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# Cutting edge

Goddard's Emerging Technologies

# The Innovators and Their Progeny

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# The Best in Collaboration, Infusion, and Persistence

*SpaceCube and Navigator Teams Win FY16 IRAD Innovators of the Year Award; George Suarez and Team Receive Honorable Mention*

Two teams whose accomplishments read like a "Who's Who" in NASA technology development have been selected to receive the FY16 IRAD Innovators of the Year award, Goddard's Office of the Chief Technologist has announced.

Bestowed annually on those who demonstrate the best in technology development, this year's recognition goes to the Navigator GPS and SpaceCube 2.0 teams because of their success merging their technologies to create a more powerful navigational capability — NavCube (see related story, page 4).

NavCube, which currently is planned for a demonstration aboard the International Space Station in 2018, is applicable to a broader range of missions, including the possible demonstration of X-ray communications in space — a potential NASA first, said Goddard Chief Technologist Peter Hughes, who manages the center's Internal Research and Development program that supported all three technologies.

The office also has awarded technologist George Suarez and his team, Jeffrey Dumonthier and Gerry Quilligan, an honorable mention for their behind-the-scenes persistence in developing one-of-a-kind circuits designed to enable high-profile missions and increase the reliability of CubeSat missions — a technology priority in light of the platform's growing popularity among those seeking less expensive access to space (see related story, page 6).

"We're pleased to recognize the achievements of all who are being honored this year," Hughes added. "We invest in R&D to create capabilities that NASA needs. NavCube, in particular, represents infusion at its best. The cross-pollination of the two technologies gives NASA another tool for carrying out a range of science missions. The possibility that it might help demonstrate X-ray communications in space — a technology in which we also have a vested interest — is particularly exciting."

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## About the Cover

Goddard's SpaceCube 2.0 and Navigator GPS teams collaborated, creating a more powerful navigational tool that could demonstrate another advanced technology, X-ray communications in space. Their collaboration has resulted in the teams winning the Office of the Chief Technologist's annual IRAD Innovators of the Year award. Shown on the cover are three team members: Jennifer Donaldson, Monther Hasouneh, who is holding NavCube, and Dave Petrick. Photo Credit: Bill Hrybyk/NASA

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## NavCube Parentage Highly Acclaimed


Photo Credit: Bill Hrybyk/NASA

*The winners of the FY16 IRAD Innovators of the Year award include (front, left to right): Monther Hasouneh, Dave Petrick, Milt Davis; (middle): Jennifer Donaldson, Yan-Lu "Annie" Chen, Robin Ripley, Tony Marzullo, Luke Winternitz; (back): Mike Jackson, Eric Bentley, Harry Stello, Todd Bentley, and Luke Thomas. Not pictured are Matt Owens, Peter Sparacino, Brian Tokarcik, and Sabrena Heyward Ball.*

The two technologies that parented NavCube are in themselves highly acclaimed.

Since its initial development more than a decade ago, SpaceCube has evolved into a family of computing platforms. This year's award recognizes the SpaceCube 2.0 team, led by Dave Petrick, who won the Moe Schneebaum Memorial Award for Engineering earlier this year.

Petrick specifically received the award for his work implementing the processor on a number of future, high-profile NASA missions related to robotic servicing and operations in space, including the Robotic Refueling Mission, Raven, Restore-L, and the Asteroid Redirect Mission. SpaceCube 2.0 also is the central avionics in a possible mission to detect and characterize near-Earth objects. Due to the technology's success, Petrick and his team now are working to commercialize SpaceCube 2.0.

The first-generation Navigator GPS receiver, which an Arizona-based aerospace company already has licensed, specifically was designed to meet the challenge of high-altitude GPS navigation, and is considered an enabling technology for NASA's Magnetospheric Multiscale mission, or MMS. Without Navigator, the mission couldn't fly in the exacting formation needed to gather data about magnetic reconnection, the fundamental, yet poorly understood process that MMS was specifically designed to study.

First demonstrated on the Hubble Servicing Mission 4, the Navigator technology now is providing operational navigation for NASA's Global Precipitation Mission and has been incorporated in the Orion capsule receiver. In addition, it was used in a GPS Antenna Characterization Experiment — a successful effort that led to the team winning a NASA award in 2015.

Now with the merger, the resulting NavCube has ample processing capability for tackling the next set of navigational challenges, including tracking modernized GPS and Global Navigation Satellite Systems' signals. The improved sensitivity will support higher-altitude missions, even those as far as lunar distance. In addition, the potential integration of a transponder capability could support next-generation space networks.

Those involved in NavCube's development include (from the Navigator team): Monther Hasouneh, Luke Winternitz, Luke Thomas, Sam Price, Yan-Lu "Annie" Chen, Tony Marzullo, Harry Stello, and Jenny Donaldson; (from the SpaceCube team): Dave Petrick, Robin Ripley, Milt Davis, Pietro Sparacino, Sabrena Heyward Ball, Brian Tokarcik, and Matt Owens.

All recipients will be officially recognized during the Office of the Chief Technologist's FY16 IRAD Poster Session in December. ❖

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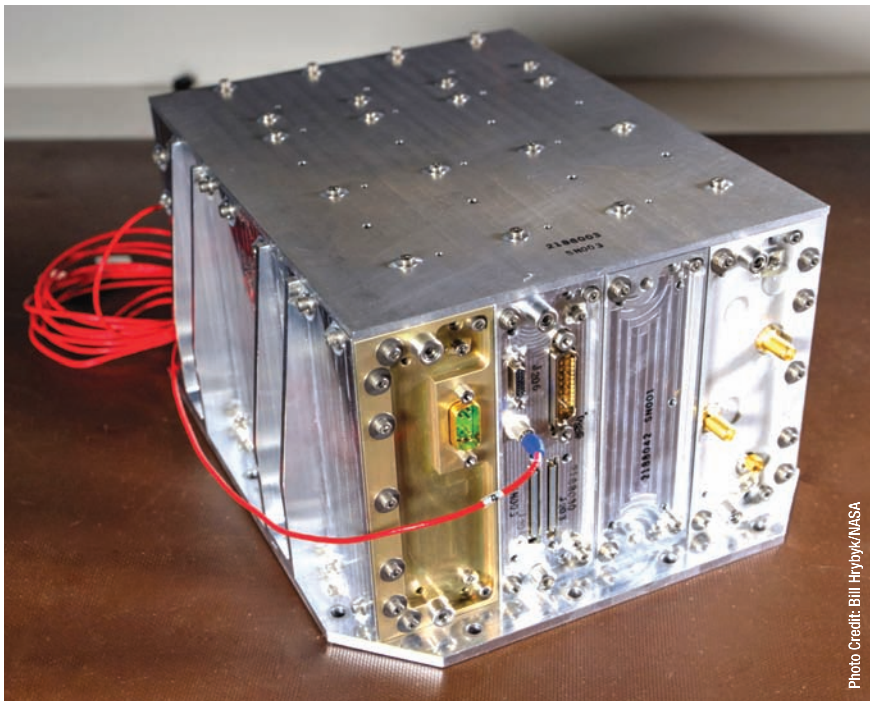
# A Progeny Is Born

*Powerful NavCube Could Support an X-ray Communications Demonstration in Space — A NASA First*

Two already-proven technologies got hitched and gave birth to a promising new technology created to meet NASA's future navigational challenges. It also may help demonstrate — for the first time — X-ray communications in space, a potentially revolutionary capability that would allow space travelers to transmit gigabits of data per second over interplanetary distances.




*NavCube, the product of a merger between the Goddard-developed SpaceCube 2.0 and Navigator GPS technologies, could play a vital role helping to demonstrate X-ray communications in space — a potential NASA first.*

The progeny — NavCube — is the result of a union between Goddard's homegrown SpaceCube, a reconfigurable, very fast flight computing platform, and Navigator GPS, an enabling navigation technology on NASA's flagship Magnetospheric Multiscale mission.

"This new product is a poster child for our R&D efforts," said Goddard Chief Technologist Peter Hughes, who announced that the NavCube development team had been selected to receive the FY16 IRAD Innovators of the Year award (see related story, page 2). "Both SpaceCube and Navigator already proved their value to NASA. Now the combination of the two gives NASA another, more robust navigational tool. NavCube represents technology infusion at its best."

This more powerful and flexible technology is slated to fly on the Defense Department's Space Test Program-H6, or STP-H6, an external experiment pallet to be deployed on the International Space Station in 2018. Once deployed, NavCube will demonstrate its enhanced navigational and processing capabilities afforded by the merger of its technological parents and provide precise timing data needed to enable X-ray communications, known as XCOM.

## 'A Marriage Made in Heaven'

As part of this planned demonstration, NavCube will drive the electronics for a device called the Modulated X-ray Source, or MXS. Also advanced through Goddard R&D support, MXS is critical to demonstrating XCOM and is one of two technology demonstrations that Principal Investigators Keith Gendreau and his deputy, Zaven Arzoumanian, want to execute with the Neutron-star Interior Composition Explorer, or NICER, once it's deployed as an attached payload on the International Space Station in early 2017.

NICER primarily will study neutron stars, the densest objects in the universe, and their rapidly spinning next-of-kin, pulsars.

However, Gendreau's team purposely designed the mission to demonstrate two potentially revolutionary technologies — XCOM as well as X-ray navigation, or XNAV. For the latter, the team will use NICER's 56 X-ray telescopes to detect the highly predictable X-ray pulsations emanating from the sweeping magnetic poles of rotating pulsars to provide high-precision timing data. With this information and specially developed algorithms, they want to show that they can stitch together a navigational solution (CuttingEdge, Spring 2015, Page 9).

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*Goddard's Steve Kenyon is the mechanical and packaging "wizard" for the MXS and STP-H6 XCOM hardware. The equipment shown are various incarnations of the hardware needed to demonstrate X-ray communications in space.*

To demonstrate one-way XCOM — the other advanced technology — MXS will generate rapid-fire X-ray pulses, turning on and off many times per second, encoding digital bits for transmitting data. Positioned inside another box on the STP-H6 pallet, MXS will transmit data via the modulated X-rays to NICER's receivers placed about 166 feet away on the opposite side the space station truss.

NavCube's all-important job is running MXS's on-and-off switch, said Jason Mitchell, a Goddard engineer who helped advance the MXS and manages NICER's XNAV effort. Because NavCube combines SpaceCube's high-speed computing with Navigator's ability to retrieve GPS signals even in weak-signal areas, the device also will allow the team to experiment with X-ray ranging, a technique for measuring distances between two objects.

"We've known about NavCube for a long time," Mitchell said. "For us, NavCube provided the best solution for running this experiment. The combination of these powerful technologies was a marriage made in heaven."

Although most of the technology is ready, the team still is seeking additional funding to complete a space-ready MXS, including its housing and high-voltage power supply. "We have most of the hardware, but we need a little more support to complete the (XCOM) package," said Jenny Donaldson, who is leading the development of the STP-H6 NavCube payload. "This is a great opportunity to demonstrate NavCube and, if all things go as planned, X-ray communications," she said.

## Hardy Genetics

NavCube traces its lineage to two already-proven technologies. SpaceCube 2.0, one in a family of onboard processors, is 10 to 100 times faster than more traditional flight processors (*CuttingEdge*, Fall 2013, Page 8). It achieves its versatility and data-crunching prowess because its developers married commercial radiation-hardened/tolerant field programmable gate array technology — circuits that can be programmed for different jobs even while on orbit — to Goddard-developed algorithms that detect and correct upsets caused by radiation.

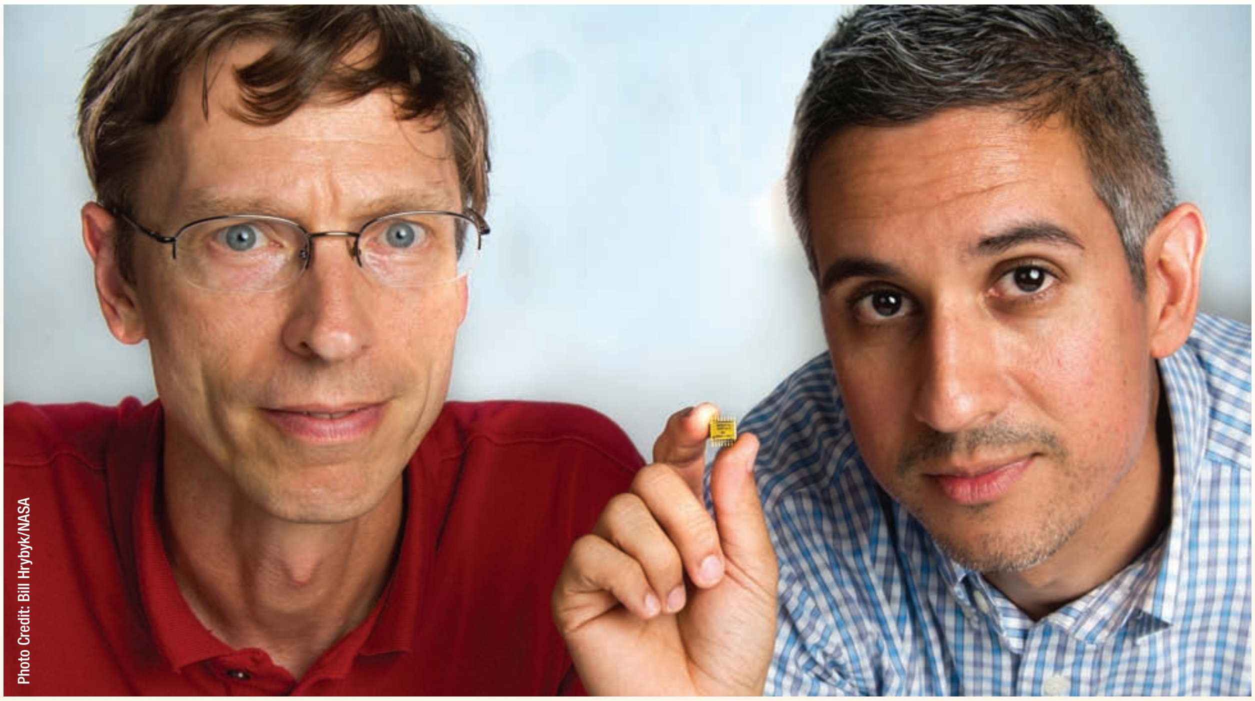
*Continued on page 20*

## Focus on CubeSat Applications

*Since their development in 1999 by the California Polytechnic State University and Stanford University, CubeSats have become increasingly more popular among organizations worldwide. Goddard understood their cost-saving, rapid-response potential more than a decade ago, but also realized NASA would need to develop new technologies to improve their reliability — critical for gathering NASA-grade science. Here we highlight Goddard's efforts to develop radiation-hardened circuits that improve the reliability of CubeSat instruments.*

# Rad-Hard Circuit Proves Mettle on CubeSat Missions

*Team Focuses on Creating Another Chip; Applies Expertise to Enable Other Missions*




*Principal Investigator George Suarez (right) holds a fingernail-sized circuit that he and Jeffrey Dumonthier (left) created for CubeSat applications. Gerry Quilligan, another team member, is not pictured.*

One of the unsung heroes in a handful of already launched and upcoming CubeSat missions is a micro-chip no larger than a fingernail. Now its designers are developing another diminutive circuit that's expected to make miniaturized space instruments even more robust and capable.

As a result of these efforts, among others, Goddard's Office of the Chief Technologist has awarded technologist George Suarez and his team, Jeffrey Dumonthier and Gerry Quilligan, an honorable mention for their behind-the-scenes persistence in developing one-of-a-kind circuits designed to enable high-profile missions and increase the reliability of CubeSat missions (see related story, page 2).

Their road to success began a few years ago when the team started work on a radiation-hardened, multi-channel digital-to-analog converter designed to reduce the size, mass, and power of CubeSat instrument electronics. The job of this diminutive device, also known as an application-specific integrated circuit, or ASIC, was to efficiently and reliably generate voltage levels for detectors, while withstanding the effects of space radiation.

"We wanted something small that was rad hard," Suarez said, referring to design techniques that assure a device's immunity from harmful radiation. Just as important, the team wanted to create a device that could simplify instrument wiring by including four channels and interfaces in one small radiation-hardened chip — something that aerospace microelectronics vendors have yet to develop.

The four-channel circuit has since proved its mettle on Goddard's Mini Ion-Neutral Mass Spectrometer

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— the smallest mass spectrometer ever built. The spectrometer flew on the National Science Foundation-funded ExoCube mission, which measured the densities of a variety of particles in the upper reaches of Earth's atmosphere (*CuttingEdge*, Fall 2015, Page 18).

It now is slated to fly on a handful of upcoming CubeSats, including missions to prospect for water on the Moon, study particles over Earth's poles, and investigate the radiation belt (*CuttingEdge*, Summer 2015, Page 2). It also will be used on the Goddard-developed Dellingr, a new 6U CubeSat purposely built to accommodate NASA-class scientific investigations at lower cost (*CuttingEdge*, Spring 2016, Page 9).

## More Chips, Other Uses

But its use isn't confined to CubeSat missions. This chip, along with another called the 32-bit Rad-Hard Remote/Output Expander, both have caught the attention of two much larger missions — NASA's Pre-Aerosols Clouds and Ocean Ecosystems, or PACE, and the Wide Field Infrared Survey Telescope, or WFIRST, Suarez said, adding that efforts are afoot to commercialize both chips.

"This is huge — at least for me," he explained. "What started as an idea for an ASIC, which we funded through Goddard's Internal Research and Development program, will finally make it to larger flight projects and possibly even commercialization."

In addition, another of the team's circuits — a work-in-progress called the multi-channel charge integrating ASIC — is baselined for the read-out electronics of the Advanced Energetic Pair, or AdEPT, a proposed mid-sized mission. "This sophisticated ASIC will allow AdEPT to explore the gamma-ray universe with exceptional angular resolution and, for the first time, with unprecedented polarization sensitivity," said AdEPT Principal Investigator Stan Hunter. "This chip will enable our mission."

## Upping the Difficulty Ante

Now, the team is using lessons learned to tackle a more difficult technological challenge: creating a multi-channel radiation-hardened analog-to-digital converter that translates analog signals to digital data, all while reducing the size, mass, and power of miniaturized instrument electronics. The circuit could be applied to CubeSat instruments, power systems, and command and data handling, among other uses.

"Analog-to-digital converters are a staple of heliophysics instruments," said Goddard heliophyscist Larry Kepko, who tracks technological advancements that improve the performance of CubeSat platforms. "This circuit will provide robustness and capability. The fact that the new circuit is radiation hardened means that we can fly it to the most radiation-intense locations in the solar system."

The development of such a chip is just one example of Goddard's quest to further advance the reliability of CubeSat instruments — improvements that could be applied to larger missions, as well, Kepko said. Although CubeSats provide less-expensive access to space, their miniaturized systems are not as reliable as those employed by larger, more traditional spacecraft mainly because they often use commercial-off-the-shelf components not built to withstand the harsh environment found in space. To overcome that disadvantage, NASA has begun investing in the technologies needed to make them more reliable.

"It is this type of advanced ASIC development that is key to miniaturizing our instruments to fit on CubeSats, while also making them more robust and reliable," Kepko added.

## Iterating Design

Suarez said the team is iterating on the design of the analog-to-digital converter, which he said is many times more complex than its digital-to-analog cousin. Like its predecessor, the finger nail-size circuit will contain multiple channels that convert analog data and commands into a digital format, all while withstanding radiation effects. According to Kepko, NASA has an identified need for such a circuit and if history is a guide, he expects Suarez's team to deliver. "This chip could enable a new class of rad-hard small satellites and CubeSats," he said.

Suarez agrees.

"Radiation-hardened ASICs are hard to develop. No one wants to fund their development," Suarez said. "It is high risk. But if you succeed, then everyone wants to use them after they're done." He continued, "If we didn't have these chips, we'd find a way. But we're providing something that we think is useful. I'm always on the look-out for what the center needs." ❖

**CONTACT**

George.Suarez@nasa.gov or 301.286.3321

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# A Very Good Year for Goddard's Gravity Group

*Scientists Never Gave Up on Gravitational-Wave Science*

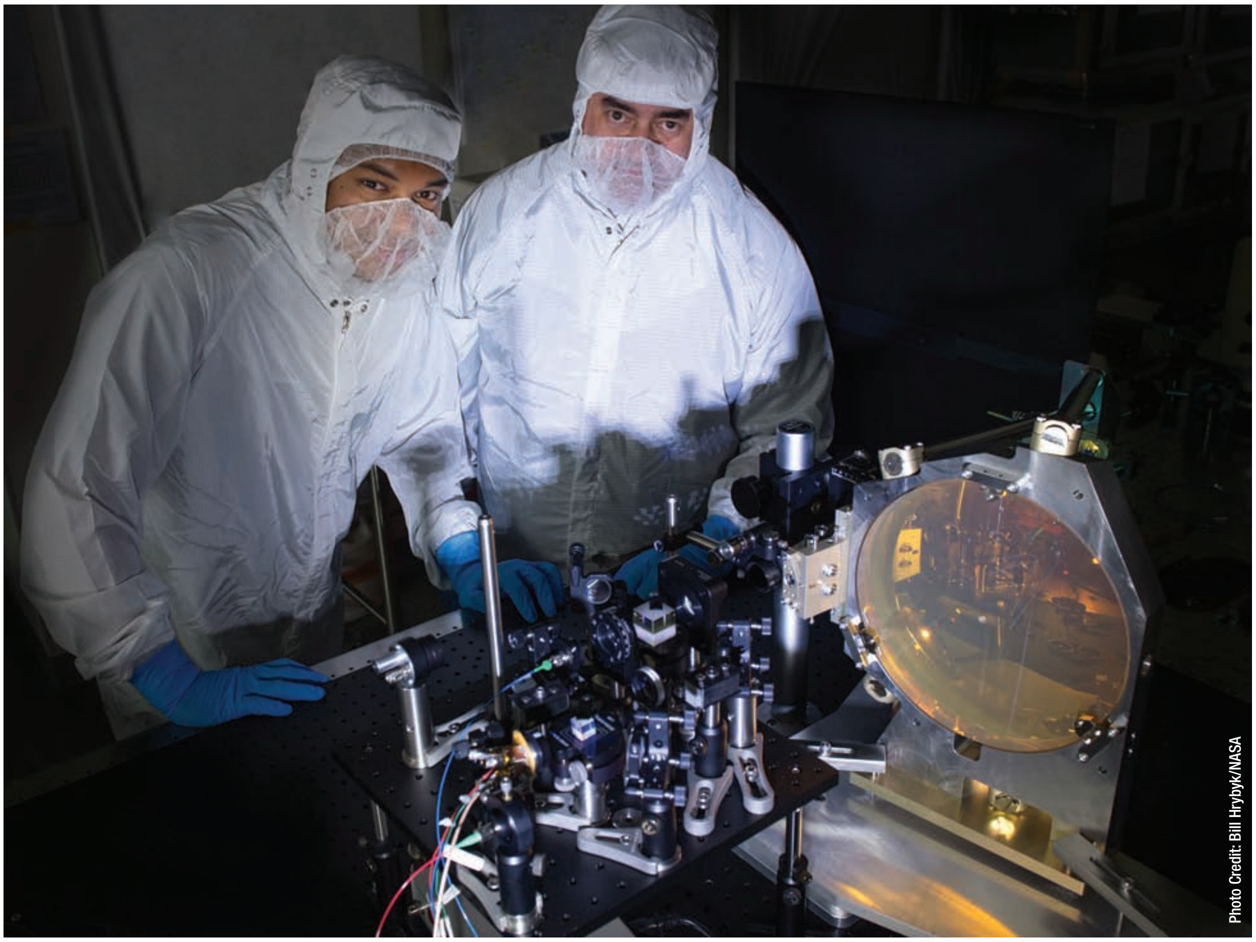

Photo Credit: Bill Hrybyk/NASA

*Shannon R. Sankar (left), a NASA postdoctoral student, has worked with Goddard scientist Jeff Livas (right) on a potential telescope for a possible gravitational-wave observatory.*

Even during the lean years, when funding for gravitational-wave research and technology development all but dried up due to severe budget constraints, a handful of Goddard scientists and engineers persisted. They cobbled together support for their research wherever they could, never doubting the science's potential or its ability to open an entirely new window on the universe.

It now appears their unwavering persistence will pay off — at least they're cautiously hopeful it will. These experts said they're ready to contribute new technologies and scientific analyses should the government restore support for a space-based gravitational-wave mission.

"We just knew the potential and we kept with it," said Joan Centrella, Goddard's deputy director of Goddard's Astrophysics Science Division, recalling her colleagues' stalwart drive to keep research efforts alive. About a decade ago, she and her team became the first to model the shape of gravitational waves (*Goddard Tech Trends*, Spring 2006, Page 2) long before scientists actually observed them. "Because we kept our team together through various R&D programs and made sure NASA was represented on international gravitational-wave science teams, we will be ready to contribute to a mission."

Due to three headline-grabbing events, all occurring in 2016, she has reason for optimism.

## Detections Lead to National Academy Recommendation

The National Academy of Sciences recently recommended in its mid-term Decadal Survey that NASA renew its support and invest in technologies for the Laser Interferometer Space Antenna, or LISA, a proposed European-led mission to observe gravita-

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tional waves from space. A NASA decision on how to respond to this report is expected this fall.

First postulated by Albert Einstein nearly a century ago, gravitational waves are produced when massive objects, such as black holes, spiral together and merge in the universe. The movement and resulting collision create waves in the fabric of space-time, radiating out in all directions, much like the water waves produced when a stone is thrown into a pond.

Although Einstein postulated their existence, no one had directly detected these powerful forces of nature until just a few months ago.

In February and then again in June, an international team of scientists announced that the recently upgraded ground-based Laser Interferometer Gravitational Wave Observatory, or LIGO, had detected not one, but two separate events in 2015 where space warped due to the collision of black holes in the distant universe.

Also in June — sandwiched between the two detection announcements — the European Space Agency reported that it had exceeded expectations in demonstrating important technologies aboard its LISA Pathfinder spacecraft (*CuttingEdge*, Summer 2015, Page 11). This technology-demonstration mission, which includes contributions from Goddard and the Jet Propulsion Laboratory, was purposely designed to demonstrate a technique called drag-free control, an important element in the LISA mission.

## "Seismic Shift"

"These announcements represented a seismic shift," said Ann Hornschemeier, chief scientist of NASA's Physics of the Cosmos Program Office and an X-ray astronomer by training. "LIGO and Pathfinder were the tipping point. The Europeans, no doubt, will develop a mission, but they recognize that NASA contributions would be of enormous benefit to such a mission. This is very interesting work," she continued. "It's complicated and at the forefront of astrophysics. We want to be a part of it."

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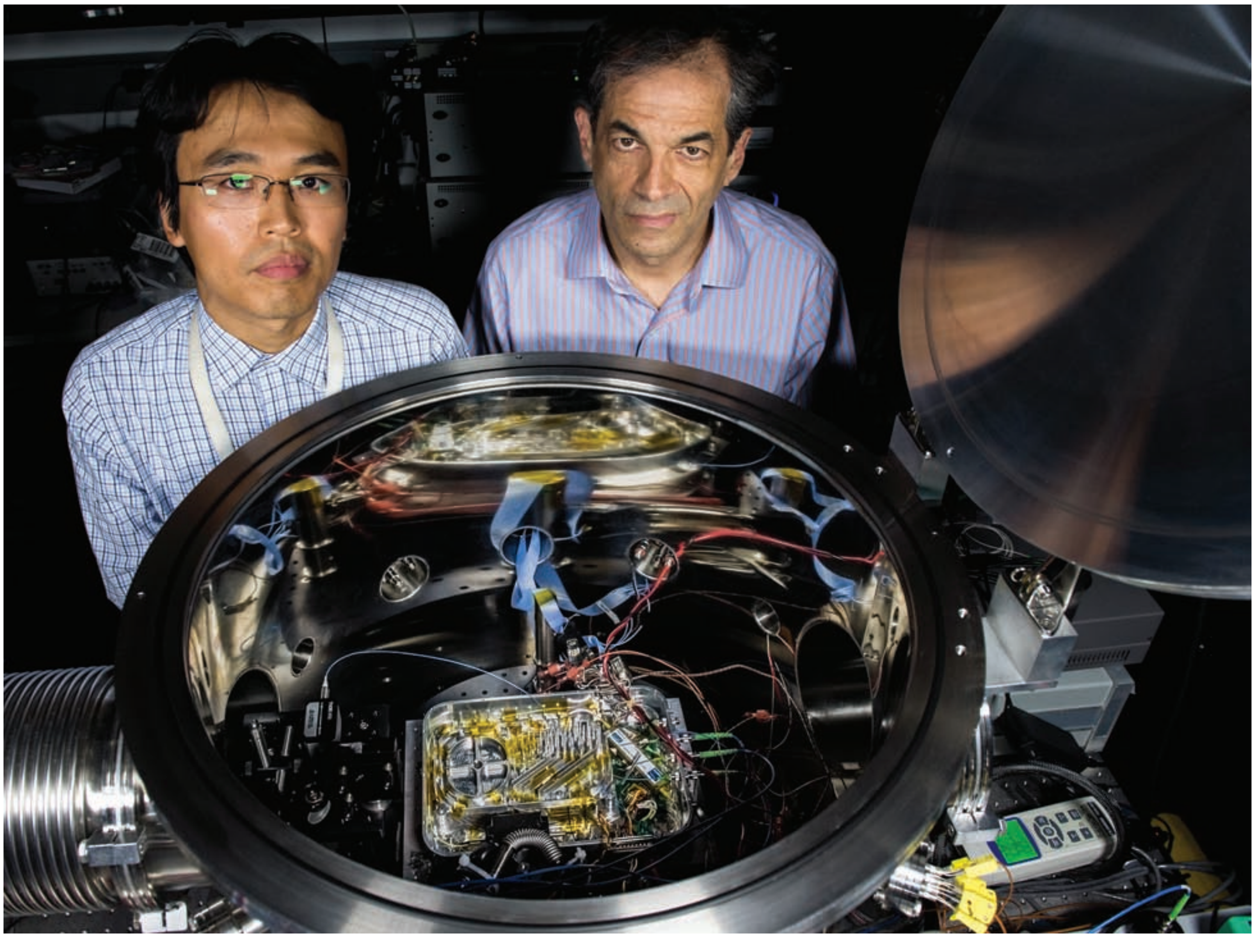
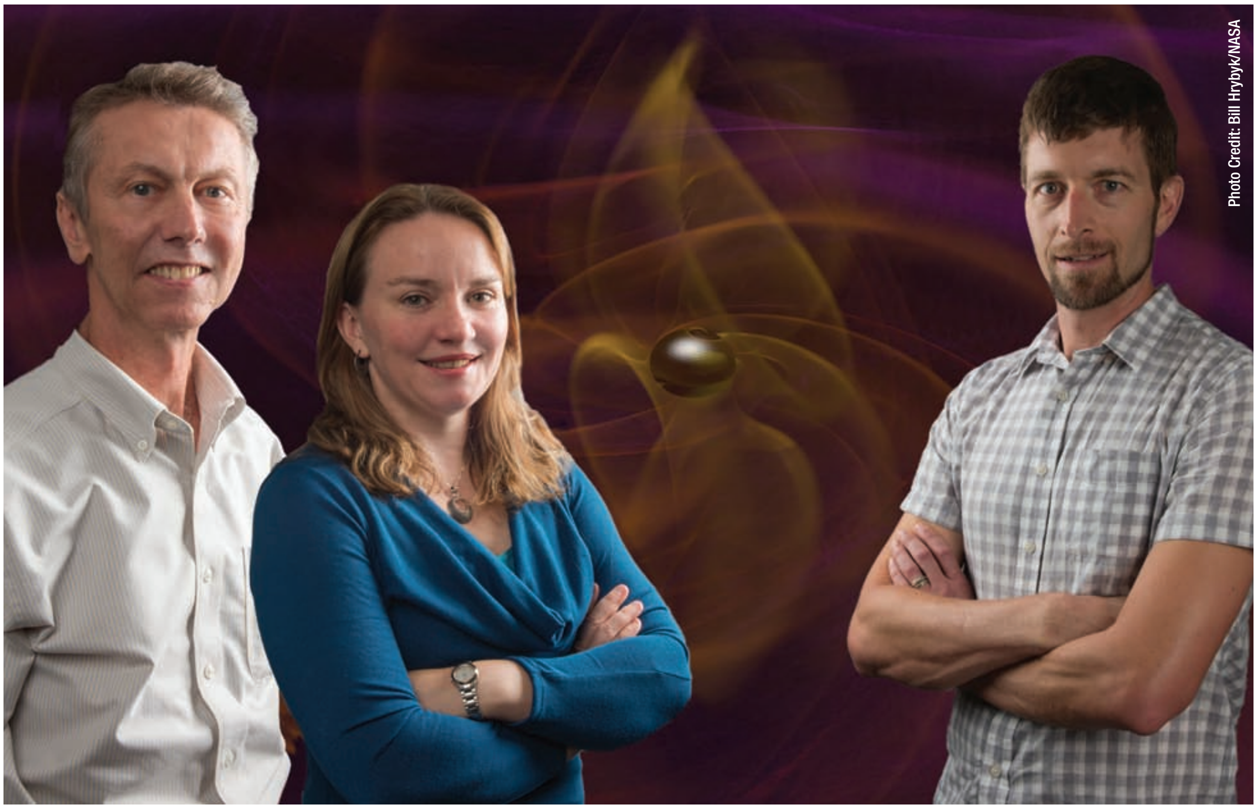


Photo Credit: Bill Hrybyk/NASA

*Kenji Numata (left), a Goddard laser expert who is building a laser system to measure CO2 and methane, is working with Jordan Camp (right) on a system designed specifically for the proposed LISA gravitational-wave mission spearheaded by the Europeans.*




*Neil Gehrels (left), Ann Hornschemeier, and Ira Thorpe stand before an artist's rendition of two merging black holes. These catastrophic collisions create ripples in the fabric of space-time. Although Einstein predicted the existence of gravitational waves a century ago, scientists announced this year that they had finally detected them.*

Currently, nearly everything scientists know about the universe comes from detecting and analyzing light in all its forms across the electromagnetic spectrum — radio, infrared, visible, ultraviolet, X-rays, and gamma rays. With LIGO's discovery, astrophysicists now have another window on the universe — one that scientists expect will provide never-before-revealed details complementing what they can learn through electromagnetic radiation. "The LIGO detections represent a much-awaited first step toward opening a whole new branch of astrophysics," Hornschemeier added.

Just as in other areas of astronomy, scientists need both ground-based and space-based observatories to take full advantage of this new window. While LIGO is sensitive to gravitational waves within the range of 10 to 1,000 cycles per second, seismic, thermal, and other noise hamper the detection of lower-frequency events, such as the merger of supermassive black holes in colliding galaxies. As with observing some frequencies of light, these lower-frequency events only can be observed from space.

"LISA will be able to probe the broad mass range of sources," said Ira Thorpe, another member of Goddard's gravitational-wave team. Thorpe, along with other center scientists, used Goddard Internal Research and Development program funding to design, model, and analyze different experiments that they could carry out with NASA's portion of the LISA Pathfinder mission, also designed to demonstrate drag-free control. He also represents NASA on the LISA Pathfinder science team.

"LISA is a new kind of mission. With it, we'll get to see properties of objects we've never before seen," he said. "Until now, we've only looked at one little slice."

## LISA Concept

Seeing beyond that small slice motivated members of the Goddard group to stay involved, with some proposing and ultimately winning NASA R&D funding to advance LISA technologies, Thorpe added.

In the LISA concept, a constellation of three spacecraft positioned millions of kilometers away from one another in a triangular-shaped orbit, would employ a measurement technique called laser interferometry to precisely monitor the distance between each spacecraft pair. As gravitational waves wash over the constellation, they would produce small changes in the distances between spacecraft.

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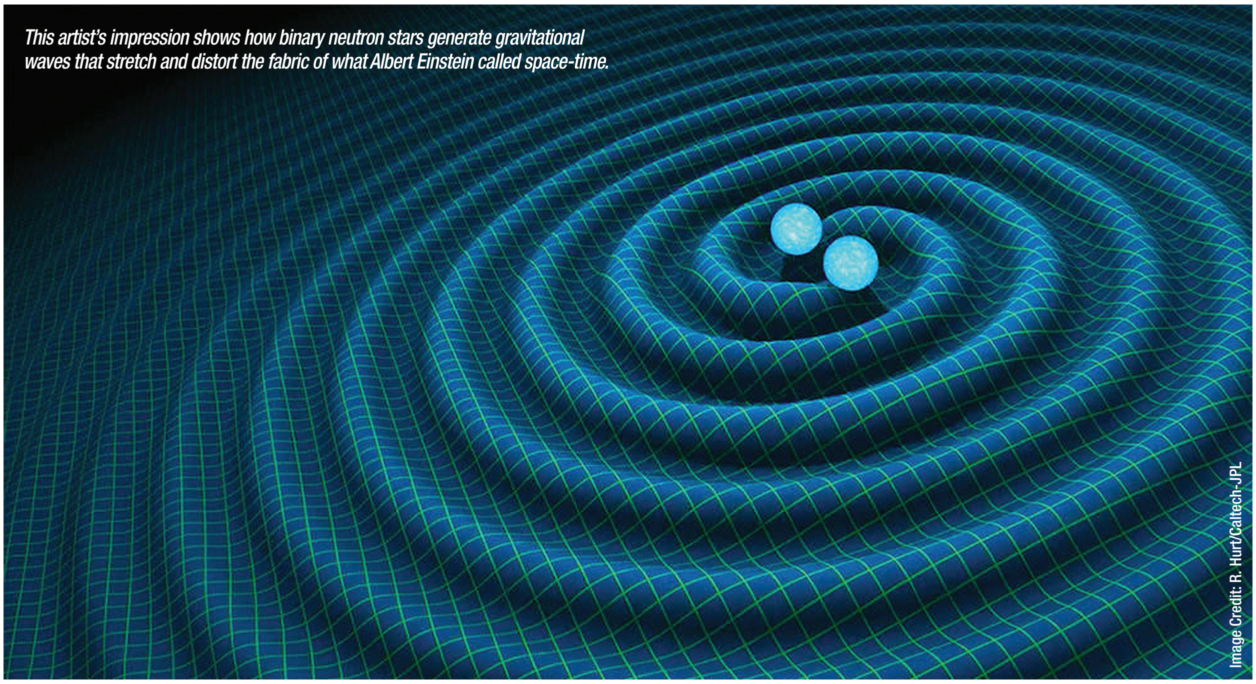

*This artist's impression shows how binary neutron stars generate gravitational waves that stretch and distort the fabric of what Albert Einstein called space-time.*

Image Credit: R. Hurt/Caltech-JPL

However, the fluctuations would be so small that the spacecraft themselves wouldn't be able to detect them due to noisy external forces, such as pressure from solar radiation. To mitigate this, LISA would use freely falling test masses placed inside each spacecraft as the reference points for the measurement. The purpose of the successful LISA Pathfinder demonstration was to check that scientists understood all the forces acting on the test mass.

"LISA Pathfinder was spectacularly successful," said Jeff Livas, currently chief of Goddard's gravitational-wave astrophysics group. "It nearly meets LISA's requirements under orbital conditions that are noisier than the expected LISA conditions."

## Goddard Ready to Contribute

Just as important as the test masses and the ability to maintain a free fall are LISA's highly precise telescopes and laser system, technologies that Livas and his Goddard colleagues, Jordan Camp and Kenji Numata, have advanced, respectively, through different NASA research-and-development support. "These awards have really kept us going," said Camp, who helped develop the lasers and optics for LIGO prior to coming to Goddard and was one of the authors on the paper announcing the facility's first detection.

Their job in LISA's complicated choreography is measuring the distance between the spacecraft, with the end point being the test masses. To do this, the telescopes must simultaneously transmit and receive highly stable laser light over the vast distances separating the spacecraft. "We need to be able to measure the changes in distance between spacecraft through the telescopes to about 10 picometers in one second," Livas said.

The merging of these continuous streams of light will create an interference pattern, which can be measured and analyzed. If one light path takes longer than another, it could indicate the passing of a gravitational wave that distorted the fabric of space-time. These discoveries, which scientists predict would occur as often as once a week, then could be followed up with observations by various space- and ground-based observatories.

## Persistence Justified

"This is exciting science," Camp said. "We really did everything we could do to maintain our team and continue LISA-related technology developments. We were perseverant. We had to be. The events of the past few months have justified that persistence."

Whether NASA restores support or the Europeans ultimately select one or more of the Goddard-advanced technologies remains to be seen, Livas and Camp said. When those decisions are made, though, "we will be ready," Livas said. ❖

**CONTACTS**

Jordan.B.Camp@nasa.gov or 301.286.3528
Ann.Hornschemeier@nasa.gov or 301.286.7632
Jeffrey.Livas-1@nasa.gov or 301.286.7289
James.I.Thorpe@nasa.gov or 301.286.5382

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# SnowEx Challenges the Sensing Techniques…Until "They Break"

*Snow-Measurement Campaign Begins in Colorado*

A Goddard-led team has kicked off an ambitious airborne campaign to determine which sensor or combination of sensors would work best at collecting global snow-mass measurements from space — currently an inconsistently collected and difficult-to-obtain data point that scientists say is critical to understanding the world's water resources.

The multi-year snow effort, called SnowEx, is different from typical science-only field campaigns, said SnowEx project scientist Ed Kim, who will use the opportunity to evaluate a bevy of sensing techniques.

"SnowEx is all about challenging the sensing techniques and algorithms…until they break," Kim said. "Only then will we learn when and where each technique works or doesn't work and, of course, why."

## SWE, The Sweet Spot

Although satellites have given scientists nearly a half-century of snow-extent records, they have proven unreliable at helping scientists determine snow-water equivalent, or SWE. This estimate reveals how much water the snowpack actually contains and can be measured in the field or acquired from space-based data.

To calculate SWE — information vitally important to climatologists and water-resource managers, to say nothing of the more than a billion people worldwide who rely on snowpacks for their water — scientists use sophisticated computer algorithms that consider snow depth and density.

Remote-sensing instruments, which typically receive or bounce microwave, visible, or infrared light waves off the surface and then receive the returning signals, don't work consistently in all snow-covered environments across the globe. Forests and complex topography complicate remotely sensed signals, leading to a paucity of accurate SWE data from space.

Radar, for example, is sensitive to SWE and snow depth, but stops working when the snow gets wet, Kim said. Lidar, on the other hand, is effective at obtaining depth measurements even in forested areas, but can't see through clouds. And passive microwave sensing is sensitive to dry snow, but the maps this technique produces are typically low-resolution and fall short of precisely estimating the impacts of snow on smaller watersheds. Furthermore, certain sensors lose sensitivity when too much snow covers the ground.

Given the pros and cons of each technique, the probability of building one sensor to gather snow data probably is low. Therefore, the focus now is on flying multiple sensors simultaneously to determine which combination of techniques works best. The knowledge will be applied to formulating a space-based mission to measure snow and other features of the cryosphere globally.

"We've never combined these particular types of sensors in one campaign," explained Dorothy Hall, a retired Goddard scientist who now works as a researcher at Michigan State University and is a consultant on the campaign. "We need to evaluate how each sensor performs. The goal of this campaign is determining how to optimize the suite of sensors on a future satellite mission. That is the reason for SnowEx — we want to design a satellite mission."

## Determining the Breaking Point

To determine the effectiveness of each remote-sensing technique and how the sensors can work together, the team will begin flying multiple airborne sensors this winter over Grand Mesa, Colorado — selected because of its varying forest cover. "It was a Goldilocks story," Kim said. "We wanted a site where there weren't too many or too few trees. We wanted a variety. In the end, Grand Mesa floated to the top."

Because the campaign is measuring snow depth, among other things, the team also needs a baseline survey of the area before snow accumulates. In September, the team flew a lidar sensor aboard the Jet Propulsion Laboratory's Airborne Snow Observatory, or ASO, to determine the lay of the land before the full-up campaign begins this winter. Likewise, the team will fly the European Space Agency's radar instrument, SnowSAR, in the summer of 2017 to obtain a no-snow baseline.

When the campaign begins in earnest in February, the suite of SnowEx instruments will be expanded to

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include the Airborne Earth Science Microwave Imaging Radiometer and the Cloud Absorption Radiometer — both developed at Goddard. Photography, which helps determine snow extent, also could be provided by ASO's hyperspectral imaging sensor or another instrument. The team also is considering flying a thermal-infrared instrument.


*This photograph was taken from the International Space Station as astronauts flew over the Himalaya range. A team of scientists wants to determine which techniques work best for measuring snow, with the ultimate aim of developing a dedicated space-based snow-measuring mission.*

## Ground Truthing

In addition to testing the sensors "until the algorithms break," the campaign also features a robust ground-truthing program designed to validate sensor data, Kim said. Kelly Elder, a snow scientist at the U.S. Forest Service in Fort Collins, Colorado, is responsible for planning this part of the SnowEx campaign. University snow experts from around the nation are assisting.

The big emphasis, however, remains on the airborne sensors themselves, said Charles Gatebe, who is the SnowEx deputy project scientist and principal investigator of the Cloud Absorption Radiometer that will fly during the campaign. "We need a satellite mission that can measure snow globally," he said. "We are looking for that tool or set of tools." ❖

**CONTACTS**

Charles.K.Gatebe@nasa.gov or 301.614.6228
Edward.J.Kim@nasa.gov or 301.614.5653

# New Instrument Created for Weather Forecasting

Take an umbrella or leave it in your car? Drive to the beach or stay at home? These everyday decisions often depend on what the weather forecaster said the night before about the possibility of rain. Unfortunately, these forecasts aren't always as spot-on as people would like.

To give credit where credit is due, weather forecasters have significantly improved their game over the past 20 years, thanks in large part to the cache of more accurate ground, aircraft, and space-based sensors that feed the increasingly more capable forecasting models. As a result, three-day forecasts dramatically outstrip the one-day forecasts delivered two decades ago.

But a Goddard technologist and a researcher at the Massachusetts Institute of Technology's Lincoln Laboratory, or MIT-LL, believe there is room for improvement.

## Rugby Ball-Size Sounder

Under a years-long collaboration, Goddard technologist Paul Racette and MIT's William Blackwell have created a compact, hyperspectral scanning sounder to passively measure atmospheric water vapor and temperature from a high-altitude research airplane, such as NASA's ER-2, DC-8, or WB-57.

"The distribution of atmospheric water vapor and temperature are important for weather forecasting, and more particularly for predicting rain," Racette said.

What distinguishes the Hyperspectral Microwave Atmospheric Sounder, or HyMAS, from other instruments designed to operate in and around storms is its high resolution and relatively small size — characteristics that make it suitable for aircraft and, perhaps in the future, small-satellite applications. Comparable in size to a rugby ball, HyMAS is equipped with six receivers that together detect an unprecedented 52 channels in two microwave bands effective for profiling temperature and the ingredients that produce storms.

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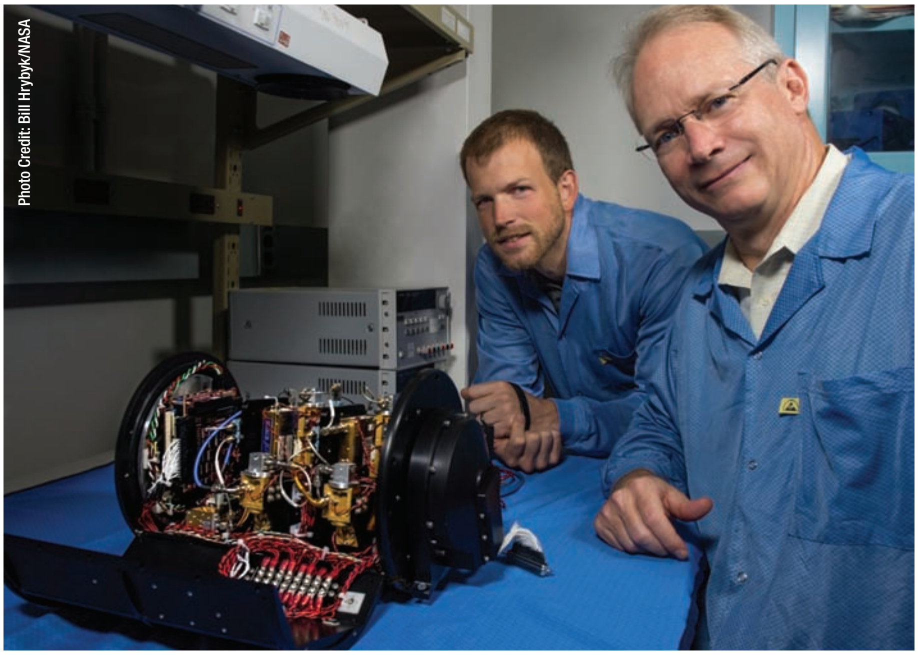
"What we do is use an ultra-miniature filter technology, which we implement in an Intermediate Frequency Processor, or IFP. The IFP, in essence, slices the two microwave wavelength bands into smaller components, which allows us to see more details of what's happening along a vertical path in the atmosphere. In other words, these 52 channels allow us to dig deeper into the data to get a higher-resolution, micro view of what's happening at different levels of the atmosphere," Blackwell said, explaining how the MIT-developed technology works. Data embedded in the 52 channels then are amplified and digitized for analysis.




*Paul Racette (right) and Matt Fritts have helped develop a new instrument, HyMAS, whose scanhead is shown here. They believe the instrument, which would fly on one of NASA's research aircraft, will improve weather forecasting.*

"This filter technology really is neat," Racette said, adding that it already is being infused into a number of existing and future CubeSat missions awarded to MIT's Lincoln Laboratory.

The Microsized Microwave Atmospheric Satellite, which measures about four inches on a side, was recently developed to collect temperature, moisture profiling, and precipitation data using 12 microwave channels enabled by MIT's IFP. Two flight units will be launched in 2017.

Also next year, another similarly sized MIT-developed CubeSat, called the Microwave Radiometer Technology Acceleration, will collect temperature, moisture, and cloud-ice measurements with 10 channels. And then in 2020, the Lincoln Laboratory team is slated to fly the Time-Resolved Observations of Precipitation Structure and Storm Intensity with a Constellation of Smallsats — known as TROPICS — that will observe severe storms. It, too, will gather data in 12 channels.

## HyMAS, One of Two Scanning Heads

At this point, however, HyMAS, with its ability to detect 52 channels, still offers the most detailed look at the atmospheric column. As a result, Racette is seeking NASA support to fly the instrument on a high-altitude aircraft, specifically in tandem with one of two other Goddard-developed precipitation-measuring instruments — the Compacting Scanning Microwave Imaging Radiometer, or CoSMIR, and the Compact Scanning Submillimeter-Wave Imaging Radiometer, or CoSSIR.

Goddard developed CoSMIR to calibrate sensors for the Defense Department's Meteorological Satellite Program. CoSSIR pioneered the use of the submillimeter wavelength bands to sense ice clouds — a technique adopted by the European Space Agency's next-generation meteorological satellite due to launch in 2022.

Together, HyMAS and either CoSMIR or CoSSIR, which scientists could interchange on a NASA research airplane, would cover a broader microwave spectral range, revealing even greater insights into the physical processes that produce rainfall, Racette said, adding the data would be useful for validating NASA's Global Precipitation Measurement mission and, of course, improving weather forecasts.

In addition to flying HyMAS on an aircraft, the collaborators also want to further improve the technology to enable 100 channels of coverage and ultimately fly it aboard a microsatellite.

"If we succeed in doing this, we'll get even greater spectral coverage in the microwave," Racette said. "HyMAS is unprecedented in terms of its size, weight, and power. We believe it will enable a set of missions to provide rapid, high-resolution sounding with global coverage." ❖

**CONTACT**

Paul.E.Racette@nasa.gov or 301.286.4756

## PROFILE

*CuttingEdge occasionally publishes profiles about Goddard employees who distinguish themselves on the job as well as off. Here we profile Christy Hansen, who last year became the airborne science manager in the Earth Sciences Division. Created to guide scientists in managing and winning airborne missions, such as the SnowEx campaign featured on page 12, the position requires a different set of skills. As her colleagues explain, the high-energy, life-long space aficionado brings those talents.*

# As Seen on TV

Photo Credit: Bill Hrybyk/NASA

*Christy Hansen applies her human spaceflight experience to helping Goddard Earth scientists organize and execute airborne missions.*

Christy Hansen has a lot in common with Harrison Ford, Johnny Depp, Charlize Theron, and even Marilyn Monroe. All can attribute their careers to being in the right place at the right time where someone ultimately discovered them.

Hansen, who the Earth Sciences Division hired last year as its first-ever airborne science manager, always wanted a career at NASA, but wasn't sure of her precise path forward or how she would make the transition from graduate school to the workplace — that is, until an engineer at the Johnson Space Center saw her in a video shot during a graduate-level distance-learning class Hansen attended at the University of North Dakota.

So taken by Hansen's enthusiasm, the engineer contacted Hansen and encouraged her to apply for a job at Johnson.

"I was sitting there in my Space Studies class, but actively involved," said Hansen, recalling the days before on-line courses streamed live over the Internet. "This engineer emailed me, telling me she had seen me in the class video. She said, 'we're looking for people just like you. We need high-energy, smart engineers, and scientists to help build the International Space Station.'"

And as they say, the rest is history.

## 'Everything I Wanted to Do'

In 1999, Hansen joined United Space Alliance, specializing in astronaut spacewalk training, flight control, and real-time mission operations for the Space Shuttle, Hubble Space Telescope, and International Space Station programs. "It was

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*While the project manager of NASA's Operation IceBridge, Christy Hansen traveled to Antarctica's McMurdo Station in 2013.*

everything I wanted to do," she said, referring to her good fortune in finding a job that positioned her to realize a childhood dream. "I always loved space. Ever since I was little, I wanted to be an astronaut or a stunt woman."

Though her career has taken a decidedly different turn, her skillset and high-octane energy working with astronauts and troubleshooting failure scenarios dovetails nicely with managing the Airborne Sciences Office, said Lisa Callahan, associate director for Mission Planning and Technology Development within the Earth Sciences Division.

According to Callahan, Goddard created the position to familiarize scientists with NASA's airborne platforms — important tools for validating new instruments or calibrating satellite data. Just as important, Goddard's Earth Sciences Division established the position to help scientists become more competitive in winning airborne missions, such as NASA's Earth Venture-Suborbital opportunities.

"Goddard participates in lots of aircraft missions," said Matt McGill, Earth Sciences Division technologist. "We have a lot of principal investigators who participate in field campaigns; so having Christy assist is a good thing."

What Hansen contributes is her background, which is unusual among the scientists she assists within the Earth Sciences Division, Callahan and McGill said.

"Christy's background in human spaceflight and experience with space operations is very relevant to her position," Callahan explained. "Airborne science campaigns involve instrument operators, pilots, aircraft — from very large to very small — instruments, and lots and lots of planning to make sure everything goes right in often extreme environments. Attention to detail and emphasis on safety is critical and Christy brings all those skills to the job. And as most people notice almost immediately, Christy is very energetic."

Hansen, who came to Goddard in 2010 to lead payload operations for the center's Robotic Refueling Mission and then accepted a position three years later as manager of the Goddard-led Operation IceBridge, agrees that her career experiences have served her well.

But what about her dream of becoming an astronaut?

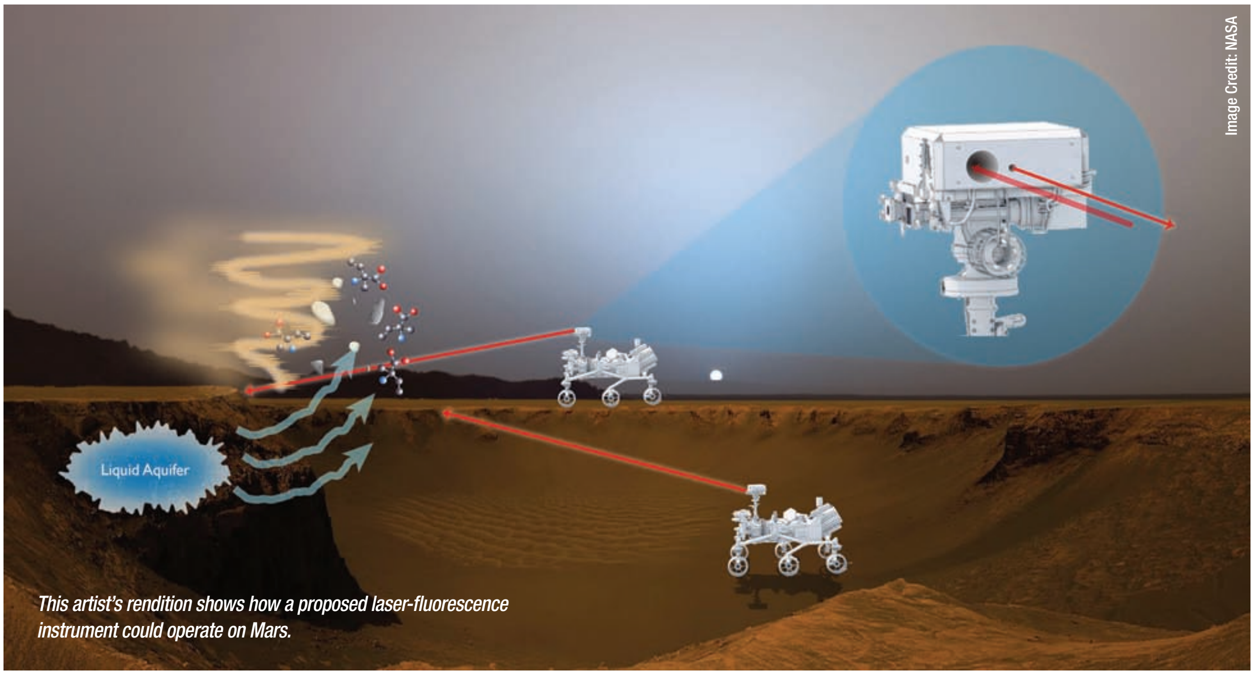
It's still on her bucket list, she said. "I'd still love to fly in space someday, but right now, contributing to important scientific and engineering research is of the utmost importance to me. I'm grateful for the opportunities afforded me. Throughout my career, I've worked on exciting and important projects that have taken me all over the planet, working with amazing and smart people in all kinds of challenging environments. What's there not to like about that?" ❖

**CONTACT**

Christy.Hansen-1@nasa.gov or 301.614.7018

# Sniffing for Signatures of Life

*Goddard Scientist Pursues Fluorescence-Based Lidar for Planetary Exploration*




*This artist's rendition shows how a proposed laser-fluorescence instrument could operate on Mars.*

A sensing technique that the U.S. military currently uses to remotely monitor the air to detect potentially life-threatening chemicals, toxins, and pathogens has inspired the development of a new instrument that would "sniff" for life on Mars and other targets in the solar system.

Goddard technologist Branimir Blagojevic, who formerly worked for a Columbia, Maryland-based company that developed the sensor now used by the Departments of Defense and Homeland Security, has applied the technology to create and successfully demonstrate a NASA instrument prototype in laboratory and field tests.

Blagojevic and Goddard scientists Melissa Trainer and Alexander Pavlov proved that the same remote-sensing technology used to identify bio-hazards in public places also would be effective at detecting organic bio-signatures on Mars.

## Long Heritage

Blagojevic now is seeking follow-on NASA funding to further advance the Bio-Indicator Lidar Instrument, or BILI. Should he receive additional support, Blagojevic plans to ruggedize the design, reduce its size, and confirm that it can detect tiny concentrations of a broad range of organic molecules, particularly in aerosols that would be found at the ground level on Mars.

"This sensing technique is a product of two decades of research," Blagojevic said, referring to the technology created by his former employer, Science and Engineering Services, LLC, a world leader in the remote sensing of bio-aerosols.

BILI is a fluorescence-based lidar. Although NASA has used fluorescence instruments to detect chemicals in Earth's atmosphere as part of its climate-studies research, the agency so far hasn't employed the technique in planetary studies. "NASA has never used it before for planetary ground level exploration. If the agency develops it, it will be the first of a kind," he said.

## A Rover's "Sense of Smell"

As a planetary-exploration tool, Blagojevic envisions BILI as primarily "a rover's sense of smell."

Positioned on a rover's mast, BILI would first scan the terrain looking for dust plumes. Once detected, the instrument, then would command its two ultraviolet lasers to pulse light at the dust. The illumination would cause the particles inside these dust clouds to resonate or fluoresce. By analyzing the fluorescence, scientists could determine if the dust contained biological or non-biological molecules created relatively recently or in the past. The data also would reveal the particles' sizes.

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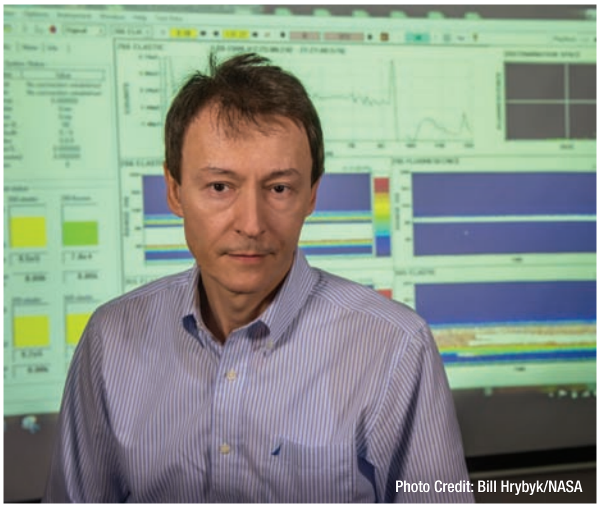
"If the bio-signatures are there, it could be detected in the dust," he said.

### BILI's Beauty

The beauty of BILI, Blagojevic added, is its ability to detect in real-time small levels of complex organic molecules from a distance of several hundred meters. Therefore, it could autonomously search for biomolecules in plumes above slopes — areas not easily traversed by a rover carrying a variety of in-situ instruments for detailed chemical and biological analysis. Furthermore, because it could do a ground-level aerosol analysis from afar, BILI reduces the risk of sample contamination that could skew the results.

"This makes our instrument an excellent complementary organic-detection instrument, which we could use in tandem with more sensitive, point sensor-type mass spectrometers that can only measure a small amount of material at once," Blagojevic said. "BILI's measurements do not require consumables other than electrical power and can be conducted quickly over a broad area. This is a survey instrument, with a nose for certain molecules."

With such a tool, which also could be installed on an orbiting spacecraft, NASA could dramatically increase the probability of finding biosignatures in the solar system, he added. "We are ready to integrate and test this novel instrument, which would be capable of detecting a number of organic biosignatures," Blagojevic said. "Our goal is increasing the likelihood of their discovery." ❖




*Branimir Blagojevic has developed a prototype instrument that would "sniff" for biosignatures in Martian dust. The screen behind Blagovevic shows the graphics user interface for the Bio-Indicator Lidar Instrument.*

**CONTACT**

Branimir.Blagojevic@nasa.gov or 301.286.8556

# Automated Tool for Calculating Trajectories Gets Better

A Goddard-developed tool that private industry and other NASA centers now use to plot a mission's path to far-flung interplanetary destinations has gotten significantly more proficient and can now even reveal — sometimes in just a matter of minutes — the specifics of the spacecraft's design.

Jacob Englander and his team originally developed the fully automated Evolutionary Mission Trajectory Generator, or EMTG, to give mission managers a preliminary set of detailed directions for steering spacecraft to hard-to-reach interplanetary destinations (*CuttingEdge*, Summer 2013, Page 3).

Originally, the EMTG would calculate these roadmaps after mission developers inputted a series of parameters, such as the spacecraft's point of origin, its final destination, launch dates, and flight times, on a standard desktop computer.

The software tool then would determine the most efficient trajectories for reaching the final destination, detailing the number of flybys around other celestial bodies to alter the spacecraft's path or speed. Depending on the mission's complexities, the EMTG would execute multiple trajectories in just a matter of minutes, Englander said.

Given its usefulness to mission planners, Englander and his team decided to make EMTG available as an open-source program. It has since been downloaded thousands of times by NASA centers, private companies, and others to run preliminary trajectories, Englander said.

### Expanded Capabilities

As good as it was, it's better now, said Matthew Vavrina, an orbital expert with a.i.solutions, a Goddard contractor.

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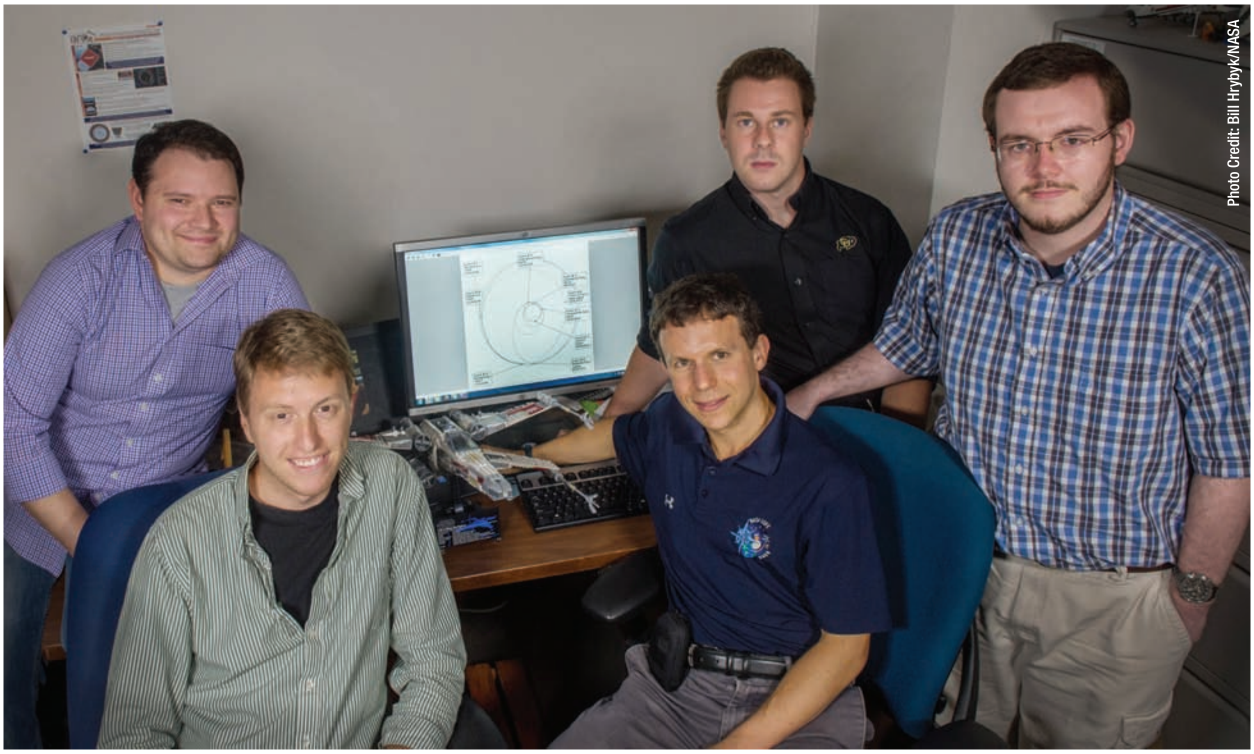


*Kyle Hughes, Jeremy Knittel, Jacob Englander, David Hinckley, and Sean Napier, who are pictured from left to right, helped enhance a fully automated tool for determining orbital trajectories and spacecraft design.*

He began working with Englander and his team in 2014. Initially, they enhanced the product to help define NASA's Asteroid Redirect Mission, or ARM, a first-ever robotic mission to visit a large near-Earth asteroid. During the mission, the ARM spacecraft will collect a multi-ton boulder from an asteroid's surface and redirect it into a stable orbit around the moon.

"We've expanded EMTG's capabilities quite a bit," Vavrina said. The original EMTG optimized a spacecraft's trajectory, which "in itself is quite difficult." Now, however, the tool simultaneously optimizes both the trajectory and the spacecraft's hardware. "We can now consider the full problem of designing a spacecraft," Vavrina said. "We can look at multiple performance criteria, including the design of the spacecraft's solar arrays, propellant tanks, and thrusters, and potential launch vehicles, for example, in a single run."

This added capability is important, Englander added. "The design of the spacecraft and its trajectory are intertwined — especially those that are electrically propelled. You can't determine a trajectory and then run off and design the spacecraft. They need to be considered together. With this tool, you can design the spacecraft and the trajectory at the same time."

## Useful for Low- and High-Thrust Spacecraft

Although the updated tool is most effective at determining the trajectories and design characteristics of electrically propelled, or low-thrust spacecraft, planners also can use it to define some aspects of a high-thrust mission, one that uses chemical propellant as its fuel.

"EMTG can do high-thrust trajectories, but since high-thrust spacecraft design and trajectory design are decoupled problems, the systems capability isn't as useful. However, launch vehicle selection and the size of propellant tanks can have big effects on chemical trajectories, and EMTG can do that trade," Englander said.

Like its forebear, the more capable EMTG is available free of charge on open-source platforms. "It's still relatively new and it takes time for people to adopt it. It will catch on, though," Vavrina said. "It's too powerful of a tool to neglect, especially for managers who can look at all these objectives and make a decision with cost and schedule in mind. It certainly was perfect for ARM." ❖

**CONTACT**

Jacob.A.Englander@nasa.gov or 301.286.4710

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## A Progeny is Born, *continued from page 5*

Having flown many times before, including on previous STP experiment pallets, SpaceCube now enjoys a growing list of customers. A couple high-profile missions, NASA's Robotic Refueling Mission 3 in 2018 and Restore-L in 2020, have baselined SpaceCube 2.0 for their computing operations.

"We're actively working commercialization agreements for SpaceCube 2.0 technology," said Dave Petrick, a Goddard branch chief engineer and SpaceCube 2.0 architect, who has earned prestigious engineering awards for his work on SpaceCube 2.0. "We don't want to be in the business of building computers for the aerospace market. We'd rather spend our time building the next one."

The other technology — Navigator GPS — was purposely designed to detect, acquire, and track faint GPS signals for NASA's MMS mission. Navigator, which has since been commercialized, now is providing positioning information to the four spacecraft that must fly in a pyramid-shaped, highly elliptical orbit to gather data (*CuttingEdge,* Spring 2015, Page 2).

Since MMS's launch, Navigator has set records. At the highest point of the MMS orbit, Navigator has tracked as many as 12 GPS satellites. The team originally expected to detect no more than two or three GPS satellites. "This is indeed one of the greatest engineering accomplishments Goddard has done," said Dean Chai, the acting chief for technology of Goddard's Mission Engineering and Systems Analysis Division.

### The Union

Even before MMS launched, however, the Navigator team had already begun improving the technology, which ultimately led to NavCube. "Navigator is adequate for MMS, but it's not very extensible," said Luke Winternitz, Navigator's chief architect. "This isn't the one we wanted to move forward with."

"At the time, we needed a more robust, re-programmable and extensible processing platform," added Monther Hasouneh, NavCube's hardware lead. "SpaceCube was already there. Furthermore, we figured that missions using SpaceCube 2.0 as a science data processor also could benefit from having a GPS receiver as a low-cost add-on," he added.

Hasouneh and his team ported the Navigator software and firmware into the SpaceCube reprogrammable platform and developed a compatible GPS radio-frequency, or RF, card — and in doing so, reduced Navigator's size. Using R&D support, the team also added new GPS signal capabilities and enhanced Navigator's sensitivity to make it appropriate for a broader range of applications, not just MMS-style flagship missions (*CuttingEdge,* Spring 2013, Page 12).

"The end result is NavCube, which is more flexible than previous Navigators because of its ample computational resources. Because we added the ability to process modernized GPS signals, NavCube has the potential to significantly enhance performance at low, and especially, high altitudes, potentially even to cis-lunar space and lunar orbits," Winternitz said.

Yet, still, further improvements are afoot, Winternitz added.

The team is investigating adding a transponder capability to support a future, next-generation beacon service. In addition, the team has plans to further reduce NavCube's size to make it appropriate for CubeSats, particularly those that fly in constellations to gather real-time, simultaneous measurements. In addition, members of the NavCube team are working with Stanford University, under a recently awarded Smallsat Technology Partnerships initiative effort, to develop and demonstrate precision GPS-based formation-flying algorithms for small satellites.

"We're really excited about winning that. The development of these algorithms won't make NavCube smaller, but they could be a good application for NavCube or a future further-miniaturized version of this technology," Winternitz said. "One thing is certain. We will continue improving this technology." ❖

**CONTACTS**

Monther.A.Hasouneh@nasa.gov or 301.286.3406
David.J.Petrick@nasa.gov or 301.286.9727
Luke.B.Winternitz@nasa.gov or 3 01.286.4831

Cutting edge Goddard's Emerging Technologies

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