National Aeronautics and Space Administration

Volume 14 | Issue 1 | Fall 2017

Cutting edge

Goddard's Emerging Technologies

The Quintessential Innovator

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Mahmooda Sultana Selected as Goddard's FY17 IRAD Innovator of the Year

As a child living in Bangladesh, Mahmooda Sultana probably followed NASA's accomplishments more so than other kids her age. This, she said, was more than likely due to the fact that a great uncle worked as a physicist at NASA's Ames Research Center, a half a world away in the heart of California's Silicon Valley.

Nonetheless, those accomplishments inspired her to also want a career at NASA. Interestingly, it almost didn't happen.

"We're fortunate she came to NASA," said Goddard Chief Technologist Peter Hughes, whose office selected her as its FY17 IRAD Innovator of the Year, an award bestowed annually on those who represent the best in R&D. Hughes and his team selected Sultana because of her groundbreaking work advancing nanomaterials and processes to create small, potentially revolutionary detectors and devices.

"Mahmooda has distinguished herself as a tenacious, creative thinker, impressing virtually everyone with her technical acumen and drive," Hughes continued. "In her relatively short time here, she has successfully competed for 10 awards under our Internal Research and Development program, compiling an impressive list of accomplishments, including the creation of advanced sensors for which a patent is pending. Perhaps most notable is her emergence as one of NASA's experts in nanotechnology. I can only imagine what she'll do in the future. She embodies the very essence of innovation."

Just before earning a Ph.D. in chemical engineering from the Massachusetts Institute of Technology in 2010, Sultana had considered a career in academia or possibly as a research engineer for one of the Department of Energy's national laboratories

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About the Cover

Mahmooda Sultana has compiled an impressive list of achievements during her relatively short career at NASA. In addition to establishing herself as one of the agency's experts in the development and use of nanomaterials and processes to create potentially revolutionary detectors and devices, Sultana has expanded her portfolio to include the development of instrument systems, particularly for CubeSats, all while continuing her research into new processes for manufacturing sensors.

Photo Credit: Bill Hrybyk/NASA

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or private industry — her dream of working for the nation's space program forgotten.

"It was lucky for me," said Sultana, who, as a teen, immigrated to California with her family and ultimately received an undergraduate degree in chemical engineering Summa Cum Laude from the University of Southern California in Los Angeles. "I met Thomas Stevenson."

At an MIT job fair, she talked with Stevenson who was recruiting talent for Goddard's Detector Systems Branch. He quickly recognized her potential. As a graduate assistant and then as a research intern with Bell Laboratories, she had already characterized, designed, and developed detectors.

A job was offered. She accepted, a childhood dream reignited and fulfilled, she said.

Hit the Ground Running

"From Mahmooda, I saw a young professional woman who would go far in the NASA environment," said Goddard technologist and colleague Mary Li.

Within just a few months of joining NASA, Sultana had become the lead in the development of graphene-based sensors — efforts that led to the filing of a still-pending patent application (*CuttingEdge,* Fall 2012, Page 10). Graphene, which is just one atom thick and composed of carbon atoms arranged in tightly bound hexagons best visualized as atomic-scale chicken wire, is 200 times stronger than structural steel and highly sensitive and stable at extreme temperatures.

"When I came to NASA Goddard in 2010, no one at the center was doing substantial work on graphene, but there was a lot of excitement," Sultana explained. "Everything was still at a very early stage; people around the world were coming up with new applications of graphene every day. I wanted to explore what graphene had to offer for space applications."

She has since expanded her research interests.

Quantum Dots and 3-D Printing

She and her team currently are collaborating with MIT to develop a prototype imaging spectrometer — an instrument used by virtually all scientific disciplines to measure the properties of light — based on the emerging quantum-dot technology that MIT researchers pioneered (*CuttingEdge,* Winter 2017, Page 11).

Invisible to the naked eye, quantum dots have proven in testing to absorb different wavelengths of light depending on their size, shape, and chemical composition. With her funding, Sultana is working to develop and demonstrate a 20-by-20 quantum-dot array sensitive to visible wavelengths needed to image the Sun and the aurora.

In another collaboration involving Boston's Northeastern University, Sultana and her team are experimenting with the university-created Nanoscale Offset Printing System to manufacture a multifunctional sensor platform made of different nanomaterials, including graphene, carbon nanotubes, and molybdenum disulfide.

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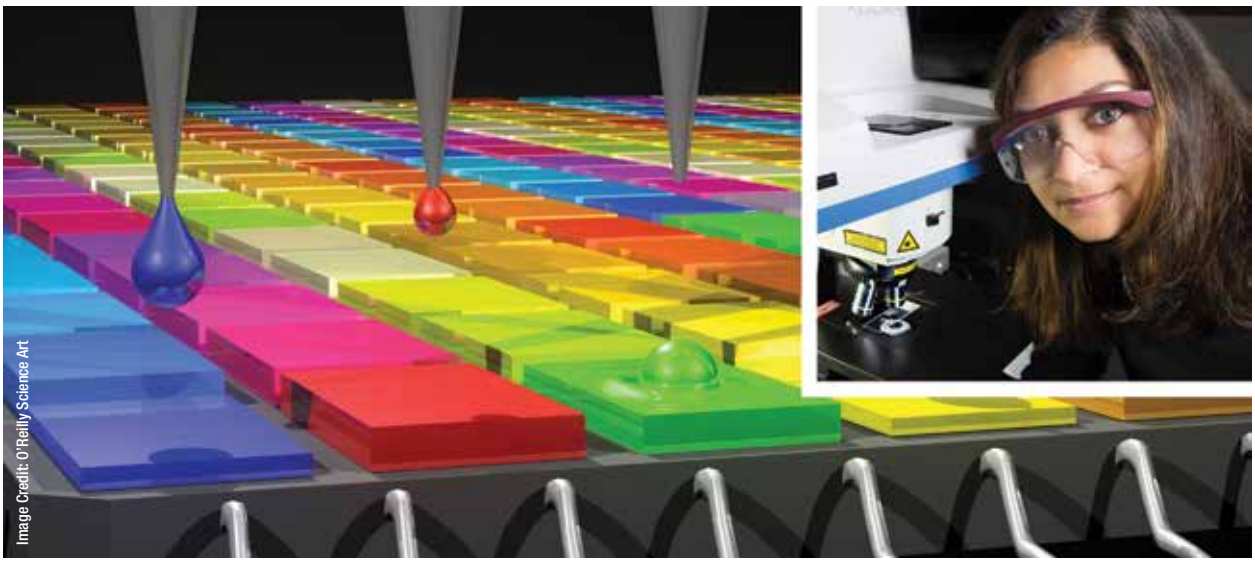

This illustration shows how a device prints the quantum-dot filters that absorb different wavelengths of light depending on their size and composition. The emerging technology could give scientists a more flexible, cost-effective approach for developing spectrometers, a commonly used instrument.

SPECIAL REPORT
Focus on Winning Mission Concepts

In FY17, NASA selected at least 25 Goddard teams to receive Phase-A and other technology-development support to advance new mission concepts, instruments, and technologies. In this issue, CuttingEdge highlights a few winning mission concepts, including three Phase-A studies on pages 4, 6, and 7, as well as those from other R&D programs on pages 9, 11, and 13.

The Gravitational-Wave Source Sentinel

Proposed Mission Employs "Lobster-Eye" Optics to Locate Source of Cosmic Ripples

A novel optics system that mimics the structure of a lobster's eyes would enable a conceptual Explorer-class mission to precisely locate, characterize, and alert other observatories to the source of gravitational waves, which are caused by some of the most powerful events in the universe.

NASA selected a Goddard-led team to study the feasibility of the Transient Astrophysics Observatory on the International Space Station, or ISS-TAO. The mission was selected, along with two other similarly classed concepts, as a potential Explorer Mission of Opportunity. In 2019, NASA is expected to choose one concept for construction and launch.

"ISS-TAO is more relevant today than ever before," said mission Principal Investigator Jordan Camp, who is leading an international team to mature the concept and fine-tune its two instruments: a Goddard-provided soft X-ray Wide-Field Imager, or WFI, and the Israel Space Agency-provided Gamma-Ray Transient Monitor. "The detection of gravitational waves in late 2015 was a watershed event. Gravitational waves are so different, so new. We want a way to connect conventional electromagnetic astronomy with this emerging science," Camp said.

From its perch aboard the International Space Station, ISS-TAO will monitor the sky in search of transient X-rays and gamma rays — those fleeting, hard-to-capture, high-energy photons unleashed during black hole and neutron-star mergers and

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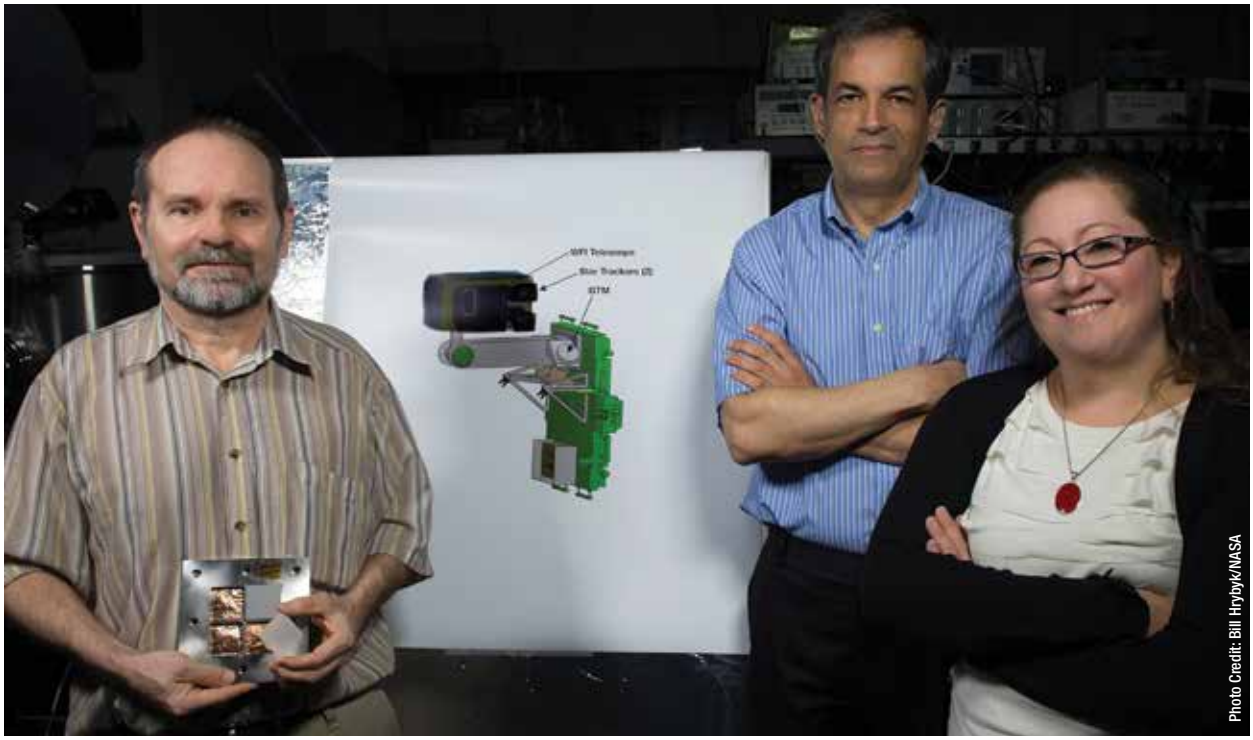


Photo Credit: Bill Hrybyk/NASA

Principal Investigator Jordan Camp (center) and Co-Investigator Judy Racusin are leading an international team advancing a proposed mission to characterize the sources of gravitational waves. Deputy Principal Investigator Scott Barthelmy (left) holds an important mission technology — the microchannel optic.

supernovae. These powerful upheavals generate gravitational waves — ripples in the fabric of space-time that radiate out in all directions, much like what happens when a stone is thrown into a pond.

Last year, scientists revealed that the ground-based Laser Interferometer Gravitational Wave Observatory, or LIGO, had detected gravitational waves from not one, but two separate events involving the collision of black holes in other galaxies; others have been reported since (*CuttingEdge,* Fall 2016, Page 8).

Most recently on October 16, LIGO announced the first-ever detection of gravitational waves from the merger of two neutron stars. Less than two seconds later after the waves washed across Earth's space-time, NASA's Fermi Gamma-ray Space Telescope detected a weak burst of high-energy light — the first ever to be unambiguously connected to a gravitational-wave source. Half a day later, observatories around the world had found the location in visible light.

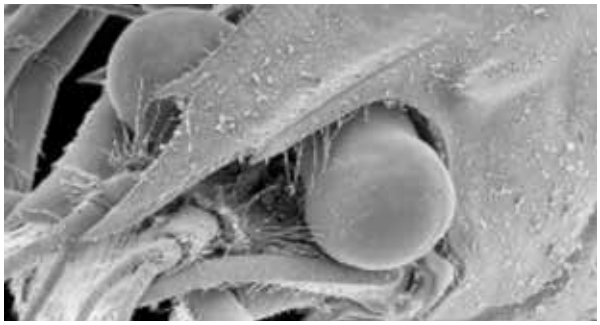
The confirmation that gravitational waves do exist has opened a new window on the universe, giving scientists a different view that will complement what they already have learned through more traditional observational approaches.

Special Niche to Fill

Camp believes ISS-TAO has a special niche to fill in this emerging branch of astrophysics. ISS-TAO will be a sentinel, said mission Deputy Principal Investigator Scott Barthelmy.

In addition to conducting all-sky surveys of transient X-ray sources, ISS-TAO will more precisely locate the X-ray counterparts to sources of gravitational-wave events, gather data, and communicate their position to other observatories so that they can begin their own observations.

"LIGO and Virgo (a recently upgraded interferometer facility in Pisa, Italy) form the advanced network of gravitational-wave observatories," Camp said. "They will alert us to the most exciting candidates. Although these facilities can detect the ripples in space-time, they can't focus gravitational waves and instead achieve their source localization by timing of noisy signals," Camp explained. "Thus, they can't precisely locate their sources."



The Goddard-provided soft X-ray Wide-Field Imager proposed for ISS-TAO borrows heavily from nature. Its optics mimic a lobster's eyes.

In contrast, ISS-TAO would point its lobster optics to the large portion of the sky identified by LIGO and Virgo and then focus the accompanying X-ray counterparts to localize and characterize these sources, he said.

Well Suited for the Task

Although dozens of space- and ground-based observatories are looking for the electromagnetic counterparts, ISS-TAO is particularly well suited for the task, said mission Co-Investigator Judy Racusin.

One of its instruments, the WFI, is equipped with the novel lobster-eye optics, which mimic the structure of the crustacean's eyes. Lobster eyes are made up of long, narrow cells that each reflect a tiny amount of light from a given direction. This allows the light from a wide viewing area to be focused into a single image.

WFI's optic works the same way. Its eyes are microchannel plates — thin, curved slabs of material dotted with tiny tubes across the surface. X-ray light can enter these tubes from multiple angles and is focused through grazing-incidence reflection, giving the technology a wide field of view necessary for finding and imaging transient events that cannot be predicted in advance.

"We started work on this mission concept before LIGO made the discovery," Camp added, referring to R&D-funded efforts that began about five years ago (*CuttingEdge,* Spring 2012, Page 6). "It certainly has added a lot of excitement and opened a revolutionary new frontier in astrophysics. We think our mission can greatly enhance gravitational-wave science." ❖

CONTACT

Jordan.B.Camp@nasa.gov or 301.286.3528

SPECIAL REPORT
Focus on Winning Mission Concepts

The Escape of the Atmosphere

Proposed Mission to Study Plasma Outflow Using Earth as a Laboratory

A team of scientists want to use Earth as a laboratory to understand how planets lose their atmospheres.

In a proposed mission that some believe represents the "Holy Grail" in the study of the Sun and its effects on space, a team led by Goddard scientist Thomas Moore is advancing a dual-satellite, polar-orbiting mission that would study the universal processes that control atmospheric erosion and its interaction with stellar winds, the continuously flowing stream of charged particles released from the Sun's corona.

Called Mechanisms of Energetic Mass Ejection-eXplorer, or MEME-X, the mission was one of five proposals that received Phase-A funding under NASA's Small Explorer Program. NASA also selected another Goddard mission, Focusing Optics X-ray Solar Imager, proposed by Principal Investigator Steven Christe (see related story, page 7). Of the five, NASA is expected to select one or two for development and implementation.

Cross-Disciplinary Mission

"MEME-X has strong cross threads across NASA's scientific disciplines — planetary, heliophysics, astrophysics, and Earth science," Moore said. In addition to providing details about the loss of mass in Earth's upper atmospheric layers, the mission could enhance scientists' understanding of the role that solar wind played in transforming Mars from a warm and wet environment that might have supported surface life to the cold, arid planet of today, he said.

To that end, MEME-X will focus on one principal question: how does plasma escape from Earth's ionosphere, which lies 50 to 620 miles above the surface, into the protective magnetosphere that shields the planet from potentially harmful solar wind and other space weather, and then out into space. "Atmospheric escape is a fundamental process with wide-reaching consequences across space and planetary sciences," Moore said.

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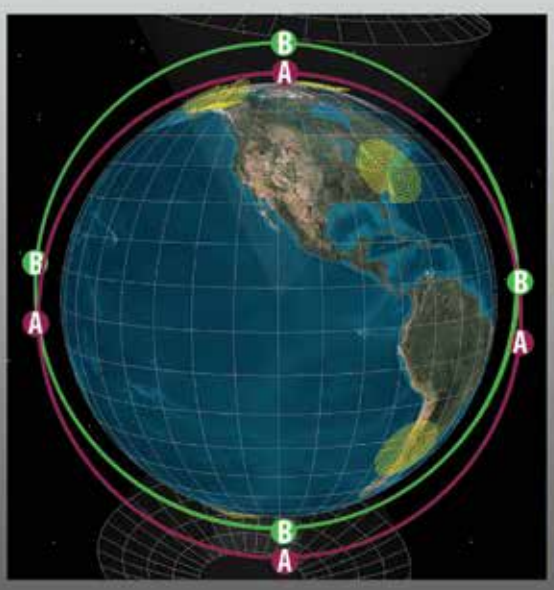
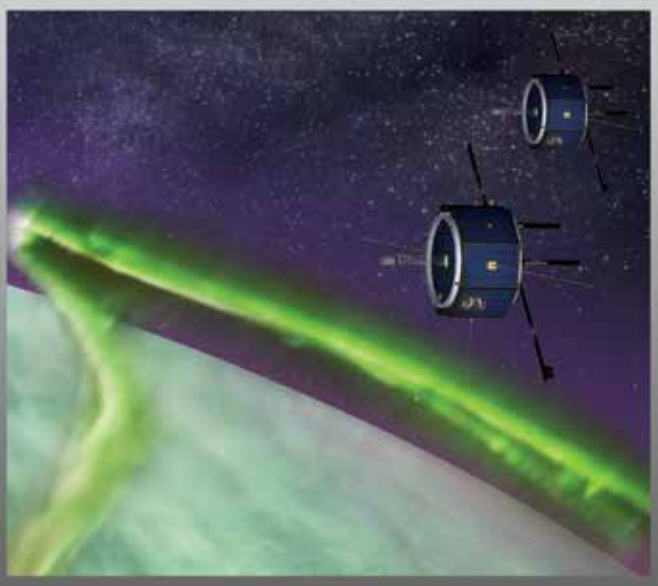


MEME-X's two spacecraft would fly in a polar orbit to find out how plasma escapes from Earth's ionosphere, which lies 50 to 620 miles above the surface, into the protective magnetosphere that shields the planet from potentially harmful solar wind and other space weather, and then out into space.



This artist's rendition shows MEME-X's dual spacecraft as they observe the aurora.

LEFT Image Credit: NASA
RIGHT Image Credit: NASA

Plasma consists of negatively charged electrons and positively charged ions; that is, atoms that have lost their electrons. It is a fourth state of matter — not a gas, liquid, or solid. It conducts electricity and is affected by magnetic fields. On an astronomical scale, plasma is common. It's found in the Sun, in the constant stream of material that flows from the Sun — the solar wind — and throughout space.

For heliophysics, understanding the outflowing of ionospheric plasma is particularly crucial, Moore added. The upflow of plasma from the high-latitude polar cap and auroral regions appears to affect the magnetosphere's response to variations in the solar wind, which in turn influences space weather, making space weather unpredictable.

"For 40 years, we've had a long-standing mystery about how a portion of the atmosphere is heated by a factor of a hundred or more and ejected into space, where it dramatically modifies the near-Earth environment," said MEME-X Deputy Principal Investigator Doug Rowland, a Goddard heliophysicist. "MEME-X, with its pair of miniaturized spacecraft and advanced instrumentation, will finally give us the tools we need to solve this problem."

Equipped with plasma analyzers, which will be mounted on short booms extending along the spacecraft's spin axes, and other instruments developed in part with Goddard R&D funding, MEME-X will provide the first multipoint measurements of plasma to determine if the matter is being ejected by pressure, as in a geyser, or vacuumed away from Earth, as in a waterspout.

Atmospheric Evolution and Habitability

In addition to revealing the plasma outflow's effect on space weather, the mission could help answer important questions regarding the evolution of planetary atmospheres and planet habitability, Moore said.

A case in point is Mars. Once wetter and warmer, and possibly congenial for life, the planet now looks dead. It's a desert world, with a sparse atmosphere and virtually no protective magnetic field. NASA's Mars Atmosphere and Volatile Evolution mission recently discovered that most of the planet's atmosphere has been lost to space, violently scraped from the planet by solar wind.

The question scientists want to answer is the role of the magnetosphere in atmospheric loss, particularly as it relates to solar wind. "This is a quest to discover and characterize fundamental processes that occur within the heliosphere and throughout the universe," Moore said. "We want to use the Earth's atmosphere as a laboratory." ❖

CONTACT

Thomas.E.Moore@nasa.gov or 301.286.5236

FOXSI to Focus on Where Space Weather Begins

NASA has selected a Goddard-led team to advance a mission revealing unprecedented details about solar flares, powerful eruptions that explode with the force of more than 100-megaton hydrogen bombs.

The proposed mission, Focusing Optics X-ray Solar Imager, or FOXSI, was one of five proposals that received Phase-A funding under NASA's Small Explorer Program. NASA also selected another Goddard mission, Mechanisms of Energetic Mass Ejection-eXplorer (see related story, page 6). Of the five, NASA is expected to select one or two for development and implementation.

Although scientists are familiar with the effects of solar flares, they don't completely understand the physical mechanisms that unleash these bursts of energy and light, or that which powers associated clouds of electrons and ions that can be accelerated up to near the speed of light.

Once unleashed, these bursts of energy and light affect all the Sun's atmospheric layers. They pass through the Sun's outermost layer — the corona where they also are known to originate — and race across the solar system. When they travel toward Earth, the particles and energy can interfere with space-based communications systems or even trip onboard electronics. The more scientists understand this process, the more situational awareness they have to protect assets in space.

"FOXSI is very new and very different," said Principal Investigator Steven Christe, who leads the multinational FOXSI team. "We've not done a mission like this before."

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With the mission's hard X-ray spectroscopic imager and soft X-ray high-resolution spectrometer, "we're going to actually peer for the first time into the region where electrons are accelerated by applying technology that was developed to study the faintest sources in the galaxy but now pointed at the Sun," he said.

Deputy Principal Investigator Albert Shih (left) and Principal Investigator Steven Christe are baselining a next-generation detector array pictured here to measure X-rays for the hard X-ray spectroscopic imager on the proposed FOXSI mission.

Technique Validated in Sounding-Rocket Missions

Validated in multiple sounding-rocket and scientific balloon missions, FOXSI will make use of a new observing technique for a solar-dedicated satellite mission using high-angular-resolution grazing-incidence optics. With this technique, which scientists traditionally use to study powerful, very distant objects in the universe, X-ray radiation literally grazes off a set of curved mirrors nested inside an optical assembly — much like how a stone skims the surface of a pond when thrown. The radiation then is focused onto very fast, solid-state pixelated detectors that measure each individual photon, including its arrival, energy, and position in the sky.

The combination of technologies is expected to result in a mission that is 20 times more sensitive, 10 times faster at imaging solar-flare events, and 10 to 100 times better at imaging the relatively faint regions within flares than previous observatories. With existing instruments, the particle-acceleration region itself is generally too faint to be directly observed.

"For the first time, we'll have high-quality observations of the largest flares, which have the most significant effect on Earth, to the smallest flares," said Deputy Principal Investigator Albert Shih. "We're trying to find out how this energy releases at different scales. Do the same mechanisms drive the full range of flares?"

Another scientific goal, Christe added, is determining the role that small flares, also known as nanoflares, play in heating the million-degree corona. According to him, they are an obvious candidate for supplying the needed energy to heat the Sun's outermost layer.

FOXSI would complement NASA's Reuven Ramaty High Energy Solar Spectroscopic Imager, or RHESSI, left off. Since its launch in 2002, RHESSI has observed thousands of X-ray flares over a broad field of view, from soft X-rays to higher-energy gamma rays.

"RHESSI gave us glimpses into the physics that leads to violent energy release on the Sun," Christe said. "With FOXSI we should have a clear view into the fundamental science going on in the acceleration sites where all the action takes place, where space weather begins." ❖

CONTACT

Steven.D.Christe@nasa.gov or 301.286.7999

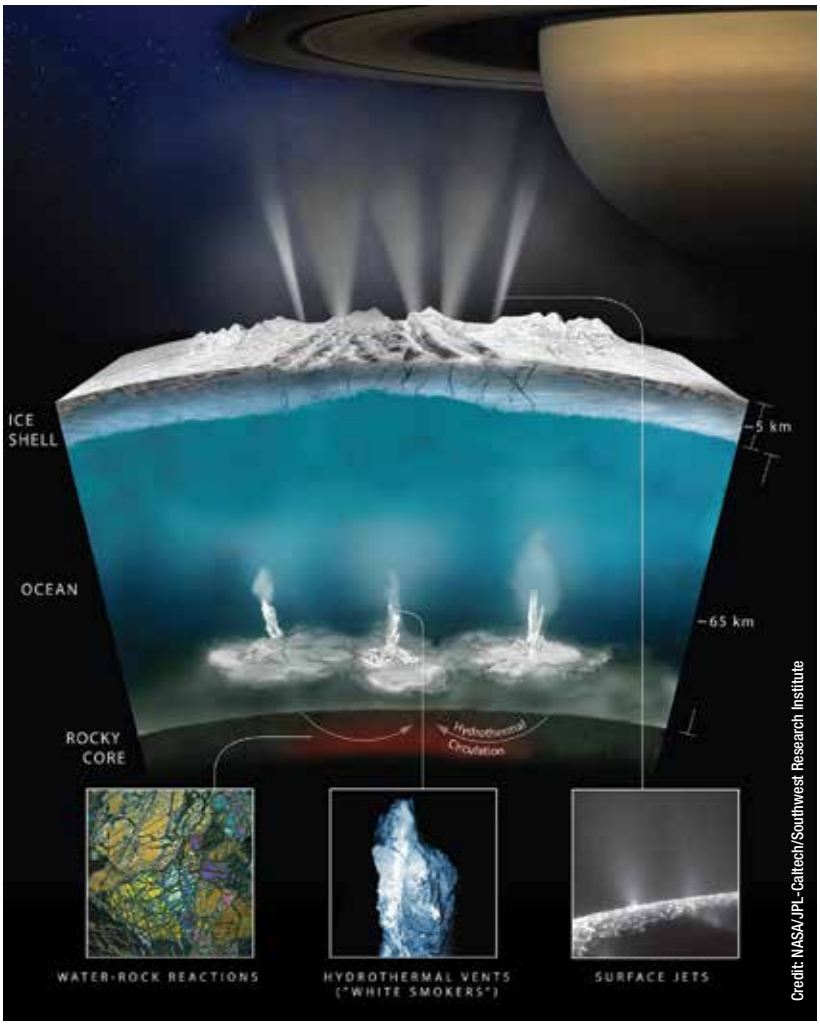
SPECIAL REPORT
Focus on Winning Mission Concepts

Picture this SELFI: Goddard Advances Instrument to Study the Plumes of Enceladus

Goddard scientists and engineers have conceived and plan to build an ambitious submillimeter-wave or radio instrument to study the composition of geysers spewing water vapor and icy particles from the south pole of Saturn's small moon, Enceladus.

The team recently received support to advance technologies needed for the Submillimeter Enceladus Life Fundamentals Instrument, or SELFI. This remote-sensing instrument represents a significant improvement over the current state-of-the-art in submillimeter-wavelength devices, said SELFI Principal Investigator Gordon Chin.

SELFI is being designed to measure traces of chemicals in the plumes of water vapor and icy particles that emanate from fissures, also known as tiger stripes, on Enceladus, Saturn's sixth largest moon. By studying the plumes, scientists believe they can extrapolate the composition of the ocean that lies beneath the moon's icy crust and its potential to host extraterrestrial life.



The Cassini spacecraft detected hydrogen in the plume of gas and icy material spraying from Enceladus during its deepest and last dive through the plume on Oct. 28, 2015. This graphic illustrates a theory on how water interacts with rock at the bottom of the moon's ocean, producing hydrogen gas. A Goddard team wants to develop an instrument that would reveal even more details about the plumes and perhaps help answer if life exists on this ocean world.

Enceladus has intrigued scientists since NASA's recently ended Cassini mission discovered the plumes that continuously spew particles, water vapor, carbon dioxide, methane, and other gases from about 100 sites on the moon's surface. Although scientists initially thought that Enceladus was frozen solid, Cassini data revealed a slight wobble in the moon's orbit that suggests the presence of a global ocean beneath the ice. Saturn's tidal forces appear to pull and squeeze Enceladus, generating enough heat to hold water liquid in the interior and crack the icy shell. This forms fissures from which jets of water spray into space.

The question scientists ultimately want to answer is whether life exists in Enceladus or on other icy worlds in the outer solar system. At the bottom of Earth's oceans, hydrothermal vents thrive with life. Does Enceladus have warm hydrothermal vents at the bottom of its ocean that might support life?

"Submillimeter wavelengths, which are in the range of very high-frequency radio, give us a way to measure the quantity of many different kinds of molecules in a cold gas. We can scan through all the

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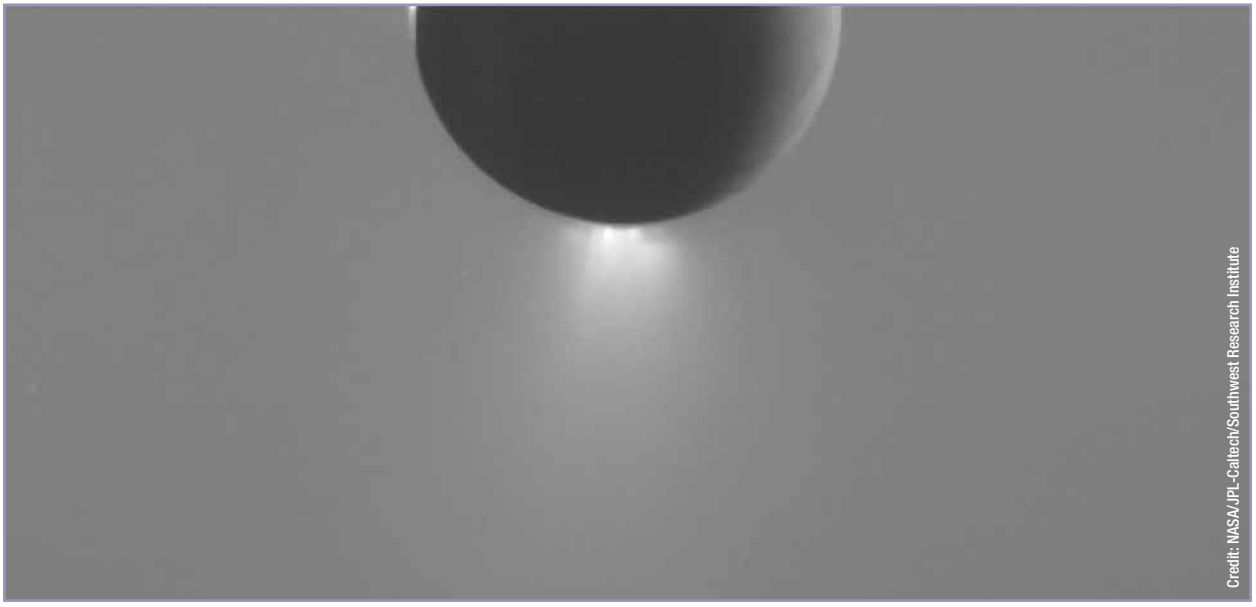

Tiny water ice particles make up the bulk of the plume, as imaged by Cassini's cameras.

plumes to see what's coming out from Enceladus," Chin said. "Water vapor and other molecules can reveal some of the ocean's chemistry and guide a spacecraft onto the best path to fly through the plumes to make other measurements directly."

"Like Tuning a Radio Station"

"Molecules such as water and carbon monoxide, and others, are like little radio stations that broadcast on very specific frequencies that say, 'hey, I'm water, I'm carbon monoxide,'" Chin continued, adding that a submillimeter spectrometer sensitive to these wavelengths is like tuning to a radio station with a specific molecular call-sign. "The spectral lines are so discrete that we can identify and quantify chemicals with no confusion whatsoever," added Paul Racette, a Goddard engineer who serves as the effort's chief systems engineer.

Used in space science across all wavelength or frequency bands, spectrometers can analyze the chemical composition of gases and solids in planets, stars, comets, and other targets, telling scientists much about their physical properties. Tuning into the submillimeter band is relatively new due to the complexity of building submillimeter-sensitive instruments.

Improving Sensitivity

"With NASA research-and-development funding, Chin and his team are increasing the instrument's sensitivity with an amplifier to boost the signal in the region around the 557 GHz frequency that has the strongest signal from water. This will improve the ability to measure even vanishingly small quantities of water and traces of other gases, even at the cold temperatures, and explore the whole system of surface vents on Enceladus, Racette said.

The team also is creating a more energy-efficient and flexible radio frequency (RF) data-processing system and a sophisticated digital spectrometer for the RF signal. The digital spectrometer will employ high-speed programmable circuitry to convert RF into digital signals that can be analyzed to measure the plumes' gas quantities, temperatures, and velocities.

Because of these enhancements, SELFI will be able to simultaneously detect and analyze 13 molecular species, including water in various isotopic forms as well as methanol, ammonia, ozone, hydrogen peroxide, sulfur dioxide, and sodium chloride, the table salt chemical that makes Earth's oceans salty.

"SELFI is really new," Chin said, adding he believes the team can sufficiently improve the instrument to propose for a future mission. "This is one of the most ambitious submillimeter instruments ever built." ❖

CONTACTS

Gordon.Chin-1@nasa.gov or 301.286.8649
Paul.E.Racette@nasa.gov or 301.286.4756

SPECIAL REPORT
Focus on Winning Mission Concepts

Chasing a Comet

Goddard Teams Eye Coin-Sized Thermometer for Characterizing Comets and Asteroids

Two Goddard teams want to deploy a highly compact, sensitive thermometer that could characterize comets and even assist in the redirection or possible destruction of an asteroid on a collision course with Earth.

In two technology-development efforts, researchers are baselining the use of a Goddard-designed infrared microbolometer camera — whose cross section is just slightly larger than a quarter — to study primitive objects formed during the solar system's origin 4.5-billion years ago.

The multi-spectral instrument, called the Comet CAMera, or ComCAM, was designed in part by Goddard scientist Shahid Aslam. He worked closely with the device's manufacturer, the Canadian-based National Optics Institute, to design the compact optics and integrated filters that make the device sensitive to chemical compounds, like water and carbon dioxide, which are of interest to cometary scientists.

Thermal sensors, like ComCAM, measure infrared or heat radiation, and are, in essence, very sensitive thermometers. When radiation strikes an absorptive element, the element heats and experiences a change in the electrical resistance, which is proportional to and can be used to derive temperature. These measurements provide insights into the physical properties of the object being studied.

To operate, however, thermal sensors typically require super cooling, which is done by placing the instrument inside a cryogenically cooled canister. In sharp contrast, ComCAM operates with minimal cooling and doesn't require placement inside a canister. As a result, the camera is lighter weight, smaller, yet still capable of sensing and recording infrared heat emanating from objects in the solar system.

Because of these attributes, scientist Tilak Hewagama, who is affiliated with the University of Maryland,

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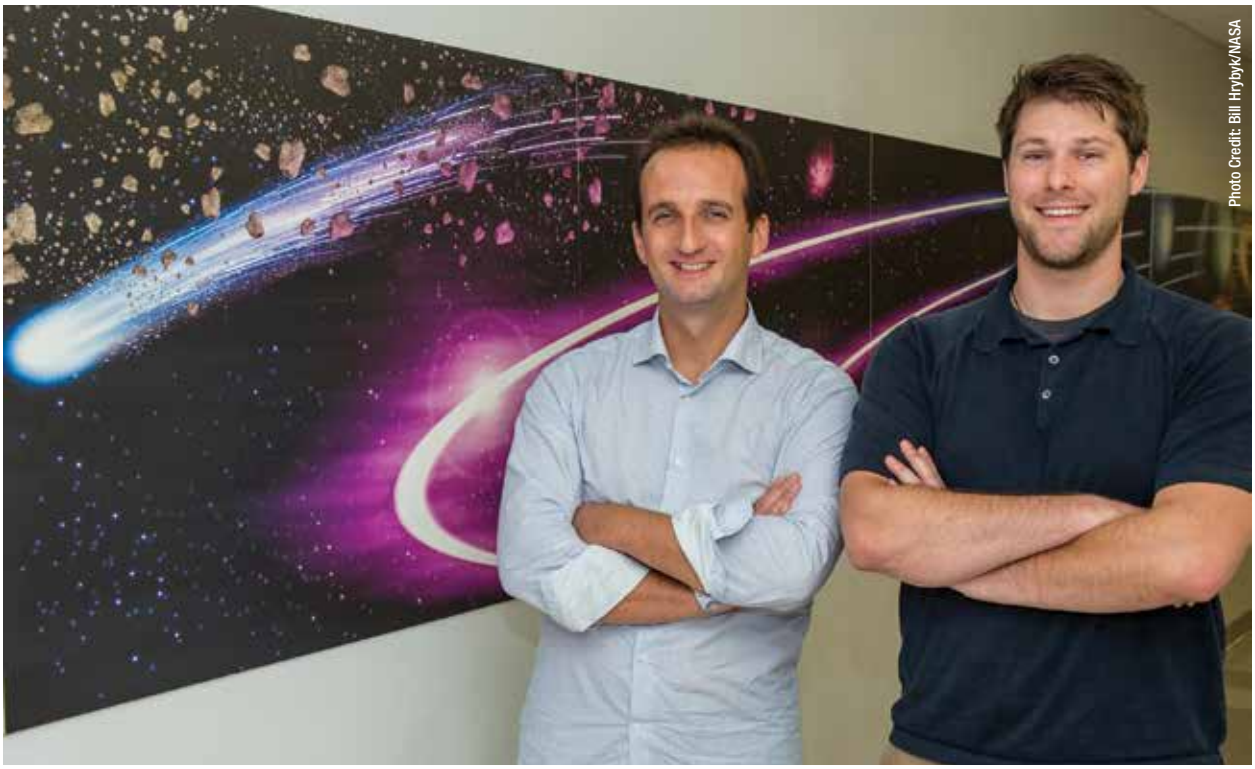

Photo Credit: Bill Hrybyk/NASA

Nicolas Gorius (left) and Goddard technologist Joshua Lyzhoft are evaluating the use of a thermometer-type device to help characterize comets and provide calculations to potentially deflect or destroy an asteroid on a collision course with Earth.

SPECIAL REPORT
Focus on Winning Mission Concepts

and his team — which includes Aslam and Catholic University's Nicolas Gorius, among others — now want to fly ComCAM and a traditional visible-light camera on a potential CubeSat mission called the Primitive Object Volatile Explorer, or PrOVE.

Comet Hartley 2 can be seen in detail in this image from NASA's EPOXI mission. It was taken as the spacecraft flew by from about 435 miles. The comet's nucleus, or main body, is about 1.2 miles long. Jets can be seen streaming out of the nucleus. A Goddard team would like to use a microbolometer to study these objects in greater detail.

Chosen by NASA's Planetary Science Deep Space SmallSat Studies, or PSDS3, program for further study, PrOVE is different from other comet missions. Under this concept, the tiny craft would be parked in a stable, deep-space orbit with the potential to access a known periodic comet or a new comet that ventures into the neighborhood.

"A CubeSat deployed from a parked orbit can produce high-quality science by traveling to any comet that passes through the accessible range, rather than a dedicated mission that cannot be prepared in time to investigate a new, pristine comet that comes into view," Hewagama said.

With the PSDS3 support, the team is identifying long-term parking orbits or "waypoints," transfer trajectories to these waypoints, spacecraft longevity, intercept trajectories, and propulsion requirements to reach specific known comets and practical ranges for missions to new comets, among other topics.

Given the fact that PrOVE is comprised of existing commercial-off-the-shelf components, including a six- or 12-unit CubeSat bus and the microbolometer camera, Hewagama believes the mission could be completed and launched as a secondary payload in relatively short order.

"Our study obviously will bear out important questions regarding PrOVE's trajectory and orbit, among other technical questions, but this is a mission that could be deployed quickly. PrOVE represents an exceptional opportunity to advance the science of comets and other primitive bodies by studying them at close range," he said.

Planetary Defense

Comet science isn't the only potential beneficiary of a PrOVE-like microbolometer camera.

Under another research effort, technologists Josh Lyhoft and Melak Zebenay are evaluating different sensor systems needed to image and characterize an asteroid on a collision course with Earth. These sensors could provide a spacecraft with the measurements needed to perform guidance maneuvers during the terminal phase of an asteroid-intercept mission aimed at either deflecting or destroying the object.

Like Hewagama, Lyhoft is intrigued by the possibilities offered by a microbolometer-sensing system. For accurately sensing the asteroid's location as the spacecraft approaches it, "microbolometers can perform the task," Lyzhoft said. "We believe they're sensitive enough for a terminal-intercept mission."

Since Lyhoft began his investigation, NASA announced that teams developing the agency's first asteroid deflection mission — the Double Asteroid Redirection Test, or DART — would begin preliminary designs.

"NASA will almost certainly be flying other asteroid-intercept missions for science, planetary defense, or both," said NASA scientist Brent Barbee, who is working with Lyhoft. "So, it's very conceivable that Josh's work will benefit future NASA asteroid missions, and that is certainly the intent of his work." ❖

CONTACTS

Tilak.Hewagama@nasa.gov or 301.286.9130
Joshua.R.Lyzhoft@nasa.gov or 301.286.8690

SPECIAL REPORT
Focus on Winning Mission Concepts

Drawing a Complete Picture in the Lunar Night

Funding Awarded to Evaluate Proposed CubeSat Mission for Measuring Lunar Water

A team of Goddard scientists wants to draw a more complete picture of where water exists on the Moon and whether it and other volatiles migrate across the lunar surface, including in the permanently shadowed regions that haven't seen sunlight in perhaps a billion years or more.

Scientist Noah Petro has received follow-on funding to advance a CubeSat mission called the Mini Lunar Volatiles Mission, designed to draw a more complete picture of where water exists on the Moon. Behind him is a mosaic assembled from images taken by the Lunar Reconnaissance Orbiter.

The first hint of potential water at both lunar poles came in 1994, with the Clementine mission flown jointly by NASA and the Department of Defense. Since then, subsequent missions, such as Chandrayann-1, the Lunar Reconnaissance Orbiter, and the Lunar CRater Observation and Sensing Satellite, have detected three flavors of volatiles or chemicals that evaporate quickly: a global layer of hydroxide and water that's just one molecule thick, subsurface polar water ice, and polar surface water frost.

Past Missions Altered Perspectives

"The remote detection of lunar volatiles, specifically water and hydroxide, has dramatically changed our perspective of a dry Moon to a wetter Moon, both within and on the surface," said scientist Noah Petro. "However, these missions were not able to draw a complete picture of the distribution and possible mobility of volatiles."

With funding from NASA's Planetary Science Deep Space SmallSat Studies, or PSDS3, program, Petro and his team, which also includes University of Hawaii researcher Paul Lucey as well as Goddard instrument experts, will study a CubeSat mission concept called the Mini Lunar Volatiles Mission, or MiLUV.

The six-unit MiLUV would detect water on the lunar surface using a laser spectrometer that traces its heritage to similar Goddard-developed lidar-type instruments built to map the topographies of Mars and the Moon.

"Understanding volatiles in the solar system is a major planetary-science objective for NASA," Petro said. "We believe that the best-suited instrument to answer where these volatiles exist and their possible movement is a laser spectrometer that measures surface reflectance at several wavelengths. The benefit of this approach is that by using an active instrument, we can measure in areas that are not illuminated."

Repackaging Existing Laser Spectrometer

With the funding, the team is studying the repackaging of an existing instrument concept, the Lunar Ice Lidar Spectrometer, or LILIS, to determine if it might fit onto a small satellite and performing an engineer-

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ing study to show that the agency could successfully fly MiLUV, Petro added.

The instrument is an adaptation of successful planetary lidar systems: the Lunar Orbit Laser Altimeter and the Mercury Laser Altimeter. These instruments bounced laser light off the surfaces of the Moon and Mercury, respectively, and used the returning signal to map their topographies. "We want to expand the instrument's capabilities beyond topography," Petro said.

Unlike the previous instruments which used a single wavelength, LILIS would include a multi-band spectrometer. The laser would bounce light off the lunar surface and the spectrometer would analyze the reflected or returning signal to determine the presence of water and other volatiles.

Like all chemicals, water absorbs light at specific infrared wavelengths. By carefully tuning the instrument's detectors to those wavelengths — in this case, 1.6 and 3.0 microns — scientists would be able to detect and then analyze the level of water in the laser's vertical path. The more water along the light's path, the deeper the absorption lines.

Around-the-Clock Measurements

Because the instrument carries its own light source — the laser — the mission literally could operate day and night, regardless of sunlight conditions. This means MiLUV also could study the Moon's permanently shadowed regions, gathering a complete data set that would show how surface volatiles vary as a function of lunar time, if at all, Petro added.

"This is a focused science mission, ideal for a CubeSat mission," Petro said. "It directly addresses the science goal of understanding how the chemical and physical processes in our solar system operate, interact, and evolve. We're hopeful that our study will show this is a feasible mission." ❖

CONTACT
Noah.E.Petro@nasa.gov or 301.614.6498

SpaceCube Family Expecting Addition to the Clan

Team Wins NASA Funding to Advance Faster Hybrid Flight Processor

If anyone thought that computer engineer Tom Flatley and his team were finished upgrading the hybrid computing system already crunching ones and zeros on a host of missions, think again.

The creators of the Goddard-developed SpaceCube family of flight processors and their NASA and academic partners have won agency funding to advance a next-generation model that is expected to be up to 10,000 times faster than its predecessor, SpaceCube 2.0. SpaceCube 2.0 — itself a follow-on to previous models — is the enabling technology behind Raven, the ambitious experiment currently testing relative navigation and autonomous docking capabilities from the International Space Station (*CuttingEdge,* Spring 2017, Page 12).

The SpaceCubeX development team includes the University of Southern California as well as Goddard, the Ames Research Center, and the Jet Propulsion Laboratory. With funding from the agency's Earth Science Technology Office Advanced Information Systems Technology program, the team is advancing the system's architecture, design, simulation and emulation tools, and plans to demonstrate the technology in a laboratory test within two years.

The SpaceCubeX design and tools ultimately will lead to the development of the actual next-generation system, which will be called SpaceCube 3.0, said Flatley, a co-investigator.

Like its forebears, the new SpaceCube platform will be reconfigurable, but orders-of-magnitude faster. And like its forebears, it will achieve its prowess because its developers are marrying updated and more powerful radiation-tolerant integrated circuits, which are programmed to execute specific computing jobs simultaneously, with algorithms that detect and fix radiation-induced upsets in application programs and collected data.

Constellation-Like Missions to Benefit

Although SpaceCube 2.0 has proven its mettle since its roll-out a few years ago — including a pat-

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ent license enabling the Maryland-based Genesis Engineering Solutions, Inc., to build and sell SpaceCube 2.0-based processors in the future (*CuttingEdge,* Spring 2017, Page 15) — changing science needs are necessitating version 3.0, particularly those in Earth science, Flatley said.

Developers of SpaceCube processors are pictured here with the products they've developed. From left to right: Alessandro Geist; Dave Petrick; Tom Flatley; and Gary Crum. The products include (from left to right): SpaceCube 1.0 and 1.5 prototypes; SpaceCube 2.0 and Mini prototypes; and SpaceCube 1.5 flight unit.

"NASA, NOAA (National Oceanic and Atmospheric Administration), and USGS (U.S. Geologic Survey) all cite the need to fly constellations of satellites equipped with 'intelligent' instruments that react to information they observe or to something occurring within the spacecraft itself," Flatley explained. "These measurement needs translate into roughly another 10 to 100 times demand for onboard computing, to say nothing of the increased processing needed to allow the satellites to communicate with one another, while operating autonomously."

As a result, the team is completely updating the system. Using the SpaceCube 2.0 as the baseline, the developers plan to equip the new platform with more powerful, state-of-the-art flight and commercial radiation-tolerant elements and memory to handle heavier data loads, as well as plug-in modules or daughter cards that make it easier for users to modify the platform to meet mission-specific observational needs.

HPSC Compatible

One such planned plug-in will accommodate the general-purpose High-Performance Spaceflight Computing, or HPSC, chiplet, now being developed by the Boeing Co. under a contract with NASA and the Air Force Research Laboratory (*CuttingEdge,* Spring 2013, Page 8). The chiplet, which will be capable of processing billions of operations per second, ultimately will replace the current RAD750 flight processor used in a range of space missions, including the Solar Dynamics Observatory, the Curiosity rover on Mars, and the Fermi Gamma-Ray Telescope, among others.

Although power efficient and completely radiation hardened — in other words, immune from upsets and damage caused by ionizing radiation in space — the RAD750 computes only 200 million operations per second. To get around these limitations, mission planners implement highly customized radiation-hardened field programmable gate array technology, which can handle higher data loads.

With the HPSC chiplet, SpaceCube 3.0 would offer improved radiation and fault tolerance, along with the much faster computing speeds, potentially making it attractive to a broad range of missions.

"Our SpaceCubeX effort will allow us to expand the SpaceCube architecture and make our hybrid-computing approach even more powerful, which will, in turn, enable even more capabilities for future science and exploration missions," Flatley said. ❖

CONTACT

Thomas.P.Flatley@nasa.gov or 301.286.7029

NASA Investigates Use of Medical-Like Tools to Study Samples of the Solar System

A diagnostic tool, similar in theory to those used by the medical profession to non-invasively image internal organs, bones, soft tissue, and blood vessels, could be equally effective at "triaging" extraterrestrial rocks and other samples before they are shipped to Earth for further analysis.

Goddard engineer Justin Jones (right) holds a pristine lava rock containing a zeolite crystal. Goddard Chief Scientist James Garvin holds in his right hand an impact melt breccia from the Elgygytygyn impact crater in Siberia and in his left hand a hawaiite with green olivine crystals. The background graphic shows the CT scans that reveal the internal structure and unique minerology of the lava rock from Earth's newest land — Hunga Tonga Hunga Ha'apai in the Kingdom of Tonga.

In an effort designed to find creative uses of technology for future robotic and human missions to the Moon, Mars, and asteroids, Goddard engineer Justin Jones used an industrial X-ray Computed Tomography, or CT, scanner to evaluate volcanic rocks from a newly formed island in the South Pacific and other specimens ensconced inside thick glass and metal enclosures.

"Imagine taking something this big and scaling it down to breadbox size, then readying the equipment to be spaceflight worthy," Jones said, referring to the scanner that occupies a small room inside Goddard's Non-Destructive Evaluation, or NDE, Laboratory. "Such instruments could be tested on the International Space Station and then transitioned to a future deep space gateway where crew members could analyze new samples from the Moon or asteroids or even Mars before shipping them back to Earth for further analysis."

"We're thrilled with our results," continued Jones, who carried out his technology-demonstration project with support from the Goddard Fellows Innovation Challenge, a research-and-development program designed to advance potentially high-reward technologies and investigations that are new and cross-disciplinary. "The demonstrations provided a few new insights into the 3-D structure of the samples we tested and underscored the value of potentially creating a CT capability specifically for use in space, especially for triage purposes."

Jones, who helped his management acquire the CT scanner six years ago, doesn't normally spend his days examining rocks. "When something fails, when a part fails, engineers want us to diagnose what happened, and we will use a suite of tools like those in the medical industry to help pinpoint the defect," he said.

The beauty of an X-ray CT scanner, which operates like a medical CAT scanner, is that it allows high-resolution, 3-D views inside materials that otherwise would need difficult, often-times destructive sample preparation, including cutting and use of chemicals, just to analyze the sample's composition. With Goddard's CT system, which is non-destructive, users can see details as small as a couple microns in size, which is several times smaller than a human hair.

With the scanner, Jones and his team from Goddard's Materials Branch, including Ryan Kent and Olivia Landgrover, evaluated samples from a newly formed volcanic island, Hunga Tonga-Hunga Ha'apai, in the Kingdom of Tonga in the southwest Pacific Ocean. This new island formed in January of 2015 after the volcano's explosive eruption — a potential analogue

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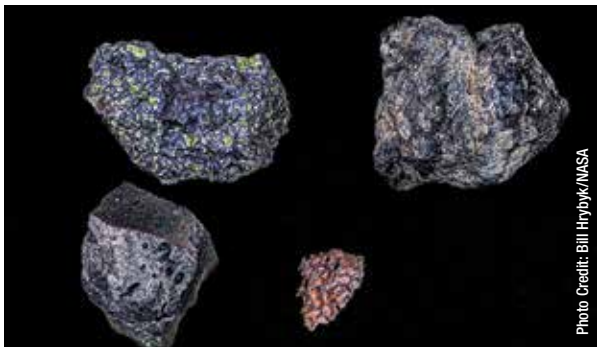
to some volcanic activity on Mars, said Goddard Chief Scientist James Garvin, who, along with his university partners, are using advanced remote-sensing methods to explore the island in a pilot study for NASA's Earth Sciences Division.

"CT techniques are permitting rapid assessment for understanding the potential lifetime of the fragile new volcanic landscapes in the region," Garvin said. "Already, Justin and his team have identified the possibility of minerals known as zeolites," minerals commonly used in adsorbents that purify water, among other applications, and catalysts that speed up chemical reactions. "These findings have a direct bearing on how similar processes could have operated on Mars," Garvin said.

The technology-demonstration project didn't end there. Garvin, who is interested in researching and advancing new technological approaches for studying extraterrestrial rocks and minerals, asked the team to evaluate rocks produced in large impact cratering events here on Earth, as well as meteorites.

Even with samples encased in protective glass and metal cases filled with nitrogen, Goddard's CT scanner revealed previously undetected minerals and 3-D arrangements," Garvin said. "The future of in-situ and sample-based planetary exploration will revolve around measurement techniques that reveal details at new scales and in ways that don't destroy samples or contaminate them," Garvin continued. "Based on Justin's work, I believe that someday, astronauts on Mars or the Moon will be able to use off-planet CT laboratory techniques just as we do in the labs here on Earth today." ❖



A NASA team scanned these terrestrial rock samples, all measuring two to four inches in diameter, to investigate possibilities for future in-space use of non-destructive evaluation techniques.

CONTACTS

James.B.Garvin@nasa.gov or 301.286.5154
Justin.S.Jones@nasa.gov or 301.286.4197

NASA-Developed Drone Aircraft Offer One-of-a-Kind Capabilities

NASA scientists, who always are on the hunt for new platforms from which to carry out their research, now may avail themselves of two agency-developed unmanned aerial systems, or UASs, that some say represent the future for drone aircraft.

Unlike most commercially available unmanned aircraft systems, Vanilla Aircraft's VA001 and Black Swift Technologies' S2 small Unmanned Aircraft System, or sUAS, purposely were designed for scientific investigations. Both provide one-of-a-kind capabilities that represent a significant success for NASA's Small Business Innovative Research, or SBIR, program, which funded their development, said Geoff Bland, a Wallops research engineer.

"Our goal always is to advance state-of-the-art airborne capabilities and platforms tailored to the needs of our scientists," said Bland, who oversaw the aircrafts' development. "The SBIR program offered us an outstanding venue for engaging small businesses in our quest to develop new tools for gathering scientific data."

Swift Technologies' S2 Unmanned Aircraft System is highly versatile and can be deployed virtually anywhere. The aircraft now is being used by a Goddard scientist to map vegetation and climate dynamics.

Now operational after months of development, the aircraft are offering the scientific community complementary, easy-to-use capabilities at a lower cost.

Vanilla Aircraft's VA001 provides a case in point.

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The VA001 can carry 35 pounds of payload, flying at 500 to 15,000 feet above sea level. Its primary attraction — and the primary reason NASA funded its development through the SBIR program — is its ability to carry out research over some of the most forbidding locations on Earth.

The VA001 can carry 35 pounds of payload and fly at 500 to 15,000 feet above sea level. Its primary attraction — and the reason NASA funded its development through the SBIR program — is its ability to carry out research over the most forbidding locations on Earth. It can cover thousands of square miles of treacherous terrain and bone-chilling temperatures in a single flight.

It runs on jet-grade fuel, which contains corrosion inhibitors and anti-icing additives crucial to operations in the Arctic or Antarctica. "It was an important part of the aircraft's design to fly under the toughest and coldest conditions," said Joe Famiglietti, the technology-infusion manager for Goddard's SBIR/Small Business Technology Transfer programs.

Since NASA's initial SBIR investment in the aircraft's development, the Virginia-based Vanilla Aircraft has garnered support from the U.S. Department of Defense, which funded a second prototype as well as test flights. In one non-stop test flight, the VA001 flew for 56 hours on a single tank of fuel, proving the aircraft could meet both NASA and DoD's needs, Bland said.

"The dream mission would be for the VA001 to leave the Wallops Flight Facility, fly over Antarctica, and then return after two days of mapping the changing ice. We could do this on demand for quick response to changing phenomena over the poles," Bland said.

Black Swift's sUAS offers a completely different set of capabilities. The company originally developed the aircraft to fit inside a vehicle trunk, take off anywhere, and fly up to 90 minutes over 705 acres, with a full payload.

"The company did more than just develop a unique aircraft," Famiglietti said. The company also integrated a specialized radiometer developed by the University of Colorado in a partnership with Black Swift. Its miniature antennas are used to detect proportions of energy reflected from the objects over which the sUAS flies.

Scientists can use the energy readings, along with other aircraft sensors, to differentiate between water contained within the soil or vegetation. With this data, NASA scientists can better understand soil-moisture levels and ground-truth NASA's Soil Moisture Active Passive satellite.

Because the sUAS has a modular "plug-and-fly" instrument capability and can be toted to virtually any location, its use is not restricted to soil-moisture measurements, however.

Goddard scientist Miguel Román is using the sUAS to map vegetation and climate dynamics under a pathfinding mission called MALIBU, short for the Multi Angle Imaging Bidirectional Reflectance Distribution Function sUAS. In 2016, his team integrated MALIBU's two multispectral imagers onto the platform at different angles to precisely match the viewing geometry of polar-orbiting satellites. It proved so effective that he and his team have acquired a second platform, Román said.

The aircraft is continually evolving, and will be able to observe volcanic plumes in the future, said Black Swift Founder and Chief Executive Officer Jack Elston, a MALIBU partner.

"Through NASA's SBIR program, we are enabling new types of science," Bland said. "These aircraft represent the future." ❖

CONTACT

Geoff.Bland@nasa.gov or 757-824-2855

Goddard Scientist Details Next-Generation Monitoring Stations for the Moon and Mars

When NASA sends a crew to the Moon or Mars, astronauts will need more than a place to live, food to eat, oxygen to breathe, and rovers to drive. They'll also need a passel of remotely operated instruments keeping tabs on everything from temperatures and winds to seismological disturbances in and around their landing sites.

Photo Credit: Bill Hrybyk/NASA

In an R&D-funded study, Goddard scientist Scott Guzewich and his team designed a potential environmental and geophysical monitoring station for use on the Moon and Mars. He investigated his concept at Goddard's Mission Design Lab.

A team of Goddard scientists and engineers has completed a detailed mechanical and engineering design study outlining the specifics of what a monitoring station might look like, including its overall size and power requirements. The team has submitted a report detailing its engineering design and is seeking additional funding to carry out additional studies examining potential instruments and communications systems.

"NASA's current plan is that humans will go to Mars in the 2030s," said Principal Investigator Scott Guzewich, a planetary scientist who has for years noodled back-of-the-envelope designs of what he calls the Geophysical and Environmental Monitoring Station, or GEMS. With funding from the Goddard Fellows Innovation Challenge, an R&D program sponsored by Goddard's Senior Fellows, Guzewich received the support he needed to apply engineering principles to his sketches.

"It's time to start planning these monitoring stations now. If you wait another 10 years, you're behind the curve. These types of instruments must be designed, built, and tested long before the first mission is launched," he added.

GEMS-type facilities aren't new to NASA. During the Apollo program, scientists and engineers packaged seismometers, magnetometers, and other instruments inside the so-called Apollo Lunar Science Experiments Package to monitor the lunar environment.

"We expect future astronauts and robotic missions exploring Mars, its moons, asteroids, and our Moon will deploy similar, but more sophisticated autonomous instrument packages," Guzewich said. "We also expect that future human and robotic missions will be longer in duration, relative to Apollo, which would allow us to build up a large network of instruments throughout a wide region. This network of instruments, packaged inside these deployable stations, will enhance both scientific data collection and provide notice of potentially hazardous events."

Due to the importance of getting an advanced warning of environmental and geophysical hazards, the rectangular-shaped GEMS would be robotically placed by a rover before astronauts landed on the Moon or Mars. Guzewich envisions each unit measuring about three feet tall and 20-inches wide and outfitted with a communications antenna and fold-down solar panels.

Once deployed, the units would begin working as a network gathering space weather-related data, including solar wind and charged particles, as well geophysical phenomena, including quakes, temperatures, and atmospheric pressure — information necessary to assure the overall safety of human explorers as well as to gather scientific data of interest to planetary scientists.

The study, which Guzewich and his colleague, Jake Bleacher, carried out at Goddard's Mission Design Laboratory, confirmed the feasibility of his concept, but also underscored areas that need further investigation. One such challenge is figuring out how the multiple sensor packages would talk with one another. "The engineering side is done. We now need to dig deeper into which instruments already are being developed, what's on the horizon," Guzewich said. ❖

CONTACT

Scott.D.Guzewich@nasa.gov or 301.286.1542

Sultana, *continued from page 3*

The 3-D printing system is like offset printers used to produce money or newspapers, Sultana said. Instead of ink, however, this system applies nanomaterials to a mold through a process called electrophoresis, a standard laboratory technique by which charged molecules move through a solvent guided by an electrical field. With 3-D printing, the nanomaterials stick to certain parts of the mold when a voltage is applied, allowing technologists to custom design and quickly produce multiple copies of the sensor.

The goal is to use 3-D printing to fabricate a suite of sensors on the same platform. With this technique, she could apply different nanomaterials directly onto a daughter board, which she then could bond onto a printed circuit board. This could substantially simplify the assembly of sensors that typically require time-consuming hand work to wire together the components. With 3-D printing, these components would be laid down in one pass.

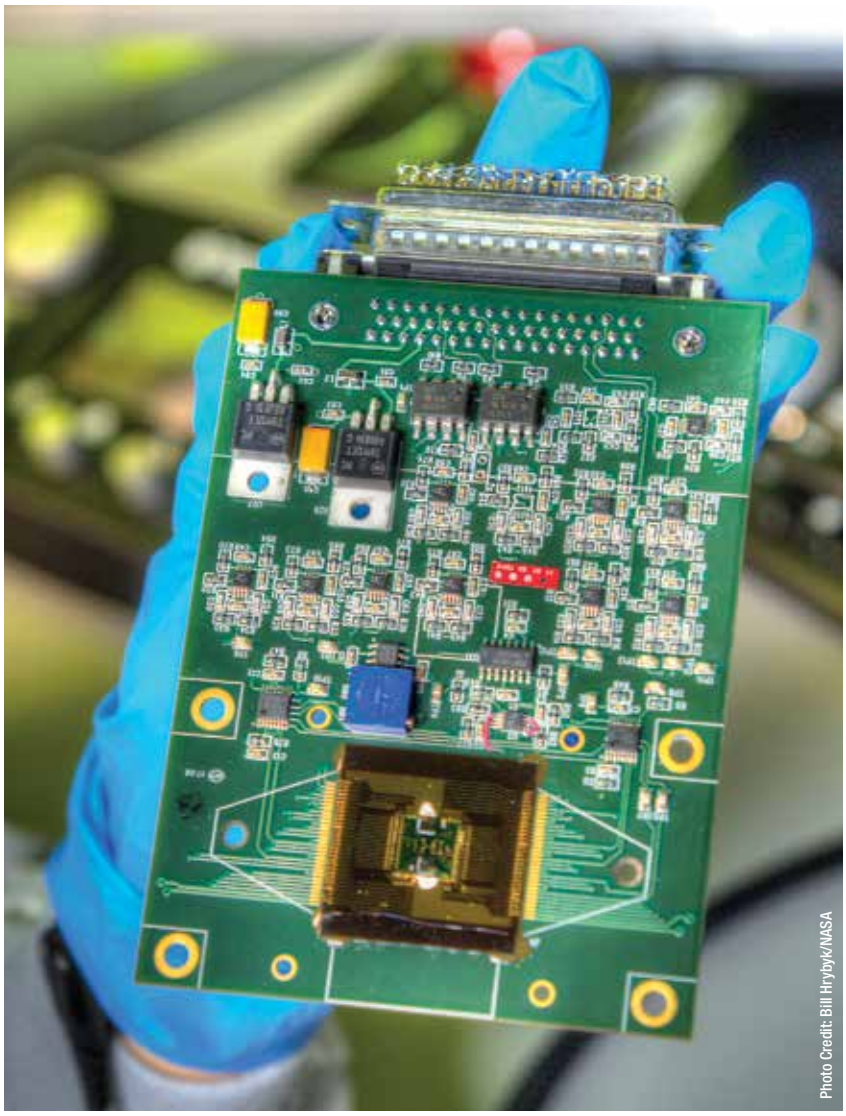

Photo Credit: Bill Hrybyk/NASA

This is one of the sensor platforms that FY17 IRAD Innovator of the Year recipient Mahmooda Sultana has created with her research and development funding.

Consummate Multi-Tasker

The consummate multi-tasker, Sultana now represents NASA on national and regional nanotech councils and is the recipient of many NASA awards and honors. She also has shown her mettle in management, recently being named as the associate branch head of Goddard's Instrument/Payload Systems Engineering Branch — a position that will allow her to apply her detector expertise to the creation of next-generation instruments and missions, including CubeSats.

"She is a real go-getter," said Ted Swanson, senior technologist for strategic integration for Goddard's Office of the Chief Technologist. "Mahmooda always has stayed current with new developments. She leverages the expertise of her colleagues, constantly looks for ways to advance the readiness of our technologies, and isn't afraid to seek vehicles for financial support — the hallmark of a successful innovator." ❖

CONTACT

Mahmooda.Sultana@nasa.gov or 301.286.2158

CuttingEdge is published quarterly by the Office of the Chief Technologist at the Goddard Space Flight Center in Greenbelt, Maryland. The publication describes the emerging, potentially transformative technologies that Goddard is pursuing to help NASA achieve its mission. For more information about Goddard technology, visit the website listed below or contact Chief Technologist Peter Hughes, *Peter.M.Hughes@nasa.gov*. If you wish to be placed on the publication's distribution list, contact Editor Lori Keesey, *Lori.J.Keesey@nasa.gov.* NP-2017-10-105-GSFC