National Aeronautics and Space Administration

Cutting edge
Goddard's Emerging Technologies

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The Pressure Is On!

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Goddard Develops Satellite Concept to Exploit Rideshare Opportunities

Capsulation Satellite to Undergo Testing

Each time a rocket blasts off to deliver a primary payload into space, it typically does so with room to spare — a reality that got Goddard engineer Joe Burt thinking.

Why not exploit that unused capacity and create a pressurized, thermally controlled capsule that could take advantage of rideshare opportunities while accommodating less-expensive, off-the-shelf instrument components typically used in laboratory-like settings? Several years in the making, Burt and his team now are ready to validate portions of such a system.

Called the Capsulation Satellite, or CapSat for short, the system is a hockey puck-shape structure that measures roughly 40 inches wide and 18 inches tall. Purposely designed as either a standalone or stacked system depending on payload needs, each capsule is capable of carrying about 661 pounds of payload into orbit — a microsatellite-class weight not accommodated by the increasingly popular CubeSat platform whose instruments typically weigh two to six pounds.

With funding from NASA's Earth Science Technology Office, or ESTO, Burt and his team will validate CapSat's all-important thermal-control system in a thermal-vacuum chamber test later this summer. The system uses thermostatically controlled fans — much like those used to cool electronic equipment on Earth — to circulate air over hot and cold plates installed inside the craft. This maintains a constant temperature where instruments would experience little, if any, degradation while on orbit, Burt said.

Under the ESTO-funded effort, Burt and Goddard detector expert Murzy Jhabvala also are conducting a study to scope out the specifics of flying a next-generation photodetector camera on a sealed CapSat. The idea is that NASA could fly the detector on a constellation of CapSats to gather multiple,

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About the Cover

Each time a rocket blasts off to deliver a primary payload into space, it typically does so with room to spare. Goddard engineer Joe Burt now is developing a satellite system that would take advantage of this unused capacity while accommodating less-expensive, off-the-shelf instrument components typically used in laboratory-like settings. Several years in the making, Burt and his team now are ready to validate portions of the CapSat system shown in this image.

Photo Credit: Bill Hrybyk/NASA

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CapSat is a pressurized platform designed to carry laboratory-style instruments into space.

simultaneous measurements (see related story, page 6).

To show the concept's feasibility, Jhabvala will install a laboratory breadboard of his Strained-Layer Superlattice Infrared Detector Camera inside the CapSat model. "The main purpose of the camera demonstration is to show how easily a laboratory-based instrument could become a flight instrument, complete with flyable electronics and software that would connect it all the way back to the ground for data display and analysis," Burt said.

Nothing New Under the Sun

Burt is the first to admit that pressurized spacecraft are not new, and aside from its thermal-control system, CapSat is not in the technological vanguard.

"Flying a mission with pressurized volume goes back to Sputnik," he said. "There is nothing magical here."

Russia's Global Navigation Satellite System, known as GLONASS, included pressurized space-

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craft. For 19 years, NASA offered flight opportunities to scientists and students with its Getaway Specials, pressurized canisters that took advantage of excess cargo space on the Space Shuttle.

And more recently, NASA's Ames Research Center developed a rapid-prototype, low-cost pressurized spacecraft called the Cost Optimized Test of Spacecraft Avionics and Technologies, or COTSAT. Late last year, Ames executed a licensing agreement on two of COTSAT's pending patents with the San Jose, California-based Hera Systems. The company plans to leverage this technology in the development of an ultra-high-resolution commercial imaging system that it anticipates launching in 2017.

"Terrestrial pressure in space is a tried-and-true approach," Burt added. "It happens on the ISS (International Space Station) where scores of laptops are running every day. This is not a new idea."

NASA used the so-called ESPA ring to deploy its Lunar Crater Observation and Sensing Satellite, or LCROSS, which flew as a secondary payload on the Lunar Reconnaissance Orbiter, or LRO. In this image, two proud "fathers," Dan Andrews, LCROSS project manager (left), and Craig Tooley, LRO project manager, stand in front of their "babies."

CapSat's Distinguishing Attributes

What distinguishes CapSat is the fact that the capsule can accommodate heavier payloads. Perhaps more important, Burt specifically designed it to take advantage of a U.S. Air Force-developed secondary-payload carrier called the Evolved Expendable Launch Vehicle Secondary Payload Adaptor, or ESPA ring. Working with Moog CSA Engineering, of Mountain View, California, the Air Force created the ring to accommodate as many as six payloads beneath the primary spacecraft, exploiting the thousands of pounds of unused cargo space on many rockets.

Goddard's new Rideshare Office estimates that between 2015 and 2023, NASA will launch a number of missions whose total combined unused mass-to-orbit will exceed 46,300 pounds. "At an average launch cost of a million dollars per kilogram to orbit — even CubeSats cost about that much — hundreds of millions of dollars in launch-vehicle costs are going unutilized," said Bob Caffrey, who heads the Rideshare Office (see related

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story, page 8). "There really needs to be a paradigm shift," he added.

In sharp contrast, Burt estimates that CapSat would reduce today's launch costs to just $50,000 per kilogram to orbit just by taking advantage of the unused capacity. "Furthermore, if CapSat modules were produced in quantity in advance, then the time to flight for a working laboratory instrument becomes extremely short. This reduced schedule, in turn, significantly reduces the overall cost of a mission while significantly increasing the science opportunities," Burt said.

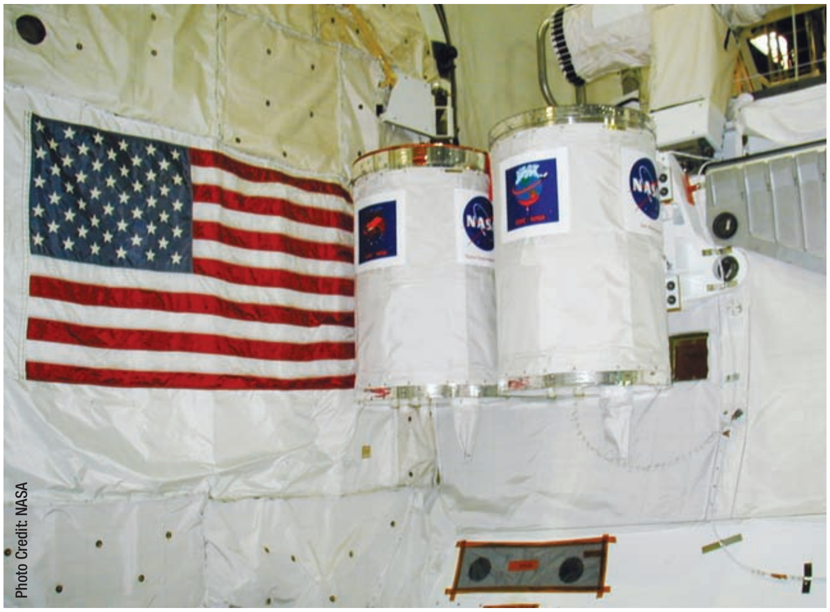

Photo Credit: NASA

For 19 years, NASA offered flight opportunities to scientists and students with its Getaway Special canisters, which are shown here in the Space Shuttle cargo bay.

Rideshare Opportunities Blossom

Also to consider, he added, is the fact that since its initial development in the early 2000s, the ESPA ring has become the de facto standard for secondary payload carriers, with a growing list of users and opportunities.

In 2009, NASA used the ESPA ring to deploy its Lunar Crater Observation and Sensing Satellite, which flew as a secondary payload on the Lunar Reconnaissance Orbiter. Private industry now is using it, too. Late last year, SpaceX, of Hawthorne, California, used ESPA rings to mount 11 ORBCOMM OG-2 communication satellites inside the Falcon 9 rocket, resulting in a successful deployment.

In the meantime, the U.S. Air Force has announced that it plans to fly the ESPA ring on all future launch vehicles. It also has developed a process for selecting potential rideshare payloads and is creating other versions of the carrier to accommodate a broader range of users. NASA, too, plans to take better advantage of the unused cargo capacity and will be providing rideshare opportunities on its future missions, Burt said.

"Secondary payloads are part of a growing trend toward the increasing diversity of platforms used in pursuing space and Earth science," said NASA Science Mission Directorate Deputy Associate Administrator for Programs Greg Robinson. "Today, many U.S. government, academic, and industry partners are looking for ways to use secondary payloads as platforms to enable science, mature technologies, and enable workforce development," Robinson added.

Time is Ripe

Given this confluence of events, Burt believes the time is ripe for NASA to develop a platform like CapSat. Not only is it compatible with the ESPA ring, it also is capable of carrying heavier instruments, even those originally built for terrestrially based laboratory testing. Such a platform, which Burt believes industry ultimately should manufacture and offer at competitive prices, would significantly reduce mission-development schedules and costs.

"The bottom line is that the CapSat concept has the potential to make science missions more affordable," said Azita Valinia, the ESTO executive who awarded the ESTO study. "If proven successful, the CapSat architecture can change the cost paradigm for science missions."

Robinson agrees. "It's exciting to see what is being built by the Goddard team to provide researchers a capable and reliable platform for fast turn-around, lower-cost payloads," he continued. "When combined with the wide array of launch opportunities for these secondary payloads, the opportunities for platforms like CapSat are showing real promise," he said. ❖

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Next-Generation Photodetector Camera Studied for CapSat Application

An advanced photodetector camera that traces its heritage to one now flying on NASA's Landsat Data Continuity Mission is being studied as a potential payload on a conceptual satellite system purposely designed to take advantage of the expected boom in secondary-payload launch opportunities.

Under the study funded by NASA's Earth Science Technology Office, or ESTO, a Goddard team will define a mission architecture in which multiple Capsulation Satellites, or CapSats, would be outfitted with the so-called Strained-Layer Superlattice Infrared Detector Camera, also known as SLS (see related story, page 2).

"The CapSat concept can be very powerful when used in distributed architectures, such as flying multiple instruments on a constellation of CapSats," said Azita Valinia, the ESTO executive who funded the study. "In this study, SLS detectors are used for land-imaging applications, but the constellation architecture can be applied to both Earth and space science measurement scenarios."

Valinia chose SLS for the study because it's already far along in its development and appears to be a good fit for a potential CapSat mission. "ESTO previously funded several detector projects, in addition to the recent SLS detector development, as part the of the Sustained Land Imaging Technology study portfolio. It shows possible potential for future land-imaging applications," said George Komar, ESTO director.

Detector Improvements

SLS is the next-generation of a previous infrared camera system based on the Quantum Well Infrared Photodetector, or QWIP, technology. God-

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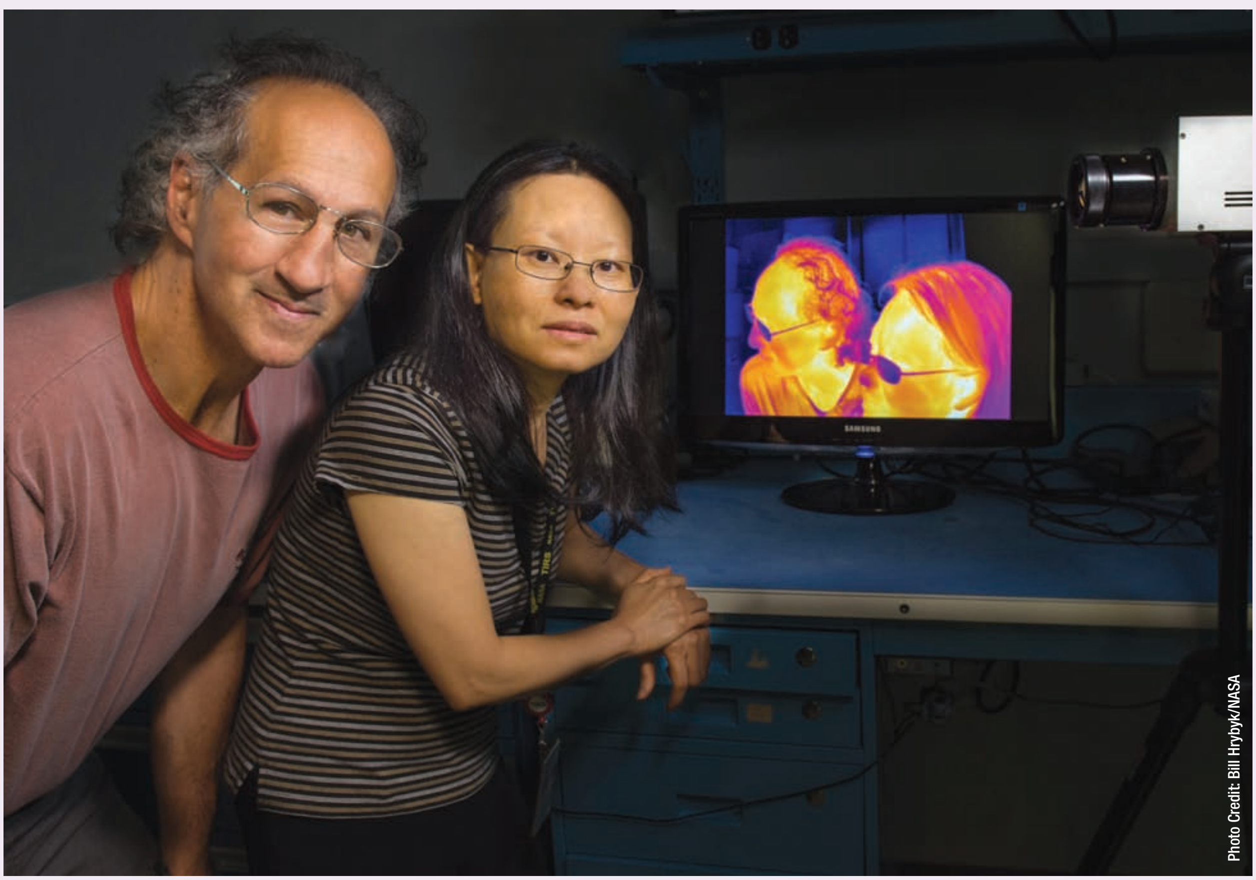
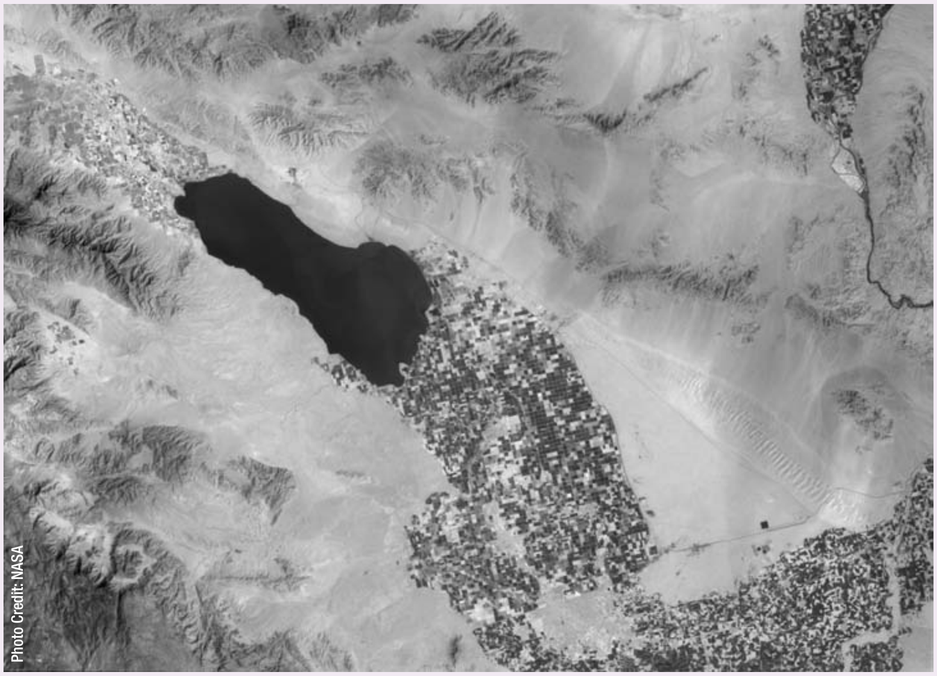


Goddard technologists Murzy Jhabvala and Anh La are advancing a next-generation detector technology called the Strained-Layer Superlattice Infrared Detector Camera, which took the image displayed on the computer monitor. The system now is being studied as a potential CapSat payload.

dard technologist Murzy Jhabvala spent nearly two decades refining QWIP technology before NASA selected it for use on Landsat's Thermal Infrared Sensor, or TIRS (Goddard Tech Trends, Summer 2010, Page 6). TIRS now is monitoring the ebb and flow of land-surface moisture levels and the health of vegetation — data that western states use to monitor water consumption.

Since Landsat's launch, Jhabvala and his industry partner, QmagiQ, a Nashua, New Hampshire-based company, have further improved the large-format SLS detector technology.



This Thermal Infrared Sensor, or TIRS, image of the Salton Sea area in the Southern California desert shows the amount of heat (thermal energy) radiating from the landscape. Cooler areas are dark, while warmer areas are bright. A next-generation of the TIRS detector technology, with more than 10 times the sensitivity, is being studied for a CapSat opportunity.

Like its QWIP predecessor, SLS is a band gap-engineered detector. Detector arrays are fabricated on a gallium-antimonide semiconductor wafer coated with alternating epitaxial layers of gallium antimonide, indium arsenide, and indium antimonide, repeated more than 600 times. The very thin layers absorb infrared photons and convert them to electrons — the fundamental particles that carry an electric current — and only light with a specific energy, or wavelength, can release them.

Infrared radiation with the correct energy is absorbed in the SLS structure, which releases an electron that a silicon-readout chip directly mated to the SLS detector array then collects. The readout chip converts the electron to a voltage that corresponds to the incident signal and a computer then uses this information to recreate an image of the infrared source. Detector developers can vary the composition and thickness of the layers to tune the detector's sensitivity to specific wavelength bands.

Compared with its QWIP predecessor, SLS detectors are more than 10 times more sensitive, can operate at warmer temperatures, and exhibit a wider range of spectral selectivity, among other things, said Jhabvala, adding that the technology, like QWIP, is relatively inexpensive to build.

First Flight Demonstration

Jhabvala and his team will have a chance to demonstrate SLS when they fly an experimental unit on NASA's next Robotic Refueling Mission. Scheduled for 2017, the mission will advance and demonstrate the capability to service and refuel satellites on orbit. "If we get just one image of Earth, we will have been successful. Of course, we hope to collect many more than just one image," Jhabvala said. "We want to prove that this technology is spaceflight worthy."

In the meantime, as part of the ESTO study due this fall, he and CapSat developer Joe Burt are studying the viability of launching the photodetector technology on a handful of CapSats.

"What we wanted to do was to perform a quick concept definition and feasibility study, leveraging already-funded detectors that are a good fit for the spacecraft," Valinia said. "If the concept is determined viable — and that is my hope by funding this study — then plans can be made to secure funding to fly such a constellation tailored to specific science or commercial applications." ❖

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New Rideshare Office Opens

The move to fly a greater number of secondary payloads on future launch vehicles, thereby taking advantage of the thousands of pounds of unused capacity, has led to the creation of Goddard's new Rideshare Office.

The new organization, led by Bob Caffrey, focuses on helping Goddard scientists and technologists identify and secure rideshare opportunities on NASA, Air Force, and commercial launches; however, it also supports scientists from universities and other organizations. The other NASA centers also are supporting rideshare opportunities.

The office now is developing a process for vetting a spectrum of potential payloads — from PicoSats and CubeSats to larger-class satellites weighing as much as 11,000 pounds. The office is matching them to launch vehicles and payload carriers, including the Evolved Expendable Launch Vehicle Secondary Payload Adaptor, or ESPA ring, and others developed by both the government and private industry (see related story, page 2).

Currently, the Air Force may have six to eight missions a year, while NASA flies about two or three large missions a year. NASA is expected to include a rideshare opportunity in its upcoming Small Explorer Announcement later this summer, Caffrey said.

"The Air Force sees the situation the same way NASA does," Caffrey continued. "Most of the launch vehicles go up half full. Instead of wasting space and mass, both organizations agree that we should share the excess capacity on our launch vehicles. The point is, so many new opportunities would be enabled through rideshare."

Caffrey continued, "this is a different way of doing things. I see it as a wonderful opportunity for everyone — NASA, the Air Force, industry, and universities." ❖

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Photo Credit: SpaceX

SpaceX's Falcon 9 rocket delivered ORBCOMM's OG2 communication satellites to low-Earth orbit. This image shows the ESPA ring on which the satellites were attached.

Aircraft Radar Technology Investigated for Planetary Missions

An innovative imaging radar system that proved its mettle measuring biomass during multiple aircraft demonstrations is now being investigated for possible use on planetary missions — particularly those that would explore geologic features lying hidden beneath the surfaces of these alien worlds.


Photo Credit: Bill Hrybyk/NASA

Lynn Carter and Rafael Rincon are investigating an innovative imaging radar system for possible use on planetary missions. Behind them is the airborne EcoSAR upon which the new system is based.

Under the technology-development program awarded by NASA's Planetary Instrument Concepts for the Advancement of Solar System Observations program, also known as PICASSO, a team of Goddard scientists and engineers will advance a number of components making up the Space Exploration Synthetic Aperture Radar, or SESAR. SESAR will be capable of executing simultaneous, multiple radar-imaging techniques.

"SESAR's remote-sensing techniques are capable of penetrating meters of regolith to image buried features at high resolution," said Rafael Rincon, a Goddard radar expert who is working with Goddard scientist Lynn Carter to advance the technique for planetary missions. "It's perfect for a mission to Mars, for example, where you would want to see if water-ice exists beneath the surface. SESAR can easily penetrate the upper few meters beneath the dry Martian surface."

A regolith-penetrating imaging radar also could be used for missions to the moon, Mercury, Venus, and asteroids, he added.

"I'm really excited about SESAR's potential for future planetary missions," said Carter. "It will be able to image features like ice deposits, lava flows, and fluvial channels that are buried under dust. It's also a very flexible radar system, capable of acquiring full polarimetry — which has never been done before with a planetary mission — while simultaneously performing imaging, scatterometry, and altimetry measurements."

The technology is a next-generation version of the L-Band Digital Beamforming Synthetic Aperture Radar, or DBSAR. Installed below the fuselage of a NASA P-3 research aircraft, DBSAR demonstrated for the first time the ability to simultaneously synthesize multiple L-band radar beams directed at targets below and then produce high-resolution data of very large surface areas from the returning signals (*Goddard Tech Trends*, Winter 2008, Page 7). Prior to its development, conventional radar systems could only gather high-resolution data along a narrow swath on one side of the flight track.

Taking the technique one step further, Rincon and his colleague, Lola Fatoyinbo, then adapted the same general approach to tune the system to the P-band — a lower microwave frequency ideal for piercing forest canopies. The goal was obtaining unprecedented two-and three-dimensional fine-scale measurements of the biomass. In 2013, EcoSAR made its aircraft debut aboard a P-3 aircraft.

"We wanted to demonstrate that (the P-band radar technique) could be done; now, we want to take it to space," Rincon said. Adapting the P-band EcoSAR instrument for use in space won't be easy, however. "A major challenge with orbital beamforming radars is the power required to drive and steer the multiple beams," Rincon said. As a result, the team specifically will use the three-year PICASSO funding to lower the power and mass of one of SESAR's key components: its digital electronics subsystem. ❖

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Moth's Eye Inspires Critical Component on SOFIA's Newest Instrument


Photo Credit: Bill Hrybyk/NASA

Christine Jhabvala and Ed Wollack hold the sketch of the absorber technology they created. Containing thousands of tightly packed, micro-machined spikes or cylindrical protuberances no taller than a grain of sand, the absorber is a critical component of the three 1,280-pixel detector arrays used in SOFIA's new High-Resolution Airborne Wideband Camera-plus, known as HAWC+.

Nature, and more particularly a moth's eye, inspired the technology that allows a new camera to image with far greater sensitivity astronomical objects emitting light over a broader range of the far-infrared wavelength band.

The absorber technology is a silicon structure containing thousands of tightly packed, micro-machined spikes or cylindrical protuberances no taller than a grain of sand. It is a critical component of the three 1,280-pixel detector arrays that a team of Goddard scientists and technologists created for the High-Resolution Airborne Wideband Camera-plus, known as HAWC+ (*CuttingEdge*, Winter 2013, Page 8).

NASA now is commissioning HAWC+ onboard the Stratospheric Observatory for Infrared Astronomy, or SOFIA, a joint venture involving NASA and the German Aerospace Center, or DLR. This heavily modified 747SP can carry an eight-foot telescope and eight instruments to altitudes above 99 percent of the water vapor in Earth's atmosphere, a gas that blocks most of the infrared radiation from celestial sources.

The upgraded camera not only images sources, but also measures the alignment of incoming light waves with its onboard polarimeter. With this instrument, scientists will be able to study the early stages of star and planet formation and map magnetic fields in the environment around the supermassive black hole at the center of the Milky Way.

Never Before Used in Astronomy

The device that helps absorb the elusive far-infrared wavelengths needed to make these observations has never been used in astronomy,

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said Goddard scientist Ed Wollack. He worked with Goddard detector expert Christine Jhabvala to devise and build in just six months the broadband micro-machined far-infrared absorber critical to the bolometer detectors.

Bolometers are commonly used to measure infrared or heat radiation, and are, in essence, very sensitive thermometers. When radiation strikes an absorptive element, typically a material with a resistive coating, the element heats. A superconducting sensor then measures the resulting change in temperature, revealing details about the object being studied.

To be effective, the bolometer detector must absorb as much far-infrared light as possible.

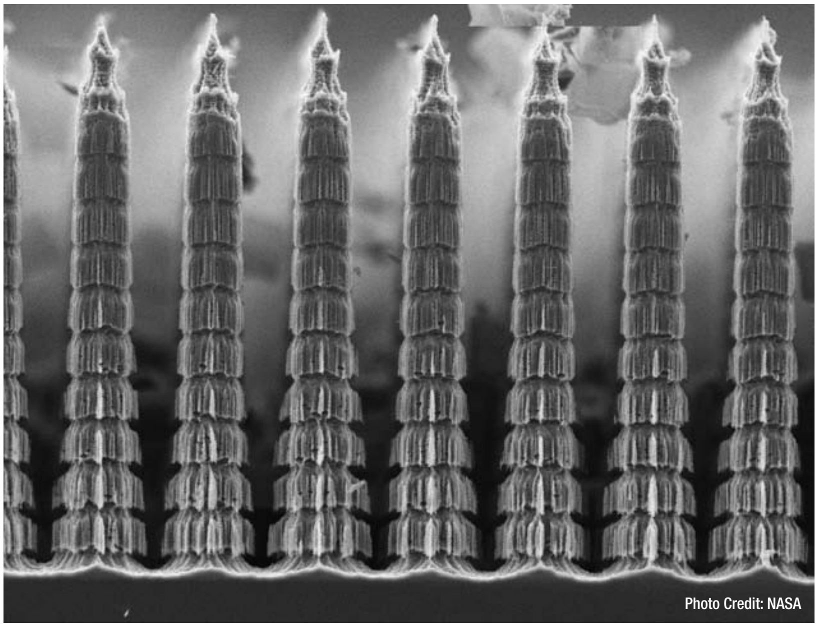

Photo Credit: NASA

This image taken with a scanning-electron microscope shows details of a new absorber that will enable observations by the High-Resolution Airborne Wideband Camera-plus, or HAWC+, a new SOFIA instrument. The spikes were inspired by the structure of a moth's eye.

Wollack and Jhabvala had experimented with carbon nanotubes as a potential absorber. However, the cylindrically shaped tubes proved challenging when implemented with other elements of the detector array.

The Moth, the Muse

Wollack looked to the moth as a possible solution.

When examined up close, a moth's eye contains a very fine array of tapered, cylindrical protuberances. Their job is to reduce reflection, allowing these nocturnal creatures to absorb as much light as possible so that they can navigate in the dark.

The same concept would apply to a far-infrared absorber, Wollack said, recalling the moment inspiration struck. As in the moth's eye, tiny, nearly invisible spikes would reduce reflection to assure that the absorber collected the maximum amount of far-infrared light. With such a system, even minute variations in the light's frequency and direction could be measured. "This enables the detector to be used over a wider bandwidth. It makes the detector far more sensitive — especially in the far infrared," he said.

To create the structure, Jhabvala and her team used specialized machining tools to etch the silicon wafer according to a blueprint, a specially produced fabrication mask showing the proper size and placement of the spikes to assure maximum absorption. When machining silicon, a ubiquitously used material in many types of technological devices, silicon dust falls, creating "pillars that look like grass," Jhabvala explained. This dust helps create the pillars.

Without the mask, the end result would have been a mish-mash of haphazardly placed spikes incapable of doing the job it was created to do. The team then used another technology called atomic layer deposition to coat the structure with a very thin metal resistive film, she said.

People, Machines, and Material

"I don't think anyone has ever made this structure deliberately. This is controlled grass," Jhabvala said. The carefully placed spikes positioned just 20 microns apart — the size of many types of bacteria — give the absorber its ability to broadly absorb the far-infrared band, making it idea for use on a general-purpose SOFIA instrument.

"You can be inspired by something in nature, but you need to use the tools at hand to create it," Wollack said. "It really was the coming together of people, machines, and materials. Now we have a new capability that we didn't have before. This is what innovation is all about." ❖

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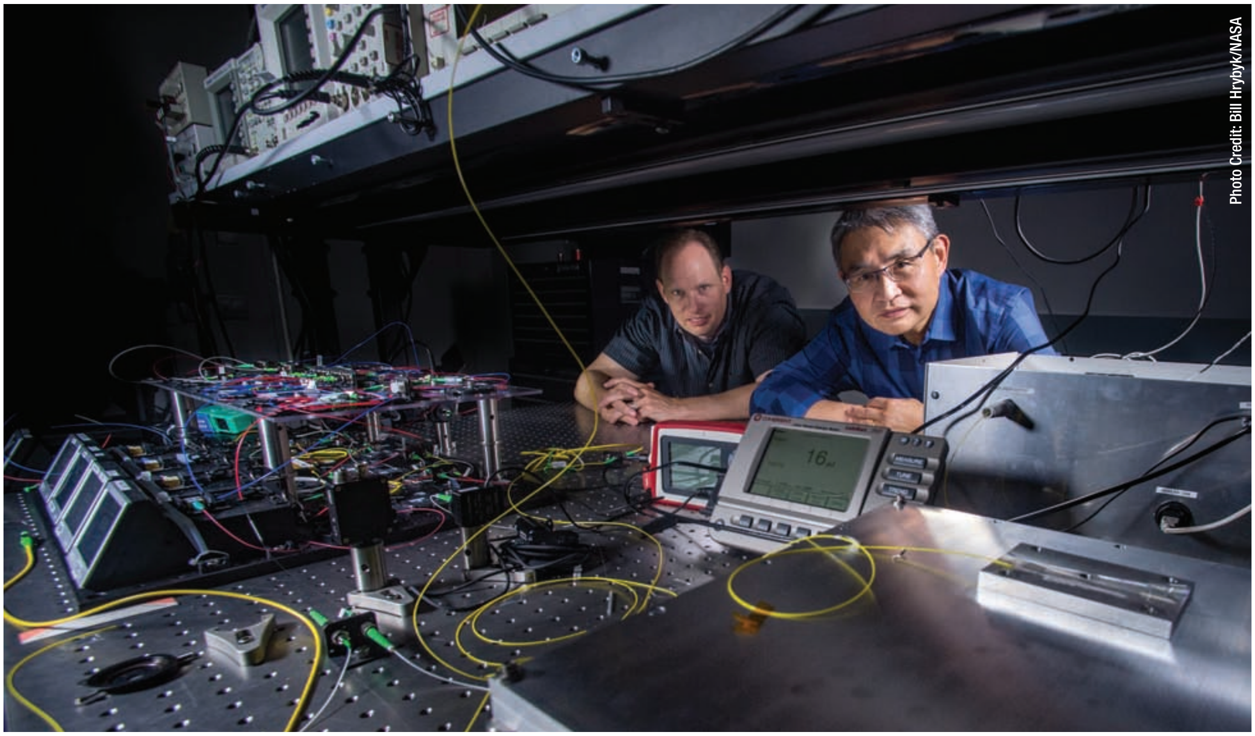
New CO_2 Sounder Nearly Ready for Primetime

Development Team Reports Significant Progress



Mark Stephen and Tony Yu are part of the team, including Jeffrey Chen (not pictured), who developed the advanced laser system used on the CO_2 Sounder Lidar.

After years of work, a team of Goddard scientists and engineers is poised to realize a lifetime goal: building an instrument powerful and accurate enough to gather around-the-clock global atmospheric carbon-dioxide (CO_2) measurements from space.

The instrument, called the CO_2 Sounder Lidar, is a strong contender for a potential next-generation carbon-monitoring mission, the Active Sensing of CO_2 Emissions over Nights, Days, and Seasons, or ASCENDS. Although the scientific community fully supports such a mission, scientists say its development depends on whether the technology is mature enough to measure the greenhouse gas with unprecedented precision and resolution, regardless of the season or time of day.

CO_2 Sounder Lidar team members believe they can make the case — especially now that they've analyzed data gathered during the instrument's most recent aircraft campaign over California and Nevada earlier this year. The team, led by Goddard scientist Jim Abshire, presented these results at the International Workshop on Greenhouse Gas Measurements from Space in Kyoto, Japan, just a few weeks ago.

Proven Aircraft Demonstrations

The team's work began about a decade ago with support from Goddard's Internal Research and Development program and later with support from NASA's Earth Science Technology Office. The lidar operates by bouncing infrared laser light off the Earth's surface. Like all atmospheric gases, carbon dioxide absorbs light in narrow wavelength bands. By carefully tuning the laser across those absorption lines, scientists can detect and then analyze the level of gases in that vertical path. The more gas along the light's path, the deeper the absorption lines.

Recent data analyses indicated that the CO_2 Sounder can execute its job faster and with greater accuracy than earlier incarnations of the instrument. Team members attribute their success to several key technologies.

For one, the lidar is equipped with the world's first solid-state detector that is highly sensitive to the near- and mid-infrared wavelengths — a spectral sweet spot for detecting greenhouse gases in Earth's atmosphere (CuttingEdge, Summer 2015,

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Page 6). Made of a special alloy called Mercury-Cadmium-Telluride, this breakthrough detector literally counts each returning infrared photon, and as a result, enjoys unparalleled sensitivity.

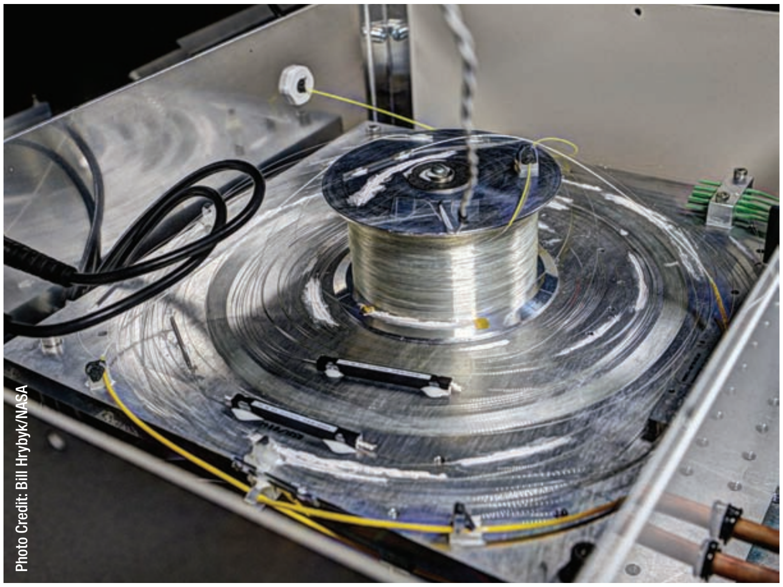
Photo Credit: Bill Hrybyk/NASA

This image shows the special fiber used in the CO_2 Sounder's laser amplifier developed by Goddard technologists Tony Yu and Mark Stephen. The technology is currently being tested for performance and space qualification.

Faster, More Efficient Retrieval

"During the CO_2 Sounder's 2016 (aircraft) campaign, we realized the detector's high sensitivity," said Anand Ramanathan, a team member. "It took 10 seconds to accumulate enough light to make a measurement in our 2013 campaign. In 2016, it took just one second. This is like improving the photographic film speed so that the camera exposure can get shorter and one can get a higher frames-per-second rate. Besides the high sensitivity, the detector also demonstrated a high-linear dynamic range, which was of great help flying over snow, which is surprisingly dark in the infrared," he added.

Equally important, Abshire said, is the sounder's laser system, a capability not enjoyed by current space-based carbon-monitoring missions. Unlike existing instruments, which rely on passive or reflected sunlight to gather measurements, the CO_2 Sounder's laser system provides the light source, giving it the ability to measure carbon dioxide day and night, regardless of the season — an essential capability for ASCENDS.

Laser Demonstrates Pluck

"The laser team deserves many kudos," Abshire said, referring to Goddard laser engineers Mark Stephen, Jeffrey Chen, and Tony Yu, who are advancing the instrument's tunable laser system. "The laser keeps getting better all the time."

To measure trace gases like carbon dioxide and methane, the laser should produce many different wavelengths of light, particularly those around the wavelength known to absorb the gas of interest. While other lidar groups use one laser per wavelength, the Goddard approach uses a single laser that rapidly and accurately tunes to up to 30 different wavelengths. Called a 'step-locked' system, the laser can rapidly switch between the different wavelengths. "It's so fast you can precisely step through the wavelengths a hundred times, all within the blink of an eye," Ramanathan said. For scientists interested in knowing the atmosphere's chemical makeup, the laser offers another important benefit: the ability to measure water vapor whose absorption lines lie next to CO_2's absorption lines. "The step-locked system enabled us to make simultaneous water-vapor measurements along with the CO_2 measurement," he added.

Between the highly sensitive detector and rapidly improving laser system, the team believes it's on the cusp of maturing a flight-ready ASCENDS-type instrument. The one remaining hurdle, Abshire said, is assuring that the laser is powerful enough to deliver a beam of light and accurately measure the returning signals for spectroscopic analysis — all from space. But even there, Abshire is confident.

"We need to increase the power so we can take our instrument into space. These guys have figured a way to do that," Abshire said, referring to the special type of fiber amplifier the team has advanced to literally increase the laser's power by a factor of 100. The sounder's final design will include six laser amplifiers used in parallel, Stephen said, adding that testing of the laboratory breadboard will occur over the next year.

"The advancement of technology has been amazing. I wouldn't have thought this was possible just a few years ago," Ramanathan said. ❖

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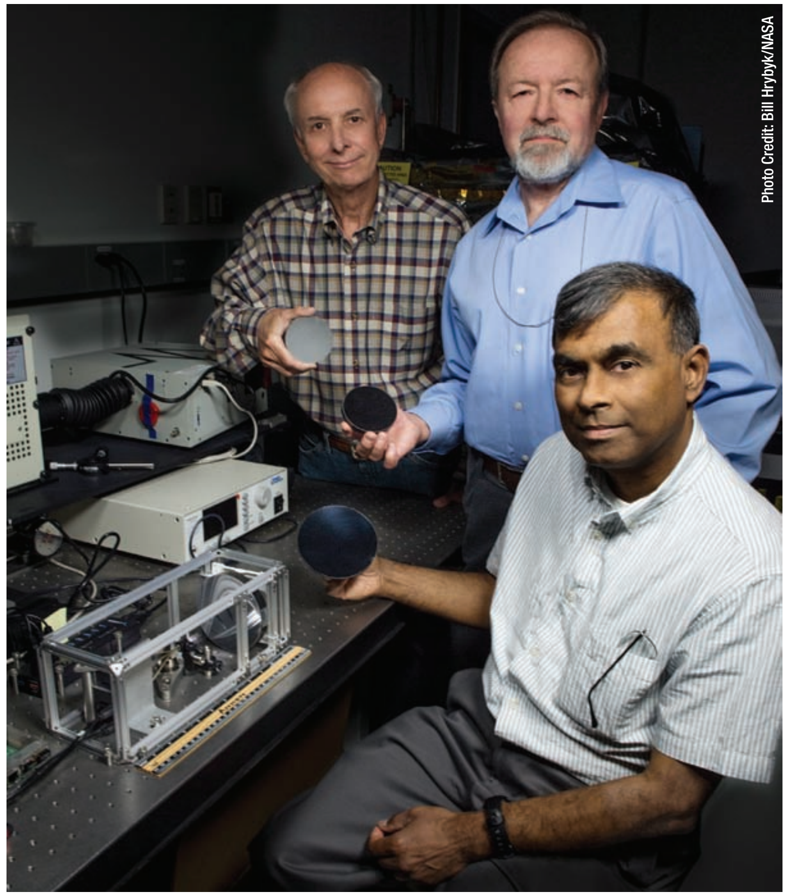
First-Ever Carbon-Nanotube Mirrors Eyed for CubeSat Telescope

A lightweight telescope that a team of Goddard scientists and engineers is developing specifically for CubeSat scientific investigations could become the first to carry a mirror made of carbon nanotubes in an epoxy resin.



John Kolasinski (left), Ted Kostiuk (center), and Tilak Hewagama (right) hold mirrors made of carbon nanotubes in an epoxy resin. The mirror, built by Peter Chen, is being tested for potential use in a lightweight telescope specifically for CubeSat scientific investigations.

Led by Goddard scientist Theodor Kostiuk, the technology-development effort is aimed at giving the scientific community a compact, reproducible, and relatively inexpensive telescope that would fit easily inside a CubeSat.

Sensitive to the ultraviolet, visible, and infrared wavelength bands, such a telescope would be equipped with commercial-off-the-shelf spectrometers and imagers and would be ideal as an "exploratory tool for quick looks that could lead to larger missions," Kostiuk explained. "We're trying to exploit commercially available components."

While the concept won't get the same scientific return as say a flagship-style mission or a large, ground-based telescope, it could enable first order scientific investigations or be flown as a constellation of similarly equipped CubeSats, added Kostiuk.

With support from Goddard's Internal Research and Development program, the team has created a laboratory optical bench made up of three commercially available, miniaturized spectrometers optimized for the ultraviolet, visible, and near-infrared wavelength bands. The spectrometers are connected via fiber-optic cables to the focused beam of a three-inch diameter carbon-nanotube mirror. The team is using the optical bench to test the telescope's overall design.

First-Ever Carbon-Nanotube Resin Mirror

By all accounts, the new-fangled mirror could prove central to creating a low-cost space telescope for a range of CubeSat scientific investigations.

Unlike most telescope mirrors made of glass or aluminum, this particular optic is made of carbon nanotubes embedded in an epoxy resin. Sub-micron-size, cylindrically shaped carbon nanotubes exhibit extraordinary strength and unique electrical properties, and are efficient conductors of heat. Owing to these unusual properties, the material is valuable to nanotechnology, electronics, optics, and other fields of materials science, and, as a consequence, are being used as additives in various structural materials.

"No one has been able to make a mirror using a carbon-nanotube resin," said Peter Chen, a Goddard contractor and president of Lightweight Telescopes, Inc., a Columbia, Maryland-based company working with the team to create the CubeSat-compatible telescope.

"This is a unique technology currently available only at Goddard," he continued. "The technology

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is too new to fly in space and must first go through the various levels of technological advancement. But this is what my Goddard colleagues (Kostiuk, Tilak Hewagama, and John Kolasinski) are trying to accomplish through the CubeSat program."

Advantages Abound

The use of a carbon-nanotube optic in a CubeSat telescope offers a number of advantages, said Hewagama, who contacted Chen upon learning of a NASA Small Business Innovative Research program awarded to Chen's company to further advance the mirror technology. In addition to being lightweight, highly stable, and easily reproducible, carbon-nanotube mirrors do not require polishing — a time-consuming and often times expensive process typically required to assure a smooth, perfectly shaped mirror, said Kolasinski, an engineer and science collaborator on the project.

To make a mirror, technicians simply pour the mixture of epoxy and carbon nanotubes into a mandrel or mold fashioned to meet a particular optical prescription. They then heat the mold to cure and harden the epoxy. Once set, the mirror then is coated with a reflective material of aluminum and silicon dioxide.

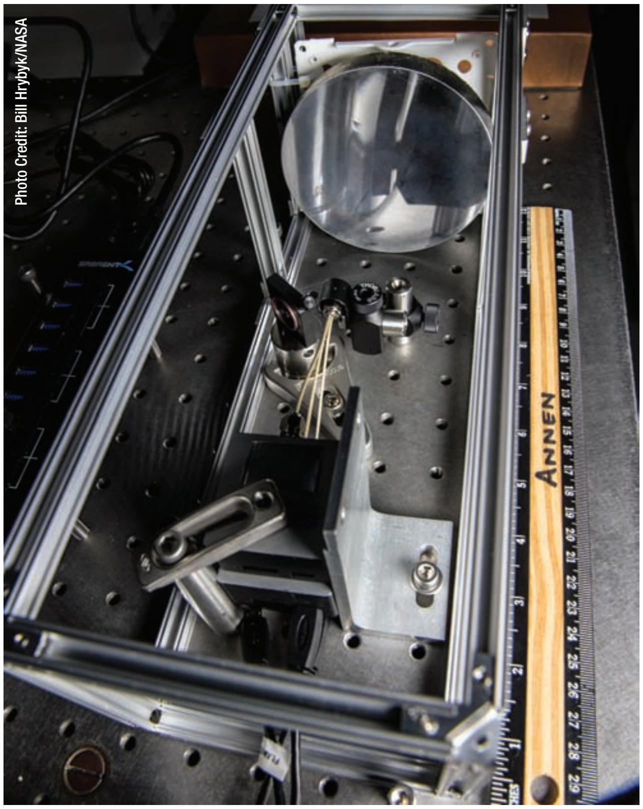
"After making a specific mandrel or mold, many tens of identical low-mass, highly uniform replicas can be produced at low cost," Chen said. "Complete telescope assemblies can be made this way, which is the team's main interest. For the CubeSat program, this capability will enable many spacecraft to be equipped with identical optics and different detectors for a variety of experiments. They also can be flown in swarms and constellations."

Other Applications

A CubeSat telescope is one possible application for the optics technology, Chen added.

He believes it also would work for larger telescopes, particularly those comprised of multiple mirror segments. Eighteen hexagonal-shape mirrors, for example, form the James Webb Space Telescope's 21-foot primary mirror and each of the twin telescopes at the Keck Observatory in Mauna Kea, Hawaii, contain 36 segments to form a 32-foot mirror.

Many of the mirror segments in these telescopes are identical and can therefore be produced using a single mandrel. This approach avoids the need to grind and polish many individual segments to the same shape and focal length, thus potentially leading to significant savings in schedule and cost.



This laboratory breadboard is being used to test a conceptual telescope for use on CubeSat missions.

Moreover, carbon-nanotube mirrors can be made into smart optics. To maintain a single perfect focus in the Keck telescopes, for example, each mirror segment has several externally mounted actuators that deform the mirrors into the specific shapes required at different telescope orientations.

In the case of carbon-nanotube mirrors, the actuators can be formed into the optics at the time of fabrication. This is accomplished by applying electric fields to the resin mixture before cure, which leads to the formation of carbon-nanotube chains and networks. After curing, technicians apply power to the mirror, thereby changing the shape of the optical surface. This concept has already been proven in the laboratory.

"This technology can potentially enable very large-area technically active optics in space," Chen said. "Applications address everything from astronomy and Earth observing to deep-space communications." ❖

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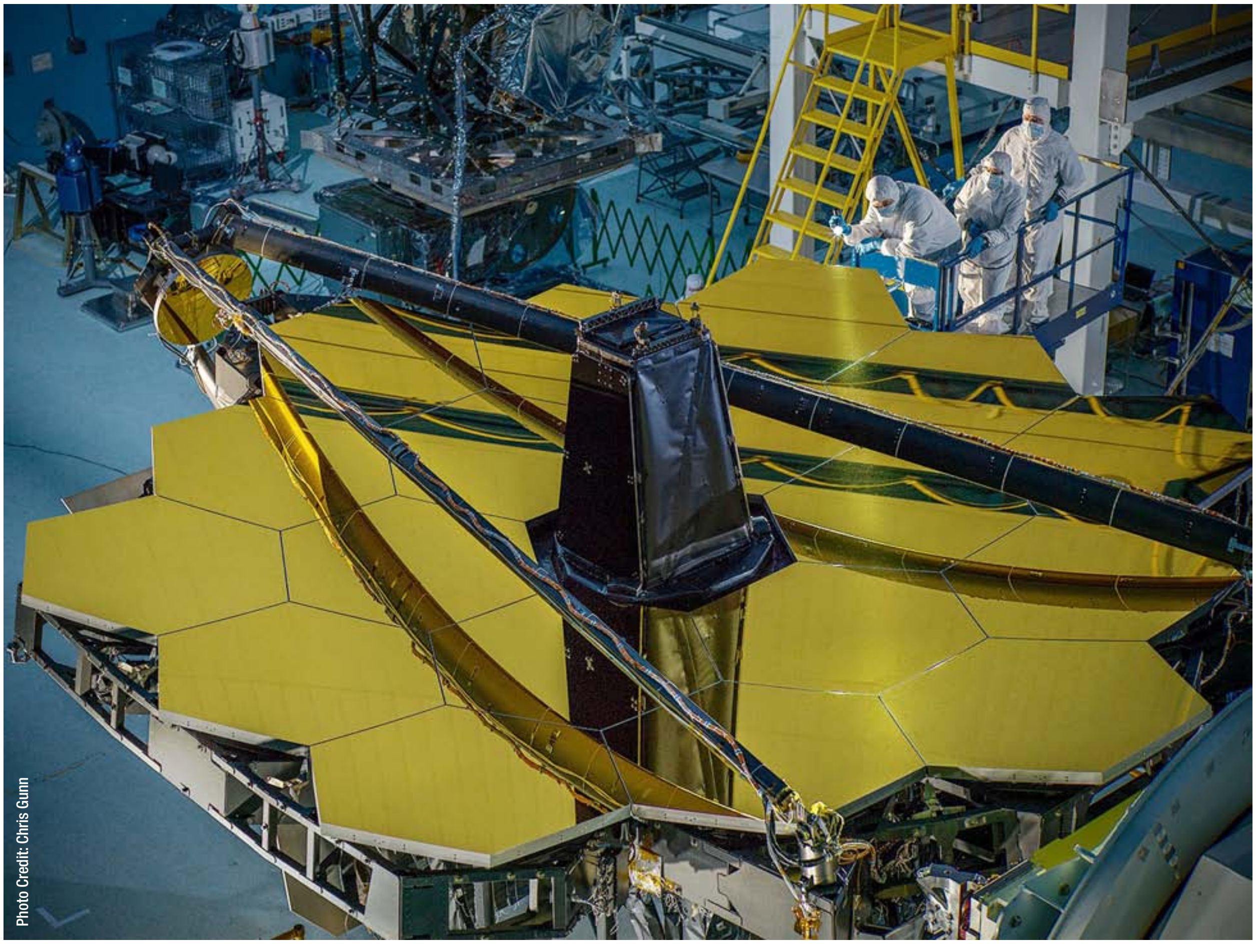
Seeking Picometer Accuracy

Goddard Team Develops New Measurement Tool



At a Goddard cleanroom, technicians unveil the James Webb Space Telescope's segmented mirror in preparation for an alignment test. The tool used to determine the segments' alignment has inspired Goddard technologists to create another that offers picometer accuracy for next-generation observatories.

Finding and characterizing dozens of Earth-like planets beyond our solar system will require a super-stable space telescope whose optical components move or distort no more than a few picometers — a measurement smaller than the size of an atom. It also will require next-generation tools with which to assure that level of stability.

A team of Goddard scientists has begun working with an Arizona-based company to develop a highly sophisticated laboratory tool — a high-speed interferometer — capable of assuring picometer-level stability, a feat not yet accomplished.

To date, NASA has not launched an observatory with such demanding stability requirements. However, the scientific community is studying the possibility. Last year, the Association of Universities for Research in Astronomy endorsed the High-Definition Space Telescope. It found that with proper stability and instrumentation, a 33-39 foot (10-12 meter) telescope could find and characterize Earth-like planets. Another study group evaluating a similar concept known as the Large Aperture Ultraviolet-Optical-Infrared Space Telescope, or LUVOIR, has reached similar conclusions.

"If the agency wants to search for and analyze Earth-like planets in other solar systems, the telescope it designs and builds will have to be orders of magnitude more stable than anything launched to date, including the James Webb Space Telescope," said Babak Saif, a Goddard optics specialist.

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New Tool to Assure Picometer-Level Stability

To help NASA reach this next level of precision, Saif and his Goddard colleague, Lee Feinberg, have begun working with 4-D Technology, of Tucson, Arizona, to develop the instrument.

Like all interferometers, the instrument would split light and then recombine it to measure tiny changes, including motion. With this tool, technicians would measure distortions in mirror segments, mounts, and other supporting telescope structure primarily during thermal, vibration, and other types of environmental testing.

> *"You need to measure what you're interested in and the instrument needs to calculate these motions quickly so that you can understand the dynamics."*
>
> ***– Babak Saif, Goddard Optics Expert***

Displacements and movement occur when materials used to build the optics shrink or expand due to wildly fluctuating temperatures, such as those experienced when traveling from Earth to the frigidity of space or when exposed to fierce launch forces more than six-and-a-half times the force of gravity.

If optics must conform to a specific prescription to carry out a challenging mission, even nearly imperceptible, atomic-size movements caused by thermal and dynamic changes could affect their ability to gather and focus enough light to distinguish a planet's light from that of its parent star — to say nothing of scrutinizing that light to discern different atmospheric chemical signatures, Saif said.

Leveraging Instrument Developed for Webb Testing

The effort leverages a similar instrument that 4-D Technology created to test the optics of the James Webb Space Telescope, which will be the most powerful observatory ever built once it launches in October 2018. From its orbit 930,000 miles from Earth, it will study every phase in the history of our universe, from the first luminous glows after the Big Bang to the evolution of our own solar system. Among many other firsts, the observatory will carry a 21-foot primary mirror made of 18 separate ultra-lightweight beryllium segments that deploy and adjust to shape after launch.

To carry out its job, the observatory also must be highly stable. However, the movement of materials used to construct the telescope is measured in nanometers — the unit of measure that scientists use to determine the size of atoms and molecules.

"What we did was measure the surface of each mirror after each environmental test to see if we could see changes," Saif said. "I started questioning, what if something behind the mirror moves. Just measuring the surface isn't enough."

To assure nanometer-level stability — 4-D Technology worked with the Webb Observatory team at Goddard to develop a dynamic laser interferometer that instantaneously measured displacements in the mirror segments as well as those in their mounts and other structural components, despite vibration, noise, or air turbulence.

"The high-speed interferometer actually enables you to do nanometer dynamics for large structures," Saif said. "This is absolutely new. The instrument is four orders of magnitude more sensitive than other measurement tools and it measures the full surface of the mirrors." That instrument now is used in laboratories, manufacturing areas, clean rooms, and environmental-testing chambers operated by the project's major contractors.

LUVOIR-Type Mission Ups the Ante

However, a next-generation LUVOIR-type mission will demand even greater stability, and consequently an instrument capable of quickly measuring picometer displacements, which are two orders of magnitude smaller than an atom. Although it is possible to calculate picometer movements with existing tools, the physics are non-linear and the resulting calculations might not accurately reflect what actually is going on, Saif said.

"Every subsystem needs to be designed on a picometer level and then tested at picometers," Saif explained. "You need to measure what you're interested in and the testing instrument needs to calculate these motions quickly so that you can understand the dynamics."

The team is developing the tool with $1.65 million in funding from NASA's Cosmic Origins Strategic Astrophysics Technology program. It expects to complete the work in four years. ❖

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Goddard Team Begins Testing New-Fangled Optic

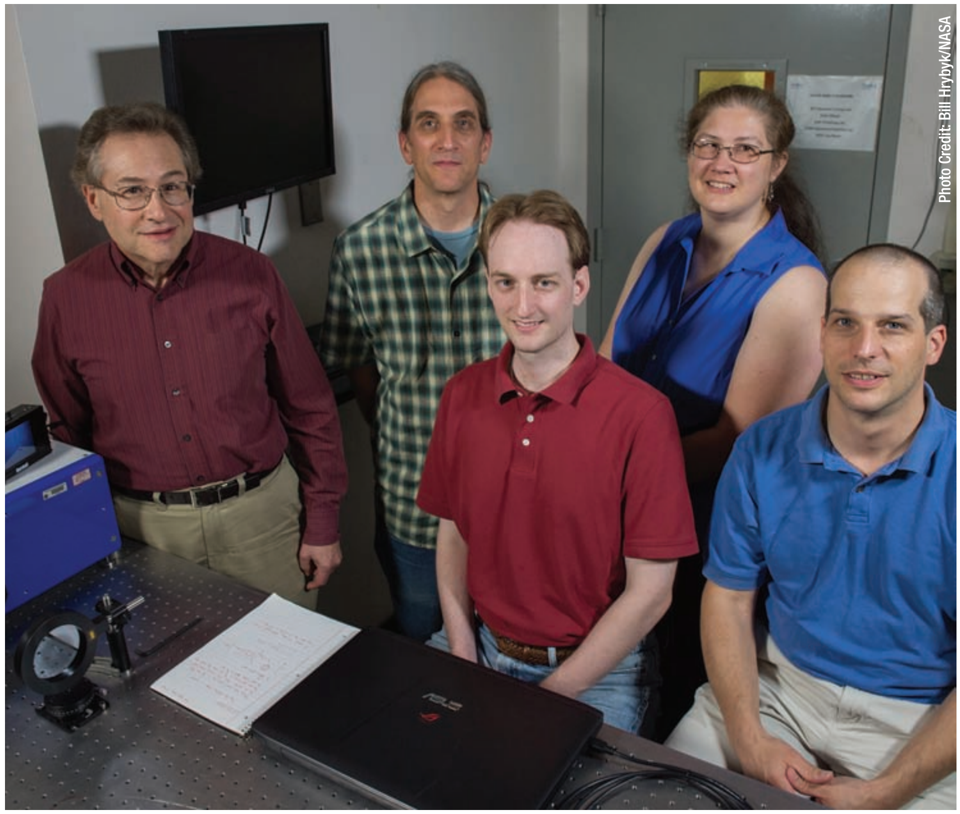

Photo Credit: Bill Hrybyk/NASA

Doug Rabin, Adrian Daw, John O'Neill, Anne-Marie Novo-Gradac, and Kevin Denis are developing an unconventional optic that could give scientists the resolution they need to see finer details of the physics powering the sun's corona. Other team members include Joe Davila, Tom Widmyer, and Greg Woytko, who are not pictured.

It's an age-old astronomical truth: To resolve smaller and smaller physical details of distant celestial objects, scientists need larger and larger light-collecting mirrors — a challenge not easily overcome given the high cost and impracticality of building and flying large-aperture telescopes.

However, a team of Goddard scientists and engineers has begun testing a potentially more affordable alternative called the photon sieve. This new-fangled telescope optic could give scientists the resolution they need to see finer details now invisible with current observing tools.

Although potentially useful at all wavelengths, the team specifically is developing the photon sieve for studies of the sun in the ultraviolet, a spectral zone that would reveal details about the physical processes powering the sun's million-degree corona. The team has fabricated three sieves and now plans to begin testing to see if they can withstand the rigors of space — milestones achieved in less than a year. "This is already a success," said Doug Rabin, who is leading the R&D initiative.

Variant of Fresnel Zone Plate

The optic is a variant of the Fresnel zone plate, which focuses light through diffraction rather than refraction or reflection. These devices consist of a set of alternating transparent and opaque concentric rings. Light hitting the plate diffracts around the opaque zones, which are precisely spaced so that the diffracted light interferes at the desired focus to create an image that can be recorded by a solid-state sensor.

The sieve operates in largely the same way. However, the rings are dotted with millions of holes precisely "drilled" into silicon. Their positions and sizes are configured so that the light diffracts to a desired focus. The sieve is self-supporting and can be patterned on a flat surface and scaled up in size.

The team's goal is creating a photon sieve that measures at least three feet, or one meter, in diameter — a size deemed necessary for achieving up to 100 times better angular resolution in the ultraviolet than even NASA's Solar Dynamics Observatory.

"For more than 50 years, the central unanswered question in solar coronal science has been to understand how energy transported from below is dissipated in the corona," Rabin said. "Current instruments have spatial resolutions about 100 times larger than the features that must be observed to understand this process."

Rabin believes his team is well along the way in building an optic that can help answer this question.

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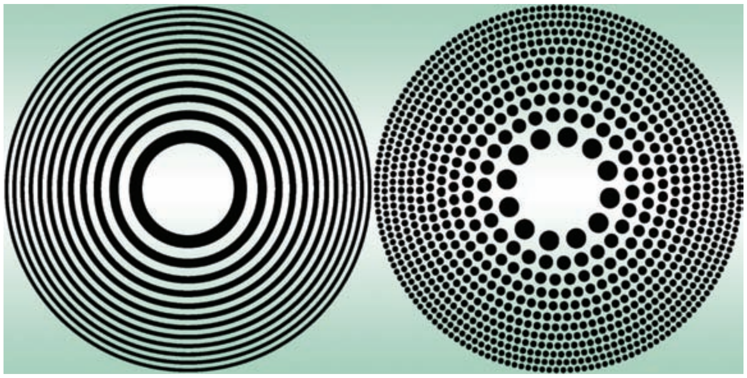

This drawing shows the differences between a Fresnel zone plate (left) and the photon sieve (right). The latter is dotted with millions of precisely machined holes. Image Credit: NASA

Millions of Holes

In just a few months' time, his team built three devices measuring three inches wide — five times larger than the initial optic developed four years ago under a previous R&D-funded effort (*CuttingEdge*, Spring 2012, Page 8). Each device contains 16 million holes whose sizes and locations were determined by team member Adrian Daw. Another team member, Kevin Denis, then etched the holes in a silicon wafer to Daw's exacting specifications using a fabrication technique called photolithography.

Team members Anne-Marie Novo-Gradac and John O'Neill now are acquiring optical images with the new photon sieves. Two other team members, Tom Widmyer and Greg Woytko, have prepared them for vibration testing to make sure they can survive harsh g-forces encountered during launch.

"This testing is to prove that the photon sieve will work as well as theory predicts," Rabin said. Although the team has already accomplished nearly all the goals it set forth when work began late last year, Rabin believes the team can enlarge the optics by a factor of two before the end of the fiscal year.

Formation-Flying CubeSat

But the work likely won't end there. In the nearer term, Rabin believes his team can mature the technology for a potential sounding-rocket demonstration. In the longer term, he and team member Joe Davila envision the optic flying on a two-spacecraft formation-flying CubeSat-type mission designed specifically to study the sun's corona. "The scientific payoff is a feasible and cost-effective means of achieving the resolution necessary to answer a key problem in solar physics," he said. ❖

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Quest to Mature Planet-Finding Instruments Progresses

Goddard Team's Expertise in Spectrograph Design Enhances State-of-the-Art

NASA's quest to mature more powerful tools to detect and analyze planets outside the solar system has taken several steps forward due in part to the efforts of a team of Goddard scientists involved in the development of next-generation ground- and space-based spectrographs.

In one of two related developments, Goddard scientist Michael McElwain and his team recently delivered a tabletop-size integral field spectrograph — the Prototype Imaging Spectrograph for Coronagraphic Exoplanet Studies, or PISCES — to the Jet Propulsion Laboratory, or JPL. JPL will use it to test starlight-suppression technologies for future planet-finding missions.

A similar-type instrument also has been baselined for NASA's Wide-Field Infrared Space Telescope, or WFIRST, a mission concept to detect exoplanets and study dark energy.

A few weeks earlier, McElwain, who had joined an instrument-proposal team led by Penn State University, learned that NASA had selected the team to build a cutting-edge instrument to measure the miniscule "wobbling" of stars caused by the gravitational tug of planets in orbit around them.

NEID — short for NN-EXPLORE Exoplanet Investigations with Doppler Spectroscopy — will be completed in 2019 and is to be installed on the 11.5-foot WIYN telescope at Kitt Peak National Observatory in Arizona. The instrument is the centerpiece of a new NASA partnership with the National Science Foundation.

"The work we did on the PISCES spectrograph and detectors translated to the NEID design," McElwain said. "Our expertise in spectrograph designs made these instruments possible."

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PISCES: Beyond the Zodiac

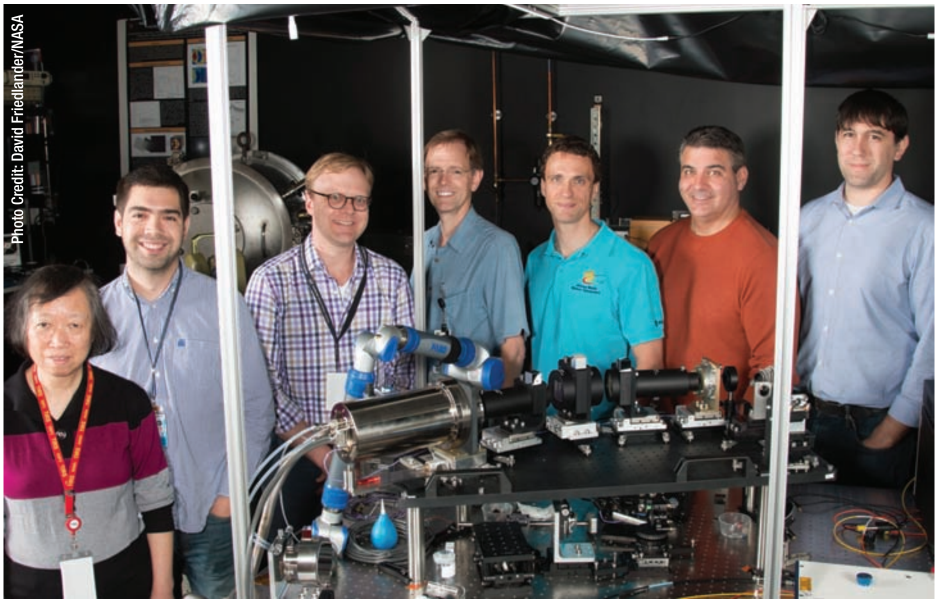

Photo Credit: David Friedlander/NASA

A team of Goddard technologists has delivered a tabletop-size device, known as PISCES. It will test candidate starlight-suppression techniques at the Jet Propulsion Laboratory. The team includes (from left to right): Qian Gong, Jorge Llop-Sayson, Michael McElwain, Norm Dobson, John Chambers, George Hilton, and Avi Mandell.

Spectrographs are among the most effective in a scientist's toolkit. While cameras image objects, spectrographs separate light by its wavelength and record the data, revealing details about a target's physical properties, including its chemical make-up.

PISCES is a type of integral field spectrograph, or IFS, a 3-D-type device that can gather spectral data at every spatial element in its field of view. Once installed on JPL's High-Contrast Imaging Testbed, PISCES will evaluate starlight-suppression techniques (CuttingEdge, Fall 2012, Page 4).

Indeed, extracting spectroscopic data from a distant planet is tricky business. The light of a host star dwarfs that of the exoplanet. But as long as scientists can get even a pinprick of light, they can measure the different wavelengths of light emanating from that object's atmosphere to learn more about its formation and evolution, and perhaps discover the presence of atoms and molecules that could indicate signatures of life.

Due to steady improvements in technology, an IFS-type spectrograph, such as PISCES, is baselined for WFIRST's coronagraph. This next-generation mission is currently being planned to perform an extraordinarily broad set of scientific investigations: studying the newly discovered phenomenon of dark energy, measuring the history of cosmic acceleration, completing the exoplanet census begun by the agency's Kepler Space Telescope, and demonstrating technology for direct imaging and characterization of exoplanets.

NEID Contributions

Taking lessons learned from PISCES, McElwain's team advanced a number of technologies to be used on NEID whose development is led by Penn State's Suvrath Mahadevan. Among them is a portal adapter that focuses light the telescope collects, using a wavefront sensor that counts the individual photons that make up that light, and directs the light via fiber-optic cabling to the spectrograph.

Penn State will build the spectrograph and Goddard will support the instrument's design, integration, testing, and commissioning, McElwain said. In exchange, NASA will get up to 50 nights of observing time each year.

Once commissioned, the ground-based telescope will search for and study new planets and planetary systems, following up on discoveries of NASA's Kepler Space Telescope and the Transiting Exoplanet Survey Satellite, or TESS, which the agency expects to launch in either 2017 or 2018. ❖

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Cutting edge Goddard's Emerging Technologies

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