

National Aeronautics and
Space Administration



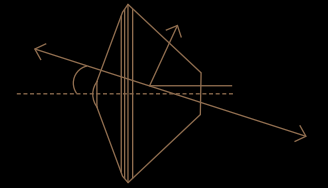
JET PROPULSION LABORATORY 2018 ANNUAL REPORT





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Mars Reconnaissance Orbiter imaged sand dunes in Mars' north polar regions, with pale orange dust partially coating dark basaltic sand, and seasonal dry ice patches around the dunes' edges.



DIRECTOR'S MESSAGE

The successful launch and orbits of JPL's Explorer I in January of 1958 led Congress to form a national space agency. Sixty years later JPL maintains a unique position in the exploration of space and our home planet. 2018 was the year we set a seismometer on Mars, put a quantum-scale laboratory on the space station, and launched the first suitcase-sized satellites into orbit around another planet.

2018 marked the safe journey of InSight and the twin MarCO CubeSats to the Red Planet, the launch of GRACE-FO, ECOSTRESS and several other Earth missions, the arrival of Cold Atom Lab at the International Space Station, and an Emmy from the Academy of Television Arts & Sciences for the Lab's live interactive broadcast of the 2017 Cassini Grand Finale.

The Interplanetary Network Directorate's Deep Space Network celebrated a fundamental change in the way it is operated that enabled coverage of major launches — and InSight's descent and landing — with improved efficiency and reliability. We marked Voyager 2's passage into interstellar space, and bid a bittersweet goodbye to the Dawn and Kepler missions.

The Mars 2020 mission built momentum toward launch with delivery of the rover chassis and flight back shell, as well as key instruments for probing the composition of the planet and taking weather measurements.

Newly appointed NASA Administrator Jim Bridenstine made his first official visit to JPL, touring the Lab and holding a town hall in which he noted JPL's historic and ongoing contributions to space exploration.

We had a record amount of work in 2018 that tested our facilities and workforce, and 2019 looks no less busy. Expected launches include the Orbiting Carbon Observatory-3 and Deep Space Atomic Clock; Mars 2020 will move into final assembly and testing, including integration of Mars Helicopter; and InSight will begin to reveal the secrets of Mars. The Deep Space Network will deliver two new antennas in Spain as part of ongoing enhancements of ground system capabilities boosting data return from future deep-space missions.

The Lab will follow the direction set by 2018's Strategic Implementation Plan, which calls on JPL to

- pursue a diverse and bold portfolio of science missions
- create the Laboratory of the future, defined by a talented and inclusive workforce, rapid information sharing, and a culture of innovation
- strengthen our end-to-end capability while accelerating technology infusion into our missions.

I am proud of the professionalism and dedication of JPLers in this challenging year and I invite you to read about the achievements of 2018 in the following pages, and to accompany us on our journey of exploration in the years and decades to come.

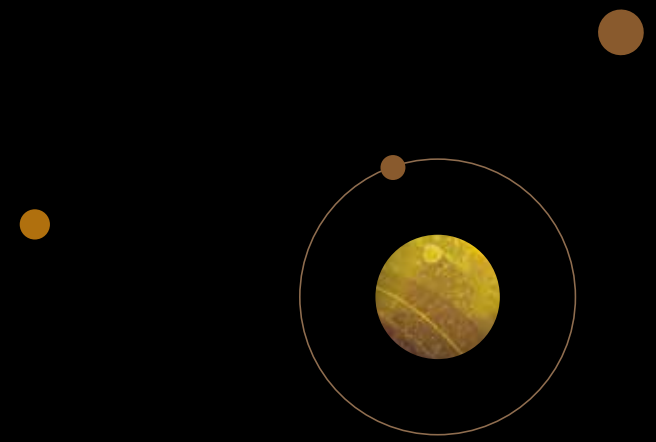
MICHAEL WATKINS



The presence of a fleet of spacecraft scattered around the solar system, launched over several decades and with varied lifespans, means fresh starts and bittersweet farewells will inevitably intersect.

In the fall of 2018, cheers on Earth heralded the successful arrival of the InSight lander on Mars, while the Dawn asteroid belt mission finale evoked a mix of sadness and pride in those who guided it and analyzed its discoveries over the past 11 years.

SOLAR SYSTEM





ABOVE: Cheers erupted in JPL's Mission Support Area when the InSight team confirmed that the spacecraft had successfully touched down on Mars.

BELOW: InSight's heat probe is designed to drill below the Martian surface to learn more about the planet's interior.



Shortly after InSight touched down, when the cheers had barely subsided, its traveling partners, two Mars Cube One (MarCO) CubeSats, relayed to Earth the first picture from the lander.

InSight: Studying Solar System 'Rock Stars'

It's a familiar scene: engineers and scientists crouch over computers in JPL's Mission Control, following every beep and bit of data streaming from a spacecraft that has zoomed millions of miles to an alien planet through extreme conditions in deep space. Once the craft signals its safe arrival, the anxious crew back home erupts with a medley of cheers, leaps, high-fives and — in the case of InSight's safe landing at Elysium Planitia on Mars on Nov. 26, 2018 — an elaborate handshake inspired by the NFL.

A brew of elation and relief triggers the hoopla, the payoff for enduring the immense challenges, risks and calculated uncertainty baked into each mission.

Shortly after InSight touched down, when the cheers had barely subsided, its traveling partners, two Mars Cube One (MarCO) CubeSats, relayed to Earth the first picture from the lander. By completing the first interplanetary journey by CubeSats and sending InSight's first post-landing communications, the two mini-satellites expanded the portfolio of spacecraft that can travel through the solar system.

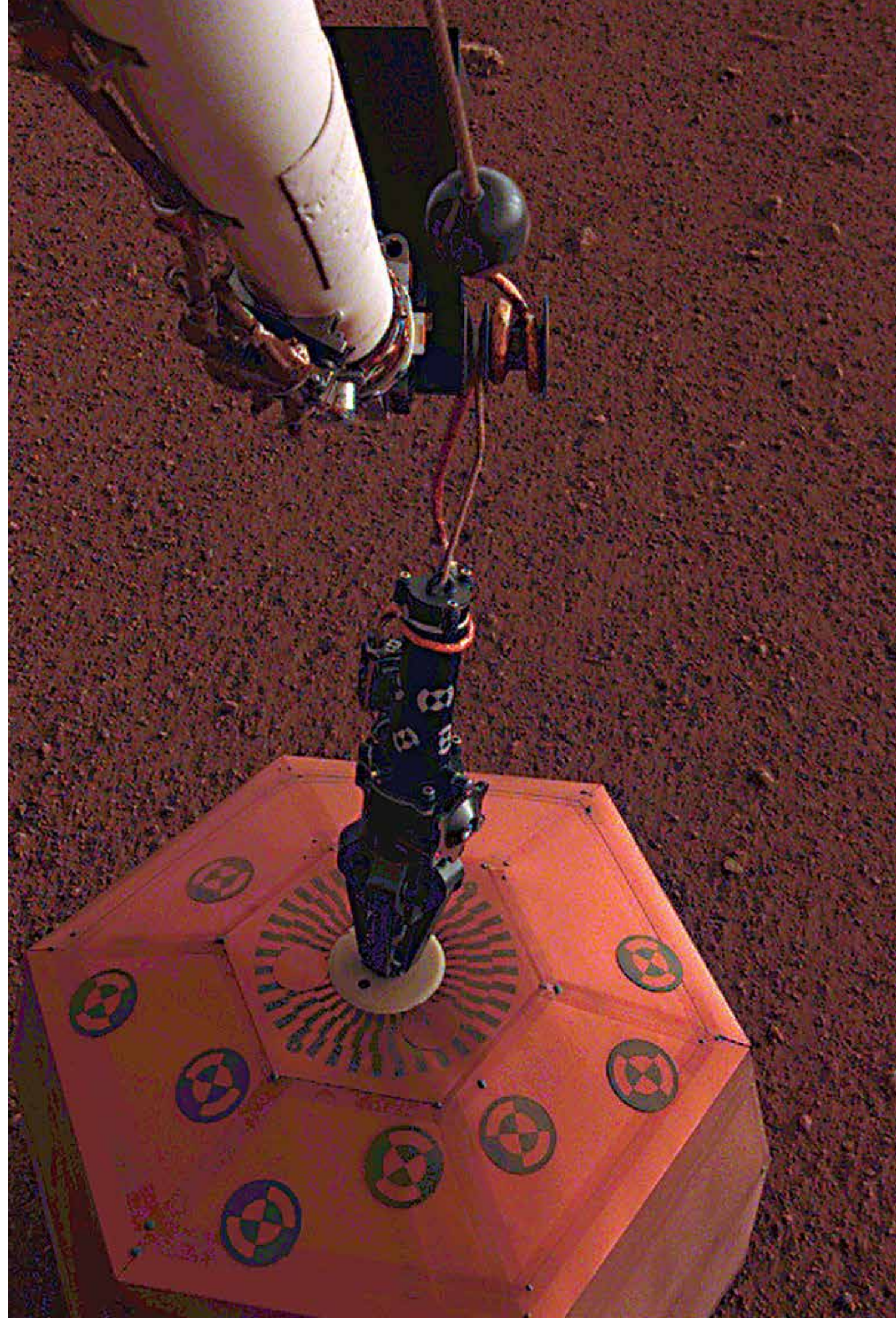
The long-term payoff will be to use the Red Planet as a natural laboratory to learn about the formation and inner structure of all rocky planets.

The design of the InSight lander, short for Interior Exploration using Seismic Investigations, Geodesy and Heat Transport, is based heavily on Mars Phoenix, which landed in 2008. The new lander totes three main investigations in its high-tech bag of tricks.

The Seismic Experiment for Interior Structure can detect marsquakes. While Mars doesn't have tectonic plates as Earth does, other processes can cause seismic movements. The seismometer has three sets of sensors, with two sensor types per set — a pattern that can measure ground motions in any direction over multiple frequencies.

A self-hammering mole on the Heat Flow and Physical Properties Probe is designed to burrow below the surface to measure heat escaping from the Martian interior, considered a vital sign of the planet's inner structure.

RIGHT: InSight's seismometer on the surface of Mars listens for quakes, meteorite strikes and other phenomena.



RIGHT: Artist's illustration depicts what scientists believe the inside structure of dwarf planet Ceres is like.

To help pin down the size and composition of Mars' core, the Rotation and Interior Structure Experiment precisely tracks InSight's location to determine how the Martian North Pole wobbles as it orbits the Sun.

Within a couple of weeks after landing, InSight had already deployed its robotic arm and placed its seismometer on the surface, taken a selfie, and achieved a remarkable planetary first: the seismometer and air pressure sensor "heard" the wind on Mars by picking up the vibration from sound waves and changes in air pressure.

"Capturing this audio was an unplanned treat," said Bruce Banerdt, InSight's principal investigator at JPL.

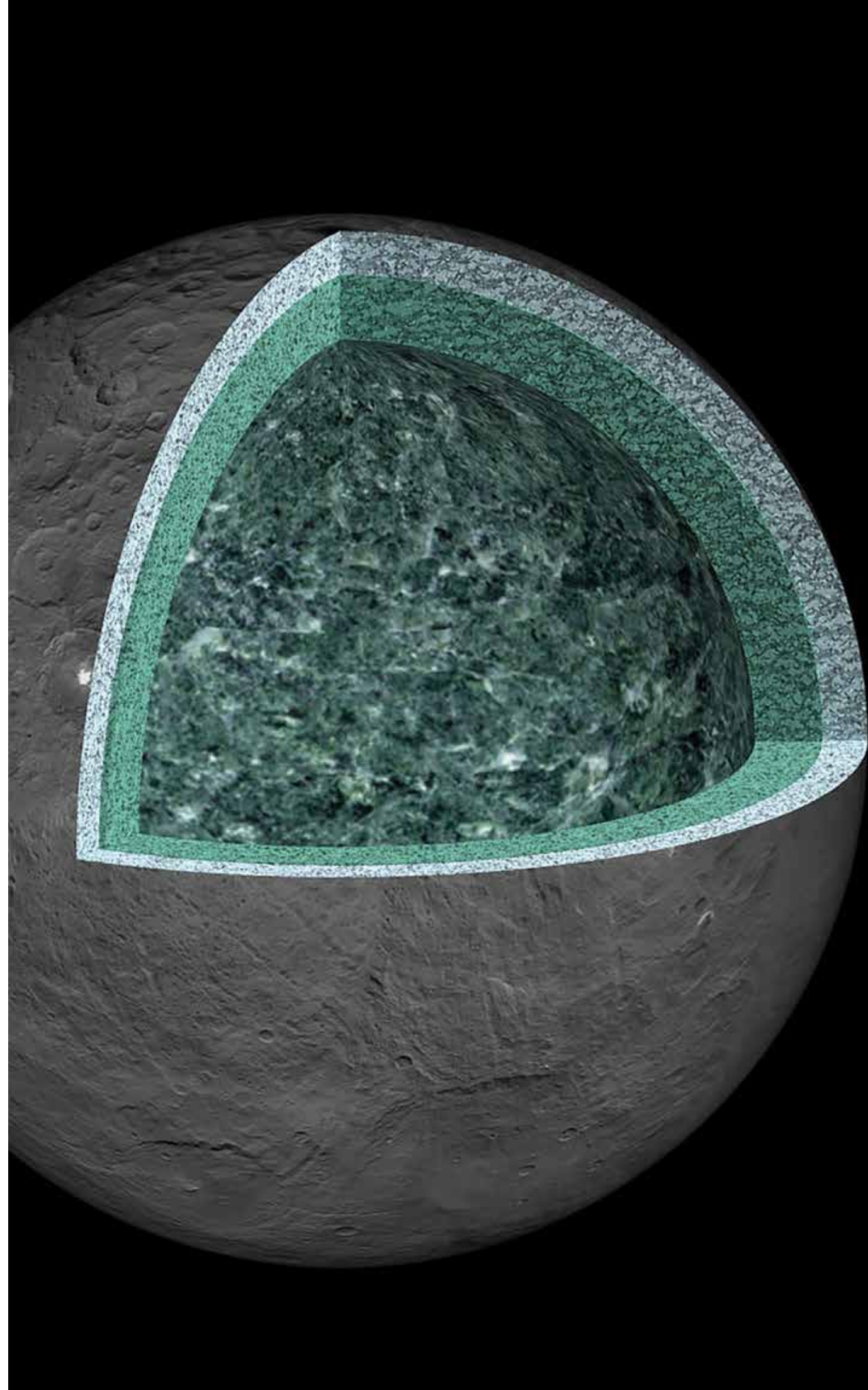
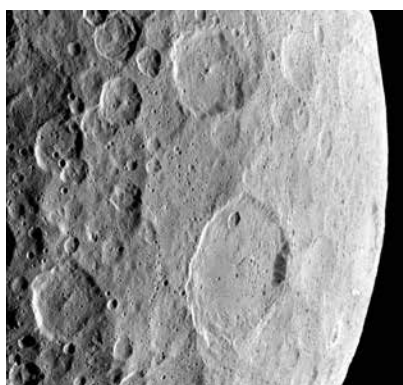
A Fond Farewell to a Spacefaring Pioneer

Less than a month before InSight landed, another historic space traveler ended its highly successful 4.3-billion-mile mission. The Dawn spacecraft launched 11 years ago on a journey to the main asteroid belt between Mars and Jupiter. Propelled by ion engines — the stuff of science fiction — Dawn became the first spacecraft to orbit two solar system targets — giant asteroid Vesta and dwarf planet Ceres. As anticipated, the mission eventually ran out of hydrazine fuel and could no longer operate. Dawn's team bid farewell to the spacecraft, which will remain incommunicado in orbit around Ceres for at least 20 years, and likely much longer.

"The astounding images and data that Dawn collected from Vesta and Ceres are critical to understanding the history and evolution of our solar system," said Thomas Zurbuchen, associate administrator of NASA's Science Mission Directorate in Washington.

Dramatic images from Dawn captured craters, canyons and mountains on Vesta, and a cryovolcano and mysterious bright spots on Ceres. Scientists later deter-

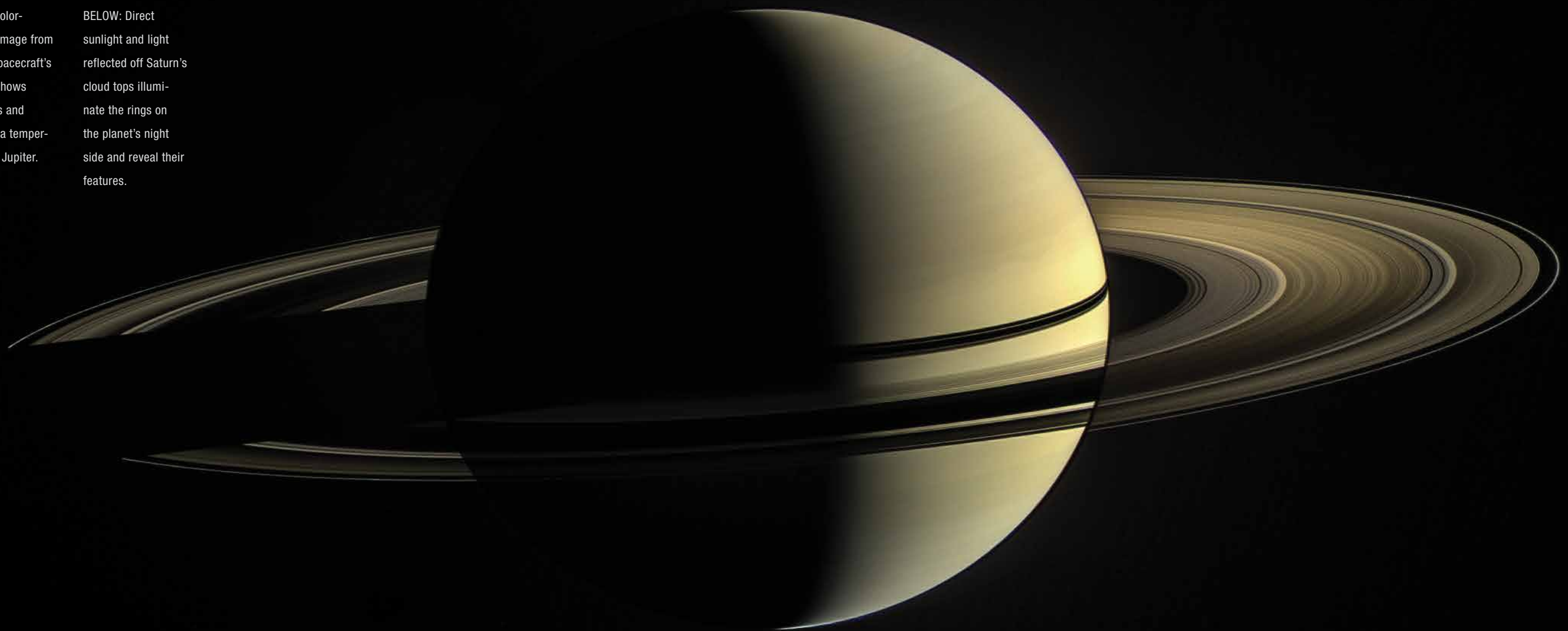
Dawn flew over complex fractures near the center of Ezinu crater on dwarf planet Ceres.





ABOVE: A color-enhanced image from the Juno spacecraft's JunoCam shows intense jets and vortices in a temperate belt on Jupiter.

BELOW: Direct sunlight and light reflected off Saturn's cloud tops illuminate the rings on the planet's night side and reveal their features.





mined those spots were probably salt deposits originating from briny liquid in Ceres' interior. The finding expanded the list of possible ocean worlds in our solar system.

"Dawn has shown us alien worlds that for two centuries were just pinpoints of light amidst the stars," said Marc Rayman, Dawn's mission director and chief engineer at JPL. "And it has produced richly detailed, intimate portraits and revealed exotic, mysterious landscapes unlike anything we've ever seen."

Elsewhere in the Solar System...

The Juno mission, orbiting Jupiter since July 2016, is halfway done collecting data during its prime mission and has already provided extensive information about Jupiter's atmosphere and magnetic field.

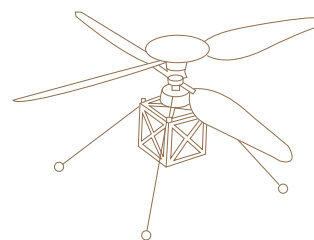
"The second half should provide the detail that we can use to refine our understanding of the depth of Jupiter's zonal winds, the generation of its magnetic field, and the structure and evolution of its interior," said Scott Bolton, Juno principal investigator from the Southwest Research Institute in San Antonio.

Although the Cassini mission ended its long, productive journey in Sept. 2017, scientists are still harvesting its data, and a crop of new findings has detected the presence of complex organics bubbling up from Saturn's geyser-emitting moon, Enceladus, and the first known dust storms on its largest moon, Titan.

Another breed of solar system explorer is in the works — a four-pound experimental helicopter that will hitch a ride with the Mars 2020 mission to become the first heavier-than-air vehicle flying on another planet. The four-pound helicopter with two four-foot-wide blades will cut through the thin Martian atmosphere and potentially carve a new path in space exploration for low-flying scouts and aerial vehicles for other worlds.

"The ability to see clearly what lies beyond the next hill is crucial for future explorers," said Zurbuchen.

LEFT: Magnificent, swirling currents above Jupiter feature bright-white "pop-up" clouds and a white oval storm.





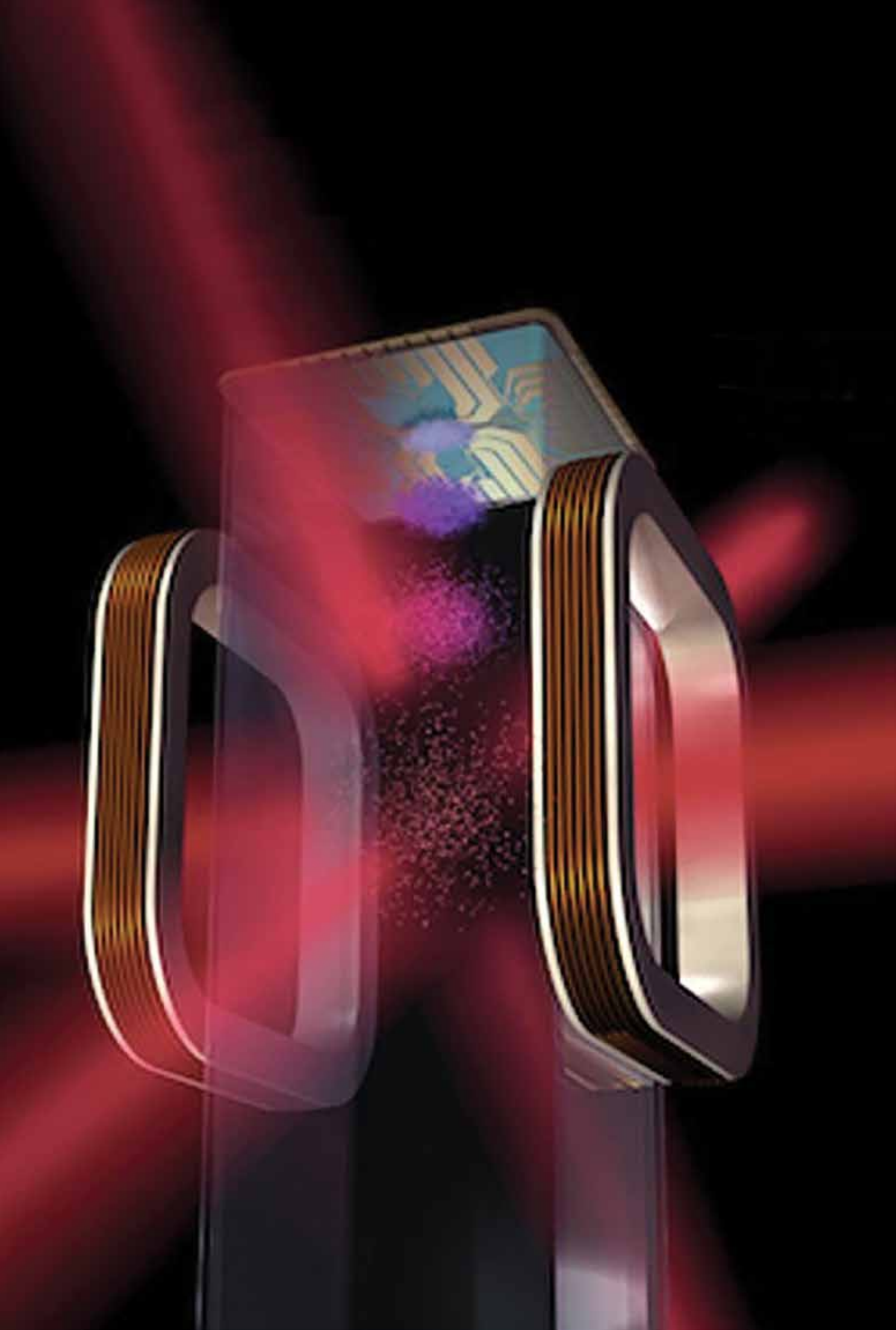
ASTRONOMY AND PHYSICS

The year was full of vivid contrasts for astronomy and physics missions: extreme cold and distance, success for spacecraft veterans and newcomers, milestones and memories.

The Quantum Big Chill

From its perch on the International Space Station, its home since May, the Cold Atom Lab (CAL) is the “coolest experiment in the universe.” The Lab is the first facility in orbit to produce clouds of “ultracold” atoms that plunge to a fraction of a degree above “absolute zero” — the lowest possible temperature for matter anywhere in the universe (minus 459.67 degrees Fahrenheit, or minus 273.15 Celsius).





At ultracold temperatures, atoms slow to less than a snail's pace, which opens new ways to study and manipulate the atoms. The microgravity environment of the space station prevents gravity from quickly dragging down the atom clouds, which means scientists can observe how the clouds evolve over longer time periods. Given more time to expand, the atom clouds could reach colder temperatures than are possible on Earth. The research could lay the groundwork for extremely precise gravity-measurement devices.

It was a mean feat to design CAL to survive launch and the trip to the space station, then work effectively in microgravity. CAL uses technologies never before flown to space, including specialized vacuum cells that contain the atoms.

"Several parts of the system required redesigning, and some parts broke in ways we'd never seen before," said Robert Shotwell, chief engineer for JPL's Astronomy, Physics and Space Technology Directorate and CAL project manager. "The facility had to be completely torn apart and reassembled three times."

A Missive From the Edge of the Solar System

Slightly more than 11 billion miles (18 billion kilometers) deeper into space, Voyager 2 became the second human-made object to reach interstellar space, the space between the stars. Its twin, Voyager 1, passed that milestone in 2012, but Voyager 2 has an onboard working instrument that can provide unique observations of this region. The Voyager 2 milestone occurred when it crossed the outer edge of the heliosphere — the bubble of particles and magnetic fields generated by the Sun. Voyager 2 is NASA's longest-running mission. Both Voyagers completed their original missions to the outer planets of our solar system decades ago.

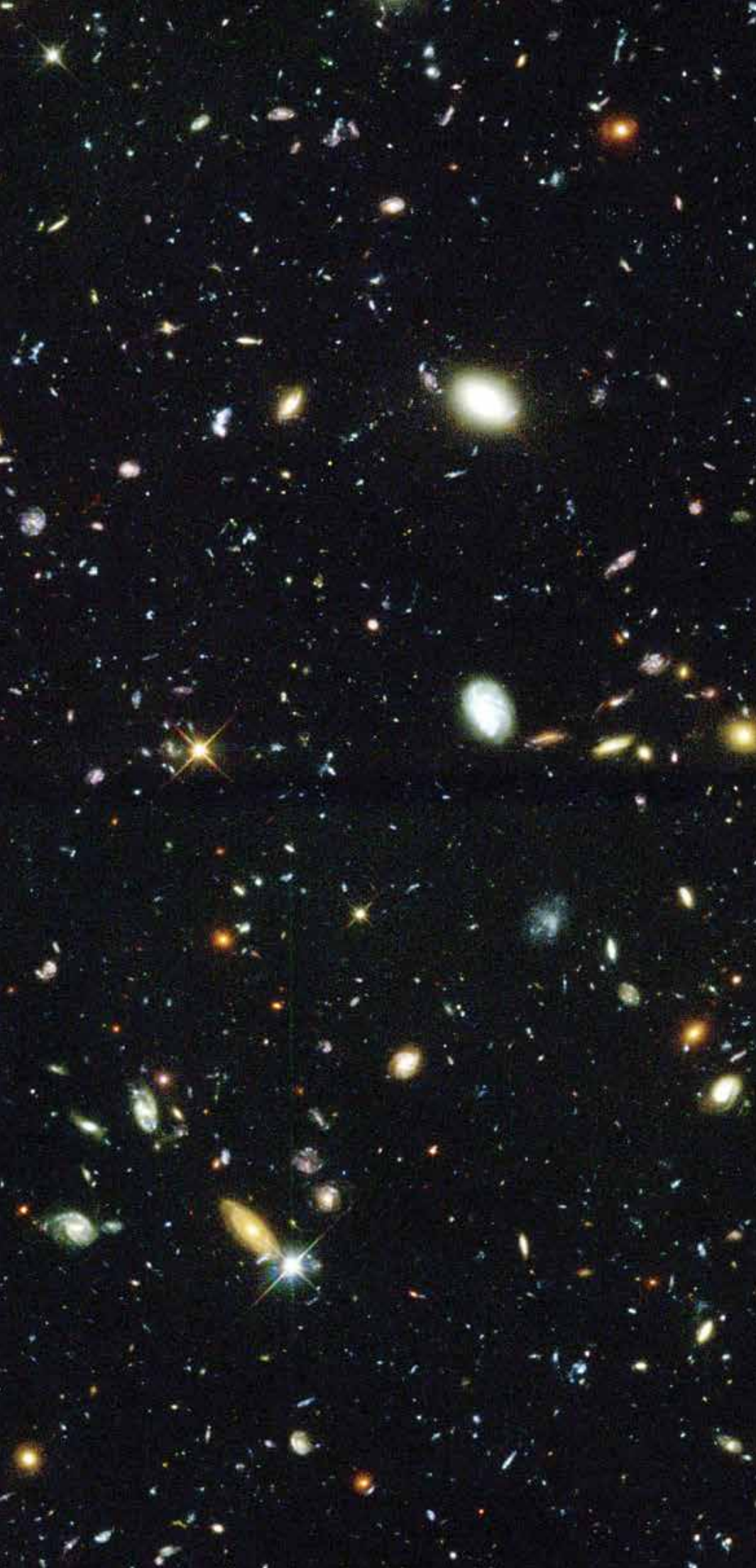
Anniversary of "The Camera That Saved Hubble"

December was the 25th anniversary of perhaps the most famous "eyeglasses" in history. The JPL-designed and built Wide Field and Planetary Camera 2 (WFPC2) helped save the imaging capabilities of NASA's Hubble Space Telescope after the telescope's 1990 launch, when a small but devastating flaw in its primary mirror blurred its long-awaited pictures.

A JPL-led team devised a way to correct the mirror error with a new onboard camera, which they designed and built methodically but as quickly as possible.

After that camera, WFPC2, launched in December 1993, astronauts on space shuttle Endeavour grabbed Hubble 353 miles (568 kilometers) above Earth. They first installed hardware from NASA's Goddard Spaceflight Center to fix three other Hubble instruments. Then they removed the original WFPC instrument and installed JPL's four-camera WFPC2, and Hubble's flawed vision was corrected.

LEFT: Cold Atom Lab on the International Space Station deep-freezes atoms in a magnetic-field trap to just above absolute zero.



FAR LEFT: The iconic WFPC2 "Hubble Deep Field" image covers a mere speck of the sky, yet it reveals at least 1,500 galaxies at various stages of development.

LEFT: Among the historic images gathered by WFPC2 is the famous Ring Nebula (M57). The telescope looked down a barrel of gas cast off by a dying star.



BELOW: In these combined Planck images, diffuse emission from the Milky Way galaxy was superimposed on a “baby picture” of the universe.

It’s hard to imagine a world without the stunning, iconic images from WFPC2. The Hubble fix is a source of great pride to JPL and was achieved through teamwork and ingenuity under great stress.

“There’s a lot of pressure when you’re building a space instrument even under normal circumstances,” said Dave Gallagher, JPL’s associate director for strategic integration, who was the WFPC2 integration and test manager. “But when you’re fixing something that will essentially make or break the reputation of the entire agency, the pressure goes through the roof.”

During its 15 years on Hubble, WFPC2 captured more than 135,000 views of the universe before a newer camera replaced it in 2009. WFPC2 now resides in the Smithsonian Air and Space Museum.

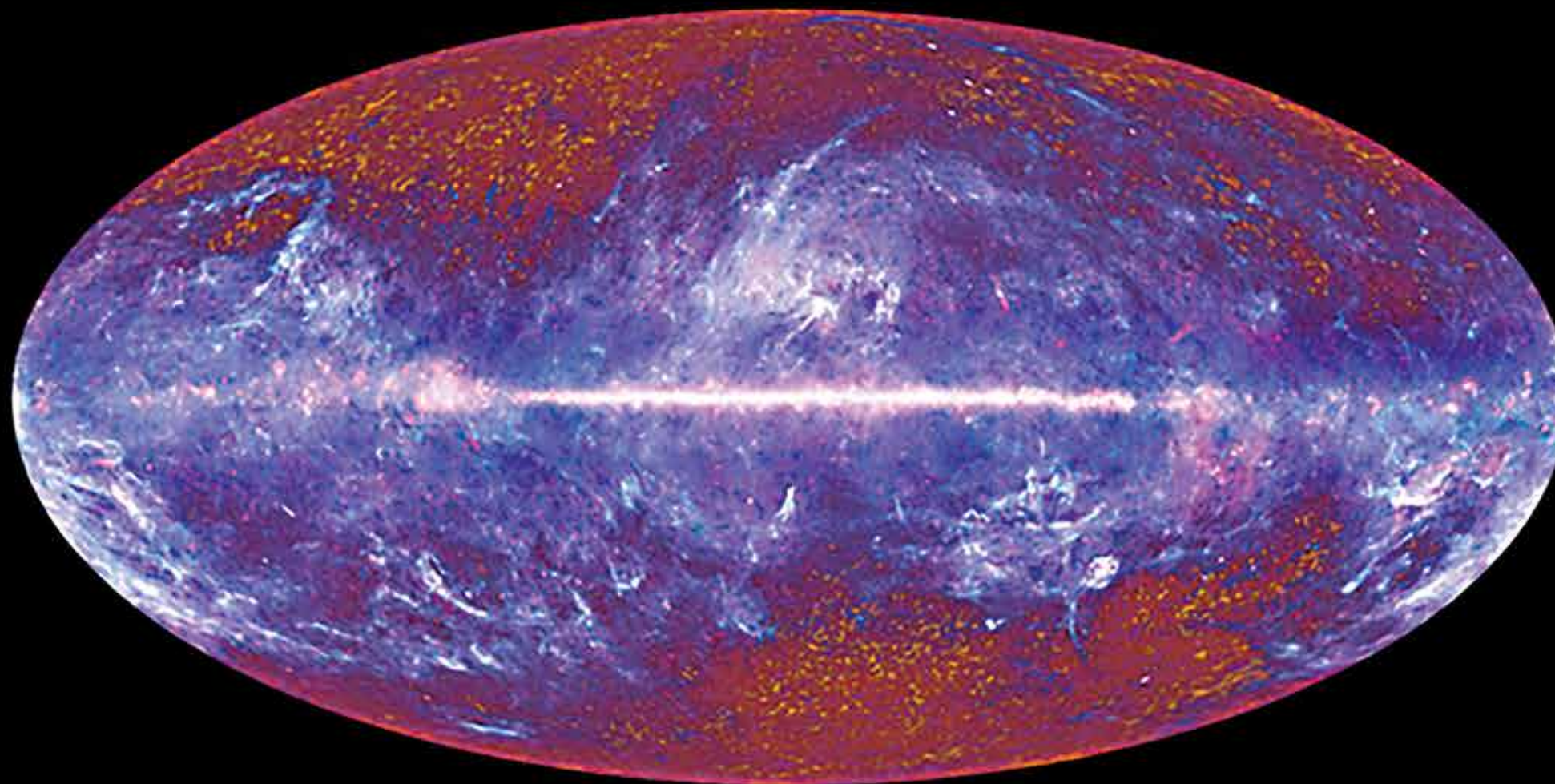
A Planet-hunting Mission Retires

Nine years and more than 2,600 exoplanet confirmations later, the Kepler space telescope received final commands to stop communicating with Earth in November. As expected, the spacecraft had run out of fuel and could no longer conduct science. Kepler continues to drift in a safe orbit around the Sun.

“The Kepler mission was based on a very innovative design. It was an extremely clever approach to doing this kind of science,” said Leslie Livesay, director for astronomy and physics at JPL. Livesay was Kepler project manager during mission development. JPL managed mission development before turning over management to NASA Ames Research Center.

NASA’s Planck Project Office was based at JPL.

Planck, launched in 2009, made a high-resolution map of the cosmic microwave background—the oldest light in the universe.



ASTERIA achieved a milestone in the quest for CubeSats to help detect exoplanets by looking for a dip in star brightness as an orbiting planet blocks its light.

RIGHT: Artist's illustration of the ASTERIA CubeSat in orbit.

“As NASA’s first planet-hunting mission, Kepler has wildly exceeded all our expectations and paved the way for our exploration and search for life in the solar system and beyond,” said Thomas Zurbuchen, associate administrator of NASA’s Science Mission Directorate.

A Prize for Planck

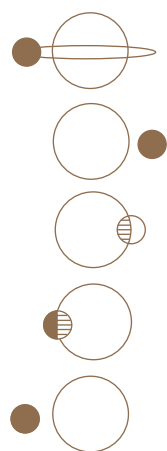
In 2018, JPL scientists shared in what is generally considered the world’s most prestigious cosmology award — the Gruber Cosmology Prize — for contributions to the European Space Agency’s Planck mission. The Lab played a key role in instrument design and construction and scientific data analysis. NASA’s Planck Project Office was based at JPL. Planck, launched in 2009, made a high-resolution map of the cosmic microwave background — the oldest light in the universe. This “baby picture” helps scientists learn about the history of the universe.

Kudos for a Newbie

A new astrophysics CubeSat team earned the Small Satellite Mission of the Year award from an American Institute of Aeronautics and Astronautics committee. The award says ASTERIA “demonstrated a significant improvement in the capability of small satellites.”

ASTERIA, or Arcsecond Space Telescope Enabling Research in Astrophysics, is a JPL–MIT collaboration funded by the JPL Phaeton Program to train early career hires.

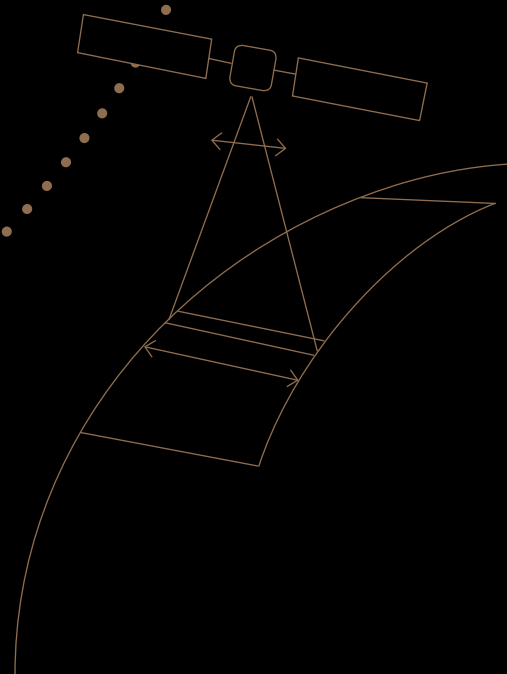
The mission tests miniaturized technology to precisely measure star brightness, which requires spacecraft stability for long observations. By proving it can do that, ASTERIA achieved a milestone in the quest for CubeSats to help detect exoplanets by looking for a dip in star brightness as an orbiting planet blocks its light.





EARTH SCIENCE

Since water covers more than two-thirds of our planet and sustains life, NASA/JPL devotes significant resources to its study. With a series of Earth-observing satellites and ground-based studies enabled by groundbreaking technologies, JPL supports observations on every stop/stage in the water cycle: in soil and deep aquifers, rivers and lakes, ice and snow, oceans, and the vapor, clouds and precipitation in the atmosphere.

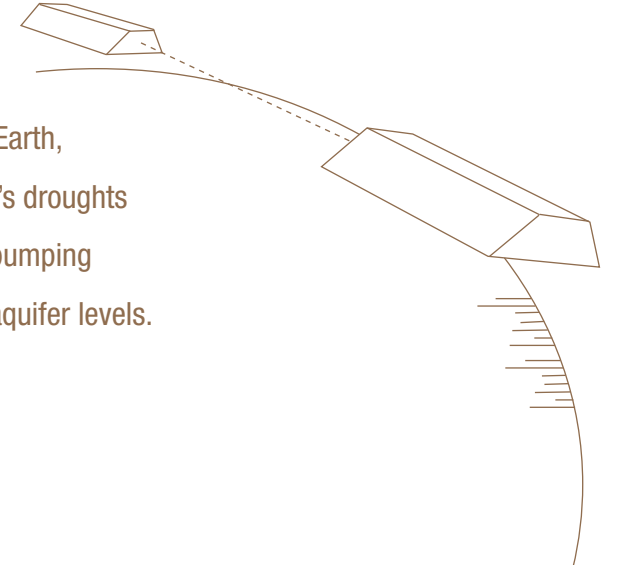


The Grace of Gravity Studies

The twin GRACE-FO (Gravity Recovery and Climate Experiment Follow-On) satellites, launched in May, continue the work of the original GRACE mission from 2002 to 2017. GRACE-FO tracks the movement of water around the planet, allowing scientists to monitor melting ice sheets and glaciers and changes in groundwater levels.

By precisely measuring the distance between the satellites, the mission's microwave ranging interferometer records how changes in mass on Earth's surface

By measuring the movement of mass around the Earth, GRACE-FO data provide unique insights into Earth's droughts and earthquakes, and how human activities, like pumping underground water for agricultural uses, change aquifer levels.



RIGHT: Meltwater from Antarctica glaciers affects sea levels around the world.



RIGHT: Just hours after it was switched on, TEMPEST-D captured its first images as Hurricane Florence pummeled the Carolinas.

BELOW: Sharmila Padmanabhan and Boon Lim at JPL with TEMPEST-D.

are changing the strength of the tug of gravity on each passing spacecraft, very slightly altering the distance between them. While most of Earth's mass remains stationary over the short term, water is always moving across the Earth's landscape, including between the land, atmosphere, oceans and ice sheets. GRACE's and GRACE-FO's very accurate record of the movement of water provides unique insights into Earth's droughts and earthquakes, and how human activities, like pumping underground water for agricultural uses, change aquifer levels.

GRACE measured how much ice was melting and how fast, particularly for the world's largest ice sheets in Antarctica and Greenland. GRACE-FO continues that quest. The missions have illuminated key parts of the water cycle, such as the volume of water added to the oceans when ice melts. This information allows them to calculate how much sea level has changed due to added melt water, compared to expansion due to warming water. Data from both missions help scientists distinguish these two impacts from climate change, as well as help identify and characterize water-cycle variations due to natural variability — as when an El Niño phenomenon warms or cools ocean water.

The GRACE-FO mission also includes an onboard technology demonstration — the laser-ranging interferometer — that paves the way for future, even more precise missions. The instrument's first measurements, made in parallel with the main microwave ranging instrument, show that both instruments are in agreement.

JPL manages GRACE-FO, a mission that is a partnership between NASA and the German Research Centre for Geosciences.

Satellites Come in Many Sizes

Some smaller cousins joined the family of traditional, large Earth-observing satellites in 2018. The International Space Station deployed the experimental TEMPEST-D weather satellite into low-Earth orbit in July. The satellite, no bigger than a cereal box, has a miniature microwave radiometer instrument to penetrate thick clouds and see the insides of a storm. Just hours after it was switched on, TEMPEST-D captured its first images, of Hurricane Florence battering the Carolinas. The detailed images are comparable to those from larger, more costly weather satellites.

Another experimental small satellite, RainCube (Radar in a CubeSat), emits





Images from the MISR instrument of California's Ferguson and Carr fires in July 2018 helped scientists track how their smoke disperses, which affects air quality.



Multi-angle Imaging SpectroRadiometer (MISR) carries nine cameras fixed at different angles, each of which viewed Hurricane Michael over the course of approximately seven minutes when it was just off Florida's west coast.

radar "chirps" that bounce off raindrops to profile the precipitation within the guts of a storm. The satellite caught views of a storm developing over Mexico, and the first rainfall of Hurricane Florence.

Many tiny satellites of this type could potentially fly in constellations to provide extensive storm coverage.

Earth-observing Satellites: In the Right Place at the Right Time

The grand, diverse terrain that inspires us on Earth also presents a backdrop for tumultuous events and hazards. 2018 saw many such occurrences, including massive, historic fires in the western U.S., hurricanes and volcanic eruptions. JPL resources were frequently able to monitor these events and help first responders. These activities supported the NASA Disasters Program, which mobilizes for natural and human-made hazards.

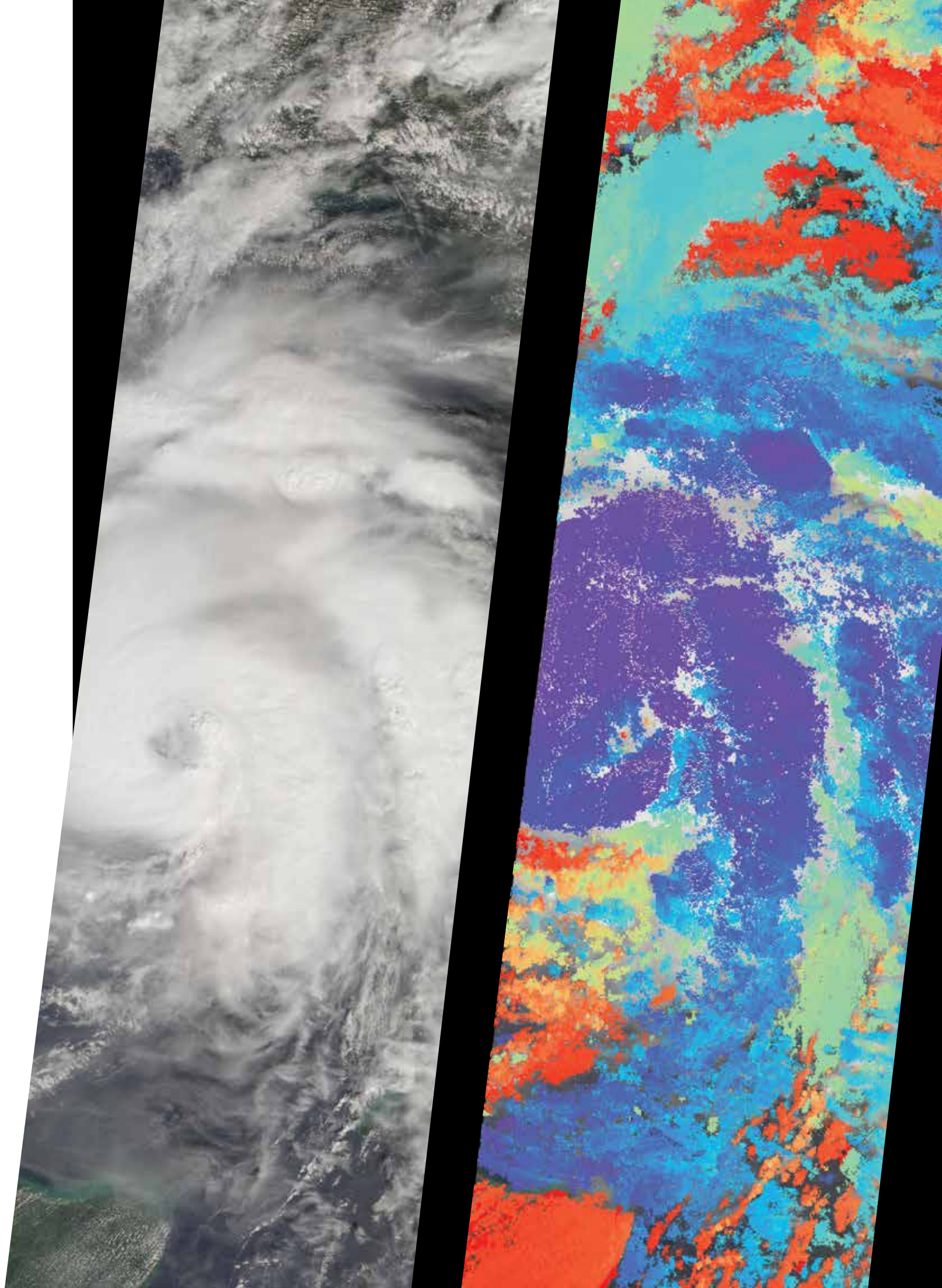
Fire Watchers

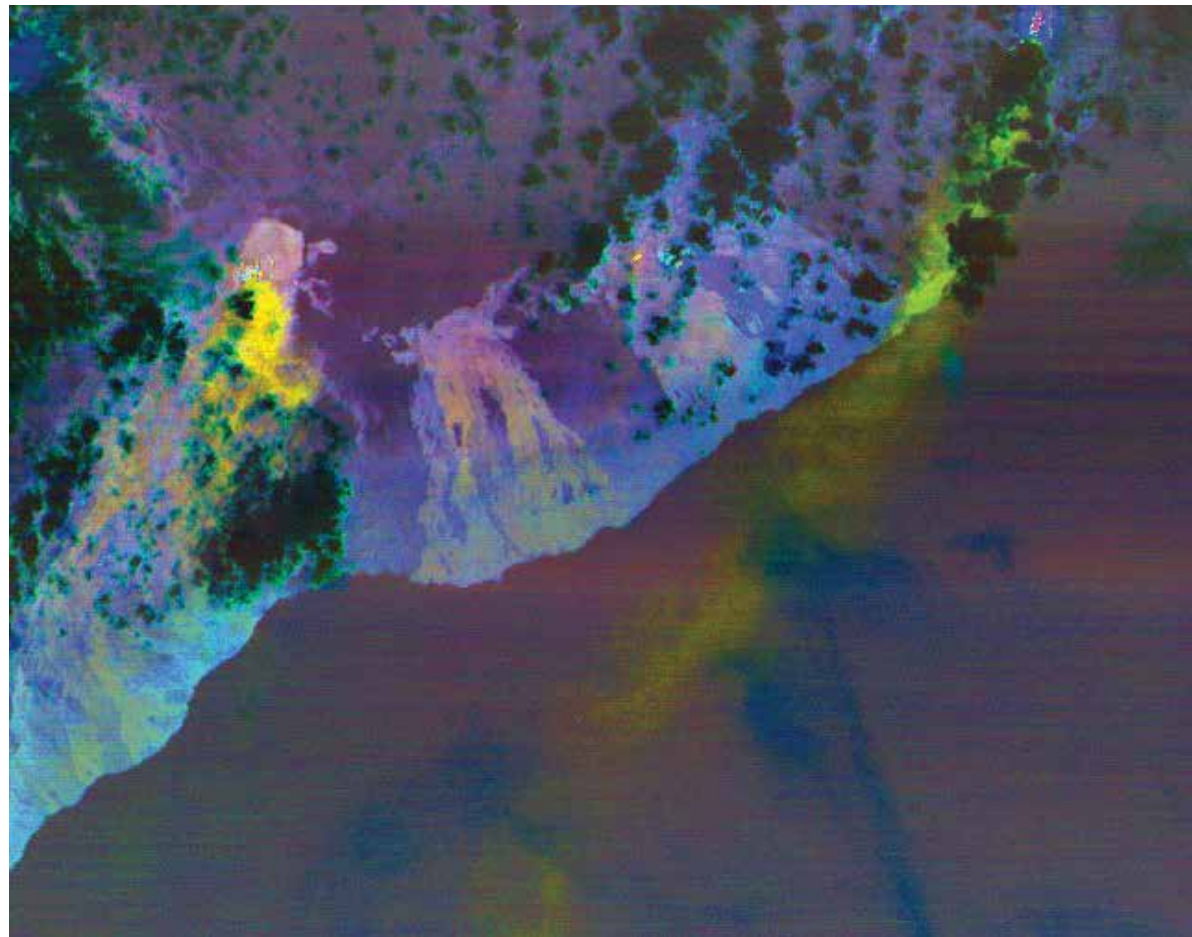
The nine cameras of the Multi-angle Imaging SpectroRadiometer (MISR) instrument on NASA's Terra satellite imaged two raging California fires in July.

With its ability to characterize changes in Earth's surface through clouds, smoke and dust, the JPL-built and managed UAVSAR (Uninhabited Aerial Vehicle Synthetic Aperture Radar) was ideally suited to assess damage over the Woolsey Fire near Malibu. In addition, based on similar imagery from European satellites, JPL's Advanced Rapid Imaging and Analysis (ARIA) team quickly produced "damage proxy maps" showing fire devastation. And a newcomer, ECOSTRESS, imaged the temperature characteristics of three of the raging fires in California. This achievement came mere weeks after ECOSTRESS began its work, after a SpaceX Falcon 9 rocket delivered it to the International Space Station in June and robotic arms transferred it to its docking point.

ECOSTRESS (Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station) also acts as a "space-based Earth botanist" by monitoring our planet's surface temperature to detect plant health and measure how plants react to environmental stresses like drought. That information affects food security and may provide guidance on how and where to grow crops as climate changes.

RIGHT: One of MISR's nine cameras captured a dramatic view of Hurricane Michael off Florida's west coast.





ABOVE: The ASTER instrument captured Kilauea volcano eruptions on the island of Hawai'i (the Big Island). A color composite depicts vegetation in red, with old lava flows in black and gray. Small hotspots superimposed in yellow indicate newly formed fissures and fresh lava flow.

Other Hazards

When Hurricane Michael slammed the Florida panhandle, becoming the strongest hurricane ever in that region, the Atmospheric Infrared Sounder (AIRS) and Multi-angle Imaging SpectroRadiometer (MISR) observed very cold clouds linked to heavy rainfall that were pushed high into the atmosphere by deep thunderstorms.

After the Kilauea Volcano erupted in Hawai'i, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) onboard NASA's Terra satellite observed new fissures and lava flows, including a molten lava stream cascading from the Leilani Estates to the Pacific Ocean.

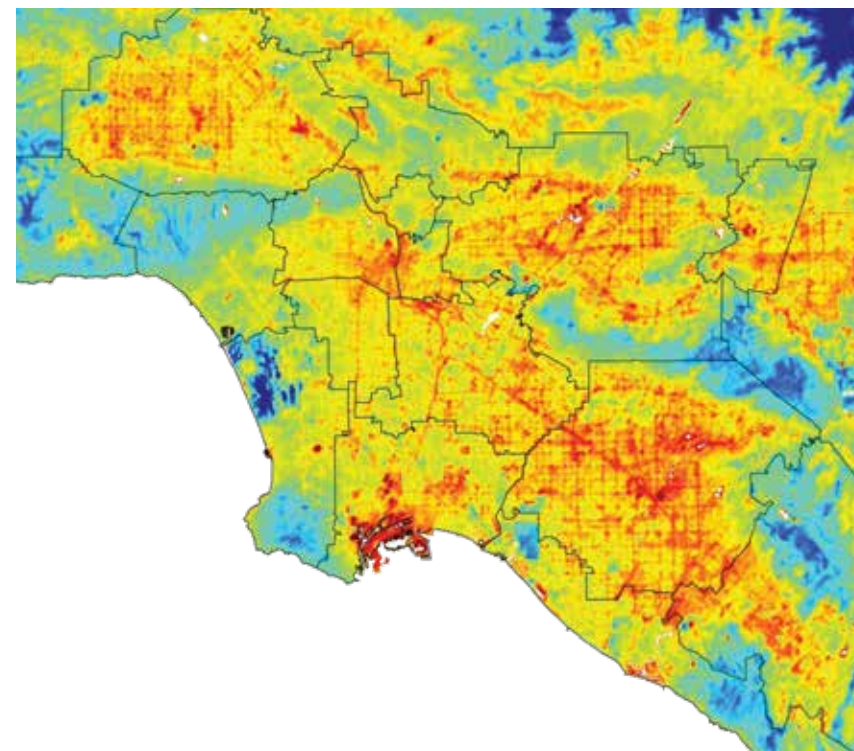
Two Earth-observing Missions Sign Off

Originally designed to monitor ozone in Earth's lower atmosphere, the Tropospheric Emission Spectrometer (TES) demonstrated its capability for also detecting other atmospheric gases. TES contributed extensively to studies of atmospheric chemistry and climate change, and cycles of water, nitrogen and carbon. Launched in 2004 on NASA's Aura Satellite, TES outlived its original five-year mission. Its mechanical arm started stalling intermittently in 2010, and after the stalling became more frequent and affected data collection, NASA ended the mission in January 2018.

In October, engineers switched off the SeaWinds scatterometer instrument and decommissioned the QuikSCAT spacecraft. For nearly two decades, QuikSCAT created an unprecedented record of ocean-surface wind speed and direction, and monitored sea ice, an important element of the water cycle. QuikSCAT also became the gold standard for calibrating new spaceborne scatterometers, and helped with weather forecasts, shipping routes, offshore wind farms and search-and-rescue operations at sea.

A New Carbon Observer

The Orbiting Carbon Observatory 3 (OCO-3), scheduled to launch in 2019, will investigate important questions about the distribution of carbon dioxide on Earth, such as changing emission patterns from urban growth and fossil fuel combustion. OCO-3, like its predecessor, OCO-2, will also detect emission hotspots and volcanoes, as well as solar-induced fluorescence from plants, helping to quantify the exchange of carbon between the atmosphere and biosphere.



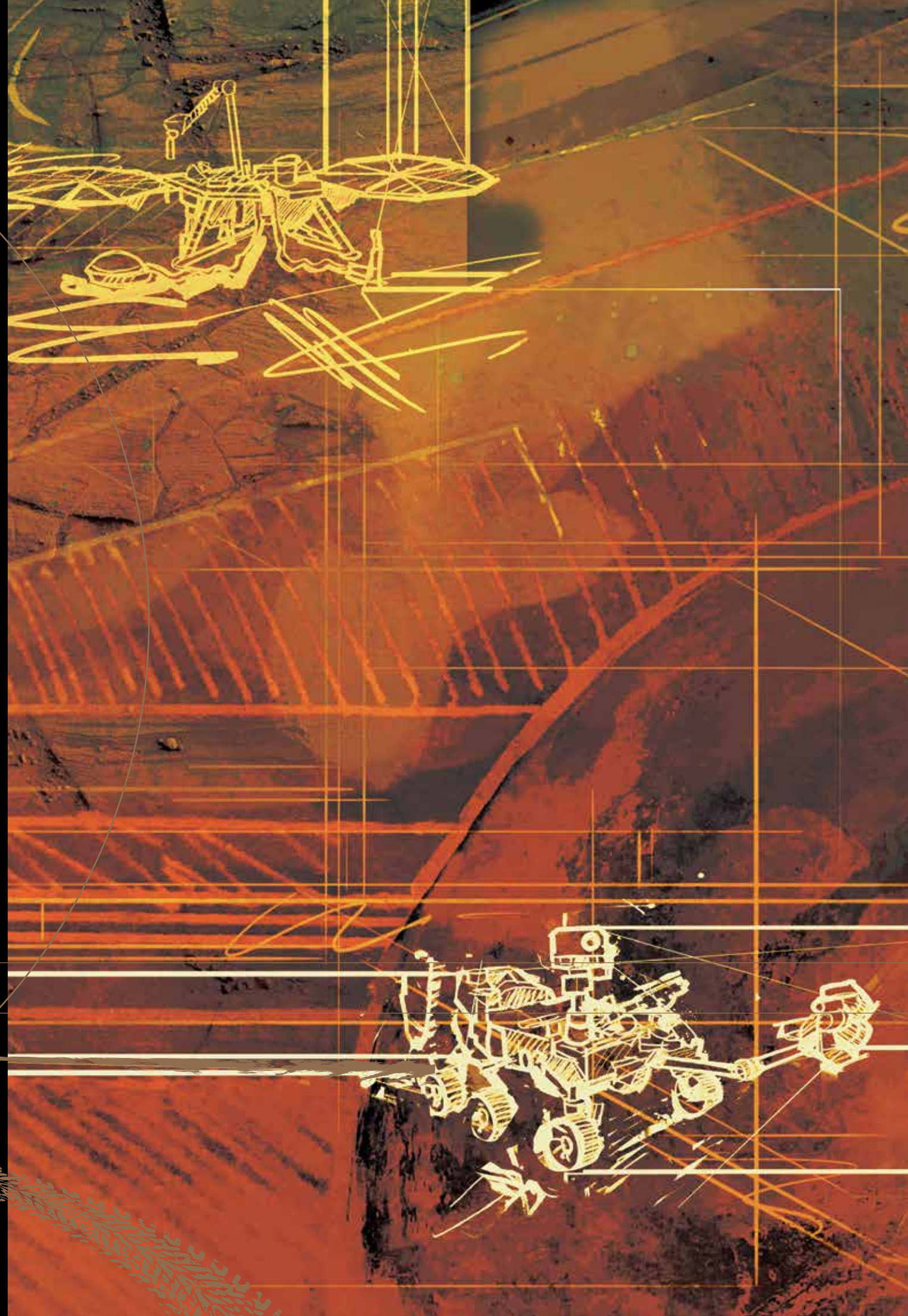
ECOSTRESS captured surface temperatures at different times of day during a 2018 Los Angeles heat wave. Red is used to show hottest areas, which retain heat even at night — for example, unshaded dark asphalt on freeways and parking lots. Orange and yellow are warm, while cooler blue areas indicate clouds and higher mountains.

Formidable conditions on Mars, such as colossal dust storms and massive boulders and cliffs, challenge engineers and scientists preparing to land a spacecraft on the planet.

They must devise elaborate plans to beat daunting odds by selecting optimal equipment, timing and locations for Mars missions. These factors heavily informed the choice of a daring but tempting landing site for Mars 2020, the next rover mission to the Red Planet.

The latest and boldest mission in NASA's Mars Exploration Program, Mars 2020 crossed several crucial hurdles in 2018 in preparation for a July 2020 launch. Mars 2020 will address high-priority science goals, including key questions about the potential for life on Mars. Building on the legacy of past and present explorations, the mission will continue the quest to gather evidence for ancient habitable conditions, and will be the first mission to hunt specifically for biosignatures of past microbial life.

MARS



With its treacherous rocks, boulders, cliffs, and depressions with sand ripples, past mission teams considered Jezero too dangerous as a landing site.

Location Scouting

On the Red Planet, perhaps even more so than on our own planet, it's all about location, location, location. An ideal Mars landing site should be rich in intriguing science, but poor in challenging terrain that could sabotage the mission from the moment it lands.

To balance those potentially conflicting requirements, the Mars 2020 mission team and the planetary science community conducted an exhaustive five-year search. They scrutinized 60 potential landing sites, whittling the list down to the final choice, announced in November 2018: Jezero Crater.

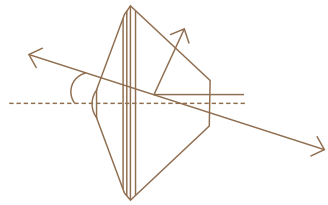
The immense depression (28 miles wide, or 45 kilometers) boasts a rich and dynamic history and some of the oldest, most scientifically promising landscapes on Mars. It lies just north of the Martian equator, on the western edge of a huge impact crater named Isidis Planitia. Scientists believe Jezero Crater once housed an ancient river delta, where flowing water and sediments could have transported and preserved signs of microbial life, such as ancient organic molecules.

“Getting samples from this unique area will revolutionize how we think about Mars and its ability to harbor life,” said Thomas Zurbuchen, associate administrator for NASA’s Science Mission Directorate.

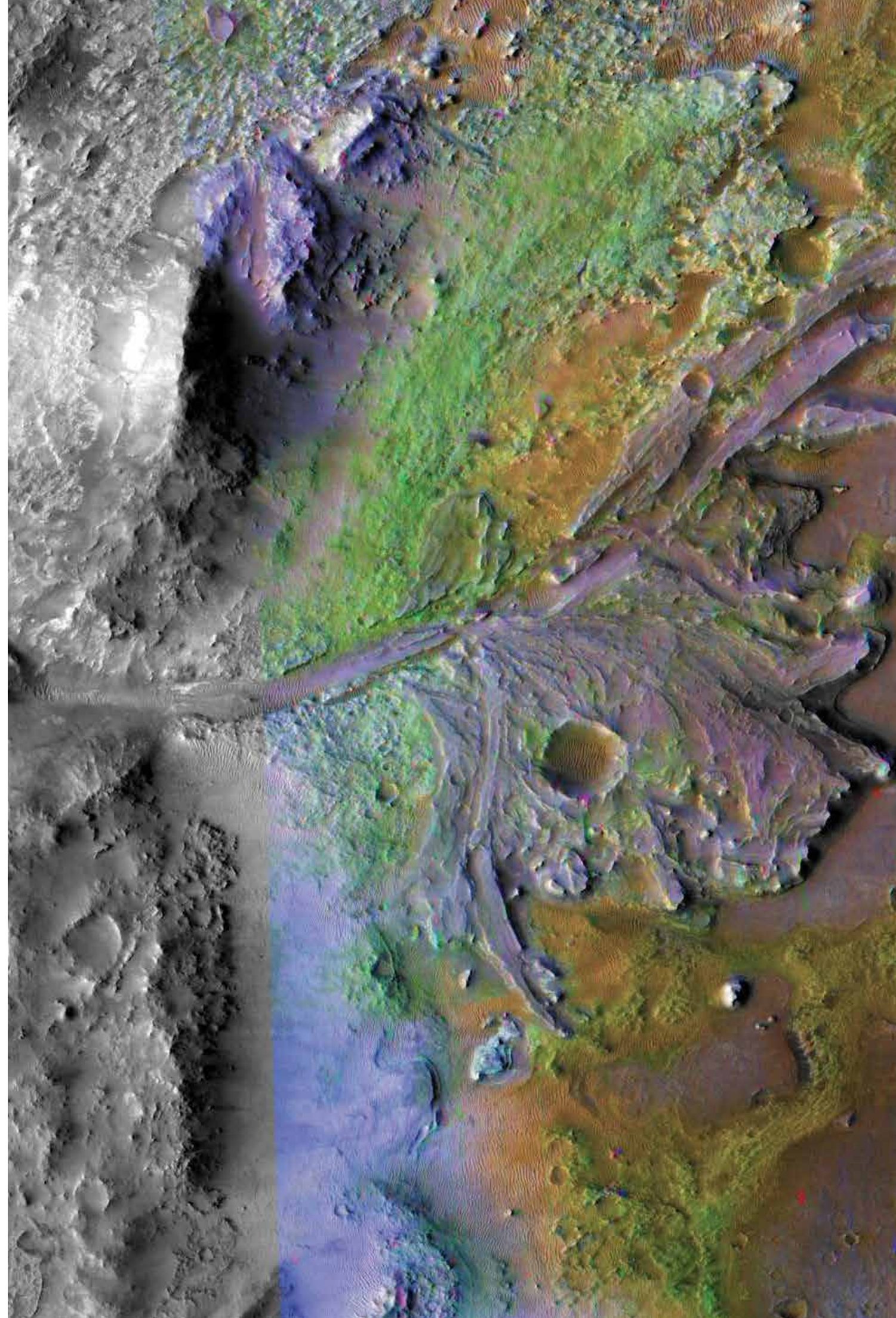
The landing site aligns beautifully with the scientific goals of Mars 2020. The seven onboard instruments include devices to produce small amounts of oxygen from the Martian atmosphere and potentially detect organic matter or abundant water. The mission also includes plans for the rover to collect rock and soil samples and store them in a cache on the Martian surface. A future mission could pick up the stowed treasures and ferry them back to Earth for laboratory analysis, including life-detection tests. NASA and the European Space Agency are jointly studying concepts for such a sample-return mission.

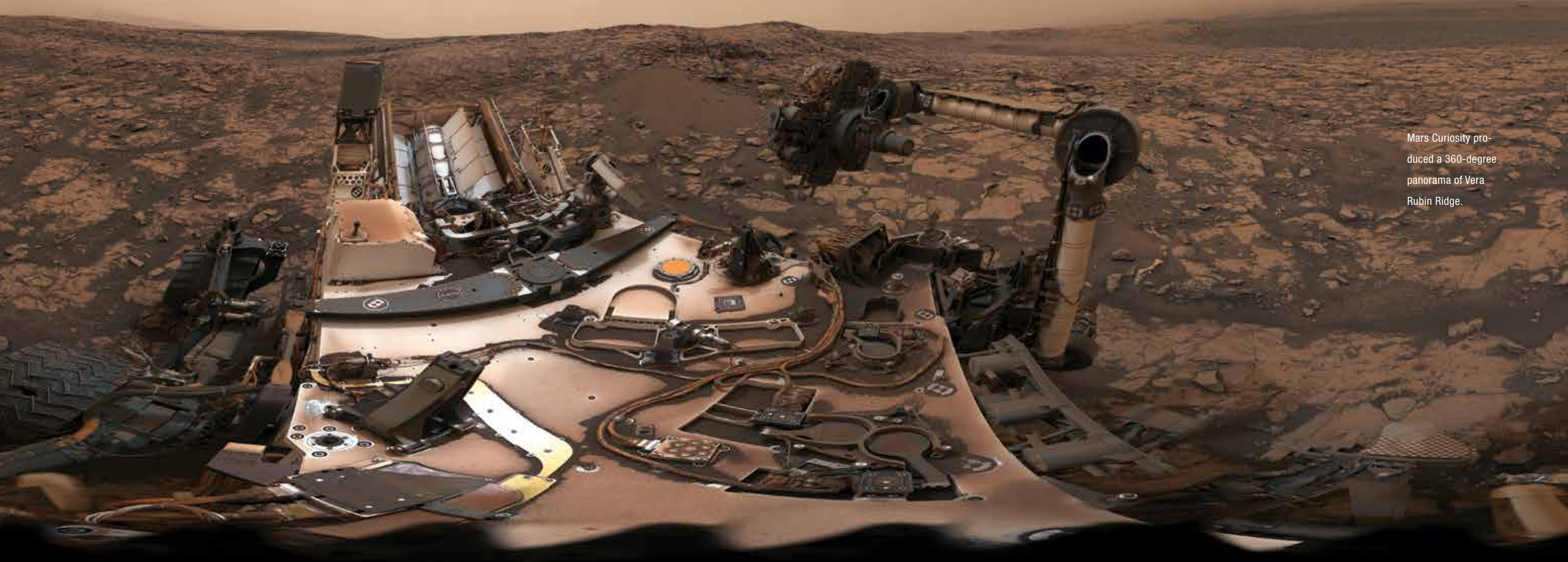
With its treacherous rocks, boulders, cliffs, and depressions with sand ripples, past mission teams considered Jezero too dangerous as a landing site. Engineers now deem it feasible for a Mars 2020 landing because the mission has added a Terrain Relative Navigation capability to the Entry, Descent and Landing process. This technology allows the descent stage to tweak its flight path to avoid certain landing-site hazards.

As a bonus, Mars 2020 will carry the first helicopter to visit another planet. In May, NASA approved development of Mars Helicopter, an experiment to test the technology of using heavier-than-air vehicles on Mars. The helicopter weighs under four pounds, or 1.8 kilograms, with a softball-size fuselage and two blades measuring 4 feet wide, or about 1.2 meters, tip to tip. The blades will slice through the thin Martian atmosphere 10 times faster than a helicopter on Earth.

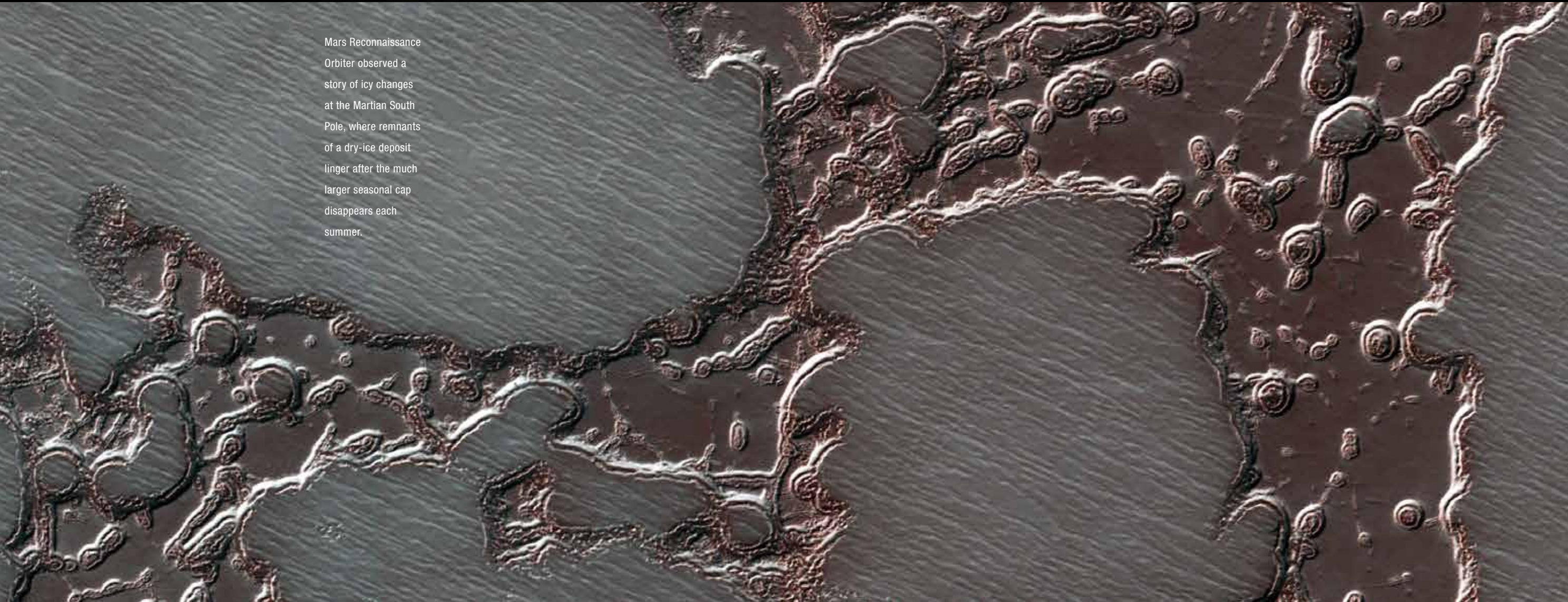


RIGHT: A false-color image from Mars Reconnaissance Orbiter shows Jezero Crater, the Mars 2020 rover landing site.





Mars Curiosity produced a 360-degree panorama of Vera Rubin Ridge.



Mars Reconnaissance Orbiter observed a story of icy changes at the Martian South Pole, where remnants of a dry-ice deposit linger after the much larger seasonal cap disappears each summer.

RIGHT: Two images from Curiosity depict the change in the color of light illuminating the Martian surface since a dust storm engulfed Gale Crater.

BELOW: These two views from the Curiosity rover show dust thickening over three days during a major Martian storm.

The Mars 2020 team also completed development of multiple flight hardware systems to be delivered for spacecraft integration. The mission passed its System Integration Review in February, and in May received formal approval for overall system hardware integration and testing.

The spacecraft is taking shape in the High Bay 1 area of JPL's Spacecraft Assembly Facility, with the cruise and descent stages nearing completion.

Epic Dust Storm Ended the Mission of a Veteran Rover

The Opportunity rover and its twin, Spirit, which operated on Mars until 2010, revealed strong evidence of past water activity and possible habitable conditions early in Martian history. Remarkably, Opportunity had explored Mars since 2004, even though the twin rovers were designed originally for a three-month mission.

A mission-threatening hazard to Opportunity developed in June 2018 as strong winds kicked up a big dust storm on Mars. Within a few weeks, the storm encircled the entire planet with a dense haze. That haze, and dust falling on the solar panels, blocked the Sun's rays from energizing Opportunity, which had been exploring Perseverance Valley. The haze and accumulated dust led to a sharp drop in the rover's power, rendering it unable to operate and communicate with Earth. The mission team's efforts to communicate with Opportunity were not successful through the end of 2018, and by Feb. 2019, NASA announced the official end of the 15-year mission.



On the flip side of Mars, the nuclear-powered Curiosity rover fared well and gleaned useful data from the storm, as did the orbiters Mars Odyssey and Mars Reconnaissance Orbiter, and Mars Atmosphere and Volatile Evolution (MAVEN) mission, managed by the NASA Goddard Space Flight Center.

“Are there signs of life on Mars? We don't know, but these results tell us we are on the right track.”

— Michael Meyer, lead scientist for NASA's Mars Exploration Program

Two key findings from Curiosity in 2018 have major implications in the search for life — past or present — on the Red Planet.

Curiosity drilled into 3-billion-year-old sedimentary mudstone rocks, which the Sample Analysis at Mars (SAM) instrument suite then analyzed. The result: the samples contained “tough” organic molecules. Scientists don't yet know the source, but organics may, though not always, indicate linkage to the presence of life.

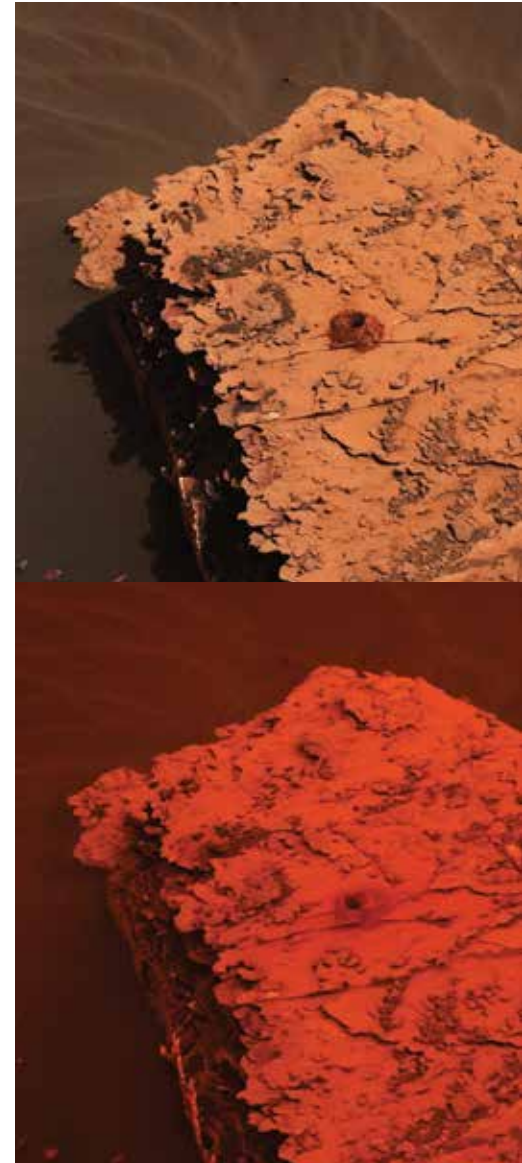
SAM also detected seasonal variations in methane levels in the Martian atmosphere over nearly three Mars years — almost six Earth years. Scientists learned that the levels above Gale Crater peak in summer months and drop in chillier winter. Researchers continue to monitor this phenomenon and try to understand its origin.

“Are there signs of life on Mars? We don't know, but these results tell us we are on the right track,” said Michael Meyer, lead scientist for NASA's Mars Exploration Program.

Odyssey has operated at Mars longer than any other spacecraft. It scans for signs of past or present water or ice, while Mars Reconnaissance Orbiter gathers data about Martian geological features, weather, surface conditions and subsurface structure. Both orbiters, as well as MAVEN, relay telecommunications between the rovers and Earth.

A Mars Touchdown With a Unique Goal

On Nov. 26, cheers echoed through JPL Mission Control and around the world when InSight landed successfully on Mars. InSight is studying how terrestrial planets form, using Mars as a natural laboratory to study marsquakes and other geophysical activity. More information about InSight is in the solar system section of this annual report.



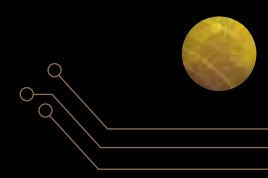


A marriage of visionary ideas and grit leading to breakthrough technologies has produced a history peppered with phenomenal achievements at JPL. Yet we don't take that success for granted, and no matter how grand or daring the accomplishment, a question from the Lab's bright innovators inevitably follows: what's next?

To anticipate that question, JPL's technologists continually hunt for promising ideas from research and concepts. The Office of the Chief Technologist outlines a new forward-looking plan in the 2019 Strategic Technology Directions report, which includes innovative concepts and priorities to 2035 in autonomy; miniaturization; advanced manufacturing, design and materials; distributed systems; communication, navigation and data science; instruments and sensors; and robotics and mobility systems to enable future scientific missions.

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TECHNOLOGY



Many new technologies are already finding their niche — with a one-way ticket to Mars.

RIGHT: A new instrument, PIXL, scheduled to fly on the Mars 2020 mission, will examine sand-grain-size samples for signs of life, past or present.

A CubeSat with lasers to illuminate the mysterious far side of the Moon, a navigation system to help a future Mars mission dodge rocks and other hazards during its high-risk landing, a system to make oxygen out of Martian air, and the first heavier-than-air vehicle — a four-pound helicopter — to fly on another planet: These are just a few of the futuristic technologies JPLers created in 2018.

These technologies and many more are key to JPL's Quests, helping us answer such questions as: Are there planets like Earth out there? How did the universe begin, and how is it evolving? How can JPLers use their unique expertise to serve our nation and its people?

High-tech Additions to Mars 2020

Many new technologies are already finding their niche — with a one-way ticket to Mars. Mars 2020, currently under construction in a JPL clean room, will land at a site on the Red Planet that intrigued scientists but was considered too risky for its predecessor in 2012, the Mars Science Laboratory, with its Curiosity rover.

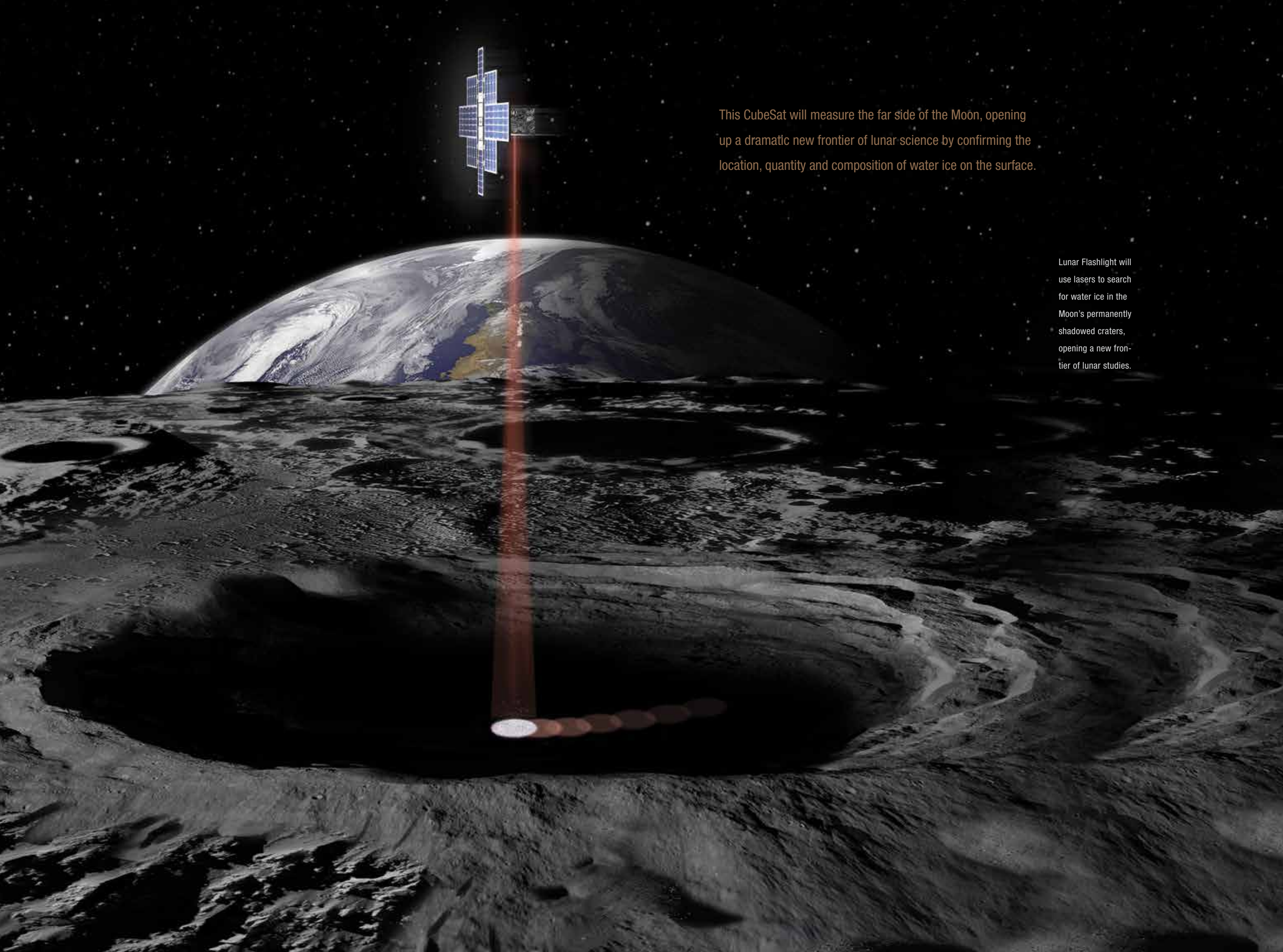
Jezero Crater's rocky terrain and cliffs hardly resemble a welcome mat for a complex lander millions of miles from Earth. But this time, engineers and scientists have confidence in attempting a Mars 2020 landing at the site, thanks to the new, technologically advanced Terrain Relative Navigation system. The system will refine landing accuracy and speed estimates, and may boost confidence in the viability of safely landing future missions on other solar system bodies, such as Europa.

Mars 2020 also will carry an imaginative and promising first test of capabilities to fly a helicopter on another planet. Weighing less than four pounds, the Mars Helicopter will be deployed after the lander safely settles on the surface. The helicopter's four-foot-wide blades will whirl through the thin Martian atmosphere — 100 times thinner than our planet's—about 10 times faster than any chopper on Earth. If all goes well, this will pave the way for future flying vehicles, which would add an important capability to the current exploration toolkit of landers and orbiters.

Small But Mighty Satellites

When the most recent Mars mission, InSight, landed safely in November, a pair of traveling companions — CubeSats named Mars Cube One and Two (MarCO) — proved their mettle by successfully navigating through deep space, then beaming back to Earth the first post-landing image from InSight.





This CubeSat will measure the far side of the Moon, opening up a dramatic new frontier of lunar science by confirming the location, quantity and composition of water ice on the surface.

Lunar Flashlight will use lasers to search for water ice in the Moon's permanently shadowed craters, opening a new frontier of lunar studies.

RIGHT: An artist's illustration of the twin Mars Cube One (MarCO) spacecraft flying over Mars with Earth in the distance.

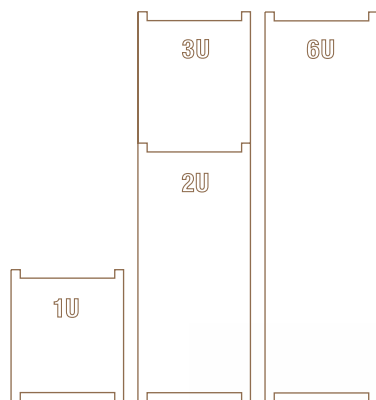
The MarCOs became the first interplanetary CubeSats and added an extra thrill for millions of people around the world watching live landing coverage. The tiny travelers have boosted plans to use small, low-cost CubeSats for other solar system targets, even opening up new paths to those with high risk.

One example of a future use is the Lunar Flashlight technology demonstration, sponsored by the NASA Human Exploration and Operations Mission Directorate's Advanced Exploration Systems. This CubeSat will measure the far side of the Moon, opening up a dramatic new frontier of lunar science by confirming the location, quantity and composition of water ice on the surface.

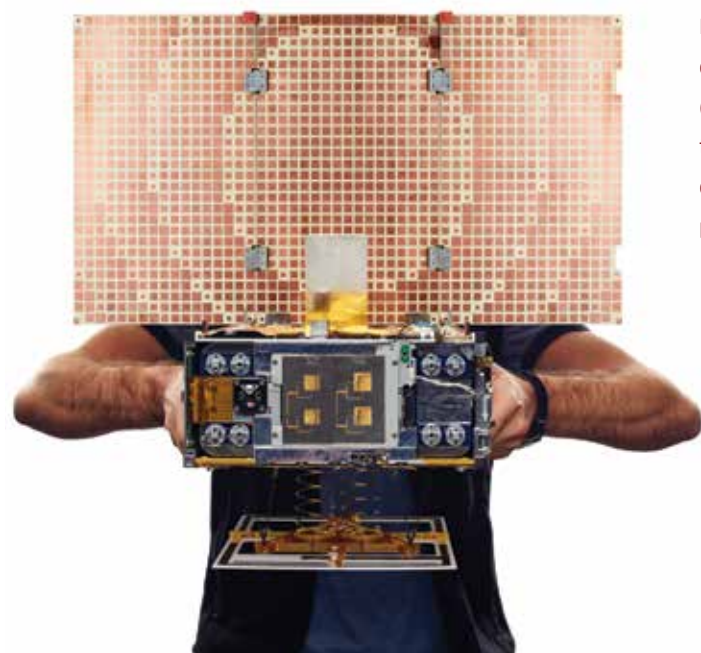
When it orbits the Moon, Lunar Flashlight will demonstrate several technologies to enable future missions. With its green micro-propulsion system, the instrument will become the first 6U-sized CubeSat to orbit a body beyond Earth. The satellite will use compact high-energy lasers for remote sensing, a technology that could potentially boost the use of optical communications for speedy communications to Earth from faraway space destinations. To ensure a lifetime of several years, Lunar Flashlight will use mostly rad-hard avionics parts and some parts from the commercial sector. Tests have shown the parts are hardy enough to last that long.

With CubeSats now being used in deep space, and for Earth-orbiting science, the next dramatic step may be swarms, or constellations, of lower-cost spacecraft. Such swarms may be a valuable addition to the current space-exploration repertoire. They could provide greater flexibility, performance and longer mission life. The low cost would allow for spares to be taken along for the ride as backups. Fear of potential malfunctions would be diminished, since damage to some of the spacecraft would not end an entire mission. That means spacecraft swarms could take more risks. Swarms could create large, reconfigurable telescopes, or other structures traditionally kept on one spacecraft.

Multi-spacecraft systems could dramatically increase the number of options available to mission planners, helping them answer the perennial question, "What's next?"



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Deployed Reflectarray on the Mars Cube One (MarCO) Cubesat shows the mosaicked array of printed circuit board patches.





CAMPUS AND LAB

When a team of artists from JPL and Caltech dabbed colorful chalk onto the sidewalk in the shapes of planets, they hoped the convergence of art and science would inspire future scientists and explorers.

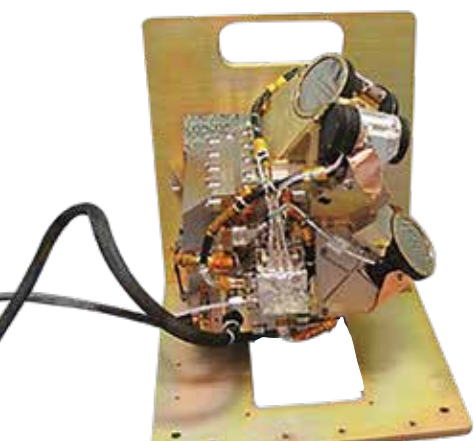
The team's artistic prowess was on display at the Pasadena Chalk Festival, held in June at the city's popular Paseo Pasadena. Their "Out-of-this-World" chalk mural represented past, present and future space missions, and honored the late Apollo astronaut Alan Bean, who had a second career as an artist after retirement.



“JPL scientists and engineers exemplify the fearlessness and creativity that transform understanding and spark the imagination of the public. Together, colleagues across campus and Lab illuminate the mysteries of our world and the worlds around us.”

— Thomas F. Rosenbaum, Caltech President
Sonia and William Davidow Presidential Chair
Professor of Physics

The energetic particle instrument from NASA Parker Solar Probe.



The chalk event was a hit with festival attendees, who peppered the artists with questions about planets and missions. Sarah Flores, a JPL software engineer and veteran street painter, left the event hopeful that festival-goers had absorbed a sense of excitement about space exploration and the beauty of the solar system.

The sidewalk festival was undoubtedly one of the less technical of the many collaborations between JPL and Caltech, which manages the Lab for NASA. Collaborations in 2018 ranged from a near-mythical quest to approach the Sun, to better models for predicting the long-term effects of climate change on Earth.

Journey to “Touch the Sun”

NASA’s Parker Solar Probe launched in August on a mission to “Touch the Sun” by zooming into the star’s atmosphere, within 4 million miles of its molten surface. That’s closer than any previous spacecraft, exposing the probe to extreme heat and radiation.

The mission will help answer many questions about the Sun’s corona. Mark Wiedenbeck of JPL, a Caltech alumnus (PhD ’78) led a team that included scientists from Caltech and NASA Goddard Space Flight Center in developing one of Parker’s instruments. The Energetic Particle Instrument-Hi, or EPI-Hi, will attempt to solve a mystery about charged solar particles that originate in the corona and zip toward Earth, sometimes at nearly the speed of light. Specifically, what causes some of the particles to speed up so drastically?

The probe will also gather data on solar activity and boost our ability to forecast major space-weather events that affect us and our technology here on Earth.

The spacecraft is looping closer and closer to the Sun during 24 flybys. During the first, in November, the probe soared within 15 million miles of the Sun. It also completed an October Venus flyby, the first of seven such flybys.

Mineral Matters on Mars

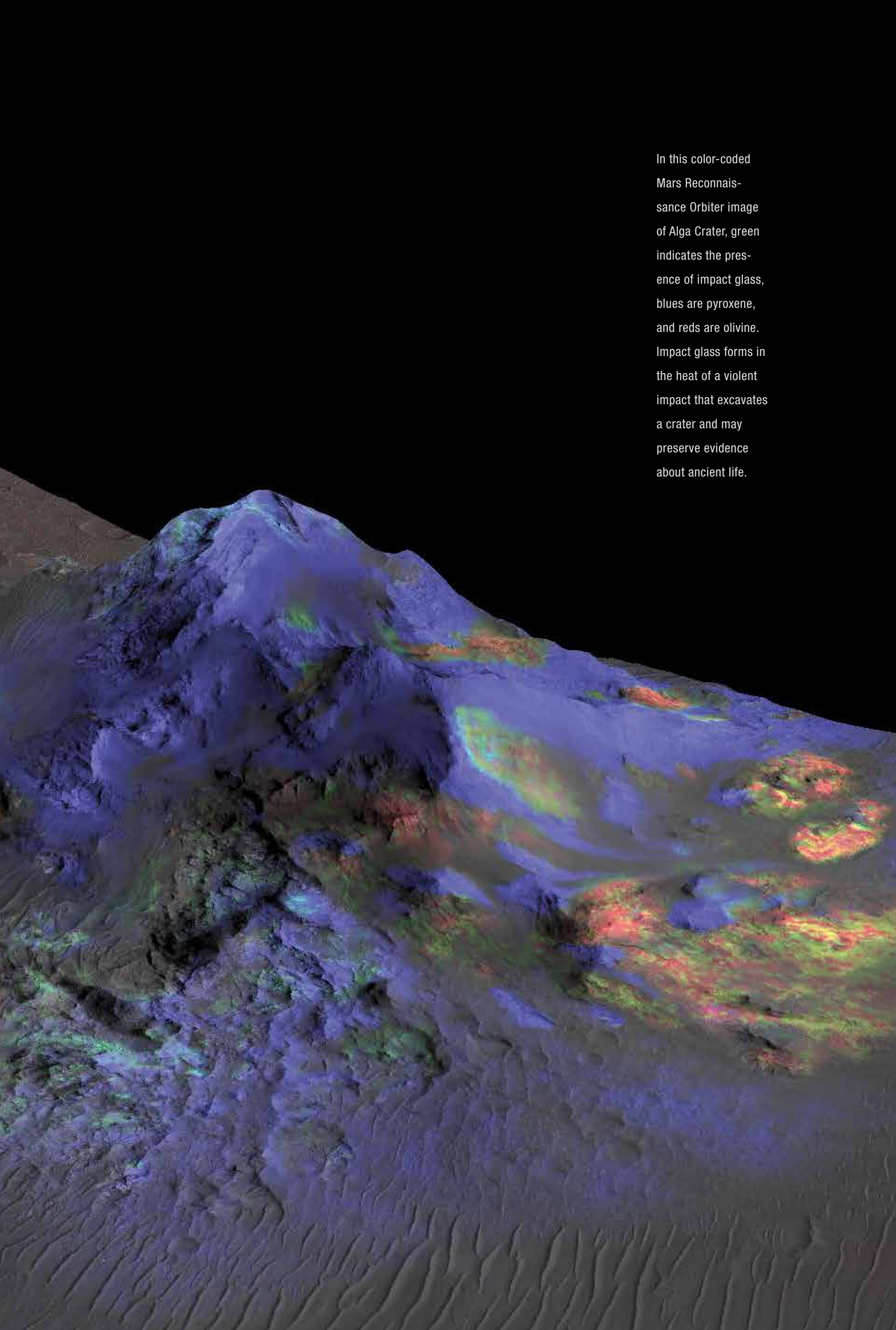
In 2018, a Caltech team brought a new perspective to scientific debate about whether or not perchlorate minerals are present on the surface of Mars, with a study published in Geophysical Research Letters.

The presence of perchlorates, used on Earth to produce rocket fuel, missiles and fireworks, would support the idea of cold, salty waters at the Martian surface. Water, essential to life as we know it, is a key part of ongoing investigations into past or present habitability on Mars.

The CRISM instrument (Compact Reconnaissance Imaging Spectrometer for Mars) onboard NASA’s Mars Reconnaissance Orbiter has been capturing visible-light and infrared images that reveal “fingerprints” from various minerals absorbing light at

Parker Solar Probe launched from Cape Canaveral, Florida, on a mission to study the Sun and unlock mysteries of its corona.





In this color-coded Mars Reconnaissance Orbiter image of Alga Crater, green indicates the presence of impact glass, blues are pyroxene, and reds are olivine. Impact glass forms in the heat of a violent impact that excavates a crater and may preserve evidence about ancient life.

different wavelengths. A 2015 report cited evidence from CRISM that cold, salty waters trigger seasonally dark streaks on Mars' surface. This raised the prospect of perchlorate on Mars.

After researchers also found possible perchlorate signatures in images of potential landing sites for NASA's Mars 2020 rover, Bethany Ehlmann, a Caltech planetary science professor, led a vigorous review of the CRISM data, with the instrument team at Johns Hopkins University Applied Physics Laboratory.

Their conclusion: a data-processing artifact plus carbon dioxide signatures in the Martian atmosphere could, in rare cases, show the presence of perchlorate when there actually is none.

Adding More Lifelike Clouds to Climate Models

Armed with vast amounts of data about Earth, and increasingly powerful computer capabilities, Caltech is leading a research consortium, in partnership with JPL, MIT and the Naval Postgraduate School, to build a more realistic type of climate model.

The Climate Modeling Alliance consortium will work in a fast-paced atmosphere, like that found in many startups. They will merge Earth observations with high-resolution simulations. Their models will show clouds, turbulence and other small-scale features more reliably than current models. The goal is to project future changes in cloud cover, rainfall and the extent of sea ice with half the uncertainty of existing models.

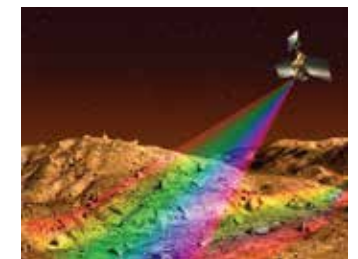
Tapio Schneider, Caltech's Theodore Y. Wu Professor of Environmental Science and Engineering, senior research scientist at JPL and principal investigator of the consortium, explained one potential benefit. "Projections with current climate models — for example, of how features such as rainfall extremes will change — still have large uncertainties, and the uncertainties are poorly quantified. For cities planning their stormwater management infrastructure to withstand the next 100 years' worth of floods, this is a serious issue; concrete answers about the likely range of climate outcomes are key for planning."

A Fluoride Battery Breakthrough

Batteries of various types power everything from components of distant spacecraft to cell phones here on Earth. JPL and Caltech are collaborating with other institutions to develop a new generation of rechargeable fluoride batteries.

Batteries drive electrical currents by shuttling ions — charged atoms — between a positive and negative electrode. The process is easier at room temperatures when moving ions in liquids. Previous fluoride batteries used solid components and could only function at high temperatures.

"We are still in the early stages of development, but this is the first rechargeable fluoride battery that works at room temperature," said Simon Jones, a chemist at JPL and corresponding author of the new study.



This artist's illustration shows the CRISM instrument on Mars Reconnaissance Orbiter looking for various minerals by gathering visible-light and infrared images.



PUBLIC ENGAGEMENT

The stars aligned in 2018 for JPL's Communications and Education Directorate, and for colleagues across Lab involved in public programming and products sharing Cassini's 2017 Grand Finale at Saturn. On Sept. 8, 2018, JPL received its first Emmy award, presented for an inventive campaign that shared the finale with millions around the world.

As one mission ends, another begins. Barely six months after Cassini's plunge, the Mars InSight roadshow through California brought the Red Planet to the Golden State; and millions around the world witnessed a thrilling Mars landing by InSight on Nov. 26.

Cassini Emmy

For the first time in its history, JPL picked up an Emmy award for a real-life space drama: the Cassini spacecraft's dramatic plunge into Saturn's atmosphere after a 13-year study of the ringed planet. JPL won the Emmy Award for Outstanding Original Interactive Program for its coverage of Cassini's Grand Finale at the Creative Arts Emmy Awards in Los Angeles, presented by the Academy of Television Arts and Sciences. Team members in Communications and Education, and Cassini mission leaders, picked up the trophy.

"This award represents the special magic that happens when we combine the stunning imagery and powerful science from a mission such as Cassini with the extraordinary talents of an innovative media and communications team," said Michael Greene, the Lab's director for Communications and Education.

JPL's beloved Cassini spacecraft bid farewell on Sept. 15, 2017 with a spectacular, mission-ending plunge. The Lab's communications and education teams created a multi-month digital campaign to celebrate the mission's science and engineering accomplishments and communicate why the spacecraft needed to meet its end in the skies of Saturn.

The multifaceted interactive campaign included a steady drumbeat of articles and social media posts; multiple live social, web and TV broadcasts; a short film to preview the mission's endgame; NASA's first 360-degree livestream of a mission event from inside JPL mission control; state-standards aligned educational materials; and software to provide real-time tracking of the spacecraft, down to its final transmission to Earth.

Clutching the Emmy at the awards ceremony, JPL's Public Engagement manager Alice Wessen gave a touching tribute to Cassini.

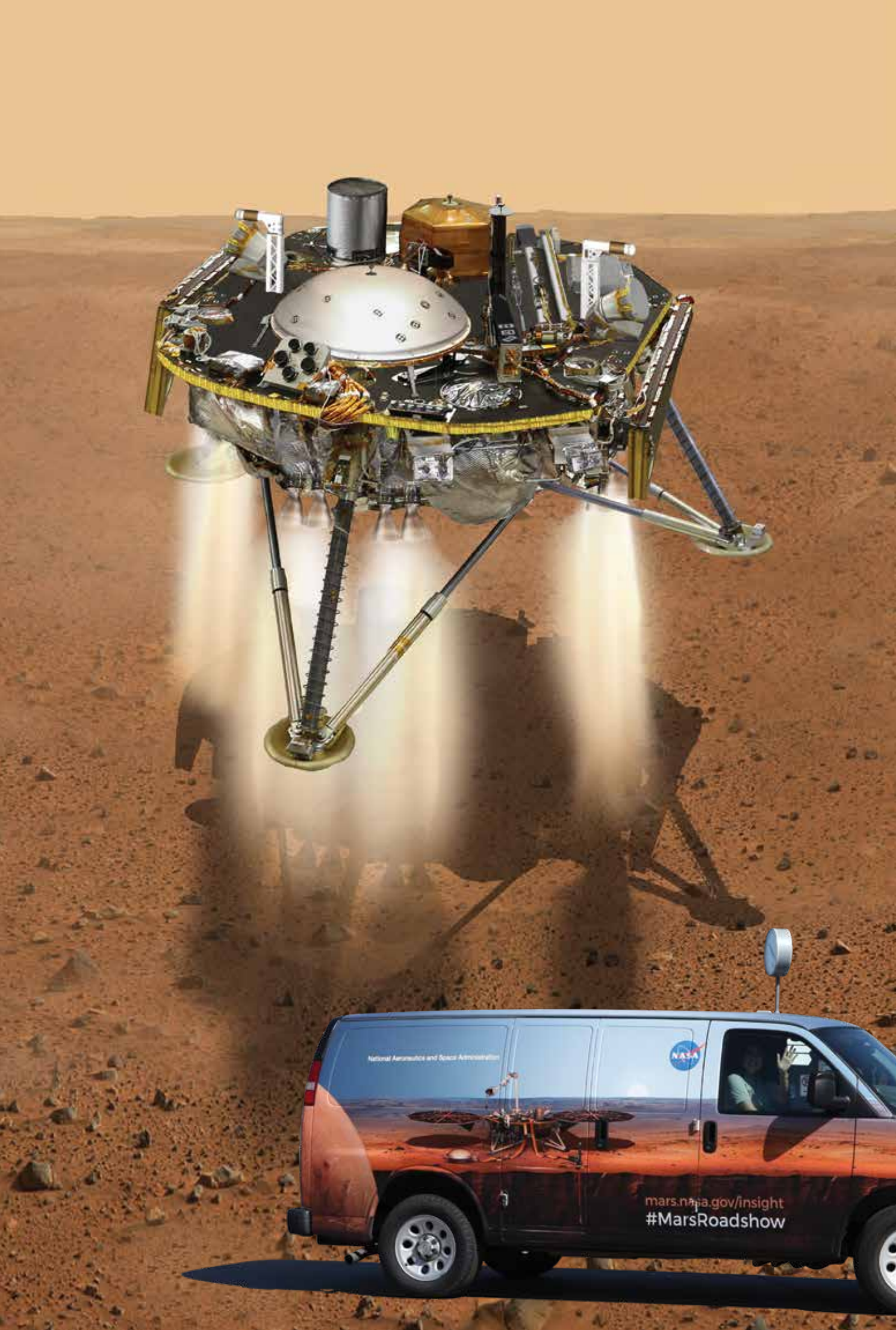
BELOW: In this artist's illustration, the Cassini spacecraft prepares to dive between Saturn and its innermost rings as part of the mission's Grand Finale.

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"To an incredible spacecraft that could and did. To an amazing mission that guided her. To our public that followed her for 20 years before she plunged into Saturn but sent science to the end."

— Alice Wessen, Public Engagement manager





“To an incredible spacecraft that could and did. To an amazing mission that guided her. To our public that followed her for 20 years before she plunged into Saturn but sent science to the end. Go NASA!” said Wessen.

Veronica McGregor, manager of JPL’s Media Relations Office, thanked NASA and JPL “for having a culture that tells us to shoot for the stars in all of our positions, whether we are explorers or storytellers,” she said. “This is for science, for science literacy and discovery.”

InSight Roadshow

Mars got its wheels in 2018. JPL’s Public Engagement team pulled off a cross-California roadshow that brought the Red Planet to tens of thousands of residents. The tour kicked off in March when a decal-decorated van hit the road on a state-wide journey to help people learn about marsquakes and how InSight will study the “inner space” of Mars: its crust, mantle and core.

The roadshow stopped in 16 cities, focusing on museums, planetariums and libraries that are members of the NASA Museum Alliance — a program run by JPL’s Informal Education Group since 2002 that provides access to NASA staff, resources and professional development. Stops also included Redding’s Turtle Bay Exploration Park, San Francisco’s Exploratorium, the Lompoc City Airport for the InSight launch viewing and the Griffith Observatory.

The roadshow concept was new for JPL’s public engagement team, building off some of its previous public exhibits by bringing a sense of “locality” to the InSight mission.

“We thought a roadshow through quake-prone California made sense because it highlighted InSight’s mission of studying seismic activity on Mars, and also because the launch from Vandenberg Air Force Base was the first interplanetary mission ever to originate from the West Coast,” said Carolina Carnalla-Martinez, the Mars Public Engagement manager.

The roadshow drew its biggest crowd at the “Americafest” Fourth of July celebration in Pasadena, California — “down the road” from JPL — where more than 30,000 attendees were treated to fireworks and marsquakes demonstrations courtesy of JPL’s Mars InSight Roadshow team. Participants checked out a half-scale model of InSight at the main entrance, learned about the then-upcoming landing on Mars and simulated InSight’s seismometer on the “Make Your Own Marsquake” jump pad.

LEFT: A simulated view of InSight about to land on the surface of Mars, which the probe accomplished successfully on Nov. 26.

LEFT BOTTOM: The Mars InSight Roadshow van brought activities, exhibits and talks to towns across quake-prone California to explain how the robotic lander will study seismology on Mars.



“This accomplishment represents the ingenuity of America and our international partners, and it serves as a testament to the dedication and perseverance of our team.”

— Jim Bridenstine, NASA administrator

LEFT: NASA Deputy Associate Administrator Melanie Saunders and astronaut Mike Massimino rang the NASDAQ closing bell after InSight successfully touched down on Mars on Nov. 26.

InSight Landing

At 11:53 a.m., Monday, Nov. 26 — nearly seven months after blasting through the fog at Vandenberg Air Force Base and traversing 300 million miles through space—InSight let the humans at JPL know it was alive and functioning on the planet’s biggest parking lot: Elysium Planitia.

“Touchdown confirmed,” announced spacecraft engineer Christine Szalai. “InSight is on the surface of Mars.”

The landing kicked off a two-year mission to study the deep interior of Mars and learn how it and other rocky planets, including Earth, formed. The mission was decades in the making, and a top event for NASA in terms of international cooperation.

Millions around the world witnessed the landing, thanks to careful orchestration by JPL’s Public Engagement and Media Relations offices. The campaign included news releases, web feature stories, live commentary shows on NASA TV, live 360 video of mission control, regular social media updates across multiple platforms and a NASDAQ/Times Square event.

InSight was all over national TV and in more than 700 print, online and broadcast stories across the country, with more than 7 million social media users watching the landing live, and #MarsLanding as the No. 1 trending Twitter topic. NASA arranged “landing watch “ parties around the country — including gatherings at the Los Angeles Central Library, the Adler Planetarium in Chicago and the American Museum of Natural History in New York.

“Today, we successfully landed on Mars for the eighth time in human history,” NASA Administrator Jim Bridenstine said on landing day. “This accomplishment represents the ingenuity of America and our international partners, and it serves as a testament to the dedication and perseverance of our team.”

MAJOR CONTRACTOR PARTNERS

Ball Aerospace & Technologies Corporation

CloudSat, Europa Clipper, GRACE-FO, NEOCam, NEOWISE, SPHEREx

Lockheed Martin Corporation

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

Applied Physics Laboratory, The Johns Hopkins University

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

Columbus Technologies and Services Incorporated

Labor Support Services

Peraton, Inc.

Deep Space Network Operations

ManTech Advanced Systems

Institutional Computing

Raytheon

Data Systems Implementation and Operations, Monolithic Microwave Integrated Circuit Development

Southwest Research Institute

Cassini, Europa Clipper, Mars Science Laboratory, Rosetta

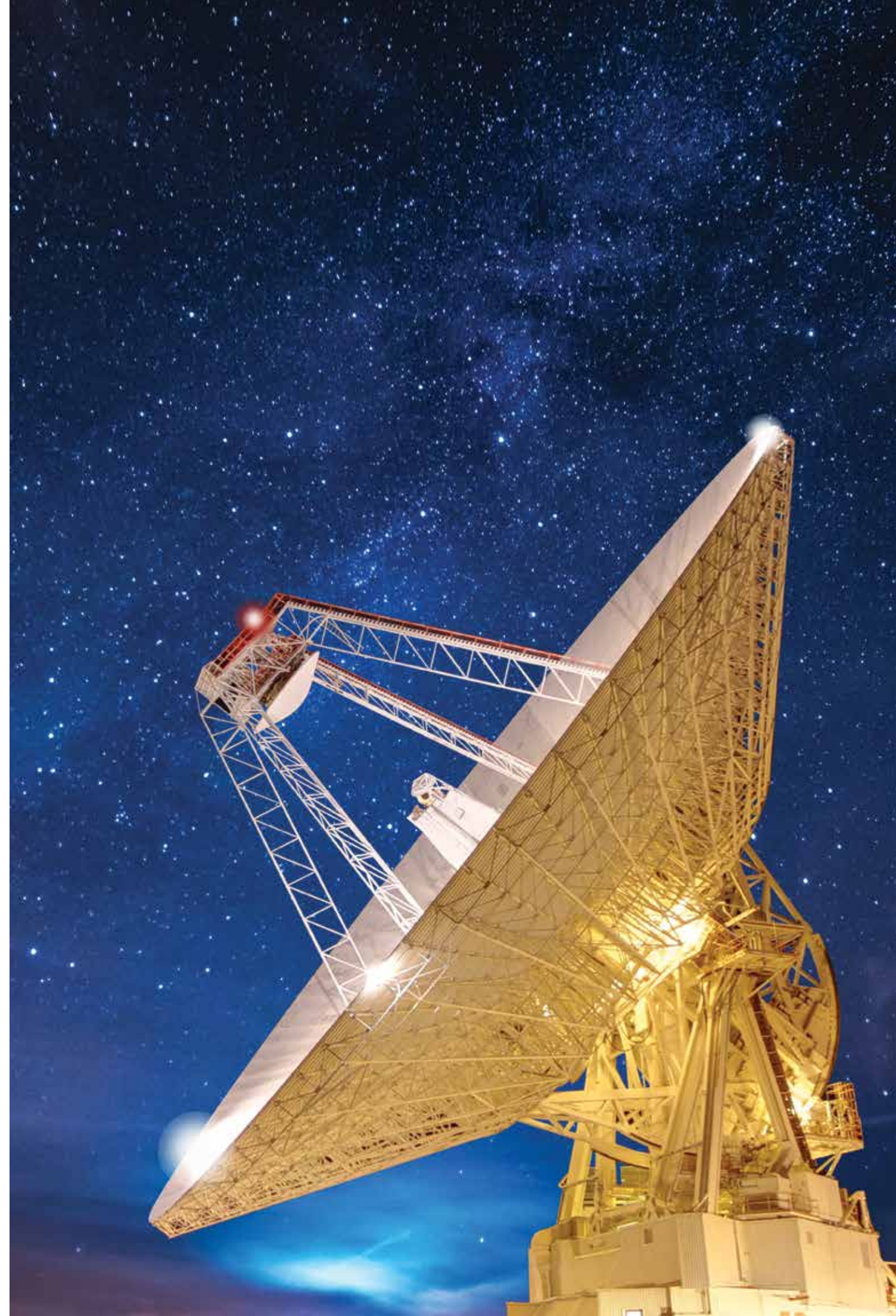
Space Systems Loral

GRACE, Europa Clipper, Exoplanets, Psyche, SWOT

Airbus

GRACE, NISAR, SWOT

RIGHT: The Deep Space Network communications complex in Goldstone, California, is one of three, with the other two in Canberra, Australia, and Madrid, Spain. Changes to the network improved efficiency and reliability for coverage of major launches—and for InSight's Mars descent and landing.



MAJOR EXTERNAL AWARDS

Bonnie Buratti

Carl Sagan Medal for Excellence in Public Communication
American Astronomical Society

Morgan Cable

“Talented 12” Rising Star
Chemical and Engineering News

John Casani, Suzanne Dodd, Edward Stone

Joint Honorary Doctor of Science
New York University

Cassini Mission Team

John L. “Jack” Swigert, Jr., Award for Space Exploration
The Space Foundation

Cassini Mission Team and Communications and Education Directorate

Emmy Award for Outstanding Original Interactive Program
Academy of Television Arts & Sciences

Nacer Chahat

Future Technology Leader Award
Engineers’ Council

Janis Chodas

Honorary Doctorate
University of Toronto

Erik Conway

Guggenheim Fellow
John Simon Guggenheim Memorial Foundation

Mik Cox

2018 Rising Star
Government Innovation Awards

Communications and Education Directorate

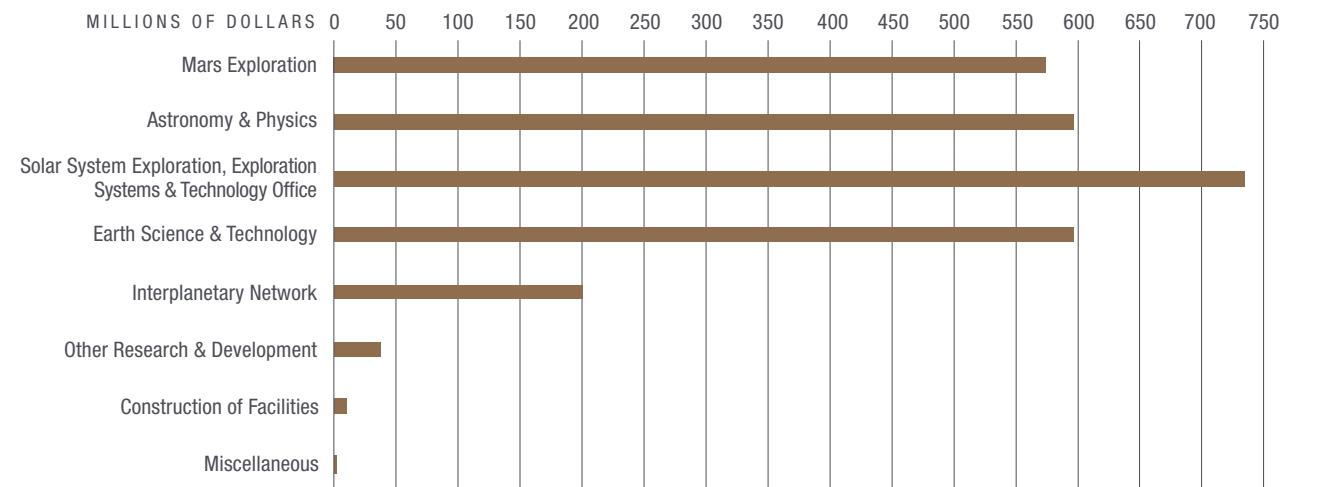
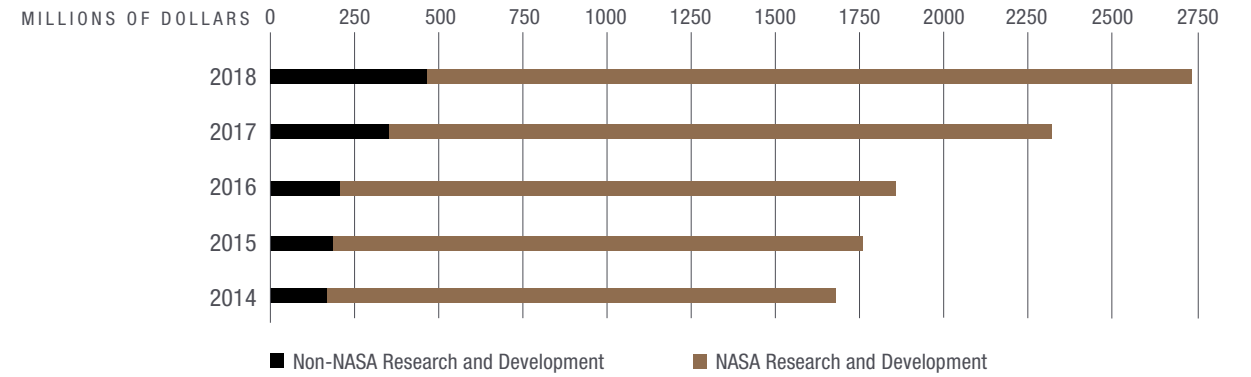
Webby Award: Solar System Exploration website
Webby People’s Voice Awards: JPL Social Media team,
Exoplanet Exploration and Solar System Exploration websites
Webby Best Use of Online Media Award: Cassini Grand Finale
International Academy of Digital Arts and Sciences

Graeme Stephens

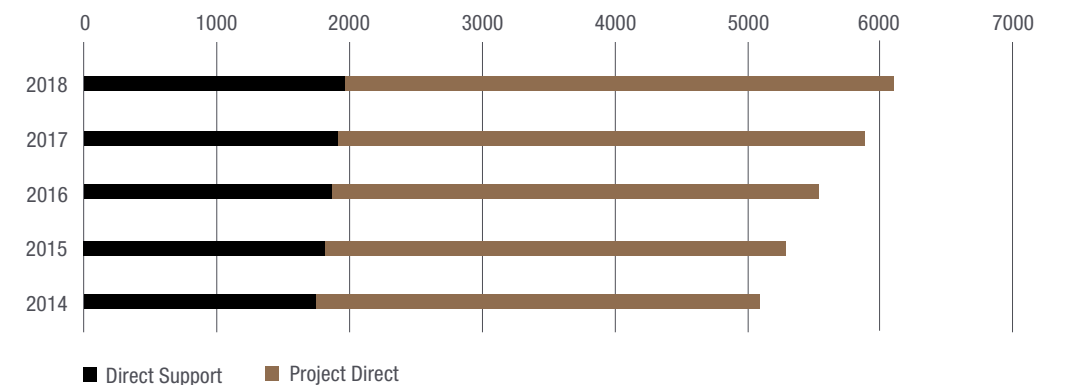
Fellow
Royal Society

BUDGET WORKFORCE

2018 BUDGET



JPL PERSONNEL • Full-Time Equivalents



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NASA's Spitzer and Hubble space telescope data were combined in this image of distant interacting galaxies, known collectively as Arp 142. It spans the visible and infrared parts of the spectrum and resembles a penguin guarding an egg.





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