the nature of gravity itself, said Ira Thorpe, a Goddard scientist who currently serves on the LISA Pathfinder science team.

Among his other activities supporting the LISA Pathfinder mission, Thorpe and his Goddard colleagues have designed, modeled, and analyzed different experiments that scientists could carry out with the ST7-DRS payload, which also includes a Goddard-developed algorithm. The payload is designed to provide valuable information to those who will design future gravitational-wave missions, Thorpe added.

The Concept

In the LISA concept, a constellation of three spacecraft positioned in a triangular-shape orbit would use a measurement technique called laser interferometry to precisely monitor the distance between each spacecraft pair. As gravitational waves produced by distant cataclysms wash over the constellation, they would produce small fluctuations in these distances that scientists then could use to detect the waves, characterize them, and infer properties of their sources.

However, the fluctuations would be so small that the spacecraft themselves would not be able to

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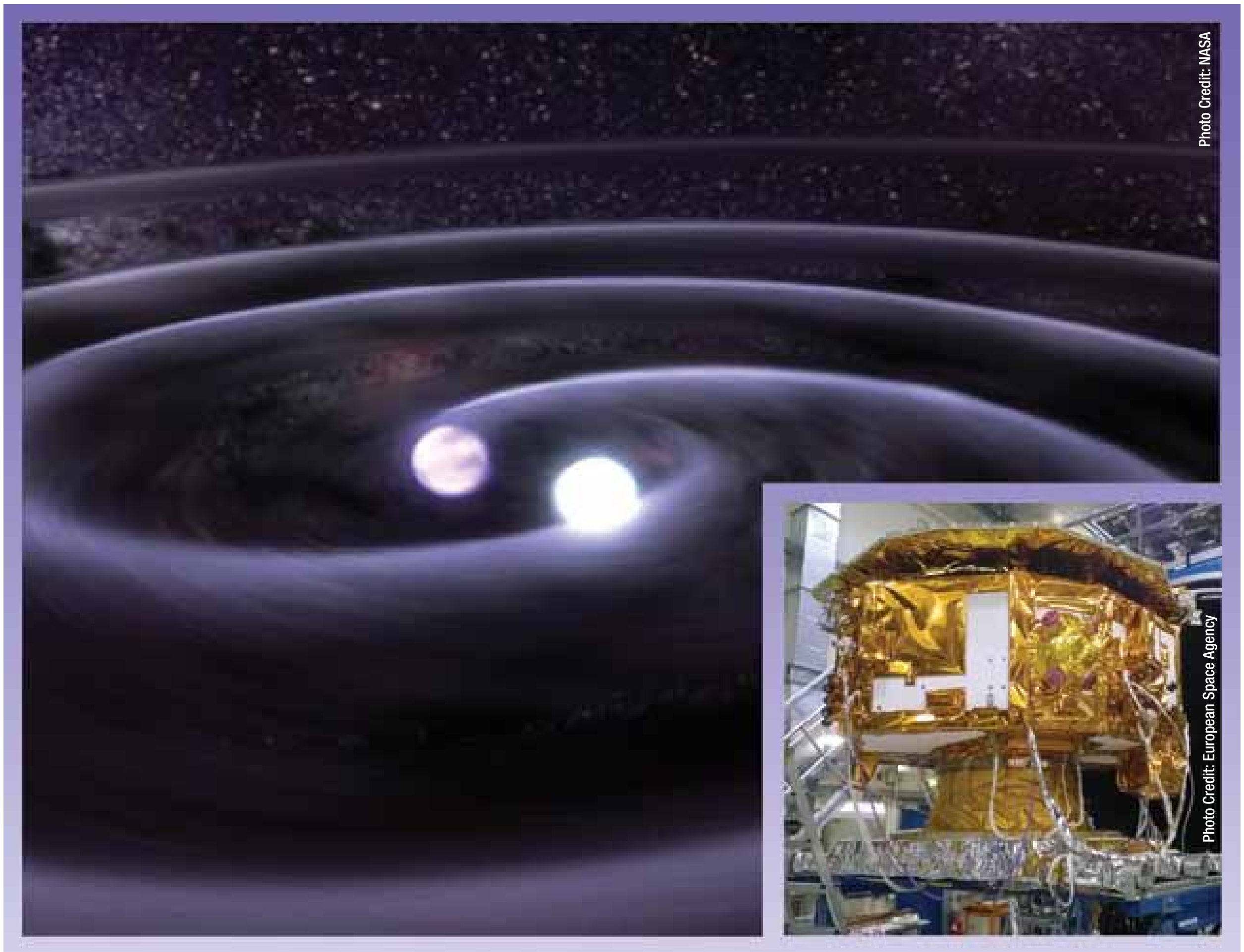

Main Image: *Cataclysmic events, such as this artist's rendition of a binary-star merger, are believed to create gravitational waves that cause ripples in space-time.* *Inset Image:* *LISA Pathfinder, which will fly a Goddard-developed algorithm, will demonstrate technologies essential for detecting gravitational waves in space. It is set to launch this fall.*

detect them because they are subject to noisy external forces, such as pressure from solar radiation. To mitigate this, LISA will use freely falling test masses placed inside each spacecraft as the reference points for the interferometric measurement.

The primary objective of LISA Pathfinder, therefore, is to demonstrate this freely falling test-mass technique, known as drag-free control. LISA Pathfinder's two test masses — gold-platinum cubes measuring nearly two inches on a side and weighing about four pounds — will be allowed to drift freely inside cavities within the spacecraft.

A laser interferometer will measure their locations inside the spacecraft, while a control system steers the spacecraft around the test masses using micro-propulsion systems. To maintain this free-fall trajectory, the thrusters will continuously fire to adjust the spacecraft's position so that the spacecraft stays centered about the test masses.

The European LTP payload includes the test masses and a laser-control system to measure their distances, as well as micro-thrusters and control algorithms that calculate when the thrusters should fire. NASA's payload, managed by the Jet Propulsion Laboratory, also includes micro-thrusters producing thrusts equivalent to the weight of a mosquito and a Goddard-developed algorithm that will use LTP's sensor information to control the NASA-provided thrusters, developed in collaboration with the Massachusetts-based Busek Company.

"It really is a major event in gravitational-wave detection and could determine what the LISA mission will become," Thorpe said. "Our goal is to give birth to gravitational-wave astronomy and this could be a big part of that." ❖

CONTACTS

Robin.T.Stebbins@nasa.gov or 301.286.3642
James.I.Thorpe@nasa.gov or 301.286.5382

Radar System Gets Facelift and a Set of Wheels

A formerly inoperative Doppler radar system has received a major facelift, its first set of wheels, a new name, and is now filling an important data gap in ground-based precipitation measurements needed to validate Global Precipitation Measurement (GPM) mission data.

Photo Credit: Bill Hrybyk/NASA

Amber Emory and her colleague, Michael Coon, who served as the lead engineer on the X-BADGER radar project, stand outside the trailer now housing the refurbished instrument that debuted in a field campaign in Kansas.

For the past couple years, self-described “storm chaser” Amber Emory dedicated herself to breathing new life into the ER-2 Doppler (EDOP). This stationary, ground-based vertically pointing radar was built in 1994 to measure precipitation in the X-band, a segment of the microwave radio spectrum ideal for weather monitoring.

Since its decommissioning in 2011, no other ground-based instrument has been available to gather measurements in the X-band, leaving a void in NASA’s ground-based radar suite needed to validate satellite data.

Now rechristened X-BADGER — short for the X-band Atmospheric Doppler Ground-based Radar — the newly refurbished instrument is making its debut in Kansas as part of the six-week Plains Elevated Convection At Night field campaign begun in June. Dispatched to augment NASA ground-based lidars at the same deployment site in Greenburg, X-BADGER has measured everything from cloud droplets to graupel — soft hail — in the atmosphere.

“I couldn’t be happier with its performance,” Emory said. “Our goal was to upgrade the instrument and bring it back to working status. We succeeded.” She and her team also are preparing for another field campaign in the Pacific Northwest this winter.

In some respects, X-BADGER bears little resemblance to its former incarnation.

In addition to moving the entire system onto a research trailer that makes it easier to deploy during field campaigns, Emory and her team built a new solid-state radar, with two digital receivers. One receiver gathers returned signals from the instrument’s vertical- or zenith-pointing radar beam and the other is dedicated to those from a newly added forward-pointing, dual-polarized radar beam. The two beams — one positioned at the 12 o’clock position and the other roughly at 1 o’clock, give X-BADGER a unique ability to gather time-height and cross-sectional data.

In addition, its new solid-state power amplifier prevents the radar beams from attenuating, which means they can travel higher into clouds and return higher-resolution data.

“The completion of X-BADGER is giving us detailed information, such as raindrop sizes and their distributions, which are critical for estimating precipitation,” Emory said. The forward-pointing beam, in particular, is allowing scientists to compare reflectivity and precipitation microphysics, she said. Furthermore, the addition of the digital receivers allows for real-time data processing — something that EDOP couldn’t do.

Her next stop is the Pacific Northwest. The newly mobile X-BADGER will travel to the Olympic Peninsula in Washington to participate in the OLYMPEX campaign to validate GPM data. “Our instrument is filling a gap, but it’s doing more than that,” she said. “In so many respects, it is more robust, rugged, and capable. At last, we now have another tool in the tool belt,” she said. ❖

CONTACT

Amber.Emory@nasa.gov or 301.614.6274

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Innovator PROFILE

10 years cutting edge 2004-2014 Chronicling Goddard Innovation

As CuttingEdge completes the celebration of its 10th anniversary with this issue, it's fitting that we would publish a profile about Goddard scientist Nikolaos Paschalidis. A little more than a year after Goddard's Office of the Chief Technologist published its first edition of CuttingEdge (then named Goddard Tech Trends), NASA launched its New Horizons mission — the first to visit Pluto. Onboard the spacecraft were five instrument-enabling computer circuits that Paschalidis had created. He has waited nearly a decade to see how they perform while flying past this icy world. Here's the story.

Goddard Scientist Waits Nearly 10 Years for Pluto Flyby

When NASA's New Horizons mission to Pluto flies past the distant, icy world on July 14, Goddard space scientist Nikolaos Paschalidis will be one happy man: he created a mission-enabling technology that will help uncover details about the atmosphere of the never-before-visited dwarf planet.

"We have been waiting for this for a long time," said the Greek native. "That's what happens when it takes more than nine years to get to your destination."

When employed by the Johns Hopkins University's Applied Physics Laboratory (APL), which is operating the New Horizons mission for NASA, Paschalidis designed five application-specific integrated circuits — some now patented — for the mission's Pluto Energetic Particle Spectrometer Science Investigation (PEPSSI) developed by APL Principal Investigator Ralph McNutt.

The instrument, one of seven flying on New Horizons, is designed to measure the composition and density of material, such as nitrogen and carbon monoxide, which escapes from Pluto's atmosphere and subsequently is ionized by solar ultraviolet light. The atmospheric chemicals pick up energy from the solar wind and stream away from Pluto.

Until now, knowledge about the mysterious planet's atmosphere has come mainly from stellar occultation, when the planet passes in front of bright stars during its highly elliptical orbit around the sun. From these observations, scientists discovered that the planet's atmosphere resembled that of Neptune's moon, Triton. Although Triton is more massive than Pluto, Pluto's atmosphere is thicker and, like Triton's, likely consists of clouds and winds.

During its flyby, the New Horizons mission will use its onboard suite of instruments — three optical, two plasma, a dust sensor, and a radio science receiver/radiometer — to take images and spectroscopic measurements to learn more about Pluto's atmospheric structure, composition, and temperature, as well as its surface geology and composition.

Microchips Enable Small Size

Of the mission's payloads, PEPSSI is the most compact at just 3.3 pounds (1.5 kilograms). In fact, it's the most compact, lowest-power energetic particle spectrometer flown on a space mission, Paschalidis said.

"The challenge with this mission, and the PEPSSI instrument in particular, was making it as small as

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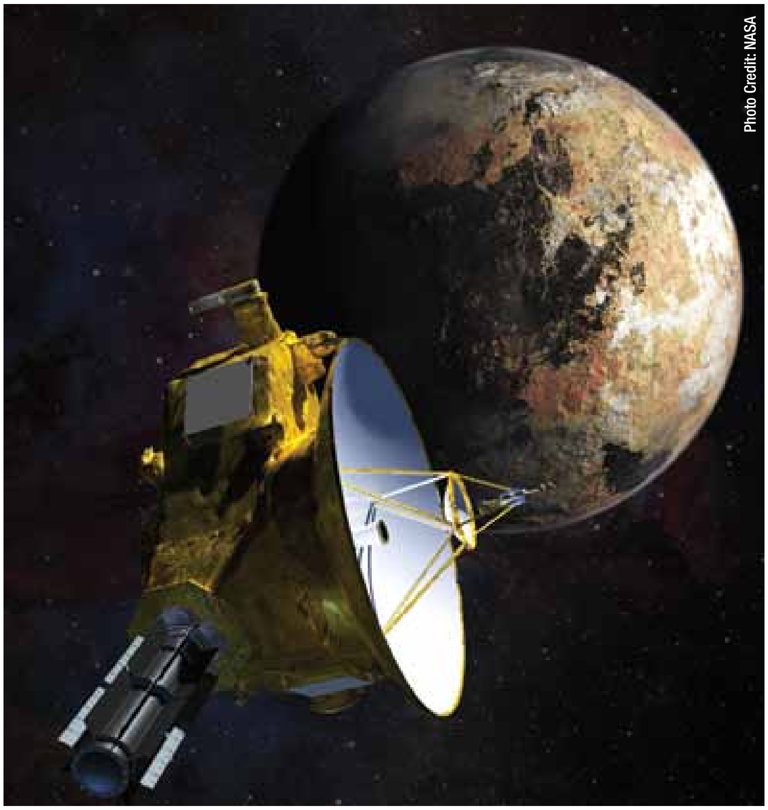
Photo Credit: Bill Hrybyk/NASA

Goddard space scientist Nikolaos Paschalidis created five instrument-enabling microchips for one of the instruments flying on NASA's New Horizons mission to Pluto.

possible, capable of taking highly reliable measurements using low power, under extreme environmental conditions," Paschalidis recalled.

As a classic "time-of-flight" particle instrument, particles enter PEPSSI's sensor and knock secondary electrons from a thin foil. These particles then zip toward another foil, placed about two inches away, before striking the instrument's solid-state detector. The instrument uses just 2.5 watts of power to measure the time between the foil collisions, with an accuracy exceeding one nanosecond. This information reveals the particle's speed and its total energy when it collides with the detector. From this, scientists are able to determine the mass and energy of each particle.



This is an artist's concept of the New Horizons spacecraft as it approaches Pluto in July 2015.

Paschalidis's five microchips helped McNutt overcome the size and power constraints, while advancing science performance. Two in particular advanced the capabilities needed to take time-of-flight, energy, and look-angle measurements of particles, while another not only monitored and digitized PEPSSI's temperatures, voltages, and currents, but also those of several spacecraft subsystems. "This set of chips was an innovation. It combined science with engineering," resulting in significant spacecraft mass and power savings, Paschalidis said.

"A mission to Pluto was the ultimate use for the technology," he added. "Without these chips, I don't think we could have put this instrument on the spacecraft."

Technology Infusion

Although he has waited nearly 10 years to witness his technology in action as New Horizons investigates the last known unexplored planetary body in the solar system, he already knows his microchips will work. The first indication came one year after launch during the mission's Jupiter encounter. "PEPSSI collected excellent data," Paschalidis said.

While New Horizons was racing across the solar system for its rendezvous with Pluto, Paschalidis was infusing the technology into many other instruments and missions. His microelectronic technology was used on NASA's MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) spacecraft, which studied the planet closest to the sun — Mercury — and the Interstellar Boundary Explorer that probed the heliospheric boundary with the interstellar medium.

He also used a second-generation version of the technology on NASA's Juno mission, which is expected to reach Jupiter next summer, the Van Allen Probes, and the recently launched Magnetospheric Multiscale mission. Now under development, NASA's Solar Probe and the European Space Agency's Solar Orbiter missions also will fly the technology, as will a recently selected interplanetary CubeSat mission called the CubeSat Mission to Study Solar Particles over the Earth's Poles (see related story, page 3).

"The New Horizons and MESSENGER/Solar Probe missions represent the two solar-system extremes of fire and ice, and the Juno/Van Allen Probes represent the extremes of space radiation, with the others in between," Paschalidis said. "But New Horizons drove innovation for ultra-miniaturized, low-power, and highly reliable instruments. I can't wait to see this probe finally reach its destination after all these years. Gathering data at Pluto was something that really motivated me." ❖

CONTACT

Nikolaos.Paschalidis@nasa.gov or 301.286.0166

Infusion Success

Technology Helps Prevent Outgassing Problems During Webb Observatory Testing

In yet another "infusion" win for Goddard, a new, patent-pending coating designed to prevent outgassed contaminants from adhering to and harming sensitive instrumentation is being used to protect the James Webb Space Telescope during thermal-vacuum testing.

Goddard engineer Nithin Abraham places a MAC panel at the very bottom of Chamber A, a thermal-vacuum test facility at the Johnson Space Center.

Goddard engineer Nithin Abraham treated custom-designed panels with the Molecular Adsorber Coating or "MAC" and installed them recently in "Chamber A," the thermal-vacuum test facility at NASA's Johnson Space Center where the Webb Observatory currently is being tested.

The coating, created under Goddard's Internal Research and Development program (CuttingEdge, Fall 2012, Page 7), was specifically developed to entrap potentially harmful outgassed molecular contaminants — a process similar to what happens when plastics and other materials outgas and create the new car smell in vehicles.

Made of zeolite, a mineral widely used in industry for water purification and other uses, and a colloidal silica binder that acts as the glue holding the coating together, the new adsorber is highly permeable and porous — attributes that trap the emitted gases.

According to Abraham, MAC is being used to capture outgassed contaminants that exist in the space of the vacuum chamber — not from the Webb components — and prevent them from affixing to Webb's sensitive components. "Although we cannot stop contaminants within the vacuum chamber from outgassing, we can try to capture them with MAC before they reach the expensive hardware, which are housed inside the test chamber," Abraham said.

To that end, technicians installed the panels in strategic locations within Chamber A to capture contaminants from persistent sources, such as silicones and hydrocarbons that outgas and spread easily, even at ambient temperatures.

Besides being used in vacuum chamber tests, including a smaller-scale application last year for the Magnetospheric Multiscale mission, the coating is now being proposed for several other spaceflight applications. "It's definitely exciting and rewarding to see MAC being used on NASA missions," Abraham said. "I believe this technology will continue to mature and advance for more complex applications. I believe it will be infused into many more future missions." ❖

CONTACT

Nithin.S.Abraham@nasa.gov or 301.614.7070

Cutting edge Goddard's Emerging Technologies

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