National Aeronautics and Space Administration

Cutting edge

Goddard's Emerging Technologies

Forecasting Solar Tantrums

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Space Weather Center to Add World's First 'Ensemble Forecasting' Capability

Improved Forecasting to Coincide with Peak in Solar Activity

After years of relative somnolence, the sun is beginning to stir. By the time it's fully awake in about 20 months, the Goddard team charged with researching and tracking solar activity will have enabled a greatly enhanced forecasting capability.

Goddard's Space Weather Laboratory recently received support under NASA's Space Technology Program to implement "ensemble forecasting," a computer technique already used by meteorologists to track potential paths and impacts of hurricanes and other severe weather events. Instead of analyzing one set of solar-storm conditions, as is the case now, Goddard forecasters will be able to simultaneously produce as many as 100 computerized forecasts by calculating multiple possible conditions or, in the parlance of heliophysicists, parameters. Just as important, they will be able to do this quickly and use the information to provide alerts of space weather storms that could potentially harm astronauts and NASA spacecraft.

"Space weather alerts are available now, but we want to make them better," said Michael Hesse, director of Goddard's Heliophysics Division. "Ensemble forecasting will provide us with a distribution of arrival times, which will improve the reliability of our forecasts. Once it's implemented, "there will be nothing like this in the world. No one has done ensemble forecasting for space weather," he said.

Sun Growing Restless

The state-of-the-art capability, which the organization is implementing now and expects to complete within three years, couldn't come too soon, either.

A widespread display of aurorae erupted August 5 and 6, when the August 3, 2011 double-CME hit Earth's magnetic field and sparked a G4-category geomagnetic storm. Scott Lowther in Thatcher, Utah, took this image on August 6, 2011.

Since the sun reached its solar minimum in 2008 — the period when the number of sunspots is lowest — it has begun to awaken from its slumber.

On August 4, the sun unleashed a near X-class solar flare that erupted near an Earth-facing sunspot. Although flares don't always produce coronal mass ejections (CMEs) — gigantic bubbles of charged particles that can carry up to 10 billion tons of matter and accelerate to several million miles per hour as they erupt from the sun's atmo-

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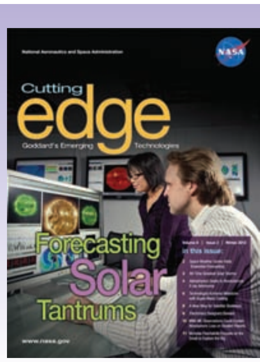

About the Cover

Goddard's Space Weather Services is implementing "ensemble forecasting," a computer technique currently used by meteorologists to track potential paths and impacts of hurricanes and other severe weather events. The enhanced capability, which will be unmatched anywhere in the world, will improve space weather forecasts prepared by the center's forecasting team, led by Yihua Zheng and Antti Pulkkinen shown here.

Cover Photo Credit: Chris Gunn

sphere and stream through interplanetary space — this one did.

The CME overtook two previous CMEs — all occurring within 48 hours — and combined into a triple threat. Luckily for Earthlings, the CMEs produced only a moderate geomagnetic storm when solar particles streamed down the field lines toward Earth's poles and collided with atoms of nitrogen and oxygen in the atmosphere. Even so, "it was the strongest storm in many years," said Antti Pulkkinen, one of the laboratory's chief forecasters.

However, the repercussions could be far worse in the future. As part of its 11-year cycle, the sun has entered its solar maximum, the period of greatest activity. It is expected to peak in 2013.

More powerful CMEs, often associated with M- and X-class flare events, could become more numerous and affect any planet or spacecraft in their path. In the the past, solar storms have disrupted power grids on Earth and damaged instrumentation on satellites. They also could be harmful to astronauts if they aren't warned to take

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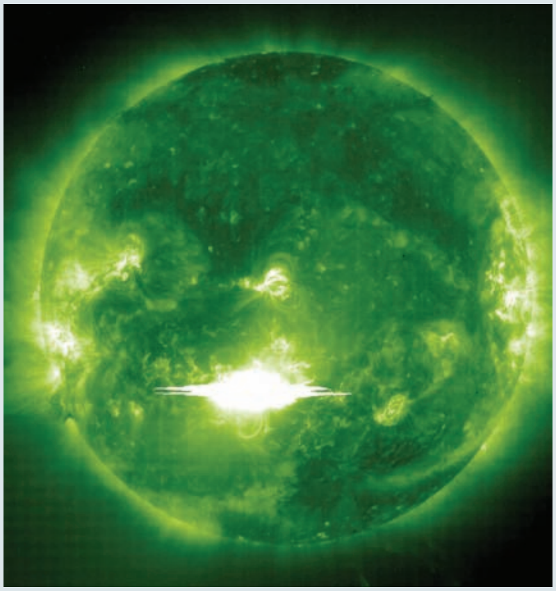
The All-Time Greatest Solar Storms

Meteorologists get excited about big storms, and can relate chapter and verse the particulars of the biggies. The same can be said for space weather forecasters.

"We all have our own favorites," says Antti Pulkkinen, one of Goddard's chief forecasters. But for him, the "Quebec Blackout Storm" on March 13, 1989, the "Halloween Storm" on October 29, 2003, and the so-called "Carrington Event" on September 1-2, 1859 all hold a special place in his heart.

And for good reason. They were doozies.

The "Quebec Blackout Storm" is well named. Three days after the sun disgorged a massive cloud of superheated gas, electrical ground currents created by the magnetic storm found their way into the power grid of the Hydro-Quebec Power Authority, and within seconds, the lights went out for six million Canadians.



The Solar and Heliospheric Observatory captured this image of a solar flare as it erupted from the sun early on Tuesday, October 28, 2003 — an event later known as the "Halloween Storm."

Fourteen years later, in an event that would become known as the "Halloween Storm," the sun unleashed one of the most powerful X-ray flares ever detected, swamping the sensors on dozens of satellites. Astronauts hid deep within the International Space Station, but still reported radiation effects and ocular "shooting stars."

But the Carrington Event of 1859 probably holds all records. Named after British astronomer Richard Carrington who observed a mega-flare on September 1 and later connected it to the widespread damage that followed, the event is considered the mother of all storms. Less than 24 hours after Carrington's observation, the fast-moving storm swept past Earth. Aurorae literally were seen around the world.

Telegraph Goes Haywire

Telegraph systems worldwide went haywire. Spark discharges shocked telegraph operators and set the telegraph paper on fire. Even when the telegraphers disconnected the batteries powering their lines, storm-induced electric currents in the wires still allowed them to send messages.

Could the Carrington Event happen today? Only time will tell. But if it does, experts at the National Research Council believe a solar storm of this caliber would cause more than $2 trillion in damage. ❖

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Indomitable Astrophysicist Seeks to Revolutionize X-ray Astronomy

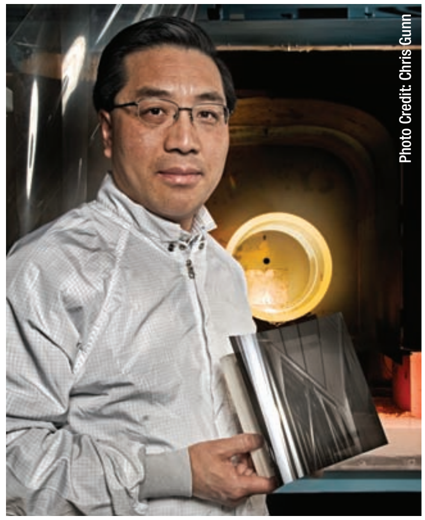
Pursues Two Technologies for Advanced Mirror Fabrication

Will Zhang is at it again.

The Goddard astrophysicist last year produced and delivered 9,000 super-thin, curved glass mirrors for NASA's Nuclear Spectroscopic Telescope Array (NuSTAR) mission using a novel manufacturing technique he developed with Goddard R&D funding.

The indomitable Zhang now has embraced a new challenge.

He has launched two parallel technology-development programs both aimed at developing the world's first lightweight X-ray mirror that offers high-angular resolution and a photon-collection area 10 times larger than the current state-of-the-art — all at a reduced cost.



In 2011, Will Zhang delivered 9,000 curved mirror segments for the NuSTAR mission, which NASA is launching later this year. He has since begun developing new fabrication techniques to create more capable, less expensive X-ray mirrors that could potentially revolutionize X-ray astronomy.

"The trick for scientists is finding the sweet spot," Zhang said. "NASA's Chandra had a thick, heavy mirror with a very small collecting area, but it had good angular resolution. The European Space Agency's XMM-Newton had a larger collecting area for the same mass, but it traded off the angular resolution. And the Japanese, in their Suzaku mission, went for a small, light telescope with a large collecting area relative to its weight. But it, too, sacrificed resolution. You need all three to get a perfect mission. Our technology will realize good angular resolution and large collecting area on one lightweight telescope."

Goddard's Internal Research and Development (IRAD) and NASA's Physics of the Cosmos programs are funding the first effort, which leverages technology Zhang employed to manufacture NuSTAR's mirrors. The other, supported by NASA's Astronomy and Physics Research and Analysis (APRA) program, is more ambitious. Instead of fabricating mirror segments with glass, which is traditional, Zhang would create them from large blocks of mono-crystalline silicon — the same material used for making computer chips.

The goal is to advance their technology-readiness levels to the point where Zhang could offer either of the two for small missions in the near term and at least one large flagship mission in the next decade.

Leveraging NuSTAR

With NuSTAR, Zhang proved it was possible (*Goddard Tech Trends*, Spring 2008, Page 2) to develop modest-resolution, low-cost mirrors — not an insignificant undertaking given the difficulty of constructing these highly specialized mirrors measuring only 200 microns thick — about 100 times thinner than Chandra's mirrors.

To collect X-rays, the mirrors must be curved and nested inside an optical assembly so that highly energetic photons graze their surface, instead of passing through them — much like a stone skimming the surface of a pond. To make these segments, Zhang used flat sheets of smooth lightweight glass and placed them on a mandrel or rounded mold that provided NuSTAR's exact optical prescription.

He and his team then placed the entire assembly inside an oven that heated the glass to about 1,100 degrees Fahrenheit. As the glass heated, it softened and folded over the mandrel to produce a curved mirror. Colleagues at the Danish Technical University in Copenhagen coated the mirrors with layers of silicon and tungsten to maximize their X-ray reflectance.

"Precision slumping of thin glass sheets has shown to be an excellent way of making lightweight, higher-resolution X-ray mirrors, as evidenced by the delivery of the NuSTAR mirrors," Zhang said. But the resolution can be even better.

The secret lies in aligning and assembling the many mirror segments into a higher-precision mirror module, he said. Zhang is leading a team

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Photo Credit: Chris Gunn

A Goddard technologist holds one of the super-thin glass segments that Goddard scientist Will Zhang created for NASA's NuSTAR mission.

to develop a new system, which he believes will improve the angular resolution of the slumped-glass optics by a factor of five. With IRAD support, he has constructed the module and plans to complete testing by the end of the year. The goal is achieving a technology-readiness level of five — the level typically required for a successful Explorer-class mission proposal — by December 2012.

Parallel Track

At the same time, Zhang is working with Goddard technologist Vince Bly to construct super-thin X-ray mirrors from large blocks of mono-crystalline silicon, a commercially available material never before polished and figured for X-ray mirrors.

The key lies with the material itself. Traditional materials used for making mirrors — glass, ceramics, and metals — suffer from high internal stress, especially when cut or exposed to changing temperatures. These stresses become increasingly unpredictable as the mirror becomes thinner. "When I cut glass, I may not be able to predict how it will behave," Zhang said, comparing it to plywood, which can distort after being cut into pieces.

But silicon, on the other hand, "is a perfect material," Zhang said. "Every atom is in the right place. If plywood were made of silicon, it would be flat; even after cutting it, it wouldn't distort."

Because of the material's stability, technologists would be able to polish the silicon first and then lightweight it by machining away the excess material. Currently, mirror makers do the exact opposite. They grind first and then polish mirror surfaces — a time-consuming and expensive process, Zhang said.

Under his three-year APRA, Zhang and Bly plan to first make very thin flat mirrors to demonstrate the method. In the second year, he will fabricate curved mirror segments whose resolutions compare to or exceed those of Chandra. By the third year, he will attempt to fabricate integrated mirror segments from the same block of silicon, which would eliminate the complexity of aligning and integrating the segments into a module.

If successful, the application could revolutionize X-ray astronomy and make it even faster and less expensive to fabricate high-quality mirrors, Zhang said.

"It takes a lot of money to launch spacecraft into orbit. Driving down costs permeates everything we do," Zhang said. "The key is developing a lightweight, high-resolution mirror that costs much less to manufacture. It is essential to the future of X-ray astronomy in particular and to the well-being of NASA's science enterprise in general." ❖

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Goddard Technologist Achieves Milestone

Super-Black Material Eyed for Multiple Spaceflight Applications

A new super-black material has shown in testing to absorb on average more than 99 percent of the ultraviolet, visible, infrared, and far-infrared light that strikes it — a never-before-achieved milestone that promises to open new frontiers in scientific discovery.

Due in part to test results, the technology now is being applied to a variety of spaceflight applications that could make it easier to gather hard-to-obtain measurements of objects so distant in the universe that astronomers no longer can see them in visible light. Efforts also are underway to apply the technology to an ocean-monitoring instrument and one that would study the outer planets, said Principal Investigator John Hagopian, who is leading a team funded under Goddard's Internal Research and Development (IRAD) program.

Photo Credit: Chris Gunn

Principal Investigator John Hagopian shows samples of the new, highly absorbent material he and his team are developing for a wide variety of space applications.

The nano-based material is a thin coating of multi-walled carbon nanotubes made of pure carbon about 10,000 times thinner than a strand of human hair. These tiny hollow tubes are grown vertically on silicon, silicon nitride, titanium, and stainless steel — materials commonly used in space-based scientific instruments. Tiny gaps between the tubes collect and trap light and prevent it from reflecting off surfaces. Because only a small fraction of light reflects off the coating, the human eye and sensitive detectors see the material as black.

Effective Over Multiple Wavelength Bands

Reflectance tests, recently reported at the SPIE Optics and Photonics conference, have confirmed the material is blacker than originally expected across multiple wavelength bands.

"The reflectance tests showed that our team had extended by 50 times the range of the material's absorption capabilities," Hagopian said. "Though other researchers are reporting near-perfect absorption levels mainly in the ultraviolet and visible, our material is darn near perfect across multiple wavelength bands, from the ultraviolet to the far infrared. No one else has achieved this milestone yet."

In particular, the team found that the material absorbs 99.5 percent of the light in the ultraviolet and visible, dipping to 99 percent in the longer or far-infrared bands. "The advantage over other materials is that our material is from 10 to 100 times more absorbent, depending on the specific

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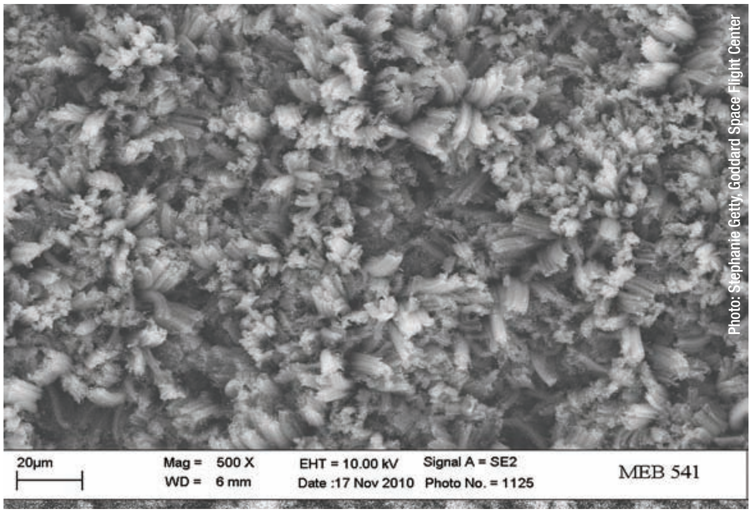
wavelength band," Hagopian said.

"We were a little surprised by the results," added Goddard engineer Manuel Quijada, who co-authored the SPIE paper and carried out the reflectance tests. "We knew it was absorbent. We just didn't think it would be this absorbent from the ultraviolet to the far infrared."

Its near-perfect blackness makes it an important new technology for suppressing stray light, calibrating infrared-sensitive instruments, radiating away heat, and absorbing infrared light for highly precise temperature measurements.



This high-magnification image, taken with an electron microscope, shows a closer view of the hollow carbon nanotubes that make up a highly absorbent coating developed by at team of Goddard technologists. This material is seen as black by the human eye and sensitive detectors because the tiny gaps between the tubes collect and trap light, preventing reflection.

Better Than Black Paint

Currently, instrument developers apply black paint to baffles and other components to help prevent stray light from ricocheting off surfaces and contaminating measurements. However, black paints absorb only 90 percent of the light that strikes it. The effect of multiple bounces makes the coating's overall advantage even larger, potentially resulting in hundreds of times less stray light. Furthermore black paints don't remain black in the mid to far infrared or when exposed to cryogenic temperatures. They take on a shiny, slightly silver quality.

As a result, developers of the proposed Ocean Radiometer for Carbon Assessment (ORCA), a next-generation instrument that would measure marine photosynthesis, are evaluating its use on components to prevent errant atmospheric light from overcoming the faint signal ORCA is supposed to retrieve.

Because the material remains black under cryogenic conditions, Goddard scientist Ed Wollack is evaluating the carbon-nanotube coating for use as a calibrator on far-infrared-sensing instruments. These instruments must operate in super-cold temperatures to gather far-infrared signals emanating from objects in the very distant universe. If they aren't cold, thermal heat generated by the instrument and observatory swamp the faint infrared they're designed to collect.

Goddard engineer Jim Tuttle, meanwhile, believes the coating would make an ideal radiator — especially for instruments measuring faint, far-infrared light. The blacker the material, the more heat it radiates away. In other words, super-black materials, like the carbon-nanotube coating, can be used on devices that remove heat from instruments and radiate it away to deep space. This cools the instruments to lower temperatures, making them more sensitive to faint signals.

In another application, Hagopian's team is developing a 1 X 4 detector array to demonstrate the material's use as an absorber for a thermopile, an electronic device that converts thermal energy — specifically, mid- to far-infrared light — into electrical energy. The carbon nanotubes absorb the light and heat up an ultra-sensitive thermometer, which changes the output voltage. "This makes the entire assembly exquisitely sensitive to minute variations in the infrared radiation, thereby enabling more sensitive measurements," Hagopian said. This particular effort supports a possible follow-on to the Goddard-developed Composite Infrared Spectrometer, which flew on the Cassini mission.

"When we began growing carbon nanotubes four years ago, we knew the material could be widely used as a light-suppression technique," Hagopian said. "We're pleased that we can develop the technology for other uses to support the scientific community."

"This is a very promising material," Wollack added. "It's robust, lightweight, and extremely black. It is better than black paint by a long shot." ❖

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A New Alloy for Satellite Skeletons

Materials scientist Timothy Stephenson has created a new material that combines the strength of ceramics with the thermal-dimensional stability of a 100-year-old metal alloy.

Photo Credit: William Hrybyk

Timothy Stephenson has developed a new alloy that combines the strength of ceramics with the toughness of metals. He poses here with the types of samples he plans to test.

Funded by Goddard's Internal Research and Development (IRAD) program, Stephenson's material is ideal for building super-stable, lightweight "skeletons" that support satellite mirrors and other instruments. While developing the new alloy, Stephenson also developed a recipe for creating metal alloys with specific thermal expansion properties that could be used for satellite brackets and base plates. The components would offer the same bend and stretch as the instruments they support.

Mixing Ceramic with Invar

Along with aluminum, stainless steel, and other commonly known metals, engineers often build satellite parts from an alloy called Invar. Invented more than 100 years ago by Swiss Nobel Prize winner Charles Édouard Guillaume, Invar is short for invariable because, unlike most other metals, this nickel-iron alloy expands very little when it's heated. Likewise, it also contracts very little when it's cool.

Consequently, Invar is used in everything from satellites to toasters and is great for any application where the instrument needs to keep its shape during extreme temperature changes. But Invar is heavy, and it could be stronger and stiffer. "Every pound you save, you can save on everything else," Stephenson says.

With his IRAD funding, Stephenson began experimenting with ways to create an Invar-like material rigid enough to be shaped into a lightweight structure, but still capable of enduring the temperature extremes found in space. He thought ceramic might be an ingredient worth investigating. "So the question became, how much ceramic could you put in it and still have it maintain its properties," Stephenson says.

A Dirty Process – But a Proof of Concept

Stephenson's first experiment, carried out at the Michigan Technological University, mixed different combinations of nickel-iron Invar with a silicon-nitride ceramic. His colleagues placed the powdered ingredients into a container about the size of a coffee can and then mechanically mixed them with marble-sized metal balls and a metal stirrer. When the powders were uniform, technicians sucked out the air inside the metal can and then

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pressurized it in a process called hot isostatic pressing or HIP, for short. "That means it's compressed from all directions at a high temperature," Stephenson says. "That fuses it all together."

The result was a ceramic-Invar alloy — a proof of concept that these materials could be combined and offer the same coefficient of thermal expansion or CTE as Invar. "It was a finger-sized sample made of iron powder, mixed in proportion with the nickel powder and a bit of ceramic. We actually got a higher specific stiffness alloy with the desired CTE," Stephenson says.

However, Stephenson's sample was "dirty," he says. Metal from either the balls, the stirrer, or the can contaminated the material.

So, Stephenson tried a non-mechanical alloying process.

Hot Off the (Isostatic) Presses

Working under a second IRAD, Stephenson acquired fine powders of Invar and silicon nitride, which Bodycote in Andover, Mass., stirred together like a cake mix and then pressurized.

The finished product was about the size of a large loaf of bread, but Stephenson believes the process could yield any shape an engineer would need. "It's possible that the satellite components wouldn't have to be machined into shape, but instead created whole using net-shape HIP. We could make a mold of whatever the engineers want, like a ring or something with a curve," he says. "We could then put the powder in, create the alloy, and then pop out the finished piece."

Now that he has created the new alloy, Stephenson has begun securing support for a contractor to open up the canisters and machine out samples of the new material. Those samples will be put to the test to ensure their composition and characteristics.

But they'll also undergo a second, more informal test. Stephenson wants to give the engineers who design, construct, and build satellites something they can hold in their hands. "These projects are science-driven, they're mission-driven," Stephenson says. "So, if you want to get something new accepted and used, you need to get the best tools and materials in the right hands." ❖

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Designers Beware

Electronics designers beware: A potentially catastrophic phenomenon once thought impossible in spacecraft instruments operating below certain temperatures has proven to be a threat after all.

A Goddard team, led by Principal Investigator Cheryl Marshall, found that "single-event latchup" (SEL) poses a threat to infrared-sensitive instruments operating in super-cold conditions. SEL occurs when a cosmic ray or high-energy particle strikes a semiconductor device, creating an excessive amount of current that can overheat and permanently damage the device.

The radiation-effects community is well aware of its potentially harmful effects on instruments operating in warmer temperatures. Consequently, electronics designers use radiation-hardening design or fabrication techniques to protect the electronics. However, they didn't know the condition could occur at temperatures below -279.67 degrees Fahrenheit. Marshall's team, which used Goddard and NASA funding to carry out experiments on CMOS readout integrated circuits, found otherwise.

CMOS, which stands for complementary metal oxide semiconductor, is the most prevalent technology in integrated circuits for both commercial and space applications.

During experiments at Texas A&M University, the team discovered that latchup could occur at temperatures as low as -416.47 degrees Fahrenheit, depending on the device. Due to these findings, also enabled by Goddard's Detector Characterization Laboratory, Marshall is urging flight-instrument teams to address these threats in component selection and design and testing. She is seeking resources to develop testing methodologies to enable this.

"I know people don't like cryogenic testing because it's expensive and difficult to do, but I'd like to see people test their devices," said Marshall, who recently received a "Goddard Engineering Award" and the IEEE's "Outstanding Conference Paper Award" for uncovering the problem. ❖

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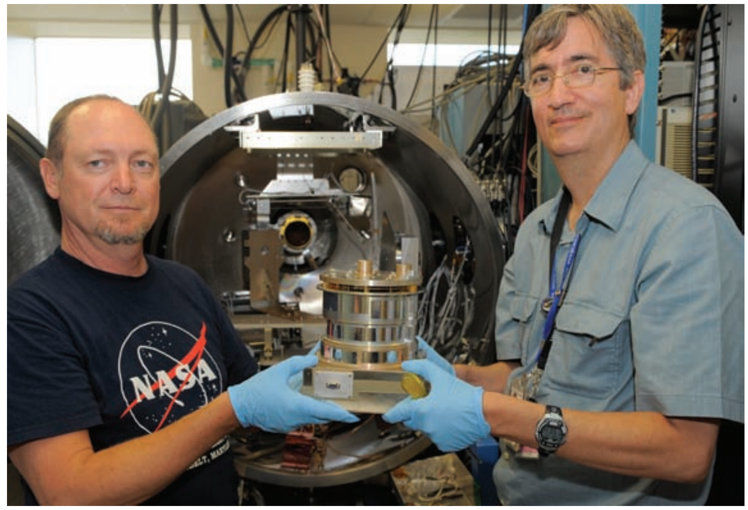
FASTSAT Observations Reveal Connections that Could Explain Atmospheric Loss on Smaller Planets

Two miniaturized heliophysics instruments, developed and built in part with Goddard R&D funding, have made interesting new observations of a process that may contribute to planets losing their atmospheres — something that happens slowly on Earth, but more quickly on smaller planets with weaker magnetic fields, like Mars.



Paul Rozmarynowski (left), who provided MINI-ME's mechanical design, poses with scientist John Keller, who developed the original MINI-ME concept. The instrument, which the two are holding, weighs only three kilograms. It's now flying as one of several miniaturized payloads on the FASTSAT spacecraft.

The instruments, which just celebrated their first anniversary on orbit as one of several tiny instruments on the Air Force-sponsored microsatellite, FASTSAT, are studying Earth's ionosphere. This region seethes with constantly changing electric and magnetic fields. Charged particles flow through the area and create electric currents that, in turn, produce aurorae. Many of these particles stream in via the solar wind, but some areas are dominated by particles coming from a more local source — Earth's atmosphere.

FASTSAT's Miniature Imager for Neutral Ionospheric Atoms and Magnetospheric Electrons (MINI-ME) instrument is watching these particles and has pieced together a detailed picture of a host of interrelated phenomena — such as electric current and outflowing particles — occurring together.

"We're seeing structures that are fairly consistent throughout a handful of instruments," says Michael Collier, MINI-ME principal investigator. "We put all of these observations together and it tells a story greater than the sum of its parts."

Unlike the hotter hydrogen coming from the sun, Earth's upper atmosphere generally supplies cooler oxygen ions that course outward along Earth's magnetic field lines. This "ion outflow" occurs continuously, but is especially strong during solar storms, and more particularly intensive auroral events.

Understanding Atmospheric Loss

"These ion outflow events are important because they help us understand the space weather environment around Earth," says Goddard's Doug Rowland, the principal investigator of FASTSAT's Plasma Impedance Spectrum Analyzer (PISA). "The heavy ions flowing away from Earth can act as a brake, or damper, on incoming energy from the solar wind. The flow also indicates ways in which planets can lose their atmospheres — something that happens slowly on Earth, but more quickly on smaller planets with weaker magnetic fields, like Mars."

MINI-ME has been successfully spotting such outflows since the instrument first began collecting data in the winter of 2010. However on March 31, 2011, the FASTSAT spacecraft flew through an ion outflow with well-defined areas of increased fast moving, or energetic, particles. Simultaneous observations from PISA, which measures the density of material in the atmosphere, also showed a highly structured auroral zone.

"This is just one event, but it helps confirm the idea that the current and ion outflows are all connected. And atmospheric loss resulting from solar wind-planetary body interaction occurs on other planets like Mars, as well. As we continue to go through the data, there will be many more events to follow. We'd like to pin down the origin of all these mechanisms in the ionosphere." ❖

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PROFILE

On occasion, CuttingEdge profiles people who are making a difference promoting and advancing Goddard technology. In this issue, we focus on Nicholas "Nick" Paschalidis, who last year became the lead for coordinating technology development within Goddard's Heliophysics Division.

Meet Nicholas Paschalidis:

Focusing on the Small to Explore the Big

Nicholas Paschalidis focuses on the small to explore the big.

Photo Credit: Debora McCallum

The Greek native, who joined Goddard last June after a nearly 20-year stint with the Applied Physics Laboratory, helps coordinate technology development within Goddard's Heliophysics Division. To his way of thinking, the future lies in miniaturization and the use of non-traditional platforms to fly heliophysics instruments that study the sun, Earth's magnetic environment, and all the space weather in between.

Experience to Bear

He brings a wealth of experience. As an experimental space scientist, he spent much of his career developing miniaturized, low-power instruments that have become de rigueur in space missions these days.

His proficiency is in microsystems and application specific integrated circuits (ASICs), tiny, highly specialized computer chips now used to replace instrument systems that previously weighed about two pounds and required more energy to operate. They're also being incorporated into many of the upcoming heliophysics missions, such as the Radiation Belt Storm Probes, Magnetospheric Multiscale mission, Solar Orbiter, and Solar Probe Plus.

Over the course of his career, he developed a family of about 10 important ASICs that help measure three scientific basics: time of flight, look angle, and energy down to a single photon or particle resolution. The most well known — one of two for which he holds patents — is the time-of-flight chip that measures time down to a trillionth of a second. Scientists use the data to understand the velocity of a particle and its direction. Another ASIC — the energy chip — measures the energy distribution of radiation. A third, an engineering-focused ASIC called the TRIO chip, replaces miles of wiring on spacecraft by digitizing and serializing multiple distributed sensors.

Paschalidis now wants to focus on low-cost access to space through commercial telecom satellites — an idea he has advocated for the last five years — and increased deveopment of small, Cubesat-type instruments. "Commercial satellites are increasingly willing to host scientific instruments and small payloads flying on Cubesats are easily accommodated on commercial launch vehicles," says Paschalidis. "These small instruments can be added to the greater heliosphere and the geo-grid to study space weather at a fraction of the price."

The Big Picture

"There's a bigger picture here," he says. "For instance, there's a lot of instrument development work and many mission ideas going on not only on the particle side — which I have been more involved in — but on the whole electromagnetic spectrum, from infrared to visible to ultraviolet, X-rays, gamma rays. Thinking big and small simultaneously will be just what is needed to help create the cutting-edge technology that drives science forward," he says. ❖

Ensemble Forecasting, *continued from page 3*

cover. "No one knows exactly what the sun will do, and if someone says he or she knows, they're not telling the truth," Pulkkinen said. "We can't even tell in a week, let alone a year or two, what the sun will do. All we know is that the sun will be more active."

Given the expected uptick in activity, Hesse, Pulkkinen, and Yihua Zheng, another chief forecaster, were anxious to enhance their forecasting acumen. They partnered with the Space Radiation Analysis Group at the Johnson Space Center in Houston, which is responsible for ensuring that astronauts' exposure to deadly radiation remains below established safety levels, and won NASA funding to develop the Integrated Advanced Alert/Warning Systems for Solar Proton Events.

Weakness in Current System

"Ensemble forecasting holds the key" to an enhanced alert system, Hesse said. "We agreed that this was the way to go."

Currently, the laboratory is running one CME model — calculating one set of parameters — at a time. The parameters are derived from near real-time data gathered by a number of spacecraft. "But since these are scientific research missions, we have no guarantee of a continuous real-time data stream," Zheng said.

Furthermore, imperfections exist in the data. These imperfections grow over time, leading to forecasts that don't agree with the evolution of actual conditions. For NASA, the Air Force, and other organizations, which use Goddard's forecasts to decide whether steps are needed to protect space assets and astronauts, uncertainty is as unwelcome as the storm itself.

Ensemble forecasting, however, overcomes the weaknesses by allowing forecasters to tweak the conditions. "Generating different parameters is easy — just varying a little bit of all parameters involved in characterizing a CME, such as its speed, propagation direction, and angular extent," Zheng explained. In essence, the multiple forecasts provide information on the different ways the CME can evolve over the next few hours. "We'll be able to characterize the uncertainties in our forecasts, which is almost as important as the forecast itself," Pulkkinen added.

Antti Pulkkinen (center) works with a team of scientists to formulate space weather forecasts. With him are (from left to right): Hyesook Lee, M. Leila Mays, and David Berrios.

The team already has installed new computer systems to run the varying calculations and hope to develop the ability to generate more specialized forecasts.

"We recognize there is a huge gap in our current capability," Pulkkinen continued. "We certainly don't want to miss the solar maximum with this capability. We're really pushing the envelope to have it done. When we do, we'll be the first in the world to have it." ❖

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