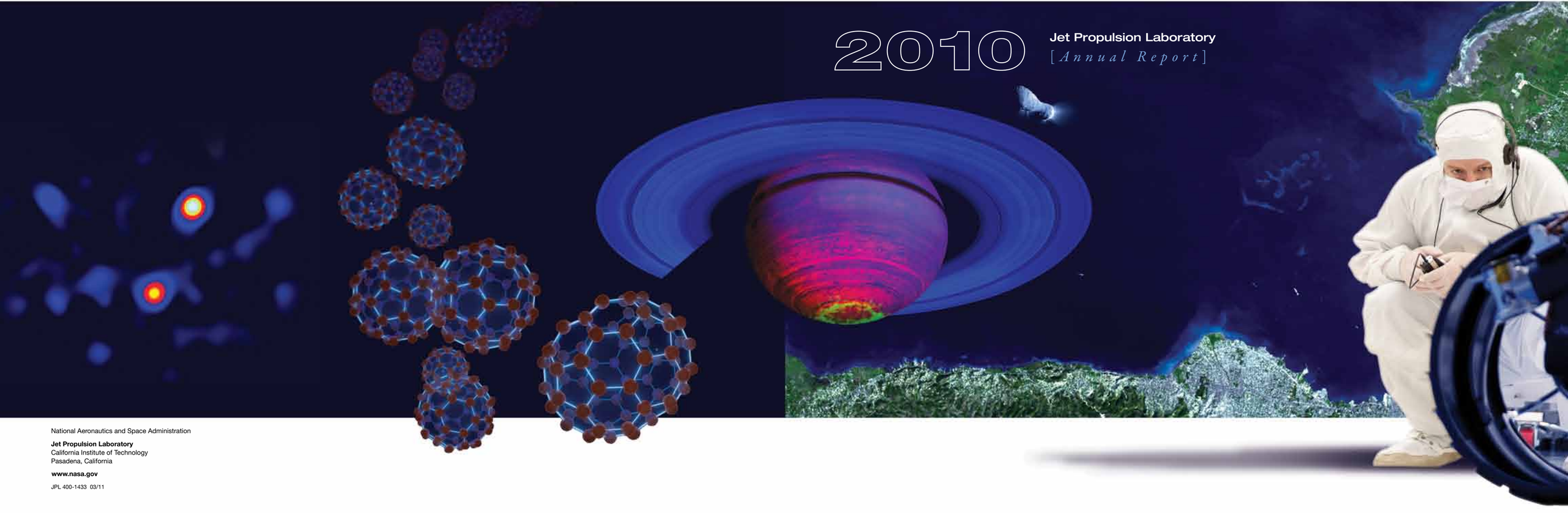
National Aeronautics and Space Administration



2010

Jet Propulsion Laboratory

[Annual Report]

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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CONTENTS

On the Cover: JPL's 2010 highlights included developments in such diverse areas as cosmic buckyball science, Earth remote sensing, comet studies and Mars rover development.

A curious visitor inquires about rover wheel design at JPL's 2010 Open House. The popular event attracted more than 36,000 people this year.

Director's MESSAGE

" . . . while our day-to-day work takes us far into realms of abstractions, in the end what is most important about what we do is how it touches individual human lives. Our technologies are only as good as the improvements they make in human experience."

Charles Elachi

As I reflect on JPL's accomplishments in 2010, I'm struck by the diverse ways our missions and programs explored not only space, but touched the lives of so many people.

The year certainly had its exciting moments off the planet. Perhaps the highlight was in November when one of our well-traveled spacecraft flew closely past a comet — the smallest such body ever visited, one described by our scientists as "hyperactive, small and feisty." Numerous other missions continued to hold our attention with important science results from Mars, Saturn and the stars and galaxies beyond.

There were high points in engineering. Who could fail to feel their pulse quicken as we watched our next Mars rover take final shape in a clean room in preparation for its fall 2011 launch — joined by millions who tuned in to watch it being assembled via our live webcam? Our largest dish antenna in California's Mojave Desert — a colossus of space communication that has served as the gateway to dozens of spacecraft since it was built a half century ago — was the beneficiary of a critical overhaul to keep it tracking smoothly across the sky. This tuneup will prepare us well for an array of mission activities in 2011–2012, when we launch five new missions and execute key flight events including landings and arrivals.

But I was especially proud of how we were able to help improve the quality of life on Earth. Soon after a major earthquake struck the island nation of Haiti, our instruments on aircraft and satellites went into action, helping to spot landslides and mapping the rupture to better prepare for earthquakes in the future. When an explosion at an offshore platform in the Gulf of Mexico caused the largest marine oil spill in history, one of our airborne instruments was dispatched and imaged the slick in detail, improving estimates of how much oil was likely to impact the shoreline.

We also touched lives in more local ways. I was very honored when NASA selected JPL as the location to kick off Summer of Innovation, an agencywide effort to create summer educational experiences to improve the prospects of disadvantaged students in science, technology, engineering and math, or STEM, fields. Our country has arrived at the realization that it is no longer inevitable that the United States will be the world's leader technologically and economically. Improving students' achievements in STEM will be critical to our national future.

As this annual report was going to press in January 2011, the laboratory was recovering from the sudden death of Rick Grammier, our senior executive in charge of solar system exploration. This was a great loss for me and for the laboratory. Rick's passing also reminded me that, while our day-to-day work takes us far into realms of abstractions, in the end what is most important about what we do is how it touches individual human lives. Our technologies are only as good as the improvements they make in human experience.

As you look through the months of 2010 I hope that, like me, you will find meaning in the broad scope of missions and research that our many teams undertook throughout the year.

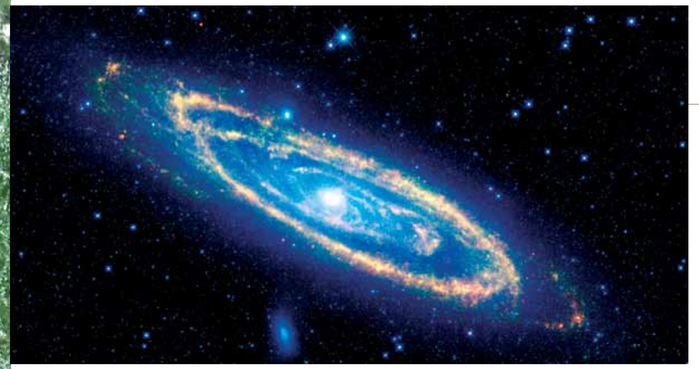
JANUARY

Finding Faults

Late in the afternoon on January 12, a magnitude 7.0 earthquake struck near Haiti's capital of Port-au-Prince. In a seismically active region prone to destructive earthquakes, it was the worst in many decades for the Caribbean island nation, the western hemisphere's poorest country.

Within days, scientists pored over images of Haiti captured by the Advanced Spaceborne Thermal Emission and Reflection Radiometer, an instrument developed by JPL with Japan's space agency flying on NASA's Terra satellite. By comparing them to images collected a year before, they were able to flag locations of possible landslides.

As it turned out, a JPL airborne instrument called the Uninhabited Aerial Vehicle Synthetic Aperture Radar was already booked to fly to Central America to study rainforest canopies. Researchers added a side trip to Haiti to see what the imaging radar could show of the faults on the island. At first they assumed the quake was the handiwork of a major fault that stretches across southern Haiti and the Dominican Republic, marking the juncture of the enormous tectonic plates underlying North America and the Caribbean. One JPL scientist, however, analyzed more radar images from a Japanese satellite and concluded the quake was caused by slippage on several faults — chiefly a previously unknown subsurface fault. The radar work will serve as a baseline for monitoring future quakes.



In WISE's infrared mosaic image of the Andromeda Galaxy, mature stars glow bright blue while yellow and red mark dust heated by massive newborn stars.

Chilling While You Can

For the Wide-field Infrared Survey Explorer — or WISE — it was a whirlwind 10 months. Like other infrared telescopes rocketed into space, WISE depended on a supply of coolant to chill its detectors to temperatures just above absolute zero to tease out the most subtle objects in the distant universe. WISE's hydrogen coolant would provide for a prime mission lasting just under a year. Following its launch at the end of 2009, mission planners made the most of the precious time they had.

In January 2010 the telescope began a six-month campaign to map the entire sky. Within days, it discovered a never-before-seen near-Earth asteroid — proving the space telescope's usefulness not only as a portrait photographer of distant stars and galaxies, but also serve as a sentry for rocks passing close to Earth. By July WISE had accomplished its all-sky map, in the process producing a colorful array of images – astronomers called it a "candy store of images coming down from space" — capturing hundreds of millions of space objects ranging from distant quasars and galaxies to nebulas and comets.

By October, WISE's coolant had run out. But the party wasn't over — there was more to come for the mission. Half of the telescope's four detectors work at warmer temperatures, so WISE embarked on an extended mission focusing on finding and observing asteroids and comets within the solar system. By year's end WISE had discovered 20 comets and 34,000 asteroids — some of which have orbits that take them relatively close to Earth's path around the sun.

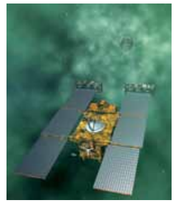
FEBRUARY

Cassini: No Game Over

For Saturn's moon Mimas, life has been a bounce from one cultural icon to another. For years after Voyager 1 viewed it during its flyby in 1980, Mimas was known as the Death Star due to a large crater on one side that lent it an uncanny resemblance to the planet-destroying space station in Star Wars. And now it's gone on to a new notoriety as — Pac-Man? That at least is the improbable likeness that jumps out from thermal maps that Cassini's composite infrared spectrometer instrument collected during the spacecraft's closest-ever flyby of the diminutive moon in February. The cause of the resemblance remains a mystery, though scientists are sure it's strictly natural; the temperature variations, they say, could be caused by electrons bombarding the moon.

Saturn's system held still other surprises for Cassini, which marked its sixth anniversary orbiting the ringed planet. For the first time, the spacecraft got a glimpse of lightning flashing in Saturn's atmosphere in visible light, and found evidence of currently inactive ice-spewing volcanoes on Saturn's largest moon, Titan. Perhaps most intriguingly, some scientists speculated that chemical reactions they are seeing on Titan could be the handiwork of methane-based life. Not everyone agreed, however; some argued that the reactions could have a non-biological explanation. The answer will have to wait on a future mission with a lander or balloon equipped to study Titan's chemistry in greater detail.

Its Pac-Man discovery notwithstanding, there is no game over for Cassini. NASA approved a new extended mission for the flagship orbiter that, barring any technical problems, will ensure it remains on station at the stately planet through 2017.



It's been a quiet cruise for **Stardust** After flying by Comet Wild 2 in 2004 and delivering a capsule of cometary dust to Earth in 2006, the spacecraft has spent four years in the expanses between the planets orbiting the sun. But that changed in February, when Stardust fired its thrusters on a new course. Early in 2011, the spacecraft will fly by a second comet, Tempel 1. That comet was previously visited by another mission, Deep Impact, which fired a penetrator at the comet nucleus to excavate a crater.

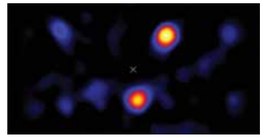
Saturn's dramatic structure as seen in the near-infrared is brought to the fore by Cassini. This composite image includes a view of the temperature distribution on the surface of the small moon Mimas.

MARCH

Pressed for Time

If it seems like there aren't enough hours in the day, there could be a reason. A day really isn't as long as it used to be. But it's not a difference that even the most acutely attuned human could ever detect.

In March, JPL scientists announced that a magnitude 8.8 earthquake in Chile at the end of February shifted Earth's axis by about eight centimeters (three inches). As a result, the length of a day was shortened by 1.26 millionths of a second. In truth, the effect was not unique — earthquakes have similar, near-negligible effects all the time. A magnitude 9.1 earthquake in Sumatra, for example, shortened the length of a day by 6.8 microseconds. The Chilean quake packed relatively more punch for its size, however — since it was farther from the equator, it affected Earth's axis more.



Looking for planets around other stars doesn't have to require monster telescopes. Pushing instrument technologies to their fullest, a team of JPL astronomers showed it's possible to take pictures of exoplanets using a relatively modest ground-based telescope less than five feet in diameter. Combining two techniques — **adaptive optics and a coronagraph** — they succeeded in imaging three planets orbiting a star 120 light-years distant using a small portion of Palomar Observatory's Hale Telescope to simulate a small telescope. Their method could equally help large telescopes increase their planet-finding power even more.

MAR

[*Short Takes*]

APRIL

Smoke Gets In Your Eyes

Iceland is no stranger to volcanic eruptions — perched at the juncture of continent-sized tectonic plates between Europe and Greenland, the island nation is peppered with 130 volcanic peaks. (Jules Verne's adventure to the contrary, none of them lead to the center of the Earth.) But when an otherwise unremarkable ice-capped caldera with the tongue-twisting name Eyjafjallajökull rumbled in April, it made news with a decidedly economic bottom line.

Though small by volcanic standards, Eyjafjallajökull's eruption pushed an enormous ash cloud 9 kilometers (30,000 feet) into the air, shutting down most air flights in Europe — the largest air travel disruption since World War II. Several NASA satellite instruments gathered views of the plume, including JPL's Multi-angle Imaging SpectroRadiometer on the Terra satellite. The radiometer's images provided a three-dimensional view that helped estimate the size of the plume.

In this false-color infrared image taken by the Advanced Land Imager flown under NASA's New Millennium Program, the bright red curved area (far left) indicates a strong thermal signature at the base of the Eyjafjallajökull plume. Lava flows and lava fountains also glow red (above and to the right).

Tracking the Spill

One Tuesday evening in late April, an immense bubble of methane gas shot up a pipeline 5,500 meters (18,000 feet) from the ocean floor to a platform on the surface 66 kilometers (41 miles) off the coast of Louisiana. As the methane hit the platform's electrical generators a huge explosion erupted, killing 11 workers, injuring 17 others and setting off a fire that burned for a day and a half until the platform sank. By the time the undersea British Petroleum well was capped three months later, an estimated 4.9 million barrels of oil had gushed into the Gulf of Mexico, spawning the largest U.S. environmental disaster in history.

Within days after the explosion, JPL satellites and instruments were flying over to take the measure of the spill. Some of the most critical observations were gathered by the Airborne Visible/Infrared Imaging Spectrometer, which crisscrossed the gulf 11 times in May on a NASA high-altitude plane. In two weeks, the instrument collected as much data imaging oil on the ocean's surface as it usually does in an entire year of scientific campaigns. The director of the U.S. Geological Survey praised JPL's instrument for its role in estimating the size of the oil release, as well as the amount of oil likely to impact shorelines. The Jason 1 and 2 satellites, meanwhile, kept tabs on the Loop Current in the gulf, which could have transported the spill around the Florida peninsula and up the East Coast. Thankfully, that scenario appears to have been averted.

MAY

MAY

[*Short Takes*]

Southern Californians can't get enough of JPL. When the laboratory opened its doors for its annual **Open House**, more than 36,000 members of the public came to get a firsthand look at rovers, orbiters, space telescopes and more. In addition to traditional favorites like Mission Control and the RoboDome, crowds enjoyed JPL's newly retooled Visitor Center. More than ever, the weekend was also becoming a virtual experience — in addition to those visiting in-person, another 14,000 experienced the Open House online.

As a strong new signal of **climate change**, JPL scientists and outside colleagues announced that the upper layer of Earth's ocean has warmed since 1993. If the new heat added to the ocean were converted to electricity, it would be enough to power nearly 500 100-watt light bulbs for each of the 6.7 billion humans living on the planet. According to the team, the ocean is the biggest reservoir for heat; as the planet warms, 80 to 90 percent of the growing heat ends up in the ocean.

These two views from the Multi-angle Imaging SpectroRadiometer show the spreading oil slick approaching the Mississippi River delta from the lower right.

Where the Heart Is

There's no place like home? Not according to the Kepler spacecraft. Scrutinizing stars in a small patch of sky, the space telescope has found at least 700 worlds that might be something like our home planet. But it will be years before astronomers can say for sure.

Launched in 2009, Kepler spent 2010 on the hunt for Earth-like planets orbiting other stars. Its tool of choice: highly sensitive instrumentation capable of detecting the minute dimming of a star's light as a planet passes in front of it. By June, the Kepler team announced that, after eyeing 156,000 stars, 706 were flagged as potentially hosting planets. Armed with that information, the team will scrutinize stars with space telescopes such as Hubble and Spitzer and ground-based observatories before making any final calls.

But the process will take time. Astronomers have agreed that they need to witness three passages of a planet in front of a star — or "transits" — before deciding whether it exists. Planets like Earth that orbit in the "habitable zone" around stars tend to orbit about as quickly as Earth does — once a year, plus or minus. So it will be at least three years before the Kepler team is willing to venture whether worlds like our own are out there.

Bolstering "STEM"

America's competitiveness is rapidly becoming a national preoccupation. And rightly so — in recent years U.S. teenagers, soon to become the country's workforce, have been far from the top in the all-important areas of science, technology, engineering and mathematics, or "STEM." In one study, for example, they ranked 28th in math literacy and 24th in science literacy. The government thus looks to NASA, both for inspiring youth to pursue STEM careers and providing opportunities to help their skills flower.

In June, JPL hosted the agencywide kickoff for NASA's Summer of Innovation, a campaign to broaden summer learning for students from segments of the population traditionally underrepresented in STEM fields. While students from more affluent families typically have more access to summer educational enrichment, those without those opportunities usually slip the most academically during the break between school years.

Across the summer of 2010, NASA piloted the new program with students in grades 4 through 9. Summer also brought 500 students and faculty to JPL for scientific and technical work. Hands-on experience provides vital career guidance while contributing to both their research goals and the work of the laboratory.

JUNE

[Short Takes]

Earthquakes sometimes trigger massive tsunamis that menace coastal areas with tragic consequences. Other times, even major quakes don't result in much ocean movement. Why are some tsunamis created and others are a fizzle? A team of researchers believe they have the answer with a **tsunami prediction system** announced in June. They used data from Global Positioning System stations to correctly predict that the February 2010 magnitude 8.8 earthquake in Chile would spawn only a modest local tsunami effect. The system could help coastal communities prepare for larger tsunamis in the future.

You can goose a lot of speed out of just a tiny bit of acceleration if you keep your foot on the gas pedal long enough. That's what the ion-propelled **Dawn spacecraft** proved when it set a new record for speeding itself up in space more than any other spacecraft. Most robotic craft get nearly all their push as they initially blast off from Earth; apart from gravity assists when passing planets, en route their speed changes from thruster firings are tiny. Dawn, by contrast, used its ion engines to accelerate gradually by 24,000 kilometers per hour (15,000 miles per hour) since its launch in 2007, and has much more ion thrusting ahead. The propulsion technology will enable it to become the first spacecraft to orbit two space bodies in succession — the giant asteroid Vesta in 2011 and the dwarf planet Ceres in 2015.

Celestial Soccer Balls

Life, they say, at times imitates art. But who'd have thought that chemicals in space would impersonate architecture? That at least was how it looked when the Spitzer Space Telescope turned its eye on a dying star. Sifting through the spectral signatures of chemicals in the star, Spitzer detected the unmistakable sign of an exotic molecule composed of 60 carbon atoms called buckminsterfullerene — or "buckyball" for short. The whimsical name comes from the molecule's resemblance to the geodesic domes designed by Buckminster Fuller — somewhat like the chemical equivalent of a soccer ball.

First predicted 40 years ago, buckyballs were discovered in the laboratory in 1985. But they weren't viewed in the cosmos until Spitzer's sighting. Later in the year, astronomers reported finding bucketloads of the molecule throughout the galaxy.

That wasn't the only science highlight for Spitzer. Observing a planet orbiting a star in the constellation Andromeda, Spitzer found a warm spot in an odd location on the Jupiter-like world. In another observation, Spitzer found a copious amount of dust around a tight-knit pair of double stars that could be the remnants of pulverized planets. Such star systems are probably not the most benign neighborhoods for planets to mature in. Astronomers hoped other findings would be in store as the telescope continued its "warm mission" after depleting the coolant that chilled the space telescope during its main mission.

JULY

Hot Off the Production Line

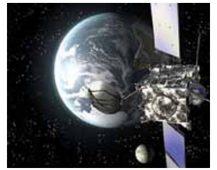
Unlike Detroit, JPL's rover designers don't come out with a new model every year. But when they do, it's a doozy.

For much of 2010, bunny-suited engineers were busy in a JPL clean room putting together Curiosity, the bulked-up rover that will launch to the Red Planet in 2011 under the Mars Science Laboratory mission. If Spirit and Opportunity were the size of ride-on-top lawnmowers, Curiosity is the Mini Cooper in this product line — at 2.7 meters (9 feet) long and weighing 900 kilograms (1,984 pounds), it's nearly twice as long and more than five times as heavy as the rovers currently at Mars. While Spirit and Opportunity bounced onto Mars' surface on airbags, Curiosity will be lowered via a novel piece of hardware that engineers call a sky crane — a cable unreeled from a rocket-powered descent platform.

In July, Curiosity's wheels were attached and took their first spin. Later in the year, Curiosity took brief test trips rolling over ramps, and practiced flexing its tool-packed robotic arm. By fall, JPL went online with a live webcam in the clean room that attracted 2 million viewers in its first two months.

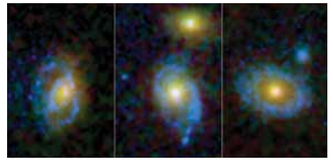
Curiosity's size will enable it to carry many more science instruments than previous rovers, equipping it to address the chief question scientists hope to solve. Could Mars ever have hosted environments conducive to life? Once it rolls, Curiosity may find out.

One of Curiosity's cameras took an "eye" test after delivery to JPL (it passed). The standardized test target is used to measure optics systems' resolving power as a function of contrast.



For Europe's Rosetta spacecraft, you could call it a heavy-metal warmup act. En route to a rendezvous with a comet, the spacecraft — with a **JPL microwave instrument onboard** — executed a July flyby of the asteroid Lutetia, the first visit by any spacecraft to a metal asteroid, and the largest asteroid ever encountered by a spacecraft. While Lutetia (the Latin name for Paris) is so dense it must be high in metal, the flyby showed its surface is a thick layer of dust and broken rock. Sailing past, the spacecraft then put itself into hibernation until its 2014 arrival at Comet 67P/Churyumov-Gerasimenko.

[*Short Takes*]



A few galaxies in deep space seem to have found the fountain of youth. Astronomers using **JPL's Galaxy Evolution Explorer** and NASA's Hubble Space Telescope have spotted aged, massive galaxies that seem to have caught a second lease on life. The galaxies have somehow been infused with fresh gas to form new stars powering mysterious, gargantuan rings of ultraviolet light, some of which could encircle several Milky Way galaxies. Where is the gas coming from, and how are the rings created? Scientists are still perplexed.

El Niños aren't what they used to be. But that doesn't mean they're fading away. For years, scientists have understood the ocean phenomenon to revolve around water warming in the eastern Pacific, causing heavy rain in South America. In recent years, a study found, **El Niños are becoming more intense**, forming with the warmest pool of water in the central Pacific — leading to increased hurricanes in the Atlantic and typhoons in the northwest Pacific near Japan. Researchers don't yet know if the change is due to natural factors or linked to climate change caused by human-produced greenhouse gas emissions.

Wellsprings of Life?

Did life ever exist on Mars? If it did, most scientists say the most promising era for it to have flourished was more than 4.7 billion years ago, when evidence suggests Mars was wet and warm. But new observations by Mars Reconnaissance Orbiter show that life-friendly conditions could have persisted for billions of years longer. Researchers used the orbiter's spectrometer to study light-colored mounds on the flanks of a small volcano near the planet's equator that look to be the remains of ancient hot springs. With the one-time presence of warm water, that would also make them one of the most promising places to scavenge for remnants of ancient microbes. "Recent," however, is relative — the hot springs were probably last active 3 billion years ago.

Now in its fifth year at the Red Planet, Mars Reconnaissance Orbiter provided yet more wallpaper-ready beauty shots thanks to its telescopic camera — releasing hundreds of new views in August — as well as the makings of other scientific findings. Turning its ground-penetrating radar on the Martian arctic, the orbiter helped scientists solve a decades-long mystery surrounding what created distinctive spiral troughs in the ice cap at the planet's pole. Radar images point to wind as being the predominant factor shaping the swirling patterns in the ice. Other orbiter pictures zoomed in on fresh gullies trailing away from ridges in sand dunes. Though they look tantalizingly like gullies cut by water on Earth, new pictures indicate the Martian ravines were probably cut by carbon-dioxide frost.

False color in this Mars Reconnaissance Orbiter image highlights textures, dark slope streaks and other characteristics of the layered sand dunes in the Martian north polar region.

AUGUST

SEPTEMBER

Ultimate Road Trip

The Red Planet held very different fates for the twin Mars Exploration Rovers in their seventh year in residence. Times were tough for Spirit, which struggled unsuccessfully to free itself from a sand trap only to slip into hibernation for the Martian winter, perhaps never to reawaken.

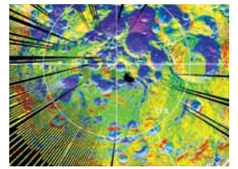
Opportunity, meanwhile, continued to rack up the mileage in an extensive road trip across a windswept Martian plain that would take it years to accomplish. In September, Opportunity reached the halfway point in its four-year trek from Victoria Crater, an 800-meter-diameter (half-mile-wide) bowl it investigated for two years, to the much larger Endeavour Crater. Along the way, it spied a whirling dust devil — the first ever seen on the side of Mars it has explored — and checked out a rock scientists believe may be an iron meteorite. It also spent six weeks at a small, evidently young crater marked by a strange mixture of soil types that scientists likened in appearance to a blueberry muffin.

But it was Spirit, ironically, that was responsible for some of the most exciting science results from the mission. Half a planet away, Spirit hunkered down for the long haul. By January, mission managers rededicated the rover as a fixed research station after months of efforts to release Spirit from a sand bog. With the advent of winter in the Martian south, electricity generated by Spirit's solar panels dipped and, by late March, the rover fell silent, as was expected as it put itself into a low-power hibernation state. The team planned to step up efforts to contact the rover in early 2011 with arrival of Martian southern spring, but they did not rule out the possibility that extreme cold could have done the rover in and that it would never be heard from again.

Even with Spirit sidelined, analysis of data it sent earlier continued to yield science. Most significantly, extensive detective work with rocks it examined in 2005 confirmed that an outcrop called Comanche showed signs of a past environment that was wet and non-acidic, possibly favorable to life. And the ground where Spirit became stuck held evidence that water, perhaps as snow melt, trickled into the subsurface relatively recently.

In this image composed of data taken by three instruments onboard Spirit, the Comanche outcrop is the dark reddish mound above center. False color emphasizes differences between materials.

SEPT



So you could call it Earth's problem child. The moon, scientists announced in September, had a more complex and turbulent youth than was previously known. The news, rather, is that in the early era after the moon split off from Earth, it was bombarded by two distinct populations of asteroids or comets. Scientists came to the conclusion after studying differences in soil in different regions around the moon revealed by **JPL's Diviner instrument** on NASA's Lunar Reconnaissance Orbiter spacecraft. Thankfully, the moon's later years have been more serene.

Figuring out cause and effect in the world of environment and climate can be challenging. But that didn't stop a team of scientists from determining that human activities in the Colorado River Basin over the past 150 years have resulted in a reduction of water flow in the river. The smoking gun: dust. Land development has caused much more dust to blow, some of it ending up on top of snow pack in the mountains that feed the Colorado River. As a result, **snow is warming up faster** in the spring, and the peak spring runoff now comes three weeks earlier than it did before the region was settled. In the process, more water evaporates; the net impact is a loss of 1 billion cubic meters (about 35 billion cubic feet) of water, enough to supply Los Angeles for 18 months. That could be bad news for the 27 million people in the seven U.S. states and Mexico who rely on water from the river.

OCTOBER

A Cure for Middle Age

More than 3 million kilograms (about 7 million pounds) of steel rolling on an enormous concrete pad, the giant Mars antenna in California's Mojave Desert has slewed across the sky daily and night, listening for the faint radio whispers of spacecraft spread throughout the solar system. Though named for the Mars missions it first enabled in the 1960s, the 70-meter-diameter (230-foot) dish has been an all-purpose communication outpost, tracking and commanding JPL's most celebrated missions from Voyager to Cassini. But after decades of constant duty, the middle-aged blues were setting in — time for a makeover.

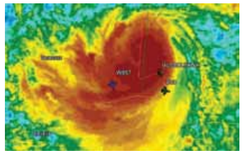
All told, the operation at JPL's Deep Space Network complex in Goldstone took seven months, as engineers used a dozen jacks to lift the colossal dish just 5 millimeters (less than a quarter inch) off its base to change out steel runners, wall and grout — the antenna equivalent of a knee repair. Completed in October, the operation is expected to keep the antenna running another 20 years.

While similar tuneups are planned for the antenna's hulking siblings in Australia and Spain, engineers aren't putting all their eggs in the basket of the giant dishes. They also began deploying groups of smaller antennas based on design called a beam waveguide that can be linked together in arrays to create the equivalent of one large antenna. And they continued refining plans for a deep space optical terminal that would use lasers instead of radios to communicate with spacecraft of the future.

Workers used laser-assisted measurements to ensure a flat surface for pouring new epoxy grout for the Goldstone antenna's hydrostatic bearing assembly.

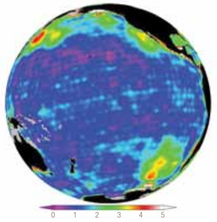
[*Short Takes*]

2010



Compared to other years, 2010 was relatively quiet for Atlantic hurricanes. But that didn't stop researchers from breaking new ground by using new instruments to understand the powerful storms better. **JPL flew two instruments** in the NASA campaign, on both piloted and remote-controlled aircraft, tracking storms such as Hurricane Karl as it intensified when it hit Mexico's Yucatan Peninsula. Scientists expect to spend years analyzing the results from the two-month campaign.

Rain, scientists fear, is falling in all the wrong places for all the wrong reasons. A group of researchers studying satellite data to track how much water flows from land into the ocean each month concluded that, across the globe, there is more rain than there used to be. In the 12 years from 1994 to 2006, 18 percent more water fed into the seas. But unfortunately the rain is coming where it's needed least — creating stronger storms in the tropics and arctic — and not in arid regions, which increasingly are drying up. The cause appears to be related to global climate change, though the researchers say more work is needed to understand it fully. JPL satellites contributing data to the study included **Topex/Poseidon** and the Gravity Recovery and Climate Experiment, or **Grace**.



NOVEMBER

Cosmic Snow Storm

If there's one thing that Deep Impact proved in 2010, it was that if you've seen one comet, you haven't seen them all.

And the spacecraft was in a good position to know. Launched in 2005, Deep Impact made history in November by becoming the first spacecraft to visit more than one of the solar system's primordial dirtballs. A few months after launch, Deep Impact released a penetrator as it flew past one comet, Tempel 1, excavating a crater. With the spacecraft in fit condition, NASA set it on a new course to fly by another comet, Hartley 2, under an extended mission called Epoxi.

As Deep Impact approached within 700 kilometers (435 miles) of the peanut-shaped nucleus — the smallest comet ever visited by a spacecraft — scientists were in for a surprise. Spewing out from the ends of the nucleus was a storm of fluffy ice particles ranging in size from golf ball to basketball that one scientist likened to a shaken snow globe. Scientists were intrigued by the fact that the chunks of water ice were not being lifted off the nucleus by water vapor warmed by the sun, but rather by frozen carbon dioxide — dry ice — turning from solid to gas. That was completely different from what Deep Impact saw at Tempel 1 or what other spacecraft have witnessed at other of the icy bodies. Comets, the science team concluded, are a varied and complicated family that will require much more exploration.

Controllers savored the moment during the close flyby of Comet Hartley 2. Scientists observed that jets of carbon dioxide were carrying tons of water off the comet every second.

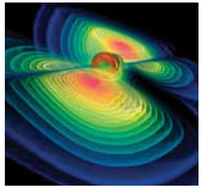
[*Short Takes*]

NOV

Earth's lakes are warming, two **JPL scientists reported in a new study**. Using satellites to measure the surface temperatures of 167 large lakes around the world, they found that on the average the bodies of water are warming 0.45 degree Celsius (0.81 degree Fahrenheit) per decade. Such changes could be worrisome, as even a small temperature increase can trigger algae blooms making a lake toxic to fish. The results were consistent with expected changes due to global warming.

Get ready to dust off the soundtrack from Hair. In 2011 it will be the dawning of the age of Aquarius, at least when the satellite instrument of that name is launched from California's Vandenberg Air Force Base. Hitching a ride to orbit on a satellite built by Argentina, **Aquarius** will provide monthly global maps of how salt concentration varies on the ocean surface — offering insights into ocean circulation, the global water cycle and climate. In November, JPL engineers traveled to Argentina for a key test of the satellite in a vacuum chamber in preparation for the launch the following June.

Do gravity waves exist? Albert Einstein thought so, but no one has ever detected one directly in the wild. JPL scientists and engineers would like to rectify that with a proposed mission, the Laser Interferometer Space Antenna, or **Lisa**. The mission would fly a triangle of three spacecraft, all connected by laser beams, in order to detect the ripples in the fabric of space-time predicted by the theory of general relativity. In November, engineers announced that they successfully quieted the noise in lasers to make them sensitive enough to catch the elusive waves.



DECEMBER

Take That, Energizer Bunny

Chalk one up for Mars Odyssey. In December, the orbiter became the longest-running mission at the Red Planet — racking up more than nine years of active duty circling Mars since its launch and arrival in 2001. On December 15 it logged its 3,340th day on station, surpassing the record previously set by another orbiter, Mars Global Surveyor.

Despite its age, Odyssey continued to generate science news. Earlier in the year, the science team released a planet-wide mosaic image that they described as the most accurate global Martian map ever. Odyssey's camera was also used extensively by middle-school students around the country under a program in which teenagers conduct serious research using one of Odyssey's cameras. One group of students from California used Odyssey to find a lava tube on Mars with a pit that appears to be a skylight to a cave.

But Odyssey's most high-profile role may be its critical job as a communications relay for other Mars spacecraft. Throughout 2010 Odyssey continued to serve as the prime link between Earth and Opportunity as the Mars Exploration Rover continued to trundle across the Martian landscape.

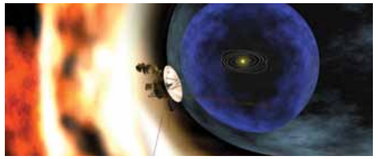
Mars Odyssey imaged the disturbed area of Noctis Labyrinthus, which formed when the Martian crust stretched and fractured. The resulting faults released subsurface ice and water, causing portions of the surface to collapse.

[*Short Takes*]

BIG

Are two eyes better than one? The designers of the **Large Binocular Telescope** would wager so. Erected in 2004 on Mount Graham in southeastern Arizona, the telescope combines two large mirrors to create the equivalent of a single large mirror. In 2010, JPL supported delivery of a new instrument for the telescope — an interferometer which combines optical data from each of the mirrors to make its observing power even greater. Astronomers plan to use the instrument to hunt for dust discs and Jupiter-sized planets around other stars.

You might call it the cosmic equivalent of the Horse Latitudes. Hurtling out of the solar system 17.4 billion kilometers (10.8 billion miles) from the sun, the **Voyager 1 spacecraft** has arrived in a zone where the solar wind stops moving outward. The "wind" — actually hot, ionized gas that streams outward from the sun — is one of the most constant features of the solar system. Scientists deduce that Voyager 1 has reached a region where the solar wind is turned sideways by the pressure from the interstellar wind between stars. That could mean that Voyager is finally — three decades after its launch and flybys of Jupiter and Saturn — approaching true interstellar space itself.



[Contractor Partners]

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Deep Space Network Operations and Maintenance

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Wackenhut Services Incorporated
Security and Fire Services

Emcor Government Services Incorporated
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[External Awards]

Atmospheric Infrared Sounder Team
Best of Green Award
Discovery Communications

Peter Bruneau
First Place, Aerospace Parts, Innovation of the Americas
DMG/Mori Seiki USA

Moustafa Chahine
George W. Goddard Award
Society of Photographic Instrumentation Engineers
Elected Full Member
Lebanese Academy of Sciences

Goutam Chattopadhyay
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Institute of Electrical and Electronics Engineers

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Chevalier de la Legion d'Honneur
Republic of France
General James E. Hill Lifetime Space Achievement Award
Space Foundation
Carl Sagan Memorial Award
American Astronautical Society

Lee-Lueng Fu
International Cooperation Medal
Committee on Space Research

Global Climate Change Website Team
People's Voice, Best Science Site, Webby Awards
International Academy of Digital Arts and Sciences

Jim Graf
Elected Associate Fellow
American Institute of Aeronautics and Astronautics

Stephanie Granger
Climate Science Services and Remote Sensing Science Services Award
California Department of Water Resources

Sam Gulkis
Doctor Honoris Causa
Paris Observatory

Sarath Gunapala
Distinguished Lecturer Award
Institute of Electrical and Electronics Engineers

Jet Propulsion Laboratory
Certificate of Appreciation
South Coast Air Quality Management District
Waste Reduction Award
California Department of Resources, Recycling and Recovery

JPL Flight Projects Center
Green Building Award
Green Technology

Otfrid Liepack
Elected Member, Social Sciences Section
International Academy of Astronautics

W. Tim Liu
Verner Suomi Medal
American Meteorological Society

Mars Exploration Rover Operations Team
Outstanding Achievement Award
International Committee on Technical Interchange for Space Mission Operations and Ground Data Systems

Firouz Naderi
William Randolph Lovelace II Award
American Astronautical Society

William Patzert
Athelstan Spilhaus Award
American Geophysical Union

Michael Shao
Michelson Interferometry Prize
International Astronomical Union and Mount Wilson Institute

Jon Sims
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American Institute of Aeronautics and Astronautics

Spitzer Space Telescope Team
Maria and Eric Muhlmann Award
Astronomical Society of the Pacific

Ashitey Trebi-Ollennu
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John A. Fleming Medal
American Geophysical Union

Vatche Vorperian
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Randii Wessen
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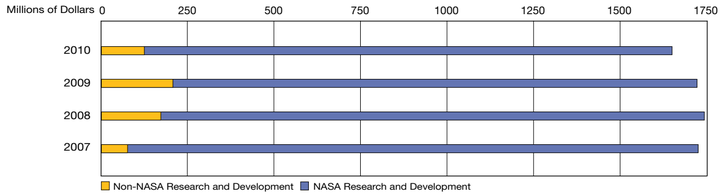
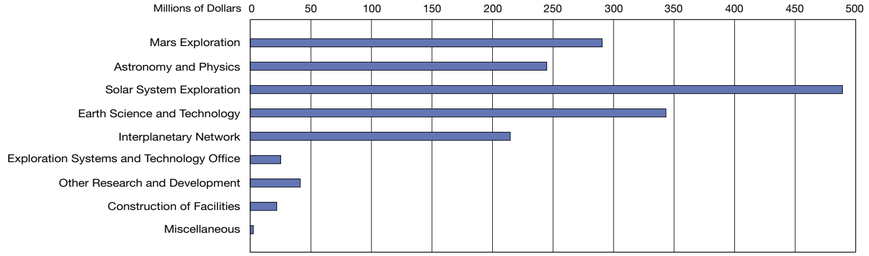
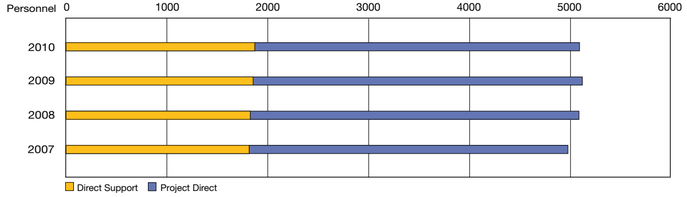
Budget and Workforce

CHARTS







JPL's revamped Visitor Center features colorful museum-quality displays about space exploration that drew rave reviews during the year.

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Comet encounter special guest Malcolm Hartley, discoverer of Comet Hartley 2, is greeted by Caltech President Jean-Lou Chameau (left) and JPL Director Charles Elachi.

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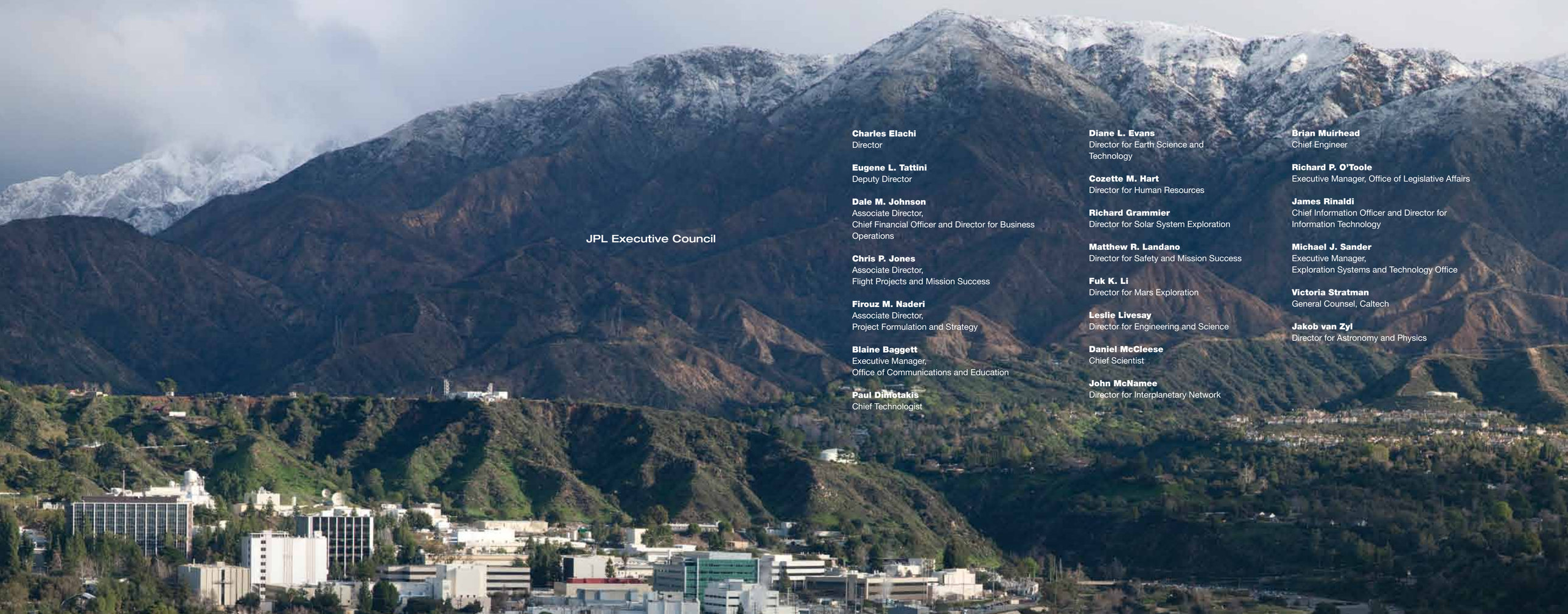

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