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Strain Talks Technology

goddard tech trends

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Perspectives on Technology:

Center Director Rob Strain Speaks Out

On the job for only six months, Center Director Rob Strain recently shared his views about technology development at NASA in general, and Goddard in particular. In a discussion with Peter Hughes, Strain, the former chief of the Applied Physics Laboratory's (APL) Space Department, gave a no-nonsense view on advanced technology, along with a charge to better leverage R&D investments and become more open to collaborating with others.

What are your initial observations about technology development at NASA in your six months on the job?

If the U.S. and NASA are going to provide technology leadership, we have to invest. Investment can be a lot of things. It can be dedicating our resources to the development of a particular technology. It can be leveraging the technologies of others. It also can be collaborating with others to advance a technology of mutual interest. In other words, we don't have to do it all. We have to be clever and resourceful about leveraging our precious resources if we're going to stay in the forefront.

Could you elaborate on those thoughts?

We need to partner and leverage our investments because everyone has more constrained budgets for technology development. Goddard is not alone. The Jet Propulsion Laboratory, the Air Force Research Laboratory, and the Naval Research Laboratory, for example, are all finding their niche. We need to ask ourselves what technology areas do we need to own? What areas do we need to be smart about? What are the commodities — technologies that we don't necessarily have to spend our precious resources on? My challenge to you is to pick a handful of areas where we need to be on the leading edge.

That's why I think our focus on our lines of business is so terribly important. They help us choose which areas to make investments. We have people who I know could contribute to our nation's energy issues, for example, but that's not what we do. It's not our charge. That's not to say our technology can't be used by different agencies, but it would have to be a secondary concern. It goes without saying our lines of business help us to focus on those things that are important to us. They help us to focus on where we need to be on the leading edge.

In which areas do you believe Goddard needs to be on the leading edge?

I can think of multiple areas, but I'll specifically mention satellite communications, spacecraft, and scientific instruments.

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About The Cover:

Center Director Rob Strain, who formerly headed the Applied Physic Laboratory's Space Department, recently shared his views about technology development with Goddard Chief Technologist Peter Hughes. During the conversation, he stressed the importance of collaboration to develop technologies needed by NASA to meet its mission and goals. He urged the Center to select the areas where it needs to be on the leading edge.

Photo Credit: Bill Hrybck

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Are we doing all we can do to position ourselves for new work in these areas or to form collaborations with others?

We know the Science Mission Directorate (SMD) inside and out. The Exploration Systems Mission Directorate, on the other hand, has been more of a challenge for us. That aside, however, I believe the Science Operations Mission Directorate is one area where we should have the same relationship that we have with SMD.

I also think we have to do everything we can do to break down barriers to collaborating with others and leveraging their solutions. This is another strong belief I have. We have to become more intellectually curious about how other agencies solve their technological challenges. Perhaps the Air Force has encountered a problem and developed a solution that we can leverage to solve our own problems. We have to be more open to that. This

approach may be outside many people's paradigm. I agree that we've made strides forming partnerships with other government agencies and private corporations. We do have a foothold into their worlds, but it could be larger.

Is there anything else Goddard could do to secure its technology future?

We have to stay close to all the Mission Directorates at Headquarters. We need to think about what we can bring to their mission. This is particularly true as we go through the transition to a new administration. Undoubtedly new people will be coming into the Agency. We can't assume that they will know what we do here at Goddard. My hope is that when mid-level managers and those higher start scratching their heads because of a problem, they will know someone at Goddard who can solve it for them. I want Goddard to be the go-to organization.

What are your thoughts about the possibility of NASA dedicating additional resources to technology R&D?

I hope it would be true, but we have to allow for the possibility that it won't be enormously enhanced. Obviously, we will push to have more total resources. Whether we get them won't change our charge, however. Again, this gets back to what I said earlier. We need to be as clever as we can be with our technology investments. We need to carefully select which technologies we fund, and we have to do it without complaining.

What other challenges do you see on the horizon?

A concern for me is the demographics at Goddard. We have a very high number of people who could retire if they chose. We need to attract the best and brightest to fill these positions. We need to make Goddard an attractive place for young people to work. Technology development is a discriminator for some and I believe our technology investments can be a means to attract new talent. ◆

Photo Credit: Bill Hrybyk

Al Kogut, the principal investigator of the balloon-borne Primordial Inflation Polarization Explorer, will search for clues of cosmological inflation. He is pictured here (third from the left) with students who are helping him build the instrument (left to right): Samelys Rodriguez, Andrew Ziegelstein, Erin Wilson (now a NASA employee), and James Hinderks.

Did Inflation Happen?

Goddard Scientist Builds Instrument to Prove Cosmology Theory

In 2012, Goddard scientist Al Kogut will loft a balloon-borne instrument to an altitude of 120,000 feet — where the atmosphere thins into the vacuum of space — to search for definitive proof that the infant universe expanded from subatomic scales to the galactic in a fraction of a second after its birth.

To find the evidence, Kogut is building the Primordial Inflation Polarization Explorer (PIPER). It will measure the faint signal of primordial gravity waves imprinted in the polarization of the cosmic background radiation, the remnant light from the first moment of the universe's creation that bathes the sky in all directions. The instrument is slated to fly four times as a balloon payload, gathering 96 hours of data.

"It's What Put the 'Big' in the Big Bang"

"If we see this signal, we will have proved that inflation happened. We will have shown that the inflation theory is right and the others are wrong," Kogut said. "If inflation did occur, we'll also learn at what energy this occurred. This number is important for understanding the physics. It's what put the 'big' in the big bang."

Considered a staggering idea just two decades ago, the inflation theory postulates that the universe expanded far faster than the speed of light and grew exponentially almost instantaneously. Scientific results from the Goddard-developed Cosmic Background Explorer (COBE) revealed tantalizing clues that inflation did, in fact, occur. It found tiny temperature differences in the cosmic background radiation. These differences varied by only a few millionths of a degree and pointed to density differences that eventually gave rise to the stars and galaxies seen today.

COBE's successor, the Wilkinson Microwave Anisotropy Probe (WMAP), studied the afterglow radiation in more detail and also showed that the geometry of the universe was flat — a physical dimension also attributable to inflation, Kogut said.

However, other theories also explain these dynamics, Kogut said. What the science community needs is definitive proof of the primordial gravity waves — phenomena that the other theories can't explain.

R&D Funds Critical

Building the instrument that could provide that proof, however, is challenging. PIPER must carry four very large detector arrays — each containing 1,280 pixels — to collect as many photons as possible. To prevent the faint signal from being overwhelmed by instrument-generated heat, Kogut's team must place the instrument inside a dewar and cool it to just 1.5 degrees above absolute zero — even colder than the cosmic microwave background radiation where the gravity waves could lie hidden. The detectors needed to sense the signal will be maintained at an even colder temperature of 0.1 Kelvin.

Due to Goddard's investment in related technologies, he's gotten a head start building his instrument. The detector

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arrays are based on the Goddard-IRAM Superconducting 2-Millimeter Observer (GISMO) that Goddard technologist Christine Jhabvala developed in part with Internal Research and Development funding. She and her colleagues successfully demonstrated GISMO at an observatory in Spain in 2007 as a way to validate a next-generation detector architecture she developed to dramatically ease the assembly of detector arrays. With her technique, the pixels are constructed on a single silicon wafer bonded onto a read-out circuit. This reduces the amount of handwork, making it easier for technologists to increase the size of the array. Despite the breakthrough, Kogut said it still would take three years to build the detectors. "They're so complicated," he said.

With R&D funds, Kogut also developed the dewar to keep the instrument cold. That dewar flew on the Absolute Radiometer for Cosmology, Astrophysics, and Diffuse Emission experiment, another balloon payload that he flew in 2006 to detect heat from the first generation of stars (see story below). PIPER will use the same dewar.

"This is why Goddard is so successful," Kogut added. "We build on technologies that work."

In addition to solving a longstanding cosmological question, PIPER could set the stage for Goddard winning a follow-on mission — CMBPol — that NASA hopes to fly within a decade. "PIPER is a pathfinder to demonstrate new technologies and determine whether CMBPol has something to measure," Kogut said. If he and his team see the signal, CMBPol would carry out identical science, except the mission would spend years, not hours, gathering the faint gravity-wave signal. "PIPER will be able to detect the signal, it just won't be as precise as CMBPol," he said. "It's similar to what COBE did. COBE found the temperature differences in the cosmic background radiation and WMAP came along to provide the details." ◆

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Cosmic Radio Mystery

Goddard scientist Al Kogut set out to find the heat signal of the first stars created about 200 million years after the big bang. What he discovered was a cosmic radio mystery — a discovery that made headlines at the 2009 American Astronomical Society annual meeting in January.

Using the Absolute Radiometer for Cosmology, Astrophysics, and Diffuse Emission (ARCADE), a balloon experiment he flew in 2006 from Palestine, Texas, Kogut found not a faint radio signal, which he expected, but a noise six times louder than anyone had predicted. "I saw a big radio background and stumbled onto an exciting new discovery. Theorists don't have a ready-made explanation."

Kogut's intention was to learn more about the nature of the first stars, which scientists believe could have been 500 times larger than the Sun. To gather data about these objects, Kogut tuned ARCADE to the radio wavelengths because the objects are too distant to be seen in the optical.
Although many objects in the universe emit radio waves, there don't appear to be enough radio galaxies to account for the signal ARCADE detected, Kogut said. Detailed analyses that took a year to perform ruled out an origin from these early stars or from known radio sources, including gas in the outermost halo of the Milky Way.

So what could have produced the noise detected? "We have some speculations, but not a well-established solution," Kogut said. "But one could speculate that what we found was death of the first stars."

Once the theorists have a chance to look at the data more closely, Kogut said he might fly the experiment again after adjusting the instrument to make it more precise and sensitive to help determine precisely what's causing the signal. ◆

SPECIAL REPORT: NEW MISSIONS

Goddard has managed and built instruments for hundreds of missions over the past half century. Last year was a particularly good year for the Center, whose principal investigators secured millions of dollars to continue advancing next-generation technologies or to build flight instruments for new missions. Here we focus on two new Goddard missions — the Mars Atmosphere and Volatile Evolution Mission (MAVEN) and the Lunar Atmosphere and Dust Environment Explorer (LADEE).

A Goddard First

Center Begins Work on MAVEN — Its First Mission to Mars

Earth isn't the only planet to experience climate change. Mars, taking climate change to an extreme, lost its formerly dense atmosphere several billion years ago. Now, a Goddard-managed mission — the Center's first-ever to Mars — will precisely measure the current-day atmospheric loss to learn more about the planet's climate history and potential habitability.

Aside from the scientific insights this mission is expected to provide, the $485-million Mars Atmosphere and Volatile Evolution (MAVEN) mission represents a first-of-a-kind opportunity — at least for Goddard, said Senior New Business Liaison Bill Cutlip. "Although Goddard has developed more instruments for planetary missions than anyone in the world, MAVEN is the first Mars mission we've ever managed," he said. "It's wonderful that the mission's principal investigator, Bruce Jakosky, and NASA have entrusted this very important mission to us. Obviously, we're very excited."

To win the mission, the MAVEN team gave "decisionmakers everything they were looking for," Cutlip added. "We gave them a low-cost mission, with high-payoff science" — a winning combination made possible by tried-and-true instrument technologies provided in part by Goddard, a Lockheed Martin-designed spacecraft modeled on the Mars Reconnaissance Orbiter and the Mars Odyssey, and "strong leadership" by Jakosky, who is the associate director for science at the University of Colorado's Laboratory for Atmospheric and Space Physics (LASP), Cutlip added.

Solving a Longstanding Mystery

MAVEN's primary mission is solving a longstanding mystery: Whatever happened to Mars's atmosphere? Although its atmospheric pressure today is only one percent of Earth's, previous NASA missions have shown that the planet's atmosphere was once so thick that water flowed across its surface. One theory suggests that solar wind — a blast of charged particles escaping from the Sun's million-degree corona at nearly 3 million miles per hour — is stripping away the planet's carbon dioxide-based atmosphere.

Although solar winds also sweep across Earth, Earth's strong magnetic shield deflects the particles before they penetrate the atmosphere. Mars, on the other hand, has no global magnetic field, offering no protection from the continuous solar wind.

Complicating matters further, the Mars Global Surveyor (MGS) detected a very patchy magnetic field originating from the Martian crust, predominately in the southern hemisphere. The natural thought would be that this patchy field would provide some limited protection for the atmosphere. However, new research with the MGS data actually suggests that this crustal magnetic field may actually accelerate the air loss.

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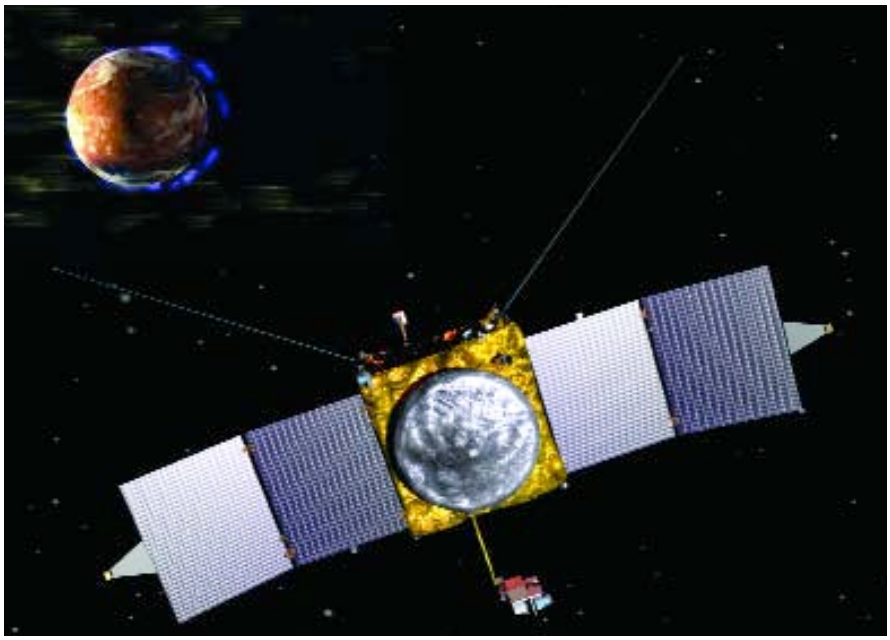

The Mars Atmosphere and Volatile Evolution spacecraft, which NASA plans to fly in late 2013, will gather data on the planet's current-day atmospheric loss. The artist's rendition of Mars at the top of the image shows the disappearance of the planet's magnetic field, which may have triggered the atmospheric loss.

Communicating by Laser Beam

LADEE Mission to Include an Optical-Communications Demonstration

Each year, NASA spends millions of dollars operating its communications network, which consists of ground- and space-based assets located around the globe. In an era of burgeoning U.S. budget deficits, reducing those costs and achieving even more capability have become a top Agency priority.

To realize its ambitions, the Agency has tapped the Goddard Space Flight Center to lead and demonstrate the Lunar Laser Communications Demonstration (LLCD), an experiment to provide the proof-of-concept for laser-based communications from lunar orbit. During the experiment, Goddard plans to transmit more than 600 megabits of data per second using a Lincoln Laboratory-built 4-inch telescope and a half-watt laser installed on the $80-million Lunar Atmosphere and Dust Environment Explorer (LADEE), which NASA plans to launch in 2012 to characterize the Moon's wisp-thin atmosphere and dust environment.

First Step

"This is the first step in augmenting or replacing some of our current communications infrastructure — which is made up entirely of radio frequency (RF) communication systems — with an optical system that offers more tool flexibility. In other words, we can use the right communications tool for the right job. This will unburden the Agency's existing infrastructure," said Julie Crooke, who oversees astrophysics and communications programs for the Center's New Opportunities Office. "This likely will result in overall cost savings on the ground and in space, while providing more capability. It is a huge step for the Agency in becoming more efficient with its limited resources."

Currently, NASA's communications network consists of three main elements: the Space Network, the Near-Earth Network, and the Deep Space Network. Goddard leads and operates the Space and Near-Earth Networks and the Jet Propulsion Laboratory operates the Deep Space Network. These networks provide communications and tracking in the RF bands to all NASA assets, everything from the International Space Station to spacecraft orbiting Earth and traveling out to the very edge of the solar system.

However, operating these networks has become increasingly more expensive, which has motivated NASA to investigate potentially more cost-effective solutions.

Optical communications is one possible solution. It transmits data using the visible and near-infrared wavelength bands, which the Federal Communications Commission and the International Telecommunications Union do not regulate. However, they do regulate the radio bands to prevent interference among users, said Harry Shaw, who is managing the LLCD project for Goddard. Due to the lack of interference, future missions would be able to transmit very high data-rate communications, provided the system provided enough power to the receiver, he said.

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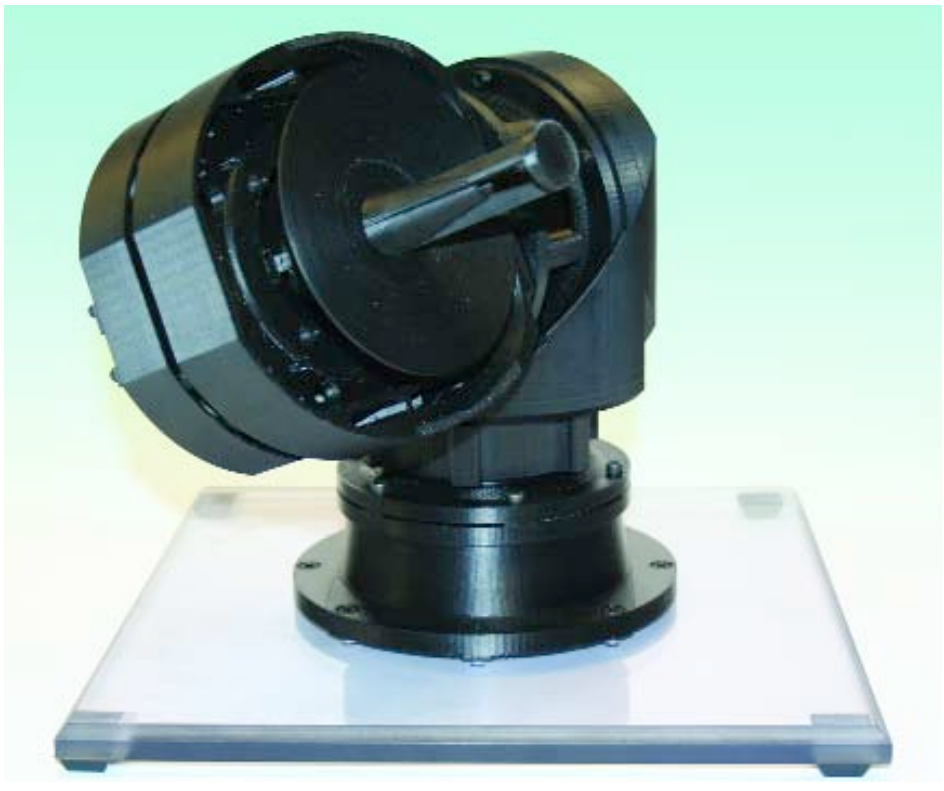

This image shows the three-dimensional mass model of the optical module that will comprise the optical interface of the optical communications experiment flying on the Lunar Atmosphere and Dust Environment Explorer.

Infusion Works!

Combination of R&D Funding Advances Readiness of a New Lidar System

An instrument concept that Goddard technologist Matt McGill first began developing more than a decade ago with R&D funds has found a potential berth on a next-generation Earth-observing mission aimed at improving climate models and air-quality forecasts.

The Cloud-Aerosol Transport System (CATS) lidar is a contender for the proposed Aerosol-Cloud-Ecosystems (ACE) mission, which would answer questions about aerosols, clouds, air quality, and global ocean ecosystems. NASA hopes to begin developing the spacecraft sometime next decade. The instrument's evolution from idea to possible flight testifies to the value of R&D funding and the strategic leveraging of other instrument-development programs, McGill said.

"It is the mother of all leveraging," McGill said. "We used funds from the Internal Research and Development (IRAD) program, the Earth Science Technology Office (ESTO), and at least five Small Business Innovation Research (SBIR) efforts to develop subsystems for this instrument. This is a success story. It demonstrates how infusion can work."

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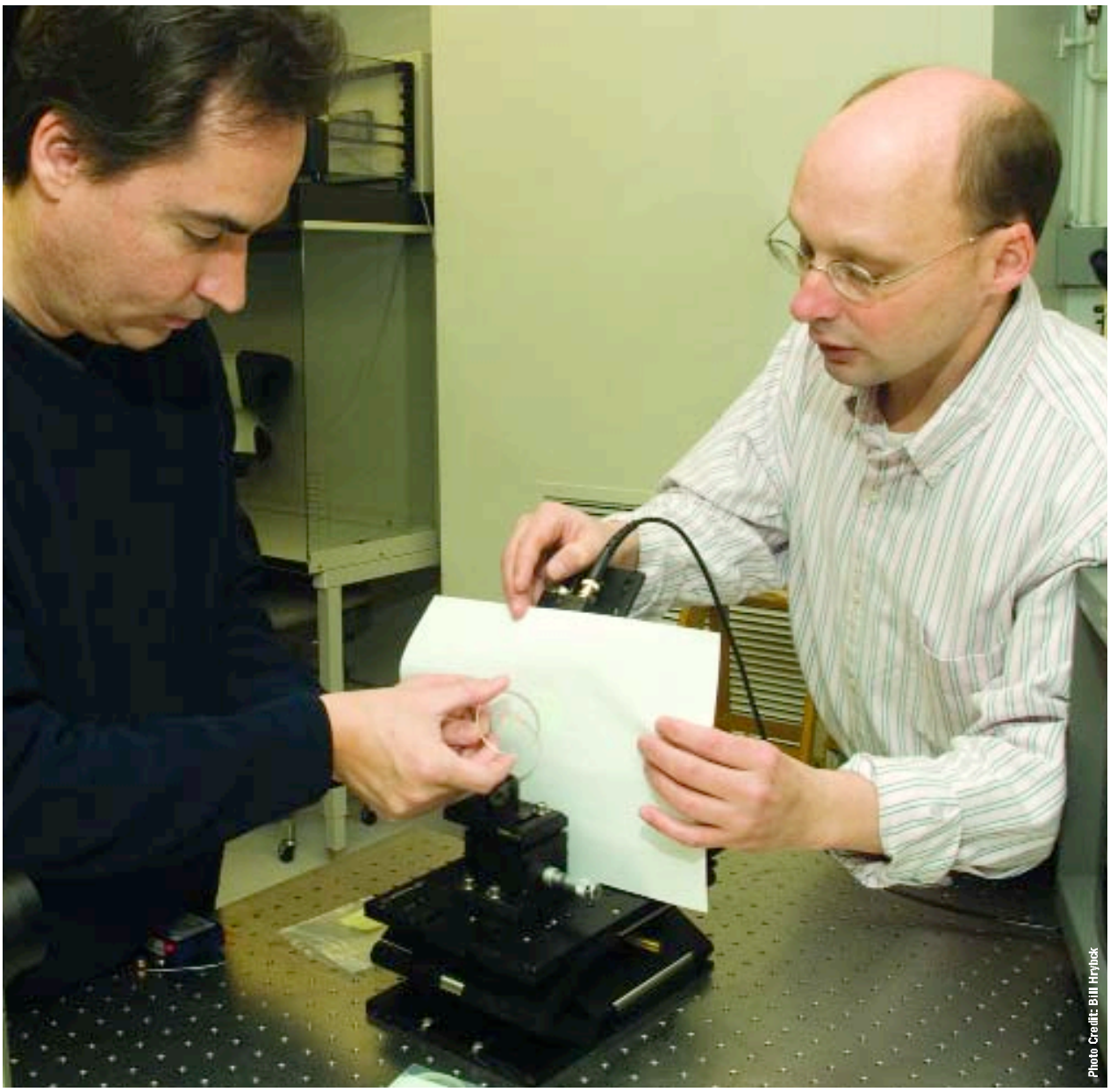

Principal Investigator Matt McGill (right) and Co-Principal Investigator Stan Scott (left) are working on the optical component of their proposed Cloud-Aerosol Transport System lidar, which could find a berth on a next-generation Earth-observing mission.

Infusion... Continued from page 8

Right Place, Right Time

It also demonstrates the value of being at the right place, at the right time.

When McGill began working on the instrument's novel optical system more than 10 years ago, he envisioned an instrument that would measure wind speeds. A flight opportunity never presented itself. What did present itself, however, was ACE, which the National Research Council recommended in its first-ever Decadal Survey for Earth-observing missions in 2007.

Among other instruments, ACE is expected to carry a high-spectral resolution lidar to measure cloud and aerosol properties. "In essence, that's what my instrument is," McGill said. "The added bonus is that you also get wind information to determine where the aerosols are moving. This is particularly useful for tracking dust storms or pollution outbreaks, for example."

Lidar, which stands for light detection and ranging, is a remote-sensing technology that scientists use to measure the distance from a sensor to an object. With this technique, the instrument transmits a series of laser pulses toward Earth's surface. Each laser pulse bounces off objects on its journey toward the ground and returns skyward toward the sensor.

With this particular application, the light will scatter when it comes into contact with aerosols and molecules. The instrument's telescope will then collect the backscattered signal and pass it along to the receiver system, which will be tuned to measure properties of clouds and aerosols and how the aerosol particles interact with clouds — questions that the ACE mission is supposed to answer. McGill's instrument also can measure the Doppler shift of light scattered by moving particles, which will be used to provide information on aerosol transport.

On Track for a 2010 Demonstration

Having secured IRAD, ESTO, and additional Headquarters funding, McGill said he's on track to complete an aircraft-ready instrument in time for an ER-2 aircraft demonstration in late 2010. "This meshes well for ACE requirements," he said. "Starting with the numerous system components already developed through SBIR greatly reduces the time needed to develop the instrument. In this case, two years is definitely a do-able timeframe." ◆

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Laser Beam... Continued from page 7

In addition, optical-communications systems consume less mass, volume, and power, especially compared with similar RF systems, Shaw added. As the technology evolves, the transition to these types of communications systems will ultimately reduce mission costs and provide opportunities for new science payloads, he said.

To demonstrate the concept, Goddard plans to transmit more than 600 megabits of data per second from the LLCD on LADEE to a small array of four 16-inch ground telescopes, also built by Lincoln Laboratory. The optical ground terminal, which is 10 times more efficient at these data rates than any optical receiver ever demonstrated in a spaceflight application, will operate at White Sands, New Mexico, as a first step toward supplementing Goddard's longstanding RF ground network capability. LLCD on LADEE is the first of three planned demonstrations.

Natural Fit for Goddard

"The LLCD experiment is a natural fit for Goddard," Crooke added. "Since NASA's inception, we've operated communications networks for spacecraft operating in low- and near-Earth orbits. We also have a tremendous amount of experience building laser-based instruments. This demonstration combines both areas of expertise. It also leverages the R&D investments we've made to build our optical-communications expertise," Crooke said.

First Lunar Mission to Launch from Wallops

"To say this is exciting is an understatement," said Mike Krainak, a Goddard technologist and expert in laser applications, adding that Goddard succeeded in securing a flight opportunity for the technology by proposing a low-cost mission. Not only is LADEE the first to include an optical-communications demonstration, he said, it's also the first lunar mission to launch from the Wallops Flight Facility onboard a Minotaur-5 launch vehicle. "When it launches, it will get a tremendous amount of publicity," he said. ◆

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Goddard Builds High-Thermal Conductivity Composite Structure

Goddard technologists have developed a lightweight, carbon-fiber reinforced plastic thermal shield — the largest composite structure they've ever developed in-house for a possible spaceflight application.

Ken Segal, an engineer with Goddard's Mechanical Systems Branch, built the 5-foot-tall thermal radiation shield to encase a subscale cryogenic fuel-storage system. The Center's Cryogenic and Fluids Branch is developing the storage system to store super-cold liquid propellants for extended periods of time — a capability that NASA may need to power its Constellation suite of vehicles and ultimately increase the payload capacity of its transportation system.

Cryogenic propellants, such as liquid oxygen and hydrogen, have been used to fuel launch vehicles or orbital-insertion stages for more than 50 years. They perform better and consume less mass than other propellants. However, they are difficult to store because they can boil off quickly unless properly insulated. As a result, NASA has confined their use to launch vehicles where hold times are short.

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Goddard technologist Ken Segal poses with the mold he used to develop a carbon-fiber reinforced plastic thermal shield — the largest composite structure he and has team have ever developed in-house for a possible spaceflight application.

Composite... *Continued from page 10*

Boil-Off Not Seen as a Showstopper

However, Goddard technologist Ed Canavan doesn't see boil-off as a showstopper and envisions the potential use of his technology for the Ares V Earth-Departure Stage, the Orion Service Module, the Altair Lunar Ascent and Descent Vehicle, and the lunar rover power system.

"Our group comes at it from a different angle," Canavan said. The Cryogenic and Fluids Branch long ago established itself as a technological leader developing long-life dewars to store cryogenic fluids needed to cool astronomical instruments to near absolute zero. Canavan's group is applying that expertise to scaling up designs required for vehicle-propulsion systems.

The composite shield is part of that development effort and a key insulating technology to prevent boil-off. "Normally, you would use aluminum, but to reduce mass, which is always important for spaceflight applications, we are better off using a carbon-composite material. It's much stiffer and lighter," Canavan said. "Ken Segal is an expert in the use of composites and I asked him to join the effort."

Application of Hair-Like Fibers

To create the dome-like shield, Segal and his team applied hair-like, high-thermal conductivity fibers — made of cynate-ester polymer — onto a mold. The entire structure then was placed inside an oven to set the epoxy, Segal said. The result, he said, is a stiff, yet lightweight shield that weighs a fraction of more traditional aluminum shields used for similar space applications.

"No one has ever used this material for this type of application," Canavan added. Over the next few months, the Cryogenics and Propulsion Branch will augment its cryogenic propellant storage testbed and demonstrate the thermal shield as a component of its "co-storage experiment." Co-storage is a concept that uses one cryogenic propellant to reduce the boil-off from another cryogenic propellant. ◆

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Annual Report Now Available

FY 2008 was a good year for Goddard technologists, who secured millions of dollars in new missions and follow-on funding to further advance their work. Learn more about their accomplishments in the Office of the Chief Technologist's annual report, **"R&D Achievements: Collaboration + Innovation = Mission Success"** *now available at:* **http://gsfctechnology.gsfc.nasa.gov**

Maven... Continued from page 6

Eight Instruments Flying

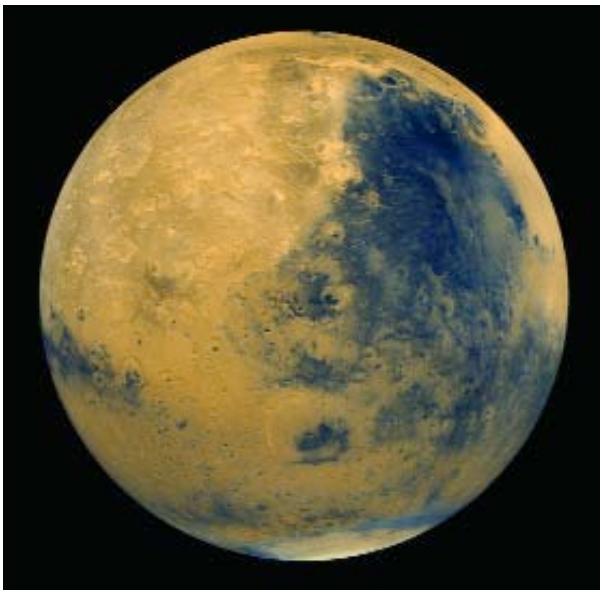
To get a better handle on what's causing the loss, MAVEN will fly eight different instruments packaged into three instrument suites.

Goddard's Paul Mahaffy will provide the Neutral Gas and Ion Mass Spectrometer, which will measure the composition and isotopes of neutral ions in the atmosphere. "What we're developing is a basic mass spectrometer," Mahaffy said. "It's much simpler than the ones we built for Cassini or the Mars Science Laboratory, but nevertheless we need to make sure we do it right."

Meanwhile, Goddard instrument Principal Investigator Mario Acuná will build a magnetometer to precisely measure the planet's magnetic field. His instrument is included in the Particles and Fields Package managed by the University of California-Berkeley. Similar to the magnetometer his team built for the Solar Terrestrial Relations Observatory, it, too, is less complex than other magnetometers his group developed for MGS and other NASA missions. Modern analog-to-digital converters simplify the instrument's front-end design and allow for more compact electronics, Acuná said. Consequently, the instrument consumes less power, while still offering the same level of performance as older instruments.

For the MAVEN instrument, Acuná's team will place two small sensor packages on the end of the spacecraft's solar arrays to prevent the instrument from measuring magnetic activity on the spacecraft itself. "What we're measuring is relatively weak, so we want to place the sensors away from the spacecraft," Acuná said. "We're not just providing the hardware, either," added Jack Connerney, a member of Acuná's team. The team also is advising spacecraft and component developers on steps they need to take to assure a magnetically clean spacecraft. "We will assure that MAVEN's measurement requirement is met. It's a package deal."

IASP, which also is coordinating the science team under Jakosky's direction, is managing the development of MAVEN's third instrument suite, the Remote Sensing Package.



2013 Launch Date Planned

NASA plans to launch MAVEN — the second in NASA's Mars Scout Program — in late 2013. The spacecraft will arrive at its destination in the fall of 2014, where it will carry out its investigations for one year from an elliptical orbit, ranging from 150 km (about 93 miles) to 6,200 km (about 3,853 miles) above its surface. It also will dip to an altitude of 125 km (about 78 miles) above the planet to sample Mars's entire upper atmosphere.

From the data gathered, scientists plan to track the composition of the Martian air and create a precise record of current atmospheric loss and of the total loss through time. Only by understanding the role of escape to space will scientists fully understand the history of Mars's atmosphere, climate, and water, and therefore, its habitability, Cutlip said. ◆

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Goddard Tech Trends

Goddard Tech Trends is published quarterly by the Office of the Chief Technologist at the Goddard Space Flight Center in Greenbelt, Maryland. The newsletter describes technology developments at Goddard and explains how they are helping NASA to achieve its missions. If you want more information about Goddard technology, contact the Chief Technologist. If you wish to be placed on the newsletter distribution list, contact the editor. **NP-2007-10-853-GSFC (revised 1/09)**

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