FALL OF AN ICON: The Past, Present, and Future of Arecibo Observatory

Credit: University of Central Florida.

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FALL OF AN ICON: The Past, Present, and Future of Arecibo Observatory

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For nearly six decades, Arecibo Observatory in Puerto Rico served as a scientific leader at the forefront of space and atmospheric sciences, radio astronomy, and planetary radar astronomy, as a marvel of science and engineering, as a source of inspiration, and as a cornerstone of the local community and the island itself.

In the late 1950s, the concept of Arecibo Observatory was the vision of William E. (Bill) Gordon of Cornell University for a large radar facility on the order of 305 meters (1000 feet) in diameter, necessary for detailed study of Earth's ionosphere. The original design called for a stationary parabolic dish that only viewed the zenith point directly overhead; however, it was realized that a large spherical dish with a movable focusing platform suspended some 150 meters (500 feet) overhead would allow for tracking of astronomical objects. In a proposal written by Gordon in 1958, the main objective of the facility would be to study the electron density and temperature of the ionosphere, but it is noted that the same facility could perform radar observations of solar system objects and receive radio emissions from distant sources in outer space. In 1959, Cornell signed a contract to design and build the telescope with Air Force Cambridge Research Laboratories, which had been designated by the federal Advanced Research Projects Agency to manage the project. Many members of the neighboring communities around Arecibo helped construct the observatory, including author Rivera-Valentín's grandfather. Finally, on November 1, 1963, Arecibo Observatory was inaugurated and took its place as a leader in multidisciplinary science.

Arecibo Observatory was built in northwest Puerto Rico at the southern edge of the municipality of Arecibo, nestled in a limestone sinkhole among the surrounding karst terrain abutting the Tanama River. The sinkhole provided a natural depression that could support the massive spherical-cap shape of the dish with minimal modification to the environment. The initial form of what became known as the William E. Gordon telescope (see Fig. 1) was made of a metal mesh, similar to chicken wire, allowing one to see straight through it into the sinkhole below. This is because the first observations with Arecibo were at sufficiently long wavelengths (low enough frequencies) that the mesh was opaque to radio waves. The triangular structure that held the line feeds, used to focus and receive the reflections from the spherical dish, was suspended by steel cables from three towers around the perimeter of the sinkhole. A circular track mounted below the triangle and an arc-shaped track below that gave the feeds the ability to move in azimuth and elevation to track specific regions of the atmosphere and astronomical objects in the sky.

As intended, early atmospheric radar observations at Arecibo studied the composition of the ionosphere and led to characterization of the electron temperature and electron density with time. However, with such a powerful facility, radar studies moved beyond the ionosphere, making several important observations in the nascent field of planetary radar astronomy. Radar observations of the planet Mercury showed that it rotates prograde (west to east) in 59 days rather than synchronously with its 88-day orbital period about the Sun, while radar observations of Venus confirmed it slowly rotates retrograde (in a reverse or backward direction) in about 245 days. The ability of radar to measure the distance to objects with extreme precision led to refinement of the astronomical unit, which sets the distance scale for the solar system, and measurement of the perihelion shift of Mercury in accordance with the theory of general relativity. When not actively transmitting radar signals, Arecibo was used for radio astronomy, studying the universe at frequencies of tens of megahertz (MHz) to 600 MHz (wavelengths of tens of meters to 0.5 meters). In 1968, Arecibo observations of the Crab Nebula determined the pulsar at its center (pulsars having been discovered only a year prior) rotated once every 33 milliseconds.

In the late 1960s, ownership of Arecibo Observatory was transferred to the National Science Foundation (NSF) and in the early 1970s, in partnership with NASA, the surface of the telescope was upgraded to 38,778 perforated aluminum panels. Shrinking the size of the holes in the dish allowed for higher-frequency (shorter-wavelength) observations including the 1.42-GHz (21-centimeter) line of hydrogen for radio astronomy and the addition of a

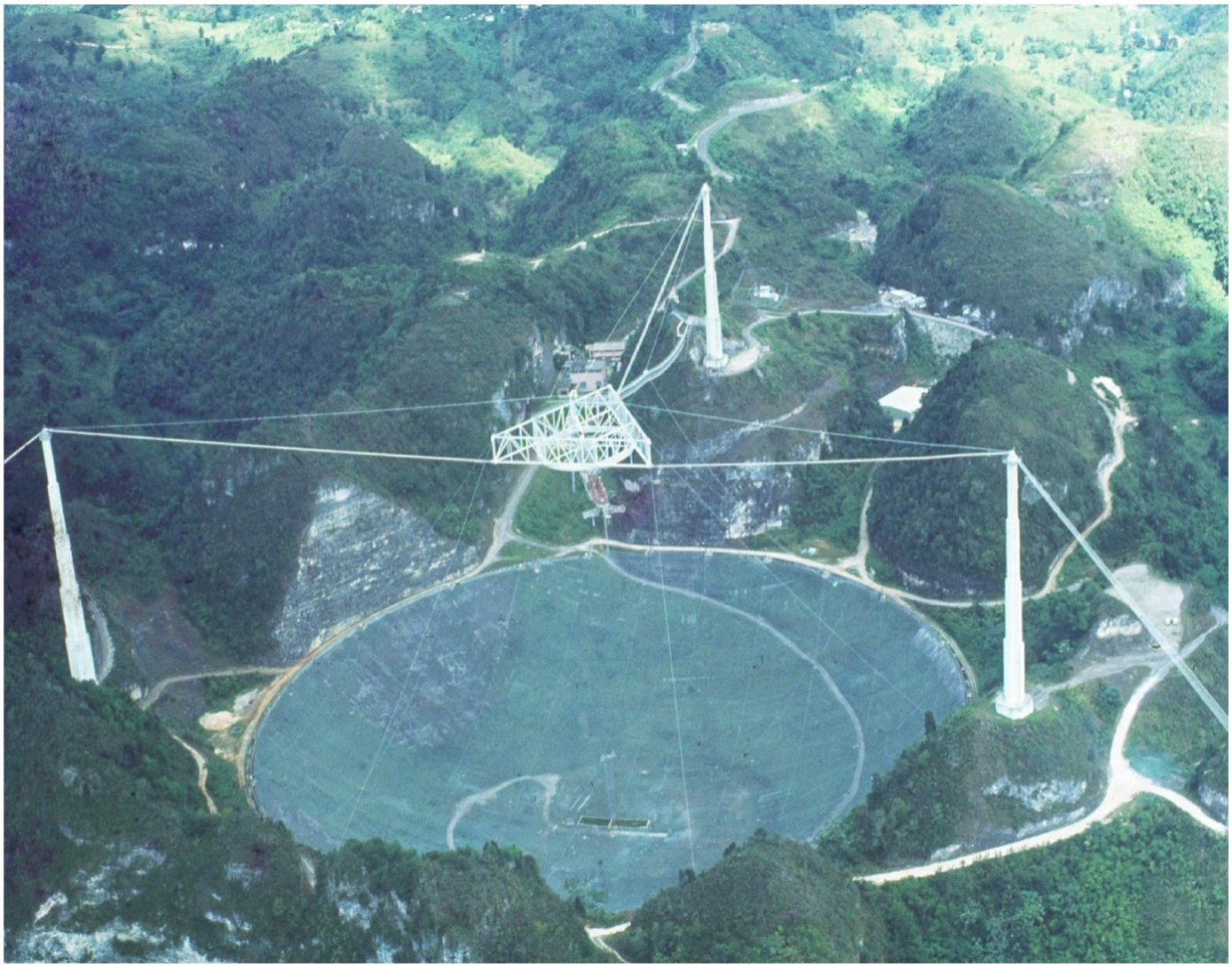


Fig. 1. Aerial view of the William E. Gordon telescope in its first form with the three towers holding the steel platform above the see-through dish. Note the road to the bottom of the sinkhole and the vegetation underneath the dish itself. Credit: Cornell University/Arecibo Observatory.

powerful 2.38-GHz (12.6-centimeter) transmitter for planetary radar.

Over the next two decades, Arecibo continued to make breakthroughs in its main fields of study. The atmospheric radar was used to simultaneously heat and study the E and F regions of the ionosphere and detect an ionized layer of helium. For the first time, the radar was used to simultaneously measure two ion temperatures (O^+ and H^+) and three compositions (O^+, H^+, and He^+), continuing the original objective of the facility to understand the abundance and temperature of species in the upper atmosphere.

Some of the seminal discoveries by Arecibo of this era for radio astronomy again related to pulsars. Arecibo was used to discover the first binary pulsar in 1974, which resulted in the 1993 Nobel Prize in physics awarded to Russell A. Hulse and Joseph H. Taylor. Periodic monitoring of this double-pulsar system provided indirect evidence for gravitational waves as predicted by the theory of general relativity. In 1982, the first millisecond pulsar was discovered at Arecibo, leading to the refined use of pulsars as extremely precise clocks in the search for direct evidence of gravitational waves. In 1992, precise timing of a pulsar led to the discovery of the first exoplanets outside our own solar system.

For planetary radar, increased sensitivity allowed for detection and characterization of near-Earth asteroids, main-belt asteroids, and the nuclei and comae of comets. Meanwhile, radar observations of the terrestrial planets continued with improved resolution, producing geologic maps of the Moon and the surface of Venus as well as finding evidence for ice at the poles of Mercury. This was a bountiful time for science at Arecibo and it continued to improve with the Gregorian upgrade in the mid-1990s, which, for planetary radar specifically, increased sensitivity by a factor of 15.

The Gregorian upgrade gave the William E. Gordon telescope the form that most are familiar with (see Fig. 2). The golf-ball-like dome was the equivalent of a four-story building suspended above the dish and housed the planetary radar, a suite of receivers up to 10 GHz (3 centimeters), and the secondary and tertiary reflectors used to remove the spherical aberration caused by the

spherical primary dish. While a line feed remained in use for the atmospheric radar, the optics of the Gregorian dome allowed for wider-bandwidth receivers and increased sensitivity at the expense of adding weight to the suspended structure, totaling some 900 tons.

In addition to improvements in sensitivity, space and atmospheric sciences benefited from the long baseline of observations over time with Arecibo. Observations of neutral winds in the thermosphere show strong variations with time and season based on data collected over three decades. A similarly lengthy baseline found that the momentum balance between ionospheric O^+ and oxygen in the thermosphere varies with local time, season, and solar cycle, whereas trends with solar cycle were only detectable on the decadal timescales provided by the long-term operation of Arecibo. With the upgraded facility, radio astrometry milestones with Arecibo included using a multi-beam receiver to efficiently map hydrogen in the galactic and extragalactic neighborhood; detecting organic molecules, the building blocks of amino acids, in other galaxies; discovering the first repeating fast radio burst (extragalactic millisecond pulses); and timing a pulsar in a triple-star system, providing the most stringent test yet to the strong equivalence principle of the theory of general relativity, among many other accomplishments.

Planetary radar efforts, especially the study of small bodies, accelerated after the Gregorian upgrade with over 850 detections of near-Earth asteroids (see Fig. 3) and several historic results, including the first direct evidence for binary near-Earth asteroids (asteroids with their own moon); the first direct evidence for triple near-Earth asteroids (asteroids with two moons); evidence for non-gravitational accelerations affecting the orbits and spin states of asteroids; detection of asteroids as small as 2 meters (described at the time as detecting President Obama at five times farther away than the Moon); and extensive spacecraft mission support, providing precise astrometry to aid in navigation as well as physical characterization and shape modeling of small bodies eventually visited by NASA spacecraft. Radar observations of the Moon produced maps of the lunar nearside with resolution (~100 meters) surpassed only by the most recent generation of spacecraft. While spacecraft imaging can provide finer-resolution images, radar provides the added dimension of penetration into the subsurface, revealing geologic structure below the dusty regolith unseen by optical cameras. Radar of the terrestrial planets was pushed to kilometer-scale resolution to understand the distribution of ice at the poles of Mercury, search for active volcanism on Venus, and characterize spacecraft landing sites on Mars (see Fig. 4).

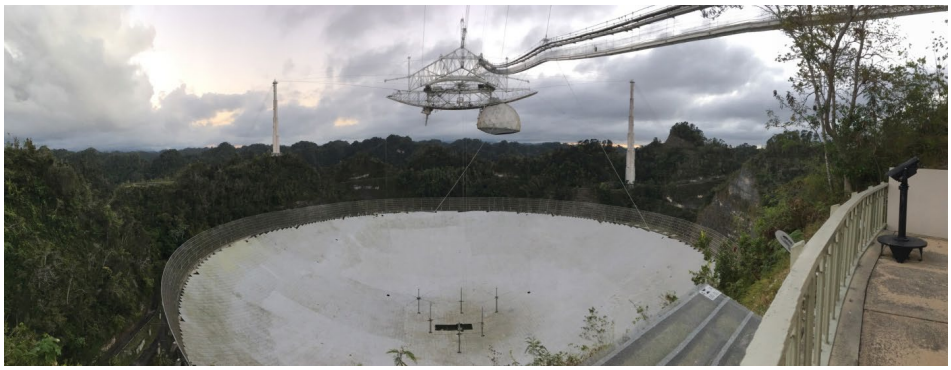


Fig. 2. The William E. Gordon telescope as seen from the Ángel Ramos Science and Visitor Center in 2019 with the Gregorian dome, but after the line feed (left of the dome) for the atmospheric radar had been broken off during Hurricane Maria. The dipole antennae for ionospheric heating experiments are at bottom center. The mesh at the lower right is one of the perforated aluminum panels used as the surface of the dish. Credit: Patrick A. Taylor.

Fittingly, one of the final acts of Arecibo planetary radar was the removal of potentially hazardous asteroid 2020 NK1 from the list of possible future Earth impactors. As a newly discovered asteroid in the summer of 2020, the exact orbit of 2020 NK1 was uncertain and impacting trajectories were possible later this century. Arecibo radar observations on July 31, 2020, provided precise measurements of the asteroid's velocity and distance from Earth that greatly reduced its orbital uncertainties and allowed accurate prediction of its trajectory more than 400 years into the future, ruling out an Earth impact. Just 10 days later, observatory operations were shut down. The final observations completed were searching for new pulsars, timing known pulsars to detect gravitational waves, monitoring repeating fast radio bursts, and mapping extragalactic hydrogen, all appropriate representatives of the science of Arecibo Observatory.

On August 10, an "auxiliary" cable that supported the suspended platform slipped free from its socket atop one of the three towers and slashed through the dish below. The auxiliary cables were

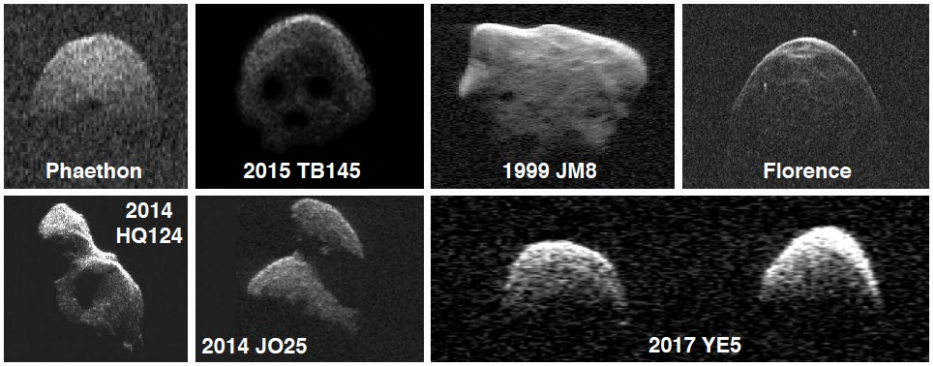


Fig. 3. A subset of the homogeneous population of near-Earth asteroids observed with Arecibo Observatory. Clockwise from top left: Phaethon, parent body of the Geminid meteors; spheroidal 2015 TB145; angular and pockmarked 1999 JM8; triple asteroid Florence; equal-mass binary asteroid 2017 YE5 (observed with the Green Bank Telescope receiving); double-lobed 2014 JO25; and irregularly shaped 2014 HQ124 (observed with Goldstone transmitting and Arecibo receiving). Credit: Arecibo Observatory, NASA, NSF, Goldstone Solar System Radar, Green Bank Observatory.

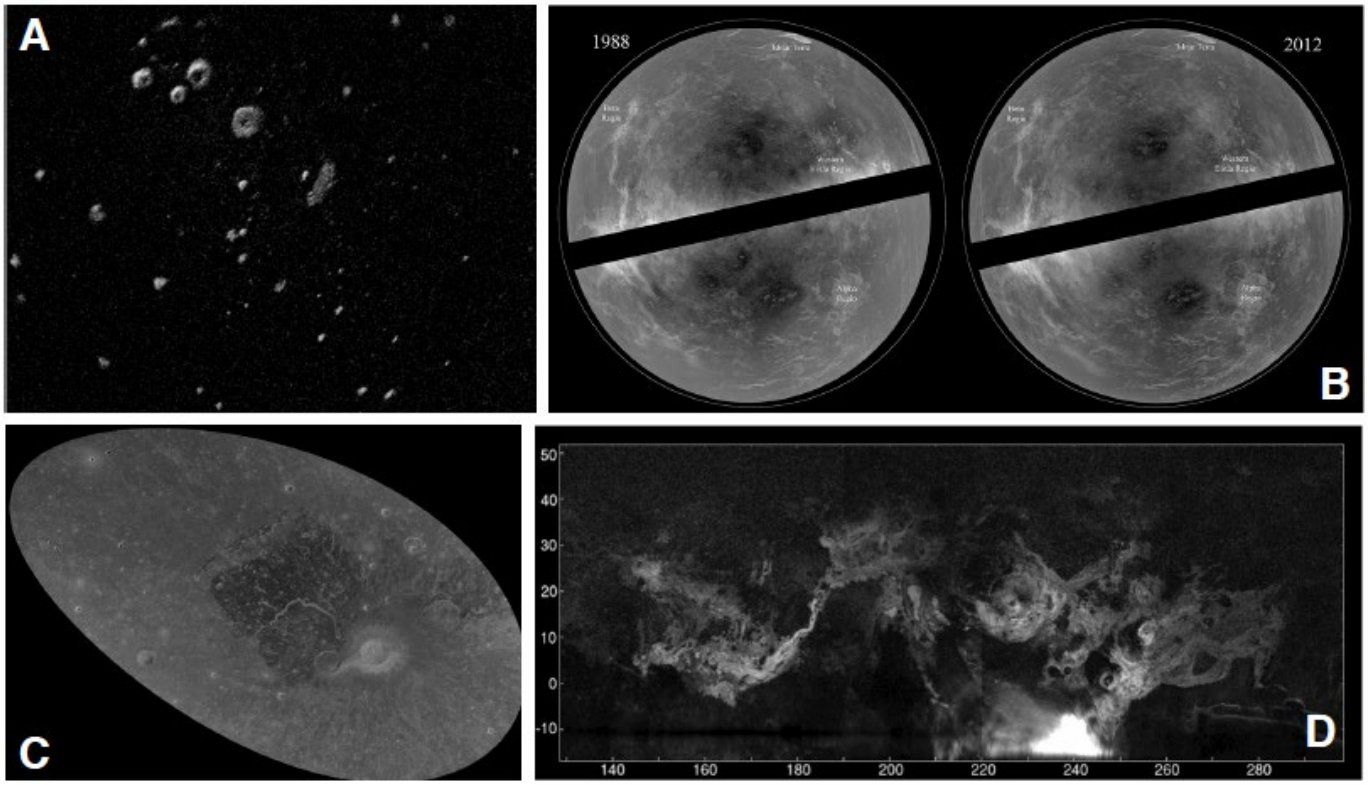


Fig. 4. Arecibo radar observations of planetary surfaces (A) showing the distribution of water ice at the north pole of Mercury, (B) searching for active volcanism on Venus, (C) illustrating surface variation in the Aristarchus region on the Moon, and (D) revealing linkages between the major ancient volcanic provinces on Mars buried under the dusty regolith. Credit: (A) Rivera-Valentín et al. (2021) 51st LPSC, Abstract #2104, Fig. 1; (B) Adapted from Maps of Venus, B. Campbell/Smithsonian Institution, available online at https://airandspace.si.edu/multimedia-gallery/9776hjpg; (C) adapted from Campbell et al. (2008) *Geology*, 36, 135–138, Fig. 2; and (D) adapted from Harmon et al. (2012) *Icarus*, 220, 990–1030, Fig. 1.

added between the towers and platform in the 1990s to help support the weight of the Gregorian dome. The cause of the failure remains under investigation. Observations were immediately halted and engineers began studying the stability and safety of the structure and how to proceed with repairs. On November 6, in the midst of the study to stabilize the structure, one of the main cables from the telescope's original construction gave way, snapping at the top of the same tower as the auxiliary cable. After this failure, on November 19, NSF announced the decommissioning of the observatory in an abundance of caution given that another cable failure would likely result in the collapse of the structure. In the early morning of December 1, that break happened and the platform fell. The rapid change in tension ripped the tops off of all three towers. The falling cables gouged the dish. The 900-ton platform crushed everything below it as it plummeted like a pendulum into the side of the sinkhole. [Note: Following the writing of this article, NASA released the findings of an investigation into the failure of the auxiliary cable: https://ntrs.nasa.gov/citations/20210017934.]

In the months since, crews have worked to prevent environmental damage from potentially harmful materials such as oil and lead that fell to the ground inside the sinkhole, to salvage pieces of historical and sentimental interest, and to remove the fallen structure. While the iconic image of the platform suspended above the dish is gone, a significant fraction of the dish itself remains. The dipole antennae for the ionospheric heating facility that peeked through the bottom of the dish were relatively undamaged as well as the instruments not located on the platform, e.g., the 12-meter radio telescope and other atmospheric monitoring equipment on neighboring hills. While this is a tremendous loss of an incredibly sensitive instrument for space and atmospheric sciences, radio astronomy, and planetary radar astronomy, the site infrastructure and much of the primary surface remains, giving hope for possible reopening for science and the public in the future.

Of course, there is no way to do justice in this article to the generational scientific advancements made over six decades at Arecibo Observatory. And the legacy of Arecibo goes beyond pure science; it extends to the people and students inspired by the observatory. Arecibo Observatory has hosted a research experience for undergraduates program since 1972, including this summer, serving hundreds of students plus many more funded through other means. These programs have been especially helpful in serving underrepresented groups in science, technology, engineering, and mathematics (STEM). Additionally, hundreds of undergraduates, graduate students, postdocs, faculty, and staff at other institutions have visited Arecibo over the years for observer training and performing their own observations. Many of these students have gone on to complete undergraduate and graduate degrees in STEM fields, including writing nearly 400 Ph.D. theses involving research done at Arecibo.

Over the last several years, Arecibo extended its student development to hosting a pre-college research and

supplemental education program for high school students from across Puerto Rico called the Arecibo Observatory Space Academy (AOSA). As part of the program, students experienced the full breadth of the research cycle by proposing a work plan, conducting their research, and presenting their results at an onsite symposium. AOSA served more than 300 students, and of those that are of college age, more than 90% have pursued degrees in STEM fields. Former students have developed space exploration clubs at their universities and won the NASA Revolutionary Aerospace Systems Concepts Academic Linkage mission architecture design competition three years in a row.

The awe-inspiring structure of the William E. Gordon telescope has motivated so many to seek careers in science and engineering. Part of this process is facilitated by the Ángel Ramos Science and Visitor Center, which includes exhibit space and an auditorium overlooking the telescope. The visitor center brings in up to 120,000 visitors per year; some are tourists, but many are Puerto Rican school children on field trips to see the observatory, often called El Radar, that has become part of their community identity. Arecibo Observatory is more than a landmark for Puerto Ricans; it is a source of pride and inspiration and an invaluable connection to science at the national and international level. In the wake of the tragic events of last December, many Boricuas shared on social media the momentous impact Arecibo had on them by using the hashtag #WhatAreciboMeansToMe. The loss of Arecibo is truly, deeply felt by the community in Puerto Rico and its diaspora.

The collapse of the William E. Gordon telescope, at the forefront of space and atmospheric sciences, radio astronomy, and planetary radar astronomy for six decades, is a tremendous loss to the science, engineering, and local communities. For all three fields, the loss of Arecibo is immense in terms of sensitivity, flexibility, and redundancy. For instance, without Arecibo, planetary radar relies solely upon the Goldstone Solar System Radar (GSSR) in California, whose primary objective is spacecraft communication and is less sensitive than Arecibo by a factor of 15 or so. While tremendously capable in its own right, the GSSR cannot replace the workhorse nature of Arecibo for planetary radar in tracking near-Earth asteroids, characterizing main-belt asteroids, studying the polar deposits of Mercury, or mapping the surface of Venus. These losses will act as the motivation to develop a new telescope at Arecibo Observatory. The observatory's science and technical staff has already begun looking into designs for a next-generation Arecibo telescope; the government of Puerto Rico has pledged several million dollars to pursue design studies and NSF hosted a workshop to discuss pathways forward for the Arecibo Observatory site. Whatever the next steps for a next-generation telescope at Arecibo Observatory, whether a single dish, an array of smaller dishes, or something completely different, all concepts will require extensive design, evaluation, community input, and, most of all, funding.

> **“The legacy of Arecibo will live on for decades into the future, just as Arecibo served for decades prior, in whatever form the future of the observatory takes.”**

In the wake of Hurricane Maria's devastation of Puerto Rico in 2017, a common social media hashtag, #PRSeLevanta, emerged, saying that Puerto Rico will recover, and it remains apt here. The island of Puerto Rico and its people are resilient and Arecibo Observatory has countless supporters among those who have used it and been inspired by it. Many of us watched a huge part of our professional careers come crashing down that fateful day last December and a community suffered the loss of its beloved, inspirational icon. There may be some solace in knowing that the Arecibo legacy of science, engineering, and education cannot be taken away by this unfortunate event. The legacy of Arecibo will live on for decades into the future, just as Arecibo served for decades prior, in whatever form the future of the observatory takes.

For more information, visit the official website of Arecibo Observatory at https://www.naic.edu. Updates from the National Science Foundation on the status of Arecibo Observatory can be found at https://www.nsf.gov/news/special_reports/arecibo/index.jsp.

About the Authors

Patrick A. Taylor spent nine years as a staff member at Arecibo Observatory, including as group lead for planetary radar, before joining the Lunar and Planetary Institute. Edgard G. Rivera-Valentín is the first Arecibo-born staff scientist to work at Arecibo Observatory and spent four years there working with planetary radar, education, and public engagement before joining the Lunar and Planetary Institute.

FROM THE DESK OF **LORI GLAZE**

NEVER GIVE UP, NEVER SURRENDER

Lori S. Glaze

Director, NASA's Planetary Science Division, July 2021

Back in 2018, before I came to NASA Headquarters as the Planetary Science Division Director, I gave a talk at the 49th Lunar and Planetary Science Conference titled "Exploring Venus: Never Give Up, Never Surrender," where I laid out the scientific case and mission needs for renewed exploration of Venus in the twenty-first century. It has been more than 30 years since NASA last sent a mission dedicated to exploring the second planet, and for many in the U.S. planetary science community, it felt like Venus had become the forgotten planet. But fast forward to just over three years later, and Venus fans are feeling a lot happier in the wake of the recent selection of the two newest Discovery missions — Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS) and Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI) — as well as EnVision [as a European Space Agency (ESA) medium-class mission]. (As stated publicly on several occasions, because of my long history of involvement in the Venus community and the DAVINCI mission, I was recused from the Discovery mission selection process.) After many years wandering the proverbial desert, Venus is now back firmly on NASA's — and ESA's — exploration agenda.

As an added benefit, the selection of these three missions, to fly in the same time frame, means we will enable science results that are greater than the sum of their individual contributions and we will be able to combine their data to resolve long-standing questions synergistically. Venus' moment has come at this time because the Venus science community has established a truly compelling set of reasons for us to go back — in a coordinated manner. Space exploration — at its essence — is about stories. It's about the major driving questions that we seek to answer by visiting the other worlds our solar system offers us.

In terms of size, mass, and distance from the Sun, Venus and Earth are pretty much twins. Yet present-day conditions on the two planets are vastly different. As we try to unravel the history — and predict the future — of Earth (e.g., climate change), studying Venus and learning more about its evolution will help us better understand our own planet. Combining an improved picture of Venus, with the data we have garnered about Mars and its climate history, will provide an even more complete picture of how terrestrial planets with atmospheres evolve. Moreover, the huge increase in the number of confirmed exoplanets — including several that closely orbit their host star — means that we are compelled to better characterize the planets in our own backyard so that we can discern

even more about these distant exoplanets. The potential detection of phosphine in Venus' clouds in the past year, and the rigorous scientific discussion that has followed, also highlight how hungry scientists are to go back to Venus and continue to explore the astrobiological potential of our entire solar system.

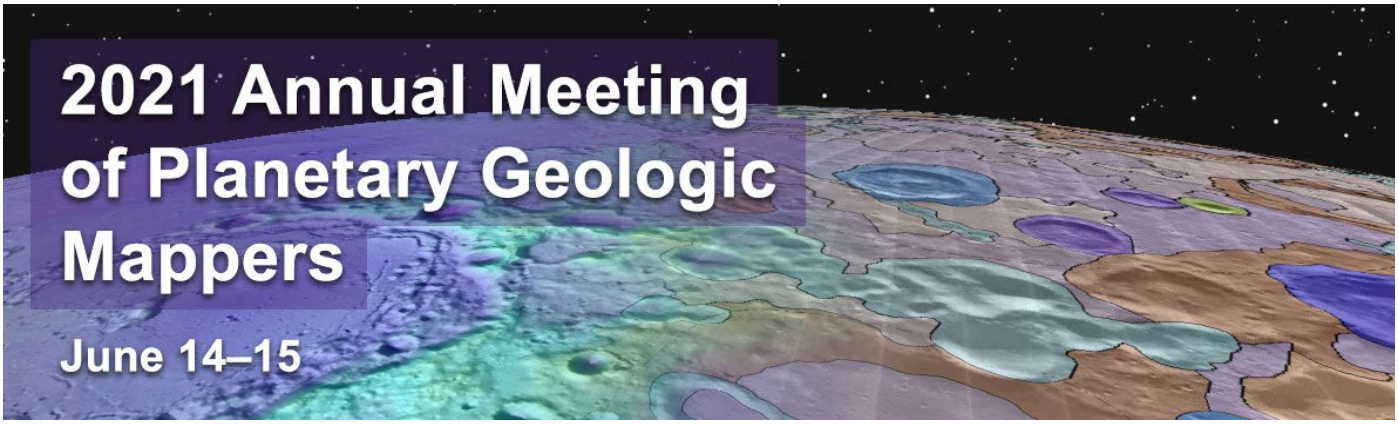
VERITAS, DAVINCI, and EnVision have been designed to address all these scientific themes and more. For example, DAVINCI will provide new precise measurements of noble gases and other species in Venus' atmosphere so that we can study the evolution of Venus' atmosphere, including the history of water and what led to its "runaway greenhouse" state. DAVINCI will also be providing the first high-resolution pictures of Venus' tesserae, which are thought to be equivalent to Earth's continents. In concert with the global high-resolution topography, synthetic aperture radar images, and near-infrared emissivity measurements from VERITAS, we will start to really get a handle on the nature and evolution of Venus' lithosphere, and may even find that the planet is still geologically and tectonically active.

I'm also extremely proud that NASA will be making a substantial contribution to ESA's EnVision mission. As part of the mission's comprehensive payload, aimed to provide an all-encompassing global view of the planet, we will be providing a synthetic aperture radar instrument (VenSAR) that will operate at complementary wavelengths to VERITAS' InSAR. We will also be providing Deep Space Network support for the mission as well as funding for some U.S. scientists working on the mission. VenSAR will make targeted high-resolution observations of the surface that complement EnVision's Subsurface Radar Sounder (SRS) and VenSpec, a suite of spectroscopy instruments.

More than just being excited about the science that these missions will yield, I'm aware that by selecting three missions to visit the same planet in a short timeframe, we are investing in people and our community. By creating this major, renewed, focus in planetary science, we have the opportunity now to build the Venus community — engineers and scientists — for the next generation(s). In addition, by having Venus missions from NASA and ESA (as well as the ongoing JAXA Akatsuki mission and the planned 2024 Shukrayaan-1 Venus mission from the Indian Space Research Organisation), we have the chance to create an international, diverse, and sustainable community who will continue to drive the exploration of Venus for many decades.

I also want to acknowledge the hard work of the two mission teams — IVO and TRIDENT — that were not selected this time in the Discovery Program. In an ideal world, we would have the resources to select all the worthy missions, these two included. Working in planetary science and exploration is not for the faint of heart, and I know firsthand how hard it is when something you pour your sweat and soul into for years (or decades) is over in a moment. I hope that those of you who are disappointed after the Discovery selections are finding ways to stay positive. I hope that you will continue working to make your dreams a reality — never giving up and never surrendering. Meanwhile, I hope that you can also celebrate your colleagues' success. After all, the endeavor of exploring space is a community-wide process. No one person can do it alone. As researchers, we are all driven by our individual curiosities and goals, but when I step back and remember why I originally became a planetary scientist, it wasn't about a specific question or a specific place; it was about looking up at the sky, wondering what is out there, and how human ingenuity can take us there.

2021 ANNUAL MEETING OF PLANETARY GEOLOGIC MAPPERS



The Annual Meeting of Planetary Geologic Mappers (PGM) was held virtually on June 14–15, 2021. As in previous years, this meeting provided the opportunity for NASA-funded investigators to give an update on their progress towards completing their geologic maps that will be published by the U.S. Geological Survey (USGS). The meeting was also attended by community members who conduct geologic mapping outside of the USGS review and publication process.

Thanks to the virtual aspect of the meeting this year, we were fortunate to have 35 participants from outside the United States (27 of whom were from Europe), with a total of 115 attendees. Much of the meeting was devoted to 10-minute presentations related to mapping on many planetary bodies, including Mercury, Venus, the Moon, Mars, Io, Europa, Titan, Triton, Dione, Ceres, Pluto, and Comet 67P. In addition, participants selected for poster presentations gave a 3-minute summary of their work, with numerous discussion sessions after each set of topics.

The meeting began with an update on the NASA-USGS Planetary Geologic Mapping Program from Jim Skinner (Planetary Map Coordinator, USGS). There are 31 maps in progress, 11 in revision, and 8 in production. The number of maps in production is the highest in two decades and results in part from a revised technical review process consisting of a coordinated panel review that has sped up the review and production efforts.

Discussions beyond the scientific content of the presented maps included updates on a pair of mapping workshops. The first workshop already took place at the University of Padova, Italy. The second will be held at the University of Northern Arizona next year before the 2022 Annual Meeting of Planetary Geologic Mappers. The goal of these workshops is to introduce planetary geologic techniques to a broader community. Other meeting discussions included further updates to the crater chronology software to produce age estimates of planetary surfaces, the production of seamless controlled mosaics from CTX images, and improving the accessibility to planetary maps via web-based resources.

Next year's meeting is planned to be held in person in Flagstaff, Arizona, the week of June 20, 2022. It will be a challenge to maintain the strong participation of European investigators who benefitted from the virtual aspect of this year's meeting. At this year's meeting, the consensus was that future PGM meetings should be held as a hybrid meeting (in-person and virtual elements) to promote convenient international participation.

For more information about the 2021 Annual Meeting of Planetary Geologic Mappers, including links to the program and abstracts, visit the meeting website at www.hou.usra.edu/meetings/pgm2021/pdf/pgm2021_program.htm

— Text provided by Peter Mouginis-Mark (University of Hawaii)

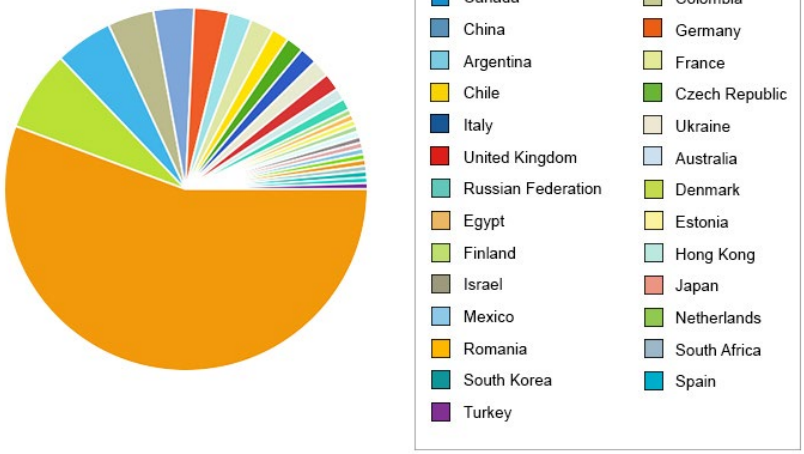
11TH PLANETARY CRATER CONSORTIUM MEETING

The 11th Planetary Crater Consortium (PCC) Meeting, hosted by the Planetary Crater Consortium and managed by the Lunar and Planetary Institute (LPI), was held on August 5–7, 2020. The annual meeting focused on the results of scientific work and had a total of 185 registrants. Thirty abstracts were accepted in five categories of presentations, and 17 print-only abstracts were accepted in four categories. The five presentation categories were Crater Populations, Surface Ages, and Crater Databases; Crater Morphology and Morphometry; Crater Ejecta and Secondaries; Terrestrial Impacts; and Crater Modification and Climate Effects. The print-only presentations were distributed among the categories Crater Morphology and Morphometry; Crater Populations, Surface Ages, and Crater Databases; Laboratory Experiments; and Terrestrial Impacts.

Presentations were given on all three days of the meeting. They included observational, theoretical, experimental, and numerical modeling studies of impact craters on planets, dwarf planets, moons, asteroids, and other small solar system objects. Each presentation had adequate time for an in-depth discussion of crater-related issues and research topics, which stimulated collaborations. There was also social time, which allowed meeting attendees to acquaint and reacquaint themselves with each other.

The PCC business meeting addressed topics such as crater naming and items for the upcoming 12th annual meeting (August 11-13, 2021). PCC members elected Kassie Martin-Wells to the Executive Council.

LPI provided the production and hosting of the meeting website (www.hou.usra.edu/meetings/crater2020/). The collaboration with LPI boosted attendance by more than a factor of three over attendance from past PCC annual meetings, giving the PCC the benefit of a much larger audience. In addition, the web meeting support sta facilitated a smooth, effortlessly-run meeting. The 11th Planetary Crater Consortium Meeting was a resounding success, and we look forward to the 12th annual meeting in August 2021.



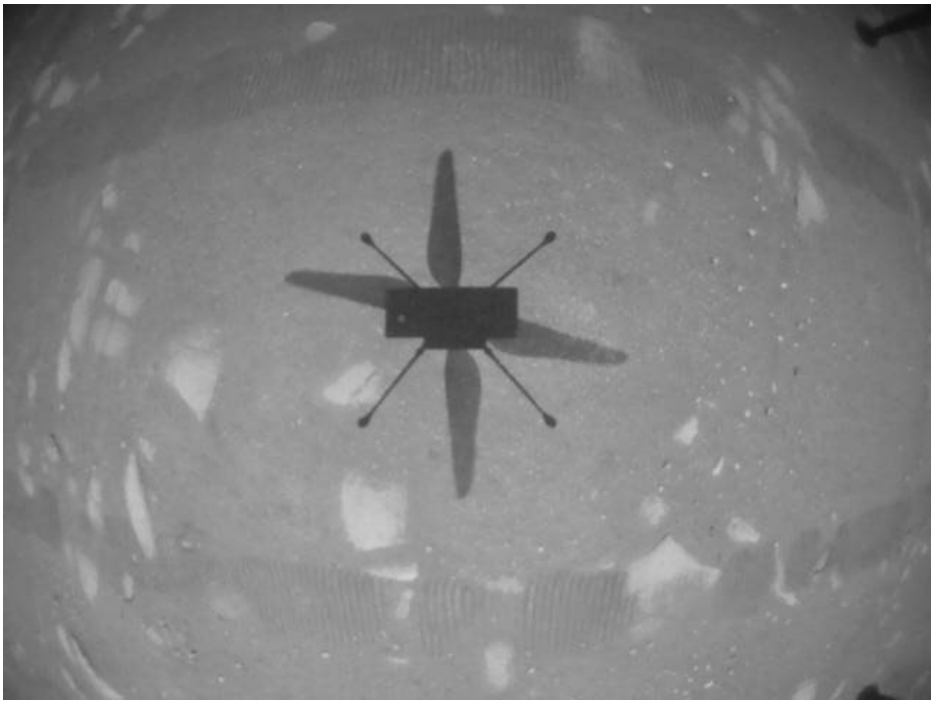
Country	No. of Registrants
United States	108
India	14
Canada	10
Colombia	8
China	7
Germany	6
Argentina	4
France	4
Chile	3
Czech Republic	3
Italy	3
Ukraine	3
United Kingdom	3
Australia	2
Russian Federation	2

Country	No. of Registrants
Denmark	1
Egypt	1
Estonia	1
Finland	1
Hong Kong	1
Israel	1
Japan	1
Mexico	1
Netherlands	1
Romania	1
South Africa	1
South Korea	1
Spain	1
Turkey	1

11th Annual PCC participation by country. Credit: USRA/Lunar and Planetary Institute.

— Text provided by the Planetary Crater Consortium Executive Committee

NASA'S INGENUITY MARS HELICOPTER SUCCEEDS IN HISTORIC FIRST FLIGHT



NASA's Ingenuity Mars Helicopter captured this shot as it hovered over the martian surface on April 19, 2021, during the first powered, controlled flight on another planet. It used its navigation camera, which autonomously tracks the ground during flight. Credit: NASA/JPL-Caltech.

On April 19, 2021, NASA's Ingenuity Mars Helicopter became the first aircraft in history to make a powered, controlled flight on another planet. The Ingenuity team at the agency's Jet Propulsion Laboratory (JPL) in southern California confirmed the flight succeeded after receiving data from the helicopter via NASA's Perseverance Mars rover at 6:46 a.m. EDT.

"Ingenuity is the latest in a long and storied tradition of NASA projects achieving a space exploration goal once thought impossible," said former acting NASA Administrator Steve Jurczyk. "The X-15 was a pathfinder for the space shuttle. Mars Pathfinder and its Sojourner rover did the same for three generations of Mars rovers. We don't know exactly where Ingenuity will lead us, but today's results indicate the sky — at least on Mars — may not be the limit."

The solar-powered helicopter first became airborne at 3:34 a.m. EDT — 12:33 Local Mean Solar Time (Mars time) — a time the Ingenuity team determined would have optimal energy and flight conditions. Altimeter data indicate Ingenuity climbed to its prescribed maximum altitude of 3 meters (10 feet) and maintained a stable hover for 30 seconds. It then descended, touching back down on the surface of Mars after logging a total of 39.1 seconds of flight. Additional details on the test are expected in upcoming downlinks.

Ingenuity's initial flight demonstration was autonomous — piloted by onboard guidance, navigation, and control systems running algorithms developed by the team at JPL. Because data must be sent to and returned from the Red Planet over hundreds of millions of kilometers using orbiting satellites and NASA's Deep Space Network, Ingenuity cannot be flown with a joystick, and its flight was not observable from Earth in real-time.

NASA Associate Administrator for Science Thomas Zurbuchen announced the name for the martian airfield on which the flight took place.

"Now, 117 years after the Wright brothers succeeded in making the first flight on our planet, NASA's Ingenuity helicopter has succeeded in performing this amazing feat on another world," Zurbuchen said. "While these two iconic moments in aviation history may be separated by time and 173 million miles of space, they now will forever be linked. As an homage to the two innovative bicycle makers from Dayton, this first of many airfields on other worlds will now be known as Wright Brothers Field, in recognition of the Ingenuity and innovation that continue to propel exploration."

Ingenuity's chief pilot, Håvard Grip, announced that the International Civil Aviation Organization (ICAO) — the United Nations' civil aviation agency — presented NASA and the Federal Aviation Administration with official ICAO designator IGY, call-sign INGENUITY.

These details will be included officially in the next edition of ICAO's publication *Designators for Aircraft Operating Agencies, Aeronautical Authorities, and*

> "We have been thinking for so long about having our Wright brothers moment on Mars, and here it is."

Services. The location of the flight has also been given the ceremonial location designation JZRO for Jezero Crater.

As one of NASA's technology demonstration projects, the 49-centimeter-tall (19.3-inch-tall) Ingenuity Mars helicopter contains no science instruments inside its tissue-box-size fuselage. Instead, the 1.8-kilogram (4-pound) rotorcraft is intended to demonstrate whether future exploration of the Red Planet could include an aerial perspective.

This first flight was full of unknowns. The Red Planet has a significantly lower gravity — one-third that of Earth's — and an extremely thin atmosphere with only 1% the pressure at the surface compared to our planet. This means there are relatively few air molecules with which Ingenuity's two 1.2-meter-wide (4-foot-wide) rotor blades can interact to achieve flight. The helicopter contains unique components, as well as off-the-shelf-commercial parts — many from the smartphone industry — that were tested in deep space for the first time with this mission.

"The Mars Helicopter project has gone from 'blue sky' feasibility study to workable engineering concept to achieving the first flight on another world in a little over six years," said Michael Watkins, director of JPL. "That this project has achieved such a historic first is testimony to the innovation and doggedness of our team here at JPL, as well as at NASA's Langley and Ames Research Centers, and our industry partners. It's a shining example of the kind of technology push that thrives at JPL and fits well with NASA's exploration goals."

Parked about 64.3 meters (211 feet) away at Van Zyl Overlook during Ingenuity's historic first flight, the Perseverance rover not only acted as a communications relay between the helicopter and Earth but also chronicled the flight operations with its cameras. The pictures from the rover's Mastcam-Z and Navcam imagers will provide additional data on the helicopter's flight.

"We have been thinking for so long about having our Wright brothers moment on Mars, and here it is," said MiMi Aung, project manager of the Ingenuity Mars Helicopter at JPL. "We will take a moment to celebrate our success and then take a cue from Orville and Wilbur regarding what to do next. History shows they got back to work — to learn as much as they could about their new aircraft — and so will we."

For more information about Ingenuity, visit go.nasa.gov/ingenuity-press-kit.

NASA'S PERSEVERANCE MARS ROVER EXTRACTS FIRST OXYGEN FROM RED PLANET

The growing list of firsts for Perseverance, NASA's newest six-wheeled robot on the martian surface, includes converting some of the Red Planet's thin, carbon dioxide-rich atmosphere into oxygen. A toaster-size experimental instrument aboard Perseverance called the Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) accomplished the task. The test took place April 20, 2021, the 60th martian day, or sol, since the mission landed on February 18. While the technology demonstration is just getting started, it could pave the way for science fiction to become science fact — isolating and storing oxygen on Mars to help power rockets that could lift astronauts off the planet's surface. Such devices also might one day provide breathable air for astronauts themselves. MOXIE is an exploration technology investigation — as is the Mars Environmental Dynamics Analyzer (MEDA) weather station — and is sponsored by NASA's Space Technology Mission Directorate (STMD) and Human Exploration and Operations Mission Directorate.

"This is a critical first step at converting carbon dioxide to oxygen on Mars," said Jim Reuter, associate administrator for STMD. "MOXIE has more work to do, but the results from this technology demonstration are full of promise as we move toward our goal of one day seeing humans on Mars. Oxygen isn't just the stuff we breathe. Rocket propellant depends on oxygen, and future explorers

Technicians at NASA's Jet Propulsion Laboratory lower the Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) instrument into the belly of the Perseverance rover. Credit: NASA/JPL-Caltech.

will depend on producing propellant on Mars to make the trip home."

For rockets or astronauts, oxygen is key, said MOXIE's principal investigator, Michael Hecht of the Massachusetts Institute of Technology's Haystack Observatory.

To burn its fuel, a rocket must have more oxygen by weight. Getting four astronauts off the martian surface on a future mission would require approximately 7 metric tons (15,000 pounds) of rocket fuel and 25 metric tons (55,000 pounds) of oxygen. In contrast, astronauts living and working on Mars would require far less oxygen to breathe. "The astronauts who spend a year on the surface will maybe use one metric ton between them," Hecht said.

Hauling 25 metric tons of oxygen from Earth to Mars would be an arduous task. Transporting a 1-ton oxygen converter — a larger, more powerful descendant of MOXIE that could produce those 25 tons — would be far more economical and practical.

Mars' atmosphere is 96% carbon dioxide. MOXIE works by separating oxygen atoms from carbon dioxide molecules, which are made up of one carbon atom and two oxygen atoms. A waste product, carbon monoxide, is emitted into the martian atmosphere.

The conversion process requires high levels of heat to reach a temperature of approximately 800°C (1470°F). To accommodate this, the MOXIE unit is made with heat-tolerant materials. These include 3D-printed nickel alloy parts, which heat and cool the gases flowing through it, and a lightweight aerogel that helps hold in the heat. A thin gold coating on the outside of MOXIE reflects infrared heat, keeping it from radiating outward and potentially damaging other parts of Perseverance.

In this first operation, MOXIE's oxygen production was quite modest — about 5 grams, equivalent to about 10 minutes worth of breathable oxygen for an astronaut. MOXIE is designed to generate up to 10 grams of oxygen per hour.

This technology demonstration was designed to ensure the instrument survived the launch from Earth, a nearly seven-month journey through deep space, and touchdown with Perseverance on February 18, 2021. MOXIE is expected to extract oxygen at least nine more times over the course of a martian year (nearly two years on Earth).

These oxygen-production runs will come in three phases. The first phase will check out and characterize the instrument's function, while the second phase will run the instrument in varying atmospheric conditions, such as different times of day and seasons. In the third phase, Hecht said, "we'll push the envelope" — trying new operating modes, or introducing "new wrinkles, such as a run where we compare operations at three or more different temperatures."

"MOXIE isn't just the first instrument to produce oxygen on another world," said Trudy Kortes, director of technology demonstrations within STMD. It's the first technology of its kind that will help future missions "live off the land," using elements of another world's environment, also known as in situ resource utilization.

"It's taking regolith, the substance you find on the ground, and putting it through a processing plant, making it into a large structure, or taking carbon dioxide — the bulk of the atmosphere — and converting it into oxygen," she said. "This process allows us to convert these abundant materials into useable things: propellant, breathable air, or, combined with hydrogen, water."

For more about Perseverance, visit mars.nasa.gov/mars2020/.

METHANE IN THE PLUMES OF SATURN'S MOON ENCELADUS — POSSIBLE SIGNS OF LIFE?

An unknown methane-producing process is likely at work in the hidden ocean beneath the icy shell of Saturn's moon Enceladus, suggests a new study published in *Nature Astronomy* by scientists at the University of Arizona and Université Paris Sciences et Lettres. Giant water plumes erupting from Enceladus have long fascinated scientists and the public alike, inspiring research and speculation about the vast ocean that is believed to be sandwiched between the moon's rocky core and its icy shell. Flying through the plumes and sampling their chemical makeup, the Cassini spacecraft detected a relatively high concentration of certain molecules associated with hydrothermal vents on the bottom of Earth's oceans, specifically dihydrogen, methane, and carbon dioxide. The amount of methane found in the plumes was particularly unexpected.

"We wanted to know: Could Earth-like

This artist's impression depicts NASA's Cassini spacecraft flying through a plume of presumed water erupting from the surface of Saturn's moon Enceladus. Credit: NASA.

microbes that 'eat' the dihydrogen and produce methane explain the surprisingly large amount of methane detected by Cassini?" said Regis Ferriere, an associate professor in the University of Arizona Department of Ecology and Evolutionary Biology and one of the study's two lead authors. "Searching for such microbes, known as methanogens, at Enceladus' seafloor would require extremely challenging deep-dive missions that are not in sight for several decades."

Ferriere and his team took a different, easier route. They constructed mathematical models to calculate the probability that different processes, including biological methanogenesis, might explain the Cassini data.

The authors applied new mathematical models that combine geochemistry and microbial ecology to analyze Cassini plume data and model the possible processes that would best explain the observations. They conclude that Cassini's data are consistent with microbial hydrothermal vent activity or processes that do not involve life forms but are different from those known to occur on Earth.

On Earth, hydrothermal activity occurs when cold seawater seeps into the ocean floor, circulates through the underlying rock, and passes close by a heat source, such as a magma chamber, before spewing out into the water again through hydrothermal vents. On Earth, methane can be produced through hydrothermal activity, but at a slow rate. Most of the production is due to microorganisms that harness the chemical disequilibrium of hydrothermally produced dihydrogen as a source of energy and produce methane from carbon dioxide in a process called methanogenesis.

The team looked at Enceladus' plume composition as the end result of several chemical and physical processes taking place in the moon's interior. First, the researchers assessed what hydrothermal production of dihydrogen would best fit Cassini's observations and whether this production could provide enough "food" to sustain a population of Earth-like hydrogenotrophic methanogens. To do that, they developed a model for the population dynamics of a hypothetical hydrogenotrophic methanogen, whose thermal and energetic niche was modeled after known strains from Earth.

The authors then ran the model to see whether a given set of chemical conditions, such as the dihydrogen concentration in the hydrothermal fluid, would provide a suitable environment for these microbes to grow. They also looked at what effect a hypothetical microbe population would have on its environment — for example, on the escape rates of dihydrogen and methane in the plume.

"In summary, not only could we evaluate whether Cassini's observations are compatible with an environment habitable for life, but we could also make quantitative predictions about observations to be expected, should methanogenesis actually occur at Enceladus' seafloor," Ferriere explained.

The results suggest that even the highest possible estimate of abiotic methane production — or methane production without biological aid — based on known hydrothermal chemistry is far from sufficient to explain the methane concentration measured in the plumes. Adding biological methanogenesis to the mix, however, could produce enough methane to match Cassini's observations.

"Obviously, we are not concluding that life exists in Enceladus' ocean," Ferriere said. "Rather, we wanted to understand how likely it would be that Enceladus' hydrothermal vents could be habitable to Earth-like microorganisms. Very likely, the Cassini data tell us, according to our models. And biological methanogenesis appears to be compatible with the data. In other words, we can't discard the 'life hypothesis' as highly improbable. To

reject the life hypothesis, we need more data from future missions," he added.

The authors hope their paper provides guidance for studies aimed at better understanding the observations made by Cassini and that it encourages research to elucidate the abiotic processes that could produce enough methane to explain the data.

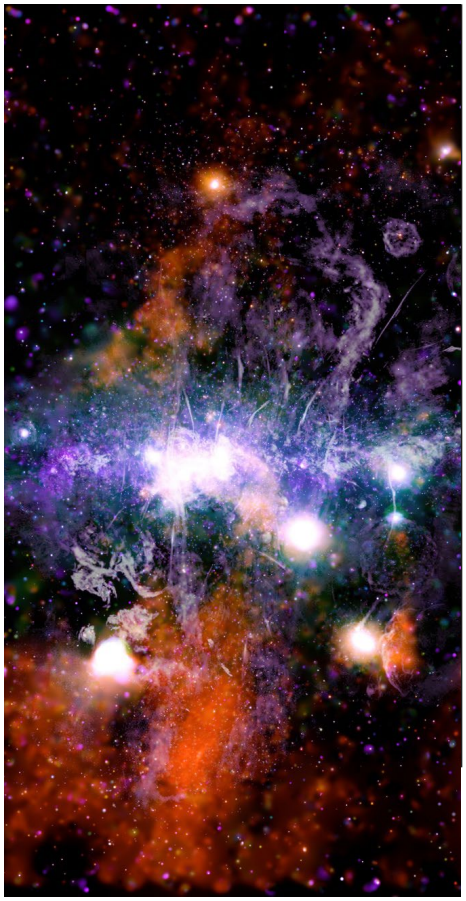
For example, methane could come from the chemical breakdown of primordial organic matter that may be present in Enceladus' core, and that could be partially turned into dihydrogen, methane, and carbon dioxide through the hydrothermal process. This hypothesis is very plausible if it turns out that Enceladus formed through the accretion of organic-rich material supplied by comets, Ferriere explained.

"It partly boils down to how probable we believe different hypotheses are to begin with," he said. "For example, if we deem the probability of life in Enceladus to be extremely low, then such alternative abiotic mechanisms become much more likely, even if they are very alien compared to what we know here on Earth."

According to the authors, a very promising advance of the paper lies in its methodology. It is not limited to specific systems such as interior oceans of icy moons and paves the way to deal with chemical data from planets outside the solar system as they become available in the coming decades.

A full list of authors and funding information can be found in the paper, "Bayesian analysis of Enceladus's plume data to assess methanogenesis," in the July 7, 2021, issue of *Nature Astronomy*.

CHANDRA X-RAY OBSERVATORY REVEALS NEVER-BEFORE-SEEN DETAIL OF VIOLENT ENERGY AT THE CENTER OF OUR GALAXY



New research by University of Massachusetts (UMass) Amherst astronomer Daniel Wang reveals details of violent phenomena in the center of our galaxy with unprecedented clarity. The images, published recently in Monthly Notices of the Royal Astronomical Society, document an X-ray thread, G0.17-0.41, which hints at a previously unknown interstellar mechanism that may govern the energy flow and potentially the evolution of the Milky Way.

"The galaxy is like an ecosystem," says Wang, a professor in UMass Amherst's astronomy department, whose findings are a result of more than two decades of research. "We know the centers of galaxies are where the action is and play an enormous role in their evolution." And yet, whatever has happened in the center of our galaxy is hard to study, despite its relative proximity to Earth, because, as Wang explains, it is obscured by a dense fog of gas and dust. Researchers can't see the center, even with an instrument as powerful as the famous Hubble Space Telescope. Wang, however, has used a different telescope, NASA's Chandra X-Ray Observatory, which "sees" X-rays rather than the rays of visible light that we perceive with our own eyes. These X-rays are capable of penetrating the obscuring fog — and the results are stunning.

Wang's findings, which were supported by NASA, give the clearest picture yet of a pair of X-ray-emitting plumes that are emerging from the region near the massive black hole lying at the center of our galaxy. Even more intriguing is the discovery of an X-ray thread called G0.17-0.41, located near the southern plume. "This thread reveals a new phenomenon," says Wang. "This is evidence of an ongoing magnetic field reconnection event." The thread, writes Wang, probably represents "only the tip of the reconnection iceberg."

Threads of superheated gas and magnetic fields are weaving a tapestry of energy at the center of the Milky Way galaxy, seen in this composite X-ray and radio wavelength image of the X-ray thread G0.17-0.41. The image is about 1000 light-years across and 2000 light-years long. Credit: NASA/CXC/UMass/Q.D.Wang; NRF/SARAO/MeerKAT.

A magnetic field reconnection event happens when two opposing magnetic fields are forced together and combine, releasing an enormous amount of energy. "It's a violent process," says Wang, and is known to be responsible for such well-known phenomena as solar flares, which produce space weather powerful enough to disrupt power grids and communications systems here on Earth. They also produce the spectacular northern lights. Scientists now think that magnetic reconnection also occurs in interstellar space and tends to take place at the outer boundaries of the expanding plumes driven out of our galaxy's center.

"What is the total amount of energy outflow at the center of the galaxy? How is it produced and transported? And how does it regulate the galactic ecosystem?" These are the fundamental questions whose answers will help to unlock the history of our galaxy, says Wang. Although much work remains to be done, Wang's new map points the way.

For more information, including additional images and video, visit https://chandra.harvard.edu/.

LIFE COULD EXIST IN THE CLOUDS OF JUPITER BUT NOT VENUS

Jupiter's clouds have water conditions that would allow Earth-like life to exist, but this isn't possible in Venus' clouds, according to groundbreaking new research led by a Queen's University Belfast scientist.

For decades, space exploration missions have looked for evidence of life beyond Earth where we know that large bodies of water, such as lakes or oceans, exist or have previously existed. However, the new research shows that it isn't the quantity of water that matters for making life viable, but the effective concentration of water molecules — known as water activity.

The new study also found that research published by an independent team of scientists last year, claiming that the phosphine gas in Venus' atmosphere indicates possible life in the sulphuric acid clouds of Venus, is not plausible.

This illustration of stormy clouds on Jupiter is based on images from the Stellar Reference Unit camera of NASA's Juno mission. Credit: NASA/JPL-Caltech/SwRI/MSSS/Gerald Eichstädt/Heidi N. Becker/Koji Kuramura.

Through this innovative research project, Dr. John E. Hallsworth from the School of Biological Sciences at Queen's and his team of international collaborators devised a method to determine the water activity of atmospheres of a planet. Using their approach to study the sulphuric acid clouds of Venus, the researchers found that the water activity was more than a hundred times below the lower limit at which life can exist on Earth.

The research also shows that Jupiter's clouds have a high enough concentration of water, as well as the correct temperature, for life to exist there. The study has been published in *Nature Astronomy*.

Hallsworth said, "Our research shows that the sulphuric acid clouds in Venus have too little water for active life to exist, based on what we know of life on Earth. We have also found that the conditions of water and temperature within Jupiter's clouds could allow microbial-type life to subsist, assuming that other requirements such as nutrients are present. This is a timely finding given that NASA and the European Space Agency just announced three missions to Venus in the coming years. One of these will take measurements of Venus' atmosphere that we will be able to compare with our finding."

Dr. Philip Ball, a co-author of the report and an expert on the physics and chemical biology of water, commented, "The search for extraterrestrial life has sometimes been a bit simplistic in its

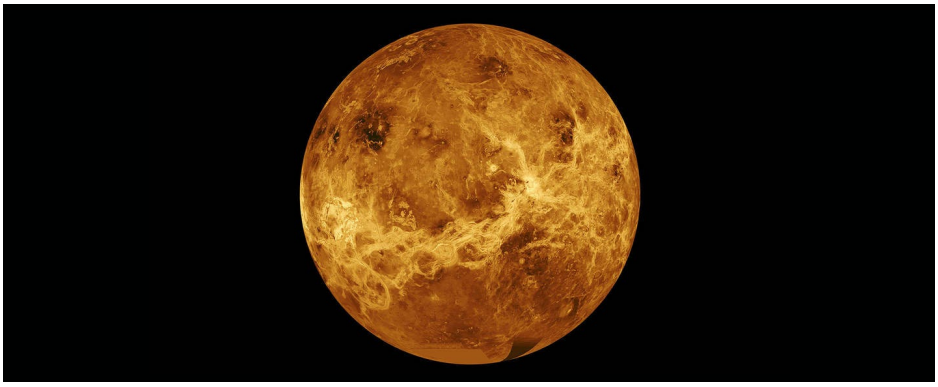
attitude to water. As our work shows, it's not enough to say that liquid water equates with habitability. We've got to think too about how Earth-like organisms actually use it — which shows us that we then have to ask how much of the water is actually available for those biological uses."

NASA-based planetary scientist Dr. Christopher P. McKay, another co-author of the report, said, "We derive water activity of atmospheres without a model of any sort, based only on direct observations of pressure, temperature, and water concentration."

Hallsworth added, "We have also performed calculations for Mars and Earth and show that these calculations can be done for planets outside our solar system. While our research doesn't claim that alien (microbial-type) life does exist on other planets in our solar system, it shows that if the water activity and other conditions are right, then such life could exist in places where we haven't previously been looking."

NASA SELECTS TWO MISSIONS TO STUDY THE LOST HABITABLE WORLD OF VENUS

NASA has selected two new missions to Venus, Earth's nearest planetary neighbor. Part of NASA's Discovery Program, the missions aim to understand how Venus became an inferno-like world when it has so many other characteristics similar to ours — and may have been the first habitable world in the solar system, complete with an ocean and Earth-like climate.



Venus hides a wealth of information that could help us better understand Earth and exoplanets. NASA's JPL is designing mission concepts to survive the planet's extreme temperatures and atmospheric pressure. This image is a composite of data from NASA's Magellan spacecraft and Pioneer Venus Orbiter. Credit: NASA/JPL-Caltech.

These investigations are the final selections from four mission concepts NASA picked in February 2020 as part of the agency's Discovery 2019 competition. Following a competitive, peer-review process, the two missions were chosen based on their potential scientific value and the feasibility of their development plans. The project teams will now work to finalize their requirements, designs, and development plans.

NASA is awarding approximately $500 million per mission for development. Each is expected to launch in the 2028–2030 timeframe.

The selected missions are:

DAVINCI (Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging)

DAVINCI will measure the composition of Venus' atmosphere to understand how it formed and evolved and determine whether the planet ever had an ocean. The mission consists of a descent sphere that will plunge through the planet's thick atmosphere, making precise measurements of noble gases and other elements to understand why Venus' atmosphere is a runaway hothouse compared to Earth's.

In addition, DAVINCI will return the first high-resolution pictures of the unique geological features on Venus known as "tesserae," which may be comparable to Earth's continents, suggesting that Venus has plate tectonics. This would be the first U.S.-led mission to Venus' atmosphere since 1978, and the results from DAVINCI could reshape our understanding of terrestrial planet formation in our solar system and beyond. James Garvin of Goddard Space Flight Center in Greenbelt, Maryland, is the principal investigator. Goddard provides project management.

VERITAS (Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy)

VERITAS will map Venus' surface to determine the planet's geologic history and understand why it developed so differently from Earth. Orbiting Venus with a synthetic aperture radar, VERITAS will chart surface elevations over nearly the entire planet to create 3D reconstructions of topography and confirm whether processes such as plate tectonics and volcanism are still active on Venus.

VERITAS also will map infrared emissions from Venus' surface to map its rock type, which is largely unknown, and determine whether active volcanoes are releasing water vapor into the atmosphere. Suzanne Smrekar of NASA's Jet Propulsion Laboratory in southern California is the principal investigator. JPL provides project management. The German Aerospace Center will provide the infrared mapper with the Italian Space Agency and France's Centre National d'Etudes Spatiales contributing to the radar and other parts of the mission.

"We're revving up our planetary science program with intense exploration of a world that NASA hasn't visited in over 30 years," said Thomas Zurbuchen, NASA's associate administrator for science. "Using cutting-edge technologies that NASA has developed and refined over many years of missions and technology programs, we're ushering in a new decade of Venus to understand how an Earth-like planet can become a hothouse. Our goals are profound. It is not just understanding the evolution of planets and habitability in our own solar system, but extending beyond these boundaries to exoplanets, an exciting and emerging area of research for NASA."

Zurbuchen added that he expects powerful synergies across NASA's science programs, including the James Webb Space Telescope. He anticipates data from these missions will be used by the broadest possible cross-section of the scientific community.

"It is astounding how little we know about Venus, but the combined results of these missions will tell us about the planet from the clouds in its sky through the volcanoes on its surface all the way down to its very core," said NASA scientist Tom Wagner, who leads the Discovery Program. "It will be as if we have rediscovered the planet."

In addition to the two missions, NASA selected a pair of technology demonstrations to fly along with them. VERITAS will host the Deep Space Atomic Clock-2, built by JPL and funded by NASA's Space Technology Mission Directorate. The ultra-precise clock signal generated with this technology will ultimately help enable autonomous spacecraft maneuvers and enhance radio science observations.

DAVINCI will host the Compact Ultraviolet to Visible Imaging Spectrometer (CUVIS) built by Goddard. CUVIS will make high-resolution measurements of ultraviolet light using a new instrument based on freeform optics. These observations will be used to determine the nature of the unknown ultraviolet absorber in Venus' atmosphere that absorbs up to half the incoming solar energy.

Established in 1992, NASA's Discovery Program has supported the development and implementation of over 20 missions and instruments. These selections are part of the ninth Discovery Program competition.

For more information about NASA planetary science, visit www.nasa.gov/solarsystem.

VOLCANOES ON MARS COULD BE ACTIVE, RAISING THE POSSIBILITY OF RECENT HABITABLE CONDITIONS

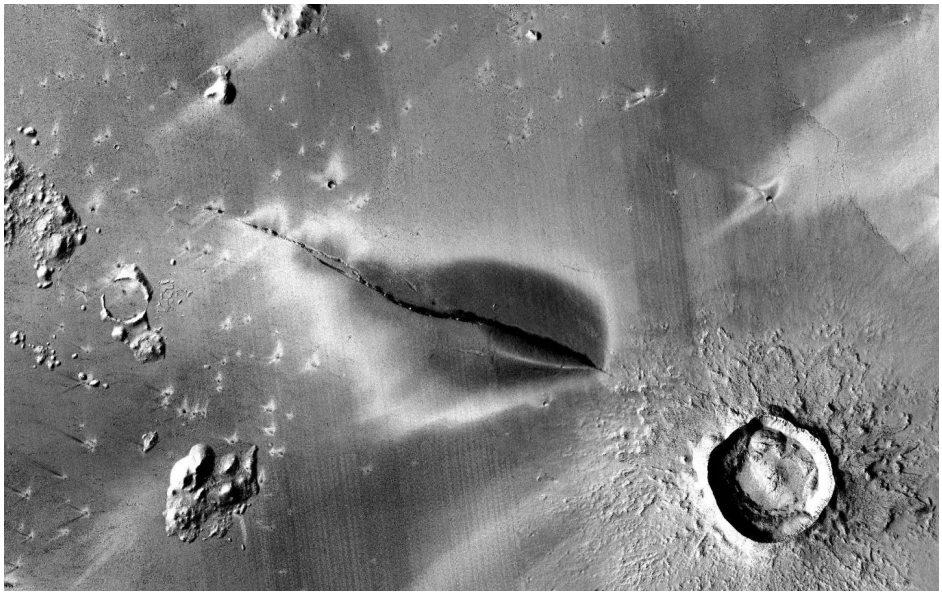
Evidence of recent volcanic activity on Mars shows that eruptions could have taken place within the past 50,000 years, says a paper by Planetary Science Institute Research Scientist David Horvath.

Most volcanism on the Red Planet occurred between 3 and 4 billion years ago, with smaller eruptions in isolated locales continuing perhaps as recently as 3 million years ago. But, until now, there was no evidence to indicate whether Mars could still be volcanically active.

Using data from satellites orbiting Mars, the research team found evidence of an eruption in a region called Elysium Planitia that would be the youngest known volcanic eruption on Mars, said Horvath, lead author on "Evidence for geologically recent explosive volcanism in Elysium Planitia, Mars" that appears in the September 2021 issue of *Icarus*.

"This feature is a mysterious dark deposit, covering an area slightly larger than Washington, DC. It has a high thermal inertia, includes high-calcium pyroxene-rich material, and is distributed symmetrically around a segment of the Cerberus Fossae fissure system in Elysium Planitia, atypical of aeolian, or wind-driven, deposits in the region. This feature is similar to dark spots on the Moon and Mercury suggested to be explosive volcanic eruptions," Horvath said. "This may be the youngest volcanic deposit yet documented on Mars. If

"The young age of this deposit absolutely raises the possibility that there could still be volcanic activity on Mars."



Recent explosive volcanic deposit around a fissure of the Cerberus Fossae system. Credit: NASA/JPL/MSSS/ The Murray Lab.

we were to compress Mars geologic history into a single day, this would have occurred in the very last second."

The majority of volcanism in the Elysium Planitia region and elsewhere on Mars consists of lava flowing at the surface, though there are numerous examples of explosive volcanism on Mars. However, this deposit appears to be different. "This feature overlies the surrounding lava flows and appears to be a relatively fresh deposit of ash and rock, representing a different style and time period of eruption than previously identified pyroclastic features," Horvath said. "This eruption could have spewed ash as high as 10 kilometers into the martian atmosphere, but likely represents a last gasp of erupted material. Elysium Planitia hosts some of the youngest volcanism on Mars, dating around 3 million years ago, so it is not entirely unexpected. It is possible that these sorts of deposits were more common but have been eroded or buried."

The site of the recent eruption is about 1600 kilometers (1000 miles) from NASA's InSight lander, which has been studying tectonic activity on Mars since 2018. Two marsquakes have been localized to the region around the Cerberus Fossae, and recent work has suggested the possibility that these could be due to the movement of magma at depth.

"The young age of this deposit absolutely raises the possibility that there could still be volcanic activity on Mars, and it is intriguing that recent marsquakes detected by the InSight mission are sourced from the Cerberus Fossae," Horvath said. "However, sustaining magma near the surface of Mars so late in Mars history with no associated lava flows would be difficult, and thus a deeper magmatic source would likely be required to create this eruption."

A volcanic deposit such as this also raises the possibility for habitable conditions in the near-surface of Mars in recent history, says Horvath. "The interaction of ascending magma and the icy substrate of this region could have provided favorable conditions for microbial life fairly recently and raises the possibility of extant life in this region."

Horvath's work on the research took place when he was a postdoctoral researcher at the University of Arizona's Lunar and Planetary Laboratory. He is now a Research Scientist at the Planetary Science Institute.

ASTRONOMERS DISCOVER FOUR NEW "HOT JUPITERS"

An international team of space scientists has discovered four new "hot Jupiters" in our galaxy.

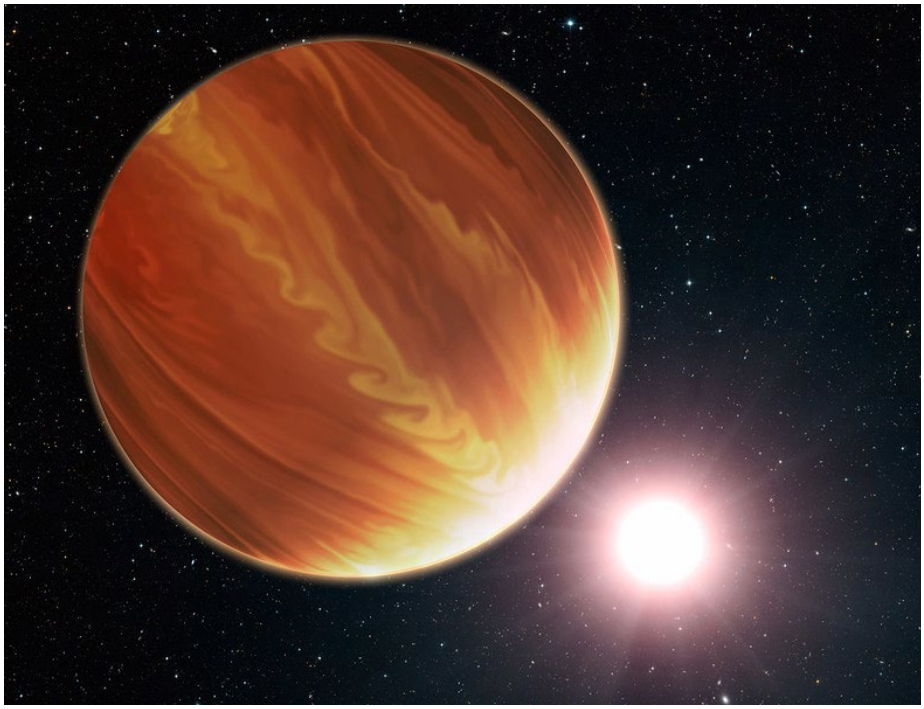
University of Leicester Ph.D. researcher Rosanna Tilbrook led and co-authored the study alongside colleagues in the UK, Switzerland, Chile, Germany, the USA, and South Africa.

Their research discovered four new exoplanets — NGTS-15b, NGTS-16b, NGTS-17b, and NGTS-18 — between 2500 and 3500 light-years away from Earth using the Next Generation Transit Survey telescope.

All four exoplanets orbit Sun-like stars but have short orbital lengths of less than five Earth days, and therefore experience temperatures of around 1000°C (1832°F). Planets such as these are dubbed "hot Jupiters" due to their massive size and proximity to their host star.

Observations show that three of the four exoplanets (NGTS-16b, NGTS-17b, and NGTS-18) could be between 8–12 billion years old — more than 3–7 billion years older than Earth.

Each so-called "hot Jupiter" receives



This artist's impression shows NGTS-15b, one of the newly discovered "hot Jupiters". Credit: NASA, ESA, and G. Bacon (STScI).

enough energy from its star that it should be "inflated" — the term for when the radius of the planet is larger than astronomers would otherwise expect.

Research lead and Ph.D. researcher in astrophysics Rosanna Tilbrook said, "Inflated planets are mysterious — we don't know exactly how inflation works, but we do know that in general, the most highly irradiated planets will be the most inflated. In this case, three of the planets show signs of inflation, but nothing can be said for sure about NGTS-15b. This is because it's very difficult to pin down the age of NGTS-15b."

"We think that the mysteries of inflation might be uncovered by updating current scientific models of these planets, which currently only look at the relationships between energy, mass, and radius, and don't account for a range of other factors which are believed to play an important role in planet inflation. Other interesting properties include what the planets are made of and whether they may have spiraled closer towards their sun with time."

Professor Emma Bunce is head of the University of Leicester's School of Physics and Astronomy and President of the Royal Astronomical Society. She said, "This is a fascinating discovery which furthers our understanding of worlds beyond our own, and serves as an important example of the critical contribution our post-graduate researchers make to the overall research program in our school, and at the university more generally.

"With the first phase of our Space Park Leicester development set to open this summer, I am excited to see our researchers continuing to lead across a variety of areas in the space sciences, from astrophysical observations of distant objects like these, through to advancing our understanding of our own planet Earth and the wider solar system."

"NGTS 15b, 16b, 17b, and 18b: Four hot Jupiters from the Next Generation Transit Survey" is an accepted manuscript in *The Monthly Notices of the Royal Astronomical Society*.

STILL TAKING GIANT LEAPS FROM LUNAR SMALL STEPS — PURDUE SCIENTISTS ANALYZE MOON DUST COLLECTED BY APOLLO 17 ASTRONAUTS

Humans have not set foot on the Moon for nearly 50 years, but the Apollo Moon missions aren't over. The echoes from Neil Armstrong's first steps are still helping scientists make giant leaps in understanding the Moon's geology.

When the Apollo 17 astronauts packed up for home in 1972, they brought rock samples with them. NASA locked many of the rocks and core samples away in a vault, awaiting technological innovations that would allow future scientists to study them better than 1970s technology allowed.

Now, Purdue University scientists Michelle Thompson and Marc Caffee are working on teams that will analyze

some of the Moon rocks and lunar soil samples from that mission. Thompson is an assistant professor of Earth, Atmospheric, and Planetary Sciences in Purdue's College of Science. Caffee is a professor of Physics and Astronomy with a courtesy appointment in the Department of Astronomy and Physics.

Thompson and her team are partnering with some of the original scientists, including Harrison "Jack" Schmitt, the first and only geologist ever to walk on the Moon, to learn more about the Moon itself through the rock samples.

"When these samples were collected, when men walked on the Moon, I hadn't even been born yet," Thompson said. "This sample has been on Earth longer than I have. It has been sitting in storage, waiting for scientists to analyze it since it was returned. Scientists now have tools and technologies that the original generation of astronauts could only dream of. So now it's our turn to follow in their footsteps and study the Moon rocks they brought back."

The Apollo Next Generation Sample Analysis Program (ANGSA) is only possible because much of the more than 381 kilograms (840 pounds) of Moon rocks and dust has been kept pristine for nearly half a century. Now, scientists believe they have even better tools that are more sensitive, allowing them to study the samples comprehensively.

Thompson is an expert in the way rocks interact with and change due to their exposure to the vacuum of space — a phenomenon called space weathering. Analyzing the chemistry of Moon rocks and Moon dust can tell her about the environment, evolution, and history of the Moon.

Thompson is studying a lunar core sample, a small column of Moon dust extracted from the lunar surface by Apollo 17 astronauts Schmitt and Eugene Cernan, a Purdue alum. It comes from a part of the Moon that may have experienced an avalanche, giving even deeper insight into the distribution of minerals and the chemistry of the Moon. Thompson is hoping that they will be able to understand what the surface of the Moon was like before and after the avalanche, gaining greater knowledge of how the Moon's soil, or regolith, has developed over time.

Harrison "Jack" Schmitt was the only geologist to walk on the Moon. Some of the samples he collected have been preserved for nearly 50 years and are now being studied with modern sample analysis techniques. Credit: NASA.

The samples are tiny to the naked eye. Originally a column of dust about 60 centimeters (24 inches) long, the lunar core has been sealed in the same metal tube it was placed in after Cernan and Schmitt extracted it from the Moon. Thompson and her graduate student, James McFadden, traveled to NASA's Johnson Space Center in Houston, where the sample is stored, to help safely separate the material into several smaller samples from different depths of the core.

Thompson and her team are analyzing the lunar dust, tiny grains of mineral that she describes as "sticking to absolutely everything." Understanding the chemistry and structure of this material, which coats astronauts' suits and vehicles as well as shelters and solar panels, will be vital for any long-term Moon base plans. The dust coats the lids of the sample containers and sticks to everything it touches. The only way to study it is through chemistry and studying its microstructure using tools including electron microscopes.

Caffee is studying another aspect of the lunar core sample in a joint project with the University of California, Santa Barbara. Researchers will dissolve minute quantities of the Moon dust and send elements isolated by this process to Caffee. Caffee will study radionuclides to determine how cosmic radiation has interacted with the Moon.

Cosmic rays permeate the whole galaxy; they are usually made up of protons accelerated in supernovae explosions. When these energetic cosmic rays collide with the elements comprising rocks or an atmosphere, they liberate a massive secondary cascade of particles that ultimately produce

> **“One of the reasons that they archived these cores is that 50 years after the missions were done, they knew we would have much better analytical techniques.”**

stable and radionuclides, referred to as cosmogenic nuclides. Cosmogenic nuclides occur in meteorites, lunar samples, and terrestrial rocks.

“For us cosmogenic scientists, the lunar cores are like a holy grail,” Caffee said. “We love lunar cores because they have so much they can teach us about radionuclide production rates, solar activity, and the depositional history of the core itself. We can use them to calibrate production rates of radionuclides on Earth, which is extremely useful to us.”

Although initially focused on exploration and testing technologies, much of the later research on the Moon related to geology and exploration of the Moon’s surface. The last lunar missions, Apollo 15, 16, and 17, all brought lunar rovers along to cover more area and get Moon rocks and regolith from different geographic regions. Apollo 17 put a geologist on the Moon.

“These astronauts, these guys were good,” Caffee said. “They were trained by geologists, and of course, Schmitt is a geologist. Having geologists on the lunar surface was extremely important because they recognized patterns and features. They were able to make informed decisions about where the best and most useful places to take samples would be. I think they recognized that this core was near a landslide, and we’re really curious to see what it looks like.”

Caffee had just started studying lunar geology after the Apollo missions returned to Earth. He recalls that early analysis of samples required a large amount of dust or rocks to get significant and accurate results.

“One of the reasons that they archived these cores is that 50 years after the missions were done, they knew we would have much better analytical techniques,” Caffee said. “Now we can get the same, or better, results using only milligrams of material, meaning we can do so much more research than they would have been able to using the same rocks.”

SCIENTISTS MODEL SATURN’S INTERIOR

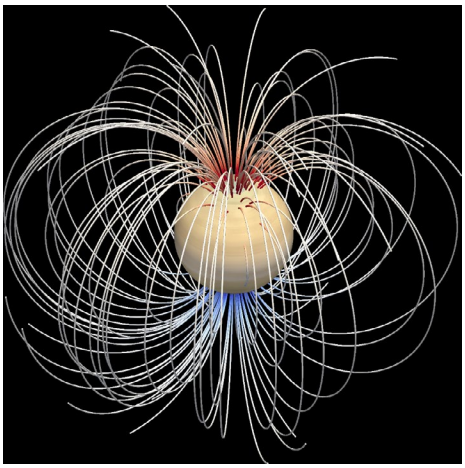
New Johns Hopkins University simulations offer an intriguing look into Saturn’s interior, suggesting that a thick layer of helium rain influences the planet’s magnetic field.

The models, published in *AGU Advances*, also indicate that Saturn’s interior may feature higher temperatures at the equatorial region, with lower temperatures at the high latitudes at the top of the helium rain layer.

It is notoriously difficult to study the interior structures of large gaseous planets, and the findings advance the effort to map Saturn’s hidden regions.

“By studying how Saturn formed and how it evolved over time, we can learn a lot about the formation of other planets similar to Saturn within our own solar system, as well as beyond it,” said co-author and Johns Hopkins planetary physicist Sabine Stanley.

Saturn stands out among the planets in our solar system because its magnetic field appears almost perfectly symmetrical around the



The magnetic field of Saturn. Credit: Ankit Barik/Johns Hopkins University.

rotation axis. Detailed measurements of the magnetic field gleaned from the last orbits of NASA's Cassini mission provide an opportunity to better understand the planet's deep interior, where the magnetic field is generated, said lead author Chi Yan, a Johns Hopkins Ph.D. candidate.

By feeding data gathered by the Cassini mission into powerful computer simulations similar to those used to study weather and climate, Yan and Stanley explored what ingredients are necessary to produce the dynamo — the electromagnetic conversion mechanism — that could account for Saturn's magnetic field.

"One thing we discovered was how sensitive the model was to very specific things like temperature," said Stanley, who is also a Bloomberg Distinguished Professor at Johns Hopkins in the Department of Earth and Planetary Sciences and the Space Exploration Sector of the Applied Physics Laboratory. "And that means we have a really interesting probe of Saturn's deep interior as far as 20,000 kilometers down. It's a kind of X-ray vision."

Strikingly, Yan and Stanley's simulations suggest that a slight degree of non-axisymmetry could exist near Saturn's north and south poles.

"Even though the observations we have from Saturn look perfectly symmetrical, in our computer simulations, we can fully interrogate the field," said Stanley.

Direct observation at the poles would be necessary to confirm it, but the finding could have implications for understanding another problem that has vexed scientists for decades: how to measure the rate at which Saturn rotates, or, in other words, the length of a day on the planet.

SOLAR SYSTEM SAMPLES TOUCH DOWN IN LEICESTER

Samples from other worlds will be examined by space scientists at the University of Leicester as they continue to study the building blocks of the solar system.

Some of the first particles from asteroid Ryugu — returned by Japan Aerospace Exploration Agency (JAXA) probe Hayabusa2 in 2020 — and samples from the Winchcombe meteorite, which fell to Earth earlier this year, will be scrutinized by planetary scientists in the School of Physics and Astronomy.

Both Ryugu and the unknown body which produced the Winchcombe meteorite — so-called for the Gloucestershire town where it was found in February — are examples of carbonaceous chondrites, considered one of the most primitive forms of planetary material. However, they are extremely rare and make up less than 5% of meteorite falls on Earth.

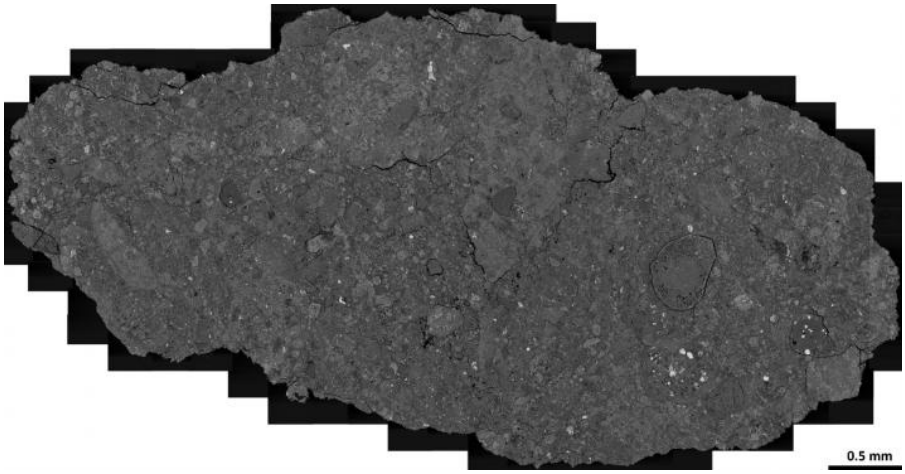
John Bridges is a Professor of Planetary Science and Dr. Leon Hicks is a planetary materials researcher at the University of Leicester. They have been involved in several sample return missions, including JAXA's first Hayabusa mission and NASA's Stardust mission.

Professor Bridges said, "A key advantage of a sample return mission such as Hayabusa2 is that it allows us to look at the properties of a known asteroid which we can observe from Earth, and compare to other samples in a lab setting. However, we have been incredibly lucky with the recent Winchcombe meteorite fall, as that is such a rare event. We can not only learn about the processes that led to the formation of asteroid Ryugu, but we will also learn more about similar samples in our meteorite collections."

Samples from the Winchcombe meteorite arrived at Leicester in June, with some of the first particles from asteroid Ryugu expected later this summer.

Researchers at the University of Leicester's Space Research Centre and Advanced Microscopy Centre use a range of techniques to study the origin of asteroids and comets and the evolution of Mars. Methods include scanning electron microscopes, transmission electron microscopes, and focused ion beam. Hicks and Bridges will take the samples to the Diamond synchrotron facility in Harwell, Oxfordshire for further analysis.

"A key advantage of a sample return mission such as Hayabusa2 is that it allows us to look at the properties of a known asteroid which we can observe from Earth."



This scanning electron microscope image of the Winchcombe meteorite interior was taken at the University of Leicester's Advanced Microscopy Centre. Initial analyses indicate the presence of both high-temperature minerals and low-temperature water-rock reactions 'superimposed' upon them. Credit: University of Leicester.

This work helps scientists better understand the processes taking place at the formation of the solar system as well as the changes which these bodies have undergone in the past 4.5 million years and informs how Earth came to possess the resources required to sustain life.

Planetary scientists have previously examined high-profile samples from the near-Earth asteroid Itokawa (Hayabusa), the comet Wild 2 (Stardust), plus lunar rocks and soil returned to Earth by NASA's Apollo Program.

Professor Bridges is also a participating scientist and ChemCam team member on the NASA Mars Science Laboratory mission and is a key collaborator on the ExoMars mission — a joint project between the European Space Agency (ESA) and Russia's Roscosmos — which aims to land a Leicester-built instrument on the Red Planet in 2023.

UPCOMING PUBLIC EVENT OPPORTUNITIES

For upcoming educator and public engagement opportunities regarding NASA planetary exploration, contact local astronomical societies, planetariums, museums, local scientists, and NASA's Solar System Ambassadors. Ask them to join your events and share their experiences or resources with your audience.

Perseid Meteor Shower, August 12–13

The Perseid meteors are made of pieces from comet Swift-Tuttle and appear to originate from the constellation Perseus, hence their name. In 2021, the Perseids will peak on the night between August 12–13. For more information about the Perseids, visit https://solarsystem.nasa.gov/small-bodies/meteors-and-meteorites/perseids/in-depth.

Lucy Mission Launch to the Trojan Asteroids, October 16

Lucy will be the first space mission to explore the Trojan asteroids. Conduct a public event to celebrate the launch of this historic mission. For more information, visit http://lucy.swri.edu/.

International Observe the Moon Night, October 16

The 2021 International Observe the Moon Night will be held on October 16. International Observe the Moon Night is an annual worldwide public event that encourages observation, appreciation, and understanding of our Moon and its connection to NASA planetary science and exploration. Everyone is invited to join the celebration by hosting or attending an event. For more information, visit https://moon.nasa.gov/observe-the-moon-night/.

EUGENE M. SHOEMAKER IMPACT CRATERING AWARD

The Eugene M. Shoemaker Impact Cratering Award is for undergraduate or graduate students of any nationality working in any country in the disciplines of geology, geophysics, geochemistry, astronomy, or biology. The award is to be applied for the study of impact craters, either on Earth or on the other solid bodies in the solar system. Areas of study may include but are not limited to impact cratering processes; the bodies (asteroidal or cometary) that make the impacts; or the geological, chemical, or biological results of impact cratering. The application deadline is August 27, 2021. For more information, visit www.lpi.usra.edu/science/kring/Awards/Shoemaker_Award/.

RESOURCES FOR PLANETARY SCIENTISTS INVOLVED IN PUBLIC ENGAGEMENT

The Lunar and Planetary Institute's education and public engagement team is pleased to assist planetary scientists in their communication and public engagement activities. The LPI conducts scientist workshops that address meeting audience needs, among other relevant topics. For more information, visit www.lpi.usra.edu/education/scientist-engagement.

SUBMIT A 2021 AGU FALL MEETING EDUCATION ABSTRACT

Share your education and outreach experiences with the AGU community. Submitting an education abstract won't count against your first author science abstract submissions! For submission guidelines, visit agu.org/Fall-Meeting/Pages/Present/Abstracts. The 2021 Fall AGU abstract submission deadline is August 4, 2021, at 11:59 p.m. EDT. For more information, visit agu.confex.com/agu/fm21/prelim.cgi/Home/0.

Consider submitting an education abstract to one of these sessions:

ED033 – Sharing Best Practices for Space Science Outreach and Engagement

We invite authors to share their range of experiences in space science outreach and engagement provided by large observatories, science centers, schools, clubs, non-profits, NASA missions and NASA centers, and other institutions. We are particularly interested in how these projects enable members of the public to participate in space science and are seeking synthesized best practices to share with the community.

Questions? Contact Sanlyn Buxner at buxner@psi.edu. For more information, visit agu.confex.com/agu/fm21/prelim.cgi/Session/123601.

ED034 – Sharing Their Science: Enabling Scientists to Engage Audiences

We welcome presentations supporting scientists in communicating with and engaging audiences, such as professional development for scientists and creating partnerships to connect scientists with audiences. We particularly invite presentations with recommendations on ways to encourage and enable diverse scientists to participate in education and public engagement programs.

Questions? Contact Christine Shupla at shupla@lpi.usra.edu. For more information, visit agu.confex.com/agu/fm21/prelim.cgi/Session/123323.

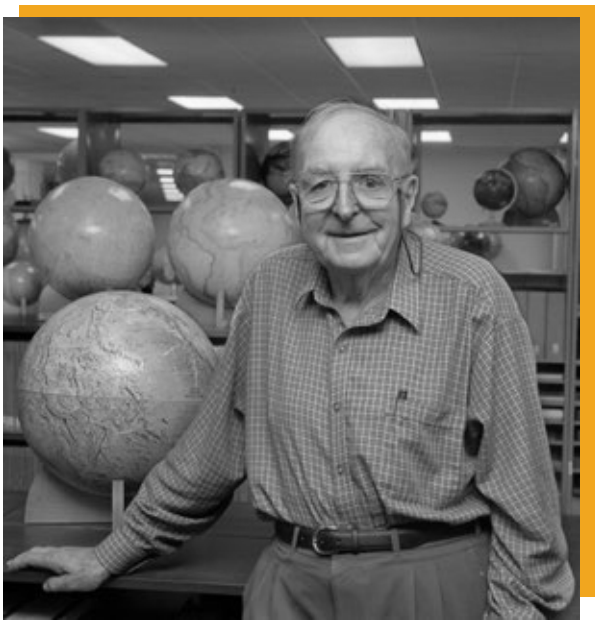
ED035 – Sharing Your Science: Engaging Diverse Audiences through Communications and Outreach Programs

We welcome presentations demonstrating the breadth of scientists' activities to engage these diverse audiences and modalities. We particularly invite recommendations about the resources and authentic partnerships that enable engaging diverse audiences through programs incorporating justice, equity, diversity, and inclusion principles.

Questions? Contact Christine Shupla at shupla@lpi.usra.edu. For more information, visit agu.confex.com/agu/fm21/prelim.cgi/Session/123387.

"Spotlight on Education" highlights events and programs that provide opportunities for planetary scientists to become involved in education and public engagement. If you know of space science educational programs or events that should be included, please contact the Lunar and Planetary Institute's Education Department at education@lpi.usra.edu.

IN MEMORIAM



Credit: Lunar and Planetary Institute.

STUART ROSS TAYLOR

1925–2021

Stuart Ross Taylor, one of the founding fathers of planetary science, passed away on May 23, 2021, in Canberra, Australia. Taylor served as the first visiting scientist at the Lunar and Planetary Institute (LPI) (then the Lunar Science Institute) in 1969 and returned to the Institute many times over the subsequent decades. Taylor used many of these periods of residency at the Institute to write some of his most renowned publications, including the books *Planetary Science: A Lunar Perspective* and *Solar System Evolution: A New Perspective*.

Taylor was involved in the study of lunar samples from the first sample return in July 1969. He was a member of the Preliminary Examination Team at NASA's Johnson Space Center in Houston, Texas, and carried out the first analysis of the first lunar samples returned to Earth. Subsequently, as a NASA principal investigator for 20 years, he worked on lunar composition, evolution, and origin models.

Taylor grew up on a farm in New Zealand. He earned both master's and bachelor's degrees in chemistry and geology at the University of New Zealand before completing his Ph.D. in geochemistry at Indiana University with Brian Mason. He lectured at the Universities of Oxford and Cape Town before moving to the Research School of Earth Sciences at the Australian National University, where he was an emeritus professor.

Taylor worked on the composition and evolution of the Moon, the continental crust, tektites and impact glasses, island arc rocks, and many other topics involving trace element geochemistry. He published 240 papers in scientific journals and nine books.

Taylor was awarded the Goldschmidt Medal of the Geochemical Society, the Leonard Medal of the Meteoritical Society, the Bucher Medal and the Bowen Award of the American Geophysical Union, the Gilbert Award of the Geological Society of America, and the Shoemaker Distinguished Lunar Scientist Award. Asteroid 5670 is named Rosstaylor.

He was a foreign member of the National Academy of Sciences of the United States of America, a fellow of the Australian Academy of Science, and held honorary fellowships of the Royal Society of New Zealand, the Geological Society (London), and the Geological Society of India. He was a former president of the Meteoritical Society, held a Doctor of Science degree from Oxford, and was a Companion of the Order of Australia (AC).

See Taylor's full obituary in The Canberra Times.

NASA ASSOCIATE ADMINISTRATOR STEVE JURCZYK RETIRES

After more than three decades of service at NASA, Steve Jurczyk, who served as acting NASA administrator from January 20 to May 3, retired on May 14, 2021.

"Steve was instrumental to NASA over the past 32 years and had overseen incredible successes as associate administrator the last three years. His inclusive, collaborative, and creative leadership has had an incredible impact on this agency," said NASA Administrator Bill Nelson. "Steve's legacy at NASA is one of excellence, and I wish him well in his future endeavors."

Credit: NASA.

Jurczyk served as associate administrator, the agency's highest-ranking civil servant, since May 2018, leading NASA throughout the pandemic and, most recently, overseeing the successful landing of the Perseverance rover on Mars, a successful Green Run test of the core stage of the Space Launch System rocket, the naming of the Mary W. Jackson NASA Headquarters, the launch of Crew-2 to the International Space Station, and the return of Crew-1 back to Earth.

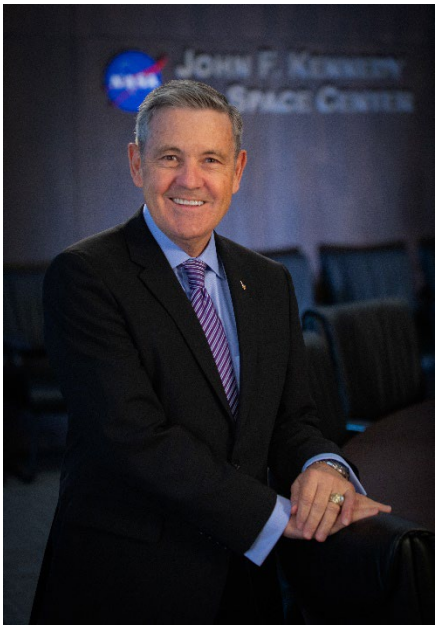
Before being named associate administrator, Jurczyk served in a number of leadership roles at NASA, including associate administrator of the Space Technology Mission Directorate and director and deputy director of the agency's Langley Research Center in Hampton, Virginia. He is the recipient of the NASA Distinguished Service Medal, two Outstanding Leadership Medals, the Presidential Rank Award for Meritorious Executive in 2006, and the Presidential Rank Award for Distinguished Executive in 2016 — the highest honors attainable for federal government leadership.

Steve Jurczyk was a 2021 Service to America Medal "Sammies" finalist, one of the highest honors for federal civil servants. He was nominated in the management excellence category for his leadership in response to the coronavirus.

BOB CABANA NAMED NEW NASA ASSOCIATE ADMINISTRATOR

NASA Administrator Bill Nelson announced that Robert D. Cabana, who has served as director of NASA's Kennedy Space Center in Florida since 2008, began serving as associate administrator effective May 17, 2021. Steve Jurczyk, who held the position since 2018, has retired.

"Bob has a relentless determination to expand America's role in space. Under his leadership, Kennedy has emerged as a modern, world-class multi-user spaceport, partnering with commercial customers and supporting NASA's science and human exploration missions,"



Credit: NASA.

Nelson said. "Bob is the real deal — he has the vision and management skills to bring NASA to even higher heights."

"I'm honored to have been selected by Senator Nelson to serve as associate administrator of NASA," Cabana said. "Bill and I have a shared passion for America's space program, and I look forward to serving NASA and our nation in this new capacity. As much as I am going to miss the incredible team at Kennedy, I can't wait to take on this new challenge."

Nelson and Cabana first met in 1985 while Nelson was training to fly on the space shuttle, and Cabana was an astronaut candidate. At Kennedy, Cabana managed all NASA programs and activities at the spaceport, including the team of civil service and contractor employees who operate some of NASA's most critical programs, including its Commercial Crew Program.

Cabana graduated from the U.S. Naval Academy in 1971 with a degree in mathematics. He was commissioned in the U.S. Marine Corps and completed Naval Flight Officer training in Pensacola in 1972. He was designated a naval aviator in September 1976 and logged more than 7,000 hours of flight time in more than 50 different aircraft.

Janet Petro, who has served as deputy director of Kennedy since 2007, will serve as acting center director. Petro was also central to Kennedy's transition to a multi-user spaceport. She led cross-agency initiatives with the Federal Aviation Administration and U.S. Air Force to streamline government processes, support commercial space operations, increase government efficiency, and limit redundancy.

Cabana will join a senior NASA Headquarters team including Pam Melroy, nominee for deputy administrator; Margaret Vo Schaus, nominee for chief financial officer; Susie Perez Quinn, chief of staff; Bhavya Lal, senior advisor for budget and finance; Marc Etkind, associate administrator for communications; and Alicia Brown, associate administrator for legislative and intergovernmental affairs.

PAM MELROY SWORN IN AS NASA DEPUTY ADMINISTRATOR

NASA Deputy Administrator Pam Melroy took office on June 21, 2021, after NASA Administrator Bill Nelson gave her the oath of office during a ceremony at the Mary W. Jackson NASA Headquarters building in Washington, DC.

"It is a joy to be back in the NASA family, the smartest and most dedicated workforce of any place that I've ever worked. I always knew this was the most exciting place to work from the time I was a child, inspired by the first landing on the Moon," Melroy said. "I'm very honored to be teamed with Administrator Nelson and our Associate Administrator Bob Cabana and the rest of the NASA team. We do have a lot of work to do, but it's our intention not to just lead today's NASA, but also lead us forward into the future and support the generations of fantastic things that NASA will continue to do."

Melroy was nominated in April by President Biden and confirmed by the Senate on June 17. Along with Nelson, Melroy is responsible for providing overall leadership, planning, and policy direction for NASA.

"What a grand occasion for us! Pam is extremely skilled, experienced, and ready for this job," Nelson said. "Pam is an ROTC graduate and an Air Force officer. She was one of two female test pilots for the Air Force and one of two female NASA astronaut commanders; she's logged over 6,000 hours in aircraft, and she has logged many, many days in space. And, now, Pam is the first woman astronaut to serve as deputy administrator here at NASA."

Melroy will perform the duties and exercises under the powers delegated by the administrator, assist the administrator in making final agency decisions, and act for the administrator in his absence by performing all necessary functions to govern NASA operations. Melroy also is responsible for outlining the agency's vision and representing NASA

to the Executive Office of the President, Congress, heads of federal and other appropriate government agencies, international organizations, and external organizations and communities.

One of only two women to command a space shuttle, Melroy logged more than 38 days in space. She served as a pilot on two flights, STS-92 in 2000 and STS-112 in 2002, and was the mission commander on STS-120 in 2007. All three of her missions were assembly missions to build the International Space Station.

After graduating from the United States Air Force Test Pilot School, Melroy logged more than 6,000 flight hours in more than 50 different aircraft. She is a veteran of Operation Desert Shield/Desert Storm and Operation Just Cause, with more than 200 combat and combat support hours.

Pam Melroy was ceremonially sworn in as the 15th NASA Deputy Administrator by NASA Administrator Bill Nelson, as her husband, Doug Hollett, holds their family Bible, on June 21, 2021, at the Mary W. Jackson NASA Headquarters building in Washington, DC. Melroy is a former NASA astronaut. Credit: NASA/Bill Ingalls.

After serving more than two decades in the Air Force and as a NASA astronaut, Melroy took on a number of leadership roles, including at Lockheed Martin, the Federal Aviation Administration, the Defense Advanced Research Projects Agency, Nova Systems Pty, Australia, and as an advisor to the Australian Space Agency. She also served as an independent consultant and a National Space Council's Users Advisory Group member.

Melroy holds a bachelor's degree in physics and astronomy from Wellesley College and a master's degree in Earth and planetary sciences from the Massachusetts Institute of Technology.

NASA ADMINISTRATOR ANNOUNCES NEW MEMBERS OF LEADERSHIP TEAM

NASA Administrator Bill Nelson announced four new additions to the agency's senior staff.

NASA Senior Advisor for Engagement Shahra Lambert. Credit: NASA/Bill Ingalls.

Shahra Anderson Lambert will serve as senior advisor for engagement, and Bale Dalton will serve as the deputy chief of staff. Nelson also announced Bryan Gulley as media relations specialist and Justin Weiss as deputy press secretary.

Lambert comes to NASA after serving as director of strategic initiatives for Nicole "Nikki" Fried, commissioner of the Florida Department of Agriculture and Consumer Services. Before that, Lambert spent 15 years as a regional director for Nelson during his service as a U.S. senator from Florida. She began her career working for then-Senator Bob Graham of Florida as a constituent advocate in his Tallahassee office. Lambert then transitioned to state government, working for State Representative Bruce Antone of Orlando as his chief of legislative affairs.

She received a bachelor's degree in Spanish from Mercer University and a master's degree in Spanish and Latin American and Caribbean studies from Florida State University.

NASA Deputy Chief of Staff Bale Dalton. Credit: NASA/ Bill Ingalls.

A native of Orlando, Florida, Bale Dalton was previously director of Navy programs at Air Center Helicopters, Inc., an expeditionary aviation services provider headquartered in Burleson, Texas.

Dalton graduated from the U.S. Naval Academy with a bachelor's degree in ocean engineering and from the Harvard Kennedy School with a Master of Public Policy in international and global affairs. He is a Master of Business Administration candidate at the Wharton School of the University of Pennsylvania.

Dalton served as a military legislative assistant to Senator Nelson and a foreign service officer at the Department of State working in the Office of Global Partnerships. Dalton is a commissioned naval officer and designated naval aviator, with multiple deployments in support of Operations Iraqi and Enduring Freedom. He is now a reservist, previously commanding the special operations support squadron HSC-85 and continuing service as the Training Airwing Five Reserve Component commander.

NASA Media Relations Specialist Bryan Gulley. Credit: NASA/ Bill Ingalls.

Bryan Gulley joins NASA after nearly two decades of service in the United States Senate. He spent time as the communications director for the Committee on Commerce, Science, and Transportation, and the Special Committee on Aging, serving under the leadership of Senator Nelson. Prior to his committee work, Gulley served as press secretary in Nelson's Senate office. More recently, Gulley served as a senior analyst with Imbue Group, supporting the Department of Defense's Office of Small Business Programs and the Defense Production Act Title III program.

Gulley received a bachelor's degree in international studies from the University of South Carolina.

NASA Deputy Press Secretary Justin Weiss. Credit: NASA/ Bill Ingalls.

Justin Weiss most recently served as communications director for U.S. Representative Adam Smith, chairman of the House Armed Services Committee. Weiss worked in the congressman's office and partnered closely with the committee. Previously, he was employed by the public relations firm Rational 360 to run campaigns for advocacy coalitions, trade associations, and nonprofits. Before that role, Weiss worked in public affairs at Forbes Tate Partners and federal advocacy at LNE Group.

Weiss is an Ohio native and earned a bachelor's degree in both communication and French from Denison University.

2022 LEROY E. DOGGETT PRIZE AWARDED TO WILLIAM H. DONAHUE

Dr. William H. Donahue (St. John's College/Green Lion Press) is the recipient of the 2022 LeRoy E. Doggett Prize for Historical Astronomy. The Doggett Prize, awarded biennially by the American Astronomical Society's (AAS) Historical Astronomy Division (HAD), goes to an individual who has significantly influenced the field through a career-long effort.

In his decades-spanning career, Donahue has made many contributions to the history of astronomy from antiquity to the early modern period. The most significant are his essential translations into English of Johannes Kepler's *Astronomia Nova (New Astronomy, 1609)* and *Astronomiae Pars Optica (Optical Part of Astronomy, often referred to simply as Optics, 1604)*. The translation of these complex scientific works demonstrates his scientific knowledge, necessary to understand the technical aspects of the books, and his linguistic skill, essential to read the original texts and convert them to English correctly.

The Doggett Prize will be presented to him at a plenary session of the 239th AAS meeting in January 2022 in Salt Lake City, Utah. For more information, visit https://had.aas.org/awards_and_prizes/doggett_prize/2022.

Dr. William H. Donahue, recipient of the 2022 LeRoy E. Doggett Prize for Historical Astronomy. Photo courtesy of William Donahue.

NATIONAL ACADEMY OF SCIENCES ELECTS NEW MEMBERS

The National Academy of Sciences announced the election of 120 members — 59 of whom are women, the most elected in a single year — and 30 international members in recognition of their distinguished and continuing achievements in original research.

Those elected bring the total number of active members to 2,461 and the total number of international members to 511. International members are nonvoting members of the Academy, with citizenship outside the United States.

Among the newly elected members are the following scientists in the planetary science community:

- Robert S. Anderson, Distinguished Professor, Department of Geological Sciences, University of Colorado, Boulder, CO
- Frances Bagenal, Senior Research Scientist, Laboratory for Atmospheric and Space Physics and Department of Astrophysical

and Planetary Sciences, University of Colorado, Boulder, CO

- Linda T. Elkins-Tanton, Managing Director, Interplanetary Initiative, School of Earth and Space Exploration, Arizona State University, Tempe, AZ
- Debra Fischer, Professor, Department of Astronomy, Yale University, New Haven, CT
- Stephen A. Fuselier, Executive Director, Space Science Directorate, Space Science and Engineering Division, Southwest Research Institute, San Antonio, TX
- Harry Y. McSween, Jr., Chancellor's Professor Emeritus, Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN

New international member:

- Ulrich Christensen, Director, Max Planck Institute for Solar System Research (Germany)

For more information, visit www.nasonline.org/news-and-multimedia/news/2021-nas-election.html.

2021 BARRINGER AWARD RECIPIENTS ANNOUNCED

Credit: NASA Earth Observatory.

The LPI is pleased to announce the 2021 grant awardees of the Barringer Family Fund for Meteorite Impact Research:

Anna Barbaro
University of Pavia, Italy

Renato Borges Bernardes
University of Brasilia, Brazil

Jennifer Davis
University of Colorado – Boulder, United States

Nicolas Garroni
University of Western Ontario, Canada

Daniela Guerror Gutierrez
University of Brasilia, Brazil

Anders Plan
Lund University, Sweden

Gavin Tolometti
University of Western Ontario, Canada

The Barringer Crater Company established this special fund in 2002 that provides competitive grants to eligible students to support their field research at known or suspected impact sites worldwide.

The Barringer Family Fund for Meteorite Impact Research was established as a memorial to recognize the contributions of the Barringer family to the field of meteoritics and their strong interest in and support of research and education. The Fund also reflects the family's long-standing commitment to responsible stewardship of the Barringer Meteorite Crater and the family's resolve to maintain the crater as a unique scientific research and education site.

For more information, visit www.lpi.usra.edu/science/kring/Awards/Barringer_Fund/.

PUBLIC NAMES "MOONIKIN" FLYING AROUND MOON ON NASA'S ARTEMIS I MISSION

"Commander Moonikin Campos" is the official name of the manikin launching on Artemis I, NASA's uncrewed flight test of the Space Launch System (SLS) rocket and Orion spacecraft around the Moon later this year. The Moonikin received its name as the result of a competitive bracket contest honoring NASA figures, programs, or astronomical objects. NASA received more than 300,000 votes.

The name Campos is a dedication to Arturo Campos, a key player in bringing Apollo 13 safely back to Earth. The final bracket challenge was between Campos and Delos, a reference to the island where Apollo and Artemis were born, according to Greek mythology.

"Our return to the Moon through Artemis is a global effort — and we're always looking at new ways to engage the public in our missions. This contest, which is helping pave the way for a human return to the Moon, also honors an important individual in our NASA family — Arturo Campos," said Brian Odom, NASA's acting chief historian at Marshall Space Flight Center in Huntsville, Alabama. "It is a fitting tribute that the data gained from Artemis I will help us prepare to fly astronauts — including the first woman and first person of color — to the Moon, where we will get ready for Mars."

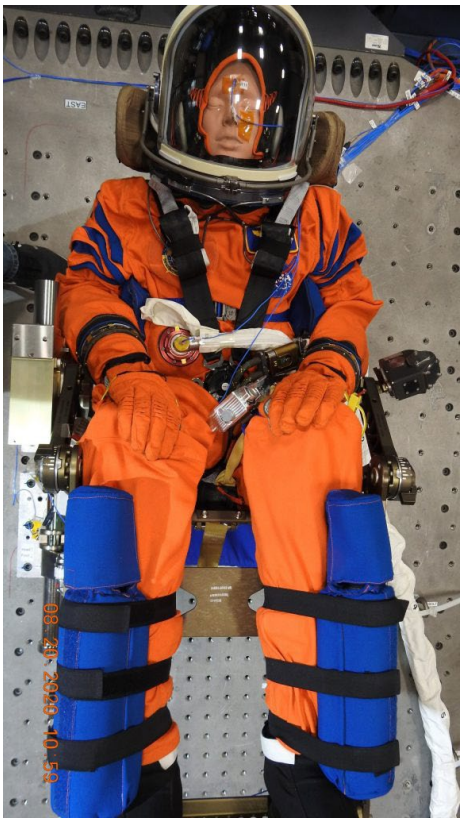
Arturo Campos, electrical power subsystem manager for the Apollo 13 lunar module. Photo courtesy of the Campos family.

The other six names under consideration were:

- Ace, for "Artemis Crew Explorer"
- Duhart, a dedication to Irene Duhart Long, chief medical officer at Kennedy Space Center from 2000 to 2010
- Montgomery, dedication to Julius Montgomery, the first African American to work as a technical professional at Cape Canaveral Air Force Station, now known as Cape Canaveral Space Force Station
- Rigel, a giant superstar in the Orion constellation
- Shackleton, a crater on the Moon's south pole named after famous Antarctic explorer Ernest Shackleton
- Wargo, a dedication to Michael Wargo, NASA's first chief exploration scientist

The Moonikin is a male-bodied manikin previously used in Orion vibration tests. Campos will occupy the commander's seat and wear an Orion Crew Survival System suit — the same spacesuit that Artemis astronauts will use during launch, entry, and other dynamic phases of their missions.

Campos will be equipped with two radiation sensors and have additional sensors under its headrest and behind its seat to record acceleration and vibration data throughout the mission. Data from the Moonikin's experience will help



Engineers at Kennedy Space Center use a suited manikin to conduct vibration testing on Orion's seat and energy dampening system – called the Crew Impact Attenuation System – for qualification ahead of Artemis II. Credit: NASA.

NASA protect astronauts during Artemis II, the first mission in more than 50 years to send crew around the Moon.

The Moonikin is one of three "passengers" flying onboard Orion to test the spacecraft's systems. Two female-bodied model human torsos, called phantoms, will also be on board. "Zohar" and "Helga," named by the Israel Space Agency (ISA) and the German Aerospace Center (DLR), respectively, will support the Matroshka AstroRad Radiation Experiment (MARE), an experiment to provide data on radiation levels during lunar missions.

NASA's SLS rocket and Orion spacecraft, along with a commercial human landing system and Gateway in lunar orbit, are vital to the agency's deep space exploration plans. Working with commercial and international partners, NASA is committed to establishing the first long-term presence on and around the Moon under Artemis. Using robots and humans to explore more than ever before, NASA also will use the Moon for humanity's next giant leap — sending the first astronauts to Mars.

For more information about NASA's Artemis missions on and around the Moon, visit www.nasa.gov/artemis.

NASA SELECTS NEW SCIENCE INVESTIGATIONS FOR FUTURE MOON DELIVERIES

As NASA continues plans for multiple commercial deliveries to the Moon's surface per year, the agency has selected three new scientific investigation payload suites to advance understanding of Earth's nearest neighbor. Two of the payload suites will land on the far side of the Moon, a first for NASA. All three investigations will be sent to the lunar surface as part of NASA's Commercial Lunar Payload Services (CLPS) initiative, part of the agency's Artemis approach.

The payloads mark the agency's first selections from its Payloads and Research Investigations on the Surface of the Moon (PRISM) call for proposals.

"These selections add to our robust pipeline of science payloads and investigations to be delivered to the Moon through CLPS," said Joel Kearns, deputy associate administrator for exploration in NASA's Science Mission Directorate. "With each new PRISM selection, we will build on our capabilities to enable bigger and better science and prove technology which will help pave the way for returning astronauts to the Moon through Artemis."

Lunar Vertex, one of the three selections, is a joint lander and rover payload suite slated for delivery to Reiner Gamma — one of the most distinctive and enigmatic natural features on the Moon, known as a lunar swirl. Scientists don't fully understand what lunar swirls are or how they form, but they know they are closely related to anomalies associated with the Moon's magnetic field. The Lunar Vertex rover will make detailed surface measurements of the Moon's magnetic field using an onboard magnetometer. The rover will collect magnetic field data from the lunar surface, which will enhance the data the spacecraft collects in orbit around the Moon. This will help scientists better understand how these mysterious lunar swirls form and evolve, as well as provide further insight into the Moon's interior and core. Dr. David Blewett of the Johns

Credit: NASA.

Hopkins University Applied Physics Laboratory leads this payload suite.

NASA also has selected two separate payload suites for delivery in tandem to Schrödinger basin, a large impact crater on the far side of the Moon near the lunar South Pole. The Farside Seismic Suite (FSS), one of the two payloads to be delivered to Schrödinger basin, will carry two seismometers: the vertical Very Broadband seismometer and the Short Period sensor. NASA measured seismic activity on the near side of the Moon as part of the Apollo program, but FSS will return the agency's first seismic data from the far side of the Moon — a potential future destination for Artemis astronauts. This new data could help scientists better understand tectonic activity on the far side of the Moon, reveal how often the lunar far side is impacted by small meteorites, and provide new constraints on the internal structure of the Moon. The FSS will continue taking data on the lunar surface for several months beyond the lifetime of the lander. The FSS package will be self-sufficient with independent power, communications, and thermal control to survive the two-week-long lunar nights. Dr. Mark Panning of NASA's Jet Propulsion Laboratory in California leads this payload suite.

The Lunar Interior Temperature and Materials Suite (LITMS), the third payload headed to Schrödinger basin, is a suite of two instruments: the Lunar Instrumentation for Thermal Exploration with Rapidity pneumatic drill and the Lunar Magnetotelluric Sounder. This payload suite will investigate the heat flow and electrical conductivity of the lunar interior in Schrödinger basin, providing an in-depth look at the Moon's internal mechanical and heat flow. LITMS data also will complement seismic data acquired by the FSS to provide more of a complete picture of the near- and deep-subsurface of the far side of the Moon. Dr. Robert Grimm of the Southwest Research Institute leads this payload suite.

While these selections are final, negotiations are continuing for each award amount.

"These investigations demonstrate the power of CLPS to deliver big science in small packages, providing access to the lunar surface to address high priority science goals for the Moon," said Lori Glaze, director of NASA's Planetary Science Division. "When scientists analyze these new data alongside lunar samples returned from Apollo and data from our many orbital missions, they will advance our knowledge of the lunar surface and interior, and increase our understanding of crucial phenomenon such as space weathering to inform future crewed missions to the Moon and beyond."

With these selections in place, NASA will work with the CLPS office at the agency's Johnson Space Center in Houston to issue task orders to deliver these payload suites to the Moon in the 2024 timeframe.

For these payload suites, the agency has also selected two project scientists to coordinate science activities, including selecting landing sites, developing concepts of operations, and archiving science data acquired during surface operations. Dr. Heidi Haviland of NASA's Marshall Space Flight Center in Huntsville, Alabama, will coordinate the suite slated for delivery to Reiner Gamma, and Dr. Brent Garry of NASA's Goddard Space Flight Center in Greenbelt, Maryland, will coordinate payload deliveries to Schrödinger basin.

CLPS is a key part of NASA's Artemis lunar exploration efforts. The science and technology payloads sent to the Moon's surface as part of CLPS will help lay the foundation for human missions and a sustainable human presence on the lunar surface. The agency has made six task order awards to CLPS providers for lunar deliveries between late 2021–2023, with more delivery awards expected at least through 2028.

For more information, visit www.nasa.gov/content/commercial-lunar-payload-services.

NASA INVESTS $105 MILLION IN U.S. SMALL BUSINESS TECHNOLOGY DEVELOPMENT

Credit: NASA.

NASA has a long history of supporting America's entrepreneurs as they develop technologies from ideas to commercial readiness. The agency's Small Business Innovation Research (SBIR) program is furthering that legacy with 140 new Phase II awards to 127 U.S. small businesses that will help them move their innovations to market.

The awards to these small businesses, located across 34 states and Washington, DC, total $105 million. NASA's small business program is dedicated to finding the most useful technologies for the agency and the commercial marketplace and sourcing those innovations from a diverse group of entrepreneurs with different backgrounds and perspectives. The companies chosen for Phase II funding include 33 women-owned, minority-owned, and veteran-owned small businesses.

The awardees all received initial SBIR Phase I contracts in 2020 to demonstrate the merits of their innovations and show how they could contribute to NASA's efforts in human exploration, space technology, science, and aeronautics. The Phase II awards will provide them with up to $750,000 to advance their technologies toward potential commercialization. The companies will spend up to two years developing, demonstrating, and delivering their proposed projects.

To view the full list of the latest NASA SBIR Phase II selections, visit https://sbir.nasa.gov/prg_selection/node/66870.

NASA LAUNCHES ENTREPRENEURS CHALLENGE TO IDENTIFY INNOVATIVE IDEAS

NASA is announcing its 2021 Entrepreneurs Challenge to invite fresh ideas and new participants that will lead to new instruments and technologies with the potential to advance the agency's science mission goals.

The agency's Science Mission Directorate is seeking novel ideas that focus on priority areas for the commercial sector. The Entrepreneurs Challenge aligns with NASA's goal to foster innovation and develop new technologies at lower costs while sourcing ideas from across the country with an emphasis on reaching out to underserved communities.

NASA's call for innovative technology ideas in the 2021 Entrepreneurs Challenge includes seeking ideas on collecting samples from ocean worlds, such as Jupiter's moon Europa, pictured here in an artist's rendition. Credit: NASA/JPL-Caltech.

"NASA relies on innovative technology to advance our crucial science goals," said Nicole Rayl, the acting chief technologist for science at NASA Headquarters in Washington. "Today's novel ideas enable tomorrow's cutting-edge research — and we sponsor and support such technology development through every step of that process. We're always so excited to see the creativity launched by challenges like this."

Successful participants will contribute ideas in three broadly defined science technology focus areas:

- Small satellite capabilities to enable science
- Metamaterials-based sensor technologies
- Sample handling and processing technology for the detection of biomarkers in highly dilute samples

To encourage entrepreneurs to participate in the challenge, the Science Mission Directorate will award finalists as much as $90,000 through a two-stage process. NASA will encourage all awardees to take part in follow-on activities provided by its Small Business Innovative Research program to learn about additional ways to work with the agency. In Round One, each participant will submit a five-page white paper that broadly describes the capability their idea offers and its relevance to a specific science-enabling area of technology. A NASA panel will select as many as 20 top ideas to advance to the next round of the competition, awarding each winner $10,000.

Companies that advance to Round Two will develop their concepts into detailed submissions. Participants will submit a more comprehensive white paper and participate in a live Virtual Pitch Event. A NASA judging panel will evaluate them based on their white papers and pitches. Venture capital firms with interest in the topic areas will be invited to attend the Virtual Pitch Event. At the conclusion of the event, the judging panel will award up to 10 of the highest-scoring teams $80,000 each.

To learn more about the Entrepreneurs Challenge and to apply, visit nasa-science-challenge.com.

For more information about NASA's science and technology activities, visit science.nasa.gov.

NASA AND NORTHROP GRUMMAN FINALIZE MOON OUTPOST LIVING QUARTERS CONTRACT

Illustration showing a close-up of the Habitation and Logistics Outpost (HALO), one of the elements of Gateway. Credit: NASA.

NASA and Northrop Grumman of Dulles, Virginia, have finalized a contract to develop the Habitation and Logistics Outpost (HALO) for Gateway, which will be a critical way station and outpost in orbit around the Moon as part of NASA's Artemis program.

NASA and its commercial and international partners are building Gateway to support science investigations and enable surface landings at the Moon, which will help prepare astronauts for future missions to Mars.

The firm, fixed-price contract is valued at $935 million. Under the contract, Northrop Grumman will be responsible for attaching and testing the integrated HALO with the Power and Propulsion Element (PPE) built by Maxar Technologies. Northrop Grumman will also lead the integrated PPE and HALO spacecraft turnover and launch preparation with SpaceX and support activation and checkout of HALO during the flight to lunar orbit. NASA is targeting November 2024 to launch the integrated spacecraft on a SpaceX Falcon Heavy rocket.

"NASA is building the infrastructure to expand human exploration further out into the solar system than ever before, including Gateway, the lunar space station that will help us make inspirational scientific discoveries at and around the Moon. Just as importantly, these investments will help NASA carry out the United States' horizon goal: to further develop and test the technology and science needed for a human trip to Mars," said NASA Administrator Bill Nelson. "The HALO is a critical component of Gateway, and this exciting announcement today brings us one step closer to landing American boots on both the Moon and Mars."

HALO is where astronauts will live and conduct research while visiting the Gateway. The pressurized living quarters will provide command and control systems for the lunar outpost and docking ports for visiting spacecraft, such as NASA's Orion spacecraft, lunar landers, and logistics resupply craft. The HALO module will serve as the backbone for command and control and power distribution across Gateway and will perform other core functions, including hosting science investigations via internal and external payload accommodations and communicating with lunar surface expeditions. HALO also will enable the aggregation of additional habitable elements to expand Gateway capabilities. Immediately after launch, the Heliophysics Environmental and Radiation Measurement Experiment Suite, built by NASA's Goddard Space Flight Center in Greenbelt, Maryland, will begin conducting research outside of the integrated spacecraft.

"This is a major step on the path for Artemis, not just for NASA, but for the combined team, including our

commercial and international partners," said Kathy Lueders, NASA associate administrator for Human Explorations and Operations. "Gateway will provide unprecedented access to the Moon and symbolizes the expansion of our partnerships into deep space."

The integrated PPE and HALO will be the Gateway's foundation, enabling humanity's first permanent outpost in orbit around the Moon. Located tens of thousands of miles from the lunar surface at its farthest point and within easy range of lunar landers at its closest, the Gateway will be in a near-rectilinear halo orbit. This orbit will allow NASA and its international and commercial partners to conduct unprecedented deep space science and technology investigations and conduct sustainable lunar exploration.

"This action puts in place the final contract component of a diverse, multi-faceted team — distributed across the country and within some international partner facilities — working together to create and implement the initial Gateway capability. We are excited to work with Northrop Grumman and all the partners to deliver the cornerstone of sustainable human exploration in cis-lunar space," said Dr. Jon Olansen, NASA's manager of the HALO project.

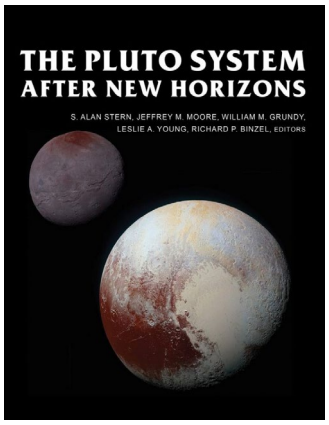
HALO leverages contributions from the Gateway international partners for robust capabilities. Batteries provided by the Japan Aerospace Exploration Agency (JAXA) will power HALO until PPE solar arrays can be deployed and during eclipse periods. Robotic interfaces provided by the Canadian Space Agency will host payloads and provide base points for Canadarm3 robotic operations. The European Space Agency (ESA) will provide a lunar communications system to enable high-data-rate communications between the lunar surface and Gateway. With three docking ports, HALO will be the hub for international Gateway expansion in the future, including an international habitat that ESA and JAXA will provide and an ESA-provided refueling module. The docking ports also will host a human landing system for lunar surface expeditions and logistics resupply spacecraft. As the Gateway hub, HALO will provide power, data, airflow to each of these ports, as well as thermal conditioning to assist future elements and spacecraft in controlling the temperature of their equipment and habitable environment.

"Leveraging our success with our Cygnus spacecraft, Northrop Grumman is perfectly positioned to deliver the HALO module, a critical piece for NASA's Artemis program and our journey to the Moon and beyond," said Frank DeMauro, vice president and general manager for tactical space systems at Northrop Grumman. "After recently completing a successful preliminary design review, we now look forward to completing the detailed design efforts and eventually bringing HALO to life in our Gilbert, Arizona, facility while also providing integration services for the final, combined vehicle before launch."

HALO's design is based on Northrop Grumman's Cygnus spacecraft, which has completed 15 resupply missions to the International Space Station to date. A previous contract for HALO, awarded in June 2020, funded work through preliminary design review, one of a series of checkpoints for the complex engineering project. The review process for the module, completed in May, assessed all of the spacecraft's design to ensure the overall system is safe and reliable for flight and meets NASA's mission requirements.

To explore more details about NASA's Gateway program, visit www.nasa.gov/gateway.

NEW AND NOTEWORTHY

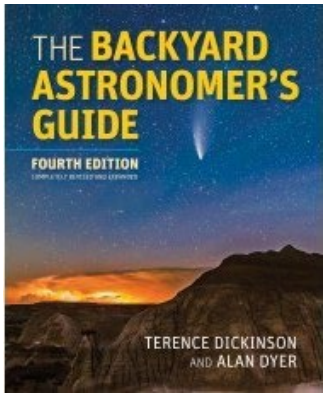


THE PLUTO SYSTEM AFTER NEW HORIZONS

Edited by S. Allan Stern, Jeffrey M. Moore, William M. Grundy, Leslie A. Young, and Richard P. Binzel

University of Arizona Press, 2021, 926 pp., Hardcover. $65.00. www.uapress.arizona.edu

In the decades following Voyager mission, a mission to the Pluto system was not only imagined but also achieved, culminating with the historic 2015 flyby by the New Horizons spacecraft. Pluto and its satellite system ("the Pluto system"), including its largest moon, Charon, have been revealed to be worlds of enormous complexity that fantastically exceed preconceptions. The Pluto System After New Horizons seeks to become the benchmark for synthesizing our understanding of the Pluto system. The volume's lead editor is S. Alan Stern, who also serves as NASA's New Horizons Principal Investigator; co-editors Jeffrey M. Moore, William M. Grundy, Leslie A. Young, and Richard P. Binzel are all co-investigators on New Horizons. Leading researchers from around the globe have spent the last five years assimilating Pluto system flyby data returned from New Horizons. The chapters in this volume form an enduring foundation for ongoing study and understanding of the Pluto system. The volume also advances insights into the nature of dwarf planets and Kuiper belt objects, providing a cornerstone for planning new missions that may return to the Pluto system and explore others of the myriad important worlds beyond Neptune.



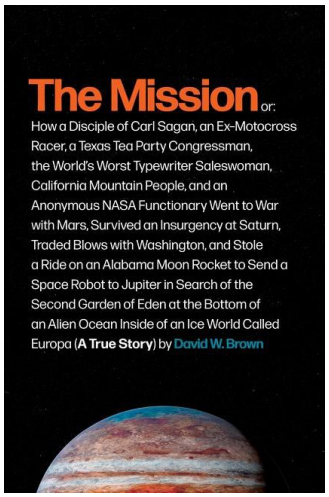
THE BACKYARD ASTRONOMER'S GUIDE, FOURTH EDITION

By Terence Dickinson and Alan Dyer

Firefly Books, 2021, 416 pp., Hardcover. $49.95. www.fireflybooks.com

This classic, groundbreaking guide has been the go-to field guide for both beginning and experienced amateur astronomers for nearly 30 years. The fourth edition brings Terence Dickinson and Alan Dyer's invaluable manual completely up to date. Setting a new standard for astronomy guides, it will serve as the touchstone for the next generation of stargazers as well as longtime devotees. Illustrated throughout with all-new photographs and star charts, this edition boasts a refreshed design and features five brand-new chapters, including three essential essays on binocular, telescope, and Moon tours by renowned astronomy writer Ken Hewitt-White. With new content on naked-eye sky sights, LED lighting technology, WiFi-enabled telescopes, and the latest advances in binoculars, telescopes, and other astronomical gear, this fourth edition of *The Backyard Astronomer's Guide* is sure to become an indispensable reference for all levels of stargazers.

Note: Product descriptions are taken from publishers' websites. LPI is not responsible for factual content.

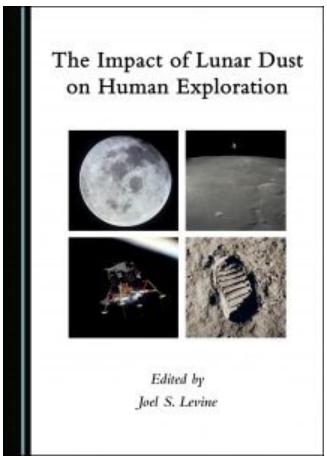


THE MISSION: A True Story

By David Brown

HarperCollins, 2021, 480 pp., Hardcover. $35.00. www.harpercollins.com

In the spirit of Tom Wolfe and John McPhee, The Mission reveals how a motley, determined few expanded the horizon of human achievement. When scientists discovered the first ocean beyond Earth, they had two big questions: "Is it habitable?" and "How do we get there?" To answer the first, they had to solve the second, and so began a vivacious team's 20-year odyssey to mount a mission to Europa, the ocean moon of Jupiter. This book presents the Homeric, never-before-told story of modern space exploration and provides a magnificent portrait of the inner lives of scientists who study the solar system's mysterious outer planets. Author David Brown chronicles the remarkable saga of how Europa was won, and what it takes to get things done — both down here, and up there.

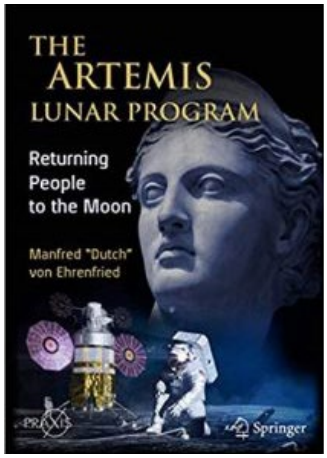


THE IMPACT OF LUNAR DUST ON HUMAN EXPLORATION

Edited by Joel S. Levine

Cambridge Scholars Publishing, 2021, 303 pp., Hardcover. £64.99. www.cambridgescholars.com

When the Apollo 11 astronauts landed on the Moon on July 20, 1969, they made a very important discovery. During their landing on the surface of the Moon, the exhaust gases released from the Lunar Module landing rockets caused large amounts of surface dust to move into the thin lunar atmosphere, causing obscuration of the lunar surface. Once they landed, they found that the surface of the Moon was covered with several inches of very fine, tiny particles composed of sharp, glassy material. The lunar dust stuck to everything it came in contact with, and, once on the lunar surface, the dust eroded their spacesuits, caused overheating on equipment and instrumentation, compromised seals on their spacesuits and on lunar sample collecting boxes, irritated their eyes and lungs, and generally coated everything very efficiently. On the return to Earth in the Apollo Command Module, lunar dust inadvertently brought aboard floated freely in their cabin, causing problems. Now, 50 years later, humans will return to the Moon in the Artemis Program as early as 2024. This book summarizes what we know about lunar dust, its structure and chemical composition, its impact on human health, and how to reduce/mitigate its effects on future human exploration. The four dozen contributors to the 14 chapters in the book are planetary scientists, engineers, mission planners, medical researchers, and physicians from NASA and the European Space Agency, as well as universities and industry from the United States, Australia, Germany, Italy, the Netherlands, Portugal, and Sweden.



THE ARTEMIS LUNAR PROGRAM:

Returning People to the Moon

By Manfred "Dutch" von Ehrenfried

Springer, 2020, 307 pp., Paperback. $34.99. www.springer.com

This book describes the future of the Artemis Lunar Program from the years 2017 to about 2030. Despite the uncertainty of the times and the present state of space exploration, it is likely that what is presented in this book will happen, to one degree or another. Elements of the proposed program are described from several perspectives, including that of NASA, the commercial space industry, and international partners. The book also includes descriptions of the program's many vehicles, habitats, landers, payloads, and experiments.

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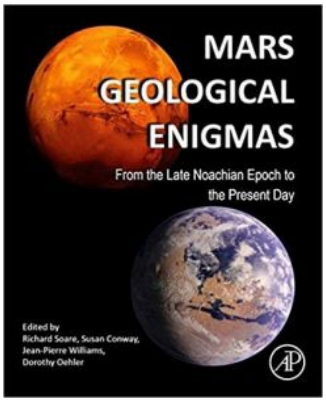


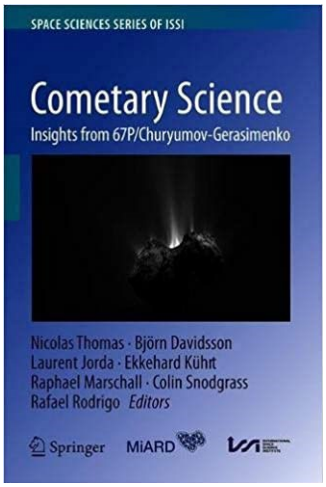
MARS GEOLOGICAL ENIGMAS:

From the Late Noachian Epoch to the Present Day

Edited by Richard Soare, Susan Conway, Jean-Pierre Williams, and Dorothy Oehler

Elsevier, 2021, 560 pp., Paperback. $150.00. www.elsevier.com

Mars Geological Enigmas: From the Late Noachian Epoch to the Present Day presents outstanding questions on the geology of Mars and divergent viewpoints based on varying interpretations and analyses. The result is a robust and comprehensive discussion that provides opportunities for planetary scientists to develop their own opinions and ways forward. Each theme opens with an introduction that includes background on the topic and lays out questions to be addressed. Alternate perspectives are covered for each topic, including methods, observations, analyses, and in-depth discussion of the conclusions. Chapters within each theme reference each other to facilitate comparison and deeper understanding of divergent opinions. This title is suitable for advanced undergraduate students, graduate students, postdocs, researchers, and faculty members in planetary science.



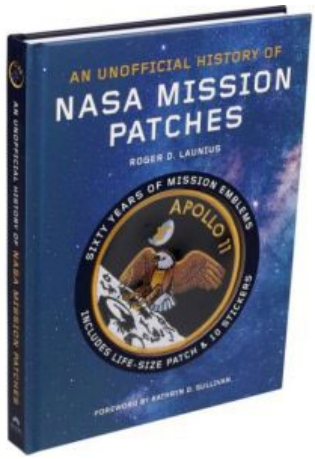
COMETARY SCIENCE:

Insights from 67P/ Churyumov-Gerasimenko

Edited by Nicolas Thomas, Björn Davidsson, Laurent Jorda, Ekkehard Kührt, Raphael Marschall, Colin Snodgrass, and Rafael Rodrigo

Springer, 2021, 421 pp., Hardcover. $169.99. www.springer.com

This book gives a status report on where we stand today in studies of cometary nuclei and their immediate environment. The papers were derived from a Horizon 2020 project called MiARD (Multi-instrument Analysis of Rosetta Data), which was designed to use multiple datasets from the Rosetta mission to Comet 67P/Churyumov-Gerasimenko to place further constraints on the properties of the nucleus of the comet and its immediate environment. The individual chapters are the result of a significant effort by leading researchers to establish clear statements on what we know from current cometary data. Based on a workshop held in 2018 at the International Space Sciences Institute, the book focuses on the nucleus itself and the relationship between the surface properties and the observed outgassing. Additionally, it makes a first critical assessment of the Rosetta dataset, establishing what would be an appropriate next step in cometary research.



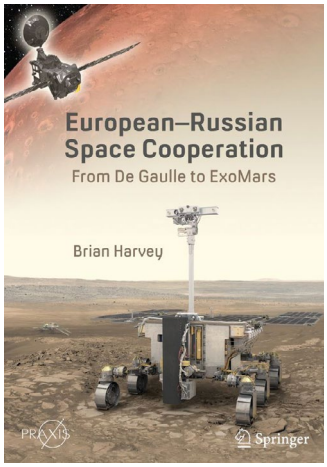
AN UNOFFICIAL HISTORY OF NASA MISSION PATCHES

By Roger D. Launius

Thunder Bay Press, 2020, 208 pp., Hardcover. $22.99. www.thunderbaybooks.com

Celebrate 60 years of the U.S. space program with *An Unofficial History of NASA Mission Patches*, featuring the astronauts' patches from more than 170 of the most important NASA missions. Each entry includes a full-color image of the patch, details about the space mission, the patch's design, and the crew. Ten sticker patches and an embroidered patch on the cover make this a unique gift for every space enthusiast.

Note: Product descriptions are taken from publishers' websites. LPI is not responsible for factual content.

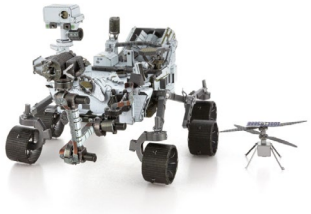


EUROPEAN-RUSSIAN SPACE COOPERATION:
From de Gaulle to ExoMars

By Brian Harvey

Springer, 2021, 406 pp., Paperback. $34.99. www.springer.com

The story of European-Russian collaboration in space is little known and its importance all too often understated. Because France was the principal interlocutor between these nations, such cooperation did not receive the attention it deserved in English-language literature. This book rectifies that history, showing how Russia and Europe forged a successful partnership that has continued to the present day. Space writer Brian Harvey provides an in-depth picture of how this European-Russian relationship evolved and what factors — scientific, political, and industrial — propelled it over the decades. The history begins in the cold war period with the first collaborative ventures between the Soviet Union and European countries, primarily France, followed later by Germany and other European countries. Next, the chapters turn to the missions when European astronauts flew to Russian space stations, the Soyuz rocket made a new home in European territory in the South American jungle and science missions were flown to study deep space. Their climax is the joint mission to explore Mars, called ExoMars, which has already sent a mission to Mars. Through this close examination of these European-Russian efforts, readers will appreciate an altogether new perspective on the history of space exploration, no longer defined by competition, but rather by collaboration and cooperation.

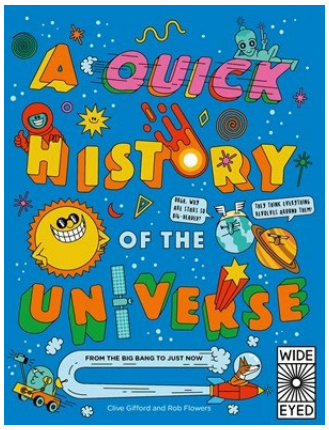


MARS ROVER PERSEVERANCE & INGENUITY HELICOPTER MODEL KIT

Produced by Metal Earth

$24.95. www.metalearth.com

This unassembled 4.5-sheet model is packed in an envelope with easy-to-follow instructions. No glue or solder is required for assembly — parts can be easily clipped from the metal sheets. Pop out the pieces and connect using tabs and holes. Tweezers are the recommended tool for bending and twisting the connection tabs. The 1:30-scale model has a challenging difficulty level and is ideal for ages 14 and up.



A QUICK HISTORY OF THE UNIVERSE:
From the Big Bang to Just Now

By Clive Gifford

Wide-Eyed Editions, 2021, 128 pp., Paperback. $14.99. www.quartoknows.com

Strap in for a rip-roaring ride through the history of the universe, starting with the Big Bang, and bringing us right up to present day. What was the universe like when it was a few seconds old? How had it changed by its millionth birthday? And when did time even start, for that matter?! The story of the last 13.8 billion years is in one handy volume, and you can read about the start of stars, the growth of galaxies, and the production of planets. Find out how the universe developed and discover what the beginning of the universe was actually like, what the universe will be like in the next few billion years, and how scientists figure it all out. Packed with fun cartoons and facts, this book tackles the biggest topics in the universe in chronological order. For ages 8 to 12.

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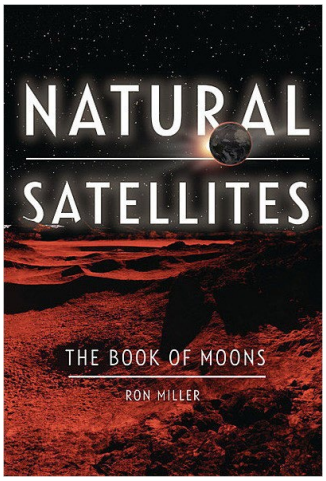

NATURAL SATELLITES: The Book of Moons

By Ron Miller

Lerner Publishing, 2021, 104 pp., Hardcover. $27.99. www.lernerbooks.com

For centuries, astronomers have placed a special interest on the other planets of the solar system. But with the advent of spacecraft and the tremendous missions undertaken by the Voyager and Cassini probes, astronomers have discovered that the natural satellites of the planets — the solar system's moons — are some of the most extraordinary places imaginable. There are moons with towering geysers, erupting volcanos, and subterranean oceans of warm, mineral-rich water. Some of the highest mountains and deepest canyons can be found on the moons. There are moons that have shattered into pieces and then reassembled. There is even a moon where it rains rocket fuel. Recently, scientists have turned to the moons for answers in their investigations of the origins of the solar system and the evolution of life on our own planet. Featuring full-color, scientifically accurate illustrations by NASA artist Ron Miller, this book chronicles these investigations and the questions we have yet to answer in our exploration of the solar system's moons. For grades 6 to 12.

3-D PLANETS IN A TUBE

Produced by Fat Brain Toys

$8.45. www.fatbraintoys.com

This set of nine glow-in-the-dark celestial bodies can be hung from your ceiling in perfect orbital order using the 25 feet of string and adhesive putty that is included. Then switch off the lights, and suddenly they all glow beautifully brilliant and bright! This set encourages an interest in space exploration and astronomy and makes learning about the solar system fun. The planets are made of strong materials for lasting durability. For ages 5 and up.

APOLLO: A Game Inspired by the Moon Missions

Produced by Buffalo Games & Puzzles

$29.99. www.buffalogames.com

Apollo is a cooperative strategy game inspired by the NASA Moon missions. Walk in the footsteps of NASA's pioneers and embark on the missions that made history. Play as a mission controller or as an astronaut. Both sides must work together and strategize to complete flight stages, overcome obstacles, repair the spacecraft, and keep communications clear. It is the team that determines if the mission is a success or failure. This game includes two mission packs, Gemini and Apollo, with real NASA mission facts for basic and advanced play. For two to five players ages 12 and up.

Note: Product descriptions are taken from publishers' websites. LPI is not responsible for factual content.

CALENDAR

2021 Upcoming Events

August | September | October | November | December

August

12th Planetary Crater Consortium Meeting

August 11–13
Virtual
www.hou.usra.edu/meetings/crater2021/

84th Annual Meeting of the Meteoritical Society

August 15–21
Chicago, Illinois
www.metsoc2021-chicago.com/

Lunar Surface Science Workshop

August 18–19
Virtual Session 10: Fundamental and Applied Lunar Surface Research in Physical Sciences
www.hou.usra.edu/meetings/lunarsurface2020/

Outer Planets Assessment Group (OPAG) Fall Meeting

August 30 – September 1
Virtual
www.lpi.usra.edu/opag/meetings/upcoming/

2021 Annual Meeting of the Lunar Exploration Analysis Group (LEAG)

August 31– September 2
Virtual
www.hou.usra.edu/meetings/leag2021/

September

Europlanet Science Congress 2021

September 13–24

Virtual

www.epsc2021.eu

TP4: Impact Processes in the Solar System

September 20

Virtual

meetingorganizer.copernicus.org/EPSC2021/session/41622

Spatially Resolved Spectroscopy with Extremely Large Telescopes

September 20–24

Oxford, UK

elt2020.web.ox.ac.uk/

October

53rd Meeting of the AAS Division for Planetary Sciences

October 3–8

Virtual

aas.org/meetings/dps53

Gaps, Rings, Spirals, and Vortices: Structure Formation in Planet-Forming Disks

October 4–29

Munich, Germany

www.munich-iapp.de/planet-forming-disks21

Space Tech Expo USA

October 6–8

Long Beach, California

www.spacetechexpo.com

Geological Society of America

October 10–13

Portland, Oregon

community.geosociety.org/gsa2021/home

PLATO Mission Conference 2021: Exploring Exoplanets in the Habitable Zone of Solar-Like Stars

October 11–15
Virtual
platomissionconference2021.iaa.es

Brines Across the Solar System: Modern Brines

October 25–28
Virtual
www.hou.usra.edu/meetings/modernbrines2021/

November

Hayabusa 2021: 8th Symposium of Solar System Materials

November 15–18
Virtual
curation.isas.jaxa.jp/symposium/2021/index.html

Venera-D: Venus Cloud Habitability System Workshop (Hybrid)

November 30–December 3
Moscow, Russia
www.hou.usra.edu/meetings/venera_d2021/

December

AGU 2021 Fall Meeting (Hybrid)

December 13–17
New Orleans, Louisiana
www.agu.org/Fall-Meeting

2022 Upcoming Events

January | March | April | May | June

January

Rocky Worlds II

January 10–12
Oxford, United Kingdom
www.rockyworlds.org

March

Cloud Academy II

March 6–11

Virtual

leap2010.wp.st-andrews.ac.uk/the-project/cloud-academy-ii/

53rd Lunar and Planetary Science Conference

March 7–11

The Woodlands, Texas

www.hou.usra.edu/meetings/lpsc2022/

Protostars and Planets VII

March 21–27

Kyoto, Japan

ppvii.org/

April

16th Spacecraft Charging and Technology Conference (SCTC)

April 4–8

Cocoa Beach, Florida

www.hou.usra.edu/meetings/sctc2022/

May

Origins and Exploration: From Stars to Cells (AbSciCon)

May 15–20

Atlanta, Georgia

www.agu.org/abscicon

June

Mercury: Current and Future Science of the Innermost Planet

June 7–10

Orléans, France

mercury2020.ias.u-psud.fr/main_1st.php

Meteoroids 2022

June 13–17

Huntsville, Alabama

www.hou.usra.edu/meetings/meteoroids2022/