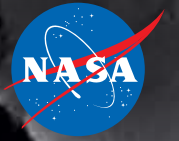
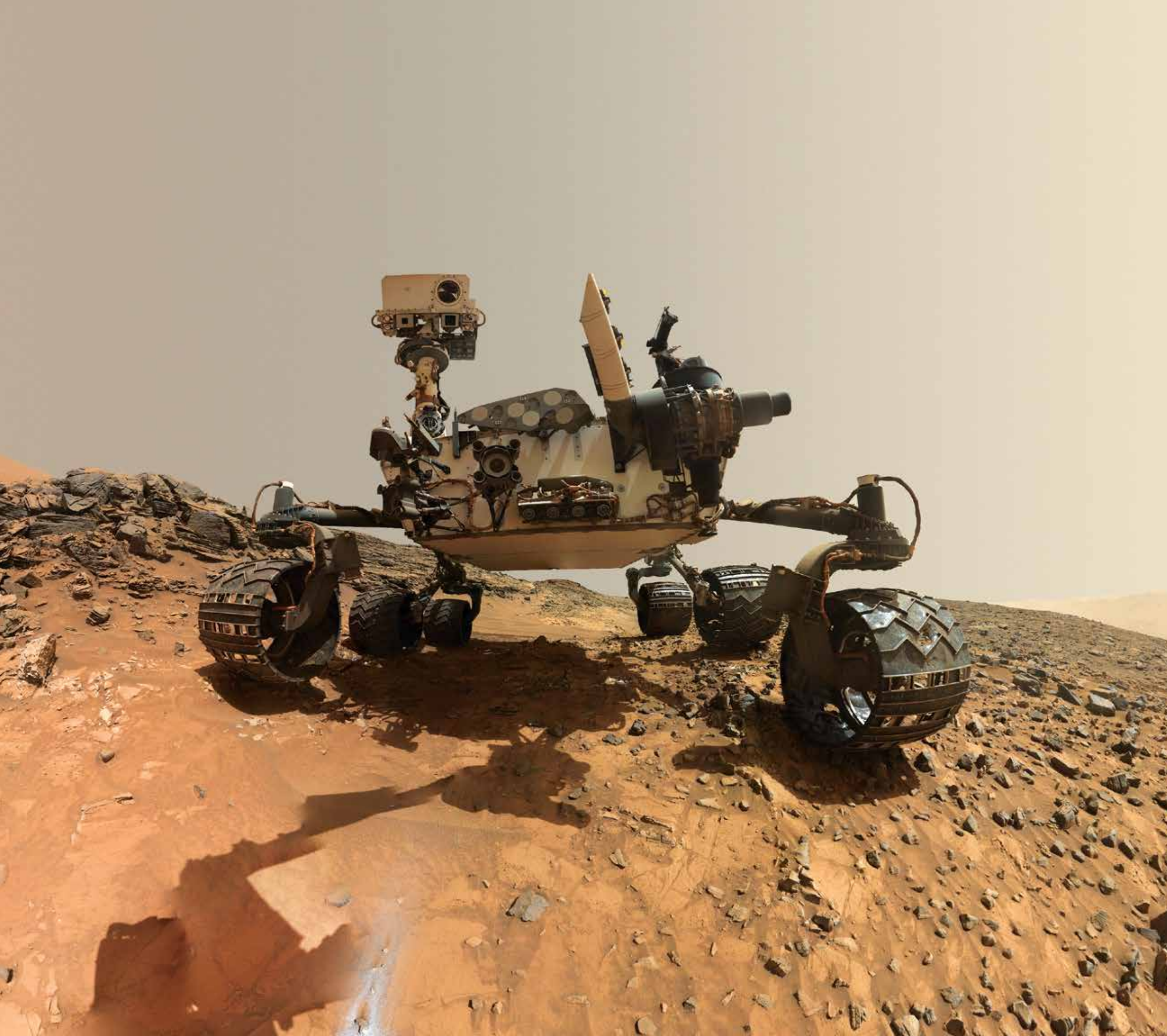


National Aeronautics and  
Space Administration



JET PROPULSION LABORATORY  
**2015 ANNUAL REPORT**





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Left: A low-angle self-portrait by the Mars Curiosity rover. Due to the way the image is built up, the rover's arm does not appear.

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Cover: Dawn spacecraft's view of Kupalo, one of the youngest craters on Ceres.



D I R E C T O R

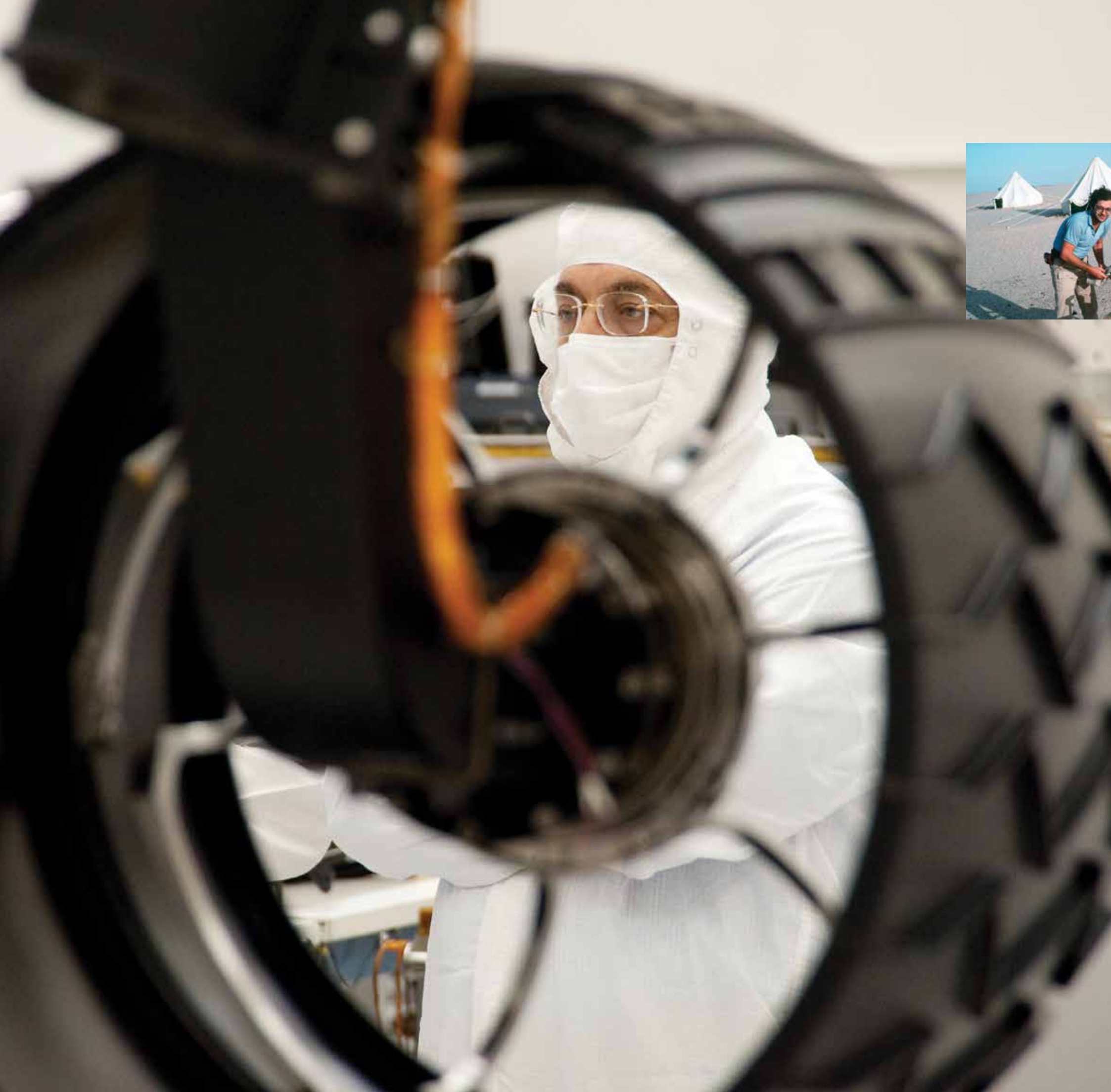
CHARLES ELACHI

2015 has proven to be a year as full of surprises and intriguing science as any during my time at JPL. The ion-propelled Dawn became the first spacecraft to orbit two target bodies when it arrived at the never-explored dwarf planet Ceres. Mars Reconnaissance Orbiter produced exciting news about current-day water at the Red Planet. Kepler and Spitzer continued the remarkable pace of their discoveries of planets orbiting other stars. Our Earth scientists delivered important findings on California's serious drought and the ongoing changes in Earth's climate.

Of course, we always have the expectation of being able to share stories each year — stories of impressive engineering and science achievements. That's certainly been the case for the last 15 years, during which I have had the great honor of serving as director of JPL. And what an amazing 15 years it has been! We've established a permanent presence on Mars using landers, rovers and orbiters; revolutionized our understanding of ocean moons around Jupiter and Saturn; learned that there are liquid lakes of methane on Titan, and geysers on Enceladus; identified and tracked asteroids; visited two protoplanets with a single mission; brought back samples from one comet and collided with another; provided critical data on Earth's changing climate and geological processes; pierced the clouds of dust surrounding galaxies to reveal them in all their states of evolution; uncovered millions of black holes; discovered over a thousand worlds circling other stars; and reached interstellar space for the very first time. We've also advanced technology and taken an incredibly appreciative public along on our journeys of discoveries.

All these accomplishments are the result of teamwork: highly gifted and motivated engineers, scientists, technologists, and business and administrative staff who have made the improbable, and even seemingly impossible, possible. For me, it has been the dream of a lifetime to lead the women and men of JPL during this time. Everyone at the Lab knows I am fond of quoting Teddy Roosevelt — especially his classic quote, "Dare mighty things." It has become something of a byword at the Lab. As I near the time in 2016 when I step down as director, I will always look back and take enormous pride not only in what has been accomplished, but knowing that JPLers are full of the kind of passion and dedication that will keep them driving for "Mighty Things" for many years to come.





## THE ELACHI ERA

When Charles Elachi joined JPL as a young intern in 1970, he thought he would stay a year or two. Instead, his time at the Laboratory turned into a lifetime of adventures and discoveries, including 15 years as the Laboratory's director.

From his early days developing imaging radar as a major scientific field, to his time on JPL's Executive Council expanding the Laboratory's portfolio of instruments and missions, and then in his decade and a half as JPL's director, Elachi has left a legacy of unprecedented successes.

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Left: The JPL director in clean-room garb framed by a wheel of the Mars Curiosity rover.

Above: From left, seeking the lost city of Ubar on the Arabian Peninsula with imaging radar; helping to create the next generation of space explorers; and celebrating a successful flight event.





Does someone need to tell the teenagers of Ceres not to shine lights at incoming space probes? That was some of the flavor of Internet chatter when the Dawn spacecraft discovered a pair of incredibly bright spots as it arrived at the dwarf planet in early 2015. But the mission's scientists knew better: The

# SOLAR SYSTEM

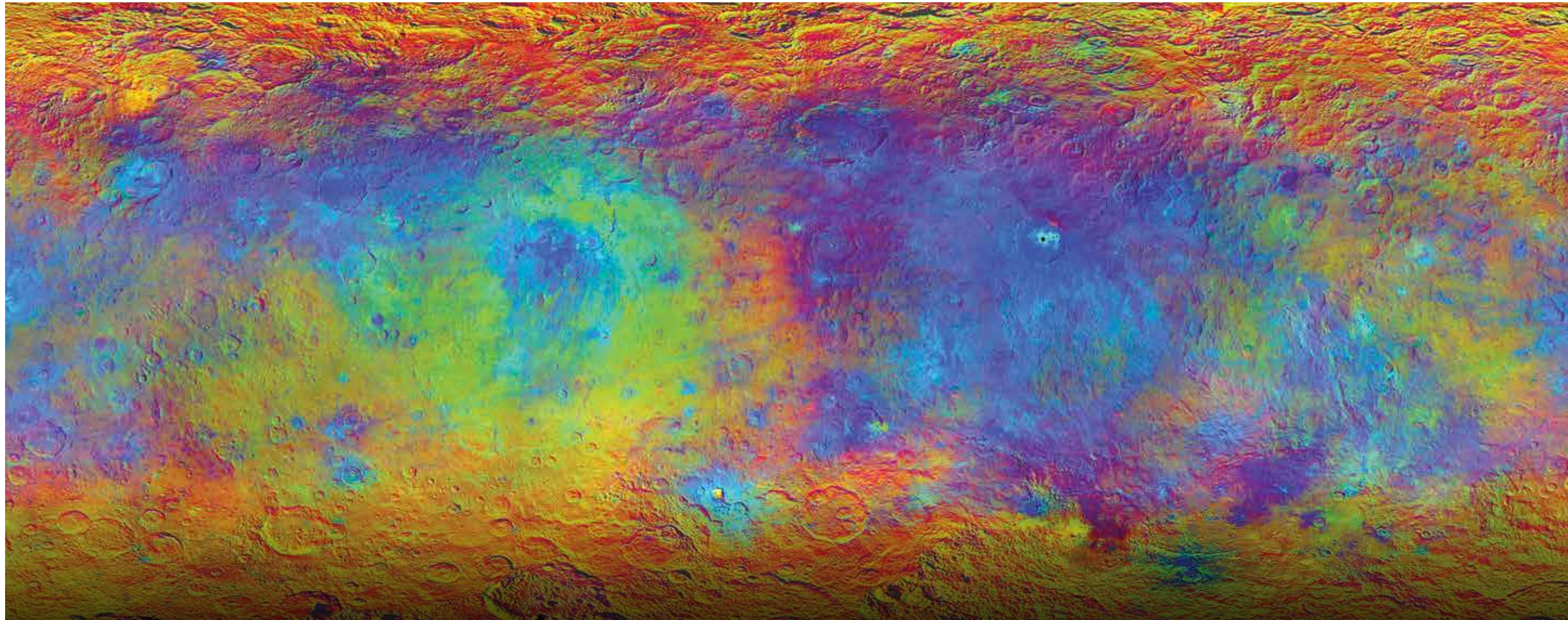
## AN UNEXPLORED WORLD

largest object in the asteroid belt between Mars and Jupiter, icy Ceres is no environment for an advanced civilization. But the bright spots — there ended up being more than a hundred of them spotted as orbiting Dawn surveyed the world — are important pieces of the puzzle of Ceres' history. By year's end, the best thinking was that the shiny material was a salty compound similar to Epsom salt, exposed by a mysterious process that Dawn scientists are still working to uncover.

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Left: Artist's concept of the Dawn spacecraft as it used its ion propulsion to drop into orbit around Ceres.





DID CERES ITSELF FORM IN THE OUTER  
SOLAR SYSTEM AND LATER MIGRATE  
INWARD TO ITS CURRENT NICHE?

Scientists were also thrown a curve by the amount of ammonia detected by one of Dawn's instruments. That substance is stable in the colder outer solar system, but finding so much at Ceres' distance from the sun was a surprise. Did Ceres itself form in the outer solar system and later migrate inward to its current niche? Or did icy planetesimals bring the ammonia to Ceres after they were nudged inward from colder orbits? That is part of a bigger story about the solar system's formation and history that has been the topic of lively debate by scientists over the past decade. By becoming the first spacecraft ever to orbit two target bodies — Ceres, and the very

different Vesta — the ion-propelled Dawn has contributed key grist to shape future models.

In December, Dawn dropped into a very low orbit, closer to Ceres than the International Space Station is to Earth. After the propellant used to control its orientation runs out and it is no longer able to point to Ceres or Earth, it is expected to remain in that orbit as a silent sentry for centuries to come.

For **Cassini**, 2015 was the season of icy moons. With an orbit that took it close to the plane of Saturn's rings and large moons, the long-lived spacecraft was ideally positioned

Above: Ceres' surface appears nearly uniformly gray, but the colors assigned to spectral regions in this collage of images from Dawn bring out differences in composition.



## MORGAN CABLE

### Planetary Chemist

A box of rocks might not strike most 13-year-olds as an ideal gift, but for Morgan Cable it was everything she could hope for — and more.

The daughter of a NASA chemist in Florida grew up watching launches — that's when her school near the Cape scheduled fire drills — so it was no shock when as a middle-schooler she opted to do a science project on Martian geology. Striking up an online acquaintance with a working planetary scientist in Arizona, she was surprised but pleased when a large carton of basaltic rocks (think: solidified lava) showed up on her doorstep as raw material for the effort.

During her third year as a college undergrad in chemistry, Cable put in an application for a summer internship at JPL. This led to graduate work at Caltech, where she earned her Ph.D. in 2010.

Cable's main interest is biomarkers — chemical signatures of life — on worlds

like Mars and Saturn's moon Titan. In her JPL lab she mixes extremely cold liquids and gases to create "mini-Titan lakes." The other half of her time she does science planning for Cassini. Cable is also a collaborator on the imaging spectrometer that will fly on the JPL-led Europa Mission. Away from work, she likes to surf (Bolsa Chica and San Onofre are favorite haunts), and enjoys mountain unicycling. Every summer for the past seven years, she has run a space camp in South Korea.

Cable long had a dream of becoming a NASA astronaut — and says she would still go if selected — but she is getting increasingly settled into a career as a planetary scientist at JPL. With the variety of missions and instruments on the horizon, there are many options. "It's hard to say no," she says, "when interesting things come up."



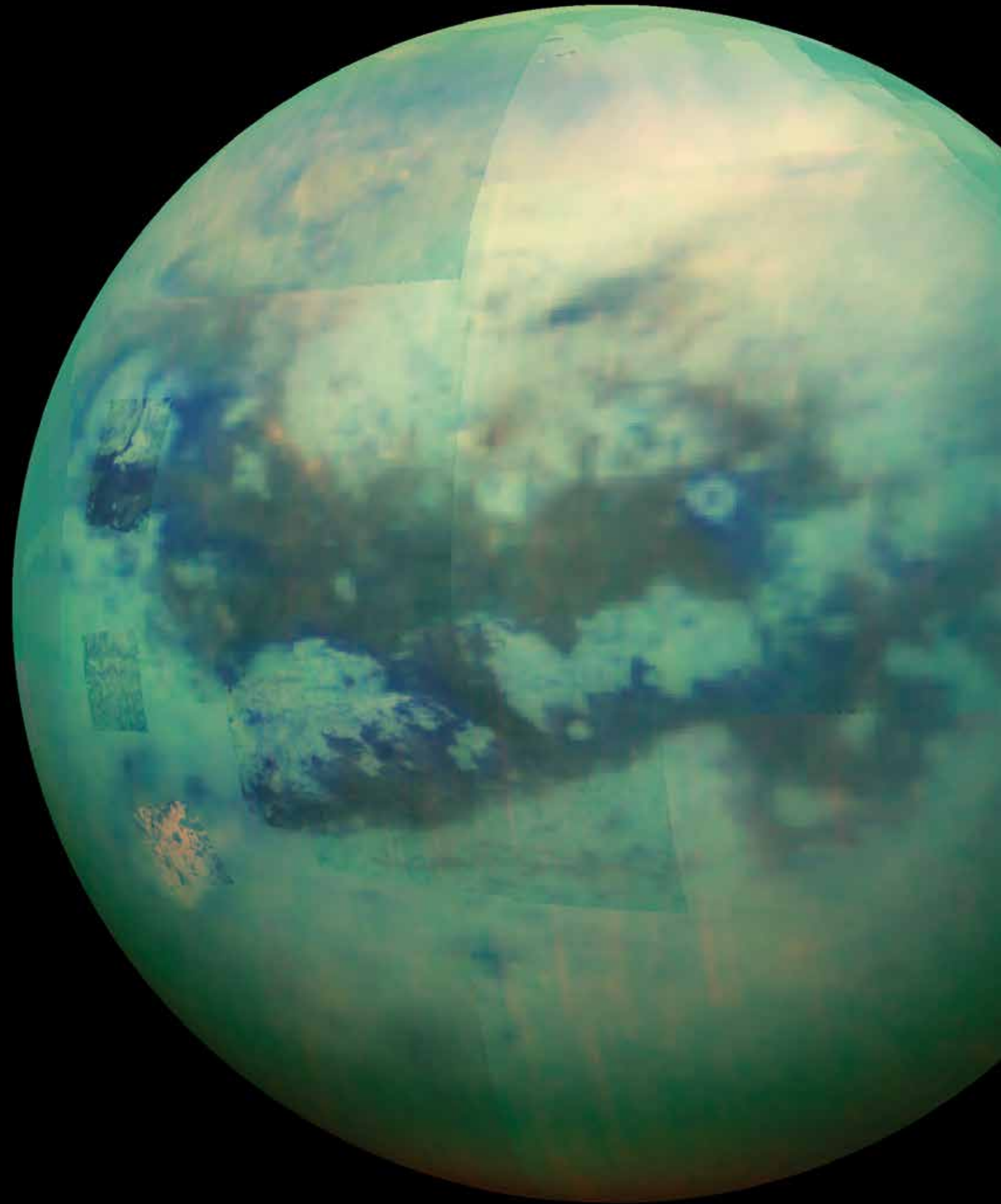
IN 2016, CASSINI WILL SHIFT TO  
AN ORBIT DESIGNED TO GET  
A CLOSE LOOK AT SATURN'S  
RINGS BEFORE IT CRASH-DIVES  
INTO THE GIANT PLANET IN 2017.

Right: An infrared view of  
Saturn's moon Titan from the  
visual and infrared mapping  
spectrometer on the Cassini  
spacecraft.

for close studies of such natural satellites as Dione, Tethys, and especially Enceladus. During the year, scientists announced that Enceladus has a global ocean of salty water beneath its frozen crust. That ocean supplies the astonishing plume of vapor and ice particles, discovered a decade earlier by Cassini, erupting near the moon's south pole. During one of three memorable flybys near the end of the year, Cassini flew directly through the plume in one of its closest encounters ever. In 2016, Cassini will shift to an orbit designed to get a close look at Saturn's rings before it crash-dives into the giant planet in September 2017.

When the going gets tough, the tough — keep an eye on their data? That could have been the byword for Europe's Rosetta spacecraft in orbit around comet 67P/Churyumov-Gerasimenko with JPL's **MIR0** instrument onboard. After reaching the comet in 2014 and sending its Philae lander to the surface, Rosetta kept tabs as the comet made its closest approach to the sun. In that relatively hot zone, just beyond Earth's orbit, **MIR0** watched as the amount of water given off by the comet leapt by a factor of a thousand. Later in the year, as the comet moved away from the sun, **MIR0** and all the other instruments remained vigilant, studying details of how the comet changed over time.

The JPL-led **Europa Mission** made major strides in 2015, as the new flagship project to study this ocean-bearing moon of Jupiter in the 2020s got the green light to move into its formulation phase. Along with that transition, JPL was asked by NASA to study the feasibility of adding a possible lander to the mission, planned as a Jupiter orbiter that will make more than 45 close flybys of Europa over 2½ years to investigate whether the moon might harbor habitable environments beneath its icy crust. NASA also selected a science payload for the mission, with JPL building three of the nine instruments.







When astronomy histories of the future are set down, the first years of the 21st century no doubt will be celebrated as a golden age of exoplanet discovery. Planets orbiting other stars are seemingly as thick as thieves, and JPL missions have been producing some of the key discoveries.

# ASTRONOMY

## NO END OF NEW PLANETS

Six years after its launch, the Kepler spacecraft is proving itself the prolific bounty hunter of alien worlds that it was designed to be. Surveying more than 150,000 stars in a nearby section of the galaxy, Kepler turned up more than 1,000 confirmed planets. In 2015, the story got even better: The mission confirmed the first planet roughly the size of Earth in what astronomers consider the habitable zone around another star. The take-away: Planets are common, most sun-like stars have at least one planet, and the worlds detected are wildly diverse.

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Left: An artist's concept of Kepler-186f, the first validated planet approximately the size of Earth orbiting in the habitable zone of a distant star.



## NICK SIEGLER

### Exoplanet Explorer

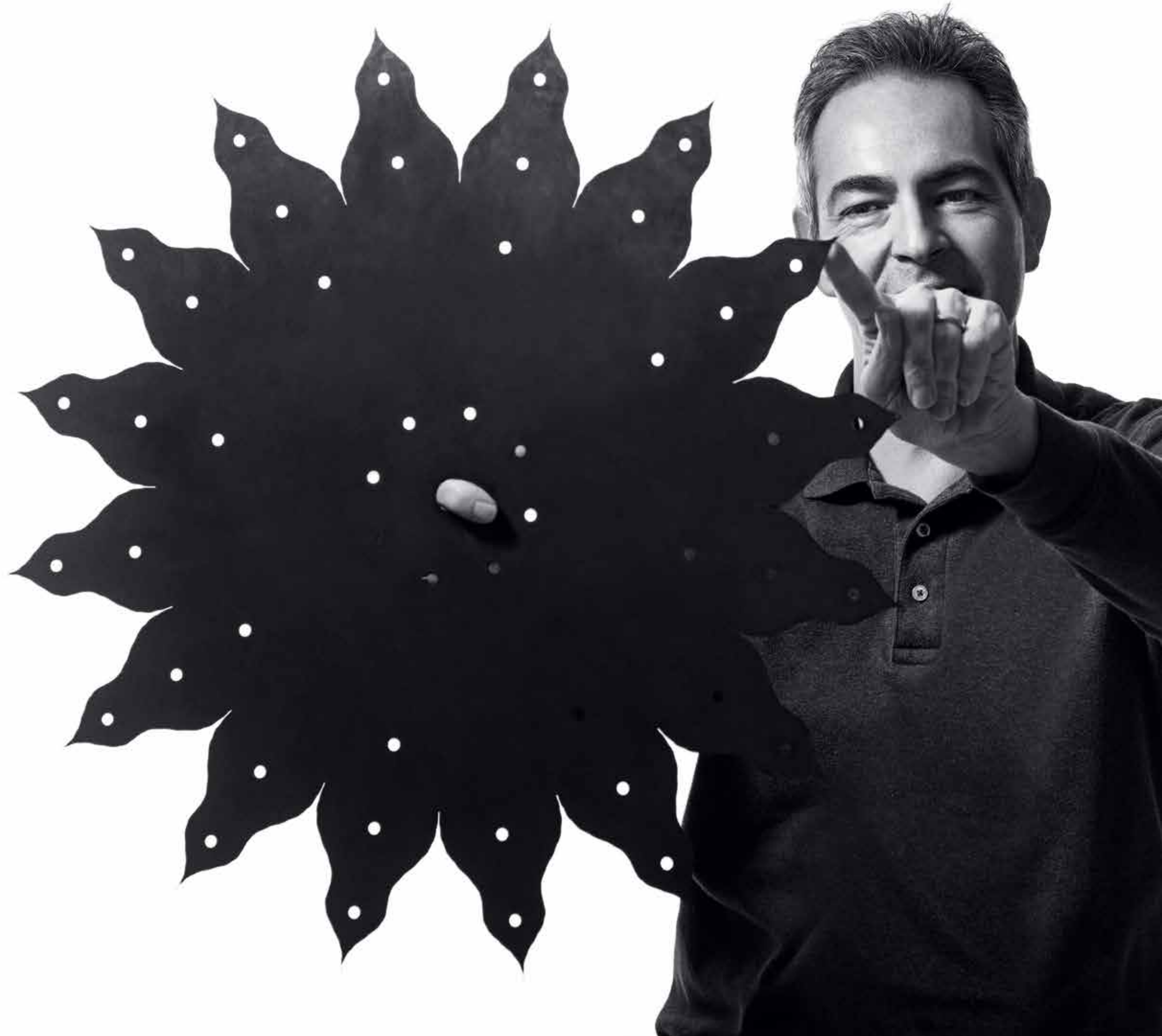
Second acts in careers are not uncommon, but in Nick Sieglar's case the new path he chose in his professional life took him to the stars — literally. Well, almost literally.

Growing up in New Jersey, Sieglar was encouraged by his parents to take up chemical engineering. That led to 13 years with a major multinational company managing manufacturing facilities around the world. By his early thirties, however, Sieglar felt something was missing — something connected to his childhood inspirations of the Apollo program, the Voyager missions and Carl Sagan's *Cosmos*. He decided to become an astronomer.

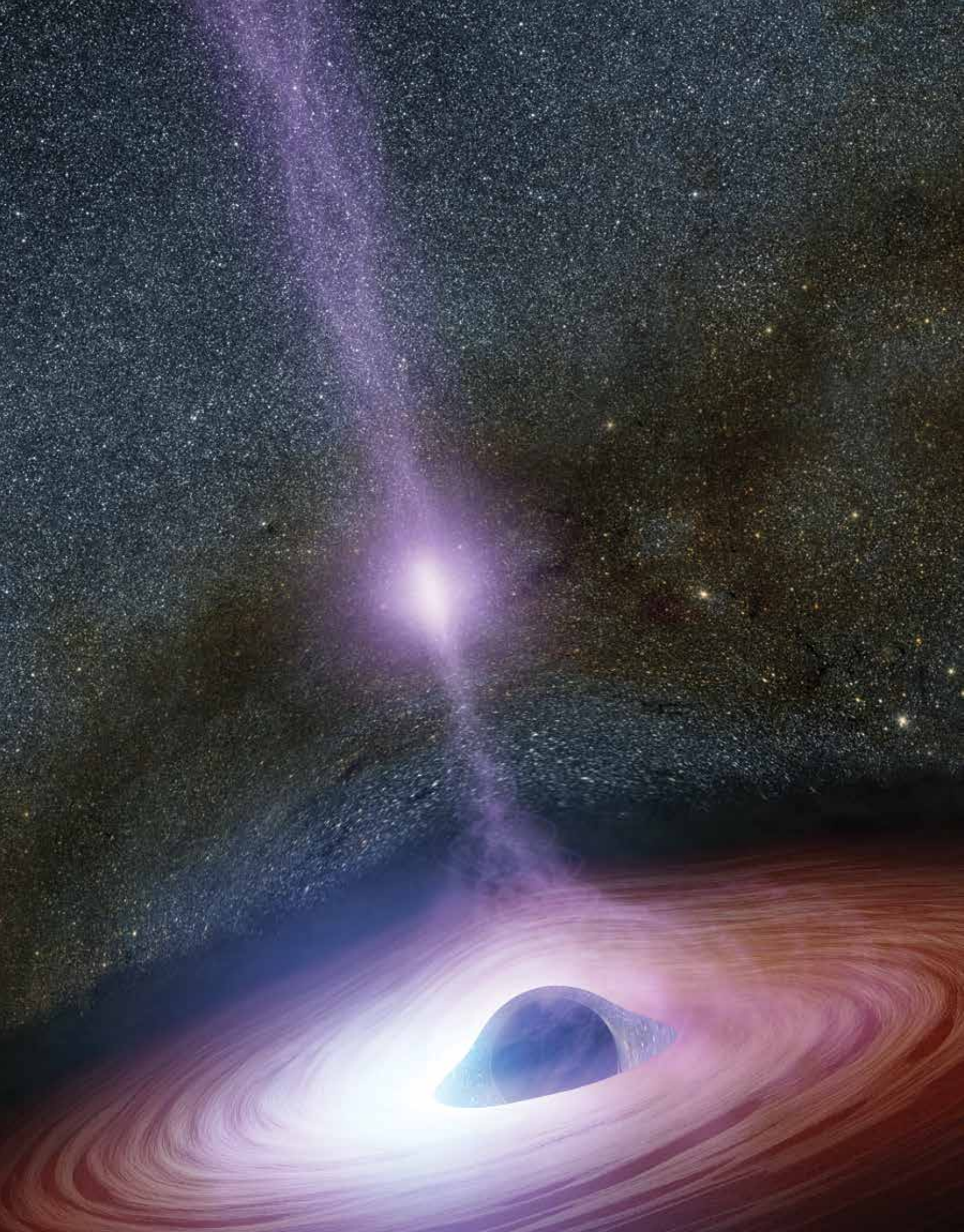
The transition wasn't rapid. In fact he spent another 9½ years in school, first in Harvard University's special students program that afforded him the opportunity to consider a change of focus. From Boston he went on to the University of Arizona, where he earned a master's and Ph.D. in astronomy. "It was a major change in my life direction," Sieglar recalls. "There is a very fine line between courage and insanity."

But the effort paid off, and Sieglar ended up at JPL. After six years on a defense project, Sieglar two years ago was offered a job as chief technologist for NASA's Exoplanet Exploration Program located at JPL.

Today Sieglar focuses on defining and developing technologies to enable future exoplanet missions. "The big thing is starlight suppression," he says. "Earth is 10 billion times fainter than the sun. To find an Earth 2.0 out among the stars, we will have to bring imaginative ideas to bear."







STARS ARE VASTLY BRIGHTER THAN PLANETS, SO SUCH HUNTS WILL REQUIRE CLEVER TECHNOLOGIES TO BLOCK OUT STARLIGHT.

The **Spitzer Space Telescope**, never created with this aim in mind, achieved unexpected prominence in exoplanet discovery. In July, its team announced the discovery, made in tandem with ground-based measurements, of the nearest rocky planet outside our solar system — a mere 21 light-years away.

That planet, and most of the ones found by Kepler, are too close to their parent stars to support life as we know it. Neither mission images the exoplanets directly; they detect them by catching faint fluctuations in the brightness of the parent star. To step up the exoplanet search, future missions will need to find ways to detect exoplanets directly, which means imaging them. Stars are vastly brighter than planets, so such hunts will require clever technologies to block out starlight. Two are in the works at JPL — one, a coronagraph, would be a mask inside a space telescope to block starlight, while the other, called a star shade, is a flower-petal-like design that would fly as a separate spacecraft. Astronomers are betting that when such missions become reality, the best is yet to come in the exoplanet hunt.

Plying energy bands far beyond what we can see with our eyes, the **NuSTAR** mission three years after launch remains the go-to spacecraft for studying black holes. Sensitive to high-energy X-rays, NuSTAR has provided remarkable data on supermassive

black holes in colliding galaxies as well as fierce winds blowing in all directions from some of the super-dense objects. Close to home, it has even revealed the X-rays streaming away from our own sun.

They're everywhere, but invisible. Ever since being identified, dark matter and dark energy have been puzzling astrophysicists. Dark matter must be far more common than regular matter, and dark energy drives the expansion of the universe. Yet, they remain stubbornly difficult to study. But the **Euclid** mission should be able to help. Built by the European Space Agency with important contributions from JPL, the spacecraft will map two billion galaxies across a third of the sky to reveal indirectly the presence of dark matter and dark energy. In December, Euclid got the green light to begin construction for a 2020 launch.

Left: Artist's concept of the glowing corona above a supermassive black hole, thought key for generating the X-ray emission observed by the NuSTAR mission.

Below: Artist's impression of the Euclid spacecraft. Courtesy ESA







# THE CAMPUS-LAB CONNECTION

A world-class university paired with a leading space exploration facility? The possibilities seem endless. And proving just how far such synergies can take the scientific enterprise is at the heart of the increasingly close collaborations between JPL and the Caltech campus.

As JPL's parent organization, Caltech is situated not only to provide institutional oversight but also to work with the Lab on joint initiatives. Those prove to be a two-way street, enriching the campus as much as it does JPL. Many collaborations are spun out of the Keck Institute for Space Studies, a joint Campus-Lab think tank created seven years ago. Since then, nearly four dozen science and technology investigations teaming campus faculty with JPL and external researchers have been completed. Initiatives active in 2015 included a study of Martian methane, a look at how life could form when water isn't present, instruments to study Earth's carbon cycle, and work on extremely high-precision clocks using devices called microcombs. One thing that makes the institute's efforts unique is that they are highly interdisciplinary — bringing together scientists from many disciplines with instrument-builders and other technologists.

Campus-Lab synergy has benefited as well from the President's and Director's Fund, a program founded two years ago to support research teaming Caltech and JPL investigators. The 2015 output included numerous papers on topics ranging from modeling factors influencing Greenland ice loss to exoplanets and cosmology.

In all, 12 JPL missions benefit from campus participation, including two (Mars 2020 and NuSTAR) with Caltech principal investigators, and 109 JPL staff serve as lecturers or associates at Caltech. Seven Caltech faculty have joint appointments at JPL.

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Left: A view of our sun combining data from NASA spacecraft including the Caltech-led NuSTAR.





Earth is a complex place. In 2015 JPL scientists continued to study developments related to our changing climate. But they were equally busy tracking emerging threats across a variety of dimensions, from the planet's water and ecosystems to weather and geological hazards.

# EARTH SCIENCE

## WEATHERING THE DROUGHT

One of the most significant stories was California's drought. The nation's most populous state experienced its fourth consecutive year of below-normal rainfall and snowpack, and it was inevitable that it would impact human life in many areas. As the drought wore on, Californians in the state's agricultural regions adapted by pumping groundwater, but that was not without consequences. Based on data from radar satellites and airborne instruments, JPL scientists determined that land in the San Joaquin Valley was sinking by nearly two inches per month in some areas, potentially putting nearby infrastructure at risk. Groundwater declined to levels approaching or surpassing historical lows.

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Left: An aerial view of the Tuolumne River Basin captured as the Airborne Snow Observatory surveyed drought-impacted snowpack in 2015.



The news was not any better from studies of the snowpack in California's Sierra Nevada, a major source of water for the state. JPL's **Airborne Snow Observatory** measured the volume of water held in that mountain range's Tuolumne River Basin and found it to be just 40 percent of its highest level of 2014, another dry year.

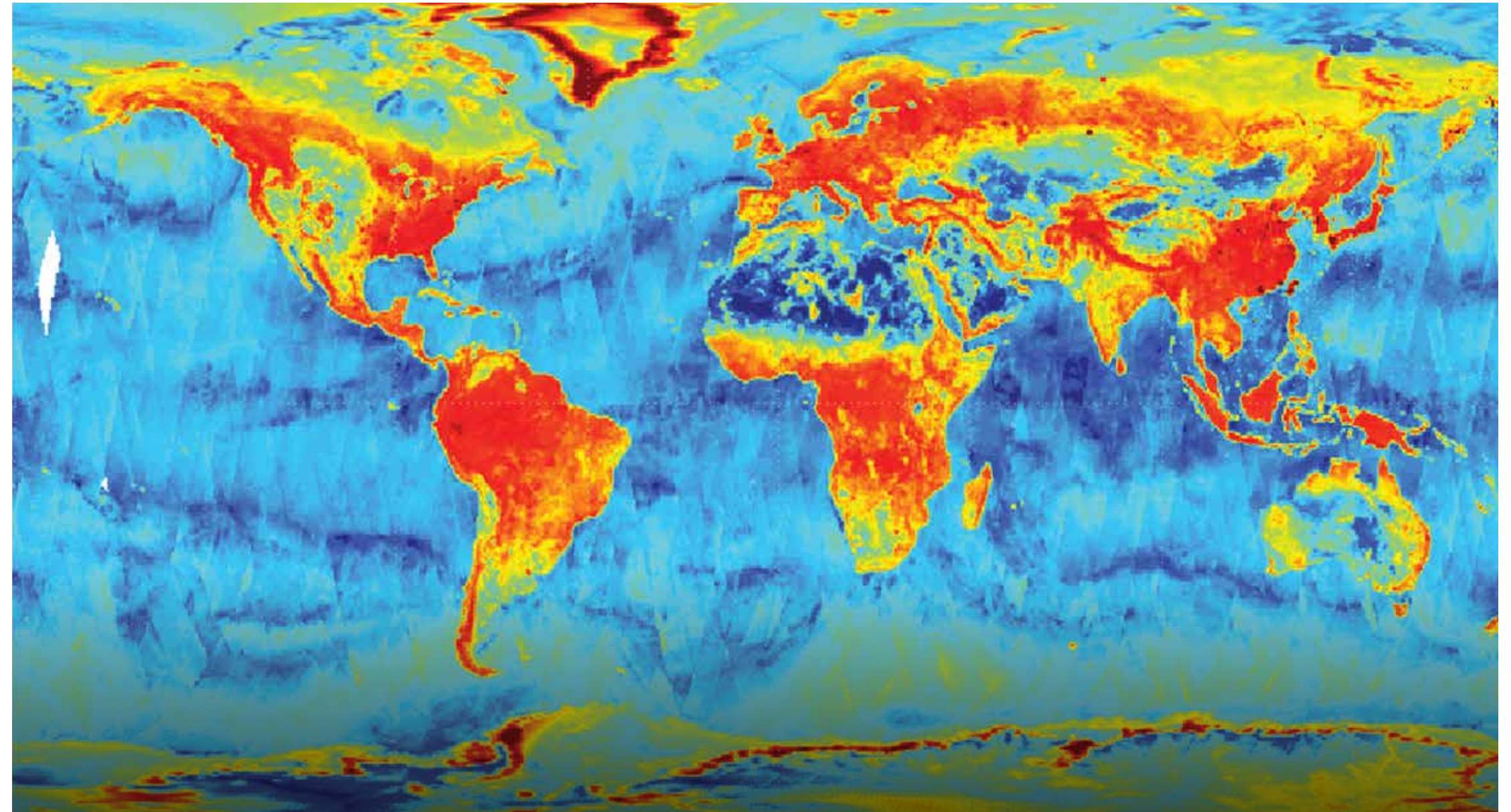
Groundwater issues were not limited to California. One study using data from the twin **GRACE** gravity satellites found that about a third of the planet's largest groundwater basins are being rapidly depleted by human consumption.

Later in 2015, data from **Jason 2** provided unequivocal evidence of a developing El Niño event among the largest in recorded history. Although that could offer some relief to California, climatologists said that a single year of high rain would not pull the state out of the drought.

Throughout the year, JPL scientists continued their ongoing collaboration with government agencies to provide information that could help leaders and planners make decisions about long-term policies in response to environmental change.

Understanding links between Earth's water, energy and carbon cycles is the target for JPL's **Soil Moisture Active Passive** satellite, which launched in January. By April its science mission began, and scientists released the first global maps of soil moisture. In summer, however, the satellite's radar stopped transmitting due to an issue with a power amplifier. Despite the loss of that instrument, the satellite's radiometer continued to send high-quality data that can be used to meet many of the mission's science goals.

Ocean temperatures have been gradually rising for many years, but not necessarily uniformly. Using data from the **GRACE** and **Jason** satellites with other measurements, JPL scientists found that a disproportionate amount of heat from greenhouse gases is trapped in a specific layer of the Pacific and Indian oceans some 300 to 1,000 feet



below the surface. That, they say, explains a slowdown in ocean surface temperatures measured around the globe over the past decade.

For several years, the Four Corners intersection of Arizona, Colorado, New Mexico and Utah has been the locale of a methane hotspot so pronounced that it can be seen from space. JPL scientists joined colleagues from other institutions to study the phenomenon with a suite of airborne

UNDERSTANDING LINKS BETWEEN  
EARTH'S WATER, ENERGY AND  
CARBON CYCLES IS THE TARGET FOR  
JPL'S SOIL MOISTURE ACTIVE PASSIVE  
SATELLITE.

Right: A global view from the SMAP satellite. Weaker radar signals (blues) show low soil moisture or lack of vegetation, found in areas such as deserts. Strong radar signals (reds) are seen in forests and areas of high soil moisture.





and ground-based instruments. They determined that the most likely sources for the methane were venting from oil and gas activities, active coal mines and natural gas seeps.

Closer to home, a natural gas leak was discovered in late October at the Southern California Gas Company's Aliso Canyon Storage Facility in Porter Ranch, displacing thousands of residents. Soon after the discovery, JPL was called upon by government agencies for its expertise and to provide independent measurements. In 2012 JPL had established the **Megacities Carbon Project** to evaluate and demonstrate methods of monitoring methane, carbon dioxide and carbon monoxide across the Los Angeles basin as part of a broader strategy to develop global carbon monitoring systems. Thus the Lab was well positioned to provide critical data to those involved in trying to resolve this local crisis.

Unfortunately, there was more cause for concern about greenhouse gases for the western region of the United States.

Although this part of the nation reduced its production of ozone-forming pollutants by a remarkable 21 percent between 2005 and 2010, ozone in the atmosphere above the region did not drop as expected in response, a JPL study found. The reason: a combination of naturally occurring atmospheric processes and pollutants crossing the Pacific Ocean from China. The finding was based on data from instruments on NASA's **Aura** satellite.

Amid other changes, the steady march of ice loss continued near the planet's poles. Antarctica's Larsen B Ice Shelf partially collapsed in 2002, and its last section is likely to disintegrate within five years, a JPL study found. Other researchers discovered a pair of seafloor troughs that could bring warm water to Antarctica's Totten Glacier, hastening its thinning.

## THE STEADY MARCH OF ICE LOSS CONTINUED

### NEAR THE PLANET'S POLES.

Left: Glaciologists from JPL and the University of California, Irvine, map remote Greenland fjords by ship. Their findings show that Greenland's glaciers are likely to be melting faster than previously thought. Courtesy UCI/Maria Stenzel



**SUE OWEN**  
Hazards Scientist



As the world's population increases, people are increasingly exposed to dangers such as earthquakes, volcanic eruptions and tsunamis. Sue Owen sees it as her mission to make that world at least a little safer.

Thanks to networks of GPS stations on the ground and radar satellites in orbit, there is plenty of data to help understand natural hazards — even to move people out of harm's way during real-time emergencies. “But that doesn't mean it is easily usable. If this can be automated, data can be available when it can make a difference.”

That's the idea behind a rapid imaging analysis center, called ARIA, created as a joint venture between JPL and Caltech with Owen as principal investigator. The center was able to provide data following the April 2015 7.8-magnitude earthquake

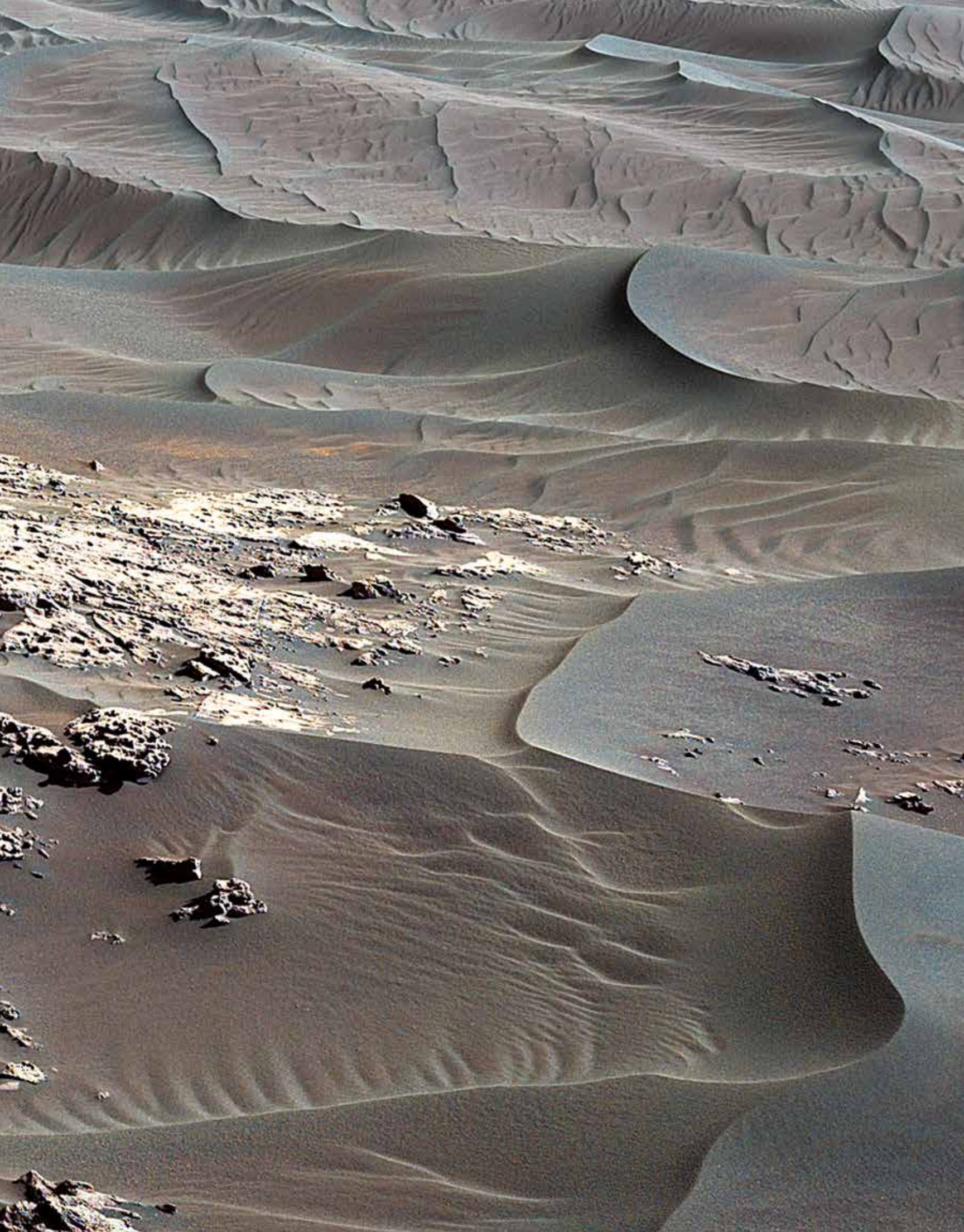
in Nepal advising government leaders on areas with collapsed buildings and the potential for follow-on quakes.

Growing up in Rhode Island and Massachusetts, Owen says that as a girl she “was interested in everything. I was one of those kids who loved every single class.”

At Harvard, she studied astrophysics as a physics major before a geology class persuaded her that her love of the outdoors would be better served concentrating on geophysics in her senior year. After earning a Ph.D. at Stanford, she taught at USC for a few years before coming to JPL.

In the years since, Owen has come to appreciate her choice of life's work because it has the potential to make a difference in people's lives. “It's a great combination of working with data from space missions that has important applications on Earth,” says Owen, who also finds time to run ultra-marathons. “This is the sweet spot for me.”





Don't grab the waterslide gear just yet. When NASA in September announced new evidence that current-day streaks on Mars involve liquid water, it was an exciting new turn in the space agency's "Follow the water" strategy. But what it means to long-term questions about habitability and life is less clear.

# MARS EXPLORATION

## MARS WATER, TODAY

The story began four years ago, when scientists working with JPL's Mars Reconnaissance Orbiter announced finding dark streaks on slopes of Martian craters that appeared and disappeared with the seasons. Ultimately, the streaks — called "recurring slope lineae" — were spotted in thousands of locales around the planet.

In the latest finding, scientists used the orbiter's spectrometer to identify changes in salts associated with the streaks that indicate the presence of water. This constituted decent evidence that liquid water exists at least briefly now and then on the surface of Mars today.

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Left: Rippled surface near the edge of the first Martian sand dune ever studied up close — part of the Bagnold Dunes visited by the Curiosity rover.





THE SALTS INVOLVED DERIVE FROM PERCHLORATE — A SUBSTANCE COMMONLY USED AS AN OXIDIZER IN ROCKET PROPELLANTS — BUT ONE NOT VERY FRIENDLY TO LIVING THINGS.

Scientists continue to debate, however, just how much water might be involved and where it comes from. And, even if any water is seeping just beneath the surface, liquid water on Mars' surface will rapidly evaporate in the planet's thin atmosphere.

The salts involved derive from perchlorate — a substance commonly used as an oxidizer in rocket propellants — but one not very friendly to living things. Some scientists, in fact, say that similar environments on Earth are totally devoid of life, while others leave it an open question. Perchlorates aside, the quest to know whether life might have at least once existed on Mars persists. And that is one of the goals of the next rover destined for Mars in the year 2020. Development of this Curiosity-like rover continued in full swing in 2015.

Perhaps the point that all the scientists can agree on is that Mars today is far from a static world. In its decade at the planet, Mars Reconnaissance Orbiter has found not only the streaks but moving sand dunes, more than 400 freshly made impact craters and dust storms that come and go. Whether or not there is life, in many ways Mars is an ever-changing planet.

Now the going is steeper, but the Mars **Curiosity** rover team is up for the challenge. After spending more than two years prospecting in the environs near its landing site, the rover started climbing Gale Crater's Mount Sharp in earnest. Along the way, scientists released findings from early studies at Yellowknife Bay showing that fixed nitrogen, a requisite of life, is in minerals at the site — a boost for the area's ancient habitability. Scientists also announced that, based on the pebbles, sandstones and mudstones they found as Curiosity headed

out from its touchdown location, the lower part of Mount Sharp must have built up over time in a series of lakes. At the end of the year, Curiosity arrived at a spot called the Bagnold Dune Field where winds continue to form and shift sand dunes today — the first such visit by any Martian rover.

A marathon, and then some: Incredibly, the Mars Exploration Rover **Opportunity** was spending its 12th year actively roaming the planet's surface (remember the original mission was for 90 days?). And it had a milestone to mark the occasion — it became the first machine on another world to log a total travel distance of 26.2 miles, the length of a terrestrial marathon race. To celebrate, the Opportunity team nicknamed the site it arrived at as Marathon Valley. There, mission scientists looked forward to scrutinizing clay minerals from Mars' most ancient era.

Above: A composite view of Mount Sharp, as captured by Curiosity.



## RAY BAKER

### Spacecraft Engineer

Some parts of the Curiosity rover's landing system may have been new and innovative, but for the basics of the propulsion system that Ray Baker worked on when he joined JPL, they were not starting with a blank sheet of paper.

"It was all based on Viking technology," he says of the rover mission's heritage rooted in the historic Mars lander of the 1970s. "We were taking old drawings in ink on vellum and turning them into CAD files. We worked with flight spares of Viking engines that had been kept in crates at JPL. It was like engineering archaeology."

As they did for Viking, the designs — updated and adapted for Curiosity — worked brilliantly. "That landing was almost too good to be true," says Baker, who has been full-time on Mars rovers for nearly all of his 14 years at JPL. "Now, with Mars 2020, we're sticking very close to what worked with Mars Science

Laboratory. But we have an opportunity to look it all over very carefully."

A native of Pittsburgh, Baker says he got hooked on space when as a five-year-old he watched the launch of the first space shuttle on TV with his father. "I read all the books in the library on space and space exploration," he says. That path took him to Penn State for a bachelor's in aerospace engineering, then to Caltech for a master's in mechanical engineering.

As product delivery manager for the cruise and entry, descent and landing systems for Mars 2020, Baker's role has grown beyond propulsion. "It's a challenge," he says. "In industry, you create a prototype, then set up a production line to make copy after copy. In our case, we're making what is only the second-ever experimental prototype — and Curiosity's amazing success has set expectations very high. That raises the stakes."







In the parlance of spacecraft builders, every mission has a class. The Class A outings are the flagship missions that must succeed at all cost. Then there are the Class B projects that can take calibrated risks, on through Class C, and Class D. And then there is Class U. These

# NEW TECHNOLOGY

## SMALL IS BIG

small missions — also known as CubeSats — got their start in universities a decade and a half ago. Now the micro-sized projects have gone well beyond academia and have become the biggest thing in the flight development realm. JPL has embraced CubeSats big time. Already the Lab is home to some 23 CubeSats in varying stages of development, spanning not only Earth science but also heliophysics, astrophysics and planetary exploration. Students are often, but not always, involved. JPL's efforts are attracting attention for their strong focus on science objectives. One slated to fly in 2018, an Earth orbiter featuring a radar to study rain, would become the first CubeSat equipped with an active sensing instrument.

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Left: An artist's rendering of two upcoming JPL-teamed CubeSats planned for release from the International Space Station.



## CHARLES NORTON

CubeSat Technologist



Why do so many people with advanced math and science skills have a special affinity for music? That may be a question for neuroscience, but nowhere is it more true than at JPL, where sheet music and guitar picks are as likely to be found as calculators in many briefcases and backpacks. And at the Lab there is no better exemplar of this skill mix than Charles Norton.

After getting a taste of the bassoon as a sixth grader in Long Island, Norton went on to tour with a regional youth orchestra, performing in 35 countries over six summers. By the time he was leaving high school, he had to decide whether to accept an audition invitation as a principal with the New York Philharmonic. “It was the kind of opportunity that only comes along once every 40 years,” Norton remembers now. “But it was also a challenging time to be a musician.”

Instead, Norton headed to Princeton for a bachelor’s in electrical engineering, followed by a master’s and Ph.D. in computer science at Rensselaer. That led him

to JPL as a postdoc working on high-performance computing in Earth science.

He was offered a role managing technology tasks around the same time colleagues were getting involved in CubeSats, and the two threads intertwined. Today he has a hand in managing nearly all of the Lab’s nearly two dozen CubeSat projects.

Norton — whose love of music is shared by his daughters, one an oboist and the other active in ballet — says it provides an inspiration that carries over into his technical work. “It’s hard to put into words,” he reflects, “but both the technical work and the music are very satisfying.” And speaking of carrying over in your work, Norton arranged for the Los Angeles Youth Orchestra — one of its members is his oboe-playing daughter — to perform at JPL in July. Among the compositions was one called “Cosmic Dust,” a new work inspired by the Hubble Space Telescope and its JPL-built camera.



AFTER A 7.8-MAGNITUDE EARTHQUAKE DEVASTATED NEPAL IN APRIL, A SUITCASE-SIZED DEVICE DEVELOPED AT JPL CALLED FINDER WAS USED TO LOCATE AND SAVE FOUR MEN BURIED UNDER THE RUBBLE OF A COLLAPSED TEXTILE FACTORY AND ANOTHER BUILDING.



Above: More flexible than any human, JPL's RoboSimian demonstrates capabilities that could be useful in disaster recovery.

Right: The FINDER device helped save several men trapped in the 7.8-magnitude earthquake in Nepal.

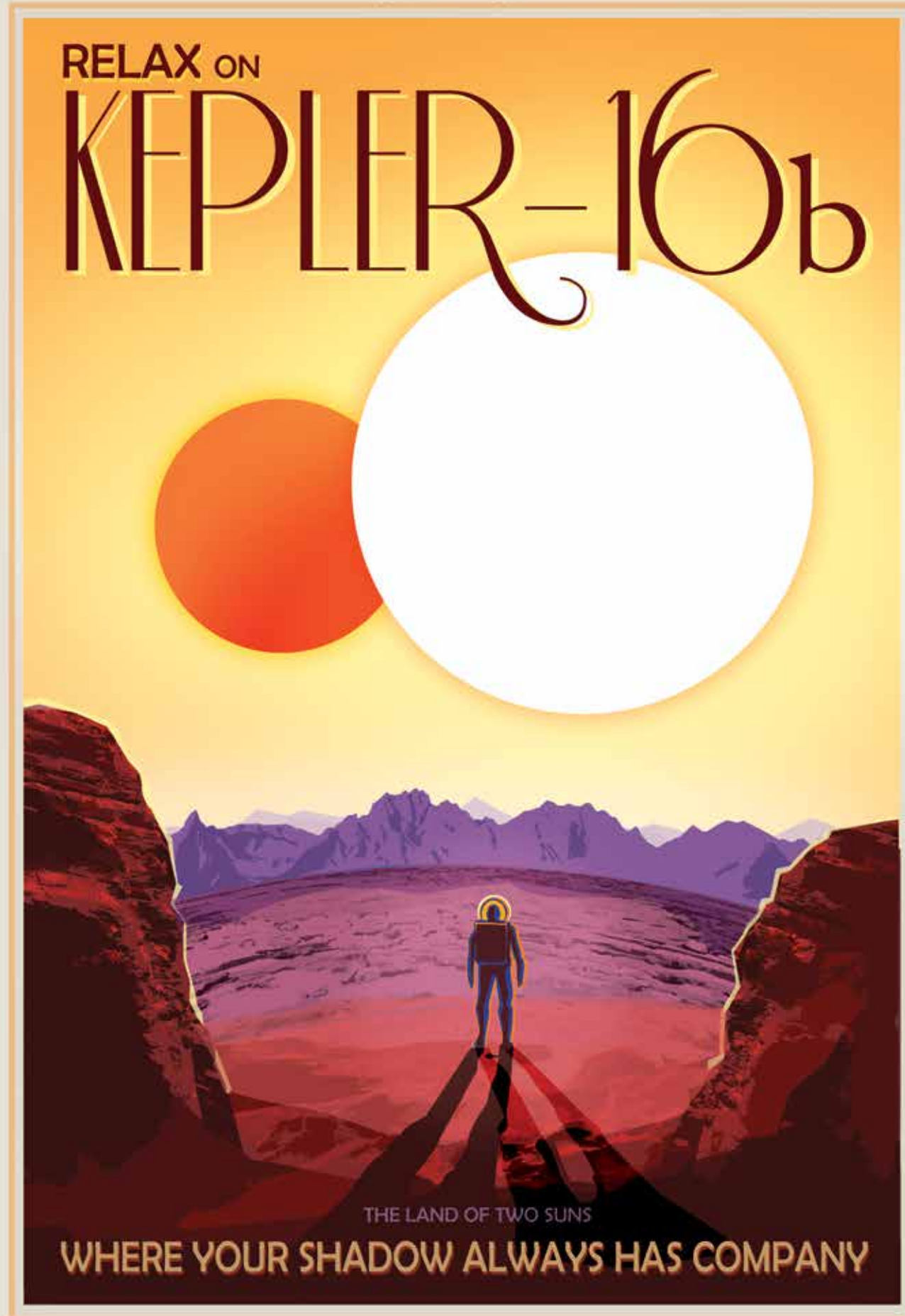
Technology spinoffs can be lifesavers — literally. After a 7.8-magnitude earthquake devastated Nepal in April, a suitcase-sized device developed at JPL called **FINDER** was used to locate and save four men buried under the rubble of a collapsed textile factory and another building. The device used a microwave signal only one-thousandth the power of a mobile phone to locate the men under 10 feet of brick, mud, wood and other debris.

It won't win any tango contests, but **JPL's RoboSimian** is more flexi-jointed than any dancer out there. The ape-like robot, equipped with four limbs and seven pairs of stereo cameras, is designed to get across challenging terrain and perform complex tasks — capabilities that would be useful in fields like disaster recovery. In 2015, the robot went to the finals of a DARPA-sponsored contest, placing fifth out of the 22 advanced robots in competition.

Flying saucers back over Hawaii? That might have been an understandable conclusion as **JPL's Low-Density Supersonic Decelerator** went to the islands a second year to flight-test technologies designed to help land large payloads at Mars. The project's doughnut-shaped inflator successfully expanded, but the parachute did not survive the test. Engineers weren't distressed, however, knowing the old engineering adage that it's possible to learn more when things go wrong than when they go right. The test provided highly valuable data to be put to use for the project's next hardware attempt.







## PUBLIC ENGAGEMENT

### THE ALLURE OF SPACE

Is there a thing as too much love and attention? Maybe so, if JPL's 2015 Open House is the example. JPL hosted its latest weekend Open House during what turned out to be an early-October heat wave — just as the box office movie hit “The Martian” arrived at the theaters. But even temperatures in the high 90s and traffic jams on the 210 freeway couldn't keep away more than 45,000 visitors, some of whom walked for miles to be part of the overflowing event. To cope with so much public interest in the future, the Lab will likely have to rethink how it opens its doors to an adoring public.

Of course, you don't have to be physically present to experience JPL missions, thanks to the rich websites presenting information on Lab programs to the public at large. In 2015, two websites and a mobile app brought home Webby awards — one each for the JPL public home page, the Global Climate Change site and the Earth Now mobile app.

Then there are the few lucky ones who get to visit JPL not for just a day — but for weeks at a time. They are JPL's student interns. In the past 15 years, JPL's competitively selected internship program has grown by 550 percent, in 2015 bringing more than 700 high school students, college undergraduates, grad students and postdoctoral researchers to JPL for the summer or year-round work.

JPL also takes its sights and sounds out into the world at large. In May, the Lab's visual designers exhibited Orbit Pavilion, a massive walk-through sculpture, at the World Science Festival in New York City. The installation allowed visitors to hear sounds representing the orbits of NASA Earth-observing satellites as they pass overhead. And visitors to Washington, DC, can check out JPL's tours of Eyes on the Earth, Solar System and Universe (also available on the web at JPL's home page). These kiosk versions were installed in 2015 at the Smithsonian National Air and Space Museum, the nation's most visited museum.

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Left: Public interest was exceptionally high when JPL released a series of posters imagining future travel to space destinations such as newly discovered exoplanets.



## MAJOR EXTERNAL AWARDS

### John Brophy

Electric Rocket Propulsion Society  
Ernst Stuhlinger Medal

### Robert Carlson

American Geophysical Union  
Named Fellow

### Nacer Chahat

Regional Council of Brittany  
Brittany Prize for Young Researchers

### Evan Chan

Federal Computer Week  
Rising Star

### Climate Change Website

International Academy of Digital Arts and Sciences  
Webby Award, People's Voice Award, Green Website

### Tracy Drain

Women in Engineering  
Champion Award

### Earth Now App

International Academy of Digital Arts and Sciences  
Webby Award, Mobile Sites & Apps/Education and Reference

### Bethany Ehlmann

American Geophysical Union  
James B. Macelwane Medal

### Dan Goebel

National Academy of Engineering  
Elected Member

### Matt Golombek

Geological Society of America  
G.K. Gilbert Award

### Gerard Holzmann

Institute of Electrical and Electronics Engineers Computer Society  
Harlan D. Mills Award

### Jet Propulsion Laboratory

Information Week  
Elite 100 Companies

### Jet Propulsion Laboratory

Climate Registry  
Cool Planet Award

### JPL Public Website

International Academy of Digital Arts and Sciences  
Webby Award, People's Voice Award, Best Government Website

### Kepler Mission Team

International Association of Meteorology and Atmospheric Sciences  
Early Career Scientist Medal

### Attila Komjathy

Institute of Navigation  
Named Fellow

### Jacob Matijevic

Illinois Institute of Technology  
Lifetime Achievement Award

### Multi-Angle Rear Viewing Endoscopic Tool Team

Federal Laboratory Consortium for Technology Transfer

Outstanding Technology Development Award

### Firouz Naderi

Carnegie Corporation of New York  
Great Immigrants Honoree

### Ron Ross

Cryogenic Society of America  
Named Fellow

### Graeme Stephens

National Academy of Engineering  
Elected Member

### Jakob van Zyl

Stellenbosch University  
Honorary Doctorate

### Yuan Wang

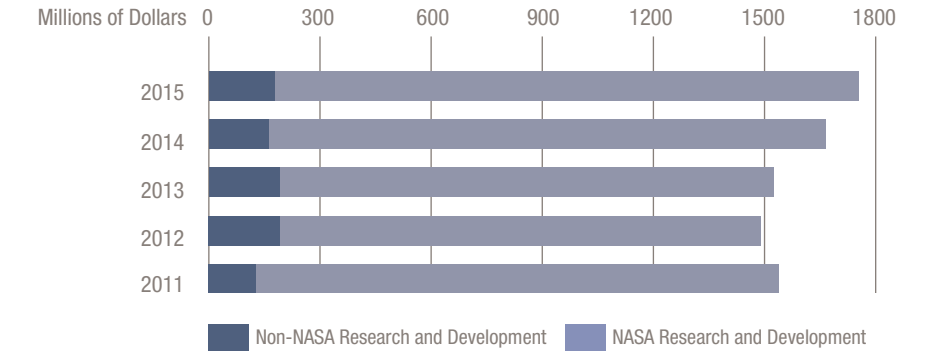
International Association of Meteorology and Atmospheric Sciences  
Early Career Scientist Medal

### Josh Willis

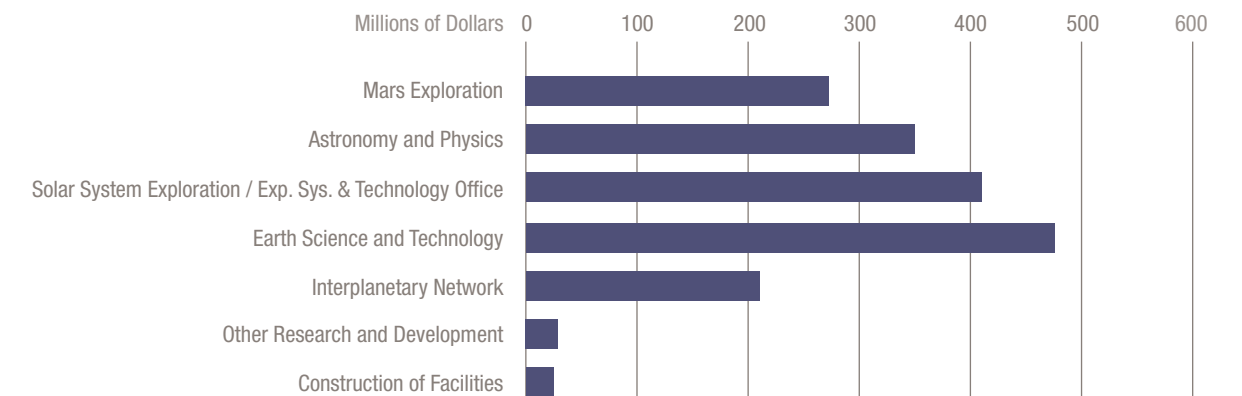
American Meteorological Society  
Nicholas P. Fofonoff Award

## BUDGET AND WORKFORCE

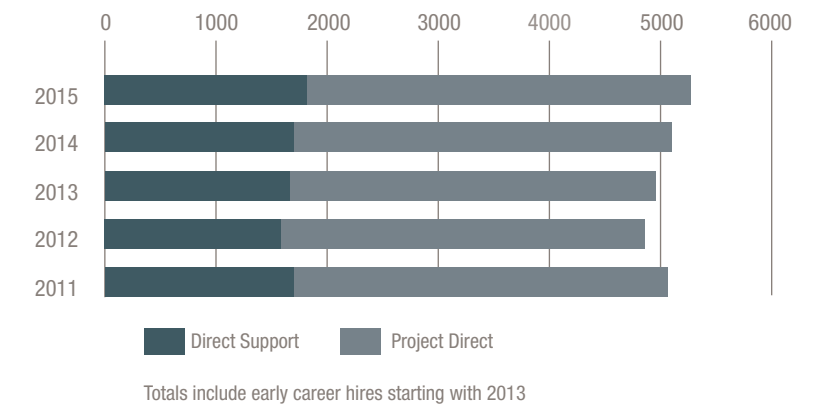
### Total Costs



### Total Costs by Program



### Total Personnel





## MAJOR CONTRACTOR PARTNERS

### Lockheed Martin Corporation

Desktop Institutional Computing, InSight, Juno, Mars 2020, Mars Odyssey, Mars Reconnaissance Orbiter, Mars Science Laboratory, Rosetta, Spitzer Space Telescope

### Exelis Incorporated

Deep Space Network Operations

### Northrop Grumman Systems Corporation

Atmospheric Infrared Sounder, James Webb Space Telescope Mid-Infrared Instrument, NASA-ISRO Synthetic Aperture Radar, Soil Moisture Active Passive

### Airbus

Gravity Recovery and Climate Experiment, Surface Water and Ocean Topography

### Raytheon

Data Systems Implementation and Operations

### EMCOR Government Services Incorporated

Facilities Maintenance and Operations

### Applied Physics Laboratory Johns Hopkins University

Europa, Mars 2020, Mars Reconnaissance Orbiter

### Teledyne Technologies Incorporated

Airborne Visible InfraRed Imaging Spectrometer, Euclid, Near-Earth Object Camera, Orbiting Carbon Observatory 2, Portable Remote Imaging Spectrometer 2

### MORI Associates

Information Technology Infrastructure Support

### Orbital ATK Incorporated

Active Cavity Radiometer Irradiance Monitor, Dawn, Europa, Jason 2, Low-Density Supersonic Decelerator, Orbiting Carbon Observatory 2, Mars 2020, Near-Earth Object Wide-field Infrared Survey Explorer, Ocean Surface Topography Mission, SeaWinds

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**Victoria Stratman**

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**Jonas Zmuidzinas**

Chief Technologist

Right: Scores of baby stars shrouded by dust in a star-forming region nicknamed the Monkey Head, as captured by the Spitzer Space Telescope.





National Aeronautics and Space Administration

**Jet Propulsion Laboratory**

California Institute of Technology

Pasadena, California

[www.nasa.gov](http://www.nasa.gov)