SOUTHWEST RESEARCH INSTITUTE®

FALL 2018

# TECHNOLOGY TODAY®

## AVERTING ASTEROID ARMAGEDDON

# DAZZLING DETERRENT

SwRI engineers are working on a smaller, more compact version of the Long Range Ocular Interrupter (LROI). This nonlethal technology is designed to assess, slow and even thwart potential threats, such as an unidentified boat approaching a naval vessel.

LROI uses a high-intensity eye-safe laser to deliver a dazzling, brilliant beam to fend off intruders without harming people. The beam can slow or suppress an individual's ability to take action and encourage retreat. The system detects the range to the target and adjusts the beam to maintain a consistent intensity level.

SwRI's 1,200 acres provide ample space to test the deterrent system, sometimes by the light of the moon, as seen in this photo.

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# TECHNOLOGY TODAY®



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Address correspondence to the Editor, Communications Department, Southwest Research Institute, P.O. Drawer 28510, San Antonio, Texas 78228-0510, or e-mail **dschmid@swri.org**.
To be placed on the mailing list or to make address changes, call 210.522.2257 or fax 210.522.3547, or visit **update.swri.org**.



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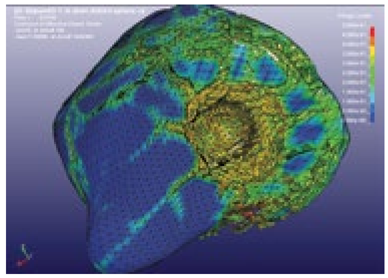

ON THE COVER

SwRI conducted computational analysis of a projectile impacting a simulated asteroid. This crater side view of the impacted pumice target shows strain and radiating cracks. Colors provide a quantitative value of the damage to the target. Red indicates the most damage, while blue indicates undamaged rock.

## CONTENTS



## EMPLOYMENT

Southwest Research Institute is an independent, nonprofit, applied research and development organization. The staff of nearly 2,600 employees provide client services 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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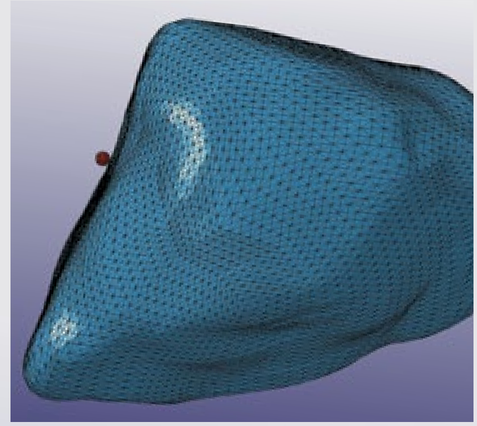
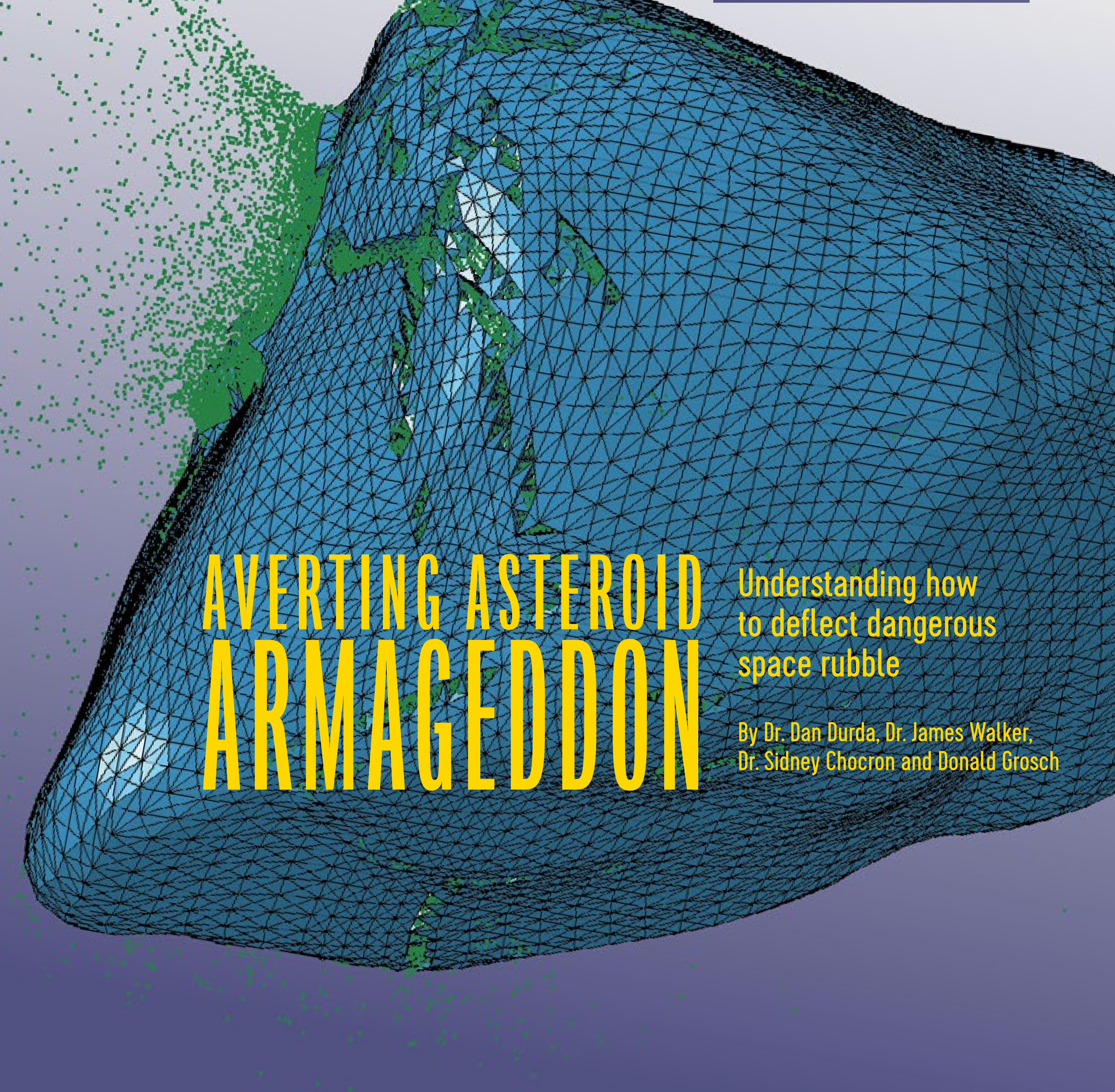




# AVERTING ASTEROID ARMAGEDDON

Understanding how to deflect dangerous space rubble

By Dr. Dan Durda, Dr. James Walker, Dr. Sidney Chocron and Donald Grosch

Our precious home planet orbits within a veritable shooting gallery of rocky and metallic asteroids. Most of these so-called near-Earth asteroids (NEAs) originated in the main asteroid belt between the orbits of Mars and Jupiter. This zone separates the rocky planets in the inner solar system from the gas giants. These asteroids are remnants left over from the formation of the inner planets. These relics provide valuable evidence of the processes at work some 4.5 billion years ago as our own blue world began to take shape. For this reason, asteroids in general, and relatively easy-to-reach NEAs in particular, are beckoning targets for scientific exploration.

But some of these same lumpy little neighbors approach so close to Earth that they could potentially slam into us. The nearly 200 impact craters preserved in landscapes across the world are clear evidence that large impacts have happened in the past, sometimes having globally devastating effects. One of the most infamous impacts happened 65 million years ago, when scientists theorize an asteroid or comet struck the earth and caused the extinction of the dinosaurs.

**DETAIL**

In the time of the dinosaurs, an impactor less than 10 miles in diameter hit the Earth, forming the Chicxulub crater buried beneath the Yucatan Peninsula in Mexico. Scientists theorize that the event caused worldwide climate disruptions resulting in a mass extinction of 75 percent of the plant and animal species on Earth, including all non-avian dinosaurs.

Scientists have detected nearly 19,000 NEAs to date, including comets, out of a population thought to number in the millions. The good news is NASA has identified and tracked 95 percent of the potential civilization-enders — those more than half a mile in size — and none are an impending threat to the Earth. But what about the smaller, more prevalent NEAs that are considered city killers?

### DODGING A BULLET, SORT OF

Asteroid impacts of that size are unique in the range of natural disasters in that they potentially can be prevented. Unlike the dinosaurs, humans have knowledge of the threat and the technology to deflect the path of a small NEA, turning an impending impact into a harmless near miss. Only a small change in a threatening asteroid's orbit is needed to swing it away from Earth, as long as it happens in sufficient time before the predicted impact. Southwest Research Institute space scientists have combined forces with SwRI ballistics engineers to better understand how to accomplish that.

One of the more technically practical methods of deflecting a potentially hazardous NEA is by kinetic impact. A spacecraft or other projectile aimed at the object could slam into it, changing its momentum enough to cause the minor orbital change required to avert impending disaster.

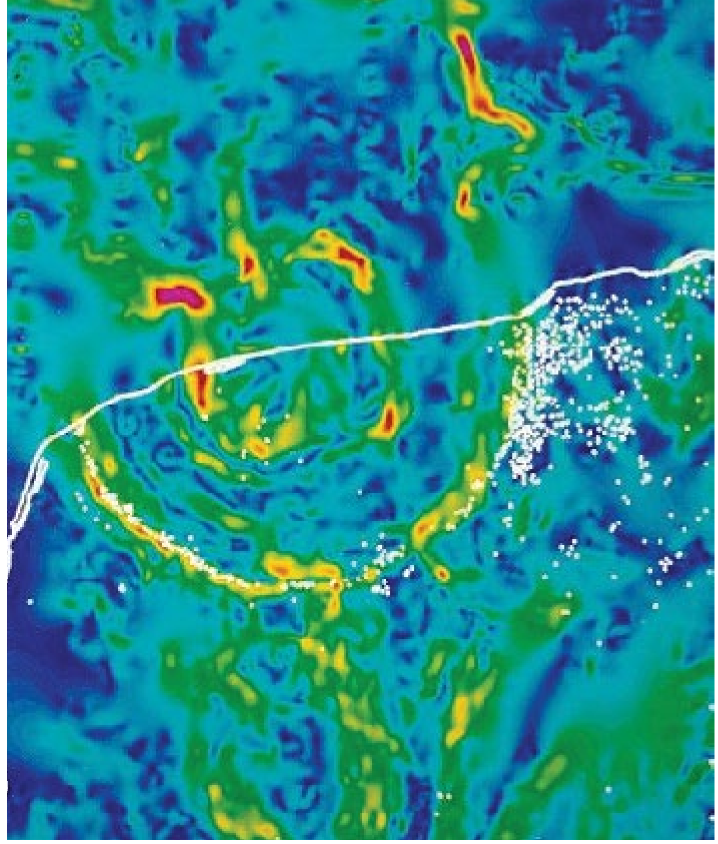


IMAGE COURTESY USGS

A gravity anomaly data map shows the concentric features of the Chicxulub impact crater, associated with the dinosaur extinction event around 65 million years ago. The Mexican coastline is shown as a white line. White dots represent sinkholes tracing the boundary of the underlying crater thought to have been caused by an asteroid roughly the size of Manhattan.

Changing the momentum of an asteroid this way offers a veritable one-two punch: the direct momentum transfer of the impacting projectile, pushing it forward, and the asteroid's recoil from the crater ejecta, or debris erupting from the impact crater. The ejecta transfers momentum, propelling the target away in an "action-reaction" fashion, much like a rocket launches when high-speed gas erupts from the rear of the vehicle.

Knowing just how much momentum change is needed to change an NEA's path adequately is a function of its size, composition and structure. Gathering this information about representatives of the known population of potentially hazardous objects is crucial.

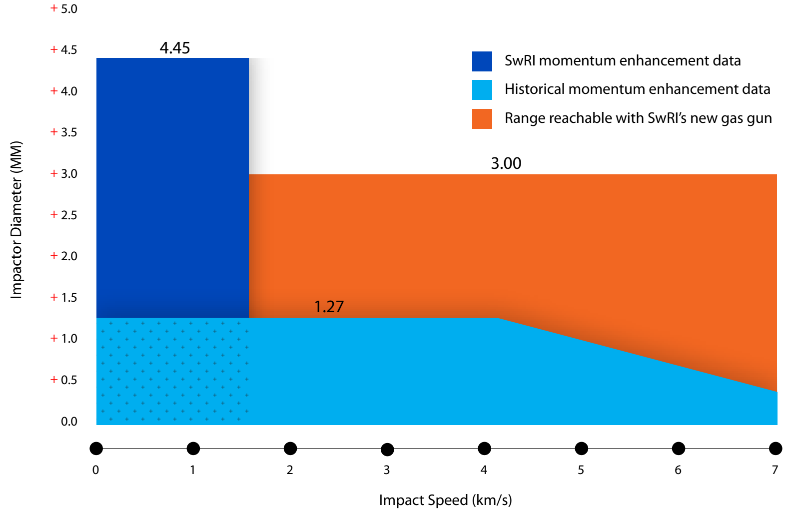
### RELIC RECONNAISSANCE

Most asteroids are irregularly shaped, with only a handful of the largest having enough gravity to pull them into spherical shapes. The majority of asteroids from the outer reaches of the Asteroid Belt are classified as C-type. Made of carbon with other rocks and metals, these dark objects are thought to be fragments of collisions between asteroids. Closer to the Sun, most asteroids are reddish S-types, principally made of silicate compound rock. Some rare asteroids are mostly metallic.

Many asteroids are solid, while others are more like piles of rubble left over from collisions and held together by the force of

(Left top) For computational analyses, engineers scanned a large pumice rock to obtain mesh and geometry measurements prior to impact testing. The aluminum projectile in red had an initial velocity of 2 km/s. (Left bottom) Computational models at 9 milliseconds after impact show particles ejected in the direction opposite the impact, creating enhanced momentum effects. Large cracks also appeared in the rock.

To better understand how to deflect incoming asteroids with kinetic impactors, the team will use SwRI's new large two-stage light-gas gun featuring a 38-mm-diameter launch tube with the ability to achieve velocities close to 16,000 miles per hour. This hypervelocity launcher expands test parameters to help the team understand how impact ejecta change the momentum of targets.




Currently, SwRI has momentum enhancement data for sizes and speeds provided by our 50-mm powder gun and the AVGR light-gas gun experiments, which fall in the lower blue region. The new large hypervelocity gas gun will expand the understanding of impact ejecta effects on momentum change.

their gravity. Some are binaries, where two similar-sized asteroids orbit around each other as they collectively circle the Sun.

To design and plan mitigation strategies using the kinetic impact method, scientists need to perform experimental laboratory studies to represent the various asteroid compositions and configurations. Then, experiments need to be scaled-up to represent actual real-world applications based on analytical relationships, experimental studies and numerical models.

Current research suggests that momentum added by the crater ejecta can exceed that from direct impactor momentum transfer by a factor of 10 or more for some types of targets. How this varies with target size and composition is uncertain.

## HITTING A BULL'S-EYE

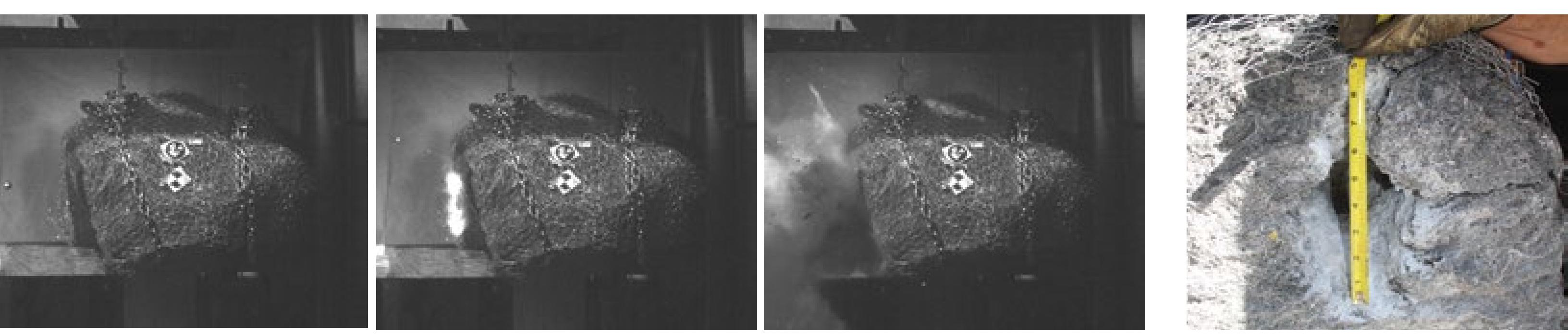
Borrowing a page from 1998's top-grossing film Armageddon, NASA's Double Asteroid Redirection Test (DART) mission, scheduled to launch in 2020/21, offers a more realistic solution to an asteroid aimed at Earth. DART is the first full-scale planetary defense-driven test to understand how to prevent an asteroid Armageddon using a kinetic impact. The binary NEA Didymos is the target for DART. While Didymos' primary body is approximately half a mile across, its partner is a tiny moon less than a tenth of a mile wide.

**DETAIL**

Ballistics is the science dealing with the launch, flight, behavior and effects of projectiles, such as bullets.

The Didymos binary is a handy test-bed; DART is designed to slam into its "moonlet," nudging its orbit around its primary, while not changing Didymos' orbit around the Sun. That way, scientists can study the effects of an impact with minimal risk to Earth. When the DART spacecraft crashes into the moonlet, scientists will use ground- and space-based optical and radar observations to assess how "Didymoon's" orbit changes in respect to its primary body.

SwRI scientists and engineers are playing a lead role in efforts aimed at better understanding the ejecta momentum enhancement factor (often designated "β") to help predict the outcome of the DART impact. In a separate NASA-funded project, SwRI's team has made important progress in scaling laboratory impact experiments. Using data from centimeter- and decimeter-scale target



The SwRI Ballistics and Explosives Range experiments used this meter-scale pumice target to understand how the impact ejecta affect momentum change during kinetic impact with an asteroid of a similar composition. This experiment corresponds to the simulation on the cover.

laboratory experiments and meter-scale outdoor range experiments, SwRI scientists can get a better idea of how β actually scales.

For these experiments, engineers fire a projectile of known mass into a target of known mass suspended in a pendulum test fixture to measure the recoil from the impact. Historically, ballistic pendulums have been used to measure the speed of bullets by measuring the magnitude of the target's recoil and applying the conservation of momentum principle — for an inelastic collision, the momentum in must equal the momentum out. But in SwRI's experiments, the speed or momentum of the impacting projectile is known — it is a controlled input. These experiments use the recoil momentum of targets to measure the momentum enhancement factor β associated with the impact ejecta.

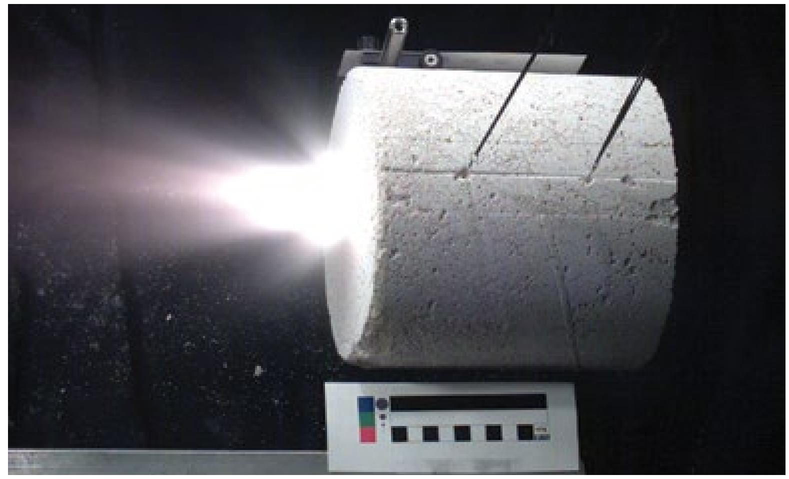
**DETAIL**

In ballistics, caliber is the approximate internal diameter of a gun barrel or the diameter of the projectile it shoots, historically measured in inches. For example, a .45-caliber firearm has a 0.45-inch barrel diameter, slightly less than half an inch.

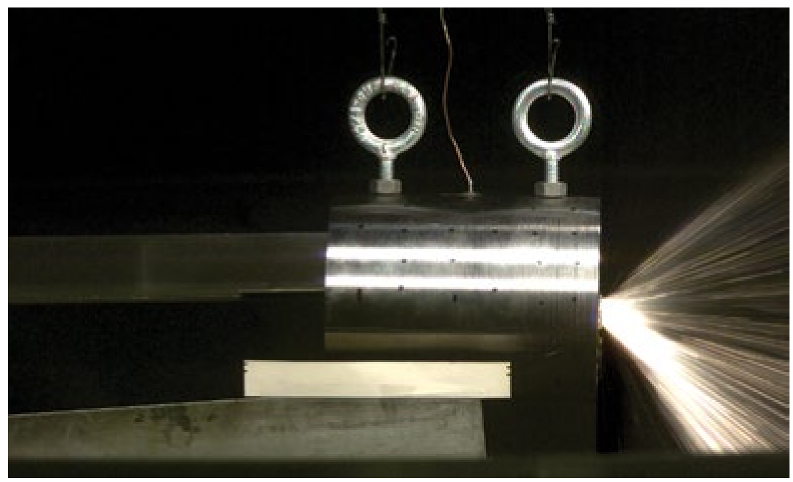
The team has used a 50 mm cannon at the SwRI Ballistics and Explosives Range, supplemented by smaller scale, higher energy experiments using the NASA Ames Vertical Gun Range (AVGR) to cover the full range of experiment parameters. SwRI's 50 mm gun fires up to a 260-gram, 4.45 cm aluminum sphere about the size of a golf ball at about 2 kilometers per second. AVGR's two-stage light gas gun is capable of shooting quarter-inch BBs at speeds of about 6 km/s, replicating the actual speed of the DART spacecraft as it crashes into Didymos' moonlet. To extend the parameters, SwRI recently commissioned a 38 mm two-stage light-gas gun, which will be able to launch 39-gram aluminum spheres about the size of a 50-cent piece at speeds up to 7 km/s, which is over 15,000 miles per hour. The capability to launch larger projectiles is very important because with asteroid kinetic impacts, size matters. The scaling of momentum enhancement is nonlinear. For example, doubling the size of the impactor often will more than double the impact's resulting momentum enhancement.

Ideally, impact experiments would use targets made from actual asteroid material. But large meteorite samples are too rare and valuable, so targets are typically asteroid analogs. These stand-ins include cylinders of natural rock such as granite, pumice and sandstone as well as faux asteroids made of concrete and a porous mixture of plaster and sand. Experiments used iron-nickel alloys that mimic the rare metallic asteroids. Related AVGR research conducted ballistic tests with small meteorite specimens. Those data provide important context, helping link larger-scale impacts to analog materials with calculations and simulations for impacts on asteroids such as the planned DART impact.

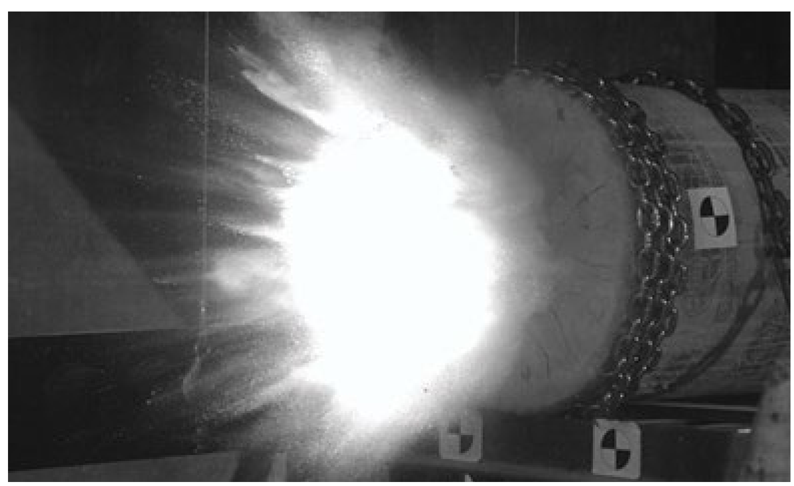
The team is still analyzing the data, but some important results have emerged that not only support previous notions about how β might scale with target size and impact speed but also raise new



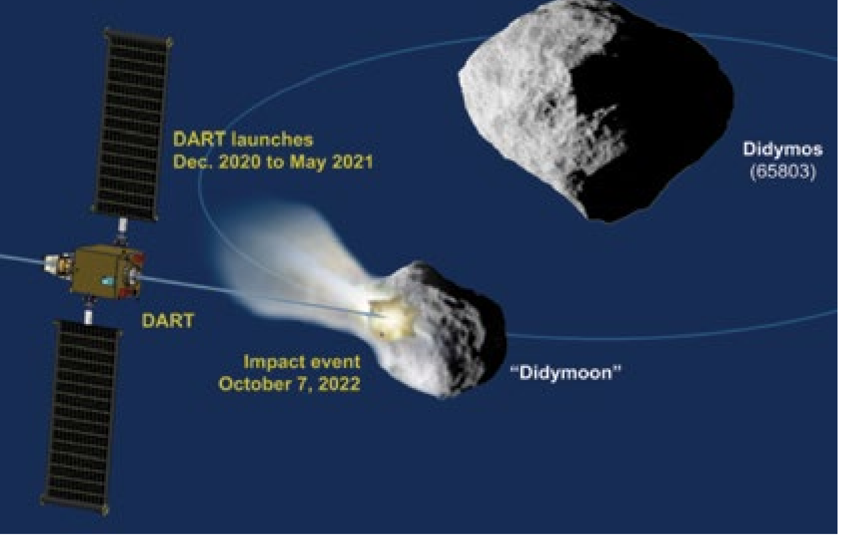
Momentum enhancement impact experiments conducted under the NASA-funded project show examples covering a range of material types and target scales, including AVGR experiments with decimeter-scale plaster-sand asteroid stand-ins.



SwRI conducted AVGR experiments to simulate impacts with rare metallic asteroids using iron-nickel cylinders.



Meter-scale experiments with granite and concrete targets assessed momentum change with harder target materials.




Schematic of the DART mission shows the impact on the moonlet of asteroid (65803) Didymos. Post-impact observations from Earth-based optical telescopes and planetary radar would, in turn, measure the change in the moonlet's orbit about the parent body.

questions that beg for follow-up investigation. SwRI data clearly show that the momentum enhancement increases with impact speed, a result that agrees well with expectations from analytical predictions and other research. Somewhat surprisingly, however, size scaling appears to depend heavily on composition. Impacts into materials like granite or concrete scale differently than those into porous plaster-sand and pumice. The size of these latter targets did not affect the push provided by the ejecta as much.

The SwRI team thinks the difference lies in the inherent structures of the materials. For example, the larger the chunk of granite, the larger the flaws traversing its crystalline structure. Consider a large piece of chalk, which snaps easily under pressure due to the length of its structural flaws. However, a nub of chalk is much more difficult to break apart by hand. In contrast, pumice is characterized by similar-sized voids distributed throughout the rock, regardless of the sample size. So if the theory holds, a heftier size does not necessarily offer king-sized flaws that cause more substantial shifts associated with impact ejecta; the object's composition is a key factor to consider.

Several questions naturally arose from these results. What is the fundamental difference between the internal structure of plaster-sand and pumice targets, and those of granite, concrete and aluminum? How do impact data relate to data from observed meteor fireballs that suggest low-strength meteorites? What are the implications for the strength and size scaling of $\beta$ for small asteroids? Exploring answers to these questions and others raised in light of planning activities in support of the DART mission will be the focus of continuing research.

The answers are critical to protecting the Earth from a potentially devastating asteroid impact.

*Questions about this article? Contact Durda at 303.541.9084 or daniel.durda@swri.org, or Walker at 210.522.2051 or james.walker@swri.org.*

Acknowledgement: EPIC hydrocode computations were performed with the assistance of SwRI Staff Engineer Steve Beissel.

IMAGE COURTESY NASA

ABOUT THE AUTHORS

Above, Dr. Dan Durda, a planetary scientist at SwRI's branch in Boulder, Colorado, specializes in impact studies, hypervelocity experiments and asteroid evolution and exploration. Here he's pointing to a gray layer in the rock that marks the boundary between the Cretaceous period, dominated by dinosaurs, and the Paleogene period, when dinosaurs had disappeared from the face of the Earth. The Cretaceous-Paleogene boundary, found in sedimentary rock around the world, contains iridium, an uncommon element associated with asteroids.

Below, from left, Dr. James Walker, director of SwRI's Engineering Dynamics Department, is internationally known for his research in impact physics, particularly military armor designs and hypervelocity impacts. Donald Grosch manages SwRI's on- and off-site ballistics and explosive ranges, overseeing impact evaluations associated with armor, shaped charges and hypervelocity impact studies. Dr. Sidney Chocron, manager of SwRI's Computational Mechanics Section, specializes in material models for computer simulations. He has served as the president of the International Ballistics Society since 2017.

# SWRI-UTSA CONNECT THROUGH RESEARCH

SwRI and The University of Texas at San Antonio (UTSA) announced two new Connecting through Research Partnerships (Connect) projects, each receiving $125,000 in funding. One project will research using a new class of DNA-based tracers to map groundwater resources. The other will investigate an implant designed to deliver a controlled dose of medicines.

"The Connect projects selected this year deal with human health and critical resources," said SwRI Executive Vice President and COO Walt Downing. "UTSA faculty and graduate students working together with SwRI scientists and engineers will develop innovative technologies to improve disease therapies and to protect water resources."

The Connect program enhances scientific collaboration between SwRI and UTSA and increases their research funding base. Since 2010, the joint SwRI-UTSA Connect Program has funded 15 projects.

## DETECTING CONTAMINATION SOURCES WITH DNA

One SwRI-UTSA team is developing new DNA-based tracers to map the flow path of the Edwards Aquifer. The tracers, made of environmentally safe capsules that store a synthetic double-stranded DNA, will help detect the sources of aquifer contamination.

"Because DNA is made of the four basic molecules that can be combined in any random order, the DNA-based tracer system allows for the fabrication of thousands of unique tracers," said Dr. Vikram Kapoor of UTSA's College of Engineering.

The Edwards Aquifer is the primary water source for a vast number of people living in Central and South Texas. As a naturally occurring water resource, it's vulnerable to contamination from storm water runoff, leaking septic tanks and municipal waste. When contamination occurs, it's vital to detect the source quickly, which can be challenging.

"It's very difficult to discern flow paths in the Edwards Aquifer," said Dr. Ronald Green of SwRI's Space Science and Engineering Division. "The aquifer is made up of limestone, which has partially dissolved over time, creating a honeycomb structure that makes it impossible to visually identify the water's path."

The DNA tracers will make this task easier. They will be released at different points in the aquifer, and water samples will be collected and examined. The team will note which tracer and unique DNA have appeared at each sample location to determine their path through the aquifer. The SwRI-UTSA team will also use the information to create a robust database to calibrate surface water and groundwater modeling and to support other hydrogeological studies.

## 3D THERAPY

Patients with chronic illnesses like cancer, AIDS and arthritis could one day get personalized doses of medicine through a 3D-printed device implanted in their bodies. SwRI and UTSA are collaborating on an implant designed to deliver a controlled dose of medicine directly to a treatment site, such as a cancerous tumor.

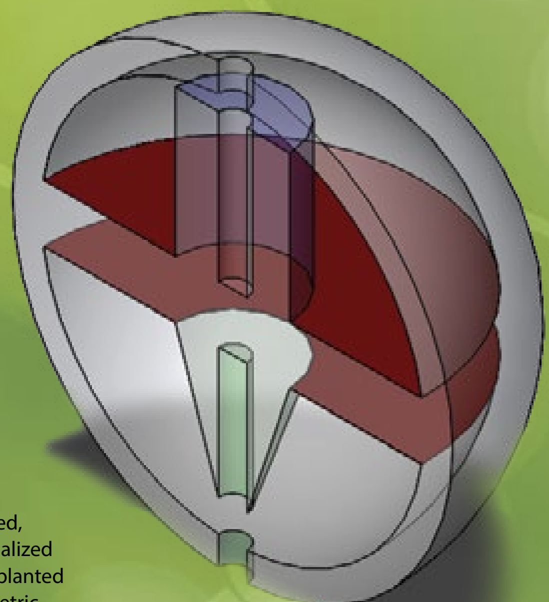
"The implant addresses a specific patient's illness in addition to their medical history and other health issues," said Albert Zwiener of SwRI's Chemistry and Chemical Engineering Division. "We inject this noninvasive device into the body to deliver medicine over a significant period of time."

The implant is engineered to trigger localized immunotherapy, enlisting the body to attack cancers. The SwRI-UTSA team believes that the device's localized treatment capabilities can trigger the body to destroy invasive cancer.

"In immunotherapy, most strategies employ systemic circulation through an IV line, much like chemotherapy. This can cause issues with immune reactions far away from the intended target," said Dr. Lyle Hood of UTSA's College of Engineering. "We hope that by delivering locally, we can keep acute effects constrained to the diseased region."

The team will use a specialized 3D printer that can output biodegradable materials. This makes implant removal unnecessary, as it will simply dissolve inside the body when the treatment is complete.

While the implant is ideal for cancer treatment, it's designed to be drug agnostic, meaning that it can work with any type of drug and could have a significant impact on a wide array of diseases and ailments.



SwRI and UTSA are collaborating to create the 3D printed, biodegradable device illustrated here to allow a personalized medicine approach to treating a variety of illnesses. Implanted for localized delivery, the device uses specialized geometric shapes to control drug release and dissolves after treatment.

# STEREO Reveals Solar Corona in Hi-Fi

by Dr. Craig DeForest

Just as it can be hard to pick out a single conversation in a noisy room, it can be difficult to isolate and refine a particular light signal in a light-saturated environment. Scientists wanting a clear image of the part of the Sun's atmosphere known as the corona find it particularly challenging, because the Sun itself is so incredibly bright. A coronagraph, a telescope that masks the solar disk, solves part of the problem. However, ambient light from stars and background noise from the instrument itself have resulted in fuzzy imagery. Until now.

Using advanced algorithms and data-processing techniques, a team of scientists discovered never-before-detected, fine-grained structures in the outer corona. The corona is the source of the solar wind, a stream of charged particles that flow away from the Sun in all directions. Near the Earth, the solar wind is turbulent and gusty. But scientists have wondered how it gets that way. Does it leave the Sun smooth and become turbulent as it crosses the solar system? Or are the gusts telling us something about the Sun itself?

Answering this question requires observing the outer corona in extreme detail. If the Sun itself causes the turbulence in the solar wind, then it should be apparent right from the beginning of the wind's journey. Previous images of the corona showed the region as a smooth, laminar structure. As it turns out, that apparent smoothness was due to a limitation in image resolution.

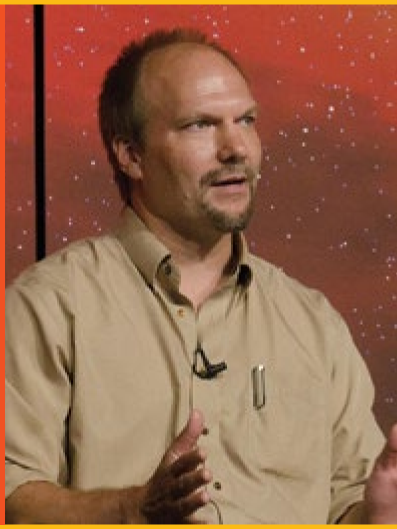
## STEREO ANALYSIS

To understand the corona, the Southwest Research Institute-led team started with coronagraph images from NASA's Solar and Terrestrial Relations Observatory (STEREO) spacecraft. The STEREO mission consists of two identical spacecraft placed in two different orbits around the Sun. Two white-light coronagraphs, COR1 and COR2, are on board each spacecraft, to image the solar corona. In April 2014, STEREO-A would pass behind the Sun, and scientists wanted to grab some interesting data before communications went quiet.

During a special three-day data collection campaign, STEREO-A's COR2 coronagraph took longer and more frequent exposures of the corona than usual. These long exposures allowed more time for light from faint sources to strike the instrument's detector, collecting details it would otherwise miss. However, to make full use of the instrument's optical resolution, the scientists needed still-deeper exposures than the instrument could support. With COR2 already in deep space aboard STEREO-A, the options were limited. Because they couldn't tinker with the instrument itself, the

ABOUT THE AUTHOR

Dr. Craig DeForest, a senior program manager in heliophysics, specializes in solar wind studies and matter-magnetic field interactions in the solar atmosphere. His experience includes instrument design and construction, observation planning and execution, data analysis, software development and theoretical studies. DeForest is an expert in signal processing and extraction, particularly image processing.



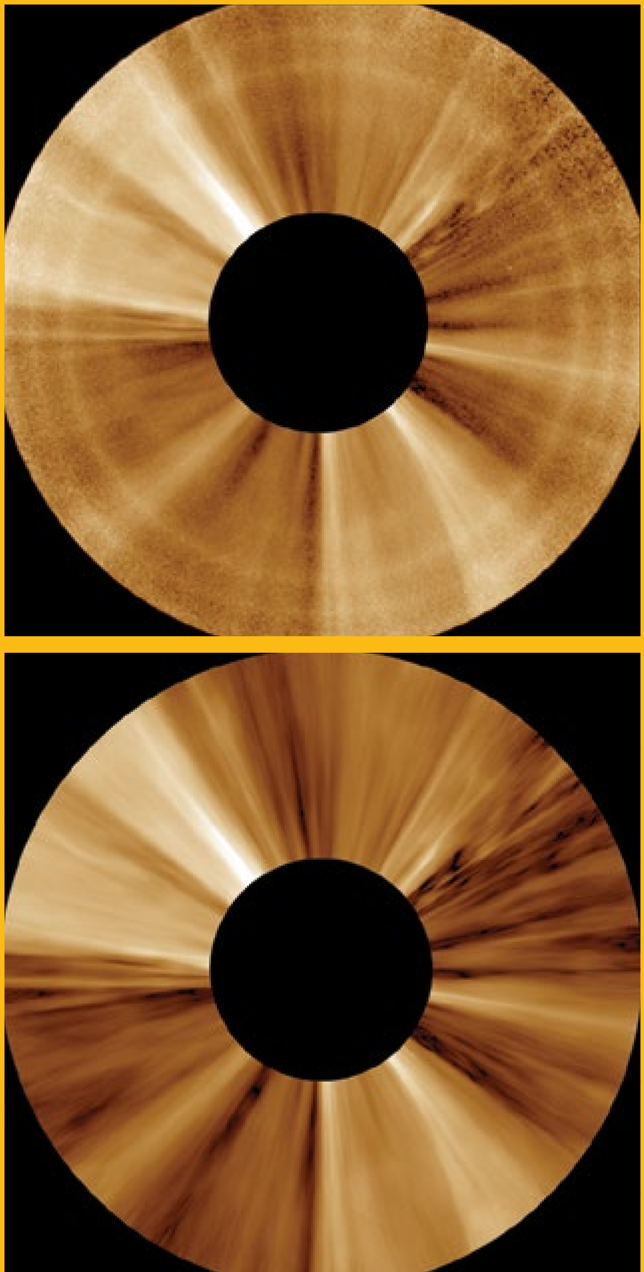
# Advanced processing exposes previously unseen structure

scientists took a software approach, squeezing out the highest quality data possible by improving the data's signal-to-noise ratio after the fact.

### SEPARATING SIGNALS FROM NOISE

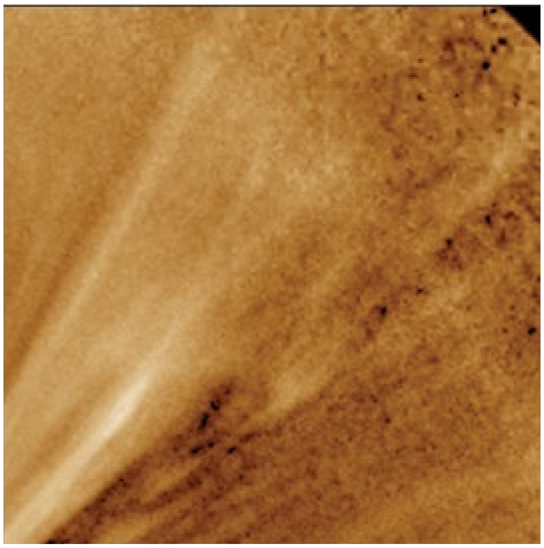
The signal-to-noise ratio is an important concept in all scientific disciplines. It measures how well you can distinguish the thing you want to measure — the signal — from the things you don't — the noise. While the Sun is quite bright, the corona is over a million times fainter — and it is seen against a bright background of dust and stars that must be removed digitally. In practice, coronal images have been limited by noise from this background, the space environment, and the intrinsic quantum noise that comes from counting individual electrons in each pixel of the camera. While COR2's coronagraphs are optically capable of imaging the corona in great detail, in practice the noise limits the actual useful resolution of the images. Identifying and separating out that noise while boosting the signal-to-noise ratio has revealed the outer corona in unprecedented detail.

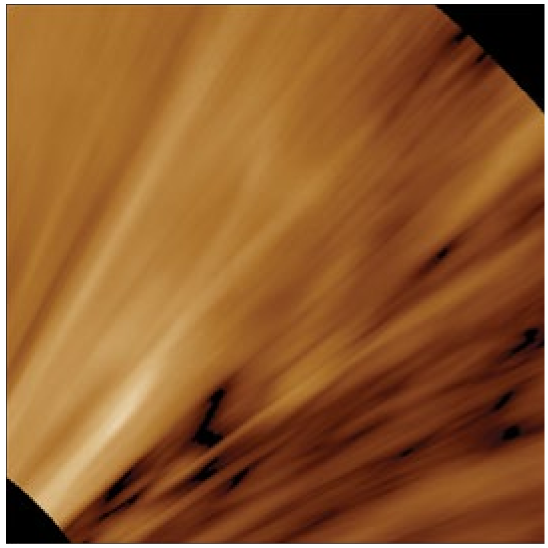
Gathering longer-exposure images was the first step in improving the signal-to-noise ratio. Longer exposures allowed more light into the detector and reduced the noise level — the team estimates noise reduction by a factor of 2.4 for each image, and a factor of 10 when combining them over a 20-minute period. The remaining steps used sophisticated algorithms designed to extract the true corona from the noisy data. They filtered out light from stars creating bright spots in the image that are not part of the corona. They corrected for millisecond differences in how long the camera's shutter was open. They removed the baseline brightness from the images and normalized it so brighter regions wouldn't wash out dimmer ones. But the most challenging obstacle was inherent to the



Conventional images of the Sun's outer corona (above right) lack detail. But the corona is not laminar and smooth as previously thought. Newly applied noise-reduction techniques reveal a surprisingly dynamic and structured outer corona (bottom right).

IMAGES COURTESY NASA/SwRI/STEREO



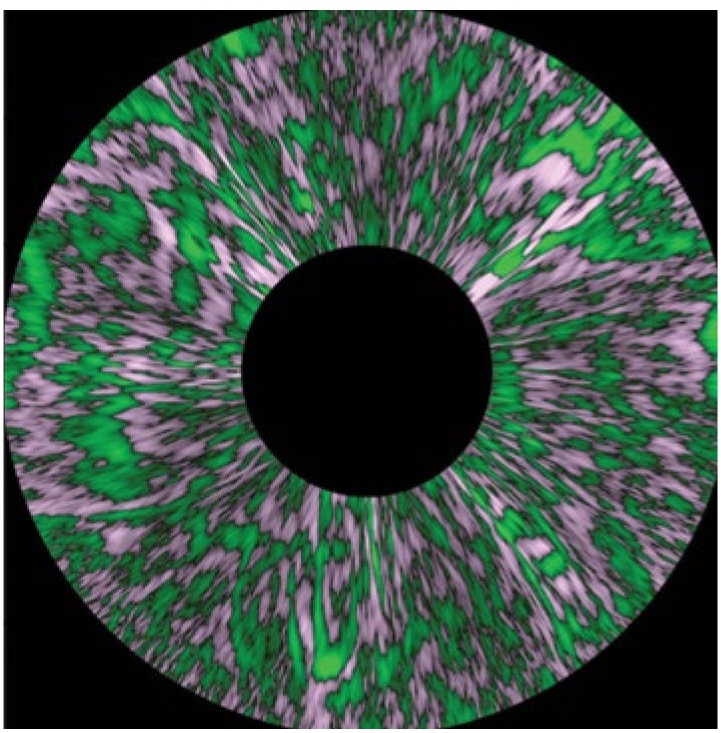


An SwRI-led team developed novel astrophysical processing techniques and applied them to extra-long exposures of the solar corona collected by NASA's STEREO-A spacecraft (far left) to bring this hard-to-image region into sharp focus (near left).

corona itself: the motion blur associated with the supersonic solar wind. To overcome this issue, the team borrowed a technique from other scientific disciplines to create an algorithm to smooth the data over time.

## DATA DOUBLE TAKE

If you've ever done a "double take," you are familiar with how the scientists performed smoothing over time. A double take — taking a second glance to verify your first one — is just a low-tech way of combining two pictures or measurements taken at different times into one higher confidence measurement. Scientists turned this smoothing across time into an algorithm. The principle is simple: take two (or more) images, overlap them and average their pixel values together. Random differences between the images are cancelled out, leaving behind only what is consistent.



The SwRI-led team processed solar coronal images to reveal universal gusts, jets and streams (green) emanating from the Sun, offering a possible explanation for the gusty solar wind found around Earth.

But when it comes to the corona, there's a problem: It's a dynamic, persistently moving and changing structure. Solar material is always streaming away from the Sun and becoming the solar wind. Smoothing in time would create motion blur — the same kind of blurring seen in photographs of moving objects. If the goal is to see fine detail, blur is a problem.

To remove the motion blur from the solar wind, the SwRI scientists tried a new approach: While they did their smoothing, they estimated the speed of the solar wind and shifted the images along with it. To understand how this works, think about taking snapshots of the freeway as cars drive past. If you simply overlapped your images, the result would be a big blurry mess — too much has changed between each snapshot. But if you calculated the traffic speed and shifted your images accordingly, suddenly the details of specific cars would become visible. For the sake of comparison, the cars are the fine-scale structures of the corona, and the freeway traffic is the solar wind.

Of course, first you need to determine how fast things are moving. To figure out exactly how much to shift the images before averaging, the team scooted the images pixel-by-pixel, correlating them with one another to compute how similar they were. Eventually they found the sweet spot, where the overlapping parts of the images were as similar as possible. The amount of shift corresponded to an average solar wind speed of about 140 miles per second. Shifting each image by that amount, they lined up the images and averaged them together in a moving space-time coordinate system.

Now the team had high-quality images of the corona and a way to tell how much it was changing over time. The most surprising finding wasn't a specific physical coronal structure — it was the presence of the intricate physical structure in and of itself.

Compared with the dynamic, turbulent inner corona, scientists had thought the outer corona was smooth and homogenous. But that smoothness was just an artifact of poor signal-to-noise ratio.

IMAGES COURTESY NASA/SwRI/STEREO

After removing as much noise as possible, the SwRI-led team realized that the corona contains structure all the way down to the optical resolution of the instrument. Like the individual leaves on a tree visible only up close, the scientists unveiled complex physical structure in unprecedented detail. And from that physical detail, three key findings emerged.

**DETAIL**

The theoretical Alfvén surface, named for noted plasma physicist Hannes Alfvén, was thought to be a specific boundary between the outer solar corona and interplanetary space.

### STRUCTURED STREAMERS

One finding involves coronal streamers, bright structures that develop over regions of the Sun with enhanced magnetic activity. Readily observed during solar eclipses, magnetic loops on the Sun's surface are stretched out to pointy tips by the solar wind and can erupt into coronal mass ejections, or CMEs. These large explosions of matter eject solar particles into surrounding space. The team's observations revealed that streamers are far more structured than previously thought. There is no such thing as a single streamer. Rather, they are composed of myriad fine strands that together produce the bright feature.

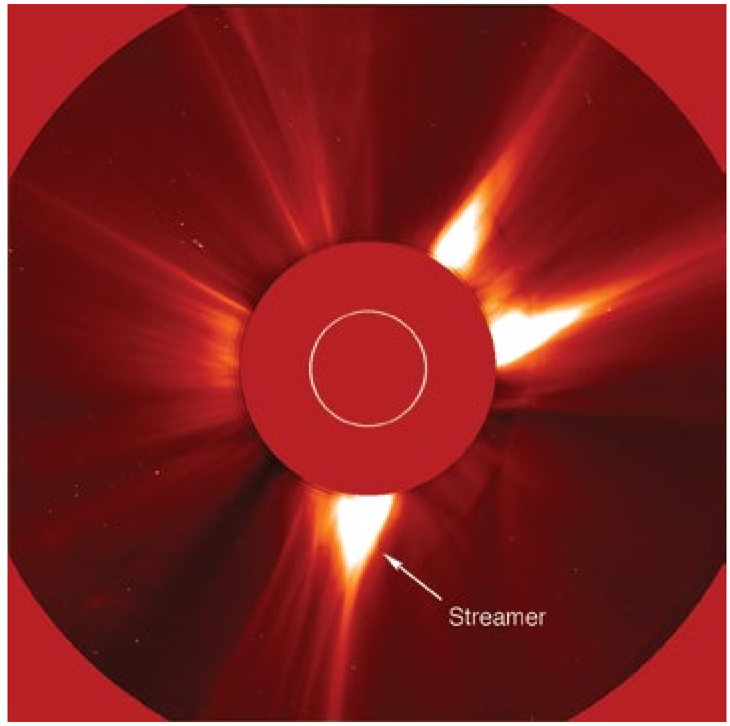
### SURFACE VS. ZONE

The next finding addressed theories about where the corona ends and the solar wind begins. Previously, scientists theorized that this took place at the "Alfvén surface." This theoretical boundary is where, once solar materials pass, they can no longer affect the corona directly. Physicists have long believed this surface, or sheet-like layer, was where the accelerating solar wind smoothly passed a critical speed and separated from the Sun. However, the new images reveal that there isn't a clean Alfvén surface. The observations reveal a patchy framework where some plasma is moving fast enough to stop "backsliding," while nearby streams are not. The streams are close enough, and fine enough, to create a partially disconnected region between the corona and the solar wind. The team now refers to this wide "no-man's land," where the solar wind gradually disconnects from the Sun, as the "Alfvén zone."

### ENIGMA AT 10 SOLAR RADII

And finally, in addition to answering some questions, this new view of coronal structures also raised new questions. The technique used to estimate the speed of the solar wind pinpointed the altitudes, or distances from the Sun's surface, where things changed rapidly. And that's when the team noticed something peculiar. At a distance of 10 solar radii, even back-to-back images stopped matching up well. But they became more similar again at greater distances — meaning that it's not just about getting farther from the Sun. It's as if things suddenly change once they hit 10 solar radii and then realign again at a distance. This suggests some interesting, unexpected physics at play.

IMAGE COURTESY NASA/SOHO




These coronal streamers, observed by the Solar and Heliospheric Observatory (SOHO) spacecraft, are actually composed of many individual fine strands.

### WHAT'S NEXT?

The findings made headway in a long-standing debate over the source of the solar wind's complexity. While the observations don't settle the question, the research identified a missing link in the Sun-to-solar-wind chain. Knowing that the solar wind is variable as it hits the Earth's magnetosphere, scientists have wondered if it is possible that the variability could be traced back to the Sun. It turns out the answer could be yes. The new images allowed the team to explore the connectivity through the corona and compare how tangled the magnetic fields get in the corona versus the solar wind.

These first observations also provide key insight into what NASA's Parker Solar Probe — which launched August 12 — will encounter (see page 12). The spacecraft will be the first-ever mission to gather measurements from within the outer solar corona. Based on these new data, the probe should encounter steep density and magnetic fluctuations, explosive reconnection events and no well-defined Alfvén surface.

Combining these new imaging techniques with Parker Solar Probe's *in situ* measurements could revolutionize our understanding of the Sun, our closest star.

*Questions about this article? Contact DeForest at 303.546.6020 or craig.deforest@swri.org.*

The author acknowledges the contributions of Miles Hatfield from NASA's Goddard Space Flight Center to this feature.

# PARKER SOLAR PROBE

NASA's Parker Solar Probe (PSP) launched Aug. 12 on a journey into the Sun's atmosphere, or corona, carrying hardware SwRI helped develop. Scientists will probe the enigmatic features of the Sun to answer many questions, including how to protect space travelers and technology from the radiation associated with solar events.

"Our main goal is to determine the acceleration mechanisms that create and transport dangerous high-energy particles from the solar atmosphere into the solar system," said Dr. Mihir Desai, a mission co-investigator managing the Integrated Science Investigation of the Sun (IS⊙IS) instrument suite. IS⊙IS consists of two instruments, Energetic Particle Instrument-High (EPI-Hi) and Energetic Particle Instrument-Low (EPI-Lo). "Once EPI-Hi and EPI-Lo measure these particles, we will discover how they are related to the solar wind and coronal structures that are observed by the other three instruments on PSP."

PSP will get within 4 million miles of the Sun's surface, facing unprecedented heat and radiation. It will collect new data on solar activity to help scientists understand the mystery of how the solar atmosphere is so much hotter than the surface of the Sun itself. It will also make critical contributions to forecasting major solar events that impact life on Earth. Coronal mass ejections and solar flares peak roughly every 11 years. They release huge quantities of energized matter, magnetic fields and electromagnetic radiation into space.

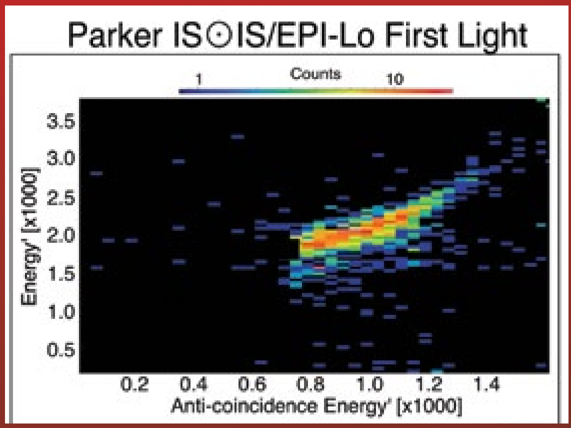
"The sea of materials coming from the Sun is essentially smeared by the time it arrives at Earth," Desai said. "We can't tell how particles are selected and accelerated to higher energies, and we can't tell if interplanetary turbulence and large-scale solar wind structures affect their transport to Earth orbit."

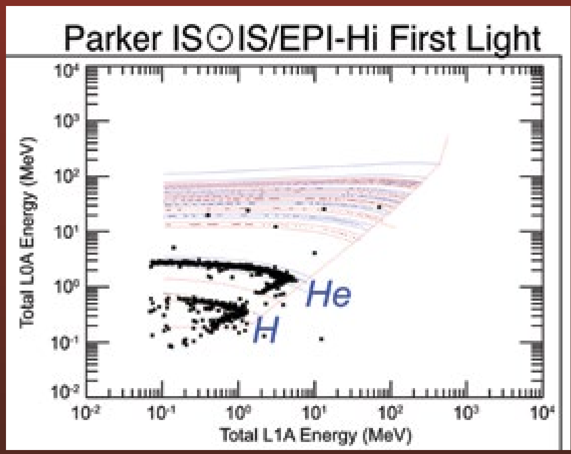
The solar energetic particles (SEPs) present a serious radiation threat to human explorers living and working outside low-Earth orbit and to technological assets such as communications and scientific satellites in space. The mission will make the first-ever direct measurements of both the low-energy source populations as well as the more hazardous, higher-energy particles in the near-Sun environment, where the acceleration takes place.

The IS⊙IS instrument suite has two instruments mounted to the spacecraft on an SwRI-designed and -fabricated bracket. The EPI-Lo instrument measures the lower-energy particles. SwRI collaborated with Caltech in the mechanical fabrication and analyses for the EPI-Hi instrument, which measures the higher-energy materials.

"By measuring the full range of energetic populations and correlating the data with other measurements, we hope to get a clear picture of the origin and acceleration processes," Desai said. "We will also integrate the data into models to better understand the origin of SEPs and other materials. Parker Solar Probe will answer so many questions — and is guaranteed to generate some new ones as well."

SwRI engineers worked with Caltech to build and analyze the PSP EPI-Hi instrument, designed to measure higher energy solar materials.




Just over a month into its mission, Parker Solar Probe returned first-light data from its instruments. EPI-Lo's initial data (middle right) show background cosmic rays, particles energized and rocketed into our solar system from elsewhere in the Milky Way. As PSP gets closer to the Sun, instruments will operate at full power and scientists will see more solar energetic particles accelerated in bursts and streaming from the Sun and corona. EPI-Hi (bottom right) detected both hydrogen and helium particles from its lower-energy telescopes. Once nearer to the Sun, the instrument will also detect heavier elements and particles with much higher energies, especially during solar energetic particle events.

IMAGES COURTESY NASA

# ULTIMA THULE READY FOR ITS JAN. 1 CLOSE-UP

Despite clouds and rain, oppressive heat and humidity, and myriad logistical challenges, a NASA science team in Sénégal saw what they came to see on Aug. 4.

The next flyby target for New Horizons, an ancient Kuiper Belt object nicknamed Ultima Thule, passed in front of a star and momentarily blocked its light. This brief obstruction of starlight, called an occultation, provided information about the object's size, shape and hazard environment.

"Personnel and logistical support came from around the globe. We owe the success of these observations in large part to this amazing, multinational collaboration," said SwRI's Marc Buie, New Horizons occultation expedition leader. "This work is in preparation for our next New Horizons flyby, coming up fast on Jan. 1. We expect to learn much more about Ultima Thule by examining it up close."

For this occultation, as well as a similar one in July 2017, NASA's Hubble Space Telescope probed the region around Ultima for potentially hazardous rings or debris.

"This year the Hubble Telescope was in a much better position and could probe for rings down to around 1,000 miles altitude," said New Horizons team member Josh Kammer, of SwRI. "There were no detectable ring signatures for either event, so using the Hubble data we were able to set important constraints on the presence of any rings or dust that could jeopardize a safe flyby."

Ancient Kuiper Belt objects like Ultima Thule hold clues to the formation of planets and the "third zone" of our solar system where they reside, beyond the giant planets. Ultima Thule, officially known as 2014 MU69, orbits the Sun from more than a billion miles beyond Pluto. The New Year's Day flyby will be the first ever exploration of such a body and the farthest planetary encounter in history.

Follow New Horizons on its voyage at pluto.jhuapl.edu.

Above, occultation expedition leader Dr. Marc Buie (center), flanked by an international team, gets his first look at the stellar occultation of Ultima Thule from Louga, Sénégal. In the background image, the telescope team led by SwRI's Dr. Cathy Olkin waits for the occultation in Senegal, hoping to catch the moment a star winks out, indicating that Ultima Thule has passed in front of it. The New Horizons team uses these "occultations" to learn more about the mysterious object in advance of a historic encounter Jan. 1.

IMAGES COURTESY NASA/JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY/SOUTHWEST RESEARCH INSTITUTE/ANNE J. VERBISCER

## STEP Into Tomorrow's $sCO_2$ Energy Solutions

Construction of a novel **Supercritical Transformational Electric Power (STEP)** pilot plant is underway at Southwest Research Institute to demonstrate supercritical carbon dioxide ($sCO_2$) technology. SwRI is a leader in $sCO_2$ power cycles and has conducted more than 20 U.S. Department of Energy projects, including the development of a patented, highly efficient $sCO_2$ power cycle. SwRI is working with GTI and GE to create the first-of-its-kind STEP plant. The goal is to replace water with $sCO_2$ as the thermal medium in power cycles, to reduce fuel, water, emissions and capital costs.

# STEP

## SUPERCRITICAL TRANSFORMATIONAL ELECTRIC POWER

60%

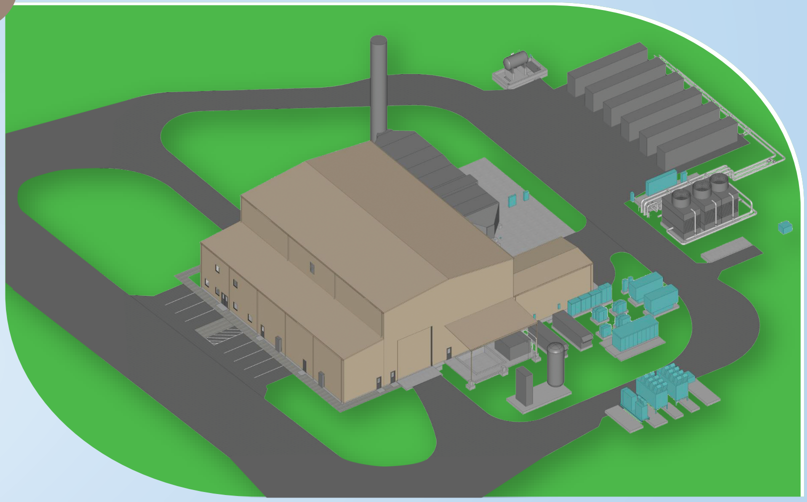
30+

35%

10%

**STEP Efficiency**

- 60% of U.S. power comes from fossil fuels.
- Conventional power plants are often 30+ years old & maxed out at 35% efficiency.
- $sCO_2$ could offer a 10% increase in efficiency.



STEP DEMO

**STEP 10 MW Pilot Plant**

- 15-acre site at SwRI
- \$119M in costs (\$80M DOE)
- 2020 completion

**STEP Goals**

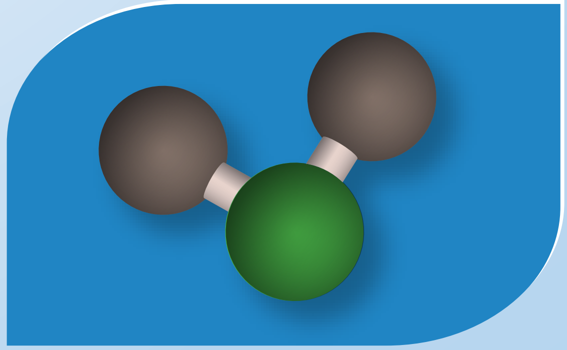
- Refine the $sCO_2$ power cycle
- Demonstrate performance & scalability to 50 MW
- Support variety of technologies

**$sCO_2$ Physical Footprint**

- 1/10 the size of conventional components
- Desk-sized $sCO_2$ turbine could power 10,000 homes
- Shrinks the size of power plants & their capital costs

**$sCO_2$ Carbon Footprint**

- Increased fuel efficiency decreases emissions



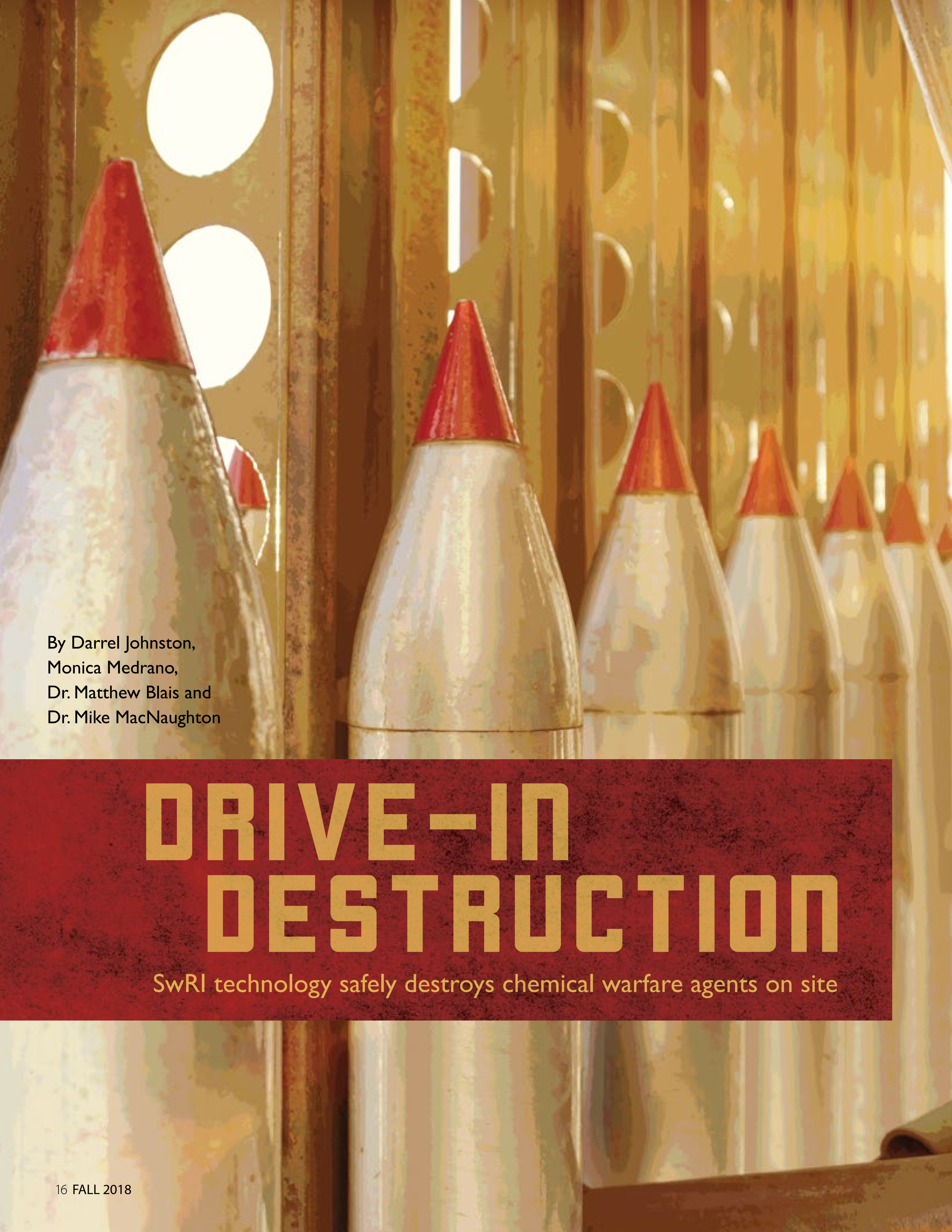
O=C=O

**$sCO_2$ Medium**

- $CO_2$ held above a critical temperature & pressure
- Acts like a gas with the density of a liquid
- Small temperature/pressure changes = large density changes
- Stable, nontoxic & nonflammable

**Texas Power Play**

- Attracts jobs
- Secures R&D funding for 25+ years
- Cements role as a technology leader



By Darrel Johnston,
Monica Medrano,
Dr. Matthew Blais and
Dr. Mike MacNaughton

# DRIVE-IN DESTRUCTION

## SwRI technology safely destroys chemical warfare agents on site

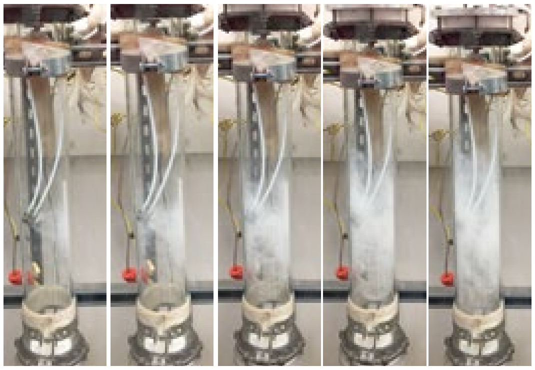
Destroying chemical warfare agents is a complex and inherently risky process. Conventional demilitarization methods require tremendous amounts of water, and significant quantities of hazardous waste are often created as a byproduct. Transporting stockpiles to a destruction site is costly and precarious, adding significant hurdles to the process. How do you solve a problem with so many safety and logistical issues?

In 2015, the Defense Advanced Research Projects Agency (DARPA) initiated the Agnostic Compact Demilitarization of Chemicals (ACDC) program to address this complex dilemma. The program aims to develop portable technology to destroy chemical agents without using water or producing hazardous waste. Current eradication methods include thermal treatment or hydrolysis, processes that require significant amounts of water. In some remote locations, water can be a scarce commodity. DARPA envisioned a method that would incorporate a readily available, ubiquitous resource for the destruction process — soil. Afterward, any soil used in the destruction process must be nontoxic.

Southwest Research Institute responded to a DARPA solicitation and was awarded a contract to explore innovative methods to address the problem. SwRI proposed a novel process: burning chemical warfare agents (CWA) as fuel in an internal combustion engine. Then, resulting engine exhaust can be scrubbed free of acid gases using the alkaline chemistry of soils or, as the development progressed, other chemical techniques.

**DETAIL**

Chemical warfare uses the toxic properties of chemical agents as weapons. Nuclear, biological and chemical weapons make up the "NBC" class of weapons of mass destruction (WMD).



Chemical engineers analyze the process of using ammonia to scrub acid gases produced when a diesel engine destroys CWA through internal combustion.

### CHEMICAL AGENT STOCKPILES

Following World War II, nations around the world stockpiled chemical weapons during the Cold War arms race. In 1969, President Richard Nixon issued an executive order to halt U.S. production of chemical warfare agents, stating: "These steps should go a long way toward outlawing weapons whose use has been repugnant to the conscience of mankind." In 1984, President Ronald Reagan declared the U.S. stockpile of chemical weapons obsolete and called for its destruction. The world soon followed suit. By the 1990s, most nations had signed the international Chemical Weapons Convention treaty, which outlaws chemical weapons and mandates the destruction of existing stores. However, the international community continues to face challenges in this area.

For instance in 2014, the U.S. successfully destroyed Syria's stockpile of chemical weapons and precursors onboard a large ship but produced a huge volume of liquid hazardous waste in the process. In response, DARPA sought a field-deployable system to neutralize dangerous chemicals and chemical weapons without creating hazardous waste byproducts.

**DETAIL**

The initial estimated disposal cost for the U.S. stockpile of chemical weapons was $1.7 billion; however, this cost was greatly underestimated. In 2013, CNBC reported that the U.S. has spent $40 billion to date to destroy its chemical weapons.

ABOUT THE AUTHORS

Left to right: Dr. Michael MacNaughton is vice president of SwRI's Chemistry and Chemical Engineering Division. Dr. Matthew Blais leads the Fire Technology Department. Monica Medrano is a research engineer overseeing a range of chemical and fuel processing techniques, particularly developing pilot plant setups, and Darrel Johnston is a senior program manager with extensive experience managing activities associated with chemical weapons destruction and biological threat reduction.

### COLLABORATIVE INNOVATION

For more than 30 years, SwRI has supported chemical agent disposal, contributing to our mission of using innovative science and technology for the betterment of mankind. SwRI scientists provided chemical agent monitoring and laboratory services to the U.S. Army's first large-scale demilitarization facility, the Johnston Atoll Chemical Agent Demilitarization System (JACADS). We also supported similar activities at Pine Bluff Chemical Demilitarization Facility in Arkansas, the Newport Chemical Disposal Facility in Indiana and the Umatilla Chemical Agent Disposal Facility in Oregon.

For this new venture, DARPA and SwRI's chemistry and chemical engineering staff agreed that no water other than what is created in the destruction process could be used, and soil would be used to neutralize any hazardous byproducts. SwRI staff proposed an

SwRI has been in the chemical demilitarization business for more than 30 years. Our staff provided chemical agent monitoring and laboratory services at the first large-scale demilitarization facility located on Johnston Island in the middle of the Pacific Ocean.

innovative concept — a system that could fit into a shipping container using an engine and locally sourced soils to destroy CWA on site without producing hazardous waste.

To achieve those goals, SwRI brought together a multidisciplinary team of scientists and engineers to brainstorm novel ideas to address the challenges. On Johnston Island, diesel generators powered the island facility, sparking interest in using an engine as the primary chemical destruction mechanism. In particular, engineers proposed using SwRI's patented Dedicated Exhaust Gas Recirculation (D-EGR®) engine. Its design allows more complete combustion and reduced emissions, a great combination for CWA destruction. An SwRI chemical engineer suggested that the alkaline chemistry of most soils could scrub the acid gas exhaust an engine would produce burning CWA as fuel. But there were many challenges to such a novel approach.

**DETAIL**

Johnston Atoll is a ring-shaped coral reef with four islands located in the Pacific Ocean 750 nautical miles southwest of Hawaii. Prior to demilitarization activities, Johnston Island held more than six percent of the U.S. stockpile of chemical weapons. Over a decade of operations, the Johnston Atoll Chemical Agent Disposal System destroyed 412,000 individual chemical munitions, including 2,000 tons of nerve agents.

## SCRUBBING WITH SOIL

DARPA's production schedule was demanding, requiring a prototype demonstration in six months. To meet the challenge, the team focused on two objectives. First, the team needed to design and build a D-EGR engine front end with a soil-filled fluidized bed reactor back end. Second, the team needed to test the soil purifying scheme using an acid gas stream. While the hardware was under development, the soil testing hit "pay dirt." The team demonstrated that local soil, taken right from the SwRI campus and high in limestone content, could efficiently scrub acid from exhaust gases. The project team characterized the capacity, limits and environmental boundaries to optimize soil scrubbing and then tested other types of soil. Meanwhile, the team was integrating the D-EGR engine with a soil-based fluidized bed reactor. This device passes a gas through a granular material at velocities high enough to create a chemical reaction. In this case, high-velocity exhaust gas is pumped into the soil, creating a fluidized environment that reacts with the acids and scrubs them from the exhaust stream.

Just ahead of DARPA's six-month deadline, SwRI demonstrated the D-EGR engine using simulated CWA, delivering the resulting exhaust gases to a fluidized bed reactor for processing. The demonstration proved the concept — the engine burned the CWA simulant, and the exhaust leaving the soil scrubber system was normal engine exhaust, free of acid gases.

For two months after the initial demonstration, SwRI continued to optimize the system. The team introduced a soil-filled packed bed scrubber downstream of the fluidized bed reactor to increase acid gas scrubbing efficiency and capacity. SwRI scaled-up models

SwRI chemical engineers evaluated various processes to scrub acid gas from exhaust emissions produced by an engine burning CWAs as fuel.

Above, SwRI's first mobile destruction system, designed to fit into a shipping container, used an engine and locally sourced soils to destroy CWA on site without producing hazardous waste.

With the latest 'drive-in' design, the system can destroy approximately 10 gallons per hour at a munitions site without transport of agent or hazardous waste.

for the soil-filled exhaust scrubbing system and identified CWA-simulant destruction limits for the D-EGR engine.

At this point in the development process, DARPA requested SwRI build its soil-based solid scrubber (S3) system as a modular back-end system — without the engine front end — for use downstream of a plasma torch system. Because this CWA destruction system had been under development for much longer than SwRI's engine, it was considered at a higher "technology readiness level," nearing the point where it could be tested with actual CWA. In just eight months, SwRI designed, built and tested the soil-based modular solid scrubber system. Staff operated the S3 during independent verification and validation (IV&V) testing of the integrated plasma torch and S3 combination using a CWA simulant. An independent third party oversaw the IV&V testing and considered the system an overwhelming success. S3 scrubbed 99.99997 percent of the acid gases emitted by the plasma torch, exceeding DARPA requirements. This demonstrated the effectiveness of the SwRI system and validated the modular approach of a mix-and-match front end — engine or plasma torch — and back end — a wet scrubber developed for the plasma torch system or SwRI's dry solid scrubber system.

## MOBILITY FOCUS

As the design and development of the technology evolved, the next version planned to use an industrial 16-liter diesel engine front end and a dump truck with soil in the bed serving as the packed-bed scrubber back end. This version was designed to have the capacity to consume 28 gallons of CWA an hour on a continuous basis. This system, if pursued, would have had the capacity to handle volumes similar to the Syrian CWA stockpile, on site, with a logistical footprint of only four vehicles. While this was viewed as impressive and achievable, the various government agencies needing CWA destruction capabilities were seeking smaller-scale tactical units.

To meet these needs, SwRI pivoted and focused on developing a smaller, single-vehicle tactical system. First, the team demonstrated that a small, conventional diesel engine had better throughput and scalability than the D-EGR engine. Then the Institute analyzed alternatives to consider for a smaller, tactical system that runs on CWA on site, and scrubs acid gases. Ultimately, the team determined that mobility demanded more efficient, lightweight scrubbing media than soil.

## GOING TACTICAL

Moving forward, SwRI is designing and building a pickup-sized system that destroys agents using a 4.5-liter diesel engine in a pickup truck at a CWA storage site. An ammonia-based scrubber and particulate capture system will scrub acid gases from the vehicle exhaust stream. Once staff members have evaluated the system with CWA simulant, an independent third party will validate the system with CWA simulant. After successful verification and validation, the system will be shipped to a government facility for testing with actual CWA while the system is remotely operated by SwRI staff.

Following this final IV&V, the system will be ready for field testing and final upgrades for military deployment. If only limited numbers of systems are needed, SwRI may produce them. If many systems are required, then the SwRI team may work with a commercial partner for production. If the small, tactical unit is successful, the project team will revisit developing a system that could handle something on the scale of the 2014 Syrian CWA destruction.

In the end, the U.S. and its international counterparts would like to see all chemical warfare agent stockpiles — large and small — eliminated. SwRI technology could help achieve that goal.

*Questions about this article? Contact Johnston at 210.522.2160 or darrel.johnston@swri.org.*

# BINARY PAIR POINT TO EARLY SOLAR SYSTEM SHAKE-UP

SwRI scientists studied an unusual pair of asteroids and discovered that their existence points to an early planetary rearrangement in our solar system. These bodies, called Patroclus and Menoetius, are targets of NASA's upcoming Lucy mission. They are around 70 miles wide and orbit around each other as they collectively circle the Sun. They are the only known large binary in the population of ancient bodies referred to as the Trojan asteroids. The two swarms of Trojans orbit at roughly the same distance from the Sun as Jupiter, one swarm orbiting ahead of, and the other trailing behind, the gas giant.

"The Trojans were likely captured during a dramatic period of dynamic instability when a skirmish between the solar system's giant planets — Jupiter, Saturn, Uranus and Neptune — occurred," said SwRI Institute Scientist Dr. David Nesvorny. This shake-up pushed Uranus and Neptune outward, where they encountered a large primordial population of small bodies thought to be the source of today's Kuiper Belt objects, which orbit at the edge of the solar system. "Many small bodies of this primordial Kuiper Belt were scattered inward, and a few of those became trapped as Trojan asteroids."

A key issue with this solar system evolution model, however, has been when it took place. In a recently published paper, scientists demonstrate that the very existence of the Patroclus-Menoetius pair indicates that the dynamic instability among the giant planets must have occurred within the first 100 million years of solar system formation.

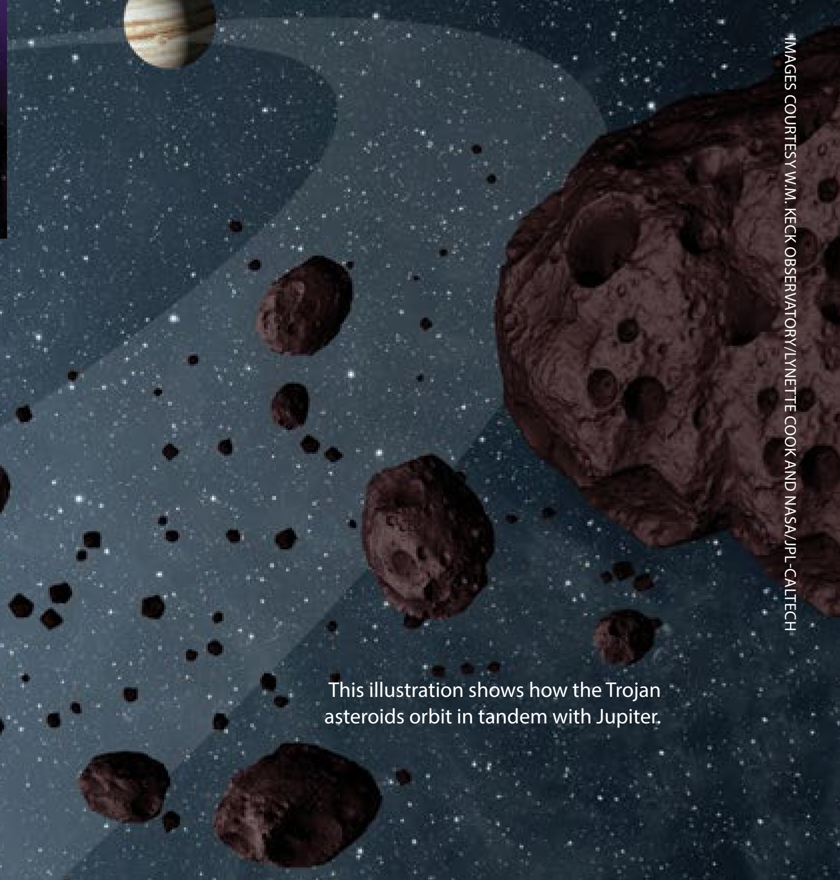
"Observations of today's Kuiper Belt show that binaries like these were quite common in ancient times," said Dr. William Bottke, director of SwRI's Space Studies Department. "Only a few of them now exist within the orbit of Neptune. The question is how to interpret the survivors."

Had the instability been delayed many hundreds of millions of years, as suggested by some solar system evolution models, collisions within the primordial small-body disk would have disrupted these relatively fragile binaries, leaving none to be captured in the Trojan population.

This work underscores the importance of the Trojan asteroids in illuminating the history of our solar system. Much more will be learned about the Patroclus-Menoetius binary when NASA's Lucy mission, led by SwRI scientist and paper coauthor Dr. Hal Levison, surveys the pair in 2033, culminating a 12-year tour of both Trojan swarms.

This research was featured in the paper "Evidence for Very Early Migration of the Solar System Planets from the Patroclus-Menoetius Binary Jupiter Trojan," published in Nature Astronomy. NASA's Solar System Exploration Research Virtual Institute (SSERVI) and Emerging Worlds programs, as well as the Czech Science Foundation, funded this work. Lucy is a Discovery class mission managed by NASA's Goddard Space Flight Center in Greenbelt, Maryland.

SwRI scientists studied the binary asteroid Patroclus-Menoetius, shown above in this artist's concept, to determine that a shake-up of the giant planets likely happened within the first 100 million years of the solar system's history.



This illustration shows how the Trojan asteroids orbit in tandem with Jupiter.

IMAGES COURTESY W.M. KECK OBSERVATORY/LYNETTE COOK AND NASA/JPL-CALTECH

## RESOURCE RECONNAISSANCE

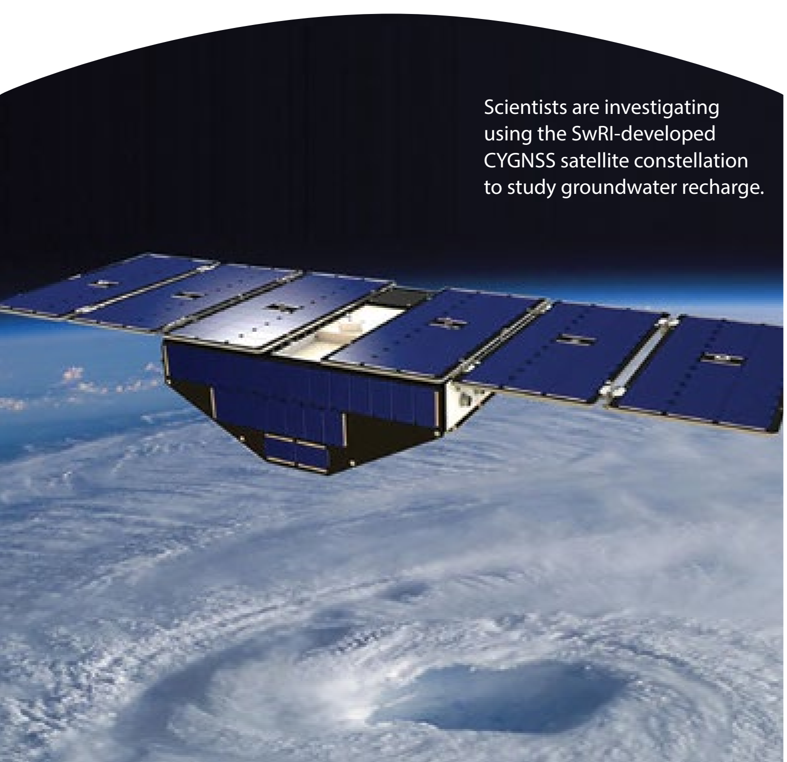
SwRI scientists are investigating using the latest remote-sensing technology to assess groundwater recharge more accurately. Groundwater collects in the cracks and spaces in soil, sand and rock. It supplies drinking water for about half of the U.S. population, including 99 percent of the rural population. Resources are replenished or recharged by precipitation moving slowly through geologic formations called aquifers.

"When managing groundwater resources, particularly in more arid environments, the greatest uncertainty lies in calculating recharge rates," said Dr. Ronald Green, a groundwater hydrologist at SwRI. "Improvements in data acquisition and interpretation will improve recharge estimates. This is particularly important in drier regions where water demand is rapidly outpacing availability."

Measuring recharge is difficult. Scientists have used various surface-based techniques to evaluate, model and infer recharge. Increased availability of remotely sensed data from multiple satellite platforms could allow scientists to estimate recharge more precisely.

"Hilly topography and arid environments pose special challenges and opportunities for remote-sensing applications," said co-investigator Dr. Stuart Stothoff. "Using the Google Earth Engine, we combine precise elevation models, optical data and the Sentinel-1 satellite's two- and three-dimensional images of landscapes."

The SwRI team also integrates data from an existing satellite system, the Soil Moisture Active Passive (SMAP) platform, and the recently deployed Cyclone Global Navigation Satellite System (CYGNSS). The SMAP observatory measures the amount of water in the top 2 inches of soil. While designed to measure ocean winds during hurricanes, the SwRI-built CYGNSS constellation also makes measurements over land. These data might prove complementary to SMAP measurements.



Scientists are investigating using the SwRI-developed CYGNSS satellite constellation to study groundwater recharge.

IMAGE COURTESY UNIVERSITY OF MICHIGAN


## Cobot Coworkers

SwRI has launched a Collaborative Robotics Laboratory featuring collaborative robots or "cobots."

While conventional industrial robots are typically walled off from humans for safety, cobots are different. They work alongside human operators performing manual tasks and heavy lifting. SwRI develops deep-learning algorithms, perception technologies and advanced path planning capabilities that enable cobots to collaborate with humans while performing multiple tasks.

"Cobots, when combined with adaptive perception-rich software, can perform complex tasks safely next to humans," said Paul Evans, director of SwRI's Manufacturing and Robotics Technologies Department. "Demand for SwRI's technical expertise in these areas inspired this capital investment in next-generation robotics."

Engineers use the new robotics lab as a test bed for software development, working in close proximity to smaller cobots, before porting advanced capabilities to larger industrial robots. The SwRI-managed ROS-Industrial Consortium also uses the lab for open-source Robot Operating System (ROS) projects, including a robotic arm that fuses markerless motion capture technology with machine learning to autonomously pick and place objects from human hands.

SwRI's Collaborative Robotics Laboratory will support client projects, internal research, industry workshops, software development and manufacturing.

ROS®
industrial
consortium

## NAVIGATING THE FDA

How does a new drug get Food and Drug Administration (FDA) approval? SwRI hosted a one-day workshop Oct. 8 to address the concepts, strategies and tools needed to successfully submit investigational new drugs (IND) to the FDA.

SwRI's "Small Molecule Drug Development: From Concept to IND" one-day course delved into the chemistry, manufacturing and control (CMC) and nonclinical decisions needed to support IND submission. Proper CMC and decisions during development can critically affect IND approval from the FDA. IND approval is needed for new drugs to start clinical trials and ultimately enter the market.

"The process of bringing a small-molecule drug to market is complex. In addition to presentations based on actual IND experiences and a tour of SwRI's CGMP (Current Good Manufacturing Practices) manufacturing facility, the course offered a real-world group exercise to help participants practice tackling drug development issues," said Varsin Archer, a research scientist in SwRI's Chemistry and Chemical Engineering Division. "Drugs can fail IND submission if the CMC quality and process do not meet standards and regulations."

Participants worked with experienced staff in the pharmaceutical and drug development area and learned about the challenges, decision processes and tools used to ensure smoother IND submissions. The course also covered technical transfer, formulation and analytical development, CGMP manufacturing, safety and costs. Twenty participants attended the workshop, designed for beginner to intermediate professionals.

## $AC^2AT$™ EMISSION TECHNOLOGY INNOVATIONS


SwRI is launching the second phase of the Advanced Combustion Catalyst and Aftertreatment Technologies consortium — $AC^2AT$-II — focusing on engine emissions solutions and innovative catalyst technologies.

SwRI initiated the $AC^2AT$ consortium in 2014 with members representing engine manufacturers and affiliated businesses in the automotive industry. $AC^2AT$ research focused on improving the understanding of catalysts and emission control systems, modeling those systems and characterizing the emissions produced by advanced combustion regimes.

"In the first phase, $AC^2AT$ made considerable advances in understanding how complex emissions control systems affect today's high-performance, high-efficiency gasoline and diesel engines," said Scott Eakle, a principal engineer in SwRI's Diesel Engine and Emissions Research and Development Department. The second phase will continue advances made in the first phase. These include new models developed to understand how the properties of lube oil-derived ash affects aftertreatment performance and to predict deposit formation, growth and composition in aftertreatment systems.

SwRI is a leader in managing vehicle research consortia, which allow members to collaborate to advance the state of the art in gas, diesel and electric vehicles. The $AC^2AT$-II consortium allows companies to share costs, supporting more advanced combustion and novel catalyst research than would be feasible if funded individually. $AC^2AT$-II participants will decide which research projects to investigate and receive royalty-free licensing for all intellectual property the consortium produces.

For more information about the $AC^2AT$-II consortium, contact Eakle at 210.522.5095 or visit consortia.swri.org.

## INGREDIENTS FOR LIFE IN ENCELADUS

IMAGE COURTESY NASA JPL SPACE SCIENCE INSTITUTE

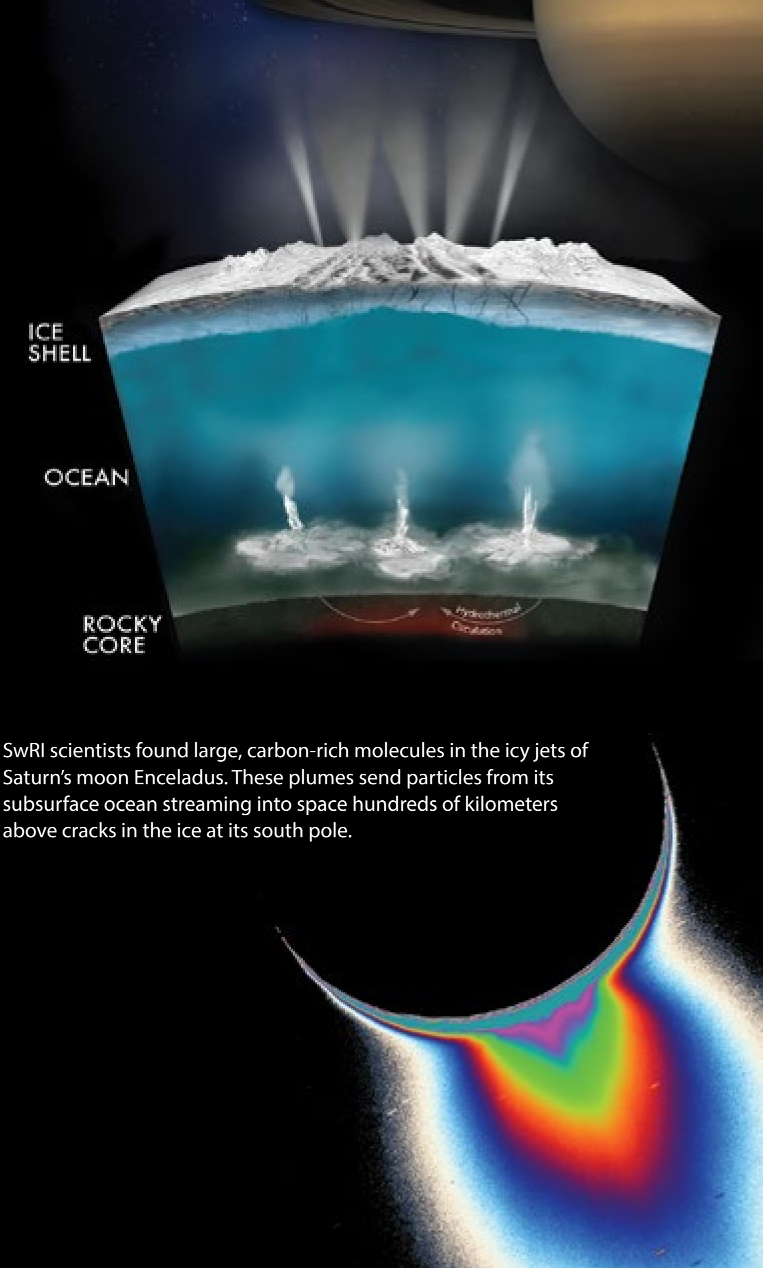
SwRI scientists are part of a team that discovered complex molecules in geysers spewing from Saturn's moon, Enceladus. These large, carbon-rich organic molecules indicate that the moon could have the potential to support life.

"We are, yet again, blown away by Enceladus. We've found organic molecules with masses above 200 atomic mass units. That's over 10 times heavier than methane," said Dr. Christopher Glein, an SwRI space scientist specializing in extraterrestrial chemical oceanography. He is coauthor of a paper in Nature outlining this discovery. "With complex organic molecules emanating from its liquid water ocean, this moon is the only body besides Earth known to simultaneously satisfy all of the basic requirements for life as we know it."

Scientists found the molecules using mass spectrometry data from NASA's Cassini spacecraft, which sampled the plume of material emerging from the subsurface of Enceladus. The Cosmic Dust Analyzer (CDA) and the SwRI-led Ion and Neutral Mass Spectrometer (INMS) made measurements within both the plume and Saturn's E-ring, which is formed by plume ice grains escaping Enceladus' gravity. INMS previously also detected molecular hydrogen in Enceladus' plume.

"Hydrogen provides a source of chemical energy supporting microbes that live in the Earth's oceans near hydrothermal vents," said SwRI's Dr. Hunter Waite, the INMS principal investigator who also coauthored the Nature paper. "Once you have identified a potential food source for microbes, the next question to ask is 'What is the nature of the complex organics in the ocean?'"

The paper, "Macromolecular organic compounds from the depths of Enceladus," was published in the June 28, 2018, issue of Nature.




SwRI scientists found large, carbon-rich molecules in the icy jets of Saturn's moon Enceladus. These plumes send particles from its subsurface ocean streaming into space hundreds of kilometers above cracks in the ice at its south pole.

## UNDERWATER ENDEAVORS

SwRI engineers are continuing our long history of undersea vehicle research and development activities. The Institute is one of 23 organizations recently awarded a contract for the U.S. Navy valued up to nearly $800 million over the next five years.

"SwRI has extensive experience providing innovative services in ocean engineering and subsea research," said Joe Crouch, program director of Marine and Offshore Systems at SwRI. "Our expertise in the construction of marine structures, such as low-cost, high-quality pressure hulls, is particularly beneficial to this Navy program."

The contract is an indefinite delivery, indefinite quantity (IDIQ) award, a contract vehicle that funds work tasks over specified periods of time — five years, in this case. The IDIQ supports the procurement of materials and services used to develop, build, fabricate and support the Navy's unmanned undersea family of vehicles.

SwRI designed and built the pressure hull for the Alvin research submersible, allowing it to reach over 90 percent of the ocean floor. SwRI specializes in the design and construction of pressure hulls and other marine systems.

## CALIBRATION ACCREDITATION

SwRI's particle emissions laboratory is now the only facility fully accredited by the American Association for Laboratory Accreditation (A2LA) for calibrating equipment to ISO/IEC 17025. SwRI is qualified to calibrate devices that measure and quantify particle number and size as small as 10 nanometers in diameter.

"SwRI has pioneered measuring and characterizing fine, ultrafine and nanoparticle emissions," said Dr. Imad Khalek, a leading expert in particle emissions R&D at SwRI. "The industry is deploying particle sensor systems to accurately measure particle mass and number in emissions. This is critical to understanding the pollutants emitted by cars, trucks and airplanes, to name a few sources."

SwRI is now the only organization accredited by A2LA to calibrate devices to the full cadre of national and international particle emissions specifications, using a suite of particle instruments.

Of particular recent interest are health concerns associated with solid particles emitted from combustion sources including automotive and aircraft engines. Particle number (PN) is now regulated in the European Union, China and India, and PN measurements are used in emissions research and engine certification applications worldwide. The instruments needed to perform PN measurement require special calibrations involving particle size and number. SwRI now provides such calibrations for:

- Particle sizers in accordance with ISO 15900
- Particle counters in accordance with ISO 27891
- Particle number measurement systems for automotive applications in compliance with United Nations Economic Commission for Europe UNECE R49 and 83
- Particle number measurement systems for aircraft applications in compliance with the International Civil Aviation Organization and Society of Automotive Engineers SAE AIR6241

"We are now the only laboratory able to perform both ISO-compliant calibration and standardized testing that conforms to standards in the U.S. and abroad," Khalek said. "These accreditations cement our research and innovation leadership in the industry."

SwRI's state-of-the-art particle calibration laboratory includes instruments to measure particle number, surface area, mass, size and morphology. The facility also houses an SwRI-developed universal particle generator that can generate soot, semi-volatile hydrocarbons, sulfate and nitrate for particle research and instrument calibration.

For more information, go to: swri.org/particle-science.

## WAR ON MALARIA

SwRI is developing new technology to lower the cost of artemisinin, the primary drug used to treat malaria. The Institute received a Bill & Melinda Gates Foundation grant of $267,870 to combat the mosquito-borne disease. Worldwide, malaria causes more than 400,000 deaths and 200 million medical visits annually, according to the World Health Organization.

While artemisinin-based combination therapies (ACT) are more than 90 percent effective at treating the disease, the cost of treatment exacts a heavy financial burden in the regions most heavily stricken.

"Malaria remains one of the oldest known diseases to plague humans. We will be working to develop a new chemistry technique to develop artemisinin treatment," said Dr. Shawn Blumberg, a research scientist in SwRI's Chemistry and Chemical Engineering Division. "We think this concept will deliver a viable, lower-cost artemisinin to inexpensively address one of humanity's most deadly infectious diseases."

Currently, artemisinin is extracted from the sweet wormwood plant, which takes around eight months to mature and yields about 15 grams of artemisinin for every kilogram of plant. Previous efforts to lower the cost of artemisinin involved the use of bioengineered yeast to produce artemisinic acid (AA), a synthetic precursor of the drug. This process, however, has yet to replace sweet wormwood as the primary source of the drug. SwRI is developing a novel process to use the more abundant Amorpha-4, 11-diene (AMD) as a cost-effective starting material to make high-quality, semisynthetic artemisinin.

SwRI is collaborating with Dr. Doug Frantz from The University of Texas at San Antonio on this potentially life-saving therapeutic.

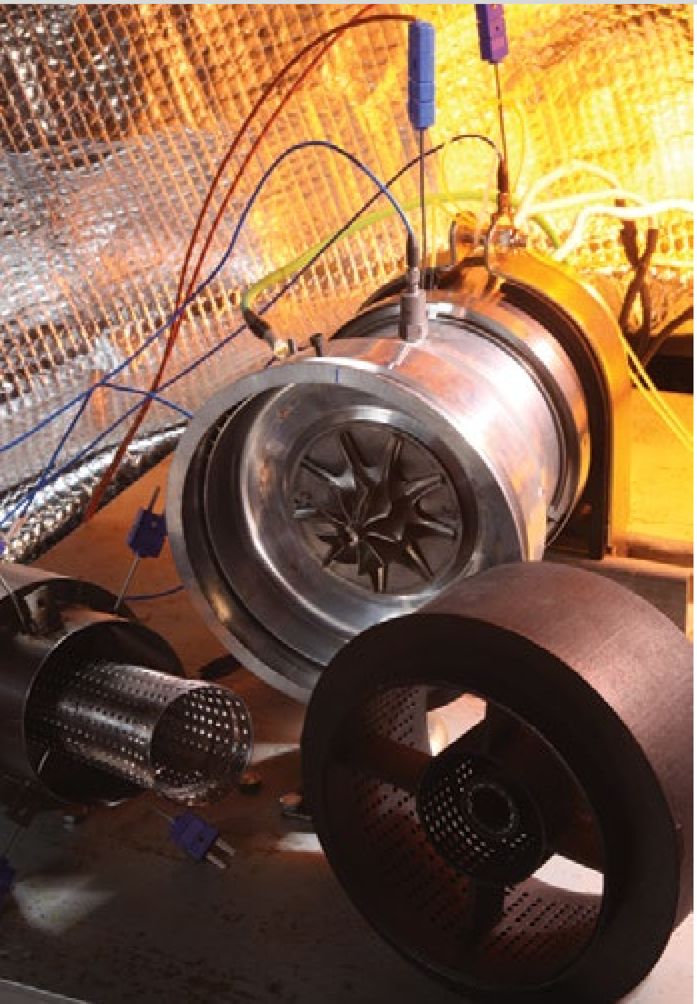
## SAFE CONNECTIONS

SwRI has introduced new hardware and software tools to help make vehicles safer. Connected vehicles (CVs) use wireless communication to share information between vehicles and infrastructure to improve safety and mobility.

SwRI's comprehensive CV test tool suite verifies compliance with SAE International's performance requirements for vehicle-to-vehicle safety communications. The SAE standards ensure interoperability and data integrity when devices communicate over wireless networks.

"This suite of tools will verify that connected vehicle devices perform as expected for deployment in vehicles and along public roads," said Eric Thorn, manager of SwRI's Cooperative Systems Section.

The SwRI Connected Vehicle Test Tool evaluates all vehicle-level requirements with data collection, data analysis, reporting software tools and all required hardware in a simple, portable package. It generates an easy-to-follow summary report for each requirement evaluated. SwRI is making the test tool suite available to clients for purchase, but SwRI also offers testing services for interested vendors with connected vehicle devices.



## Cool Turbine Design Extends Life of Drones

SwRI is developing a new radial gas turbine generator to provide thousands of hours of power for a hybrid unmanned aerial vehicle (UAV). This "cooled" design offers a significant improvement over current UAV technology that requires maintenance after several hundred hours.

"The turbine is similar to those in portable generators used to power your house in emergencies," said David Ransom of SwRI's Mechanical Engineering Division. "But the version we created is more compact and quiet, tailored to the needs of small, unmanned aircraft."

Turbines are rotary devices that can mechanically drive a generator to produce electrical power. The problem with current designs is that the combustion process bathes the turbine in high-temperature gas that ultimately damages or destroys it.

"The hotter the turbine gets, the better it performs," Ransom said. "But these smaller turbines can't survive the heat long term. Our design has tiny airflow passages that cool the turbine, permitting hotter gas temperatures."

Similar airflow passages are common in large high-temperature turbines used in power plants and passenger airplanes. To create the intricate airflow design for a small turbine, engineers are using a new selective laser melting (SLM) machine. Unlike other 3D printers, the SLM machine builds highly detailed parts layer by layer from metal rather than plastic.

"Normally with small turbines, you have to make a choice between performance and reliability," Ransom said. "Our goal is to make it possible to have both."

# DATABASE FOR STELLAR-EXOPLANET "EXPLORATION"

**Stellar chemistry hints at composition, potential habitability of alien worlds**

SwRI's Dr. Natalie Hinkel created the Hypatia Catalog to help scientists connect the elements in nearby stars with the compositions of orbiting exoplanets to better understand potential habitability.

An SwRI scientist is using big data to help the scientific community characterize exoplanets, especially alien worlds orbiting nearby stars. Of particular interest are exoplanets that could harbor life.

"At first, scientists focused on temperatures, looking for exoplanets in the 'Goldilocks zone' — neither too close, nor too far from the star, where liquid water could exist," said Dr. Natalie Hinkel, a planetary astrophysicist at SwRI. "But the definition of habitability is evolving beyond liquid water and a cozy temperature."

The planets also need the building blocks for life (such as hydrogen, carbon, nitrogen, oxygen and phosphorus) as well as a rocky composition (including elements such as iron, silicon and magnesium) for a planet to be habitable. Active geochemical cycles and a protective atmosphere are also considered optimal.

"With current technology, we can't measure the composition of an exoplanet's surface, much less its interior," Hinkel said. "But we can measure the abundance of elements in a star spectroscopically, studying how light interacts with the elements in a star's upper layers. Using these data, scientists can infer what a star's orbiting planets are made of, using stellar composition as a proxy for its planets."

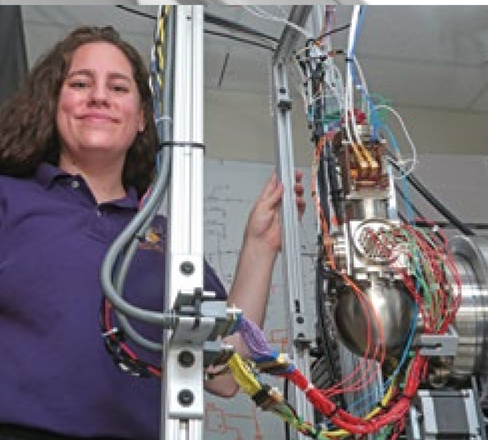
Hinkel built a publicly available database, called the Hypatia Catalog, to help researchers explore thousands of stars, as well as potential star-exoplanet systems, observed over the last 35 years. It's the largest database of stars and their elements for the population within 500 light years of our Sun. At last count, Hypatia had stellar chemical abundance data on 6,156 stars, 365 of which are known to host planets. The database also catalogs 72 stellar elements from hydrogen to lead. Hinkel named the catalog after one of her scientific heroines, a leading mathematician and astronomer in the late 300s, early 400s — the only woman known to have had this level of scientific influence in her time.

For more information, please see swri.org/astrophysics or hypatiacatalog.com.

# SwRI, CRIEPI Extend 20-Year Collaboration

IMAGE COURTESY JOSH BALBOA

On Oct. 3, SwRI extended a 20-year agreement with the Central Research Institute of Electric Power Industry (CRIEPI) in Tokyo, Japan, for an additional five years. The collaboration allows SwRI to support CRIEPI efforts to provide technology and services to member utilities, such as development of advanced inspection technology and more efficient, environmentally friendly energy sources.



The SwRI team, including INMS operations lead Rebecca Perryman, analyzed and interpreted "ring rain" measurements collected during Cassini's final orbits around Saturn. The team used experimental data from this engineering model of the INMS instrument for calibration and verification.

## SwRI SCIENTISTS DISCOVER DOWNPOUR AT SATURN

Using some of the Cassini spacecraft's final measurements, Southwest Research Institute scientists have discovered that complex organics rain down from Saturn's rings into its upper atmosphere. Cassini's final orbits allowed instruments to sample particles in the ring environment, discovering that the inflow of water and other material is much heavier than expected.

"For its final adventure, Cassini dove into the unknown region between Saturn's rings and its atmosphere," said SwRI's Dr. Kelly Miller, who coauthored the paper "Chemical interactions between Saturn's atmosphere and its rings" published Oct. 4 in the journal Science. "Based on previous work, scientists expected material was raining from the rings into Saturn's atmosphere, so the spacecraft used its radio antenna as an umbrella to protect it from debris."

After almost 20 years in space and 13 years in the Saturn system, the Cassini spacecraft was running out of fuel. NASA decided to use its last orbits to study the upper atmosphere and the edge of the inner rings before taking its final destructive dive into the planet's atmosphere in September 2017.

"Turns out, ring rain is more like a ring downpour," said SwRI's Dr. Hunter Waite, the paper's lead author and principal investigator of Cassini's Ion and Neutral Mass Spectrometer (INMS).

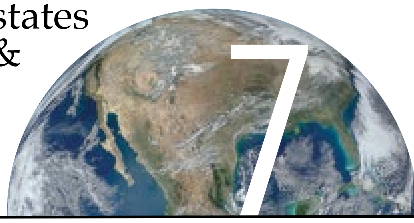
The team found that molecular hydrogen was, as expected, the most abundant constituent of Saturn's atmosphere. However, the infalling material also contained methane, nitrogen, and carbon monoxide gases, as well as water, ammonia and carbon dioxide ices mixed with complex organic molecules.

"The large mass of infalling material has implications for ring evolution, hinting that material from the C ring repeatedly replenishes the neighboring D ring," Waite said. "This infalling material likely affects the atmospheric chemistry and the carbon content of Saturn's ionosphere and atmosphere."

## BY THE NUMBERS
June — August 2018

**73** presentations given in

**17** states & **7** COUNTRIES



**11** papers published in **9** PUBLICATIONS

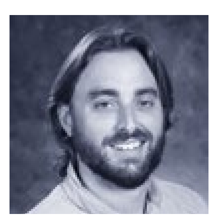
**5** patents awarded

Director **Dr. Terry Alger** has been named a Distinguished Mechanical Engineer by The University of Texas at Austin Cockrell School of Engineering's Department of Mechanical Engineering. As part of this recognition, Alger will be inducted into the Mechanical Engineering Academy of Distinguished Alumni. Alger, who holds doctorate and master's degrees in mechanical engineering from UT Austin, is one of 12 department alumni honored this year.

Manager **Dr. Barron Bichon** has been named an Associate Fellow of the American Institute of Aeronautics, recognized for overseeing important work in materials engineering and evaluations. His contributions include using data analysis techniques and computational frameworks to create a predictive manufacturing process control model for bonded structures, such as aircraft.

Associate Vice President **Dr. Robin Canup** was one of four invited scientists to speak about "Transformative Lunar Science" at NASA headquarters in Washington. The talk was sponsored by NASA's Solar System Exploration Research Virtual Institute (SSERVI) program.

Director **Paul Evans** joined the American Society of Mechanical Engineers (ASME) Robotics Technology Advisory Panel. Evans and other industry leaders will share their expertise and market insights in robotics, one of ASME's five technology focus areas. Evans also received the Friend of Manufacturing Award from the Austin Regional Manufacturers Association for helping launch the organization.



Institute Scientist **Dr. David Ferrill** along with Scientist **Kirk Gulliver**, Manager **Dr. Kevin Smart** and Principal Scientist **Ronald McGinnis** received the 3rd Place Thomas A. Philpott Excellence of Presentation Award from the Gulf Coast Association of Geological Societies. The award recognized the paper "Mechanical stratigraphic and tectonic controls on natural fracturing in the Eagle Ford Formation" presented at the 2017 GCAGS Convention.

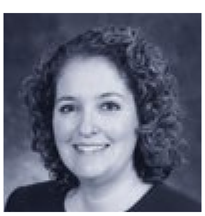
Senior Program Manager **Dr. Imad Khalek** was elected chairman of the Society of Automotive Engineers (SAE) Exhaust Aftertreatment and Emissions Committee for a two-year term. Khalek also received a 2018 SAE Excellence in Oral Presentation Award for his talk on "Solid Particle Number and Ash Emissions from Heavy-Duty Natural Gas and Diesel w/SCRF Engines" presented at the SAE World Congress in Detroit.

Staff Engineer **Dr. Peter Lee** gave the keynote address at the 2nd Annual George Arbocus Education Course at the Simeone Foundation Automotive Museum in Philadelphia. Hosted by the Philadelphia Section of the Society of Tribologists and Lubrication Engineers, Lee's talk was "Racing to the Future of Automotive Efficiency."

Research Engineer **Dr. Amy McCleney** received the New Member Impact Award from the American Petroleum Institute's Committee on Petroleum Measurement. The award recognizes service and significant contributions as a new member of the committee.

Associate Vice President **Dr. Alan Stern** is coauthor of a new book, "Chasing New Horizons," that tells the inside story of the many challenges and successes of the first mission to Pluto and its moons. Stern is principal investigator of NASA's New Horizons mission. He also received the 2018 Lowell Thomas Award in Engineering Excellence from the Explorers Club for ground-breaking expeditions and expeditionary science.

Director **Dr. Ben Thacker** was the plenary keynote speaker at the ASME Verification and Validation Symposium in Minneapolis. Thacker spoke about "Verification, Validation and Uncertainty Quantification: Are We Making Any Progress?" He serves as vice chairman of the ASME Verification and Validation Standards Committee.



SwRI General Counsel **Mónica Trollinger** received the 2018 Bexar County Women's Bar Foundation's Belva Lockwood Outstanding Lawyer award. The honor recognizes her long history of service in the legal profession as well as her charitable and volunteer work in the community.

IEEE®

The Institute of Electrical and Electronics Engineers unveiled the IEEE Region 5 Stepping Stone Award presented at SwRI's Boulder office in June. The award recognizes the "historic achievement of NASA's New Horizons Spacecraft Project supported by SwRI's engineering, science and program management." A duplicate of the award was presented to San Antonio staff members in April 2017.

## COMING UP

### TRAINING

SwRI is hosting these short courses:

Lateral & Torsional Rotordynamics for Centrifugal & Reciprocating Machinery, San Antonio, December 4, 2018

Turbomachinery Design Training Week, San Antonio, February 25, 2019

Penetration Mechanics Short Course, San Antonio, March 4, 2019

Pulsations & Vibrations: Analysis and Testing, San Antonio, April 17, 2019

### CONFERENCES

ASIP Conference, San Antonio, November 26-29, 2018, Booth 4

SAE 2019 International Powertrain, Fuels & Lubricants Meeting, San Antonio, January 22-24, 2019, Booth 1

Specialty & Custom Chemicals America, Fort Worth, Texas, February 11-14, 2019, Booth 306

Technology & Maintenance Council (TMC) Annual Meeting, Atlanta, March 18-21, 2019, Booth 1814

NACE Corrosion Conference & Expo, Nashville, Tenn., March 24-28, 2019, Booth 945

INTERPHEX, New York, April 2-4, 2019, Booth 2140

Advanced Bioeconomy Leadership Conference (ABLC), Washington D.C., April 3-5, 2019

Automate, Chicago, April 8-11, 2019, Booth 8214

35th Space Symposium, Colorado Springs, Colo., April 8-11, 2019, Booth 1213

AUVSI Xponential, Chicago, April 29-May 2, 2019, Booth 1807

CPhI North America/InformEx, Chicago, April 30-May 2, 2019, Booth 2253

For more information visit **swri.org/events**.