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Cutting edge
Goddard's Emerging Technologies

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Innovator of the Year:
Michael Amato

DAVINCI+

The Trusted, Encouraging Innovator

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Persistence, Encouragement, Innovation Helped Amato Keep DAVINCI on Track

Goddard's Office of the Chief Technologist named engineer Michael Amato as this year's Internal Research and Development (IRAD) Innovator of the Year, an honor the office bestows annually on individuals who demonstrate the best in innovation. Amato is recognized for his work leading to the selection of the DAVINCI mission in 2021.

The concept of a NASA-led Venus deep atmosphere chemistry probe was developed and evolved over more than a decade at Goddard. Through multiple mission bids starting in 2008, rejections, and tailored re-designs, a team of Goddard-based scientists and engineers finally prevailed with the selection of the Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging, or DAVINCI mission.

Among a team of dedicated scientists and engineers, Amato always found the silver linings, and looked for innovative ways to strengthen their mission for the next round through sustained leadership of IRAD developments associated with the probe flight system.

In 2021, DAVINCI was selected as a NASA Discovery Program in situ probe to Venus with scientific flybys and a science-guided descent to the Venus surface, vindicating the hard work, research and development, and persistence of a team of scientists and engineers determined to unravel the secrets of Earth's sister planet (see: https://ssed.gsfc.nasa.gov/davinci). The DAVINCI team is led at Goddard by Principal Investigator Dr. James Garvin, Deputy PI's Dr. Stephanie Getty and Dr. Giada Arney, and a project management team led by Ken Schwer, Deputy Project Manager Arlin Bartels, and DPM for Resources Vince Elliott. Amato has been part of the engineering team since the very first mission proposal bid in late 2008.

Fueled by six Internal Research and Development, or IRAD-funded technologies, and capable of carrying advanced analytical instruments into

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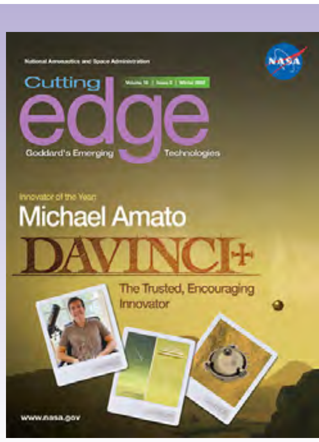
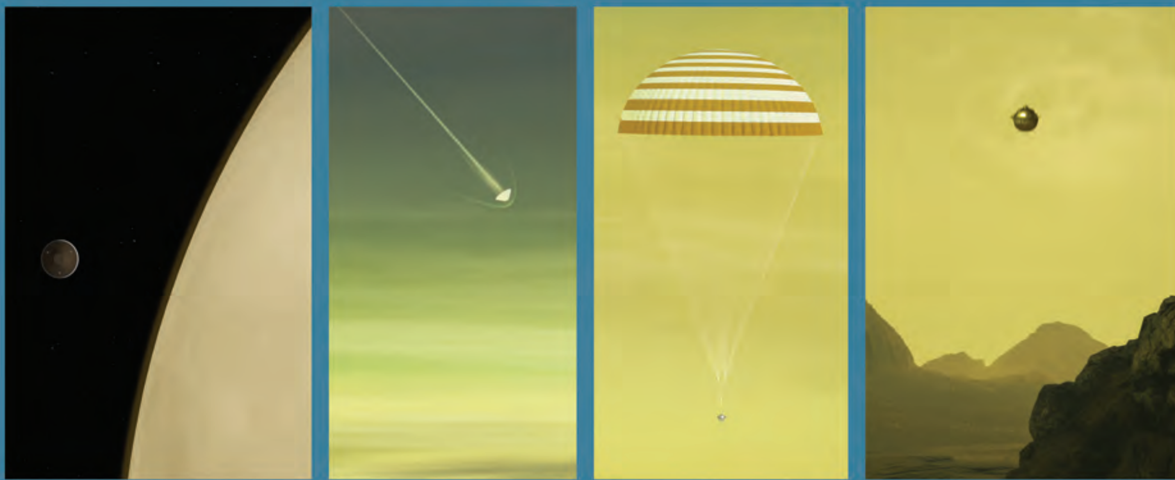


About the Cover

Michael Amato received this year's Internal Research and Development Innovator of the Year Award for his work assisting with the development and selection of the Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging, or DAVINCI mission in 2021. In addition to more than a decade of work on DAVINCI, Amato ranks as one of Goddard's most prolific innovators, seeking out necessary innovations to enable NASA's exploration mission. Records show he has been the principal investigator for dozens of IRAD awards over the past decade.

(Image Credit: NASA's Goddard Space Flight Center/Dave Stonehouse)



DAVINCI uses observations from orbit and chemical analysis of the planetary atmosphere to answer major questions about how Venus formed, evolved, and lost its possible past habitability and surface oceans. Its "natural vertical mobility" extends from the top of the atmosphere to just above the surface, where it will image mountain landscapes in 3D.

Image credit: NASA's Goddard Space Flight Center/CI Labs/Michael Lentz

a hostile planetary atmosphere, DAVINCI will be the first NASA-built probe to explore the deepest atmosphere of Venus and the first U.S.-built Venus probe since 1978. The DAVINCI team are thrilled with the opportunity to implement this bold new step back to Venus together with two sister orbiter missions by the end of the decade.

In helping to develop the technical case for DAVINCI, Amato orchestrated the IRAD engineering development of a prototype probe flight system, including window seal technology and parachute technologies capable of surviving Venus's punishing atmosphere. His sustained dedication ultimately contributed to this exciting planetary in situ probe mission win – a first for Goddard to Venus. DAVINCI is also the first Discovery mission with an in-situ probe carrying analytical instruments similar to those typically flown on larger Martian rovers such as Curiosity. Michael Amato's colleagues describe him as persistent and tenacious, with the strong engineering and technology connections to keep the Venus probe mission investments going through multiple proposals.

"There was a cadre of us pushing new boundaries on planetary exploration at that time, and one of the bright young engineers involved was Michael Amato. He was the trusted, encouraging innovator who got the engineers together to keep going, even when many people said, 'we aren't really the center that does planetary probe missions'."

– DAVINCI principal investigator James Garvin

"There was a cadre of us pushing new boundaries on planetary exploration at that time," said Garvin, who is also Goddard's Chief Scientist, "and one of the bright young engineers involved was Michael Amato. He was the trusted, encouraging innovator who got the engineers together to keep going, even when many people said, 'we aren't really the center that does planetary probe missions'."

Venus and Earth are similar in size and orbital distance from the Sun, but they are very different worlds today. Garvin and other scientists think Venus may have once been more like Earth, and DAVINCI will try to help understand how these planets ended up so different.

Garvin described Venus as "the exoplanet in our backyard" and that studying it could help us understand similar worlds orbiting distant stars that will be investigated with missions like the James Webb Space Telescope. To do so, DAVINCI will sample Venus's atmosphere while imaging the planet's mountainous regions in 3D. Many of Amato's technological innovations focus on helping the probe survive the descent and protect the keystone instruments inside.

Goddard Chief Technologist Peter Hughes described Amato as a prolific innovator maintaining multiple projects supporting NASA's Artemis and planetary sciences in addition to DAVINCI.

"Mike is just an amazing innovator leading the design for these technologies while working with multiple organizations inside and outside of NASA," Hughes said. "He does this on top of a ton of other

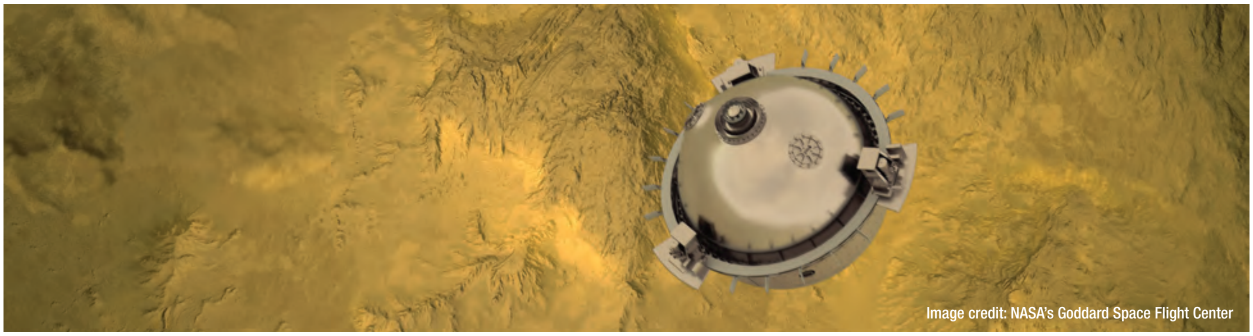


Image credit: NASA's Goddard Space Flight Center

projects. He's probably the most prolific IRAD innovator within the planetary sciences."

On receiving the award at the conclusion of the FY21 IRAD Poster Session, Amato shared the recognition with the DAVINCI team and his engineering colleagues in the Goddard community of innovators.

"Obviously it takes a team - a lot of people," he said. "And the IRAD program is so amazing because it gives us a lot of time to pursue strategic technologies. We couldn't do most of these things without that program."

Members of the DAVINCI mission said Goddard's health-related closing to on-center work due to COVID-19 restrictions shortly after DAVINCI was selected for Phase-A development in February of 2020 overshadowed but couldn't dampen the mission team's spirit.

"You get that sense of a team that works together even if you can't necessarily physically work together," said Deputy Principal Investigator Dr. Giada Arney. "I think we got to know each other in the virtual environment over Phase-A, then also, after selection. This is my first mission ever, so it's been a lot of learning on the go for me. I quickly got the sense that it was a cohesive team."

Picking things up as she went along, Arney said she's come to know Amato as a driving force within the team.

"People really respect Michael for his ongoing work in this area," she said. "He seems to have a large depth of knowledge about DAVINCI and its history. It really shows, especially given how some of the more experienced team members turn to him for knowledge about it."

Deputy Principal Investigator Dr. Stephanie Getty said he puts the same vision and talents into all of his projects at Goddard.

"I've worked with Michael on other things for many years," she said. "He's a visionary who's really dedicated to seeing something through, and he's not easily discouraged. I would say that the DAVINCI probe work might be the prime example of these characteristics of Michael."

Everyone on the DAVINCI team both at Goddard but also at key partner Lockheed Martin respects Amato's drive and dedication to bring probe-related innovations to planetary sciences in general, Garvin said, even beyond the fabulous opportunity with Venus (DAVINCI). "We can expect Michael Amato to never cease from leading technology innovations to enable the next great missions that scientists cannot wait to propose and then fly." ❖

Photo Credit: Deborah Amato

Michael Amato enjoys his Innovator of the Year Award at home.

Space Weather Forecast - It's Raining Neutrons

George Suarez, Dr. Georgia de Nolfo and Grant Mitchell pause at UC Davis during testing of their neutron spectrometer technology.

High-energy neutrons can be found anywhere and can penetrate spacecraft and human bodies. They pose a considerable radiation risk to the safety of astronauts and space assets.

In our local environment, they are produced as the secondary products of galactic cosmic ray interactions with the surrounding environment. Earth's atmosphere acts as a buffer to these secondary neutrons, but on the lunar surface, neutrons account for a formidable source of radiation exposure. Neutrons detected at the lunar surface can also be used to identify critical lunar resources such as water ice, and to monitor the Sun's activity.

Goddard researcher Dr. Georgia de Nolfo leads an Internal Research and Development (IRAD) team working on prototype instruments to track and analyze free, fast neutrons.

"Trying to really nail down the neutron background is important for protecting astronauts," de Nolfo said. "We're also very interested in observing the neutron component from the Sun so we can better understand how and when particles get accelerated by solar eruptive events. While some energetic particles escape the Sun and form harmful space radiation, others are trapped along closed magnetic fields and end up interacting in the solar atmosphere to produce a host of secondaries including free neutrons and gamma rays."

A lunar-based neutron observatory would benefit from the long lunar day, with uninterrupted extended observations of the Sun.

Their Lunar OutpOst Neutron Spectrometer (LOONS) tracks incoming neutrons' energy and incident direction to reveal a wealth of information about their origin as well as materials they may have interacted with along the way.

"LOONS is both a science instrument and an operational instrument," said Heliophysics Line of Business Lead Steven Christe. "It sits at the intersection providing data that will help us better understand the physics of the Sun and of the Moon and provides the radiation dose measurements to keep the astronauts safe. We hope that this is a model for future instrumentation."

Designed to measure neutrons of solar, terrestrial, and lunar origin, LOONS is a pathfinder for future Moon to Mars opportunities based on state-of-the-art techniques for neutron detection. It uses segmented organic scintillators – a crystalline structure made of p-terphenyl, which releases photons when hit by gamma rays or neutrons. The crystals are coupled to robust, low-power, and compact silicon photomultipliers (SiPMs) which collect the light and produce an electronic signal.

"When a neutron comes in, it can interact with one crystal and that crystal scintillates," de Nolfo said. "Sometimes it interacts with a second crystal and we can get a time of flight between the two crystals that enables us to measure the neutron's velocity."

The segmentation of the crystals also allows for some coarse imaging.

Neutrons can also interact with the Moon or Mars soil, called regolith, and with the hydrogen in the form of water ice, hidden within ancient permanently shadowed regions, said team member and graduate student Grant Mitchell. "The intensity of neutrons produced from the interactions of cosmic rays and

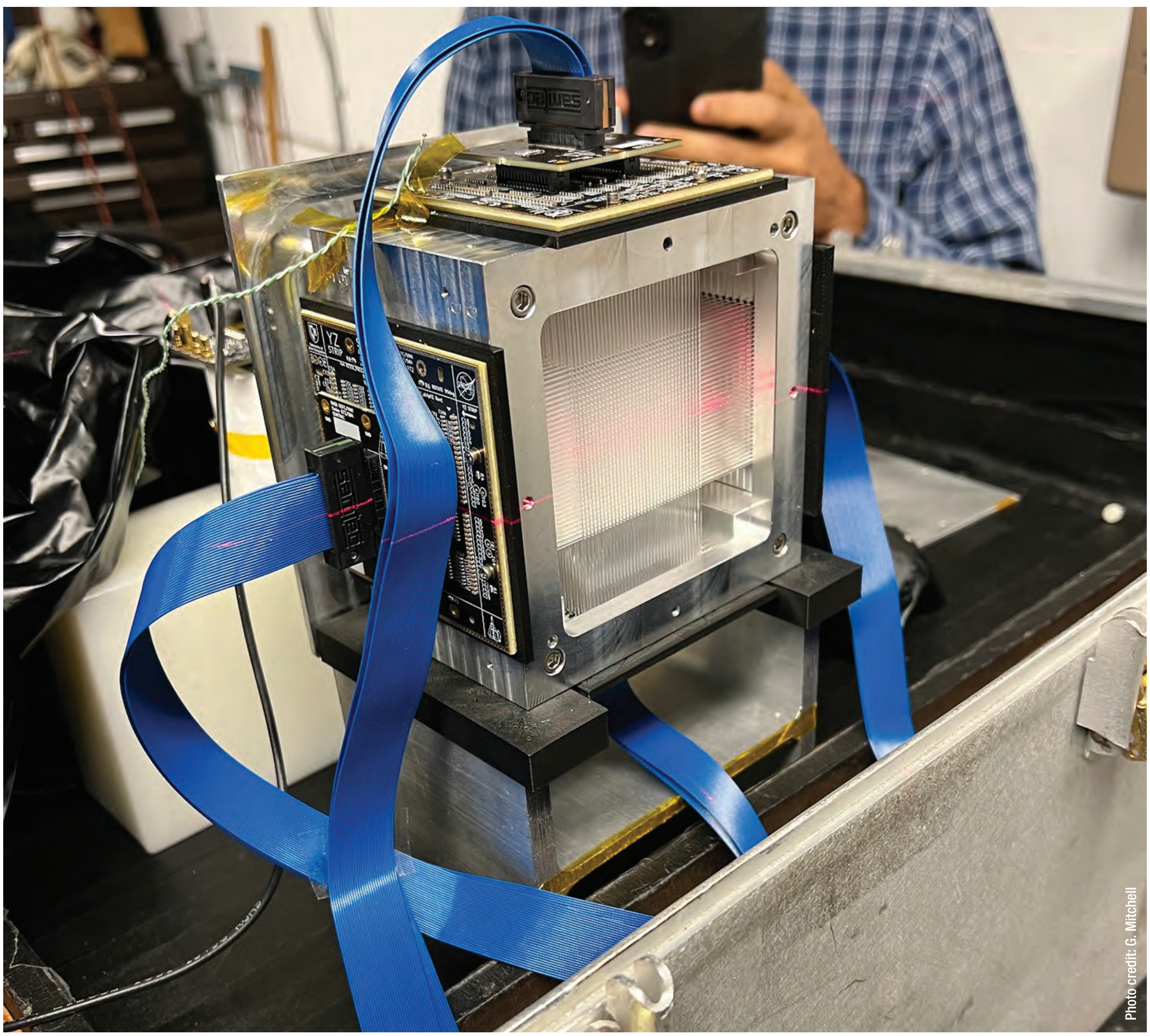


Photo credit: G. Mitchell

The SONTRAC neutron spectrometer readies for testing.

the lunar regolith is highly dependent on the regolith composition, making it possible to identify key locations on the Moon with potential resources, which are important for sustaining future exploration." The team also includes Goddard experts George Suarez, Jeff Dumonthier, Matt Daehn, Teresa Tatoli, Liam Williams, Dr. Alessandro Bruno, and collaborators from the University of New Hampshire.

Bringing up the Next Generation

Mitchell has worked with de Nolfo on neutron spectroscopy for about seven years, beginning when he was an undergraduate intern. "It's been interesting to see the technology mature over time," he said.

While LOONS prepares for missions of opportunity with the Artemis Program to the Moon or Mars, their team is already adapting what they've learned to develop a next generation neutron spectrometer with NASA funding. The SOlar Neutron TRACking (SONTRAC) instrument will use a bundle of scintillating fibers to provide higher-resolution imaging.

"With LOONS, you have two layers of arrays of crystals," Mitchell said. "SONTRAC will have 35 orthogonally stacked layers of plastic scintillating fibers, each monitored by 1-mm SiPMs. These will image protons knocked out of place by the interactions of neutrons within the bundle. Knowing the recoil proton tracks allows us to reconstruct the energy and direction of incoming neutrons." The team just completed a calibration run of the SONTRAC instrument at the Crocker National Lab's cyclotron accelerator using a beam of protons and neutrons.

"SONTRAC allows for a much more compact instrument", Mitchell said, "because you eliminate the dead space required for more traditional double scatter spectrometers such as LOONS". That, combined with compact, low-power silicon photomultipliers clears the way for a neutron spectrometer that would fit on a smaller spacecraft, such as an inner heliospheric CubeSAT or lunar lander.

The ability to cheaply and easily include neutron spectroscopy to spacecraft supporting Artemis and future exploration goals will help ensure the safety of astronauts and spacecraft as well as provide new science data about the Moon, Sun, and solar system planets, de Nolfo said. ❖

CONTACT

Georgia.A.Denolfo@NASA.gov or 301-286-1512

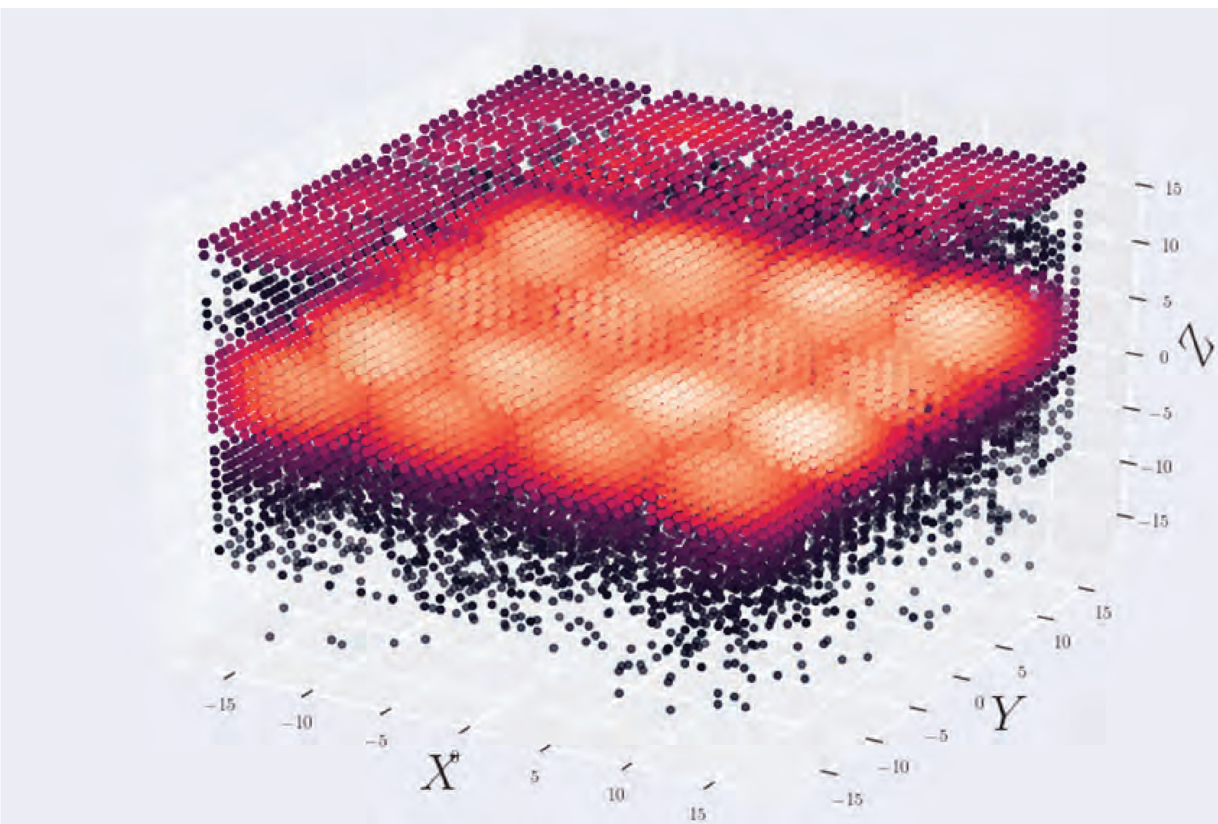


Image Courtesy: Georgia de Nolfo

Data from a particle accelerator beam run in November for SONTRAC shows the protons stopping midway through the bundle (known as the Bragg peak).

Dissecting the Lower Atmosphere Through Hyperspectral Microwave Imaging

The part of the atmosphere people live in, and have the most experience studying, is the hardest to measure from space due to the volume of gases above it.

"The planetary boundary layer is where we live and where our weather takes place," said Goddard Researcher Dr. Antonia Gambacorta. "It's been studied in great detail with lots of ground-based measurements, but there are large gaps, like over oceans and polar regions where we don't have as many ground-based instruments. Having the capability from space to sound and measure the boundary layer is important to study the connections between this layer and the rest of our atmosphere on a global basis."

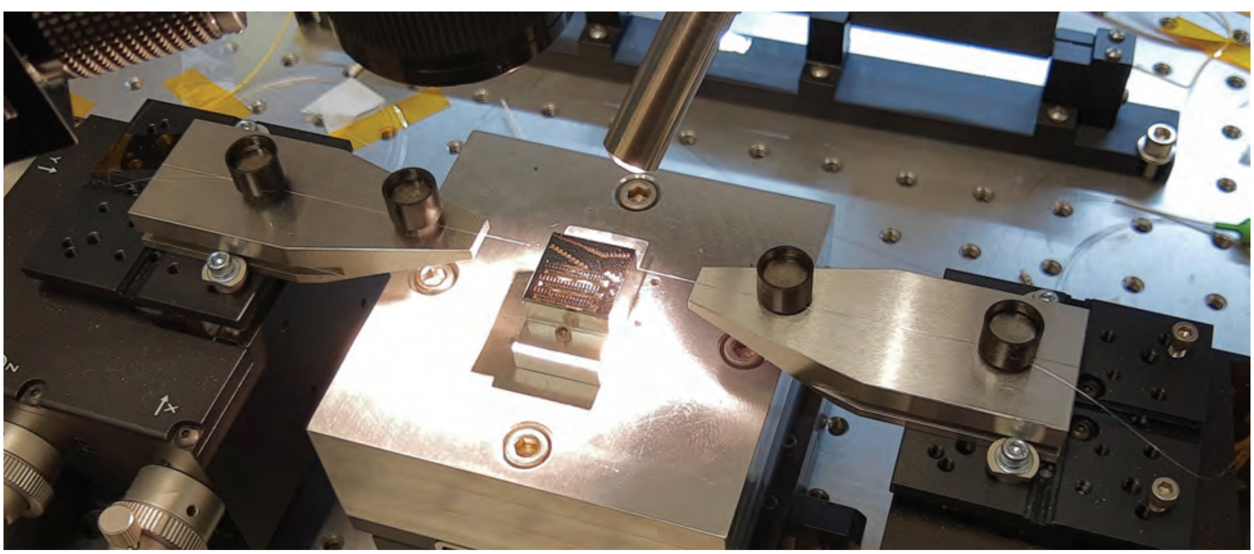
Space-based observations of Earth's planetary boundary layer, or PBL, on a global level is a key Earth science focus area for the coming decades. Studying the global system will enable scientists to better understand the interaction between the surface and the atmosphere and how that is evolving in a global, changing climate. The PBL is where weather occurs. Accurate, real-time measurement of PBL temperature and water vapor from space enables more accurate prediction of rapidly changing extreme events, providing significant benefits to the economy. However, measuring this layer from space presents significant challenges.

"From space, you're trying to measure a signal that gets weakened as it gets absorbed and re-emitted along the way," said Gambacorta, an Earth science researcher. "You also have interfering noise from the surface and clouds."

The problem is accentuated by the presence of clouds. However, while liquid droplets and ice particles absorb Earth's radiation in the infrared region, in the microwave domain they are partially transparent. This enables retrieval of atmospheric temperature and water vapor information, under all sky conditions, including in the critical lower reaches of the PBL. Operational microwave spaceborne sensors from the current Program of Record (POR) and even planned sensors, however, continue to be constrained to only a couple dozen channels. This limits the vertical resolution and accuracy of the data, especially in the boundary layer.

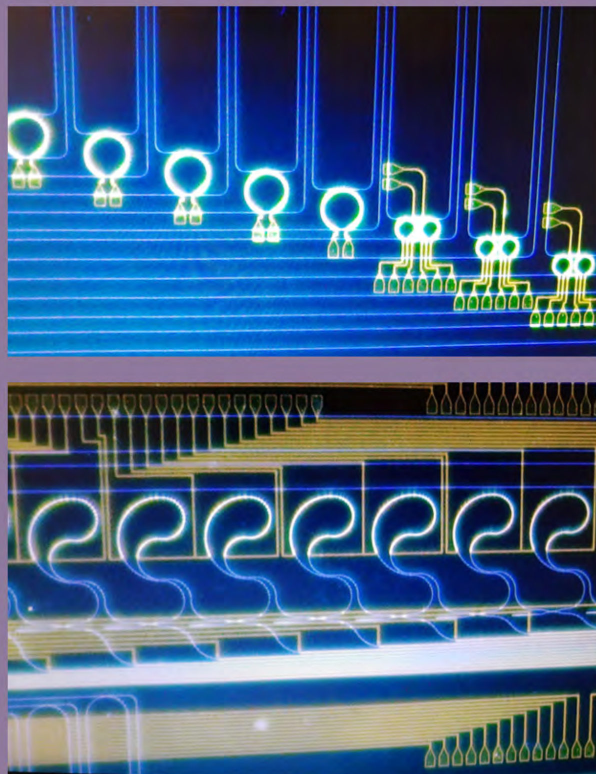
Hyperspectral (hundreds to a few thousand channels) microwave measurements hold promise to significantly improve over the existing constraints, Gambacorta said.

She works with engineers and researchers from Goddard, academia, and the private sector to develop software and hardware to peel back the planetary boundary layer like an onion using hyperspectral microwave measurements of Earth's thermal radiation. Instead of a paring knife, her technology combines data from microwave and other passive and active sensors. Collecting data



A photonics integrated chip including several circuits rests on a stage in a characterization setup. Photo Cedit: Fabrizio Gambini on hundreds, if not thousands of wavelengths could provide as clear a view as possible of this crucial layer from a global perspective.

Hyperspectral microwave measurements have been long advocated by meteorological and space agencies worldwide to improve temperature and water vapor data collection from orbit, suitable for climate and weather prediction, Gambacorta said. The NASA planetary boundary layer incubation study team report lists hyperspectral microwave sensors as an essential component of the future global PBL observing system.



Images of photonic circuits: the blue lines are photonic integrated waveguides, while the yellow lines are metal lines for integrated heaters.

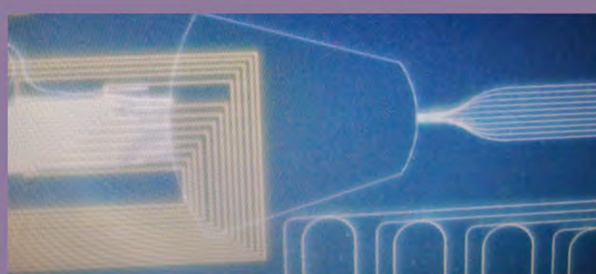


Image credit: Fabrizio Gambini

Two-Front Approach

Her team approaches the problem on two fronts - developing the technology to expand the frequencies a single spacecraft can detect while pursuing algorithms to process the massive amounts of data those sensors will generate. They seek to generate meaningful information and visualizations that are easier for scientists and meteorologists to grasp by working in coordination with data users such as NOAA and the EPA..

On the electronic side, they are looking to convert microwave radio frequencies to optical signals to reduce the mass and power demands of processing these signals.

"We have computer models and a preliminary breadboard system assembled to show that it should work," said Dr. Mark Stephen, an engineer with Goddard's Research Engineering Partnership. "If we can convert radio frequency into an optical signal and back into radio, we can show that we can reduce the size weight, power and cost of the instrument without degrading the information content in the signal."

The proposed photonic integrated circuits (PICs) that process the signal are the missing puzzle piece, he said. What they are working to produce is a first of its kind hyperspectral microwave photonic instrument (HyMPI) capable of measuring the full microwave radiation spectrum escaping the top of the atmosphere, carrying information about Earth's surface and the PBL.

"There's a lot of development work left to get those all put together into a single system," said Dr. Fabrizio Gambini, a team engineer from the University of Maryland, Baltimore County's Canter for Research and Exploration in Space Science and Technology II. "We may need multiple PICs from different platforms on the same board."

Last year, the team wrapped up a three-year Internal Research and Development, or IRAD, investigation to fine tune the target deliverables and instrument design. This year they begin a three-year Earth Science Technology Office grant to build and test their instrument. Gambacorta is also conducting another IRAD study this year to advance the data processing software effort.

"We have already concluded how hyperspectral microwave sounding performs under clear sky conditions," Gambacorta said. "This year, we're modeling how clouds affect hyperspectral microwave measurements compared to the clear sky observations. This remote sounding capability will help achieve a global perspective on the makeup and behavior of the boundary layer." ❖

CONTACT

Antonia.Gambacorta@NASA.gov or 301-614-6202

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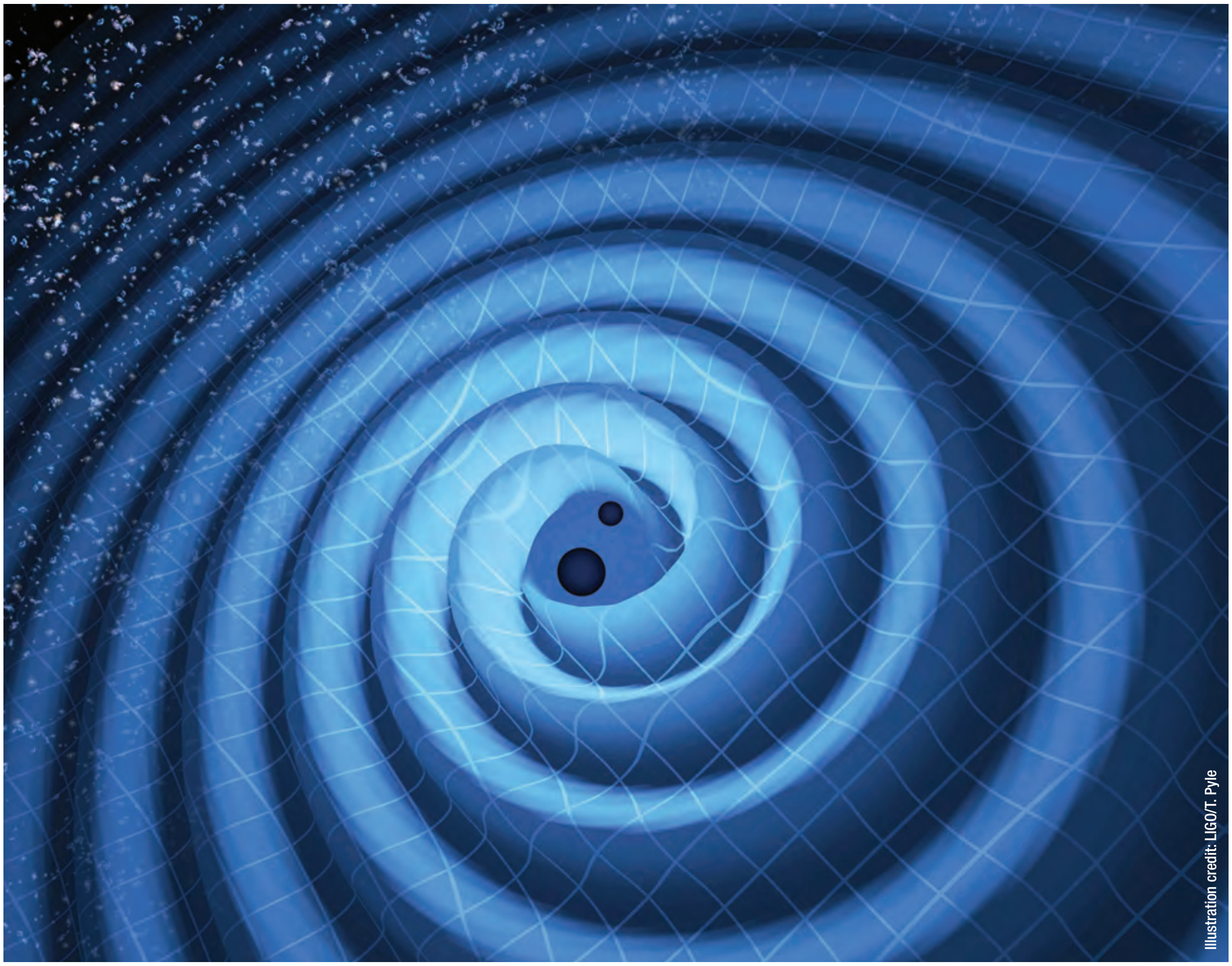
Multimessenger Astronomy Made Easier



This illustration shows the merger of two black holes and the gravitational waves that ripple outward as the black holes spiral toward each other. The black holes — which represent those detected by LIGO on Dec. 26, 2015 — were 14 and 8 times the mass of the sun until they merged, forming a single black hole 21 times the mass of the sun.

Goddard scientists are developing a new, open-source software toolkit to help observatories quickly zero in on the sources of gravitational waves.

The telltale ripples in gravitational fields caused by the mergers of neutron stars, black holes, and supermassive black holes in space, gravitational waves bring to us information about these cataclysmic events, but current detectors only locate their origins to a generalized area in the sky. Multimessenger astronomy combines different types of cosmic signals, like gravitational wave detections and electromagnetic observations from traditional astronomical observatories, to reveal deeper information about their sources. This combination lets astronomers pinpoint the event's exact location.

Astrophysicist Leo P. Singer's Multi-Mission Multi-Messenger Observation Planning Toolkit, or M^4OPT, could optimize the coordination of a global network of orbital and ground-based observatories to study the source of a gravitational wave event.

"Multimessenger astronomy events require promptly re-tasking facilities to quickly tile large and irregular regions of interest on the sky," Singer said. "They also require balletic coordination of observatories in space and on the ground to acquire well-sampled data across the electromagnetic spectrum."

The Laser Interferometer Gravitational-Wave Observatory (LIGO), a pair of ground-based observatories in Hanford, Washington, and Livingston, Louisiana, combined with the Virgo detector in Italy and KAGRA observatory in Japan, detect gravitational waves by precisely measuring minute changes in the distance between a laser emitter and receiver.

Singer is working with astronomers at the Space Telescope Science Institute in Baltimore (STScI), scheduling and optimization experts at NASA's Ames Research Center in Silicon Valley, as well as astronomers with the Zwicky Transient Facility (ZTF) at Palomar Observatory, run by the California Institute of Technology. His M^4OPT toolkit provides solutions to finding the most efficient pointing and scheduling of a variety of participating telescopes with their own field of view, spectra, and limitations in order to get the best return on multimessenger astronomy efforts.

Scheduling requires solving large and complex mathematical optimization problems to ensure all observatories collect the right information at the right time. "The math that we are using is not new for astronomy," Singer said. "But it's never been used before to plan these challenging wide-field, time-sensitive targets of opportunity."

ZTF, a wide-field camera attached to the robotic 48-inch Oschin telescope at Palomar, has a roughly 50-square-degree viewing area, Singer said, as does the Dorado space telescope – a mission in the concept phase. Dorado is designed to follow up gravitational wave observations and uses an early prototype of M^4OPT for observation planning. These observatories and others with large fields of view need to respond quickly to locate the source of the signal for more sensitive telescopes with higher resolution but comparatively tiny fields of view to further observe.

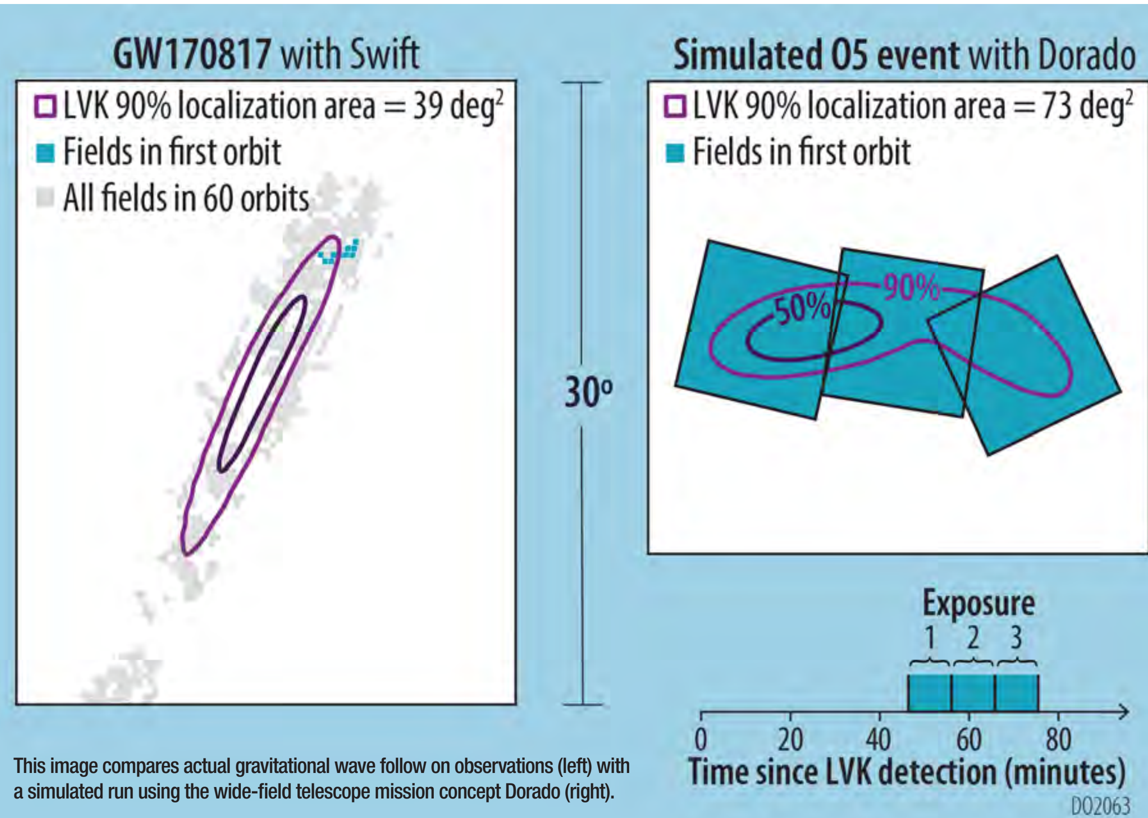
STScI scientist Ori Fox helps develop image analysis tools incorporating Astropy – a community-built library of software tools based on the Python programming language. He said observatories like the James Webb Space Telescope and Hubble Space Telescope have dedicated plans to follow up on gravitational wave events.

Singer said he hopes M^4OPT will be picked up and used by new and future observatories of all sizes. If the core functionality generalizes well to both the space- and ground-based communities, the field of astronomy will have lots of contributors adding to the available electromagnetic data to study these massive collisions that can shape the cosmos.

"Software for space missions can be very costly to develop because it's so specialized," Singer said. "If we can build open-source tools that work equally well for everyone, then we can make something together with the community that would have been very costly for each mission to build individually." ❖

CONTACT

Leo.P.Singer@NASA.gov or 301-286-5439



This image compares actual gravitational wave follow on observations (left) with a simulated run using the wide-field telescope mission concept Dorado (right).

Image credit: Leo Singer

Zeroing in on Lunar Ice in New Ways

A new investigation seeks to build something akin to a traditional metal detector, but for detecting subsurface water ice on the Moon or Mars.

"In order to establish long term human habitation on the Moon, you need to be able to find resources such as water ice very locally," said Principal Investigator Manohar Deshpande. He is working with Goddard's Chief Scientist James Garvin to build a very low radio frequency probe to identify valuable resources for the Artemis Program's exploration of the Moon and Mars.

"We are trying to establish the definitive signature of water ice and other materials useful for long-term human exploration goals including metals," Deshpande said.

His ultra-low frequency sensor technology depends on a phenomenon called dielectric relaxation – when atoms or molecules re-orient and align under the influence of an external electric field. This happens at different frequencies depending on the material being measured. Water ice responds to a 400 Hz radio frequency signal, Deshpande said, while typical ground penetrating radar, operating around the 1 to 2 GHz frequency range would not be able to detect this definitive dielectric relaxation phenomenon."

In his Step 1 Internal Research and Development, or IRAD, project, Deshpande is working with faculty at the University of Vermont to fabricate the instrument electronics, and a multi-electrode sensor array. The team will also develop data processing techniques to interpret the results.

For now, they are working on a low voltage system that can penetrate a few centimeters into the soil (which is called regolith on the Moon), he said. Further development would be needed for it to be ready to mount on a lunar lander such as those that are part of the Commercial Lunar Payload Services program. From there it could be deployed via a small robotic rover. A higher voltage system could probe more deeply into the lunar soil, but would also require more electric insulation.

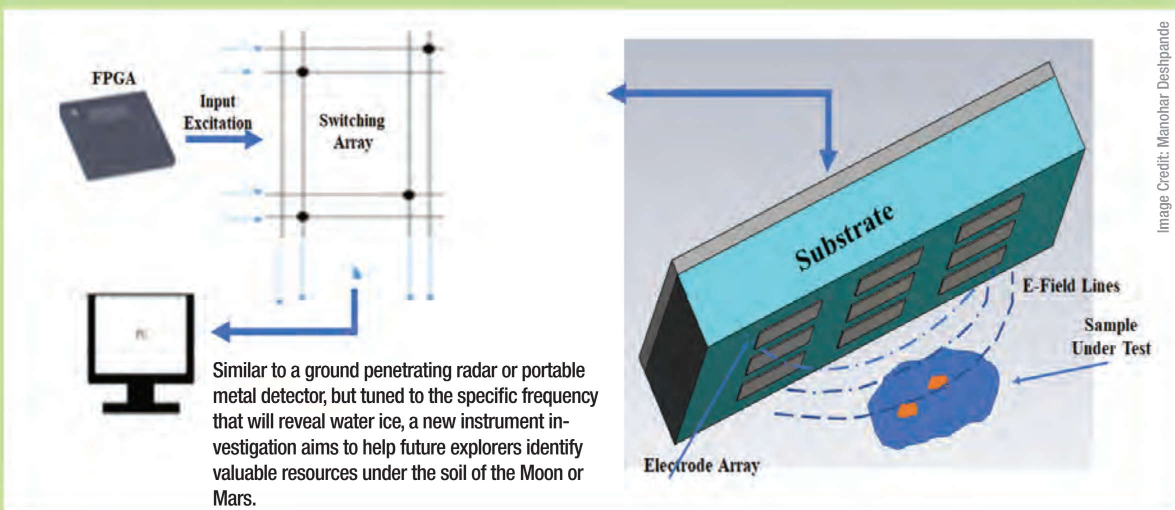
"This measurement technique allows us to actively seek out materials of interest in the Lunar subsurface," said Terry Hurford, Associate Director for Planning, Research and Development in the Solar System Directorate at Goddard. "Most planetary surface instruments make their measurements passively, but Deshpande's technique allows for targeted active detection of water to depths of a meter or more."

Deshpande has secured some analog lunar soil samples for testing and plans to analyze the impedance of the sample to a very low frequency radio signal. The team will also test against rock samples prepared with water, ice, and CO_2 ice.

"At the end of this project we will have an instrument that can make these measurements," he said. "It's a completely new way of detecting water ice on the Moon and more clear-cut because of the unique dielectric relaxations." ❖

CONTACT

Manohar.D.Deshpande@NASA.gov or 301-286-2435



Similar to a ground penetrating radar or portable metal detector, but tuned to the specific frequency that will reveal water ice, a new instrument investigation aims to help future explorers identify valuable resources under the soil of the Moon or Mars.

Catching up: 3D-Printed, Flexible Electronics Put to Work in X-ray Polarimeter

Goddard investigator Beth Paquette has been developing techniques and best practices for printing circuits and detectors on curved or flexible surfaces for a variety of projects. The technology can reduce the volume required for electronics in future spacecraft as NASA looks to send smaller instruments farther out into space.

Currently she is working with Margaret H. Samuels, a graduate student researcher, exploring ways to use Optomec's 5-Axis aerosol jet printer to create the Readout Board Assemblies for a High-Energy X-Ray Photoelectric Polarimeter (HXPP). This instrument measures the polarization of radiation by tracking photoelectrons produced by X-rays. HXPP would detect X-rays by a change in the resistance on the 3D-printed lines.

"The traditional X-ray polarimeter assembly could be simplified, because right now they use a substrate that's pretty flimsy and can tear easily," said Beth Paquette, a NASA Goddard Space Flight Center technologist who started working with aerosol jet printing in 2014 (*CuttingEdge* Winter 2014, Page 3) and leads several Internal Research and Development (IRAD) projects focused on printed hybrid electronics.

Aerosol jet printing is an air-based 3D printing method in which gases regulate an ink stream made of metal nanoparticles suspended in a liquid. Traditionally, circuits are printed on boards by either depositing on or etching away layers of copper from the substrate and then adding components. These 2D circuit boards are assembled in a box when integrated into a spacecraft, occupying valuable space.

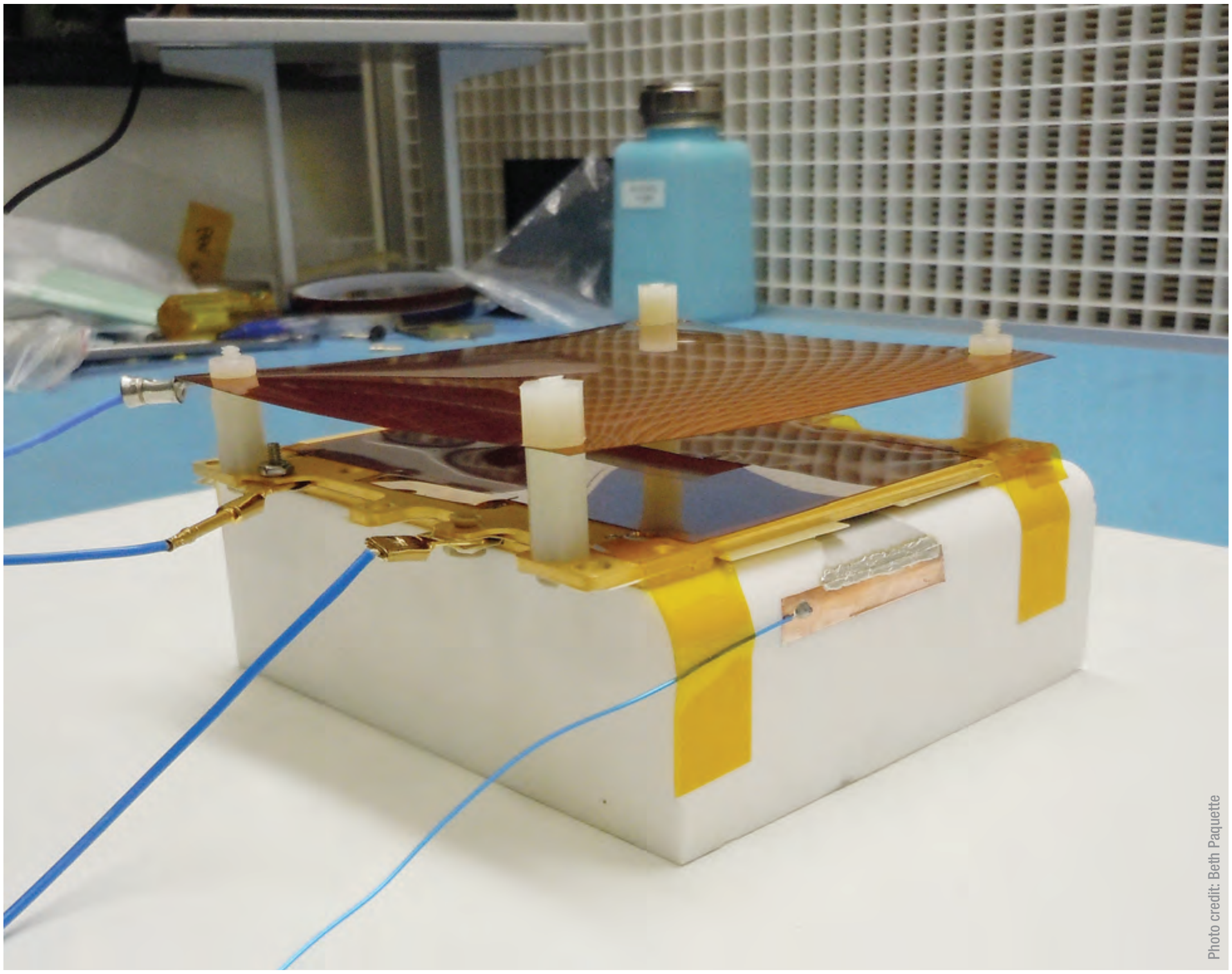


Photo credit: Beth Paquette

Printed traces around a 90-degree bend in a test configuration survived 40 hours of X-ray testing for a High-Energy X-Ray Photoelectric Polarimeter (HXPP) instrument project. Testing Traces printed are 45 microns wide with 120 micron spacing.

Additive manufacturing techniques, like the aerosol jet printer, can place traditional electrical components onto a surface and then print traces and connecting structures called interconnects to the circuit. HXPP's X-ray detector is printed with silver ink over a ceramic substrate.

"An obvious perk for NASA engineers and scientists is being able to print a circuit on a curve," said Margaret H. Samuels, a graduate student researcher working with Paquette. "This means you can print on the inside of a rocket, and you don't have to take up extra space and mass of a whole printed circuit board."

Samuels works with the 3D printers at the Laboratory for Physical Sciences (LPS), which partners with the University of Maryland. She is the principal investigator of a related IRAD project that generates software for printing HXPP assemblies.

Aerosol jet printing offers two main benefits: printing traces as small as 10 microns wide (a fraction of the thickness of a hair), which is 100 times smaller than current circuitry, and printing circuits directly onto 3D surfaces such as around a corner or on a dome.

Another application of the technology is a microcontroller circuit, which tracks basic electrical functions. The circuit will be printed on a waterproof section on the inside of a door on SubTEC-9, a sounding rocket demonstration set to launch in 2022. Temperature and humidity sensors developed by NASA's Marshall Space Flight Center in Huntsville, Alabama, will collect data during flight to evaluate the circuit's functioning.

Aerosol jet printing could aid development of the Next Generation Microshutter Array assemblies for spectrographs, as well as a housekeeping circuit demonstration to be tested on a future CubeSat, and superconducting circuits produced in extremely high temperatures. ❖

CONTACT

Beth.M.Paquette@NASA.gov or 301-286-8647

Cutting edge Goddard's Emerging Technologies

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