National Aeronautics and Space Administration

Cutting edge

Goddard's Emerging Technologies

The Microshutter Breakthrough

Revolutionary Technology Gets Better

Goddard engineer Lance Oh and the next-generation microshutter arrays *(Photo Credit: Bill Hrybyk/NASA)*

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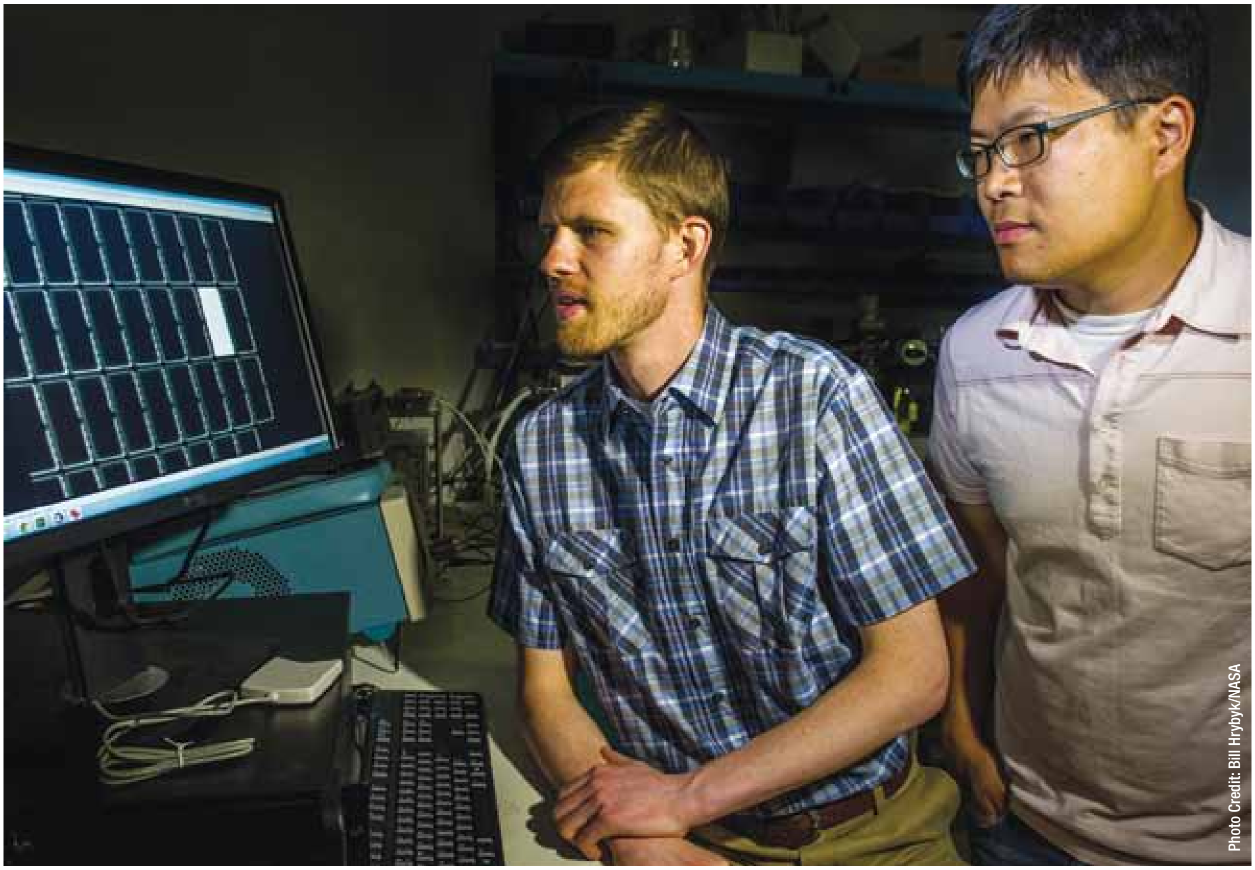
Revolutionary Observing Technique Gets Better

Team Advances Microshutter Array Technology



A good team is behind every success story. Goddard engineers Devin Burns and Lance Oh are pictured here with the next-generation microshutter arrays. Other team members include scientists Harvey Moseley, Alexander Kutyrev, Stephan McCandliss (Johns Hopkins University), Sara Heap, and engineers Mary Li, Ed Aguayo, Knute Ray, Justin Jones, Dan Kelly, Fred Wang, Yiting Wen, George Manos, Nick Costen, and Bing Guan.

Goddard technologists have hurdled a number of significant technological challenges in their quest to improve an already revolutionary observing technology originally created for the James Webb Space Telescope.

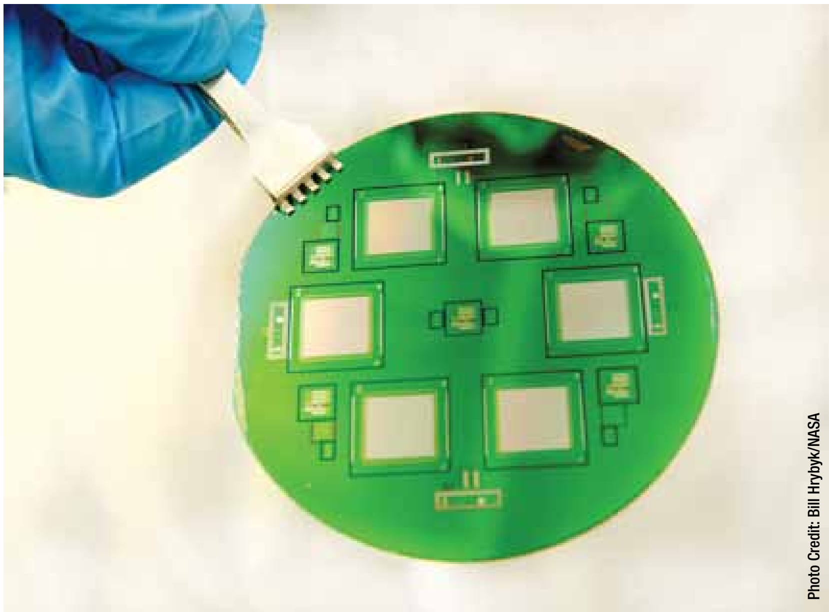
The team, led by Principal Investigator Harvey Moseley, has demonstrated that electrostatically actuated microshutter arrays — also known as next-generation arrays — are as functional as magnetically actuated arrays, making them a highly attractive capability for potential Explorer-class missions designed to perform multi-object observations.

"We have identified real applications — three scientists want to use our microshutter arrays and the commercial sector has expressed interest," said Mary Li, who is working with Moseley and other team members to fully develop this already groundbreaking observing technology. "The electrostatic concept has been fully demonstrated and our focus now is on making these devices highly reliable."

Progress, she said, is in large part due to the fact that the team successfully eliminated all macro-moving parts and dramatically lowered the voltage needed to operate the next-generation microshutter arrays. In addition, the team applied advanced electronic circuitry and manufacturing techniques to assure the microshutter arrays' dependable operation in orbit, Li added.

The Microshutter Breakthrough

Considered among the most innovative technologies to fly on the Webb telescope, the microshutter assembly is created from micro-electro-mechanical technologies and comprises thousands of tiny shutters, each about the width of a human hair. Assembled on four postage-size grids or arrays, the 250,000 shutters open or close individually to allow only the light from targeted objects to enter Webb's Near Infrared Spectrograph (NIRSpec), which will help identify types of stars and gases and measure their distances and motions. Because Webb will observe faint, far-away objects, it will take as long as a week for NIRSpec to gather enough light to obtain good spectra.



This image shows a close-up view of the next-generation microshutter arrays during the fabrication process. The technology advances an already groundbreaking multi-object observing technique.

NIRSpec's microshutter array, however, enhances the instrument's observing efficiencies. It will allow scientists to gather spectral data on 100 objects at a time, vastly increasing the observatory's productivity. When NASA launches the Webb telescope in 2018, it will represent a first for multi-object spectroscopy.

Quest to Improve Design

Determined to make the microshutter technology more broadly available, Goddard technologists have spent the past four years experimenting with techniques to advance this capability.

One of the first things the team did was eliminate the magnet that sweeps over the shutter arrays to activate them. As with all mechanical parts, the magnet takes up space, adds weight, and is prone to mechanical failure. Perhaps more important, the magnet cannot be easily scaled up in size without creating significant fabrication challenges. As a result, the instrument's field of view — that is, the area that is observable through an instrument — is limited in size. This greatly impedes next-generation space observatories that will require larger fields of view, such as NASA's proposed Advanced Large Aperture Space Telescope, a potential user (see related story, page 4).

Magnetic activation also takes longer. With the Webb telescope, the magnet must first sweep over the array to open all the shutters before voltages are selectively applied to open or close specific shutters.

Achieving the Voltage Sweet Spot and Other Milestones

To accommodate the needs of future observatories, the team replaced the magnet with electrostatic actuation. By applying an alternating-current voltage to electrodes placed on the frontside of the microshutters, the shutters swing open. To latch the desired shutters, a direct current voltage is applied to electrodes on the backside. In other words, only the needed shutters are opened; the rest remain closed. "This reduction in cycles should allow us to extend the lifetime of the microshutter arrays 100 times or more," Li explained.

And because the magnet no longer dictates the size of the array, its elimination will allow scientists to assemble much larger arrays for instruments whose fields of view are 50 times larger than Webb's NIRSpec, she said.

Just as significant is the voltage needed to actuate the arrays. When the effort first began four years ago, the team only could open and close the shutters with 1,000 volts. By 2011, the team had slashed that number to 80 volts — a level that still could exceed instrument voltage specifications. By last year, the team had achieved a major milestone by activating the shutters with just 30 volts — a voltage sweet spot, Li said.

"But we also did something else," she added. Through experimentation, the team used atomic layer deposition, a state-of-the-art fabrication technology, to fully insulate the tiny space between the electrodes to eliminate potential electrical crosstalk that could interfere with the arrays' operation.

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Laying Plans to Observe New Worlds

Goddard-Led Team Casts Its Eyes to the Future

It can take decades to mature an astrophysics flagship mission from concept to launch pad.

For example, the iconic Hubble Space Telescope — arguably the greatest telescope in history and certainly the most recognized — was proposed in the 1940s. Its development began in the 1970s and it launched in 1990. Similarly, the James Webb Space Telescope will launch in 2018, 23 years after work began on the concept. And if approved for development, the Wide-Field Infrared Space Telescope-Astrophysics Focused Telescope Assets (WFIRST-AFTA), currently in a study phase, could launch by the mid-2020s. Early versions of this mission were first proposed in the early 2000s.

Photo Credit: NASA

A Hubble Space Telescope Servicing Mission-4 crewmember snapped this photo of the observatory just after the Space Shuttle Atlantis captured it with its robotic arm. A team is now investigating a potential successor to Hubble and the James Webb Space Telescope.

Given the long lead times, it's time to lay plans for a future flagship mission, scientists and engineers agree.

A team led by Goddard scientists and engineers is now studying the scientific and technical requirements and costs associated with building a successor to Hubble and the Webb telescope. Dubbed the Advanced Technology Large-Aperture Space Telescope (ATLAST), the observatory will build upon key technologies developed for Hubble and Webb. "Conceptually, ATLAST would leverage the technological advances pioneered by the Webb telescope, such as deployable, large segmented-mirror arrays," said Mark Clampin, ATLAST study scientist and Webb's project scientist.

The study team also includes world-renowned experts in science and technology from the Space Telescope Science Institute, which manages the Hubble program, the Jet Propulsion Laboratory, and the Marshall Space Flight Center.

NASA already has identified an ATLAST-type mission in its recent 30-year vision for astrophysics, "Enduring Quests, Daring Visions." "While people expect Hubble and Webb to operate for many years, we are looking ahead to the telescope and instrument requirements needed to answer the questions posed in NASA's 30-year vision," said Harley Thronson, the Goddard senior scientist for Advanced Concepts in Astrophysics and ATLAST study scientist.

The investigation ultimately will result in design studies, science justifications, and technology roadmaps that the National Research Council (NRC) then could use when developing its 2020 Decadal Survey for Astrophysics, which recommends priority research areas, observations, and priority missions for the subsequent decade. These surveys take advantage of significant input from the astronomical community and represent a consensus opinion of priorities NASA should pursue.

Different Science Objectives

The Webb telescope is often referred to as Hubble's scientific successor, though its science mission is different. Equipped with a 21-

foot (6.5-meter) segmented primary mirror, this cold observatory will peer into the cosmos from its orbital outpost nearly 1-million miles (1.5-million kilometers) from Earth to study the birth and evolution of galaxies and the formation of stars and planets. Its suite of four instruments operates from long-wavelength visible to mid-infrared wavelength bands ideal for studying very distant objects in the universe or peering into dusty regions of our own galaxy where visible light is blocked.

WFIRST-AFTA, the current version of WFIRST using a nearly 8-foot (2.4-meter) mirror, will be equipped with an imager and a slitless spectrometer to study dark energy, the mysterious form of

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Hubble's Greatest Hits

Despite its rocky start, the Hubble Space Telescope is now considered one of the most powerful and prolific science machines ever made. Next year, the observatory will celebrate its 25th anniversary in space — an event that some believe is notable because of its longevity. It is the longest-operating space telescope ever built.

But the iconic telescope has proven to be more than just long-lived. Since its deployment in 1990, followed by a series of servicing missions that made it 100 times more powerful than the day it began operations, Hubble has made revolutionary discoveries. Here are just a few.

The iconic Hubble Space Telescope just celebrated its 24th anniversary in space. The program marked the milestone with this infrared image of a nearby star factory some 6,400 light-years away. (Photo Credit: NASA, ESA, and the Hubble Heritage Team STScI/AURA)

The Hubble Constant

Edwin Hubble, the astronomer for whom the telescope is named, first reported that the universe was expanding. It was the telescope's job to pin down this rate of expansion, called the Hubble Constant. To find out, the observatory measured the brightness of dozens of pulsating stars called Cepheid variables, which are a thousand times brighter than the sun.

Through these studies, scientists pinned down the rate of expansion to less than five percent — a calculation that then enabled them to derive the age of the universe, which, before Hubble, ranged from 10 to 20 billion years. From the observatory's measurements, scientists now know that the universe is 13.75 billion years old.

Dark Energy

By determining the rate at which the universe is expanding, and therefore the age of the universe, the telescope uncovered yet another mystery. It discovered that the universe's rate of expansion isn't slowing down or remaining constant. It's accelerating, apparently in defiance of the pull of gravity.

The culprit? Dark energy. Scientists now believe that nearly 70 percent of the universe is made up of this mysterious stuff. NASA now plans to launch the Wide-Field Infrared Survey Telescope-Astrophysics Focused Telescope Assets mission to investigate this mysterious force that some believe might be a dynamic energy field.

Dark Matter

The universe also contains an invisible form of matter that makes up most of its mass and forms its underlying structure. Dark matter's gravity allows normal matter in the form of gas and dust to collect and build up into stars and galaxies. Although no one can see this substance, astronomers can detect its influence in galaxy clusters by observing how its gravity bends and distorts the light of more distant background galaxies, a phenomenon called gravitational lensing.

Astronomers used these gravitational-lensing techniques to construct a three-dimensional map, which shows that normal matter in the form of galaxies accumulates along the densest concentration of dark matter.

Fomalhaut b

Although ground-based telescopes and NASA's Kepler observatory have discovered most of the extrasolar planets found so far, it was the Hubble Space Telescope that actually imaged in visible light the first planet, named Fomalhaut b, which is three times larger than Jupiter and is located about 25 light-years away.

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Goddard's IceCube No Longer On Ice

NASA Chooses Mission as its First Earth-1 CubeSat

NASA's Science Mission Directorate (SMD) has chosen a Goddard team to build its first Earth science-related CubeSat mission.

The tiny payload, known as IceCube or Earth-1, will demonstrate and validate a new 874-gigahertz submillimeter-wave receiver that could help advance scientists' understanding of ice clouds and their role in climate change.

Under the same solicitation, SMD also selected five heliophysics-related missions, two involving Goddard scientists who will serve as co-investigators responsible primarily for data analysis and instrument design. All will fly on a three-unit or 3U CubeSat, which is comprised of individual units each about four inches on a side. Each satellite will weigh about three pounds.

Typically found at heights greater than 20,000 feet, cirrus clouds are composed of ice crystals, which IceCube will measure as the Science Mission Directorate's first Earth-1 CubeSat mission.

For the IceCube team, led by Principal Investigator Dong Wu, the news was sweet.

The team originally submitted the proposal nearly two years ago. Although SMD reviewers gave the proposal high marks, they ultimately did not select it, said Jeff Piepmeier, associate head of Goddard's Microwave Instruments and Technology Branch. "Needless to say, we were thrilled when we got the news that the Directorate had chosen it as its first Earth-1 CubeSat," he said. "I really pushed this. I really think it's an important opportunity. There is a need to do Earth science on CubeSats, a need for constellations of satellites that can carry out simultaneous, multipoint observations. As of now, CubeSats offer the only financially feasible platform for achieving this goal."

Qualifying COTS Receiver

As the Directorate's first Earth Science CubeSat mission, IceCube will demonstrate and space-qualify a commercially available 874-gigahertz submillimeter-wave receiver developed by Virginia Diodes, Inc., of Charlottesville, Virginia, under a NASA Small Business Innovative Research contract. Ultimately, the team wants to infuse this receiver into an ice-cloud imaging radiometer for NASA's proposed Aerosol-Cloud-Ecosystems (ACE) mission recommended by the National Research Council.

If NASA develops ACE, the mission would accurately assess on a daily basis the global distribution of atmospheric ice. Knowing these values would help scientists describe the linkage between the hydrologic and energy cycles in the climate system. Ice clouds ultimately are a product of precipitating cloud systems and dramatically affect the Earth's emission of infrared energy into space and its reflection and absorption of the sun's energy over broad areas. To this day, the amount of atmospheric ice on a global scale remains highly uncertain.

The key is obtaining measurements over a broader frequency band, from the infrared to submillimeter wavelengths, IceCube team members said. Submillimeter wavelength coverage fills the data gap in the middle and upper troposphere where ice clouds are often too opaque for infrared and visible sensors to penetrate. Microwave wavelengths are not sensitive to ice.

Although NASA has flown submillimeter receivers in airborne missions — a capability that was non-existent just a decade ago before VDI began advancing its 874-gigahertz receiver — it has not flown them in space.

"What we want to do is modify this receiver to fly in space and raise its technology-readiness level for ACE, which is the most relevant mission for this technology," said Goddard scientist Paul Racette, a member of the IceCube team. Although the technology itself has proven its mettle in aircraft demonstrations mainly through a Goddard-developed instrument called the Compact Scanning Submillimeter-wave Imaging Radiometer (*Goddard Tech Trends,* Winter 2008, Page 5), challenges remain.

"The receiver technology is very challenging," Racette added. "The team must make sure the receiver is sensitive enough to detect and measure ice clouds using little power from a very small platform. This project will help us develop the processes required to space-qualify commercial-off-the-shelf components," he said.

Goddard Heliophysicists Play Role

IceCube, however, wasn't the only winning proposal involving Goddard scientists and engineers.

Co-Investigator Eric Christian is serving as the Goddard lead on the CubeSat Mission to Study Solar Particles over the Earth's Poles (CuSPP), led by the Southwest Research Institute. With an innovative miniaturized sensor, the mission will study the sources and mechanisms that accelerate solar and interplanetary particles in near-Earth orbit. It also will examine ion precipitation emanating from the magnetosphere into the high-latitude ionosphere.

This image shows a model of CuSPP, or CubeSat Mission to Study Solar Particles over the Earth's Poles. CuSPP will study the sources and mechanisms that accelerate solar and interplanetary particles in near-Earth orbit.

His team will apply lessons learned developing the IRAD-funded Compact Radiation belt Explorer (CeRES), another CubeSat mission led by Goddard scientist Shri Kanekal (*CuttingEdge,* Spring 2014, Page 8). CeRES, which is being developed under NASA's CubeSat Launch Initiative, will study charged-particle dynamics in Earth's radiation belts.

While the CuSPP instrument is different from the one flying on CeRES, "we're definitely leveraging lessons we learned from CeRES," Christian said. "IRAD certainly helped, and, in fact, I think the work we did is one of the main reasons we won this mission."

Under the other heliophysics-related CubeSat mission, scientist Phil Chamberlin will analyze data collected by the Miniature X-ray Solar Spectrometer (MinXSS), a mission led by the University of Colorado. The objective is to better understand the energy distribution of soft X-rays emitted by solar flares and discovering how they affect Earth's ionosphere, thermosphere, and mesosphere.

"Right now, we don't know their distribution," Chamberlin said, adding that solar-flare events adversely affect satellites and other assets in low-Earth orbit. "This will be the first time we've accurately measured the distribution of soft X-rays." ❖

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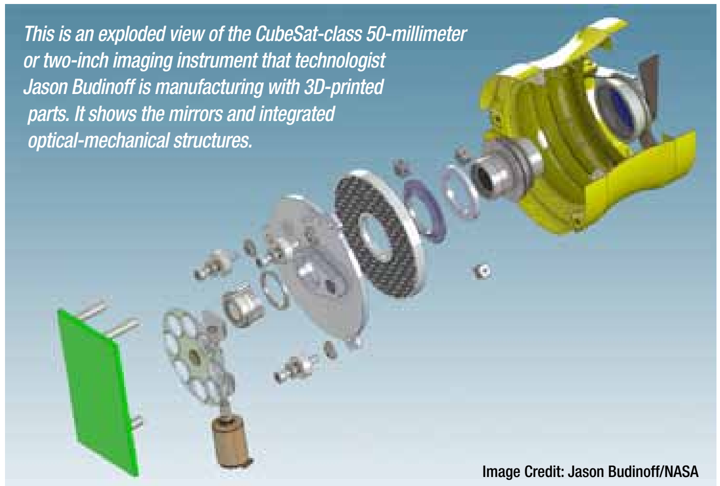
Aerospace Engineer Set to Complete First 3D-Printed Space Cameras

By the end of September, Goddard aerospace engineer Jason Budinoff is expected to complete the first imaging telescopes ever assembled almost exclusively from 3D-manufactured components.

"As far as I know, we are the first to attempt to build an entire instrument with 3D printing," Budinoff said.

Under his multi-pronged project, funded by Goddard's Internal Research and Development (IRAD) program, Budinoff is building a fully functional, 50-millimeter or two-inch camera whose outer tube, baffles, and optical mounts are all printed as a single structure. This instrument, which is appropriately sized for a CubeSat, will be equipped with conventionally fabricated mirrors and glass lenses and will undergo vibration and thermal-vacuum testing next year. He also is assembling a 350-millimeter or 14-inch dual-channel telescope whose size is more representative of a typical space telescope.



This is an exploded view of the CubeSat-class 50-millimeter or two-inch imaging instrument that technologist Jason Budinoff is manufacturing with 3D-printed parts. It shows the mirrors and integrated optical-mechanical structures.

Image Credit: Jason Budinoff/NASA

Pathfinder Project

Budinoff is developing both to show that telescope and instrument structures can benefit from advances in 3D or additive manufacturing. With this technique, a computer-controlled laser melts and fuses metal powder in precise locations as indicated by a 3D CAD model. Because components are built layer by layer, it is possible to design internal features and passages that could not be cast or machined using more traditional manufacturing approaches.

The goal isn't to fly them, at least not yet. "This is a pathfinder," he said. "When we build telescopes for science instruments, it usually involves hundreds of pieces. These components are complex and very expensive to build. But with 3D printing, we can reduce the overall number of parts and make them with nearly arbitrary geometries. We're not limited by traditional mill- and lathe-fabrication operations," he said.

In particular, the two-inch instrument design involves the fabrication of four different pieces made from powdered aluminum and titanium. A comparable, traditionally manufactured camera would require between five to 10 times the number of parts, he said. Furthermore, the instrument's baffling — the component that helps reduce stray light in telescopes — is angled in a pattern that instrument builders cannot create with traditional manufacturing approaches in a single piece.

When he completes the camera's assembly at the end of the fiscal year — ready for space-qualification testing — the project will have taken a mere three months to complete for a fraction of the cost. "I basically want to show that additive-machined instruments can fly. We will have mitigated the risk, and when future program managers ask, 'can we use this technology,' we can say, 'yes, we already have qualified it.'"

Other Objectives

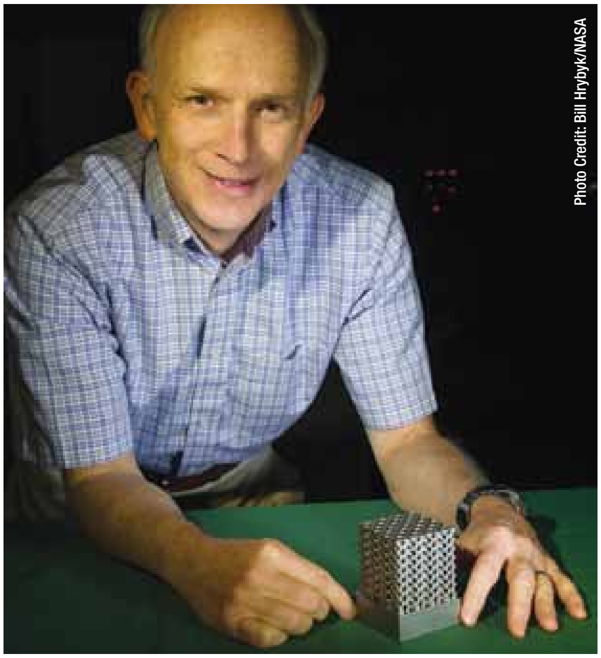
Budinoff also wants to demonstrate that he can use powdered aluminum to produce 3D-manufactured telescope mirrors — a challenge given the porosity of aluminum, which makes it difficult to polish the surfaces. Under his plan, a 3D-manufacturing vendor will fabricate an unpolished mirror blank appropriate for his two-inch instrument. He then will place the optic inside a pressure chamber filled with inert gas. As the gas pressure increases to 15,000 psi, the heated chamber in essence will squeeze the mirror to reduce the surface porosity — a process called hot isostatic pressing.

"We think this, combined with the deposition of a thin layer of aluminum on the surface and Goddard-developed aluminum stabilizing heat treatments, will enable 3D-printed metal mirrors," Budinoff said.

Should he prove the approach, Budinoff said NASA scientists would benefit enormously — particularly those interested in building infrared-sensing instruments, which typically operate at super-cold temperatures to gather the infrared light that can be easily overwhelmed by instrument-generated heat. Often, these instruments are made of different materials. However, if all the instrument's components, including the mirrors, were made of aluminum, then many of the separate parts could be 3D printed as single structures, reducing the parts count and material mismatch. This would decrease the number of interfaces and increase the instrument's stability, Budinoff added.

Next year, he also plans to experiment with printing instrument components made of Invar alloy, a material being prepared for 3D printing by Goddard technologist Tim Stephenson (*CuttingEdge*, Winter 2012, Page 8). The 100-year-old iron-nickel alloy offers extreme dimensional stability over a range of temperatures. The material is ideal for building super-stable, lightweight skeletons that support telescopes and other instruments.

"Anyone who builds optical instruments will benefit from what we're learning here," Budinoff said. "I think we can demonstrate an order-of-magnitude reduction in cost and time with 3D printing." ❖



Next year, Principal Investigator Jason Budinoff plans to experiment with printing instrument components made of Invar alloy, a material being prepared for 3D printing by Goddard technologist Tim Stephenson who is pictured here along with his Invar structure.

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Three Radars Are Better Than One

Field Campaign Demonstrates Two New Instruments

Putting three radars on a plane to measure rainfall may seem like overkill. But for the Integrated Precipitation and Hydrology Experiment field campaign in North Carolina recently, more definitely was better.

The three instruments, developed by Goddard's High Altitude Radar group with support from the center's Internal Research and Development (IRAD) program, flew as part of the Global Precipitation Measurement (GPM) mission's six-week ground-validation program that took place in the southern Appalachians specifically to measure rain in difficult-to-forecast mountain regions. In addition to validating measurements, the campaign tested data-processing algorithms made by the GPM Core Observatory, launched in February.

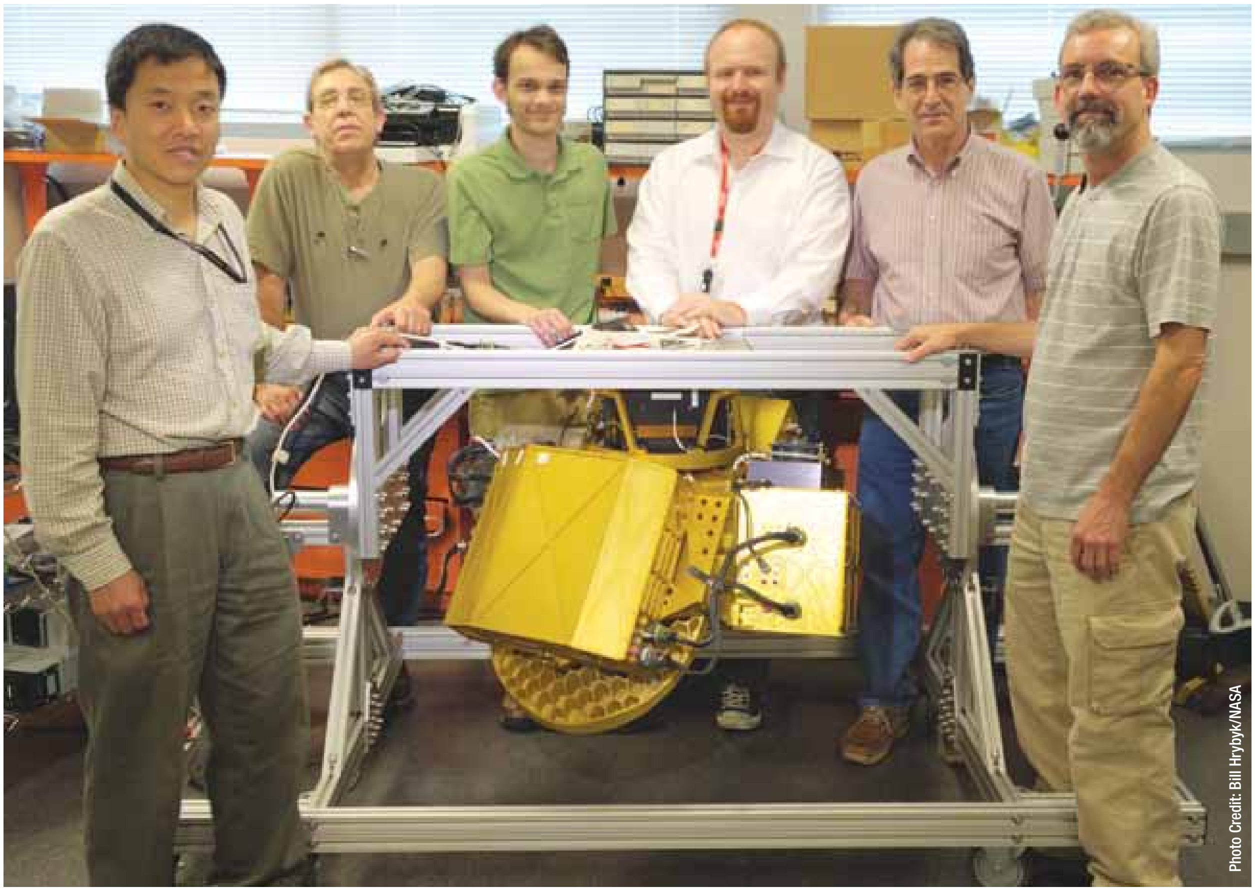
The campaign represented a first for NASA. Never before had the Agency flown more than two radar systems, tuned to different frequencies, to measure rainfall in the field. In addition, two of the instruments were making their maiden flight to demonstrate technological improvements that may pave the way for future high-performance airborne or space-borne precipitation radars essential for studying storms.

Future precipitation missions and, more particularly, the Aerosol-Clouds-Ecology (ACE) mission, which the National Research Council recommended in its Earth Science Decadal Survey, have made the development of new radar systems to observe clouds and light precipitation a priority.

Why Radar and Why Three?

According to campaign scientists, the decision to fly three different systems was far from overkill.

Rainfall comes in more than 31 flavors, from tiny cloud droplets and misty drizzle, to fat raindrops and two-inch hailstones, and, of course, everything



Also flying on the campaign was the Goddard-developed High–altitude Wind and Rain Profiler, developed by the High Altitude Radar Group. The team includes (from left to right): Lihua Li, Gerry McIntire, Michael Coon, Matthew McLinden, Gerry Heymsfield, and Martin Perrine. McLinden led the work on the Cloud Radar System and Li led the work on EXRAD.

in between. Different radar frequencies pick up different precipitation types, generally based on size and whether the particles are ice or liquid. Radars flying with multiple frequencies can study more precipitation types and identify where they occur inside clouds, giving scientists a more complete picture of the inner workings of a rainstorm.

In particular, lower-microwave frequencies can detect heavy rain all the way to the ground. But tiny cloud particles require a higher-microwave frequency signal to detect them. Because that signal sometimes gets absorbed before it makes it all the way through the cloud and back to the radar, precipitation radars traditionally require a large, high-powered antenna.

What's Old is New Again

Enter the Cloud Radar System, a 20-year-old radar that has been completely rebuilt from the inside out, said Gerry Heymsfield of Goddard's High Altitude Radar group, which revamped the instrument with support from the ACE mission and Goddard's IRAD program. "The old one was a good radar," Heymsfield said, "but the big difference in the new one is we're using a solid-state transmitter." The new transmitter, which sends the radar pulse, requires less power, occupies less space, and returns more reliable results — advances that make a radar system more suitable for aircraft and satellites.

The Cloud Radar System also sports a new antenna for receiving the data-laden return signals, or backscatter, of the radar pulse. Partners at Northrup Grumman designed the new antenna that was developed under NASA's Instrument Incubator Program (IIP) led by Goddard Principal Investigator Paul Racette. The result is a scaled down, proof-of-concept of what may one day fly in space, Heymsfield said.

The Cloud Radar System design grew out of a similar approach the High Altitude Radar group used to build the two other radars that measured rainfall during the campaign: the High–altitude Wind and Rain Profiler (HIWRAP), funded by IRAD and IIP, and the ER-2 X-Band Radar (EXRAD), also funded by Goddard's IRAD program and NASA's Airborne Instrument Technology Transition program.

Satellite Simulator

All three radars flew at an altitude of 65,000 feet on NASA's ER-2 aircraft. Beneath the ER-2, a second plane flew through clouds to collect data on the details of the precipitation and cloud particles. A ground-based radar scanned the air between the surface and the rainclouds, and a network of rain gauges and other instruments captured precipitation as it hit the ground.

During the six-week field campaign, HIWRAP — one of several instruments also used on NASA's high-profile Hurricane and Severe Storm Sentinel mission (*CuttingEdge* Summer 2013, Page 6) — stood in for the GPM satellite. Its two radar frequencies — 35 gigahertz for light rain and 13.5 gigahertz for heavy rain — are nearly identical to the GPM Core Observatory's Dual-frequency Precipitation Radar. Scientists collected the data, which they now will process with computer algorithms specifically designed to convert radar-retrieval data into rain estimates. They then will compare those estimates with the ground data to determine whether they need to fine-tune the algorithms, Heymsfield said.

EXRAD, like the retooled Cloud Radar System, made its flight debut during the campaign. It complemented HIWRAP by gathering data in the 10-gigahertz frequency band ideal for measuring big raindrops and hail in thunderstorms. Unlike other radars that are fixed only to point down, EXRAD also has a scanning capability to capture rainfall over a wider field of view below.

Unique Capability

Multiple radars with multiple frequencies looking at the same storm provided the science team with a unique capability, Heymsfield said. As the ER2 flew overhead, the radars and other instruments captured how the range of cloud droplets, raindrops, and ice pellets moved and changed relative to one another over time. Those observations got at the heart of how storm systems behave, which in turn will lead to better models used for weather and flood forecasting, Heymsfield said.

"When you look at different clouds with different frequencies, it tells a lot about the cloud particles that are in there," said Heymsfield. "Having four frequencies on the ER-2 allowed us to measure a much broader range of cloud and precipitation that will help both GPM and future cloud and precipitation missions." ❖

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This image shows severe thunderstorms over South Carolina, as observed from NASA's ER-2 aircraft flying at 65,000 feet during the Integrated Precipitation and Hydrology Experiment recently.

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NASA's Robotic Refueling Mission to Demonstrate New Satellite Inspection Tool

Photo Credit: Chris Gunn/NASA

Photo Credit: Jon Kraeuter/NASA

Left image: Even inspection tools get inspected before they fly to orbit. Robotic tool engineer Jon Kraeuter examines VIPIR in preparation for its launch to the International Space Station. Right image: At a mere 1.2 millimeters in diameter — the thickness of a dime — VIPIR's borescope camera is the smallest commercial camera ever screened by NASA for use in space. Here, the device is shown next to a dime.

A new borescope inspection tool named VIPIR — the Visual Inspection Poseable Invertebrate Robot — is being put to the test later this year as part of NASA's Robotic Refueling Mission (RRM) on the International Space Station. Designed and built by Goddard's Satellite Servicing Capabilities Office (SSCO), the VIPIR toolset could one day help mission operators who need robotic eyes to troubleshoot anomalies, investigate micrometeoroid strikes, and carry out teleoperated satellite-repair jobs.

The Automated Transfer Vehicle is slated to deliver VIPIR to the orbital outpost in July. Later in the year, SSCO then will conduct a series of teleoperated technology demonstrations involving the RRM module and the Canadian Dextre robot. On-orbit results will help the team determine which cameras are best suited for different tasks on potential servicing endeavors in the future.

SSCO's Robotic Refueling Mission, of which VIPIR is a part, has been demonstrating satellite-servicing tools, technologies, and techniques on orbit since 2011."Back when we started identifying a foundational set of servicing capabilities, we recognized early on that we'd need a close-range inspection tool to assist during detailed teleoperated repair jobs," said Benjamin Reed, deputy project manager of SSCO. "We also identified the need for advanced inspection capabilities to help operators diagnose anomalies on orbit."

VIPIR — a robotic, articulating borescope equipped with a second motorized, zoom-lens camera — was designed to demonstrate technologies that would satisfy both needs.

For close-range inspections needed for internal repairs, VIPIR carries nearly three feet of deployable, flexible tube that allows the tool to insert a miniaturized camera through tight openings down to an inch in diameter. Mission controllers can remotely command the tip of the tube to rotate up to 90 degrees in four opposing directions, giving them control over their field-of-view.

At the end of the tube's tip is a color camera whose diameter is roughly the thickness of a dime, making it the smallest camera NASA has ever flown in space. Manufactured commercially and tested by NASA to assure its performance in space, it is typically used by the medical industry for endoscopies and other similar procedures. With its 100-degree

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Bruce Woodgate: A Tribute to a Prolific Innovator, Scientist, and Leader

Even as a boy, Bruce Woodgate seemed to know the professional path he would blaze as a grown man.

Fascinated by rockets, the young Woodgate was attempting to build one when he picked up a piece of unexploded ordinance that littered England following World War II, recalled Joe Gurman, who heard the story while working with Woodgate in 1979 on the Ultraviolet Spectrometer and Polarimeter (USVP), an instrument on NASA's Solar Maximum Mission. It exploded, taking two of his fingers and injuring his brother. "I think Bruce was a lot more careful later in life," Gurman said.

Photo Credit: David Friedlander/NASA

Woodgate may have been more careful, but he certainly never lost his verve or his curiosity, Gurman conceded. Over his nearly 40-year NASA career, Woodgate, who passed away peacefully after suffering several strokes in late April, distinguished himself as a prolific scientist innovator, and leader.

"Bruce was great at cutting through the bureaucracy. He just knew how to get things done," said Gurman, one of Woodgate's many protégés and collaborators. "He cut to the quick and understood instinctively what was most important. He was an excellent instrument designer, data analyst, and a great leader."

The ever-curious Woodgate was interested in a broad range of subjects, from Earth science and stellar atmospheres to exoplanets and large-scale structure in the universe. Among his many accomplishments, including the development of UVSP and publication of 188 scientific and technical journal papers that earned more than 5,300 citations, he probably was best known for his pioneering work on Hubble's Space Telescope Imaging Spectrograph (STIS), which still operates today.

In fact, STIS has played a key role in some of Hubble's most famous discoveries, gathering spatially resolved spectral data of the nuclei of galaxies — information that indicated the presence of supermassive black holes. It also detected for the first time the atmospheric composition of a planet around another star (HD 209458), discovering sodium, carbon, oxygen, and hydrogen.

Woodgate, who received Goddard's Award of Merit and NASA's Distinguished Service Medal, also invented many other technologies and was an active participant in Goddard's Internal Research and Development program. Early in his career, he developed a technique for making conically shaped mosaics of thin crystals to produce large-area X-ray spectrometers. The machines he helped develop to create those thin crystal wafers are known worldwide, and, in fact, he held a U.S. patent on an early version of the device.

At the time of his passing, the recently retired Woodgate was still working as an Emeritus scientist. His work centered on developing a next-generation photon-counting ultraviolet detector, employing advances in solid-state physics and nano-fabrication techniques.

"Bruce was always aware of everything that was going on," said Randy Kimble, who worked with Woodgate for 10 years on STIS. "If there was a new approach for manufacturing gratings or reading out detectors, for example, Bruce knew about it. He always was thinking, 'how can I incorporate this to improve my instrument.' That was very impressive to me."

Throughout the many challenges of a complex instrument development, Woodgate always kept his good humor, Kimble added. "He was generous to his colleagues and truly appreciated the efforts of others. He was everything you would want from a principal investigator." ❖

Cutting edge

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energy that permeates all of space and accelerates the expansion of the universe. It also will carry a coronagraph, which will allow it to image giant exoplanets and debris disks in other solar systems.

"One of the killer apps currently planned for ATLAST is the ability to detect signatures of life in the atmospheres of Earth-like planets in the solar neighborhood," Clampin said. While other observatories will image larger exoplanets, they will not have ATLAST's advanced ability to identify chemicals that may indicate the presence of life in these far-flung, Earth-size worlds.

ATLAST's large primary mirror will enable other scientific investigations, too. In addition to studying star and galaxy formation in detail, ATLAST will be able to resolve stars in galaxies more than 10 million light-years away and star-formation regions of sizes greater than 100 parsecs anywhere in the universe.

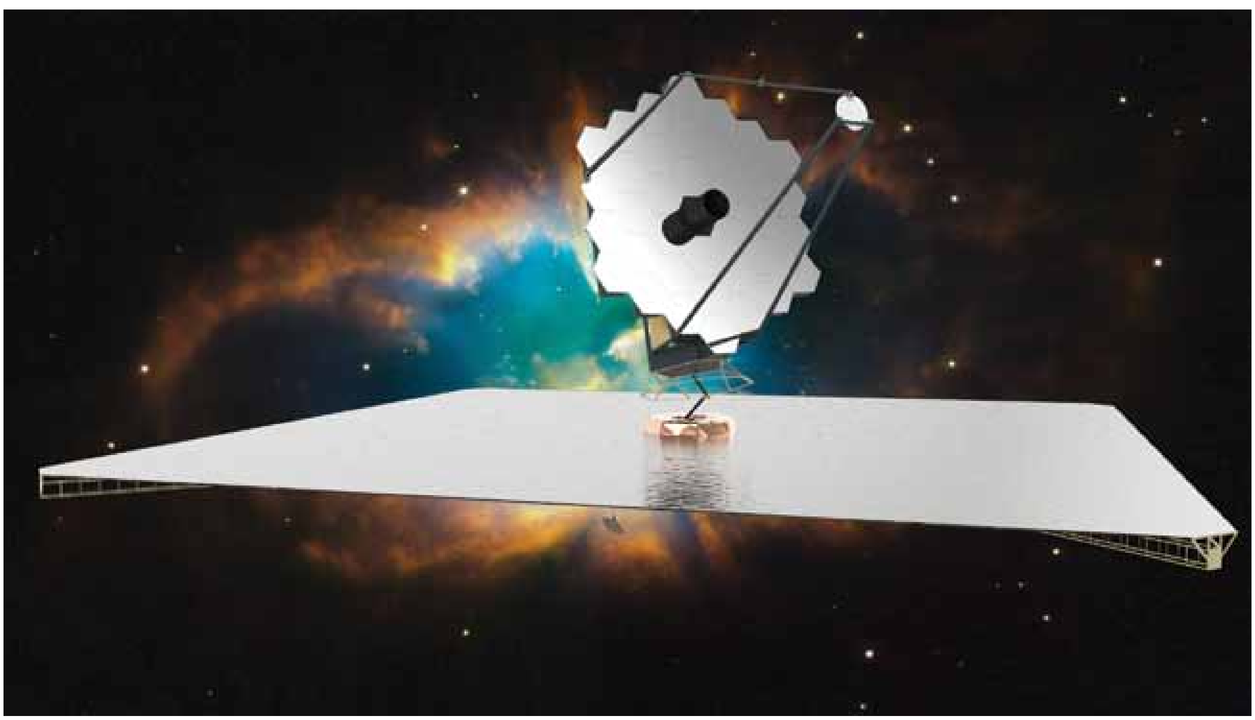
General-Purpose, Serviceable Telescope

To carry out these scientific investigations, ATLAST — envisioned as a long-lived space observatory, like Hubble — will study celestial objects in the ultraviolet, visible, and near-infrared wavelength bands.

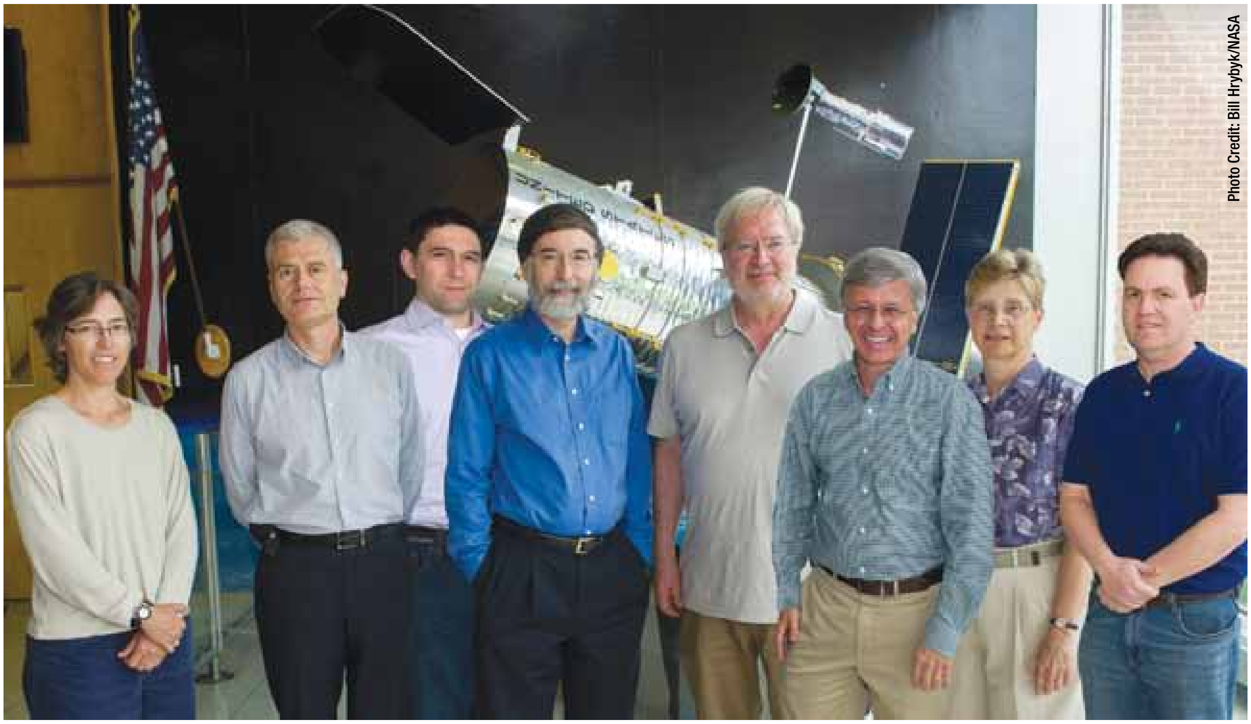
"One of the pertinent attributes about ATLAST is that it's being designed to be modular and serviceable, following the Hubble Space Telescope model," observed Julie Crooke, one of the Goddard study leads. Mission planners will design the observatory so that it could be serviced to upgrade instrumentation — a potential capability that depends on available budget and science requirements. "Serviceability has been one of the great paradigms in mission architecture that separates the Hubble Space Telescope from all of the other space missions to date," Crooke said.

To achieve these ambitious goals, the observatory needs to be thermally and mechanically very stable, which can be achieved by operating in the Sun-Earth L2 orbit — the same orbit chosen for the Webb telescope — and be equipped with a coronagraph and/or occulting star shade to mask the parent star's light, which otherwise would swamp the faint light emitted by an Earth-like planet. But perhaps more important, it would have to carry a significantly larger primary mirror — one even larger than Webb's, which will be the largest segmented mirror ever flown by NASA.

For now, however, the team is studying the viability of a 33-foot (10-meter) glass or carbon-fiber segmented mirror, which would give the telescope a larger light-gathering surface, but still fit inside the fairing of an existing launch vehicle. Currently,



This artist's rendition shows a possible design of a potential successor to the Hubble Space Telescope. A Goddard-led team of experts is now investigating the viability of this conceptual mission, called the Advanced Telescope Large-Aperture Space Telescope.



A Goddard-led team is studying a conceptual successor to the Hubble Space Telescope and the James Webb Space Telescope. A few of those investigators include (from left to right): Julie Crooke, Mark Clampin, Avi Mandell, Norman Rioux, Harley Thronson, Carl Stahle, Kathy Hartman, and Lee Feinberg.

the team is baselining the Delta-IV Heavy launch vehicle because it offers the largest mass-to-orbit capability.

"This gives seventeen times greater light-gathering capability than Hubble's mirror," added Carl Stahle, who is leading the team evaluating the technologies needed to pull off the ATLAST mission. The resulting technology roadmaps will show the NRC that NASA has identified technology requirements and risks, which the agency is maturing now.

In addition to building a larger segmented primary mirror, which, like the Webb telescope's mirror, would fold up for launch and then deploy in space, mission planners would have to fine-tune techniques to align the mirror segments and assure stability. One of the big technical challenges for exoplanet imaging and spectroscopy is building a very stable observatory, Stahle said. ATLAST would require the wavefront error to be stable to 10 picometers for 10 minutes, a factor of 1,000 better than the Webb telescope's stability requirements.

"We will be leveraging a lot of heritage from the Webb telescope and then developing new technologies over the next few years for the primary-mirror assembly, wavefront sensing and control, and ultra-stable structures to achieve this wavefront error stability," Clampin said.

Stahle also said that while NASA has invested heavily in near-infrared detectors and mirror coatings, technologists must devote more resources to improve the sensitivity of ultraviolet (UV) detectors and the reflectivity of UV mirror coatings that would extend into the visible and near infrared.

The 2010 Astrophysics Decadal Survey recommended that NASA invest in UV technologies for a future large mission, and indeed, NASA's Cosmic Origins Office has begun to make these investments, Clampin said. "With a sustained effort, ATLAST will have vastly more efficient UV instruments than prior observatories, giving it a high-definition view of the UV and visible universe."

"ATLAST will achieve critically important science goals not possible with ground-based observatories or with any other planned space missions," added Thronson. "Now is the time to plan for the future." ❖

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Microshutter, *continued from page 3*

The team also applied a very thin anti-stiction coating to prevent the shutters from sticking when opened. Before applying the coating, a 3,000-cycle laboratory test indicated that a third of the shutters stuck. After coating them, the team ran a 27,000-cycle test and not a single shutter adhered to the sides, Li said.

Success Breeds Success; More Work Ahead

As a result of the progress, Li said three astrophysicists now are interested in applying the technology to their own mission concepts, which include observing nearby star-forming regions in the ultraviolet, studying the origins of astronomical objects to better understand the cosmic order, and understanding how galaxies, stars, and black holes evolve. In fact, one of those scientists is so committed to advancing the microshutter array that he plans to demonstrate it during a sounding-rocket mission next year, Li said.

Although spectroscopy — the study of the absorption and emission of light by matter — is the obvious beneficiary of the technology's advance, Li said it also is applicable to lidar instruments that measure distance by illuminating a target with a laser and analyzing the reflected light. A major automotive company also has expressed interested in the technology, she added.

However, before others can use the new and improved microshutter technology, Li said the team must develop an assembly and packaging to house multiple arrays. "If you want to use the microshutter array on a large telescope, we need to make a larger field of view. To make this happen, we need to take multiple arrays and stitch them together," Li said.

Currently, the technology relies on a large computerized switch box — a heavy device unsuitable for spaceflight missions. The team plans to incorporate an integrated circuit, or silicon chip, that drives the switching functions. Placed next to the shutters, the circuit would take up only a fraction of the space. The team currently is identifying circuits from different vendors and plans to begin testing shortly.

"In just four years, we have made great progress. A major private company has expressed interest in our technology, to say nothing of the three potential astrophysics missions," Li said. "Given our progress, I am confident that we can make this technology more readily accessible to the optics community." ❖

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Inspection Tool, *continued from page 12*

field-of-view and 224 x 224 pixel resolution, the video camera met the requirements for close-range inspection jobs — situations when the camera will be only one to two inches away from its subject.

For inspection tasks not requiring a borescope, VIPIR carries a side camera equipped with a miniature, motorized optical zoom lens. Two spaceflight-quality motors measuring a mere half-inch in diameter — making them the smallest of their kind to fly in space — control the zoom-and-focus capabilities. With this capability, mission controllers can zoom in to resolve worksite details as tiny as the thickness of a credit card, even though the tool remains a safe distance away from the spacecraft. A third VIPIR camera helps ground operators control the tool during operations.

As soon as the design began to come together, future applications began to emerge, Reed said. Mars-bound astronauts, for example, might deploy their spacecraft's robotic arm and a version of VIPIR to determine if a micrometeorid strike has adversely affected essential internal components. "While a robot inspects the site, the crewmembers could save their energy and spacesuits to fix — not diagnose — the problem," Reed said. ❖

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Cutting edge Goddard's Emerging Technologies

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