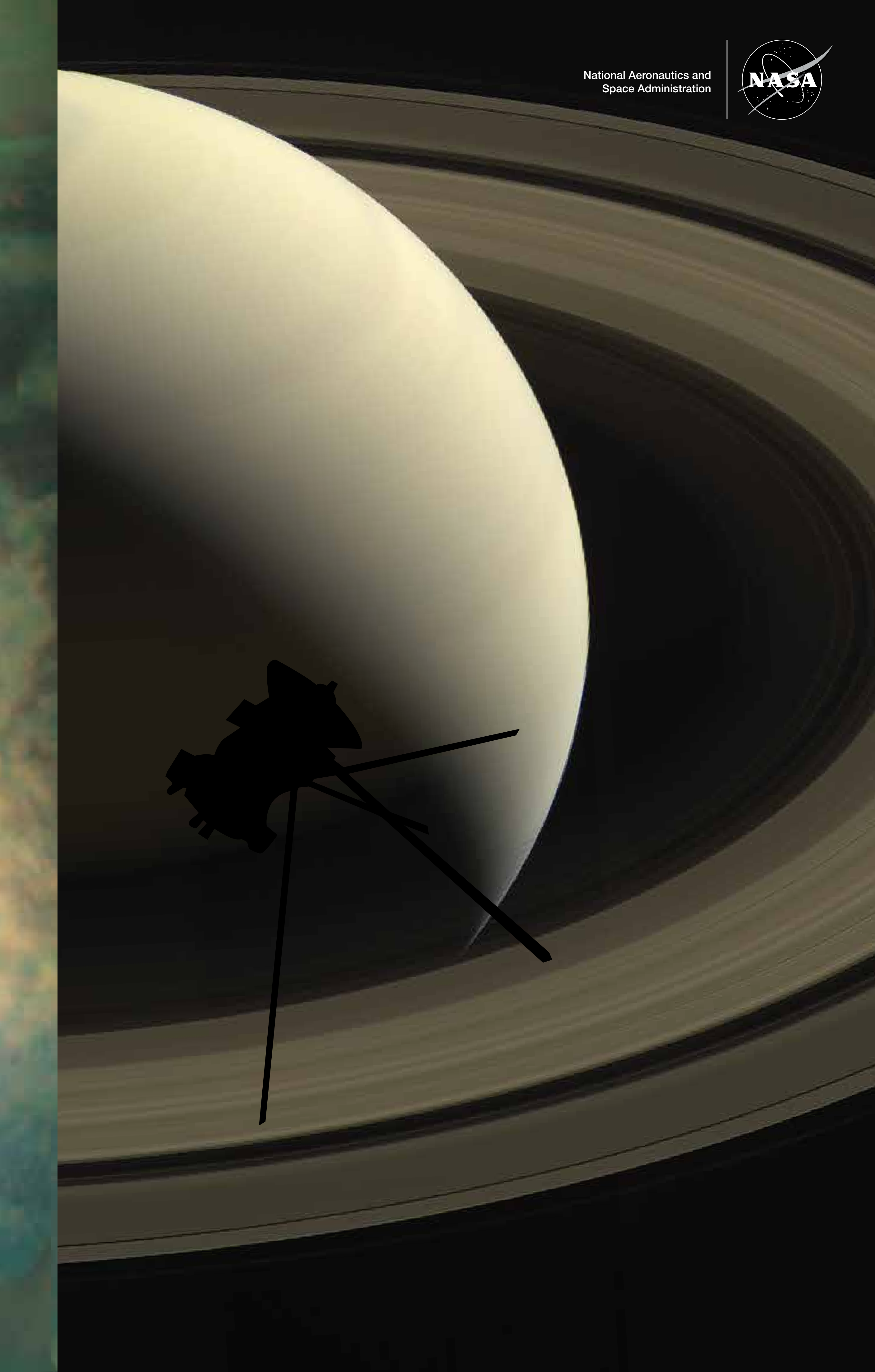


National Aeronautics and
Space Administration

JET PROPULSION LABORATORY 2017 ANNUAL REPORT

CONTENTS

Cover: Cassini plunged into Saturn on Sept. 15, 2017, ending an historic 20-year mission to the outer planet, its rings and moons.

Left: The Juno spacecraft captured this image when the spacecraft was less than 12,000 miles, or half of Earth's circumference, from the tops of Jupiter's clouds.

DIRECTOR'S MESSAGE

2017 WAS A YEAR TO CELEBRATE REMARKABLE ACHIEVEMENTS AND PREPARE FOR OUR NEXT GREAT MOMENTS OF EXPLORATION.

After 20 years, Cassini ended its mission in the skies above Saturn in a Grand Finale followed around the world. The spacecraft moved ever closer to the gas giant in its last few months, taking one dive after another between the planet and its rings. Cassini's data from those dives, along with its studies of methane lakes on Titan and discovery of an ocean encased in ice on Enceladus, will generate new insights in planetary science for decades to come.

Voyager continued to journey far beyond the planets. The only mission to reach interstellar space turned 40 in 2017, its twin spacecraft still sending data back to Earth. Voyager 1 and 2 each carry a Golden Record, a repository of human history and culture inscribed with visual instructions for unlocking its content. The Golden Record will endure billions of years as one of humanity's last surviving artifacts.

Farther across interstellar space, though still in our galactic neighborhood, lies the TRAPPIST-1 system of seven Earth-size planets orbiting a single star. Their discovery in 2017 by the Spitzer Space Telescope is all the more remarkable because it came in the mission's late stage, during which a spacecraft operates outside its ideal limits and procedures. JPL engineers and Caltech scientists optimized the search for exoplanets at warmer operating temperatures to compensate for the telescope's expected loss of coolant over time.

Before looking ahead to future projects and discoveries, I want to recognize what an extremely busy year we had in 2017. JPLers deserve our gratitude for managing a very large portfolio of work with professionalism and dedication.

In addition to several instruments, two spacecraft neared completion in preparation for 2018 launches: Mars InSight will take the Red Planet's vital signs, measuring its seismic activity, inner heat flow and density distribution, while GRACE Follow-On will continue the spectacular measurements of its predecessor augmented with new technology.

Progress accelerated in 2017 on our two flagship missions, Mars 2020 and Europa Clipper, with the former starting to take shape on Lab at our Spacecraft Assembly Facility.

Our current operating fleet continues to reveal new insights from the bottom of our ocean to the Asteroid Belt, Jupiter, and the vast reaches of interstellar space.

I am grateful to be able to share our exploration with people around the world. When our spacecraft venture into the void, they carry a handful of instruments and the imaginations of millions.

I look forward to sharing another year of discovery with the talented and dedicated JPL community, with our partners at NASA and Caltech, and with everyone who looks to the skies with wonder.

MICHAEL WATKINS

EVER SINCE GALILEO SPIED SATURN'S RINGS, humans have wondered what they are made of. In venturing closer to the rings than any observer in history, the Cassini spacecraft discovered what it was made of.

Cassini capped a glorious 20-year mission with a spiral of daring dives between Saturn and its rings. One of the hardiest spacecraft to plumb the solar system, Cassini succumbed only to the will of its makers and the inescapable end of a tightening orbit.

SOLAR SYSTEM

Left: Artist's rendering of one of Cassini's last views of Saturn and its rings as the spacecraft made its final dive.

Data from Cassini's 22 dives will return discoveries for many years, adding to a legacy for the ages.

The spacecraft had already steered planetary science towards a previously unimagined frontier: "ocean worlds," so named after Cassini's discovery of a restless sea forcing plumes of water vapor through the icy crust of Enceladus and of a liquid water ocean beneath methane lakes on the surface of Titan.

Jupiter's moon Europa was already thought to harbor a liquid ocean, but the churning seas of Enceladus galvanized the hunt for alien life.

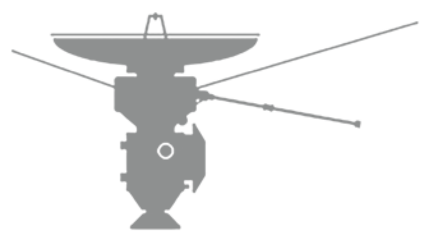
The 127 fly-bys of Titan revealed a factory for organic chemicals where clouds rain methane, redefining oceanography to encompass alien worlds. Cassini also released the Huygens probe, designed and built by the European Space Agency, to descend to Titan and collect information on the moon's atmosphere and surface.

A joint project of JPL/NASA, ESA, and the Italian Space Agency, Cassini demonstrated the potential of interagency collaboration as much as the potential existence of life in the coldest reaches of the solar system.

"Cassini has transformed our thinking in so many ways, but especially with regard to surprising places in the solar system where life could potentially gain a foothold," said Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate.

Titan also provided the gravitational slingshot effect that powered much of Cassini's mission. The Europa Clipper mission of the 2020s will imitate Cassini by using Jupiter's largest moons for energy to make repeated close observations of Europa.

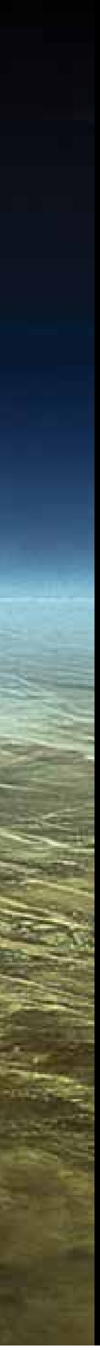
In Cassini's last five months, the spacecraft took in unprecedented views of Saturn's rings, sampled the Saturnian atmosphere and captured the closest views of Saturn's clouds and its inner rings.

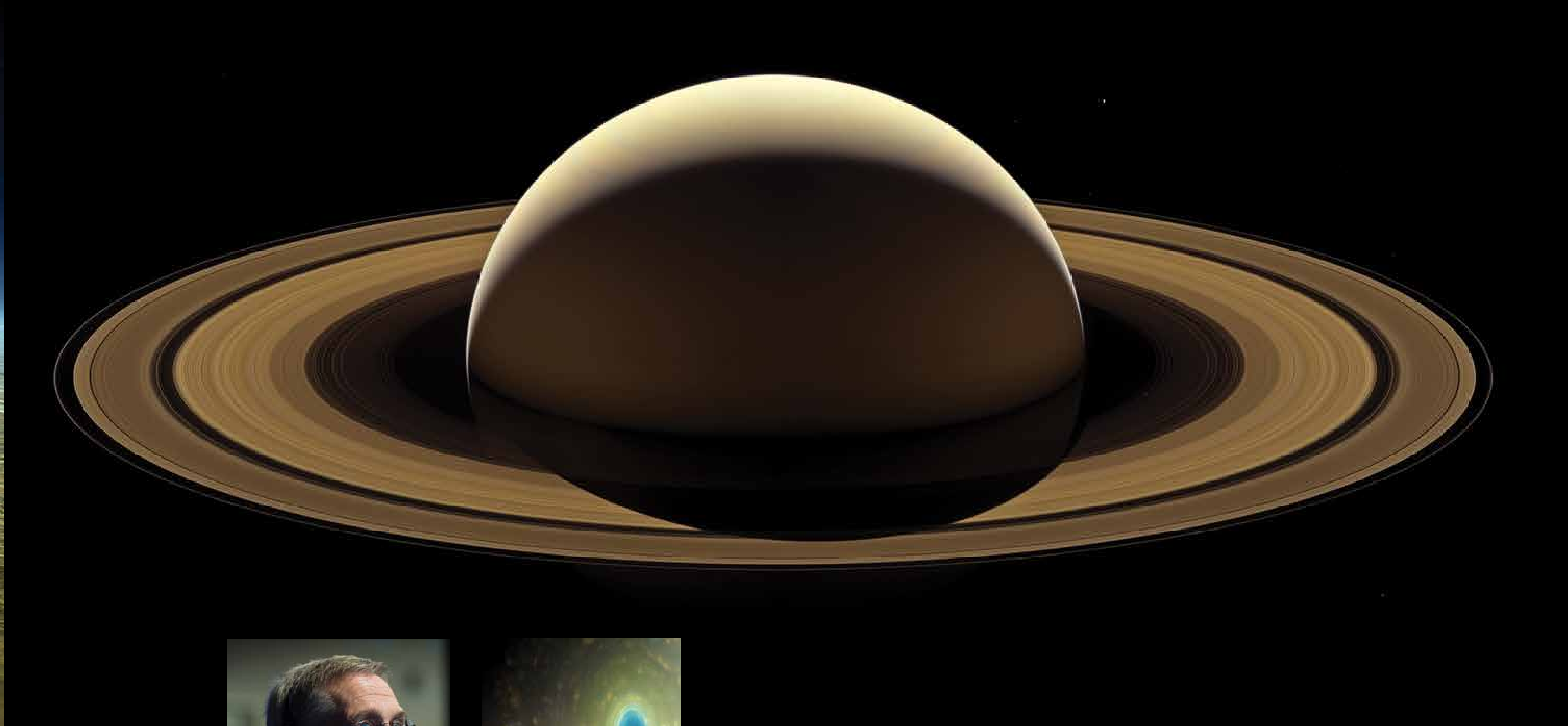


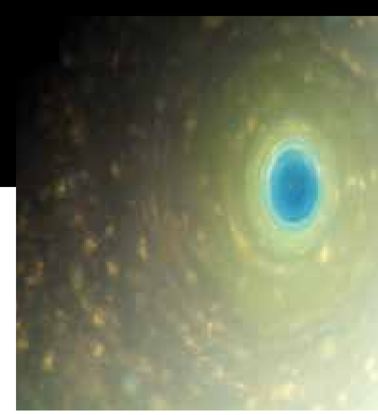
CASSINI

Above: Cassini team members after the spacecraft lost contact as it entered Saturn's atmosphere on Sept. 15, 2017.

Right: Artist's rendering of Cassini's final moments.







Cassini captured this last, full mosaic of Saturn and its rings two days before its plunge.

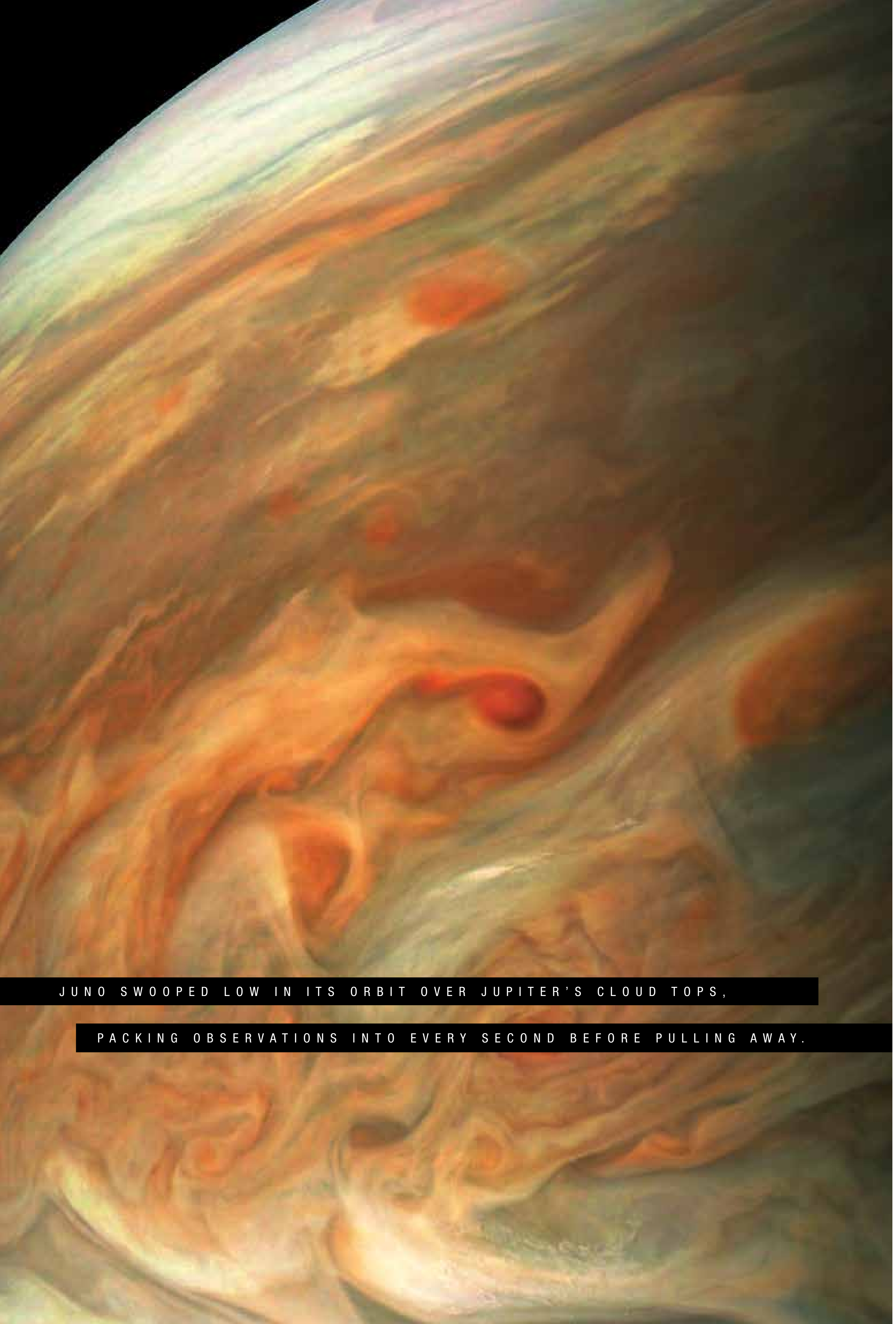
Insets: Cassini program manager Earl Maize and a close-up image of the planet's mysterious polar vortex.

Running low on fuel after 20 years in space, Cassini ended its mission on Sept. 15 with an intentional plunge into Saturn's atmosphere so as to prevent accidental contamination of Enceladus, Titan, or other potentially habitable moons.

As Cassini dived into Saturn, **Juno** continued to swoop low over Jupiter's cloud tops, packing observations into every second of the nearest point of its orbit before pulling away to escape the withering radiation of the solar system's biggest planet.

Launched in 2011, Juno settled into orbit around Jupiter on July 4, 2016. A year later, Juno made its first pass over Jupiter's Great Red Spot. In late 2017, the project's scientists revealed that the iconic feature penetrates far below the clouds, reaching 200 miles into the atmosphere.

"Juno's Microwave Radiometer has the unique capability to peer deep below Jupiter's clouds," said Michael Janssen, Juno co-investigator at JPL. "It is proving to be an excellent instrument to help us get to the bottom of what makes the Great Red Spot so great."



JUNO SWOOPED LOW IN ITS ORBIT OVER JUPITER’S CLOUD TOPS,

PACKING OBSERVATIONS INTO EVERY SECOND BEFORE PULLING AWAY.

The spot is a giant oval storm of crimson-colored clouds in Jupiter’s southern hemisphere, driven counter-clockwise by winds greater than any storm on Earth. Measuring 10,000 miles (16,000 kilometers) in width, the Great Red Spot is 1.3 times as wide as Earth.

“Juno found that the Great Red Spot’s roots go 50 to 100 times deeper than Earth’s oceans and are warmer at the base than they are at the top,” said Andy Ingersoll, professor of planetary science at Caltech and a Juno co-investigator. “Winds are associated with differences in temperature, and the warmth of the spot’s base explains the ferocious winds we see at the top of the atmosphere.”

Juno also discovered a powerful radiation field just above the atmosphere. Racing close to light speed, hydrogen, oxygen, and sulfur ions bombarded the spacecraft.

“The closer you get to Jupiter, the weirder it gets,” said Heidi Becker, Juno’s radiation monitoring investigation lead at JPL. “We knew the radiation would probably surprise us, but we didn’t think we’d find a new radiation zone that close to the planet. We only found it because Juno’s unique orbit around Jupiter allows it to get really close to the cloud tops during science collection flybys, and we literally flew through it.”

On the way to Jupiter and Saturn is Ceres, an intriguing fossil from the early days of the solar system. The dwarf planet once may have held an ocean, and its rigid crust covers a deformable layer full of minerals containing water. Volcanoes and fissures have erupted with salty water and deposited brine on the surface, suggesting an active geological cycle. Landslides are common, and their structure suggests that water ice is plentiful.

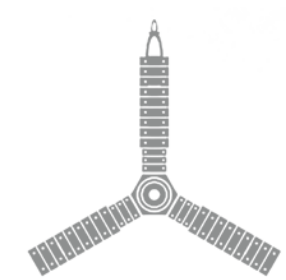
All this was largely unexplored before the **Dawn** spacecraft arrived at Ceres in 2015, eight years after launch and following a 14-month tour of the giant asteroid Vesta and its huge craters. NASA this year authorized a second extension of the mission, during which Dawn will cut its distance from Ceres to under 25 miles at closest approach.

Dawn will use its closer passes to better observe the planet’s uppermost layers by measuring highly energetic particles to detemine the adundance of geologically important elements.

This striking image of Jupiter was captured by NASA’s Juno spacecraft as it performed its eighth flyby of the gas giant planet on Sept. 1, 2017.

Citizen scientist Gerald Eichstädt processed this image using data from the JunoCam imager.

JUNO



Below: This simulated perspective view shows Occator Crater, which contains the brightest area on Ceres. This region has been the subject of intense interest since Dawn's approach to the dwarf planet in early 2015.

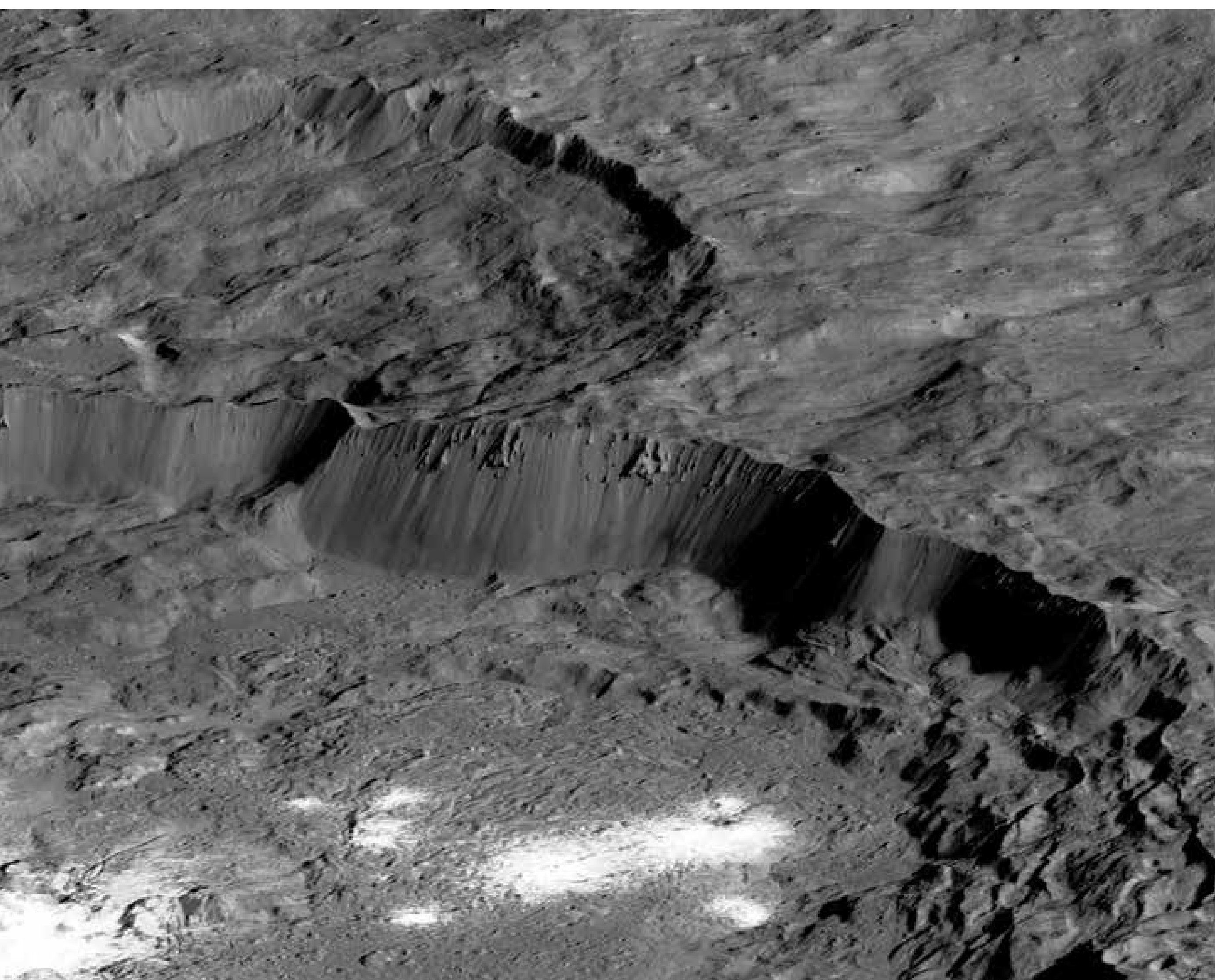
Right: Evidence of landslides on Ceres, interpreted by researchers to indicate the presence of a significant amount of water ice.

The spacecraft also will take close-up photos of Ceres' geology and study surface minerals with a visible and infrared mapping spectrometer.

So far Dawn has found that Ceres' crust is a mixture of ice, salts, and hydrated materials marked by past and possibly recent geologic activity. The crust appears to be the solidified remnant of an ancient ocean. Beneath the crust is a softer, easily deformable layer that could also have been formed by residual liquid.

"More and more, we are learning that Ceres is a complex, dynamic world that may have hosted a lot of liquid water in the past, and may still have some underground," said Julie Castillo-Rogez, Dawn project scientist at JPL.

DAWN



Talk to Tracy Drain for any length of time, and the word "fun" peppers the conversation, even when discussing things most people don't relish. Tests at school? "Oh, they were so much fun!" she exclaims with bright eyes and a smile.

Since she was young she's loved puzzles and brain teasers, and she tackles engineering challenges as more problem-solving games to enjoy.

Her playful attitude was inherited from her mother, who made sure both she and her kids had toys even though money was always tight: Drain's mom worked at McDonald's and her grandmother was a housekeeper. Drain describes this time in her life as idyllic, running around during the hot Kentucky summers with her older brother and immersing herself in books like "A Wrinkle in Time" and the works of science fiction authors Arthur C. Clarke and Isaac Asimov.

A deeply practical side balances her exuberant spirit. In considering future careers, job assurance was a major factor. The first member of her family to go to college, she wanted to be sure the investment was worth it. She loved music and was often first clarinet in her class band, but she didn't see it leading to a financially stable long-term career. She was attracted to astronomy, but didn't have a clear sense of what opportunities were available. She decided to pursue engineering, choosing mechanical over aerospace since it seemed broad enough to guarantee future employment.

"If I could've designed fighter jets, that would've been just fine," she says, and then laughs as she remembers how she wasn't allowed to play with a toy F-14 tomcat that her mom had bought for herself.

Drain didn't leave aerospace behind – she studied controls and vibration during her master's studies at Georgia Tech, and her ball-bearing stress load project had applications for helicopters. That research, as well as summer internships at NASA's Langley Research Center, helped her get her first job at JPL in 2000. At first she worked on advanced studies proposals, "pie-in-the-sky stuff, like how would you build an entire robotic outpost on Mars? It was stupid amounts of fun."

Since then she's worked on the Mars Reconnaissance Orbiter and the Kepler mission to discover exoplanets, and for the last eight years has been with the Juno mission to Jupiter. Her newest role will be Deputy Project Systems engineer for Psyche, a mission to the metallic asteroid Psyche set to launch in 2022.

"It's the coolest asteroid I've ever heard of, the most massive metal asteroid in the belt. The scientists think it's quite possibly the core of a proto-planet where the mantle got stripped off in a series of collisions. How cool and fun will this mission be?"

FINDING THE FUN

TRACY DRAIN

THE SPITZER SPACE TELESCOPE'S OBSERVATION of the TRAPPIST-1 system upended planetary astronomy.

Seven Earth-size planets orbit a single star 40 light-years (235 trillion miles) from our sun. All seven could hold liquid water under the right conditions, and three share the habitable zone, the area around a star where water is most likely to flow over a rocky planet. Announced in February of 2017, Spitzer's discovery set a record for the most habitable-zone planets known to orbit a star.

ASTRONOMY + PHYSICS

This artist's concept imagines a view from the surface of the exoplanet TRAPPIST-1f, located in the TRAPPIST-1 system in the constellation Aquarius.

NGC 1365, known as the Great Barred Spiral Galaxy, as captured by the Dark Energy Survey.

TRAPPIST-1 took its name in May 2016 from the Transiting Planets and Planetesimals Small Telescope in Chile, which discovered three planets in the system. Spitzer then confirmed the existence of two of the planets, and discovered five additional ones, with assistance from several ground-based telescopes, including the European Southern Observatory's Very Large Telescope.

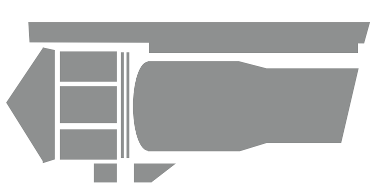
Scientists also used Spitzer to measure the sizes of the seven planets and estimate the masses of six. The approximate densities suggest all the planets are rocky, like Earth and Mars.

Unlike Earth and Mars, a person standing on a TRAPPIST-1 planet could look up and easily see at least one neighbor, hovering larger at times than the moon in Earth's sky.

Spitzer observes the heat signatures of celestial objects. Significantly, the telescope made its TRAPPIST-1 discovery at the start of the "Beyond" phase of its mission, when the spacecraft began operating outside of its ideal limits and procedures. This is an extended phase of the "warm" mission that began after the spacecraft's cryogen, used to cool the instruments, ran out as expected five years after launch. The rise in temperature was enough to compromise two instruments. JPL engineers and Caltech scientists optimized the remaining instrument to look for slight dips in the measured starlight intensity as orbiting planets passed in front of their stars.

JPL manages the Spitzer Space Telescope mission for the Astrophysics Division of NASA's Science Mission Directorate, with science operations conducted at Caltech's Spitzer Science Center. TRAPPIST-1 was not Spitzer's only major discovery in 2017. Among others, the telescope helped confirm the transformation of a budding supernova into a dark and cool object that astronomers concluded had to be a black hole. The previously unknown collapse process may explain the origin of massive gravitational waves.

Through the emerging disciplines of gravitational wave and dark matter studies, cosmology is entering a golden



S P I T Z E R

age of ever more precise models of the universe. JPL scientists are lending their expertise to the quest for understanding our place in the firmament.

JPL astronomers and physicists participated in the **Dark Energy Survey (DES)**, which this year confirmed predictions based on data from the universe in its infancy.

Theories of the universe propose that it is mostly composed of invisible and competing dark matter and dark energy. The former holds galaxies and galaxy clusters together through gravity, while the latter forces them apart, driving the acccelerating expansion of the universe.

The best estimates of the composition of the early universe come from the European Space Agency's Planck satellite, based on the light from about 400,000 years after the Big Bang.

The Cerro Tololo Observatory in Chile, a key participant in the Dark Energy Survey.

Examining the composition of the very recent universe, the Dark Energy Survey finds good agreement with Planck data in the context of leading theories of dark energy and matter.

"It is truly amazing that you have a model that describes the universe at 400,000 years old, and now we have a similarly precise measurement of the universe at 13 billion years [old] that agrees with the model," said JPL's Tim Eifler, who led the Dark Energy Survey analysis team.

According to both models, about 70 percent of the energy in the universe is contained in dark energy. Of the other 30 percent, almost all is dark matter. Only about 5 percent of the energy in the universe resides in visible matter.

The DES results mark the first time that observations from the more recent universe, with a technique known as gravitational lensing and galaxy clustering, have matched results from the infant universe preserved in the cosmic microwave background radiation.

"There is a feeling of true discovery in the collaboration. We are all excited to explore the physical nature of dark energy," Eifler said. "In particular we want to see if there are hints in the data that suggest modifying the laws of gravity on the largest scales in the universe."

"We each hold part of the human dream with us in the spirit of exploration."

MICHAEL WATKINS

VOYAGER TURNS 40 AMONG THE STARS

Often called The Farthest, in a frame of reference that still places Earth at its center, the Voyager spacecraft are the nearest of all human objects to the stardust from which we sprung.

Voyager 1 and 2 celebrated their 40th anniversaries this year from deep in space. Voyager 1 has crossed the heliospause, the region where the sun's influence wanes, revealing the signature of interstellar space. Voyager 2 is likely to enter interstellar space in the next several years.

Each carries a Golden Record, a 12-inch gold-plated copper phonograph disc containing sounds and images chosen to portray the diversity of life and culture on Earth.

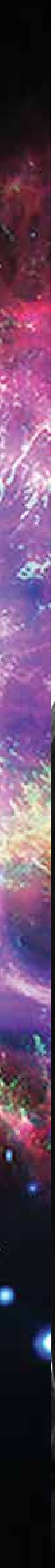
"Voyager's ability to remind us of our place in the universe, through its image of our pale blue dot, and through its carrying of the Golden Record to be our messenger, our ambassador out in the dark parts of space for a hundred million years to come, is something that I think reminds each of us of the greatness that humanity can achieve," said JPL Director Michael Watkins at an anniversary event at Caltech.

"We each hold part of the human dream with us in the spirit of exploration."

The Voyager mission explored Earth's largest and farthest neighbors, discovering active volcanoes on Io and liquid hydrocarbon oceans on Titan. After passing Jupiter and Saturn, Voyager 2 became the first and only spacecraft to study Uranus and Neptune.

"I believe that few missions can ever match the achievements of the Voyager spacecraft during their four decades of exploration," said Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate. "They have educated us to the unknown wonders of the universe."

Running low on fuel, the spacecraft will shut down no later than 2030. But even as silent ambassadors, they will continue orbiting the Milky Way galaxy every 225 million years, their Golden Records in time outlasting other sources of human history, science, and wisdom.



UNIVERSAL PUSH AND PULL

ALINA KIESSLING
JASON RHODES

The greatest mysteries in the universe are dark matter and dark energy, and a husband and wife at JPL are united in their quest to solve them. In fact, the hunt for these strange phenomena is what first brought Jason Rhodes and Alina Kiessling together.

The universe is expanding at an ever-faster pace, with no discernible force propelling it. Scientists have named this effect “dark energy.” Meanwhile, galaxies spin in a way not explained by our understanding of physics. Extra mass could account for this disparity, but all attempts to directly detect this dark matter have come up empty.

Dark matter has been detected indirectly, by seeing how its gravity bends light. Using this “gravitational lensing” effect, Rhodes helped create the first high-resolution maps of dark matter in 2007.

Rhodes grew up in Des Moines, Iowa, and when he was seven he suddenly decided he wanted to be an astronaut. He went to space camp three times, and physics was the only goal when he entered college. He doesn’t know where his attraction to science came from, since no one else in his family shares that interest. “I’m the anomaly,” he says.

Kiessling grew up in Melbourne, Australia, and her interest in science also sparked at age seven. Her family was on a camping trip near an opal-mining town, and the glitter in the ground that caught her eye was not a generic gem, but an opalized dinosaur bone.

“That discovery made me wonder how the Earth began,” she says. By the time she was a teenager she decided that question was too small; instead she should be asking how the universe began. Astrophysics became her life’s goal.

Starting from a friendship born of shared research interests, Kiessling and Rhodes gravitated closer at JPL as they studied the mysterious push and pull of the universe. They married in 2014.

They’ve banded together in a JPL group known as the Dark Sector, where different experts meet to share their ideas about the unseen aspects of the cosmos.

Rhodes and Kiessling are also involved in the European Space Agency’s Euclid space telescope, set to launch in the 2020s.

“To explain dark energy and dark matter will require new physics, because they don’t fit with our current models,” Rhodes says.

“Whatever that new physics is, we need good evidence for it. We’ll find some answer, or at least we’ll shrink the error bars on our ignorance,” he adds.

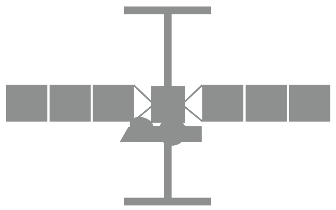
“We might be able to say what is happening, but still not have an understanding why.”

SATELLITES AND INSTRUMENTS DESIGNED AND SUPPORTED BY JPL have transformed Earth science by finding big answers in the smallest places.

Never before has Earth been understood in such detail. Spacecraft soaring hundreds of miles above the planet can resolve features as small as a three-foot wave in the open ocean. Relative to the size of the planet, such resolution is comparable to imaging single molecules in the human body.

EARTH

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument on NASA's Terra spacecraft captured this image of the area around Bay City, Texas, southwest of Houston, on Sept. 5, 2017. Hurricane Harvey caused extensive inland flooding, identifiable as dark blue areas where the water is relatively clear, and green-grey where the water carries sediment.



S W O T

The **TOPEX-Poseidon** satellite shot into orbit 25 years ago, leaving its doubters far behind. Some oceanographers considered the satellite's sensors incapable of the resolution required to measure a rising ocean among the waves and tides.

The satellite's radar-based instruments beat expectations from the start. Over 25 years of continuous operation, TOPEX-Poseidon and its successors, the **Jason** series of satellites, have recorded 2.8 inches (7 centimeters) of global average sea level rise.

The missions also have mapped global ocean currents and tides, bettered our understanding of oceanic patterns such as El Niño, and improved forecasting of extreme weather events.

Mapping the contours of the world's oceans every 10 days, TOPEX-Poseidon was the first satellite to quantify how ocean currents change with the seasons and provided the clearest picture to date of how circulation affects weather by moving heat around the planet.

The mission made the first global maps of tides and showed that a third of tidal energy goes into the open ocean, where it plays a previously unknown role in seawater circulation.

TOPEX-Poseidon and the Jason satellites provided the first frequent and global views of the life cycles of El Niño and La Niña events. On a local scale, Jason-2 measurements of water levels in large rivers enabled the most accurate forecasts of lethal floods for the people of Bangladesh. A multi-agency collaboration led by NASA and the French space agency CNES, the satellites also provide detailed navigational data for the U.S. Navy, civilian sailors, and offshore drilling operators.

The next collaboration of NASA and CNES, together with the Canadian Space Agency, will be the **Surface Water and Ocean Topography** mission, or SWOT. Slated for launch in 2021, the satellite will measure the ocean's surface with 10 times the resolution of current technologies and will vastly expand the inventory of freshwater resources, measuring hundreds of lakes and the discharge from many rivers.

SWOT's finer resolution will allow the study of small-scale features containing clues to the exchange of heat and carbon between ocean and atmosphere. The data also will provide more insight into small-scale ocean currents and eddies, with applications to navigation, erosion control, and pollutant dispersion.

Sea levels increase from two factors: the melting of ice sheets, and the expansion of water as it warms. TOPEX-Poseidon observed the rise in the oceans but could not quantify the different contributions. It took **GRACE** to do that.

The twin satellites of the U.S./German Gravity Recovery and Climate Experiment, launched on March 17, 2002, demonstrated an insight as powerful as it was novel: It should be possible to understand changes on the surface of Earth by measuring changes in gravity.

"With GRACE, we created a new field of spaceborne remote sensing: tracking the movement of water via its mass," said Michael Watkins, the

Artist's rendering of the Suface Water and Ocean Topography satellite, slated for launch in 2021.

original GRACE project scientist and now director of JPL.

Different features on Earth exert differing gravity on orbiting objects. A satellite approaching the Rocky Mountains will accelerate very slightly, then slow down as it moves beyond the mountains. Similar changes occur as the satellite passes over a body of water, which differs in density and mass from the earth around it.

The GRACE satellites followed each other, and as one experienced a change in gravity before its twin, the distance between the two changed minutely. Oceans, rivers, glaciers and aquifers are in constant change. The mass associated with shifting water caused a change in gravitational pull on GRACE. GRACE's instruments measured the changes in gravity and translated them to a map of water movements on the face of the Earth.

The mission enabled the first comprehensive survey of aquifers, which showed that a third of Earth's largest groundwater basins are being rapidly depleted. Using GRACE data, scientists prepared weekly maps of U.S. drought risk based on deep soil moisture and groundwater content.

Changes in water storage affect the rotation of Earth, and GRACE data underpin the best calculations of the effect of shifting water mass on the planet's spin. Seismologists have even used GRACE to track ground movement after a large quake.

GRACE showed that ice sheets on Greenland and Antarctica are melting much faster than previously anticipated, in Greenland's case shedding about twice the weight of Mt. Everest into the ocean every year.

The cause of sea level rise? According to GRACE, about a third from warming water, a third from melting ice sheets, and a third from melting glaciers and snow.

GRACE lived into old age, operating into its 15th year. GRACE Follow-On, scheduled to launch in spring 2018, will extend the mission's legacy of revolutionary measurements.

JPL's **Advanced Rapid Imaging and Analysis (ARIA)** team used satellite imagery of ground-level changes to create maps of damaged areas following earthquakes and wildfires. The effort is part of the NASA Disasters Program, in which teams of Earth-observation specialists at NASA centers mobilize to respond in near-real time to catastrophes around the globe.

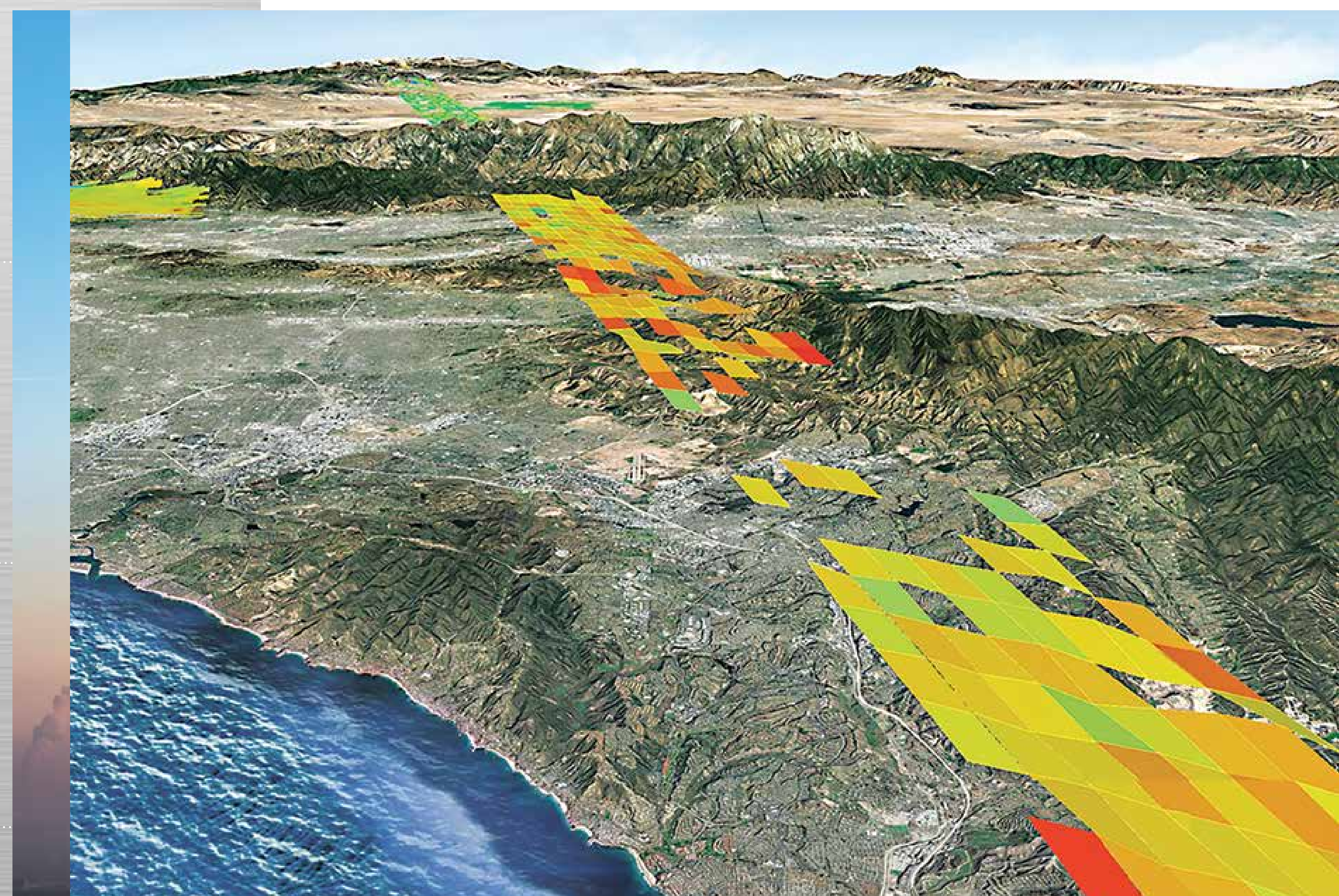
GRACE pioneered the tracking of water flows by measuring their gravitational pull.

OTHER EARTH SCIENCE AND TECHNOLOGY DIRECTORATE 2017 ACCOMPLISHMENTS

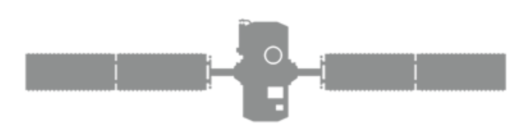
JPL scientists used data from **NASA's Orbiting Carbon Observatory-2** to help reveal the subtleties of the carbon cycle and the roles of the ocean, land, atmosphere, terrestrial ecosystems, and human activities. So precise is the data from the three-year-old mission, scientists are able to estimate carbon dioxide emissions from cities, volcanoes and power plants.

A new, airborne radar instrument developed by JPL is the first to measure both wind and current in real time, taking a snapshot of the interaction of ocean and atmosphere. Named **DopplerScatt**, the spinning radar bounces signals off the ocean's surface, allowing it to take measurements from multiple directions at once. The instrument uses the Doppler effect to calculate the speed and direction of both wind and current near the ocean's surface.

NASA's **Atmospheric Infrared Sounder (AIRS)** instrument, launched 15 years ago on NASA's Aqua satellite, increased the accuracy of weather forecasts with extraordinary three-dimensional maps of clouds, air temperature and water vapor. AIRS continues to assist forecasters worldwide with its 7 billion daily observations.



NASA's Orbiting Carbon Observatory-2 is able to quantify carbon dioxide emissions over metropolitan areas such as the Los Angeles basin, above. Red areas represent the highest emission levels.



OCO-2

JPL'S ADVANCED SPACEBORNE THERMAL EMISSION RADIOMETER ON NASA'S TERRA SATELLITE CAN MONITOR THE CHANGING SURFACE OF OUR PLANET, INCLUDING AREAS DAMAGED BY WILDFIRE.

The path of a hurricane set the course for Michelle Gierach's life.

Twenty-five years ago, in the sultry month of August, one of the most destructive storms in history barreled into Florida's southern coast.

Winds averaging 165-miles-per-hour roared through the Everglades and flattened nearby towns. Gierach's grandmother lived in Homestead, where the hurricane packed the biggest punch. Her grandmother's house survived, but the surrounding damage made a deep impression.

"I was fascinated that something in nature could have that much power," she says.

Since she was young she's loved learning about weather and the ocean, and hurricanes combine the two in an unstoppable elemental force.

"Warm ocean water fuels hurricanes, but at the same time hurricanes influence the ocean," she says. Hurricanes can act as a giant blender, mixing different temperature water layers and churning up nutrients from the ocean depths.

In college, her hurricane studies mainly relied on satellite observations, but she also traveled to the sea near Taiwan to capture storm data. "The Western Tropical Pacific is a 'genesis region,' so you're guaranteed that a storm will develop and pass through," she says.

Like a nautical version of the movie "Twister," she and her colleagues rushed to place data-collection moorings in the path of a category 5 typhoon. "To be safe we had to leave before the typhoon hit, but we still suffered massive waves and got really seasick."

Her work at JPL currently revolves around an imaging spectrometer, called PRISM, that's used to study inland and coastal water systems, including coral reefs. Storms of another sort are sweeping through the world's coral reefs and causing massive die-offs, but the extent and rate of this change are poorly understood.

Flying on an airplane at 28,000 feet, PRISM has surveyed large swaths of ocean coastline and provided a quicker and more comprehensive picture of the reefs than can be achieved by teams of camera-toting scuba divers. Gierach is also modifying a submarine vehicle to use artificial intelligence to navigate the reefs, and future goals include an Earth-orbiting observation instrument to keep a watchful eye on changes over time.

One of her dreams is to someday fly on a storm-chaser plane, such as NOAA's Hurricane Hunters. Even though she scuba dives, she does not have a similar desire to plunge into wild, tempestuous seas.

"I would say I'm respectful of the ocean, rather than scared," she says. "I know the power of it, and how deep the abyss goes."

FORCES OF CHANGE

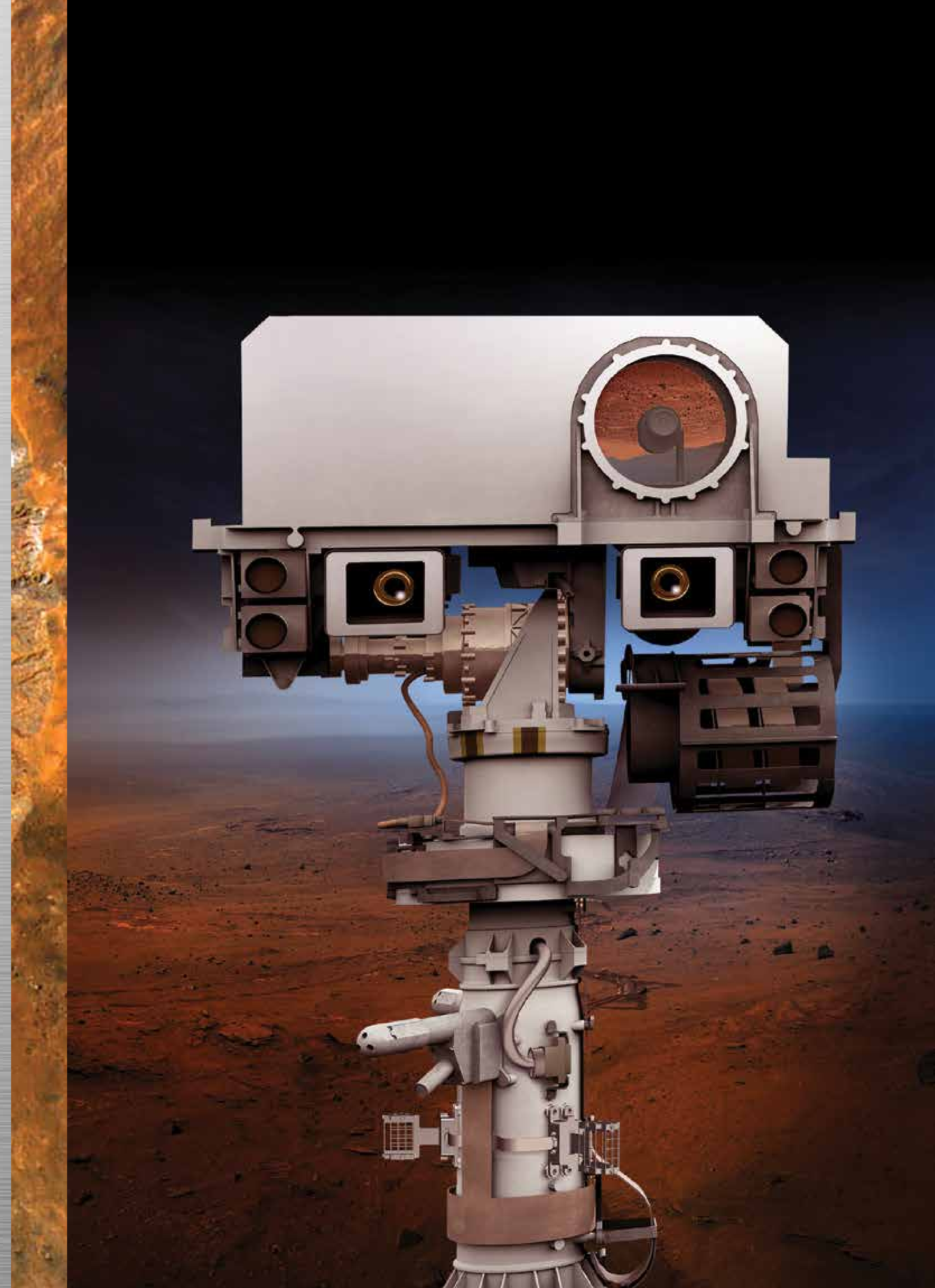
MICHELLE GIERACH

BEFORE HUMANS CAN GO TO MARS, Mars needs to come to Earth.

The Mars 2020 rover will collect a pound of alien rock as down payment on a long-term goal: collecting material from Mars in one mission and picking it up with another. Understanding the geological composition of Mars, and returning to Earth after touching the Red Planet, are important precursors to any future astronaut mission.

MARS

The Mars 2020 rover will carry a laser blaster capable of revealing the chemical composition of Martian rocks and soil from a distance by vaporizing and analyzing their components.



The rover also will search for signs of past microbial life on Mars and test a system to make breathable oxygen from the planet's thin blanket of carbon dioxide.

Mars 2020 is a JPL mission from head to tread. In addition to the rover and lander, three of four new instruments are being designed, tested, and built at JPL.

If organic matter and plentiful water once existed on Mars, SHERLOC has a good chance of sniffing them out An acronym of Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals, the instrument will use spectrometers, a laser, and a camera to search for organics and minerals altered in liquid environments. Evidence for either could indicate that Mars once hosted life.

"What we learn from the samples collected during this mission has the potential to address whether we're alone in the universe," said Ken Farley, Mars 2020's project scientist.

Another suggestively named tool, PIXL, will photograph Martian rock and soil and identify their chemical elements. The Planetary Instrument for X-ray Lithochemistry combines an X-ray spectrometer with a camera capable of resolving features as small as a grain of salt – or what passes for salt on the Red Planet.

Human explorers on Mars will need to have their own oxygen and fuel. MOXIE, the Mars Oxygen In-Situ Resource Utilization Experiment, will produce oxygen on a small scale from the Martian atmosphere.

2017 brought a successful supersonic parachute test, a selection of three possible landing sites, and constant if unseen progress in the march to assembly and launch.

The Mars 2020 spacecraft will enter the Martian atmosphere at over 12,000 mph (5.4 kilometers per second). If the parachute fails, so does the mission. The first of many tests took place Oct. 4 in Earth's upper atmosphere, which mimics that of Mars in density.

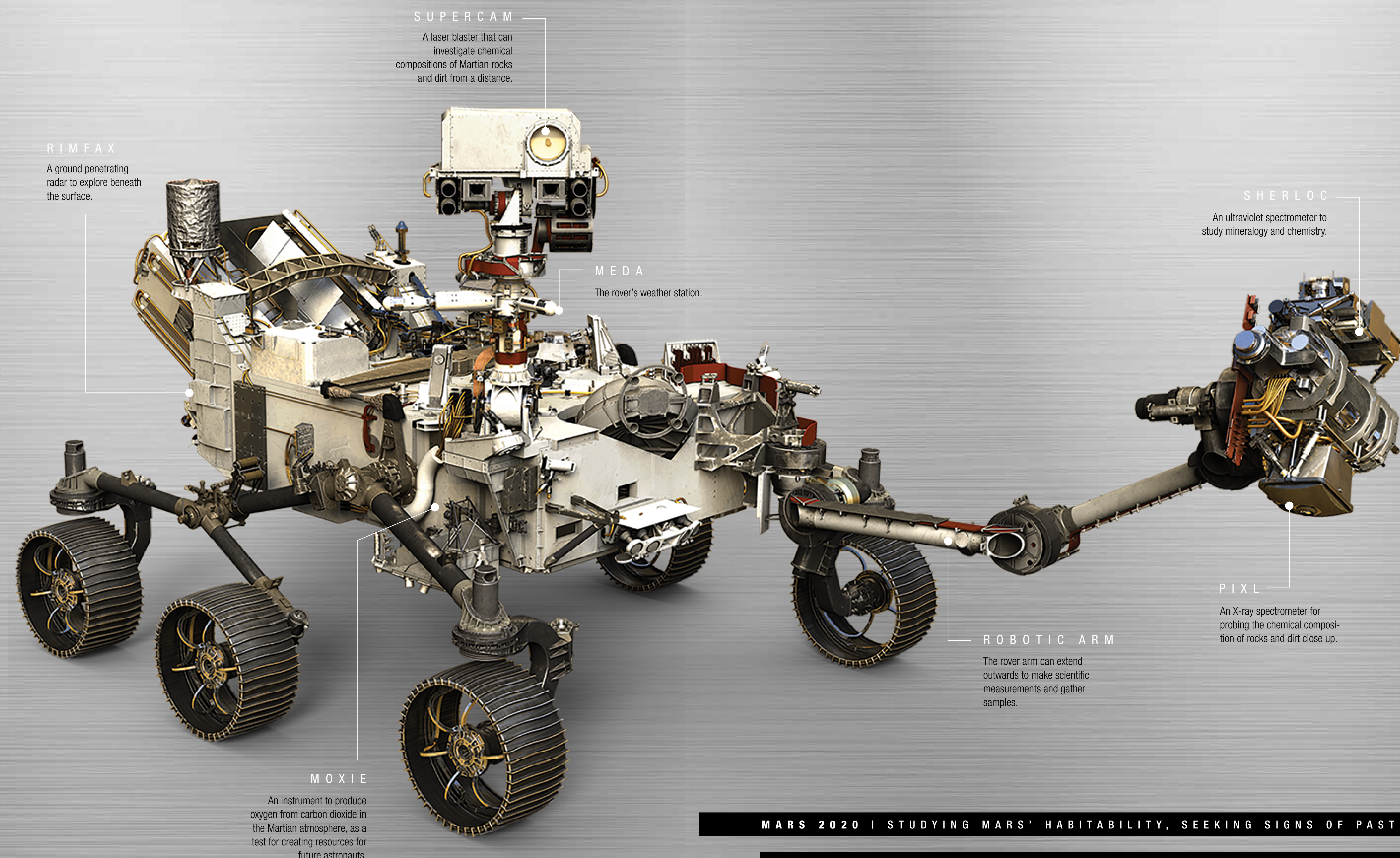
A 58-foot-tall (17.7-meter) Black Brant IX rocket launched from NASA's Wallops Flight Facility, carrying its payload more than 30 miles above Earth. At an altitude of 26 miles (42 kilometers) and at 1.8 times the speed of sound, in conditions as close to a Mars descent as can be replicated on this planet, the parachute successfully unfurled. Thirty-five minutes after launch, the gently dropping rocket splashed down in the Atlantic Ocean about 34 miles (54 kilometers) southeast of Wallops Island.

"For the first time, we got to see what it would look like to be in a spacecraft hurtling towards the Red Planet, unfurling its parachute," said Ian Clark, the test's technical lead.

The parachute was an almost exact replica of the one used to land NASA's Mars Science Laboratory successfully on the Red Planet in 2012. Future tests will evaluate the performance of a strengthened parachute, and the Mars 2020 team will use data from these tests to finalize its parachute design.

In February, the science community narrowed the list of potential landing sites from eight to three. The final-

Mars 2020 started taking shape in 2017 at JPL's Spacecraft Assembly Facility.



MARS 2020 | STUDYING MARS' HABITABILITY, SEEKING SIGNS OF PAST MICROBIAL LIFE, COLLECTING AND CACHING SAMPLES, AND PREPARING FOR FUTURE HUMAN MISSIONS.

ists represent different but potentially promising environments for primitive life: an ancient lakebed called Jezero Crater; Northeast Syrtis, where warm waters may have chemically interacted with subsurface rocks; and a possible hot springs at Columbia Hills previously explored by NASA's Spirit rover.

All three sites are geologically rich and could harbor signs of past microbial life.

"In the coming years, the 2020 science team will be weighing the advantages and disadvantages of each of these sites," said Farley. "It is by far the most important decision we have ahead of us."

Mars 2020 relies heavily on the design and hardware of MSL's Curiosity rover, which landed in 2012. The new and improved version features four new and three redesigned instruments, redesigned wheels, and more autonomy. The mission reuses the MSL cruise stage, which will fly the rover through space, and the descent stage, a rocket-powered "sky crane" that will lower it to the planet's surface.

"The fact that so much of the hardware has already been designed — or even already exists — is a major advantage for this mission," said Jim Watzin, director of NASA's Mars Exploration Program. "It saves us money, time, and most of all, reduces risk."

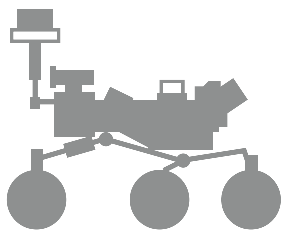
To allow access to interesting scientific sites that may include patches of rough ground, Mars 2020 adds Terrain-Relative Navigation, which will allow the rover to detect and avoid hazardous features by changing trajectory during descent.

A Fleet for Mars

Mars 2020 will join what has become a fleet of robotic explorers surveying and orbiting Earth's nearest cousin.

Opportunity, the second of two rovers launched in 2003, was designed to last three months. She continues to traverse the Red Planet 14 years later. Opportunity's discoveries include startling evidence of sustained moisture during past periods on Mars, with conditions potentially suitable for microbial life.

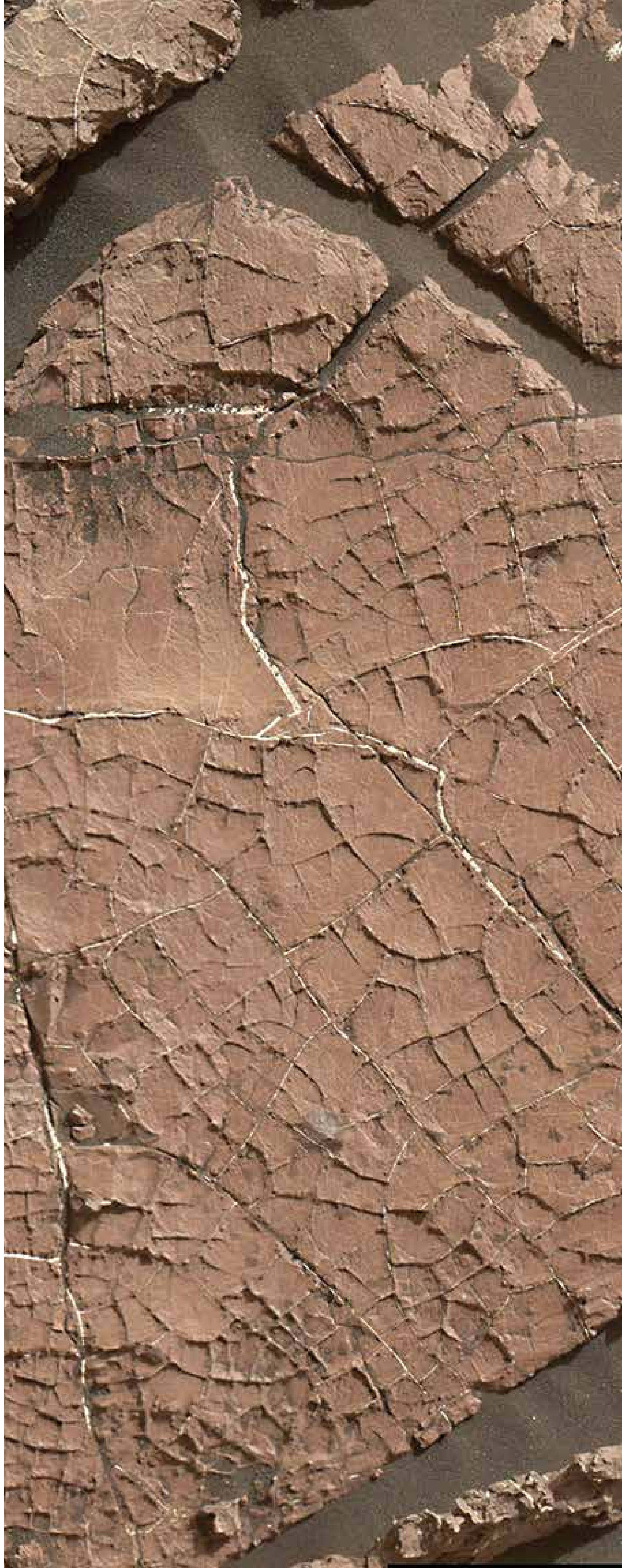
The **Mars Science Laboratory** and its rover Curiosity, known for its audacious "sky crane" landing in 2012, also is assessing the planet's past habitability for smaller life forms.



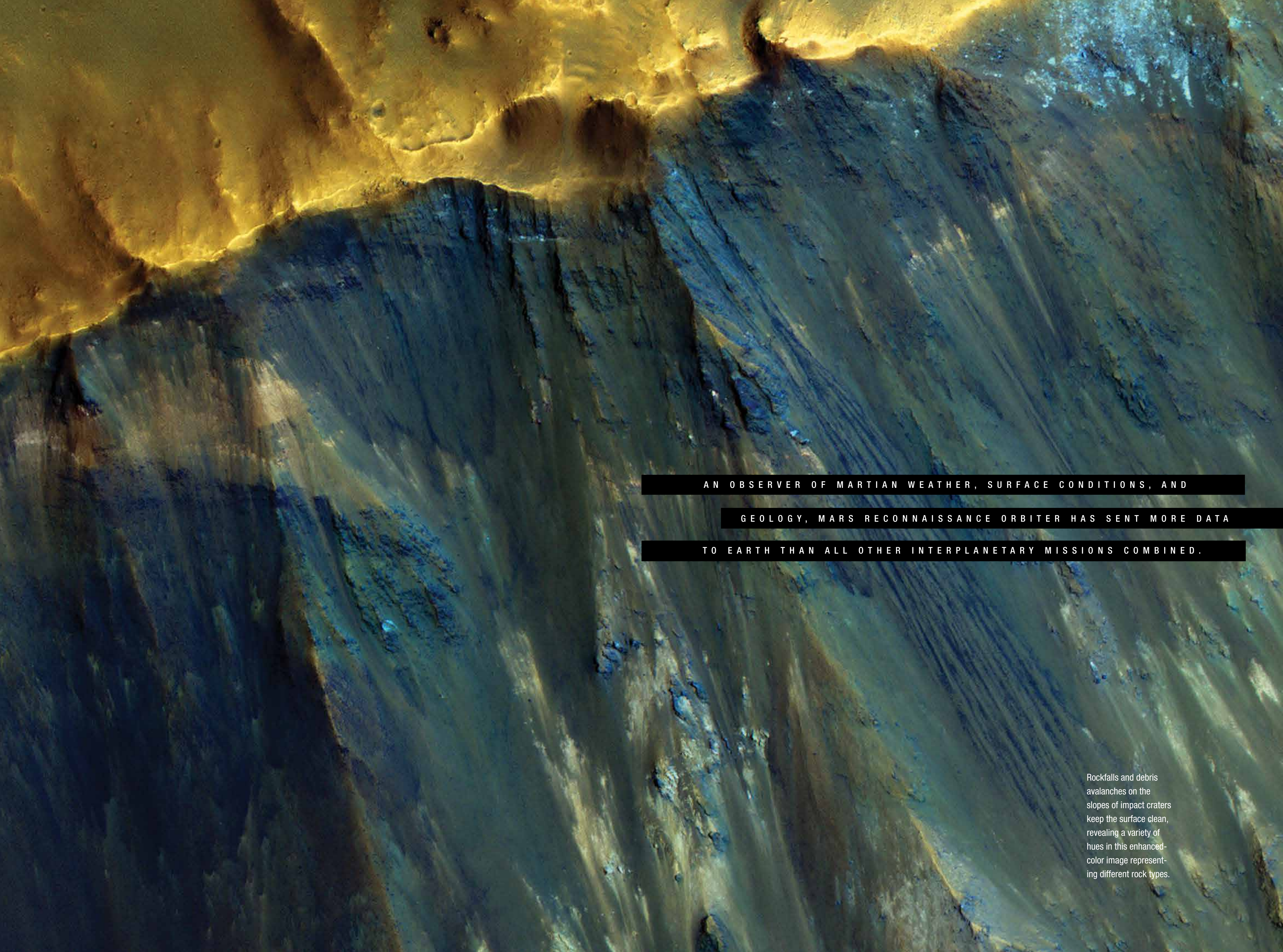
Launched in 2001, **Mars Odyssey** is the longest-serving spacecraft orbiting Mars. It uses spectrometers and a thermal imager to search for evidence of past or present water or ice. During its long career, Odyssey also has studied the planet's geology and calculated the levels of radiation future astronauts might experience.

Mars Reconnaissance Orbiter (MRO), launched in 2005, analyzes the geology of Mars and monitors the planet's daily weather and surface conditions, sending more data to Earth than all previous interplanetary missions combined, and preparing the way for future spacecraft to land in safe locations and conditions.

By the time humans touch the surface of Mars, they will know more about the landing site than most places on Earth.



The cracks in this Martian rock slab called "Old Soaker" may have formed from the drying of a mud layer more than 3 billion years ago. The view spans about 4 feet (1.2 meters) left-to-right and combines three images from the Curiosity Mars rover.



AN OBSERVER OF MARTIAN WEATHER, SURFACE CONDITIONS, AND GEOLOGY, MARS RECONNAISSANCE ORBITER HAS SENT MORE DATA TO EARTH THAN ALL OTHER INTERPLANETARY MISSIONS COMBINED.

Rockfalls and debris avalanches on the slopes of impact craters keep the surface clean, revealing a variety of hues in this enhanced-color image representing different rock types.

BALANCING ACT

ELIZABETH CÓRDOBA

Imagine you're a doctor, overseeing a patient who needs a multiple-organ transplant. You're supervising a group of surgeons who each specialize in a body part: this one has the beating heart, another has the liver, a third the kidneys. Some of the surgeons are from other countries, accustomed to different languages and systems of measurement. Your job is to make sure the operation is choreographed so perfectly the patient not only survives, but lives a long and healthy life.

That is the task of Elizabeth Córdoba. As a payload systems engineer for the Mars 2020 mission, she oversees engineers who are integrating the seven instruments for the mission rover. She ensures the rover's instruments work together, and that can be like constructing an intricate jigsaw puzzle. One challenge was the MEDA instrument which collects data on weather, including wind.

"Wind interacts with the rover – for instance, as it passes over the RTG, it'll heat up. We tried placing the wind sensor on the rover mast or on the side of the rover, but when you do that, it changes the geometry of the rover and affects the other instruments. The solution was to have it spring out from the rover, opening up to extend far enough away that there were no other negative side effects," she says. "You really have to open your mind to be able to meet the needs of the scientists and engineers."

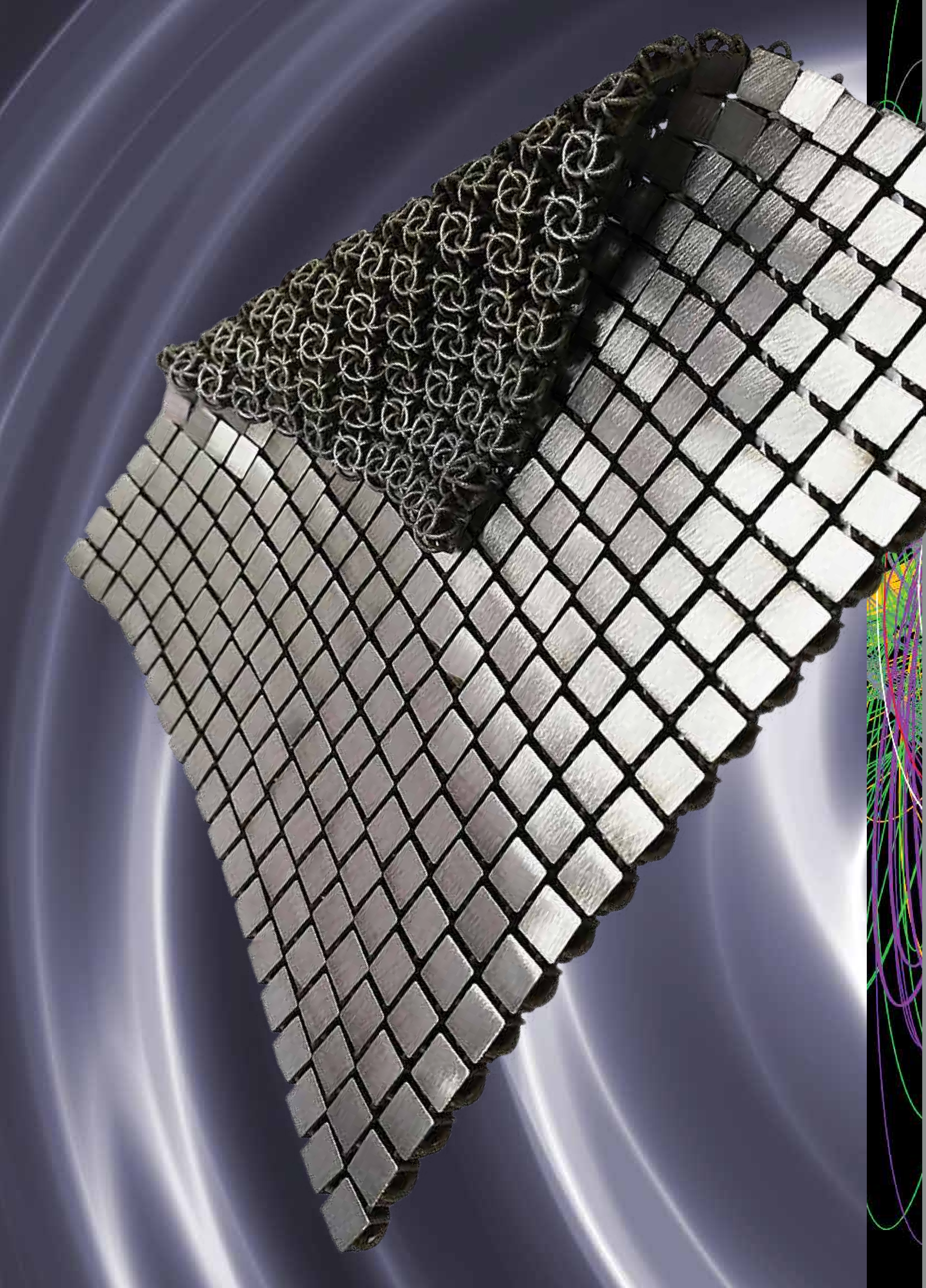
As a child, Córdoba opened her mind to another way of thinking – she became enchanted with Spanish language and culture. She minored in Spanish while in college and studied abroad in Spain and Mexico for a semester. She's now married to an electrical systems engineer at JPL who is originally from Colombia, and that relationship has helped hone her Spanish skills. She gave a talk entirely in Spanish at the US Embassy in Madrid. "I was nervous, but it went well, and I was even featured on the local news. It helped that some fellow JPLers were in the front row and helped me with some of the trickier translations."

Her attraction to space science also began in childhood, but in that case, fear held her back.

"I wanted to be an astronomer, but I was afraid of the dark and thought astronomers only worked at night, so I decided I couldn't have that particular career," she says.

Then when she was 9 years old, her father brought her to his office for "Take Our Daughters to Work Day." His workplace was NASA's Johnson Space Center in Houston, and she got to meet astronauts and see with their eyes through virtual reality simulations. "When you looked down you could see your hand wearing an astronaut glove, and you could move around the Space Shuttle." This opened her up to a new possibility: aerospace engineering.

After studying at Georgia Tech and MIT, she joined JPL in 2007. One of her favorite aspects of being a systems engineer is that she stays involved at every level of the project. "It's all about listening to what people need, prioritizing the needs, and then compromising when we have to," she says. "In the end, we as a team will have designed, built, and tested the most advanced suite of instruments ever to go to Mars."



IN TODAY'S WORLD OF PRINTABLE MATERIALS, the mantra is flexibility: of form, of function, of imagination.

Imagination fires fashion, and it was fashion that inspired the space fabrics in development at JPL. One prototype looks like the kind of flexible chain mail that might hang on a model at the fall/winter edition of Paris Fashion Week. No threads or mills were used in the making of this garment. JPL engineers adapted 3-D printing equipment to make the fabric out of thin stacked layers of metal.

TECHNOLOGY

An additive printing process builds flexible and strong metal fabric layer by layer.

The links in traditional chain mail, always the most vulnerable to a lance or a clumsy designer, become part of the whole, thinner than the cubes they connect, but strong and flexible.

Such layered fabrics are easily folded, and could be useful in space for large antennas and other devices deployed out of cramped compartments. Metal fabrics could shield spacecraft and astronauts from tiny meteorites. They could insulate as well as protect, potentially serving as flexible booties for spacecraft on icy worlds such as Jupiter's moon Europa.

Building by layers brings another advantage: different layers can perform different functions. One side of the fabric may reflect light, helping that surface stay cooler, while the opposite side retains heat.

Many other functions could be built into layered fabrics as the technology evolves.

"We call it '4-D printing' because we can print both the geometry and the function of these materials," says Raul Polit Casillas, a systems engineer who pioneered the technology at JPL. "If 20th Century manufacturing was driven by mass production, then this is the mass production of functions."

Casillas and his team used a process known as direct laser metal sintering, or DLMS. The process cuts the steps required to manufacture such fabrics, and enables unique architectures. The researchers printed and tested fabrics made of stainless steel, as well as of carbon-fiber reinforced nylon, and of the same material coated with chrome.

As costs drop and techniques improve, the fabrics may not only be made for space, but in space.

Polit Casillas imagines a future where astronauts print materials as needed and even recycle old materials — breaking them down, printing new structures, and making the most of their limited resources.

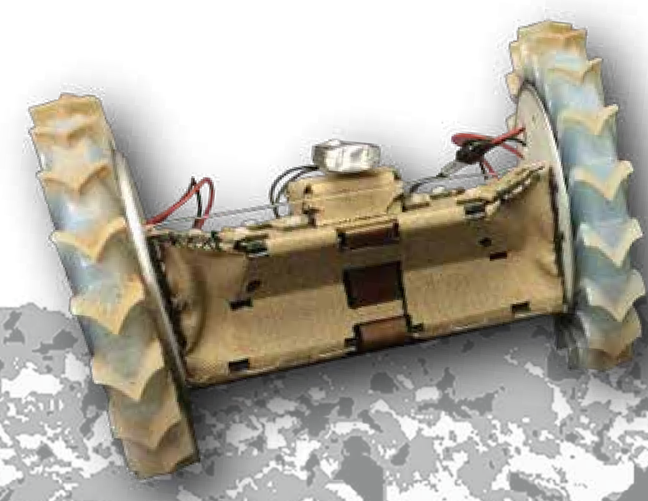
The fabrics could also be used on Earth for shielding, protective clothing, shading, facades, or improved traction for vehicles in harsh terrains.

Roving robots can also flex

This robot folds almost as well as space fabric.

Inspired by origami, the **Pop-Up Flat Folding Explorer Robot (PUFFER)** can flatten itself, tuck in its wheels, and crawl into openings a planetary rover could never explore.

But PUFFER could accompany a rover as its miniature scout. Developed at JPL and tested in rugged terrain from the Mojave Desert to Antarctica, PUFFER can climb 45-degree slopes, dangle off overhangs, and drop into pits and craters.



Right: PUFFER, short for Pop-Up Flat Folding Explorer Robot, can boldly, and nimbly, go where no robot has gone before.

The phone-sized scout is also stackable. If approved for future missions, it will be light and small enough for a rover to carry at least one spare, or even to bring a small fleet for team scouting –- the planetary equivalent of space exploration with multiple CubeSats.

Deploying a PUFFER is even simpler than launching a CubeSat. The parent rover spits it out. Regardless of how the PUFFER lands, it unfolds and rights itself and begins exploring independently.

The core of the folding robot is a printed circuit board made flexible by incorporating innovative materials such as textile electronics. PUFFER also could carry custom-designed miniaturized instruments, such as a ground-pointing microscope.

PUFFERs can operate in temperatures as low as minus 211 degrees F (–135 C), survive drop tests up to 100 feet (30 meters), and explore up to 330 feet (100 meters) from their parent rover or operator.

The tiny bots won't need to reach Mars to prove their value. Geologists on Earth could stow a few in a backpack and set them loose where even Vibram soles fear to tread.

Credit: Dylan Taylor

MOVING IN ALL DIRECTIONS

KALIND CARPENTER

"If I want to get from here to there, I know walking isn't the only option," says Kalind Carpenter. "I can do a cartwheel, I can do a back handspring, I can do a dive roll. There are different ways I can take all of that force when I hit, so I'm not going to break my leg."

Carpenter has been a gymnast, skier, snowboarder, mountain biker, scuba diver, and rock climber since he was 12 years old. The robots he develops for JPL benefit from his penchant for active exploration.

"One way I think of myself is a robot footwear designer, because I design how a robot interacts with its environment," he says. "I'm putting the physical ability into robots so they're able to walk, roll, swim, climb, fall, or fly to places where we might be able to find something interesting or revolutionary."

One of his early challenges at JPL was to have a wheeled robot scale a wall. He devised new ways for the robot to grip the wall and pull itself up, and his experience as a rock climber informed his design.

"Knowing what it is to be on a cliff, totally reliant on yourself where a mistake means falling, to feel around the rocks, to know this one will hold me, this one won't, how do I move forward, how do I progress -- that's some of the knowledge base I was able to draw from when I was tasked with the wall-climbing robots," he says.

Carpenter revels in new construction methods, materials, and manufacturing processes. His design inspirations range from Chinese finger traps to umbrellas to cockroaches. Rather than focus on a single answer, he tries several avenues in tandem, ranging from the highly conservative to the "Hail Mary."

Trying multiple approaches can result in new possibilities. Robots that crawl into volcanic vents lead to others that climb up Martian slopes, or drive through ice and snow. Asteroid grippers branch off into deep-sea divers that attach to hydrothermal vents, or ice anchors for ocean worlds.

Carpenter's passions for adventure and discovery were fed from an early age: he worked for his gymnastics coach's bungee-jumping company, gave tours for his mom's outdoor adventure business, and also developed inventions and experiments with his dad, a physics and chemistry teacher. He's lived abroad and traveled to more than 50 countries, and now his sights are set on exploring other worlds through his robots.

"Looking toward the places we'll be going to, like Valles Marineris, the big trench on Mars, or the icy moons Europa and Enceladus -- they're going to require extreme solutions," he says. "That's when some of those more 'out there' ideas I've been playing with could pay off."

JPL IS THE LEADING CENTER FOR ROBOTIC SPACE EXPLORATION and an outlying division of one of the world's leading universities — which, for Caltech and JPL researchers developing smarter autonomous systems, makes the pursuit of a drone delivery service seem almost a no-brainer.

A drone courier between campus and Lab is one demonstration goal of CAST, Caltech's new Center for Autonomous Systems and Technologies. CAST unites researchers from campus and JPL in pursuit of seemingly fantastical goals that serve pressing societal needs.

CAMPUS + LAB

Bipedal robot Cassie takes a stroll through the Advanced Mobility Lab, part of the new Center for Autonomous Systems and Technologies, a research collaboration of Caltech and JPL.

A full-size robotic ambulance would be able to take off and land vertically and travel 15 miles at a top speed of 150 miles per hour.

Could flying ambulances soar past traffic on their own in an ever more crowded world? Could prosthetic legs automatically adjust to a wearer's gait, carrying their owner farther with less effort? Every moonshot quest of **CAST** is designed to return breakthroughs along the way. CAST researchers may or may not create a robot that can walk on its own from Canada to Mexico. They will, however, build a new generation of self-thinking, self-driving, other-serving machines.

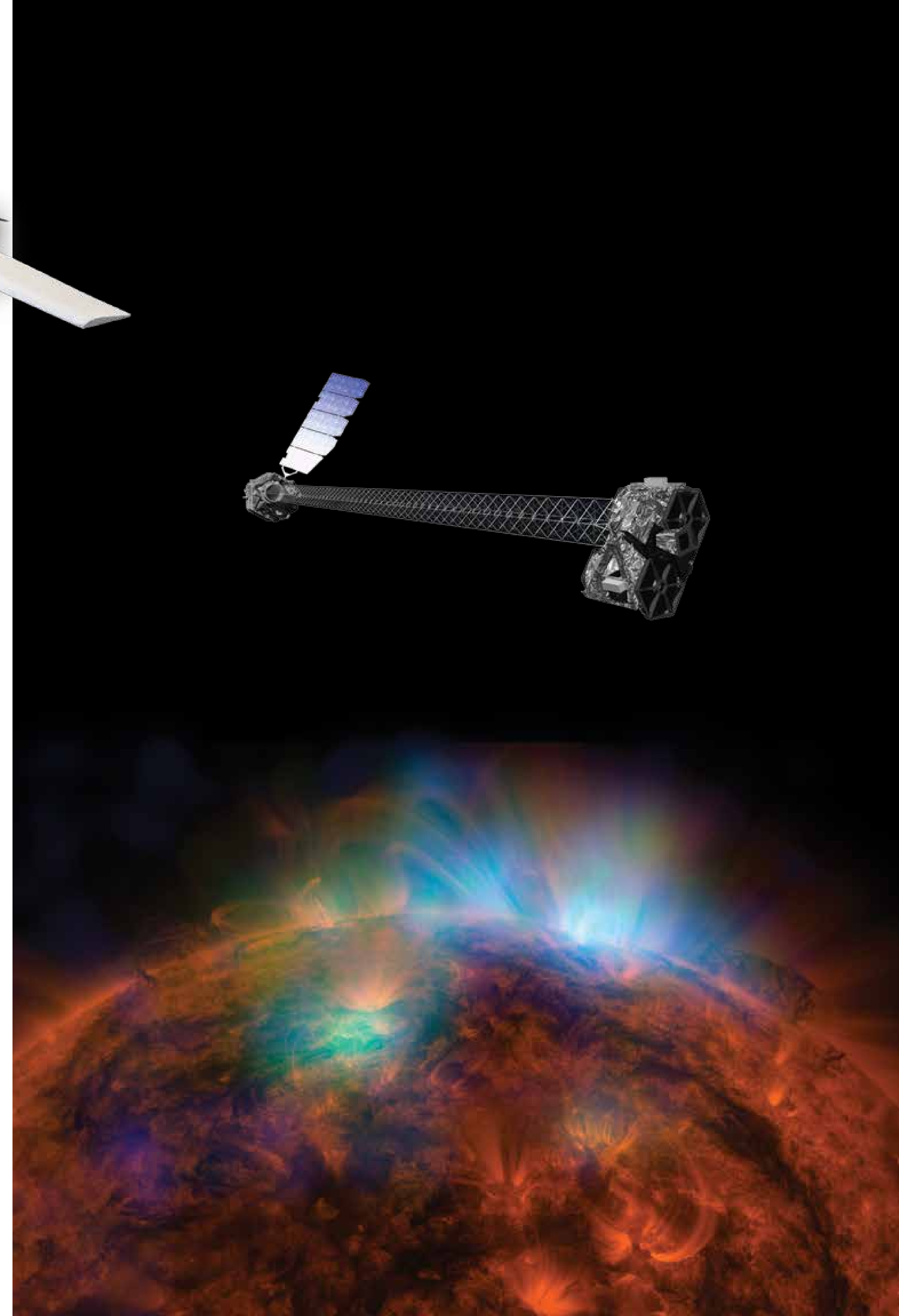
Among those, an autonomous flying ambulance for cities is one of CAST's most pressing and challenging goals, says CAST Director Mory Gharib, Hans W. Liepmann Professor of Aeronautics and Bioinspired Engineering at Caltech, who leads a group of more than two dozen researchers from campus and JPL.

"You need a fault-tolerant vehicle that can adapt autonomously to shifting weather conditions and navigate through skies without colliding with other unmanned aerial vehicles. You need the best in aerospace engineering, machine learning, GPS-free navigation — and all of it scalable," Gharib says. "It's a huge challenge, but at CAST, we can and will build it."

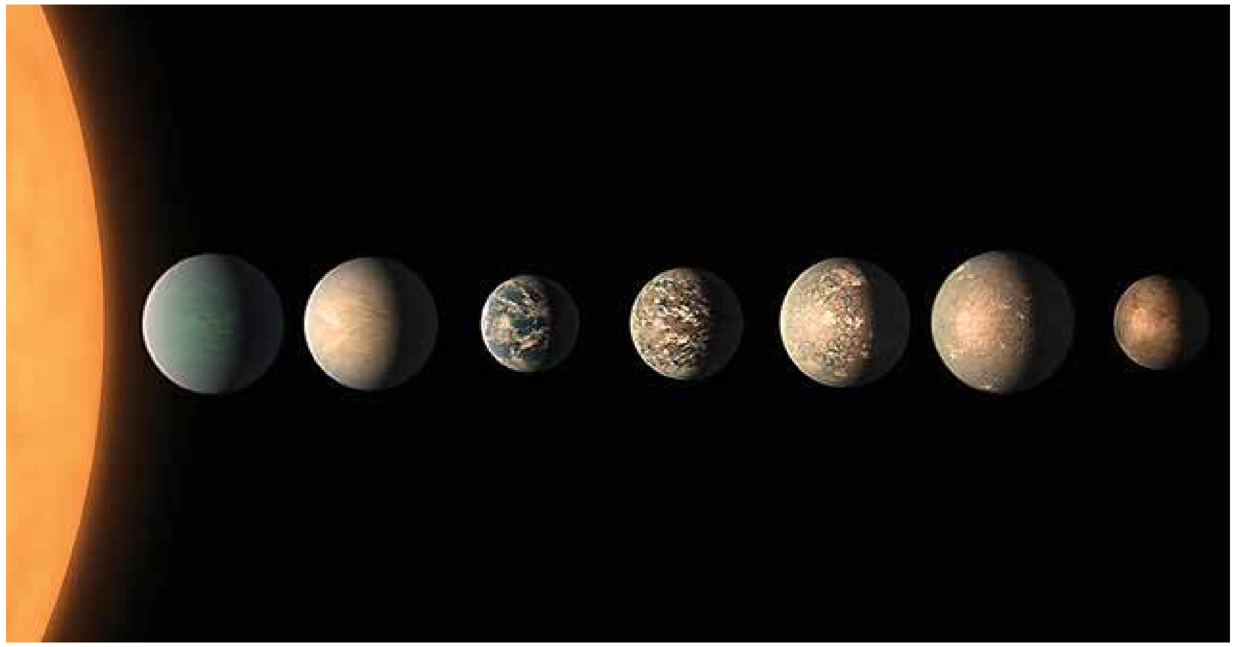
CAST also will work on the next generation of drones and robots to explore the solar system, including submersibles for the ice-covered oceans of Europa, a moon of Jupiter that is one of NASA's prime candidates in the search for alien life.

"The goal is to teach autonomous systems to think independently and react accordingly, preparing them for the rigors of the world outside of the lab," Gharib says.

CAST opened Oct. 24, featuring an 85-foot-long oval track for walking robots, and a high-precision flat floor for simulating



X-rays stream off the sun in this image showing observations from NASA's Nuclear Spectroscopic Telescope Array, or NuSTAR, overlaid on a picture taken by NASA's Solar Dynamics Observatory (SDO). This is the first picture of the sun taken by NuSTAR.



Artist's rendition of the TRAPPIST-1 system discovered by the Spitzer Space Telescope. JPL manages the telescope, and the Spitzer Science Center at Caltech oversees science operations.

the frictionless motion of space flight with robotic craft that hover on high pressure jets.

The centerpiece of the 10,000-square-foot building is a three-story-tall indoor aerodrome to test flying robotic machines. To make the tests rigorous, the aerodrome includes a wall of 1,296 fans capable of generating wind speeds of up to 44 mph, with a side wall of 324 fans to create a crosswind. The wall can create limitless wind conditions for drones to learn from and can be tilted 90 degrees to simulate vertical takeoffs and landings.

The researchers at CAST also will learn from the machines. Robots within CAST will help run the facility, guided and observed by 46 cameras that provide complete coverage of the interior, tracking each robot's motion down to within 100 microns (about the thickness of a human hair).

Another NASA/JPL-Caltech collaboration, **NuSTAR** has taken some of the most detailed high-energy X-ray images of the sky in history since its launch on June 13, 2012, allowing scientists to watch black holes spinning, to map the radioactivity from the remnant of an exploded star, and to detect extremely bright pulsars that hold some of the answers to our origins.

The year's biggest news in the search for life also came from the partnership between campus and Lab. The **Spitzer Space Telescope** discovered the largest batch of Earth-size planets around a single star — seven, with three firmly in the star's habitable zone, where liquid water can exist on the surface.

"This is the most exciting result I have seen in the 14 years of Spitzer operations," Sean Carey, manager of NASA's Spitzer Science Center at Caltech/IPAC, said of the TRAPPIST-1 planetary system.

JPL manages the Spitzer Space Telescope mission for NASA's Science Mission Directorate, while science operations are conducted at the Spitzer Science Center at Caltech. Data are archived at the Infrared Science Archive, housed at Caltech/IPAC.

THE SPIRIT AND AMBITION OF JPL HELPS DEFINE THE CHARACTER OF CALTECH. TOGETHER, WE UNLOCK THE SECRETS OF THE UNIVERSE, TRACE THE CHANGES ON OUR PLANET, CAPTURE THE IMAGINATION OF OUR FELLOW CITIZENS, AND INSPIRE THE NEXT GENERATION OF SCHOLARS. WE ARE ABLE TO THINK BIG BECAUSE THE SEPARATION BETWEEN OUR CAMPUSES REMAINS SMALL.

Thomas F. Rosenbaum
President
Caltech

IN 2017, AS WE DISCOVERED NEW WORLDS, visited unexplored destinations, and prepared for journeys still to come, the Laboratory's public engagement efforts helped the imaginations of millions to inhabit distant worlds and experience fantastical events.

"The Great American Eclipse" of August 21, 2017, was the first total eclipse visible in the continental U.S. in 38 years, and an unparalleled opportunity to highlight Earth science and our home planet's connection to the Sun. The JPL-led NASA Solar System Ambassadors hosted nearly 1,400 events across the country, reaching more than 300,000 eclipse watchers.

PUBLIC ENGAGEMENT

Enthralling millions, the total eclipse of Aug. 21, 2017 darkened a swath of the country from coast to coast and revealed the mystical power of a celestial event revered by humans from prehistory.

And at one of NASA's biggest events, in the path of totality at Idaho Falls, JPL's Public Engagement team supported dozens of talks over four days.

Proving again that the most engaging experiences in space exploration are personal, more than two million would-be Mars explorers will land on the Red Planet on Thanksgiving weekend of 2018, their names inscribed on two microchips aboard **InSight**.

The mission is the first to launch for Mars from the West Coast, and the first in other ways. InSight aims to study the planet's vital signs, and its instruments make up the first planetary doctor's bag. The first seismometer to leave Earth in more than 40 years will act as a Martian stethoscope, listening for faint motions in the core and mantle, for the rumble of meteorite impacts, and for any tremors that may develop even in the absence of tectonic plates.

InSight also will deploy a heat flow probe that will hammer five meters (about 15 feet) below the ground to try to map the planet's heat flow and thermal history. A third instrument will track the wobble of the planet as the lander communicates with Earth, helping to determine the mass and density distribution within Mars.

The microchips carrying the names of millions will add a feathery load. Inscribed at JPL's

Left: JPLers enjoy the 2017 total solar eclipse in Idaho Falls, Idaho.

Below left: Two microchips will carry more than two million names to Mars on InSight.

Below right: Delighted visitors feel the tread of a rover at the annual Explore JPL weekend.

SCIENCE ISN'T DONE UNTIL IT'S SHARED. MORE THAN TWO MILLION NAMES WILL LAND ON MARS WITH INSIGHT.

Microdevices Laboratory, the chips carry characters 400 nanometers wide – more than two thousand times narrower than the letters on this page.

As NASA's **Cassini** spacecraft dove into its dramatic final year of operations at Saturn, the stage was set for an eventful finale. Not only would the spacecraft be ending its journey in September, but its last months were in many ways a new mission, trading the risk of swooping journeys between the rings and the planet for the rewards of the closest studies of Saturn in history.

Cassini's public engagement team brought millions of followers along for the ride on a wide variety of NASA web and social media platforms, including Facebook Live events, Snapchat stories, and the mission's Webby-winning website, which captured the award for best science site of 2017.

One of the biggest science stories of the year was NASA's announcement about the most Earth-size planets ever found in the habitable zone of a single star, called **TRAPPIST-1**. In support of the news, the JPL-led public engagement team for NASA's Exoplanet program published a huge collection of material, including artwork, video, articles, and interactive 3-D and 360-degree-video experiences.

In 2017, we shared our thrilling story of exploration with tens of thousands of attendees to some of the most impactful events in the country. Teams of JPL communicators engaged face-to-face with future explorers at learning events like the USA Science & Engineering Festival — the nation's largest STEM celebration — and they reached new audiences at cultural festivals like SXSW and ComicCon.

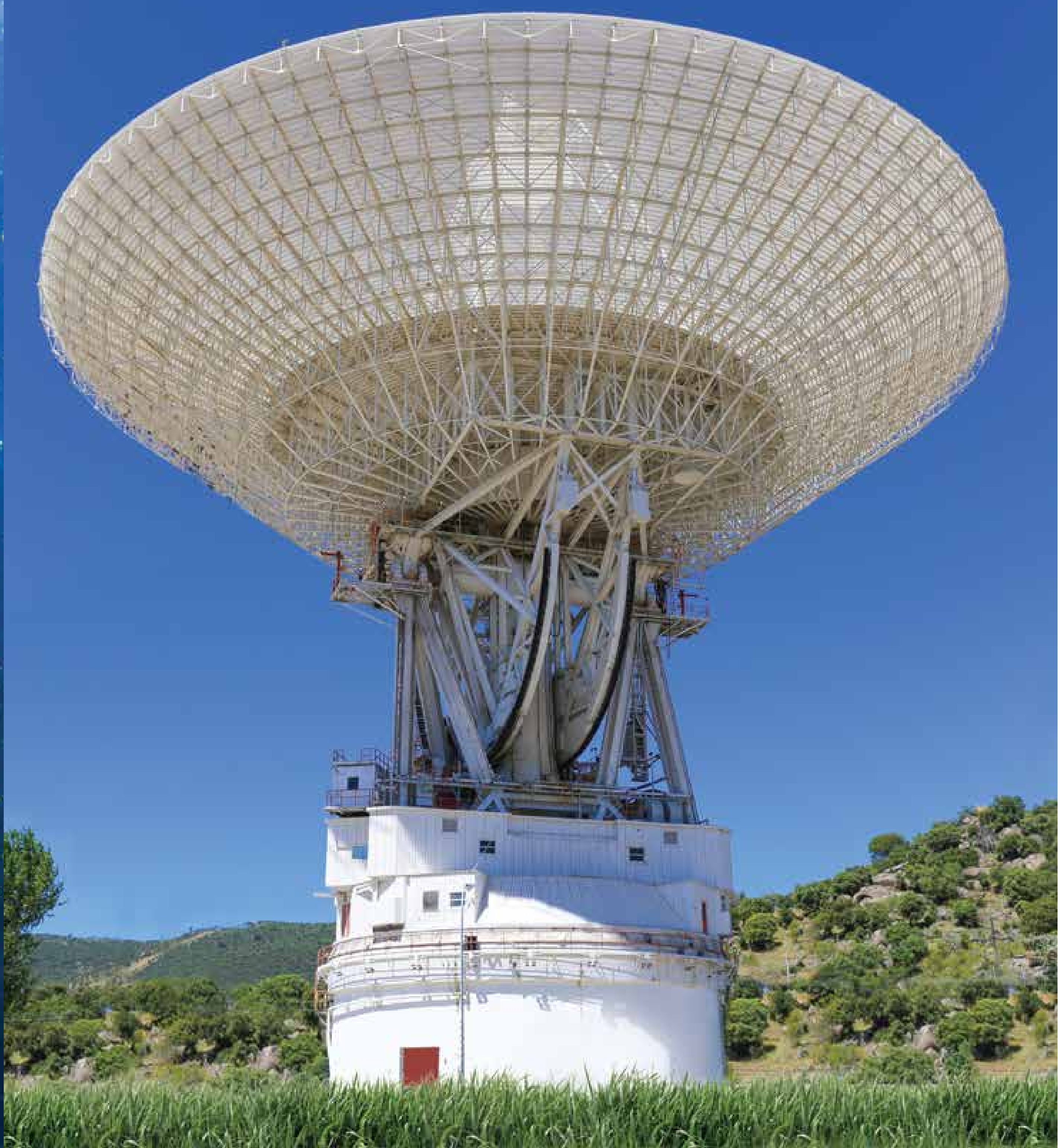
Back in Pasadena, the Laboratory's annual free visitor weekend, "**Explore JPL**," continues to draw capacity crowds while improving the experience for our guests using a ticketed, timed entry system for a second year. In all, JPL welcomed about 22,000 visitors to Explore JPL in 2017.

DEEP SPACE NETWORK

A large dish in Madrid, Spain, forms part of the Deep Space Network, the largest and most sensitive scientific telecommunications system in the world, with other sites in California's Mojave Desert and near Canberra, Australia.

JPL manages NASA's international array of giant radio antennas supporting the world's interplanetary spacecraft missions. The DSN also provides radar and radio astronomy observations that improve our understanding of the solar system and the larger universe.

The antennas of the DSN are the indispensable link to explorers venturing beyond Earth. They provide the crucial connection for commanding our spacecraft and receiving their never before seen images and scientific information on Earth, propelling our understanding of our solar system, the universe, and ultimately our place within it.



MAJOR EXTERNAL AWARDS

Justin Ariel
Federal Computer Week
Rising Star Award

Josette Bellan
American Institute of Aeronautics and Astronautics
Pendray Aerospace Literature Award

Bonnie Buratti
American Geophysical Union
Elected Fellow

Goutam Chattopadhyay
Indian Institute of Engineering Science and Technology
Distinguished Alumni Award

European Conference on Antennas and Propagation
Best Paper Award in Antenna Design and Applications

Erik Conway
American Geophysical Union
Athelstan Spilhaus Award

Bethany Ehlmann
American Astronomical Society
Awarded Harold C. Urey Prize

Khanara Ellers
27th Congressional District
Congressional Woman of the Year

Dan Goebel
National Academy of Inventors
Elected Fellow

Hook Hua
American Geophysical Union
Charles Falkenberg Award

Samuel Gulkis
American Association for the Advancement of Science
Elected Fellow

Erik Ivins
American Geophysical Union
Elected Fellow

GTOC-9 JPL Team
Co-leads:
Anastassios Petropoulos
Daniel Grebow
Global Trajectory Optimization Competition
First Place

Ronald Kwok
American Geophysical Union
Elected Fellow

Shouleh Nikzad
National Academy of Inventors
Elected Fellow

Bill Patzert
Radio & Television News Association of Southern California
Freedom of Information Award

Tomas Soderstrom
Federal Computer Week
Fed 100 award

Sara Tompson
Special Libraries Association
Elected Fellow

Duane Waliser
California Department of Water Resources
Climate Science Service Award

Jakob van Zyl
Member
International Academy of Astronautics

MAJOR CONTRACTOR PARTNERS

Ball Aerospace & Technologies Corporation

CloudSat, Europa Clipper, FINESSE, GRACE, NEOCam, NEOWISE, QuikSCAT, SPHEREx

Lockheed Martin Corporation

Europa Clipper, InSight, Juno, Mars 2020, Mars Odyssey, Mars Reconnaissance Orbiter, Mars Science Laboratory, Rosetta, Spitzer Space Telescope

Applied Physics Laboratory, The John Hopkins University

Europa Clipper, Mars 2020, Mars Reconnaissance Orbiter, Mars Science Laboratory, Psyche

Peraton, Inc.

Deep Space Network Operations

Columbus Technologies and Services Incorporated

Labor Support Services

Leidos Innovations Corporation

Desktop Institutional Computing

Raytheon

Data Systems Implementation and Operations, Monolithic Microwave Integrated Circuit Development

EMCOR Government Services Incorporated

Facilities Maintenance and Operations

Southwest Research Institute

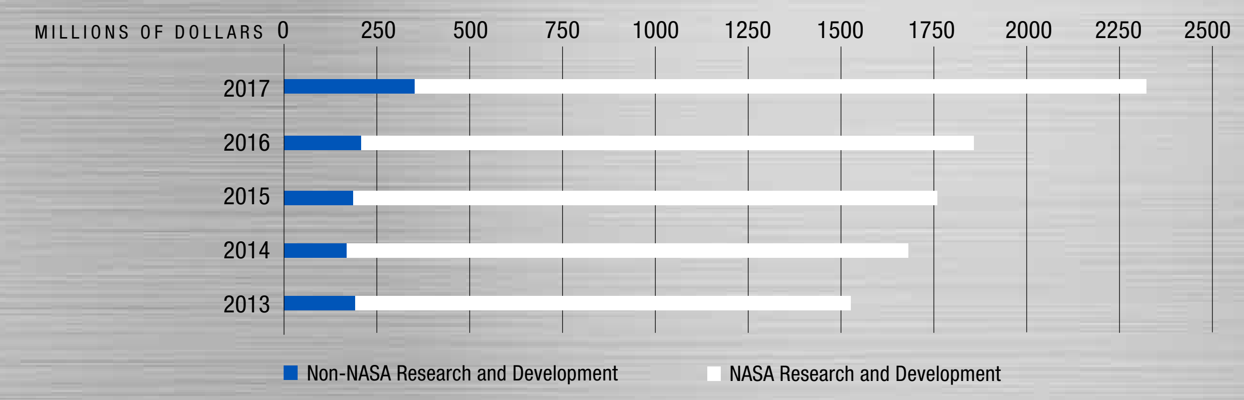
Cassini, Europa Clipper, Mars Science Laboratory, Rosetta

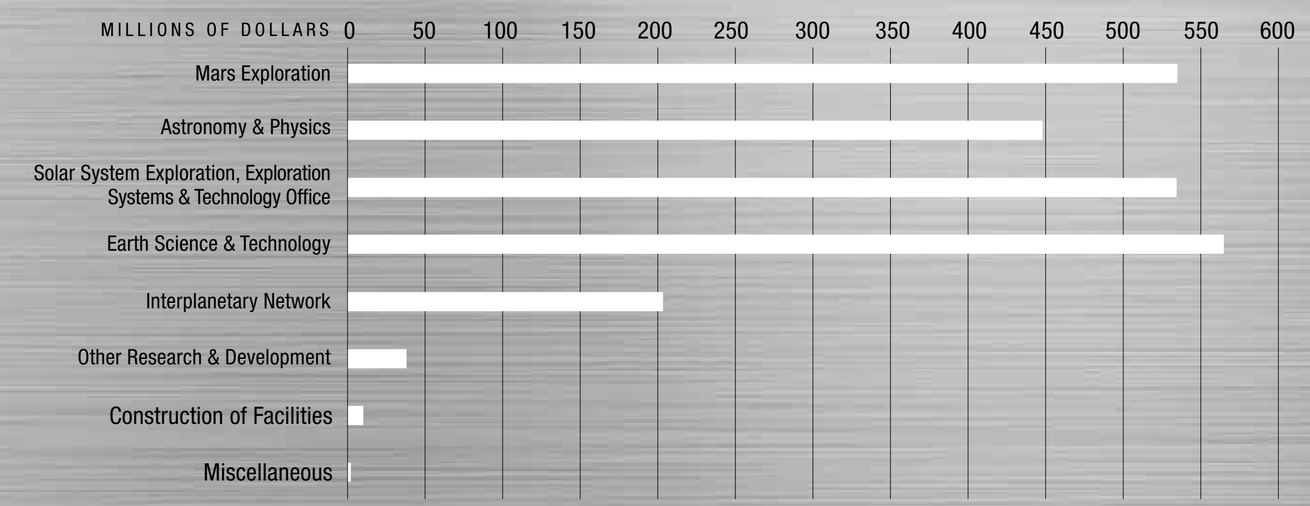
Airbus

GRACE, NISAR, Surface Water and Ocean Topography

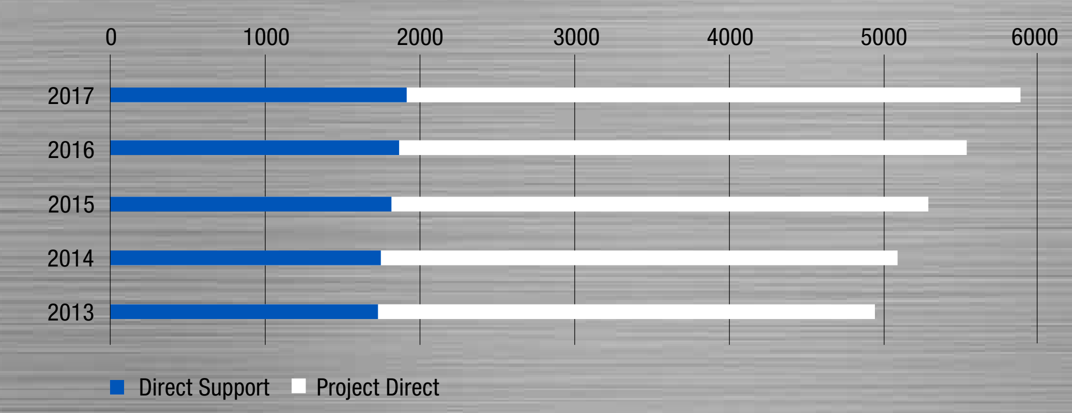
BUDGET AND WORKFORCE

2017 BUDGET





JPL Personnel • Full-Time Equivalents



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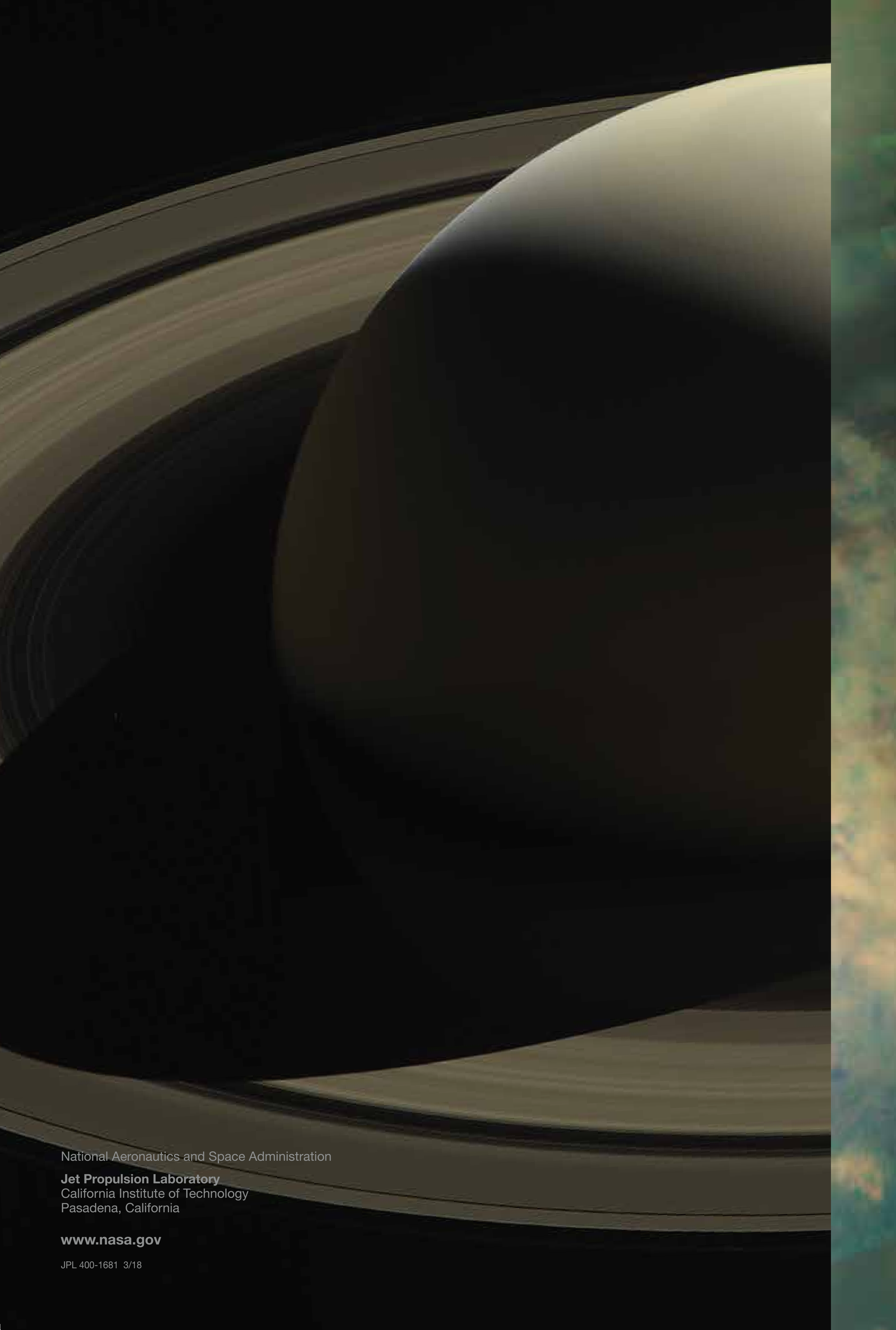
Jakob van Zyl
Director for Solar System Exploration



National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

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