OSIRIS-REX: Preparing to Collect a Pristine Sample of a Carbonaceous Asteroid

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After a nearly two-year journey since its launch in September 2016, the OSIRIS-REx spacecraft arrived at its target asteroid Bennu in December 2018. The initial images sent back to Earth revealed a rocky surface with unexpected roughness. The spacecraft is currently characterizing the asteroid in preparation for sample collection in August 2020.

The OSIRIS-REx mission was selected in May 2011 in the third New Frontiers Program. Pristine carbonaceous asteroid material is not part of any collection on Earth; carbonaceous chondrite meteorites are heated upon entering the atmosphere and undergo chemical and mineralogical transformation on Earth. These Earth effects hinder the understanding of which organic compounds in meteorites originate from space and which are formed on Earth, and whether any become unstable and disappear after arrival at Earth's surface. Getting a pristine piece of a carbonaceous asteroid would eliminate this uncertainty and allow scientists to better understand the organic chemistry of the early solar system.

This idea led mission planners to choose near-Earth asteroid (101955) Bennu as the mission target. Bennu is accessible, volatile-rich, sufficiently large, and sufficiently characterized to allow fundamental navigation and encounter planning, and among the bodies most likely to collide with Earth in the future. The mission has five main goals, which are reflected in its name: OSIRIS-REx stands for Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer. First, as noted, pristine samples will allow scientists to understand the origin of organic compounds present in carbonaceous asteroids and their potential contribution to life on Earth. Second, the characterization of spectral features combined with detailed analyses of returned samples will allow evaluation of connections between asteroids and meteorites. Third, the volatile-rich nature of asteroids may offer important resources for space exploration, and OSIRIS-REx will provide a better understanding of the type and amount of volatiles present on a typical low-albedo asteroid. Fourth, the mission will better characterize the variables that control Bennu’s orbital evolution and, thus, its potential for Earth impact. Finally, the
The mission is a partnership between the University of Arizona, NASA Goddard Space Flight Center, and Lockheed Martin. University of Arizona planetary scientists Michael J. Drake and Dante Lauretta were the Principal Investigator (PI) and Deputy PI when the mission was selected, and Lauretta serves as the current PI. Scientific payloads onboard the spacecraft include the OSIRIS-REx Laser Altimeter (OLA), provided by the Canadian Space Agency; the OSIRIS-REx Thermal Emission Spectrometer (OTES), built by Arizona State University; the OSIRIS-REx Visible and InfraRed Spectrometer (OVIRS), built by NASA Goddard; the OSIRIS-REx Camera Suite (OCAMS), built by the University of Arizona; and the Regolith X-Ray Imaging Spectrometer (REXIS), built by the Massachusetts Institute of Technology (Fig. 1). The returned sample will be stored and curated at the NASA Johnson Space Center (JSC) in Houston.

Construction and Launch

Building the spacecraft began in 2015 with the Assembly, Testing, and Launch Operations (ATLO) phase of the mission. Because one of the mission goals is to study the organic geochemistry of the collected sample, special attention was given to building and assembling in a “clean” environment. (In this context, a clean environment refers to one that is as free from any kind of biological contaminants as humanly possible.) Mission scientists and curators made a considerable effort to acquire data and materials that allow a complete understanding of the ATLO environments as well as the materials composing the spacecraft and its components. Monitoring of the ATLO environments was focused on both particle and volatile characterization. Witness plates (materials that have defined open and closed periods at points throughout the mission, exposing and protecting them from environmental conditions) were deployed in the various ATLO environments in Denver and Florida. In addition, materials are archived at JSC from various spacecraft and instrument components that will have direct or indirect contact with collected samples.

As ATLO activities shifted from the Denver cleanrooms to Florida, so did monitoring for contamination, including efforts focused on the payload fairing containing the spacecraft. The most challenging aspects involved the last days before launch, as the fairing (the nose cone used to protect the spacecraft against the impact of dynamic pressure and aerodynamic heating during launch through an atmosphere) had to move through a number of environments on the way to assembly on the launchpad. This collection of witness plates and materials is being stored and curated at JSC in Houston. These items will be available indefinitely with the purpose of allowing evaluation of any possible contamination of the collected sample by the spacecraft hardware or assemblies.

The launch of OSIRIS-REx was carried out with tremendous efficiency. The 21-day launch window for OSIRIS-REx afforded flexibility in the launch schedule. However, OSIRIS-REx, under the guidance of United Launch Alliance (ULA) at Cape Canaveral, lifted off from launch complex 41 at only 100 milliseconds into the launch window at 7:08 p.m., September 8, 2016. This portion of the mission was described in Issue 146 of this publication (see suggested reading below).

Activities since Launch

In February 2017, the spacecraft undertook a search for the enigmatic class of near-Earth objects known as Earth-Trojan asteroids. Trojan asteroids are trapped in stable gravity wells, called Lagrange points, which precede or follow a planet. OSIRIS-REx traveled through Earth’s fourth Lagrange point, located 60° ahead in Earth’s orbit around the Sun. The mission team took multiple images in this region with the OCAMS MapCam camera in the hope of identifying Earth-Trojan asteroids. Although none were discovered, the spacecraft’s camera operated flawlessly and demonstrated that it could image objects two magnitudes dimmer than originally expected.

The spacecraft used an array of small rocket thrusters to match Bennu’s velocity and rendezvous with the asteroid. After nearly 20 months of instrument checkouts and testing along the way, the OSIRIS-REx spacecraft entered the approach phase of the mission in August 2018. As the spacecraft closed in on Bennu, surface features began to sharpen, and upon arrival in December the spacecraft sent back beautiful images of the entire asteroid (Fig. 2). One remarkable observation is that the shape model for Bennu derived from previous Earth-based observational data was an excellent match to the actual shape as imaged by the mission. By early 2019, several exciting discoveries had already been made. First, OVIRS measured an absorption peak near the 2.7-micrometer (0.0001-inch) wavelength, which is a key signature of OH in minerals and in this case a confirmation that Bennu has hydrated phyllosilicates, like CM chondrite meteorites (Fig. 3). Second, as JAXA’s Hayabusa2 mission found at asteroid Ryugu, the surface of Bennu is rougher than expected and even contains very large boulders. Some of the boulders appear to have embedded clasts (Fig. 4). The paucity of finer-grained material, as observed at other asteroids such as Itokawa (by Hayabusa in 2006) or Eros (by the Near-Earth Asteroid Rendezvous mission in 1999), was puzzling, as were particle ejection events that were observed almost immediately upon entering orbit in January 2019. Initial assessments indicate that the shape of Bennu is consistent with a rubble-pile structure. Many of the boulders and large rocks exposed at the surface contain evidence for brecciation, and the loose material on the surface is diverse with respect to color, reflectance, and grain size (Fig. 5). Another import-
Finding is that Bennu is spinning faster over time. The images and findings from the mission have captured the interest of meteoriticists who study brecciated carbonaceous chondrites and planetary scientists who study orbital and dynamic aspects of asteroids.

The detailed imaging initially led to the recognition of 50 regions of interest (ROIs) for sampling on the surface that were explored in more detail using the spacecraft instrumentation. From these 50 ROIs, the mission downselected to 16, and then to a final 4, named after Egyptian birds: Kingfisher, Osprey, Nightingale, and Sandpiper (Fig. 6). These four sites were selected in part due to their sampleability (the presence of centimeter-scale particles that can be ingested by the TAGSAM) and relative safety (presenting minimal hazards to the spacecraft). All four sites show the hydration feature that is ubiquitous across Bennu.

After a thorough evaluation of all four candidate sites, the mission team selected Nightingale as the site with the greatest amount of sampleable material that is safely accessible. Nightingale is located in a 20-meter (66-foot) crater within a larger crater in the northern hemisphere of Bennu. Its northern location means that it experiences lower temperatures than elsewhere on the asteroid, and the presumably young crater is well preserved. These characteristics support the possibility that the site will allow for a pristine sample of the asteroid, giving the team insight into Bennu’s history. The Osprey site was selected as a backup sample collection site, as it appears to have less sampleable material but is safer. The spacecraft is designed to autonomously “wave off” the sampling attempt if its predicted position is too close to a hazardous area. During this maneuver, the exhaust plumes from the spacecraft’s thrusters could potentially disturb the surface of the site, due to the asteroid’s microgravity environment. In any situation where a follow-on attempt at Nightingale is not possible, the team will try to collect a sample from the Osprey site instead.

Near Future

The primary and backup sites will be the focus of even more detailed characterization during lower flyovers in early 2020. This new information will be used to plan the detailed approach and maneuvers required for sample acquisition. For example, the original mission plan envisioned a sample site with a diameter of 50 meters (164 feet), and while the Nightingale crater is larger than that, the area safe enough for the spacecraft to sample is much smaller: 16 meters (52 feet). This means that the spacecraft has to very accurately target Bennu’s surface.
After the detailed characterization, the mission will rehearse the sampling maneuvers without touching down. The actual sampling attempt is nominally scheduled for August 25, 2020.

The TAGSAM head is at the end of a long arm with an elbow and pogo-stick-like mechanism for flexibility at the surface. The head is roughly 38 centimeters (15 inches) in diameter and has an internal circular cylindrical cavity where the sample will be collected and stored. The sampling mechanism utilizes a jet of nitrogen gas to mobilize loose material into the bulk sample collector. Collection tests in Earth-gravity and low-gravity environments have resulted in the collection of up to 1.5 kilograms (3.3 pounds) of material. In addition, asteroid material will be trapped in surface contact pads that are on the side of the sampler head that touches the asteroid surface. In September 2023, the spacecraft will make a close approach to Earth and release the Sample Return Capsule (SRC), which will be recovered in a parachute landing at the Utah Test and Training Range near Salt Lake City.

Upon landing in Utah, the SRC will be recovered and safely kept in a portable cleanroom before being transported to JSC — the home of all of NASA’s astromaterials, including Apollo moon rocks, Antarctic meteorites, cosmic dust particles, Stardust comet particles, and Genesis solar wind collectors. The curation cleanroom for the storage and handling of Bennu samples is currently under construction at JSC and will be completed in 2020.
The mission science team looks forward to unraveling the geologic history of Bennu, including its origins, impact record, and more recent dynamic history. JAXA’s Hayabusa2 mission to the carbonaceous asteroid Ryugu, occurring in parallel with OSIRIS-REx, offers an enhanced understanding of the volatile-bearing and carbonaceous asteroids that make up more than 50% of the asteroid belt. We look forward to the many new discoveries these missions will make and the corresponding advancements in understanding the solar system.

**Suggested Reading**


Lauretta D. S. et al. (2017) OSIRIS-REx: Sample return from asteroid (101955) Bennu. Space Science Reviews, 212, 925–984.


OSIRIS-REx Mission to Bennu, Nature journals collection, [https://www.nature.com/collections/jhgaigjig](https://www.nature.com/collections/jhgaigjig).

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Fig. 6. The final four candidate sample collection sites on asteroid Bennu are designated Nightingale, Kingfisher, Osprey, and Sandpiper. Each circle has a 5-meter (16.4-foot) radius. Credit: NASA/Goddard/University of Arizona.
Because humankind has never traveled into space beyond the Moon, most of the exploration of our solar system is done using robotic spacecraft. NASA has been conducting such exploration for over half a century and has explored planetary bodies from Mercury out to the Kuiper belt. But the solar system is an enormous place with a huge diversity of bodies, including giant, gaseous planets, terrestrial planets, dwarf planets, rocks and icy small objects, satellites of all sizes around these bodies, all the way down to dust. Despite 50 years of effort, NASA, now accompanied by other space-faring nations, is still only just beginning to fully explore the solar system. The OSIRIS-REx mission is a huge step in this massive endeavor.

Robotic exploration of any location in space is tailored to our science objectives and advances as we learn more and more about that target body. NASA has flown by objects like the ice giant planets Uranus and Neptune, and Kuiper belt objects like Pluto and Arrokoth; we’ve orbited Mercury, Venus, Jupiter, and Saturn, as well as the dwarf planets Vesta and Ceres, and asteroid Eros; we’ve landed on Mars, and our international partners have done the same on Venus, an asteroid, and a comet. But the climax of robotic exploration — sample return — has been much harder to achieve. NASA did it non-robotically on the Moon with the Apollo program, which was followed by several Soviet robotic missions. We did it for a comet in the Stardust mission, collecting greatly altered dust in a high-velocity flyby through the tail. We collected material from the Sun in the Genesis mission, not by touching the Sun, but by passively collecting solar wind in the vicinity of Earth. And Japan heroically survived adversity near an asteroid, as Hayabusa succeeded in collecting and returning microscopic dust particles. Other than a few dust grains embedded in orbiting spacecraft, this is the extent of human sample return missions to date. All other samples of extraterrestrial material that we have in scientific collections were delivered to Earth by natural processes, through its atmosphere, being compromised to varying extents in the process, and only in special cases do we know the point of origin.

Why is sample return so important? Although we can learn a huge amount about planetary bodies by remote sensing with cameras, spectrometers, and other instruments, and we can learn even more with instruments with in situ exploration, most sample science cannot be done this way. Exquisitely sensitive laboratory instruments on Earth are capable of determining the chemical, isotopic, and geological histories of extraterrestrial matter.
mineralogical, structural, and physical properties of extraterrestrial samples from the macroscopic level down to the atomic scale, frequently all on the very same sample. This allows us to determine the origin and history of the material and answer questions far beyond the reach of current robotic technology. Moreover, sample return provides us with “ground truth” about the visited body, verifying and validating conclusions that can be drawn by remote sensing (both Earth-based and by spacecraft) and via landed instruments on other bodies. In addition, returned samples can be compared to astromaterials such as meteorites and cosmic dust, which give us clues about where those materials come from, potentially increasing their scientific value as natural space probes. And finally, returned samples can be preserved for decades and used by future generations to answer questions we haven’t even thought of yet using laboratory instruments that haven’t even been imagined. Thanks to the policies of NASA and other space agencies, returned samples are freely made available to qualified scientists around the world to study.

The 2020s promise a bounty of new sample returns, and some are even calling it the “Decade of Sample Return.” Leading off will be the return of samples from two small, carbonaceous asteroids, Ryugu, by JAXA’s Hayabusa2 mission in late 2020, and Bennu, by NASA’s OSIRIS-REx mission in 2023; these are in many ways sister missions, both in the kind of body being visited, and in the close cooperation of scientists and the sponsoring agencies. OSIRIS-REx promises to provide the largest sample returned since Apollo. The feature article in this issue explains some of the great science OSIRIS-REx hopes to achieve, including learning about organic material that may have played a role in the origin of life. NASA is aiming to return to the Moon in the mid-2020s and hopes to return samples from previously unexplored regions, including the lunar south pole, which may have deposits of water ice within the regolith of permanently shadowed regions. China is also planning to return samples from the Moon in the early part of the decade as part of the Chang’E 5 mission. JAXA’s Martian Moons eXploration (MMX) mission late in the decade, with NASA participation, hopes to return samples from Mars’ moon, Phobos. And the Mars 2020 mission, which launches in July 2020, begins a multi-mission, decade-long campaign to return samples from the surface of the Red Planet, which will help answer the question of whether Mars ever hosted life. It is an exciting time to be a planetary explorer!
In mid-July, nearly 600 “martians” from more than 20 countries gathered at the Ninth International Conference on Mars (aka 9th Mars) to discuss the status and future of our exploration of the Red Planet. As in the past, the aim of this conference was to pull together the breadth of current Mars knowledge in order to identify current paradigms in our understanding of Mars evolution. Then, based on current understandings of Mars’ history, state, and processes, conference attendees were asked to look to the future and identify top science questions for the next decade of Mars exploration. 9th Mars was held at a particularly relevant time for gathering the international Mars community, as the 2020s will begin with multiple Mars missions from multiple space agencies, and yet few subsequent missions have been confirmed. This period will be considered by the next U.S. Planetary Science Decadal Survey, which will be a key input for NASA’s planetary science priorities in 2023–2032.

In the 9th Mars conference program, approximately 100 oral presentations were scheduled in two parallel sessions organized according to high-level science questions, and approximately 300 posters were divided into four poster sessions. Plenary presentations and panel discussions about the state of Mars science understanding and forward-looking plans such as Mars Sample Return and Human Exploration served as focal points for pulling the attendees back together into one group. Additionally, four integration teams (focused on Climate, Geology, Life, and Preparation for Human Exploration) were tasked with listening to all presentations in their respective topic areas to seek out high-priority, repeated, or connecting concepts. These designated “Integrators,” drawn from across disciplines and career levels, presented their results on the final day of the conference and gathered final input from attendees. Their Integration Reports, available on the conference website, will serve as inputs to discussions within the Mars Exploration Program Analysis Group (MEPAG) and, in particular, the ongoing MEPAG Goals revisions.

Key perspectives that emerged at the conference included the growing diversity and number of possibly habitable environments on Mars. Key elements for life have been detected in situ, and remote sensing shows increasing numbers of sites with evidence of past hydrothermal and other hydrologic activity. One sobering note was that surface dust and mineral properties can obscure the true abundance and distribution of key minerals (i.e., if seen from orbit, there is something there, but a lot is hidden), leading to the question, “How can the true diversity of Mars mineralogy be sampled at reasonable cost?”

Growing evidence of active processes shows that modern Mars remains a dynamic planet that is still changing today. When seeking to understand the present-day environment, measurement of winds and water vapor within the
Planetary boundary layer, including their diurnal behavior, remain high-priority knowledge gaps. The volatility of H2O and CO2 play important roles in modifying the surface. Understanding the role of dust remains an ongoing challenge, especially the chain of events that leads to episodic planet-scale dust events, such as the planet encircling dust event observed in detail during summer 2018, when the local opacity was high enough to starve a solar-powered rover. Continued investigation of how such high-level dust activity has altered both atmospheric and surface processes is needed. While recurring slope lineae (RSL) were a key topic of debate at 8th Mars, at 9th Mars the accumulating evidence seemed to indicate that these landforms are more dry than wet.

One of the top areas of discussion at 9th Mars concerned methane, and a spirited panel discussion focused around potential explanations for why different missions are measuring some or none of this trace gas. Given general agreement that the differing measurements are correct, the discussion turned to what is the source of methane that was detected by MSL (including perhaps from the rover?) and how the gas could be so rapidly destroyed that it was detected at the surface but not at higher altitudes. The methane discussion was part of a much broader discussion about where to look for possible extant life. That led to discussion of ideas and measurement approaches about where and how to search the subsurface, which is thought to be more habitable than the surface.

Understanding the nature and evolution of the ancient environment(s) continues to challenge us, and new data and modeling efforts are needed to advance our knowledge. The debate about the existence of an ancient ocean continues (and if it was there, how long was it there?). Attempts to simulate an ancient greenhouse atmosphere able to support an early hydrological cycle were much debated, particularly about the role of reducing gases (H2, CH4). However, isotopic measurements and credible extrapolations of measured current-day atmospheric loss rates show that most of the early Mars atmosphere has been lost to space. The timing of elements of that atmospheric evolution (solar forcing, water availability, etc.) and its nature (episodic, punctuated, trending) remain challenging targets for future measurement and research.

There was also continued progress in understanding the climate and climate shifts of Amazonian Mars, including evidence of prolonged, if episodic, water activity early on; the abundance of mid-latitude ground ice (exposed in craters, cliffs, and surface/near-surface properties); and models connecting the radar-revealed internal layers of the polar caps with layering at the edges and shifts in accumulation/ablation due to obliquity cycles.

In addition to the vigorous, broad, and illuminating science discussion, it was wonderful to see the diversity in countries, disciplines, institutions, and people who are involved in Mars exploration. For example, many presentations and attendees were from the United Arab Emirates, who join the Mars mission community with the Emirates Mars Mission Hope orbiter, launching in 2020. This community expansion bodes well for continued tremendous advancement as we move into the next decade and define what future Mars exploration may look like.

9th Mars was convened by the Jet Propulsion Laboratory, California Institute of Technology, and NASA, with funding provided by NASA and assistance by the Lunar and Planetary Institute. The 9th Mars plenary conference presentations, all abstracts, the integrator reports, and many e-posters are available at the conference website.

Text provided by Serina Diniega (Jet Propulsion Laboratory/Mars Program Office), Rich Zurek (Jet Propulsion Laboratory/Mars Program Office), Michael Meyer (NASA Mars Exploration Program), Bethany Ehlmann (California Institute of Technology), Brandi Carrier (Jet Propulsion Laboratory/Mars Program Office), and David Beaty (Jet Propulsion Laboratory/Mars Program Office)
In mid-January, 50 Mars scientists and 21 students gathered in Ushuaia, Tierra del Fuego, Argentina, to bring together the state of knowledge for Mars Polar Science. The meeting consisted of 13 plenary oral sessions and 1 poster session. There were also panel discussions on the topics of the upcoming Decadal Survey and how the Mars Polar Community would prepare for that by engaging with the Mars Exploration Analysis Group (MEPAG) and by writing white papers.

Topics covered in the conference ranged from atmosphere, surface-atmosphere interactions, polar geology, the stored climate record, laboratory experiments that teach us about Mars polar science, and terrestrial field investigations that reveal secrets about Mars by virtue of their analog processes and morphology.

This meeting was the seventh in the International Conference on Mars Polar Science and Exploration series, following the sixth meeting in 2016. The two primary organizers are affiliated with Planetary Science Institute and York University (Smith) and the University of Bern (Becerra). They were supported by local organizers, especially Jorge Rabassa and Andrea Coronato, from two Argentina research institutions: el Centro Austral de Investigaciones Científicas (CADIC) and Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET).

Travel grants for early career researchers and students (who numbered almost 30% of the total attendees) were supported by the International Association of Cryosphere Sciences (IACS), the International Association of Geomorphologists (IAG), and by funds collected from registration fees. In total, eight students were supported at varying levels.

Two of the hallmarks of this conference series are extended discussion sessions. During this seventh conference we had over five hours of discussion open to all attendees, and produced a summary report that includes the major scientific questions facing the Mars Polar Community today. During the meeting, a group of synthesizers collected notes and interacted to record the primary scientific findings and discussions that we had. During the last session, a panel shared a synthesis of the notes with the assembly and solicited feedback. The compilation of notes and feedback will become the outline for the summary report. This and the major open questions will be published later this year as a summary document.

— Text courtesy of Isaac Smith (Planetary Science Institute and York University, Toronto) and Patricio Becerra (University of Bern)
The 2019 annual meeting of the Lunar Exploration Analysis Group (LEAG) was held at the Washington Hilton in Washington, DC, on October 28–30. Approximately 300 people from commercial, academic, research, and government institutions registered from both national and international entities.

The 2019 meeting brought together members of the lunar science and exploration community to discuss, organize, and prioritize lunar science goals in preparation for the Decadal Survey and to offer input into NASA’s plans for Project Artemis. This was followed by several hours of discussion in five breakout groups: Solar Systems (formation and evolution), Planetary Formation (interior evolution and processes), Planetary Geology (surface processes), Habitability (how to become habitable and sustained), and Resources and Hazards. Groups reconvened to present their goals and potential white paper topics, and the day closed with a poster session focusing on mission concepts.

Day 2 predominantly consisted of invited talks and panel discussions. Representatives from NASA provided overviews of different aspects of Project Artemis as well as updates on lunar-specific programs and missions. Findings from the recent ISRU workshop were also presented. The afternoon held a panel discussion of international partners and two panels featuring Commercial Lunar Payload Services (CLPS) providers. The day ended with a poster session focused on ISRU and instrumentation concepts, and was held in conjunction with a networking session with the CLPS providers.

Day 3 was a half-day that focused on moving forward as a community with Project Artemis, the Lunar Exploration Roadmap, and how the two entities fit together. This was accomplished through invited talks and a panel discussion.

The 2019 LEAG annual meeting findings will be released to the community soon. To view the program, poster abstracts, and recordings of most of the oral presentations, please visit the meeting website at https://www.hou.usra.edu/meetings/leag2019/. Recordings can be accessed via the program.
NASA has announced that our next destination in the solar system is the unique, richly organic world Titan. Advancing our search for the building blocks of life, the Dragonfly mission will fly multiple sorties to sample and examine sites around Saturn's icy moon. Dragonfly will launch in 2026 and arrive in 2034. The rotorcraft will fly to dozens of promising locations on Titan looking for prebiotic chemical processes common on both Titan and Earth.

Dragonfly will launch in 2026 and arrive in 2034. The rotorcraft will fly to dozens of promising locations on Titan looking for prebiotic chemical processes common on both Titan and Earth. Dragonfly marks the first time NASA will fly a multi-rotor vehicle for science on another planet; it has eight rotors and flies like a large drone. It will take advantage of Titan's dense atmosphere — four times denser than Earth's — to become the first vehicle ever to fly its entire science payload to new places for repeatable and targeted access to surface materials.

Titan is an analog to the very early Earth, and can provide clues to how life may have arisen on our planet. During its 2.7-year baseline mission, Dragonfly will explore diverse environments from organic dunes to the floor of an impact crater where liquid water and complex organic materials key to life once existed together for possibly tens of thousands of years. Its instruments will study how far prebiotic chemistry may have progressed. They also will investigate the moon's atmospheric and surface properties and its subsurface ocean and liquid reservoirs. Additionally, instruments will search for chemical evidence of past or extant life.

“With the Dragonfly mission, NASA will once again do what no one else can do,” said NASA Administrator Jim Bridenstine. “Visiting this mysterious ocean world could revolutionize what we know about life in the universe. This cutting-edge mission would have been unthinkable even just a few years ago, but we’re now ready for Dragonfly’s amazing flight.”

Dragonfly took advantage of 13 years’ worth of Cassini data to choose a calm weather period to land, along with a safe initial landing site and scientifically interesting targets. It will first land at the equatorial “Shangri-La” dune fields, which are terrestrially similar to the linear dunes in Namibia in southern Africa and offer a diverse sampling location. Dragonfly will explore this region in short flights, building up to a series of longer “leapfrog” flights of up to 8 kilometers (5 miles), stopping along the way to take samples from compelling areas with diverse geology. It will finally reach the Selk impact crater, where there is evidence of past liquid water, organics — the complex molecules that contain carbon, combined with hydrogen, oxygen, and nitrogen — and energy, which together make up the recipe for life. The lander will eventually fly more than 175 kilometers (108 miles) — nearly double the distance traveled to...
Titan is unlike any other place in the solar system, and Dragonfly is like no other mission,” said Thomas Zurbuchen, NASA’s associate administrator for science at the agency’s headquarters in Washington. “It’s remarkable to think of this rotorcraft flying miles and miles across the organic sand dunes of Saturn’s largest moon, exploring the processes that shape this extraordinary environment. Dragonfly will visit a world filled with a wide variety of organic compounds, which are the building blocks of life and could teach us about the origin of life itself.”

Titan has a nitrogen-based atmosphere like Earth. Unlike Earth, Titan has clouds and rain of methane. Other organics are formed in the atmosphere and fall like light snow. The moon’s weather and surface processes have combined complex organics, energy, and water similar to those that may have sparked life on our planet.

Titan is larger than the planet Mercury and is the second largest moon in our solar system. As it orbits Saturn, it is about 1.4 billion kilometers (886 million miles) away from the Sun, about 10× further than Earth. Because it is so far from the Sun, its surface temperature is around −179°C (−290°F). Its surface pressure is also 50% higher than Earth’s.

Dragonfly was selected as part of the agency’s New Frontiers program, which includes the New Horizons mission to Pluto and the Kuiper Belt, Juno to Jupiter, and OSIRIS-REx to the asteroid Bennu. Dragonfly is led by Principal Investigator Elizabeth Turtle, who is based at Johns Hopkins University’s Applied Physics Laboratory in Laurel, Maryland. New Frontiers supports missions that have been identified as top solar system exploration priorities by the planetary community. The program is managed by the Planetary Missions Program Office at NASA’s Marshall Space Flight Center in Huntsville, Alabama, for the agency’s Planetary Science Division in Washington.

“The New Frontiers program has transformed our understanding of the solar system, uncovering the inner structure and composition of Jupiter’s turbulent atmosphere, discovering the icy secrets of Pluto’s landscape, Revealing mysterious objects in the Kuiper belt, and exploring a near-Earth asteroid for the building blocks of life,” said Lori Glaze, director of NASA’s Planetary Science Division. “Now we can add Titan to the list of enigmatic worlds NASA will explore.”

For more information about Titan, visit:
https://solarsystem.nasa.gov/moons/saturn-moons/titan/overview

Read more about NASA’s New Frontiers Program and missions at: https://www.nasa.gov/planetarymissions/newfrontiers.html

**New VIPER Lunar Rover to Map Water Ice on the Moon**

About the size of a golf cart, the Volatiles Investigating Polar Exploration Rover, or VIPER, will roam several miles, using its four science instruments — including a 1-meter drill — to sample various soil environments. Planned for delivery to the lunar surface in December 2022, VIPER will collect about 100 days of data that will be used to inform the first global water resource maps of the Moon.

“The key to living on the Moon is water — the same as here on Earth,” said Daniel Andrews, the project manager of the VIPER mission and director of engineering at NASA’s Ames Research Center in Silicon Valley. “Since the confirmation of lunar water-ice ten years ago, the question now is if the Moon could really contain the amount of resources we need to live off-world.

This rover will help us answer the many questions we have about where the water is, and how much there is for us to use.”

Scientists had long considered the lunar poles as promising spots to find water ice — a resource of direct value for humans that could provide oxygen to breathe and hydrogen and oxygen to fuel future landers and rockets. The Moon’s tilt creates permanently shadowed regions where water ice from comet and meteor impacts, as well as the Sun’s interaction with the lunar soil, can collect without being melted by sunlight. In 2009, NASA crashed a rocket into a large crater near the South Pole and directly detected the presence of water ice. Data from this mission and other orbiters have confirmed that the Moon has reservoirs of water ice, potentially amounting to millions of tons. Now, we need to understand the location and nature of the water and other potentially accessible resources to aid in planning how to extract and collect it.

“It’s incredibly exciting to have a rover going to the new and unique environment of the South Pole to discover where exactly we can harvest that water,” said Anthony Colaprete, VIPER’s project scientist. “VIPER will tell us which locations have the highest concentrations and how deep below the surface to go to get access to water.”

To unravel the mysteries of the Moon’s South Pole, the rover will collect data on different kinds of soil environments affected by light and temperature — those in complete...
darkness, occasional light and in direct sunlight. By collecting data on the amount of water and other materials in each, NASA can map out where else water likely lies across the Moon. As the rover drives across the surface, it will use the Neutron Spectrometer System, known as NSS, to detect “wet” areas below the surface for further investigation. VIPER will then stop and deploy a drill to dig up soil cuttings from up to a meter beneath the surface. These drill samples will then be analyzed by two instruments: the Mass Spectrometer Observing Lunar Operations, or MSolo, developed out of NASA’s Kennedy Space Center; and the Near InfraRed Volatiles Spectrometer System, known as NIRVSS, developed by Ames. MSolo and NIRVSS will determine the composition and concentration of potentially accessible resources, including water, that were brought up by TRIDENT.

With Mars Methane Mystery Still Unsolved, Curiosity Serves Scientists a New One: Oxygen

For the first time in the history of space exploration, scientists have measured the seasonal changes in the gases that fill the air directly above the surface of Gale Crater on Mars. As a result, they noticed something baffling: Oxygen, the gas many Earth creatures use to breathe, behaves in a way that scientists cannot yet explain through any known chemical processes.

Over the course of 3 Mars years (or nearly 6 Earth years) an instrument in the Sample Analysis at Mars (SAM) portable chemistry lab inside the belly of NASA’s Curiosity rover inhaled the air of Gale Crater and analyzed its composition. The results SAM spit out confirmed the makeup of the Martian atmosphere at the surface: 95% by volume of carbon dioxide (CO2), 2.6% molecular nitrogen (N2), 1.9% argon (Ar), 0.16% molecular oxygen (O2), and 0.06% carbon monoxide (CO). They also revealed how the molecules in the Martian air mix and circulate with the changes in air pressure throughout the year. These changes are caused when CO2 gas freezes over the poles in the winter, thereby lowering the air pressure across the planet following redistribution of air to maintain pressure equilibrium. When CO2 evaporates in the spring and summer and mixes across Mars, it raises the air pressure.

Within this environment, scientists found that nitrogen and argon follow a predictable seasonal pattern, waxing and waning in concentration in Gale Crater throughout the year relative to how much CO2 is in the air. They expected oxygen to do the same. But it didn’t. Instead, the amount of the gas in the air rose throughout spring and summer by as much as 30%, and then dropped back to levels predicted by known chemistry in fall. This pattern repeated each spring, though the amount of oxygen added to the atmosphere varied, implying that something was producing it and then taking it away.

“The first time we saw that, it was just mind boggling,” said Sushil Atreya, professor of climate and space sciences at the University of Michigan in Ann Arbor. Atreya is a co-author of a paper on this topic published on November 12 in the Journal of Geophysical Research: Planets.

As soon as scientists discovered the oxygen enigma, Mars experts set to work trying to explain it. They first double- and triple-checked the accuracy...
of the SAM instrument they used to measure the gases: the Quadrupole Mass Spectrometer. The instrument was fine. They considered the possibility that CO₂ or water (H₂O) molecules could have released oxygen when they broke apart in the atmosphere, leading to the short-lived rise. But it would take five times more water above Mars to produce the extra oxygen, and CO₂ breaks up too slowly to generate it over such a short time. What about the oxygen decrease? Could solar radiation have broken up oxygen molecules into two atoms that blew away into space? No, scientists concluded, since it would take at least 10 years for the oxygen to disappear through this process.

“We’re struggling to explain this,” said Melissa Trainer, a planetary scientist at NASA’s Goddard Space Flight Center in Greenbelt, Maryland who led this research. “The fact that the oxygen behavior isn’t perfectly repeatable every season makes us think that it’s not an issue that has to do with atmospheric dynamics. It has to be some chemical source and sink that we can’t yet account for.”

To scientists who study Mars, the oxygen story is curiously similar to that of methane. Methane is constantly in the air inside Gale Crater in such small quantities (0.00000004% on average) that it’s barely discernable even by the most sensitive instruments on Mars. Still, it’s been measured by SAM’s Tunable Laser Spectrometer. The instrument revealed that while methane rises and falls seasonally, it increases in abundance by about 60% in summer months for inexplicable reasons. (In fact, methane also spikes randomly and dramatically. Scientists are trying to figure out why.)

With the new oxygen findings in hand, Trainer’s team is wondering if chemistry similar to what’s driving methane’s natural seasonal variations may also drive oxygen’s. At least occasionally, the two gases appear to fluctuate in tandem.

“We’re beginning to see this tantalizing correlation between methane and oxygen for a good part of the Mars year,” Atreya said. “I think there’s something to it. I just don’t have the answers yet. Nobody does.”

Oxygen and methane can be produced both biologically (from microbes, for instance) and abiotically (from chemistry related to water and rocks). Scientists are considering all options, although they don’t have any convincing evidence of biological activity on Mars. Curiosity doesn’t have instruments that can definitively say whether the source of the methane or oxygen on Mars is biological or geological. Scientists expect that non-biological explanations are more likely and are working diligently to fully understand them.

Trainer’s team considered Martian soil as a source of the extra springtime oxygen. After all, it’s known to be rich in the element, in the form of compounds such as hydrogen peroxide and perchlorates. One experiment on the Viking landers showed decades ago that heat and humidity could release oxygen from Martian soil. But that experiment took place in conditions quite different from the Martian spring environment, and it doesn’t explain the oxygen drop, among other problems. Other possible explanations also don’t quite add up for now. For example, high-energy radiation of the soil could produce extra O₂ in the air, but it would take a million years to accumulate enough oxygen in the soil to account for the boost measured in only one spring, the researchers report in their paper.

“We have not been able to come up with one process yet that produces the amount of oxygen we need, but we think it has to be something in the surface soil that changes seasonally because there aren’t enough available oxygen atoms in the atmosphere to create the behavior we see,” said Timothy McConnochie, assistant research scientist at the University of Maryland in College Park and another co-author of the paper.

The only previous spacecraft with instruments capable of measuring the composition of the Martian air near the ground were NASA’s twin Viking landers, which arrived on the planet in 1976. The Viking experiments covered only a few Martian days, though, so they couldn’t reveal seasonal patterns of the different gases. The new SAM measurements are the first to do so. The SAM team will continue to measure atmospheric gases so scientists can gather more detailed data throughout each season. In the meantime, Trainer and her team hope that other Mars experts will work to solve the oxygen mystery.

“This is the first time where we’re seeing this interesting behavior over multiple years. We don’t totally understand it,” Trainer said. “For me, this is an open call to all the smart people out there who are interested in this: See what you can come up with.”

For more information about SAM, visit: https://mars.nasa.gov/msl/spacraft/instruments/sam/
NASA’s Solar Dynamics Observatory Sees New Kind of Magnetic Explosion on Sun

NASA’s Solar Dynamics Observatory has observed a magnetic explosion the likes of which have never been seen before. In the scorching upper reaches of the Sun’s atmosphere, a prominence — a large loop of material launched by an eruption on the solar surface — started falling back to the surface of the Sun. But before it could make it, the prominence ran into a snarl of magnetic field lines, sparking a magnetic explosion. Scientists have previously seen the explosive snap and realignment of tangled magnetic field lines on the Sun — a process known as magnetic reconnection — but never one that had been triggered by a nearby eruption. This observation, which confirms a decade-old theory, may help scientists understand a key mystery about the Sun’s atmosphere, better predict space weather, and may also lead to breakthroughs in the controlled fusion and lab plasma experiments.

“This was the first observation of an external driver of magnetic reconnection,” said Abhishek Srivastava, solar scientist at Indian Institute of Technology (BHU), in Varanasi, India. “This could be very useful for understanding other systems. For example, Earth’s and planetary magnetospheres, other magnetized plasma sources, including experiments at laboratory scales where plasma is highly diffusive and very hard to control.”

Previously a type of magnetic reconnection known as spontaneous reconnection has been seen, both on the Sun and around Earth. But this new explosion-driven type — called forced reconnection — had never been seen directly, thought it was first theorized 15 years ago. The new observations have just been published in the Astrophysical Journal.

The previously-observed spontaneous reconnection requires a region with just the right conditions — such as having a thin sheet of ionized gas, or plasma, that only weakly conducts electric current — in order to occur. The new type, forced reconnection, can happen in a wider range of places, such as in plasma that has even lower resistance to conducting an electric current. However, it can only occur if there is some type of eruption to trigger it. The eruption squeezes the plasma and magnetic fields, causing them to reconnect.

While the Sun’s jumble of magnetic field lines are invisible, they nonetheless affect the material around them — a soup of ultra-hot charged particles known as plasma. The scientists were able to study this plasma using observations from NASA’s Solar Dynamics Observatory, or SDO, looking specifically at a wavelength of light showing particles heated 1–2 million Kelvin (1.8–3.6 million° F).

The observations allowed them to...
directly see the forced reconnection event for the first time in the solar corona — the Sun’s uppermost atmospheric layer. In a series of images taken over an hour, a prominence in the corona could be seen falling back into the photosphere. En route, the prominence ran into a snarl of magnetic field lines, causing them to reconnect in a distinct X shape.

Spontaneous reconnection offers one explanation for how hot the solar atmosphere is — mysteriously, the corona is millions of degrees hotter than lower atmospheric layers, a conundrum that has led solar scientists for decades to search for what mechanism is driving that heat. The scientists looked at multiple ultraviolet wavelengths to calculate the temperature of the plasma during and following the reconnection event. The data showed that the prominence, which was fairly cool relative to the blistering corona, gained heat after the event. This suggests forced reconnection might be one way the corona is heated locally. Spontaneous reconnection also can heat plasma, but forced reconnection seems to be a much more effective heater — raising the temperature of the plasma quicker, higher, and in a more controlled manner. While a prominence was the driver behind this reconnection event, other solar eruptions like flares and coronal mass ejections, could also cause forced reconnection. Since these eruptions drive space weather — the bursts of solar radiation that can damage satellites around Earth — understanding forced reconnection can help modelers better predict when disruptive high-energy charged particles might come speeding at Earth.

Understanding how magnetic reconnection can be forced in a controlled way may also help plasma physicists reproduce reconnection in the lab. This is ultimately useful in the field of laboratory plasma to control and stabilize them.

The scientists are continuing to look for more forced reconnection events. With more observations, they can begin to understand the mechanics behind the reconnection and often it might happen.

“Our thought is that forced reconnection is everywhere,” Srivastava said. “But we have to continue to observe it, to quantify it, if we want prove that.”

Get Ready for More Interstellar Objects, Yale Astronomers Say

Gregory Laughlin and Malena Rice weren’t exactly surprised a few weeks ago when they learned that a second interstellar object had made its way into our solar system.

The Yale University astronomers had just put the finishing touches on a new study suggesting that these strange, icy visitors from other planets are going to keep right on coming. We can expect a few large objects showing up every year, they say; smaller objects entering the solar system could reach into the hundreds each year. The study has been accepted for publication in The Astrophysical Journal Letters.

“There should be a lot of this material floating around,” said Rice, a graduate student at Yale and first author of the study. “So much more data will be coming out soon, thanks to new telescopes coming online. We won’t have to speculate.”

The first interstellar object known to pass through our solar system was ‘Oumuamua, first spotted in October 2017. Its arrival generated intense debate over its origins and how to classify it. Laughlin, an astronomy professor at Yale, has contributed valuable research indicating ‘Oumuamua likely has properties similar to a comet, despite the fact that it doesn’t have a comet’s telltale tail, called a coma.

The new object, recently dubbed 2I/Borisov, came on the scene this summer. Amateur astronomer Gennady Borisov first noticed 2I/Borisov in August, and researchers will have about a year to observe the object with telescopes — a considerably longer time than the few weeks they had to observe ‘Oumuamua. The new object is also larger than ‘Oumuamua and has a pronounced coma.

Of course, for scientists one of the big questions arising from the appearance of interstellar objects is: “Where did they come from?” An easy answer would be that they are ejected planetary building blocks — planetesimals — from other solar systems. But upon first look, there’s a problem with that.
A close study of the roughly 4,000 confirmed planets outside our solar system shows that most of them are located too close to their parent stars to readily eject a planetesimal. Planetesimals stirred up by most currently known planets would remain stuck in orbits in the systems where they formed.

So where do the interstellar objects originate?

Rice and Laughlin’s work proposes for the first time that interstellar objects could be material ejected from large, newborn planets, orbiting farther away from their sun, which have carved out pronounced gaps in the cosmic platters of gas and dust that astronomers call protoplanetary disks.

When a star is newly formed, it is surrounded by a thin, rotating “protoplanetary” disk of dense gas and dust. The disk is a volatile environment in which gas and dust are heated up by the young star, as well as the star’s gravitational energy, leading to movement, collisions, and eventually, the formation of planets.

Although most known planets form close to their sun, there are some that develop much farther away and create large gaps in the protoplanetary disk. According to Rice and Laughlin, those more distant planets are able to fling out material that could leave their home solar systems. However, they are also much more difficult to directly observe than their closer-in counterparts, which is why not many of these planets have been confirmed, the researchers said. To test their theory, the researchers looked at three protoplanetary disks from the Disk Substructures at High Angular Resolution Project (DSHARP), a survey conducted by a large consortium of astronomers. DSHARP focuses on images of 20 nearby, bright and large protoplanetary disks taken by the Atacama Large Millimeter/submillimeter Array telescope in Chile.

“We were looking for disks in which it was pretty clear a planet was there,” Rice said. “If a disk has clear gaps in it, like several of the DSHARP disks do, it’s possible to extrapolate what type of planet would be there. Then, we can simulate the systems to see how much material should be ejected over time.”

“This idea nicely explains the high density of these objects drifting in interstellar space, and it shows that we should be finding up to hundreds of these objects with upcoming surveys coming online next year,” Laughlin said.

Beyond the mere novelty of noticing interstellar objects passing through our solar system, the idea of observing such objects offers major possibilities for advancing our knowledge of the cosmos, the researchers added.

Unlike many astronomical discoveries, in which data is observed and interpreted from tremendous distances, interstellar objects are an up-close look at another part of the galaxy, they said.

“You’re not looking at a distant star through a telescope,” Rice said. “This is actual material that makes up planets in other solar systems, being flung at us. It’s a completely unprecedented way to study extrasolar systems up close — and this field is going to start exploding with data, very soon.”

The research was supported by the NASA Astrobiology Institute through a cooperative agreement between Yale University and the NASA Ames Research Center and by the National Science Foundation Graduate Research Fellowship Program.
Young Jupiter was Smacked Head-on by Massive Newborn Planet

A colossal, head-on collision between Jupiter and a still-forming planet in the early solar system, about 4.5 billion years ago, could explain surprising readings from NASA’s Juno spacecraft, according to a study this week in the journal Nature.

Astronomers from Rice University and China’s Sun Yat-sen University say their head-on impact scenario can explain Juno’s previously puzzling gravitational readings, which suggest that Jupiter’s core is less dense and more extended than expected.

“This is puzzling,” said Rice astronomer and study co-author Andrea Isella. “It suggests that something happened that stirred up the core, and that’s where the giant impact comes into play.”

Isella said leading theories of planet formation suggest Jupiter began as a dense, rocky or icy planet that later gathered its thick atmosphere from the primordial disk of gas and dust that birthed our sun.

Isella said he was skeptical when study lead author Shang-Fei Liu first suggested the idea that the data could be explained by a giant impact that stirred Jupiter’s core, mixing the dense contents of its core with less dense layers above. Liu, a former postdoctoral researcher in Isella’s group, is now a member of the faculty at Sun Yat-sen in Zhuhai, China.

“It sounded very unlikely to me,” Isella recalled, “like a one-in-a-trillion probability. But Shang-Fei convinced me, by shear calculation, that this was not so improbable.”

The research team ran thousands of computer simulations and found that a fast-growing Jupiter can have perturbed the orbits of nearby “planetary embryos,” protoplanets that were in the early stages of planet formation.

Liu said the calculations included estimates of the probability of collisions under different scenarios and distribution of impact angles. In all cases, Liu and colleagues found there was at least a 40% chance that Jupiter would swallow a planetary embryo within its first few million years. In addition, Jupiter mass-produced “strong gravitational focusing” that made head-on collisions more common than grazing ones.

Isella said the collision scenario became even more compelling after Liu ran 3D computer models that showed how a collision would affect Jupiter’s core.

“Because it’s dense, and it comes in with a lot of energy, the impactor would be like a bullet that goes through the atmosphere and hits the core head-on,” Isella said. “Before impact, you have a very dense core, surrounded by atmosphere. The head-on impact spreads things out, diluting the core.”

Impacts at a grazing angle could result in the impacting planet becoming gravitationally trapped and gradually sinking into Jupiter’s core, and Liu said smaller planetary embryos about as massive as Earth would disintegrate in Jupiter’s thick atmosphere.

“The only scenario that resulted in a core-density profile similar to what Juno measures today is a head-on impact with a planetary embryo about 10× more massive than Earth,” Liu said.

Isella said the calculations suggest that even if this impact happened 4.5 billion years ago, “it could still take many, many billions of years for the heavy material to settle back down into a dense core under the circumstances suggested by the paper.”

The Juno mission was designed to help scientists better understand Jupiter’s origin and evolution. The spacecraft, which launched in 2011, carries instruments to map Jupiter’s gravitational and magnetic fields and probe the planet’s deep, internal structure.

For more information on the study’s findings, visit: https://www.nature.com/articles/s41586-019-1470-2.

For more information on the Juno mission, visit: https://www.jpl.nasa.gov/missions/juno/.
NASA’s InSight Lander Captures Audio of First Likely Quake on Mars

NASA’s Mars InSight lander has measured and recorded for the first time ever a likely “marsquake.”

The faint seismic signal, detected by the lander’s Seismic Experiment for Interior Structure (SEIS) instrument, was recorded on April 6, the lander’s 128th Martian day, or sol. This is the first recorded trembling that appears to have come from inside the planet, as opposed to being caused by forces above the surface, such as wind. Scientists still are examining the data to determine the exact cause of the signal.

“InSight’s first readings carry on the science that began with NASA’s Apollo missions,” said InSight Principal Investigator Bruce Banerdt of NASA’s Jet Propulsion Laboratory (JPL) in Pasadena, California. “We’ve been collecting background noise up until now, but this first event officially kicks off a new field: martian seismology!”

The new seismic event was too small to provide solid data on the martian interior, which is one of InSight’s main objectives. The martian surface is extremely quiet, allowing SEIS, InSight’s specially designed seismometer, to pick up faint rumbles. In contrast, Earth’s surface is quivering constantly from seismic noise created by oceans and weather. An event of this size in Southern California would be lost among dozens of tiny crackles that occur every day.

“The martian sol 128 event is exciting because its size and longer duration fit the profile of moonquakes detected on the lunar surface during the Apollo missions,” said Lori Glaze, Planetary Science Division director at NASA Headquarters.

NASA’s Apollo astronauts installed five seismometers that measured thousands of quakes while operating on the Moon between 1969 and 1977, revealing seismic activity on the Moon. Different materials can change the speed of seismic waves or reflect them, allowing scientists to use these waves to learn about the interior of the Moon and model its formation. NASA currently is planning to return astronauts to the Moon by 2024, laying the foundation that will eventually enable human exploration of Mars.

InSight’s seismometer, which the lander placed on the planet’s surface on Dec. 19, 2018, will enable scientists to gather similar data about Mars. By studying the deep interior of Mars, they hope to learn how other rocky worlds, including Earth and the Moon, formed.

Three other seismic signals occurred on March 14 (sol 105), April 10 (Sol 132), and April 11 (sol 133). Detected by SEIS’ more sensitive Very Broad Band sensors, these signals were even smaller than the sol 128 event and more ambiguous in origin. The team will continue to study these events to try to determine their cause.

Regardless of its cause, the sol 128 signal is an exciting milestone for the team.

“We’ve been waiting months for a signal like this,” said Philippe Lognonné, SEIS team lead at the Institut de Physique du Globe de Paris (IPGP) in France. “It’s so exciting to finally have proof that Mars is still seismically active. We’re looking forward to sharing detailed results once we’ve had a chance to analyze them.”

Most people are familiar with quakes on Earth, which occur on faults created by the motion of tectonic plates. Mars and
the Moon do not have tectonic plates, but they still experience quakes — in their cases, caused by a continual process of cooling and contraction that creates stress. This stress builds over time, until it is strong enough to break the crust, causing a quake.

Detecting these tiny quakes required a huge feat of engineering. On Earth, high-quality seismometers often are sealed in underground vaults to isolate them from changes in temperature and weather. InSight’s instrument has several ingenious insulating barriers, including a cover built by JPL called the Wind and Thermal Shield, to protect it from the planet’s extreme temperature changes and high winds.

SEIS has surpassed the team’s expectations in terms of its sensitivity. The instrument was provided for InSight by the French space agency, Centre National d’Études Spatiales (CNES), while these first seismic events were identified by InSight’s Marsquake Service team, led by the Swiss Federal Institute of Technology.

“We are delighted about this first achievement and are eager to make many similar measurements with SEIS in the years to come,” said Charles Yana, SEIS mission operations manager at CNES.

For more information about InSight, visit: https://www.nasa.gov/insight

First NASA Parker Solar Probe Results
Reveal Surprising Details About Our Sun

The Sun is revealing itself in dramatic detail and shedding light on how other stars may form and behave throughout the universe — all thanks to NASA’s Parker Solar Probe. The spacecraft is enduring scorching temperatures to gather data, which are being shared for the first time in four new papers that illuminate previously unknown and only-theorized characteristics of our volatile celestial neighbor.

The information Parker has uncovered about how the Sun constantly ejects material and energy will help scientists rewrite the models they use to understand and predict the space weather around our planet, and understand the process by which stars are created and evolve. This information will be vital to protecting astronauts and technology in space — an important part of NASA’s Artemis program, which will send the first woman and the next man to the Moon by 2024 and, eventually, on to Mars.

The four papers, now available online from the journal Nature, describe Parker’s unprecedented near-Sun observations through two record-breaking close flybys. They reveal new insights into the processes that drive the solar wind — the constant outflow of hot, ionized gas that streams outward from the Sun and fills up the solar system — and how the solar wind couples with solar rotation. Through these flybys, the mission also has examined the dust of the coronal environment, and spotted particle acceleration events so small that they are undetectable from Earth, which is nearly 149.6 million kilometers (93,000,000 miles) from the Sun.

During its initial flybys, Parker studied the Sun from a distance of about 24 million kilometers (15 million miles). That is already closer to the Sun than Mercury, but the spacecraft will get even closer in the future, as it travels at more than 342,790 kph (213,000 mph), faster than any previous spacecraft.

“This first data from Parker reveals our star, the Sun, in new and surprising ways,” said Thomas Zurbuchen, associate administrator for science at NASA Headquarters in Washington. “Observing the Sun up close rather than from a much greater distance is giving us an unprecedented view into important solar phenomena and how they affect us on Earth, and gives us new insights relevant to the understanding of active stars across galaxies. It’s just the beginning of an incredibly exciting time for heliophysics with Parker at the vanguard of new discoveries.”

Among the findings are new understandings of how the Sun’s constant outflow of solar wind behaves. Seen near Earth, the solar wind plasma appears to be a relatively uniform flow — one that can interact with our planet’s natural magnetic field and cause space weather effects that interfere with technology. Instead of that flow, near the Sun, Parker’s observations reveal a dynamic and highly structured system, similar to that of an estuary that serves as a transition zone as a river flows into the ocean. For the first time, scientists are able to study the solar wind from its source, the Sun’s corona, similar to how one might observe the stream that serves as the source of a river. This provides a much different perspective as compared to studying the solar wind were its flow impacts Earth.

Switchbacks

One type of event in particular caught the attention of the science teams — flips in the direction of the magnetic field, which flows out from the
The WISPR instrument on NASA’s Parker Solar Probe captured imagery of the constant outflow of material from the Sun during its close approach to the Sun in April 2019. Credit: NASA/NRL/APL.

Sun, embedded in the solar wind and detected by the FIELDS instrument. These reversals — dubbed “switchbacks” — appear to be a very common phenomenon in the solar wind flow inside the orbit of Mercury, and last anywhere from a few seconds to several minutes as they flow over the spacecraft. Yet they seem not to be present any farther from the Sun, making them undetectable without flying directly through that solar wind the way Parker has.

During a switchback, the magnetic field whips back on itself until it is pointed almost directly back at the Sun. These switchbacks, along with other observations of the solar wind, may provide early clues about what mechanisms heat and accelerate the solar wind. Not only does such information help change our understanding of what causes the solar wind and space weather affecting Earth, it also helps us understand a fundamental process of how stars work and how they release magnetic energy into their environment.

**Rotating Wind**

In a separate publication, based on measurements by the Solar Wind Electrons Alphas and Protons (SWEAP) instrument, researchers found surprising clues as to how the Sun’s rotation affects the outflow of the solar wind. Near Earth, the solar wind flows past our planet as if it travels initially in almost straight lines — or “radially,” like spokes on a bicycle wheel — out from the Sun in all directions. But the Sun rotates as it releases the solar wind, and before it breaks free, the solar wind is expected to get a push in sync with the Sun’s rotation.

As Parker ventured to a distance of around 32 million kilometers (20 million miles) from the Sun, researchers obtained their first observations of this effect. Here, the extent of this sideways motion was much stronger than predicted, but it also transitioned more quickly than predicted to a straight, strictly outward flow, which helps mask the effects at a larger distance. This enormous extended atmosphere of the Sun will naturally affect the star’s rotation. Understanding this transition point in the solar wind is key to helping us understand how the Sun’s rotation slows down over time, with implications for the lifecycles of our star, its potentially violent past, as well as other stars and the formation of protoplanetary disks, dense disks of...
gas and dust encircling young stars.

**Dust in the Wind**

Parker also observed the first direct evidence of dust starting to thin out around 11 million kilometers (7 million miles) from the Sun — an effect that has been theorized for nearly a century, but has been impossible to measure until now. These observations were made using Parker’s Wide-field Imager for Solar Probe (WISPR) instrument, at a distance of about 6.4 million kilometers (4 million miles) from the Sun. Scientists have long suspected that close to the Sun, this dust would be heated to high temperatures, turning it into a gas and creating a dust-free region around the star. At the observed rate of thinning, scientists expect to see a truly dust-free zone beginning at a distance of about 3.2–4.8 million kilometers (2-3 million miles) from the Sun, which the spacecraft could observe as early as September 2020, during its sixth flyby. That dust-free zone would signal a place where the material of the dust has been evaporated by the Sun’s heat, to become part of the solar wind flying past Earth.

**Energetic Particles**

Finally, Parker’s Integrated Science Investigation of the Sun (ISIOS) energetic particle instruments have measured several never-before-seen events so small that all traces of them are lost before they reach Earth. These instruments have also measured a rare type of particle burst with a particularly high ratio of heavier elements — suggesting that both types of events may be more common than scientists previously thought. Solar energetic particle events are important, as they can arise suddenly and lead to space weather conditions near Earth that can be potentially harmful to astronauts. Unraveling the sources, acceleration and transport of solar energetic particles will help us better protect humans in space in the future.

“The Sun is the only star we can examine this closely,” said Nicola Fox, director of the Heliophysics Division at NASA Headquarters. “Getting data at the source already is revolutionizing our understanding of our own star and stars across the universe. Our little spacecraft is soldiering through brutal conditions to send home startling and exciting revelations.”

For more information about Parker, visit: [https://www.nasa.gov/parker](https://www.nasa.gov/parker)

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**New Horizons Kuiper Belt Flyby Object Officially Named ‘Arrokoth’**

In a fitting tribute to the farthest flyby ever conducted by spacecraft, the Kuiper Belt object 2014 MU69 has been officially named Arrokoth, a Native American term meaning “sky” in the Powhatan/Algonquian language.

With consent from Powhatan Tribal elders and representatives, NASA’s New Horizons team — whose spacecraft performed the record-breaking reconnaissance of Arrokoth 6.4 billion kilometers (4 billion miles) from Earth — proposed the name to the International Astronomical Union and Minor Planets Center, the international authority for naming Kuiper Belt objects. The name was announced at a ceremony today at NASA Headquarters in Washington, DC.

“The name Arrokoth reflects the inspiration of looking to the skies and wondering about the stars and worlds beyond our own,” said Alan Stern, New Horizons principal investigator from Southwest Research Institute, Boulder, Colorado. “That desire to learn is at the heart of the New Horizons mission, and we’re honored to join with the Powhatan community and people of Maryland in this celebration of discovery.”

New Horizons launched in January 2006; it then zipped past Jupiter for a gravity boost and scientific studies in February 2007 and conducted an historic first flight through the Pluto system on July 14, 2015. The spacecraft continued its unparalleled voyage on New Year’s 2019 with the exploration of Arrokoth — which the team had nicknamed Ultima Thule — 1.6 billion kilometers (1 billion miles) beyond Pluto, and the farthest flyby ever conducted.
Arrokoth is one of the thousands of known small icy worlds in the Kuiper system, the vast third zone of the solar system beyond the inner terrestrial planets and the outer gas giant planets. It was discovered in 2014 by a New Horizons team — which included Marc Buie, of the Southwest Research Institute — using the powerful Hubble Space Telescope.

“Data from the newly-named Arrokoth, has given us clues about the formation of planets and our cosmic origins,” said Buie. “We believe this ancient body, composed of two distinct lobes that merged into one entity, may harbor answers that contribute to our understanding of the origin of life on Earth.”

In accordance with IAU naming conventions, the discovery team earned the privilege of selecting a permanent name for the celestial body. The team used this convention to associate the culture of the native peoples who lived in the region where the object was discovered; in this case, both the Hubble Space Telescope (at the Space Telescope Science Institute) and the New Horizons mission (at the Johns Hopkins Applied Physics Laboratory) are operated out of Maryland — a tie to the significance of the Chesapeake Bay region to the Powhatan people.

“We graciously accept this gift from the Powhatan people,” said Lori Glaze, director of NASA’s Planetary Science Division. “Bestowing the name Arrokoth signifies the strength and endurance of the indigenous Algonquian people of the Chesapeake region. Their heritage continues to be a guiding light for all who search for meaning and understanding of the origins of the universe and the celestial connection of humanity.”

The Pamunkey Reservation in King William County, Virginia, is the oldest American Indian reservation in the U.S. — formed by a treaty with England in the 1600s, it finally received federal recognition in July 2015. The Pamunkey tribe and its village were significant in the original Powhatan Confederacy; today, Pamunkey tribal members work collaboratively with other Powhatan tribes in Virginia and also have descendants who are members of the Powhatan-Renape Nation in New Jersey. Many direct descendants still live on the Pamunkey reservation, while others have moved to Northern Virginia, Maryland, D.C., New York, and New Jersey.

For more information about New Horizons, visit: https://www.nasa.gov/mission_pages/newhorizons/main/index.html

A Terrestrial Magma Ocean Was Key to the Moon’s Formation

A Moon-forming collisional event is simulated with the Earth covered by a magma ocean. Much more terrestrial material is ejected, helping form the Moon as we observe it. Credit: Nature Geoscience.

The origin of the Moon is one of the fundamental questions in planetary science. Its presence and size relative to us are unique in the inner solar system, and its influence on the Earth’s rotation and tides has been crucial to the development of life. Samples brought back from the Apollo missions show that the Moon is composed largely of material derived from Earth’s mantle, and that it formed later than the Earth itself.

This discovery became the core of the Giant Impact Hypothesis. The hypothesis states that a large planetary body, about the size of Mars, impacted Earth early in its history. Material dislodged from that collision was ejected into orbit, eventually coalescing to form the basis of the Moon. However, when this idea was tested in computer simulations, it turned out that the material that formed the Moon would be made primarily from the impacting object — not Earth’s mantle. Simulation conditions in which the Moon had its proper complement of Earth-derived materials required a small subset of impact angles and angular velocities, making the formation of the Moon by this method seem less likely.

A new study published April 29 in Nature Geoscience, co-authored by Yale geophysicist Shun-ichiro Karato, offers...
an explanation. The key, Karato says, is that the early, proto-Earth — about 50 million years after the formation of the Sun — was covered by a sea of hot magma, while the impacting object was likely made of solid material. Karato and his collaborators set out to test a new model, based on the collision of a proto-Earth covered with an ocean of magma and a solid impacting object.

The model showed that after the collision, the magma is heated much more than solids from the impacting object. The magma then expands in volume and goes into orbit to form the Moon, the researchers say. This explains why there is much more Earth material in the Moon's makeup. Previous models did not account for the different degree of heating between the proto-Earth silicate and the impactor.

“In our model, about 80% of the Moon is made of proto-Earth materials,” said Karato, who has conducted extensive research on the chemical properties of proto-Earth magma. “In most of the previous models, about 80% of the Moon is made of the impactor. This is a big difference.”

Karato said the new model confirms previous theories about how the Moon formed, without the need to propose unconventional collision conditions. The requirement that Earth’s surface be a magma ocean at the time is more plausible than it sounds. At the likely time of the Moon-forming impact, the solar system was still a chaotic place, filled with small planetary bodies that had yet to coalesce into planets. An impact by a body large enough to melt the Earth’s surface, but not large enough to disrupt it (as suggested by the Giant Impact Hypothesis) was a much more common event.

For the study, Karato led the research into the compression of molten silicate. A group from the Tokyo Institute of Technology and the RIKEN Center for Computational Science developed a computational model to predict how material from the collision became the Moon.

Portions of this article were provided by Yale News.
SPOTLIGHT ON EDUCATION

Public and Scientist Engagement Events at the 51st Lunar and Planetary Science Conference

At the 51st Lunar and Planetary Science Conference, a variety of engagement opportunities for scientists, students, and the public will take place during LPSC. For more information, visit www.hou.usra.edu/meetings/lpsc2020/education or contact education@lpi.usra.edu.

**Planetary Palooza**
March 15, 2020, 2:00–5:00 p.m.,
Montgomery Ballroom A

The public is invited to attend this free event with hands-on activities and presentations about ongoing solar system exploration. Scientists, members of NASA’s Science Activation Community, and public engagement specialists are welcome to participate in this year’s event. LPSC attendees who wish to participate may contact Christine Shupla (shupla@lpi.usra.edu).

**Early Career Presenters Review**
March 15, 1:30–5:00 p.m. (orals only)
March 16, 7:00–9:00 p.m. (posters only)
March 18, 11:45 a.m.–1:15 p.m. (orals only)
March 18, 7:00–9:00 p.m. (posters only)
Location for each date is TBD.

Students, post-doctoral fellows, and other early career scientists preparing to present research at LPSC 2020 are invited to receive feedback from senior scientists before presenting during the regular meeting. Registration is required, and space is limited. Register at www.surveymonkey.com/r/lpsc51_presenters. If you have any questions or would like to volunteer as a reviewer, please contact Andy Shaner (shaner@lpi.usra.edu).

**LPSC Insights: Get Connected, Stay Connected**
March 16, 12:00–1:15 p.m.
Montgomery Ballroom Foyer

Are you a student attending LPSC for the first time? Are you unsure how to navigate the conference? Are you nervous about networking? The LPSC Insights: Get Connected, Stay Connected program is here for you! First-time student attendees who register for this program will be introduced to an experienced LPSC attendee, and the pair will spend time attending sessions and networking together. Registration will open after the LPSC program has been posted; check the LPSC website for the registration link. Space is limited. If you have questions, please contact Andy Shaner (shaner@lpi.usra.edu).

**Meet with educators from the NASA Science Activation Program**
Throughout the conference

Members of the NASA Science Activation Collaborative will be present at LPSC with posters and at a booth. Come hear about NASA SMD activities and resources and discuss ways to partner and incorporate your science into these projects.

**Planetary Scientist Workshop: Sharing Planetary Science**
March 19, 12:00–1:15 p.m.,
Montgomery Ballroom

It can be challenging to communicate when your audience’s experiences are different from your own. Explore models, metaphors, and analogies that do not rely on specific cultural experiences, and learn about making culturally relevant connections. Planetary scientists attending LPSC are invited to this free workshop. For more information, please contact Christine Shupla (shupla@lpi.usra.edu).
The public is invited to join this teleconference to hear about the hot topics and ongoing research presented at LPSC. We will be joined by planetary scientists who will share their thoughts about this year’s presentations and discussions and respond to questions.

## Educator and Public Engagement Opportunities

Upcoming opportunities exist for educator and public engagement around the broader topics of NASA planetary exploration. Contact local astronomical societies, planetariums and museums, local scientists, and NASA's Solar System Ambassadors (solarsystem.nasa.gov/ssa/directory.cfm). Ask them to join your events and share their experiences or resources with your audience.

### Solar Orbiter Launches

**February 5, 2020**

ESA’s Solar Orbiter first opportunity to launch. Solar Orbiter seeks to solve the mysteries of the 11-year solar cycle and its impact on Earth and the rest of the solar system. Host a launch viewing or solar observing event to highlight the sun’s place in the solar system!

[www.esa.int/Science_Exploration/Space_Science/Solar_Orbiter](http://www.esa.int/Science_Exploration/Space_Science/Solar_Orbiter)

### Lyrids Meteor Shower

**April 22–23, 2020**

The Lyrids Meteor Shower is produced by dust particles left behind by comet C/1861 G1 Thacher. The shower peaks this year on the night of April 22 and the morning of April 23. Meteors will radiate from the constellation Lyra, but can appear anywhere in the sky. Meteor showers provide a great opportunity to discuss comets with your audiences!

[www.amsmeteors.org/meteor-showers/meteor-shower-calendar/#Lyrids](http://www.amsmeteors.org/meteor-showers/meteor-shower-calendar/#Lyrids)

### Apollo 50th Anniversary

NASA continues to celebrate the Apollo missions and their contributions to the field of planetary science into 2020. Find NASA events and resources at [www.nasa.gov/specials/apollo50th/](http://www.nasa.gov/specials/apollo50th/).

## Undergraduate and Graduate Student Opportunities

### MSA Grant for Student Research in Mineralogy and Petrology

The Mineralogical Society of America offers two grants of up to $5,000 each for research in mineralogy and petrology. Students, including undergraduates and graduates, are encouraged to apply. All proposals are considered together. The award selection will be based on the qualifications of the applicant; the quality, innovativeness, and scientific significance of the research; and the likelihood of success of the project. Applications are due 1 March 2020. For more information, visit [www.minsocam.org/MSA/Awards/Min_Pet_Award.html](http://www.minsocam.org/MSA/Awards/Min_Pet_Award.html).
Nominate a Scientist or Educator for an ASP Education Award

Nomination deadline for all awards is March 1, 2020.

Richard H. Emmons Award

The Richard H. Emmons Award of the ASP is awarded annually to an individual demonstrating outstanding achievement in the teaching of college-level introductory astronomy for non-science majors. 
astrosociety.org/who-we-are/awards

Klumpke-Roberts Award

The ASP bestows the annual Klumpke-Roberts Award on those who have made outstanding contributions to the public understanding and appreciation of astronomy. 
astrosociety.org/who-we-are/awards

Thomas J. Brennan Award

The Thomas J. Brennan Award recognizes excellence in the teaching of astronomy at the high school level in North America. The recipients have demonstrated exceptional commitment to classroom or planetarium education, as well as the training of other teachers. 
astrosociety.org/who-we-are/awards

Nominate a Scientist or Educator for an AGU Education Award

The nomination cycle for 2020 AGU Union awards, medals, and prizes is now open until March 15.

AGU's Spilhaus Award

The Athelstan Spilhaus Award is given annually to one honoree, recognizing individual achievement in the enhancement of the public engagement with Earth and space sciences through conveying to the general public the excitement, significance, and beauty of the Earth and space sciences. 
www.agu.org/Honor-and-Recognize/Honors/Union-Awards/Athelstan-Spilhaus-Award

Excellence in Earth and Space Science Education Award

The Excellence in Geophysical Education Award (EGEA) is presented annually to acknowledge a sustained commitment to excellence in geophysical education by a team, individual, or group. Examples include educators who have had a major impact on geophysical education at any level (kindergarten through postgraduate); who have been outstanding teachers and trainers for a number of years; or who have made a long-lasting, positive impact on geophysical education through professional service. 
www.agu.org/Honor-and-Recognize/Honors/Union-Awards/Excellence-in-Education-Award
IN MEMORIAM

Bruce F. Bohor
1932–2019

Geologist Bruce Bohor died on November 17, 2019. He was born May 4, 1932 in Chicago, Illinois, to Alexandria and Rudolph Bohor, both of whom were teachers in the Chicago school system. After graduating from Fenger High School, Bohor continued his education, receiving his B.S. from Beloit College in Wisconsin where he was a member of the Sigma Chi Fraternity and graduated Magma Cum Laude; his Master's Degree from the University of Indiana; and his Ph.D. from the University of Illinois.

As a geologist he began his career at Conoco in Ponca City, Oklahoma, in the Production Research Division. His next career move was to Illinois State Survey in the Clay Mineral Section and then to the U.S. Geological Survey (USGS) in Lakewood, Colorado, in the Coal Resources Branch.

Bohor continued to be involved with study and research in his field with funding from the USGS and NASA. He defined altered volcanic ash beds (tonsteins) in the western U.S. and China. He established the presence of detritus from the asteroid impact at the Cretaceous/Tertiary (K/T) boundary 65 million years ago that caused the extinction of the dinosaurs. He discovered shocked and metamorphosed quartz grains occurring in the boundary clays-tones worldwide, which confirmed their impact origin. He also discovered several sites of the impact debris layers in the western U.S. and studied many other sites around the world. For his exceptional achievement in meteoritics he was awarded the Barringer Medal at the Meteoritical Society meeting in London, England, in 2011.

After his retirement from the Survey in 1995, Bohor continued as an emeritus and volunteer at the USGS. During this time he also did follow up to research that he had co-investigated with a graduate student 40 years before by investigating the occurrence of attapulgite, a clay mineral used by both ancient and present day Mayan potters in the Yucatan Peninsula of Mexico. He authored or coauthored more than 100 technical publications over his research career. For health reasons, Bohor discontinued his active research and moved to Green Valley, Arizona, as a full time resident in 2010.

— Portions of text courtesy of the Green Valley News
The Breakthrough Prize today announced Jeffery Chen, 17, of Burlingame, California, as the winner of the fifth annual Breakthrough Junior Challenge, a global science video competition designed to inspire creative thinking about fundamental concepts in the life sciences, physics, and mathematics.

Jeffery, his teacher, and his school will share prizes worth a combined $400,000. Currently a senior at Burlingame High School, Jeffery will receive a $250,000 college scholarship. His science teacher, Heather Johnson, who sparked Jeffery’s interest in science, mentored him, and helped him launch an environmental science club, will win a $50,000 prize. Additionally, his school will receive a state-of-the-art science lab valued at $100,000.

Mesmerized by astronomy after visiting a planetarium in elementary school, Jeffery’s submission to the Breakthrough Junior Challenge explained the neutrino particle and its implications for astronomy – enabling astronomers to look at high energy cosmic events, gaze at the core of stars, and even look at the universe moments after it began.

Jeffery was recognized alongside some of the world’s top scientists and mathematicians as they were awarded the world’s largest annual science prize, the Breakthrough Prize. The ceremony was broadcast live on National Geographic in the United States.

2020 Breakthrough Prize Live Stream: Seeing the Invisible

“I was very impressed with Jeffery Chen’s grasp of the complex subject of neutrino astronomy and also with the way in which he was able to describe it for a general audience,” said Art McDonald, Breakthrough and Nobel Prize laureate for the discovery of neutrino oscillations. “Well done, Jeffery!”

This is the fifth consecutive year in which students ages 13-18 were invited to create original videos (up to three minutes in length) that illustrated a concept or theory in physics, the life sciences, and mathematics. The submissions were evaluated with respect to the students’ abilities to communicate complex scientific ideas in the most engaging, illuminating, and imaginative ways.

Breakthrough Junior Challenge is a global initiative to develop and demonstrate young people’s knowledge of science and scientific principles, generate excitement in these fields, support STEM career choices, and engage the imagination and interest of the public-at-large in key concepts of fundamental science.
NASA Administrator Names Robert Pearce Head of Agency Aeronautics

NASA Administrator Jim Bridenstine has named Robert Pearce as the next associate administrator for the Aeronautics Research Mission Directorate (ARMD). Pearce replaces Jaiwon Shin, who retired from the agency on August 31, 2019.

Pearce has served as the acting associate administrator for ARMD since September 1, responsible for the agency’s overall aeronautics research strategic direction, including research in advanced air vehicle concepts, airspace operations and safety, integrated aviation systems, and the nurturing and development of transformative concepts for aviation.

Prior to this appointment, Pearce served as the deputy associate administrator for ARMD. He also has been ARMD’s director for strategy, architecture and analysis, and has held various strategic and program management positions within NASA.

Pearce’s full biography is available online.

NASA Administrator Presents Medal to John Culberson

NASA honored John Culberson, former U.S. representative from Texas, with an agency Distinguished Public Service Medal. NASA Administrator Jim Bridenstine presented the award to Culberson at the 70th International Astronautical Conference in Washington.

Culberson served in the House of Representatives from 2001 to 2019 representing Texas’ seventh congressional district in west Houston. He served 16 years on the House Appropriations Committee and four years as Chairman of the Commerce, Justice, Science and Related Agencies, which funds NASA, the National Science Foundation, and other science agencies.

NASA’s Distinguished Public Service Medal is awarded to individuals not employed by the U.S. government for sustained performance that embodies multiple contributions on NASA projects, programs, or initiatives.

“I am deeply grateful to Administrator Bridenstine for this singular honor,” Culberson said. “I also want to thank my congressional colleagues for their steadfast support to help me significantly increase overall NASA funding, double Planetary Science funding, help ensure that it will be an American orbiter and lander that are the first to seek out life in the oceans of Europa, and help ensure that an American spacecraft will be the first interstellar mission to travel to the nearest Earthlike planet.”

For more information about NASA and agency programs, visit: https://www.nasa.gov.

John Culberson, former U.S. representative from Texas, gives remarks after receiving a NASA Distinguished Public Service Medal, NASA’s highest award for a non-NASA individual, presented by NASA Administrator Jim Bridenstine during the 70th International Astronautical Congress on October 25, 2019, in Washington. Credits: NASA/Bill Ingalls
NASA Pays Tribute, Says Goodbye to One of Agency’s Great Observatories

NASA celebrated the far-reaching legacy of the agency’s Spitzer Space Telescope—a mission that, after 16 years of amazing discoveries, soon will come to an end.

**Spitzer’s Final Voyage (live public talk)**

In a special live broadcast, which aired on January 22, featured experts such as NASA’s Director of Astrophysics Paul Hertz; and from the agency’s Jet Propulsion Laboratory (JPL) Spitzer Project Scientist Mike Werner, astrophysicist Farisa Morales, current Mission Manager Joseph Hunt, and former Mission Manager Suzanne Dodd paid tribute to the mission.

One of NASA’s four Great Observatories, Spitzer launched on August 25, 2003 and has studied the cosmos in infrared light. Its breathtaking images have revealed the beauty of the infrared universe.

Spitzer made some of the first studies of exoplanet atmospheres (atmospheres of planets around stars other than our Sun). It confirmed two and discovered five of the seven Earth-sized exoplanets around the star TRAPPIST-1, the largest batch of terrestrial planets ever found around a single star. On January 30, 2020, engineers will decommission the Spitzer spacecraft and bring this amazing mission to a close.

For more information about Spitzer, visit: https://www.nasa.gov/spitzer.

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2019 Breakthrough of the Year and Runners-up

Each year, Science’s editors and writers choose several runners-up and one Breakthrough of the Year. This year, the top honor went to the first image of a black hole — the culmination of more than 10 years of work. There were many other advances that were recognized.

Learn about the Breakthrough of the Year and nine runners-up in this video:

2019 Breakthrough of the Year
NASA Named Best Place to Work in Federal Government for 8th Straight Year

For the eighth consecutive year, NASA has been selected by the Partnership for Public Service as the Best Place to Work in Government. The rankings reflect NASA’s unified focus and dedication to sending humans farther into space than ever before and the agency’s highest employee satisfaction results since this index was developed.

“NASA’s selection as the Best Place to Work in Government for the eighth year in a row is a testament to the excellence of our workforce and their determination to maintain America’s leadership in space exploration,” said NASA Administrator Jim Bridenstine. “Throughout this year as I have visited each of our centers, I have personally witnessed their unparalleled commitment to accomplishing our mission. The daily devotion of our employees makes them well-deserving of this award. I am honored to lead such a dedicated team. They are what makes NASA the Best Place to Work in Government.”

The Best Places to Work rankings are based on responses from almost 883,000 employees at 490 federal agencies and subcomponents to the Office of Personnel Management’s annual Federal Employee Viewpoint Survey. This is the 16th edition of the Best Places to Work rankings since the first in 2003.

For the complete list of rankings, visit: https://bestplacetowork.org

NASA Selects Informal Learning Institutions to Engage Next Generation

NASA’s Teams Engaging Affiliated Museums and Informal Institutions (TEAM II) program has selected four informal education organizations to promote STEM learning and help inspire the next generation of explorers.

The projects provide students the opportunity to engage in NASA’s Moon to Mars exploration approach through science, technology, engineering, and math, and aim to reach populations that are historically underrepresented in STEM professions.

Approximately $3.5 million in total will be awarded through cooperative agreements, which provide more opportunities for interaction between recipients and NASA than the grants previously awarded through TEAM II.

The selected institutions and their projects are:
Bell Museum of Natural History and Planetarium, Minneapolis
_A Charge Forward: Activating the Nation's Planetariums to Excite the Public about Human Space Exploration of the Moon and Beyond_

Bell Museum of Natural History will provide a planetarium show and activity kit on long-duration spaceflight with the goal of reaching the hearing-impaired community and participants with disabilities. The show and activity kit will also highlight careers of such employees within NASA.

Carnegie Institute, Pittsburgh
_Blueprints to Blast Off: Making Our Way to the Moon to Mars_

Carnegie Institute will create dynamic programs for schools and museums where participants can act as team members of NASA's Artemis program by creating solutions to problems encountered in an imaginative space journey to the Moon.

EcoExploratorio, Museo de Ciencias de Puerto Rico, San Juan
_Innovative Space Learning Activities (ISLA) Center_

EcoExploratorio will provide STEM experiences around NASA's Moon to Mars content to schools and community centers across Puerto Rico including a NASA Summer Exhibition and STEM Interactive Learning Center at Plaza Las Americas, the largest shopping center in the Caribbean.

Science Museum of Minnesota, Saint Paul
_Build a Mars Habitat – Survive and Thrive..._

The Science Museum of Minnesota will provide a museum exhibit for visitors to construct their own imaginary habitat for successful living on Mars.

Nasa Selects Minority-Serving Institutions to Advance Aerospace Manufacturing

The Minority University Research and Education Project (MUREP) of NASA's Office of STEM Engagement is partnering with the agency’s Aeronautics Research Mission Directorate to provide students at minority-serving institutions the education and experience needed to help address manufacturing needs in the U.S. aerospace sector.

The MUREP Aerospace High-Volume Manufacturing and Supply Chain Management Cooperative will provide almost $1.5 million to fund curriculum-based learning, research, training, internships, and apprenticeships at three institutions to meet the growing demand for expertise and techniques in high-volume aerospace manufacturing.

During the next two years, these institutions will develop innovative opportunities for students to learn about designing and building aerospace parts using high-volume manufacturing practices, as well as supply chain management of those parts.

The selected institutions and their proposals are:

**Tuskegee University (TU), Alabama**
Impact of Additive Manufacturing on Aerospace High-Volume Manufacturing and Supply Chain Management: Workforce Alignment through Research and Training

**University of Texas at El Paso (UTEP)**
Southwest Alliance for Aerospace and Defense Manufacturing and Talent Development

**Virginia State University (VSU), Petersburg**
Donor Materials Enabled High-Volume Friction Welding of Blisks

New Companies Join Growing Ranks of NASA Partners for Artemis Program

NASA has added five American companies to the pool of vendors that will be eligible to bid on proposals to provide deliveries to the surface of the Moon through the agency’s Commercial Lunar Payload Services (CLPS) initiative.

The additions, which increase the list of CLPS participants on contract to 14, expand NASA’s work with U.S. industry to build a strong marketplace to deliver payloads between Earth and the Moon and broaden the network of partnerships that will enable the first woman and next man to set foot on the Moon by 2024 as part of the agency’s Artemis program.

“American aerospace companies of all sizes are joining the Artemis program,” said NASA Administrator Jim Bridenstine. “Expanding the group of companies who are eligible to bid on sending payloads to the Moon’s surface drives innovation and reduces costs to NASA and American taxpayers. We anticipate opportunities to deliver a wide range of science and technology payloads to help make our vision for lunar exploration a reality and advance our goal of sending humans to explore Mars.”

The selected companies are:

• Blue Origin, Kent, Washington
• Ceres Robotics, Palo Alto, California
• Sierra Nevada Corporation, Louisville, Colorado
• SpaceX, Hawthorne, California
• Tyvak Nano-Satellite Systems Inc., Irvine, California

The CLPS contracts are indefinite-delivery/indefinite-quantity contracts with a combined maximum contract value of $2.6 billion through November 2028. The agency will look at a number of factors when comparing the bids from all vendors, such as technical feasibility, price and schedule.

For more information on the delivery assignments to advance Artemis, visit: https://www.nasa.gov/feature/first-commercial-moon-delivery-assignments-to-advance-artemis

For more information about CLPS, visit: https://www.nasa.gov/clps

NASA’s Planetary Protection Review Addresses Changing Reality of Space Exploration

NASA released a report with recommendations from the Planetary Protection Independent Review Board (PPIRB) the agency established in response to a recent National Academies of Sciences, Engineering, and Medicine report and a recommendation from the NASA Advisory Council. With NASA, international, and commercial entities planning bold missions to explore our solar system and return samples to Earth, the context for planetary protection is rapidly changing. NASA established the PPIRB to conduct a thorough review of the agency’s policies.

Planetary protection establishes guidelines for missions to other solar system bodies so they are not harmfully contaminated for scientific purposes by Earth biology, and Earth, in turn, is protected...
from harmful contamination from space.

The board’s report assesses a rapidly changing environment where more samples from other solar system bodies will be returned to Earth. Commercial and international entities are discussing new kinds of solar system missions, and NASA’s Artemis program is planning human missions to the Moon and eventually to Mars.

The report discusses 34 findings and 43 recommendations from the PPIRB, which was chaired by planetary scientist Alan Stern of the Southwest Research Institute to address future NASA missions and proposed missions by other nations and the private sector that include Mars sample return, robotic missions to other bodies, eventual human missions to Mars, and the exploration of ocean worlds in the outer solar system. NASA plans to begin a dialogue about recommendation from the PPIRB report with stakeholders and international and commercial partners to help build a new chapter for conducting planetary missions and planetary protection policies and procedures.

For more information about planetary protection, visit: https://sma.nasa.gov/sma-disciplines/planetary-protection
EVOLVING THEORIES ON THE ORIGIN OF THE MOON

By Warren D. Cummings
Springer, 2019, 311 pp., Hardcover. $110.00. www.springer.com

This book follows the development of research on the origin of the Moon from the late 18th century to the present. By gathering together the major texts, papers, and events of the time, it provides a thorough chronicle of the paradigmatic shift in planetary science that arose from the notion that the Earth-Moon system was formed from two colliding planetary bodies. The book covers pre-Apollo ideas, the conceptual evolution during and subsequent to the Apollo explorations of the Moon, and the development of the Earth-Moon system consensus. A plethora of excerpts from key publications are included to demonstrate the shift in scientific focus over the centuries. Through its comprehensive review of lunar science research and literature, this book shows how new technologies and discoveries catalyzed the community and revolutionized our understanding of the Moon’s formation. Author Warren D. Cummings was the Chief Operating Officer for the Universities Space Research Association (USRA) for thirty years and is currently USRA’s Senior Advisor and Historian.

HOST STARS AND THEIR EFFECTS ON EXOPLANET ATMOSPHERES: An Introductory Overview

By Jeffrey Linsky

Like planets in our solar system, exoplanets form, evolve, and interact with their host stars in many ways. As exoplanets acquire material and grow to the final size, their atmospheres are subjected to intense UV and X-radiation and high-energy particle bombardment from the young host star. Whether a planet can retain its atmosphere and the conditions for significant mass loss both depend upon the strength of the host star’s high-energy radiation and wind, the distance of the exoplanet from its host star, the gravitational potential of the exoplanet, and the initial chemical composition of the exoplanet atmosphere. This introductory overview describes the physical processes responsible for the emission of radiation and acceleration of winds of host stars that together control the environment of an exoplanet, focusing on topics that are critically important for understanding exoplanetary atmospheres but are usually not posed from the perspective of host stars. This text is primarily for researchers and graduate students who are studying exoplanet atmospheres and habitability, but who may not have a background in the physics and phenomenology of host stars that provide the environment in which exoplanets evolve. It provides a comprehensive overview of this broad topic rather than going deeply into many technical aspects but includes a large list of references to guide those interested in pursuing these questions. Nonspecialists with a scientific background should also find this text a valuable resource for understanding the critical issues of contemporary exoplanet research.

Note: Product descriptions are taken from publishers’ websites. LPI is not responsible for factual content.
THE DELIVERY OF WATER TO PROTOPLANETS, PLANETS AND SATELLITES

Edited by A. Morbidelli, M. Blanc, Y. Alibert, L. Elkins-Tanton, P. Estrada, K. Hamano, H. Lammer, S. Raymond, and M. Schön bä chler


Liquid water is essential for the emergence of life, at least as we know it on Earth. Written by recognized experts in the field, this volume provides a complete inventory of water throughout the solar system and a comprehensive overview of the evolution of water from the interstellar medium to the final planetesimals and planets. Through a series of up-to-date review papers, the book describes how water influences the geophysical evolutions of bodies and how it is in turn affected by such evolutions. Processes like atmospheric escape under the effect of stellar irradiation and collisional impacts are discussed in detail, with specific emphasis on the consequences for the budgets of water and volatile elements in general. Specific papers on the emergence of life on Earth and the prospects of habitability on extrasolar planets are included. The papers take an interdisciplinary approach to habitability, addressing it from the perspectives of astronomy, planetary science, geochemistry, geophysics, and biology. Comprehensive yet easy to read, this volume serves as an invaluable resource to scholarly, professional, and general audiences alike.

THE WORLD AT NIGHT: Spectacular Photographs of the Night Sky

By Babak Tafreshi

White Lion Publishing, 2019, 240 pp., Hardcover. $45.00. www.quartoknows.com

See the full beauty of our night sky revealed as never before in over 200 photographs from around the world. Bringing together the images of over 40 photographers across 25 countries, be astounded by the lights of the night sky in some of the darkest places on Earth; discover the beauty of galaxies, planets, and stars; view great celestial events; and see some of the world’s most important landmarks against the backdrop of an incredible nightscape. Author Babak Tafreshi, founder of the international organization The World at Night, has curated the images in this collection — many of them previously unseen — to reveal the true splendor of the sky at night. This specialist guide to night-sky photography will help you capture your own gorgeous images of the heavens. Commentary on the science, astronomy, and photography accompany stunning images organized by theme: symbols of all nations and religions embraced by one sky of endless beauties; UNESCO World Heritage Sites at night; the universe revealed through constellations, sky motions, atmospheric phenomenon, auroras, and other wonders; images highlighting the beauty of dark skies away from light-polluted urban areas; celestial events, from great comets to spectacular eclipses; and astro-tourism destinations, like ancient astronomical monuments and modern observatories.

ADVANCES IN IMAGING AND ELECTRON PHYSICS

Edited by Peter W. Hawkes

Elsevier, 2019, 376 pp., Hardcover. $245.00. www.elsevier.com

Advances in Imaging and Electron Physics merges two long-running serials, Advances in Electronics and Electron Physics and Advances in Optical and Electron Microscopy. The series features extended articles on the physics of electron devices (especially semiconductor devices), particle optics at high and low energies, microlithography, image science, digital image processing, electromagnetic wave propagation, electron microscopy, and the computing methods used in all these domains. Sections in this new release cover electron energy loss spectroscopy at high energy losses, examination of two-dimensional hexagonal band structure from a nanoscale perspective for use in electronic transport devices, and more. This title is of interest to physicists, electrical engineers, and applied mathematicians in all branches of image processing and microscopy, as well as electron physics in general.
HEAT TRANSPORT AND ENERGETICS OF THE EARTH AND ROCKY PLANETS

By Anne Hofmeister


*Heat Transport and Energetics of the Earth and Rocky Planets* provides a better understanding of the interior of Earth by addressing the processes related to the motion of heat in large bodies. By addressing issues such as the effect of self-gravitation on the thermal state of Earth, the effect of length-scales on heat transport, important observations of Earth, and a comparison to the behavior of other rocky bodies, readers will find clearly delineated discussions on the thermal state and evolution of our planet. Using a combination of fundamentals, new developments, and scientific and mathematical principles, the book summarizes the state of the art. This timely reference is an important resource for geophysicists, planetary scientists, geologists, geochemists, and seismologists to gain a better understanding of the interior, formation, and evolution of planetary bodies.

SPACE EXPLORATION: A History in 100 Objects

By Sten Odenwald

Workman Publishing, 2019, 224 pp., Hardcover. $25.00. www.innovatoys.com/space

This is no ordinary space book. Within the pages of this eclectic pop-history, scientist and educator Sten Odenwald examines 100 objects that forever altered what we know and how we think about the cosmos. From Sputnik to Skylab and Galileo’s telescope to the Curiosity rover, some objects are iconic and some obscure — but all are incredibly important. The objects include the Nebra sky disk (1600 BCE) that features the first realistic depiction of the Sun, Moon, and stars; the Lunar Laser Ranging Retroreflector that in 1969 showed us how far we are from the Moon; the humble, rubber O-ring that doomed the space shuttle Challenger; and the Event Horizon Telescope that gave us our first glimpse of a black hole in 2019. This book showcases the tools and technologies that have altered the course of space history.

METAL EARTH SPACE 3D METAL MODEL KITS

Produced by Metal Earth

Various models with prices from $6.95 to $16.95. www.innovatoys.com/space

Metal Earth metal model kits come unassembled, packed in an envelope with easy to follow instructions. Parts can be easily clipped from the metal sheets, and no glue or solder is needed. Pop out the pieces and connect using tabs and holes. Kits include illustrated instructions. Tweezers are recommended for bending and twisting the connection tabs. Models of the InSight Mars Lander, the Hubble Telescope, the Apollo Lunar Rover, the Kepler spacecraft, and many more are available. Collect and build them all. For ages 14 and up.

THE BOOK OF FLYING MACHINES

By Neil Clark


Cogz the Robot Dog and his mice sidekicks, Nutty and Bolt, are up in the sky, looking at different flying machines. But how do they work? Discover all about forces, learn about wings, find out about the fastest planes in the world, and much more! Covering key STEM themes of engineering, physics, and inventions, and with a fun quiz to test your knowledge, this book will get children engaged and hands-on with learning. The books covers helicopters, airplanes, jet engines, fighter jets, hot air balloons, jumbo jets, drones, and jet packs. Bite-sized text and colorful, informative illustrations introduce the transport topics in a simple, engaging way for young readers with a passion for machines. For ages 5 to 7.
NEW AND NOTEWORTHY

**EXPERIMENT WITH HYDROPHOBIC SAND SCIENCE KIT**

*Produced by Surprise Ride*

$24.95. [www.surpriseride.com](http://www.surpriseride.com)

Send your imagination on a mission to Mars! For as long as we’ve been gazing at the Red Planet through our telescopes, humans have been imagining and wondering just what visiting Mars would really be like. With this kit, kids can pretend they’re on a mission to Mars as they experiment with the out-of-this-world properties of hydrophobic sand. The kit comes with a book that is packed with amazing martian facts, profiles of famous astronauts and cosmonauts, plus plenty of planetary jokes to share with friends. There’s even a little green martian to befriend! Send your young space cadet’s imagination rocketing into orbit with this kit. It encourages exploration, experimentation, and an interest in space, geology, and astronomy, and provides a fascinating adventure for future astronomers. This kit includes all required supplies plus a custom book, bendable martian figurine, parent guide, and kid-friendly learning materials. For ages 5 to 10.

**NEVER STOP WONDERING**

*By Emily Morgan*

National Science Teachers Association, 2019, 32 pp., Hardcover. $18.95. [www.nsta.org/store](http://www.nsta.org/store)

This colorful book celebrates our sense of wonder and shows how curiosity is key to cracking the mysteries of the universe. Packed with lively rhymes and fun illustrations, Never Stop Wondering demonstrates how the need to know can lead to great scientific discoveries. And the activities at the end of the book will prompt readers to do exactly what scientists do: study their surroundings, come up with questions, test ideas, and then question some more. Ready, set, wonder! For ages 5 to 9.

**PLAYFUL PLANETS CLASSIC CARD GAMES**

*Produced by Playful Planets*

$14.95. Available on [Amazon.com](http://Amazon.com)

This set of ten classic kids’ card games has a planetary twist. Playful Planets has turned card games like Old Maid (The Lonely Astronaut), Go Fish (Fly to the Sky!), and Slap Jack (Slap Jupiter) into fun educational games that teach kids about our solar system. Did you know that kids tend to retain more information when they are having fun learning? Discovering the secrets of the sky has never been more fun! These ten card games teach kids fun facts about our planets, galaxies, Sun, the Moon, and astronauts. The set packs into one small box that fits easily into a purse, backpack, travel bag, even a back pocket. Playful Planet is a fun way to develop critical skills like pairing, matching, and memory retention while encouraging healthy competition, cooperation, creativity, imagination, and confidence. For ages 5 and up.
February

Tackling the Complexities of Substellar Objects: From Brown Dwarfs to (Exo-)Planets
📅 February 10–14
📍 Leiden, Netherlands
☑️ [link](https://lorentzcenter.nl/lc/web/2020/1193/info.php3?wsid=1193&venue=Oort)

The Impact of Lunar Dust on Human Exploration
📅 February 11–13
📍 Houston, Texas
☑️ [link](https://www.hou.usra.edu/meetings/lunardust2020/)

3rd International Planetary Caves Conference
📅 February 18–21
📍 San Antonio, Texas
☑️ [link](https://www.hou.usra.edu/meetings/3rdcaves2020/)

PERC International Symposium on Dust and Parent Bodies (IDP2020)
📅 February 25–27
📍 Tokyo, Japan
☑️ [link](http://www.perc.it-chiba.ac.jp/meetings/IDP2020/)

8th Virtual MEPAG Meeting (VM8)
📅 February 28
📍 Virtual
☑️ [link](https://jpl.webex.com/jpl/j.php?MTID=m4938f1c9b2c74d9923980c97e0eafa20)

March

Next Generation Suborbital Researchers Conference (NSRC-2020)
📅 March 2–4
📍 Broomfield, Colorado
☑️ [link](http://nsrc.swri.org)
51st Lunar and Planetary Science Conference
March 16–20
The Woodlands, Texas
https://www.hou.usra.edu/meetings/lpsc2020/

Astronomy from the Moon: The Next Decades
March 18–19
London, United Kingdom
https://royalsociety.org/science-events-and-lectures/2020/03/astronomy-moon/

2020 International Conference and Exhibition on Catalysis and Chemical Science
March 26–27
Madrid, Spain
https://researchlake.com/conferences/catalysis/

Thermal Infrared Astronomy-Past, Present and Future
March 30 – April 3
Garching, Germany

16th Spacecraft Charging and Technology Conference
March 30 – April 3
Cocoa Beach, Florida
https://www.hou.usra.edu/meetings/sctc2020/

Preventing Harassment in Science: Building a Community of Practice Toward Meaningful Change (#PreventScienceHarassment2020)
March 31 – April 2
Phoenix, Arizona
https://www.hou.usra.edu/meetings/anti-harassment2020/
April

Titan Through Time Workshop V
📅 April 14–16
🔗 https://titanthroughtime.org/

European Conference on Laboratory Astrophysics
ECLA 2020: Linking Dust, Ice and Gas in Space
📅 April 19–24
📍 Anacapri, Capri Island, Italy
🔗 http://frcongressi.net/ecla2020.meet

Hera Workshop
📅 April 20–22
📍 Nice, France
🔗 https://www.cosmos.esa.int/web/hera-community-workshop

The Sharpest Eyes on the Skies
📅 April 20–24
📍 Exeter, United Kingdom
🔗 http://sites.exeter.ac.uk/sharpesteyes2020/

Apophis T-9 Years: Knowledge Opportunities for the Science of Planetary Defense
📅 April 23–24
📍 Nice, France
🔗 https://www.hou.usra.edu/meetings/apophis2020/

Lunar Surface Science Workshop
📅 April 28–30
📍 Denver, Colorado Area
🔗 https://www.hou.usra.edu/meetings/lunarsurface2020/

In Situ Science and Instrumentation Workshop for the Exploration of Europa and Ocean Worlds
📅 April 28–30
📍 Pasadena, California
🔗 https://www.europa-insitu.caltech.edu/
May

Atmospheres and Exospheres of Terrestrial Planets, Satellites, and Exoplanets
🌿 May 3–8
📍 Vienna, Austria
🔗 https://meetingorganizer.copernicus.org/EGU2020/abstractsubmission/36525

Planet Mars V
🌿 May 3–8
📍 Les Houches, France
🔗 https://www.cosmos.esa.int/web/planet-mars-5/home

Women in Space Conference
🌿 May 6–8
📍 Saint-Hubert, Quebec
🔗 https://www.womeninspacecon.com/

17th AIP Thinkshop on Protoplanetary Disk Chemodynamics
🌿 May 11–15
📍 Potsdam, Germany
🔗 https://thinkshop.aip.de/17

8th European Lunar Symposium
🌿 May 12–14
📍 Padua, Italy
🔗 https://els2020.arc.nasa.gov/

Sixth International Planetary Dunes Workshop
🌿 May 12–15
📍 Alamosa, Colorado
🔗 https://www.hou.usra.edu/meetings/dunes2020/

Workshop on Observatory for the Outer Heliosphere, Heliosheath, and Interstellar Space
🌿 May 21–22
📍 Boulder, Colorado
🔗 http://lasp.colorado.edu/home/mop/resources/hosted-meetings/outer-heliosphere-workshop/
June

Towards Other Earths III: From Solar System to Exoplanets
- June 1–5
- Lamego, Portugal
- [http://www.iastro.pt/toe3/](http://www.iastro.pt/toe3/)

Planet Formation: From Dust Coagulation to Final Orbit Assembly
- June 1–26
- Garching, Germany
- [http://www.munich-iapp.de/planetformation](http://www.munich-iapp.de/planetformation)

Mercury: Current and Future Science of the Innermost Planet
- June 2–4
- Orléans, France
- [https://mercury2020.ias.u-psud.fr/main_1st.php](https://mercury2020.ias.u-psud.fr/main_1st.php)

7th Mars Atmosphere Modelling and Observations Conference
- June 8–11
- Paris, France

Asteroids, Comets, Meteors Conference
- June 14–19
- Flagstaff, Arizona
- [https://www.hou.usra.edu/meetings/acm2020/](https://www.hou.usra.edu/meetings/acm2020/)

2020 Annual Meeting of Planetary Geologic Mappers
- June 16–18
- Denver, Colorado
- [https://www.hou.usra.edu/meetings/pgm2020/](https://www.hou.usra.edu/meetings/pgm2020/)

European Astronomical Society Annual Meeting
- June 29 – July 3
- Leiden, the Netherlands
- [https://eas.unige.ch//EAS_meeting/](https://eas.unige.ch//EAS_meeting/)
July

Exoplanets III
📅 July 27–31
📍 Heidelberg, Germany
🔗 [https://hdconfsys.zah.uni-heidelberg.de/exoplanets3/index.php](https://hdconfsys.zah.uni-heidelberg.de/exoplanets3/index.php)

August

11th Planetary Crater Consortium Meeting
📅 August 5–7
📍 Honolulu, Hawai‘i
🔗 [https://www.hou.usra.edu/meetings/crater2020/](https://www.hou.usra.edu/meetings/crater2020/)

83rd Annual Meeting of The Meteoritical Society
📅 August 9–14
📍 Glasgow, Scotland

43rd COSPAR Scientific Assembly
📅 August 15–23
📍 Sydney, Australia
🔗 [https://www.cospar-assembly.org](https://www.cospar-assembly.org)

September

Planetary Science: The Young Solar System
📅 September 6–12
📍 Quy Nhon, Vietnam
🔗 [https://www.icisequynhon.com/conferences/2020/planetary_science](https://www.icisequynhon.com/conferences/2020/planetary_science)

Europlanet Science Congress
📅 September 27 – October 2
📍 Granada, Spain

From Clouds to Planets II: The Astrochemical Link
📅 September 28 – October 2
📍 Berlin, Germany
🔗 [https://events.mpe.mpg.de/event/12/](https://events.mpe.mpg.de/event/12/)
October

Martian Geological Enigmas: From the Late Noachian Epoch to the Present Day (#marsenigmas2020)
- October 5–8
- Houston, Texas
- [https://www.hou.usra.edu/meetings/martianenigmas2020/](https://www.hou.usra.edu/meetings/martianenigmas2020/)

GSA Annual Meeting
- October 25–28
- Montreal, Quebec, Canada
- [https://community.geosociety.org/gsa2020/home](https://community.geosociety.org/gsa2020/home)

52nd Meeting of the Division for Planetary Sciences of the American Astronomical Society
- October 25-30
- Spokane, Washington
- [https://dps.aas.org/meetings/current](https://dps.aas.org/meetings/current)

November

Magnetism and Accretion
- November 16–20
- Cape Town, South Africa

5th International Workshop on Instrumentation for Planetary Missions 2020
- November 18–20
- Tokyo, Japan
- [https://www2.rikkyo.ac.jp/web/ipm2020/](https://www2.rikkyo.ac.jp/web/ipm2020/)

December

AGU Fall Meeting
- December 7–11
- San Francisco, California
- [https://www.agu.org/](https://www.agu.org/)