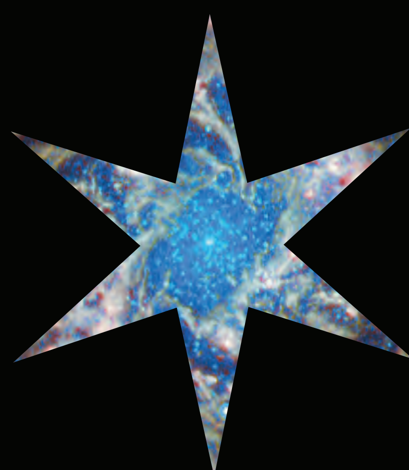
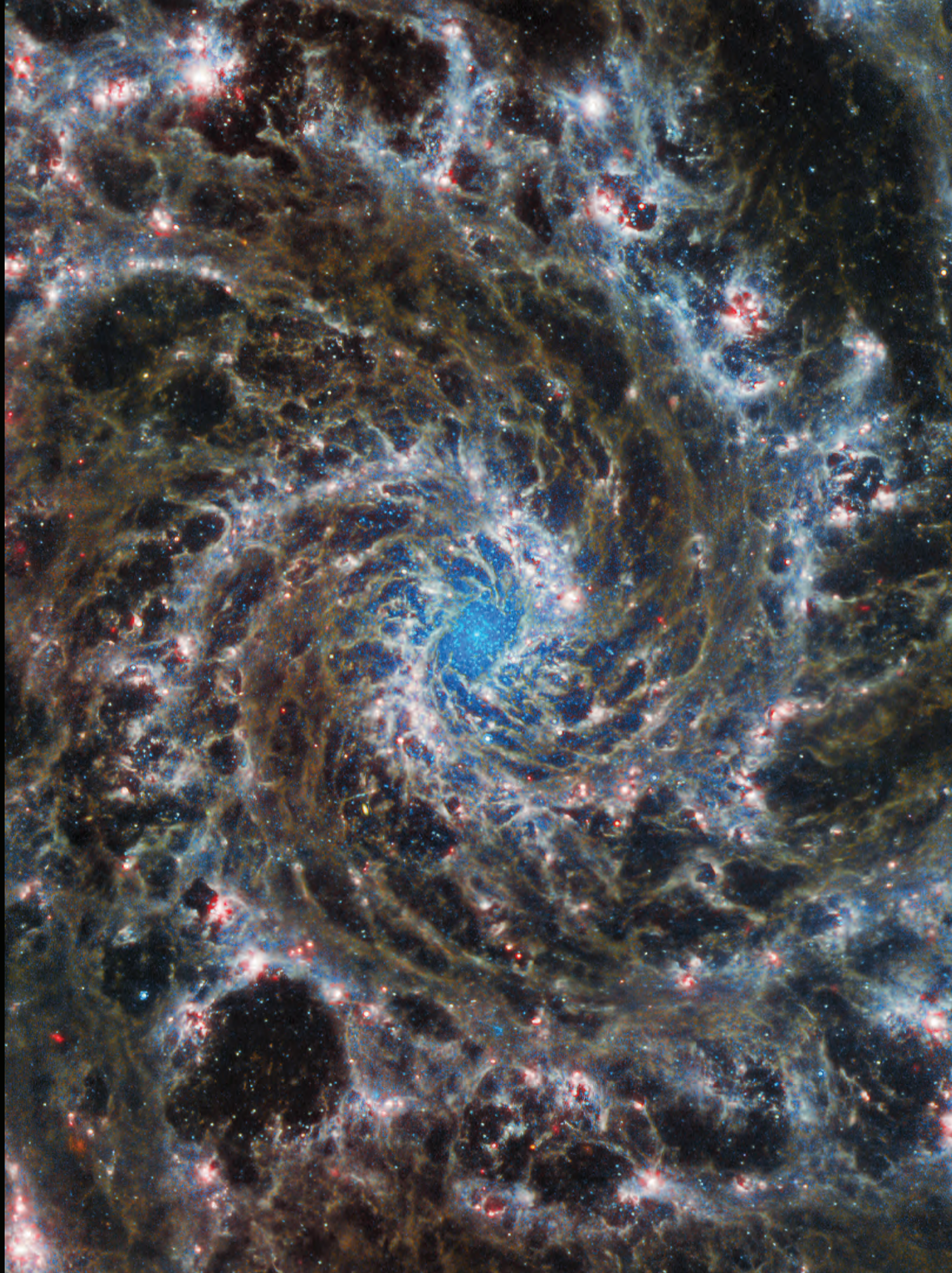
National Aeronautics and
Space Administration



JET PROPULSION LABORATORY 2022



The Mid-Infrared Instrument on the James Webb Space Telescope imaged the heart of M74, the Phantom Galaxy. Visible wavelength images of M74 are dominated by starlight from the mature stars in the spiral arms, but MIRI allows us to see the intricately-detailed structure in the dust clouds where new generations of stars are being born, both in, and between, the spiral arms. JPL managed MIRI through development, construction and commissioning.

Churning clouds on Earth captured from the International Space Station.

CONTENTS

DIRECTOR'S MESSAGE

If 2021 marked a year of resilience, 2022 was the year of resurgence. JPL emerged from a long stretch of lockdowns as we headed back to a revitalized Lab — and I assumed my new role as Lab director. Together, we experienced successes, learned tough lessons, and worked through real challenges that strengthened our team. JPL has a history of delivering what others think is impossible and this year truly exemplified that.

We made incredible progress on an iconic and historic portfolio of missions. After two decades of planning and construction, the James Webb Space Telescope launched and our Mid-Infrared Instrument revealed breathtaking imagery of ancient galaxies and newly formed stars.

Our Deep Space Network continued to support NASA-wide deep space missions, including the launch of JWST and the launch and operations for Artemis-1, the first in a series of expeditions to establish a human presence on the Moon. We also supported the navigation and communications of the Double Asteroid Redirection Test to bump a near-Earth object off course. The aftermath was spectacularly captured by NASA's Hubble Space Telescope.

We had another outstanding year of discovery and momentum on Mars. The Ingenuity helicopter completed more than 35 flights in the Red Planet's thin atmosphere. The Perseverance rover collected and cached more than 15 samples and finished the year on the ancient remnants of Jezero Crater's delta — an incredible feat. The rock, soil and atmospheric samples, which would be collected on the future Mars Sample Return mission and brought back to Earth, would enable study of the Red Planet for generations to come. It will search for signs of ancient, microscopic life and will also help NASA prepare to send humans to Mars.

Closer to home, the Earth Surface Mineral Dust Source Investigation launched to the International Space Station to help improve climate projections of airborne dust effects on Earth's temperature. EMIT's instruments have also detected methane plumes from flaring oil wells, providing vivid examples of planet-warming gas leaks around the globe. We closed out the year with the successful launch of the Surface Water and Ocean Topography mission, which will track Earth's rivers, lakes and oceans in unprecedented detail to help us better understand our changing climate.

As we look ahead to the future of our missions, technology and research, it's bright and busy. After a challenging season for Psyche, and with the help of an independent board review, the mission is back on track for an October 2023 launch. Europa Clipper, which will explore Jupiter's icy moon, has moved into its assembly, test, launch and operations phase. The Mars Sample Return program marked an important milestone as it moved into Phase B of development. JPL is also completing the development of the NASA-ISRO Synthetic Aperture Radar payload, which is perhaps the largest technical collaboration between India and the United States.

To sustain our pace and scale of innovation, and to continue pushing the boundaries of scientific and technological achievement, we need to be working from a unified foundation. After joining JPL in May 2022, I hosted a series of 'EngageJPL' discussions with thousands of JPLers to hear about the future we all hope to enable at the Lab. These insights will help inform our strategic priorities that guide us into our bold future.

We redoubled our commitment to our core value of Inclusion, as 2022 marked a year of firsts for JPL. We appointed our first chief inclusion officer with full membership in the Executive Council. As the first woman to hold the Lab director role in JPL's 86-year history, I'm committed to creating a safe, inclusive and exciting workplace where everyone can thrive and leverage their unique capabilities to advance our mission. We are also continuing to invest in the next generation of scientists and engineers — we need the best and brightest minds to help us explore the frontiers of space.

The extraordinary progress we've made this year is because of the dedication, collaboration and commitment of the JPL community. As we inspire the world to think bigger and imagine what's possible, it is truly a privilege to lead this exceptional team into the next era of our scientific exploration and groundbreaking innovation. Our vision is clear and my hope is that 2023 will be defined by new inspiration, new energy and new discoveries as we Dare Mighty Things Together!

DR. LAURIE LESHIN
Director, JPL

UNIVERSE

↖ **CGI Integration**

Flight technicians Joshua Nachtigal and Juan Gloria prepare for the installation of the warm radiator on the Coronagraph Instrument.

Humans saw the universe in a new light, and beheld wonders veiled from view since the origins of time. JPL's next telescope instrument will enable the first images of giant planets circling distant suns. Close to home, JPL teams are studying small objects of great significance.

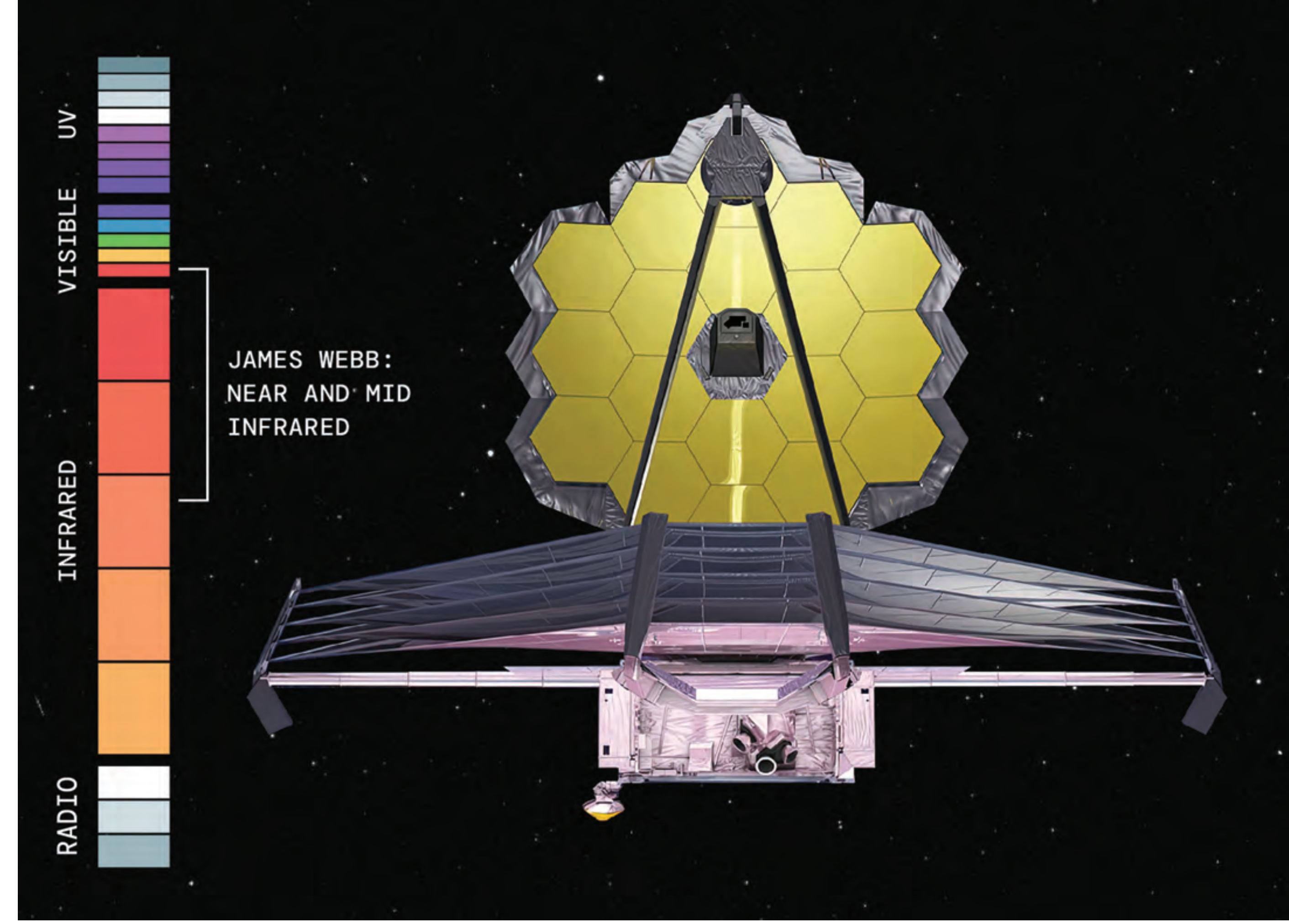
COLD EYES DELIVER HOT SCIENCE

Until it proved otherwise, the James Webb Space Telescope was nothing but an expensive payload catapulted into space.

Then — as with the early universe Webb was built to study — there was light.

And what light. The White House released the first public image in July, a cluster of galaxies whose gravitational pull bends light and distorts the view of older and dimmer primordial stars. Days later, NASA unveiled a chef's menu for galactic foodies: the spectrum of an exoplanet atmosphere; an exquisitely detailed view of the Southern Ring Nebula once imaged by the Hubble telescope; a grouping of spiral galaxies in the process of merging; and the Carina Nebula nursery for new stars.

↘ Improving on Hubble
The Southern Ring Nebula imaged by MIRI



Webb sees in the infrared because in our expanding universe, the most distant stars from Earth are also the ones receding the fastest. Sound and light from receding objects drop in pitch, or wavelength. Of all the instruments on Webb, JPL's Mid-Infrared Instrument sees the farthest back in time because it detects light from the most distant and rapidly receding objects. Those are also the oldest objects: if their light took billions of years to reach us, we see them as they were then.

MIRI's sensitive detectors allow Webb to see the redshifted light of distant galaxies, newly forming stars, and faintly visible comets. MIRI's camera provides wide-field, broadband imaging that will continue the breathtaking astrophotography that has made Hubble so universally admired.

MIRI brings these tremendous advances through the combination of a cold, large aperture telescope in space, plus state-of-the-art detector arrays in a powerful, flexible instrument. An elaborate cryocooler weaves throughout the telescope, dumping heat to keep MIRI's detectors within seven degrees of absolute zero. All warm objects radiate in the infrared. If not for the cryocooler, MIRI's components would be blinded by their own heat.

MIRI will make important contributions to all four mission goals for Webb:

- Discovery of the 'first light' in the universe
- Assembly of galaxies: history of star formation, growth of black holes, production of heavy elements
- How stars and planetary systems form
- Evolution of planetary systems and conditions for life

MIRI was developed by JPL and a consortium of 24 astronomical institutes in 10 European countries, in a partnership between NASA and the European Space Agency.

↖ Infrared Eyes
The Mid-Infrared Instrument enables Webb to see the red-shifted light of distant objects.

Integration & Test

Joshua Nachtigal inspects the multi-layer insulation protecting an avionics box on CGI.

FLEXING OUR WAY TO NEW LIGHT

The Nancy Grace Roman Space Telescope is designed to peer at nearby star systems through some of the most sophisticated sunglasses ever designed: the Coronagraph Instrument, or CGI.

This multi-layered technology demonstration is a system of masks, prisms, detectors, and self-flexing mirrors built to block out the glare from stars and reveal the planets in orbit around them. Designed and built at JPL, CGI passed its system integration review in 2022 and is on schedule, with the rest of the telescope, for a 2027 launch.

CGI will enable the first direct imaging of Jupiter-size exoplanets. As it captures light directly from large, gaseous exoplanets, the coronagraph will point the way to future missions to characterize rocky planets in the habitable zone of their star where liquid water could exist. For Jupiter-size planets, the parent star outshines the planet by a factor of 10 million, effectively blinding telescopes and keeping the planets hidden. A coronagraph is an instrument inside the telescope that blocks starlight while letting through the light of the planet.

CGI's two flexible mirrors form the critical enabling technology. As light that has traveled tens of light-years from an exoplanet enters the telescope, thousands of actuators move like pistons, changing the shape of the mirrors. The flexing of these mirrors compensates for tiny flaws and changes in the telescope's optics. These changes are so precise they can compensate for changes smaller than the width of a strand of DNA.

Using CGI technology, Roman will observe planets so faint that special detectors will count individual photons of light as they arrive, seconds or even minutes apart. No other observatory has done this kind of imaging in visible light before, providing a vital step toward discovering habitable planets and potentially learning whether life exists on a world like Earth's.

MISSION
NANCY GRACE ROMAN SPACE TELESCOPE

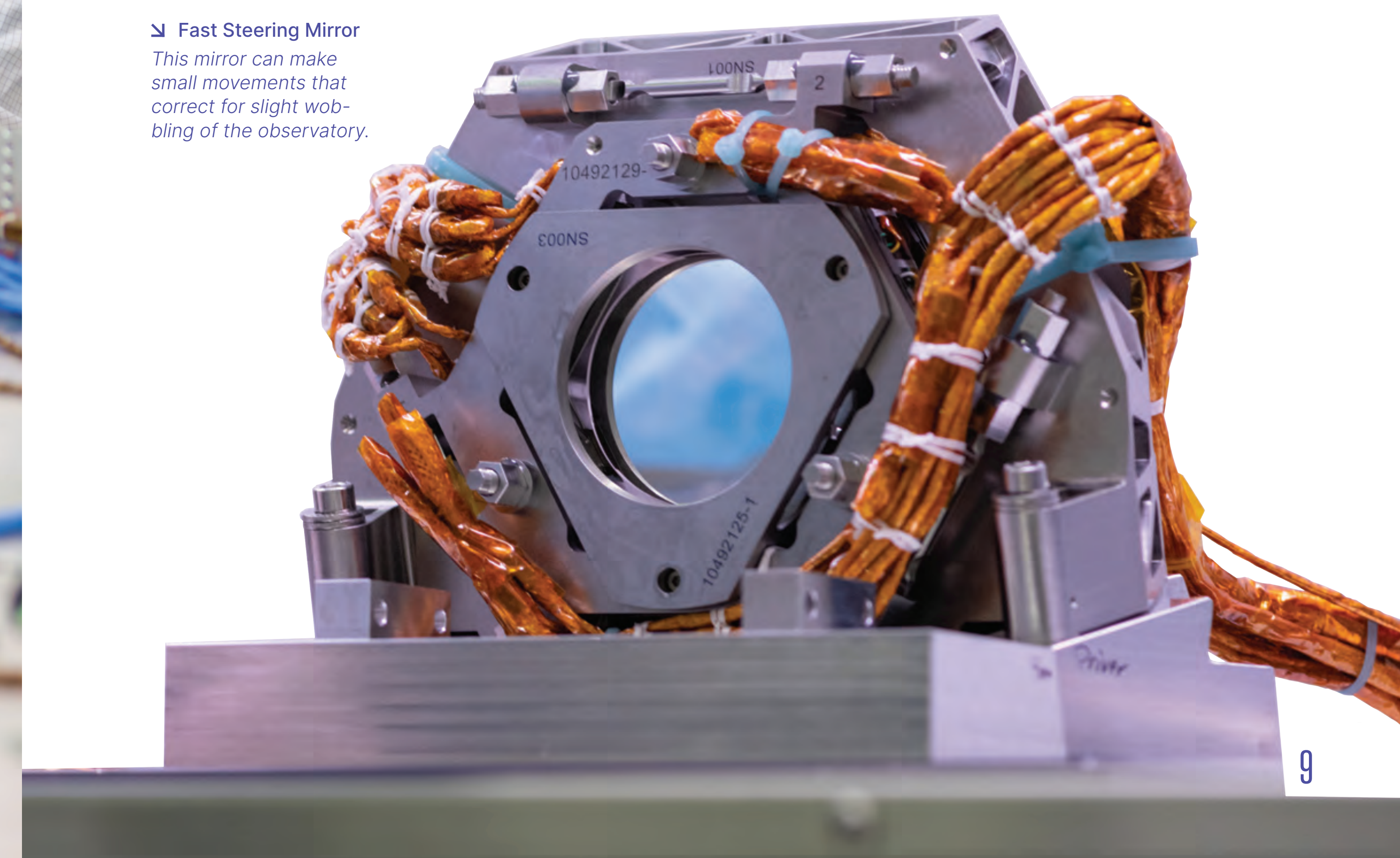
TARGET
THE UNIVERSE

STUDYING
EXOPLANETS, DARK MATTER & DARK ENERGY

LAUNCH
2027

Fast Steering Mirror

This mirror can make small movements that correct for slight wobbling of the observatory.



↘ Neo Surveyor
Artist's rendering

A PROVEN LINE OF NEO HUNTERS

MISSION
NEO SURVEYOR

STUDYING
NEAR EARTH OBJECTS

GOAL
PLANETARY DEFENSE

LAUNCH
2028

Throughout our planet's history, asteroids and comets have been agents of change: they may have delivered the ingredients needed for life, and they have caused mass extinctions.

The Near-Earth Object Surveyor (NEO Surveyor) is the latest line of defense to help advance NASA's planetary defense efforts to discover the most potentially hazardous asteroids and comets that come within 30 million miles of Earth.

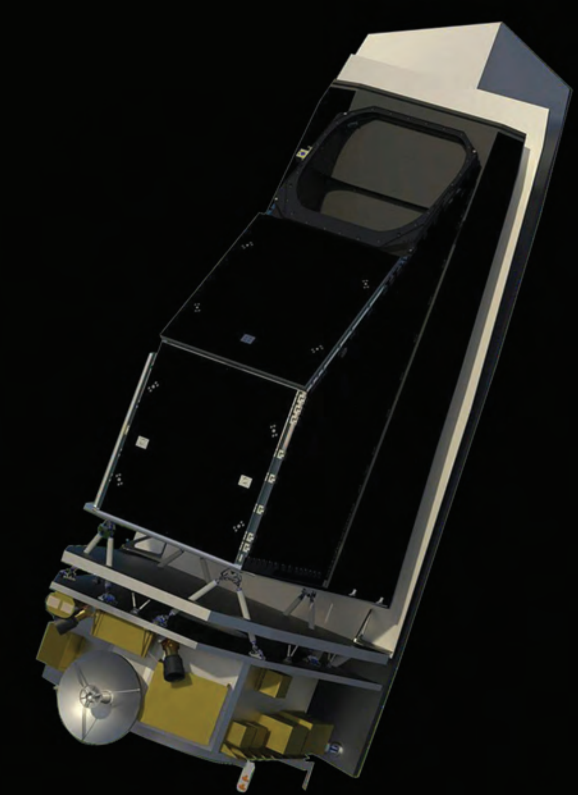
NASA confirmed NEO Surveyor at the end of 2022 after a successful preliminary design review in September — a major step allowing the mission to proceed into the next phase of development.

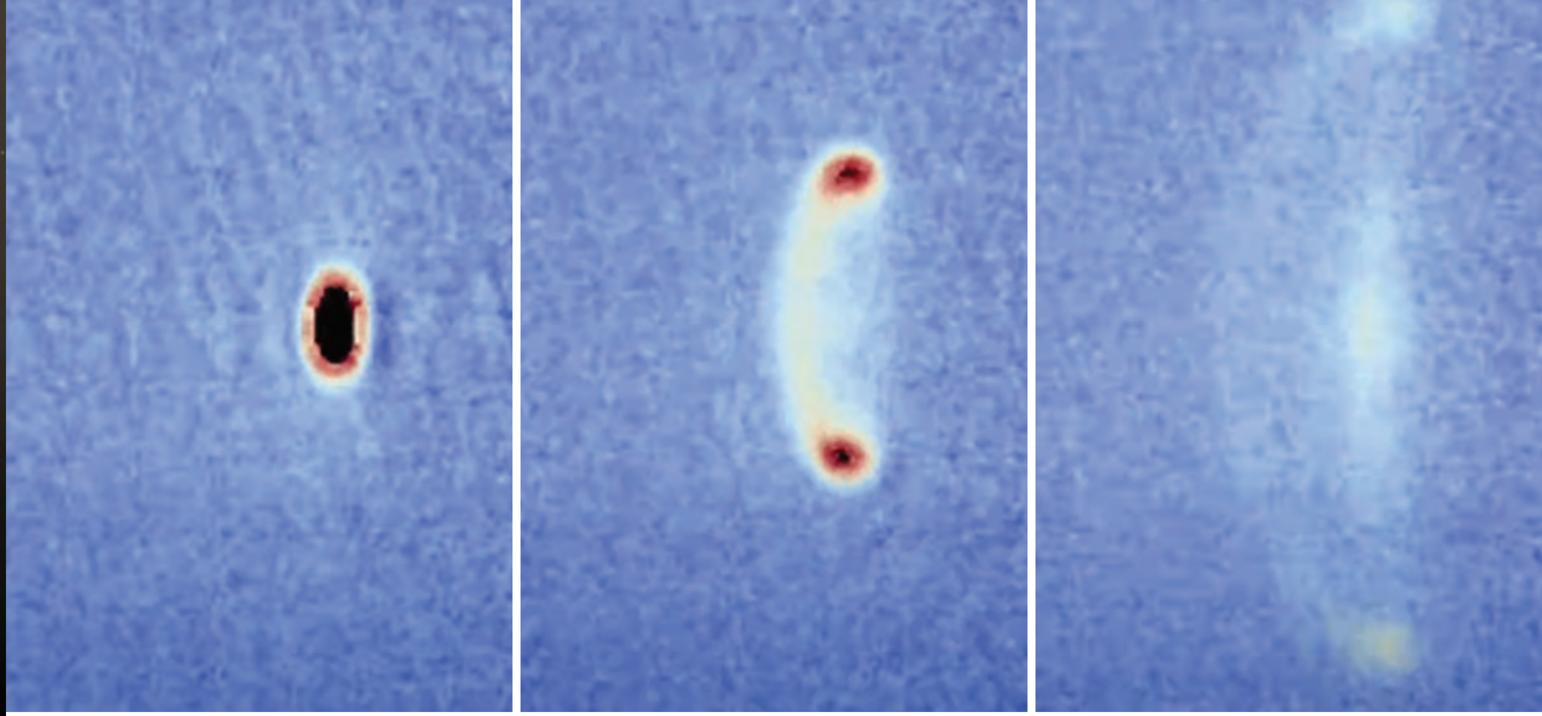
NEO Surveyor follows in the successful footsteps of NEOWISE and DART. It will complement the capabilities of NEOWISE, which has been on the hunt since 2013, and enable NASA to find NEOs much faster. The DART spacecraft proved in late 2022 that an object launched from Earth could deflect an asteroid through a direct collision.

NEO Surveyor's 20-inch telescope operates in two heat-sensing wavelengths to make accurate measurements of NEO sizes and gain valuable information about their composition, shapes, rotational states, and orbits.

Its five-year survey will make significant progress in meeting the U.S. Congress's mandate to find more than 90 percent of all NEOs larger than 140 meters. These are large enough to cause major regional damage in the event of impact.

In addition to NEOs, NEO Surveyor will likely detect more than a million asteroids in the Main Belt between Mars and Jupiter and about a thousand new comets.





NOT YOUR AVERAGE SOAP BUBBLE

Since the days of NASA's Apollo program, astronauts have documented how liquids behave differently in microgravity — coalescing into floating spheres instead of bottom-heavy droplets. Now, researchers using JPL's Cold Atom Laboratory on the International Space Station have demonstrated this effect with a much more exotic material: gas cooled to nearly absolute zero. That's colder than any known place in the universe.

Chilling atoms to such low temperatures slows them down significantly. Room-temperature atoms move faster than the speed of sound, while ultracold atoms move slower than a garden snail.

The cold gas starts out in a small, round blob, like an egg yolk, and is sculpted into something more like a thin eggshell or bubble. These ultracold bubbles can be used in new kinds of experiments with an even more exotic material: a fifth state of matter (distinct from gases, liquids, solids, and plasmas) called a Bose-Einstein condensate (BEC).

Durable clouds of these condensates exhibit wave-like properties including interference. Free from Earth's gravity, these cold atoms have lifespans on the order of seconds on the International Space Station, and in the future will be able to measure exquisitely small motions by acting as interferometers: merging light waves from two or more sources to create an interference pattern that can be used to infer physical properties of the light sources.

Exposing materials to different physical conditions is central to understanding them. It's also often the first step to finding practical applications for those materials. At such low temperatures, quantum behavior, usually the realm of the microscopic universe, becomes visible at macroscopic scales. By hosting experiments in conditions different from those of any place on Earth, CAL expands our understanding of matter and promises applications unimaginable under gravity's cloak.

↖ Gas Bubbles
Growth of an ultra-cold quantum gas bubble at close to absolute zero in CAL

MISSION
COLD ATOM LABORATORY

LOCATION
ISS

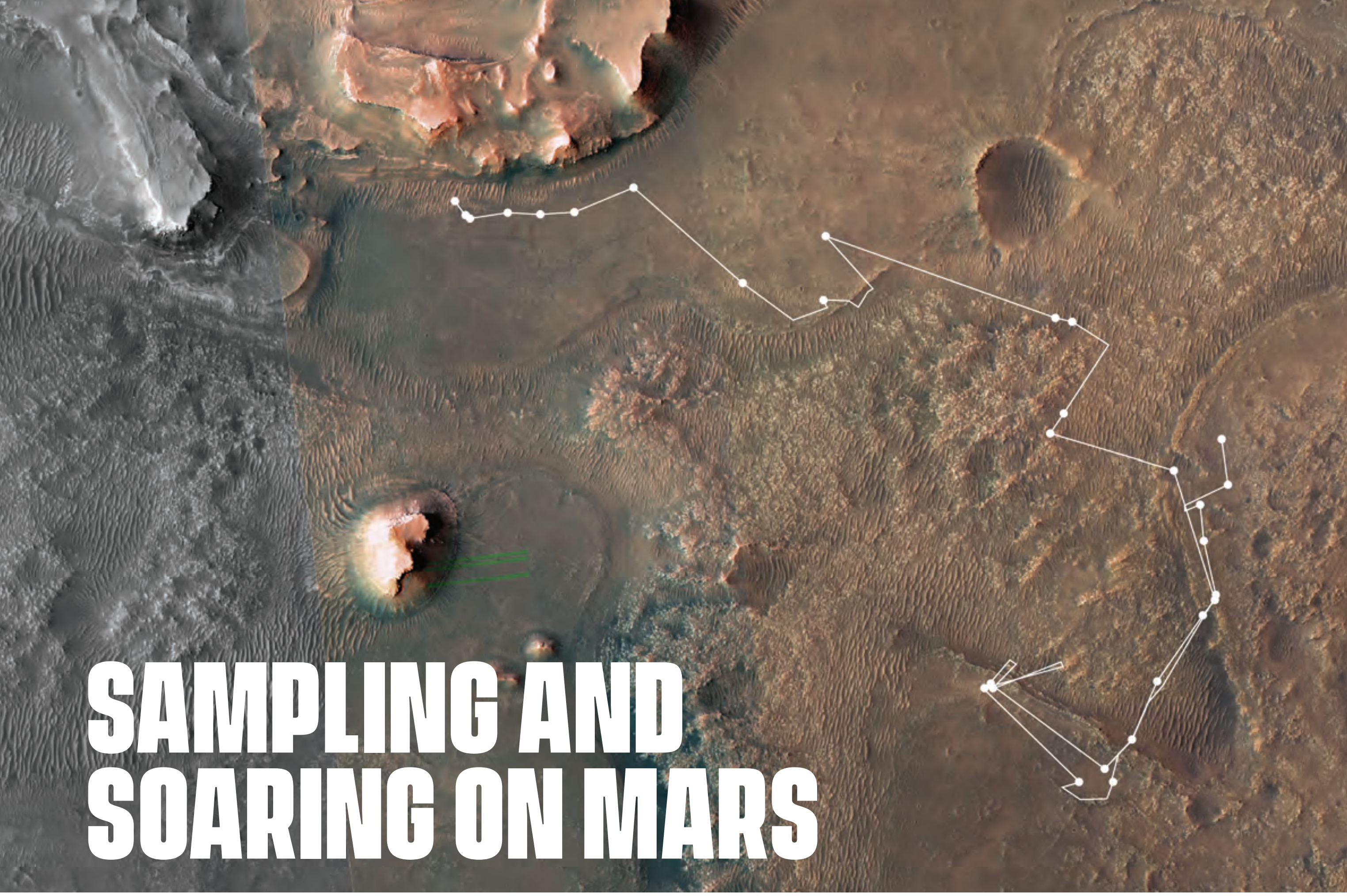
STUDYING
ULTRA-COLD QUANTUM GASES

LAUNCHED
2018

PLANETARY

↖ Family Portrait
Perseverance captures a selfie with Ingenuity on the surface of Mars.

Martian explorers whirled into higher gear with extensive drilling, caching and helicoptering — the latter two activities untried before 2021, and a year later taken almost for granted. Europa Clipper, the Lab's next flagship mission, began assembly and test in the high bay in preparation for a 2024 launch to an icy ocean world, and small but powerful spacecraft supported a new age in Moon studies.



SAMPLING AND SOARING ON MARS

↗ Out of Thin Air
Flight paths of the Ingenuity Mars Helicopter in Jezero Crater

NASA's Perseverance rover is well into its second science campaign to characterize Martian geology and past climate, pave the way for human exploration of the Red Planet, and become the first mission to collect and cache Martian rocks.

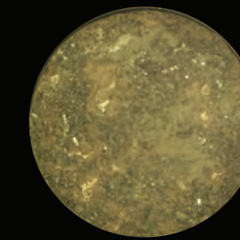
The rover has been extracting rock-core and regolith samples from an ancient river delta in Jezero Crater, an area long considered by scientists to be a top prospect for finding signs of ancient microbial life.

By the end of 2022, the rover had collected and cached more than 17 samples, with many more to go. The depot construction has started, with the first sample tube having been placed on the surface successfully. Perseverance is designed to collect up to 38 samples. In cooperation with European Space Agency, the next mission — Mars Sample Return — would retrieve the sealed samples and return them to Earth for in-depth analysis.

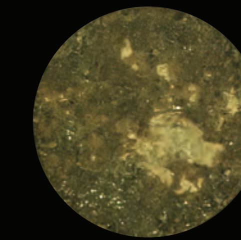
Also on Mars, Ingenuity, the little chopper that could, soared to its highest altitude of 46 feet on its 35th flight in Dec. 2022. The helicopter now has traveled 24,631 feet and remained aloft for a total of just over an hour on its Mars sorties.

Ingenuity landed with Perseverance and soon deployed from the rover's belly, embarking on a campaign to show that powered flight is possible in the thin Martian atmosphere. Initially designed as a technology demonstration, Ingenuity earned a mission extension from NASA that allowed the rotorcraft to keep pushing the envelope of Red Planet flight, performing reconnaissance for Perseverance, and implementing new capabilities such as landing hazard avoidance. Ingenuity's successes proved the operational value of rotorcraft on Mars, leading to the baselining of two Ingenuity-derived helicopters as part of the Mars Sample Return program.

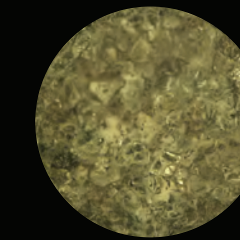
SAMPLE #1
ROUBION
DATE
AUG. 6, 2021



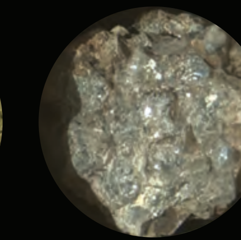
SAMPLE #2
MONTDENIER
DATE
SEPT. 6, 2021



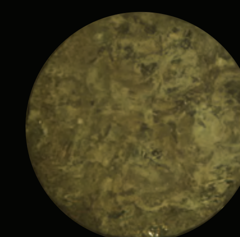
SAMPLE #3
MONTAGNAC
DATE
SEPT. 8, 2021



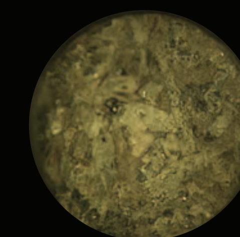
SAMPLE #4
SALETTE
DATE
NOV. 15, 2021



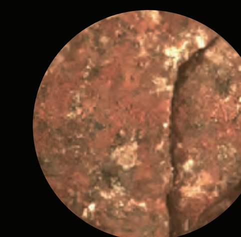
SAMPLE #5
COULETTES
DATE
NOV. 24, 2021



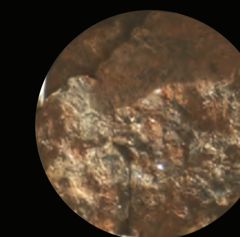
SAMPLE #6
ROBINE
DATE
DEC. 22, 2021



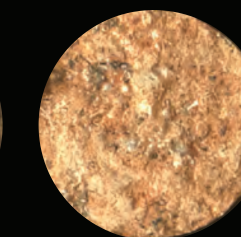
SAMPLE #7
MALAY
DATE
JAN. 31, 2022



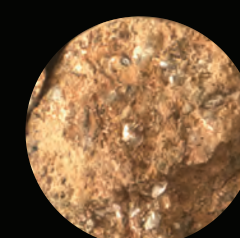
SAMPLE #8
HA'AHÓNI
DATE
MARCH 7, 2022



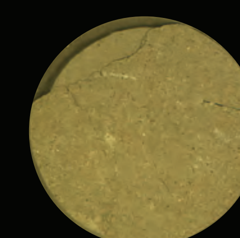
SAMPLE #9
ATSÁ
DATE
MARCH 13, 2022



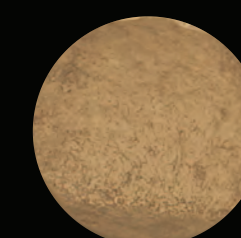
SAMPLE #10
SWIFT RUN
DATE
JULY 7, 2022



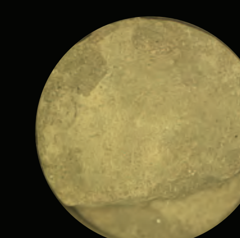
SAMPLE #11
SKYLAND
DATE
JULY 12, 2022



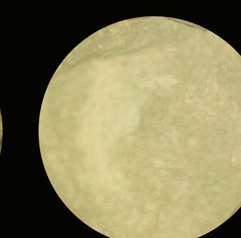
SAMPLE #12
HAZELTOP
DATE
JULY 27, 2022



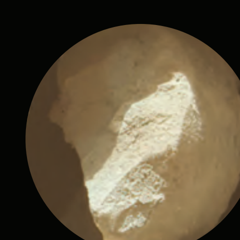
SAMPLE #13
BEARWALLOW
DATE
AUG. 3, 2022



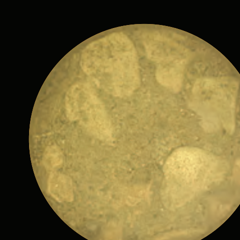
SAMPLE #14
SHUYAK
DATE
OCT. 2, 2022



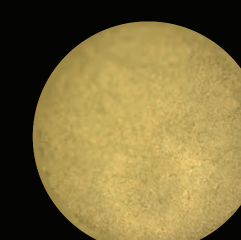
SAMPLE #15
MAGEIK
DATE
NOV. 16, 2022



SAMPLE #16
KUKAKLEK
DATE
NOV. 29, 2022



SAMPLE #17
ATMO MOUNTAIN
DATE
DEC. 2, 2022



SAMPLE #18
CROSSWIND LAKE
DATE
DEC. 7, 2022

COLLECTED SAMPLES

Of the 43 tubes Perseverance brought to Mars, 38 are for collecting samples, and five are "witness tubes" designed to document the cleanliness of its sampling system throughout the mission. As of the end of 2022, Perseverance had used 18 of the 38 sample tubes.

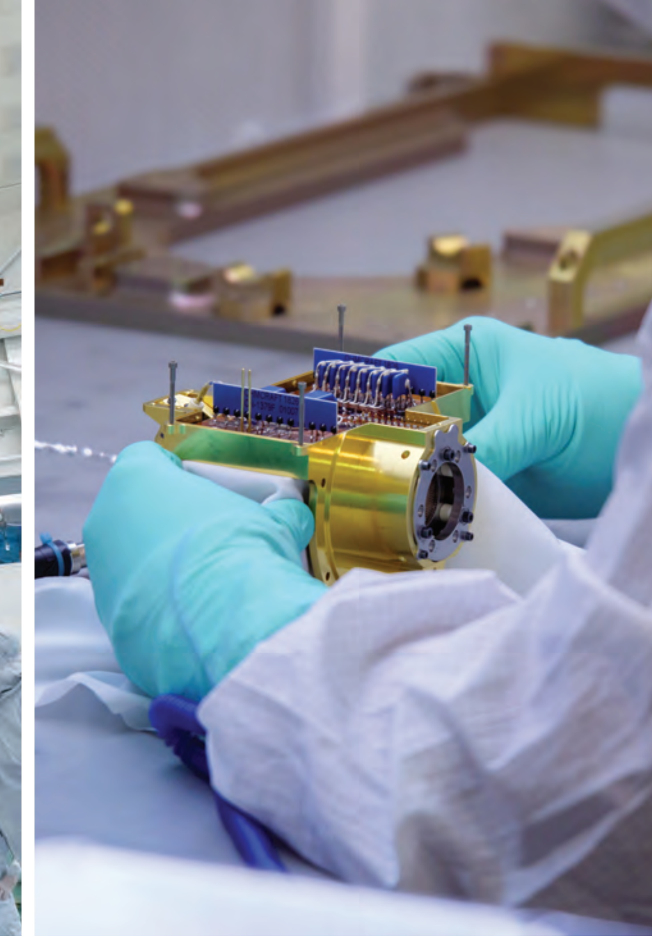
MISSION
EUROPA CLIPPER

TARGET
SECOND OF THE GALILEAN MOONS OF JUPITER

STUDYING
CONDITIONS POTENTIALLY HOSPITABLE TO LIFE

LAUNCH
2024

↖ Europa Clipper
Artist's rendering of the spacecraft above the icy moon



BUNNY SUIT HEROES, ICY MOONS, AND LIFE

NASA's bold mission to explore Jupiter's icy moon Europa is particularly tantalizing because scientists believe that, under its icy crust, the moon hides a global ocean that may harbor conditions hospitable to life. The Europa Clipper mission aims to investigate conditions on and below the surface of one of the four largest moons among the 80 orbiting the fifth planet from the sun. Europa Clipper is scheduled to launch in 2024, arrive at Jupiter in 2030, and perform three years of flybys to gather data to send back to Earth.

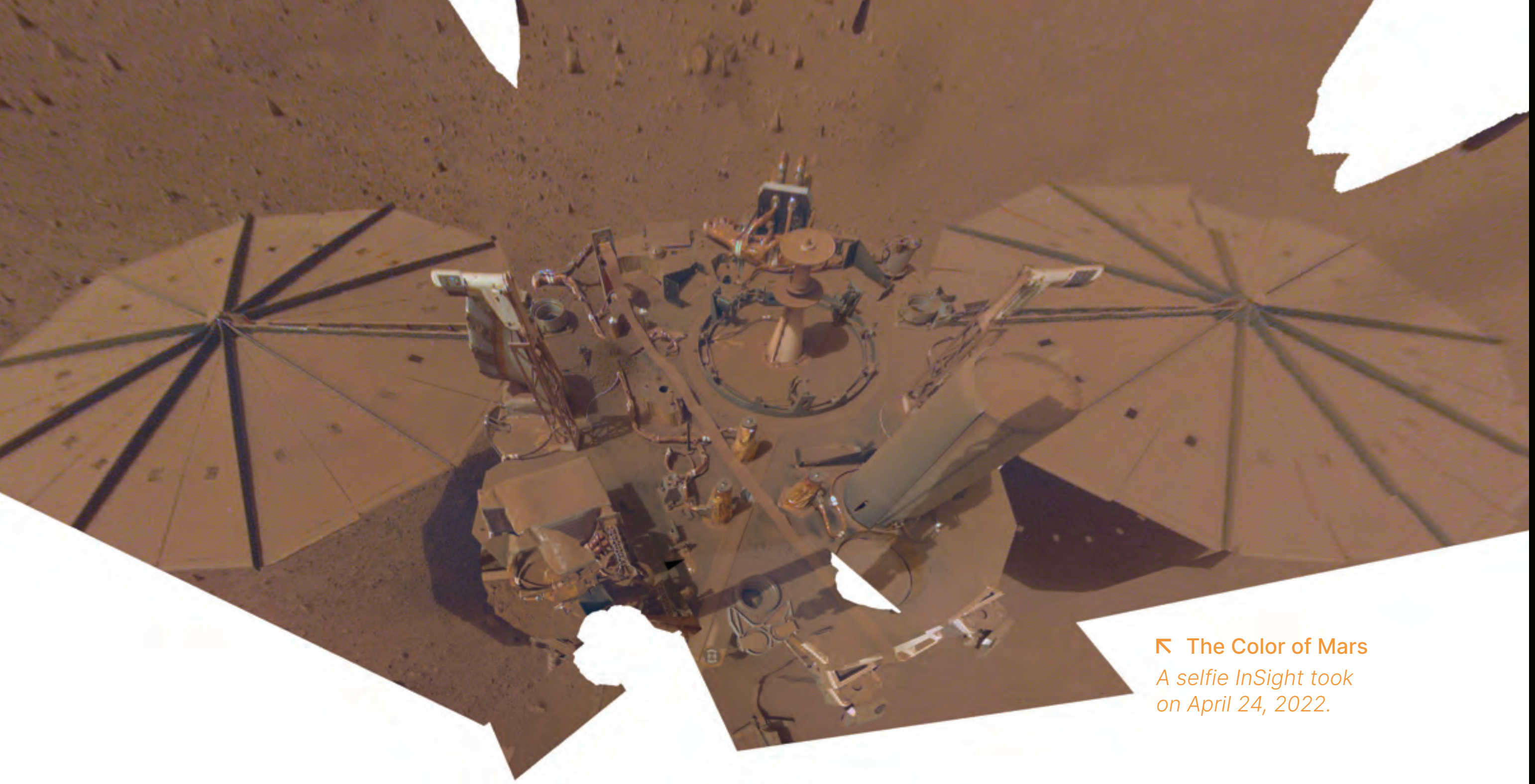
Europa Clipper will carry nine key instruments, including cameras, magnetic field sensors and other devices to identify materials at the moon.

Engineers are currently assembling the spacecraft in a clean room at JPL as the mission heads towards its next major milestone in early 2023. "You should recognize that every person you see in a bunny suit is a hero," Curtis Niebur, Europa Clipper program scientist at NASA, said during a meeting of the Outer Planets Assessment Group. JPL's assembly, test and launch operations engineers and technicians are an essential resource for mission development, and dozens of space missions have come through JPL's clean room.

Europa Clipper also will provide key reconnaissance data for a potential future Europa Lander mission, which could interact directly with the icy moon and further our understanding of potential life beyond Earth.

↖ Europa Rising
Flight technicians look up at Europa Clipper in the Spacecraft Assembly Facility.

↗ Detecting Specks
Integrating electronics onto the ion detector for Europa Clipper's SUrface Dust Analyzer (SUDA)



The Color of Mars
A selfie InSight took on April 24, 2022.

A DUSTY END FOR A GRITTY EXPLORER

MISSION
INSIGHT

TARGET
MARS

MEASURES
MARSQUAKES

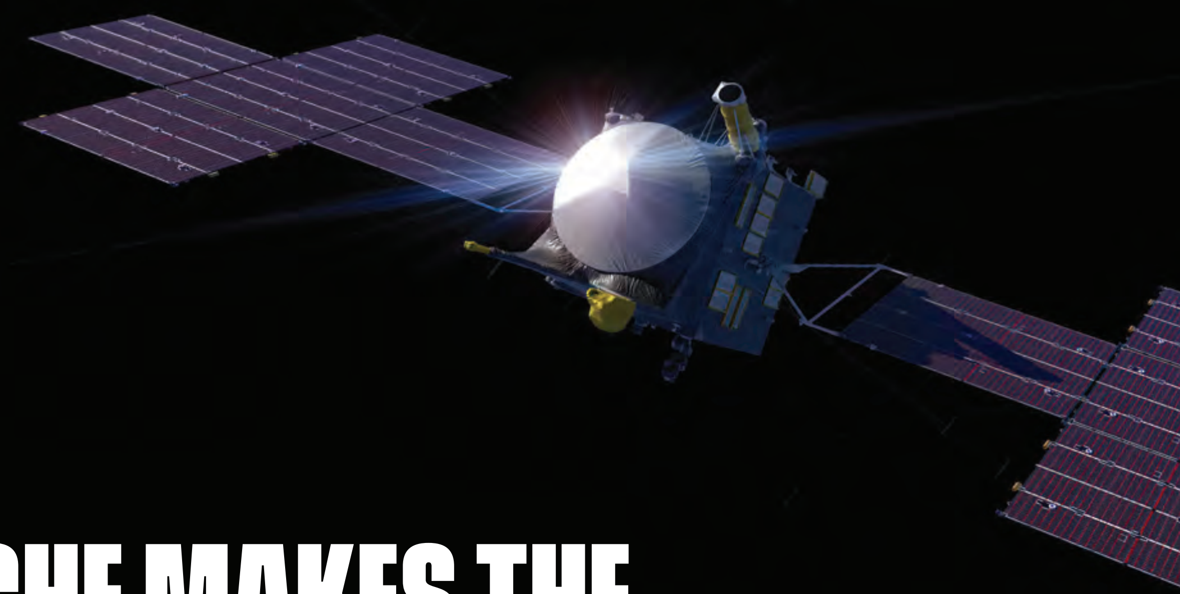
LIFESPAN
2018 - 2022

The end finally arrived in Dec. 2022 for NASA's Marsquake hunter, the InSight Mars Lander.

After four years of captivating scientific exploration, doubling its original two-year mission timeline, InSight entered its final days of operation. As thick layers of Martian dust blocked the craft's solar panels, it was time to say goodbye.

InSight was the first robotic lander to peer deep within Mars' interior to study its crust, mantle, and core. InSight has helped answer key questions about how rocky planets form and evolve in our solar system and throughout the universe. Over four years on Mars, InSight used over 1,300 Marsquakes to map the planet's crust, mantle and core; opened (with Mars Reconnaissance Orbiter) a new window into the study of meteoroid impacts; and recorded weather and magnetic field data that will prove invaluable to any future human mission.

The mission officially ended on Dec. 20, 2022, after the lander missed two consecutive communication sessions with the Mars Relay Network. Afterwards, NASA's Deep Space Network tuned in for a while, just to make sure the final curtain had fallen.

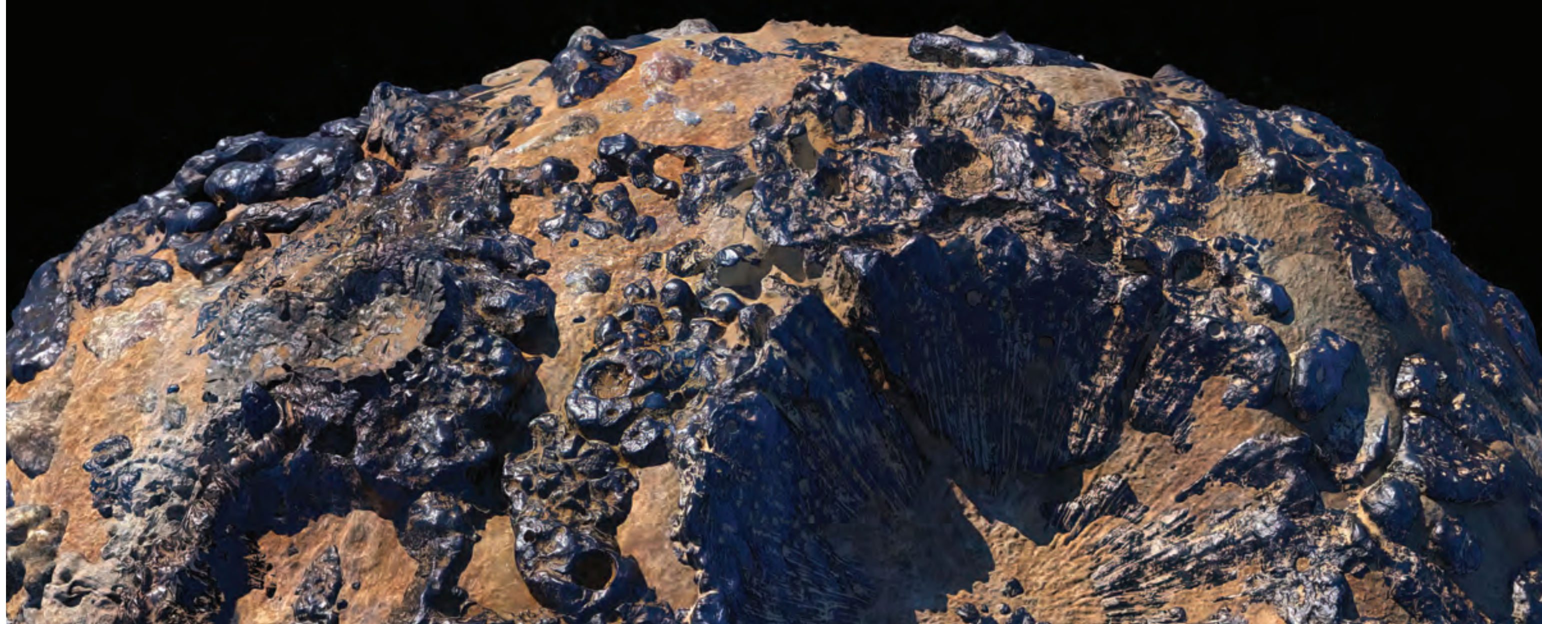


PSYCHE MAKES THE HARD DECISION

The Psyche mission completed hardware integration and environmental testing at JPL, and shipped to the launch site. However, the project team recommended a launch delay to complete critical functional testing and better prepare for operations. An independent review board, commissioned by NASA and JPL, identified multiple factors that contributed to the delay, including communication and efficiency impacts from the Covid work environment. Psyche responded fully to the board findings and established a comprehensive replan, approved by NASA in October, to complete work for launch in Oct. 2023.

The review board also found that JPL has an unprecedented workload with the implementation of spaceflight projects and many smaller missions. Based on a recommendation to balance JPL's workload and available resources, NASA decided to delay the VERITAS launch readiness date to no earlier than 2031.

Target in Sight
Artist's rendering of the Psyche spacecraft and metal asteroid



A THAW IN LUNAR SCIENCE

On Site
Engineers at Lockheed Martin integrate a JPL-developed Moon mapper onto the Lunar Trailblazer spacecraft.

Credit: Lockheed Martin Space

In Flight
Artist's rendering of Lunar Trailblazer

Earth's nearest neighbor still holds surprises: it was only a dozen years ago that water — in the form of ice — was discovered on the Moon by JPL's Moon Mineralogy Mapper (MMM) instrument.

Lunar Flashlight, a technology demonstration mission launched in Dec. 2022, and the upcoming Caltech-led Lunar Trailblazer, scheduled to launch in late 2023, are two of NASA's smaller missions for conducting water science at the Moon. These missions have medium-to-low complexity, short lifetimes (less than two years), low costs, few launch constraints, and significant alternative launch or re-flight opportunities.

No larger than a briefcase, Lunar Flashlight is designed to use four lasers to look for definitive signs of surface water ice. The mission is managed by JPL and operated by Georgia Tech, including graduate and undergraduate students.

Lunar Flashlight is the first interplanetary spacecraft to use a new kind of propellant that is safer to transport and store. One of the mission's primary goals is to test this technology for future use.

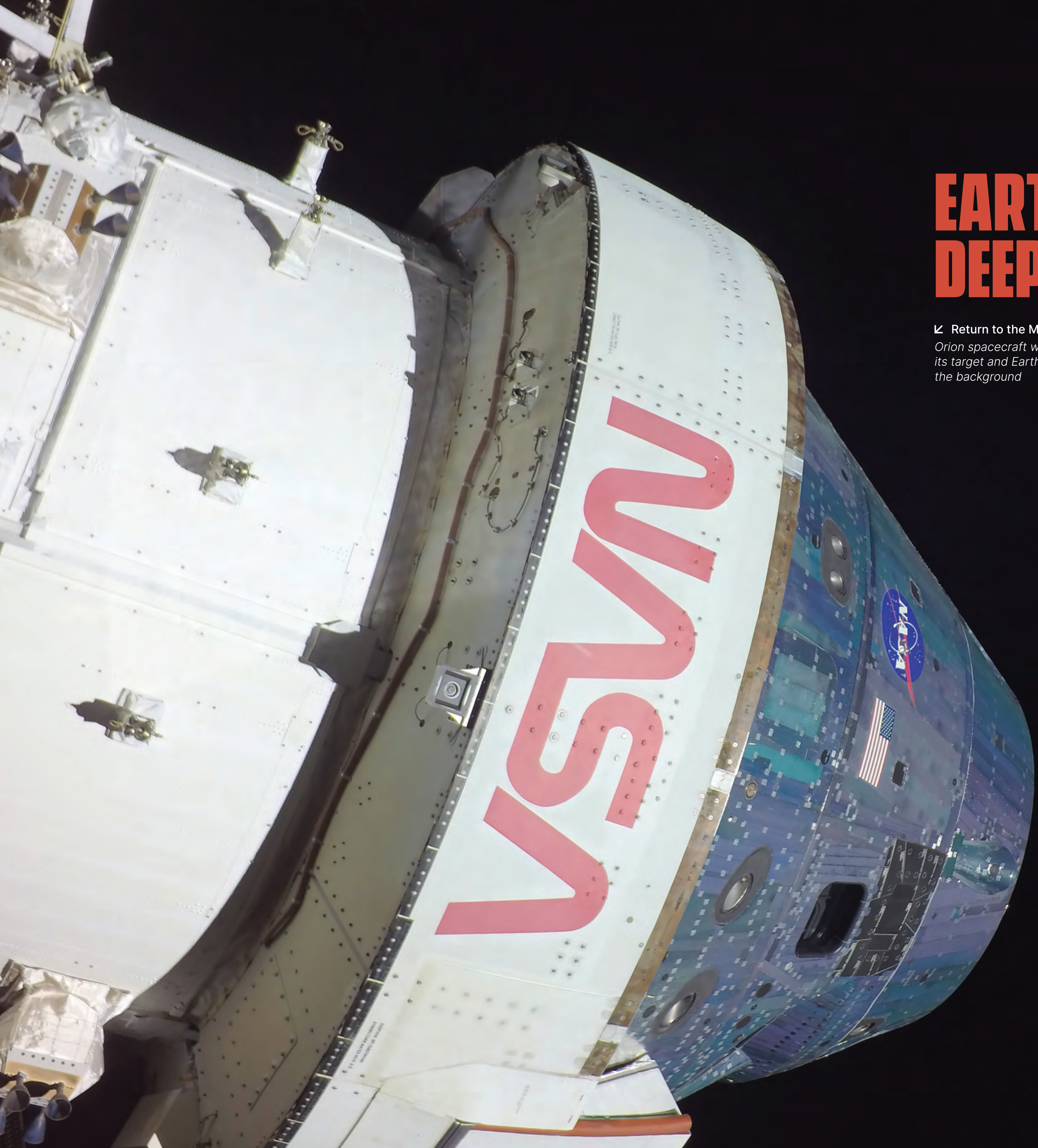
Trailblazer will place advanced infrared sensors in orbit for characterization of water on the Moon over space and time. Trailblazer remote sensing may help resolve questions about the character and origin of water in the Earth-Moon system, as well as characterize resources for future exploration.

The data collected by the two missions will enable comparisons with observations made by other expeditions, helping to chart the distribution of surface water ice on the Moon for planetary science and for potential use by future astronauts.

INTER-PLANETARY

↖ **A Dish of History**
Archival film image of the 70-meter DSS-14 antenna at the Goldstone complex in 1993

Behind every heroic feat of space exploration is an unsung hero. From Apollo to Artemis, from Viking to Voyager, the Interplanetary Network Directorate has supported almost every deep space mission in human history. The directorate's antennas and operations products answer the question other teams, centers and nations are spared from asking: who will track our missions in the void? Spacecraft conduct the science, and JPL's network conveys the data to Earth.



EARTH'S DEEPEST NETWORK

Return to the Moon
Orion spacecraft with its target and Earth in the background

At the heart of nearly all of NASA's complex space missions is an unseen quartermaster, a key system often referred to as the agency's ears: the Deep Space Network. Operated by JPL's Interplanetary Network Directorate, the DSN has played a crucial role in deep space communications since it began continuous operation in 1963.

The largest and most sensitive telecommunications system on the planet, the DSN maintains constant communication with spacecraft that venture beyond Earth's orbit. As of 2022, the network tracks and supports about 40 missions regularly, and still follows NASA's Voyager probes — the twin spacecraft that launched in 1977 and continue to fly far beyond our solar system.

For perspective, sending and receiving data to the Moon and back would take only a few seconds, but the same signal sent to Mars could take anywhere from 10 to 20 minutes to arrive. For a craft as far out of humanity's range as Voyager-1, it takes over 22 hours.

In its youth, the network was a critical part of tracking and communicating with the Apollo 11 Moon landing mission, and has since contributed to the success of dozens of NASA's most historic projects. One of those is the Artemis I program.

In late 2022, NASA's Orion spacecraft brushed the Moon, taking jaw-dropping new high-definition images of its crater-dotted surface — images beamed home thanks to the DSN. If Orion is one of Earth's latest heroes, then the DSN is the voice in our hero's ear. The DSN supported NASA's Artemis I program, its uncrewed capsule Orion, and the eight CubeSats released along the way.

As humanity seeks to plant a more enduring flag on the Moon, and to venture farther and deeper into our universe, the success of a spacecraft's mission often depends on its ground-based tracking system, the supporting character far from the limelight.

The DSN also supported another new hero: the James Webb Space Telescope. Webb will directly observe a part of space and time never seen before. The telescope will gaze into the epoch when the earliest stars and galaxies formed, over 13.5 billion years ago. Webb is designed to perceive their first light with unprecedented resolution and sensitivity.

The network supported all of Webb's 150 mission-critical deployments: sending messages to guide the spacecraft to its orbit one million miles from Earth, overseeing the unfolding of its 18 gold-plated hexagonal segments to create a 6.5-meter mirror, and activating its four science instruments.

As we peer ever deeper into space, the DSN is there to ensure we don't miss a single photon.

SPACE FLIGHT OPERATIONS FACILITY

The DSN operates out of the Space Flight Operations Facility at JPL. Established in 1963 at the conception of the DSN, this building is recognized as a national historical landmark.

ON ORDER: A FULL SET OF DISHES

To keep up with NASA's packed mission schedule, the nearly 60-year-old DSN is growing.

Deep Space Station 53 is a new 34-meter antenna that went online in February 2022 at DSN's ground station in Madrid. This is the fourth of six antennas being added to expand the DSN's capacity and meet the needs of a growing number of spacecraft. The fifth and sixth antennas to be added at Goldstone and Canberra will create a 15-antenna network by 2029.

The three DSN sites are located in Madrid, Spain; Canberra, Australia; and Barstow, California. DSN ground stations are spaced almost evenly around the world to ensure that NASA is able to monitor space missions while Earth rotates. Each complex is currently home to a 230-foot-wide antenna and several 111-foot-wide cousins that, besides communicating with spacecraft as Earth rotates, are also used to conduct radio science for studying planets and black holes.

Additional DSN improvements over the next few years will ensure the network has the capability to support new missions, specifically NASA's Gateway, an outpost that will orbit the Moon and provide support for long-term human lunar and deep space exploration.

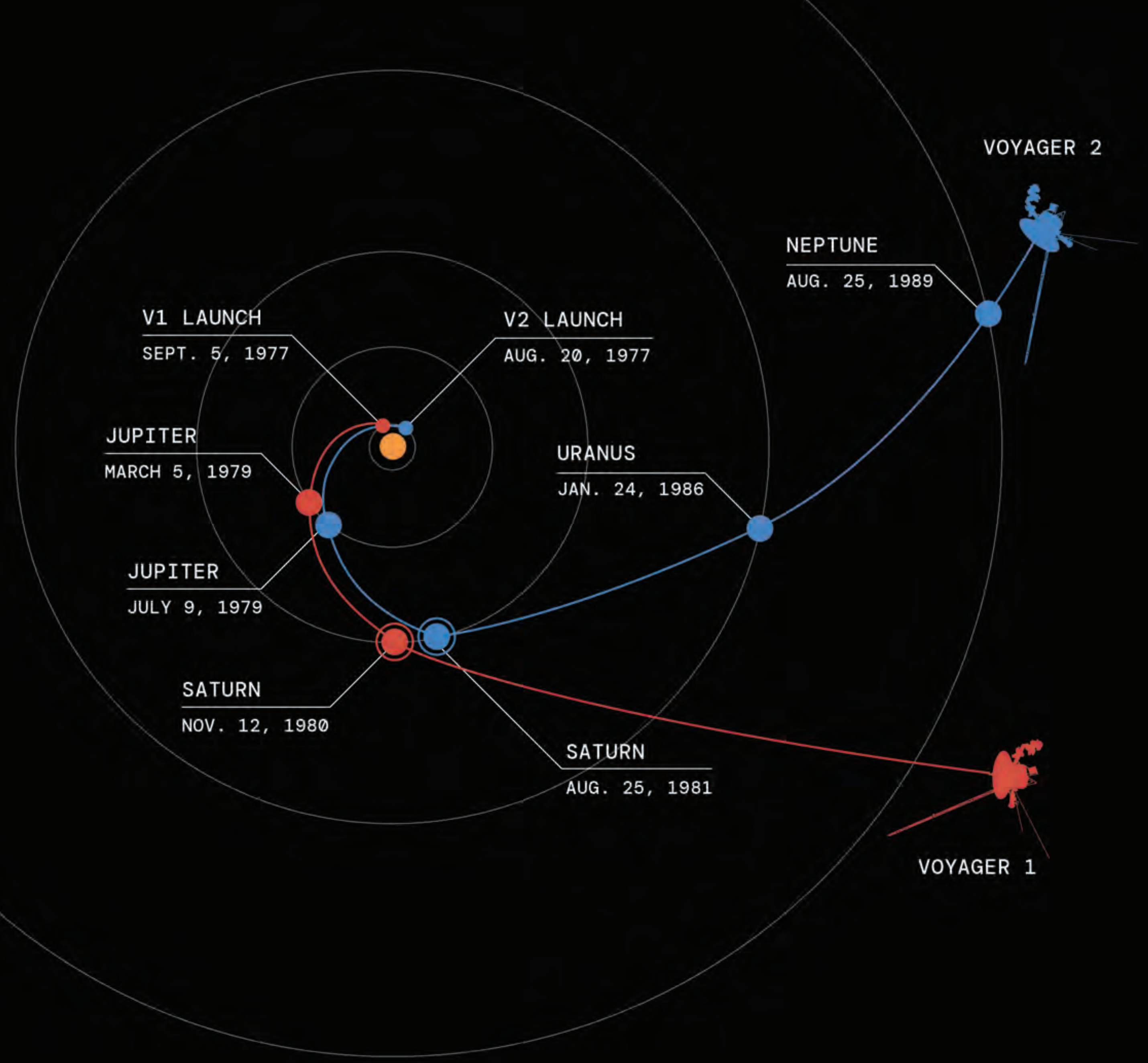
NAME
DEEP SPACE NETWORK

NUMBER OF ANTENNAS
14

SUPPORTS
OVER 40 MISSIONS

LOCATIONS
MADRID, SPAIN
GOLDSTONE, USA
CANBERRA, AUS

↗ A Newcomer
The 34-meter DSS-53 antenna in Madrid, Spain

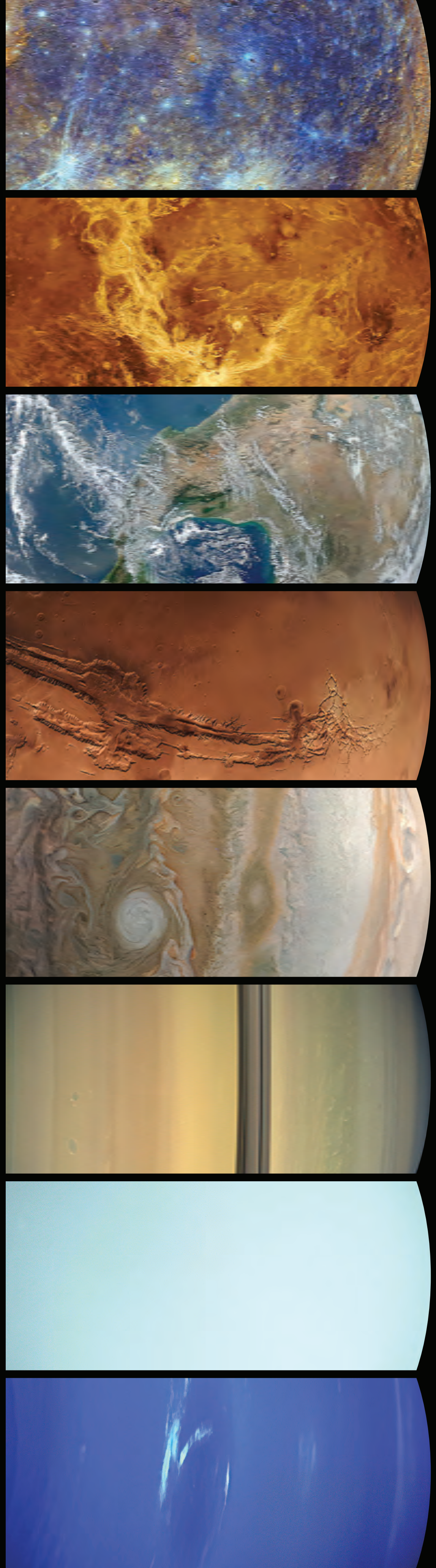


45 YEARS OF VOYAGER

The twin Voyager 1 and 2 spacecraft, launched in 1977, took advantage of a rare geometric arrangement of the outer planets, which only occurs every 175 years. The spacecraft have now flown far beyond the planets in our solar system and are deep in interstellar space, billions of miles from home.

Voyager has been supported by the Interplanetary Network across its entire 45-year journey, from the use of AMMOS products to near constant communications with the Deep Space Network.

Note: Graphic not to scale



↖ Go-to for Going Places
AMMOS products and services have supported missions to every planet in our solar system.

AMMOS: OPS IN A BOX

Developed and managed by the Interplanetary Network Directorate, the Advanced Multi-Mission Operations System (AMMOS) is NASA's recommended provider of operational products and services for NASA space science missions. AMMOS is a low-cost, highly reliable system used by more than 50 missions, including planetary exploration, deep space, Earth science, heliophysics, and astrophysics, and by multiple organizations including NASA, the European Space Agency, private ventures and academia.

AMMOS is based on a simple idea: for those elements of a mission operations system that are common to multiple projects, build once rather than duplicate that development and maintenance effort for each project. AMMOS provides a core set of products and services that can be readily customized to accommodate the specific needs of individual missions. The net results are:

- Lower costs for projects and NASA
- Shortened development cycles — weeks or months compared with years
- Reduced risk — projects enjoy the greater reliability of a mature, well-tested and exercised set of capabilities

AMMOS supports the full lifecycle of flight projects or experimental investigations specializing in support for critical events such as entry, descent, and landing, deep space trajectory correction maneuvers, and orbit insertion. AMMOS software also offers principal investigators, regardless of geographical location, the capability to interact with their instruments and their data.

Ultimately, behind every far-reaching, data-hungry spacecraft is a harmony of antennas and multi-mission products and services enabling humanity's sentries to explore farther.

EARTH SCIENCE

EMIT's Eyes
A color-coded view of minerals in desert dust in South Central Algeria, captured by the EMIT instrument aboard the ISS

Observation and application marched in parallel in 2022, as JPL's Earth Science Directorate launched the first mission to map the planet's waters, charted the movement of climate-altering dust, and worked with policymakers to translate awareness into action.

A WATERSHED MOMENT FOR EARTH STUDIES

↗ **Aloft at Last**
Artist's rendering of the SWOT spacecraft

The year ended with a new start for the study of Earth's waters, as the Surface Water and Ocean Topography mission launched into orbit in December 2022.

SWOT is designed to chart the levels and flows of more than 90% of the planet's water: oceans, seas, millions of lakes and nearly all rivers wider than a football field. Centuries after map makers mastered the contours of Earth's land masses, SWOT will become history's first water cartographer.

A collaboration of U.S. and French oceanographers and hydrologists, SWOT will use next-generation radar interferometry to make the first global survey of Earth's surface water, observe the fine details of the ocean's surface topography, and measure how water bodies change over time. As with stereoscopic vision and audio, radar interferometry combines signals reflecting off surfaces from slightly different angles to create three-dimensional maps.

↖ **Mississippi Flooding**
SWOT will monitor surface water changes, such as this 2016 flood along the Mississippi River.

SWOT will observe major lakes, rivers and wetlands while detecting ocean features with unprecedented resolution. The orbiter also will demonstrate how energy is transported by eddies and currents that previously were too small to measure from space. The mission's datasets are expected to prove critical in assessing water resources on land, tracking regional sea level changes, monitoring coastal processes, and revealing small-scale ocean dynamics.

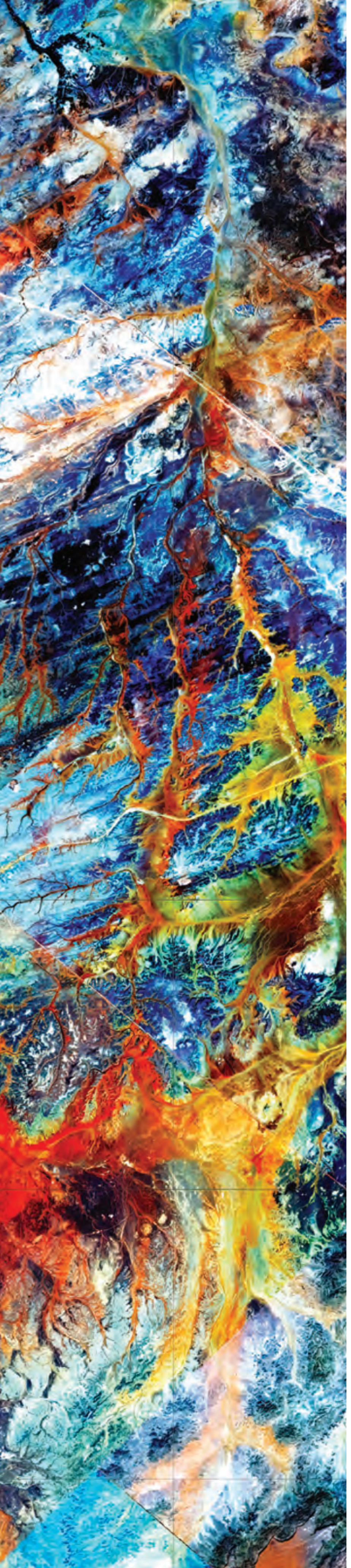
An important part of predicting our future climate is determining at what point the ocean will slow down its absorption of excess heat trapped in the atmosphere by increasing greenhouse gases, leaving them in the atmosphere to contribute directly to the warming of our global air temperature.

SWOT will provide crucial information about this global ocean-atmosphere heat exchange, improving forecasts of climate impacts and sea level rise. The mission's focus on rivers, lakes and inundation will help inform policymakers and their constituencies on the impacts and mitigation strategies for floods and droughts that are growing more frequent by the decade.

A mission already in orbit will work in synergy with SWOT by complementing observations of surface water with data on the hidden changes to our water reservoirs in the planet's vast aquifers. NASA's GRACE-FO, or Gravity Recovery and Climate Experiment Follow-On, consists of two satellites that follow each other 137 miles apart. Movements in massive stores of water underground cause minute changes in Earth's gravitational pull, which cause equally minute but measurable changes in the distance between the two satellites as they pass over the hidden bodies of water.

Aquifers — porous underground rocks or sediment containing groundwater — can provide lifelines to farmers and cities. But pumping them dry causes the land around them to sag, creating sinkholes, destroying infrastructure, and potentially collapsing this underground water storage system.

With SWOT and GRACE-FO, researchers will be able to combine data on water loss underground with information on surface water changes, creating a new model for monitoring agricultural regions that depend on water stored beneath the soil.



Dust in Full Color

EMIT identifies components in Northern Libya's ancient crystalline rocks by color based on mineral composition.

THE ANSWER IS BLOWING IN THE WIND

What blows through the Sahara doesn't stay in the Sahara.

The vast African desert regularly burps up clouds of dust that fly into Europe, sometimes turning snow-capped mountains orange. The clouds even travel across the Atlantic, fertilizing the Amazon rainforest and reaching the United States.

Theoretical models notwithstanding, scientists lack data to show definitively how dust may affect the planet, either by accelerating or slowing human-caused climate change.

NASA's Earth Surface Mineral Dust Source Investigation mission (EMIT) takes spectroscopy — which astronomers have used for decades to determine the composition of faraway objects — and directs it earthward. EMIT's maps will produce a global map of where dust is coming from, what it's made of, and how it might be influencing the climate.

Launched in 2022 and idled temporarily by a power outage on the ISS, the mission is expected to produce enough mineral dust maps within a year of operation to start revising climate models with reliable inputs on the influence of dust on our planet's temperature.

MISSION
EMIT

MEASURES
MINERAL DUST

TARGET
EARTH

LAUNCHED
2022

READING EARTH'S THERMOSTAT

A pair of toaster-sized satellites are poised to gather missing data to help scientists better understand how the polar regions regulate Earth's temperature and climate.

The Polar Radiant Energy in the Far Infrared Experiment (PREFIRE) will probe a little-studied portion of the radiant energy emitted by Earth for clues about Arctic warming, sea ice loss, and ice sheet melting. The satellites should operate for at least a year, but could potentially provide the team with data for up to four years.

In 2022, the PREFIRE team delivered two miniaturized spectrometers for integration onto its miniaturized satellites. The instruments will orbit Earth's poles to observe and measure emissions, allowing scientists to assess how changes in emissions at the top of Earth's atmosphere are related to climate change.

PREFIRE Orbit

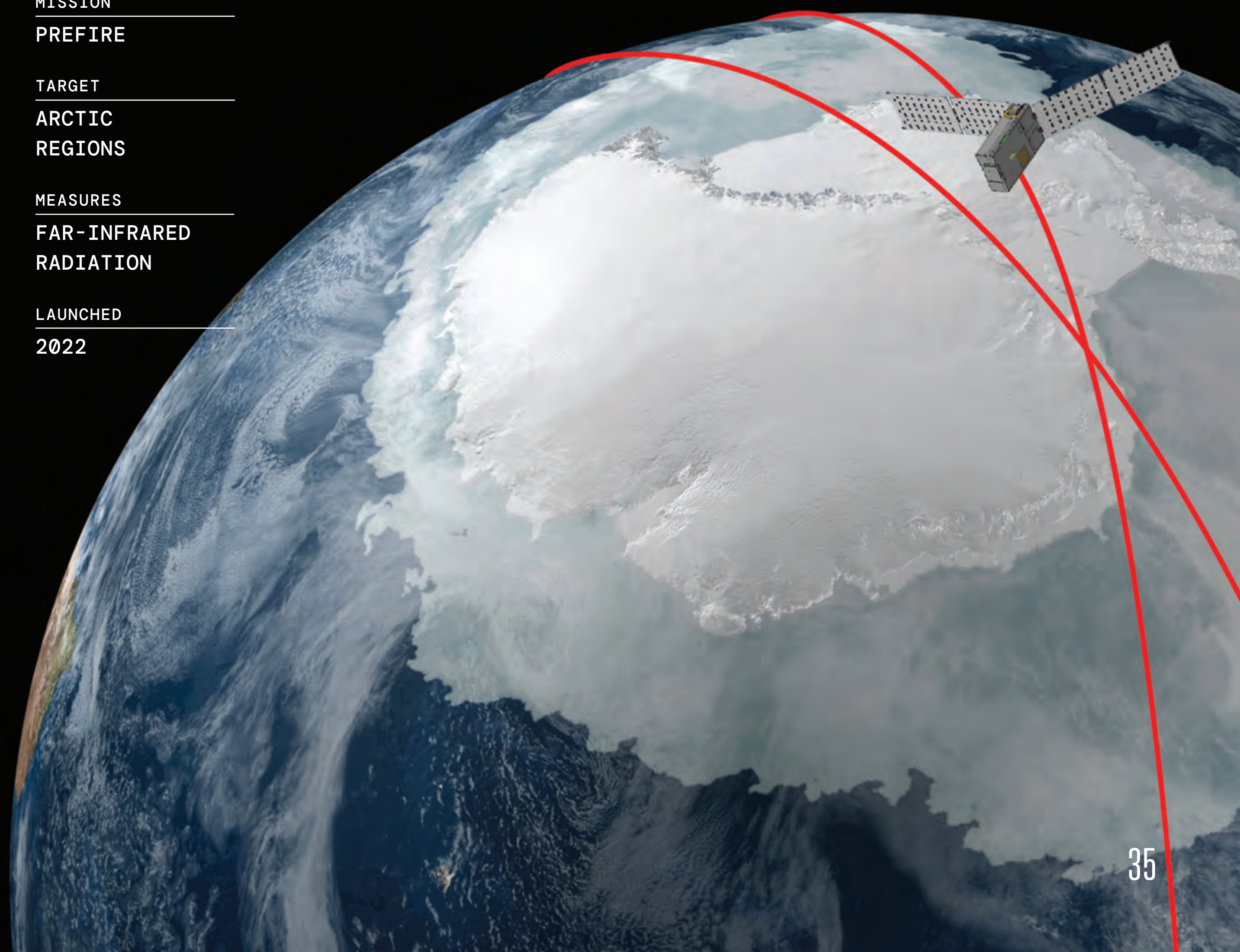
Two CubeSats in polar orbits sample Arctic and Antarctic surfaces and clouds.

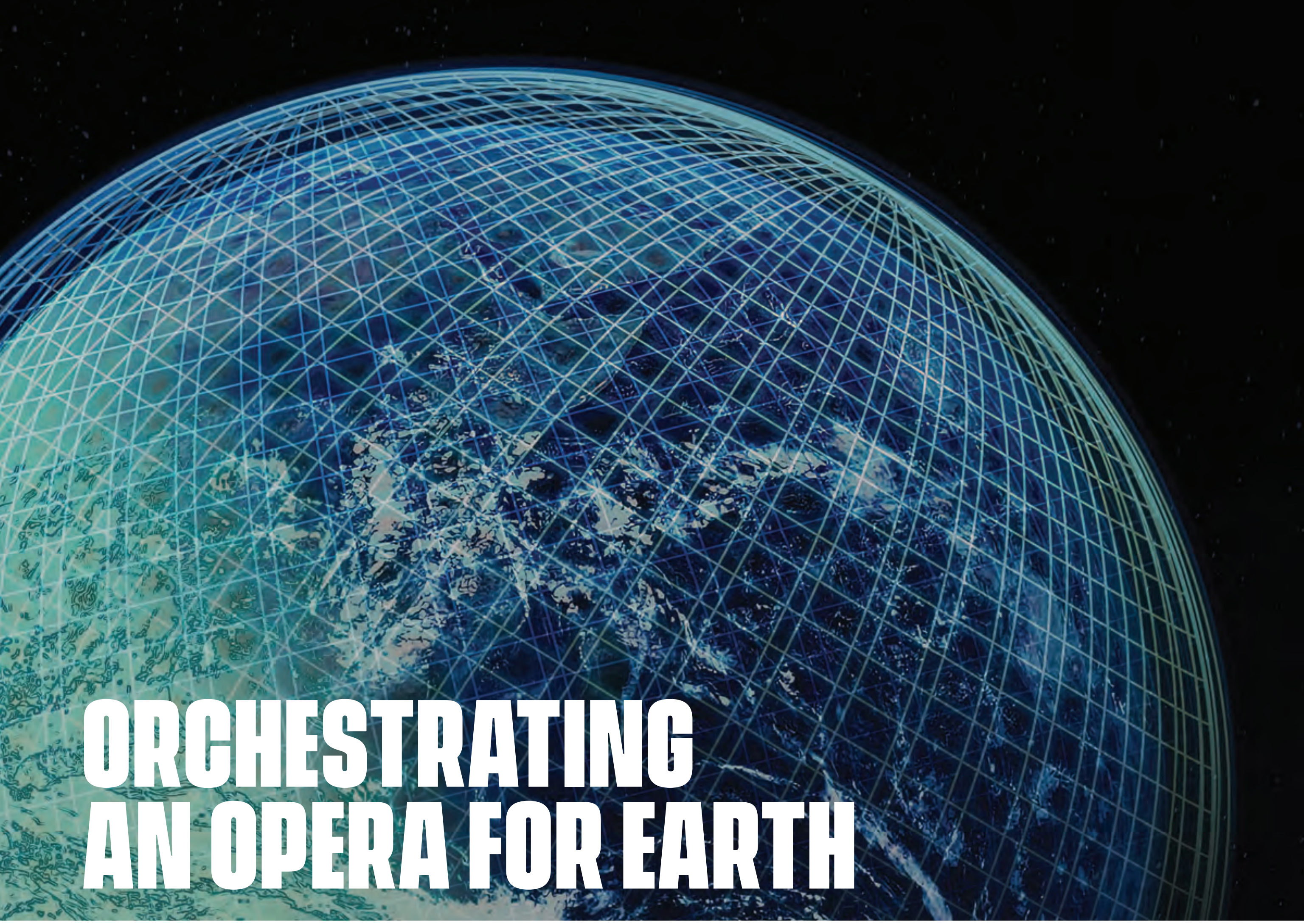
MISSION
PREFIRE

TARGET
ARCTIC REGIONS

MEASURES
FAR-INFRARED RADIATION

LAUNCHED
2022





ORCHESTRATING AN OPERA FOR EARTH

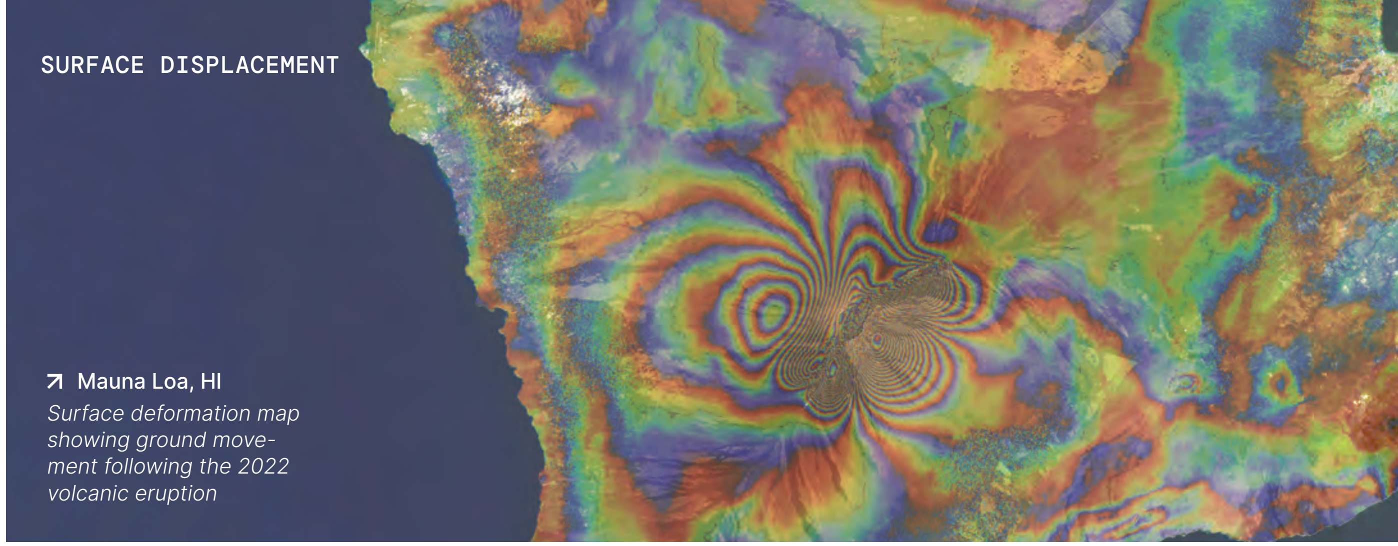
Decoding Earth
OPERA will use data from current and future Earth-orbiting satellites to generate three product suites for policymakers.

Bringing together data and making it sing requires the right conductor.

JPL is the conductor of Observational Products for End-Users from Remote Sensing Analysis (OPERA), an initiative to produce analysis-ready data products from satellite radar and optical instruments. These data products address 31 distinct needs from 20 federal agencies. OPERA aims to inform agency leads and decision makers, as well as practitioners involved in hazard monitoring, resource management, and environmental monitoring.

In collaboration with several government and academic partners, Earth scientists and engineers at JPL are leading the development of three product suites that track near-global surface water extent; near-global surface disturbance; and North American land surface displacement. In 2022, JPL led two workshops that brought together 186 participants from 25 federal agencies, several state and federal institutions, academia, and the private sector to ensure that the OPERA products in development will hit the right notes.

In a parallel project to bridge the distance between data and decisions, JPL and Caltech's Keck Institute for Space Science (KISS) led two one-week, in-person workshops with over 30 scientists and engineers to discuss the challenges and opportunities associated with establishing a better framework for achieving continuity for the most important satellite observations of Earth. Increasingly, sustained observations are becoming critical to support Earth and climate change science, future projections of climate, and climate and environmental services. The participants were set to release their report in early 2023.



Mauna Loa, HI
Surface deformation map showing ground movement following the 2022 volcanic eruption

Lake Mead, CA
Lake level in 2016 (light blue) compared to 2022 (dark blue)

Mosquito Fire, CA
Red areas showing vegetation loss from California's largest wildfire of 2022

ENVIRONMENTAL MONITORING

OPERA products allow us to assess, understand and respond to changes on Earth. The examples above overlay data on satellite imagery and demonstrate applications for monitoring surface displacement, surface water extent, and surface disturbance.

MONITORING EARTH'S VITAL SIGNS

↖ Testing, Testing
NISAR undergoes testing in the 25-foot Space Simulator at JPL.

↘ NISAR in Context
Artist's rendering of the spacecraft above Earth with person (5'6") for scale

MISSION
NISAR

TARGET
EARTH

MEASURES
HAZARDS
BIOMASS
ICE LOSS

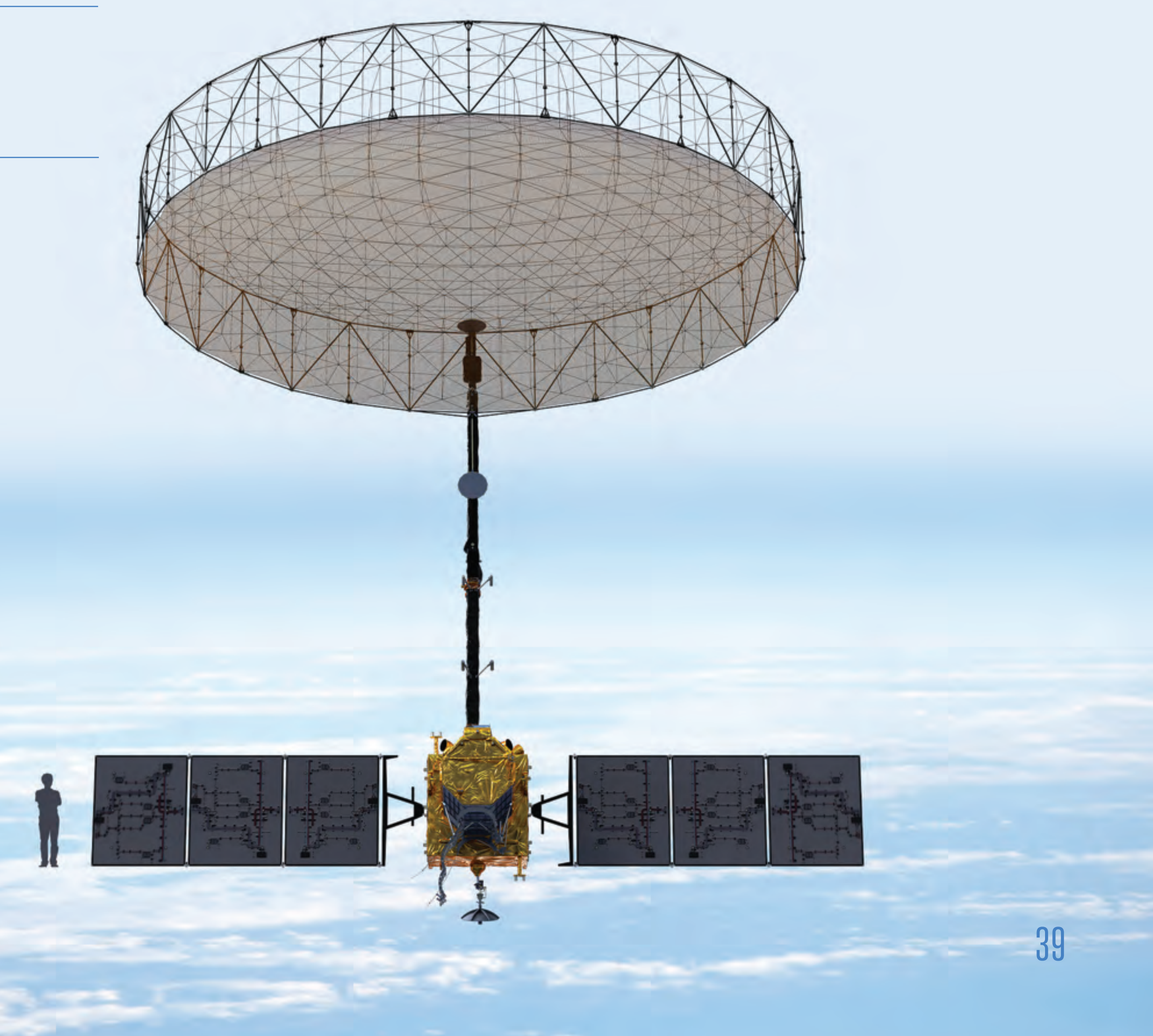
LAUNCH
2024

NASA and the Indian Space Research Organization (ISRO) have developed a unique system, scheduled to launch in the fall of 2023, for taking measurements of our planet's vital signs.

The NASA/ISRO Synthetic Aperture Radar mission, or NISAR, is designed to observe and provide detailed views of some of our planet's most complex surface ground movements, such as ecosystem disturbances, ice sheet collapse, earthquakes, tsunamis, volcanoes, and landslides.

NISAR will be the first satellite mission to measure these changes by using two different radar frequencies (L-band and S-band) to sample Earth every six days for three years.

The data will reveal information about the evolution and state of Earth's surface, including its land surface, ice sheets, and vegetation, to help scientists better understand our planet's processes and changing climate, and aid future resource and hazard management around the globe.



TECHNOLOGY

↖ Switch on for Water
Contactless rotating microswitch enables water detection for comet and planetary radar science

JPL technology in development today inspires the missions of the future. From the tracking of wildfire plumes to the parting of cosmic curtains, innovations breaking the surface on Lab may take flight in coming decades, deepening our knowledge of the universe and of our changing planet.

↙ Visible from Space
Wildfire plumes over Texas as seen from the ISS

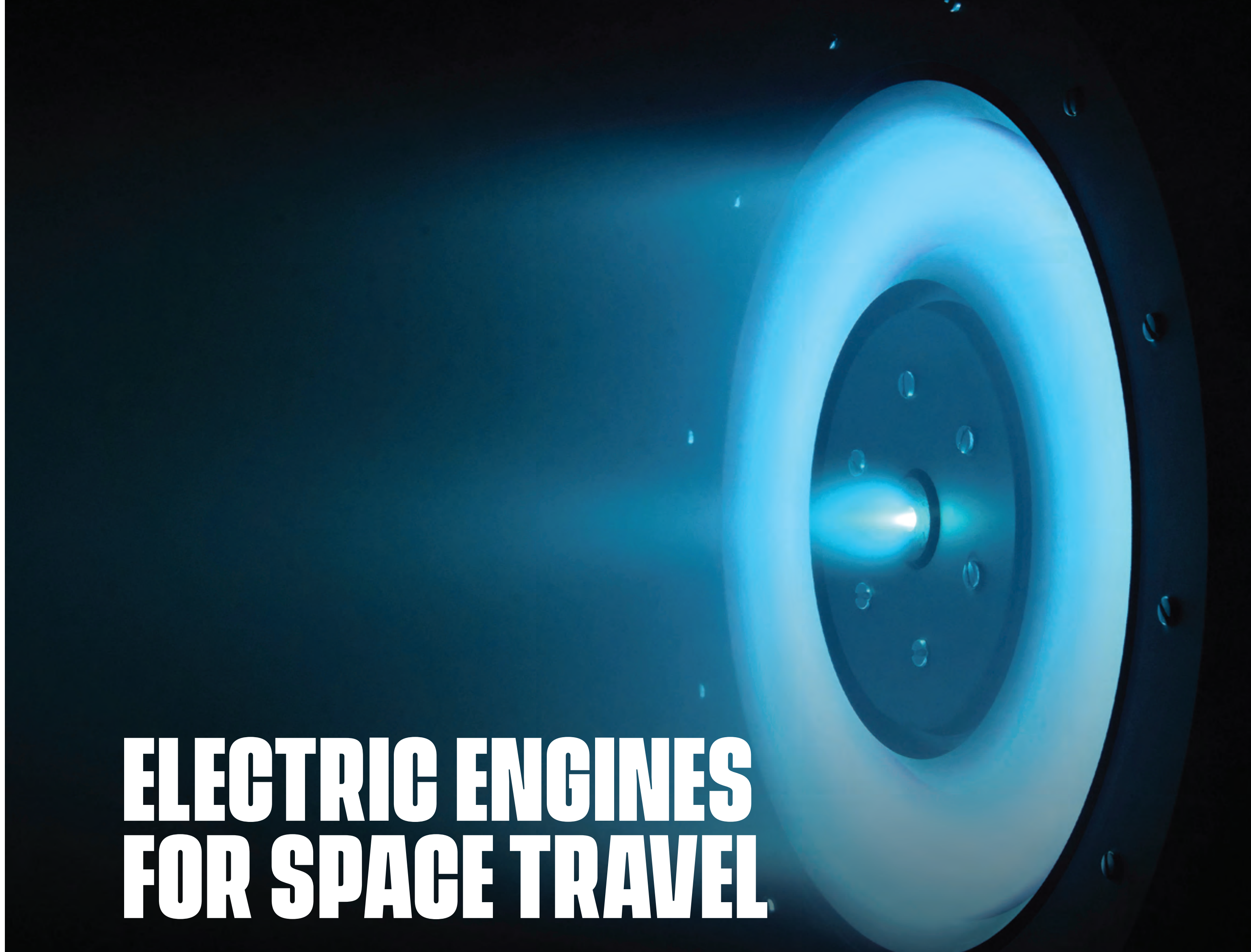
WHERE THERE'S FIRE

We are in the decade — maybe the century — of the wildfire. From the west coast of the United States to the Brazilian rainforest, climate change-induced wildfires are raging across the globe. Above the blackened ecosystems and habitats rise massive ash clouds of carbon particulates that have adverse effects on living creatures.

Modeling these massive smoke plumes is a bit like trying to predict the behavior of a wild animal — they move in random and unpredictable ways. JPL is working on software that will help track the plumes by integrating time-based observations, artificial intelligence, and machine learning.

This software will be able to learn from past plume behavior to better model and predict the impact of future wildfire events. The software will also be able to capture and integrate data from upcoming NASA Earth missions focused on particulates, providing increasingly detailed analyses and predictions of future ash clouds, including those from volcanoes.

Better understanding the mechanisms behind the spread and propagation of these clouds will become increasingly important as greenhouse gases continue to build in our atmosphere, magnifying the climate changes that raise the risk and severity of wildfires across large swaths of Earth.



ELECTRIC ENGINES FOR SPACE TRAVEL

↗ Pushing Forward
Next-generation thrusters are being designed that operate at power densities many times higher than existing technology.

Propulsion — or the lack of it — remains a major hurdle for extended robotic missions and for NASA's ambitions to send humans into deep space.

Conventional rockets, which use chemicals as fuel and are best suited for short-duration, high-power propulsive needs, are already at the outer edge of their limits. Nuclear thermal propulsion as a high-performance alternative has been studied since the 1960s, but while progress has been made, there remain significant technical challenges to overcome.

Electric propulsion is showing new promise for long-duration missions at great distances. Able to accelerate continuously — albeit at a low thrust level for months or years at a time — electric thrusters have proven their utility on expeditions such as the Dawn mission to the asteroids Vesta and Ceres and the Psyche mission slated to launch in 2023.

JPL engineers are optimizing these electric engines by developing a 10-kilowatt Hall thruster, the H10, that features 50% greater propellant efficiency than current designs, made possible by power densities two to three times greater than currently available. The H10 will also be capable of large throttling ratios in thrust, a feature that will greatly expand the reach of future mission designs.

These high-performance, deep-throttling thrusters will open the door for a new generation of compact, less costly, and highly efficient spacecraft that will expand JPL's mission of exploring the solar system and beyond.

NEW RECIPE FOR GEOMETRIC FREEDOM

As robotic spacecraft become increasingly capable of detecting faint signals from stars, planets, and other objects in the universe, they also become more and more sensitive to interference from “noisy” onboard subsystems like reaction wheels and cooling systems.

Currently, these noisy devices are shielded by metallic enclosures. The shields are usually machined by carving solid pieces of metal. Also known as subtractive manufacturing, the process is expensive, time-consuming, and a disproportionate contributor to the overall weight of the spacecraft.

Complicating the fabrication of these shields is the need to produce intricate shapes such as baffles and other challenging geometries to maximize shielding effectiveness.

In contrast, a new additive manufacturing approach at JPL uses a combination of blown powder laser deposition, 3D metal printing, and post-process thermal treatments. The result: a giant leap in performance over shields carved from a block of metal. For example, different magnetic alloys can be used in a single part to fine-tune shield performance. And unusual geometric features become a simple matter of code, rather than a conundrum of carving.

This approach creates the geometric freedom to rapidly manufacture complex, high-performance and lightweight shield designs for ever more capable robotic explorers.

↖ **More than the Sum**
High-intensity laser-based 3D printing system for additive manufacturing

↘ **Printing Metal**
Close-up of a 3D printed multi-material magnetic shield with unique geometry

A QUANTUM LEAP IN SENSITIVITY

NAME
QUANTUM CAPACITANCE DETECTOR

TARGET
FAINT, DISTANT OBJECTS

MEASURES
INFRARED LIGHT AND PHOTONS

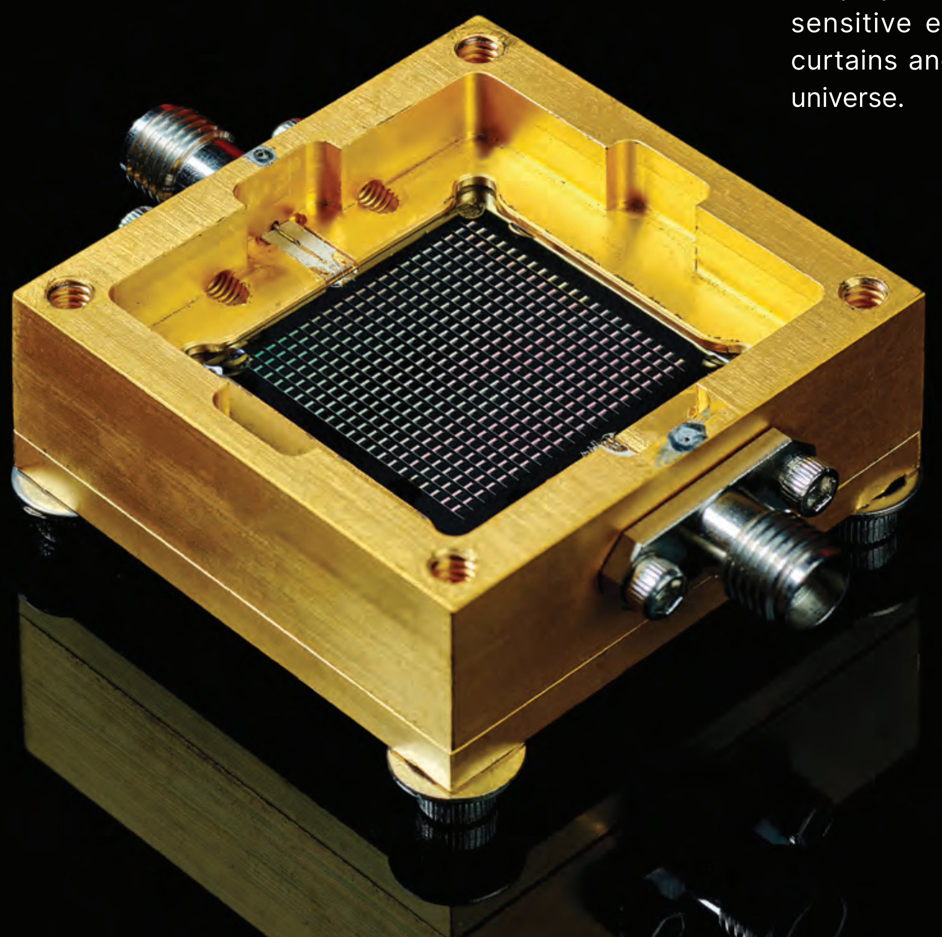
The universe is a dirty, dusty place.

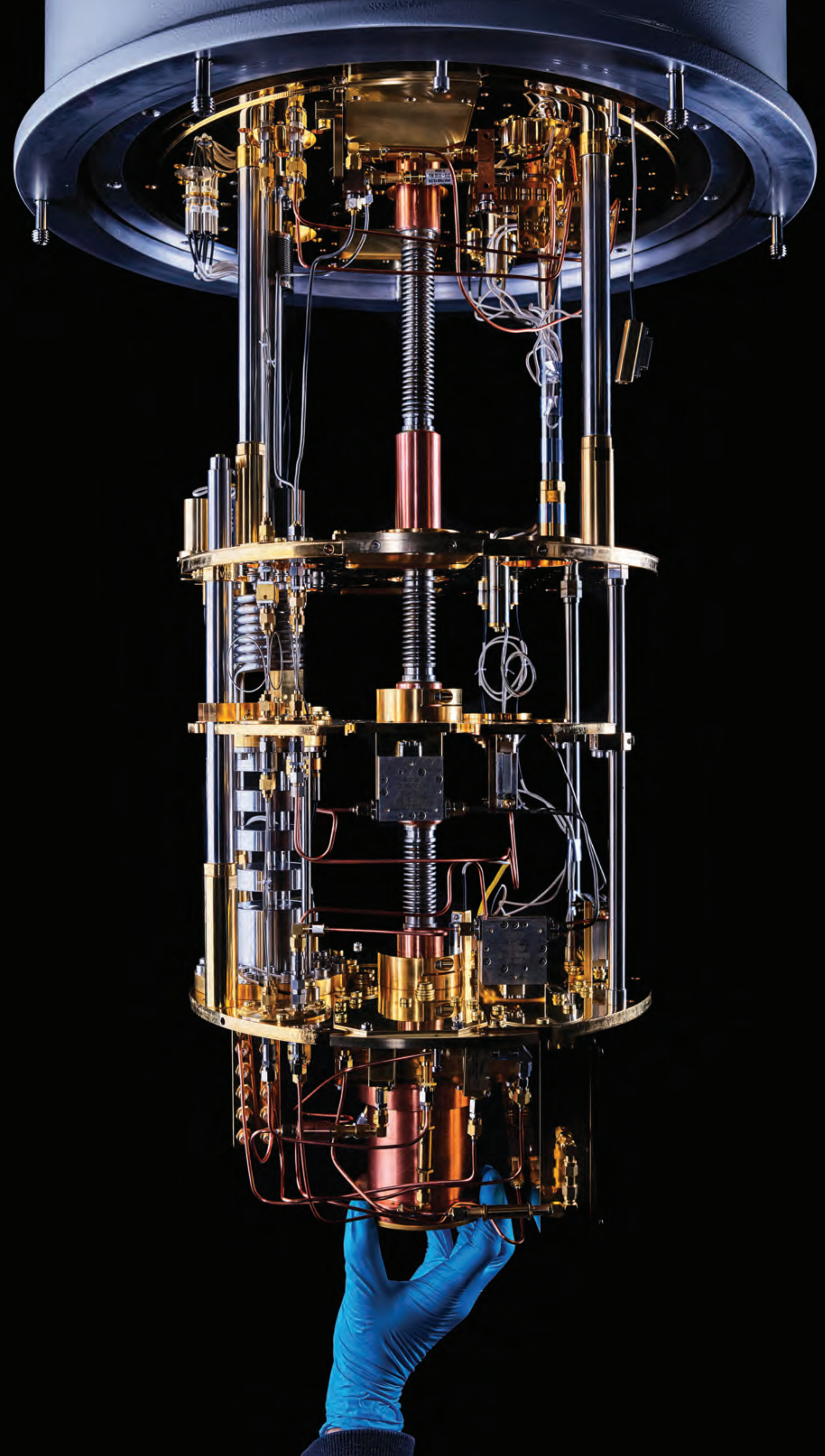
Huge particle clouds, left over from the formation of the universe, shroud vast swaths of the cosmos and prevent us from making deeper observations. Fortunately, these clouds are transparent to infrared light.

Infrared astronomy is not new. But JPL is planning to break through even the thickest clouds by developing a new class of extra-sensitive infrared detectors called Quantum Capacitance Detectors. Quantum detectors use superconducting surfaces designed to generate an "artificial atom" that is extremely sensitive to external energy — in this case, infrared light or photons coming from very faint, distant objects. Because the electrons within this superconductor are held together very weakly, the bonds are easily broken by incoming photons. Each time a bond is broken, a photon is detected.

These sensitive detectors, arranged in large arrays, promise to help unveil the origins of galaxies and black holes, trace the trail of water from molecular clouds to proto-planetary disks, and revolutionize our understanding of planetary system formation.

After centuries of observing visible deep space, we will have instruments sensitive enough to part the heavy curtains and view the first act of the universe.





↗ Quantum Fridge
A cryogen-free dilution refrigerator used in the characterization of QCDs

↖ Up Close
An array of QCDs with lenses to focus radiation on the detectors

"JPL embraces the limits of the possible: from deciphering the effects of Earth's changing climate to hopscotching among the planets of our solar system to revealing the mysteries of the universe. JPL and Caltech campus researchers create knowledge for the ages and invent technologies that improve people's lives today."

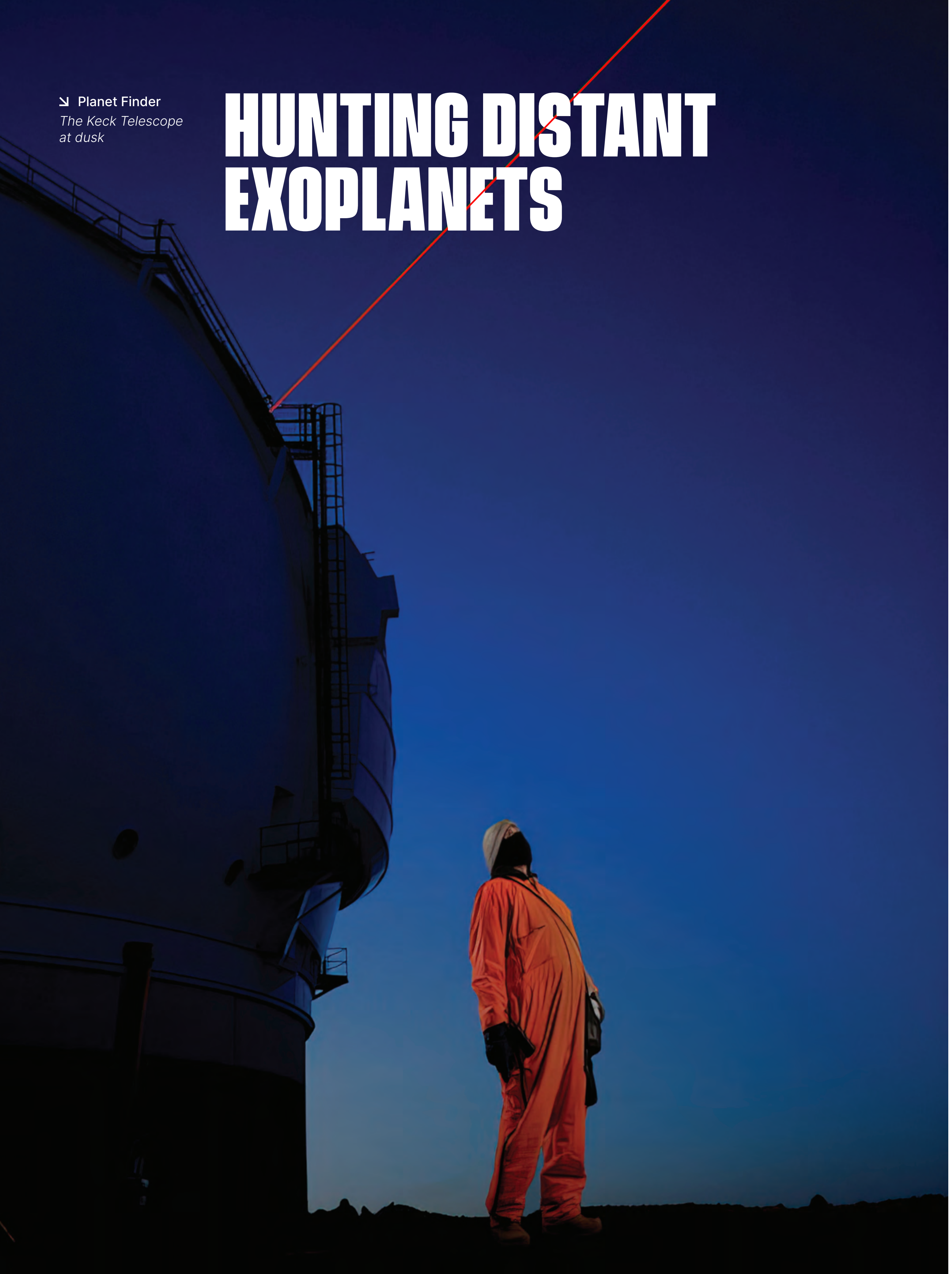
THOMAS F. ROSENBAUM
President, Caltech

CAMPUS & LAB

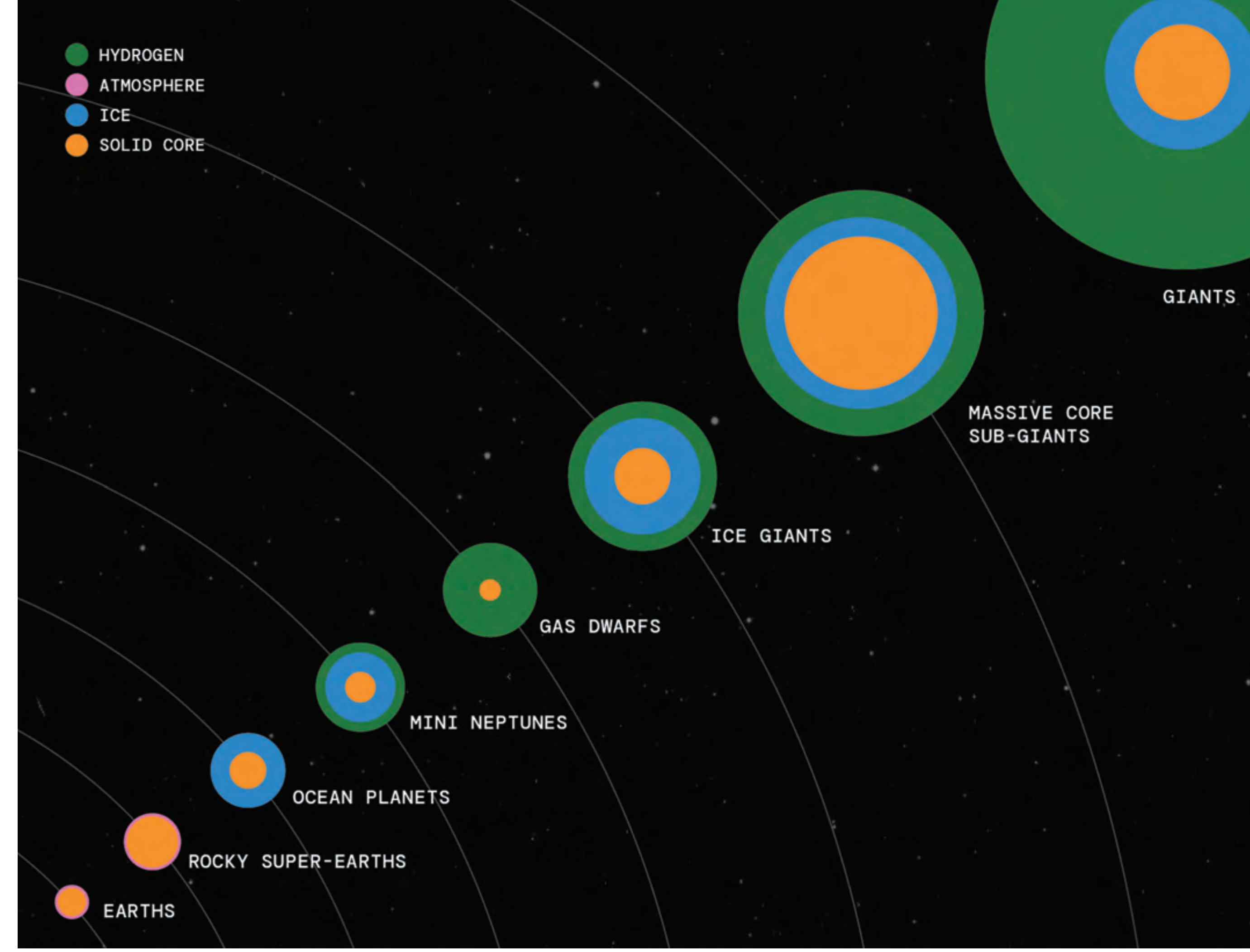
↖ Caltech Campus
Beckman Auditorium

On campus, on Lab, and across the world, scientists and engineers from Caltech and JPL, which Caltech manages for NASA, illuminate the details of our universe — from melting ice shelves on Earth to black hole winds in our galaxy — and collaborate on a wide array of boundary-pushing projects and proposals, including the search for distant exoplanets, a flying carpet-like constellation of solar panels, and a self-deploying lunar robotic transport system.

HUNTING DISTANT EXOPLANETS



Planet Finder
The Keck Telescope at dusk



Worlds Apart
Different types of exoplanets and their compositions

The Caltech-led Keck Planet Finder (KPF) at the W. M. Keck Observatory in Hawaii is poised to search the night sky for undiscovered exoplanets that may be promising candidates for alien life. Over the last few decades, astronomers have identified thousands of planets orbiting stars outside of our solar system, but the limits of current technologies have hampered the search for Earth-sized exoplanets.

As exoplanets, which range from molten lava worlds to giant gas planets, orbit their host stars, their gravitational tugs cause their stars to move back and forth ever so slightly. This wobble creates a periodic shift in the wavelength of light emitted by the star, and that shift contains clues to the presence and properties of an exoplanet. Currently, our ability to identify smaller exoplanets is limited due to their minuscule gravitational effects on their stars.

The main planet-hunting predecessor to KPF, known as the High Resolution Echelle Spectrometer (HIRES), can detect movement at a speed of 200 centimeters/second, whereas KPF should be able to detect stellar motions of only 30 centimeters/second. That translates to less than a foot per second, or a slower speed than the average human walk. This improved accuracy — better than one part in a billion — has the potential to uncover hundreds or thousands of exoplanets including Earth analogs.

"This scale of measurement represents a significant technological challenge and require(s) that every layer of the KPF system, from the all-Zerodur spectrometer to the fiber delivery system, to the data analysis software, be carefully optimized to maximize performance," said Sam Halverson, the KPF instrument scientist and an astronomer and optical engineer at JPL.

NAME
KECK PLANET FINDER

TARGET
EXOPLANETS

MEASURES
STELLAR MOTIONS

LOCATION
HAWAII

CLEAN AND AFFORDABLE ENERGY FROM SPACE

↗ SSPP Leaders
(L-R) Professors Sergio Pellegrino, Harry Atwater, and Ali Hajimiri

Through the Space-based Solar Power Project (SSPP), a team of Caltech and JPL researchers is tackling one of the most significant challenges of our time: providing clean and affordable energy to the entire planet.

The researchers envision a massive solar farm in space that will collect, convert, and transmit solar energy for use wherever it is needed down on Earth, including in areas that are currently underserved by terrestrial infrastructure.

The apparatus would consist of a constellation of hundreds of thousands of ultralight modular panels, creating a "flying carpet" system of satellites with a sunlight-gathering surface measuring 3.5 square miles.

Athough the project was initially envisioned as an energy solution for Earth, the collaboration with JPL led to the exploration of space-based applications.

"The discussion about energy, that was implicitly limited to powering the Earth, actually extends to space exploration also," said Sergio Pellegrino, Joyce and Kent Kresa Professor of Aerospace and Civil Engineering, co-director of SSPP, and a senior research scientist at JPL. "We're opening new chapters in the way JPL is thinking about future missions."

The project is led jointly by Pellegrino; Ali Hajimiri, Bren Professor of Electrical Engineering and co-director of SSPP; and Harry Atwater, an SSPP researcher and Otis Booth Leadership Chair of Caltech's Division of Engineering and Applied Science.

THE BIG IDEA: LUNAR ARCHITECTURE

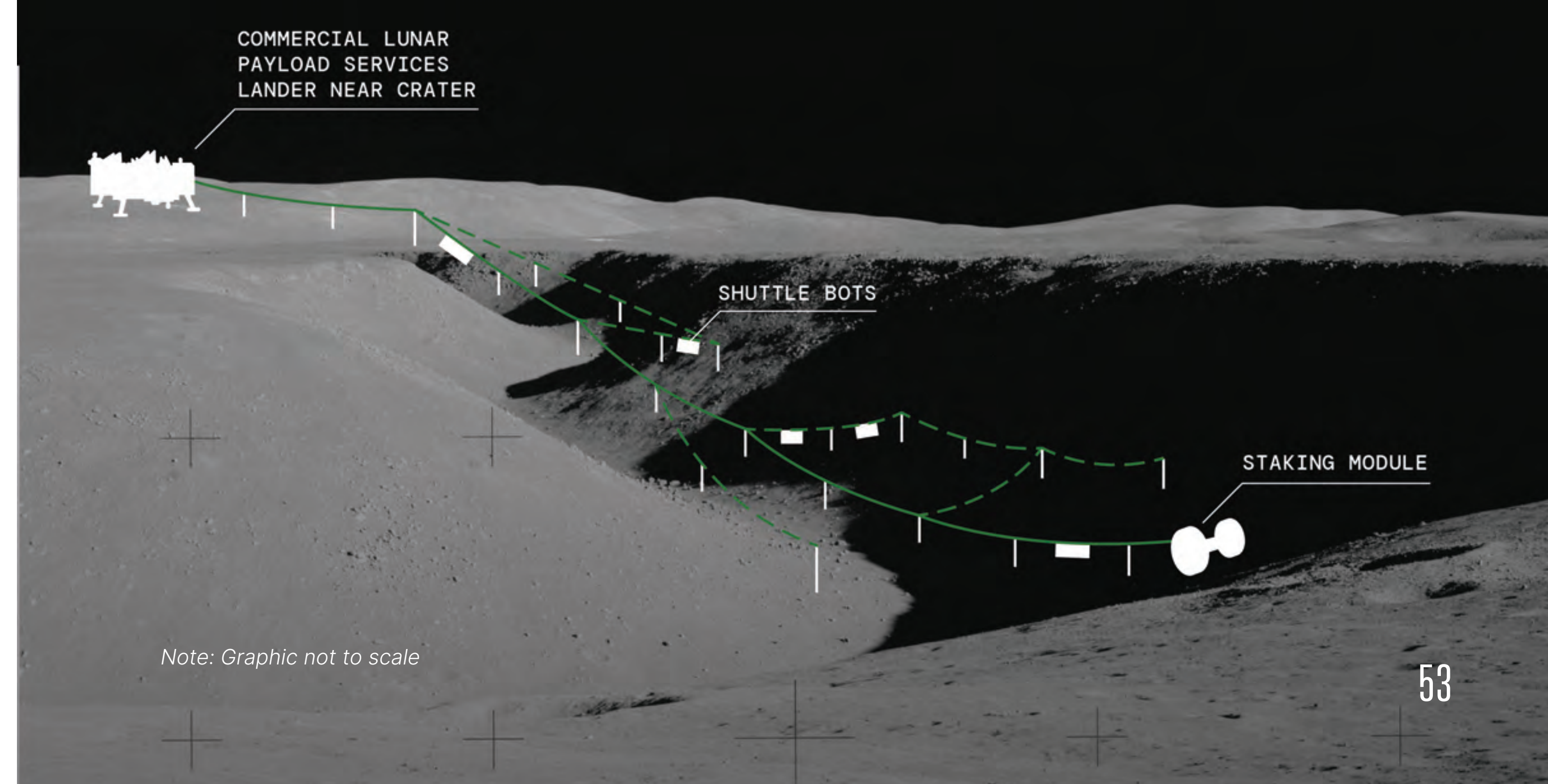
A team of Caltech undergraduates took home the Visionary Concept Award in NASA's Breakthrough, Innovative, and Game-changing (BIG) Idea Challenge for their work on a robotic system that could traverse lunar craters.

The craters of the Moon's pockmarked face, created by pelting asteroids, comets, and other astronomical objects, contain materials for building sustained human settlements on the Moon. But accessing these materials poses serious challenges. Steep slopes, electrostatic charges, and finely textured surfaces create hazardous terrain for the sensors and wheels of lunar vehicles. The Caltech team's proposal, known as LATTICE (Lunar Architecture for Tree Traversal in-service-of Cable Exploration), imagines a self-deploying, modular robotic system able to transport materials and hardware in and out of lunar craters using an infrastructure of cables and stakes.

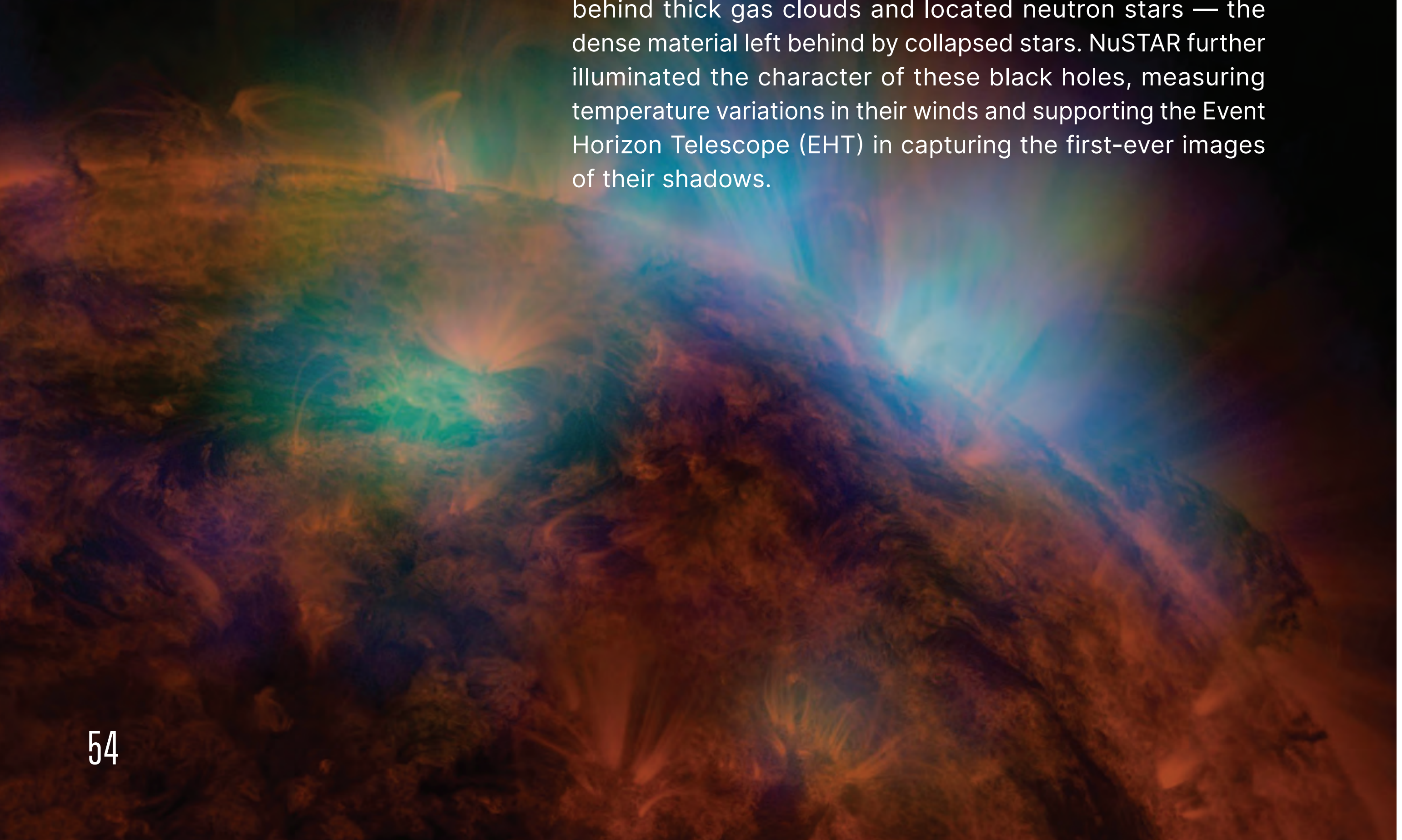
The team of over 30 undergraduates, mentored by Soon-Jo Chung, Bren Professor of Aerospace and Control and Dynamical Systems and JPL research scientist, enjoyed wide access to the Lab's expertise.

"The fact that the engineers at JPL are giving us advice and treating students as engineers on the same level is invaluable," said fourth-year Caltech undergraduate student Polina Verkhovodova.

And while LATTICE was conceptualized for use on lunar craters, the project's potential applications are not limited to the Moon. The team's concept may help pioneer travel and transport systems on the rough terrain of Mars and beyond.



Note: Graphic not to scale



↘ X-Ray Vision

X-rays stream off the sun in this image by NuSTAR, overlaid on a picture taken by the Solar Dynamics Observatory.

NUSTAR TELESCOPE'S FIRST DECADE

MISSION
NUSTAR

TARGET
HIGH ENERGY OBJECTS

MEASURES
X-RAY WAVELENGTHS

LAUNCHED
2012

NASA's Nuclear Spectroscopic Telescope Array (NuSTAR) celebrated its 10th anniversary in June 2022. The space telescope, led by Caltech and managed by JPL, detects X-ray light at the higher end of the range, allowing it to study some of the most energetic objects and processes in our solar system and beyond.

NuSTAR's observations of high-energy X-rays from the Sun could help scientists understand why the corona, or outer region, is so much hotter than its surface.

The telescope's X-ray vision has allowed astronomers to probe environments that otherwise would be impossible to observe. The telescope has discovered black holes hidden behind thick gas clouds and located neutron stars — the dense material left behind by collapsed stars. NuSTAR further illuminated the character of these black holes, measuring temperature variations in their winds and supporting the Event Horizon Telescope (EHT) in capturing the first-ever images of their shadows.

A NEW UNDERSTANDING OF ANTARCTICA'S MELTING ICE

A study conducted by Caltech and JPL researchers led to the development of a new model for understanding the accelerated melting rate of Antarctica's ice shelves.

The model included an often-overlooked ocean current along the Antarctic coast as well as the effects of rapidly flowing fresh meltwater from the ice shelves themselves — factors that reveal a greater acceleration than previously supposed. The less-dense freshwater from the ice shelves skims quickly across the coastal current, trapping relatively warm ocean water against the undersides of the ice shelves, which causes them to melt from below.

The paper appeared in the journal *Science Advances* and is titled "Antarctic Peninsula warming triggers enhanced basal melt rates throughout West Antarctica." Along with Andy Thompson, Caltech professor of environmental science and engineering, additional coauthors are Mar Flexas of Caltech, Michael Schodlok and Hong Zhang of JPL, and Kevin Speer of Florida State University.

↖ Autumn Thaw

Satellite image showing an area of reduced sea ice in March of 2022

COMMS & EDUCATION

Orbit Pavilion

From 2016–2022, this JPL-designed sound installation taught visitors to the Huntington Gardens in Pasadena about NASA's Earth science missions.

Life quickened on Lab in 2022, as a receding pandemic freed communications and education teams to resume large events and to celebrate the return of visitors, interns, news media — and thousands of JPLers.

↗ A Fresh Start
Laurie Leshin mingles with JPLers at the first Welcome Table event on May 18, 2022.

EMPLOYEES GREET A NEW DIRECTOR, AND ONE ANOTHER

↖ Director's Greeting
(L-R) Martin Peticco, Olivia Ernst, Clara MacFarland, and Tyler Colenbrander take a selfie with Laurie Leshin at her arrival event.

Though it was hardly clear on that sunny afternoon, the post-pandemic era at JPL began Monday, May 16 with the arrival of new Director Laurie Leshin, the first woman to lead the Lab. Hundreds gathered on the Mall in the Lab's first large event in more than two years.

The pandemic left a legacy of social distance. Leshin closed that distance symbolically in her first public action as director. Walking down the steps from Building 180, she passed the speaker's podium and crossed the Mall to shake hands with well-wishers assembled on the other side.

Formal remarks could wait. Several minutes of chats and selfies made up the real inauguration. Once Leshin returned to the podium, she acknowledged the extraordinary moment and what had come before: "To keep this place going, during something none of us ever thought we'd have to deal with — the fact that you're here today, back on Lab, it's touching to me that you've all come out."

Two days later, Leshin and most of the Lab's Executive Council were back on the Mall, sharing lunch with dozens of JPLers in a deceptively simple innovation: a long Welcome Table without assigned seats or gaps between groups. Participants renewed friendships and made new acquaintances. A giant "Welcome" sign covered the space that Leshin had crossed 48 hours earlier.

"When we don't see each other, it's easy to forget how much we like each other," said Welcome Table organizer David Delgado, cultural strategist for Lab Engagement in 18x, the Communications and Education Directorate.

The JPL community gathered on the Mall several more times in 2022, including at two encores of the Welcome Table and at EngageJPL: a week-long series of discussions on the Lab's future. The event took place under a big tent, literally and figuratively. All employees were invited to share ideas and suggestions with Leshin and with their colleagues. Over 2,000 did so.

INTERNS RETURN TO LAB...

Interns never left JPL's vaunted program, but they participated from their screens. JPL funded over 500 remote internships in 2021. When interns returned in person the following year, the Lab continued to offer a remote option, and about one in five interns participated from their home, workplace or college in the summer of 2022.

Adjustments forced by two years of pandemic will promote equity and access far into the future. Starting in 2023, JPL will offer remote "externships" to students whose circumstances would make it difficult to come on site. Other students also will become eligible for remote internships after they have completed an internship at the Lab.

The 18x Education Office has also been promoting equity through its Historically Black Colleges and Universities (HBCU)/Underrepresented Minorities (URM) Initiative. Now in its sixth year, the program has grown from seven interns at its inception to 50 in 2022.

The Education Office and the Human Resources Directorate, which also offers internships, have been collaborating with JPL's Office of Inclusion on other initiatives to expand access to JPL's program — traditionally the Lab's biggest pipeline for science and engineering positions.

↘ We're In!
Students gather on the JPL Mall to celebrate their internships.

↖ Family at the Center
JPLers and their loved ones tour SFOF during the Family Days event.

AND VISITORS, TOO

As with internships, the pandemic's forced adjustments have become welcome benefits. Prospective visitors can choose from a traditional tour of the Lab with a guide from the 18x Public Services Office; a virtual tour, also with a guide from Public Services; or a self-guided virtual tour that allows anyone in the world to peek into Mission Control, the High Bay, Mars Yard and several other iconic locations.

At the "Center of the Universe" — the floor of Mission Control — Space Flight Operations Manager Jim McClure is back in his role as chief storyteller for new hires and interns. The PSO has been offering additional tours for JPLers hired during the pandemic. In October, PSO staff organized and led the first post-pandemic JPL Family Days, an opportunity for employees and affiliates to bring their relatives to Lab for an exclusive day of tours and exhibits.

And while Deputy Director Larry James often joins McClure in welcoming JPLers to Mission Control, on May 16, Laurie Leshin showed up to address that Monday's new hire cohort — which included herself as new director.

Other VIPs who made the obligatory stop in Mission Control included Gov. Gavin Newsom; Conan O'Brien; physicist and BBC podcaster/broadcaster Brian Cox, who brought a crew to film the documentary *Seven Days on Mars*; the *Property Brothers* Drew and Jonathan Scott, who visited the Mars Yard; and the *Today Show*, for a segment on Leshin.

↗ Mars Samples
(L-R) Ken Farley, Sunanda Sharma and Rick Welch speak at a press event for the Perseverance rover.

↘ In Orbit by Dawn
SWOT payload sits at Vandenberg Space Force Base, ready for launch.

↘ A Stellar Debut
JPLers gather to watch the reveal of JWST's first images.

A STELLAR YEAR FOR MISSIONS, AND FOR MISSION OUTREACH

How do you top a year like 2021, when history's most advanced rover rolled onto Martian soil and an experimental helicopter achieved the first controlled flight on another planet? Maybe you don't. But with support from 18x outreach teams, 2022 boasted an equally impressive mission highlight reel.

Late in the year, JPL launched the Surface Water & Ocean Topography mission, which intends to survey the world's water the way early explorers charted solid ground. Thousands of years after the first map, SWOT will become water's cartographer.

Media Relations, Public Engagement, and Education teams supported a mission as remarkable and important as any planetary venture through a combination of traditional news releases and outreach, social media, "Teachable Moments" targeted to educators, and immersive visualization tools such as "Eyes on the Earth."

18x outreach teams also supported Europa Clipper, in assembly and on schedule for a 2024 launch to Jupiter's icy moon; Mars Sample Return, the enormously complex expedition to bring Martian rock, soil and atmospheric samples to Earth for analysis; and first light on the James Webb Space Telescope, with the JPL-managed Mid-Infrared Instrument. Within weeks, MIRI was already capturing images of the early universe in exquisite detail.

Behind every mission, and behind every outreach campaign, are the directorate's technical writers and analysts. The team supports the development and sharing of JPL's scientific and technical information, with over 5,000 documents publicly released in 2022. Team members also collaborated with the JPL Library and other stakeholders to establish a new JPL Open Repository, furthering JPL's commitment to open research and knowledge sharing.

A mission from an earlier time, Opportunity, earned another turn in the spotlight three years after its beloved rover shut down far from home. *Good Night Oppy*, filmed with extensive support from Media Relations and Communication Services and featuring many mission members, was named Best Documentary Feature at the Critics Choice Documentary Awards.

MAJOR CONTRACTOR PARTNERS

APPLIED PHYSICS LABORATORY, THE JOHNS HOPKINS UNIVERSITY
Europa Clipper, Mars Reconnaissance Orbiter, Mass Change, Psyche

BALL AEROSPACE & TECHNOLOGIES CORPORATION
CloudSat, Mass Change, NEOSurveyor, NEOWISE, SPHEREx

MANTECH ADVANCED SYSTEMS
Institutional Computing

PERATON, INC.
Deep Space Network Operations and Mission Operations Support, Mars 2020

RAYTHEON TECHNOLOGIES
Engineering, Implementation, Science, Operations and Communications (EISOC)

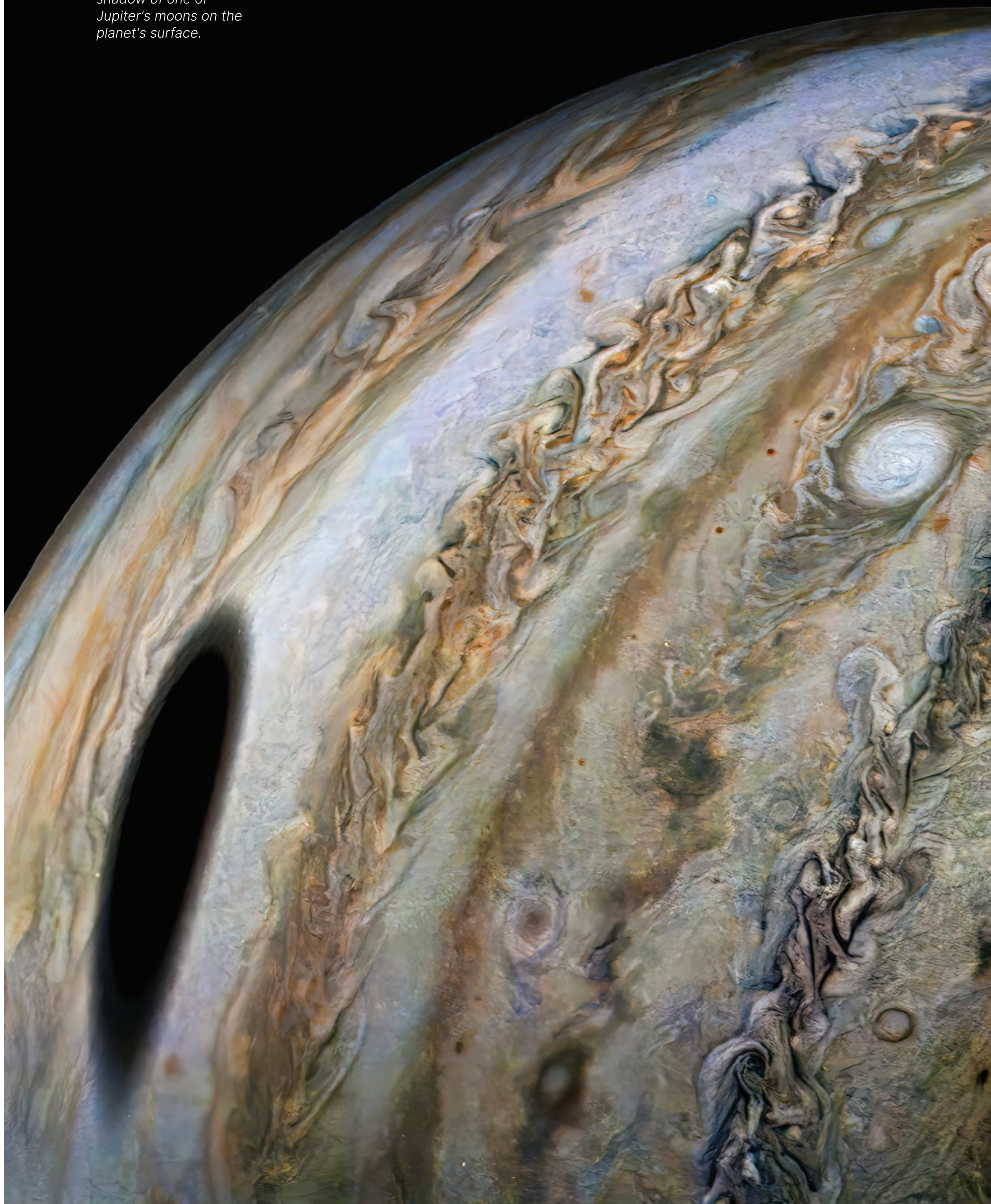
LOCKHEED MARTIN CORPORATION
Engineering Support Services, Europa Clipper, InSight, Juno, Mars Odyssey, Mars Reconnaissance Orbiter, Mars Sample Return, VERITAS

MCCARTHY HOLDINGS
Construction of Flight Electronics Integration Facility

MORI ASSOCIATES, INC.
Information Technology Infrastructure Support

EMCOR GOVERNMENT SERVICES
Facilities Maintenance and Operations

MAXAR
Psyche



↘ Great Black Spot
Juno captures the shadow of one of Jupiter's moons on the planet's surface.

MAJOR EXTERNAL AWARDS

BLAINE BAGGETT
International Academy of Astronautics (IAA)

LAURIE BARGE
Scialog "Signatures of Life in the Universe" Award

BONNIE J. BURATTI
2022 Gerard P. Kuiper Prize

JULIE CASTILLO-ROGEZ
2022 Farinella Prize

CENTER FOR NEAR-EARTH OBJECT STUDIES TEAM
National Space Club Nelson P. Jackson Aerospace Award

GOUTAM CHATTOPADHYAY
Institution of Electronics and Telecommunication Engineers (IETE) Biman Behari Sen Memorial Award 2022

CLIMATE.NASA.GOV
Anthem Award

COMMUNICATIONS & EDUCATION DIRECTORATE
Webby Awards:
- NASA's Global Climate Change
- NASA's Solar System Exploration

People's Voice Awards:
- NASA's Global Climate Change
- NASA's Jet Propulsion Laboratory Virtual Tour

ELIZABETH CÓRDOBA
Georgia Tech Alumni 40 Under 40

SHAILEN DESAI
AIAA Associate Fellow

HENRY GARRETT
American Institute of Aeronautics and Astronautics James A. Van Allen Space Environments Award

DAN GOEBEL
Stuhlinger Medal for Outstanding Achievement in Electric Propulsion

MARIANNE GONZALEZ
Forbes 30 Under 30

MICHAEL GREENE
International Academy of Astronautics (IAA)

SONA HOSSEINI
Nancy Grace Roman Technology Fellowship in Astrophysics

INGENUITY MARS HELICOPTER TEAM
- IEEE Spectrum Emerging Technology Award
- National Space Club Dr. Robert H. Goddard Memorial Trophy
- National Space Society (NSS) Awards
- Robert J. Collier Trophy
- Royal Aeronautical Society - Team Gold Medal
- Vertical Flight Society Howard Hughes Award

INGENUITY MARS HELICOPTER TEAM AND MIMI AUNG
National Air & Space Museum Collins Award for Current Achievement

DEPUTY DIRECTOR LARRY JAMES
NASA Outstanding Public Leadership Medal

JPL
- Glassdoor's "Best Places to Work in 2022"
- 2022 U.S. CIO 100 Honoree: Celebrating IT innovation and leadership

LAURA KERBER
NASA's Planetary Science Program, Early Career Award

OTFRID LIEPACK
International Academy of Astronautics (IAA) - Social Sciences Award

KIMBERLEY MINER
Smithsonian's New 'Women's Futures Month'

RYAN PARK
American Astronautical Association (AAS) Fellow

PERSEVERANCE MARS ROVER
The Engineers Council Distinguished Engineering Project of the Year Achievement Award

CAROL POLANSKEY
American Association for the Advancement of Science (AAAS) Fellow

ASHWIN VASAVADA
Honorary Fellowship, Royal Astronomical Society

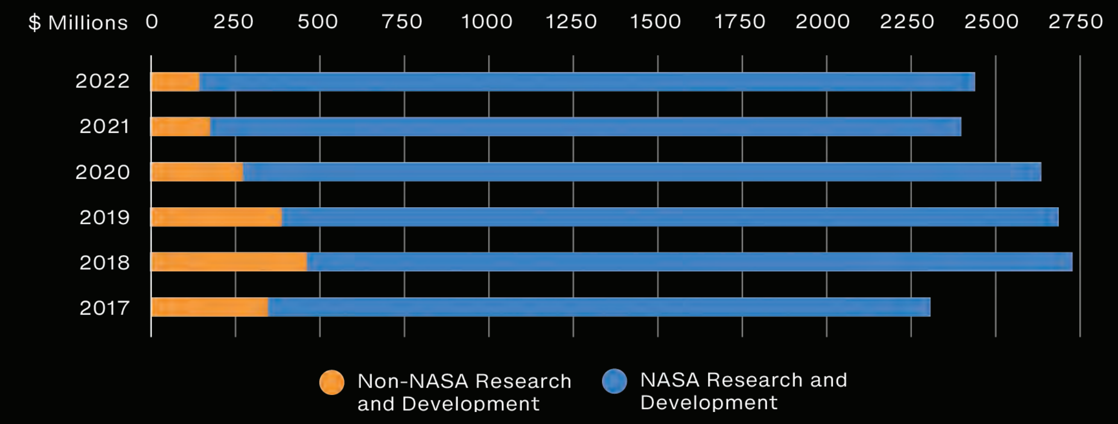
VITAL VENTILATOR
Anthem Awards - 2 categories

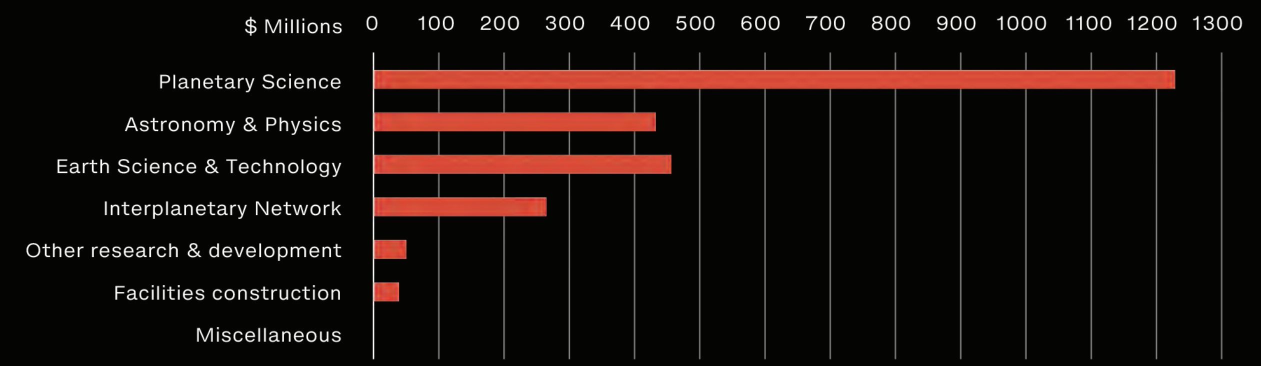
THE VITAL DESIGN TEAM
Fast Company Innovation by Design Awards
- Finalist: Pandemic Response category
- Honorable Mention: Rapid Response category

MICHAEL WATKINS
The German Research Centre for Geosciences Rolf Emmermann Medal

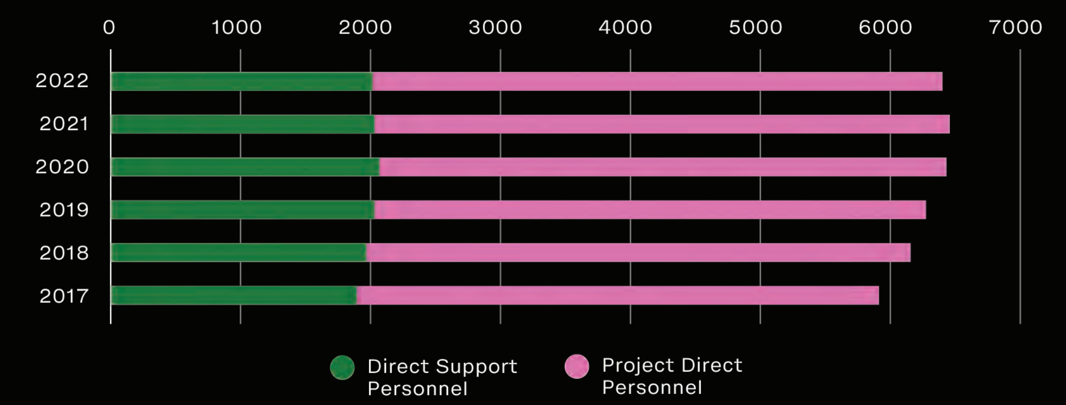
BUDGET AND WORKFORCE

2022 BUDGET



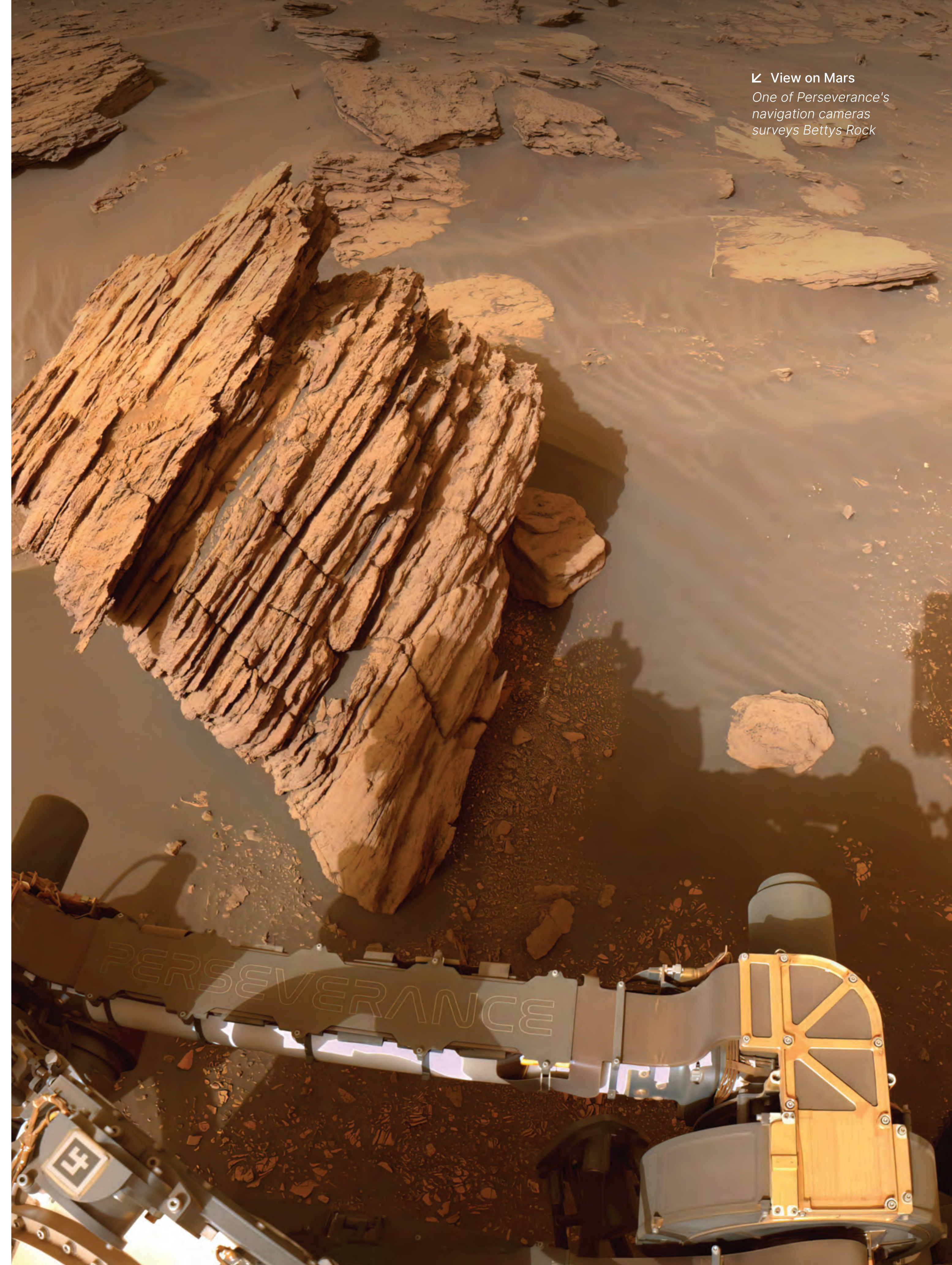


JPL PERSONNEL • FULL-TIME EQUIVALENTS



LEADERSHIP

CALTECH BOARD OF TRUSTEES JPL COMMITTEE



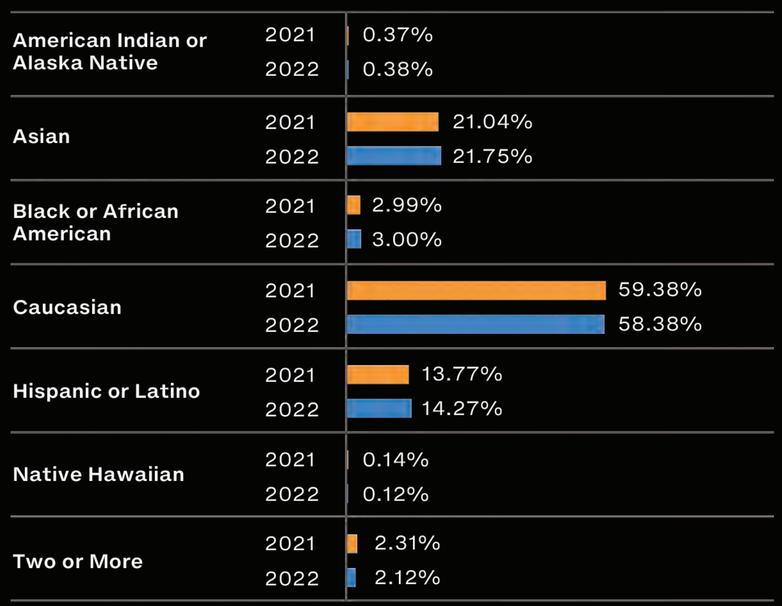
↙ View on Mars
One of Perseverance's navigation cameras surveys Bettys Rock

WORKFORCE DEMOGRAPHICS

RACE AND ETHNICITY

The workforce racial and ethnic breakdown at JPL had small increases across most groups between FY 2021 and FY 2022.

The Asian and Hispanic/Latino groups saw the largest increases.



MINORITY AND FEMALE HIRING

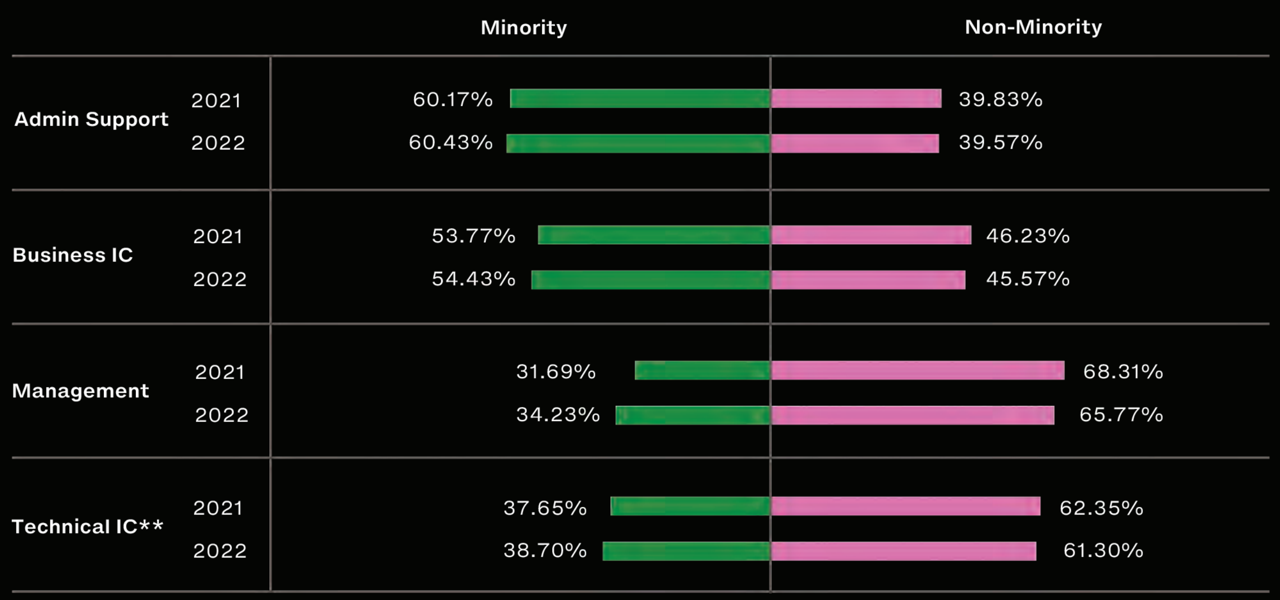
JPL hired females and minorities at a higher rate than they appeared in the total Lab and technical discipline populations. Minority and female employees also had an increased presence in management and technical individual contributor (IC) roles.

*Total Lab Population: The population consists of JPL employees in the Core Workforce (which excludes Students, Part-Time, and Temporary workers) on Active or Paid Leave Status.

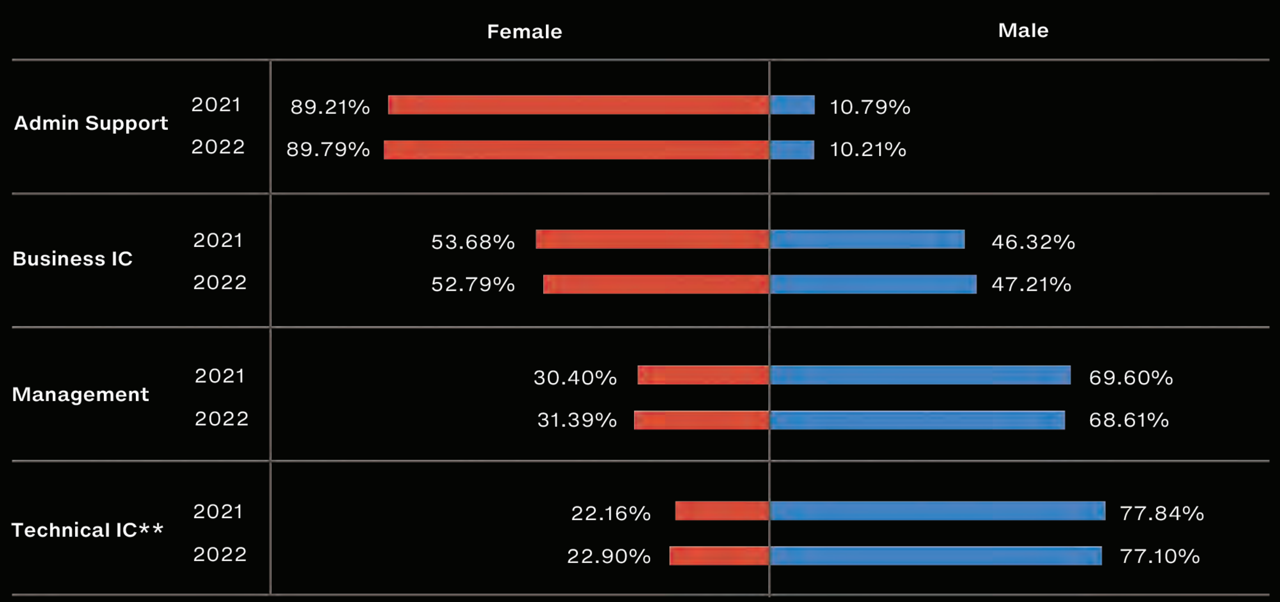
**Technical: This population consists of JPL employees in the Core Workforce whose assignment is in the following job families: Engineering, Institutional Leadership, LPPL, Research, and Software and Computing Systems.

			Total Lab %*	Technical Discipline %**
Minority	% in population	2021	40.62%	36.78%
		2022	41.64%	37.98%
	% hired	2021	47.87%	43.84%
		2022	46.69%	47.38%
Female	% in population	2021	30.99%	22.18%
		2022	31.26%	22.94%
	% hired	2021	40.76%	29.45%
		2022	36.46%	29.20%

MINORITY REPRESENTATION BY JOB TYPE



FEMALE REPRESENTATION BY JOB TYPE



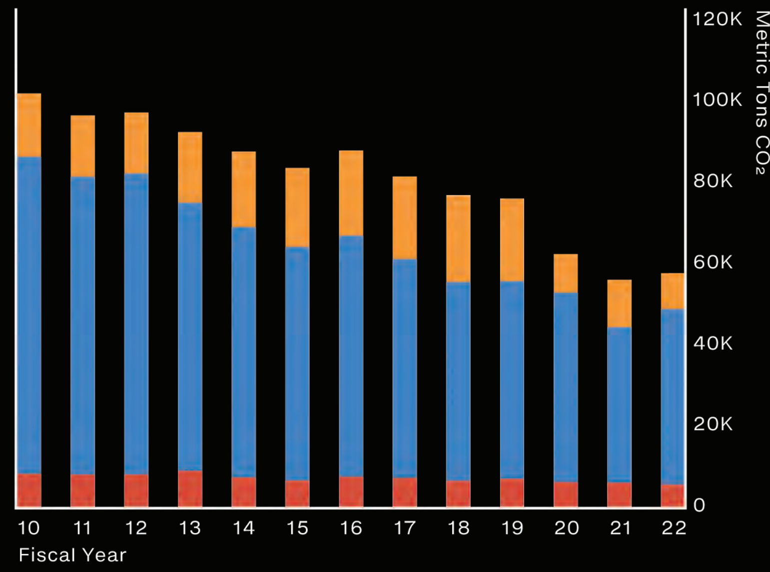
SUSTAINABILITY

GREENHOUSE GAS EMISSIONS

SUSTAINABLE BUILDINGS
In FY22, 24% of JPL gross square footage met sustainable building criteria. JPL continued LEED Existing Building and New Construction Certification efforts for FY23.

FLEET MANAGEMENT
JPL decreased petroleum consumption by 94% compared to baseline 2005 and reduced petroleum use by 3% in 2022 compared to 2021.

- Individual Emissions (business travel, commuting, etc.)
- Indirect GHG Emissions (electricity, etc.)
- Direct GHG Emissions (natural gas, fleet, etc.)



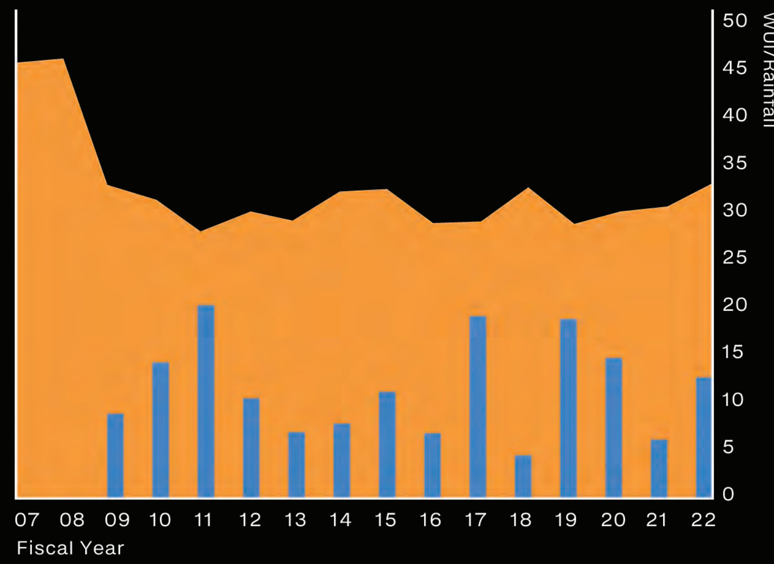
WATER EFFICIENCY

NASA's annual goal is to achieve a 20% reduction relative to FY07 and reduce water use intensity each year.

WATER INTENSITY
JPL decreased water intensity by 28% in FY22 compared to baseline FY07.

JPL increased water intensity by 5% in FY22 compared to FY21.

- Water Use Intensity (gal/gross square foot)
- Rainfall (in/year)



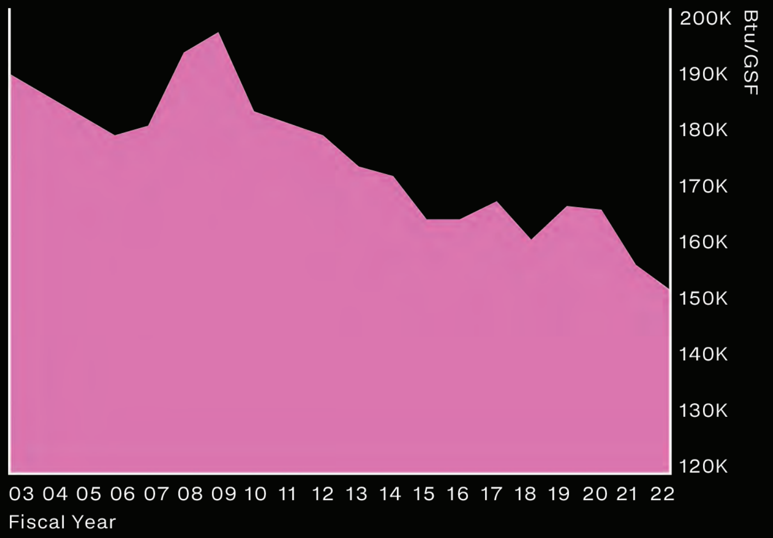
ENERGY EFFICIENCY

NASA's goal is to meet or exceed a 30% reduction in Btu/GSF from the 2003 baseline, and reduce energy intensity each year.

ENERGY INTENSITY
Decreased energy intensity by 16% in FY22 compared to baseline FY03.

Decreased energy intensity by 2% in FY22 compared to FY21.

RENEWABLE ENERGY
3% of electricity was sourced from on-Lab renewable sources in FY22.



WASTE REDUCTION AND DIVERSION

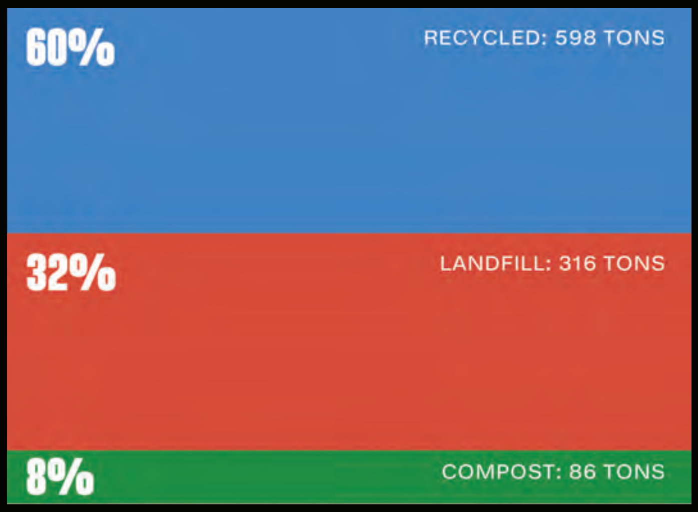
NASA's goal is to divert 50% of construction and demolition debris waste and 50% of non-C&D solid waste from landfills.

WASTE DIVERSION
60% overall waste diversion rate in FY22

87% diversion of C&D waste

64% diversion of non-C&D solid waste

SUSTAINABLE ACQUISITIONS
Percentage of sustainable (e.g. containing recycled material) acquisition purchases by dollar value was 49% in FY22 compared to 65% in FY21.



EXECUTIVE COUNCIL

LAURIE LESHIN
Director

LARRY D. JAMES
Deputy Director

DAVID GALLAGHER
Associate Director, Strategic Integration

SAMMY KAYALI
Chief Financial Officer, Manager of Operations Integration

LESLIE LIVESAY
Associate Director, Flight Projects and Mission Success

BETH APILLANES
Acting Chief Information Officer, Director for Information and Technology Solutions

JANIS CHODAS
Director for Planetary Science

RICHARD COOK
Program Manager for Mars Sample Return

TOM CWIK
Chief Technologist

SUZANNE DODD
Director for Interplanetary Network

MARC GOETTEL
Director for Business Operations

JAMES GRAF
Director for Earth Science and Technology

MICHAEL GREENE
Director for Communications and Education

COZETTE M. HART
Director for Human Resources

MARTIN HERMAN
Director for Safety and Mission Success

JENNIFER LUM
General Counsel, Caltech

KEYUR PATEL
Director for Astronomy and Physics

NEELA RAJENDRA
Chief Inclusion Officer

MARK SIMONS
Chief Scientist

CHARLES WHETSEL
Director for Engineering and Science

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

JPL 400-1747 4/2023