

SOUTHWEST RESEARCH INSTITUTE®

SUMMER 2021

TECHNOLOGY TODAY®

2 LUCY MISSION
TO TROJAN
ASTEROIDS

8 ENERGY
STORAGE
SOLUTIONS

22 JUNO'S EXTENDED
MISSION BEGINS



In the Supercritical Transformational Electric Power (STEP) pilot plant located on the SwRI grounds, this bypass compressor provides supercritical carbon dioxide at high pressures, in excess of 3,500 pounds per square inch. The CO₂ is then heated to over 1,300 F and expanded through a turbine, which drives both the compressor and generator, outputting 10 megawatts of electrical power. This high-efficiency power cycle is a leading technology for concentrating solar power, waste heat recovery, fossil-fuel, nuclear and geothermal applications.

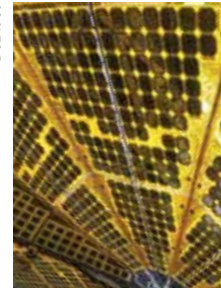
TECHNOLOGY TODAY

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ON THE COVER

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The SwRI-led Lucy mission is powered by solar panels that, once fully extended, could cover a five-story building. Shown here in a close-up, the enormous arrays will allow the Lucy spacecraft to travel farther from the Sun than any previous solar-powered mission.

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IN THIS ISSUE

This edition of Technology Today magazine takes us beyond Mars, the asteroid belt and out to the orbit of Jupiter, the largest planet in our solar system. The Juno spacecraft, which launched in 2011, has been orbiting the gas giant since 2016. One article highlights the extension of the Juno mission, which is led by SwRI's Dr. Scott Bolton, through September 2025, expanding its exploration to three of the planet's most intriguing moons. The story also discusses several recent findings made by Juno scientists.

Orbiting in tandem with Jupiter are some of the most ancient objects in our solar system — the Trojan asteroids. Technology Today's cover story highlights the SwRI-led Lucy mission, an epic journey with an audacious flight path, traveling 12 years and 4 billion miles to visit a record-breaking eight targets, including seven Trojans. Lucy is set to launch this October on a mission to better understand the origins of our world.

Closer to home, another story highlights how our staff members are working with government and industry to propel power production into a

more environmentally friendly future. This feature describes no fewer than six new technologies, all under development at SwRI, designed to fill the gap between climate-friendly renewable energy systems that require active wind or sunlight, and more reliable fossil-fuel systems that create climate-damaging emissions.

Other stories in the magazine illustrate the broad range of SwRI's research program, including the newest breakthroughs in medicine and traffic management.

Next year we will celebrate 75 years of futuristic research, ranging from cars, chemistry and communications to sensors, spacecraft and submarines. Or as we like to say: From deep sea to deep space, and everywhere in between.

Sincerely,

Walter D. Downing, P.E.
Executive Vice President/COO

DIAMONDS IN THE SKY

In this artist's concept (not to scale), the Lucy spacecraft is flying by Eurybates, the first of six asteroids it will visit after reaching the Trojans, a population of two asteroid swarms that orbit in tandem with Jupiter.



The SwRI-led Lucy spacecraft will fly past eight asteroids over 12 years

By Katherine Kretke, Ph.D.

DETAIL

Asteroids are rocky fragments ranging from less than a half mile wide to 500 miles across.

One of NASA's principal roles is to help us understand how our world came to be — how a swirling mass of gas and dust orbiting the Sun eventually turned into our Earth, a complex planet that can support life. We now understand that the Earth did not form in a vacuum (pun intended), but instead grew in a system where young protoplanets pushed each other around, fighting for the resources needed to grow. Asteroids and comets are the leftovers of this epic battle. The planetary formation process sculpted these so-called small body populations, and they remain as largely unchanged relics that contain vital clues to our origins. If we want to understand the Earth, we must understand these small worlds. Given their enormous value in understanding our history, asteroids are like rare diamonds in the sky.

Led by Principal Investigator Dr. Hal Levison and Deputy Principal Investigator Dr. Cathy Olkin, a group of scientists at Southwest Research Institute conceived the first space mission to explore a population of small bodies known as the Trojan asteroids. These space rocks orbit the Sun in tandem with Jupiter in two swarms, one preceding the gas giant and the other trailing it. Jupiter is so massive that it normally scatters all asteroids in its vicinity. However, the combined gravitational influences of the Sun and Jupiter have trapped these Trojan asteroids in stable orbits, probably since the planets formed more than 4 billion years ago.

In 2017, NASA selected the SwRI-led Lucy mission as the lucky 13th mission in its Discovery program. The mission was named after the fossilized skeleton of an early hominid found in Ethiopia in 1974, which in turn was named after a celebratory evening the paleontologists spent dancing and singing to the Beatles' song "Lucy in the Sky with Diamonds." Just as the Lucy fossil provided unique insights into the origin of humanity, the Lucy mission promises to revolutionize our knowledge of the origin of humanity's home world.



The Lucy mission is led by SwRI's Dr. Hal Levison, Lucy principal investigator, and Dr. Cathy Olkin, deputy principal investigator.

DETAIL

Cryomechanics is the production and behavior of materials at very low temperatures, including cryocoolers needed for some space instruments.

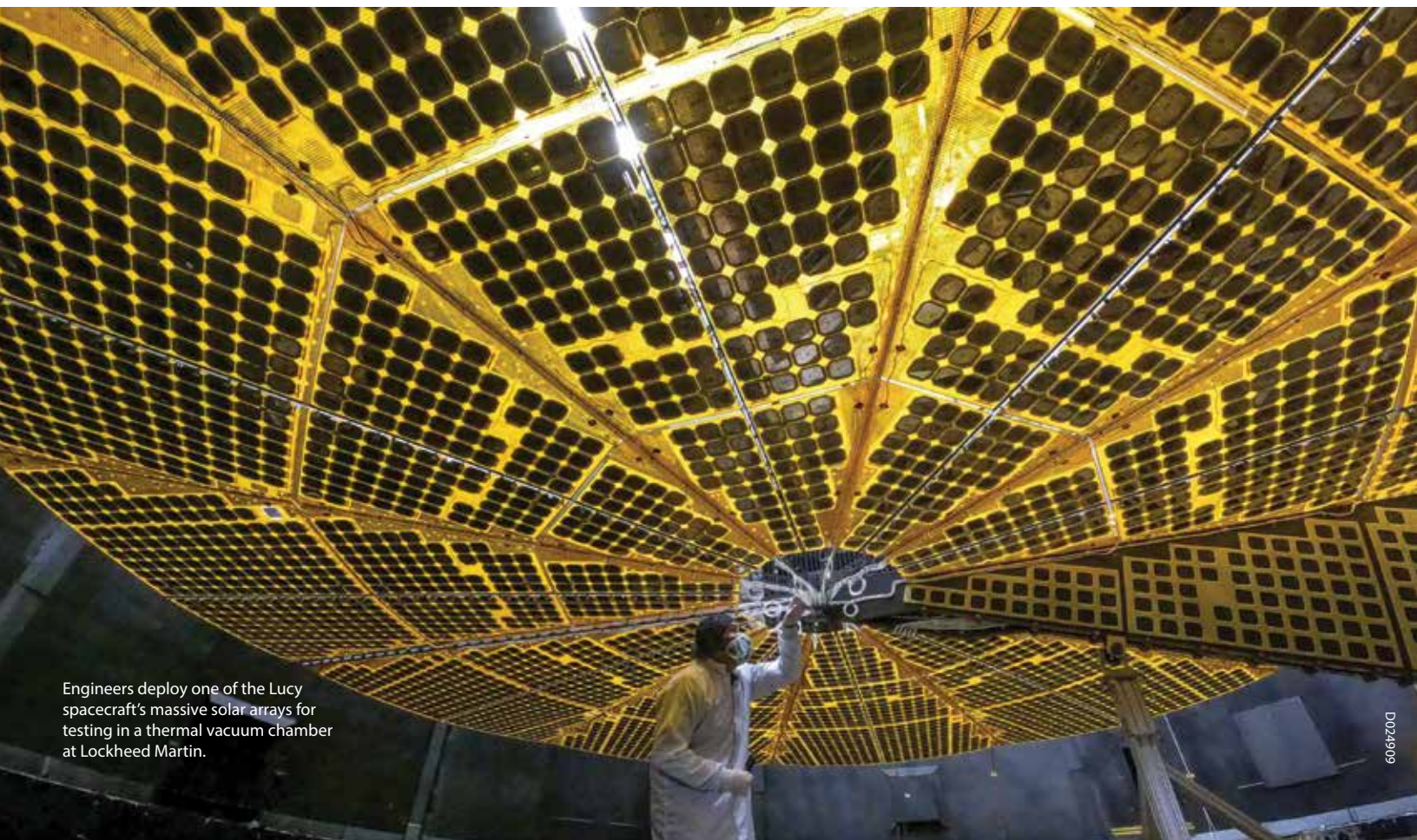
The Trojans include a mix of physically distinct asteroids in a relatively small region. How did such a diverse population of objects come to occupy their particular region in space? To understand what this clue reveals about the history of the solar system, we need to visit a sampling of these objects. Lucy will study a record number of objects — seven Trojan asteroids, counting binary pairs, plus one main belt asteroid. No other space mission has included so many different destinations in independent orbits around the Sun.

THE SPACECRAFT

The Lucy spacecraft, built by Lockheed Martin Space, will be more than 46 feet (14

meters) from tip to tip. Two huge solar panels, each almost 24 feet (7 meters) in diameter, will power the spacecraft as it flies beyond the orbit of Jupiter, the farthest any solar-powered spacecraft has traveled from the Sun — another record for Lucy. Yet despite their impressive size, the solar panels will only deliver about 500 watts of power once the spacecraft reaches the planned 530 million miles (850 million kilometers) from the Sun. Lucy will carry a suite of remote sensing instruments. Various institutions across the nation contributed Lucy's primary instruments, L'LORRI, L'TES and L'Ralph. Designing, building and testing instruments to survive a 12-year, 4-billion-mile trip is challenging.

L'Ralph is the most complicated instrument, combining an infrared spectrometer, the Linear Etalon Imaging Spectral Array (LEISA) and a visible-light color camera, the Multi-spectral Visible Imaging Camera (MVIC), which was built at SwRI's San Antonio headquarters. Lucy's MVIC is small enough to fit in one hand, yet its five color bands cover the complete visible spectrum. Each band was specifically chosen to help scientists identify different asteroid components. For example, the red band is sensitive to phyllosilicate, a hydrated mineral scientists expect to find on the Trojans' surfaces, while the violet band will help determine whether the asteroids' surfaces contain troilite, a rare iron sulfide mineral. The violet band is also



Engineers deploy one of the Lucy spacecraft's massive solar arrays for testing in a thermal vacuum chamber at Lockheed Martin.



An SwRI team including Lead Scientist Dr. Todd Veach built the MVIC camera, the only visible light multicolor imager in Lucy's payload.

sensitive to cyanide absorption, which, if detected around an asteroid, would indicate active outgassing even after eons orbiting far from the Sun in the frigid cold. While making a camera for a planetary mission is a first for SwRI, the team had all the expertise needed in detectors, optics and cryomechanics. L'Ralph's other

camera, the imaging spectrometer LEISA, and the rest of the instrument were fully assembled and tested at Goddard Space Flight Center. LEISA detects absorption lines that serve as the fingerprints for different silicates, ices and organics of interest on the surface of the Trojan asteroids.

An SwRI team also constructed L'Ralph's main electronics box, which contains systems that control the instrument and communicate with the spacecraft. Once a spacecraft travels beyond Earth's protective magnetosphere, it enters an extremely harsh radiation environment that

would damage unprotected electronics. Because L'Ralph is such a complicated instrument, and because mass and power are at a premium for deep space missions, the custom-built electronics box had stringent requirements. Its electronics collect MVIC and LEISA data, digitizing and reformatting for downlink before forwarding to another electronics box that sends the data to Earth. Even the computer logic was specially designed to gracefully recover from any disruptions caused by cosmic rays and other random events that the spacecraft will undoubtedly encounter over its 12-year journey.

L'LORRI, Lucy's Long Range Reconnaissance Imager, is a high spatial resolution visible imager built by Johns Hopkins University's Applied Physics Laboratory. This black-and-white panchromatic visible light imager will provide the most detailed images of the surfaces of the Trojans. L'TES, Lucy's Thermal Emission Spectrometer, was built at Arizona State University. This far-infrared spectrometer is effectively a touchless thermometer that will help scientists understand how effectively the Trojans retain heat while also providing information about the composition and structure of asteroid surface materials.

Lucy's 6.5-foot high-gain antenna not only communicates with Earth but also allows scientists to infer the mass of its targets based

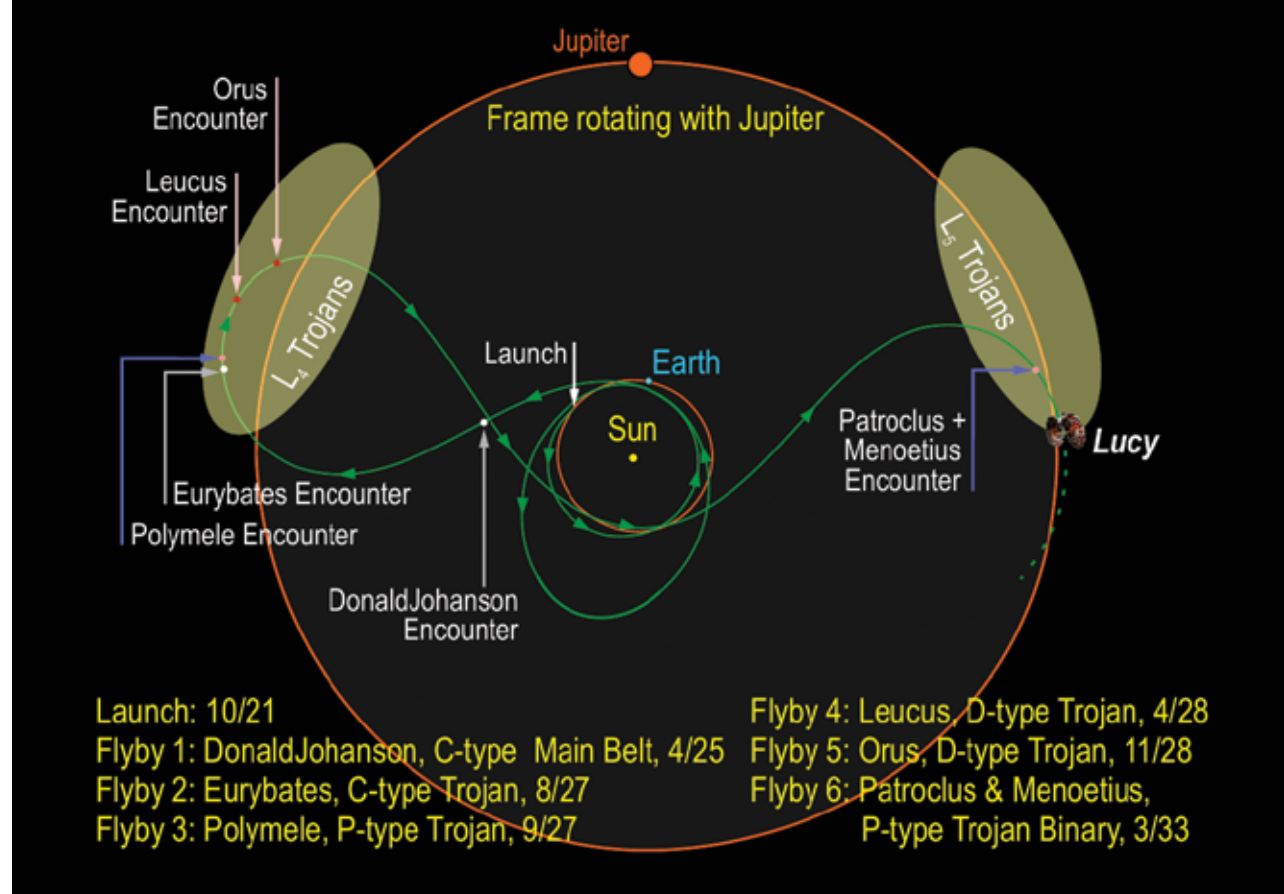
Engineers integrate instruments onto Lucy's instrument pointing platform prior to installation on the spacecraft.



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DETAIL

The Lucy payload includes high-heritage, space-proven science instruments: The "L" before the name designates the latest "Lucy" version of a proven line of instruments. L'TES is based on an instrument that flew on the Mars Global Surveyor spacecraft (1996-2007). L'Ralph and L'LORRI are based on instruments still flying aboard New Horizons, now 50 astronomical units away, traveling through the Kuiper Belt at the edge of the solar system. An astronomical unit (AU) is roughly the distance from Earth to the Sun or about 93 million miles.



This diagram shows the trajectory of the Lucy spacecraft.

DETAIL

Lagrange points are five positions in space where the gravitational forces of a two-body system, like the Sun and Jupiter, produce regions where small-mass objects can orbit in a constant pattern with the two larger bodies. Of the five points, three are unstable and two are stable. The unstable Lagrange points are called L1, L2 and L3, whereas the stable Lagrange points are labeled L4 and L5.

on the Doppler shift of radio signals. Lucy's terminal tracking camera (T2CAM) will both track the asteroids during close approach and take wide-field images of the asteroids to better ascertain their shapes. All the instruments except the antenna are located on the spacecraft's instrument pointing platform.

THE JOURNEY

Lucy is slated to launch from NASA's Kennedy Space Center at Cape Canaveral, Florida, on an Atlas V 401 rocket during a 23-day launch period starting October 16, 2021. The spacecraft will fly past Earth for two gravity assists to slingshot Lucy toward the Trojan asteroids.

In April 2025, en route to the outer solar system, Lucy will travel through the main asteroid belt that orbits between Mars and Jupiter. There it will encounter its first target, Donald Johanson, an asteroid that the Lucy team named after one of the paleontologists who discovered the Lucy fossil. Following this encounter, Lucy will continue to the leading swarm of Trojan asteroids, the L4 Trojan swarm. Known as the "Greek camp" of Trojan asteroids, they are named after Greek heroes from the Trojan war (except for one named for the Trojan "spy" Hektor). Lucy will fly past four of these Trojans: (3548) Eurybates and its satellite Queta in

August 2027, (15094) Polymele in September 2027, (11351) Leucus in April 2028 and (21900) Orus in November 2028.

The spacecraft's orbit will then take Lucy back toward Earth. When its orbit takes the spacecraft outward again, Jupiter and the Trojan swarms will have rotated enough to cause the spacecraft to pass through the trailing L5 swarm, known as the "Trojan camp." In March 2033, Lucy will fly past the Greek "spies" in the Trojan camp, (617) Patroclus and its binary companion Menoetius. The flyby of this binary pair will be the grand finale of the mission. However, Lucy will remain in a stable orbit, continuing to fly through the Trojan swarms for many years to come.

THE SUPPORT

Throughout this journey, the spacecraft will explore the asteroids and send data back to Earth. The mission's Science Operations Center (SOC) at SwRI's office in Boulder, Colorado, will act as the interface between the science team, which determines the mission's observations, and the Mission Operations Center at Lockheed Martin Space in Littleton, Colorado, which manages and sends commands to the spacecraft. SwRI Planetary Science Director Joel Parker oversees Lucy's SOC, which controls spacecraft instruments. It develops

commands to capture images, automate data processing, return data to Earth and archive the data for generations to come.

Supporting a long-running outer solar system mission like Lucy is nothing new for SwRI. The team has supported the New Horizons mission to Pluto and beyond as well as the Juno mission to Jupiter. SwRI also supports operations for a number of instruments on other planetary and heliophysics missions.

The Lucy team had to overcome some unique challenges, such as building instruments and assembling a spacecraft during a pandemic. However, the team persevered and remains on schedule for an October launch. Lucy's epic journey will be quite unlike any other, with an audacious flight path, traveling 4 billion miles to visit eight unique bodies. Because the objects vary widely in spectral type, color, size and collisional history, visiting these diamonds in the sky promises to reveal much about the early history of the solar system and our place in it.

Led by SwRI's Levison and Olkin, the mission is managed by NASA Goddard in Greenbelt, Maryland. The spacecraft is built by Lockheed Martin Space in Littleton, Colorado. Instruments have been contributed by Goddard Space Flight Center, Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland, and Arizona State University in Tempe, Arizona. KinetX in Simi Valley, California, will provide mission navigation. Launch operations will be conducted by NASA's Kennedy Space Center. As a Discovery Class mission, Lucy is overseen by the Planetary Missions Program Office at the Marshall Space Flight Center in Huntsville, Alabama, for NASA's Planetary Science Division.

Questions about this story? Contact Kretke at katherine.kretke@swri.org or (720) 208-7209.



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ABOUT THE AUTHOR

Dr. Katherine Kretke is an astrophysicist with expertise in modeling planet and planetary system formation. She leads education and public outreach for NASA's Lucy mission and manages the Lucy student collaboration program, the Lucy Student Competency Accelerator and Pipeline Enabler (LSPACE).



Shown approaching completion, the Lucy spacecraft will be ready when the Cape Canaveral launch window opens October 16.

6

Power Plant- and Grid-Scale Storage Solutions

Making the Most of
Renewable Resources

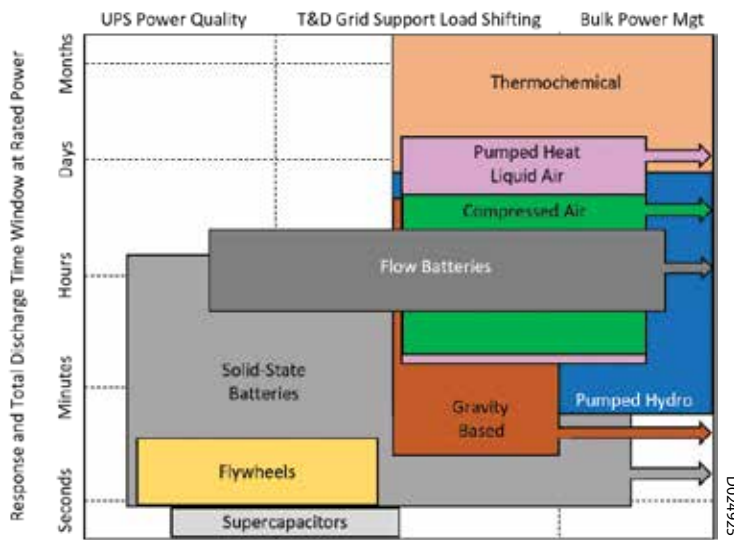
Tim Allison, Ph.D.

From coastal towns to rural farms to urban centers, climate change threatens not just the environment, it also affects human health, community stability, national security and overall economic well-being. Climate change fuels extreme weather, from droughts and floods to tornados, wildfires and other catastrophic events that wreak havoc on our communities, institutions and the environment. To address these issues, the international community has focused on decarbonization — reducing the most prevalent greenhouse gases emitted by burning fossil fuels, clearing land and producing food and manufactured products.

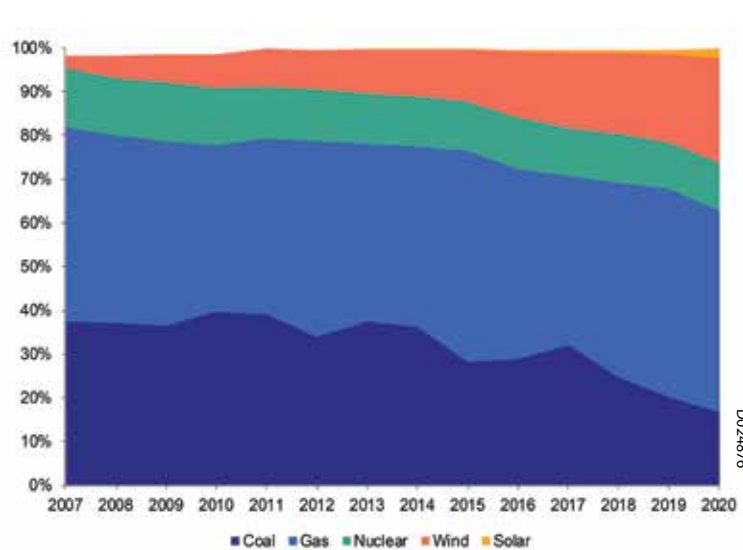
This shift has resulted in significant changes to the power generation mix on global, national and local scales. Growth in energy demand has slowed in recent years, and the fuel mix has shifted from coal toward natural gas and renewables. While fossil-based sources and nuclear power still accounted for 75% of the power generated, the remaining 25% was produced by hydroelectric (15.8%), wind (4.8%), solar (2.2%) and geothermal/ biomass (2.4% combined) sources. Wind and solar sources remain a relatively low percentage of the overall energy mix, but they are the fastest-growing categories globally and particularly for Organisation for Economic Co-operation and Development (OECD) member countries, including the United States. From 2017 to 2018, the International Energy Association reported overall declines in electricity production in OECD countries from combustible fuels — particularly coal and oil — which were substantially offset by a 19.8% and 7% growth in solar and wind production, respectively.

The rapid introduction of renewable resources into the energy mix has introduced two significant challenges. First, the capacity growth provided from solar and wind generators is highly variable. Output can fluctuate significantly by the minute, hour and season. Wind speed varies with weather patterns or diurnal effects. Likewise, solar power output is affected by storms, passing clouds, ambient temperature and wind. The second challenge is the mismatch between availability of





This graph illustrates mature and developing energy storage technologies, identifying nominal discharge times and operating scales for various technologies.



Many of SwRI's energy storage research projects are conducted in cooperation with Texas power generators. This graph shows the historic power generation mix for ERCOT, which manages the majority of Texas' power grid.

wind and solar resources and typical electrical demand profiles, leading to daily imbalances in generation and demand. This means renewable power sources must be supplemented by more traditional power plants that can take a long time to ramp up and shut down.

Simple-cycle gas turbines allow fast-startup and high-turndown capabilities but with relatively poor efficiency and high emissions at low loads.



Combined-cycle gas turbines and steam turbines used in large baseload fossil or nuclear plants incorporate large heat exchangers that limit ramp-rate capabilities to minimize thermal stress but with higher partial-load efficiencies and lower partial-load emissions.

Significant global integration of renewable energy sources with high variability into the power generation mix requires new cost-effective, efficient and reliable grid-scale energy storage technologies. These systems store energy when excess renewable power is available and discharge it when renewable generation drops off or when demand exceeds supply. The many forms of energy have resulted in a wide range of technologies for energy storage, some that are commercially mature and others that are currently under development. Notably, the application space for electrochemical (usually lithium-ion) batteries has grown significantly in recent years up to the 100-plus MW scale. But these systems are still only cost-effective for up to about four hours of storage, which is inadequate for accommodating deep penetration of renewables. Longer-duration grid-scale technologies include commercially mature technologies such as pumped hydro energy storage and compressed air energy storage (CAES) as well as developing technologies that target unprecedented storage durations at low cost, including pumped heat energy storage, liquid air energy storage, hydrogen-based thermochemical storage and advancements to pumped hydro and CAES.

Southwest Research Institute is developing and advancing technologies aimed at providing cost-effective, long-duration storage for the electric grid, including projects funded by the U.S. Department of Energy and commercial collaborators. This article provides an overview of some these technology development efforts.

Dr. Tim Allison is director of SwRI's Machinery Department, which performs applied research in power systems, including advanced energy systems, thermal-mechanical-chemical energy storage, oxy-combustion, and turbomachinery design, fabrication, instrumentation, testing and control.

1

STORING SUNLIGHT

Jason Wilkes, Ph.D.

In a Department of Energy project, SwRI is helping develop machinery for a concentrated solar power (CSP) plant that combines supercritical carbon dioxide (sCO₂) power cycles with integrated thermal energy storage. CSP technology uses mirrors or lenses to concentrate a large amount of sunlight onto a receiver, which typically converts concentrated light to heat and extracts thermal energy to generate power using steam turbines. Next-generation CSP systems will store the energy as heat, which can be converted to on-demand energy using sCO₂ power cycles, improving efficiency and reducing operating costs. sCO₂ is carbon dioxide held above a critical temperature and pressure, which causes it to act like a gas while having the density of a liquid.

This state makes sCO₂ a highly efficient fluid for power generation because small changes in temperature or pressure cause significant shifts in density. Utilizing sCO₂



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SwRI is developing new technology and processes to create concentrated solar power plants that combine sCO₂ power cycles with integrated thermal energy storage.

as a working fluid can increase the efficiency of a CSP plant by as much as 10 percentage points.

Additionally, integrating thermal energy storage will allow for a more stable grid. Renewable power sources such as CSP can be variable, but the ability to store excess power at peak production times will help meet peak demands. Existing CSP plants typically use thermal oil or molten nitrate salts as a storage medium at temperatures up to 565 degrees Celsius. Next-generation sCO₂ plants target lower-cost solid media allowing thermal storage at higher temperatures, potentially up to 630–750 C. The sCO₂ machinery design features an innovative compact skid-based arrangement with the potential for containing all turbomachinery (in this case an integrally geared compander, or compressor/expander), recuperators, control systems and ancillary hardware on a single skid. This simplifies installation by reducing the number of field welds and gas, electrical and piping connections made on site. With this approach, the project team can realize a drastic reduction in deployment and commissioning time while increasing operational flexibility, paving the way for cost-competitive modular power plants in the near future.

The development team includes SwRI and Hanwha Power Systems. Engineers are combining competitive costs with power on demand, enabling CSP plants to deliver on a brighter future.

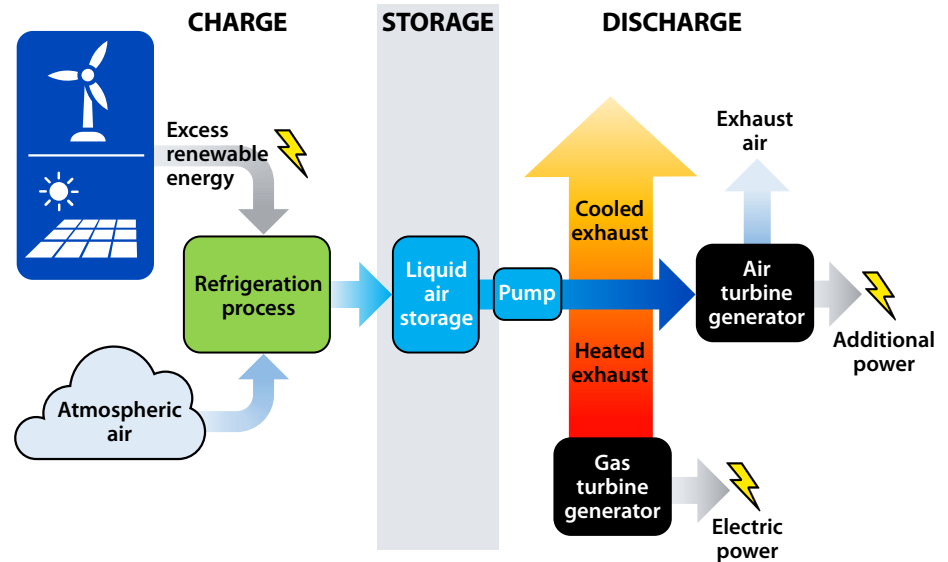
As part of a CSP power plant application, Manager Dr. Jason Wilkes leads a team developing modular, skid-based power cycle technologies including specialized high-temperature, high-pressure sCO₂ turbomachinery.

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SwRI is researching techniques to store cooled liquid air when the demand and cost for electricity is low. When energy demand is high, waste heat converts the liquid air into high-pressure gas that is expanded through an air turbine to drive an electrical generator and produce additional power.

2 LIQUID AIR

Aaron Rimpel



SwRI is leading a DOE project to develop a conceptual design for large-scale, long-duration energy storage with the potential for hundreds of megawatts and tens of gigawatt-hours output. SwRI is working on patent-pending commercial technology to implement liquid air energy storage (LAES), leveraging commercially mature cryogenic refrigeration equipment to liquefy ambient air and store it at near-ambient pressure. Liquid air, stored in large insulated vessels at temperatures as low as -193 C, would experience storage losses of less than 0.1% per day.

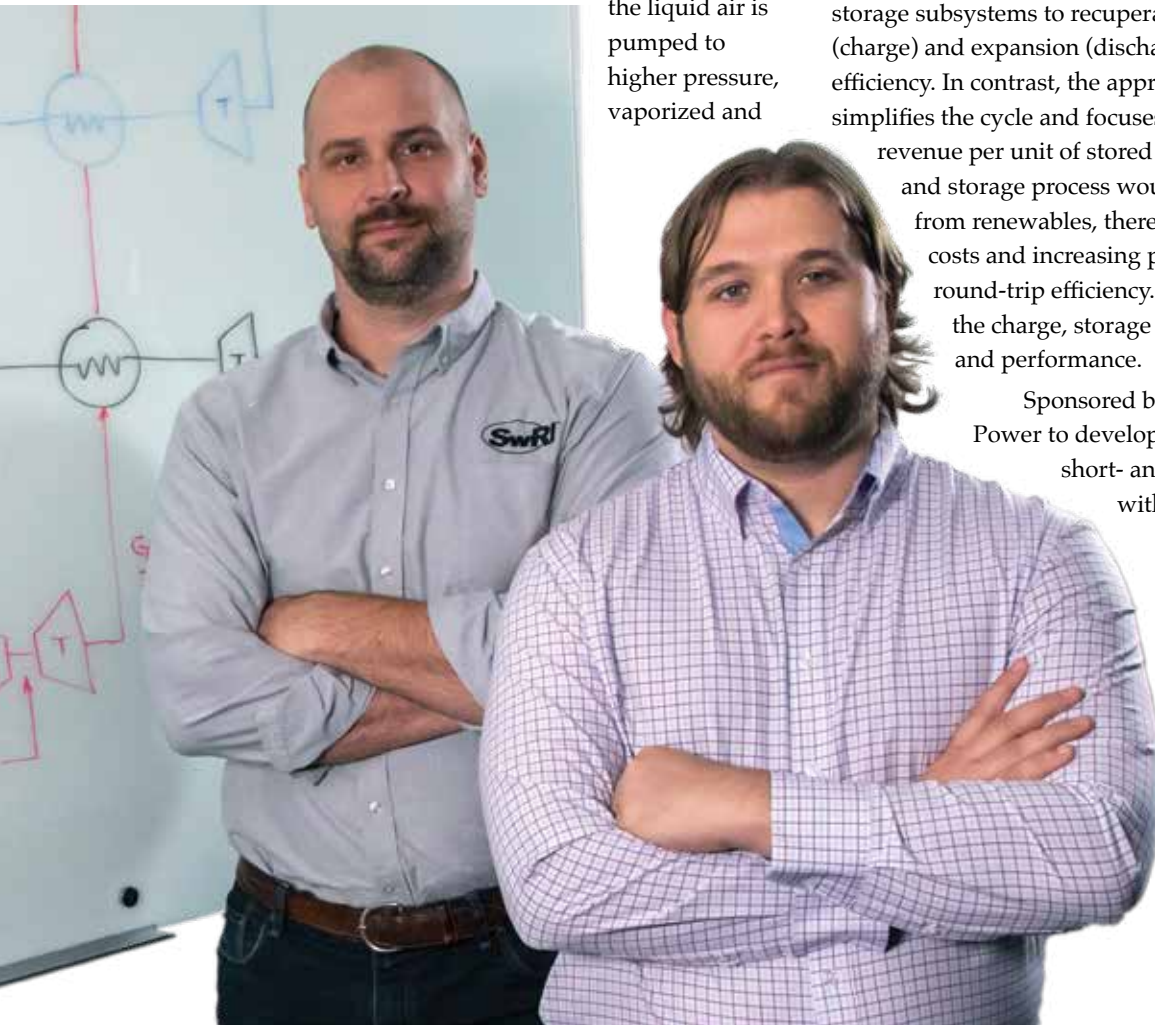
Liquid air can be stored when the demand and cost for electricity from conventional or renewable sources is low. When energy demand is high, the liquid air is pumped to higher pressure, vaporized and

superheated by a waste heat source such as a gas turbine exhaust stream. The resulting high-pressure gas is expanded through an air turbine, which drives an electrical generator to produce power.

The process uses mature, readily available technologies and draws heavily on established processes and equipment from the power generation and industrial gas sectors. The known costs, performance and life cycles minimize technical risk and promote earlier commercial adoption. In addition, the storage medium, air, is free and ubiquitous, and liquefied air storage can be installed anywhere. Because the exhaust from the power turbine is air, additional energy is produced without further emissions.

Other LAES system concepts utilize additional hot and cold storage subsystems to recuperate energy from the refrigeration (charge) and expansion (discharge) cycles to improve round-trip efficiency. In contrast, the approach being developed on this project simplifies the cycle and focuses on maximizing energy output and revenue per unit of stored liquid air. Because the refrigeration and storage process would utilize low-cost or excess energy from renewables, there is more value in reducing capital costs and increasing power output rather than increasing round-trip efficiency. This conceptual design will optimize the charge, storage and discharge cycles based on cost and performance.

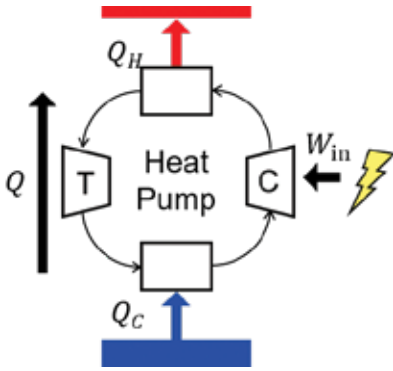
Sponsored by DOE, SwRI is working with Pintail Power to develop its LAES technology to manage the short- and long-term variability associated with renewable resources.



Group Leader Aaron Rimpel (left) and Research Engineer Dr. Owen Pryor are working on a conceptual design for large-scale, long-duration liquid air energy storage with the potential for hundreds of megawatts and tens of gigawatt-hours output.

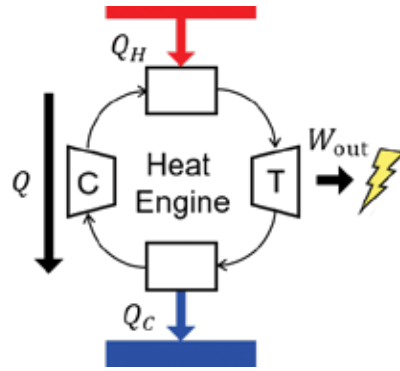
CHARGE MODE

Use excess energy to run heat pump and store energy in hot and cold reservoirs



DISCHARGE MODE

Use thermal reservoirs to run heat engine and generate power



This figure illustrates the basic thermodynamic operation of PHES technology.

3

PUMPED HEAT

Natalie Smith, Ph.D.

Pumped Heat Energy Storage (PHES) is another potential long-duration, grid-scale energy storage technology to help maintain grid reliability and security. A PHES system stores energy in hot and cold tanks for later use. Depending on the system, the hot storage media can be molten salt, crushed rock or other materials. The cold storage media is similar to anti-freeze. When excess energy is available, the PHES system runs as a heat pump, similar to any household refrigerator, making the hot store hotter and the cold store colder. Then, when energy demands exceed production, the PHES runs as a heat engine converting the large temperature difference between the hot and cold stores into electricity via a generator.

The PHES heat pump and heat engine use compressors, turbines and heat exchangers connected by piping filled with an inert gas, such as air or CO₂. PHES offers high potential system performance of more than 60% round-trip efficiency and can store energy for more than 10 hours.

PHES is a promising technology offering

DETAIL: In energy storage applications, the round-trip efficiency is the storage-to-discharge energy efficiency of the system or the fraction of energy put into storage that can be retrieved as useful energy.

implementation versatility without geological and geographical constraints.

SwRI is conducting two PHES research projects. The first is developing a small-scale PHES facility to demonstrate system operations and control strategies.

The SwRI PHES uses air as the working fluid and is configured similarly to a proposed full-scale system. This first-of-a-kind demonstration will also tackle first-implementation challenges and reduce risk for full-scale systems. This PHES demonstration facility is currently under construction on the SwRI campus with testing planned at the end of 2021.

The second project is studying how a full-scale PHES system can improve the environmental and economic performance of a natural gas power plant. The goal is to help balance the diverse power generation on electric grids while improving the reliability and resiliency of the electric system as more intermittent renewables come online. SwRI will use a Texas-based natural gas plant for this feasibility study, where the local energy market is subject to negative pricing at night due to abundant wind energy. In wholesale power markets, negative prices mean a big electricity consumer like a factory or a water treatment plant is paid to consume more power, to meet production and keep the power grid stable. Production and demand must remain balanced to avoid excesses that could damage equipment or cause blackouts.

Establishing the value of using PHES to help balance fossil-fuel energy sources with increased renewable energy capacity will help provide pathways enabling full penetration of renewable resources, like solar and wind, into the electricity grid.

SwRI is collaborating with Malta Inc. and Vistra, a Texas-based integrated retail electricity and power generation company, on these DOE-funded projects.



Senior Research Engineer Dr. Natalie Smith is leading a project to develop a small-scale pumped heat energy storage facility, demonstrating system operation and control strategies, addressing first implementation challenges and reducing risk for the full-scale technology. Custom machinery components were developed to enable adequate PHES system performance, including the new discharge turbine impeller shown here.



SwRI is helping develop a next-generation power plant that will incorporate an sCO₂ power cycle, renewable energy, oxygen storage and carbon capture.

4

ZERO EMISSIONS

Jeff Moore, Ph.D.

SwRI is part of a team designing, modeling and optimizing plans for an innovative new zero-emission fossil fuel power plant. With funding from the DOE's Advanced Research Projects Agency-Energy (ARPA-E), the team will develop the plant, which will incorporate a supercritical carbon dioxide (sCO₂) power cycle, renewable energy, oxygen storage and carbon capture.

The electric grid of the future with variable renewable energy sources such as wind and solar power will typically experience surplus energy with low demand, followed by periods of high demand requiring supplemental power from fossil fuel plants. The team proposes using a direct-fired sCO₂ power cycle,

which uses sCO₂ instead of water as a thermal medium and allows for more efficient power generation as well as smaller turbomachinery. The fuel is burned with pure

oxygen directly in the working fluid, allowing higher firing temperatures of as much as 1,200 C, approaching those of conventional gas turbines. This process requires an air separation unit (ASU) to provide the power cycle with pure oxygen while extracting CO₂ at pressures between 30 and 300 bar, permitting carbon capture while producing no other emissions.

In this power cycle, the ASU requires 13% of the power plant output with an additional 2% required to compress the oxygen. By operating the ASU at higher capacities when excess low-to-zero cost power from alternative energies is available and storing liquid oxygen (LOX) for later use, the power plant achieves higher outputs during periods of peak demand.

Evaporative cooling of the oxygen can reduce the compression power of CO₂ in the power cycle and allow additional savings. The ASU equipment is electrically driven, requiring no changes to the power block while producing up to 20% higher power plant output during peak demand. The proposed scheme leverages low-cost power to store a significant amount of energy in the form of LOX, reducing the effective operating costs by up to 20%.

The team includes Air Liquide, 8 Rivers Capital LLC and SoftinWay Inc. and anticipates completing the design stage by the end of 2022.

Institute Engineer Dr. Jeff Moore and his team designed this full-scale, internally cooled turbine blade similar to those that will be used in an oxy-fuel direct-fired supercritical carbon dioxide (sCO₂) turbine. Each blade generates 600 kW (800 hp) for a total of 450 MW (600,000 hp) of electricity.



5

WEST OF THE PECOS

Gordon Wittmeyer, Ph.D.

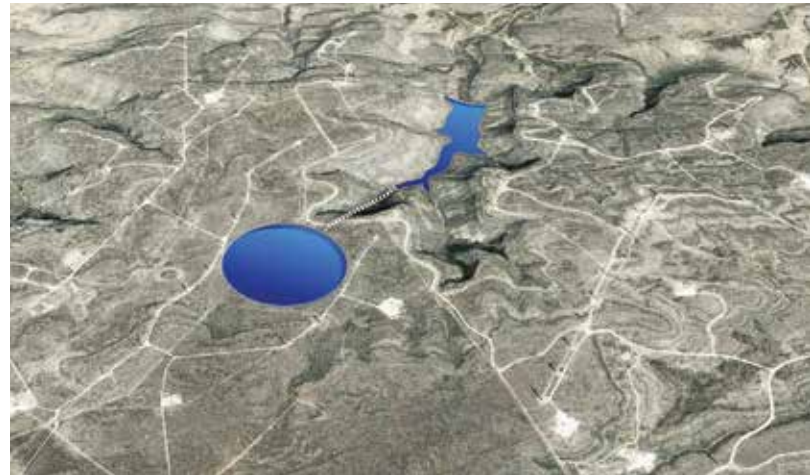
If Texas were a country, it would rank fifth in the world in installed wind capacity. Although the Texas grid operator transmits much of the renewable energy generated in western Texas across the state, most wind energy is generated at night when demand and prices are low. Combined with growing solar capacity, the industry has deployed high-ramp-rate gas plants to meet peak evening demand. SwRI proposes using closed-loop pumped storage hydropower (PSH) units to store wind power generated at night, holding it for late afternoon the following day when solar generation drops and reducing the need for more CO₂-producing gas peaking plants.

SwRI scientists and engineers have developed technologies and engineering solutions to rapidly deploy low-cost PSH to provide high-volume grid-scale energy storage. In West Texas, storage is needed to stabilize and integrate abundant intermittent wind and solar renewable energy. However, relatively few locations offer both significant topographic relief and flowing rivers to support conventional PSH.

To address this problem, SwRI engineers identified many moderate (300 to 500 foot) to high (650 to 1,000 foot) head sites in West Texas where 50 to 1,000 MW PSH units with four to 16 hours of storage could be constructed. Because the region is semiarid, PSH plants may need to be operated using groundwater; however, groundwater, even saline groundwater, is a precious resource in this region. Instead of groundwater, SwRI scientists determined that waste brines produced by oil and gas operations in the adjacent Permian Basin would be adequate and suitable for PSH units.

Collaborating with the National Renewable Energy Laboratory and Argonne National Laboratory, SwRI has further advanced a low-cost, low-technology modular PSH design that can compete with small grid-scale battery energy storage systems using lithium-ion technology. The team has combined low-weight prefabricated modular steel dams transported by flatbed trailer with low-cost Pumps-As-Turbines (PAT) power units to limit capital expenditures per unit of energy to \$100–200/kWh. The team believes the availability of a 10 MW, 100 MWh PSH unit that can be built in a year for \$10 million will reinvigorate the PSH industry and can bolster the resilience of the national grid as well as the isolated Texas grid.

Senior Scientist Dr. Gordon Wittmeyer (right) and Staff Engineer Dr. Biswajit Dasgupta developed an award-winning modular steel dam using standard building materials such as I-beams to accelerate construction of pumped storage. When energy production exceeds demands, PSH systems pump water into a top reservoir using excess power. When power demands exceed production, water is discharged to the lower reservoir, running centrifugal pump impellers such as the one shown in reverse, generating electricity to meet peak demands.



D023772

SwRI identified Indian Mesa as a potential PSH site where an upper reservoir (circle) could be built on top of the mesa and lower reservoirs could be built into the canyons below, as illustrated on this Google Earth image. In this PSH application, water is pumped to the high elevation reservoir using low-cost surplus off-peak electric power. During periods of high electrical demand, the stored water is returned to the lower reservoir, driving turbines to produce electric power when demand and prices are highest.



6

CRYOGENIC FLUX CAPACITOR

Joshua Schmitt

Although it may sound like science fiction, SwRI engineers are working on a hydrogen energy storage solution using a high-density Cryogenic Flux Capacitor (CFC). CFC technology stores fluids at high densities, accepts gaseous hydrogen at ambient conditions and charges up over time. On discharge, controlling heat and regulating the flow of hydrogen gas provides operational flexibility for the total

DETAIL: An electrolyzer uses electricity to break water into hydrogen and oxygen in a process called electrolysis, creating hydrogen gas.

system and allows a wide range of demand loads and duty cycles. The project will demonstrate a CFC storage system using an electrolyzer and assess the inherent flexibility of the coupled system.

The CFC's cold, dense fluid storage core integrates design features that provide new possibilities for the storage and discharge of energy. This new technology rivals the energy storage capacity of liquefied gases and exceeds battery energy storage, particu-

larly in the case of stored hydrogen. By exploiting a unique attribute of nano-porous materials, aerogel in this case, fluid commodities such as oxygen, hydrogen, methane, etc. can be stored in a molecular surface-adsorbed state. This cryogenic fluid can be stored at low pressure and high densities, on par with liquid, and then quickly released as a gas on demand.

For this project, the team will develop a techno-economic assessment and commercialization plan for integration of the technology with various power generation assets. These include using existing natural gas turbines to generate electricity. With incremental conversion and modification of these turbines, asset owners can blend cleaner-burning hydrogen with natural gas in ratios from 15–50%. Higher ratios can be achieved with new turbine designs with an eventual goal of using 100% hydrogen fuel by 2030.

Senior Research Engineer Joshua Schmitt is leading a hydrogen energy storage project, investigating using a high-density cryogenic flux capacitor to store energy as super-cooled fluids at high densities.

D024883/ D024900

The information, data or work presented herein was funded in part by the U.S. Department of Energy, under award numbers DE-FE0032002, DE-AR0001313, DE-FE0032003, DE-AR0001018, DE-EE0007114 and DE-FE0032031. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

SwRI is studying how NASA-developed cryogenic flux capacitor technology could be used to store 100 megawatt hours of energy.

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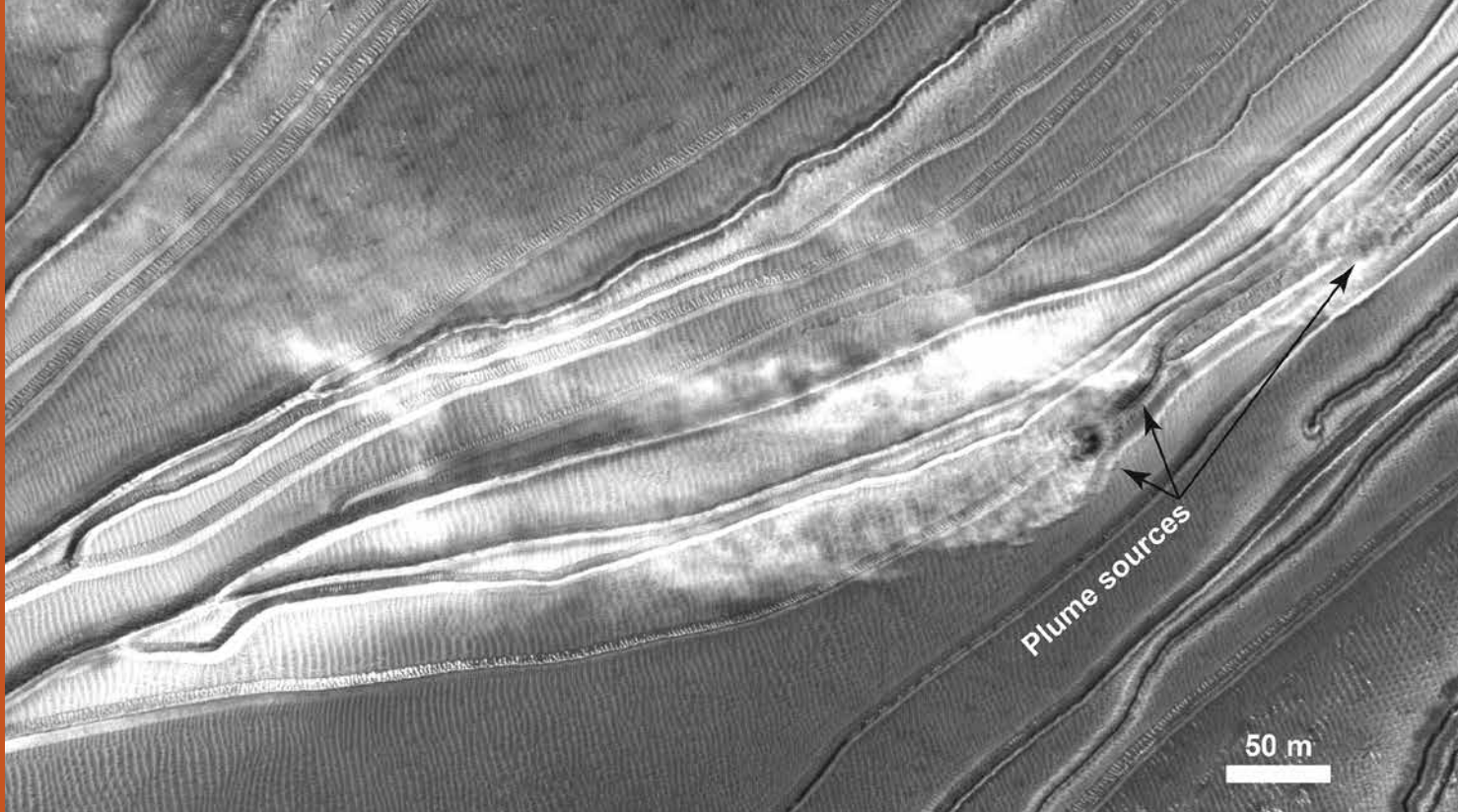


The high energy density of CFC-stored hydrogen allows long-term storage, ranging from daily to monthly cycling, which corresponds to approximately 10 to 100 hours, respectively. Many natural gas power plants could accommodate racks of CFC storage units, corresponding electrolysis modules and ancillary equipment. The study would examine a range of storage possibilities for commercial viability. The team is exploring a near-term demonstration at a natural gas combined-cycle power plant. The expected storage size will be 100 megawatt hours (MWh), where the hydrogen will be provided by a 20-megawatt (MW) electrolyzer.

Funded by the Department of Energy, the project team also includes the University of Central Florida, NASA Kennedy Space Center, Air Liquide and Turbine Technology Services.

Questions about these six projects? Contact Allison at tim.allison@swri.org or 210-522-3561.





The airborne plumes of dust located above the downwind slope of this Martian megadune allowed an SwRI scientist to infer that chunks of frozen CO₂, or dry ice, slide down the gullies in the spring, kicking up sand and dust.

DYNAMIC ACTIVITY ON MARTIAN SAND DUNE

An SwRI scientist examined 11 Mars years of image data to understand the seasonal processes that create linear gullies on the slopes of a giant Martian sand dune.

In some early spring images from the Mars Reconnaissance Orbiter, SwRI's Dr. Cynthia Dinwiddie noticed airborne plumes of dusty material associated with the linear gullies on the sand dune's downwind slope. These clues point to active processes involving chunks of frozen CO₂, or dry ice, sliding down the sand dune, kicking up sand and dust along the way.

Russell Crater on Mars is home to the largest known sand dune in the solar system, providing a frequently imaged locale to study modern surface activity on the Red Planet.

"For two decades, planetary scientists have had many ideas about how and when very long, narrow gullies formed on frost-affected sand dunes on Mars," said Dinwiddie, a principal scientist in SwRI's Space Science and Engineering Division. "Initially, scientists thought linear dune gullies were remnants of an ancient time when the climate on Mars supported liquid water on its surface. Then, repeat imaging

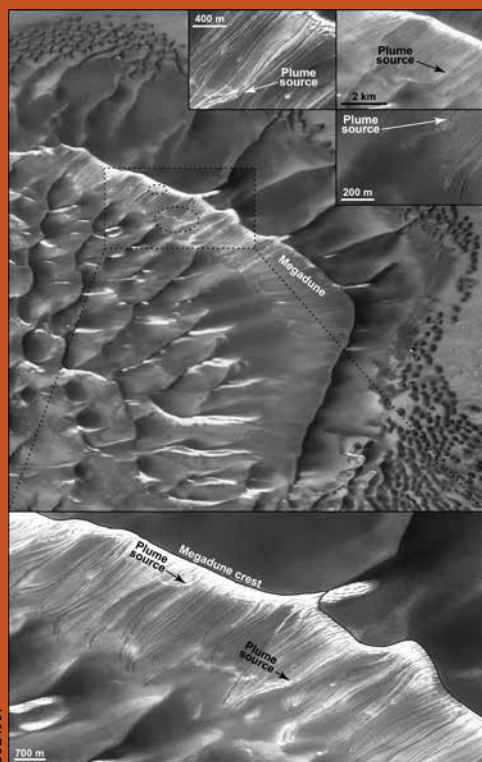
showed that changes were happening now, when Mars is cold and arid."

Imagery showing bright CO₂ ice blocks at rest in dune gullies suggests a causal relationship between the blocks and the gullies. Research has shown that in the winter and early spring, slabs of translucent CO₂ ice allow solar radiation to heat dark sand below, causing some ice to transition to gas.

"This latest research offers compelling new evidence that venting CO₂ gas dislodges CO₂ ice blocks, expelling sand and dust," Dinwiddie said. "The slabs slide down the slope, carving and modifying dune gullies."

"While trace amounts of seasonally condensed water are present, it behaves like an innocent bystander, not actively participating in the processes," said coinvestigator Dr. Tim Titus of the U.S. Geological Survey.

Read a Geophysical Research Letters paper about this research, which has been funded to continue for three more years, at <https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020GL091920>



Plumes of airborne dust emanate from gullies in the Martian megadune in Russell Crater. The plume phenomenon supports the hypothesis that CO₂ ice blocks, dislodged by venting CO₂ gas, slide down slope in the Martian spring, redistributing dust.

PUNCH REACHES MILESTONE, LAUNCHES NEW INITIATIVE

The Polarimeter to UNify the Corona and Heliosphere (PUNCH) mission achieved an important milestone, passing NASA's Preliminary Design Review (PDR) of its spacecraft and payload experiments. The mission also launched a new associate investigator initiative to encourage young career scientists to participate in the SwRI-led mission. PUNCH aims to integrate understanding of the Sun's corona, which is visible during total solar eclipses, with the "solar wind" that fills the solar system.

The solar wind, a supersonic stream of charged particles emitted by the Sun, fills the heliosphere, the bubble-like region of space encompassing our solar system. Its boundary, where the interstellar medium and solar wind pressures balance, demarks the end of the Sun's influence.

"Passing PDR gets us one step closer to launch, verifying the design options, interfaces and verification methods for the mission," said PUNCH Principal Investigator Dr. Craig DeForest of SwRI's Space Science and Engineering Division.

SwRI's Ronnie Killough, PUNCH project manager, elaborated on the challenges the mission had to overcome. "PUNCH has had to conduct the entire preliminary design remotely — this is possibly an unprecedented accomplishment for a NASA mission and a testament to the strength and resiliency of the PUNCH team."

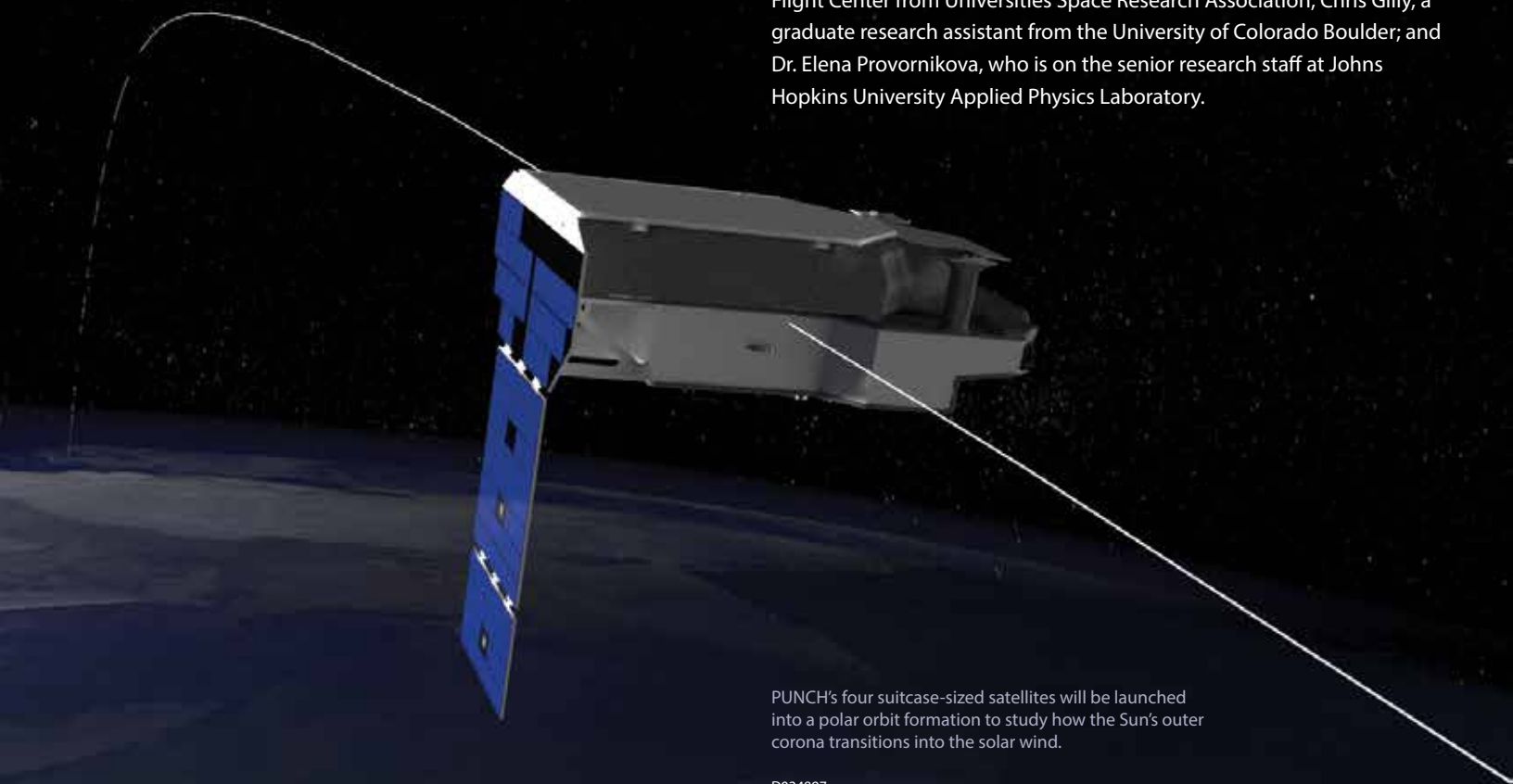
PUNCH is a constellation of four small suitcase-sized satellites scheduled to launch in 2023 into a polar orbit formation. One satellite carries a coronagraph, the Narrow Field Imager, that images the Sun's corona continuously. The other three each carry SwRI-developed WFI wide-angle cameras, optimized to image the solar wind. These four instruments work together to form a field of view large enough to capture a quarter of the sky, centered on the Sun.

"Just as in astronomy when a new telescope like Hubble opens a new window on the universe, PUNCH's four satellites are going to visualize a mysterious process, imaging how the solar corona transitions into the solar wind," said Dr. James L. Burch, vice president of SwRI's Space Science and Engineering Division. "As an authority in heliophysics research, SwRI is not only leading the science of this mission but also building the spacecraft and three of the four sensors designed to let us see, for the first time, the birth of the solar wind."

The PUNCH mission recently selected four early career scientists as associate investigators to pursue solar science under the mentorship of senior PUNCH science team members.

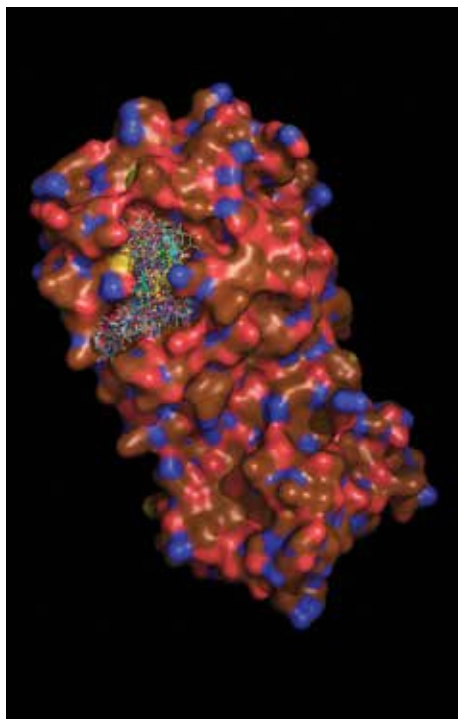
"We instituted this program to recognize and encourage young scientists to explore problems that support and enhance PUNCH mission science," DeForest said. "In addition to lending their unique expertise to the team, we hope the associate investigators will act as liaisons, communicating PUNCH science to the broader solar research community — and community needs back to the project."

The associate investigators appointed are Dr. Raphael Attie, a NASA researcher and assistant professor at George Mason University; Dr. Bea Gallardo-Lacourt, a post-doctorate researcher at NASA's Goddard Space Flight Center from Universities Space Research Association; Chris Gilly, a graduate research assistant from the University of Colorado Boulder; and Dr. Elena Provornikova, who is on the senior research staff at Johns Hopkins University Applied Physics Laboratory.



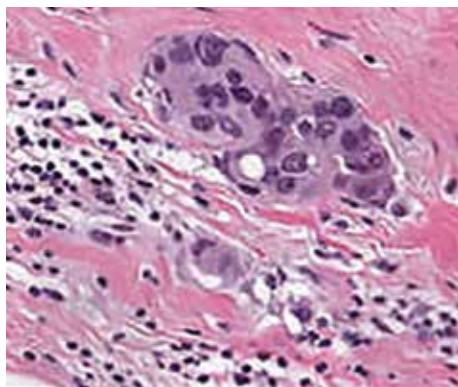
PUNCH's four suitcase-sized satellites will be launched into a polar orbit formation to study how the Sun's outer corona transitions into the solar wind.

SwRI's Rhodium™ virtual screening software used this 3D model of a SARS-CoV-2 protease to evaluate millions of drug compounds to identify therapies effective against COVID-19. Rhodium is now being used to attack the virus from a different angle, evaluating compounds that stop a virus protein from entering human cells.



D024880

SwRI Collaborates on Bioscience Projects



D024911

These images show a tumor sample (top) and cancer cells detected in that sample (bottom) using an SwRI machine learning algorithm. Artificial intelligence improves the speed and accuracy of cancer diagnosis and treatment, leading to better outcomes for patients.

Collaborative teams that include SwRI staff received two of six recently awarded San Antonio Medical Foundation (SAMF) bioscience grants. SwRI, in collaboration with UT Health San Antonio and University Health System, received a nearly \$200,000 grant to develop machine learning algorithms for cancer detection. A team from SwRI, UT Health San Antonio, The University of Texas at San Antonio and Texas Biomedical Research Institute also received a grant of nearly \$200,000 for its work to identify drug molecules that interfere with the entry of SARS-CoV-2, the virus that causes COVID-19, into human cells.

A team including Hakima Ibaroudene, a program manager, and David Chambers, a principal engineer, in SwRI's Intelligent Systems Division is developing cancer detection algorithms using artificial intelligence (AI) to improve the speed and accuracy of cancer diagnosis and treatment, leading to better outcomes for patients. AI involves training a computer to recognize patterns and make predictions. Researchers will focus on follicular lymphoma, a type of non-Hodgkin's lymphoma, and Philadelphia chromosome-negative myeloproliferative neoplasms, malignancies caused by mutated bone marrow stem cells. They are training an algorithm to quantify immune cells and proteins expressed by these cancer cells, eliminating the guesswork for pathologists and providing information about tumor characteristics to guide treatment.

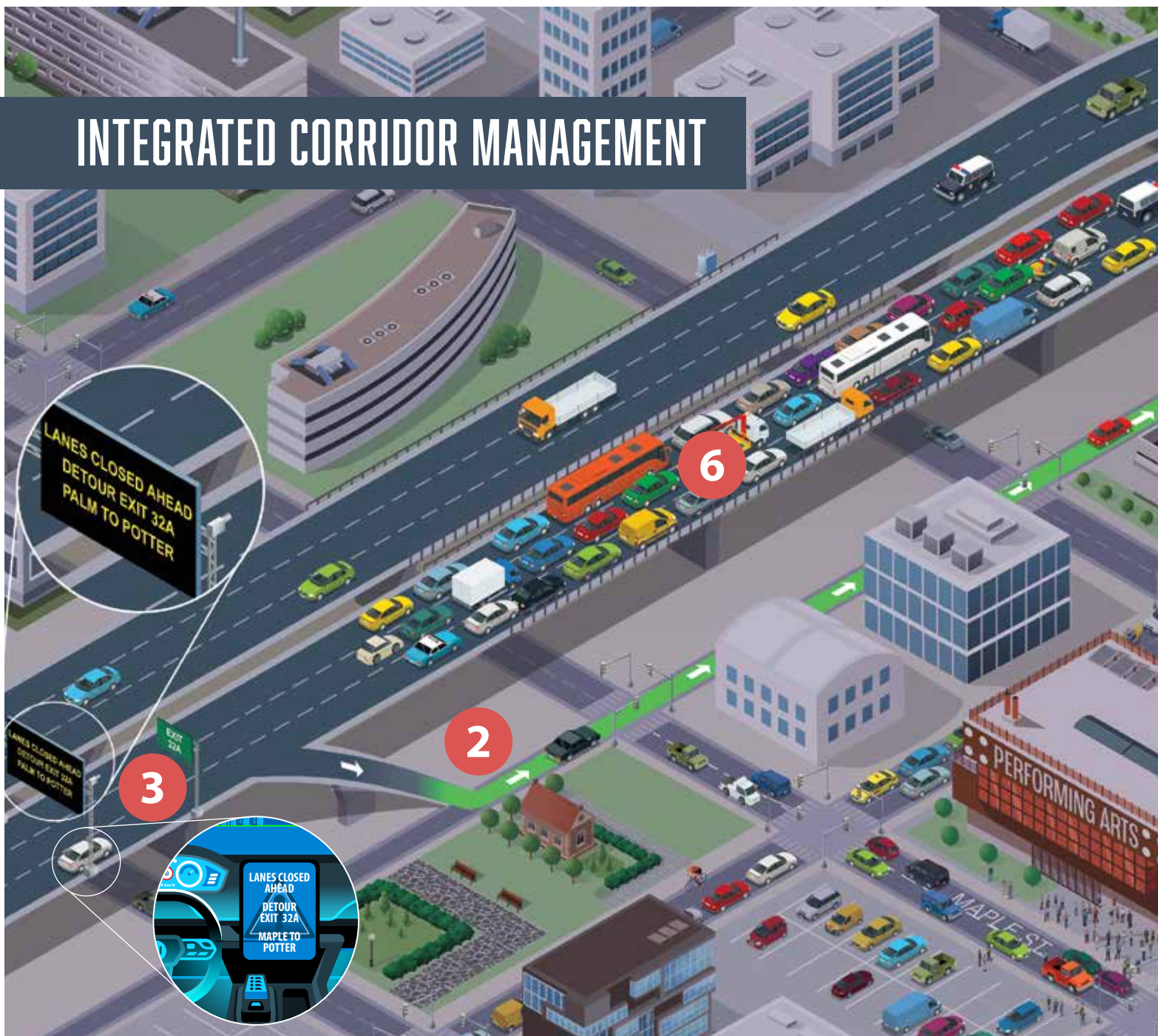
"AI can improve diagnosis and prognosis by analyzing patterns that may be overlooked or are not easily visible to the pathologist," Ibaroudene said. "It allows a deeper analysis of statistics across sets of images and more precisely quantifies cells and their attributes. The ultimate goal is to give the patient the best chance for successful treatment."

Dr. Jonathan Bohmann, a staff scientist in SwRI's Chemistry and Chemical Engineering Division, jointly leads a team identifying drug compounds that thwart SARS-CoV-2. The highly infectious virus spreads by entering host cells. Using SwRI's Rhodium™ virtual screening software to survey 2 million drugs, the team is looking for compounds that interrupt the binding action between the virus protein and host cells to prevent infection.

"I am eager to be a part of this critical collaboration to identify drug molecules that interrupt the virus' attack on human cells," Bohmann said. "The goal of this research is to develop sets of candidate drug compounds that stop the virus' entry process. The SAMF funding allows us to focus on this piece of the puzzle and gather vital data, which will move us into safety testing, the next phase of study."

The nonprofit San Antonio Medical Foundation awarded six grants totaling more than \$1 million in this round of funding from a pool of 44 applicants. Grant proposals were selected based on collaborative effort, how well the projects leverage the strengths of each institution, and whether the work will raise the national and international research profile of the San Antonio bioscience community.

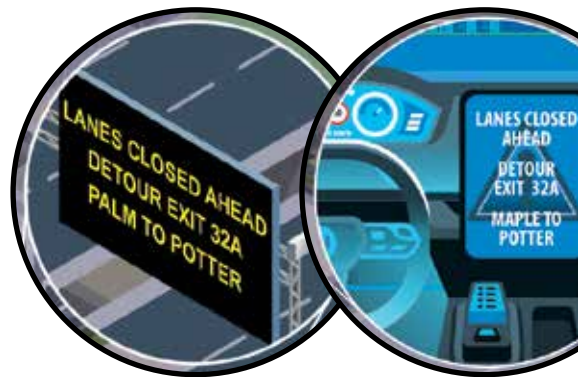
INTEGRATED CORRIDOR MANAGEMENT



1 ICM detects incident & evaluates response



2 ICM recommends new route



3 ICM communicates new routing

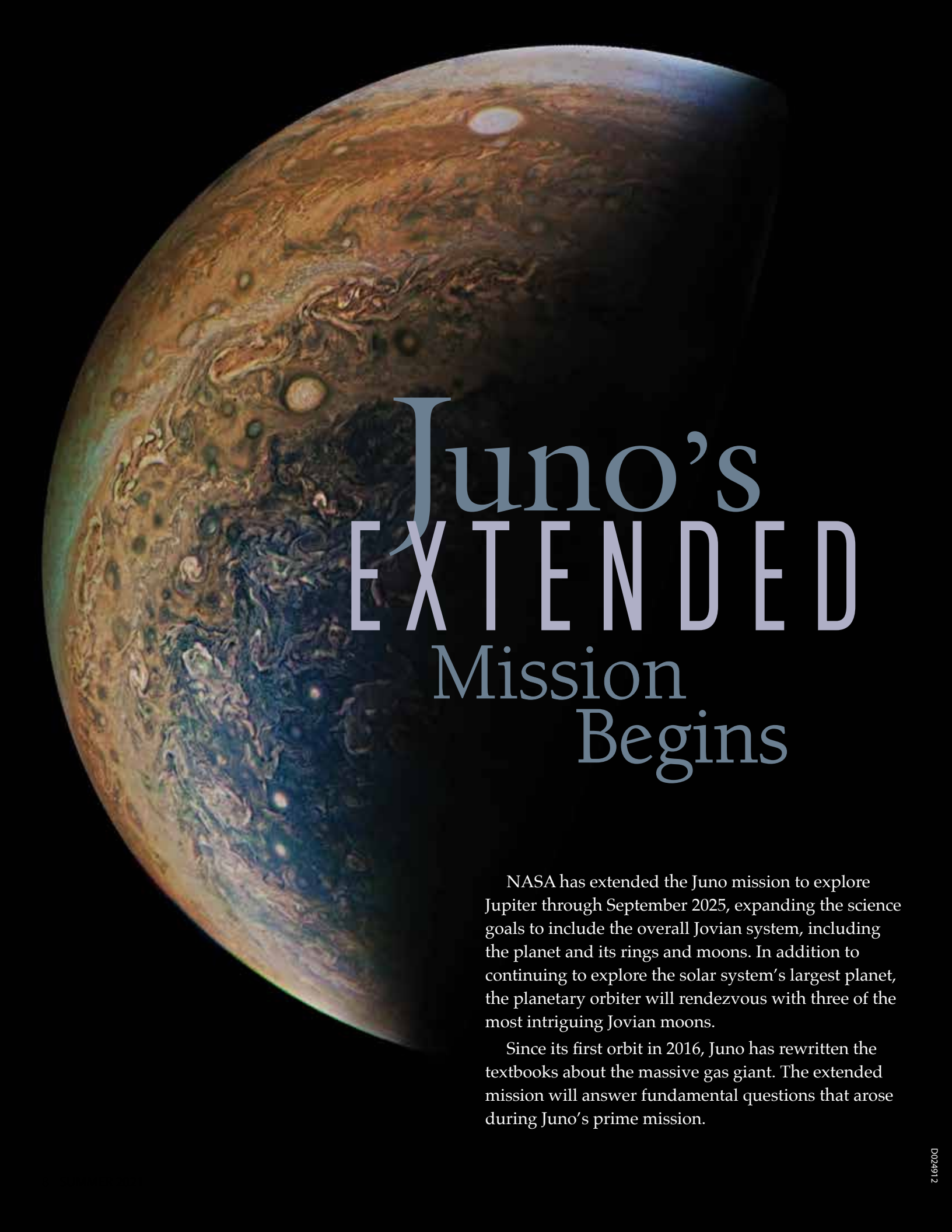


SwRI develops integrated corridor management (ICM) systems to optimize the performance of a regional transportation system as an integrated network rather than independently operated assets. ICM systems coordinate across freeways, surface streets and transit systems to balance traffic flow and improve performance of the entire corridor. These systems rely on fusing tremendous amounts of data from various public and private sources.

For example, SwRI is developing technology to improve traffic incident response through data fusion and analysis of third party and crowdsourced data.

SwRI is automating a coordinated incident response using a decision support system, integrating transportation management systems, regional operators and infrastructure into a seamless real-time corridor solution.





Juno's EXTENDED Mission Begins

NASA has extended the Juno mission to explore Jupiter through September 2025, expanding the science goals to include the overall Jovian system, including the planet and its rings and moons. In addition to continuing to explore the solar system's largest planet, the planetary orbiter will rendezvous with three of the most intriguing Jovian moons.

Since its first orbit in 2016, Juno has rewritten the textbooks about the massive gas giant. The extended mission will answer fundamental questions that arose during Juno's prime mission.

Juno was proposed in 2003 by a team led by SwRI's Dr. Scott Bolton and launched in 2011. As the prime mission was wrapping up, the spacecraft and its instruments remained healthy, allowing for a mission extension beginning in August 2021. This expanded mission includes 42 additional orbits including close passes over Jupiter's north polar cyclones and flybys of the Galilean moons Ganymede, Europa and Io, as well as the first extensive exploration of Jupiter's ring system.

The extended mission's science campaigns expand on discoveries Juno has already made about Jupiter's interior structure, internal magnetic field, magnetosphere and atmosphere, including its polar cyclones and auroras. With this extension, Juno essentially has become its own follow-on mission. Close-up observations of the poles, radio occultations, Galilean moon flybys, and focused magnetic field studies combine to make a new mission, the next logical step in the exploration of the Jovian system.

For example, scientists will target Jupiter's enigmatic "Great Blue Spot," an isolated patch near the planet's equator exhibiting an intense magnetic field, deploying high spatial resolution magnetic surveys during six flybys. As Juno's orbit evolves, two flybys of Ganymede, three of Europa and 11 of Io are planned en route to multiple passages through Jupiter's tenuous rings.

The natural evolution of Juno's polar orbit around the gas giant provides new science, and the extension was crafted to conserve the mission's single most valuable resource — fuel. Gravity assists from the multiple flybys of Jupiter's moons will steer the spacecraft through the Jovian system while providing a wealth of science opportunities.

As the prime mission was coming to a close, Juno buzzed its largest moon Ganymede and scientists made several interesting new discoveries about Jupiter's auroras, stratospheric winds and meteorite impacts as well as finding evidence for the source of Earth's zodiacal lights, vertical phenomena seen at dusk and dawn.

BUZZING GANYMEDE

The science team has received the first images from NASA Juno's June 7, 2021, flyby of Jupiter's giant moon Ganymede. The photos — one from the Jupiter orbiter's JunoCam imager and the other from its Stellar Reference Unit star camera — show the surface in remarkable detail, including craters, distinct dark and bright terrain, and long structural features possibly linked to tectonic faults.

The spacecraft's JunoCam visible-light imager captured almost an entire side of the water-ice-encrusted moon, providing a color portrait of Ganymede at a resolution of about 0.6 miles (1 kilometer) per pixel.

In addition, Juno's Stellar Reference Unit, a navigation camera that keeps the spacecraft on course, provided a black-and-white picture of Ganymede's dark side (the side opposite the Sun) bathed in dim light scattered off Jupiter. Image resolution is between 0.37 and 0.56 miles (600 to 900 meters) per pixel.

The solar-powered spacecraft's encounter with the Jovian moon is expected to yield insights into its composition, ionosphere, magnetosphere and ice shell while also providing measurements of the radiation environment that will benefit future missions to the Jovian system.

NEW AURORAL FEATURES

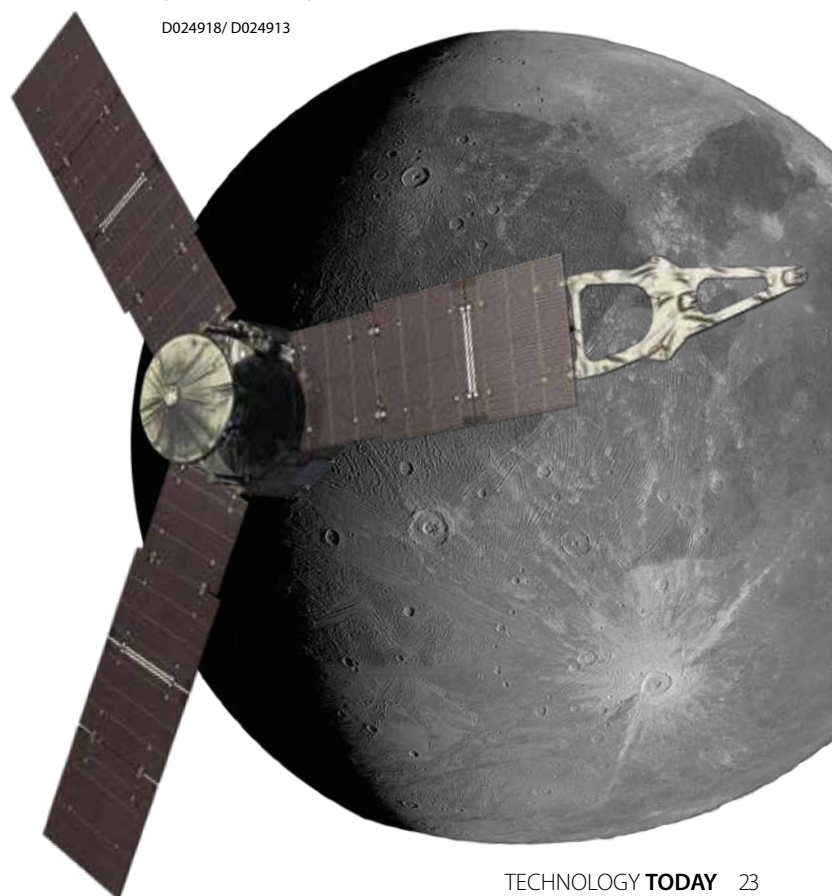
The SwRI-led Ultraviolet Spectrograph (UVS) orbiting Jupiter aboard Juno has detected new faint aurora features, characterized by ring-like emissions that expand rapidly over time. SwRI scientists determined that charged particles coming from the edge of Jupiter's massive magnetosphere likely triggered these auroral emissions.

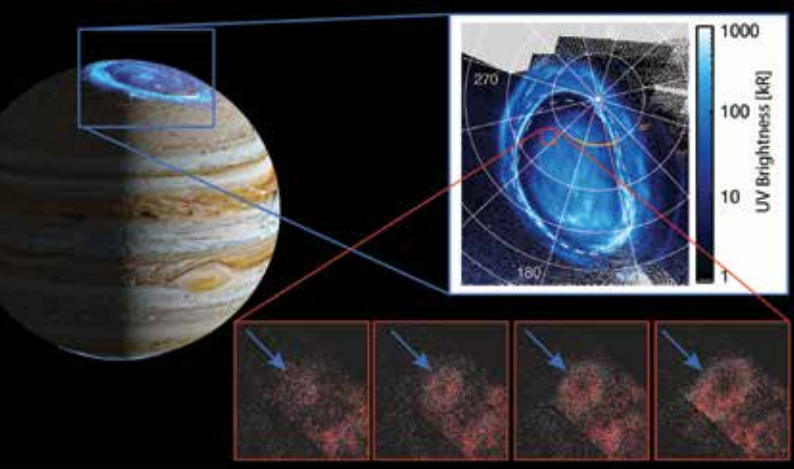
A team led by SwRI's Dr. Vincent Hue thinks these newly discovered faint ultraviolet features originate millions of miles away from Jupiter, near the Jovian magnetosphere's boundary with the solar wind. The solar wind is a supersonic stream of charged particles emitted by the Sun. When they reach Jupiter, they interact with its magnetosphere in a way that is still not well understood.

Previous observations with the Hubble Space Telescope and Juno have allowed scientists to determine that most of Jupiter's powerful auroras are generated by processes essentially related to the planet's rapid 10-hour rotation. However, on numerous occasions, UVS has detected a faint type of aurora, characterized by rings of emissions expanding rapidly with time.

The Juno spacecraft flew closer than any other in more than two decades to Jupiter's largest moon Ganymede, offering dramatic glimpses of the icy orb.

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The SwRI-led UVS instruments allowed scientists to discover faint aurora features likely triggered by charged particles coming from the edge of Jupiter's massive magnetosphere. This occurrence, shown in the false color series of images recorded 30 seconds apart (red panels), displays the characteristically ring-like emissions, expanding rapidly over time.

The high-latitude location of the rings indicates that the particles causing the emissions are coming from the distant Jovian magnetosphere, near its boundary with the solar wind. In this region, plasma from the solar wind often interacts with the Jovian plasma in a way that is thought to form "Kelvin-Helmholtz" instabilities. These phenomena are associated with shear velocities, such as at the interface between two fluids moving at different speeds. Another possible candidate to produce the rings is dayside magnetic reconnection events, where oppositely directed Jovian and interplanetary magnetic fields converge, rearrange and reconnect.

Both of these processes are thought to generate particle beams that could travel along the Jovian magnetic field lines, to eventually precipitate and trigger the ring auroras on Jupiter. The Juno extended mission will capture and study more of these faint transient events to isolate the causes. For more information, see the JGR Space Physics paper about this research at doi.org/10.1029/2020JA028971.

STRATOSPHERIC WINDS

Working with a team led by French astronomers, SwRI scientists helped identify incredibly powerful winds in Jupiter's middle atmosphere for the first time. The team measured molecules exhumed by the 1994 impact of comet Shoemaker-Levy 9 to trace winds in excess of 900 miles per hour near Jupiter's poles.

Jupiter's distinctive orange and white bands of swirling clouds allow scientists to track winds in the planet's lower atmosphere, and the SwRI team members have particular expertise in the vivid Jovian aurora, associated with strong winds in the gas giant's upper atmosphere. Until now, wind patterns in the cloudless stratosphere, between the two atmospheric layers, have eluded observation.

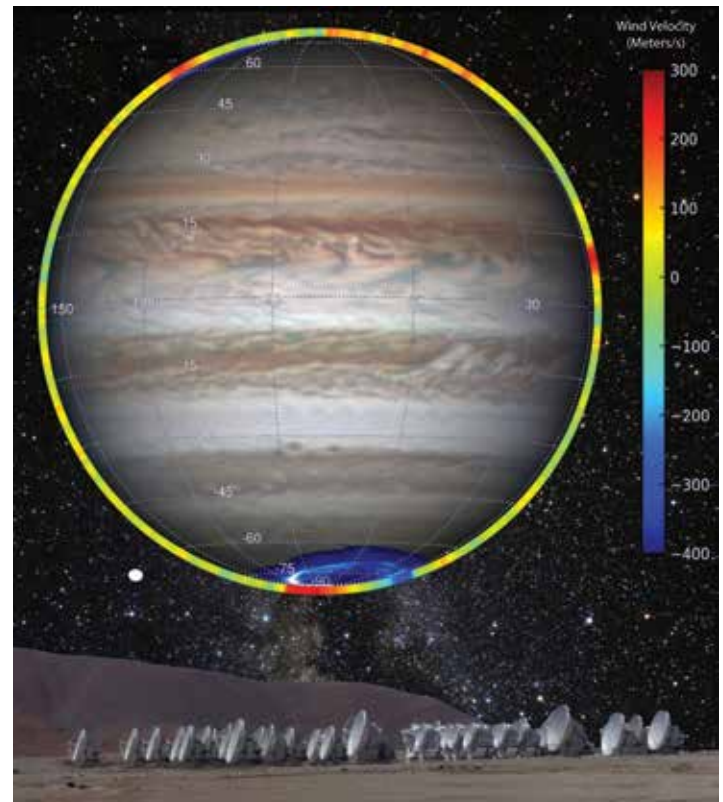
The team of astronomers led by Laboratoire d'Astrophysique de Bordeaux (LAB) in France got creative using the Atacama Large

Millimeter/submillimeter Array (ALMA) radio telescope facility — the largest astronomical radio facility in the world — to measure stratospheric winds for the first time. They followed fallout from a long-ago comet impact to track molecular evidence, specifically hydrogen cyanide, to measure stratospheric 'jets' — like Earth's high-altitude jet streams — on Jupiter.

Previous studies predicted that upper-atmosphere winds would decrease in velocity and disappear well before reaching as deep as the stratosphere. The new ALMA data beg to differ, finding surprisingly strong stratospheric winds near Jupiter's pole. Using 42 of ALMA's 66 high-precision antennas, the team measured the Doppler shift of hydrogen cyanide molecules — tiny changes in the frequency of radiation emitted by the molecules — caused by the winds in this region of the planet.

In addition to the surprising polar winds, the team also confirmed the existence of strong stratospheric winds around the planet's equator. The jets spotted in this part of the planet have average speeds of about 370 mph. For more information about this research, see the Astronomy & Astrophysics paper at doi.org/10.1051/0004-6361/202140330. Dr. Thibault Cavalié of the Laboratoire d'Astrophysique de Bordeaux is the lead author.

D024915



SwRI scientists collaborated on a French-led study that identified remarkably powerful polar winds in Jupiter's stratosphere, expressed in this March 22, 2017, composite image. Using ALMA observations, the team discovered that the most remarkable jet (in red and blue) aligns with Jupiter's southern aurora, studied with the SwRI-led UVS instrument. Wind speeds were measured up to 400 meters per second (900 miles per hour).

EXPLODING METEORITE

From aboard the Juno spacecraft, an SwRI-led instrument observing auroras serendipitously spotted a bright flash above Jupiter's clouds. The UVS team studied the data and determined that they had captured a bolide, an extremely bright meteoroid explosion in the gas giant's upper atmosphere.

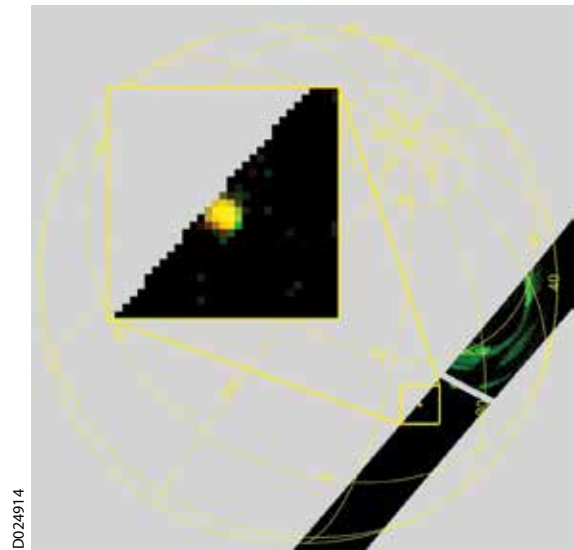
Impacts themselves are not rare, but they are short-lived, so it is relatively unusual to see them. Only larger impacts can be seen from Earth, and a telescope must be pointed at Jupiter at exactly the right time and place. The primary goal of the UVS instrument is to study the morphology, brightness and spectral characteristics of Jupiter's auroras as the spacecraft cartwheels close to the planet every 53 days. Each time the spacecraft spins around its own axis, UVS observes a swath of the planet. In addition to the auroras, these observation swaths occasionally show short-lived, localized ultraviolet emissions outside of the auroral zone, including this singular event on April 10, 2020.

The flash lasted at least 17 milliseconds but not much more, as it was not seen on an earlier or later spin. The team, led by SwRI's Dr. Rohini Giles, initially thought this bright flash might be a Transient Luminous Event (TLE), an atmospheric phenomenon caused by lightning activity; however, it was different in two key ways. It lasted much longer than a TLE, which is only a few milliseconds long, and it had very different spectral characteristics. This bolide event had a smooth "black-body" curve, which is what is expected from a meteor. Based on the brightness of the flash, scientists estimated it was caused by an impactor with a mass of 550–3,300 pounds.

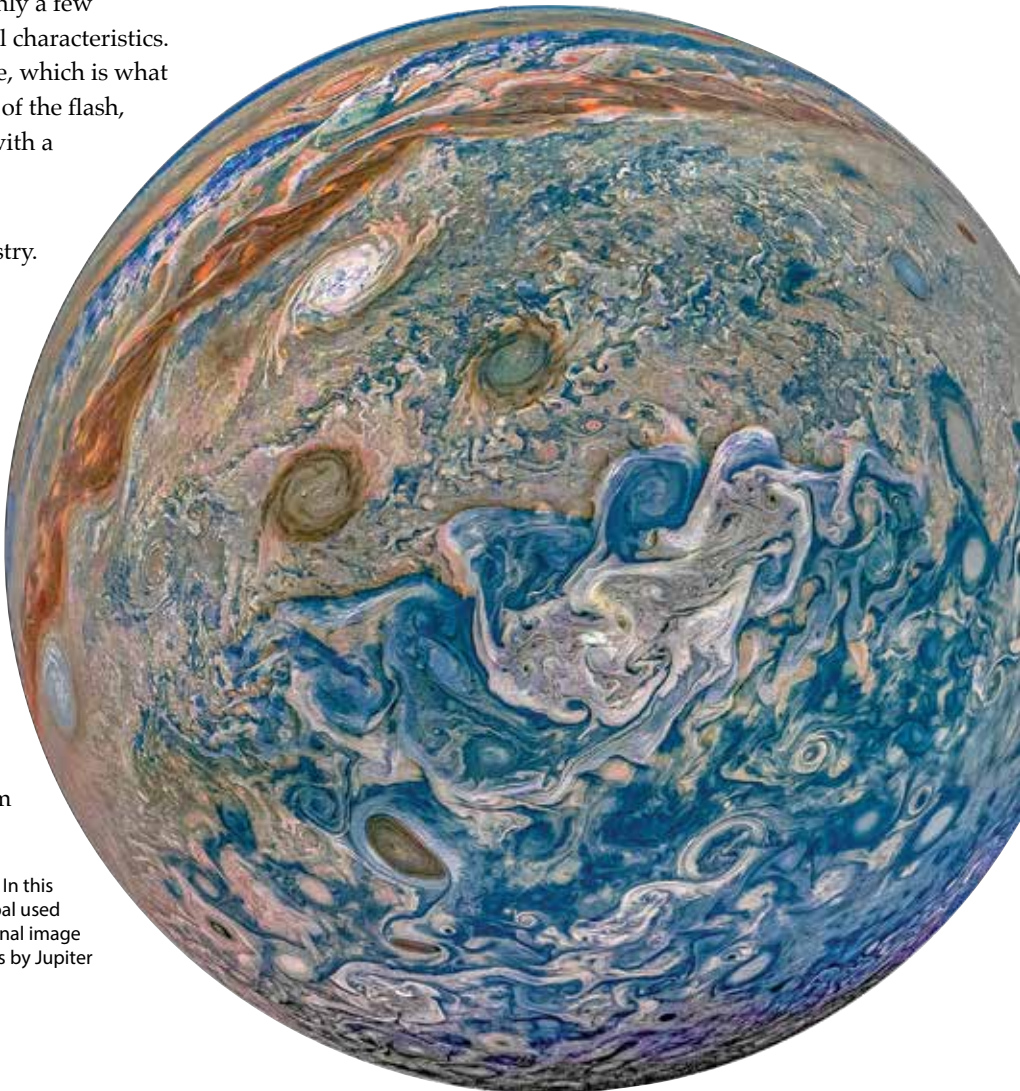
Impacts from asteroids and comets can have a significant impact on Jupiter's stratospheric chemistry. For example, 15 years after the impact of comet Shoemaker-Levy 9, it is still responsible for 95% of the planet's stratospheric water. Continuing to observe impacts and estimating the overall impact rates is an important element of understanding Jupiter's composition. For more information, see the Geophysical Research Letters paper about this research at doi/full/10.1029/2020GL091797.

ZODIACAL LIGHT

Sunlight reflected by a cloud of tiny dust particles orbiting the Sun creates zodiacal light, a faint column of light on the Earth's horizon before dawn or after dusk. Previously, scientists thought asteroids and comets from the outer solar system brought this dust into the inner region. Now, a team



SwRI scientists studied the area imaged by Juno's UVS instrument on April 10, 2020, and determined that a large meteoroid had exploded in a bright fireball in Jupiter's upper atmosphere. The UVS swath includes a segment of Jupiter's northern auroral oval, appearing purely in green, representing hydrogen emissions. In contrast, the bright spot (see enlargement) appears mostly yellow, indicating significant emissions at longer wavelengths.



Jupiter inspires artists and scientists with its beauty. In this image, south is up, and citizen scientist Prateek Sarpal used enhanced color to evoke an exotic marble. The original image was captured by JunoCam on Juno's 22nd close pass by Jupiter on Sept. 12, 2019.

D024917

of Juno scientists argues that Mars may be the source.

An instrument aboard the Juno spacecraft detected dust particles slamming into the spacecraft during its journey from Earth to Jupiter. The impacts provided important clues to the origin and orbital evolution of the dust, resolving some mysterious variations of the zodiacal light.

Examining anomalies in star tracker data, researchers calculated the apparent size and velocity of objects in the images, realizing that dust grains smashing into Juno solar arrays at about 10,000 miles per hour were chipping off submillimeter pieces. Fortunately, Juno's solar arrays escaped harm because the dust hit the backside of the arrays.

The debris tracked interplanetary dust particle impacts, allowing researchers to compile a distribution of dust as the spacecraft traveled to Jupiter. Most dust impacts were recorded between Earth and the asteroid belt. Before now, scientists have been unable to measure the distribution of these dust particles in space. Juno scientists determined that the dust cloud ends at Earth because Earth's gravity sucks up all the dust that gets near it, creating zodiacal light.

The outer edge of the dust cloud ends just beyond Mars, where the influence of Jupiter's gravity acts as a barrier, preventing dust particles from crossing from the inner solar system into deep space and vice versa. Because the only object in this orbit is Mars, scientists inferred that the Red Planet is a source of this dust. How dust escapes the grip of gravity on Mars, the dustiest known planet, remains a mystery. For more information, see the JGR Planets paper about this research at [doi/10.1029/2020JE006509](https://doi.org/10.1029/2020JE006509). The lead author is Dr. John Leif Jørgensen, a professor at the Technical University of Denmark.



This photo shows the zodiacal light as it appeared on March 1, 2021, in Skull Valley, Utah. The Pleiades star cluster is visible near the top of the light column. Mars is just below that.

IMAGE COURTESY NASA/BILL DUNFORD

D024920

INTELLIGENT TRANSPORTATION ADVANCES, INITIATIVES



SwRI, a national leader in intelligent transportation systems (ITS), is launching new initiatives in Tennessee and Pennsylvania. Our ActiveITS advanced traffic management system software already covers more than 10,000 miles of roadways across the United States

We are collaborating with Vanderbilt University to develop machine learning algorithms to help the Tennessee Department of Transportation (TDOT) coordinate traffic management and incident response in the rapidly growing Nashville region. The project will use artificial intelligence to enhance an integrated corridor management (ICM) system, using software and systems to promote smart mobility and improve collaboration among various transportation entities.

"SwRI's ICM solutions fuse data from freeways, surface streets and transit systems to help balance traffic flow and improve performance of the entire corridor," said Samantha Blaisdell, a program manager at SwRI.

Integrated corridor management (ICM) is making its way out of the laboratory and hitting the road following two decades of research led by the Federal Highway Administration. ICM systems manage freeways and arterial roadways with dynamic lane control, speed harmonization, traffic signal control, ramp metering, demand management and other strategies. Deployment, however, has been limited by reliance on conventional traffic simulation modeling, which can be cost-prohibitive due to the time and resources required to develop and maintain traffic models.

Using artificial intelligence instead of simulation models, the system will learn from and mimic operator behavior and decision making. The smart ICM system accelerates accident response and mitigation by

rerouting traffic around problem areas quickly and efficiently while ensuring state and local agency collaboration.

"SwRI's TDOT research aims to overcome the roadblocks of ICM traffic modeling by using artificial intelligence algorithms to speed up the analysis of traffic," said SwRI's Clay Weston, who is leading the project through a TDOT grant funded by the U.S. Department of Transportation. "After training the system using traffic patterns, the algorithms will be able to recommend alternative routes in real time, taking advantage of high-capacity urban roads and surface streets."

Farther to the northeast, SwRI recently began supporting, maintaining and enhancing Pennsylvania's statewide Advanced Traffic Management System (ATMS), supporting PennDOT roadway management. Activities include launching two new initiatives to implement variable speed limits and queue detection and warning systems along I-76, a particularly congested stretch of highway in the Philadelphia area.

Serving roughly 130,000 vehicles per day, this road had 2,580 crashes between 2015 and 2019, highlighting the need to address congestion-related incidents. The goal is to improve traffic flow to reduce stop-and-go conditions and the potential for rear-end crashes. In April, variable speed limit signs began adjusting limits between 35 and 55 miles per hour based on real-time traffic conditions.

"SwRI has been working on variable speed applications for over 15 years, developing the algorithms needed to manage traffic in real time, enhancing driver safety and corridor efficiency," said Dan Rossiter, an assistant program manager at SwRI. "We have researched and implemented similar systems in Texas and Florida."

This is just the first phase of a long-range, comprehensive multimodal transportation management plan designed to enhance travel and safety. SwRI will help PennDOT implement additional active traffic management strategies, modernize traffic signal systems and plan a flexible travel lane to improve traffic flow during peak travel times.



At top, SwRI recently began supporting, maintaining and enhancing Pennsylvania's statewide ATMS software, working on corridor-wide improvement initiatives including variable speed limits.

At left, SwRI is applying machine learning to integrated corridor management systems to improve traffic incident response in Tennessee.

DM24454_0560

SmallSat Added to NASA Catalog

NASA has selected SwRI's 100 kg-class small satellite platform to be listed in the Rapid Spacecraft Development Office (RSDO) IV catalog used by the U.S. government to rapidly contract for flight-proven spacecraft. The Southwest Space Platform-100 (SwSP-100) is now available through the \$6 billion, indefinite delivery/indefinite quantity (IDIQ) Rapid Spacecraft Acquisition IV contract.

According to one industry forecast, as many as 11,600 small satellites — defined in this case as satellites with masses under 500 kilograms — will be placed in orbit between 2018 and 2030, an average of nearly 1,000 per year. Rapid IV contracts serve as a fast and flexible means for the government to acquire spacecraft and related components, equipment and services in support of NASA missions and/or other federal government agencies. The spacecraft designs, related items and services may be tailored, as needed, to meet the unique needs of each mission.

"Being selected for the RSDO IV catalog is a major milestone for the SwRI spacecraft development program," said Michael McLelland, executive director of SwRI's Space Systems Directorate. "Our strong heritage in all phases of science and technology development missions, combined with our collaborative approach to working with customers, makes us an excellent choice as a spacecraft provider for the unique missions developed under RSDO."

Under the RSDO multiple-award IDIQ contracts, SwRI can provide spacecraft and related services that include delivery-on-orbit. The SwSP-100 is a versatile spacecraft platform designed to accommodate a range of missions and their payloads.

"SwRI's SwSP-100 will be listed along with our smaller CYGNSS-based SwSP-35 platform, which was added to the RSDO catalog in 2020," said Randy Rose, technical lead for SwRI's RSDO program. "The combination of SwRI's mission-centric focus and our clients' needs for rapid response is the basis for the SwSP-100 spacecraft. We don't take a one-size-fits-all approach."



D0248771 D024878

Biomechanics Joint Industry Project Launched

SwRI has launched a joint industry project to advance markerless 3D analysis of biomechanics for sports and medical applications.

The Markerless Motion Capture Joint Industry Project (M2CJ) will leverage SwRI-developed BIOCAP™ technology. BIOCAP measures human motion using machine vision, artificial intelligence (AI) deep learning, sensor fusion and biomechanical modeling. Professional and collegiate sports teams, in addition to military and medical personnel, have used BIOCAP to optimize human performance.

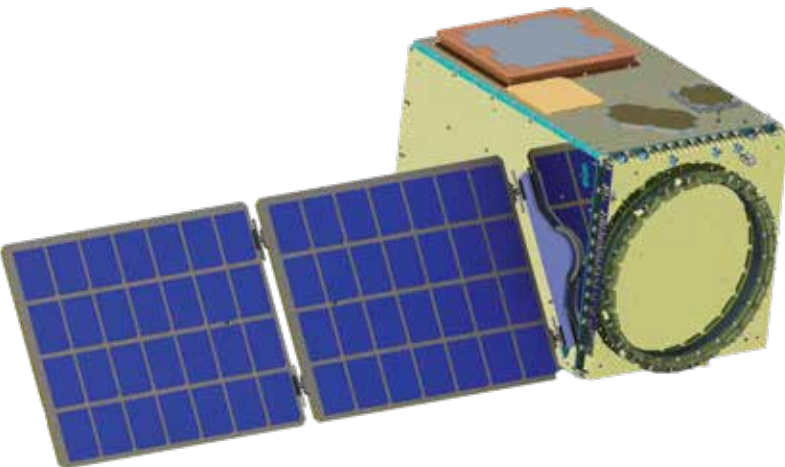
"M2CJ will enable cost-effective precompetitive research and system development through a collaborative forum," said Kase Saylor, codeveloper of the BIOCAP system. "Industry professionals can improve insights with BIOCAP, one of the most accurate markerless biomechanics tools available."

Markerless motion capture leverages computer vision algorithms to circumvent the tedious process of attaching physical body markers to a human subject to capture 3D motion data for biomechanical analysis in research, clinical and sport science applications.

BIOCAP is portable and features a user-friendly graphical interface. It uses off-the-shelf cameras and custom machine learning algorithms to quantify musculoskeletal biomechanical performance related to walking, running, sports and other precise physical movements.

"BIOCAP is a highly accurate technology that uses biomechanically informed models instead of the more commonly used animation-based posed model approach," said Dr. Dan Nicolella, who codirects SwRI's Human Performance Initiative and leads biomechanical research for the Institute. M2CJ will focus on precompetitive technology development, leaving the analytics to participants and their respective organizations.

"The program will bring together a community of professionals to facilitate sharing participant experiences and insights as well as receiving early knowledge of new technological developments in markerless biomechanics analysis," Nicolella said. "This will give participants the confidence and expertise to further develop their own advanced, proprietary analytics."



D024879

FRACKING WITH FOAM

SwRI has completed a pilot-scale facility to create and test natural gas foam as a safe, stable alternative to water for hydraulic fracturing, commonly known as “fracking.” The six-year Department of Energy project shows that natural gas foam can be generated on site at fracking locations, using commercially available products.

Fracking involves injecting high-pressure fluids into deep wells to fracture rock formations and stimulate the flow of oil and natural gas. This process typically requires millions of gallons of water, plus injecting sand and chemicals into these fractures to enhance production. The natural gas byproduct is typically burned off, creating carbon emissions.

“Fracking doesn’t always occur near water resources, so the water has to be trucked in,” said Griffin Beck, the project’s principal investigator. “That process is time-consuming and can wreak havoc on local roads and related transportation infrastructure, not to mention the tens of millions of gallons of water consumed by the fracking process.

Natural gas is available right there, on site.”

Additionally, water can hinder reservoir production in clay, which swells in contact with water, blocking oil flow. In 2014, the SwRI team began exploring creating natural gas foam and using it as an alternative to water in the fracking process.

The team used standard compressors to efficiently pressurize natural gas, then mixed it with water to create foam, slashing the amount of water needed for fracking by 80 percent. After demonstrating that foam could be created on site as an additional step to the fracking process, the team created an apparatus capable of supplying high-pressure foam to a fracture test stand.

The foam can carry sand particles into fractures as efficiently as pressurized water while also producing less swelling in clay environments and possibly increasing production rates. Models indicate a 25% improvement in foam-based oil production. Beck hopes to see the foam method eventually tested in the field.



D024888

SwRI’s pilot-scale facility creates and tests natural gas foam as a safe, stable alternative to water for hydraulic fracturing, commonly known as “fracking.”

NEXT-GENERATION AUTOMOTIVE TECHNOLOGY

The U.S. Department of Energy awarded SwRI a three-year, \$5.25 million contract extension to continue developing its cutting-edge connected and automated vehicle (CAV) technologies that help passenger vehicles operate more efficiently, reducing energy consumption and carbon emissions.

The project is the second phase of the Advanced Research Projects Agency-Energy’s Next-Generation Energy Technologies for Connected and Autonomous On-Road Vehicles (NEXTCAR) program. Phase I focused on developing CAV technologies for all vehicle classes — including cars, trucks and buses — with the goal of reducing energy consumption by 20%. Phase II will build on these goals, integrating technology into light-duty vehicles with Level 4 automation, which allows vehicles to perform all driving operations autonomously with optional human override, to reduce energy consumption by 30%.



“We are excited to have the opportunity to continue developing this technology to optimize vehicle efficiency,” said Scott Hotz, assistant director of the Automotive Propulsion Systems Department. “It will provide enormous benefits to the automotive industry, and more importantly, to the public, by lowering energy consumption and reducing carbon emissions.”

During the first phase, SwRI demonstrated a 20% energy consumption improvement in real-world driving conditions using eco-routing, eco-driving and power-split optimization control algorithms.

“Vehicle connectivity and automation are already being used to effectively improve vehicle safety and driver convenience,” said Sankar Rengarajan, manager of SwRI’s Powertrain Controls Section. “We tapped into those existing data streams and put the information to use in a new way to help us achieve a 22% gain in fuel efficiency.”

In the second phase, SwRI will expand those control strategies. Eco-driving helped the human driver save 10% by making smarter decisions based on traffic information available through connectivity. With the advanced perception and actuation precision of a Level 4 autonomous vehicle, SwRI will expand the eco-driving framework, optimizing for multi-lane dynamics and further reducing energy consumption.

SwRI’s connected and automated vehicle chassis dynamometer interfaces with traffic simulation software to provide a controllable, repeatable environment for testing tools developed for the ARPA-E program. Located at SwRI’s Ann Arbor, Michigan, facility, the dynamometer runs the vehicle in response to traffic information, while a data acquisition system collects relevant operating data to measure efficiency improvements.

D024888

New Timeline for Mars Terrains

An SwRI scientist has updated Mars chronology models to find that terrains shaped by ancient water activity on the planet's surface may be hundreds of millions of years older than previously thought. This new chronology for Mars, based on the latest dynamical models for the formation and evolution of the solar system, is particularly significant as NASA's Mars 2020 Perseverance rover conducts its mission on the Red Planet.

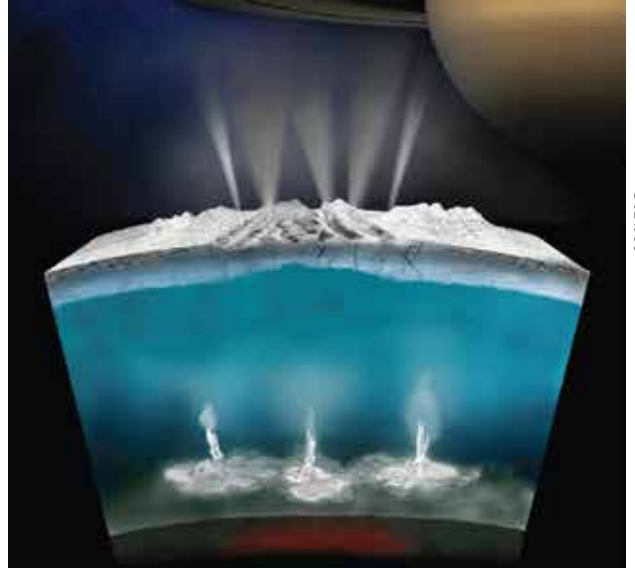
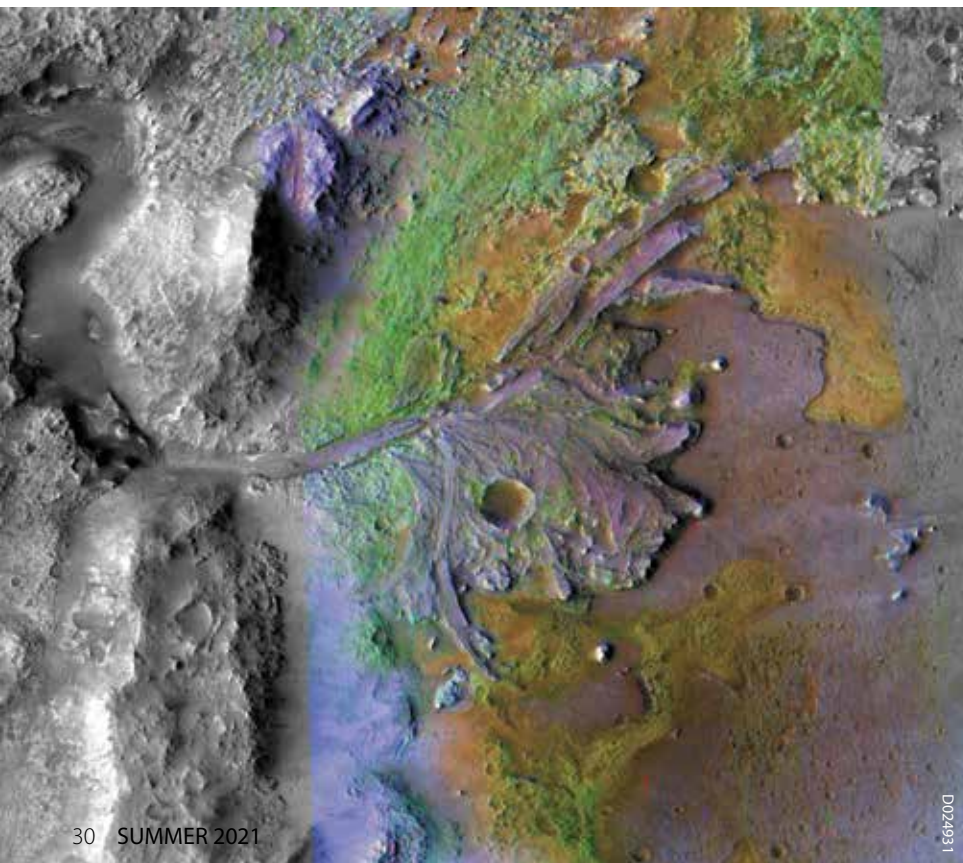
Unlike on Earth, where terrains are commonly dated using the natural radioactivity of rocks, scientists have largely constrained the chronology of Mars by counting impact craters on its surface.

"The idea behind crater dating is not rocket science; the more craters, the older the surface," said Dr. Simone Marchi, who published a paper about these findings in *The Astronomical Journal*. "But the devil is in the details. Craters form when asteroids and comets strike the surface. The rate of these cosmic crashes over the eons is uncertain, hampering our ability to convert crater numbers to terrain ages. I took a fresh look at this and built on recent developments in the way we understand the earliest evolution of the solar system."

Scientists have used radiometric ages of lunar rocks brought back by the Apollo missions of the late 1960s and early 1970s to calibrate a lunar crater chronology. This lunar chronology is then extrapolated to Mars. The new model improves upon how the critical Moon-to-Mars extrapolations are done.

"For this paper, I looked particularly at the Jezero Crater because that is the landing site for the Mars 2020 Perseverance rover," Marchi said. "These surfaces could have formed over 3 billion years ago, as much as 500 million years earlier than previously thought."

Jezero Crater on Mars, the landing site for NASA's Mars 2020 mission, shows evidence of water-carved channels and transported sediments, with colors added to highlight the distribution of clays and carbonates. New Mars chronology models predict that these surfaces could have formed more than 3 billion years ago.



SUBSURFACE OCEANS MAY BE CONDUCTIVE TO LIFE

One of the most profound discoveries in planetary science over the past 25 years is that worlds with oceans beneath layers of rock and ice are common in our solar system. Such worlds include the icy satellites of the giant planets, like Europa, Titan and Enceladus, as well as distant planets like Pluto.

SwRI's Alan Stern thinks the prevalence of interior water ocean worlds (IWOWs) in our solar system suggests they may be common in other star systems as well, vastly expanding the conditions for planetary habitability and biological survival over time.

Worlds with surface oceans, like Earth, must reside in a relatively small "Goldilocks" zone that is neither too hot nor too cold to preserve those oceans. However, IWOWs are found at a wide range of distances from their stars, greatly expanding the number of habitable worlds likely to exist across a galaxy.

Planets like Earth with habitable surfaces face many threats to life, ranging from asteroid and comet impacts to radiation from stellar flares, to nearby supernova explosions and more. Potentially habitable oceans of IWOWs, meanwhile, are protected by a thick roof of ice and rock. "Interior water ocean worlds provide more environmental stability," Stern said.

If such worlds are the predominant abodes for life in the galaxy, and if intelligent life arises in them — both big "ifs," Stern emphasizes — then IWOWs may also help crack the so-called Fermi Paradox. Posed by Nobel Laureate Enrico Fermi in the early 1960s, the Fermi Paradox questions why we have not discovered evidence of life if it's prevalent across the universe.

"The same protective layer of ice and rock that creates stable environments for life also sequesters that life from easy detection," Stern said.

Moons that harbor oceans under a shell of ice, such as Europa and Titan, are already the targets of NASA missions to study the habitability of these worlds.

EXPANDED ANTENNA ANALYSES

To meet the increasing interest in antenna and related services, SwRI's Defense and Intelligence Solutions Division is expanding office space and enlarging high-bay laboratory facilities. The division is also augmenting and improving the Institute's antenna measurement facility to automate precision antenna measurements at extended frequency ranges. This project involves building new facilities including a compact range as well as a spherical near-field antenna range. Near-field testing processes are complex but can provide unexcelled accuracy in compact, controlled laboratory settings. In addition to these facility expansions, the division recently completed AS9100 quality management recertification.

SwRI's 200-acre outdoor radiolocation testing range supports antenna, system and subsystem evaluations. The facility includes a 4,000-square-foot lab, two 70-foot-tall nonconducting towers for mast/tower-mounted antenna testing, an updated control building and this ground-level rotary test facility.

NEW CONSORTIUM TO TARGET "E-FLUIDS"

As electric and hybrid vehicles become increasingly prevalent on roads and highways around the world, SwRI is launching a new Advanced Fluids for Electrified Vehicles (AFEV) consortium to help the industry understand the unique stresses placed on electric vehicle fluids, or "e-fluids." Original equipment manufacturers, lubricant manufacturers and suppliers are invited to join the consortium, which kicked off May 18, to move electric vehicle powertrain advancements forward.

"Having the best lubricant for an application can allow for significant advances in hardware technology for the future," said Peter Morgan, a program manager in the Powertrain Engineering Division. "However, the wrong lubricant can result in very expensive design decisions. As electrified vehicles continue to diverge from conventional internal-combustion powertrains, lubricant requirements are also changing. To optimize the system as a whole, we need to know more about the lubricants' roles."

The consortium will take a multidisciplinary approach to help solve the challenges posed by e-fluids. In addition to powertrain specialists with expertise in automotive hardware, experts in fuels, lubricants and chemistry will round out the consortium management team.

"Like all automotive applications, lubricants and hardware work together to form a complete system," said Rebecca Warden, a manager in the Fuels and Lubricants Research Division. "Electrified vehicle fluids place a stronger importance on heat transfer properties, corrosion resistance, electrical conductivity and performance under high-speed conditions. The variety of architectures and diversity in design on the market and in development will require a different emphasis on fluid performance."

Industry consortia programs are an economical way for companies to maximize their research dollars. Members pay an annual fee for each year of the three-year term, sharing both the costs and benefits of the research.

SwRI will suggest research topics for consideration and provide monthly presentations and progress reports. Potential areas of research include durability, oxidation control, aeration, heat transfer, electrical conductivity and fluid aging. SwRI-funded internal research projects may also complement the consortium's research.

Combining its expertise in powertrain development and automotive fluids, SwRI is targeting electric vehicle fluids, or "e-fluids," as part of the new Advanced Fluids for Electrified Vehicles (AFEV) consortium.



WEBINARS, WORKSHOPS and TRAINING COURSES HOSTED by SwRI:

GD&T (Geometric Dimensioning and Tolerancing) Fundamentals, July 14, 2021. Virtual three-day course.

Dry Gas Seals, July 21, 2021. Free webinar.

Turbine Case Design with ASME VIII-2, July 28, 2021. Free webinar.

Transient Hydraulic Modeling, August 4, 2021. Free webinar.

ISO 9001 Internal Auditor, August 5, 2021. Virtual two-day course.

Rotordynamics Fundamentals, August 11, 2021. Free webinar.

Avoiding Lateral Rotordynamic Instabilities in Turbomachinery, August 18, 2021. Free webinar.

Introduction to CFD for Turbomachinery, August 25, 2021. Free webinar.

Thermal Transient Modeling and Analysis, September 1, 2021. Free webinar.

Thermal Stress Analysis: Balancing Vibrations, Thermal Growth and Flange Loads, September 8, 2021. Free webinar.

Penetration Mechanics Short Course, September 13, 2021. Week-long short course.

Cycle Design & Optimization, September 15, 2021. Free webinar.

CONFERENCES/MEETINGS:

Small Satellite Conference, Virtual, August 7, 2021.

Offshore Technology Conference, Houston, August 16, 2021, Booth No. 3014.

36th Space Symposium, Colorado Springs, CO, August 21, 2021.

Texas Groundwater Summit, San Antonio, August 31, 2021.

Technology & Maintenance Council (TMC) Annual Meeting, Cleveland, September 12, 2021, Booth No. 4040.

Digital Avionics Systems Conference (DASC), San Antonio, September 26, 2021.

American Association of Petroleum Geologists (AAPG), Denver, September 26, 2021, Booth No. 608.

31

presentations
given



at 31

virtual
conferences



by the numbers

SPRING 2021 –
SUMMER 2021



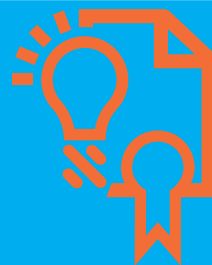
10

papers
published in



4

publications



3

patents
awarded

D019345_0953



Dr. Scott Bolton, associate vice president of SwRI's Space Science and Engineering Division, recently received the National Space Society's 2020 Space Pioneer Award for his accomplishments as principal investigator of the Juno mission and for his role in opening space frontiers.

D024892



Dr. David Ferrill, an Institute scientist in SwRI's Space Science and Engineering Division, was recently elected as a Fellow of the Geological Society of America. This honor recognizes his outstanding contributions to structural geology focused on the understanding of deformation processes and their consequences.

D021468



Dr. Stephen Fuselier, executive director of SwRI's Space Science Directorate, was elected a member of the National Academy of Sciences (NAS), one of the highest honors given to a scientist or engineer in the United States. With this distinction, Fuselier was also elected to the Academy of Medicine, Engineering & Science of Texas (TAMEST).

D023568



Svtlana Kroll, a principal scientist in SwRI's Powertrain Engineering Division, has been selected to receive the Forest R. McFarland Award, presented by SAE International, whose mission is to advance mobility knowledge and solutions for the benefit of humanity.

D022790



Rebecca Nunu, a scientist in SwRI's Space Science and Engineering Division, recently received the Outstanding Thesis Award from the University of Texas at San Antonio. Nunu graduated in December with a master's in geology. The award recognizes the top thesis in UTSA's College of Sciences for 2020.

D024890



Dr. Andrés Munoz-Jaramillo, a lead scientist in SwRI's Space Science and Engineering Division, was recently appointed to the National Academy's Committee on Solar and Space Physics. The committee will contribute to "Decadal Surveys" developed to determine heliophysics research priorities over the next 10 years.

D024423_8509



Dr. James Walker, a director in SwRI's Mechanical Engineering Division, has published a new textbook, "Modern Impact and Penetration Mechanics," a guide to extreme dynamic events. The graduate text describes the mechanics and material models used in understanding impact and penetration events.

SUMMER 2021 • VOLUME 42, NO. 2

TECHNOLOGY TODAY

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