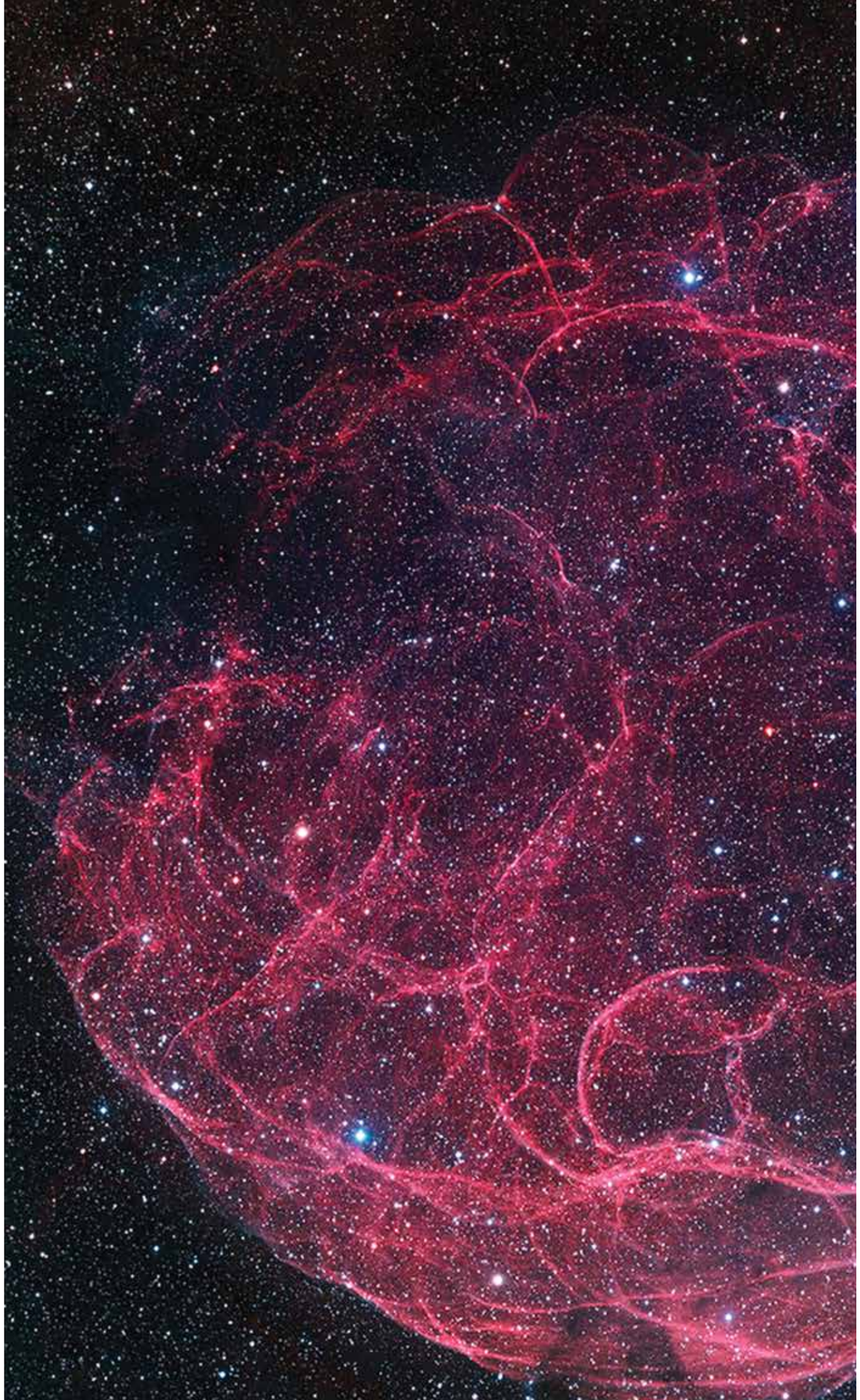
JET PROPULSION LABORATORY / ANNUAL REPORT / **2019**

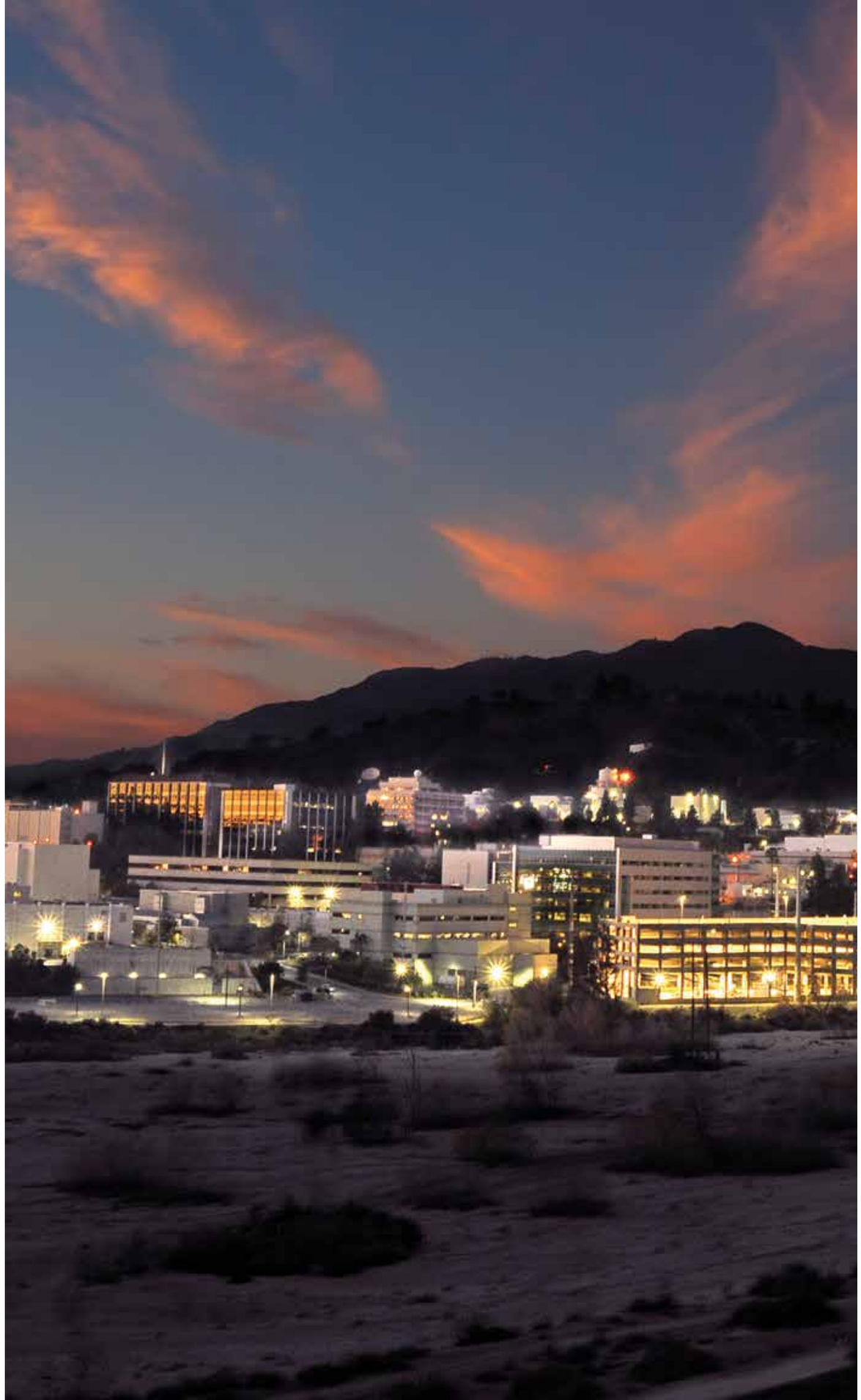
National Aeronautics and Space Administration

NASA



Spitzer / Simeis 147 (Spaghetti Nebula) FRONT COVER: Supernova remnant N49, in the Large Magellanic Cloud / Distance: 160,000 light-years.

2019 / CONTENTS



2019 closed a decade of preparation for the next advance in space. The 2010s had opened with a radical scheme for landing a rover of unprecented size and mass on an alien world. As 2019 wound to a close, so did finishing work on Mars 2020, the most advanced mission to the Red Planet in human history — able to rove, fly, and cache Martian soil samples for retrieval by the next decade's revolutionary mission. The march to Mars goes on.

As 2019 completed the decade, the Spitzer Space Telescope finished its final year as one of NASA's Great Observatories. Spitzer peered at the stars through an infrared lens, and transformed the cosmos we thought we knew. Celebrated for discovering the largest batch of terrestrial exoplanets in a single star system, Spitzer also identified the first molecules in an exoplanet atmosphere, and made the first measurements of wind and temperature variations above an exoplanet. Working with another Great Observatory, the Hubble Space Telescope, Spitzer discovered the most distant galaxy observed to date, whose light first radiated near the beginning of time.

2019 also saw the start of assembly for the Psyche asteroid mission, while Europa Clipper moved into final design and the Lab's next generation of flight projects advanced to the starting line.

Mars InSight began to chart the inner life of its home planet, and interactive coverage of the probe's landing in 2018 won an Emmy for the mission team and their communications colleagues. More than 20,000 space fans toured the Lab during Explore JPL, and nearly 11 million added their names to a chip that, if all goes well, will land in Jezero Crater aboard the newly named Mars Perseverance rover.

Our most advanced Martian explorer will join Curiosity and honor its forerunner Opportunity, which rests in Perseverance Valley after a record 15 years of Martian roving.

In July 2019, the Interplanetary Network Directorate marked the 50th anniversary of the Apollo moon landings, supported by the Deep Space Network (DSN), and looked forward to the return of DSN enabling human spaceflight missions to the Moon with the planned launch of Artemis I late in 2020. Through the directorate, JPL also took the leading role in the international Lunar Communications Architecture final report, which will be used by the Artemis program for human lunar exploration.

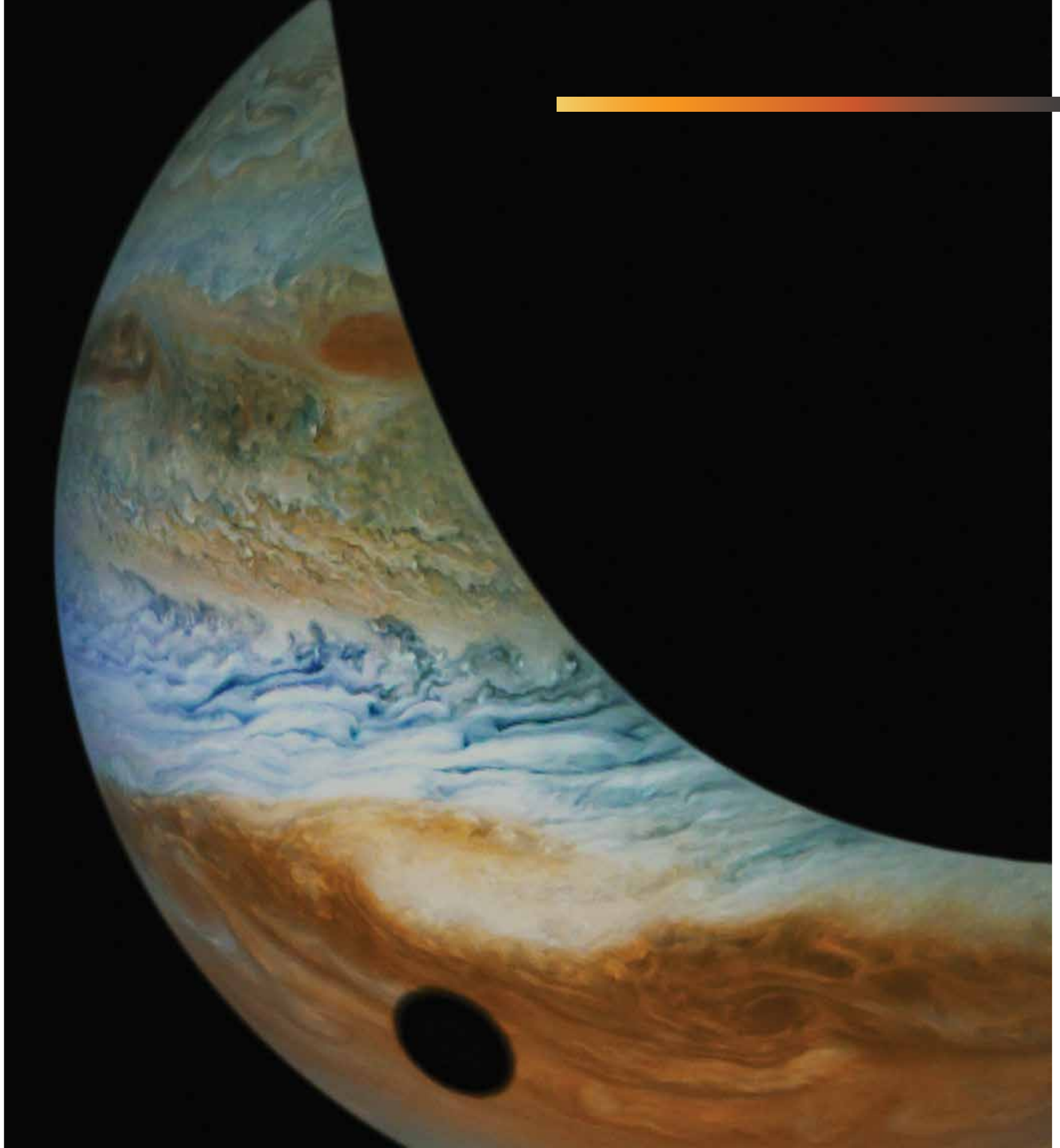
The past year also saw the successful launch and commissioning of the Deep Space Atomic Clock, an extremely stable atomic timekeeper expected to enable more precise navigation and data collection.

The Earth Science & Technology Directorate made news with a survey of highly concentrated methane emissions in California. The orbiting GRACE-FO mission and the airborne Oceans Melting Greenland together documented the ongoing evolution of the Greenland ice sheet, and the newest Orbiting Carbon Observatory (OCO-3) began measuring worldwide carbon dioxide emissions.

The Astronomy & Physics Directorate celebrated NASA's selection of SPHEREx, a mission to survey the universe that promises to return a wealth of data far out of proportion to its modest cost.

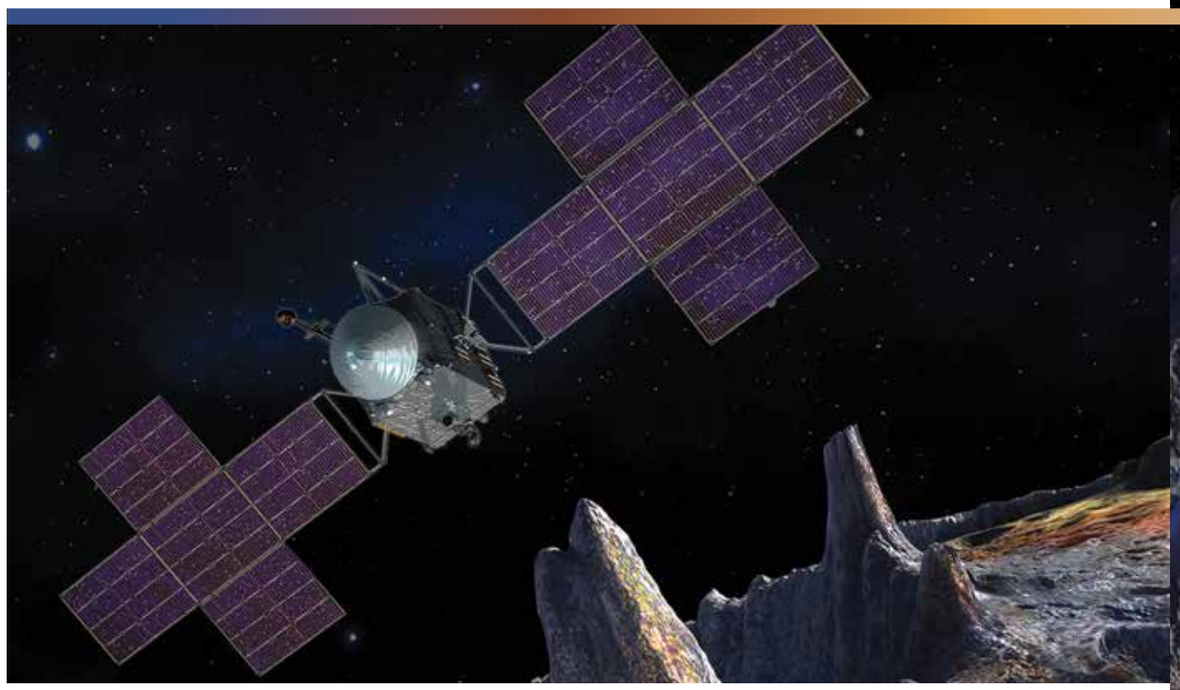
As I write this message, the world is laboring under the spreading threat of a new virus. We can plan a precise landing on Mars, but we find ourselves on alien ground at home. While we should honor JPL's achievements of 2019, I hope for our greatest accomplishment of 2020 to be our shared commitment to the health, safety and peace of mind of each other, our families and our communities.

MICHAEL WATKINS



The astonishing diversity of our solar system is reflected in JPL's menu of current, future and potential missions: orbiters to a metal asteroid, our Moon, and an ocean-bearing icy satellite of Jupiter; an experimental Mars helicopter; and a marsquake-detecting lander.

ANALYZING PSYCHE

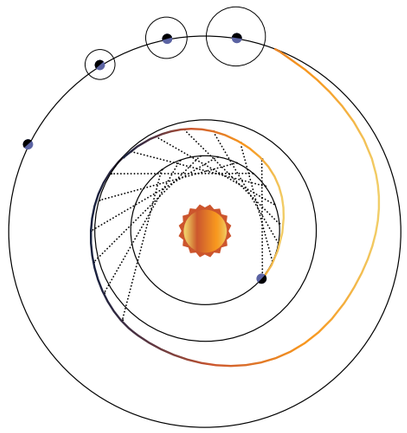


JPL's quest to explore an asterod vaulted forward in 2019, as NASA authorized the Psyche mission to start bending metal.

At last approved for final design and fabrication, the Psyche team saw years of planning and formulation start to bear fruit during the mission's November semi-annual meeting. The first pieces of flight hardware were unveiled for the spacecraft's solar-electric propulsion chassis. The mission will carry an imager, magnetometer and gamma-ray spectrometer, to help us better understand the building blocks of planet formation – in particular whether the asteroid is the core of an early planet, when it was formed, what types of terrain and materials characterize its surface and whether it formed in similar ways to Earth's core.

Principal investigator Lindy Elkins-Tanton of partner institution Arizona State University said, "With the transition into this new mission phase, we are one big step closer to uncovering the secrets of Psyche, a giant mysterious metallic asteroid, and that means the world to us."

Launch is targeted for August 2022, with arrival at the asteroid on January 31, 2026, and a 2023 flyby of Mars along the way.

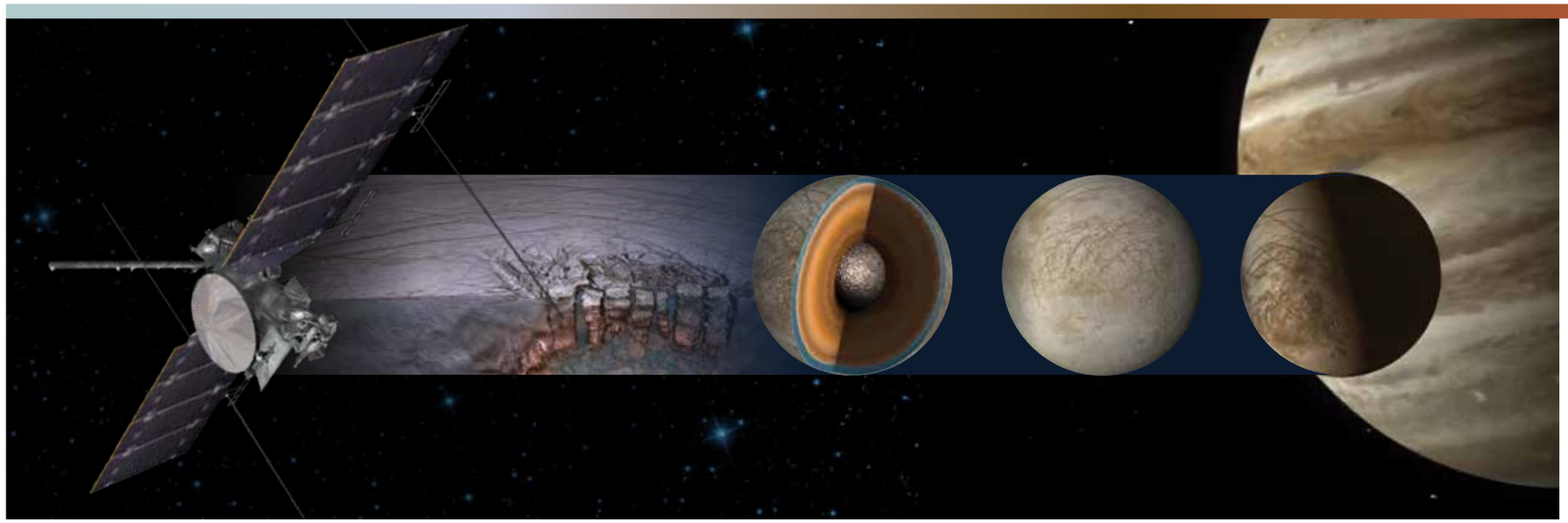


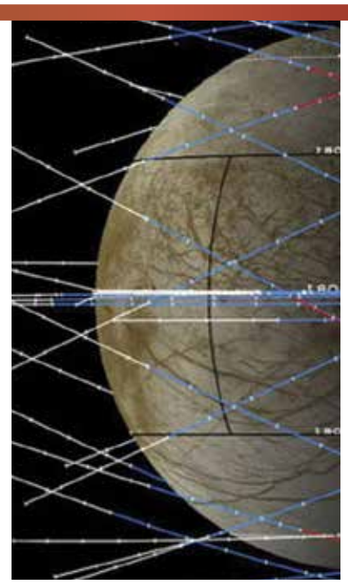
Psyche Mission Trajectory

Artist Concept of Psyche / Credit: ASU/Peter Rubin

CIRCLING CLOSER TO EUROPA

V Europa Clipper will settle into orbit around Jupiter to perform repeated close flybys of Europa.





The Lab's planned journey to Jupiter's icy moon got its own dose of good news this year, with confirmation that the Europa Clipper mission could advance to its next phase. Now the team can progress to complete final design, then spacecraft and science payload construction and testing.

"We are all excited about the decision that moves the Europa Clipper mission one key step closer to unlocking the mysteries of this ocean world," said Thomas Zurbuchen, associate administrator for the Science Mission Directorate at NASA Headquarters in Washington. "We are building upon the scientific insights received from the flagship Galileo and Cassini spacecraft and working to advance our understanding of our cosmic origin, and even life elsewhere."

Progress in 2019 included completion of engineering model testing and the start of flight hardware fabrication for several of the Europa Clipper instruments, including JPL's radar and spectrometer. The radar demonstrated in-vault electronics end-to-end functionality, and tested its 18m High Frequency antenna at JPL's antenna facility, while the spectrometer demonstrated that the instrument can collect imaging spectrometer data in Europa's high radiation environment.

One of Europa Clipper's major elements, the flight Prop Module Lower Cylinder, completed its design and fabrication at the Applied Physics Laboratory and commenced the installation of its Heat Rejection System here at JPL. The Prop Module reflects the close partnership with APL and hosts the GSFC-developed Europa Clipper Propulsion Subsystem. The flight Vault panels and Nadir Deck began final machining, representing a milestone in the maturation of the interfaces across the Europa Clipper Flight System.

Scheduled to launch in the mid-2020s, Europa Clipper will settle into orbit around Jupiter to perform repeated close flybys of Europa. Its fleet of science instruments includes cameras and spectrometers that will beam back high-resolution images to help researchers understand not only Europa's composition and processes, but ultimately the habitability of this water world.

Europa Campaign

A high number of Europa flybys (40-50) executed over the course of 3-4 years from highly elliptical orbits around Jupiter. These orbits minimize the amount of time the spacecraft spends in the harsh radiation environment Europa resides in.

MISSION

EUROPA CLIPPER

PROGRESS

1/NEXT MILESTONE PROJECT CRITICAL DESIGN REVIEW

demonstrates that system detailed design meets its requirements

2/INTEGRATE AND TEST FLIGHT SYSTEM

assembles and tests engineering hardware and instruments

3/SYSTEM ENVIRONMENTAL TEST PROGRAM

measures flight system's performance under realistic environmental conditions

TO LEARN

Unlock mysteries of ocean world / build upon insights of Galileo and Cassini / determine habitability of Europa.

LAUNCH

MID – 2020s

WILL CARRY

Cameras, spectrometers, radar, and field and particle instruments to describe Europa's interior, geology, composition, and activity.

Pump Down Orbits

Series of Ganymede and Callisto gravity assist flybys geared towards reducing the spacecraft orbit period and setting up the correct geometric conditions to begin Europa science collection.

SOLAR SYSTEM /

BUCKLING UP MARS HELICOPTER

"...we look forward to the day when Mars helicopters can play an important role in future explorations of the Red Planet."

– Mimi Aung (Mars Helicopter project manager)

A new kind of buzz will accompany JPL's next mission to the Red Planet next summer, as the Mars Helicopter — the first aircraft designed to fly on another planet — now is attached to the belly of the Mars 2020 rover.

The helicopter represents a technology demonstration with high risk and reward. If the small craft encounters difficulties, the science-gathering of the Mars 2020 mission won't be affected. But if it takes flight, future Mars missions could add an aerial dimension to exploration.

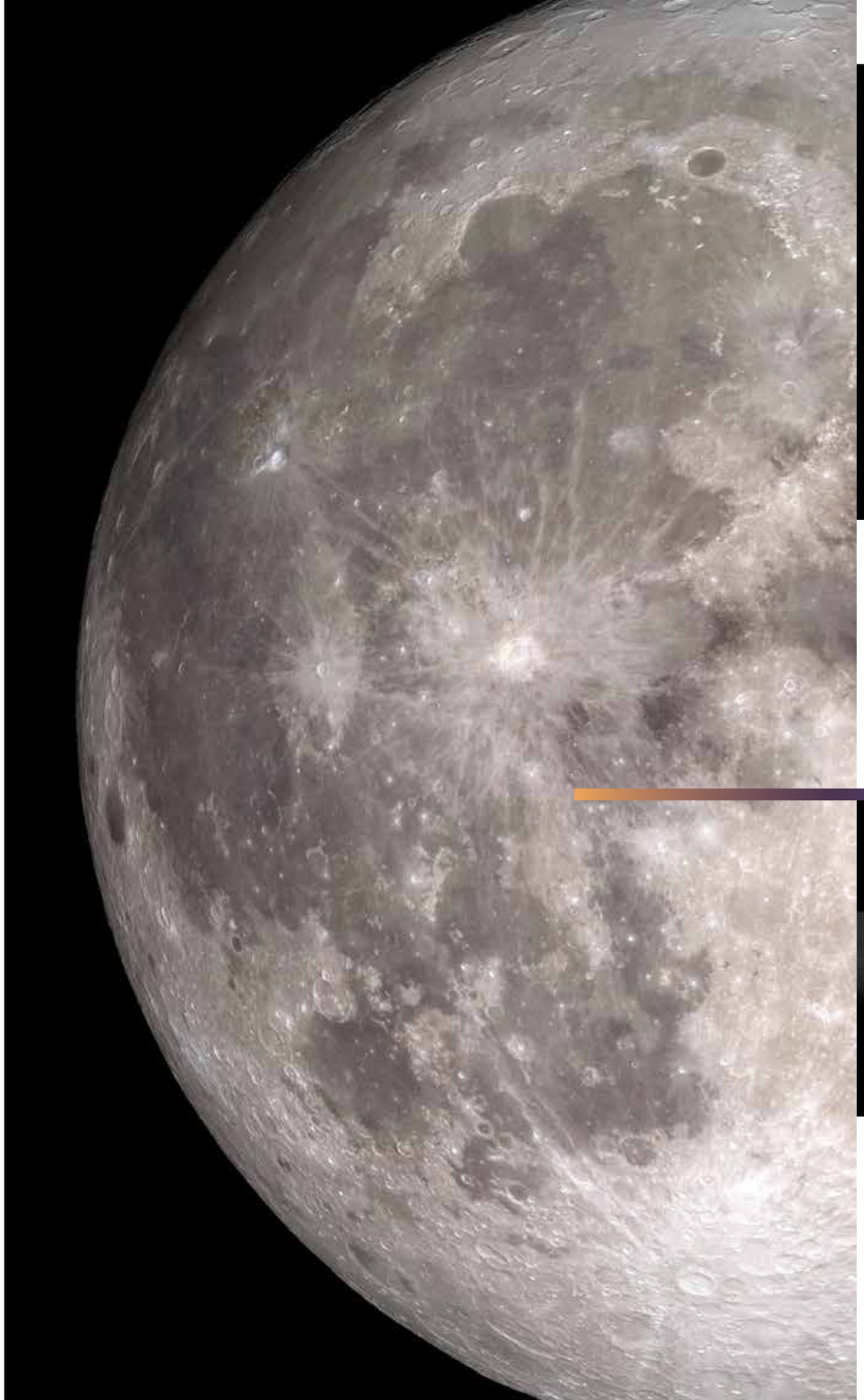
"Our job is to prove that autonomous, controlled flight can be executed in the extremely thin Martian atmosphere," Mars Helicopter project manager Mimi Aung said. "If we prove powered flight on Mars can work, we look forward to the day when Mars helicopters can play an important role in future explorations of the Red Planet."

SOLAR SYSTEM /

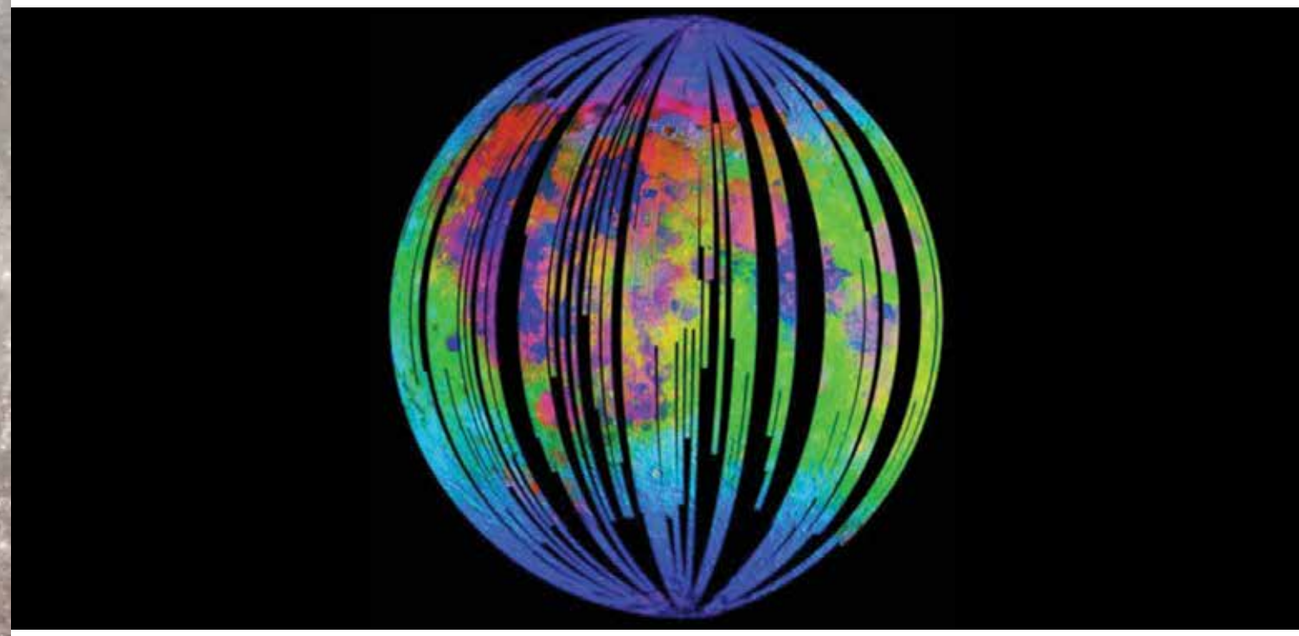
INSIGHT ROCKS – ON MARS AND EARTH

Meanwhile, up on Mars, the Solar System Exploration Directorate's InSight mission pushed the boundaries of science when its ultra-sensitive seismometer, called the Seismic Experiment for Interior Structure (SEIS), picked up "marsquakes" for the first time ever. The recordings will help researchers determine how seismic waves move through the planet's interior, revealing the deep inner structure of Mars.

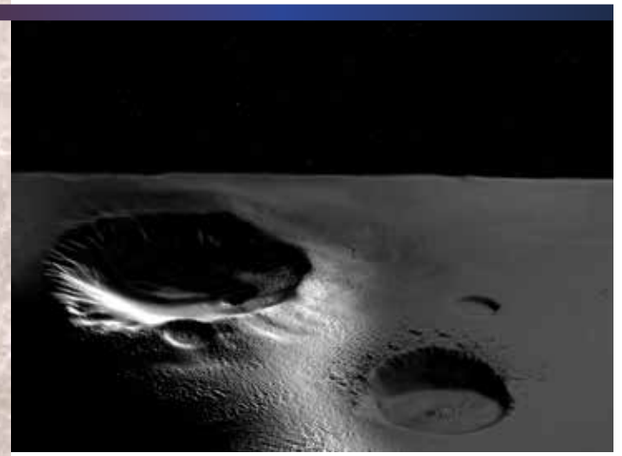
"InSight's first readings carry on the science that began with NASA's Apollo missions," said InSight principal investigator Bruce Banerdt of JPL. "We've been collecting background noise up until now, but the first event officially kicked off a new field: Martian seismology!"



Lunar impact craters on the 37th quadrant of the Moon.



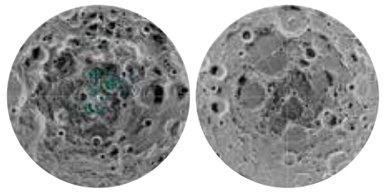
Map of water and hydroxyl (in blue and violet) across the surface of the moon, from the Moon Mineralogy Mapper (M^3).

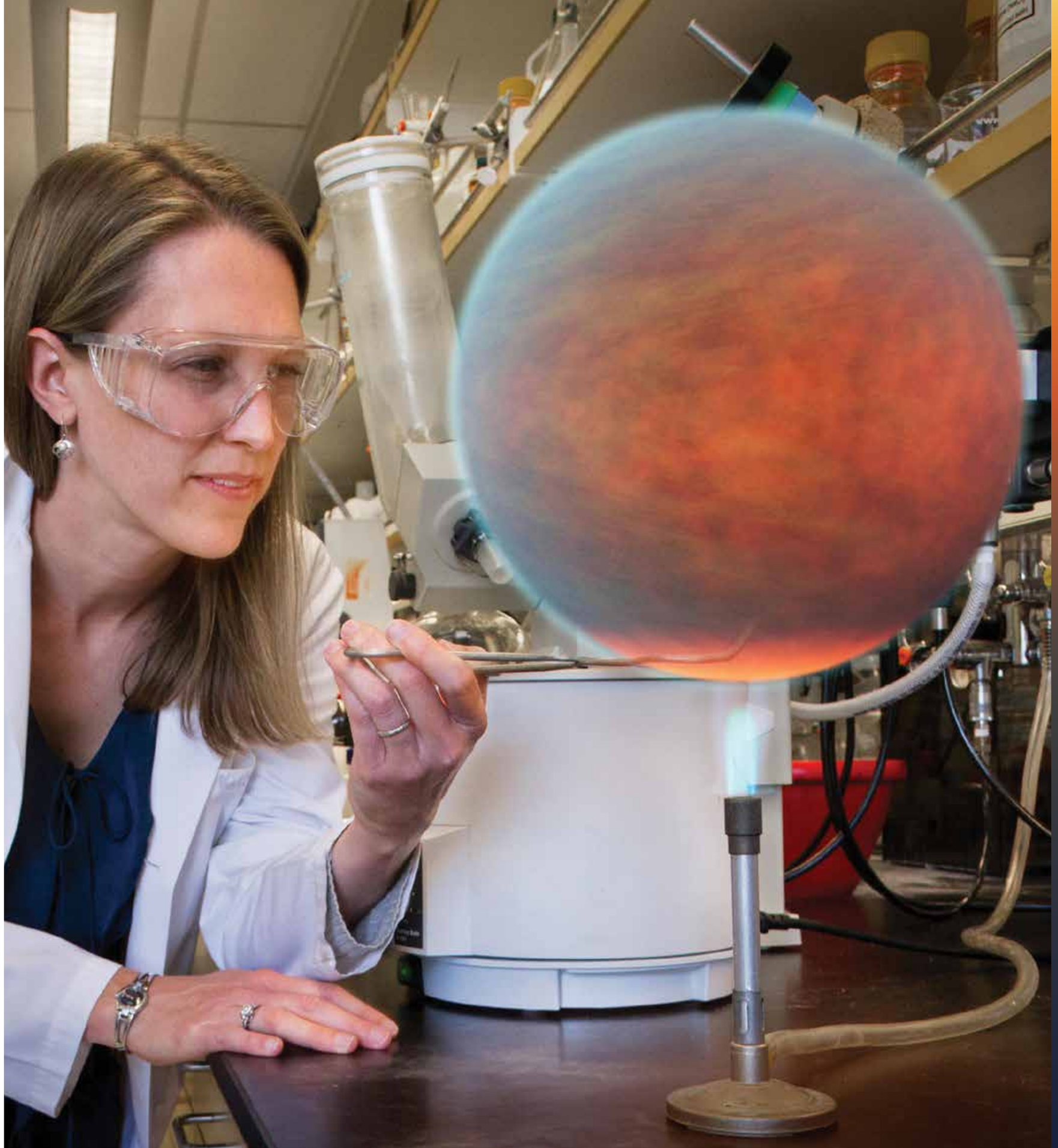


Artist's rendering of water ice in the Moon's permanently shadowed regions.

SOLAR SYSTEM / LUNAR TRAILBLAZER

The Caltech-led Lunar Trailblazer mission was one of three finalists selected by NASA in 2019 as a potential future mission to orbit Earth's Moon. The small satellite would directly detect and map water on the lunar surface to determine how its form, abundance and location relate to the moon's geology. The principal investigator is Bethany Ehlmann at Caltech, with JPL providing project management.





A veteran space observatory wrapped up an illustrious 16-plus-year career after unveiling an array of cosmic treasures with its powerful infrared detectors. The rich legacy of the Spitzer Space Telescope will benefit future missions and generations to come. Its science contributions include exoplanet breakthroughs – a burgeoning field of research in which JPL is playing an active role.

Spitzer researcher Heather Knutson seen here in a Caltech lab, used Spitzer to monitor a hot Jupiter exoplanet, called HAT-P-2b.

THE UNIVERSE /

WRAP-UP FOR AN INFRARED VETERAN

It was the final year of operations for the Spitzer Space Telescope, one of NASA's four Great Observatories, which lasted far beyond its original mission and gathered dramatic infrared observations from its Earth-trailing orbit. From that orbit, Spitzer could dodge infrared radiation from Earth and make discoveries that spanned the distant reaches of our universe. Its ability to pierce the thick dust pervasive in the cosmos and detect very faint infrared light enabled it to observe objects too cold to radiate visible light. By studying stellar nurseries, the mission revolutionized our understanding of how stars are born and grow up. The mission also contributed bonus science about exoplanets — a bonus because that capability was not in the original Spitzer mission plans.

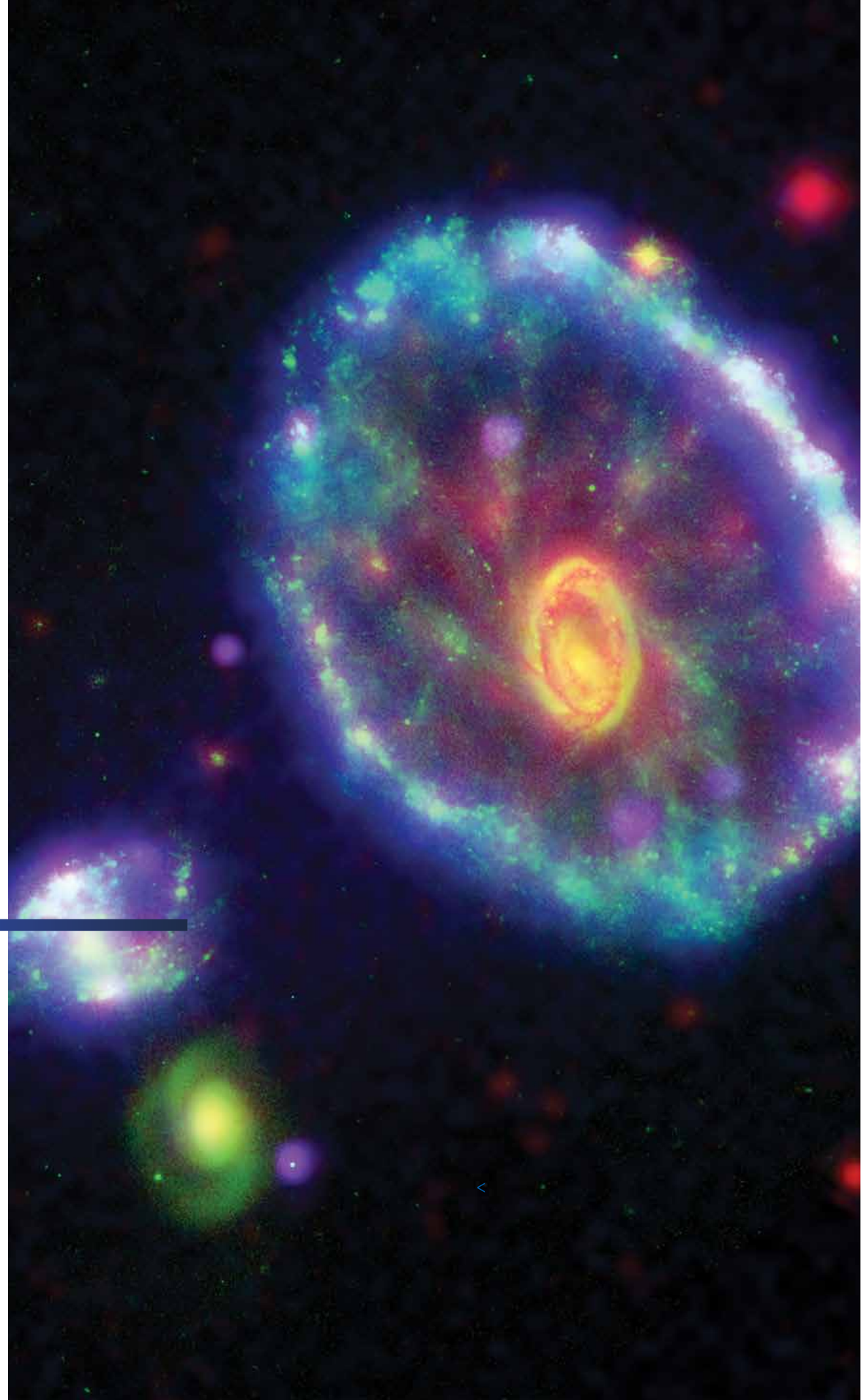
Spitzer's exoplanet discoveries included detecting seven possibly habitable Earth-sized planets in the TRAPPIST-1 system and determining their masses and densities; finding the first molecules in an exoplanet atmosphere; and mapping temperatures on an exoplanet for the first time.

The mission also trained its infrared eyes within our own solar system, studying comets and asteroids, and finding an enormous, faint ring around Saturn that was previously unknown.

The rich legacy of Spitzer will benefit future missions and generations to come. Its findings help pave the way for future exoplanet studies and help set the stage for NASA's upcoming James Webb Space Telescope, for which JPL is providing the Mid-Infrared Instrument.

"Spitzer's legacy is twofold – first of course is the rich scientific return," said Michael Werner, Spitzer project scientist starting when the mission was merely a concept in 1983, and continuing through its development, launch and 16 years of discoveries. "The second element of Spitzer's legacy is human. Spitzer exemplifies the very best that people can achieve."

This illustration shows an artist's rendition of the seven Earth-size planets of TRAPPIST-1, an exoplanet system about 40 light-years away.



Spitzer / Cartwheel, one of the most powerful UV-emitting galaxies in the nearby universe / Distance: 500,000,000 light-years.

THE UNIVERSE / PLANETS LIKE US

As the universe continues to expand slowly, we are making dramatic leaps in studying it and the teeming galaxies, stars and exoplanets within the cosmos.

The latest work in exoplanet detection includes development of two technologies that block the glare of parent stars from a space telescope's view to reveal faint planets that would not otherwise be visible. A coronagraph is a complex hardware system positioned inside a telescope that blocks light from a star, making it possible to directly observe orbiting planets. A starshade has the same goal, but is positioned outside a spacecraft.

An elaborate, JPL-developed coronagraph contains masks, prisms, detectors and deformable mirrors to help detect large, gaseous exoplanets. The innovative device may serve as a proving technology for use in future missions, such as those that will look at small rocky planets.

WFIRST (Wide-Field Infrared Survey Telescope) seeks to demonstrate the technology that can pave the way for future missions. The mission is a Goddard Space Flight Center-led decadal survey priority that passed a NASA preliminary design review in 2019.

A starshade, currently under technology development at JPL, could potentially join the coronagraph. It would fly on a second spacecraft up to 25,000 miles distant from its light-filtering cousin, carrying an 85-foot-wide flat shade that would unfurl like a flower, blocking starlight that saturates the faint light from an exoplanet. The team has shown that the technology is feasible; the next step is to design a mission that would fly the devices in tandem.

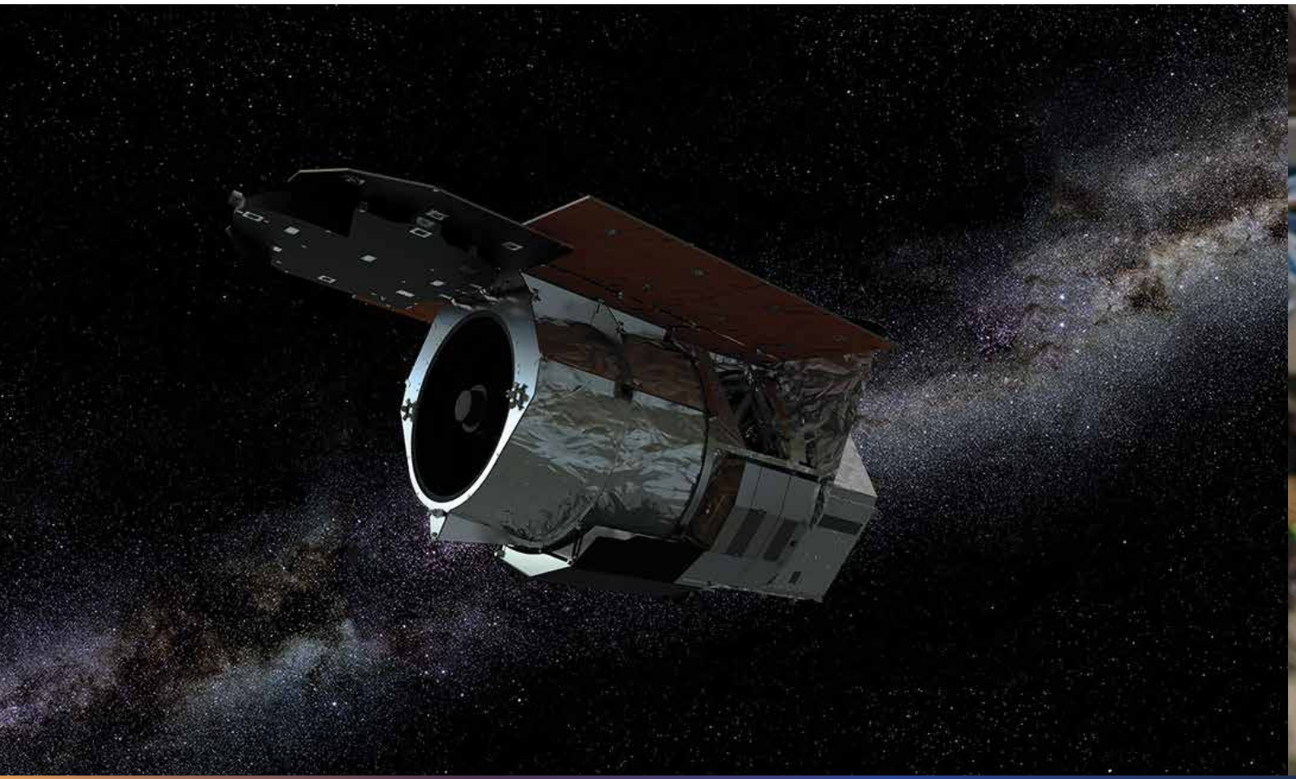
JPL also is providing the CASE (Contribution to ARIEL Spectroscopy of Exoplanets) instrument and its world class detectors for the European ARIEL mission to study atmospheres of hundreds of exoplanets.

"The more information we have about exoplanets, the closer we get to understanding the origins of our solar system, and advancing our search for Earth-like planets elsewhere," said Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate.

< A starshade would fly on a second spacecraft up to 25,000 miles distant from its light-filtering cousin, carrying an 85-foot-wide flat shade that would unfurl like a flower, blocking starlight that saturates the faint light from an exoplanet.

^ JPL is providing the CASE (Contribution to ARIEL Spectroscopy of Exoplanets) instrument for the European ARIEL mission.

THE DARK SIDE OF MATTER AND ENERGY



If approved, WFIRST's primary mission is to explore dark energy, the unexplained force that makes up about 68% of the total energy in the cosmos. Understanding dark energy will give us a better sense of the past and future evolution of the universe.

An already approved dark energy mission, the European Space Agency's Euclid, will study dark matter, which we can't see, even though it is five times more plentiful than the "regular" matter of planets, stars and everything else visible. JPL and NASA Goddard have delivered enabling detector technologies for Euclid and have lead science roles.

^ WFIRST (Wide-Field Infrared Survey Telescope).

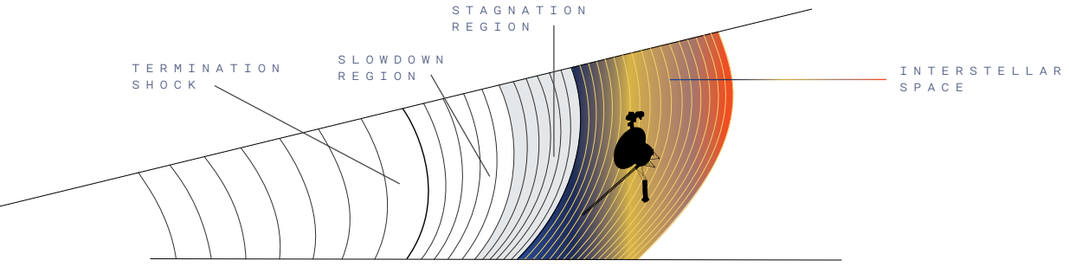
> Astronaut Christina Koch unloads new hardware for the Cold Atom Lab aboard the International Space Station.

> The Deep Space Atomic Clock.

TINY ATOMS, BIG GOALS

The International Space Station hosts some of JPL's cutting-edge fundamental physics research, to understand how nature works at the most basic levels. The Cold Atom Lab (CAL) uses microgravity as a tool to study atoms. It received a major upgrade when an atom interferometer was delivered in December.

The Deep Space Atomic Clock technology demonstration, launched in June, will enable spacecraft to navigate independently and safely, without awaiting instructions from Earth.

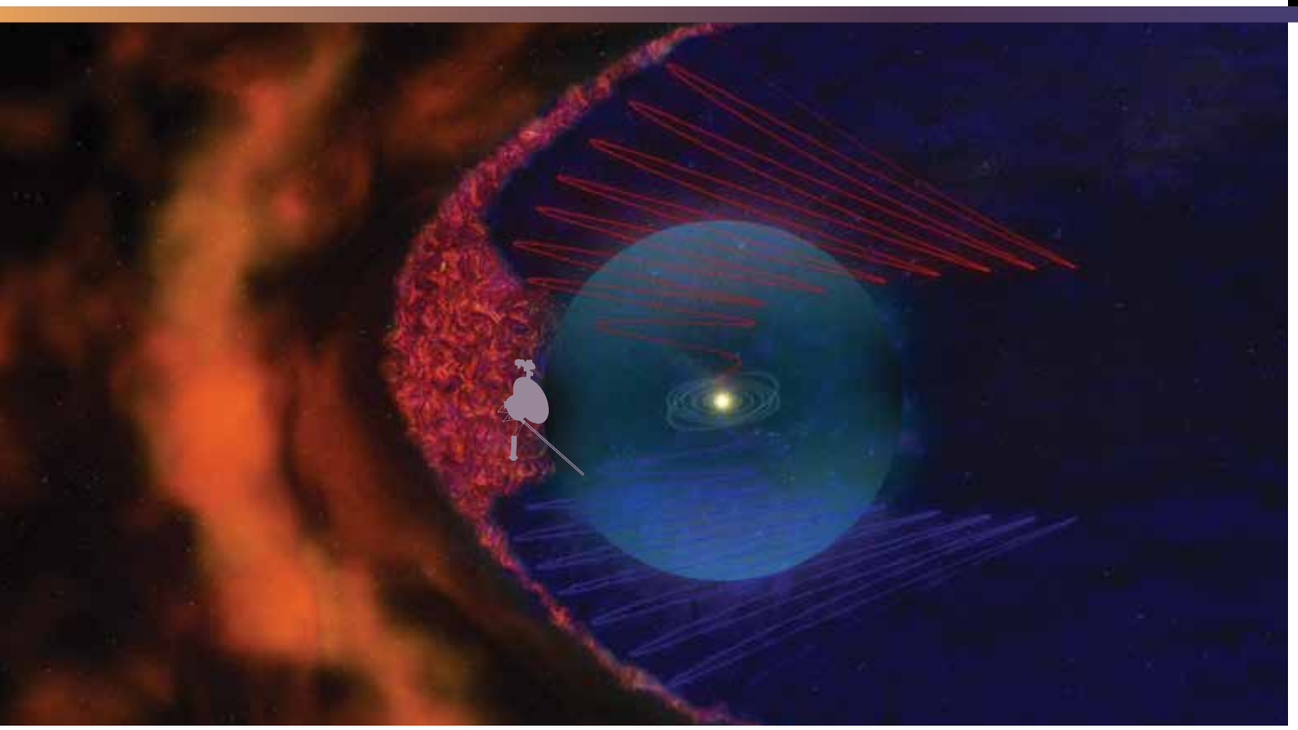


THE UNIVERSE /

VOYAGERS IN THE ZONE — OF INTERSTELLAR SPACE

Now that both veteran Voyager spacecraft have exited the heliosphere — the area in our solar system influenced by the solar wind — and are now in interstellar space, scientists are eagerly poring over data from the region. A batch of five research papers in Nature Astronomy confirmed that, like its twin, Voyager 2 seems to be in a perturbed transitional region, where a trickle of particles from inside the heliosphere is leaking into interstellar space.

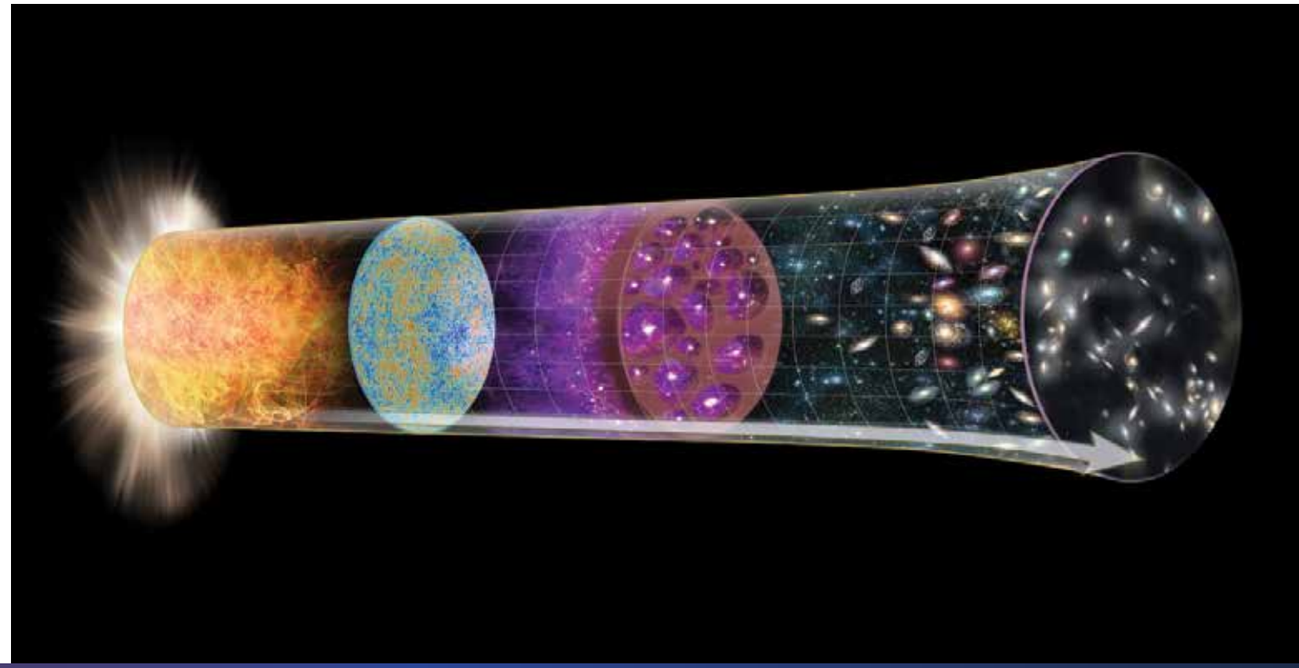
An artist's rendering depicts NASA's Voyager 2 spacecraft as it studies the outer limits of the heliosphere — a magnetic 'bubble' around the solar system.



THE UNIVERSE /

NEW KIDS ON THE COSMIC BLOCK

SPHEREx measures the cosmic history of galactic light production.



With seemingly endless possibilities for astronomy and physics research, JPL is focused on maximizing its reach by teaming up on efficient and mutually beneficial missions.

The recently selected JPL-Caltech SPHEREx mission, targeted for a 2023 launch, will study the evolution of our universe and the prevalence of the ingredients for life in planetary systems within our Milky Way galaxy. JPL manages the mission and will develop the mission payload with Caltech.

MISSION

SPHEREx

NUMBER / OBJECT

450 MILLION
Galaxies

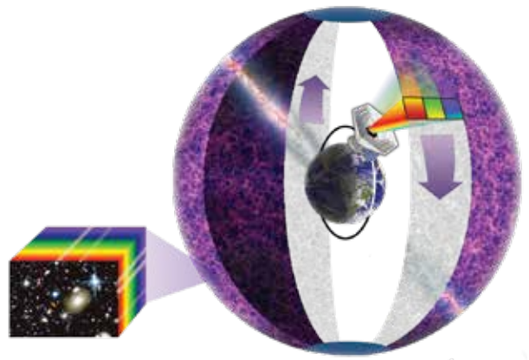
600 THOUSAND
Exoplanet target stars

1 MILLION
Quasars

100 THOUSAND
Clusters

1 THOUSAND
Stars with hot dust

100 THOUSAND
Asteroids and comets



< From low-Earth orbit, SPHEREx uses a single observing mode with no moving parts to measure the spectrum of every 6-arcsecond pixel, five times smaller than the smallest dot you can see, over the whole sky in six months.

As the world turns, a fleet of instruments watches from the skies and from space as a complex story unfolds between powerful natural forces and important human influences. The highly successful Jason-2 sea level mission ended in 2019 and passed the measurement record baton to Jason-3, and a new OCO-3 instrument continued the critical carbon dioxide record started by OCO-2. Scientific insights from the entire mission fleet are yielding a myriad of societal benefits.

Earth's curvature, seen from the vantage point of the International Space Station during a delivery from home. Credit: NASA

EARTH /

A SUPER-SIZED CONTRIBUTION FROM CALIFORNIA METHANE SOURCES

A priority in the State of California is to cut human-caused emissions of the potent greenhouse gas methane. But you can't fix what you can't find.

Enter JPL. During a two-year partnership with the California Air Resources Board and the California Energy Commission, JPL researchers flew a plane equipped with the Airborne Visible InfraRed Imaging Spectrometer – Next Generation (AVIRIS-NG) over 270,000 sites, including oil and gas fields, large dairies and landfills.

The result: a detailed inventory of more than 550 sources emitting plumes of highly concentrated methane. Ten percent of these "super-emitter" sources contributed the majority of emissions. The team estimates that contribution is one-third of the state's methane emissions budget — the total amount of emissions from all sources, natural and human-produced. Results have been shared with facility operators to help them improve methane-leak detection processes and control emissions more effectively.

^ Shiprock, New Mexico, is in the Four Corners region where an atmospheric methane "hot spot" can be seen from space. Researchers are currently in the area, trying to uncover the reasons for the hot spot.

< Half of Alaska's methane emissions occur in winter – mostly during times when soil temperatures hover near freezing. Credit: NASA/JPL-Caltech

EARTH /

VARIABILITY IN GREENLAND ICE LOSS

Ice loss from Greenland, the second largest home of ice on Earth, has been observed every year for the last two decades via the GRACE and GRACE-FO satellite missions. It is projected to continue, and likely accelerate, for the foreseeable future due to Earth's warming climate. However, in-situ observations and spaceborne GRACE-FO data revealed a slowdown in the loss rate between 2015 and 2018, with some glaciers, like Jakobshavn, re-advancing towards the ocean rather than melting and retreating.

Thanks to JPL's OMG (Ocean Melting Greenland) airborne campaign, scientists now understand that part of this slowdown was the result of a temporary cooling of ocean water near Greenland due to a North Atlantic ocean circulation pattern that oscillates between warm and cool phases every five to 20 years. OMG has been measuring ocean temperature and salinity around Greenland for the past three years.

In 2019, Greenland's total mass loss accelerated rapidly. GRACE-FO data show that in July, the mass loss rate was almost 50% above average. That's second only to the peak mass loss rate observed in 2012 during the GRACE and GRACE-FO observation period. Overall, Greenland's ice mass is proving to be variable and particularly responsive to climate changes and forcings.

MISSION

GRACE-FO

ICE LOSS MEASURED

4,761
gigatons Greenland

2,703
gigatons Antarctica

1 GIGATON
1 kilometer-sided cube

2
satellites

137
miles apart

MILES TRAVELED

2.7 BILLION
by GRACE satellites over the life of the mission

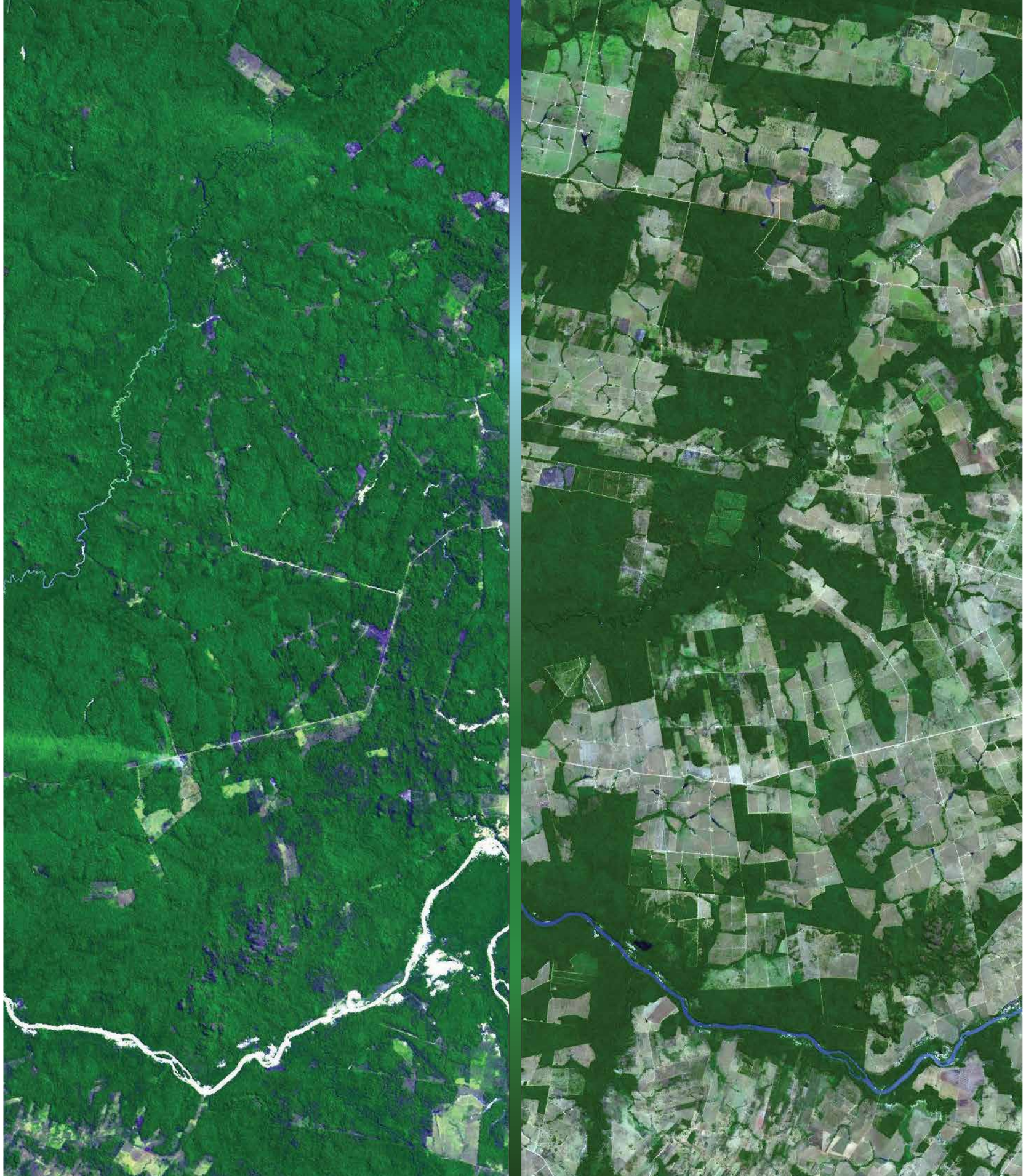
EARTH /

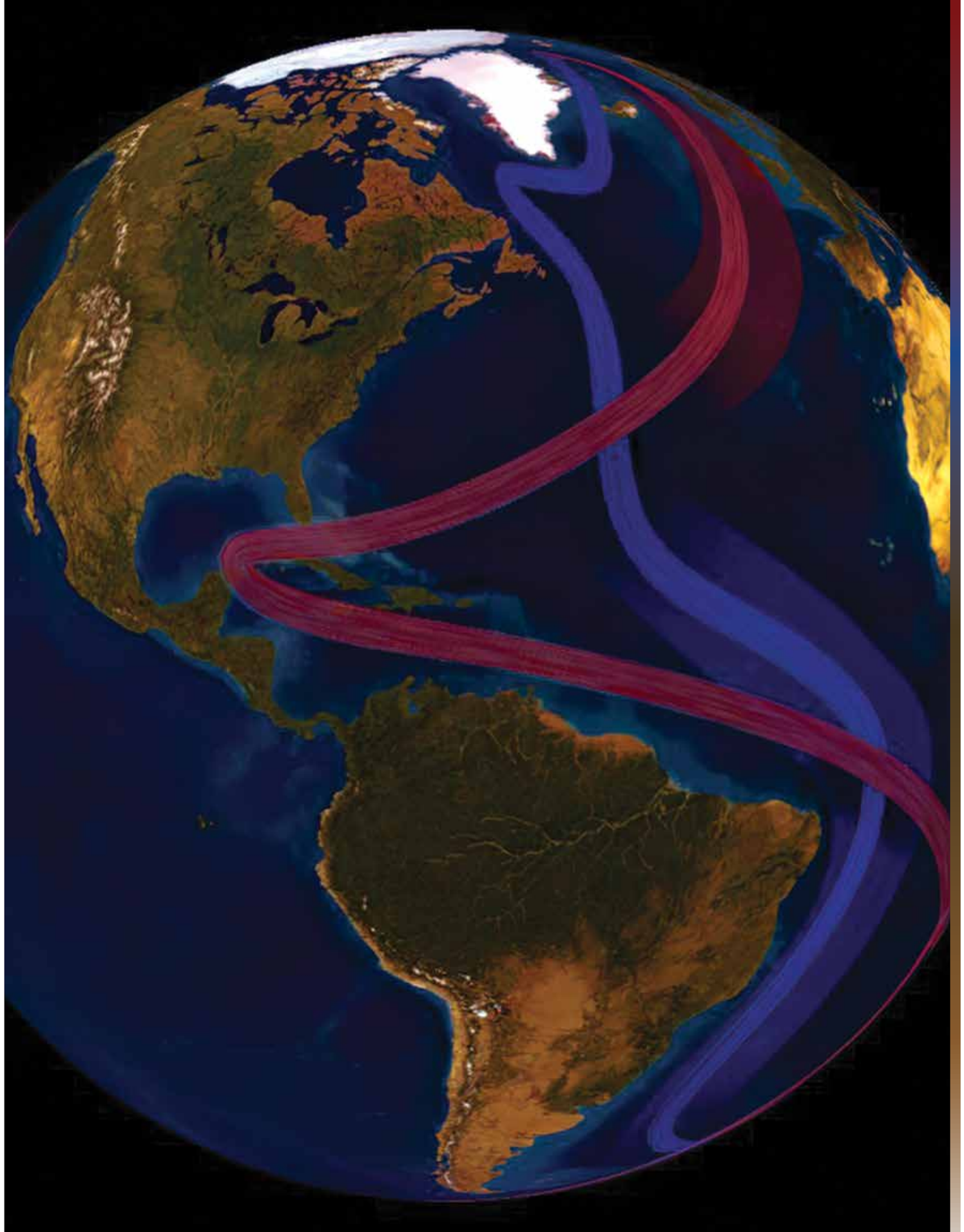
AN INCREASINGLY THIRSTY AMAZON

As the largest rainforest on Earth, the Amazon plays an important role in regulating world temperatures by breathing in carbon dioxide. Recent analysis of two decades' worth of data from ground-based observations and JPL's AIRS spaceborne instrument has revealed that the atmosphere above the Amazon has been drying out over that period. Based on the pattern of drying, scientists attribute the trend to a combination of climate warming and human-induced deforestation for agriculture and grazing.

Drier air may portend future difficulty in the ability of trees to fend off water stress. As a poignant example, during the past summer, the ECOSTRESS instrument on the International Space Station observed that massive fires in the Amazon basin were concentrated in water-stressed areas of the forest.

> Dense green vegetation gives way to pale fields in these satellite images of deforestation in the Brazil Amazon rainforest. This image is from NASA/ JPL's Terra satellite.





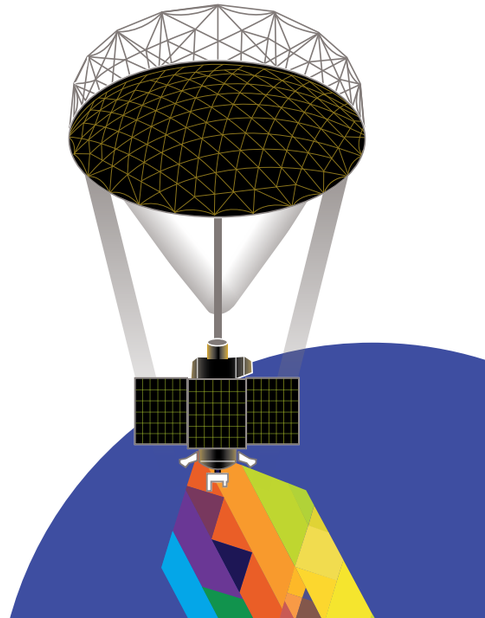
EARTH / A JAM IN THE OCEAN CONVEYOR BELT

Ocean currents strongly influence local and regional climates by conveying massive quantities of heat around the globe. Recent ocean salinity measurements by the Soil Moisture Active Passive (SMAP) mission have helped explain the mystery of why this global conveyor belt of heat between the Pacific and Indian oceans slows dramatically near the surface during the December to March monsoon season.

SMAP data have yielded important insights into rain, sea levels and ocean salinity in some areas. For example, SMAP studied how local precipitation in parts of Southeast Asia, which can total 10 feet of water during monsoon season, dilutes and lowers local ocean salinity. This effect then raises the Indian Ocean water level and volume, pushing back against the normally wind-driven flow from the Pacific.

By slowing the local transport between the Pacific and Indian oceans, this phenomenon also slows the global ocean conveyer belt that transports heat northward into the Atlantic Ocean. This means that long-term, because of the Indian Ocean connection, any precipitation increases in the Southeast Asia region may result in colder Atlantic water.

< SMAP studied how local precipitation in parts of Southeast Asia, which can total 10 feet of water during monsoon season, dilutes and lowers local ocean salinity. Credit: NOAA

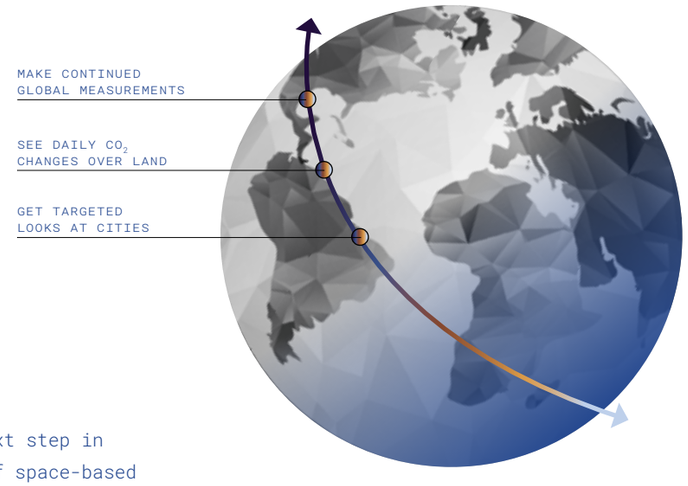


EARTH /

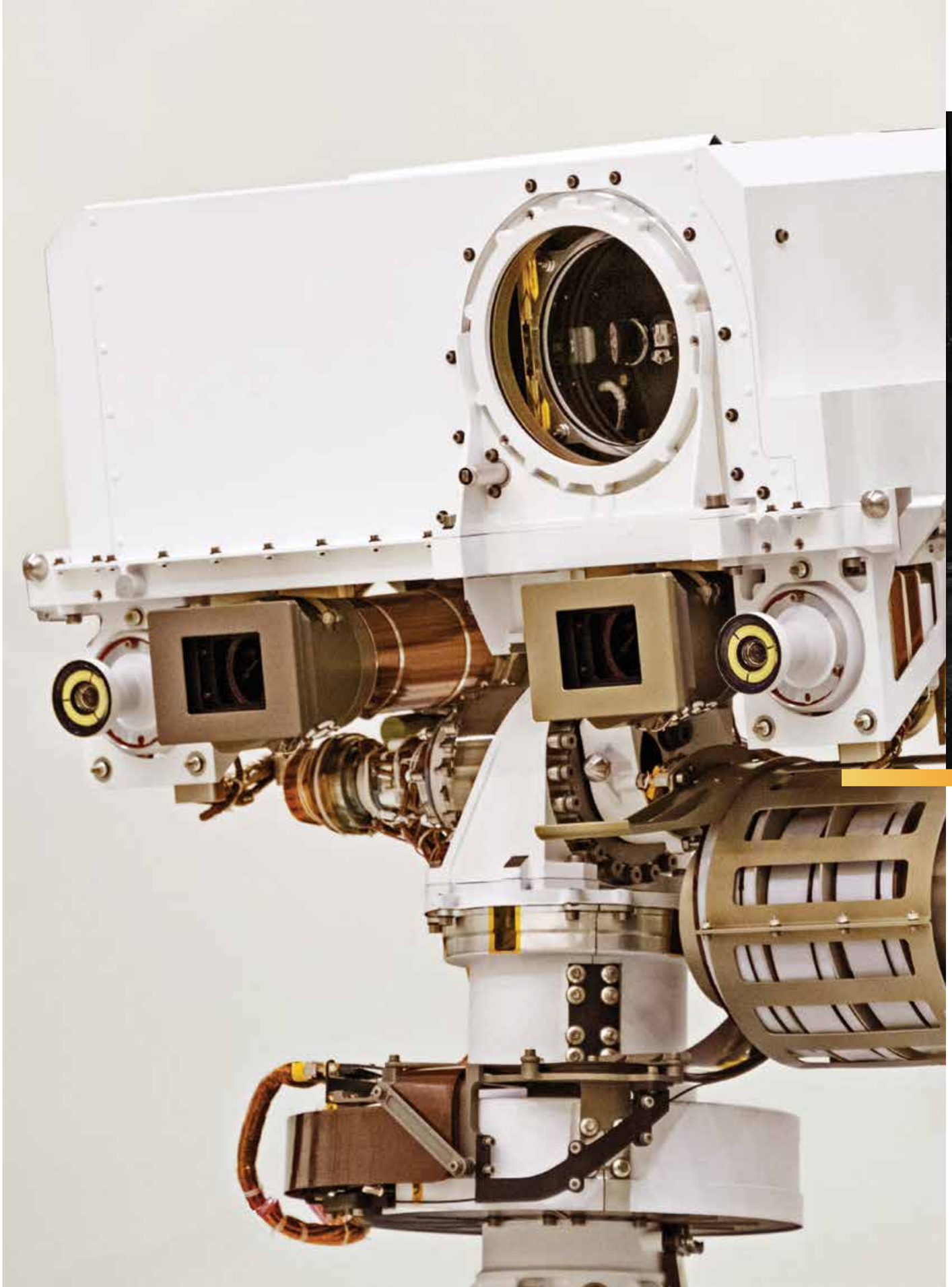
THE CARBON WATCH CONTINUES

NASA's Orbiting Carbon Observatory-3 (OCO-3), the agency's newest spaceborne carbon dioxide-measuring mission, launched to the International Space Station in May 2019. The mission began its work by capturing its first glimpses of sunlight reflected by Earth's surface, allowing measurements of atmospheric carbon dioxide, and by measuring solar-induced fluorescence — the "glow" plants emit from photosynthesis, which captures carbon from the atmosphere. More results are expected in 2020.

Initial measurements are consistent with those of the older, still-active OCO-2, meaning the newcomer is on track to continue and extend its sibling's data record. With a new pointing mirror assembly and its space station perch, the mission can map local carbon dioxide fluctuations throughout the day with multiple flyovers.



OCO-3 lets us take the next step in demonstrating the value of space-based measurements to constrain emissions.



^ A solar intensity probe is used to measure and compare the amount of artificial sunlight that reaches different portions of Perseverance, the Mars 2020 rover.

When Mars 2020 launches this summer, its suite of sophisticated instruments will advance the work of the decades-long series of orbiters, landers and rovers that are piecing together our knowledge about past or present life on the Red Planet.

Clean rooms and test chambers buzzed with activity throughout 2019 in preparation for the launch of Mars 2020.

The perilous Mars entry, descent and landing process was simulated, “rewound,” then simulated again multiple times to thoroughly test the spacecraft’s processors, sensors and transmitters.

The rocket-powered descent stage, the rover (or a test model) and a protective back shell were stacked, unstacked and restacked to make sure everything fit perfectly. A high-risk, high-reward technology demonstration, Mars Helicopter, was strapped under the rover for the ride to Mars.

The spacecraft braved a pre-launch boot camp in JPL’s Environmental Test Facility, where it experienced the extreme sound waves of a rocket launch and the drastic temperatures and near-vacuum conditions of a long, harsh journey to the Red Planet. The rover also completed its surface environment tests, enduring the expected low temperatures on Mars.

The rover passed its first driving test in December. It rolled forward and backward and pirouetted in a clean room, demonstrating its readiness to rove the Martian surface.

Once on Mars, the mission’s high-priority science goals will include tackling key questions about the planet’s potential for life. The rover will continue its predecessors’ search for signs of ancient habitable conditions, and for the first time will search for signatures of past microbial life. Also for the first time, a drill will collect core samples of promising rocks and soils, and will cache them on the Martian surface for potential pickup by a future mission that will return them to Earth for detailed studies. The rover will even assess natural resources and hazards that might await future human explorers.

During its long journey and anxiety-inducing landing, Mars 2020 will have a global cheering squad back on Earth. A wildly successful “Send Your Name to Mars” campaign brought 10.9 million signups from vicarious space explorers all over the world. Their names are etched on chips that will travel on the spacecraft and land on Martian soil.

MISSION

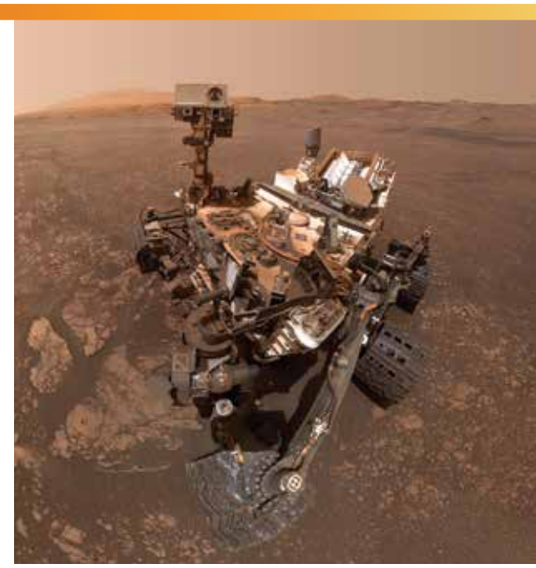
MARS 2020/ PERSEVERANCE ROVER

SCHEDULED FOR LAUNCH

SUMMER 2020

< Curiosity has discovered the highest amounts of clay minerals ever found during its mission.

V Curiosity is exploring Mount Sharp to see if it had the conditions to support life billions of years ago.



MARS / CURIOSITY, CLAY AND METHANE

Mars 2020's most direct design influence, the Curiosity rover, passed its seventh anniversary on the planet in August with all its science instruments working.

Much of the rover's work in 2019 was centered around clay.

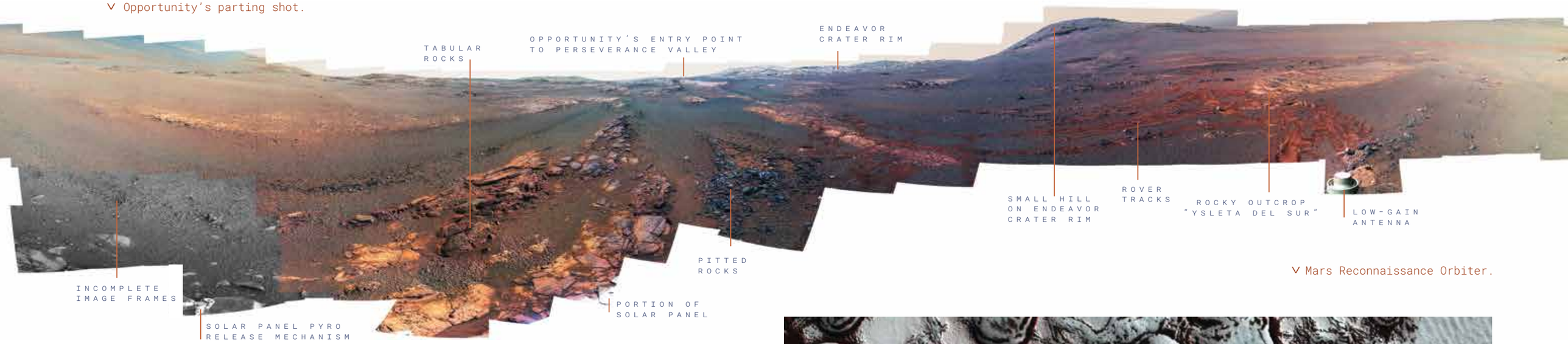
Curiosity left Vera Rubin Ridge for a promising region of Mount Sharp inside Gale Crater that is rich in clay minerals — promising because such minerals often form in water, which is essential for life. Two drilled samples revealed the highest amounts of clay of the entire mission. The latest drill holes sit on top of 1,200 vertical feet of rock that all contain evidence of water in Gale Crater. "Curiosity's extensive exploration has shown that Mars was habitable not just for a moment, but for millions of years," said the mission's project scientist, Ashwin Vasavada of JPL.

The team performed a "wet chemistry" experiment on a drilled sample for the first time, using the SAM instrument to search for organic molecules in the ancient rocks that could have served as building blocks for life.

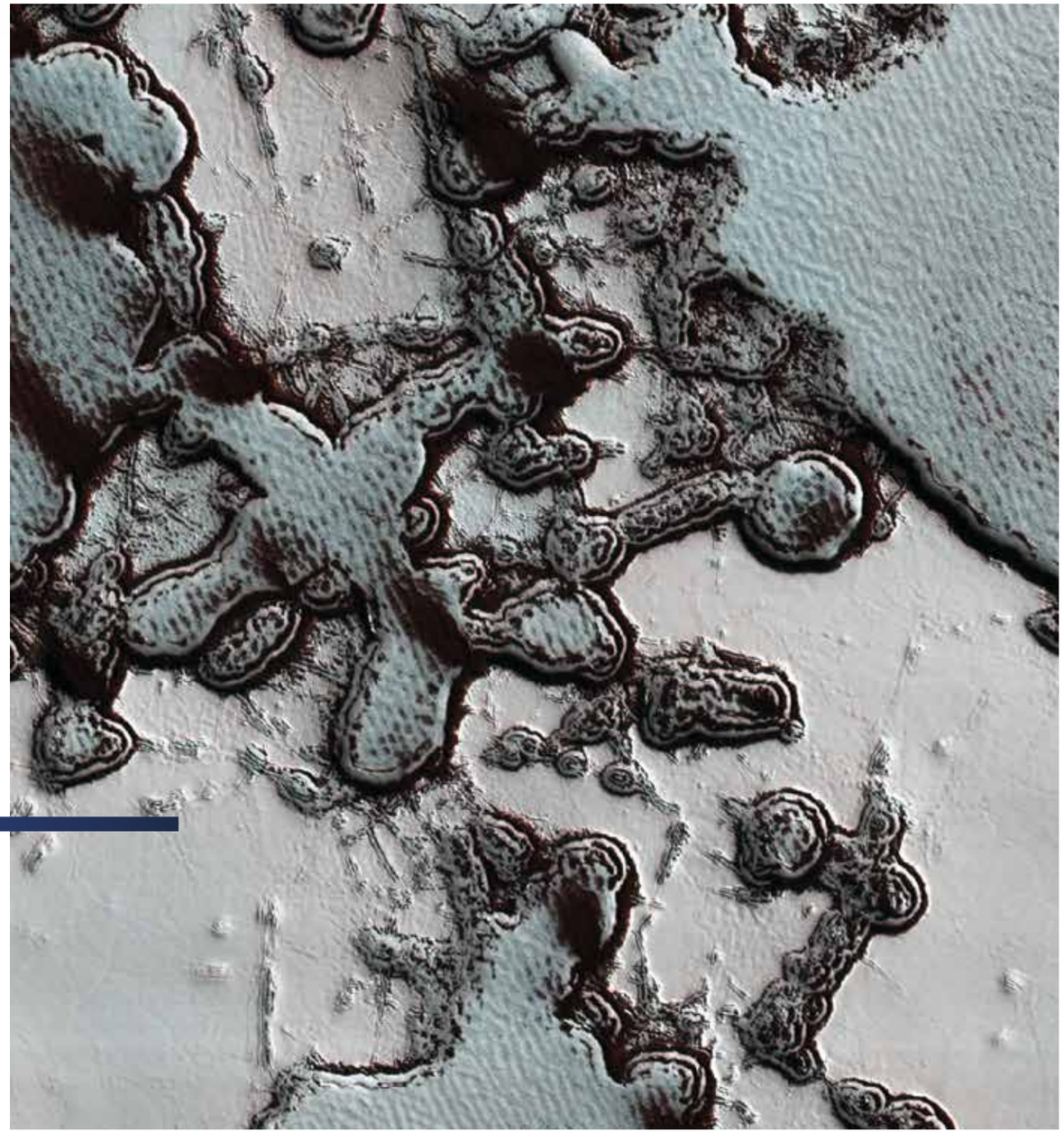
Methane also stirred up interest when Curiosity detected a large spike in its abundance that vanished after a few days. It was an intriguing but ambiguous find, since methane could be a waste product from microbes...or it could be created geologically. To gather multiple observations, the mission team is coordinating with ExoMars Trace Gas Orbiter, which is specifically designed to look for methane, and European Space Agency's Mars Express, which can also look for it.

Curiosity also observed seasonal changes in higher oxygen levels at Gale Crater that baffle scientists. The levels seem to follow seasonal trends previously observed with methane, which might possibly be from a chemical source not yet identified.

Opportunity's parting shot.



Mars Reconnaissance Orbiter.



MARS / **MARS FAMILY MILESTONES**

In February, the Opportunity rover mission came to an end in Perseverance Valley, an apt name for a rover originally designed for a 90-day mission, but which lasted 15 years before a mammoth dust storm in 2018 shrouded the rover from sunlight that was essential to its operation.

Despite more than a thousand attempts to restore contact, by early 2019 the time had come to say goodbye and celebrate Opportunity's gigantic legacy. The rover and its twin, Spirit, showed that rolling robots on Mars can communicate with Earth through orbiter relays, use 3D vision to navigate, and make autonomous science observations.

The Mars exploration family tree over the decades has included landers, rovers and orbiters. All have unique capabilities that advance the quest to answer questions about the past and present habitability of Mars, and all contribute to the exploration strategy. For example, the Mars 2020 landing site in Jezero Crater was selected based on observations of Mars orbiters, including Mars Reconnaissance Orbiter.

The Orbiter passed its 60,000-orbit milestone in 2019. After 13 years spent looping around the Red Planet, the Orbiter's instruments are mostly still functioning, and they've returned more than 360 terabits of data and nearly 380,000 images. The spacecraft has also beamed back to Earth data from previous rovers and landers, and will continue to do so with Mars 2020.

The longest-running spacecraft around the Red Planet, Mars Odyssey, has been orbiting the planet for 18 years and continues its observations and role as a communications relay from the rovers to Earth.

MISSIONS

MARS FAMILY

MILESTONES IN 2019

OPPORTUNITY/15
years in operation, originally a 90-day mission

MRO/60,000
orbit milestone reached in 2019

MARS ODYSSEY/18
years in orbit

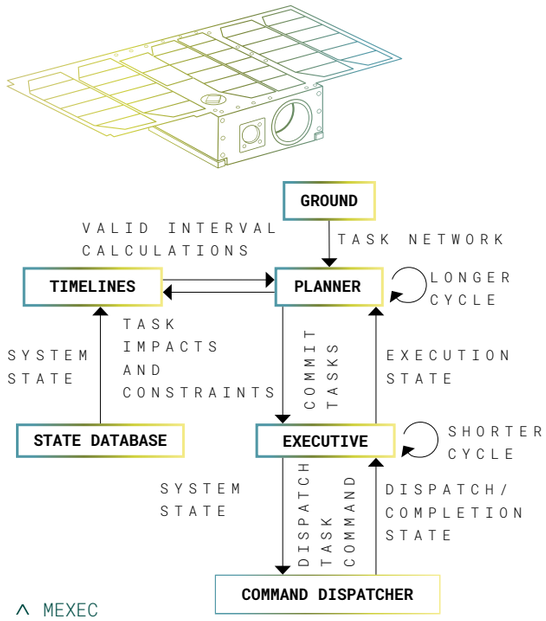
JPL is making the future happen now, defining technologies for space exploration that will enable NASA science not yet achievable. By identifying and investing in game-changing technologies strategic to our future missions and science goals, we maintain our leadership role as the center for robotic exploration of the universe, and benefit humankind with technologies adaptable for medical and public safety applications on our home planet.

TECHNOLOGY /

SMART AND ADAPTABLE SPACECRAFT

Future science exploration objectives will require increasingly intelligent platforms that can avoid danger or seize opportunities for science without waiting for a command to travel all the way from Earth. Onboard autonomy may someday guide a drill through Europa's crust to its underwater ocean, for example. Coordinating hundreds of spacecraft to function as a massive virtual telescope in space would also require technologies that do not yet exist. The same is true for exploration deep underground on Mars, where there is new hope for detecting life.

JPL-developed autonomous system architectures are being tested in varied locations — land, sea, air and space — every environment we want to explore in worlds beyond our own. For example, onboard systems can detect, diagnose and recover from a failure without interrupting the mission or waiting for commands from Earth. Capabilities like this will be critical to mission survival in new, unknown and dangerous environments.



^ MEXEC Multi-mission Executive software (on Asteria).

> BRUIE / Buoyant Rover for Under-Ice Exploration.

v LEMUR / Limbed Excursion Mechanical Utility Rover.

< ORPHEUS deep sea submarine.

A small sample of autonomy field tests from the past year: LEMUR (Limbed Excursion Mechanical Utility Rover) and Ice Worm learned how to climb better with practice. BRUIE (the Buoyant Rover for Under-Ice Exploration) may eventually explore ice layers of solar system bodies. Other submersibles, like Orpheus, explore autonomously underwater. Hexacopters have demonstrated an ability to map their environment on the fly with JPL software. And in space, MEXEC (Multi-mission Executive) software autonomously controlled the orbiting Asteria CubeSat.

Increased autonomy would not only allow missions to harvest abundant and immediate science in uncertain environments, but would also reduce ground involvement and related costs.

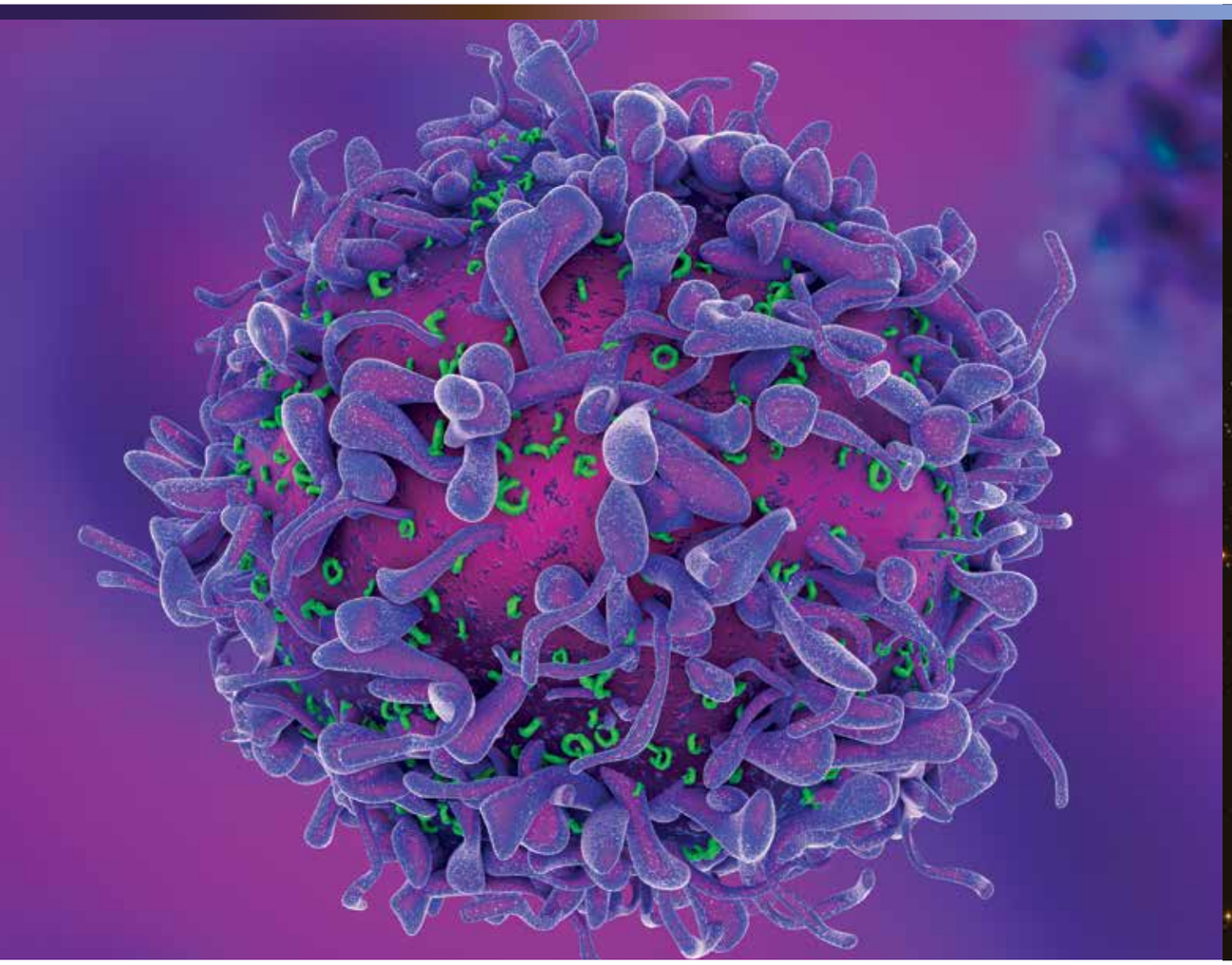
Without question, this key technology poses a great system engineering challenge. JPL is investing resources and building teams to integrate autonomy from the moment design begins, then continuing through each stage of development. The Lab is also addressing the mounting challenges of handling colossal amounts of data collected by spacecraft and ground instruments.

< Field testing the Ice Worm prototype in a glacier cave.

TECHNOLOGY / SMALL, BUT MIGHTY

Putting highly miniaturized instruments on smaller, more autonomous platforms will be a paradigm shift in how we explore the universe. JPL technologists have developed a spectrometer about the size of a thumb that can use high-spectral resolution with a unique capability called spatial heterodyne spectroscopy. By splitting apart wavelengths of light with great sensitivity, the device may be used to detect water or other volatiles in a comet, on the Moon, or in other rich science environments.

Benefits on Earth may include providing a fingerprint to identify atoms and molecules in medicine, or monitoring anesthesia and respiratory gas mixtures during surgeries and in combat fields. This mini-tech may play a role in personalized medicine, by scanning eyes or blood, with analysis from a smart phone. Similar types of miniaturized technology can also be deployed for weather forecasting and environmental monitoring.



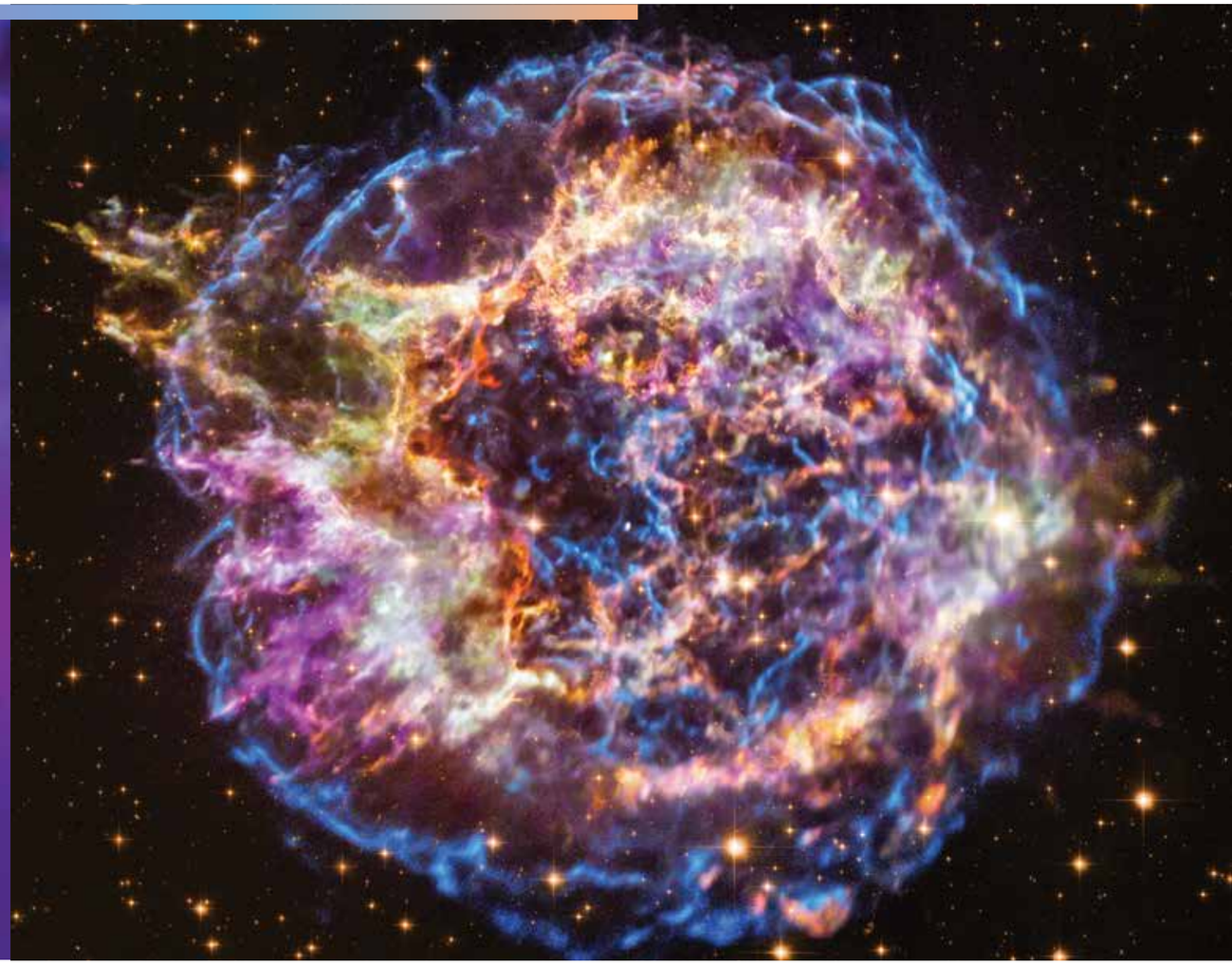
^ 3D illustration of T-cells.

TECHNOLOGY / SPACE TECHNOLOGY: IT'S GOOD FOR YOU

Astronomers study cosmic objects by observing in ultraviolet, X-ray and infrared wavelengths. If they could access it, a "terahertz gap" at the end of the infrared portion of the spectrum could reveal how stars and galaxies formed, as well as detect organic molecules, water and minerals simultaneously.

Designing technology for space missions often has unintended benefits for other sectors. In collaboration with the National Institutes of Health, JPL is studying viruses at the cellular level by developing a mini-MRI at terahertz wavelengths. If this new avenue is successful, it could allow us to see inside cells to learn how disease spreads in very early stages, potentially leading to new treatments and cures.

This work uses a JPL-patented circuit design, "on-chip power-combining," and a second technique of "on-chip frequency duplexing" to double the bandwidth of the frequency.



^ The Cassiopeia A supernova remnant is located 10,000 light-years away.

TECHNOLOGY /

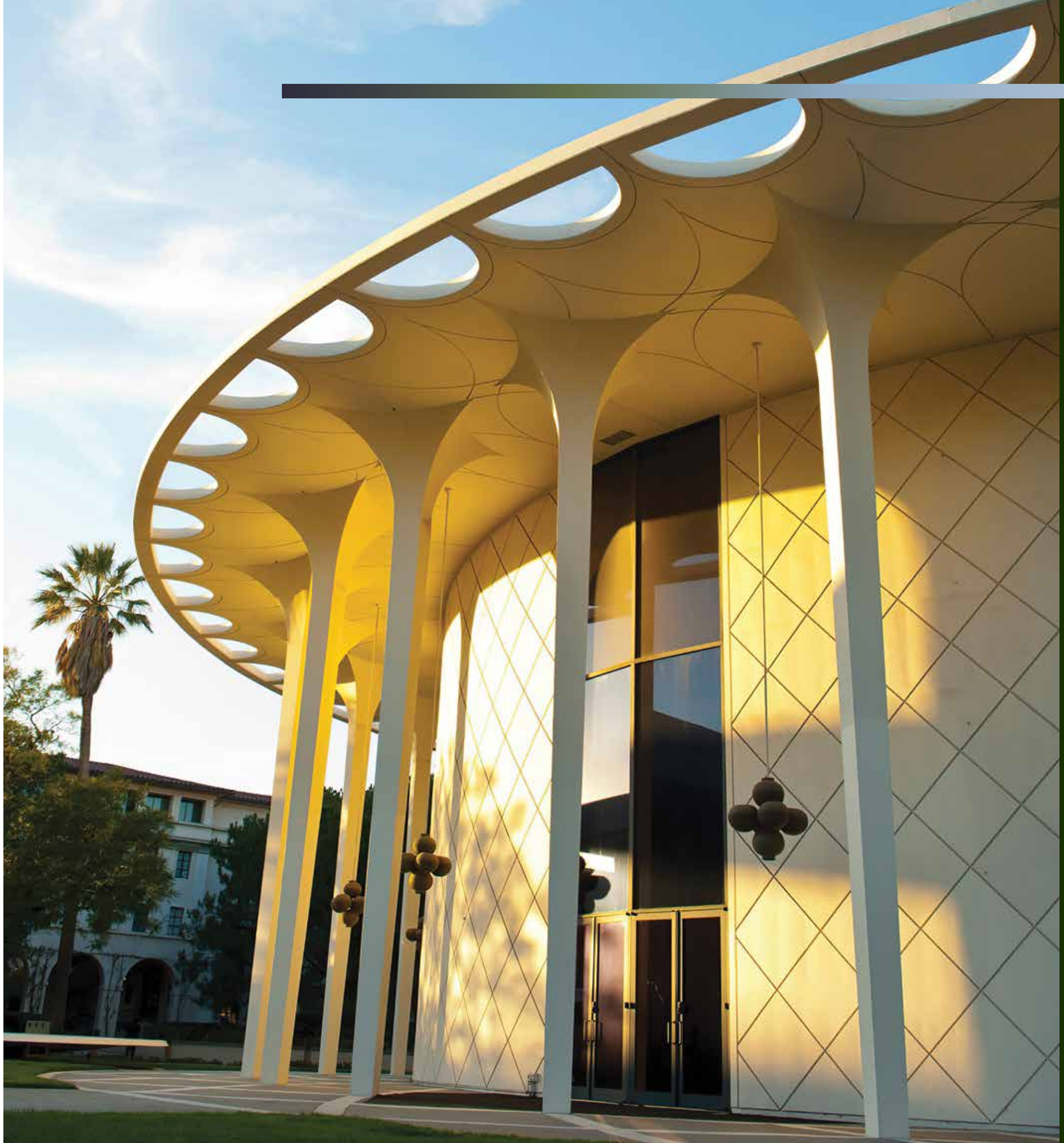
FORWARD IS MORE THAN ONE DIRECTION

What has four legs with three actuators each, weighs 165 pounds, can walk in any direction, is nearly as fast as a human, has two onboard computers, and can carry equipment? The innovative Legged Locomotion and Movement Adaptation (LLAMA) — a quadruped robot under development that could be used on rough, uneven terrain, and in other challenging environments not suited for robots with wheels or tracks. This has been a limitation to our exploration of planetary surfaces. LLAMA could also help first responders and civilians in risky scenarios such as security and disaster response.

LLAMA can do this because it has custom, adjustable actuators with low gear ratios and no mechanical springs that make its legs move and allow it to carry weight. Traditional robots with the customary actuator design can move fast and carry less, or vice versa. The LLAMA team is using rapid design and iteration to drive its advance.

Our passion to do difficult things never done before makes JPL the home for humanity's firsts in exploration, science and technology.

The innovative four-legged LLAMA could be useful on rough, uneven terrain, which could potentially help first responders in risky scenarios on Earth, and in exploration of uneven surfaces on other planets.



Caltech and JPL, which Caltech manages for NASA, continued to cement their historical ties and longstanding research relationships by sharing talent, expertise, and a vision of a better future for humanity. Collaborations included the study of climate, earthquakes and astrophysics, along with research to potentially help people paralyzed by injuries or strokes.

In a bold step toward addressing climate-change challenges, Lynda and Stewart Resnick, owners of The Wonderful Company, pledged $750 million to Caltech to spur research in environmental sustainability.

Announced in September 2019, this commitment is the largest ever for sustainability research, the largest in Caltech's history, and the second-largest gift to a U.S. academic institution.

THE RESNICKS

The Resnicks' gift will be used to establish a permanent endowment supporting investigators across Caltech's academic divisions and JPL in four core research initiatives: developing efficient solar fuels and a smart electricity infrastructure (aka "Sunlight to Everything"); measuring, modeling and potentially mitigating climate change; effectively managing water resources; and creating breakthroughs in global ecology and biosphere engineering, including the use of biological tools to improve soil fertility.

Mark Simons, JPL's chief scientist and a Caltech professor of geophysics, will lead the new water resources initiative. Heading the other new programs will be campus researchers Harry Atwater ("Sunlight to Everything"), Paul Wennberg (climate science) and Dianne Newman (global ecology and biosphere engineering).

In addition to supporting key initiatives, the $750 million gift will enable the construction of a new building on campus — the Resnick Sustainability Resource Center — to serve as the hub for energy and sustainability research as well as the home of state-of-the-art undergraduate teaching laboratories.

"Sustainability is the challenge of our times," said Caltech president Thomas F. Rosenbaum. "Stewart and Lynda Resnick's generosity and vision will permit Caltech to tackle issues of water, energy, food and waste in a world confronting rapid climate change."

REASEARCH INITIATIVES

"SUNLIGHT TO EVERYTHING"

CLIMATE CHANGE

GLOBAL ECOLOGY

BIOSPHERE ENGINEERING

MARK SIMONS

HARRY ATWATER

DIANNE NEWMAN

PAUL WENNBERG

CAMPUS & LAB / **TRACING TEMBLOR NETWORKS**

In 2019, a team of Caltech and JPL geophysicists shed light on how massive earthquakes can be generated by a web-like network of smaller interconnected faults, in a study of the July Ridgecrest earthquake sequence published in Science.

The Ridgecrest study stands in sharp contrast to the common view that major earthquakes are caused by the rupture of a single long fault, such as the more than 800-mile-long San Andreas fault.

The team used data gathered by orbiting radar satellites and ground-based seismometers to assemble a picture of an earthquake rupture that is far more complex than that found in models of many previous large seismic events. The Ridgecrest temblor sequence, the largest to rattle Southern California in two decades, peaked with a magnitude-7.1 mainshock followed by more than 100,000 aftershocks. The sequence involved about 20 previously undiscovered faults crisscrossing in a geometrically complex and geologically young fault zone.

According to Zachary Ross, assistant professor of geophysics at Caltech and lead author of the study, the Ridgecrest event is ". . .going to force people to think hard about how we quantify seismic hazard and whether our approach to defining faults needs to change. We can't just assume that the largest faults dominate the seismic hazard if many smaller faults can link up to create these major quakes."

ZACHARY ROSS

CAMPUS & LAB /

LEARNING TO WALK AGAIN

A campus-JPL collaboration with other researchers in academia and industry holds the promise of restoring at least some mobility to individuals paralyzed by spinal cord injuries and strokes.

The new research effort, RoAMS (the Robotic Assisted Mobility Science initiative), combines devices such as exoskeletons and prostheses with artificial intelligence (AI)–infused neurocontrol. A key goal is to provide hands-free mobility. Currently available exoskeletons — devices that employ robotic legs and fit to a user's body — require the use of crutches to maintain stability.

AARON AMES

JOEL BURDICK

Fueling the effort is the work of two roboticists (in collaboration with others): Aaron Ames at Caltech, who creates the algorithms that enable walking by bipedal robots and translates these to govern the motion of exoskeletons and prostheses; and Joel Burdick at campus and JPL, whose transcutaneous spinal implants have already helped paraplegics in clinical trials to recover some leg function and, crucially, torso control. The implant provides electrical stimulation to the epidural space around the lower spinal cord while using AI to learn, in real time, the stimulation patterns that yield the best results for wearers.

To help people walk, RoAMS will develop powerful new exoskeletons for paraplegics; create smart prosthetic devices, such as a powered leg for above-the-knee amputees; and pioneer soft exoskeletons — or exosuits — for individuals who are not paralyzed but are mobility impaired.

CAMPUS & LAB /

AIMING AT COSMIC QUESTIONS

Caltech is leading a new space mission planned for NASA that will tackle big questions about the birth of our universe, the role of water and organic ices in the formation of planetary systems, and the cosmic history of galaxy formation.

Selected by NASA in February, the Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx) mission is led by principal investigator James (Jamie) Bock, a Caltech professor of physics and JPL research fellow.

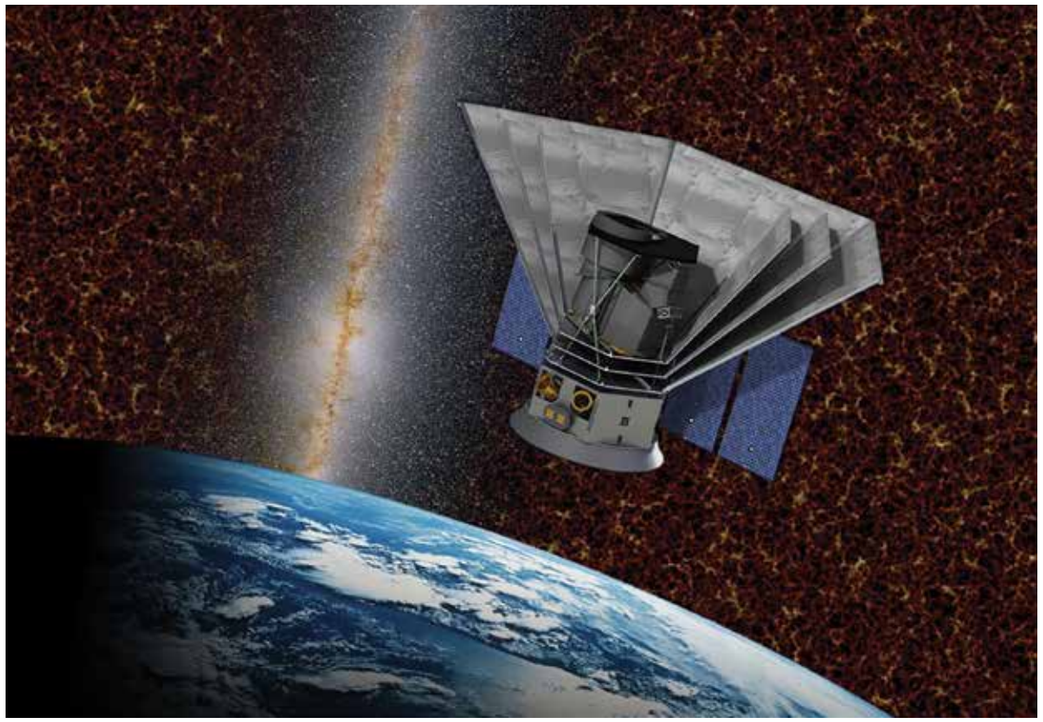
SPHEREx will survey hundreds of millions of galaxies in optical as well as near-infrared light. In the Milky Way, the mission will search for water and organic molecules — essentials for life as we know it — in stellar nurseries, regions where stars are born from gas and dust, and in disks around stars where new planets could be forming.

The mission is planned for a 2023 launch and will operate in Earth orbit. Every six months over two years, SPHEREx will survey the entire sky, creating a map in 96 different color bands, far exceeding the color resolution of previous all-sky maps.

Caltech and JPL will partner to develop the payload of science instruments, and Ball Aerospace will build the spacecraft. The mission team includes scientists from Caltech/JPL as well as researchers from other U.S. institutions and international organizations.

JAMES BOCK

Artist's concept of SPHEREx, which will study the evolution of our universe, and our galaxy's planetary systems.



JPL's team of Public Engagement specialists seeks to draw people far and wide into a limitless universe.

Public Engagement speaks to a special audience: everyone, because the team translates complex space and science news into compelling, accessible narratives for all ages and interests. JPL's Public Engagement team traverses the country to share these stories with thousands at events, festivals and conferences, while crafting content for NASA websites that millions visit every month.

In 2019, achievements included the memorable Send Your Name to Mars Campaign; "Galaxy of Horrors" posters depicting inhospitable exoplanets; the record-setting Global Climate Change website; and a connection with new audiences at an Airborne Science exhibit in the heart of the country.

PUBLIC / **SPOTLIGHT ON THE RED PLANET**

Mars 2020 won't be making its seven-month voyage solo. In fact, it will have more than 10 million passengers on board — at least in name, stenciled on chips affixed to the rover.

Between May and September, the Mars Public Engagement team enticed a record 10.9 million humans to journey in spirit to the Red Planet in the Send Your Name to Mars Campaign. JPL's Microdevices Laboratory used an electron beam to stencil the submitted names onto silicon chips, with lines of text measuring 75 nanometers high — smaller than one-thousandth the width of a human hair. The chips will ride on the rover, protected by glass covers.

The team saw its participation numbers skyrocket, thanks to the public fascination with the Red Planet, as well as some smart maneuvering. A "frequent flyer" program lets users collect points each time they send their name on a mission. Miles are awarded for each "flight," with souvenir boarding passes and corresponding digital mission patches available to download and share.

"As we get ready to launch this historic Mars mission, we want everyone to share in this journey of exploration," said Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate.

While millions of names will soon head into space, Mars is also making headlines back on our home planet. JPL's 2018 InSight landing broadcast won an Emmy Award for interactive coverage, and Robert Downey Jr. revealed during a Rolling Stones concert at Pasadena's Rose Bowl Stadium that the InSight team had named a Martian rock for the band.

v Brad Pitt sends his name to Mars

> InSight received an Emmy Award in 2019 for interactive coverage.

v InSight team named a Martian rock for the Rolling Stones.

^ JPL's Microdevices Laboratory used an electron beam to stencil the submitted names onto silicon chips.

PUBLIC / EARTH-SHATTERING RECORDS FOR NASA CLIMATE

2019 was the most significant year yet for the NASA Climate website.

The New York Times recognized the site as one of the top resources for climate information. The site also claimed the number two spot for most-visited NASA websites of the year, with 2-3 million page views per month.

An independent user study by George Mason University found the website to be extraordinarily effective: “Americans respond well to NASA’s Climate website, and learn from it. It also reinforces their positive views about NASA’s climate science.” The majority of users in the study also found the website easy to use, easy to understand, engaging and trustworthy.

NASA Climate is frequently the number one Google search result for the terms “climate change” and “global warming,” and has won five Webby Awards, including Best Science Site, Best Green Site, and Best Education and Reference App for “Earth Now,” a real-time visualization of NASA’s Earth-orbiting satellites. The site is also a frequently-cited resource for media, op-ed writers and newspaper letters to the editor.

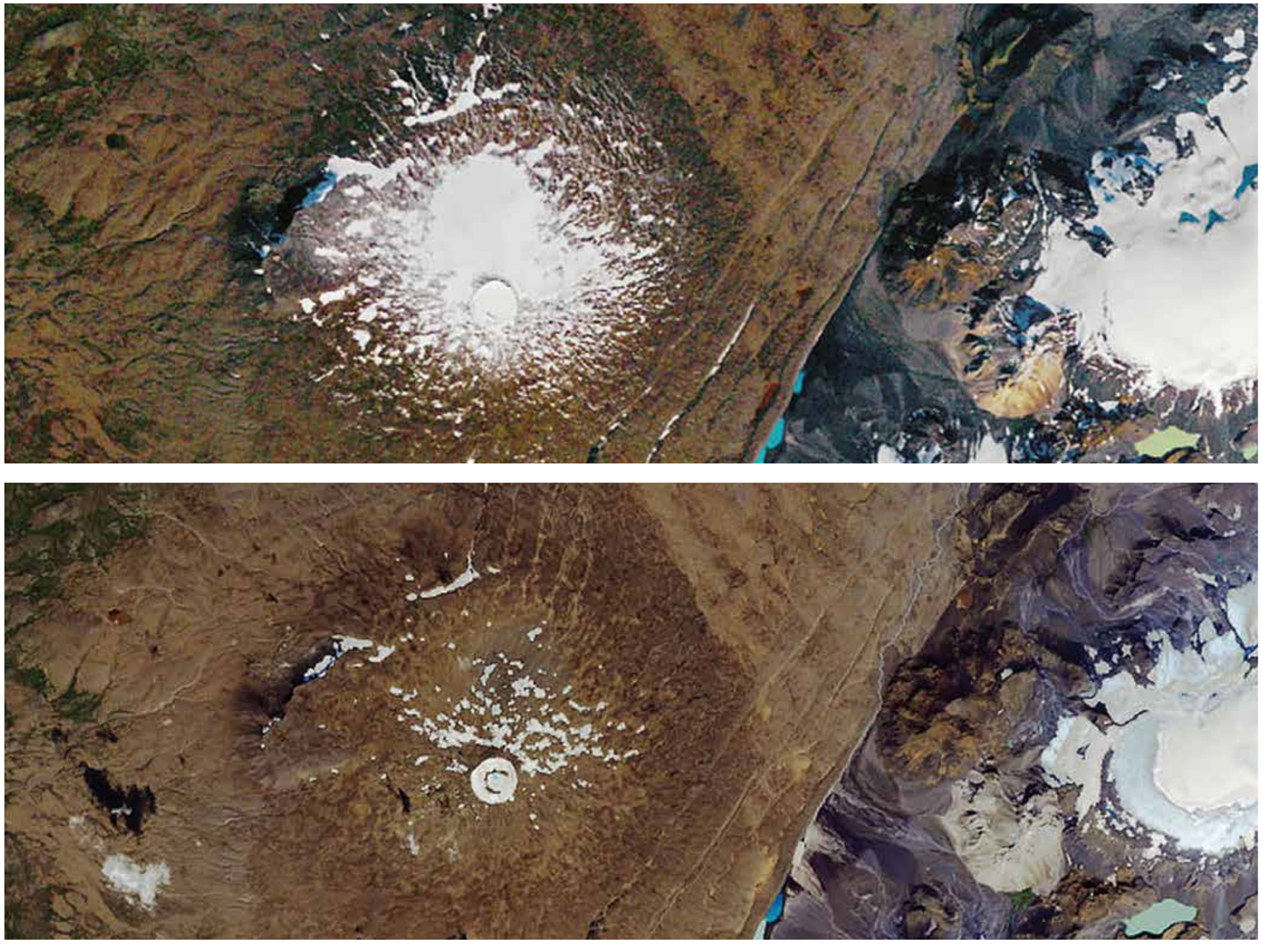
The 50th anniversary of Earth Day is April 22, 2020. JPL Earth Public Engagement is leading the NASA effort to promote the agency’s Earth science over the past 50 years and inspire the public to look toward the future of our home planet.

> Iceland’s Ok glacier melts away: Sept. 14, 1986 - Aug. 1, 2019. These images show the latter stages of the decline of Okjökull, a melting glacier atop Ok volcano in west-central Iceland.

MISSION

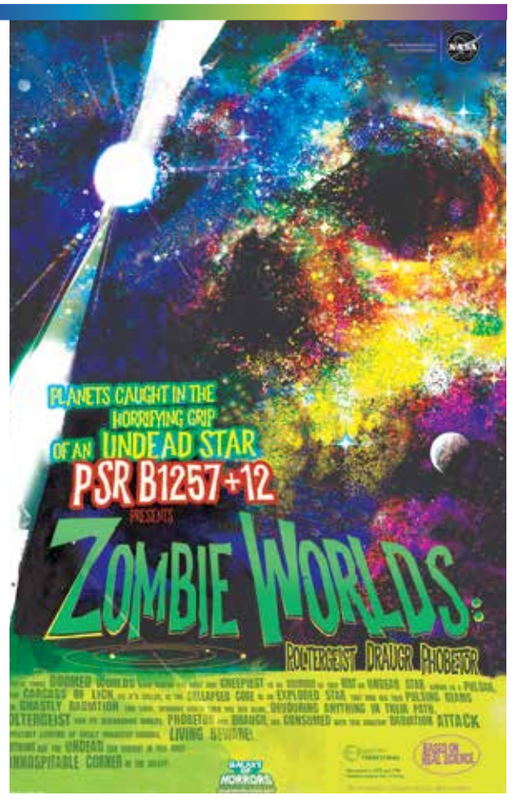
EARTH

CARBON DIOXIDE	GLOBAL TEMPERATURE	ARCTIC ICE MINIMUM	ICE SHEETS
413 parts per million	**1.9** ℉ since 1880	**12.85** percent per decade	**428** gigatons per year
CARBON DIOXIDE LEVELS IN THE AIR ARE AT THEIR HIGHEST IN 650,000 YEARS.	NINETEEN OF THE 20 WARMEST YEARS ON RECORD HAVE OCCURRED SINCE 2001.	IN 2012, ARCTIC SUMMER SEA ICE SHRANK TO THE LOWEST EXTENT ON RECORD.	SATELLITE DATA SHOWED THAT EARTH’S POLAR ICE SHEETS ARE LOSING MASS.



PUBLIC /

GALAXY OF HORRORS A MAIN ATTRACTION



^ Colorful, imaginative posters depict artistic visions of bizarre planets beyond our solar system.

Until technology exists to photograph exoplanets directly, we can only imagine what they look like based on available science data. One result of that imagining: JPL scientists and artists teamed up to create two free, downloadable “Galaxy of Horrors” posters depicting horribly inhospitable worlds, just in time for Halloween.

The first poster featured HD 189733 b, an exoplanet with an atmosphere full of silicates — the key component in sand and glass — and winds blowing at over 5,400 mph. At those speeds, the silicates whipping through the air could create a perpetual storm of flying glass. Even if human or robotic explorers could travel 63 light-years from Earth to get there, they would never survive this planetary hellscape. The second poster featured three planets — Poltergeist, Draugr and Phobetor — orbiting the pulsar PSR B1257+12, located about 2,000 light-years from Earth. Sometimes called a “dead star,” a pulsar is the remains of a star that has ceased burning fuel at its core and collapsed. Like other pulsars, PSR B1257+12 produces dual beams of intense radiation that can sometimes be seen across the galaxy. Stray radiation and high-energy particles would attack the three nearby planets, and life as we know it could never form on these worlds.

“There are so many other amazing, mystifying planets out there that are completely unlike Earth and that show us the huge variety of ways planets can form and evolve,” said Thalia Rivera, JPL outreach specialist for the Exoplanet Exploration Program. “My favorite thing about exoplanets is how extreme they can get.”

PUBLIC /

SKY’S THE LIMIT FOR AIRBORNE EXHIBIT

In July, Earth Public Engagement Team members staffed an Airborne Science exhibit in the NASA pavilion at the Experimental Aircraft Association’s annual AirVenture in Oshkosh, Wisconsin. The exhibit featured aircraft displays and handouts about missions including FIREX-AQ, CAMP-EX, SnowEx, OMG and UAVASR.

AirVenture is billed as “The World’s Greatest Aviation Celebration,” and 2019 attendance set an overall record, with 642,000 visitors. The NASA exhibit reached a segment of the public not usually found at the agency’s events.

^ The North American AT-6 Texan aircraft, originally a trainer but now souped up to perform in air shows, is one of thousands of aircraft that show up at Oshkosh each year.

2019 / MAJOR CONTRACT PARTNERS

APPLIED PHYSICS LABORATORY, THE JOHN HOPKINS UNIVERSITY

Europa Clipper, Mars 2020, Mars Reconnaissance Orbiter, Psyche

BALL AEROSPACE & TECHNOLOGIES CORPORATION

CloudSat, NEOCam, NEOWISE, SPHEREx

COLUMBUS TECHNOLOGIES AND SERVICES INCORPORATED

Labor Support Services

MANTECH ADVANCED SYSTEMS

Institutional Computing

LOCKHEED MARTIN CORPORATION

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

PERATON, INC.

Deep Space Network Operations, Mars 2020

SPACE SYSTEMS LORAL

Europa Clipper, Exoplanets, Psyche, SWOT

SOUTHWEST RESEARCH INSTITUTE

Cassini, EMIT, Europa Clipper, Mars Science Laboratory, Rosetta

RAYTHEON

Data Systems Implementation and Operations (DSIO); Engineering, Implementation, Science, Operations and Communications (EISOC); Monolithic Microwave Integrated Circuit Development; Systems Administration Support Services

BASTION TECHNOLOGIES INC.

Mission Assurance Support Services

Spitzer / Supernova remnant, the Crab Nebula / Distance: 6,500 light-years.

TAGUHI ARAKELIAN
Institute of Environmental Sciences and Technology Exceptional Women Contributor Award

MIMI AUNG
BBC's 100 Women of 2019

LAURIE BARGE
Presidential Early Career Awards for Scientists and Engineers

THIERRY CAILLAT
International Thermoelectric Society Outstanding Achievement Award

GOUTAM CHATTOPADHYAY
Institute of Electrical and Electronics Engineers Outstanding Engineer of the Year

COMMUNICATIONS / EDUCATION DIRECTORATE
Webby Awards:
People's Voice-Social-Education and Discovery—NASA's InSight Mission to Mars Social Media
People's Voice-Science—Solar System Exploration website

DAWN MISSION
John L. "Jack" Swigert, Jr., Award for Space Exploration

CHARLES ELACHI
International Academy of Astronautics von Karman Award

JEAN-PIERRE FLEURIAL
International Thermoelectric Society Outstanding Achievement Award

HENRY GARRETT
International Academy of Astronautics Fellow

SARATH GUNAPALA
Military Sensing Symposia Levinstein Award

LARRY JAMES
International Academy of Astronautics Fellow

APRIL JEWELL
SPIE Defense and Commercial Sensing Rising Researcher Award

MARCO MISSION
American Institute of Aeronautics and Astronautics Small Satellite Mission of the Year

MARS INSIGHT / COMMUNICATIONS / EDUCATION DIRECTORATE
Emmy Award for Outstanding Original Interactive Program
Academy of Television Arts & Sciences

SON NGHIEM
American Geophysical Union Fellow

SHOULEH NIKZAD
IEEE Photonics Distinguished Lecturer Award 2019-2020

JOHN REAGER
Presidential Early Career Awards for Scientists and Engineers

MIGUEL SAN MARTIN
National Academy of Engineering Fellow

JONATHAN SAUDER
Presidential Early Career Awards for Scientists and Engineers

DAVID SEIDEL
American Astronautical Society 2019 Sally Ride Excellence in Education Award

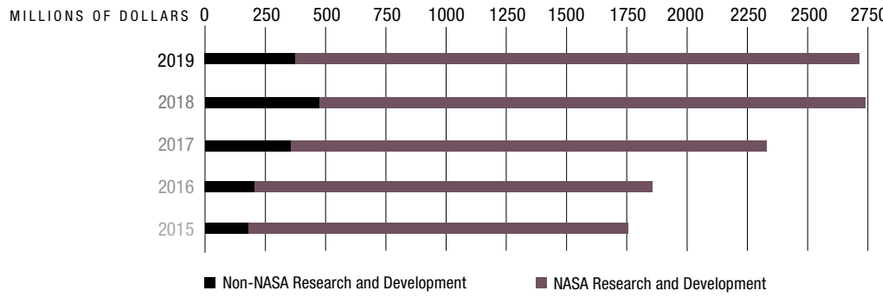
SMALL BUSINESS PROGRAMS OFFICE
U.S. Small Business Administration's Dwight D. Eisenhower Award for Excellence

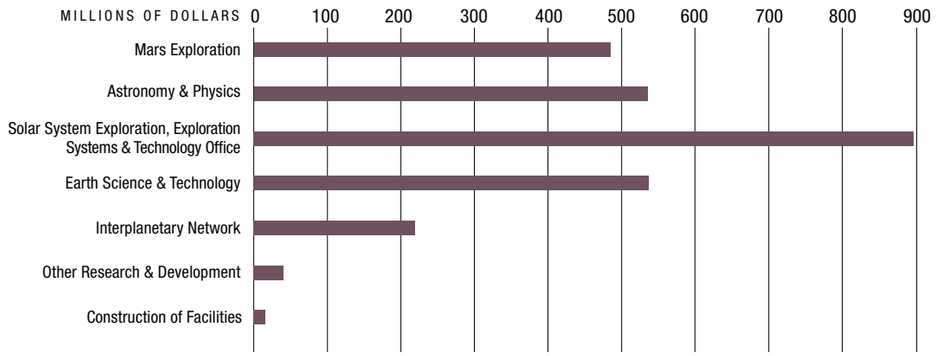
BENEDIKT SOJA
EGU Geodesy Division's Outstanding Early Career Scientist Award

EDWARD C. STONE
The Shaw Prize in Astronomy

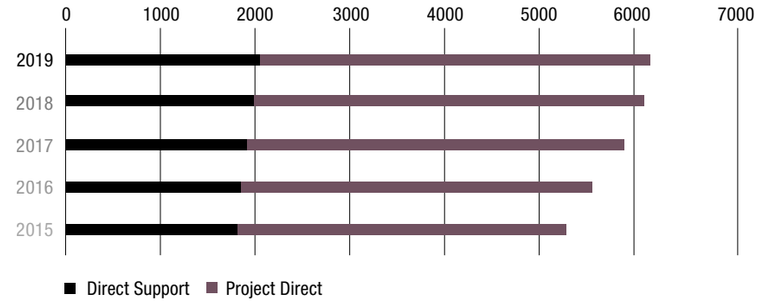
MICHAEL WERNER
American Astronautical Society Carl Sagan Memorial Award

FY2019 BUDGET





JPL PERSONNEL / Full-Time Equivalents



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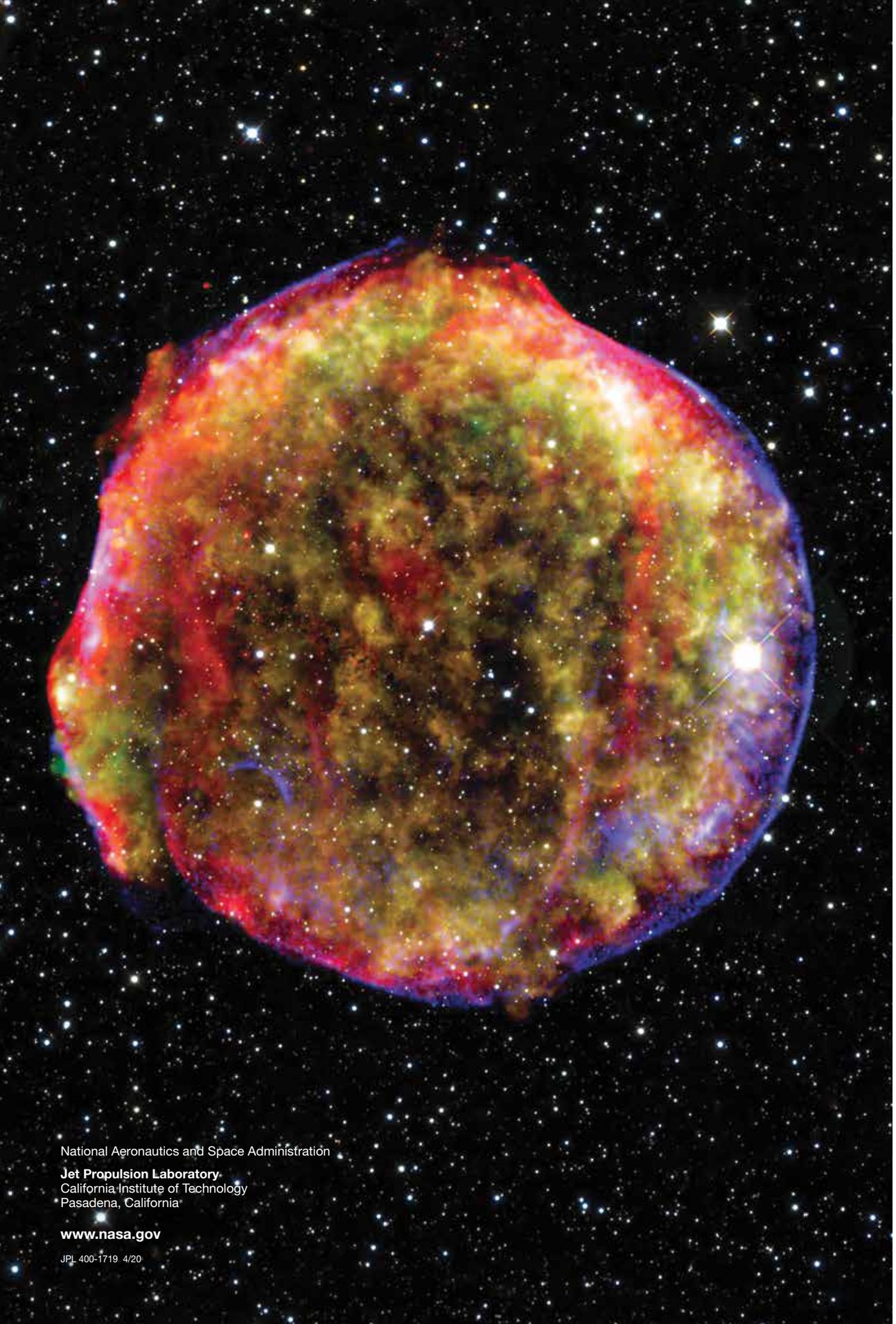
Spitzer / The North American nebula / Distance: 2,000 light years / BACK COVER: Tycho supernova remnant / Distnace: 7,500 light-years.



National Aeronautics and Space Administration

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Pasadena, California

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JPL 400-1719 4/20