National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
www.jpl.nasa.gov

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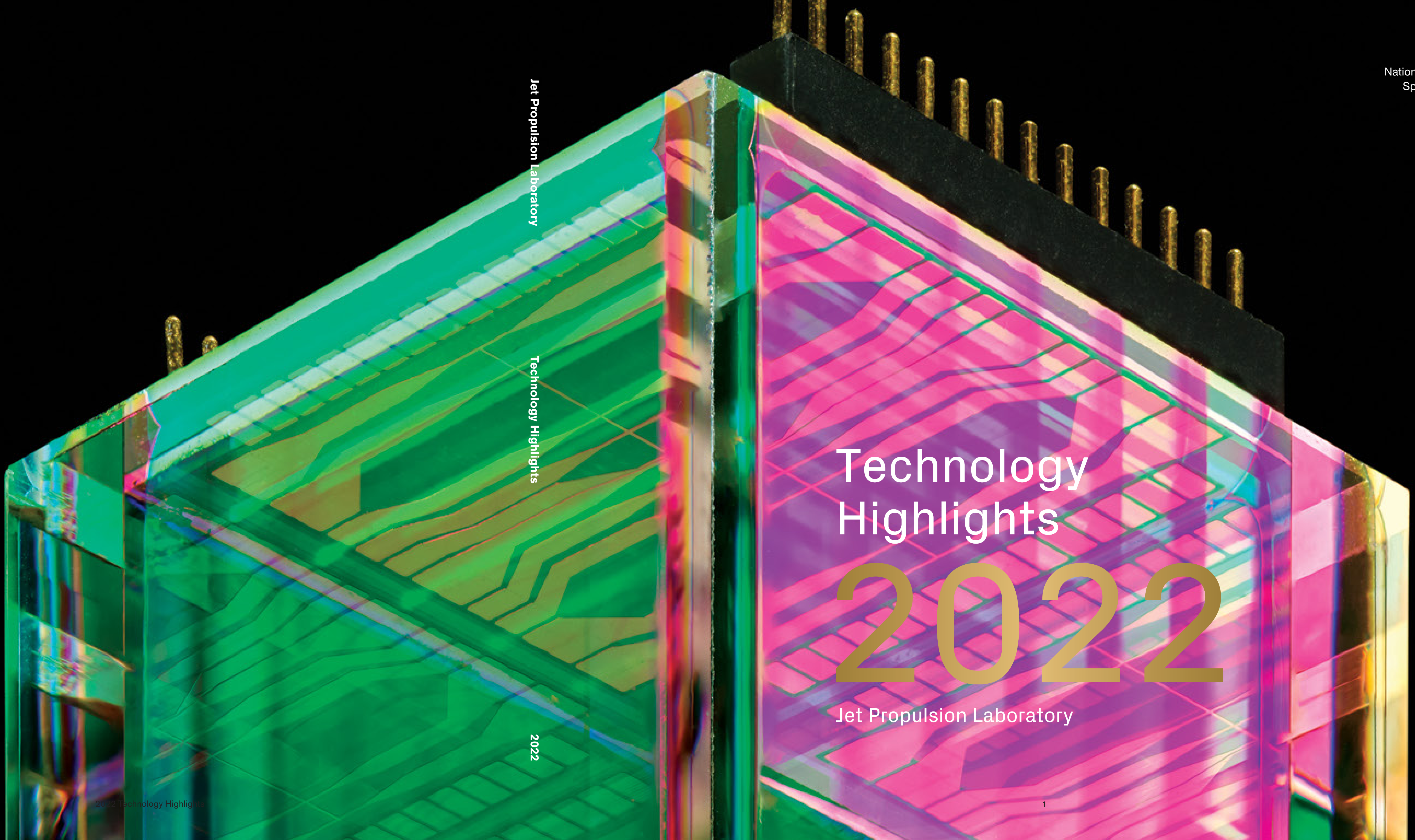


Jet Propulsion Laboratory Technology Highlights 2022

National Aeronautics and
Space Administration

Technology Highlights

2022

Jet Propulsion Laboratory

Office of the JPL Director
Laurie Leshin

Laurie Leshin | JPL Director

At JPL we are dedicated to driving the forefront of scientific discovery and enabling extraordinary benefit to humanity. The technology we develop impacts our Earth, astrophysics, and planetary science missions, enabling us to share our discoveries with the world.

Groundbreaking measurements from the Earth Surface Mineral Dust Source Investigation (EMIT) are bringing new understanding to the role of dust and methane "super-emitters" on climate change. Spectacular images from the Mid-Infrared Instrument on the James Webb Space Telescope, made possible by JPL focal plane and detector technology, are changing how we view our universe. The Perseverance mission has successfully cached rock and soil samples, and numerous key technological advances are currently in development to ensure their safe return to Earth.

Today, we are in the midst of a renaissance in space exploration where our ability to lead within our industry, and achieve future mission success, is dependent on how we seed our forward-looking ventures. These themes of *succeed*, *seed*, and *lead* are prevalent within the technologies highlighted in this book and are a product of our creative teams and global partnerships. I invite you to join us on this journey of discovery as *we dare mighty things together*.

Atomic Chips!

Ultracold Atoms Make Cool Sensors

When chilled to near absolute zero and confined in a trap, neutral atoms can collectively become a coherent quantum gas, a cloud of indistinguishable particles that together exhibit unique properties. This state of matter, called a Bose-Einstein Condensate (BEC), less than 100 microns in size, can exhibit macroscopic quantum behavior such as wavefunction interference, enabling ultra-precise instruments like clocks, accelerometers, and gravity sensors.

New sensors that operate in quantum states may revolutionize remote sensing technology.

JPL technologists, collaborating with ColdQuanta Inc., have developed low-power "atom chips" that use microelectronics and small wires carrying electrical currents, switched every couple of seconds, to manage the BEC cloud. Because of the strong fields and gradients near the wires, these chips can harness and control the ultracold BEC atoms despite their neutrality.

While this quantum-mechanical sensor technology is in its infancy, the next generation could provide instruments much smaller and requiring less power than those currently in use, enabling greater science returns and untold possibilities.

A state-of-the art glass cell is integrated with an "atom chip" forming the top surface about one-inch (two-centimeters) across. Inside this compact vacuum chamber, physicists orchestrate a series of precisely timed cooling stages by applying laser beams, dynamic magnetic fields and chirped radio waves, culminating in a condensed cloud of quantum gas near absolute zero.

Office of the JPL Chief Technologist
Tom Cwik

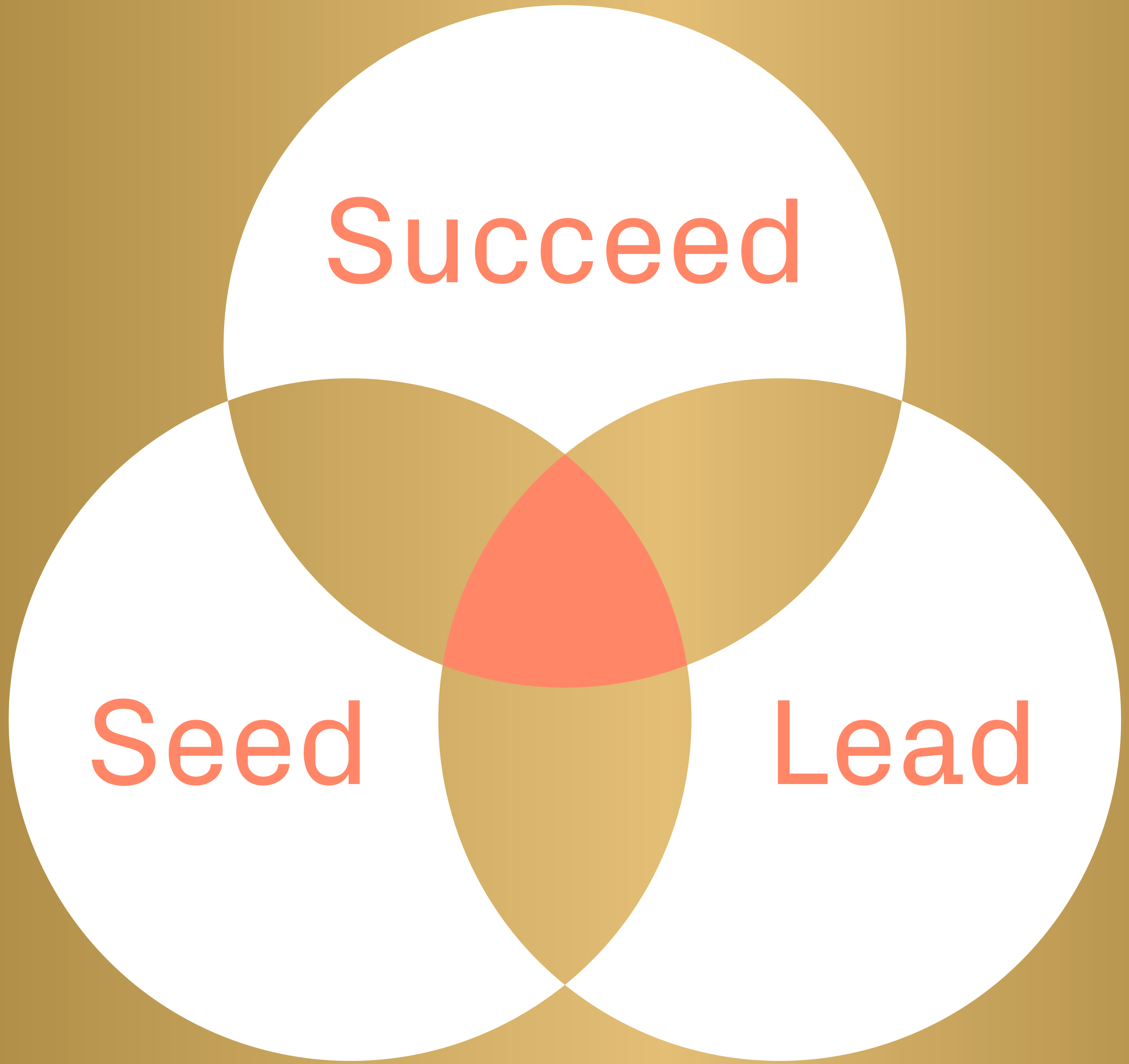
Tom Cwik | JPL Chief Technologist

At JPL, we dare mighty things together. We dare as a laboratory, and as a global community, to explore our Earth, the planets, and the stars beyond. We dare with every student who explores these places through our images, and with everyone who stares into the night sky with wonder.

Our inherent desire to explore beyond where we've been starts by asking daring questions: are there other planets like ours; how is our home planet changing; and what possible impacts will there be? Inspired and seeking answers, we consider technologies that will lead to solutions—and when current technologies fail to meet our goals, we seek to create new technologies to push beyond.

Our imagination is the birthplace of new ideas fostered through collaborations both internal and external to JPL. As you will see, these range from devices built at the atomic level, to miniaturized spectrometers that examine the faintest inner workings of other stars, to information systems that combine our observed data with predictive models. Each of these innovations result from existing science questions, or motivates a new set of questions, jointly pursued through the ingenuity of technologists working in close collaboration with scientists and engineers.

Please enjoy this brief sample of our work, and after reviewing these technology highlights, flip to the back pages to see the people that are pushing us boldly into new frontiers, a journey that will benefit everyone on Earth.

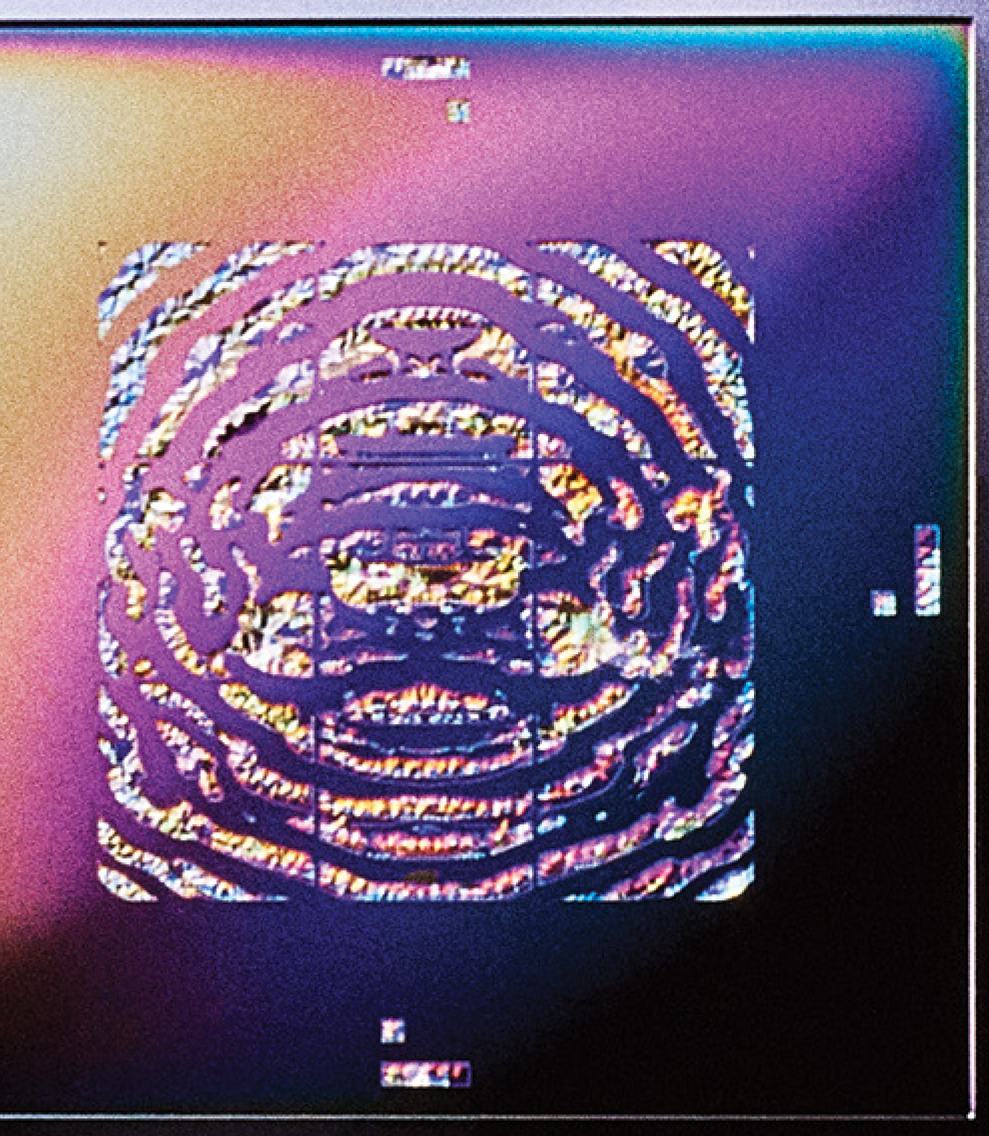


Technology enables our strategic imperatives.

Succeed:
We drive discovery through mission success.

Seed:
We constantly look over the horizon to deepen our capabilities.

Lead:
We remain inspirational within a changing space ecosystem.

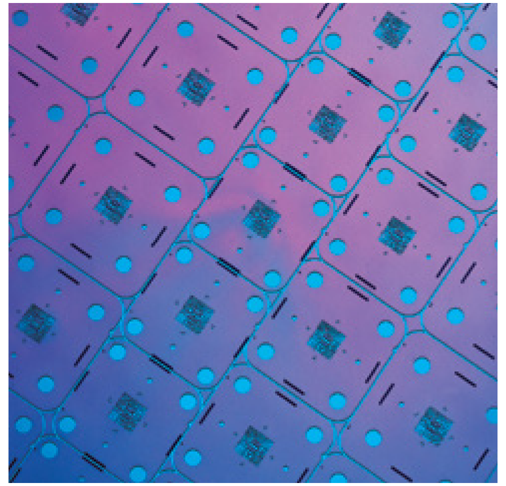


The Meta(uni)verse

Optical Systems Made of Layered Tiny Wavelength-Size Cubes

An extreme close-up of JPL's new volumetric metaoptics device.

A new class of optical systems called volumetric metaoptics can be customized for specific purposes.



Individual layers of a volumetric metaoptics device being fabricated on a silicon wafer. The different squares seen here will ultimately be stacked to make a 3D optical device for a compact spectrometer.

Lenses have been the lifeblood of optical observation for centuries. Every spacecraft with an optical component—cameras and telescopes, for example—has flown with intricately-crafted lenses, often in complex optical trains. The results have been stunning—just look at the incredible legacy of the Hubble Space Telescope as an example.

However, some instruments don't create dramatic visual images, but are designed to provide input for spectrometers and other non-imaging devices that make other types of observations. While classic optical designs have served well in producing high-resolution images, they are not always perfectly suited to the task at hand, may not work in the spectral regions of interest, and can become complex, bulky, and heavy by the time they are flown.

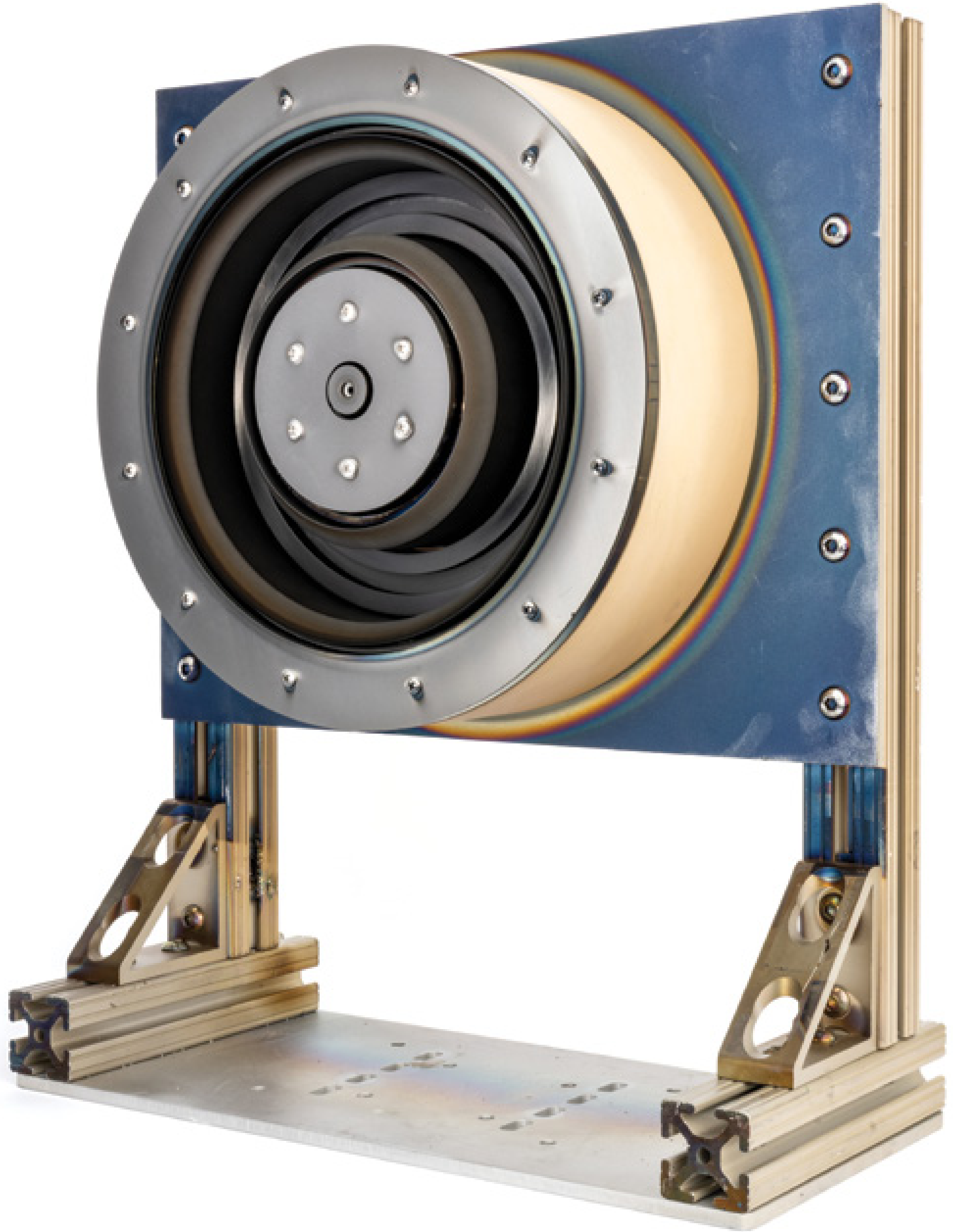
JPL engineers have gone back to the drawing board to take a fresh look at how to more efficiently achieve some types of optically-based tasks. This involves evaluating literally billions of possible designs to come up with a system that will fulfill requirements in the simplest, most elegant way possible using modern computational algorithms that can sort through countless possible variants quickly and efficiently.

The resulting devices involve stacked optical layers patterned with incredibly small cubes only a few wavelengths in length per side. Called volumetric metaoptics, they perform functions that cannot be achieved by traditional crystalline optics. The resulting systems are optimized specifically for their purpose and are used in devices such as THz spectrometers—devices that can focus light onto detectors highly sensitive to a specific wavelength, improving the volume and quality of data collected. Additionally, because the instruments are highly task-oriented, they are simpler, lighter, and smaller, all of which benefit spacecraft design.

Full-scale image of the device.

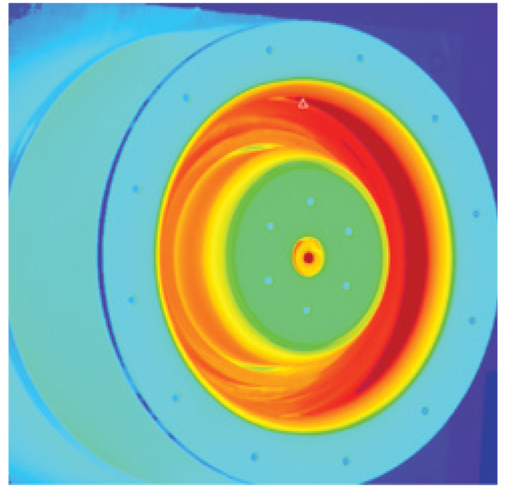
Electric Drive

Powerful, Throttleable Electric Thrusters Drive Future Space Exploration



JPL's H9 graphite-wall Hall thruster for high power density pathfinder testing leading toward the H10 thruster design.

Thermal imagery of JPL's H9 Hall thruster during high power density testing.



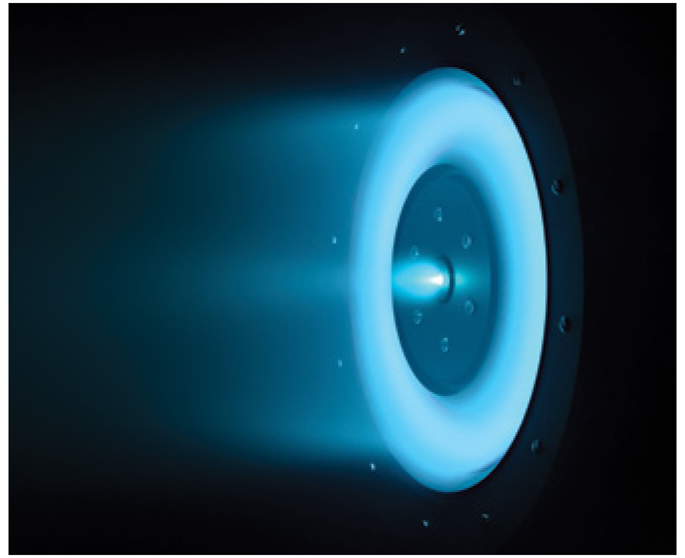
For extended deep space missions, conventional rocket thrusters, which use chemicals as fuel, have their limits—fuel storage can require complex systems and repeated firings can cause components to wear. These thrusters are best for short-duration, high-powered firings to reach or fly beyond Earth orbit. But for long-duration missions across great distances—say, the outer solar system—electric propulsion has proved to be a boon for exploration. Able to thrust continuously for months and sit unused in standby for years, electric rocket motors have proven their utility for missions beyond Mars.

There are two basic types of electric rocket motors. Ion thrusters, like the NSTAR motor first used on NASA's Dawn mission to the asteroids Vesta and Ceres, provide high levels of thrust but are expensive to build. The second type, Hall Effect thrusters, typically have lower power density but are simpler in design and less expensive to manufacture. An ideal solution for deep space missions would be to develop a more powerful evolution of the Hall thruster that has propulsive output closer to levels achieved by ion thrusters.

JPL engineers are developing a 10-kilowatt Hall thruster, the H10, that will provide efficiency closer to NSTAR's output (a specific impulse, or ISP, of about 3,000 seconds)—an increase of about 50 percent over current Hall thruster designs. This increased output is achieved by using higher voltage and power densities than previous generations allowed. This thruster will also be throttleable, which can greatly simplify some mission designs. While there are still hurdles to surmount, JPL's current development version, the H9, has performed well in testing and has identified the remaining developmental issues facing the H10.

These optimized, throttleable Hall Effect thrusters will open the way for a new generation of compact, less costly, and highly efficient spacecraft that will expand JPL's mission of exploring the solar system.

Pushing the power density of electric propulsion to new limits.



JPL's H9 Hall thruster was fired for short periods up to power densities three times higher than the state-of-the-art, paving the way towards the new H10 design.

The Fine Print

Simplifying Large Antennas with Additive Manufacturing

Design for an “organic” 7.8-inch (20-centimeter) reflector showing the highly optimized backstructure that could result only from computerized optimization and which could not be made by traditional machining.

Views of reflective surface and backstructure of 3.9-inch (10-centimeter) diameter symmetric parabolic reflector created using additive manufacturing.

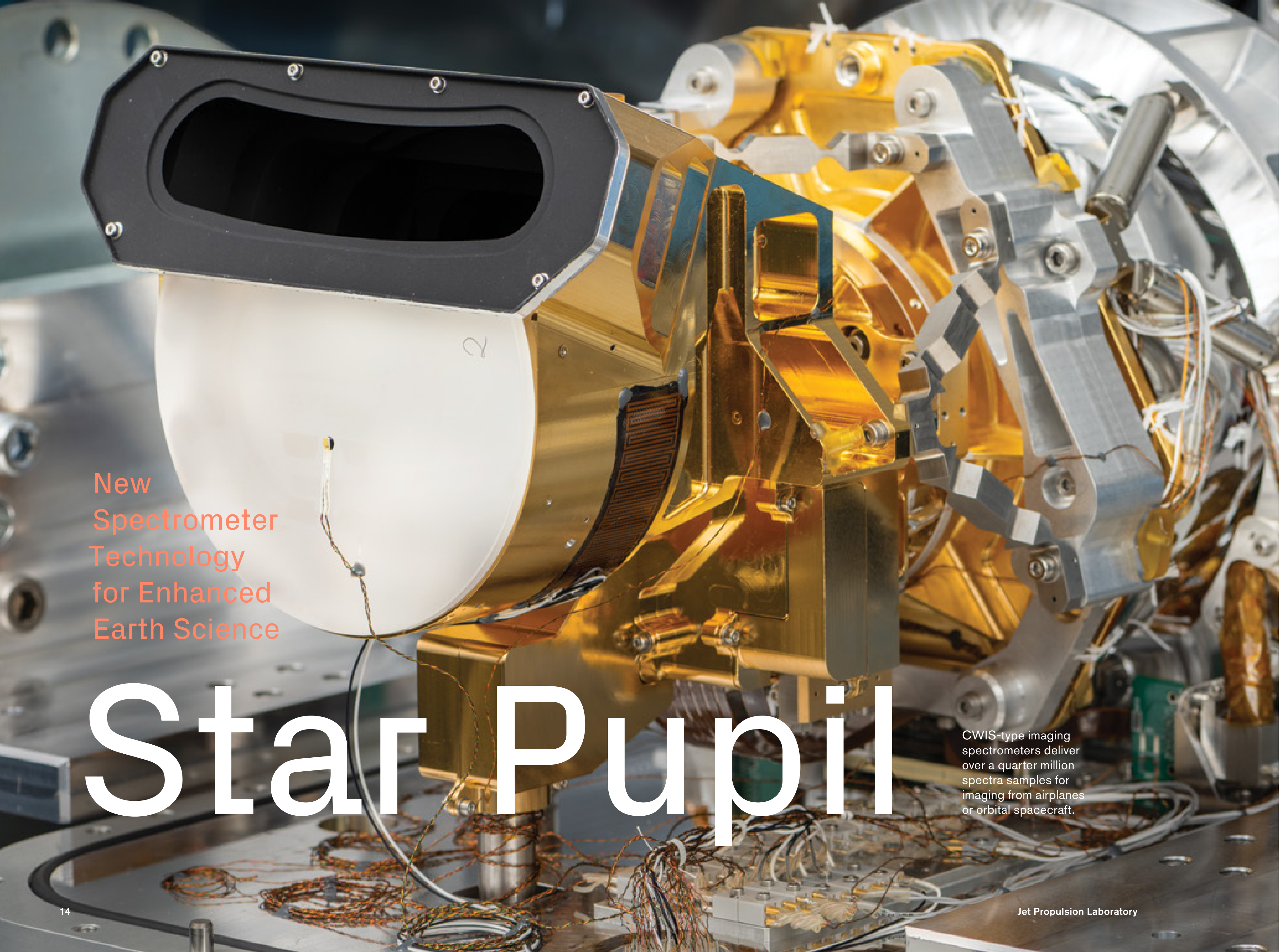
Designing and fabricating antennas for spacecraft and high-altitude balloons is difficult. By their very nature, antennas are bulky, and building them to withstand the stresses of flight and maintain dimensional stability has been a challenge. Submillimeter antennas, which are used in a variety of Earth observation, planetary science, and astronomy applications, can be fragile as well. Since they operate on tiny wavelengths, they must be free of the smallest imperfections to work properly and to be capable of operating across a broad range of temperatures.

Traditionally, these antennas have been fabricated using glass forms to create the antenna’s surface, over which a thin reflective material like nickel is deposited. A supporting structure, made of metal honeycomb or strips, is then glued to the back. This process is time-consuming, exacting, and prone to manufacturing errors. The resulting antennas also have potential shortcomings when operating in extreme temperatures, as the materials expand and contract at different rates, introducing stresses and possibly uneven deformation into the antenna.

JPL engineers are experimenting with a new process that involves additive manufacturing—3D printing—that is low-cost, can be readily adapted for different applications, and is straightforward to accomplish. This new approach uses a single material to create both the support structure and the reflecting surface, which results in a greatly simplified manufacturing process and a single coefficient of expansion—the entire unit reacts to temperature changes uniformly. This results in fewer stresses on the antenna and less deformation, providing a superior signal during use.

> Additive manufacturing enables fabrication of high-performance, thermally-stable antennas for astronomy and remote sensing.

By printing the antenna from aluminum powder, more complex antenna designs can be created with reduced mass, resulting in mission-optimized shapes that cannot be made using traditional fabrication techniques. By using sophisticated design software, the components of the antenna’s supporting elements can be made thinner or thicker as required, which further contributes to an extremely high performance, efficient design.

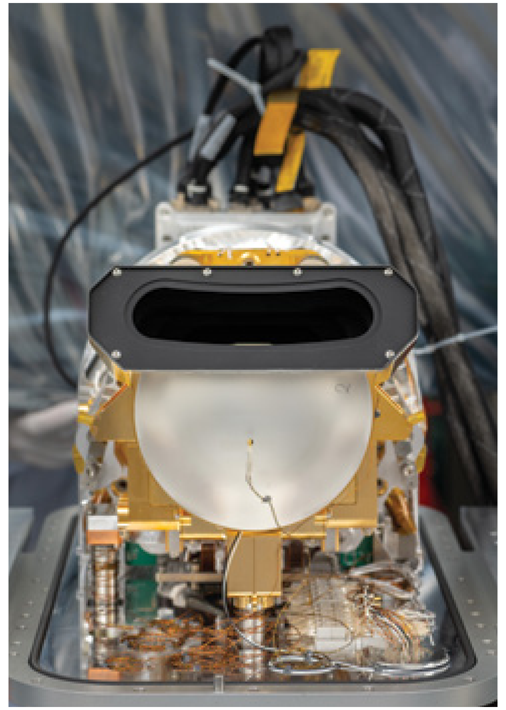


Star Pupil

New Spectrometer Technology for Enhanced Earth Science

CWIS-type imaging spectrometers deliver over a quarter million spectra samples for imaging from airplanes or orbital spacecraft.

New designs for compact spectrometers enable expanded monitoring of Earth's climate.



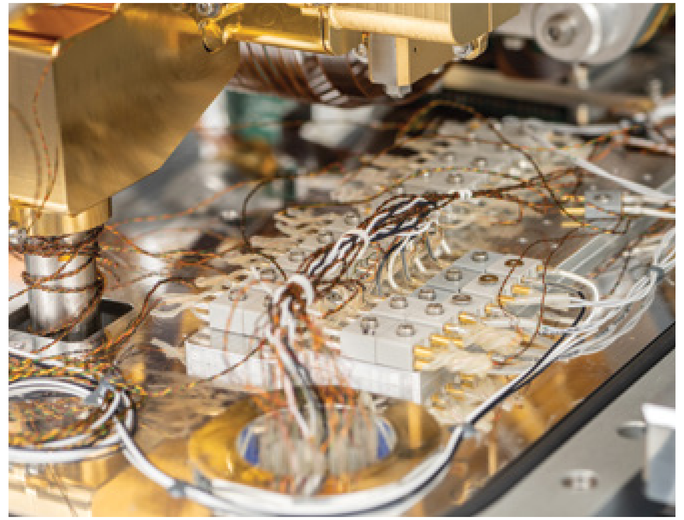
View from the telescope end of the spectrometer shows cryocoolers, the primary mirror, and the complex thermal shielding structure.

Imaging spectroscopy has been a pivotal technology for monitoring agriculture, forestry, environmental science, mineralogy, plant studies, hydrology, air pollution and snowpack measurement. While this is a broad list of applications, perhaps the most important among them is the monitoring of climate change.

Like any technology, imaging spectroscopy has its limits—the instrumentation has been bulky, power-hungry, and multiple units have been required to gather the range of data desired by scientists. New spectrometers developed at JPL have moved imaging spectroscopy into high gear by offering higher resolution, improved signal-to-noise ratios, lighter weight, and reduced power requirements. The result is greatly improved data-gathering by smaller and lighter instruments.

The enhanced technology uses a new design approach with faster optics and a much wider pupil size to increase light throughput. A critical development is the use of a new concave diffraction grating design developed by JPL's Microdevices Lab, which specializes in the design and manufacture of sensory elements at a microscopic scale. The improvements in sensor design result in devices—dubbed Compact Wide-swath Imaging Spectrometers (CWIS)—that are a fraction of the mass of traditional spectrometers, with lower power requirements and improved efficiency and reliability.

The spectrometer's electronics tracks dozens of operational parameters and captures sensor data.

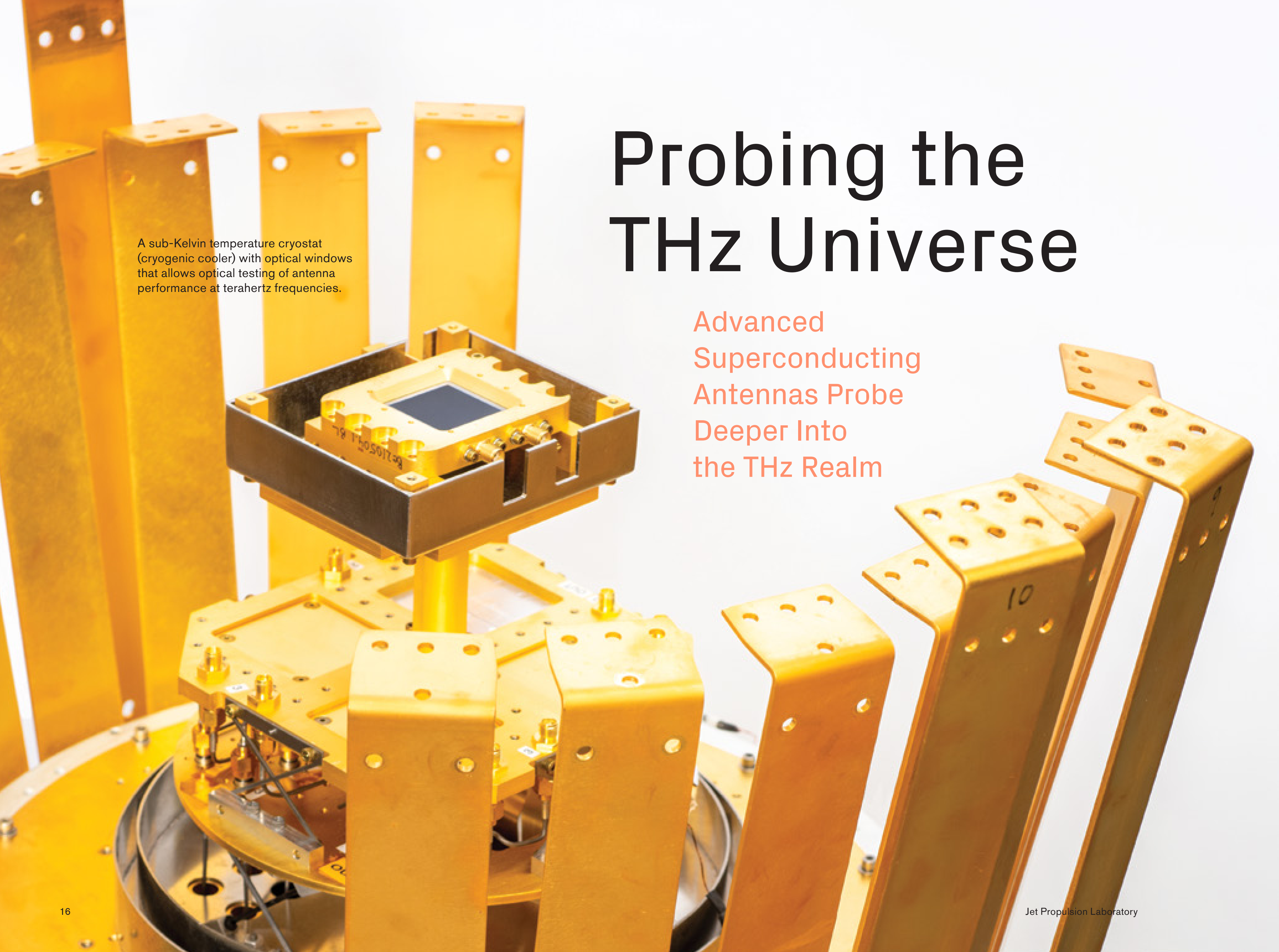


These highly miniaturized spectrometers provide over four times the measurements of the previous generation, are one-quarter the size of their predecessors, and consume only about ten percent of the power previously required. The net result is vastly improved capability in a much smaller, more efficient package. They can also be specifically tailored to gather data at specific wavelengths depending on mission requirements.

Smaller, lighter, and more efficient instrumentation are key technological advancements for expanding the monitoring of our ever-changing climate, and offer advancements for optimizing improved agricultural yields, forest preservation, air pollution monitoring, and the ability to better monitor the world's oceans.

Probing the THz Universe

Advanced Superconducting Antennas Probe Deeper Into the THz Realm



A sub-Kelvin temperature cryostat (cryogenic cooler) with optical windows that allows optical testing of antenna performance at terahertz frequencies.

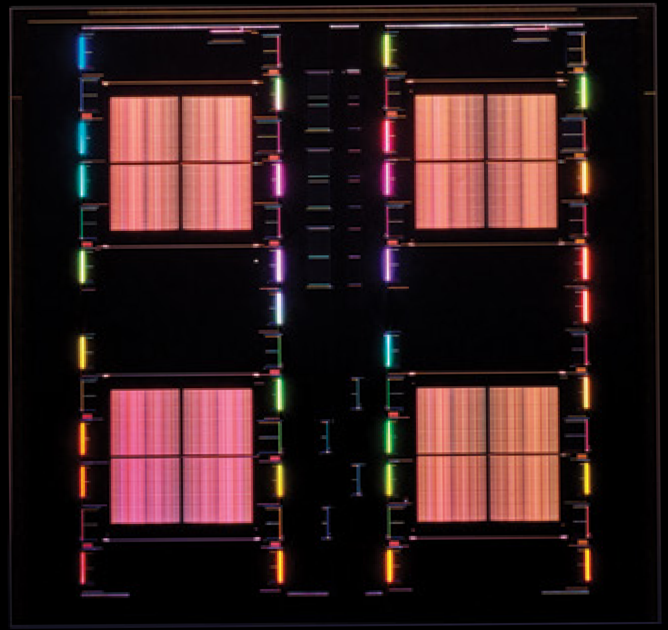
The universe is full of secrets, and while we learn more every year, many of the answers we seek are hidden in difficult-to-probe parts of the electromagnetic spectrum. The terahertz (THz) spectral range is such a region, and is where signals—and answers—from the farthest reaches of the universe dwell. What is the mass of the cold molecular gas available to form new stars? How does the interstellar medium cool as new, hot stars form? Even enhanced measurements of redshift, the “speedometer” of the expanding universe, may be hiding in THz range emissions.

Current THz measurement devices are limited in performance by the standard quantum limit (SQL), which constrains the accuracy of measurements made at quantum scales.

Sophisticated routing and linking of superconducting antennas using spectrometers-on-a-chip expand our ability to explore the universe at THz frequencies.

To move beyond such limits, JPL and Caltech engineers are developing superconducting spectrometers with phased-array antenna hierarchies that will extend the range of detectable frequencies from a bandwidth of less than an octave to more than 5.5 octaves. Small enough to fit on a microchip, these devices overcome the limitations of the SQL via supercooled antennas and detectors embedded on the chip—which are much more sensitive than those available today—being limited only by statistical fluctuations of the photons collected.

Because these sensors are so small, they can be deployed in large arrays that can fill the entire field-of-view of an observing instrument. These arrays would allow true three-dimensional mapping of the universe over time at THz frequencies, which would greatly enhance existing observations at optical, infrared, and ultraviolet frequencies. An added benefit is that these THz observations would be limited by diffraction, not the atmospheric seeing and absorption problems that can limit terrestrial measurements in other spectral ranges. The result? Ever-greater strides in our understanding of cosmology.



A JPL/Caltech device with four hierarchical antennas demonstrating high efficiency sampling from 0.125 to 0.35 THz. The hierarchical antennas are two-by-two arrays of a square, smaller fundamental antenna element that achieves high performance over half an octave. Light picked up by the two-by-two hierarchical array and filtered on-chip enables continued high performance down to lower frequencies, extending high performance to 2.8 octaves in the device shown.

Searching for Optical Counterparts of Fast Radio Bursts

Photo Finish

Artist's impression of a pulsar, an ideal target for researching Fast Radio Bursts with JPL's high-speed optical photometers.

New high-speed cameras will search for optical twins to FRBs, helping to unravel their mysteries.

Top: The seven-segment optical aperture installed on a radio tracking antenna at Goldstone.

Bottom: Close-up of the optical aperture of JPL's new optical photometer system.

Since 2007, astronomers have puzzled over a phenomenon known as Fast Radio Bursts or FRBs, a quick and intense burst of radio energy from deep space. These electromagnetic eruptions last for just a moment, from milliseconds to a few seconds, yet can emit as much energy in that brief time as our Sun does in three days. Now that we are tracking them, it is estimated that as many as a thousand FRBs of varying intensities may occur daily, yet only a very small number of these events appear to recur from the same source. This begs the question of how to best observe them, especially if we're looking for corresponding energy emissions in optical wavelengths?

One model of the origins of these intense energy bursts suggests that they may come from magnetars—very dense neutron stars with massive magnetic fields. The decay of these fields may create periodic and powerful energy pulses, especially as X-rays or gamma rays. But might there be a matching emission in optical wavelengths? If the source of such emissions is indeed magnetars, the models suggest there should be.

Of the large numbers of FRBs observed, about 20 of them appear to repeat from the same source, though they tend to be unpredictable and with a wide spread of arrival times. We currently don't know where to look for visual corollaries to FRB radio emissions, and attempting to survey the entire sky at optical wavelengths would be quite costly.

To address this, JPL engineers have developed high-speed optical photometers that can measure variations in brightness within a targeted area. A number of these devices have been mounted on a radio telescope/communication dish at NASA's Goldstone Deep Space Communications Complex, a part of the agency's Deep Space Network (DSN) from which robotic spacecraft are tracked and controlled. By positioning this optical camera on the same dish that is being used to search for the radio signal of FRBs, we can cover a similar area as the radio dish does at optical wavelengths. If the astronomers' predictions are correct, when one instrument sees a transient burst in radio frequencies, the other should see a corresponding burst of light.

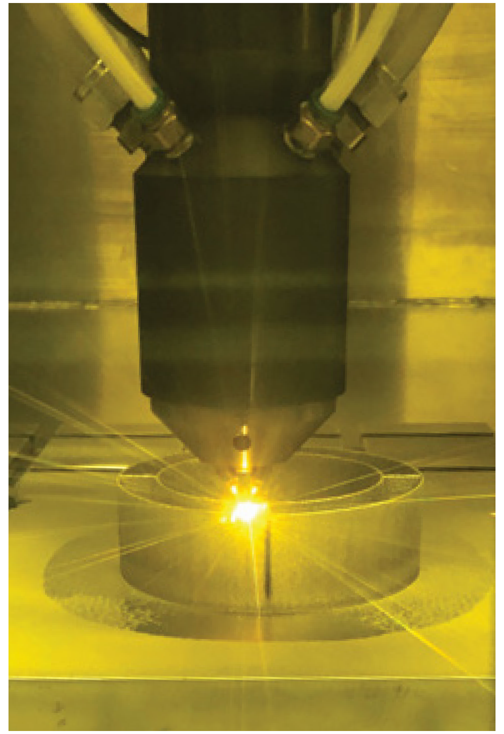
This hybrid radio/optical observing system offers a win-win scenario, encompassing both radio and optical observations with little additional cost to the observing program. The mysteries surrounding FRBs may soon be narrowed significantly.

A view of the camera box as attached to the tracking dish.

Shields Up!

Additive Manufacturing Enables Rapid Fabrication of High-Performance Magnetic Shielding

A magnetic shield created with blown powder laser deposition.



Top: Microscopic image of the printed magnetic shielding alloy.

Bottom: Shield printing in process with a high-intensity laser melting the blown metallic powder.

As NASA's robotic spacecraft become increasingly capable of detecting faint signals from stars, planets, and other targets, they also become more and more sensitive to interference from onboard machinery like reaction wheels, electric motors, and cooling systems. Anything using an electric motor, for example, can be a problem for sensitive magnetometers.

In traditional designs, electronically "noisy" devices are shielded by metallic enclosures. To optimize their performance, these enclosures have traditionally been machined from solid pieces of metal. This method, called subtractive manufacturing, is expensive and time-consuming, and the final product can be mass intensive. Complicating these designs is the need to create intricate shapes—baffles and other exotic geometries to maximize the effectiveness of the electromagnetic shield—and these complex designs can be very difficult to fabricate.

A new twist on additive manufacturing enables fabrication of multi-material magnetic shields with improvements in shielding performance.

New techniques in use at JPL are leveraging the strengths of additive manufacturing to create better magnetic shielding more quickly and easily than ever before. Using a process called blown powder laser deposition, metallic dust is forced through a nozzle, using an inert gas, directly into the beam of a high-powered laser. The resulting melted metallic blob fuses to the emerging part, which is built up layer-by-layer under computer control. By changing the composition of the powder, different metallic alloys can be deposited where they are most effective. This enables the creation of exotic parts that cannot be made using any other method and in far less time than current processes require. The result is more effective shielding with less mass and at a lower cost than previously available, leading to more capable spacecraft that can be smaller and lighter than anything that has gone before.

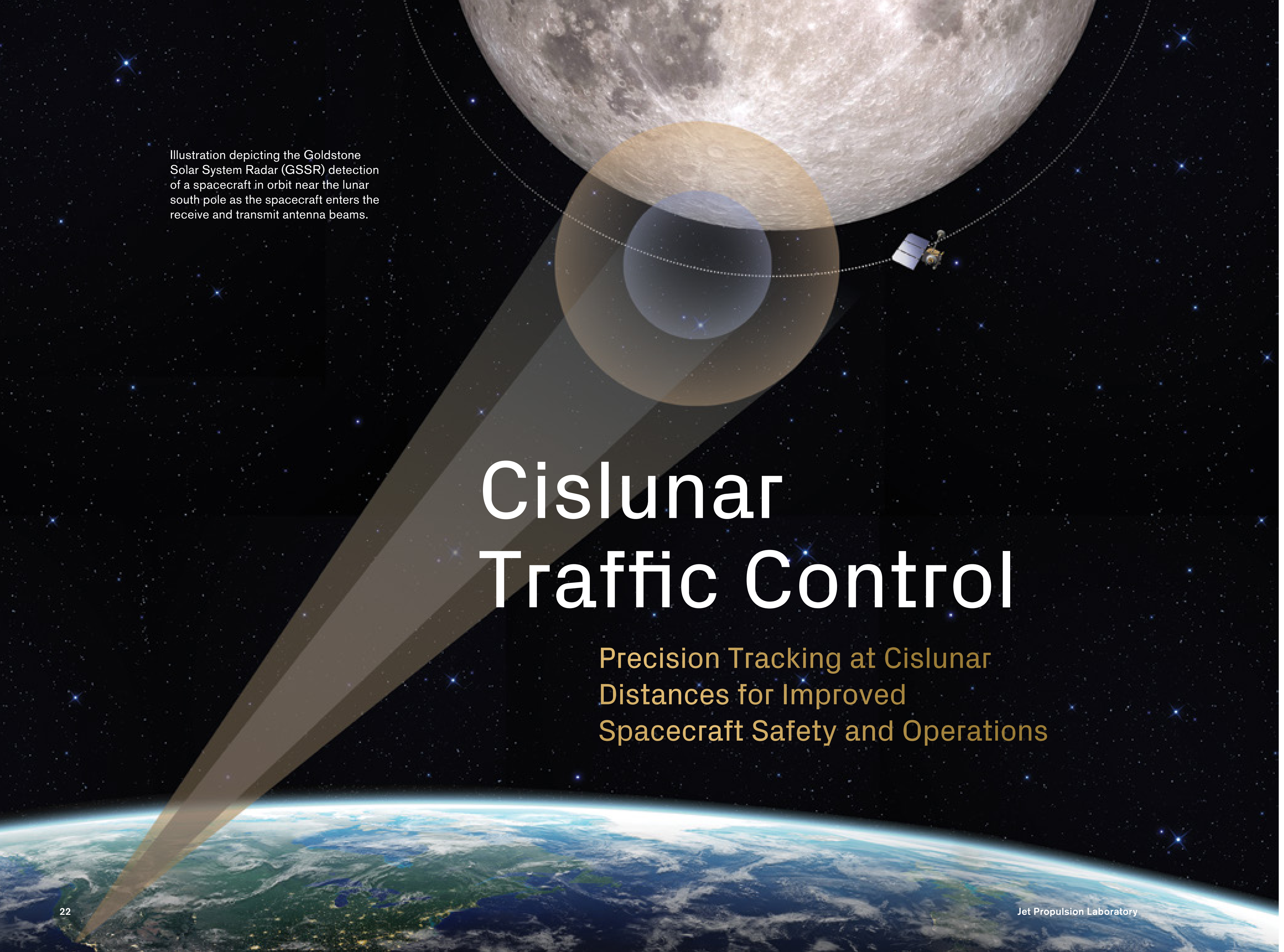
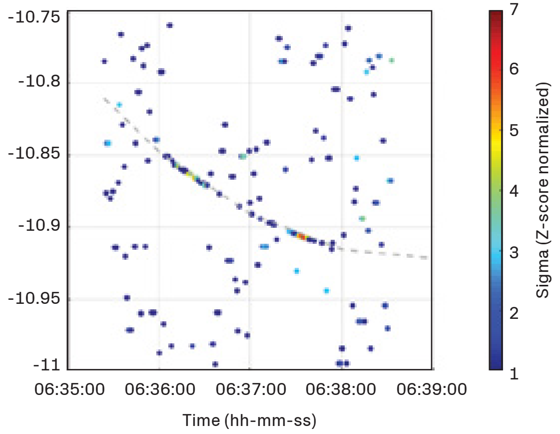


Illustration depicting the Goldstone Solar System Radar (GSSR) detection of a spacecraft in orbit near the lunar south pole as the spacecraft enters the receive and transmit antenna beams.

Cislunar Traffic Control

Precision Tracking at Cislunar Distances for Improved Spacecraft Safety and Operations

Cislunar space, a region that extends from low-Earth orbit (LEO) to the Moon, is poised to become the busiest sector of space in the coming decades. After 60 years of developing the economy of LEO, both government and private industry have their sights set on the Moon and the vast resources there. But cislunar space also plays host to a cloud of detritus—natural bits of rock and ice left over from the formation of the solar system as well as defunct spacecraft—that can endanger operations near and around the Moon. As exploration and commerce extend outward, better and more precise tracking systems for both spacecraft and dangerous, inert objects must be developed.



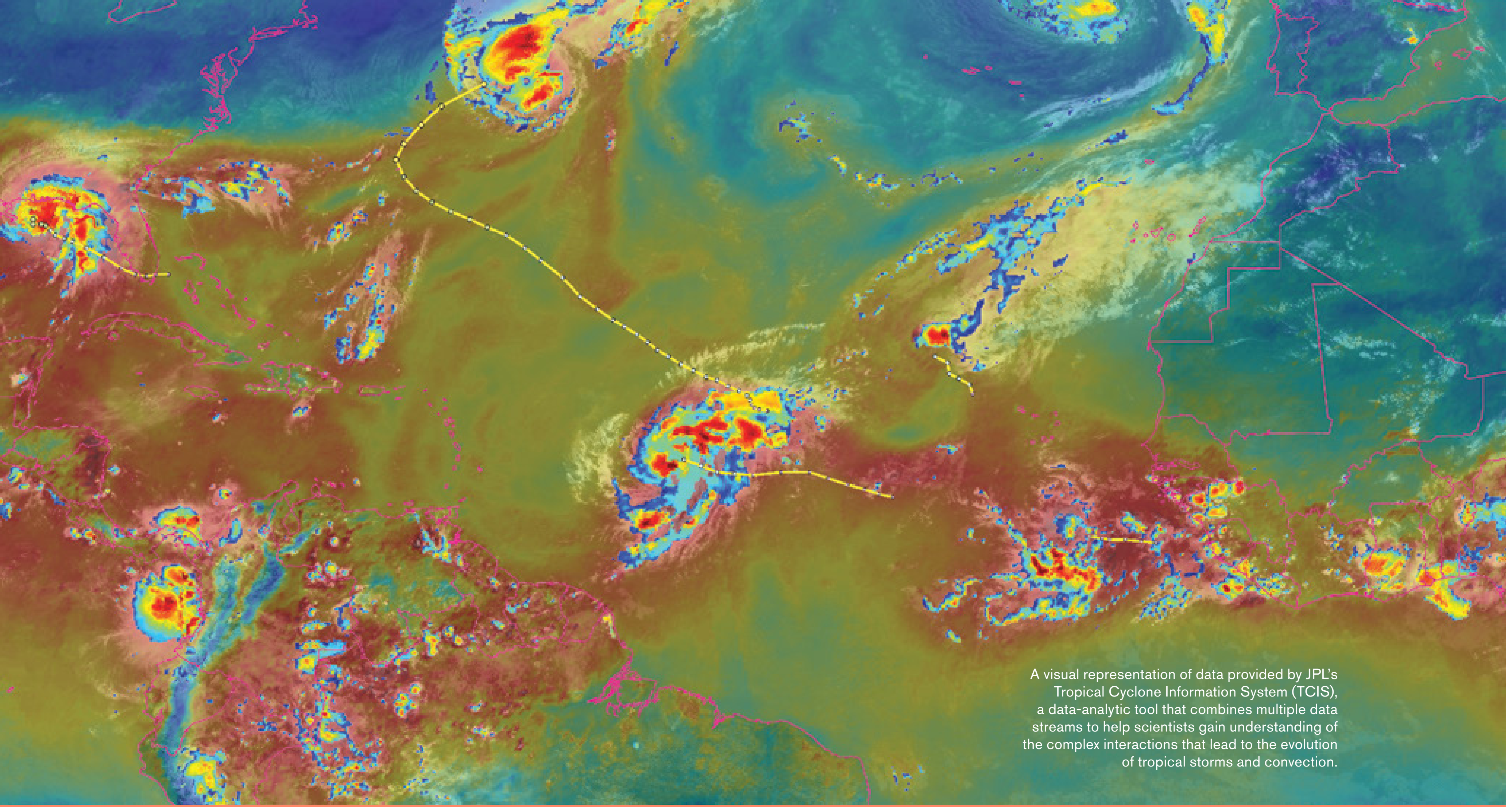
Detection of the Lunar Reconnaissance Orbiter at the lunar south pole, using the Deep Space Network (DSN), by tracking the return spectrum's peak power as a function of time. The detection was confirmed by the peak power's tracking returns exactly overlaying the expected returns (dotted line). The color axis represents power. The left-hand vertical axis is Doppler frequencies in kHz. The time axis is hours and minutes.

During the Space Race, NASA and the U.S. Army built the Goldstone radio observatory in California's Mojave Desert to track early probes. Since then, it has been greatly expanded into a multi-antenna facility, operated by NASA and JPL, that continues to track and communicate with numerous interplanetary spacecraft. To address the safety needs for increasing cislunar traffic, JPL engineers are adapting a part of the facility, the Goldstone Solar System Radar (GSSR), to better track stray objects beyond low-Earth orbit. The new system is called the Cislunar Space Debris Radar (CSDR) and operates in conjunction with the Green Bank Radio Telescope in West Virginia.

CSDR has now been successfully tested on several targets, including the Lunar Reconnaissance Orbiter (LRO) spacecraft and the THEMIS-B probe, both now orbiting near the Moon. Experience tracking Near-Earth Objects has aided the development of sophisticated CSDR signal processing software and the tracking of SmallSat-sized spacecraft (about the size of a small microwave oven) such as those deployed in a lunar trajectory from the launch of Artemis I. The trick is to separate the spacecraft and potentially dangerous objects from background clutter returned from radar sweeps passing through low-Earth orbit. This technology is maturing rapidly and will soon help to provide real-time tracking of risks to active missions, both robotic and human-crewed, as they make the long transit to and around the Moon.

> Using existing infrastructure, JPL has engineered greatly improved tracking of spacecraft and debris in cislunar space.

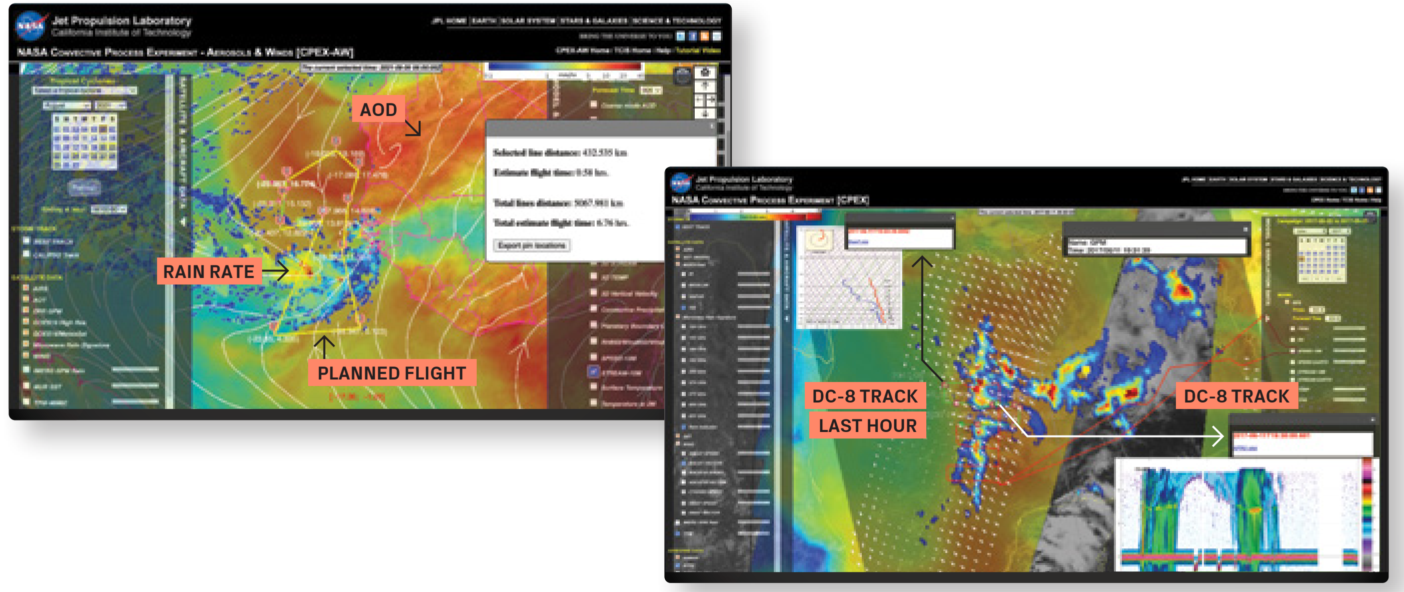
The 70-meter DSN antenna that houses the GSSR 450 kW transmitter.



A visual representation of data provided by JPL's Tropical Cyclone Information System (TCIS), a data-analytic tool that combines multiple data streams to help scientists gain understanding of the complex interactions that lead to the evolution of tropical storms and convection.

Digital Storm Chasers

JPL's New Data Portal Integrates Diverse Weather Observations to Enable Better Prediction and Modeling of Dangerous Storms



Left: Mission planning using model forecasts and the Flight Planning tool to design a flight mission.

Right: Post-campaign research analyses using satellite and airborne observations combined with model forecasts to create a user-defined depiction of a storm and its environment.

Tropical storms can be furious and surprisingly destructive, causing rampant damage to affected areas, especially low-lying coastal regions. Yet, despite more than a century of investigation, many questions remain about their origins and evolution, from minor squalls to raging storm systems.

NASA has spent decades collecting data on storm systems from their earliest stages to their exhaustion, and continues to do so. But organizing and properly utilizing the many types of data collected from myriad sources is surprisingly difficult. The information collected via satellite and aircraft is archived in different formats, measured in different durations and in different resolutions, and is housed across multiple databases hosted by agencies covering different regions. This makes evaluating this data difficult and time-consuming, and there is one more complication—plots of future satellite overflights and predicted weather systems need to be factored in for planning future campaigns.

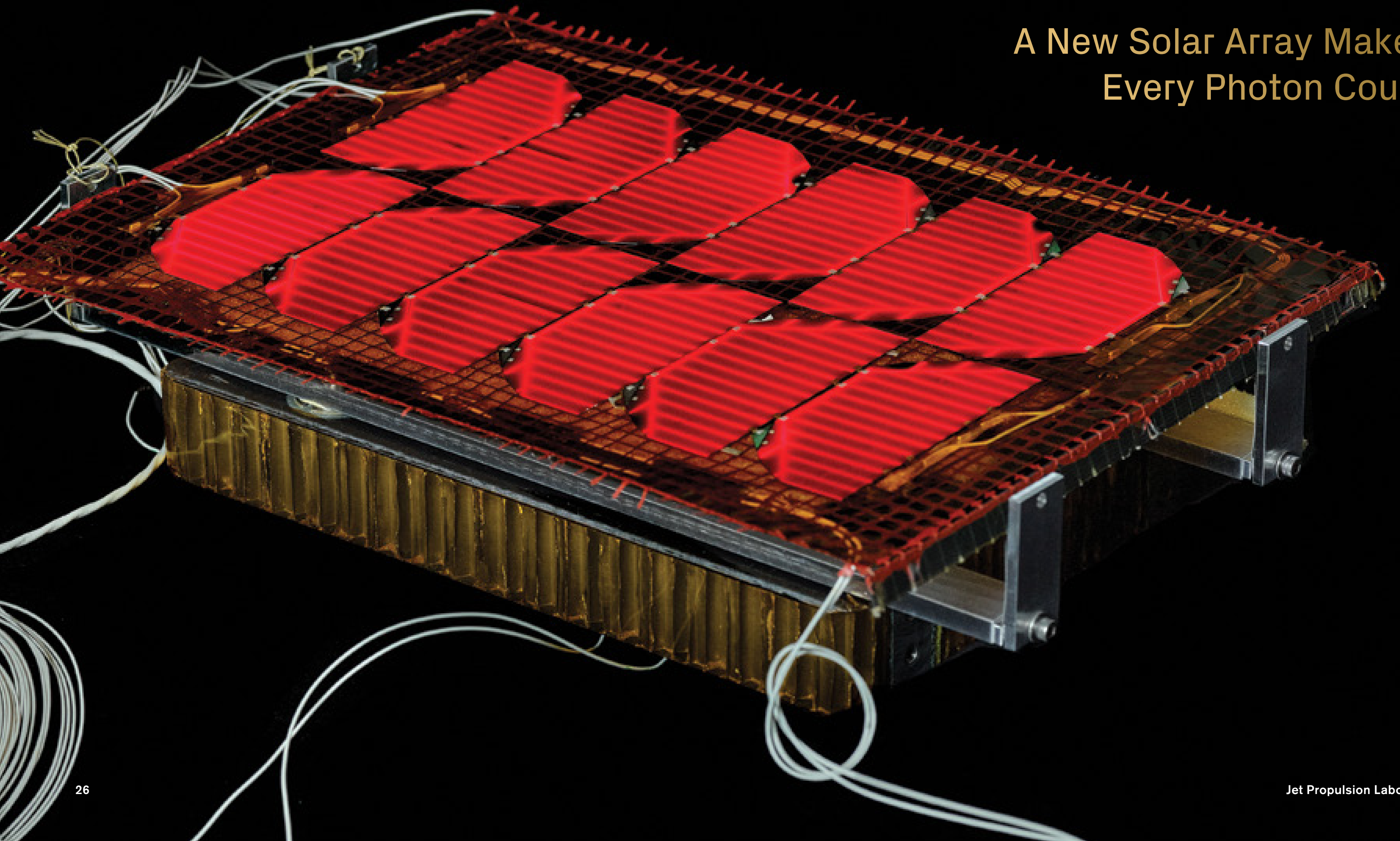
To address this, JPL has developed the Tropical Cyclone Information System (TCIS), a data-analytic framework that can ingest dozens of data streams of different types. TCIS can also integrate weather forecasts with satellite and airborne observations, bringing them into a common, interrelated system. TCIS supports interactive visualization, which assists planners and enables on-line analyses, which aids researchers. It also provides flight planning tools to support mission design and post-campaign research. Using TCIS, researchers can access multiple atmospheric and ocean variables, make model-observation comparisons, and support validation of satellite data by comparing them with airborne observations.

A new portal integrating weather data from multiple sources will help to unravel the mysteries of tropical storm formation and propagation.

Using TCIS, data sets from NASA, the National Oceanic and Atmospheric Administration (NOAA), and other organizations, can be merged into one large interactive planning and investigative tool, simplifying research into the origins, magnitude, and paths of potentially destructive tropical storms. The savings in both property and lives will be significant.

Power Through the Darkness

A New Solar Array Makes Every Photon Count



A Deep Space Solar Array prototype as successfully tested in an environment simulating Saturn mission conditions.

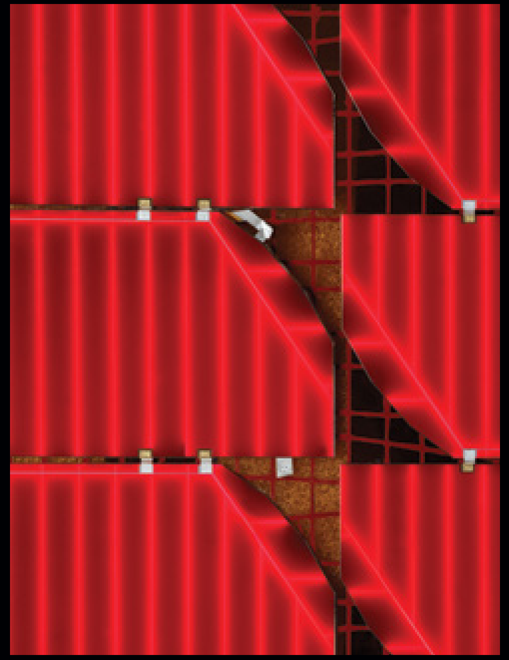
Beyond the asteroid belt, the Sun appears much dimmer and smaller than it does at Earth. Yet spacecraft such as Juno, which is currently in operation around Jupiter 500 million miles (800 million kilometers) from the Sun, can use that dim light to generate operational power, but it's challenging. At Jupiter, for example, the Sun's light intensity is only about four percent of what it is at Earth.

Outer solar system missions can also use plutonium-powered Radioisotope Thermoelectric Generators (RTGs), but RTGs are relatively heavy and expensive compared to solar arrays, and plutonium is a limited resource, making RTGs a challenging option for some future mission concepts to Saturn and beyond. Additionally, plutonium is dangerous and great care must be taken to avoid the contamination of solar system bodies via an errant spacecraft impact.

New solar array technology extends the range of solar power into the outer solar system.

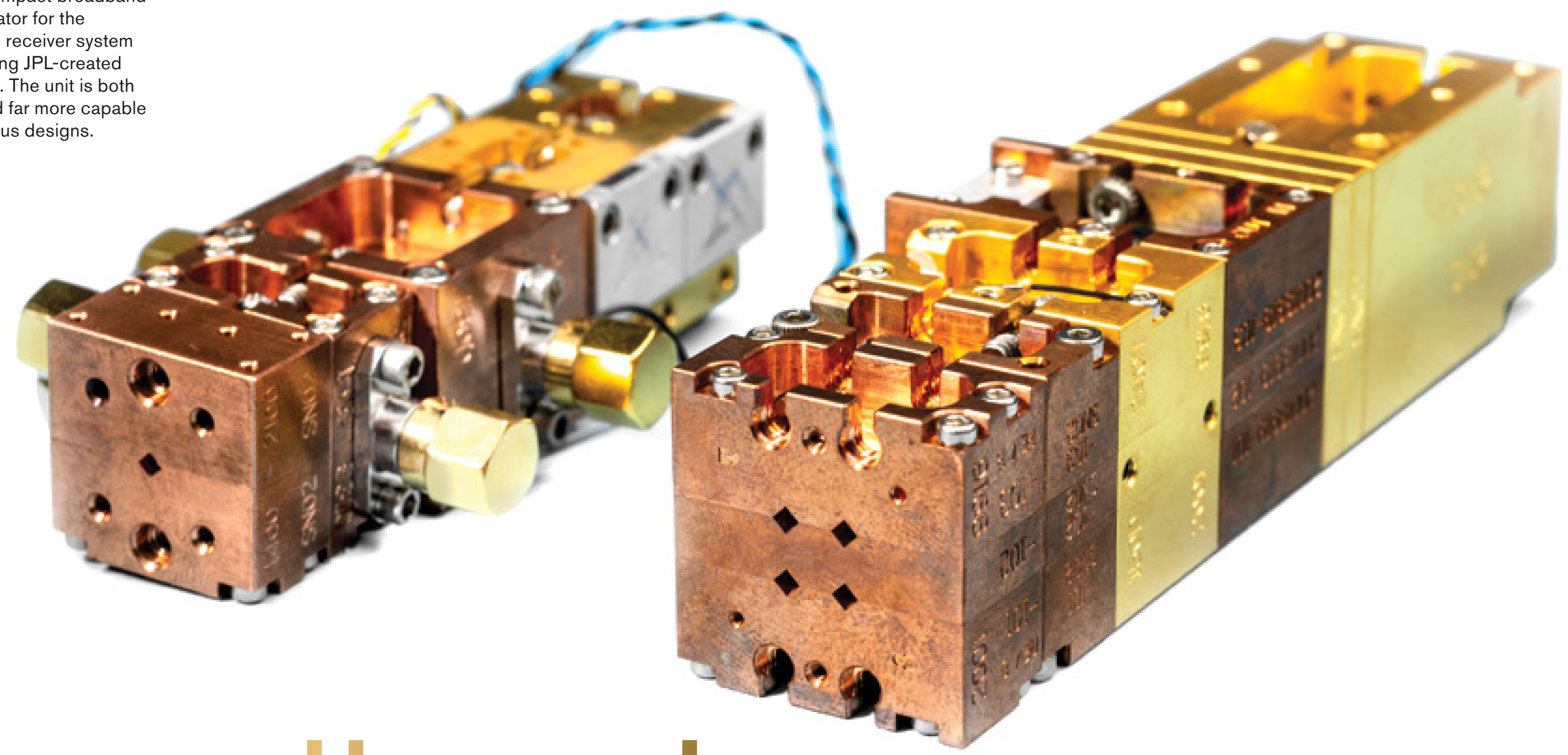
By leveraging recent developments in photovoltaic cells, JPL has developed a new, highly efficient solar power source—the Deep Space Solar Array. Missions beyond Jupiter can now be flown using solar power, but to assure their performance the array must be optimized for that hostile environment. The hardware must be able to withstand desperately cold conditions, about minus 400 degrees Fahrenheit (minus 240 degrees Celsius) at Saturn, and possibly colder farther out. The panels must also survive hot temperatures during a Venus flyby, often required for spacecraft to reach the outer solar system, when temperatures can reach 300 degrees Fahrenheit (150 degrees Celsius). JPL's new solar power array has been shown to function even in the ultra-cold conditions found at Uranus. Ultimately, its use will be based on overall mission tradeoffs.

The Deep Space Solar Array achieves a delicate balance between mass, complexity, performance, and longevity. It is 50 percent lighter than currently available RTGs and about one-fifth the mass of current space-rated solar panels. JPL has prototyped and tested the array to the state of readiness necessary for future inclusion in outer solar system missions.



Close-up view of the Deep Space Solar Array panel structure.

An ultra-compact broadband local oscillator for the ASTHROS receiver system incorporating JPL-created technology. The unit is both smaller and far more capable than previous designs.



Broadband to the Stars

New Broadband Receivers Will Expand Our Understanding of Stellar Origins

A fuller understanding of stellar birth is a long-standing dream for astronomers and astrophysicists. While many techniques, and the instruments to achieve them, have been employed over the centuries, one modern method that promises great returns is the observation of molecular lines using radio astronomy in the far infrared. At these frequencies, astronomers can record the emissions from molecules distributed in vast clouds of dust and gas in interstellar space.

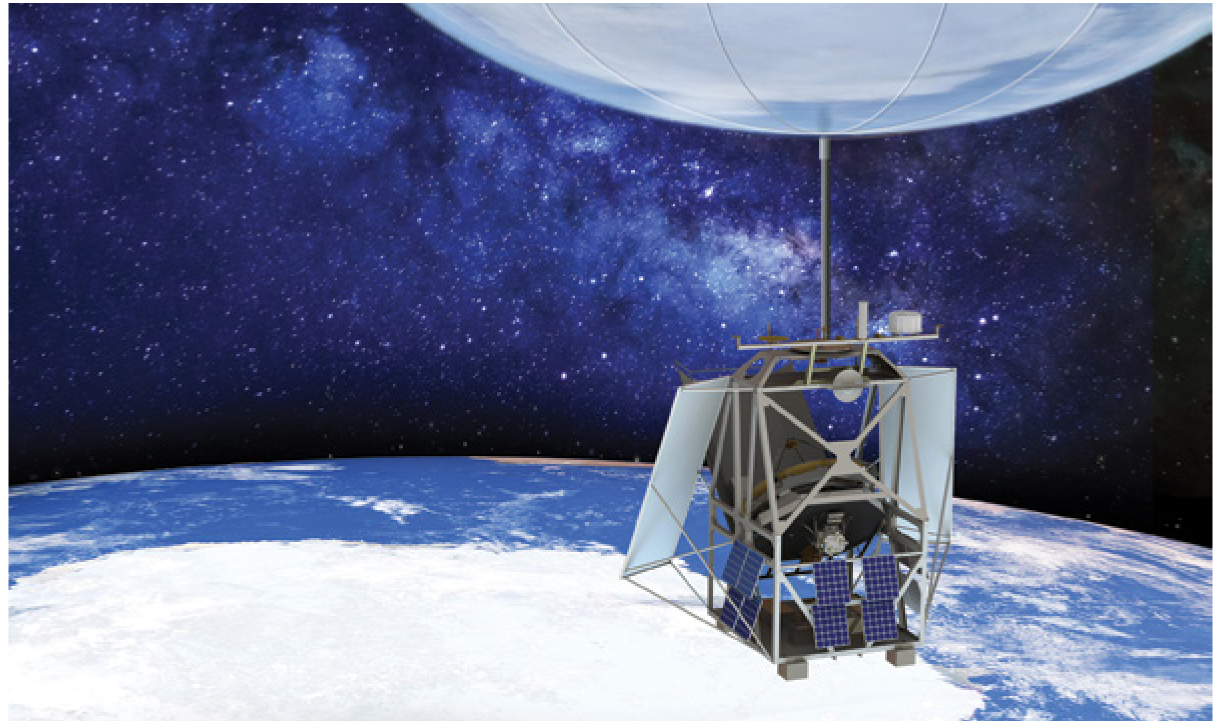
Utilization of this technique has, however, been limited by the available technology. Current systems operate in narrow bandwidths, so in order to observe at a wide range of infrared frequencies, multiple devices tuned to different bandwidths must be flown. This adds weight and complexity to the system design, both of which are anathema to cost-efficient missions.

JPL has developed new ultra-broadband high-spectral resolution receivers for far-infrared astrophysics missions that represent a dramatic enhancement over the current state-of-the-art. This technology utilizes a new technique called on-chip diplexing —multiple channels on a single chip— to combine multiple bands in one receiver channel, increasing the frequency coverage by up to a factor of three. The net result is more powerful receivers that can do the same work as multiple units have accomplished in the past, with smaller, lighter, and less complex support systems and lower power requirements.

The new receiver design will be used in a NASA mission called ASTHROS, a balloon-carried observatory that will be lofted over Antarctica this year, the success of which will pave the way for eventual deployment in long-term Earth-orbital missions.

The truth of star formation and evolution is out there, and these technological advancements will greatly expand our understanding of stellar origins.

A novel on-chip diplexing technique enables powerful high-resolution infrared instruments for molecular spectroscopy.



Artist's impression of the ASTHROS balloon mission during flight.

Observing Earth’s Weather at Lower Cost

Blown Away

View past the Compact Ocean Wind Vector Radiometer (COWVR) as tested on the International Space Station, gathering data on a hurricane.

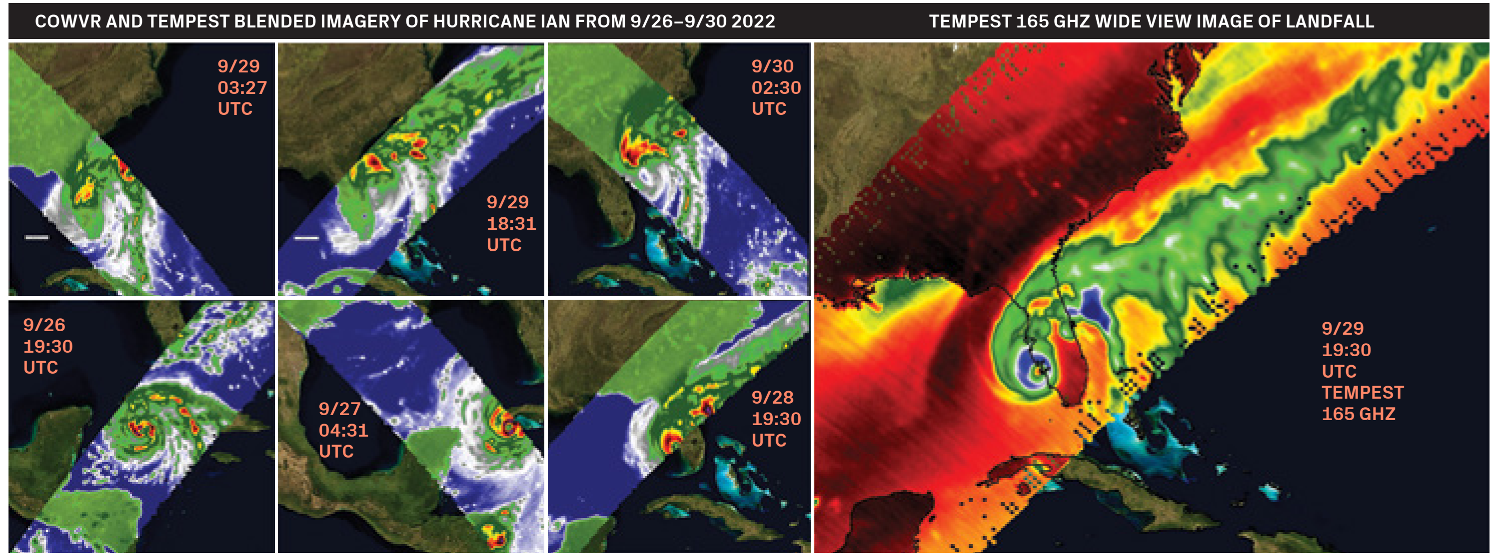
Forecasting the weather is a notoriously tricky business, as the variety of late-night comedy routines on the subject will attest. But in the last decade, the science of weather forecasting has advanced rapidly, with relatively reliable predictions up to 10 days in advance having become routine. But this ability comes at a cost—weather satellites are large, heavy, and expensive to build and launch, and large numbers of them are needed to provide the raw data required for accurate prediction around the clock.

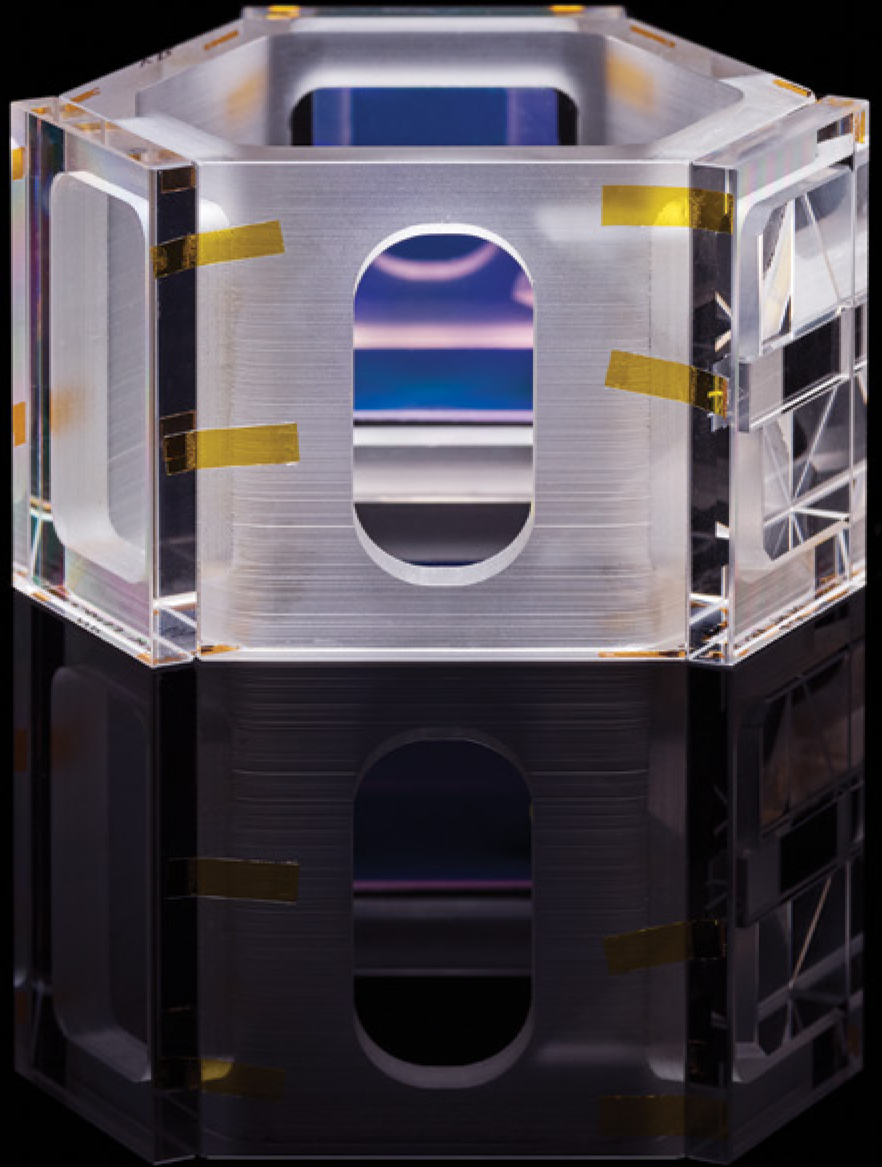
JPL technologists, working with the U.S. Space Force, have reimagined how weather sensors can be designed and built. Leveraging of state-of-the-art technology and novel signal processing techniques, they have developed COWVR—the Compact Ocean Wind Vector Radiometer—a simpler, lighter, and less expensive weather sensor. COWVR leverages new signal processing techniques to measure wind speed and direction over the ocean and water in the atmosphere (whether it’s in the form of vapor, clouds, rain, or snow) and provides the data necessary for highly accurate forecasts.

Due to its simplified design, lower mass, and reduced power requirements, building and launching COWVR-equipped satellites will cost far less than existing systems, so a constellation of them can be flown for about the same cost as a single traditional weather satellite today, offering continuous weather tracking and better prediction of weather events. A prototype of COWVR is currently flying a multi-year test on the International Space Station and the technology may soon be deployed across a large number of satellites. The resulting improvements in forecasting will benefit agriculture, transportation, and a wide variety of other commercial activities, as well as enhancing the safety of millions of people as climate change endangers ever-larger regions of our planet.

> Cutting-edge technology and new signal processing algorithms enable constellations of low-cost weather satellites for enhanced weather prediction.

Visual representation of data from Hurricane Ian as gathered by COWVR.



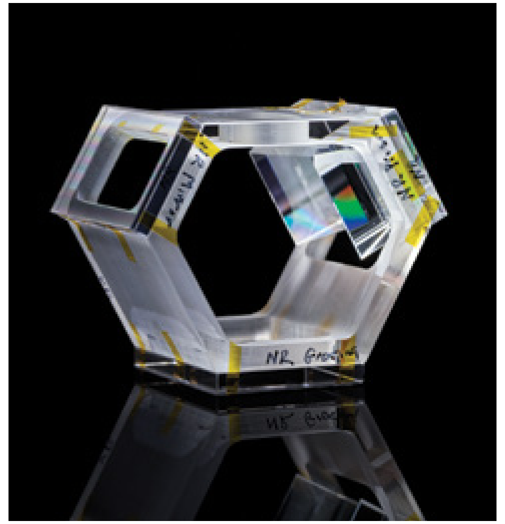


Mapping Spectral Signatures with Highly Miniaturized Optics

Chasing Distant Rainbows

All-reflective SHS that comprises a compact two-beam cyclical interferometer. The optical elements are contact-bonded to the supporting structure, effectively creating one solid block of glass weighing approximately 5.4 ounces (155 grams).

Spectroscopy, the study of spectral lines from distant objects in space, has been the backbone of astronomy since the 1800s, when the spectrum of sunlight was first measured and characterized into indicative “strips” of specific elements. In the subsequent centuries, spectroscopy has evolved to encompass most areas of astronomy, providing insight into what distant worlds are made of and answers no other technique can.



Side view of the monolithic cyclical SHS breadboard hardware. Fabricating the monolithic structure from the same material as the optical elements (in this case fused silica) enables low thermal distortion in a compact and robust form suitable for deep space missions.

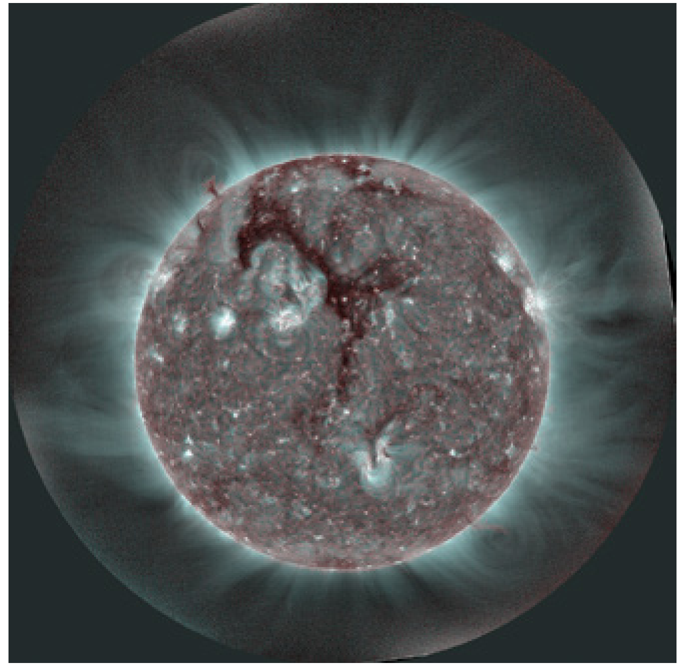
Low-resolution (low-R) spectrometry provides information about the composition, photochemical evolution, energy distribution, and density of astronomical targets. In contrast, high-resolution (high-R) spectrometry offers access to essential properties such as temperature, velocity, isotopic ratios, and the separation of detailed spectral signatures and sources.

However, the most effective telescope-based high-resolution spectroscopy requires large-apertures or high-R interferometers that are bulky and require moving parts that can wear and compromise accuracy. Furthermore, the use of refractive optical components limits their effectiveness in the ultraviolet and shorter wavelengths.

Spatial Heterodyne Spectrometry (SHS) overcomes many low-R and high-R spectrometry issues by eliminating moving parts and using an ultra-compact design that can be built in an all-reflective structure, thereby eliminating unwanted absorption due to refracting light through the optical elements typically associated with these spectrometers.

SHS-based instruments can be configured in various forms, making them ultra-sensitive, compact, and robust for specific scientific objectives. SHSs are an ideal science sensor for spacecraft instruments, especially those headed into the outer solar system, where mass and power are at a premium. The use of Spatial Heterodyne Spectrometry will help answer crucial questions in planetary science, heliophysics, and astrophysics.

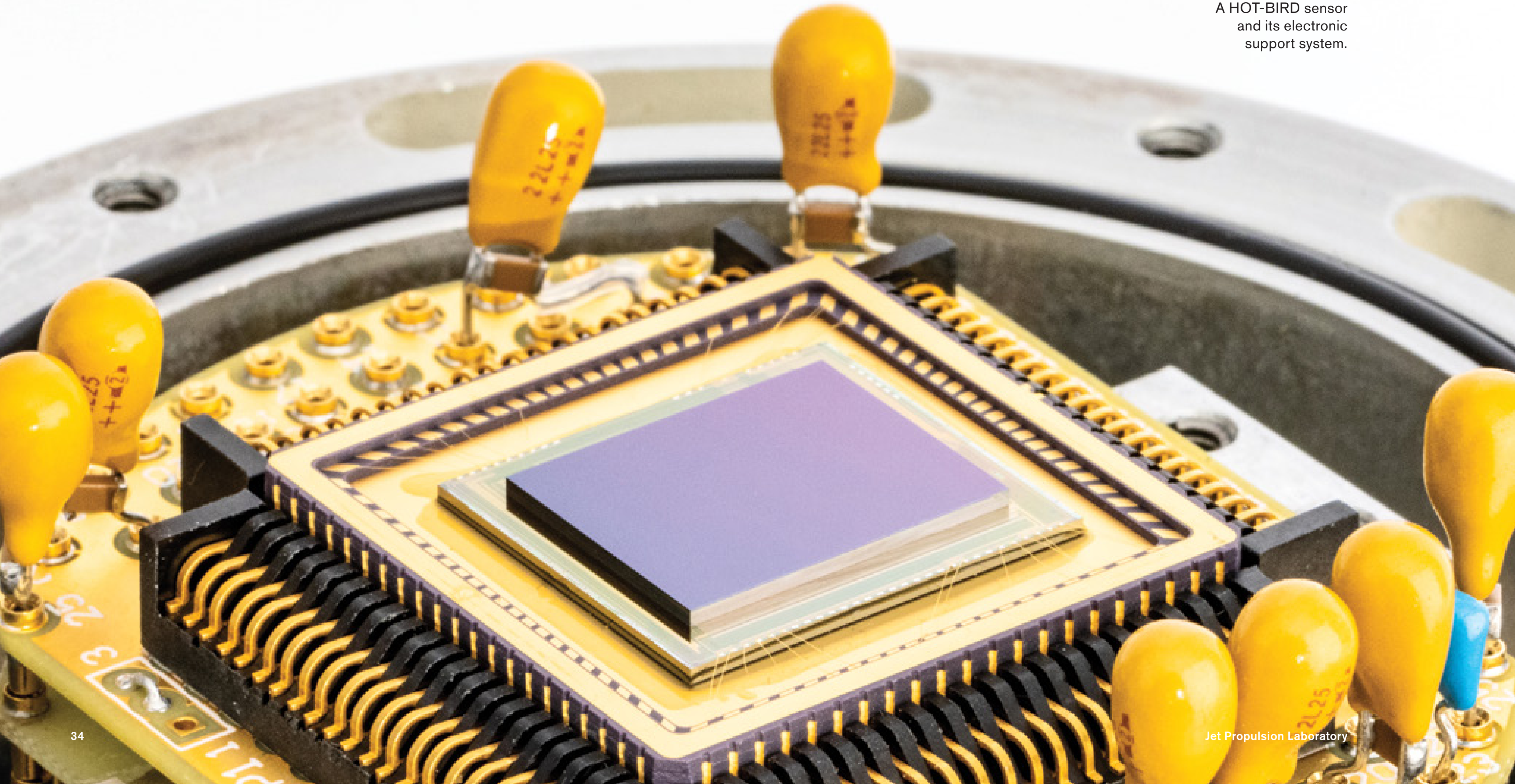
New, miniaturized spectroscopic sensors are sensitive to a wider range of light than ever.



A full disk image from EUVI on STEREO taken at 19.5 nanometers, demonstrating the structural and thermal complexity of the solar corona. SHS allows scientists to identify locations in the solar atmosphere rich in energetic particles through their imprint in the emission spectral line shape. Using SHS in multiple wavelengths also enables fine 3D-mapping of the solar magnetic field that gives rise to the observed structure and leads to explosive energy release.

Bird Watching

Better Water Sensing for a Thirsty World

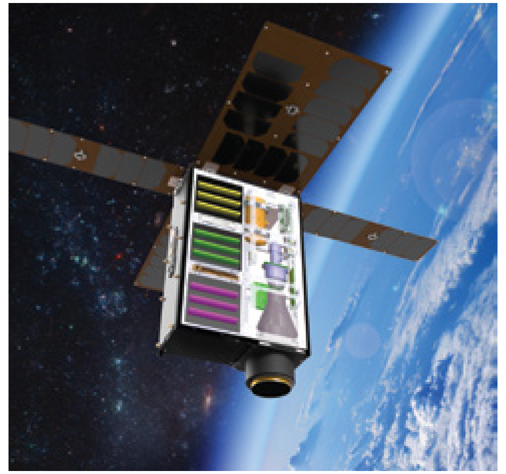


A HOT-BIRD sensor and its electronic support system.

Water is rapidly becoming one of Earth's most critical resources. Without sufficient fresh water, societies cannot exist, and as the climate shifts toward a warmer environment, tracking the state of this life-giving resource has become increasingly critical to our collective well-being. To accomplish this task, satellites must identify not just bodies of water, but also track its flow and distribution, evaporation, availability, and even the temperature of nearby land surfaces.

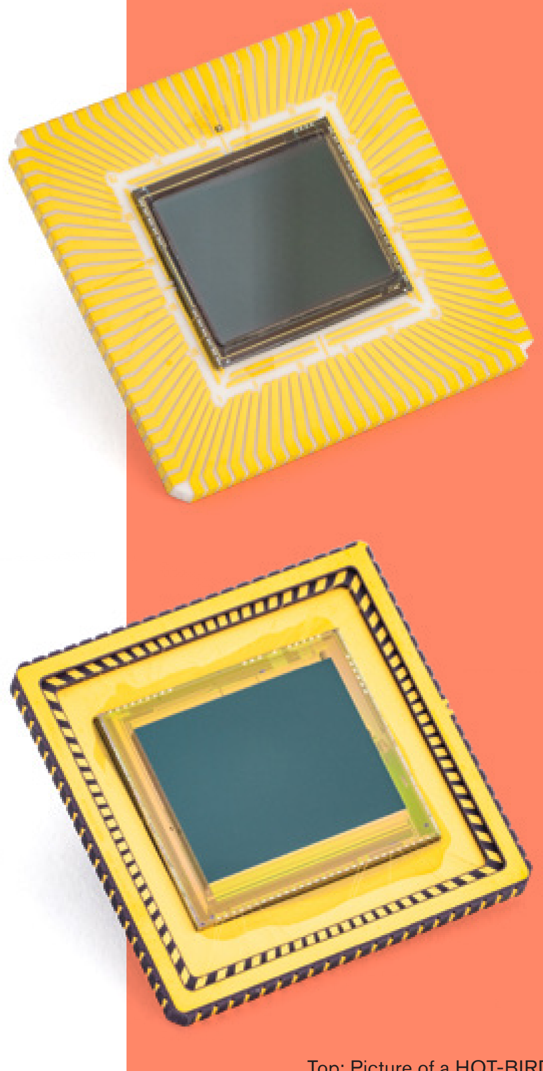
Traditional satellites focused on this goal have been large, complex, and costly to build, launch, and maintain. They have also been limited in their ability to measure land temperatures, a critical step toward understanding the ultimate fate of water supplies. Thermal measurement sensors have been used to overcome these limitations, but must operate at cryogenic temperatures, and these extreme-cold generating systems are expensive to build and very energy intensive to operate. Fortunately, JPL engineers have developed a better way.

New thermal sensors using exotic semiconductors provide high resolution thermal imaging of Earth's water resources.



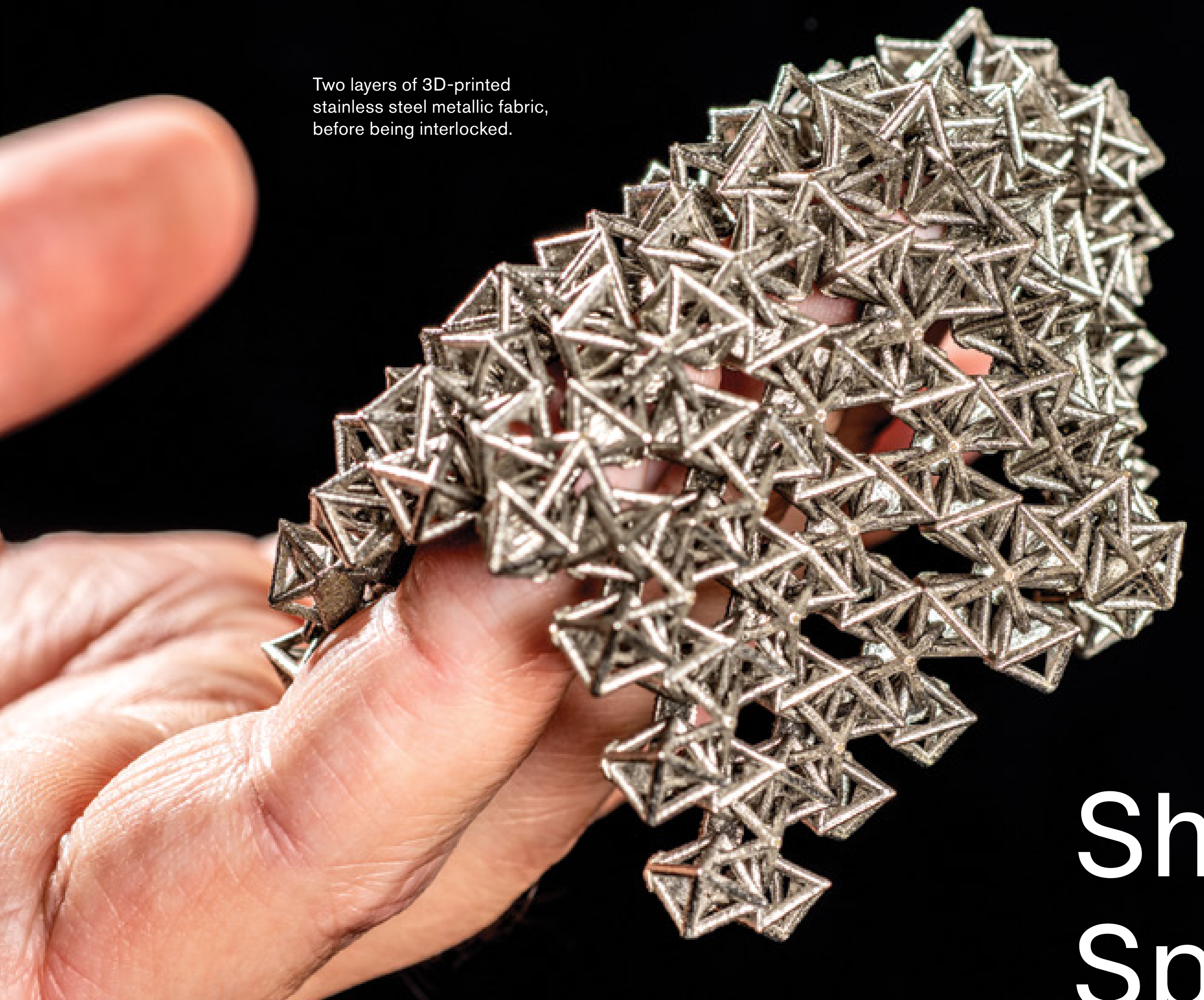
The HyTI (Hyperspectral Thermal Imager) 6U CubeSat will demonstrate the possibility of creating a constellation of 25–30 low-Earth orbit satellites that will provide data needed for water resource management. The constellation, which will cost well under that of a single conventional satellite, will also be able to monitor land temperature and carbon dioxide releases as indicators of potential volcanic eruptions.

JPL's HOT-BIRD sensor (High Operating Temperature Barrier Infrared Detector) is based on exotic semiconducting materials, specifically an indium arsenide and indium arsenide antimonide lattice, which has the unique capability to operate at room temperature, eliminating the need for bulky, power-hungry cryogenic cooling systems. The HOT-BIRD sensor is an enabling technology for the HyTI CubeSat mission designed to map irrigated and rain-fed cropland, determine the crop water use, and establish crop water productivity of global agriculture. HOT-BIRDs are simpler to manufacture than current infrared sensors of similar capability, are customizable across a broad range of frequencies, and are robust enough to survive in the orbital environment over the long term. HOT-BIRD technology is a huge step forward in the identification and allocation of desperately needed water resources worldwide.



Top: Picture of a HOT-BIRD focal plane array, which enabled the compact 2U HyTI instrument for a 6U SmallSat.

Bottom: The same sensor in a leadless chip carrier for testing.



Two layers of 3D-printed stainless steel metallic fabric, before being interlocked.

Fabric Spacecraft Components That Stiffen on Demand

Shape-Shifting Spacecraft

Some space mission components, like antennas and habitation modules, are bulky and constrained by the size of a rocket's fairing. What if this limitation were removed and components could be larger and more capable without increasing the size of the launch vehicle?

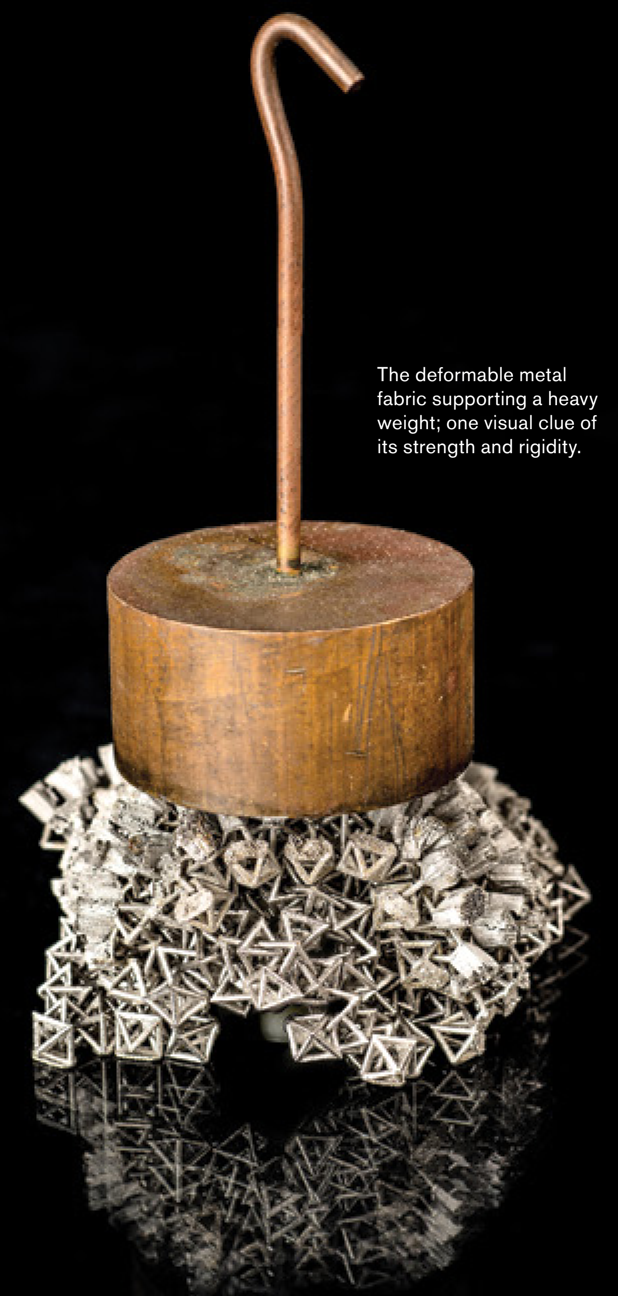
JPL has developed a new 3D-printable fabric that can be stiffened into a desired shape after deployment in space. These shape-morphing materials, inspired by chain mail armor, are fabricated by printing interlocking particles that can each independently move a short distance, allowing for customized configurations, ideal for specific purposes. These flexible sheets can then be rolled or folded into very small dimensions to be packed into a rocket fairing for launch.

Creating a morphable structure requires a general, but not necessarily exact, knowledge of the final rigidized structure as well as designing appropriate interlocking particles. The sheets can be shaped while they are flexible, and the stiffness can be tuned by varying the pressure, to achieve the desired shape. Then force is applied to adjacent sheets as they jam together, interlocking into a final, rigidized configuration.

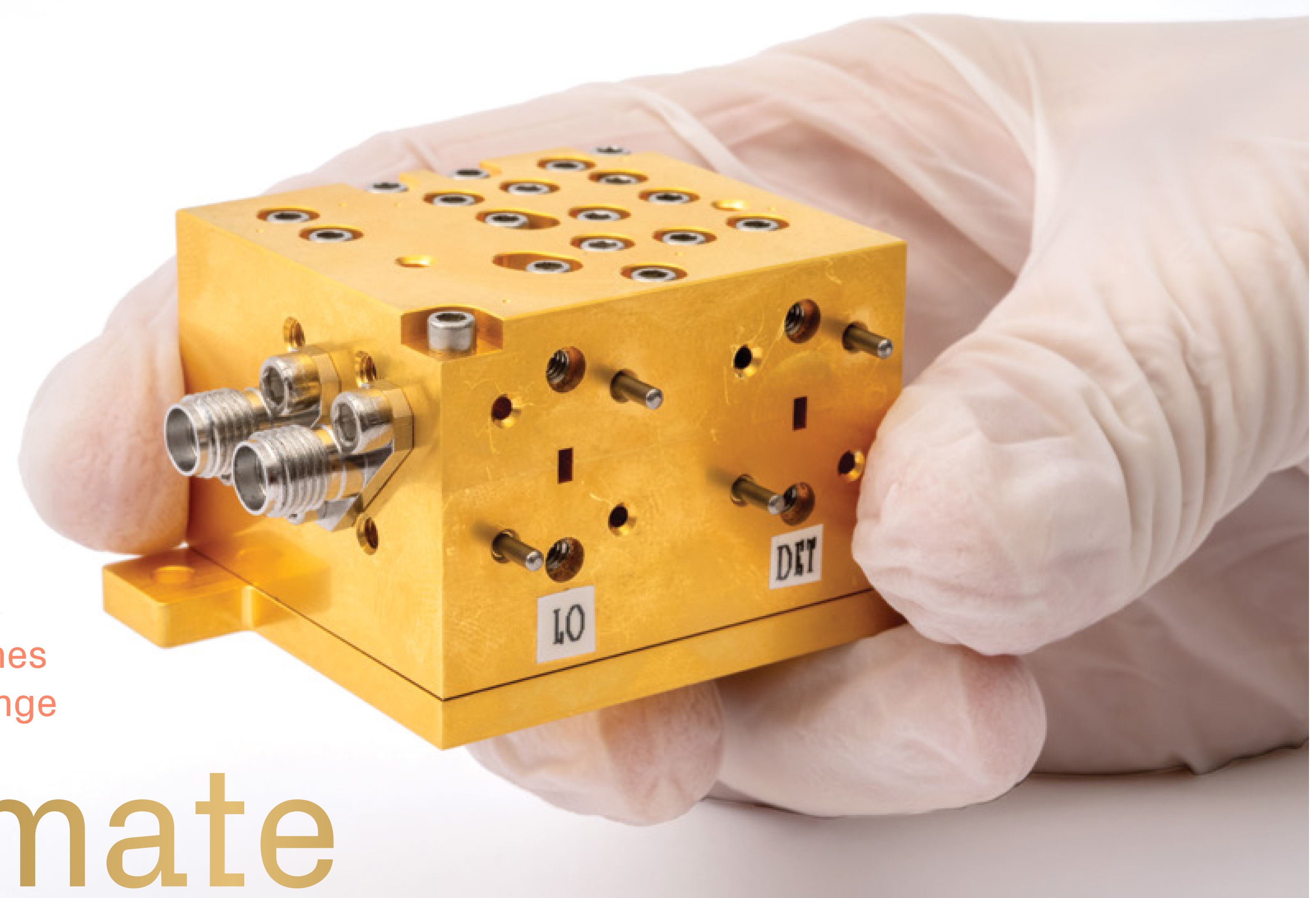
Tunable spacecraft structural fabrics will give missions new capabilities in smaller packages.

These structural fabrics have many potential applications in both NASA missions and consumer products. They can be used as deployable radiators, antennas, solar panels, radiation protection blankets, or micrometeoroid shields. They could also be used as body-conforming exoskeletons for astronauts exposed to long-duration microgravity. On Earth, the structural fabrics could be used in healthcare as adaptive casts that adjust their stiffness as an injury heals or as impact-absorbing clothing for firefighters or soldiers.

Their characteristic of being foldable and stowable, then deploying into larger, rigid shapes once in space, will result in much larger and customizable components shaped for optimal performance.



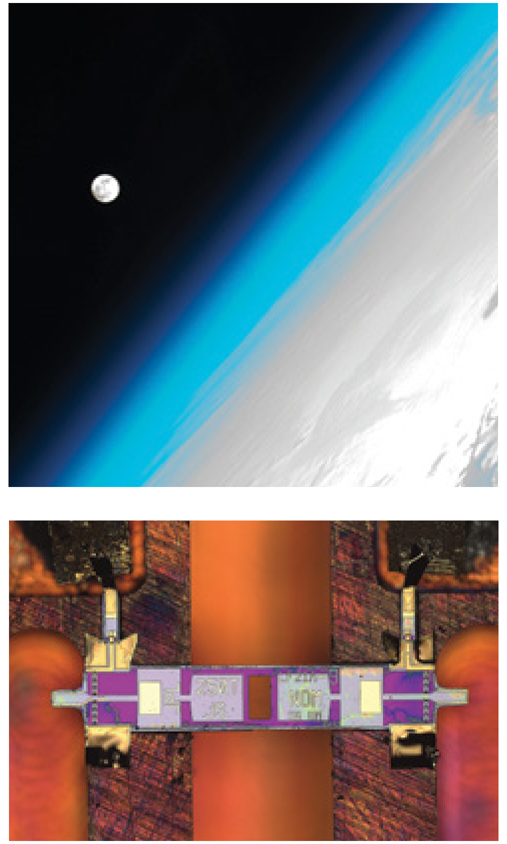
The deformable metal fabric supporting a heavy weight; one visual clue of its strength and rigidity.



Atmospheric Radar Watches Climate Change

Climate Overwatch

A compact down-conversion assembly module at the heart of CloudCube that will help to enable the deployment of large fleets of weather-monitoring SmallSats, increasing coverage and accuracy.



Top: Earth's limb, photographed from orbit, showing cloud cover, atmospheric layers, and the full Moon.

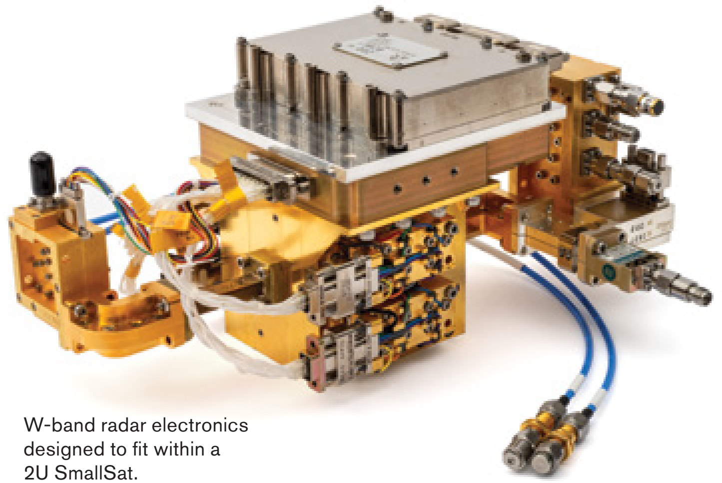
Bottom: State-of-the-art high-efficiency frequency-multipliers are a newly developed, compact, reliable, low-energy and high-power system on a chip.

To understand the complexities of climate change, we need to grasp weather in three dimensions. Our ability to do this spans a number of technologies and platforms—both airborne and orbital—but is limited by both the frequency of aerial coverage and the cost of the instrumentation. For a deeper understanding of our changing climate, continual monitoring on a global scale is necessary—a perfect job for satellites. But with an orbital period of about 90 minutes, current satellites can only provide intermittent data.

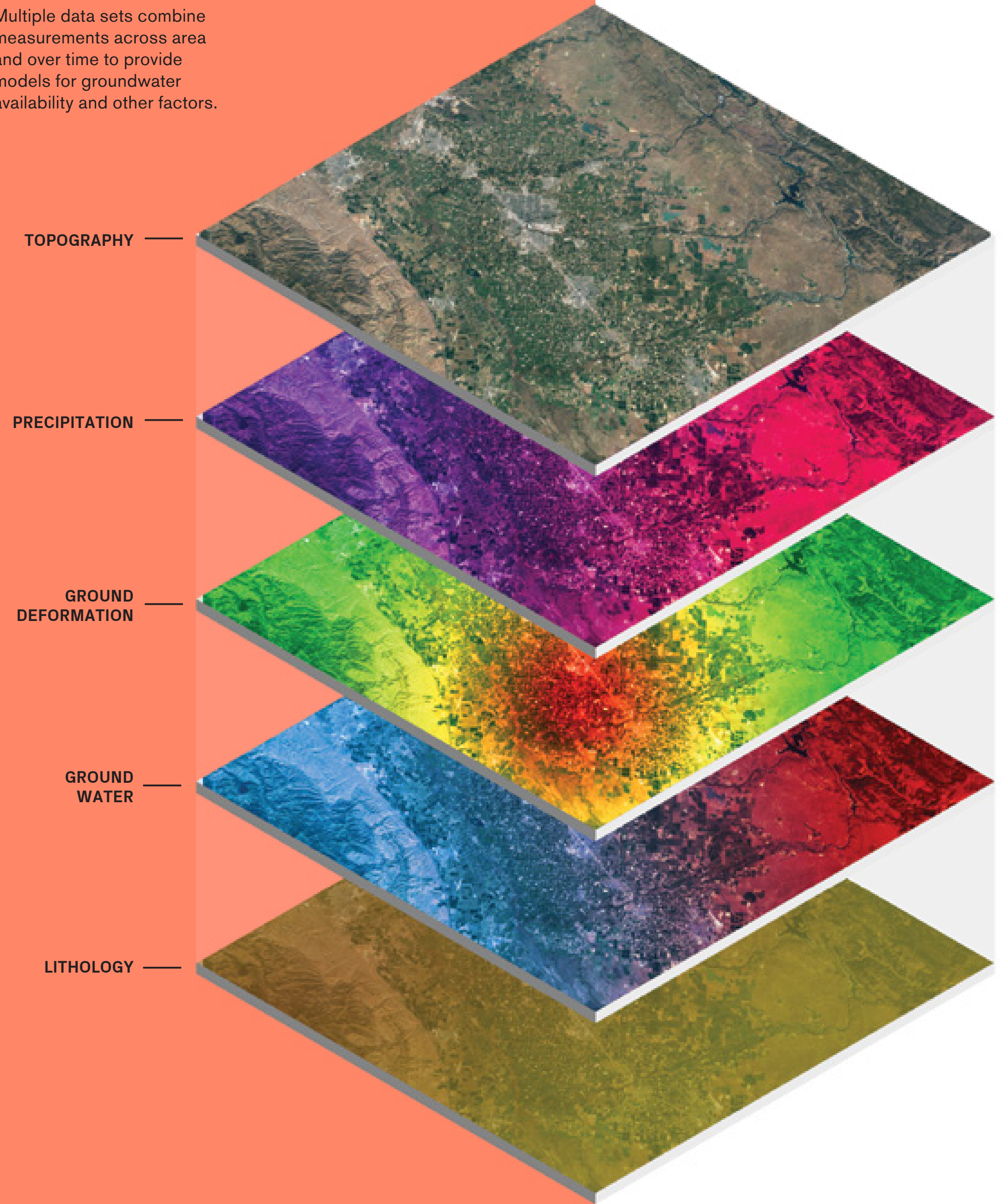
JPL's new CloudCube technology is a compact radar system that can operate across a range of frequencies and is sufficiently affordable to be flown in constellations in low-Earth orbit. By distributing CloudCube MiniSats around the globe, nearly continuous coverage of weather patterns can be observed and recorded.

CloudCube uses newly developed radar technology to provide a high degree of functionality from a more compact and less power-hungry structure than its predecessors. It can observe in Ka-, W-, and G-bands, returning multiple data sets from varying altitudes that can be modeled in three dimensions. In effect, CloudCube provides the data equivalent of a virtual reality view of global weather patterns many times per hour. Besides regular, global weather patterns, CloudCube will provide views of hard-to-spot snowfall events and anvil clouds—some of the largest of cloud formations—as well as a global survey of the interior dynamics of convective storms. The increased understanding of weather patterns and climate change will have a broad impact on transportation safety, increased public safety in areas affected by large storms, and better planning for extreme weather events.

Global constellations of JPL CloudCube MiniSats will increase our understanding of climate change.



W-band radar electronics designed to fit within a 2U SmallSat.



Multiple data sets combine measurements across area and over time to provide models for groundwater availability and other factors.

What Lies Beneath

Estimation of Geologic Composition Using Remote Sensing

California's Central Valley produces an estimated $17 billion of annual agricultural output, including approximately one-fourth of all food in the United States. However, in some regions of the Central Valley, the land surface is sinking at a rapid rate—as much as seven inches (18 centimeters) per year during droughts—due to continued groundwater pumping for crop irrigation. This surface subsidence has a significant impact on infrastructure and groundwater sustainability, so it is important to understand subsidence and groundwater depletion in a consistent framework. However, information on subsurface geological structure is sparse and has been sampled irregularly, compromising our understanding of the complex dynamics of groundwater changes and the resulting subsidence. JPL's novel data analysis technique may offer a new opportunity to see beneath the ground.

Temporal changes (those occurring over time) in surface deformation resulting from groundwater pumping can be a function of the soil's underlying geological composition. This prompted JPL scientists to utilize a deep neural network to interpolate Interferometric Synthetic Aperture Radar (InSAR) data sequences to a consistent spatial and temporal resolution, which provides the ability to calculate estimates of geologic composition.

New high-resolution radar terrain survey data analysis software aids in understanding ground surface subsidence and water availability.

InSAR observation sequences show the temporal history of integrated land surface movement in groundwater regions of interest. The analysis of InSAR remote sensing data has provided predictions of geologic composition, and this technique can be generalized to other regions to provide indirect and remote geologic estimates of water availability.

Groundwater and subsidence prediction and management are critical to understanding how Earth is changing. This technology will empower new data processing approaches to estimate future groundwater availability and observe Earth's response to natural and human-induced events, including rainfall and agricultural groundwater usage. The project has produced a data analysis framework that can be applied to the study of aquifers and their future management worldwide.

California's Central Valley provides a quarter of the U.S.'s food. Identification and tracking of available water supplies is critical.

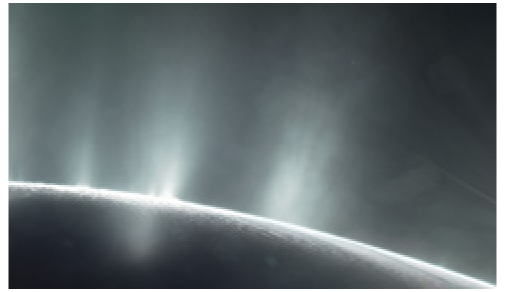
Cold Play

A New System for Testing Sample Collection and Transfer Technologies for Icy Moons

A view inside the CITADEL extreme environment simulation chamber, showing a collection tool attached to the end of a robotic manipulator.

Since before the Space Age, scientists have pined for geological samples from other worlds. During the Apollo program we retrieved hundreds of pounds of Moon rocks, and since then, tiny samples from asteroids and comets. NASA is planning to return a scientifically selected set of core samples back from Mars as soon as 2033, but that's where active planning for such sample returns has stopped—going beyond has generally been thought of as too difficult; perhaps a goal for later in this century.

In the past two decades, however, interest in surface samples from the icy moons of the outer solar system has grown, especially from Saturn's moon Enceladus and Jupiter's moon Europa, under whose surfaces warm oceans appear to dwell. Where there is warm water, there may well be life or its precursors. Samples from these and other planetary moons, especially those collected near areas where internal ocean waters spring forth and freeze, could generate important scientific returns.

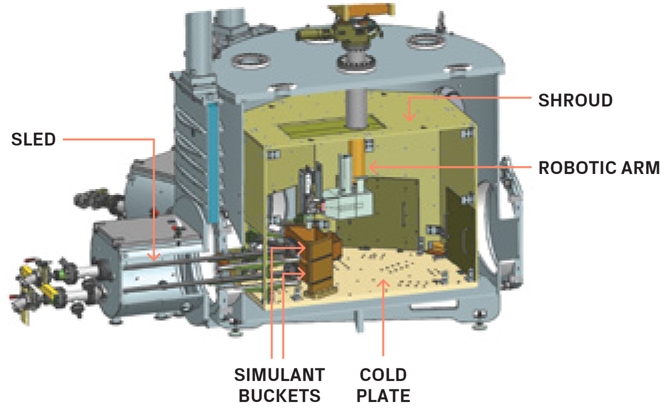


Saturn's moon Enceladus hosts an ice-covered, warm-water ocean that erupts through cracks into space, forming freezing plumes that fall back to the surface. Sampling and analyzing the plume ice, which appears to contain the basic requirements of terrestrial life, could reveal important insights into its potential presence on these worlds.

JPL's CITADEL cryogenic-vacuum test chamber mimics outer solar system moons to test advanced sampling technologies.

As challenging as returning rocks and small cores from Mars is proving to be, however, drilling into an icy moon's rock-hard ice is even more daunting, especially under the frigid conditions many hundreds of millions of miles from Earth—the surface temperatures can plunge to minus 330 degrees Fahrenheit (minus 200 degrees Celsius), causing metal to become brittle. They are also bathed in radiation and exist in a hard vacuum.

JPL engineers, working with Honeybee Robotics, are developing a suite of tools for extracting ice samples in these regimes, and are testing them in environmental conditions similar to those found on the icy moons. For example, inside the JPL-designed vacuum and environmental cryo-chamber, called CITADEL, a robotic arm guides a tool with spinning blades to shave material off an ice target, collects the sample, then transfers it into a collection cup using pressurized gas. In the future, samples collected in this fashion could be evaluated on-site or chilled for transport to Earth for detailed analysis. The resulting data would expand our understanding of the formation dynamics of icy moons and may provide early answers in our quest to find extraterrestrial life.



Top: View of the CITADEL test lab. The icy moon environment chamber is at the center.

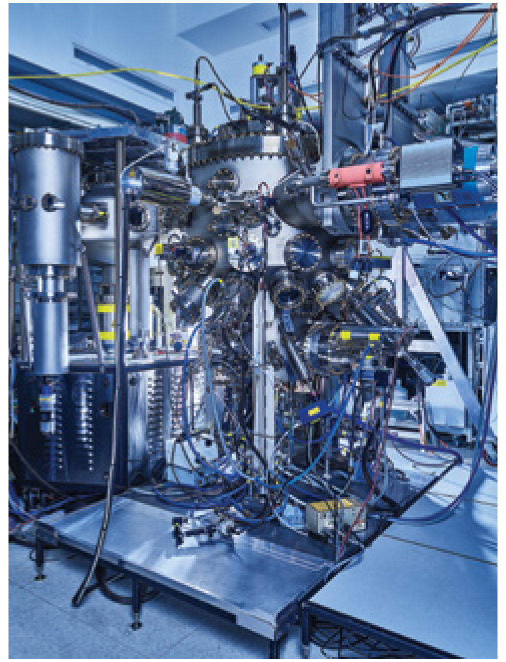
Bottom: Schematic rendering of the CITADEL test chamber.

A photon-counting CCD wafer prepared for nanoscale bandstructure engineering.

Small Deposits, Big Returns

Nanoengineered Silicon Detectors Will Answer Complex Questions in Astronomy

The MBE vacuum chamber in which nanoscale chips are fabricated to exacting tolerances.



It's not easy to fabricate highly sensitive silicon-wafer detectors for deep space missions. These devices are engineered at nanoscale, and the tiniest manufacturing irregularities can impair their functionality via particle traps and other defects at the atomic level. Another challenge is their sensitivity to damage from the intensely radioactive deep space environment. Improvements in fabrication techniques and in-flight stability are the holy grail of chip designers and engineers designing spaceflight sensors.

JPL is tackling the problem at the atomic scale. Using molecular beam epitaxy (MBE) and atomic layer deposition techniques that apply the layers of materials at the depth of one atom at a time allows for nanoscale chip fabrication with extreme precision. Employing the JPL-developed delta-doping technique, fabricators can deliberately introduce layers of impurities into semiconducting surfaces that create structures able to modulate electrical and optical properties for a desired effect. These nano-surfaces can be tailored with specific properties that are reliable, stable, and perfectly tuned to their desired application, improving efficiency at a quantum level. They are less expensive and quicker to manufacture than previous generations of sensors and are resistant to the deleterious effects of spaceborne radiation while providing two-to-three times more sensitivity than their predecessors.

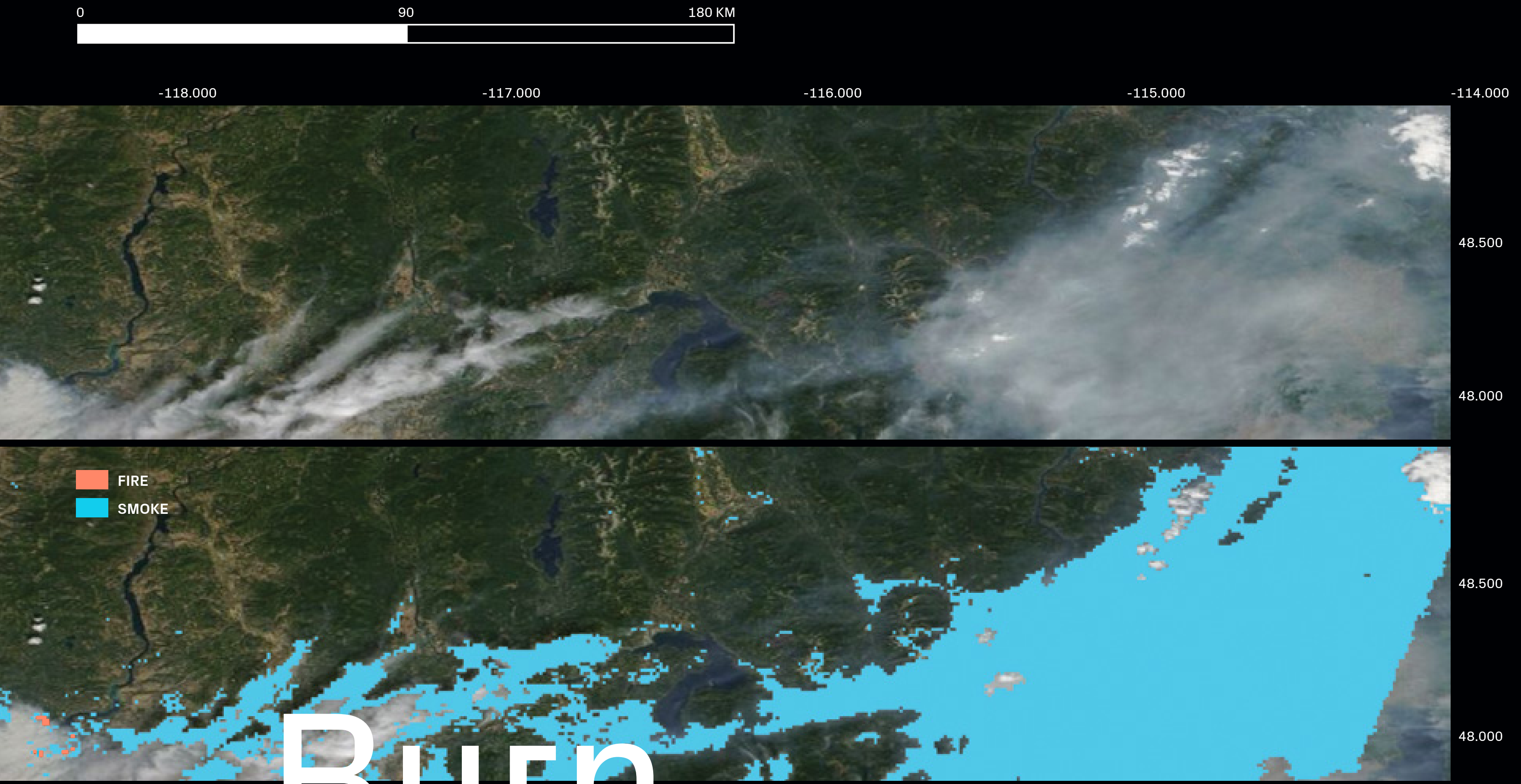
These nano-engineered devices will be used in NASA's upcoming Star-Planet Activity Research CubeSat (SPARCS) mission, which will measure flares and sunspot activity in red dwarf stars in ultraviolet (UV) wavelengths. They will also be used in the Ultraviolet Explorer (UVEX) mission to perform an all-sky survey in UV. Other future missions will utilize these detectors in wavelengths ranging from infrared to optical, extreme UV, and even X-Rays, offering greater understanding of the cosmos that surrounds us.

Manufacturing spacecraft nano-sensors at the atomic scale improves accuracy, efficiency, and longevity.

Microdevices laboratory researchers next to the sophisticated electronics that control and monitor the MBE system.

Burn Notice

AI and Advanced Modeling Predict the Spread of Dangerous Wildfire Ash Clouds



Top: Tracking the smoke plume of the Williams Flat fire in Washington state, 2019.

Bottom: Map of the same region overlayed with the segmentation of fire and smoke. These static identifications are also used for automated tracking from separate resources.

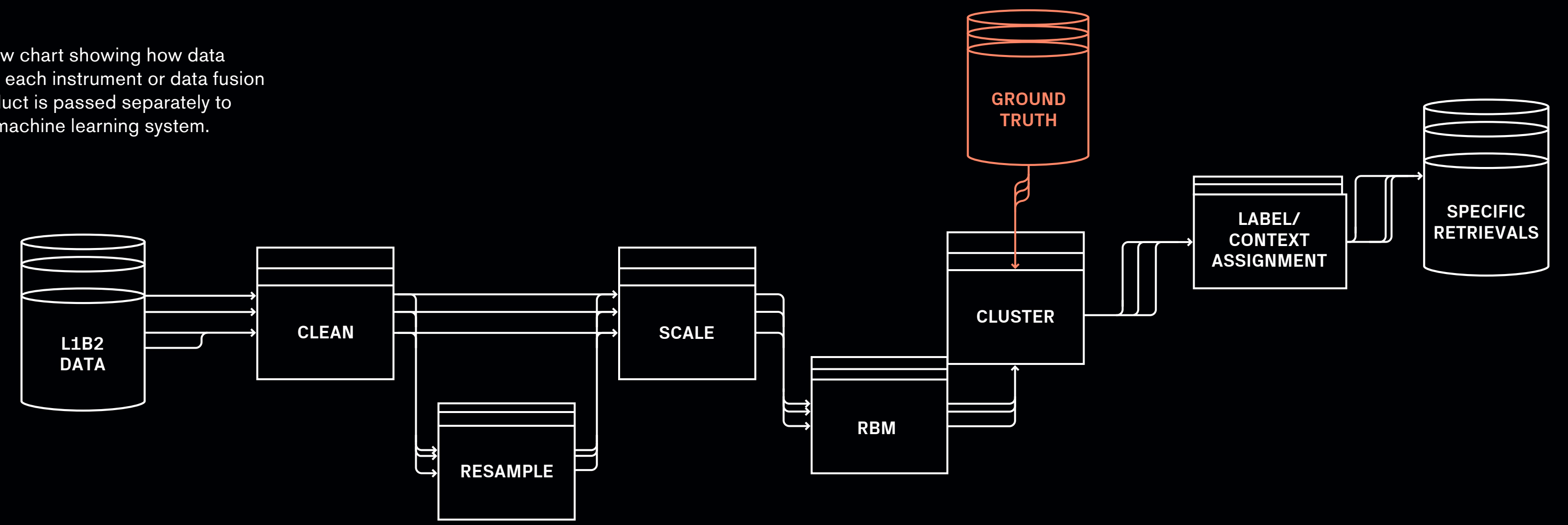
This is the decade of the wildfire. From the west coast of the United States to the Brazilian rainforest to parts of Indonesia and Australia, climate change-induced wildfires rage across vast regions annually. An addition to the massive damage to natural ecosystems and habitats, both animal and human, are the dangerous effects of massive plumes of smoke. These clouds of carbon particulates are bad for human and animal health and can also have adverse effects on regional economies.

Modeling these enormous smoke plumes is a bit like trying to predict the behavior of a wild animal—they can spread in seemingly random and unpredictable ways. Better methods of tracking and predicting the formation and extent of these dangerous clouds of ash will become increasingly important as greenhouse gases continue to build up in our atmosphere, causing the spread of wildfires into ever larger regions.

JPL is working on software that will help to “tame the beast” by integrating time-based observations, artificial intelligence (AI), and machine learning to better predict the spread of these smoky veils. By using high-tech tools such as time-aware deep neural networks (DNNs) and topological data analysis systems (TDAs), the AI can learn from past behaviors of these plumes to better model and predict the impact of future wildfire events. Better understanding of the hidden mechanisms behind the spread and propagation of these clouds may lie within the large swarms of tracking data and will be critical to prediction of effects. The software will also be able to capture and integrate data from upcoming NASA Earth observation programs such as the Multi-Angle Imager for Aerosols (MAIA) and the Tropospheric Emissions: Monitoring of Pollution (TEMPO) missions, providing increasingly detailed analyses and predictions of past and future wildfire storms and their potentially devastating effects.

Modeling the spread of wildfire ash clouds is challenging, but new AI-enhanced machine learning software provides improved modeling and prediction.

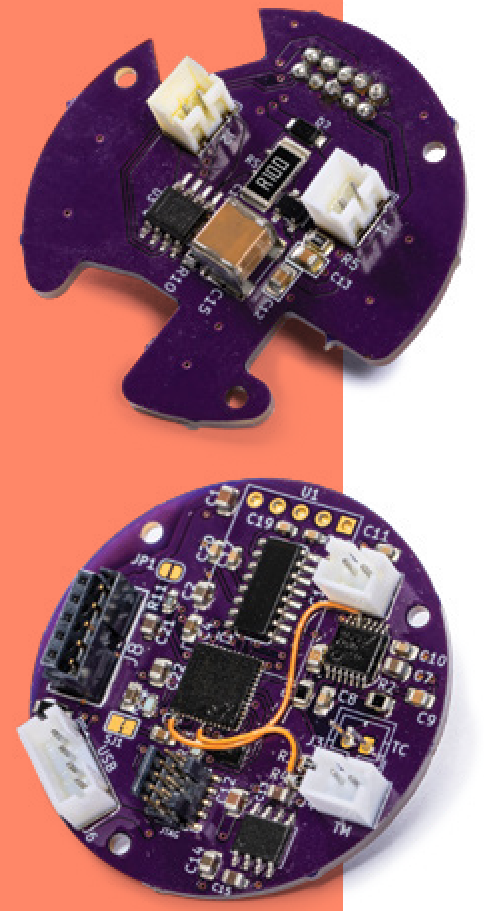
A flow chart showing how data from each instrument or data fusion product is passed separately to the machine learning system.



Two views of an oil-flooded valve switching housing. The unit to the left shows the interior components; the one on the right is inside its protective housing.

Grace Under Pressure

Miniaturizing Hot Spring Samplers for a New Class of Deep Sea Explorers



At top, the motor driver electronics board. At bottom, the main avionics board layer.

Deep-sea hydrothermal vents are among Earth's most technically challenging environments to sample, reaching up to 750 degrees Fahrenheit (400 degrees Celsius) and 50 megapascals of pressure. Chemical analyses of hot fluids extruding from these undersea fissures have transformed our understanding of the chemistry of the sea floor, extreme forms of microbes, and have even provided insights into possibilities for life's emergence inside the watery worlds of the outer solar system. But to investigate those far-flung oceans, robotic spacecraft must carry fluid sampling tools to frigid moons like Enceladus and Europa, and they must be small enough—and robust enough—to be practical for flight.

Miniaturized, pressure-hardened electronics will open the door to exploring the outer solar system's ocean worlds.

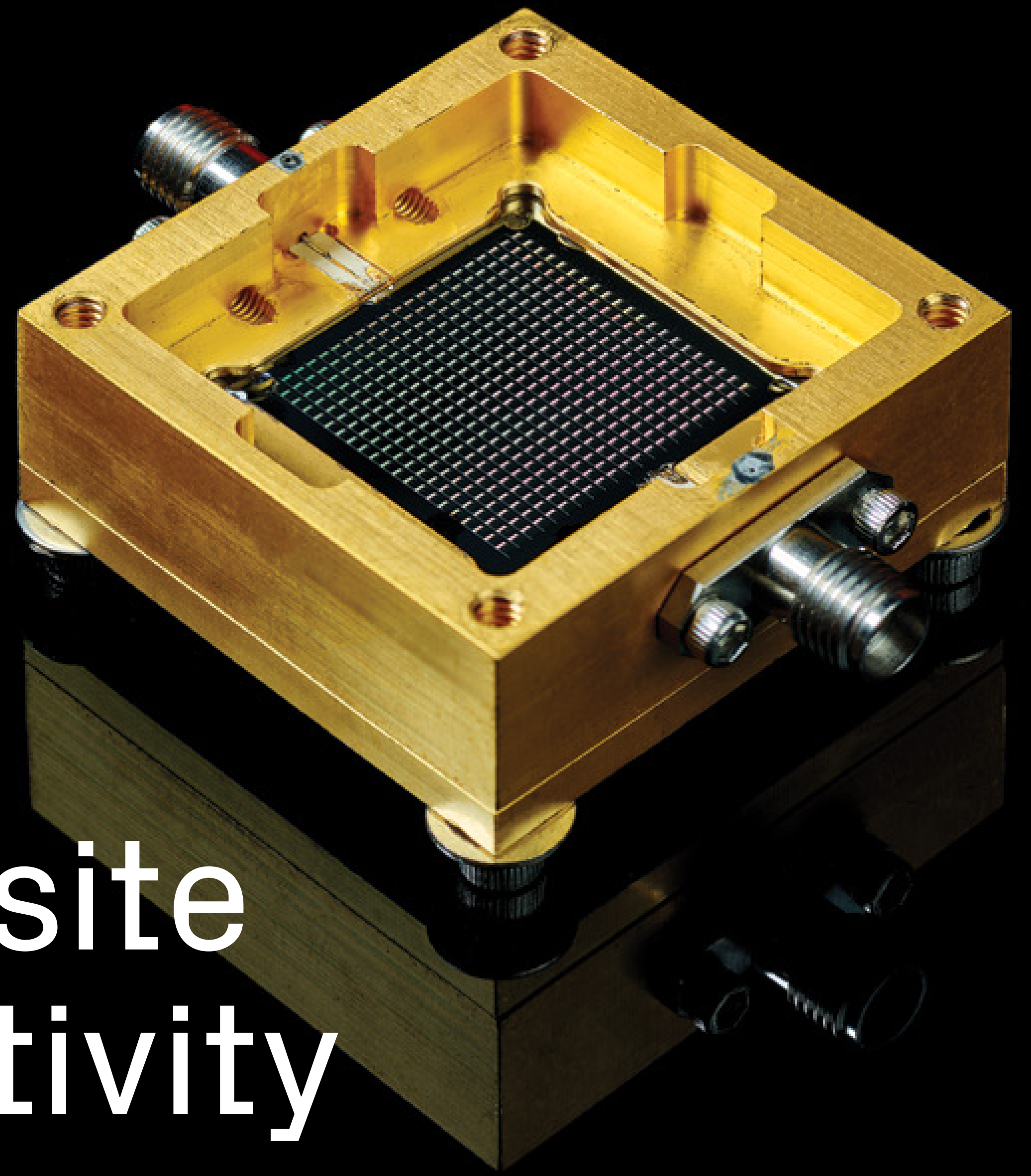
Isobaric gas-tight samplers (IGTs) are the best technology for these investigations, but such instruments are heavy, complicated, and prone to failure in operation. Their tolerances must be extremely precise to operate at a variety of temperature and pressure extremes, especially when dealing with potential grit or ice particles within the sample fluid. Such instrumentation has traditionally been built big and heavy, and is used primarily on large Earth-bound submersibles, where mass and long-term reliability are not issues.

JPL technologists, working with the Woods Hole Oceanographic Institution, have designed miniaturized, less complex, and highly reliable IGTs, including them in small robotic submersibles that can operate more efficiently on Earth and may one day explore outer solar system oceans.

The sample containment system is optimized for life-related gases like hydrogen and methane, and the associated electronics have been pressure-hardened by sealing them in a compression-resistant oil-filled vessel. The resulting miniaturized robotic explorer, the MiniGT sampler, will begin testing this year with a goal of operating reliably at a depth of over six miles (9.7 kilometers). Small tools can pave the way for big dreams.

Exquisite Sensitivity

Quantum Capacitance Detectors Count Far-Infrared Photons One-by-One



An array of quantum capacitance detectors with lenses to focus radiation onto the detectors.

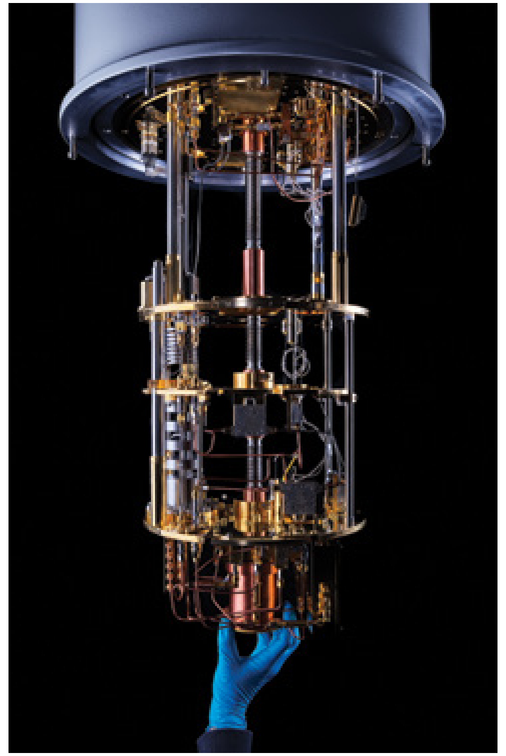
New detector technology enables far-infrared spectroscopy from spaceborne telescopes.

The universe is a dirty, dusty place. While we think of space as large and empty, huge clouds of dust particles, left over from the formation of the universe, shroud vast swaths of the cosmos. These clouds obscure enormous regions we would love to see more clearly at visible and ultraviolet frequencies, but in a bit of physics sleight-of-hand, infrared light slips past them nicely and is critical to making such observations.

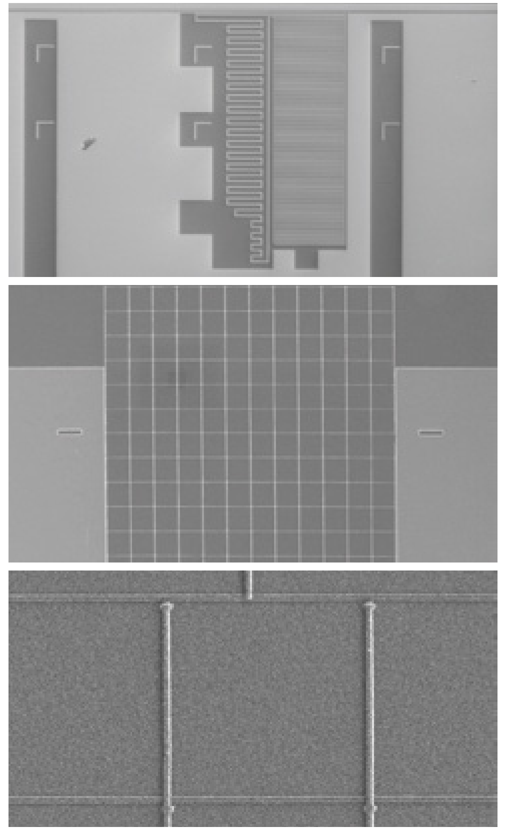
Another gift from nature is that the universe is expanding, with the light from distant objects shifting into infrared wavelengths as they move away from us. The result is that the farthest galaxies are easily observed in the infrared.

The trick to making these observations is the use of extra-sensitive infrared detectors, and a new class of these devices, called Quantum Capacitance Detectors, is being developed at JPL. Quantum detectors use superconducting surfaces to generate an "artificial atom" that is extremely sensitive to external energy—in this case, infrared light coming from very faint, distant astronomical targets. Because the electrons within this superconductor are bound very weakly, these bonds are easily broken by incoming photons, even by a single photon. When this occurs, the capacitance of the detector changes, and this change can be measured. This sensitivity in the infrared, using detectors arranged in large arrays, may unveil the origins of galaxies and black holes, allow us to trace the trail of water from molecular clouds to protoplanetary disks, and revolutionize our understanding of planetary system formation.

Finally, after centuries of observing deep space at optical wavelengths, and more recently in the ultraviolent and infrared, we will have instruments of sufficient sensitivity to see through the dusty universe with greater clarity than ever before, providing a new window into its earliest processes.



A cryogen-free dilution refrigerator used in the characterization of the detectors.

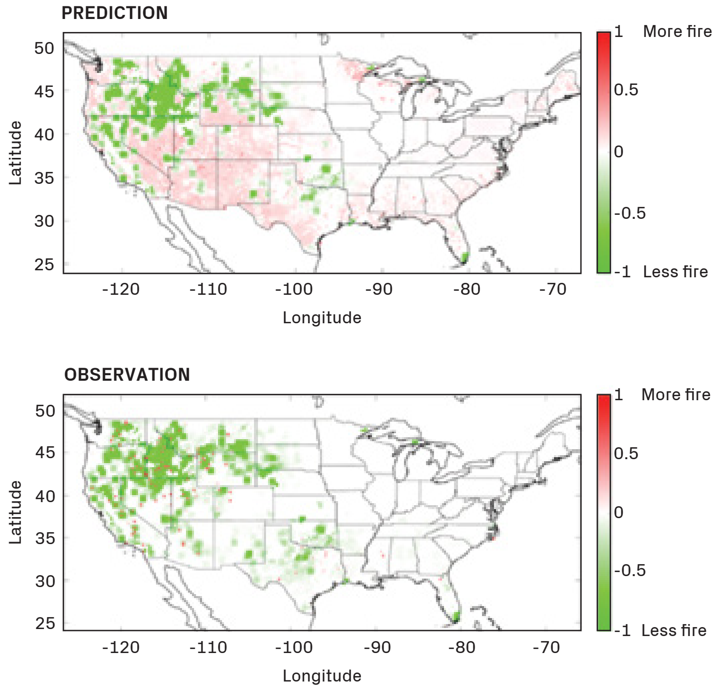


Micrograph of a Quantum Capacitance Detector pixel showing, from top to bottom, the resonator, the mesh radiation absorber, and the tunnel junction that provides the signal to detect single photons.

Predicting Fire Dangers

JPL Technology Enables Increased Lead-Times in Wildfire Prediction

The Eagle Creek Wildfire in the Columbia River Gorge, Oregon is just one of an increasing number of devastating wildfires affecting the western U.S. annually.



Shown at the bottom are actual burnt area deviations from normal in August 2013. Above that are burnt area deviations from normal for August 2013 predicted using the JPL technique. The legend on the right indicates expected burn area deviations (red means more deviation, green means less, and white is as expected). The correlation between predicted and actual events can be critical in combatting the worst effects of wildfires.

The sooner we can spot wildfire dangers, the better we can prepare to combat them and deal with the outcomes. The state-of-the-art for predicting wildfire danger has involved combining weather forecasts with fire danger models; unfortunately, this methodology offers only about ten days' lead time. With less than two weeks' warning, however, it can be difficult to preemptively stage firefighting assets, such as firetrucks, fire crews, and aircraft.

JPL technologists are tackling this problem with new software called Fire Danger from Earth Observations (FDEO), which combines multiple sources of weather data from the continental U.S. to offer longer lead times in fire prediction. The software blends land cover type, relative air humidity, surface soil moisture, and the enhanced vegetation index (a measure of vegetation amount and tree canopy structure), and incorporates the United States Forest Service's historical fire database to develop a framework to predict fire danger. Test results have shown accurate prediction of fire probability across more than half of the continental U.S. over time, and for up to three-quarters of the fire season. Future NASA efforts such as the Wildland FireSense project and the JPL-led Surface, Biology, and Geology (SBG) satellite mission concept will be able to capitalize on this novel technology.

Advance wildfire prediction allows long-lead allocation of mitigation resources.

With FDEO, wildfire potential can be predicted up to two months in advance with high reliability, resulting in increased safety, better asset preparation, reduced firefighting costs, and enhanced safety for both people and property. Combined with the future evolution of NASA efforts, longer lead times and higher accuracy will result.

Artist's impression of JPL's Gravity Imaging Radio Orbiter (GIRO) concept.

Gravity Matters

Gravitational Measurements of Outer Solar System Moons will Map their Mysterious Interiors

Saturn's moon Enceladus is generally considered to be a geological El Dorado of the outer solar system. Over 100 huge, high-temperature plumes eject about 1,000 tons of water skyward every hour and are indicative of intense geological activity on the tiny, 310-mile (500 kilometer) moon, making them points of keen interest for NASA's research efforts.

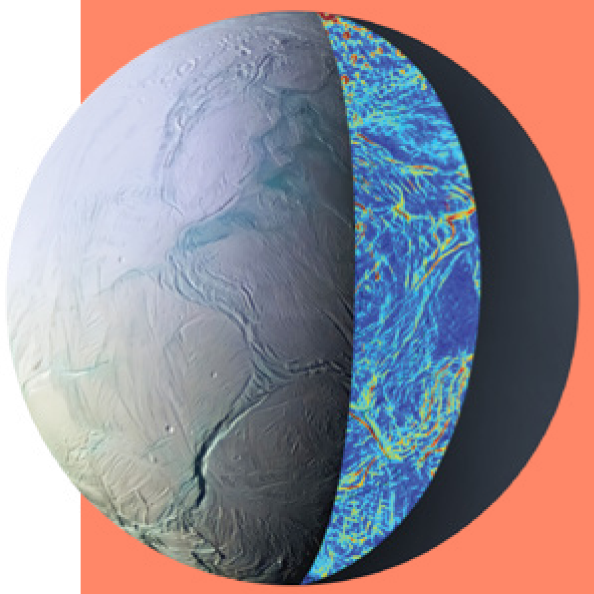
To better understand the dynamics behind these plumes, which are unique in scope within the solar system, planetary scientists want to map the interior structure of Enceladus. One way to accomplish this without landing seismometers on the surface—a very complex endeavor—is to measure the moon's gravitational field to a high degree of accuracy from orbit. Mapping a moon's gravitational field in detail can provide information about its interior structure.

Similar results have been demonstrated by satellites in low-Earth orbit during the GRACE and GRAIL missions with great success. Each of those missions utilized twin spacecraft capable of tracking their separation distance as they crossed over varying gravity fields—measuring minute changes in the distance between them indicating variances in that field.

Since sending twin orbiters to Enceladus would be expensive and tricky to accomplish, JPL engineers have devised a gravity-measuring tool called the Gravity Imaging Radio Orbiter (GIRO) that can accomplish the task with a single spacecraft that releases multiple gravity probes. These free-flying instruments will provide wide separations for data gathering, allowing a single, unified gravity map to be built of the moon's interior. The resulting models will offer a greater understanding of subsurface ice masses and possible solid cores. GIRO will also be able to measure the mass of Near-Earth Objects, asteroids that may one day present a threat to Earth—and understanding their mass and composition is a first step toward defending our planet.

> Multiple free-flying gravity probes deployed from a single spacecraft can map the interiors of outer solar system moons and measure the mass of Earth-endangering asteroids.

Interior depiction of Saturn's moon Enceladus that will be more accurately mapped by GIRO.



A hermetically-sealed enclosure for heat-resistant solar panels.

Some Like it Hot

Heat-Resistant Power Sources for the Venusian Surface

The surface of Venus presents one of the most challenging environments known for robotic spacecraft. Surface temperatures hover around 870 degrees Fahrenheit (464 degrees Celsius), and the atmospheric pressure is equivalent to about two-thirds of a mile (one kilometer) underwater on Earth. Venus' atmosphere is also host to corrosive compounds—the rain there is like the inside of an old car battery, laced with acid. It's not a place to send spacecraft casually.

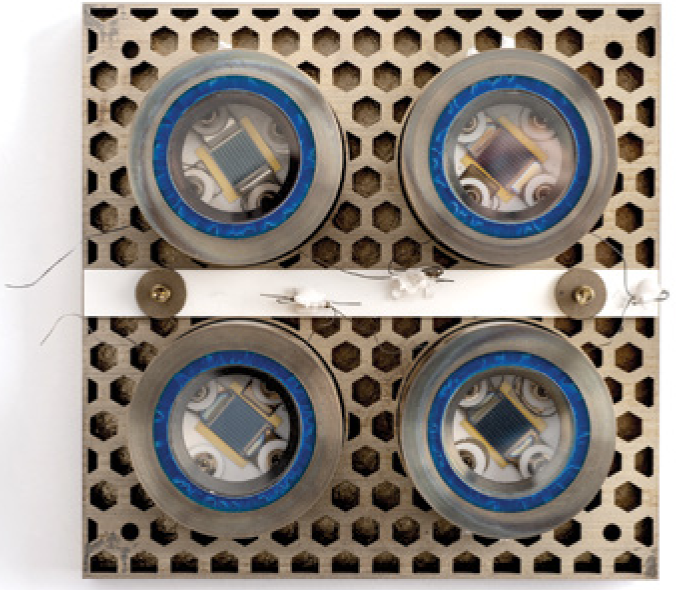
Radar image of the Venusian surface, where temperatures average a spacecraft-killing 867 degrees Fahrenheit (464 degrees Celsius) and acid rains from the skies.

New solar panel designs will produce long-lasting power for Venus landers.

The Soviet Union had some luck with a series of short-lived Venera landers in the 1970s and 1980s, operating just a few hours at best; since then, all missions to Venus have avoided the scorched surface.

JPL engineers would like to change that by developing new technologies that are highly heat-resistant. Critical among these will be a power system capable of operating under hot conditions and in dim sunlight—Venus' smoggy atmosphere is nearly opaque and lighting at the surface is roughly equivalent to an overcast day on Earth.

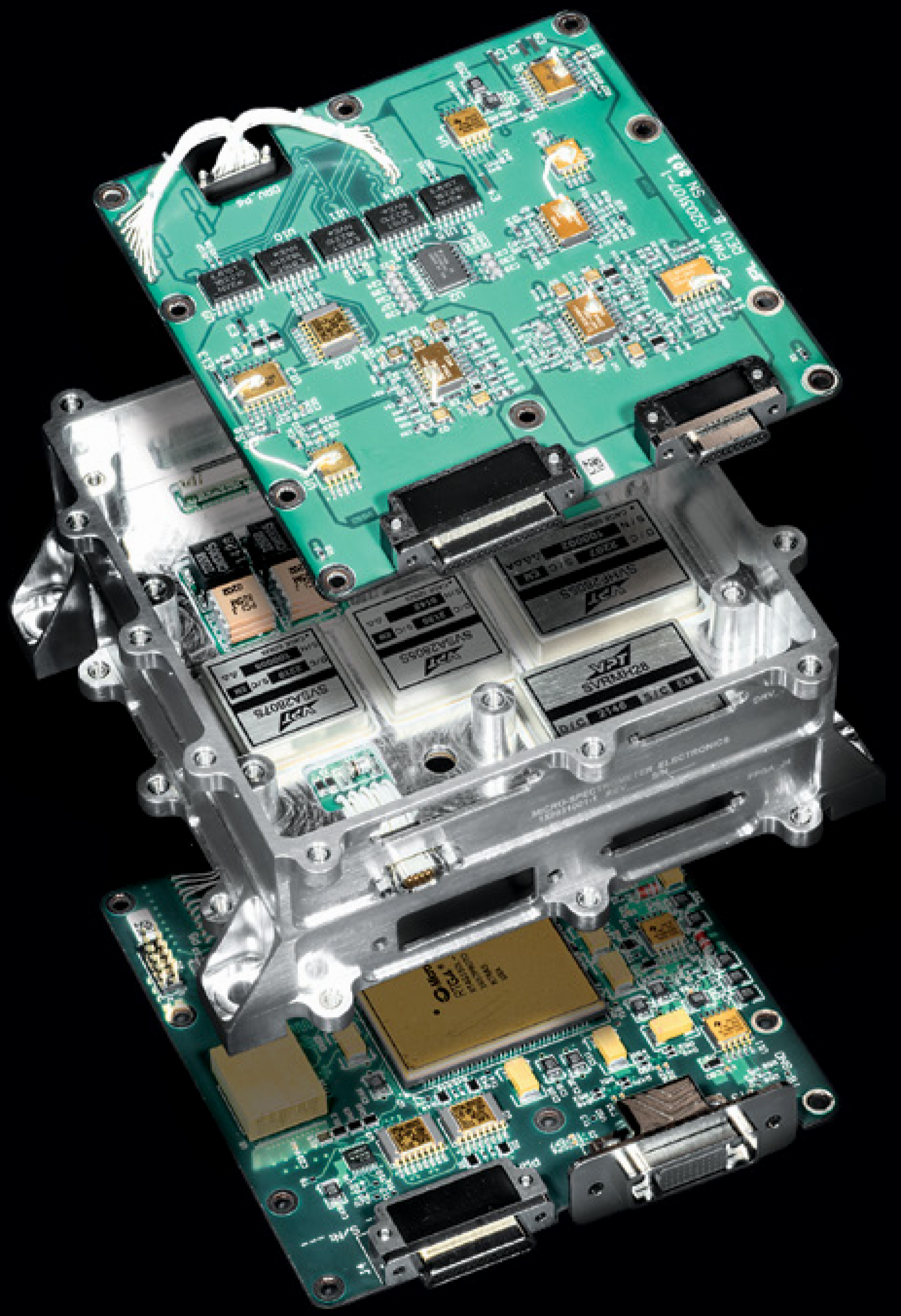
These are not ideal conditions for solar panels, and current designs are not up to the task. JPL's novel design uses a hermetically sealed enclosure to protect the solar array from corrosive compounds and high atmospheric pressure. To withstand the intense heat, the transparent top surface is fabricated from heat-resistant lab-grown sapphire sheets, and the chassis and wiring are made of Inconel, a nickel alloy with a melting point well over 2,000 degrees Fahrenheit (1,100 degrees Celsius). These new solar panels have been successfully tested in Venus-like conditions at NASA's Glenn Research Center, and are currently undergoing full-up environmental tests to prepare for inclusion onto a future Venus surface lander.



The fully assembled prototype of the Venus-surface solar array undergoes electroluminescence inspection.

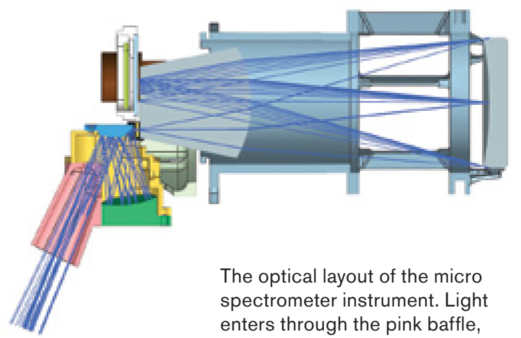
Extending Our Ingenuity

Miniaturized Spectrometer Technology Will Enhance Mars Helicopter Capabilities



Exploded view of the micro-Visible Mid-wave Dyson Imaging Spectrometer, showing three circuit boards combined into one compact assembly.

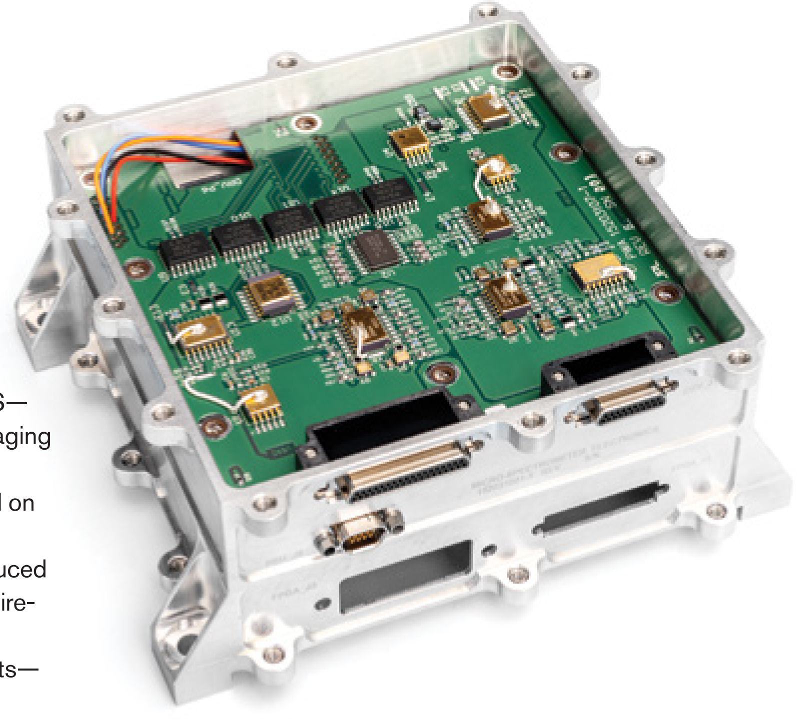
The unparalleled success of the Ingenuity Mars Helicopter has prompted the development of larger exploration helicopters capable of surveying wider regions of the Red Planet. One such concept, the Mars Science Helicopter, would have the ability to carry up to 11 pounds (five kilograms) of science payload and traverse many miles in each flight. A Dyson imaging short-wave infrared (SWIR) spectrometer would be at the core of the science instrumentation, providing high-resolution compositional information about the Martian surface, including the distribution and geologic setting of mafic (igneous rock rich in magnesium and iron) minerals, sulfates, clays, carbonates, and water. This knowledge, collected at geologically important sites across Mars, would continue to expand our understanding of the evolution of terrestrial planets and their potential habitability.



The optical layout of the micro spectrometer instrument. Light enters through the pink baffle, is focused onto a narrow slit, and dispersed into its constituent wavelengths by the spectrometer.

To realize the potential of these technologies, JPL is developing µVMDIS—the micro-Visible to Mid-wave Dyson Imaging Spectrometer, a new class of imaging spectrometer small enough to be carried on the Mars Science Helicopter—which combines compact electronics with reduced mass, smaller size, and lower power requirements. These "pushbroom" spectrometers provide three-dimensional data sets—measuring along track and cross-track positions generating a full spectrum for each sample position. The sensitive µVMDIS imaging system is extremely accurate, thanks to a tiny concave grating manufactured at JPL's Microdevices lab. The instrument's telescope has a field of view of about 62 degrees, offering a wider perspective than its predecessors with low distortion and a higher signal-to-noise ratio, which enables a new class of spectroscopic measurements. The instrument design was included in the Earth Surface Mineral Dust Source Investigation (EMIT) instrument, now on the International Space Station, and will be incorporated on NASA's Mapping Imaging Spectrometer for Europa (MISE) mission, as well as the Visible Mid-wave Dyson Imaging Spectrometer (VMDIS) technology demonstrator.

Once assembled, the micro-spectrometer electronics occupy a compact volume with low mass.



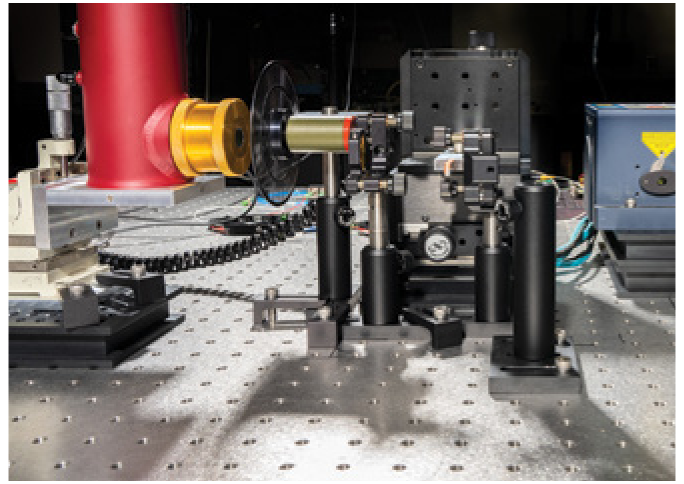
A new class of miniaturized Dyson imaging spectrometers promises to revolutionize the exploration of Mars from the air.

Spectrometers and High-Speed Detectors That Use Photonic Waveguides for Interferometry

Constructive Interference

Advanced infrared photodetectors being examined under a microscope.

A laboratory rig to test the long infrared transmission of planar optical waveguides.



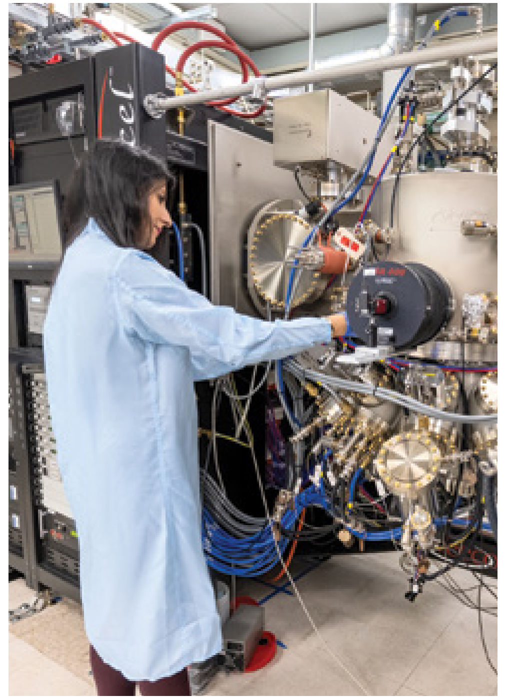
Observing faint exoplanets, which are often lost in the glare of their parent stars, requires both high angular resolution—the ability to resolve detail—and the blocking of the parent star's light. Ideally, one would build telescopes several miles wide with specialized optics to block the parent star's light and provide the needed resolution. Another approach would be to exploit the fact that planets are relatively bright in infrared wavelengths and use interferometry, a technique that extracts data from the interference of light waves from widely separated small optical instruments observing the same parent star, and digitally process the data to simulate a single large instrument. The resolution of the collected individual instruments would be equivalent to a similarly large single telescope. Unfortunately, building huge telescopes or interferometers remains challenging.

To overcome this problem, JPL engineers are developing advanced electronic interferometry systems, each with two or more separately-orbiting small telescopes that simultaneously detect the light from a parent star and its exoplanets. Each telescope, operating at wavelengths of about 10 microns, employs an advanced spectrometer chip that uses heterodyning—familiar from station tuning in radios—to separate its telescope's light into distinct spectral bands that are routed through planar photonic waveguides to dedicated infrared detectors. Planar waveguides—micron-size channels lying in the chip's plane that guide photon beams—allow ease of chip fabrication using microelectronic techniques, and can process hundreds of spectral bands simultaneously.

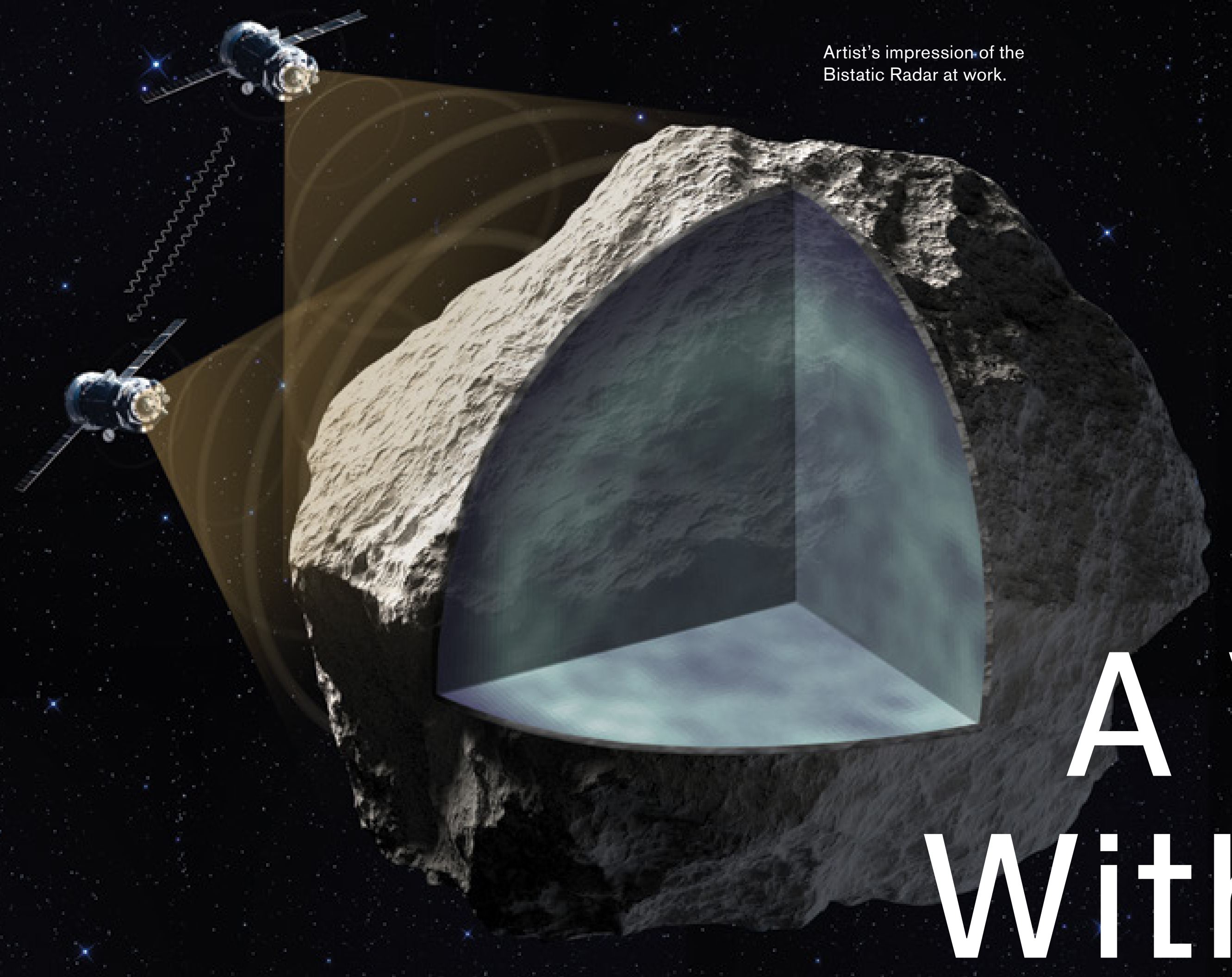
The spectrometer chip combines light from its telescope with the lines of a laser frequency comb, a reference device that provides a "ruler" of evenly spaced spectral lines. The combined incoming light is dispersed in a high-resolution spectrometer and transmitted individually through the waveguides to a row of advanced infrared photodetectors, one for each spectral band, that are bonded to the chip. Time stamps from a highly accurate clock are used to correlate the time-varying signals from the individual telescopes, and the correlated signals can be digitally processed to reconstruct an image.

The resulting observations offer extremely high bandwidth and detection near the frequency comb's quantum noise limit, providing performance comparable to direct detection approaches with strikingly simpler, and far less costly, systems.

Infrared heterodyne interferometers can allow a leap in astrophysical imaging for exoplanet research.



Advanced infrared photodetector molecular beam epitaxy growth setup.



Artist's impression of the Bistatic Radar at work.

A View Within

A Multi-Spacecraft Radar to Peer Inside Asteroids

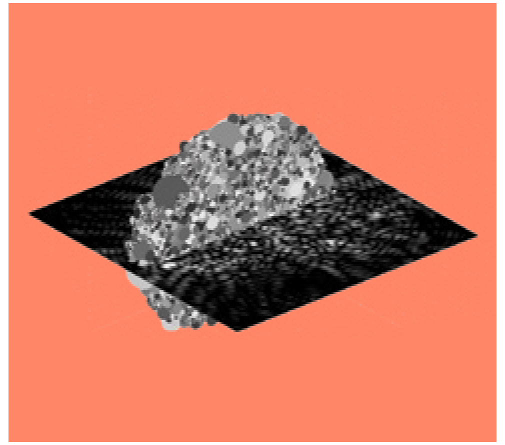
The solar system is a shooting gallery. Detritus left from its formation—some of which are large asteroids that can pass dangerously close to Earth—wanders in wide orbits. A number of these Near-Earth Objects (NEOs) could one day threaten our world, so learning more about them—and how to intercept and redirect them, if necessary—is of paramount importance.

NASA's recent Double Asteroid Redirection Test (DART) was a great start, but in the future, we'll need to understand NEOs better before we can know how to deal with them. What is known about their composition? Are they solid bodies or piles of conglomerated rubble? Or are they combinations of both—a solid core surrounded by loose rock? If so, how massive is that core? All these parameters can help to determine their threat level.

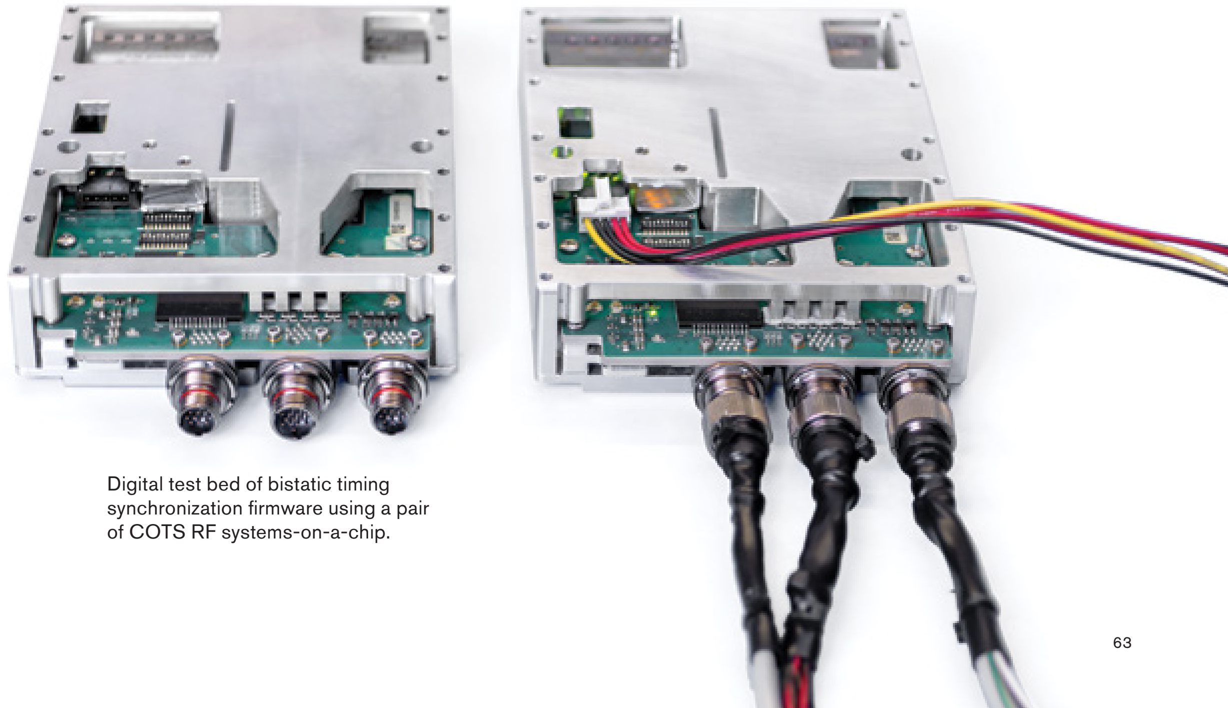
Telescopic observations from Earth offer little more than measurements of an asteroid's trajectory and a size estimate, which only offer hints to their essential composition. To really understand them, we need to visit NEOs where they live, in deep space, before they become threats.

JPL is developing signal processing technology that will allow twin spacecraft to probe the interior of target asteroids using multiple radar sources. Signals from two or more investigating spacecraft can be synchronized with 25 picosecond accuracy using off-the-shelf components and a novel call-and-response algorithm, resulting in a low-cost, transferable digital solution for measuring time and distance between two spacecraft or instruments. The resulting high-fidelity, multiple-source measurements of asteroid composition will provide not just enhanced science return, but also additional information critical to generating a defensive response should one of these bodies threaten our world. An additional bonus is the technology's applicability to probing the secrets of icy moons, like Enceladus and others, deep in the outer solar system.

A new bistatic radar can create high-resolution 3D images of the interiors of asteroids.



Simulated results of radar measurements of the interior of a 984-foot (300-meter) rubble-pile asteroid.



Digital test bed of bistatic timing synchronization firmware using a pair of COTS RF systems-on-a-chip.

Micro-Components Can Revolutionize Water-Seeking Spectrometers

Rotary Club

The Contactless Rotating MEMS Switch, a tiny rotary microswitch that operates without contact surfaces.

Advanced spectroscopy is useful for exploring comets, icy moons, and other objects beyond the reach of traditional optical telescopes. Some of the best results come from the analysis of high-frequency radar signals using radar molecular spectrometers. These specialized instruments are highly sensitive to water, which is of great interest to researchers due to its critical role in biology and geology.

The system that supplies data to the spectrometer must be able to switch the receiver frequently between the radar antenna and a known signal load for calibration. This has traditionally been achieved by flipping a mirror from the antenna to a known internal source. These mirror-activation systems are bulky, power hungry, and prone to mechanical failure, traits that are far from ideal for a spacecraft operating in cold, distant environments.

Traditional micromechanical switching systems have been an improvement, reducing size and power requirements, but since they still use mechanical electrical contacts, can also be prone to failure. JPL engineers have developed a tiny rotary microswitch that operates without contact surfaces and can be located next to the receiver without causing interference. It is microfabricated from silicon coated with gold to enable its electromagnetic properties. By rotating the switch via electrostatic activation, the receiver can either be connected to the calibrating load or to the antenna, with reduced size and power draw and greatly enhanced reliability.

Highly miniaturized switching components make all the difference for flight spectrometers.

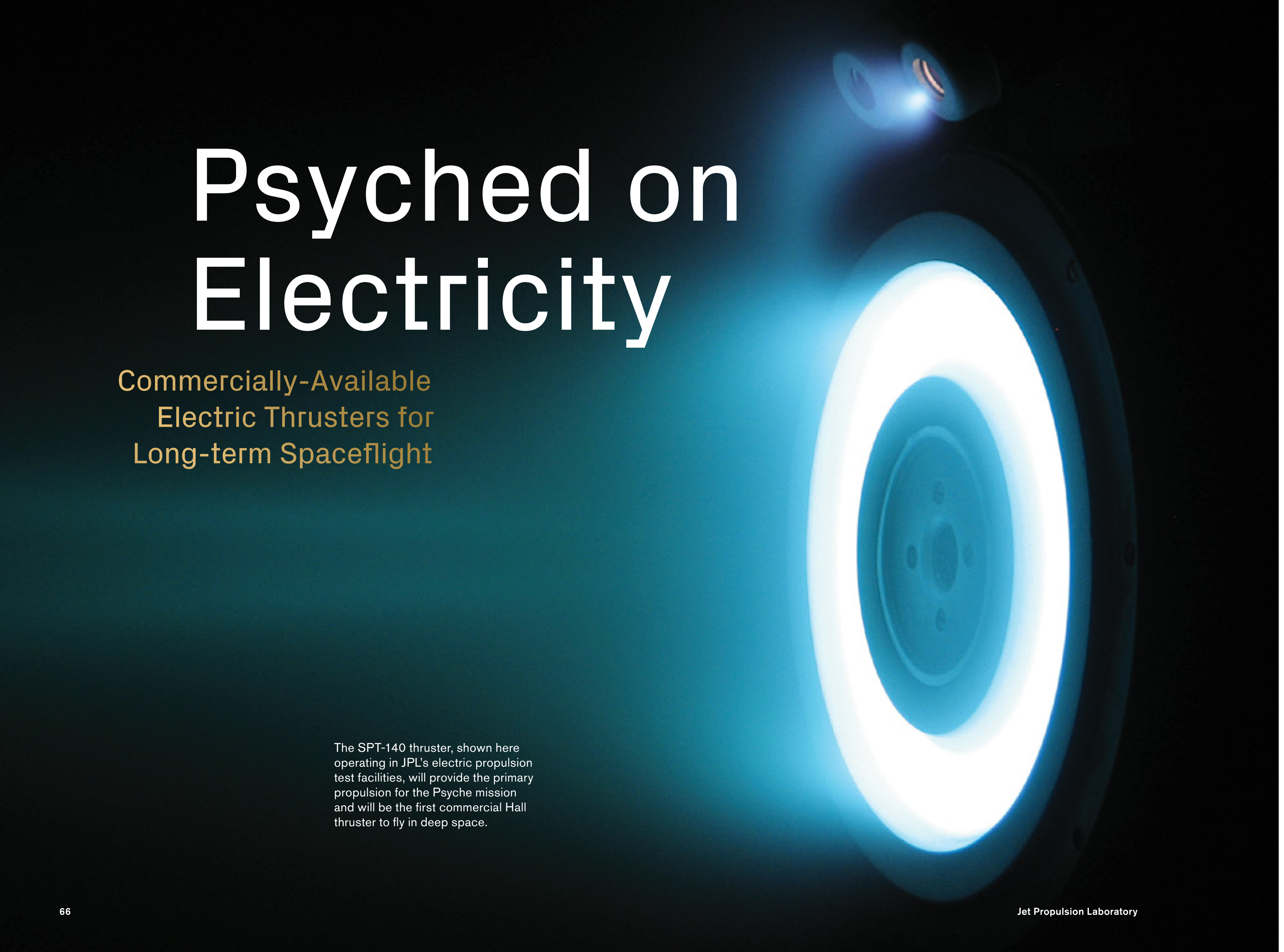
This new contactless microswitch will allow molecular spectrometers to operate in the most distant and hostile environments in our solar system. The resulting high-sensitivity spectroscopic data should offer exciting new discoveries from comets, icy moons, and other cold bodies, especially when seeking water, a key component of life.

Top: Jupiter's moon Europa has a surface that is primarily water ice floating on a warm subterranean ocean. Radar molecular spectroscopy will identify chemical constituents, including any biochemicals that are present.

Bottom: Microscopic view of the device seen from the top while actuated.

Psyched on Electricity

Commercially-Available Electric Thrusters for Long-term Spaceflight



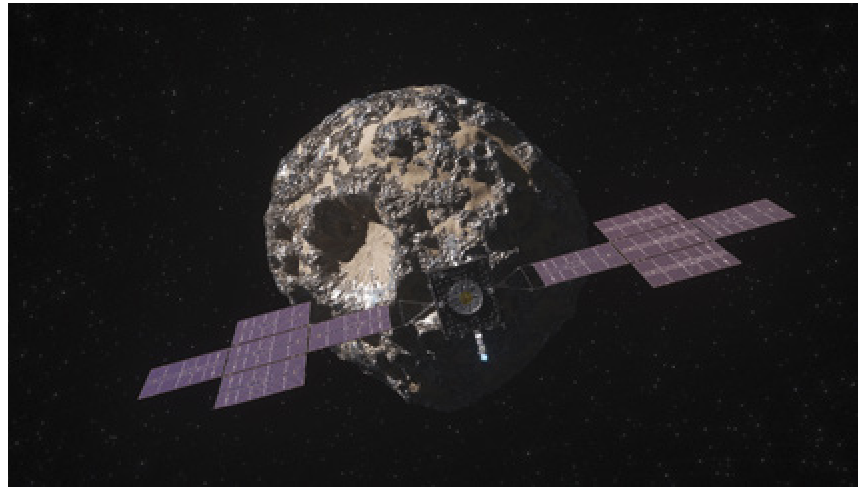
The SPT-140 thruster, shown here operating in JPL's electric propulsion test facilities, will provide the primary propulsion for the Psyche mission and will be the first commercial Hall thruster to fly in deep space.

Electric propulsion systems generate thrust with electricity rather than chemical reactions. The ability of these thrusters to fire continuously, for extended periods of time, has revolutionized spacecraft and mission designs. Over a thousand electric propulsion systems, called Hall thrusters, are currently in use on satellites in low-Earth orbit. They are small, simple in design, frugal with fuel, and able to be "parked" in standby mode for months or years with no ill effects, something conventional chemical rocket engines simply cannot do.

However, going deeper into space over longer periods of time requires a more robust design. Outer solar system missions can stretch for years and even decades before completing all their objectives. One such program, the Dawn mission, used an experimental Ion thruster to reconnoiter Ceres and Vesta, two large objects in the asteroid belt between Mars and Jupiter. While successful, the thruster for that mission was comparatively complex and expensive to produce. For ongoing investigations beyond the terrestrial planets, a simpler, less expensive alternative is needed.

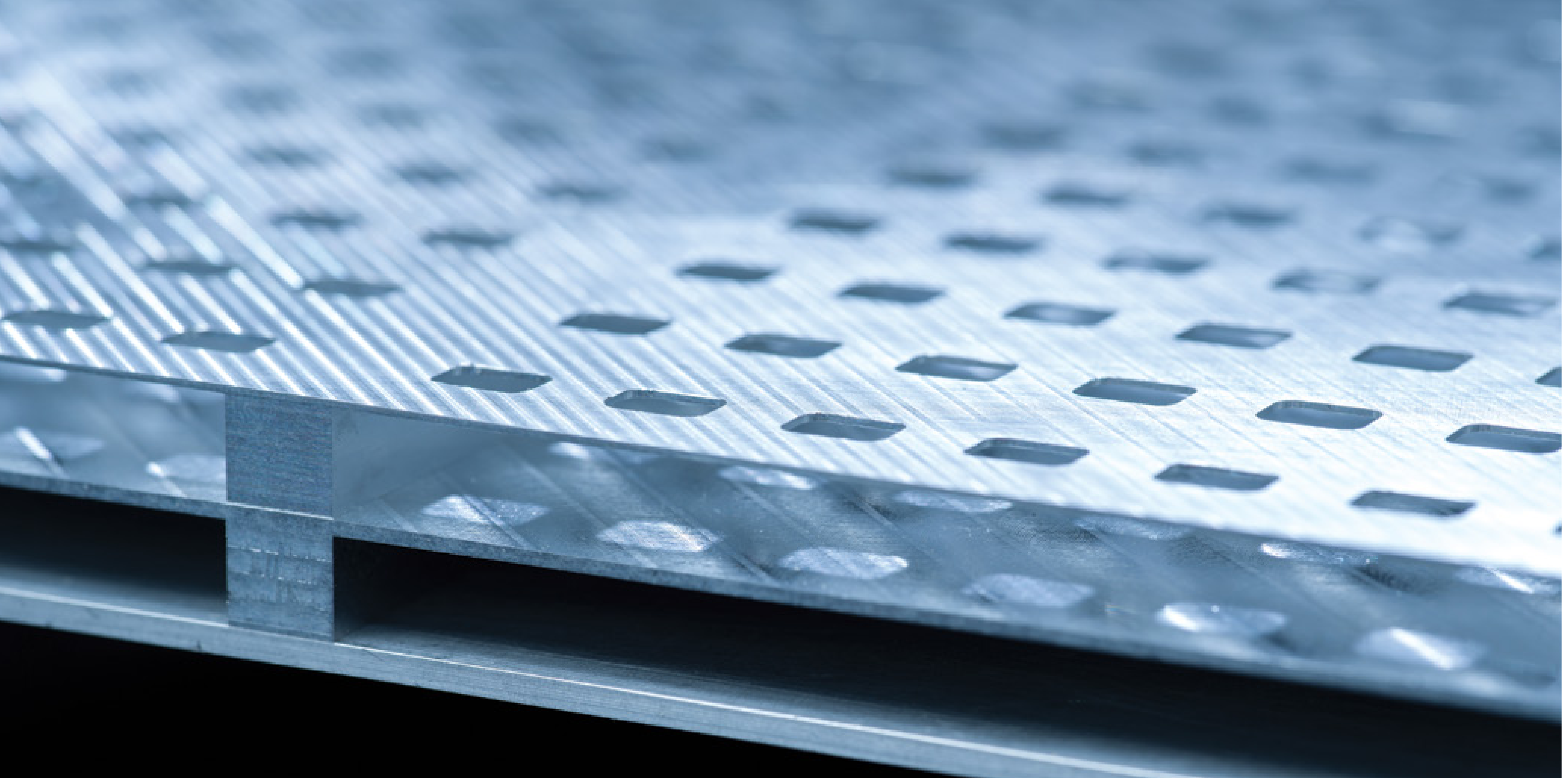
JPL engineers have been evaluating a number of commercially available Hall thrusters to meet this need, and the first use of a commercial Hall thruster will be on the upcoming Psyche mission. Psyche is a very dense metal-rich object in the asteroid belt, and the most massive of its kind. The Hall thruster for this mission comes from Maxar Technologies and has passed JPL's tough testing protocol.

Artist's impression of the Psyche spacecraft in transit to the unique metal-rich asteroid using solar-electric propulsion.



That said, as available from the manufacturer, the thruster was not assured to be quite ready for deep space duty. To power the Psyche mission, the thruster must be rated for a larger range of power than would be required in Earth orbit, and be capable of operating for over 20,000 hours of intermittent firing over nearly a decade. JPL employed its world-class thruster physics models and state-of-the-art test capabilities to show that this commercially manufactured propulsion system is up to the task. The result is a cost-effective Hall thruster that can propel spacecraft to the asteroid belt and beyond, and that will be a proving ground for future government-commercial deep-space collaborations.

JPL is testing a commercially available Hall thruster made by Maxar Technologies for use in deep space.

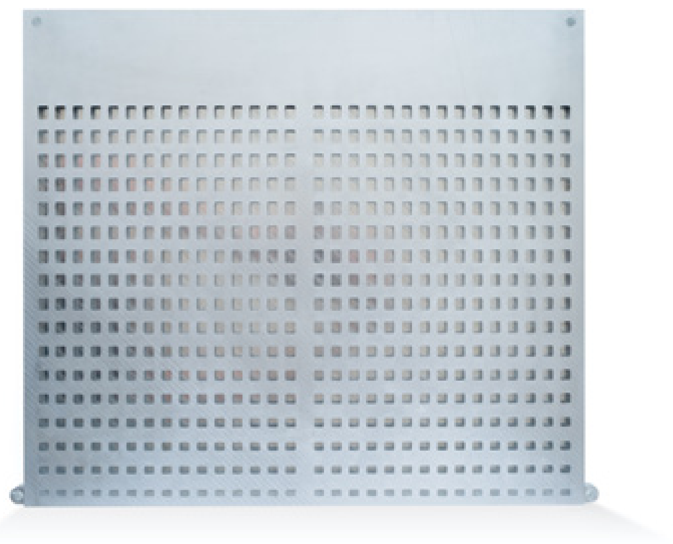


Extreme close-up of JPL's new metasurface antenna design.

Fashionably Flat

New Designs for Flat Antennas Enhance Earth Orbital Missions

Structural detail of a rectangular metasurface antenna. These antennas can be fabricated in a number of shapes as dictated by mission requirements.



Designing satellite antennas can be quite difficult. Traditional antennas have been complex and bulky, making them hard to fit inside rocket fairings and to deploy once in orbit. Flat designs, like reflectarrays, are an improvement, but still require tricky mechanical deployment.

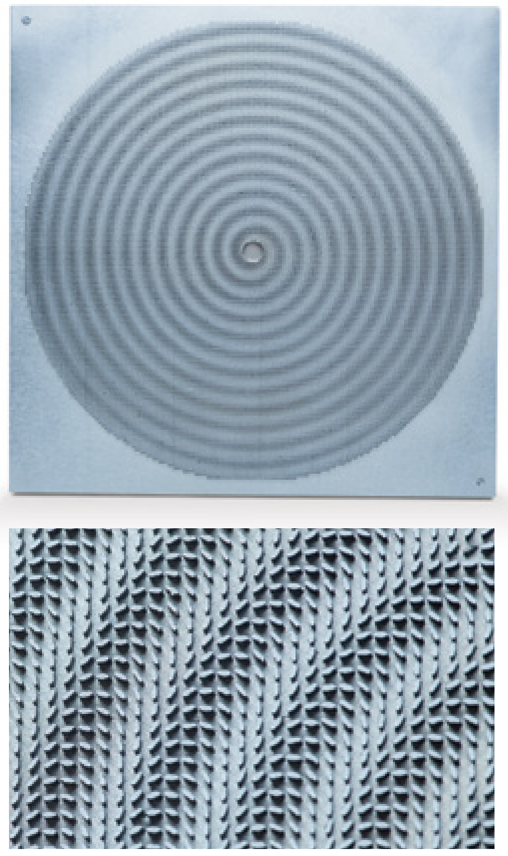
Enter metasurface antennas, which use specially shaped and positioned sub-wavelength, microscopic elements on their surfaces to control their radiation fields. JPL's new metasurface antenna designs make antennas smaller, flatter, and simpler to deploy. They have enhanced capabilities, are easier and less expensive to fabricate, and can be customized in terms of beam shape, bandwidth, and polarization, making them far more efficient.

JPL's new metasurface antenna designs can operate in wavelengths such as the X-, Ku-, Ka-, and W-bands, with improvements in efficiency reaching 70 percent. These antennas are especially attractive for large spacecraft constellations since costs and fabrication times are significantly reduced. Metasurface antennas also permit electronic steering, saving wear and fuel by allowing antenna pointing without mechanical aiming or reorientation of the spacecraft. The net result is smaller, simpler, and more agile systems with lower power requirements.

One example of metasurface antenna utility is sensing snow-water equivalent, critical to understanding how much fresh water is available in a mountaintop snowpack on Earth. Measuring the depth of snow requires two-way radar measurements with the antenna in transmit and receive modes simultaneously. In traditional antenna designs, this can create interference between the transmitted and the returning radar signals, but with highly tunable metasurface antennas, this interference is minimized. The result is better data from a smaller, lighter, and less power-hungry antenna system.

Metasurfaces are finding their way into a variety of spaceflight systems, but their use in antennas is especially compelling. Their wide variety of applications in remote sensing and radar surveys will improve weather forecasting and enhance our understanding of both climate change and resource utilization.

New design tools and additive manufacturing techniques enable flat metasurface antennas that can increase satellite versatility and enable new scientific instruments.



Top: A circular form factor for a metasurface antenna.

Bottom: Extreme close-up view of a disk-shaped metasurface antenna.

Contributors

Tom Cwik

JPL Chief Technologist

Dr. Cwik has worked at JPL for 34 years and currently serves as the Chief Technologist. He provides strategic leadership for research in advanced technology and serves as the focal point for technology interactions between NASA and external companies, universities, and the broader community. Dr. Cwik is responsible for guiding the infusion of new technology into JPL's mission portfolio, and has authored over 200 publications and holds four patents. He received his PhD in electrical engineering from the University of Illinois, Urbana. He has been a co-founder of a startup company, consults for and is an adjunct Professor at the University of Washington, and is an IEEE Fellow.

Charles Norton

JPL Deputy Chief Technologist

Dr. Norton holds a PhD in computer science from Rensselaer Polytechnic Institute and a BSE in electrical engineering and computer science from Princeton University. He has led research in high-performance scientific computing and advanced information systems and has recently served as NASA's Special Advisor for SmallSat missions. Dr. Norton is a JPL Principal Technologist, a frequent study committee member to the National Academies, and is the recipient of numerous awards including JPL's Lew Allen Award and the NASA Exceptional Service and Outstanding Public Leadership Medals.

David Aveline—p.2

Principal Investigator, Atomic Chips

Dr. Aveline is a research technologist in the Quantum Sciences and Technology group at JPL, and co-Investigator on NASA's Cold Atom Lab, studying ultracold atomic bubbles aboard the ISS. He received a BS from Cornell University in applied and engineering physics and a PhD in physics from the University of Southern California. Dr. Aveline is a 2019 recipient of the NASA Exceptional Engineering Achievement Medal for developing integrated quantum technologies for space applications.

Goutam Chattopadhyay—p.8

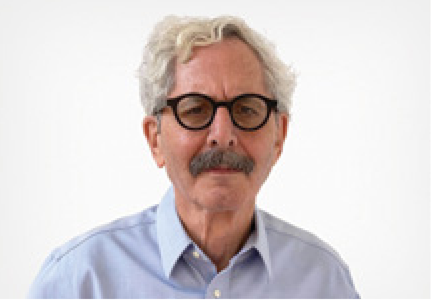
Principal Investigator, Wavelength-Size Cubes

Dr. Chattopadhyay is a JPL Senior Research Scientist and a Visiting Associate at Caltech. He received a PhD in electrical engineering from the California Institute of Technology (Caltech), Pasadena, and is a Fellow of IEEE (USA) and IETE (India) and an IEEE Distinguished Lecturer. His research interests include microwave, millimeter-wave, and terahertz receiver systems and radars and the development of space instruments for the search for life beyond Earth.

Richard Hofer—p.10

Principal Investigator, Deep-Throttling, High Specific Impulse Hall Thruster

Dr. Hofer is an expert in Hall thruster technology who has made significant contributions to the field through his research and leadership. He is a Principal Engineer and Supervisor of the Electric Propulsion Group and has received several awards including JPL's Lew Allen Award and NASA's Exceptional Engineering Achievement Award. Dr. Hofer is also an AIAA Associate Fellow. In addition to his nine patents, he has published over 180 papers on electric propulsion.



Paul F. Goldsmith—p.12

Principal Investigator, Printed Submillimeter Antenna

Dr. Goldsmith is a Senior Research Scientist at JPL, following 30 years in academia as Professor of Astronomy at the University of Massachusetts, Amherst, and Cornell University. He received a BA and PhD in physics from the University of California at Berkeley. Dr. Goldsmith is interested in the development of new technologies including quasi-optical components and antennas for millimeter and submillimeter spectroscopy and in carrying out observations from the ground, balloons, and spacecraft to understand the structure and evolution of interstellar clouds and their relationship to star formation.

Sven Gaier—p.14

Principal Investigator, Advanced High-Fidelity Compact Imaging Spectrometers

Dr. Geier is a Group Lead for imaging spectroscopy at JPL. He studied physics at the University of Hamburg, Germany and received his PhD building airborne spectroscopy instrumentation at NASA's Goddard Space Flight Center. Since 2000 he has been working at Caltech and JPL designing, building, calibrating, deploying, and operating spectrometers in ground-based, airborne, and spaceborne contexts.

Andrew Beyer—p.16

Principal Investigator, THz Spectrometers

Dr. Beyer is a Microdevices Engineer who came to JPL after graduating from Caltech in 2009 with a PhD in physics. His expertise is in superconducting detectors, including fabrication and characterization, aimed at NASA applications and instruments that require infrared imaging and spectroscopic capabilities.

Walid Majid—p.18

Principal Investigator, Hybrid Radio/Optical Receiver

Dr. Majid is a Senior Research Scientist at JPL and is the supervisor of the Planetary Radar and Radio Sciences Group. He holds a PhD in physics and a BA in physics and mathematics. Dr. Majid has over twenty years of experience in astrophysics research, and his interests include the study of neutron stars, interferometry, instrumentation, and time-domain astronomy. He has over 70 refereed publications, including several first author papers in astrophysics. Dr. Majid has been a Visiting Associate in Astrophysics at Caltech since 2015.

Samad Firdosy—p.20

Principal Investigator, High Permeability Magnetic Shielding (HIPERMASH)

Mr. Firdosy received his MS in materials engineering from California State Polytechnic University, Pomona. He is a Materials Technologist in the Materials Development and Manufacturing Technology Group at JPL. His research interests include additive manufacturing of soft and gradient magnetic alloys, as well as new materials and processes for spacecraft applications.

Clement Lee—p.22

Principal Investigator, Cislunar Space Debris Radar and Advanced Signal Processing for GSSR

Mr. Lee received a BS in electrical engineering from UCLA in 1999 and an MS in electrical engineering from the University of Southern California in 2003. He is a senior member of the JPL Planetary Radar and Radio Science Group and is the Goldstone Solar System Radar (GSSR) System Engineer. Mr. Lee has wide expertise on signal processing in radar and communications systems, and has supported numerous GSSR asteroid tracking and radio science operations for many years.

Svetla Hristova-Veleva—p.24

Principal Investigator, JPL Tropical Cyclone Information System

Dr. Hristova-Veleva is a scientist in the Radar Science and Engineering Section at JPL. She received a PhD in atmospheric sciences from Texas A&M University. Her principal research interests focus on mesoscale atmospheric dynamics, observations, and modeling of precipitating systems. Dr. Hristova-Veleva leads a group of computer and atmospheric scientists at JPL who are working to develop the Tropical Cyclone Information System.

Contributors

Andreea Boca—p.26

Principal Investigator, Deep Space Solar Array

Dr. Boca is a systems engineer in JPL's Solar Array Technology and Engineering Group. Her work on solar cells and solar arrays covers both research and flight projects with a focus on extreme environments. She is currently supporting Europa Clipper and the Mars Sample Retrieval Lander and Far-Side Seismic Suite, as well as various technology development tasks. Dr. Boca holds a PhD from Caltech and a BA from Harvard, both in physics.

Jose V. Siles—p.28

Project Manager and Technical Lead, ASTHROS

Dr. Siles is an RF engineer in the Submillimeter-Wave Advanced Technology group and the recipient of JPL's 2018 Lew Allen Award for Excellence. He received a PhD in electrical engineering from the Technical University of Madrid. Dr. Siles works on ultra-broadband receivers for high-spectral resolution submillimeter-wave instruments for astrophysics, planetary science and Earth science. He is the project manager and technical lead for the ASTHROS mission, a long-duration, balloon-borne, far-infrared observatory planned for launch from Antarctica in 2024.

Shannon Brown—p.30

Principal Investigator, Compact Ocean Wind Vector Radiometer

Dr. Brown is a principal technologist in the Microwave Instrument Science Group at JPL. He received a BA in metrology from Pennsylvania State University and PhD in geoscience and remote sensing from the University of Michigan. At JPL, he works with scientists from various disciplines and institutions to develop next-generation passive microwave instruments to push the boundaries of our understanding of physical processes at Earth and within the solar system.

Sona Hosseini—p.32

Principal Investigator, Spatial Heterodyne Spectrometry

Dr. Hosseini is a research and instrument scientist in JPL's Science Division. Her work is focused on developing innovative miniature UV-VIS interferometers with no moving parts to enable high-sensitivity spectrometry without the need for large aperture telescopes. Dr. Hosseini's research helps answer key science questions by obtaining high spectral resolution profiles of UV-VIS wavelength emissions from solar and astrophysical sources. Hosseini received her PhD in engineering applied science from the University of California at Davis.

Sarath Gunapala—p.34

Principal Investigator, Hyperspectral Thermal Imagers

Dr. Gunapala is the Deputy Section Manager of the Microdevices and Sensor Systems Section at JPL. He is a Fellow of SPIE, IEEE, & OSA, a senior research scientist and a Fellow of the Jet Propulsion Laboratory. He has authored over 300 publications, including 14 book chapters. Dr. Gunapala holds 27 U.S. patents and is the co-investigator responsible for the development and delivery of the Hyperspectral Thermal Imager (HyTI) instrument to the HyTI SmallSat project funded by NASA's InVEST program.

Douglas Hofmann—p.36

Senior Research Scientist and Principal, Materials Development and Manufacturing Technology; Principal Investigator, NASA Fabrication of Amorphous Metals in Space (FAMIS) flight experiment.

Dr. Hofmann is a technologist in the Materials Development and Manufacturing Technology Group at JPL. He received his PhD in materials science from Caltech. He is a JPL Senior Research Scientist and a member of JPL's Senior Research Scientist Council. Dr. Hofmann received the 2012 Presidential Early Career Award for Scientists and Engineers.

Raquel Rodriguez Monje—p.38

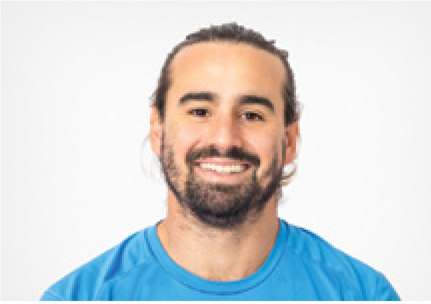
Principal Investigator, CloudCube

Dr. Rodriguez Monje is a system engineer in the Radar Concepts and Formulation Group at JPL. Her primary research interests include radar systems and millimeter and submillimeter instrumentation for Earth, planetary and astronomy applications. She is currently leading a JPL team in the development of a new low-cost millimeter-wave atmospheric radar funded under NASA's Earth Science and Technology Office Instrument Incubator Program. Dr. Rodriguez Monje received her PhD in electrical engineering from Chalmers University of Technology.

Kyongsik Yun—p.40

Principal Investigator, Remote Estimation of Geologic Composition

Dr. Yun is a technologist in machine learning and data science at JPL and a senior member of the American Institute of Aeronautics and Astronautics (AIAA). His research focuses on building brain-inspired technologies and systems, including deep learning computer vision, natural language processing, and brain-computer interfaces. He received the JPL Explorer Award in 2019 for scientific and technical excellence in machine learning applications. In addition to his research, Dr. Yun cofounded two biotechnology companies that have raised $45 million in investment funding.



Luis Phillipe Tosi—p.42

Principal Investigator, Sample Cutting, Collection, and Pneumatic Transfer of Icy Simulant in Cryo-Vac Conditions

Dr. Tosi is a mechanical aerospace engineer working as a robotics technologist in the Extreme Environment Robotics Group at JPL. He obtained his MS and PhD from Caltech and graduated with a BA and ME from Cornell. His work focuses on technology research and development, including a pneumatic sample transfer system for a Europa lander mission, Mars drilling and flight technology, and concepts for a future Enceladus mission.

Michael Hoenk—p.44

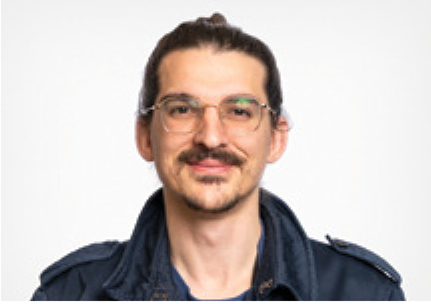
Principal Investigator, Delta-doped Silicon Detectors for UV/Optical/NIR and X-ray Astronomy

Dr. Hoenk is a Senior Research Scientist and Principal Engineer in the Advanced Detectors and Nanoscience Group at JPL. He co-invented delta-doped CCDs, publishing an important paper in the field that led to an ongoing technology program at JPL in high performance back-illuminated silicon imaging devices. Dr. Hoenk holds over 25 patents, many of which have been licensed by industry, and has received multiple awards and recognitions, including the Lew Allen Award for Excellence and the NASA Exceptional Achievement Medal. He is an SPIE Fellow.

Nick LaHaye—p.46

Principal Investigator, Detecting Wildfire Plumes in Multi-Resolution Satellite Observations via Deep Multiparameter Persistence Learning

Dr. LaHaye is a data scientist in the Processing Algorithms and Calibration Engineering Group at JPL. He earned his PhD in computational and data sciences from Chapman University. His research focuses on applying unsupervised deep learning to large multi-sensor datasets to segment and track objects in low and unlabeled environments. Dr. LaHaye is passionate about applying machine learning to help understand and mitigate climate change, natural hazards, and biodiversity loss.



Russell Smith—p.48

Principal Investigator, Miniaturized Isobaric Gas-Tight Sampler

Mr. Smith is a robotics engineer in the Embedded Robotics Systems Group at JPL and graduated with a BS in mechanical engineering from Caltech. His work is focused on designing and field-testing systems to explore extreme environments on Earth and in our solar system. He is currently the Avionics Lead for CADRE, a mission sending three shoebox-sized rovers to the moon in 2024 to demonstrate multi-agent cooperative autonomy.

Contributors

Pierre Echternach—p.50

Principal Investigator, Quantum Capacitance Detector

Dr. Echternach received a PhD in physics from the University of Southern California. After completing post-doctoral research at USC, he joined the Low Temperature Science and Engineering Group at JPL in 1993. In 1998 he moved to the Superconducting Devices and Materials in the Microdevices Laboratory. Dr. Echternach specializes in radio-frequency techniques to study mesoscopic superconducting devices at millikelvin temperatures. His current research concentrates on developing quantum capacitance detectors for applications in astrophysics.

John T. Reager—p.52

Principal Investigator, Early Warning for Fire Danger

Dr. Reager is an Earth scientist specializing in the topic of freshwater. His research focuses on measuring changes in Earth's water cycle and leverages innovative approaches in space-based observation. These measurements quantify changes in the cycling of water between the global ocean and global land, and to connect those changes to local and regional hydrologic hazards like extreme floods and droughts, or to measure the availability of water resources in snow, surface water, and groundwater.

Ryan S. Park—p.54

Principal Investigator, Gravity Imaging Radio Orbiter (GIRO)

Dr. Park is a Principal Engineer and the supervisor of the Solar System Dynamics Group at JPL, responsible for maintaining and improving JPL's ephemeris database, which includes planets, natural satellites, asteroids, and comets. Dr. Park has been involved in numerous NASA missions and studies, including serving as the Dawn Gravity Science Lead at Ceres and the Juno Gravity Science Lead. Dr. Park was also the Principal Investigator of the Advanced Pointing Imaging Camera, and Project Manager of the Center for Near-Earth Object Studies.

Clara MacFarland—p.56

Principal Investigator, Venus-Surface Solar Array

Ms. MacFarland is a systems engineer in JPL's Solar Array Technology and Engineering Group. Her work supports the research and development of solar arrays for diverse environments across the solar system from deep space to the surface of Venus. Ms. MacFarland also leads the recent solar cell testing efforts for the Europa Clipper and Mars Sample Retrieval Lander missions. She has a BS degree in materials science from Caltech.

Peter Sullivan—p.58

Principal Investigator, Micro-visible Mid-wave Dyson Imaging Spectrometer

Mr. Sullivan is an electrical engineer specializing in detector and electronics for imaging spectrometers. He received a BS from Cornell University and an SM from the Massachusetts Institute of Technology.

Arezou Khoshakhlagh—p.60

Principal Investigator, Waveguide Coupled High Speed Quantum Well Detectors for Astronomy Applications

Dr. Khoshakhlagh joined the JPL Infrared Focal Planes and Photonics Technology Group in 2010, and has led the material growth and material characterization of midwave IR, long-wave IR, and two color superlattice arrays. She is the recipient of several awards including the Lew Allen Award for Excellence, NASA's Early Career Achievement Medal, the NASA Environmental Award, Discovery Award, and multiple Group Achievement Awards.

Mark Haynes—p.62

Principal Investigator, Cubesat Bistatic Radar

Dr. Haynes is a radar system engineer in JPL's Radar Science and Engineering Section. He received a BSE in electrical engineering and a cello performance degree in 2006, an MSEE in 2001, and a PhD in applied physics in 2012 from the University of Michigan, joining JPL in 2013. His background is in radar, inverse scattering, and scientific computing. He worked on the SWOT, AirSWOT, and REASON instruments and has received the NASA Early Career Public Achievement Medal.

Sofia Rahiminejad—p.64

Principal Investigator, Contactless Rotating MEMS Switch for Water Detection at 557 GHz

Dr. Rahiminejad is a microdevices engineer in the Advanced Microsensors and Microsystems Group at JPL. She received her PhD in micro- and nanotechnology from Chalmers University of Technology, Sweden. Dr. Rahiminejad became a Wenner-Gren Fellow in 2017, has co-invented five patented technologies, and won Best Poster Award at Jet Propulsion Laboratory Postdoc Research Day in 2019. Her research is focused on silicon micromachining of high frequency components, MEMS sensors, and optical MEMS components.

Steve Snyder—p.66

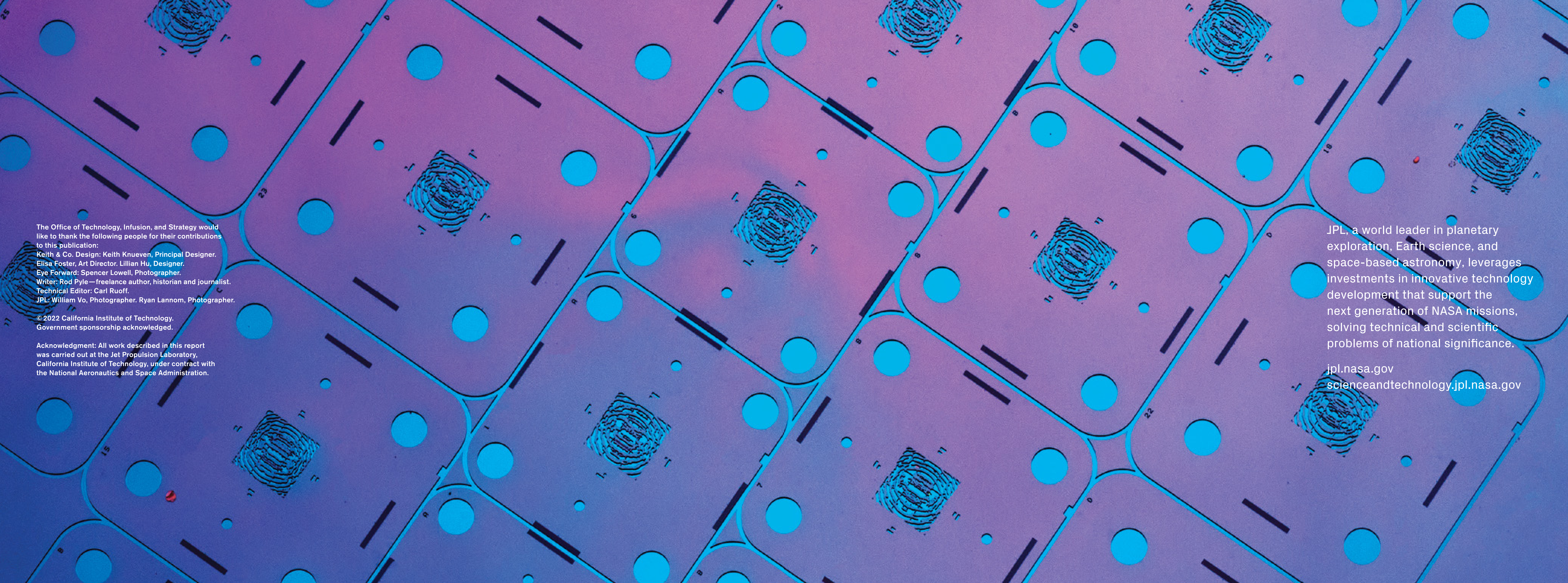
Principal Investigator, Electric Propulsion for Spaceflight

Dr. Snyder received his PhD in mechanical engineering from Colorado State University with a focus on ion thrusters and plasma devices. He has 30 years of experience in the field of electric propulsion systems, including research and development, mission formulation, systems engineering, and flight implementation. Dr. Snyder is a Principal Engineer in the Electric Propulsion Group and has contributed to the success of multiple Earth-orbiting and interplanetary missions using ion and Hall thruster technologies.

Nacer Chahat—p.68

Principal Investigator, Metasurface Antennas

Dr. Chahat is a SWOT payload system engineer and the Principal Investigator on multiple antenna research projects, and was noted as the youngest IEEE Fellow for his contribution to spacecraft and CubeSat antennas for space exploration. His contributions include antennas for the Mars 2020 mission, the Ingenuity Mars Helicopter, SWOT, MarCO, Raincube, the Europa Lander, and other mission designs. He is the author of the book "CubeSat Antenna Design" published by Wiley IEEE Press, has published more than 100 technical papers, and has been granted more than 10 patents.



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