SOUTHWEST RESEARCH INSTITUTE®

FALL 2017

TECHNOLOGY TODAY®

CASSINI'S GRAND FINALE

Fires endanger lives and do extensive damage in just minutes. In fact, Southwest Research Institute recently demonstrated how a nursery can become engulfed in flames in less than 4 minutes. To put that in context, the average response time for a fire department is six minutes following dispatch.

For this demo, SwRI constructed and furnished two infant nurseries and conducted a room burn test with only one difference — one of the rooms had a sprinkler system installed. The one pictured did not.

In the nursery with the sprinkler, the system activated approximately one minute after the smoke detector sounded, potentially saving the lives of the entire household.

Flashover in the nursery pictured occurred at 3 minutes 30 seconds, when the entire room went up in flames. A child would not have survived, and the fire would likely have prevented the rest of the family from escaping the house.

For nearly 70 years, SwRI has been conducting fire research and testing to help save lives, certifying materials to standards and studying ways to improve them.

Learn more at fire.swri.org.

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Southwest Research Institute is a premier independent, nonprofit research and development organization. With nine technical divisions, we offer multidisciplinary services leveraging advanced science and applied technologies. Since 1947, we have provided solutions for some of the world's most challenging scientific and engineering problems.

swri.org

IMAGE COURTESY NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE

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ON THE COVER

Cassini's Finale
Saturn's main rings, along with its moons, are much brighter than most stars. Dione (698 miles, 1123 kilometers across) is seen in this view, above the rings at left.

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EMPLOYMENT

Southwest Research Institute is an independent, nonprofit, applied research and development organization. The staff of nearly 2,700 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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CASSINI'S GRAND FINALE

SwRI plays featured role in the spacecraft's swan song at Saturn

By J. Hunter Waite, Ph.D.

In 2017, after almost 20 years in space, NASA's Cassini spacecraft began the final chapter of a remarkable story of exploration of the Saturn system.

The Cassini spacecraft — named after the 17th-century astronomer Giovanni Cassini — launched from the Kennedy Space Center at Cape Canaveral, Florida, in October 1997. At that time, Google didn't exist and the first Harry Potter novel had not yet been published in the United States. The spacecraft arrived at Saturn in 2004. It completed its original prime mission in 2008, and then the mission was extended twice.

In April 2017, Cassini began its Grand Finale, completing a daring set of orbits around the gas giant. Following a close flyby of Saturn's largest moon, Titan, Cassini dived inside the planet's icy rings and explored the region between the planet and its innermost ring.

Then, on its final orbit, Cassini took its final plunge into Saturn's atmosphere, sending back new and unique science to the very end. The Southwest Research Institute-led Ion Neutral Mass Spectrometer (INMS) was one of the last instruments standing, sending atmospheric data back to Earth as the spacecraft penetrated the gas giant's outer cloud layers and ultimately burned up like a meteor.

BIRTH OF A MISSION

In the late 1980s, Dave Young, Ph.D., and I joined SwRI's relatively young space science and engineering program. Soon thereafter, an opportunity arose to take part in NASA's Cassini-Huygens mission to Saturn. A flagship-class, joint NASA-ESA-ASI (Italian Space Agency) robotic spacecraft, Cassini was the fourth space probe to visit the ringed planet and the first to enter orbit. ESA's Huygens probe, which traveled to Saturn onboard the Cassini spacecraft, was designed to travel through the atmosphere and crash-land on the surface of Saturn's moon, Titan, shortly after arrival.

Dave, who is now retired, had gained considerable experience with ion mass spectrometers associated with planetary and Earth-based missions while at the University of Bern and Los Alamos National Laboratory. Although I was a relative newcomer to space science, I did have some experience in ion mass spectrometry from my time at NASA's Marshall Space Flight Center. Together, we assembled the Cassini Plasma Spectrometer (CAPS) team of some 25 co-investigators from eight countries. Meanwhile, I also worked on an ion neutral mass spectrometer proposal team.

The CAPS team put together a winning proposal, but NASA did not select a neutral mass spectrometer team initially. Instead, the agency decided that the Gas Chromatograph Mass Spectrometer (GCMS) from ESA's Huygens lander should serve as the basis for a similar instrument for the orbiter's payload.

I led a subsequent proposal to modify the GCMS design for the Cassini orbiter. We were fortunate to win that competition and form Cassini's Ion Neutral Mass Spectrometer team in 1992.

PAYLOAD DEVELOPMENT

The early to mid-'90s was a time of instrument development for the Cassini mission. The orbiter's 12 instruments were designed to image, survey, sniff, analyze, and scrutinize the Saturn system. As is always the case with space missions, the science instruments faced myriad challenges to be overcome.

CAPS, by itself, was a complex instrument, consisting of three separate sensors built in eight different countries. It was designed to sample ions and electrons in a variety of regions around Saturn. Scientists would use the data to learn about the composition, density, flow velocity, and temperature of ions and

Adorned with thousands of beautiful ringlets, Saturn is sometimes called the jewel of the solar system. Saturn is the second largest planet orbiting our sun. While not the only planet to have rings made of chunks of ice and rock, none are as spectacular or as complicated as Saturn's. Like fellow gas giant Jupiter, Saturn is a massive ball of mostly hydrogen and helium.

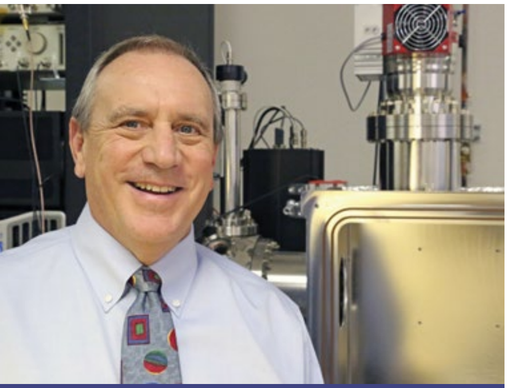
Surrounded by more than 50 moons, Saturn is home to some of the most fascinating landscapes in our solar system. From the jets of Enceladus to the methane lakes on smoggy Titan, the Saturn system remains a rich source of scientific discovery.

In the ultraviolet image of Saturn's rings below, the bluer an area appears, the richer it is in water ice. Conversely, the redder an area appears, the richer it is in "dirt." This Cassini data reveals that the inner rings are more tenuous and dustier while the outer rings are denser and icier, providing hints about the origin and evolution of the ring system. The thin red band in the otherwise blue outer ring is known as the Encke Gap.

IMAGES COURTESY NASA/JPL/UNIVERSITY OF COLORADO D022732 D022746 electrons in Saturn's huge magnetosphere. By measuring the composition of the ions, CAPS helps determine the sources of plasma in the magnetosphere.

INMS's role was to detect low-energy "thermal" ions as well as neutral particles such as atoms and molecules. INMS "sniffed" Saturn and its moons Titan and Enceladus to learn more about their atmospheres. The instrument also characterized the environments around Saturn's rings and icy moons. Because GCMS was designed to operate for two hours on Titan's surface, the INMS team needed to adapt the design for long-term orbital operations and add an ambient ion mass spectrometer.

The CAPS and INMS challenges were met, along with those of the rest of the science payload, and they were integrated into the 22-by-4-foot spacecraft for a dramatic nighttime launch onboard a Titan/IVB/Centaur rocket. The seven-year cruise to Saturn was an equally challenging time. To keep costs in scope, the spacecraft and instrumentation were launched with a minimum of flight software loaded. A tremendous amount of work was required during cruise to ready the spacecraft and its instruments for the science mission.



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ABOUT THE AUTHOR

J. Hunter Waite Ph.D. is a specialist in mass spectrometry applications to study solar system evolution and astrobiology. In addition to leading the two Cassini instruments, he is principal investigator of the Mass Spectrometer for Planetary Exploration (MASPEX) instrument selected for NASA's Europa Clipper mission, which is scheduled to launch in the 2020s.

LORD OF THE RINGS

To get into orbit around Saturn, Cassini-Huygens fired its rockets over the ring plane to reduce its speed. The team met the Saturn Orbital Insertion challenge on July 4, 2004, and Cassini began its 13-year residence among the largest ring system in the solar system. Both instruments got off to a great start, discovering unexpected complexity in the atmosphere and ionosphere associated with the rings. In the first months, CAPS and INMS had a ringside seat to survey both Saturn's magnetosphere and Titan's upper atmosphere as the orbiter successfully delivered the Huygens probe to Titan's surface.

TITANIC DISCOVERIES

CAPS and INMS were the heart of the in situ composition investigation to explore the upper atmosphere and ionosphere of Titan and its interaction with Saturn's vast magnetosphere. CAPS and INMS then discovered that chemistry creating Titan's organic aerosol shroud takes place largely in the upper atmosphere. This work was published in a joint CAPS/INMS paper in Science (Waite et al., 2007) and set the stage for the surface imaging that followed. The surprise was that Titan's frigid surface included liquid lakes of methane/ethane and large dune fields made of organic compounds. We learned Titan's

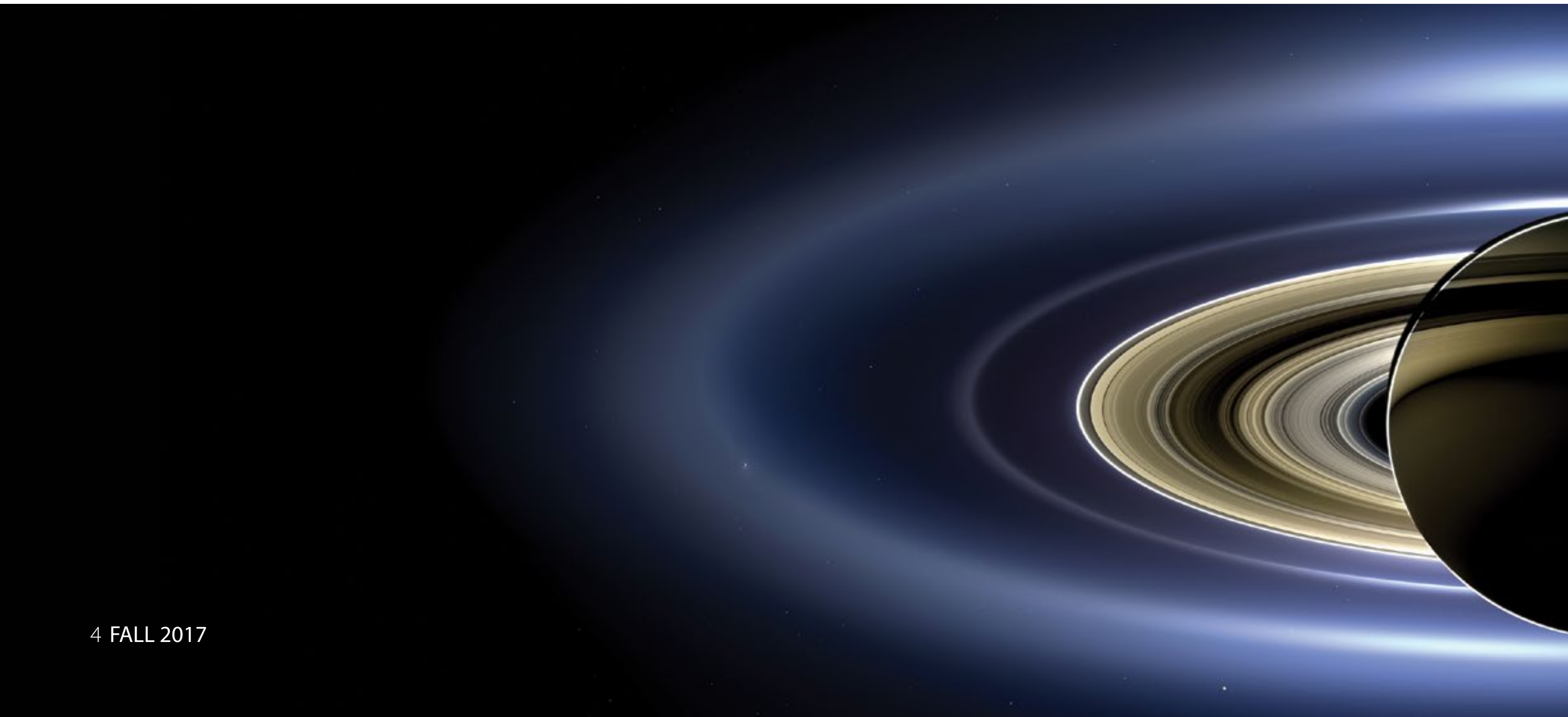

IMAGE COURTESY NASA/JPL/SPACE SCIENCE INSTITUTE surface contains more than 100 times the coal, gas, and oil reserves of Earth. While on Earth, fossil fuel reserves are largely bio-derived from ancient marine life, but Titan's hydrocarbons are produced by neutral-ion chemistry, not from living organisms.

CAPS made the crucial observations to clinch the discovery of the organic process. It sensed large charged ions, which play an important role in the formation of aerosols in the moon's upper atmosphere. The complex organics created ultimately end up on Titan's surface.

Another highlight of the mission was the serendipitous discovery of the cryo-geysers emanating from Enceladus' South Pole. Early in the mission, Cassini's MAGnetometer (MAG) sensed a curious disturbance in the magnetic field near the icy moon. To investigate, scientists adjusted an upcoming flyby to pass close to the moon.

INMS discovered water plumes spewing from cracks in the southern region of the moon. The plumes contain small amounts of carbon dioxide, ammonia, methane, and organic compounds. CAPS found negatively charged water ions that had formed from the condensing vapor. These ions slowed the plasma flowing by Enceladus to a near standstill, which explained the magnetic field disturbance. This discovery was published in a special issue of Science in 2006.

By sheer luck, INMS had been designed with the ability to measure the deuterium/hydrogen (D/H) ratio in the water vapor. The D/H ratio in water is related to the formation history of planetary bodies, including comets and the solar system as a whole. The D/H ratio of the water from Enceladus is more like that of comets than the D/H ratio associated with Saturn. That means Enceladus likely formed outside the Saturn system and was captured from the interplanetary or protosolar disc sometime in the solar system formation process.

HABITABLE REAL ESTATE

All this was just the prelude to a fabulous story of uncovering the habitability of an interior ocean at Enceladus. Ice grain measurements in the plume, taken by Cassini's Cosmic Dust Analyzer (CDA), demonstrated the presence of salts from an interior sea under the ice. Extensive heavy organics were inferred by both INMS and CDA measurements.

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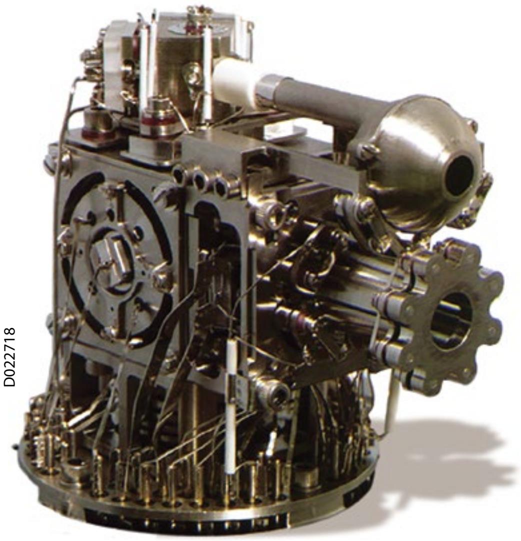
SwRI operated two of Cassini's 12 science instruments, as part of the fields, particles, and waves experiment package. The Cassini Plasma Spectrometer (CAPS), above, and the Ion and Neutral Mass Spectrometer (INMS), below, both studied plasma in the Saturn system. While they didn't produce actual "pictures," the information they collected is critical to scientists' understanding of the Saturn system, including its moons and rings.



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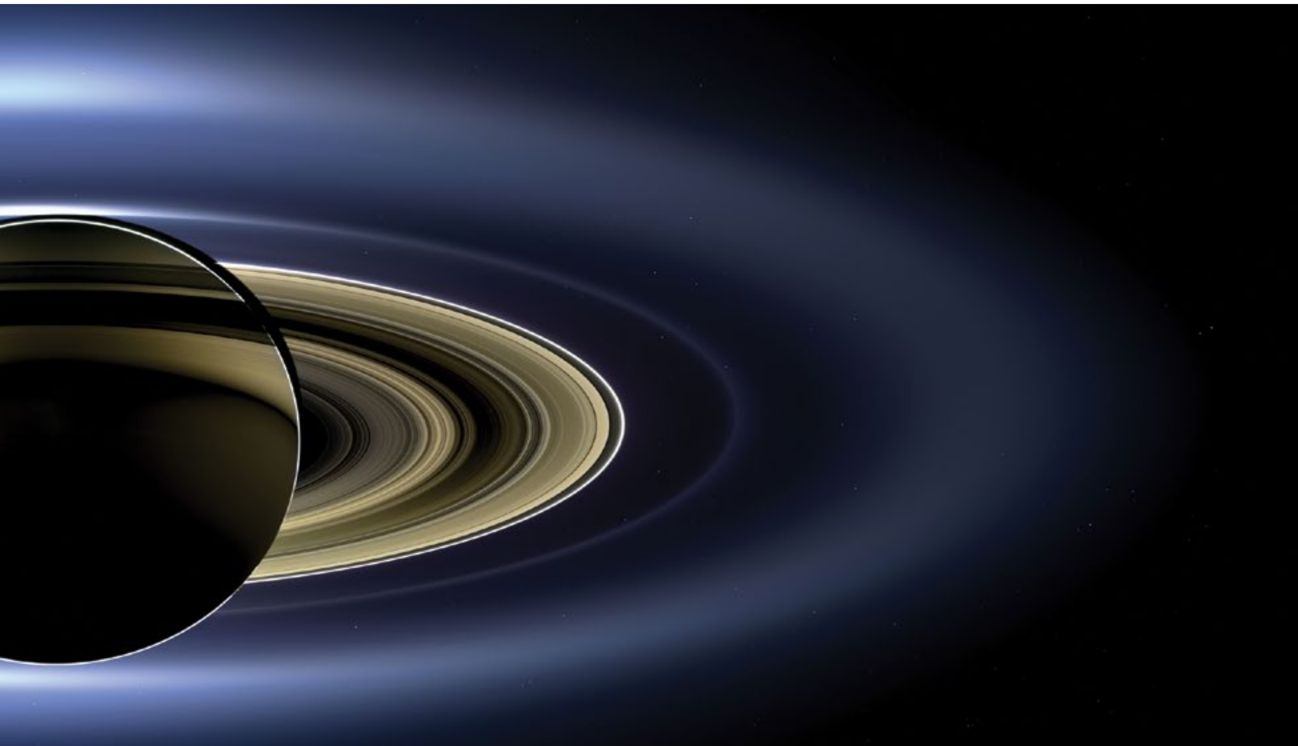

With giant Saturn hanging in the blackness and sheltering Cassini from the sun's blinding glare, the spacecraft viewed the rings as never before, revealing previously unknown faint rings and even glimpsing its home world. This panoramic view was created by combining a total of 165 images taken by the Cassini wide-angle camera.

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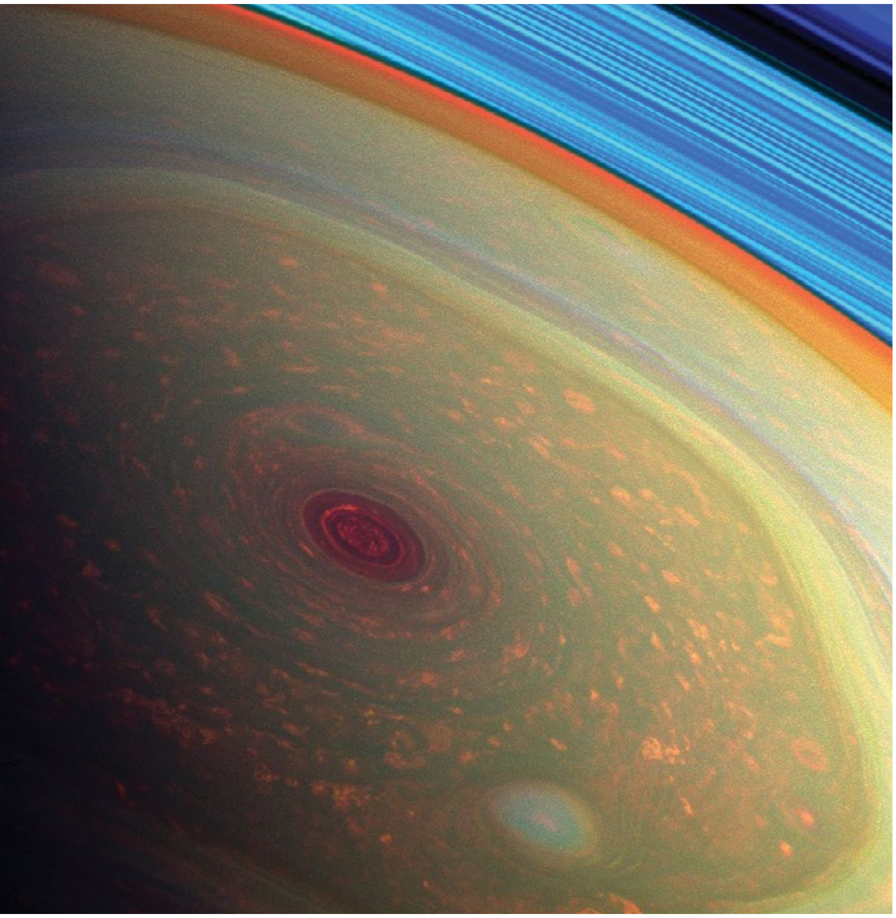

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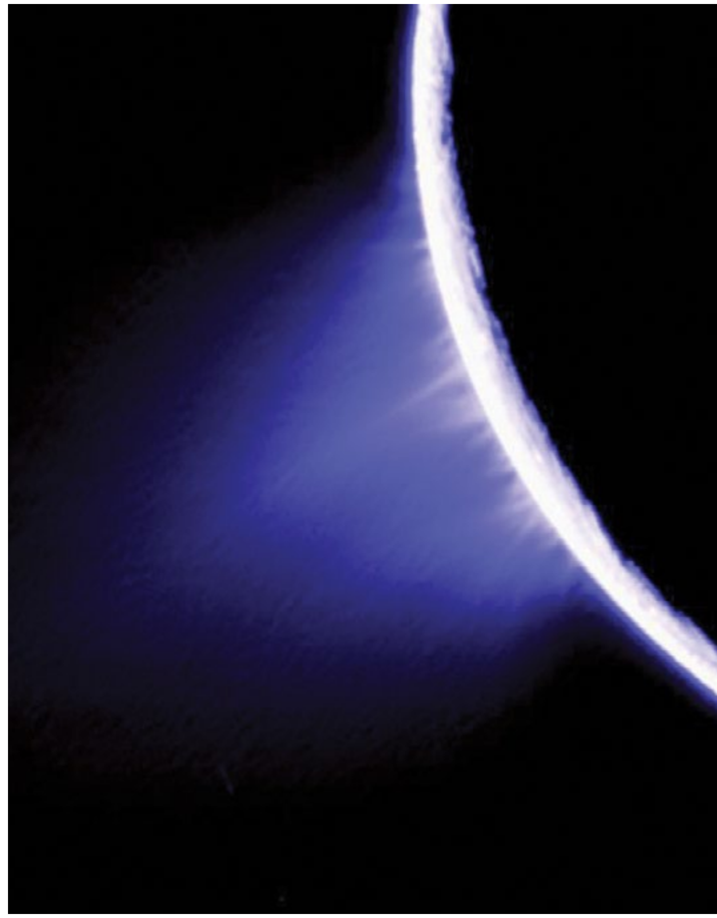


Gravity and imaging measurements confirmed interior water exists below the icy surface of Enceladus. The key to this finding was the detection of libration, which is an oscillating motion of the moon's icy crust relative to its core. Libration observations confirmed Enceladus' subsurface ocean is global. As a result of these scientific findings, the evidence was mounting for habitability — a large and stable source of liquid water, organic compounds, and the elements of life, such as carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur.

The final piece of evidence was acquired by INMS on Oct. 15, 2015, and published in Science in April 2017. INMS identified molecular hydrogen in the plume. Its relationship to the carbon monoxide and methane also found in the plume suggests Enceladus' ocean floor could include features analogous to hydrothermal vents on Earth, which are known to support life on the seafloor. The evidence of molecular hydrogen arising from hydrothermal vents is reinforced by CDA's observation of silica nanoparticles in the icy grains from the plume.

Hydrogen is a source of chemical energy for microbes that live in the Earth's oceans near hydrothermal vents. On the Earth's ocean floor, hydrothermal vents emit warm, hydrogen-rich fluid, allowing unique ecosystems teeming with unusual creatures to thrive. Microbes that convert this mixture into metabolic energy make these ecosystems possible. INMS results indicate the same chemical energy source is present in the ocean of Enceladus. We have not found direct evidence of the presence of microbial life. However, the discovery of molecular hydrogen and the evidence for ongoing hydrothermal activity is a tantalizing suggestion that habitable conditions could exist in the ocean beneath the moon's icy crust.

GRAND FINALE

So, with these two pivotal scientific findings and a host of other absolutely amazing results, Cassini was ready to begin its final chapter — the Grand Finale.

Above left: This spectacular, false-color image highlights the storms at Saturn's north pole. The eye of a hurricane-like storm appears dark red while the fast-moving hexagonal jet stream is a yellowish green. The rings of Saturn appear in vivid blue at the top right.
Above right: Jets of ice and salty water spew from cracks in Enceladus' south pole. When mission scientists flew the spacecraft through these plumes, INMS sniffed out, among other things, molecular hydrogen, providing a tantalizing hint that life could possibly exist in the ocean beneath the moon's icy surface.

DETAIL

Planetary protection is a guiding principle in the design of interplanetary missions. The policy aims to prevent biological contamination of celestial targets as well as the Earth, when samples are being returned. Planetary protection acknowledges the unknown nature of the space environment and the scientific community's desire to preserve the pristine nature of celestial bodies so they can be studied in detail.

IMAGES COURTESY NASA/JPL/CALTECH/SPACE SCIENCE INSTITUTE

Cassini was running out of fuel, so the Grand Finale was designed to dispose of the spacecraft in a fiery entry into Saturn's atmosphere. Otherwise, the spacecraft, once depleted of fuel, would wander uncontrolled within the Saturn system — a serious breach of planetary protection protocols. This dramatic end removed any chance that Cassini might accidentally strike Enceladus or Titan, which could contaminate these interesting worlds.

The first step was to get the spacecraft into a high-latitude orbit, grazing the outer edge of Saturn's outer F ring. The spacecraft then used additional gravity assists from Titan flybys to jump inside the inner edge of the D ring — the ring closest to the planet. Cassini then passed through the rings 22 times, allowing MAG to measure the rings' mysterious spin-aligned magnetic field. These data will provide insight into the origin and interior of Saturn.

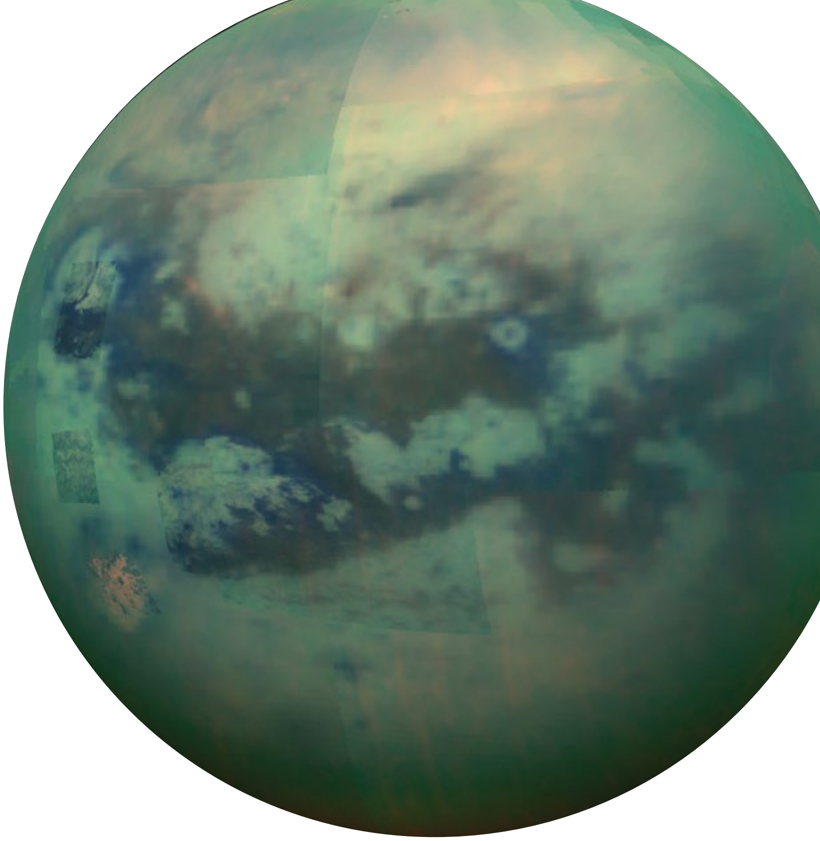
Furthermore, we measured the perturbations on the Cassini spacecraft as it passed near Saturn, sensing the Doppler shift in the radio signal back to Earth, hoping to ascertain if Saturn has a solid core. This science is similar to the measurements the Juno spacecraft is collecting simultaneously at Jupiter, allowing scientists to compare the interiors of the two gas giants in our solar system.

These proximal orbits also put Cassini in position to orbit at varying distances between Saturn and the inner edge of the D ring. This allowed INMS to sample the ring atmosphere and Saturn's atmosphere to understand the interaction between the rings and the planet. This phenomenon, known as "ring rain," had already been detected by ground-based infrared observations. However, the INMS measurements were — perhaps to no one's surprise — nothing like what we expected. The rain appears to be composed of methane and heavier organic particles raining down from the rings, mixed with some water and possibly carbon monoxide, perhaps a remnant of a past encounter between a comet and Saturn's rings. Stay tuned for that story, which is still evolving.

On the morning of Sept. 15, 2017, Saturn took its final plunge. The spacecraft lost radio contact with Earth within minutes after beginning its descent into Saturn's upper atmosphere. On the way down, INMS was the prime instrument collecting data during that final voyage into Saturn's atmosphere. INMS directly sampled the atmosphere's composition to provide insight about the giant planet's formation and evolution. Real-time data were transmitted until the atmospheric torque on Cassini's 10-meter magnetometer boom turned the antenna away from Earth. When that happened, it lost its connection to the Deep Space Network and all went silent. Seconds later, it disintegrated in Saturn's atmosphere.

Silenced, but not forgotten, Cassini lives on in the imaginations of its science team, and in the massive amounts of data they will be combing through for years to come. We anticipate that Cassini will inspire the next generation of scientists to plan a return mission to understand the profound mysteries of Saturn's moons and seek signs of extraterrestrial microbial life in the ocean of Enceladus.

Questions about this article? Contact Waite at 210.522.2034 or hunter.waite@swri.org.



This composite image shows an infrared view of Saturn's moon Titan from Cassini. The spacecraft's visual and infrared mapping spectrometer (VIMS) instrument made these observations.

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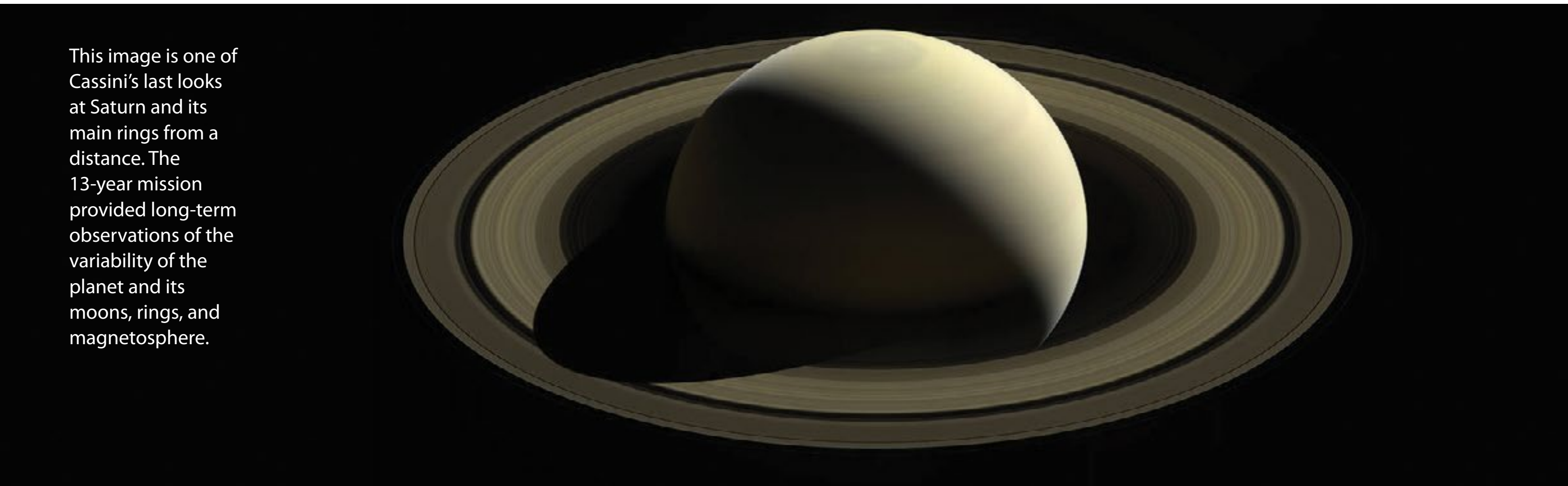
IMAGE COURTESY NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA/UNIVERSITY OF IDAHO



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This image is one of Cassini's last looks at Saturn and its main rings from a distance. The 13-year mission provided long-term observations of the variability of the planet and its moons, rings, and magnetosphere.

CASSINI-HUYGENS
MISSION TO SATURN

4.9 BILLION MILES TRAVELED since launch

27 NATIONS participated

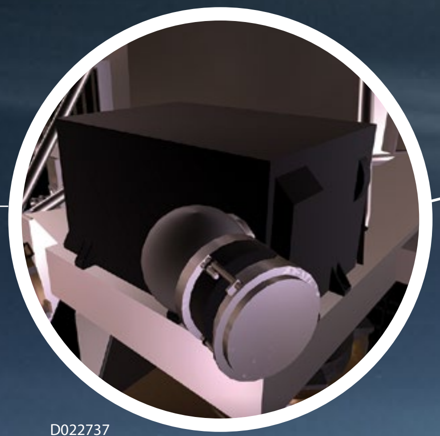
3,948 SCIENCE PAPERS published

2.5 MILLION COMMANDS executed

SwRI-LED INMS

Mass: 9.25 kg
Average Operating Power: 27.70 W
Average Data Rate: 1.50 kilobits/s

The Ion Neutral Mass Spectrometer (INMS) characterized the composition of the gaseous and volatile components in Titan's atmosphere and ionosphere, Saturn's magnetosphere, and the ring environment. The instrument also measured the positive ion and neutral environments of Saturn's rings and icy moons. INMS identified molecular hydrogen in the plumes spewing from Enceladus, an indication that life could exist below the moon's icy surface.



D022737

SwRI-LED SwRI-BUILT CAPS

Mass: 12.50 kg
Average Operating Power: 14.40 W
Average Data Rate: 0.5-16 kilobits/s

When particles approached the Cassini Plasma Spectrometer, known as CAPS, they could travel into one of three sensors: the electron sensor, the ion mass spectrometer, or the ion beam sensor. All three sensors measured particles' kinetic energy (a result of its mass and speed), direction, and mass. The scientific data CAPS collected contributed to new revelations about the moons Titan and Enceladus, the source of plasma in Saturn's magnetosphere, and much more.

D022733

294 SATURN ORBITS completed

453,048 IMAGES TAKEN

635 GIGABYTES OF SCIENCE DATA collected

23 TARGETED ENCELADUS flybys

6 NAMED MOONS discovered

127 TARGETED TITAN flybys

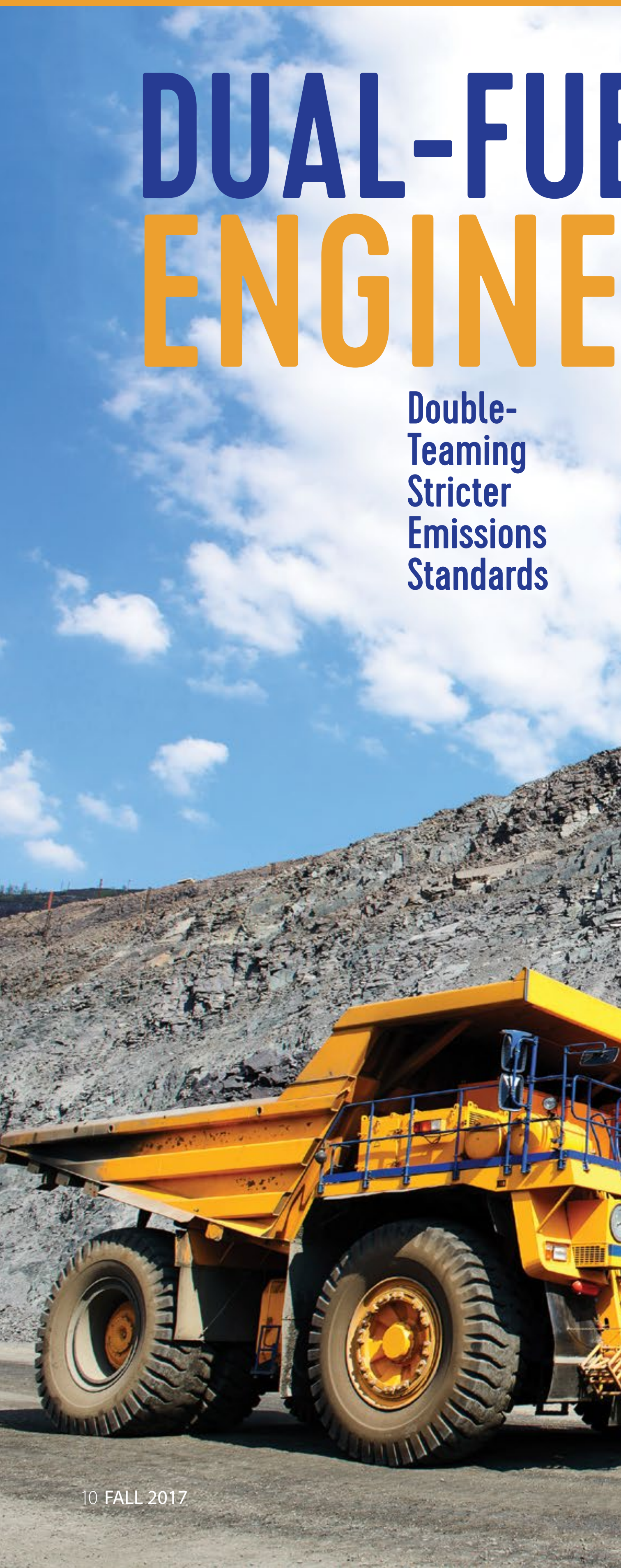
CASSINI ORBITER

Dimensions: 22 feet (6.7 meters) high; 13.1 feet (4 meters) wide
Weight at launch: 12,593 pounds (5,712 kilos) with fuel, Huygens probe, adapter, etc.
Weight at end of mission: 4,685 pounds (2,125 kilos)

MILESTONES

Launch: Oct. 15, 1997, from Cape Canaveral Air Force Station, Florida
Launch vehicle: Titan IVB/Centaur
Venus flybys: April 26, 1998, at 176 miles (234 km)
June 24, 1999, at 370 miles (600 km)
Earth flyby: Aug. 18, 1999, at 727 miles (1,171 km)
Jupiter flyby: Dec. 30, 2000, at 6 million miles (10 million km)
Saturn arrival: July 1, 2004, UTC (June 30, 2004 PDT)
Huygens Probe: Titan Release Dec. 24, 2004
Titan Descent Jan. 14, 2005

IMAGES COURTESY NASA/JPL-CALTECH D022735



DUAL-FUEL ENGINES

Double-Teaming Stricter Emissions Standards

By Tim Callahan, David Branyon, David Meyers, and Ryan Johnson

The latest U.S. Environmental Protection Agency emissions standards for large off-road engines, known as Tier 4 Final (4f), are encouraging construction and agricultural equipment manufacturers to consider alternatives to the standard diesel engine. High-horsepower marine and locomotive manufacturers face similar challenges.

Tier 4 compliant engines must reduce emissions of particulate matter (PM) and

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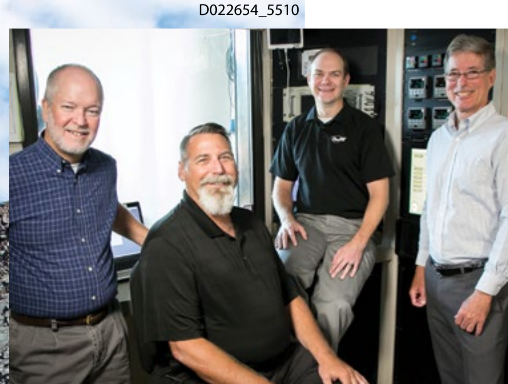


From right, Tim Callahan, a staff engineer in SwRI's Powertrain Engineering Division, led the dual-fuel engine demonstration project. The project team included Ryan Johnson, manager of the Large Engine Development section, and David Meyers and David Branyon, staff engineers specializing in powertrain development.

oxides of nitrogen (NOx) significantly. Compared to previous emissions standards, reductions would cut more than 95 percent of emissions for most agricultural and construction equipment and almost 90 percent for locomotives and marine vessels.

The temptation was to follow the example set by the automotive and on-road truck industries, adding selective catalytic reduction (SCR) equipment to reduce NOx and/or diesel particulate

During a time of price disparity between low-cost natural gas and more expensive diesel fuel, SwRI engineers developed a large dual-fuel engine for mine haul trucks. The emissions performance of these engines led engineers to investigate using dual-fuel engine designs to potentially meet Tier 4f without the need for bulky, expensive exhaust aftertreatment systems.

DETAIL

Dual-fuel engines typically rely on conventional diesel engine hardware modified to operate with natural gas. Under dual-fuel operation, natural gas is introduced at low pressure and mixed with the intake air. Diesel fuel is injected directly into the combustion chamber near the end of the compression stroke to ignite a lean mixture of natural gas and air, using compression ignition.

filters (DPF) to reduce particulate matter. Alternately, some manufacturers are examining exhaust gas recirculation (EGR) combined with DPF for NOx and particulate control. However, aftertreatment systems and engine modifications both require complex control systems and pose difficulties in fitting the systems into existing vehicle designs and then maintaining them in-service.

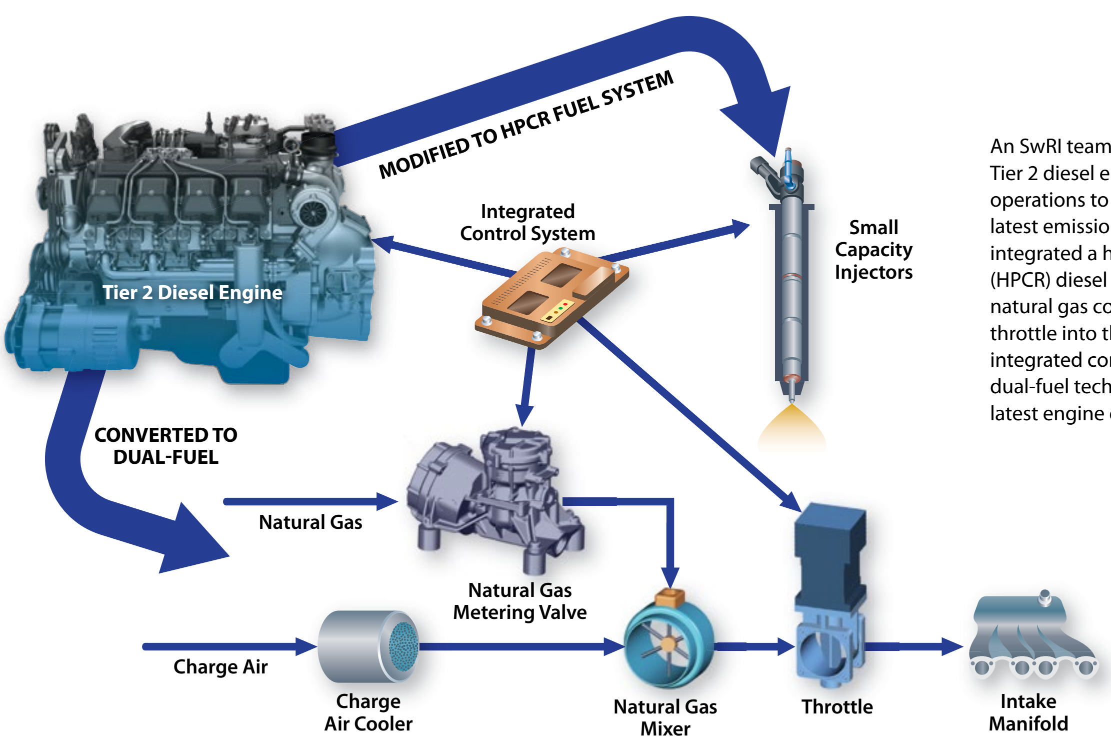
There is a third alternative, one that originally looked appealing for its economics rather than its environmental benefits. During a time of price disparity between low-cost natural gas and more expensive diesel fuel, some off-road manufacturers became interested in dual-fuel engines that run on natural gas in combination with diesel. These compression-ignition engines mix natural gas in the inlet air stream with a small amount of injected diesel fuel for ignition. During that period, Southwest Research Institute (SwRI) engineers developed large dual-fuel engines for mine haul trucks.

The SwRI-designed high-horsepower off-road engines demonstrated that well-engineered dual-fuel engines could easily meet the prior EPA Tier 2 regulations. With that result, SwRI engineers began investigating using dual-fuel engine designs to potentially meet Tier 4f without the need for catalysts, exhaust gas recirculation, or particulate filters. The goal was to design and demonstrate a dual-fuel engine that would reduce or eliminate the aftertreatment packaging issue while reducing the product and operating costs associated with adding these systems. The technologies not only add to the initial cost of the vehicles but also can increase fuel consumption, reduce engine performance, and add costs to operate and maintain the equipment.

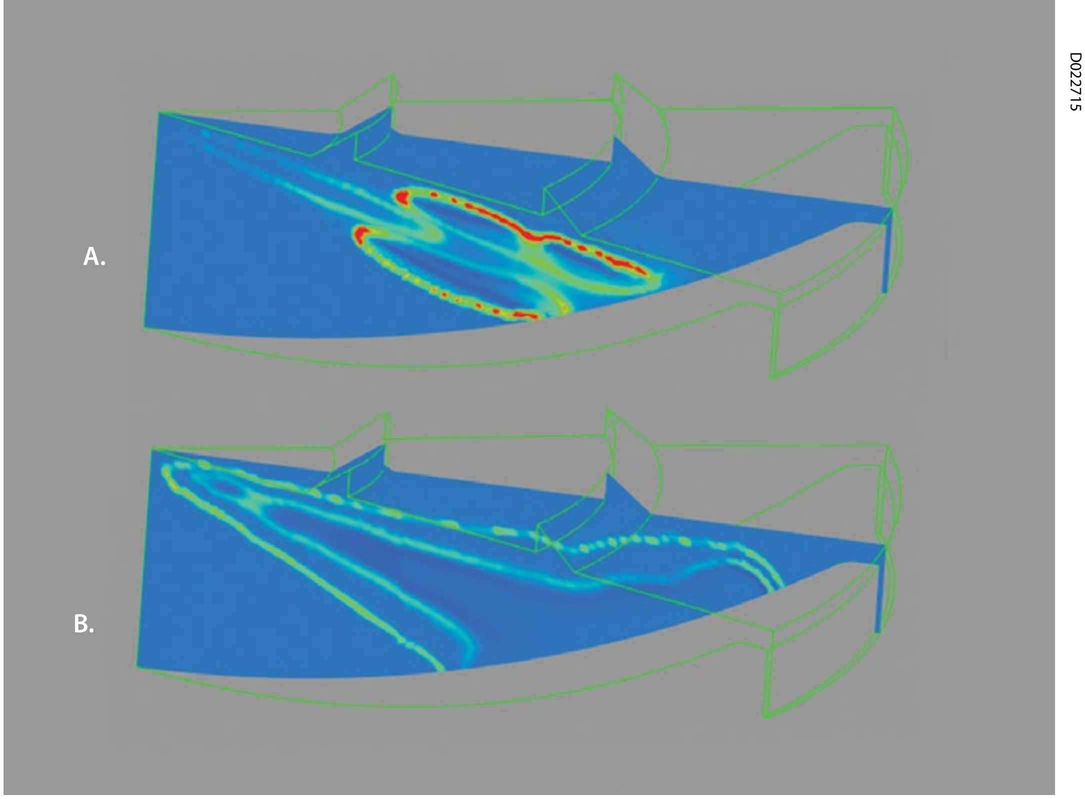
ENGINEERING EMISSIONS REDUCTION

"Tailpipe" emission standards specify the maximum amount of pollutants allowed in vehicle exhaust gases. Today, emissions from internal combustion engines are regulated throughout the world. The regulated diesel emissions include diesel PM, NOx, hydrocarbons (HC), and carbon monoxide (CO).

Trying to meet Tier 4f regulations using conventional techniques requires aftertreatment with "active control" SCR and DPF for compliance. SCR requires injection of diesel exhaust fluid (DEF), a urea/water mixture that reduces NOx in exhaust that contains oxygen. The fluid itself is often more expensive than diesel fuel and must be replenished periodically.



An SwRI team explored modifying a Tier 2 diesel engine for dual-fuel operations to cost-effectively meet the latest emissions standards. The team integrated a high pressure common rail (HPCR) diesel fuel injection system and natural gas control valves, mixers, and throttle into the non-road HD engine. An integrated control system tunes the new dual-fuel technology to meet the EPA's latest engine emissions standards.



SwRI frequently uses computational fluid dynamics to understand the dual-fuel combustion process. Frame A shows the initial diesel ignition, while Frame B shows later diffusion burning of the diesel plume inside, with natural gas flame front on the outer edges.

An alternative to SCR is cooled EGR, which works to reduce NOx in-cylinder. But this can decrease fuel conversion efficiency and has its own issues related to packaging, durability, and reliability. Adding a filter to capture particulates requires active regeneration to periodically oxidize the captured PM, as well as periodic ash removal. Currently, the primary paths to Tier 4f are SCR only, SCR + DPF, or EGR + DPF. Each of these solutions leads to mobile packaging difficulties, increases initial and operating costs, and introduces durability, reliability, and maintenance concerns.

To explore a cost-effective solution to the current regulatory environment, the SwRI team adapted a Tier 2 non-road diesel engine for this demonstration project. The engine was converted for dual-fuel operation and optimized to achieve Tier 4f emission levels. SwRI optimized diesel injection timing and pressure, the gas/diesel substitution ratio, and air-fuel ratio to meet the emissions standards while still providing stable, knock-free operation. The project aimed to reach Tier 4f without EGR or active aftertreatment, and to do so while burning a very high percentage of natural gas, even at moderate to low speeds and loads.

THE DUAL-FUEL ALTERNATIVE

Instead of taking advantage of lower natural gas prices, currently the best incentive for dual-fuel lies in its ability to meet today's lower emissions standards for large engines cost-effectively.

Another goal for dual-fuel engines is to achieve the highest substitution ratio, or percent of natural gas that replaces diesel fuel. To date, this ratio is typically limited by an engine's ability to accurately and consistently inject very small quantities of diesel. Knocking, erratic combustion that can cause engine damage, also limits substitution ratios. This phenomenon, occurring under high-load conditions when substitution ratios and in-cylinder temperatures are high, is typically avoided by operating on diesel fuel only when providing full power output. Low to moderate loads present an alternate problem with poor combustion of very lean air-fuel mixtures. As a result, existing dual-fuel engines typically revert to 100 percent diesel below about 50 percent load and at low engine speeds.

The SwRI-modified test engine featured both an inlet air throttle and a reduced-flow, high-pressure common rail fuel system. These two features facilitate natural gas usage in the low-speed and -load region, while maximizing substitution throughout the engine's operating range. Typical dual-fuel engines reach peak ratios of 80 to 90 percent natural gas, and a duty cycle average of 40 to 75 percent. The goal for this project was to

DETAIL

In internal combustion engines, the air-fuel ratio is critical for controlling pollution and tuning performance. If the air-fuel ratio completely burns all of the fuel, consuming all available oxygen, the ratio is considered stoichiometric or the exact proportion needed for combustion. Ratios lower than stoichiometric are "rich." Rich mixtures are less efficient, resulting in incomplete combustion due to lack of oxygen. Ratios higher than stoichiometric are "lean." Optimized lean mixtures are more efficient, producing low NOx, but improper control of lean air-fuel ratios can lead to misfire, or poor combustion, with high levels of CO and HC exhaust emissions.

increase the duty cycle average to at least 90 percent with peak ratios of 95 plus percent substitution.

EQUIPPING THE ENGINE

To improve combustion and minimize emissions, the SwRI team outfitted its test engine with a smaller-capacity diesel fuel injection system, using low-cost injectors with increased flow tips from a light truck engine. Modified valve covers allowed high-pressure fuel line access to the injector. Two injection pumps and four fuel rails facilitated fuel injection. Minimal intrusion on the original design and the use of commercial, off-the-shelf parts whenever possible reduced the cost of parts and engineering, minimizing changes to the base engine. This strategy also controlled durability and reliability risks. Natural gas metering valves and mixers were added downstream from the turbochargers. A throttle just downstream of the mixers controlled the air-fuel ratios.

In the quest for Tier 4f, engineers programmed an integrated control unit to govern the diesel fuel injection event, natural gas metering, and throttling. State-of-the-art metering valves and close-coupled gas addition systems provided precise, near-real-time control of gas flow.

The engine was fully instrumented to measure temperatures and pressures. The team used a cylinder pressure transducer on each cylinder to monitor combustion, measured diesel and natural gas fuel flow, and characterized exhaust emissions.

Non-road applications require engines to operate over a wide range of speed and load conditions. The SwRI team adjusted the natural gas substitution rate, diesel injection timing and pressure, and air-fuel ratios to optimize operations over a range of speed and load combinations. This also provided the best trade-off between NOx and CO. At some operating points, an intake air throttle reduced the air flow to reduce the overall air-fuel ratio, minimizing CO and unburned hydrocarbons while keeping NOx below the regulated value.

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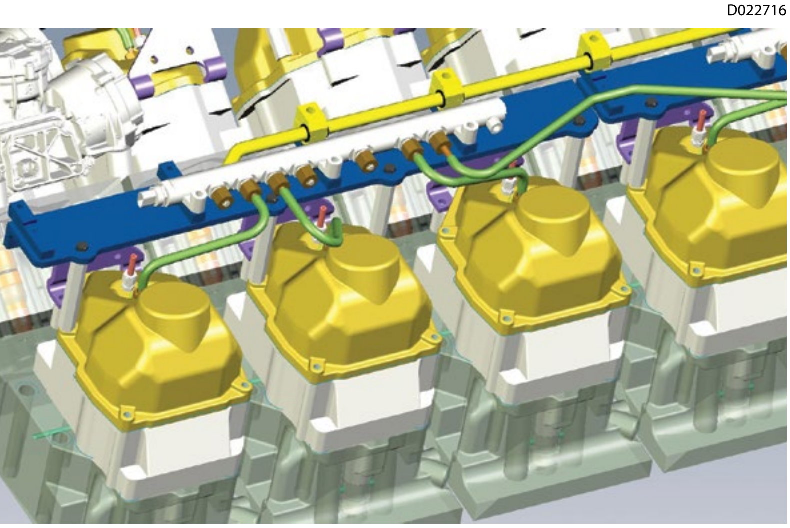


SwRI engineers outfitted the dual-fuel demonstration engine with a reduced-capacity, high-pressure common rail diesel fuel system to accommodate high natural gas substitution rates.

MEASURING EMISSIONS

The emission test cycle for this class of engine is the ISO 8178-C1 weighted 8-mode test. SwRI's test matrix for dual-fuel optimization included six of the eight test conditions, which account for approximately 96 percent of engine emissions. The other two modes measure emissions at 10 percent power and low idle, where dual-fuel operation is not feasible. Instead, the team used the base diesel mode to supply emissions data for those points in the cycle. The SwRI engineers added another evaluation point: 900 rpm at 50 percent load. Dual-fuel engines typically struggle to utilize a significant amount of natural gas at this point, so the engineers hoped to demonstrate the engine's improved capabilities in that range.

Recently the EPA went from exempting only methane from hydrocarbon emissions subject to regulation, to exempting both methane and ethane. This shift, which lowers the net exhaust under regulation, means that dual-fuel engines may not even require a catalyst to meet Tier 4f. If needed, a passive oxidation catalyst, which is simpler and less expensive than an active catalyst system, should suffice. The SwRI evaluations measured non-methane-only emissions, with the knowledge that meeting those criteria are more difficult than the newer EPA specs.

THE RESULTS

The SwRI engineers optimized the test engine's operating parameters at each test point to meet the desired Tier 4f emission targets. The focus was on optimizing the NOx/CO tradeoff while achieving the highest engine efficiency. The CO levels were well below the standards at all timings, indicating good combustion. Although non-methane, non-ethane emissions were above the regulated value, results showed good potential to reach the regulation with additional development and no oxidation catalyst. Significantly, the entire set of data was collected at 97 percent substitution ratio. This high ratio maximizes the use of natural gas, which could accelerate payback when natural gas prices fall below those of diesel.

Work continues on refining the dual-fuel concept as a solution for Tier 4f emission standards. Dual-fuel engine technology, initially developed for fuel cost savings, could now offer an even larger incentive by avoiding expensive and unnecessary aftertreatment systems while delivering superior efficiency and 4f emissions compliance.

Questions about this article? Contact Callahan at 210.522.6890 or timothy.callahan@swri.org.

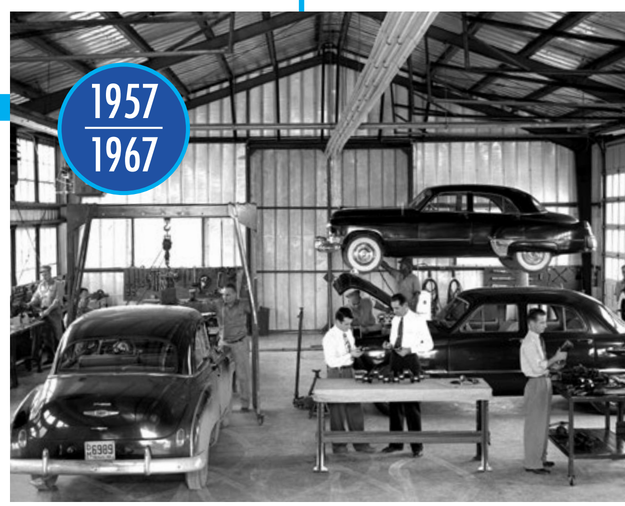
70 YEARS OF INNOVATION AND CLIENT SERVICE

By Adam L. Hamilton, P.E.
SwRI President and CEO

DC5778

Radio Direction Finding
Institute engineers conducted direction finding research using shielded loop antennas and carefully calibrated instrumentation.

Fuels and Lubes Research
SwRI expanded its fuels and lubricants test program, adding more than 75 semi-automated engine test stands.



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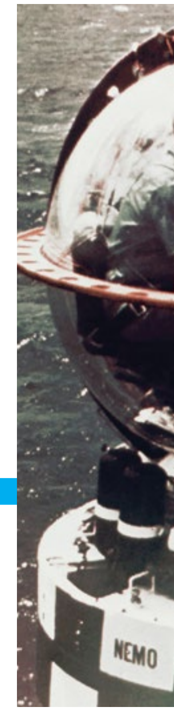

Seventy years ago, when robots and space exploration were still largely science fiction, Southwest Research Institute began as a small, unlikely research organization on the outskirts of San Antonio, Texas. Since then, we've grown to be an international center of science and engineering excellence with nearly 2,600 staff members and a research volume in excess of half a billion dollars a year. From developing nanoparticle technology to probing the vastness of space, SwRI applies science and engineering to advance human progress and scientific achievement.

It all started when 31-year-old Texas millionaire Thomas Baker Slick Jr., son of an oilman known as the "King of the Wildcatters," opened a new research institute on his sprawling cattle ranch in September 1947.

Before joining the Navy in 1942, Slick already had established what today is known as Texas Biomedical Research Institute. He had also begun putting together the 4,000-acre Essar Ranch (phonetic for "SR," an abbreviation of "Scientific Research"), known for champion purebred cattle and innovative livestock nutrition and animal husbandry techniques.

Slick agreed with those who believed that the rapid scientific advances achieved during World War II could benefit a peacetime America, and that non-military institutions should sustain the momentum. A number of independent research and development organizations had sprung up in several parts of the country; he chose to plant SwRI on the edge of the Texas Hill Country.

Our founder may be considered an early version of "the most interesting man in the world." Not only a successful oil man and businessman, he invented lift-slab construction technology,

Benefiting government, industry and the public through innovative science and technology

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Submersibles
SwRI engineers tested NEMO, the Naval Experimental Manned Observatory. The submersible had a 5-foot diameter hull and could operate for up to 8 hours at depths of 600 feet.

Chemistry
SwRI chemists began a long-standing program, conducting environmental monitoring to support chemical weapons destruction. The initial site was at Johnston Atoll in the Pacific.

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FR8

Robotics
SwRI built its first aircraft paint-stripping robots for the U.S. Air Force in the late 1980s.

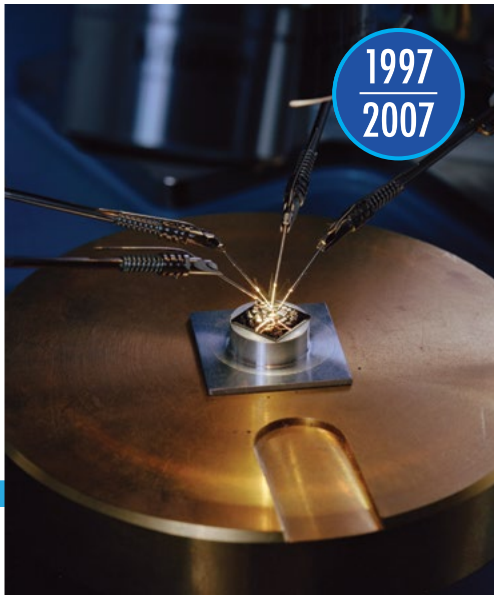
developed the Brangus breed of cattle, and conducted cloud seeding experiments, flying a private plane across South Texas skies. This real-life adventurer led expeditions in the Himalayas to search for Yeti. He started a freight airline, Slick Airways, with his brother and even wrote books about world peace.

Although Slick perished in a plane crash in 1962 at the age of 46, his legacy has continued to benefit our clients and the business and research communities. Today, SwRI is one of the largest independent, nonprofit research and development organizations in the country.

From its earliest years, SwRI performed research in wide-ranging areas to solve our clients' most challenging problems. In the early days, that included developing direction finding antennas for U.S. and allied warships, fire technology, oil and gas transmission research, and microencapsulation of foods, medicines, and industrial products. All these technologies remain active SwRI research topics today.

Another long-standing research area is the development and testing of fuels, fluids, and lubricants for automotive, military, and off-road vehicles, as well as locomotives. Since the 1970s, SwRI also has performed emissions research that has grown to include everything from chainsaws and lawn mowers to cars, trucks, and trains. Today, two of the Institute's nine technical divisions are devoted to engines, fuels, and lubricants testing and development as well as powertrain and emissions research.

Early work in experimental road materials, construction techniques, and information technology paved the way for self-driving vehicles, sophisticated industrial robots, and next-



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MEMS
SwRI designed and tested microelectromechanical systems (MEMS), devices with miniature moving parts that respond to electrical and physical stimuli.

Space Science
Several SwRI-led NASA missions made history, including New Horizons. The spacecraft buzzed past Pluto, returning breathtaking images of an unexpectedly complex and geologically young surface.

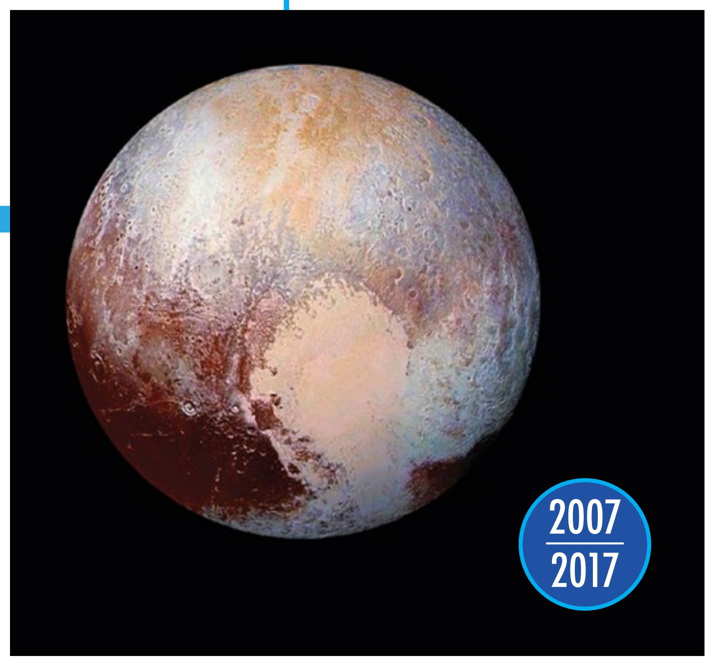

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IMAGE COURTESY NASA/JHUAPL/SwRI

generation automotive engines, as well as spacecraft and science payloads. SwRI scientists and engineers have improved the deep-diving capability of the Alvin research submersible, isolated the cause of the Columbia space shuttle disaster, and led NASA space missions to Jupiter, Pluto, and beyond.

With projects from deep sea to deep space and everything in between, innovation and exploration are in our corporate DNA. What comes next will depend — as always — on what clients need. It's been that way since the beginning. After recruiting talent from across the nation, Tom Slick challenged his team of scientists and engineers to make the world a better place through advanced science and applied technology. SwRI's mission today remains unchanged.

SOUTHWEST RESEARCH INSTITUTE®
1947
2017
Deep Sea to Deep Space

CLOUD-BASED SOFTWARE: VIRTUAL POWER TOOLS

Space scientists are used to dealing with things out of this world. To properly study this complex, real-time, data-abundant domain demands powerful digital infrastructure and broad technical expertise. Southwest Research Institute brought together a diverse team of experts to break new ground by moving space science, manufacturing, and project management applications into the cloud, the virtual world beyond individual computers.

In 2011, Technology Today interviewed Robert L. Thorpe, a senior program manager in SwRI's Space Science and Engineering Division, about the Project Information Management System (PIMS), a specialized software tool for project managers. Since then, increased demands for both capacity and reliability have led to the development of a line of high-availability, cloud-based applications. We recently sat down to ask him about the transition.

Technology Today: Bring us up to date on PIMS, and refresh our memory about the friendly bet that led to it.

Robert Thorpe: Of course. Back in the late 1990s, I was on a team supporting the Ion and Neutral Mass Spectrometer, one of the science instruments aboard NASA's Cassini mission to Saturn (see related story page 2). Near the end of one of the team meetings, the project manager began handing out action items on sheets of paper. To make a long story short, I suggested creating a web application to track our action items. It seemed like a good idea to digitally track and document progress. To counteract resistance about cost and schedule, I said I could do it in a week. I knew it could be done with some newer web-database technologies. This generated a certain amount of disbelief, so as a last resort I made a bet that it could be done in a week.

The manager wasn't convinced, but a week wasn't much to risk so he took a chance. A week later, the Action Item Management System — now called PIMS (pims.swri.org) — was born. Since then, PIMS has been adopted by not only NASA and European Space Agency missions, but also by commercial clients. It supports hundreds of multi-million, even billion dollar projects simultaneously. We began licensing it for customer sites, eventually offering it as a cloud application. That's the most recent evolution — migrating PIMS into the cloud.

DETAIL

Cloud computing provides access to applications and services via the internet, instead of from your hard drive or local servers. Cloud providers manage remote infrastructure and platforms that run applications. Cloud applications fall into the "software as a service" or "on-demand software" category.

In the meantime, we've developed more than 30 different science, manufacturing, and project management production applications. Some are large, some are small. Some, like our Progress project-based manufacturing software (progress.swri.org) and our Juno Science Operations Center (JSOC), need to be online continuously. The respective clients want zero downtime, or as close as we can get.

TT: What is project-based manufacturing?

RT: It's the opposite of mass production or in-line manufacturing. In-line manufacturing is used to make large quantities of a standardized product, things like smartphones, televisions, cars, and other assembly-line products. There are a lot of great software products out there that support in-line manufacturing. However, with project-based manufacturing, you're building one or two or small groups of products, and for space applications, you've really got to get them right. Examples include building space science instruments, space-qualified custom computer boards, and custom parts for spacecraft, which are a few of the things we do here at SwRI. We have found very few commercial software products that specifically address managing the high-quality, small-quantity manufacturing the way Progress does. If you're doing this sort of project-based manufacturing, SwRI's Progress manufacturing software is for you. It's become such an integral part of our manufacturing process, we need it to be online 24/7/365.

TT: Interesting. And what is the Juno Science Operations Center?

RT: JSOC is the science planning and data management center for the NASA Juno mission to Jupiter (missionjuno.swri.edu). The JSOC data system was designed and deployed at SwRI. It's key to planning the science activities for the Juno mission.

Scientists are passionate about the data they collect from planets like Saturn, Jupiter, and Pluto. However, there's only so much data that can be transmitted back from the spacecraft. You can think of it as a fixed-capacity pipeline that exists from Jupiter back to Earth — only so much data can go through it. Each Juno science instrument is collecting data during each Jupiter orbit and especially during the flybys. The teams for the 11 science investigations work together to allocate the "pipeline" resources based on science priorities. Additionally, the science teams monitor the data flowing through the pipeline in near-real-time as the data return to earth, to see if they should adjust their plan for the next Jupiter orbit and flyby.

The JSOC data system is the platform for all this planning and collaboration. It also supports data management, document

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Robert Thorpe is a senior program manager who oversees the development and implementation of software data systems that support NASA and ESA missions. He spoke with Technology Today about how many of these are now offered as high-availability, cloud-based applications.

DETAIL

Relational database failover supports high-availability, high-reliability applications. A **relational database** is a collection of data organized as a set of tables, which allows data to be accessed or reassembled in many different ways without affecting the database tables. **Failover** protects computer systems from failure; secondary equipment automatically takes over when components fail.


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Creating SwRI's cloud-based architecture required a multidisciplinary team from across the Institute. Key contributors include (seated, from left) Prachet Mokashi, Paul Leopold, James Jehl, Sonny Kriewald, (standing, from left) Susan Pope, Robert Thorpe, John Kaiser, and Jeremy Schleicher.

management, and archiving science data to the NASA Planetary Data System nodes, which puts data out in the public domain. The project team wants this large data system continuously available.

TT: Why move these applications into the cloud?

RT: Based on risk analysis for our manufacturing environment, we determined that Progress is such a critical application, it can't be offline more than 5 minutes, ever. Putting it in the cloud makes it a lot easier to keep it online. JSOC was another easy candidate to be a cloud application. Originally, the mission was planned for orbits around Jupiter that were only 14 days long, so we knew from the beginning the science teams would want JSOC online constantly. The science and operations pace was going to be very intense. Due to changes in the mission after arriving at Jupiter, the orbits are at a more relaxed 53 days. Still, everyone wants the application on all the time. That did not get relaxed.

TT: How hard was it to create a cloud-based architecture?

RT: Although it does require specialized expertise, setting up a basic cloud architecture is not too complex. The first cloud we set up was pretty easy, mainly because space sciences didn't set it up at all. We arranged a deal with SwRI's Information Technology Center (ITC) to duplicate a cloud they already had in place. The space science division provided the hardware, and ITC set it up and now manages day-to-day operations. In return, they use a percentage of the cloud for other SwRI divisions that are interested in cloud application support. We use it for a lot of our support applications that need to be online most of the time but don't have special uptime requirements or lots of customers.

The cloud we developed for PIMS, Progress, and JSOC was significantly more complex than the first one. It had special requirements, including completely redundant hardware in two different buildings, many terabytes of storage on advanced storage arrays, and high-end relational database failover capability. This setup essentially means any single piece of cloud hardware could fail and everything would still run.

For the second high-end cloud, lots of people helped. Project managers and division management helped define requirements and get equipment purchased. SwRI's IT experts did all the technical "heavy lifting" setting up the cloud – configuring the servers, networking, and high-end database technologies. That's one of two things I've always liked about SwRI: First, I've never met anyone who didn't appreciate a good idea. Second, SwRI is not too small to find someone who can help, and not so big that lots of red tape gets in the way.

TT: With these clouds in place now, will you use them for other applications?

RT: Absolutely. It's a lot easier than buying individual servers and setting them up. One example is the recent launch of our Supernova Analysis Application, or SNAP, as a cloud application. It provides functions to import models of supernovas as well as actual supernova observations, and correlates the two using scientific formulas and database links. With new supernova-detecting surveys coming online, the full-sky telescope observations will be pouring in. SNAP is an excellent example of an application that fits easily into a cloud architecture to provide web-based supernova analysis capabilities.

TT: Do all of your products need to be cloud-based?

RT: It really depends on what the client needs. Cloud-based applications are much easier to maintain, but well-trained cloud experts must be available. It's very important to maintain redundant expertise in cloud technologies, so if one of your cloud specialists wins the lottery and leaves, you're not left out in the cold. SNAP, JSOC, Progress, and PIMS fit well into the cloud environment. Other applications fit best on physical servers, and sometimes we use physical servers as backup servers or for other tasks where things are better kept simple.

TT: So, in addition to developing new applications, you're offering cloud applications to external customers?

RT: Yes, for example, Progress and PIMS have supported more than 150 NASA, ESA, commercial, and defense projects to date. If a client purchases one of these applications, we are happy to host it in our cloud. While there are commercial clouds we could use, we prefer hosting apps in our cloud where we have direct control over security and backups. Plus, we don't have to contend with issues storing proprietary data in a third-party cloud.

Once we built our clouds, and placed our applications in them, it became easy to clone these applications for other clients, who get all the benefits of an application being in the cloud. Additionally, if you need an individual application to run faster, you just allocate more cloud resources to the virtual server. If you're running low on cloud resources, you just add more hardware to the cloud.

TT: Can you quantify how these cloud-based products have improved processes?

RT: Compared to legacy systems, the complementary PIMS and Progress tools improve responsiveness by three or four times: expediting on-time deliveries, customer response time, troubleshooting, and problem resolution. They have become key components of our manufacturing and project management processes and provide a highly integrated foundation for our electronic quality management system. Our cloud-based architecture helps us keep these critical systems online, and also directly aligns with today's modern project teams, which may be spread out across the U.S. or even the world.

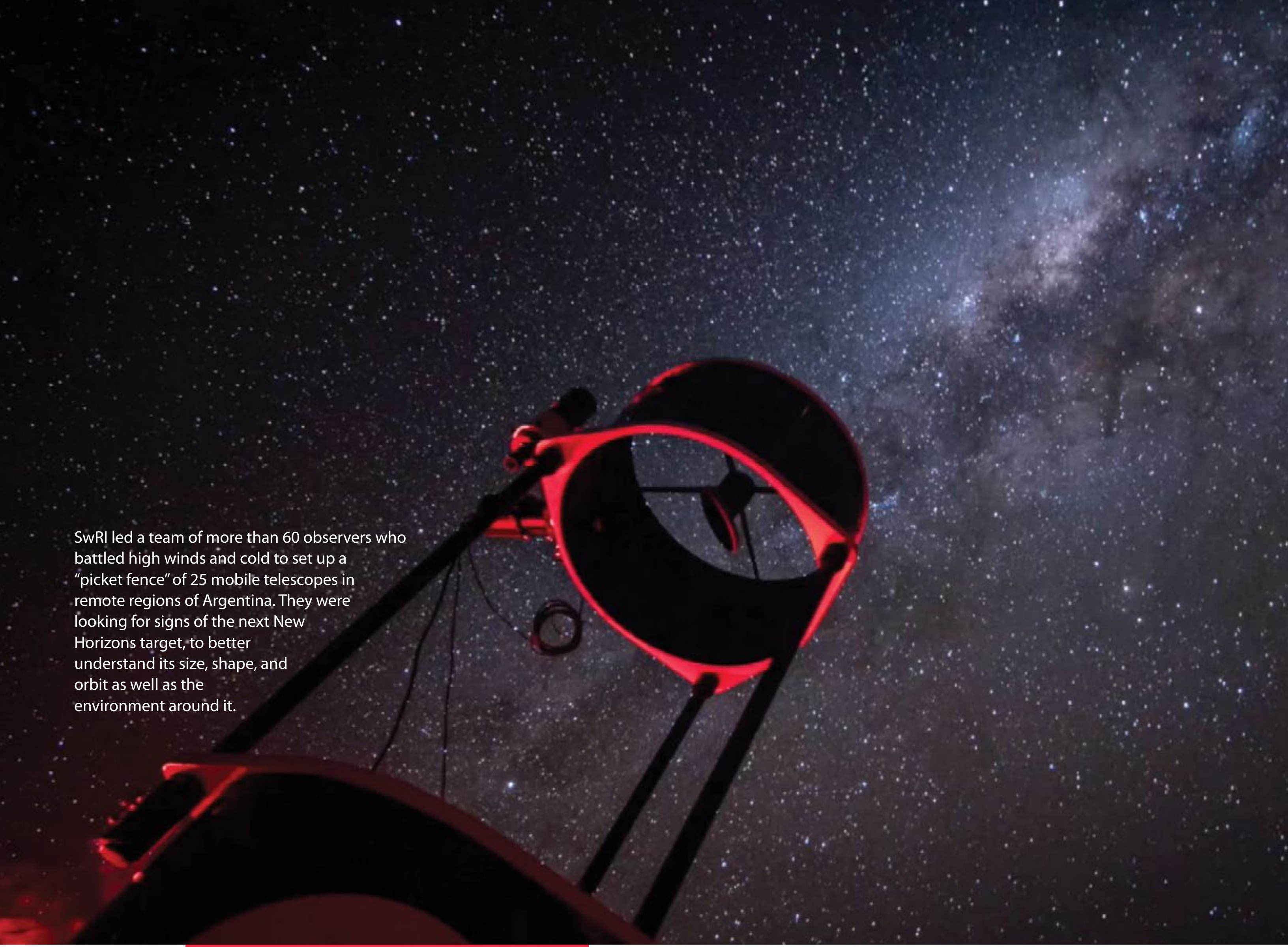
TT: What's next?

RT: For now, the wave of the future is cloud computing. We're doing our best to ride the right part of the wave – not too far out in front where you can wipe out, but not so far behind where you miss the wave entirely. We want to be in the ideal place to provide our clients with the best possible solutions.

As far as what comes next, that's somewhat challenging to predict. Maybe in 10 or 20 or 30 years, we'll be able to run something as complex as our second cloud on two quantum memory, fusion-powered super-smartphones that synchronize with each other and provide services anywhere in the world … or maybe even off-planet.

Whatever technologies evolve, we'll always aim to bring the appropriate technical experts together to provide the best possible solutions for our clients.

Questions about this article? Contact Thorpe at 210.522.2848 or robert.thorpe@swri.org.



SwRI led a team of more than 60 observers who battled high winds and cold to set up a "picket fence" of 25 mobile telescopes in remote regions of Argentina. They were looking for signs of the next New Horizons target, to better understand its size, shape, and orbit as well as the environment around it.

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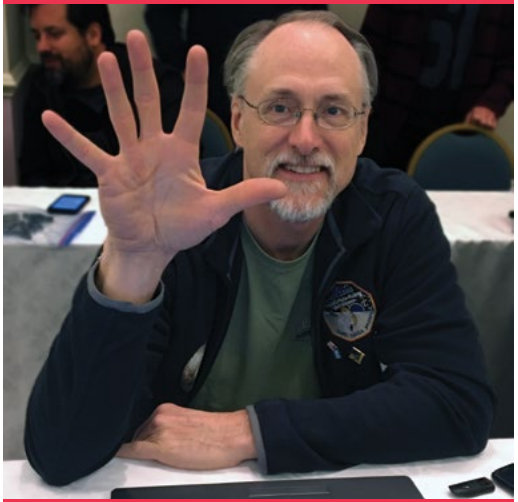

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ABOUT THE AUTHOR
SwRI's Dr. Marc Buie led the successful New Horizons occultation campaign. Five mobile telescopes in Argentina detected the fleeting shadow of 2014 MU69.

IMAGES COURTESY NASA/JHUAPL/SwRI/ALEX PARKER/ADRIANA OCAMPO

NASA's New Horizons spacecraft is hurtling across the solar system, heading for a close encounter with Kuiper Belt Object (KBO) 2014 MU69 on January 1, 2019. We get just one shot to use the instruments onboard to learn about this distant relic, left over from the formation of our solar system.

Since the beginning of the SwRI-led New Horizons mission, this phase of the mission has been a race against the clock. The tremendously successful 2015 Pluto-Charon flyby that generated breathtaking images was the mission's primary objective. But we also anticipated extending New Horizons' journey, to visit another KBO. The Kuiper belt is a zone of small bodies at the edge of the solar system, similar to the main asteroid belt between Mars and Jupiter, but far larger. The search for New Horizons' second target began in 2004 but didn't discover anything useful until 2014, just in time to let the navigators know where to go after Pluto. Now, as we settle down to plan our observations, we are gathering as much data about the target as possible to increase the scientific returns from the flyby.

Our target, nicknamed MU69, is very difficult to study from afar. Its size and distance put it out of reach of even the largest ground-

OCCULTATION EXPEDITIONS

Going to the Ends of the Earth to Search for Signs of New Horizons' Next Target

by Marc Buie, Ph.D.

based telescopes. Even the Hubble Space Telescope can just barely detect it, and from that data, we could only guess at its size. If the surface were very dark, it could be as large as 40 km across, about half the size of Pluto's moons, Nix and Hydra. If the surface were more reflective, it could be even smaller than we thought. That posed a big problem.

New Horizons observations must take into account how bright a surface is. If we planned for a bright surface and it is actually dark, the pictures will be dark and grainy. If we planned for a dark surface and it is actually bright, we risk saturating the images or wasting time on longer exposures.

To get critical mission data, we identified three opportunities in 2017 when MU69 would likely pass directly in front of a star — an event known as an occultation — that could possibly be observed from somewhere on the Earth. By timing the duration of the star disappearance and combining that information with its known orbital velocity, we could not only measure the size of MU69 but also ascertain its surface brightness.

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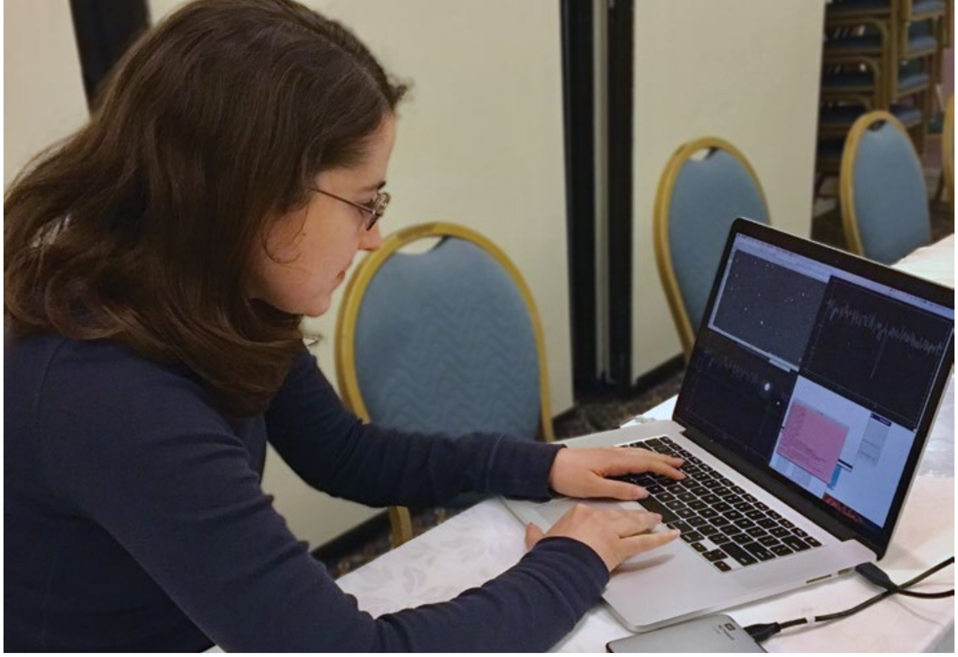
This artist's concept of Kuiper Belt object 2014 MU69 is based on telescope observations made at Patagonia, Argentina, on July 17, 2017. Scientists think it could be a single body with a large chunk taken out of it or two bodies so close together they may be touching.



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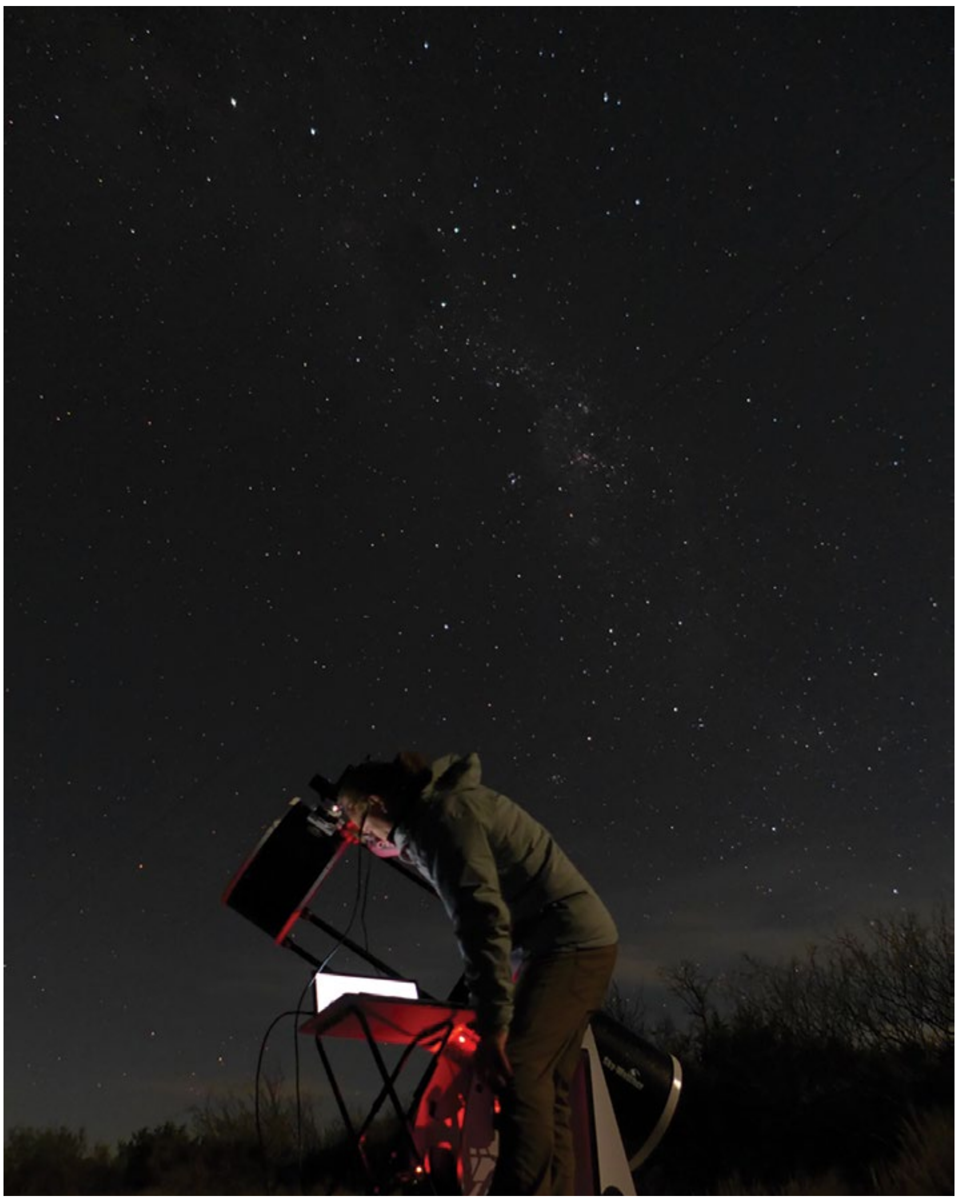

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At top: SwRI's Dr. Amanda Zangari was the first occultation campaign scientist to see the telltale signature of MU69 while analyzing data from July 17.
Above: In Argentina, SwRI's Dr. Alex Parker looks for the stellar occultation of 2014 MU69.

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The first occultation opportunity was June 3 with potential visibility from South Africa and southern South America. We sent 13 teams to Cape Town and 12 to Mendoza, Argentina, to line up a string of portable telescopes to look for signs of MU69. While all the teams got data at the right time, sadly, no occultation signature was seen.

We tried again on July 10, using the Stratospheric Observatory for Infrared Astronomy (SOFIA) telescope, which is mounted on a modified Boeing 747PS. Again, nothing obvious was seen.

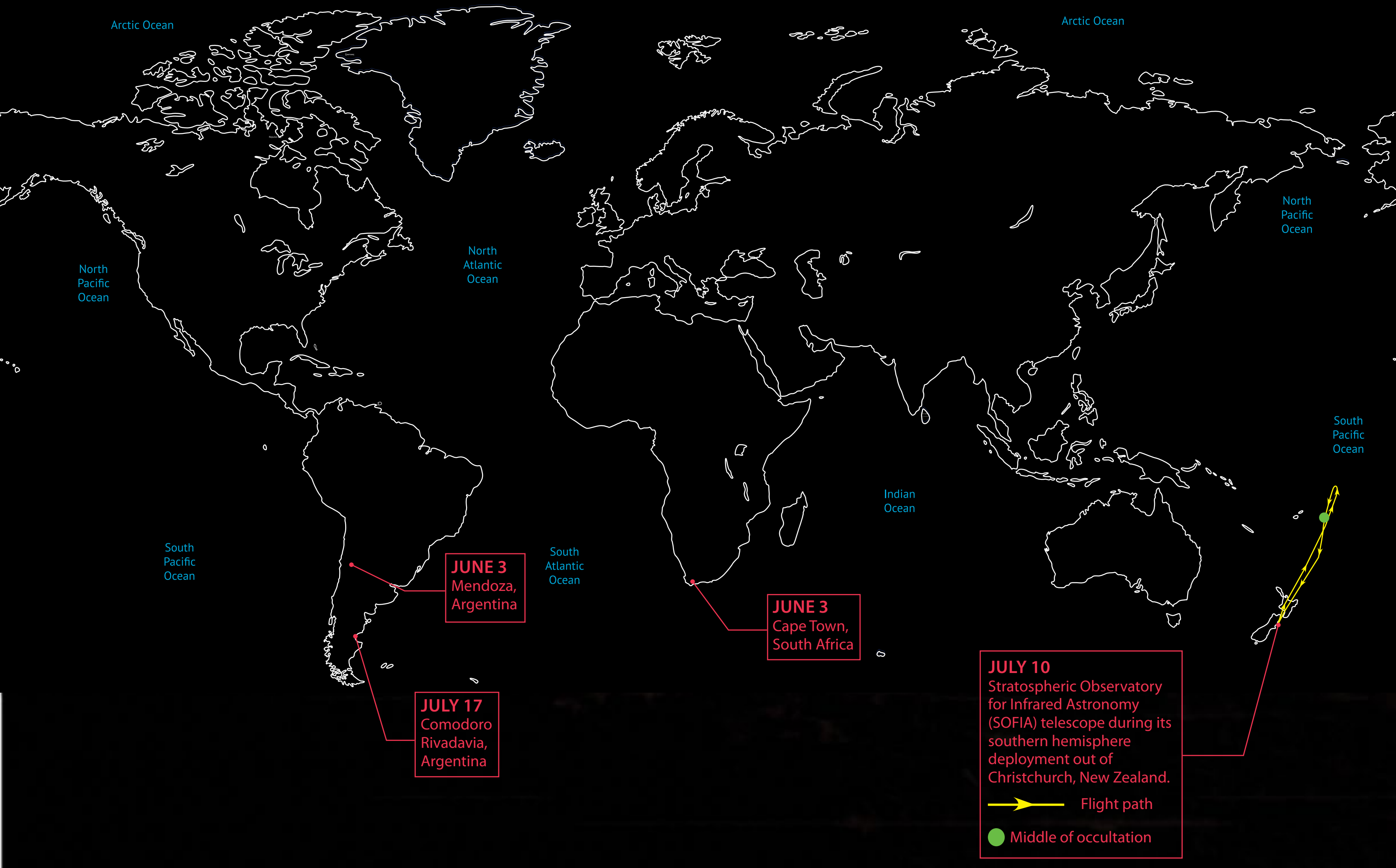
The final shot we had was July 17, from extreme southern Argentina in Comodoro Rivadavia, the "city of the winds." Our Argentina-based advisers thought we were crazy to even try. It was the middle of their winter and conditions could be very harsh. All 25 teams assembled there, each with its own telescope. We set up a "picket fence" of observing stations to try to catch the elusive shadow of our target passing in front of the star and held our breath.

We battled wind: The locals helped us build wind shelters and provided large trucks as windbreaks. We battled headlights and street lights: The locals shut down a national highway for two hours to give us a clear view. The teams were amazing and persevered through the cold, windy conditions. In the end, we had success! Incredibly, five of the teams recorded a brief — one second or less — disappearance of the star. We now have a reasonable guess for the reflectivity of MU69's surface. Armed with that critical information, we are now developing the final plan for the flyby event.

In the meantime, we are still puzzling over the July 17 results. What we saw in terms of size and shape has multiple interpretations, and we continue to delve into the data to better understand this enigmatic object. Even if we cannot sort it all out in advance, we know that New Horizons will be there soon to answer — we hope — our questions definitively.

IMAGES COURTESY NASA/JHUAPL/SWRI/HENRY THROOP/ ADRIANA OCAMPO/ KAI GETROST

Four members of the New Horizons' South African observation team scan the sky, waiting for the MU69 occultation, in the wee hours of June 3, 2017.



NEXT-GEN SPACE RESEARCH

A new generation of suborbital space vehicles is poised to come online for space research, education, and space tourism over the next two years. The 2017 Next-generation Suborbital Researchers Conference (NSRC), organized by SwRI and the Commercial Spaceflight Federation, will bring together hundreds of researchers, educators, flight providers, spaceport operators, government officials, and others in late December.

"Rocket and balloon companies have demonstrated more mature flight-tested systems over the past year, and a new era of routine access to suborbital space for payloads and people is soon approaching," said SwRI Associate Vice President Dr. Alan Stern, NSRC-2017 convener and program chair. "NSRC-2017 is poised to benefit researchers and educators looking to take advantage of that new era."

NSRC is the premier conference for the suborbital space research and education community. NSRC-2017 follows five highly successful NSRC meetings, the first held in 2010. It will focus on research and education opportunities offered by human-tended commercial suborbital vehicles. The conference will provide an in-depth forum for attendees to learn about how they can conduct research and public outreach using new commercial suborbital spaceflight systems.

NSRC-2017 will be held in Broomfield, Colorado, Dec. 18–20. For more information visit: **nsrc.swri.org**.

PIPELINE INSPECTION TECHNOLOGY BREAKS NEW GROUND

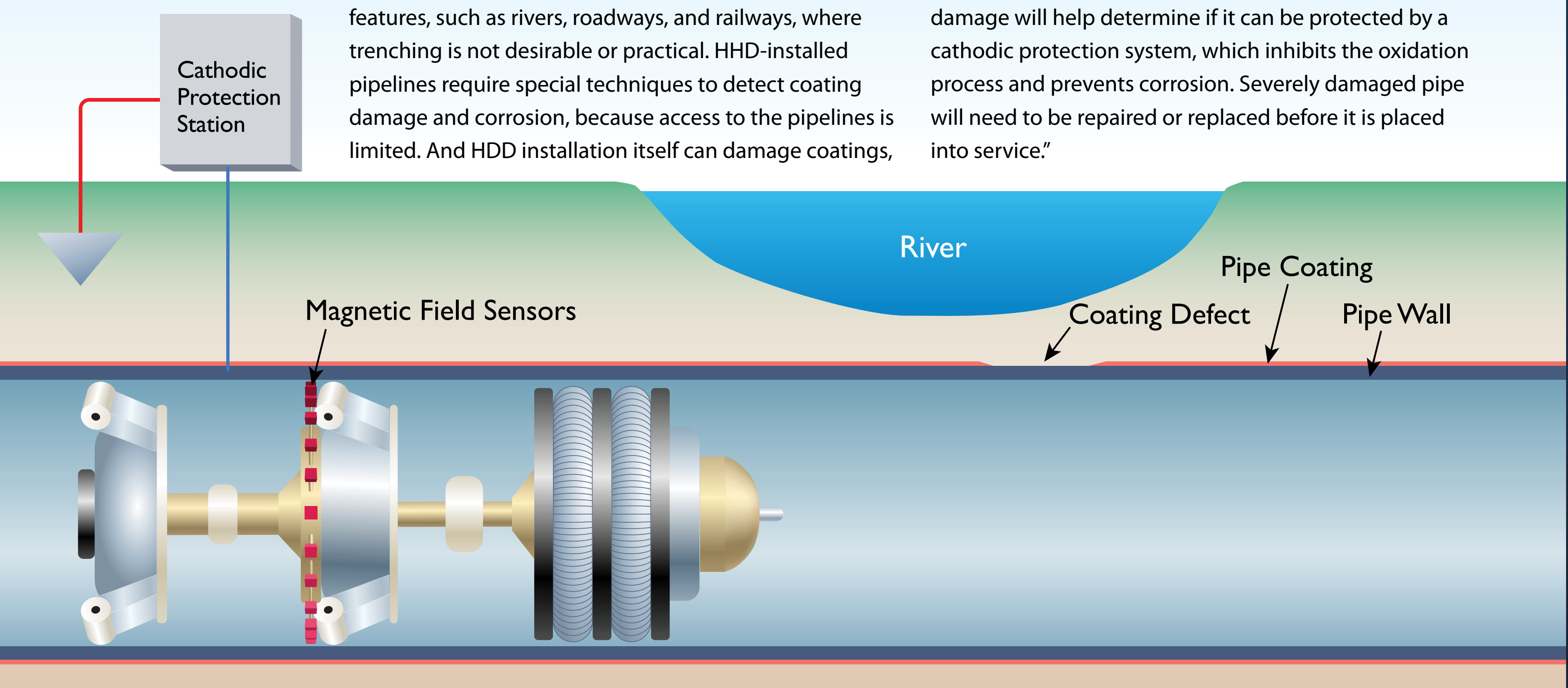
SwRI patented new technology to inspect the coatings of pipelines installed using horizontal directional drilling (HDD), a trenchless technology that has gained widespread acceptance over the past 20 years. The patented magnetic field sensor array can determine both the extent and configuration of any pipe coating damage that occurs during HDD installation.

Traditionally, pipelines were installed in open trenches, damaging or destroying roads, sidewalks, and environmentally sensitive areas in their path. But pipeline coating damage is less likely and easier to detect in open trench installations.

HDD is ideal for pipelines that run under surface features, such as rivers, roadways, and railways, where trenching is not desirable or practical. HHD-installed pipelines require special techniques to detect coating damage and corrosion, because access to the pipelines is limited. And HDD installation itself can damage coatings, as pipeline segments are pulled through a borehole, across soil, rock, and other debris.

SwRI's patented magnetic field sensor array system inspects pipeline segments for coating damage immediately after HDD installation. As the array moves along within the pipe, engineers analyze sensor outputs to determine the location, configuration, and extent of coating damage. The system can also be used to inspect conventionally installed pipes.

"It is important to determine the condition of the coating on the pipeline segment immediately after installation," added Dr. Jay Fisher, a co-inventor of the technology. "Understanding the extent of any coating damage will help determine if it can be protected by a cathodic protection system, which inhibits the oxidation process and prevents corrosion. Severely damaged pipe will need to be repaired or replaced before it is placed into service."



The two research aircraft, based in Houston, reached an altitude of 50,000 feet. The mission lasted more than five hours flying at an average speed of 420 miles per hour.

IMAGE COURTESY NASA/FAROE ISLANDS/SwRI D022580

CHASING THE SHADOWS

Two NASA WB-57F research aircraft successfully tracked the August 21 solar eclipse from Nashville to Kansas City to study the solar corona and Mercury's surface.

"The visible and infrared data look spectacular," said SwRI's Dr. Amir Caspi, principal investigator of the NASA project. "We're already seeing some surprising features, and we are very excited to learn what the detailed analysis will reveal."

Initial analysis of the data gathered during the flights shows clear images of the Sun's corona — its outer atmosphere — and bright infrared emissions from Mercury. Initial results are expected to be presented at the fall meeting of the American Geophysical Union in December 2017 in New Orleans.

Total solar eclipses are unique opportunities for scientists to study the hot atmosphere above the Sun's visible surface. The faint light from the corona is usually overpowered by intense emissions from the Sun itself. During a total eclipse, however, the Moon blocks the glare from the bright solar disk and darkens the sky, allowing weaker coronal emissions to be observed.

"This is the best-observed eclipse ever," said Dr. Dan Seaton, co-investigator of the project from the University of Colorado. "With the results from the WB-57s and complementary observations from space and other experiments on the ground, we have an opportunity to answer some of the most fundamental questions about the nature of the corona."

The eclipse also provided an opportunity for scientists to study Mercury, which is notoriously difficult to image because of its proximity to the Sun.

"The infrared images of Mercury were much brighter than we originally expected," Caspi said. Using infrared observations in near darkness through very little atmosphere, the team received data enabling it, for the first time, to attempt to estimate the surface temperature distribution over the planet's night side.

"It will be incredibly interesting to dig into these data," said SwRI coinvestigator Dr. Constantine Tsang.

The team used stabilized telescopes with sensitive, high-speed, visible-light and infrared cameras aboard the research aircraft from an altitude of 50,000 feet, providing a significant advantage over ground-based observations. These are the first astronomical observations for the Houston-based WB-57Fs. Southern Research, of Birmingham, Ala., built the Airborne Imaging and Recording Systems (AIRS) and worked with the scientific team to upgrade its DyNAMITE telescopes onboard the planes with solar filters and improved data recorders and operating software.

"The pilots, instrument operators, and engineers did a phenomenal job getting us exactly the data we asked for," said Caspi. "Achieving this quality of measurement required an enormous effort and precise timing, and everyone hit their mark exactly. I am honored to be part of such an exceptionally talented and professional team, and grateful for everyone's dedication and hard work."

The SwRI-led team includes scientists from the University of Colorado, the National Center for Atmospheric Research High Altitude Observatory, and the Smithsonian Astrophysical Observatory, as well as international colleagues at Trinity College Dublin in Ireland and the Royal Observatory of Belgium.

IMAGE COURTESY SMSGT THOMAS MENEGUIN D022727

Avionics to Avert Enemy Forces

The U.S. Air Force awarded SwRI a $13.1 million contract to continue improvements to aircraft electronic attack pods.

Attack pods are countermeasure devices mounted on an aircraft. The pods contain a suite of electronic instrumentation – receivers, antennas, and transmitters – designed to alter the flight of an incoming enemy missile or prevent tracking by enemy forces by jamming radar signals.

SwRI will provide software engineering, evaluation, and support, as well as system testing and evaluation for attack pods found on a host of U.S. military aircraft including the F-16, A-10, F-15, and C-130. The five-year project will be performed at Robins Air Force Base in Georgia.

INSPIRING FUTURE SPACE EXPLORERS

As part of a NASA-funded education program, 30 San Antonio students will spend the next three years working closely with SwRI engineers and local educators to simulate a manned mission to the moon.

The Lunar Caves Analog Test Sites (LCATS) program kicked off Sept. 8 at the Scobee Planetarium at San Antonio College, where SwRI researchers demonstrated the types of experiments middle and high school students will conduct every other Saturday.

"This is such a unique opportunity for both the students and SwRI, as we help students understand the years of work that go into a major NASA mission," said SwRI's Susan Pope, who spoke at the kickoff event.

"Everybody worked very hard to make the TexPREP Kickoff Event successful," said Dr. Marius Necsoiu, the SwRI project manager and grant co-investigator. "We can't wait for the students to start their experiments!"

LCATS is offered through the San Antonio Prefreshman Engineering Program at the University of Texas at San Antonio through a $1.24 million NASA grant to the WEX Foundation.

"These students are the next generation of space explorers," said SwRI's Ed Patrick, also a grant co-investigator. "We hope we inspire them as much as they have inspired us."

The program includes development of robotics and simulations of a lunar mission, including science investigations, space exploration, mission operations, technology development, and architecture of habitable space systems.

D022484_1973

NEW FLOW COMPONENT FACILITY OPERATIVE

SwRI now offers a 60,000-square-foot outdoor complex for fluid dynamics research and development testing of flow components. The new facility complements a suite of test facilities and laboratories dedicated to evaluating instrumentation, equipment, and devices for the oil and gas industry.

The new facility features a 3,800-square-foot high bay with a 10-ton overhead crane. A reinforced concrete pad can support heavy equipment. The area is ideal for setting up temporary flow loops for fluid dynamics research such as erosion testing or flow performance testing. A nearby control room provides remote control and monitoring. A fenced-in area within the facility supports research activities performed with flammable fluids, such as fugitive emissions testing.

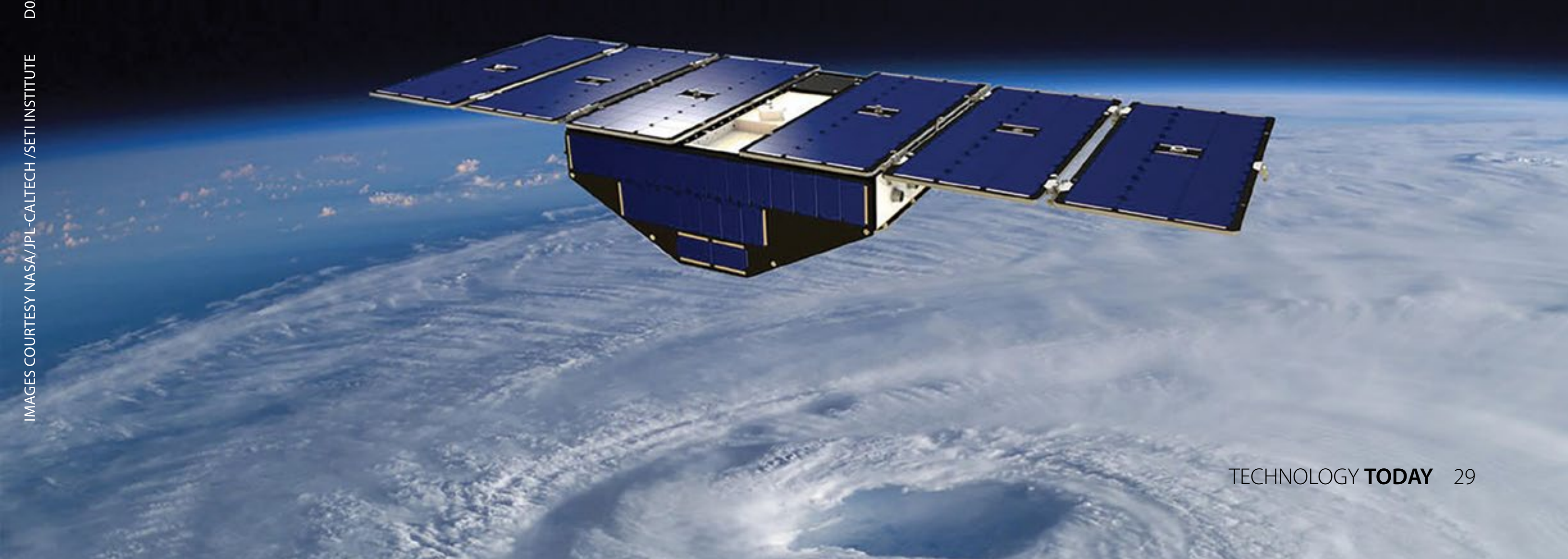
CYGNSS Wins AIAA SmallSat Mission of the Year

NASA's Cyclone Global Navigation Satellite System (CYGNSS) won the "Mission of the Year" award at the American Institute of Aeronautics and Astronautics (AIAA) 2017 Small Satellite Conference. CYGNSS, a constellation of eight microsatellite spacecraft built and operated by SwRI, was launched into low-inclination, low-Earth orbit over the tropics in December 2016.

The award is presented annually to a mission that has demonstrated a significant improvement in the capability of small satellites. Over 1,200 small satellite enthusiasts voted for this year's 10 small satellite nominees, which were selected by experts on the AIAA SmallSat technical committee.

"It is very rewarding that we were selected by such a large number of peers and colleagues in the smallsat community," said SwRI's Randy Rose, CYGNSS project systems engineer, who accepted the award on behalf of the CYGNSS team and Principal Investigator Dr. Christopher Ruf of the University of Michigan. "I think we'll be seeing a paradigm shift toward more small satellite science constellations like CYGNSS in the future."

CYGNSS makes frequent measurements of ocean surface winds to monitor the location, intensity, size, and development of tropical cyclones, particularly how they intensify. In recent decades, forecasters have greatly improved models that predict the path of hurricanes, but the ability to predict a storm's rapidly changing intensity has lagged. CYGNSS will provide the data necessary to enable significant improvement of this key piece of the puzzle.



IMAGES COURTESY NASA/JPL-CALTECH/SETI INSTITUTE D022728

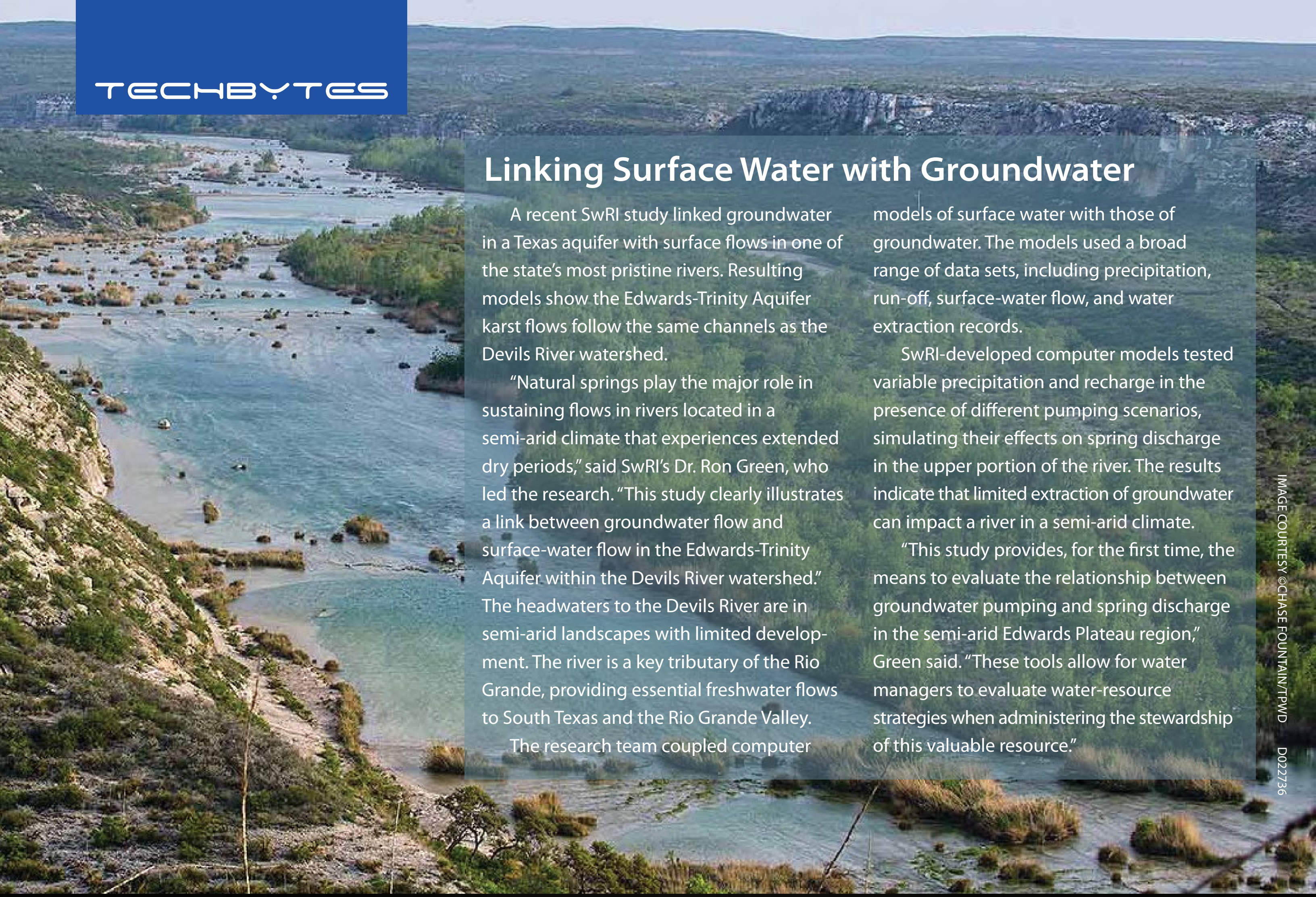


IMAGE COURTESY ©CHASE FOUNTAIN/TPWD D022736

Linking Surface Water with Groundwater

A recent SwRI study linked groundwater in a Texas aquifer with surface flows in one of the state's most pristine rivers. Resulting models show the Edwards-Trinity Aquifer karst flows follow the same channels as the Devils River watershed.

"Natural springs play the major role in sustaining flows in rivers located in a semi-arid climate that experiences extended dry periods," said SwRI's Dr. Ron Green, who led the research. "This study clearly illustrates a link between groundwater flow and surface-water flow in the Edwards-Trinity Aquifer within the Devils River watershed." The headwaters to the Devils River are in semi-arid landscapes with limited development. The river is a key tributary of the Rio Grande, providing essential freshwater flows to South Texas and the Rio Grande Valley.

The research team coupled computer models of surface water with those of groundwater. The models used a broad range of data sets, including precipitation, run-off, surface-water flow, and water extraction records.

SwRI-developed computer models tested variable precipitation and recharge in the presence of different pumping scenarios, simulating their effects on spring discharge in the upper portion of the river. The results indicate that limited extraction of groundwater can impact a river in a semi-arid climate.

"This study provides, for the first time, the means to evaluate the relationship between groundwater pumping and spring discharge in the semi-arid Edwards Plateau region," Green said. "These tools allow for water managers to evaluate water-resource strategies when administering the stewardship of this valuable resource."

GENEALOGY OF PRIMORDIAL ASTEROIDS

An international team that includes SwRI scientists recently discovered a relatively unpopulated region of the main asteroid belt, where the few asteroids present are likely pristine relics from early in solar system history. The team used a new search technique that also identified the oldest known asteroid family.

The main belt contains vast numbers of irregularly shaped asteroids, also known as planetesimals, orbiting the Sun between Mars and Jupiter. As improved telescope technology finds smaller and more distant asteroids, astronomers have identified clusters of similar-looking bodies clumped in analogous orbits. These familial objects are likely fragments of catastrophic collisions between larger asteroids eons ago. Finding and studying asteroid families allows scientists to better understand the history of main belt asteroids. However, identifying the very oldest families, those billions of years old, is challenging because over time, a family spreads out.

"By identifying all the families in the main belt, we can figure out which asteroids have been formed by collisions and which might be some of the original members of the asteroid belt," said SwRI astronomer Dr. Kevin Walsh, a co-author of an online Science paper detailing the findings. "We identified all known families and their members and discovered a gigantic void in the main belt, populated by only a handful of asteroids. These relics must be part of the original asteroid belt. That is the real prize, to know what the main belt looked like just after it formed."

The research was supported by the French National Program of Planetology and the National Science Foundation. The resulting paper, "Identification of a primordial asteroid family constrains the original planetesimal population," appears in the Aug. 3, 2017, online edition of Science.

IMAGE COURTESY ESA/ATG MEDIALAB D022729

PUNCH SATELLITE PROPOSAL ADVANCES

SwRI contributes to multiple NASA programs

D022605

NASA has selected SwRI's "Polarimeter to Unify the Corona and Heliosphere" (PUNCH) program for a mission concept study. PUNCH is a proposed small satellite mission designed to image the Sun's outer corona.

The PUNCH program proposes a constellation of four suitcase-sized satellites or "smallsats" that will orbit the Earth in formation to study how the Sun's atmosphere, or corona, connects with the interplanetary medium. PUNCH could one day advance the understanding of how coronal structures fuel the solar wind with mass and energy.

"The vacuum of space between the planets is not empty — it is actually filled with a very tenuous, hypersonic 'solar wind' streaming out from the Sun," said SwRI's Dr. Craig DeForest, PUNCH principal investigator. "PUNCH will study how the corona and solar wind are connected by making global images of the poorly understood transition between them."

If selected for flight, PUNCH will track and measure the solar wind as it emerges from the solar corona, transitions to interplanetary space, and streams through the solar system, bathing the planets and other solar system bodies. It's important to understand the direct connection between the star itself and the gusty, turbulent flow near Earth that causes terrestrial "space weather," which can damage satellites, black out power grids, and disrupt communication and GPS signals.

In addition, the PUNCH satellites would track coronal mass ejections, also known as "CMEs" or "space storms," as they erupt from the Sun out into interplanetary space. PUNCH will investigate new techniques to predict space weather via three-dimensional imaging.

"Most of what we know about the solar wind and space weather comes from direct sampling by spacecraft embedded in it," DeForest said. "This is like understanding global weather patterns based on detailed measurements from a few individual weather stations on the ground. PUNCH is more like a weather satellite that can track and measure a complete storm system as it evolves across an entire region."

In addition, SwRI is contributing to the "Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites" (TRACERS) and "Focusing Optics X-ray Solar Imager" (FOXSI) proposals that were also selected for further development by NASA. SwRI's Dr. Stephen Fuselier is deputy principal investigator of TRACERS, designed to investigate global variability in magnetic reconnection events through new, unique in situ measurements. TRACERS principal investigator is Dr. Craig Kletzing at the University of Iowa, in Iowa City. SwRI's Dr. Amir Caspi is an instrument lead on FOXSI, a telescope that would detect hot plasma and energetic electrons released by the solar corona. FOXSI principal investigator is Dr. Steven Christe at NASA's Goddard Space Flight Center.

If the design studies go well, these missions could launch as early as 2022. NASA's Small Explorers missions provide frequent flight opportunities for world-class scientific investigations from space using innovative, efficient approaches within the heliophysics and astrophysics science areas.

BY THE NUMBERS
June — September 2017

127
presentations
given in

23
states

and 12
COUNTRIES

36
papers
published in

20
PUBLICATIONS

13
patents
awarded

SwRI'S ARMY LAB RECOGNIZED

The U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI), known around SwRI as "the Army Lab," recently received a **Certificate of Appreciation** from the Defense Logistics Agency – Energy (DLA–Energy).

The DLA honor recognizes the lab's outstanding efforts in support of DLA–Energy and the Energy Readiness Program. Specifically, the DLA cited SwRI's contributions and tireless efforts, representing the finest examples of partnership, to help the agency best serve the warfighter and U.S. Department of Defense customers. In 2017, SwRI's Army Lab celebrated 60 years of serving the needs of both military and commercial clients in ensuring that fuels and lubricants meet military specifications and demands.

DC6522

SwRI broke ground on the Army Lab on July 18, 1956.

E113700

SwRI SHARES POPSCI AWARD

Popular Science magazine recently recognized the Uptane software update security system for automobiles with a **2017 Best of What's New Award.**

Today's highly computerized vehicles are increasingly connected, making them a possible target for hackers. The greatest potential vulnerability is when a vehicle system needs an update. SwRI is working with the University of Michigan Transportation Research Institute, the project lead, and New York University's Tandon School of Engineering to solve the problem.

"Uptane is an open-source solution, so there are no restrictions on who can benefit from the security improvements," said Cameron Mott, the engineer leading SwRI's efforts. "Uptane was designed to make it extremely difficult for attackers to install malware on vehicles maintained by a manufacturer. This improves the safety and security of their products, which is important for public trust."

Mott says "car hacking" is more of a theoretical threat than an immediate concern. However, the automotive industry is working to address public concerns, giving Uptane greater visibility with calls for white-hat hackers to find potential issues and offer improvements.

To support the effort, SwRI is conducting system and software engineering, design, and is creating a reference implementation. Mott hopes to begin testing in coming months.

"The Institute has the valuable capability to both design and test security improvements for future automobiles," he said.

D022603

Mary Gonzalez received a 2017 Outstanding Member Award from the National Property Management Association, recognizing her outstanding service and dedicated commitment to the property/asset management profession. Gonzalez has more than 39 years of experience in logistics management, including 20 years with the U.S. Air Force and more than 15 at SwRI.

D018572_5360

Institute Scientist **Dr. Ron Green** has been elected chairman of the board of the National Cave and Karst Research Institute. This nonprofit, government-supported organization conducts, facilitates, and promotes programs in cave and karst research, education, environmental management, and data acquisition and sharing.

D019192

Erica Macha received the top research excellence award in 2017 from the Department of Defense's Corrosion Policy and Oversight Office. The award recognized her role in exploring the effects of aerospace primers on galvanic multi-electrode arrays in controlled relative humidity environments.

D022610

Tony Magaro, executive director of Human Resources, received the National Industry Liaison Group's 2017 Lois Baumerich Lifetime Achievement Award for his work promoting equal opportunity and affirmative action. Named for a founding member of NILG, the award recognizes those who dedicate their careers to promoting equal opportunity and affirmative action.

D019449

Dr. Simone Marchi received the Farinella Prize for his research on the impact history and evolution of the inner solar system. The prize honors the memory of Paolo Farinella (1953–2000), an Italian planetary scientist who made significant contributions in the fields of asteroids and small bodies.

D022662_9875

Vice President and General Counsel **John McLeod** won a Magna Stella Award for in-house excellence in leadership and management in the Nonprofit/Government category from the Texas General Counsel Forum. The Forum strives to improve the professional lives of members through peer networking, knowledge exchange, and professional development.

D022723

Dr. Alan Stern was honored with the University of Texas at Austin College of Natural Sciences 2017 Hall of Honor Distinguished Alumni Award. As a recipient of the college's most prestigious award, Stern joins a remarkable and diverse group of individuals who have been inducted into the Hall of Honor since 1991.

D018058

Institute Scientist **Steven R. Westbrook** recently received the Lowrie B. Sargent Jr. Award from ASTM International's committee on petroleum products, liquid fuels, and lubricants. The award recognizes Westbrook's outstanding leadership in the standardization of petroleum products and lubricants.

COMING UP

Natural Gas High Horsepower Summit, Jacksonville, FL; Nov. 6-9, 2017, Booth 234

Torsional Analyses: A Basic Primer, San Antonio; Nov. 8, 2017. SwRI is hosting this webinar.

American Association of Pharmaceutical Scientists (AAPS), San Diego; Nov. 12, 2017, Booth 2634

Gas Turbine & Compressor Training Week, San Antonio; Nov. 13-17, 2017. SwRI is hosting this one-week training.

Aircraft Structural Integrity Program Conference, Jacksonville, FL; Nov. 27-30, 2017, Booth 17

Power-Gen International, Las Vegas; Dec. 5, 2017, Booth 10905

Lateral & Torsional Rotordynamics for Centrifugal & Reciprocating Machinery, San Antonio; Dec. 5, 2017. SwRI is hosting this short course.

46th Turbomachinery Symposium & 33rd International Pump Users Symposium (TPS), Houston; Dec. 12, 2017, Booth 2726

Natural Gas Sampling Technology (NGSTech) Houston; Jan. 16, 2018

DistribuTECH Conference & Exhibition, San Antonio; Jan. 23, 2018, Booth 1359

Texas Life Science Forum, Houston; Jan. 23, 2018

Turbomachinery Design Training Week, San Antonio; Feb. 5, 2018. SwRI is hosting this training week.

Underwater Intervention, New Orleans; Feb. 6, 2018, Booth 337

Technology & Maintenance Council (TMC) Annual Meeting, Atlanta; March 5, 2018, Booth 1342

Dixie Crow Symposium, Warner Robins, GA; March 19, 2018

6th International Supercritical CO_2 Power Cycles Symposium, Pittsburgh; March 27, 2018

Drug Discovery Chemistry, San Diego; April 2, 2018, Booth 306

NACE Corrosion Conference & Expo; Phoenix, April 15, 2018, Booth 231

Space Symposium, Colorado Springs, CO; April 16, 2018, Booth 1101

Interphex, New York; April 17, 2018, Booth 2140

Pulsations & Vibrations: Analysis and Testing, San Antonio; April 18, 2018. SwRI is hosting this three-day short course.

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