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FALL 2016

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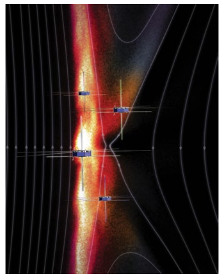

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ON THE COVER

EMPLOYMENT

Southwest Research Institute is an independent, nonprofit, applied research and development organization. The staff of nearly 3,000 employees pursues activities in the areas of communication systems, modeling and simulation, software development, electronic design, vehicle and engine systems, automotive fuels and lubricants, avionics, geosciences, polymer and materials engineering, mechanical design, chemical analyses, environmental sciences, space science, training systems, industrial engineering, and more.

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FINDING THE NEEDLE IN THE HAYSTACK

With NASA's Magnetospheric Multiscale Mission

By Jim Burch, Ph.D., and William Lewis, Ph.D.

Million-degree coronal plasma trapped on magnetic field lines emerging from the Sun's surface forms loops and arcades that glow in extreme ultraviolet light. The amount of energy released by magnetic reconnection in an average coronal mass ejection could power the U.S. for nearly one hundred thousand years at the present rate of energy consumption.

COURTESY NASA/GSFC D022128

Many people think of space as a vast empty vacuum. In reality, it's populated with hot ionized gases, known as plasmas, threaded with magnetic fields. The density of these plasmas is exceedingly low, so much so that, when space plasma physicists are asked what they study, they've been known to answer: "Practically nothing." Nevertheless, the magnetic fields that thread these sparse plasmas store massive amounts of energy, which can erupt into tremendous electromagnetic space explosions when they interact.

Southwest Research Institute (SwRI) has been conducting plasma physics experiments in the Earth's magnetosphere for 39 years. In the early 2000s, the SwRI-led IMAGE mission captured the first global images of the Earth's magnetosphere, adding significantly to our understanding of its interaction with the solar wind. Currently, SwRI is leading the science investigation for NASA's Magnetospheric Multiscale (MMS) mission, which recently made the first direct detection of the source of magnetic reconnection, an explosive physical process that converts the magnetic energy in plasmas into kinetic energy and heat.

ABOUT THE AUTHORS

Dr. Jim Burch (right), vice president of SwRI's Space Science and Engineering Division, is a renowned expert in space plasma physics. He is the principal investigator of NASA's MMS mission. Dr. William Lewis has interests in a range of topics in heliophysics and currently serves as the MMS project manager.

A PRIMER IN PLASMA PHYSICS

Plasma is considered a fourth state of matter, having some of the attributes of the other, more familiar states of gas, liquid, and solid. In space, plasmas contain equal numbers of electrons and ions, which behave collectively and flow along field lines much as a train moves along a track. This motion of accelerated particles produces electrical currents within plasmas, which are shaped by magnetic fields. The sculpting of plasma by a magnetic field can be seen most clearly in coronal loops formed by magnetic field lines emerging from the Sun's visible surface.

SwRI uses the Earth's magnetosphere as a giant plasma physics laboratory. The Sun emits a constant flow of plasma particles known as the solar wind, which is diverted by a teardrop-shaped bubble formed by the terrestrial magnetic field. These two forces create the dayside magnetopause, a rounded magnetic boundary between the Sun and the Earth. On the other side of the world, the solar wind drags the Earth's magnetic field into a long tail on the night side. The Earth's magnetosphere is populated with a plasma consisting predominantly of protons and electrons.

DETAIL

If space is filled with hot gases, why is it "cold?"

A constant stream of electrically charged particles — the solar wind — flows through interplanetary space. Their average speed is close to 900,000 miles per hour and their temperatures range from the hundreds of thousands to millions of degrees! So why, given these extremely high temperatures, is space cold? The reason is that interplanetary space is almost a complete vacuum, with an average of only about five solar wind protons per cubic centimeter. Heat from this minuscule number of particles doesn't transfer effectively through conduction. The main source of heating in space is solar radiation, which plummets as distance from the Sun increases. Mercury, the planet closest to the Sun, has a surface temperature of 800 degrees Fahrenheit on its daylit side, compared with minus 400 degrees F on the sunny surface of icy Pluto on the outskirts of the solar system.

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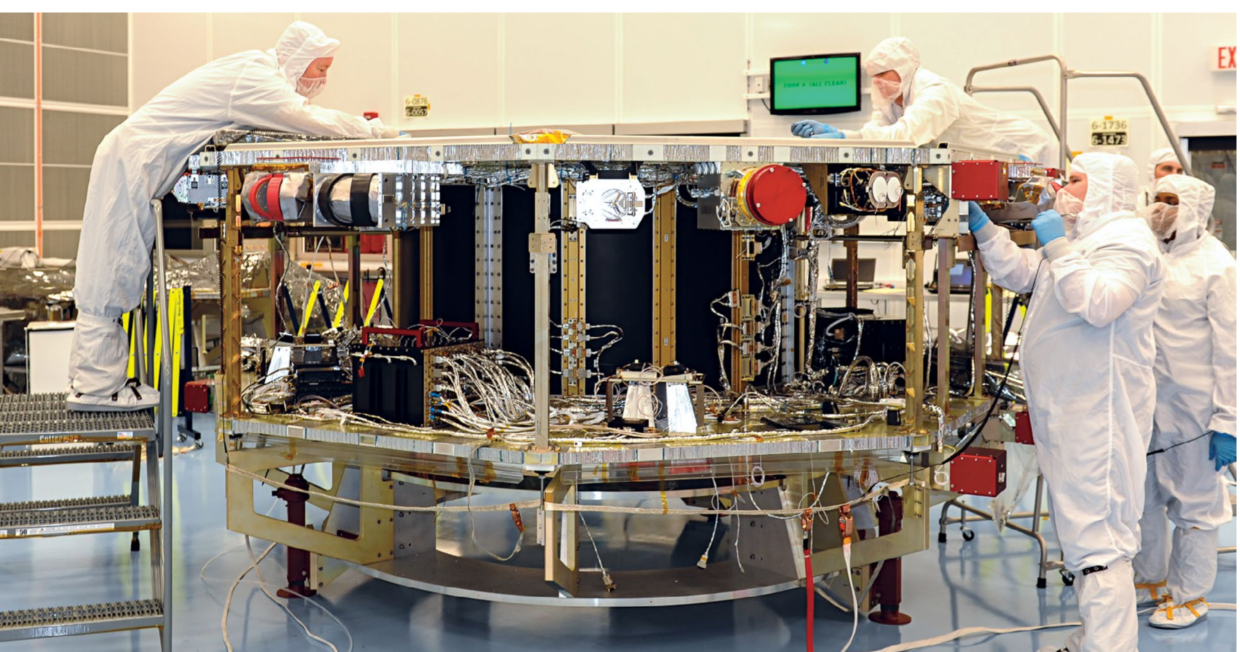


The four identical MMS spacecraft fly in formation at the boundary of the magnetosphere, collecting data at incredible rates, looking for evidence of magnetic reconnection. Here, technicians integrate the 25-instrument payload into one of the spacecraft.

Plasmas threaded with magnetic fields shape the Earth's magnetosphere. They also populate the Milky Way and other galaxies. These magnetic fields are generated by powerful dynamos within stars and planets, and by the rotation of ionized gas in galactic discs. Magnetic reconnection occurs both in our solar system and in distant astrophysical systems. It lies at the heart of space weather and drives solar flares and coronal mass ejections, as well as disturbances in Earth's space environment. These disturbances produce the northern and southern lights and, when severe, can shut down power grids and disrupt satellite-based communications and navigation systems. Reconnection is also an important phenomenon in laboratory plasma physics, where it is one of the impediments to achieving controlled nuclear fusion because of its disruptive effects in magnetic containment devices.

CONNECTING THE DOTS

Magnetic reconnection is a fundamental process in nature, at least in the 99 percent of the observable universe in the plasma state. In broad terms, the conditions under which reconnection occurs are well understood. When two plasmas with oppositely oriented magnetic fields come into contact, the field lines "break" on the dayside and then reconnect on the nightside, releasing energy and allowing the plasmas to mix.

This process occurs frequently at the boundary of Earth's magnetosphere. Earth's magnetic field has a northward orientation: the magnetic field lines emerge near the southern geographic pole and re-enter near the northern geographic pole. The solar wind's magnetic field, on the other hand, is highly variable. When it has a southward orientation, the solar wind and terrestrial fields are oppositely directed and can experience reconnection, allowing the solar wind and magnetospheric plasmas to mix and produce "jets" of accelerated plasma.

That's the big picture, observed and documented by previous space missions such as Cluster and THEMIS. But why do oppositely directed field lines break? How is reconnection initiated? What controls the rate at which it occurs? These are the questions that the MMS mission is designed to answer. Data acquired during the first six months of the mission suggest that the MMS team is well on the way to answering them and solving the decades-old mystery of reconnection.

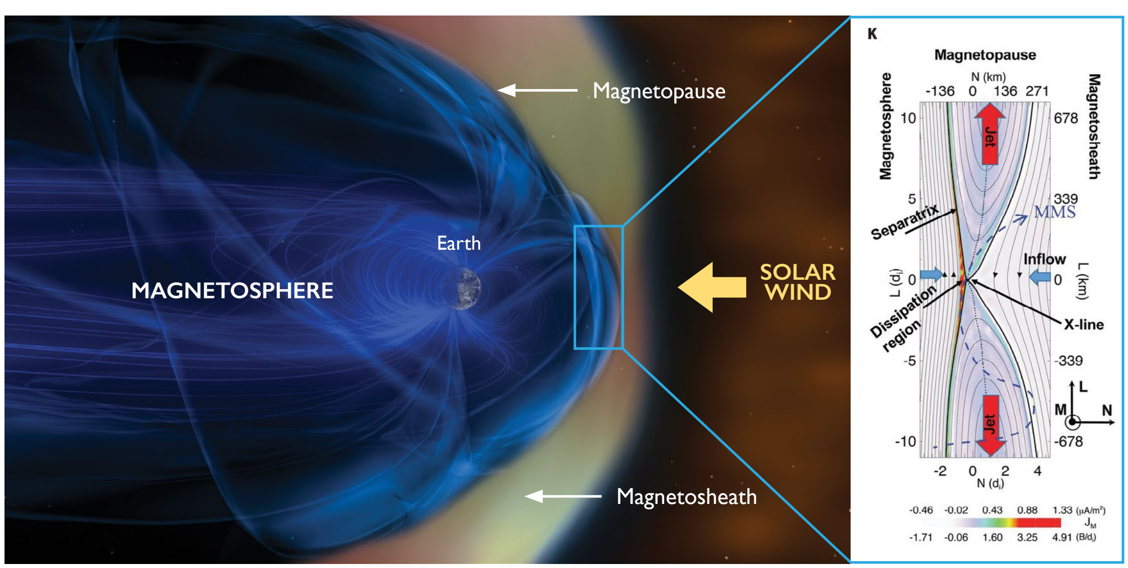
THE ELECTRON DIFFUSION REGION: THE NEEDLE

One of the fundamental properties of a plasma is that its constituent ions and electrons are tied to the magnetic field lines threading it. For reconnection to occur, the ions and electrons must become decoupled from the field lines, or "demagnetized." Analytical theory and numerical simulations indicate that the critical and final stage in this process occurs in a narrow boundary layer, where the two oppositely directed magnetic fields meet and the physics is dominated by the electrons. The magnetic field lines of the Earth break and then almost instantly reconnect with solar magnetic field lines, allowing solar energy to flow unimpeded into the magnetosphere. This transfer of energy drives magnetic storms and dramatic auroral displays.

It is this narrow region — the electron diffusion, or dissipation, region (EDR) — that the MMS team targeted to collect the enigmatic measurements needed to unlock the secrets of magnetic reconnection. MMS's four identical spacecraft fly in formation at the boundary of the magnetosphere, collecting data at incredible rates, looking for EDRs.

MOVING TARGET, FLEETING EVENT

An EDR is not an easy target to hit. Visualize a ribbon some 6 to 60 miles wide and extending many thousands of miles across the sunward face of the magnetopause, the boundary that separates the solar wind from magnetospheric plasmas. That may sound really large, but not when considering the vastness of space. The location and orientation of an EDR vary constantly with changes in the speed and density of the solar wind as well as with the



This artist's concept shows the interface between the magnetospheric plasma, with Earth's northward magnetic field, and the magnetosheath — the compressed and heated solar wind plasma — with a southward field. To the right is a close-up view of the reconnection region measured by the MMS spacecraft on October 16, 2015. The dotted blue line shows that the MMS spacecraft flew right through the event.

COURTESY NASA/GSFC D022144

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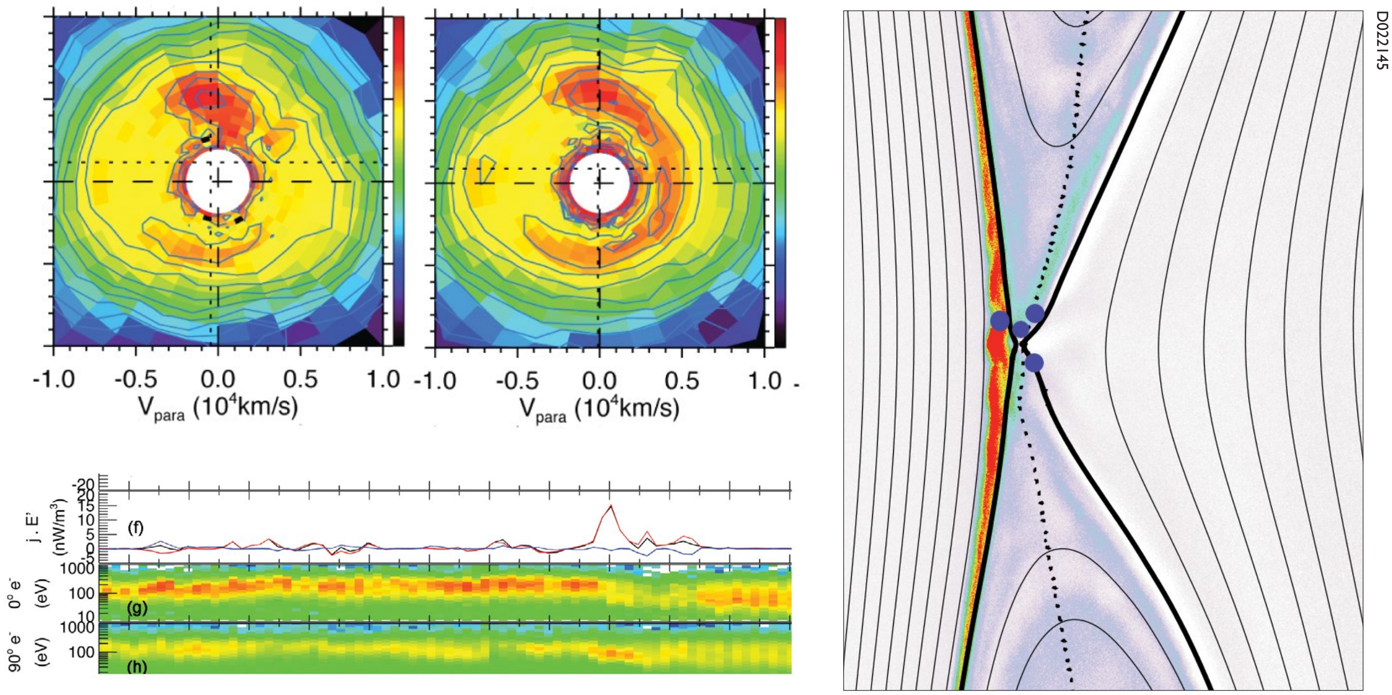
Each of the four MMS observatories is octagonal in shape, approximately 11 feet across by 4 feet high. When stacked together inside the Atlas V launch vehicle, the observatories are more than 16 feet tall.

direction of the solar wind's magnetic field. As part of the mission planning process, the MMS team developed statistical models to predict where reconnection would most likely occur. The team then calculated how many times the four MMS spacecraft were likely to encounter the magnetopause and how likely these encounters were to bring the spacecraft close to a reconnection region. The models predicted that MMS would have about a 3 percent chance of coming within roughly 2,000 miles (about the distance between Los Angeles and Washington, D.C.) of a reconnection event — but not necessarily of encountering the EDR itself. If the EDR is the needle in a haystack, all the models could tell the team was where haystacks were likely to be found. MMS still had to locate the needle, and that involved more luck than design.

Measuring the EDR plasma presents another challenge. The magnetopause is in constant motion, moving inward and outward at speeds of up to 100 kilometers per second, buffeted by the solar wind. Obtaining the necessary three-dimensional plasma data in a rapidly moving EDR requires substantially faster measurements than previously possible. Instead of relying on a single analyzer per spacecraft and the spacecraft's three-rotation-per-minute spin rate to provide coverage, the team equipped each of the four spacecraft with multiple identical plasma analyzers. This approach



The red spike in the line graph above indicates a burst of electric power generated by the electrons. This peak is the predicted "smoking gun" for reconnection, observed for the first time with MMS. The round data plots at top show electron activity. Simultaneous with this spike, the electron activity (shown in red), which is initially localized to the equatorial plane on closed magnetic field lines (left), rapidly turns to move along the newly opened magnetic field lines toward the Earth (right). This is the first measurement of the opening of a magnetic field line using electrons as tracers. At right: Three of the four MMS spacecraft (shown in blue) were located above the X-line — the location where the magnetic fields would have crossed if they had not been annihilated — while the fourth was located below the X-line.

allows scientists to make critical electron measurements from every direction a hundred times faster than ever before. This configuration does much the same thing for plasma physics as high-speed movies did for ballistics science: it allows scientists to see the step-by-step process of a magnetic reconnection event.

But this approach generates massive amounts of data, more than can efficiently be sent back to Earth. Only a small fraction (4-5 percent) of the highest-resolution MMS data collected can be transmitted back due to downlink limits. The first cut at selecting potentially interesting data to download is made automatically by the instrument suite's central computer. But because machines, however smart, are no substitute for a scientist who knows what to look for, the MMS team also implemented a manual data selection system. A "scientist in the loop" (SITL) examines summary data for interesting features that the automated system may have missed.

The wisdom of this approach was proven early in the science operations phase of the MMS mission. Reviewing summary data from a magnetopause encounter on Oct. 16, 2015, the SITL identified the signature of a possible reconnection site — a jet of heated ions. It was a signature that the onboard computer had missed. Once the high-resolution data from the encounter were selected and downloaded, scientists began a rigorous analysis. The result: Not only had the spacecraft passed near a reconnection site — they had in fact flown through an EDR and made the first definitive measurements of the electron physics responsible for magnetic reconnection. MMS had found the needle in the haystack.

LIKE A BLOWN FUSE

So what happened when MMS sampled the dissipation region? As the four spacecraft moved along the boundary, MMS allowed scientists for the first time to visualize a reconnection event. Comprehensive data show what's happening in this explosive event, not unlike how high-speed video can delineate events such as a balloon popping or a bullet penetrating armor. And MMS collects data at the very smallest of scales, looking at the electron populations that govern the reconnection phenomena.

What did the electron sensors see? MMS measures the entire surrounding environment, measuring electron fluxes every 30 milliseconds. Previous sensors could only make a measurement every 4 seconds or so. The data contained more than 100 electron measurements; previous spacecraft capabilities could provide only one. This resolution is what opened up the new window on reconnection. Like most explosive events, reconnection is fleeting, so the high-speed MMS data allow scientists to map out the process at an electron scale.

Examining the data from the encounter, the MMS team saw a drop in the magnetic field to near zero, oppositely directed ion flows, accelerated electrons, an enhanced electric field, and a strong electrical current — all indications that the spacecraft had entered the dissipation region. The telltale signature of reconnection, however, was a spike observed in the electric power generated by the electrons, like a fuse blowing in space. This "blown fuse" was the predicted "smoking gun" for reconnection, observed for the first time with MMS.

As the electrons become demagnetized and the magnetic fields of the Sun and the Earth interconnect, solar wind and magnetospheric plasmas mix. The MMS electron images reveal a distinct crescent shape of concentrated energetic particles when solar wind electrons penetrate the magnetosphere (see figure to the left). But they don't stay there. These weave in and out across the boundary region, carrying the current and picking up energy from the electric field produced as part of the same process. Scientists had predicted these crescents in computer simulations but were surprised when data revealed that the crescents turned and flowed out along open magnetic field lines. This first measurement of the interconnection of magnetic field lines documented the occurrence of reconnection.

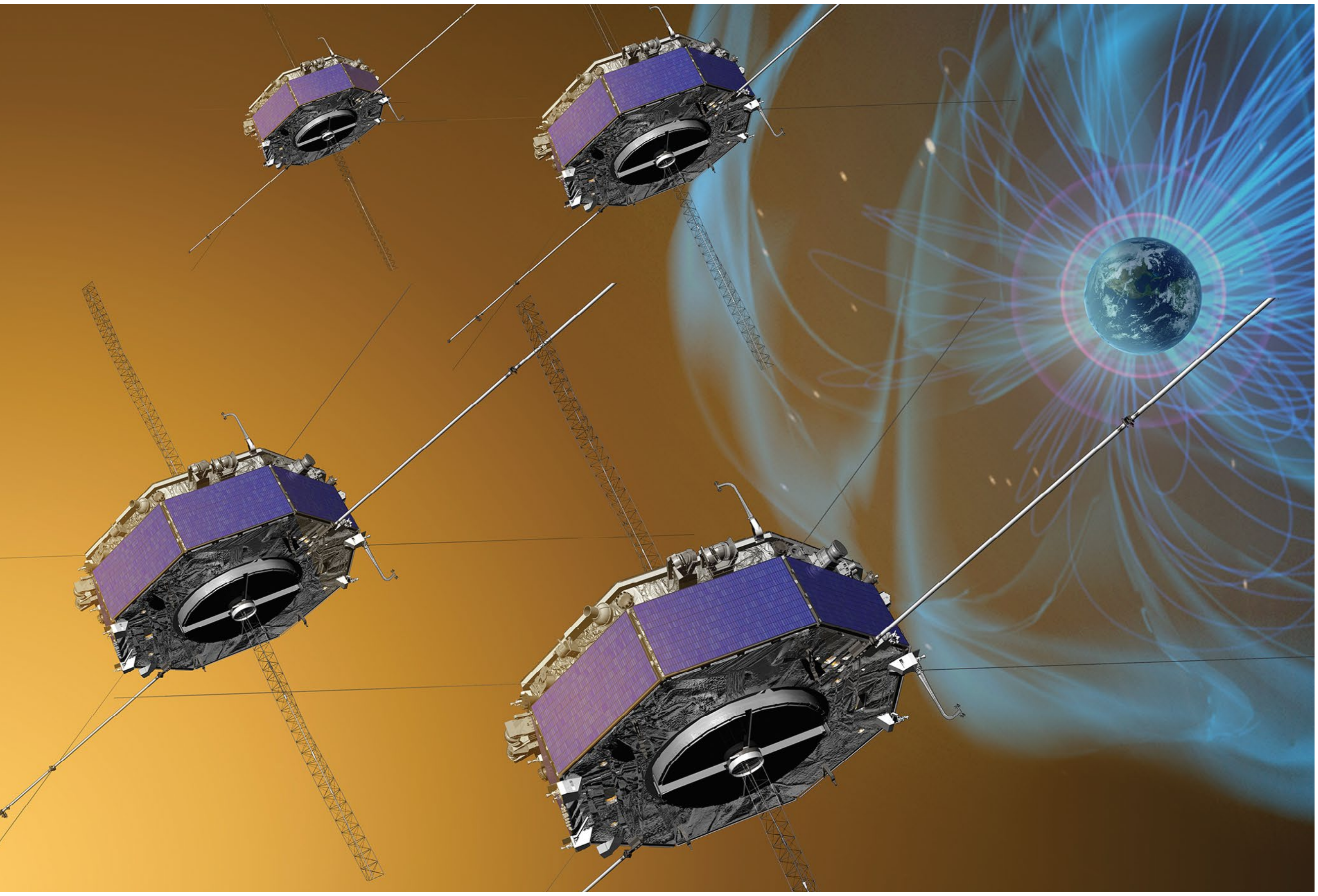
THE NEXT STEPS

After its first measurements of magnetic reconnection, MMS spent the next five months searching for more such events during its journey around the dayside of the Earth. MMS has since measured eight more reconnection events, each having different magnetic orientations and plasma conditions, on both sides of the boundary. The next step is to determine how energy is transferred from the magnetic field to the electrons. Theories and plasma simulations suggest that dissipation of various types of electromagnetic waves and plasma oscillations are responsible. MMS data contain all the information needed to solve the cause and effect part of the reconnection puzzle. And the entire MMS dataset is publicly accessible, so a large international contingent of space physicists is involved in this quest.

In September 2016, the MMS spacecraft began their second traversal of the dayside magnetopause before moving to the Earth's nightside and magnetic tail. It's in the magnetotail that field lines previously opened on the dayside are closed in an explosive manner — driving magnetic storms and auroral displays — while ensuring that there are no loose ends. Reconnection in the tail region is fundamentally different from that on the dayside. It is more symmetrical because plasma densities and magnetic field strengths are very similar on either side of the reconnection layer, while dayside reconnection is very asymmetric.

The fundamental nature of reconnection will allow the MMS results to be applied directly to understanding reconnection in solar, astrophysical, and laboratory settings through theory and modeling. Because these settings are either inaccessible — solar and astrophysics — or too small — laboratory plasmas — for direct comprehensive measurements, MMS will provide key insights into these areas.

Questions about this article? Contact Burch at (210) 522-2526 or jim.burch@swri.org.



Launched March 12, 2015, the four identical MMS spacecraft skim the sunward boundary of Earth's magnetosphere in a close tetrahedral formation. Each spacecraft carries a payload of 25 instruments to measure with unprecedented resolution the plasma, energetic particles, and electric and magnetic fields near and in magnetic reconnection sites.

COURTESY NASA/GSFC/CONCEPTUAL IMAGE LAB

D022146

Above the Storm

CYGNSS satellite fleet ready to take wing

By John Scherrer and Alan Henry

DETAIL

A cyclone is a tropical storm with a rotating, organized system of clouds and thunder-storms that originates over tropical or subtropical waters. When the storm reaches maximum sustained winds of 74 miles per hour or higher, it is classified as a hurricane, typhoon, or cyclone depending upon where the storm originates.

Hurricanes are more deadly and cause more damage than any other type of storm, with the largest releasing energy equivalent to 10 atomic bombs per second. Today's hurricane-tracking computers are 50 percent better at predicting the paths of tropical storms and hurricanes than they were in 1990. This improvement has increased warning times, enabling large-scale evacuations and allowing more time to protect property in a storm's path. However, the same quarter-century has seen almost no progress in predicting how strong a storm will be when it makes landfall. One reason is that the innermost core of a hurricane, down near the ocean surface, remains hidden from the view of weather satellites.

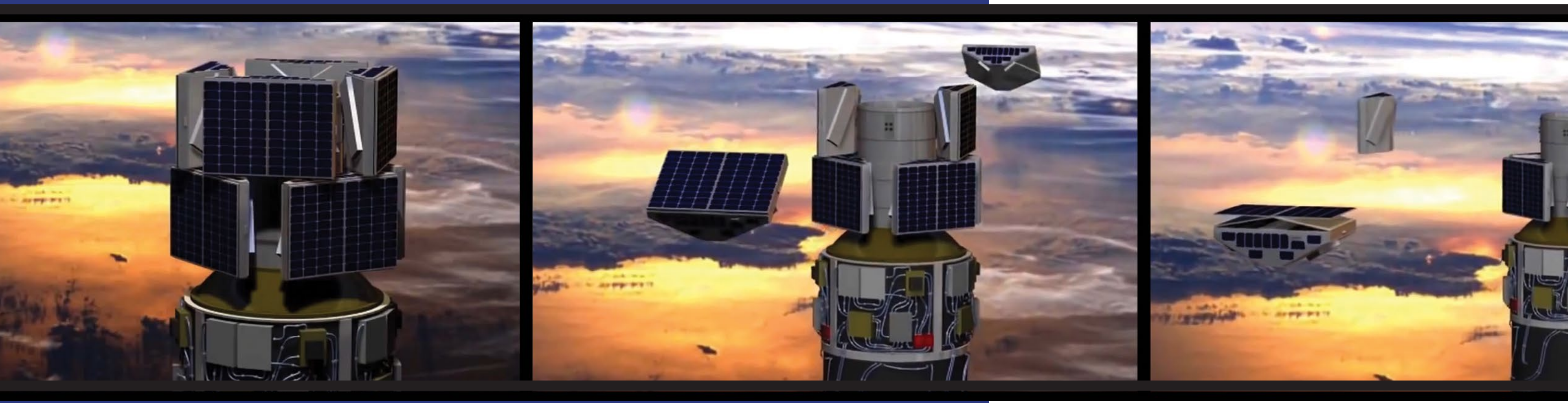
Like a home satellite TV system that loses programming due to "rain fade," most weather satellite-borne radar signals can't "see" through the thick clouds and heavy rains of a tropical storm. Measuring the movement of ocean waves beneath the hurricane could provide valuable clues to what drives the genesis of the hurricane as well as its wind speed and storm surge potential. But up to now, those measurements simply weren't possible.

Researchers and engineers at Southwest Research Institute (SwRI) and the University of Michigan expect all that to change with NASA's Cyclone Global Navigation Satellite System (CYGNSS), scheduled to launch in late 2016 or early 2017 from Cape Canaveral Air Force Station in Florida.

CYGNSS MISSION

Hurricanes are categorized into 5 types, depending upon their wind speed and their capacity to cause damage. The CYGNSS constellation of eight microsatellites will collect data based on GPS satellite signals to measure wind speeds and hurricane intensification, from the weakest through category 5.

After flying to high altitude on an Orbital-ATK L-1011 Stargazer jumbo jet, the CYGNSS satellites will be boosted into low-Earth orbit by a solid-fueled Pegasus XL rocket system. The satellites will be deployed sequentially, in opposing pairs, into a 320-mile-high circular orbit, traversing back and forth across the Equator from latitudes 38 degrees north to 38 degrees south. That path covers the zone where most of Earth's typhoons, hurricanes, and tropical storms originate. Most current weather satellites are in a polar orbit, looking at the whole globe for a worldwide sample of all kinds of weather conditions, spending a significant amount of time over locations where hurricanes do not exist. Ultimately, the eight CYGNSS microsatellites will be distributed in a pattern that allows successive satellites to pass over the same region every 12 minutes, with a median revisit time of less than three hours. As the CYGNSS and GPS constellations move around the rotating Earth, the two satellite systems will allow scientists to measure wind speeds over the entire tropic region every few hours.



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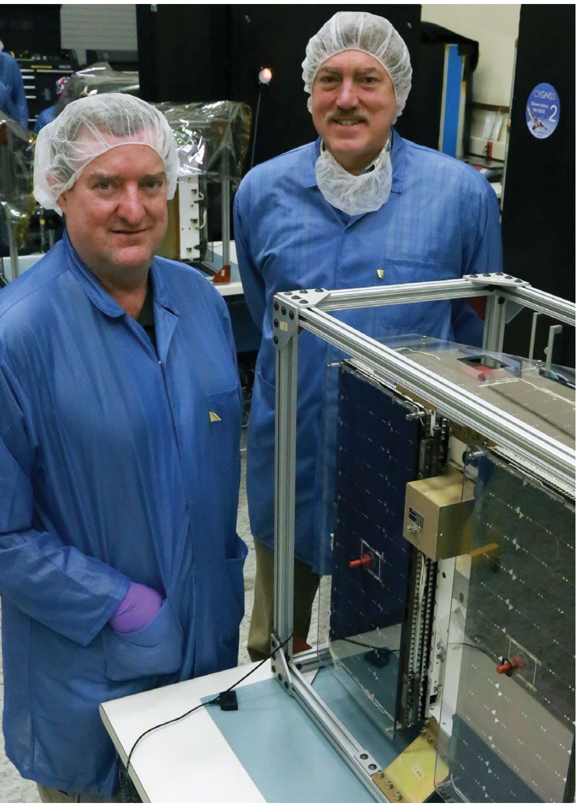
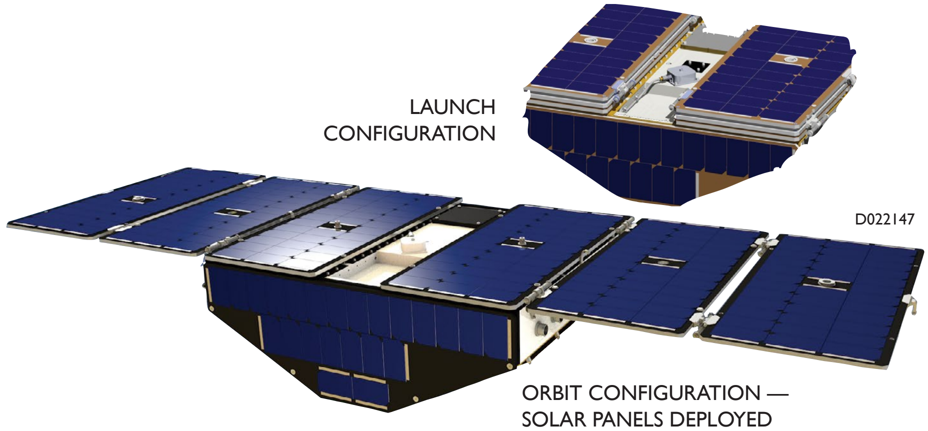


ABOUT THE AUTHORS

With more than 32 years of expertise developing space systems, John Scherrer (right) serves as mission project manager of CYGNSS, overseeing the development, launch, and operation of the eight microsatellites. Alan Henry (left) brings 20 years of experience to managing the assembly, integration, and testing of the CYGNSS constellation.



Because CYGNSS focuses on tropical weather, it can gather more frequent and timely data on the particularly intense weather spawned in the tropics.

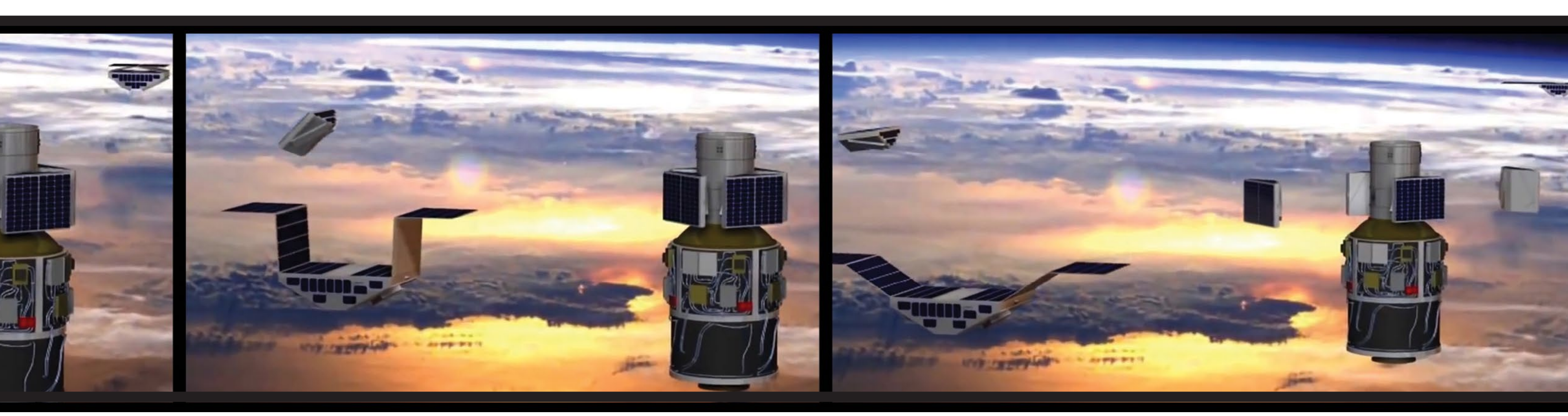
AN SwRI FIRST

For the first time in its long history of involvement in NASA space missions, SwRI designed, fabricated, and integrated the CYGNSS constellation of eight microsatellites. Assembly of the CYGNSS microsatellites began a year ago, in August 2015. For each microsatellite, the SwRI team integrated multiple components and subsystems, including many that were developed at SwRI for other space programs. Following assembly, technicians inspected interfaces and tested each system's function. Then the satellites were subjected to environmental testing, including evaluation in SwRI's electromagnetic and radio frequency facilities. With so many systems and subsystems in such a small package and the hyper-sensitive CYGNSS GPS receiver, this evaluation was particularly critical to ensure that the operation of one component didn't interfere with another. Then the spacecraft underwent thermal vacuum tests in a new SwRI chamber that simulates the environments encountered in space. This new chamber, much larger than other similar SwRI facilities, allowed four spacecraft to be tested together, saving months in the overall project schedule.

After thermal vacuum testing was completed in August 2016, the satellites were moved to SwRI's mechanical test labs and installed on the deployment module for vibration testing and subsequent post-environmental separation testing. Because the flight package — the deployment module plus the eight satellites — was so large, SwRI upgraded its vibration facility.

Each satellite packed for launch measures roughly 20x25x11 inches, slightly larger than a standard carry-on suitcase. Fully assembled, each satellite weighs about 64 pounds and, when the solar panels are deployed, has a wingspan of 5.5 feet.

The eight microsatellites will be launched from a single rocket. Once the rocket gets to the right altitude, it will deploy pairs of satellites in opposite directions two at a time. The solar arrays will then deploy autonomously within the first orbit.



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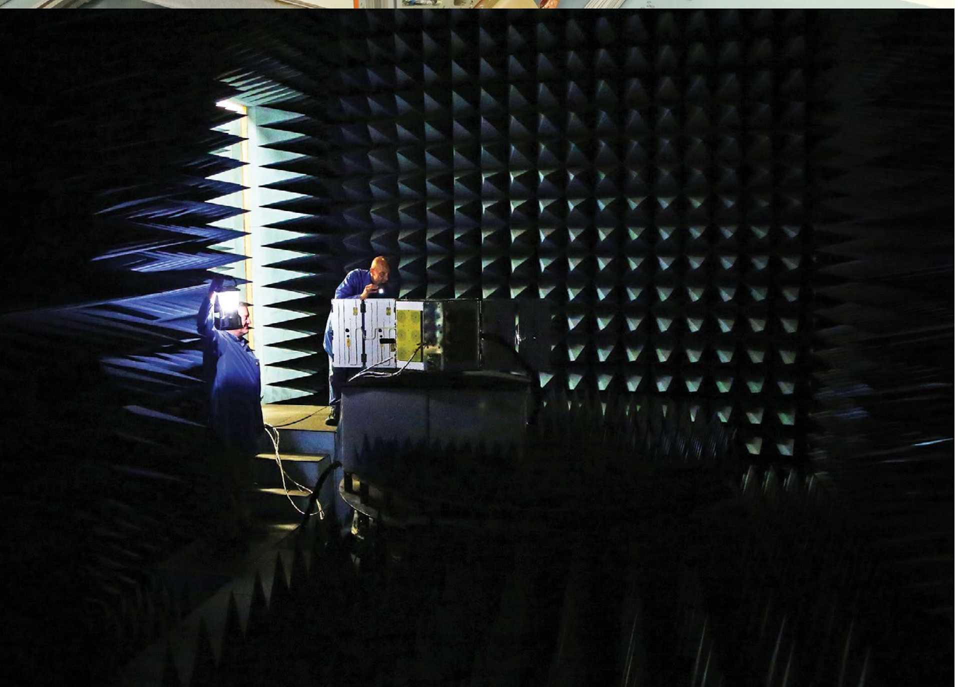

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Top: SwRI is designing, fabricating, and integrating the CYGNSS constellation of eight microsatellites.

Center: The satellites were subjected to environmental testing, including evaluation of electromagnetic compatibility (EMC) and interference (EMI) in SwRI's EMI/EMC and radio frequency facilities.

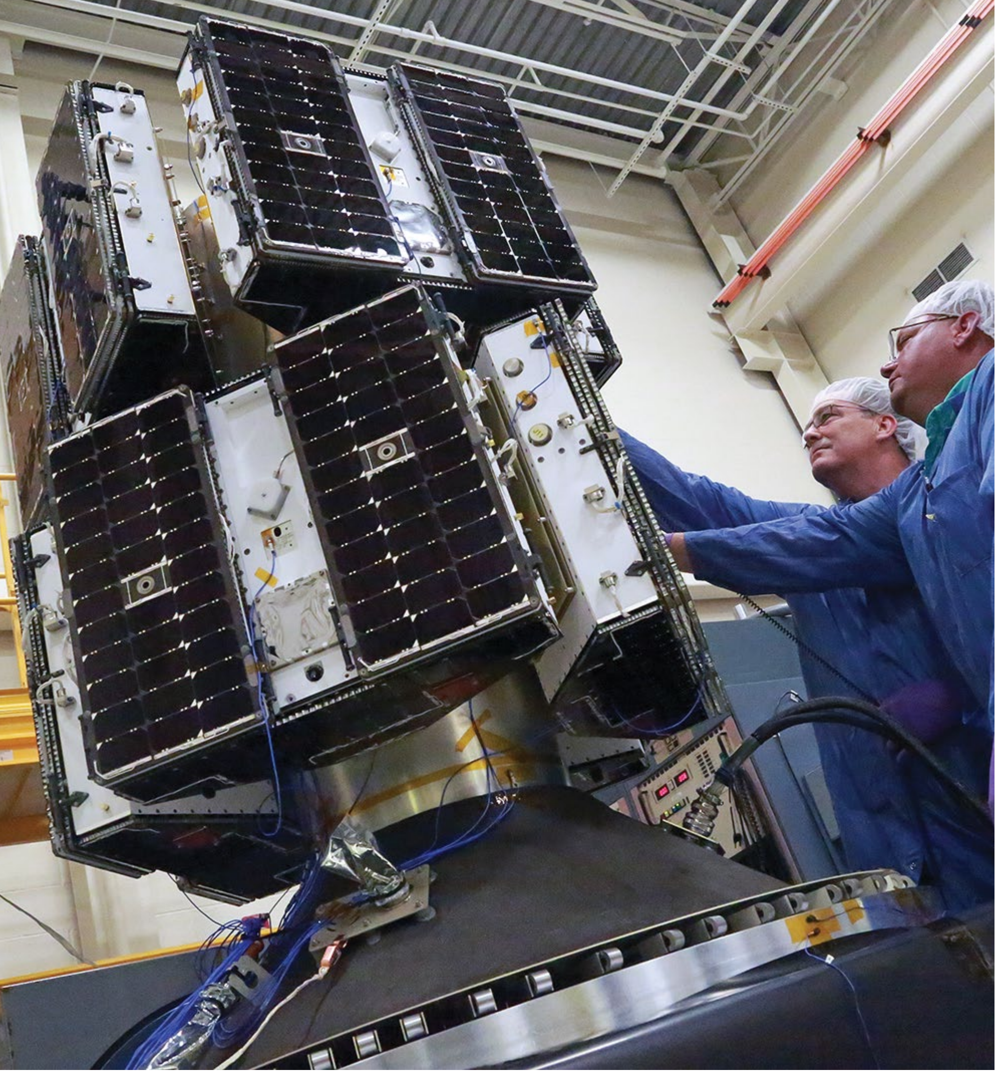
Bottom: In SwRI's new, larger thermal vacuum chamber, the CYGNSS spacecraft were cycled through the extreme hot and cold temperatures they will face in orbit.

SEEING THROUGH THE CLOUDS

A hurricane can be 300 miles in diameter and reach 40,000 to 50,000 feet up into the sky. The largest storms can generate wind speeds in excess of 160 miles per hour. Achieving the resolution needed for real-time remote sensing of tropical storms has been frustrated by technology limitations and high costs. However, recent gains in modeling techniques, plus the development of microsatellite technolog y using lower-cost commercial off-the-shelf equipment, make it possible for CYGNSS to provide science measurements to hurricane watchers at a level of detail never before available. Each microsatellite carries a GPS bi-static radar receiver. CYGNSS won't produce its own radar signals, but rather will receive reflected signals from the extensive constellation of GPS satellites already in orbit.

Just as they can measure small distances on the ground, the reflected GPS signals can sense the height of ocean waves with considerable sensitivity. When waves change rapidly and heights vary greatly, the signal reflections become scattered. The degree to which they are scattered yields valuable information about wind speed and direction, based on how much the wave action has distorted the GPS signal.

The process is similar to what a photographer sees when taking a picture of a scenic mountain lake. On a calm day, the mountains are reflected with almost mirror-like clarity. But if it's windy, waves on the lake blur the reflection of the mountains. CYGNSS will measure the amount of scatter in the reflected GPS signals. A perfectly calm ocean would yield a pinpoint-like reflection, but a storm-ridden ocean would scatter the signal's reflection into a blurry "glistening zone." CYGNSS bases its hurricane intensity findings on the size and behavior of these glistening zones. The GPS-reflecting instruments measure these zones and



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SwRI engineers prepare NASA's eight Cyclone Global Navigation Satellite System (CYGNSS) microsatellites, mounted on the deployment module, for vibration testing.

compare them to known parameters of winds and sea swells. When the signals are processed, the scattering becomes the source of an information-rich dataset for weather forecasters.

Hurricanes can generate in excess of 2 trillion gallons of rainfall per day, thwarting some space-borne measurements of ocean winds. The signal attenuation from heavy rain is associated with the radar frequency that most weather satellites use. Different radar bandwidths vary greatly in their ability to penetrate heavy precipitation. For example, weather satellites that use the C- and Ku- radar bands are heavily attenuated or even completely blocked by heavy rain.

However, even the highest rainfall rates have only a negligible effect on the L-band radar frequency used by GPS satellites. Using L-band radar provides a double benefit that was a major factor in the CYGNSS system design. Measuring reflected signals of existing GPS meant the satellites didn't need to produce their own radar signals, avoiding the cost, complexity, and power demands of eight onboard radar broadcast systems. The small, low-power design means all eight microsatellites can be placed in orbit with a single, cost-effective Pegasus rocket.

IMPLEMENTING CYGNSS

Hurricanes affecting the continental United States are most likely to form from June to November, when seas are the warmest. Upon landfall, strong winds, heavy rains, and waves can cause widespread devastation associated with the storm surge. Ninety percent of fatalities are associated with flooding.

The radar detection instruments aboard the CYGNSS constellation will create mapping images representing ocean surface roughness, which is directly related to the surface wind speed. Each microsatellite produces a map image of a GPS radar reflection point at a rate of up to four images per second. Wind speeds are derived from measurements of signal reflections covering 15.5 square miles of ocean surface. Together, the eight CYGNSS satellites can produce 32 wind measurements per second.

The satellites will downlink data via the Universal Space Network remote antenna sites located in Australia, Hawaii, and Chile. From there, data will be routed to the SwRI Mission Operations Center in Boulder, Colorado, for initial processing. Then, they will be forwarded to the Science Operations Center at the University of Michigan in Ann Arbor, Michigan. Meteorologists will use data to generate windspeed maps, graphs, and charts detailing the formation and intensity of cyclones and hurricanes.

CYGNSS will launch this winter, allowing scientists about six months to adjust the satellite spacing and calibrate the onboard instruments in anticipation of the 2017 hurricane season. The constellation will cover the Earth's historically active hurricane region as the eight microsatellites sweep high above the tropics. Once they have been positioned evenly around the world, the spacecraft are expected to continue operating with minimal course adjustments throughout the two-year primary mission.

Ultimately, CYGNSS data will be shared with the National Oceanic Atmospheric Administration to improve hurricane intensity models and help emergency managers make decisions regarding weather-related plans, such as evacuations.

The Space Physics Research Laboratory at the University of Michigan College of Engineering leads the overall mission execution, and its Climate and Space Sciences and Engineering Department leads the science investigation. The Earth Science Division of NASA's Science Mission Directorate oversees the mission.

Questions about this article? Contact Scherrer at (210) 522-3363 or john.scherrer@swri.org.

CYCLONE GLOBAL NAVIGATION SATELLITE SYSTEM

SwRI leads development and integration of the eight microsatellites that make up the CYGNSS constellation. The University of Michigan leads the mission and science investigation.

CYGNSS will be the first satellite mission focused on studying the formation and intensification of hurricanes.

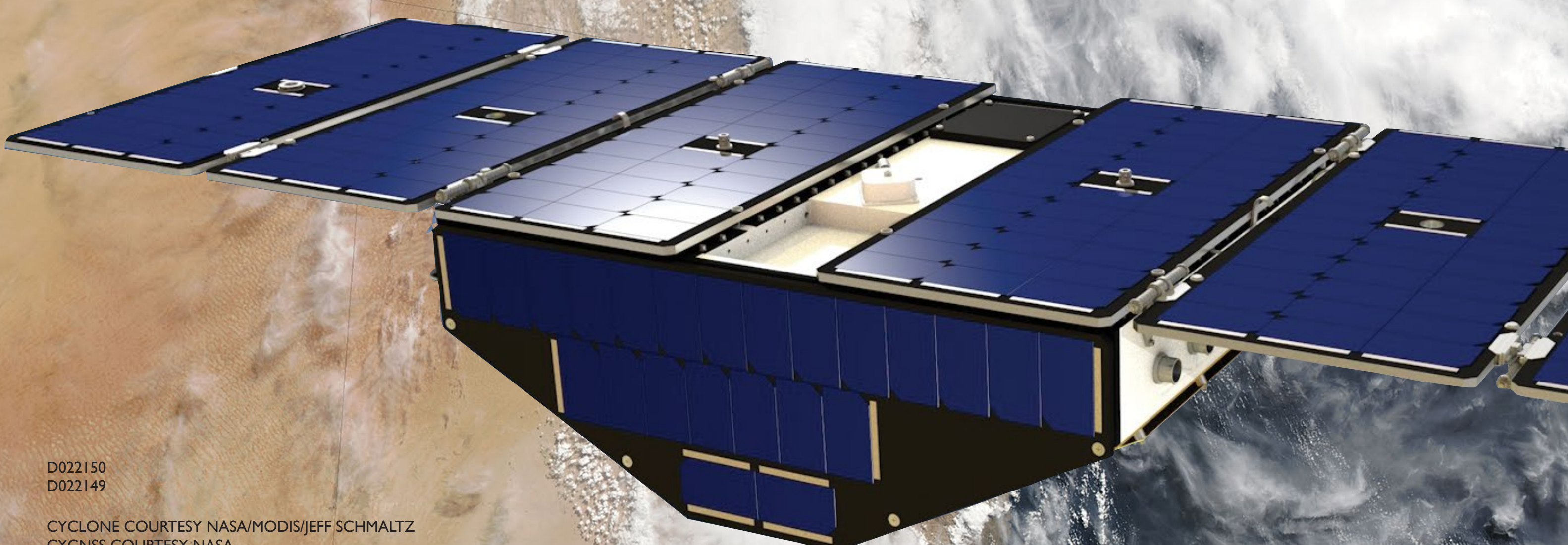
1

As CYGNSS and GPS constellations move around the rotating Earth, the two satellite systems will allow scientists to measure wind speeds over the entire tropics every few hours.

2

A constellation of eight identical microsatellites will measure ocean surface wind speeds in and near the hurricane core.

8



D022150
D022149

CYCLONE COURTESY NASA/MODIS/JEFF SCHMALTZ
CYGNSS COURTESY NASA

CYGNSS

BY THE NUMBERS

12

The CYGNSS constellation will survey a region every 12 minutes, covering more ocean surface than can be measured by Hurricane Hunter aircraft.

32

Producing 32 wind measurements per second, CYGNSS will allow forecasters to improve models used to predict the intensity of hurricanes.

38

CYGNSS will observe tropical cyclone development and movement between 38° north latitude and 38° south latitude.

65

Each of the microsatellites weighs about 65 pounds and has a wingspan of 5.5 feet — about the same as a swan in flight.

320

From a 320-mile-high circular orbit, the payload will "see through" the intense hurricane rainfall, allowing scientists to study the inner core of the hurricane and how it intensifies.

Powering the Science of Violent Storm Research

SwRI engineers retrofit an A-10 Thunderbolt II into a storm-penetrating aircraft

By Mike Rafferty, Barney Tannahill, Jordan Nielson, and Daniel Broesche

The A-10 Thunderbolt II, commonly called the Warthog, is an aerial workhorse that's been a mainstay of the U.S. close-air support mission since it entered military service in the mid-1970s. Since then it's seen action from the Middle East and Afghanistan to Grenada and the Balkans. Essentially built around a 30-mm, seven-barrel rotary cannon, the A-10 originally was designed to protect ground troops from tanks and light armored vehicles. Unlike other modern fighters, it flies neither fast nor high, but was built to survive battle damage and return its pilot safely home. The A-10 can take off and land on short, unimproved airstrips. It features redundant hydraulics and engine and flight controls, and the pilot is protected by a 1,200-pound "bathtub" of titanium armor.

Being heavy, slow, and decidedly ungraceful, Warthogs have limited usefulness outside of this military combat role. That is, unless you're looking for a suitable ride for flying into a thunderstorm. And that is exactly what a team of weather researchers has in mind. Working with a commercial client on a National Science Foundation-funded program, engineers in the Defense and Intelligence Solutions Division at Southwest Research Institute (SwRI) helped to modify a mothballed A-10C into an aerial laboratory to help scientists research and better understand the life cycles of violent storms as well as improve tornado prediction.

The SwRI team designed a new power system to run a suite of scientific meteorology equipment without interfering with the aircraft's existing power generation systems. Finding room for the dual-power system was relatively easy: Take out the GAU-8 cannon and its ammunition, and you save 4,000 pounds and create four-by-eight feet of usable space. Into that space goes a peacetime payload of standard laboratory instrumentation the plane will take into a whole new world of hazardous duty — violent thunderstorms in the U.S. and around the world.

The A-10's rugged design and reinforced armor plating made it a perfect fit for its new role in the Storm Penetrating Aircraft (SPA) project. It replaces a Korean War-vintage, propeller-powered T-28 trainer that was retired in 2005 after 35 years of storm chasing. In flight, the A-10 is a much more capable aircraft for in-situ storm research. The T-28 had a ceiling of about 18,000 feet; the A-10 can fly more than twice as high, and with a larger payload.

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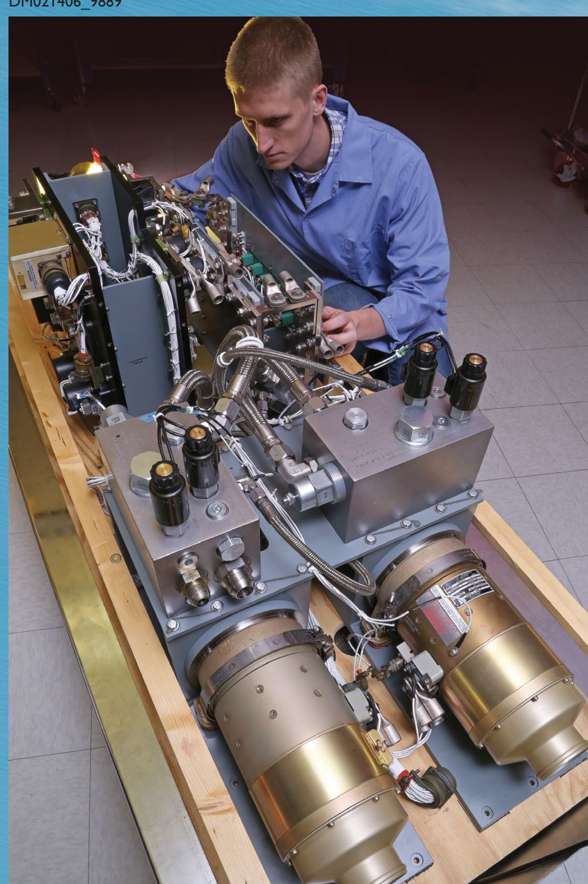


SwRI researchers were able to find generators that could fit inside the cannon's former home and supply enough electricity to power the weather research instruments. The hydraulic supply that once powered the gun now powers the SwRI-installed generators. Using hydraulics to power onboard instrumentation is what makes this installation unique. Typically, an aircraft has a hydraulic generator only as a backup in the event the primary electrical system fails. However, because the primary weapon system was driven by hydraulics, SwRI engineers were able to tap into that configuration to power the research equipment.

It was crucial that the hydraulically powered auxiliary power systems be independent of the plane's own electrical system, which relies on generators powered by the turbofan engines. That way, the scientific equipment doesn't draw power away from any flight-critical systems. If either or both of the auxiliary generators fail, the plane will still fly. While an auxiliary power failure likely would restrict some research, the pilot could still land safely.

One of the bigger challenges was installing a power system in the place of the aircraft gun system while balancing system-operating requirements — hydraulic, electrical, and cooling. The SwRI team approached the project as a single unit with dual independent power supplies. The advantage of this design was to use both hydraulic supplies, one from each engine, to drive each power supply. Each engine-driven hydraulic pump can deliver a rate of 40 gallons per minute (GPM) sustained flow at 3,000 psi. To power the new systems and still maintain existing aircraft hydraulic systems, the team could use up to 20 GPM for the power supplies. The team picked a motor with enough power and large displacement to achieve the 20 GPM target needed during normal operations. The hydraulic system spins the generator that sends the electricity out for distribution to the connected equipment. Each power system can produce both AC and DC current and provides 350 amps steady-state and 400 amps at peak, at 28 volts of DC electricity. Each side has a set of inverters for AC power that can pull 65 to 68 amps at 115 volts AC of 60Hz electricity.

When the plane is on the ground, the system needs to be able to cool itself to avoid overheating. This was accomplished using existing fans on the generators connected to external ducts to draw in cool air. However, when cruising at altitudes up to 40,000 feet, where outside temperatures are as low as minus 40 F, the generator and hydraulic motors generate heat to offset the external temperatures.

Designing the control loop for the hydraulic motors was another engineering challenge. The system controls the motor, which powers the generator. During operation, the generator's electrical load varies depending on which instruments are in use. A spring-loaded mechanical flow valve that controls the hydraulic motor caused unacceptable oscillations of +/- 4,000 RPM. Smaller control valves to minimize the oscillations were tried, but those limited the

Left: SwRI engineers designed a new power system to run meteorology instruments for the A-10's new storm-chasing mission. The package was designed to fit the 4x8-foot space left when the aircraft's cannon and ammunition were removed from the nose of the aircraft.

D022151

COURTESY DEPT. OF DEFENSE

D021406_9837

This control panel allows the pilot to operate dual power systems from the cockpit. This design provides more flexibility to choose which scientific instruments should be turned on or off during severe thunderstorms.

motor's power output. Ultimately, SwRI engineers installed an electronic controller programmed to maintain a constant RPM and still meet the generator's peak operating requirements.

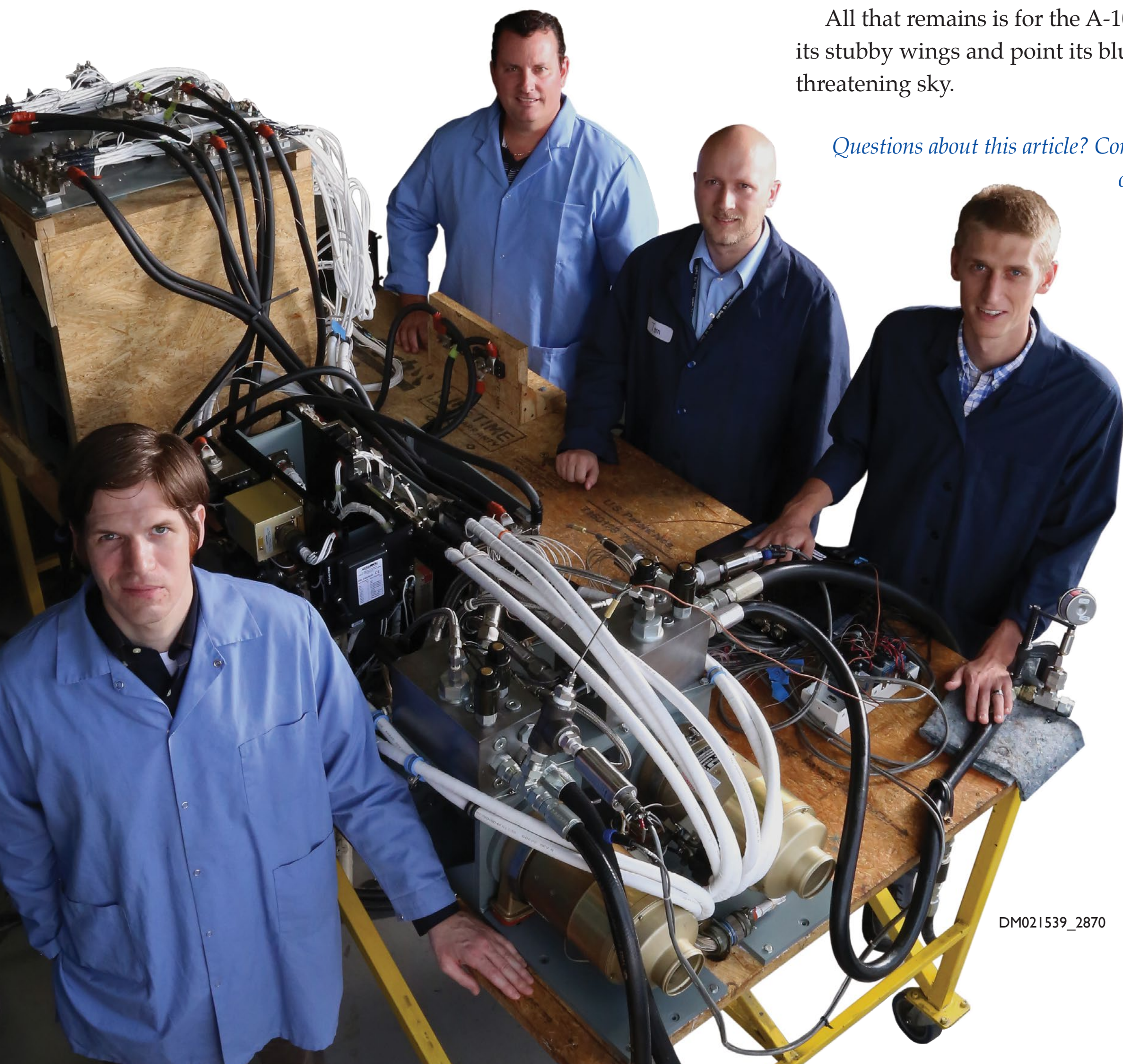
Meanwhile, researchers from SwRI's Engine, Emissions, and Vehicle Research Division assisted with a pressure problem on the hydraulic motor seals. The hydraulic motors, which run between 7,500 and 9,000 RPM, have a seal on their shaft designed to endure about 70 pounds per square inch (psi) of pressure. The A-10's hydraulic system accumulators, however, never allow the back pressure to fall below 70 psi. To compensate, the SwRI team built a suitably rated face seal on a separate outside shaft to relieve pressure on the motor seal.

Removing the Warthog's two-ton primary weapon system created an issue that aerospace engineers rarely have to deal with — adding weight to maintain the plane's aerodynamics. The A-10's cannon and ammunition were stored forward of the wing. That means that for the "Weatherhog" A-10 to not be tail-heavy in flight, its center of gravity must match that of its military siblings. The two hydraulic generators together weigh roughly the same as the 620-pound cannon that was removed. However, the weight of the scientific payload doesn't come close to matching the Warthog's bulky ammunition load. SwRI engineers installed ballast to compensate for some of that weight loss. Additional ballast can be added later depending on the weight of other instrumentation packages to be installed.

Because flight testing wasn't possible during the project, all mechanical and electrical issues had to be resolved on the ground. For this reason, the system design had to be more complex with redundant and backup features to ensure the systems are safe once in the air. Engineers in SwRI's Mechanical Engineering Division provided space and equipment to conduct some of the final testing. This allowed the team to resolve the pulsation problem in the hydraulic control system and to conduct structural analysis of the new framing and mounts that support the dual power systems. They also analyzed force and shear strength data and verified that the system would remain structurally sound during flight.

All that remains is for the A-10 SPA "Weatherhog" to spread its stubby wings and point its blunt nose into a suitably threatening sky.

Questions about this article? Contact Rafferty at (210) 522-5251 or mike.rafferty@swri.org.



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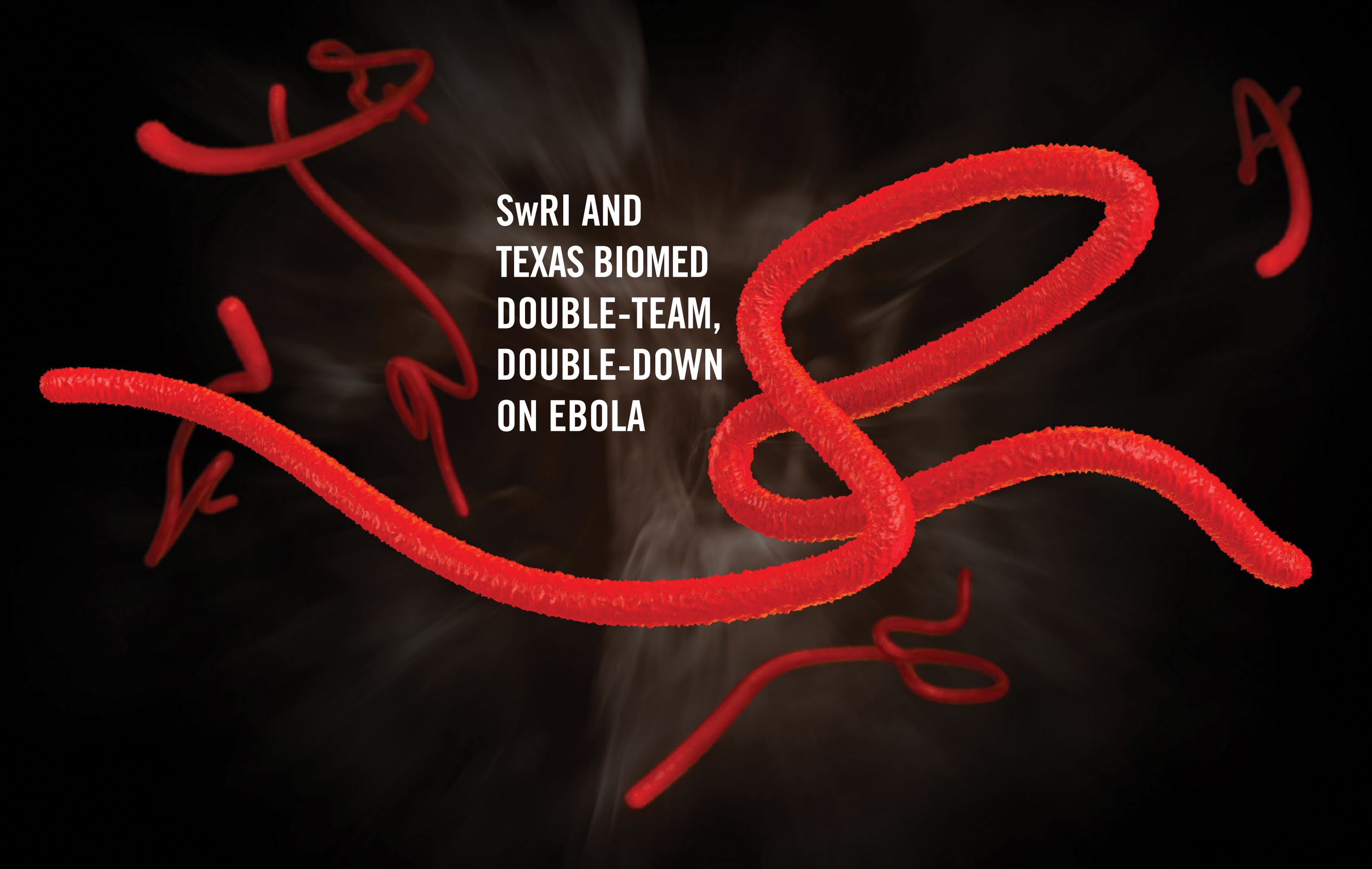
ABOUT THE AUTHORS

A team of SwRI engineers — (left to right) Mike Rafferty, Daniel Broesche, Barney Tannahill, and Jordan Nielson — designed a new power system that turned a mothballed A-10 Warthog into a Weatherhog storm-chasing aircraft. The dual, independent power systems ultimately will run a suite of scientific meteorology equipment without interfering with the aircraft's existing power generation systems.

SwRI AND TEXAS BIOMED DOUBLE-TEAM, DOUBLE-DOWN ON EBOLA



SwRI is working with Texas Biomedical Research Institute (TBRI) on two drug development projects targeting the Ebola virus. The Defense Threat Reduction Agency (DTRA) awarded the team a three-year, $9.1-million contract to combine two available medications, while the National Institute of Allergy and Infectious Diseases (NIAID) awarded a three-year, $3.7-million grant to modify a compound used to treat high blood pressure in China.

Hemorrhagic fevers like Ebola have very low survival rates. No proven treatments for these viruses mean outbreaks can result in fatalities as high as 90 percent.

"We are at the forefront of rapidly developing and fielding these new treatments," said Dr. Joe McDonough, director of SwRI's Pharmaceuticals and Bioengineering Department. "We are taking a unique approach to repurpose existing or develop novel therapeutics that can be enhanced to target emerging biothreats like Ebola."

For DTRA, SwRI will use core pharmaceutical capabilities to create a more bioavailable, or more easily absorbed, formulation of cepharanthine (CEPN). CEPN is a Japanese drug that has been safely used for more than 40 years to treat a wide range of illnesses. In screening for chemical compounds that could potentially fight an Ebola infection, Texas Biomed scientists discovered CEPN was effective at combatting the Ebola virus but required very high doses. This new formulation of CEPN will be combined with chloroquine, a drug used to treat malaria.

"We had found that chloroquine, a drug traditionally used to treat malaria, also stopped the Ebola virus, but again, at very high doses," said Dr. Robert Davey, scientist and chair of the department of Virology and Immunology at Texas Biomed. "After reading that chloroquine combined with cepharanthine had a synergistic effect in treating malaria, we put two and two together. We want to test the idea that this combination could create a powerful Ebola virus inhibitor cocktail. Our collaboration with McDonough's group at SwRI and funding from DTRA gives us the means to test the idea." Texas Biomed will conduct efficacy testing of the formulations in its state-of-the-art Biosafety Level 4 Laboratory.

For NIAID, SwRI is modifying the compound tetradrine, based on TBRI research showing the compound can inhibit Ebola infections. Tetrandrine, a drug derived from an Asian herb, is banned everywhere but in China because it can cause blood pressure to drop precipitously. The compound has been found to improve the survival of mice infected with Ebola, but equivalent doses could be toxic for humans. The SwRI-TBRI team is looking at ways to improve the drug's efficacy while overcoming dangerous side effects.

"We expect these efforts will provide significant new countermeasures to improve readiness to treat Ebola," McDonough said.

SwRI is the primary contractor on both programs with TRBI providing virology expertise and drug efficacy evaluations. Both organizations are part of the Vaccine Development Center of San Antonio (VDCSA). The global nature of epidemics emphasizes the importance of international collaborations, and VDCSA coordinates these efforts for the region.

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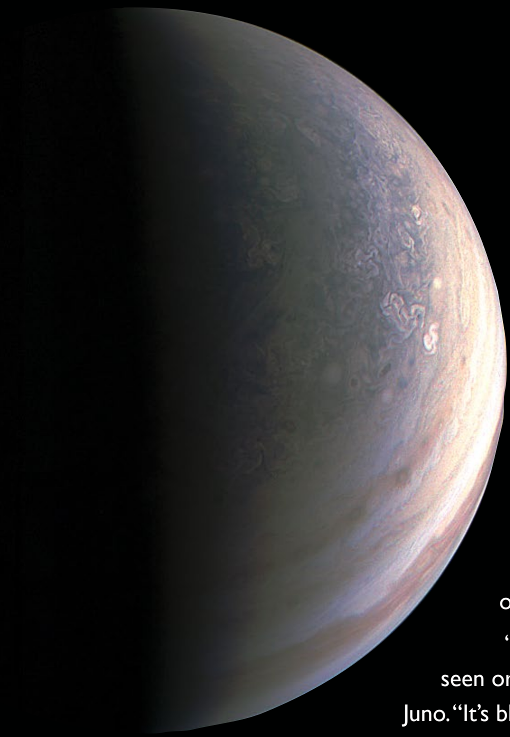


JUNO UNVEILS JUPITER'S POLES

NASA's Juno spacecraft successfully executed the first of its 36 orbital flybys of Jupiter Aug. 27, passing about 2,600 miles above the gas giant's swirling clouds. At the time, Juno was traveling at 130,000 mph. This flyby was the closest Juno will get to Jupiter during its prime mission.

The first-ever images of Jupiter's north pole, taken during the spacecraft's initial flyby with its instruments switched on, show storm systems and weather activity unlike anything previously seen on any of our solar system's gas-giant planets.

"First glimpse of Jupiter's north pole, and it looks like nothing we have seen or imagined before," said SwRI's Dr. Scott Bolton, principal investigator of Juno. "It's bluer up there than other parts of the planet, and there are a lot of storms. There is no sign of the latitudinal bands or zone and belts that we are used to. This image is hardly recognizable as Jupiter. We're seeing signs that the clouds have shadows, possibly indicating that the clouds are at a higher altitude than other features."

Another first: The Jovian Infrared Auroral Mapper (JIRAM) acquired infrared close-ups of the planet, including dramatic images of Jupiter's southern aurora. No other instrument, either from Earth or space, has been able to see these phenomena.

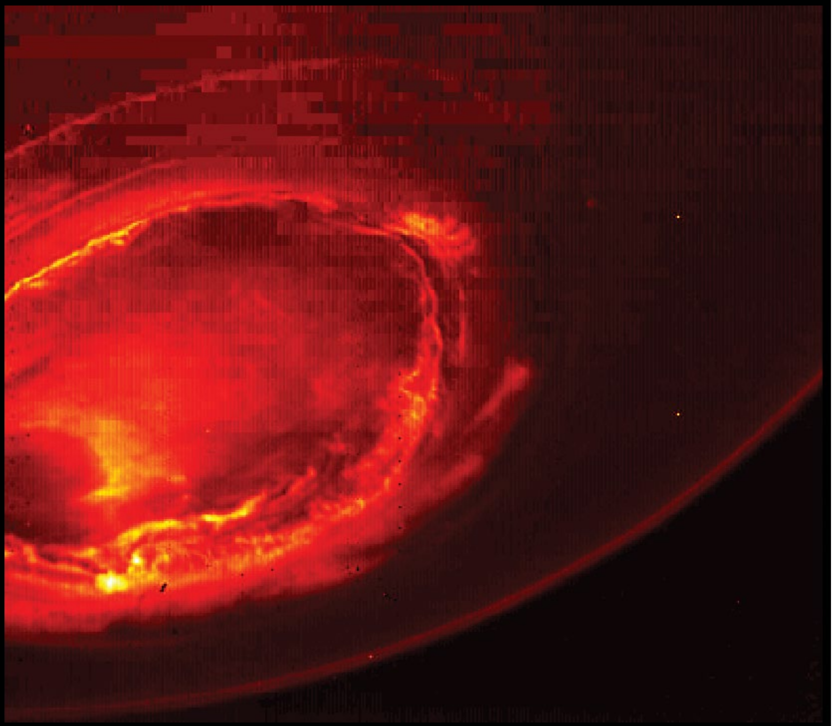
The two SwRI-led instruments — the Jovian Auroral Distributions Experiment (JADE) and Ultraviolet Spectrograph (UVS) — were successfully commissioned during this first orbit.

"JADE operated smoothly as it collected the first plasma data directly over the poles of Jupiter," said SwRI's Dr. Phil Valek, lead co-investigator of the instrument. JADE measures the auroral electron and ion populations along the planet's magnetic field lines to understand which particle populations create the Jovian aurora. "The science team is now working to understand all the amazing observations Juno made. We can't wait to find out what we will see next."

UVS images ultraviolet emissions from the Jovian aurora, allowing space scientists to correlate those observations with JADE's observations of the particle populations that create them.

"We are very happy with the data we obtained and are amazed by the data collected by the other instruments," said SwRI's Dr. Randy Gladstone, the instrument's lead co-investigator. "UVS is healthy and dealt with the radiation very well. We learned a lot about how to operate UVS, and are very much looking forward to the science orbits that begin in November."

COURTESY NASA/SWRI/MSSS



Top: NASA's Juno spacecraft captured this view as it closed in on Jupiter's north pole, about two hours before closest approach on Aug. 27, 2016.

Right: This infrared image from Juno provides an unprecedented view of Jupiter's southern aurora. Such views are not possible from Earth.

COURTESY NASA/SWRI/ASI

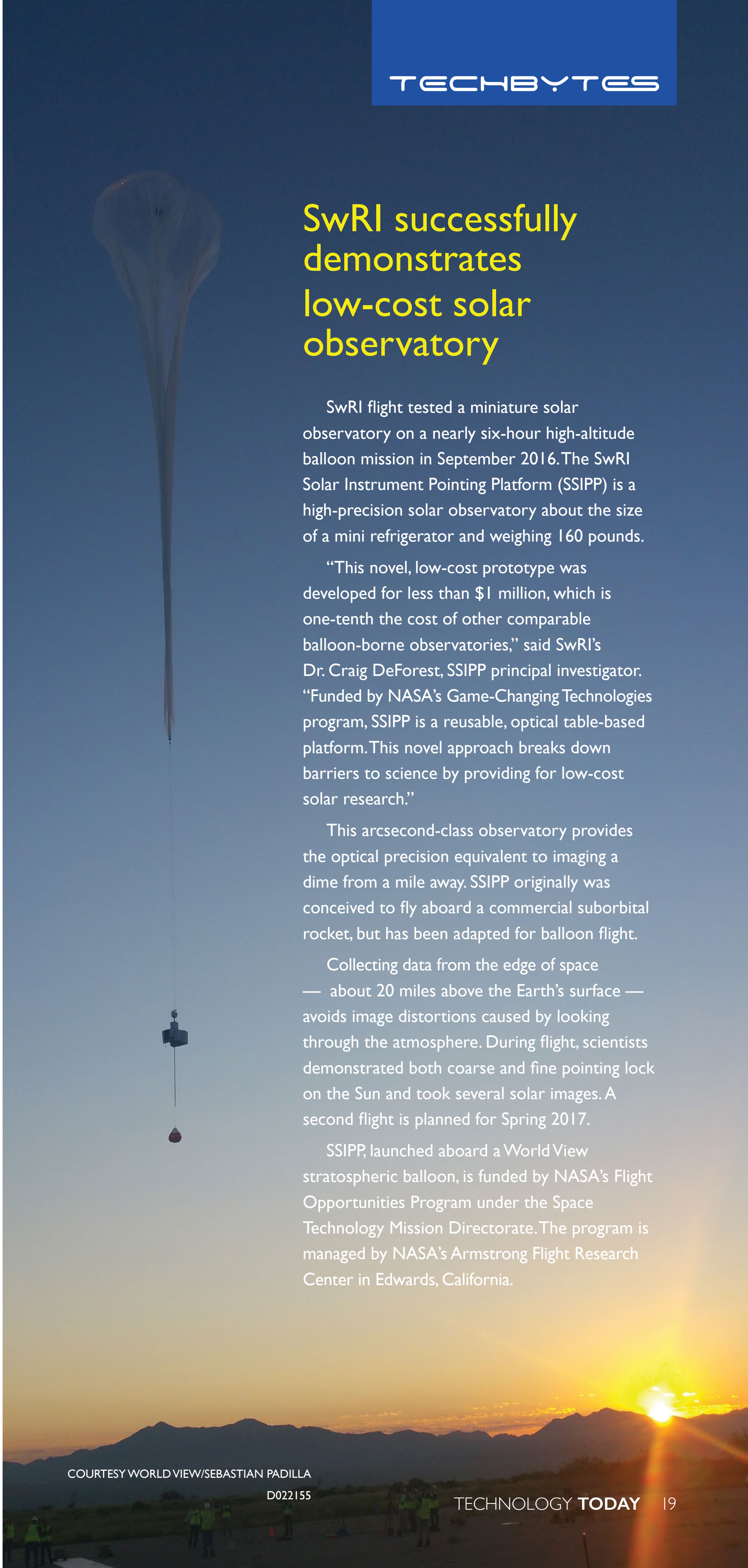
D022154

SwRI, UTSA Collaboration Continues

SwRI and The University of Texas at San Antonio (UTSA) Office of the Vice President for Research announced two new projects funded by the Connecting through Research Partnerships (Connect) Program. The projects will receive $125,000 each in funding to investigate biofilm-related corrosion in pipelines and an ultrasound drug delivery methodology.

Biofilms can cause microbiologically influenced corrosion (MIC) and are a serious problem in pipelines and other infrastructure. To better understand MIC, the SwRI and UTSA team will collect genomic and metabolic data from biofilms to develop models that can predict corrosion and identify techniques to inhibit formation. The project targets MIC problems in the petroleum industry, but has broad implications in other pipeline industries as well as medical applications, where MIC can affect dental and other types of implants.

The ultrasound drug delivery project will explore new ways to control the release of drugs, delivering therapies to targeted tissue at an adjustable rate. The team will develop soundwave-sensitive liposomes to control drug release using ultrasound and then monitor the real-time drug concentrations in deep tissue. This project is particularly applicable to the field of precision medicine, which recognizes that because people react differently to treatments, medical decisions should consider the drug response of the individual.



COURTESY WORLD VIEW/SEBASTIAN PADILLA

D022155

SwRI successfully demonstrates low-cost solar observatory

SwRI flight tested a miniature solar observatory on a nearly six-hour high-altitude balloon mission in September 2016. The SwRI Solar Instrument Pointing Platform (SSIPP) is a high-precision solar observatory about the size of a mini refrigerator and weighing 160 pounds.

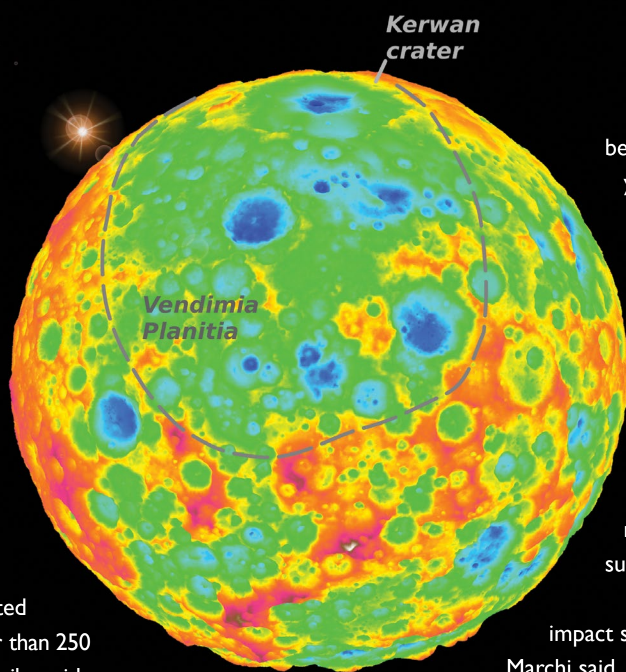
"This novel, low-cost prototype was developed for less than $1 million, which is one-tenth the cost of other comparable balloon-borne observatories," said SwRI's Dr. Craig DeForest, SSIPP principal investigator. "Funded by NASA's Game-Changing Technologies program, SSIPP is a reusable, optical table-based platform. This novel approach breaks down barriers to science by providing for low-cost solar research."

This arcsecond-class observatory provides the optical precision equivalent to imaging a dime from a mile away. SSIPP originally was conceived to fly aboard a commercial suborbital rocket, but has been adapted for balloon flight.

Collecting data from the edge of space — about 20 miles above the Earth's surface — avoids image distortions caused by looking through the atmosphere. During flight, scientists demonstrated both coarse and fine pointing lock on the Sun and took several solar images. A second flight is planned for Spring 2017.

SSIPP, launched aboard a World View stratospheric balloon, is funded by NASA's Flight Opportunities Program under the Space Technology Mission Directorate. The program is managed by NASA's Armstrong Flight Research Center in Edwards, California.

The Mystery of the Missing Craters



An SwRI-led team of scientists made a puzzling observation while studying the size and distribution of craters on the dwarf planet Ceres. It has no large craters.

Ceres is the largest object in the tumultuous Main Asteroid Belt between Mars and Jupiter. Collision models predicted Ceres should have 10 to 15 craters larger than 250 miles wide and at least 40 craters over 62 miles wide. Instead, NASA's Dawn spacecraft found only 16 craters larger than 62 miles across and none larger than 175 miles in diameter.

Crater size and distribution offer planetary scientists important clues to the age, makeup, and geologic history of planets and asteroids. Ceres is believed to have originated about 4.5 billion years ago at the dawn of our solar system.

"We concluded that a significant population of large craters on Ceres has been obliterated beyond recognition over geological time scales, likely the result of Ceres' peculiar composition and internal evolution," said SwRI's Dr. Simone Marchi, lead investigator. A closer look at Ceres' topography reveals up to three roughly circular, shallow basins as much as 500 miles wide may lie hidden beneath a surface subsequently marked with small craters.

"Somehow Ceres has healed its largest impact scars and renewed old, cratered surfaces," Marchi said.

The top of this false-color image includes a grazing view of Kerwan, Ceres' largest impact crater. Kerwan gradually degrades as one moves toward the center of the image into a 500-mile wide, 2.5-mile deep depression (in green) called Vendimia Planitia. This depression is possibly what's left of one of the largest craters from Ceres' earliest collision history.

COURTESY SWRI/SIMONE MARCHI D022156

ROS-INDUSTRIAL CONSORTIUM GOES GLOBAL

D022157

The ROS-Industrial Consortium (RIC) has expanded with a new branch serving the Asia-Pacific region. SwRI, working with the Singapore-based Advanced Remanufacturing and Technology Centre (ARTC) and Nanyang Technological University (NTU), launched RIC-APAC in July 2016.

SwRI initiated ROS-Industrial in 2012 through an internal research program conducted with industry collaborators. This open-source project extends the advanced capabilities of Robot Operating System (ROS) software to manufacturing. The RIC — with branches in the Americas, Europe, and now Asia — provides cost-shared applied research and development for advanced factory automation. Consortium members drive new capabilities in ROS-I by championing Focused Technical Projects based on their near-term automation requirements.

RIC-APAC also will get support from the European consortium, started in 2014 and managed by Fraunhofer IPA in Stuttgart, Germany. In addition to member-led initiatives, the European Consortium acquires EU public funding for ROS-I to make it complementary, rather than an alternative, to government-led initiatives such as Industrie 4.0.

Supported by the international consortia, SwRI maintains a ROS-Industrial repository that provides interfaces for common industrial manipulators, grippers, sensors, and device networks. It also provides software libraries for automatic sensor calibration, process path/motion planning, applications like Scan-N-Plan, developer tools like the Qt Creator ROS Plugin, and manufacturing-oriented training curriculum.

SIMULATED MOON MISSIONS TO INSPIRE AT-RISK STUDENTS

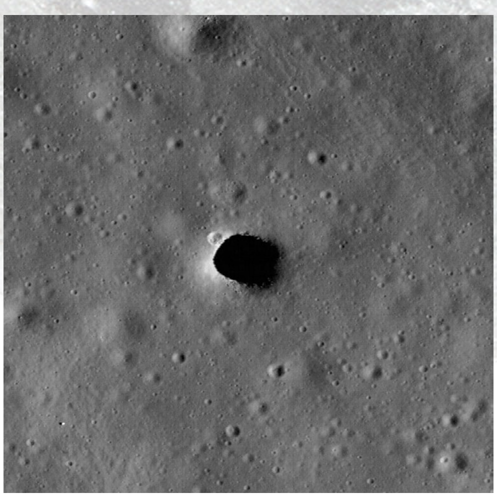
Starting in 2017, SwRI will develop experiments for a NASA-funded education program — designed to inspire students to pursue science, technology, engineering, and technology studies — using simulated missions to explore and settle the moon.

"We want students to get excited about science by thinking of multidisciplinary solutions to big problems," said Dr. Marius Necsoiu, an SwRI remote-sensing scientist and grant co-investigator. "Participants will be challenged with experiments and a commitment to see a mission to its conclusion."

Through a $1.24 million NASA grant to the WEX Foundation, the Lunar Caves Analog Test Sites program will be offered through the San Antonio Prefreshman Engineering Program at The University of Texas at San Antonio. The program will identify at-risk secondary students to help improve their education and career trajectories.

"Participating students will have an opportunity over three years to get world-class instruction and experience as they learn scientific techniques and planning that go into a long-term space mission," said Edward Patrick, an SwRI co-investigator on the grant.

Each year will offer new missions, with remote-sensing and reconnaissance experiments in the first two years, and habitation and human settlement studies in the third year.



COURTESY NASA/ LROC/ ASU D022168

South Texas caves and karst features, including Robber Baron Cave in San Antonio, will serve as analogs for features such as the Marius Hills Skylight shown here. Large enough to accommodate the White House, this lunar cavern is under consideration for a potential underground human settlement on the moon.

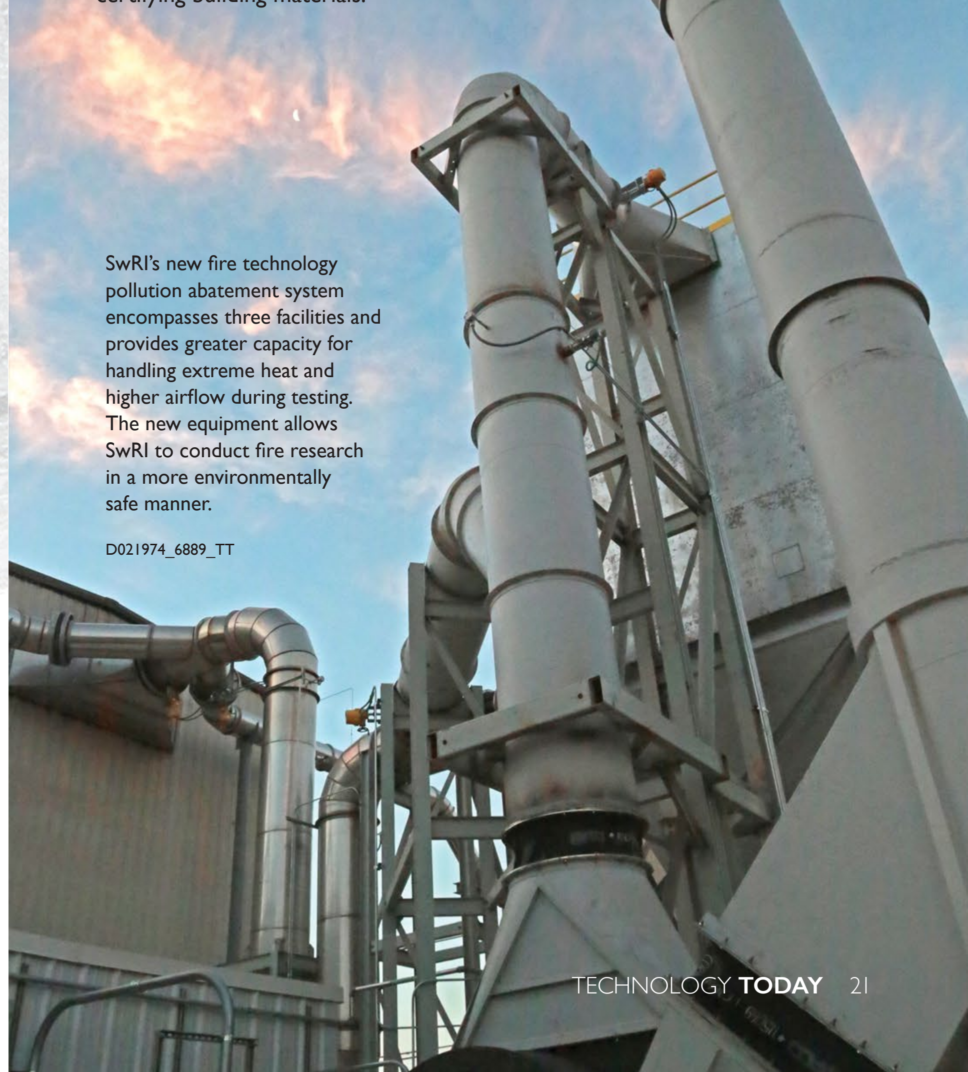
BURNING "GREEN" FIRES

Burning materials for fire safety certifications and research can produce tremendous amounts of smoke and emissions. SwRI offers "green testing" of products and materials with custom-built pollution abatement systems.

In 2015, SwRI invested in a $2.5 million pollution abatement system for fire research, including furnace fire, jet fire, and car burn laboratories. In all, SwRI has invested $5.4 million providing cleaner, greener testing practices for SwRI's diesel engine and fire technology laboratories.

"This multi-year continuous improvement project makes us more competitive with other fire testing labs and increases SwRI's reputation for environmental stewardship," said Dr. Matt Blais, who leads SwRI's Fire Technology Department. "With organic vapor and particulates removed, the air coming out of the pollution abatement systems is actually cleaner than the air in the surrounding environment."

"All fire laboratories are now connected to state-of-the-art pollution abatement systems providing greener, more environmentally friendly testing," added Karen Carpenter, a manager in SwRI's fire research area. "The construction industry, architects, and manufacturers are particularly interested in cleaner techniques for certifying building materials.



SwRI's new fire technology pollution abatement system encompasses three facilities and provides greater capacity for handling extreme heat and higher airflow during testing. The new equipment allows SwRI to conduct fire research in a more environmentally safe manner.

D021974_6889_TT

SwRI SOFTWARE TRACKS LIFE OF MECHANICAL SYSTEMS

Solutions help foreign military clients with aerospace maintenance

Tracking the usage of thousands of parts in a typical jet engine fleet is critical to ensure parts are taken out of service or repaired before they fail. Also important is tracking compliance with new maintenance directives.

To better manage these tasks, SwRI has developed a logistics solution that tracks when maintenance is needed before a breakdown occurs. SwRI's Engine Tracking Database System (ETDS) has become a go-to logistics utility for foreign military clients. In the past five years, the web-based ETDS software has been picked up by a half-dozen clients worldwide for F-15 and F-16 aircraft with the F110 family of GE engines.

"We have grown the program on average by one new country every year, and there are more in the pipeline," said SwRI's Tom Arnold. "Extensive experience in software development and turbine engine management allowed us to develop this secure system to support end-to-end management processes."

ETDS provides analysis and tracking of time and temperature cycles against engine parts and assemblies. It also defines time change intervals for individual part numbers and manages parts configuration of weapon systems and engines. Among other capabilities, users can track part and serial numbers of components installed on engines, serviceable spares, and other components awaiting maintenance.

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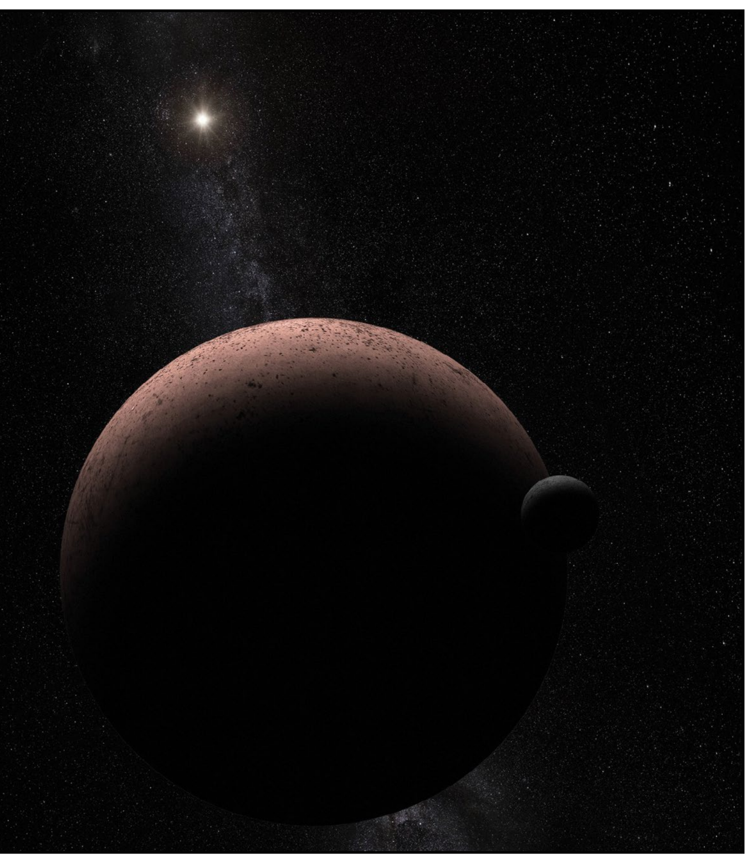
D022160 COURTESY NASA/HUBBLE WFC3/SWRI/ALEX PARKER



Moon over Makemake

An SwRI-led team has discovered an elusive, dark moon orbiting Makemake, one of the "big four" dwarf planets populating the Kuiper Belt region at the edge of our solar system.

"Makemake's moon proves that there are still wild things waiting to be discovered, even in places people have already looked," said Dr. Alex Parker, the SwRI astronomer credited with discovering the satellite. Using data collected by the Hubble Space Telescope's Wide Field Camera 3, Parker spotted a faint point of light close to the dwarf planet.

"Makemake's moon — nicknamed MK2 — is very dark, 1,300 times fainter than the dwarf planet," he said. A nearly edge-on orbital configuration helped the moon evade detection, placing it deep within the glare of the icy dwarf planet during a substantial fraction of its orbit.

Makemake is one of the largest and brightest known Kuiper Belt Objects (KBOs), second only to Pluto. The moon is likely less than 100 miles wide while its parent dwarf planet is about 870 miles across. Discovered in 2005, Makemake has a Pluto-like surface sheathed in frozen methane.

With the discovery of MK2, all four of the currently designated dwarf planets are known to host one or more satellites. The fact that Makemake's satellite went unseen despite previous searches suggests that other large KBOs also may host hidden moons.

Dr. Alex Parker's illustration shows Makemake's bright red surface and the inferred darker surface of the moon, known as MK2.

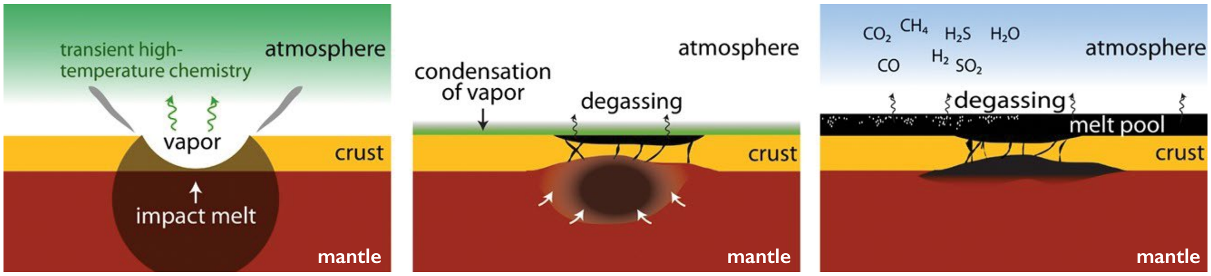
RESOLVING THE FAINT SUN PARADOX

In the first billion years of Earth's history, the planet was bombarded by primordial asteroids, while a faint Sun provided much less heat than it does today. An SwRI-led team posits that this tumultuous beginning may have ultimately fostered life on Earth, particularly in terms of sustaining liquid water.

"Today Earth is in the 'Goldilocks zone,' where liquid water can exist on its surface," said SwRI's Dr. Simone Marchi. Referencing the fairy tale about the three bears, the Goldilocks zone is an orbit around a star where it's not too hot, nor too cold, for liquid water. Liquid water is generally considered a key ingredient for life. When the Sun was much fainter, the Earth, with its present atmospheric composition, would have been frozen solid. If the oceans were frozen, life might not have formed.

Marchi's team created a new model for impact-generated outgassing showing that as the planet was pummeled by primordial asteroids — some larger than 100 kilometers in diameter — impacts would melt large volumes of rock, creating temporary lakes of lava. These pools of lava could have released large quantities of carbon dioxide to the atmosphere, creating a greenhouse effect that warmed the young planet enough to sustain liquid water.

This research was partially funded through an Exobiology Grant and supported by the Solar System Exploration Research Virtual Institute. SSERVI is funded jointly by the Science Mission and Human Exploration and Operations Mission directorates at NASA headquarters in Washington, D.C.



COURTESY SIMONE MARCHI (SwRI), BENJAMIN BLACK (CITY COLLEGE OF NEW YORK)

D022162

SwRI scientists created a new model for impact-generated outgassing on early Earth. The model shows how pools of lava could release gases and create a greenhouse effect that warmed the planet.

For two hours of its day (1.7 Earth days), Io is eclipsed by Jupiter. The resulting temperature drop freezes sulfur dioxide gas, causing Io's atmosphere to "deflate."

D022161

Io atmosphere collapses in Jupiter's shadow

An SwRI-led team has documented atmospheric changes on Io, Jupiter's volcanically active satellite, as the giant planet casts its shadow over the moon's surface during daily eclipses.

Io is the most volcanically active object in the solar system. Its thin atmosphere consists primarily of sulfur dioxide (SO_2) gas emitted from volcanoes. A study led by SwRI's Constantine Tsang concluded that Io's atmosphere collapses as the SO_2 freezes onto its surface as ice when Io is shaded by Jupiter. When the moon moves out of eclipse and the ice warms, the atmosphere re-forms through sublimation, as ice converts directly to gas.

"This research is the first time scientists have observed this phenomenon directly, improving our understanding of this geologically active moon," said Tsang.

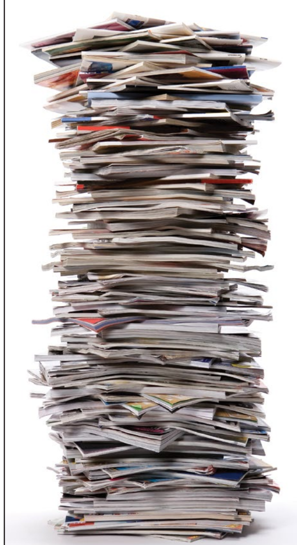
The team used data from the 8-meter Gemini North telescope in Hawaii and the Texas Echelon Cross Echelle Spectrograph (TEXES). This breakthrough was possible because TEXES measures the atmosphere using heat radiation, not sunlight, and the giant Gemini telescope can sense the faint heat signature of Io's collapsing atmosphere.

"This confirms that Io's atmosphere is in a constant state of collapse and repair, and shows that a large fraction of the atmosphere is supported by sublimation of SO_2 ice," said SwRI's Dr. John Spencer, who also participated in the study.

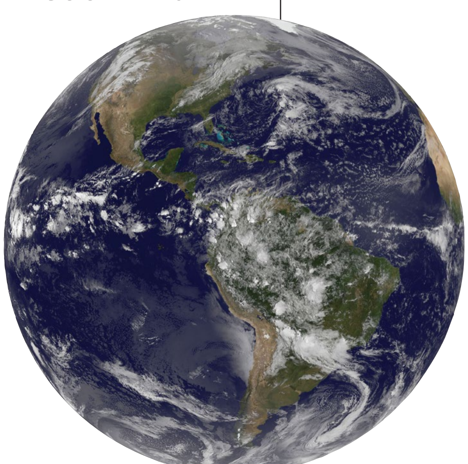
BY THE NUMBERS
JULY — OCTOBER

96 presentations given in **14** COUNTRIES and **18** states

$3.3 MILLION in SwRI Internal Research funding approved for **27** projects



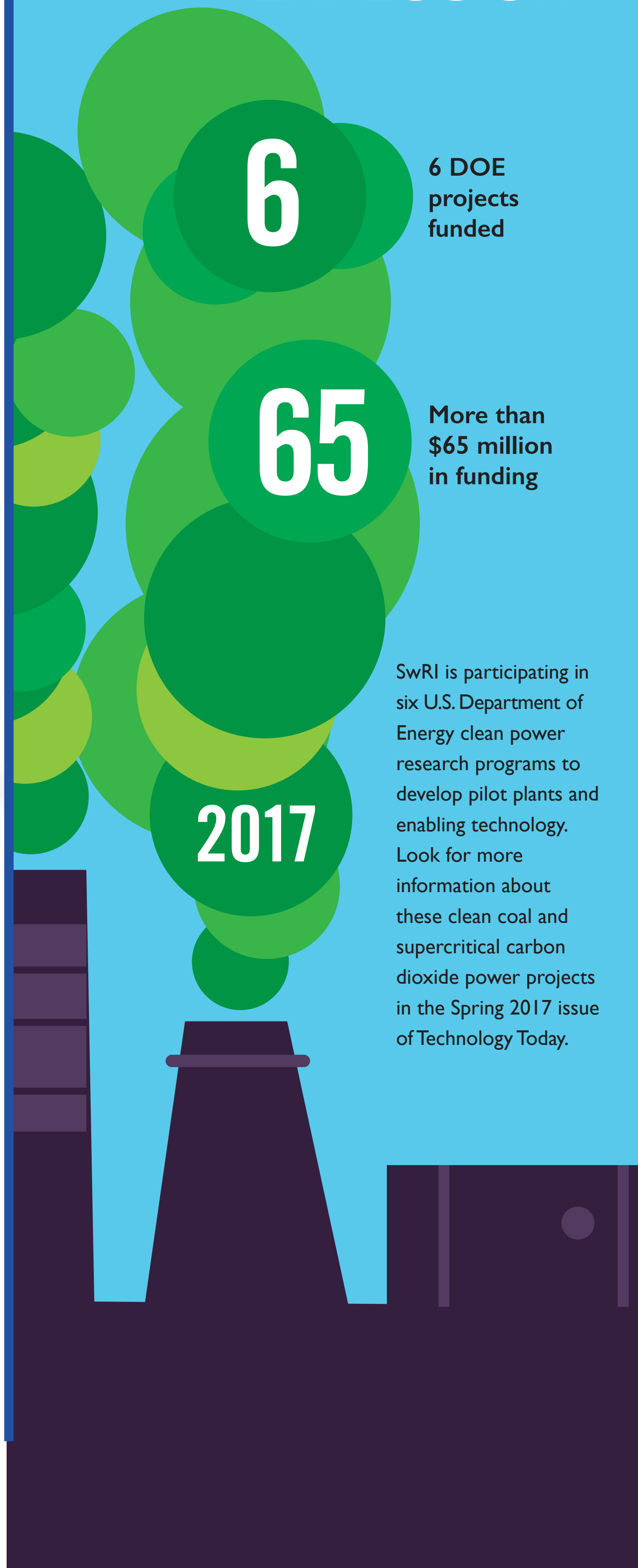
64 articles published in **33** DIFFERENT PUBLICATIONS



COURTESY NASA

7 patents awarded

CLEAN ENERGY EXPLOSION



6 DOE projects funded

More than $65 million in funding

SwRI is participating in six U.S. Department of Energy clean power research programs to develop pilot plants and enabling technology. Look for more information about these clean coal and supercritical carbon dioxide power projects in the Spring 2017 issue of Technology Today.

COMING UP

AWARDS

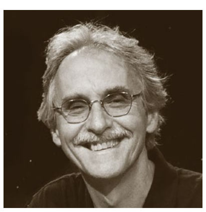
Dr. Terry Alger, director of the Spark Ignited Engine Research and Development Department, received the 2016 Internal Combustion Engine Award from the American Society of Mechanical Engineers (ASME). The award recognizes "exceptional technical and business leadership that has led to multiple innovations in internal combustion engine technologies and the transition of these innovations to production engines for significant real-world impact on vehicle fuel economy."

Dr. Kathryn A. Dannemann, a principal engineer in SwRI's Mechanical Engineering Division, has been named a Fellow of ASM International, the world's largest association of metals-centric materials scientists and engineers. The honor is bestowed on ASM members "in recognition of their distinguished contributions to materials science and engineering."

D022165

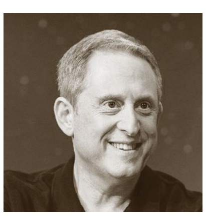
Dr. Roger Phillips, who recently retired as an Institute scientist in SwRI's Space Science and Engineering Division, received the prestigious NASA Exceptional Public Achievement Medal "for exceptional achievement in the application of spacecraft data, particularly radar, to the study of the geophysics of the moon and terrestrial planets."

D022164



Dr. John Spencer, an Institute scientist in SwRI's Space Science and Engineering Division, is receiving the 2016 Planetary Sciences Section Whipple Award from the American Geophysical Union (AGU). The award, named for comet astronomer Fred Whipple, recognizes individuals who have made outstanding contributions in the field of planetary science. Spencer will receive the award and present the Whipple Lecture at the 2016 AGU Fall Meeting in San Francisco in December.

D022163



Dr. Alan Stern, associate vice president of SwRI's Space Science and Engineering Division, received NASA's highest honor, the Distinguished Public Service Medal, recognizing his role as principal investigator of the New Horizons mission. In this historic role, Stern led the team that returned remarkable imagery and other data from the Pluto system last summer, generating headlines worldwide and setting a record for the farthest world ever explored.

D022169

TRADE SHOWS

International Telemetering Conference, Glendale, Ariz.; November 7-10, 2016, Booth No. 815

Transpo 2016, West Palm Beach, Fla. November 13-16, 2016, Booth No. 302

ExxonMobil Process Development Symposium Vendor Fair, The Woodlands, Texas; January 31, 2017

Underwater Intervention, New Orleans, La.; February 21-23, 2017, Booth No. 223

Technology & Maintenance Council (TMC), Nashville, Tenn.; February 27-March 3, 2017

SATELLITE, Washington, D.C.; March 7-10, 2017, Booth No. 123

Dixie Crow Symposium, Warner Robins, Ga.; March 20-24, 2017

AAPG 2016 Annual Convention & Exhibition, Houston, Texas; April 2-5, 2017

Space Symposium, Colorado Springs, Colo.; April 3-6, 2017

Automate, Chicago, Ill.; April 3-6, 2017

Xponential, Dallas, Texas; May 8-11, 2017, Booth No. 424

ISHM, Oklahoma City, Okla.; May 16-18, 2017

Valve World Americas Expo & Conference, Houston, Texas; June 20-21, 2017, Booth No. 3

ASME Turbo Expo, Charlotte, NC; June 26-30, 2017, Booth No. 512

Sensors Expo & Conference, San Jose, Calif.; June 27-29, 2017, Booth No. 1240

44th Annual Meeting & Exposition of the Controlled Release Society, Boston, Mass.; July 16-19, 2017, Booth No. 410

IFT Food Expo, Las Vegas, Nev.; July 26-28, 2017, Booth No. 4939

IASH Symposium, Rome, Italy; September 10-14, 2017

46th Turbomachinery & 33rd International Pump Symposia, Houston, Texas; September 11-14, 2017

American School of Gas Measurement Technology (ASGMT); September 18-21, 2017

GMRC Gas Machinery Conference, Pittsburgh, Penn.; October 1-4, 2017

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